National Aeronautics and Space Administration

EXPLORE SOLAR SYSTEM & BEYOND

Astrophysics Sounding Rocket Missions Update

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POC for Sounding Rockets in APD and PS for Balloon Program
Astrophysics Division, Science Mission Directorate

Astrophysics Advisory Committee
October 19, 2020

Suborbital Programs
Low-Cost Rapid Access to Space

In addition to yielding science results, suborbital investigations are also critical in maturing new technologies for future space missions and developing NASA future workforce.

PI led effort,

- PI is in full control of the mission from proposal, instrument development, launch, data analysis, to publication.
- NASA is in control of the platform and launch operations

Suborbital payloads are Microcosm of large-scale Missions

- Students fully engaged in entire mission lifecycle within grad school tenure
  - Define Science Questions
  - Science Requirements Flowdown to Technical Requirements
  - Design and Fabrication
  - Testing, Integration, and Calibration Experiment/Payload
  - Staging, Launch, Recovery, Data Analysis and Presentation

Acceptance of Appropriate Risk and Risk Mitigation

- Value lies in building the instrument and the carrying out the mission
  - Suborbital program is operated under NPR 7120.8
  - New Science is defined. Technology Readiness is raised to Flight Level (TRL-7).
  - Risk of failure is accepted in low cost environment. Lessons are learned.
  - Systems are exercised prior to deployment on more advanced missions
  - Proof of Science and Technical Concepts

Sounding Rocket Program Office

Heliophysics Division manages the Sounding Rocket Program for all NASA.

The Sounding Rocket Program Office at WFF (Code 810) provides implementation:

Led by Giovanni Rosanova
Day-to-day operation of the Sounding Rocket Program
Management/Oversee of the Contractor (NSROC III)
Safety and Mission Assurance (Range, Termination, recovery)

SRPO manages technologies/capabilities development

- Higher Data Rate Telemetry
- Water Recovery
- Higher Performance Vehicles 650-700 seconds above 150 km
- Sub-Payload Technology
- Component and sub-system miniaturization and modernization

SRPO provides reimbursable rocket launch services outside of their core missions, which is SMD science, education, and SRP technology development.

- ~10 flights/year SMD Science (Heliospheric, Solar, Astro, Planetary)
- ~3-4 flight/year SRPO Education + Technology Development
- ~1-4 flight/year Reimbursable flights outside of the Core Mission above

I’m the Sounding Rocket Program Point of Contact within Astrophysics; Valerie Connaughton and Michael R Garcia are the Technical Officers for the High Energy and UV/Visible Portfolios, respectively.

Sounding Rocket Launch Locations

Astrophysics Sounding Rocket Manifest

MISSION 02-04	EXPERIMENTER	PROJECT	RANGE	DATE (ET)	DISCIPLINE
36.323 UG	FRANCE	CHESS	WSMR	2017-06-27 00:10:00 S S S S	UV/OPTICAL
36.311 UG	GREEN	DEUCE	WSMR	2017-10-30 05:00:00 S F – F	UV/OPTICAL
36.329 UH	GALEAZZI	DXL	PFRR	2018-01-19 07:17:00 S S S F	HIGH ENERGY
36.330 UH	MCENTAFFER	WRX-R	KWAJ	2018-04-04 06:40:00 S S S S	HIGH ENERGY
36.333 UG	FRANCE	CHESS	KWAJ	2018-04-16 5:16:47 S S S S	UV/OPTICAL
36.245 UH	FIGUEROA	MICRO-X	WSMR	2018-07-23 02:00:00 S F S F	HIGH ENERGY
36.331 UG	GREEN	DEUCE	WSMR	2018-12-18 02:46:00 S S S S	UV/OPTICAL
36.346 UG	FRANCE	SISTINE	WSMR	2019-08-11 02:07:00 S S S S	UV/OPTICAL
36.343 GG	NUTH	DUST-1	WSMR	2019-10-07 11:00:00 S S S S	LAB ASTRO
36.352 UG	MCCANDLISS	FORTIS	WSMR	2019-10-28 00:30:00 S S S S	UV/OPTICAL
36.365 GG	NUTH	DUST-2	WSMR	2020-09-08 14:00:00 S S S S	LAB ASTRO
36.368 UH	GREEN	DEUCE	WSMR	2020-11-02	UV/OPTICAL
36.281 UG	ZEMCOV	CIBER-2	WSMR	2021-02-15	UV/OPTICAL
36.347 UH	MCCAMMON	XQC	AUS	2021-06-28	HIGH ENERGY
36.367 UH	MCENTAFFER	tREXS	WSMR	2021-07-01	HIGH ENERGY
36.339 UG	FRANCE	SISTINE	AUS	2021-07-04	UV/OPTICAL
36.350 UG	GREEN	DEUCE	AUS	2021-07-14	UV/OPTICAL
36.355 UH	FIGUEROA	MICRO-X	WSMR	2021-11-01	HIGH ENERGY
36.363 UH	GALEAZZI	DXL-3	WFF	2021-12-06	HIGH ENERGY
36.298 UH	MCENTAFFER	OGRE	PFRR	2022-10-24	HIGH ENERGY

DUST Mission

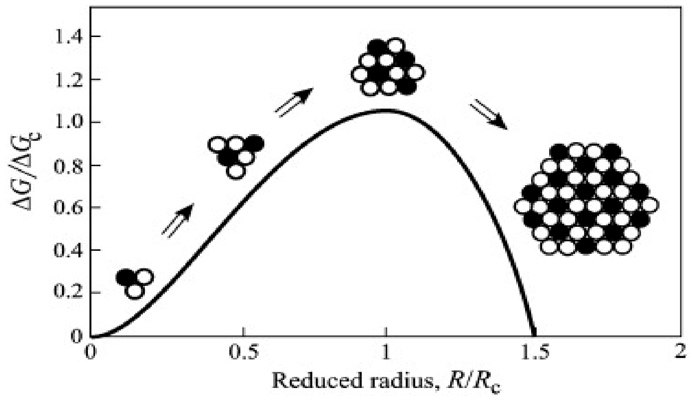
Determining Unknown yet Significant Traits is a Laboratory Astrophysics investigation studying dust grain formation. The Sounding Rocket flight provides the microgravity study environment for this sample return mission.

Led by PI Joseph Nuth, GSFC in collaboration with Hokkaido University.

The gas-solid phase change is unstable at first due to the surface energy of the clusters which must grow large enough to be dominated by internal energy before they grow into dust grains.

Theory assumes that every SiO colliding with an unstable cluster sticks and that every SiO that strikes a stable cluster also sticks and contributes to the growing dust grain.

In practice these processes are much less efficient by several orders of magnitude.



First build stable clusters by addition & loss of SiO.

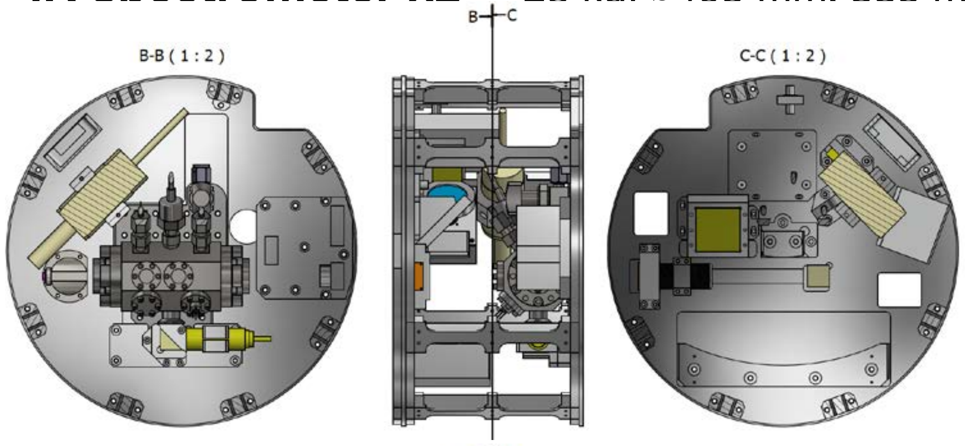
B

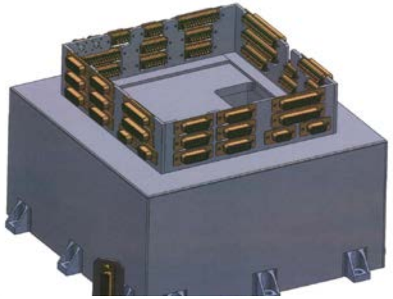
Objectives of the DUST Payloads

- Use the Interferometer experiments (see next slide) to measure the temperature and pressure at which SiO, Fe-SiO and Mg-SiO nucleate.
- Use the IR Spectrometer experiments to measure the spectrum of freshly condensed amorphous silica, iron silicate and magnesium silicate dust.
- Based on Interferometer data and using Classical Nucleation Theory, calculate the efficiency of cluster growth for unstable clusters.
- Based on the partial pressure of condensates, gas temperature, time and measured particle size distribution, calculate the dust growth efficiency.
- Based on the number density of nucleated dust grains, available time and size of dust aggregates, calculate the aggregation efficiency.
- Determine the effect of background gas [Ar, Ar+O2, Ar+H2] on nucleation, growth, aggregation and particle morphology.

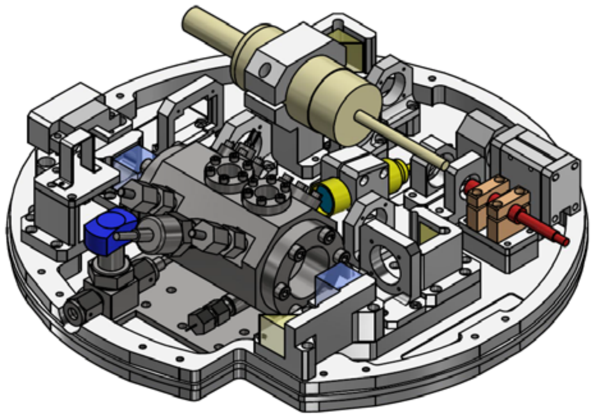
The DUST Payload

IR spectrometer x2 ~28 kg, ⌀405 mm, 335 mm in height





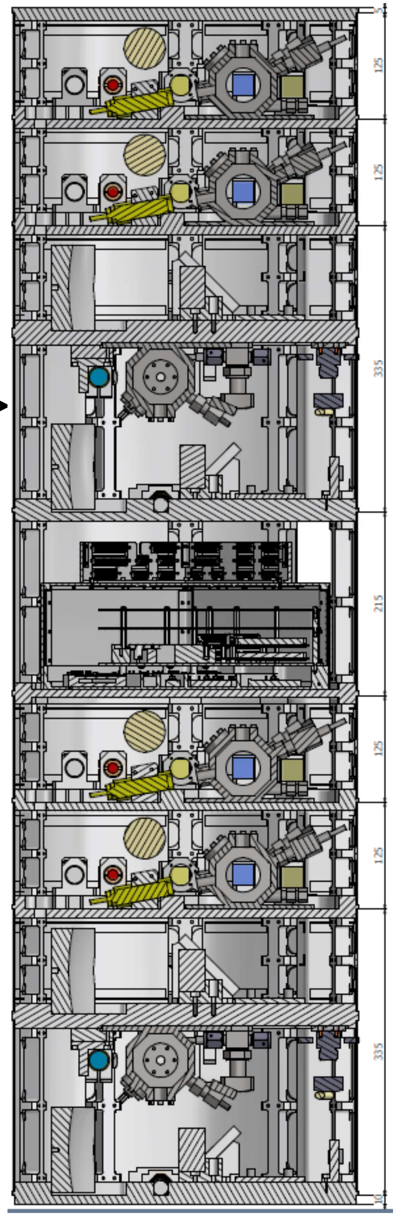
Interface circuit system
15 kg
⌀405 mm
215 mm in height



Interferometer x4

17 kg
⌀405 mm
125 mm in height

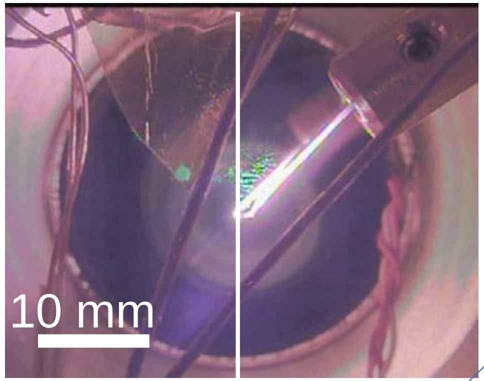
payload stack



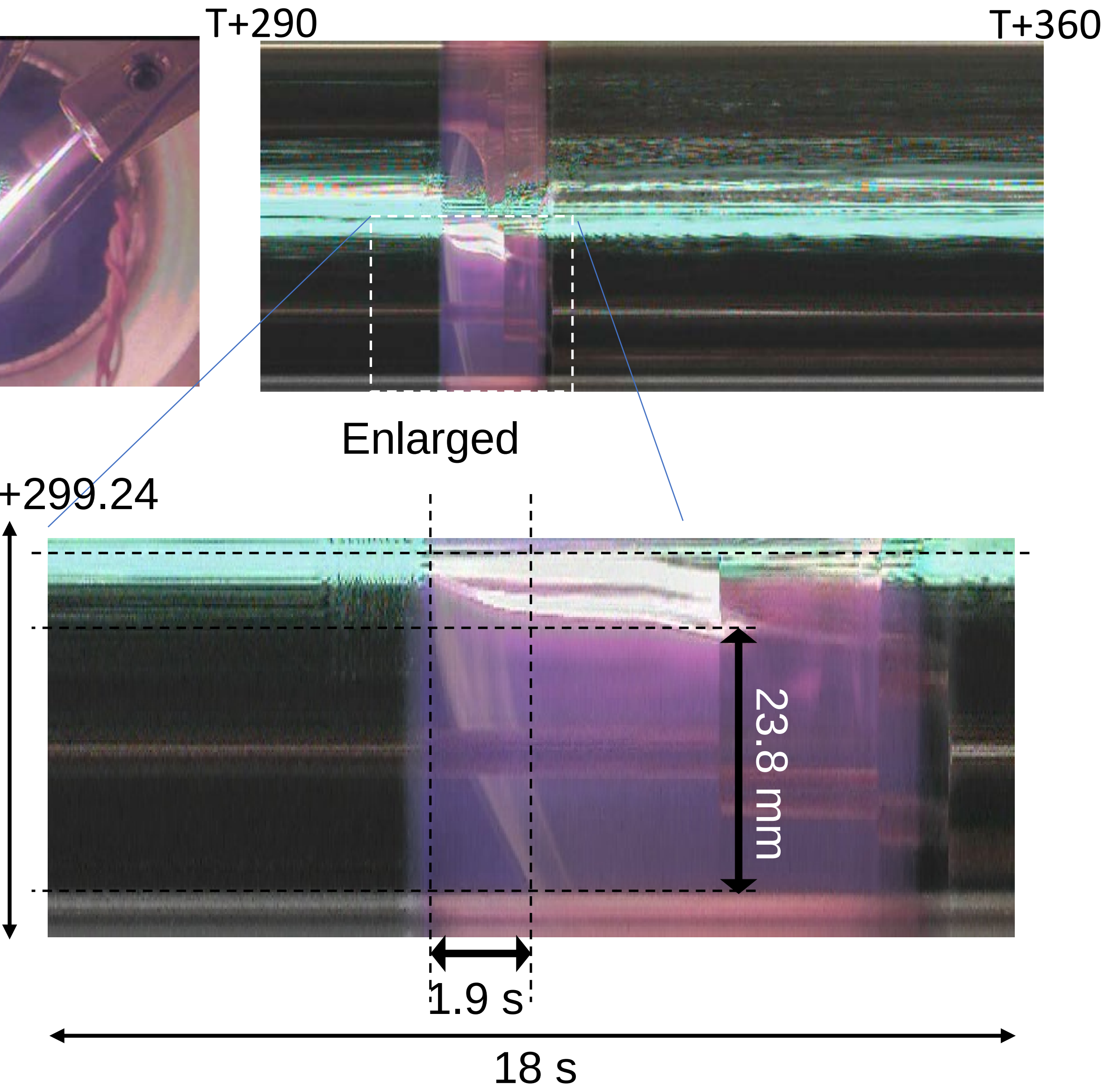
Total: 138 kg
Height: 1400 mm
Diameter: 405 mm
without skin and cables

IFC2 FeSiO Nucleation

(1) Visual image of the hot filament and dust nucleation.



Time series of visual images along the white line (1).



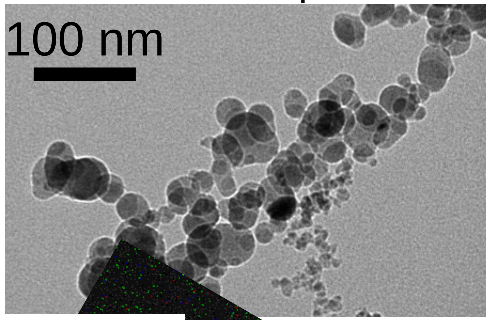
Expanded time series of visual images along the white line in (1) showing dust nucleation.

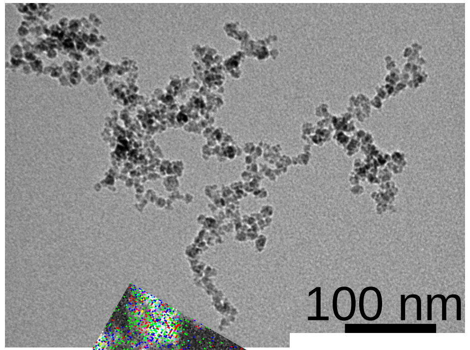
TEM Images of IFC2 FeSiO

30 – 100 nm: Separation of Fe-silicate from amorphous silica

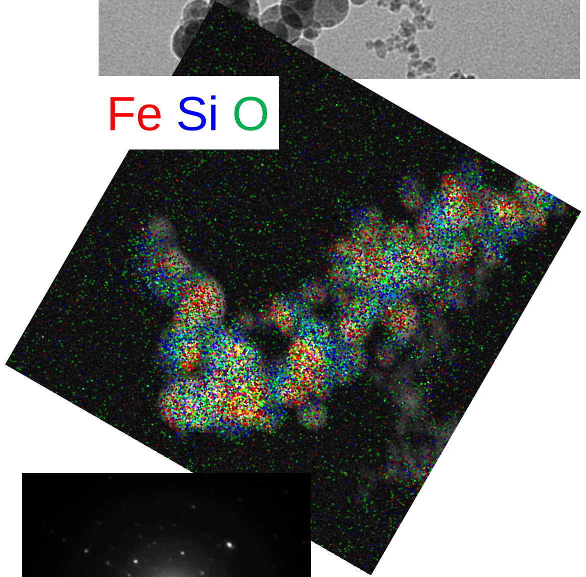
~10 nm: Amorphous Fe-silicate

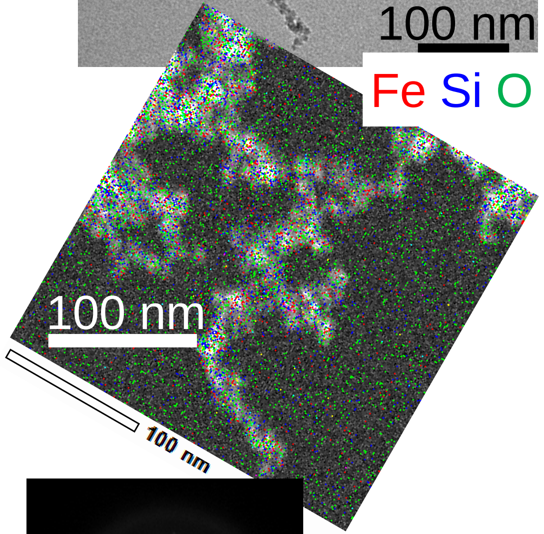
TEM Images



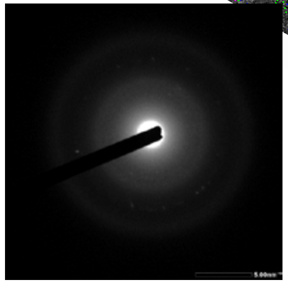


Chemical Compositions





Electron Diffraction Patterns



TEM – Transition Electron Microscope

DUST Analysis

The DUST-1 payload arrived in Hokkaido in late December 2019.

TEM analysis of particles began January 2020.

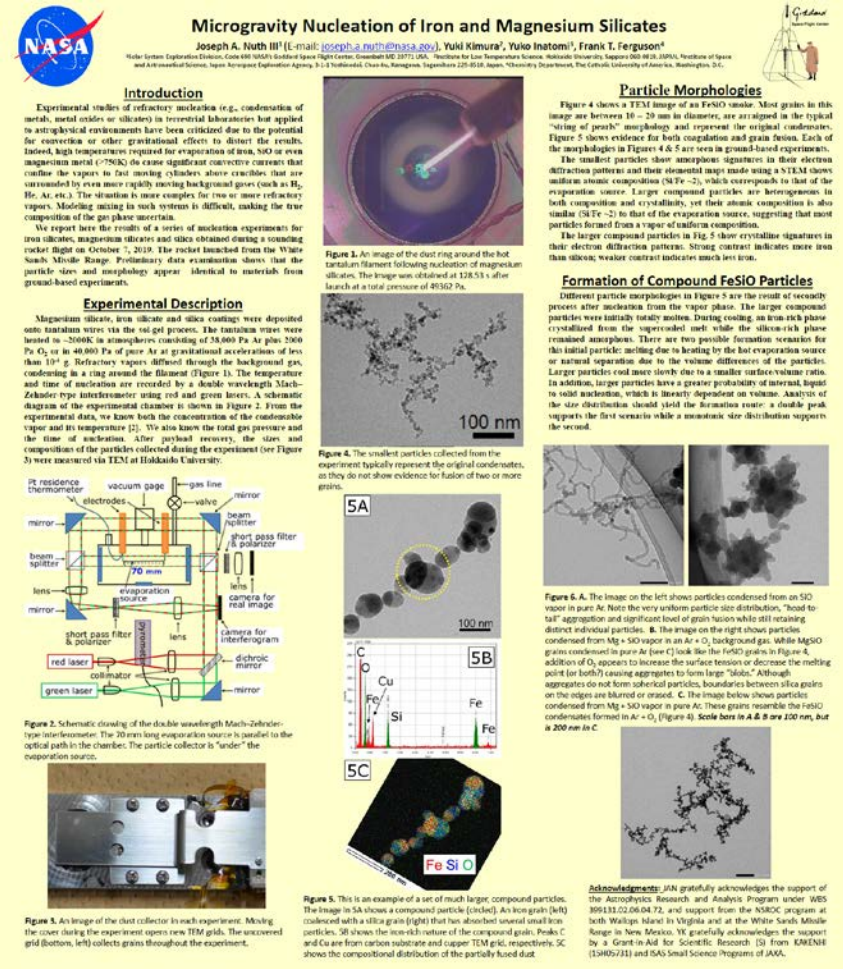
A Science Team meeting in February 2020 resulted in this poster for the LPSC.

COVID shut down Hokkaido University.

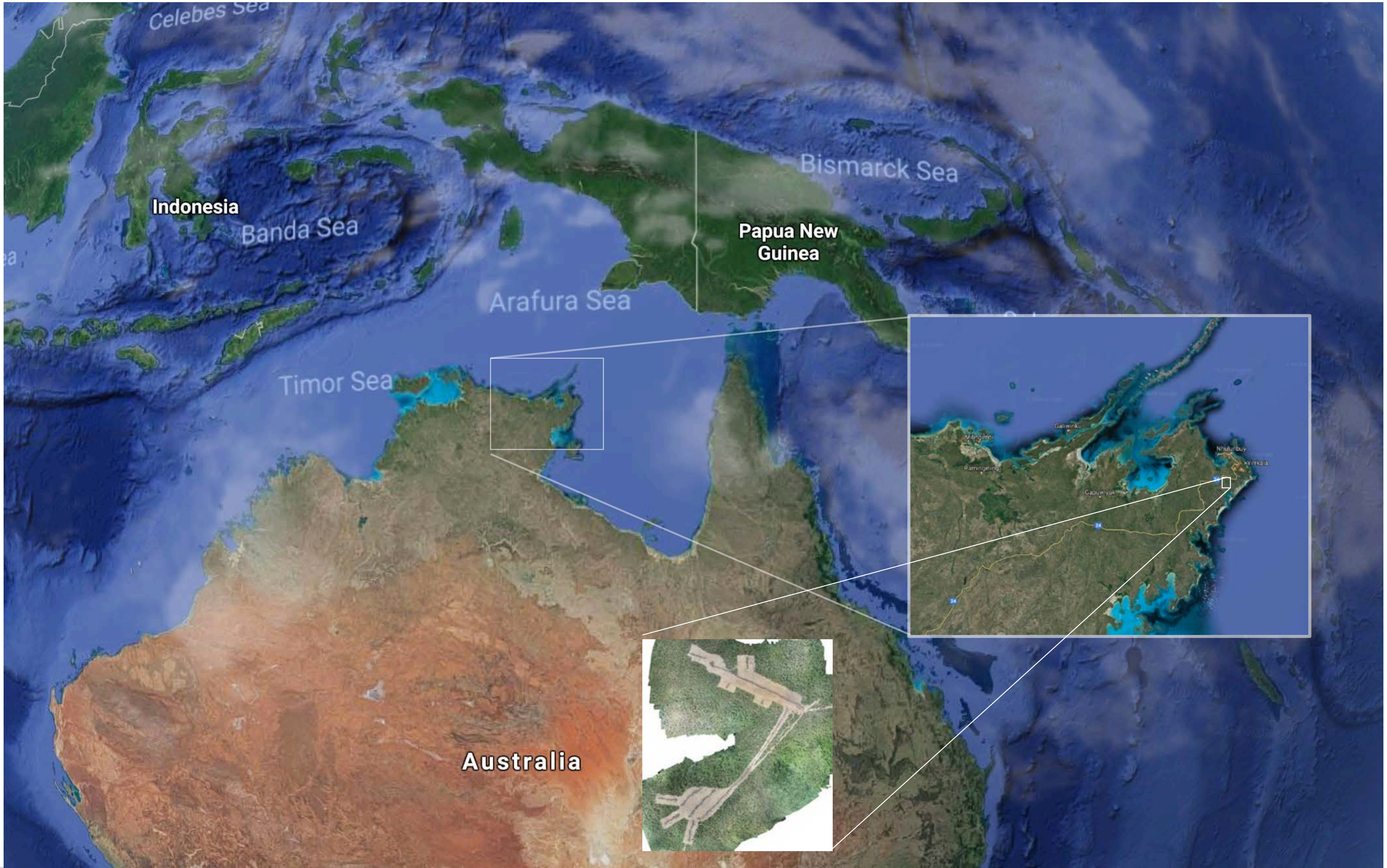
Upon being allowed back in the laboratory the JAXA team worked to refurbish the payload in order to support launch of DUST-2.

DUST-2 successfully launched on 7 September 2020, was recovered and was shipped back to JAXA on September 15, 2020.

Once in Japan, full data analysis will begin.



Equatorial Launch Australia (ELA)



Timing of the APD Australia Campaign

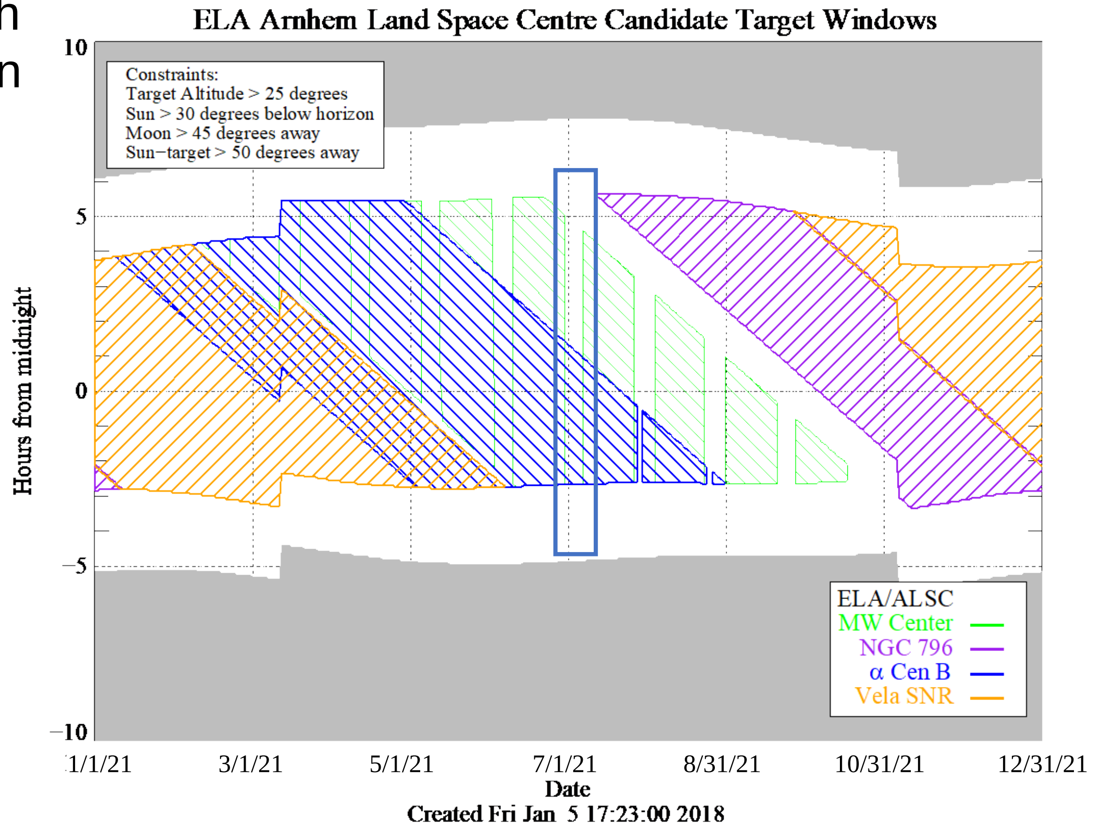
Sounding Rocket Program Office (SRPO) is working with the commercial Equatorial Launch Australia (ELA) site. The plan is to have three (3) payloads launched in the June/July of 2021, which is the maximum number of science teams that can see their targets in a narrow 3-week window.

MW Center: **McCammon**
NGC796: McCandliss
A Cen B: **France, Green**
Vela SNR: McEntaffler

(PI in high lighted above can see prime science target in the June/July time frame)

SRPO anticipates to have an Australia Sounding Rocket campaign every 3 years.

Recently a second commercial launch site further south is presently being explored of potential future use APD Sounding Rocket.



Backup Slides

Suborbital Platforms Overview

Sounding Rockets

- Exoatmospheric > 100 km
- Flight duration of up to 20 min at altitude
- Payload Masses typically 500 kg
- Mature payload sub-systems provided by the SRP (Skins, Doors, TM, Pointing, Guidance, Recovery)
- Fine pointed standard capability < 1”
- Science Disciplines: X-ray, EUV, UV, IR
- Recoverable/re-flyable

Balloons Payloads

- Float altitude 34 km (super pressure) to 39 km (conventional)
- Float time of avg 21 days (conventional) and 60-100 days (super pressure)
- Payload Masses up to 1000 kg (super pressure) to 3600 kg (conventional)
- Experimenter provides gondola
- Fine pointing ~1” is available (WASP)
- Science Disciplines: Particle Astrophysics, γ-ray, hard X-ray, 2100 ± 100 Å window far-IR, sub-mm
- Recoverable/re-flyable

Balloon Program

Balloon Program COVID Impact Timeline

Wanaka, NZ

~ 02/21/20 COSI science team deploys

03/14/20 BPO decision to cancel the Wanaka 2020 Campaign and redeploy teams.

Palestine, TX

04/08/20 BPO decision to move the payload (PIPER) from Palestine to the Ft. Sumner Campaign.

Fort Sumner, NM

For all but one payload (PIPER), the PI have withdrawn from Ft Sumner campaign.

07/09/20 BPO decision to cancel the Ft. Sumner campaign (Nevada the recovery side for Ft. Sumner balloon launches was at the peak of their COVID outbreak).

McMurdo, Antarctica

06/21/20 NSF informed NASA the due to COVID-19 they can not support a 20/21 LBD campaign.

FY20 Balloon Program Manifest

Mission	Discipline	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Fort Sumner, New Mexico	***Fall '19***												
Toon/JPL-Remote/Bailey/VATech/GLO	Upper Atmosphere	*Success*											
Kogut/GSFC/PIPER	IR-Submillimeter	*Success*											
Young/SwRI/THAI-SPICE (Hand Launch)	UV/Visible	*Success*											
Tang/JPL/RECKTANGLE (Hand Launch)	IR-Submillimeter	*Success*											
Livesey/JPL/SWITCH (Hand Launch)	IIP/Upper Atmosphere	*Successful Ground Test*											
McMurdo, Antarctica	***Winter '19***												
Rauch/WUSTL/SuperTIGER	Cosmic Ray/Particle			*Success*									
Devlin/UPENN/BLASTPOL	Gamma Ray/X-Ray				*Launch Success with Anomaly / Science Component Failure*								
Salter/CSBF/TRAVALB	Test Flight			*First Flight Aborted due to Balloon Anomaly, Second Launch Success*									
Wanaka, New Zealand	***Spring '20***	***Campaign cancelled by Program following coronavirus outbreak.***											
SPB Test/Boggs/UCSD/COSI	Test Flight/COSI (PB)			*Delayed by Program due to COVID-19*									
Salter/CSBF/TRAVALA	Test Flight				*Cancelled by Program*								
Palestine, Texas	***Summer '20***	***Campaign cancelled by Program due to CSBF closure due to COVID-19.***											
Kogut/GSFC/BOBCAT	IR-Submillimeter				*Delayed by Program due to COVID-19*								
Kogut/GSFC/PIPER	IR-Submillimeter					*Delayed by Program due to COVID-19*							
Fort Sumner, New Mexico	***Fall '20***	***Campaign cancelled by Program due to COVID-19.***											
Field/CSBF/CSBF Test Flight-I/II	Test Flight							*Delayed by BPO due to COVID-19*					
Kogut/GSFC/BOBCAT-II/III	IR-Submillimeter	*BOBCAT-II delayed by BPO and BOBCAT-III delayed by Principal Investigator due to COVID-19*											
Kogut/GSFC/PIPER	IR-Submillimeter								*Delayed by BPO due to COVID-19*				
Tang/JPL/WHATSUP (Hand Launch)	Planetary Sciences							*Delayed by Principal Investigator due to COVID-19*					
Bailey/VATech/GLO	Upper Atmosphere						*Delayed by Principal Investigator due to COVID-19*						
Bloser/LANL/LTT (Hand Launch)	Gamma Ray					*Delayed by Principal Investigator due to COVID-19*							
Chakrabarti/UMASS/PICTURE-C	UV/Visible						*Delayed by Principal Investigator due to COVID-19*						
Martin/CalTech/FIREBall-2	UV/Visible					*Delayed by Principal Investigator due to COVID-19*							
Young/SwRI/THAI-SPICE	UV/Visible					*Delayed by Principal Investigator due to COVID-19*							

FY21 Balloon Program Manifest

Mission	Discipline	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Wanaka, New Zealand	***Spring '21***												
Hall / BPO / SPB Test / Boggs / UCSD / COSI	Test Flight / COSI (PB)						◊						
Fort Sumner, New Mexico	***Spring '21***												
Chakrabarti / UMASS / PICTURE-C	UV/Visible							◊					
Kogut / GSFC / BOBCAT-21A/B	IR-Submillimeter								◊ ◊				
Kogut / GSFC / PIPER-21A	IR-Submillimeter								◊				
Salter / CSBF / CSBF Test Flight	Test Flight								◊				
Esrange, Sweden	***Summer '21***	***Campaign to be held if New Zealand LDB campaign is cancelled due to COVID.***											
Hall / BPO / SPB Test SN 07	Test Flight								◊				
Roth / BPO / 60 MCF Test / Sample / MU / BOOMS	Test Flight / BOOMS (PB)								◊				
Palestine, Texas	***Summer '21***												
Tang / JPL / WHATSUP	Solar System (H/L)									◊			
Salter / CSBF / CSBF Test Flight	Test Flight									◊			
Salter / CSBF / Test Flight / Jackson / UCSD / ASHI	Test Flight / ASHI (PB)									◊			
Fort Sumner, New Mexico	***Fall '21***												
Salter / CSBF / CSBF Test Flight	Test Flight											◊◊	
Stachnik / JPL / JPL-SLS	Upper Atmosphere											◊	
Kogut / GSFC / BOBCAT-21C/D	IR-Submillimeter											◊	◊
Martin / CalTech / FIREBall-2	UV / Visible												◊
Toon / JPL / JPL-Remote	Upper Atmosphere												◊
Nowicki / LANL / LANL Test Flight	Gamma-Ray (H/L)												◊
Kogut / GSFC / PIPER-21B	IR-Submillimeter												◊
Guzik / LSU / HASP	Education Outreach												◊
Boering / UCB / MATTADOR TF	Upper Atmosphere												◊
Young / SwRI / THAI-SPICE	UV / Visible												◊

Qualification of the Super-Pressure Balloon

Pre-COVID-19 plan was to conduct two qualification flights of the super-pressure balloon (SPB) design before GUSTO launches on an SPB from Antarctica in December 2021

- Spring 2020 and Spring 2021 from Wanaka NZ

The Spring 2020 balloon campaign was cancelled in March 2020 due to COVID-19 restrictions

Current plan is to conduct one qualification flight of the SPB

- Spring 2021 from Wanaka NZ, if possible within COVID-19 restrictions
- Summer 2021 from Sweden, if New Zealand campaign cannot be conducted; the thermal environment of a Sweden launch, where the Sun is not setting on the balloon, is similar to the initial GUSTO SPB Antarctica launch environment

The use of a zero-pressure balloon (ZPB) for GUSTO is being studied as a backup

- Preliminary meteorological studies indicate that there is a high probability that GUSTO would attain its threshold requirements if launched on a ZPB
- ZPBs have less restrictive weather conditions for launch, so there are more launch opportunities in Antarctica for a ZPB than a SPB

Sounding Rocket Program

DUST, PI Nuth

Determining Unknown yet Significant Traits

DUST & DUST II

Microgravity Sounding Rocket Payloads

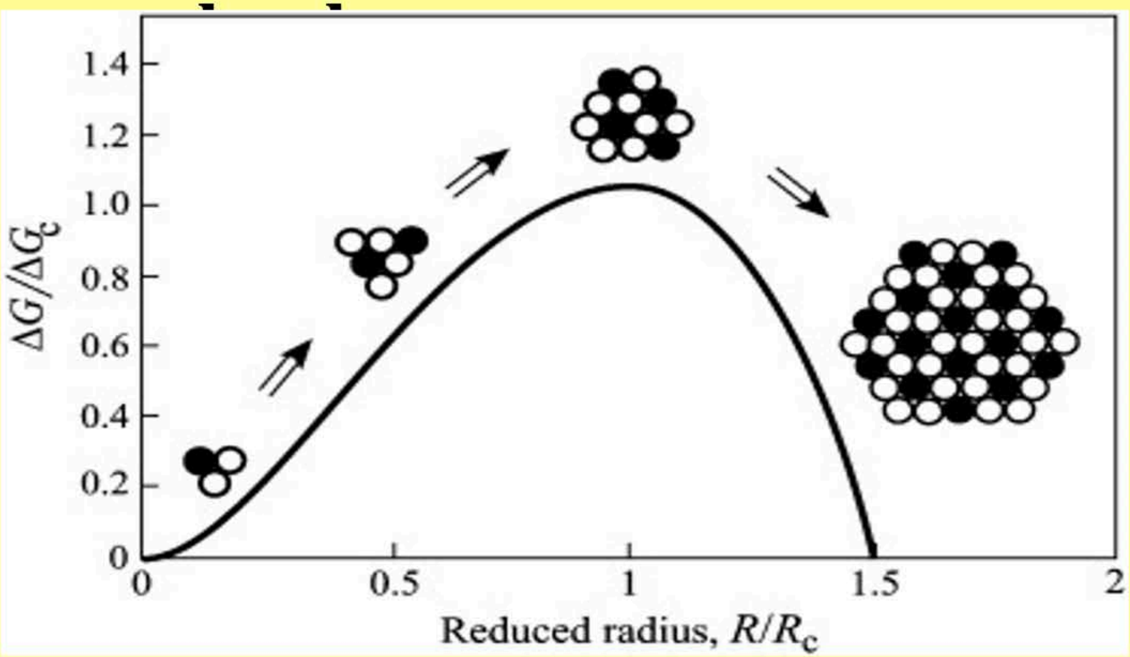
A collaborative research project between NASA and JAXA through Goddard Space Flight Center and Hokkaido University

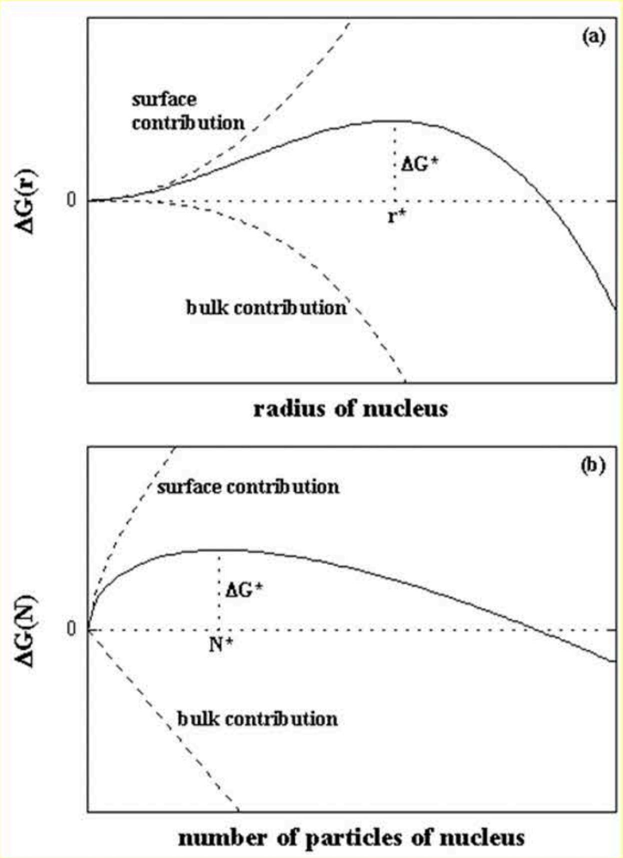
DUST launched from White Sands Missile Range on 8 October 2019

DUST II launched from WSMR on 7 September 2020

Dust Formation: Going from Theory to Practice

- **First build stable clusters by addition & loss of SiO**





The gas-solid phase change is unstable at first due to the surface energy of the clusters which must grow large enough to be dominated by internal energy before they grow into dust grains.

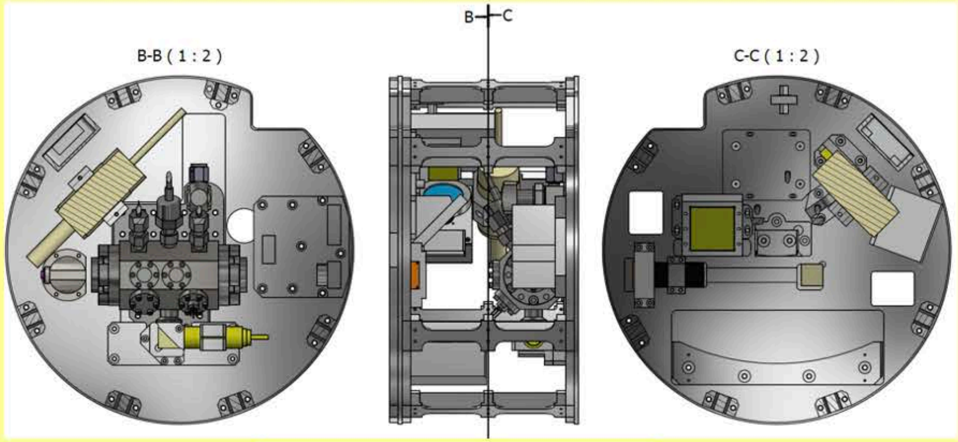
<u>Theory</u> assumes that every SiO colliding with an unstable cluster sticks and that every SiO that strikes a stable cluster also sticks and contributes to the growing dust grain.
<u>In practice</u> these processes are much less efficient by several orders of magnitude.

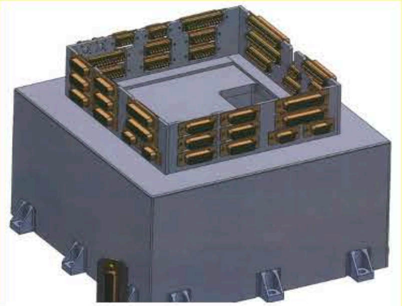
Objectives of the DUST & DUST II Payloads

- Use the Interferometer experiments (see next slide) to measure the temperature and pressure at which SiO, Fe-SiO and Mg-SiO nucleate.
- Use the IR Spectrometer experiments to measure the spectrum of freshly condensed amorphous silica, iron silicate and magnesium silicate dust.
- Based on Interferometer data and using Classical Nucleation Theory, calculate the efficiency of cluster growth for unstable clusters.
- Based on the partial pressure of condensates, gas temperature, time and measured particle size distribution, calculate the dust growth efficiency.
- Based on the number density of nucleated dust grains, available time and size of dust aggregates, calculate the aggregation efficiency.
- Determine the effect of background gas [Ar, Ar+O_2, Ar+H_2] on nucleation, growth, aggregation and particle morphology.

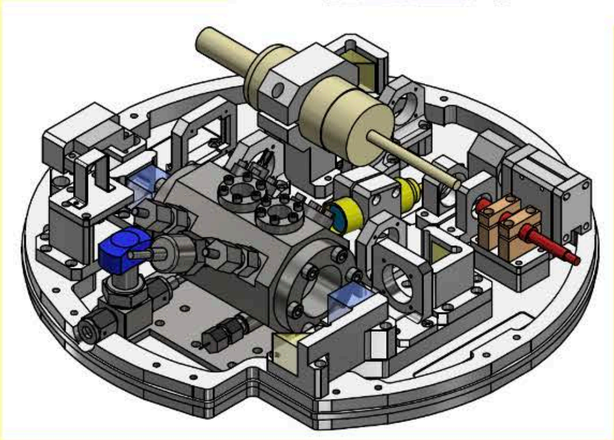
Schematic Diagram of the DUST Payload

IR spectrometer x2 ~28 kg, 405 mmϕ, 335 mm in height





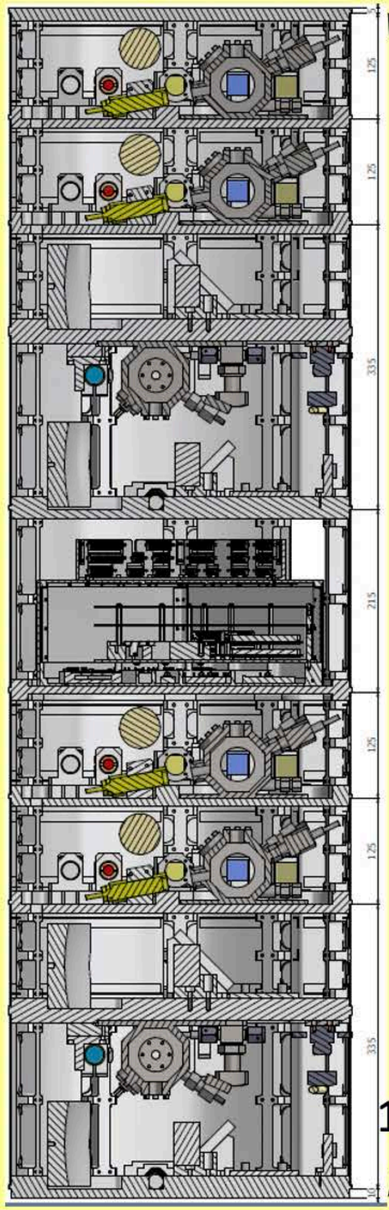
Interface circuit system
15 kg
405 mmϕ
215 mm in height



Interferometer x4

17 kg
405 mmϕ
125 mm in height

Stacking of the payload system



5 mm plate

Total: 138 kg
Height: 1400 mm
Diameter: 405 mmϕ
without skin and cables

10 mm plate

Black Brant IX, 36.343: IFC2 FeSiO Nucleation

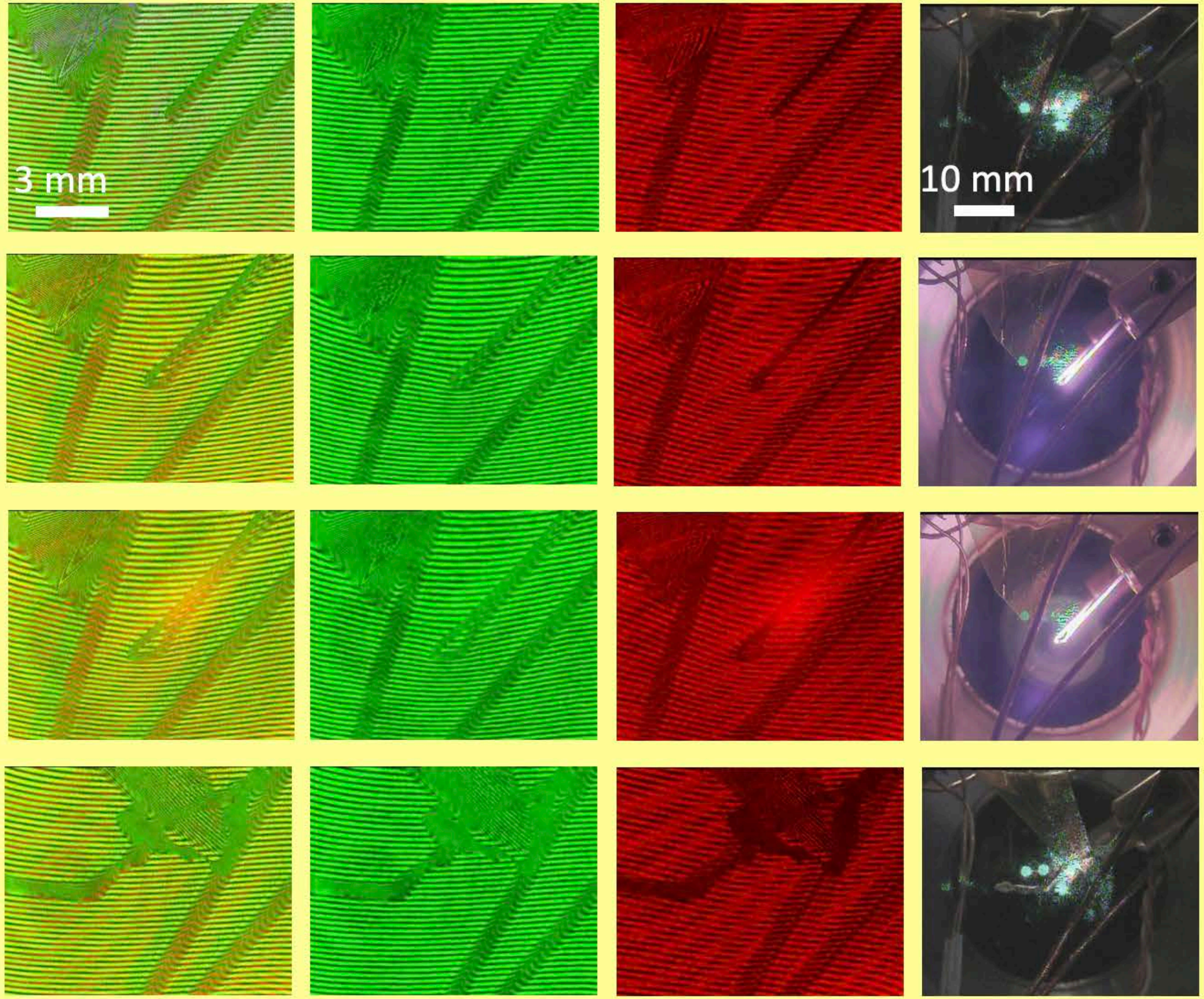
T: Time after launch; T: Temperature at the chamber wall; P: Total pressure

Before heating
T+ 299.25 s
T: 21.76°C
P: 41389 Pa

Just before nucleation
T+ 306.36 s
T: 22.20°C
P: 48334 Pa

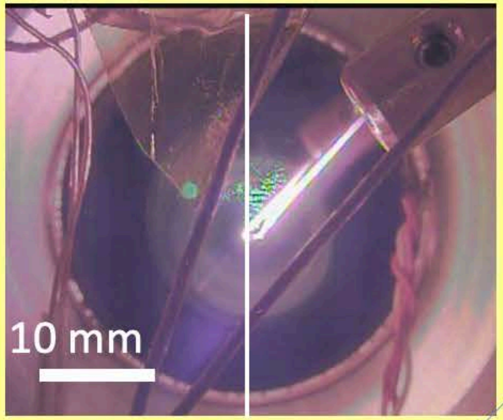
Nucleation
T+ 307.02 s
T: 22.20°C
P: 50450 Pa

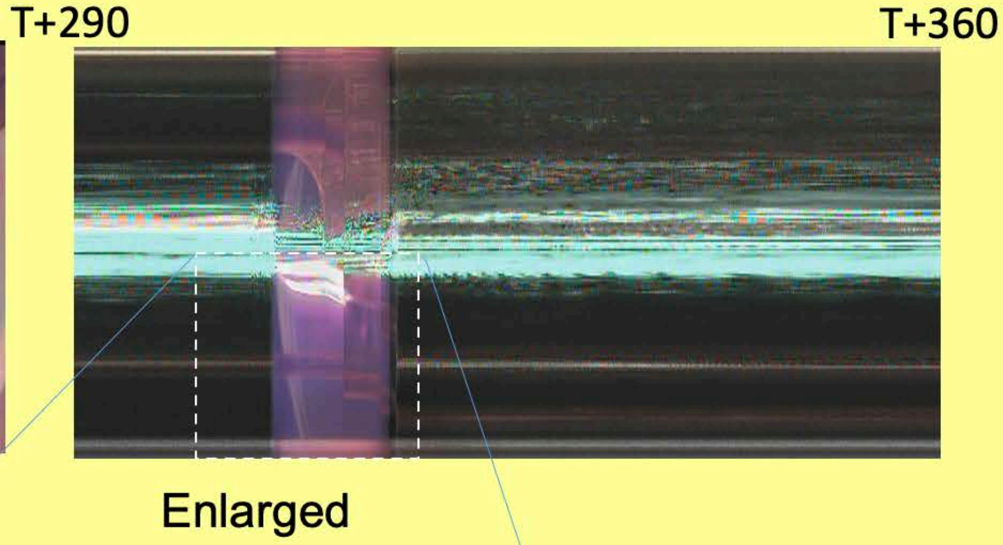
After experiment
T+360.0 s
T: 24.64°C
P: 37207 Pa



Black Brant IX 36-343: IFC2 FeSiO Nucleation

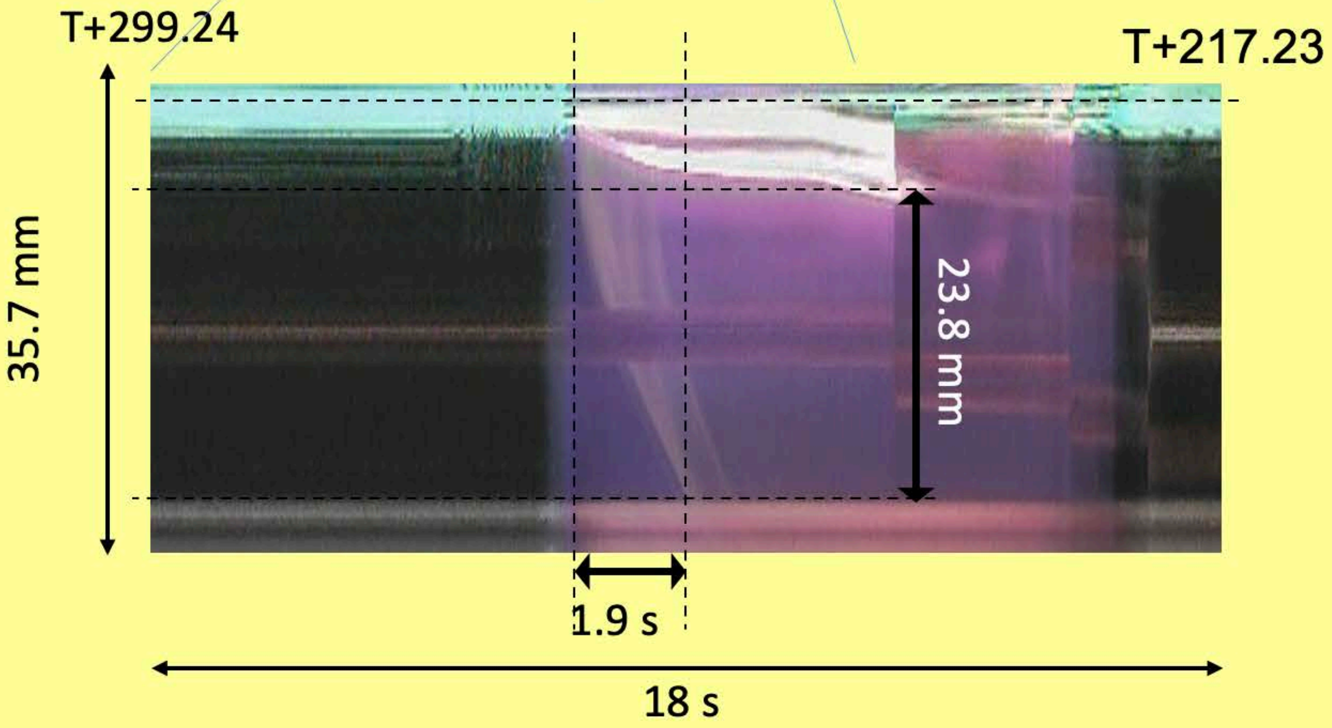
(1) Visual image of the hot filament and dust nucleation



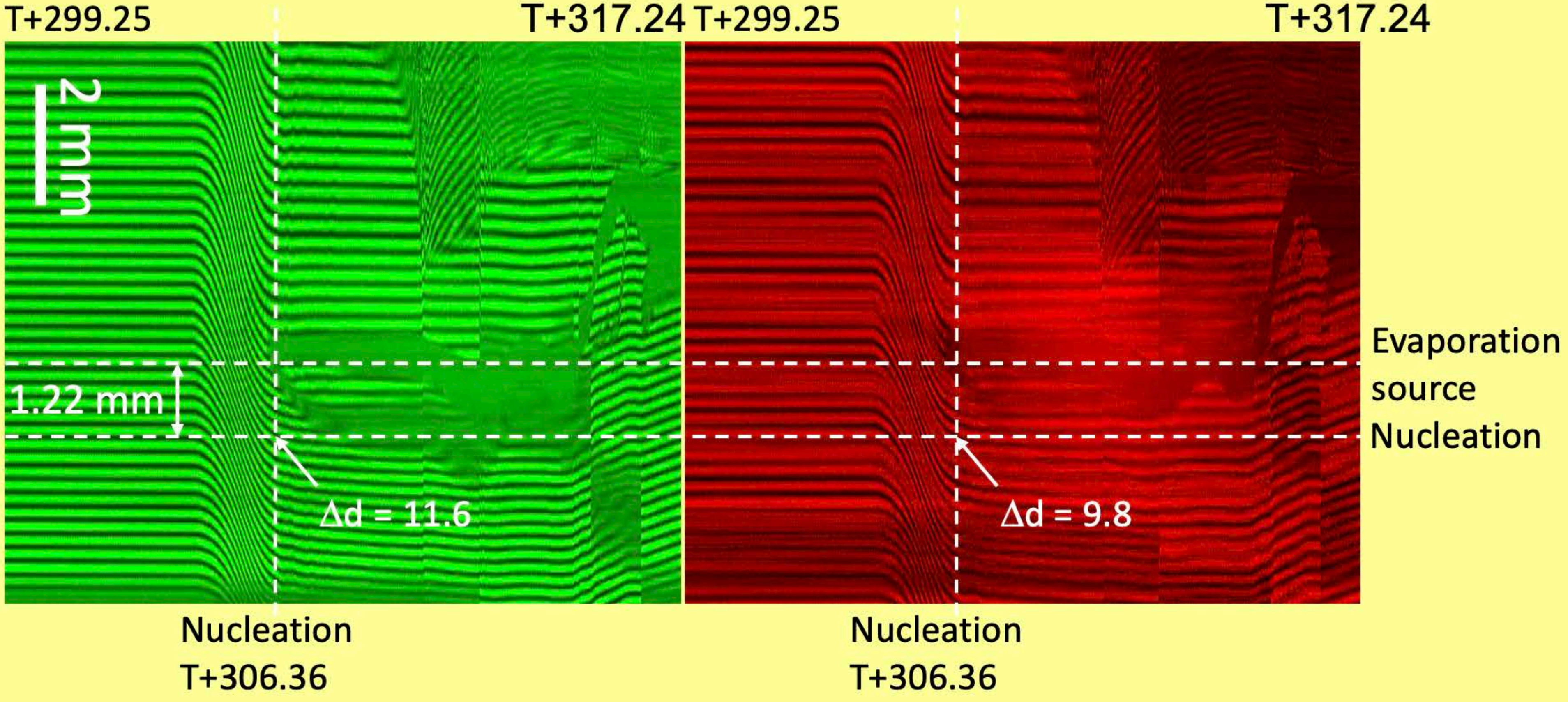


Time series of visual images along the white line (1)

Expanded time series of visual images along the white line in (1) showing dust nucleation

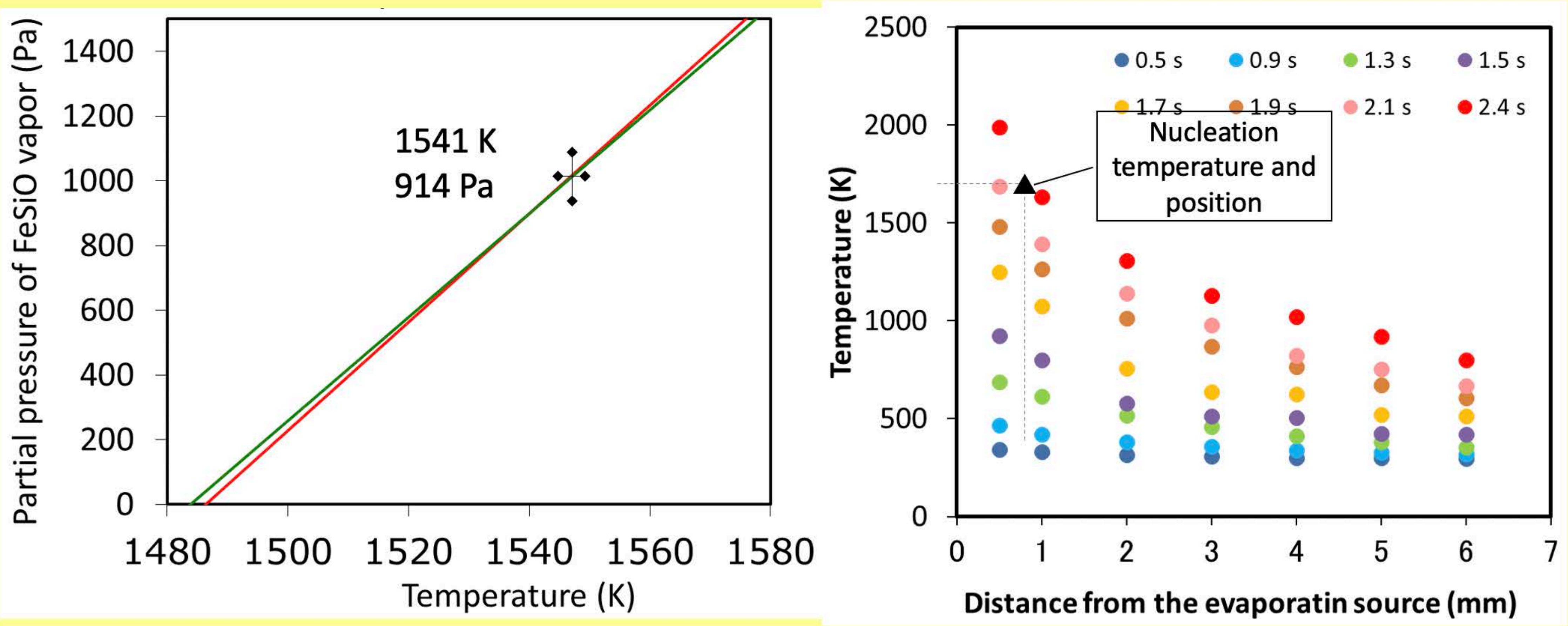


Black Brant IX, 36.343: IFC2 FeSiO Nucleation



Time-series images of the interference fringes. Horizontal and vertical axes correspond to the time and position from the evaporation source, respectively. The horizontal dotted lines show the evaporation source. The vertical broken white lines show the time of nucleation.

Black Brant IX, 36.343: IFC2 FeSiO Nucleation



Nucleation temperature and partial pressure of Fe-SiO vapor (left) and temperature profile around the evaporation source (right) obtained from the deviation of the interference fringes. The temperature profiles from bottom to top correspond to 0.5, 0.9, 1.3, 1.5, 1.7, 1.9, 2.1 and 2.4 s after the start of heating.

Black Brant IX: TEM images of IFC2 FeSiO

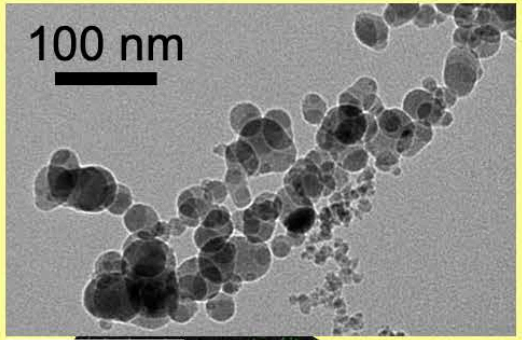
4A

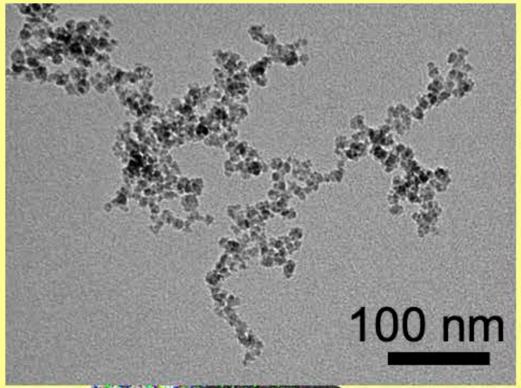
There are two different kinds of particles.

30 – 100 nm: Separation of Fe-silicate from amorphous silica

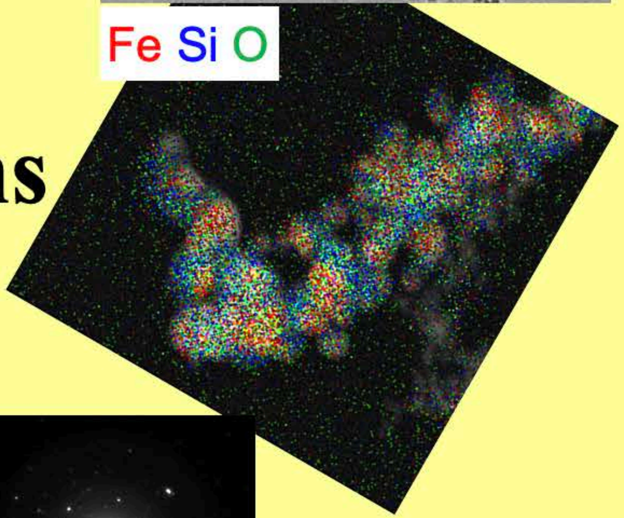
~10 nm: Amorphous iron-silicate

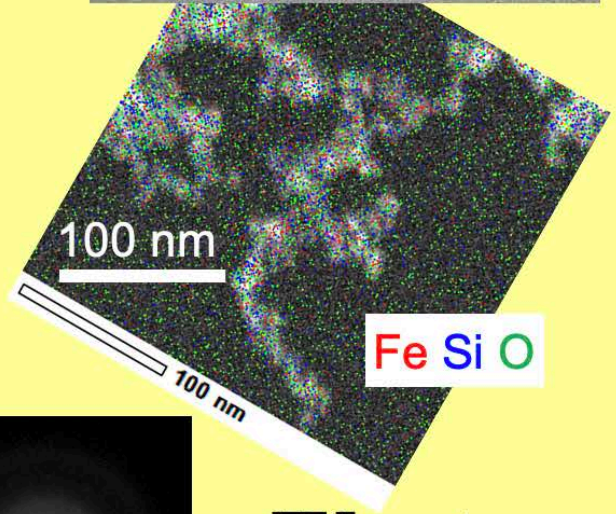
TEM Images





Chemical Compositions

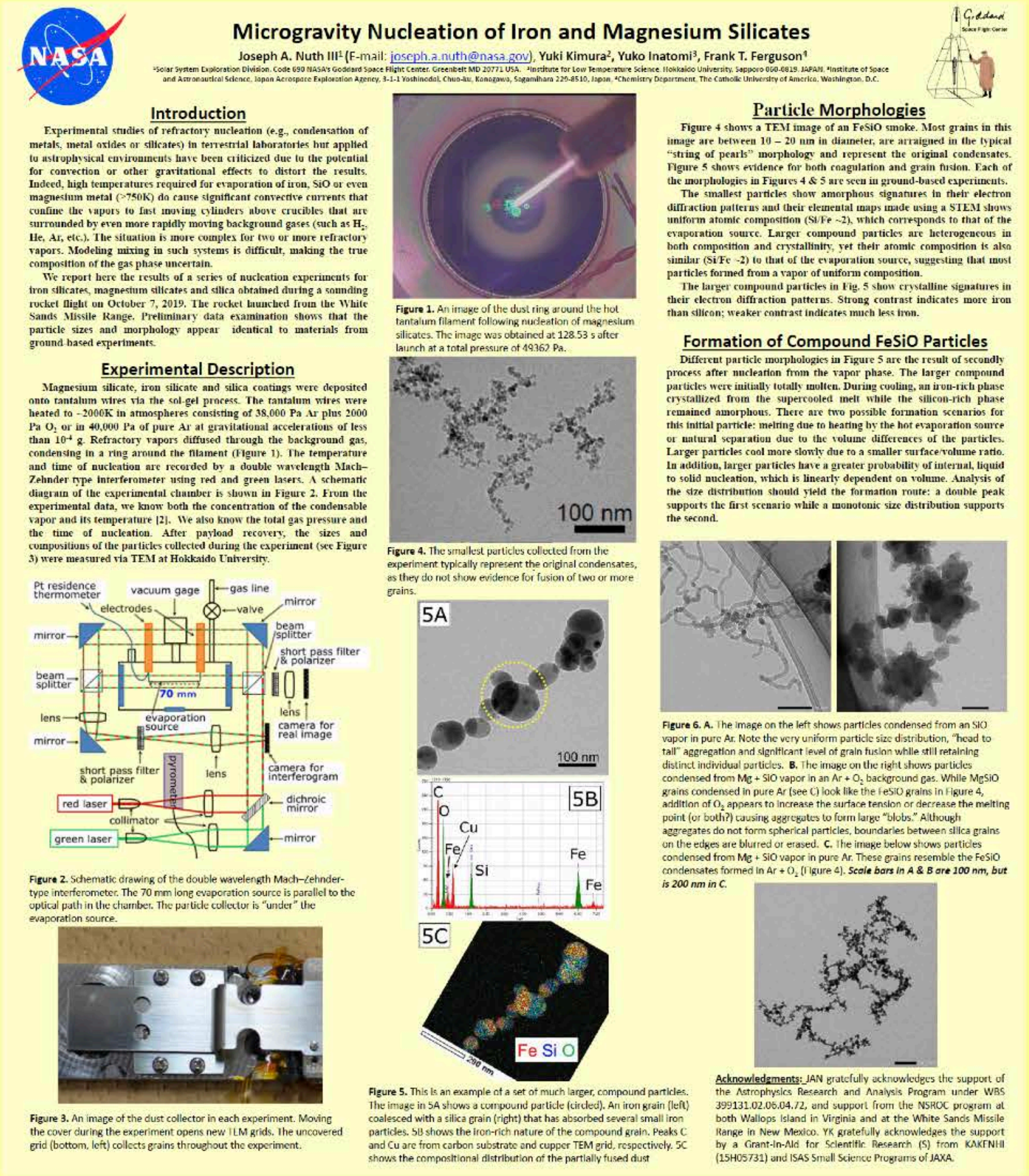




Electron Diffraction Patterns

Analysis of this data has just begun.

- The DUST payload arrived in Hokkaido in late December 2019.
- TEM analysis of particles began January 2020.
- A Science Team meeting in February 2020 resulted in this poster for the LPSC.
- COVID shut down Hokkaido University.
- Upon being allowed back in the laboratory the JAXA team worked to refurbish the payload in order to support launch of DUST II.
- DUST II successfully launched on 7 September 2020, was recovered and was shipped back to JAXA on September 15, 2020.
- Once in Japan, full data analysis will begin.



DEUCE/INFUSE, PI Green

The DEUCE and INFUSE Sounding Rocket Program at the University of Colorado Boulder

Principal Investigator: James Green

This program is funded from April 1, 2019 – March 31, 2023 and is a continuation on decades of UV sounding rocket programs at CU Boulder. This is a separate program from the program led by Dr. Kevin France at CU Boulder.

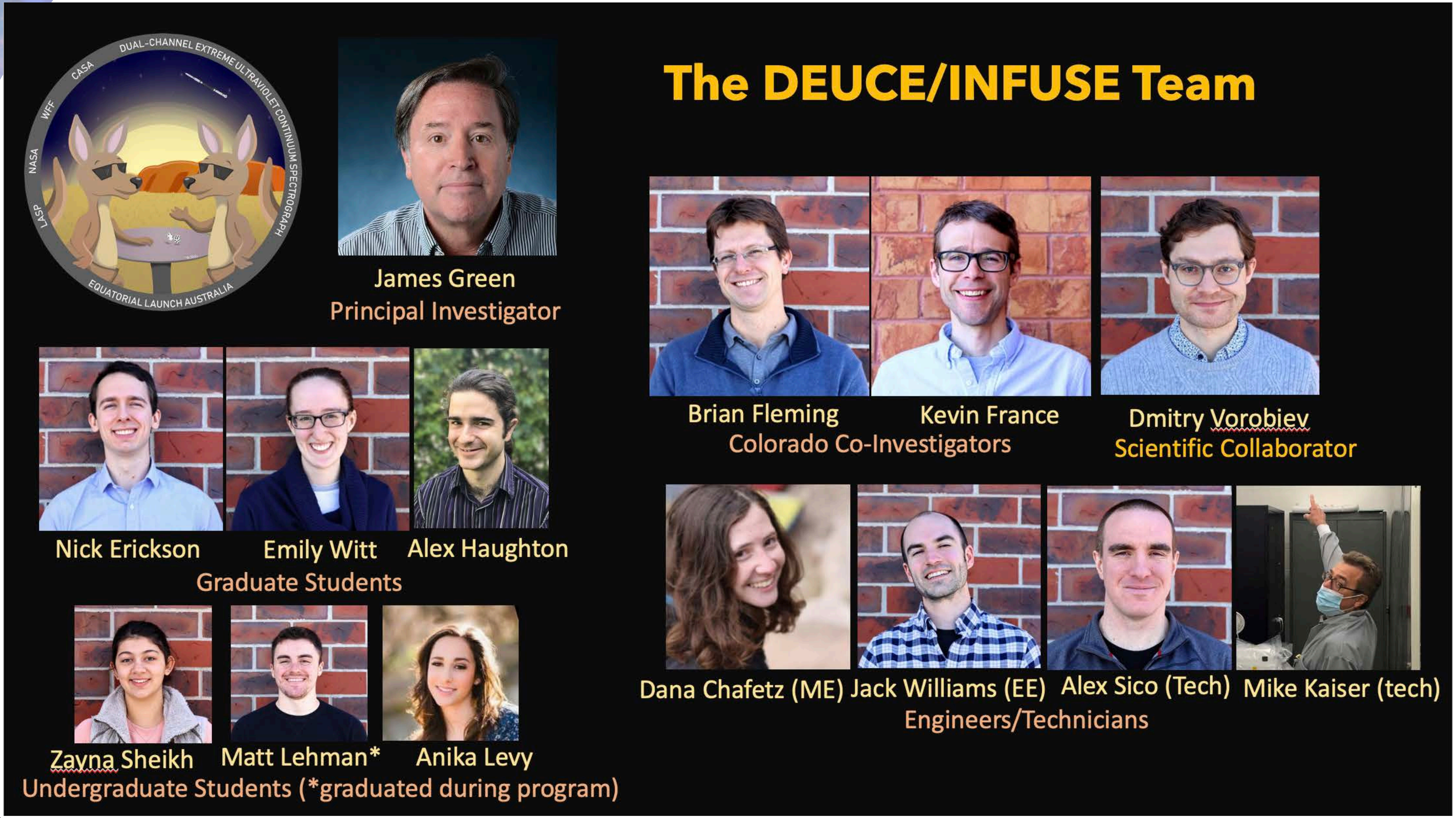
DEUCE and INFUSE

The program has two separate payloads:

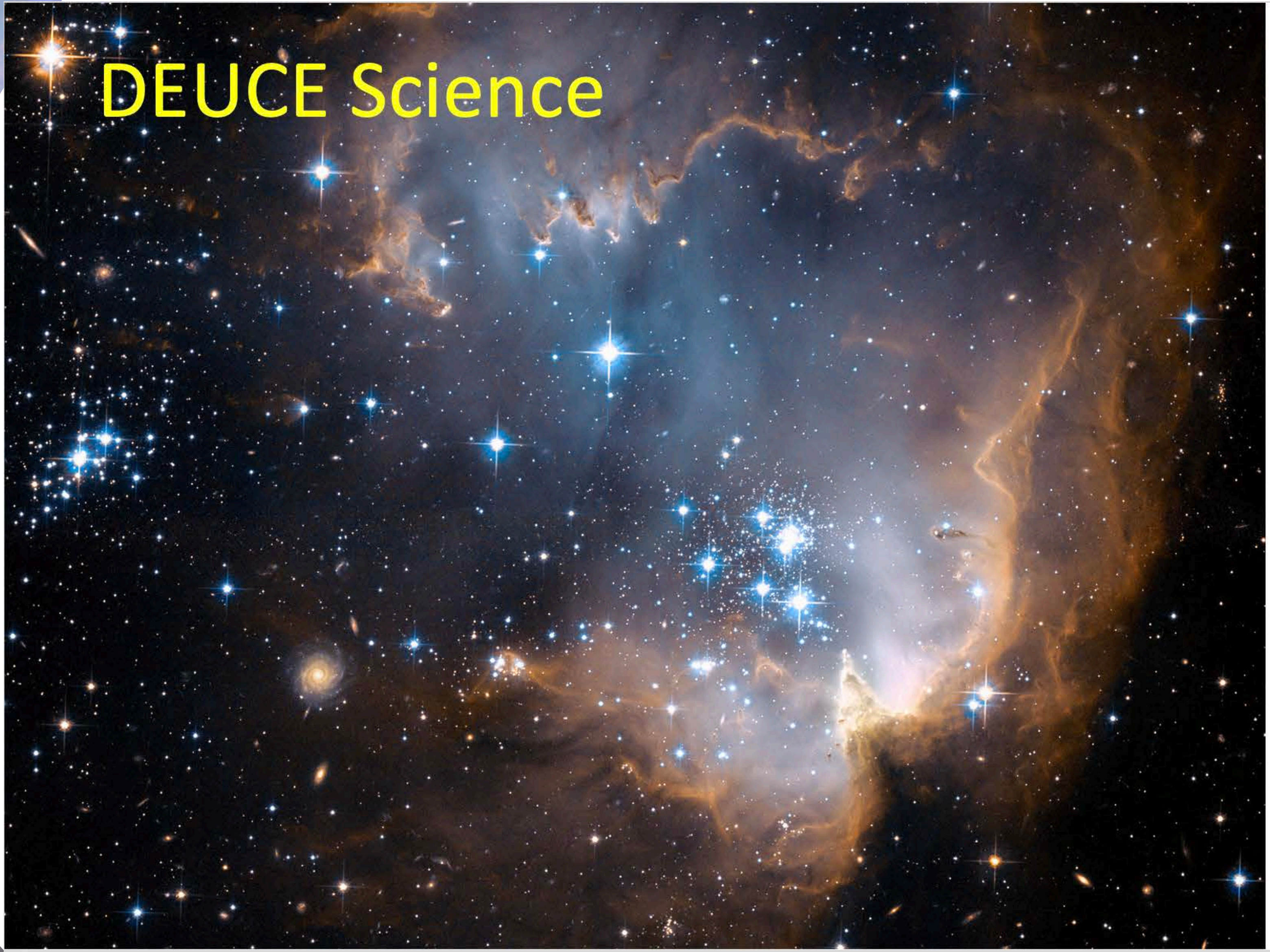
The Dual Channel Extreme Ultraviolet Continuum Payload (DEUCE) and The Integral Field Ultraviolet Spectroscopic Experiment (INFUSE)

DEUCE is complete, has flown twice (in 2017 and 2018) and is scheduled to launch in November 2020 from WSMR and in July 2021 from Australia.

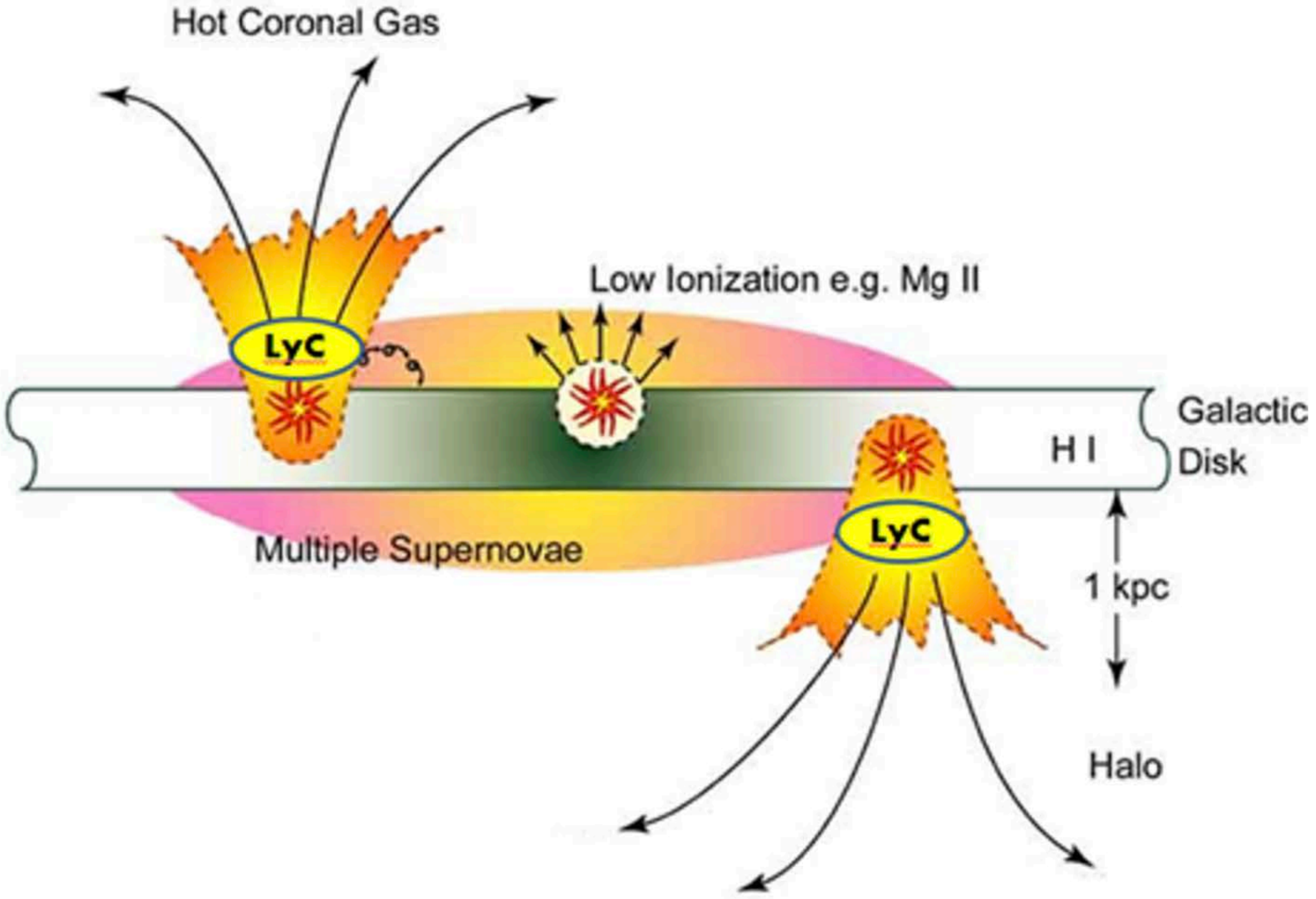
INFUSE is in development with a target launch date of early 2023.


DUAL-CHANNEL EXTREME ULTRAVIOLET CONTINUUM SPECTROGRAPH
CASA
WFF
NASA
LASP
EQUATORIAL LAUNCH AUSTRALIA
The DEUCE/INFUSE Team
James Green
Principal Investigator
Brian Fleming
Kevin France
Colorado Co-Investigators
Dmitry Vorobiev
Scientific Collaborator
Nick Erickson
Emily Witt
Alex Haughton
Graduate Students
Dana Chafetz (ME)
Jack Williams (EE)
Alex Sico (Tech)
Mike Kaiser (tech)
Engineers/Technicians
Zayna Sheikh
Matt Lehman*
Anika Levy
Undergraduate Students (*graduated during program)

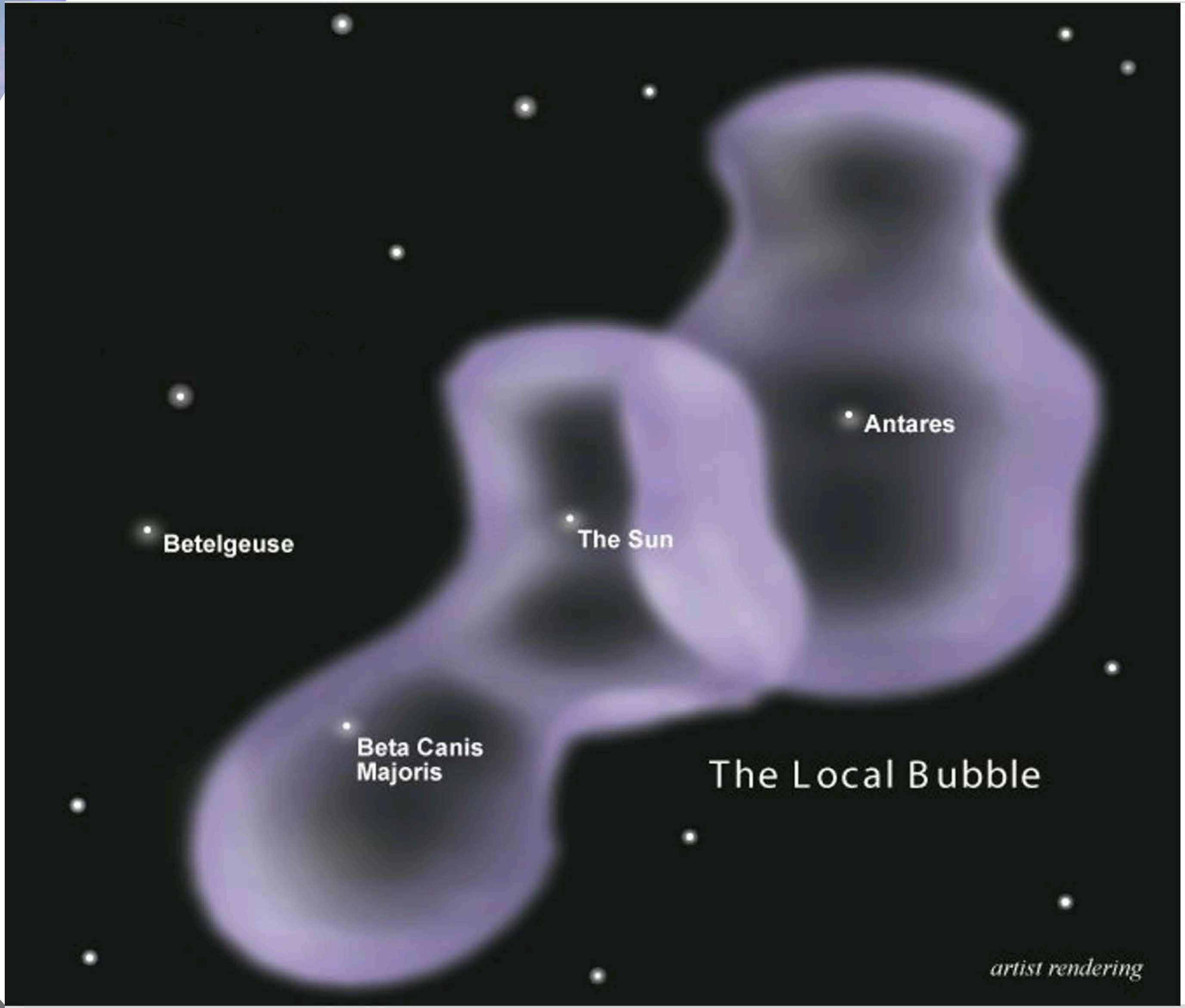
DEUCE Science



Ionizing photons from hot stars must escape from their galaxies in order to ionize hydrogen in the intergalactic medium. Current models assume that only the hottest stars (O stars) can provide the flux needed to maintain the ionization. However, these models also predict that their ionizing radiation will rarely escape from their galaxies.



One possible solution is that longer-lived, but slightly cooler B stars might provide the necessary flux, after the O stars clear a pathway to the intergalactic medium

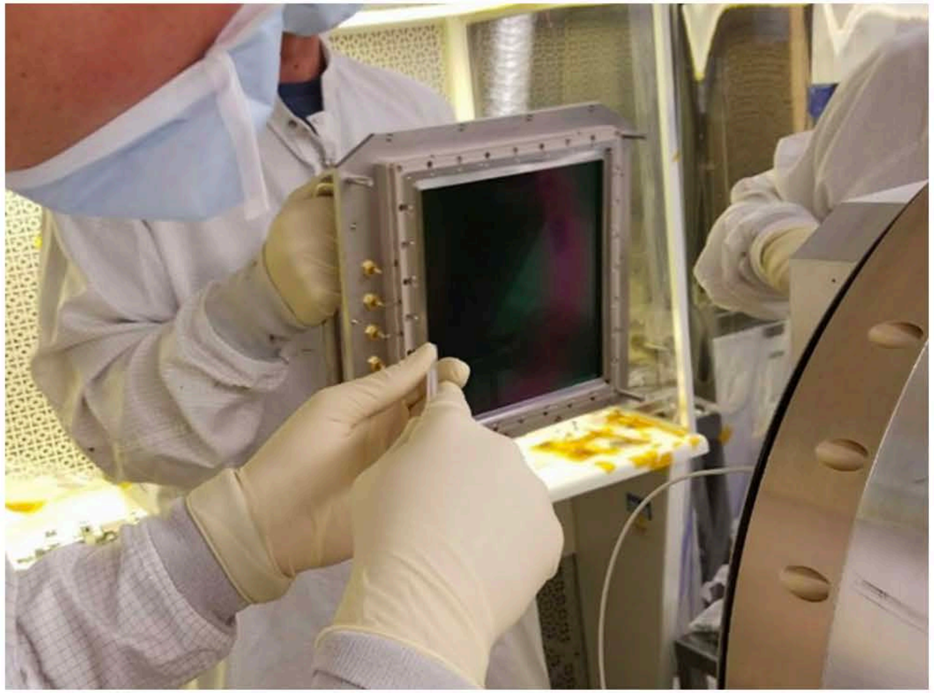


To test this model, we need to observe one or more B stars and measure their ionizing output. However, ionizing radiation is readily absorbed by the interstellar medium of our own galaxy, and there are only 2 B stars (and no O stars) for which this measurement can be made: Epsilon and Beta Canis Majoris

DEUCE Technology Development

DUECE utilizes a novel large format MCP detector (200mm X 200 mm) utilizing ALD (Atomic Layer Deposition) boro-silicate plates. The detector performed as expected on both flights. This is the technology commonly assumed to be incorporated in future UV large missions, e.g. flagship and/or probe.

We are also looking to incorporate an etched silicon diffraction grating for the Australia flight.



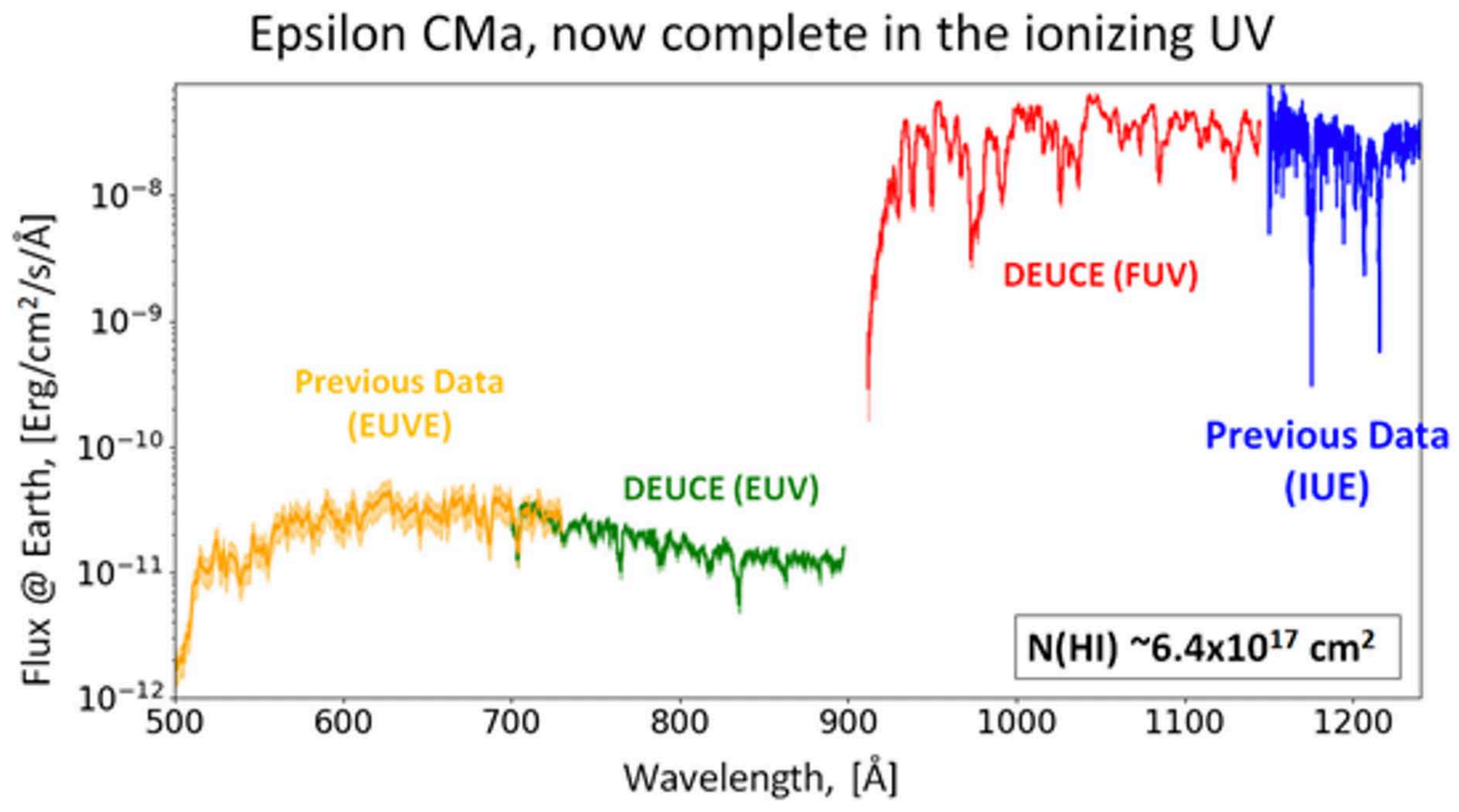
DEUCE Launches

Fall 2017: Mission failure due to failure in attitude control system. Target was not acquired, and no scientific data was obtained.

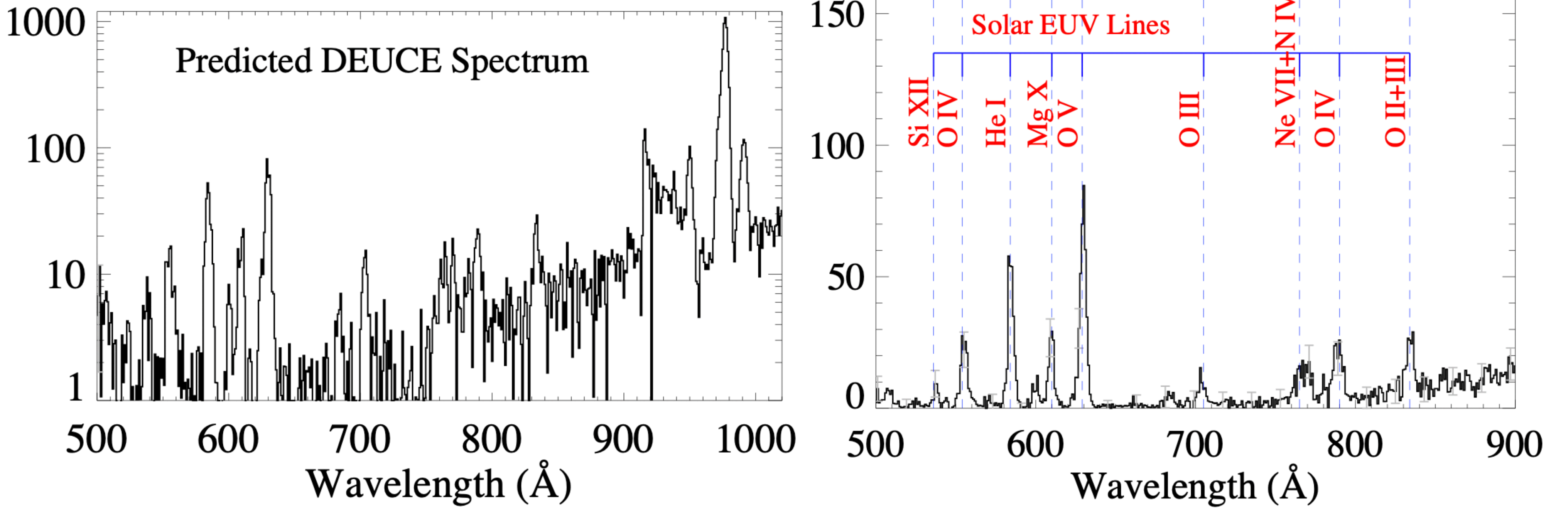
Fall 2018: Mission Success, spectrum of Epsilon CMa obtained. (see next slide)

Fall 2020: Planned observation of Beta CMa.

Summer 2021 (Australia): planned observation of Alpha Centauri to assess the EUV radiation environment of any potential habitable planet in the system.


Epsilon CMa, now complete in the ionizing UV
Flux @ Earth, [Erg/cm²/s/Å]
Wavelength, [Å]
Previous Data (EUVE)
DEUCE (EUV)
DEUCE (FUV)
Previous Data (IUE)
N(HI) ~6.4x10¹⁷ cm²
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
500
600
700
800
900
1000
1100
1200

α Cen A+B, DEUCE simulation

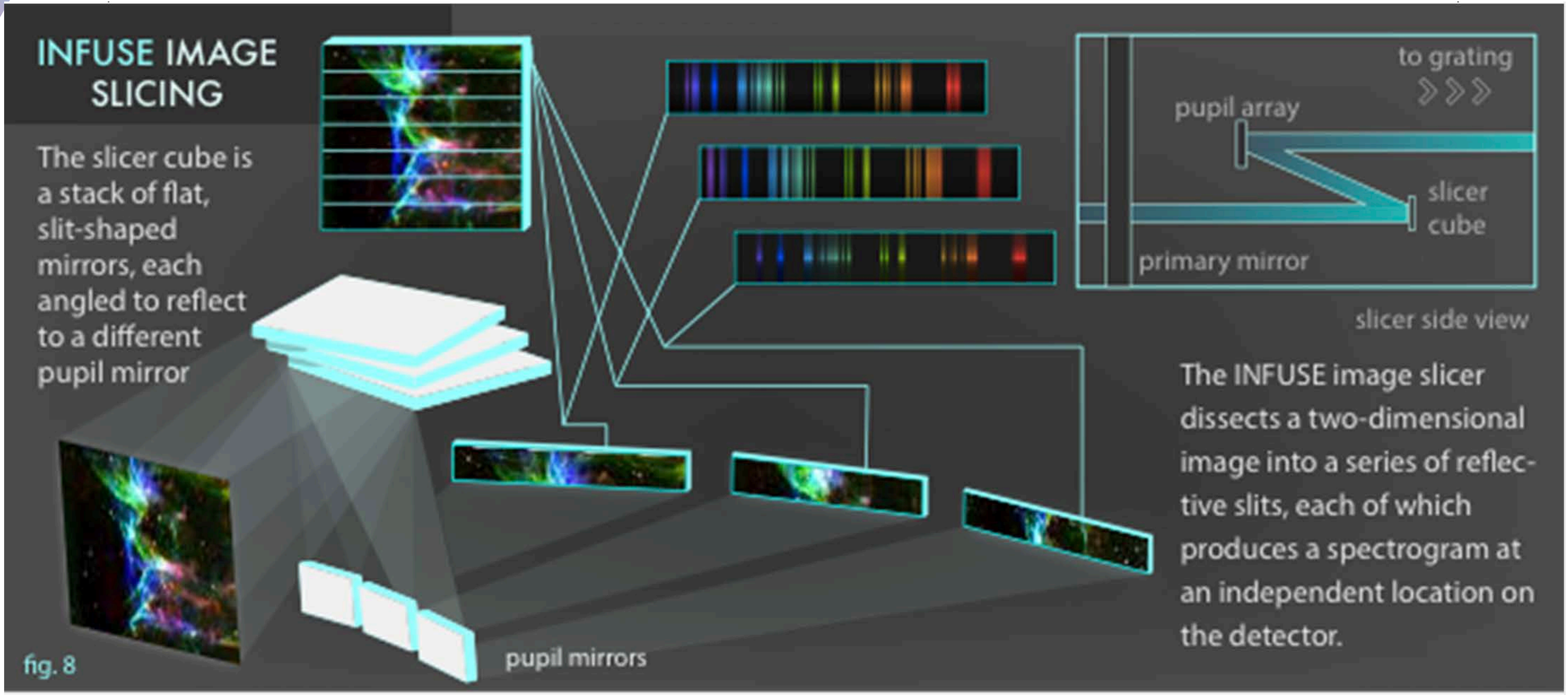


Important Transition and Coronal region lines – important for habitability models!

INFUSE Science and Technology

INFUSE will be the first integral field spectrograph in the vacuum ultraviolet. Such capability is essential to support the science objectives on the next generation of UV missions.

INFUSE will observe the Cygnus loop, a nearby supernova remnant, to study the impact of massive stars on their galactic environments by quantifying the shock-velocity distribution of the remnant. Such a study is infeasible with point source or long slit UV spectroscopy (e.g. COS/STIS)


INFUSE IMAGE SLICING
The slicer cube is a stack of flat, slit-shaped mirrors, each angled to reflect to a different pupil mirror
to grating
pupil array
slicer cube
primary mirror
slicer side view
The INFUSE image slicer dissects a two-dimensional image into a series of reflective slits, each of which produces a spectrogram at an independent location on the detector.
pupil mirrors
fig. 8

CIBER-2, PI Zemcov

The Cosmic Infrared Background Experiment (CIBER-2)

Active Members

Students in **Bold**, Postdocs in *Italic*

RIT

PI Michael Zemcov
Dr. Priya Bangale
Chi Nguyen
Mike Ortiz

California Institute of Technology / JPL — Jet Propulsion Laboratory, California Institute of Technology

Co-I Jamie Bock
Yun-Ting Cheng
Viktor Hristov
Dr. Phil Korngut
Richard Feder-Staehle

UCIrvine — University of California, Irvine

Co-I Asantha Cooray
Derek Wilson-Diaz

Kwansei Gakuin — Mastery for Service

Co-I Shuji Matsuura
Ryo Hashimoto
Arisa Kida
Dr. Kei Sano
Hiroko Suzuki
Koji Takimoto

Tokyo City University

Co-I Kohji Tsumura

Korea Astronomy and Space Science Institute

Co-I Dae Hee Lee
Dr. Won Kee Park

Over the past decade, the CIBER program has produced 6 PhD theses, 4 MS theses, and involved over two dozen undergraduate students.

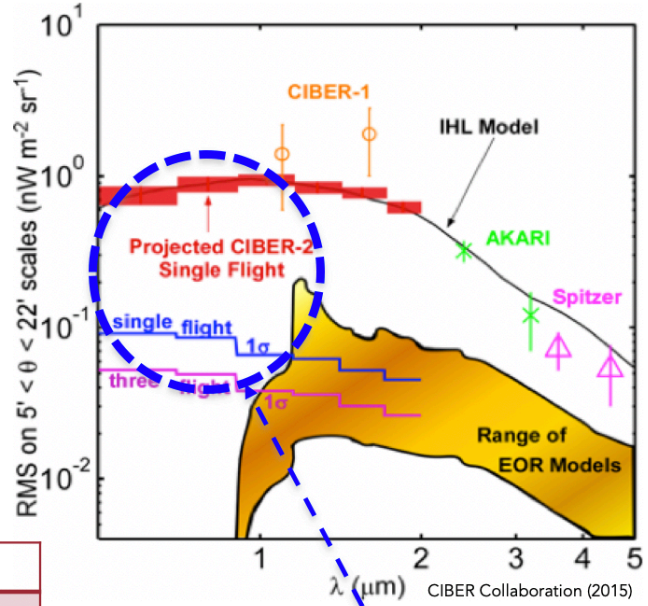
CIBER Science and Instrumentation Papers

CIBER-2	**Published**		
	Nguyen *et al.* 2018, *SPIE*, 10698, 4	Instrument	CIBER-2 Integration Update
	Park *et al.* 2018, *SPIE*, 10698, 49	Instrument	CIBER-2 Warm Electronics & Data Storage
	Shirahata *et al.* 2016, *SPIE*, 9904, 4	Instrument	CIBER-2 Optics
	Lanz *et al.* 2014, *SPIE*, 9143, 3	Instrument	CIBER-2 Design
CIBER-1	**In Preparation**		
	Korngut *et al.*	Scientific	ZL Intensity estimates from Fraunhofer absorption lines.
	Cheng et al.	Scientific	A 4th flight cross-correlation analysis.
	Published		
	Matsuura *et al.* 2017, *ApJ*, 839, 7	Scientific	The EM spectrum of the near-IR EBL from absolute measurements.
	Kim *et al.* 2016, *ApJ*, 153, 84	Scientific	Spectral (0.8-1.6 μm) catalog of bright stars in standard cosmology fields.
	Arai *et al.* 2015, *ApJ* 806, 69	Scientific	First optical to IR spectral measurement of DGL in the diffuse IGM.
	Zemcov *et al.* 2014, *Science* 346, 732	Scientific	The origin of near-IR extragalactic background light anisotropy.
	Korngut *et al.* 2013, *ApJS*, 207, 34	Instrument	Narrow Band Spectrometer design and flight performance.
	Tsumura *et al.* 2013, *ApJS*, 207, 33	Instrument	Low Resolution Spectrometer design and flight performance.
	Bock *et al.* 2013, *ApJS*, 207, 32	Instrument	Imager design and flight performance.
	Zemcov *et al.* 2013, *ApJS*, 207, 31	Instrument	Payload design and flight performance.
	Lee *et al.* 2010, *JASS*, 27, 401	Instrument	CIBER detector properties.
	Tsumura *et al.* 2010, *ApJ*, 719, 394	Scientific	First detection of 0.9 μm silicate absorption in the ZL spectrum.
	Zemcov *et al.* 2010, *SPIE*, 7735, 1	Instrument	First flight performance.
	Lee *et al.* 2007, *PKAS*, 22, 169	Instrument	CIBER instrument calibration.
	Bock *et al.* 2006, *NAR*, 50, 215	Instrument	CIBER experiment description paper.
	Cooray *et al.* 2004, *ApJ*, 606, 611	Scientific	First star signature in infrared EBL anisotropy, science concept paper.

Also many presentations and posters at various conferences, workshops, etc.

CIBER-2 Science

- Fluctuations in the near-IR background measured at 1.1 and 1.6 μm are unexpectedly bright (Zemcov et al 2014).
- This signal is strongly correlated with *Spitzer*-IRAC measurements.
- These measurements call for some new, significant component of the cosmic near-IR energy budget.
- *But what do the fluctuations do at shorter wavelengths?*



CIBER-2 improves on CIBER-1 with 6 bands and ~5x greater AΩ to maximizes sensitivity to angular scales of interest.

Aperture	**28.5**						**cm**
Pixel Size	4						arcsec
FOV	1.61°x2.2° for imager bands, 0.4° for LVF						degrees
Array	3x 2048^2 H2RG						
λ	600	800	1030	1280	1550	1850	μm
νI_ν (sky)	525	450	400	380	320	224	nW m^{-2} sr^{-1}
$\delta \nu I_\nu$ (1σ/pix)	38	45	34	31	25	23	nW m^{-2} sr^{-1}
δF_ν (3σ)	21.5	21.1	21.0	21.0	21.0	20.9	Vega mag

Coverage into the optical is critical to separate IHL from early galaxies.

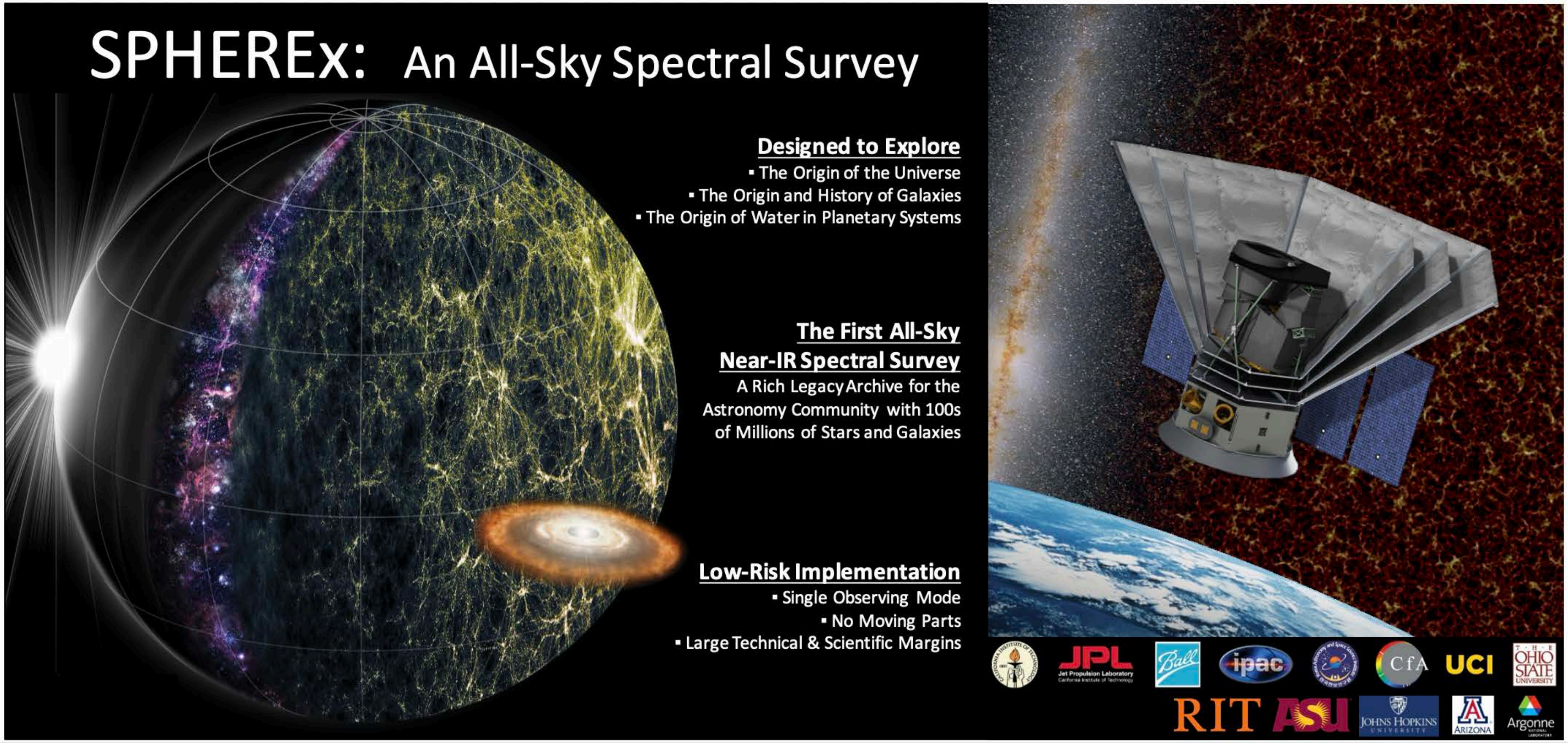
CIBER-2 Recent History and Schedule

Task	Location	Schedule
Experiment System Integration	Caltech	01/2019 - 05/2019
Payload Integration	WFF	06/2019 - 07/2019
Institutional Handoff	Caltech → RIT	08/2019
Pre-flight Calibration and Test	RIT	09/2019 -12/2019
Flight Qualification (Passed)	WFF	01/2020 - 02/2020
Flight Deployment	WSMR	03/2020 - 04/2020
Currently Scheduled Launch	WSMR	04:10 MST 2/15/2021

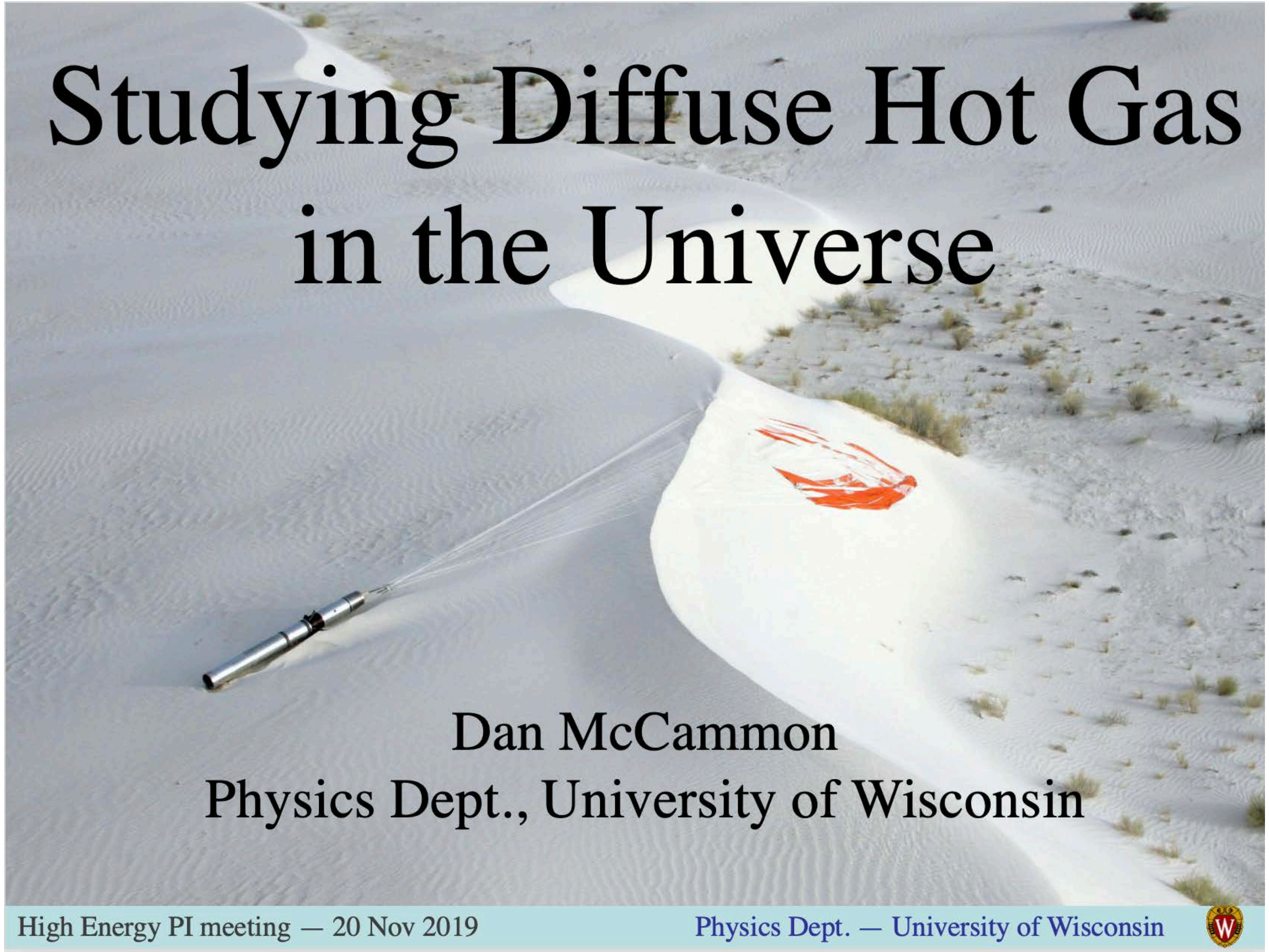
Cancelled Due to Pandemic

We plan for ~4 flights of CIBER-2 over the next 5 years.

CIBER Informs the Development of SPHEREx



XQC, PI McCammon


Studying Diffuse Hot Gas in the Universe
Dan McCammon
Physics Dept., University of Wisconsin
High Energy PI meeting — 20 Nov 2019
Physics Dept. — University of Wisconsin

<u>Most</u> of the normal matter in the Universe is at temperatures $T \geq 10^6$ K

➔it (mostly) only shows up in X-rays

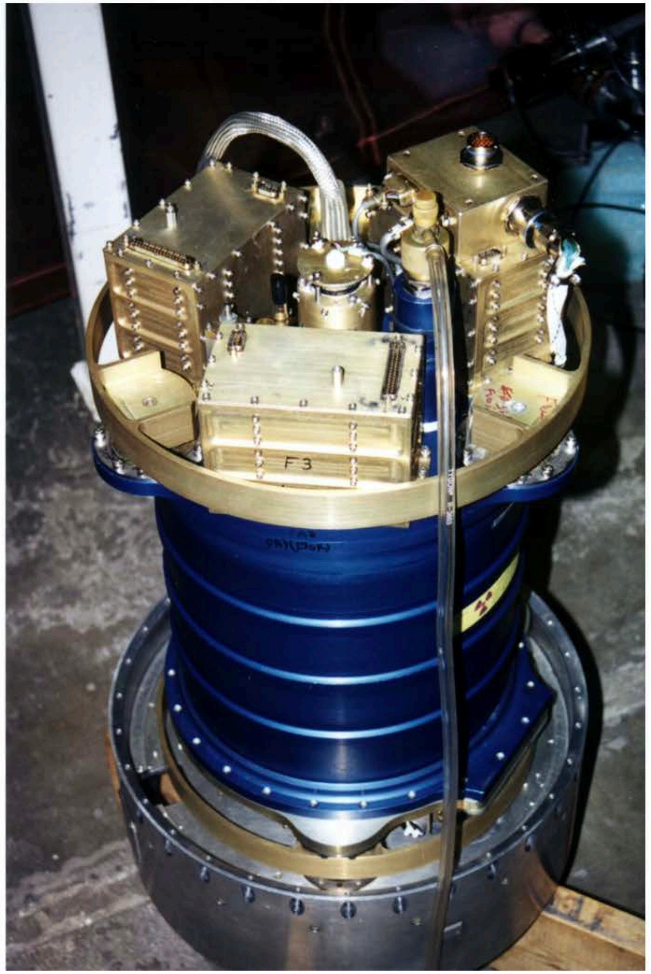
ISM – CGM – IGM

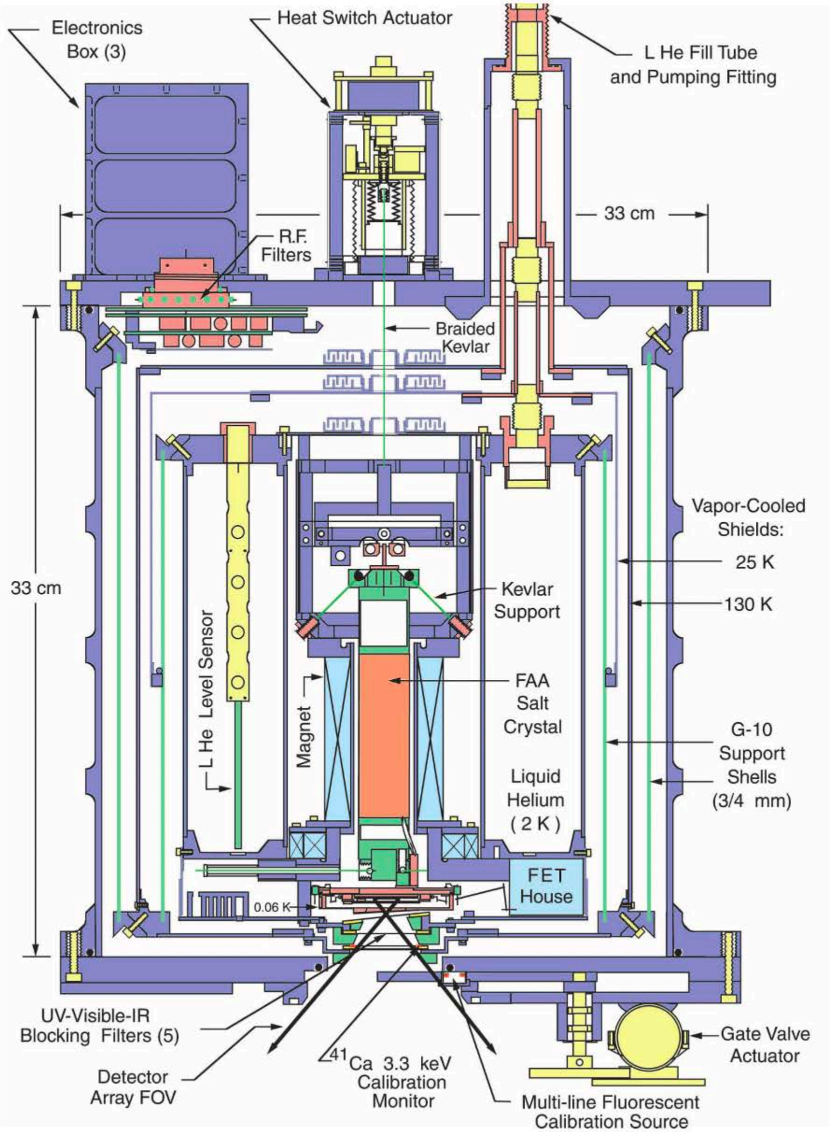
Bad: Cools very slowly, so faint and hard to observe.

Good: At most common temperatures, emission is all in lines — lots of plasma diagnostics.

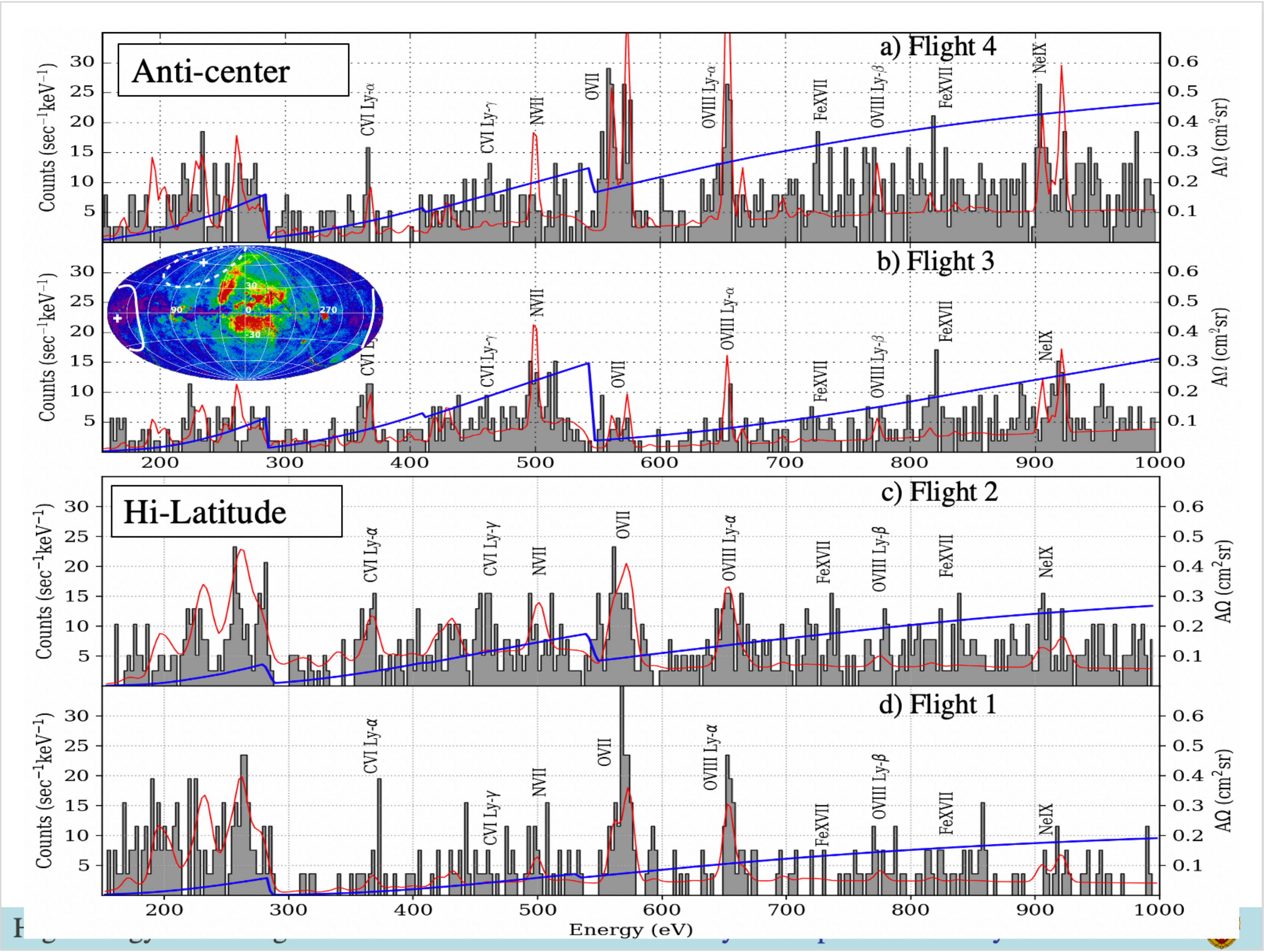
Problem: Extended source can't use gratings for emission spectroscopy. Need high resolution detectors.

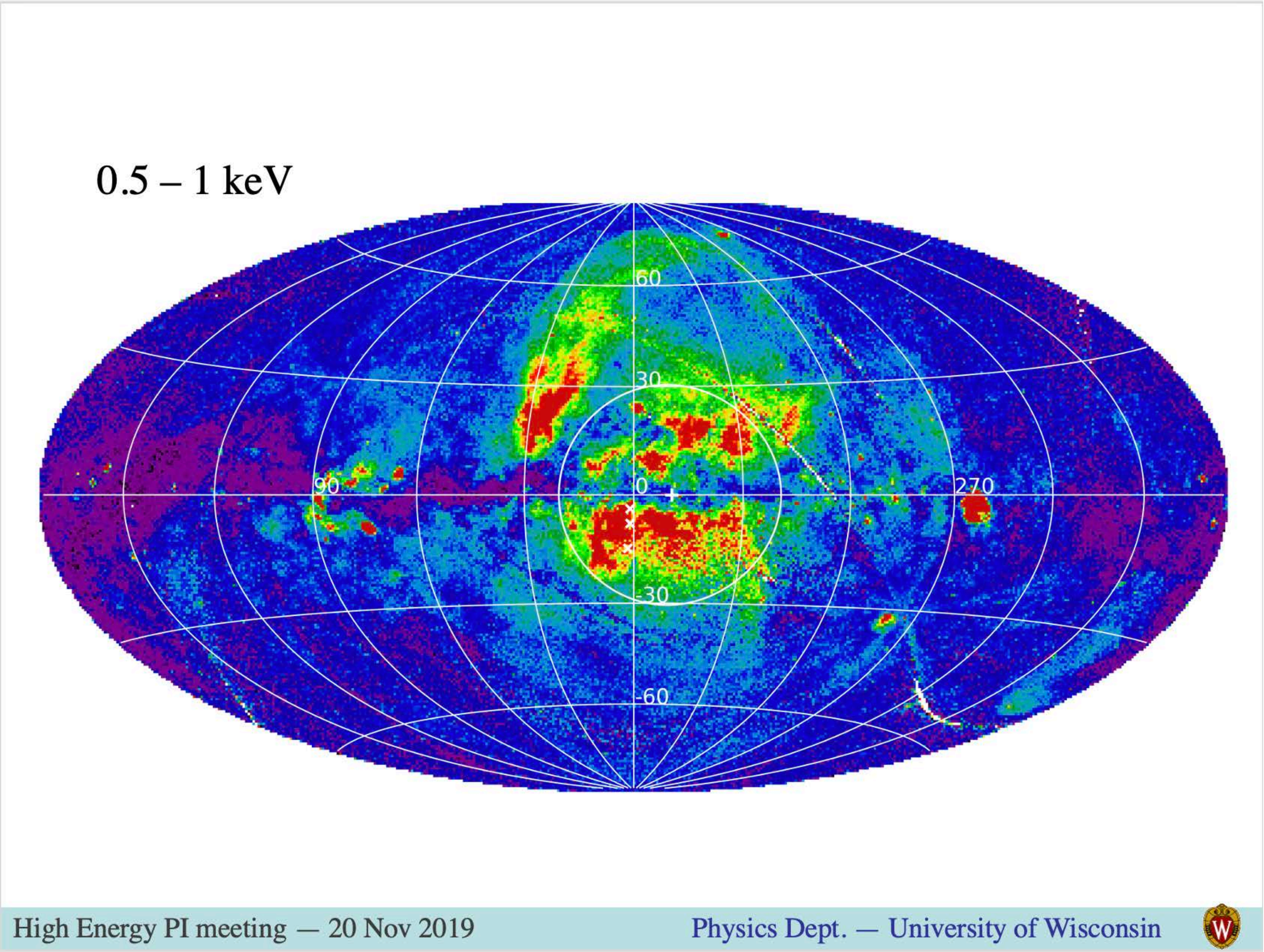
Microcalorimeters to the rescue!



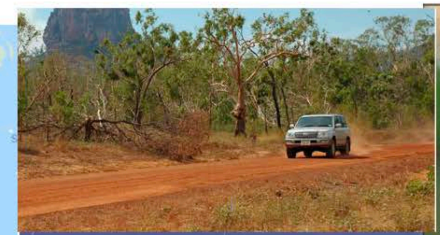


Need 50 mK temperatures


Anti-center
Hi-Latitude
a) Flight 4
b) Flight 3
c) Flight 2
d) Flight 1
Counts (sec⁻¹keV⁻¹)
AΩ (cm²sr)
Energy (eV)
CVI Ly-α
CVI Ly-γ
NVII
OVII
OVIII Ly-α
FeXVII
OVIII Ly-β
NeIX
200
300
400
500
600
700
800
900
1000

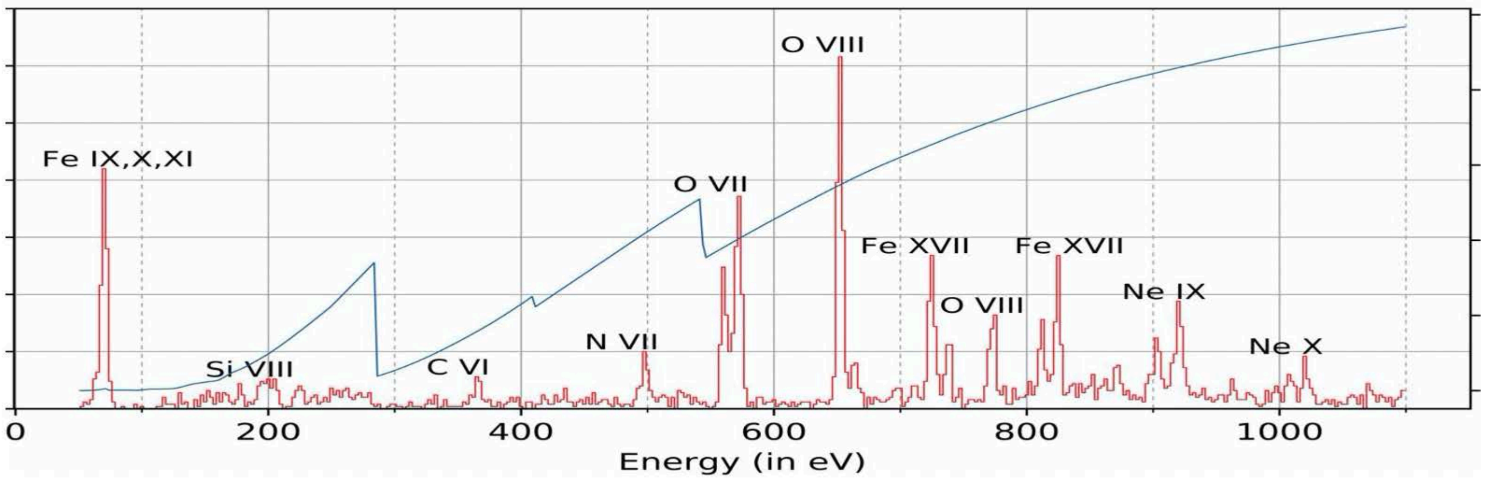

0.5 – 1 keV
60
30
0
90
270
-30
-60
High Energy PI meeting — 20 Nov 2019
Physics Dept. — University of Wisconsin


Papua New Guinea
Arafura Sea
Timor Sea
SUNDA ISLANDS
NORTHERN TERRITORY
QUEENSLAND
WESTERN AUSTRALIA
Australia
SOUTH AUSTRALIA
Perth
Brisbane
NEW SOUTH WALES
Great Australian Bight
Adelaide
Newcastle
Sydney
ACT
VICTORIA
Melbourne




GOODAY MATE
WELCOME TO AUSTRALIA


E137°30'
S12°30'


O VIII
Fe IX,X,XI
O VII
Fe XVII
Fe XVII
O VIII
Ne IX
Si VIII
C VI
N VII
Ne X
0
200
400
600
800
1000
Energy (in eV)

WRXR, tREXS, OGRE, PI McEntaffer

The McEntaffer Group (early 2020)

Acknowledgements

- Collaborators:
  - Pennsylvania State University
    - Ted Schultz, James Tutt, Fabien Grise, Jake McCoy, Drew Miles, Ben Donovan, Ningxiao Zhang, Ross McCurdy; Dave Burrows, Abe Falcone, Mitch Wages, Sam Hull, Evan Bray, Tanmoy Chattopadhyay, the Nanofabrication Lab of the Materials Research Institute
  - NASA Goddard Space Flight Center
    - Will Zhang, Ryan McClelland, Kai-Wing Chan, Timo Saha, Raul Riveros, Michael Biskach
  - Czech Technical University
    - Ladislav Pina, Adolf Inneman, Vladimir Daniel, Tomas Baca
  - The Open University
    - Andrew Holland, Matthew Soman, Matthew Lewis
  - University of Iowa – Casey DeRoo
  - University of Colorado, Boulder – Kevin France, Brian Fleming, Nick Kruczek
  - Johns Hopkins University – Stephan McCandliss
  - Southwest Research Institute – Matt Beasley
  - XCAM – Karen Holland
  - Dynamic Imaging Analytics – Neil Murray
  - NASA Sounding Rocket Program Office and Orbital contract – NSROC
- Funding:
  - NASA grants: 80NSSC18K0282, NNX17AD87G, NNX17AD19G, NNX17AF98G, NNX12AF23G, NNX17AC88G

Water Recovery X-ray (WRX) Rocket

<u>A Technology Development payload (launched 4/4/18)</u>

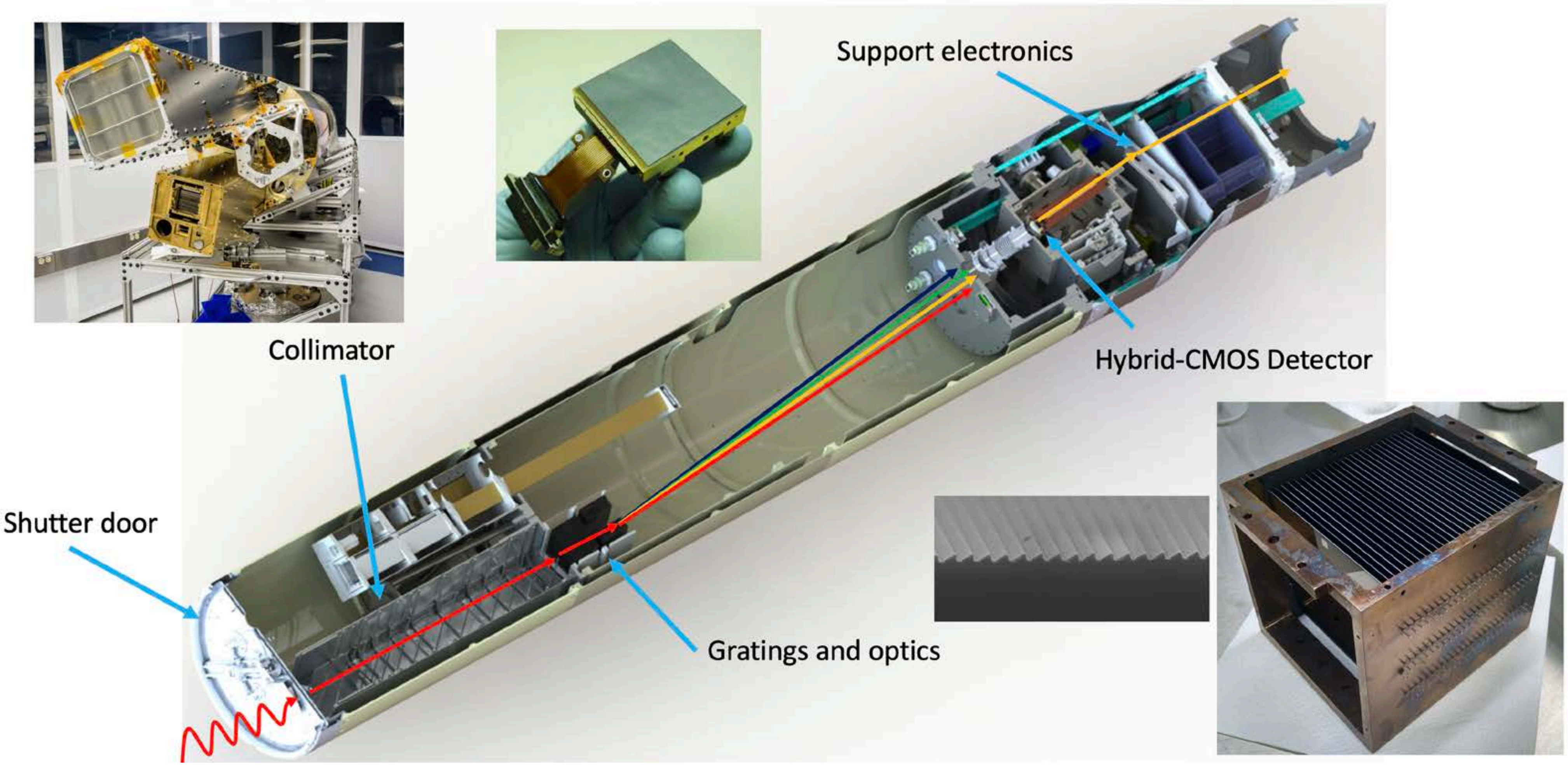
- First use of an X-ray hybrid CMOS detector*, similar to those proposed for Lynx
- First flight of aligned array of large-format, low-profile, high-performance X-ray reflection gratings* produced via nanofabrication
- Designed to test water-recovery tech for upcoming OGRE mission
- First recovered payload at Kwajalein Missile Range
- First astronomical payload at Kwaj (9.4° N Lat)
- First sealed NASA payload section
- Detected astrophysical X-rays, although at low significance

*Both critical NASA technologies co-funded by SAT/APRA

The WRXR team

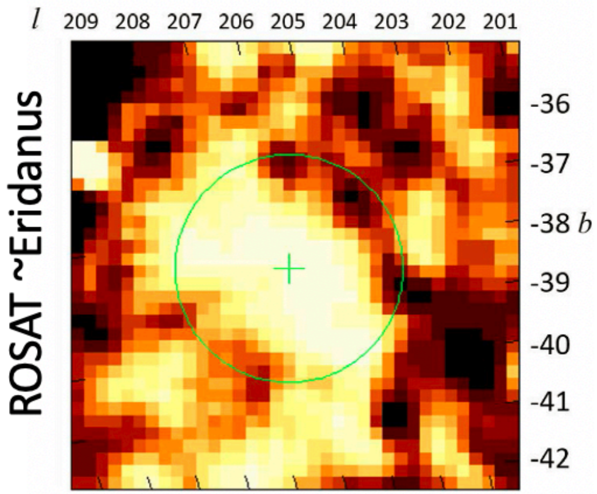
- Main payload team
  - Dr. Randall L. McEntaffer (PI), Dr. James Tutt (Asst. Research Prof.), Mr. Ted Schultz (Lead Engineer), Mr. Drew Miles (Lead Grad Student), Mr. Benjamin Donovan (Junior Grad Student), Mr. Christopher Hillman (Undergrad Asst.), Bailey Myers (Undergrad Asst.), Mr. Daniel Yastishock (Undergrad. Eng.)
- Nanofabrication team
  - Dr. Chad Eichfeld (Nanofab Lab Director), Dr. Fabien Grisé (Group Nanofab Lead), Mr. Jake McCoy (Grad Student), Ningxiao Zhang (Grad Student)
- WRXR HCD team
  - Dr. Abe Falcone (Detector Lead), Dr. David Burrows (Detector Co-Lead), Dr. Tyler Anderson (Electrical Engineer), Dr. Tanmoy Chattopadhyay (Postdoc), Mr. Mitchell Wages (Research Tech.), Mr. Samuel Hull (Grad Student Detector Lead), Mr. Evan Bray (Junior Grad Student), Ms. Maria McQuaide (Undergrad Engineer)
- Publications
  - Miles, D. M., et al., “Water Recovery X-ray Rocket grating spectrometer,” JATIS, 5(4), 044006, 2019.
  - Wages, M., et al., “Flight camera package design, calibration, and performance for the Water Recovery X-ray Rocket mission,” Proc. SPIE, 11118, 111180D, 2019.
  - Tutt, J. H., McEntaffer, R. L., Miles, D. M., Donovan, B. D., & Hillman, C., “Grating Alignment for the Water Recovery X-ray Rocket (WRXR),” Journal of Astronomical Instrumentation, 8(3), 1950009, 2019.

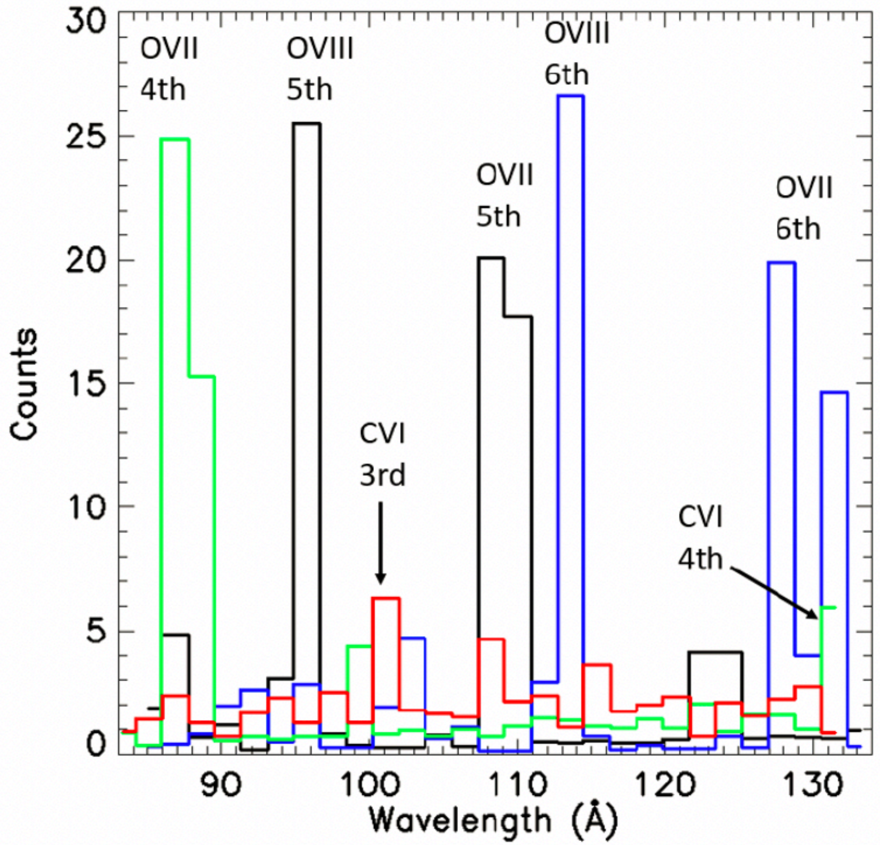
Science payload – Water Recovery X-ray Rocket (WRX)



the Rocket for Extended X-ray Spectroscopy (tREXS)

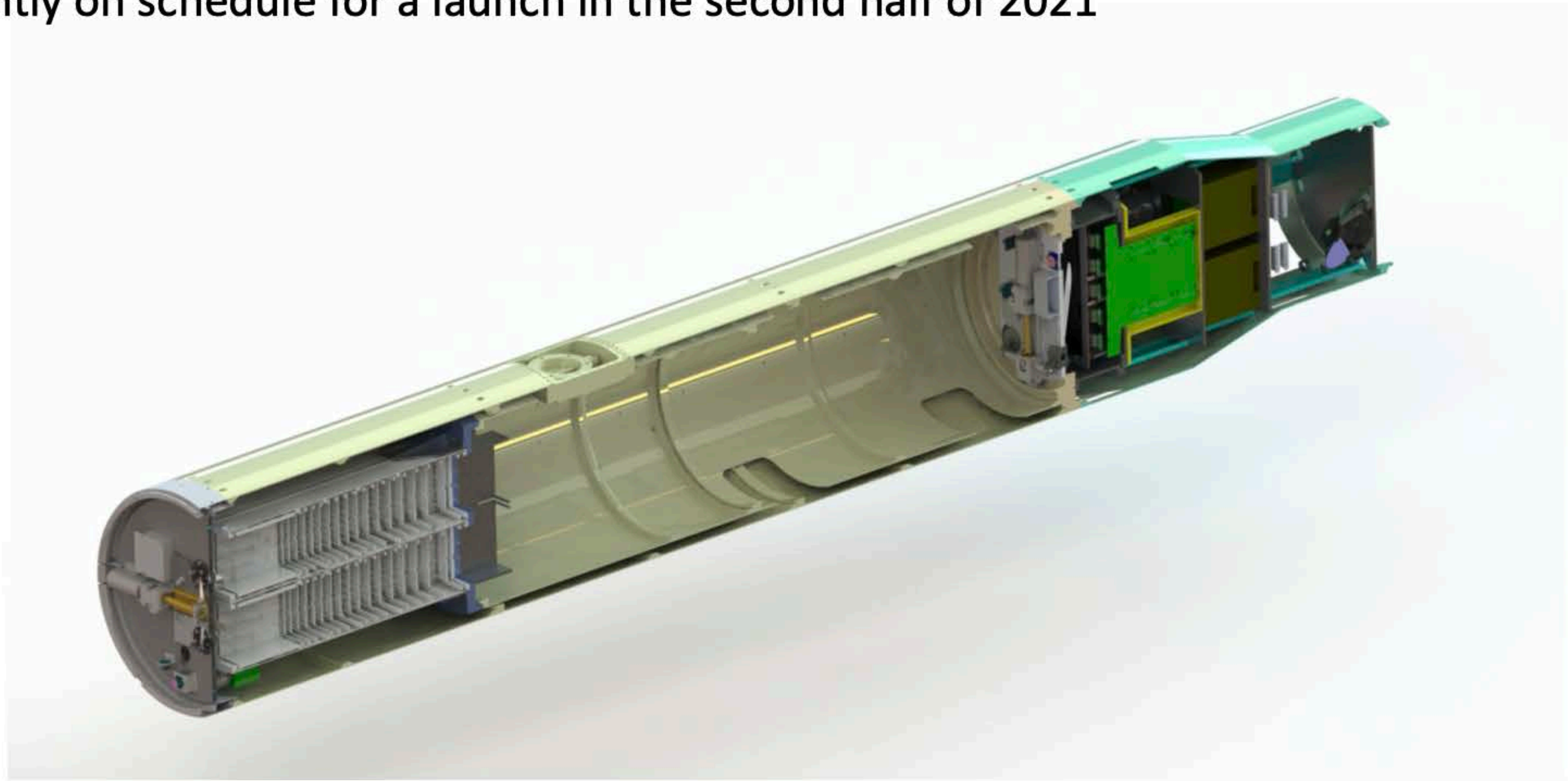
- Launch Q3/Q4 2021 from WSMR
- Spectrally resolve the soft X-ray background
  - High galactic latitude enhancements
  - Draco (REXS-1) and Eridanus (REXS-2)
  - Drive toward resolving OVII triplet
    - Line-sensitive not broadband
  - Do trends in the soft x-ray background hold true at smaller spatial scales with good spectral resolution?
    - Spatial confusion abounds…





tREXS status

- tREXS has passed the Requirements Definition Meeting and is approaching Design Review
- Currently on schedule for a launch in the second half of 2021



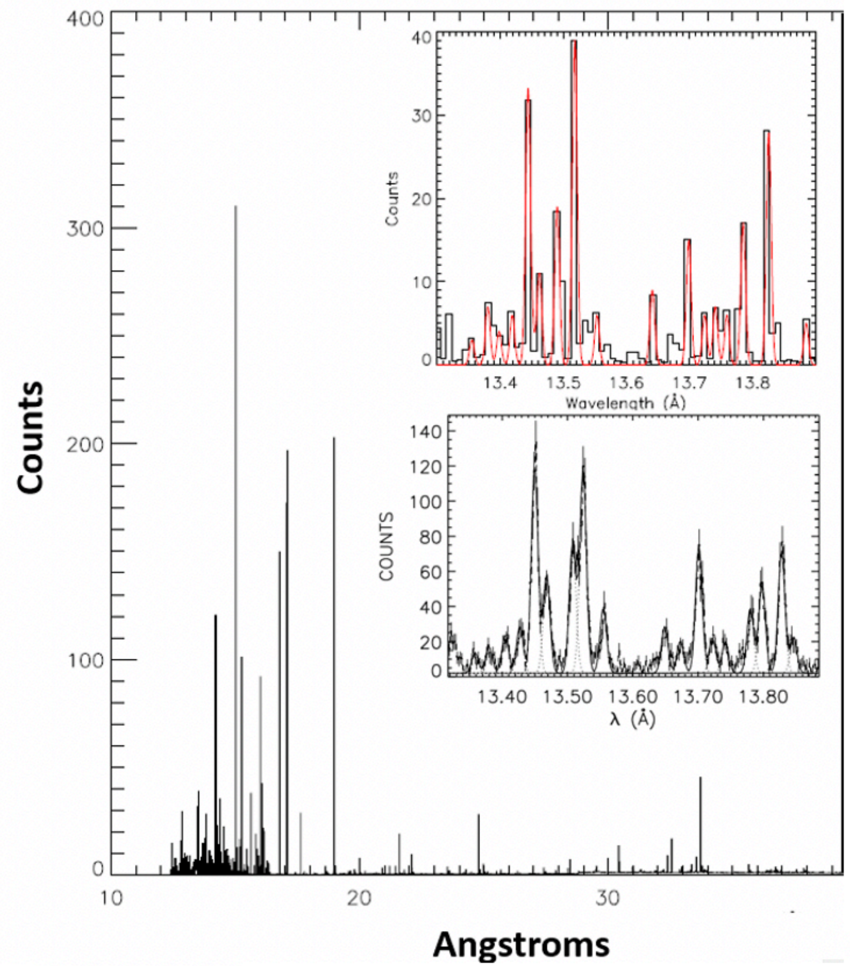
Off-plane Grating Rocket Experiment (OGRE)

Launch window opens in Nov 2022 from Poker Flats Research Range

Science Goals:

- High resolution spectrum of Capella (G8 III and G1 III giant star binary)
- Line emission dominated by Fe XVII, Fe XVIII, and OVIII

- R > 2000, 8-42 Å; peaks at R ~ 3000
- A_{eff} > 20 cm^2, 8-42 Å; >75 cm^2, 9.5-26 Å
- F = 3.5 m



Simulated OGRE observation of Capella. Inset: bottom – Chandra observation of Capella; top – OGRE observation of the same energy range showing less line blending and tighter diagnostic constraints.

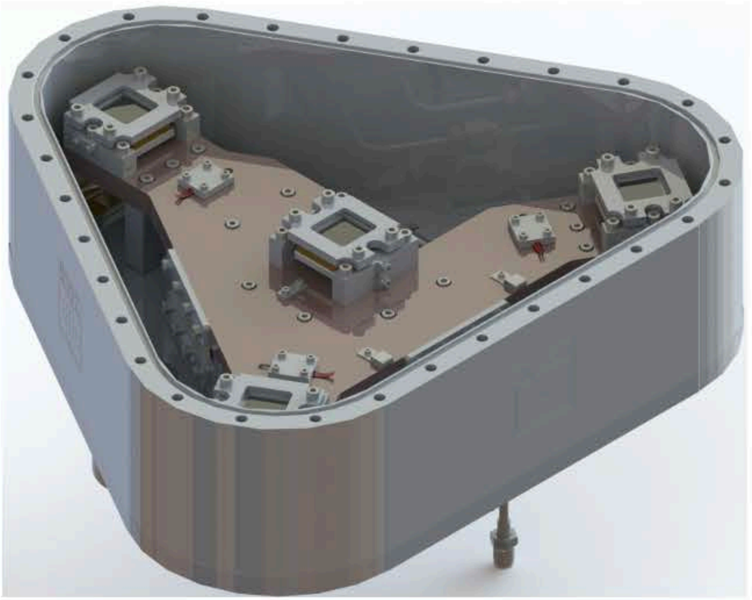
OGRE Technology Development

- OGRE is a mini-Lynx: polished Si optics + high-performance reflection gratings + EMCCDs for high resolution grating spectroscopy

Si mirrors from GSFC

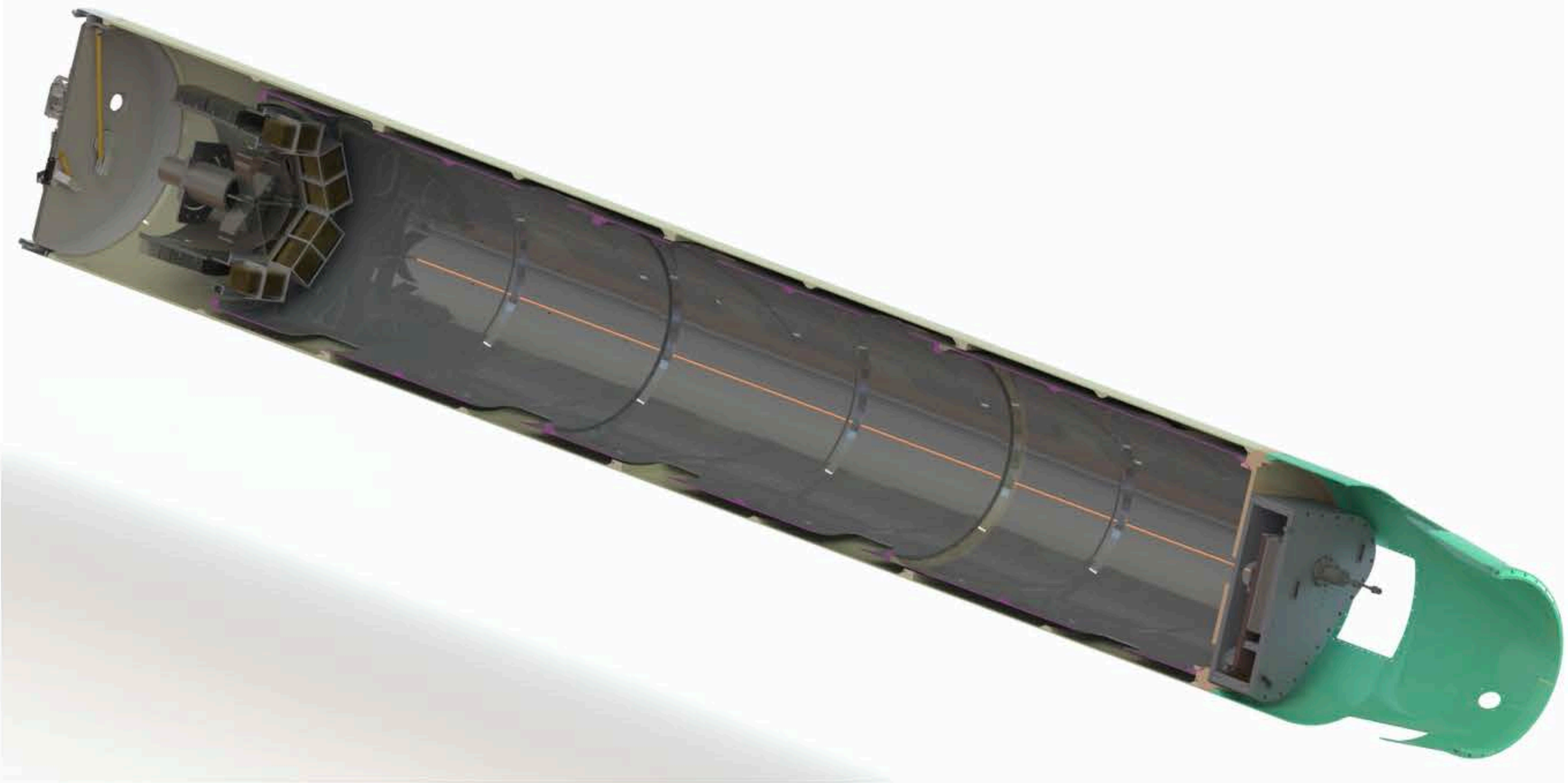
Grating modules from PSU

EMCCD camera from XCAM/OU (UK)



OGRE status

- OGRE mirrors and gratings currently undergoing fabrication
  - Initial mirrors and gratings have tested within OGRE specs
- Design currently concentrating on grating to optic interface and alignment
- Flight camera in production with delivery early next year



McEntaffer group rocket publications

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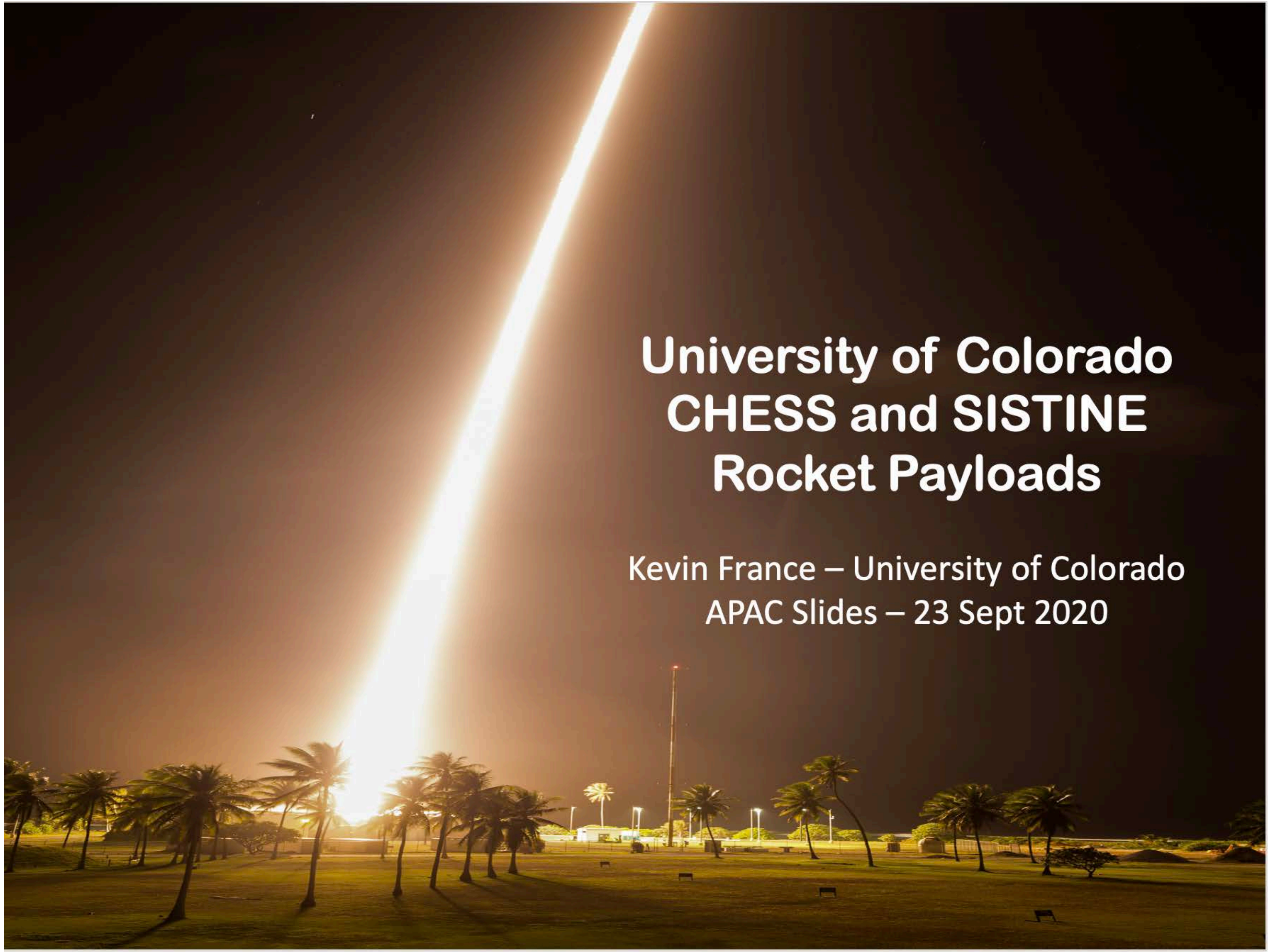
CHESS, SISTINE, PI France


University of Colorado
CHESS and SISTINE
Rocket Payloads
Kevin France – University of Colorado
APAC Slides – 23 Sept 2020

CHESS and SISTINE Rocket Payloads

- **High-resolution spectroscopy of the local interstellar medium (CHESS)**
- **High-energy radiation environments in exoplanet habitable zones (SISTINE)**

- **Hardware Development**:

1. UV/visible optical coatings
2. UV Detectors
3. Diffraction Grating Technology

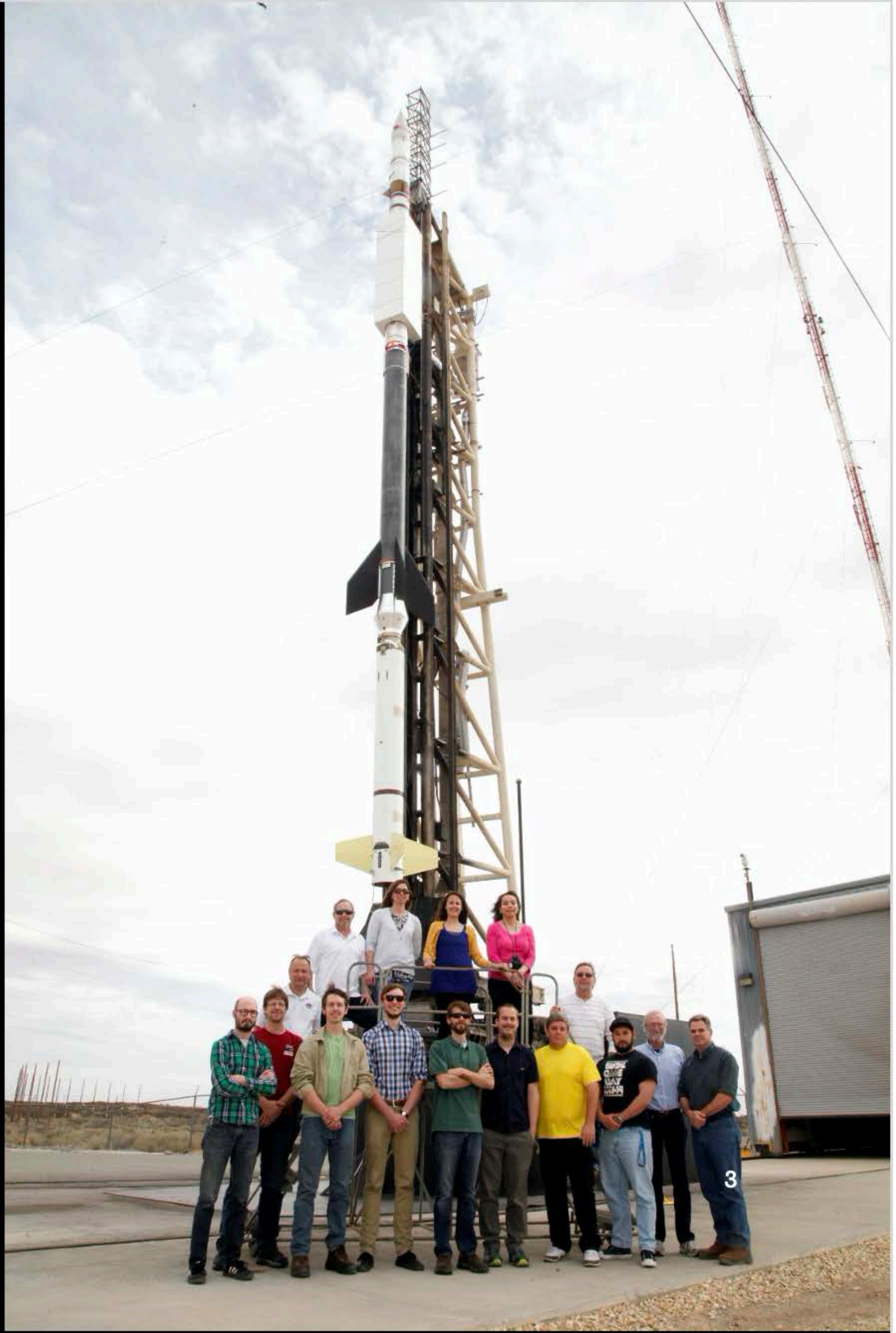
- **Student, postdoctoral, and PI Training**

PI – K. France

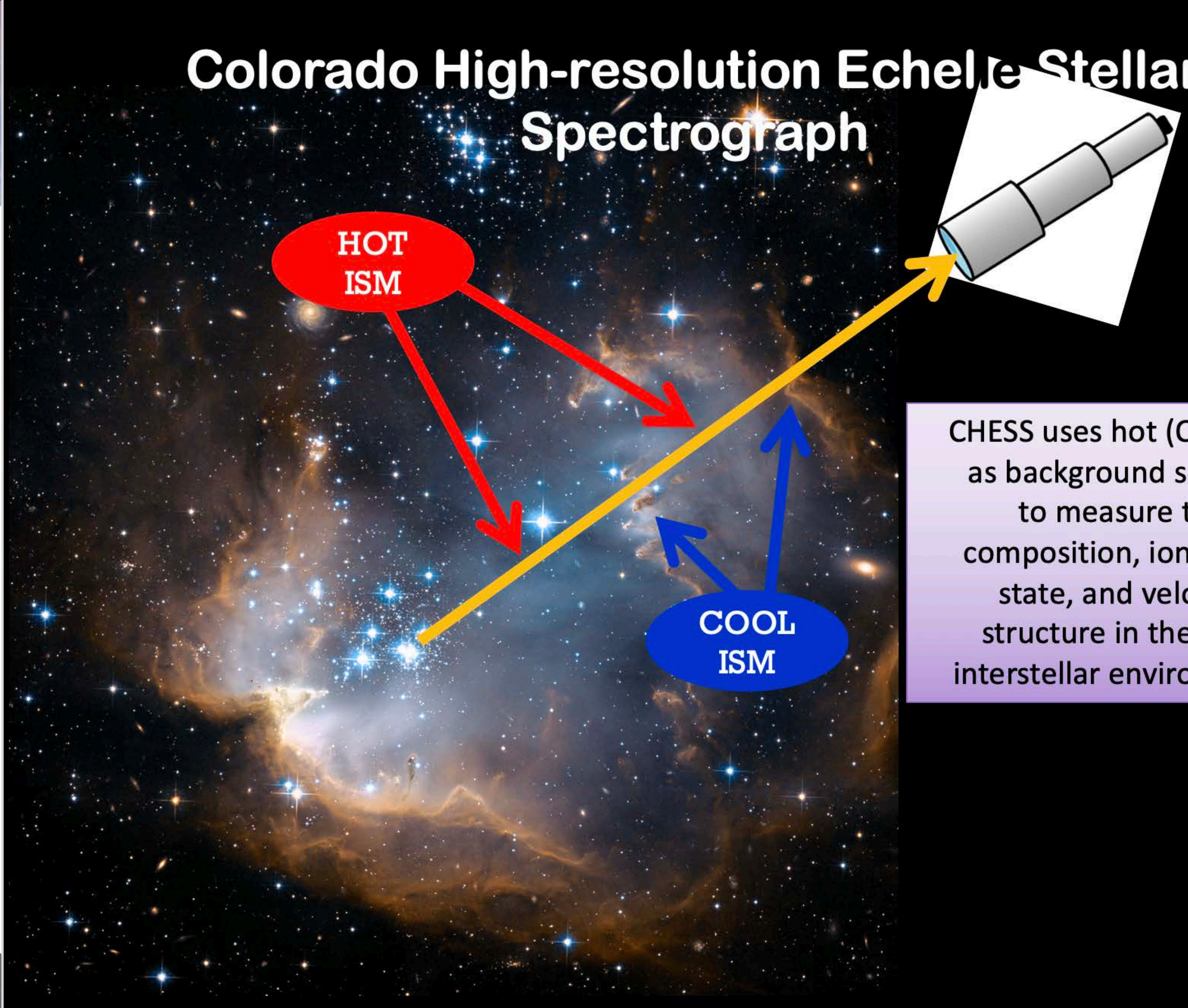
2

The CHESS Payload
36.285, 36.297, 36.323, 36.333

Colorado High-resolution Echelle Stellar Spectrograph
CHESS
CASA NASA WFF WSMR



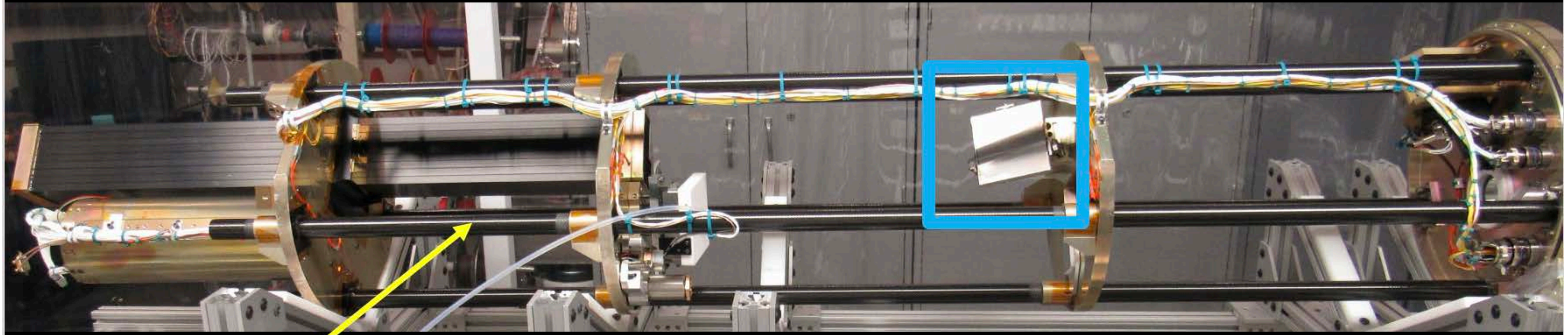
Colorado High-resolution Echelle Stellar Spectrograph



CHESS uses hot (OB) stars as background sources to measure the composition, ionization state, and velocity structure in the local interstellar environment.

CHESS Technology Development: UV Gratings

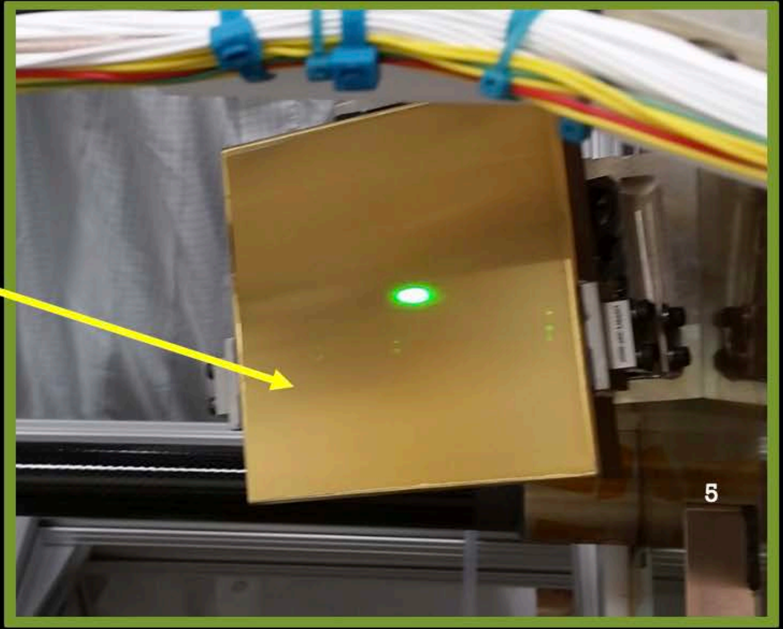
Hoadley et al. 2014, 2016, 2020
France et al. 2016
Kruczek et al. 2017, 2018, 2019

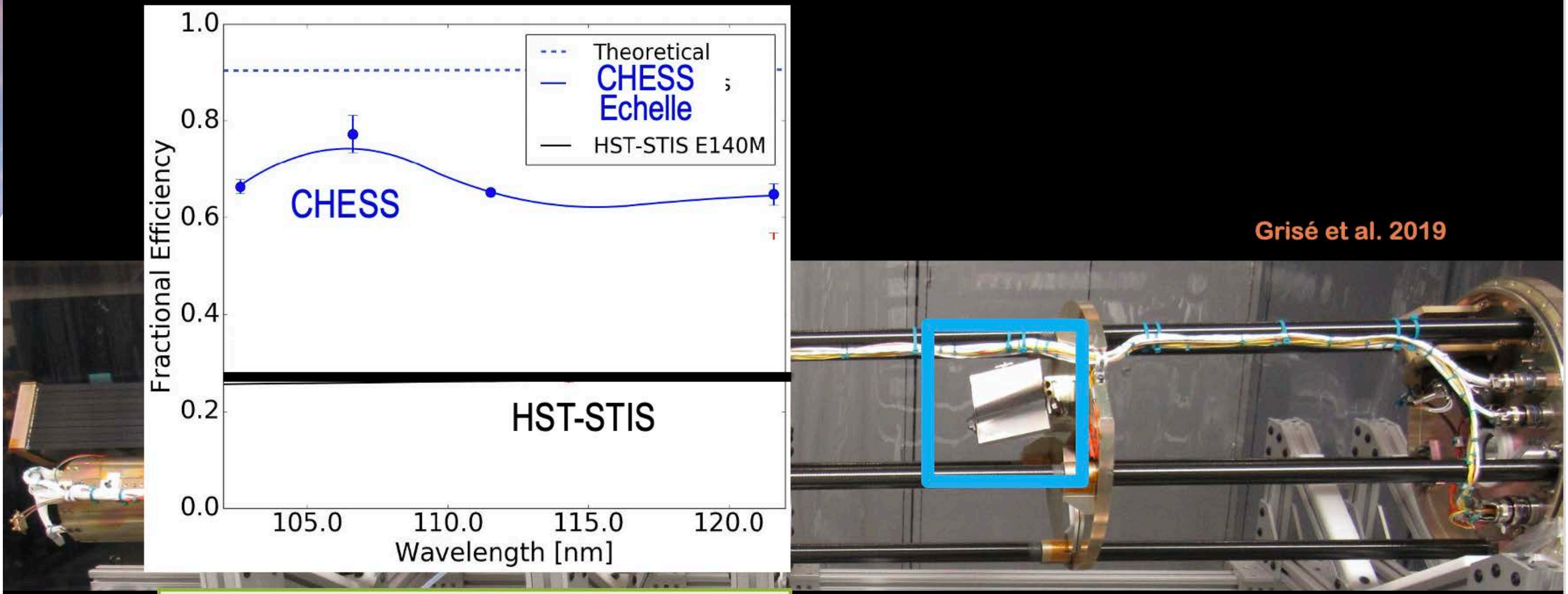


CHESS instrument in Colorado lab

CHESS Echelle gratings:

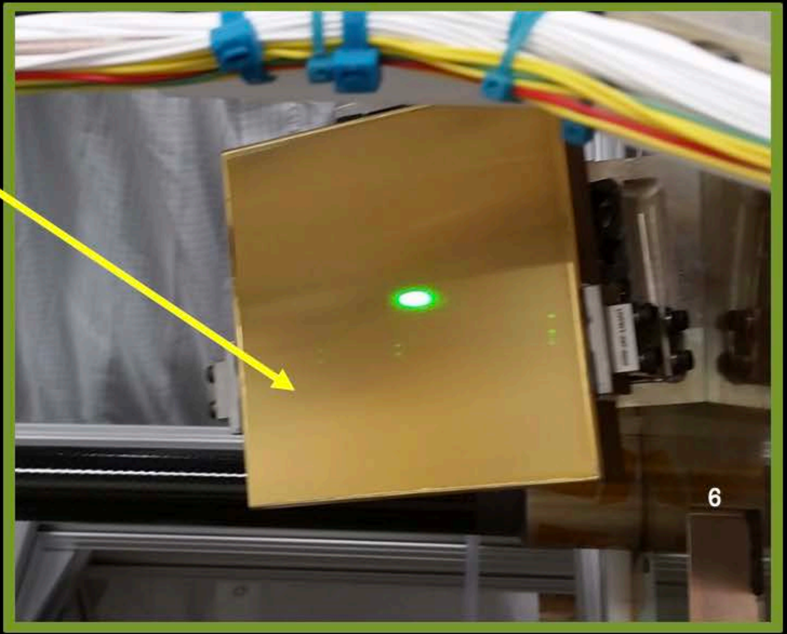
E-beam lithograph, in collaboration with Penn State University



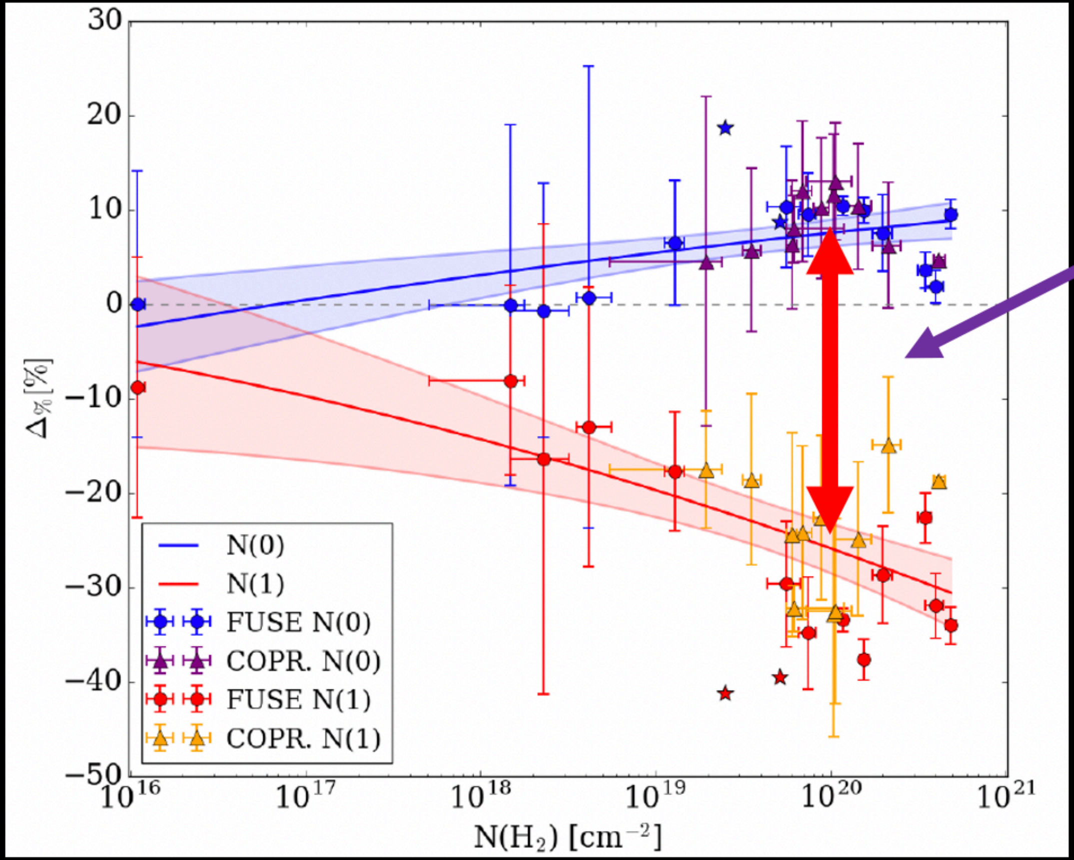


CHESS Echelle (PSU e-beam etching):

- **Factor of ~2-3 higher groove efficiency than state-of-the-art UV echelle gratings**
- **Incorporated into LUVOIR / LUMOS baseline; motivated dedicated SAT program (PI – Fleming)**



CHESS Science Results

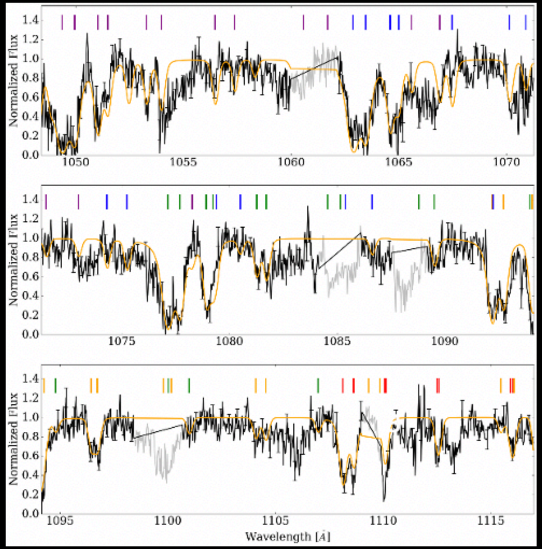


Kruczek+ 2019

H_2 rotational temperatures (T_{01}) systematically lower than previous results: blending of higher-J lines with R(1) absorption lines.

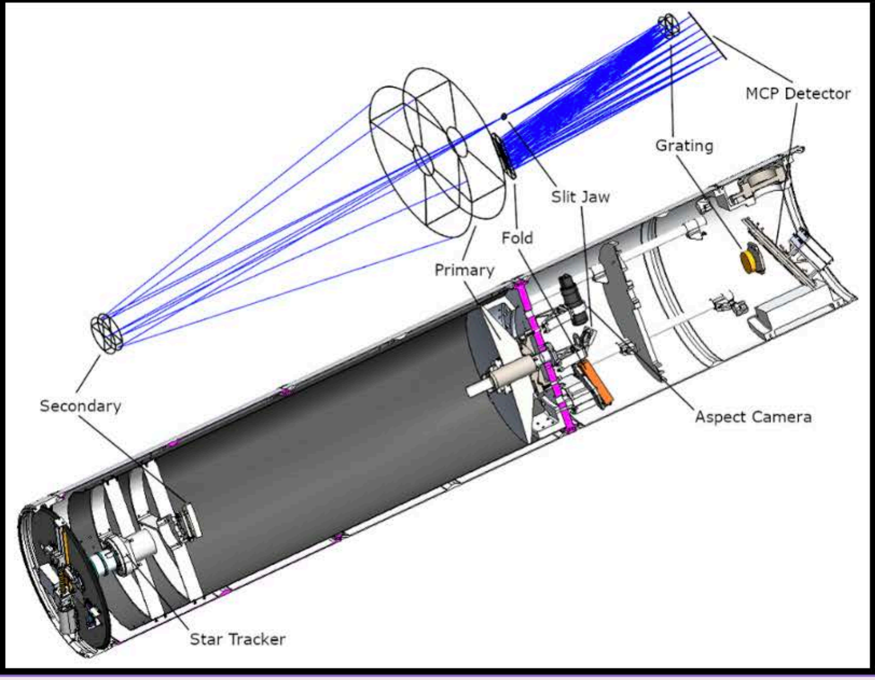
→ Temperature of the diffuse ISM ~20 – 30% lower than canonical 77 K

CHESS Flight Data



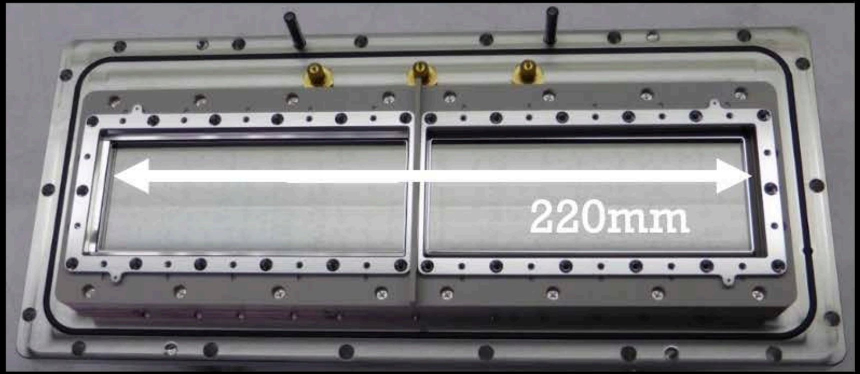
Kruczek+ 2019
Hoadley+ 2020

UV Coatings and Large-format Detectors for LUVOIR – Flight Demonstration on the SISTINE Rocket Payload



Large format, photon-counting UV detectors.

Baselined for LUVOIR/LUMOS



SISTINE Pathfinder Spectrograph:

--**Instrument design** leveraging additional reflection to control aberrations over field (high spectral and angular resolution)

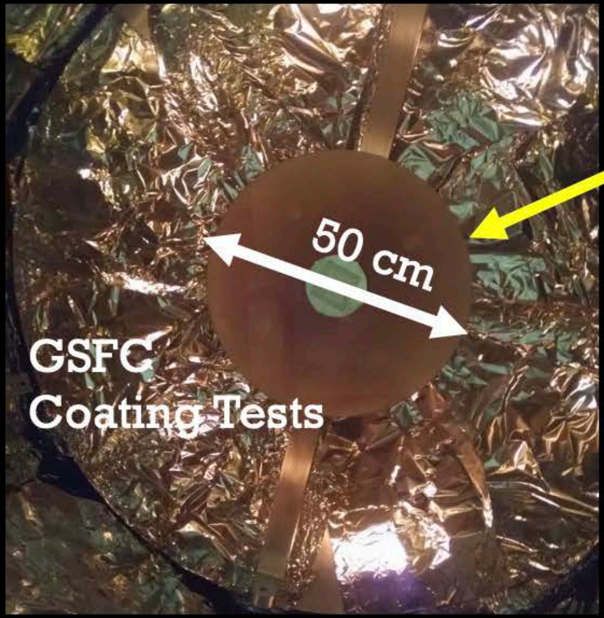
Analogous design trades adopted on LUVOIR/LUMOS baseline design

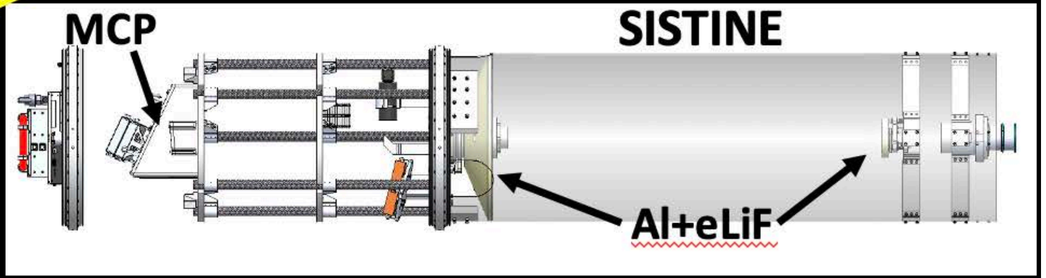
UV Coatings and Large-format Detectors for LUVOIR – Flight Demonstration on the SISTINE Rocket Payload

SISTINE Pathfinder Spectrograph:

--Al+eLiF coatings on shaped mirrors, up to 0.5m

--first time these coatings, baselined for LUVOIR, have been deposited on large (> 2”) and shaped optics, tested as a full instrument





Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

UV Coatings and Large-format Detectors for LUVOIR – Flight Demonstration on the SISTINE Rocket Payload

SISTINE Pathfinder Spectrograph:

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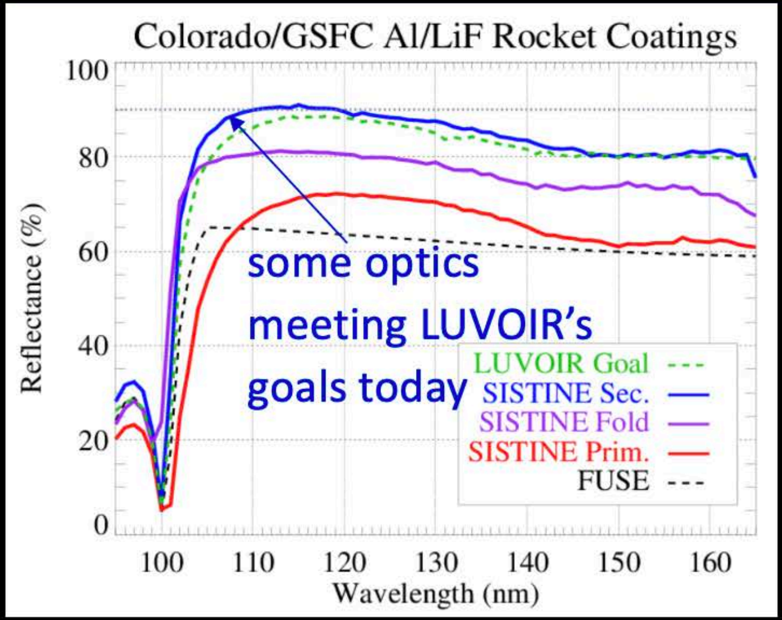
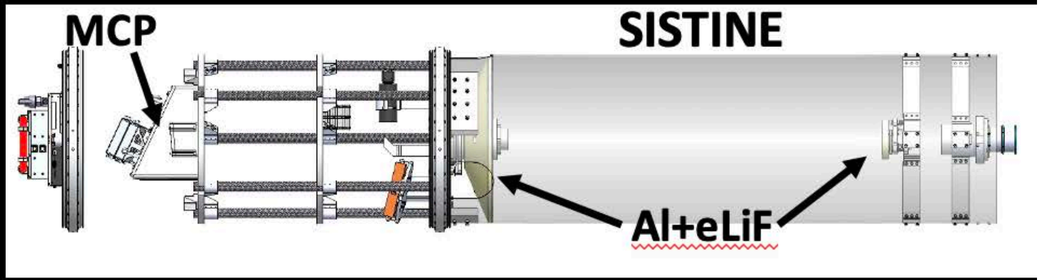




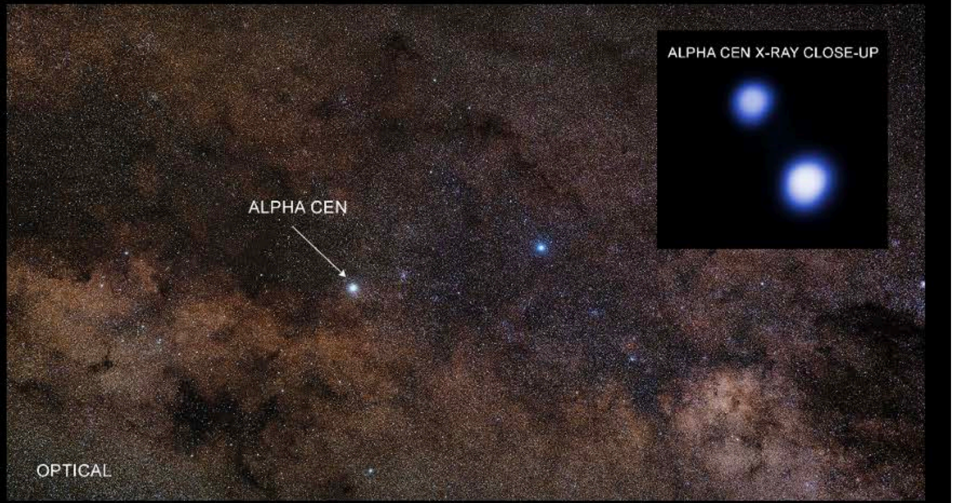
Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

SISTINE Science Mission

36.339 UG / SISTINE-2
Summer 2021

A joint rocket campaign to obtain EUV+FUV radiation fields of representative exoplanet host stars at wavelength inaccessible to HST and X-ray observatories.

Object	Spectral Type	d (pc)	E(B-V)
α Cen A	G2V	1.33	0.71
α Cen B	K1V	1.26	0.88



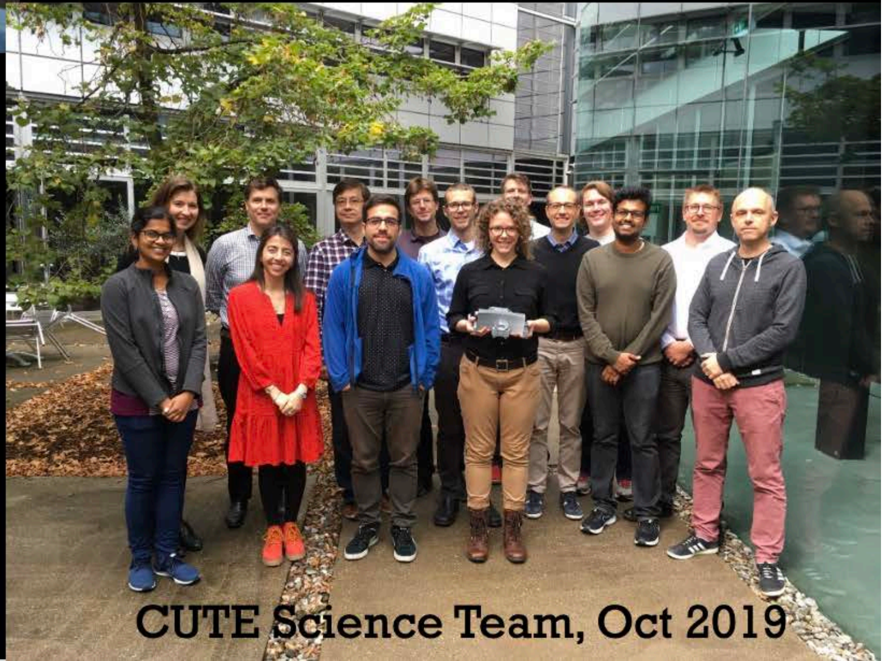
• The UV radiation fields of exoplanet's host stars control the atmospheric heating/stability and photochemical structure of their atmospheres – including atmospheric retention and formation of 'biosignatures' (e.g., O_2, O_3, CO_2, CH_4)

12


Student Training in the Colorado Suborbital Program
PIs:
Profs. Kevin France, Brian Fleming, Jim Green
(PIs of CUTE, SPRITE cubesats, HST-COS,
and numerous rocket missions)
Research
Scientists:
Dr. Ambily Suresh
Dr. Dmitry Vorobiev
Junior Engineers: Ted Schulz,
Stefan Ulrich, Nick DeCicco
Ph.D. and M.S. Students:
Arika Egan
Dr. Keri Hoadley
Fernando
Cruz-Aguirre
Dr. Chris
Moore
Robert
Kane (ME)
Parker
Hinton
Nico
Nell (AE)
Nick
Erickson
Emily Witt
Dr. Nick Kruczek
Dr. Allison
Youngblood

Student & Postdoctoral Training

CUSP
THE COLORADO ULTRAVIOLET SPECTROSCOPY PROGRAM



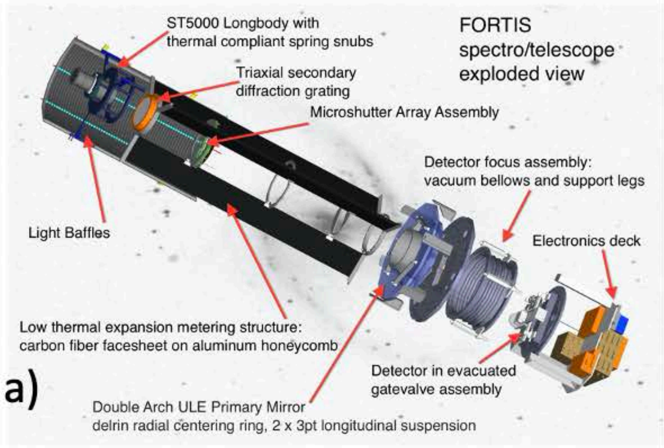
FORTIS, PI McCandliss

Next Generation FORTIS*

*Far-UV Off Rowland-circle Telescope for Imaging and Spectroscopy

PI: Stephan McCandliss, JHU

- ***Objectives:***
  - Demonstrate the scientific utility and feasibility of multi-object spectroscopy over wide angular fields in the far-UV.
  - First Science Investigation:
    - Spectroscopy of Hot Star Clusters in galaxy M33
      - How does matter circulate from Disk to CGM?
  - Other Investigations
    - Blue Stragglers in Globular Clusters
    - Low Metallicity Star Formation in Magellanic Bridge
    - Shocks in SNe Remnants
    - Comets as Targets of Opportunity



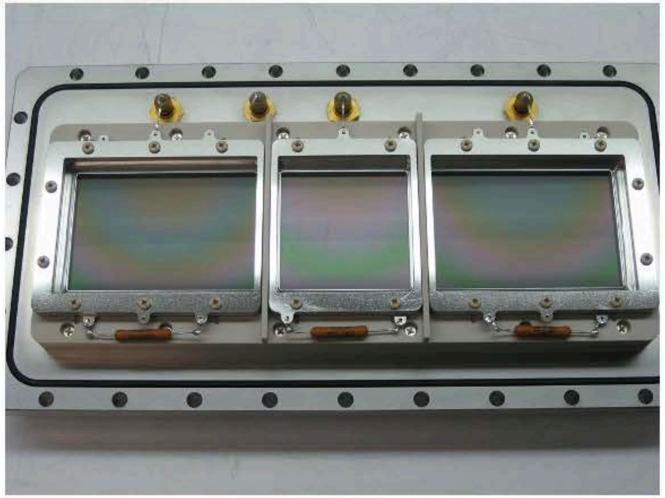
a)

- ***Key Challenges/Innovations:***
  - Pulsed Actuated Next Gen Microshutter Arrays(NGMSA)
  - Low scatter 3D-printed baffles to trap geo-Lyman **α**
  - Longlife, High QE, Large Area Borosilicate MCP's
  - Autonomous Target Acquisitions

- ***Sci and Tech Relevant to LUVOIR, HabEX, CETUS:***

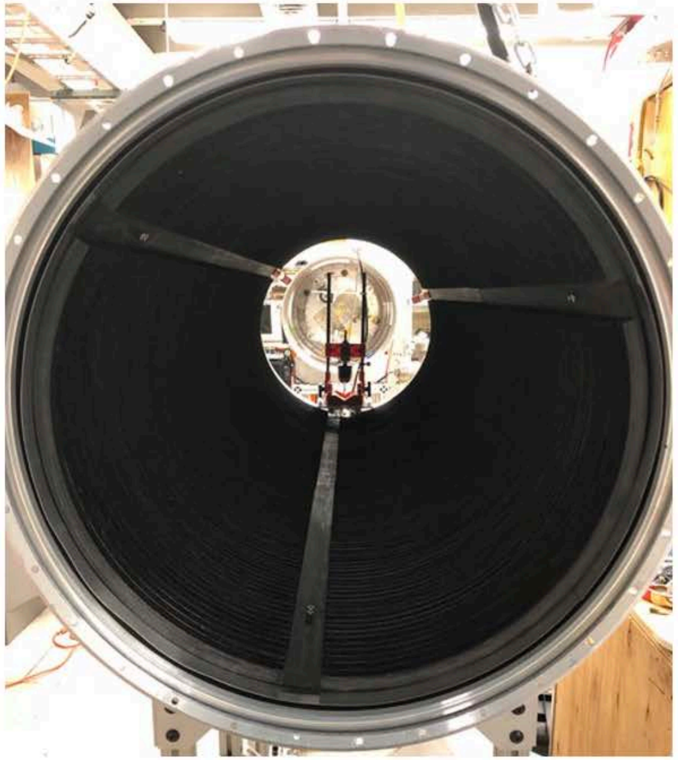
Technical Innovations

Borosilicate MCPs – **Developed with Sensor Sciences**



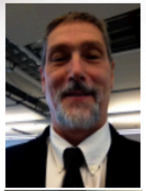
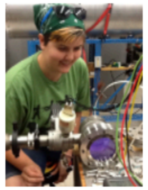
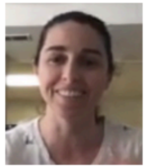
Pulsed Next Gen MSA – **Developed in Partnership with GSFC**

3D Printed Baffles – **Stratasys**



Rocket Team

- **JHU**

	Stephan McCandliss – PI
	Brian Welch – Grad Student (4th yr)
	Alex Carter – Grad Student (Masters Program)
	Russell Pelton – Systems Engineer
	Isu Ravi – Grad Student (3rd yr)
	Mackenzie Carlson – Grad Student (1st yr)

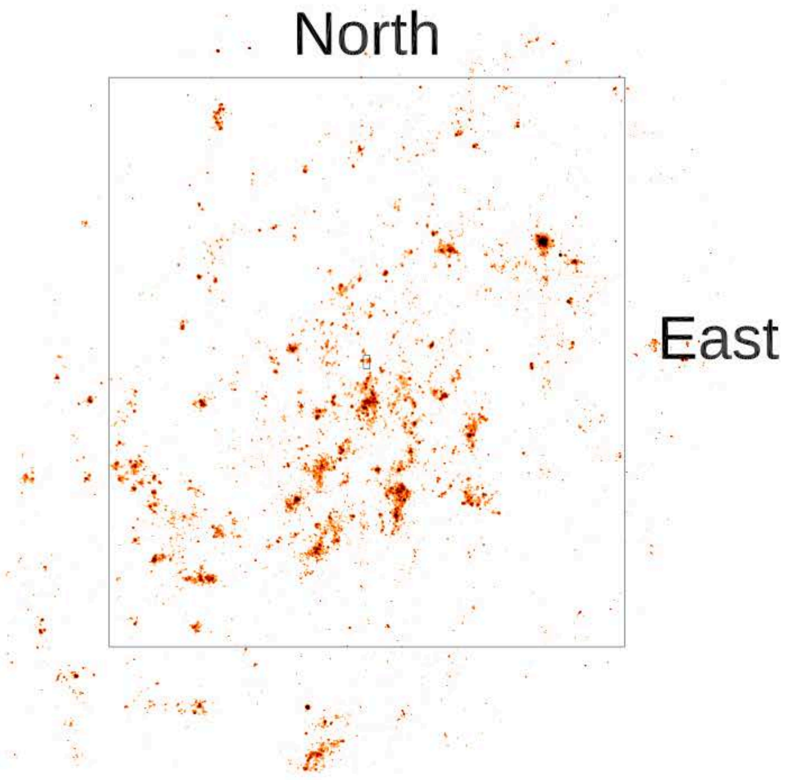
- **GSFC**

Matt Greenhouse – PI
Alexander Kutyrev – CoI
Mary J. Li – CoI
Kyowan Kim – Test Engineer
S. Harvey Moseley – Former PI

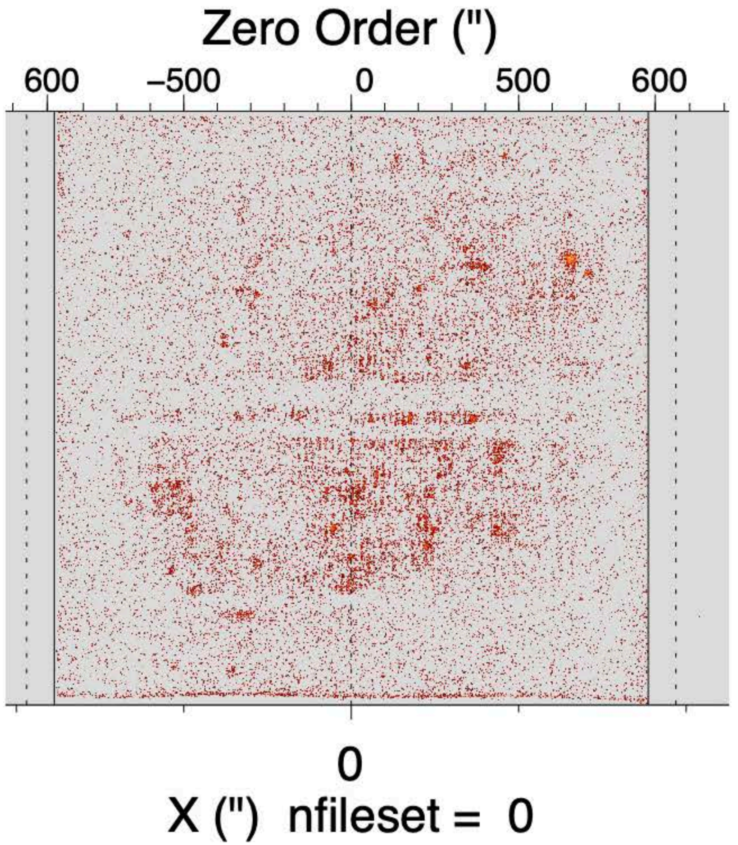
APAC

36.352UG Launched on 27 October 2019
Mission to Observe M33

GALEX



FORTIS MSA ALL OPEN (46s)



APAC

4

Results

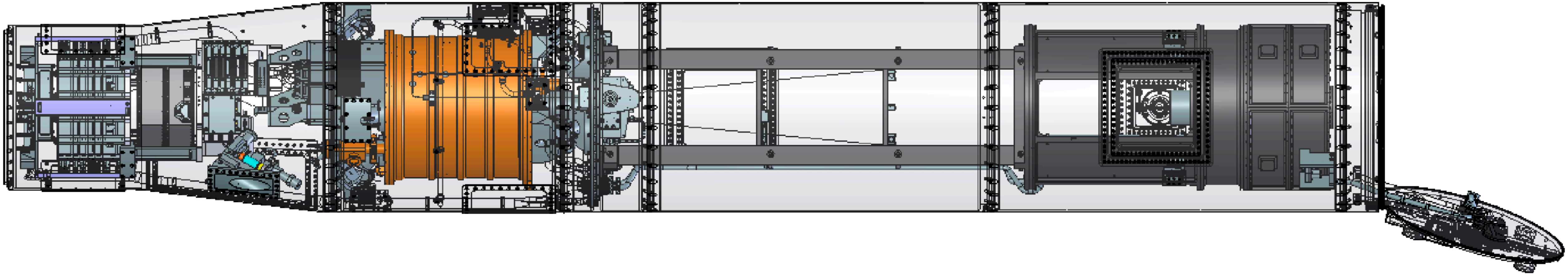
- **Mission achieved technical success**
  - Opened array and acquired image of M33
  - Successful executed autonomous targeting algorithm, transitioned from all opened to brightest target per row after 46 second integration
    - First successful deployment of Next Gen Microshutter Array!!!
  - Subtle "mirror" error in targeting code frustrated spectral acquisition
- **Scattered geo-Ly α light still an issue**
  - Tests ongoing to reconfigure FORTIS from on-axis to off-axis design
- **Reconfiguration and Redeployment stalled by COVID**

Micro-X, PI Figueroa

Micro-X

The High-resolution Microcalorimeter X-ray Imaging Rocket

36.355 Figueroa



Enectalí Figueroa-Feliciano

Northwestern

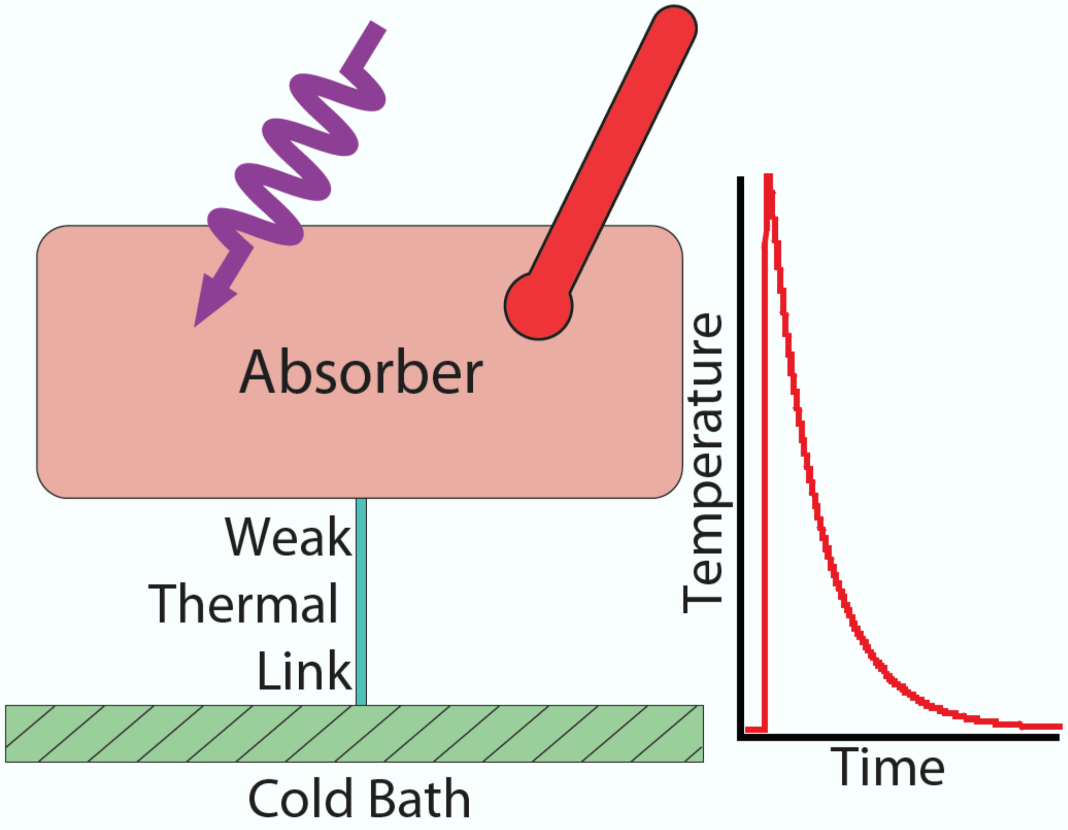
THE UNIVERSITY of WISCONSIN MADISON

NIST

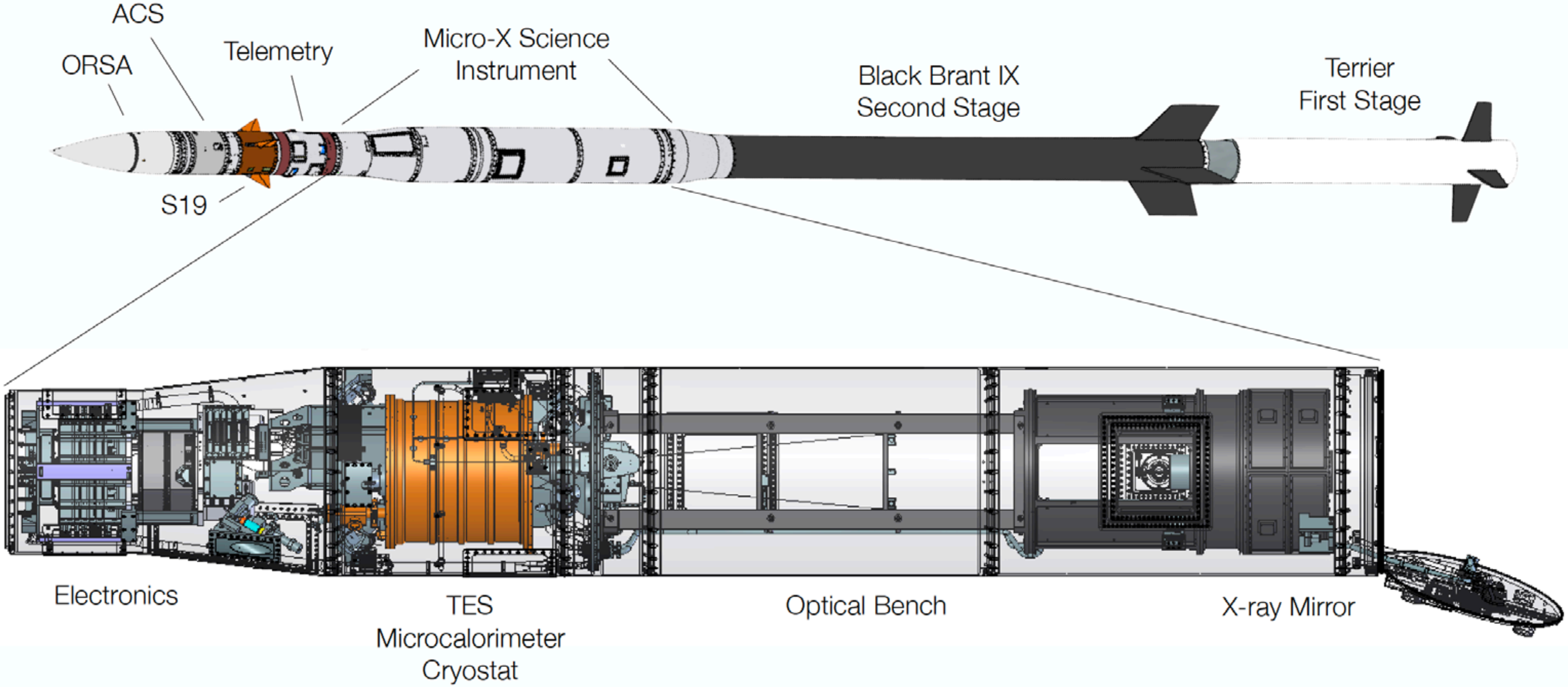
Microcalorimeters: IFUs for the X-ray band

- For high resolution spectra of diffuse and extended sources we need a non-dispersive spectrometer.
- Cryogenic Microcalorimeters are single-photon-counting imaging spectrometers with resolving powers of 500-3000 in the X-ray band.
- Absorber and thermometer are connected to a thermal bath through a weak thermal link.
- Theoretical resolution is a function of T and E_{max}
- Need cryogenic temperatures to reach target resolution!
- Si Thermistors:
  - XQC: 1995-present
  - XRISM: (2021)
- Transition-Edge Sensors (TES):
  - Micro-X: 2018
  - Athena: (2030s); Lynx (2030s)

$$\Delta E_{\mathrm{FWHM}} \simeq 2.35\sqrt{4kTE_{\mathrm{max}}}$$



The Micro-X Sounding Rocket

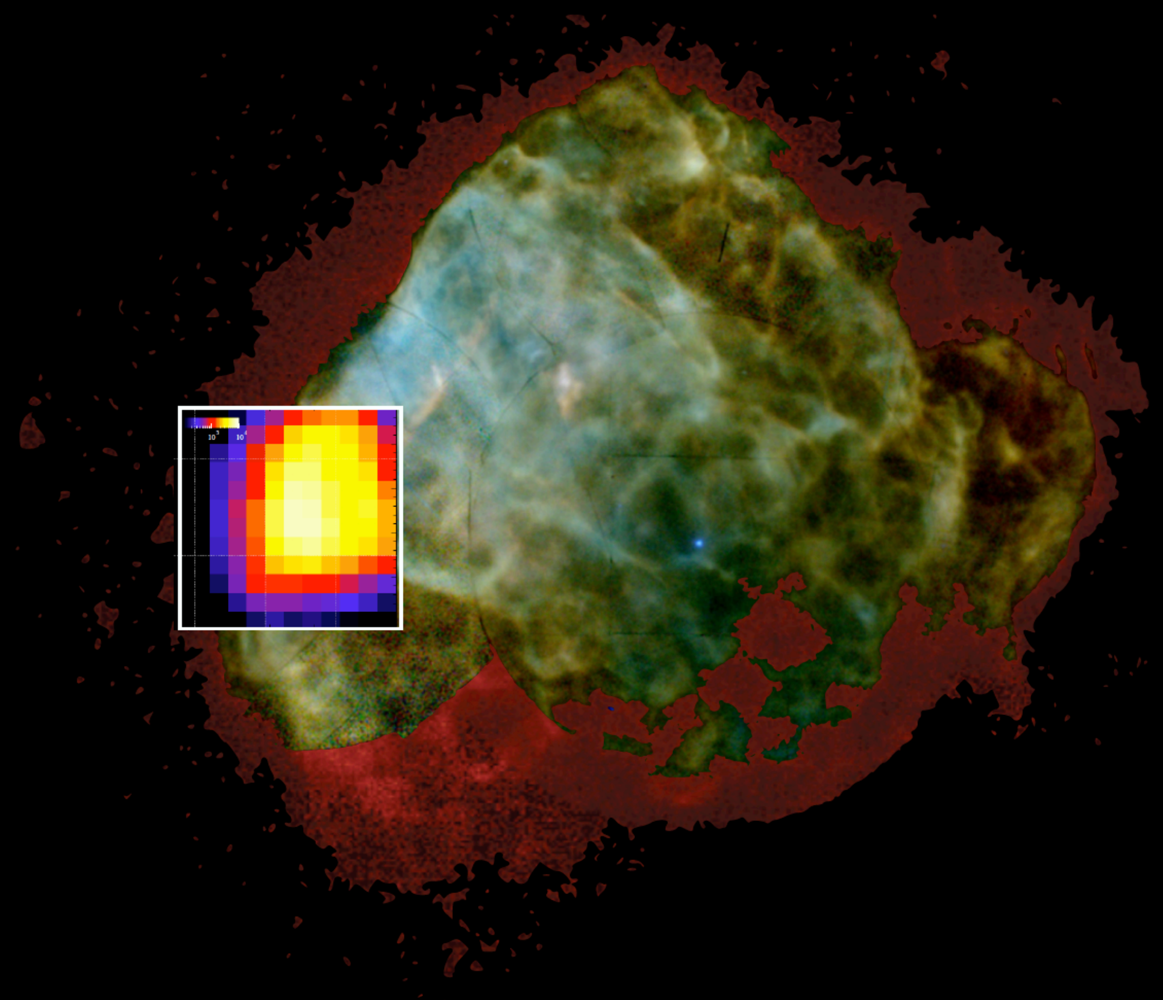


Micro-X Specifications

The Micro-X Instrument	
Science Observation Time (time above 160 km)	~300 sec
Bandpass	0.2 – 2.5 keV (but will see some bright lines at higher energy)
Field of View	11.8 arcmin
X-Ray Optics	Conical approximated Wolter optics Collecting area ~ 300 cm^2 @ 1 keV Focal Length: 2.1 m 2.4' Point Spread Function
Microcalorimeter Array	128 pixels read out by 2 parallel TDM SQUID MUX (2 x 8 columns x 16 rows) Pixel pitch: 600 um = 59 arcsec/pixel 5 - 10 eV energy resolution @ 1 keV

Micro-X Main Science Target - Puppis A

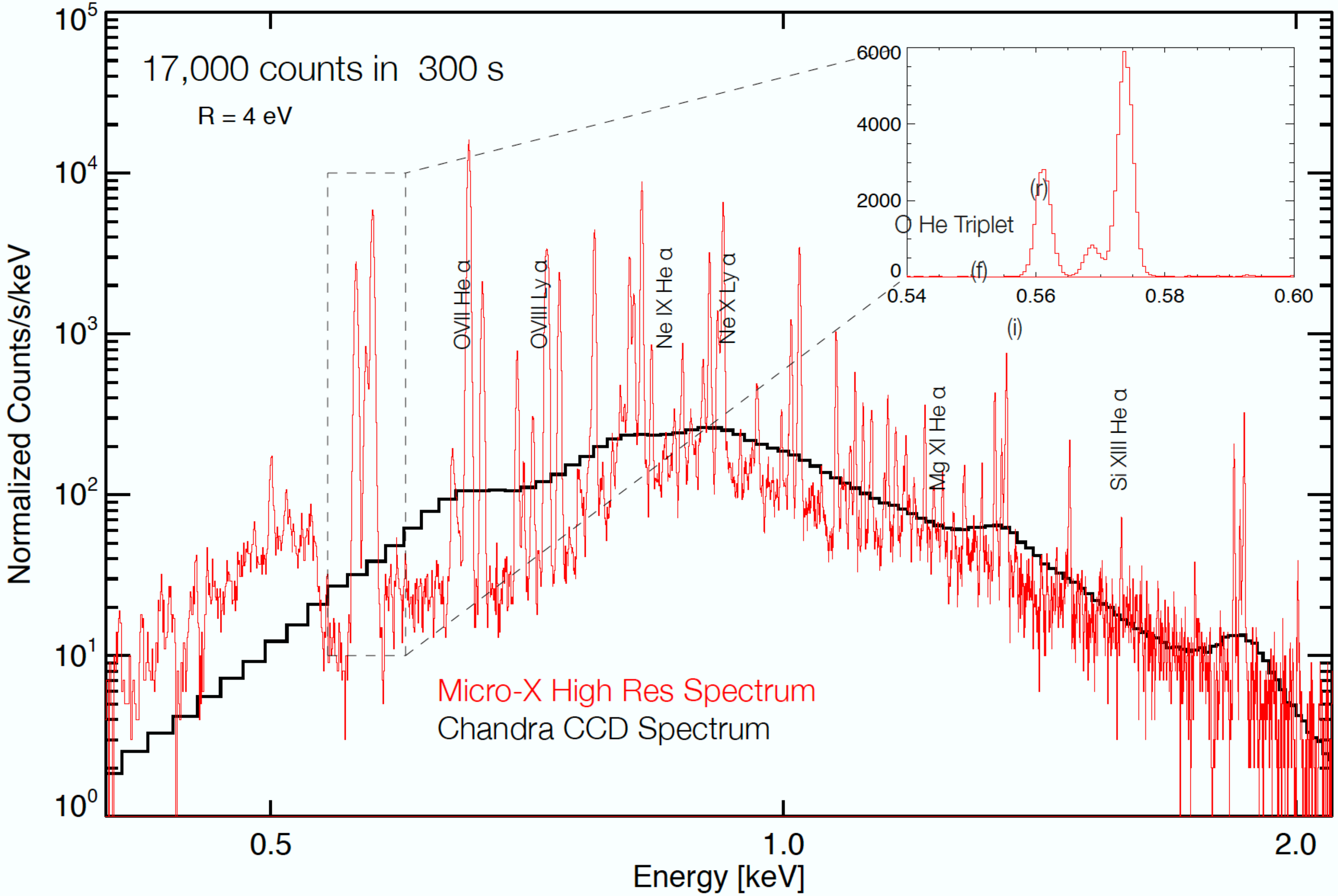
Bright Eastern Knot Observation



Katsuda et al. 2010

- Launch Scheduled for March 19, 2020
- Measure the velocities and line structures of the various emission lines to obtain information about the dynamics and turbulence of the shock and surrounding plasma.
- Perform plasma diagnostics to obtain ion thermodynamic states for individual elements.
- Study the shock physics and look for potential connections to cosmic ray acceleration.

Puppis A Micro-X Simulation



Conclusions

- The maiden flight of Micro-X 36.245 saw the first operation of TES and MUX readout in space. The initial results have been published, a longer instrument paper is in the works.
- The rocket pointing error means this first flight was effectively an engineering flight
  - Issues only observable in flight have been identified, and improvements have been implemented
- 36.355 will launch in November 2021 and target Puppis A.

DXL & DXG, PI Galeazzi

The DXL & DXG programs

Two sounding rocket programs lead by the University of Miami

Collaborators: NASA/GSFC, John Hopkins University, University of Wisconsin, University of Michigan, University of Kansas, LATMOS/IPSL (France), NASA/MSFC, Boston University

Young personnel trained by the mission: one PostDoc (now a scientist at MSFC), 4 graduate students trained directly on the projects (three graduated, one still at Miami), two additional PostDocs and three graduate students worked on the project on data analysis and calibration, >10 undergraduate students, >10 high school students

Technology highlights: Micropore optics (lobster eye optics) were flown for the first time as piggyback experiments onboard of DXL in 2012

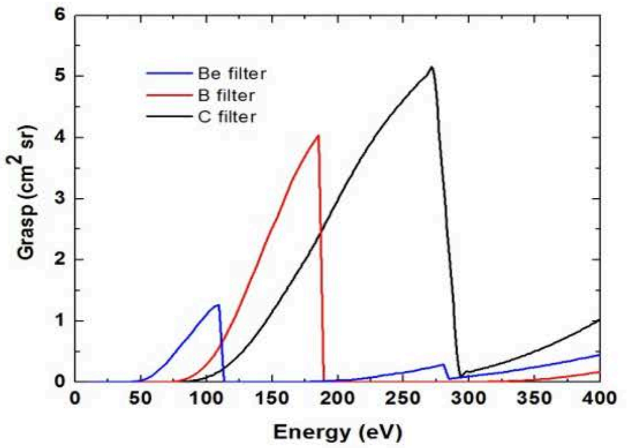
Science highlights: The existence of the Local Hot Bubble was confirmed by the DXL mission. The contribution from Solar Wind Charge eXchange to the Diffuse X-ray Emission was measured.

Diffuse X-rays from the Local galaxy (DXL)

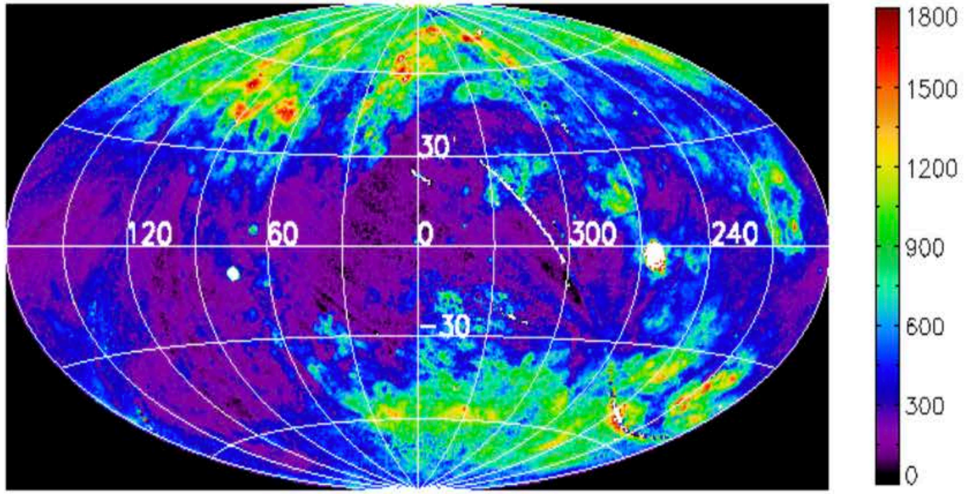
- Sounding rocket mission for the **study of the Local Hot Bubble and SWCX**
- 4 co-aligned X-ray proportional counters
- >1,000 cm^2 effective area, 7.5 deg FOV
- C, B, and Be filters
- High response from 40 eV to 10 keV
- 1-D images generated by rolling the payload
- Launched from WSMR, NM on 12/12/2012 and 12/6/2015 and from PFFF, AK on 1/16/2018
- Flight #4, December 2021 from WFF

DXL Science highlights

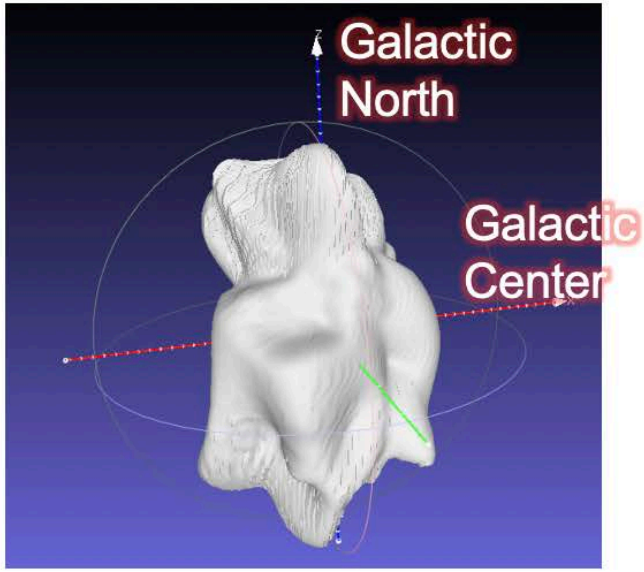
- DXL is the only mission with large grasp in the 1/4 keV band
- Confirmed the existence of the Local Hot Bubble and studied its properties
- Measured the contribution from SWCX to the Diffuse X-ray emission in the ¼ keV and ¾ keV band
- Measured the SWCX cross section with He
- One more flight scheduled in 2021 to measure the SWCX cross section with H



DXL low Energy grasp



ROSAT ¼ keV band cleaned of SWCX using DXL



3D representation of the LHB from DXL

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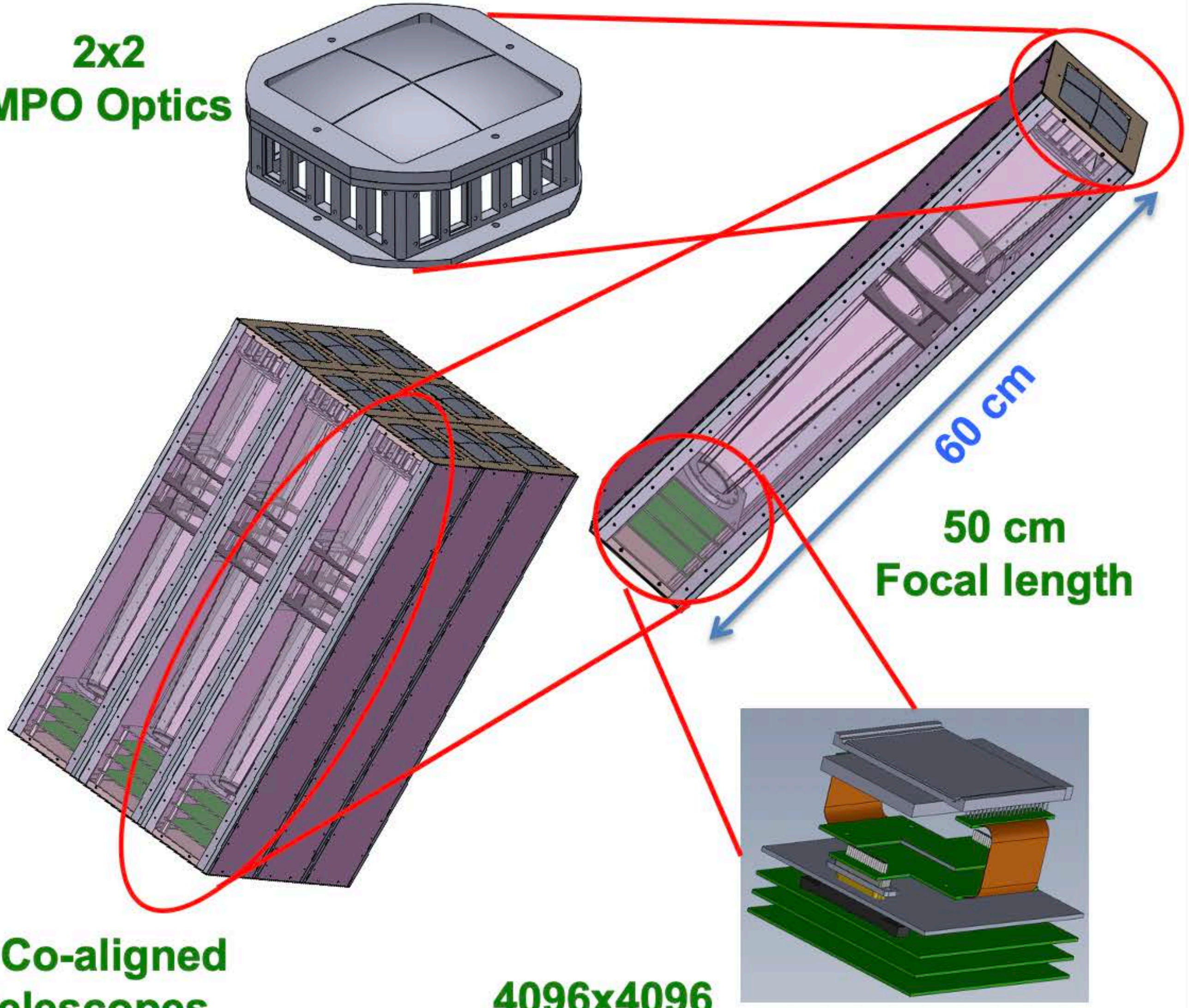
Diffuse X-rays from the Galaxy (DXG)

MicroPore Optics (Lobster Eye Optics) coupled to large area CCD detectors

- 5x5 deg^2 field of View (FoV)
- better than 10 armin angular resolution
- effective area >150 cm^2 at 1 keV
- optimized for the energy range from 100 eV to 10 keV.



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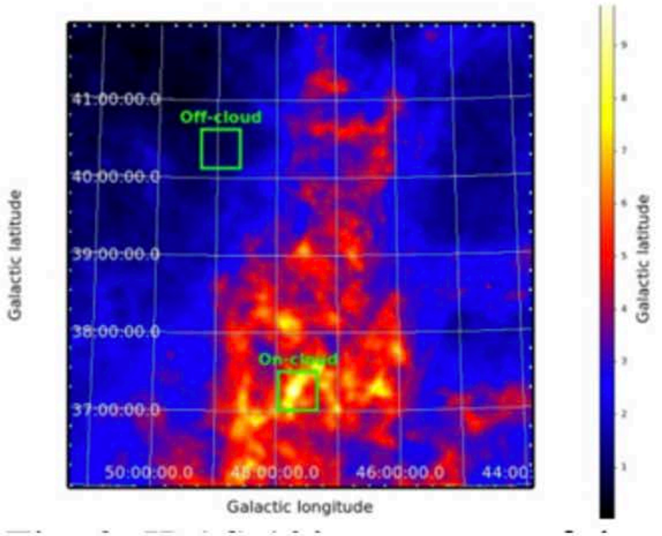
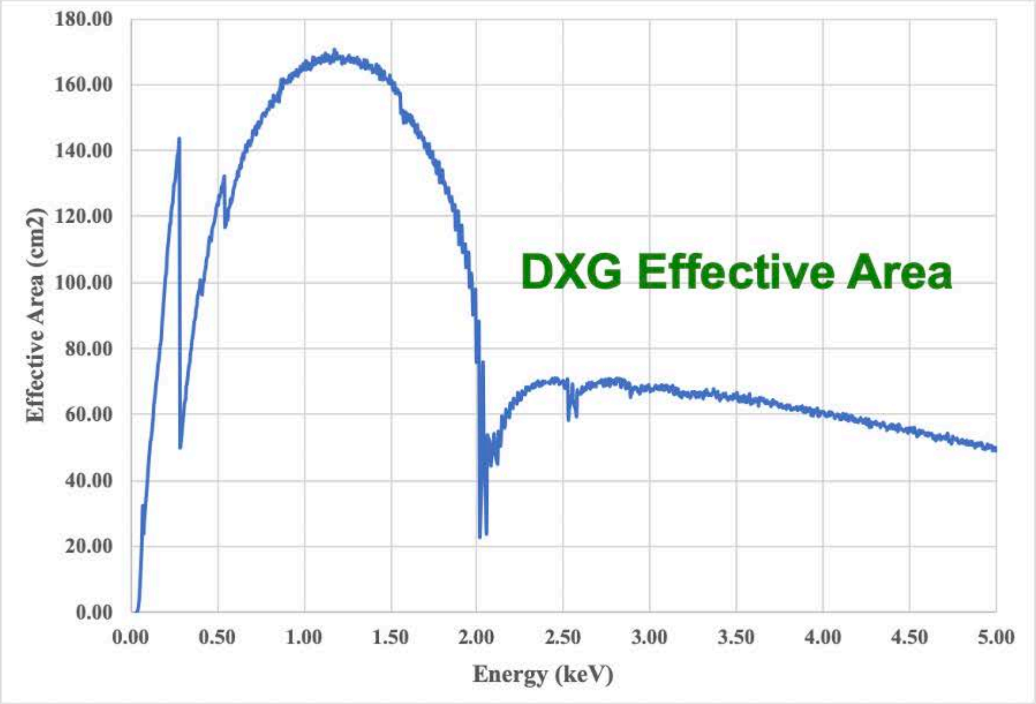
DXG FOV AND EFFECTIVE AREA



DXG's 5 deg FOV, the Green Boxes represent XMM-Newton FOV for comparison



DXG has been approved in 2017 for instrument development (together with the last DXL flight).

- **The optics have been characterized and calibrated**
- **The optical bench has been designed**
- **The focal plane array has been designed**

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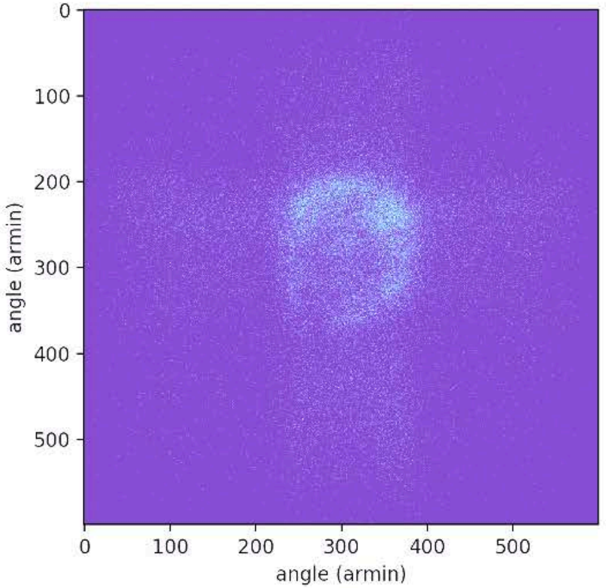
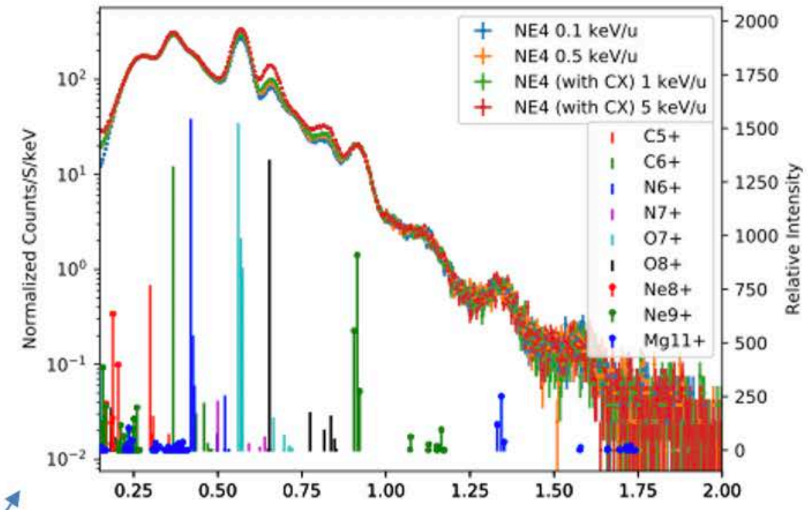
A proposal for a 2-flight campaign will be submitted in December.

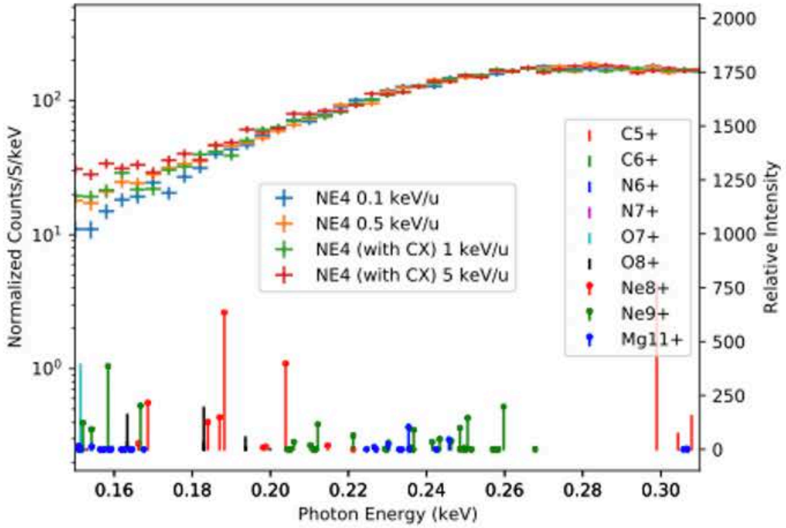
DXG Science

DXG will image the complete Cygnus loop in one single pointing, reducing contamination from SWCX, with CCD energy resolution and angular resolution of <10 arcmin



Simulated DXG Image of the Cygnus loop





Simulated spectrum of the NE4 region of the Cygnus Loop in two different energy bands, including a significant amount of CX at 5 different collision velocities calculated with the Atomdb-CX (ACX2) package.

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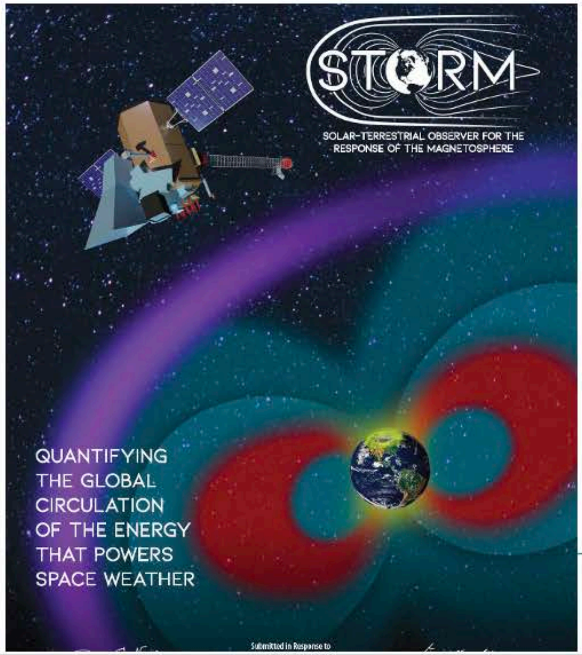
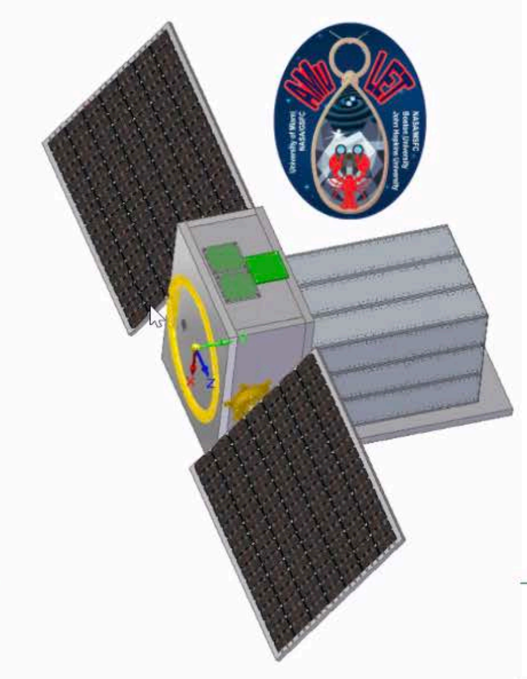
Program Spinoffs

- **CuPID** (flown as piggyback in 2015) will launch as a Heliophysics Cubesat in 2021
- **LEXI** (flown as a piggyback in 2012) will be sent to the surface of the moon as part of the Artemis program in 2022
- **STORM** has been approved for Phase A for the Heliophysics Explorer Program
- **AMuLET** (All-sky Multimessenger Lobster Eye Telescope - a standalone version of DXG) is being proposed for the Pioneers program to detect EM counterparts to GW events and for identify fast transients
- **SIBEX** (Shock Interaction/Breakout EXplorer) is being proposed to next Astrophysics Explorer call to study supernova show breakout






LEXI - KDP A - September 2020