Table of Contents - CD

5. Cross Divisional Programs (CD)

5.a. Demographics

5.a.i. Principal Investigators (PIs)

5.a.i.1. Limitations of the data – CD PIs

26,043 submitted proposals are included in the ROSES 2016-2021 database. Please see Appendix Table 1 to see which programs are included. The total number of proposals submitted and selected for each ROSES year and the total number of proposals submitted to each SMD Division cannot be reported due to the Office of the Chief Scientist's suppression guidelines. See *Yearbook Introduction Section 1.a.ii.1 Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information. The number of proposals rounded to the nearest hundred are included for these two circumstances to provide context. For the Cross-Divisional Research Division, there are ~1,300 submitted proposals over all ROSES years: ~1,000 for ROSES 2016-2020 and ~300 for ROSES 2021.

Proposals with PIs who took the survey but selected "prefer not to answer" for all demographic survey questions:

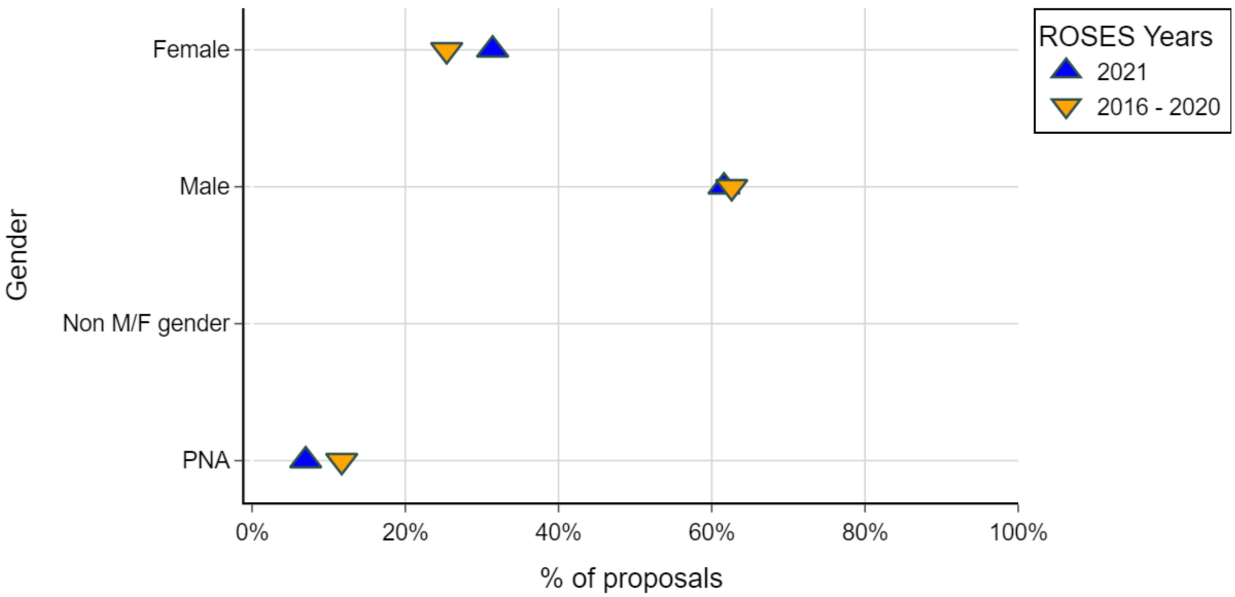
- Submitted proposals: CD 2016 - 2020: 11% | CD 2021: 7%
- Selected proposals: CD 2016 - 2020: 9% | CD 2021: 2%

Unique identifiers in the dataset are not completely unique. Less than 1% of PIs of submitted ROSES 2016-2021 proposals have more than 1 unique ID in the NSPIRES system.

5.a.i.2. Gender – CD PIs

CD PIs: Submitted Gender - Plot

CD 2016 - 2020 vs. 2021: Submitted PIs - Gender



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Non M/F gender (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

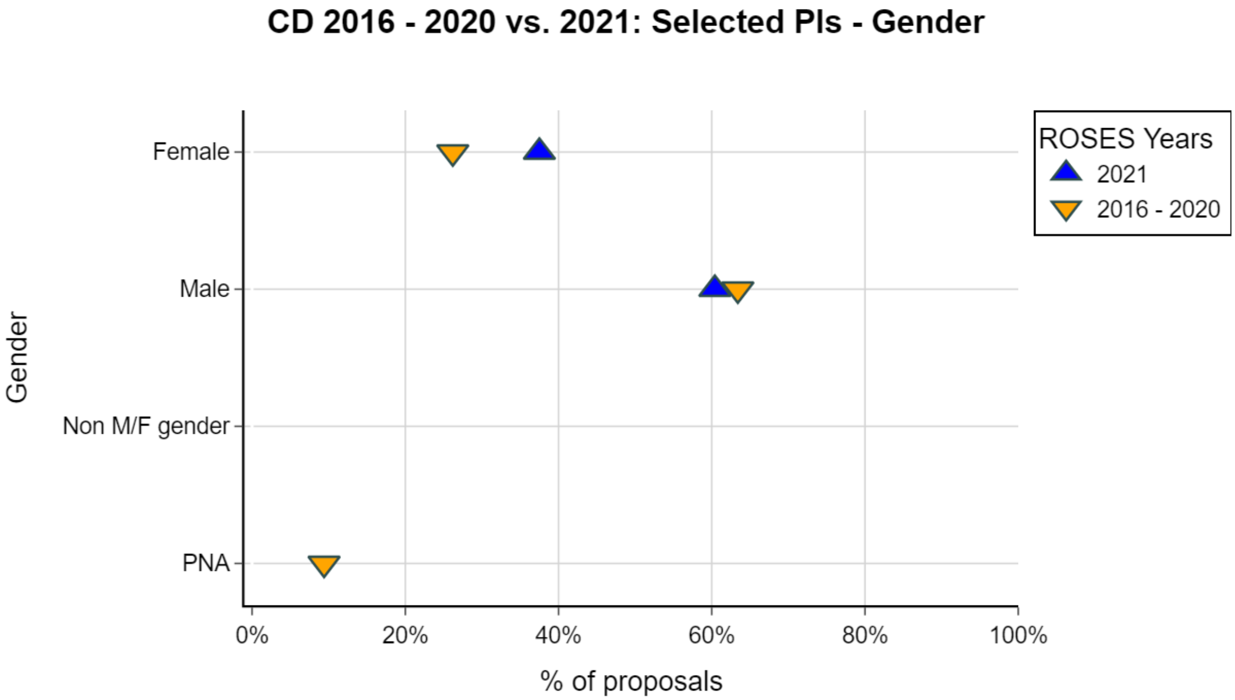
CD PIs: Submitted Gender - Data Table

CD 2016 - 2020 vs. 2021: Submitted PIs - Gender

Gender	CD 2016 - 2020	CD 2021
Female	25%	31%
Male	63%	62%
Non M/F gender	NR	NR
PNA	12%	7%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Selected Gender - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Non M/F gender (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

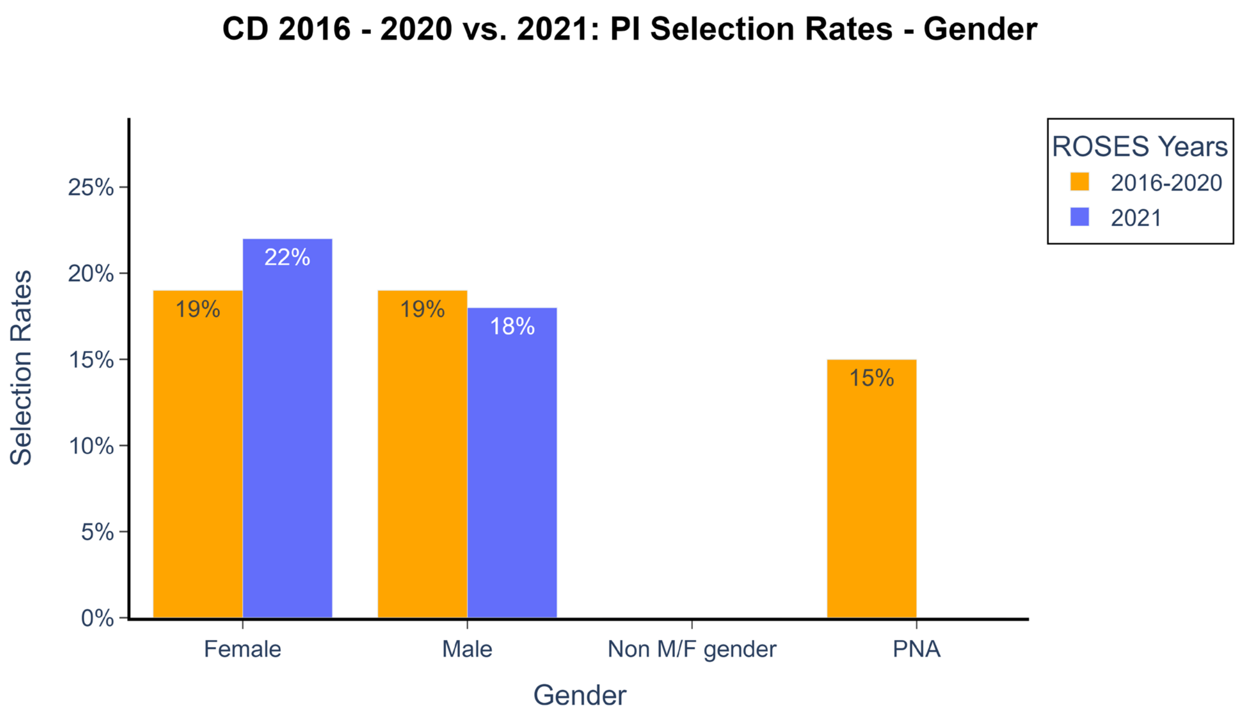
CD PIs: Selected Gender - Data Table

CD 2016 - 2020 vs. 2021: Selected PIs - Gender

Gender	CD 2016 - 2020	CD 2021
Female	26%	38%
Male	63%	60%
Non M/F gender	NR	NR
PNA	9%	NR

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Gender Selection Rate - Bar Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppressed categories: Non M/F gender (All years), PNA (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD PIs: Gender Selection Rate - Data Table

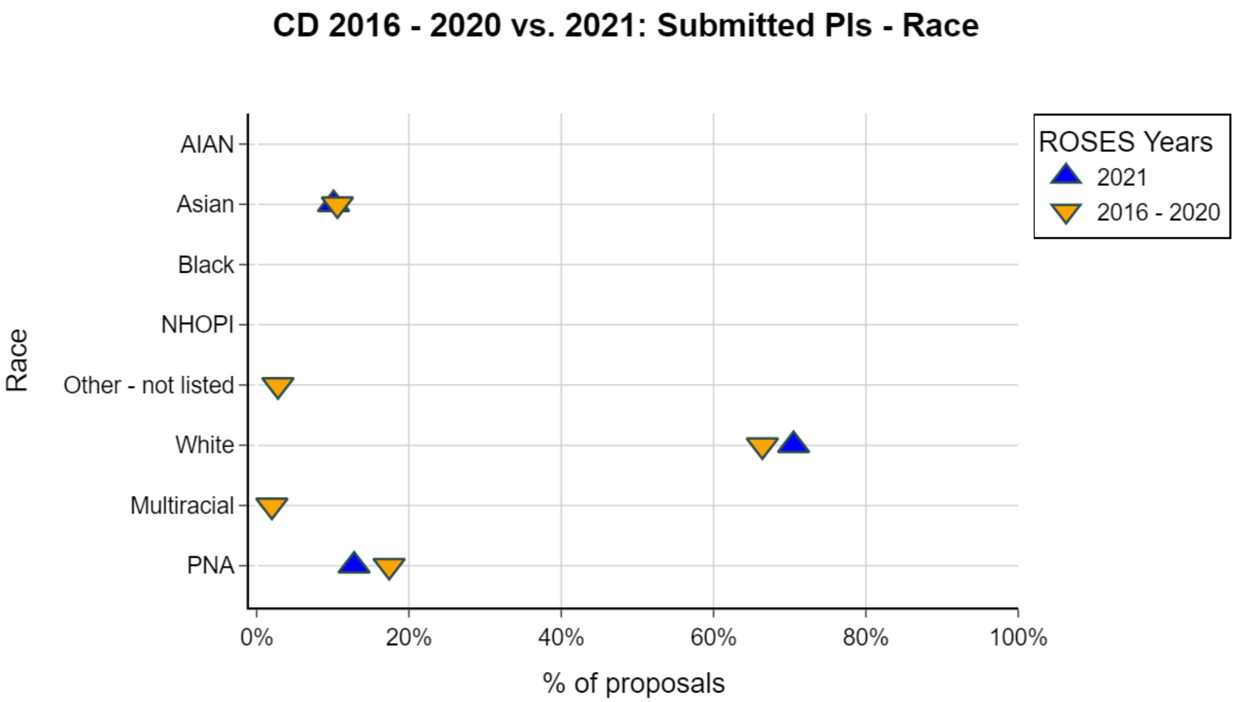
CD 2016 - 2020 vs. 2021: PI Selection Rates - Gender

Gender	CD 2016-2020	CD 2016-2020 Response/All Genders	CD 2021	CD 2021 Response/All Genders
Female	19%	1.06	22%	1.16
Male	19%	1.06	18%	0.95
Non M/F gender	NR	NR	NR	NR
PNA	15%	0.83	NR	NR
All Genders	18%	1	19%	1

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

5.a.i.3. Race – CD PIs

CD PIs: Submitted Race - Plot



AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: AIAN (All years), Black (All years), NHOPI (All years), Other – not listed (ROSES 2021), Multiracial (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

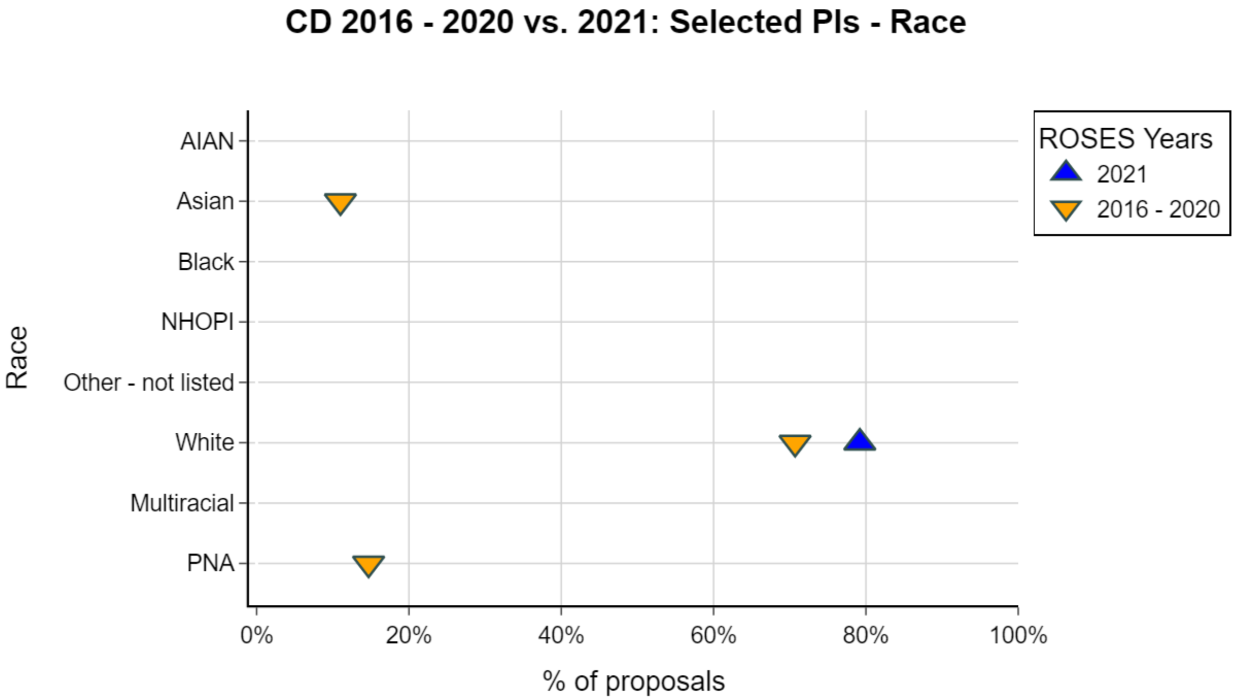
CD PIs: Submitted Race - Data Table

CD 2016 - 2020 vs. 2021: Submitted PIs - Race

Race	CD 2016 - 2020	CD 2021
AIAN	NR	NR
Asian	11%	10%
Black	NR	NR
NHOPI	NR	NR
Other - not listed	3%	NR
White	66%	70%
Multiracial	2%	NR
PNA	17%	13%

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Selected Race - Plot



AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: AIAN (All years), Asian (ROSES 2021), Black (All years), NHOPI (All years), Other – not listed (All years), Multiracial (All years), PNA (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD PIs: Selected Race - Data Table

CD 2016 - 2020 vs. 2021: Selected PIs - Race

Race	CD 2016 - 2020	CD 2021
AIAN	NR	NR
Asian	11%	NR
Black	NR	NR
NHOPI	NR	NR
Other - not listed	NR	NR
White	71%	79%
Multiracial	NR	NR
PNA	15%	NR

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Race Selection Rate - Bar Plot

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppression categories: AIAN (All years), Asian (ROSES 2021), Black (All years), NHOPI (All years), Other – not listed (All years), Multiracial (All years), PNA (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD PIs: Race Selection Rate - Data Table

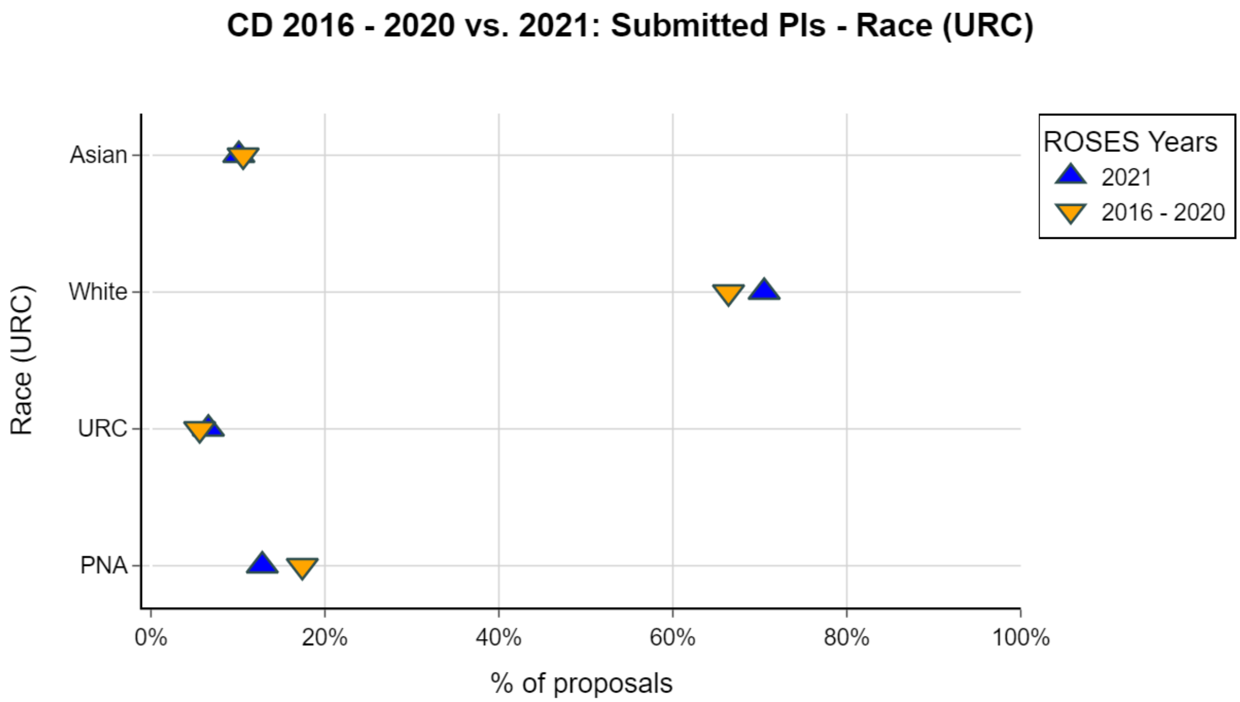
CD 2016 - 2020 vs. 2021: PI Selection Rates - Race

Race	CD 2016-2020	CD 2016-2020 Response/All Races	CD 2021	CD 2021 Response/All Races
AIAN	NR	NR	NR	NR
Asian	19%	1.06	NR	NR
Black	NR	NR	NR	NR
NHOPI	NR	NR	NR	NR
Other - not listed	NR	NR	NR	NR
White	19%	1.06	21%	1.11
Multiracial	NR	NR	NR	NR
PNA	15%	0.83	NR	NR
All Races	18%	1	19%	1

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

5.a.i.4. Race using Under-Represented Community (URC) – CD PIs

CD PIs: Submitted Race (URC) - Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

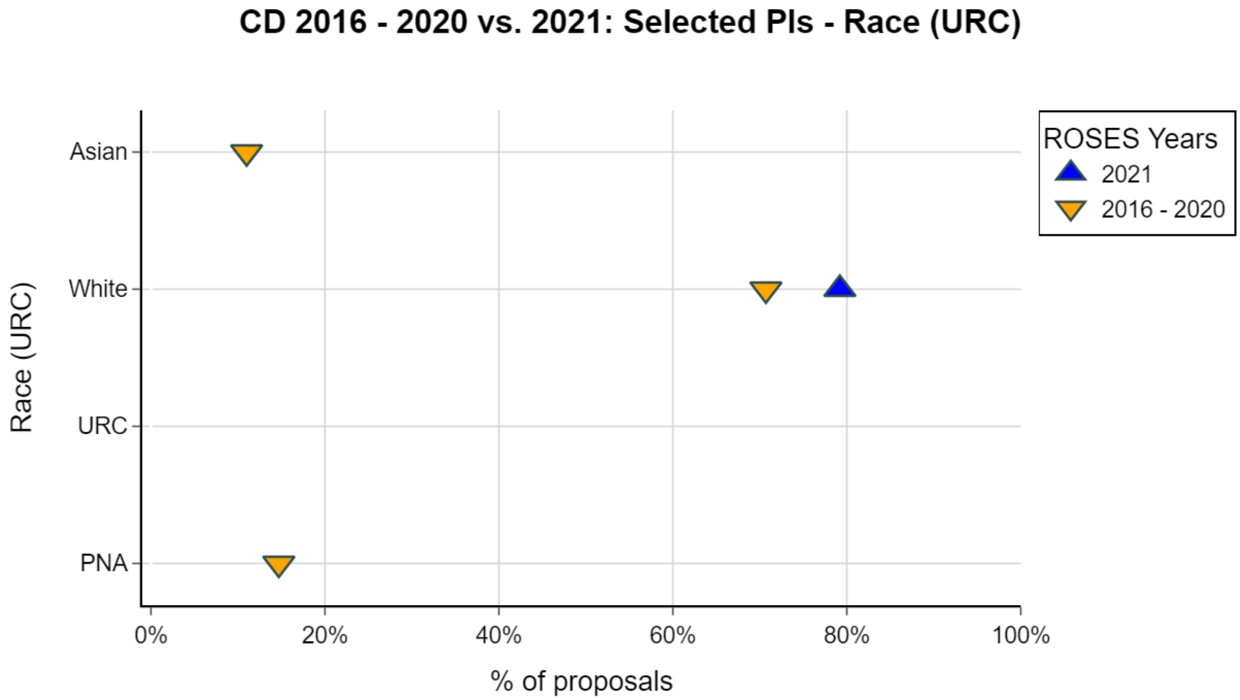
CD PIs: Submitted Race (URC) - Data Table

CD 2016 - 2020 vs. 2021: Submitted PIs - Race (URC)

Race (URC)	CD 2016 - 2020	CD 2021
Asian	11%	10%
White	66%	70%
URC	6%	7%
PNA	17%	13%

Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Selected Race (URC) - Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: Asian (ROSES 2021), URC (All years), PNA (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

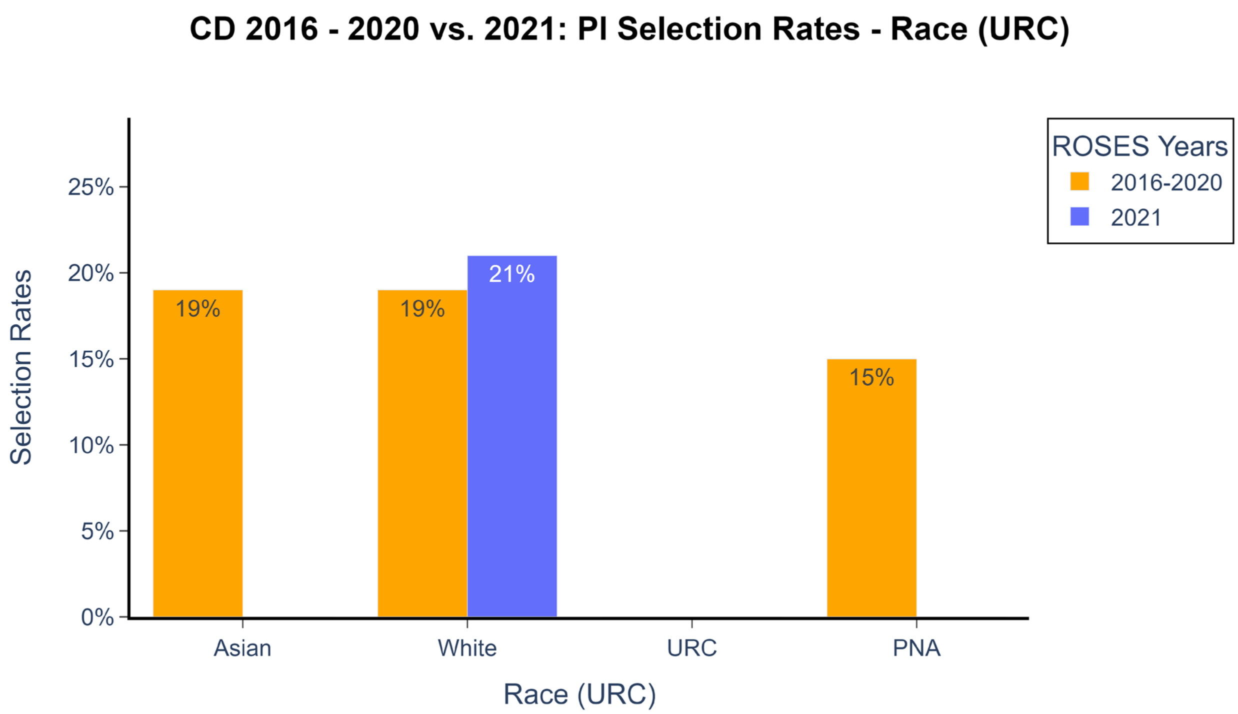
CD PIs: Selected Race (URC) - Data Table

CD 2016 - 2020 vs. 2021: Selected PIs - Race (URC)

Race (URC)	CD 2016 - 2020	CD 2021
Asian	11%	NR
White	71%	79%
URC	NR	NR
PNA	15%	NR

Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Race (URC) Selection Rate - Bar Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppression categories: Asian (ROSES 2021), URC (All years), PNA (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD PIs: Race (URC) Selection Rate - Data Table

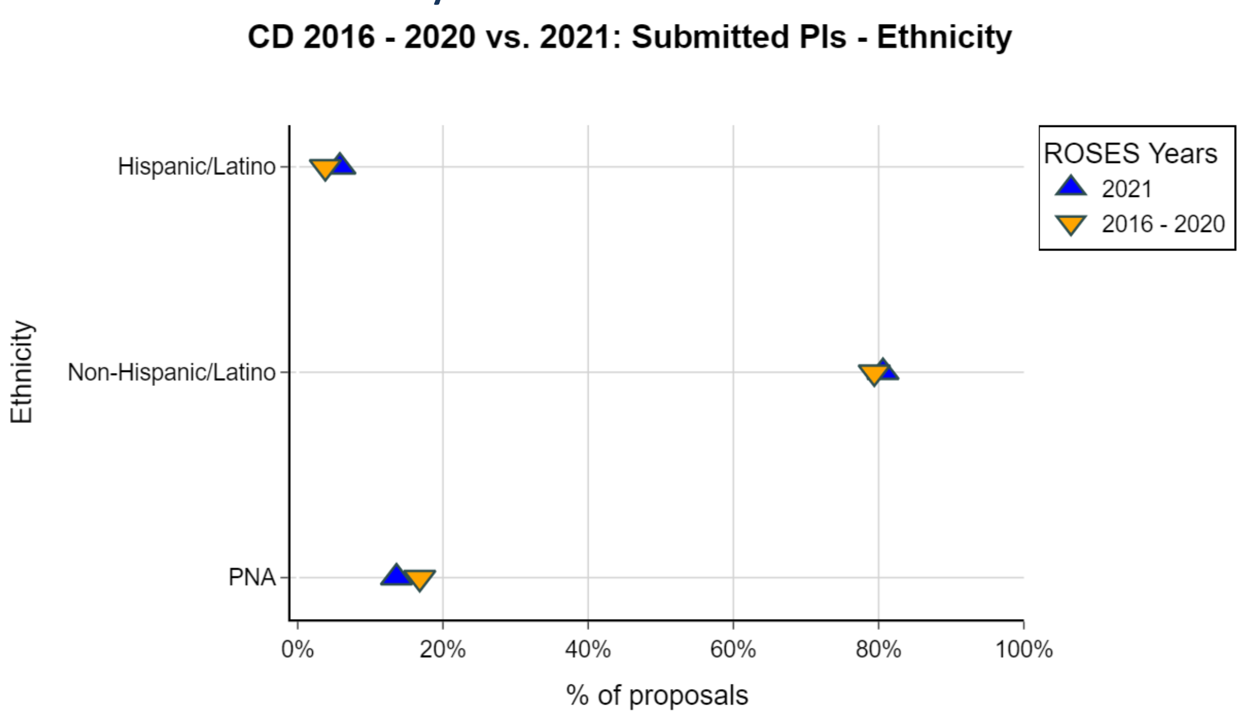
CD 2016 - 2020 vs. 2021: PI Selection Rates - Race (URC)

Race (URC)	CD 2016-2020	CD 2016-2020 Response/All Races (URC)	CD 2021	CD 2021 Response/All Races (URC)
Asian	19%	1.06	NR	NR
White	19%	1.06	21%	1.11
URC	NR	NR	NR	NR
PNA	15%	0.83	NR	NR
All Races (URC)	18%	1	19%	1

Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

5.a.i.5. Ethnicity - CD PIs

CD PIs: Submitted Ethnicity - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

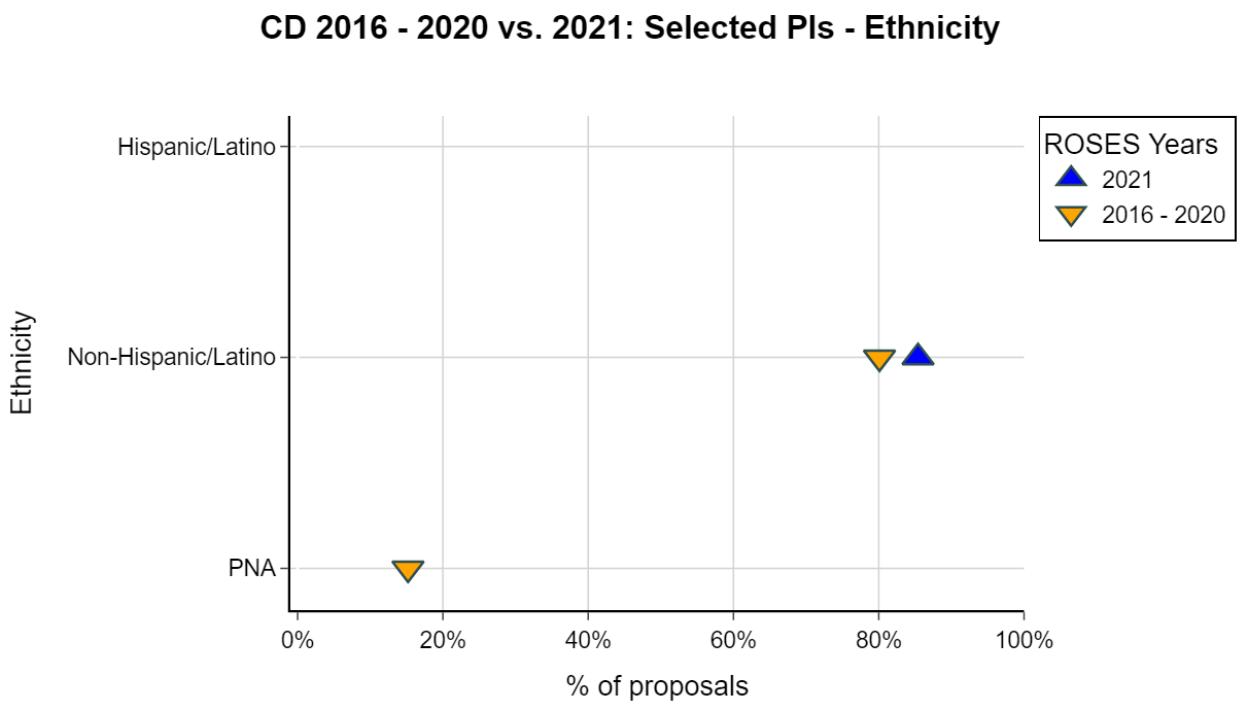
CD PIs: Submitted Ethnicity - Data Table

CD 2016 - 2020 vs. 2021: Submitted PIs - Ethnicity

Ethnicity	CD 2016 - 2020	CD 2021
Hispanic/Latino	4%	6%
Non-Hispanic/Latino	79%	81%
PNA	17%	14%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Selected Ethnicity - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: Hispanic/Latino (All years), PNA (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

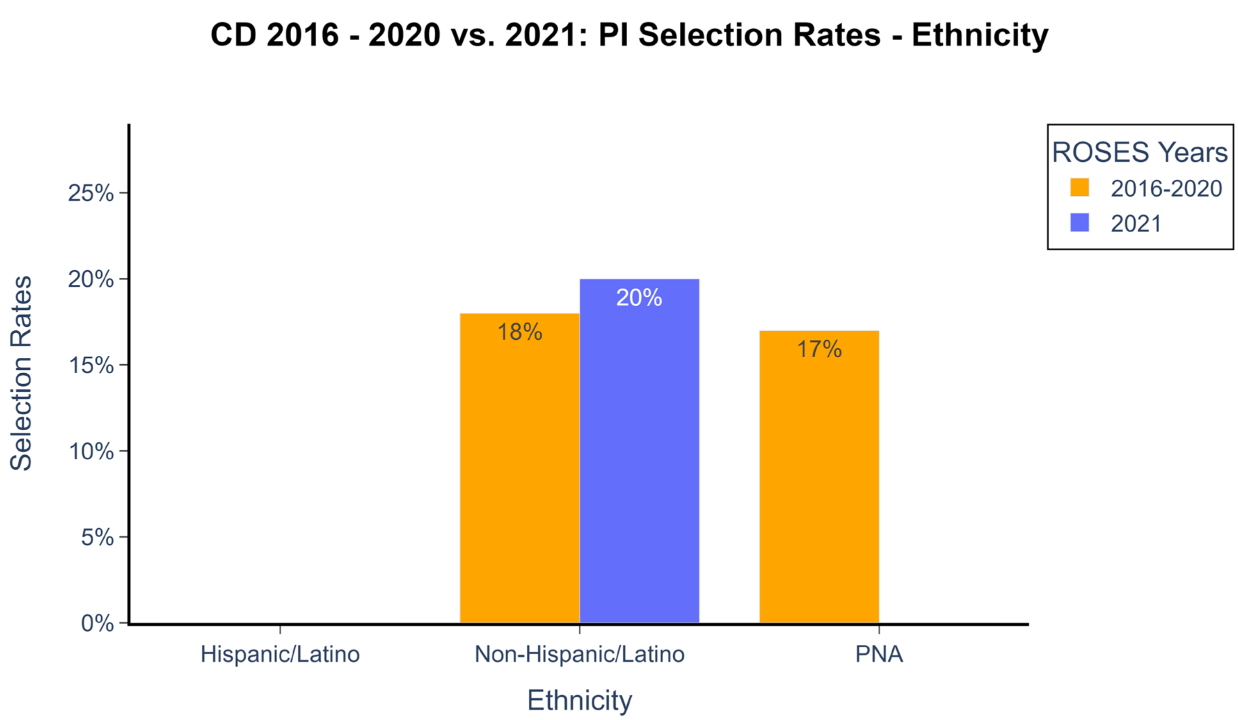
CD PIs: Selected Ethnicity - Data Table

CD 2016 - 2020 vs. 2021: Selected PIs - Ethnicity

Ethnicity	CD 2016 - 2020	CD 2021
Hispanic/Latino	NR	NR
Non-Hispanic/Latino	80%	85%
PNA	15%	NR

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Ethnicity Selection Rate - Bar Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppression categories: Hispanic/Latino (All years), PNA (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD PIs: Ethnicity Selection Rate - Data Table

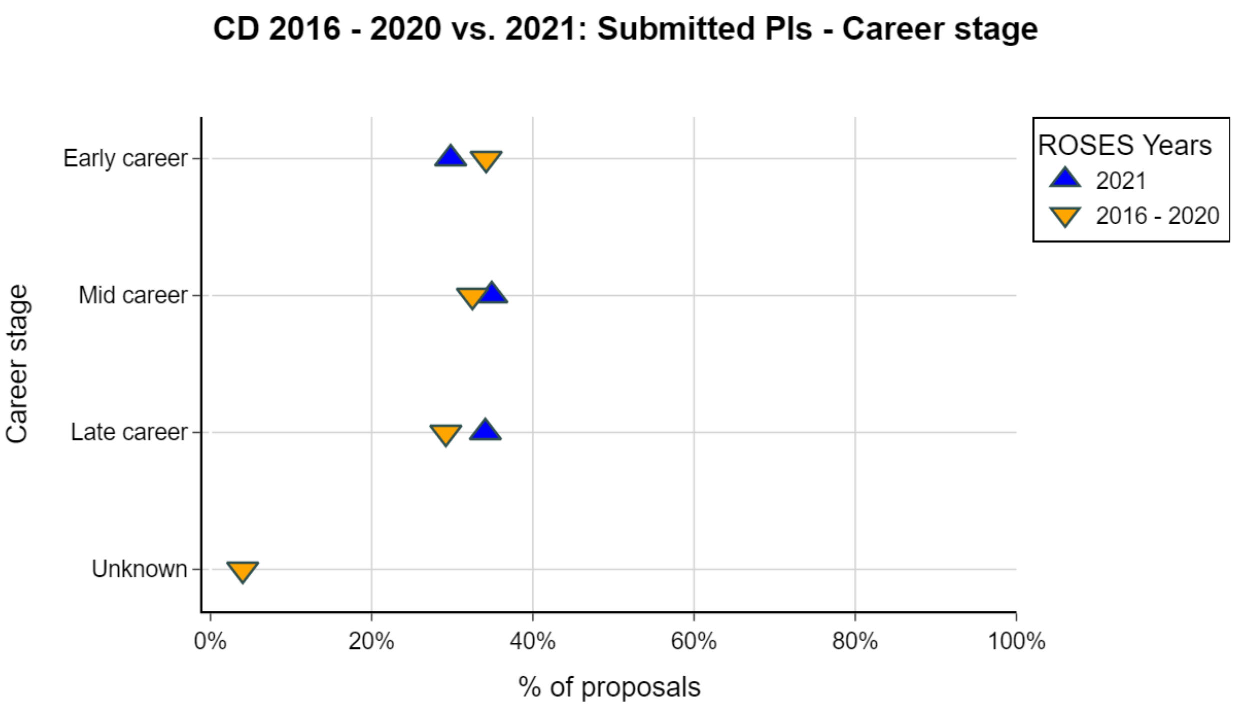
CD 2016 - 2020 vs. 2021: PI Selection Rates - Ethnicity

Ethnicity	CD 2016-2020	CD 2016-2020 Response/All Ethnicities	CD 2021	CD 2021 Response/All Ethnicities
Hispanic/Latino	NR	NR	NR	NR
Non-Hispanic/Latino	18%	1	20%	1.05
PNA	17%	0.94	NR	NR
All Ethnicities	18%	1	19%	1

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

5.a.i.6. Career Stage – CD PIs

CD PIs: Submitted Career Stage - Plot



Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: Unknown (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

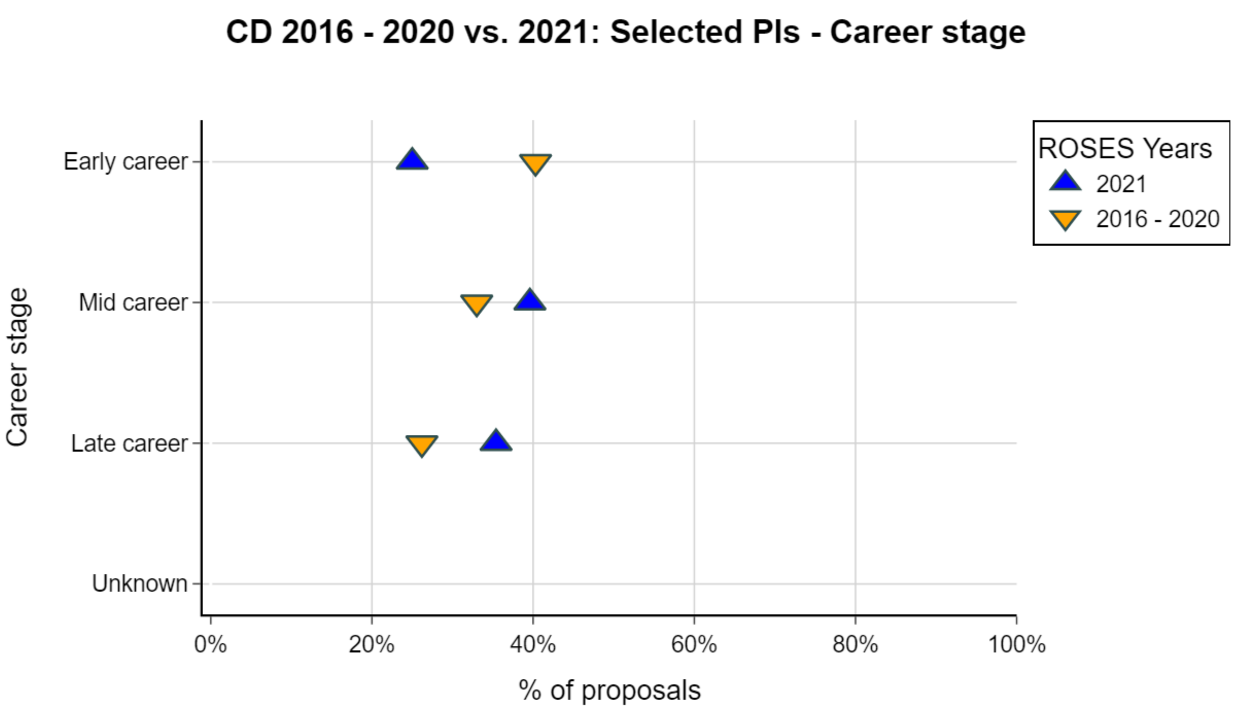
CD PIs: Submitted Career Stage - Data Table

CD 2016 - 2020 vs. 2021: Submitted PIs - Career stage

Career stage	CD 2016 - 2020	CD 2021
Early career	34%	30%
Mid career	32%	35%
Late career	29%	34%
Unknown	4%	NR

Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Selected Career Stage - Plot



Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: Unknown (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

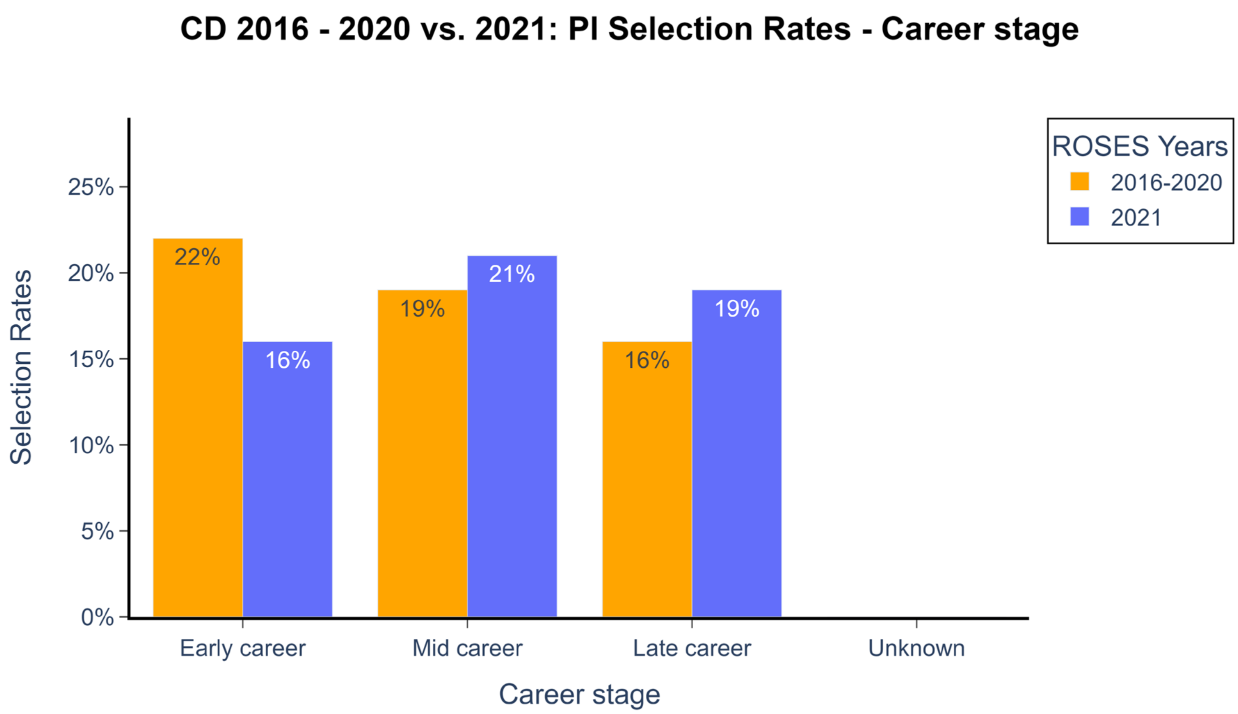
CD PIs: Selected Career Stage - Data Table

CD 2016 - 2020 vs. 2021: Selected PIs - Career stage

Career stage	CD 2016 - 2020	CD 2021
Early career	40%	25%
Mid career	33%	40%
Late career	26%	35%
Unknown	NR	NR

Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Career Stage Selection Rate - Bar Plot



Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppression categories: Unknown (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD PIs: Career Stage Selection Rate - Data Table

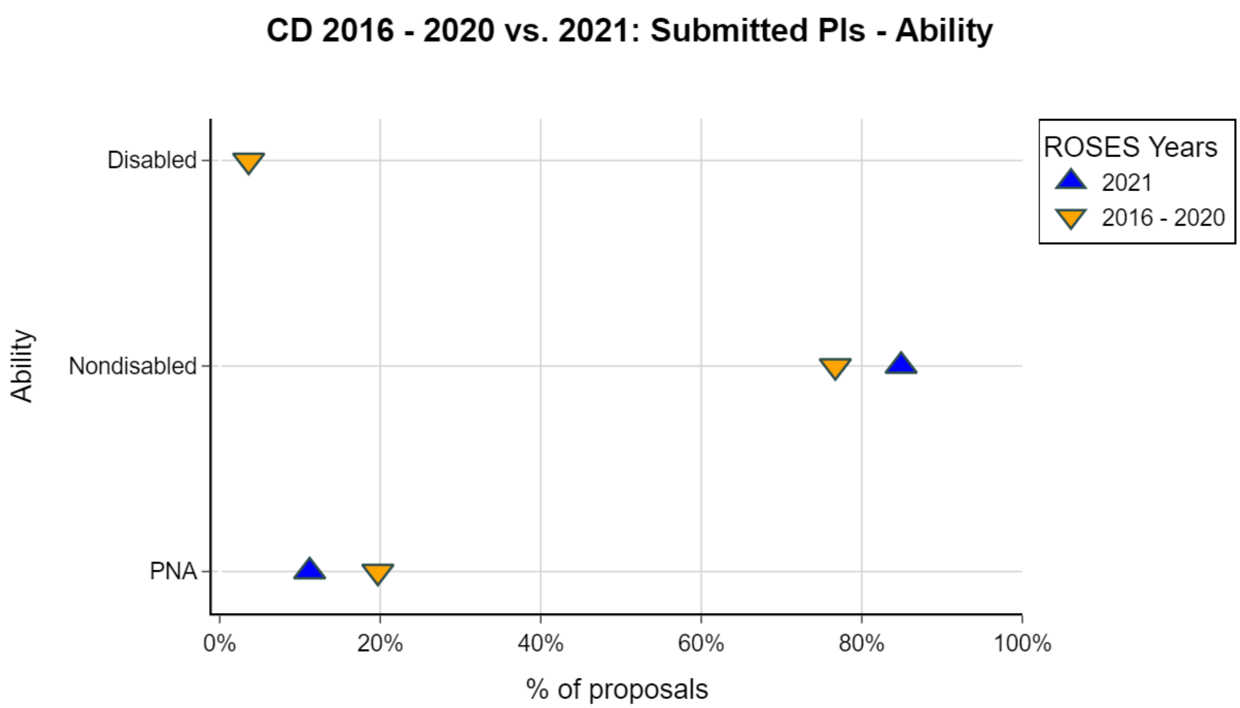
CD 2016 - 2020 vs. 2021: PI Selection Rates - Career stage

Career stage	CD 2016-2020	CD 2016-2020 Response/All Career stages	CD 2021	CD 2021 Response/All Career stages
Early career	22%	1.22	16%	0.84
Mid career	19%	1.06	21%	1.11
Late career	16%	0.89	19%	1
Unknown	NR	NR	NR	NR
All Career stages	18%	1	19%	1

Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

5.a.i.7. Disability Status – CD PIs

CD PIs: Submitted Ability – Plot



Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: Disabled (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

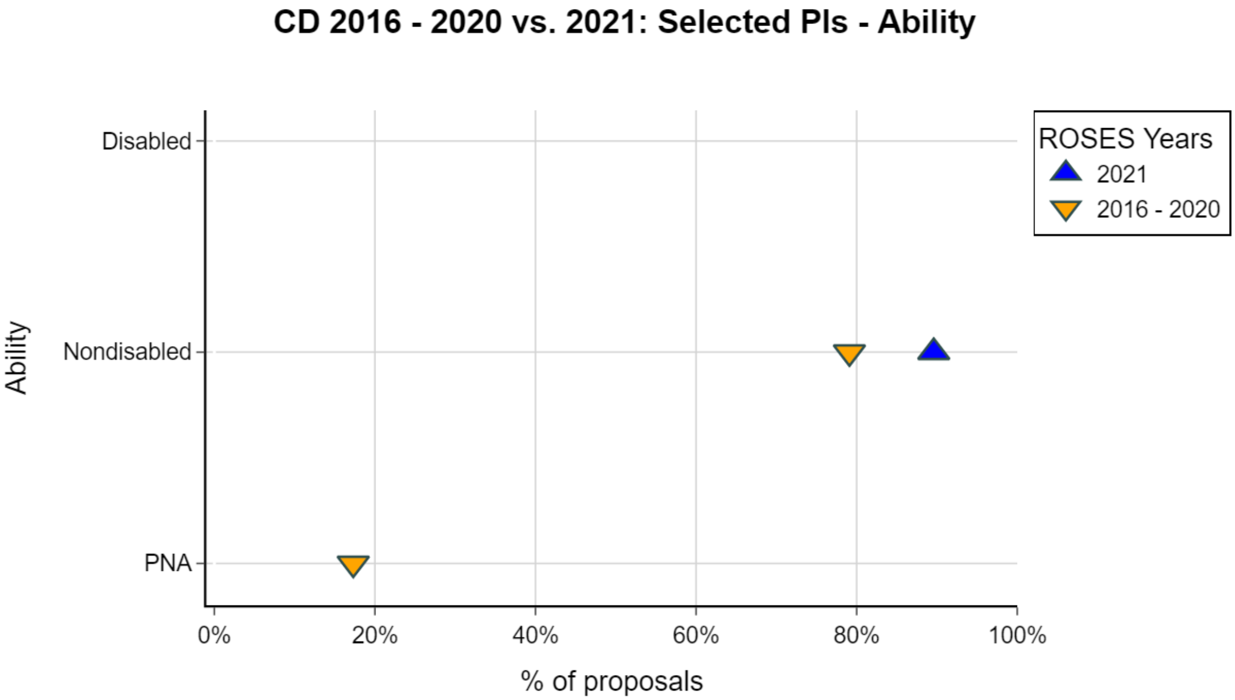
CD PIs: Submitted Ability - Data Table

CD 2016 - 2020 vs. 2021: Submitted PIs - Ability

Ability	CD 2016 - 2020	CD 2021
Disabled	4%	NR
Nondisabled	77%	85%
PNA	20%	11%

Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Selected Ability - Plot



Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: Disabled (All years), PNA (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

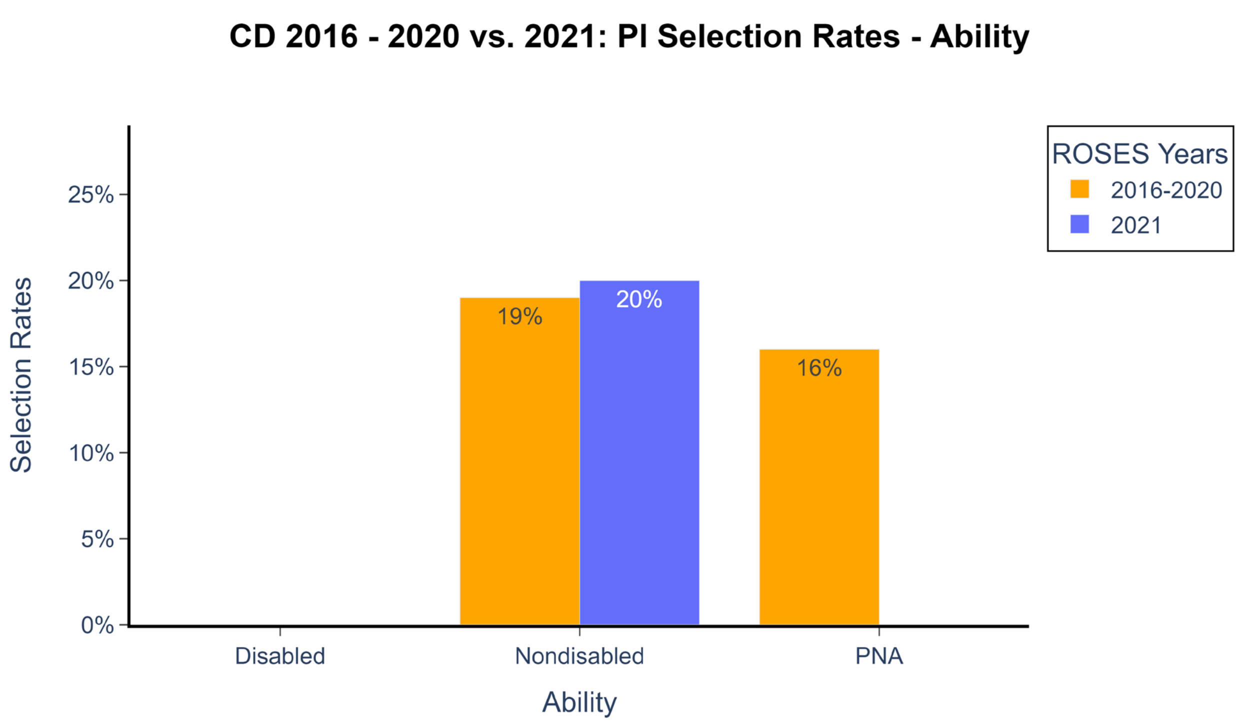
CD PIs: Selected Ability - Data Table

CD 2016 - 2020 vs. 2021: Selected PIs - Ability

Ability	CD 2016 - 2020	CD 2021
Disabled	NR	NR
Nondisabled	79%	90%
PNA	17%	NR

Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Ability Selection Rate - Bar Plot



Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppression categories: Disabled (All years), PNA (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD PIs: Ability Selection Rate - Data Table

CD 2016 - 2020 vs. 2021: PI Selection Rates - Ability

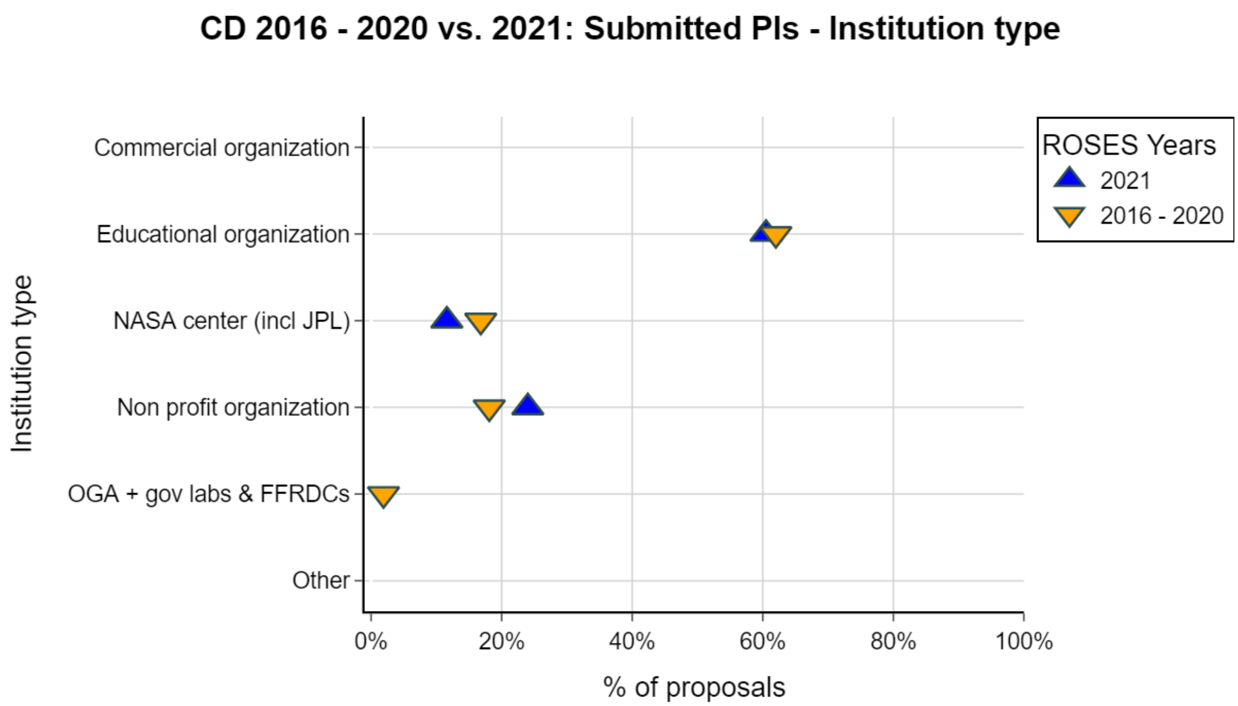
Ability	CD 2016-2020	CD 2016-2020 Response/All Abilities	CD 2021	CD 2021 Response/All Abilities
Disabled	NR	NR	NR	NR
Nondisabled	19%	1.06	20%	1.05
PNA	16%	0.89	NR	NR
All Abilities	18%	1	19%	1

Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

5.a.i.8. Institutional Analysis

5.a.i.8.a. Institution Type - CD PIs

CD PIs: Submitted Institution Type - Plot



OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: Commercial organization (All years), OGA + gov labs & FFRDCs (ROSES 2021), Other (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

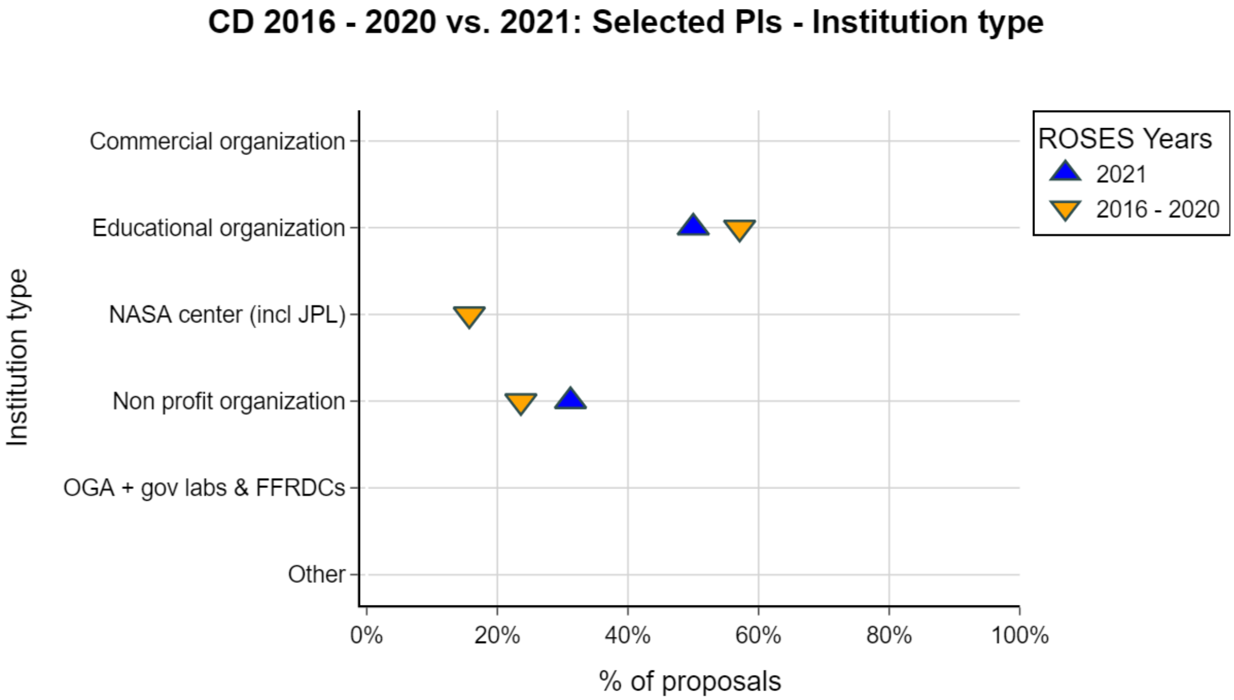
CD PIs: Submitted Institution Type - Data Table

CD 2016 - 2020 vs. 2021: Submitted PIs - Institution type

Institution type	CD 2016 - 2020	CD 2021
Commercial organization	NR	NR
Educational organization	62%	60%
NASA center (incl JPL)	17%	12%
Non profit organization	18%	24%
OGA + gov labs & FFRDCs	2%	NR
Other	NR	NR

OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Selected Institution Type - Plot



OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: Commercial organization (All years), NASA center (incl JPL) (ROSES 2021), OGA + gov labs & FFRDCs (All years), Other (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

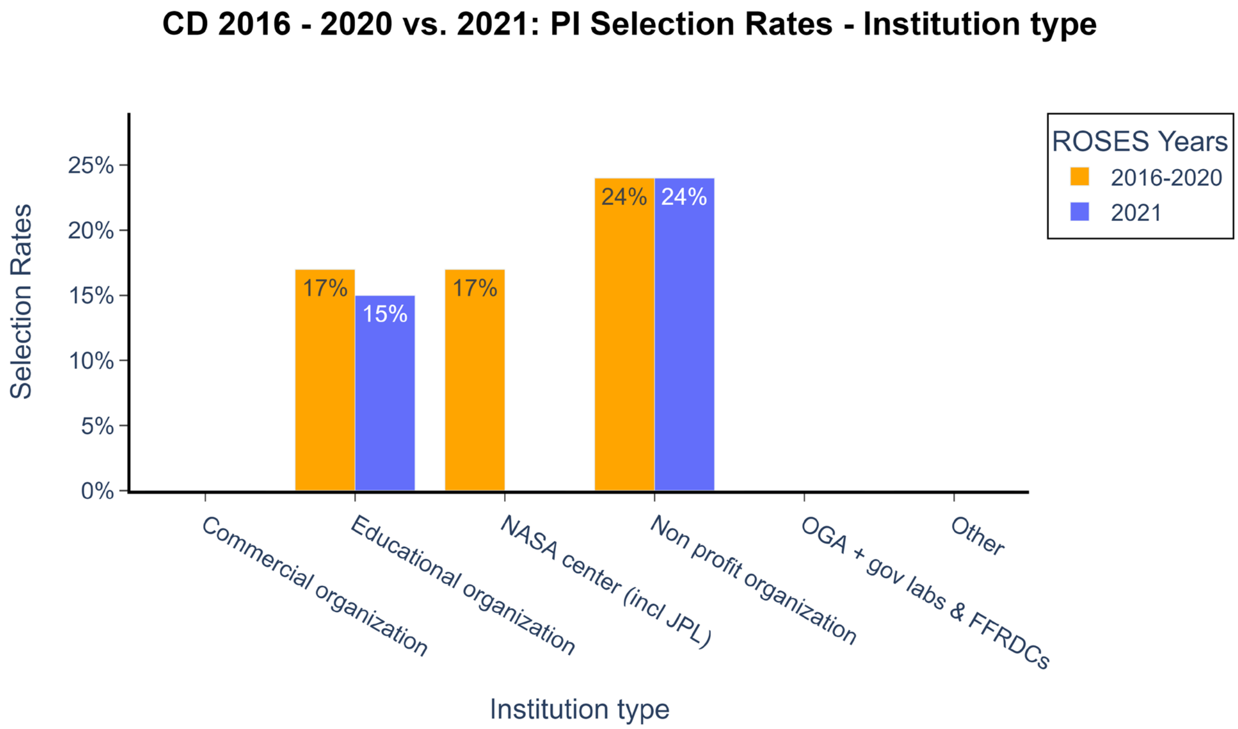
CD PIs: Selected Institution Type - Data Table

CD 2016 - 2020 vs. 2021: Selected PIs - Institution type

Institution type	CD 2016 - 2020	CD 2021
Commercial organization	NR	NR
Educational organization	57%	50%
NASA center (incl JPL)	16%	NR
Non profit organization	24%	31%
OGA + gov labs & FFRDCs	NR	NR
Other	NR	NR

OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Institution Type Selection Rate - Bar Plot



OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppression categories: Commercial organization (All years), NASA center (incl JPL) (ROSES 2021), OGA + gov labs & FFRDCs (All years), Other (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD PIs: Institution Type Selection Rate - Data Table

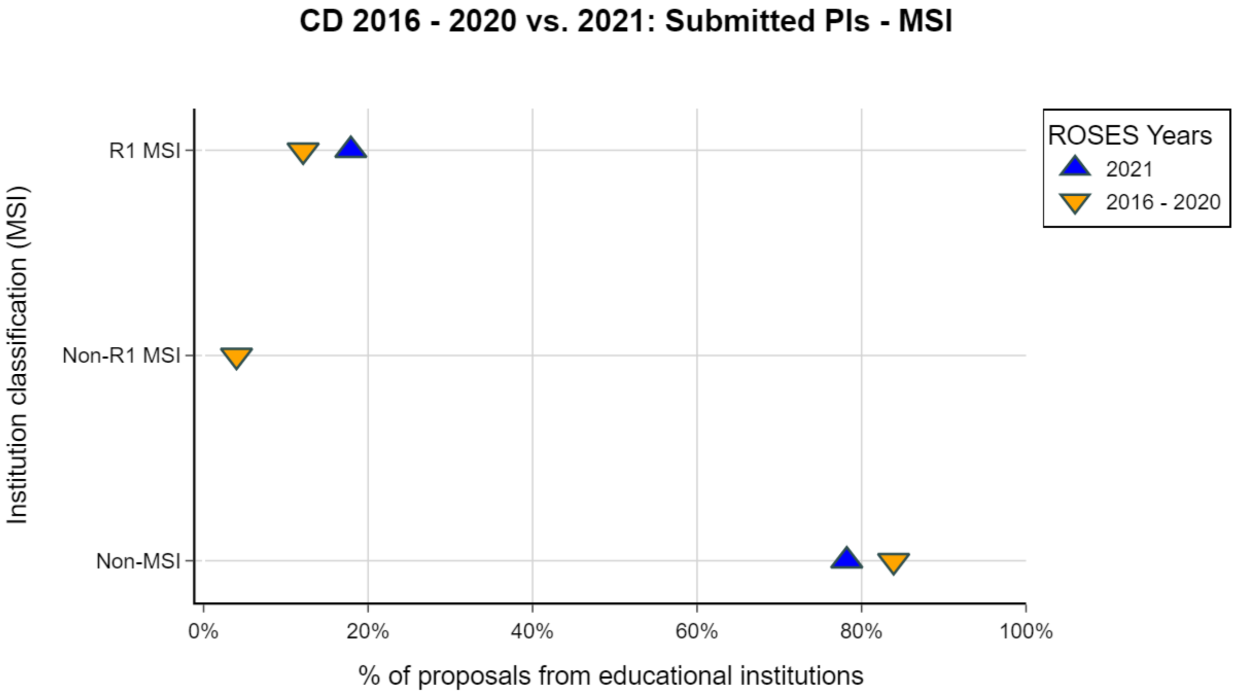
CD 2016 - 2020 vs. 2021: PI Selection Rates - Institution type

Institution type	CD 2016-2020	CD 2016-2020 Response/All Institution types	CD 2021	CD 2021 Response/All Institution types
Commercial organization	NR	NR	NR	NR
Educational organization	17%	0.94	15%	0.79
NASA center (incl JPL)	17%	0.94	NR	NR
Non profit organization	24%	1.33	24%	1.26
OGA + gov labs & FFRDCs	NR	NR	NR	NR
Other	NR	NR	NR	NR
All Institution types	18%	1	19%	1

OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

5.a.i.8.b. Minority Serving Institutions (MSIs) - CD PIs

CD PIs: Submitted MSI - Plot



MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: Non-R1 MSI (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

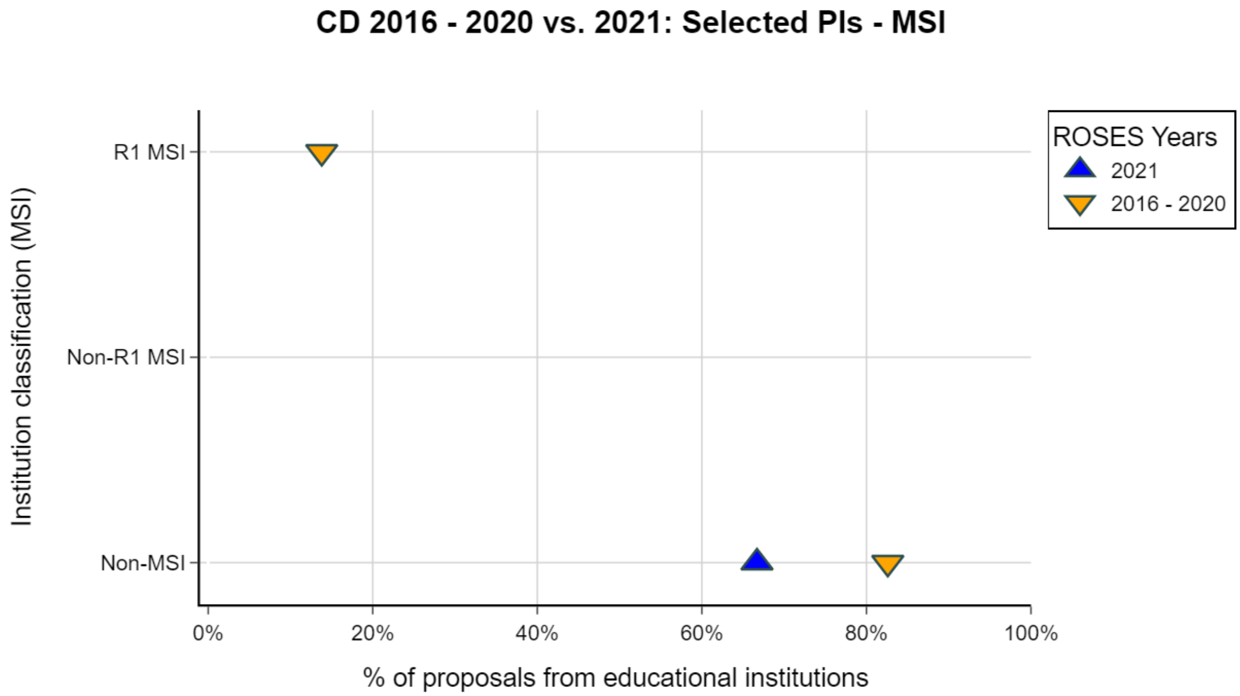
CD PIs: Submitted MSI - Data Table

CD 2016 - 2020 vs. 2021: Submitted PIs - MSI

MSI	CD 2016 - 2020	CD 2021
R1 MSI	12%	18%
Non-R1 MSI	4%	NR
Non-MSI	84%	78%

MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Selected MSI - Plot



MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: R1 MSI (ROSES 2021), Non-R1 MSI (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

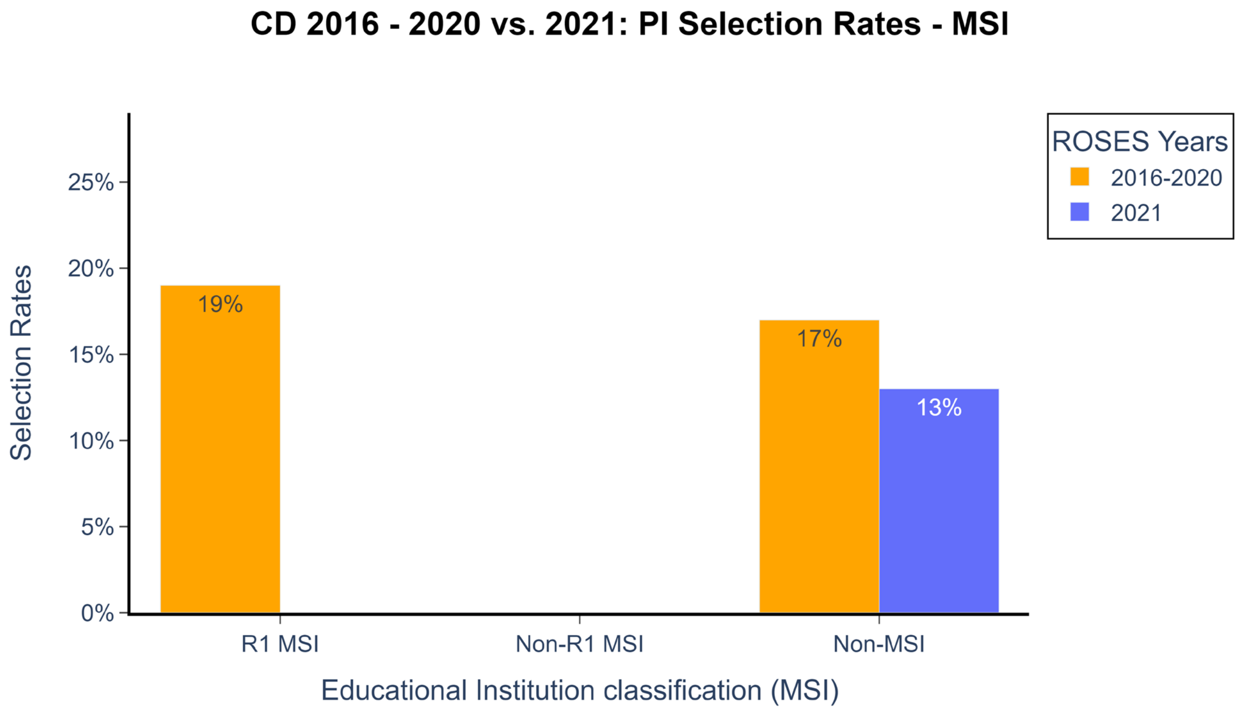
CD PIs: Selected MSI - Data Table

CD 2016 - 2020 vs. 2021: Selected PIs - MSI

MSI	CD 2016 - 2020	CD 2021
R1 MSI	14%	NR
Non-R1 MSI	NR	NR
Non-MSI	83%	67%

MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: MSI Selection Rate - Bar Plot



MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppression categories: R1 MSI (ROSES 2021), Non-R1 MSI (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD PIs: MSI Selection Rate - Data Table

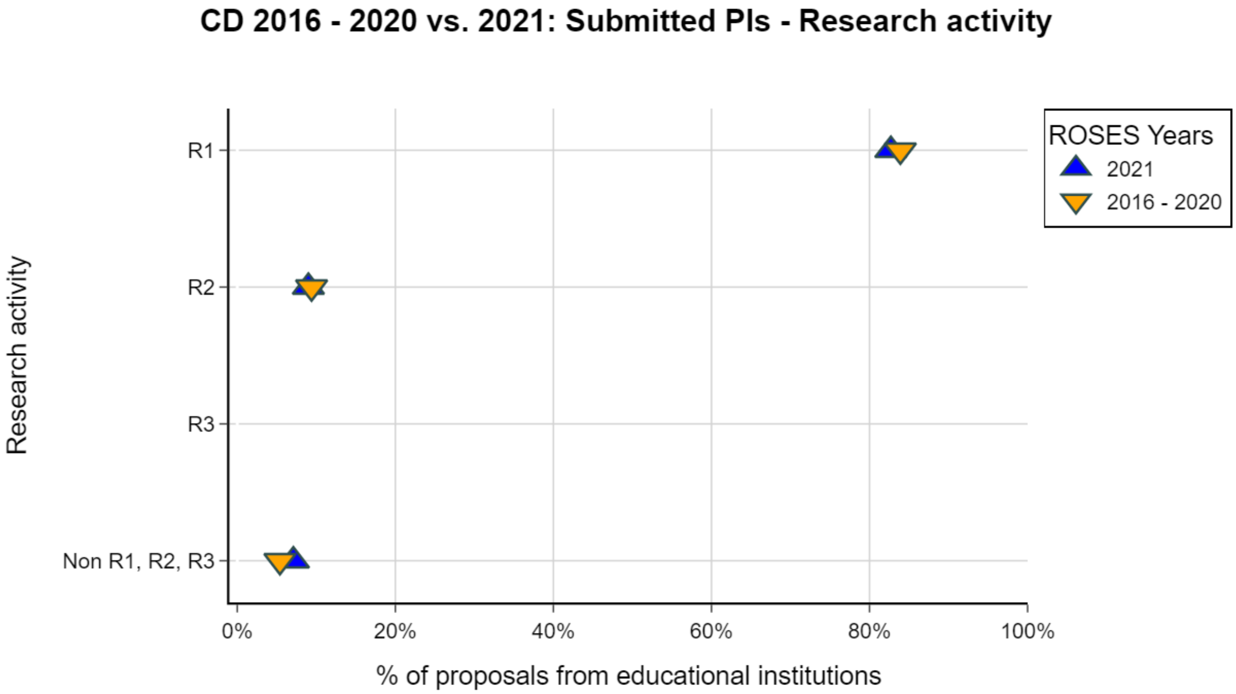
CD 2016 - 2020 vs. 2021: PI Selection Rates - MSI

MSI	CD 2016-2020	CD 2016-2020 Response/All Educational Institutions	CD 2021	CD 2021 Response/All Educational Institutions
R1 MSI	19%	1.12	NR	NR
Non-R1 MSI	NR	NR	NR	NR
Non-MSI	17%	1	13%	0.87
All Educational Institutions	17%	1	15%	1

MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

5.a.i.8.c. Carnegie Classification Research Activity - CD PIs

CD PIs: Submitted Research Activity - Plot



R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: R3 (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

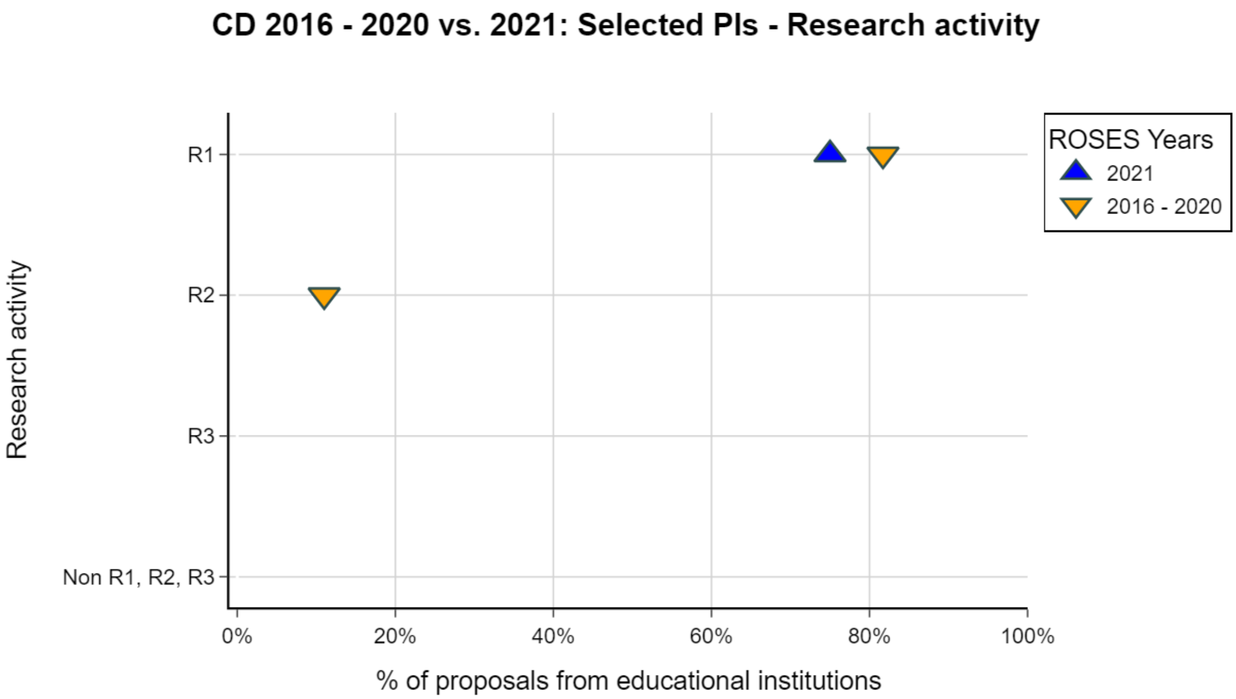
CD PIs: Submitted Research Activity - Data Table

CD 2016 - 2020 vs. 2021: Submitted PIs - Research activity

Research activity	CD 2016 - 2020	CD 2021
R1	84%	83%
R2	9%	9%
R3	NR	NR
Non R1, R2, R3	5%	7%

R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Selected Research Activity - Plot



R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | ROSES 2016-2020 proposal data are aggregated.

Suppression categories: R2 (ROSES 2021), R3 (All years), Non R1, R2, R3 (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

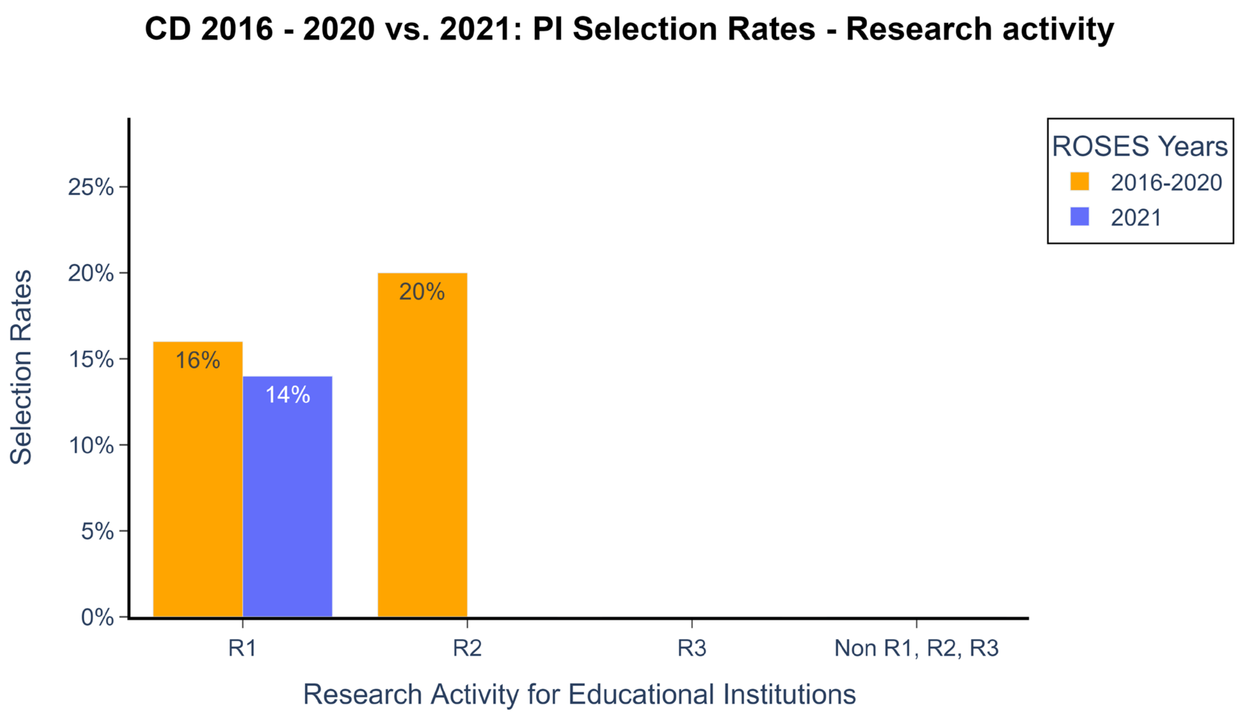
CD PIs: Selected Research Activity - Data Table

CD 2016 - 2020 vs. 2021: Selected PIs - Research activity

Research activity	CD 2016 - 2020	CD 2021
R1	82%	75%
R2	11%	NR
R3	NR	NR
Non R1, R2, R3	NR	NR

R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD PIs: Research Activity Selection Rate - Bar Plot



R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppression categories: R2 (ROSES 2021), R3 (All years), Non R1, R2, R3 (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD PIs: Research Activity Selection Rate - Data Table

CD 2016 - 2020 vs. 2021: PI Selection Rates - Research activity

Research activity	CD 2016-2020	CD 2016-2020 Response/All Educational Institutions	CD 2021	CD 2021 Response/All Educational Institutions
R1	16%	0.94	14%	0.93
R2	20%	1.18	NR	NR
R3	NR	NR	NR	NR
Non R1, R2, R3	NR	NR	NR	NR
All Educational Institutions	17%	1	15%	1

R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university. | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

5.a.ii. Science Team

5.a.ii.1 Limitations of the data – CD Science team

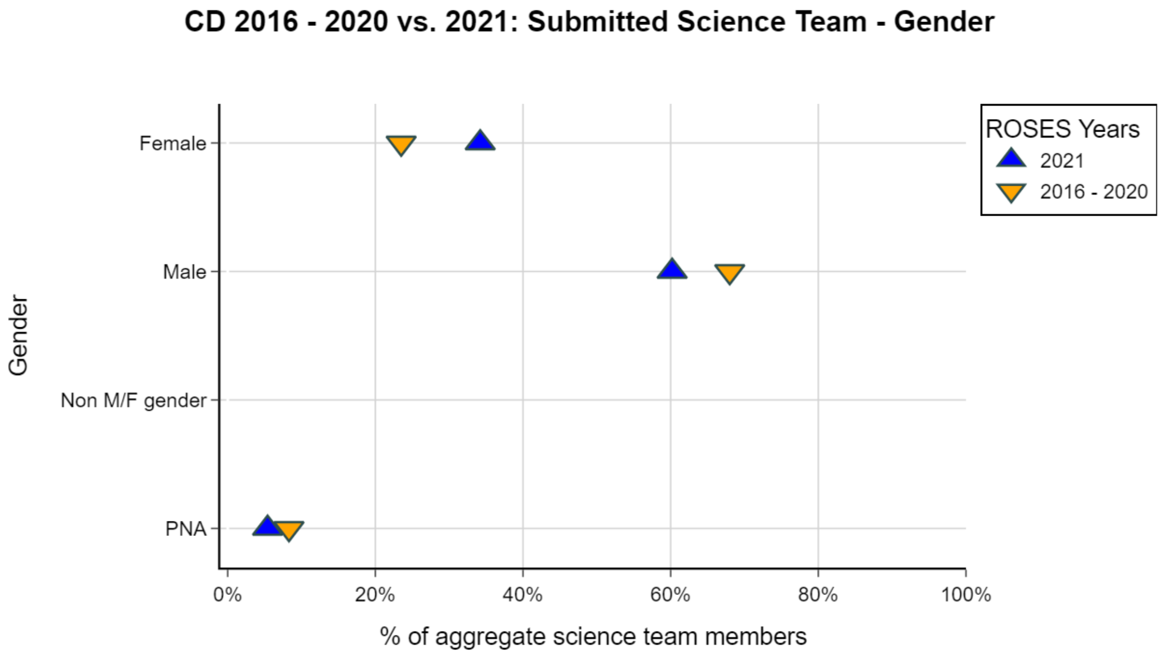
26,043 submitted proposals are included in the ROSES 2016-2021 database. Please see Appendix Table 1 to see which programs are included. The total number of proposals submitted and selected for each ROSES year and the total number of proposals submitted to each SMD Division cannot be reported due to the Office of the Chief Scientist's suppression guidelines. See *Yearbook Introduction Section 1.a.ii.1 Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information. The number of proposals rounded to the nearest hundred are included for these two circumstances to provide context. For the Cross-Divisional Research Division, there are ~1,300 submitted proposals over all ROSES years: ~1,000 for ROSES 2016-2020 and ~300 for ROSES 2021.

Instances in the science team member dataset where a science team member took the survey but selected "prefer not to answer" for all demographic survey questions:

- Submitted proposals: CD 2016 - 2020: 8% | CD 2021: 5%
- Selected proposals: CD 2016 - 2020: 8% | CD 2021: 3%

5.a.ii.2. Gender - CD Science Team

CD Science Team: Submitted Gender - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Non M/F gender (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

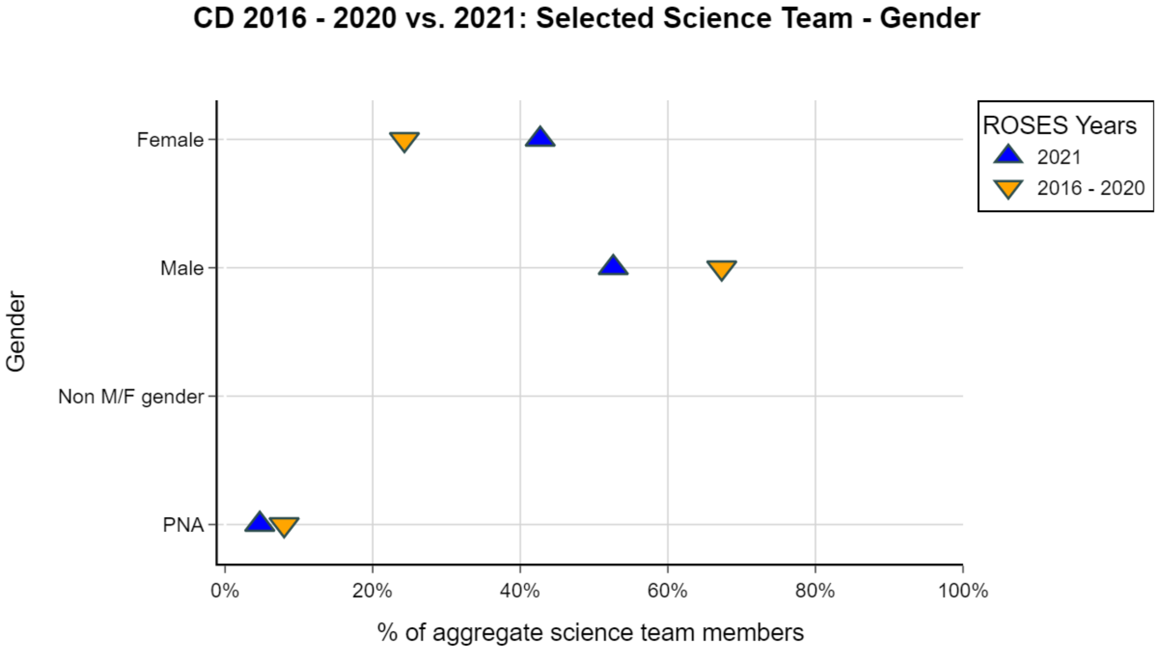
CD Science Team: Submitted Gender - Data Table

CD 2016 - 2020 vs. 2021: Submitted Science Team - Gender

Gender	CD 2016 - 2020	CD 2021
Female	24%	34%
Male	68%	60%
Non M/F gender	NR	NR
PNA	8%	5%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD Science Team: Selected Gender - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Non M/F gender (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

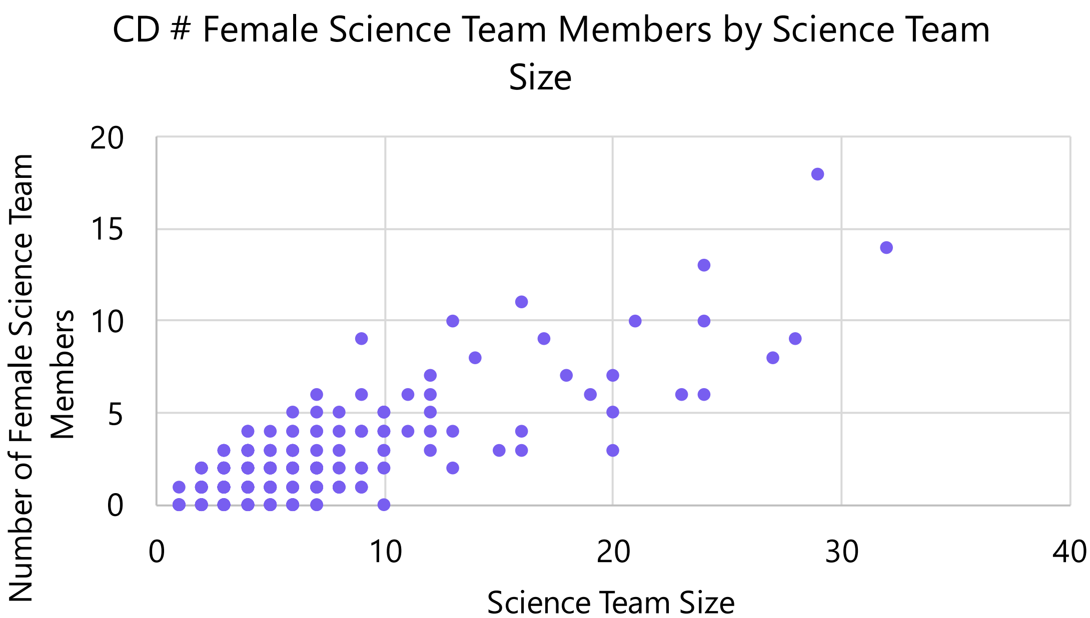
CD Science Team: Selected Gender - Data Table

CD 2016 - 2020 vs. 2021: Selected Science Team - Gender

Gender	CD 2016 - 2020	CD 2021
Female	24%	43%
Male	67%	53%
Non M/F gender	NR	NR
PNA	8%	5%

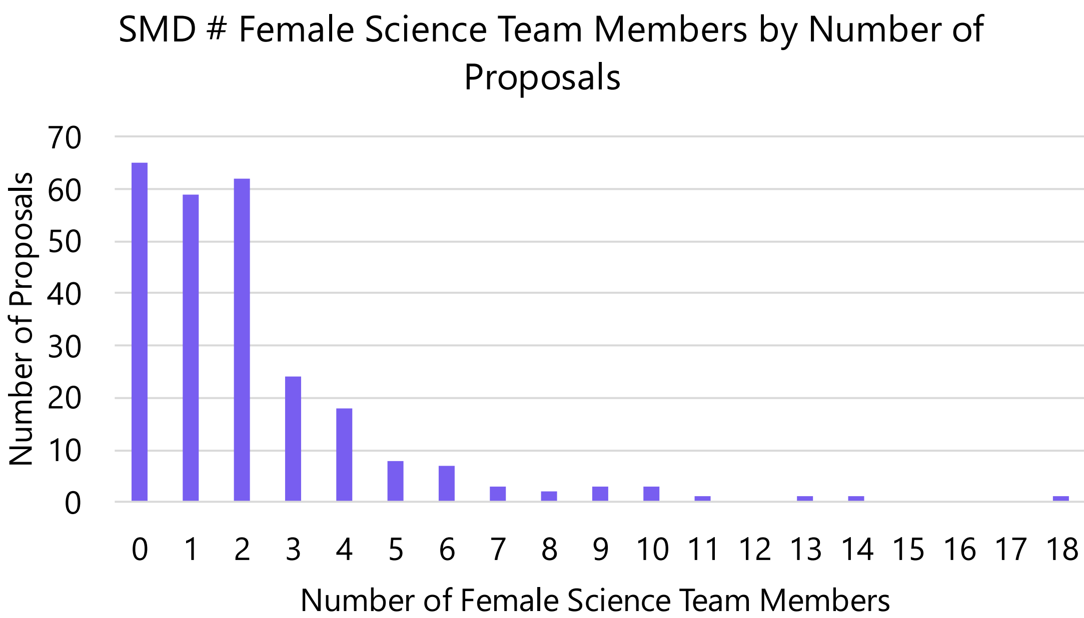
PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD ROSES 2021 Science Teams: Female Science Team Members by Science Team Size – Scatter Plot



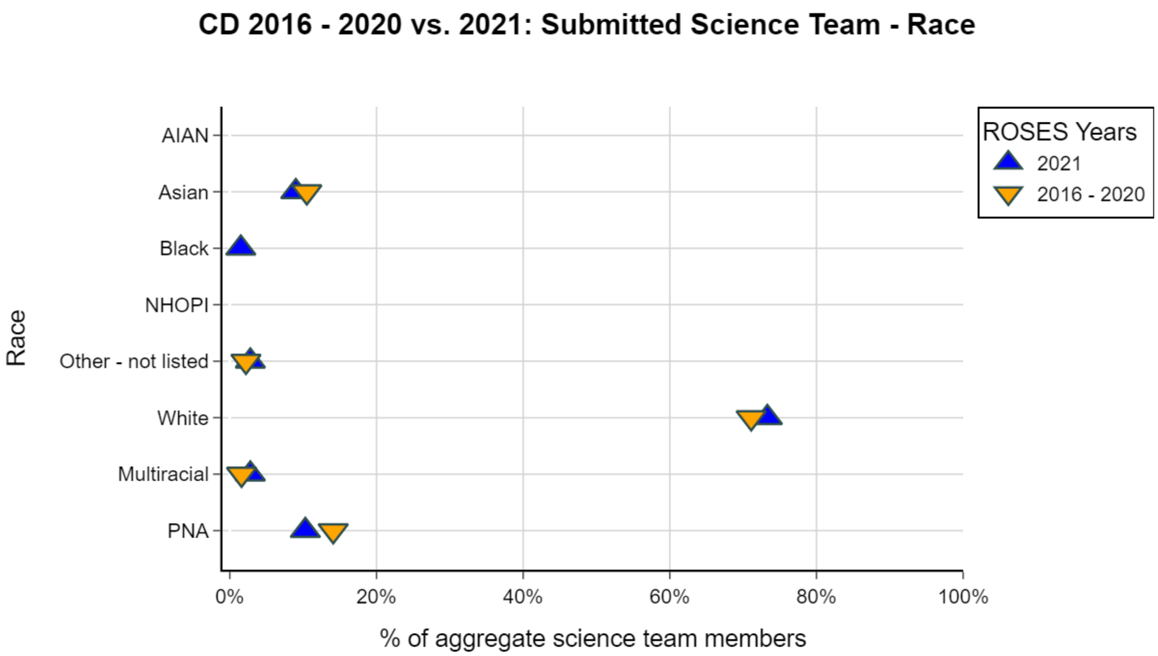
Note: 25% of proposals submitted to ROSES 2021 Cross Divisional programs did not include female researchers in their science team. 3% of proposals submitted to ROSES 2021 Cross Divisional programs only included the PI as the science team.

CD ROSES 2021 Science Teams: Female Science Team Members by Number of Proposals – Bar Plot



5.a.ii.3. Race - CD Science Team

CD Science Team: Submitted Race - Plot



AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: AIAN (All years), Black (ROSES 2016-2020), NHOPI (All years).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

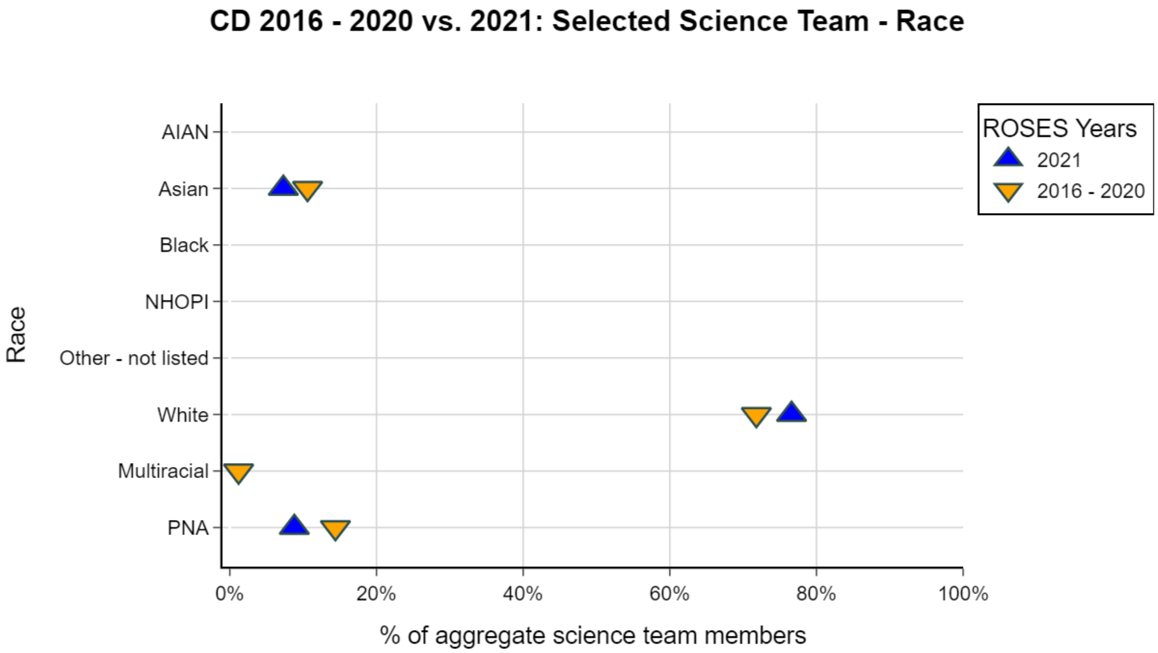
CD Science Team: Submitted Race - Data Table

CD 2016 - 2020 vs. 2021: Submitted Science Team - Race

Race	CD 2016 - 2020	CD 2021
AIAN	NR	NR
Asian	10%	9%
Black	NR	2%
NHOPI	NR	NR
Other - not listed	2%	3%
White	71%	73%
Multiracial	2%	3%
PNA	14%	10%

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD Science Team: Selected Race - Plot



AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: AIAN (All years), Black (All years), NHOPI (All years), Other – not listed (All years), Multiracial (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD Science Team: Selected Race - Data Table

CD 2016 - 2020 vs. 2021: Selected Science Team - Race

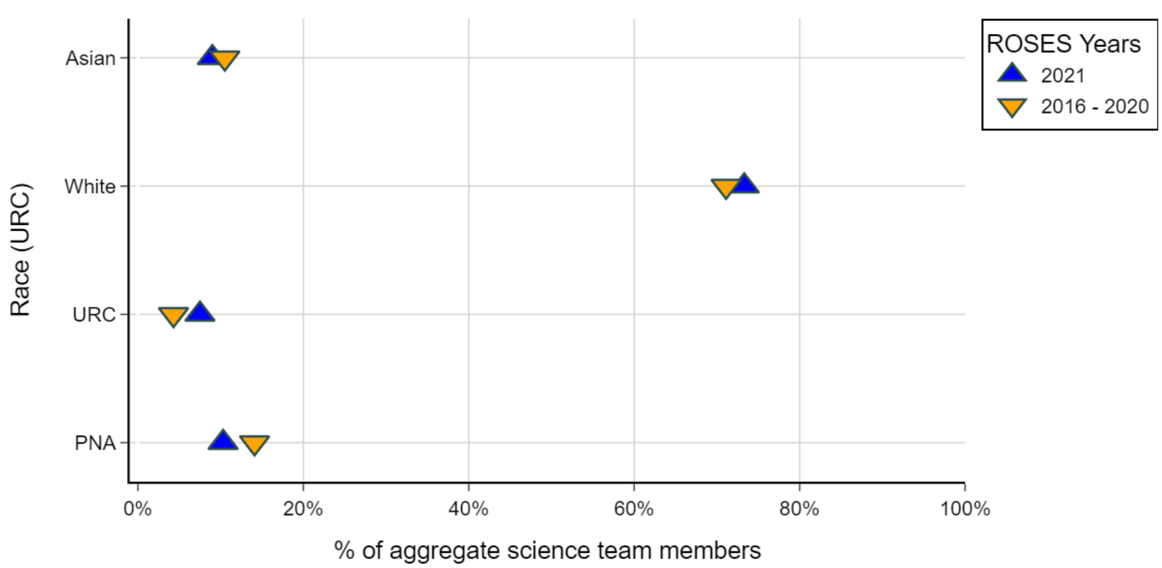
Race	CD 2016 - 2020	CD 2021
AIAN	NR	NR
Asian	11%	7%
Black	NR	NR
NHOPI	NR	NR
Other - not listed	NR	NR
White	72%	77%
Multiracial	1%	NR
PNA	14%	9%

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

5.a.ii.4. Race using Under-Represented Community (URC) - CD Science Team

CD Science Team: Submitted Race (URC) - Plot

CD 2016 - 2020 vs. 2021: Submitted Science Team - Race (URC)



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, Other. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

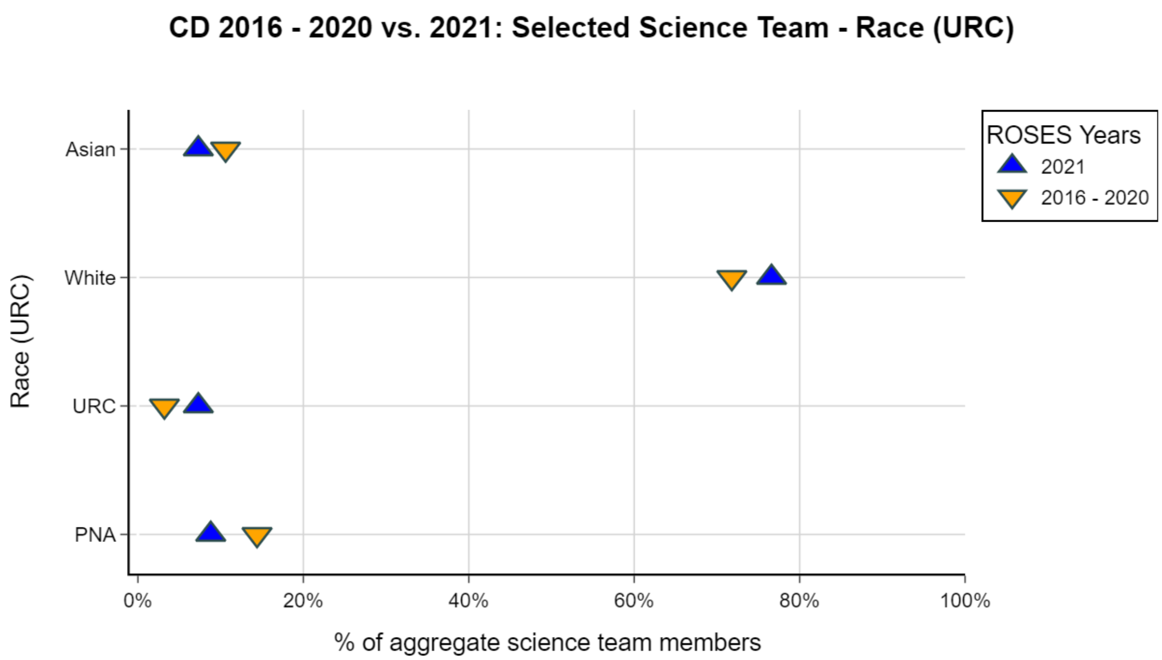
CD Science Team: Submitted Race (URC) - Data Table

CD 2016 - 2020 vs. 2021: Submitted Science Team - Race (URC)

Race (URC)	CD 2016 - 2020	CD 2021
Asian	10%	9%
White	71%	73%
URC	4%	8%
PNA	14%	10%

Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD Science Team: Selected Race (URC) - Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, Other. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

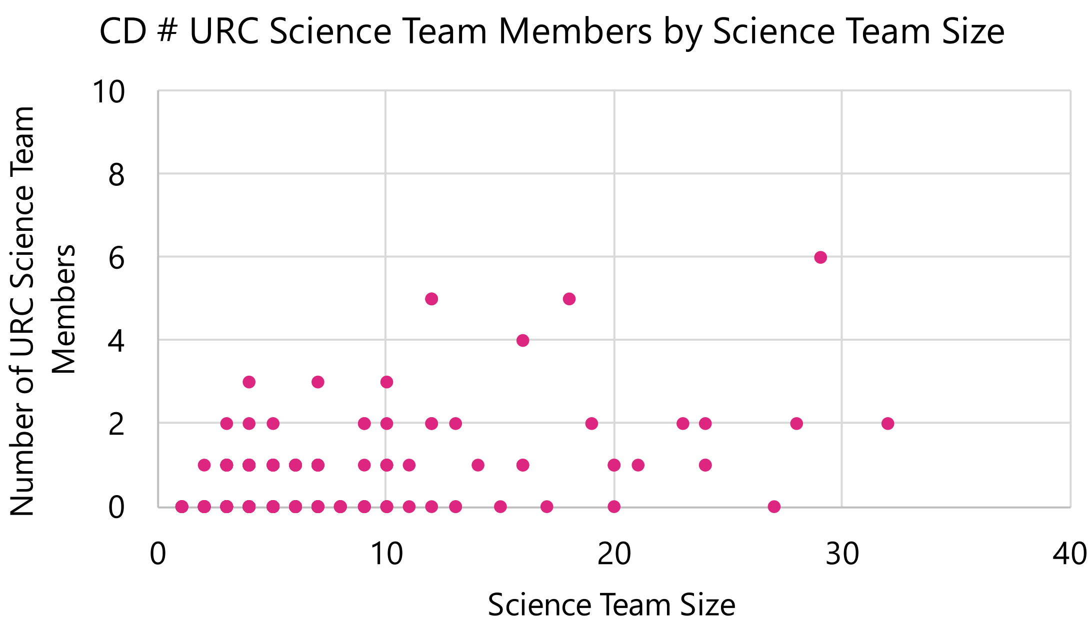
CD Science Team: Selected Race (URC) - Data Table

CD 2016 - 2020 vs. 2021: Selected Science Team - Race (URC)

Race (URC)	CD 2016 - 2020	CD 2021
Asian	11%	7%
White	72%	77%
URC	3%	7%
PNA	14%	9%

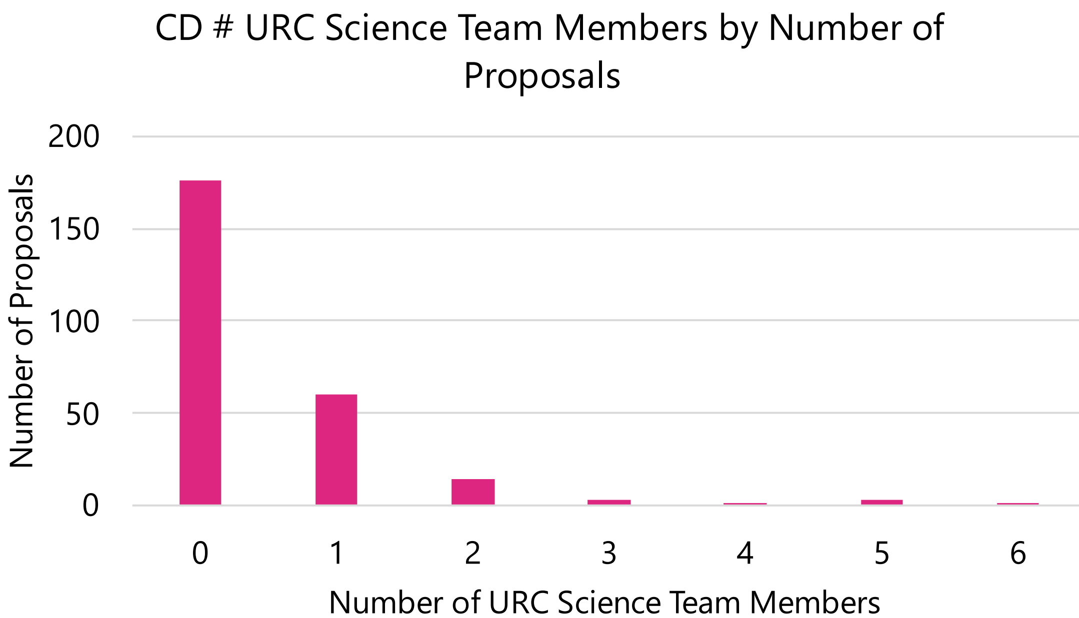
Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD ROSES 2021 Science Teams: URC Science Team Members by Science Team Size – Scatter Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, Other. | Note: 68% of proposals submitted to ROSES 2021 Cross Divisional programs did not include URC researchers in their science team. 3% of proposals submitted to ROSES 2021 Cross Divisional programs only included the PI as the science team.

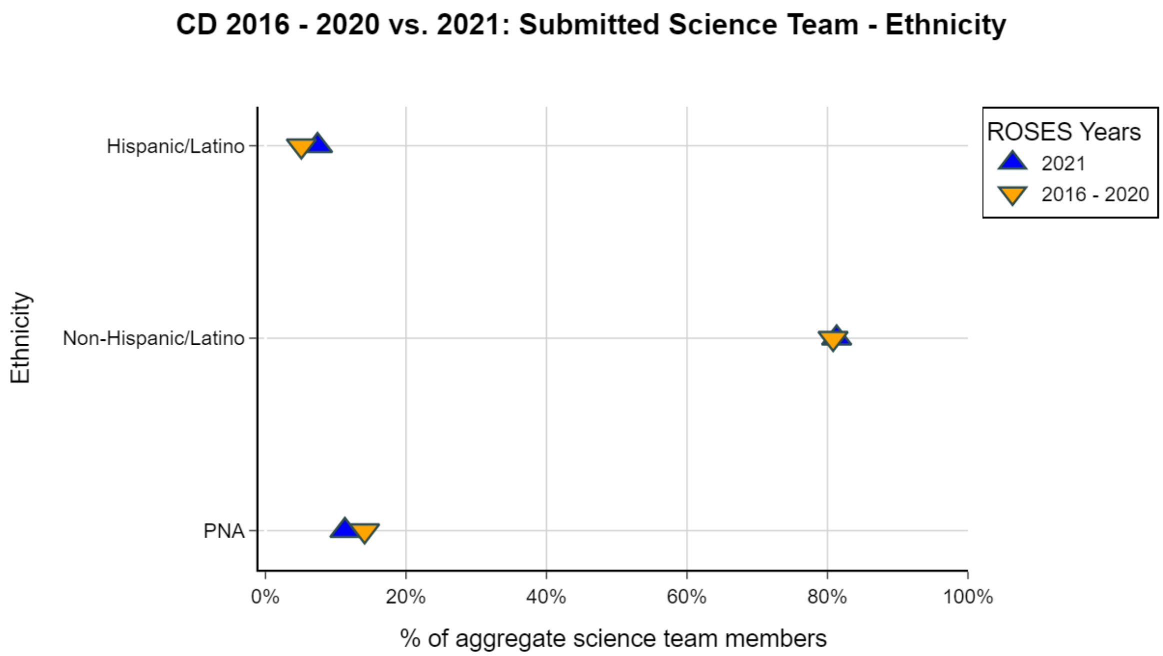
CD ROSES 2021 Science Teams: URC Science Team Members by Number of Proposals – Bar Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, Other. Note: 170 proposals did not include URC researchers in their science team. This is 66% of the total number of proposals submitted.

5.a.ii.5. Ethnicity - CD Science Team

CD ROSES 2021 Science Teams: Submitted Ethnicity - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

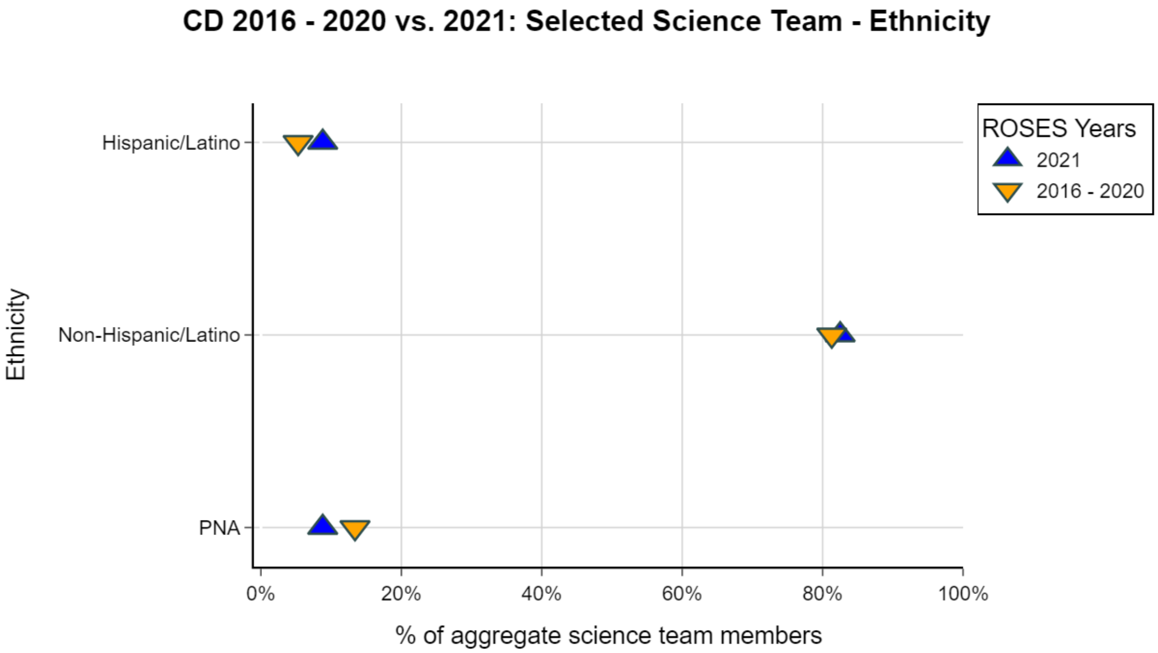
CD Science Team: Submitted Ethnicity - Data Table

CD 2016 - 2020 vs. 2021: Submitted Science Team - Ethnicity

Ethnicity	CD 2016 - 2020	CD 2021
Hispanic/Latino	5%	7%
Non-Hispanic/Latino	81%	81%
PNA	14%	11%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD Science Team: Selected Ethnicity - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

CD Science Team: Selected Ethnicity - Data Table

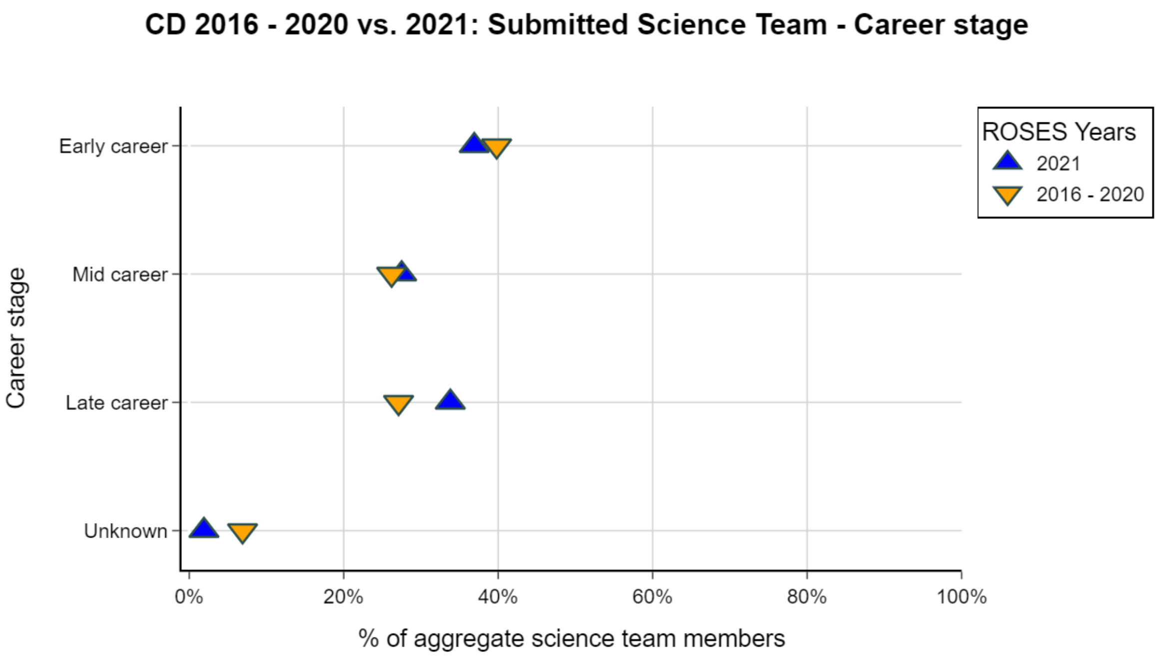
CD 2016 - 2020 vs. 2021: Selected Science Team - Ethnicity

Ethnicity	CD 2016 - 2020	CD 2021
Hispanic/Latino	5%	9%
Non-Hispanic/Latino	81%	82%
PNA	13%	9%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

5.a.ii.6. Career Stage - CD Science Team

CD Science Team: Submitted Career Stage - Plot



Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | ROSES 2016-2020 proposal data are aggregated.

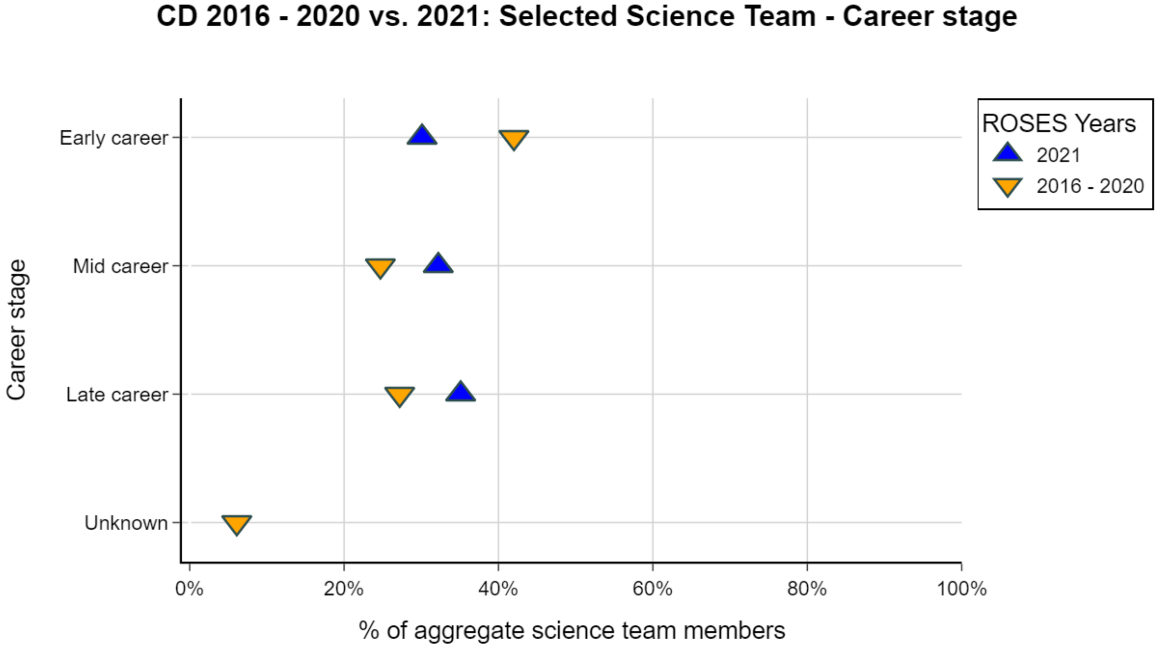
CD Science Team: Submitted Career Stage - Data Table

CD 2016 - 2020 vs. 2021: Submitted Science Team - Career stage

Career stage	CD 2016 - 2020	CD 2021
Early career	40%	37%
Mid career	26%	28%
Late career	27%	34%
Unknown	7%	2%

Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD Science Team: Selected Career Stage - Plot



Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Unknown (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

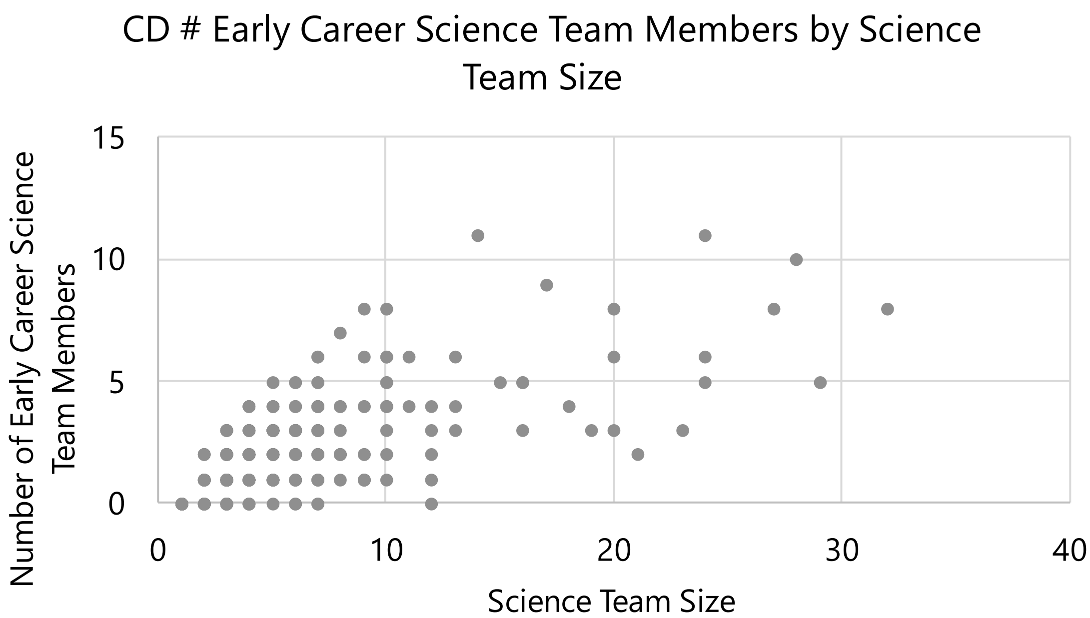
CD Science Team: Selected Career Stage - Data Table

CD 2016 - 2020 vs. 2021: Selected Science Team - Career stage

Career stage	CD 2016 - 2020	CD 2021
Early career	42%	30%
Mid career	25%	32%
Late career	27%	35%
Unknown	6%	NR

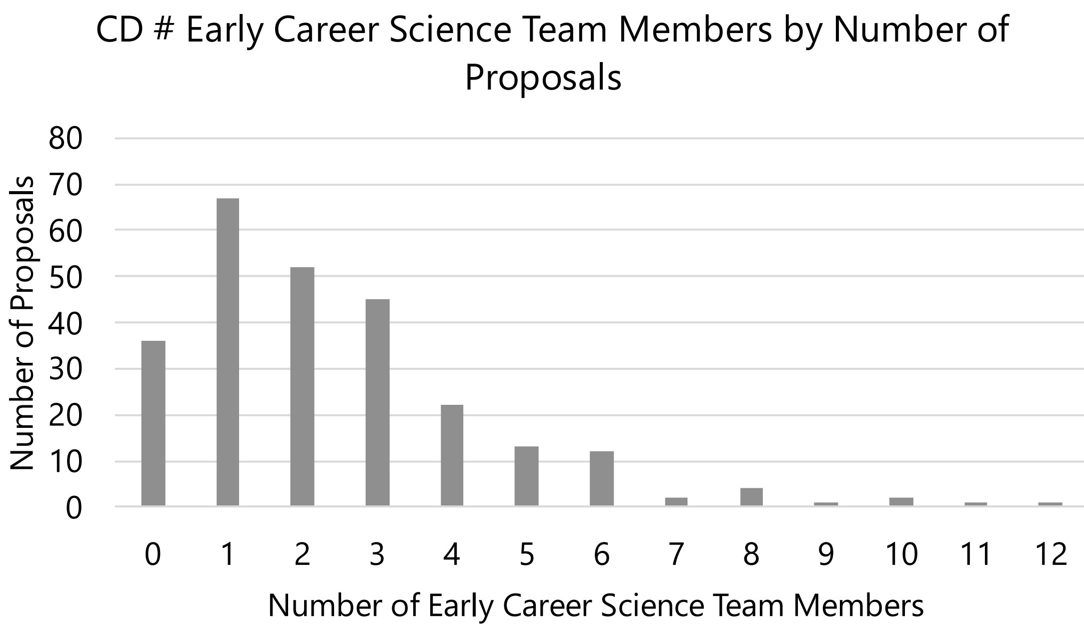
Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD ROSES 2021 Science Teams: Early Career Science Team Members by Science Team Size – Scatter Plot



Early career: < 10 years since earning final degree | Note: 14% of proposals submitted to ROSES 2021 Cross Divisional programs did not include early career researchers in their science team. 3% of proposals submitted to ROSES 2021 Cross Divisional programs only included the PI as the science team.

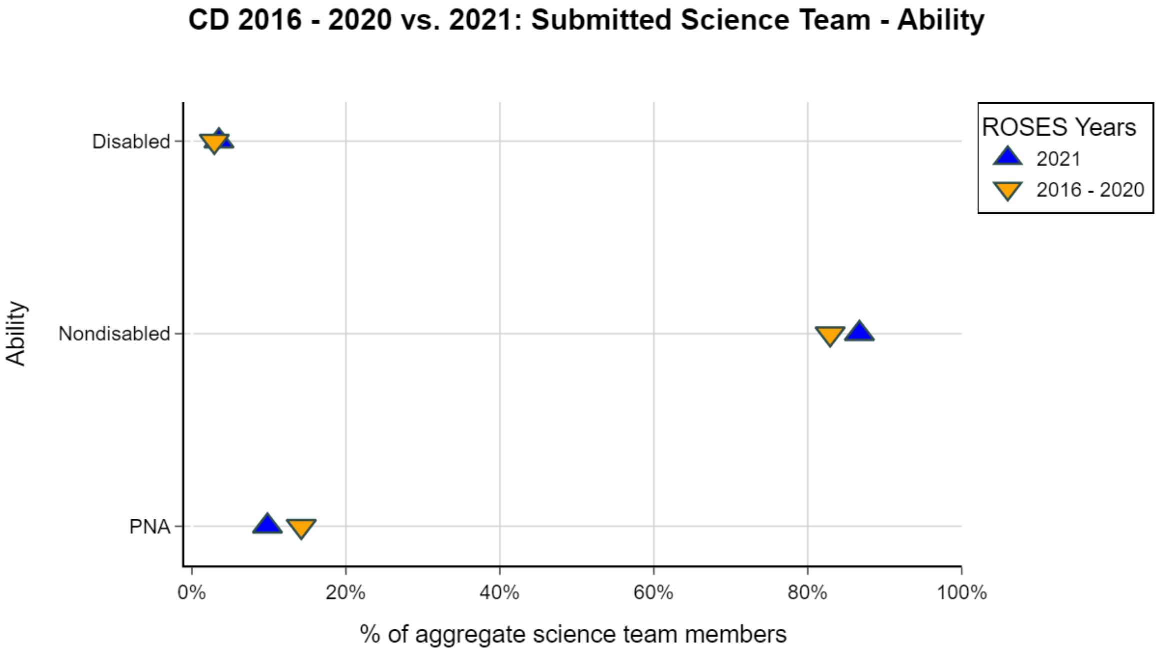
CD ROSES 2021 Science Teams: Early Career Science Team Members by Number of Proposals – Bar Plot



Early career: < 10 years since earning final degree

5.a.ii.7. Disability Status - CD Science Team

CD Science Team: Submitted Ability - Plot



Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

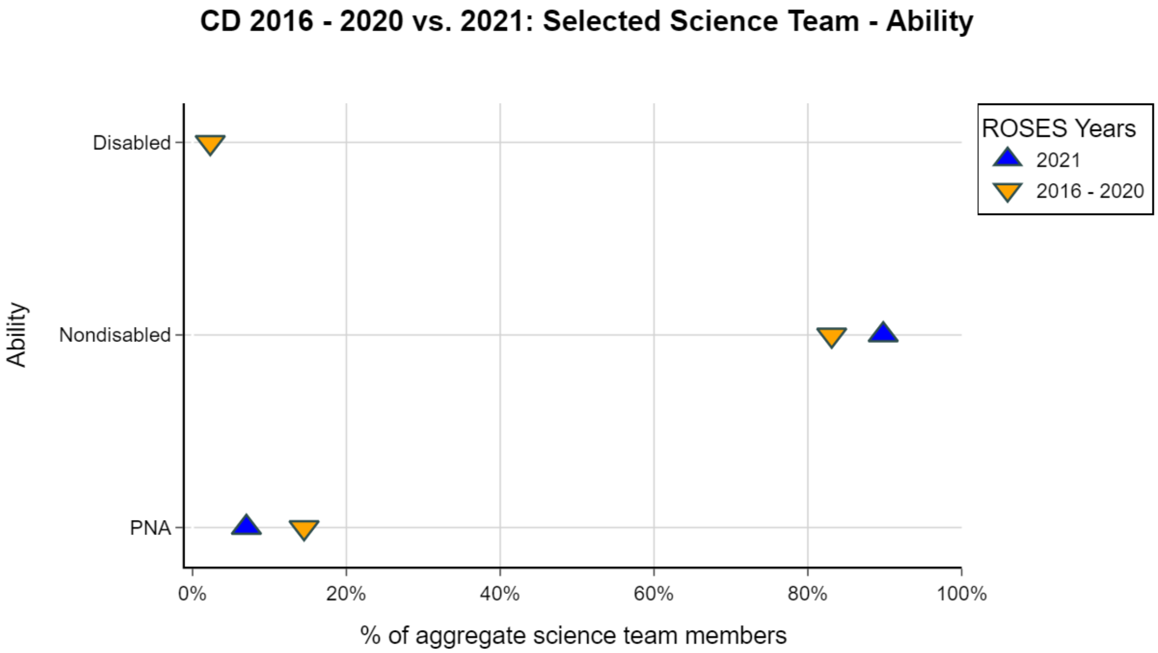
CD Science Team: Submitted Ability - Data Table

CD 2016 - 2020 vs. 2021: Submitted Science Team - Ability

Ability	CD 2016 - 2020	CD 2021
Disabled	3%	4%
Nondisabled	83%	87%
PNA	14%	10%

Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

CD Science Team: Selected Ability - Plot



Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Disabled (ROSES 2021).
See *Yearbook Introduction Section 1.a.ii.1. Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information.

CD Science Team: Selected Ability - Data Table

CD 2016 - 2020 vs. 2021: Selected Science Team - Ability

Ability	CD 2016 - 2020	CD 2021
Disabled	2%	NR
Nondisabled	83%	90%
PNA	14%	7%

Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

5.b. CD Proposal Data

5.b.i. New PI

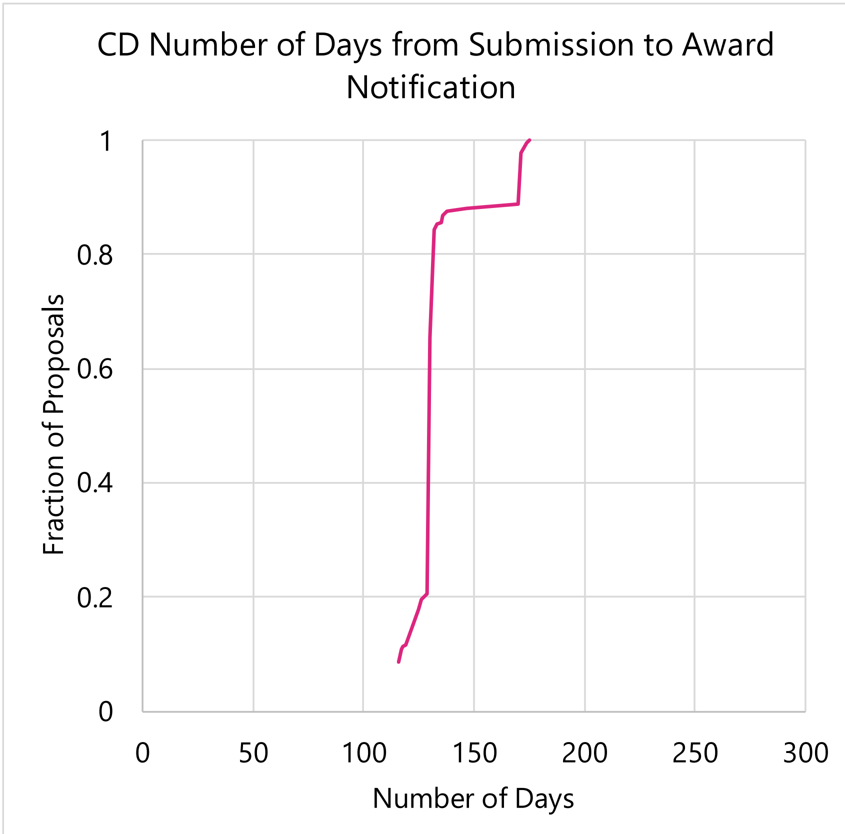
Comparison of Proposal Statistics of New PIs and Unique PIs for ROSES 2021

CD 2021	New PIs	Unique PIs	New PI %
Selected	41	48	85%
Submitted	201	237	85%
Selection Rate	20%	20%	

New PI (Division): A PI that was selected by any program in the given SMD Division in ROSES 2021 but was not selected by any program in that SMD Division in the previous five ROSES years.
New PIs Submitted: an individual submitting a proposal that would be a new PI if the submitted proposal were selected.
Unique PIs: participation of individuals and not proposals.

5.b.ii. Time from Proposal Submission to Award Notification for ROSES 2021

Number of Days from Proposal Submission to Award Notification for CD - Empirical Distribution Function



Note: Number of days from proposal submission to 80% of award notifications for CD is 132 days. SMD Policy Document SPD-22A applied to proposals submitted to ROSES 2016-2021 and included this statement: "Proposers shall receive a status notification from the Program Officer concerning their proposal no later than 150 days after the proposal due date, if selections have not yet already been made and announced."

5.c. ROSES 2021 Selection Announcements

Appendix F. Cross Divisional Research

Appendix	Program Element Name
F.2	Topical Workshops, Symposia, and Conferences
F.3	Exoplanets Research Program
F.5	Future Investigators in NASA Earth and Space Science and Technology (FINESST)
F.5.1	FINESST Astrophysics
F.5.2	FINESST Biological and Physical Sciences
F.5.3	FINESST Earth Science
F.5.4	FINESST Heliophysics
F.5.5	FINESST Planetary Science
F.5.6	FINESST Science Engagement and Partnerships
F.6	Science Activation Program Integration
F.9	Citizen Science Seed Funding Program
F.10	Payloads and Research Investigations on the Surface of the Moon

Topical Workshops, Symposia, and Conferences
Abstracts of Selected Proposals
(NNH21ZDA001N-TWSC)

The National Aeronautics and Space Administration (NASA) Science Mission Directorate (SMD) solicited proposals for topical workshops, symposia, conferences, and other scientific/technical meetings that advance the goals and objectives funded by the following Divisions: Astrophysics, Biological and Physical Science, Earth Science, Heliophysics, Planetary Science, and Science Engagement and Partnerships. TWSC-21 reviewed a total of 31 proposals and selected 27 proposals. This document lists in order of the Principal Investigator's Last Name, the Submitting Organization, each proposal's NSPIRES proposal number, title and a shortened summary, i.e. proposed event's abstract.

Kelsey Bisson/Oregon State University
21-TWSC21-0006/Ash in the Ocean: What is the Biological Response & Consequence of Volcanic Eruptions?

We are proposing an interdisciplinary working group to address key questions related to ash deposition in the ocean from a combined atmospheric / ocean perspective. There is a lack of ocean and atmospheric coupling that includes a link to broader biogeochemical assessments as well as societally relevant consequences. A quick fertilization event (e.g., a one-time eruption) may have a timescale of up to a few weeks, but any effects at higher trophic levels may persist for a year(s). At the moment, there are many studies quantifying ash in the atmosphere but very few focusing on ash in the ocean. The ocean studies that do exist focus on the short-term effects of ash on satellite [Chl] and phytoplankton, and have not considered longer term effects. We expect this working group to produce a synthetic paper that can advise future work related to ash in the ocean, based on current advancements and limitations. We will also work with stakeholders to identify their needs as well as how existing and future research may advise. We propose meeting virtually twice per month.

Donna Charlevoix/UNAVCO, Inc.
21-TWSC21-0017/NISAR Science Community Workshop

The upcoming NASA-ISRO Synthetic Aperture Radar (NISAR) mission has the potential to revolutionize 1) the primary disciplines that have been involved in planning the mission, and 2) a range of emerging scientific applications. We propose a 2.5-day workshop with the goal of encouraging and facilitating the widespread use of NISAR data across the science community. We expect that the workshop will engage around 300 people, assembled from SAR users and researchers with a demonstrated interest in using SAR data to address science questions across the solid earth, cryosphere, and ecosystems sciences, as well as other relevant science areas such as hydrology and environmental justice. The free and open catalogue of regular, reliable repeat observations at L-band will be first of its kind, making the mission attractive to a new set of users – however, the complexities of working with SAR data as well as the sheer volume of data that users will need to manage also create challenges that scientists are already starting to address with the complementary SAR data sets available from the international constellation. The workshop organizers include members of the NISAR science team as well as other community members who have been deeply involved in the development of science data products and calibration and validation plans. Among the six primary objectives of the workshop is to encourage broader and more diverse participation in the NISAR science community. We seek support for expenses associated with the venue, workshop logistics, and travel for invited speakers and some early career participants. Outcomes will include an archive of workshop presentations that will be publicly posted on the NISAR website as well as a summary report from the workshop.

Winnie Chu/Georgia Tech Research Corporation
21-TWSC21-0020/Future Of Greenland Ice Sheet Science (FOGSS) Workshop 2022–2024

A proposal to convene for three years a series of FOGSS Workshops for 2022–2024. FOGSS is designed to: 1. Merge two long-running NASA and NSF-sponsored meetings (PARCA and Geosummit). 2. Provide a unified annual workshop dedicated to assessing, coordinating, and planning synergistic Greenland Ice Sheet (GrIS) science. FOGSS will gather students, early-career and senior scientists who are investigating GrIS using ground-based investigations, airborne surveys, satellite remote sensing and numerical modeling.

Instead of the traditional presentations of completed research, to promote trans-disciplinary knowledge exchange, the three-day workshop structure of FOGSS will prioritize discussion groups, short-format results presentations, and field-planning sessions. FOGSS will be held at Georgia Institute of Technology, Atlanta, GA (2022), University of Idaho, Moscow, ID (2023), and Dartmouth College, Hanover, NH (2024). The primary meeting mode at these locations will be in-person, accompanied by audiovisual technology to support virtual live-streaming or recorded options to increase diversity and access for attendees from international or community colleges.

Henderson Cleaves/Blue Marble Space
21-TWSC21-0013/Support for Student Participation in the Virtual Triennial Meeting of the International Society for the Study of the Origins of Life (ISSOL)

ISSOL has sponsored an international congress every three years since it was founded in the late 1950s. With a dues-paying membership of ~500 scientists, it is the only international scientific society dedicated to research on the origin of life. The 19th

International Conference on the Origins of Life (aka Origins2021), the tri-annual meeting of ISSOL will take place virtually due to the COVID-19 pandemic from October 18th to 22nd. We expect approximately 300 attendees.

The meeting will consist of plenary sessions, keynote talks, invited and contributed talks and poster sessions. Lectures will range from summaries of entire fields of research, to updates on long-standing projects, to new developments that have emerged during the 3 years since the last ISSOL conference in La Jolla, USA (2017). The NASA funding will be used specifically to support attendance for approximately 100 U.S. based students and postdocs. The funds would be used to offset costs related to conference registration and on-line meeting operation. Students will be selected based on eligibility and need, and recipients will need to fill in a request form to receive funding.

Origins2021 is directly relevant to the primary goals of NASA's Astrobiology, Exobiology and Evolutionary Biology programs, e.g., "The strategy is to investigate the planetary and molecular processes that set the physical and chemical conditions within which living systems may have arisen." An essential aspect for developing the careers of young investigators is for them to interact personally with senior scientists. The event will attract outstanding scientists, and presents a unique opportunity for interactions for experienced and beginning scientists.

William Diamond/SETI Institute
21-TWSC21-0040/Astrobiology: Information Signatures of Biotic vs. Abiotic Processes

Information Signatures of Biotic vs. Abiotc Processes Frontier Development Lab (FDL) Eight Week Sprint. The FDL's 2022 eight week sprint will engage a full research team in consultation with the team leads - known as Faculty. The Faculty are domain specialists from both the astrobiological and data sciences who provide a clear definition of the 'science problem' and the 'machine learning problem'. The Sprint's primary goals are to: (1) Use Artificial Intelligence (AI) to understand the information metrics characterizing biotically-generated versus abiotically-generated patterns. (2) Produce a toolbox to test potential hypotheses relevant to the detection of life beyond Earth.

Liam Gumley/University Of Wisconsin, Madison
21-TWSC21-0039/Proposal to NASA Science Mission Directorate via ROSES Topical Workshops, Symposia, and Conferences (TWSC) program element to provide support for the 24th International TOVS Study Conference

This proposal seeks NASA support for the 24th International TOVS Study Conference (ITSC-24) to be held in Tromsø, Norway, 16-22 March 2023. The International TOVS Working Group (ITWG) brings together operational and research users and providers of infrared and microwave satellite sounding data. It is convened as a sub-group of the International Radiation Commission (IRC) of the International Association of Meteorology and Atmospheric Physics (IAMAP) and the Coordination Group for Meteorological Satellites (CGMS). The ITWG organizes International TOVS Study Conferences (ITSCs) that have met approximately every 18 to 24 months since 1983.

Through this forum, relevant experts exchange information on all aspects of the satellite infrared and microwave sounder data processing and exploitation, with a focus on inferring information on atmospheric temperature, moisture, and cloud fields. This includes evaluation of new data, processing algorithms, derived products, impacts in numerical weather prediction (NWP) and climate studies. The group considers data from all sounding instruments that build on the heritage of the TIROS Operational Vertical Sounder (TOVS), including hyperspectral infrared instruments.

Regine Hock/University Of Alaska (UAF), Fairbanks
21-TWSC21-0029/Summer school in Glaciology 2022

We propose to hold an international Summer School in Glaciology. The summer school will be held 7-17 June, 2022 in McCarthy, a small village in central Alaska with large glaciers in immediate vicinity. We will accept 28 students (about 14 from US-based institutions and 14 from abroad) and invite a few guest lecturers in addition to instructors from the glaciology lab at UAF. We have received additional funding from international organizations to cover the costs of most international students. The course will consist of a combination of lectures, computational exercises, student projects, glacier excursions, and student poster presentations. The course will include a wide variety of topics in glaciology with focus on remote sensing and modeling.

Tracey Holloway/University Of Wisconsin, Madison
21-TWSC21-0038/Satellite Data for Energy Analysis & Policy

We are requesting funds for a two-year conference project to advance applications of satellite data to energy applications, including energy resources (e.g. solar, biomass, offshore wind); energy demand (e.g. per capita electricity consumption, on-road transportation); energy impacts (e.g. emissions, air quality); and energy disasters (e.g. oil spills, black outs). Working with stakeholders in the public and private sectors, we plan to host a major conference in 2022 and a series of topical workshops in 2023. The series will launch with a conference entitled “Satellite Data and Energy Analysis and Policy;” hosted at the University of Wisconsin—Madison. With 200-300 attendees expected, the conference will be hosted by the interdisciplinary Energy Analysis and Policy (EAP) program. To support networking, engagement, and learning, the conference will include technical training, a two-day line-up of topical panels, and three follow-up workshops (likely topics: energy supply, demand, and impacts).

This initiative supports the work of the NASA Applied Sciences Program by broadening the utilization of NASA data and tools and by advancing the societal benefit from public investments in Earth Observations.

Brian Jackson/Boise State University
21-TWSC21-0019/A Workshop on Optimizing Planetary In-Situ Surface-Atmosphere Interaction Investigations

The funding requested primarily will support travel and lodging for U.S-based students and early-career scientists to attend the topical workshop, and includes requests to support remote attendance and other in-person accessibilities. Our goal is to enable science and its dissemination by facilitating attendance for individuals who may otherwise not be able to attend the conference but would greatly contribute to it.

The purpose of our workshop is to foster a multi- and interdisciplinary discussion to address key gaps regarding in-situ investigations of planetary surface-atmosphere interactions. These interactions play key roles in the climates, geology, and broad evolution of worlds across the Solar system. The workshop will bring together planetary and terrestrial scientists and engineers to blend the broad thinking required for exploring other worlds with the deep knowledge of analogous Earth-based techniques. The workshop may be held 2022 June 28-July 1 in Boise, Idaho at Boise State University.

Relevance to SMD's Goals and Objectives - The workshop will advance high-level NASA SMD goals and objectives, particularly (but not limited to) the Planetary Science Research Program, including:

- Understanding processes the occur throughout the Solar System -- Planet-atmosphere interactions operate across the Solar System, and few other categories of physical process have such widespread influence in the Solar System.
- Using knowledge of Earth’s history and life to explore habitability -- Exchange of volatiles between surface and atmosphere profoundly affects planetary climate and determines availability of habitable niches, especially on Mars.
- Enhancing scientific return of PSD missions -- The workshop will also explore novel uses and analyses of already available data from the fleet of prior NASA missions.
- Advancing laboratory-based instrument technology -- Discussion of instrumental development and application form a cornerstone of our workshop's planned science program.
- Analog studies, laboratory experiments, or fieldwork to increase our understanding of the Solar System

The workshop may feature a short excursion to a planetary analog field site, the Bruneau Sand Dunes State Park.

Daniel Jacob/President and Fellows of Harvard College
21-TWSC21-0026/The 10th International GEOS-Chem Meeting (IGC10)

This proposal solicits travel support for participants to attend the 10th International GEOS-Chem Meeting (IGC8) to be held at Washington University in St. Louis on June 7-10, 2022. GEOS-Chem is an open-source global model of atmospheric composition used by hundreds of research groups worldwide. It is centrally managed at Harvard with core support from the NASA Atmospheric Composition Modeling and Analysis Program (ACMAP). It serves NASA's mission by providing a state-of-the-science platform for the international research community to improve knowledge of atmospheric composition, including through the interpretation of NASA satellite data. GEOS-Chem also serves as atmospheric chemistry module for the NASA GEOS Earth System Model (GEOS) of the Goddard Modeling and Assimilation Office (GMAO). We are planning IGC10 as a hybrid meeting and expect ~150 in-person attendees. Funds will be provide travel support for presenters. A general outcome of the meeting will be increased capability for the GEOS-Chem community to exploit NASA data and contribute to NASA models. Specific outcomes may include (1) a prioritized compilation of model development priorities for the next two years to serve as blueprint for the GEOS-Chem Steering Committee and Support Team, (2) new foci and initiatives for the GEOS-Chem Working Groups. All IGC10 presentations will be posted on an open-access website.

Michael Jones/TMA Bluetech
21-TWSC21-0008/"Application of Earth Observation to the Ocean & Water on Land", part of 13th annual BlueTech Week

TMA BlueTech (TMA) is applying for NASA funding to support the 13th annual BlueTech Week (BTW2021) scheduled as a series of virtual events Nov. 15-19, 2021. Two and a half (Monday-Wednesday) of the five days are focused on the intersection of earth observation and BlueTech. There are expected to be a number of NASA speakers and attendees. CNES (French space agency), JAXA (Japanese space agency), and the UK Satellite Applications Catapult have agreed to organize panels/speakers alongside NASA. In addition, space agencies of other developed and developing countries are being invited to participate.

TMA plans an active outreach campaign to Minority-Serving Institutions (MSIs) with a focus on the oceans and water cycle on earth and NASA funding will be used to allow faculty and students to participate. Participation in BTW2021 provides a number of opportunities for NASA Earth Sciences including to:

- Encourage/facilitate the use of SMD mission data related to the ocean & water on land;
- Increase the efficiency of investigators through open exchange of ideas and interfacing with industry leaders developing innovative technology/service solutions to problems with special opportunity to promote more full utilization of earth observation data with "ground truthing" possible with innovative BlueTech instruments/vehicles;
- Introduce investigators to new subject areas and potential new applications;
- Promote international linkages with other space agencies and users;
- Promote STEM opportunities for under-served communities with special emphasis on faculty and students from Minority-Serving Institutions; and
- Promote job linkages/networking for young space professionals globally.

Some specific opportunities that will be addressed at BTW2021 include:
- Promote collaboration and new applications at the interface between NASA earth observation and BlueTech companies that utilize space assets for communications, PNT (Positioning, Navigation & Timing), remote sensing, weather prediction, etc.
- Promote international collaboration between space agencies related to the Blue Economy and BlueTech;
- Capacity building for young space professionals from developing countries related to earth applications (i.e. ocean and water).

Kirk Knobelspiesse/NASA Goddard Space Flight Center
21-TWSC21-0002/The Advancement of POLarimetric Observations (APOLO-2022) conference

Advancement of POLarimetric Observations (APOLO) is a biennial conference devoted to the use of polarimetry for remote sensing of the earth from space. NASA and NASA-funded scientists and engineers are key players in the development of this type of passive remote sensing, which is used to observe the atmosphere, oceans, and surfaces of the Earth and other planetary bodies. Several NASA missions that will make polarimetric observations are in development and will be launched in the coming years. Space agencies in Europe and Asia also develop polarimetric remote sensing missions, and it is through international exchange of ideas that the community has advanced from the early days of the first POLarization and Directionality of the Earth's Reflectances (POLDER) mission, a joint French and Japanese effort launched in 1996. We would like to bring APOLO to the Washington, DC area in July of 2022. Our team includes NASA GSFC, the University of Maryland, Baltimore County (UMBC), the Naval Research Laboratory (NRL), and a logistics contracting company. Our schedule represents a COVID-19 associated delay of six months from the original plan of Fall, 2021.

The scope of APOLO has included discussion of the theory of polarimetric remote sensing, optimization of observation quality and information content of these measurements, and algorithm development for the retrieval of geophysically relevant parameters. Hosting this meeting in the United States would be highly relevant to NASA's goals, and timely given the ongoing mission development. It also would bring the world's attention to NASA's polarimetric remote sensing efforts, and provide an opportunity for cross fertilization with the international community.

John Lessard/American Association For Aerosol Research
21-TWSC21-0003/NASA Funding Support for the American Association for Aerosol Research (AAAR) 2021 Annual Conference

We are requesting NASA support travel for 30 undergraduate or graduate students to attend the 2021 American Association for Aerosol Research (AAAR) Annual Conference from October 18th-22, 2021. Students who are an author or co-author on an accepted scientific abstract would apply for the grant through the conference website, and the number of selections would be based on the number of applicants and the amount of funds available. If the number of applicants exceeds the funds available, selections will be based on 1) the quality of the student, 2) the impact of the student's research, and 3) establishing a diversity of student backgrounds at the meeting.

The 2021 AAAR Annual Conference directly relates to NASA's Earth Science goals and objectives through improving our understanding of aerosols and how they relate to air quality, radiation impacts, and climate. Since 1982, this conference has provided a forum for sharing and discussing cutting edge research across a variety of aerosol-related disciplines. Through the proposed grant to subsidize student participation, NASA will benefit the scientific community by helping to give the next generation of aerosol scientists the opportunity to interact with these cutting-edge scientists and engineers as well as to present their own ideas.

Hanne Mauriello/University Corporation For Atmospheric Research (UCAR)
21-TWSC21-0018/Space Weather Workshop

The Space Weather Workshop is a premier meeting for the Space Weather community to share information and network with the industry, academia, and government agencies. Building on previous meetings, held separately for space weather researchers and users, the first Space Weather Workshop was held in 1996. It has now evolved into the nation's leading conference on all issues relating to space weather. The conference addresses the remarkable diverse impacts of space weather on today's technology. The program highlights space weather impacts in several areas, including communications, navigation, spacecraft operations, aviation, and electric power. The conference also will focus on identifying the highest priority needs for operational services that can guide future research and identifying new high-value research capabilities that can be transitioned into operations. The workshop supports significant student participation that will help to develop the next generation of space weather professionals. Diversity and inclusion are important and growing aspects of the Space Weather workshop to bring together the best professionals and ideas from the Space Weather enterprise. Data about demographics will be collected at the time of registration but will only be used to report back to our funding agency. The workshop fosters communication among researchers, space weather service providers, and users of space weather services. Researchers have the opportunity to discuss relevant research in many areas of the space environment. Researchers will be partnering with other agencies and academic community to develop models, observing systems, and technologies to enhance national preparedness.

Charles Miller/Jet Propulsion Laboratory
21-TWSC21-0033/4th Carbon from Space Workshop

The impact of anthropogenic emissions of carbon dioxide and methane on climate is a critical societal concern. Quantifying, understanding, and articulating the feedbacks within the carbon-climate system are crucial if we are to employ Earth system models to inform effective mitigation regimes that would lead to a stable climate. The 4th Carbon from Space Workshop (to be convened virtually from 18-21 October, 2022) will highlight recent advances in space-based measurements of carbon exchange and its component processes—photosynthesis, respiration, and biomass burning— and how remote sensing adds key spatial and process resolution to the existing in situ systems needed to provide enhanced understanding and advancements in Earth system models. The Workshop will review progress against the recommendations from the 3rd Workshop (2015) and establish a strategic plan of research and development activities to guide programmatic actions and investments on terrestrial carbon research for the 2023–2028 time frame.

We request travel funds to support five early career scientists to travel to the ESA/ESRIN Science Hub to help develop the workshop report and 2023-2028 strategic plan.

Jessica Mitchell/University Of Montana, Missoula
21-TWSC21-0005/Broadening the use of NASA datasets by the species distribution modeling community

University of Montana Spatial Analysis Lab proposes to host a virtual workshop on broadening the use of NASA datasets by the species distribution modeling community. The workshop will consist of a series of six virtual sessions for 12 workshop participants. Participants will identify NASA data products that capture important predictive distribution variables, but are under-used because of accessibility, interoperability, or other technological challenges. The group will perform evaluations and develop recommendations using a traceability matrix approach. Evaluation criteria includes information management and technological needs, coverage, use of spatial and temporal scales that are appropriate to the underlying processes of interest, workflow automation, and integration with longer-term time-series trends (30 years). The group will prioritize candidate variables based on level of effort to modify products or technologies for dissemination and use, and potential for significantly boosting accuracy results for a wide-range of species distribution models across the US. There is potential for significant impacts under the Citizen Science for Earth Systems Program by establishing pathways between biodiversity citizen science, species distribution modeling, and expanded use of predictor variables derived from NASA remotely sensed data products.

Adina Paytan/University Of California, Santa Cruz
21-TWSC21-0032/Goldschmidt 2022 Geology Through a Cultural Lens – Diverse Perspectives on the Natural World

Goldschmidt 2022 will be in Hawaii. To emphasize the connection between "Geochemistry and Society", Theme 15 in 2022 will focus on Geology through a cultural lens, i.e., diverse perspectives on the natural world. Each afternoon, the Theme will feature a dedicated oral session open to the public with several invited talks followed by a panel discussion on selected topic. Speakers and panelists will include key experts and representatives from Hawaii and the region with local knowledge. These special lectures will be recorded to provide an online resource for the community and beyond. The sessions will be open for local students from the university, high schools catering to underserved populations and the community.

Support from NASA is requested for the partial covering of travel costs for key invited speakers who would traditionally not participate in this conference. The specific special sessions are designed to increase the awareness and training of meeting participants (on site and remotely) on several topics of relevance to the scientific community and society at large and to encourage contribution to the current Earth and Space science challenges facing science and society in the 21st century and to amplify the voices of indigenous communities and local knowledge for designing global solutions. The event will share Papakū Makawalu knowledge - the dynamic Hawaiian world view of the physical, intellectual, and spiritual foundations from which life cycles emerge. Earth, environmental, and space science (EESS) is evolving rapidly. We are observing Earth, the solar system, and space at all scales. Environmental sensors and satellites are producing data at high temporal resolution and at both global and local scales. These data and the science derived from them have huge societal impacts that will continue to increase as a growing global population taxes Earth's finite resources, alters chemical cycles, and enhances anthropogenic impacts such as climate change and degraded ecosystems.

Mikel Robinson/International Association of Wildland Fire
21-TWSC21-0031/IAWF Fire & Climate Conference

The International Association of Wildland Fire (IAWF) is hosting the Fire & Climate Conference in Pasadena, CA and Melbourne, Australia. Fire and Climate 2022 will bring attention to one of the most important forces shaping wildfire and better prepare how we can focus and respond to this formidable challenge in the new decade. Fire & Climate will highlight NASA assets and science for wildfire science and management and serve as a professional in-person and virtual space for direct networking of NASA scientists and sponsored researchers with wildland fire professionals, managers, and policymakers.

Fire and Climate 2022 will feature insights, case studies, innovations and opinions from around the world to begin to form a collective, global approach to the wildfire challenge. California often has been at the forefront of innovation in wildland fire management. Holding a conference in California will leverage the lessons learned and adaptive behaviors that are emerging after the 2018 Camp Fire and the 2020 and 2021 fire seasons that will benefit the international wildland fire community.

The Fire & Climate Conference 2022 is relevant for researchers and practitioners with expertise in a range of wildland fire areas including air quality monitoring and/ or regulation, land management, fire responders, public health, fire weather, climate change and forecasting, among others. The conference will leverage the lessons learned in extreme wildfire seasons around the globe and discuss emerging adaptive behaviors to benefit the entire international wildland fire community. During the conference, participants will discuss the latest scientific advances, explore how scientific information is being put to practical use in the field and utilized to inform public policy, as well as consider gaps and limits in our current understanding.

Nancy Ryan Gray/Gordon Research Conferences, Inc.
21-TWSC21-0015/2022 Microbiology of the Built Environment Gordon Research Conference

This proposal is written to support the June 2022 Gordon Research Conference (GRC) on the Microbiology of the Built Environment (MoBE) to be held at Proctor Academy in Waterville Valley, NH. This meeting was originally planned for June 2020; however, it was postponed in response to COVID-19. Gordon Research Conferences are prestigious international scientific meetings operated and partly funded by the non-profit organization of the same name. The Microbiology of the Built Environment Conference was added to the list of GRC's in 2017, and the theme of this meeting is "Microbes at the Interface of Water, Air, and Human Health in Built Environments". Specific objectives include the following: (1) host a scientific conference on the frontiers of microbiology, the built environment, and human health and, (2) create connections at the interfaces of the scientific, engineering and medical communities within the MoBE field.

The MoBE field seeks to understand microbiomes of the built environment, built environment design, and built environment use converge to impact human health and wellbeing. Due to the inherent interdisciplinary nature of this pursuit, this field has integrated multiple fields including microbiologists, environmental engineers, architects, physicians, epidemiologists, and others. Prior to establishing the 2018 MoBE GRC, there was no standing meeting that served to unite these fields, and this remains the case today. This event is necessary to exchange research results, build collaborations from researchers in disparate fields, and to foster this interdisciplinary community of researchers by

1. Continuing to be a pre-eminent forum for scientists, engineers, and medical professions working with the MoBE fields.
2. Providing a specific focus on building interfaces, especially the interface between water, air, and human health.

We have worked with NASA Space Life and Physical Sciences Research and Applications Division's Space Biology Program to ensure adequate conference input, including four NASA-funded or affiliated speakers and one NASA-affiliated moderator. A major outocme is the continued development of the MoBE community via a standing meeting venue to enable the exchange of knowledge relevant to the MoBE field. In addition to established researchers, we plan to use raised funds to support trainee (i.e., student and postdoc) attendance at the MoBE GRC.

Nancy Ryan Gray/Gordon Research Conferences, Inc.
21-TWSC21-0034/ 2022 Ocean Mixing Gordon Research Conference and Seminar

We request NASA funding to support the Gordon Research Conference on Ocean Mixing. Turbulent mixing results from complex and chaotic motions that span a large range of spatial and temporal scales. Turbulent mixing controls transport of heat, freshwater, dissolved gasses, and pollutants. It is crucial for ocean biology because it both determines the flow field for the smallest plankton, and it sets large-scale gradients of nutrient availability. It also is central to understanding the energetics of the ocean and reducing the uncertainties in global circulation and climate models: recent work has shown that the spatial and temporal non-homogeneity in deep-ocean mixing may play a critical role in climate; understanding the physics that drives the distribution of deep-ocean mixing intensity is critical. Mixing is one of the greatest sources of uncertainty plaguing todays models with impact of great societal relevance. The purpose and scope of this conference is to provide a forum for discussion of the rapidly evolving field of ocean mixing. Emphasis is threefold: observations of mixing in the world, new insights into dynamics that control mixing rates, and impacts of mixing on regional and global circulation and budgets.

Through NASA support, this Ocean Mixing GRC will: (1) Provide a forum to improve the broader community's understanding of turbulent mixing in the ocean, and with it a variety of deep and broad implications for everything from climate change to global nutrient patterns that underlie our fisheries. (2) Help our scientific community be the most vibrant and inclusive it can be. The ocean mixing community has historically suffered from poor diversity, which, while improved in recent years, still needs an influx of new people, a broadening of ties amongst domestic and international collaborators, and increased interdisciplinary interactions. NASA support will be used to expand the demographic, professional and geographic diversity of participants by supporting attendance of under-represented and under-resourced groups who stand to benefit from the intellectual environment and networking opportunities of the GRC format.

Robyn Sanderson/University Of Pennsylvania
21-TWSC21-0028/Towards Real-Time Galactic Dynamics

For more than a century, astronomers have modeled the positions and velocities of Galactic stars to infer their accelerations. However, thanks to Gaia's groundbreaking observations, there are now many indications that our Galaxy has a dynamic history, implying that kinematic estimates of the mass density (which assume equilibrium) differ significantly from the true mass density in interacting systems. To move forward in understanding our dynamic Galaxy, we need direct acceleration measurements of individual stars. Advances in technology have begun to make it possible to directly measure these tiny accelerations with at least four independent techniques: pulsar timing, direct astrometry, eclipsing binary timing, and extreme-precision radial velocities.

We propose a week-long workshop to bring together experts from these disparate branches of observational astrophysics with experts in theoretical Galactic dynamics for the first time, to define the new subfield of direct acceleration measurement. The workshop will establish the viability of these four methods of directly measuring the acceleration of stars in the Galaxy, and produce a review paper on the topic. For each method, we will: (a) define the greatest challenges and confounders for precision acceleration measurements, (b) estimate the number and extent of sources that can be probed, and (c) identify future developments that will improve the value of that method. Additionally, in discussion with theoretical dynamics experts, we will determine the precision and number of sources needed to map different parts of the Galaxy, and how these measurements can distinguish between different models of dark matter physics and galaxy formation. This work represents a novel way to probe the nature of dark matter, answering the NASA SMD scientific goal ”How does the Universe work?” Measuring Galactic accelerations will make use of space-based photometry from Kepler, Hubble, and Roman, and the EPRV component will extend the science output of instruments such as NEID.

The workshop will be held at the Lorentz Center in Leiden, Netherlands, on 25–29 July 2022, and will host about 50 participants: about 10 from each of the four detection methods, and 10 from Galactic theory and dynamics. We have contacted a diverse group of researchers who are working across these areas and have received a tremendously positive response to our proposed program, including from dozens of early-career researchers (ECRs). As is fitting for a brand-new astrophysics subfield, we plan to center the contributions of junior scientists in both the discussions at the workshop and the resulting review paper.

This proposal requests funds to address a salient challenge to the impact of our workshop: the ability of ECRs from the United States to attend. We request funding from NASA to support travel costs for 15 US-based researchers to attend and present at the workshop, and contribute to the associated paper. We will prioritize support for ECRs and others who may not otherwise be able to attend this workshop due to limited funds. We anticipate that this relatively small investment will have an outsize impact on the careers of upcoming astrophysics researchers in the US, and strengthen connections across borders during this important and field-defining event.

David Schimel/Jet Propulsion Laboratory
21-TWSC21-0009/The 11th International Carbon Dioxide Conference (ICDC)

The 11th ICDC is expected to be a hybrid meeting. The physical venue for the meeting will be in the greater Washington DC area, to allow maximum participation, in proximity to the US government and many Non-Governmental Organizations, as well as a major international airport. The actual venue remains TBD but candidates include both of DC's major conference venues. Only venues that comply with discrimination and disabled access guidelines will be considered.

The proposed meeting will bring together the carbon science as well as carbon policy and management communities. Much of the meeting will be a state-of-the-science conference but ICDC 11 intends to also engage the carbon reporting, policy and management communities. This will provide an improved dialogue between the carbon communities with a focus on understanding the scientific capabilities as well as the needs, priorities and open questions from the policy and management. The scientific communities (observations, models and process studies) will share new discoveries with the policy and management communities. Both groups should benefit from mutual learning about the latest innovations, gaps in knowledge and policy requirements across research and applications.

Paul Secor/American Society For Gravitational and Space Research, INC.
21-TWSC21-0012/2021 Annual ASGSR Conference - Revised

Proposal to support the 2021 Annual Meeting of the American Society for Gravitational and Space Research The American Society for Gravitational and Space Research (ASGSR) seeks support for its 2021annual meeting. This request includes partial support that includes plenary symposia, workshops, information sessions, results from NASA sponsored researchers in biological and physical sciences, travel support for young researchers (middle/high school, undergraduate and graduate), and the Ken Souza Suborbital Spaceflight Competition. This year ASGSR will be hosting two preconference workshops.

The 37th annual meeting will be hosted at the Baltimore Inner Harbor Hotel, Baltimore, Maryland November 3-6, 2021. This venue allows ASGSR to locate the meeting in different geographical locations to facilitate travel for all members of the gravitational physical and life science community. This meeting provides the U.S. community with unique opportunities to utilize the International Space Station (ISS), other gravitational platform research, and ground research collaborations with scientists around the world.

ASGSR is committed to diversity and inclusion and this year the society intends to invite 25 students from HBCU and Other Minority Serving Institutions to attend the conference. The ASGSR will use funds requested in this proposal to ensure that there will be an experienced community of space biologists, physical scientists, engineers, technologists and students to utilize the ISS National Laboratory, and enable missions beyond low Earth orbit. Many of the symposia are directly relevant to the convergence of life and physical sciences. The meeting will include at least 30 technical sessions.

A special workshop geared towards all students will be held during the meeting, entitled "Meet the Scientists". Student poster sessions will be held during the meeting, one for undergraduate and graduate researchers, and the second for middle school and high school researchers. Meeting support will enable our Society to provide a venue for presentation and discussion of discovery and applied research in space biology and physical sciences. Funding this meeting is especially critical during this time of increased research in microgravity sciences. The NASA grant will enable the Society to support information exchange between scientists, engineers, and future science PIs. Providing open communication among scientists and engineers across the country and the world is a major objective of the ASGSR annual meetings.

Alex Sessions/California Institute of Technology
21-TWSC21-0025/Support for International Geobiology Course

The International Geobiology Course is a 5-week intensive training course for graduate students working at the intersection of earth science, microbiology, and astrobiology. We admit 16 students, mostly early-mid Ph.D., from around the world via competitive admissions. In 2022 the course will includes 16 days of field-based research in the Owens Valley based out of Mammoth; 8 days of lab rotations at Caltech where the students learn techniques such as DNA amplification and sequencing, secondary-ionization mass spectrometry (SIMS), X-ray spectroscopy, biomarker analysis, and isotope-ratio mass spectrometry; and 11 days of data analysis and lectures at the Wrigley Marine Science Center on Catalina. The course includes four separate projects, and two 1-day mini-symposia on “The Geobiology of Mono Lake”, and “The evolution of metabolism”. The course is directed by Alex Sessions, Woody Fischer, and Victoria Orphan (all at Caltech), but we bring in nearly 25 outside faculty as field and lab instructors, speakers, and project advisors. This represents a remarkable networking opportunity for the students, as they become acquainted with some of the biggest names in the field and build their professional networks in a casual environment.

The Course is directly relevant to NASA's Astrobiology goal of "training the next generation of astrobiology researchers". We teach them field and laboratory techniques, concepts, and research questions that overlap strong with those being addressed by the Exobiology and Astrobiology programs, and believe that many of our students will go on to conduct NASA-relevant research including, potentially, the study of returned Martian rocks. Many of the past Course alumni have conducted relevant astrobiology research, and all three of the course directors have been involved in multiple NASA-funded projects. This year the Course will take place from June 12 – July 19, 2022.

Shelley Stall/American Geophysical Union (AGU)
21-TWSC21-0023/Ethics in Use of Artificial Intelligence (AI) and Machine Learning (ML) in Science

The primary objective of this proposed event is to engage a multi-disciple group of Artificial Intelligence (AI) and Machine Learning (ML) stakeholders and others to develop a set of principles and responsibilities for using artificial intelligence and machine learning in Earth and environmental science-focused research. We feel this work will be relevant to related scientific disciplines as well.

AGU proposes to convene a series of three virtual workshops that includes broad stakeholders to gather inputs and to develop a set of community-based principles, practices, and responsibilities. The final outcomes and recommendations will be included in the scientific Code of Conduct (https://www.agu.org/Learn-About-AGU/About-AGU/Ethics). In the first workshop we will review existing material and identify gaps. By the end of the first workshop, we will establish working groups to develop recommendations around specific topics or needs that are identified (e.g., reporting uncertainties, ensuring replicability, identifying risks and unintended consequences). Working groups will present their progress and receive feedback during the second workshop. Final material will be presented during the last working group with discussion moving toward adoption and implementation by participants and their organizations.

In preparation for the first workshop, AGU will conduct a survey, with the support of Joel Cutcher-Gershenfeld, co-founder of WayMark Analytics, that will be used to gain momentum at the first workshop so that participants can have a reliable resource for alignment and gaps between the use of AI/ML by researchers and the perceived ethics behavior in order to build community around this effort.

AGU commits to adding these new principles and responsibilities to their existing Scientific Code of Conduct and working to communicate these broadly. It is hoped that the relevant stakeholders will also add to the communication and outreach. They will be selected in part based on having influential roles in relevant organizations.

Alexandra Tyukavina/University of Maryland, College Park
21-TWSC21-0033/A joint-workshop to develop community good practices and product accuracy protocols for cropland and crop type products by the Committee on Earth Observation Satellites working group

There has been increased cooperation between the Committee on Earth Observation Satellites (CEOS) and the Group on Earth Observations (GEO) in the framework of a global stock-take of current space agency capabilities and future needs to inform the international data and information needs for the United Nations Framework Convention on Climate Change (UN FCCC) and Intergovernmental Panel on Climate Change (IPCC) Agriculture Forestry and other Land Uses (AFOLU) agenda and UN 2030 Sustainable Development Goals (UN SDGs). The proposed workshop builds on this cooperation and is being called jointly between the international CEOS Working Group on Calibration and Validation (WGCV), Land Product Validation (LPV) subgroup, Land Cover focus area and the international GEO Global Agricultural Monitoring (GEOGLAM) program’s Essential Agricultural Variables (EAV) working group (GEOGLAM EAV).

The proposed workshop will involve substantial participation by interagency partners and practitioners. Participants will be invited from the remote sensing research community that are producing cropland extent and crop type products, interested private sector entities that are starting to generate related products, and the product users community. Joint funding for the workshop is being requested from the NASA’s Science Mission Directorate (SMD) Research and Analysis (R&A) and Applied Sciences (AS) Programs. The workshop will be hosted by the International Center for Geospatial Innovation at the University of Maryland. The workshop will extend NASA’s on-going participation and contribution to both CEOS and GEO.

David Williams/Arizona State University
21-TWSC21-0022/Planetary Data Training Workshops, 2022-2024

The objective of this proposal is to fund a series of Planetary Data Training Workshops during a 24-month period in 2022-24, at four institutions from the former NASA Regional Planetary Information Facility (RPIF) Network, as well as at two other national conferences each year. These Workshops, which would focus on planetary data management, planetary Geographic Information Systems (GIS) training (ArcGIS, open source GIS, and JMARS), ISIS3 for image processing, and SOCET SET-Ames Stereo Pipeline for digital elevation model (DEM) production, would be open to all members of the U.S. planetary science community, from undergraduate and graduate students to postdocs and early career scientists to established professional scientists.

These Workshops would be distributed throughout the 12-month period each year, and may be distributed geographically across the United States to enable greater access. Workshops are organized by institution as separate tasks and with separate budgets, so that NASA can descope specific training if funding is limited without non-selection of the whole proposal. In the interests of supporting diversity, equity, and inclusion, two travel grants FOR EACH EVENT would be funded to support participation by planetary scientists from underrepresented communities.

This proposal is submitted to address the need to establish planetary data training workshops to support the US planetary science community, as recommended by the Planetary Data Ecosystem Independent Review Board (Besse, 2021). We emphasize that the goal of this proposal is to establish a mechanism to enhance planetary data training for the US planetary science community, and to leverage the existing staff and resources of the recently sunset RPIF Network nodes before they are irretrievably lost. By funding a series of planetary data training workshops, NASA will enhance the use of planetary data from the Planetary Data System, and will enhance the scientific return of PSD missions by enabling new analyses of data collected by those missions by members of our community. Furthermore, as articulated in the NASA Science Strategy for the Science Mission Directorate, “Science 2020-2024: A Vision for Scientific Excellence”, these proposed workshops would “Encourage and facilitate the use of SMD mission data” and “Increase the efficiency of investigators through advanced scientific/technical training” as noted in that document.

Exoplanets Research Program
Abstracts of selected proposals
NNH21ZDA001N-XRP

Below are the abstracts of proposals selected for funding for the XRP Exoplanets Research Program (PI) name, institution, and proposal title are also included. 171 proposals were received in response to this opportunity. On September 27, 2021, 22 proposals were selected for funding.

Adams, Elisabeth/Planetary Science Institute
Finding the Next Doomed Worlds

Overview

Ultra-hot Jupiters (UHJs), defined here as giant planets with orbital periods under 2 days, are so large that tidal effects play a critical role in their formation and long-term dynamical stability. The population of hot-Jupiter host stars is younger than the general population of either field stars or planet-hosting stars, suggesting that many giant, close-in planets quickly inspiral or are otherwise destroyed. One UHJ, WASP-12 b, has been observed to have a decreasing orbital period, corresponding to a remaining lifetime of 3 Myr and a stellar tidal dissipation parameter $Q_*' = 1.8 \times 10^5$ However, even relatively rapid decay such as WASP-12 b demonstrates takes many years (10+) to observe, requiring observations over a long time span and across many instruments. UHJs are also relatively rare among planets, and the possible range of tidal dissipation parameters is unknown, making it hard to predict which particular UHJs might be decaying on human observable time scales. This proposal will observe 400+ transits of 38 UHJs over four years to provide a population of precisely timed objects, and will reveal how close to the brink these doomed worlds are.

Methodology

We will observe 38 UHJs using three sites in the northern and southern hemisphere, using mostly moderate-aperture, roboticized telescopes to acquire hundreds of transits with midtimes accurate to 1-2 minutes. We will update the transit ephemerides, so that future transits may be more accurately predicted. Combining four years of new data with literature data will give most of our target UHJs 10+ years of observations, which we will search for deviations from constant periods. If WASP-12 b is typical, we would expect some of the population we observe to have detectable orbital decay during the course of this proposal. If none is detected, than we can place constraints on the allowed $Q_\star^\prime$ value, providing the first empirical estimate of this fundamental property for a broad range of stars hosting UHJs.

Significance

We will monitor a population of bright (V<13), deep (>0.9\%), transiting ultra-hot-Jupiters for deviations from constant period. This population is extremely valuable for many future research projects, including (but not limited to): high-precision atmospheric observations, possibly of escaping atmospheres, with JWST and other telescopes; theoretical modeling of how Q_*' varies with planetary and stellar properties; and investigations into the formation and evolution of systems with giant, close-in planets.

Relevance

This proposal directly addresses three of the four XRP goals:
(1) "Detection of exoplanets and/or confirmation of exoplanet candidates";
(2) "Observational characterization of exoplanets, their atmospheres, their interactions with their host stars, or specific host star properties that directly impact our understanding of exoplanetary systems"; and
(4) "Improvements to our understanding of the origins of exoplanetary systems."

Bakos, Gaspar/Princeton University
The Big-Planet Small-Star Survey: Exploring Planet Formation Around the Smallest Stars

Objectives:

The scientific objective of the proposed research program is to significantly expand the small sample of transiting giant planets known around M dwarf stars, and to use this sample to explore giant-planet formation, and the properties of those planets, around stars that are much smaller than our Sun.

Methods:

We propose to achieve this objective by leveraging existing data from the HAT ground-based transit surveys and the NASA TESS mission, and by analyzing new data expected to be obtained by these projects over the three year proposed period of performance. We will extract image subtraction light curves for 8 million M dwarfs observed in the TESS Full-Frame Images from Cycles 1-3, increasing the sample of M dwarfs with TESS light curves by a factor of 100, and we will search these for transiting planet candidates. Assuming a theoretically-motivated low intrinsic occurrence rate of giant planets around M dwarfs, we expect to identify some 400 candidate transiting giant planets around M dwarfs, of which 200 may be real systems. If the occurrence rate is higher, as hinted at by some observations, than many more will be found. We will also re-process the existing HAT data, accounting for proper motion and filtering rotational variability from the light curves, and will search these light curves for transiting planet candidates that were missed by earlier analyses that were not tailored to M dwarf host stars. This effort will find the highest priority candidates, which have exceptionally deep transits, and will take advantage of the higher spatial resolution of HAT compared to TESS. We will combine the TESS and HAT light curves and search for candidates with periods longer than 15 days. We will reduce new observations from HAT and TESS to light curves, and search these for transiting giant planet candidates around. M dwarfs. We will carry out RV and photometric follow-up observations for dozens of candidates per year, expecting to confirm approximately 10 new transiting giant planets around M dwarfs each year. Finally, we will determine the transit detection efficiency for finding giant planets transiting M dwarfs from TESS and HAT, and our confirmation follow up efficiency, to determine the population statistics for these planets.

Perceived Significance:

Currently very few giant planets are known around M dwarfs, primarily due to the faintness of the host stars. By finding many more such systems, determining their population statistics, and comparing these to prior studies of giant planets around higher mass stars, we will be able to explore how the formation of giant planets depends on host star mass. Specifically we will test a key prediction of core-accretion models that giant planets should be much less common around M dwarfs than around higher mass stars. We will also explore whether effects such as giant planet radius inflation also occur for giant planets around lower mass stars. Finally, due to the very deep transits enabled by the large planet size and small host star size, the planets discovered through this effort will be prime targets for subsequent atmospheric characterization using JWST or other NASA facilities.

Batalha, Natasha/NASA Ames Research Center
Towards High Metallicity: Integrated Composition-Dependent Molecular Opacities for Modeling Super-Earth to Neptunian Atmospheres

One of the key findings regarding exoplanet science is that majority of the detected close-in planets from Kepler fall within the super-Earth/sub-Neptune regime 1-3.5 Earth Radii and have no representation within our own Solar System. Planet formation models of these systems suggest broad compositional diversity in this radius regime, with a high likelihood for large atmospheric metal content 100-1000xSolar. Our ability to unlock the mysteries of this new class of planet hinge on our ability to link the spectral observations to theoretical models, and then our ability to link those models to fundamental molecular and atomic opacities. However, there is a critical lack of data that is required to compute opacities and the subsequent theoretical atmosphere for high-metallicity atmospheres. This is because high-metallicity atmospheres are expected to contain larger fractional quantities of H2O, CO, CO2, and CH4, relative to H2-dominated systems that have been the focus of majority of previous observing campaigns. Therefore, they require fundamentally different pressure-broadening parameters that are currently lacking. Nevertheless, ignoring the impact of these parameters will lead to errors in the calculation of the planet's energy budget, as well as errors in the ultimate atmospheric spectra.

We aim to fill this gab in data and compute compositionally diverse and publicly opacities that we will use to create high-metallicity atmospheric models. Critically, this three-year proposal includes four main integrated components. 1) Aggregate and evaluate available pressure-broadening coefficients for the key atmospheric absorbers in different expected broadening gas mixtures relevant to high-metallicity atmospheric composition; 2) Calculate pressure broadening data and their temperature dependence for key absorbing molecules with no experimental data; 3) Combine the aggregated/calculated pressure-broadening coefficients with the latest molecular line lists in order to generate a homogeneous publicly-available, composition-dependent opacity database for high-metallicity exoplanet atmospheres in a timely fashion; and 4) Integrate the newly computed composition-dependent, pressure-broadened opacity data into exoplanet radiative transfer models in order to refine our understanding of the physical process that shape high-metallicity atmospheres.

Results from our ``proposed investigations in Task #1-2 ... have significant impact on the field of exoplanetary science, through the ... collection and interpretation of laboratory data". One crucial output

of our proposal is composition-dependent molecular opacities which are the required inputs for modeling exoplanet atmospheres and interpreting the telescope data. Our proposal has ``laboratory, theoretical, or modeling components ... [and it] clearly describe[s] how results will ... improve interpretation of existing [and future observational] data".
 This proposal will also respond to the NASA XRP broad objective by leveraging the ``Observational characterization of exoplanets, [and] their atmospheres".

Eastman, Jason/President and Fellows of Harvard College
MINERVA: A Dedicated, Global, Precise Radial Velocity Machine for Follow-up Observations of Transiting Planets

We propose to use the two dedicated and robotic MINiature Exoplanet Radial Velocity Arrays (MINERVAs) to validate, confirm, and characterize planets discovered by the NASA Transiting Exoplanet Survey Satelite (TESS) mission using Doppler Tomography (DT) and Precise Radial Velocity (PRV) measurements.

 MINERVA-Australis atop Mt Kent in Queensland, Australia and MINERVA-North atop Mt Hopkins in Arizona, each have a high-resolution Kiwispec visible wavelength spectrograph, coupled to four Planewave 0.7-meter telescopes, and both have demonstrated the ability to obtain the measurements required by this proposal. Together, they can follow-up candidates from the entire sky.

 TESS is an all-sky survey of bright stars, and is delivering thousands of transiting exoplanet candidates. However, there is a severe shortage of ground-based instruments with the radial velocity precision needed to follow up those discoveries. The number of new and interesting planet candidates already discovered by TESS require a number PRV measurements that greatly exceeds the time budgets of currently available observatories. This shortage is the rate-limiting step in realizing the full benefits of \textit{TESS} for exoplanetary science.

 DT observations yield a valuable measurement of the alignment between the stellar spin axis and planet's orbital axis. DT observations require continuous PRV measurements during the entire transit window plus some baseline on both sides. While MINERVA's ability to do DT observations on an individual target is not unique, its cost effectiveness and flexible scheduling is in a class of its own, which enables DT observations on a scale that enables truly unique science.

 We will double the number of systems with precisely measured spin-orbit alignments, providing a unique insight into the formation and evolution of planetary systems as a function of the planet properties and environment. We will also vet, confirm, and characterize 350 additional TESS candidate exoplanets.

Faherty, Jacqueline/American Museum of Natural History
Read Between the Lines: Determining Atmosphere and Bulk Compositions for Planetary Mass Objects Using Spectral Retrievals

Directly-imaged exoplanets are laboratories for in depth atmospheric studies of worlds formed beyond the solar system. They resemble what Jupiter looked like in the solar system's infancy, and techniques for studying their properties are critical stepping stones along the path towards interpreting extrasolar terrestrial planets. In the coming era of the James Webb Space Telescope (JWST) and beyond, increased wavelength coverage and spectral resolution will enable us to more deeply characterize their atmospheres and investigate the connection between chemical composition and planetary formation and evolution. However, in order to maximize the scientific output from all collected data, we must be prepared with well calibrated tools.

Atmospheric retrievals are one of the most powerful techniques for solving questions about the physics and chemistry at play in planetary atmospheres. They were originally developed to handle the wealth of mission data for solar system planets and then modified to tackle transmission and emission spectroscopy of extrasolar worlds.

Over the last decade, nearly 30 retrieval codes have been developed to characterize exoplanet atmospheres via thermal emission, transmission, and reflected light spectra. However, retrieval codes are rarely compared and most are proprietary, often leading to different results in the literature when analyzing the same spectrum. Each code uses different assumptions and approaches, such as different opacity databases, P-T profile parameterizations, and cloud treatments. These varying assumptions can significantly impact the resultant atmospheric properties derived, especially for high signal-to-noise datasets. With the wealth of directly-imaged exoplanet and analogous brown dwarf spectra from JWST forthcoming, a critical examination of underlying retrieval assumptions is vital to ensure reliable atmospheric properties are derived. In order to do this we have assembled a team of exoplanet and brown dwarf experts to:
(1) Explore the impact various assumptions and approaches have on retrieved properties using synthetic data with 3 different retrieval codes.
(2) Apply our findings to a sample of 10 objects inclusive of directly imaged exoplanets and their analogous Teff brown dwarfs.
(3) Robustly decouple temperature, gravity, composition, and cloud properties for all objects.
(4) Compare and contrast the results between retrieval codes to develop a best practice for interpretation and formulation.
(5) Investigate the diversity in thermal structure, cloud properties, and intrinsic composition (e.g. C/O ratio) of the sample to glean insights into what formation mechanisms are at play among the objects.

As a community product of this proposal, we will create a guided data challenge based on our benchmark sample and encourage other teams with retrieval codes to compare and contrast their results. The work proposed here will be crucial for planning and interpreting exoplanet direct imaging studies with JWST and Roman.

Kraus, Adam/Univ. of Texas - Austin
Gaia Unveils the Perilous Lives of Planets in Binary Star Systems

The majority of all solar-type stars form with a binary companion, and while binary systems are likely hostile sites for planets to grow and survive, nonetheless even some very close binary systems do host planets. Past observational biases in exoplanet discovery have left the frequency, properties, and provenance of planets in binary systems largely unconstrained until Kepler. These demographic questions are especially crucial for estimating the planetary content of many of the nearest stars (Alpha Cen, Sirius, 61 Cyg, 40 Eri) that also host stellar companions on solar-system scales and are high-priority targets for NASA direct imaging missions. The impact of binarity is also a crucial input to measuring eta-Earth. If some systems are inhospitable to planet occurrence, then they will pull the inferred value of eta-Earth across all systems downward, even if the true rate is higher in more hospitable environments. The binarity of planet-host stars also has crucial implications for the inferred properties of the planets. The flux of a binary will dilute the transit depth of a planet, leading to systematically underestimated planetary radii. Understanding this potential bias in the radius distribution is particularly crucial for the Kepler sample because its long time baseline and high sensitivity make it the most robust planetary demographic sample for the foreseeable future.

Many Kepler targets remain unobserved with resolution beyond the seeing limit, and even most candidate planet-host stars were only observed with adaptive optics on small telescopes (e.g., RoboAO; resolution ~0.2 arcsec or 100 AU at 500 pc). The majority of binary companions therefore remain undiscovered. However, the Gaia revolution offers a new opportunity to identify likely binaries in the Kepler sample, based on the presence of excess noise in the astrometric fit. This noise results from PSF mismatch between the default fitting model (one star) and the real double-profile of binary systems. We demonstrate that Gaia is so stable this mismatch emerges even for very tight pairs (~0.04 arcsec, inside lambda/D in the near-IR for the largest telescopes) with several magnitudes' contrast. However, the Gaia spacecraft analyzes data on-orbit and only downlinks the results, so Gaia data does not reveal the actual separation and contrast of the binary.

We propose a multi-stage program to efficiently survey all Kepler planet hosts and false positives, plus an equal-size control sample. We therefore will probe the influence of binarity on planet occurrence and correct the errors in planetary properties that result from flux dilution. We already find that among the ~7000 Kepler Objects of Interest (including candidates and false positives) and 3500 control stars, only ~10% show excess astrometric noise, indicating that the other 90% are free of companions down to a tight limit. We are now pursuing observing campaigns for these likely binaries, consecutively observing each candidate with increasing spatial resolution (smaller telescopes like WIYN/NESSI, and then Keck/NIRC2 and Gemini/`Alopeke) until the companion is resolved. This strategy reserves expensive large-aperture observations for only the targets that require it. We therefore are efficiently building a sample with resolution limits as if they had all been observed on Keck or Gemini, but at a tiny fraction of the cost, achieving a sample >10 times larger than previously achieved. Our program will remove the systematic biases on planetary demographics that result from binary star contamination and directly probe planetary demographics within the binary stars that make up the majority of all stars in the Milky Way.

Lupu, Roxana/Bay Area Environmental Research Institute, Inc.
The UV Life of Extrasolar Planets

The vast majority of exoplanet research is focused on the infrared portion of the spectrum, using transit, secondary eclipse, and phase curve observations. This spectral region contains most of the thermal flux of the planet and molecular absorption lines that can be observed either in thermal emission or reflected light. However, multiple other non-thermal chemical and physical processes occur and can be observed at shorter wavelengths. At blue optical and ultraviolet (UV) wavelengths, scattered stellar radiation replaces the thermal continuum, while the highly energetic UV radiation also leads to photodissociation, photoionization, haze formation and drives atmospheric escape. These processes have a profound impact on both the long-term evolution of planetary atmospheres and their detectable signatures, as well as on the potential habitability of the planets. However, atmospheric modeling and characterization across the electromagnetic spectrum is lagging behind. As multiwavelength observations of exoplanet atmospheres become more common, coupling these different regimes in our models also becomes increasingly important.

Recent white papers for the Astro2020 decadal survey have discussed these phenomena and identified the study of exoplanet atmospheres in the UV as essential for their characterization ([113], [25], [44]). We propose to build for the first time a library of exoplanet spectra covering the infrared to far-ultraviolet spectral range, while taking into account all the radiation-driven processes that affect it, by using and updating a set of tools already at our disposal. This library is necessary to inform the development of the UV-capabilities of future flagship missions, such as LUVOIR/HabEx, and the related design decisions which will take place within the next 5 years. Having a pan-chromatic exoplanet spectral library will be needed to coordinate observations with different instruments and develop retrieval tools that use the synergy between observations at multiple wavelengths to break degeneracies among model parameters. Our spectral library will span a range of planet types and compositions, from hot Jupiters to rocky planets. We acknowledge the vast diversity of exoplanet atmospheres, and thus we plan that this 3-year project will both cover some of the most important types, as well as form the basis for future work that will expand this library of models. Since atmospheric modeling in the optical and infrared is comparatively mature, our proposed work will focus on extending these models into the ultraviolet. While detailed models have been developed separately for the optical/infrared and the UV part of exoplanet spectra, this work aims to bring together both sides into a comprehensive story. Our goals are: 1) to perform 1-step atmospheric modeling from the infrared (IR) to the far-ultraviolet (FUV) taking into account actual measured stellar spectra and radiation-induced physical and chemical processes that involve high energy radiation; 2) to generate high resolution spectra from IR to the FUV, which will inform the interpretation of data from upcoming missions and the design of new instruments in the next 5 years; and 3) to investigate the effects of XUV-UV-driven processes and stellar flares on the overall structure and response of the atmosphere. The last goal will make use of recent measurements of flare spectra and help better understand the properties and evolution of the numerous exoplanets discovered around M-dwarfs. This proposal is based on identified community needs and will provide a library of several thousand models and spectra that will be made publicly available.

Lynch, Benjamin/University of California-Berkeley
Observationally Constrained Modeling of the Origin and Impacts of Exoplanetary Space Weather

OBJECTIVES: Detection of over 4700 exoplanets suggests that close-in, rocky exoplanets of magnetically active G, K and M dwarfs should be exposed to high stellar coronal X-ray and extreme ultraviolet (XUV) and large stellar wind mass fluxes. The Kepler and TESS missions have revealed frequent superflares on cool G--M planet-hosting dwarf stars, providing a mechanism by which host stars could directly influence the physical and chemical evolution of exoplanetary atmospheres. Solar studies suggest that large flares are accompanied by the eruption of magnetized coronal plasma referred to as coronal mass ejections (CMEs). While stellar superflares can be directly detected and characterized in XUV, optical, and radio wavelengths, the signatures of stellar winds and superflare CMEs remain elusive and require detailed theoretical modeling. Our major science questions are:

1.) What are the coronal XUV emission and stellar wind mass fluxes from active G--M dwarfs?
2.) How does the evolution of the magnetic field and stellar atmosphere trigger stellar superflares? What is the nature of the stellar flare--CME relationship and what are their observational signatures?
3.) How are exoplanetary space weather impacts driven by the host star's XUV emission, ambient stellar winds, superflares and their associated CMEs and energetic particle fluxes?

The science goals of the proposed interdisciplinary study are to use available HST, XMM-Newton, TESS, NICER and spectropolarimetric observations of active G--M dwarfs as inputs and constraints for multi-dimensional magnetohydrodynamic (MHD) modeling of (a) the structure and energization of the magnetic field configurations of starspot groups/stellar active regions, and (b) the rapid release of free magnetic energy during stellar superflares and the dynamics and observational signatures of their associated CMEs.

METHODOLOGY: Our team will use astronomical observations to run data-constrained numerical simulations of stellar superflares and their associated CMEs from the target stars using the three-dimensional MHD codes the Adaptively Refined MHD Solver (ARMS) and the Alfven Wave Solar Model (AWSoM) which have been used to model solar and stellar coronal processes successfully. We will use Kepler, TESS, XMM-Newton, Chandra and ground-based spectropolarimetry provided data on starspot size, magnetic field, temporal evolution and association with optical and X-ray flares in order to model the initiation of flares and CMEs from a number of magnetically active dwarfs including kappa1 Cet (G star), epsilon Eri (K star), AU Mic and Proxima Cen (both M dwarfs). These theoretical models will output observational signatures to be used to define methodologies to search for and characterize stellar CMEs from G--M planet hosts, a crucial factor for exoplanetary habitability. This project will significantly advance our understanding of exoplanetary space weather and its consequences for habitability as no direct observations of star--planet space weather interactions are currently available.

RELEVANCE: The proposed investigation is highly relevant to XRP programmatic questions as it crosses NASA's multi-divisional boundaries through the coupling of data obtained with flagship astrophysics missions with heliophysics models to address the program's goal: "Observational characterization of exoplanets, their atmospheres, their interactions with their host stars, or specific host star properties that directly impact our understanding of exoplanetary systems." The proposed project will have a potentially transformative impact on the field of exoplanet research because it expands the definition of habitable zones exposed to stellar ionizing radiation and provides critical inputs for modeling and characterization of exoplanet atmospheres and their evolution. This project is directly relevant to data from HST, Kepler and TESS and will lead to predictions that can be tested with observations.

May, Erin/Johns Hopkins University
Consistency is Key: A Uniform Reanalysis of Spitzer Phase Curves

Between the first exoplanet phase curve observed with the Spitzer Space Telescope and the end of mission in January 2020, a total of nearly 60 phase curves at 3.6 and 4.5 microns have been observed for 30 unique exoplanets. Spitzer observations have been plagued by systematic signals that are typically larger than the underlying planetary signal itself – with the primary effect being the intra-pixel sensitivities of the IRAC instrument which cause variations in measured flux as the centroid drifts within a single pixel on the detector. Systematic models to correct for this have evolved substantially over the years, with different groups having their own preferred models. WASP-43b is a prime example of the problems imposed by the strength of Spitzer systematics - several different groups get different results on the same 4.5 -micron phase curve data using different reduction methods. Even multiple observations of the 3.6-micron phase curve seem to disagree in published results using the same systematic techniques.

With these examples, the need for a uniform reanalysis of published Spitzer phase curves is clear – we cannot hope to draw comparisons across planetary parameters or between data and models when results are inconsistent and potentially unreliable. To address this problem, here we propose to use a new fixed sensitivity map method to remove the intrapixel sensitivity systematic. This map was generated with several million observations of standard calibrator stars at 4.5 microns which were normalized and scaled relative to their date of observation to remove trends in sensitivity with time. As applied to WASP-43b this new master map results in all observations of the planet's phase curve agreeing within uncertainties – suggesting that this technique is accurately and reliably removing the instrument systematics regardless of centroid position. We propose to apply this master sensitivity map to all previously published and publicly available Spitzer exoplanet phase curve data sets to generate a uniform and consistent catalogue of phase offsets, heat redistribution efficiencies, nightside temperature, etc. as a function of planetary parameters.

We will use 3D General Circulation Models (GCM) to explain the observed phase curves – such as how the winds are contributing to the efficiency of heat transport from the day side to night side and how shifted the hot spot is relative to the substellar point (that of highest irradiation). However, with previous inconsistencies in results, it has been hard to match phase curve observations with current modeling efforts. Discrepancies between 3D GCMs and observed phase curves have been able to be shrugged off as systematics that are not fully understood or removed, which has been a valid argument when every published result has used different systematic removal methods. In this work, the proposed application of a uniform systematic model to the entire suite of Spitzer phase curves will allow us to better understand why our atmospheric models don't appear to match observations, and what can be done to remove the mismatch between them. A uniform data set will demand a better modeling scheme and therefore in this work we will apply relevant updates to our team's 3D GCM, including moving away from double grey radiative transfer for a more accurate representation of the energy budget in the atmosphere, as well as exploring additional parameters for atmospheric composition, wavelength dependent absorptions coefficients, and clouds and hazes.

This proposal addresses the XRP goal of observationally characterizing exoplanets and their atmospheres. It will greatly improve upon the currently published exoplanet phase curves to better enable exoplanet characterization, as well as provide advancements in our modeling capabilities for Hot Jupiters to better explain and understand the observations.

Melis, Carl/University of California, San Diego
Quantitative assessment of the difference between planetary systems around A-type and Sun-like stars

Planets identified to date around main sequence A-type stars either fall into the category of close-separation hot Jupiters or wide-separation massive planets detected via direct imaging; radial velocity surveys of "retired A-type" giant stars can detect massive companions with intermediate separations. These A-type planetary systems exhibit characteristics that are sometimes compatible with those observed for Sun-like stars, and sometimes seemingly at odds with what is seen for their lower-mass counterparts. While there appears to be a dearth of lower mass/smaller planets detected around A-type stars, it isn't clear if limits from these non-detections are sufficiently deep to robustly establish that A-type planetary systems are truly different from those around Sun-like stars. With this work we set out to comprehensively assess planet sensitivity limits for A-type stars and answer the question: how different are planetary systems around massive stars from those around lower-mass stars? Space-based transit lightcurves are capable of delivering the necessary sensitivity to enable this assessment, and as such we propose to utilize Kepler and TESS data to make the desired measurements. We will search a large sample of A-type stars for exoplanet transits -- carefully mitigating stellar variability where present -- and calculate transiting planet sensitivities to enable a comparison of their planet occurrence rates to those for Sun-like stars. The proposal goals are well-aligned with the scope of the Exoplanet Research Program and directly inform the NASA Science Mission Directorate to understand our cosmic origins, especially to determine if planetary system properties depend on the mass of their central host star, and if so how.

Moses, Julianne/Space Science Institute
The Chemistry of Sulfur and Phosphorus Species in Exoplanet Atmospheres

Science Objectives:

Most theoretical models of atmospheric chemistry on extrasolar giant planets have focused on hydrogen, helium, oxygen, carbon, and nitrogen species. The neglect of other cosmically abundant elements is not due to their lack of importance in exoplanet atmospheres, but rather due to a lack of current observational motivators (other than potential clouds/hazes) and to a dearth of relevant chemical-kinetics and thermodynamic parameters needed to accurately predict the abundance and fate of species containing these elements in the warm, reduced atmospheres of extrasolar giant planets. With James Webb Space Telescope (JWST) observations looming on the horizon, new chemical models that consider additional elements, such as phosphorus and sulfur, are urgently needed. Molecules such as H2S and PH3 will be present in giant-exoplanet atmospheres, and simulated infrared transit and eclipse spectra show that these molecules should be detectable by JWST for a range of atmospheric temperatures. Recent chemical models that include sulfur demonstrate that H2S photochemistry can significantly affect the abundance of other detectable C, N, and O species. Moreover, recent laboratory experiments that include H2S indicate that a wide variety of gas-phase sulfur products are expected to be produced photochemically in exoplanet atmospheres and that sulfur is readily incorporated into photochemically produced hazes. Sulfur matters. The photochemistry of PH3 in exoplanet environments has received little study to date, and the state of the thermochemical parameters of phosphorus species in the literature is frankly a mess. As with H2S, the photolysis of PH3 will introduce a deep source of atomic hydrogen to exoplanet atmospheres that can affect the abundance of other observable species. Accurate interpretations of JWST spectra will therefore require a theoretical framework that considers the chemical consequences of S and P species. We propose to develop chemical models that will improve our understanding of the thermochemical-equilibrium and disequilibrium chemical behavior of sulfur- and phosphorus-bearing constituents in exoplanet environments to better predict, interpret, and explain upcoming JWST spectral observations of giant-exoplanet atmospheres.

Methodology:

We will (1) clean up and correct the existing problematic literature and database values for phosphorus thermodynamic parameters, (2) perform a thorough literature review and compile an extensive reaction list containing sulfur and phosphorus reactions relevant to transiting-exoplanet conditions, and (3) develop new sophisticated 1D and pseudo-2D models of coupled C, H, O, N, P, S photo/thermochemistry and quenching for sub-Neptune through Jupiter-sized exoplanets that will be targeted during JWST campaigns within the next couple years. The model results will be used to simulate transit, eclipse, and phase-curve spectra from infrared instruments aboard JWST for comparison with upcoming observations.

Relevance:

This proposed investigation will expand our knowledge and understanding of the chemistry and composition of extrasolar planets, including those that will be observed by JWST during the time frame of the proposed work. As such, this work is well suited for the NASA Exoplanets Research Program, whose objectives are "[exploring] the chemical and physical processes of exoplanets (including the state and evolution of their surfaces, interiors, and atmospheres)" and "observationally [characterizing] exoplanets [and] their atmospheres" using models that "will improve interpretation of existing data and/or be tested by observational data." The proposed research addresses the NASA 2021 Exoplanet Exploration Program Science Gap List category SCI-02 (modeling exoplanet atmospheres – chemical composition).

Nataf, David/Johns Hopkins University
A Three-dimensional Extinction Map for Microlensing Planet Discovery and Characterization

The combination of data from the upcoming Roman Galactic Bulge Exoplanet Survey (formerly the WFIRST microlensing survey), as well as that from ground-based microlensing surveys such as KMTNet and OGLE, will further the planet census begun by radial velocity surveys and greatly expanded by

Kepler and TESS. The predicted yield from the survey is 1,400 planets from microlensing, at typical planet-star separations of 3 AU, with planet masses potentially as low as that of Ganymede. The predicted yield of transiting planets is a colossal 150,000 detections, orbiting a population of stars substantially more metal-rich than that of the Kepler field, and spanning a broader range of stellar masses. Given these outcomes, we expect substantial efforts at jointly modelling the demographics of exoplanetary systems as a function of both planet properties and stellar properties.

These endeavors require an accurate and precise understanding of these stars, and to that end, we propose to construct the "Roman Galactic Bulge Exoplanet Survey Input Catalog", which will be for both that survey and other surveys of planets targeting the inner Galaxy. The ten years of progress since the Kepler Input Catalogue was developed grant us access to precise parallax data, more and better photometry, and over ten thousand spectroscopic standards. The primary challenge to this endeavor will be that the interstellar extinction toward the inner Galaxy, which often exceeds 10 magnitudes in V-band, and is characterized by a highly variable and non-standard dependence on wavelength.

To resolve this challenge, we propose this program composed of three phases. First, we will construct the most precise and most accurate 2D extinction maps of the inner Galaxy, which will both enable a mapping of the interstellar extinction curve, and provide a boundary condition to the eventual 3D reddening maps. In the second phase, we will use 13,000 stars with high-resolution spectra from the SDSS/APOGEE survey to calibrate the zero points of our reddening maps, and to begin to extend the 2D reddening map in the third dimension, that which is along the line of sight. In the third phase, we will use the newfound bounty of parallax and photometric data for every detected main-sequence star between the Earth and the Bulge to complete the 3D extinction map, and to derive probabalistic priors on the stellar parameters of each of these stars, which will include the vast majority of the transiting-planet hosts. We are aiming for precision on the estimated distances, temperatures, and metallicities of the detected main-sequence stars toward the Bulge of 10%, 100 Kelvin, and 0.10 dex respectively.

By characterizing the host stars of exoplanets, this program will further one of the two priorities in exoplanet research of the 2018 Exoplanet Science Strategy report: "To understand the formation and evolution of planetary systems as products of the process of star formation, and characterize and explain the diversity of planetary system architectures, planetary compositions, and planetary environments produced by these processes."

Percival, Carl/Jet Propulsion Laboratory
Understanding Observations of Exoplanet Atmospheres Through Laboratory Based Chemical Kinetics

Objectives: The imminent launch of JWST and later ESA’s ARIEL (with NASA’s CASE contribution), promise to revolutionize spectroscopic measurement of exoplanetary atmospheres in the optical-IR. Deriving atmospheric properties from these new measurements requires advances in modeling capabilities. For example, thus far atmospheric retrievals often assume that composition closely follows thermochemical equilibrium. Improving the understanding the origin and physics of these atmospheres through their spectroscopic signatures relies on the underlying chemistry to be correct.
The two key drivers of disequilibria are transport-induced quenching and photochemistry, both involving

chemical kinetics. Kinetic processes will affect the spectral properties of atmospheres through the influence on atmospheric composition and have important observational consequences. Despite the importance of chemical kinetics, there is a lack of experimental data, and atmospheric models currently rely on some key theoretically derived rate constants and product pathways. In this proposal, we address the paucity and uncertainty of experimental kinetic data on key disequilibrium processes of relevance to extraplanetary atmospheres.

This project will explore these disequilibria drivers by focusing on NH3 and PH3 chemical kinetics where these species are expected to be abundant enough to affect the atmospheric spectra of exoplanets ranging from sub-Neptunes to Jupiters. NH3-N2 quenching, e.g. in the deep atmosphere of HD189733b, predicts NH3 mixing ratios that vary by an order of magnitude, purely from uncertainty in the kinetic parameters of NHx species. The absence of phosphorous in the atmosphere of Neptune, compared to Saturn and Jupiter, raises key questions about planetary evolution. PH3 is expected to be the dominant form of phosphorus, but it is destroyed readily by UV radiation, and the resulting photochemical products are uncertain under transiting exoplanet conditions.

Methodology: In this work we propose to study the recombination and cross reactions of NH2 and PH2 radicals where the current experimental/theoretical kinetic parameters disagree by up to 8 orders of magnitude. These critical reactions will be studied over the 10-800 Torr and 250-850 K pressure and temperature ranges using laser induced fluorescence and infrared wavelength modulation spectroscopy for reactant and product quantification. The experimental derived reaction parameters will be used in a 1-D chemical kinetics and transport model to determine their impact on atmospheric composition. Furthermore, infrared spectra will be simulated to inform and validate observations of transit and eclipse spectra of exoplanetary atmospheres. These laboratory measurements are paramount to the characterization of NH3/PH3 abundance in exoplanet atmospheres, in comparison with spectra obtained from NASA's observation missions (particularly the JWST observation range of 0.5 – 28.0 μm).

Relevance: The project falls within the scope of XRP as it will "explore the chemical and physical processes of exoplanets (including the state and evolution of their atmospheres)." The new chemical kinetics measurements resulting from this project will further our understanding of exoplanet atmospheric chemistry. The consequences of the new measurements on the observable composition and current and future spectra will be investigated with chemical models and synthetic spectra.

Quinn, Samuel/Harvard-Smithsonian Center for Astrophysics
Planet Formation Revealed by a Uniform Analysis of all Giant Planets

The processes that drive planet formation and evolution strongly affect our understanding of our place in the universe, yet the way in which planetary systems are assembled remains an open question. We know from observation that the outcomes of planet formation are myriad, and many system architectures look nothing like our Solar System: multiple small planets packed tightly on orbits close to their star; giant planets on eccentric or highly inclined orbits; and even circumbinary planets. How do initial conditions and evolutionary processes combine to produce this diversity of planets? Recent breakthroughs in understanding the evolution of small planets have been enabled by the reanalysis of an ensemble of small planets using uniform data sets and techniques. However, most giant planets have been discovered from the ground by a large number of teams. As a result, the data, analysis tools, and even important assumptions about how the data should be modeled have varied from one planet to the next. These differences can contribute to systematic errors in planetary properties, obfuscating underlying commonalities in their characteristics, and ultimately weakening constraints for the models of formation and migration that we apply to observations.

Three recent developments now make a useful ensemble analysis of giant planets possible: 1) TESS has completed its two-year all-sky survey and embarked on its extended mission that will observe most of the remaining gaps in sky coverage. It detects---with precise photometry---nearly all transiting giant planets orbiting bright stars with periods shorter than 10 days. 2) Gaia has provided exquisite measurements of the distance and brightness for all of these systems, which enables precise, uniform characterization of the masses and radii of the host stars. 3) The field of exoplanets has embraced the open-source development of sophisticated analysis tools such as EXOFASTv2, which can be employed for a self-consistent analysis of all known planetary systems. EXOFASTv2 simultaneously fits the physical and orbital properties of planets and stars using photometric and spectroscopic time series data, trigonometric parallaxes, broadband fluxes, and current stellar models. We therefore propose to carry out such an analysis to create (and make public) a uniform database of updated parameters of transiting giant planets and their host stars. These physical and orbital parameters will facilitate population studies that can reveal characteristics previously obscured by the heterogeneity of analyses and available data. We will conduct a study to examine the eccentricity distribution of hot Jupiters as a function of their orbital periods and ages, which can reveal the mechanisms by which they form and migrate; many-body dynamical interactions tend to excite eccentricities, while disk migration and in situ formation produce a more circular population. We will further examine this distribution as a function of stellar properties (e.g., mass, chemical abundance), to identify the dependence of these evolutionary properties on the birth environment. We will also provide refined transit ephemerides, which are required for atmospheric characterization efforts using facilities like the James Webb Space Telescope (JWST) and the next generation of extremely large telescopes. Such atmospheric characterization may provide complementary evidence---through measurement of atmospheric composition and internal structure---about the birth environments and migration histories of giant planets. Our proposed work will represent the first uniform analysis of all known hot Jupiters and will quantify the processes that drive giant planet migration. Our work will also benefit studies of star-planet interactions, the efficiency of tidal dissipation inside stars and planets, and radius inflation, each of which depends crucially on the properties of short-period giant planets and their host stars.

Ragozzine, Darin/Brigham Young University
The True Exoplanet Mass-Radius Distribution from Homogeneous Photodynamical Modeling

We propose to perform a homogeneous photodynamical analysis of all Kepler MTSs (Research Objective 1), including dynamical stability constraints (Research Objective 2), to provide a several-fold improvement in the true mass-radius-period distribution of Kepler exoplanets with a focus on small rocky temperate planets (Research Objective 3).

During its four year “prime” mission, NASA’s Kepler Space Telescope discovered thousands of transiting exoplanets. Systems of multiple transiting exoplanets (“MTSs”) are the most information-rich exoplanetary systems as they combine the determination of the physical properties of exoplanets (e.g., radii), the context provided by system architecture, and insights from orbital dynamics. Kepler discovered 1767 planet candidates in 706 MTSs, the largest homogenous sample by far.

Dynamical interactions between exoplanets can be manifested through deviations from a periodic Keplerian ephemeris. These “Transit Timing Variations” (TTVs) are particularly powerful in Kepler MTSs because the perturbing planet is usually transiting and Kepler’s four years of precision photometry enables the detection of hundreds of TTV signals. As a result, about 100 planets in Kepler MTSs have inferred masses and densities. Kepler MTSs are thus a primary contributor to the exoplanet “mass-radius relation”, the joint distribution of exoplanet mass and radius measurements. The exoplanet mass-radius relation is a fundamental characterization of exoplanets with crucial implications for the formation, evolution, architectures, and habitability of exoplanetary systems.

Despite this treasure trove of data, existing TTV analyses for mass determination are incomplete or suboptimal. For example, only a handful of systems have been analyzed with a photodynamical model that 1) extracts near-maximal information from the lightcurve, 2) is fully self-consistent, 3) can study the smallest planets, and 4) uses the better Short Cadence data.

We will use the publicly-available PhotoDynamical Multi-planet Model (PhoDyMM) with the explicit goal of provide state-of-the-art photodynamical analysis of the entire set of Kepler MTSs. PhoDyMM uses Differential Evolution Markov Chain Monte Carlo methods to provide Bayesian posteriors on the physical and orbital properties. We have completed preliminary applications of PhoDyMM to all Kepler MTSs.

We anticipate that this will update the ~100 known masses and provide constraints on ~50 new planets which have been hitherto missed because they were small and/or had weaker TTV signals. We will also use constraints for long-term orbital stability following new methods from the literature which we quantitatively estimate will prove another ~50 meaningful mass upper limits.

This major effort (including use of our ~30000 CPU-days) will provide updated and improved parameters for all planets in MTSs, which is already a major benefit to the community.

We propose to use PhoDyMM's stability-pruned posteriors as input into a single ensemble underlying mass-radius-period relationship through Hierarchical Bayesian Modeling, following recently developed techniques. Through a major increase in input data and improved methods, our results will provide a several-fold increase in the information content of the underlying mass-period-radius distribution. This will provide powerful insight into the formation, evolution, and habitability of planets.

These investigations are an important part of addressing three gaps identified in NASA’s 2021 Exoplanet Exploration Program Science Gap List: SCI-05 (``Occurrence rates and uncertainties for temperate rocky planets"), SCI-09 (“Dynamical confirmation of exoplanet candidates and determination of their masses and orbits”), and SCI-14 ("Exoplanet interior structure and material properties"). This proposal is directly relevant to the Exoplanet Research Program with its primary focus on Kepler exoplanet data analysis.

Schwieterman, Edward/University of California, Riverside
Experimental Constraints for Improving Terrestrial Exoplanet Photochemical Models (ExCITE-PM)

A key goal of exoplanet science is the characterization of terrestrial exoplanet atmospheres, for which the most compelling targets include the TRAPPIST-1 system. The 7 terrestrial planets of TRAPPIST-1 are uniquely accessible to atmospheric characterization due to the proximity and small size of TRAPPIST-1. These worlds receive diverse stellar irradiation, providing an exceptional opportunity for comparative planetology [106]. Consequently, TRAPPIST-1 is a high-priority observational target for upcoming facilities like the James Webb Space Telescope (JWST). Notably, multiple approved JWST programs target the atmospheres of the TRAPPIST-1 worlds.

Photochemical models are required to plan and interpret observations of terrestrial exoplanets like TRAPPIST-1bcdefgh. However, these models are only as good as their input chemical data, and "the limited laboratory and ab initio data covering the parameter space relevant to exoplanets is a barrier to accurate models of exoplanet atmospheres" [76]. We propose 5 investigations targeted at this barrier, rendered urgent by the upcoming JWST observations:

1. CO/O2 Runaway: [46] report that planets with CO2-rich atmospheres orbiting M-dwarfs (e.g., TRAPPIST-1e(fg)) should have abundant photochemical O2 and CO (>0.05 bar). We will attempt to replicate the finding of [46] with 2 models, identify any sensitivity to photochemical assumptions, and flag them for priority empirical follow up (e.g. [83]).

2. HSO and HNO Sensitivity Tests: The cross-sections of HSO and HNO are not known; these molecules are included in models by proxy. We will conduct sensitivity tests to determine the prioritization of these parameters for detailed characterization.

3. S2 UV Cross-Sections: S2 photolysis is a key process en route to observationally-detectable species like S8, but UV absorption properties of S2 are not known. Rather, S2 photolysis is estimated, based on e.g., scaling from comet measurements. We will use recent experimental data [103] to construct line-by-line and cross-section parametrizations of S2 UV absorption.

4. Rate Constants for Key Sulfur Reactions: The reaction S+CO+M–>OCS+M has not been measured or calculated, but is nonetheless commonly assumed to proceed in models by analogy with O+CO+M–>CO2+M. Absent this reaction, [OCS] is suppressed by >15 orders of magnitude, and models cannot reproduce Venusian [OCS]. Similarly, the reaction S+CO2–>SO+CO has not been observed, but is often assumed in photochemical models where it significantly influences atmospheric composition, e.g., the abundance of CO. We will experimentally evaluate the rates of both reactions using shock tube measurements conducted over a range of temperature, pressure and mixture composition and employing a variety of species-sensitive optical diagnostics.

5. Model incorporation: We will incorporate our results into 2 independent photochemical models [6,47], and explore the implications for potential observables in the TRAPPIST-1 system. Investigations 1-4 are relevant for potentially habitable planets, e.g., TRAPPIST-1(d)ef(g). Investigations 2-4 are relevant for potentially Venus-like planets, e.g., TRAPPIST-1bc(d) [106]. While motivated by TRAPPIST-1, our investigations are applicable to terrestrial exoplanets in general.

Our proposal aligns with the Exoplanets Research Program goal of “Exploration of the chemical...processes of exoplanets (including...their...atmospheres)”. Our work addresses Objective 1.1 “Searching for Life Elsewhere” of the 2018 NASA Strategic Plan, the “Laboratory Measurements and Ab Initio Calculations” overarching challenge in the 2018 NAS Exoplanet Science Strategy, and the community mandate for better exoplanet model inputs [26,27].

[106] Turbet et al. 2020 [76] NAS Exoplanet Science Strategy 2018 [46] Hu et al. 2020 [83] Ranjan et al. 2020 [103] Stark et al. 2018 [47] Hu et al. 2012 [6] Arney et al. 2016 [26] Fortney et al. 2016 [27] Fortney et al. 2019

Simon, Jacob/Iowa State University
Early Planet Formation in Young, Protostellar Disks

How solids in planet forming disks grow from sub-micron scales to ~10,000 km (or larger) planets remains a major open question in the planet formation field. More recently, an additional question has emerged: when does this long road to planets begin? Recent observational studies have lent strong support to the notion that planets form much earlier than originally thought, namely in the Class 0/I phases, in which the circumstellar disk is still embedded in the cloud out of which it was born. These studies contrast with assumptions, made in many prior studies, that planet formation begins in the more evolved Class II stage, in which the disk is older and is no longer embedded in its nascent envelope.

Class 0/I (protostellar) disks are considerably younger and more massive than their Class II counterparts. Thus, in addition to the magnetic effects also present in Class II disks, Class 0/I disks are subject to self-gravitating dynamics of the gas. The dynamical interactions between magnetic fields (and instabilities that emerge from these fields) and the self-gravitating nature of the gas very likely fundamentally alter the nature of disk turbulence as well as disk substructures (e.g., rings, spirals, vortices).

These considerations have enormous consequences for planet formation studies, as the earliest stages of planet formation are strongly influenced by gas dynamics. For instance, the final size to which sub-micron grains grow depends very strongly on the amplitude of disk turbulence. Furthermore, the efficiency of planetesimal formation is strongly affected not only by turbulence but also by the presence of disk substructures.

These considerations lead us to three critical questions that must be addressed in order to understand how and when planets form. First, what is the nature of gas dynamics in young, massive Class 0/I disks? That is, are these disks largely laminar (as recent results have suggested for Class II disks), or are they rendered turbulent via the interaction of magnetic fields and self-gravity (the latter of which can generate turbulence on its own)? Second, how does the growth of submicron grains into much larger particles (which is required by planetesimal formation models) proceed in this Class 0/I environment? Finally, how does the gas dynamics influence the growth of these larger grains to 1-100 km scale planetesimals? To answer these questions, we will use the state-of-the-art Athena and DustPy codes to carry out three tasks:

Task 1: Test whether the gas in Class 0/I disks is turbulent or laminar and determine what substructures emerge as a result of interactions of magnetic and self-gravitational effects.

Task 2: Determine whether sub-micron grains can grow to larger sizes in the presence of magnetic and self-gravitational interactions.

Task 3: Determine whether planetesimal formation can begin as early as the Class 0/I phase.

RELEVANCE:
This proposal aims to address the question of how and when planetary systems are born, and as such strongly aligns with the goal of NASA and the XRP to "improve our understanding of the origins of exoplanetary systems".

Su, Kate/University of Arizona
Characterizing Rejuvenated Exoplanetary Systems -- A Comprehensive View of Dusty White Dwarfs Using Archival Spitzer Data

Planetary systems are ubiquitous around stars. Thanks to advanced search techniques (transit, radial velocity, direct imaging and micro-lensing), a plethora of extrasolar planets are known. In addition to planets, planetary systems also harbor minor bodies like asteroids and comets, signaling their presence as dusty and gaseous circumstellar material. Through various observing techniques (e.g., infrared excesses and metal pollution in white dwarf atmospheres), we now know that white dwarfs can host dynamically young, rejuvenated planetary systems. It is well established that the relative abundances of rock-forming elements in polluted white dwarfs are exogenous to the star, having been delivered by minor bodies disrupted inside of the Roche limits of the star. However, we do not yet know which physical processes govern the observed behavior. Standard models suggest that these dusty disks are formed by the tidal disruption of a scattered planet or minor bodies, feeding heavy elements onto white dwarfs that pollute their otherwise pure hydrogen or helium atmospheres. Although the bulk composition of polluted material suggests they are rocky bodies commonly found in the inner solar system, the exact mineralogy of the exoplanetary bodies remains unknown because the polluted measurements represent an ensemble of all material accreted by the white dwarf and backtrack to the original makeup is difficult.

To better understand the composition of exoplanetary bodies and the formation and evolution of dusty disks around rejuvenated exoplanetary systems, we propose to systematically analyze existing archival infrared data for a sample of dusty white dwarfs, and combine these data with state-of-the-art models to comprehensively probe the structure and dust composition in the disk. Detailed dust mineralogy derived from this program will allow for a direct comparison with the metal abundance measured from the atmospheric pollution, and shed light on the size and formation condition of disintegrating bodies. The proposed research is fundamental to understanding the formation and evolution of the end stage of exoplanetary systems, therefore, directly relevant to the Exoplanets Research Program. The proposed work makes uses of Spitzer, WISE and HST data and enhances the legacy value of these NASA missions, and aims to build tool sets and methodology to better understand these evolved exoplanetary systems. The proposed research is particularly timely and will pave the way to interpret future JWST observations.

Tobin, John/National Radio Astronomy Observatory
Characterizing Protostellar Disk Structure at the Dawn of Planet Formation

The widely accepted framework for star and planet formation begins with the gravitational collapse of a dense cloud of gas and dust. A disk forms around the nascent protostar due to conservation of angular momentum and the protostar is fed by the envelope falling onto the disk and this material accretes through the disk and onto the protostar. Most of the luminosity at this time is generated accretion onto the protostar. Planets and/or companion stars are then expected to form within this disk and it later becomes known as the proto-planetary disk once the envelope has dissipated. These proto-planetary disks are found to have an abundance of substructure, increased resolution seemingly always finds substructure that was not apparent in previous observations at lower resolution. These disk substructures take the form of rings, gaps, azimuthal asymmetries, spirals, etc. in the dust emission (and sometimes gas emission as well). Numerous mechanisms can explain the presence of these structures, but the most simple and universal mechanism that can explain these observations is the presence of proto-planets. The frequent occurrence of massive (super-earth to Jupiter mass) planets in proto-planetary disks, inferred from their ability to open gaps and influence on gas kinematics, implies that planet formation is beginning earlier in the star formation process, when the disk and star are both still building up their mass.

We propose to study the emergence of planet formation in the disks around protostars. The team will examine the properties of forming disks, protostar masses, and mass accretion onto protostars using multi-wavelength radio interferometry surveys of continuum and spectral lines, and broadband photometry and spectroscopy from the near infrared to millimeter. To better understand the conditions of planet formation and how early it begins, the properties of forming disks in protostellar systems will be examined, using continuum and spectral line surveys from the VLA and ALMA. These surveys will break new ground in resolution and sensitivity, making the team poised to revolutionize the understanding of planet formation's initial conditions. The survey is being conducted toward 19 Class 0 and Class I protostars at distances <200 pc with a spatial resolution between 5 to 8 au.

The goals of this project are to: 1) Resolve substructures in protostellar disks and determine any evolutionary dependence to elucidate the timescale of their emergence. 2) Constrain the dust disk physical structure: radial density profile, temperature, profile, mass, and vertical density profile via radiative transfer modeling with parameter space sampled using Markov Chain Monte Carlo. 3) Make use of longer wavelength data from the VLA in conjunction with the ALMA data and radiative transfer modeling to characterize evidence of dust growth in disks. 4) Measure the protostar masses using the available millimeter spectral lines, by fitting Keplerian disk models either directly to the data or via line radiative transfer modeling. 5) Determine the gas disk radii of protostellar disks and determine if there is significant different relative to the dust dist sizes. 6) Estimate the mass accretion rates for the protostellar systems with knowledge of their masses and relate these estimates to observations of direct accretion indicators from JWST.

The outcome of this project will elucidate a more clear understanding of the dawn of planet formation, telling us just how early in the life of a star that its disk becomes ‘proto-planetary.

Turner, Neal/Jet Propulsion Laboratory
Birth and Death of Hot Rocky Planets

JWST and other infrared telescopes offer opportunities to observe the births and deaths of hot rocky planets, bookending our understanding of their lives. Planets disintegrating from the heat of their star offer up information on their mantles and cores that we cannot access even for the Earth. In a similar way, protostellar disks' hottest central zones present unique chances to determine the compositions of refractory planetary components that are hidden when farther from the stars. We propose a campaign of modeling backed by laboratory validation, enabling the upcoming measurements of mature stars' disintegrating short-period planets and young stars' innermost disks to be translated into intrinsic compositions, thus yielding start and end points for the evolution of rocky planets.

Disintegrating hot rocky planets provide samples of their interiors in the form of escaping gas and dust. This debris in several cases has an optical cross-section greater than the planet itself and will be observed in the next few years with JWST through transits or thermal emission. The planets likely share constituent minerals and molecules with the inner parts of protostellar disks, whose infrared radiation reveals the composition of their surface dust and gas. Thus it is becoming possible to determine the makeup of the hot planet growth and migration zone within through JWST spectroscopy and VLT interferometry with interpretation guided by modeling. We will enable the compositions to be measured for both the dying planets and the young disks, through a campaign of (1) refractory solid-liquid-vapor modeling, connecting debris tail to planet; (2) radiation-hydrodynamics modeling, connecting disk spectra to interior compositions; and (3) high-temperature experiments validating both sets of models. We will turn the modeling results into synthetic infrared line and continuum spectra and images for testing against archival and planned measurements. Comparing compositions between the planetary interiors and planet-forming disks will open new windows on planets' lives, informing efforts to understand the orbital migration of the building blocks, the migration of the planets themselves, their internal differentiation, and the enrichment or loss of their outer layers in impacts.

The project's three tasks will: (1) Connect escaping gas and dust back to the disintegrating planet's composition by determining what minerals condense from a given vapor, and what fraction of a surface magma ocean vaporizes in the first place. We will focus on the Fe-rich compositions inferred for the hottest rocky planets from their survival against tidal disruption. (2) Connect the shape, size, and emitted spectrum of the silicate sublimation front and nearby hot gas to the rock-forming elements' distributions near young stars, using radiation-hydrodynamical models treating starlight heating, minerals' sublimation, condensates' compositions, and the condensate particles' movements. (3) Strengthen both the birth and the death models by empirically validating the compositions of the sublimating gases and the recondensed particles in laboratory experiments. Modeling and laboratory efforts of these kinds are essential for turning measurements from JWST and other telescopes into knowledge of hot rocky planets' birth sites and death throes, opening new ways to explore planets' life stories.

The investigation outlined above addresses the Exoplanets Research Program's goals by (1) improving understanding of exoplanetary systems' origins, (2) exploring the chemical and physical processes of exoplanets (including the evolution of their surfaces, interiors, and atmospheres), and (3) generating predictions to help in observationally characterizing exoplanets.

Zhang, Xi/University Of California, Santa Cruz
Towards a Holistic Understanding of Exoplanet Aerosols using Microphysical Modeling

Objectives: The goal of this theoretical proposal is to systematically investigate the formation, distribution and observational consequences of haze and clouds (aerosols) on warm and hot tidally locked exoplanets, such as hot Jupiters and warm Neptunes. Haze and clouds are ubiquitous in exoplanetary atmospheres. They exhibit complex behaviors and have significant influences on transmission, emission and reflection spectra and light curve observations. Recent aerosol formation models have demonstrated the importance of bin-scheme microphysics and fractal aggregate physics to interpret the observations from Hubble Space Telescope (HST) and Spitzer Telescope collected in the past decade. But the detailed microphysical mechanisms and their impacts on interpretations of the observational data remain poorly understood. This will significantly hinder the understanding of the high-quality data in the upcoming James Webb Space Telescope (JWST) era. In this project, we plan to achieve three specific objectives:

(1) Understanding the inhomogeneous spatial distribution and size distribution of aerosol particles on tidally locked gas giants with equilibrium temperatures, different metallicities, and transport processes.

(2) Systematically investigating chemical haze formation on warm Neptunes and identify possible systematic trends in observational signatures.

(3) Exploring the vapor depletion due to cloud condensation on hot gas giants where the distribution of some condensational elements (such as magnesium and iron) can be detected in the upper atmospheres.

Methodology: We will use a new modeling framework including a 2D (longitude-pressure) bin-scheme aerosol microphysical model with radiative transfer, gas chemistry and zonal wind transport. Our approach treats the chemistry and cloud formation in detail but simplifies the atmospheric dynamics. This innovative approach is complementary to the common approach in the field that simulates the clouds in a dynamical model with simplified cloud formation schemes. We will use our models to systematically explore the fundamental mechanisms that govern the aerosol formation, spatial distribution and particle size distribution on hot Jupiters and warm Neptunes. We will construct synthetic spectra and phase curves based on the simulations and compare with the existing HST and Spitzer observations and predict observations for future JWST observations.

Relevance and Perceived Significance: This work will not only shed light on the mechanisms underlying various observations of exoplanets to date, but will also provide cutting-edge theoretical tools in aid of interpretation of observations on exoplanets for JWST. The proposed work is directly relevant to the NASA Exoplanet Research program (XRP) as our aerosol study will advance our knowledge and understanding of "the chemical and physical processes of exoplanets (including...atmospheres)". The simulated spectra and light curves will be "improving the interpretation of data on exoplanetary systems, through collection and interpretation of laboratory data for comparison to observations and/or providing an observationally testable prediction or theory." This work will "support past and current NASA missions" such as HST, Spitzer, JWST and Roman, and "facilitate the formulation and development of future NASA missions and strategic exoplanet programs."

Zhu, Zhaohuan/University of Nevada, Las Vegas
The interaction between young planets and the turbulent protoplanetary disk within 1 AU

A large fraction of discovered exoplanets are within 1 au from the central star. These close-in exoplanets are also prime targets for current and future space missions (e.g. TESS, JWST). However, these planets' evolutionary history is largely unknown. Giant planets may form further away and need to migrate to the inner disk. On the other hand, planet migration can be too efficient for earth-sized planets. If planets migrate in protoplanetary disks, we want to understand why they stop at where they are now.

With the latest numerical tools (e.g. including non-ideal MHD, and chemistry calculation), we know protoplanetary disk structure in greater details. However, most disk simulations focus on disk regions beyond 5 au, where ALMA can directly image. Those regions are largely governed by non-ideal MHD effects, which sensitively depends on detailed microphysics (including disk chemistry and dust evolution). The physics in the inner disk (within 1 au) is better understood, although may not be easier to simulate. Ideal MHD largely governs the inner disk and the disk should be turbulent due to the magnetorotational instability (MRI). Adopting the mesh-refinement numerical technique, recent global MRI turbulent simulations can finally simultaneously capture both large scale disk winds and small scale turbulence.

In this proposal, we plan to carry out global MHD simulations in three steps, to study inner protoplanetary disks and the planet's interaction with the inner disks.

1. We will carry out simulations to study how planets interact with MRI turbulent disks that are threaded by large scale vertical magnetic fields. The protoplanetary disks within 1 AU should be MRI turbulent and are likely affected by the star's large scale magnetic fields. We will include planets in global MRI simulations threaded by large scale magnetic fields to study how planets migrate and open gaps in such disks.

2. We will carry out simulations including the stellar surface, the stellar magnetic fields, and the inner disk to study the magnetospheric accretion. We will be able to understand how disk material is channelled from the MRI turbulent disk to the stellar surface. The structure of the magnetosphere will be thoroughly explored.

3. We will add planets in the magnetospheric accretion simulation to study how planets can be stopped at the truncation radius of the magnetosphere. To stop migration, either a sharp density or a temperature gradient is required. At the very inner disk, this condition is naturally produced at the magnetosphere truncation radius. We will test if this is indeed the case and under what conditions the magnetosphere can stop the planet.

These first-principle MHD simulations can significantly advance our understanding of both the planet-disk interaction within 1 au and the magnetospheric accretion process. It thus has far reaching implications for both the exoplanet and star formation communities. The predictions from these simulations will serve as a foundation for understanding planet formation and exoplanet properties for future space missions (e.g. JWST, WFIRST).

F.5 Future Investigators in NASA Earth and Space Science and Technology
SOLICITATION: NNH21ZDA001N-FINESST

NOTICE: November 21, 2022. The following revisions have been made to Table 1: i) The Astrophysics Division's (APD) selection number is 28. ii) The Heliophysics Division's selection number and publication date are added. iii) Total number selected by SMD added. Additionally, an abstract that was published in error in July has been removed.

The Science Mission Directorate (SMD) reviewed a total of 927 proposals that were submitted to the **F.5 Future Investigators in NASA Earth and Space Science and Technology (FINESST)** competition within the NASA Research Announcement entitled "*Research Opportunities in Space and Earth Sciences" (ROSES-2021)*. Six SMD divisions at NASA Headquarters conducted/provided oversight for the review and selection process: Astrophysics, Biological and Physical Sciences, Earth Science, Heliophysics, Planetary Science, and Science Engagement and Partnerships (SE&P).

FINESST accepts proposals for graduate student-designed research projects that contribute to SMD's science, technology, and exploration goals. The maximum, three-year total FINESST award amount is $150,000. FINESST grants are limited cost awards. For example, SMD suggests a student stipend of $40,000 per 12 months. Not all projects, however, require the maximum amount available in the period of performance.

FINESST is similar to what 2 CFR200.1 Definitions calls a "Fixed Amount Award". "Fixed amount awards means a type of grant or cooperative agreement under which the Federal awarding agency or pass-through entity provides a specific level of support without regard to actual costs incurred under the Federal award. This type of Federal award reduces some of the administrative burden and record-keeping requirements for both the non-Federal entity and Federal awarding agency or pass-through entity. Accountability is based primarily on performance and results."

SMD's estimated timeframe to communicate the selection or intent-to-award decisions is late May through late July. Selection documents are released first, followed by non-selections. Non-selections may not be available until August 15, 2022, or later. The NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) will announce decisions via a system generated email to the PI and AOR. *NSPIRES makes detailed documentation of the selection and non-selection decisions available for each reviewed proposal to both the Principal Investigator (PI) and Authorized Organization Representative (AOR).* Access to proposal-specific documentation requires logging in to NSPIRES and navigating to the submitted proposal, and not just visiting the web page. FIs, however, cannot receive or access FINESST decisions or review results directly via NSPIRES. If by August 15, the PI or AOR have not contacted the FI, then the FI should ask them to log in to NSPIRES to see if the proposal status has changed and download and share the results.

For assistance with NSPIRES log in, please contact the NSPIRES Help Desk at (202) 479-9376 Monday – Friday, excluding Federal Holidays, (e.g., Juneteenth National Independence observed for 2022 on June 20, July 4, i.e., Independence Day, etc.) 8 AM to 6 PM Eastern Time or by email at nspires-help@nasaprs.com.

Table 1: FINESST-21 Proposal Data

Division	Proposals Reviewed	Proposals Selected (Estimated)	NSPIRES Publication Date
Science Engagement & Partnerships	2	1	May 26, 2022
Biological and Physical Sciences	25	2	July 21, 2022
Earth Science	394	62	June 30, 2022
Planetary Science*	224	32	July 5, 2022
Astrophysics	222	**28**	July 25,2022
Heliophysics	60	14	September 26, 2022
Total**	927	139	July 25**,** 2022 (Target)

NOTE For Selected PI-FI Teams: Once SMD receives selection acceptance, the FINESST proposal will be transferred to the NASA Shared Services Center (NSSC). NSPIRES cannot track the NSSC grant processing activities. A grant's status may be tracked via a web search on the PI's name (do not use the FI name or NSPIRES proposal number) at: https://www.nasa.gov/centers/nssc/forms/grant-status-form, telephoning the NSSC at 1-877-NSSC123, or e-mailing nssc-contactcenter@nasa.gov.

Any pre-award costs incurred are at the proposer's risk. All new awards receive an automatic 90 days of pre-award spending approval on award, meaning that NASA has waived the requirement for FINESST award recipients to obtain written approval prior to incurring project costs up to 90 calendar days before NASA issues an award. However, expenses incurred more than 90 calendar days before the award require prior written (i.e., email) approval from a Grants Office at the NSSC.

NOTE for Non-Selected PI-FI Teams: SMD received a far greater number of proposals than available funds can support. NASA plans to publish the next FINESST solicitation as a cross-divisional appendix to the NASA Research Announcement entitled "Research Opportunities in Space and Earth Science (ROSES-2022)."

A non-selected 2021 FINESST proposal may be eligible to be revised and resubmitted to the 2022 competition. Entirely new, eligible proposals also are welcome. When the new FINESST solicitation (F.5) is published in final form it will be available at https://go.nasa.gov/FINESST22. Proposal intake will continue for an approximate minimum of 60 days from the release barring any unforeseen circumstances. In the interim, SMD's Cross Division FINESST team welcome general comments, questions, and FINESST-improvement suggestions via email at: HQ-FINESST@mail.nasa.gov.

*Technical Note: *The Planetary Science Division (PSD) will make all notifications (selections and declines) available on NSPIRES at the same time in order to be consistent with other PSD program practices.*

***This total may be different than what a selection letter may indicate due to administrative adjustments.*

Astrophysics Division Selection, (29, Alphabetical by PI Last Name)

Mitchell Begelman (PI)/ Hannalore Gerling-Dunsmore (FI)
University of Colorado, Boulder
21-ASTRO21-0029: Magnetization as a Mechanism of AGN Disk Survival

Standard accretion disk theory predicts that the accretion disks of luminous active galactic nuclei (AGN) become gravitationally unstable outside the broad line region (BLR), causing the disks to fragment into stars. If this happens, the disks might not support sufficient accretion to power the central engines, or even to grow the central supermassive black holes (SMBHs) to their inferred masses in the first place. Thus, accretion disk survival at large radii is a critical problem in understanding other accretion disk phenomena (e.g. jets and winds), SMBH formation, and galactic feedback. The magnetorotational instability (MRI) has long been understood to play a critical role in accretion physics and is believed to be a primary source of turbulent viscosity, which drives the outward transport of angular momentum necessary for matter to progress inward through the accretion disk. If not too severe, gravitational instability (GI) can also transport angular momentum, and is expected to be active in regions that overlap with MRI. An intriguing possibility is that magnetically elevated accretion, characterized by a moderately strong net vertical magnetic flux producing a horizontal field sufficient to support the disk against gravity, might help to soften the effects of GI. However, until recently, resolving both GI and MRI was computationally infeasible, resulting in a poor understanding of how magnetic effects in AGN disks impact fragmentation due to the GI, and vice versa. In this project, we will investigate how GI impacts the evolution of MRI in the disk and the implications for disk survival, as well as the accretion rate, disk structure, and its potential for launching winds. We will pursue this project using shearing box simulations, to ensure sufficient resolution to capture both GI and MRI, adopting properties comparable to those of the outer regions of AGN disks and different strengths of the initial vertical magnetic field, ranging from weak to very strong. Using an innovative self-gravity implementation, we will gradually increase the disk density so that we can isolate the effects of self-gravity on the MRI. We will quantify the evolution of various properties of the disk, including the internal magnetic field strength and configuration, the Maxwell, Reynolds and gravitational stresses, the viscosity parameter alpha, and the mean density perturbations, as well as determine the development of qualitatively distinct, vertically stratified regions seen in previous magnetically elevated disk studies. In our preliminary study of the moderately magnetized case, we observed a novel disk elevation mechanism driven by the expulsion of the toroidal magnetic field from the midplane due to self-gravity, as well as unprecedented amplification and oscillation of the Reynolds stress. We will investigate these phenomena further, in particular exploring the impact of stronger magnetization on these behaviors, and determine their relevance to accretion disk evolution. Through these simulations and analyses, we will address questions fundamental to NASA's astrophysics program: how luminous AGN are fueled, how supermassive black holes grew rapidly during the epoch of galaxy formation, and how accretion and star formation may be interrelated in the vicinities of supermassive black holes.

Edo Berger (PI)/ Floor Broekgaarden (FI)
President and Fellows of Harvard College
21-ASTRO21-0177: From Gravitational Wave Sources to Massive Stars: A Comprehensive Framework to Infer Binary and Cosmic Evolution from Future Gravitational Wave Catalogs

Over the next few years, the population of detected gravitational-wave events from binary black hole, black hole-neutron star, and binary neutron star mergers will rapidly increase as new gravitational-wave observing runs and next generation detectors provide data with ever increasing precision, volume, and to higher redshifts. Learning about their progenitors from this wealth of data requires comparing the observations to theoretically synthesized populations. However, this is difficult due to the so-called progenitor uncertainty challenge": uncertainties within the theoretical population synthesis modeling of these sources are so large that, in combination with the large computational costs of the simulations, learning about their properties from gravitational-wave observations is completely out of reach. Utilizing my background in population synthesis simulations of gravitational-wave progenitors as well as my background in astro-statistics, I propose to combine state-of-the-art theoretical simulations with this growing set of observed gravitational-wave sources to ultimately answer two of the biggest open questions in gravitational-wave astronomy today: How do these gravitational-wave sources form?" and What can we learn from their gravitational waves about the birth, lives and explosive deaths of massive stars? More specifically, I propose two interconnected, multi-scale projects that are highly relevant to many NASA-led efforts including JWST's quest to probe stars and galaxies over cosmic time, as well as several of the transient surveys that aim to capture the formation, lives, and deaths of massive stars by NASA telescopes including Hubble, Fermi, SWIFT and The Nancy Roman Space Telescope. (1) Drawing from my expertise with developing statistical methods in Astronomy as well as population synthesis studies of isolated binary evolution channels, I will apply a deep neural network Machine Learning tool to population synthesis studies of the isolated binary evolution channel to explore the power of constraining model hyper-parameters from (future) gravitational-wave detections for this formation channel. (2) Using my experience with modeling and analyzing large population synthesis datasets, I will then develop a population synthesis catalog that presents the most extensive set of isolated binary evolution models spanning many population synthesis codes, stellar evolution uncertainties, and cosmic history assumptions. I will also add uncertainties representing alternative double-compact-object formation channels and apply this to the neural network from (1) to take into account this larger uncertainty span. The complementarity of the different methods and probes my proposal spans has the potential to help resolve the population synthesis uncertainty challenge and thereby enable learning about the birth, lives, and explosive deaths of massive stars through cosmic time from (future) gravitational-wave observations.

Michael Bottom (PI)/ Jingwen Zhang (FI)
University of Hawaii, Honolulu
21-ASTRO21-0211: Direct Detection and Characterization of Exoplanets with Imaging Fourier Transform Spectroscopy

Space-based high contrast imaging facilities are required to study the spectra of Earth-like planets around Sun-like stars from ultraviolet (UV) to infrared (IR) wavelengths. The top recommendation from the decadal survey was for such a mission, specifically, a 6-meter space telescope to image and spectroscopically analyze habitable-zone exoplanets in search of biosignatures. Integral field spectroscopy is the current prevailing choice for these missions. However, multiple independent studies have revealed that an integral field spectrograph (IFS) is severely limited by detector noise in obtaining spectra of exoplanets, leading to very long integration times and lower mission yield. Imaging Fourier transform spectrographs have not been studied as an option for exoplanet spectroscopy, though such instruments are generally far less sensitive to detector noise. We propose to explore the possibility of applying imaging Fourier transform spectrographs (iFTS) to space-based exoplanet imaging and spectroscopy. We will (1) compute a detailed error budget for exoplanet imaging with an iFTS, and compare the capabilities of an iFTS with those of an integral field spectrograph in identifying key atmospheric features for a range of planets, including biosignatures in Earth twins, (2) perform detailed optical modeling to understand how an iFTS would interface with high contrast imaging instruments, and (3) perform statistical mission modeling to explore how yields and operational principles would change with an iFTS. The results will explore a compelling option for NASA's future space-based exoplanet imaging and spectroscopy missions.

Blakesley Burkhart (PI)/ Diane Malinda Salim (FI)
Rutgers University, New Brunswick
21-ASTRO21-0200: A Revolution for Astrophysical Turbulence with Machine Learning Methods

Turbulence is of paramount importance in developing an informed understanding of a myriad of physical phenomena. It is found in the fluids in our everyday lives to the fantastical plumes captured by the Hubble telescope. However, the mechanics of turbulence are still a poorly understood, unsolved problem in classical physics. The core of my research is understanding and quantifying the keystone role that fluid turbulence plays in various astrophysical environments such as the Interstellar Medium (ISM). Understanding these processes is vital for attaining a holistic description of star formation, and ultimately galaxy evolution. Not only are such systems incredibly complex, with multiple competing factors contributing to the phenomena observed, given the unfathomable distances that these objects are away from us, turbulence is especially difficult to quantify observationally in extraterrestrial systems. It is difficult, if not impossible, to attain neat analytic solutions to such chaotic systems involving multiple spatial and temporal scales. However, following an incredible decade in the rapid development of automation tools, Machine Learning (ML) techniques and Neural Networks (NN) are the state of the art when it comes to pattern recognition technology, and I will leverage these advances to bring about symbiotic development of both realms of astronomy and ML. My approach is to develop new interpretable ML tools for turbulence that simultaneously address challenges both in fluid mechanics and deep learning (DL) practices. A grand challenge in the study of fluid turbulence is to achieve detailed numerical simulations. To address this, a portion of this research focuses on developing physics-informed Convolutional Neural Networks for super-resolution on simulations of turbulent Rayleigh-Bénard convection (RBC). My research will probe beyond numerics, developing novel ML techniques to learn fluid properties from experimental data of turbulent RBC. This portion of the research will help address open fundamental questions in turbulence, tying together rigorous scientific numerics, experiments and theory with ML. Due to the well behaved statistical properties of turbulent systems, turbulence studies utilise an expansive suite of some of the most robust statistical analysis tools of any scientific field, like the power spectrum. By leveraging such techniques and properties, the performance of the ML model's output will be quantitatively measured and scrutinised, extending beyond simple monitor of loss functions as primary performance indicators, which is the current standard in the ML community. This approach is key for developing innovative tools that aid in facilitating scientific discoveries rather than poorly considered black-box automation. The intersection of fluid dynamics and ML is thus an ideal experimental ground for developing new ML architectures and techniques. Applying the suite of statistical analysis techniques for turbulence tests the limitations of ML tools in generating physically realistic outcomes. As a NASA FINESST Fellow, I propose to expand on these initial works to develop ML technologies to upscale magnetohydrodynamic (MHD) turbulence simulations to higher resolutions, which will aid in verifying fundamental theoretical frameworks for turbulent astrophysical systems.

Daniela Calzetti (PI)/ Sarah Betti (FI)
University of Massachusetts, Amherst
21-ASTRO21-0023: Probing the Physical Mechanisms Responsible for Brown Dwarf and Giant Planet Formation

Recent observations of giant forming protoplanets are providing the first-ever direct measurements of ongoing planet formation. However, interpretation of these measurements remains challenging, relying heavily on assumed parallels between stellar and planetary accretion. Brown dwarfs provide the critical bridge between the stellar and planetary domains as they lie in a mass regime where the two overlap. Brown dwarfs have been observed as both isolated free-floating objects and as bound companions orbiting a larger primary star. It is hypothesized that isolated (free floating") brown dwarfs form similarly to stars from collapsing molecular cloud cores, while bound companions form similarly to the most massive exoplanets through fragmentation of a gravitationally unstable circumstellar disk. Recent simulations suggest that bound companions have a larger reservoir of material to accrete from after formation, and thus accrete at higher rates. These high accretion rates may be a signature, therefore, of their formation mechanism. However, companion brown dwarfs can be ejected from their host system and isolated brown dwarfs can be gravitationally attracted to a larger system after formation. Furthermore, observational signatures of accretion are not well-calibrated in the substellar regime. My project strives to conduct a comparative study of the observational signatures of isolated and bound brown dwarfs to probe their formation mechanisms, as well as probe the accretion paradigm for planets and brown dwarfs by establishing new accreting object templates and scaling relations for the substellar regime. As different formation mechanisms are predicted to result in differences in accretion rates, I will: 1. Complete new near infrared measurements of mass accretion rates to perform the largest uniform statistical study of accretion properties for substellar objects to date. 2. Compile and uniformly process/update all known mass accretion rates for low mass stars, brown dwarfs, and exoplanets to date to disentangle physical and systematic effects leading to observed scatter in mass accretion rates for objects of the same mass. 3. Probe model-predicted differences in the physical sources of accretion excess for substellar objects by conducting multiwavelength measurements and calculating new scaling relations for brown dwarfs. My project will lay the foundation for understanding the formation of BDs and giant exoplanets and addresses the central NASA Cosmic Origins goal to discover how stars and planetary systems form within the galaxies”. It is critical to understand how these planets form and evolve, if we want to answer the questions: Are we alone? How did we get here?", another central component of the NASA Astrophysics mission.

Christine Chen (PI)/ Kadin Worthen (FI)
Johns Hopkins University
21-ASTRO21-0028: Characterizing Exoplanetary Systems with JWST

Direct imaging has led to the discovery of exoplanetary systems that contain giant planets and collections of dust, asteroids, and planetesimals known as debris disks. Due to their young age, systems with directly imaged exoplanets and debris disks provide great opportunities to study the early evolution of exoplanetary systems and understand how exoplanets and disks interact. For example, it is unknown if dust and rocky material, such as silicates, are accreted from debris disks onto giant planets. The presence of silicate clouds in the atmosphere of giant planets has been predicted but not yet observed (Madhusudhan et al 2019). This gives rise to the question, what is the origin of the silicate particles in giant exoplanets and how do the silicate particles get processed in the exoplanet atmospheres? Are the silicates accreted onto giant planets from the circumstellar environment, delivered to giant planets through collisions with asteroids and comets, or do they originate within the planet and are released through mechanisms such as core erosion (Moll et al. 2017)? By studying the composition of the silicates in debris disks, one can understand how giant planets sculpt exoplanetary systems. In our solar system, it is thought that Jupiter divided the meteorites into two distinct populations based on composition. A question of interest is, do exoplanetary systems that have giant exoplanets and debris disks also exhibit compositionally distinct populations of dust and asteroids, or is our solar system unique in that sense? These questions will only be able to be investigated using spatially resolved mid-infrared spectroscopy with the James Webb Space Telescope (JWST) Mid-infrared Instrument (MIRI) Medium Resolution Spectrograph (MRS). I will develop Point-Spread Function (PSF) subtraction and spectral extraction techniques using simulated JWST MIRI MRS observations to enable spatially resolved spectroscopy of giant exoplanets and debris disks with the MRS. The MRS is expected to revolutionize our understanding of giant exoplanet atmospheres and debris disks by enabling the first measurements of the 10 µm silicate cloud feature in giant exoplanet atmospheres as well as the spatially resolved characterization of silicates in debris disks. The development of PSF subtraction techniques is necessary for the advancements that the MRS will enable with spatially resolved spectroscopy of exoplanetary systems. There are already planned Cycle 1 programs that will study the atmospheres of giant planets and debris disks, including GTO 1294 that will study the Beta Pic debris disk and Beta Pic b giant planet. PSF subtraction has not been developed for the MRS and the techniques and results from this project will support planned Cycle 1 observations and prepare the community to be most effective during the lifetime of JWST for using the MRS to study exoplanetary systems.

Steven Cranmer (PI)/Aylecia S. Lattimer (FI)
University of Colorado, Boulder
21-ASTRO21-0009: Expanding the Spectral Database: An Updated Formalism for Line-Driven Winds and Consequences for Stellar and Quasar Outflows

The study of photon-driven flows has a long history. These outflows exist in various astrophysical environments, including accreting objects such as protostars, cataclysmic variables, and active galactic nuclei (AGN). For example, a line-driven disk wind is a promising hydrodynamic scenario for AGN outflows. The driving is often referred to as radiation pressure," where the force of radiation from the absorption and reemission in spectral lines acts on the material of the wind or outflow. The large number of spectral lines in any given ion have a dominant effect on this pressure on the flow material. Characterizing mass and energy flows is critical in the understanding of how objects evolve and interact with their surroundings. Absorption and re-emission of photons leads to a strong negative effective gravity in the outer layers of a star, resulting in a continuous mass flow. Models based on line-driven wind theory have yielded results that agree well with observations of mass loss and terminal flow rates. Because all spectral lines contribute to this radiation pressure, the inclusion of as many lines as possible is imperative in developing a more complete understanding of this phenomenon. While the line-driving radiation pressure is often thought of as analogous to the more familiar fluid pressure, a more general way to express this force on a parcel of gas is as a product of the radiative flux and the opacity of the material. Opacity is necessary for any acceleration due to the radiation field to occur; without opacity, the radiation cannot interact with the material of the flow, and no force on the material will occur. We propose to develop refined models of radiatively driven outflows in a variety of astrophysical environments, including but not limited to massive OB stars and AGN, by updating the characterization of the line-force due to radiation driving. As the line-force is directly dependent on this form, any changes will have direct effects on the line-force and consequently our understanding of the phenomena that are shaped by these outflows. The groundwork for this project has already been completed, including: the compilation of an updated line list from multiple sources, calculation of the force multiplier for preliminary environment parameters, characterization of an alternate force-multiplier form, and calculation of mass-loss rates that result from this updated form. Intermediate work will include adapting this pre-existing framework to be applicable to AGN outflows by modifying environmental parameters such as the central source SED and the ionization balance in the outflow material. The end result will be models of these outflows that are valid under a variety of assumptions and parameters, to be used in comparison to observational predictions for constraint of outflow features such as mass loss, clumping, and shocks. To determine if these updated calculations reproduce realistic physical features in model outflows for the relevant environments, synthetic spectra for comparison with observed spectra from massive stars and AGN will be computed, in addition to wind characteristics such as mass loss rates and velocity profiles. For example, archival data from the Cosmic Origins Spectrograph can be used for comparison in the UV, where the broad absorption line region has been observed in AGN spectra. Powerful stellar winds from high-mass stars are a major component in the recycling of mass and energy into the interstellar medium and in the driving of galactic outflows. Understanding these stellar systems is a fundamental step in the characterization of astrophysical evolution at galactic and greater scales. Similarly, because these outflows so strongly influence their host systems, careful understanding of the driving mechanisms of these winds is critical. This work therefore directly supports the Astrophysics Research Program, and addresses questions pertaining to stellar and galactic evolution.

Rana Ezzeddine (PI)/ Nicholas Barth (FI)
University of Florida, Gainesville
21-ASTRO21-0075: Tagging our Solar Siblings with GALAH and Gaia

Since the Sun's birth, its natal cluster has long been dispersed across the Galaxy, with its siblings being scattered among billions of other stars. With the advent of precise all-sky surveys that record kinematic and chemical abundances for hundreds of thousands of stars, the search for the Sun's siblings has become a feasible endeavor. In this work, we propose a new method of constraining solar siblings through (1) the use of high dimensional clustering algorithms and (2) chemodynamically tagging of rapid neutron capture (r-process) elements. Previous studies of open and globular clusters have confirmed that stars clusters are internally chemically homogenous, allowing clusters to be identified through their chemical and kinematic profiles. Using a cross-matched catalog of Gaia astrometric data and GALAH abundance measurements, we propose using a machine learning clustering algorithm, HBDScan, to form a preliminary selection of solar sibling candidates of those that share the same high dimensional parameter space as the Sun. Follow-up observations of the preliminary selection will be focused on obtaining r-process element abundances to be used as unique trackers of individual birth clouds. Stars that lie in same N-dimensional chemodynamical parameter space and share the same r-process enrichment pattern as the Sun and Solar System will be determined to have the highest probability of belonging to the same birth cluster as the Sun. The methodology we propose of incorporating r-process into chemical tagging is a useful tool for studying other stellar clusters that have been dispersed throughout the Milky Way, leading to a better understanding of the Galaxy's interaction and evolution with star clusters. The selection of high fidelity solar siblings aligns with the Astrophysics Research Program's goal of probing the origin and evolution of stars and planets, and will give scientists the opportunity to study stars that bare the same chemical composition that formed life in the Solar System. Our proposed work will not only provide a catalog of solar sibling stars, but also high quality spectra and measurements of each star, allowing for future scientists to follow-up the stars in the search for exoplanet systems and study analogs of the Solar System.

Donald Figer (PI)/ Lazar Buntic (FI)
Rochester Institute of Technology
21-ASTRO21-0088: Developing the Largest IR Detectors for Future NASA Focal Planes
Panel: Technology Development

The primary goal of the HELLSTAR project is to produce the highest pixel count IR detector ever made for astronomy. We aim to design, fabricate, and characterize a new large format detector using existing ROICs created by Sensor Creations Inc. and the new MCT detector bulk developed by our team and Raytheon Vision Services. The initial phases of the project will focus on the development of new readout hardware and software, as well as the characterization and optimization of the HELLSTAR device. The final phase will consist of deployment of the device to a telescope to demonstrate its capabilities, as well as possible deployment in Antarctica via the Cryoscope project. The HELLSTAR detectors will pave the way for extremely large IR focal planes in the next generation of NASA space and ground missions.

Wendy Freedman (PI)/ Abigail Lee (FI)
University of Chicago
21-ASTRO21-0179: Measuring the Hubble constant with Carbon Stars

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Objective: The Hubble constant (H0) is one of the most impactful values in cosmology, setting the current expansion rate, size, and age of the Universe. However, discrepant measurements of H0 between early and late Universe probes have led to one of the most intriguing inconsistencies in modern astronomy. Recent measurements of H0 from type Ia supernovae (SNe Ia) distance ladders calibrated by Cepheids disagree at the 5-sigma level with values inferred from observations of the cosmic microwave background (CMB), which assume the standard Lambda cold dark matter (LCDM) model. There are currently two paths to a resolution: (1) The LCDM model must be overhauled to bring the two measurements into agreement, or (2) Yet-to-be-revealed systematic errors in the Cepheid data are the real culprit driving the Hubble tension. We propose to utilize a novel standard candle, the J-region asymptotic giant branch (JAGB) method, to not only independently measure the Hubble constant, but also act as a cross-check on the Cepheid distances. The JAGB method capitalizes on the stable intrinsic luminosities of a subset of color-selected, carbon-rich asymptotic giant branch stars. The peak of the JAGB star luminosity function has been found to be constant in absolute magnitude from galaxy to galaxy, demonstrating the potential of the JAGB method as a powerful standard candle. Methods: We plan to use archival Hubble Space Telescope (HST) observations for the three objectives in this proposal. First, we will test for astrophysical systematics in the JAGB method; for example, how the host galaxy's star formation history, metallicity, and internal reddening affect the JAGB star luminosity function. To quantify these effects, the shape of the JAGB star luminosity function can be compared to existing high-resolution maps of star formation history, metallicity, and reddening in the spiral galaxy M31, for which there exists a plethora of data from the Panchromatic Hubble Andromeda Treasury (PHAT). Second, we will measure the distances to nine type Ia supernovae host galaxies using the JAGB method using archival HST observations. And then finally, we will use these distances to calibrate the absolute brightness of type Ia supernovae. We can use that calibration to then measure the Hubble constant using the publicly available Carnegie Supernova Project SNe Ia sample, where the slope of the SN Ia magnitude-redshift relation is the Hubble constant. Significance to NASA interests: This research directly supports the NASA Astrophysics Division's Cosmic Origins objective to study the origin and evolution of the Universe by measuring the Hubble constant to high accuracy, which quantifies the age and size of the universe. This proposal also supports the HST and JWST mission science goals in two ways: (1) The photometry pipeline and photometric catalogs of archival HST observations that we produce will be open-source and clearly documented to be easily used for other science objectives, (2) The carbon star luminosity function analysis will inform future observing strategies of carbon-rich asymptotic giant branch stars for the HST and JWST missions.

Donghui Jeong (PI)/ Joseph Tomlinson (FI)
Pennsylvania State University
21-ASTRO21-0024: Fast and Accurate Calculation of Nonlinear Galaxy Bispectrum

Dark energy contributes a majority of the energy of the universe so understanding its origin is essential. Through stronger theoretical tools we can extract additional understanding of both dark energy and many other cosmological questions: neutrino mass, non-Gaussianity, etc. This proposal would allow for both past and future galaxy clustering studies to have stronger constraints with smaller theoretical systematics with no additional data, merely extracting the information that was already there in the nonlinear bispectrum. This would make it easier to determine if dark energy is truly constant, is there a massless neutrino, which mass hierarchy do the neutrinos obey, and various other cosmological questions that can be answered solely by shrinking error bars. This project would develop the bispectrum as a fully usable tool in precision LSS cosmology.

Saurabh Jha (PI)/ Lindsey Kwok (FI)
Rutgers University, New Brunswick
21-ASTRO21-0141: Modeling the Near-Infrared Spectral Diversity of Thermonuclear Supernovae

Thermonuclear supernovae, and especially their most common variety, type Ia supernove (SN Ia), are cosmic explosions with far-reaching implications for nearly all aspects of astronomy, including cosmology, stellar evolution, galaxy formation, and chemical enrichment of the universe. The largest systematic uncertainties in cosmological research are now coming from errors in the SN Ia spectral model and intrinsic scatter in SN Ia properties. Thus, understanding SN Ia physics has now become essential to the progress of cosmology. Despite decades of study, many open questions remain regarding the progenitor systems and explosion mechanisms of both normal SN Ia and the variety of extreme and peculiar classes of exploding white dwarfs. In addition to the cosmological implications, thermonuclear supernova physics is fundamental to explaining stellar evolution and death, and how baryons cycle through galaxies.

The most promising avenue for improving our understanding of SN Ia physics is in the infrared (IR). SN Ia are better standard candles in the near-IR (NIR) than in the optical and characterizing their NIR behavior will lead to cosmological advancements. Additionally, extreme SN Ia and peculiar classes of other thermonuclear supernovae exhibit striking spectral differences in the NIR; understanding these differences will allow us to map progenitor and explosion channels to supernova outcomes. We propose to develop publicly accessible spectral models of SN Ia in the NIR using the open-source radiative-transfer code TARDIS. TARDIS is a mature, established code with the features and capabilities required to complete this project. We will update the NIR treatment in TARDIS and extend models of normal SN Ia with a range of decline rates to the NIR, with implications for cosmological research. To investigate the physical properties that give rise to the distinctive NIR signatures found in extreme SN Ia and peculiar objects, we will use TARDIS to model the combined optical and NIR spectra of extreme and peculiar thermonuclear supernovae for the first time. Our proposed work will achieve two critically important and connected science goals: a deeper understanding of the astrophysics of exploding white dwarfs and spectral models for improving cosmological distance estimates. Our proposed work is both pressing and timely as it will provide essential modeling groundwork for interpreting and understanding the NIR spectra that JWST and Roman will produce. The work detailed in this FINESST proposal directly supports both the Cosmic Origins and Physics of the Cosmos NASA science priorities by exploring the origin, evolution, and death of stars; the evolution of the elements; and improving cosmological distance measurements to constrain the nature of dark energy and the expansion of the universe.

Erin Kara (PI)/ Jingyi Wang (FI)
Massachusetts Institute of Technology
21-ASTRO21-0089: Towards Precision Measurements of Accreting Black Holes: Revolutionizing X-ray Reverberation Mapping

Accreting black holes (BHs) are a fundamental tool to understand accretion and ejection physics, and are an ideal laboratory to ultimately test Einstein's general relativity (GR) in the strongest gravity regime in the Universe. High-fidelity GR tests require a precise knowledge of the physical environments in which particles move. Two biggest challenges there are how close to the event horizon inspiraling gases reach, and how the relativistic jets are launched. The puzzle piece linking these two challenges together is the nature and geometry of the hot (hundreds of keV) X-ray emitting plasma called the "corona". X-ray Reverberation Mapping, where X-rays produced close to the BH reverberate off inspiraling gas, allows us to map out scales close to the event horizon -- orders of magnitude better than the resolution of our telescopes. Reverberation lags result from the light travel time difference between the direct coronal emission and the reflected disk emission, and therefore the lag properties probe the disk-corona geometry. The goal of this proposal is to exploit the wealth of X-ray observational data of accreting BHs to systematically probe the innermost X-ray emitting regions and to study their connection with the environment. To achieve this, we will: (1) simultaneously model the spectral and timing products using a physically-driven and state-of-the-art reverberation model, to quantify the disk-jet-corona geometry and dynamics, and to measure fundamental black hole properties, e.g., mass and spin; (2) pioneer an entirely new machine learning-based fitting methodology that will allow us to extract maximal information from our energy- and time-tagged photons.

Allison Kirkpatrick (PI)/ Kurt Hamblin (FI)
University of Kansas Center for Research

21-ASTRO21-0087: How much do AGN Host Galaxies Contribute to Cosmic Star Formation?

Main Objective: We will measure the amount of star formation rate density (SFRD) and black hole accretion rate density (BHARD) within a single sample of galaxies from z=1-3. We will identify whether galaxy and AGN mass buildup is coeval within the same population. Significance: Understanding the link between Supermassive Black Hole (SMBH) and host galaxy evolution requires assessing not just these high-luminosity AGN, but also previously unseen low-luminosity AGN. The James Webb Space Telescope (JWST) will push further down the AGN luminosity function than ever before, allowing identification of elusive low-luminosity AGN. We will have access to two JWST MIRI galaxy surveys (through involvement of the PI), and will utilize machine learning to robustly identify low-luminosity AGN in the first JWST study of AGN at z~1-2. With a complete sample of identified AGN, we will be able to measure the SFRD and BHARD in the same sample of galaxies, which has never before been done. Methods: We are developing a machine learning network, utilizing ensemble based learning of neural networks (EBNN), to identify AGN in JWST. The network will be trained on state-of-the-art mock JWST MIRI band galaxy images from involvement in the CEERS survey, in separate bins of redshift for z~1,1.5,2; these redshift bins ensure that our analysis traces features indicative of star formation. Combinations of the JWST MIRI photometries will be used as input features, in the same manner as done for traditional color selections. We expect a total of approximately 800 AGN or composite AGN+star forming galaxies to be identified from all up surveys. SED fitting will then be performed on these galaxies (with X-CIGALE) in order to measure star formation rates and black hole accretion rates. We will use these measures to determine how of the BHARF is attributable to AGN in star forming hosts. Perceived Impact: Previous work by the PI indicates that JWST will be able to select >4 times as many AGN than previously possible, namely including previously elusive low-luminosity AGN. This proposed study will develop a more robust method of AGN identification than traditional color selection method using modern machine learning methods. This tool will be released publicly, to be used for AGN identification within JWST MIRI datasets. Analysis of AGN identified with this tool will answer the question of whether galaxy and AGN mass buildup is truly coeval within the same population. Relevance to ADAP Solicitation: This project is well aligned with the goals of the FINESST program in that it transcends traditional wavelength regimes and uses existing archival data to address several open questions regarding obscured AGN and the co-evolution of SMBHs and their host galaxies. Our science objectives are key components of the galaxy formation and evolution objectives outlined in NASA's Strategic Plan and Astrophysics Subcommittee Roadmap.

Nikole Lewis (PI)/ Trevor Froote (FI)
Cornell University
21-ASTRO21-0008, Exploring the Use of Transition-Edge Sensors for High-Precision Characterization of Exoplanet Atmosphere

Within the field of exoplanet science, our limitations on understanding the atmospheres of these strange worlds are increasingly due to uncertainty in our measurements due to systematic instrumental noise sources. For this reason, the development of detectors that operate as near the quantum noise limit as possible is becoming critically important to the advancement of the field. I propose to develop and test transition-edge sensors (TES), for use as the first single-photon detectors to be applied to the observation of exoplanet atmospheres in the visible and mid-infrared spectrum. This work will involve the development of a new energy extraction algorithm that will allow the TES detectors to operate outside their linear dynamic range enabling high precision atmospheric characterization. A simulator will also be created during the testing process to assist engineers and scientists in the design and application of instruments using TES detectors. To complete this project, the behavioral response of TESs will need to be probed in a variety of conditions, including changes in parameters like operating temperature, photon energy, or the number of photons per recorded event. This proposed work is of interest to NASA as it focuses on the development of a new measurement technique and its implementation that will lead to new scientific discoveries. Through improvement of TES detectors sensitivity and allowing for a wider range of operating temperatures, this work will pave the way for TES detectors to be implemented in exoplanet atmospheric science instruments providing us an opportunity to better understand the worlds beyond our solar system.

Michael Line (PI)/ Peter Smith (FI)
Arizona State University
21-ASTRO21-0104: Innovations in Characterizing Exoplanet Atmospheres with High Resolution Cross-Correlation Spectroscopy

High resolution cross correlation spectroscopy (HRCCS) is an emerging method for ground based characterization of exoplanet atmospheres. Robust statistical methods (retrievals") for placing reliable, quantitative constraints on the properties of exoplanet atmospheres have only been recently developed. The FI proposes to leverage data from ongoing and future HRCCS surveys of bright planets led by ASU and close collaborators to develop and refine the framework of high resolution atmospheric retrievals. Additionally, the FI proposes to develop forward modeling frameworks that capture 3D atmospheric effects, which manifest at high resolution, with the computational efficiency of 1D modeling codes. This study will enhance our understanding of fundamental atmospheric properties of exoplanets as well as develop the methods needed to utilize HRCCS with near future facilities with higher data volumes. This work will support the NASA SMD programs of Cosmic Origins and Exoplanet Exploration by studying crucial properties needed to elucidate the mechanisms by which planetary systems form, as well as developing cutting edge techniques that will be used to study exoplanets in the future.

Vasileios Paschalidis (PI)/ Erik Keoni Wessel (FI)
University of Arizona
21-ASTRO21-0217: Multimessenger Modeling of Binary Neutron Star Mergers at the Frontier

Multimessenger astronomy arrived with GW170817, the first detection by LIGO and Virgo of a binary neutron star (BNS) merger, and the subsequent observation by ground and space-based observatories of associated EM signatures across the spectrum. A second BNS merger, GW190425, was subsequently confirmed, although no significant EM counterparts were found. Current estimates suggest many more such events are likely to be observed in the near future. In the search for EM counterparts, NASA missions play an indispensable role detecting and characterizing GRBs and other EM transients. However, there exist significant uncertainties in the BNS merger models that link the binary parameters (extracted from GWs) to the ejecta properties that determine EM signatures, leaving the data collected by these NASA missions with substantial unrealized potential. In particular, gravitational waves (GWs) provide an accurate measurement of the total mass of the binary, which determines the ultimate fate of the remnant. In the high-mass case, the remnant undergoes prompt-collapse on dynamic timescales. Observations of BNS mergers such as GW170817 and GW190425 have the potential to narrow down this prompt-collapse threshold mass, which in turn helps narrow down the neutron star equation of state. However, at present GWs alone are unable to significantly constrain the spins of the binary, and the effect of spin on the BNS prompt-collapse threshold mass is under-explored, stymieing efforts to learn about the neutron star equation of state this way. For lower masses the merger remnant lives long enough to emit significant neutrino radiation that has a major effect on the post-merger dynamics, including ejecta velocities, masses, and composition. However, neutrino transport (NT) in the merger aftermath is poorly modeled by existing methods, resulting in an order-of-magnitude discrepancy between the Kilonovae-inferred ejecta mass and numerical relativity predictions for GW170817, as well as lingering questions about the role neutrinos play in launching the post-merger jets believed to produce associated GRBs. To fix all these issues, reliable theoretical modeling is needed. We propose cutting-edge numerical relativity studies of BNS mergers. First, a detailed study of the effect of spin on BNS prompt-collapse will be performed. Simultaneously, we will develop a novel first-principle-based NT solver for dynamical spacetime designed to be reliable even in the extreme BNS merger environment. The public release of this code will have a massive impact on the field of numerical relativity. We will then use this code to conduct the first BNS merger simulations fully modeling the dynamics of post-merger neutrino winds, and their effects on ejecta outflow and jet launching. This will greatly increase the scientific return of EM follow-up observations by missions such as Fermi, INTEGRAL, Swift, and others in NASAs Physics of the Cosmos Program, helping to fulfill the promise of multimessenger astronomy.

Erik Petigura (PI)/ Judah Van Zandt (FI)
University of California, Los Angeles
21-ASTRO21-0218: A Doppler Survey to Measure the Prevalence of Jovian Companions to Close-in TESS Planets

The Distant Giants survey is a three-year search for Jupiter-like planets around stars that have known Earth-like planets. Specifically, the survey uses the radial velocity (RV) technique to measure the conditional probability that there is a long-period giant planet in a system, given that there is already a known close-in small planet. Distant Giants is geared toward understanding system architectures that is, the dynamical layout of all of the bodies orbiting a star with a specific emphasis on the relationship between Earth and Jupiter. The result of the survey will help us to understand how the interactions between gas giants and their rocky neighbors dictate planet formation. Additionally, determining the frequency of Jupiter-Earth pairs will give us clues as to whether the solar system is rare or common. To obtain a sample of stars with known inner small planets, I began with a set of targets from NASA's TESS mission, which has discovered thousands of transiting planet candidates since it began in 2018. I isolated a high-purity sub-sample of 47 of these stars by demanding that they be similar to the sun and amenable to follow-up RV observations. For the past 18 months, I have observed each of my sample targets once per month, making my survey 50% complete. I will continue at this cadence until all targets have a baseline of three years. I have already begun characterizing the developing time series of each star. In the case of orbits longer than ~12 years, we can only detect a small part of the planetary signal; to address this obstacle, I developed a forward modeling tool to characterize companions based only on long-term RV variations. My model extends the effective baseline of the survey, granting sensitivity to long-period companions that would otherwise be detectable only by a longer, more resource-intensive survey. The Distant Giants survey addresses the NASA Astrophysics division's strategic objective of searching for life on planets around other stars. Understanding how the Earth developed as a habitable planet is crucial to the search for extraterrestrial life. For example, if Jupiter was instrumental in that development, then the solar system analogs found by the Distant Giants survey will be promising candidates for follow-up atmospheric characterization using JWST. The results of my survey will strengthen our understanding of exoplanet formation and exosystem architecture, giving insights into our own solar system as well as those around other stars.

Enrico Ramirez-Ruiz (PI)/ Ricardo Yarza (FI)
University of California, Santa Cruz
21-ASTRO21-0068: The Hydrodynamics of Planetary Engulfment

In many planetary systems, including our own, the host star will expand during post-main-sequence evolution to engulf close-orbiting planets and/or brown dwarfs (hereafter substellar bodies, SBs). This ubiquitous process stands as a possible solution for several unexplained observations in stellar and planetary astrophysics, such as: (i) stellar remnants with close-orbiting SBs, (ii) evolved stars with unusually high surface abundances of the 7Li lithium isotope, and (iii) rapidly-rotating evolved stars. Our understanding of engulfment is, however, limited: there is no consensus on the efficiency with which the SB's orbital energy is transferred to the envelope, and there are no detailed studies of the the processes by which the SB could be destroyed during engulfment. Moreover, regardless of the fate of the engulfed SB, there is also not a detailed understanding of engulfment-induced effects to the host star, such as spin-up, mass loss, surface abundances changes, and changes to the magnetic field strength. The goal of this proposal is to develop and employ a combination of analytical and numerical three-dimensional hydrodynamical models to provide a deeper physical understanding of substellar engulfment and its accompanying observational properties. We propose a set of simulations that isolate the different spatial and temporal scales of the problem to gradually build a complete and physically accurate picture of engulfment: Task 1: Local simulationsmodeling only the flow in the vicinity of the SBusing realistic models for the SB's internal structure. These simulations will help us understand how engulfment changes the internal structure of the SB, as well as quantitatively determine the envelope conditions in which the SB will be destroyedvia tidal disruption, ram pressure disruption, and/or ablation. Task 2: Global simulations of engulfmentmodeling the stellar host in its entirety. These simulations treat the SB as a point particle, employing a realistic model of the internal structure of the star. These simulations will study the impact of engulfment on the properties of the star. Task 3: Global simulations of engulfment using realistic models for both the SB and the star. These simulations will provide a complete self-consistent hydrodynamical picture of engulfment. The past decade has brought revolutionary advances in space-based astronomical instrumentation. Missions such as Kepler, CoRoT, and TESS have provided an unprecedented photometric view of planetary population statistics and of the physical properties of individual exoplanets. Combined with models that couple stellar evolution to the orbital evolution of exoplanets, these data confirmed that planetary engulfment is a common phenomenon. More recently, dozens of SBs orbiting evolved stars and stellar remnants have been discovered, including several by ongoing TESS surveys (with tens or hundreds more expected in the near future). Similarly, the James Webb Space Telescope will provide an unprecedented window to the atmospheres of these SBs. These extreme systems represent a new frontier in exoplanet studies with the potential to offer critical constraints on the late-stage evolution of planetary systems. The rapid pace of revolutionary observational discoveries demands a theoretical understanding of the underlying physical processes at workprogress that will undoubtedly hinge on computational models. Given the relatively nascent stage of modeling, the work we propose here would significantly contribute towards the theoretical understanding necessary to maximize the scientific returns of these revolutionary missions, improving our understanding of substellar engulfment and the evolution of planetary systems at large.

Paul Robertson (PI)/ Corey Beard (FI)
University of California, Irvine
21-ASTRO21-0057: Unlocking Ultra-precise Doppler Exoplanet Masses with Kepler and TESS Photometry

In order to measure the masses of small exoplanets with radial velocities, we must mitigate stellar activity contamination at the m/s level. Photometry is an excellent tool for characterizing stellar activity, but the community has not yet developed reliable techniques to model RVs with photometry when the data are not taken at similar times. Taking RVs contemporaneously with photometry has proven effective, but restrictive. Systems observed by Kepler have multiple years of data that describe the activity patterns of stars, but those data are now many years removed from new ultra-precise RV measurements. The TESS spacecraft, on the other hand, is recent, but lacks the multi-year baseline of Kepler. We will study the best ways to utilize both photometric datasets when mitigating activity in RVs. This project is already using the ultra-precise NEID spectrometer to obtain high cadence RVs of modestly active Kepler systems while TESS observes them. We will soon compare newly-developed joint photometry/RV analysis methods to determine the best ways to utilize both Kepler and TESS to probe below the 1 m/s astrophysical noise floor. We expect to obtain refined mass measurements for several high-value transiting exoplanets as a result of this study.

David Schiminovich (PI)/ Meghna Sitaram (FI)
Columbia University
21-ASTRO21-0186: Pioneering Ultraviolet Integral-Field Spectrograph Technologies for Deep Mapping of Galaxy Halos

Ionized gas in the circumgalactic medium (CGM) traces the interaction between galaxies and their surrounding medium, fuels future star formation in galaxies, and may hold a significant proportion of undetected baryons in the present universe. However, because it is extremely diffuse and faint, it has been difficult to map in emission and has previously been explored mainly in single absorption sight lines. Instruments such as the Faint Intergalactic medium Redshifted Balloon (FIREBall-2) and Circumgalactic H-alpha Spectrograph (CHaS) will survey the complex dynamics of the CGM and have developed technology for observing this faint emission. We propose DiffuSAT, a cubesat carrying an integral field spectrograph which will map the CGM of nearby galaxies in UV deeper than ever before. DIFFUSat's wide field of view, high grasp, and moderate resolution will allow it to obtain three-dimensional spatial and kinematic information over the entire CGM of nearby galaxies, giving us an unprecedented view of its large-scale structure and the cycling of gas between galaxies and halos. The design of this instrument will involve development of key technologies such as lenslet arrays in the UV and in space and CCD coatings enhancing efficiency in the UV, for use in future NASA missions.

Paul Shapiro (PI)/ Joohyun Lee (FI)
University of Texas, Austin
21-ASTRO21-0091: Forming Dark Matter Deficient Galaxies By High-Speed Collisions: Simulations to Test Cold Dark Matter and Constrain Self-Interacting Dark Matter

In the standard Cold Matter Model (CDM) of cosmology and structure formation, galaxies form when dark matter density fluctuations grow until they collapse gravitationally to form galactic haloes of dark and baryonic matter, in relative amounts which reflect their average contributions to the cosmic mass density budget. Dark matter dominates the mass and formation of the halo. In fact, when baryons later form stars inside a galactic halo, the energy they release in stellar winds, jets and explosions and ionizing radiation can even reduce their contribution to the galaxy mass budget by blowing interstellar gas out, making the galaxy even more dark-matter-dominated, especially for low-mass galaxies. For this reason, it was very surprising when recent surveys of ultra-diffuse galaxies (UDGs) discovered a new class of galaxies without dark matter - the so-called dark matter deficient galaxies" (DMDGs) - challenging the standard CDM paradigm. Since then, observations by NASA's Hubble Space Telescope have added support for the existence of DMDGs, while theoretical attempts to explain it within the CDM framework have succeeded in showing that such objects can form as the product of high-speed collisions between galaxies, at hundreds of km/s. This is analogous to the famous Bullet Cluster in which two cluster-sized haloes collided at thousands of km/s and their collisionless components -- dark matter and stars -- passed thru each other and separated, while their gaseous baryons, colliding supersonically, were left behind, prevented from interpenetrating by fluid-dynamical behavior involving shocks. Our previous work involved the first simulations to demonstrate that this mini-bullet" model can explain the observed DMDGs within the standard CDM paradigm, including formation of their observed stellar masses and unconventional globular cluster population. As new observations accumulate additional details, our previous proof-of-principle simulations must now be followed-up by new high-resolution, cosmological N-body and gas dynamics simulations to match them. Advances will include: (1) a higher degree of physical realism by improved treatment of radiative processes and subgrid algorithms for stellar physics; (2) larger simulation volumes, to follow each collision history more fully, from widely-separated initial halos to the final stage of widely-separated, dark-matter-dominated halos, far from the central DMDGs they leave behind; (3) improved initial conditions to better match the latest DMDG observations, by refined choice of colliding halo properties and their self-consistent emergence during cosmological structure formation; (4) to determine the statistical likelihood of occurrence of these initial conditions in the LambdaCDM universe, large volume, dark-matter-only simulation halo catalogues already available will be analyzed. Our results will test the CDM paradigm by determining both the collision parameters capable of reproducing observed DMDGs and their statistical likelihood, while predicting what future surveys should detect. The mini-bullet" model works to explain DMDGs because of the difference between the collisionless nature of CDM and fluid-like behavior of gaseous baryons. DMDGs, therefore, present a unique opportunity to test and constrain alternative dark matter models with fluid-like behavior on small scales, such as self-interacting dark matter (SIDM). Just as the Bullet Cluster provides a fundamental upper limit to the SIDM particle scattering cross section, we propose now to use DMDGs to push this constraint to the lower energy of particle collisions in mini-bullets. This will be done by replacing the code used above for CDM, by one for SIDM, with a Monte-Carlo algorithm for its elastic scattering. This research serves NASA's strategic objective, by advancing our understanding of the origin and evolution of galaxies and structure in the universe, as well as the nature of dark matter.

Lorenzo Sironi (PI)/ Navin Sridhar (FI)
Columbia University
21-ASTRO21-0092: Unveiling the Nature of Fast Radio Bursts

Fast Radio Bursts (FRBs) are intense pulses of coherent radio emission of cosmological origin, typically lasting a few milliseconds, the discovery of which has opened a new window into high-energy plasma astrophysics. While most of the observed sources of FRBs do not exhibit repetition, some of them do, and a couple of them even exhibit periodicity in their repetitions. Despite the rapid progress in observations, our theoretical understanding of FRBs is still incomplete. Major unknowns include the emitting progenitors and the radiation mechanisms. While a consensus has slowly begun to emerge pointing to magnetars as one of the sources of at least some of the repeating class of FRBs, not all FRB sources have shown evidence for repetition, and cataclysmic events like neutron star mergers could be plausible avenues. Regarding the radiation mechanismwe do not yet possess a reliable theory built from first principles for the properties of the emitting particles, and for the efficiency, spectrum, and polarization of the coherent FRB emission. Our research program involves modeling FRB sources from the microphysics of the emission to the macrophysics of the environment. Using multi-dimensional Particle-In-Cell (PIC) and Magnetohydroynamical (MHD) simulations, we will investigate at a fundamental level, the plasma physics of relativistic magnetized shocks and the associated instabilities, which will place FRB models (as well as models of other astrophysical high-energy sources) on a solid footing. We will convolve our results from the first-principle PIC and MHD simulations of relativistic magnetized shocks, with radiative transfer and photo-ionization codes, in order to account for propagation effects and to retrieve FRBs pulses, as observed from Earth. Our first-principles simulations of various plausible models will have the predictive power to remark on the expected observables i.e., the spectral, polarization, multi-wavelength fluence of FRBs, and the temporal variation of dispersion and rotation measures. The multi-wavelength signatures of FRBs informed from our first-principle simulations will directly assist NASA with its missions' observing strategies under the 'Physics of the Cosmos' program (e.g, Chandra, NICER, IXPE, etc.). In the future, the X-ray polarization measurements from NASA's IXPE are expected to unravel the magnetic field geometry in magnetars and determine how particles are accelerated in Pulsar Wind Nebulae. The predictions from our simulations will be 'testable' with the observations from IXPE.

Charles Steidel (PI)/ Zhuyun Zhuang (FI)
California Institute of Technology
21-ASTRO21-0061: New Dimensions in the Chemical Compositions of Galaxies with Integral Field Spectroscopy

We live in the golden age of observational studies on the chemical evolution of nearby galaxies. Over the last decade, the combined power of HST, ground-based spectroscopic campaigns, and high-resolution cosmological simulations has enabled a concordant theory of the baryon cycle, the role of feedback, and galactic chemical evolution in the Local Group. However, our knowledge in galactic chemical evolution of more distant field galaxies is still limited. A deeper understanding of chemical compositions in these galaxies is essential to unveiling the full picture of the growth of galaxies. In this proposal, we aim to further our understanding of galactic chemical evolution in two ways: (1) Recent work has attempted to extend abundance studies for distant galaxies to include [alpha/Fe] in addition to the stellar metallicity [Fe/H] and gas metallicity [O/H], providing us with valuable information on the star formation timescales of galaxies. Compared to [O/Fe] commonly used in high-z studies, [Mg/Fe] may be a better indicator of [alpha/Fe] because the systematic offsets between stellar and gas abundances bias [O/Fe]. If we can connect [Mg/H] and [Fe/H] in the stellar phase to [O/H] in the gas phase for the same galaxies, it will not only tell us how metals are recycled between stars and gas but also inform us how to interpret the new results of high-z star-forming galaxies observed by JWST. (2) Different mechanisms of galactic feedback predict different shapes in the mass-metallicity relation (MZR). At $8 < \log(M^*/M_{sun}) < 10$, the gas MZR is controversial because of the large systematic discrepancies between different techniques used to measure gas metallicity in different mass ranges. Measurements of the stellar MZR are sparse in this mass range due to the difficulty in measuring stellar metallicities in highly star-forming galaxies. If we can construct a stellar-phase MZR in the mass gap alongside the gas-phase MZR, we will have a better understanding of how feedback mechanisms change as galaxies grow in mass. To address these two questions, we will develop a new method to measure the stellar [Fe/H] and [Mg/H] as well as gas-phase [O/H] of the same galaxies from the available Keck/KCWI data of local star-forming galaxies at 8 < log(M*/Msun) < 10. Integral field spectroscopy allows us to disentangle the stellar continuum from the passive regions and the nebular emission from the highly star-forming regions using the spatial information of certain spectral features, which enables us to measure the stellar abundances and gas abundances simultaneously and much more accurately. These results will (1) make an apples-to-apples comparison of instantaneously recycled alpha elements (O and Mg) in both the stars and the gas, (2) reveal the complete shape of the stellar MZR for the first time, and (3) uncover the physics by which galaxies lose gas to stellar feedback. Relevance: This proposal is relevant to the SMD Astrophysics Division in the scope of the ROSES-2021 D.3 Astrophysics Research and Analysis research. It develops a new technique to determine the chemical properties of galaxies in a better way and helps improving our understanding of the evolution of galaxies. The results will be essential for interpreting the data from NASA missions like JWST. It is also highly related to D.7 Strategic Astrophysics Technology under the Cosmic Origins Program because the proposed projects will be pioneering in constraining metal cycles between stars and gas.

Todd Thompson (PI)/ Dustin Nguyen (FI)
Ohio State University
21-ASTRO21-0174: Physics and Phenomenology of Galactic Starburst Winds

Galactic winds shape the evolution of galaxies. They carry enriched gas and dust out of their host, quenching star formation and affecting the transformation of galaxies from active and star-forming, to passively evolving. Yet, their driving mechanisms remain unknown. Although many processes have been proposed, like supernovae, radiation pressure, and cosmic rays, there is no clear physics that has been shown to dominate over a range of galaxy parameters, and that explains observations within that range. Simulators put in feedback that generates outflows in their calculations of galaxies, but there is little comparison with observations, and few maps of galaxy parameter space delineating a given mechanism's importance. In addition, a wealth of observations now exists in different wavebands, probing different gas tracers and different dynamical components from galaxies at all redshifts. The investigators argue that a focus of modern galaxy formation theory should be to put galactic winds on a firmer theoretical footing in light of the tremendous increase in data on winds in all gas phases across the universe. The combination of very recent advances in theory and observations have the chance to refigure our understanding of galactic winds. The investigators propose a suite of projects aimed at understanding the physics, evolution, and dynamics, of galactic winds in rapidly star-forming galaxies. Their goal is to simultaneously address the physics and phenomenology of galactic winds, connecting theory and observation. They will do both broad sweeps through parameter space, and focused studies of individual systems. Among the projects they will pursue, they will (1) study the stability of mass-loaded hot supersonic winds using 3D hydrodynamic simulations, (2) study the formation of radiative cores, and subsequent production of cometary cloud structures amidst a hot wind background, using 3D hydrodynamic simulations, and (3) apply the new wind models to currently available X-ray analyses of M82 and NGC 253 to make qualitative predictions for XRISM. Finally, they will compare the properties of the cool gas produced by the instabilities they identify in the proposal with optical/UV absorption and emission observations of starburst winds. The proposed research program has a duration of 2 years. The proposed work will be used to interpret multi-wavelength observations of galaxies, and is thus directly relevant for a number of current and past NASA missions, including Hubble, Spitzer, Chandra, GALEX, and Fermi, and for the upcoming JWST and XRISM. More broadly, our proposed research addresses NASA's Strategic Objective (Sub-goal 3D) to Discover the origin, structure, evolution, and destiny of the universe" and to address the questions What are the origin, evolution, and fate of the universe?" and How do planets, stars, galaxies, and cosmic structure come into being?". The proposal falls under both the Astrophysics Data Analysis (D.2) Program in the research area of Active Galaxies and Galactic (6) and the Astrophysics Theory (D.4) Program.

Sarah Vigeland (PI)/ Gabriel Freedman (FI)
University of Wisconsin, Milwaukee
21-ASTRO21-0074: Searches for Gravitational Waves from Supermassive Black Hole Binaries using Hamiltonian Monte Carlo

Supermassive black hole binaries (SMBHBs) radiate energy in the form of gravitational waves (GWs). The GWs emitted during the pre-merger inspiral period span from nHz to mHz frequencies. The primary method for observing low-frequency GWs is through pulsar timing arrays (PTAs), which can detect GWs by looking for correlated deviations in the arrival times of pulses from millisecond pulsars. GWs in the mHz regime will be observable through the Laser Interferometer Space Antenna (LISA), a future space-based interferometer with arm length 2.5 million km that will detect sources both inside and outside of the Milky Way. In both experiments, the primary method for performing the GW analyses is through Bayesian statistical techniques and Markov Chain Monte Carlo sampling. Such searches with PTAs are currently hampered by the large number of parameters needed to be sampled concurrently, a problem that will only worsen as the data span increases. Likewise, the large number of different sources that will be contained in LISA observations, combined with the need for a global fit of the data, lead to slow convergence times of potential data pipelines. An alternative Monte Carlo sampling method, Hamiltonian Monte Carlo (HMC), utilizes Hamiltonian dynamics to produce sample proposals informed by first-order gradients of the model likelihood. This in turn allows it to converge faster to high dimensional distributions, and more efficiently sample parameter spaces that are not highly constrained. We propose to develop, validate, and implement an HMC pipeline as an alternative sampling routine for analyzing GWs emitted from SMBHBs. We first plan to utilize an HMC pipeline for analyzing low-frequency GWs for signals of a stochastic gravitational wave background generated from a cosmic population of SMBHBs. Next we expect to expand the HMC sampling code to accommodate searches for other low-frequency GWs originating from individual SMBHBs. Lastly we propose to build and validate an HMC pipeline for modeling GW signals from SMBHBs in the LISA band, in order to add to a global fit of LISA data. Quick and efficient GW searches will be important for targeted multi-messenger follow-ups of potential binary systems. This will aid present NASA missions such as Swift, where X-ray observations can identify potential binary AGN candidates, and GW analyses can determine if the candidates are in fact binary systems. Future missions such as LISA will also benefit from this work, as it will allow for rapid detection and analysis of SMBHBs and other compact binary objects.

John Wise (PI)/ Snigdaa Sethuram (FI)
Georgia Tech Research Corporation
21-ASTRO21-0065: AI-enhanced Simulations and Synthetic Observations of the first Galaxies and Active Galactic Nuclei

The proposed work is aiming to better understand how star formation and feedback affects global galaxy properties and their formation during the Epoch of Reionization with resolved cosmological simulations. We will do so by using AI to enhance cosmological simulations, which often have to choose between volume and resolution of physics. Because of this, subgrid physics, or generalized physics templates/simplified analytic models, are often used to resolve small-scale physics so that realistic cosmological simulations can cover large volumes of space. We propose a three-phase plan. The first is to use a convolutional neural network trained on super-resolved and highly-resolved simulations to replace star formation and feedback subgrid models, which should retain physics fidelity at low scales and speed up simulation calculations significantly. In the second phase, we will work on super-resolution enhancement techniques, or adding detail below the original resolution scale of simulations. We will do this by training a Generative Adaptive Network (GAN) which are neural networks used to generate data and have been used as a resolution tool in astrophysics, e.g. resolving observational images or dark matter only simulations. We will train the GAN on a super-resolution simulation and attempt to super-resolve a high-resolution simulation. We expect that it will produce features below the resolution scale that are present in the training set for the GAN. In the third phase, we will create a larger, lower-resolution cosmological simulation using our surrogate model to replace the traditional subgrid model, and then run our super-resolution GAN on it to test the culmination of our two networks. We will then create a galaxy catalog from this simulation to aid interpretation of JWST observations of high-redshift galaxies. The project is relevant to a few different stratagems, such as Strategy 3.4: increasing opportunities for academic and non-profit institutions to contribute to the mission. This project would spark a collaboration with my connections at the Flatiron Institute with whom I will have an ongoing project, as well as with Azton Wells, whose work motivates our objective. The project would also allow for direct cross-collaboration with computer science or applied mathematics groups, which will foster collaboration in pursuit of a common goal, or Strategy 2.2. As the resultant neural networks of our project are aimed at reducing computational power and allowing higher quality cosmological simulations with less time and computational power, we would be contributing to strategy 4.1, fostering a more inclusive and accessible environment. Groups that may not have access to high-performance computing or may not be able to afford much time on the processors would benefit from our work. They would be able to create higher resolution cosmological simulations with average computing power due to the surrogate model, and then upscale the physics further using our GAN. Finally, the proposed work focuses on the Cosmic Origins objective of the SMD and will inform NASA's mission of understanding Cosmic Dawn. Our work will inform JWST observations into the Epoch of Reionization, and particularly is focused on early galaxy formation and evolution.

Ellen Zweibel (PI)/ Roark Habegger (FI)
University of Wisconsin, Madison
21-ASTRO21-0016: The Impact of Localized Cosmic Ray Injections on Galactic Evolution

Cosmic rays tie together local processes and global dynamics in the interstellar medium (ISM). The proposed research project examines how localized cosmic ray injection changes ISM structure. We will produce magnetohydrodynamic (MHD) simulations which examine the effect of localized cosmic ray injections from supernova shock scales to circumgalactic medium (CGM) scales. Our previous simulations show how cosmic ray buoyancy drives change in the structure of the ISM. We will improve these simulations by adding other physical processes, and use the results to develop models of the effect of cosmic rays on ISM structure. These improved simulations will examine how cosmic ray buoyancy and thermal instability couples with a multiphase ISM and with spiral density waves. We will calculate how cosmic rays change the average temperature of a galaxy and its high energy (X-ray and γ-ray) emission. Using these estimates, we will develop observational diagnostics for the impact of cosmic ray injections. Additionally, we will use our results to develop analytical models describing the effect of cosmic rays on ISM structure. We will package these models into a sub-grid algorithm for large scale galaxy simulations. Our work will help determine how cosmic rays are involved in the evolution of galaxies, directly aiding the NASA Astrophysics Division's `Cosmic Origins' program.

F.5 Future Investigators in NASA Earth and Space Science and Technology SOLICITATION: NNH21ZDA001N-FINESST

The Science Mission Directorate (SMD) reviewed a total of 927 proposals that were submitted to the **F.5 Future Investigators in NASA Earth and Space Science and Technology (FINESST)** competition within the NASA Research Announcement entitled "*Research Opportunities in Space and Earth Sciences" (ROSES-2021)*. Six SMD divisions at NASA Headquarters conducted/provided oversight for the review and selection process: Astrophysics, Biological and Physical Sciences, Earth Science, Heliophysics, Planetary Science, and Science Engagement and Partnerships (SE&P).

FINESST accepts proposals for graduate student-designed research projects that contribute to SMD's science, technology, and exploration goals. The maximum, three-year total FINESST award amount is $150,000. FINESST grants are limited cost awards. For example, SMD suggests a student stipend of $40,000 per 12 months. Not all projects, however, require the maximum amount available in the period of performance.

FINESST is similar to what 2 CFR200.1 Definitions calls a "Fixed Amount Award". "Fixed amount awards means a type of grant or cooperative agreement under which the Federal awarding agency or pass-through entity provides a specific level of support without regard to actual costs incurred under the Federal award. This type of Federal award reduces some of the administrative burden and record-keeping requirements for both the non-Federal entity and Federal awarding agency or pass-through entity. Accountability is based primarily on performance and results."

SMD's estimated timeframe to communicate the selection or intent-to-award decisions is late May through late July. Selection documents are released first, followed by non-selections. Non-selections may not be available until August 15, 2022, or later. The NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) will announce decisions via a system generated email to the PI and AOR. *NSPIRES makes detailed documentation of the selection and non-selection decisions available for each reviewed proposal to both the Principal Investigator (PI) and Authorized Organization Representative (AOR).* Access to proposal-specific documentation requires logging in to NSPIRES and navigating to the submitted proposal, and not just visiting the web page. FIs, however, cannot receive or access FINESST decisions or review results directly via NSPIRES. If by August 15, the PI or AOR have not contacted the FI, then the FI should ask them to log in to NSPIRES to see if the proposal status has changed and download and share the results.

For assistance with NSPIRES log in, please contact the NSPIRES Help Desk at (202) 479-9376 Monday – Friday, excluding Federal Holidays, (e.g., Juneteenth National Independence observed for 2022 on June 20, July 4, i.e., Independence Day, etc.) 8 AM to 6 PM Eastern Time or by email at nspires-help@nasaprs.com.

Table 1: FINESST-21 Proposal Data

Division	Proposals Reviewed	Proposals Selected (Estimated)	NSPIRES Publication Date
Science Engagement & Partnerships	2	1	May 26, 2022
Biological and Physical Sciences	25	2	July 21, 2022
Earth Science	394	62	June 30, 2022
Planetary Science*	224	32	July 5, 2022
Astrophysics	222	TBD	Pending
Heliophysics	60	TBD	Pending
Total**	927	TBD	July 25, 2022 (Target)

NOTE For Selected PI-FI Teams: Once SMD receives selection acceptance, the FINESST proposal will be transferred to the NASA Shared Services Center (NSSC). NSPIRES cannot track the NSSC grant processing activities. A grant's status may be tracked via a web search on the PI's name (do not use the FI name or NSPIRES proposal number) at: https://www.nasa.gov/centers/nssc/forms/grant-status-form, telephoning the NSSC at 1-877-NSSC123, or e-mailing nssc-contactcenter@nasa.gov.

Any pre-award costs incurred are at the proposer's risk. All new awards receive an automatic 90 days of pre-award spending approval on award, meaning that NASA has waived the requirement for FINESST award recipients to obtain written approval prior to incurring project costs up to 90 calendar days before NASA issues an award. However, expenses incurred more than 90 calendar days before the award require prior written (i.e., email) approval from a Grants Office at the NSSC.

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*Technical Note: *The Planetary Science Division (PSD) will make all notifications (selections and declines) available on NSPIRES at the same time in order to be consistent with other PSD program practices.*

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Biological and Physical Science Division Selections (2, Alphabetical by PI Last Name)

Safa Jamali (PI)/Robert Campbell (FI)
Northeastern University
21-BPS21-0017, Parameterizing Colloid Assembly and Structure Evolution in Microgravity with Particle Simulations

This project proposes to study the physics of particle assembly and structure in attractive colloidal suspensions. Colloids are nanometer-to-micrometer sized solid particles suspended in a fluid. They are common in biology, geophysics, and a wide variety of industrial products (e.g. blood, mud, shampoo, medicines, battery materials, etc.). Colloids can also can exhibit unusual mechanical properties (shear thickening, thixotropy, etc.) as a result of their particle structure. If colloid particles attract each other, they will self-assemble into clusters, crystals, and space-spanning networks. The formation of these structures changes their bulk mechanics, and in this way colloids can be considered a model system for how particle structure produces bulk material properties. Understanding that relationship is important for advancing soft matter science and materials design.

On Earth, colloid structures are easily disrupted by gravity, which has made the International Space Station (ISS) an important place to study colloid structure. Both on Earth and in space most research on colloids has focused on systems made of a single type of particle (monodisperse); however, real-world colloidal systems are usually made of a variety of particles with different sizes and characteristics (polydisperse). Four polydisperse colloidal systems have been studied on the ISS. This project will build a computer simulation platform that uses the mesoscale method Dissipative Particle Dynamics (DPD) to simulate polydisperse attractive colloids and track all of the particle interactions that occur during the self-assembly of particle structures. The objectives are to (1) quantify the time-dependent mesoscale particle structure of attractive colloid systems in microgravity, (2) explain the dynamics of self-assembly in polydisperse colloids (for application in other simulations, analyses, and the design of real-world colloidal systems), and (3) establish this new simulation platform as a generalizable, open-source method for interpreting data from future experiments. To achieve this, the simulation platform will first be validated against the existing ISS data by replicating the results of each of the 4 systems that have been studied. This will also generate new data about the details of those system's microstructure and the dynamics of polydispersity. The platform will then be used to simulate variations of those four systems across a combination of new colloid particle volume fractions, attraction strengths, and attraction ranges.

The results of these simulations will advance the field of colloidal physics by generating one of the first comprehensive theoretical frameworks for understanding the structure and dynamics of polydispersity in colloidal systems in microgravity. This is directly relevant to applications that use colloids and other particle systems, including several active applied research areas on the ISS that rely on manipulating and predicting particle structure, including high-performance wearable materials, consumer and personal care products, and bioprinting. The results will also be significant to NASA’s interests in investigating the fundamental laws of physics using microgravity.

Nozomi Nishimura (PI)/Christopher Brunkhorst (FI)
Cornell University
21-BPS21-0030, Waste Clearance from the Brain in Altered Gravity

Resources on Earth are finite. With human population continuing to rise, shortages, famine, and contagious diseases are a real danger. Climate change is real. Extreme weather events, and droughts pose a credible threat for people everywhere. Space exploration is not only an important scientific endeavor, but also a necessity. Unfortunately, space flight carries innumerable health risks that are not yet fully understood. We do know there is an acute fluid redistribution as astronauts enter microgravity. Fluid, once trapped by gravity, shifts from the lower extremities into the upper body and head causing swelling in face. Intracranial pressure increases as more fluid fills the ventricles and sinuses within the brain and skull, leading to vestibular dysfunction and impaired vision. Continued exposure to microgravity causes cerebrospinal fluid (CSF) volume to increase and as it increases more pressure is put on the brain compacting the interstitial fluid (ISF) spaces and shrinking the perivascular spaces. This is problematic because it disrupts the core anatomy and physiology essential to proper waste removal from the brain. The brain tissue does not possess the traditional lymphatics that are present throughout the rest of the body. Instead, the brain is thought to rely on the circulation of CSF around the surface of the brain and through perivascular spaces surrounding blood vessels deep into the brain tissue to drive convective flow of solutes out of the ISF into the CSF and back out to the area surrounding the brain, where it can be cleared by more traditional lymphatics that were recently discovered near the skull. Impairment of the normal waste removal system may lead to acute and long-term neurological effects which could be detrimental to astronaut health both during and after their space missions. Due to the sensitivity of the waste removal system in the brain to environmental perturbations, we hypothesize fluid transport and protein clearance in mouse brains is fundamentally altered when exposed to hypergravity or simulated microgravity conditions. We will first modify our genetically encoded secretion tracers (iGESTs) to create a secreted fluorescent protein tracer that can be selectively turned on during experimental conditions. We will use an adeno-associated virus injection to deliver the iGEST into a small group of neurons in the cortex of adult mice. After a short recovery period, we turn on the iGEST by incorporating doxycycline, as an activator, into the animals’ diet. We will use histological sections to determine the distribution of endogenously produced proteins at several timepoints relative to expression start and stop allowing us to trace the removal of waste products from the brain parenchyma. Finally, we will evaluate the effect of simulated microgravity (using hind-limb suspension) and hypergravity (using a custom-built centrifuge) on protein clearance and ISF flow. Upon completion of this grant, we aim to create a tool and methodology to be used aboard the ISS to study protein clearance from the brain in animal models with feasible space-based experimental requirements and maximal impact for the scientific community. Besides the obvious impact of this research proposal for astronaut neurological health, our proposed research is also important for understanding neurological disease. By looking at how ISF flow and protein clearance from the brain is altered in abnormal gravity environments we can increase our understanding of the driving mechanisms for these processes in normal physiological conditions. We can then apply these insights to the affects seen in neurological diseases. The goal is to understand the mechanisms involved in ISF flow and waste removal to develop a measure of protection for astronauts and many more people here on Earth. Space exploration is not only an important scientific endeavor, but also a necessity.

F.5 Future Investigators in NASA Earth and Space Science and Technology SOLICITATION: NNH21ZDA001N-FINESST

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EARTH SCIENCE DIVISION SELECTION (62, Alphabetical by PI Last Name)

Stephen Ackley (PI)/Mansi Joshi (FI)
University of Texas, San Antonio
21-EARTH21-0298, Analyzing Sea Ice Formation, Growth and Deformation in the Weddell Sea, Antarctica Using IceSAT-2

The Southern ocean sea ice plays an important role in the elements of the earth system which include oceans, atmosphere and the stability of the Antarctic ice sheet. Sea ice provides an essential habitat for many species, including seabirds, seals, and krill. When sea ice freezes, it rejects brine that densifies the underlying water mass causing it to sink to lower depths. It therefore also plays a vital role in the thermohaline circulation and global climate system. The decadal changes in salinity in the Antarctic Bottom Water (AABW) may affect the strength of the deep thermohaline circulation. The Weddell Sea is the largest source of AABW, the southern limb of the global thermohaline circulation, as it plays a significant role in sea ice formation. Sea ice formation in the Weddell Sea accounts for 5 %–10% of annual ice production around Antarctica, making the region a significant source of AABW. The sea ice in the Weddell Sea was observed to have an increasing trend since the satellite period of 1978, however, the sea ice extent started to decrease from 2016-2017. Thus, it becomes important to measure seasonal and interannual sea ice variability over the Weddell Sea to understand its role in global climate on longer temporal scales.

In this project we have proposed three objectives. First, estimation of sea ice thickness using ICESat-2. This objective will allow us to estimate the sea ice thickness using photon-level point cloud data from

NASA's ICESat-2 laser altimetry mission which will provide us with unique capabilities to analyze changes in ice thickness at a finer spatial scale (10m). Second, to compute the combined thermodynamic and dynamic ice growth from ICESat-2 thickness distributions and compare it with the thickness computed from 1D thermodynamic growth model. The results from the first objective and the results from a 1D model called CICE-Icepack will be used for comparison to better understand the contributions of different processes such as snow ice contributions. Third, the results from the first and second research objectives will be compared interannually and seasonally to understand the recent trends and changes in the thickness and, with the sea ice extent, the sea ice volume over the Weddell Sea sector.

The proposed research broadly addresses NASA's strategic objective 1.1, to understand the sun, earth, solar system, and universe and earth science research program overarching objectives i.e., to improve the ability to predict climate changes by better understanding the roles and interactions of the ocean, atmosphere, land and ice in the climate system. As the work will be based on ICESat-2 data, it is directly relevant to one of the principal ICESat-2 science objectives i.e., estimate the thickness of sea ice and monitor any changes. The analysis in this project will help us understand the changes in sea ice processes in recent years, especially after a decrease in sea ice in 2016-2017 and provide the basis for estimating interannual changes in water mass transformation in the Weddell Sea from sea ice variability.

George Allen (PI)/Emily Ellis (FI)
Texas A&M, College Station
21-EARTH21-0358, Remote Sensing of River Temperature and Discharge: Defining Connections and Assessing Changes

The goal of this proposed project is to understand the connections between river discharge and temperature in order to determine how water quality and water quantity can be combined within the field of remote sensing. This central goal will be addressed through three main study objectives. Objective 1 will seek to integrate remotely sensed river discharge and temperature data in order to better estimate river temperatures. Objective 2 will quantify the spatial patterns and determine the drivers of short-term (subdaily) river temperature variability. Objective 3 will map the spatial patterns and determine the drivers of long-term (daily-annual) river temperature changes.

This project will use a combination of remote sensing and machine learning techniques to accomplish the proposed study objectives. The first objective will extract surface temperature and river discharge from optical imagery and satellite altimetry at USGS river gage locations to create a machine learning and remote sensing-based means of estimating river temperature. The results of the first objective will inform the final two objectives by providing a method for estimating river temperatures via remote sensing. These temperature estimates will be used to address what factors impact river temperature changes over time. The second objective will employ the concept of hysteresis loops to determine what drives subdaily river temperature variability by using upstream and downstream Landsat imagery to assess changes in river temperature in a space-for-time substitution framework. The third objective will assess long-term changes in river temperature by identifying trends in river temperature, air temperature, and river discharge.

This proposed research would contribute to several categories of the Earth Science Division SMD science goals (e.g. water and energy cycle, carbon cycle and ecosystems, societal benefit). Additionally, the project relates to objectives H-2 and H-3 in NASA's most recent Decadal Survey. These objectives center around freshwater availability, the impact of environmental changes on earth cycles, ecosystems, and society, and the development of methods for monitoring water quality for both human and ecosystem health. As proposed, this project would make novel contributions to the study of water quality. This project also has the ability to incorporate river discharge data from the Surface Water and Ocean Topography (SWOT) mission when it becomes available. Satellite imagery from the

Landsat program will also be used for all optical remote sensing portions of the project, which will contribute to Landsat missions' legacy of monitoring, investigating, and understanding changes to the environment and resources.

Sridhar Anandakrishnan (PI)/Amanda Willet (FI)
Pennsylvania State University
21-EARTH21-0243, Fracture and Crevassing of Greenland Glaciers from ICESat-2 Data

Climate change poses an acute global threat, with large uncertainties depending especially on the success of mitigation efforts, but also on the response of the Earth system to human emissions. As assessed by the IPCC, warming drives widespread ice loss, including loss of sea ice, snow cover, glacier mass, and other ice. Increasing ice loss is contributing to global sea level rise, which will have significant and perhaps catastrophic effects on coastal communities and ecosystems (Meredith, et al., 2019). Significantly, the sum of glacier and ice sheet contributions is now the dominant source of global mean sea level rise (Oppenheimer, et al., 2019). Thus, improved understanding of glacier and ice sheet dynamics is of critical importance for determining and mitigating the risks of a warming climate.

The large uncertainty in projections of future sea-level rise for specified warming arises especially from imperfectly modeled ice sheet processes and unpredictable climate variability (Robel et al., 2019). The work proposed here seeks to reduce these uncertainties by better understanding important controls on ice-sheet stability at marine terminating glaciers, which discharge ice from inland to the sea and currently are responsible for up to 50% of Greenland's mass loss through iceberg calving (Melton et al., 2022). Specifically, this study proposes to use the dense and high-resolution surface elevation measurements collected by the Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2), together with supporting data sets including Landsat 8 imaging and offset tracking from SAR, to characterize the statistical distribution of crevasse morphology on marine terminating outlet glaciers on Greenland and the relationship with calving, velocity, surface hydrology, and mélange structure. A major goal is to understand the origins of damage that speeds calving, and the possibility of changing damage in a warming climate. Research addressing this goal will include comparing the timing of forcings (calving events, surface meltwater drainage, mélange breakout) to the timing of observed changes in damage (as observed in 2-D from Landsat and 3-D from the sparser-time ICESat-2 data) to test hypotheses for the causes of damage.

Within the Earth Science Division, this study specifically focuses on research and analysis (R&A), with an emphasis on the development of new scientific knowledge using the analysis of data from NASA's ICESat-2 satellite mission. Using the associated science data products to improve complex ice sheet models, I will be able to improve the current predictive capabilities of sea level rise projections. Climate change is one of the major themes guiding Earth System Science today. NASA is at the forefront of quantifying forcings and feedbacks of recent and future climate change, for which studying cryosphere dynamics is of critical importance. This study seeks to address the challenging questions associated with climate variability and change as related to cryosphere dynamics and associated sea-level rise. The work proposed in this study is directly relevant to NASA's Earth Science mission directorate and will utilize high-resolution observations and data assimilation to determine what changes are occurring in the mass and extent of Earth's ice cover, and what drives them. To successfully accomplish this ultimate objective of NASA, which is to enable a predictive capability of climate change on time scales ranging from seasonal to multidecadal, this work is necessary to better constrain the controls on fracture features that control the instability of ice sheets.

Ashley Ballantyne (PI)/Marie Johnson (FI)
University of Montana, Missoula
21-EARTH21-0407, An Open Source, Multiplatform Framework to Estimate Ecosystem Resilience to Forest Fire (EARTH21)

Fire and other climate driven disturbances are shaping the future of our forests. Given the vital ecosystem services provided by forests, it is crucial that we manage forests for their continued existence under changing climate conditions. This requires the immediate investigation of forest resilience, the ability of an ecosystem to withstand a disturbance by regaining its function, structure, and composition before a threshold is crossed and an ecosystem transitions to a new state. It has been widely recognized in ecology that resilience should be the primary goal of forest restoration and management, however, few studies have been designed to comprehensively examine forest resilience to wildfire across broad ecoregions. The objective of this project is to gain a comprehensive understanding of forest resilience and the important environmental drivers across the western US.
To advance our understanding of forest resilience to fire we have developed the OpenRes project to combine multiple metrics of ecosystem recovery into a forest ecosystem resilience framework. We will use several different remote sensing platforms available to examine the functional, structural and compositional recovery of forest ecosystems following wildfire. Specifically, our project is designed to address the following research hypotheses: (H1) Ecosystem function will recover much faster than structure and/ or composition and that topographic diversity will be the most important environmental driver of ecosystem functional recovery, especially in drier ecoregions of the southwest. (H2) Ecosystem structure will recover slower than function but faster than composition and that burn severity will be the most important environmental driver of ecosystem structural recovery, regardless of ecoregion. (H3) Ecosystem composition will recover the slowest, compared to function and structure and that topographic diversity will be the most important environmental driver to predict the recovery of composition. To test these hypotheses we will rely on both conventional and novel remote sensing platforms.

Advances in remote sensing technologies and analyses now allow scientists to characterize many different forest properties and how they are changing simultaneously from landscape to regional scales. Specifically, to estimate the recovery of ecosystem function (H1) we will use recently derived high resolution (30m) estimates of net primary productivity and evapotranspiration that have been derived from MODIS and LandSat data products. To estimate structural recovery of forest ecosystems (H2) we will rely on GEDI data of gridded canopy height and interpolated biomass. Lastly to evaluate the recovery of forest composition (H3) we will utilize a recently
developed vegetation change detection algorithm and validate it against the National landcover database and a recently derived map of tree cover for the western
US.
This project will contribute directly to NASA's earth science mission to advance our understanding of interactions among major processes in the Earth system. Our research will utilize both conventional and novel remote sensing data to detect changes in ecological resilience to forest fire. This research will result in high resolution analyses of how fires are transforming the function, structure, and composition of fires across the Western US. This research will also directly benefit society by producing actionable science, such as maps of integrated forest resilience across the Western US that will be useful for management and policymakers.

Gil Bohrer (PI)/Theresia Yazbeck (FI)
Ohio State University
21-EARTH21-0004, Improve Methane Estimation in Earth System Models Using HLS-Derived Within-Wetland Ecohydrological Patch Types

Our goal is to reduce earth system models' prediction errors of wetland fluxes by incorporating model-resolved within-wetland vegetation patch types as classified from NASA's HLS surface reflectance observations. The large uncertainty in wetlands' methane budget is mainly attributed to the small-scale temporal and spatial heterogeneity of wetland hydrological and ecological structure that drives highly variable methane flux rate. Spatial heterogeneity is typically at a scale of tens of meters and associated with alternating vegetation patch types within a wetland. Temporal variability is typically at a scale of seasons and years and driven by anthropogenic and ecological disturbances, changes to hydrology, and in coastal wetlands, sea level rise.

An ongoing Department of Energy (DOE) funded project at Bohrer's lab has recently updated the DOE's Exascale Earth System Model (E3SM) Land Model (ELM) to be able to resolve within-wetland ecological patch types. However, to apply this model development for simulations of wetlands, prior knowledge of patch-type distribution within the wetland sites must be available. Such information could be provided by high resolution satellite imagery. NASA's HLS product provides medium-high resolution surface reflectance (~30m) with short (few days) return time, which can be used to classify within-wetland patch-types. While the 30m resolution of HLS leads to more mixed pixels as compared to much higher resolution multi-spectral products, the frequent return time guaranties the availability of a full growing season timeseries of NDVI every year. This is a clear advantage over higher-resolution images because cloud-free high-resolution multi-spectral images may not be available at all for many sites in most years. In a previous project in our lab, conducted at a coastal wetland in Ohio, it has been demonstrated that seasonal HLS NDVI timeseries for a few ground-truth or expert classified "pure" pixels constitute a seasonal temporal fingerprint that can be used to accurately classify each HLS pixel within a wetland to its dominant vegetation patch types.

The proposed project will start by producing classified within-wetland patch type maps from HLS NDVI time series for NDVI time series for three wetland sites in Louisiana for each year during the last decade, 2015-2025. Site-level eddy covariance flux and patch-level chamber flux observations of CO2 and methane fluxes are conducted in these 3 Louisiana sites and the Ohio site. Next, we will develop functions to incorporate the information from these patch-type maps into ELM initialization, thus providing the model with the required patch-type coverage, which are needed for applying its new within-wetland patch resolution capabilities. ELM updates will be validated with flux measurements in the four study sites using the PEcAn workflow comparing patch-level and whole-site model and observed CO2 and methane fluxes. Lastly, we will contact the PIs of wetland sites from the FLUXNET-CH4 dataset and request for minimal ground-truth information needed to define the patch types relevant to their sites. We will use these data to produce HLS-based annual patch-type classification maps for 20-30 of the FLUXNET-CH4 sites within the conterminous US and regions surrounding them with wetlands of similar types. We will conduct long-term sensitivity analyses of the regions represented by these sites. We will compare modeled and observed site-level fluxes of the original single-patch simulations with simulations using the HLS-classified multi-patch approach and quantify the reduction of uncertainty in model prediction gained by implementing remote-sensing based, within-wetland, patch types.

Camrin Braun (PI)/Emmett Culhane (FI)
Woods Hole Oceanographic Institution
21-EARTH21-0403, Integrating Ships and Satellites to Understand the Global Biogeography and Biophysical Coupling of Surface and Deep Ocean Ecosystems (EARTH21)

Recent research has revealed that the ocean twilight zone (OTZ; 200-1000m) hosts the highest vertebrate biomass on Earth (7-10 billion metric tons) and provides vital ecosystem services. This region houses the largest portion of the biome that is invisible to satellites, thus estimates of animal biomass in the deep ocean are primarily based on remote observations made by shipboard echosounders (SIMRAD EK60) from the surface. In contrast to synoptic global observations of many of the physical, chemical and biological components of the Earth system, the limited spatial and temporal extent of echosounder data has prevented the development of a global-scale understanding of the OTZ.

Acoustic Doppler Current Profilers (ADCPs) have been routinely used on research cruises since the late 1980's and contain signals that can be used to observe the relative density and distribution of mesopelagic scattering communities. Recent studies have used large archival datasets of ADCP backscattering to characterize patterns in the diel vertical migrations (DVM) of OTZ communities at a quasi-global scale. These studies have used ADCP raw received signal strength (RSSI), which can be

used to detect relative day-night differences in backscattering (and thus DVMs) though does not provide a standard metric that can be compared across
ADCP instruments and frequencies. This has prevented ADCP-based analyses from describing properties of deep scattering layers themselves such as density and distribution, which are critical to understanding the structure and function of OTZ biology. An alternative approach is to use uncalibrated ADCP data to calculate mean volumetric backscattering (MVBS), though the process requires the estimation of instrument-specific calibration parameters and environmental variables, which is labor-intensive and introduces complex error that is not well described. This proposal will outline a process for the calculation of MVBS from archival ADCP data and provide a quantitative description of the associated parametric error. The derived MVBS will then be integrated with a suite of remotely sensed observations of ocean components to 1) investigate the biophysical drivers of variability in the density, depth and thickness of deep scattering layers; 2) estimate a novel global biogeography of mesopelagic biology for use in more directed studies; and 3) provide forecasts for the time-evolution of deep scattering layers in response to climate warming and anthropogenic disturbance.
The goal of this research is to improve our understanding of the structure, function and distribution of deep ocean communities through the development of a novel, large-scale dataset of mesopelagic scattering measurements and a synergistic analysis of remotely sensed observations of oceanic components. These efforts leverage NASA capabilities to expand our understanding of the pelagic ocean and the biophysical interactions that modulate the connectivity between the surface and deep-ocean. The project is directly aligned with the Earth System Science Division's commitment to utilizing NASA's unique capabilities to measure a comprehensive
suite of Earth system components and specifically exploits these for an interdisciplinary project grounded in understanding enigmatic ecosystems that have proven particularly difficult to study with other approaches. The analysis provides a key link between the deep ocean and surface properties that can be measured by satellites, thus extending the observational capabilities of NASA into this critical, understudied and currently 'invisible' habitat.

Joern Callies (PI)/Scott Conn (FI)
California Institute of Technology
21-EARTH21-0154, NIW–Current Interactions in Observations of Sea Surface Height and Velocities

Near-inertial waves (NIWs) in the ocean are excited by passing storms. The ocean is resonant at the inertial frequency, making this ringing in response to wind forcing a ubiquitous feature in surface currents. But when the ocean circulation is observed from space, which is currently done using satellite altimeters that measure the sea surface elevation, NIWs are invisible. Altimeters only pick up on mesoscale eddies, turbulent currents with length scales of order a hundred kilometers, which are in what is known as geostrophic balance; a force balance between the pressure gradients produced by a tilting sea surface and the Coriolis force due to the Earth's rotation. Altimeters measure tilts in the sea surface, and geostrophic currents can be inferred. Despite producing currents of similar magnitude in many regions of the world ocean, NIWs have no comparable signature in the sea surface elevation, and so we lack global observations of them. This may be about to change, however, because the proposed Winds and Current Mission (WaCM) would measure surface currents directly and thus give access to a global view of NIWs. This proposal aims to anticipate the advances made possible by such a mission by improving our dynamical understanding of how NIWs evolve, particularly by interacting with mesoscale eddies and fronts at the edges of such eddies.

This proposal has three objectives: (1) Assess where and when NIWs modify the geostrophic balance that has been at the core of the interpretation of decades of altimetry data. This will be done by estimating the wave effect from surface drifters and comparing it to sea surface elevation observations from altimetry. (2) Extend existing theory describing the dynamical interaction between NIWs and mesoscale eddies to account for the effects that occur at strong fronts. (3) Identify NIW–front interactions in observations collected as part of NASA's S-MODE project, which includes aircraft measurements using the instrument proposed to be employed in WaCM. The developed theory and numerical simulations will be used to guide the interpretation of these observations. Evidence of NIW–current interactions will also be sought in data collected by the Surface Water and Ocean Topography (SWOT) mission that is scheduled to launch later this year.

This proposal has relevance to a number of current and proposed NASA missions. WaCM would make simultaneous measurements of the surface currents and the winds. Its surface current observations would have a strong NIW signal, affording a global view of NIWs and their entanglement with mesoscale eddies and sharp fronts. The proposed work would both clarify the dynamics of NIWs and provide guidance on the interpretation of concurrent WaCM and altimetry data, including SWOT data that will offer unprecedented resolution of the sea surface elevation field. The work would highlight how a future WaCM may be used to constrain small scale dynamics that is currently not simulated in numerical climate models. The proposal would also make direct use of data collected as part of S-MODE. Investigating the interaction between NIWs and fronts would aid in S-MODE's goal to understand the evolution of the observed fronts.

Jui-Yuan Chiu (PI)/Chen-Kuang Yang (FI)
Colorado State University
21-EARTH21-0354, Assessing the Role of Near-Cloud Aerosols in Radiation Budget Using Retrievals from 3D Radiative Transfer and Machine Learning

The presence of aerosols can heat or cool the atmosphere, depending on their interactions with clouds and radiation. These interactions remain one of the primary sources of uncertainty in climate change predictions. To understand the role of aerosols in climate and their interactions with clouds, the observational constraints for aerosol properties and radiative forcing have largely relied on satellite observations. Specifically, shortwave reflectance measurements have been widely used to provide information on the aerosol type, particle size, and optical thickness.

While aerosol retrievals over oceans in regions far from clouds are robust, properties of aerosols in the vicinity of clouds remain challenging to retrieve and yet, are scientifically important. The retrieval challenge arises because the reflectance near clouds is enhanced by aerosol property changes due to the high humidity environment and other chemical processes and by 3D cloud radiative effects that the existing retrieval methods cannot account for. As a result, many near-cloud observations are discarded, which significantly affects the current aerosol radiative forcing estimates.

The proposed project aims to address the lack of near-cloud aerosol retrievals, fill the critical gap in the existing aerosol products, and assess the direct radiative effect of near-cloud aerosols. The proposed project will use MODIS observations over oceans, focusing on aerosol types that are most sensitive to humidity and on cumulus regimes where 3D cloud radiative effects are expected to be most significant. To achieve our goal, the following objectives will be pursued:

- Develop a machine-learning-based method that incorporates 3D cloud radiative effects and aerosol hygroscopic growth for retrieving near-cloud aerosol properties, using shortwave reflectance observations from MODIS
- Quantify the global impacts of near-cloud aerosols on clear-sky and all-sky direct radiative effects over oceans, and contrast two years that have significant changes in emission
- Exploit the new aerosol retrievals to study the variability of aerosol direct radiative effects with organizations of marine shallow cumulus and to understand the implication for a warmer climate

The proposed project is expected to provide new global and regional estimates of aerosol direct radiative effects that include near-cloud aerosols for the first time and directly contribute to enhancing the current MODIS operational aerosol retrieval algorithm. Given the importance of satellite-based aerosol retrievals, results from this project will be of considerable interest to both climate modeling and observational communities for studying aerosols and their interactions with clouds and radiation.

Winnie Chu (PI)/Angelo Tarzona (FI)
Georgia Tech Research Corporation
21-EARTH21-0083, Analyzing Multi-Decadal Changes at Ross Ice Shelf Through Historical SPRI-NSF-TUD and Modern NASA/NSF Operation IceBridge and ROSETTA-Ice Radar Sounding Data

Embayed ice shelves like Ross Ice Shelf (RIS) restrict or “buttresses” the seaward movement of inland grounded ice. The aim of this research is to assess whether RIS basal melt rate were underestimated due to lack of observations that dates back before 2000s. This proposal will focus on using historic radar sounding data from the historical 1974 campaign of Scott Polar Research Institute (SPRI), National Science Foundation (NSF), and the Technical University of Denmark (TUD) at RIS. I will directly compare these historic data with modern radar sounding observations from the NASA/NSF Operation IceBridge (OIB) (2011, 2013, and 2017) and NSF ROSETTA-Ice (2015-2017) to quantify multi-decadal changes in RIS ice shelf thickness and derive basal melt rate estimates. The results from this proposal contributes to the long-term understanding of RIS vulnerability with respect to atmospheric and ocean warming.

Belay Demoz (PI)/Maurice Roots (FI)
University of Maryland Baltimore County
21-EARTH21-0268, Facilitating the Next Generation of Air Quality Science: Synergy of NASA's Ground-Based Observation Networks

Ozone is an important gas throughout Earth’s atmosphere. Prolonged exposure to ozone is associated with respiratory illness and degradation of land and marine ecosystems. Policymakers have imposed regulation on the emissions that produce ozone [nitrogen oxides (NOx: NO & NO2) and volatile organic compounds (VOCs)] in the atmosphere, however high ozone episodes continue to be observed, especially in domains of complex surface terrain like coastal areas. The processes that contribute to the production and dispersion of pollutants in the air we breathe are more complex in coastal regimes, especially within the Chesapeake Bay airshed. The effect of variable topography in the mid-Atlantic region generates three distinct mesoscale features in wind paters: Nocturnal Low-Level Jets (NLLJ) which have to enhance pollutant transport and vertical mixing, Downslope Winds (DWS) which enhance dispersion and lofting, and Bay-Breeze which causes recirculation of polluted air mass. Previous data gaps have left these three mechanisms lesser studied phenomena than their counterparts in other parts of the U.S. (i.e. the Great Plains LLJ, the Denver DSW, or the Houston Bay-Breeze). These mechanisms are strong dynamic drivers of atmospheric chemistry which are able to inhibit or enhance ozone production and alter chemical budgets and thus constitute a need for further study. To facilitate this, networks of routine high-resolution observations are needed to capture the full temporal and spatial evolution of air quality episodes. Ground-based remote-sensing instruments like advanced lidars (wind, ozone, water vapor, and aerosol profiling), ceilometers, and spectral radiometers (Pandora, AERONET), as well as in-situ samplers like sondes (meteorology and ozone) and surface analyzers (VOCs, NO2, and O3), are needed at sub-hourly timescales (high temporal resolution) with stations in major terrain differences (i.e. urban, suburban, rural, mountainous, marine) for effective four-dimensional (4D, space and time) characterization of coupled chemistry and dynamics. The proposed work will combine these observations of winds, aerosols, and trace-gas pollutants to complement and extract new science from NASA’s existing networks of ozone lidars (Tropospheric Ozone Lidar Network, TOLNet) and Pandora spectrometers. Two overarching questions will be addressed: Q1) Can the high-resolution observations from TOLNet and Pandora be harmonized with regional surface air pollution observations and dispersion models, like the NOAA HYSPLIT, to capture and quantify the evolution and regional impact of air quality episodes? Q2) To what extent are vertical profile observations of ozone from TOLNet and radio-sondes as well as column integrated values from Pandora properly represented by large-scale chemical transport models? Do the results show relevance and a good comparison with planned retrievals from space? This work will rely on datasets from recent NASA coastal air-quality campaigns conducted in the Chesapeake Bay, Galveston Bay, and Lond Island Sound. The results of this work will serve to foster new process-level science on the coupling of chemistry and dynamics coastal area, facilitate the improvement of NASA's chemical transport models with observational validation, and meet a data gap within the agency for validation of planned ozone retrievals from space. The synergistic approach to air quality episode analysis will directly address the 2017 NASA Decadal Survey Questions: (W-5) What processes determine the spatiotemporal structure of important air pollutants and their concomitant adverse impact on human health, agriculture, and ecosystems?; (W-7) what processes determine observed tropospheric ozone variations and trends, and what are the concomitant impacts of these changes on atmospheric composition/chemistry and climate?

Belay Demoz (PI)/Kylie Hoffman (FI)
University of Maryland Baltimore County
21-EARTH21-0269, Understanding Dynamic Convection Organization Using Passive and Active Profiling

The planetary boundary layer (PBL) is a turbulent, well-mixed layer in the lower troposphere which plays an essential role in mesoscale dynamic processes and the transport of chemical species, aerosols, and water vapor. For decades, forecasting skill for afternoon thunderstorms driven by synoptic scale forcings and high values of convective available potential energy (CAPE) have steadily improved, while skill in predicting nocturnal thunderstorms driven by more nuanced forcings such as bore waves and converging boundaries in the PBL have not made the same appreciable advances. In the Southern Great Plains (SGP) where agriculture is a vital component of the economy and precipitation has a direct impact on soil fertility, forecast accuracy is critical both from an economic and public safety perspective.

This project will address uncertainties of observing PBL moisture and temperature organization relevant to the initiation of convection in the SGP in two major ways. First, passive and active remote sensing observations will be used to expand theories based on idealized simulations (thermodynamic and dynamic aspects) and second, comparisons between observing systems, algorithms, and instrument resolution will be conducted to identify optimal patterns for capturing observations of PBL mesoscale organization. Preliminary work based on a SGP symmetric convergence case study event demonstrates that CAPE, Convective Inhibition (CIN), and Vorticity can be calculated from remote sensing observations and results from this case study have revealed correlations between moisture and temperature observations with elevated CAPE hours before the arrival of a surface-based convergence boundary.

Future research aims to extended analyses from the case study to additional events observed during the 2015 Plains Elevated Convection At Night (PECAN) field campaign which took place over the same region, the SGP. Incorporating new events into this research will enhance or modify our early theories of the skillfulness surrounding ground-based remote sensing in early detection of parameters relevant to convection initiation. Analyses from the preliminary case study (CAPE, CIN, Vorticity calculations) will be extended to PECAN events where substantial LASE water vapor Differential Absorption Lidar (DIAL) measurements are available. Airborne DIAL observations will be incorporated into future research to allow for more rigorous analyses of how convection forms across a more expansive domain of observation. We believe that a more rigorous investigation of LASE DIAL data from PECAN and its integration with models will inform future suborbital and space-based instruments for PBL profiling, as well as lay the foundation for similar analyses with the High Altitude Lidar Observatory (HALO) water vapor DIAL.

Forecasting nocturnal convection has remained a challenge in the atmospheric science research community for decades, largely hindered by a lack of observations at night. This research aims to provide a unique perspective of the PBL by merging observations, theory, and modeling. Methods tested on a single case study will be extended to additional events of interest to expand theories surrounding convergence driven convection initiation. Additionally, observation systems, retrieval algorithms, and resolution will be cross exanimated to identify the most ideal systems for resolving features of convection at night. Finally, many of the methods and areas of motivation within this project align with goals outlined in NASA's Decadal Survey and PBL Incubation Report. Most notably, one of the key science topics, "The interactions between the mesoscale and PBL thermodynamic structure" is labeled as "critical", recommending a global PBL observing system.

Chunyuan Diao (PI)/Yilun Zhao (FI)
University of Illinois, Urbana-Champaign
21-EARTH21-0378, Evaluating the Influence of Biocontrol Program on the Colorado River Biodiversity with Multi-Source Time Series Imagery

Biodiversity is essential to maintain ecosystem health, lower greenhouse gas emissions, and provide commercial, agricultural, and recreational values. Based on current studies, the Sixth Mass Extinction is arriving, and more than 20,000 species have been extinct or endangered in the past few decades. Invasive species is the second most common driver that leads to the extinction of native species. One important way to control invasive species is to introduce their predators to decrease the population size and dispersion range. However, it is critical to monitor the effects of biocontrol programs on biodiversity in case that the introduced predators threaten native species. The invasive species Tamarix, together with its biocontrol program using Diorhabda, will be studied in this project. The advances in multi-source satellite remote sensing, in combination with drone and in-situ observations, provide new opportunities to investigate the plant biodiversity change in the context of Tamarix biocontrol at both local and landscape scales.

This study aims to investigate the effects of a long-term and large-scale Tamarix biocontrol program on riparian plant biodiversity of the Colorado River in Arizona using multi-source remote sensing imagery. This overarching goal will be achieved through three objectives: 1) detect Tamarix defoliation and vegetation regrowth timing at Diorhabda observed and surrounding areas with the COntinuous monitoring of Land Disturbance (COLD) model; 2) evaluate local and landscape biodiversity change caused by the biocontrol program with convolutional autoencoder (CAE)-based time series clustering, and 3) investigate the effects of pre-biocontrol biodiversity, soil water content, and soil salinity on biodiversity change.

This study will generate the most thorough analysis of the effects of the Tamarix biocontrol program on riparian plant biodiversity at both local and landscape scales, and thus will be instrumental for evaluating the success of the Tamarix biocontrol program from the biodiversity aspect to inform the conservation agencies of enhanced riparian restoration strategies. This study will also explore the potential of using multi-source time series data with in-situ observations to study the biodiversity change. A novel deep learning method (CAE-based time series clustering) will be employed to quantify the species richness and distributions, and can be generalized to study the biodiversity change across scales. This study will advance the understanding of the theoretical and operational implications of how biodiversity changes after the biocontrol program over space and time.

Ralph Dubayah (PI)/Tiago De Conto (FI)
University of Maryland, College Park
21-EARTH21-0321, Characterizing Structural Complexity of the Earth's Forests with GEDI

Forest structural complexity is a metric that aims to summarize the amount, variability and 3D spatial arrangement of structural attributes. Forest structure is widely recognised for having strong relationships to ecosystem function and composition, as well as an effective surrogate to measure restoration effectiveness. However, measuring forest structural complexity is a hard task since it requires extensive surveys that account for several components of structure in order to generate reliable estimates. LiDAR technology is the gold standard for quantifying forest structure, as it provides 3D measurements that enable complementary structural assessments in high detail from above or below the forest canopy - using terrestrial laser scanning (TLS) and airborne laser scanning (ALS), respectively. The NASA Global Ecosystem Dynamics Investigation (GEDI) is a spaceborne LiDAR mission that was designed to map the structure of Earth's tropical and temperate forests, minimizing measurement and sampling limitations for mapping forest structural complexity comprehensively. This proposal aims at characterizing the current structural complexity of the Earth's forests using GEDI and other remote sensing data to advance our understanding of how environmental factors and disturbance affect its variability. It is subdivided into three objectives: (1) refine and validate a GEDI Waveform Structural Complexity Index (WSCI) suitable for global application by linking TLS, ALS and GEDI observations of forest structure; (2) create a global map of WSCI and characterize observed complexity as a function of edaphic, climatic and topographic factors; and (3) explore the role of disturbance history on deviations between potential and actual complexity at fine spatial resolution using fusion with Landsat and Synthetic Aperture Radar (SAR) imagery. Rigorous validation and refinement of the GEDI-WSCI will be performed using a robust forest Stand Structural Complexity Index (SSCI) designed for TLS point clouds and upscaled through ALS, thus providing a mechanism to quantify the dominant controls of WSCI and define limits on retrieval of forest structural complexity. The refined WSCI will then be applied to map the actual state of forest structural complexity globally, subsequently used to identify the geographical factors that control it on a large scale. Further wall-to-wall mapping of WSCI will be done at high spatial resolution through SAR-GEDI data fusion, generating regional maps for assessing the relationship between current levels and spatial patterns of structural complexity against the disturbance history in regions where environmental factors do not explain structural complexity. That work will provide invaluable information on the current state of structural complexity of the Earth’s forests and help in expanding our understanding on how it develops in face of environmental controls and disturbance regimes. Furthermore, the outputs of the proposed work will be useful to guide future management and policy making initiatives related to nature conservation and ecosystem restoration from a strong quantitative standpoint.

Bethany Ehlmann (PI)/Abigail Keebler (FI)
California Institute of Technology
21-EARTH21-0362, From Spectra to Mineralogy: A Remote Sensing Approach to Understanding Arid Dust Source Regions

As Earth’s climate changes, our need to understand the complex processes controlling climate and Earth’s biogeochemical cycles increases. Major Earth systems models consider the role of atmospheric mineral dust, which is known to have a net radiative forcing effect in the atmosphere, influence cloud formation, and alter ocean biogeochemistry, among other roles. However, the nature and extent of mineral dust aerosols’ impacts on climate cycles depends on its mineralogy and grain size and is currently unclear, including whether dust has a warming or cooling effect and how it influences cloud formation. Characterizing the mineralogical composition and grain size distribution of dust source regions on Earth’s surface will provide a key perspective on the role of arid landscapes and dust on biogeochemical cycles.

Dust mineralogy can be inferred directly from dust source region mineralogy; currently, models rely on mineralogical atlases derived from agricultural soil databases. However, such databases over-represent agricultural soils, excluding some of the most important dust source regions. Additionally, existing mineralogical soil atlases are constructed by inferring mineralogy from literature reviews of soil descriptions and are thus subject to inconsistencies. Thus, there is a need for more comprehensive, representative maps of arid dust source region soil mineralogy.

Remote sensing in the visible/near infrared (VNIR) wavelength range can provide valuable information about mineralogical composition and is an ideal method for collecting data which spans a large percentage of dust source region land area; the Jet Propulsion Laboratory will be sending the NASA Earth surface Mineral dust source InvesTigation (EMIT) infrared imaging spectrometer to the International Space Station in 2022 for this purpose. Presently, mineralogy is characterized from spectra through optical properties-based methods like the Tetracorder algorithm by Clark et al. or through various implementations of the Hapke radiative transfer model. However, inferring direct mineralogy from spectra presents a challenge, and current methods have associated uncertainties of tens of percent in some relevant cases.

Given the limitations of current soil databases and the challenges associated with extracting mineralogical composition from spectra, the proposed project seeks to improve our understanding of current methods for spectral analysis of arid soil mineralogy and explore a potential new method. We will develop a unique database of samples of natural soils from arid dust source regions which represent key global dust sources, composed of in situ VNIR spectra, XRD analysis for mineralogical composition, grain size distribution, and laboratory VNIR spectra on bulk samples and grain size separates. Our dataset will include soils previously excluded from agricultural-leaning atlases and directly link natural soil spectra to exact, known mineral composition and grain size distribution. Then, we will use our novel database to test existing physics-based modeling methods and constrain associated uncertainties and limitations with the current state-of-the-art as it relates to natural soil surfaces. We anticipate nontrivial errors, as have been documented for these methods already. So, we will trial an empirical modeling approach supported by computation and machine learning to classify mineralogy and grain size distribution from our spectral database.

The proposed work supports the Science Mission Directorate's Earth Science Research Program's mission to "seek to characterize [Earth's] properties on a broad range of spatial… scales" by establishing a database characterizing the span of dust source regions' local and global compositional diversity. Furthermore, the project will "improve our capability for predicting [Earth's] future evolution" by providing a critical assessment of modeling techniques which play an integral role in Earth systems modeling.

Emily Fischer (PI)/Kimberley Corwin (FI)
Colorado State University
21-EARTH21-0300, Historical and Forecasted Impact of Wildfire Smoke on U.S. Solar Energy Resources Due to Aerosol-Driven Changes in Surface-Level Solar Radiation

Between 2020 and 2050, the U.S. plans to shift from 3% solar energy to 45% as climate change motivates a rapid transition to renewable energy. Understanding the impact of wildfire smoke and solar photovoltaic (PV) generation is essential for ensuring the U.S. meets renewable energy goals. Previous studies document sizable PV generation losses on smoke-impacted days but are limited to single fire events or seasons, small numbers of PV plants, and narrow geographical areas. I propose the first longitudinal study (2006-2020) of past wildfire smoke impacts on solar resource potential and utility-scale PV output across the CONUS. I also propose to isolate and quantify how fire emissions may affect solar resources and development potential in the mid- and late 21st century. I will leverage data from multiple NASA products to conduct this research, including MAIAC, MERRA-2, AERONET, and GEOS-Chem. Data from the NOAA/NESDIS HMS and NREL NSRDB, which are derived from NASA satellite observations and model simulations, will also be incorporated in the proposed analyses. These Earth observation datasets will be integrated with solar energy records from the EIA operational reports as well as solar capacity and cost projections from the NREL reV model.

To understand the historical impact of smoke on PV resources from 2006-2020, I will 1) analyze the spatial overlap between smoke and solar potential (i.e., irradiance), and 2) develop a regression model to quantify smoke-driven changes in PV generation at existing solar plants. I will use the HMS smoke plume and MAIAC 550 nm aerosol optical depth (AOD) data to characterize smoke frequency and plume thickness. These datasets will be merged with the NSRDB global horizontal irradiance (GHI) data to characterize seasonal and annual smoke exposure across GHI zones. I will then use the SHDOM radiative transfer model to simulate surface shortwave irradiance with and without smoke based on MAIAC AODs, MERRA-2 cloud optical depths, and regional smoke optical properties. Results will be validated with AERONET. After calculating the change in irradiance due to smoke, I will integrate the EIA plant-level data and develop a regression model to determine smoke's impact on PV generation. The regression model will estimate a plant's capacity factor (ratio of capacity to generation) as a function of smoke-driven changes in irradiance and account for panel material, location, month, and year. I hypothesize that PV generation will decline more substantially in the western U.S. due to the more absorbing and optically thicker nature of western smoke plumes.

To predict the impact of smoke on future PV resources, I will use GEOS-Chem with RRTMG to simulate surface shortwave irradiance under variable smoke conditions and compare results to PV capacity and cost projections from the reV model. GEOS-Chem simulations for present-day (2017-2021) will be run with and without QFED emissions. Present-day fire emissions will be scaled using fire emission projections for the mid- and late 21st century that account for RCP and SSP scenarios. I will calculate the change in irradiance due to smoke for the present-day, midcentury, and late century scenarios and compare the results to the reV model's PV capacity and cost forecasts. I will use the GEOS-Chem results in the proposed CF regression model to scale the reV capacity and quantify the impact of smoke on future PV generation.

In the 2021 Solar Futures Study, the DOE highlights the need for "evaluation of the effects of wildfires on PV generation" to strengthen solar forecasting. The proposed research leverages NASA observations and models to provide a foundation for understanding smoke's impact on solar energy. In doing so, this project supports the NASA Earth Science Division's science goal to "further the use of Earth system science research to inform decisions and provide benefits to society."

Qiang Fu (PI)/Aodhan Sweeney (FI)
University of Washington, Seattle
21-EARTH21-0072, Investigating 21st Century Land-Sea Warming Contrast in Observations and Model Simulations

A robust feature of climate change simulations is enhanced warming over land compared to over oceans. This phenomenon is referred to as the Land-Sea Warming Contrast (LSWC). Due to its robust signal, the LSWC has been used as a metric for climate change and for pattern scaling approaches of climate change prediction. The LSWC has also been shown to have large impacts on both the climate system and society. Previous investigations of the LSWC use in-situ surface temperature data, which suffers from gaps in spatial coverage and inconsistent land and sea surface temperature (SST) measurements. These biases in the in-situ data degrade our ability to validate model simulations of LSWC and limit what we can learn from observations. Comparisons of simulated and observed LSWC show discrepancies in the latitudinal structure, yet it is unclear whether these differences are caused by deficiencies in the models, observations, or both. Another less studied aspect of the LSWC is its vertical structure, which in the tropics will be affected by both the vertical temperature amplification and weak horizontal tropospheric temperature gradient. Investigating the interaction of the LSWC and vertical temperature amplification could provide new perspectives on climate change in the tropics. Recent studies have also questioned the relative importance of SST trends versus local radiative effects in controlling continental warming, and thus the LSWC. To investigate these aspects of the LSWC, studies using both observations and model simulations are critically important.

The objective of this proposal is to address current gaps in documentation and understanding of the LSWC by using observations and model simulations. Key to this proposal is the use of data from the Atmospheric Infrared Sounder (AIRS). The AIRS instrument measures both land and sea surface skin temperature (and atmospheric temperature profiles) using the same instrument with global coverage, and thus it does not suffer from biases present in the in-situ products. This proposal will be completed in three phases. In Phase I observational estimates of the LSWC will be obtained globally, latitudinally, and vertically by using data from AIRS and in-situ products when applicable. Phase II will quantify uncertainty in observations by comparison to the highly accurate Advanced Microwave Sounding Unit (AMSU) and Advanced Technology Microwave Sounder (ATMS) measurements from the AQUA, MetOp-A, Suomi-NPP, and JPSS-1 satellites. Phase III will evaluate whether observational estimates of the LSWC with quantified uncertainty fall within the coupled atmosphere-ocean and prescribed SST model estimates from the Coupled Model Intercomparison Project Phase 6 (CMIP6). Experiments will also be run with the Whole Atmosphere Community Climate Model version 6 (WACCM6) using prescribed SSTs with fixed and time-varying external radiative forcings. These simulations will help quantify the relative control of continental warming (and thus the LSWC) by SST changes versus local radiative effects.

By using high quality AIRS observations with quantified uncertainties this proposal will help reconcile differences between the LSWC in observations and simulations. Observations obtained in this study will provide an opportunity to validate LSWC in CMIP6 simulations. Experiments using the WACCM6 will help elucidate the importance of SSTs in controlling the LSWC. The proposed investigation of the LSWC using observations and model simulations will significantly escalate our understanding of one of the most salient and high-impact features of climate change. This proposal will directly contribute to the Exploration and Scientific Discovery priority in the NASA 2020-2024 Science Plan through its focus on "reducing climate uncertainty and informing societal response."

Colin Gleason (PI)/Jonathan Flores (FI)
University of Massachusetts, Amherst
21-EARTH21-0069, Monitoring the Flow of Proglacial Rivers in High Mountain Asia

Proglacial rivers play a crucial role in the hydrologic processes and water resource management in cold regions, such as High Mountain Asia (HMA). Direct monitoring of these rivers can be used to quantify the volume of glacial melt, and remote sensing is ideal to track these rivers due to logistical difficulties. However, glacial outflow streams are typically narrower than the resolution of satellite platforms such as Landsat (30 m) and Sentinel (10 m). I will leverage the use of multitemporal high-resolution Planet imagery to map smaller streams (<15m wide) and their changes over time across HMA from 2016–2022. Previous work has shown that repeated satellite widths can be used to estimate discharge, and therefore this mapping enables river discharge and therefore glacial monitoring. Traditional remote sensing techniques struggle to classify these small rivers due to geophysical constraints (e.g., shallow and muddy waters, wet glacial outwash sediment, and mountain shadows) and the lack of information further into the infrared spectrum (for Planet imagery). Given these issues, I hypothesize that the use of computer vision algorithms from the computer science literature can address these constraints and accurately classify these small rivers, and thus retrieve accurate river width variation measurements and ultimately Bayesian discharge inference solely from satellite imagery. High frequency Planet imagery will therefore augment almost nonexistent in situ gauging of HMA proglacial rivers and improve our understanding of the past, present and future hydrology of "Asia's Water Tower". Specifically, I propose the following science goals to develop a novel approach to monitor how much water is flowing in proglacial rivers of HMA based on remotely sensed observations: 1) develop a computer vision algorithm to accurately map the proglacial rivers in HMA using high resolution satellite imagery; 2) use established Bayesian techniques for reach-scale discharge inference from the classified images; and 3) validate the estimated discharge and quantify the discharge of every individual proglacial river in HMA to better understand this cryospheric input to the hydrologic cycle. This research will address one the of highest priorities of 2017 NASA Earth Science Decadal Survey (Objective H-1a) by accurately quantifying a component of the water cycle and offering relevant information to close the water balance in HMA. Overall, this research will principally contribute to the Earth Science Division's objective to advance knowledge of Earth as a system in order to meet the challenges of environmental change and to improve life on our planet.

Nancy Glenn (PI)/Brenton Wilder (FI)
Boise State University
21-EARTH21-0249, The Snow Albedo Feedback Under a Changing Climate: Improving Energy Balance Snowmelt Modeling in the Anthropocene

NASA's study of the Surface Biology and Geology (SBG) Designated Observable has significant potential to lead to a mission that will provide critical data for global mapping of snow properties, like snow surface albedo. Prior to a SBG mission, uncertainty analysis of prototype SBG data will enable the scientific community to identify key uses of SBG data for quicker adoption in the snow and vegetation communities. The central objectives of this study are to A) Ground validate precursor SBG data and assess uncertainties of snow albedo for mid-high latitude sites; B) Quantify changes in snowmelt timing for mid-high latitude wildfires and characterize the physical processes that drive these changes to better inform modeling; and C) Use land surface model(s) with SBG snow surface albedo forcing data to analyze parameter sensitivity and reduce uncertainties in energy balance snowmelt modeling. To accomplish the first objective, in-situ measurements via the Analytical Spectral Devices (ASD) FieldSpec4 spectroradiometer and imaging spectroscopy (hyperspectral) data via satellite PRISMA and airborne AVIRIS-NG instruments, as precursor SBG data, will be analyzed and statistically compared for snow-on conditions in Alaska and Idaho. To accomplish the second research objective, NDSI (normalized difference in snow index) via multispectral satellite imagery, as well as ancillary lidar and climactic data, will be analyzed for fires across the northern hemisphere to quantify and characterize relative changes in date of disappearance of snow for a variety of burn and climate conditions. Finally, a land surface model (Crocus coupled to Noah-MP forced with WRF) will be calibrated with SBG snow surface albedo (precursor) data inputs and validated with in-situ data for the Caribou-Poker Creeks Research Watershed in Alaska. The outcomes of the research will include quantifying uncertainties in (precursor) SBG snow albedo data, identifying disturbance impacts on snowmelt processes, and sensitivity quantification of SBG snow albedo in a physics-based land surface model. The proposed work has significant implications for the SBG mission, NASA SnowEx community science, and NASA's Earth Science Water and Energy Cycle and Carbon Cycle & Ecosystems. The work will also contribute to NASA's Arctic-Boreal Vulnerability Experiment (ABoVE) science.

Scott Goetz (PI)/Shelby Sundquist (FI)
Northern Arizona University
21-EARTH21-0275, Characterizing Immediate and Mid-Term Climate Effects on Boreal Forest Dynamics to Model Long-Term Forest Dynamics and Management Outcomes

Boreal forests of Alaska and western Canada are experiencing rapid climate change characterized by higher temperatures, more extreme droughts, and changing disturbance regimes, resulting in forest mortality and composition changes. Black spruce, a dominant boreal forest species that stores vast amounts of carbon in deep organic soils, is not resilient to today's droughts and fire regime. As deciduous species like aspen and birch, which grow taller and form more open forests, expand into new locations, complex interactions between vegetation, soil, and disturbance contribute to considerable uncertainty about future carbon fluxes in the boreal region. Here, I propose to address this gap by 1) characterizing climate and drought legacy effects on tree growth using tree-ring measurements, 2) incorporating these findings in a state-of-the-art model for the boreal forest, 3) verifying the forest model's performance with site-level and remote sensing data, and 4) predicting future forest composition under various climate and management scenarios. My research objectives seek to answer the questions, will the future boreal forest be a carbon source or sink, what will the boreal forest look like in a century, and what are the short- and long-term impacts of common forest management practices. The answers to these questions are vital for informing climate and earth system models, conservation decisions, and forest management strategies for the 21st century.

Jonathan Greenberg (PI)/Theodore Hartsook (FI)
University of Nevada, Reno
21-EARTH21-0236, Augmenting Landscape Level Remote Sensing with 3D Reconstructions of Forest Plots

The goal of this study is to evaluate a methodology by which I can "archive" forest stands in three dimensions for the purposes of post-hoc forestry measurements and to provide rapidly-collected baseline information to examine changes in vegetation over time with enough fidelity and precision to be able to measure length, area, and volume, as well as more complex characteristics such as species, all within a virtual environment. To accomplish this, I plan to use first person view (FPV) video to collect sets of imagery of forest stands, and adapt structure from motion (SfM) techniques using machine learning to reconstruct the three-dimensional structure of the stands. From this, I will evaluate the capability of these datasets to 1) capture forest stands with enough fidelity such that classic and advanced forest measurements can be collected within a virtual environment, 2) simulate three-dimensional remotely sensed datasets such as those collected from airborne and terrestrial LiDAR, as well as UAV-based SfM, 3) demonstrate how these data can be used to calibrate/validate landscape scale remote sensing of vegetation as well as vegetation change, and 4) the archiving of a research and teaching forest.

Kevin Grise (PI)/Xinhuiyu Liu (FI)
University of Virginia, Charlottesville
21-EARTH21-0071, Regional Characteristics of the Jet Streams and the Role of Moist Processes

Jet streams are relatively narrow bands of strong west-to-east winds in the upper troposphere and are important characteristics of the atmospheric circulation. Averaging over all longitudes, there are two jet streams, the subtropical jet (STJ) and polar front jet (PFJ), located in both the Northern and Southern Hemispheres. Understanding variability in the position and strength of the jet streams is important, as they directly influence impactful surface weather events, such as heatwaves, cold air outbreaks, and extratropical storm tracks and their associated heavy precipitation events. However, the dominant physical mechanisms controlling the mean-state jet streams and their variations in position and/or strength remain an area of active research.

Some recent studies have hypothesized that moist processes have significant impact on the jet streams in the current climate and in response to climate change. However, the separate influence of latent heating and cloud radiative heating on the jet streams and their relative importance has not been examined in detail yet. In addition, previous studies, which focused on vertically-integrated latent heating/cloud radiative heating or zonal-mean jets, may fail to capture some significant relationships at individual longitudes and at specific vertical levels. This study will examine the regional characteristics of the jet streams and the role of moist processes in modulating the mean-state and variability of their positions and strengths.

The proposed project has two parts. The first part of the project will examine how the mean-state jet streams are influenced by moist processes in two ways: latent heat release and cloud radiative effects. Latent heating and cloud radiative effects will be defined from MERRA-2 reanalysis and NASA satellite products from the GPM and CloudSat missions. Experiments will be conducted using a stationary wave model to partition the influence of latent heating and cloud radiative heating on the mean-state jet streams. A series of experiments will be conducted with the stationary wave model, with different latitudes or vertical levels of latent heating or cloud radiative heating absent as perturbation experiments. The second part of the project will examine the relationship between jet variability and latent heating/cloud radiative heating in observations and try to understand the direction of causality between them using various regression techniques.

This study, which will contribute to the Ph.D. dissertation and career development of the future investigator (FI), will use multiple NASA satellite and reanalysis datasets along with conducting experiments in a stationary wave model to fill a knowledge gap of how moist processes influence the mean-state jet streams and their variabilities in the current climate. The proposed work will support the research interests of multiple NASA programs within the Earth Science Division. By investigating the role of latent heating/cloud radiative heating on the jet streams and their variabilities, the project will directly support the goal to "better understand the overall state of Earth's climate and the physical processes that affect it (Modeling, Analysis, and Prediction Program, Climate Variability and Change Focus Area)". By using the satellite observations to validate MERRA2 reanalysis products, the project will also support the "Reducing climate uncertainty" focus area for NASA Earth Science division in the "SCIENCE 2020-2024: A Vision for Scientific Excellence".

Kaiyu Guan (PI)/Qu Zhou (FI)
University of Illinois, Urbana-Champaign
21-EARTH21-0316, Quantifying Field-Level over Cropping Across the U.S. Midwest Using Multi-Source Satellite Data

The corn and soybean crop system in the U.S. Midwest, contributing to one-third of the world's production, faces grand environmental challenges related to excessive use of fertilization, soil carbon loss, and water quality degradation. Planting cover crops has been considered an essential solution to these environmental issues. To stimulate more widespread adoption of cover crops, the government has invested huge resources and efforts in cover crop programs. However, accurate quantification of large-scale cover crop adoption in the U.S. Midwest remains vastly understudied, which is critical for benchmarking historical patterns, enabling sustainable agriculture, evaluating outcomes of cover crop policies, and designing effective agricultural practices.

Remote sensing provides cost-effective and scalable approaches to detect cover crops, while traditional surveys are time-consuming, labor-intensive, and cost-prohibitive to scale up to large regions and long periods. However, remote sensing-based cover cropping remains in early stages and is limited to small regions and short periods. To fill the big gap in using remote sensing to quantify cover crop adoption at field scales across large spatial and temporal extents, this project proposes to integrate knowledge in satellite remote sensing, large-scale computation, plant phenology, and artificial intelligence, for developments of cover crop quantification framework, based on multi-source satellite observations, densely collected ground truth of cover crop adoption, and supercomputing systems. Ultimately, this project will provide field-level cover crop maps of the U.S. Midwest for the first time and enhance our understanding of cover crop adoption under climate change and government management.

To accomplish this goal, this project will produce annual field-level cover crop maps by leveraging multi-source satellite data, densely collected field cover crop data, environmental driver data (climate and soil), and knowledge-guided machine learning models. Specifically, this project will (1) evaluate multi-source satellite data, i.e. daily 250 m NASA's MODIS, ~3-day 30 m NASA's HLS, daily 30 m PI Lab's STAIR fusion, and daily 3 m Planet's PlanetScope for detecting cover crop fields from multiple spatial and temporal scales; (2) quantify cover crop adoption in the U.S. Midwest at field level using plant phenology to remove bare soil and cash crop signals and extract cover crop features from satellite data, and using machine learning and environmental factors to determine thresholds of cover crop features; and (3) investigate how cover crop adoption responds to climate conditions and agricultural policies by analyzing cover crop adoption under extreme climate conditions and cover crop spatiotemporal patterns along with cover crop policies. Our overarching science question is: what are the variations of cover crop adoption over space and time from a remote sensing perspective, and how is cover crop adoption affected by climate change and anthropogenic management?

This project will support the NASA Earth Science Research Program and NASEM 2017 Decadal Survey for Earth Observation from Space by expanding our knowledge on how cover crops are affected by natural and anthropogenic factors from multiple spatial and temporal scales utilizing NASA's multi-satellite datasets. The solicitation “highly encouraged” the use of remote sensing to understand our Earth's surface, which is the focus of our work. Furthermore, by characterizing the dynamics of cover crops, information will be provided to policymakers and farmers for more effective policymaking and agricultural management, which is an essential element of NASA's Earth Science Program to inform decisions and provide benefits to society.

Jennifer Haase (PI)/Harriet Yin (FI)
University of California, San Diego
21-EARTH21-0133, Using InSAR from the Recent Haiti Earthquakes to Investigate Post-Seismic Creep and Evolving Hazard on Adjacent Faults

Earthquakes pose a major threat to Haiti, as illustrated by the catastrophic M7.0, 2010 earthquake (USGS, 2010), and more recently by the M7.2 earthquake on Aug 14, 2021 (USGS, 2021). These events both occurred within the Enriquillo Plantain Garden Fault Zone (EPGFZ), a strike-slip fault zone which runs through the southern peninsula of Haiti and is a primary source of seismic hazard in the region. Neither earthquake ruptured the intervening Miragoâne segment between the two event rupture planes, raising the question of whether this segment is seismically loaded and there-fore hazardous or if it's accommodating strain in some other way. Further study of this complex rupture sequence is therefore highly relevant for both developing resilience to future earthquakes in Haiti and for improving our understanding of seismic hazard in strike-slip margins in general. Sat-ellite-based geodetic techniques such as InSAR (Interferometric Synthetic Aperture Radar) are crit-ical for this analysis due to the scarcity of field observations in Haiti.

Preliminary InSAR analysis of the 2021 event shows post-seismic shallow creep migrating on the EPGFZ, directly east of the rupture in the segment that was skipped. In this work I aim to an-swer the questions: What characteristics of the EPGFZ led to the 2021 rupture skipping over the portion of the Miragoâne segment adjacent to the 2010 Haiti earthquake and could explain the mi-grating creep? What are the implications of these behaviors for future seismic hazard in Haiti and other oblique strike-slip margins? To interrogate these questions, I propose to 1) process and ana-lyze comprehensive InSAR datasets from Sentinel-1, ALOS-2 and eventually NISAR to measure the deformation field during and after the 2021 earthquake; 2) determine the coseismic slip distribu-tion of the 2021 event using a static slip inversion and estimate the resulting static stress changes on surrounding fault segments; 3) investigate the driving mechanism of observed post-seismic creep; and 4) prepare my processing methods for the availability of NISAR data, to exploit the unique advantages of NISAR in this densely vegetated area. Results from this work will not only advance understanding of the strike-slip margin in Haiti but can also be generalized to other strike-slip boundaries, allowing for improved decision-making and broad benefits to society. This work will also develop InSAR tools and methods for NISAR which will benefit the community.

Xianglei Huang (PI)/Chongxing Fan (FI)
University of Michigan, Ann Arbor
21-EARTH21-0011, Impacts of Solar Farming on Surface Energy Budget and Climate from Long-Term NASA Satellite Observations

Motivation: To reduce carbon emissions from thermal power plants and approach the state of net-zero carbon dioxide emissions (i.e., carbon neutrality), many countries are paving the way to support the renewable energy industry. One important source of renewable energy is the radiating Sun. Converting solar energy to electricity by solar panels, commonly referred to as so-lar farming, becomes increasingly popular due to easy accessibility and relatively mature technology. While solar farming can reduce carbon emissions in the power production sector, dark solar panels also reduce surface shortwave reflectance and absorb more solar radiation, which is especially significant when they are deployed on highly reflective deserts. Solar panels also have different surface longwave emissivity and thermodynamic properties, affecting surface skin temperature and upward longwave radiative flux. We have analyzed MODIS observations over six solar farms in the Southwestern U.S to successfully quantify changes in surface spectral reflectances, spectral emissivities, and temperature. Similar analyses can be done in solar farms around the globe. Due to the small size of current operational solar farms, the radiative effects due to solar farming are localized. However, with solar panels covering a larger area, these effects can accumulate and propagate to a larger extent and even remote regions. It is imperative to carry out climate model simulations to predict the climatic impacts of solar farms to better inform decision makers.

Methods: I propose extending our previous work on six solar farms to other representative so-lar farms and, aided by climate models, investigating the radiative and dynamical response of the climate system due to large-scale solar farming activities. Specifically, I will continue to use MODIS observations in selected solar farms around the world to obtain the differences in surface spectral reflectances, spectral emissivities, and temperature before and after the installation of solar farms. This will provide a more robust estimation of the surface energy budget in a typical solar farm. Constrained by satellite observations, I will then modify the land model step by step to include the solar farm as a land type. By applying the new land type to the model grid points, I can simulate putting solar farms in different places at different scales. I will use CESM as an example due to its public accessibility and popularity, while similar treatment can be applied to other models. Finally, I will carry out sensitivity experiments to test how different scales and locations of solar farming activities could induce different responses in the climate system.

Relevance: This investigation uses NASA observations and reanalysis to provide a critical understanding of surface energy balance by surface type change. It directly relates to the water and energy cycle as well as applied science programs in NASA. The expected outcome of this study can improve our knowledge of the potential environmental impacts of large-scale solar farming, which can be used to guide future development. The discussion of attributing observed changes to physics or artifacts could also suggest the correction of satellite retrieval algorithms. All of them ultimately align with NASA’s Strategic Objectives.

Matthew Huber (PI)/Qinqin Kong (FI)
Purdue University
21-EARTH21-0333, Investigating Physical Mechanisms Relating Soil Moisture to Moist Heat Stress

The lethality of moist heat stress (MHS) jointly depends on temperature and humidity. To predict extreme MHS events entails a better understanding of the controls on atmospheric boundary layer (ABL) temperature and moisture. Soil moisture (SM) in particular can substantially affect both parameters by regulating the partitioning between surface latent and sensible heat flux. It is well established that a wet soil reduces ABL temperature due to a reallocation of surface available energy from sensible to latent heat flux. But soil moistening also raises ABL humidity making the collective effects on MHS unclear. Recent modeling studies reported a modest net detrimental impact of irrigation on MHS. Such studies use either coarse-resolution GCM or regional climate models at ~30km spatial resolution with convection parameterized. However, MHS depends critically on the build-up of hot-humid air near the surface, and ventilation into the free troposphere, which are processes handled in an ad hoc fashion by convection schemes. In addition, a good understanding of the physical mechanisms that link SM to MHS is important for improving prediction of extreme MHS events. Despite a qualitative sketch of the physical pathways by previous studies, a comprehensive and quantitative examination of the SM-MHS process chain has proven elusive potentially due to the complex nonlinear land-atmosphere interaction and ABL dynamics.

Motivated by this, the objectives of this proposal is to: (1) provide a more reliable estimate of the sign and magnitude of SM's effects on MHS by modeling at sufficiently high resolutions that can explicitly resolve convection; (2) decipher the physic processes governing the SM-MHS link in a quantitative manner.

To accomplish the objectives, we will: (1) diagnose SM-MHS relation using multi-source observational data; (2) develop a process-level understanding of the SM-MHS link using a one-dimensional ABL model; (3) examine SM's contribution to real-world MHS events using the Weather Research and Forecasting (WRF) model coupled with NASA's Land Information System (LIS) at convection-permitting scale.

This project will improve our understanding of the physical processes that govern SM-MHS link. The outcome of this project will benefit both the early-warning and future climate change projection of extreme MHS events. It is directly aligned with the NASA Science Mission Directorate Earth Science Research goal to "improve the capability to predict weather and extreme weather events" and to "improve the ability to predict climate changes by better understanding the roles and interactions of the oceans, atmosphere, land, and ice in the climate system".

Walter Jetz (PI)/Diego Ellis Soto (FI)
Yale University
21-EARTH21-0163, Using Detailed Human Activity and Remote Sensing Data to Assess Wildlife Responses to Altered Human Behavior During the COVID-19 Pandemic

Most of the Earth's surface has been substantially altered by human activities driving severe declines in wildlife abundance, behavioral changes, restrictions in movement, and extinction of species. Despite the clear, negative consequences for biodiversity as a whole, behavioral plasticity and evolution may enable adaptation to a changing world, allowing some species to thrive in the Anthropocene. The contradictory and variable responses of wildlife to anthropogenic drivers indicate that the mechanisms that govern human-wildlife interactions and coexistence are complex; and in some cases, may be of benefit for a subset of species. A large body of research suggests that animals respond to both the built infrastructure of humans, as well as the direct presence and activities of humans. Much less research has focused on assessing how the movements of humans' impact wildlife and a more synthetic, comparative view across multiple species is necessary to understand current and future abrupt changes of human activities. The ongoing COVID-19 pandemic has led to an unprecedented period of reduced human activity. While brought under the most unfortunate of circumstances, these changes in human activity offer a unique opportunity to disentangle the effects of biotic and abiotic elements from anthropogenic disturbances. I propose to evaluate how animals across 59 species of terrestrial birds and mammals altered their (1) space use and (2) niche breadth across the United States before, during, and after COVID-19 induced lockdowns in 2020. By integrating remotely sensed products with animal tracking data and auxiliary information on human mobility data, I will investigate whether there are key correlates of particular response types (body size, generalist vs specialist, urban tolerance). Given the unfortunate likelihood of future drastic reductions of human activity in response to pandemics, understanding the mechanisms underlying human impacts on animal behavior and archiving animal tracking of the ongoing COVID-19 pandemic will be crucial. Finally (3) I plan to create a COVID-19 animal telemetry repository that future researchers can access will lead to a wider understanding of human-wildlife dynamics. Expected results of this research will provide a first national scale understanding of wildlife responses to changes in human activity during the anthropause. Specifically, we will be able to distinguish the effect between static infrastructure and human mobility. This work is relevant to NASA Earth Science Division and the 2020-2024 vision exploration and scientific discovery, innovation, and interconnectivity and partners (Priority 1-3) and also supports the NASA Carbon Cycle and Ecosystems Earth science goal to detect and predict changes in ecological and biogeochemical cycles, such as land cover and biodiversity.

Jennifer Kay (PI)/Jonah Shaw (FI)
University of Colorado, Boulder
21-EARTH21-0371, Can Spectral Observations from AIRS Enhance the Detection of Recent and Future Arctic Climate Change?

Spectrally-resolved observations of infrared radiation such as those made by NASA's Atmospheric Infrared Sounder (AIRS) instrument provide valuable information about the Earth's climate and energy budget. Yet, spectral observations are rarely used in climate change detection research. One central reason for this omission is that climate models do not produce and save spectral output. Without such model output, it is challenging to compare modeled and observed spectral radiation and to determine if observed spectral changes can be explained by natural variability alone.

Our proposed research will assess how and when forced climate change (i.e., changes driven by increased greenhouse gases) can be detected in spectral infrared measurements. In particular, we will assess if less time is needed to detect a forced change when using narrow spectral bands such as those observed by NASA's AIRS instrument than when using broadband fluxes. To accomplish these goals, we will build a tool to simulate spectrally-resolved infrared radiances akin to AIRS observations within climate models. Using this tool, we will answer two research questions: 1) What are the spectral responses to greenhouse gas forcing and surface warming in the Arctic and can they be identified in observations from AIRS?, 2) Where in the infrared spectrum are changes in the Arctic climate first detected and what climate processes are responsible for these signals? To answer the first research question, we will perform targeted climate model experiments to isolate the spectral responses to increased carbon dioxide and surface warming. Using simulated AIRS observations, we will then investigate if these spectral responses can be identified in the AIRS record. To answer the second research question, we will perform fully-coupled climate model experiments to estimate spectral outgoing infrared fluxes under a constant climate and in response to increasing carbon dioxide. Using our constant climate benchmark, we will determine where in the infrared spectrum Arctic climate change is first detected as carbon dioxide increases. In summary, our proposed research develops a valuable tool for linking spectral observations and climate models, and applies it to study Arctic climate change. Central to NASA's core mission, this work applies spectral satellite observations to better understand and quantify Earth's changing climate.

Trevor Keenan (PI)/Sophie Ruehr (FI)
University of California, Berkeley
21-EARTH21-0241, Quantifying Ecosystem Reliance on Groundwater

Climate change is causing our planet to experience increasingly extreme droughts. Dry surface conditions often limit plant growth, thereby diminishing the strength of the terrestrial carbon sink and resulting in a positive feedback to climate change. Many terrestrial ecosystems rely on groundwater during drought. However, groundwater-vegetation dynamics are challenging to quantify across spatial scales and therefore are largely excluded from land surface models. Leveraging both in situ and NASA products to estimate ecosystem function and groundwater availability, this work will improve understanding of the regions, ecosystems, and processes that influence vegetation dependence on groundwater. In turn, this research will also improve our ability to manage groundwater-dependent ecosystems in a changing world.

Chris Limbach (PI)/Robert Randolph (FI)
Texas A&M Engineering Experiment Station
21-EARTH21-0307, Active Sub-Doppler Atomic Filters for Adaptive High Sensitivity Wind Measurements

Improvements in spatially and temporally resolved wind velocimetry are essential to more accurately initialize numerical weather forecasts, improve models, predict aerosol circulation, and identify wind shear, among other uses. This project aims to improve the accuracy and precision of LIDAR wind velocity profiling through the development of an optically controlled velocity selective vapor filter. The proposed approach will take advantage of hot rubidium vapor and the phenomena of spectral hole burning. In this process, rubidium particles in the spectral vicinity of a pump laser are transferred to a trapping state, vastly reducing light transmission at this frequency and creating a spectral hole. Modulating the frequency of the pump beam shifts the spectral location of the hole. This filter will be used to analyze backscattered light from an atmospheric LIDAR, creating a filter transmission related to the line of sight wind velocity. Due to the large spectral slope from the narrow transmission hole, the precise frequency of the Doppler shifted light may be determined, providing measurement sensitivity an order of magnitude beyond state-of-the-art thermally broadened absorption lines and etalon filters.

Investigation of this concept will proceed in three distinct steps. First, table-top experiments will be used to characterize the spectral hole, its dependence on the pump laser properties, and to quantitatively observe how the pump laser frequency modulation alters the location and depth of the spectral hole. Next, Rayleigh scattering experiments in a small-scale laminar jet will be used to validate the measurement technique against existing approaches such as particle doppler anemometry and hot wire probes. In the final step, atmospheric measurements will be obtained at the remote sensing facility at the Aerospace Laboratory for Lasers, Electromagnetics and Optics at Texas A&M University. This facility contains a fiber-coupled three-channel LIDAR detection system integrated with a 16-inch diameter Ritchey-Cretien receiver telescope. The optimal configuration of the rubidium filter parameters will be chosen based on bench-top and small-scale testing.

The project outcome will include valuable data characterizing the spectral hole creation in rubidium vapor; data and modeling relating to dynamic modulation of the spectral hole location, width, and amplitude; and proof-of-principle demonstrations of wind measurements in the lab and field, including quantification of error sources. If successful, this work could lead to technology transfer and commercial development of new LIDAR systems for ground, air, and space-based monitoring of earth's atmosphere.

Eric Lindsey (PI)/Jeng Hann Chong (FI)
University of New Mexico
21-EARTH21-0148, Investigating the Mechanics of Strain Partitioning with L-band InSAR Timeseries: A Study of the Rakhine-Bangladesh Megathrust and Crustal Faults in South and Southeast Asia

This proposal aims to develop L-band InSAR processing strategies and improved numerical methods to study the earthquake hazards represented by subduction zones. Our primary region of interest is the heavily sedimented Rakhine-Bangladesh megathrust in western Myanmar and Bangladesh. This region is densely populated and tectonically active but has been historically under-studied compared to similarly active regions worldwide, and the hazard represented by the megathrust and related faults remains debated. The availability of geodetic observations such as the Global Navigation Satellite

System (GNSS) and Interferometric Synthetic Aperture Radar (InSAR) have greatly improved our ability to map tectonic strain accumulation, but difficulties remain in remote and densely vegetated areas such as our proposed study area, which are not suitable for C-band imaging and lack dense GNSS networks.

Here, we propose to optimize the processing of 5 years' worth of L-band ALOS-2 InSAR imagery to generate timeseries and an average line-of-sight velocity map across the Indoburman range on the overriding plate. The results will allow us to precisely map strain accumulation across the plate boundary zone as well as any transient features related to creep processes that could influence the earthquake hazard in the region. We will then combine the processed interseismic velocities with existing GNSS data to generate a regional interseismic velocity map and develop an improved block modeling framework that incorporates vertical rates to examine more accurately how strain is partitioned between the Rakhine-Bangladesh megathrust and crustal faults.

The research proposes the development of an improved set of processing strategies for L-band InSAR timeseries in a densely vegetated region, and a new block modeling framework for analysis of tectonic velocities that correctly accounts for vertical motion on dipping faults. The expected outcomes are an improved understanding of tectonic deformation of subduction zones, particularly close to the trench, an examination of the interaction between the megathrust and crustal faults, and will inform processing strategies for the upcoming NASA-ISRO Synthetic Aperture Radar (NISAR) L-band InSAR mission.

Lori Magruder (PI)/Jonathan Markel (FI)
University of Texas, Austin
21-EARTH21-0374, Investigating Arctic Coastal Erosion Through Satellite-Derived Elevation Modeling and Scalable ICESat-2 Bathymetric Data Fusion

The rapid erosion of Arctic coastlines is threatening coastal communities, ecosystems, and infrastructure. Arctic permafrost coastal erosion is irreversible, and the rate of erosion will quicken as sea ice continues to decrease. There is a critical environmental need to determine the rates of coastal erosion throughout the Arctic, better model the processes driving shoreline retreat, and predict erosion rates into the future.

Coastal digital elevation models (DEMs) which combine terrain height (topography) and seafloor depth (bathymetry) into a seamless elevation map are a one solution to this need if they can be developed with sufficient spatial extent, resolution, and vertical accuracy. This research will develop satellite derived Arctic coastal DEMs by fusing ICESat-2 coastal profiles, satellite imagery, and topographic elevation.

First, we will focus on improving satellite derived and ICESat-2 bathymetry in the Arctic. We will quantify impacts of the optically complex Arctic coastal environment (e.g., turbidity, cloud cover, and sea ice) on ICESat-2's bathymetric capabilities. We will then derive bathymetric DEMs from satellite data and assess the accuracy of different methods at study sites along the Alaskan coast. This will help establish a comprehensive understanding of spaceborne bathymetric performance in the high latitudes. Second, despite ICESat-2 producing approximately 1 TB of data per day, with much of that the Arctic/Antarctic, there are currently no bathymetric signal finding techniques that have been validated outside of temperate climates. We will design a robust algorithm for bathymetric signal finding and classification in turbid and icy coastal environments. We will then develop techniques to fuse bathymetric classifications and with land and vegetation data products, creating unique topobathymetric profiles from ICESat-2 in an automated manner. Lastly, we will generate satellite derived, coastal DEMs through multi-source and multi-temporal data fusion. By using ICESat-2 profiles for registration and quality assessment, we will combine topographic and bathymetric models to create coastal DEMs. Ultimately, this research will result in the creation and validation of satellite-derived three-dimensional coastal models throughout the Arctic.

This research will make progress towards several Earth Science Program Objectives. Principally, it significantly improves the coverage, frequency, and vertical uncertainty of Arctic coastal DEMs derived from public satellite data. This elevation data is useful for improving flood predictions in areas facing increased storm activity and rising relative sea level, for modeling coastal sediment transport, erosion, and deposition, and for measuring the rate of Arctic coastal erosion caused by anthropogenic climate change.

Matthew Mazloff (PI)/Youran Li (FI)
University of California, San Diego
21-EARTH21-0026, Southern Ocean Tidally Driven Mixing: Tracking Lateral Energy Transport via SWOT

Turbulence from breaking internal waves drives vertical transport of water, heat, carbon, and other important tracers, influencing the ocean general circulation and climate. The past decades have seen an increased interest and success in mapping global internal tides to better understand tidally driven mixing (Dushaw et al., 2011; Zhao et al., 2016; Carrere et al., 2021). However, mapping internal tides in the energetic Southern Ocean (poleward of 35S degree) has been problematic due to signal contamination by Antarctic Circumpolar Current (ACC) jets and eddies, resulting in weak and uncertain derived amplitudes. This proposal aims to track the lateral propagation of low-mode internal tides that can travel thousands of kilometers and act as a huge remote energy source from the Southern Ocean. Quantifying this energy is essential for determining tidally driven mixing and helping improve studies focusing on internal-wave-eddy-topography interactions in the Southern Hemisphere oceans.

The proposed tools include an eddy and tide resolving 1/48 degree resolution model simulation LLC4320 from NASA and the unprecedented fine-scale Sea Surface Height (SSH) data from SWOT, which is being developed jointly by NASA and CNES and scheduled to launch later this year. Being the first swath altimeter, and thus the first altimeter able to provide across-track information, will enable SWOT to provide an excellent opportunity to better track the internal tides and study the pathways of energy cascades by providing ocean measurements with a resolution 2 km (Morrow et al., 2019).

A plane-wave fitting method, which can provide information on internal tide propagation direction, phase, and interference pattern, is proposed to resolve the full lateral picture of trajectories of low mode internal tides. Internal tidal waves are extracted by fitting plane waves using SSH measurements in moving fitting windows. In the window, the amplitude and phase of one single plane wave are determined by the least-squares fitting method in each compass direction. The technique was initially developed by Zhao et al. (2016) and has been modified to increase computational efficiency by the FI, with help from the PI and Dr. Cornuelle (UCSD) so that it can successfully analyze the unprecedented large dataset with a high spatial resolution of both LLC4320 and SWOT. To resolve multiple internal tides, the second largest internal tide is extracted by removing the largest component from the initial SSH measurements. This process can be repeated to extract an arbitrary number of internal tides. Via extraction of M2 internal tides with both spatial and temporal coherence, the method greatly suppresses mesoscale contamination, which is essential in the Southern Ocean.

In summary, the proposal will complement the global maps of internal tides developed by Zhao, with attention being paid to the previously unresolved internal tides and to tracking lateral energy transport in the Southern Ocean via SWOT. We will first develop our methods and hypotheses via model analysis, and then aim to apply our methods to SWOT observations. With the help of NASA's LLC4320 and SWOT and the proposed methods, we believe that the signatures of the internal waves and mesoscale eddies, and the tidally driven mixing can be better understood. The proposal is also a good match with a subset of SWOT mission goals - measuring fine-scale feature at scales as small as 20 km and improving ocean circulation models to make better future climate projections.

Nicholas Meskhidze (PI)/Bethany Sutherland (FI)
North Carolina State University
21-EARTH21-0343, Estimates of PM2.5 Concentration and Chemical Composition by Application of KORUS-AQ High Spectral Resolution Lidar Retrievals and CATCH Algorithm

Particulate matter is one of the six criteria air pollutants that the United States Environmental Protection Agency (EPA) has established national ambient air quality standards (NAAQS) for under the Clean Air Act. Particles with aerodynamic diameter less than 2.5 ?m (PM2.5) have been found to have the most serious adverse effect on human health and the environment. While the importance of measuring PM2.5 has been clearly demonstrated, doing so remotely remains challenging. We have developed a methodology for using High Spectral Resolution Lidar (HSRL) retrieved information about aerosol extinction and types to derive model-independent estimates of surface PM2.5 concentration and chemical speciation. We showed that for the DISCOVER-AQ BW campaign the results from the new methodology compared with the ground measurements better than the EPA CMAQ model predictions. Recently we have tested the methodology using the KORUS-AQ campaign. Our preliminary data analysis shows the method did not perform as well on retrievals from Korea as it did for the aerosols from the eastern US. We hypothesize, that this is due to two main factors: (1) particularly low mixed layer heights encountered during KORUS-AQ and (2) differences in the chemical composition and optical properties for Asian aerosols versus eastern American. For shallow mixed layer heights below ~300 m, decoupling between the surface and the air aloft makes aerosol retrievals through HSRL (and subsequent characterization by our methodology) particularly intractable. It has been shown previously that the chemical composition of aerosols (e.g., more black carbon) affects their optical properties and subsequently their type-resolved characterization (e.g., for urban aerosols).
In this work, we intend to test/improve our methodology for remotely estimating PM2.5 concentration and chemical speciation in east Asia using HSRL retrievals. This will include an introduction of a threshold for retaining the data using the HSRL derived mixed layer heights. We also plan on retraining the CATCH algorithm for east Asian aerosols using a small portion of the KORUS-AQ campaign data. Retraining will “teach” the CATCH algorithm how to treat aerosol types that may have different optical properties from the ones observed in the North American domain. Once these two steps are successfully achieved the method validation will be conducted by comparing estimated PM2.5 concentrations and chemical speciation with data from National Institute of Environmental Research (NIER) ground sites. The successful completion of this project will mean that a new methodology has been developed and validated which can be used to estimate PM2.5 concentration and chemical speciation in both North America and Asia with region-specific chemical speciation. Since the method developed in this study is designed for the NASA Langley HSRL sensor, this work will lay the groundwork for PM2.5 concentrations and chemical speciation retrievals from space a part of the NASA Atmosphere Observing System (AOS).

Dev Niyogi (PI)/Xinxin Sui (FI)
University of Texas, Austin
21-EARTH21-0314, Urbanization Impacts on Extreme Precipitation

This research investigates the influences of urbanization on extreme precipitation globally using different satellite and reanalysis precipitation products. Past studies investigated urbanization influences on precipitation either as case studies, short-term simulations, or statistical analysis typically for a city or a region. While this has advanced our understanding, there is still no systematic study considering different cities covering a wide range of geography and climatological conditions. This is important as cities under different local conditions, such as coastal and inland cities, will be dominated by different urban precipitation mechanisms. This, in turn, influences urban rainfall modification.

Therefore, this study proposes to develop a more generalized understanding of urban effects on extreme precipitation under the mountain, inland, and coastal environments. The work is highly aligned with three Science Mission Directorate (SMD) Earth Science Focus Areas of i) Water and Energy Cycle, ii) Climate Variability and Change, and iii) Weather and Atmospheric Dynamics.

The research will be guided by three science questions/tasks.
I) Where are the urban rainfall hotspots across the globe? Task I will analyze the precipitation over global urban and corresponding non-urban grids to assess urban precipitation hotspots. A map of global urban rainfall anomalies will be identified and investigated with IMERG, 3km NASA GEOS DYAMONDv2 output, and other precipitation datasets in Task I by comparing the urban and rural areas (2001 – 2020).

II) What is the influence of geography (coastal, inland, terrain complex) on urbanization rainfall anomaly? Focusing on the hotspots, Task II will target 10 to 20 cities covering the mountain, inland, and coastal environments and conduct an in-depth analysis of urban rainfall trends and distribution changes to understand the different processes. The target cities will preferably be in local clusters that are representative of coastal, inland, and complex terrain (topography) along a transect (e.g. Houston – Austin/San Antonio – Dallas; Lagos – Ibadan in Nigeria; Mumbai – Pune – Bangalore), so as to have relatively similar weather patterns affecting the rainfall.

III) What do causal/statistical approaches reveal about urban impacts on extreme precipitation? Task III will further focus on 3 to 5 cities within the hotspot locales and study the urban effects on extreme precipitation around these cities with statistical and data-driven causal analysis methods. We will assess the urban impacts on extreme precipitation using the long-term series of urban (built-up condition, impervious percentage, population, and nighttime light) and environmental factors (column water vapor, evapotranspiration, temperature, humidity, and wind). Quantitative relationships between the extreme precipitation data and urbanization variables will be developed.

This study will utilize seven satellite and reanalysis precipitation datasets with high spatial and temporal resolutions. It aims to develop a robust assessment to ensure that results are not influenced by the biases in individual precipitation datasets.

Among these seven products, four satellite and reanalysis datasets were developed or sponsored by NASA, such as IMERG, GSMaP, MERRA-2. These products will be compared and evaluated with other high quality products such as ERA5-Land and CHIRPS. Uniquely, the high-resolution (3 km) GCM output, GEOS DYAMOND Phase II dataset (provided by NASA GSFC collaborators) will be used for a fine resolution analysis of the meteorological evolution of precipitation events. This study will also use land surface and other environmental variables retrieved from NASA satellite platforms such as MODIS, Landsat, and SRTM. The utilization of NASA remote sensing data and model outputs will advance our understanding of the performance of NASA products and be helpful in assessing where improvements are needed.

Jessica O'Connell (PI)/Kyle Runion (FI)
University of Texas, Austin
21-EARTH21-0185, BERM, a Geospatial Informatics Approach for Estimating Coastal Marsh Blue Carbon and Vulnerability to Sea Level Rise

Coastal wetlands are key ecosystems for soil carbon sequestration because of high primary production. Wetland soil organic material accumulates due to reduced decomposition in water-logged anoxic soils. This encourages vertical soil accretion and resilience to sea level rise and other stressors. However, broad-scale remote sensing of productivity in existing earth system models does not accurately capture coastal wetland dynamics. The Belowground Ecosystem Resiliency Model (BERM) is a recently developed geospatial informatics tool to characterize salt marsh productivity and resilience, and is informed by aboveground biophysical metrics. The purpose of this study is to improve BERM in order to assess broad-scale salt marsh productivity, ecosystem resilience, and soil carbon sequestration potential.

For this effort, we will expand the BERM calibration dataset through field data collection, calibrate BERM to apply to additional marsh vegetation species, and update the modeling framework to include information from both Landsat and Sentinel missions as well as other technical improvements. A main BERM output is spatially-explicit belowground biomass, a key aspect of marsh resilience, on a monthly timescale. But BERM also produces a suite of additional biophysical products, such as aboveground biomass, foliar nitrogen variation, flooding intensity, and soil temperature. Once the updated model is built, we will characterize marsh resilience trajectories by evaluating relationships between marsh productivity, water quality, drought, and flooding through place-based case studies. This will allow us to understand how changing conditions influence tidal marsh dynamics, with consequences for the societal benefits wetlands provide, such as flood control, shoreline stabilization, wildlife habitat, and water purification.

To expand BERM, we will collect ground-truth data for model calibration that cover additional wetland vegetation types, hydrodynamic, and biogeochemical conditions. We will also broaden the model and associated workflows to include additional remote sensing data products, and interrogate the model results against complementary environmental data from project partners. The goal will be to identify environmental drivers of marsh resilience. This effort will expand the applicability of BERM from the East Coast, where it is currently calibrated to model one widespread salt marsh plant species, to tidal marshes on the Gulf Coast, where vulnerable low elevation areas have higher vegetation diversity as a consequence of regional differences in tide, precipitation, and water quality. This proposal will also improve the spatial, temporal, and spectral resolution of BERM remote sensing predictor variables. BERM currently relies only on Landsat-8, but this proposal will lay the ground work for including Landsat-8, -9, Sentinel-2, and combined data products.

NASA's Earth Science Division aims to better understand and forecast changes in the global earth system, as well as to identify causes of change and provide societal benefits. Products from this project will directly address these priorities in salt marshes by creating a tool to assess ecosystem response to naturally occurring and human-induced processes. Results will be delivered to coastal managers and decision-makers as quantitative assessments that can highlight priority areas for conservation and restoration activities. BERM will be made available to the scientific community as an open-source tool, and showcased through two place-based case studies, conference presentations, and publications in peer-reviewed journals. The continued development of BERM will generate a deeper understanding of salt marsh biophysical interactions and set the stage for the inclusion of BERM-derived algorithms in earth system models. Finally, BERM will provide a critical tool for preserving and maximizing the societal benefits these ecosystems provide.

Kiona Ogle (PI)/Emma Reich (FI)
Northern Arizona University
21-EARTH21-0132, Evapotranspiration Partitioning in Drylands Using ECOSTRESS and Eddy Covariance Fluxes

Drylands are experiencing higher rates of drought under climate change, so it is increasingly important to understand the timescales over which water fluxes (i.e., evapotranspiration [ET]) respond to changing climatic and biotic drivers. Partitioning ET into its components (evaporation [E] and transpiration [T]) can help us understand how and when climatic and biotic variables drive ET across different water-limited biomes, which will inform management practices and help predict how the hydrology of ecosystems could respond to climate change. Because drylands experience rapid environmental events and are spatially heterogeneous, it is important to be able to partition ET over short time periods in different ecosystem types to better understand the processes giving rise to temporal and spatial variation in these fluxes. This study will integrate eddy covariance flux tower data, ECOSTRESS data, and semi-mechanistic models within a nonlinear Bayesian framework to partition ET into T and E using a new ET partitioning method that builds on previous approaches. This framework constrains water-use efficiency (WUE) with novel methods to incorporate satellite remote sensing data and constrains E with process-based algorithms. Then, this study will implement the stochastic antecedent modeling (SAM) mixed-effects Bayesian framework to quantify the drivers of T, E, WUE and their timescales of influence. Finally, it will evaluate the spatiotemporal variability in ET, T, E, and WUE along an elevation and aridity gradient to develop a better understanding of the water cycle and relative contribution of biologically mediated processes (T) to ET. This integration of ECOSTRESS data and flux-based ET partition modeling will produce a replicable method to partition ET across flux tower sites, and result in temporally fine-scale, long-term timeseries data for T, E, and WUE.

Paola Passalacqua (PI)/Matthew Preisser (FI)
University of Texas, Austin
21-EARTH21-0264, Application of Earth Observation Data in Multi-Layer Network Analysis of Flood Hazards, Social Vulnerability, and Risk

The frequency of major flooding events continues to increase, fueling the already growing concern in numerous fields about quantifying the inequitable distribution of flood hazards. We are therefore proposing a near-real time multi-layer network model of urban flooding and social vulnerability built on survey, hydrologic point, and remotely sensed satellite data to create a comprehensive tool for impact assessments. While remotely sensed satellite data has a higher spatial coverage, point measurements can fill in gaps due to data latency and resolution challenges. Data fusion methods will integrate all available and relevant information from broad sources to provide end users with a multi-faceted picture of hazard, vulnerability, and impact of single (e.g., flood) and multiple (e.g., flood and heat) threats. Through this project, we will create a fused satellite and survey data picture of multiple hazard social vulnerability at the household level. This work will be accomplished in conjunction with existing partnerships in multiple cities to increase the adoption of scientific data for community impact.

Tamlin Pavelsky (PI)/Marissa Dudek (FI)
University of North Carolina, Chapel Hill
21-EARTH21-0263, Estimating Streamflow Gains and Losses Using In-Situ, Airborne, and SWOT Satellite Measurements

Rivers and shallow aquifers are intricately connected hydrologic systems that are vital sources of water for communities and habitats around the world. Understanding when and where rivers gain and lose streamflow to aquifers is crucial for monitoring and maintaining these valuable resources. In the United States, nearly 64% of well water levels (within 1 km of a river) lie below the river's water table, allowing more streamflow to potentially be lost to groundwater rather than gained. With a global increase in groundwater depletion and abstraction for agricultural and community use, regions with losing streams run the risk of withdrawing more groundwater than can be recharged. Over time, these losses can negatively impact local and downstream communities; aquatic, wetland, and riparian ecosystems; and infrastructure due to land subsidence. While extensively studied at local scales, we currently do not have a clear understanding of the patterns of streamflow gains and losses to aquifers for the majority of the world's rivers.

With the proposed project, I aim to provide an improved understanding and methodology to detect the net water exchange (gains and losses) of river systems on a global scale. To achieve this objective, I propose to assess whether measurements from the NASA and CNES Surface Water and Ocean Topography (SWOT) satellite, when constrained with in-situ and airborne observations (collected during a two-month field campaign), can estimate streamflow net water exchange between the Waimakariri River in New Zealand and its surrounding aquifer. With launch planned for November 2022, SWOT will enter a 90-day fast-sampling calibration and validation phase covering a nominal percentage of the Earth's surface with a daily repeat orbit. A high-priority hydrologic validation site is the Waimakariri River which will be extensively studied with in-situ and airborne observations during this time. While this data will be collected for the purpose of validating SWOT water surface elevation, width, and slope observations, there are currently no plans to use it for scientific analysis. SWOT's fast-sampling phase provides a unique opportunity to constrain high spatiotemporal resolution SWOT measurements using multitemporal in-situ and airborne observations over multiple river reaches, it will be possible to estimate changes in discharge using inverse and data assimilation methods.

I hypothesize that this highly constrained estimation method will yield suitable estimates of spatiotemporal variations in discharge, from which we can infer streamflow gains and losses. I also hypothesize that this method can be transferable to other river systems where some in situ data are available. In conjunction with previous studies of potential widespread streamflow losses and groundwater depletion, this time-critical assessment of SWOT's capability to accurately detect net water exchanges will improve our understanding of the effects on river systems to climate change and the depletion/abstractions of groundwater. This new tool will provide a quantified investigation into the connectivity for the majority of the world's rivers and their surrounding aquifers. Thus, the information gathered from this proposed research will improve our assessment, management, and decision-making regarding water quantity in rivers and aquifers on a global scale.

Robert Pierce (PI)/Juanito Jerrold Acdan (FI)
University of Wisconsin, Madison
21-EARTH21-0024, Urban-Scale Air Quality Modeling in Coastal Environments

This proposed research will utilize an optimized, high-resolution WRF-CMAQ modeling configuration developed under previous NASA Health and Air Quality (HAQ) Applied Science Program funding for studying ozone production in urban coastal regions. The main goal is to investigate the impact of utilizing high horizontal spatial resolution modeling to simulate meso-beta scale meteorological and chemical processes in coastal urban environments. This proposed research also seeks to: 1) study the relationship between column and surface concentrations of O3 and its precursors and how the relationship varies during the day, and 2) examine potential differences in weekday and weekend VOC-NOx chemistry. The studies will utilize data collected from recent and planned field campaigns to assess the model performance. This research project supports the air quality community and the TEMPO science mission by developing high-resolution modeling capabilities needed for State Implementation Plan (SIP) development and the interpretation of diurnally resolved, high-resolution TEMPO measurements.

Andrew Richardson (PI)/Jen Diehl (FI)
Northern Arizona University
21-EARTH21-0348, Impacts of Extreme Heat and Drought Events on Forest Productivity Assessed Using OCO-3, ECOSTRESS, DESIS, and GEDI

Climate change is causing the frequency and severity of extreme heat and drought events to increase dramatically in comparison to historical norms, which is having major impacts on forest health and productivity. Because of the major role that forests play in the global carbon cycle, it is more important than ever to understand the timescales (i.e., immediate and lagged) over which these effects occur. Technological advances in spatial resolution, temporal resolution, and precise measurements of forest health allow for novel approaches to this problem.

In late June to early July 2021 a record-breaking heat wave, commonly referred to as the "2021 Heat Dome", shocked the Pacific Northwest, and we have yet to fully understand its impact on regional forests. This recent event provides a case study to utilize advancements in remote sensing to research and quantify the effects on forest productivity. I will use data from several NASA instruments onboard the space station (OCO-3, ECOSTRESS, GEDI, and DESIS) in my analyses. These instruments measure key attributes of ecosystem function (proxies for photosynthesis and water use), composition and structure (estimates of biomass and canopy height), and ultimately overall health (hyperspectral canopy reflectance). To quantify the effects of the Heat Dome on forest productivity and health, I will establish an analysis framework that will allow multivariate regression and account for the spatial nature of the data.
The overall goal of this project is to leverage the unique opportunity to combine advanced remote sensing to investigate the 2021 Heat Dome and its effects as a timely example of heat stress on forest productivity, creating a possible model for better understanding of the impact of future events. The following sub-questions and corresponding hypotheses are proposed to achieve this goal:

1. What were the immediate, short-term, and lagged effects of the 2021 Heat Dome on forest productivity?
H1: As temperature increases and water availability decreases and forest exceed their critical level, forest productivity metrics will initially decrease (days). Productivity will rebound to a slightly lower steady state (weeks) as the heat dome is a pulse overlain on the more gradual press of climate change.
2. Which instrument measurement or combination of measurements most clearly captures the impact of heat-stress at short and long-term timescales?
H2: The strongest indicator of heat-stress is a fluorescence-based measurement followed by greenness metrics. (Finding any strong indicator of stress will enhance understanding of pulse effects on the press of climate change).
3. How does forest structure influence forest recovery?
H3: Higher biomass and closed canopied forests will show larger changes in the forest productivity metrics than thinner forests under heat-stress. (Discovering any differences in stress effects based on forest structure will enhance understanding of pulse effects on the press of climate change).

The outcome of the proposed work will represent an important contribution to NASA's Earth Science Division's goal of detecting and predicting changes in Earth's ecological and biogeochemical cycles by analysis of the 2021 Heat Dome case study. The proposed research also supports NASA's Earth Science Division's goal to further the use of Earth system science research to inform decisions and provide benefits to society by investigating short/long term effects and forest structure benefits. With a strong remote sensing component, the proposed research will improve predictive capability for heat stress in the context of forested ecosystems and climate change.

Dar Roberts (PI)/Clare Saiki (FI)
University of California, Santa Barbara
21-EARTH21-0194, Bridging the Gap Between Land and Atmosphere by Quantifying Wildfire Fuels and Emissions

Globally, wildfires are a significant source of greenhouse gasses and aerosol emissions that impact climate, air quality, and human health. Wildfire smoke is a complex mixture of particle pollutants that have a variety of adverse health effects such as increased susceptibility to respiratory diseases and increased risk of heart attack or failure. Because wildfires are projected to increase in frequency, severity, and extent, so too will the effects of fire emissions on the climate and human populations. The source of wildfire emissions are fire fuels, or the vegetation and biomass that burns in a fire. Fire fuels contribute to a large portion of the uncertainty in fire emissions estimates due to errors in the representations of fuel properties and their variability. Some studies have found as much as 80% of the error of calculating source emissions may be attributed to errors in estimating fuel characteristics. Fuels influence the type of combustion that occurs and subsequently the chemical composition of smoke.

Remote sensing, specifically imaging spectroscopy, allows for improved representations of fire fuels due to detailed spectral data that detect small variations between fuel types. NASA's planned Surface Biology and Geology (SBG) mission would significantly advance our ability to map the spatial and temporal variability of fire fuel type and condition. Methods to accurately quantify fuel characteristics for fire effects modeling and estimates using imaging spectroscopy data have not been fully explored; especially methods that appropriately capture spatial and temporal variability. This proposal aims to quantify the role and impact of fire fuels in wildfire emissions from a selection of fires with a range of satellite, airborne, and ground data. The proposed research first seeks to address whether detailed biochemical and structural remote sensing data can be used to accurately map characteristics of pre-fire fuels on the ground. To do this, imaging spectroscopy, LiDAR, and multispectral spaceborne remote sensing data will be used to develop relationships with measured ground fuels data to map fuel characteristics for each fire. Burn severity will be quantified to relate the amount of fuels burned to emissions. This proposal will also address whether the same type of remote sensing data and the resulting fire fuel models can be generalized to other wildfires and regions to successfully map fire fuels. This will be done by applying the same remote sensing analysis to similar data at locations of other wildfires and statistically analyzing the resulting models and maps of fire fuels to determine if they are consistent. To quantify the influence of fire fuels on fire emissions, direct comparisons will be made between fire emissions estimated using fuels mapped with remote sensing data to the commonly used homogenous fuel inputs that contribute to uncertainty. The proposed research is relevant to the Earth Science Division's Carbon Cycle Science and Terrestrial Ecology (CC&E) focus area as it seeks to address and improve our understanding of how vegetation and biomass impact the atmosphere. By doing so, we can better understand the role of wildfire in our earth system and the role it plays in climate change and carbon cycling. This study will specifically address the CC&E questions of "How do ecosystems, land cover, and biogeochemical cycles respond to and affect global environmental change?" and "What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?" Additionally, the proposed research addresses one of the most important ecosystems priorities from the SBG study of, "Quantify the distribution of the functional traits, functional types, and composition of vegetation and marine biomass, spatially and over time." Through NASA sensors, this study will constrain the role of fire fuels in fire emissions with methods capable of global application.

Summer Rupper (PI)/Emma Marshall (FI)
University of Utah, Salt Lake City
21-EARTH21-0226, A Surface Velocity Investigation of Lake-Terminating Glaciers in High Mountain Asia

Glaciers in High Mountain Asia (HMA) are important seasonal water resources as well as sources of potential hazard for millions of people living throughout downstream catchment areas. Understanding the trajectory of these land-ice bodies in a warming climate is critical to the development of robust and effective climate change adaptation and mitigation strategies. Lake-terminating glaciers appear to be a particularly important part of the overall picture of glaciers in HMA. Lake-terminating glaciers are subject to additional mass loss mechanisms (sub-aqueous melt, thermal undercutting, and calving) related to their connection to a water body that do not affect land-terminating glaciers, which lose mass dominantly through melt and sublimation. Several studies observe that these additional mass loss mechanisms seem to have consequential impacts: in recent decades, lake-terminating glaciers in many sub-regions across HMA have displayed greater terminus retreat and more negative mass balances relative to land-terminating glaciers. Coupled with projections of increases in the number and area of lake-terminating glaciers in the region in coming decades, the more negative mass balances of this group of glaciers as a whole carries important implications for the future of HMA glaciers in the 21st century.

This proposed research will improve scientific understandings of lake-terminating glaciers and the dynamics shaping their observed behavior. Beginning from the starting point of recent observations of distinct surface velocity patterns between glaciers of different terminus types, we use surface velocity as a lens through which to examine the sub-annual glacier dynamics that contribute to observations of distinct mass balances, geometric changes and surface velocities related to terminus type on annual and interannual timescales. We focus on glacier surface velocities because they offer important information about glacier dynamics and can be collected at higher temporal frequencies than other metrics such as mass balance and thickness, facilitating our focus on events and variability that drive longer-term trends. Previous results show distinct velocity patterns between lake-terminating and land-terminating glaciers on seasonal timescales. We will use a number of surface velocity datasets to develop and validate medium-to-high temporal resolution glacier surface velocity time series. These include Global Land Ice Velocity Extraction from Landsat (GoLIVE), Inter-mission Time Series of Land Ice Velocity and Elevation (ITS_LIVE), and glacier surface velocity observations derived from synthetic aperture radar (SAR) datasets such as Sentinel1 and ALOS-PALSAR (1&2). Physical glacier models will be used to assess the various physical parameters that explain the observed glacier surface velocity variability as well as the sensitivity of surface velocities to varying physical and environmental conditions. Workflows developed in this research will contribute to the future use of NASA-ISRO Synthetic Aperture Radar mission (NISAR) products to examine glacier surface velocities on sub-annual and intra-seasonal timescales in settings where L-band is more appropriate for this analysis than C-band radar. This research serves the NASA Earth Science Research Program objective to ‘improve the ability to predict climate changes by better understanding the roles and interactions of the oceans, atmosphere, land and ice in the climate system.’ With the proposed research, we will exploit the large availability of satellite imagery over the HMA region as well as glacier modeling techniques and recent advancements in computational resources in order to better understand physical systems in an area that is highly sensitive to climate change as well as where the largest density of glaciated terrain outside of the polar regions coexists in relatively close proximity with millions of people living in downstream communities.

Oscar Schofield (PI)/Michael Chen (FI)
Rutgers University, New Brunswick
21-EARTH21-0260, Biogeochemical Cycling in the Southern Ocean: Quantifying Deep Ocean and Coastal System Dynamics in a Region of Rapid Change

The Southern Ocean plays a critical role in regulating global climate, contributing to large amounts of the ocean's uptake of anthropogenic CO2 emissions. However, there still remain large uncertainties in our understanding of biogeochemical cycles here, largely due to the extreme difficulty in sampling this remote, hostile ocean. Satellites have provided enormous insights into the dynamics of the Southern Ocean, although they face many limitations such as the cloud-cover, lack of data during the dark polar night, and an inability to see past the surface ocean. Here, we seek to better understand biogeochemical cycling in the Southern Ocean, specifically in the rapidly warming western sector. Our first aim is to leverage autonomous profiling floats to study the dynamics and drivers of carbon export (which sequesters carbon into the deep ocean) in the deep ocean in this sector. Using the biogeochemical sensors on these floats, we will relate export to phytoplankton bloom dynamics and broad climate gradients. Our second aim is to use a long-term ecological research program to study a coastal region in this sector, the West Antarctic Peninsula. By collecting in situ optical data, we will enhance our understanding of the distribution of planktonic particle size in this coastal region, which is an important indicator of ecological community composition and how much carbon it might be able to sequester. The proposed work aligns with the Earth Science mission of NASA, and will help refine the large uncertainties in biogeochemical cycling in this rapidly changing, globally important region. Ultimately, it will help us better constrain global carbon budgets and predict regional and global change as the climate continues to warm.

Dustin Schroeder (PI)/Thomas Teisberg (FI)
Stanford University

21-EARTH21-0021, Development of a UAV-Based Integrated Ice-Penetrating Radar System for Ice Shelf Monitoring

Airborne ice-penetrating radar (IPR) is the primary geophysical tool for large-scale measurements of the geometry and internal structure of ice sheets and ice shelves. The cost and logistical complexity of collecting airborne IPR data has limited the spatial extent of measurements and has made repeat temporal monitoring exceedingly rare. The flow of most of the fastest-flowing Antarctic glaciers is buttressed by floating ice shelves. Rapid changes in these ice shelves, as has already been seen in some instances, could lead to dramatic increases in the mass loss from the Antarctic Ice Sheet. As such, temporal monitoring of ice shelves is critically important to both improving our understanding of the dynamics of ice shelves and predicting their future evolution. Due to the prohibitive cost of conventional airborne IPR, temporal monitoring is primarily done using surface observations and applying hydrostatic equilibrium assumptions to infer the ice-water interface. This approach, however, relies on multiple assumptions that are difficult to verify and likely not satisfied in many cases, especially on smaller ice shelves. We propose the development of an uncrewed aerial vehicle (UAV) with an integrated ice-penetrating radar system capable of repeat pass monitoring of ice shelves at a fraction of the cost and logistical complexity of conventional airborne IPR. This UAV-based IPR system will be capable of surveying ice shelves roughly the size of Totten Ice Shelf with a two person science field team, making it feasible to collect annual IPR surveys to monitor ice shelf changes. We have already demonstrated the feasibility of the instrument using a smaller-scale UAV and basic integration testing. Here we propose to tackle the remaining challenges of improving the radar system and integrating the instrument with a larger and more capable UAV platform. We would make this capability available to the other field teams to be used in a wide range of applications.

Nathan Senner (PI)/Jennifer Linscott (FI)
University of South Carolina
21-EARTH21-0404, Multi-Source Detection and Monitoring of Ephemeral Shorebird Habitats in an Agricultural Prairie System (EARTH21)

The North American midcontinent contains a mosaic of glacially-formed depressional wetlands that vary in depth and permanence. This variation draws migratory birds with diverse wetland habitat preferences from across the Western Hemisphere, including birds that require shallow, ephemeral wetlands. However, intensive row crop production in this region is reducing mosaic heterogeneity, disproportionately removing the shallow wetlands that many migratory species need to rest and refuel. Because shallow wetlands are often small and dynamic, little is known about how many remain in the region or how they respond to climatological cycles and landuse
policies. Even less is known about how migratory birds respond to their absence. We propose an effort to map these habitats over large scales using a combination of Landsat 8 and 9 multispectral imagery, Sentinel-1 Synthetic Aperture Radar data, lidar, and the movements of shorebirds, which are indicators of shallow wetlands. With this data, we will: 1.) map the spatiotemporal distribution of shallow wetlands across the region; 2.) investigate associations between their distribution, climatic fluctuations, and land-use policies, and 3.) determine the optimal spatial network to support the migratory birds that need them.

The proposed research aligns with the NASA Earth Science Division’s key aim to monitor ecosystem changes tied to biodiversity. Results will directly inform efforts to restore wetland heterogeneity and ecosystem functioning to agricultural lands in the midcontinent. Results can also provide actionable information for shorebird conservation, informing placement of conservation easements and dynamic wetland management projects for maximal impact on migrating birds during their migratory window. Finally, we offer a framework for the growing number of wildlife biologists who are capturing animal movement data to use NASA remote sensing projects to identify ephemeral habitats and trace their effects on biodiversity.

Shawn Serbin (PI)/Dedi Yang (FI)
State University of New York, Stony Brook
21-EARTH21-0006, Integrating Field Observations and Multi-Scale Remote Sensing to Understand the Environmental and Biological Controls of Tall Shrub Distribution in Arctic Tundra

Central Objectives: The climate-driven rapid expansion of tall shrub species into northern high-latitude tundra has important implications for Arctic ecosystem water, carbon, and energy cycling, as well as feedbacks to the global carbon cycle and climate system. However, our ability to understand the location and drivers of shrub expansion in the Arctic has been limited by its remote location and high level of biotic and abiotic heterogeneity. Increased temperatures and permafrost thaw have been generally linked to the increased shrub cover in the Arctic, but shrub distribution is also likely limited by other biotic or abiotic factors that do not favor their growth. Changes in these limiting factors could have larger or more direct impacts on shrub expansion than non-limiting factors. Therefore, a better understanding of the primary constraints on Arctic shrub distribution and growth would improve our mechanistic forecasts of their future expansion. However, current research has focused primarily on the impacts of shrub expansion on above and belowground processes, including albedo, snow, permafrost thaw, nutrient cycling, and hydrology. Far less attention has been placed on quantifying the factors that foster or limit the expansion of tall shrubs, including the species-specific and spatial and temporal variation in these limiting factors. This lack of research is further complicated by the limited availability of higher resolution datasets capable of quantifying the spatial variability in shrub biophysical properties and micro-environmental conditions. Methods/Techniques: I propose a novel, multi-scale approach to integrate field observations, unoccupied aerial systems, and NASA ABoVE airborne data to investigate the environmental limits of two tall shrub genera in the Arctic, i.e., alder and willow. I will carry out this research in three steps: 1) mapping alder and willow shrub cover from AVIRIS-NG using a scaling method that I have developed; 2) combining high-resolution maps of shrub cover, topography, climate, and soil properties to determine the environmental limits of alder and willow distribution using through environmental limiting factor (ELF) modeling; 3) identifying key biotic factors linked to these ELFs by measuring and linking maps of key plant functional traits with shrub ELFs. Three low-Arctic tundra field sites located on the Seward Peninsula, western Alaska will be used as testbeds for the training of ELF models. Once constructed, the ELF models will be applied to map the ELFs of alder and willow across this region. Existing trait measurements collected at these field sites, in combination with trait maps produced with AVIRIS-NG, will be used to examine the trait differences between alder and willow to identify biotic factors that differentiate shrub ELFs. The goals of this project are: 1) generate robust tall shrub cover maps from AVIRIS-NG across the Seward Peninsula, 2) determine the primary ELFs for alder and willow across the Seward Peninsula to understand environmental controls on tall shrub distribution, 3) compare the ELFs between alder and willow and link these with factors to underlying biotic controls through the connection with canopy functional traits. Significance: This study directly relates to NASA's SMD "Earth Science Research Program" and within the scope of the strategic goal "How will the Earth system change in the future". The outcome of the scaling work will provide important parameters to Earth System Modeling and new methods to the use of imaging spectroscopy for monitoring high-latitude ecosystems, which is also directly related to other NASA missions, like SBG and ABoVE. The determination of ELFs will provide new insights into the environmental limits of tall shrub expansion in the Arctic. The constructed ELF models can also be applied to future climate scenarios to provide valuable process model benchmarks to evaluate mechanistic predictions of plant distribution in the Arctic.

Sergii Skakun (PI)/Leonid Shumilo (FI)
University of Maryland, College Park
21-EARTH21-0317, Agriculture Velocity of Winter Wheat

Recent NASA research on the climate change impact on the major crop production shows that agriculture productivity changes will be noticeable much earlier than previously anticipated. The recent state-of-the-art crop growth models report that a temperature increase of 1 to 2° C can reduce the wheat productivity by 4.7% and between 2069 and 2099, there is an expected 15.3% drop in productivity. The changes in agriculture productivity are relative to the latitude of locations. Low latitude territories would have highest decline of wheat yield and cropland extend, meanwhile for high latitude areas agro-climatic conditions can became more efficient for the wheat growth and a lead to yield increases and redistribution of cropland area. To fully understand these changes, we need to conduct a fundamental research of trends in the global extent changes that already can be observed. For this purpose, we will use the new spatial-temporal redistribution indicator – agriculture velocity that is developed based on the climate velocity concept. To improve climate velocity estimation as well as to develop robust and efficient in terms of accuracy methodology for agriculture velocity estimation, we will use optical flow model of computer vision. Agriculture velocity indicator will give us possibility to map trends of winter wheat cropland structure for 11 countries that are main wheat producers in the world, explore relationships between climate change and cropland redistribution and estimate future projection of global winter wheat fraction change based on the climate change scenarios. This research objectives can be achieved by addressing the following research questions:
i. What is the magnitude of winter wheat agriculture velocity in major wheat producing countries in the past 20 years?
ii. What are the relationships between agricultural velocity and climate change?
iii. What are the future projections of winter wheat cropland extent with regard to agriculture velocity and climate change scenarios projections?
To conduct this research, we will build winter wheat classification maps based on the MODIS satellite products, establish analysis of global agro-climatic parameters change based on the NASA Power data and produce future projections of agriculture velocity and winter wheat fraction with use of NASA NEX-GDDP and NEX-DCP30 climate change scenarios.

During this project we will produce:
1. Winter wheat maps for 11 countries which are largest producers of winter wheat in the world.
2. Collection of climate velocity maps and climate velocity maps created with the new optical flow based approach, maps of future projections of winter wheat fraction.
3. Future projection of winter wheat fraction based on the climate change scenarios.
4. Three scientific papers in the peer-reviewed journals.

This project is directly addressing the NASA's strategic objective "Advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet", objectives of NASA's "The Climate Variability and Change" focus area and UN Sustainable Development Goals. Outputs of this project can contribute in the conductance of Federal climate adaptation plans, agreements between NASA and USDA "to Improve Agricultural, Earth Science Research" and can be valuable for NASA Harvest, USDA's Foreign Agriculture Service (FAS), Global Agriculture Monitoring (GEOGLAM), FAO and Global Partnership for Sustainable Development Data.

Allison Steiner (PI)/Yingxiao Zhang (FI)
University of Michigan, Ann Arbor
21-EARTH21-0014, Using Satellite Data to Understand Primary Biological Aerosols Emissions from Forest Ecosystems and Their Impacts on Cloud Properties

Primary biological aerosol particles (PBAP) are directly emitted from the Earth's biosphere, including pollen, fungal spores, viruses, bacteria, leaf litter, and other plant fragments. They can readily take up water and act as effective cloud condensation nuclei (CCN) and ice nucleating particles (INP), and therefore have significant impacts on cloud formation and reflectivity. Compared to other aerosols, PBAP can serve as INP at warmer temperatures and thereby can dominate the ice nucleation process over forest ecosystems. However, current observations of PBAP are limited by small spatial and temporal regions and this leads to large uncertainties in understanding PBAP and its atmospheric effects. Satellite observations provide a new possibility to detect PBAP continuously on a large scale using optical properties. In this study, we propose to use a suite of NASA satellite products (including CALIPSO, MODIS, and AIRIBRAD) to detect PBAP in boreal-temperate forest ecosystems over North America. Ground observations (including AERONET, MPENET, ARM SGP, and NAB AAAAI) will constrain the uncertainties of satellite-derived results. We will conduct the analysis over a relatively long period (2010-2020) to understand the seasonal and interannual variations in PBAP. In addition, we will use the observed cloud properties and precipitation from CALIPSO, CloudSat, and MODIS to investigate the role of PBAP on cloud formation and lifetime. Model simulations of pollen will be conducted to understand the role of PBAP on cloud formation, and this will be evaluated with observed cloud and precipitation processes.

Overall, this study combines satellite and ground-based observation data with model simulations to develop novel tools to identify PBAP and investigate their role in cloud and precipitation. The application of this study will provide new insight into biosphere-atmosphere interactions and the associated effects on atmospheric composition and regional cloud and precipitation. Through model simulations and an understanding of the role of PBAP in the Earth system, the work will further develop Earth system modeling and weather forecasting.

Dariusz Stramski (PI)/Anjali Narayanan (FI)
University of California, San Diego
21-EARTH21-0035, Examining Responses of Phytoplankton Community Composition to Climate-Related Changes in the Arctic Ocean Using Multiyear Observations from Multiple Satellite Missions

The Arctic Ocean (AO) is experiencing drastic environmental change such as amplified warming and sea ice loss. Such changes directly impact phytoplankton biodiversity, and recent studies have reported climate-related shifts in Arctic phytoplankton community composition. Relating these shifts to climate-related changes can help better understand the current and future implications for biogeochemical cycling and upper trophic levels. Optical remote sensing offers the capability to monitor phytoplankton communities over broad spatiotemporal scales. However, most remote sensing algorithms for assessing phytoplankton community composition are developed for lower latitudes and not well-suited for immediate application in the AO. This project will address this gap by developing an optical classification algorithm for discriminating Arctic phytoplankton assemblages and applying it to ~25 years of satellite observations within the western AO in the late spring-early fall seasons from multiple satellite missions (1997-present). Major research objectives are to: (1) Develop an optical approach to partition Arctic phytoplankton communities into cell size-based classes; (2) Demonstrate and test an optical algorithm for identifying these size classes with satellite data in the Chukchi and Beaufort Seas (CBS); (3) Apply an optical algorithm to ocean color satellite imagery from the past ~25 years to conduct a times series analysis of spatial changes in phytoplankton community composition within this region; and (4) Correlate these results with changes in satellite-derived biogeophysical parameters over this time period.

The proposed algorithms will be developed using a quality-controlled dataset comprising concurrent measurements of phytoplankton pigments, inherent optical properties (IOPs) including spectral phytoplankton absorption, and remote-sensing reflectance (Rrs) from surface waters of the CBS. The algorithms will be based on relating the optical properties to phytoplankton size-based classes calculated from pigment composition and will provide a tool to identify and discriminate pico-, nano-, and microphytoplankton-dominated assemblages from ocean color remote sensing. The ocean color algorithms based on Rrs or a combination of Rrs and IOPs will be first demonstrated and tested with satellite-in situ data matchups. Algorithms will then be applied to a time series analysis of satellite ocean color data in the CBS to determine changes and trends in phytoplankton community composition over the past ~25 years. Time series of satellite-derived biogeophysical data (e.g., sea surface temperature, sea ice concentration, chlorophyll-a concentration, water turbidity) will also be analyzed to understand the responses of Arctic phytoplankton communities to climate-related environmental changes.

This proposed work will produce an optical approach applicable to remote sensing that will allow monitoring of changes in Arctic phytoplankton communities over broad spatiotemporal scales and assessment of subsequent impacts to the AO ecosystem and biogeochemical cycles. This research will benefit ecological, biogeochemical, and climate models of the AO by adding satellite-derivable phytoplankton data products. The open-source deliverables of this project will help users understand the utility of optical remote sensing methods in studying Arctic climate change and empower them to use such scientific tools in management, education, and policy. This work contributes to key goals of NASA's Earth Science program including (1) Detect and predict changes in Earth's ecosystems and biogeochemical cycles and (2) Improve the ability to predict climate changes by better understanding the roles and interactions of the oceans, atmosphere, land, and ice in the climate system, and addresses the "Arctic Systems Interactions" and "Community Resilience and Health" priority areas of the Interagency Arctic Research Policy Committee's 2022–2026 Arctic Research Plan.

Elizabeth Tellman (PI)/Hannah Friedrich (FI)
University of Arizona
21-EARTH21-0129, Beyond Surface Water Mapping: Satellite-Based Estimates of Coastal Storm and Flood Exposure for the United States Gulf Coast

More than half of the population in the United States lives along the coast where increased development, tropical storms, and flooding have increased the exposure of population and infrastructure to hazards. Repeat floods impact human lives and infrastructure, pressing communities to recover as quickly as possible before the next storm or flood arrives. Accurate estimates of population and infrastructure exposure to flooding are critical to mitigate future damage, inform land-use planning or potential relocation of communities, and identify post-disaster delivery of assistance.

Satellite-based observation provides a unique perspective to monitor extreme events. Yet, current satellite-based methods for measuring flood inundation and rapid damage assessments often fail in capturing the maximum flood extent or spatial detail of urban damage. The under detection results in omitted human lives and infrastructure estimated as exposed and prompts improved methods for detecting floods and their impact. Research is needed to compare post-event urban damage to detected surface water, and understand how observed damage can improve existing exposure assessments. This research hypothesizes that detected urban damage following a major storm and flood event is a more accurate metric of exposure compared to the standalone inundated area.

This proposal leverages advances in the spatial and temporal resolution of remotely sensed satellite imagery and deep learning techniques to tackle the methodological gap of under detection of urban damage and inundation. The first objective is to detect coastal storm urban damage as proxied by the blue roof and building damage by training a deep learning model on labeled structures on 3-meter spatial resolution PlanetScope imagery. The second objective is to generate a 30-meter flood inundation probability using deep learning methods to fuse observations from multiple optical, and active and passive microwave sensors. Lastly, the third objective is to validate both satellite-based estimates of coastal storm damage exposure by regressing georeferenced FEMA Individual Housing Program (IHP) claims at the census block scale against the i) estimated number of buildings damaged (Objective 1), ii) estimated number of buildings inundated (Objective 2), and iii) estimated number of buildings either damaged or inundated. The FEMA IHP data are used to validate the damage and inundation models and elucidate their respective fitness of use for estimating exposure. These research objectives are applied to three Gulf Coast study areas of Hurricane Harvey in Southeast Texas, Hurricane Michael in North Florida, and Hurricane Ida which made landfall on Coastal Louisiana in

August 2021. The frequency of Gulf Coast storm events underpins the urgency of this research to understand the potential of satellite-based observation to document hazard exposure and inform disaster management for future events.

The scientific impact of this proposed research will reveal how well satellite-based information and deep learning models can aid in understanding the impacts of floods on post-event damage and exposure. We expect the results of this research to contribute insights on the advantages and challenges of satellite imagery to detect urban damage and fill gaps in current flood mapping methods. This proposal uses NASA earth observation data, including MODIS, Landsat, AMSR-2, and CSDA Program data (PlanetScope) for a novel approach to detect exposure. This proposal is relevant to NASA's Earth Science and Applied Sciences Program aims to use Earth science and satellite observation to inform decision-making related to hazards and extreme events. Aligned with NASA's commitment to connect scientific impact to equity and environmental justice, this research aims to create methods that generate more inclusive estimates of exposure given the increasing flood impacts that affect the most marginalized populations in the United States.

Mingfang Ting (PI)/Samuel Bartusek (FI)
Columbia University
21-EARTH21-0134, Causal Mechanisms of Dry and Humid Heat Extremes

Heat extremes are among the deadliest climate extremes, with wide-ranging effects on health, agriculture, and ecosystems. They have been robustly observed and projected to worsen due to global warming. However, the regional characteristics of temperature variability and extremes are less understood than global or regional mean temperature, and given their growing societal relevance and environmental justice implications it is crucial to understand them better.

Despite increasing attention, a comprehensive mechanistic understanding of the causal drivers of heat extremes, and how their drivers may change in the future, is lacking. For example, contributions to Northern Hemisphere midlatitude heat extremes from atmospheric circulation patterns and land-atmosphere interaction—and how such processes may be linked to Arctic Amplification—are difficult to untangle, and directions of causality between processes are debated. Additionally, humid heat extremes with dire health impacts are projected to increase severely in the tropics but are understudied, partly due to underreported impacts. Lacking analysis of many of the questions applied to dry heat extremes, their mechanisms and potential distinctions from dry heat extremes are poorly constrained. Finally, despite projections that heat extreme frequency, magnitude, and duration will increase, it is unclear how changes in their causal drivers may contribute to such changes. Climate model fidelity in representing the networks of heat extremes' casual drivers is unknown and can constrain projections. Our objective is to address these critical knowledge gaps by determining the causal mechanisms of dry and humid heat extremes, at a global scale, and how they may change due to warming.

We will pursue three questions: 1) What are the causal relationships and directions between heat extremes and atmospheric, land, and oceanic conditions, both dynamic and thermodynamic? 2) What are the causal drivers of humid heat extremes and how are they distinct from those of dry heat extremes? 3) How might the identified causal drivers change in the future, and how can future heat extreme projections be better understood or constrained?

To determine heat extremes' causal drivers, in addition to standard Earth-science methods we will construct Causal Effect Networks (CEN), a novel analysis tool harnessing graphical models to identify the strength and direction of causal connections among multiple variables. This method has recently been applied in climate science to uncover casual linkages previously inaccessible via correlation-based analysis (which may be confounded by common drivers, indirect linkages, and autocorrelations) or other standard causality tools (such as Granger causality). We have demonstrated proficiency through a proof-of-concept CEN and conducted a case-study analysis of the 2021 Pacific Northwest heatwave. We will construct CENs for dry and humid heat extremes throughout the globe using weather-station temperature and humidity observations (HadISD), NASA high-resolution reanalysis (MERRA-2) and satellite land-surface observations (SMAP, GRACE) supplemented by other reanalysis data (ERA5). We will further test our hypotheses in historical and future runs of the Coupled Model Intercomparison Project Phase 6 (CMIP6), Polar Amplification MIP (PAMIP), and Land Surface, Snow, and Soil Moisture MIP (LS3MIP) models to characterize the effect of complex processes like Arctic Amplification and land-atmosphere interaction on current and future heat extremes.

Our work addresses NASA's Science Mission Directorate Earth Science Division goals to "improve the capability to predict weather and extreme weather events," "improve the ability to predict climate changes by better understanding the roles and interactions of the oceans, atmosphere, land, and ice in the climate system," and "further the use of Earth system science research to inform decisions and provide benefits to society."

Morgan Tingley (PI)/Ben Tonelli (FI)
University of California, Los Angeles
21-EARTH21-0030, Linking Emerging Threats to Wildlife and Human Health to Climate Change Effects on Boreal Forest Ecosystems

Emergent disease outbreaks in human and wildlife populations are a well-established threat of ongoing climate change and habitat degradation (Sutherst 2004; Brooks and Hoberg 2013). As a result, research initiatives to better integrate knowledge from across disciplines are increasingly being employed as a means to protect the health of human and wildlife (Bidaisee and Macpherson 2014; Destoumieux-Garzón et al. 2018; Harrison et al. 2019). At the center of this research are zoonotic diseases, pathogens transmitted between animals and humans, which account for over 60% of all infectious diseases (Taylor et al. 2001). Because zoonotic diseases originate in wildlife populations, the distribution, abundance, and movement of these populations is critical in understanding risks to human populations and society.

One compelling and under-researched avian disease vector is the Pine Siskin (Spinus pinus), a species often central to Salmonellosis outbreaks in the United States and Canada (Hernandez et al. 2012). The Pine Siskin is a boreal songbird found across North America that exhibits dramatic "irruptive" migratory behaviors, during which millions of birds are found at abnormal concentrations beyond their normal range(Dawson 2020). Irruptions are affected by climatic variables (Strong et al. 2015), and occur more often following periods when conditions are poor for their main food source, conifer seeds, and when winter temperatures are more extreme (Strong et al. 2015).

Due to their innate susceptibility to Salmonella and their observed associations with large-scale Salmonellosis outbreaks (Hernandez et al. 2012), Pine Siskins may disproportionately contribute to increased rates of disease transmission among avian communities during irruption years. Dense siskin populations in a given area likely act as a source of Salmonella that then spills over into populations of susceptible species (Hernandez et al. 2012). Presently, the linkage between climatic factors, migratory dynamics and subsequent disease outbreaks is unknown.

Here, I propose a two-tiered approach using NASA-enabled remote sensing data to investigate the nature of a climate-driven source of increased disease risk to wildlife and human populations. Using Bayesian statistical techniques, I plan to 1) create a working model to predict the frequency and strength of irruptions of the Pine Siskin from MODIS-derived climate and fire products, and then 2) use land cover maps to analyze how the strength of irruptions modulates disease risk across habitat types. The emergent risks to human health are increasingly being recognized as the result of the downstream effects of anthropogenic changes to the Earth system. This proposal fits into NASA's goals to understand earth as a system and will broadly address how global ecosystems are changing. This proposal also seeks to uncover how land cover and land use change lead to consequences to human societies and ecosystem sustainability through the incursion of disease-susceptible birds into human-associated habitats. The results of this proposal will lead to a better understanding of human health risks, and thus advance NASA's goals of safeguarding and improving life on earth.

Philip Townsend (PI)/Natalie Queally (FI)
University of Wisconsin, Madison
21-EARTH21-0067, Detecting Disturbance Legacy Effects in Functional Trait Phenology Using Imaging Spectroscopy Data from the SHIFT Campaign

Disturbances drive ecosystem function and variability across space and time. Long-standing patterns of disturbance can influence plants to express certain functional traits—measurable characteristics linked to ecosystem function—that allow them to resist and/or recover from the disturbance. In the context of global change, it is crucial to understand how ecosystems change in response to different levels of disturbance, since disturbance patterns are likely to change with climate change and pressures from human development.

Although functional traits change in space and time in response to disturbance, field-based studies that measure traits are typically restricted to focusing on one factor (large spatial extent/diversity of plant types sampled) or the other (many time points sampled). Remote sensing allows us to study both. Using remotely sensed imaging spectroscopy data (many spectral bands measured at fine wavelength intervals) and short time intervals between image acquisitions over a growing season from the upcoming SHIFT field and imaging campaign in California, I will investigate how plant functional traits vary in space and time in response to two key disturbances in the study area: grazing and wildfire.

The SHIFT campaign will collect imagery from weekly flights over Santa Barbara County, CA over three months in 2022, covering a period of spring vegetation growth. As part of this campaign, I will help conduct fieldwork in two research reserves and a national forest in concert with the SHIFT image flights. The sample plots will represent many vegetation types, topographic positions, and soil types, among other environmental gradients over the full growing season and will be used to map 12 plant functional traits based on foliar samples collected from the plots. Using disturbance data provided by reserve managers and government agencies, I will assign trait map pixels to different classes based on disturbance history (grazing intensity or burn severity) and assess the effects of grazing and wildfire separately using generalized additive mixed models, statistical models that are useful for analyzing curvilinear trends that occur with time series data. I will interpret the model outputs to assess how each trait responds to different levels of disturbance across the growing period, while incorporating the influence of environmental gradients and also testing differences among vegetation types. I expect that the changes in traits across space and time in response to different disturbance levels will represent different adaptive strategies that help plants avoid or tolerate disturbance.

This study is of great relevance to the NASA Earth Science Division's goal of characterizing the ways that ecosystems are changing, and will be the first study of functional trait response to disturbance on this spatial and temporal scale. Specifically, my study will directly address phenological variation in trait expression, including its drivers. It will serve as a framework for future ecosystem function-disturbance analyses with time series data, and is a prototype application for future hyperspectral satellite missions, including NASA's Surface Biology and Geology (SBG).

Robert Trapp (PI)/Melinda Berman (FI)
University of Illinois, Urbana-Champaign
21-EARTH21-0363, Understanding the Impact of the Lower Stratospheric Thermodynamic Environment on Observed Overshooting Top Characteristics

Overshooting tops (OTs) are manifestations of deep convective updrafts that overshoot the tropopause. OTs irreversibly transport aerosols, water vapor, mass, and other tracers into the stratosphere and occur in all latitudes and seasons. OTs have also been linked to ground-based hazards like intense rainfall, tornadoes and hail. Understanding key OT characteristics such as area (OTA), depth above the tropopause (OTD) and duration (OTT) is critical for understanding this global stratospheric transport mechanism as well as the dynamical connection to hazardous weather. Although recent work has demonstrated that OTs are positively correlated to midtropospheric updraft cores, gaps remain in understanding how the thermodynamic conditions in the lowermost stratosphere impact observed overshooting top characteristics, and initial overshooting tops alter tropopause conditions such that overshooting top characteristics in subsequent storms are different from earlier storms. To address these gaps, quantifications of thermodynamic environments using MERRA-2 will be related to key OT attributes determined from Geostationary Operational Environmental Satellite (GOES)-R series satellites. Experiments with idealized modeling simulations will be used to understand the relationships between OT attributes and the thermodynamic environment and how OTs modify the tropopause, impacting subsequent OTs.

Konstantinos Tsigaridis (PI)/Maegan DeLessio (FI)
Columbia University
21-EARTH21-0112, Global Climate Role of Biomass Burning Aerosols and Brown Carbon

As biomass burning events increase in frequency and intensity, the climate role of biomass burning aerosols like brown carbon (BrC) will become more important. However, more work is needed to reduce the uncertainty such species bring to Earth system models. Using the GISS ModelE Earth system model, the proposed project will evaluate ModelE's representation of BrC and biomass burning aerosols. Model output will be compared to in-situ measurements of BrC from the ATom flight campaigns, as well as aerosol optical properties from remote sensing and ground-based datasets, including MODIS, OMI and AERONET. The evaluated aerosol scheme will then be used to predict future radiative forcing, and therefore the climate role, of biomass burning aerosols with both prescribed (from biomass burning inventories) and interactive (from the ModelE pyrE interactive fire module) emissions. This work will increase the predictive capability of ModelE by improving biomass burning aerosol representation. Additionally, predictions of future biomass burning climate effects will better equip scientists and policymakers with knowledge in climate change mitigation efforts.

Alexander Turner (PI)/Nikhil Dadheech (FI)
University of Washington, Seattle
21-EARTH21-0093, Emulating Atmospheric Transport for Dense Observing Systems

Carbon dioxide and methane are the two strongest anthropogenic greenhouse gases (GHGs) and account for more than 85% of the GHG forcing since pre-industrial times. As such, their current and future emissions can have a profound impact on the future state of our climate. Quantifying their emissions is critically important for both projecting future climate and assessing the impact of environmental policy. Previous work has shown that point sources for CO2 and methane account for a disproportionate percent of the total budget. This means that a handful of "super emitters" are responsible for a large percent of the total emissions. However, these point sources only represent a small physical area. As such, studying these point sources necessitates densely spaced measurements. Fortunately, there has been a proliferation of dense observing systems for GHGs over the past decade such as geostationary satellites.

Constructing the source-receptor relationship (also known as the “footprint” of a measurement) that allows researchers to quantify GHG fluxes requires researchers to run computationally expensive atmospheric transport models. For example, researchers will often use Lagrangian Particle Dispersion Models (LPDMs) to construct the footprint. However, constructing (and even storing) these footprints becomes computationally intractable as the number of measurements increases, as is the case for the next generation of space-borne GHG observing systems. Further, there is often a decoupling of the meteorology from the chemical transport modeling. Typically, researchers will run a mesoscale meteorological model that is, in turn, used to drive LPDM. Because of this, latent biases in the meteorology can propagate into the GHG flux estimation. It is presently computationally intractable to incorporate meteorological parameters into the GHG flux estimation. Similarly, researchers are often restricted to assuming Gaussian errors in the inverse problem to reduce computational expense.

Here we identify four major computational challenges in the use of dense observing systems for high-resolution data: (1) high computational cost of computing footprints for dense observing systems, (2) high storage cost of footprints for dense observing systems, (3) accounting for errors in the simulation of meteorology while estimating emissions is infeasible, and (4) assumption of Gaussian errors while inferring emissions.

We propose to develop a deep learning and stochastic based algorithm to efficiently interpret high-resolution atmospheric observations and quantify the emissions of GHG point sources. The neural network will serve as a surrogate model that is trained on outputs from the traditional, physics-based atmospheric transport models. This approach will exploit similarities in large-scale patterns that govern the source-receptor relationship for densely packed observations. This model, once trained, will be able to compute the source-receptor relationship of atmospheric observations (footprints) in near-real-time, meaning that researchers can reduce the storage costs associated with the footprints. Additionally, a computationally efficient representation of the forward model will open the door for stochastic methods of solving the inverse problem and incorporation of non-Gaussian errors as well as trans-dimensional MCMC methods (i.e., reversible jump MCMC) that allow for jointly solving the model selection and GHG flux estimation problems. An example of this would be to jointly constrain meteorological parameters in the GHG flux inversion.

The next generation of GHG observing systems are providing unprecedented spatial coverage yet utilizing them to estimate GHG fluxes is becoming computationally intractable. Our work will advance the tools needed to interpret these dense observations and infer GHG emission fluxes that are critically important for projecting future climate and assessing the impact of environmental policy.

Christopher Uejio (PI)/Elaina Gonsoroski (FI)
Florida State University
21-EARTH21-0287, Assessing the Impact of Hurricanes on Infrastructure and Mental Health with Satellite-Derived Measures of Disaster Exposure

Mental health conditions such as major depressive disorder and posttraumatic stress disorder place a heavy burden on the U.S. healthcare system. These conditions are also the most commonly reported after a disaster such as a hurricane, however, mental health outcomes after these events remain understudied. In response to these research gaps, experts have called for studies to cover a wider geography and more diverse outcomes under dual exposures. One such cumulative exposure includes large power outages which are frequently attributed to hurricanes and disproportionately affect those of lower socioeconomic status. In response to these research needs, this study will answer three research questions: First, to what extent can satellite derived data detect power outages? Second, are there sociodemographic disparities in power outages and restorations? And third, are dual exposures associated with adverse mental health outcomes?

To address these questions, the FI will first use NASA's Black Marble product to map power outages across the United States. Currently, there is not a centralized database of electrical disruptions. The creation of this database will serve to answer how well Black Marble can quantify power outages and how these data can be used to examine disparities in outage restoration and their impact on health. To relate the database from Research Question 1, the FI will examine the relationship between power outages and different indices through spatial regression models. These ancillary datasets include the Centers for Disease Control and Prevention's Social Vulnerability Index and the Environmental Protection Agency's Environmental Justice (EJ) Screen. Lastly, the FI will analyze the association between disaster exposure and mental health outcomes. Exposure to the storm will be determined through remotely sensed data including power outages (Research Question One) along with damage, precipitation, flooding, wind gusts, and storm path quantified by remotely sense data from NASA and other ancillary datasets. Mental health outcomes of interest include major depressive disorder, anxiety, posttraumatic stress disorder, substance use disorders, and suicide coded in state vital statistics and Medicaid records. The FI will use Difference-in-Differences analyses to examine these relationships. Ensuring power grid resilience is critical to ensuring equitable recovery especially in the aftermath of disasters. NASA's satellite derived data products are ideal to examine disparities in power restoration. NASA's remotely sensed data can also play a critical role in understanding disaster exposures and their impact on mental health. This project also meets Goal 1 of the NASA Applied Sciences Program's Strategic Plan 2021-2026 by integrating NASA Earth Science into the health community's value chain. It also meets Goal 2 by providing training to an early career scientist and building capacity in community stakeholders to understand and utilize NASA data. This project will also provide insight into economic, health and quality of life benefits to communities affected by disasters and these insights will aid project stakeholders in making informed decisions to decrease the burden of disasters.

Susan van den Heever (PI)/Gabrielle Leung (FI)
Colorado State University
21-EARTH21-0156, Impacts of Changes to Land Cover and Aerosols on Convection in the Maritime Continent

The atmosphere and land surface are strongly coupled through exchanges of heat, moisture, and momentum. Land cover changes (LCC) such as deforestation or urbanization can thus modify the atmosphere on both local and global scales. However, disagreements exist about the impact of LCC on clouds and subsequently on precipitation and radiative forcing. Furthermore, LCC often occur alongside perturbations to aerosol loadings, which confounds the influence of land surface properties on the atmosphere. Disentangling the combined effects of aerosols and LCC is difficult, and these aerosol-land surface-cloud interactions remain understudied.

This proposal aims to describe how land surface changes and concurrent aerosol perturbations impact tropical convection, particularly in the Maritime Continent (MC). Our approach combines satellite observations, realistic region-scale modeling, and idealized large eddy simulations (LES) to quantify the magnitude of aerosol-land surface impacts on convection and to describe the mechanisms behind those changes. We will address three science questions: (1) How have past land use changes impacted convection in the MC, and how will convection change under future land use scenarios? (2) Which individual or combined land surface properties are the primary drivers of land surface-cloud interactions? (3) How does the aerosol loading modulate land surface impacts on convection?

First, we will use two decades of satellite data from MODIS Aqua and Terra to compare cloudiness over deforested areas to nearby pristine forest at relatively high spatial resolution. We will further quantify trends in cloudiness as a function of aerosol optical depth (AOD) in order to assess the combined impacts of deforestation and aerosol loading on cloudiness in the MC.

Second, we will conduct high-resolution and long-duration simulations using Landsat-derived past, present-day, and future land cover maps. We will simulate the entire Philippine basin using the

Regional Atmospheric Modeling System (RAMS), a cloud-resolving model with bin-emulating microphysics and dynamic two-way surface fluxes. This will allow us to realistically estimate the impact of LCC on convection over a large domain.

Third, we will conduct a suite of idealized LES aimed at describing the mechanisms by which individual land surface properties influence clouds. We will use an advanced statistical framework to systematically perturb land surface properties and aerosol loading, then emulate model response to the full parameter space. We will estimate the impact of each input parameter and interactions on convective properties, thereby allowing us to establish processes behind aerosol-land surface-cloud interactions, which are still highly understudied and difficult to represent in climate models.

Apart from making extensive use of NASA satellite datasets, this proposal supports multiple NASA Earth Science Division focus areas. We will quantify the impact of changes to land surface properties on cloudiness and precipitation, as well as describe the mechanisms by which LCC influences the hydrological cycle (Water and Energy Cycle). In analyzing subsequent changes to the radiative budget and regional circulation, we will quantify a potentially important control on local and regional climate, which will help to separate LCC-induced changes in convection from those driven by other climate forcers (Climate Variability and Change). Finally, we will examine how those land surface impacts on convection, precipitation, and radiative forcing are exacerbated or opposed by increases to aerosol loading (Atmospheric Composition). We anticipate that this integrated observation-modeling approach will offer novel insights into the impact of land surface and aerosols on clouds in the MC, as well as into our fundamental understanding of the combined roles of aerosols, land surface, and convection within the Earth System.

Kimberly Van Meter (PI)/Shuyu Chang (FI)
Pennsylvania State University
21-EARTH21-0095, Dams, Nutrients, and Water Quality: The Application of Remote Sensing and Machine Learning for Detection and Prediction of Algal Blooms in Chesapeake Bay Watershed Reservoirs

The frequency of algal blooms is increasing in inland waters due to increased nutrient loads from heavy fertilizer use, intensive livestock production, and increasing human population. Elevated nutrient inputs to water reservoirs, especially inputs of phosphorus (P) and nitrogen (N), commonly leads to excessive growth of algae. In some cases, these eutrophic conditions lead to the development of harmful algal blooms (HABs), which we define here as algal blooms that contain species of harmful, toxic algae that can harm fish, benthic animals, and bottom vegetation as well as humans and their pets. The development of algal blooms in the many thousands of human-constructed water reservoirs is of particular concern not only from the perspective of aquatic habitat but also due to the frequent use of these reservoirs as both drinking water sources and recreational spaces. Under a warming climate, it is likely that reservoir Chla concentrations and the incidence of HABs will increase, especially in the Northeastern U.S.

The Non-Tidal Chesapeake Bay Watershed (NTCBW), is home to 1475 dams and reservoirs, from small mill dams to the large Conowingo Dam and on the lower Susquehanna River. Most large-scale nutrient modelling efforts and remote sensing approaches have been used to monitor water quality in the bay itself, but there is less understanding of the spatial and temporal extent of algal blooms in reservoirs across the NTCBW. With warmer temperatures, an intensified water cycle, and an increased frequency of extreme weather events, there is an incomplete understanding of how these changes, together with changes in reservoir nutrient cycling, will affect the timing and frequency of HABs in water bodies that are heavily relied upon as recreational spaces and sources of drinking water.
The overarching goal of the proposed work is to better our understanding of the historical occurrence of algal blooms in Chesapeake Bay Watershed reservoirs, and to predict future changes in the timing, frequency, and magnitude of large algal blooms and potential HAB events under changing climate and

management. The specific objectives of the proposed work are as follows: (1) Quantification of the spatially and temporally varying extent and magnitude of algal blooms, as measured via remote-sensing of chlorophyll-a (Chla) concentrations, in 1475 Chesapeake Bay Watershed reservoirs, and identification of historical hotspots for algal blooms (1999-present); (2) Linkage of a range of watershed and climate predictors to the occurrence of historical algal blooms. These quantitative linkages will then be used to predict the occurrence of algal blooms and potential HAB events in Chesapeake Bay Watershed reservoirs under a range of future climate scenarios as well as under simulations of future water quality. Better understanding of the role of dams in controlling both current and future water quality will help the Chesapeake Bay communities adaptively manage the landscape, to protect and restore the habitat and ecosystem.

Adam Wymore (PI)/Desneiges Murray (FI)
University of New Hampshire, Durham
21-EARTH21-0104, The Response of Atmospheric Nitrogen Deposition to Global Change: Effects on Terrestrial and Aquatic Ecosystems

Total dissolved nitrogen (TDN) in wet deposition is declining, accompanied by shifts in the ratio of oxidized to reduced forms of N. The cascading effects of these global trends on watershed N biogeochemistry remains unclear, as does the spatial and temporal variability in atmospheric TDN ratios (e.g., stoichiometry). Significant knowledge gaps also remain for long-term trends in dissolved organic N (DON) deposition, its physical origins, and geographical sources. The objective of my proposal is to quantify and characterize the response of atmospheric inorganic and organic N deposition to global change, and its effects on terrestrial and aquatic ecosystems. By leveraging NASA remote sensing data, this research will advance understanding of biogeochemical feedbacks within the Earth System and improve forecasting of N deposition across the U.S. I will address my objective through three goals:

1. Synchronize land class and terrestrial N status, with meteorology, wet deposition chemistry, and stream chemistry timeseries:
N cycling between the atmosphere and hydrosphere is largely regulated by N processing in terrestrial environments. Terrestrial ecosystem N status (e.g., %canopy N, soil C:N) is strongly correlated with near infrared (NIR) reflectance, which is collected by NASA's MODIS satellite. I will construct a data pipeline to harmonize NIR timeseries with N flux data from other proprietary organizations (e.g., NOAA, NADP, USGS) spanning the atmosphere-biosphere-hydrosphere. Developing and disseminating this data pipeline is directly relevant to NASA's Earth Science Climate Variability and Change Focus Area because it will lead to further understanding of feedbacks across the Earth System and provide a means for forecasting how the N cycle may respond to shifting and ever-present global change.

2. Address three questions regarding system-level variables driving trends in N deposition and the degree of atmospheric-watershed N coupling:
a) Is atmospheric deposition N load and stoichiometry changing at inter-annual or seasonal time scales, and are patterns consistent across the U.S.?
b) How do climate anomalies (e.g., warmer winters, drought) influence the composition of depositional N?
c) To what degree are atmospheric, terrestrial, and river N cycling coupled?
I will use the data pipeline product described in (1) to address these questions. I will apply novel statistical methods such as mixed-effects modeling, information theoretic, and counterfactual multiple linear regression. Results will provide insight on the trajectory of deposition N across the U.S. and how system-level processes (e.g., climate change and terrestrial productivity) influence N cycling. This will support NASA's 2020-2024 Vision for Science Excellence by addressing the interplay among the atmospheric, ocean, land, and ice systems.

3. Quantify long-term trends in DON wet deposition and model how global change influences DON chemical properties and source:
DON is not monitored in many deposition programs leading to knowledge gaps in its trends and response to global change. Anomalies in atmospheric DON may be explained by climate-change induced disturbance processes operating at multiple scales. My third research goal leverages a unique wet deposition DON record in the Lamprey River watershed of New Hampshire. I will report on DON trends over the past two-decades and test two mechanisms that may explain changes in DON wet deposition: (a) the lengthening of the growing season in the Lamprey River watershed and (b) increased frequency of wildfire smoke transport to the northeastern U.S. I will combine DON chemical composition data, NASA fire emission and NIR reflectance data, and meteorological models from NOAA with a novel application of aircraft hyperspectral imagery data. My project will connect hyperspectral imagery to ecosystem processes which is a priority for NASA's future Surface Biology and Geology Designated Observable satellite.

Shang-Ping Xie (PI)/Matthew Luongo (FI)
University of California, San Diego
21-EARTH21-0022, Low Clouds as a Driver of Climate Variability: Synthesizing Climate Models and Satellite Observations

It is well-known that El Nino-Southern Oscillation (ENSO) in the tropical Pacific affects global and extratropical climate via atmospheric teleconnections. However, extratropical atmospheric variability can also affect ENSO via coupled ocean-atmosphere processes. Two such processes are the Wind-Evaporation-SST (WES) and the low cloud-SST positive feedbacks. In the Northern Hemisphere WES feedback, wind forcing affects local sea surface temperature (SST) anomalies via evaporative cooling. In the Northeast Pacific's marine stratocumulus deck, low clouds reflect incoming solar radiation and cool SSTs below. Both processes locally affect subtropical SST variability; this variability may then be propagated by WES southwestward in a pattern referred to as the Pacific Meridional Mode (PMM). By affecting the tropics, these processes may affect ENSO evolution and the global climate. However, the coupled nature of these ocean-atmosphere feedback processes makes parsing out their influence on the climate system a complicated chicken-and-egg problem.

The primary goal of this work is to explore the relationship between the subtropical low cloud feedback and the Pacific Meridional Mode. While the PMM is known to be a dynamic conduit by which extratropical variability can influence the tropics, the role of the low cloud feedback in initiating and amplifying the PMM, and thus remotely impacting the equatorial Pacific, has largely been ignored. This work investigates the hypothesis that the subtropical low cloud feedback has played an important and overlooked role in shaping Pacific variability by locally amplifying SST anomalies and triggering coupled ocean-atmosphere interactions with both tropical and global impacts.

I will leverage NASA and partners' rich, global network of space-borne and terrestrial-based observations of cloud radiative effects, surface winds, and SST to perform a suite of global climate model (GCM) observational overriding simulations that seek to address the following two primary research questions:

1. To what extent has observed low cloud cover controlled the strength and timing of observed PMM events?
2. How have observed surface winds communicated changes in subtropical cloud cover to the equatorial Pacific and ENSO?

These objectives fall clearly under NASA's Science Mission Directorate Earth Science Division's key goal of "improv[ing] the ability to predict climate changes by better understanding the roles and interactions of the oceans, atmosphere, land, and ice in the climate system." More specifically, this proposal is directly relevant to the Climate Variability and Change Focus Area within the Earth Science

Division and is pertinent to the following three overarching questions: "What is the role of atmospheric composition and clouds in the climate system?", "How can predictions of climate variability and change be improved?", and "How does the global ocean circulation vary on a variety of temporal and spatial scales in response to climate variations?"

Xi Yang (PI)/Rong Li (FI)
University of Virginia, Charlottesville
21-EARTH21-0331, Diurnal and Day-to-Day Variations of Vegetation Photosynthesis from Novel Remote Sensing Measurements

Terrestrial photosynthesis is the largest CO2 flux in the global carbon cycle and affects the fluxes of water and energy between the land surface and the atmosphere. However, the estimation of gross primary productivity (GPP), particularly its temporal variation and response to environment, remains highly uncertain at the global scale. Solar-induced chlorophyll fluorescence (SIF) is radiation emitted by chlorophyll as a byproduct of photosynthesis and has recently been shown to correlate better with GPP than the traditional remote sensing products. Satellite observations have recently become available for analyzing both the diurnal (OCO-3) and day-to-day variations (TROPOMI) of SIF.
However, SIF is jointly controlled by illumination, physiology, canopy structure, and sun-sensor geometry, and its interpretation is still an active area of research. To fully exploit the available SIF observations from different platforms, I will investigate how the combination of remotely sensed SIF and canopy reflectance can be used to understand the temporal variations of vegetation photosynthesis, particularly how photosynthesis responds to environmental stresses such as high temperature and water stress using both site-level and satellite-level remote sensing products. Below are the specific aims of this project:
1. Quantify the controls of the diurnal and day-to-day variations of SIF: I propose to decompose SIF signal by combining SIF and vegetation reflectance measurements. SIF signal will be decomposed into three components: 1) illumination, 2) physiology, and 3) structure and geometry. I will apply this approach for SIF measurements at a mixed forest and at the global scale from OCO-3 and TROPOMI. The diurnal and day-to-day variations of each component and their contribution to SIF variations will be investigated. I will test the hypothesis: The illumination component explains most of the diurnal variation of SIF, while the physiological component explains more day-to-day variation of SIF for clear days at short time scales. And I will analyze if results from satellite observation conform with that from site-level observations, and if the patterns are the same for different plant functional types (PFTs).
2. Investigate the response of the fluorescence yield (physiological component of SIF) to environmental factor: I will obtain fluorescence yield indices based on site-level, OCO-3, and TROPOMI observations and environmental variables of illumination, temperature, and water stress from tower meteorological data, thermal camera, satellite products, and reanalysis data. I will analyze the relationship between the proxy of fluorescence yield and the environmental variables and test if the relationships are the same for different PFTs and from different observations. I will test if the fluorescence yield index based on SIF and vegetation reflectance can indicate plants' heat and drought stress conditions under diurnal and seasonal scales.

The proposed work directly links to the goal Carbon Cycle and Ecosystems of the Earth Science division of SMD: Detect and predict changes in Earth's ecological and chemical cycles, including land cover, biodiversity, and the global carbon cycle. My work will facilitate the interpretation of remotely sensed SIF at multiple temporal scales, corresponding to observations from platforms, thereby contributing to improving the quantification of terrestrial photosynthesis and understanding of plants' response to environment. The project will use NASA's satellite products from OCO-3, ECOSTRESS, SMAP, MODIS and GOES, and MERRA-2 reanalysis data. TROPOMI and VIIRS products will also be used. The study also brings insight into NASA's planned missions of GEOCARB and TEMPO, which has the potential to provide continuous diurnal variations of SIF from geostationary platforms.

F.5 Future Investigators in NASA Earth and Space Science and Technology
SOLICITATION: NNH21ZDA001N-FINESST

The Science Mission Directorate (SMD) reviewed a total of 927 proposals that were submitted to the **F.5 Future Investigators in NASA Earth and Space Science and Technology (FINESST)** competition within the NASA Research Announcement entitled "*Research Opportunities in Space and Earth Sciences" (ROSES-2021)*. Six SMD divisions at NASA Headquarters conducted/provided oversight for the review and selection process: Astrophysics, Biological and Physical Sciences, Earth Science, Heliophysics, Planetary Science, and Science Engagement and Partnerships (SE&P).

FINESST accepts proposals for graduate student-designed research projects that contribute to SMD's science, technology, and exploration goals. The maximum, three-year total FINESST award amount is $150,000. FINESST grants are limited cost awards. For example, SMD suggests a student stipend of $40,000 per 12 months. Not all projects, however, require the maximum amount available in the period of performance.

FINESST is similar to what 2 CFR200.1 Definitions calls a "Fixed Amount Award". "Fixed amount awards means a type of grant or cooperative agreement under which the Federal awarding agency or pass-through entity provides a specific level of support without regard to actual costs incurred under the Federal award. This type of Federal award reduces some of the administrative burden and record-keeping requirements for both the non-Federal entity and Federal awarding agency or pass-through entity. Accountability is based primarily on performance and results."

SMD's estimated timeframe to communicate the selection or intent-to-award decisions is late May through late July. Selection documents are released first, followed by non-selections. Non-selections may not be available until August 15, 2022, or later. The NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) will announce decisions via a system generated email to the PI and AOR. *NSPIRES makes detailed documentation of the selection and non-selection decisions available for each reviewed proposal to both the Principal Investigator (PI) and Authorized Organization Representative (AOR).* Access to proposal-specific documentation requires logging in to NSPIRES and navigating to the submitted proposal, and not just visiting the web page. FIs, however, cannot receive or access FINESST decisions or review results directly via NSPIRES. If by August 15, the PI or AOR have not contacted the FI, then the FI should ask them to log in to NSPIRES to see if the proposal status has changed and download and share the results.

For assistance with NSPIRES log in, please contact the NSPIRES Help Desk at (202) 479-9376 Monday – Friday, excluding Federal Holidays, (e.g., Juneteenth National Independence observed for 2022 on June 20, July 4, i.e., Independence Day, etc.) 8 AM to 6 PM Eastern Time or by email at nspires-help@nasaprs.com.

Table 1: FINESST-21 Proposal Data

Division	Proposals Reviewed	Proposals Selected (Estimated)	NSPIRES Publication Date
Science Engagement & Partnerships	2	1	May 26, 2022
Biological and Physical Sciences	25	2	July 21, 2022
Earth Science	394	62	June 30, 2022
Planetary Science*	224	32	July 5, 2022
Astrophysics	222	29	July 25, 2022
Heliophysics	60	14	September 26, 2022
Total**	927	140	~~July 25, 2022 (Target)~~

NOTE For Selected PI-FI Teams: Once SMD receives selection acceptance, the FINESST proposal will be transferred to the NASA Shared Services Center (NSSC). NSPIRES cannot track the NSSC grant processing activities. A grant's status may be tracked via a web search on the PI's name (do not use the FI name or NSPIRES proposal number) at: https://www.nasa.gov/centers/nssc/forms/grant-status-form, telephoning the NSSC at 1-877-NSSC123, or e-mailing nssc-contactcenter@nasa.gov.

Any pre-award costs incurred are at the proposer's risk. All new awards receive an automatic 90 days of pre-award spending approval on award, meaning that NASA has waived the requirement for FINESST award recipients to obtain written approval prior to incurring project costs up to 90 calendar days before NASA issues an award. However, expenses incurred more than 90 calendar days before the award require prior written (i.e., email) approval from a Grants Office at the NSSC.

NOTE for Non-Selected PI-FI Teams: SMD received a far greater number of proposals than available funds can support. NASA plans to publish the next FINESST solicitation as a cross-divisional appendix to the NASA Research Announcement entitled "Research Opportunities in Space and Earth Science (ROSES-2022)."

A non-selected 2021 FINESST proposal may be eligible to be revised and resubmitted to the 2022 competition. Entirely new, eligible proposals also are welcome. When the new FINESST solicitation (F.5) is published in final form it will be available at https://go.nasa.gov/FINESST22. Proposal intake will continue for an approximate minimum of 60 days from the release barring any unforeseen circumstances. In the interim, SMD's Cross Division FINESST team welcome general comments, questions, and FINESST-improvement suggestions via email at: HQ-FINESST@mail.nasa.gov.

*Technical Note: *The Planetary Science Division (PSD) will make all notifications (selections and declines) available on NSPIRES at the same time in order to be consistent with other PSD program practices.*

***This total may be different than what a selection letter may indicate due to administrative adjustments.*

Heliophysics Division Selection, (14, Alphabetical by PI Last Name)

Benjamin Brown (PI)/Whitney Powers (FI)
University of Colorado, Boulder
21-HELIO21-0034: Fundamental Studies of Rotating Convection at The Solar Poles: Can we See Giant Cells Under the Photospheric Convective Flows?

The basic structure of the Sun consists of a convective envelope above a stably stratified core. We can probe convective motions deep in the sun with helioseismic observations. Simulations predict that the solar convective envelope should be dominated by large scale, low spherical harmonic degree motions called giant cells. Ring diagram helioseismology results are broadly consistent with these predictions but time-distance helioseismology disagrees strongly, placing an upper bound on convective velocities approximately two orders of magnitude lower than the velocities predicted by simulations and measured by ring diagram helioseismology. This discrepancy, and the general difficulty in conclusively observing the giant cells of convection, has been called the Solar Convective Conundrum and indicates our incomplete understanding of the fundamental properties of convection in the Sun.

One possible resolution to the convective conundrum is the effect of rotation on stratified convection. Here we will study a suite of convective simulations conducted with the dedalus framework, to understand how rotation modifies the flow. Dedalus has been extensively benchmarked on NASA Pleiades and shows excellent scaling and performance for these problems. In our simulations, we will test new predictions for rotational scalings, and determine: could the giant cells exist on scales that are smaller than the surface flows of supergranulation. We will extend cartesian simulations to spherical domains, and we will study whether the realized convective structures can be observed through the surface flows of supergranulation and other photospheric motions. The combination of local modelling in cartesian boxes and global modelling in spherical shells will address both the turbulent rotationally-constrained structures, and their interactions with the global flow of differential rotation. We will seek to answer: can giant cells of convection be observed at the solar poles by future NASA missions.

Xinzhao Chu (PI)/Jackson Jandreau (FI)
University of Colorado, Boulder
21-HELIO21-0046: Exploring Antarctic Gravity Waves and Their Effects on Global Energy Transport Using a Decade of Lidar Observations

A decade-long lidar campaign in Antarctica at the edge of the polar cap and auroral oval, has made numerous surprising discoveries about the gravity waves (GWs) in the middle and upper atmosphere. GWs are a critical part of the transportation of energy and momentum throughout the atmosphere. Antarctic measurements of these waves are key to unraveling the polar atmosphere's role in global energy distribution as the polar regions of this system are host to many unique energy inputs mechanisms. GWs transfer energy from lower to higher altitudes, and also from lower to higher latitudes, coupling aspects of these regions together. Assembling a big picture of Earth's energy processes requires improvements in our understanding of the role of GW energy transportation in this picture.

This research will use 10+ years of those lidar observations above McMurdo Station, Antarctica to produce measurements of atmospheric parameters and use them to explore the effects of atmospheric GWs on energy transportation processes. The parameters to be calculated are GW potential energy density, heat flux, momentum flux, and wave drag. These parameters will be generated as profiles ranging from the stratosphere to the lower thermosphere as well as throughout various times of the year. This data will additionally be used to support research of GW parametrization schemes in general circulation models. Furthermore, with the assistance of reanalysis data and general circulation models, the study will look into mechanisms linking the behavior of Antarctic GWs to equatorial and low-latitude phenomena like the Quasi-Biennial Oscillation (QBO) and the El Niño Southern Oscillation (ENSO). This study will attempt to explain previously observed asymmetries in northern and southern QBO teleconnection behavior.

Atmospheric GWs over McMurdo will be characterized using carefully and thoroughly screened lidar data. The parameters will be calculated by utilizing recently developed techniques which can derive parameters more accurately and over a wider altitude- and seasonal-range than was previously possible. By using these methods and by developing new processes utilizing data from multiple ground and space-based sources, all of the aforementioned atmospheric parameters can be calculated. To investigate the equatorial-polar coupling, the study will use reanalysis models and general circulation models to expand correlations between phenomena in the two regions and identify the physical mechanisms by which they are linked.

These measurements can significantly advance understandings of polar GW behavior, leading to a more complete picture of polar energy transport. Characterization of Antarctic GW processes from such a unique dataset will allow researchers to better study the interaction of these waves with local atmospheric conditions, which can be used as a case-study for theory-based GW research. The wave drag measurements are of great use to modelers and will be valuable for researchers working to resolve long-standing polar modeling issues which are likely caused by inadequate GW parametrizations. Identifying coupling mechanisms between the pole and the equator will shed light on the various processes which affect polar energy transport processes, broadening the scope of their influence and further exploring links between Antarctica and the rest of the global atmosphere.

James Clemmons (PI)/Lance Davis (FI)
University of New Hampshire, Durham
21-HELIO21-0050: Development of a New Measurement Capability for Understanding Turbulence in the Upper Atmosphere: Tailoring the Winds Cross-Track Instrument

In Earth's upper atmosphere, in the mesosphere / lower thermosphere region (~80-125 km), the vertical transfer of energy and momentum from lower altitudes to higher altitudes is controlled by turbulence. Turbulence is generated when an atmospheric instability transitions from the larger-scale instability onset through finer-scale, secondary instabilities and structures, to eventually turbulence. Current methods and techniques exist to measure the larger scale instabilities. However, these current tools lack the wind, temperature, and spatial resolutions to observe fine-scale structures and variations characteristic of the transition period from instability onset to turbulence.

We propose to upgrade the Winds Cross-Track (WCT), an instrument flown on a sounding rocket, to have the high measurement resolutions required to observe this transition period in situ. In short, the WCT measures neutral winds and temperatures by modulating incoming gas with a rotating baffle. The WCT will be tailored specifically to resolve the wind and temperature profiles of the secondary instabilities generated by the Kelvin Helmholtz Instability (KHI), one of the most common instabilities in the mesosphere / lower thermosphere region. More specifically, we will 1) increase the mean molecular mass measurement resolution, and thus also the temperature resolution, of the instrument, which is currently not optimized for this measurement, 2) utilize two different baffle widths to optimize both the thermal velocity and wind velocity resolutions, and 3) increase the sampling frequency, and thereby the spatial resolution, by increasing the baffle rotation rate of the instrument

With this newly upgraded and tailored instrument, we will be able to answer the following science questions:

1. How does the Richardson number (a measure of stability) profile vary within the primary KHI instability? How do these variations impact the structure and frequency of secondary instabilities?
2. How are wind and temperature profiles structured throughout a KHI billow? How do these profiles correlate with the location and size of secondary instabilities?

The development of the instrument proposed here supports NASA's Heliophysics Strategic Science Objective to understand the Sun and its interactions with Earth and the solar system, including space weather" and more specifically the first Heliophysics science goal listed in the 2014 NASA Science Plan: Explore the physical processes in the space environment from the Sun to the Earth and throughout the solar system." Further, the proposed project aligns with NASA's Science 2020-2024 Priority 2: Innovation by opening the possibility for new understanding of atmospheric instabilities and turbulence via a tool upgraded and tailored to measure in situ, for the first time, this science at fine-scales.

Stephen Fuselier (PI)/Dinesh Kumar Veypatty Radhakrishnan (FI)
University of Texas, San Antonio
21-HELIO21-0045: Journeying through the Magnetopause: Statistical Study of the Kelvin Helmholtz Instabilities as Observed by MMS Mission

The overarching goal of this proposal is to understand what influences the development of Kelvin Helmholtz Instability (KHI) and the role KHI plays in facilitating the entry of solar wind into the magnetosphere. This goal is achieved by answering three science questions:
What is the role of KHI in mixing magnetosheath and magnetospheric ions?
What is the dominant ion heating mechanism within KHI?
What is the effect of heavy ions on the development of KHI?

These science questions are answered by performing a statistical analyses of KHI development. We will analyze at least 200 KHI events identified using data from the Magnetospheric Multiscale (MMS) mission. We use a variety of instruments and techniques to determine whether a KHI event is in its linear or non-linear state. These data are used to determine the composition within the KHI event, identify the origin of the ions within the event, and determine the velocity space distributions within the event. These observations determine the extent of the mixing, the dominant ion heating mechanism, and the influence of heavy ions on the growth of KHI.

At the end of the three-year study, we will have developed a deeper understanding of the role of KHI in facilitating the entry of solar wind into the Earth's magnetosphere. Though the proposed work is in the context of Earth's magnetosphere, the results will provide insight into the efficiency of KHI in facilitating the entry of solar wind in other planetary magnetospheres. This research is directly related to the science goals of the Magnetospheric Multiscale Mission.

Raluca Ilie (PI)/Hsinju Chen (FI)
University of Illinois, Urbana-Champaign
21-HELIO21-0054: Past the Point of No Return: The Journey of Heavy Ions throughout the Earth's Magnetosphere

OBJECTIVES
Numerous observations from satellites orbiting in the Earth's ionosphere and magnetosphere reported on the presence of heavy ions outflowing from the Earth's polar region and populating the near-Earth space. Over the past few decades, a large body of work has focused on the impact of O+ ions on the ionosphere magnetosphere dynamics. Observations from several space missions have also reported on the fact that N+ ions are a constant companion to the outflowing O+, especially during geomagnetically active times. However, due to their similar masses, only few space missions carried mass spectrometers with enough resolution to tell them apart.

The presence of N+ ions is significant in the Earth's magnetosphere, and the density ratio between N+ and O+ varies with season and solar driving conditions. In addition to them being only 12.6 % apart in mass, their ionization energies, charge exchange processes, and abundances across the Earth's different ionosphere regions are also different. It is not yet known how heavy ion species are being convected throughout the magnetosphere, and what their differential pathways of escaping to space are. This work seeks to fill this knowledge gap by tracking all relevant heavy ions species as they are lost to space, and analyze the effect of the ionospheric composition, solar wind conditions, and magnetic field strength on the overall magnetospheric dynamics and loss rate from the system. Specifically, it aims to address the following scientific questions:

1. What are the mechanisms that control the differential transport of N+ and O+ throughout the Earth's magnetosphere?
2. How does the loss of heavy ion species change in response to the solar, geomagnetic, and interplanetary variability?

METHOD/TECHNIQUES
This project employs the first multi-fluid MHD model containing N+ ions. Our preliminary studies have shown that despite their small mass difference, N+ and O+ pathways diverge within hours of a solar storm, suggesting that they can occupy different regions in space, and therefore be exposed to different means of acceleration. Utilizing the BATS-R-US MHD model, allows us to analyze the impact of variations in solar conditions, ionospheric ion composition, and geomagnetic field strengths on the transport of heavy ions throughout the global magnetosphere.

PERCEIVED SIGNIFICANCE
This research problem is aligned with one of the key science goals guided by the most recent Decadal Survey: Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs."

It is also highly relevant to two of the objectives in Our Dynamic Space Environment: Heliophysics Science and Technology Roadmap for 2014 2033, Understand the role of the Sun and its variability in driving change in the Earth's atmosphere, the space environment, and planetary objects" and Understand the coupling of the Earth's magnetosphere ionosphere atmosphere system, and its response to external and internal forcing" as well as to some extent Understand, characterize, and model the space weather effects on and within terrestrial and planetary environments." In NASA 2018 Strategic Plan, our research goals help to Advance our understanding of the connections that link the Sun, the Earth, planetary space environments, and the outer reaches of our solar system" and Explore the physical processes in the space environment from the Sun to the Earth and throughout the solar system" in the heliophysics division. Furthermore, it provides an understanding to the objectives in the planetary division, in addition to the heliophysics one, specifically Advance the understanding of how the chemical and physical processes in our solar system operate, interact and evolve" and Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere."

Davin Larson (PI)/Orlando Romeo (FI)
University of California, Berkeley
21-HELIO21-0044: Determination of Processes that Control Electron Distribution Evolution Near the Sun as Observed by PSP

In this proposal, we aim to investigate the mechanisms that control solar wind acceleration and energy balance in the near-Sun environment through Parker Solar Probe (PSP) in-situ observations and kinetic modeling. These processes are theorized to be strongly influenced by the solar wind heat flux and ambipolar electric field, both of which are dependent on electron velocity distribution functions (VDFs). While the electron core and halo components of the distribution are nearly isotropic, the strahl is represented by a beam population that is more anisotropic and typically magnetic field aligned. Due to this asymmetry and non-thermal nature, the electron strahl dominates the overall heat flux in the near-Sun environment. The population's beam-like shape can be modified from adiabatic focusing by the magnetic field or electron pitch-angle scattering due to Coulomb collisions and/or plasma instabilities. As PSP is the closest spacecraft to ever orbit the Sun, we can study the evolution of the electron strahl over a large range of heliocentric distances under varying solar wind conditions. The onboard Solar Probe ANalyzer Electron (SPAN-E) instruments have measured electron energy distributions at heliocentric distances between 16 and 80 solar radii in the inner heliosphere. We perform fits on these distributions using SPAN-E and FIELDS data to obtain the strahl direction and angular width for energies between 100 and 1200 eV. It is important to note that the strahl direction is determined independently of the magnetic field, which can allow an alternative method for inter calibration with the magnetic field instrument. To characterize the causes of strahl scattering, we also obtain measurements of the electron density, electron temperature, and solar wind velocity from these fits to compare with the strahl angular widths. This analysis is done through multivariate techniques to determine the most significant solar wind parameters that predict strahl scattering. We can then develop a solar wind kinetic model based on these parameters, expanding upon previous model efforts to include Coulomb collisions and guiding center drift effects. By studying the evolution of the electron strahl, this work addresses NASA's SMD Heliophysics research goal to advance our understanding of the Sun and its interactions within the heliosphere. Furthermore, investigating these solar wind dynamics would not only expand our knowledge of fundamental physics for the Sun, but would also be applicable to other stars and astrophysical contexts throughout the universe.

Susan Lepri (PI)/Tyler Eddy (FI)
University of Michigan, Ann Arbor
21-HELIO21-0006: Designing a Next Generation, Low-resource, Heavy Ion Composition Spectrometer

The research we propose is to develop a spaceborne science instrument used for advanced study of the charged particles emitted by the sun. One factor driving the next generation of instruments is the need for smaller, reliable models ideal for streamlining production and increasing the number of active science missions in space. The importance of this work is to establish connections between the energy and type of particles seen in space to the source regions on the surface of the sun believed to accelerate them. The conditions in space created by these particles change rapidly for often unknown reasons and present considerable danger to astronauts and Earth's infrastructure. To study the causes of these conditions we offer to perform a two-part survey of (1) the literature written on previous scientific instruments along with the data sets they produced and (2) the current outstanding science questions left unresolved by the standards met by active missions. These will be used to set the performance characteristics that must be met by next generation spaceborne particle instruments. After this, we will use simulations and analytical tools to modify and refine a heritage model successfully employed on the MESSENGER mission to Mercury to create a new design for modern applications throughout the solar system. In addition, by using available materials and resources from the Space Physics Research Laboratory at the University of Michigan we will design and construct the portions of the instrument that differ from the previous instrument used on MESSENGER. By using the calibration equipment available at the lab in conjunction with analytical and numerical models we will characterize the new design and determine its performance characteristics. Last, we will evaluate our new design using the scientific requirements that were set by the current outstanding questions and previous science missions. All results will be published for the space physics community in order to promote the standardization of instrument design, characterization, and production. This research ultimately serves to advance technology conducive for expanding the Heliospheric System Observatory through a fleet of new science probes. Making connections between detections made by multiple spacecraft dispersed around the sun is critical to NASA's objectives to understand the processes that accelerate particles, the creation and variability of the solar magnetic dynamo, and the origin and evolution of the charged particles emitted by the sun. Altogether, this study seeks to push the boundaries of our current understanding in science and instrumentation.

Robert Marshall (PI)/Erin McMurchie (FI)
University of Colorado, Boulder
21-HELIO21-0047: Investigation of Radiation Belt Loss Processes in Jupiter's Magnetosphere

One of the pivotal dynamic processes in the heliosphere is how energetic charged particles interact with bodies in the solar system and their electromagnetic environments. This project will conduct a comparison study of energetic charged particle loss mechanisms in Earth and Jupiter's radiation belt populations, utilizing in-situ data from NASA's Juno mission. In addition to precipitation driven by wave-particle interactions, the moons embedded within Jupiter's magnetosphere drive local and far-field interactions, producing Alfve n wings, auroral moon footprints, and driving particle acceleration within the radiation belts. Energetic particle dynamics driven by these interactions will be investigated by quantifying energetic particle precipitation (EPP) into the Jovian atmosphere, and comparing the total precipitation flux to a similar estimate derived for Earth's atmosphere. The EPP flux and energy spectrum observed by Juno's JEDI and JADE particle detectors will be quantitatively compared with the UV intensity observed by Juno's Ultraviolet Spectrometer (UVS), in order to quantify the importance of EPP as a key loss mechanism for Jupiter's radiation belts. In addition, we will use observations electromagnetic waves detected by the Waves instrument to study the wave sources responsible for precipitation. Juno's magnetometer (MAG) will be utilized to determine Jupiter's loss cone size and to track energetic particle pitch angle distributions in Jupiter's magnetic field. The results of this project will advance our understanding of radiation belt dynamics throughout the heliosphere, impacting our exploration of the solar system and our understanding of dynamic events in the near-Earth and near-Jupiter space environments.

Merav Opher (PI)/Chika Onubogu (FI)
Boston University
21-HELIO21-0048: Effects of Full Solar Cycle on Heliosphere Structure

The heliosphere is a complex system that leaves us with many open questions (Opher 2016). Understanding the evolution of our own heliosphere will help us understand the conditions that dictate habitable astrospheres and exoplanetary systems. Particularly, we want to know what the shape of the heliosphere is and what the driving mechanisms are that give it its shape. Our group works to predict a global model of the heliosphere using the SHIELD model that it is a self-consistent, kinetic-MHD model (Michael et al. 2022).

Recent works by Opher et al. (2015) and Drake et al. (2015) showed that 3D MHD models of the heliosphere, with inclusion of the solar magnetic field, show that magnetic tension forces that have the ability to collimate the solar wind plasma into jets. Other models showed evidence of collimation in the heliotail (Izmodenov & Alexashov 2015; Pogorelov et al. 2015). However as shown by Kornbleuth et al. (2021) the BU model show that the ISM flows between the two lobes, the so called croissant model of the heliosphere: a shortened, two-tail structured heliosphere. Among the diversely shaped heliosphere models, we are still searching for what an accurate global model of the heliosphere looks like as current models have yet to fully explain key observations from the Voyager spacecraft and IBEX. Previous works from the BU model explored the Croissant model under steady state solar wind. The Sun goes through an 11-year solar cycle in which the solar wind speed, number density, magnetic field intensity, and temperature vary. This proposal will explore the implication of the solar cycle on the croissant heliosphere model. The plans detailed in this proposal will act to address the discrepancies of our models to observations by implementing realistic solar wind conditions that more accurately represent the heliosphere environment.

This proposal will discuss how I will progress the SHIELD model by implementation of time-dependent solar wind parameters. Until this point, time-dependent simulations in our group have only been carried out using a multi-fluid approach (Zank 1999; Opher et al. 2009) where neutral hydrogen is treated as four different fluids (Provornikova et al. 2014 ; Michael et al. 2015). The more accurate representation of neutrals in the heliosphere is with a kinetic treatment, where each atom is tracked individually; this is what SHIELD does. We will obtain a more holistic model which is driven by realistic solar wind conditions and kinetic treatment of neutrals. Contained within these time-varying solar wind conditions, I will also be adding photoionization into our model as a component that contributes to the total ionization losses in the heliosphere. In order to validate the results of this updated model, I will compare the results of this model to that of ENA maps from IBEX from 2009 to 2019 that show time-dependence in ENA fluxes measured on the sky. Our group has a standing model to produce ENA maps in the same regions which IBEX probes (Kornbleuth et al. 2020). I will adapt the ENA model accordingly to reflect the changes in the solar wind parameters over time and evaluate if our time-dependent model can reproduce real observations. Furthermore, I will compare our results to in situ measurements reported by Voyager spacecraft.

This proposal also addresses all three of the key objectives from the most recent Heliophysics Decadal Survery by: 1) Investigating the role of physical processes in the the space/heliosphere environment from the Sun to the heliopause. 2) Understanding solar variability and its effect on the our solar system and interstellar medium. 3) Determining how life on Earth and society is safeguarded by the heliosphere.

Tuija Pulkkinen (PI)/Shannon Hill (FI)
University of Michigan, Ann Arbor
21-HELIO21-0003: Theta Aurora: A Visible Indicator of Global Magnetosphere Topology

Science objective: This proposal explores large-scale processes in solar wind   magnetosphere ionosphere (SW-M-I) coupling during northward interplanetary magnetic field (IMF) conditions. Specifically, we study the properties of midnight theta auroras as a function of solar wind orientation and magnetotail morphology and relate those to energy and momentum transfer in the magnetosphere.

Methodology: We use the Space Weather Modeling Framework (SWMF) in the Geospace configuration to model 15 observed midnight theta aurora events to examine the formation and persistence of such theta aurora structures under various solar wind conditions and magnetotail morphologies. We construct statistical analyses of both observations and simulation results. Expected outcome: Comparison between the observations and simulation results will reveal the likely mechanisms behind the midnight theta aurora and their relation to the SW-M-I coupling effects driven by northward IMF.

Broader space weather impact: A better understanding of SW-M-I coupling during northward IMF provides insight into the large-scale dynamics that effect the storage and supply of energy in the magnetosphere that are not typically seen during intervals of southward IMF-driven reconnection.

Hanspeter Schaub (PI)/Julian Hammerl (FI)
University of Colorado, Boulder
21-HELIO21-0024: Impact of Space Weather Related Charging on Cislunar Rendezvous Approach and Safety

The goal of the proposed research is to study how energetic particle predictions help protect our technology and astronauts in cislunar space, and how the impact of space weather related charging on the safety of rendezvous and docking operations can be mitigated using adapted approach trajectories and control strategies.

Spacecraft build up electric potentials in orbit due to various electric currents in the space environment, such as plasma currents due to the ambient electron and ion populations, or the photoelectric current due to the Sun. High electric potentials on two spacecraft in close proximity can cause hazardous electrostatic discharges between the two craft. Additionally, the electric charge on the spacecraft results in electrostatic forces and torques that significantly perturb the motion of the two spacecraft. The resulting torques can impose high rotational rates on an uncooperative spacecraft if the approach trajectory is not adapted to minimize the torques, which can lead to hazardous docking operations.

The plasma environment in lunar orbit is interesting because it changes with the position of the Moon with respect to Earth and is highly affected by the solar wind. Spacecraft orbiting the Moon can create plasma wakes with a depletion of plasma density. Electrostatic forces are more effective inside the wake than outside the wake due to electrostatic shielding effects of the plasma.

The first objective of the proposed work is to study the range of expected spacecraft potentials and impact on safe rendezvous operations for the different cislunar plasma environments. To approach this, the plasma environment is characterized using energetic particle data in lunar orbit, and the spacecraft potentials are then determined using spacecraft charging models provided in the literature.

The goal of Objective 2 is to develop a force model that takes plasma wakes and electrostatic shielding in cislunar space into account. Effective force models have been previously investigated for Earth orbit plasmas. However, the applicability of the provided models depends on the magnitude of the spacecraft potentials and the energy of the plasma, and needs to be studied for the different lunar plasma environments.

The impact of space weather and spacecraft charging on rendezvous and docking operations calls for adapted guidance, navigation and control (GNC) strategies that account for electrostatic perturbations to reduce the rotational rates imposed on the target object and increase safety. The goal of Objective 3 is to find such optimized trajectories and control laws that consider plasma wakes.

One of the key objectives of the Heliophysics program is to explore and characterize the physical processes in the space environment from the Sun to the heliopause and throughout the universe. Spacecraft charging is one of the major physical processes between spacecraft and the space environment, and understanding the impact of space weather on spacecraft charging in cislunar space is crucial to safeguard human and robotic explorers beyond Earth. Moreover, the proposed research answers the call from the Department of Defense (ROSES B.7) for enhanced operations in cislunar space in areas such as rendezvous and proximity operations (RPO), and the call for models and tools that use energetic particle and flare predictions to advance relevant capabilities for RPO. Many science missions around the Moon, its surface, and beyond will rely on rendezvous and docking operations. By advancing docking strategies to be more robust and adaptable to a variety of destinations and space weather scenarios (NASA SMD Strategic Plan 2018), the scientific output of such missions will be increased.

Joseph Wang (PI)/Jose Ferreira (FI)
University of Southern California
21-HELIO21-0062: Quantifying the Effects of Space Debris Reentry on the Atmosphere in the Era of Mega-Constellations (HELIO21)

The last decade has seen an exponential growth in commercial space infrastructure. Mega-constellations of satellites, such as SpaceX's Starlink, are beginning to populate the low Earth orbit. Consequently, there will be a significant increase of reentry of these satellites at the end of their service life time or due to space weather effects. For instance, 40 of the 49 Starlink satellites lunched by SpaceX on Feb. 3, 2022 will reenter or have already reentered the atmosphere due to increased atmospheric drag induced by a geomagnetic storm. Currently, there is very limited knowledge on the long-term environmental impacts from reentry of these constellations of satellites.

The objective of this research is to quantify long-term effects from reentry of mega-constellations" of satellites on atmospheric composition. We propose to investigate the chemical interactions between the atmosphere and typically satellite materials during reentry using reactive molecular dynamics (MD) simulations and establish the level of molecular byproducts from such interactions as a function of the number of reentry satellites. Based on the modeling results, we evaluate the possible cascade of the reactions triggered by the reentry events and the long term effects on the atmosphere, and propose an instrument design to observe such effects.

The proposed research, to our knowledge, represents the first ever attempt to apply reactive MD simulations to quantify the molecular by-products during satellite reentry from atomic scale. This research directly supports the strategic objective of NASA's Earth Science Research

Program on Advance the understand of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition".

Paul Withers (PI)/Alexandra Cramer (FI)
Boston University
21-HELIO21-0039: Solar Flares at Mars: Effects of Extreme Solar Irradiance Variability on an Unmagnetized Planetary Environment

The rapid increase in high energy photons outflowing from the Sun during a solar flare is among the most dramatic sources of solar variability. While space weather monitors and ground-based radar make near-constant record of Earth-facing solar activity and its atmospheric effects at our planet, the impact of solar flare events on the space environments of other terrestrial planets such as Mars and Venus have yet to be well characterized. The goal of the proposed work is to characterize how solar flares affect the upper atmospheric conditions at Mars. To accomplish this, I will characterize the net changes to ion (Objective 1) and neutral (Objective 2) density and composition in the upper atmosphere of Mars due to three solar flare events. I will then characterize the role of thermal expansion of the bulk atmosphere in producing these changes (Objective 3). Analysis steps detailed within the proposal utilize the outputs of time-dependent solar flare event simulations from a leading global-scale numerical model of the Martian atmosphere, with density measurements observations by the Mars Global Surveyor (MGS) and Mars Atmospheric and Volatile EvolutioN (MAVEN) spacecraft providing model-observation comparisons within each objective. Results of the proposed work will directly address the Heliophysics Division goal to "advance our understanding of the Sun's activity, and the connections between solar variability and Earth and planetary space environments."

Shasha Zou (PI)/Alanah Cardenad-O'Toole (FI)
University of Michigan, Ann Arbor
21-HELIO21-0004: SEA-EPB:A Statistical and Event Analysis of super Equatorial Plasma Bubbles

Equatorial Plasma Bubbles (EPBs) are one of the most severe space weather phenomena that occur in the ionosphere causing high levels of radio scintillation, which can degrade Global Navigation Satellite System (GNSS) signals. Due to the increasing use of satellite communication and navigation technology, it is essential to understand the characteristics and space weather impact of EPBs in order to better predict future EPBs occurrence and mitigate their impact. Recently, EPBs have been suggested to be able to extend towards midlatitudes and called 'Super EPBs'; these have the potential to cause major GNSS problems at the midlatitudes, such as deep into the US, which are not generally plagued with high scintillation levels. Due to the potential harm that these Super EPBs could cause, we propose to identify the rate of occurrence, characterize their properties and evaluate their potential scintillation impact of the Super EPBs.

In this proposal, my goal is to answer the following questions:
1) How often do Super EPBs occur?
2) Under what solar and geomagnetic conditions do Super EPBs form?
3) How severe are the Super EPBs caused scintillations in the midlatitudes?

We will perform a comprehensive multi-instrument data analysis, such as SWARM in-situ density data, VISTA TEC, and NASA GOLD mission data. We will use the EPB index providedby SWARM satellites, analyze the occurrence rate of the Super EPBs (~>20 magnetic latitude) and focus on the large-scale background and geomagnetic activity conditions of Super

EPBs to improve our understanding of when and where they tend to occur. The TEC and GOLD data will be utilized to provide the large-scale context of the ionosphere during the Super EPB events. We will then evaluate the scintillations due to these Super EPBs by analyzing the rate-of-density (ROD) and rate-of-TEC (ROT).

The proposed study is highly relevant to one of NASA's objectives in the 2014 NASA Strategic Plan. Objective 1.4 states Understand the Sun and its interactions with Earth and the solar system, including space weather." Additionally, the proposal is relevant to the key objectives of the most recent decadal survey Advance our understanding of the Sun's activity, and the connections between solar variability and Earth and planetary space environments, the outer reaches of our solar system, and the interstellar medium." This proposal directly falls into the desired category of the NASA FINESST Heliophysics AO It supports investigations focused on processes that create space weather events and investigations to enable a capability for predicting future space weather events." It would help our society be better prepared for the potential GNSS complications that can arise from Super EPBs migrating towards midlatitudes, particularly deep in the US.

F.5 Future Investigators in NASA Earth and Space Science and Technology
SOLICITATION: NNH21ZDA001N-FINESST

NOTE: Updated October 6, 2022 to include a new selection abstract by the Planetary Science Division (PSD). In addition, Table one as been updated to increase PSD's 32 selections to 33 and to add the selection numbers for the Astrophysics, Heliophysics and Biological and Physical Science Division.

The Science Mission Directorate (SMD) reviewed a total of 927 proposals that were submitted to the **F.5 Future Investigators in NASA Earth and Space Science and Technology (FINESST)** competition within the NASA Research Announcement entitled "*Research Opportunities in Space and Earth Sciences" (ROSES-2021)*. Six SMD divisions at NASA Headquarters conducted/provided oversight for the review and selection process: Astrophysics, Biological and Physical Sciences, Earth Science, Heliophysics, Planetary Science, and Science Engagement and Partnerships (SE&P).

FINESST accepts proposals for graduate student-designed research projects that contribute to SMD's science, technology, and exploration goals. The maximum, three-year total FINESST award amount is $150,000. FINESST grants are limited cost awards. For example, SMD suggests a student stipend of $40,000 per 12 months. Not all projects, however, require the maximum amount available in the period of performance.

FINESST is similar to what 2 CFR200.1 Definitions calls a "Fixed Amount Award". "Fixed amount awards means a type of grant or cooperative agreement under which the Federal awarding agency or pass-through entity provides a specific level of support without regard to actual costs incurred under the Federal award. This type of Federal award reduces some of the administrative burden and record-keeping requirements for both the non-Federal entity and Federal awarding agency or pass-through entity. Accountability is based primarily on performance and results."

SMD's estimated timeframe to communicate the selection or intent-to-award decisions is late May through late July. Selection documents are released first, followed by non-selections. Non-selections may not be available until August 15, 2022, or later. The NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) will announce decisions via a system generated email to the PI and AOR. *NSPIRES makes detailed documentation of the selection and non-selection decisions available for each reviewed proposal to both the Principal Investigator (PI) and Authorized Organization Representative (AOR).* Access to proposal-specific documentation requires logging in to NSPIRES and navigating to the submitted proposal, and not just visiting the web page. FIs, however, cannot receive or access FINESST decisions or review results directly via NSPIRES. If by August 15, the PI or AOR have not contacted the FI, then the FI should ask them to log in to NSPIRES to see if the proposal status has changed and download and share the results.

For assistance with NSPIRES log in, please contact the NSPIRES Help Desk at (202) 479-9376 Monday – Friday, excluding Federal Holidays, (e.g., Juneteenth National Independence observed for 2022 on June 20, July 4, i.e., Independence Day, etc.) 8 AM to 6 PM Eastern Time or by email at nspires-help@nasaprs.com.

Table 1: FINESST-21 Proposal Data

Division	Proposals Reviewed	Proposals Selected (Estimated)	NSPIRES Publication Date
Science Engagement & Partnerships	2	1	May 26, 2022
Biological and Physical Sciences	25	2	July 21, 2022
Earth Science	394	62	June 30, 2022
Planetary Science*	224	33	October 6, 2022
Astrophysics	222	29	July 25, 2022
Heliophysics	60	14	September 26, 2022
Total**	927	141	July 25, 2022 (Target)

NOTE For Selected PI-FI Teams: Once SMD receives selection acceptance, the FINESST proposal will be transferred to the NASA Shared Services Center (NSSC). NSPIRES cannot track the NSSC grant processing activities. A grant's status may be tracked via a web search on the PI's name (do not use the FI name or NSPIRES proposal number) at: https://www.nasa.gov/centers/nssc/forms/grant-status-form, telephoning the NSSC at 1-877-NSSC123, or e-mailing nssc-contactcenter@nasa.gov.

Any pre-award costs incurred are at the proposer's risk. All new awards receive an automatic 90 days of pre-award spending approval on award, meaning that NASA has waived the requirement for FINESST award recipients to obtain written approval prior to incurring project costs up to 90 calendar days before NASA issues an award. However, expenses incurred more than 90 calendar days before the award require prior written (i.e., email) approval from a Grants Office at the NSSC.

NOTE for Non-Selected PI-FI Teams: SMD received a far greater number of proposals than available funds can support. NASA plans to publish the next FINESST solicitation as a cross-divisional appendix to the NASA Research Announcement entitled "Research Opportunities in Space and Earth Science (ROSES-2022)."

A non-selected 2021 FINESST proposal may be eligible to be revised and resubmitted to the 2022 competition. Entirely new, eligible proposals also are welcome. When the new FINESST solicitation (F.5) is published in final form it will be available at https://go.nasa.gov/FINESST22. Proposal intake will continue for an approximate minimum of 60 days from the release barring any unforeseen circumstances. In the interim, SMD's Cross Division FINESST team welcome general comments, questions, and FINESST-improvement suggestions via email at: HQ-FINESST@mail.nasa.gov.

*Technical Note: *The Planetary Science Division (PSD) will make all notifications (selections and declines) available on NSPIRES at the same time in order to be consistent with other PSD program practices.*

***This total may be different than what a selection letter may indicate due to administrative adjustments.*

PLANETARY SCIENCE DIVISION SELECTIONS, (33, Alphabetical by PI Last Name)

Jeffrey Andrews-Hanna (PI)/Samantha Moruzzi (FI)
University of Arizona
21-PLANET21-0041, Faulting in Pluto's Ice Shell: An Investigation of Local Strain and Stress Concentrations from the Refreezing of the Ice Shell Beneath Sputnik Basin

Sputnik basin was one of the most surprising features found on the surface of Pluto during the New Horizon's flyby in 2015. With no spatially resolved gravitational data from the New Horizons mission, Sputnik basin continues to be key to understanding the lithospheric structure, interior, and evolution of Pluto, and provides an example of how large surface features on planetary objects can illuminate the structure beneath. This ~ 2000x1000 km quasi-elliptical basin is in Pluto's equatorial region and its elongated shape reflects the expected shape of large basins on a curved surface. The subsurface beneath Sputnik basin was most likely altered by the basin-forming impact, but the impact did not fully excavate through the ice shell. Sputnik's basin-forming impact would have resulted in a gravity-driven collapse, accompanied by a flow of ice and underlying ocean towards the impact center. The ice shell beneath the basin would have been thinned by the uplifted ocean. Predicted thinning would have been ~ 50 km, which is out of thermal equilibrium. Additionally, current work utilizing the topography of the N2 deposit within the basin is demonstrating that the present-day basin is uncompensated. A present-day mass deficit provides insight into Sputnik basin's evolution. A substantially thinned post-impact ice shell would have been out of thermal equilibrium leading to the refreezing of the conductive ice shell post-true polar wander reorientation until it reached its present-day equilibrium shell thickness. We can explain the mass deficit if the ice shell refroze to within ~ 20 km of the predicted present-day equilibrium shell thickness, which would agree with the present-day basin depth of ~ 2 km. Refreezing of the ice shell beneath the basin would lead to uplift, altering and potentially reversing the stress field, having tectonic consequences on the ice shell surrounding the basin. My investigation will further our understanding of the evolution of the basin through time by evaluating stress and strain in the ice shell and their tectonic consequences. We will expand on a preliminary model of the refreezing ice shell that suggest the ice shell will refreeze to its equilibrium thickness by 4 Ga post-impact by including three additional complexities. These modifications to the model will more accurately represent the potential conditions beneath the basin. We will then model the stress and strain fields from the flexure both refreezing of the ice shell beneath Sputnik basin and from the N2 deposit load in a peak-ring Sputnik basin using a thin-shell deformation model. Finally, we will compare the predicted stress and strain fields of both scenarios to previously mapped surface tectonics. This will provide insight into the evolution of the basin as both the ice shell refreezes and an N2 load is emplaced in the basin. Our proposed work will provide a new look into interior-surface interactions on Pluto through the lens of Sputnik basin. Understanding the evolution of a basin on an icy world such as Pluto provides a laboratory for insight into deformation and surface expression under foreign conditions and the processes that initiate it.

Christopher Carr (PI)/Jordan McKaig (FI)
Georgia Tech Research Corporation
21-PLANET21-0058, Planetary Brines: Impacts on Habitability, Biosignature Stability, and Life Detection

Interplanetary life-detection missions are expected in the coming decades. To effectively search for life in such environments, it is essential to understand the potential habitability of environments, the stability of biosignatures under various environmental conditions, and capabilities and limitations of onboard instrumentation and analytical techniques in planetary environments.

Nucleic acids (linear polymers responsible for storage and regulation of heritable biological information) and ribosomes (cellular machinery that conduct protein synthesis, or translation) are ubiquitous to known life and essential to cellular functioning. Thus, these molecules or their agnostic functional equivalents may be targets of future life detection missions.

Current and former habitable environments in the solar system (e.g. Mars, Europa, Enceladus) are frequently saline, so it is important to understand how salts impact organism survival, adaptation, and evolution, and influence biomolecule preservation and detection. This proposed research seeks to further explore these connections to salinity while integrating single-molecule detection technologies that are of interest for future space exploration.

Hypothesis: We hypothesize that salinity influences biosignature stability, habitability and life detection capability through the following mechanisms: salinity prompts microbes to modify their DNA (Aim 1), salts confer a stabilizing effect on nucleic acids which protects them from ionizing radiation damage (Aim 2), and salt composition and concentration influences ability to effectively detect biomolecules (DNA, RNA, and ribosomes) from irradiated brines and hypersaline environmental samples (Aim 3).

Objectives: DNA samples from environmental hypersaline brine samples will be sequenced, and genomic modifications will be mapped to determine whether they increase with salinity and/or occur in specific genomic sequences (Aim 1). The effects of salinity on extent of DNA damage from ionizing radiation in simulated icy moon conditions will be assessed (Aim 2). Impacts of brines on detection of biomolecules (DNA, RNA, and ribosomes) with a solid-state nanopore sensor will be investigated (Aim 3).

Methodology: We will investigate the effects of salinity on microbial DNA modification by extracting and sequencing DNA from various sites along a gradient of increasing salinity analogous to historical hypersaline conditions on Mars using a MinION sequencer. Then, we will use bioinformatic tools to quantify the frequency and map the genomic context of DNA methylation. To assess the effects of salinity on irradiation damage to nucleic acids, DNA suspended in brine and water solutions will be subjected to ionizing radiation in simulated icy moon conditions. Gel electrophoresis will be used to assess DNA damage under the various combinations of brine and irradiation. MinION sequencing will indicate whether this damage interferes with sequencing, and if damage occurs within specific genomic sequences. To explore how salinity affects the stability and detectability of biomolecules, we will analyze environmental brine samples and irradiated brines containing DNA, RNA, and ribosomes with a solid-state nanopore instrument capable of resolving size and structural information for individual molecules as they pass through the nanopore, enabling assessment of the effects of various icy moon and Martian analog brines on biomolecule stability and detectability.
Significance: These studies can expand understanding of microbial adaptations and biomolecule stability under hypersaline conditions on Earth and inform future interplanetary missions seeking to understand habitability and search for life in saline extraterrestrial environments. Integration of techniques for single-molecule analysis will demonstrate the potential that these technologies hold for future space exploration.

Mike Chaffin (PI)/Eryn Cangi (FI)
University of Colorado, Boulder
21-PLANET21-0122, Seasonal Variation of Deuterium Ions and Non-Thermal Deuterium Escape at Mars

Atmospheric escape from planets more strongly affects the lighter atom of an isotope pair, for example, hydrogen (H) and its isotope deuterium (D). On Mars, this isotope pair primarily occurs in water; a high D/H ratio thus indicates a history of water loss. A parameter important to the calculation of lost Mars water is the D/H fractionation factor, which captures in one value the relative efficiency of both thermal and non-thermal processes in depleting D and H from the atmosphere. My past work has shown that the D/H fractionation factor may be most sensitive to variations in non-thermal escape of D, which is expected to be the primary loss mechanism (as opposed to thermal escape) of D at Mars and is also poorly constrained relative to H escape (which is mostly thermal escape). Recent modeling studies and Mars orbiter data have shown significant seasonal variations in the water cycle and H escape. However, there are few studies on the non-thermal escape of D, and none that directly model the deuterium ion chemistry necessary to quantify the resulting non-thermal processes or examine their variation over time. The objective of this proposal is thus to model and quantify the magnitude and variations of non-thermal escape of D throughout the Mars year due to seasonal cycles. This builds on my present work quantifying non-thermal escape of D in the case of long-term atmospheric equilibrium. To accomplish this work, I will leverage my existing 1D photochemical model, written in Julia for computational efficiency and power. I have recently updated the model to include two major improvements to enable this work. First, the model now includes deuterium ion chemistry reactions, which are strictly required to study non-thermal escape of D. Second, the model is able to run without imposing photochemical equilibrium on short-lived species (ions) or fixing a constant background neutral atmosphere, which to my knowledge has not been done before with 1D photochemical models. This means results will be more precise because real-time feedbacks between ion and neutral chemistry are accounted for. I will use this model to study the time variation of the magnitude of three types of non-thermal D escape: loss of superthermal deuterium produced by dissociative recombination of the HDO cation, resonant charge exchange with neutral H, charge exchange with atomic O, and photodissociation of neutral HDO and HD. The result will be the first comprehensive look at the role of seasonal atmospheric cycles on non-thermal D escape, including the effects of temperature variation, water vapor column changes due to dust storms, and varying solar irradiation due to the orbital cycle. This project will contribute to several priority questions as defined in the most recent (2013-2022) Planetary Science Decadal Survey and the 2014 Science Plan concerning water supply and chemistry on the inner planets, past aqueous environments on Mars, and the time-evolving nature of chemical and physical processes in the solar system. More broadly, it fits into the NASA mission to pioneer advances in science and to transform our understanding of the universe" and the aspect of the SMD mission to Discover the secrets of the universe."

Philip Christensen (PI)/Alexandra E. Huff (FI)
Arizona State University
21-PLANET21-0106, Carving Out the History of Ice on Mars by Investigating Serrated Terrains in Kasei Valles

Constraining the history of ice on Mars is essential to understanding how the planet's surface was created and then changed over the past 4.6 billion years. To do this, we must locate features, deposits, or signs of erosion that indicate ice played an active role in their creation or alteration. Once found, constraining when the ice was present can inform at what time Mars' climate was hospitable to surface ice at that location. Recent studies have re-examined landforms originally interpreted to be formed by water, such as valley networks and massive outflow channels, and now suggest ice may have been involved as well. However, separating water- and ice-derived terrains is challenging due to the wide range and scale of related landforms, the fluctuating transition between water and ice phases, and the extreme age of most martian surfaces. Identifying the relative contribution of ice and glacial processes to the evolution of these surfaces can fundamentally pivot our understanding of Mars' geologic history and climatic regimes.

We have identified terrain within Kasei Valles that could provide key insights to the presence of ice on Mars. Located ~15° north of the equator, Kasei Valles are two ~2,500 km long east-west trending gorges north of Valles Marineris that are interpreted to be Hesperian aged (~2.9-3.7 billion years old). We will focus on linear sequences of evenly spaced, parallel, ~100-600 m wide ridges and grooves, which we call serrated terrain after its near sawtooth appearance, that are observed throughout the Kasei Valles area. This terrain was originally interpreted to be formed by catastrophic flooding akin to what formed the Channeled Scablands in eastern Washington, but additional interpretations include mudflow, lava flows, and most notably ice stream erosion and mega scale glacial lineations. Our understanding of these ice-related features on Earth have advanced in recent decades, therefore we are motived to take a closer look at the serrated terrain in the Kasei Valles region.

We will evaluate water, ice, mud, and lava as possible formation processes of serrated terrain by combining studies of thermal inertia, flow modeling, and geologic mapping. We will quantify the thermal inertia of the serrated terrain and adjacent features and deposits to understand the thermophysical properties of each, which will inform formation. Assuming serrated terrain preserve streamlines of the fluid velocity field, we will conduct finite element modeling and boundary layer measurements to estimate which formation process is more plausible at different locations throughout the study area. We will then place results from these two tasks into geologic context through mapping of cross-cutting relationships to deduce timing of the serrated terrain.

This project aims to observe and explore Kasei Valles to understand how it evolved over time in order to assess the role of ice in the early evolution of Mars. This work contributes to NASA's Planetary Science Division (PSD) Strategic Science Goals to observe and understand the formation and evolution of places in our Solar System, and to advance the understanding of how processes in our solar system operate, interact, and evolve. Our research also specifically contributes to the Mars Exploration Program Analysis Group (MEPAG) goal to understand the origin and evolution of Mars geology.

Josef Dufek (PI)/Paul Regensburger (FI)
University of Oregon
21-PLANET21-0094, Multiphase Modeling of Transient Cryovolcanic Eruptions as Insight to Subsurface Processes at Enceladus

Ocean worlds in the outer solar system are major scientific targets due to subsurface liquid water oceans. Enceladus, one such ocean world, possesses a system of cryovolcanic plumes emanating from its South Polar Terrain. These plumes are of interest as they provide insight into the physical and chemical processes occurring within these bodies. Current research on these plumes has illuminated several aspects of their behavior but make simplifying assumptions such as constant reservoir conditions, static crack geometry, and adiabatic flow in the jet conduit.

These assumptions are useful in understanding the physics of cryovolcanic plumes, but do not capture the transient nature of several subsurface processes related to plume output that will likely impact the height and the duration of these events.

The proposed work seeks to use computational modeling to better understand the subsurface physical processes associated with a plume event. This project will determine the effect of transient conduit processes on plume output using a multiphase numerical modeling approach. Conduit and plume components of the model will be used to simulate scenarios associated with different subsurface processes, specifically heat and mass exchange between the flow and fracture walls and local stresses affecting crack geometry. The effect of these processes will be quantified in the dynamics and structure of the plume, which can be compared to observational data. This technique can be extrapolated to other worlds such as Europa and Triton to constrain their putative transient cryovolcanic eruptions.

Catherine Dukes (PI)/Kamil B. Stelmach (FI)
University of Virginia, Charlottesville
21-PLANET21-0112, Life's Cosmic Handshake: When Chiral Surfaces Meet Chiral Organic Molecules

The almost exclusive usage by organisms of left-handed amino acids and right-handed sugars – a feature called homochirality – continues to elude explanation and remains an enigma in the story of the origin of life. However, the detection of an enantiomeric excess of left-handed amino acids and right-handed sugars in carbonaceous meteorites strongly points to a cosmic origin. This is perplexing since non-biological reactions usually lead to a racemic mixture. However, all proposed explanations come up short in explaining the measured magnitude of enantiomeric excess in meteorites.

Experiments utilizing CPL have been able to produce an enantiomeric excess of just a few percent, unlike the double-digit excesses seen in meteoritic material. Subsequent aqueous alteration has been linked to the amplification of excess levels. However, CPL should affect all species of amino acids, yet not every amino acid in meteorites show an excess. Indeed, polyols—sugar alcohols—in the same meteorite samples show the opposite handedness and, in many cases, 100% preference for the D-enantiomer. Lastly, the Paris meteorite, potentially the best representative of the presolar nebula, has racemic mixtures of amino acids. Clearly, CPL is not the only factor at play.

Amino acids in the solar nebula are expected to derive from photolysis/radiolysis of simple condensed gases, with subsequent sublimation and eventual redeposition onto proto-planetary grains. Most laboratory experiments involving amino acid redeposition ignore the surface effects of the substrate. However, chiral mineral surfaces might be fundamental in enhancing one enantiomer over another via asymmetric desorption in the protoplanetary disk. The desorbed enantiomer could then be destroyed in a myriad of processes, leaving the surface with a bias in the observed enantiomeric excess. Furthermore, not all chiral organic molecules would be affected the same way, thus providing an explanation for why some amino acids are racemic and others show an enantiomeric excess.

We propose a single-year combined computational and experimental approach to test whether astrophysically relevant chiral surfaces can enhance the appropriate enantiomers of each class of biological molecules. First, we will measure the functional groups involved in surface binding of alanine, tyrosine, and glutamic acid enantiomers on (101) quartz in an astrophysically relevant laboratory environment. Quartz is used as a model chiral mineral and the amino acids were chosen so that a diverse set of functional groups are represented.

The experimental setup consists of an UHV chamber with an X-ray photoelectron spectrometer (XPS), mass-spectrometer, hot-cold stage, and adjacent sample introduction chambers. Preliminary experiments have been run with tyrosine and glutamic acid aqueously adsorbed onto quartz. XPS data is used to determine which functional groups are utilized in surface bonding. The preliminary experiments show subtle differences between each enantiomer tested. Angle-resolved XPS can be used to determine the orientation of the molecules on the surface.

Density functional theory (DFT) calculations using the Vienna ab initio Simulation Package (VASP) will be used to interpret surface kinetics. The VASP package has been previously used to predict enantiomeric differences in surface binding energies. Energy calculations will be conducted for a suite of chiral organic molecules, quartz, and clinoenstatite.

We hypothesize that the difference in binding energies between organic enantiomers on chiral mineral surfaces is large enough that sublimation from such surfaces plays an important role in enhancing the enantiomeric excess of the molecules during planetary formation. If this hypothesis is correct then one important test will be confirmation that amino acid and polyol enantiomers show opposite chiral preferences on astrophysically relevant surfaces.

Rita Economos (PI)/Katelyn Lehman Franco (FI)
Southern Methodist University, Inc
21-PLANET21-0175, Characterizing Lunar Magmatic Reservoir Formation and Evolution via Co-located in situ Radiogenic Isotope, Stable isotope and Trace Element Analyses in Apatite

In situ analyses of apatite (Ca10(PO4)6(F, Cl, OH)2) have revolutionized our understanding of volatile budgets, magmatic sources, and geochronology on Earth and other planetary bodies. Apatite's strength stems from its ability to sequester U, Th, Pb, REE, water, and all major magmatic volatile elements (F, Cl, O, H, S) into its crystal structure. This study will utilize the apatite to investigate two questions:

1. 1.Is there a systematic relationship between reservoir evolution over time and changes in stable isotopic compositions of volatile elements on the Moon?
2. 2.Is there evidence of modification of the Cl isotopic compositions by secondary processes (e.g., localized degassing or metasomatism)?

This study's primary objective is to quantitatively characterize the isotopic composition of the reservoirs that formed the anorthositic highlands and KREEP-rich suites on the Moon through in situ analyses of U-Th-Pb isotopes, Cl isotopes, and trace element compositions of apatites. The coordinated analysis of individual crystals will aim to 1. establish a timeline of reservoir-scale isotope modification and 2. highlight the role of geochemical alterations caused by volatile loss. Specifically two hypotheses will be tested:

1) The variations in ´37Cl observed in mare basalts is due to mixing between the urKREEP reservoir with enriched ´37Cl and low ´37Cl mantle source reservoir.
2) The elevated ´37Cl of KREEP-rich samples are explained by volatile loss during LMO degassing.

To evaluate these hypotheses four tasks are required.

- Task 1: Locate and conduct elemental analysis of apatites using FE-SEM with EDS, WDS, and CL capabilities and EMPA.
- Task 2: Determine U-Th-Pb and Cl isotope ratios using SIMS.
- Task 3: U-Th-Pb Geochronology
- Task 4: Characterize the Magmatic Sources.

Comparing the Cl isotope, trace element and U-Pb isotopic fingerprints of reservoirs will highlight the processes that modify volatile elements on early planetary bodies while constraining large-scale changes that fractionated stable Cl isotopes. This may inform how volatile chemistry can be modified by differentiation in the LMO.

Bethany Ehlmann (PI)/Melanie Kanine (FI)
California Institute of Technology
21-PLANET21-0223, Reconstructing the History of Jezero Crater Lake from Remote 3D Digital Topography: A Framework for 2020 Rover Exploration

Jezero Crater, the home of the Mars rover Perseverance, hosted a paleolake and potentially habitable conditions. One of the primary Perseverance mission goals is to collect and cache rock samples most likely to preserve signs of life, should it have been present; therefore, data to drive sample location selection and contextualize cached samples is vital. Key questions remaining include: the timing and duration of the paleolake; how the climate evolved and whether it related to global trends (i.e., were there periods of wetting and drying, with an overall trend toward desiccation, as in Gale Crater (Palucis et al., 2016), or a unidirectional increase in aridity?); and how surface processes after lake and fluvial activity ceased changed the morphology of the landscape. My proposed study seeks to answer these questions and extend preliminary rover-based findings to answer the ROSES-21 solicitation NNH21ZDA001N using orbital data analysis, photogeologic mapping, and a PCA-based framework for calculating surface orientations. This study contains three main tasks: 1) understanding the three-dimensional geometry of the western delta deposit; 2) constraining the history and stratigraphic context of the mafic floor unit; and 3) investigate closed-basin era(s) of the lake's history.

Geological mapping, geomorphological and textural analyses, and measurements of strike-dips and layer thicknesses will utilize multiple datasets in a geographic information system (GIS) framework. We will use HiRISE visual imagery (~25 cm/pixel), for which coverage exists over almost the entire crater, and HiRISE digital elevation models (DEMs) (~1m/pixel), where available, and CTX visual imagery (6 m/pixel resolution) and CTX DEMs otherwise. All are available in the NASA Planetary Data System (PDS) orand via public sites like JMARS. We will use QGIS to process images and perform topographic analyses. Python modules Attitude and Orienteer (Quinn and Ehlmann, 2019) will be used to determine the best-fit plane to bedding measurements with Principal Component Analysis (PCA), while simultaneously estimating directional fit errors (Fig. 1).

This proposal addresses the NASA ROSES-21, C.1 science goals and those of the Science Mission Directorate (SMD) for Planetary Science. The proposed tasks will address habitability on ancient Mars and aid in identifying locations with high biosignature preservation potential for caching with ongoing Mars-2020 exploration; constrain climate evolution; and understand Martian depositional and erosional processes that shape the landscape.

Sarah Fagents (PI)/Gwendolyn Brouwer (FI)

University of Hawaii, Honolulu
21-PLANET21-0214, Modeling an Endogenic Origin for Raised Rim Depressions on Titan

The purpose of this project is to test the hypothesis that raised rim depressions (RRDs) in Titan's north polar region form in a manner analogous to the formation of gas emission craters (GECs) in permafrost regions on Earth. Most common in the north, RRDs are characterized by raised rims, circular planform shape, and radar-bright halos. An intriguing terrestrial analog are large craters that have recently formed in the Siberian Yamal and Gydan peninsulas, thought to be formed by the explosive release of methane gas (originating from methane clathrates) trapped and pressurized under the permafrost. In addition to the compellingly similar morphologies of GECs and RRDs, Titan's ice shell is also thought to contain methane clathrates. Previous studies have shown that clathrate destabilization is possible at shallow depths in Titan's ice shell in response to thermal perturbation by upwelling warm ice and contact with ammonia-rich liquids. We therefore propose a new formation process for RRDs:

(1) A thermal anomaly comes into contact with a region of locally elevated ammonia concentration within the ice shell;
(2) The region melts to form ammonia water liquid, which destabilizes the methane clathrates, forming a reservoir of gas and liquid;
(3) Gas continues to accumulate and becomes pressurized;
(4) The thermal anomaly decays and the reservoir liquid begins to freeze, causing further pressurization;
(5) The reservoir explodes due to overpressure, excavating and ejecting the overburden, forming a crater

To test this RRD formation hypothesis propose three tasks. We first characterize morphologies and dimensions of Titan's RRD's using Cassini Radar and SARTopo data (Task 1). We use these measurements as inputs for a numerical explosion model which yields the pre-explosion pressure conditions that formed each feature (Task 2), having first used results from the high resolution terrestrial GEC data set to verify our explosion model before application to Titan RRDs. Then we model the pre-explosion process (Task 3). We break this task into three parts: 3.1 Derive Ice Shell Parameters, 3.2 Model Gas Evolution, and 3.3 Model Reservoir Freezing. The outcome of the proposed research will be an assessment of the plausibility of the RRD formation mechanism, specifically as a potential methane exchange process between the subsurface and atmosphere. The proposed work is relevant to the Planetary Science Research Division, which invites proposals to address themes from the 2013-2022 Planetary Science Decadal Survey in the FINESST solicitation. This project addresses the question from the Decadal Survey: What is the relationship between Titan's surface morphology and its internal processes, particularly for the history of the methane budget and lakes or seas and possible replenishment of methane from the interior or subsurface?"

Andrew Freed (PI)/Gregory John Gosselin (FI)
Purdue University
21-PLANET21-0030, Unraveling the Formation and Evolution of Mercury s Caloris Basin: Gaining Insight into the Architecture of a Young Terrestrial Planet

Asteroid impacts are the most significant geologic process to have shaped our Solar System. In addition to the surface expression of the remnant crater, large impacts preserve some of the most basic characteristics of the impacted body at the time of impact. At 1550 km in diameter, the 4-billion-year-old Caloris Basin on Mercury is its largest and best-preserved impact structure. Thus, Caloris Basin provides us a window into Mercury's past from which we can begin to unravel its primordial characteristics. Observations of topography and gravity from the MESSENGER spacecraft exhibit a basin that has experienced a long and complex evolution that began with the excavation and collapse of a transient crater, followed by a prolonged period of cooling and isostatic adjustment, followed by the emplacement of volcanic plains that initiated a series of complex faulting patterns. Using new numerical techniques, we can use these present-day observational constraints to reconstruct the evolution of this basin and infer Mercury's internal conditions around the time of Caloris' formation.

Characterizing the evolution of Caloris basin requires two numerical codes applied in sequence as the physics governing the impact process (first several hours) are considerably different from that responsible for its long-term cooling and viscoelastic flow (10s to 100s of millions of years). Thus, we will couple a hydrocode that simulates the impact process to a finite element code that simulates postimpact geologic processes. The key to our two-code approach is self-consistency; results from the hydrocode are used as inputs within finite element simulations, the final result of which can then be compared to MESSENGER-observed basin topography, gravity data, and faulting styles. This will enable us to constrain a set of plausible thermal, mineralogical, and rheologic conditions inherent to a young Mercury.

The objectives of the research are to address several long-standing questions about large impact basins in general and specific to Caloris. We seek to determine what combinations of impactor size and speed and geophysical properties of Mercury best explain the contemporary observations of Caloris. Of particular interest is Mercury's thermal gradient as this is the unifying parameter between both the short- and long-term processes responsible for Caloris' evolution. In addition, we will explore the origin of the crust beneath Caloris Basin's interior volcanic plains and whether it formed as a multiring basin. To date, it has been suggested that the crust beneath large impact basins is due to differentiation of the melt pool. However, we suggest a process by which crust can flow back to the basin center during transient crater collapse. We also consider the mechanisms responsible for the faulting forms observed within Caloris Basin. Several theories have been put forth that attempt to explain various aspects of this faulting, including buried basin rings, however, no analysis has been conducted that explains all observed faulting patterns within a systematic framework. Our ability to model the entire evolution of the basin will allow us to more comprehensively test a variety of hypotheses surrounding their formation and spatiotemporal distribution.

Our ability to model Caloris' complete evolution will allow us to infer its most basic properties at the time of its formation some 4-billion-years ago. This research will further narrow the set of plausible conditions which ultimately brought Caloris, and by extension Mercury, to its present state. The goals of this research are coincident with NASA objectives, and those put forth by the Planetary Science Division as we will further our understanding of how Mercury formed and evolved, as well as advancing our understanding of how physical processes in our Solar System operate, interact, and evolve.

Robin Garrod (PI)/Drew Christianson (FI)
University of Virginia, Charlottesville
21-PLANET21-0126, Modeling Chemical Signatures of Comet Irradiation by Supernovae and Hot Stars

Comets are arguably the most pristine objects in the solar system and exist primarily in the Oort Cloud and the Kuiper Belt. They are composed of ice and dust in roughly equal amounts, with the ices containing primarily simple molecules such as water and CO2; however, recent observations, sample-return missions or visits to cometary surfaces have revealed a selection of highly complex organic molecules. Comets are also potential candidates for the delivery of water and organic molecules to the early Earth. However, little is known about the chemical processing that comets experience during the early cold period in the outer solar system where they spend most of their lives. Not only will they experience ongoing chemical and physical processing from galactic UV and cosmic rays, but they are expected have been influenced to some degree by irradiation caused by past galactic supernovae and passing hot stars. These events have the potential to alter complex organic molecule abundances in cometary ices. Therefore, it is important to understand these events and how they affect our view on solid-phase cometary molecular abundances and possible delivery to Earth. In addition to the heating produced by these events, the standard cosmic ray flux will be augmented by additional energetic particles during these events, while molecules in the outer surface of the comet will be affected by the additional UV flux. Ignoring stochastic events like supernovae, Oort Cloud conditions are still not static in relation to the constant motion of stars within the Milky Way, which allows other stars to pass close by the solar system, which may also irradiate Oort cloud and indeed Kuiper Belt comets.

The chemical kinetics model MAGICKAL is the most advanced interstellar ice chemistry model for studying complex organic molecule chemistry, and has recently been adapted to produce the only cometary ice chemical kinetics model. MAGICKAL is the first model of its kind in treating the primarily UV and Cosmic Ray driven chemistry of cold-storage cometary nuclei. Cosmic rays are a notable source for chemical change, both in the loss of volatiles as well as the production of complex organic molecules through radiolysis. In order to understand the chemical effects of these energetic events on comets, I will use the chemical model MAGICKAL to simulate the irradiation of cometary ices caused by extreme energetic events in the history of the solar system, as well as studying the influence of these possible events on comet chemistry early in the solar system's history. This work will produce the first models to simulate the chemical effects of supernovae and passing hot stars on cometary nuclear ices.

This work will be highly relevant to NASA programs; in particular, it is relevant to the Planetary Science strategic objective to advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere" as comets are reservoirs for material of the early solar system as well as potential carriers of prebiotic molecules to the early Earth. As NASA probes continue to be used to explore the outer reaches of the solar system, computational exploration of the chemical history of the solar system will only become more important.

Manavi Jadhav (PI)/Ishita Pal (FI)
University of Louisiana, Lafayette
21-PLANET21-0133, A Correlated Light and Heavy Element Isotopic Study of Presolar Graphite Grains

The FI, Ishita Pal, is a cosmochemist-in-training and is currently enrolled in an interdisciplinary PhD program at the University of Louisiana Lafayette. They seek FINESST funding to support their dissertation study on the characteristics of light and heavy element isotopes in presolar graphite grains. This will be achieved by carrying out coordinated measurements of multiple isotopes on individual presolar graphites.

Presolar grains are micron to sub-micron sized pieces of dust that condensed from the gas phase in circumstellar regions of dying stars (e.g., supernovae (SNe), asymptotic giant branch

(AGB) stars). They provide us with critical information about nucleosynthesis reactions in the parent stars. These grains also contain clues about the chemical and physical conditions in the circumstellar regions of the parent stars, where they condensed, and the surrounding interstellar environment that they were ejected into. Both light and heavy element isotopic data are essential to fully characterize the grains and obtain nucleosynthetic information about their stellar sources. While coordinated light and heavy element studies have been conducted on presolar silicon carbide grains, presolar graphite grains have not been as widely studied. Presolar graphites are less abundant in primitive meteorites, however, they tend to be much larger in size compared to other presolar grain types. This makes them perfect candidates for multi-element analyses. They also contain a larger fraction of SN grains (26%) compared to SiC grains (1.5%), providing us access to a larger set of SN grains, that SiCs do not provide, to study nucleosynthesis within high mass stars during their lifetimes and the explosive nucleosynthesis reactions that take place after such stars go supernova.

The FI will search for presolar graphite grains from low- and high-density fractions of the Orgueil meteorite, using optical and electron microscopes. Grains from each fraction represent AGB, SN, and/or, other rare, exotic stellar sources. Characterization of the grains using light element isotopic ratios will be carried out using nanoscale secondary ion mass spectrometry. Heavy trace element isotopes will be measured using resonance ionization mass spectrometry. Comparison of the isotopic data with nucleosynthesis models will give us a better picture of the neutron capture processes that take place in the parent stars and will provide tighter constraints on theoretical models. Further investigation of the data in comparison to models of circumstellar dust formation will improve our understanding of the chemical and physical conditions in circumstellar regions of AGB, SNe, and some rare stellar sources. The FI and PI team and their collaborators have successfully tested out the proposed methodology on forty-six presolar grains from Murchison in a recent preliminary study. This project will study hundred more graphite grains making it the first thorough, systematic, and coordinated investigation of light and heavy element isotopes in presolar graphite grains, especially SN graphites. Thus, this study has the potential to make important breakthroughs in our understanding of these grains and this field of study.

The proposed study falls directly under the Planetary Science Research Program's broad strategic objective to ascertain the content, origin, and evolution of the Solar System and the potential for life elsewhere" and addresses the question how did the Solar System form and evolve?". It also directly addresses the first two science goals of the Planetary Science Division to explore and observe the objects in the Solar System to understand how they formed and evolve" and advance the understanding of how the chemical and physical processes in the Solar System operate, interact, and evolve".

Xianzhe Jia (PI)/Changkun Li (FI)
University Of Michigan, Ann Arbor
21-PLANET21-0007, Modeling Mercury s Dayside Magnetopause Reconnection and Its Impact on the Global Magnetospheric Dynamics

Observations from the MESSENGER spacecraft that was in orbit around Mercury for about 4 years reveal that the planet has a miniature magnetosphere arising from the interaction of its intrinsic field with the inner heliosphere solar wind. Despite its small size, Mercury's magnetosphere appears to be more dynamic than Earth's in that the typical timescales for global plasma and magnetic flux circulation are much shorter than observed at Earth, and the dayside magnetopause reconnection occurs at much faster rates and under a much wider range of magnetic shear angles. As a product of multiple X-line reconnection, flux transfer events (FTEs) are observed to form much more frequently with occurrence rates of ~ 50 times higher than detected at Earth. Aside from the apparent difference in system size, MESSENGER observations suggest that the large differences in reconnection-driven dynamics between Mercury's and Earth's magnetospheres are likely related to the upstream solar wind conditions. Specifically, at Mercury's orbit the solar wind Alfvén Mach number and the resulting magnetosheath plasma beta are smaller than at Earth due to its proximity to the Sun, which makes Mercury's magnetopause very conducive to reconnection.

However, because of the intrinsic limitations of in-situ observations obtained through single spacecraft, there lacks a quantitative, global understanding of how magnetopause reconnection occurs at Mercury and its large-scale consequences. Many outstanding questions remain concerning the nature of the dayside magnetopause reconnection, its dependence on the upstream parameters, and the role played by FTEs in driving the global dynamics. Here we propose to use two state-of-the-art global models, BATSRUS Hall-MHD and MHD-EPIC, to simulate Mercury's magnetopause dynamics under a wide variety of solar wind and IMF conditions. The Hall-MHD model includes the Hall physics, which has been demonstrated to be able to enable fast reconnection by allowing separate bulk motions for ions and electrons, whereas the MHD-EPIC model couples the BATSRUS Hall-MHD model with a fully kinetic Particle-in-Cell code (iPIC3D) that is capable of simulating reconnection based on kinetic physics. By driving the two models with the same set of upstream conditions designed to represent a wide range of scenarios encountered at Mercury, we aim to address the following science questions:

1. How does the magnetopause reconnection rate depend on the upstream solar wind conditions (Mach number, IMF orientation, etc.)?
2. How do the FTE characteristics depend on dayside reconnection and upstream conditions?
3. What is the contribution of FTEs to global plasma and magnetic flux circulation?

Our preliminary results using Hall MHD show that lower Mach number upstream driving produces higher occurrence of FTEs, larger FTE propagation speed, stronger core field and more open fluxes carried by FTEs compared to higher Mach number cases. The general characteristics of the magnetosphere and resulting FTEs in our simulations are very consistent with the recent statistical analysis of MESSENGER observations of FTEs. By analyzing and comparing simulation results between the two models that contain different physics and with MESSENGER observations, we expect to develop much improved understanding of the nature of magnetic reconnection in low Alfvén Mach number, low plasma beta environment, as well as the dependence of FTEs on upstream conditions and the contribution of FTEs to global plasma and magnetic flux circulation in Mercury's magnetosphere. The proposed investigation is expected to greatly enhance the science return of the MESSENGER mission and to provide important scientific insight and context for the interpretation of observations from future missions to Mercury, such as the much anticipated BepiColombo mission scheduled to arrive at Mercury in late 2025.

Matthew Knight (PI)/Carrie Holt (FI)
University of Maryland, College Park
21-PLANET21-0110, Discriminating the Dynamical History of Long-period Comets Using Brightness Behavior

Comets are remnants of planet formation, spending most of their lifetime unchanged in the outer Solar System. However, when a comet enters the inner Solar System, solar irradiation will induce the outgassing of volatiles, which can cause cometary nuclei to undergo physical changes, as well as chemical changes. Comets entering the inner Solar System for the first time (dynamically new comets; DNCs) are valuable probes for connecting observed cometary properties to conditions in the pre-solar nebula and subsequent evolution, as they are considered to be mostly primordial with limited solar heating prior to discovery. Additionally, studies of these DNCs can give context to searches for volatiles in exoplanetary systems as more of these systems will be discovered and characterized in the coming decades with new instruments such as JWST and HabEx.

We propose to investigate the activity of DNCs by characterizing the onset and variations of brightness with heliocentric distance compared to returning long-period comets (LPCs). Our research is separated into two parts; the first project uses archival measurements of LPCs with known dynamical histories to investigate how past orbits affect long-term brightness behavior. The second project focuses on the early brightness behavior of inbound LPCs at large heliocentric distances by analyzing new observations currently underway beginning Fall 2020. By characterizing the brightness behavior, we will better understand (a) what processes are driving the activity of DNCs and (b) how a more primitive nucleus (without a dust mantle) affects activity. Additionally, we will be able to (c) better predict the brightness evolution of LPCs for the planning of future observations, including missions such as Comet Interceptor; and (d) assess whether brightness behavior can be used as a diagnostic to distinguish DNCs, separate from dynamical modeling. This proposed research will answer key outstanding questions related to the primitive nature of DNCs, the evolutionary processes occurring on small bodies, and the conditions in the early Solar System.

Sebastian Kopf (PI)/Ciara Asamoto (FI)
University Of Colorado, Boulder
21-PLANET21-0215, Uncovering the Evolutionary Stability of Isotope Biosignatures: Nitrate Reductases as A Model System

Summary: The stable isotopes of nitrogen (15N, 14N) are excellent tools for tracing the nitrogen cycle in both modern and ancient ecosystems (Kendall, Carol et al., 2007; Stüeken et al., 2016). Nitrogen isotopic biosignatures will also be useful in the search for life beyond Earth. Microbially mediated metabolic pathways   such as fixing nitrogen from the atmosphere or assimilating nitrogen into the biological building blocks of life   are essential to all life on Earth. Finding evidence of nitrogen cycling would be a compelling indicator of life on other planetary bodies (Chan et al., 2019). However, any inferences about life in extraterrestrial environments requires a mechanistic understanding of the origin and robustness of potential biosignatures. Signs of life that hint at metabolic activity, such as non-equilibrium isotope effects, are particularly powerful indicators but are subject to evolutionary pressures that may change biological signals in unexpected ways. Here I propose to use the isotopic signatures of different nitrate reductases as a model system to uncover the evolutionary stability of enzymatic isotope biosignatures. Specifically, I propose to study the response of the isotopic biosignature of the NarG nitrate reductase in response to changes in the genetic sequence between two modern end-members that have markedly different dual isotopic fingerprints.

Workplan in brief: To evaluate the evolutionary stability of isotopic signatures, I will complete two complementary research aims using the NarG nitrate reductase as a model system. For Research Aim 1, I will build on previously discovered differences in isotope fractionation during nitrate reduction in the Bacilliota phylum versus the Proteobacteria phylum by filling the evolutionary gap in isotope phenotypes between these endmembers. To do this, I will culture and isotopically characterize six new strains of nitrate reducing bacteria and archaea. For Research Aim 2, I will perform site directed mutagenesis experiments of the NarG enzyme active site in the well-developed and isotopically characterized (Asamoto et al. 2021) genetic model system Pseudomonas aeruginosa to emulate key sequence variations observed between the Proteobacteria and the Bacilliota. Isotopic characterization of the resulting mutant strains will allow me to determine how small evolutionary adaptations in an enzyme impact the resulting isotopic biosignature.

Relevance to NASA: Our ability to confidently interpret isotopic signatures in the rock record and on other planetary bodies is based on the assumption that isotopic biosignatures are unchanging through time. Uniformitarianism for physical geologic processes is a valid assumption, however, this may not hold for biologic pathways and there is limited data available to date that examines this directly. The results of this research will speak to the robustness of isotopic biosignatures in the rock record on Earth and inform the interpretation of potential isotopic signatures discovered on other planetary bodies. These outcomes are particularly relevant to the Planetary Science Division's goal: To improve our understanding of the origin, evolution, distribution, and future of life in the universe".

James Lyons (PI)/Megan Householder (FI)
Arizona State University
21-PLANET21-0152, Measurement of Nanoparticle Surface Energies with Application to Nucleation and Condensation in Exoplanet Atmospheres

Aerosols are a ubiquitous feature of exoplanet atmospheres, sometimes obscuring the spectral determination of atmospheric gas composition. Aerosol composition is usually determined from models of nucleation rate for condensable species in an atmospheric of a given composition. For hot Jupiters, condensable species include various silicates, sulfides, and other high temperature condensates. For lower temperature objects, such as warm Neptunes and super Earths, photochemical production of aerosol particles is predicted to be dominant. Because it is not yet possible to definitively determine aerosol composition through astronomical observations, it is important to model aerosol production as accurately as possible. A key factor in the determination of nucleation rate is the surface energy of the nucleating material. High surface energy materials, such as forsterite, will nucleate much more slowly compared to lower surface energy materials, such as sulfides. Here, we propose to measure surface energies for several important and likely exoplanet condensates including ZnS, MnS, Na2S (sodium sulfide), enstatite, and spinel. Surface energies will be determined by synthesizing nanoparticles and micron-sized particles of the compound of interest, and then using calorimetric techniques to measure the excess enthalpy as a function of particle surface area. From these data, an accurate surface energy is determined for both hydrous and anhydrous phases. The synthesis and calorimetry will be carried out in the Navrotsky laboratory at ASU. This new surface energy data, together with the existing surface energy data that has up to now been not utilized by the exoplanet community, will be included in nucleation rate calculations for hot Jupiters. Finally, we will use the Community Aerosol and Radiative Model for Atmospheres (CARMA) code to calculate particle size distribution and radiative transfer properties of nucleating aerosols for representative hot Jupiter atmospheres. The proposed research supports the Exoplanet Research Program (XRP) with respect to interpretation of observations of exoplanets, and, in particular, our research provides laboratory data of high relevance to a broad range of exoplanet atmospheres.

Alfred McEwen (PI)/Mackenzie Mills (FI)
University of Arizona
21-PLANET21-0042, Effects of Subsurface Fluid Reservoirs on Martian Geomorphology in Utopia Planitia

Enigmatic morphologies and features in Utopia Planitia (UP) which may have an origin involving fluids are compelling subjects for modeling past Martian processes. The northern plains of Mars, including UP, are proposed to have been extensively resurfaced. One proposed source of resurfacing is mud volcanism, which is the mobilization and eruption of mixed fluid and sediment reservoirs. Mud volcanism is scientifically important because it could modify surfaces, create geomorphologic features, and expose subsurface material.

Several distinctive morphologies of UP may be linked with upwelling fluids and mud volcanism. Pitted cones are conical features with central craters that display a variety of clustering styles. These features resemble constructional cones on Earth and have been proposed to form through igneous or sedimentary volcanism. Another intriguing UP morphology is a linear, smooth band-like structure. Some observed bands exhibit uplifted flanks similar to extensional graben.

In this proposal, I address the feasibility of mud volcanism to cause widespread resurfacing in UP, form bands, and create observed pitted cones. This will be accomplished with three focused objectives. In Objective 1, I propose five modifications that will advance my existing numerical model of mud volcanism applied to Mars and UP. The model will constrain what conditions were needed to produce observed resurfacing and what that implies about Martian geologic history, such as the existence and possible duration of vast fluid reservoirs under UP. Objective 2 will consist of mapping selected band parameters, modeling the local stress field using band orientations, and constraining structural conditions of two band formation scenarios that include upwelling mud slurries infilling extensional surface features. Objective 3 will map and analyze spatial distributions of pitted cone populations to probe the link between cone spacing and subsurface structures.

To accomplish my three objectives, I will use a combination of numerical model development, application of terrestrial structural software, and geomorphologic mapping. The model development will be done in Python to my existing numerical model. The structural software to be used includes the FaultKin software developed by Rick Allmendinger and the Move software. Geomorphologic mapping will be done in ArcMap 10.8. Basemaps will be spacecraft images and digital terrain models from the Context Camera and the High Resolution Imaging Science Experiment. Mapping will focus on the spatial distributions of pitted cones and the dimensions and orientations of bands.

Understanding Martian mud volcanism and potential flow sites is important because of the implications of sediment mobilization and planetary fluids. Subsurface fluids and sediments are poorly understood because they are difficult to access using remote sensing. Potential past mud flow sites would be valuable to identify because they would provide study sites for geomorphological effects of extruded material and planetary fluids. Such sites may also reveal subsurface compositions in UP.

Finally, UP is the landing site of the China National Space Administration Tianwen-1 lander and Zhurong rover, which have a scientific goal of studying UP surface morphology and composition. Thus, studying the geologic processes that may have been active in UP is increasingly important. By advancing our understanding of resurfacing processes and feature formation in UP, and the possible role of fluids, my science objectives help address high-priority questions outlined in the Planetary Science Research Program and NASA's science goals for Mars.

Claire McLeod (PI)/Aleksandra Gawronska (FI)
Miami University
21-PLANET21-0151, New Insights into Extraterrestrial Magmatic Processes through a Textural and Chemical Investigation of Apollo 11 Group A Lunar Basalts

Magmatism is a fundamental process through with rocky objects in our Solar System (e.g.., Moon, Earth) differentiate and evolve. The emplacement of basaltic magma on planetary surfaces has resulted in the generation of secondary crusts on these objects across the Solar System (e.g., Moon, Mars). Such basaltic crusts possess distinct physical and chemical attributes and have been extensively studied in terrestrial magmatic systems. This has led to the identification of distinct crystal populations within magmatic products, leading to a paradigm shift in the field of terrestrial igneous petrology. It is now widely recognized that magmatic systems are open" in nature, where distinct magma batches and their associated crystal populations interact. This contrasts with closed" systems where a single magma batch differentiates, and no exchange occurs. The goals of this project are thus to and 1) investigate the processes through which basaltic crusts are established on the surfaces of rocky planetary objects and, 2) evaluate the extent to which extraterrestrial magmatic systems are/were open" or closed" by investigating the existence of distinct crystal populations within basaltic samples directly collected from our closest planetary neighbor, the Moon, This work will be achieved through study of the texturally diverse Apollo 11 group A basalts. These samples were selected because they are hypothesized to have erupted as part of one lava flow, and originated from a mantle source distinct from the remainder of the Apollo 11 samples. All samples are enriched in K and rare earth elements, likely the result of assimilation of lunar KREEP (material enriched in K, rare earth elements, and P). Specifically, this study will be completed by employing a comprehensive textural and chemical approach to investigate magma evolution from source to surface. First, rock chips will be investigated with X-ray computed tomography to assess sample microstructures (i.e., foliation/lineation, particle size distributions) generated during emplacement at the surface. Next, polarized light microscopy will be used to evaluate textural attributes of samples, specifically by generating crystal size distributions (CSD) for major silicate phases (i.e., feldspar). CSDs will be used to evaluate whether any changes during crystal growth are recorded by crystal shapes. Next, chemistry at the thin-section scale (via elemental mapping), and the crystal scale (via in-situ spot analyses of major silicate minerals) will be evaluated to track changes in magma chemistry during crystal growth. Collectively, the work proposed here will be the first of its kind to comprehensively evaluate the evolution of an extraterrestrial magmatic system from source to surface. This project thus has the potential to advance our understanding of the nature of processes operating in extraterrestrial magmatic systems, which could impact our understanding of magmatism across the Solar System. Through this work, this project addresses NASA's Strategic Objective 1.1 to Understand the Sun, Earth, Solar System, and Universe." As humanity looks toward exploration and eventual colonization of the lunar surface, it is critical to understand the processes (such as magmatism) that once operated on the Moon and affected the lunar surface over time. The project proposed here will provide new insights into the evolution of the lunar surface and interior that may be critical to future lunar explorers, which is relevant to the Planetary Science Research and Analysis Program within the Planetary Science Division.

John Mustard (PI)/Elizabeth Fisher (FI)
Brown University
21-PLANET21-0105, Reflectance Spectroscopy as a Tool for Identifying and Understanding Surface Adsorbed Water on the Lunar Surface

This study will isolate and quantify the spectral signatures of surface adsorbed vs. internal water on lunar relevant mineral and glass, to constrain approaches for characterizing how water is sequestered in the lunar soil using remotely sensed spectral data. I will achieve this by using Hapke radiative transfer modeling (RTM) to characterize how the shape and intensity of the 3 ¼m region on lunar-like materials evolves as the abundance of surface adsorbed water increases. This research ad-dresses fundamental questions about water on rocky bodies in the solar system using the Moon as an example. How is lunar water observed on and across the surface sequestered within the soil, adsorbed to grain surfaces, or within grain interiors? Lunar water has been mapped on global scales using reflectance spectroscopy, but available spectra cannot be used to tease apart the contributions from water internal to or on the surface of mineral grains. The laboratory study proposed here is designed to provide the basis for constraining the nature of water that is sequestered on and/or in the lunar soil using remote or in situ spectroscopy measurements of the lunar surface. The study will achieve this by isolating the signature of surface adsorbed water on samples of lunar relevant materials measured in the laboratory, and using radiative transfer modeling to separate these spectral effects from those caused by water/OH internally bound within soil grains. These results will be particularly important for evaluating the origin of time-variations in hydration observed on the Moon.

Objectives:

1) Isolate the spectral signatures of surface adsorbed vs. internal water on lunar relevant mate-rials using radiative transfer modeling.
2) Determine how the presence of surface adsorbed water changes shape and the intensity of the 3¼m absorption region in lunar minerals & soil.
3) Quantify how radiative transfer estimates of water abundance on the lunar surface are affected by
   a. the presence of surface adsorbed water
   b. target mineralogy
   c. assumptions made regarding the particle size distribution of lunar soil.

Relevance & Impact. The results of this study will be critical to interpreting spectral data from future lunar missions, such as Lunar Trailblazer. Understanding how the signature of surface adsorbed water manifests in spectra of lunar like materials will help define the best approaches to measure diurnal variations in lunar hydration (e.g., will 3um band depth or shape be more relevant). Additionally, understanding potential magnitude of these changes will constrain what methods can be used to predict the abun-dance of surface water from remotely sensed data (e.g., will magnitude of model uncertainty swamp the magnitude of observed variations). Broadly, studying volatile processing on the lunar surface improves our grasp of volatile processing on all rocky airless bodies in the solar system, and supplies information that underpins our ability to utilize water resources in-situ.

Victoria Orphan (PI)/Sergio Parra (FI)
California Institute of Technology

21-PLANET21-0222, Multi-Modal Imaging Analysis of Deep-Sea, Carbonate-Hosted Microbial Communities: Connecting Distribution, Composition, and Activity in a Terrestrial Analog Site

Identifying and characterizing the effect of the rock host environment on the in situ distribution, composition, and activity of carbonate-hosted chemolithotrophic microbial communities is a key step towards understanding the habitability of carbonates on Mars and other planetary bodies. Here, we propose an important advance by applying multi-modal imaging and modelling to map and characterize the in situ distribution, composition, and chemolithotrophic activity of deep sea, carbonate-hosted microbial communities as a function of their micro-scale environment, leveraging recently collected samples from cold seep and hydrothermal settings.

The key science objectives of the proposal are thus to: 1) Characterize and quantify the physical and chemical parameters representative of the interior environment of deep-sea, authigenic and hydrothermal carbonates; 2) Model biomass distribution and activity in deep-sea, authigenic and hydrothermal carbonates as a function of their micro-scale environment; and 3) Determine and compare the identity and activity of mapped, carbonate-hosted microbial cells across different carbonate substrate types.

Specifically, we propose to use collected samples from carbonate chemoherms and chimneys on research expeditions in May and October 2021 led by PI Orphan to methane seeps at Santa Monica Basin (site 800; 33.79N, -118.67E, 750 m) and at the hydrothermal vent fields in S. Pescadero Basin (Auka, 23.96N, -108.86E, 3800 m). With these samples, we will first collect mineralogical composition using X-ray diffraction (XRD) and compare relative abundance of amplicon sequence variant (ASV) of samples using Illumina 16S rRNA sequencing on powdered incubated carbonate samples. Live carbonate samples will then be incubated at in-situ temperatures with specific, isotope-labeled substrates to monitor anabolic activity. Next, we will pursue a multi-modal imaging approach using 3D-Ray Microscopy (XRM), microimaging visible and shortwave infrared reflectance (VSWIR) spectroscopy, fluorescence in-situ hybridization coupled to nanoscale-secondary ion mass spectrometry (FISH-nanoSIMS), and scanning electron microscopy (SEM). Together, the resulting data sets will be compared, correlated, and analyzed to reveal key differences in distribution, composition, and metabolic activity across carbonate micro-environments. A modelling approach will also seek to model biomass distribution across different carbonate substrate types by modelling in-situ perfusion of carbonates and resolving spatial and temporal changes in concentrations of key metabolites.

This proposal is directly connected to NASA's 2014 Science Mission Directorate (SMD) Science Plan in Planetary Science, Strategic Goal 1 in NASA's 2018 Strategic Plan, and Strategy 1.3 from the 2020-2024 SMD Science Plan, as we will 1) expand on our knowledge of terrestrial systems as an analog for habitable systems beyond Earth by examining the environmental controls on endolithic microbes in deep-sea carbonates and 2) employ interdisciplinary approaches by leveraging in silico modelling alongside methods in molecular microbiology, isotope geochemistry and mineralogy. The proposal specifically addresses the following goals from the 2014 SMD Division Science Plan: explore and find locations where life could have existed or could exist today, and improve our understanding of the evolution of life on Earth to guide our search for life elsewhere.

Ujjwal Raut (PI)/Caleb Gimar (FI)
University of Texas, San Antonio

21-PLANET21-0145, Solar Wind Radiolysis of Hydrocarbons Pertaining to Charon's Polar Reddening

Imagery from NASA New Horizons (NH) mission revealed the presence of Charon's red-colored north polar region, which has been attributed to red-hued refractories produced by interplanetary medium (IPM) Lyman-alpha photolysis of Plutonian methane cold-trapped on Charon's winter pole. Recent studies further examined this hypothesis through laboratory experiments and exospheric modeling to conclude that IPM Lyman-alpha converts methane into higher-order hydrocarbons with a distribution that increases with latitude, consistent with the poleward darkening in the NH images. These studies also established ethane to be the dominant photoproduct at the polar latitudes; however, ethane is colorless and cannot fully explain Charon's reddish polar hue. Photolytically-produced ethane could be processed further by the solar wind over a ~30-year period post-spring sunrise, as Charon's surface temperatures gradually rise to their 60 K maximum. Specifically, solar wind (SW) protons can provide enough energy to break carbon-hydrogen bonds in the ethane frost, generating radicals and initiating the chemistry to possibly form more complex redder" refractories. However, the color of hydrocarbon ices - and more importantly, the color evolution of these ices with radiation dose - has yet to be characterized and is urgently needed to understand not only Charon's red pole, but also surface colors of other planetary bodies such as Pluto, Titan, and Triton.

To address this critical knowledge gap, we propose a laboratory study to obtain UV-Vis-NIR reflectance spectra of Charon-relevant hydrocarbon ices, and examine the effects of SW-like proton irradiation on the reflectance spectra. Specifically, we seek to answer the following Science Questions (SQs): (1) what are the colors (i.e. optical constants n, k) of hydrocarbon ices - ethane, propane, ethylene, and acetylene - likely to occur on Charon's surface and other planetary bodies of interest and (2) how does the color of these hydrocarbon ices evolve with increasing dosage from exposure to SW-like proton radiation? SQ 1 will be answered by obtaining 190-1100 nm reflectance spectra of thin films of the aforementioned ices over 10-60 K, temperatures relevant to Charon. We will fit the experimental spectra with synthetic spectra generated using Fresnel's reflectance equation and iteratively optimized via Kramers-Kronig (KK) scheme to yield the optical constants n and k and the film thickness. The key deliverables emerging from closure to SQ 1 will be a color atlas of hydrocarbon ices significant to Charon and other planetary bodies. Answering SQ 2 will require the exposure of selected ices to 1 keV protons and measurements of the reflectance spectra with incremental dose. We will then derive n and k versus radiation dose from reflectance spectra of irradiated ices. Key deliverables from closure to SQ 2 will be a color atlas of irradiated hydrocarbon ices as a function of dose and comprehensive understanding of reddening or darkening induced by SW radiation.

Understanding the color evolution of the hydrocarbon ices as a result of radiation processing directly contributes to the science goals of both current and future NASA missions. By seeking to explain Charon's surface color observed by New Horizons, this investigation is directly involved in the NASA New Frontiers program efforts. Examining the colors of a diverse set of hydrocarbon ices will benefit color investigations of other icy bodies in the solar system by future missions. In these ways, this proposed research advances scientific knowledge of the origin and history of the solar system" as articulated in the goals of the NASA Planetary Science Division and stated in the NASA SMD 2014 Science Plan.

Laura Schaefer (PI)/Andrea Zorzi (FI)
Stanford University

21-PLANET21-0089, Impact-induced Formation of Prebiotic Molecules on Terrestrial Planets

Among many effects, impacts striking rocky planets are capable of producing new species. When hitting the surface, materials from the impactor and the target vaporize and rapidly expand through the atmosphere, forming a vapor plume. The extremely high temperature and pressures that occur during expansion can induce chemical reactions with the atmosphere, leading to molecules not previously present on the planet. Previous models have given attention to hydrogen cyanide (HCN), due to its central role in organic molecules. However, those models have made simplifying assumptions by either assuming equilibrium chemistry, setting unrealistic temperature upper bounds compared to the real temperatures reached by the plume, or neglecting the presence of an atmosphere. Therefore, an accurate description of the disequilibrium processes involved in the plume-atmosphere interaction is missing. As a result, species abundances can be underestimated by up to an order of magnitude.

The objective of this proposal is to investigate the chemical reactions occurring between the vapor plume and the atmosphere of a terrestrial planet, to assess the amount of prebiotic chemical species (HCN, NH3, CH4) are produced during an impact event. We will also understand how those abundances change when we consider a different atmospheric composition, or a projectile made of different material and/or hitting the planetary surface at different velocities. We ultimately intend to constrain the contribution impacts have on planets' biological potential.

To tackle the problem, the proposal seeks to build a model capable of describing the interaction between the vapor plume and the background atmosphere. Coupled hydrodynamics and kinetic reaction modules ensure a more accurate description of the high-temperature and pressure chemical reactions occurring during the plume expansion, to quantify how the abundance of prebiotic molecules evolves over time during an impact event. Once validated, the model will be applied to assess how the identity and abundance of produced species are affected by the original composition of the impacted atmosphere, projectile material and its velocity. Finally, the model will be applied to sustained impactor flux to investigate the contribution impacts have on the budget of those molecules, and how their signature changes on solar and extra-solar terrestrial planets subject to different bombardment histories. Our model is general, so that further applications are possible, e.g. tracking other relevant species or studying the production of climatically active gases during specific impact events.

The significance of the proposed work stems in its intent to address NASA's Planetary Science Decadal Survey objective of "understanding the diversity of terrestrial planets and their evolution". Furthermore, this work will improve our understanding of the history of the Solar System and the potential for life elsewhere, as mentioned in the FINESST amendment.

Britney Schmidt (PI)/Sara Miller (FI)
Cornell University
21-PLANET21-0123, A General Circulation Model to Assess the Dynamics and Habitability of Europa s Ocean

The proposed research seeks to produce a general circulation model to study heat, salinity, and momentum transport between the ice shell and ocean at Jupiter's moon, Europa. This work will leverage the terrestrial MIT general circulation model (MITgcm) as a baseline, then modify and add numerical packages as appropriate to adapt the model to the Europa environment. An important component of the proposed model will be the ice shell code, which will capture melting and freezing physics using a modified version of a widely adopted parameterization developed for ice-covered portions of Earth's ocean. Given that global ocean circulation of heat, salt, and nutrients is an essential component of maintaining the marine biosphere on Earth, the thermal, geochemical, and momentum fluxes produced by the proposed model will shed light on the potential habitability of Europa's ocean. Moreover, using a state-of-the-art terrestrial ocean model as its foundation, the proposed model will capture a level of detail far beyond what has been done in existing planetary ocean models. The anticipated results of the proposed model will advance our understanding of the dynamical mechanisms that form and sustain ocean worlds across our solar system, as well as their potential to sustain life, which addresses key goals of NASA's Solar Systems Working and Habitable Worlds programs, and is therefore relevant to NASA and the FINESST program.

Edward Schwieterman (PI)/Daria Pidhorodetska (FI)
University Of California, Riverside
21-PLANET21-0044, High CO2 Climates and Observables in the Outer Habitable Zone

The proposed work will investigate the climate stability and spectral signatures of high CO_2 terrestrial planets in the mid-outer habitable zones of stars of various spectral types. The habitable zone (HZ) is a conceptual region that guides our search for rocky exoplanets that could maintain a surface liquid ocean and produce remotely detectable biosignatures. Thus far, Earth's atmosphere has served as the template for imagining what life might look like on an exoplanet, but the amount of atmospheric CO_2 predicted by the HZ concept ranges significantly. As most studies have been generated under the assumption of low, Earth-like CO_2 values, the implications for the climate of an Earth-like exoplanet with an atmosphere high in CO_2 have not been thoroughly investigated. Recent efforts to more accurately characterize the HZ have primarily focused on the inner edge, where CO_2 contents would be expected to be low (e.g., hundreds of ppm or less). However, JWST and future telescope missions will characterize planets throughout the HZ, including many in the middle or outer HZ, where CO_2 is predicted to be high (e.g., ~5-20 bars). This work will address the likely distribution of CO_2 on exoplanets in the outer HZ and how it is influenced by planetary conditions such as obliquity and rotation rate (Task 1: Determining the Limits of the OHZ for High CO_2 Atmospheres), as well as the impact that overlying CO_2 has on remote signatures of habitability/inhabitation (Task 2: Spectral Modeling of High CO_2 Atmospheres). To accomplish these objectives, we will use a 3D global climate model to investigate how the atmospheric states of habitable planets vary by factors such as insolation and host star spectral type, and utilize spectral and instrumental modeling to determine how this will impact future exoplanet surveys and observations. We will then apply these results to known planetary systems (Task 3: Climate Modeling of Known Planetary Systems) that are promising for future observations through further 3D global climate, spectral, and instrumental modeling (Task 4: Instrumental Modeling of Known Planetary Systems). The proposed study explicitly addresses the objective within the Planetary Science Division to ascertain the potential for life elsewhere. Gaining a more nuanced understanding of habitability in the outer HZ will allow for more efficient deployment of observational resources in the future. These goals are also relevant to cross-divisional programs including F.3 Exoplanets Research Program and F.4 Habitable Worlds.

Matthew Siegler (PI)/Angelica Martinez (FI)
Southern Methodist University, Inc
21-PLANET21-0192, Cryogenic Thermal Conductivity Measurements of Lunar Regolith

We propose laboratory investigations into the low temperature thermal properties of lunar regolith. These measurements are highly relevant for targeted missions to the lunar south pole (such as the NASA VIPER mission) and will inform studies of near-surface water ice at the lunar poles. Despite the numerous NASA missions dedicated to measuring and mapping the thermal properties of planetary surfaces, laboratory measurements that would aid in interpreting remote sensing data from these missions are sparse. Although some laboratory measurements on the thermal characteristics of lunar regolith exist, very few measurements have been carried out below 150 K. Permanently shadowed regions (PSRs) are areas near the lunar poles that remain in perpetual darkness. PSRs are key areas of interest for lunar exploration due to their incredibly cold temperatures (below 100 K), which allow them to cold-trap water ice and other volatiles. Standard lunar thermal models differ most significantly from remote sensing data collected from PSRs, and this is primarily due to a lack of low-temperature laboratory measurements of lunar regolith. Our laboratory scheme consists of measuring the thermal conductivity of lunar regolith in vacuum in the temperature range of 15   350 K. We present theoretical evidence for how these low temperature results could significantly change modeled surface properties of the lunar poles. We aim to use this data to develop a new, well-constrained thermal conductivity model, which we can then be used to update lunar polar maps. Accurate thermal modeling estimates for PSRs are essential for creating secure travel routes for VIPER (as mission planning includes traversing into PSRs) and obtaining better estimates for ground ice location.

Jacob Simon (PI)/Jeonghoon Lim (FI)
Iowa State University, Ames
21-PLANET21-0084, Formation of Kuiper Belt Objects in the Protosolar Nebula

One of the critical questions JWST seeks to answer is: how are the building blocks (planetesimals) of planets assembled? Kilometer-sized planetesimals such as Kuiper Belt Objects (KBOs) form out of micron-to-cm sized small grains, but it has been theoretically challenging to examine how the small grains behave in the outer region of proto-solar disk where the Kuiper Belt is located (~ 45 AU from the Sun for the Cold Classical Kuiper Belt), mainly due to turbulence and a magnetic field.

It has been theorized that the magnetorotational instability (MRI) rapidly destabilizes orbiting ionized gas and generates vigorous turbulence within sufficiently well-ionized regions. However, due to low ionization level in the outer region of a proto-solar disk, we must consider non-ideal (i.e., weak coupling between the magnetic field and gas) magnetohydrodynamic (MHD) effects: the Hall effect arising from ion-electron drift and ambipolar diffusion (AD) from ion-neutral drift. The AD can efficiently damp MRI-driven turbulence near the mid-plane, while the Hall effect can make the mid-plane turbulent by amplifying magnetic fields in the presence of a large-scale vertical (i.e., perpendicular to the mid-plane of a disk) field aligned with the angular momentum vector of a disk. As long as the pronounced impact of the non-ideal effects is considered, we must consider the Hall effect and the AD to properly examine how dust properties are affected by the magnetic fields and turbulence. We will directly determine quantities relevant to dust dynamics, which will inform us of realistic conditions under which growth of small grains proceeds during the earliest stages of our Solar System history.

After the micron-sized grains grow into mm-cm sized particles, they will aerodynamically interact with gas and initiate a process known as the streaming instability (SI). The growth timescale of the SI is so short that it can lead to local particle concentration within a few local orbital periods.

However, recent studies have shown that growth rate of the SI is considerably reduced when either external turbulence or multiple particle sizes is considered. Moreover, even if the initial mass function of planetesimals has been intensively studied by numerical simulations, it is not still well understood which parameters the mass function depends on. More importantly, there is the inconsistency between observation of KBOs and theory; size distributions of planetesimals produced by observations and numerical simulations are in disagreement.
In order to address the aforementioned issues, we will perform the following three tasks with the ATHENA gas+particle code:

1. Examine effects of non-ideal MHD on the dust dynamics in the outer region of the proto-solar disk and characterize magnetically driven turbulence.

2. Study how magnetically driven turbulence influences the streaming instability and clumping of the dust grains in the presence of multiple particle sizes.

3. Determine initial mass function of planetesimals formed by the streaming instability and magnetically driven turbulence compare it with observations.

The significance of the proposed work to NASA objectives is outlined here. First, we will directly determine the nature of gas and dust grains by building realistic models of the early stages of planet formation in our Solar System. Second, using the initial conditions determined by the first task, we will study mass function of planetesimals and compare it to observations of Cold-Classical KBOs. Our proposed work thus will directly address the goal of Emerging Worlds: advance scientific knowledge of the Solar System by investigating how it formed and evolved." Moreover, as JWST will observe small bodies in our Solar System such as KBOs, the proposed work will significantly contribute to JWST observations by establishing a concrete understanding of how the small bodies formed.

Mark Simons (PI)/Alexander Berne (FI)
California Institute of Technology
21-PLANET21-0039, Exploring Different Scales of Crustal Deformation on Enceladus

Saturn's moon Enceladus is a geologically active world. Geysers, which probably source material from a global ocean, continuously erupt at the satellite's thinned south pole and are powered by immense tides from Saturn. Tides also probably drive dissipation to produce enhanced heat flux within Enceladus's ice shell. Existing numerical models of tidal motion which account for important ice shell properties, including variations in thickness and the presence of weakness zones or 'faults', can reproduce several observed phenomena such as south polar thinning and enhanced heat flow. However, these models presently cannot explore the relationship between along-fault activity (e.g., slip, or relative displacement across a fault) and regional or global processes. We therefore propose constructing a novel numerical model of Enceladus which implements state-of-the-art techniques to simulate the influence of fault structures. From this work, we will directly investigate the relationship between Enceladus's tides and the satellite's present-day activity and structure.

For this proposal we will use the finite-element code Pylith, a tool commonly used in Earth Sciences to describe deformation of the Earth's crust. Using this model, we run simulations which explore the impact of faults and thickness variations on the formation of faulted terrains, the stability of large-scale topography, interpretations of large-scale gravity/topographic data, and processes controlling geyser activity. Understanding these processes are a key objective for potential spacecraft missions to Enceladus; as such, this work will provide estimates of the measurement requirements necessary for distinguishing between several investigated hypotheses. The proposed work aligns closely with the Planetary Science Mission Directorate's strategic objectives to advance scientific knowledge of 1) the origin and history of the solar system and 2) the potential for life elsewhere (NASA, 2020). Moreover, this proposal's objectives align with Priority 1 Exploration and Scientific Discovery" from NASA's 2020-2024 A Vision for Scientific Excellence (NASA, 2020), Strategic Objective 1.1: Understand The Sun, Earth, Solar System, And Universe" from NASA's 2018 Strategic Plan (Plan, 2018) and Goal II A.1 What is the thickness of the ice shell and how does this property vary spatially and/or temporally?" from NASA's 2019 Roadmap to Ocean Worlds (Hendrix et al., 2019).

Hendrix, Amanda R., et al., "The NASA roadmap to ocean worlds." Astrobio. 19.1 : 1-27., 2019.

National Aeronautics and Space Administration, Science 2020-2024: A vision for scientific excellence., 2020.

Plan, NASA. NASA Strategic. "R/OL." Washington DC: NASA., 2018.

Sabine Stanley (PI)/Mayuri Sadhasivan (FI)
Johns Hopkins University
21-PLANET21-0128, Dynamics of Ice Giant Magnetic Fields

The aim of this proposed work is to use numerical magnetohydrodynamic (MHD) simulations of thin-shell dynamos above a superionic layer as a proxy for observations of Uranus/Neptune-like magnetic fields, and use statistical analysis of the simulated fields to build stochastic models/equations that describe how thin-shell dynamos evolve. My project will help to constrain the impacts of: internal composition gradients, superionic volatile phases, and moist convection on magnetic field evolution - all phenomena that have implications for secular cooling and the energy budget in solar system and extrasolar ice giants. My project also aims to explain the displaced and tilted magnetospheres of Uranus and Neptune. By understanding the basic physics of the local giants' magnetic fields, we can predict the strength and orientation of the magnetic fields of extrasolar giants.

Nicholas Swanson-Hysell (PI)/Anthony Fuentes (FI)
University of California, Berkeley
21-PLANET21-0120, Dating Hematite in Ancient Fluviolacustrine Sedimentary Rocks: Developing the Capacity to Constrain the Timing of Hydrologic Cycling on Mars

The formation of the iron oxide hematite is strongly associated with oxidized fluids on Earth. Lithologies containing significant coarse-grained specular hematite have been previously identified on Mars in conjunction with fine grained pigmentary hematite that is the source of its characteristic red color. The presence of both specular and pigmentary hematite in sedimentary rocks on Mars are indicators of the presence of liquid water at or near the surface. Given the importance of determining the timing of liquid water on the martian surface, developing tools to determine the timing of hematite formation is a priority. We propose to develop novel high spatial resolution radiometric dating and paleomagnetic techniques to date the formation of hematite in martian analogue 1.1 billion-year-old fluvial and lacustrine sedimentary rocks on Earth. The techniques developed from this work to constrain the relative and absolute chronology of hematite formation could be applied to returned martian samples that are brought to Earth from Mars Sample Return missions to constrain the hydrologic and climatic conditions during deposition and fluid-mediated alteration. Additionally, isolating the paleomagnetic signal in martian hematite in concert with robust age constraints has the potential to provide constraints on the temporal history of the martian geomagnetic field with connections to both martian interior and paleoclimatic conditions.

Alexis Templeton (PI)/Harry Brodsky (FI)
University Of Colorado, Boulder
21-PLANET21-0219, Habitability of Serpentinizing Environments: The Phosphorus Perspective

Phosphorus must have been crucial to the emergence of life because living organisms require phosphorus to make cell membranes, energy-storage molecules and genetic material. At the origin of life, P reacted with organics leading to functional P-organic compounds (phosphorylation). The potential for life to emerge or survive in a habitat or on a planet is thus dependent on the availability of P. The availability of P refers to both the abundance/spatial distribution of P in a system and its speciation into various chemical forms.

Despite its importance, P is limited in the environment. For life to emerge, aqueous concentrations of phosphate (the most common P compound at Earth's surface) higher than those typically observed in natural waters might have been required. This mismatch between geologic observations and the phosphate requirements identified by prebiotic chemists is sometimes called the "phosphorus problem." Solutions to the P problem fall into one of two categories: finding concentrated phosphate reservoirs or discovering pathways to other phosphorylating agents.

Serpentinization is the hydration and oxidation of ultramafic rock, a process that often produces extremely reducing, mildly hydrothermal (<130 ºC), alkaline environments that seem suited for the emergence of life. Serpentinization might provide two ways around the P problem: The reducing nature of this kind of system could transform P from phosphate into phosphite (a more soluble and stronger phosphorylating agent than phosphate), and secondary minerals that form in serpentinites could strongly sorb phosphate or other P compounds, leading to a concentrated and reactive P reservoir hosted on mineral surfaces. Since interfaces between ultramafic rock and water seem to be one of the most widespread potential habitats in the solar system, it is crucial to determine whether a solution to the P problem lies therein.

The aim of the proposed project is to contribute to models of planetary habitability and the origin of life by investigating the geochemistry of P in serpentinizing environments. The investigation will have two focuses: (1) determining whether phosphite or other P compounds can be produced in serpentinizing systems and (2) characterizing the partitioning of P between solid, adsorbed and aqueous phases.

I will conduct experiments in which aqueous phosphate is incubated with a variety of minerals common to serpentinites. I will use glass serum vials and a hydrothermal reactor setup to test temperatures from 25   300 ºC, pressures of 1   350 bar, and pH 7.5   12.5.

I will use sensitive analytical methods optimized for P detection to determine the redox state(s) of P and track P partitioning within aqueous and solid experimental products and natural samples. For fluids, ion chromatography will be most important. For solids, x-ray diffraction, Raman spectroscopy, and x-ray spectroscopy methods will be used.

I will also characterize the availability of P in natural systems by analyzing samples from a field site. I have applied to sail to the mid-Atlantic ridge with the International Ocean Drilling Project to collect fluid and rock samples from a hydrothermal system. Whether or not I am selected, I also plan to analyze fluid and rock samples from the Samail ophiolite, Oman, that were collected by my advisor.

A central goal of NASA's Science Vision is to determine the potential for extraterrestrial life. First, more must be known about both the origin of life and the requirements for planetary habitability. This work will contribute to both topics. It will contribute to our understanding of the origin of life by testing whether serpentinization leads to concentrated reservoirs of prebiotically plausible phosphorylation agents. This proposal will also produce critical new knowledge about the availability of P in rock-hosted habitats, aiding our search for life elsewhere in the universe.

Laura Villafane (PI)/Nicolas Rasmont (FI)
University of Illinois, Urbana-Champaign
21-PLANET21-0185, Advancing Millimiter-wave Radar Interferometry for Landing Ejecta Measurements

The proposal Advancing millimeter-wave radar interferometry for landing ejecta measurements" addresses one of the major challenges for current and future exploration of rocky bodies of the solar system: the interaction between the plumes of landing thrusters and planetary surfaces (Plume-Surface Interaction, PSI). On the Moon, the landing of a human-class vehicle generates several tons of highly abrasive, micron-sized supersonic ejecta. These particles can cause significant damage to any infrastructure located near the landing site, as well as to the lander itself and even possibly to spacecraft in lunar orbit. Current plans for human missions to the Moon and Mars, which include heavy landers and surface bases, are more vulnerable to PSI than any mission before. The impingement of a high-temperature supersonic gas jet, such as the one generated by a rocket engine, on a granular soil, such as a planetary surface, gives rise to a set of physical phenomena that can be divided into three categories: jet impingement dynamics, ejecta dynamics, and granular media dynamics. These phenomena are strongly coupled, which requires a holistic approach for PSI modeling. The main objective of current PSI studies is to obtain analytical and numerical models with sufficiently high fidelity to support the design of future lunar and Martian landers and infrastructures, which requires the acquisition of large experimental datasets of high-quality measurements in environments relevant to PSIs, both through ground testing and flight instruments. The main problem that this proposal aims at addressing is the lack of non-intrusive ejecta concentration and velocity measurement conducted in conditions representative of lunar and martian environments. This state of affair exists because of the difficulty in constructing and operating a suitable experimental setup and due to the difficulty of performing measurements with high concentrations of opaque soil particles being suspended by the jet.

The instrument concept presented in the proposal is based on millimeter wave interferometry, which is a commonly used in plasma physics, medical, and industrial applications. When implemented using COTS single-chip FMCW radars, the instrument presents a slew of benefits when compared to optical ejecta diagnostics, as it is lighter, more compact, low power, faster, has a measurement range wider by one to two orders of magnitude, is agnostic to the size distribution of the ejecta, and allows for concurrent ejecta velocimetry measurements. These benefits makes it highly suitable both as ground test diagnostic and as a flight instrument for future planetary missions. Besides PSI studies, the instrument can be applied to many opaque flow situations of high commercial and scientific interest, such as internal solid rocket engine flow, aircraft brownout, fire smoke, dust storm, and fluidized beds.

Over the course of this project, a previously demonstrated proof-of-concept of this instrument will be matured into a practical diagnostic for ejecta concentration tomography and velocimetry during PSI ground testing. Experimental data will be collected in conditions relevant to martian and lunar landings in the TF2 PSI facility at UIUC, which will be used in conjunction with other diagnostic techniques to inform and validate PSI modeling efforts. The following tasks have been identified to achieve this goal: optimize the radiation pattern for PSI measurements, fully integrate the instrument into a practical tool, implement multi-chord ejecta tomography, and develop ejecta velocimetric measurements.

June Wicks (PI)/Tyler Perez (FI)
Johns Hopkins University
21-PLANET21-0075, Novel Experiments to Measure Viscosity of Minerals at the Conditions of Planetary Interiors

The viscosity of minerals such as magnesium oxide (MgO) and quartz (SiO2) under high pressures and temperatures strongly influences a terrestrial planet's mantle dynamics, which dictates most of the planet's chemical and thermal evolution. On Earth, the transfer of heat as well as the mechanical motion of the mantle play a crucial role in important processes like plate tectonics, volcanism, mountain building and magnetic field generation. Mantle dynamics also have a direct effect on the atmosphere and climate through interactions such as outgassing and the silicate-carbonate cycle. The mantle is expected to play a similarly important role in almost all other terrestrial planets. Characterizing mantle dynamics is crucial in our understanding of the geologic history of planets in our solar system, as well as establishing habitability of exoplanetary systems.

Despite the importance of mantle material viscosity, there is currently no consensus from either theory or experiment on its value at mantle pressure conditions (>100 GPa). In fact, current studies disagree on the value by several orders of magnitude. Accessing pressures in the laboratory relevant to deep planetary interiors requires smaller sample sizes, which makes it increasingly difficult to observe and quantify macroscopic flow behavior. The lack of experimental constraints on the viscosity of mantle materials at extreme pressures is often cited as a major source of uncertainty in planetary interior modeling, especially for super-Earths. This project will develop two techniques to experimentally constrain the viscosity of minerals at high pressures and temperatures using laser compression along with the VISAR (Velocity Interferometer System for Any Reflector) and SOP (Streaked Optical Pyrometer) diagnostics. I have created initial designs for experiments that observe the evolution of perturbations in shock waves and material interfaces by modifying existing methods to measure strength and viscosity of metals at high pressures. In this proposal, I will carry out these experiments on important mantle minerals, such as magnesium oxide, quartz and olivine and then use a combination of analytical equations and numerical simulations to analyze the data. This project will be the first to experimentally constrain the viscosity of minerals at deep mantle pressure conditions (50-500 GPa) and will improve interior dynamic models of terrestrial planets.

Paul Withers (PI)/William Saunders (FI)

Boston University
21-PLANET21-0103, Uranus and Neptune Stellar Occultations: Understanding Their Atmospheric Thermal Structure

The ice giants are the enigmas of the solar system. Uranus and Neptune have only been visited by Voyager 2, a spacecraft built in the 1970s, which flew by each of them in the late 1980s. Major gaps in the current understanding of Uranus and Neptune negatively impact NASA's efforts to understand solar system workings and evolutionary history. Furthermore, ice giants are one of the most abundant classes of exoplanets, yet applications of the tools of comparative planetology to model their various features are severely limited by poor understanding of Uranus and Neptune.

A critical, unresolved challenge in ice giant science is that the observed upper atmospheric temperatures of Uranus and Neptune are simply too hot. Voyager UV stellar and solar occultation observations reported warm stratospheric and hot thermospheric temperatures far in excess of what could be supported by solar energy alone at 20 and 30 AU. Earth-based stellar occultations, on the other hand, indicate a much cooler stratosphere.

The Goal of this proposed investigation is to reliably determine the upper atmospheric temperature structure of Uranus and Neptune. I will make progress toward this Goal by the completion of two Objectives. Objective 1. Resolve inconsistencies between Voyager 2 and Earth-based determinations of the stratospheric and lower thermospheric temperatures of Uranus and Neptune. Objective 2. Reliably determine the stratospheric and lower thermospheric temperatures of Uranus and Neptune, and quantify uncertainties.
I propose using archival, Earth-based stellar occultations light curves furnished by collaborators as well as published Voyager temperature-pressure profiles to achieve these Objectives. Two techniques will be applied to these data. 1) Traditional stellar occultation analysis, which produces temperature-pressure profiles as a result. 2) Forward modeling, which takes a temperature-pressure profile and produces a synthetic occultation light curve.

In Task A, I will apply the forward modeling technique to the Voyager 2 profiles of Uranus and Neptune. In Task B, I will use statistical tests to determine if the synthetic light curves created in Task A are consistent with dozens of observed, Earth-based light curves. In Tasks C and D, I will use the most modern version of the traditional stellar occultation analysis to create reliable temperature-pressure profiles with uncertainties for Uranus and Neptune, respectively.

This work is relevant to the Solar Systems Working Program, which seeks to understand thermal structures of planetary atmospheres. The only planetary atmospheres without well-understood thermal structures are Uranus and Neptune, a situation this proposed work will help improve.

F.5 Future Investigators in NASA Earth and Space Science and Technology SOLICITATION: NNH21ZDA001N-FINESST

The Science Mission Directorate (SMD) reviewed a total of 927 proposals that were submitted to the **F.5 Future Investigators in NASA Earth and Space Science and Technology (FINESST)** competition within the NASA Research Announcement entitled "*Research Opportunities in Space and Earth Sciences" (ROSES-2021)*. Six SMD divisions at NASA Headquarters conducted/provided oversight for the review and selection process: Astrophysics, Biological and Physical Sciences, Earth Science, Heliophysics, Planetary Science, and Science Engagement and Partnerships (SE&P).

FINESST accepts proposals for graduate student-designed research projects that contribute to SMD's science, technology, and exploration goals. The maximum, three-year total FINESST award amount is $150,000. FINESST grants are limited cost awards. For example, SMD suggests a student stipend of $40,000 per 12 months. Not all projects, however, require the maximum amount available in the period of performance.

FINESST is similar to what 2 CFR200.1 Definitions calls a "Fixed Amount Award". "Fixed amount awards means a type of grant or cooperative agreement under which the Federal awarding agency or pass-through entity provides a specific level of support without regard to actual costs incurred under the Federal award. This type of Federal award reduces some of the administrative burden and record-keeping requirements for both the non-Federal entity and Federal awarding agency or pass-through entity. Accountability is based primarily on performance and results."

SMD's estimated timeframe to communicate the selection or intent-to-award decisions is late May through late July. Selection documents are released first, followed by non-selections. Non-selections may not be available until August 15, 2022, or later. The NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) will announce decisions via a system generated email to the PI and AOR. *NSPIRES makes detailed documentation of the selection and non-selection decisions available for each reviewed proposal to both the Principal Investigator (PI) and Authorized Organization Representative (AOR).* Access to proposal-specific documentation requires logging in to NSPIRES and navigating to the submitted proposal, and not just visiting the web page. FIs, however, cannot receive or access FINESST decisions or review results directly via NSPIRES. If by August 15, the PI or AOR have not contacted the FI, then the FI should ask them to log in to NSPIRES to see if the proposal status has changed and download and share the results.

For assistance with NSPIRES log in, please contact the NSPIRES Help Desk at (202) 479-9376 Monday – Friday, excluding Federal Holidays, (e.g., Juneteenth National Independence observed for 2022 on June 20, July 4, i.e., Independence Day, etc.) 8 AM to 6 PM Eastern Time or by email at nspires-help@nasaprs.com.

Table 1: FINESST-21 Proposal Data

Division	Proposals Reviewed	Proposals Selected (Estimated)	NSPIRES Publication Date
Science Engagement & Partnerships	2	1	May 26, 2022
Biological and Physical Sciences	25	TBD	Pending
Earth Science	394	TBD	Pending
Planetary Science*	224	TBD	Pending
Astrophysics	222	TBD	Pending
Heliophysics	60	TBD	Pending
Total**	927	TBD	July 25, 2022 (Target)

NOTE For Selected PI-FI Teams: Once SMD receives selection acceptance, the FINESST proposal will be transferred to the NASA Shared Services Center (NSSC). NSPIRES cannot track the NSSC grant processing activities. A grant's status may be tracked via a web search on the PI's name (do not use the FI name or NSPIRES proposal number) at: https://www.nasa.gov/centers/nssc/forms/grant-status-form, telephoning the NSSC at 1-877-NSSC123, or e-mailing nssc-contactcenter@nasa.gov.

Any pre-award costs incurred are at the proposer's risk. All new awards receive an automatic 90 days of pre-award spending approval on award, meaning that NASA has waived the requirement for FINESST award recipients to obtain written approval prior to incurring project costs up to 90 calendar days before NASA issues an award. However, expenses incurred more than 90 calendar days before the award require prior written (i.e., email) approval from a Grants Office at the NSSC.

NOTE for Non-Selected PI-FI Teams: SMD received a far greater number of proposals than available funds can support. NASA plans to publish the next FINESST solicitation as a cross-divisional appendix to the NASA Research Announcement entitled "Research Opportunities in Space and Earth Science (ROSES-2022)."

A non-selected 2021 FINESST proposal may be eligible to be revised and resubmitted to the 2022 competition. Entirely new, eligible proposals also are welcome. When the new FINESST solicitation (F.5) is published in final form it will be available at https://go.nasa.gov/FINESST22. Proposal intake will continue for an approximate minimum of 60 days from the release barring any unforeseen circumstances. In the interim, SMD's Cross Division FINESST team welcome general comments, questions, and FINESST-improvement suggestions via email at: HQ-FINESST@mail.nasa.gov.

*Technical Note: *The Planetary Science Division (PSD) will make all notifications (selections and declines) available on NSPIRES at the same time in order to be consistent with other PSD program practices.*

***This total may be different than what a selection letter may indicate due to administrative adjustments.*

SCIENCE ENGAGEMENT & PARTNERSHIP DIVISION SELECTION

Cynthia Passmore (PI)/Tracy Ostrom(FI)
University Of California, Davis
21-SENP21-0001 – Investigating Data Expertise in All Stakeholder for Science Learning (IDEAS for Science Learning)

It is clear that the understanding and use of data are necessary in K-12 education in order to prepare 21st century citizens. (Wilkerson, M.H., Laina, V., 2018) But the question remains as to what data expertise teachers currently possess and use in their classrooms to support this learning. This research proposes to answer the following questions:

1. What type of data expertise do formal and informal science learning facilitators have that supports their use of data assets in science learning?

2. How are data assets from Science Activation Partners used in K-12 education to support science learning?

3. What data expertise training have science learning facilitators identified they need in order to use data assets in their classroom to support science learning?

This research will take place over 3 years and include two phases. Phase I will occur in years 1-2 and will focus on current Science Activation Partner stakeholders in science learning. Research for Phase I will require Science Activation Partners to identify current and former formal and informal science learning facilitators. These stakeholders will be given a quantitative data assets and expertise survey that will include an option to provide contact information for a follow up qualitative interview. Phase II will occur in years 2-3 of the proposed project and will focus on surveying science learning facilitators outside of the reach of the current Science Activation Partners. The FI will identify geographic gaps from the Science Activation reach map and attempt to collect data expertise and asset survey and interview from participants.

Phase I Science Activation Partners' Stakeholders

The purpose of Phase I is to inform the Science Activation Community of current data expertise among their stakeholders and use of data assets for science learning. The FI will work with the collaborators and the PI to create a data expertise and assets survey. The purpose of the data expertise and assets survey is three-fold: give science learning facilitators an opportunity to self-identify their data expertise, analyze how data assets are integrated in science learning, and identify the types/forms of data assets and training science learning facilitators need in order to use data assets to support student science learning. The proposed survey questions will be customized to formal and informal science learning facilitators working with students K-2, 3-5, 6-8 and 9-12. Prior to the survey and interviews, University of California Davis' (UCD) Institutional Review Board (IRB), will approve materials to ensure equity and subject anonymity.

The survey will include the option for the participant to participate in an on-to-one interview with the FI. These interviews will be with a representative number of participant volunteers. The interviews will take place at the end of the 2022-2023 school year. Interview data will be used to gain a deeper understanding of the challenges facilitators may face in terms of data integration. The interviews will also gain a better understanding of why certain data assets were chosen over others to support science learning. A timeline for

Phase II Stakeholders Outside of Science Activation Partners (Reach Map Gap Areas)

Phase II will focus on science learning facilitators currently outside of Science Activation Partners' identified stakeholders. Results from the Phase II survey will be aggregated by grade-level and a fall report to SEPD will inform the Science Activation community of data expertise and data asset practices and resources for science learning facilitators in the gap areas. After the final report to SEPD, the FI will prepare journal articles and/or conference presentations to report the findings of the research.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences
NNH21ZDA001N-SCIACT
F.6 Science Activation Program Integration

NOTICE: Updated May 12, 2022. Five additional proposals have been selected following final approval of FY22 budget levels bringing the total selections to 13 our of 30 proposals received. The new proposals also include support for biological and physical sciences. Total funding for the new selections is approximately $12 million over 3.5 years. ***Five additional selection abstracts are appended below.***

NASA's Science Mission Directorate, NASA Headquarters, Washington, DC, has selected proposals for the Science Activation Program in support of the Science Engagement & Partnerships Division (SE&PD). The Science Activation (SciAct) Program seeks to further enable NASA science experts and content into the learning environment more effectively and efficiently with learners of all ages with the ultimate goal of increasing learners' active participation in the advancement of knowledge. The focus areas specific to this solicitation included heliophysics content and the upcoming 2023/24 solar eclipses, dissemination of SMD science content and experts to communities or specific audiences, and integration of data into science learning. The SE&PD has selected 8 out of a total of 30 proposals received in response to this solicitation. Selectee activities will support astrophysics, Earth science, heliophysics and planetary science. The total funding for these investigations, over a period of four years, is approximately $33 million, with an additional $3 million in co-funding from the NASA Space Grant Program.

Negotiations for specific monetary awards now will begin and final awards are expected to be made by the end of this year.

Angela DesJardins/Montana State University
Nationwide Eclipse Ballooning Project 2022-2025
21-SCIACT21-0004

Building on the highly successful NASA-sponsored National Eclipse Ballooning Project (NEBP) implemented during the 2017 total solar eclipse, the NEBP 2022-2025 project proposed to the 2021 ROSES F.6 solicitation will fully support the Science Mission Directorate's (SMD) Science Activation (SciAct) Program goals.
The NEBP will broaden participation of STEM learners by immersing teams from a wide range of higher education institutions in an innovative NASA-mission-like adventure in data acquisition and analysis through scientific ballooning during the 10/14/2023 annular and 4/8/2024 total solar eclipses. To broaden participation, NEBP has identified three goals: 1) Enable Inclusive STEM Education for Participating Students, 2) Advance Learners' Understanding of the Process of Science, and 3) Create, Enhance, and Sustain Networks and Partnerships. In achieving these goals, the NEBP project directly addresses the top-level SMD SciAct programmatic objectives and all three focus areas of the 2021 SciAct Program solicitation, with significant opportunities for long-term sustainability.

NEBP includes development and implementation of two learner-centered activity tracks – engineering and atmospheric science. At sites along the eclipse path, student teams in the engineering track will use innovative larger balloon systems to live stream video to the NASA eclipse website, observe in situ perturbations in atmospheric phenomena, and conduct individually designed experiments. Atmospheric science track teams will make frequent observations by launching hourly radiosondes on helium-filled weather balloons. Student participants will work with atmospheric science experts throughout the project and will publish results in peer-reviewed journals.

The project will fully support 70 teams, with the capacity to include an additional 30 that purchase their own equipment and supplies. The 70 teams will be divided into ten pods to facilitate effective education. NEBP will provide a learning environment that uses evidence and equity-based practices to make certain the 1,000+ participants are (and feel) supported, engaged, and valued. In addition, NEBP will provide infrastructure tools and best practices to help participating institutions build collaborations that could continue far beyond the scope of this project.

A key feature of our proposal is to increase student STEM participation, particularly with underrepresented and underserved groups. To meet this goal, the NEBP objectives are to: 1) Promote the development of participants' STEM career skills, 2) Increase opportunities for participants to develop their STEM identities as learners and practitioners, 3) Advance participants' understanding of the importance of diversity, and 4) Grow learners' awareness of cultural perspectives of science. For the proposed project, NEBP will work to increase the level of underrepresented or underserved participants to at least 50% (from 29% in 2017). To increase diversity, inclusion, and effectiveness NEBP will leverage keen understanding of STEM education equity guidelines, the diverse Education Advisory Board, and deep connections to the Space Grant network and NASA's Minority University Research and Education Project.

In summary, NEBP addresses each of the four primary SciAct objectives, with integration into all three focus areas of the 2021 solicitation. By leveraging experience and lessons learned, augmenting an existing wide network of practitioners, and providing an exciting, research-based curriculum to a wide range of students, NEBP will fully support SMD and SciAct goals.

Denise Kopecky/ Challenger Center for Space Science Education
Broadening Participation through Learner Engagement Accessing Real-world NASA SMD Expert Resources (LEARNER)
21-SCIACT21-0006

For the ""Broadening Participation through Learner Engagement Accessing Real-world NASA SMD Expert Resources (LEARNER)"" project with NASA's Science Mission Directorate, Challenger Center for Space Science Education (Challenger Center), a 501(c)3 nonprofit organization, will partner with NASA, Challenger Learning Centers, collaborators, and SciAct partners to provide opportunities for participants with NASA science and engineering, advance learners' understanding of science and its processes using NASA SMD assets, and broaden the diversity of participants with intentional, inclusive programming.

Challenger Center's LEARNER project has two parts aimed at leveraging NASA SMD assets to broaden participation and enabling localized, personalized customization for specific communities of learners.
1. A new, participatory simulation program featuring NASA Earth Science, Earth Odyssey: Challenger Center's Center Missions have been developed and delivered in partnership with NASA over the last 35 years. Center Missions are participatory simulations delivered in 40 Challenger Learning Centers across the United States to over 150,000 students annually. For this project, we propose to develop and rollout a new Earth-focused mission - Earth Odyssey (8th grade) - to 40 Challenger Learning Centers. Earth Odyssey will incorporate the latest NASA science data and visualizations and be reviewed by subject matter experts (SMEs). SMEs will be included in learner-facing orientation videos to introduce careers that learners will be role playing and could pursue. In addition, we will leverage assets and content from SciAct partners for pre- and post-mission lessons. All content will be available in English and Spanish at three different reading levels (6th, 8th, and 10th grade).
2. Spanish Translation of Two Center Missions featuring NASA Planetary Science: We will translate two Center Missions developed in our prior SciAct Cooperative Agreement - Expedition Mars (6th grade) and Lunar Quest (7th grade) - into Spanish. Spanish is the second most spoken and studied language in the United States. Many communities that we serve (e.g., Harlingen, TX; Las Cruces, NM) include student populations with native and native heritage Spanish speakers. By adding Spanish language versions of our missions, Centers will be able to meet the needs of more students typically underserved in STEM.

Kirsten Daehler/ WestEd
Broadening Data Fluency Through the Integration of NASA Assets and Place-Based Learning to Advance Connections, Education, and Stewardship (NASA PLACES)
21-SCIACT21-0008

This NASA PLACES proposal — Broadening Data Fluency Through the Integration of NASA Assets and Place-Based Learning to Advance Connections, Education, and Stewardship — supports middle and high school teachers to integrate data into Earth science learning across the country. This research-based project focuses on place-based learning as a means to increase students' "data fluency" — their ability to collect, understand, and use data. We further aim to broaden participation of youth who bring a diversity of cultures, languages, and meanings of "place" to their understanding of science, including students who are underrepresented in STEM, such as indigenous youth and recent immigrants.

The proposed project addresses a national need — data fluent teachers who are well prepared to integrate data into Earth science learning for their middle and high school students. Our goals for this project are to: (1) understand what support teachers need in order to integrate data into science learning and identify the roadblocks to utilizing NASA assets for this purpose, (2) develop nationally-tested professional learning shown to build teachers’ data fluency, (3) increase opportunities for middle and high school students to use data and data tools in their science learning through a place-based approach, and (4) build greater capacity within the SciAct community and national partners to provide effective professional learning on data use in science learning. To accomplish these goals, we will focus on:

- Professional learning that draws on effective practices from two successful models — Making Sense of SCIENCE and Power of Data, showcases the integration of NASA assets to support a place-based approach to data-rich science learning, and focuses on the assets and perspectives of diverse communities of underrepresented students.

- Partnerships that promote an exchange of knowledge and resources, leverage the broader NASA SciAct community, and involve key national networks, such as the Council of State Science Supervisors and the U.S. GLOBE Office.

The world is awash in data, and NASA programs generate new data at an impressive rate. Yet today’s K–12 students rarely have access to data-rich learning opportunities that build the skills and habits of mind they need in science and beyond. The proposed project is designed to equip teachers with knowledge, skills, and educational resources to successfully integrate data-rich NASA assets into science learning, with recognition of students’ backgrounds, cultures, and prior experiences. These teachers will help students confidently use data to answer questions and solve problems, build their STEM identities, and engage effectively in civic life.

Darci Snowden/ Central Washington University
Northwest Earth and Space Science Pathway (NESSP) “Innovate, Inspire: Launching the NASA’s Next Generation”
21-SCIACT21-0013

The Northwest Earth and Space Science Pathways (formerly Pipeline) brings authentic, hands-on opportunities to underserved and underrepresented communities in WA, OR, ID, and MT. We do this by offering NASA-focused outreach, professional development, STEM academies, and national challenges. We have demonstrated the success and scalability of this effort in Years 1-6 of support, and we seek further support to strengthen and broaden our efforts. Significant outcomes will be a measurable increase in student aspiration towards STEM careers and an increase in teachers’ confidence in teaching STEM.

NESSP utilizes best practices formulated around the Professional Teaching and Learning Cycle. Outreach programs engage students and educators and gain local communities' trust. Next, we offer professional development that furthers the skill set of educators, giving them the confidence and support to expand on their knowledge and run extended student opportunities in STEM academies and mentorship of teams in the national challenges.

The specific yearly objectives are to reach:

- 30,000 participants in outreach programs with approximately 50% in rural areas and with 30% participation by underrepresented minorities
- 1,500 students in STEM academies, with at least 50% of the teams coming from rural areas and with 40% underrepresented minorities
- 600 teams (5,000 participants) across 25 hubs participating in yearly student challenges, with at least 50% of the teams coming from rural areas and with 40% underrepresented minority participation
- 1,000 teachers in short-term professional development, and 800 in long-term professional development or extended projects, with 40% in rural areas and 10% underrepresented minority participation

Broad partnership within the NESSP team and Science Activation members facilitates the extensive reach of the program. Participation in the Science Activation community also enables NESSP to provide subject matter experts to students and educators participating in NESSP activities.

By enabling a large community to engage underserved and underrepresented students in NASA-related STEM activities, we can have a measurable effect on students' future aspirations towards STEM careers. In doing so, NESSP will broaden the participation in STEM in underserved and underrepresented communities. NESSP participants will also feel like they are part of the NASA community and will gain a greater appreciation of NASA space exploration and Science Mission Directorate science priorities.

Vivian White/ Astronomical Society Of The Pacific
Eclipse Ambassadors Prepare Communities Off the Path for Two Solar Eclipses
21-SCIACT21-0016

The Astronomical Society of the Pacific (ASP), co-investigators at the SETI Institute (SI), and partners at the Space Science Institute (SSI) propose Eclipse Ambassadors Prepare Communities Off the Path for Two Solar Eclipses, a three-year project to recruit and train 1000 Eclipse Ambassadors in 500 communities across the country, providing direct public engagement experiences to more than 10,000 people in communities off the paths of totality for the 2023 and 2024 eclipses. Eclipse preparation and public programming generally focuses on viewers on the paths of annularity and totality. However, the majority of communities across the nation will experience the partial phases, and when properly prepared and supported, will find the experience meaningful and memorable. Because this project focuses on bringing the wonder of solar eclipses to underserved communities, it also broadens participation in astronomy and NASA science. Other project partners will bring their expertise and resources to the work, including libraries, the National Park Service, the Minority University Research and Education Project (MUREP), the American Astronomical Society (AAS) and the Solar System Ambassadors. With advance engagement and training in astronomy and safety, involved communities will receive in-depth learning experiences before and between the eclipses designed to build excitement, spark curiosity, and help people better understand the Earth-Moon-Sun relationship.

Five hundred amateur astronomers (many recruited from the NASA Night Sky Network managed by the ASP) will partner with 500 college students (recruited from community colleges and universities) and train together as Eclipse Ambassadors, ready to engage their local communities with effective and inclusive outreach techniques. After a 3-week training, the Eclipse Ambassadors will have the knowledge and skills to communicate safe viewing requirements, identify and address misconceptions related to solar and lunar science, make connections to NASA solar science, and understand how to connect and build relationships with underserved audiences in their communities.

Eclipse Ambassadors will facilitate engagement opportunities with NASA programs, expertise, and assets through community events designed to make the eclipses relevant to people who have traditionally lacked access to such programs. By providing the Eclipse Ambassadors with training in interpretive techniques, equitable engagement strategies, and accurate solar science, they will engage these communities meaningfully and respectfully. These amateur-student teams also create an intergenerational exchange of experience, knowledge, and perspectives critical to bringing the excitement of the eclipses to audiences of all ages and backgrounds. The project will also forge relationships between astronomy clubs and their local colleges, libraries, and organizations working with underserved audiences (such as faith groups, parks, and community centers). Therefore, the Eclipse Ambassadors Project directly supports Science Mission Directorate’s Science Activation (SciAct) Objectives for improving scientific literacy across the US, and more specifically to broaden participation in NASA programs and promote diversity and inclusion.

The project’s evaluation will study the extent to which the Eclipse Ambassadors Project has achieved its goals to successfully train and support Eclipse Ambassadors to deliver quality public engagement to diverse audiences, and whether the project has established sustainable partnerships between astronomy educators, colleges, community organizations such as libraries, and underserved communities. Measures of success will be consistent with SciAct Objectives of increasing science literacy, leveraging partnerships, and broadening participation.

Brian Jackson/ Boise State University
The Central Idaho Dark Sky Reserve STEM Network
21-SCIACT21-0019

We propose to develop an overlapping series of STEM engagement efforts to leverage already available NASA Science Mission Directorate (SMD) materials and infrastructure. The program would partner with communities around Idaho to support engagement efforts already underway and to help develop new ones. In particular, the program would forge a cornerstone partnership with the Central Idaho Dark Sky Reserve (https://idahodarksky.org/), the only gold star-certified dark sky reserve in the US spanning an under-served rural region and thus an ideal venue for astronomy engagement. Our program would combine several avenues of engagement: (1) active support of ongoing community education efforts hosted across Idaho and at Boise State; (2) adapting NASA Science Mission Directorate (SMD) materials and infrastructure to Idaho's public school curriculum to better facilitate its inclusion in the classroom; (3) citizen science light pollution monitoring to support the Central Idaho Dark Sky Reserve's mission; and (4) an engagement program involving an astronomer-in-residence in the CIDSR. Our program would benefit from currently active external funding.

To help run these programs, we would develop a training course in STEM outreach for Boise State students. Student training would come in the form of presentations and practicum led by a variety of experts including the following topics: (1) speaking with the media by local reporters; (2) social media by Boise State personnel; (3) fund-raising by Boise State's Office of Advancement; and (4) developing K12 curriculum by Boise State College of Education faculty; in addition to running an active and very popular outreach program based at Boise State. The grant would also support student teaching assistantships to help with astronomy courses at Boise State both to provide the students with additional training and as a way to recruit the next year's cohort of students. All training materials would be thoroughly documented and made publicly available so lessons learned could be applied and adopted by engagement programs around the country. Other planned deliverables include academic publications and a website to distribute the adapted curriculum.

Overlapping goals for our program elements allow them to mutually support one another and to support SciAct objectives. For example, the student training program and adaption of educational materials for Idaho teachers enable STEM Education by helping bring NASA directly into the classroom and advance national education goals by providing authentic science experiences for learners, with a focus on under-resourced, rural populations. The light pollution monitoring and engagement, combined with the astronomer-in-residence program, would engaging locals in citizen science in work with research-active space scientists. Such efforts would improve U.S. scientific literacy by direct involving residents of under-resourced areas in the scientific process and by leveraging efforts through the archetypal partnership of citizen science.

Alex Young/ NASA Goddard Space Flight Center
A Heliophysics Education and Eclipse Framework by NASA HEAT
21-SCIACT21-0023

Millions of people experienced the excitement of the 2017 total solar eclipse. The 2023/2024 eclipses bring two more opportunities to transform excitement into real knowledge of STEM. We can also get a "gravity-assist" from missions like Parker Solar Probe, which is delivering a new understanding of the Sun. The public wants more! The Sun is our closest star and we can use real, dynamic data to give an up-close view and learn about our connections to the universe.

We reach learners via educators. Educators want to engage learners of all ages, and heliophysics educational content is a natural fit to build on the public's excitement. Yet, educators must have a basic understanding of fundamental heliophysics (HP) concepts so they can effectively interact and deepen their audience's understanding. They also can benefit from exciting, adaptable educational materials.

HEAT will simultaneously do two related programs—both about developing & distributing HP educational content and coordinating with partners.

Overall engagement for the 2017 eclipse was record-breaking for NASA. We will leverage our experience to again lead NASA's eclipse planning and coordination efforts. The goal is to enable the public and learners of all ages to experience this rare, scientific phenomenon—in as many ways as possible before, during, and after the events. Coordination prevents duplication of effort and maximizes efficiency between NASA, SciAct partners, external organizations, and the national eclipse community. HEAT is updating eclipse glasses and previous work for 2023/2024, combining it with partner resources.

Heliophysics Education Framework (HEF) will create and distribute K-20 materials about HP to engage learners. It will connect fundamental HP descriptions with NASA assets, culturally relevant resources, and other related content. HEAT will cross-reference all of these factors so educators can bring them into their learning environments more effectively and efficiently.

Our deliverables include standards-aligned learning materials and culturally-centered HP resources. This builds on our strengths, addresses SciAct goals, and responds to needs assessments. HEAT uses evidence-based practices to broaden participation and engage learners. HEF deliverables will be available through a portal with custom search solutions and other features to meet the specific needs of the users. Our work will coordinate with NASA's website modernization efforts which are rapidly evolving.

Juan Torres-Perez/ NASA Ames Research Center
Ocean Community Engagement and Awareness using NASA Observations and Science for Low-Income Hispanic/Latino Students (OCEANOS)
21-SCIACT21-0028

The importance of the ocean is undeniable, not only for humans but for life on Earth. Coastal and ocean ecosystems in Latin America have degraded over the last century. This is related to a number of global (climate change) and regional/local (land-based sources or pollution, indiscriminate recreational use) factors. At the local level, there is a general lack of awareness on how human actions ultimately impact the ocean and the overall survival of the communities associated with these. The project aims at increasing STEM opportunities among the fastest growing ethnic group in the US (Hispanic/Latinos) using as a spearhead the low-income Puerto Rican student population within the Island.

This project aligns with NASA Science Mission Directorate's Priority 4 (Inspiration) particularly Strategy 4.1 "Increase the diversity of thought and backgrounds represented across the entire SMD portfolio through a more inclusive environment". This project further addresses NASA's cross-cutting priorities of making progress through partnerships and inspiration, and specifically targets the Focus Area of "Dissemination of SMD assets into communities or specific audience networks" of this call. It further attends all four SciAct Objectives: Enable STEM Education, Improve US Scientific Literacy, Advance National Education Goals, and Leverage Efforts through Partnerships. The proposed project centers on the hypothesis of: NASA Observations and science coupled with low-cost in-water instrumentation can significantly increase STEM education and enthusiasm among low-income 1st generation Hispanic/Latino students, particularly in regards to oceanographic and coastal issues. Our goal is to use combined NASA ocean color data and in situ oceanographic parameters to improve the capacity and awareness among low-income students on how these two can be used to monitor water quality affecting coastal shallow-water marine ecosystems in Caribbean waters. As such, the two main objectives of this project are: 1) To train low-income Hispanic/Latino (Puerto Rican) High School and undergraduate students on ocean color data acquisition and analysis of remotely-sensed freely-available imagery; and, 2) To improve scientific literacy among Hispanic/Latino students, particularly on the combined used of in situ and remotely-sensed data for ocean studies. This project will impact a minimum of 100 Spanish-speaking students and, through a web portal, will disseminate information (bilingual) on the use of NASA data for coastal and ocean studies and make it available to any bilingual (English and Spanish) high school and university student.

We will partner with local NGOs and academic institutions in Puerto Rico dedicated to capacitate low-income students on STEM careers. We are particularly interested in engaging with high schoolers and first-generation university students who would otherwise not have this opportunity. Trainings will consist on basic remote sensing image analysis techniques for ocean color and water quality assessment, coupled with the design of do-it-yourself (DIY) instrumentation for collection of in situ water quality parameters, and general benthic characterization of tropical shallow-water ecosystems with NASA's award-winning NeMO-Net application. Students will be recruited during the Spring semester. Nine-weeks classroom and field trainings will be conducted during the Summer ending with an open activity where students will be able to share their learning experiences with academics, government representatives and people from their communities. As part of the training hands-on experience, students will have the opportunity to participate in a water quality oceanographic cruise to test their DIY designs along a pre-determined bio-optical transect through Case 1 [oligotrophic] and Case 2 [eutrophic] waters during a Landsat 8 overpass in southwest PR. This study will also leverage several ongoing internship pilots in Puerto Rico.

Additional abstracts for proposals selected following final FY22 budget approval.

Paul Martin/ Arizona State University

Engaging Hispanic Communities in Authentic NASA Science: Broadening Participation in Science Activation through Local Partnerships and National Networks (Engaging Hispanic Communities)
21-SCIACT21-0005

Engaging Hispanic Communities will create and disseminate a high-quality suite of culturally relevant bilingual Spanish-English materials based on NASA assets to engage Hispanic families in learning about all four disciplines of NASA science. The project will leverage relationships across SciAct and with national networks to build professional and organizational capacity to broaden participation in SMD science and support participation of Hispanic SMEs and role models.

Despite being one of the largest and fastest-growing minority groups in the United States, Hispanics are significantly underrepresented in STEM fields. The US Census Bureau reports that 18.5% of the population (60 million people) is of Hispanic origin. Yet Hispanics comprise only 7% of all STEM workers—and in some disciplines, such as astronomy, Hispanics represent as little as 1% of the field.

Engaging Hispanic Communities will create resources and opportunities for Hispanic families to engage in authentic, culturally relevant Earth and space learning in community settings, creating a foundation for lifelong learning—and in some cases, studies and careers—in STEM. Project activities include: Disseminating existing, high-quality Spanish language and bilingual Spanish-English resources through existing networks that reach hundreds of communities located in all 50 states and several territories of the US; codeveloping and distributing a targeted suite of media-rich and hands-on learning materials with Hispanic families and subject matter experts that are specifically designed to showcase authentic NASA science, data, and personnel in a way that is culturally sustaining; and providing professional development for SciAct teams and leveraging network partners to support use of evidence-based practices in bilingual and bicultural STEM engagement. The project leadership team includes experts in informal STEM education and Hispanic community engagement who have worked together successfully on previous national-scale projects.

The project team will collaborate with NASA and the SciAct community on all major project activities: development of educational products; delivery of educational programming and educator professional development; and distribution of project products and results. The team will also build on substantial evidence from research, evaluation, and practice. As emphasized in the recent National Academies SciAct program review, NASA can have a pivotal role in broadening participation in STEM for learners of all ages and backgrounds across the United States. The proposed project is designed to support the SciAct core value to broaden participation and advance SciAct practices for equity, inclusion, and accessibility, as recommended in the NASEM review (2019).

The project is designed to contribute to the following NASA educational objectives: advance national education goals; enable STEM education; improve US scientific literacy; and leverage partnerships. The evaluation for Engaging Hispanic Communities will provide three kinds of data for the project: front-end, formative, and summative. Front-end and formative data inform the development of products and help with project decision gates, while summative data allow stakeholders to understand the project’s reach and outcomes.

Benjamin Hamlington/ NASA Jet Propulsion Laboratory
NASA and NOAA Sea Grant Collaboration to Translate Sea Level Science to Coastal Communities
21-SCIACT21-0007

Climate-driven changes in sea level are already impacting coastal communities around the world. Based on projections of future sea-level rise (SLR), the impacts are wide-ranging, global in scope, and expected to worsen in the coming years. To address and plan for these impacts, the information needs of coastal communities are both numerous and diverse. For planning efforts, there is a need for accessible science and observations along with projections of future SLR. Beyond guidance that serves as the foundation of adaptation and planning efforts, improving awareness and understanding of SLR (and climate change more broadly) and improving access to information on SLR is vital to gaining support in coastal communities for climate-related policies. Education opportunities that support these objectives are often limited for those coastal communities impacted by SLR, particularly for underrepresented, underserved communities.

In the United States, NOAA Sea Grant (Sea Grant) addresses many of these challenges by supporting coastal communities through research, extension and education. Sea Grant is a network of 34 university-based programs that brings together experts in coastal processes, hazards, climate change, urban planning, outreach and education to promote and ensure the conservation and practical use of the coasts of the U.S. Sea Grant programs are located in every coastal and Great Lakes state as well as in Guam and Puerto Rico. Sea Grant extension and education specialists are skilled at translating the latest science models and results into informational products and tools accessible by non-expert audiences, and then disseminating these through programming and activities that they create and support.

In this project, we will leverage the science translation and dissemination expertise of Sea Grant to foster the activation of NASA sea-level change science, specifically for K-12 formal, informal, and non-formal education. Ensuring the next generation of leaders, residents, and decision-makers understand the complex and interrelated challenges and opportunities of SLR is a critical component of building and maintaining momentum around resilience. Our focus will be on communicating the science behind past, present and future SLR to the coastal communities most affected. In doing so, we will leverage and extend the impact of the significant investments that have been made by NASA into the sea-level observing network and basic sea level science research. For decades, NASA has been leading advances in our scientific understanding. Various NASA sea-level observing resources and educational content have been previously developed.

However, these resources are spread across a number of platforms limiting discovery, often rely on outdated data, and are not targeted and organized to meet today's diverse sea-level education and information needs of diverse coastal communities across the U.S. An objective is to increase the impact of NASA resources and expertise by maturing existing and developing new content that provides improved educational opportunities and experiences at the coasts of the U.S. By the end of this project, the goal is to have created a lasting link between NASA and NOAA Sea Grant that will serve to better inform impacted coastal populations about future changes along the coasts of the U.S.

Rita Karl/ Twin Cities Public Television, Inc.
NASA Inspires Futures for Tomorrow's Youth (NIFTY):
The Power of Networks to Advance Equity
21-SCIACT21-0011

Twin Cities PBS (TPT), a non-profit educational institution, in partnership with the National Girls Collaborative (NGC), Space Science Institute (SSI) and Langley Research Center, submits a Notice of Intent to propose NASA Women Inspire Girls to NASA Careers: The Power of Networks to Advance Equity to the NASA SMD Science Activation solicitation. Women make up 47 percent of the U.S. workforce but hold only 28 percent of STEM jobs and only 1 in 10 employed engineers and scientists are women of color. At NASA, women make up only 34 percent of the workforce and just 24 percent of scientists and engineers are women. Racial diversity is also low, for example, in 2016, 87 percent of planetary scientists identified as white. The project goal is to increase opportunities for girls (ages 9-14), especially girls of color, to interact with and learn from diverse NASA women STEM role models to motivate them to STEM studies and NASA careers. The four-year project will engage 100 NASA women from ten centers (initially through pilot efforts at four centers, then scaling to more sites). NASA women will be recruited through NASA center champions, trained in best practices and connected to 1,000 girls in 50 girl-serving STEM programs within the NGC and SciGirls networks (45,000 educators) and SSI's STAR Library Network (16,000 libraries). NASA role models will help girls to learn about NASA missions and careers, and provide personal sources of inspiration, underscoring the idea that if girls can see it, they can be it.

SciGirls is a national initiative focused on professional development (PD) for educators and professional women to engage diverse girls in STEM. SciGirls began in 2004 in response to the need to broaden participation of girls in STEM. The SciGirls Strategies are research-based gender equitable and culturally responsive practices proven to increase middle school girls' interest in and attitudes towards STEM. The strategy around role modeling addresses the most common barrier to engaging girls in STEM: limited exposure to women in STEM fields. Research shows when girls can relate to role models, they are better able to develop a broader mental picture of what it looks like to be a STEM professional, and how they might pursue such careers. Engaging with women role models can help girls develop positive STEM identities by increasing interest in STEM, strengthening self-conception, and developing a feeling of belonging. Role models who have adopted best practices report that helping girls connect to STEM re-energizes them and gives them a chance to collaborate with colleagues.

An evaluation will follow role models through PD and programs with girls and families (engaging in STEM activities, holding discussions about their work, and sharing their personal journey). This will provide evidence-based findings around the effectiveness of connecting NASA women to existing informal STEM networks. Additionally, a cohort of ten women will be recruited to become NASA-wide trainers to sustain the initiative and exponentially increase the number of NASA women engaging with girls. The primary deliverables include:
-Recruitment and preparation of 100 NASA women to act as role models using research-based strategies for engaging girls in STEM. For long-term program sustainability, a cohort of role models will become NASA Role Model Trainers.
-Connecting role models through focused partnerships with 50 programs from the existing SciGirls, NGC and STAR Net networks through a competitive RFP process, reaching 1,000 girls and their families, with the goal of inspiring them to STEM studies and NASA careers.
-Evaluating the effectiveness of leveraged partnerships within the SciAct community, training and integration of role models into STEM programs.
-Broad dissemination of findings to the NASA and SciAct communities, academic researchers, STEM practitioners and policymakers through peer-reviewed journals and national conference presentations.

Douglas Duncan/ University Of Colorado, Boulder
Science Through Shadows: Eclipses and Solar Science, Occultations and Solar System Origins
21-SCIACT21-0021

Science Through Shadows involves the intentional and mindful collaboration of six science centers, six NASA missions focused on heliophysics and asteroids, and six nationally recognized educational networks. Our goals are to: (1) Leverage networks to disseminate NASA information to large audiences of adults and students, with special attention to underserved communities. (2) Prepare Americans for the 2023 and 2024 solar eclipses. (3) Use the eclipses to build understanding of heliophysics and the importance of studying the sun. (4) Use the missions New Horizons, OSIRIS-REx, Lucy, and Psyche to teach about Solar System origins. (5) Show how ground-based occultation measurements, some of which are citizen science, are used in asteroid studies. (6) Interest students, including those from underserved communities, in STEM careers. (7) Pioneer advanced evaluation techniques (e.g. QR codes) to survey thousands of Americans to evaluate how our programs increase public appreciation of the work that NASA does. We collaborate with four asteroid missions and the heliospheric missions Parker Solar Probe and PUNCH to support these goals.

Science Through Shadows will be led by Fiske Planetarium of the University of Colorado. Our strategies to achieve the goals are as follows. We leverage this decade’s high profile solar eclipses to promote public awareness of asteroid missions and occultations to study our Solar System. We will produce videos in both the dramatic fulldome format used by planetariums, and flat screen, used at libraries, schools, and on YouTube. Videos will highlight NASA science of the six missions and feature a diverse group of experts doing a diversity of aerospace-related jobs. Interviewed experts will talk about science, and also their careers. We will produce educational materials to accompany each video. Videos and materials will be presented nationally by our network partners: (1) NASA Solar System Ambassadors Program, (2) the Night Sky Network run by the Astronomical Society of the Pacific, (3) the group of 200 planetariums developed by Fiske over the past 5 years, (4) a new group of 300 portable planetariums, (5) the NASA@MyLibrary network of thousands of libraries, and (6) the NASA Community College Network organized by the SETI Institute.

To broaden engagement in STEM, Fiske will partner regionally with four key portable planetarium partners to train presenters and engage 400,000 students through 1,200 in-person programs involving underserved audiences. These are the Michigan Science Center, Detroit; Houston Museum of Nature and Science, covering Texas; Chabot Science Center, covering the SF Bay Area; and the NASA ASTRO CAMP Consortium covering MS and LA. In Colorado, we will work with CU-STARS, a minority and first-generation student group, to recruit and train students to work with and urban and rural schools in Colorado and Wyoming. Our partners work with underserved communities using a variety of approaches to education and outreach, which will provide the opportunity to evaluate a range of approaches. As one example, the Chabot Science Center repeatedly visits schools, libraries, rec centers, places of worship, and community centers, so that the presenters become well known. They will help us recruit students from underserved populations to be part of our production team. After learning how to produce science documentaries, these students will work with Fiske staff to lead production of two of the ten proposed videos. We will evaluate how the student-led videos appeal to students nationally.

Additionally, master's degree students at CU Boulder will build new visualizations within OpenSpace, the open-source planetarium software developed by the American Museum of Natural History. These enhancements to OpenSpace, featuring ground-based occultation campaigns and asteroid flybys, will be utilized in our videos and given to OpenSpace users across the nation to support live planetarium presentations.

Carl Lewis/ Fairchild Tropical Botanic Garden, Inc.
Growing Beyond Earth Science Activation for Middle and High Schools
21-SCIACT21-0025

Fairchild Tropical Botanic Garden (Fairchild) is proposing to work in partnership with NASA to connect NASA science experts, real content, and experiences with educators and students in ways that activate participation and promote understanding. Our proposed project seeks to use Fairchild's Growing Beyond Earth (GBE) program to disseminate Science Mission Directorate (SMD) assets into middle and high school classrooms nationwide and integrate the analysis of SMD data and student-generated data into science learning.

Developed as a STEM education program by Fairchild and SMD personnel, GBE was implemented locally and scaled nationally under NASA Grant NNX16AM32G and Cooperative Agreement 80NSSC21M0043, respectively. Now serving more than 250 schools nationwide, GBE successfully improved STEM education, sustained youth and public engagement in STEM, and increased student knowledge of and interest in STEM careers. It also contributed student-generated data to NASA, improving SMD research on the ground and on ISS.

GBE provides a uniquely effective mechanism for delivering SMD content, data, experiments, and expertise into middle and high school classrooms. Through GBE, teachers and students learn about SMD research and conduct complementary experiments using analog hardware that matches the capabilities of the Veggie habitat on ISS. The experiments, designed in coordination with SMD, include tests of new plant varieties and growing techniques. Additionally, there is an opportunity to combine student-generated data with SMD data from ground and on-orbit experiments. This will create a repository of plant data to aid teachers, students, and the broader community in developing and conducting independent research.

Broad Objectives

This proposed Science Activation aims to deliver unique SMD assets to the national educational environment. Our objectives are to
(1) enable STEM education by delivering SMD content and supporting authentic research in classrooms, (2) improve U.S. scientific literacy by training teachers and students to interpret data and develop research questions, (3) advance national education goals by addressing the priorities enumerated in the US STEM Education Strategic Plan, and (4) leverage efforts through partnerships by combining Fairchild’s citizen science capability with NASA’s research needs, information content, and expertise.

Focus Areas

- Element Focus Area 2: Dissemination of SMD assets into communities or specific audience networks— We propose to use the GBE program to deliver SMD science content and data, coordinate with research on ISS, and integrate SMD personnel into science education at the middle and high school levels.
- Element Focus Area 3: Integration of data into science learning— We propose to develop a public repository of plant data, including NASA research results and student-generated GBE data. Teachers and students will be trained to use this repository when developing and conducting independent research.

Approaches

1. Work with NASA SMD experts to deliver science content and coordinate experiments in 350 middle and high school classrooms nationwide. Fairchild will provide equipment and supplies, protocols, and datasheets, with SMD personnel delivering online training and monthly Q&A sessions.

2. Create an online data repository, including results of previous GBE experiments, ground testing at KSC, and experiments in space. This will allow teachers and students to compare their own data with results from previous studies and understand the broader significance of their work.

3. Train GBE teachers and students to use data in designing, conducting, and presenting independent research. SMD personnel will provide training and help evaluate student research proposals. Students will present their final results, in the context of the broader pool of available data, to a panel of SMD and Fairchild scientists.

CITIZEN SCIENCE SEED FUNDING PROGRAM
Abstracts of Selected Proposals
(NNH20ZDA001N-CSSFP)

Below are the abstracts of proposals selected for funding for the Citizen Science Seed Funding (CSSFP) Program. Principal Investigator (PI) name, institution, and proposal title are also included. Twenty-nine (29) proposals were received in response to this opportunity. On July 12, 2022, eleven (11) proposals were selected for funding.

Matteo Crismani/California State University, San Bernardino
Martian Cloud Watching
21-CSSFP21-0026

After decades of traditional cloud imaging by NASA and ESA missions, NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) orbiter brings a new perspective in a very literal sense. Since 2014, the MAVEN mission has used its Imaging Ultraviolet Spectrograph (IUVS) to create full disk images over many local times and seasons, which permit a novel view of cloud evolution and its drivers. While dayside clouds have a long heritage from a variety of observatories, MAVEN's unique orbit permits studies of the dayside development of orographic clouds, gravity wave clouds, street clouds, streak clouds, as well as band or belt cloud structures (e.g., ACB and twilight cloud belt (TCB)). Observations of the same cloud formation at all dayside local times, complemented by seasonal variations in observed properties, provide insight into their growth and drivers. Moreover, IUVS is uniquely positioned to be able to observe Post-Terminator Clouds (PTCs), which are identified as bright spots on the disk past solar zenith angles of 90 degrees, and are illuminated due to their substantial height above the surface (>50 km). IUVS's vast, yet approachable, image database is largely unknown and completely underutilized, with just a single publication to date (Connour et al., 2020). This is because cloud science does not appear in the mission's Level 1 requirements and the excellent imaging capability was not part of the proposed instrument concept. We will create a tool to manually identify clouds on the Zooniverse platform and disseminated throughout the California State University system to encourage citizen scientists and student scientists to interact and make discoveries in the MAVEN/IUVS dataset. These users will identify and discriminate between cloud morphologies, differentiating between surface ice and clouds, to help develop catalogs of various cloud types and their evolution.

Aaron Curtis/Jet Propulsion Laboratory
How Dynamic is the Moon? Lunar feature change detection using co-registered images from past and current missions
21-CSSFP21-0016

The common perception of Earth's Moon as a dead place, frozen in time, is incorrect. We propose the creation of a new feature of NASA's Moon Trek lunar imagery browser, to be known as MoonDiff, which will allow citizen scientists to compare new and old imagery, pinpointing changes, and generating discoveries, bringing the moon to life in the eye of the public. The citizen scientists will be presented carefully co-registered pairs of Lunar Orbiter and Lunar Reconaissance Orbiter images. They will annotate areas that appear different, including craters from meteorite impacts as well as spacecraft hardware. Following cross-verification between users and further verification by experts, the discovered lunar changes will be used to address goals relevant to the Lunar Data Analysis Program, namely using existing mission data to constrain the known flux of meteorites, and to assess hypotheses regarding lunar regolith response to spacecraft landing plumes and expected shapes of fresh craters.

Our team will build upon existing data from image comparisons and lunar flash observations conducted throughout the previous 12 years. New data from the seed phase of the citizen science program proposed here will increase the number of known impacts within that period, and extend the dataset back 43 more years by including images from Lunar Orbiter, revealing how truly dynamic the lunar surface is. Out of the 84 objects that man has left on the moon which should be observable from orbiting spacecraft, only 38 have been located so far in imagery. Therefore, in addition to locating natural impact sites, MoonDiff users are likely to find historical spacecraft hardware. Learning the fate of this equipment is valuable for future mission planning we enter a new era of lunar exploration with the Artemis program.

MoonDiff seeks to build the diversity and strength of the existing amatuer astronomy community through partnerships with educational organziations supporting minorities and disadvantaged groups. We will work with the 2,400 strong Amatuer Astronomy Selenology Project for beta testing, and have partnered with the Lewis Center for Educational Research and the NOIR Lab to bring the active phase of the project to Hawai'ian Home Lands children and Spanish speakers in a disadvantaged area of San Bernadino. MoonDiff will strive to provide an inspiring and fun experience for participants through gamification, prizes, and interaction with experts regarding each discovery.

Thomas Esposito/SETI Institute
Long-Duration Exoplanet Transit Timing with a Coordinated Citizen Astronomer Network
21-CSSFP21-0025

This proposal aims to support follow-up observations of long-duration, long-period, transiting giant exoplanet candidates discovered by NASA's TESS mission. The Unistellar Network of citizen scientists and "eVscope" telescopes that we plan to employ is uniquely capable of searching for and detecting transits by these scientifically valuable planets, thus it accesses a discovery space that other ground-based follow-up programs do not. Through a pilot program with this burgeoning, global network of ~7,000 eVscopes, we have demonstrated the necessary capabilities to achieve our science goals and we now aim to scale up the program to target planets inaccessible to other follow-up campaigns.

Since we began a pilot program in March 2020, our results have shown that a single eVscope controlled by a citizen astronomer can detect a Jupiter-sized exoplanet transiting a Sun-like star (a 1% transit depth) and combined photometry from multiple eVscopes can detect Saturn-sized exoplanets (e.g., WASP-148b at 0.65% depth). The resulting light curves provide valuable information including the time of mid-transit (to within a few minutes at 68% confidence) & transit duration. One hundred citizen scientists across the world contributed 413 transit observations and 92 detections in 2021 alone.

This global distribution of so many connected observers is a tremendous advantage   one unique to the Unistellar Network   because transit observability is time and location dependent. In late 2021, we conducted two coordinated, long-duration observations. One yielded a 27 hour span of photometry from eight eVscope observations that, when combined into a single light curve, clearly detected a 12 hour long transit by a known exoplanet and constrained it's mid-transit time to ±18 minutes (supporting a JWST Cycle 1 observation). The other collected data over a 40 hour span through 43 observations from 30 different citizen scientists around the Northern Hemisphere, yielding a preliminary detection.

Our proposed goals to support the TESS mission leverage this key ability to construct complete light curves over many hours, which we believe makes our program unique. TESS has discovered 23 solo-transit" planet candidates (just a single transit detected) and 8 duo-transit" candidates (only two transits detected) that are within our sensitivity limits. Solo-transits have no orbital period estimates and duo-transits have only period upper limits (shorter periods can be mistaken for longer ones if interim transits are unobserved). All of these solo-transit and duo-transit candidates have periods >100 days (up to ~1,000 days). Thus, we need many telescope hours to search potential transit windows for alias" periods and, even when a next transit can be predicted (e.g., by radial velocity monitoring), >10 hours of continuous observation are needed to measure the transit. Single telescopes in fixed locations cannot reliably achieve this, nor can geographically narrow networks without coordinated observing plans.

There are only 12 known examples of Jupiter-mass planets or larger on long orbits, yet they likely play major roles in the evolution of planetary system architectures. Their long periods make them particularly interesting because they may be either Jupiter analogs or proto-hot Jupiters, in the process of migrating inward. Much remains to be learned about the mechanisms behind planet migration, which/when planets migrate, and how it affects the system as a whole, so finding more objects through which to study it is valuable.

Constraining the periods of these planets (and confirming they were not false positives) is crucial to enable in-depth characterization by HST, JWST, Ariel, HabEx/LUVOIR, and missions beyond. But this takes a lot of telescope time, sky coverage, and coordination. The Unistellar Network provides this, and the program we have developed leverages its data into scientific results that no other ground-based telescopes can produce.

Karl Gebhardt/University Of Texas, Austin
Dark Energy Explorers: The Citizen Science Project Fueling the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX)
21-CSSFP21-0009

We are using the power of citizen science both to engage the public and to provide significant improvements to our large dark energy experiment. We have been running a citizen science campaign called the Dark Energy Explorers through Zooniverse, for the past two years. Not only have we engaged X individuals from X countries exploring X sources with X classifications, this pilot program has proven to be remarkably useful for machine learning inputs into HETDEX (Hobby-Eberly Telescope Dark Energy Experiment). We have learned a lot for how to generate content for the general public that we can use to address our issues with false positives in the sample. With the proposed project that will increase to the full sample of HETDEX sources, we expect about a 20% increase in the constraints on the evolution of dark energy. We will also use this platform to generate K-12 curriculum using our teacher workshop program run through McDonald Observatory. This aspect will reach a large number of students from group under-represented in STEM fields.

Chuck Higgins/Middle Tennessee State University
Radio JOVE 2.0
21-CSSFP21-0023

The Radio JOVE Project is a well-known public outreach, education, and citizen science project that uses radio astronomy and a hands-on radio telescope for science inquiry and education. The proposed Radio JOVE 2.0 will complete a critical program transition from an education-focused project using analog single-frequency radio telescopes to a science-focused program using digital radio spectrographs. We propose to provide a path for radio enthusiasts to grow into citizen scientists capable of operating their own radio observatory and providing science-quality data to an archive. Using our network, we conduct fundamental research on the radio galactic background, the ionosphere/space weather, heliophysics, and radio wave propagation. Citizen scientists will have opportunities for presenting and publishing scientific papers. Radio JOVE 2.0 uses more capable software defined radios (SDRs) and spectrograph software to make a science-quality low-cost ($300) radio spectrograph kit.

The objectives for this proposal are:
(1) Develop training modules to help a radio hobbyist become a citizen scientist.
(2) Collaborate with citizen scientists to conduct fundamental research on the radio galactic background, the ionosphere, and solar/planetary radio events.
(3) Test/develop/upgrade the scientific capability of radio spectrograph hardware/software and the data archive.

(4) Increase participant access and interactions from improved websites/listservs and expand our existing radio spectrograph network.

Radio JOVE 2.0 will be relevant and significant to NASA programs by addressing the SMD Goals 1, 2, 3, and 4: 1) Increase scientific content, allow interactions with SMEs, and give authentic experiences to participants; 2) Teach the methods of science including the process of scientific publication; 3) Advance the future workforce; and 4) Establish a partnership network of citizen scientists for solar and planetary radio astronomy.

Burcu Kosar/Catholic University Of America
Joint Analysis of Concurrent Sprite and Gravity Wave Observations Based on Citizen Science Data Collected by Spritacular Project
21-CSSFP21-0014

The region of space confined between the stratosphere and mesosphere is a zoo of electrical activity that is powered by the thunderstorms below. Their global occurrence rate is estimated to be above one per minute. Transient Luminous Events (TLEs) have been detected over the land and oceans, in Europe, North and South America, Asia, over winter storms in Japan, and on the Australian continent, covering most regions of the globe. Sprites, one of the most interesting and frequent types of TLEs, are highly dynamic and morphologically complex, occurring at the edge of space (~90 km). They are luminous electrical discharges with a lateral extent of ~5-10 km and vertical extent of ~50 km, and hence the atmospheric volume electrically and chemically affected by sprites is thousands of cubic kilometers. The study of sprites and other TLEs is essential to understand the chemistry of the upper atmosphere, how they provide feedback into the global electric circuit, and the mechanisms of coupling between various atmospheric regions (i.e troposphere-stratosphere-mesosphere-ionosphere).
The proposed work has the following goals: (1) Curate a dataset from Spritacular database and identify a subset with concurrent captures of sprites and gravity waves from multiple different locations. In addition, launch observational campaigns among experienced citizen scientists to collect several consecutive and simultaneous pictures/videos with calibrated camera clocks throughout the U.S. to expand the dataset for the investigation. (2) Obtain altitude and location information for sprites and gravity waves using star field analysis and triangulation techniques to understand the connection between them. (3) Compare results obtained from citizen science images with the findings of ground-based observations (such as high-speed recordings) reported in literature. (4) Build a collaboration framework where citizen scientists are incorporated into scientific research by allowing and training them to be a part of the analysis effort.

Amy Lien/University of Tampa
BurstChaser: Unveiling the physical mechanism of gamma-ray bursts with citizen science

21-CSSFP21-0015

Gamma-ray bursts (GRBs) are one of the most energetic explosions in the universe, and are originated from either the collapse of the massive stars, or the merges of neutron stars and block holes. GRBs are thus crucial for understanding a wide- range of astrophysical topics, including supernovae, neutron stars, block holes, stellar evolution, star-formation history, and high-energy and particle astrophysics. However, the mechanism of GRB prompt emission remains unsettled, which not only hinder our understanding of GRB physics, but also impact the studies of the universe history through gamma-ray bursts. One of the main challenges comes from the extreme diversity of GRB pulse structures. While GRB pulse structures and properties encode a rich information of GRB central engine, jet structure, and circumburst environment, it is difficult for one theoretical model to explains the diverse behavior. Better understanding of the GRB pulse shapes is thus crucial to provide a complete picture of GRB physics, and to make GRBs a better probe of the the star-formation history. However, the complexity of GRB pulse structures make it challenging to automatically classifying GRB pulse shapes for a complete population study. To address this, we have established a citizen science project, BurstChaser, to explored a novel approach of classifying GRB pulse structures with citizen scientists. We have recruited a group of extremely dedicated citizen scientists, and our preliminary results show a remarkable consistency in GRB pulse classification from these citizen scientists, indicating that this can be a feasible method to finally provide the first large population study of pulse structures. Here, we proposed to expand this project to build a better infrastructure that will enable robust classifications with a large number of citizen scientist inputs. We will use the results to provide the first complete pulse population study of the entire GRB sample from the Neil Gehrels Swift Observatory, and examine the implications on GRB physical origins and emission mechanisms.

Jean-Luc Margot/University of California, Los Angeles
Are We Alone? A Citizen Science-Enabled Search for Technosignatures
21-CSSFP21-0004

The search for life in the universe represents one of humanity's most profound scientific endeavors. All life on Earth is related to a common ancestor, and the discovery of other forms of life will revolutionize our understanding of living systems. On a more philosophical level, it will transform humanity's perception of its place in the cosmos. Here, we address two scientific questions: (1) Are we alone in the universe? and (2) What are rigorous upper bounds on the number of extraterrestrial transmitters in the Galaxy? We are eager to enable broad participation in the search for cosmic companionship by establishing a collaboration with citizen scientists. The search for radio technosignatures has the potential to reveal the presence of other civilizations through the detection of extraterrestrial narrowband radio emissions. The biggest challenge to the search is terrestrial radio frequency interference (RFI). RFI signals can lead to false detections and prevent the detection of genuine signals. RFI signals that escape automatic RFI excision also reduce the efficiency of radio technosignature searches by imposing a substantial visual confirmation burden. We propose to design, test, launch, and maintain a scalable citizen science project on Zooniverse that will improve the efficiency of an ongoing search around tens of thousands of stars. Our specific objectives are to: (1) Identify the most promising narrowband radio signals detected in ~100 directions on the sky; (2) Generate a labeled training set with up to 100,000 entries to train a machine learning tool for improved RFI excision; (3) Train >40 team members in community engagement and science communication; and (4) Inspire thousands of citizen scientists by providing a platform where they can help answer one of the most important scientific questions of our time. Through this investigation, we will address two key science questions, improve the efficiency of the search for life around tens of thousands of stars, get thousands of current and future taxpayers excited about the search for life in the universe, inspire students to pursue STEM careers, and train future scientists and science communicators.

Emily Mason/Predictive Science Inc.
Hot On the Trail: Citizen Science Empowering Active Region Life Cycle Investigations
21-CSSFP21-0001

Solar physicists have studied active regions (ARs) -- large, localized regions of very strong dipolar magnetic field on the Sun -- for decades. The strength and close proximity of opposing magnetic fields makes these regions a hotbed for events like flares, coronal mass ejections, and solar energetic particle releases. These events wreak havoc on technology and human life on and above the Earth. While we have learned much about how these structures are formed and decay, one major stumbling block stands in the way of enhanced comprehensive study of long-lived ARs: the way in which they are named. The current method results in ARs which last for multiple Carrington rotations (recurring active regions, or RARs) accumulating several unpredictably-spaced NOAA numbers, as there is no consistent relationship between the designations applied to a single region. Therefore, long-term statistical studies of more than a few ARs become tedious in the extreme, as each active region must be tracked and its subsequent numbers recorded individually.

This project has two main goals to address the challenges outlined here:
1. The creation (using citizen scientists' input) of a comprehensive list of RARs
2. Use of this list to study AR heating patterns and changes over their lifetimes.
These goals will help us answer many long-standing questions about how ARs evolve and how the corona generally is heated.

We already have a list of RAR candidates produced by prior work from the full list of ARs from the years 2011-9; the next step for the project is to validate the nearly 1000 candidates to form the full list for the first goal. We will generate the necessary observations and upload them into a Zooniverse campaign which is already under construction; beta testing will be undertaken with a group of NASA summer interns to iterate the best practices for the campaign interface and tasks. The project will then be launched, and the citizen scientists' results will be analyzed for accuracy and agreement. Then we will publish the full dataset, and conduct a case study on several of the RARs across multiple solar rotations. This case study will use an analysis method known as time lag analysis, which provides insight into heating and cooling processes. This study will also be published.

This work will provide a far more holistic understanding of AR heating, and potentially provide important physical insights into the coronal heating problem. Furthermore, we anticipate many impactful applications of this database, from solar cycle study to integration into global coronal characterization packages. It also directly addresses Priorities 1 and 4 of the NASA 2020 Science Plan, and Key Science Goals 1 and 4 of the most recent Heliophysics decadal, by incorporating a broad contingent of the general public into the scientific process with the goal of unraveling critical solar physics challenges.

Paul Secor/American Society For Gravitational and Space Research, INC.
Harnessing the Power of NASA's Physical Sciences Informatics by Engaging Citizen Scientists
21-CSSFP21-0029

The American Society for Gravitational and Space Research (ASGSR) seeks to engage Citizen Scientists in helping to generate new knowledge from rare and complex space-flight relevant datasets found within NASA's Physical Science Informatics (PSI) data repository. It will accomplish this by establishing a set of PSI Analysis Working Groups (AWGs).

The PSI data repository contains data from physical science experiments performed in reduced-gravity environments such as the ISS, Space Shuttle flights, and Free-flyers. PSI also includes data from related ground-based studies. The data repository provides the opportunity for Citizen Scientists to data mine results from prior flight investigations, expand on the existing research, and thus exponentially increase the body of knowledge in this technical area.

The concept for the PSI AWGs was inspired by NASA's highly successful GeneLab Analysis Working Groups (AWGs), and ASGSR plans to deploy best practices gleaned from that project. The primary goal of the PSI AWG project is to establish six Analysis Working Groups based on research areas, generate participation from at least 100 citizen scientists and NASA personnel, and have each group produce a central document or manuscript detailing the metadata and scientific findings from their work.

Joshua Semeter/Boston University
Adaptive Ionospheric Observatory Using Dual-frequency Smartphones
21-CSSFP21-0021

The proposed project enlists a network of citizen scientists and emerging multi-frequency, multi-constellation smartphone technology to address a persistent outstanding question in ionospheric physics: How do large scale ionospheric structures and flow fields cascade to smaller scales that produce radio-frequency scintillations? The sensor density and coverage requirements put this out of reach of a dedicated facility investment. Citizen scientist engagement offers a solution. The long term science objectives of the proposed research are: (1) to provide constraints on the space-time development of irregularity structures, in principle down to the diffraction limit (~300 m), (2) to characterize the macro-scale ionospheric process within which scintillation events occur, and (3) to provide a unique new contextual capability for forthcoming NASA geospace missions (ICON, GDC, Dynamic).

Current dual-frequency smartphones have been shown to provide a useable measurement of relative change in ionospheric total electron content (TEC) estimated from differential carrier phase samples. The expanding proliferation of these devices has moved the proposed work to a critical transition point, where we may now consider deploying networks of such devices as an augmentation to TEC images computed from reference receiver data. Our eventual vision is an adaptive citizen scientist observatory that is responsive to predictions of geomagnetic activity in a given location as disseminated through social media (in the spirit of auroral watchers).

The proposed seed effort takes a substantial step toward realizing this vision by pursuing three tasks: (1) Conduct a systematic assessment of the capabilities of dual-frequency smartphone technologies (Xiaomi Mi 8, Google Pixel 4) deployed alongside the geodetic reference receiver at the Haystack Observatory, (2) Conduct a field-deployment using 5 citizen volunteers working with the PI and members of his lab, with deployment in the neighborhood of a NOAA geodetic receiver in upstate New York (near the sub-auroral boundary). Results from task 1 will be used to develop the test plan for this deployment. (3) Explore data fusion and visualization strategies using the result of task 2 in collaboration with reference TEC images.

This effort would have a multitude of positive impacts on the heliophysics discipline, including (1) Engaging a cross-section of citizens in space weather research in a meaningful way, (2) Leveraging the remarkable sensing, computation, and networking capabilities of smartphones for heliophysics research, and (3) Providing pathways for citizens with more advanced capabilities (e.g., non-PhD STEM students, professional engineers, computer scientists) to contribute in more advanced ways (e.g., app development, sensor testing, data interpretation).

Payloads and Research Investigations on the Surface of the Moon
Abstracts of selected proposals
(NNH21ZDA001N-PRISM)

Below are the abstracts of proposals selected for funding for the PRISM program. Principal Investigator (PI) name, institution, and proposal title are also included. 29 proposals were received in response to this opportunity. On June 9, 2022, 2 proposals were selected for funding.

Kerri Donaldson Hanna/University of Central Florida
Lunar-VISE: An investigation of the Moon's non-mare silicic volcanism

The Lunar Vulkan Imaging and Spectroscopy Explorer (Lunar-VISE) investigation seeks to better understand non-mare, silicic volcanism on the Moon using in-situ surface observations from a suite of heritage instruments on the rover and a suite of heritage cameras on the lander. The main science goal is to understand how late-stage lunar silicic volcanism works, as typified by the Gruithuisen domes. This goal is accomplished through two science objectives that places critical constraints on the two main hypotheses for the formation of non-mare silicic volcanic constructs (silicate liquid immiscibility versus basaltic underplating) by 1) mapping local variations in composition and thermophysical properties of the dome and 2) relating those local-scale measurements to orbital remote sensing observations from previous and current spacecraft. The primary exploration goal is to understand the geotechnical properties of the lunar regolith on the Gruithuisen domes at lander/rover scales, which is accomplished through one objective that maps local variations in regolith properties of the region surrounding the landing site and along the rover's traverse.

Lunar-VISE's three instruments onboard the rover investigate the Gruithuisen domes across three portions of the electromagnetic spectrum: visible through infrared (Vis/NIR; ~0.36 – 1.0 μm), thermal infrared (TIR; ~7.2 – 14.3 μm), and gamma ray and neutron energies (~0.3 eV – 10 MeV). The Vis/NIR multispectral camera (LV-VIC) includes spectral filters with effective wavelengths similar to those on the Clementine UVVIS camera and the Lunar Reconnaissance Orbiter Camera and draws heritage from the Ball Aerospace's Geo Space Camera. The TIR instrument, the LV-CIRiS, is a multispectral imaging radiometer and draws heritage from the L-CIRiS instrument being built for NASA under the LSITP program, which is manifested on the first Masten lander mission to the South Pole (TO 19C). The gamma ray and neutron spectrometer (LV-GRNS) maps major elemental abundances and draws on heritage from the neutron spectrometer on LunaH-Map and gamma-ray spectrometers flown on previous missions. Additionally, the Context and Descent Cameras (LV-CC and LV-DC) onboard the lander, which have the same heritage as the LV-VIC, characterize the surface and plume interactions during and after landing and characterize the rover's interaction with the surface.

The Lunar-VISE science objectives, which focus on better understanding lunar volcanism specifically silicic volcanism, address NASA's strategic objectives in the ARTEMIS III Science Definition Team (SDT) Report, specifically, Science Objective 1 Goal 1c, "Volcanism: partial melting, eruptions, flow sequence and compositions" and Science Objective 1 Goal 1f, "Determine physical properties of regolith at diverse locations of expected human activities". Additionally, the Lunar-VISE science objectives address key science questions identified in NASA's 2 Vision and Voyages for Planetary Science Decadal Survey ("What are the distribution and timescale of volcanism on the inner planets?") and the Scientific Context for the Exploration of the Moon (SCEM) concepts ("Key planetary processes are manifested in the diversity of lunar rocks" and "Lunar volcanism provides a window in the thermal and compositional evolution of the Moon"). The Lunar-VISE exploration objective addresses NASA's strategic objectives in the SDT Report, specifically, Science Objective 1 Goal 1f, "Determine physical properties of regolith at diverse locations of expected human activities", and SDT Science Objective 7 Goal 7k "Understand lunar dust behavior, particularly dust dynamics". Additionally, the Lunar-VISE exploration objective addresses key concepts in the SCEM including "The Moon is a natural laboratory for regolith processes and weathering on anhydrous airless bodies".

Andrew Settles/NASA Ames Research Center
Lunar Explorer Instrument for Space Biology Applications (LEIA)

Radiation and reduced gravity pose biological risks to crewed deep space exploration. At the cellular level, radiation damage can be amplified by reduced gravity. Empirical evidence on cellular responses to beyond low Earth orbit (BLEO) environments is imperative to develop effective countermeasures for crew health and in-space biomanufacturing. The LEIA project will use the model organism yeast to quantify metabolism, growth, and real-time radiation exposure in culture on the lunar surface. Our research aims to identify genetic factors impacting cellular response to lunar surface radiation and gravity. To assay anabolic pathways directly, we will leverage a translational yeast strain for in situ production of crew countermeasures. The lunar south pole landing site is proposed to address objectives 7a, 7b, 7d, 7e, 7f, 7i, and 7m of the Artemis III Science Definition Team (SDT) Report priorities through four specific aims.

Aim 1. Combine yeast genetics with metabolic modeling to determine cellular sensitivity to the lunar environment.
Aim 2. Evaluate synthetic biology-enabled production of antioxidant nutrients and proteins under lunar surface conditions.
Aim 3. Evaluate genetically engineered yeast for enhanced tolerance to the lunar environment.
Aim 4. Determine the lunar radiation dose and composition corresponding to the biological responses measured in Aims 1-3.

To achieve our research aims, LEIA is developing a suite of automated instruments combining yeast cell culture assays at an unprecedented scale with precise measurements of biologically relevant radiation on the lunar surface. Ground studies will develop an optimized biological payload to evaluate the roles of reactive oxygen species and DNA damage repair in maintaining cell health, cellular homeostasis, and metabolite production. On the lunar surface, two replicate experiments, each consisting of 128 assays, will be activated using the BioSensor microfluidics incubator. Each assay consists of a culture well in which cell growth, metabolism, and engineered bioproducts are measured optically over a 96-h time course. Charged particle radiation will be measured by a linear energy transfer spectrometer. Biologically damaging neutrons will be measured by a miniaturized fast neutron detector. These instruments will produce powerful yet small-volume quantitative datasets for telemetry to Earth.

By studying genetic factors in yeast, LEIA supports sustained human presence in deep space in two ways. First, using yeast as a model organism, we will gain information about conserved tolerance pathways that can be targeted for countermeasures in humans. Second, yeast is a microbial cell factory, and we will test genetic strategies to translate fundamental knowledge to improve space bioproduction. In addition to addressing Artemis III SDT Objective 7, the proposed research addresses the 2018 NASA Strategic Plan SKGs 1.1 and 1.2, 2011 Decadal Survey on Biological & Physical Science in Space objectives P1, P2, P3, and CC9, and Space Biology Guiding Questions.
