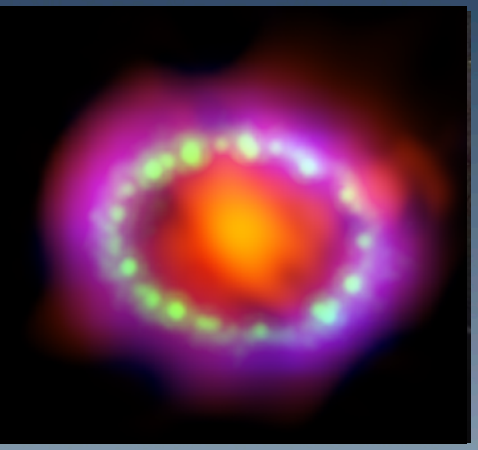
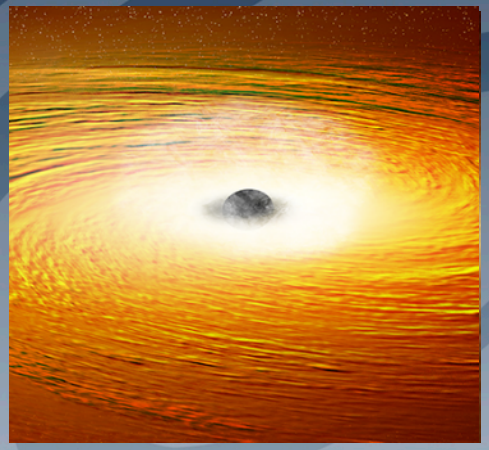
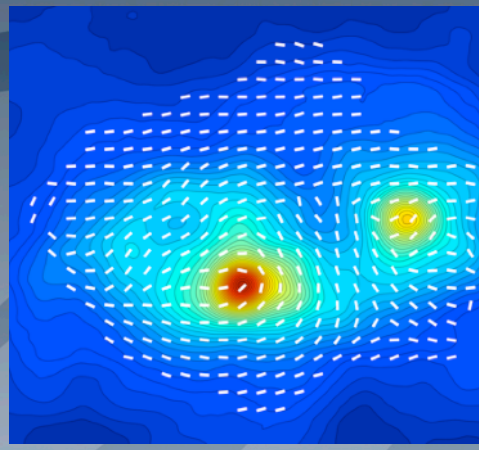
Astrophysics



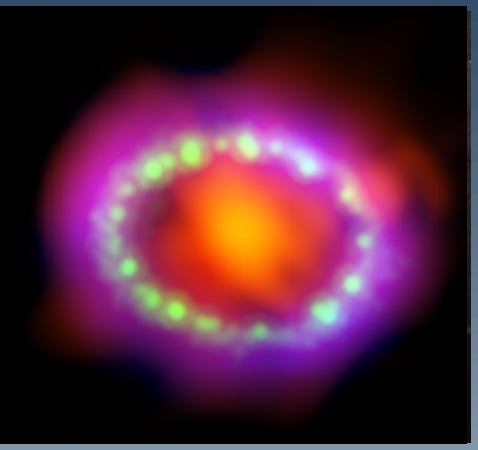



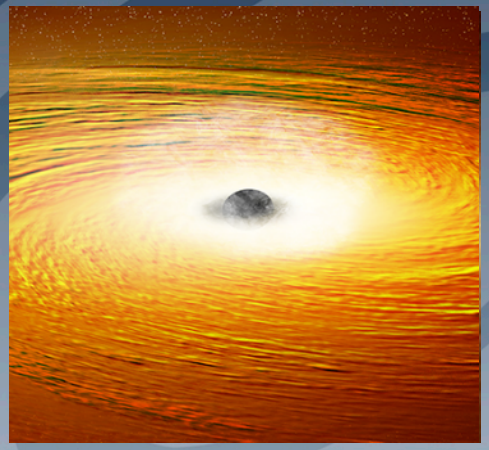
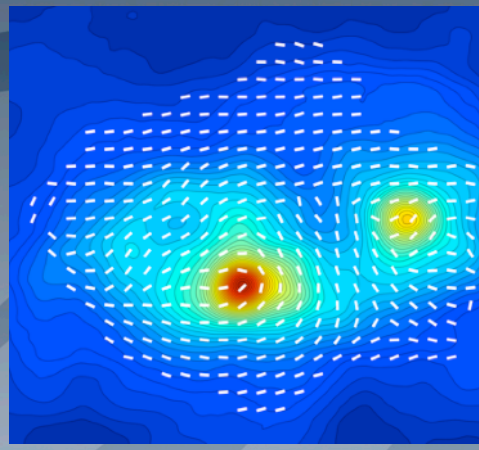
Astrophysics Sub-Orbital Science, Technology, and the Next Generation

APAC
July 20, 2017

Michael Garcia
NASA HQ
HST Program Scientist
APRA, Athena **Program Scientist**
LUVOIR, IXPE Deputy PS
APRA-UV/Vis Program Scientist
Astrophysics CubeSat POC

Astrophysics



"For the next suborbital report, the APAC would like to hear more about the science, and how the technology developed from that program flows into the large missions, with examples. The APAC would also like to hear how the awards line up with technology gaps."

Proposal Evaluation: Additional factors for APRA suborbital

- For suborbital proposals, specific factors to be considered include
  - The proposal's **scientific merit** (see previous page)
  - the degree to which the proposed work advances the technology readiness level **(TRL)** of a detector or supporting technology,
  - the degree to which the proposed work advances the readiness of **junior researchers** or graduate students to assume leadership roles on future NASA space flight missions.
- Suborbital includes sounding rockets, balloons, cubesats, and ISS-attached.

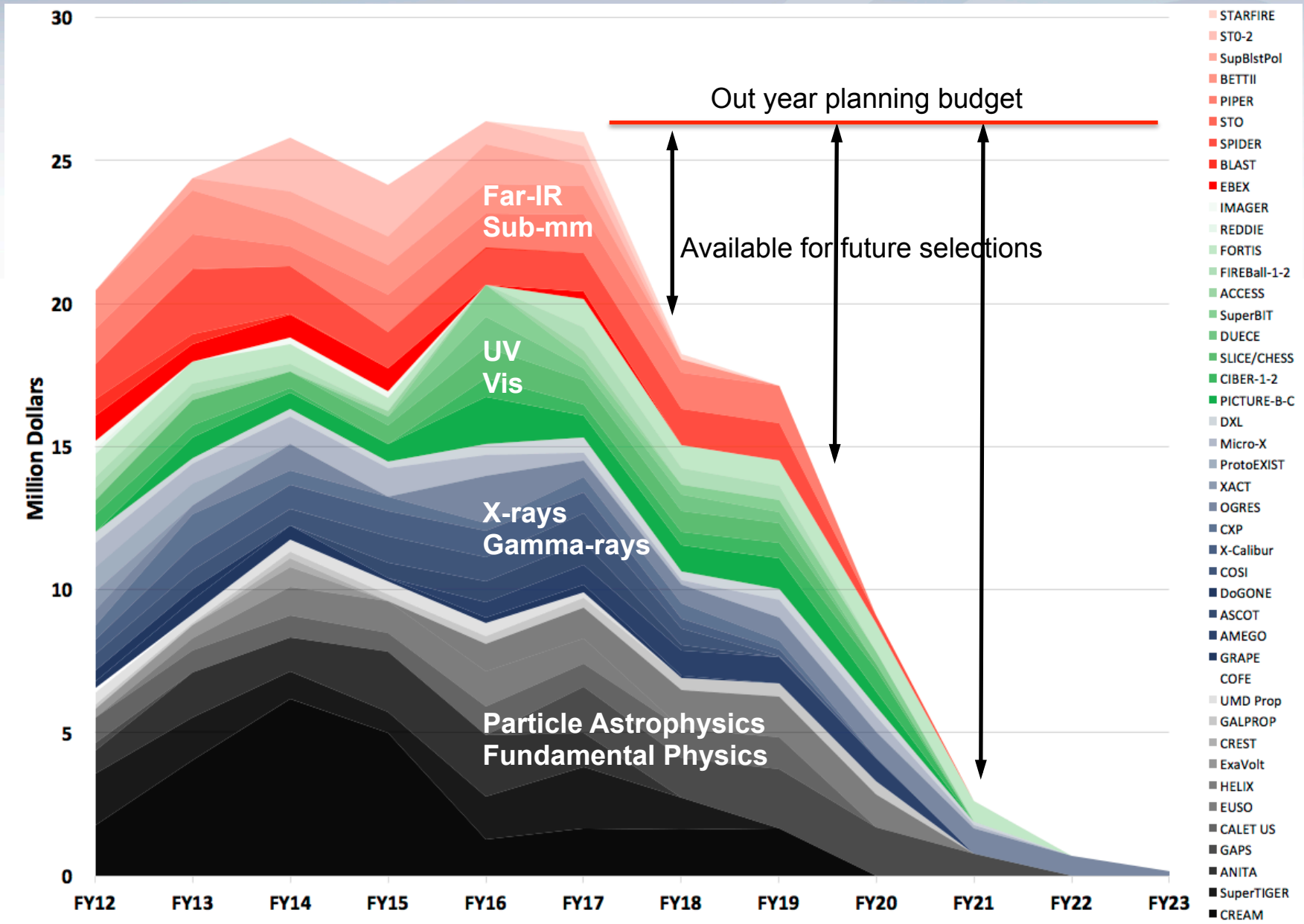
Proposal Evaluation: Additional factors for Roman Technology Fellowship (RTF)

- RTF program is now coupled with the APRA program
  - Technical proposals for **RTF are submitted and reviewed as APRA** proposals
  - The RTF proposals are identifiable by question #22 on the proposal cover page
  - RTF proposals contain a 1-page application allowing the candidate to establish **eligibility and qualification** for the fellowship. The application should be included in the APRA proposal immediately following the PI's Biographical Sketch.
- The APRA evaluation form includes specific fields for comments relative to RTF
  - The RTF comments will not be seen outside of NASA, thus content can be candid
- The RTF evaluation is independent of the technical review of the APRA proposal (no influence on scoring of APRA evaluation criteria)
- RTF Fellows will be identified from among selected eligible APRA PIs.
  - NASA is committed to selecting one or more RTF Fellows every year
  - This year, multiple selectable APRA proposals have RTF-eligible Pis
- **RTF Fellows identified** in this presentation

Sub-Orbital Statistics

- APRA-2015 Proposals and Selections:
  - 15 **Balloon** Investigations Proposed
    - 5 were new, 10 were reflights/continuations
    - 8 were selected (5 were partials)
    - Success rate # = 53%, $ = 24% (similar to APRA as a whole)
  - 6 **Sounding Rocket** Investigations Proposed
    - 3 were new, 3 where reflights/continuations
    - 4 were selected (3 partials)
    - Success rate = # = 75%, $ = 19% (similar to APRA as a whole)
  - 4 **CubeSat** Investigations Proposed
    - All were new
    - 1 was selected
    - Success rate #= 25%, $=16% (~lower than APRA as a whole)
  - 2 **ISS Payloads** Investigations Proposed
    - 1 new, 1 continuation, 1 was selected
    - Success rate # = 50%, $ = 30% (similar to APRA as a whole)
- APRA-2016 Proposals and **possible** Selections
  - 27 Sub-Orbital Investigations Proposed, 12 Balloons, 9 S/R, 4 CubeSats, 2 Other
  - POSSIBLE selections: ~5 balloons, ~3 S/R, 2 CubeSats
    - Decisions have not yet been made

APRA Suborbital Funding



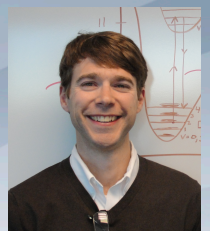
UV/Visible Suborbital Missions

- **Sounding Rockets:**
- REDDIE (complete), PI: Supriya Chakrabarti, UML, coronagraph technologies.
- IMAGER (complete). PI: Tim Cook, UML, UV ISM absorption gradient in galaxies, UV Technologies
- FORTIS, PI: Stephen McCandliss, JHU, UV technologies and Lyman-α escape science.
- ACCESS, PI: Mary Beth Kaiser, JHU, 1% absolute calibration for SNIa.
- CIBER, PI: James Bock, CalTech, Measuring IR X-Gal BG fluctuations.
- DUECE, PI: James Green, UC, UV technologies and B star FUV calibration.
- SLICE/CHESS, PI: Kevin France, UC, UV technologies and ISM science.
- PICTURE-B (complete), PI: Supriya Chakrabarti, UML, coronagraph technologies, Epsilon Eridani.

- **Balloons:**
- FIREBall, PI: Chris Walker, CalTech, UV technologies, CGM/ISM imaging.
- PICTURE-C, PI: Supriya Chakarabarti, UML, coronagraph technologies.
- SuperBit, PI: William Jones, Princeton, galaxy weak lensing, UV/Vis technologies.

- In what follows, few selected investigations are highlighted which address the APAC questions (quad charts for remainder in backup).

Colorado UV Rocket Program



PI: Kevin France **(RTF)**/University of Colorado

Description and Objectives:

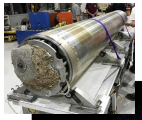
- Fabrication and laboratory testing of critical path technologies for future NASA UV/vis astrophysics missions
- Flight-testing of key technologies in operational space environment – raising the TRL of flight technologies to TRL7
- Science, education, and training the next generation of scientists and engineers who will lead future NASA missions

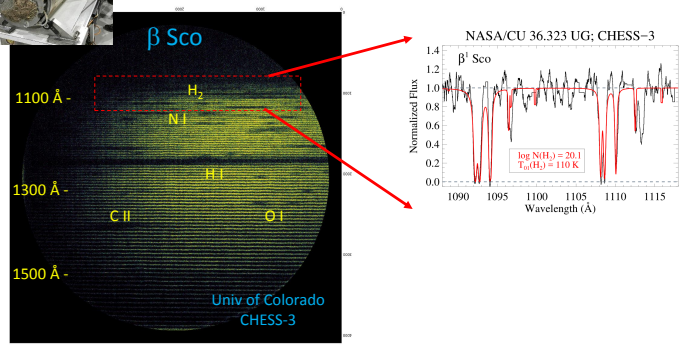
Key Challenge/Innovation:

- **Diffraction gratings** for high-resolution UV spectrographs
- **UV/vis detector** technology demonstration in space environment: larger formats, higher dynamic range, lower background equivalent flux
- High-reflectivity optical **coatings** with high wavefront control

NASA / CU 36.323 UG – France

WSMR, LC-36. 23:10 26 June 2017





Approach:

- Design rocket-borne spectrographs and telescopes
- Work with collaborators and vendors on specifications and fabrication procedures for key technologies
- Component-level efficiency and environmental testing
- End-to-end payload development and launch
- Scientific and technical analysis, student training, and publication of results

Key Collaborators:

- **Oswald** Siegmund & John Vallerga – UC Berkeley
- Paul Scowen / **Shouleh** Nikzad – ASU/JPL
- Manuel Quijada - GSFC
- Aki Roberge (GSFC), Jason Tumlinson (STScI), Ed Jenkins (Princeton) – Science and large mission application

Development Period:

- 06/01/2016 – 05/31/2020

Accomplishments and Next Milestones:

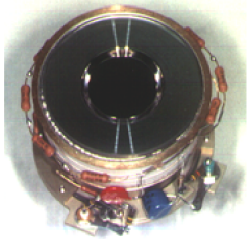
- Acquired and tested new echelle gratings (Richardson) with advanced UV coatings (GSFC optics branch). Testing of all CHESS-3 hardware to support next launch is ongoing.
- Contributed technology development and instrument design for LUVOIR study based on CU rocket payloads
- Successfully launched CHESS-2 (Feb 2016), published results from the mission (Hoadley et al. 2016), and published an overview paper on science and technology in CU program (France et al. 2016a,b)
- Build up of CHESS-3 payload with new echelle grating + advanced UV coating. Integration and field ops for 36.323 launch in May and June 2017
- Graduate and undergraduate students took lead roles on CHESS-2

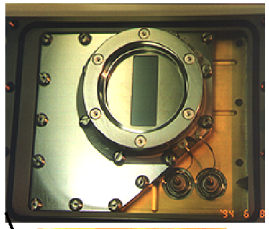
Application:

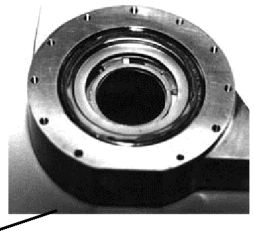
- All **UVOIR missions** requiring high spectral resolution, high-sensitivity, and low background equivalent flux [for both imaging and spectroscopy]
- **Flagship** (**LUVOIR**); Lifecycle of Baryons Probe; IGM spectral imaging and supernovae Explorer missions

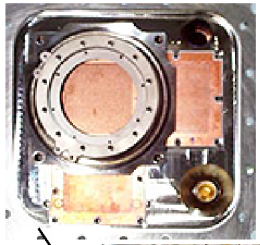
TRLin = 2/3 ***TRLcurrent = 4*** *(coatings),* ***7*** *(XS MCP)* ***TRLtarget = 6/7***

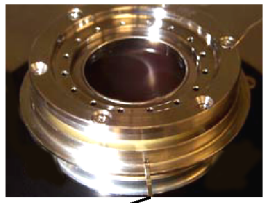
Experimental Astrophysics Group
UC Berkeley ---- Mission Experience
Dr. Oswald Siegmund

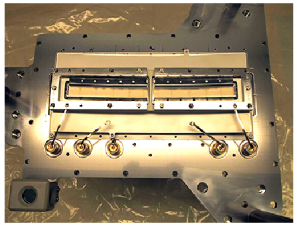


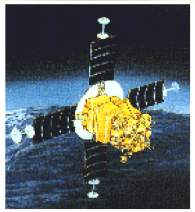


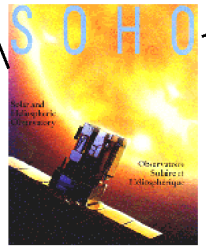




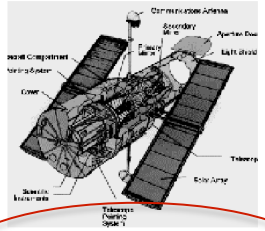








SOHO



FAUST

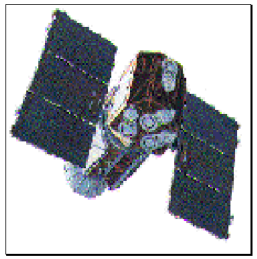
ALEXIS

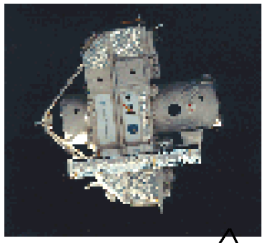
IMAGE

COS HST

1992 1993 1994 1995 1996 1997 1998 1999 2000 2000 2002 2003 2004

EUVE





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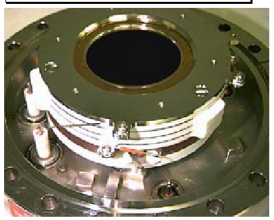

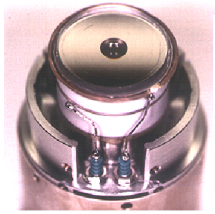

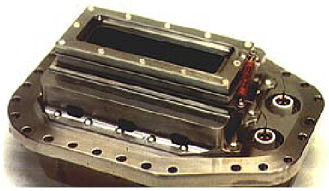

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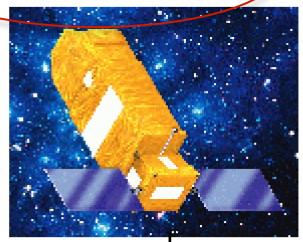

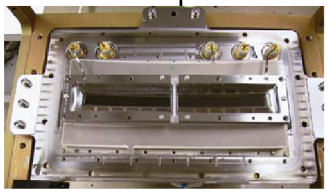

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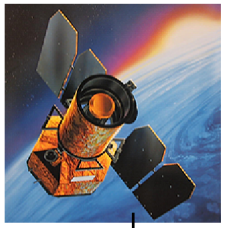

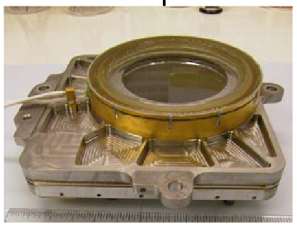

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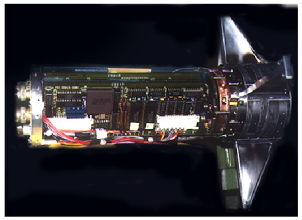
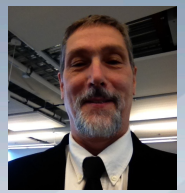
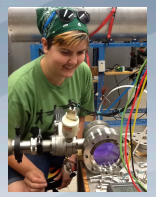


Validation and Verification of Next Generation FORTIS*

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





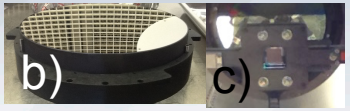
PI: Stephan McCandliss/JHU

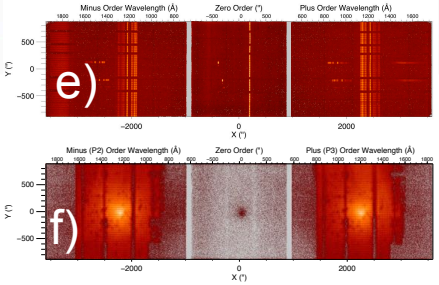
Description and Objectives:

- Demonstrate the scientific utility and feasibility of multi-object spectroscopy over wide angular fields in the far-UV. Proposed Science Investigations include:
  - Blue Stragglers in Globular Clusters; Low Metallicity Star Formation in Magellanic Bridge; Shocks in SNe Remnants; Unidentified Emissions in Star-forming Galaxies

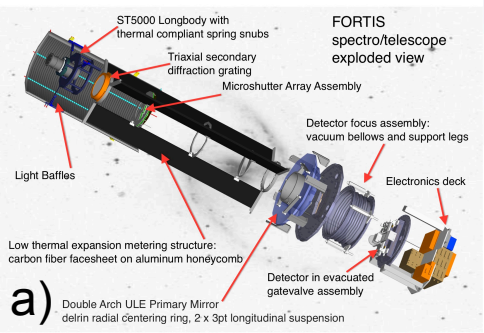
Key Challenge/Innovation:

- Two bounce Spectro/Tele; Dual-order Off Rowland-circle grating
- Pulsed Actuated Next Generation Microshutter **Arrays(NGMSA)**
- Autonomous Targeting System
- **Longlife**, High QE, Large Area Borosilicate Microchannel Plates
- New Low scatter baffles to trap geo-Lyman alpha light





a)FORTIS exploded view
b)Off Rowland-circle grating
c)MSA(JWST) on prime focus mount
d)Large Area MCP detector 170 x 43 mm^2
e)Single Slit Spectrum of Deuterium Lamp
f)Comet ISON Hydrogen and Carbon images



Approach:

- Fly FORTIS as a Sounding Rocket Experiment
- Collaborate with GSFC Partners to define NGMSA technical requirements and fabricate flight system
- Work with Sensor Sciences retrofit existing detector with new borosilicate plates coated with CsI photocathode
- Analysis and reproduce flight scattered light profiles in laboratory. Design light traps (Wood's Horn) to eliminate
- Involve **graduate** and **under**graduates in tech devel, calibration, I&T, launch, data analysis, publication of results

Key Collaborators:

- Keith Redwine (Grad Student), Anna Carter (Under Grad), Paul Feldman, William Blair, Luciana Bianchi – JHU
- Gerhardt Meurer – Univ. of West Australia
- S. **Harvey Moseley**, Alexander Kutyrev, Mary Li – GSFC

Development Period:

- 2017 January 1 – 2021 December 31

Accomplishments and Next Milestones:

- Three flights of FORTIS have proven basic design
- Science results on Comet ISON have been published
- Baseline in-flight instrument performance established:
  - Scattered geo-Lyman alpha tall pole identified
- Upcoming milestones inlcude:
  - Develop Wide Field Lyman-alpha Simulator WFLaGS
  - Reproduce in-flight scatter signature
  - Eliminate scatter points in optical train
  - Validate new low scatter baffle design
  - Verify instrument performance prior to flight
  - Fly, learn more, publish, fix, fly, learn more, publish, fix…

Application:

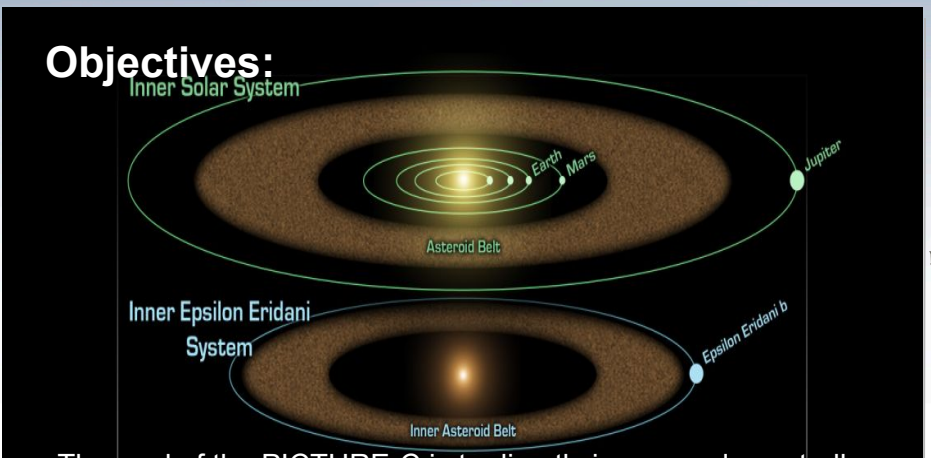
- **Explorers**
- **Probes**
- **LUVIOR**

New Tech	*TRLin =*	*TRLcurrent =*	*TRLtarget =*
Borosilicate MCPs	3	4	7
NGMSA	3	4	7
Low Scatter Baffles	3	5	7

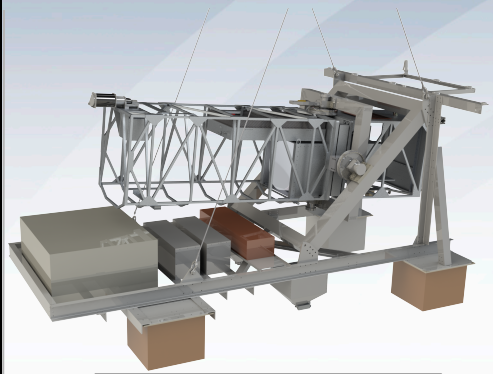
Planetary Imaging Concept Testbed Using a Recoverable Experiment - Coronagraph (PICTURE-C)

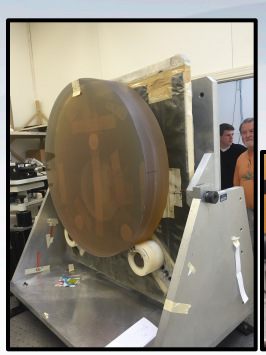
UMASS LOWELL
Learning with Purpose

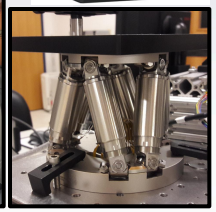
Objectives:

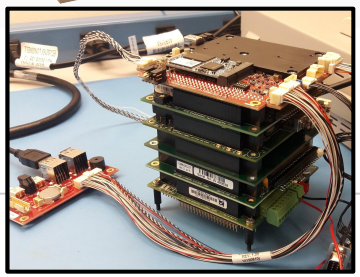


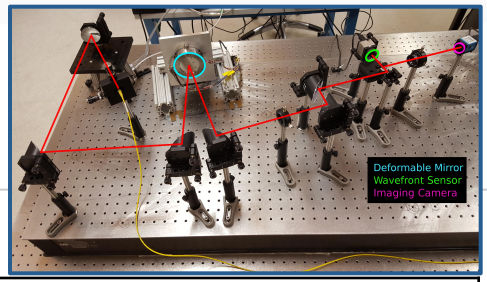
The goal of the PICTURE-C is to directly image and spectrally characterize dust and debris orbiting nearby stars with the possibility of discovering bright, gas giant exoplanets.











Approach: Two High-altitude balloon flights

Flight 1	Flight 2
Prototype VVC	**Next Gen VVC (LUVOIR)**
Contrast: 10^{-4}	Contrast: 10^{-7}
CCD Camera	**MKID (LUVOIR)**
No high-order DM	**32x32 Xinetics DM (WFIRST)**
24” Off-Axis Telescope + 6-axis Hexapod M2; LOWFC: 76ch DM + Tip/Tilt/Piston Xinetics IWC; Shack-Hartmann & Reflective Lyot Stop LOWFS	

Date	Item / Status
6/2017	Mechanical &thermal and structural analysis complete.
7/2017	**CDR**
12/2017	Instrument assembly & test.
12/2017	32x32 DM delivery from Xinetics
3/2018	Final instrument testing @ UML
4/2018	Instrument delivery to WFF
6/2018	**Flight 1: Palestine, TX**
10/2018	Instrument refurbishment, Integrate DM, Instrument testing.
4/2019	MKID integration, Broadband EFC testing.
5/2019	Payload delivery to WFF
9/2019	**Flight 2: Ft. Sumner, NM**

LOCSST

FIREBall-2: Trailblazing observations of the space UV circumgalactic medium.

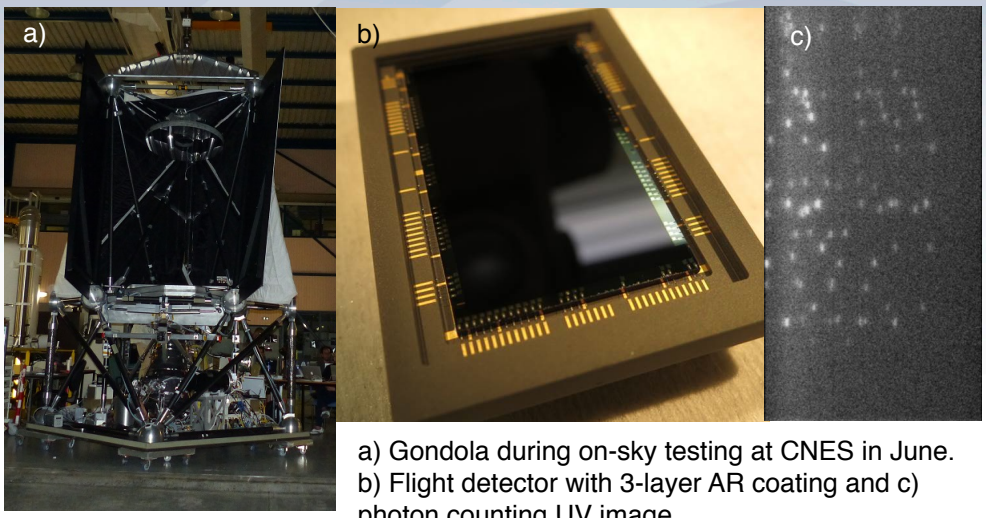
PI: Christopher Martin, Project Scientist: **Erika Hamden(RTF)**

Objective

FIREBall-2, the Faint Intergalactic medium Redshifted Emission Balloon, is designed to discover and map faint emission from the Circumgalactic Media of z=0.7 galaxies. This payload contains a multi-object spectrograph fed by a 1-m telescope, and serves as an ideal platform for testing new strategic UV photon counting detector technology.

Key Challenge/Innovation

- FIREBall-2 will provide a flight test of a **delta-doped, UV optimized CCD**, with efficiency >50% in the bandpass.
- First attempt to observe the CGM/IGM at UV wavelengths, probing the era of declining star formation.
- Challenging optical design, acquisition, and guidance (~1") challenges.



a) Gondola during on-sky testing at CNES in June. b) Flight detector with 3-layer AR coating and c) photon counting UV image

Approach:

•FIREBall-2 team has worked in close collaboration with JPL to develop and test high UV efficiency detectors. These tests include QE measurements as well as read noise, CIC, cosmic ray, and dark current noise contributions. Improved optical coatings and gratings will also improve throughput significantly.

•FIREBall-2 will observe 200+ galaxies and QSOs over 1 night with high likelihood of CGM detection.

Co-Is:

Bruno Milliard, Robert Grange (LAM, France)
Shouleh Nikzad (JPL)
David Schiminovich (Columbia)
Graduate Students: 3 completed PhDs (2 Columbia, 1 Caltech). Current students: Nicole Melso, Julia Gross, Donal O'Sullivan, Jose Zorilla.

Key Milestones

- Delivery of major EMCCD components (flight board, cryocooler, cold finger, and charcoal getter: 06/16
- Delivery of major guider components and initial 4 axis closed loop guidance testing and on sky-testing: 09/16
- Installation of flight delta-doped detector (QE >50%): 03/17
- Final integration, on-sky, and end-to-end testing: 06/17
- Shipment of gondola and spectrograph: 07/17
- Flight expected from Ft. Sumner, NM: 09/17

Applications

- **Pathfinder for detector performance, optical coatings, and design for future Explorers and Flagship class missions (including LUVOIR, in gap list)**
- Complementary to other NASA funded projects including SATs and WFIRST
- Will open a new field of CGM/IGM research at low redshifts.

TRL_{in} = 4, TRL_{target} = 6

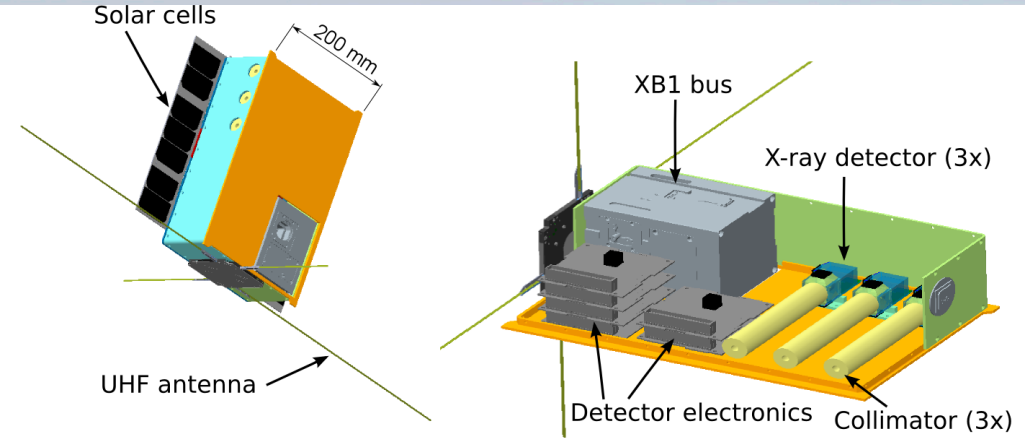
Current Award Period: 01/17-12/19

Astrophysics CubeSat/SmallSat Approach

- Astrophysics CubeSats are solicited annually via ROSES/ APRA (D.3).
- CubeSats are reviewed along with other sub-orbital proposals; they compete with balloons and sounding rockets (and potentially ISS attached payloads).
- The largest CubeSats that are eligible for CSLI (= launch at no cost to PI or APD) are 6U.
- Over the past 4 years we have received ~10 CubeSat proposals/year; 2 have been selected.
- Approximately two more CubeSats **may** be selected from the APRA-2016 proposals, bringing the APD total to 4.
- Starting FY19, there will be a $5M/year augmentation to R&A for CubeSats, which will allow 1 new selection/year.

HaloSat

A CubeSat to study the hot Galactic Halo



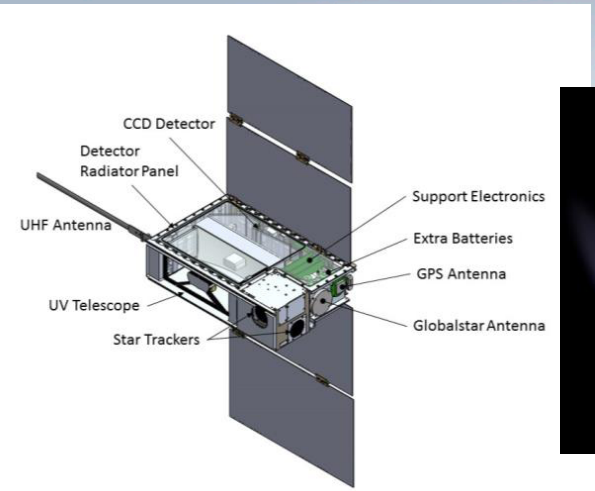
- **PI**: Phil Kaaret, U Iowa, Co-I WFF, GSFC, JHU, CNRS
- **LRD**: 3 years from initiation
- **Science Objectives:** HaloSat will map the distribution of hot gas in the Milky Way and determine whether it fills an extended, and thus massive halo, or whether the halo is compact, and thus does not contribute significantly to the total mass of the Milky Way.
- **Operations**: 2 month minimum, 1 year goal

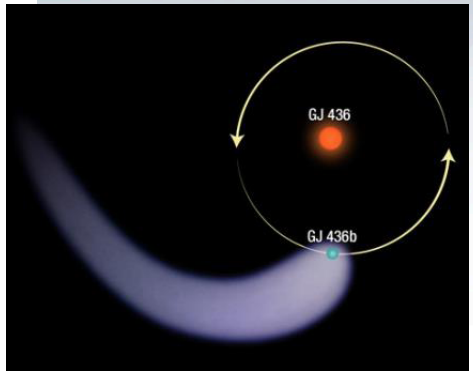
Key Facts:

- **Science**: Constrain the mass and spatial distribution of hot gas associated with the Milky Way by mapping the emission in the O VII and O VIII lines. This goal can be achieved by mapping the summed intensity of the O VII and O VIII lines to derive a total emission measure for each field. Limit background from SWCX via observing only at night.
- **Technologies:** 6U CubeSat advancing science, using COTS technologies. Blue Canyon Technologies bus, WFF design and assembly, Amptex commercial detectors, 100 square degree FOV.
- **Timeline:** APRA-2014 selection, Tentative April 2018 Launch!
- **Orbit**: ISS like.

CUTE

A CubeSat to study atmospheres and B-fields in ExoPlanets





- **PI**: Kevin France, CU, multiple s/r programs, two Helio cubesats at CU.
- **LRD**: 3 years from initiation
- **Science Objectives:** The Colorado Ultraviolet Transit Experiment (CUTE) will take multiple medium resolution UV spectra of hot Jupiters during transit, in order to measure the composition of the atmosphere being ablated away. Magnetic fields may be detected via the presence of tori or bow shocks. 14 targets.
- **Operations**: 1 month minimum, 6 month full survey of 14 exoplanets (2 done to date)

Key Facts:

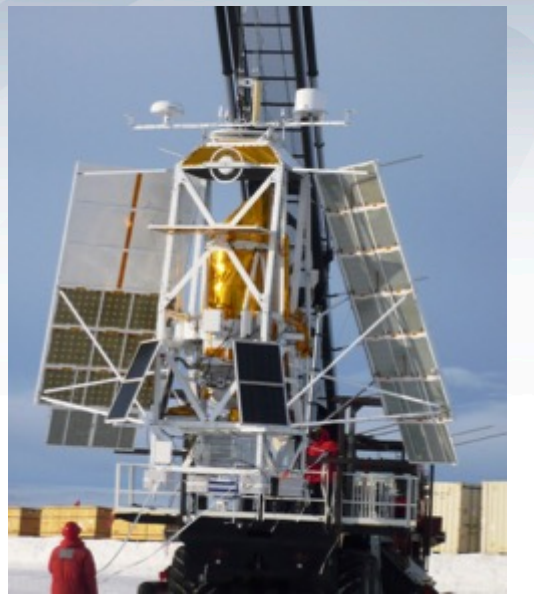
- **Science**: The atmosphere on two hot Jupiters is observed to be ablating away due to early ingress/ late egress in the UV or X-ray. The UV has multiple diagnostic lines which can determine the structure and geometry of the atmospheres. This would be the first UV survey of hot Jupiter atmospheres. This would compliment the sole existing APD cubesat, which is X-ray.
- **Technologies:** 6U CubeSat advancing science, using COTS technologies. Blue Canyon Technologies bus, **e2v UV-CCD (LUVOIR, WFIRST)**, exiting cubesat downlink station.
- **Timeline:** APRA-2015 proposal, Selected Feb 2017. LRD mid 2019.
- **Orbit**: ISS like okay, sun synchronous better

FIR, Sub-mm (CMB) Balloon Science Flights

- BOOMERanG – CMB anisotropy payload; flew 1998 & 2003
  - Discovery published in 2000 that geometry of universe is close to flat
  - **Demonstrated spiderweb bolometer technology → infused to *Herschel*/SPIRE**
- TopHat - CMB polarization anisotropy payload; flight 2001
- MAXIPol – CMB polarization anisotropy payload; flights 2002 & 2003
  - One of the first experiments to probe CMB polarization anisotropy
- BLAST – far-IR imaging payload; science flights in 2005 & 2006
  - Studied high-*z* star formation; diffuse Galactic emission
  - **Flew engineering arrays for *Herschel*/SPIRE, proving performance pre-launch**
- ARCADE – CMB spectrum payload; flights 2005 & 2006
- BLAST-Pol – far-IR polarimetric payload; flights 2010 & 2012,
  - Studies magnetic fields in the galaxy & role in star formation
- COFE – diffuse polarized foregrounds; flight 2011
- STO – far-IR heterodyne spectroscopic mapper; flight 2012
  - **Receiver technology infused to SOFIA UpGREAT instrument**
- EBEX – CMB polarization anisotropy payload; flight 2012
  - First suborbital flight of superconducting transition-edge sensor bolometers
- SPIDER - CMB polarization anisotropy payload; flight 2014
- STO-2 – upgraded STO; flight 2016
  - **Technology being transitioned to GUSTO**

Re-flight of the Stratospheric Terahertz Observatory: STO-2

PI: Chris Walker / U of Arizona



Description and Objectives:

Conduct Milky Way and LMC surveys in [CII], [NII], and [OI] to:

- Study the life cycle of Galactic interstellar gas.
- Study the creation and disruption of star-forming clouds.
- Determine the parameters that affect the star formation rate.
- Provide templates for star formation and stellar/interstellar feedback in other galaxies.

Key Challenge/Innovation:

- Successfully integrate state-of-the-art THz heterodyne receiver systems on a balloon-borne observatory.
- Implement a state-of-the art guidance & control system to meet pointing requirements.

Approach:

- Use an existing 0.8 meter aperture, balloon-borne observatory to perform On-the-Fly mapping of ~35 square degrees of the Galactic Plane and ~1 square degree of the LMC at ~1 arc minute resolution.
- Leverage from receiver development efforts at JPL, SRON.

Key Collaborators:

- Pietro Bernasconi (APL), Jon Kawamura (JPL)
- Paul Goldsmith (JPL), J. R. Gao (SRON)
- Qing Hu (MIT), Chris Groppi (ASU)
- Gary Mills (BATC) Craig Kulesa (UofA)

Development Period:

- Derived from STO
- I&T in Antarctica 2015/2016, but weather prevents launch
- Flight 2016/2017 season

Accomplishments and Next Milestones:

- 2016: Flight from McMurdo, Antarctica
- Next: Data analysis

Application:

- FIR astrophysics and planetary science missions.
- Technology application to **GUSTO**
- STO receivers **-> SOFIA UpGREAT**

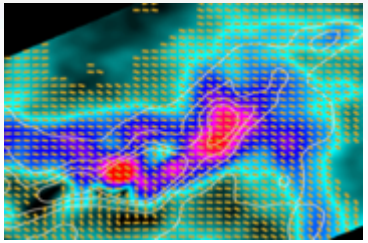
TRLin = 5 ***TRLcurrent = 8*** ***TRLtarget = 9***

Balloon-borne Large Aperture Submillimeter Telescope – Polarimeter (BLAST-Pol)

PI: Mark Devlin / UPenn

Description and Objectives:

- Map far-IR polarization to understand Magnetic Fields and Turbulence in Star Formation
- Provide guest observer capability for dust polarization



Key Challenge/Innovation:

- Dual-polarization MKID detectors
- New 2.5m carbon fiber mirror

Approach:

- 16x mapping speed improvement over BLASTPol

Key Collaborators:

- Northwestern, Stanford, ASU, NIST, Cardiff, et al.

Development Period:

- Derived from BLAST
- Polarimetric flights 2010 & 2012
- Upgraded detectors for future flights

Accomplishments and Next Milestones:

- Fabrication well underway
- Anticipate Antarctic flight 2018/2019 season

Application:

- Detect polarization & inferred magnetic fields at angular scales to bridge *Planck* all-sky and ALMA detail
- BLAST flew **Herschel/SPIRE engineering arrays**

TRLin = *TRLcurrent =* *TRLtarget =*

Primordial Inflation Polarization Explorer (PIPER)

PI: Al Kogut / GSFC

Description and Objectives:

- Sub-orbital mission to measure polarization of the cosmic microwave background in search of inflationary signature
- Only NASA mission testing inflation on angular scales larger than 20 deg where inflation signal separates from lensing
- Characterize signature of reionization / first stars
- Provide legacy maps for dust polarization

Key Challenge/Innovation:

- Cryogenic optics increase mapping speed by factor of 10
- Conventional balloon flight enables high sky coverage
- Polarization modulator enables reliable mapping on largest angular scales

Approach:

- "Observe the sky, the whole sky, and nothing but the sky"
- 5120 background-limited detectors
- Front-end polarization modulation at 3 Hz
- Series of 8 conventional balloon flights

Key Collaborators:

- GSFC, Johns Hopkins, NIST, University of Michigan, University of British Columbia

Development Period:

- Initial development begun 10/08
- First flight 9/16
- Eight-year development typical of CMB payloads

Accomplishments and Next Milestones:

- 2016: Full system integration
  Engineering flight (Ft Sumner, NM)
- Next: Science flights begin May 2017
  Back-to-back flights from Palestine, TX

Application:

- Detect signature of primordial inflation to limit $r < 0.007$
- Circular polarization to test exotic physics
- Develop technology for **Inflation Probe**

TRLin = 3--5 ***TRLcurrent = 5*** ***TRLtarget = 6***

Suborbital Polarimeter for Inflation, Dust & the Epoch of Reionization (SPIDER)

PI: Bill Jones / Princeton

Description and Objectives:

- CMB Polarimeter @ 94, 150, 285 GHz
- Science: to detect primordial fluctuations by confirming:
  - Spectral energy distribution
  - Angular power spectrum
  - Statistical isotropy

Key Challenge/Innovation:

- New NIST-produced 285GHz detectors

Approach:

- Build a double-Fourier interferometer, based upon experience with the SPIRIT mission design study and the WIIT testbed

Key Collaborators:

- U Toronto/CITA, NIST, UBC, Case-Western, JPL, Cardiff, U Illinois, UKZN, Oslo

Development Period:

- Continuation (second flight) of SPIDER payload
- Project duration through end FY18

Accomplishments and Next Milestones:

- Flight taking place 2017/2018 season

Upcoming

- Final Detector Testing
- Optical Alignment
- System-level tests

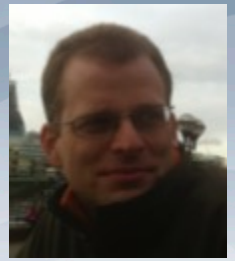
Application:

- Detect signature of primordial inflation (or upper limit)
- Develop technology for **Inflation Probe**

TRLin = **<#>** *TRLcurrent* = **<#>** *TRLtarget* = **<#>**

Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII)

PI: Stephen Rinehart, GSFC

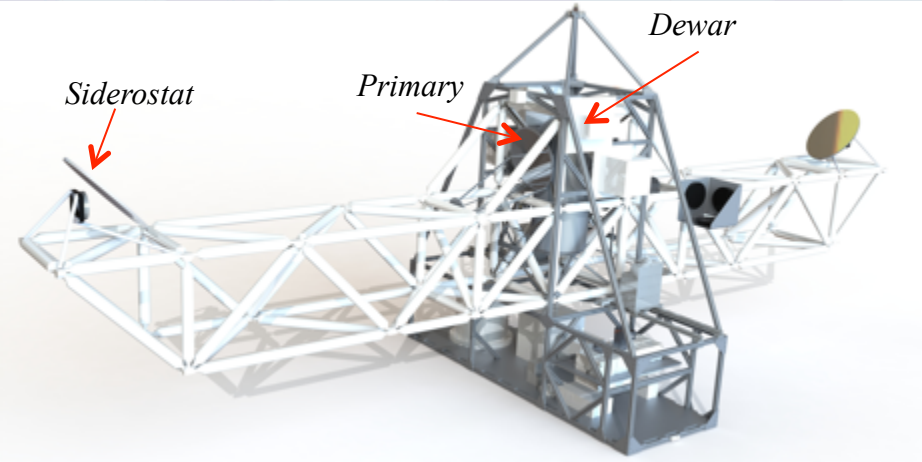


Description and Objectives:

- Develop a new Far-IR interferometer to fly on a high-altitude balloon
- Demonstrate technical feasibility and techniques for FIR interferometry
- Study early stages of star formation in clusters

Key Challenge/Innovation:

- System demonstration of free-flying interferometer



Approach:

- Build a double-Fourier interferometer, based upon experience with the SPIRIT mission design study and the WIIT testbed

Key Collaborators:

- Majority of team members at GSFC
- Co-Investigators from University of Maryland
- Collaborators at the University of Cardiff, University College London, and the FITE team in Japan

Development Period:

- Program started 1/1/2011, end program 10/31/2016

Accomplishments and Next Milestones:

- Design complete
- All major components in procurement
- Control system complete and in test
- Cryostat complete and in test

Upcoming

- Final Detector Testing
- Optical Alignment
- System-level tests

Application:

- Study of star formation
- Laying foundation for **future space-based interferometers**

TRLin = **<#>** *TRLcurrent* = **<#>** *TRLtarget* = **<#>**

APRA High-Energy Suborbital Portfolio

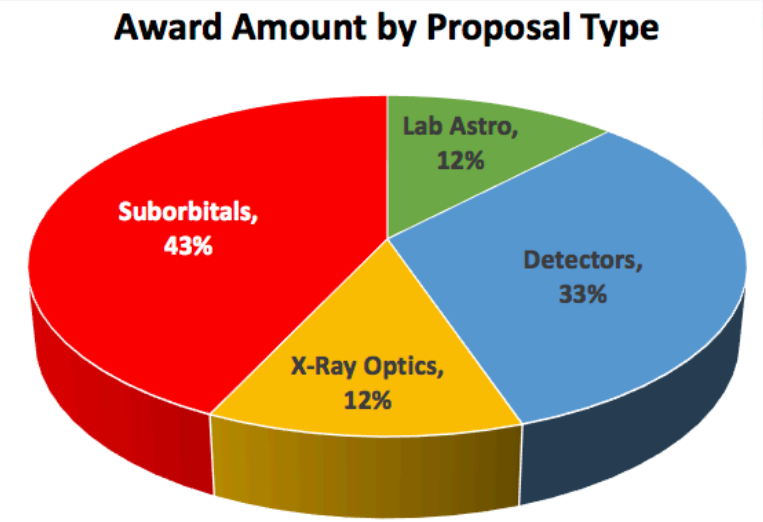
- Suborbitals make up **~40% of the entire HEA APRA** portfolio in terms of funding
- Suborbital proposals have **~30% acceptance rate** of over the past 5+ years
- APRA HEA portfolio currently supports **9 suborbital investigations**:

X-ray sounding rocket experiments:

CXP, Dan McCammmon (U Wisconsin)
Micro-X, Tali Figueroa (NWU)
DXL, Massimiliano Galleazzi (U Miami)
OGRE/WRX-R, Randy McEntaffer (PSU)

Gamma-ray balloon payloads:

COSI, Steve Boggs (UC San Diego)
X-Calibur, Henric Krawczynski (WUSTL)
ASCOT, Peter Bloser (UNH)
GRAPE, Mark McConnell (UNH)
ComPair, Julie McEnery (GSFC)

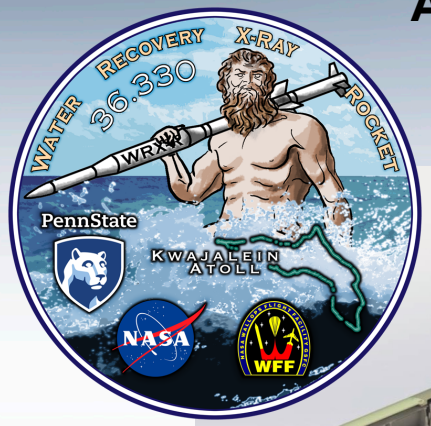


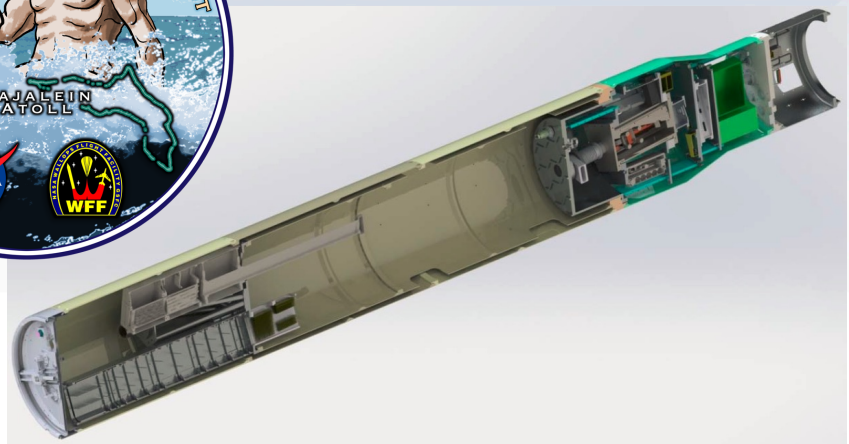
+ detectors and supporting technology investigations that will lead to suborbitals

- Suborbital programs are used to **test new technologies and advance TRL levels**
- Offer **unique science** (e.g., soft X-ray background, hard X-/gamma-ray polarization)
- High **student + postdoc** participation to train future leaders (evaluation criteria)

Water Recovery X-ray Rocket (WRX-R)

A suborbital rocket for diffuse X-ray spectroscopy





- **PI**: Randall McEntaffer, PSU
- **Science Objectives:** WRX-R will observe the diffuse soft X-ray emission from the north-central 10 sq deg of the Vela supernova remnant. This will be the first spectrally resolved measurement of this region of the remnant.
- **Operations**: Suborbital payload. April 2018 launch date. First telescope payload launched and recovered at Kwajalein Missile Range in the Marshall Islands.

Key Facts:

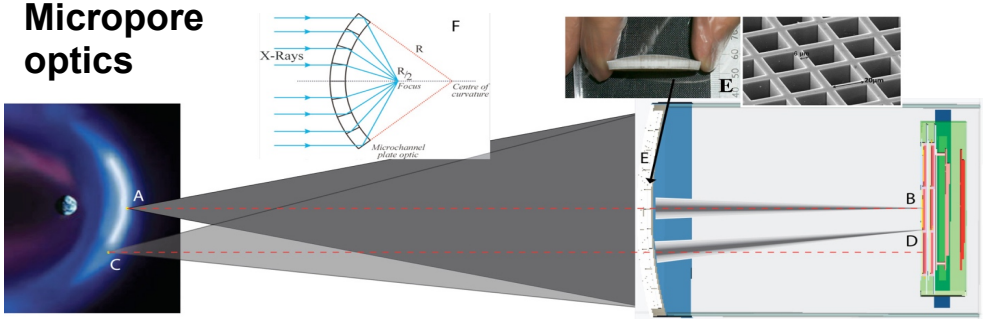
- **Science**: Provide a spectrally resolved observation of the soft X-ray line emission from the Vela supernova remnant. The lines of interest include OVII, OVIII, and CVI.
- **Technologies:** Key PCOS technologies will be tested during the WRX-R flight. This will be the **first flight of hybrid-CMOS active pixel sensor detectors for X-ray astronomy (Lynx)**. This will also be **the first flight of large format, replicated, off-plane reflection gratings (Lynx)**. The payload will also test NASA **water recovery technologies (Southern sky)** for suborbital payloads such as a water attitude control system, hermetic telemetry section, NFORSe recovery system, and water impact shutter door.
- **Timeline:** Launch in April 2018
- **Orbit**: Suborbital, ~240 km apogee

Diffuse X-rays from the Local Galaxy (DXL)

A sounding rocket mission to study the properties of the Local Hot Bubble (LHB) and Solar Wind Charge eXchange (SWCX)

The DXL Payload

Micropore optics



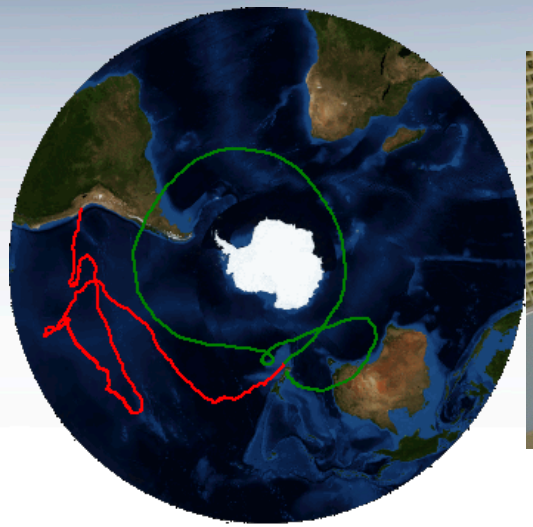
- **PI**: Massimiliano Galeazzi, University of Miami, Co-Is NASA/GSFC, U. Wisconsin, JHU
- **Science Objectives:** characterize the X-ray emission from LHB and SXCX and study the physical parameters of these objects.
- **Operations**: 2 successful flights, one scheduled, 12/12/12, 12/6/15, January 2018

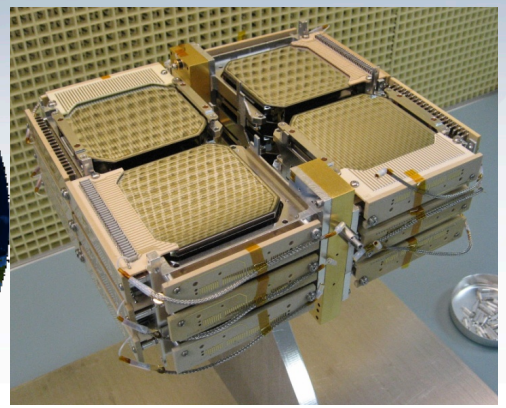
Key Facts:

- **Science**: SXB: DXL has confirmed that the Sun is in a bubble of million degree gas extending hundreds of light years in all directions, likely caused by multiple supernova explosions. SWCX: DXL has characterized the contamination due to SWCX to diffuse X-ray studies, which is critical to almost every past, present, and future soft X-ray mission.
- **Technologies:** mechanically collimated proportional counters.
- **New technology development:** DXL was the **first mission flying newly developed micropore optics** (as piggyback experiment), qualifying them for space. The technology is now being considered for several missions, including for a **future all-sky monitor**.
- **Scientific publications**: 7 peer reviewed publications so far (including 1 Nature, 1 ApJL, 2 ApJ) and 3 more in preparation (ApJ expected).
- **Timeline:** Next launch in January 2018
- **Orbit**: Suborbital, ~240 km apogee

The Compton Spectrometer and Imager (COSI)

A Balloon-Borne Gamma-Ray Survey Telescope



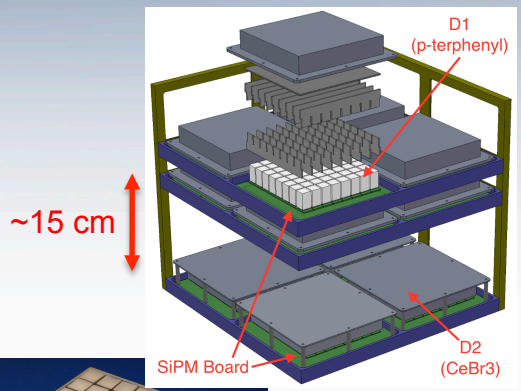


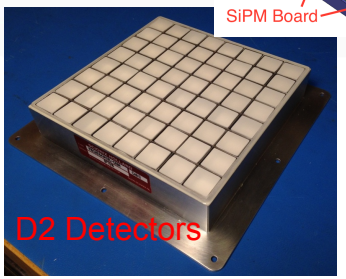
- **PI**: Steven Boggs, UC San Diego/UC Berkeley
- **Science Objectives:** Uncover the origin of positrons by mapping positron annihilation emission (0.511 MeV) from Galaxy. Study the creation of new elements in our Galaxy by mapping elements recently produce in supernova explosions (^{26}Al, ^{60}Fe, ^{44}Ti). Use novel polarimetry of Gamma-ray Bursts (GRBs), pulsars, X-ray binaries, and AGN to study the underlying source geometries and emission processes in these sources.
- **Operations**: COSI is the first science payload designed to fly on **NASA's superpressure balloon** with fully autonomous operations and full real-time science data download for 100+ days.

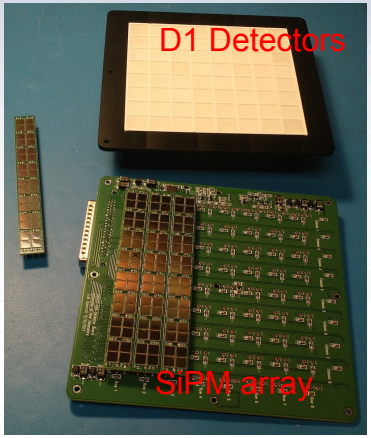
Key Facts:

- **Science**: Mapping positron annihilation emission at the Galactic Center through the annihilation lines. Study evolution of the elements through the radioactive decay of supernova products (26-Al, 60-Fe, 44-Ti). Explore polarimetry of Gamma-ray Bursts (GRBs), pulsars, X-ray binaries, and Active Galactic Nuclei to better understand emission processes and source geometries.
- **Technologies:** Large, high spectral resolution germanium gamma-ray sensors with full 3-D position resolution, including readout and cooling technologies. **40 times more effective at detecting gamma-rays compared to COMPTEL in an extremely compact payload.**
- **Timeline:** APRA-2012 selection; Antarctic flight December 2014; COSI underwent a successful 46-day science flight in 2016.
- **Orbit**: mid-latitude SPB at 110,000 feet.

Advanced Scintillator Compton Telescope Balloon Payload (ASCOT)





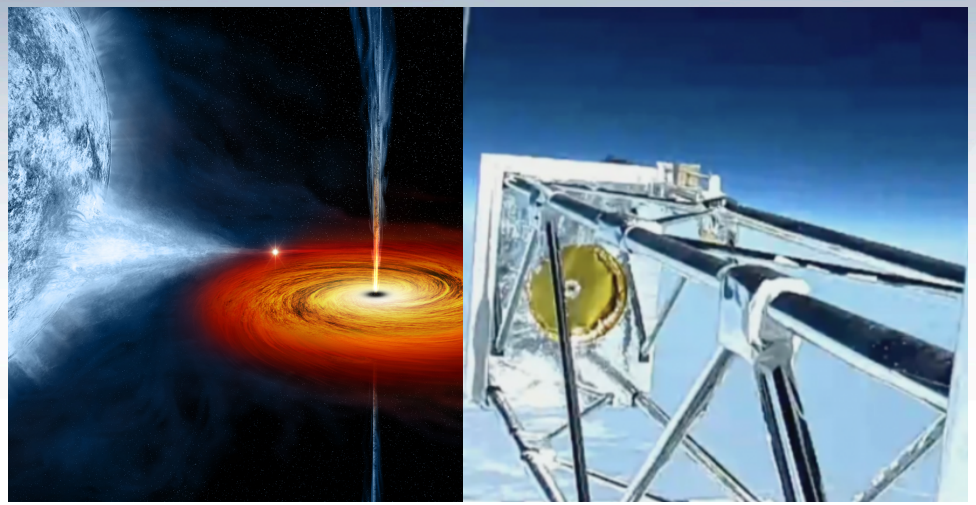


- **PI**: Peter Bloser, University of New Hampshire
- **Science Objectives:** The ASCOT balloon payload will image the Crab Nebula from ~0.2 – 2 MeV during a single transit in order to **demonstrate the performance of modern scintillator/SiPM detector technology for MeV gamma-ray astronomy**.
- **Operations**: Scientific balloon payload to be launched by CSBF from Palestine, TX in the summer of 2018. 7+ hours at float desired (minimum 4 hours).

Key Facts:

- **Science**: MeV gamma-ray imaging, spectroscopy, and polarimetry of cosmic sources, including black hole binaries, pulsars, AGN, GRBs, and nuclear lines. Balloon flight will demonstrate technological approach by imaging Crab Nebula in 0.2 – 2 MeV band.
- **Technologies:** Advanced scintillator materials: p-terphenyl organic crystal (D1) and Cerium Bromide (D2). Silicon photomultiplier (SiPM) light readouts. Fast electronics for pulse height, pulse shape, and time-of-flight (ToF) readout. Balloon flight will raise TRL to 6/7, permitting consideration **for future CubeSat, SmallSat, Explorer,** and other space flight applications.
- **Timeline:** APRA-13 selection. Launch expected summer 2018.
- **Orbit**: Scientific balloon flight from Palestine, TX. Minimum 120kft float altitude (>130kft desired). Minimum 4 hours at float (>7 hours desired).

X-Ray Polarization Studies of Black Holes and Neutron Stars (X-Calibur)



- **PI**: H. Krawczynski (Wash. U. St. Louis), Collaborators: D. Stuchlik (WFF), T. Okajima (GSFC).
- **Science Objectives:** X-Calibur observes mass accreting black holes, neutron stars, and pulsars. The observations probe the behavior of matter close to the event horizons of black holes, and the new exotic physics of highly magnetized neutron stars.
- **Operations**: Long observations with **0.5 arcsec pointing stability (WASP)** on conventional and long duration balloon flights.

Key Facts:

- **Science**: (i) Constrain accretion disk and corona geometries of mass accreting black holes; (ii) reveal high-energy particle acceleration mechanisms in X-ray pulsars; (iii) study quantum electrodynamics in strong-field regime.
- **Technologies:**
  First hard X-ray polarimeter making use of focusing X-ray mirror and scattering polarimeter, 8m long telescope pointed with <0.5 arcsec pointing stability by WASP (WFF), rotating semiconductor polarimeter (CZT) in active CsI shield. X-Calibur uses **INFOCuS (GSFC, Nagoya) segmented thin-foil mirror technology used by NuSTAR and Hitomi HXT.** Polarimetry analysis software can be used for IXPE.
- **Timeline:**
  9/17/2016: one-day balloon flight (Fort Sumner, NM).
  12/2018: 30-50 day long duration balloon flight from Antartica.
- **Orbit**: Suborbital, altitude: 125,000 feet.

Suborbital Particle Astrophysics Payloads

- The Particle Astrophysics (PA) APRA portfolio is predominately suborbital activities, i.e. design, construct, flight, and analysis of missions that addressing critically important questions to the sources, acceleration mechanism, and composition of cosmic radiation.
- In PA suborbital missions means nearly exclusively balloon payloads, since they offer both high lift capacity and long observation time (LDB) enabling large exposure factors needed to measure the steeply falling cosmic-ray flux at the higher energies or at higher charges.
- While in other disciplines suborbital mission are often use as stepping stone to demonstrate/advance a detection techniques or technologies for future space missions. In PA the balloon payloads are the may research platform to conduct cutting-edge research.
- Since APRA -10 ISS attached payloads are permitted under APRA. ISS-CREAM is the first mission that converted a balloon payload into a Space Station attached payload and is scheduled to be launched next month.

Current PA Suborbital Missions

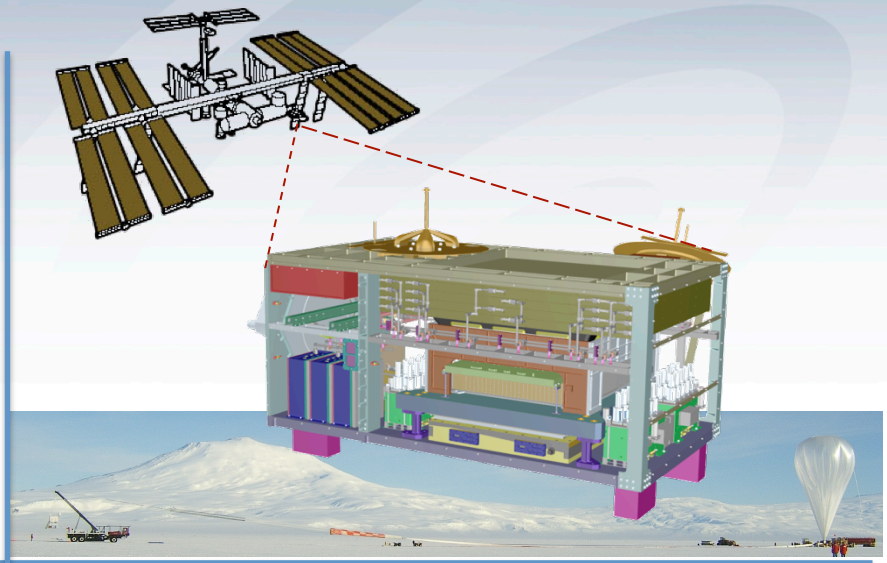
Wide range of important cosmic-ray research is currently supported by the APD R&A effort in Particle Astrophysics; From the highest energies with EUSO greater than 10^{18} eV to down to a few ~10^{8} eV with GAPS.

- Antarctic Impulsive Transient Antenna (ANITA)
- Extreme Universe Space Observatory (ESUO SPB)
- US science support of CALorimetric Electron Telescope (CALET)
- Cosmic Ray Energetics And Mass (CREAM)
- General Antiparticle Spectrometer (GAPS)
- HELIX (High Energy Light Isotope eXperiment)
- SuperTIGER (Trans Iron Galactic Element Recorder)

Cosmic Ray Energetics And Mass (CREAM)

Description and Objectives:
CREAM extends the energy reach of direct measurements of cosmic rays to the highest energy possible to probe their origin, acceleration and propagation.

Key Challenge/Innovation:
A challenge of multi TeV measurements is that the detectors must be large enough to collect adequate statistics, yet stay within the weight limit available for balloon flight. Innovative detector design allows cosmic ray measurements an energy range that was not previously possible.



Approach: Measurements of cosmic ray energy spectra from 10^{12} to $>10^{15}$ eV over the proton to iron elemental range. The instrument consists of multiple particle detectors including sampling tungsten/scintilliating-fiber Calorimeter preceded by a graphite Target for energy measurements and finely pixelated Silicon Charge Detector for particle identification.

Development period: ISS-CREAM payload was delivered to NASA Kennedy Space Center in August 2015 to await its launch to the ISS. Currently launch on SpaceX-12 is scheduled for August 10, 2017.

E. S. Seo, Univ. Maryland, PI, Key Collaborataors: Penn State, GSFC, Northern Kentucky U, SKKU (Korea), LPSC (France), UNAM (Mexico).

Accomplishments/Milestones: Balloon-borne CREAM was flown 7 times over Antarctica with ~191 days of total flight time, the longest exposure to date for a single balloon project. It discovered discrepant hardening of elemental spectra at high energies. More than 100 students were trained, and >12 Ph.D.'s were produced.

Application: Building on success of the balloon flights, the payload has been transformed for accommodation on the ISS. This ISS-CREAM would greatly reduce the statistical uncertainties and extend CREAM measurements to energies beyond any reach previously possible. At least an order of magnitude increase in the exposure is expected.

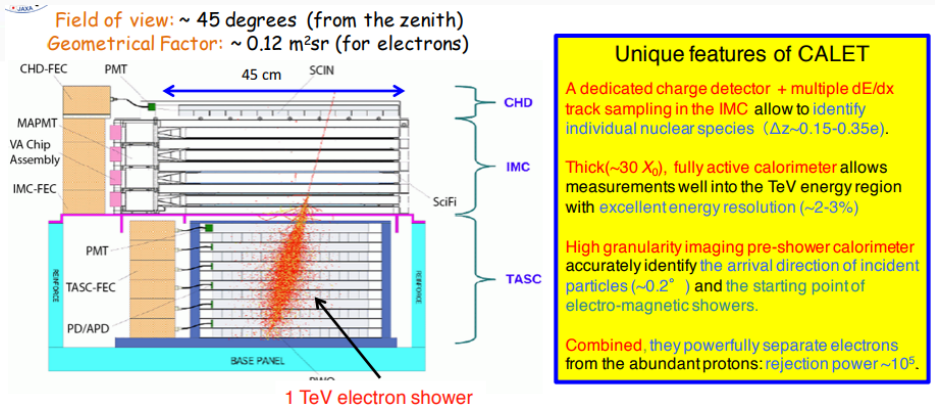
CALorimetric Electron Telescope (CALET)

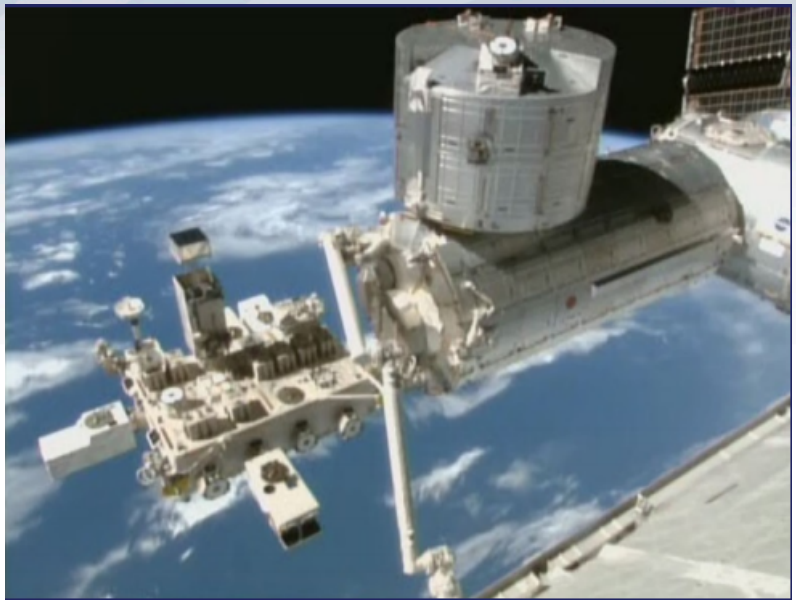
An International ISS Utilization Mission

Description and Objectives:

Science Objectives	Observation Targets
Nearby Cosmic-ray Sources	**Electron spectrum** in trans-TeV region
Dark Matter	Signatures in **electron/gamma** energy spectra in the 10 GeV – 10 TeV region
Origin and Acceleration of Cosmic Rays	**p-Fe** up to the multi-TeV region, Ultra Heavy Nuclei
Cosmic–Ray Propagation in the Galaxy	**B/C** ratio up to a few TeV /n
Solar Physics	**Electron flux** below 10 GeV
Gamma-ray Transients	Gamma-rays and X-rays in 7 keV – 20 MeV

Key Challenge/Innovation:





CALET on JEM Exposure Platform

Approach: CAL (Above) + Gamma Burst monitor. CAL consists of Charge Detector (CHD) followed by Imaging Calorimeter (IMC) followed by Total Absorption Calorimeter (TASC).

Development: Fabrication, Qualification, Test, Launch (August 2015), Check-Out, Routine Operations (October 2015).

Int. Executive Committee: S. Torii (JP), J. Wefel (US), P. Marrochessi (IT): NASA JAXA ASI: US (LSU, GSFC, WU, DU) **Japan/Italy**: Many Institutions.

Accomplishments/Milestones: Launch and Successful Operations continuing. Results for Electrons, Protons, Heavy Nuclei, Gamma Rays, Bursts/Transients.

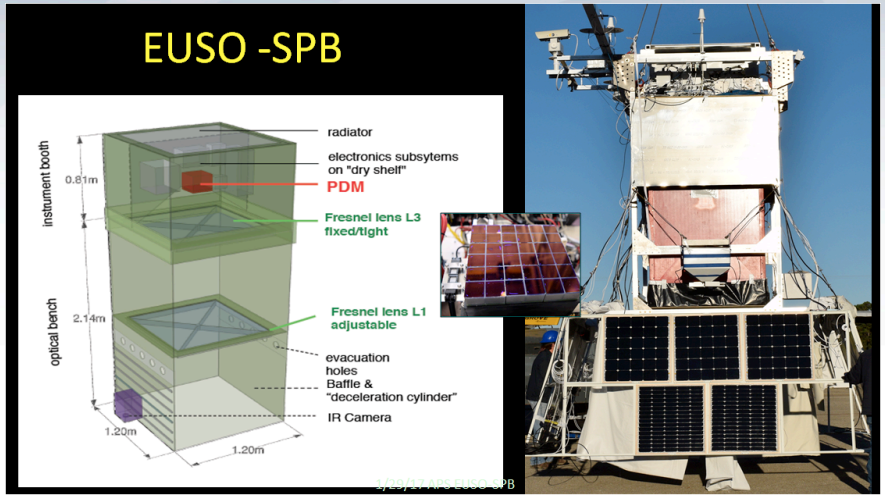
Two journal publications + numerous conference proceedings (12 papers at July 2017 Int. C.R. Conf.).

2 Graduate Students, 7 Undergraduates, 2 post-doctoral researchers.

Extreme Universe Space Observatory (EUSO-SPB)

Description and Objectives: Observe individual Ultrahigh Energy Cosmic Rays from near top of the atmosphere using air fluorescence. Ultimate goals: Discover the most energetic astrophysical accelerators; Discover cosmogenic neutrinos; Study particle interactions well above accelerator energies.

Key Challenge/Innovation: EUSO-SPB flight from Wanaka NZ successfully returned engineering and science data, proof of concept, but flight cut to 12 days due to super-pressure balloon anomaly leading to loss of payload. 1 of 2 data download links dropped out midway.



Approach: Air fluorescence view from top of atmosphere provides significantly larger detection volumes than ground based methods extending the energy reach.

Development period: Current mission, FY13-17. Proposed follow-on re-build and reflight.

A. **Olinto, U. Chicago, PI, Key Collaborators:** Colorado School of Mines, MSFC/NASA, UA Huntsville, CUNY;

B. JEM-EUSO Collaborations in Italy, France, Germany, Japan, Poland, Mexico

Accomplishments/Milestones: 8 presentations and proceedings at 35th International Cosmic Ray Conference (July 12-20 2017), including **invited highlight talk.** Successful UV detector (MAPMT) operations. Successful test of all subsystems (IR camera, 1st flight of SiPM detectors).
Aircraft under-flight with laser/flasher for in-situ calibration of 2014 (Timmins, CA) EUSO-Balloon flight.

Applications: For POEMMA (Probe of Extreme Multi-Messenger Astrophysics) and EUSO program: Technical readiness, measurements of trigger rates, UV background rates over ocean, cloud coverage, fresnel lens performance.

US Students: PhD 2, MS 3, UG 9.

Antarctic Impulsive Transient Antenna (ANITA)

Description and Objectives: ANITA is an array of broadband horn antennas synoptically observing Antarctica from stratospheric altitudes, with a goal of detecting ultra-high energy cosmic neutrinos via radio impulses produced in their collisions and resulting particle cascades within Antarctic ice sheets.

Key Challenge/Innovation: Pulse-phase radio interferometry to identify candidate events at the highest possible sensitivity in the presence of anthropogenic interference; ultra-low power GHz samplers to record RF waveforms.

Approach: Quad-ridged dual-polarized horn antennas with 200-1200 MHz bandwidth continuously search for coherent, highly polarized transient impulses, with 0.2° mapping to verify isolation from interfering sources. Custom-built low-noise RF amplifiers provide ~40K noise figure (with no cryogens) on orbit.

Development period: FY 02-07 (I), 08-11(II), 12-14 (III) Current mission, FY15-17 (IIII)

Key Collaborators: Univ. of Hawaii at Manoa (PI P. Gorham); Ohio State Univ.; Univ. of Delaware; Univ. of Chicago; Wash. Univ. St. Louis; Univ. of Kansas; Jet Propulsion Lab; Univ. Calif. at Los Angeles; SLAC/ Stanford; Cal. Poly San Luis Obispo; Univ. College London; Nat'l Taiwan Univ.

Accomplishments/Milestones: First self-triggered radio detection of ultra-high energy cosmic rays (4 Antarctic flights) (PRL 2010); Candidate tau neutrino event (PRL 2016); Completed 4th flight Dec. 2016; 23 refereed journal publications since 2006, includes 6 in Phys. Rev. Lett., and two PRL cover articles; 669 cites in 451 articles; total undergrad/grad students trained ~200; currently ~40;

Applications: developed technology includes: ultra-low-noise non-cooled RF amplifiers; broadband pulse-phase interferometry; ultra-light carbon-fiber truss structure; agile RF-interference-mitigation systems; tens-of-terabyte onboard, compact data storage systems

Summary

- Technologies - the astrophysics sub-orbital program:
  - Has infused new technologies into space flight missions.
  - Continues to mature new technologies which will be used in future space flight missions, therefore reducing risk (and cost) of future missions.

- Science – the astrophysics sub-orbital program:
  - Has allowed cutting edge science at a fraction of the cost of orbital projects.
  - Is providing new opportunities to do such science, in particular with mid-latitude long duration super-pressure balloons flights, and water recovery for sounding rockets.

- Education – the astrophysics sub-orbital program:
  - Continues to provide a path to mature the future leaders (PI) of astrophysics space flight missions, via graduate and undergraduate student and post-doc involvement.
  - Provides fellowships for such leaders in concert with the Roman Technology Fellowship program.

- Investment – the astrophysics sub-orbital program:
  - Represents approximately half the total APRA budget of ~$50M per year.
  - Supports ~3 dozen programs per year, at the rate of a few $100K to ~1$M/year each.

Backup, additional Quad Charts

Additional Particle Astrophysics Projects

The Question to Answer for the Astrophysics Advisory Committee (APAC)

"For the next suborbital report, the APAC would like to hear more about the science, and how the technology developed from that program flows into the large missions, with examples. The APAC would also like to hear how the awards line up with technology gaps."

In Particle Astrophysics in most cases the balloon payload is the mission, unlike other Astrophysics disciplines were the suborbital payload might return limited science return but certainly TRL increases. The technology gaps refer above are defined by the PCOS/COR Program Office 's Program Annual Technology Report (PATR) which leads into NASA strategic astrophysics technology (SAT) program.

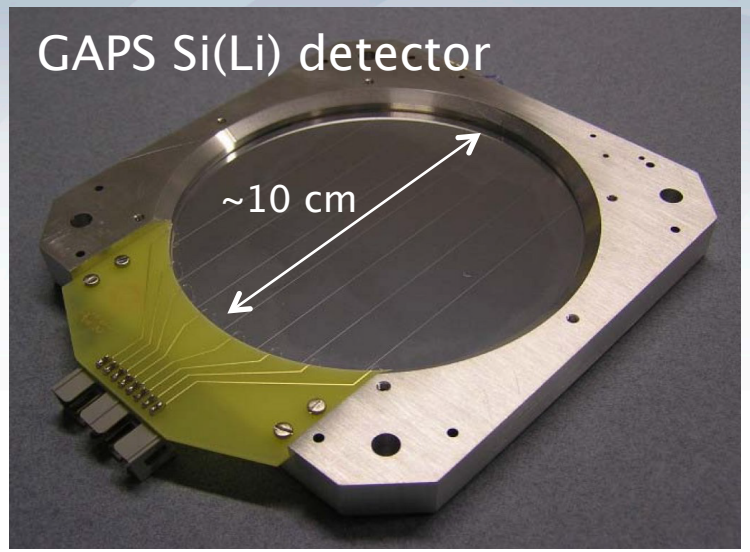
The request to the Particle Astrophysics PI is to provide a quad chart, which addresses:

1) Description and Objectives, Key Challenge/Innovation
2) Approach, Development Period, Key Collaborators
3) Picture panel
4) Accomplishments and Next Milestones (in addition project related ones , include number of Students (undergrad, grad), #science publication); Application of devel technology or technique.

General Antiparticle Spectrometer (GAPS)

Description and Objectives:
Search for ultra-low energy (<~ 0.15 GeV/n) antideuterons with 2-3 orders of magnitude better sensitivity than previous spaced-based searches. The antideuterons are a smoking-gun signature of dark matter.

Key Challenge/Innovation:
Development of large area (~20 cm^2), segmented, high resolution (~4 keV), low cost per unit area, space-qualified Li-drifted silicon detectors (Si(Li) detectors) to be deployed in ~1000 detector array.



Approach:
Exotic atom spectroscopy with silicon tracker geometry: antideuterons are captured in silicon atom, producing deexcitation X-rays of unique energies, which combined with pion and proton tracks produced in nuclear annihilation, provide a clean signature of a stopped antideuteron.

Development period:
Project start date 1/2017. 4.5 years to launch. One flight, followed by proposal for two more. Total gain in sensitivity is linear with number of launches.

Key Collaborators: Columbia University (lead), UCLA, UC San Diego, MIT, U. Hawaii, JAXA/ISAS, INFN Trieste/Bergamo/Naples, Oak Ridge National Laboratory

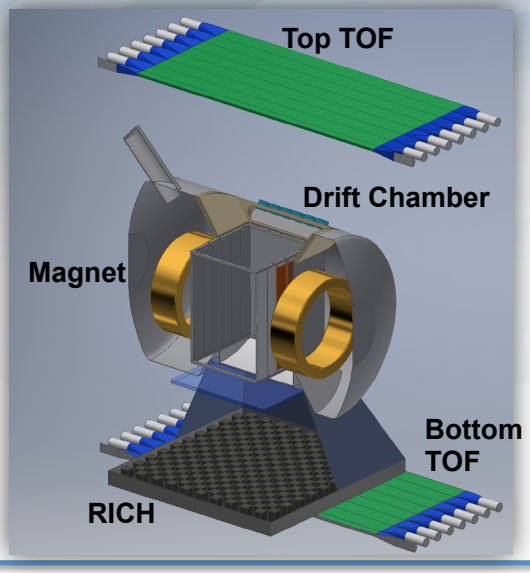
Accomplishments/Milestones:
At US universities there are currently 3 Ph.D. students (5 total expected) and ~10 undergraduates (with more than double that number expected over life of project). PDR in 1/18 and CDR in 8/18. First prototype 4" Si(Li) meeting goal of 10 nA leakage current per strip has already been demonstrated.

Application:
The exotic atom – silicon tracker approach can be scaled up to either ultra-long duration balloons or satellite experiment. In the latter case the goal would be search for anti-Helium with ~ order of magnitude better sensitivity than AMS, and at much lower anti-He energies, and a much higher sensitivity search for low energy antideuterons and antiprotons

HELIX (High Energy Light Isotope eXperiment)

Description and Objectives:
A superconducting magnet spectrometer designed to probe the propagation history of Galactic cosmic rays by measuring their detailed chemical and isotopic composition

Key Challenge/Innovation:
Achieving stable percent-level mass resolution across a wide range of particle energies. A key innovation towards this goal is the use of a SiPM-based Ring-Imaging CHerenkov (RICH) detector



Approach:

Development period:
2.5 years until launch, 0 launches thus far (but multiple launches of the magnet in the 90s), additional flights to be pursued after future detector upgrades.

Key Collaborators:
Chicago, Indiana, McGill, Michigan, Northern Kentucky, Penn State

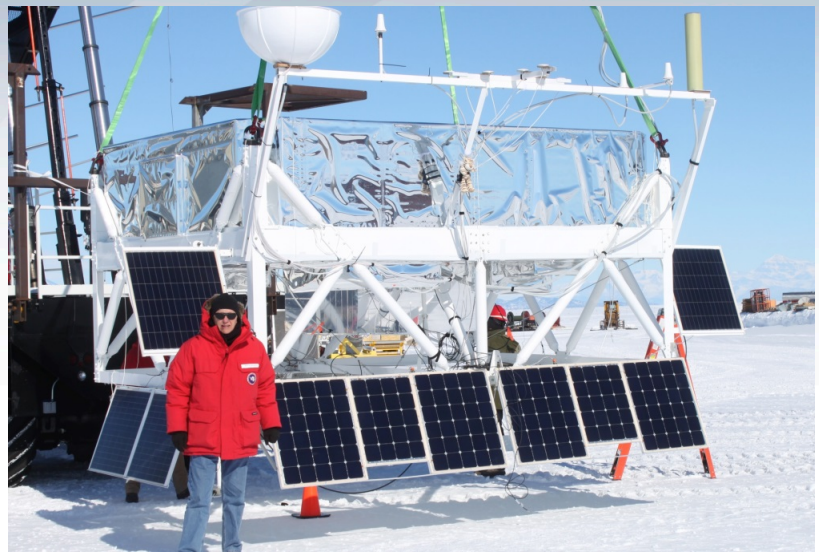
Accomplishments/Milestones:
Initial designs complete, construction underway. Currently 3 graduate students and 5 undergraduate students involved.

Application:
Lessons learned from the RICH design (SiPM use, very high channel count, thermal stability, etc.) will be of use across multiple payloads.

SuperTIGER
(Trans Iron Galactic Element Recorder)

Description and Objectives: The SuperTIGER (ST) Experiment is designed to measure the elemental composition of galactic cosmic rays over the charge range Z=10-56. The measurements enable us to test the model of cosmic ray origin in OB associations. The instrument is a forerunner of a space instrument to constrain models of r-process production of nuclei in merging compact objects.

Key Challenge/Innovation: Develop large collecting power instrument with excellent charge resolution.



Approach: The instrument consists of large area (4 m^2) plastic scintillator dE/dx detectors, acrylic and aerogel Cherenkov detectors, and a scintillating optical fiber hodoscope.

Development period:
Based on technology developed for the smaller (1 m^2)TIGER experiment flown from Antarctica in 2001 and 2003. ST-1 was developed from 2008 to 2012.

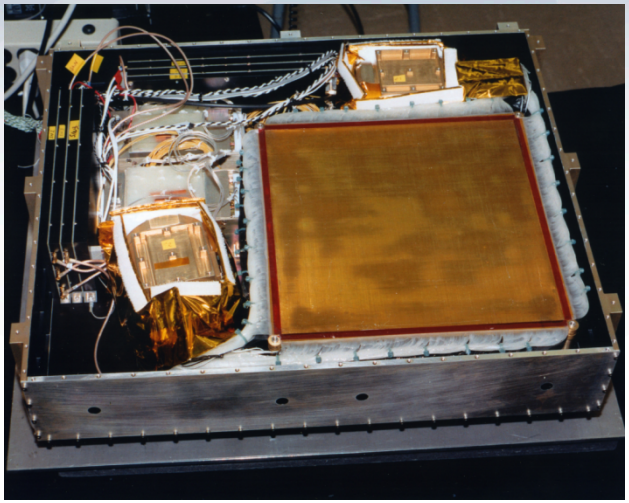
Key Collaborators: Washington University (R. Binns PI), Goddard Space Flight Center (J. Mitchell, Institutional PI), California Institute of Technology & JPL (R. Mewaldt, Institutional PI)

Accomplishments/Milestones:
ST-I flew from Antarctica in 2012-2013 and is planned for a second flight in December 2017. Ryan Murphy obtained his PhD on ST-I data. We expect Nathan Walsh to obtain his PhD based on the anticipated results from ST-II. Two publications in ApJ. Several others in ICRC proceedings.

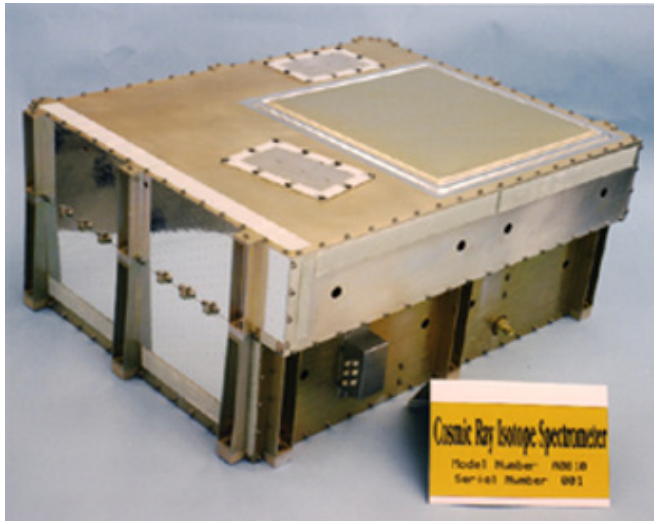
Application:
We expect to propose to launch an instrument based on detector technology to the ISS to measure elemental abundances from Z=6-83. In addition, this would form the electronic part of the HNX experiment designed to measure elements through the Actinides (Z=90-96), thus determining the age of GCRs.

Science Enabled by the Balloon Program at Washington University

- Development of scintillating fibers begun in ~1985 at WU under the ballooning program plus internal funding has led to their general use in both balloon and space experiments.
- At WU, fiber hodoscopes used for TIGER, ACE-CRIS, & SuperTIGER, Fermi, (CALET)
- Significant science has been derived from these experiments as a result of these detectors
- ACE-CRIS
  - Measurement of ^{60}Fe by ACE-CRIS. First conclusive evidence of recently synthesized nuclei in cosmic rays. Measurement made possible by relatively large area fiber hodoscope arrays.
  - Measurement of ^{59}Ni which puts a lower limit of 10^5 yrs on the time between nucleosynthesis and acceleration of GCRs
  - Measurements of isotopes for $4 \leq Z \leq 32$
- Fermi/LAT ACD scintillating fibers are used to 'seal' the gaps between the tiles of the ACD scintillator.



ACE-CRIS Scintillating Fiber Hodoscope



ACE-CRIS Instrument

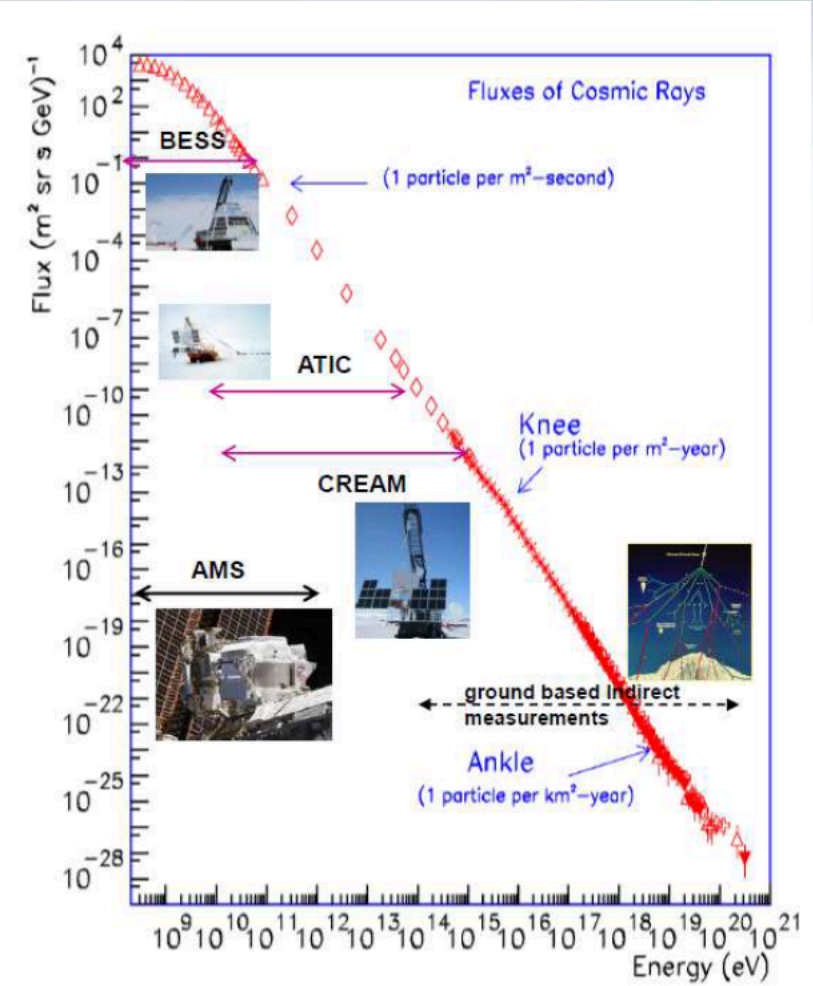
CREAM Mission

Science Questions

- Do supernovae supply the bulk of cosmic rays?
- What is the history of cosmic rays in the galaxy?
- What is the origin of the "knee" around 3×10^{15} eV in the cosmic ray energy spectrum?
- Can the energy spectra of cosmic rays result from a single mechanism?

Mission Goal

Extend the energy reach of direct measurements of cosmic rays to the highest energy possible to investigate cosmic ray origins, acceleration and propagation.



PI Eun-Suk Seo, U Maryland

From the CREAM balloon flights to ISS-CREAM

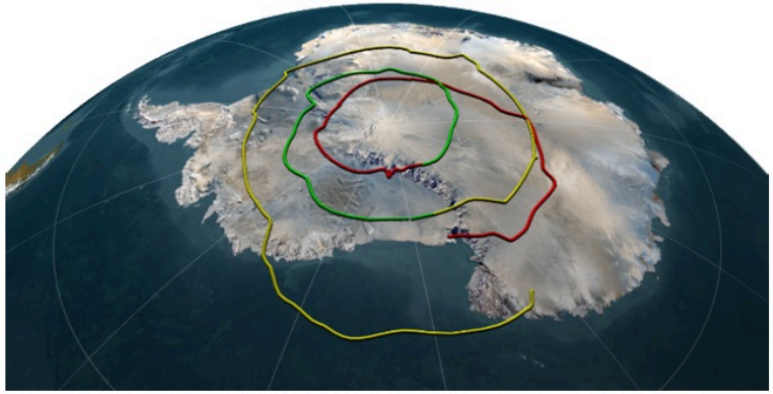
CREAM (Cosmic Ray Energetics And Mass)

- The CREAM instrument directly measures elemental spectra of cosmic rays
  - Energy range: 10^{12} – 10^{15} eV
  - Composition: proton to iron

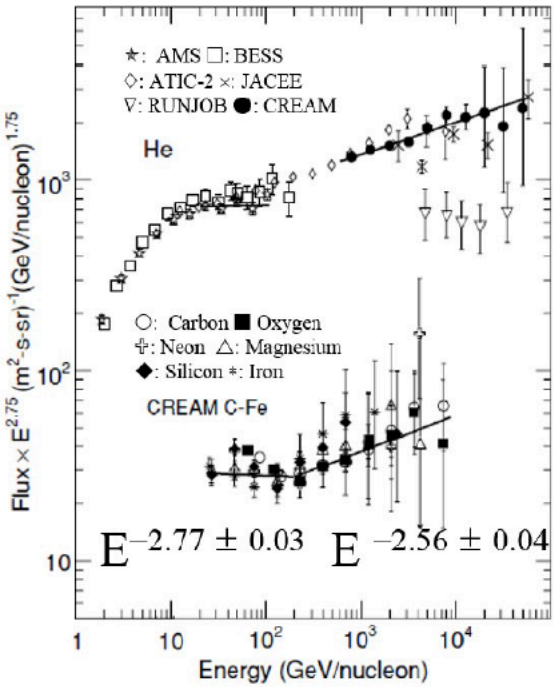
Balloon Flight Heritage

- Seven successful Long-Duration Balloon flights from McMurdo station, Antarctica 2004-2016
- ~191 days of cumulative exposures, the longest of any balloon project
- Highlight of balloon project results is discovery of spectral hardening

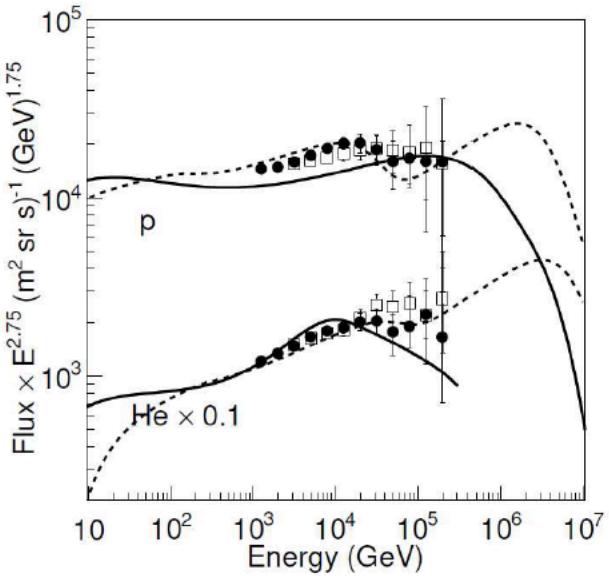
CREAM-I Flight Path



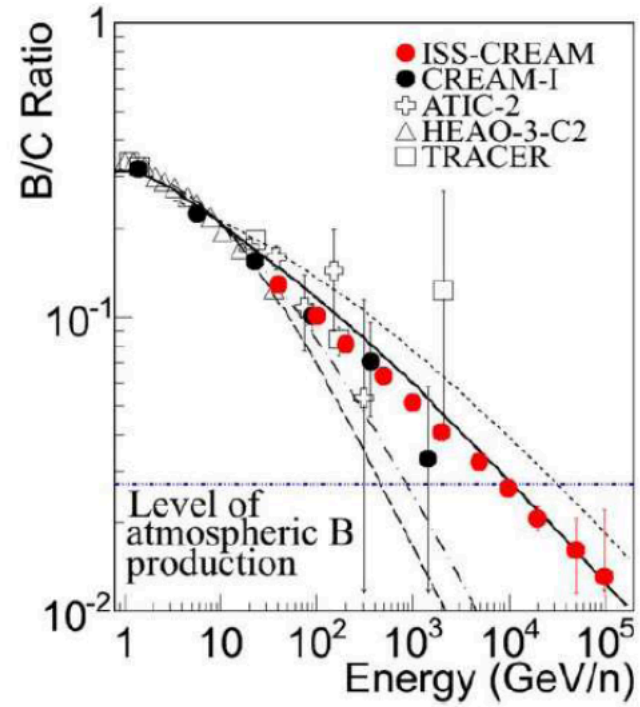
CREAM Motivation for Space



Ahn et al., CREAM Collaboration, ApJL. 714, L89-L93, 2010



Yoon et al., CREAM Collaboration, ApJ, 839, 5, 8pp, 2017



Ahn et al., CREAM Collaboration, Astrpart. Phys., 30/3, 133-141, 2008

Data from balloon experiments provide excellent motivation for space experiments

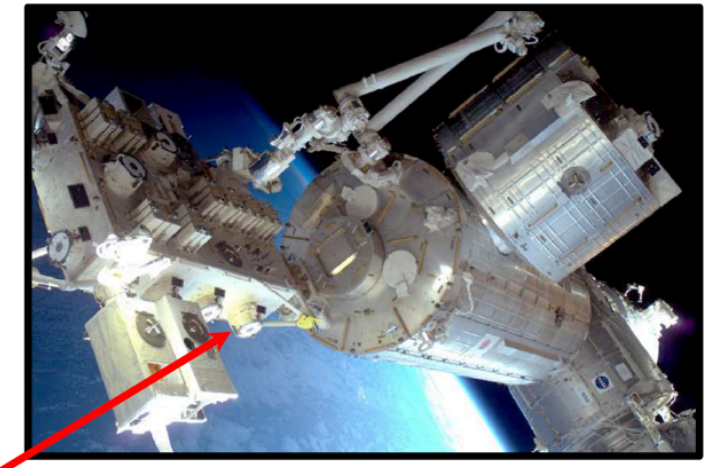
- Statistical uncertainties are very large at high energies
- Need higher energy data to distinguish models

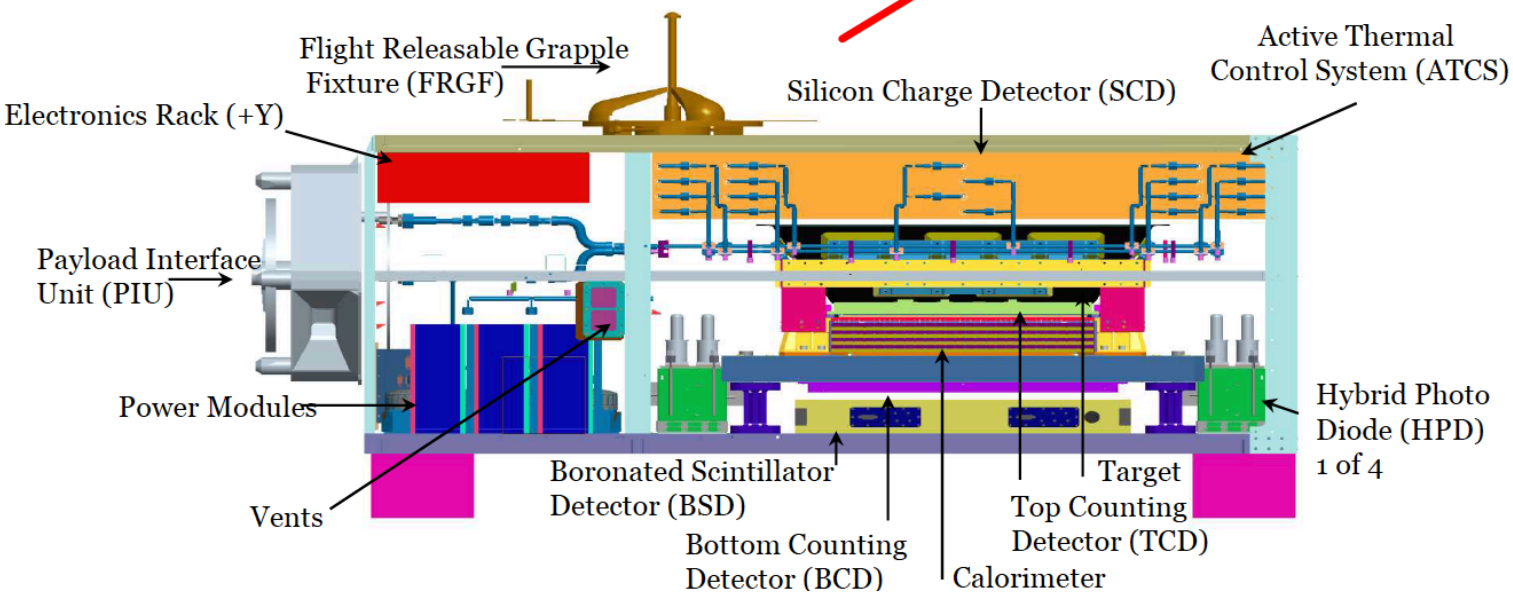
From the ISS…

- no need for atmospheric corrections
- our exposure factor will be increased by an order of magnitude or more

CREAM Configuration for ISS

- External Payload: Japanese Experiment Module (JEM) Exposed Facility #2
- Payload total mass: 1258 kg
- Payload Dimensions: 1.85 m x 1.00 m x 0.80 m
- Power On-Orbit: 415 W
- Data rate: 500 kbps for 3+ years or end of station life
- Launch vehicle: **SpaceX CRS-12, August 10, 2017**





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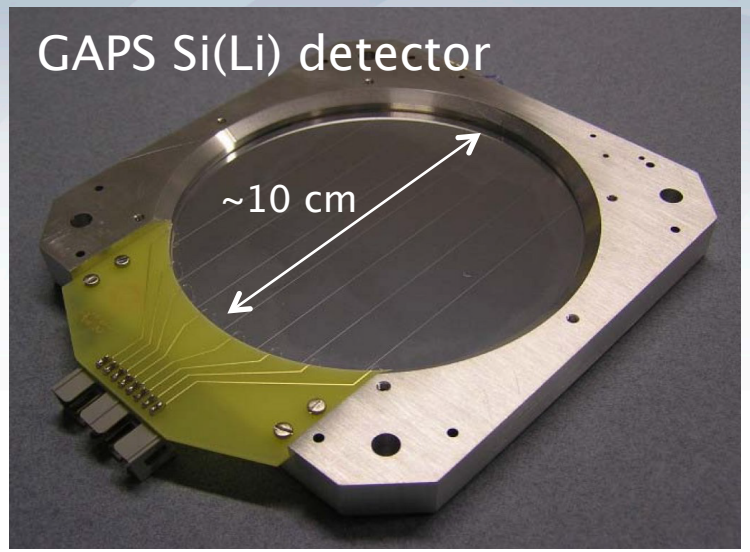

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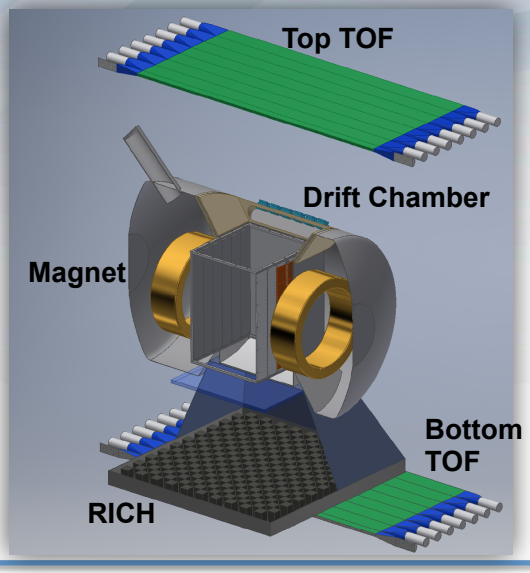

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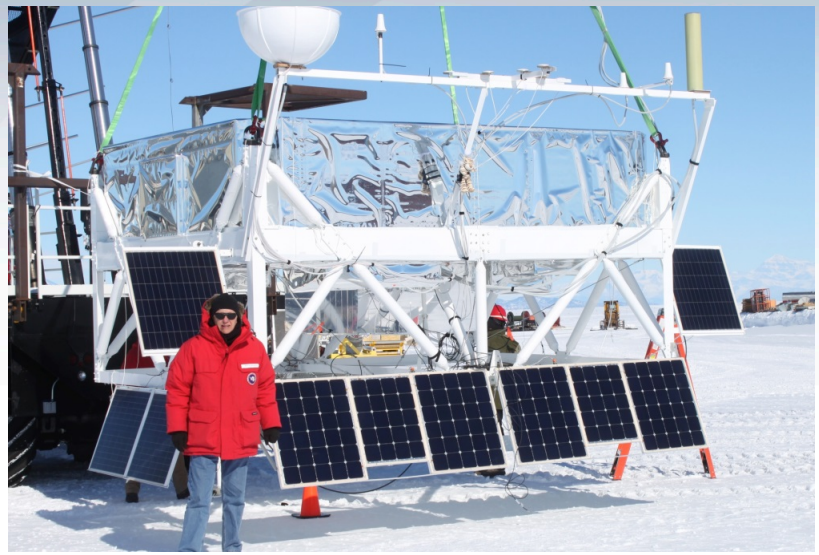

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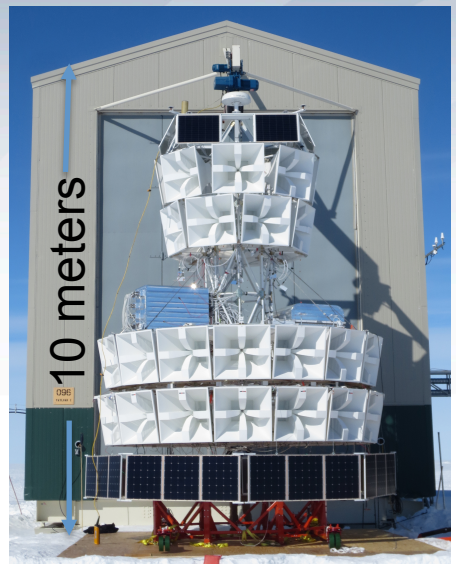
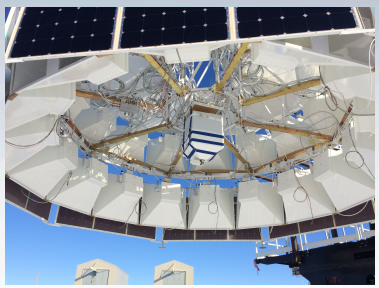
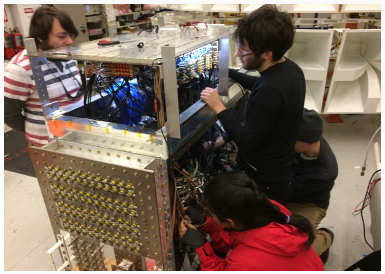
Description and Objectives: ANITA is an array of broadband horn antennas synoptically observing Antarctica from stratospheric altitudes, with a goal of detecting ultra-high energy cosmic neutrinos via radio impulses produced in their collisions and resulting particle cascades within Antarctic ice sheets.
Key Challenge/Innovation: Pulse-phase radio interferometry to identify candidate events at the highest possible sensitivity in the presence of anthropogenic interference; ultra-low power GHz samplers to record RF waveforms.







Approach: Quad-ridged dual-polarized horn antennas with 200-1200 MHz bandwidth continuously search for coherent, highly polarized transient impulses, with 0.2^{o} mapping to verify isolation from interfering sources. Custom-built low-noise RF amplifiers provide ~40K noise figure (with no cryogens) on orbit.
Development period: Current mission, FY16-18
Key Collaborators: Univ. of Hawaii at Manoa (PI P. Gorham); Ohio State Univ.; Univ. of Delaware; Univ. of Chicago; Wash. Univ. St. Louis; Univ. of Kansas; Jet Propulsion Lab; Univ. Calif. at Los Angeles; SLAC/Stanford; Cal. Poly San Luis Obispo; Univ. College London; Nat'l Taiwan Univ.

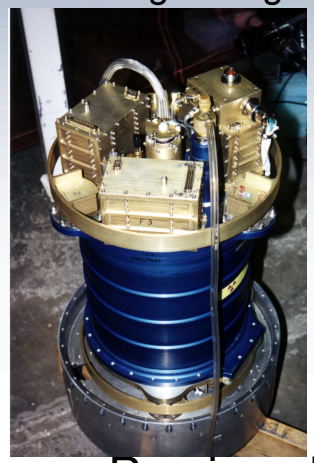
Accomplishments/Milestones: First self-triggered radio detection of ultra-high energy cosmic rays (PRL 2010); Candidate tau neutrino event (PRL 2016); Completed 4th flight Dec. 2016. total undergrad/grad students trained ~200; currently ~40; 23 refereed journal publications since 2006, includes 6 in Phys. Rev. Lett., and two PRL cover articles; 669 cites in 451 articles.
Applications: developed technology includes: ultra-low-noise non-cooled RF amplifiers; broadband pulse-phase interferometry; ultra-light carbon-fiber truss structure; agile RF-interference-mitigation systems; tens-of-terabyte onboard, compact data storage systems

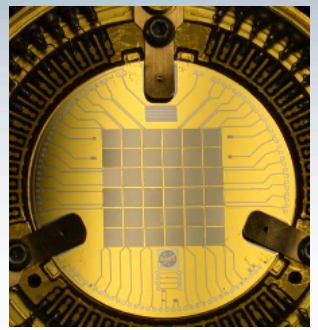
Additional High Energy Astrophysics Projects

X-Ray Quantum Calorimeter

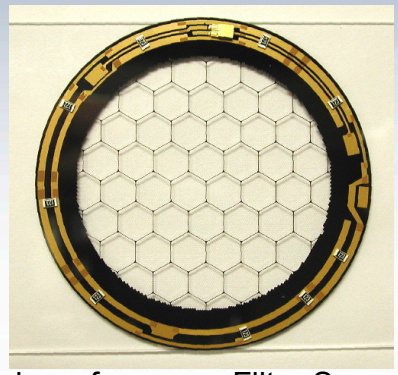
A sounding rocket payload for microcalorimeter detector development and diffuse X-ray background science

50 mK flight fridge



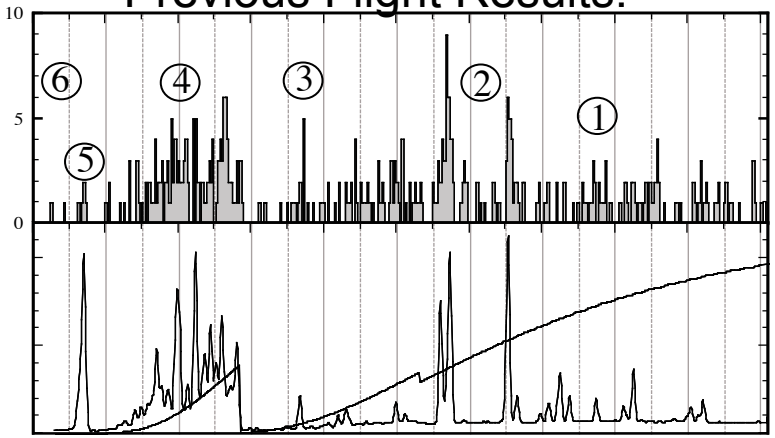


Advanced detector development



High-performance Filter Support

Previous Flight Results:



- **PI**: Dan McCammon/U. Wisc., collaborators at Miami, Yale, Northwestern, NASA/GSFC
- **Science Objectives:** Galactic Diffuse X-ray background
- **Operations**: suborbital flights

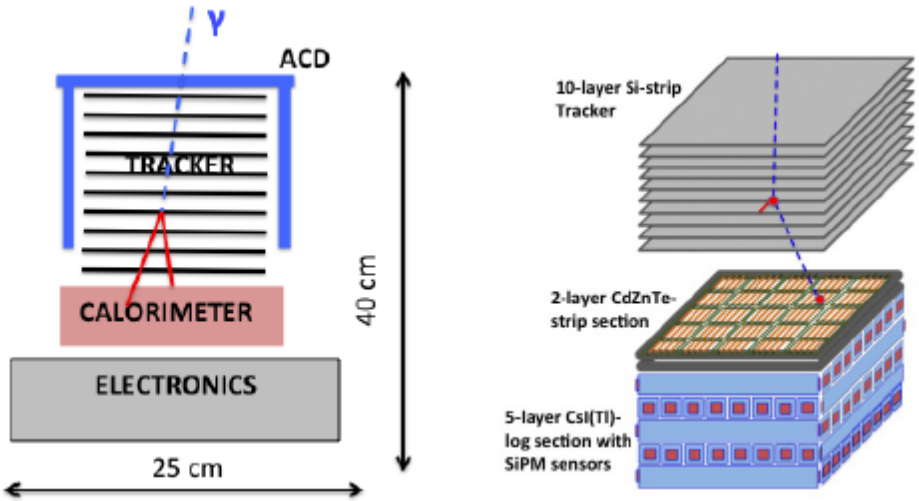
Key Facts:

- Published Science Results:
  - 1. Weak Iron lines show that most Fe is missing from Galactic hot gas.
  - 2. Bright lines with redshift <.005 show that most of thermal radiation is **not** from a hot IGM
  - 3. CVI lines could be used to determine contributions from charge exchange on solar wind heavy ions
  - 4. Plasma line diagnostics on hot gas in bubble surrounding the Sun
  - 5. First detection of long-sought Iron M-lines
  - 6. Lack of counts below 50 eV rules out Strongly Interacting Dark Matter candidates.

  More being analyzed . . .
- **Technologies:**
  - **Space Cryogenics:** salt pill technology used on **Astro-E and Astro-E2**.
  - **Detectors: First astrophysical data obtained with microcalorimeters**.
  - **Filters:** Two-level monolithic silicon meshes developed for XQC **used on Hitomi and XARM** and proposed for other missions.
- **Orbit**: suborbital

ComPair

Steps to a Medium Energy Gamma-Ray Mission



- **PI**: Julie McEnery, GSFC, Co-I NRL
- **Objectives:**
  - Develop and test technologies and components for a future medium energy gamma-ray mission.
  - Design, build and test a prototype instrument.
  - Validate instrument design in beam tests and a balloon flight.
- **Operations**: Short balloon flight (6 hours minimum) to measure and characterize charged particle backgrounds.

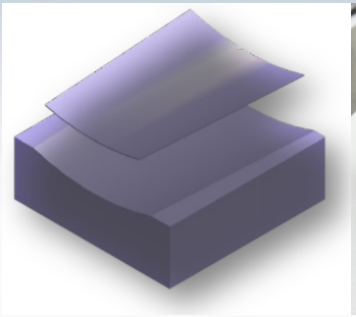
Key Facts:

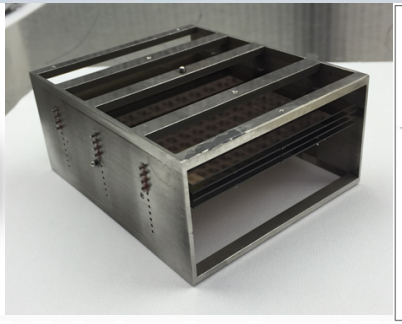
- **Science:** The All-sky Medium Energy Gamma-ray observatory (AMEGO), a candidate probe mission, will provide groundbreaking capabilities in the medium energy gamma-ray band and address key science questions:
  1. How do astrophysical jets form, evolve and acceleration particles?
  2. Which physical processes occur in the extreme conditions around compact objects?
  3. How do elements form in extreme environments?
  4. What is the particle nature of dark matter?

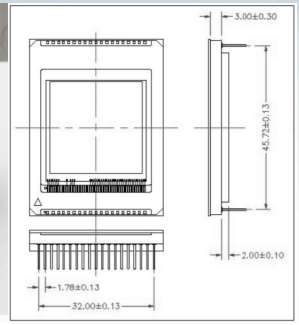
  The ComPair prototype instrument will develop, test and validate the technologies and concept for AMEGO.
- **Technologies:** Double sided Si-strip tracker, CZT calorimeter, CsI calorimeter/ SiPM readout, plastic scintillator/SiPM readout.
- **Timeline:** APRA-2014 selection, beam tests in 2018, balloon flight in 2019

Off-plane Grating Rocket Experiment (OGRE)

High performance X-ray spectroscopy on a suborbital platform





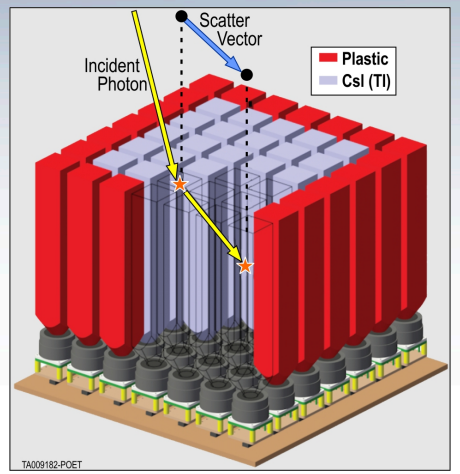


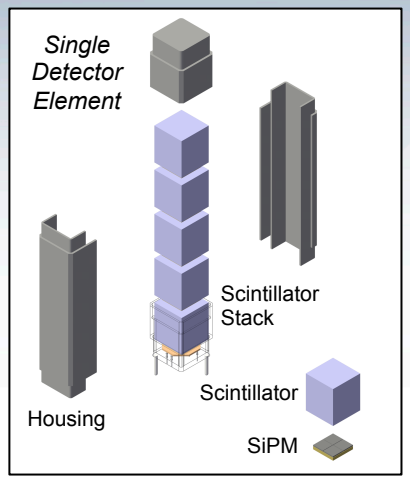
- **PI**: Randall McEntaffer, PSU; Co-I William Zhang, GSFC; Co-I Andrew Holland, Open Univ.
- **Science Objectives:** Provide the highest resolution X-ray spectrum of Capella. Achieve spectral resolving power of >1500 using a high resolution spectrograph consisting of silicon optics, replicated off-plane gratings, and EM-CCDs.
- **Operations**: Suborbital payload. November 2018 launch date. First telescope payload water recovered at Wallops Flight Facility

Key Facts:

- **Science**: OGRE will obtain the highest resolution soft X-ray spectrum of the binary giant star system Capella. The observation will model the differential emission measure of the coronal dominated X-ray emission.
- **Technologies:** Key PCOS technologies will be tested during the OGRE flight. This will be the first flight of single-crystal silicon based optics from NASA GSFC. This will also be the first flight of large format, replicated, radial grooved, off-plane reflection gratings. In addition to these key PCOS technologies, OGRE will also be the first flight of X-ray electron multiplying (EM) CCDs (EM-CCDs). The payload will also test NASA water recovery technologies still requiring development following WRX-R.
- **Timeline:** Launch date scheduled for November 2018
- **Orbit**: Suborbital, ~240 km apogee

GRAPE
Gamma Ray Polarimeter Experiment





- **PI**: Mark McConnell (UNH / SwRI)
- **Science Objectives:** GRAPE is a Long Duration Balloon (LDB) balloon payload that uses an array of Compton polarimeters to measure the polarization of gamma-ray bursts (GRBs) in the 50-500 keV energy range. The wide FOV design uses an array of scintillation detectors to determine the Compton scatter geometry of each incident photon.
- **Operations**: A series of 3-4 long duration balloon (LDB) flights providing a total exposure of 150 days at float.

Key Facts:

- **Science**: Definitive GRB polarization measurements for a sufficiently large sample of GRBs will be able to distinguish between different classes of GRB models.
- **Technologies:** The current design has evolved from the original GRAPE design flown on CONUS balloon flights in 2011 and 2014. We have developed an approach that uses stacks of small (~2 cm) optically isolated scintillator cubes, each of which is read out by its own SiPM. This arrangement provides 3-d spatial information for each Compton scatter event, sufficient to achieve Compton imaging with 10° angular resolution. The imaging capability maximizes the GRB S/N.
- **Timeline:** First LDB flight is targeted for 2020-21 McMurdo campaign.
- **Balloon Profile**: Float altitudes near 130 kft are preferred to minimize attenuation near 100 keV.

Additional UV/VI/NIR/ExoPI Projects

SuperBIT: Wide-field, sub-arcsecond Imaging from the Super Pressure Balloon

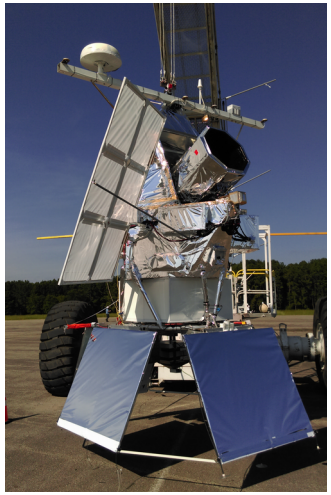
PI: William Jones (Princeton)

Description and Objectives:

SuperBIT is a wide field, 230 milli-arcsec resolution imaging telescope designed to take advantage of the persistent near space environment provided by the Super Pressure Balloon platform. The primary science goal is to produce lensing masses for a sample of hundreds of galaxy clusters, dramatically improving the mass-observable relations that are critical to understanding the cosmological matter distribution on large scales.

Key Challenge/Innovation:

SuperBIT has demonstrated the ability to provide 180 mas pointing stability *with* field rotation for long (15 minute) exposures. Even with a ½ meter primary aperture, the large format camera and space-like environment enable survey speeds comparable to the Hubble ACS.



At left, SuperBIT prior to the 2016 flight. At right, an image of the Eagle Nebula (M16) obtained during that flight. The image is derived from less than 15 minutes of total exposure over four bands from 250-900nm.

Approach:

A three-axis pointing system provides ~2 arcsecond pointing stability and field rotation. A fast tip/tilt mirror, servoed by a guide camera and a suite of advanced fiber optic gyroscopes, provides image stabilization at the sub-arcsecond level. A 29 megapixel science camera and six filters between 250 and 900 nm provide a survey speed comparable to that of the Hubble ACS.

Key Collaborators

- C. Barth Netterfield (U. Toronto)
- Richard Massey (Durham)
- Jason Rhodes (JPL)

Accomplishments and Next Milestones:

- Successful test flight in 2016
- Demonstrated 180 mas pointing stability with 300s integrations
- Demonstrated survey speeds near ½ that of Hubble ACS
- Identified & implemented areas of improvement, including fiber optic gyros and guide camera upgrades
- Design study for an improved SiC three-mirror anastigmat telescope
- Currently waiting for launch, Palestine, July 2017

Current Award Period:

- Jan 2016 - Jan 2021

Multi-Color Anisotropy Measurements of the Cosmic Near-Infrared Extragalactic Background Light with CIBER-2

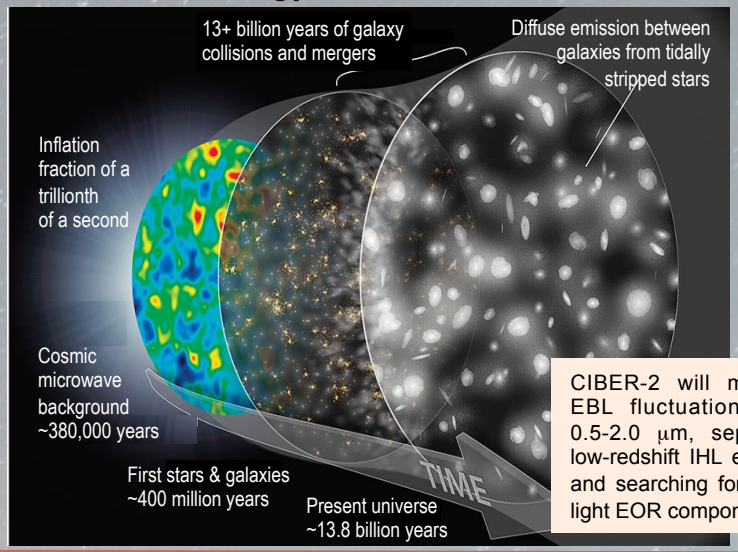
P.I. James Bock, The California Institute of Technology

Description and Objectives:

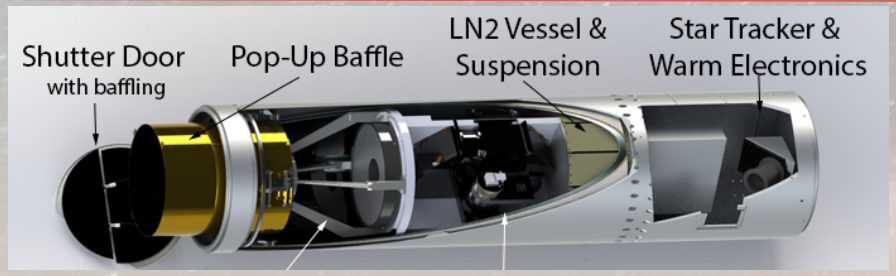
- CIBER-2 is a sounding rocket experiment designed to determine the sources of the near IR extragalactic background light (EBL) fluctuations detected by Spitzer & CIBER-1
- Multi-band imaging separates low-redshift intra-halo light (IHL) from epoch of reionization (EOR) emission.

Key Challenge/Innovation:

- Flying a LN_2-cooled 30 cm diameter telescope and using Hawaii-2RG arrays for EBL intensity mapping



CIBER-2 will measure EBL fluctuations from 0.5-2.0 μm, separating low-redshift IHL emission and searching for a first-light EOR component



Approach: Image the sky in several well-studied few square degree fields with 6 bands to allow spectral decomposition of fluctuations in the near IR extragalactic background light

Development Period: March 2016 – Feb 2021

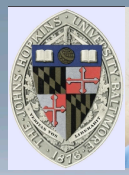
Key Collaborators: Michael Zemcov (RIT), Asantha Cooray (UC Irvine) Shuji Matsuura (Kwansei), Dae Hee Lee (KASI), Phil Korngut (Caltech)

Accomplishments and Next Milestones:

- Currently testing the optical assembly, focal planes, and deployable pop-up baffle
- NSROC has delivered rocket door and skin; cryogenic testing successful
- Three **H2RG(JWST)** detectors and readout electronics successfully integrated
- Upon delivery of optical assembly from collaborators we will begin optical integration and characterization

Application:

Continuum and spectral-line intensity mapping with wide-field optical-IR satellite data (e.g. **SPHEREx**)



ACCESS – Enabling Precision Astrophysics

Reduce Systematics / Improve SNeIa-based Discrimination of Dark Energy Models

PI: Mary Beth Kaiser - JHU

Description and Objectives:

- Enable science, e.g. SNeIa-based discrimination of dark energy models, that requires 1% precision in the flux scale.
- Tie the astrophysical flux scale to NIST absolute detector standards; reduce systematic errors associated with the flux scale to 1% across the $0.35<\lambda<1.7\mu m$ bandpass through ground-based experiments & stellar rocket-borne observations.
- Extend results into the NIR and UV – fit stellar atmosphere models to the flight targets (SAO/CfA, STScI collab)
- Educate and train the next generation of scientists

Key Challenge/Innovation:

- Precise payload calibration: $0.35<\lambda<1.7\mu m$ – (NIST collab)
- Stability & calibration of HgCdTe detector to <1% (GSFC collab)
- Thermal control: strategic & innovative material selection, mechanical (Stirling) cryocooler, phase change material (SDL collab)
- OCM: On-board Calibration Monitor - Multi-λ LED light source, photodiode feedback stabilized

TRLin = 5 ***TRLcurrent = 7*** ***TRLtarget = 9***

Methodology:

- Eliminate strong, variable, high-altitude (~70 km) OH -- need rocket (altitude > 100km)
- Single optical path & detector: eliminate visible<–>NIR errors
- Track error budget; fly OCM LED light source
- Ground calibration of payload tied to NIST standard detectors & end-to-end NIST based multi-calibration cross-check

Accomplishments:

- Telescope optics: tested & coated
- Spectrograph optics: designed, fabricated, coated, integrated
- Thermal system: modeled, fabricated, integrated, component tested
- Mechanical system: designed, fab, integrated incl detector
- Detector: electronics, software, I&T, successful vibe test.
- Telemetry: science data acq & LVDS TM software written & GSE tested
- Flight electronics: designed, fab, I&T ongoing

Next Milestones:

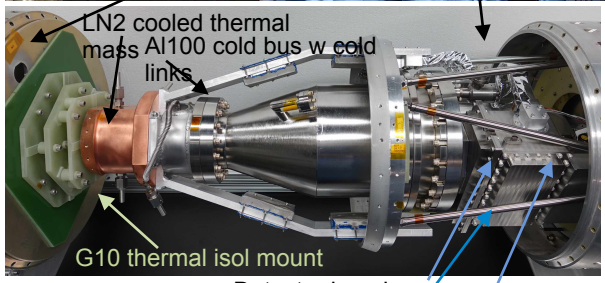
- Science channel flight telemetry test at Wallops (late July 2017)
- End-to-end test of payload & Launch– Winter 2017/2018

Applications:

WFIRST (OCM), HabEx, LUVOIR, (predictive, uniform coatings), JWST, LUVOIR, etc. (Cal standards), Explorers (cryocoolers)

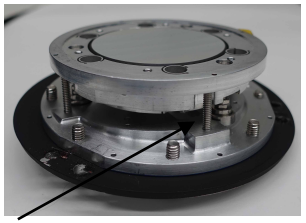
Calibration GSE, Monochromator

Grad student mounting detector in GSE dewar

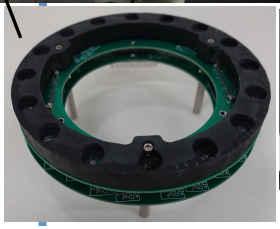


Detector housing
Lightweight, quasi-hexapod truss

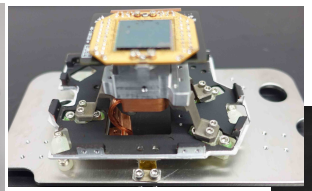
Stirling cooler & phase change mat'l

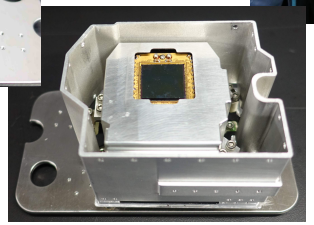


Kinematic, adjustable mount w/ partite ruled grating



OCM: Dedicated photodiode monitoring of each LED





HgCdTe detector, flex circuit design, compact thermally isolated mount

University of Colorado UV Rocket Program

Dual channel Extreme Ultraviolet Continuum Experiment (DEUCE)

PI: James Green/University of Colorado/CASA

Description and Objectives:

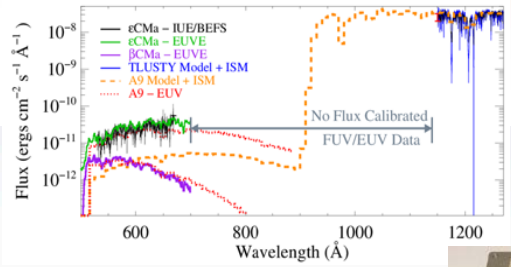
Science: Directly measure the ionizing radiation from local hot B stars to determine if B stars (as opposed to O stars) are viable candidates for providing the ionizing radiation to the modern intergalactic medium.

Technology: Incorporating a large format (200 X 200 mm) microchannel plate detector utilizing boro-silicate plates. This will be the first flight verification of this glass and this size MCP detector.

Training: Graduate student involvement (Nicholas Erickson) for the Ph.D. and 5 undergraduates supporting the lab effort.

Key Challenge/Innovation:

Large format MCP can enable wide field imaging / multi-object spectroscopy on the next large aperture UV capable probe/surveyor.



Above: Flux discrepancy between models and data, also showing the data gap between 700 and 1150 Å.
Right: 200 X 200 mm lab prototype MCP

Approach:

- Diamond turned razing incidence Wolter II telescope feeding normal incidence Rowland circle spectrograph utilizing SiC coated holographically ruled grating
- Component-level efficiency and environmental testing
- End-to-end payload development and launch
- Scientific and technical analysis, student training, and publication of results

Key Collaborators:

- Oswald Siegmund – Sensor Sciences – Detector
- Horiba JY – grating production
- GSFC – Grating coating

Development Period:

- April, 2015 – October, 2017
- First launch in October 2017

Accomplishments and Next Milestones:

- Telescope completed and ready for installation
- Mechanical and electrical design completed
- Design review at WFF 9/22/16
- Grating delivered to GSFC for coating on 9/19/16
- Detector delivery in December, 2016
- All elements on schedule for October 30, 2017 launch

Application:

- All UVOIR missions requiring large fields of view or multi-object spectroscopy in the far ultraviolet
- Flagship (LUVOIR Surveyor, ATLAST/HDST); Lifecycle of Baryons Probe; IGM spectral imaging Explorer missions

*Detector TRL development: TRLin = **3** TRLtarget = **6/7 (post flight)***