Table of Contents - BPS

4. Biological and Physical Sciences Division (BPS)

4.a. Demographics

4.a.i. Principal Investigators (PIs)

4.a.i.1. Context and Limitations of the Data – BPS 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 Biological and Physical Sciences Division, there are ~800 submitted proposals over all ROSES years: ~700 for ROSES 2016-2020 and ~100 for ROSES 2021.

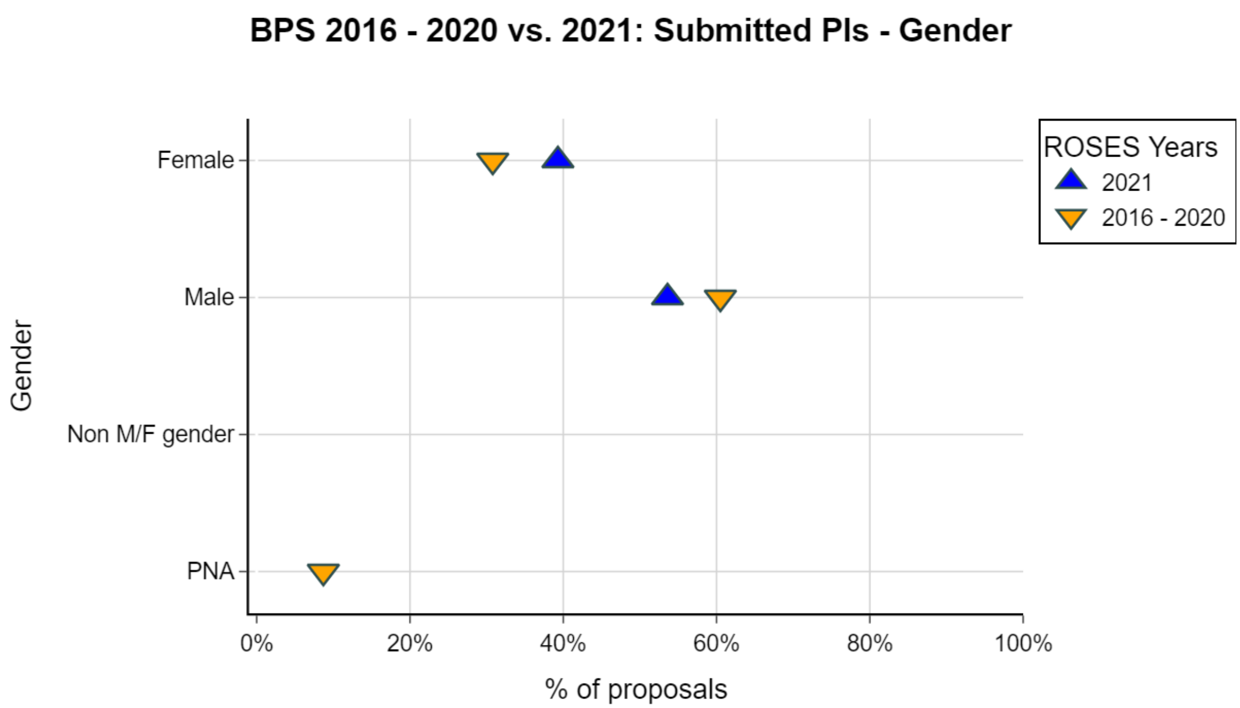
Proposals with PIs who took the survey but selected "prefer not to answer" for all demographic survey questions:

- Submitted proposals: BPS 2016 - 2020: 8% | BPS 2021: 5%
- Selected proposals: BPS 2016 - 2020: 11% | BPS 2021: 11%

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.

4.a.i.2. Gender – BPS PIs

BPS PIs: Submitted Gender - Plot



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

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.

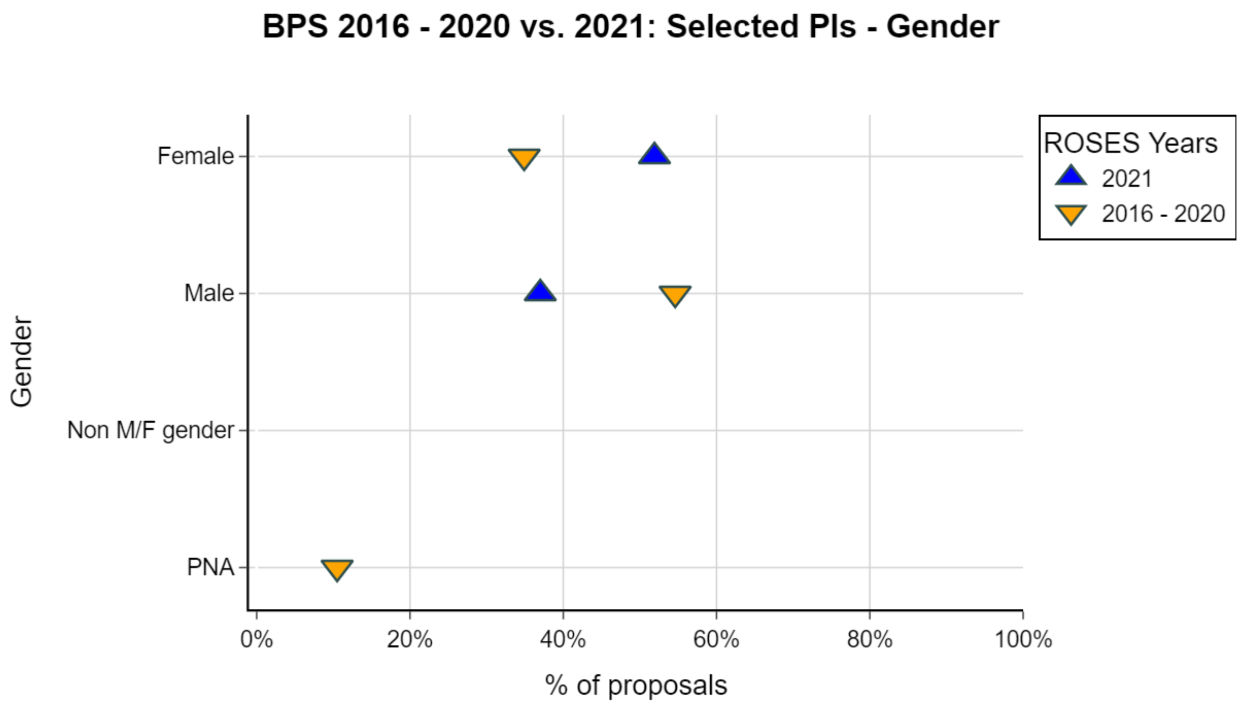
BPS PIs: Submitted Gender - Data Table

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

Gender	BPS 2016 - 2020	BPS 2021
Female	31%	39%
Male	60%	54%
Non M/F gender	NR	NR
PNA	9%	NR

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

BPS PIs: Selected Gender - Plot



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

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.

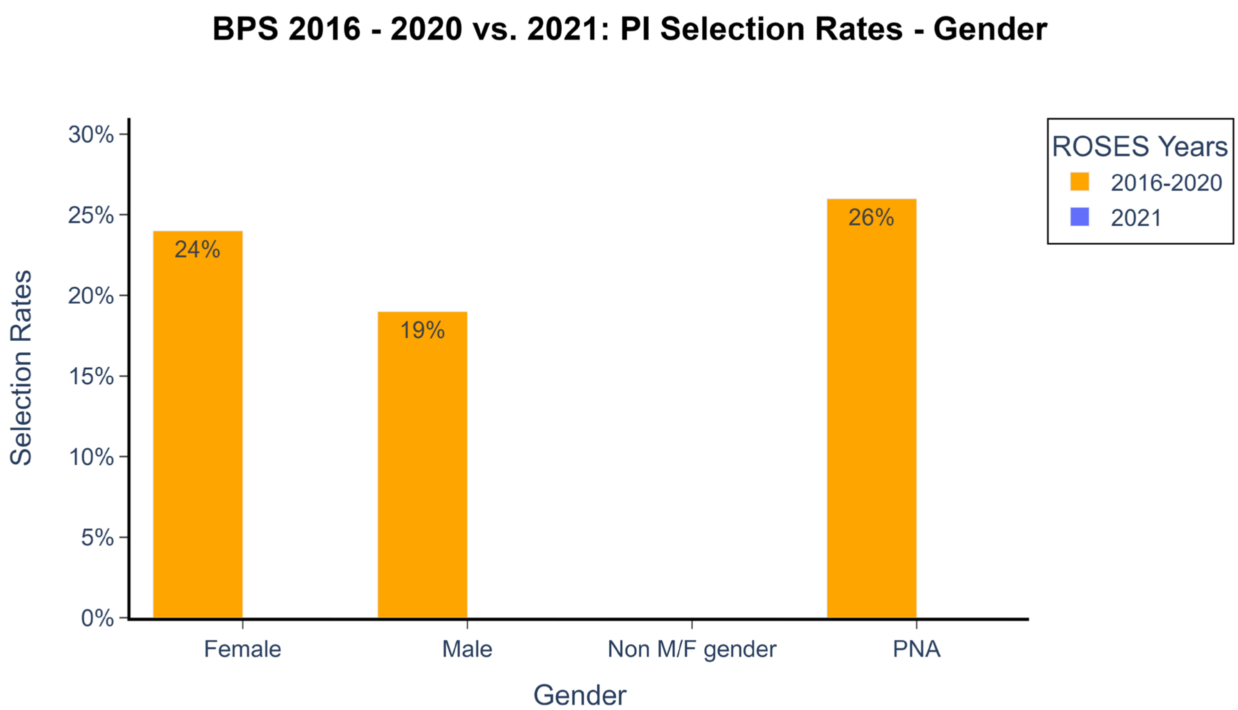
BPS PIs: Selected Gender - Data Table

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

Gender	BPS 2016 - 2020	BPS 2021
Female	35%	52%
Male	55%	37%
Non M/F gender	NR	NR
PNA	10%	NR

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal

BPS 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: Female (ROSES 2021), Male (ROSES 2021), 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.

BPS PIs: Gender Selection Rate - Data Table

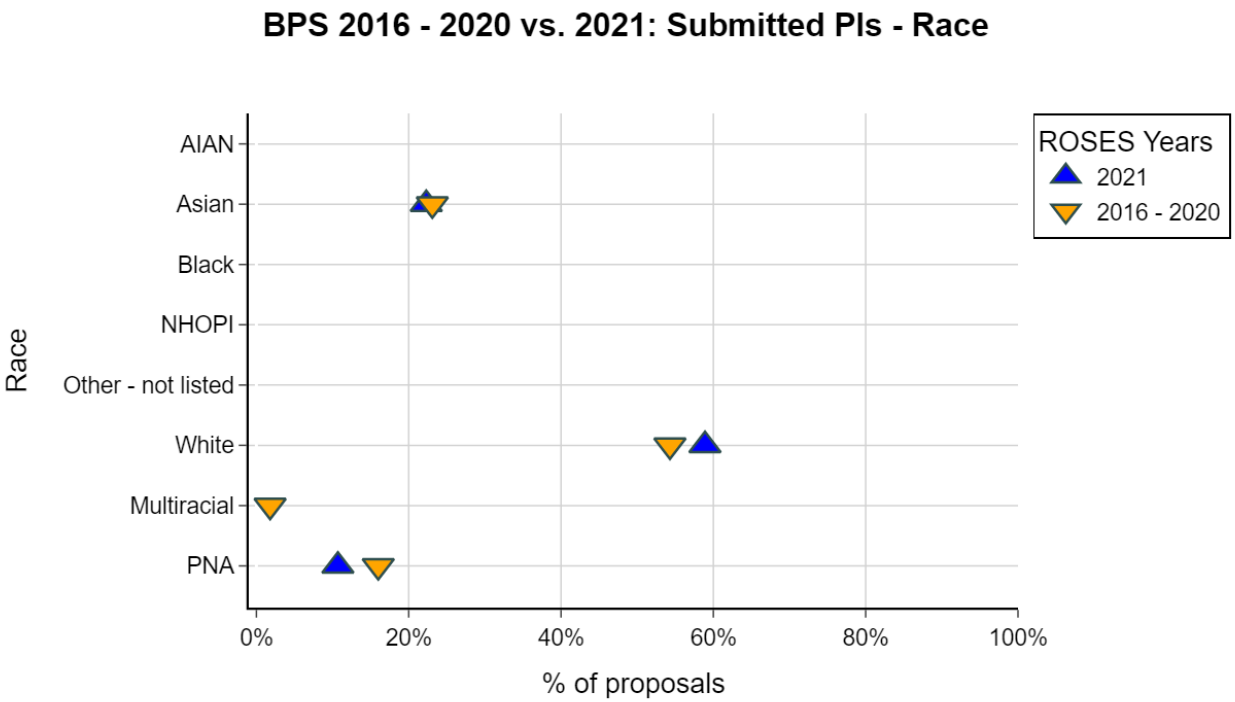
BPS 2016 - 2020 vs. 2021: PI Selection Rates - Gender

Gender	BPS 2016-2020	BPS 2016-2020 Response/All Genders	BPS 2021	BPS 2021 Response/All Genders
Female	24%	1.14	NR	NR
Male	19%	0.9	NR	NR
Non M/F gender	NR	NR	NR	NR
PNA	26%	1.24	NR	NR
All Genders	21%	1	24%	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

4.a.i.3. Race – BPS PIs

BPS 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.

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.

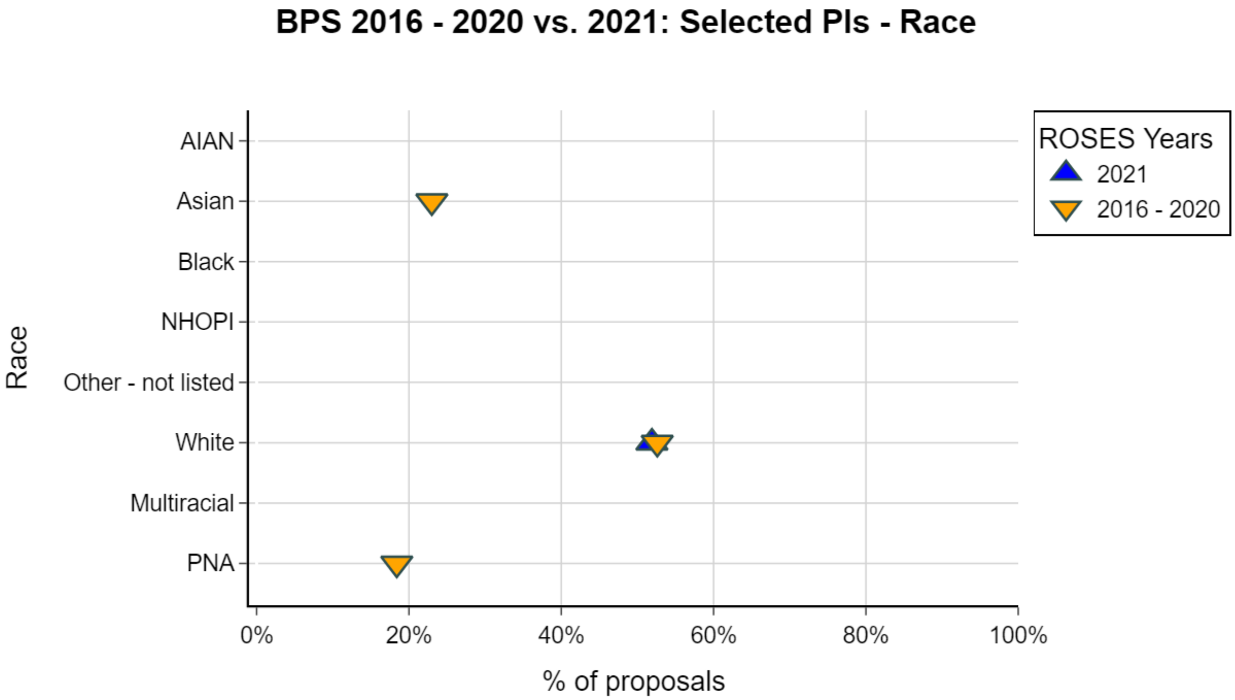
BPS PIs: Submitted Race - Data Table

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

Race	BPS 2016 - 2020	BPS 2021
AIAN	NR	NR
Asian	23%	22%
Black	NR	NR
NHOPI	NR	NR
Other - not listed	NR	NR
White	54%	59%
Multiracial	2%	NR
PNA	16%	11%

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.

BPS 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.

Suppressed 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.

BPS PIs: Selected Race - Data Table

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

Race	BPS 2016 - 2020	BPS 2021
AIAN	NR	NR
Asian	23%	NR
Black	NR	NR
NHOPI	NR	NR
Other - not listed	NR	NR
White	53%	52%
Multiracial	NR	NR
PNA	18%	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.

BPS 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

Suppressed 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.

BPS PIs: Race Selection Rate - Data Table

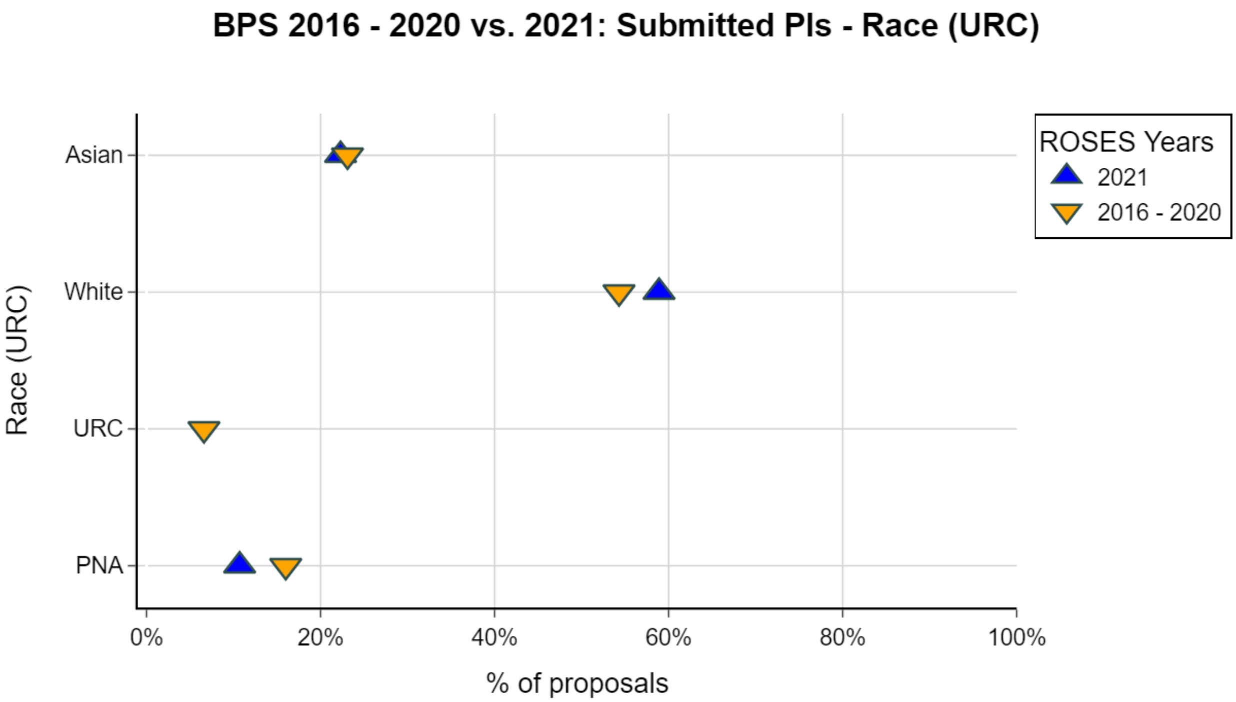
BPS 2016 - 2020 vs. 2021: PI Selection Rates - Race

Race	BPS 2016-2020	BPS 2016-2020 Response/All Races	BPS 2021	BPS 2021 Response/All Races
AIAN	NR	NR	NR	NR
Asian	21%	1	NR	NR
Black	NR	NR	NR	NR
NHOPI	NR	NR	NR	NR
Other - not listed	NR	NR	NR	NR
White	21%	1	21%	0.88
Multiracial	NR	NR	NR	NR
PNA	25%	1.19	NR	NR
All Races	21%	1	24%	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

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

BPS PIs: Submitted Race (URC) - Plot



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

Suppressed categories: URC (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.

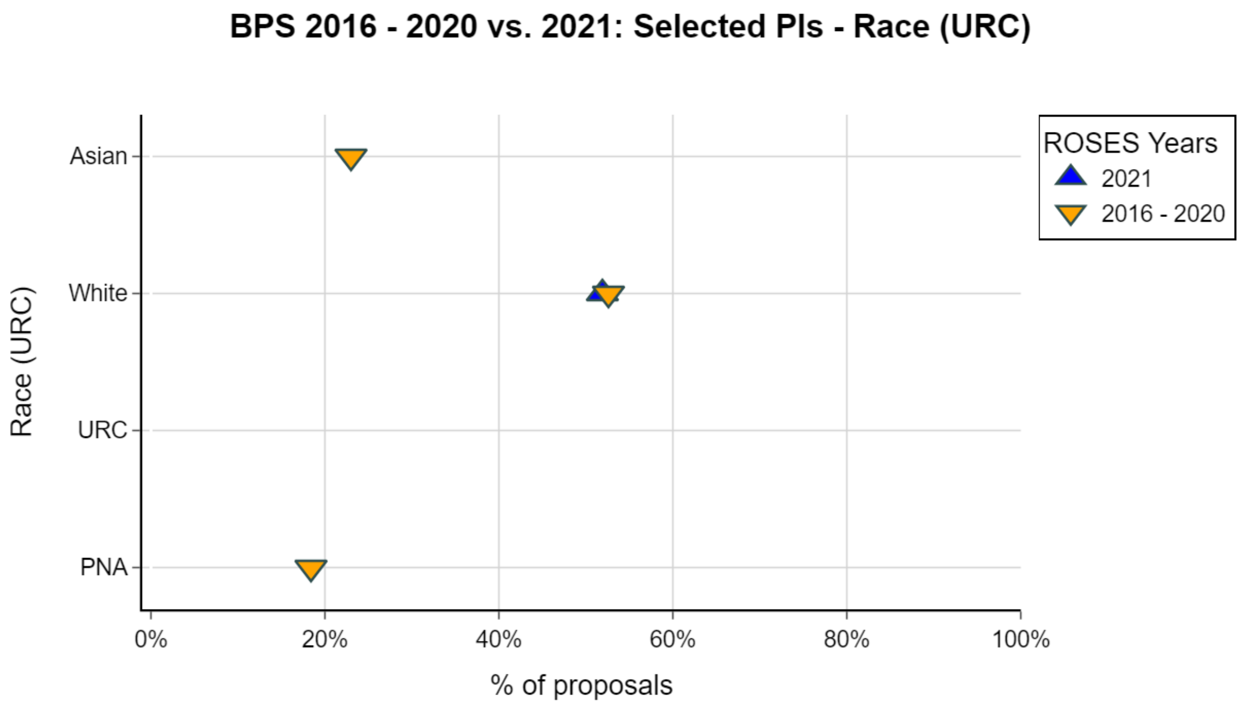
BPS PIs: Submitted Race (URC) - Data Table

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

Race (URC)	BPS 2016 - 2020	BPS 2021
Asian	23%	22%
White	54%	59%
URC	7%	NR
PNA	16%	11%

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

BPS PIs: Selected Race (URC) - Plot



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

Suppressed 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.

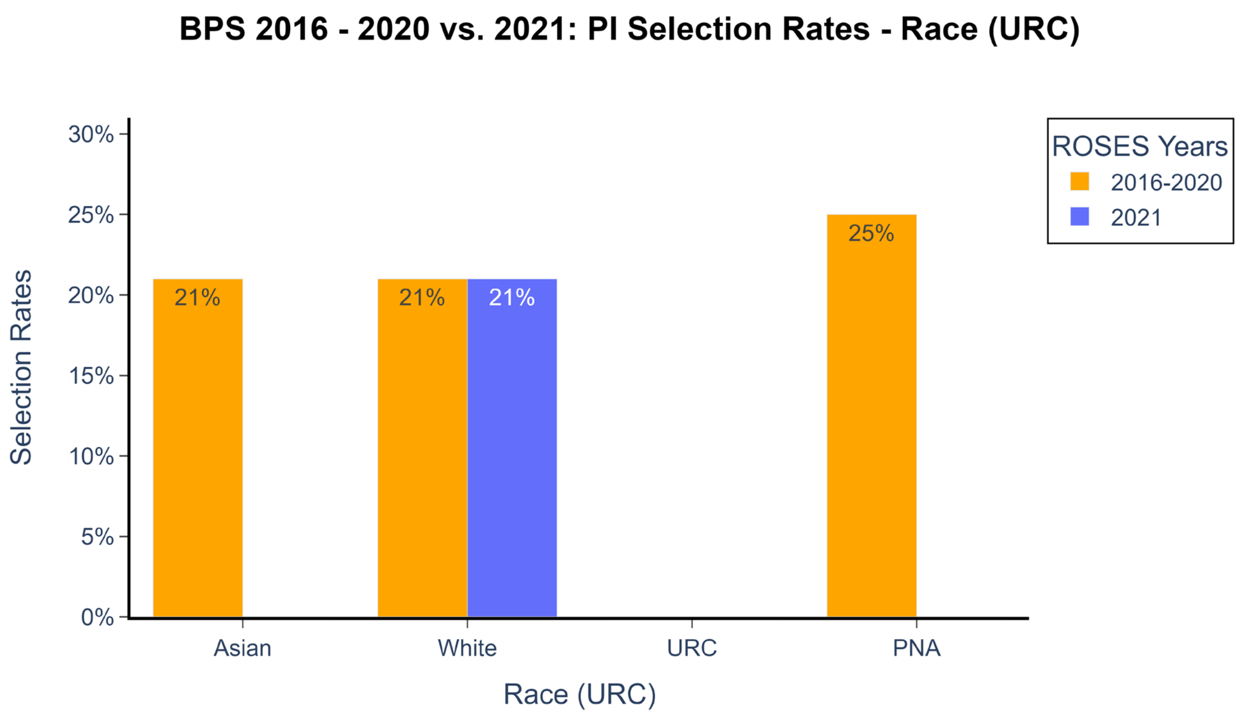
BPS PIs: Selected Race (URC) - Data Table

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

Race (URC)	BPS 2016 - 2020	BPS 2021
Asian	23%	NR
White	53%	52%
URC	NR	NR
PNA	18%	NR

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

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



Under-Represented Community (URC) includes Black, Native Hawaiian & Other Pacific Islander, American Indian & Alaska Native, 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

Suppressed 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.

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

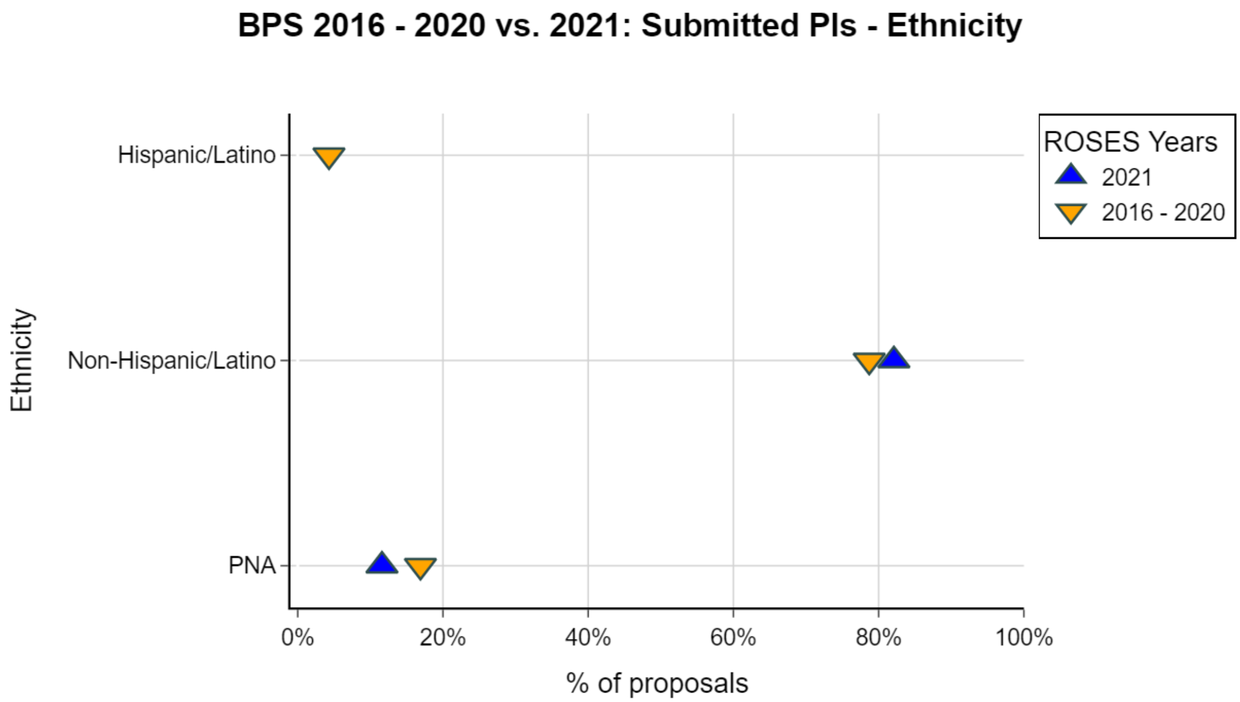
BPS 2016 - 2020 vs. 2021: PI Selection Rates - Race (URC)

Race (URC)	BPS 2016-2020	BPS 2016-2020 Response/All Races (URC)	BPS 2021	BPS 2021 Response/All Races (URC)
Asian	21%	1	NR	NR
White	21%	1	21%	0.88
URC	NR	NR	NR	NR
PNA	25%	1.19	NR	NR
All Races (URC)	21%	1	24%	1

Under-Represented Community (URC) includes Black, Native Hawaiian & Other Pacific Islander, American Indian & Alaska Native, 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

4.a.i.5. Ethnicity – BPS PIs

BPS PIs: Submitted Ethnicity - Plot



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

Suppressed categories: Hispanic/Latino (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.

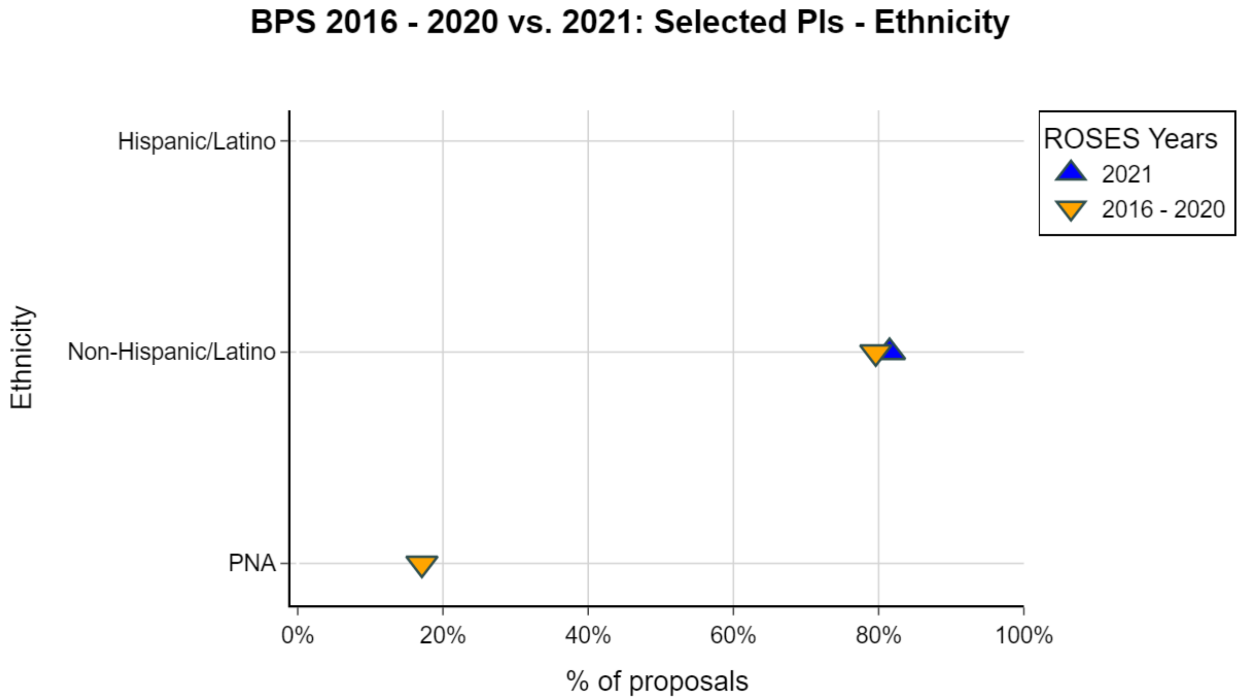
BPS PIs: Submitted Ethnicity - Data Table

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

Ethnicity	BPS 2016 - 2020	BPS 2021
Hispanic/Latino	4%	NR
Non-Hispanic/Latino	79%	82%
PNA	17%	12%

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

BPS PIs: Selected Ethnicity - Plot



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

Suppressed 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.

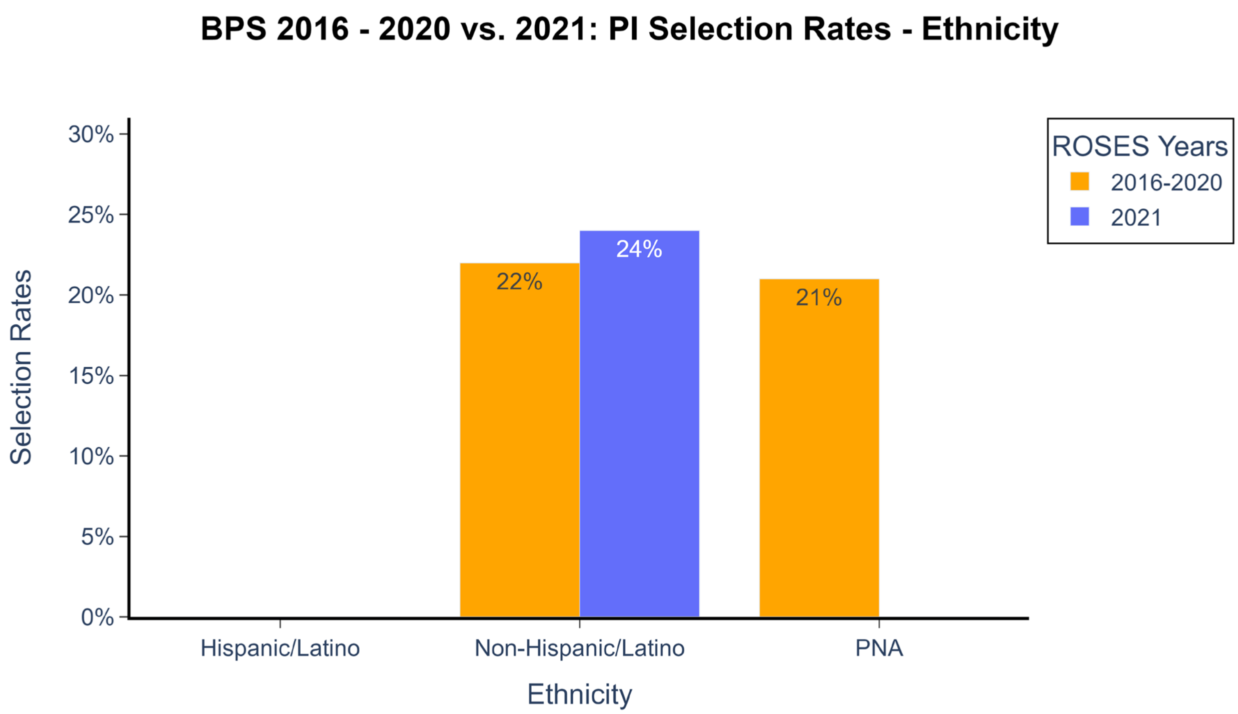
BPS PIs: Selected Ethnicity - Data Table

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

Ethnicity	BPS 2016 - 2020	BPS 2021
Hispanic/Latino	NR	NR
Non-Hispanic/Latino	80%	82%
PNA	17%	NR

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

BPS 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

Suppressed 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.

BPS PIs: Ethnicity Selection Rate - Data Table

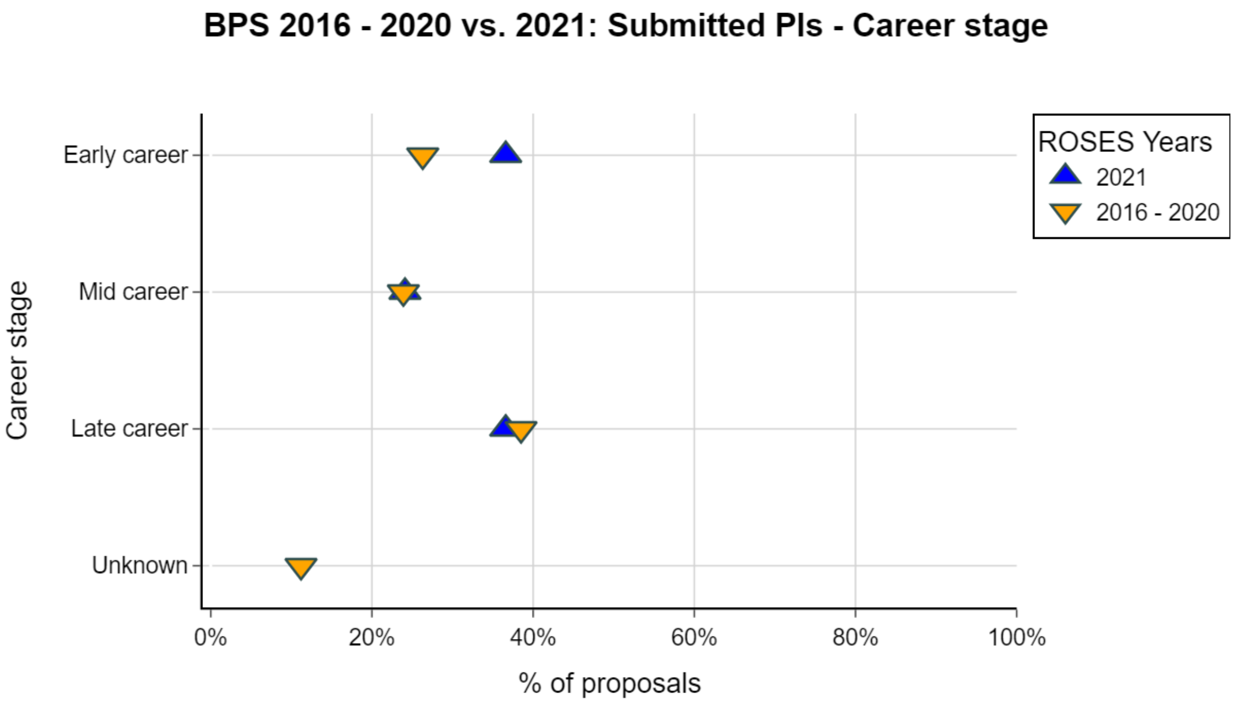
BPS 2016 - 2020 vs. 2021: PI Selection Rates - Ethnicity

Ethnicity	BPS 2016-2020	BPS 2016-2020 Response/All Ethnicities	BPS 2021	BPS 2021 Response/All Ethnicities
Hispanic/Latino	NR	NR	NR	NR
Non-Hispanic/Latino	22%	1.05	24%	1
PNA	21%	1	NR	NR
All Ethnicities	21%	1	24%	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

4.a.i.6. Career Stage – BPS PIs

BPS 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.

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.

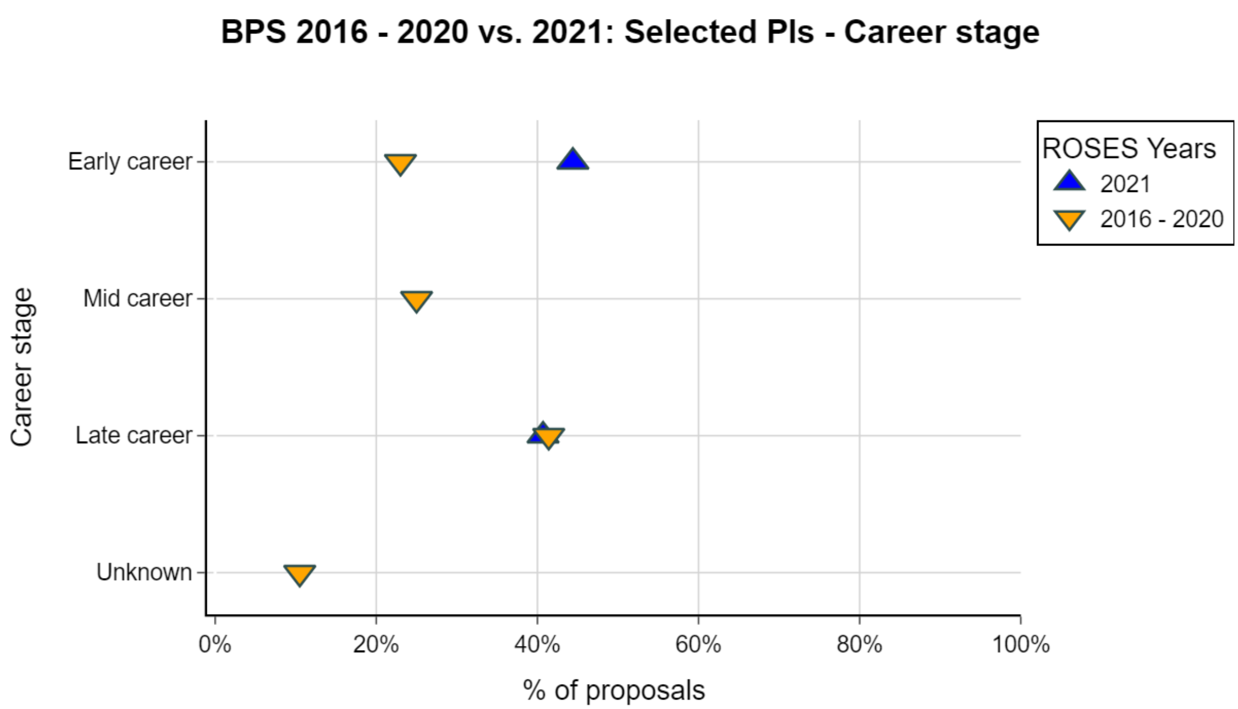
BPS PIs: Submitted Career Stage - Data Table

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

Career stage	BPS 2016 - 2020	BPS 2021
Early career	26%	37%
Mid career	24%	24%
Late career	38%	37%
Unknown	11%	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.

BPS 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.

Suppressed categories: Mid career (ROSES 2021), 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.

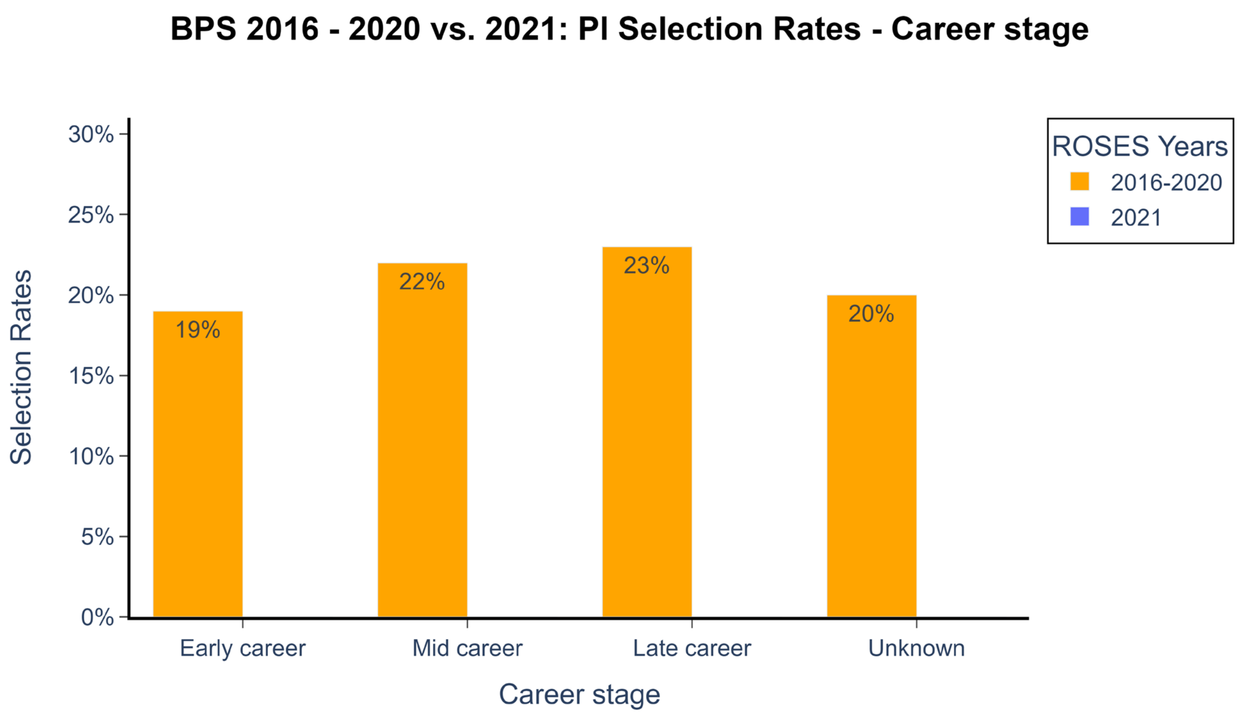
BPS PIs: Selected Career Stage - Data Table

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

Career stage	BPS 2016 - 2020	BPS 2021
Early career	23%	44%
Mid career	25%	NR
Late career	41%	41%
Unknown	10%	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.

BPS 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

Suppressed categories: Early career (ROSES 2021), Mid career (ROSES 2021), Late career (ROSES 2021), 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.

BPS PIs: Career Stage Selection Rate - Data Table

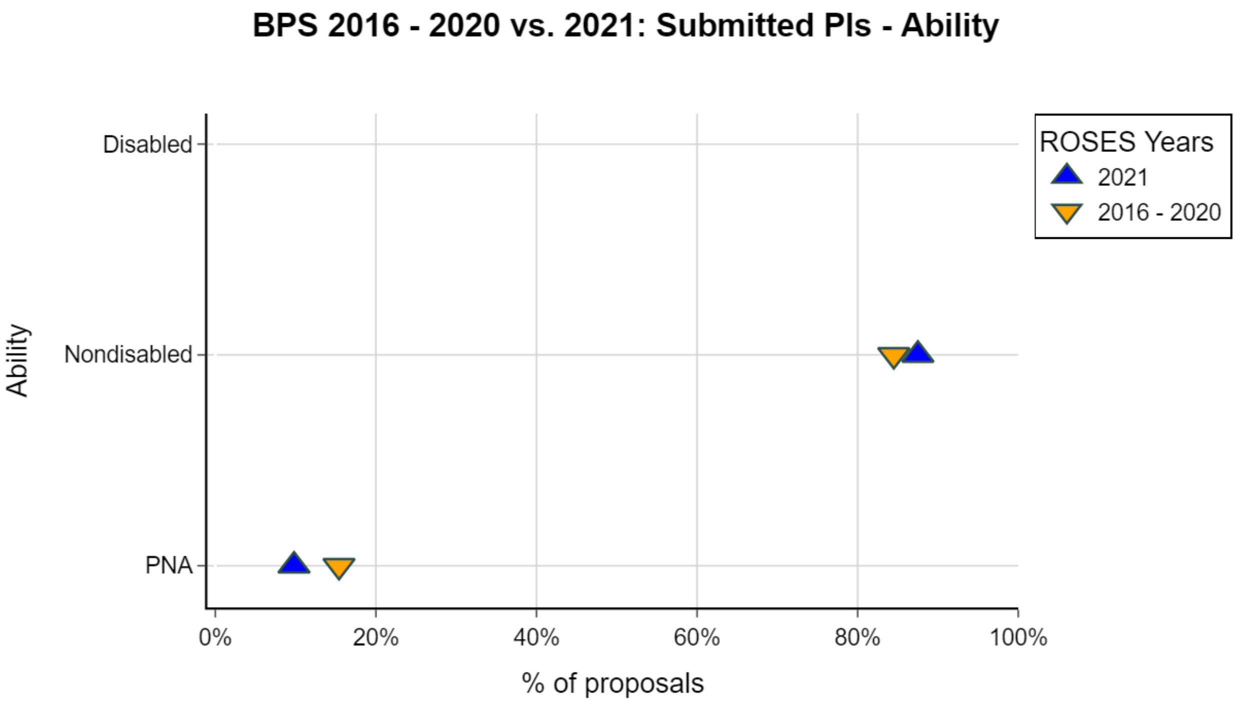
BPS 2016 - 2020 vs. 2021: PI Selection Rates - Career stage

Career stage	BPS 2016-2020	BPS 2016-2020 Response/All Career stages	BPS 2021	BPS 2021 Response/All Career stages
Early career	19%	0.9	NR	NR
Mid career	22%	1.05	NR	NR
Late career	23%	1.1	NR	NR
Unknown	20%	0.95	NR	NR
All Career stages	21%	1	24%	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

4.a.i.7. Disability Status – BPS PIs

BPS 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.

Suppressed categories: Disabled (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.

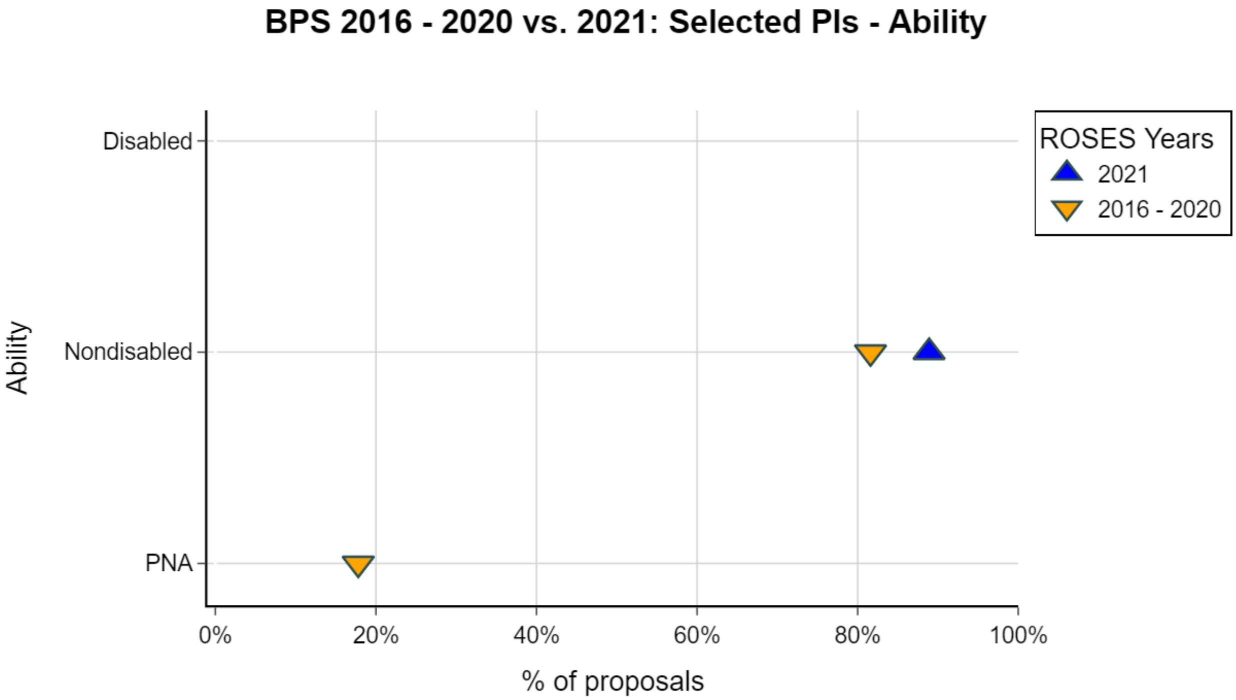
BPS PIs: Submitted Ability - Data Table

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

Ability	BPS 2016 - 2020	BPS 2021
Disabled	NR	NR
Nondisabled	84%	88%
PNA	15%	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.

BPS 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.

Suppressed 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.

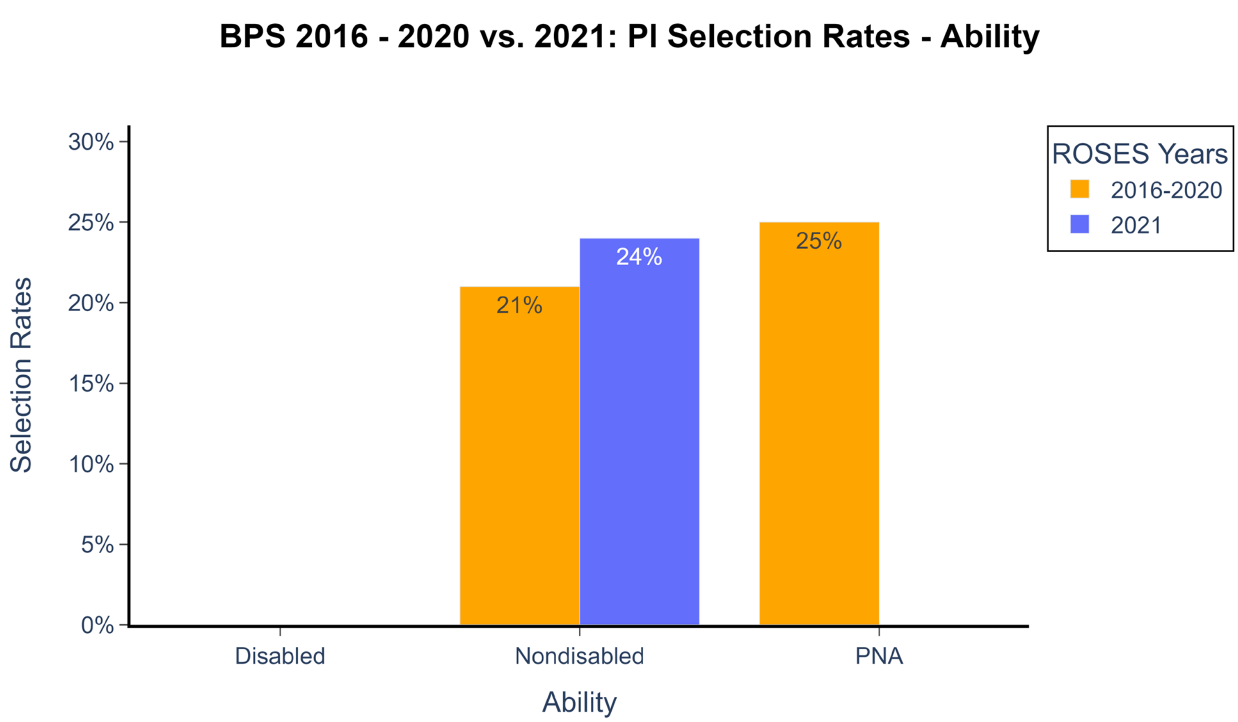
BPS PIs: Selected Ability - Data Table

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

Ability	BPS 2016 - 2020	BPS 2021
Disabled	NR	NR
Nondisabled	82%	89%
PNA	18%	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.

BPS 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

Suppressed 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.

BPS PIs: Ability Selection Rate - Data Table

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

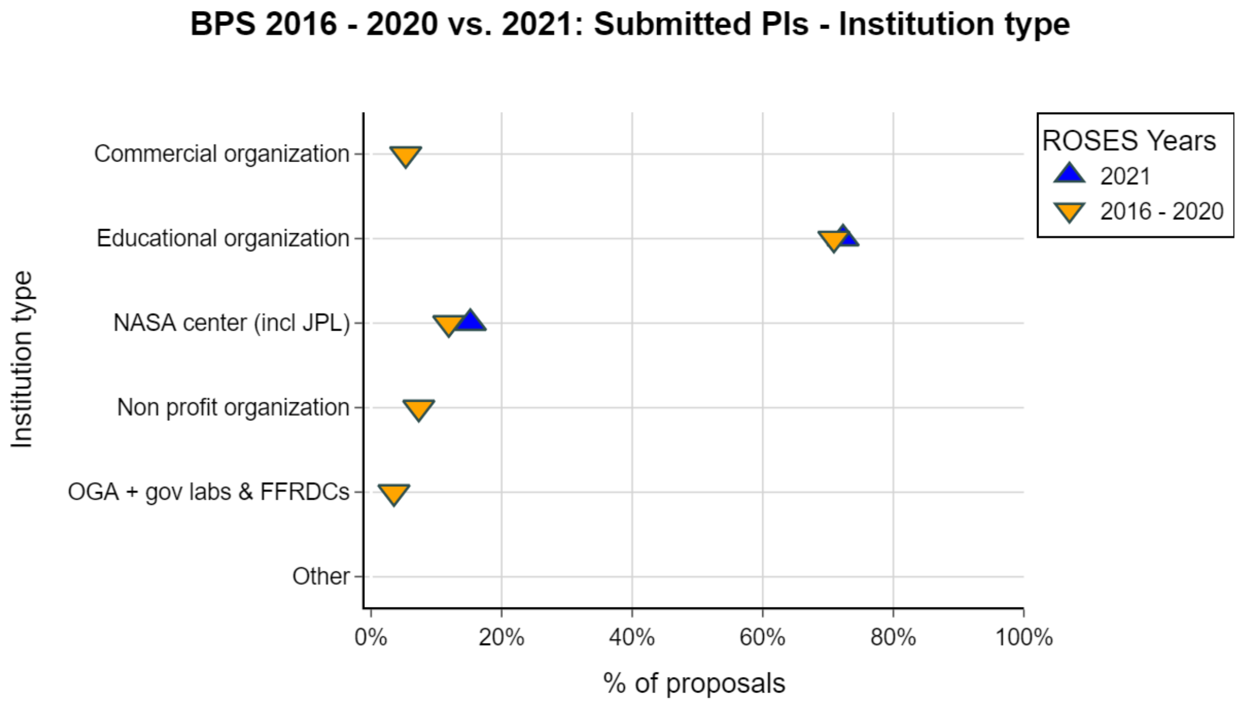
Ability	BPS 2016-2020	BPS 2016-2020 Response/All Abilities	BPS 2021	BPS 2021 Response/All Abilities
Disabled	NR	NR	NR	NR
Nondisabled	21%	1	24%	1
PNA	25%	1.19	NR	NR
All Abilities	21%	1	24%	1

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

4.a.i.8. Institutional Analysis

4.a.i.8.a. Institution Type – BPS PIs

BPS 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.

Suppressed categories: Commercial organization (ROSES 2021), Non profit organization (ROSES 2021), 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.

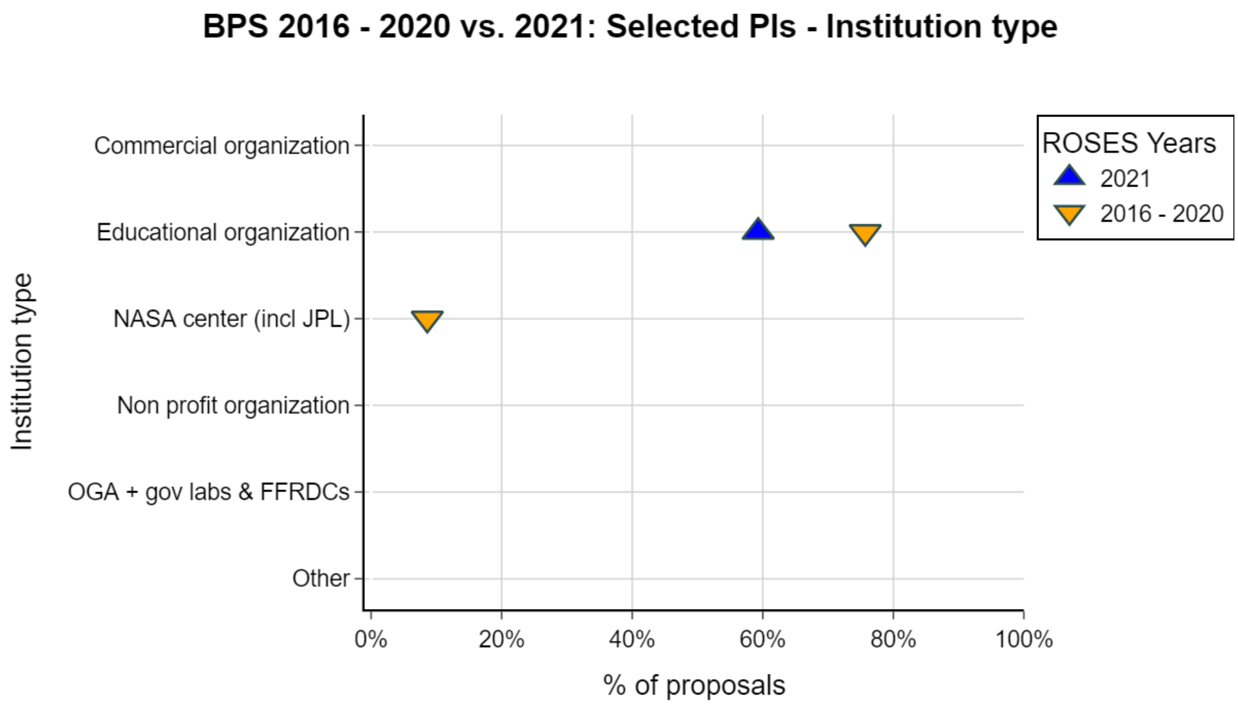
BPS PIs: Submitted Institution Type - Data Table

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

Institution type	BPS 2016 - 2020	BPS 2021
Commercial organization	5%	NR
Educational organization	71%	72%
NASA center (incl JPL)	12%	15%
Non profit organization	7%	NR
OGA + gov labs & FFRDCs	4%	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.

BPS 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.

Suppressed categories: Commercial organization (All years), NASA Center (ROSES 2021), Non profit organization (All years), 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.

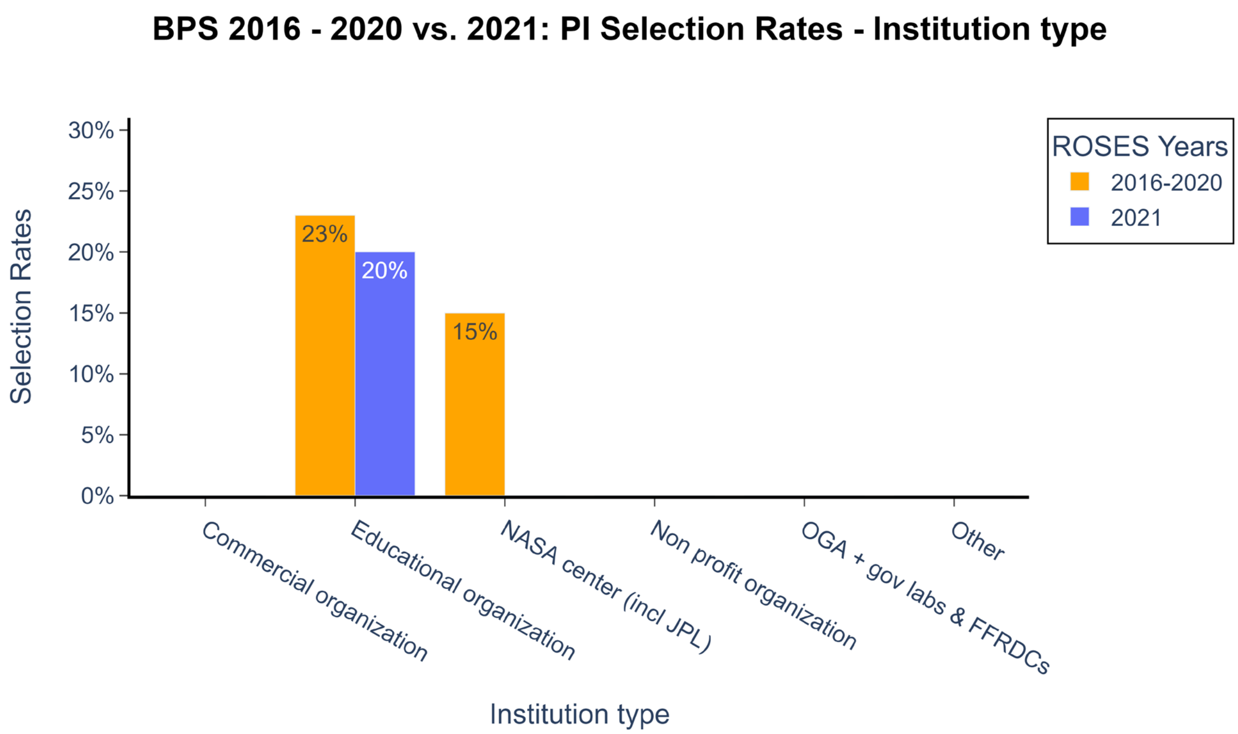
BPS PIs: Selected Institution Type - Data Table

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

Institution type	BPS 2016 - 2020	BPS 2021
Commercial organization	NR	NR
Educational organization	76%	59%
NASA center (incl JPL)	9%	NR
Non profit organization	NR	NR
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.

BPS 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

Suppressed categories: Commercial organization (All years), NASA Center (ROSES 2021), Non profit organization (All years), 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.

BPS PIs: Institution Type Selection Rate - Data Table

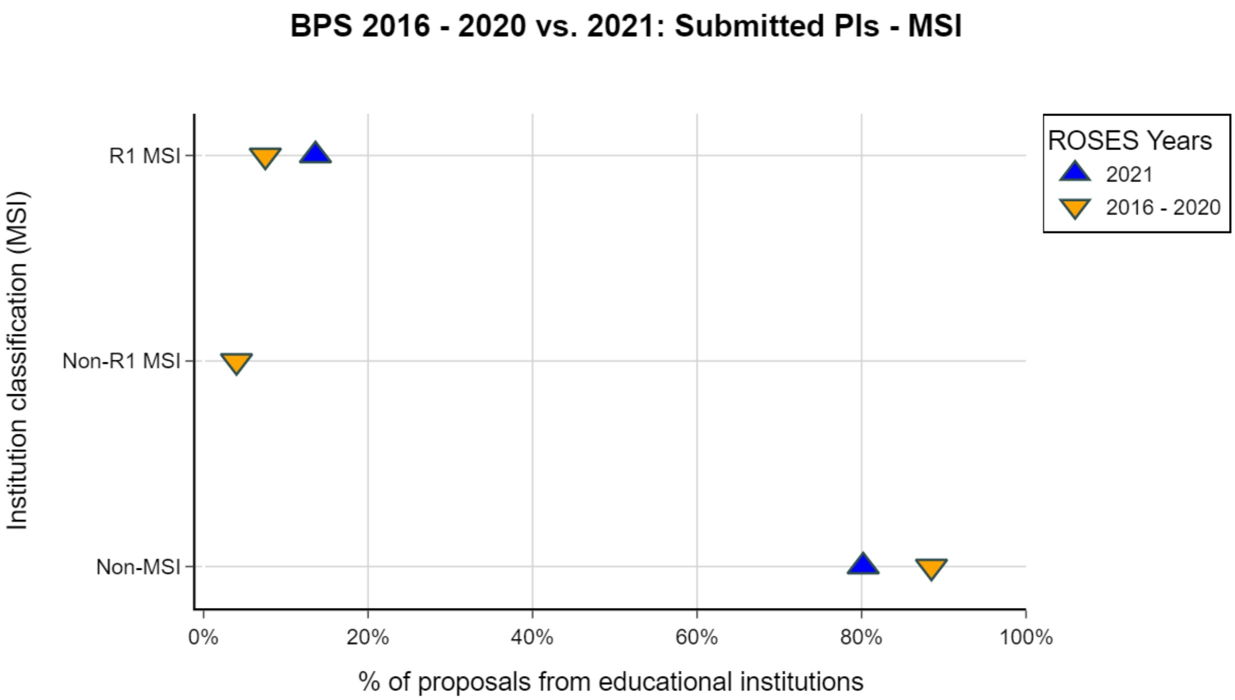
BPS 2016 - 2020 vs. 2021: PI Selection Rates - Institution type

Institution type	BPS 2016-2020	BPS 2016-2020 Response/All Institution types	BPS 2021	BPS 2021 Response/All Institution types
Commercial organization	NR	NR	NR	NR
Educational organization	23%	1.1	20%	0.83
NASA center (incl JPL)	15%	0.71	NR	NR
Non profit organization	NR	NR	NR	NR
OGA + gov labs & FFRDCs	NR	NR	NR	NR
Other	NR	NR	NR	NR
All Institution types	21%	1	24%	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

4.a.i.8.b. Minority Serving Institutions (MSIs) – BPS PIs

BPS PIs: Submitted MSI - Plot



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

Suppressed 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.

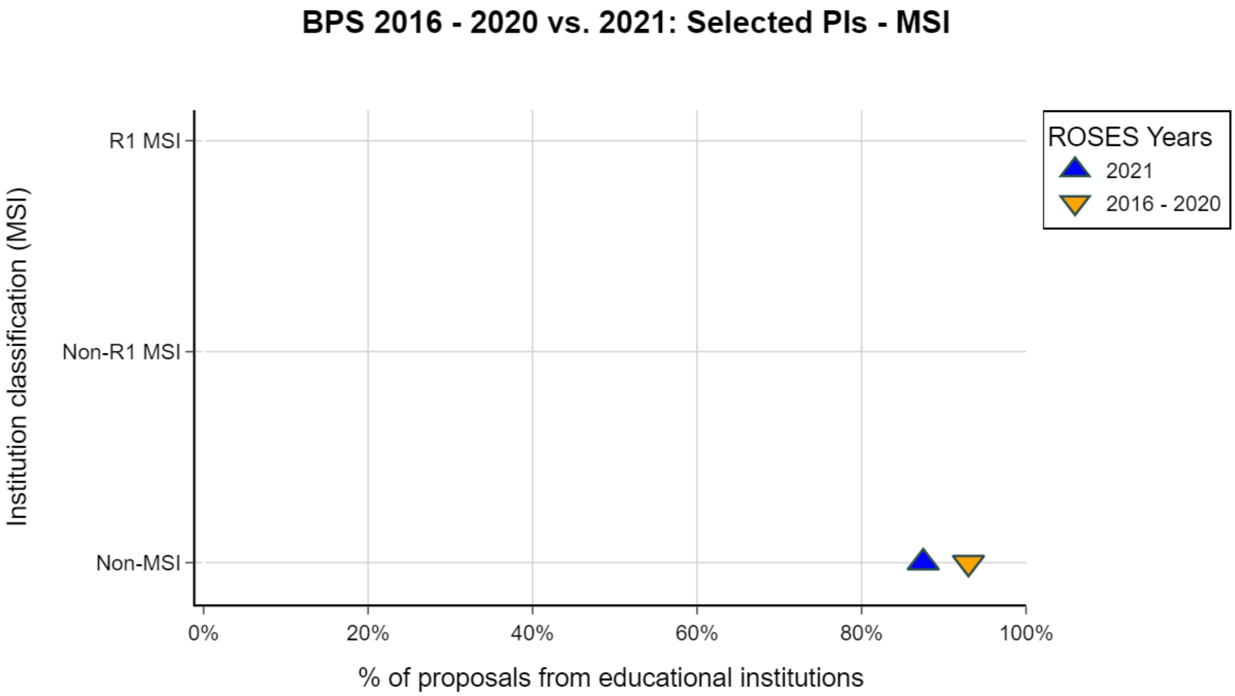
BPS PIs: Submitted MSI - Data Table

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

MSI	BPS 2016 - 2020	BPS 2021
R1 MSI	8%	14%
Non-R1 MSI	4%	NR
Non-MSI	88%	80%

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

BPS PIs: Selected MSI - Plot



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

Suppressed categories: R1 MSI (All years), 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.

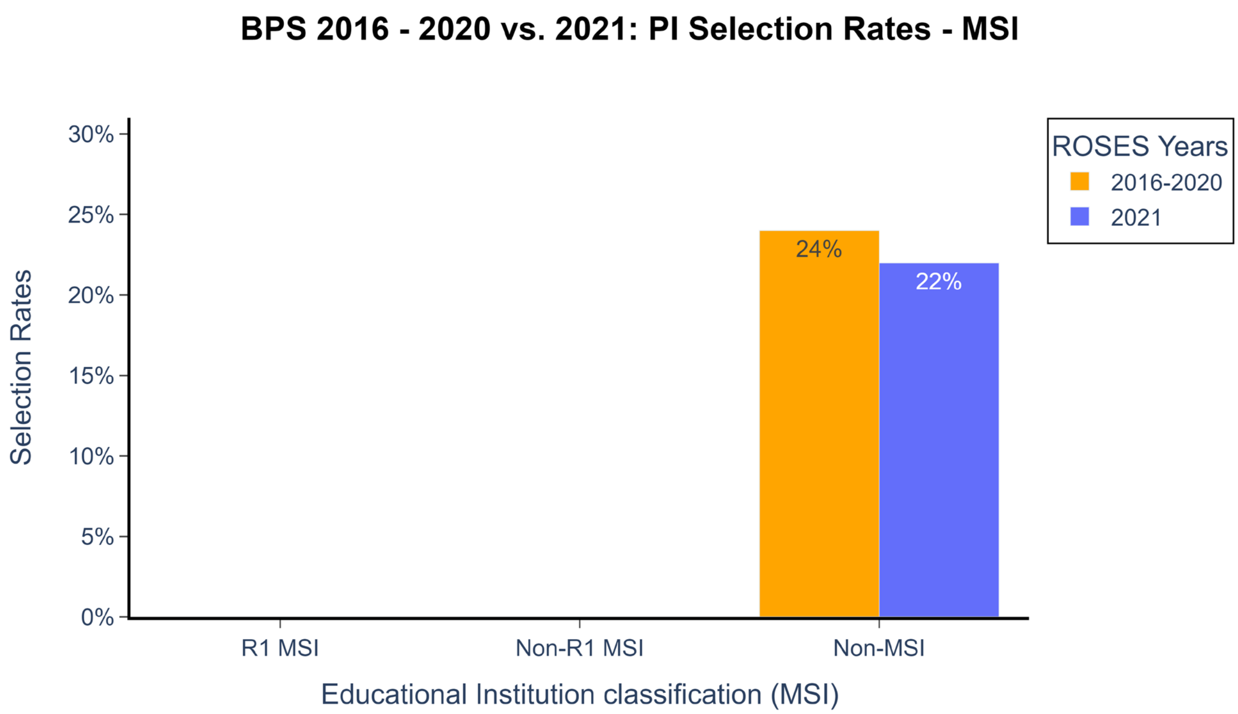
BPS PIs: Selected MSI - Data Table

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

MSI	BPS 2016 - 2020	BPS 2021
R1 MSI	NR	NR
Non-R1 MSI	NR	NR
Non-MSI	93%	88%

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

BPS 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

Suppressed categories: R1 MSI (All years), 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.

BPS PIs: MSI Selection Rate - Data Table

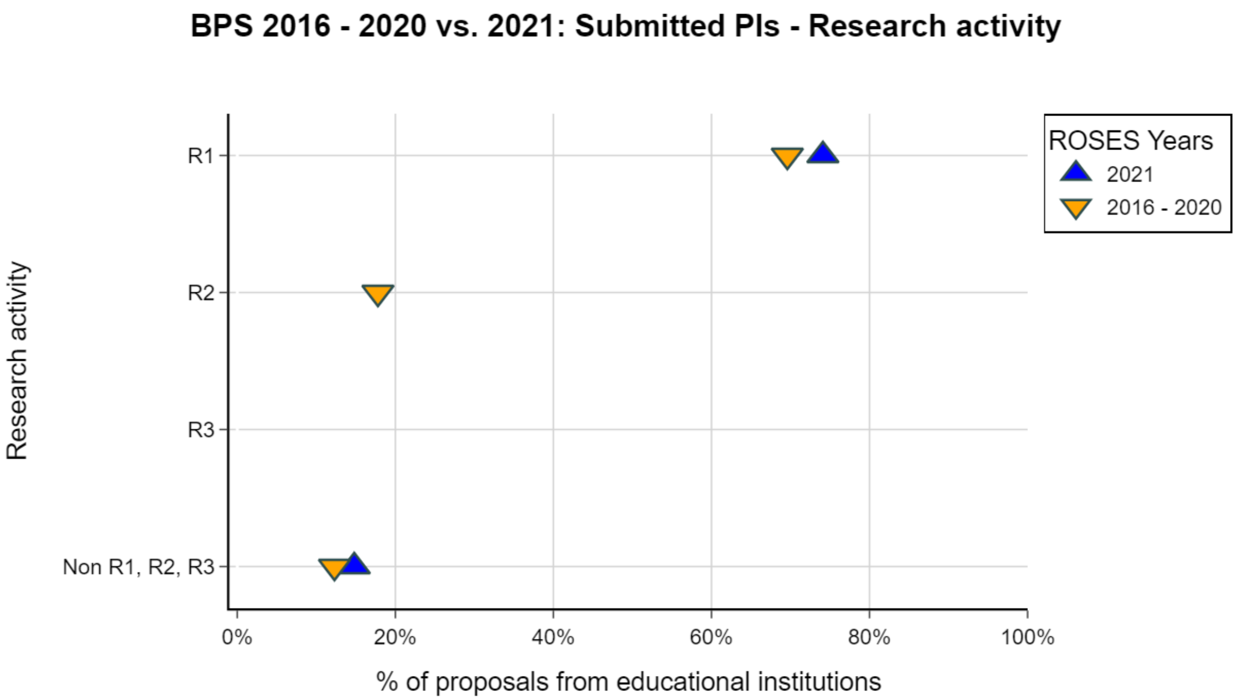
BPS 2016 - 2020 vs. 2021: PI Selection Rates - MSI

MSI	BPS 2016-2020	BPS 2016-2020 Response/All Educational Institutions	BPS 2021	BPS 2021 Response/All Educational Institutions
R1 MSI	NR	NR	NR	NR
Non-R1 MSI	NR	NR	NR	NR
Non-MSI	24%	1.04	22%	1.1
All Educational Institutions	23%	1	20%	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

4.a.i.8.c. Carnegie Classification of Research Activity – BPS PIs

BPS 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.

Suppressed categories: R2 (ROSES 2021), 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.

BPS PIs: Submitted Research Activity - Data Table

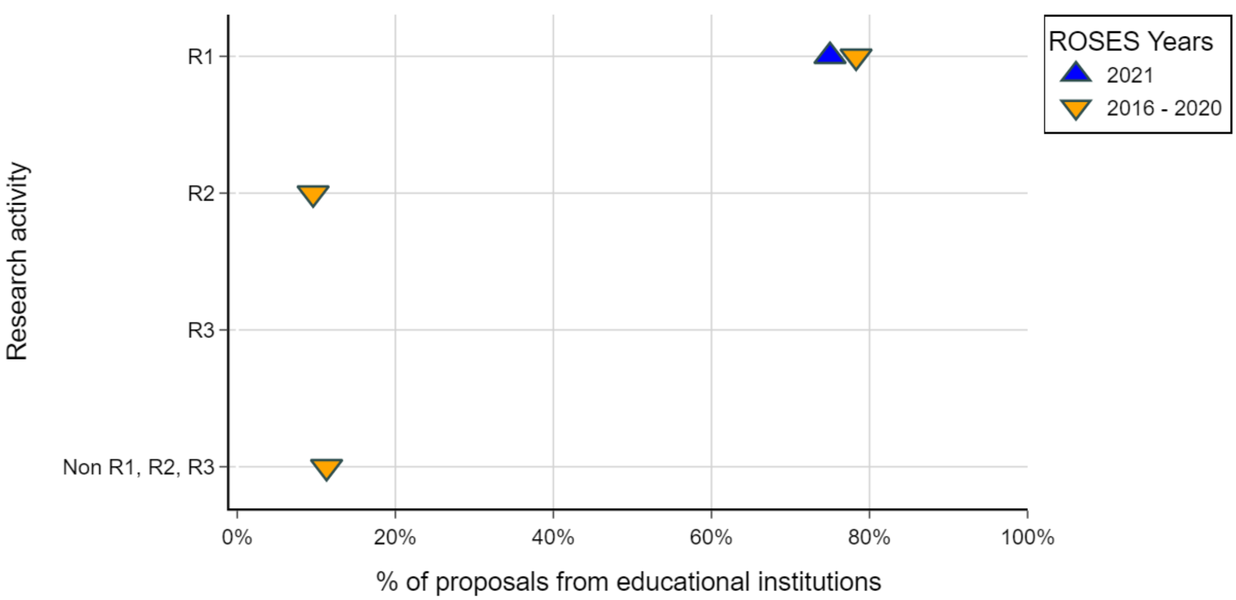
BPS 2016 - 2020 vs. 2021: Submitted PIs - Research activity

Research activity	BPS 2016 - 2020	BPS 2021
R1	70%	74%
R2	18%	NR
R3	NR	NR
Non R1, R2, R3	12%	15%

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.

BPS PIs: Selected Research Activity - Plot

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



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

Suppressed categories: R2 (ROSES 2021), R3 (All years), Non R1, R2, R3 (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.

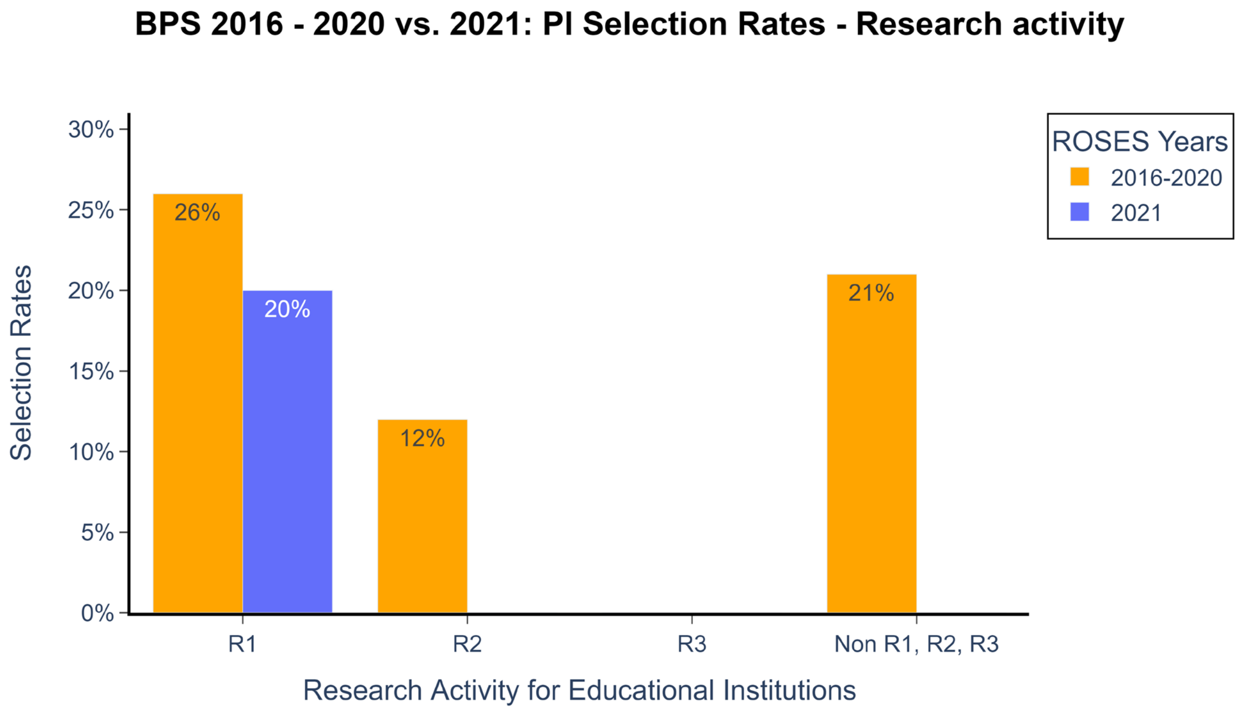
BPS PIs: Selected Research Activity - Data Table

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

Research activity	BPS 2016 - 2020	BPS 2021
R1	78%	75%
R2	10%	NR
R3	NR	NR
Non R1, R2, R3	11%	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.

BPS PIs: Research Activity Selection Rate - Bar Plot



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

Suppressed categories: R2 (ROSES 2021), R3 (All years), Non R1, R2, R3 (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.

BPS PIs: Research Activity Selection Rate - Data Table

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

Research activity	BPS 2016-2020	BPS 2016-2020 Response/All Educational Institutions	BPS 2021	BPS 2021 Response/All Educational Institutions
R1	26%	1.13	20%	1
R2	12%	0.52	NR	NR
R3	NR	NR	NR	NR
Non R1, R2, R3	21%	0.91	NR	NR
All Educational Institutions	23%	1	20%	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

4.a.ii. Science Team

4.a.ii.1. Limitations of the Data – BPS Science Team

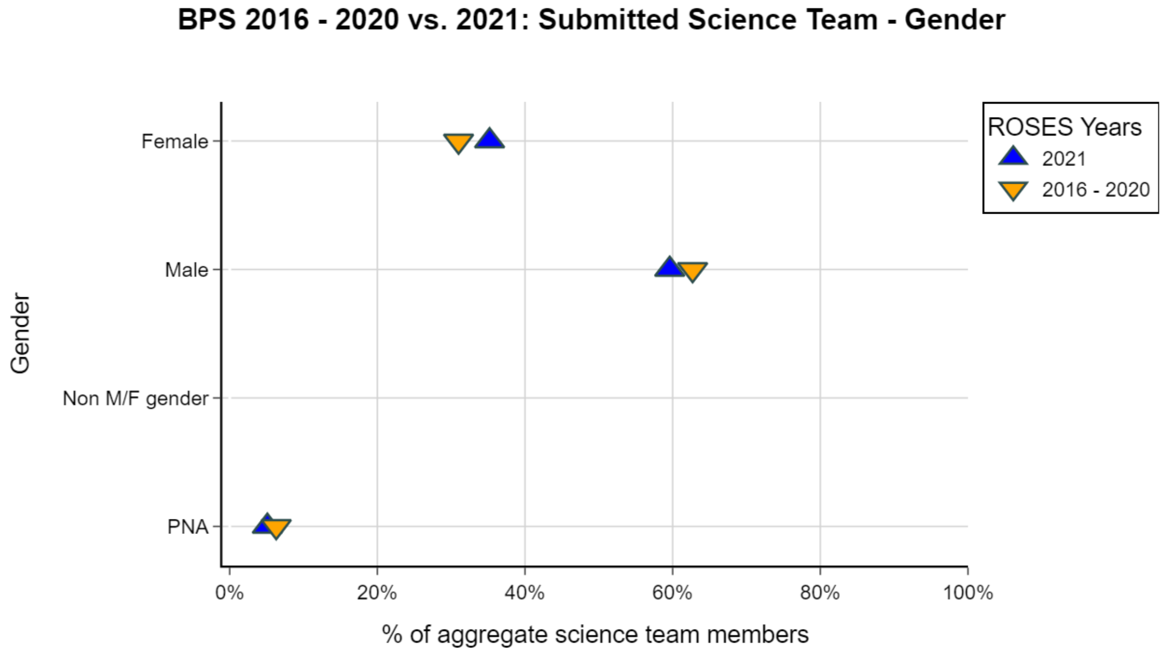
26,043 submitted proposals are included in the ROSES 2016-2021 database. Please see Appendix Table 1 to see which programs are included. The total number of proposals submitted and selected for each ROSES year and the total number of proposals submitted to each SMD Division cannot be reported due to 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 Biological and Physical Sciences Division, there are ~800 submitted proposals over all ROSES years: ~700 for ROSES 2016-2020 and ~100 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: BPS 2016 - 2020: 6% | BPS 2021: 4%
- Selected proposals: BPS 2016 - 2020: 6% | BPS 2021: 5%

4.a.ii.2. Gender – BPS Science Team

BPS 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.

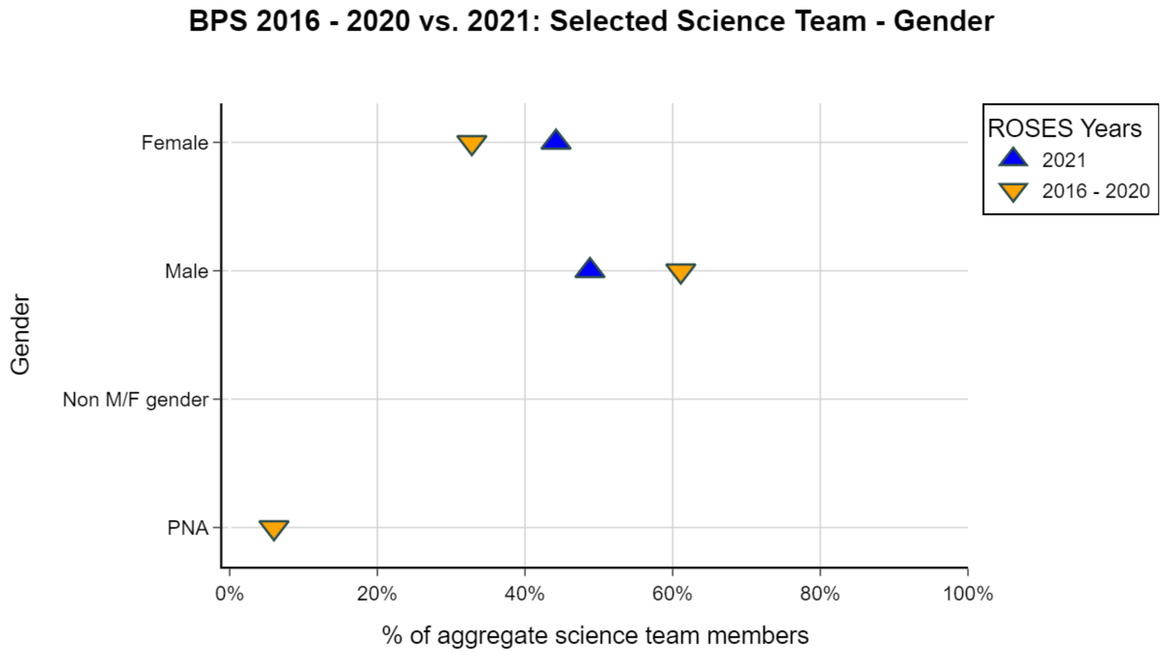
BPS Science Team: Submitted Gender - Data Table

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

Gender	BPS 2016 - 2020	BPS 2021
Female	31%	35%
Male	63%	60%
Non M/F gender	NR	NR
PNA	6%	5%

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

BPS 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), 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.

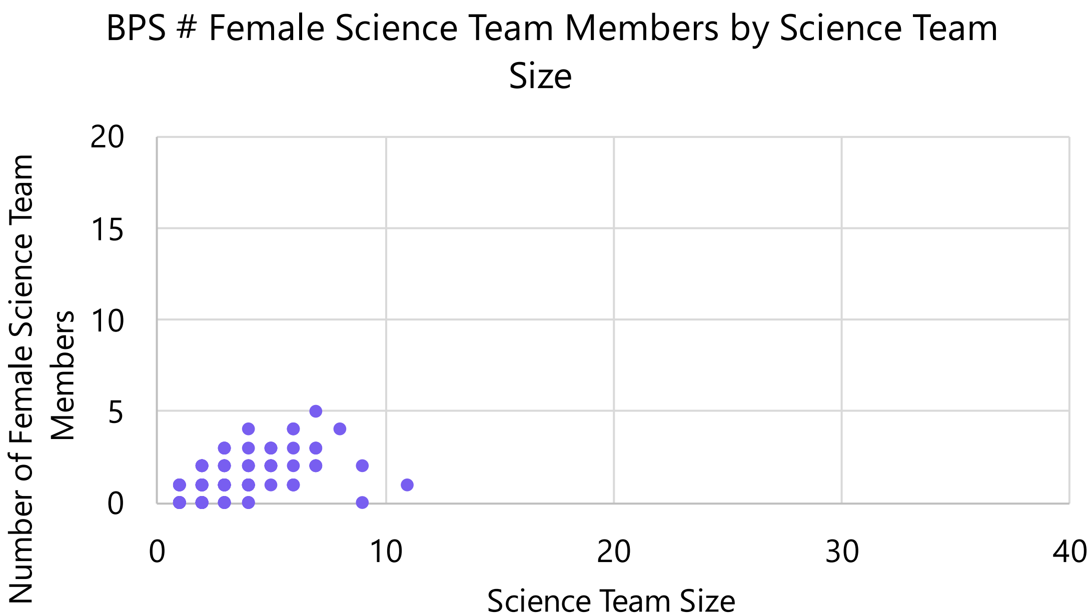
BPS Science Team: Selected Gender - Data Table

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

Gender	BPS 2016 - 2020	BPS 2021
Female	33%	44%
Male	61%	49%
Non M/F gender	NR	NR
PNA	6%	NR

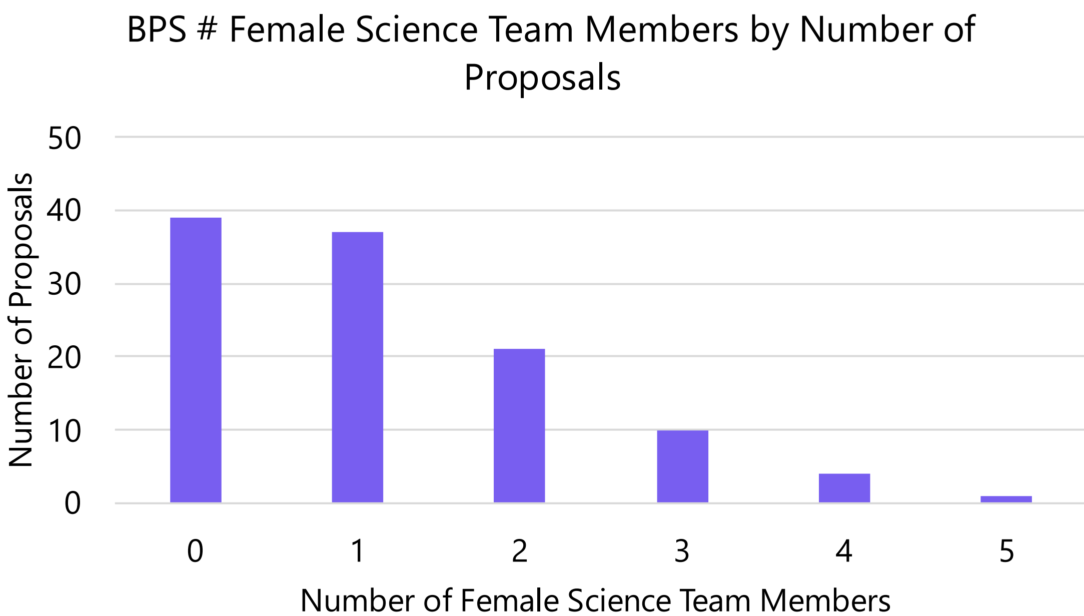
PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

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



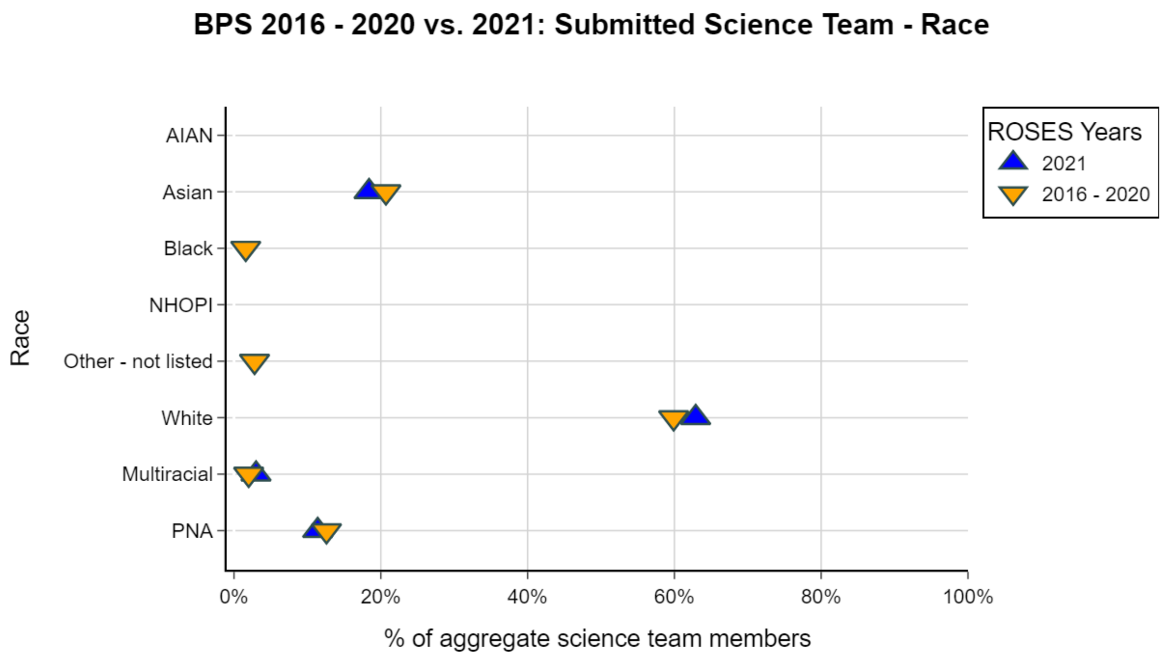
Note: 45% of proposals submitted to ROSES 2021 Biological and Physical Sciences programs did not include female researchers in their science team. 18% of proposals submitted to ROSES 2021 Biological and Physical Sciences programs only included the PI as the science team.

BPS ROSES 2021 Science Teams: Female Science Team Members by Number of Proposals – Bar Chart



4.a.ii.3. Race – BPS Science Team

BPS 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 2021), NHOPI (All years), Other – not listed (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.

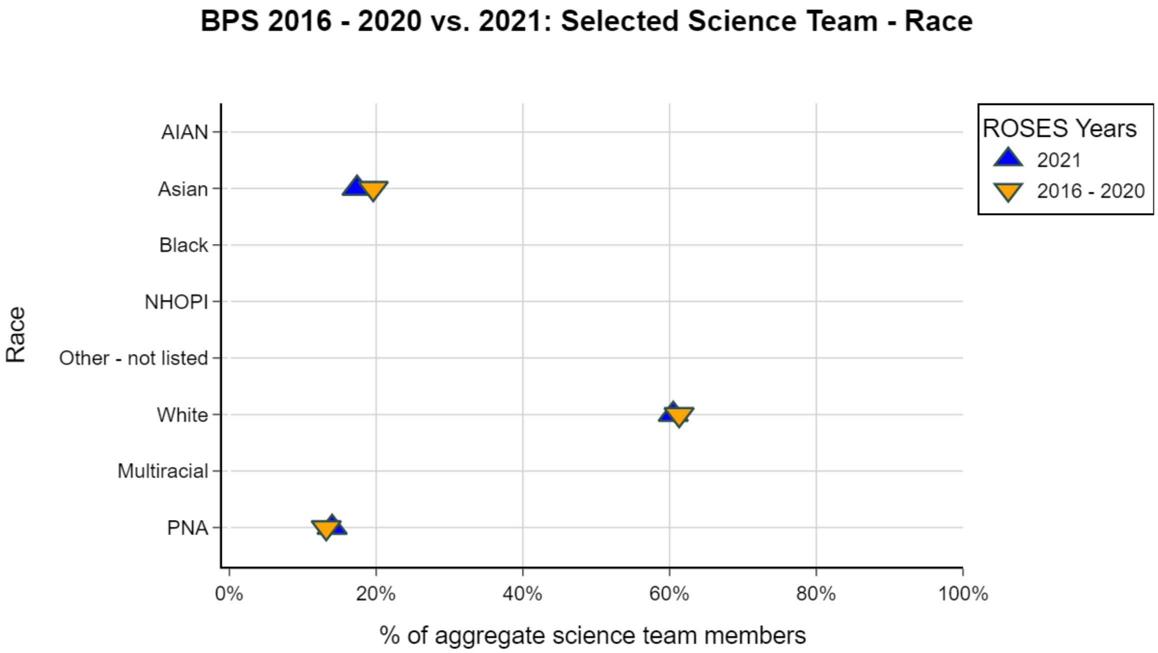
BPS Science Team: Submitted Race - Data Table

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

Race	BPS 2016 - 2020	BPS 2021
AIAN	NR	NR
Asian	21%	18%
Black	2%	NR
NHOPI	NR	NR
Other - not listed	3%	NR
White	60%	63%
Multiracial	2%	3%
PNA	13%	11%

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.

BPS 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 (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.

BPS Science Team: Selected Race - Data Table

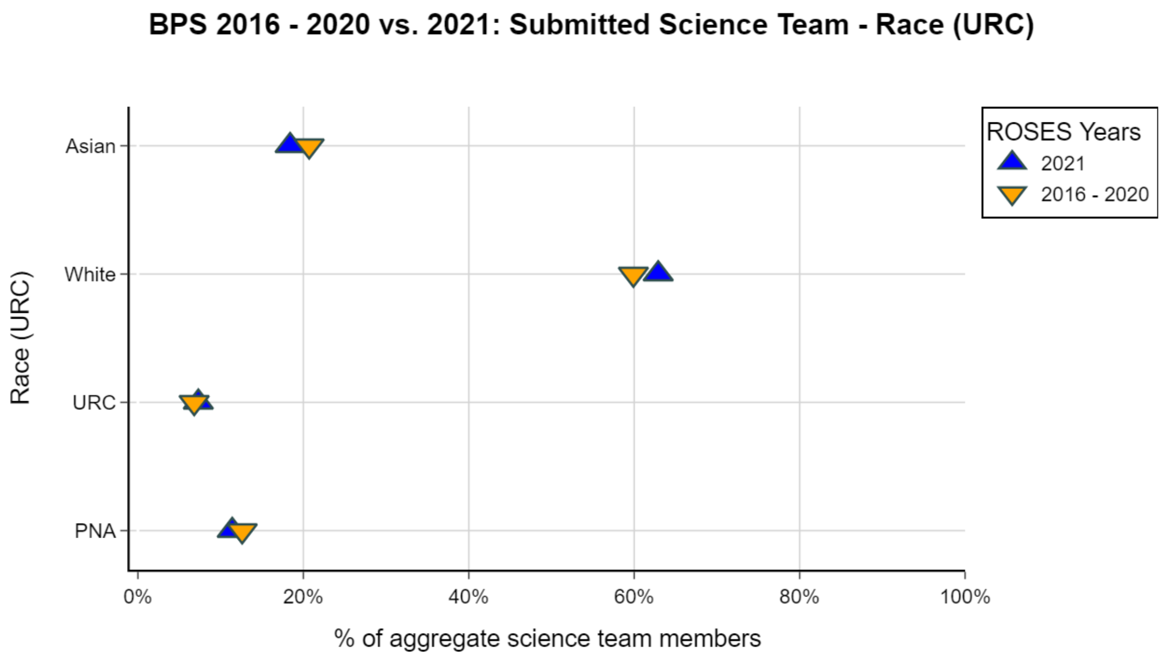
BPS 2016 - 2020 vs. 2021: Selected Science Team - Race

Race	BPS 2016 - 2020	BPS 2021
AIAN	NR	NR
Asian	20%	17%
Black	NR	NR
NHOPI	NR	NR
Other - not listed	NR	NR
White	61%	60%
Multiracial	NR	NR
PNA	13%	14%

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.

4.a.ii.4. Race using Under-Represented Community (URC)– BPS Science Team

BPS Science Team: 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.

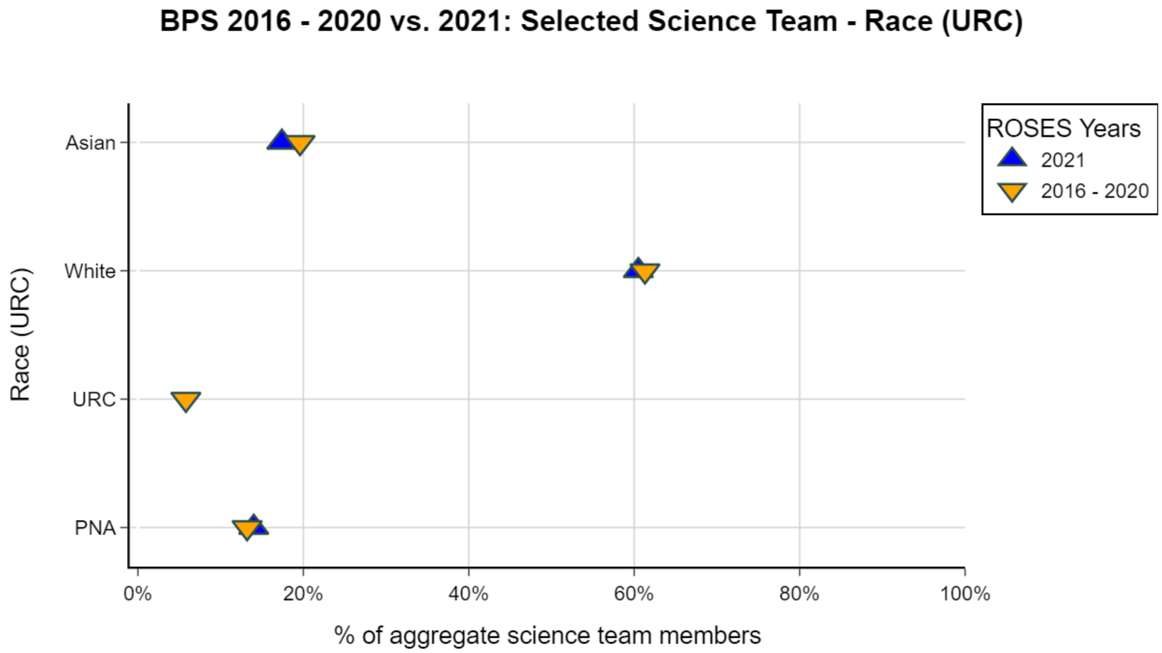
BPS Science Team: Submitted Race (URC) - Data Table

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

Race (URC)	BPS 2016 - 2020	BPS 2021
Asian	21%	18%
White	60%	63%
URC	7%	7%
PNA	13%	11%

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.

BPS Science Team: 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.

Suppressed categories: URC (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.

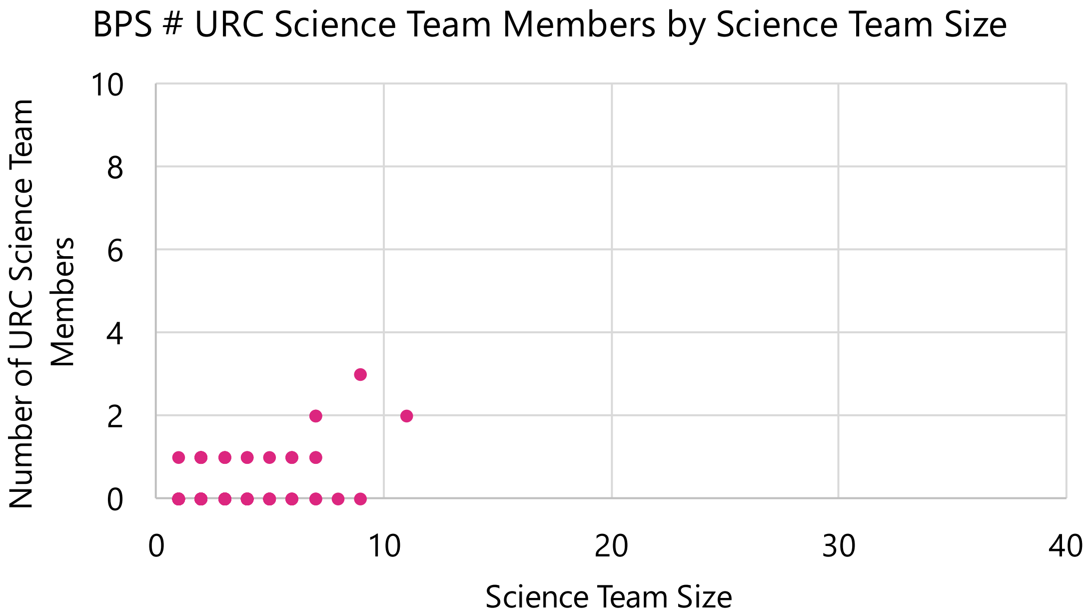
BPS Science Team: Selected Race (URC) - Data Table

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

Race (URC)	BPS 2016 - 2020	BPS 2021
Asian	20%	17%
White	61%	60%
URC	6%	NR
PNA	13%	14%

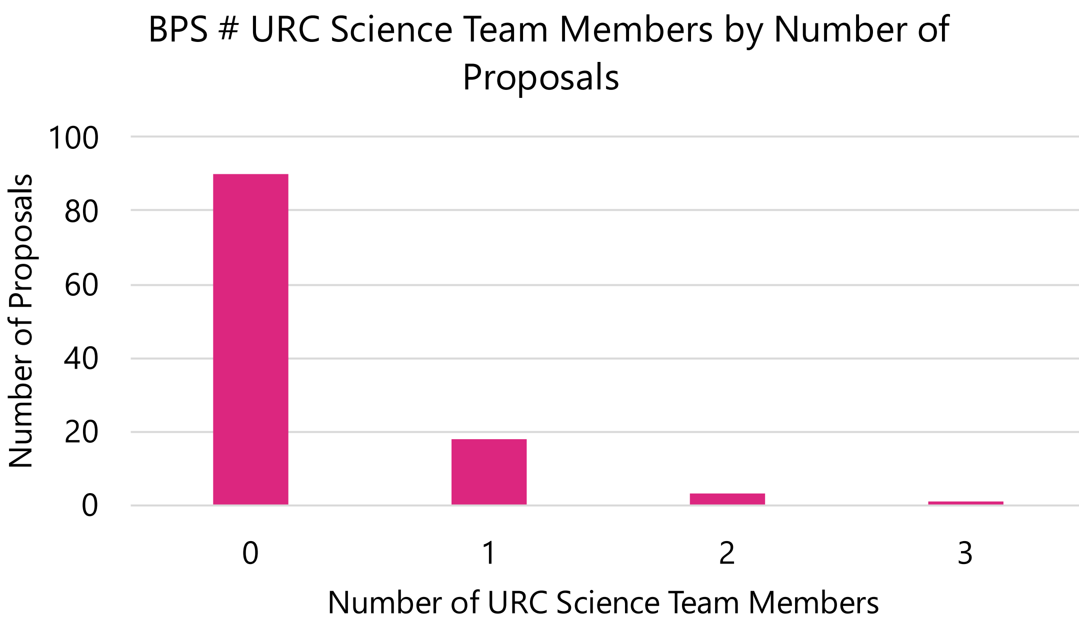
Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

BPS 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, and Other. | Note: 80% of proposals submitted to ROSES 2021 Biological and Physical Sciences programs did not include URC researchers in their science team. 18% of proposals submitted to ROSES 2021 Biological and Physical Sciences programs only included the PI as the science team.

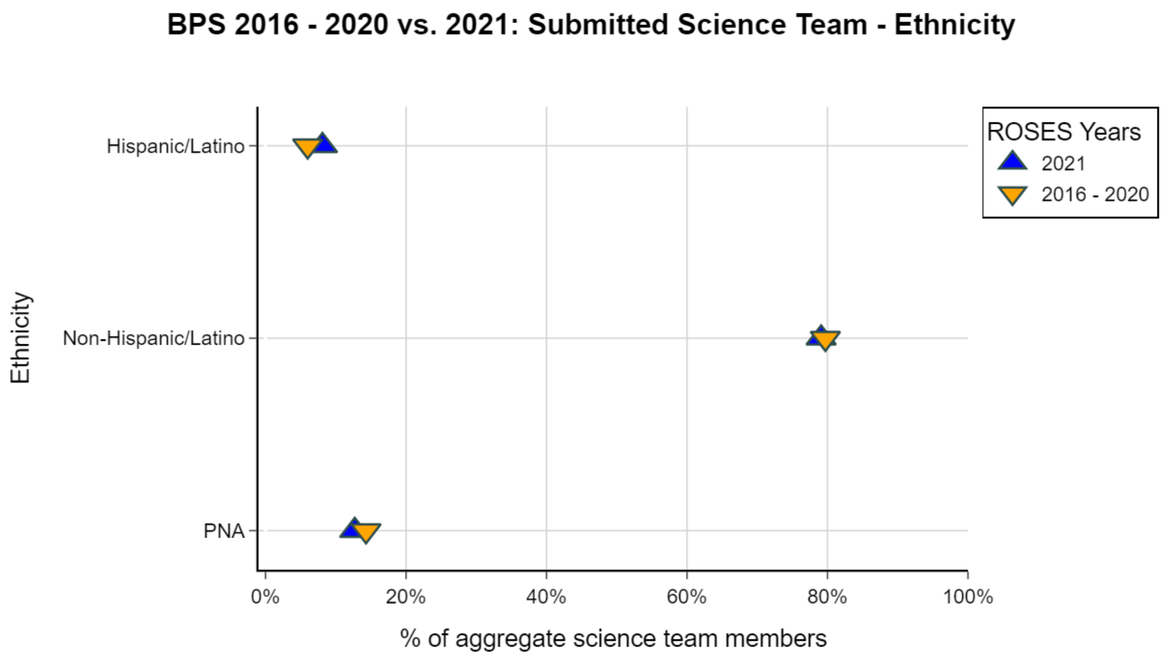
BPS ROSES 2021 Science Teams: URC Science Team Members by Number of Proposals – Bar Chart



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other.

4.a.ii.5. Ethnicity – BPS Science Team

BPS Science Team: Submitted Ethnicity - Plot



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

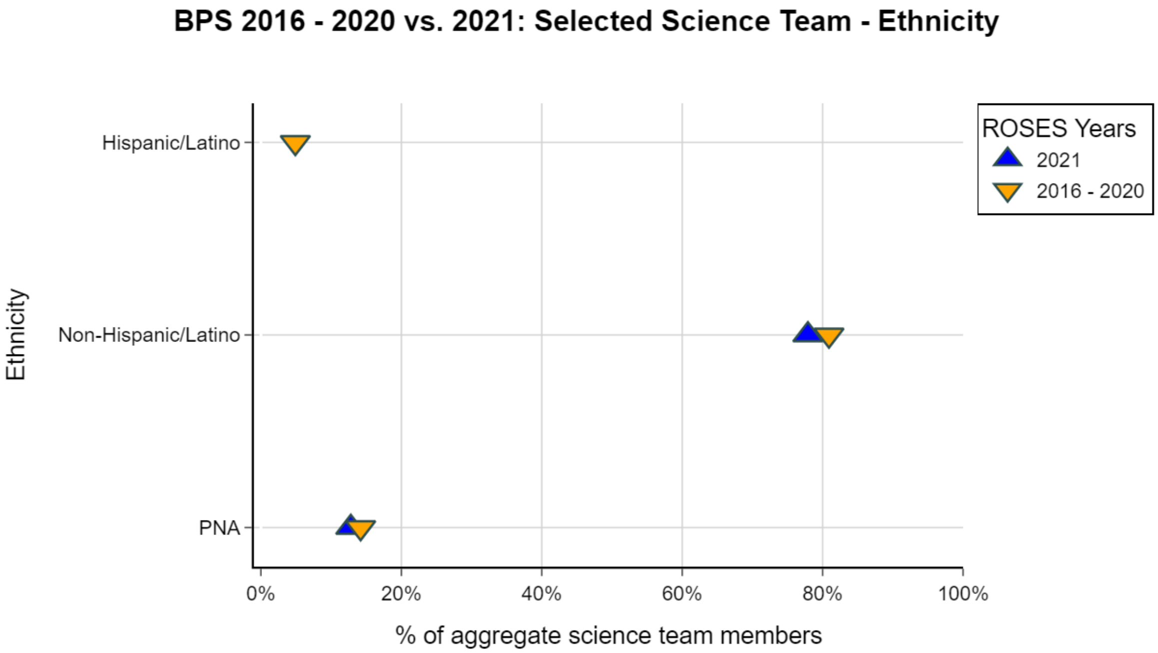
BPS Science Team: Submitted Ethnicity - Data Table

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

Ethnicity	BPS 2016 - 2020	BPS 2021
Hispanic/Latino	6%	8%
Non-Hispanic/Latino	80%	79%
PNA	14%	13%

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

BPS Science Team: Selected Ethnicity - Plot



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

Suppressed categories: Hispanic/Latino (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.

BPS Science Team: Selected Ethnicity - Data Table

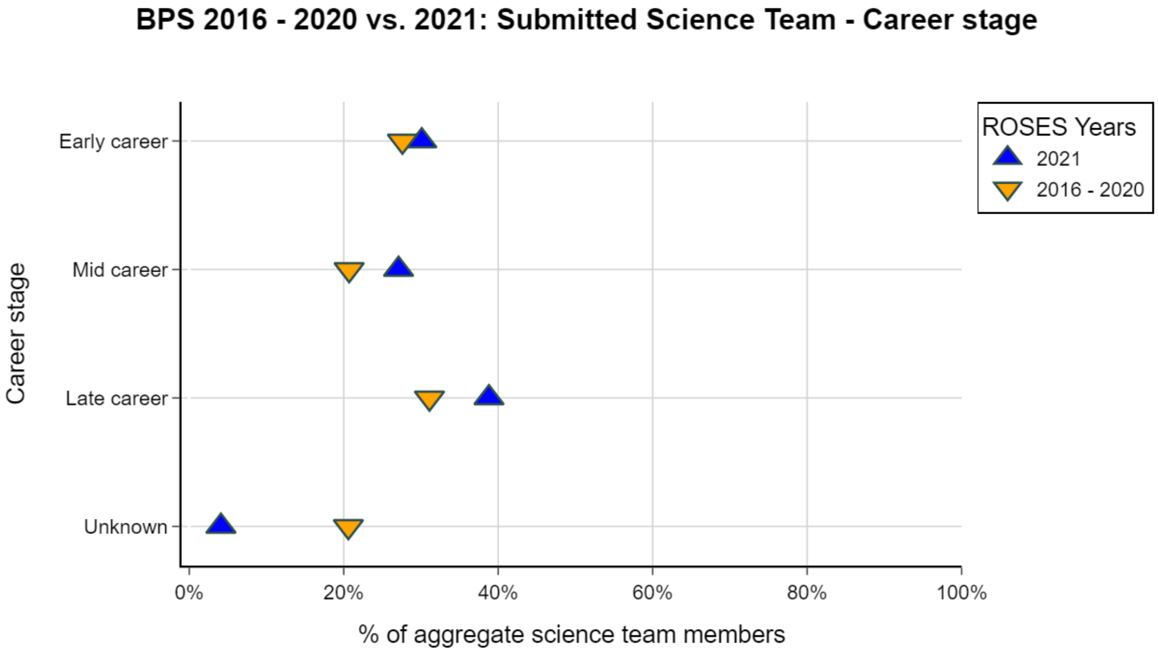
BPS 2016 - 2020 vs. 2021: Selected Science Team - Ethnicity

Ethnicity	BPS 2016 - 2020	BPS 2021
Hispanic/Latino	5%	NR
Non-Hispanic/Latino	81%	78%
PNA	14%	13%

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

4.a.ii.6. Career Stage – BPS Science Team

BPS 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.

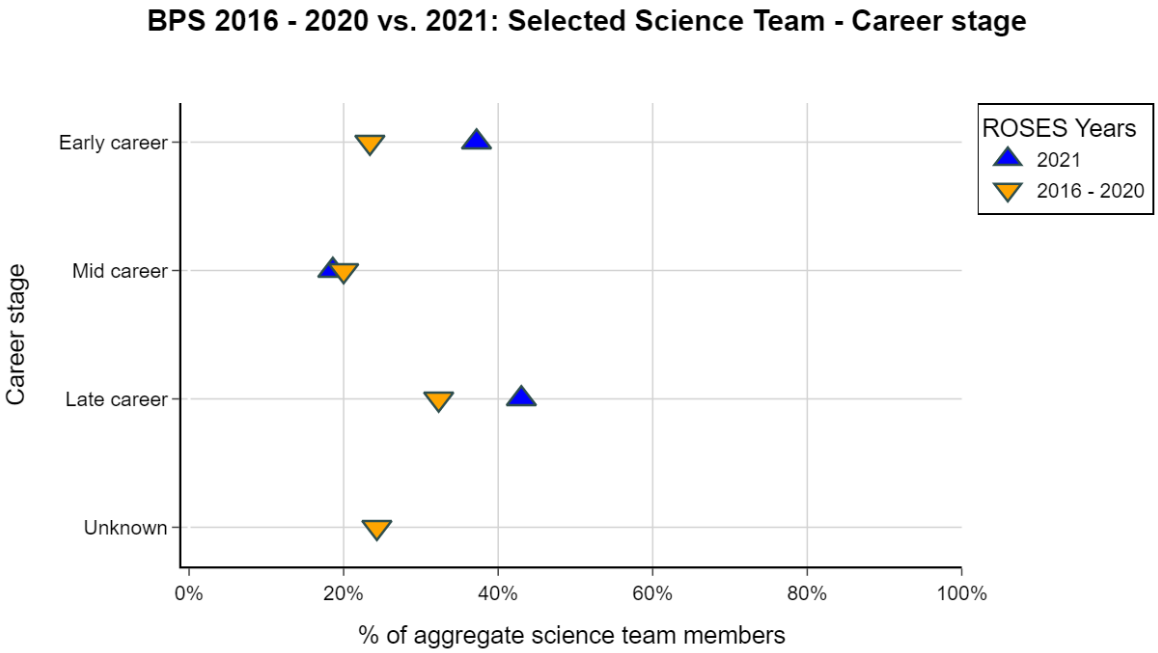
BPS Science Team: Submitted Career Stage - Data Table

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

Career stage	BPS 2016 - 2020	BPS 2021
Early career	28%	30%
Mid career	21%	27%
Late career	31%	39%
Unknown	21%	4%

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.

BPS 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.

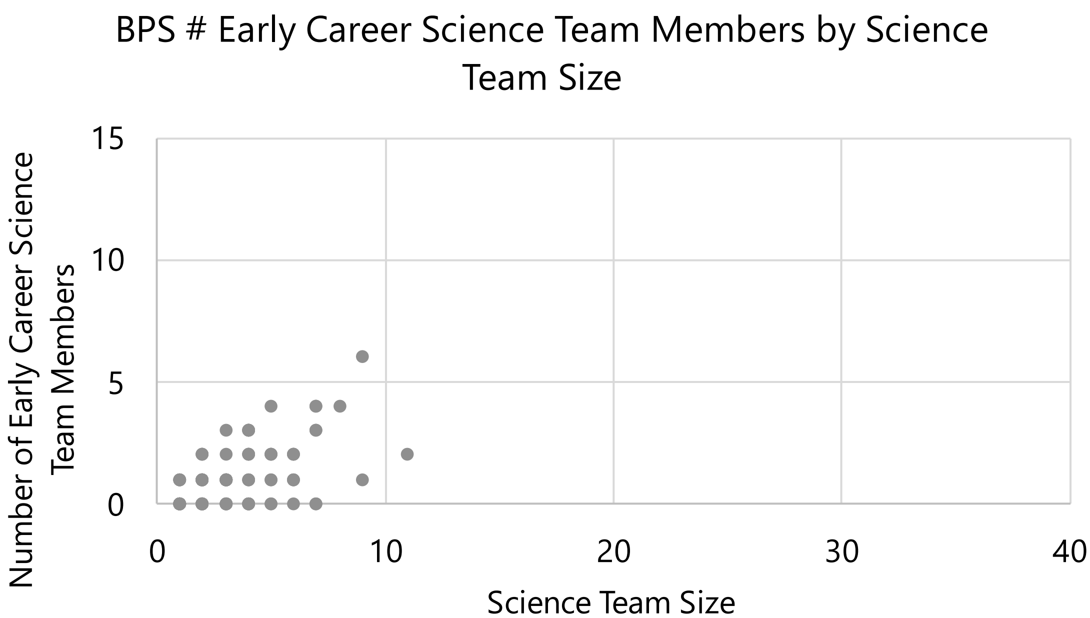
BPS Science Team: Selected Career Stage - Data Table

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

Career stage	BPS 2016 - 2020	BPS 2021
Early career	23%	37%
Mid career	20%	19%
Late career	32%	43%
Unknown	24%	NR

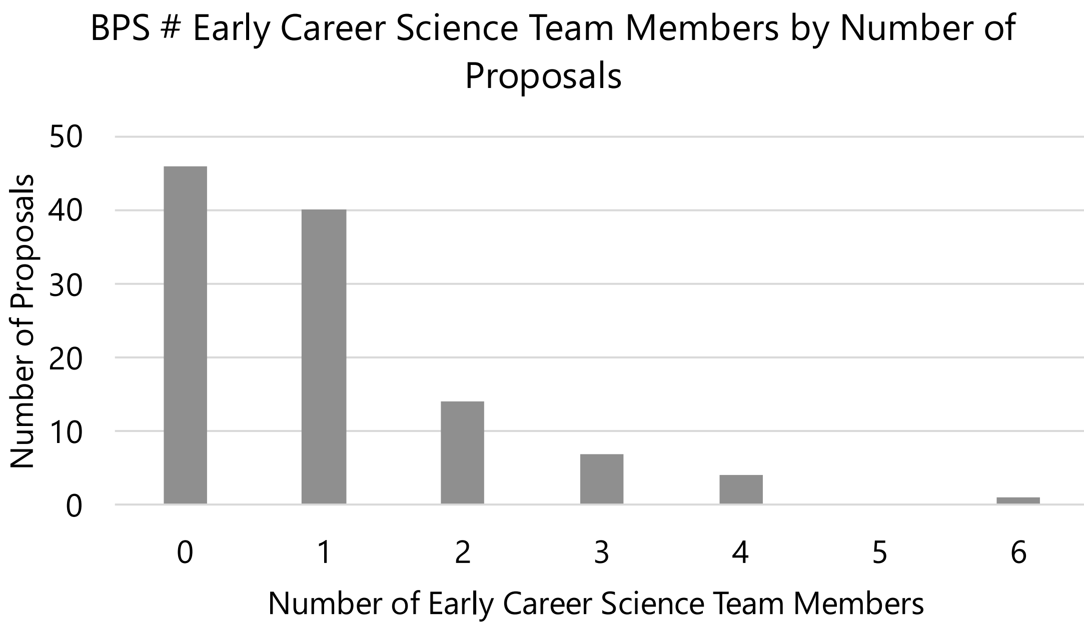
Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

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



Early career: < 10 years since earning final degree | Note: 41% of proposals submitted to ROSES 2021 Biological and Physical Sciences programs did not include early career researchers in their science team. 18% of proposals submitted to ROSES 2021 Biological and Physical Sciences programs only included the PI as the science team.

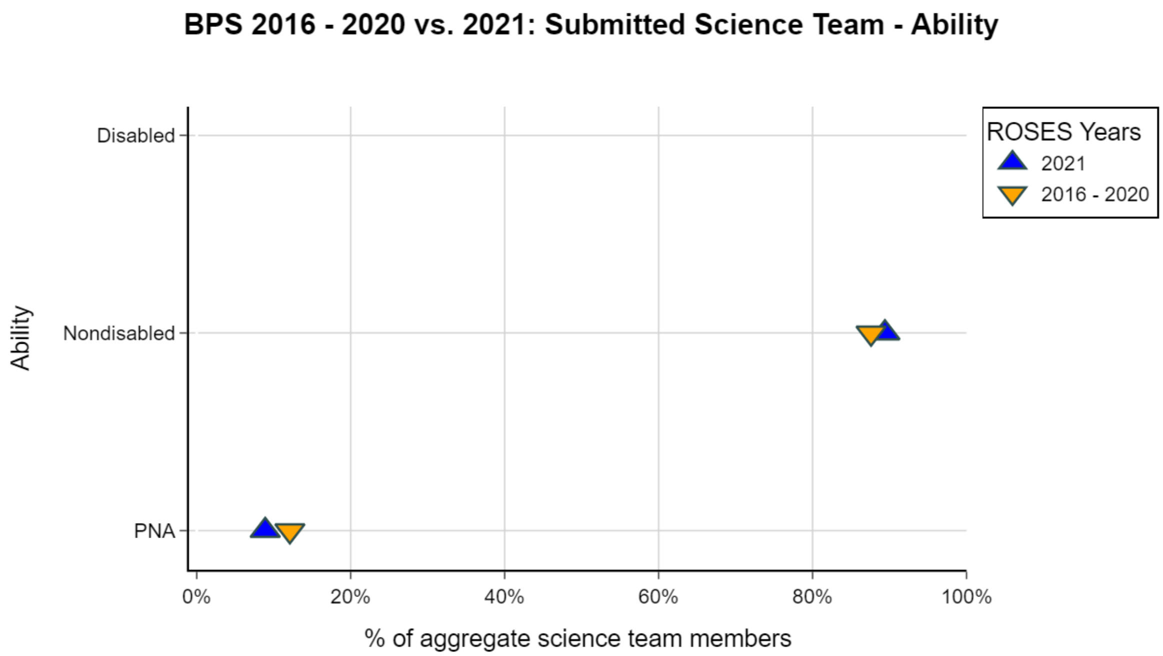
BPS ROSES 2021 Science Teams: Early Career Science Team Members by Number of Proposals – Bar Chart



Early career: < 10 years since earning final degree

4.a.ii.7. Disability Status – BPS Science Team

BPS 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.

Suppressed categories: Disabled (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.

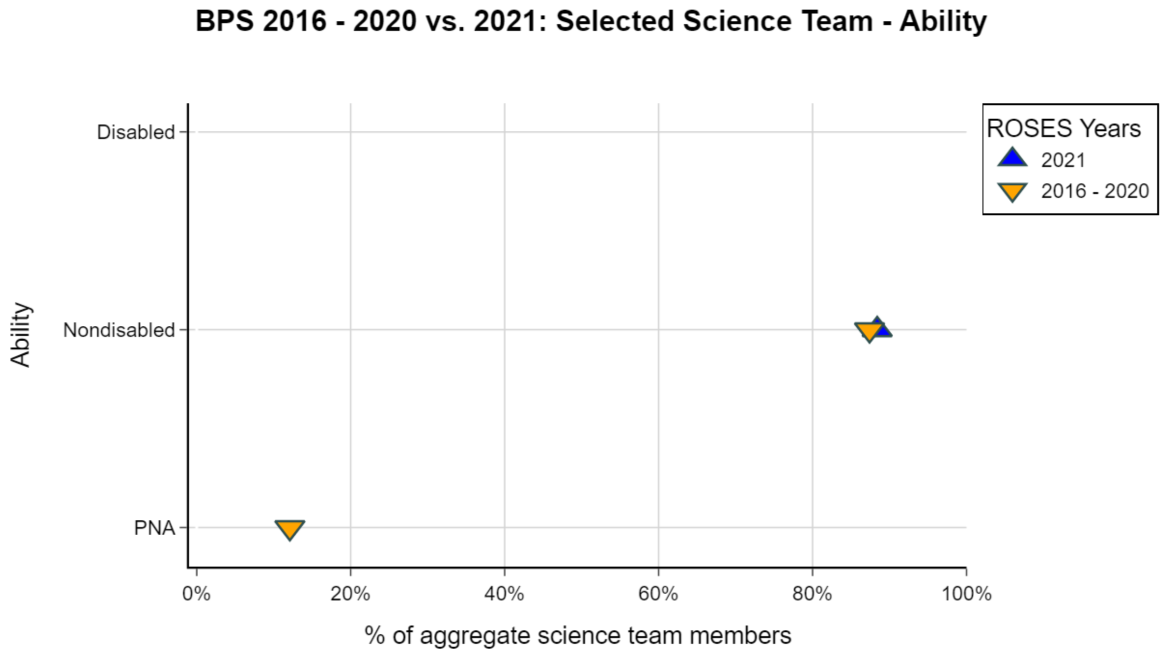
BPS Science Team: Submitted Ability - Data Table

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

Ability	BPS 2016 - 2020	BPS 2021
Disabled	NR	NR
Nondisabled	88%	89%
PNA	12%	9%

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

BPS 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 (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.

BPS Science Team: Selected Ability - Data Table

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

Ability	BPS 2016 - 2020	BPS 2021
Disabled	NR	NR
Nondisabled	87%	88%
PNA	12%	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.

4.b. Proposal Data

4.b.i. New PIs - BPS

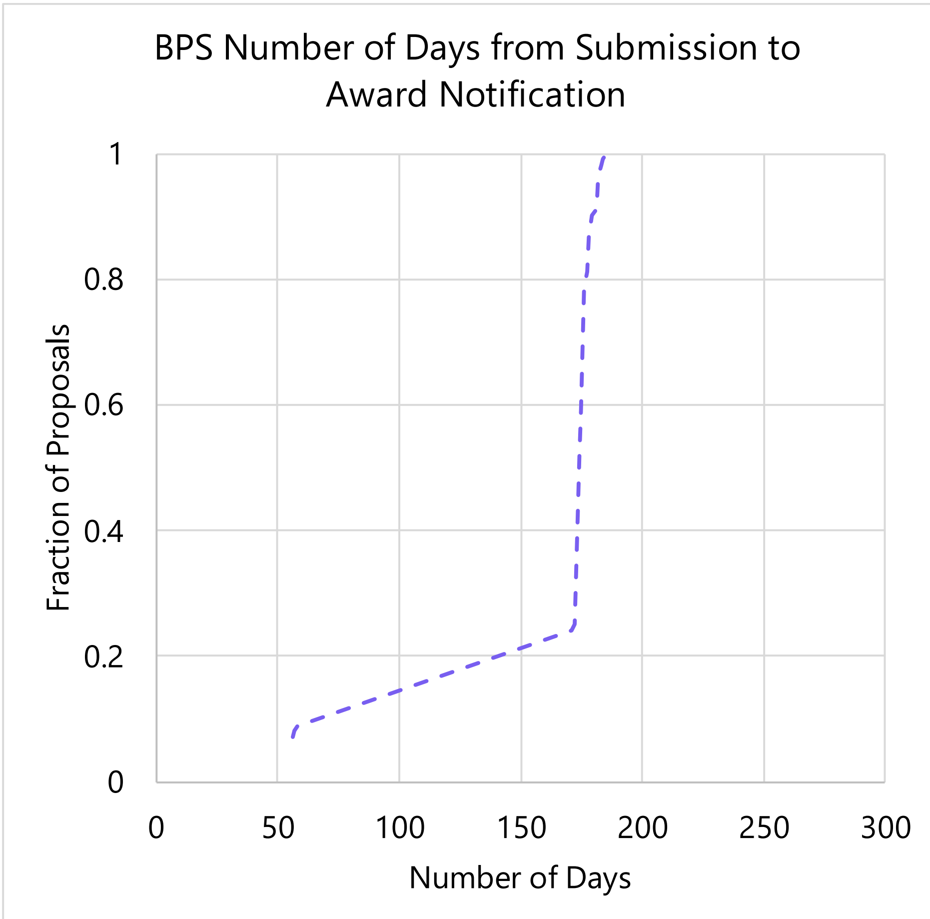
Comparison of Proposal Statistics of New PIs and Unique PIs for ROSES 2021 - Data Table

BPS 2021	New PIs	Unique PIs	New PI %
Selected	20	27	74%
Submitted	85	110	77%
Selection Rate	24%	25%	

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.

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

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



Notes: Number of days from proposal submission to 80% of award notifications for BPS is 177 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."

2 Selectable (Pending) proposals not included

4.c. ROSES 2021 Selection Announcements

Appendix E. Biological and Physical Sciences Division

Appendix	Program Element Name
E.8	Physical Sciences Informatics
E.9	Space Biology: Plant Studies
E.10	Lunar Explorer Instrument for Space Biology Applications
E.11	Space Biology: Animal Studies

E.8 Physical Sciences Informatics
Abstracts of Selected Proposals
(NNH21ZDA001N-PSI)

Below are the abstracts of proposals selected for funding for the Physical Sciences Research Program. Principal Investigator (PI) name, institution, and proposal title are also included. 29 proposals were received in response to this opportunity. On June 30, 2022, 5 proposals were selected for funding.

Ioana Cozmuta/G-Space, Inc.
Development of a computer vision based toolbox for feature extraction, analysis, modeling and prediction of microgravity data sets

Over two decades of significant effort and resources have been devoted to investigating a broad spectrum of hypotheses in microgravity across the portfolio of physical and life sciences on the International Space Station (ISS). This work has resulted in an impressive amount of data being collected, in particular images and videos. However, much of this image data to date, remains underutilized because the emphasis continues to be on individual investigations. In this proposal, G-SPACE takes a cross-cutting look at the PSI datasets to build a simple computer-vision, data analytics and machine learning tool (ATOM" toolbox) that would be an enabler to all the PSI users (in particular new PI's) to better interact with the data, standardize data output, and perform insightful analysis on the selected datasets to increase the science readiness of their investigations.

For the past two years, the G-SPACE team has been actively ingesting Microgravity data available in the NASA PSI database for the purpose of applying a suite of proprietary algorithms and models from its ATOM" software platform to extract the delta-to-gravity(") and utilize it to design and optimize products and manufacturing processes amenable for in-space manufacturing. The platform aims to bridge the gap between microgravity R&D sciences and in-space manufacturing and our team's hope was that the PSI database would have clean data sets corresponding to ground and flight experiments for ATOM" to extract the delta-to-gravity" and focus on microgravity product design and optimization.

Unfortunately the data in the PSI database is simply not ready for this approach. The video data residing in the PSI database has rarely been analyzed to track key features for research nand even if so, it has not been done in an automated manner. The sheer number of images, and the total size of the data set, require an enormous amount of hand-sorting and checking of images and is only available in an unstructured format. This makes it harder for users to find and understand the value that lies in it since to access that information it requires crossing a very high barrier, especially for new PI's who don't usually have previous familiarity.

The current proposal seeks to develop the ATOM" toolbox, a collection of generic computer vision, data analysis and machine learning functionalities to help new PI's as well as existing users to expand the meaning and interpretation of existing data sets and to extract heretofore undiscovered knowledge from the PSI database. It will also (a) enable enhancement of existing data (b) open up the ability for new researchers to leverage on existing experiments and (c) help bring the investigations to a faster conclusion. To develop the ATOM" toolbox functionalities, the G-SPACE team will look at images and videos only for 8 Material Science and 2 Complex Fluid investigations in the PSI database.

Besides being a powerful tool to extract meaningful information from existing experiments, the ATOM" toolbox could ultimately provide: (1) the means to guide ISS experiments to make better use of time in microgravity, (2) a mechanism to predict results of future experiments in space for better prioritization and structure in the decision process, (3) an open door for applications that ultimately create the path towards materials space manufacturing and beyond.

The end products of the two years effort under this proposal that will be delivered to NASA to be included in the PSI database will consist of: (1) a database of structured image/video datasets and a corresponding demo for each of the 10 investigations, (2) the ATOM" toolbox with a basic API to allow integration with the PSI database and the G-SPACE ATOM" platform.

Donald Koch/Cornell University
Dynamic response of particle-filled polymeric fluids in flows with complex Lagrangian time histories

While some function of impactor energy and/or momentum is universally acknowledged Particle-filled polymeric fluids, frequently encountered in processing composite materials into fibers or sheets, turbulent drag reduction, and hydraulic fracturing, undergo alternating periods of simple shear and extensional motion in a Lagrangian reference frame. The dynamic rheological response of a particle-polymer mixture is not a simple superposition of independent polymeric and particle stresses. Instead, there is significant coupling between the velocity disturbance produced by the particles, polymer stress, and particle orientation. There is a dearth of relevant experiments and theoretical/ numerical analyses exploring the dynamic rheology of these systems. The proposed project provides an opportunity to employ theoretical and numerical simulation methods uniquely suited to predict the particle-induced polymer stress in transient flows and validate these methods by comparison with transient extensional rheology experiments of particle-polymer mixtures subject to pre-shearing in the PSI database.

A filament stretching rheometer used in the SHERE-II experiments enabled the measurement of a particle-filled polymeric fluid's transient extensional flow response subject to variable pre-shearing rates. SHERE and SHERE-R provide complementary measurements for the same fluid without particles. The experiments use dilute particle suspensions in a well-characterized Boger fluid over a range of moderate extension rates, conditions unachievable in Earth's gravity. A statistical analysis of the SHERE data indicates a significant reduction in strain hardening by particles at high strains, which agrees with a preliminary theoretical analysis.

Prediction of the coupled particle and polymer stresses is arduous because the particle-induced velocity disturbance greatly alters the polymer stress in regions close to the particle surface leading to strong polymer stress gradients that are difficult to resolve numerically and subtle to predict theoretically. The interplay between particle orientation, velocity disturbance, and polymer stresses when fibers are suspended in polymeric fluids presents further challenges.

The project will employ theory and numerical simulations developed in our group, uniquely suited to address these problems. A finite difference method will solve the inertia-less viscoelastic flow in a spheroidal coordinate system that conforms to and rotates with the surface of a spheroidal particle and applies a time-varying linear velocity boundary condition at a nearly spherical outer boundary far from the particle. A demonstration that the ensemble average of the linear perturbation to the polymer stress due to the particle velocity disturbance is zero is essential to obtain convergent bulk rheological properties from numerical simulations.

A complementary theoretical approach will yield semi-analytical predictions of the suspension rheology valid in the limit of small polymer concentration, c. Comparison with the numerical simulation will reveal the range of c, over which this theory is quantitatively accurate, and provide useful qualitative predictions for larger c. The theory is less computationally intensive and avoids computational stability limitations typical of nonlinear viscoelastic flow computations at high Deborah numbers and polymer extensibilities. Hence, it facilitates exploring broader parameter regimes.

These methods will be applied to study the rheology of (1) suspensions of spheres in transient extensional flow with and without preshearing for comparison with the SHERE experiments; (2) suspensions of spheroids experiencing a simple shear flow preceded and followed by a period of extensional flow to model the processing of fiber-filled polymeric films; and (3) suspensions of spheroids subject to simple shear flow alternating with short bursts of extensional motion as a model of turbulent drag reduction by the coupled effects of fiber and polymer additives.

Ranga Narayanan/University of Florida, Gainesville
Reduced-Order Model and Experiments Using the PSI Data from STDCE

It is proposed to utilize PSI data of the Surface Tension Driven Convection Experiment (STDCE) to validate a low- dimensional model which takes interfacial deflections into account. This method will then be compared with a full numerical model that also tracks the interface deformation and flow dynamics of long-wave flows that accompany such experiments. The STDCE data is vital as it will be used via modern imagining software (eg., Track-Mate in Image J) to analyze flow profiles and thermal data. The full numerical model and the simplified low-order method will, upon validation, be employed to design and run a ground experiment whose objective is to use novel means via forced mechanical resonance to quench the long wave surface tension gradient flow.

The STDCE experiments were designed to understand the role of surface tension gradient-driven thermocapillary flow, often encountered in technologically relevant processes such as crystal growth. It was found that long wave steady two-dimensional convective flow gives way to oscillatory flow for certain parameter ranges. These long-wave flows are often detrimental to the relevant technological processes and ought to be suppressed.

The advantage of using a reduced-order method in addition to the full numerical model is that interface evolution may be resolved via a semi-analytical and tractable set of equations for two state variables. This feature provides great insight into the physics of the convection and the root cause of the onset of oscillatory flow from a steady base flow. The nonlinearity of the model facilitates tracking of the interface deformation, which plays a significant role in the onset of oscillatory instability in STDCE. The PSI data will be invaluable as it will provide validation for the model by providing information from image analysis of that data.

The idea behind the proposed experiment is to generate thermal convection in a test-cell that emulates the STDCE and increase the forcing temperature difference until oscillatory flow is triggered. This test cell will be placed on a shaker, currently available in the PI's laboratory, whose shaking frequency is set and amplitude is incrementally raised until the oscillatory flow is arrested and even the steady long wave flow is reduced. This is predicted to occur because resonant instabilities act on interfacial deformation and such deformation is characteristic of the STDCE. The critical amplitude to quench the undesired flow can be then compared with theory. The proposed ground-based experiments will identify operating parameter spaces where oscillatory instability may be suppressed. The semi-analytical model will also help identify the root causes for and suppression of oscillatory flow.

In summary, the PSI data is needed to validate the full numerical model and also the low-dimensional model which, in turn, allows us to extract the physical phenomena. The proposed ground experiment will provide additional validation for the model and also give information on suppression of convection via resonant forcing. The results of the study will be of great benefit to materials processing including crystal growth and in-space welding as well as additive manufacturing using directed energy deposition where free surface convection inevitably takes place. These are of high interest to NASA and identified in taxonomy TX12.

Siddartha Pathak/Iowa State University, Ames

Structure, Properties and Performance of Solder Joints in Terrestrial vs. Reduced-Gravity Environments

The investigation proposed here combines experiments and modeling to elucidate the fundamental mechanisms, phenomenology, and process conditions that govern the integrity and performance of solder joints produced in terrestrial vs. reduced gravity environments, such as the microgravity conditions onboard the International Space Station (ISS). The technical research program plans to utilize solder samples from the In-Space Soldering Investigation (ISSI) experiments from the Physical Sciences Informatics (PSI) repository, as well as expand into other non-ISSI solder compositions, and combine space- and ground-based experiments with advanced 3D materials characterization, micromechanical testing, and mesoscale modeling. In particular, the project addresses the formation and persistence of porosity through the reflow/filling/freezing processes and the deleterious effects on microstructure and mechanical properties of the solder joint. It has been established that porosity arising from flux volatilization, which is dispersed and expelled from the solder joint under terrestrial gravity, may become entrapped within the freezing solder material under microgravity conditions, given the absence of buoyancy-driven convection. Our overall goals are (i) to advance the current qualitative understanding of this phenomenon into the realm of alloy/process-specific quantitative description and prediction and (ii) to examine the effects of mechanically and acoustically stimulated flow while assessing their potential effectiveness as porosity mitigation strategies for solder-based fabrication processes in space. Considering a range of potential applications and materials, 3 solder alloys will be investigated, including the ISSI lead-based (Pb-Sn) solders, as well as lead-free (Sn-Ag-Cu and Sn-Au) solders, which have recently shown promise for high-performance joint applications due to their good thermal, electrical conductivities and excellent corrosion, fatigue resistance.

Robert Pitz/Vanderbilt University
Effect of stretch and curvature on cool flame transitions & structures using tubular flames

Cool flames are important in knock formation in internal combustion engines and in modern engine concepts operating at low temperature to achieve high efficiency and low pollution. Cool flames have been observed on the International Space Station in droplet combustion in a quiescent chamber where cool flames appeared after the hot droplet flame extinguished due to radiation. Cool flames in practical devices are subject to flow unsteadiness that stretches and curves the flames. Under NASA PSI NRA science, flat cool premixed and diffusion flames in the presence of fluid stretch have been studied in opposed-jet flames that feature the interplay of finite-rate chemistry, molecular transport, and heat transfer including radiative extinction. In opposed-jet burners, flat cool flames can transition to warm flames and hot flames with each transition driven by different chemical reactions. Flame regimes have been determined in flat cool premixed and diffusion flames including transitions between cool, warm, and hot flames, formation of multi-stage flames, and flame extinction.

Flames in nature are not flat. Studies in opposed-jet flat cool flames lack the presence of curvature found in practical internal combustion engines. The curvature of tubular flames is expected to change where the cool flames transition to warm and hot flames as well as stretch rate extinction values. Curvature and stretch rate are also known to produce cellular structure in flames. In this study, cool premixed and diffusion flames in tubular flames will be investigated both computationally and experimentally to determine the effect of curvature on cool flame regimes, transition to warm and/or hot flames, flame structure, multi-stage flame formation, and extinction stretch rates.

The project will use data from PSI system listed as Investigation #12 in Table A of the Program Element entitled Quantitative Studies of Cool Flame Transitions at Radiation/Stretch Extinction using Counterflow Flames." The computational and experimental study will expand upon this original investigation to determine the additional effect of curvature on the cool flames in terms of their transitions and structure including cellular formation. In this study, cool flames in the tubular flame geometry will be investigated both computationally and experimentally. Gaseous fuels (dimethyl ether) and liquid fuels (dibutyl ether) will be investigated in the tubular burner to parallel earlier studies in flat opposed-jet cool diffusion and premixed flames. The regime diagrams, flame transitions, flame structure, multi-stage formation, and extinction conditions will be determined computationally using the Vanderbilt Tubular Flame Code as a function of pressure. The detailed numerical simulation (DNS) code includes detailed molecular transport, complex chemical kinetics, and radiation heat loss. The cool tubular flame structure will be measured with advanced laser diagnostics. Raman scattering will be used to measure the flame temperature and major species concentrations. PLIF of CH2O and chemiluminescence will be used as a marker of the cool diffusion flame. The tubular flame experimental and computational results will be compared to the previous cool opposed jet results to determine the effect of curvature on the cool flame transitions, structure, multi-stage flame formation, and extinction.

Cool premixed and diffusion flames are found in diesel engines and other modern internal combustion engine concepts such as HCCI, RCCI and PPCI. Understanding the effects of curvature and stretch rate on cool flame transitions and structure will lead to better insight into cool flame propagation in practical internal combustion engines.

E.9 Space Biology: Plant Studies

(NNH21ZDA001N-SBPS)

Below are the abstracts of proposals selected for funding for the Space Biology Research program. Principal Investigator (PI) name, institution, and proposal title are also included. Thirty-five proposals were received in response to this opportunity. On October 19, 2022, seven proposals were selected for funding.

John Baker/Medical College Of Wisconsin, Inc.
Determining the impact of space radiation and simulated microgravity on plant root microbial community composition and function.

The proposed research will increase NASA's understanding of how living systems respond to environments encountered during missions beyond low earth orbit. While plant studies are relevant to fundamental science interests within Space Biology, the psychological and nutritional benefits of growing plants in deep space make this research valuable to the Human Research Program.

All living organisms will be constantly exposed to ionizing radiation from galactic cosmic rays and intermittent exposure to solar particle events during deep space missions. Our objective is to address the likelihood of a new, potentially showstopping effect of space radiation that could have significant impact on using plants as bioregenerative life support for extended human spaceflight, i.e., the disruption of plant root microbial community structure and function. While the biological effects of charged particle radiations on mammalian systems are actively being explored, their impact on the ecological niche of plants is poorly understood. This could have substantial ramifications for crew health and psychology.

A visionary concept is proposed where space radiation will result in shifts in the diversity of the microbial community within the rhizosphere, preventing normal microbial function and potentially promoting the proliferation of pathogenic soil microbiota. This concept is unexplored. Should space radiation decrease the diversity of the soil rhizosphere microbiome and microbial function, this could be a significant obstacle limiting our ability to deliver an adequate supply of food to astronauts. The studies proposed impact extended missions; the total dose of radiation absorbed by a living organism for a Mars mission would be ~ 0.75 Sv. Total mission dose equivalent for the soil rhizosphere microbiome would be comparable. However, the impact of galactic cosmic rays on the health of the rhizosphere microbiome is unknown. Studies proposed in this application break new ground and address an unmet mission need by determining the impact of space radiation on plant root microbial community diversity and its effect on crop growth and nutritional value.

We will use a ground-based plant model approach using a spectrum of high-energy charged particle beams produced at the NASA Space Radiation Laboratory simulates exposure to a mission-relevant dose of galactic cosmic rays.

We will explore a likely significant combinatorial effect of the multiple stressors inherent in spaceflight by determining the impact of radiation and simulated microgravity on the plant and its root microbial community composition and function. We will use the 1-d clinostat as our principal ground-based microgravity analog.

The central hypothesis of this project is that space radiation disrupts plant root microbial community composition resulting in impaired microbial function.

Aim 1. Determine dose-rate effects of exposure to space radiation on plant root microbial community composition and microbial function. Arabidopsis thaliana plants inoculated with a well-characterized publicly available synthetic community of 188 bacteria representing taxonomic and functional diversity from A. thaliana roots and soil in the natural environment will be irradiated with a single fraction or multiple fractions of simulated galactic cosmic rays given over 1 day or 30 days resulting in a cumulative dose of 0.75 Gy.

Aim 2. Determine the combined effects of space radiation and simulated microgravity on microbiota community composition. A. thaliana will be irradiated with a single fraction exposure to 0.75 Gy of space radiation with and without simulated microgravity. Responses will be analyzed as described in Aim 1.

We have assembled a strong team comprising scientists with complementary experience in ground-based studies of space radiation on rats (Baker), plant-microbiome interactions (Ané), and spaceflight and clinostat-based analyses (Gilroy).

Colleen Doherty/North Carolina State University

How do carbon fixing strategies affect nutritional content under high CO2? A comparison of C3 vs. C4 microgreens

Several carbon capture mechanisms have emerged in plant systems that provide unique advantages to plants depending on their environment. For example, while most plants use C3 photosynthesis, C4 and Crassulacean acid metabolism (CAM) carbon capture mechanisms can increase water use efficiency or temperature tolerance. These advantages have been well-characterized in the atmospheric CO2 levels on Earth, but in enclosed human habitats such as those needed for long-term space flight, CO2 levels far exceed that of the Earth’s atmosphere. Altered CO2 levels are known to affect nutritional content and water use efficiency, however, much of the prior research has used CO2 levels below that on enclosed human habitats.

This proposed work would examine how high CO2 levels affect plant physiology and nutritional content of edible microgreens that use different photosynthetic mechanisms: C3, C4, and CAM. We will monitor physiological characteristics and the nutritional profile across different CO2 levels for select microgreen species (with C3, C4, and CAM photosynthesis). The combined effects of altered CO2 levels and other spaceflight relevant stresses such as water availability will be examined to understand if these different photosynthetic mechanisms can provide advantages to enhance plant productivity in space environments.

These results would provide important baseline information on plant nutrition and performance that is needed for planning long-term space missions and thus would address the following objectives of the solicitation and NASA program goals: Decadal Survey- Priority 3: A systematic suite of plant biology experiments to elucidate mechanisms by which plants respond and adapt to spaceflight, and to facilitate their eventual use in Bioregenerative Life Support Systems; PB-1 How does gravity affect plant growth, development & metabolism (e.g. photosynthesis, reproduction, lignin formation, plant defense mechanisms) and PB-3 How can horticultural approaches for sustained production of edible crops in space be both improved and implemented (especially as related to water and nutrient provision in the root zone)?

Rebecca Lybrand/University Of California, Davis

Growing Food on Mars: Determining the impact of radiation, atmospheric composition, and rock substrate on plant growth in a Space Rock Garden Experiment

1. SCIENCE GOALS AND OBJECTIVES. As human civilization expands outside of its terrestrial cradle to explore the Moon and Mars, the sources and delivery of nutrients for long-duration missions must be identified and refined. The importance of using local mineral resources for sustaining life, and the bioengineering of such environments remain at the vanguard of sustainable human space exploration. Our overarching goal is to test how ionizing radiation, atmospheric composition, and rock substrate constrain and influence plant growth in deep space exploration, specifically the maintenance of plants in Lunar and Martian environments. This Early Career Investigation (ECI) will produce new publishable findings that integrate how food plants interactively respond to spaceflight stressors (CO2 and radiation) and environmental constraints imparted by basalt rocks containing different morphological and elemental arrangements that serve as nutrient sources for plants and microbes in Mars-relevant environments. Once constructed, the Space Rock Garden Experiment (SRGE) will serve as the framework for performing additional plant studies experiments to be proposed through full-ground based proposals and future ISS flight experiments.

We will achieve three objectives: 1) Develop and construct the SRGE, an integrated experimental system capable of controlling the mineral substrate, water, atmospheric and UV radiative conditions, and the presence of plants and microbes; 2) Identify how the flux of short wavelength (UV-B) radiation and atmospheric composition influence the rock weathering environment (e.g., nutrient elements compartmentalization), therefore assessing how coupled atmospheric and stellar energy sources influence the formation and habitability of incipient soils; 3) Integrate tomato and N-fixing plant genotypes, arbuscular mycorrhiza, and associated microbiota into the SRGE to assess how rock properties affects the growth and development of plants as viable crops for deep space exploration under increased CO2 and UV-B radiation.

2. METHODOLOGY. We will design, construct, and test the SRGE to simulate plant growth and microbe-mineral interactions under atmospheric and radiation scenarios

relevant to Martian landscape. We will assess plant and microbial stress indicators in combination with biogeochemical analyses of major and trace elements in mineral, water and biomass pools. Micro-XCT will be used to assess plant root architecture, pore space morphology, and the biogeochemical indicators required to support complex plant life. We performed a pilot study using basalt rock substrates sampled from Mars analog sites in Iceland and confirmed that: i) tomato and lentil plants successfully co-germinated and grew together in basalt rock substrates under ambient conditions; ii) DNA was can be extracted from fresh basalt rock substrates, indicating that the rock materials are capable of hosting microbial life; and iii) a microXCT (X-Ray Computed Tomography) approach successfully differentiated dense mineral particles, water-filled pores, air-filled pores, and roots from tomato plants grown in the basalt rock substrates.

3. RELEVANCE. This proposal aligns with a goal of the Space Biology program to "address fundamental questions that will advance the understanding of how plants accommodate to the spaceflight environment," including "analyzing plant and microbial growth and physiological responses to the multiple stimuli encountered in spaceflight environments" as highly recommended in the Decadal Survey on Biological and Physical Sciences in Space. This initiative will have wide applicability in answering questions central to the sustained human presence in space, as well as will expand the envelope of our fundamental understanding of plant growth and life-mineral interactions as constrained by solar radiation and atmospheric composition.

Kennda Lynch/Universities Space Research Association, Columbia

Plant Trek: Investigating Strategies for Regolith Pre-Conditioning to Support the Establishment of Plant-Microbe Systems in Martian Habitats.

A critical component to long-duration deep space exploration, specifically on Mars, is developing self-sustainable in situ food production and life support systems. To accomplish this task, it will be necessary to understand how to optimally integrate plant-microbe systems with planetary in situ resources. The overarching goal of this proposed Early Career pilot study is to develop and assess an integrated system approach for pre-conditioning and structing martian regolith into to agriculturally stable & usable soil to support plant growth, sustain microbe-plant interactions, minimize plant stress, and optimize food production & life support. As a part of this study, we will test a microbial consortium derived from a natural perchlorate-reducing system as a pre-inoculant for mitigating perchlorate toxins in martian regolith simulant. We will also evaluate the phased approach of introducing pioneer species & plant beneficial micro-organisms as an intermediate structure building step for transforming martian regolith into a viable agricultural substrate that will reduce plant stress and increase seed germination rates and overall biomass production. The results of this study will pave the way for long-term sustainable crop production in a martian habitat.

Qingwu Meng/University Of Delaware

Temporal Lighting Optimization to Improve Lettuce Productivity and Nutritional Quality Under Superelevated CO2 Stress

Growing fresh food in space provides nutritional and psychological benefits to crew members in long-term exploration missions. Light-emitting diodes (LEDs) convert electricity to photons to regulate plant photosynthesis and secondary metabolism. To minimize the energy demand and maximize desirable crop attributes, we need to better understand how crops respond to varying light spectra and intensities. Previous research and current protocols use fixed light settings throughout the crop cycle. However, new data suggest that crop responses to light stimuli depend on the crop age. Here, we propose a temporal lighting strategy to increase light use efficiency and nutritional quality of red-leaf lettuce by identifying optimal light spectra and intensities for each growth phase under superelevated CO2 stress. We will grow red-leaf lettuce hydroponically under LEDs with varying blue light, green light, red light, far-red light, and total light intensities over time in plant growth chambers at superelevated CO2 conditions observed on the International Space Station. At harvest, we will collect and analyze data on plant growth, morphology, and nutrient accumulation. These data will reveal lettuce responses to combined effects of varying light regimens and increased CO2 stress. This one-year Early Career Investigation will guide future full-scale investigations to optimize crop-specific light and environmental control strategies for a desirable balance between crop yield and nutritional quality in space life support systems.

Dorothy Shippen/Texas A&M AgriLife Research

Telomere dynamics and oxidative stress in Arabidopsis in the space radiation environment

We propose an ISS-Flight Research Investigation using Spectrum hardware, and radiation experiments at NASA Space Radiation Lab (Brookhaven) and Colorado State University. This proposal leverages the expertise of three international leaders in the fields of telomere, radiation and plant biology to explore the relationship between the space radiation environment, oxidative stress and the dynamics of plant telomeres. Our preliminary data show that in response to space flight telomerase enzyme activity in Arabidopsis is strongly induced, but telomere length is steady. Telomerase activity was not substantially elevated by simulated microgravity conditions, implying that space radiation is responsible for telomerase induction. Our central hypothesis is that exposure to the space radiation environment results in elevated ROS which in turn leads to genome oxidation and the high-telomerase activity phenotype observed in the telomere maintenance machinery of space flown plants. We will test this hypothesis with three specific Objectives. Objective 1 will examine the effect of the combined stressors associated with spaceflight on plant telomere dynamics, genome oxidation and organellar stability in Arabidopsis seedlings grown aboard ISS as compared to ground controls. We will employ a series of mutant and overexpression lines that influence telomeres and genome oxidation. Objective 2 will explore the impact of space radiation exposure on these parameters using the same Arabidopsis lines by studying the effect of fractionated schemes of simulated space radiation exposure (Galactic Cosmic Ray Simulator at the NSRL) as well as low dose, low dose-rate neutron and low dose gamma-ray exposure (irradiation facilities at Colorado State University). In Objective 3 we synthesize the data gathered from spaceflight and on-ground fractioned radiation exposure experiments to address our central hypothesis. This work is highly impactful as telomeres are an important biological marker of survivability in both plants and humans. Elucidating the relationship between the space radiation environment and telomere dynamics may prove to be a critical component of long-duration missions in the future.

Shawana Tabassum/University of Texas, Tyler
Leaf Sensor Network for In Situ and Multiparametric Analysis of Crop Stressors

This project aims to advance the fundamental understanding of the hormonal responses in plants in a spaceflight-like environment through an in situ technology that collects and analyzes data on plant phytohormones in real-time. A plant's defense mechanisms against environmental stressors are initiated by progressive variations in the phytohormone levels. Salicylic acid, Jasmonic acid, Abscisic acid, and Indole-3-acetic acid are among the most important regulators of induced defense mechanisms. Progressive variations in their levels have been reported under many drought and cold/heat-stressed conditions on earth. However, the dynamic interaction mechanism of these hormones is not fully elucidated in a "space farming" setting due to the lack of technology needed to facilitate in situ sensing. Real-time understanding of a plant's responses to stressors is essential to minimize stress-induced growth and yield declines in plants. Toward this end, this project proposes to develop a lightweight, wireless, integrated leaf sensor network with multiple sensing elements to monitor plant hormonal variations in real-time. The system will be comprised of a multiplexed hormone sensor for quantitatively measuring the primary defense hormones: Salicylic acid, Jasmonic acid, Abscisic acid, and Indole-3-acetic acid. The impact of the following stressors on the hormone levels will be analyzed: changes in CO_2 levels, temperature, and growth media. In contrast to the traditional discrete, disruptive, in vitro, time-intensive, and heavyweight instruments used for molecular analysis, our proposed leaf sensor network is energy-efficient, robust, lightweight, wireless, and provides in situ monitoring capabilities. We will develop functional correlations of the measured hormonal variations with physiological indicators (photosynthesis, respiration, and transpiration) to differentiate the effect of growing conditions on individual plant productivity during its various growth stages. The knowledge gained from this project will advance future research on predicting and improving plant growth and productivity under spaceflight stressors.

E.11 Space Biology: Animal Studies

(NNH21ZDA001N-SBAS)

Below are the abstracts of proposals selected for funding for the Space Biology Research program. Principal Investigator (PI) name, institution, and proposal title are also included. Forty-seven proposals were received in response to this opportunity. On October 14, 2022, twelve proposals were selected for funding.

Heather Allaway/Louisiana State University and A&M College
Insights into the impacts of continuous, low dose-rate neutron radiation exposure on maternal and fetal skeletal physiology

The combined effects of space environmental stressors induce pathologies in multiple organ systems. Specifically, losses to the musculoskeletal system may be very dangerous for the health and performance of astronauts on extended duration missions on the moon or arriving on Mars. A critical need remains to better understand the impact of radiation exposure, one of the key environmental stressors of deep space, on human and animal physiology to enable extended duration missions beyond low Earth orbit or setting up settlements on the moon or Mars. There is a critical gap in knowledge surrounding the impact of the space radiation environment on skeletal health and on the progress of fetal skeletal development during pregnancy. The objective of the current proposal is to capitalize on a unique tissue-sharing opportunity to examine the combined effects of continuous radiation exposure and pregnancy on maternal and fetal skeletal physiology. The parent study placed female mice, mated 24 hours prior, into housing in the Colorado State University neutron irradiator. The neutron irradiator exposes animals in the facility to high-energy neutron particles at space-relevant dose rates. Following either 12 or 18 days of continuous, radiation exposure, the hindlimb bones of the female mice and all fetal tissue were collected and stored for later analysis. We propose to assess maternal and fetal skeletal physiology through measurements of mineral and material properties, as well as assess changes in cellular dynamics of the maternal bone under the microscope. This study will be critical in assessing how a very harmful component of the space radiation environment impacts multiple aspects of skeletal health including sex-specific differences and individual variation in the impact of the space environment on the functioning of the body.

Joshua Alwood/NASA Ames Research Center
Integrated CNS assessment in rodent models of altered gravity and irradiation

To better understand gravity’s role in life’s processes, gravitational acceleration - from microgravity to hypergravity - is worthy of study in space-based and ground-based experiments across organisms. Additionally, little is known about potential interactions across the gravity continuum with exposure to ionizing radiation. In this proposed project, we aim to study the effects of gravity as a continuum, from simulated weightlessness with hindlimb unloading or from hypergravity, in combination with chronic low-dose irradiation to assess the timecourse of changes in cognitive processes and associated neurotransmitter levels and circulatory biomarkers. Rats will be treated with ground analogs of spaceflight: either hindlimb unloading combined with irradiation in Aim 1 or hypergravity at 2g combined with irradiation in Aim 2. Hindlimb unloading will be achieved using custom plexiglass cages at NASA ARC. Hypergravity treatment through centrifugation will take place at NASA ARC. Low-dose irradiation will use 137Cs gamma-ray exposure. Cognitive assessment will use touchscreen and non-touchscreen. In vivo microdialysis will be performed to collect fluid for neurotransmitter assessment in key brain regions. Blood and hippocampus will be collected and assessed for complementary biomarkers. This project has the potential to advance both the state of knowledge and the state of technology to be useful in future space missions. Specifically, this project will further mechanistic underpinnings that can be associated with inflammation and oxidative stress in both the brain and circulation to determine mechanistic and translatable biomarkers integrated with gold-standard cognitive/behavioral assessment leading to peer-reviewed publications and publicly archivable data.

Elizabeth Blaber/Rensselaer Polytechnic Institute

Unraveling the role of mitochondrial dysfunction and senescence on inhibition of tissue regeneration during spaceflight and amelioration by a novel countermeasure, PQQ.

Spaceflight factors, including microgravity and radiation, significantly affect tissue regeneration and repair in multiple physiological systems, including the skin, musculoskeletal, nervous, digestive, and immune systems. Our research, and that of others, has demonstrated activation of oxidative stress, inflammation, mitochondrial dysfunction and senescence as key factors that contribute to the decline in tissue regenerative capacity in spaceflight, leading to tissue degeneration. In this proposal, we aim to investigate the effects of mitochondrial dysfunction and senescence on the ability of two key stem cell populations, skin and bone marrow stem cells, to conduct regenerative repair during spaceflight exposure. We specifically aim to interrogate the interplay between these two cellular mechanisms in the disruption of stem cell homeostasis, driving stem cell dysfunction and inhibiting regeneration. Our research has also demonstrated that pyrroloquinoline quinone (PQQ), a potent dietary antioxidant, has anti-inflammatory and anti-senescent effects in multiple tissues. As PQQ also stimulates mitochondrial biogenesis and may be beneficial in diseases associated with mitochondrial dysfunction, including impaired tissue regeneration, we aim to test the ability of this countermeasure to ameliorate spaceflight effects on stem cell-based tissue regeneration. We specifically hypothesize that spaceflight factors cause systematic mitochondrial dysfunction and inflammatory responses resulting in cellular senescence and tissue degeneration in mammalian tissues that can be mitigated by PQQ. We will use unique animal models, including a mtDNA-depleter model developed by Dr. Singh and a senolytic mouse model (CDKN1a/p21-/--p16-3mR) developed by Dr. Blaber in collaboration with Dr. Judith Campisi, that will enable direct interrogation of the systemic regulators, including oxidative stress and inflammation, mediating mitochondrial dysfunction and senescence in stem cell populations. Furthermore, we will model regenerative repair through a full dermal thickness excisional wound, induced during exposure to simulated spaceflight exposure (hindlimb unloading and 0.5 Gy simplified Galactic Cosmic Ray simulation (simGCRsim)), enabling study of regenerative mechanisms under homeostatic conditions as well as during functional repair following injury. These studies, combined with an array of advanced analysis techniques, including spatial transcriptomics, single cell RNA sequencing, Luminex based cytokine and inflammation assays, and ex-vivo functional stem cell assays, will enable us to comprehensively determine the cellular and molecular mechanisms underpinning the deleterious impact of spaceflight induced mitochondrial dysfunction on stem-cell based tissue regeneration in two uniquely regenerating tissues. Finally, by testing efficacy of a dietary countermeasure (approved for use in humans) to promote wound healing under spaceflight conditions, our study will enable organisms to Thrive in DEep Space. Our multi-disciplinary team has the skills, experience, and expertise necessary to successfully complete this project.

Sylvain Costes/NASA Ames Research Center
Characterization of Female Reproductive Health Risks for Long-Duration Spaceflight using Federated Machine Learning

The central objectives of this proposal are to study the effects of spaceflight and space-relevant radiation exposure on female mammalian reproductive health and identify biomarkers that can be used to monitor female reproductive health during space travel. The methods proposed to accomplish this objective are ground-based irradiation of female rats and spaceflight exposure of rat oocytes, subject to biomarker collection and countermeasure testing. Additionally, the proposal includes a computational machine learning component in which space-generated data are used in conjunction with Earth-based data to train a deep learning biomarker model. The proposed work is significant to the solicitation objectives in that successful completion of this work will enhance our understanding of how animals respond to stressors in space and spaceflight-like environments, through studying the fundamental biological changes that the female mammalian reproductive system undergoes while in space or exposed to space-relevant radiation. This work also enables the identification of translational biomarkers that can be used to support human female astronaut health and the development of countermeasures for helping female astronauts thrive in Low Earth Orbit missions and deep space exploration. Further, this work is significant to NASA goals of increasing diversity and representation in the astronaut cohort by focusing on a highly understudied aspect of female health in space.

Ashley Blackwell/Eastern Virginia Medical School

Feasibility study: Use of neural networks to predict adaptability and multiday performance saving in dual motor-cognitive tasks after exposure to space flight stressors

This proposal will use a rodent model of space flight stressors (SFS), including space radiation (SR) and sleep disruptions (SD), that are known to impair mission-relevant performance that is dependent on cognitive and sensorimotor systems. Astronauts must engage in complex tasks that rely on the integration of information from these multiple systems simultaneously, both independently and cooperatively in team cohesion while on deep space missions. Engagement in multiple tasks at once, or dual tasks, is very common, such as navigating (i.e., walking or floating in space) through the environment while operating a device (i.e., tablet or radio). Independent, or individual, dual task performance has been shown to be disrupted in astronauts on both short and long duration space missions that was attributed to microgravity. Yet it is not known how SR and SD will impact performance during complex tasks, including adaptations to new stimuli and readaptations to old stimuli, nor whether these deficits will extend to team cohesion beyond the individual, which is critical for performance and mission success. Surprisingly, no work to-date has examined dual task performance in a rodent model of SFS.

Dual tasks involve performance in multiple systems simultaneously and provide the opportunity to evaluate adaptations, readaptations, and multiday performance savings in rodents and humans. Savings refers to faster relearning, or gains in performance that come from repetition on a task. Both savings and adaptations are imperative to mission success with exposure to SFS and varying task demands. Therefore, the main objectives of this proposal are two-fold: 1. to evaluate the impact of SFS, alone and combined, on neural activity during dual tasks, periods of inactivity, and sleep, and 2. to assess the feasibility of using neural activity to predict subsequent adaptations and multiday performance savings.

To accomplish these research objectives, neural recording techniques will be used to establish system wide SFS effects on independent and cooperative (team cohesion) dual task performance and to characterize the neural mechanisms underlying adaptations and savings as well as the feasibility of predicting future performance. Our state-of-the-art established wireless neural recording techniques will be conducted while rats perform versions of the behavioral assessments that vary in complexity and during offline periods of inactivity (i.e., neural replay) to examine cognitive, sensorimotor, and vestibular function. Sleep disruptions are commonly reported among astronauts which have deleterious effects on performance, including reaction time. Therefore, we will also investigate the initial effects of SR exposure on neural activity during sleep, as well as the effect of SD on sleep characteristics (spindles, stage duration). In addition, we will assess the feasibility of predicting neural network function, adaptation and savings, from sleep characteristics, including sleep stage durations and sleep spindles that are critical to memory.

Despite the fact that both independent and cooperative (team cohesion) performance depends on varying demands (single versus dual) in many of the tasks that astronauts must perform in space, the impact that SR and SD have on such performance is unknown. Thus, our proposed studies will determine the relative sensitivity of independent and cooperative (team cohesion) performance on single and dual tasks to these SFS compared to mono-dimensional tasks that have been the mainstay of rodent-based research to-date. This work also has the potential to identify underlying neurobiological mechanisms of adaptations in a rodent SFS model and to provide a basis to identify resilient and susceptible factors. This work may lead to an understanding of how to promote adaptations and performance savings across time in individuals that are especially susceptible to the effects of SFS.

Janani Iyer/NASA Ames Research Center
Sex-specific physiological and transcriptomic CNS responses to combined effects of spaceflight stressors in Drosophila melanogaster

During space exploration, damage to the central nervous system (CNS) due to altered gravity is a significant risk, along with the constant exposure to elevated CO2 levels. The combination of these stressors can negatively impact the CNS health that may lead to decrements in astronaut performance, posing a risk to the crew and the mission. Thus, there is an unmet need to unravel the mechanisms and pathways affected by these combined spaceflight stressors. In this proposal, we aim to address sex-specific and long-term responses to spaceflight stressors (mimicking the longitudinal post-flight evaluations in astronauts). We will perform behavioral, brain morphological, and biochemical assays, along with cell-specific transcriptomic profiling in Drosophila melanogaster to investigate the underlying mechanistic responses to single and combined exposures of altered gravity and elevated CO2. While this solicitation is limited in time and scope, we anticipate that our findings from this study will inform future investigations in vertebrate models and contribute to new research that will address the biomedical outcomes of deep space stressors.

Cassandra Juran/NASA Ames Research Center
Sustained effects of spaceflight on Anemia and severity of effects dependency on age.

Anemia is a significant risk to the wellbeing of astronauts. Recent studies have demonstrated that these risks do not normalize over long duration missions, as was once thought, and suppressed red blood cell numbers are retained long after return to Earth. Additionally, age influences severity of red blood cell depletion on Earth and would likely become a significant contributor to space anemia as longer duration missions to Moon, Mars or permanent colonization missions are considered. Anemia is a condition which can cause fatigue and physical weakness, both detrimental to an astronaut’s ability to conduct tasks requiring stamina, concentration and precision. Additionally, long term untreated anemia corresponds to heart failure and compromised immune system. As space anemia is associated with so many risks, there has been significant research into its cause. Recent findings determined hemolysis was a major contributor to space anemia, showing a 54% increase in hemolysis markers in expiration and blood sampling, however, this study did not probe the molecular mechanisms driving the observed hemolysis. The NASA GeneLab program has recently released a series of four single cell RNA-sequencing datasets that our proposal seeks to consult to better understand how spaceflight and aging impacts blood cell production and destruction throughout the red blood cell's lifecycle. The GeneLab datasets to be interrogated include three tissue types 1) the source of new red blood cells (bone marrow), 2) circulating blood samples (PBMCs), and 3) the site of terminal or dysfunctional red blood cell removal (spleen) collected from two two age groups, one equating to young adult humans and the other associated with the average age of the astronaut population. These data analyses are uniquely significant as the datasets include tissues pertinent for the entire life cycle of a red blood cell, allowing mechanistic explanation of suppressed red blood cell development (erythropoiesis) and increased rate of hemolysis. Future work expanding on this one-year GeneLab Analysis Investigation could probe other hematopoietic/immune cell lineages using methodology similar to those developed for erythropoiesis or could use the omics regulation findings of this proposal to investigate molecular countermeasures for space anemia. The analyses conducted herein, and methods generated, could also be impactful for future Space Biology investigations at single cell resolution. One such application is analysis of the recently completed Rodent Research 10 mission, in which single cell bone marrow flushes were cryopreserved on-orbit and processed for single cell sequencing on the ground. These analyses are critical as they will define spaceflight risks to the oxygen transport system of the body and characterize the duration of molecular changes after return to the ground. The main goal of this proposal to understand the molecular causes of anemia such to devise countermeasures to protect our astronaut population during and after return from spaceflight duties.

Caralina Marin de Evsikova/Bay Pines Foundation, Inc,

Stressors to Spaceflight: Identification of Transposon-Driven Changes to Gene Networks in GeneLab Data

Adaptation of the individual organism to a new environment, such as spaceflight, is achieved via changes in gene expression. In eukaryotic organisms, stress adaptation induces a repertoire of transcription factors and epigenetic changes (e.g. DNA methylation), which frequently reactivate transposable elements (TEs) residing in genomes. Expression of TEs in most cells is normally suppressed to avoid uncontrolled transposition, which leads to genomic instability. However, cellular stress and the loss of suppressive epigenetic modifications lead to increase in TE expression as observed, e.g., in aging and cancer. Thus, increased expression of TEs is a "genomic instability gauge", signifying dramatic genomic or epigenetic changes in the cell. Elevated expression of TEs invokes "damage control" and often manifests in activation of innate immune response, antiviral pathways, apoptosis and other cellular defense mechanisms. Ubiquitously found in all animal genomes, transposonable elements (TEs) are a significant component of eukaryotic genomes, for example occupying more than one-third of the human genome

(Lander et al 2001). In eukaryotic organisms, adaptation to stress induces a repertoire of transcription factors, as well as epigenetic changes to the genome of the cells (e.g. DNA CpG methylation, histone modifications). These changes consequently reactivate transposable elements (TEs) residing in eukaryotic genomes. TEs are a doubled-edged sword, which affect both individual organisms and species adaptation to new environments in two opposing ways: 1) via transposon-driven cis-activation of neighboring genes, which induce pathways altering cell metabolism, proliferation and survival, and 2) via facilitating establishment and maintenance of suppressive epigenetic modifications, such as CpG methylation, along the genome. Another important contribution of TEs acting as alterative promoters of neighboring genes, well documented in animal embryos, stem cells, and in cancer. Thus, TEs are powerful modulators of gene expression and disease, but so far understudied in space biology. Here, we propose to test the novel hypothesis that transposons act as a molecular driver for remodeling gene networks caused by stress and adaptation responses to the extreme environments of spaceflight across species, ranging from simpler invertebrates to more complex mammals. Using our innovative Transcript and Transposons Expression Signature Analysis (TTESA) pipeline to detect and quantify altered gene networks TE expression after space exposure, will provide data critical to understand the impact of TEs on neighboring gene expression as a potential mechanism remodeling genetic networks at both the genomic and transcriptomic levels. Albeit TEs are not considered to be reactivated from exposure to space flight, however our preliminary analysis with medaka fish exposed to low earth orbit (LEO) have up to 250X increase in some TEs and we have the first evidence spaceflight induces TE-driven gene transcription in mice. It is unknown if spaceflight-induced TE-driven genes are permanent upon return to Earth. TEs are an unrecognized and unmitigated potential risk factor for healthy space exploration, given their established roles in reproduction, stem cells, and cancer.

Marie Mortreux/Beth Israel Deaconess Medical Center, Inc.

Circadian rhythm disruption and gravitational disturbance in a Lunar mission analog: consequences for muscle function during and after the mission

Mechanical loading is the primary stimulus required for the maintenance and health of the musculoskeletal system. Exposure to microgravity or reduced gravity results in rapid bone loss and muscle atrophy, especially in the lower limbs. In recent years, the clock system in the skeletal muscle has been recognized to play a critical role in key aspects of muscle physiology, ranging from structural maintenance to functional regulation. On Earth, perturbations of the circadian rhythm affect muscle function and are associated with the development of sarcopenia. Reciprocally, studies have demonstrated that muscle activity can directly modulate the expression of muscle clock genes in a time-dependent fashion, and recent data suggest that the circadian clock could influence skeletal muscle adaptation in response to exercise training. Since Artemis astronauts will experience alterations in muscle condition and circadian rhythm simultaneously, it is critical to develop ground-based studies that will closely mimic this situation. While these stressors will occur temporarily, their effects may linger, and negatively influence muscle recovery after return from the mission.

In this ground-based ECI proposal, I hypothesize that light cycle disturbances induced by a model of Chronic Jet Lag (CJL) will severely impact the peripheral muscle clock and, combined with altered gravity, will lead to additive negative effects during the disuse period. Moreover, I hypothesize that circadian disruption will have long-lasting effects that will significantly impair muscle recovery during the reloading period.

SA1: To characterize the impact of circadian disturbance and partial gravity in a lunar analog in male and female rats. 60 adult outbred rats (30 males and 30 females) will undergo 7 days of exposure to partial weight-bearing at 20% of normal loading (PWB20) to simulate lunar gravity. 1 group will be exposed to a regular light cycle (LD), 1 group will be kept in constant light to induce circadian free-running (LL) and the experimental group will be exposed to CJL using a 6h phase advance every other day.

SA2: To determine and compare the long-term effects of circadian disturbance and altered gravity during muscle recovery in males and females. 20 animals (10/sex) will be exposed to the same PWB20+CJL paradigm as in Aim 1. Animals will be allowed to recover for 7 days at normal loading (1g) and under a standard light cycle (LD).

For this work, I plan on first assessing muscle health and function through regular testing including grip strength, fatigue resistance, force production, and muscle quality. I will also monitor circadian parameters and rest/activity over several 24h periods. Finally, I will perform biomolecular assays in the suprachiasmatic nucleus and soleus muscle, targeting specific genes involved in circadian rhythm entrainment, muscle function and inflammation.

This promising pilot study will help assess the additive effects of circadian disturbance in animals exposed to partial gravity and will help determine the existence of sex-based differences in response to spaceflight stressors. Moreover, I will determine sex-based differences during muscle recovery following disuse, and the long-term impact of circadian disturbance on muscle health and function. This study, that includes phenotypical and molecular outcomes, will assess the contribution of muscle clock genes and pathways to muscle health. Finally, targeted molecular assessment will help me use my diverse background (metabolism, neuromuscular, circadian) to explore other systems of interest that may be linked to muscle health and function (e.g., metabolic signaling pathways), and help characterize the key players that could be targeted with pharmacological approaches to provide new and effective countermeasures in future studies.

Anand Narayanan/Florida State University

Partial Gravity and Sex-Difference Effects on the Venous Circulation

NASA Space Biology aims to understand organism adaptations to the spaceflight environment. An understudied area of space biology are the spaceflight adaptations of the venous circulation. The venous circulation supports the cardiovascular system, and in turn all organs of the body, by transporting blood and its contents away from organ systems toward the heart and lungs. Consequently, venous return impacts cardiac function. As NASA aims to send astronauts to the Moon and Mars, understanding the adaptations of the venous circulation to microgravity, Lunar gravity, and Martian gravity will not only increase our knowledge of cardiovascular function in space along a gravity continuum, but also uncover new potential astronaut medical risks. Furthermore, NASA will also be sending the first female astronaut into deep space as part of the Artemis Moon venture, and to date there exists no literature on possible sex differences of the venous circulation in response to spaceflight. This study will be the first comprehensive assessment of venous circulation adaptations to a simulated gravity continuum and also investigate sex differences to increase our knowledge of male and female cardiovascular space biology adaptations. I will investigate, for the first time, the functional, structural, and molecular adaptations of veins from multiple organ beds (head, heart, digestive system, and bone) to identify vascular biology, immunological, and local organ system physiological adaptations to simulated spaceflight environment conditions. In completing this study, we will have increased our overall knowledge and understanding of space biology, as well as identify prospective health risks of our astronauts in advance on their journey into deep space.

Seward Rutkove/Beth Israel Deaconess Medical Center, Inc.
Acute and long-term effects of combined radiation and partial unloading on neurological and musculoskeletal systems in male and female rats

In this proposed work, we will evaluate the separate and combined effects of simulated space radiation and lunar gravity on the muscular, skeletal and central nervous systems over the short- and longer-term. Moreover, we will assess whether these effects differ by biological sex. This work will be accomplished by studying male and female rats of an age (in rat years) comparable to that of the astronaut corps and exposing them simultaneously to simulated galactic cosmic rays (GCRsim) at Brookhaven National Laboratory and extended 20% partial weight-bearing to mimic lunar gravity. Animals will be assessed after completing 28-days of partial weight-bearing to assess short-term effects of these exposures and several months later to assess longer-term effects with recovery. This will include a variety of functional, molecular, and histological assessments assessing bone, muscle, and brain. We believe that the research team, which has expertise in musculoskeletal and brain health and in partial weight-bearing rodent models and radiation exposure, is ideally suited to complete the proposed work. This proposal directly responds to the objectives of the solicitation and will provide valuable insights that will directly impact the upcoming Artemis program's planned lunar landings.

Craig Willis/Ohio University
The effect of different genetic mutations and pharmacologic interventions on transcriptional responses to spaceflight in C. elegans

Long-term human deep space exploration is a key goal of NASA but remains hindered by obscure (mechanistic) knowledge of how spaceflight maladaptation can be overcome. The tiny worm Caenorhabditis elegans represents a primary model for better understanding causes of and countermeasures against health decline in space, with strong forward-translation potential into people. Accordingly, a recent spaceflight experiment led by the UK Space Agency (MME2) flew various mutated or pharmacologically treated worm strains on-board the International Space Station with emphasis on ameliorating spaceflight dysregulation related to neuromuscular, musculoskeletal and/or mitochondrial signaling: key systems negatively impacted by spaceflight in, and thus highly relevant to, the human system. NASA's GeneLab will generate GLDS RNA-seq data from these samples, which The PI (Dr. Craig Willis) proposes to analyse as a GeneLab Analytical Investigation. The central objective is to establish spaceflight transcriptomic profiles for the various mutated/treated strains (using standard transcriptomic methods, including differential expression and network analysis, pathway enrichment, hub gene identification etc.) and compare them with 'normal' spaceflight responses (i.e., in wild-type worms from this mission plus past flights) to define common/unique effects toward ameliorating spaceflight gene dysregulation. By harnessing the power of omics and the GLDS, this work will therefore establish control mechanisms and efficacy of pharmacological interventions to positively alter gene expression changes during spaceflight, with findings having strong potential to be directly translatable to understand and, ultimately, counteract human health risks for future longer-term deep space exploration. As such, this work will beneficially impact NASA's Space Biology Program and its long-term goals by helping to (i) identify the underlying mechanisms and networks that govern biological processes in space, (ii) develop mechanistic understanding to support human health in space and (iii) promote open science through the GLDS.