



Astrophysical Sounding Rockets (1946-present).

*A prolific, vital, and successful
platform for science*

F. Scott Porter
Deputy Project Scientist
Sounding rocket experimenter
NASA/GSFC

- “Typical” astrophysics experiments are ~ 1000 lbs
- Launched mostly from White Sands, NM (but also Wallops, Kwajalein, Alaska, Australia)
- Are recovered, refurbished and flown again



Currently funded Astrophysics payloads (~25% of the sounding rocket program)

<u>Payload</u>	<u>PI</u>	<u>Institution</u>
CIBER-2	Michael Zemcov	RIT
DEUCE	James Green	CU Boulder
DUST	Joe Nuth	GSFC
DXL	Massimiliano Galeazzi	Univ Miami
FORTIS	Stephan McCandliss	JHU
Micro-X	Tali Figueroa	Northwestern U
OGRE	Randall McEntaffer	Penn State U
SISTINE	Kevin France	CU Boulder
TREXS	Randall McEntaffer	Penn State U
XQC	Dan McCammon	Univ Wisc

Most programs are multi-institutional:



10 Year flight history for Astrophysics payloads (“blue book”)

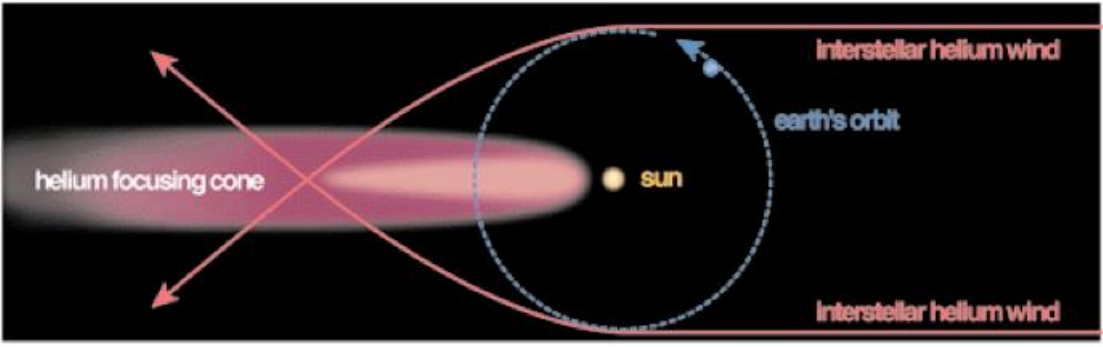
MISSION	PI	PROJECT	RANGE	DATE (ET)	DISCIPLINE
36.270 UG	Green	DICE	WSMR	2010-05-10	UV/OPTICAL
36.265 UG	Bock	CIBER	WSMR	2010-07-11	UV/OPTICAL
36.257 UG	Green	FIRE	WSMR	2011-01-28	UV/OPTICAL
36.225 UG	Chakrabarti	Picture	WSMR	2011-10--08	UV/OPTICAL
36.264 UH	McCammon	XQC	WSMR	2011-11-06	HIGH ENERGY
36.274 UH	Cash	EXOS	WSMR	2011-12-10	HIGH ENERGY
36.277 UG	Bock	CIBER	WSMR	2012-03-12	UV/OPTICAL
36.260 UG	Cook	IMAGER	WSMR	2012-11-21	UV/OPTICAL
36.283 UH	Galeazzi	DXL	WSMR	2012-12-13	HIGH ENERGY
36.271 UG	France	SLICE	WSMR	2013-04-23	UV/OPTICAL
36.268 UG	McCandliss	FORTIS	WSMR	2013-05-10	UV/OPTICAL
40.030 UG	Bock	CIBER	WI	2013-06-05	UV/OPTICAL
36.294 UH	McCammon	XQC	WSMR	2013-11-03 05:25:00 S S S	HIGH ENERGY
36.296 UG	McCandliss	FORTIS II	WSMR	2013-11-20 05:40:01 S S S	UV/OPTICAL
36.261 UG	Clarke	VESPR	WSMR	2013-11-26 10:00:01 S S S	UV/OPTICAL
36.285 UG	France	CHESS	WSMR	2014-05-24 02:35:00 S S S	UV/OPTICAL
36.292 UH	McEntaffer	OGRESS	WSMR	2015-05-02 03:30:01 S S S	HIGH ENERGY
36.293 UG	Chakrabarti	Picture	WSMR	2015-11-21 00:17:00 S S F	UV/OPTICAL
36.305 UH	Galeazzi	DXL-2	WSMR	2015-12-04 02:00:00 S S S	HIGH ENERGY
36.312 UG	McCandliss	FORTIS	WSMR	2015-12-15 02:05:00 S S S	UV/OPTICAL
36.297 UG	France	CHESS-2	WSMR	2016-02-22 23:15:00 S S S	UV/OPTICAL
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 F 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 10:16:47 S S S S	UV/OPTICAL
36.245 UH	Figuroa	MICRO-X	WSMR	2018-07-22 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	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
36.281 UG	Zemcov	CIBER-2	WSMR	2020-02-24	UV/OPTICAL
36.245 UH	Figuroa	MICRO-X	WSMR	2020-03-15	HIGH ENERGY
36.347 UH	McCammon	XQC	AUS	2020-07-09	HIGH ENERGY
36.339 UG	France	SISTINE	AUS	2020-07-15	UV/OPTICAL
36.350 UG	Green	DEUCE	AUS	2020-07-21	UV/OPTIC

What are the new scientific opportunities enabled for astrophysics by your platform?

- “The primary goal of rocket experimentation is to develop new observational opportunities that cannot be met with existing facilities or approaches. As such, the short duration of a rocket flight continues to represent an infinite increase in the time that would otherwise be available. “ -- ASRAT white paper, Astro2010
- Sounding rocket flights are short, but the payloads can be very complex
 - Typically 300 s above 160 km, Apogee 250-350 km, for recovered payloads
 - You can fly longer, but payloads not recovered, Cyber 1 flew 900s from Wallops
- Payloads are Science driven, but mindful of technology development, and lots of training
 - Missions can complete and provide data within a graduate student's tenure
 - Fast turn-around, unique opportunities: ex: Supernova's, comets
 - Measurements that would not or could not be made by orbital observatories

Example: DXL (“Diffuse X-rays from the Local galaxy”)

Goal: Prove the “local bubble” exists by making a detailed measurement of the foreground



Solves 40 year conundrum

LETTER


doi:10.1038/nature13525

The origin of the local 1/4-keV X-ray flux in both charge exchange and a hot bubble

M. Galeazzi¹, M. Chiao², M. R. Collier², T. Cravens³, D. Koutroumpa⁴, K. D. Kuntz⁵, R. Lallement⁶, S. T. Lepri⁷, D. McCammon⁸, K. Morgan⁸, F. S. Porter², I. P. Robertson³, S. L. Snowden², N. E. Thomas², Y. Uprety¹, E. Ursino¹ & B. M. Walsh^{2†}



Discuss the role of the platform in technology development and training

- Most mission and R&A PIs, project scientists, and instrument scientists started or matured in the suborbital programs
- Programs are vital for training the next generation: Suborbital and cubesat programs are the only place where a PI can take a spaceflight project from start to finish for < \$200M (SMEX+LV)

Virtually all sounding rocket payloads contain new technology that is destined for larger platforms:

Some recent examples:

- DXL: Lobster eye optics and telescopes → CuPID, LEXI, SMILE, STORM
- XQC: x-ray calorimeters, filters, cryogenics → Astro-E, Astro-E2, Hitomi, XRISM, Athena, Micro-X
- Micro-X: TES x-ray calorimeters, cryo amplifiers → Athena, Lynx
- SISTINE/ANUBIS: UV coatings, large format detectors → Luvor

Example: Lobster eye telescopes – very wide FOV x-ray telescopes

2012: DXL I carried the first lobster telescope as a ride-share

-- Refurbished telescope (LEXI) will be placed on the moon in 2022

2015: DXL II carried a small 3U cubesat lobster telescope as a ride-share

-- Same telescope will fly as a 6U cubesat in 12/2020 (CuPID)

2016: The ESA/CSA SMiLE mission used the DXL I/II flights to demonstrate technical readiness. Mission currently in phase B. Will launch in 2023

2018: BepiColombo launches with two lobster instruments to Mercury

2019: proposed STORM MIDEX uses DXL I/II to demonstrate technical readiness

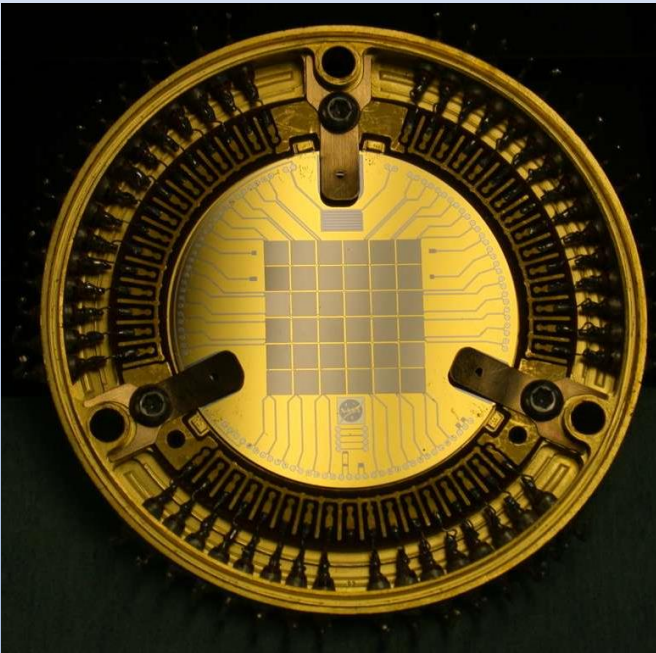
There are SMEX, MIDEX, and probe-class mission concepts (some recommended to Astro2020) using this technology



XQC, Micro-X: cryogenic x-ray spectrometers

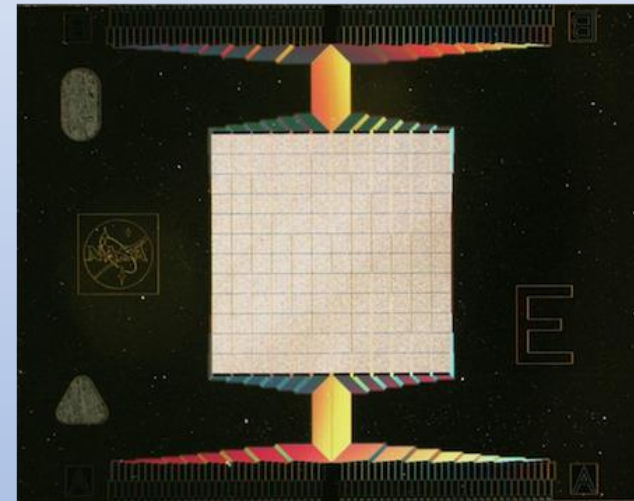
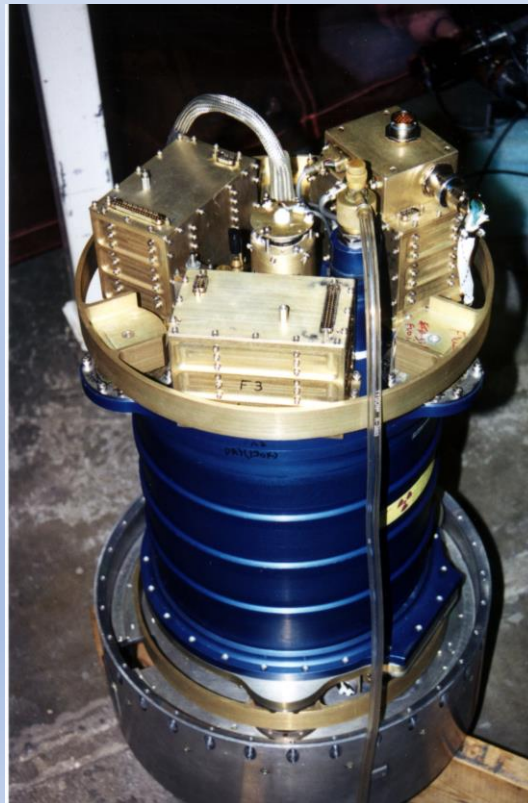
Developed and tested many of the subsystems for orbital platforms on XRISM and Athena:

- 50mK refrigerators
- Cryogenic amplifiers
- Cryogenic multiplexors
- Thin film IR/UV filters with defrosting heaters
- Event processing hardware



XQC detector array

XQC cryostat



Micro-X detector array

What are the challenges in exploiting the platform's capabilities?

(and opportunities)

Challenges:

1. Observation time is limited (~300s)
2. Payload size is constrained, although payloads keep getting heavier and longer, and are still accommodated (but there are real limits)
3. Astrophysics has been moving to larger and larger apertures for a long time
4. Starting a new rocket program can be daunting – BUT most new PIs were trained in established programs

Opportunities:

1. The cost of entry is low (new payloads ~\$3M-\$5M, reflights ~\$1M-\$3M)
2. Multiple flight opportunities/year
3. A graduate student can span a complete project
4. Can perform science that large observatories can't or won't do.
5. One scientist and/or engineer can make a big contribution, especially as an under-grad, grad-student or post-doc/

Are we training a diverse set of scientists and engineers?

Hardest question to answer without solid statistics

Many, many scientists and engineers have been trained through the program, and they are getting much more diverse.



Micro-X experiment team (NW)



CIBER 2, Experiment team (RIT)

Recent Training in the CU Suborbital Program

PIs:



Profs. Kevin France, Brian Fleming, Jim Green

Research Scientists:

Dr. Ambily Suresh



Dr. Dmitry Vorobiev



Junior Engineers: Ted Schulz, Stefan Ulrich, Nick DeCicco



Ph.D. and M.S. Students:

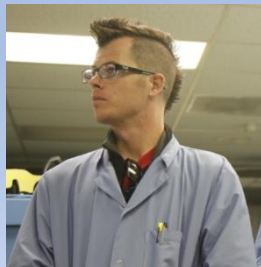
Dr. Keri Hoadley



Dr. Chris Moore



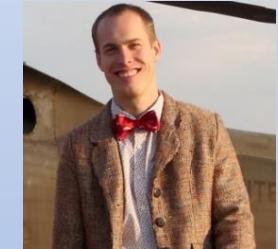
Robert Kane (ME)



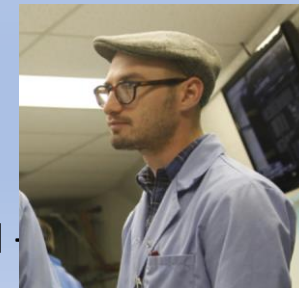
Fernando Cruz-Aguirre



Emily Witt



Dr. Nick Kruczek



Nico Nell (AE)



Dr. Allison Youngblood

RIT program and US collaborators

CIBER-2: APRA program (2015-present). (7 UG, 4 Grad, 2 postdoc)

Undergrads:

Racially or ethnically underrepresented students: 14%

- Women: 14%
- Persons with Disabilities: 14%
- Veterans: 0%

Grads:

•Racially or ethnically underrepresented students: 50%

- Women: 50%
- Persons with Disabilities: 0%
- Veterans: 0%

Postdocs:

•Racially or ethnically underrepresented students: 50%

- Women: 50%
- Persons with Disabilities: 0%
- Veterans: 0%

CSTARS: USIP program (2016-2018). (22 under grads, 2 grads):

•Racially or ethnically underrepresented students: 23%

- Women: 32%
- Persons with Disabilities: 5%
- Veterans: 0%

Alumni of the University of Wisconsin Program known to have careers in Astronomy/Physics

Graduate Students (40 PhDs)

Kat Barger*: Assistant Professor of Astronomy, Texas Christian Univ.
*Emily Barrentine**: Detector group, Goddard Space Flight Center
Jeff Bloch: Astrophysicist, Los Alamos, P.I. on Alexis
Dave Burrows: Gehrels-Swift SXRT P.I., Penn State
Gwynne Crowder: Associate Prof. Astronomy, Bellevue College, Washington
Wei Cui: Professor of physics, Purdue, Veritas; now at Tsinghua working on detector development for a major X-ray mission to study CGM
Steve Deiker: was Solar X-ray group at Lockheed, now runs company that does methane remote sensing
Dick Edgar: Chandra Operations
Brad Edwards: Did space elevator and tether dynamics for NASA, now runs startup making carbon nanotube panels for aerospace
Jose Franco: Professor of astronomy, UNAM; former director of Mexico's National Astronomical Observatory
Pete Fried: Bell Labs, navy sonar network
Deanne Iwan: Sandia National Labs
Keith Jahoda: Goddard Space Flight Center, PraXys P.I.
Mike Juda: Chandra Mission Operations Manager
Charlie Maxson: Astrophysics Staff, Smithsonian Astrophysical Observatory
Dan McCammon: Professor, X-ray astronomy at Univ. Wisconsin
Warren Miller: STSCI
Kelsey Morgan: NIST/Boulder, developing TES X-ray detectors
John Nousek: Professor, X-ray astronomy at Penn State
Tom Palmieri: OMB physics staffer for DOE projects
Dana Peters*: Professor, medical physics, Harvard
Paul Plucinsky: Chandra ACIS instrument scientist
Katherine Rawlins*: Professor of physics and dept chair, Univ of Alaska
John Raymond: Astrophysicist, Harvard Smithsonian, X-ray emission models
Lindsay Rocks: Professor of physics, Front Line College, Boulder
Wilt Sanders: GSFC/NASA Headquarters
Robin Shelton: Prof. of Physics (X-ray astronomy) & Observatory dir., Univ of GA
Jon Slavin: High Energy Astrophysics Division, Harvard Smithsonian
Barry Smith: Los Alamos National Labs
Randall Smith: Astrophysicist, Harvard Smithsonian, ARCUS P.I., Atom-DB mgr
Steve Snowden: Goddard, XMM-Newton manager
*Larry Sromovsky**: Planetary scientist, Univ. of WI, several space missions
Mel Ulmer: Astronomy Prof. & former observatory director, Northwestern Univ
Matt Vanderhill: Physicist, Lincoln Labs
Dallas Wulf: Postdoc, McGill Univ., CHIME

Undergrads (210 total)

Kelzie Beebe: Science staffer for Tammy Baldwin, U.S. Senate
Eric Bellm: Assistant Prof of Astronomy, Univ of Washington
Brad Benson: Principal Inst. scientist, Fermilab (South Pole telescope, DES, CMB S4)
Kim Chestnut: Lincoln Labs
Nick Chritensen: Aeronautical Engineering grad school, USC, rocket propulsion
Felipe Colazo: Goddard Space Flight Center
Mark Devlin: Physics Prof, U. Penn, BLAST PI, also several CMB experiments
Jeff DuMonthier: Goddard Space Flight Center
Mark Eriksson: Physics Prof., U Wisconsin
Chris Fassnacht: Astronomy Prof, U.C. Davis
Rachel Gruenke: Physics Grad school, Stanford
Cynthia Hess: Astronomy Prof, Illinois Wesleyan
Johnny Hoessel: Astronomy Prof, Univ. Wisconsin
Steve Holz: Physics, Robert College, Istanbul
Greg Jaehnig: postdoc on LiteBird, U Colorado
Kurt Jaehnig: lead engineer on ST5000 aspect camera, Space Astr. Lab, U. Wisconsin
Phil Dienes-Jones: Goddard Space Flight Center
Jane Kaczmarek: Research Scientist, CSIRO Sydney
Johann Loschnigg: Subcommittee on Space staff, U.S. House of Representatives
Steve Meyer: Professor, U. Chicago, P.I. on various balloon & ground CMB exp.
Dave Meyer: Professor of Astronomy, Northwestern University
Mackenzie Meyer: Grad school, applied physics, U Michigan, Ion propulsion
Steve Nahn: Fermilab, U.S. lead on CMS upgrade at CERN
Moire Prescott: Professor of Astronomy, New Mexico State
Akbar Sayeed: Professor of Electrical Engineering, Univ of Wisconsin
Jim Sowinski: NSF program manager for Nuclear Physics
Denise (Steffensrud) Smith: Space Telescope Institute outreach
Margaret Swaney: High school physics teacher, Madison, WI
Nelson Tansu: Professor of electrical engineering, Lehigh Univ., member NAI
Maggie Turnbull: Astrobiologist, Science Team Leader for the New Worlds Mission.

Postdocs:

Alan Bunner: AXAF Scientist at Perkin Elmer; Director of SEU, NASA HQ
Xavier Defay: CRESST Dark Matter collaboration.
Massimiliano Galeazzi: Professor of Physics, Univ of Miami; X-ray astronomy
Felix Jaeckel: Associate Scientist, X-ray astronomy group, Univ of Wisconsin
Mark Lindeman: JPL, Detector Scientist, JWST mission MIRI instrument.
Tatehiro Mihara: P.I. on MAXI all-sky monitor on ISS/JEM
John Vaillancourt: USRA Instrument Scientist, SOFIA/HAWC
F. Scott Porter: NASA/GSFC, Instrument Scientist Astro-E2, Hitomi, XRISM
Megan Eckart: LLNL, calibration lead for Hitomi, XRISM, US contrib to Athena

Summary:

- Astrophysical sounding rockets is a vibrant program
 - New Science
 - Cutting edge technology
- 3 to 5 astrophysics missions/year in an 18 missions/year program,
- Training lots of future astrophysicists, mission PIs ad instrument scientists
- By far, the most fun and rewarding experience I've had as a scientist





XQC experiment team

10 year publications (incomplete list):

CIBER: 18

CU rockets: 32

JHU rockets: 30

Penn state: 37