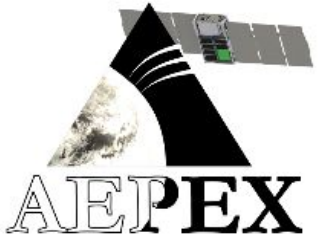

The AEPEX CubeSat Mission: Quantifying Energetic Particle Precipitation through Bremsstrahlung X-Ray Imaging

Grant Berland[1], Robert A. Marshall[1], Conner Martin[1], Deven Mhadgut[1], Joseph Buescher[1], Richard A. Kohnert[2], Spencer Boyajian[2], Christopher M. Cully[3], Michael P. McCarthy[4]

[1]University of Colorado Boulder, [2]Laboratory of Atmospheric and Space Physics, [3]University of Calgary, [4]University of Washington Seattle

UNIVERSITY OF CALGARY

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LASP

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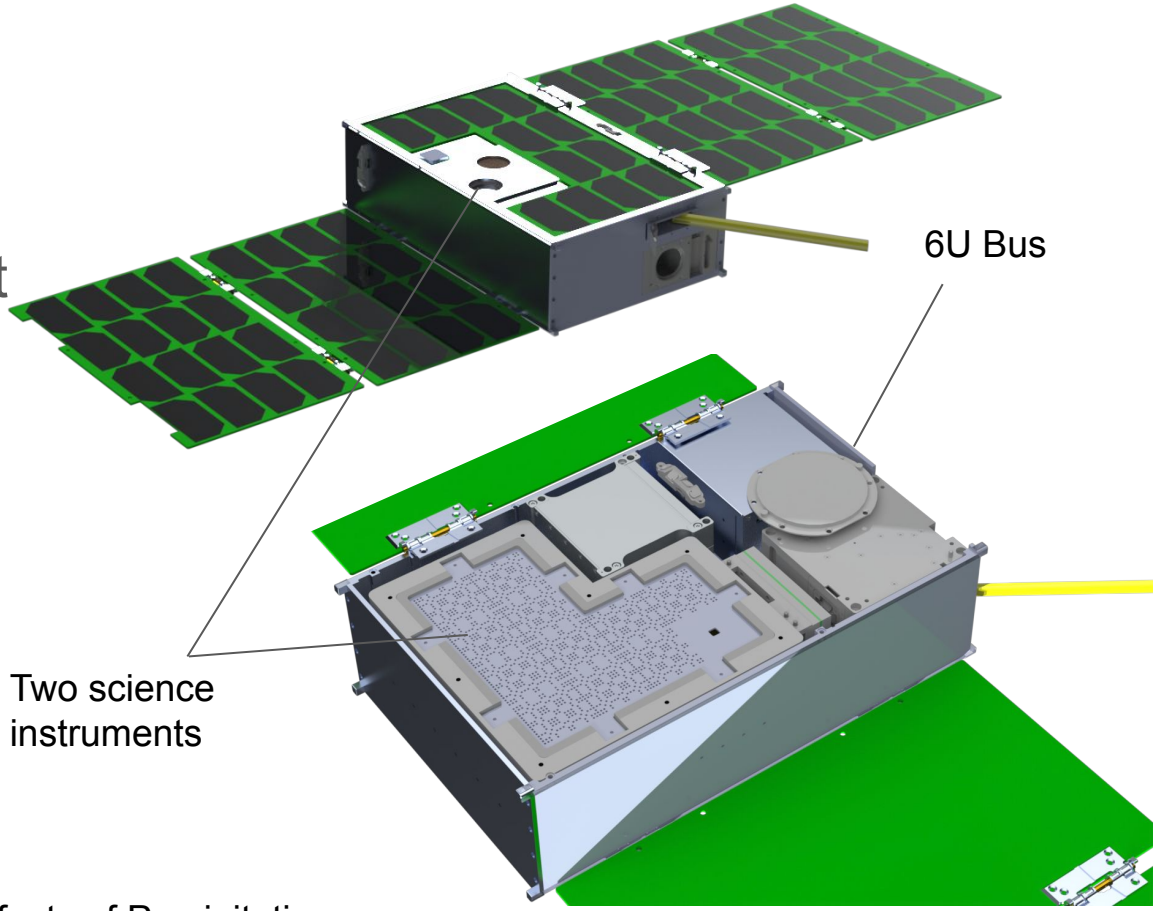
Outline

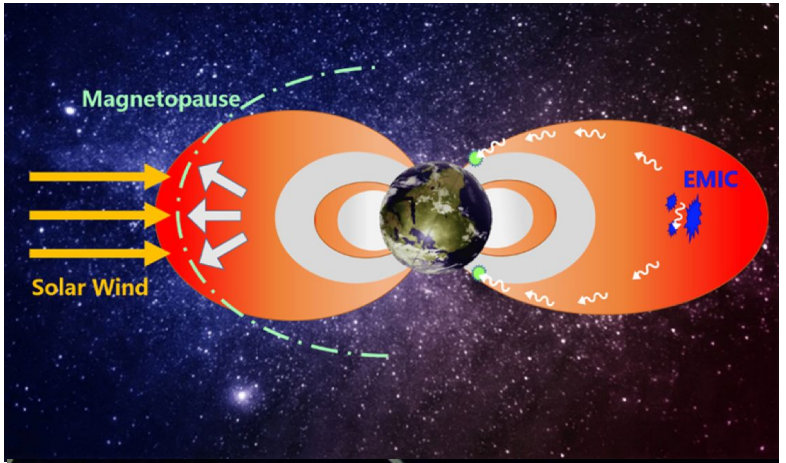
- Science Background
- Mission and Spacecraft
- Science Instruments
  - AFIRE
  - AXIS
- Testing Results

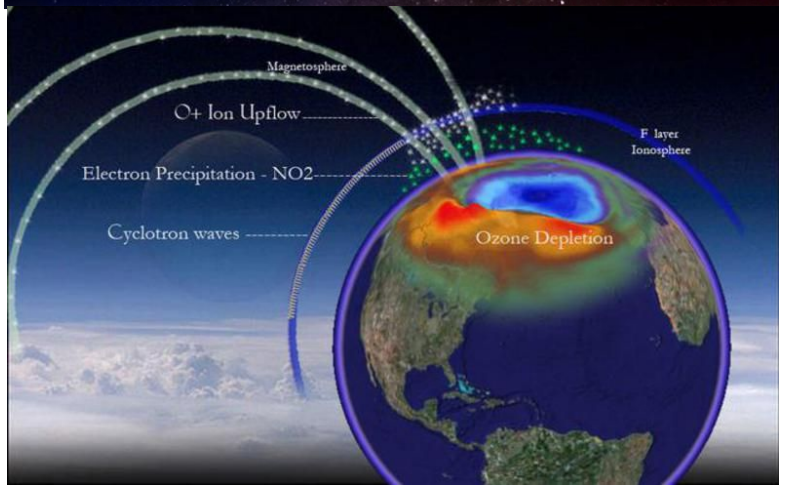


Additional Co-Investigators
Dan Baker - LASP
Cora Randall - LASP
Tom Woods - LASP
Harlan Spence - U. of New Hampshire
Allison Jaynes - U. of Iowa

Science Background

- The Van Allen radiation belts surround Earth at altitudes of
  - ~ 0.5 - 2 R_{Earth} (inner, proton belt, stable)
  - ~ 4 - 7 R_{Earth} (outer, electron belt, highly variable)
- Energetic particle precipitation (EPP) is the loss process of radiation belt charged particles to the atmosphere
- Charged particle interactions have myriad effects:
  - Spacecraft - SEE, SEL, DDD, etc.
  - Radio communication - ranging from reduced frequency ranges to radio comms blackouts
  - Indirectly destroys atmospheric ozone





Top: Xiang, et al. 2017
Bottom: LASP

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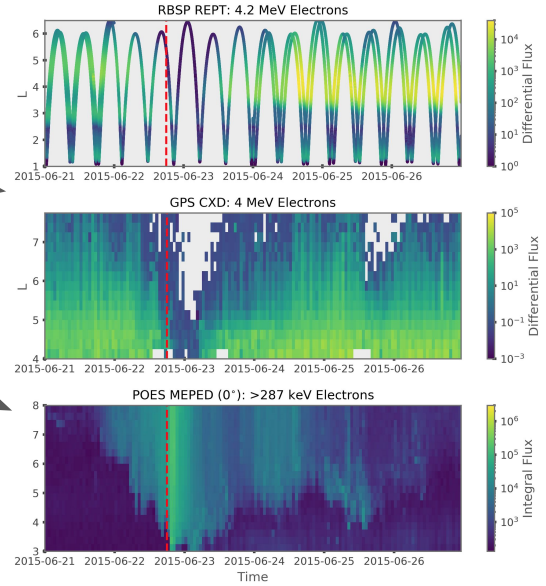
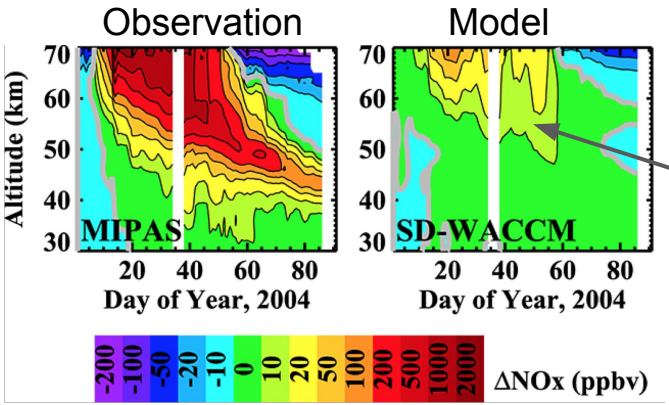
Science Background

- Outer Radiation Belt
  - Electron fluxes up to 10^5 cm^{-2} s^{-1} sr^{-1}
  - Electron energies over 1 MeV
  - Wave-particle interactions scatter particles into the atmosphere
- Atmospheric effects
  - NO_x and HO_x are produced from excess ionization
  - NO_x can descend and catalytically destroy ozone

Precipitation losses from the outer radiation belt show up in LEO



Marshall, et al. 2020



Missing NO_x descent at high latitudes

Randall, et al. 2015

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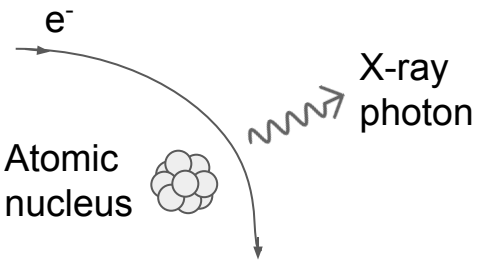
Science Background

How do we measure/quantify EPP?

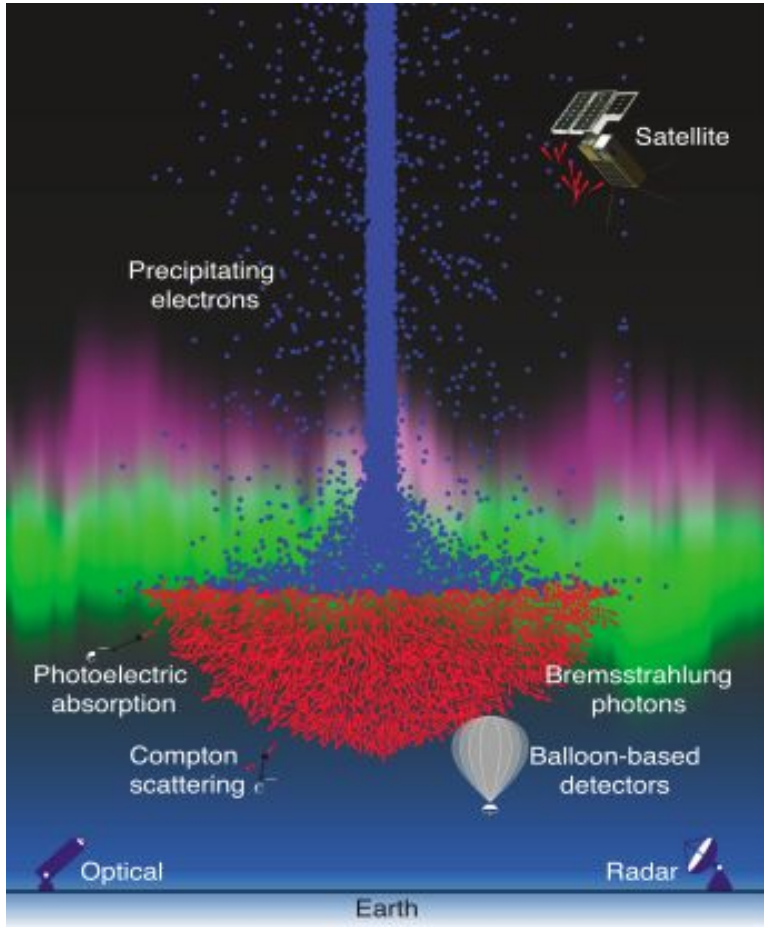
- In-situ particle measurements
  - Limited spatial and temporal coverage
- Remote sensing photon measurements
  - Relies on **Bremsstrahlung** production efficiencies
- Indirect measurements of EPP via ionization
  - Subject to other ionization mechanisms

What is Bremsstrahlung?

- Broadband X-ray emission that arises from electron-nucleus collisions



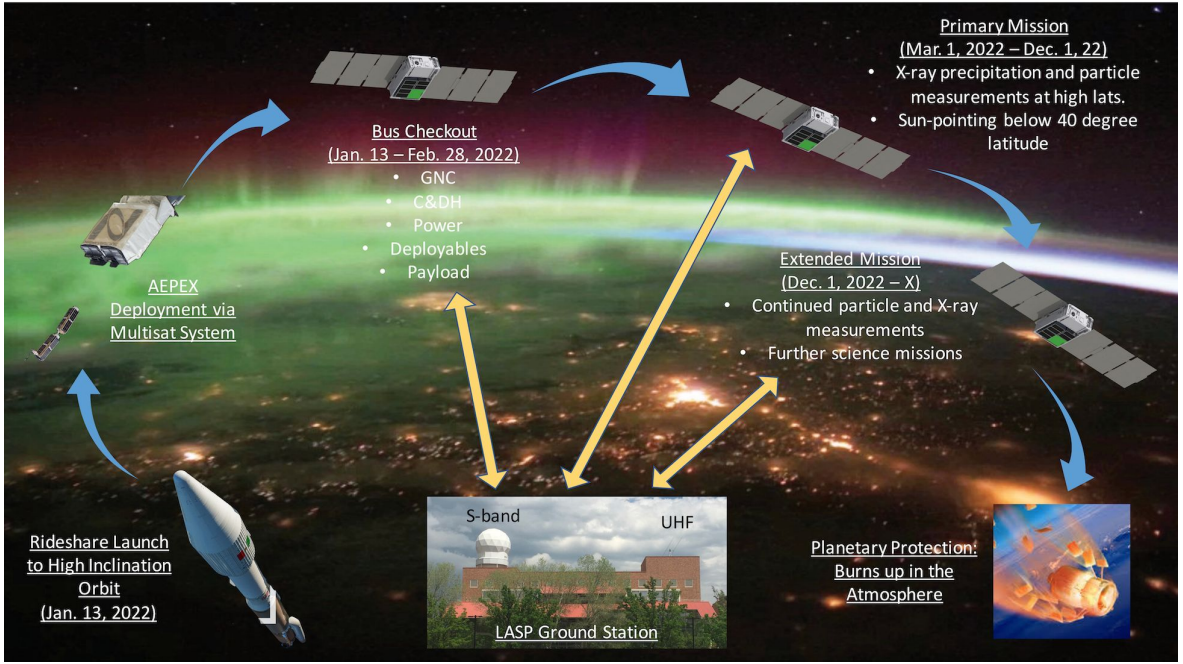
Bremsstrahlung (“braking radiation”) process



Xu, et al. 2018

Mission Requirements

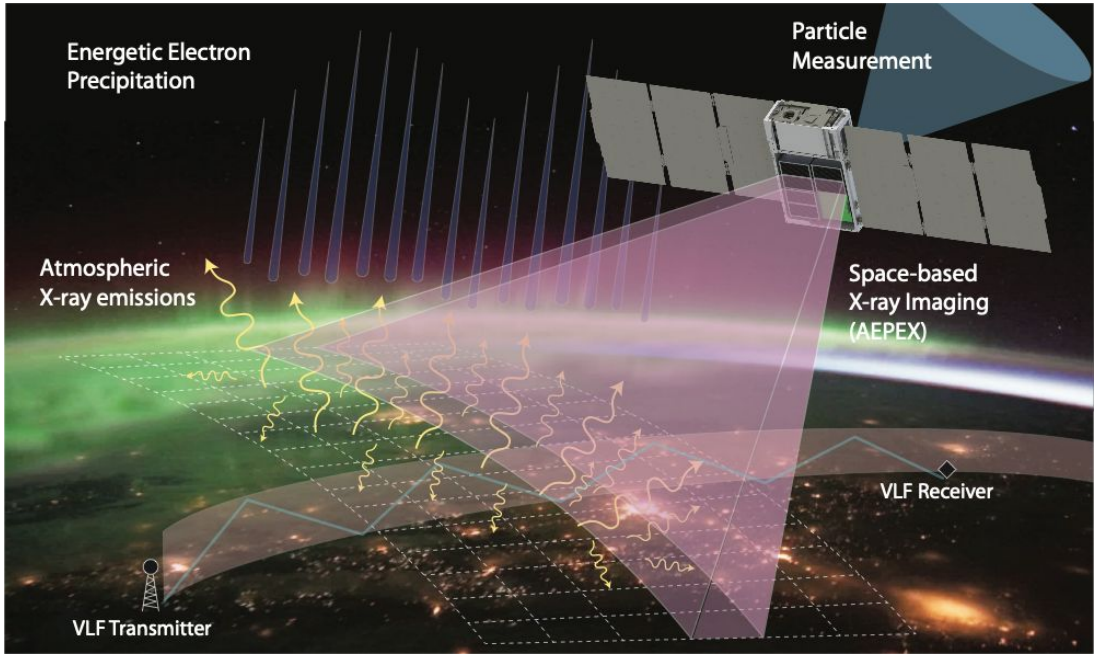
- **200 km spatial resolution**
- Measure *photon* fluxes between **10^1 – 10^4 photons/cm^2/str/sec**
- Measure *photon* energy **50–300 keV** with **20% energy resolution**
- Measure *electron* energy distribution from **200–1000 keV** with **20% energy resolution**



(See *Marshall, et al. 2020* for requirement justification)

Mission Concept

- Goals
  - Estimate the **amount of energy deposited** into the atmosphere via EPP
  - Determine the **spatial scales** of EPP
- AXIS
  - Earthward-facing **X-ray imaging spectrometer**
- AFIRE
  - Space-facing (up magnetic field line) **electron detector**
- Concept of Operation
  - Instruments operate at > 40^{o} latitude
  - Sun-pointing at < 40^{o} latitude



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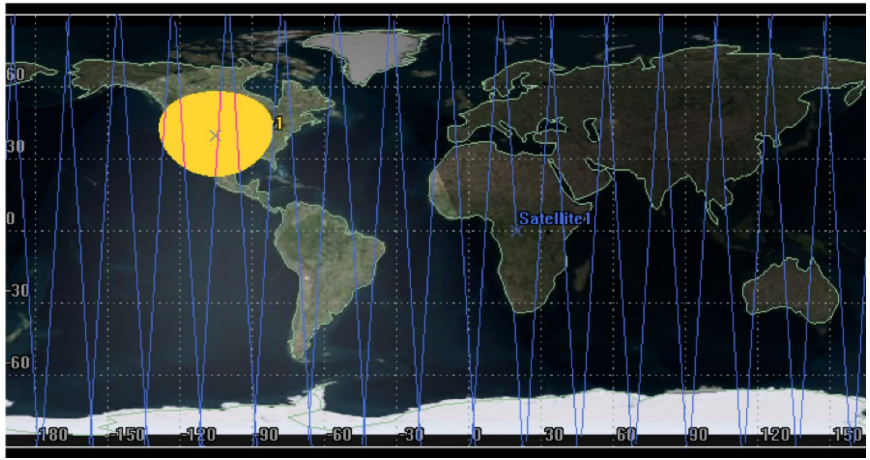
Mission

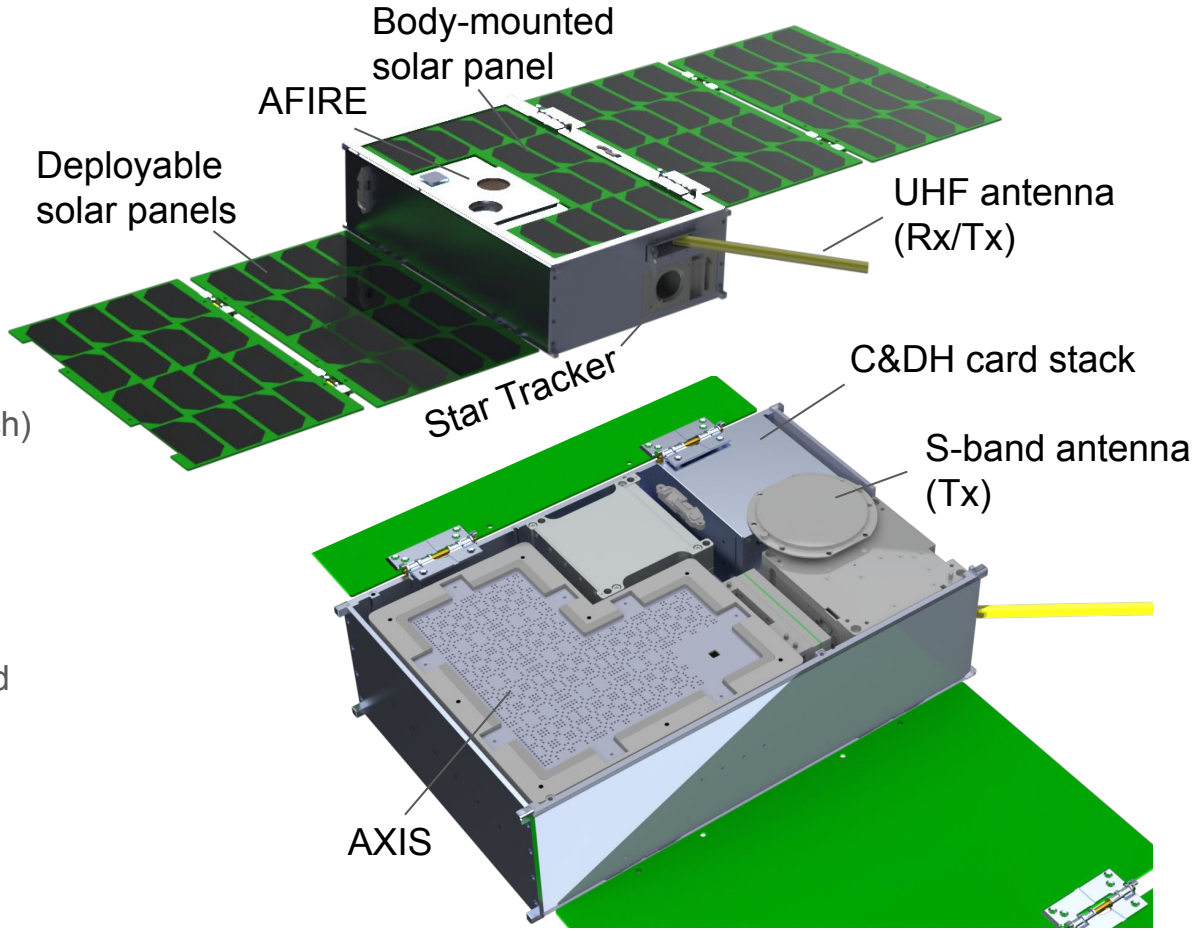
- Orbit
  - Circular orbit at 500 km altitude
  - Inclinations > 70º
- Data
  - Multispectral images
    - 16 pixels x 16 pixels x 16 energy bins
  - Electron flux and spectra
    - 180º detector
    - 45º detector
  - Instrument housekeeping



Parameter	Requirement	Reference Design
Altitude	400 - 600 km	500 km
Inclination	≥ 70 deg	98 deg
Eccentricity	≤ 0.02	0
Eclipse	no requirement	N/A
Spacecraft size	6U	6U
Mass	≤ 14 kg	11.7 kg CBE
Orbit Averaged Power	≤ 37 W	26.5 W
Data per day	≤ 210 MB/day	151 MB/day
Ground System	UHF / S-band	LASP UHF & S-band

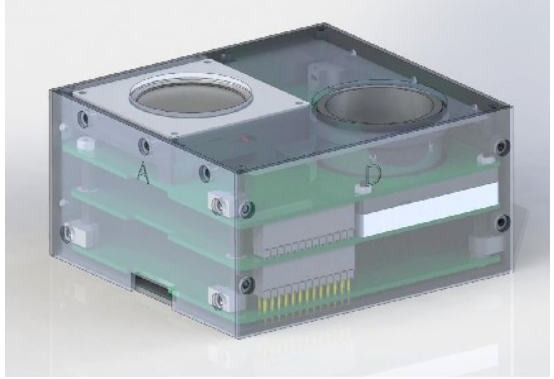
Spacecraft

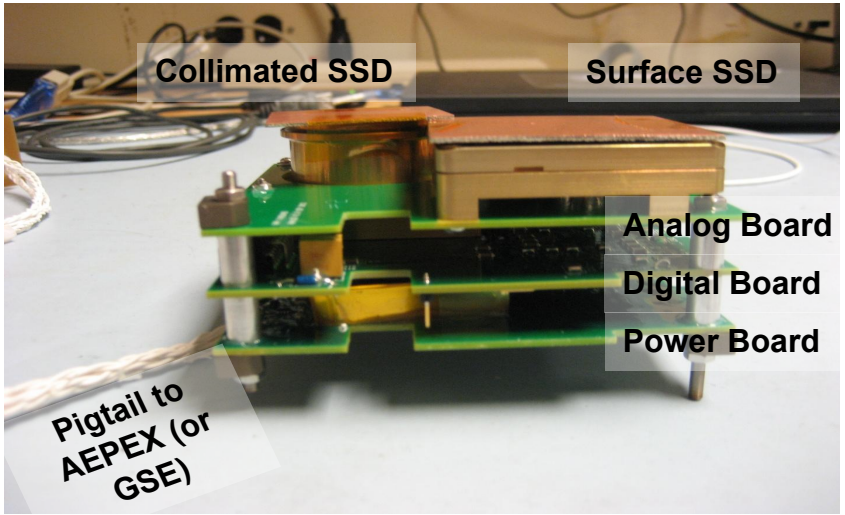
- Bus built by LASP
  - EPS
  - C&DH
- Power
  - 4 deployable panels (16 cells each)
  - 1 body-mounted panel (12 cells)
  - 75 W-hr battery
- Communication radios
  - Clyde Space S-band (science)
  - Space Quest UHF (command and telemetry, housekeeping data)
- ADCS
  - Blue Canyon Technologies XACT



AFIRE Instrument

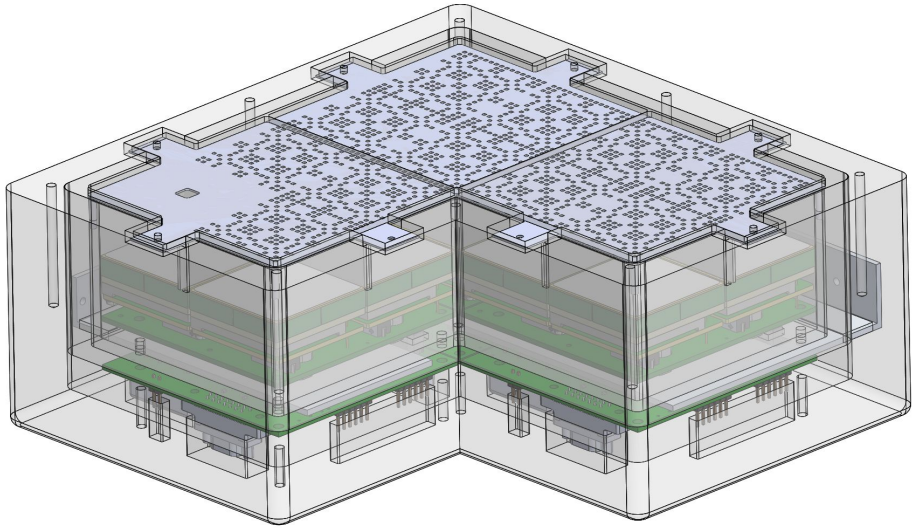
- AEPEX's FIRE (Focused Investigation of Relativistic Electrons) Instrument (AFIRE)
- Built by University of New Hampshire FIREBIRD team
- ½ U solid-state detector instrument
  - Omni-directional (180º) detector
  - Collimated (45º) detector
- 12 energy bins → 20% energy resolution between 200 keV - 1 MeV

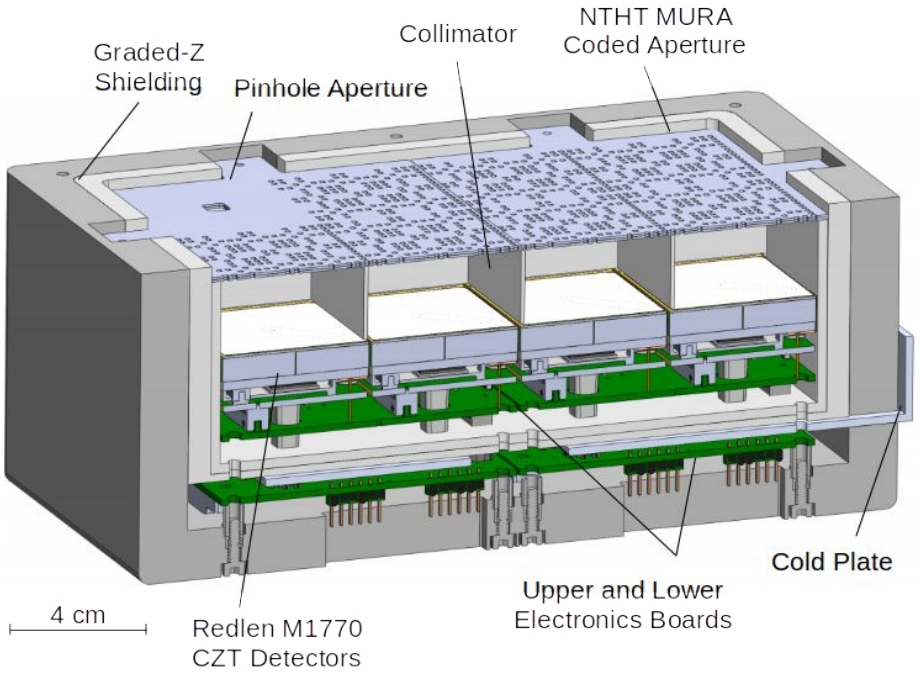




Courtesy of UNH

AXIS Instrument





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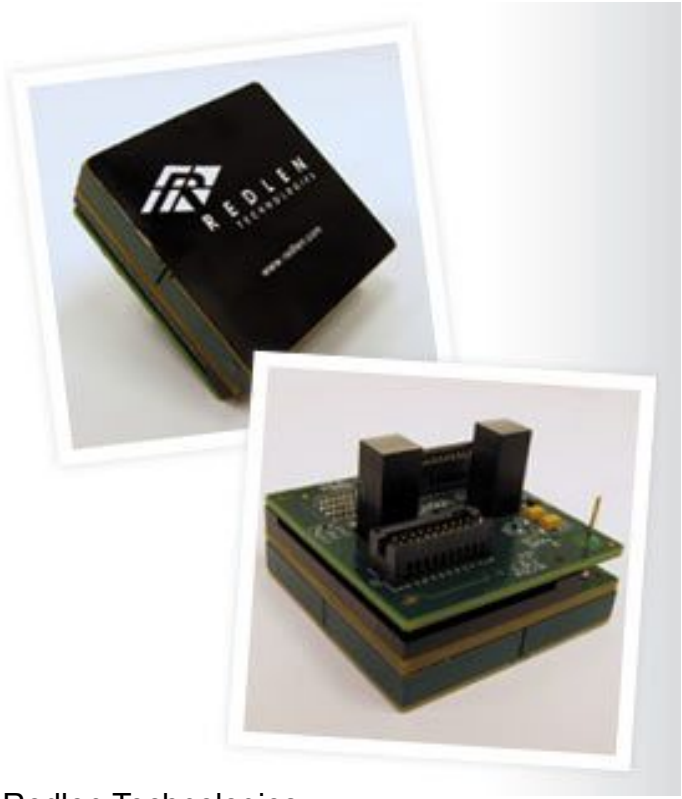
AXIS Instrument

Redlen M1770 CZT X-ray Detectors

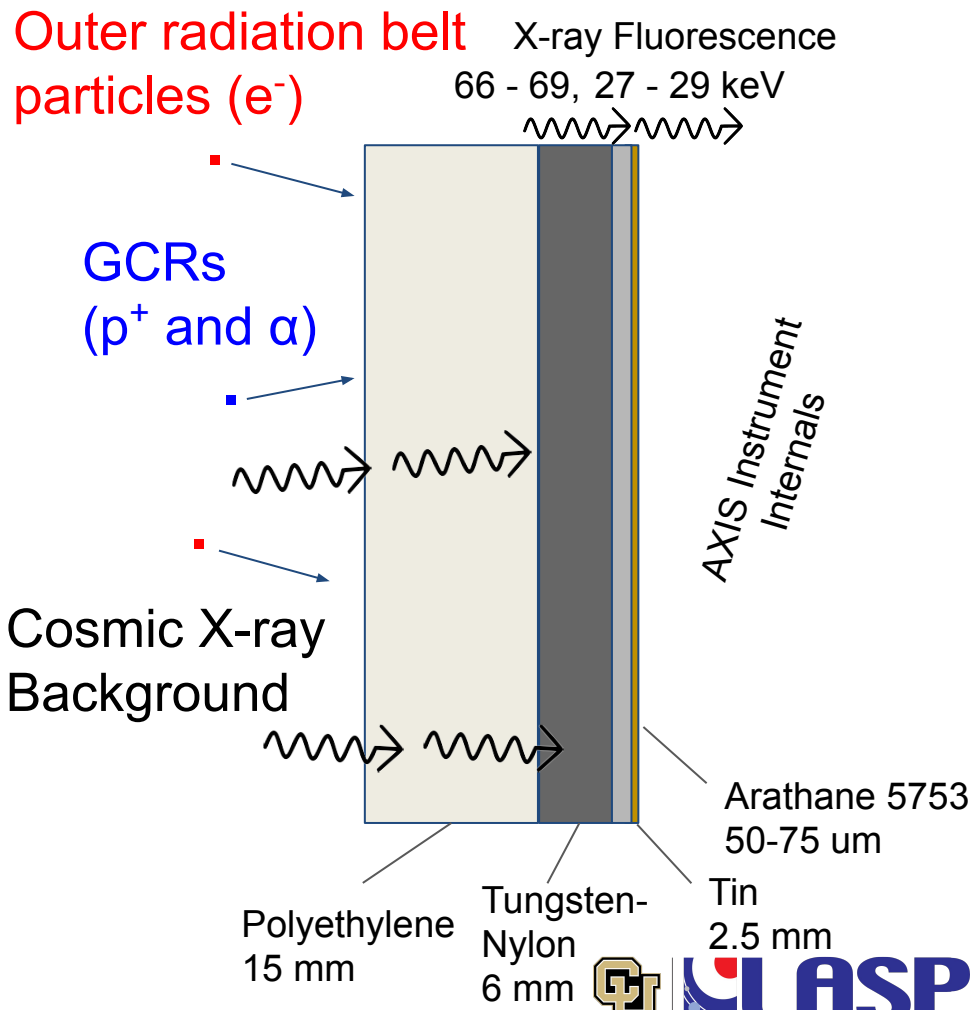
- Detectors used on CXBN-1 and -2, EPEx balloon mission
- 16 x 16 pixels
- Energy range: 50 - 300 keV
- Energy resolution: 6.5% (~3 keV at 50 keV)
- Max detection rate: 60,000 counts/sec/detector



Redlen Technologies

AXIS Instrument

- Low-Z materials
  - High collisional stopping power
  - Low radiative stopping power
  - No XRF/Bremsstrahlung production
  - Stops low energy electrons effectively
- High-Z materials
  - High collisional stopping power
  - High radiative stopping power
  - XRF/Bremsstrahlung production
  - Stops high energy electrons, photons effectively



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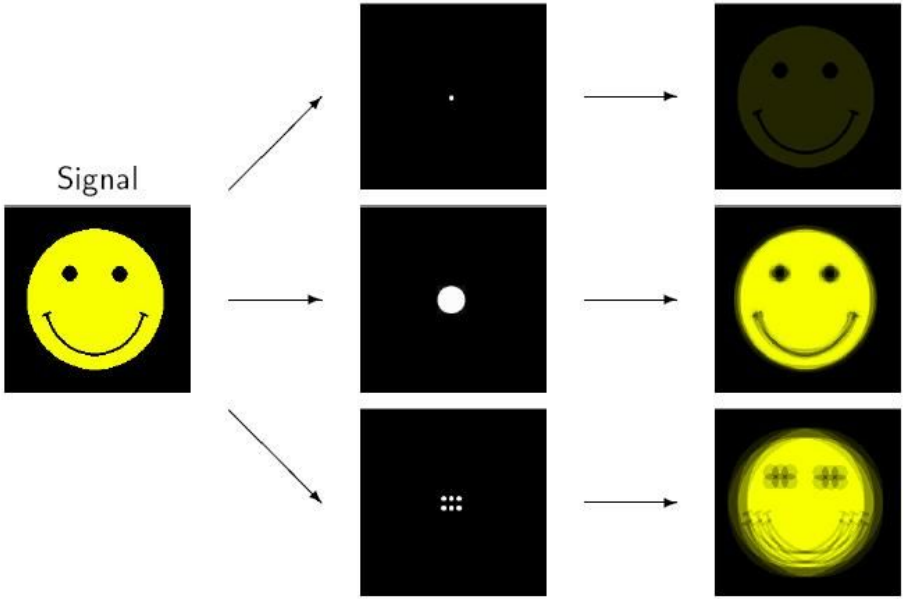
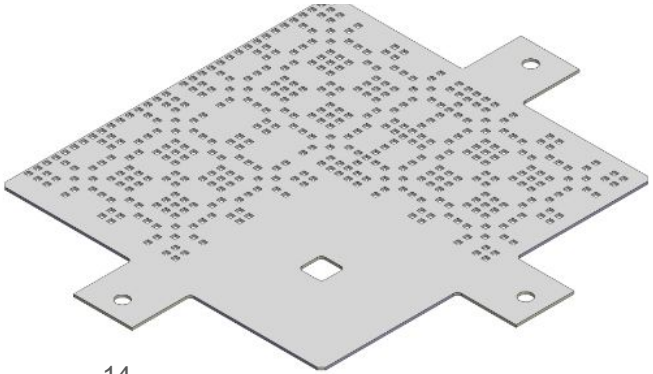
AXIS Instrument

Coded Aperture Imaging

- Combines pinholes in a well-conditioned pattern for higher SNR
- “No two holes touching” (NTHT) variant chosen for structural stability
- See paper for details on coded aperture imaging



Marcia, et al., 2008



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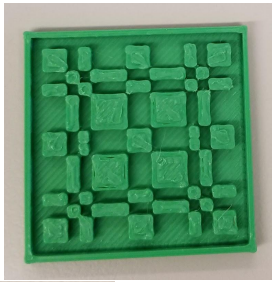
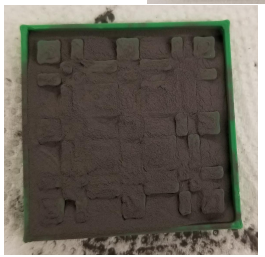
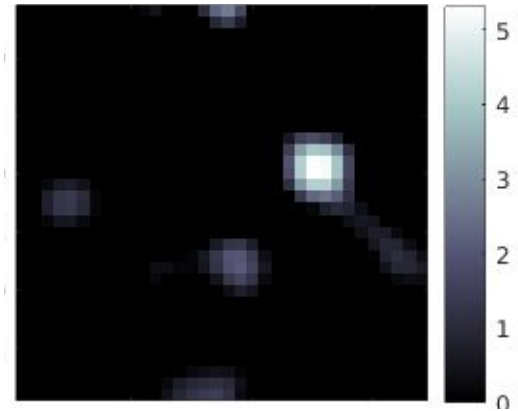
Testing Results

- Cobalt-57 “first light” test of coded apertures
- Simple tungsten powder MURA masks used
- Background thresholding removes noise and imager imperfections

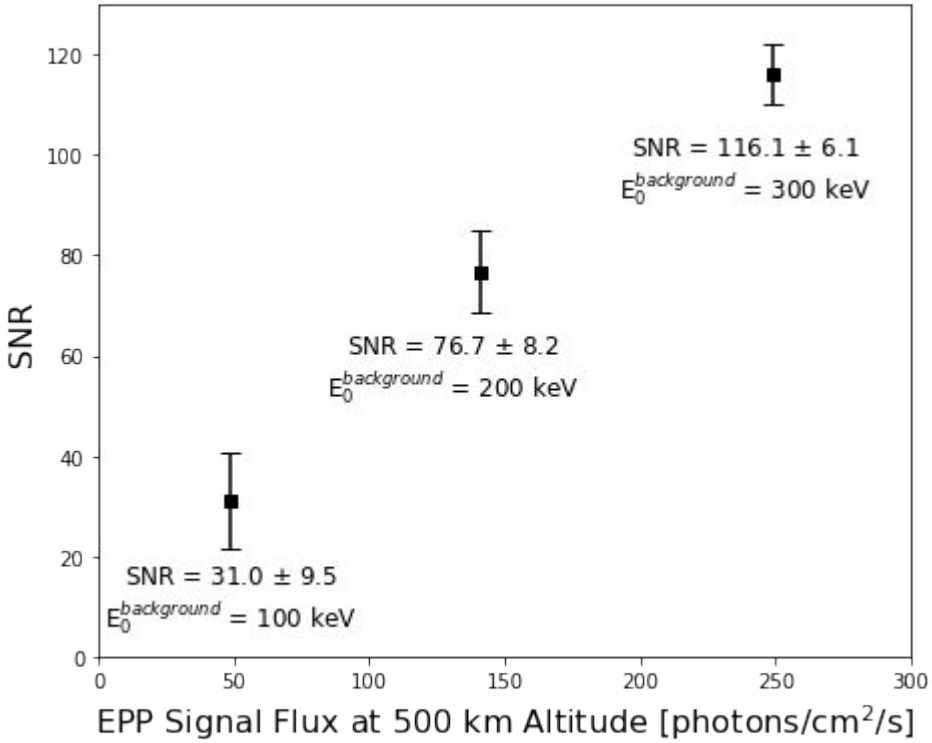






AXIS Instrument

- GEANT4 Inputs
  - 10^5 electrons/cm^2/sec/sr
  - E_0 = 100, 200, and 300 keV
- Noise Sources
  - Trapped and precipitating electrons
  - Atmospherically backscattered electrons
  - Galactic Cosmic Rays
  - Cosmic X-ray Background
  - Detector noise



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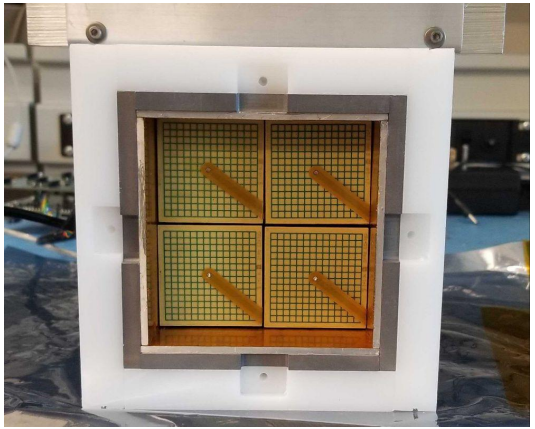
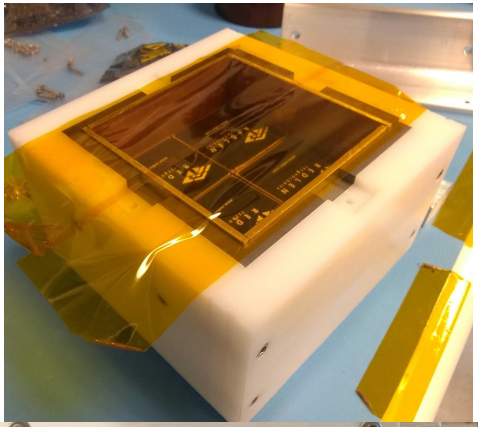
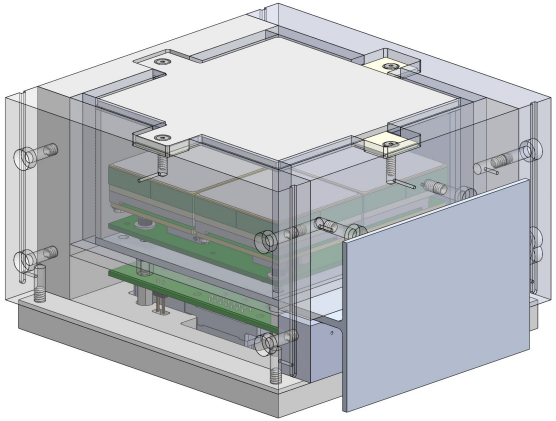
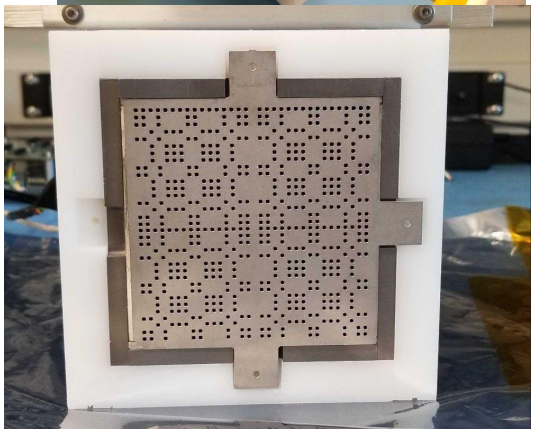
AXIS Instrument

- Prototype/engineering model instrument:
  - Four detectors
  - Graded-Z shielding
  - X-ray optics and window
- Tests performed
  - Operation in TVac
- Upcoming tests
  - Goddard electron beam testing
  - X-ray optical testing





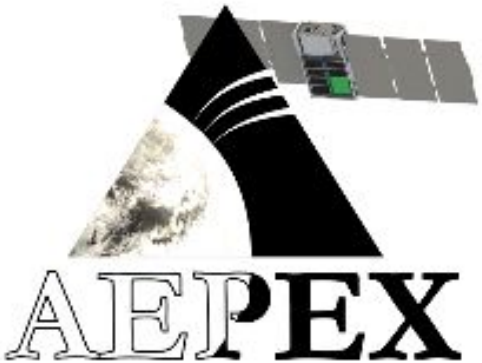




Conclusions

The AEPEX mission will estimate the **spatial extent** of EPP and **amount of energy** input into the atmosphere from EPP through **novel X-ray images of Earth** and electron spectra.

AEPEX launches late 2022



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