U.S. NAVAL RESEARCH LABORATORY

SiPM Arrays for Space-Based Detectors

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High Energy Space Environment Branch
Space Science Division

Who We Are

U.S. Naval Research Laboratory

- The corporate laboratory for the United States Navy
- Main campus located in Washington, DC
- Conducts basic research concerning the Navy's environments of Earth, sea, sky, and space
- Pioneered naval research into space
  - Vanguard: America’s first satellite program

High Energy Space Environment Branch

- Advancing the understanding of the high energy environment through:
  - the development and deployment of advanced detectors in space
  - simulation of environments & operating concepts
  - interpretation and theoretical modeling of observed phenomena

SiPM Instrumentation at NRL

- *Experience instrumenting SiPM arrays*
- *Heritage of successful space- and ground-based systems*

Applications

- Space-based
- Ground-based
- Science-focused
- Security-focused

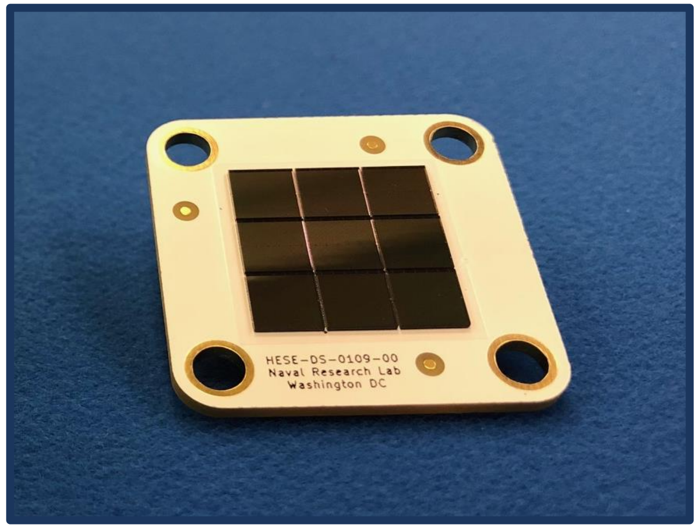
Emphasis of this presentation

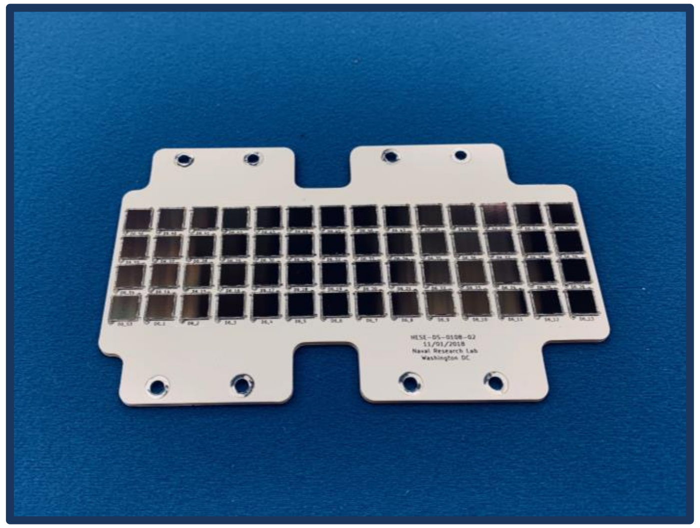
Attractive Qualities of SiPMs

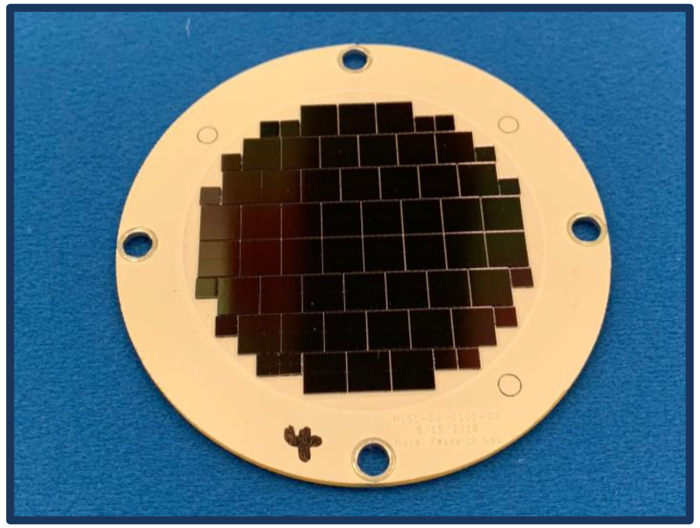
- Mechanical ruggedness
- Size
- Low voltage bias
- Relatively high quantum efficiency

Challenges with SiPMs

- Degraded performance at higher temperatures (> 30 °C)
- Large capacitance for arrays (sizes ≈ 6 cm^2 and greater)







Space Test Program

U.S Department of Defense (DoD) Space Test Program (STP)

- Provides space flight to the DoD’s space science and technology community for experiments, new technologies and demonstrations.
- Mission: space qualify new technology for the DoD
- Available competitively to qualified and relevant investigations
- Service provided at no cost to the experimenter and includes
  - Spacecraft
  - Integration and testing (on spacecraft)
  - Launch
  - One year mission operations (e.g., spacecraft and instrument commanding, data handling and delivery)
- Experimenter covers the cost of
  - Development and construction of the instrument
  - Pre-ship environmental testing
  - Analysis of data.
- A typical STP flight will host numerous experiments.

Strontium Iodide Radiation Instrument (SIRI-1)

- *Space qualification of SrI_2(Eu) and SiPMs*
- *Launch: STPSat-5 (sun-synchronous LEO) – 03 Dec 2018*

PI: Dr. Lee J. Mitchell (NRL)

Goal

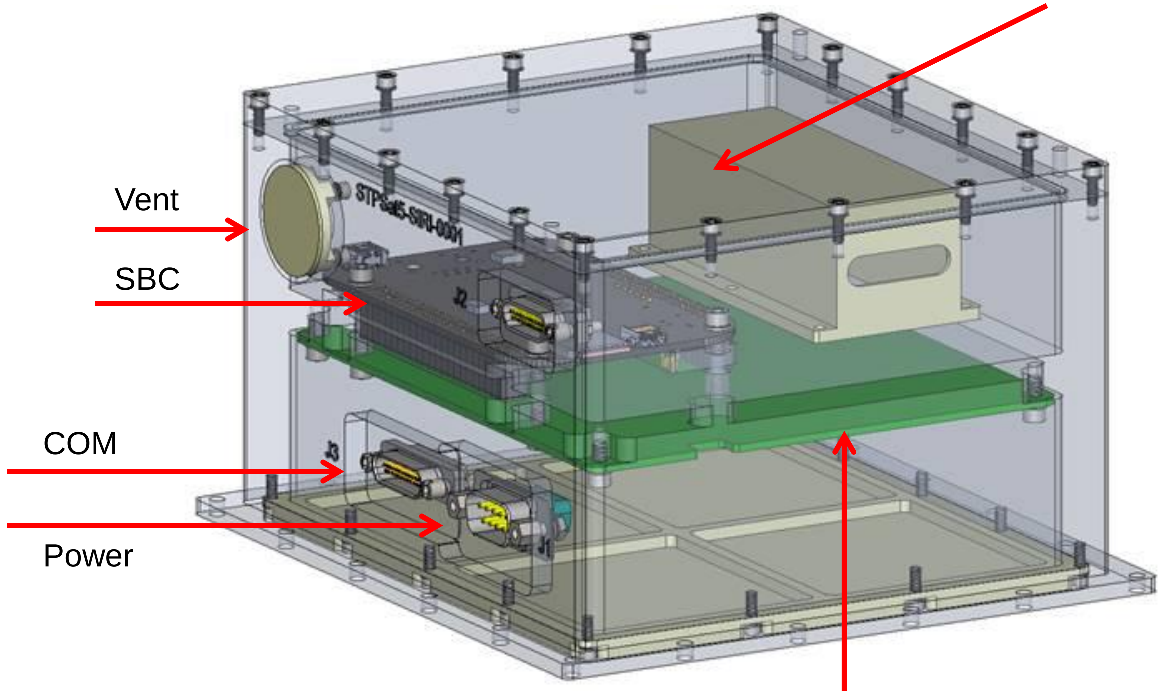
– Demonstrate and characterize this new technology for use as a component in larger space-based defense- or science-related missions

Design Overview

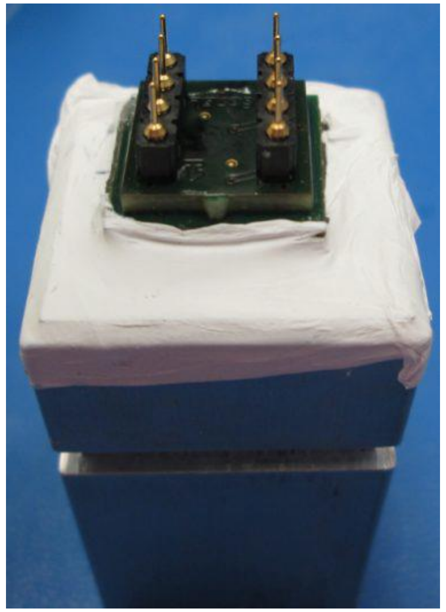
– Total SWaP
  - Size: 8.9 cm (H) x 14 cm (D) x 15 cm (L)
  - Mass: 1.620 kg
  - Power: 1.5 W

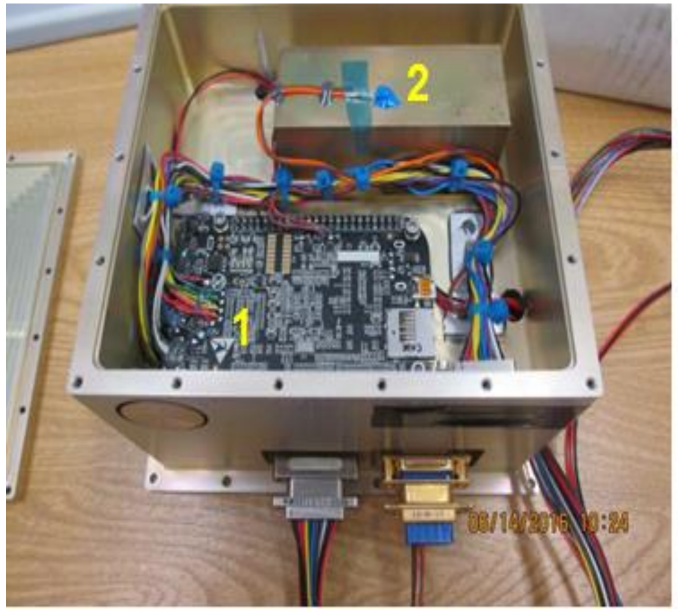
– Detector
  - Single SrI_2(Eu)
    - 17 x 17 x 40 mm^3
    - 4% resolution at 662 keV
    - Density: 4.55 g/cm^3
  - 2 x 2 array of 6-mm SensL J-series SiPMs

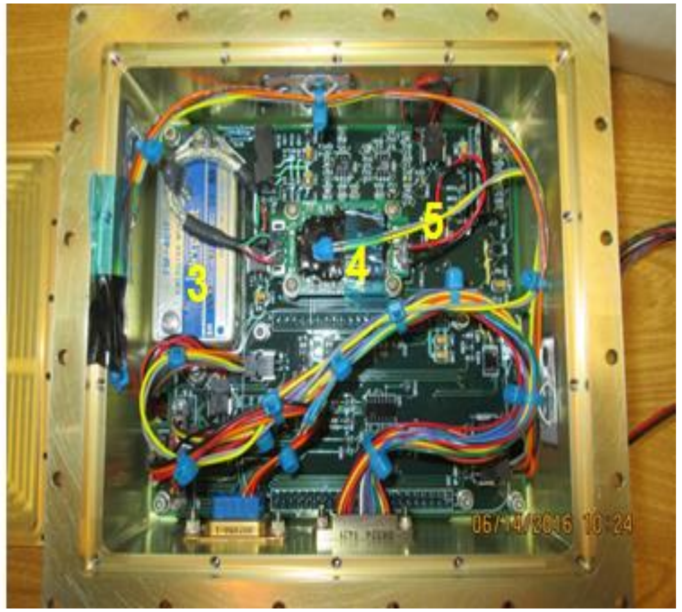
Currently successfully operating in orbit!



SIRI-1







Detector

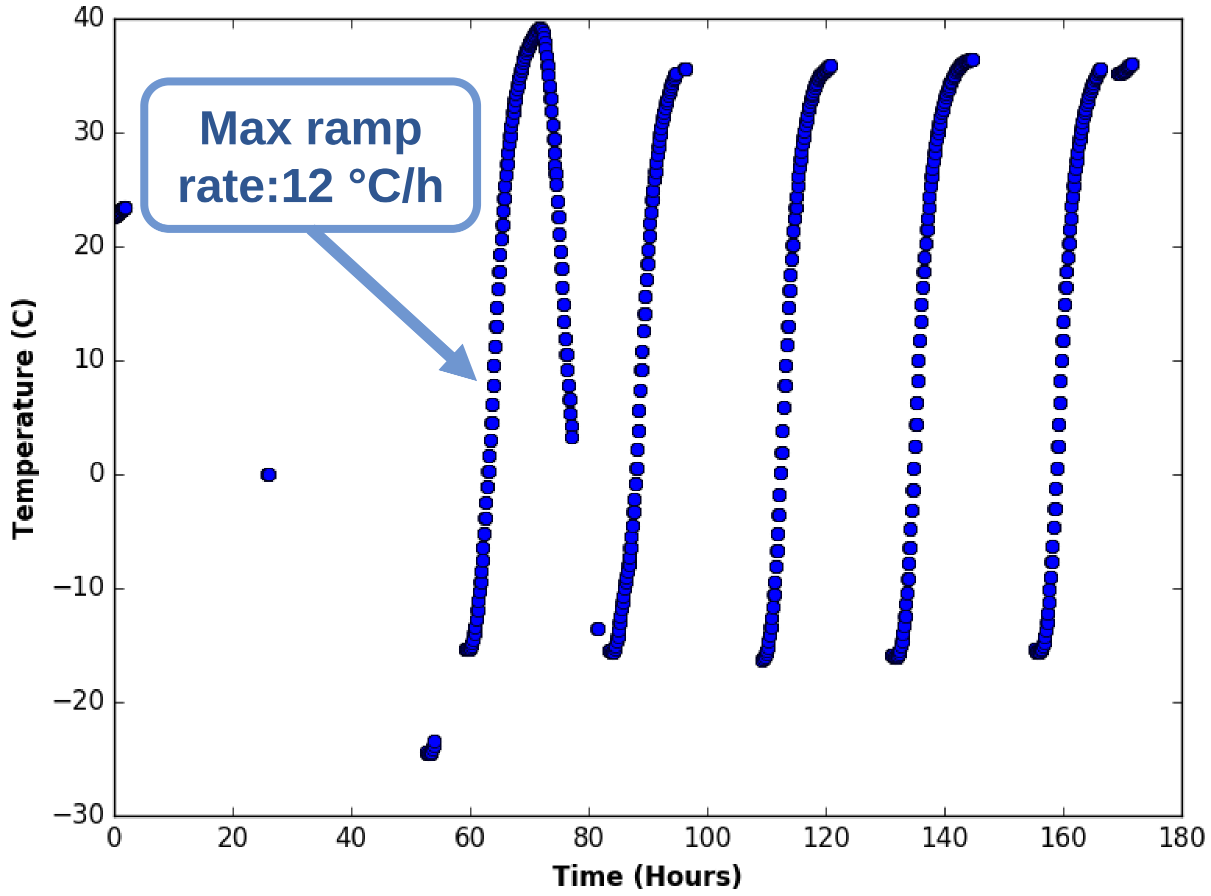
- (Left) Packaged $SrI_2(Eu)$ crystal purchased from Radiation Monitoring Devices, Inc.
  - Opted for optical window to allow experimentation with different vendor-supplied SiPMs
- Optical window and SiPMs (right) result in ~1% resolution increase compared to ultra-bialkali PMT
  - Measured resolution: 4% at 662 keV

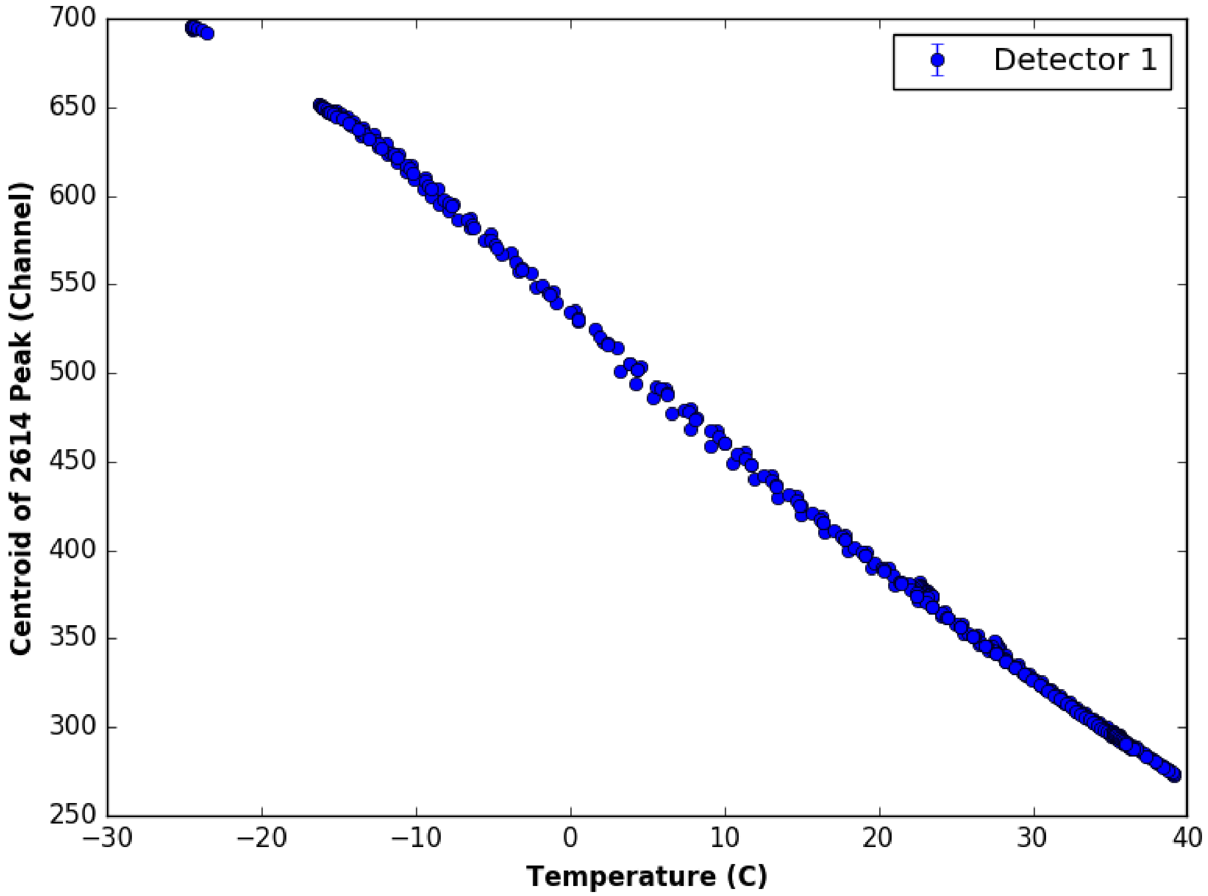
System components

1. Single-board computer: Beaglebone Black
2. Detector clamp
3. EMI filter
4. Multichannel analyzer: Kromek K102
5. Custom printed circuit board
   - Includes power conditioning, temperature sensors, preamplifier, SiPM bias control

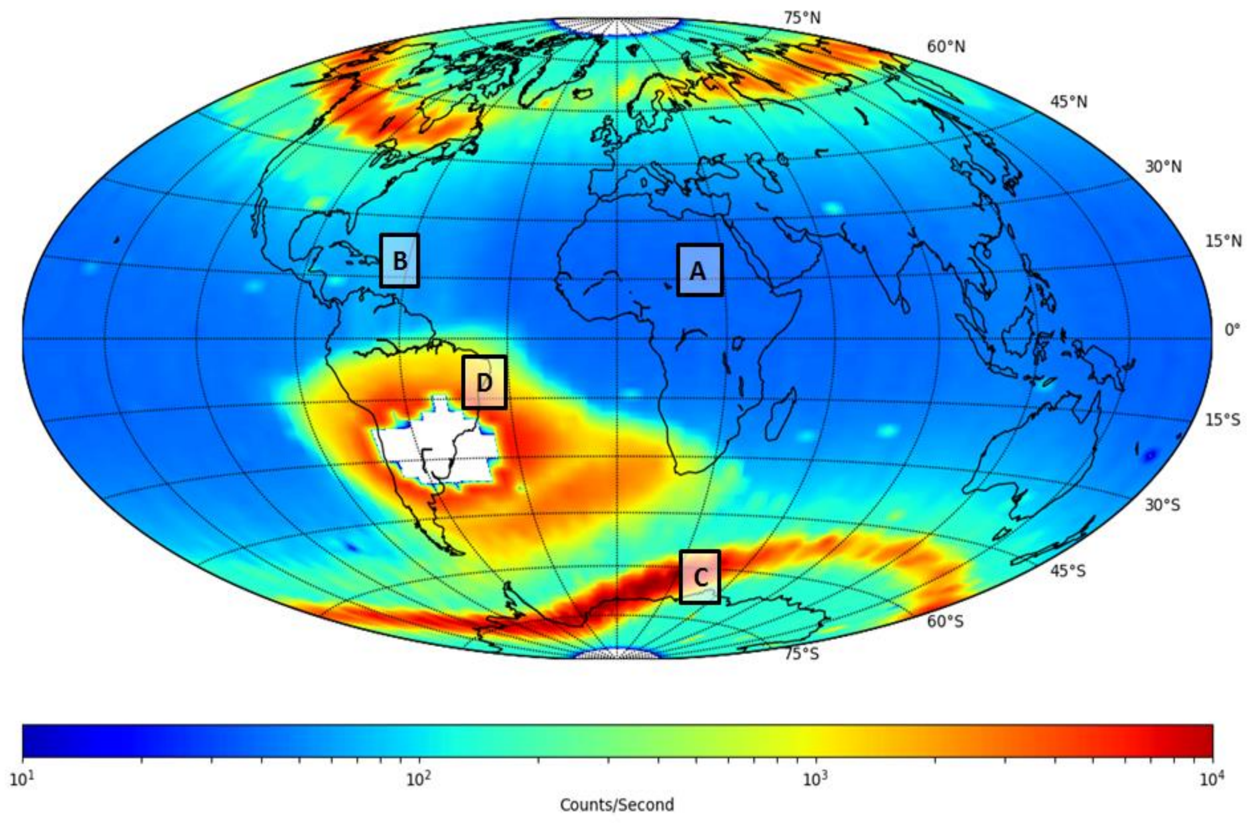
SIRI Pre-ship Testing

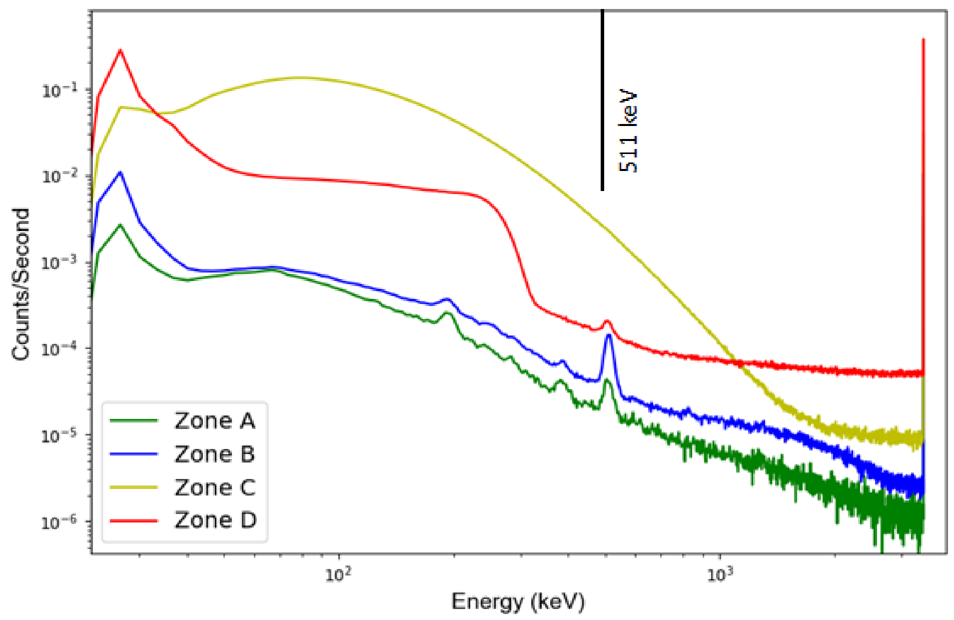
Pre-ship Temperature Testing





SIRI-1 Early Results





Gross gamma-ray count rate showing the elevated background as the instrument transitions through the various trapped particle regions. The four zones A, B, C and D were used generate the spectra shown in plot above right. No data is indicated by the white areas of the plot (when data acquisition is paused in the SAA).

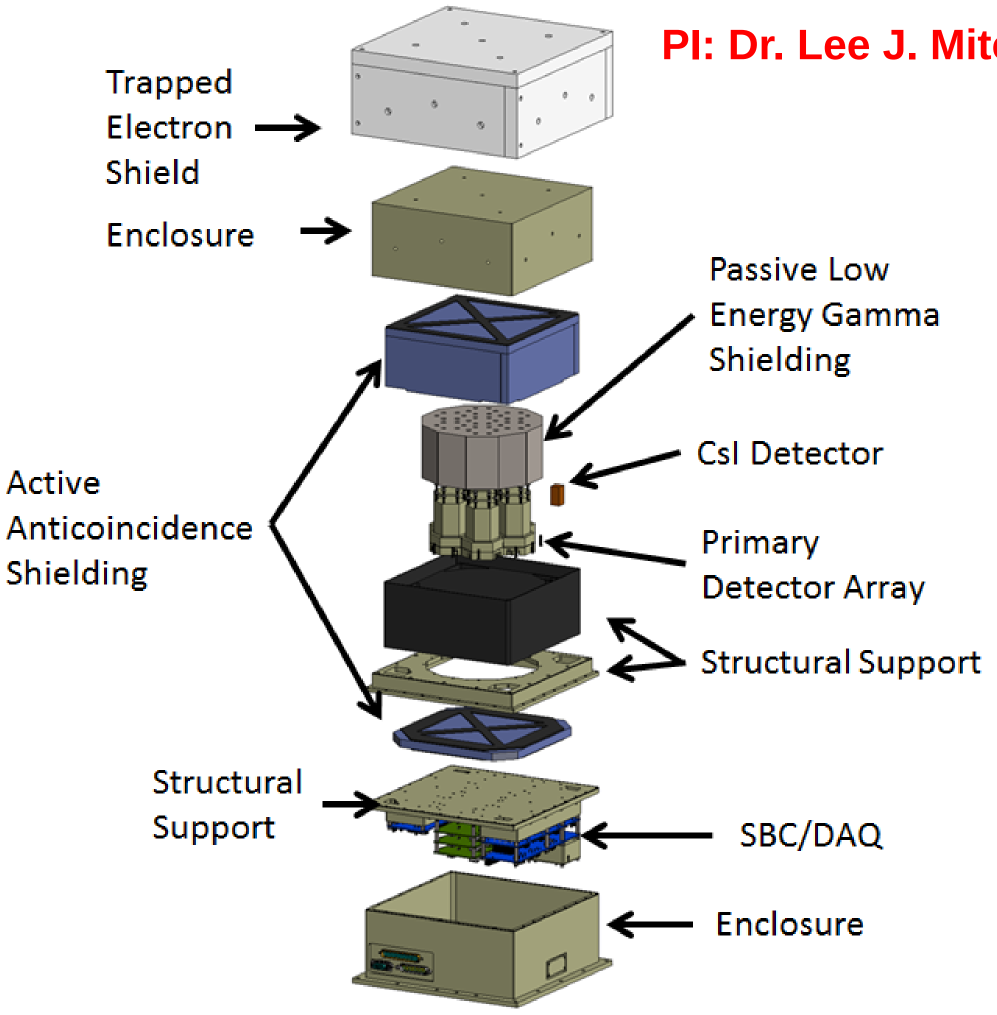
SIRI-2

- *Multi-crystal design improving upon SIRI-1*
- *Solar gamma-ray spectrometer*
- *Launch: STPSat-6 (GEO) – Aug 2020 (expected)*

PI: Dr. Lee J. Mitchell (NRL)

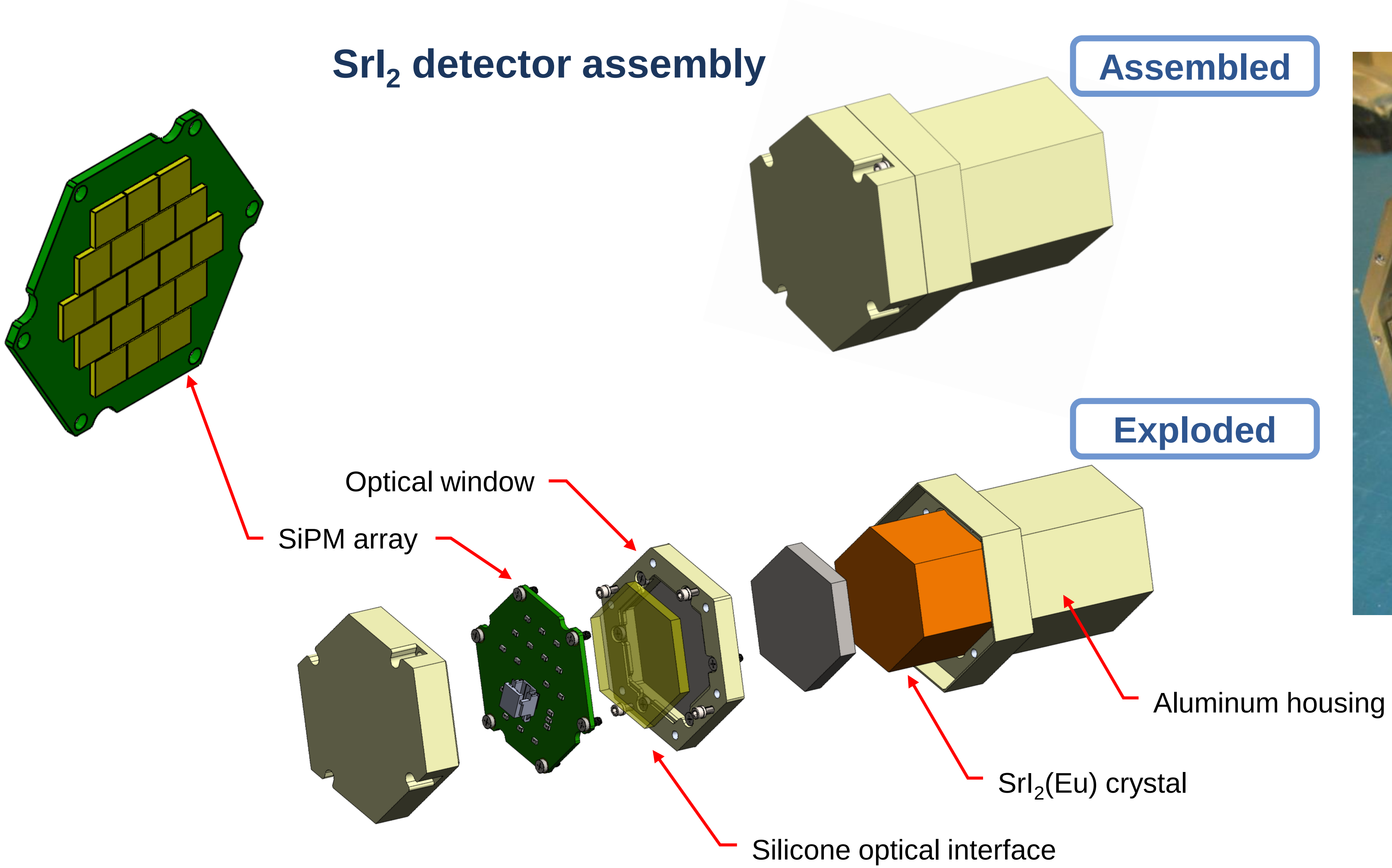
Design Overview

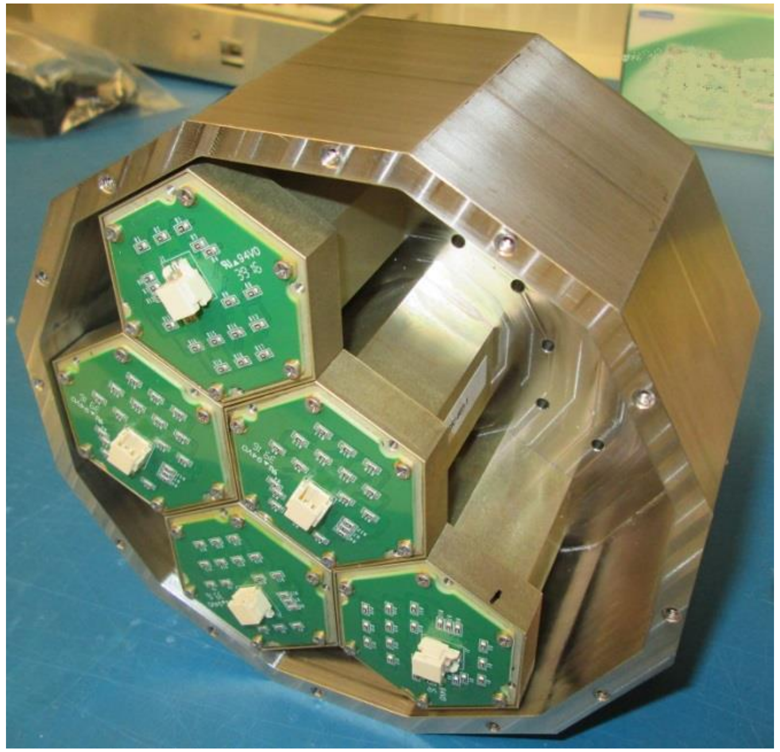
- Primary detectors
  - Seven $SrI_2(Eu)$
    - Hexagonal close-pack design
    - 38.1 mm diameter (19.05 mm per side) x 38.1 mm length
  - SiPM readouts
    - 19 6-mm SensL J-series SiPMs in hexagonal array on PCB
- Active shield
  - Six plastic detectors for approx. 4π coverage
  - Anticoincidence rejects high energy cosmic-ray protons that pass through the detector and shielding.
- Passive shield
  - Reduce low energy photons during solar events (prevent "swamping" of system)
  - Reduce Bremsstrahlung produced by electrons interacting with enclosure
- Single CsI detector
  - External to passive gamma shield
  - Measure low-energy hard x-ray component of solar flare



SIRI-2

SrI_2 detector assembly





GAGG Radiation Instrument (GARI)

- *Leveraging previous work on SIRI-1 to space qualify GAGG + SiPMs*
- *Targeting manifest: STP-H7 – April 2022 launch (expected)*

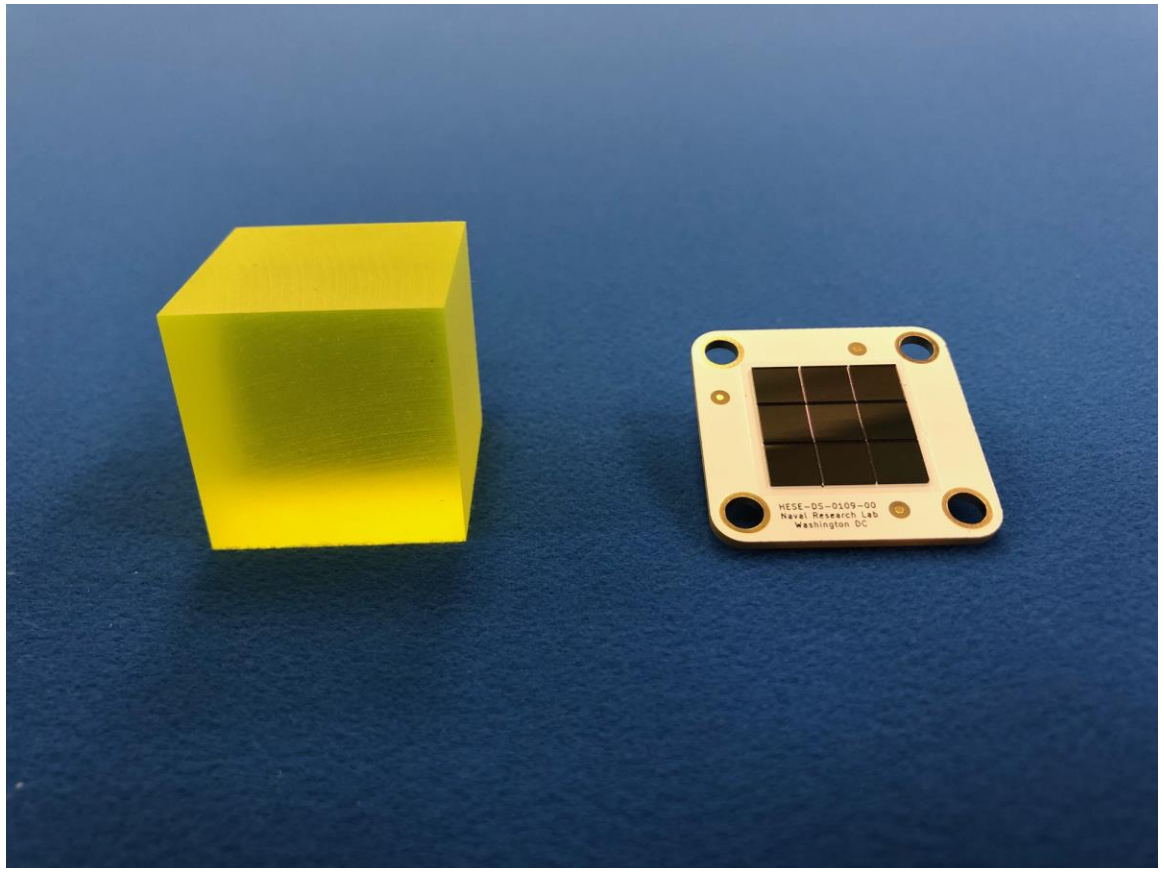
PI: Dr. Lee J. Mitchell (NRL)

Goal

- Space qualify $Gd_3(Al, Ga)_5O_{12}$ (GAGG) scintillator with SiPM array
- Wherever possible, replicate SIRI-1 design

Design Overview

- Detector
  - Single GAGG(Ce)
    - 30 x 30 x 30 mm^3
    - ~5% resolution at 662 keV
    - Good mechanical properties
    - Not hygroscopic
    - Density: ~6.3 g/cm^3
  - 4 x 4 array of 6-mm SensL J-series SiPMs
    - Currently being fabricated
    - 3 x 3 array shown right used for testing
- Proposed for STP-H7
  - Expected launch to International Space Station (ISS) in April 2022

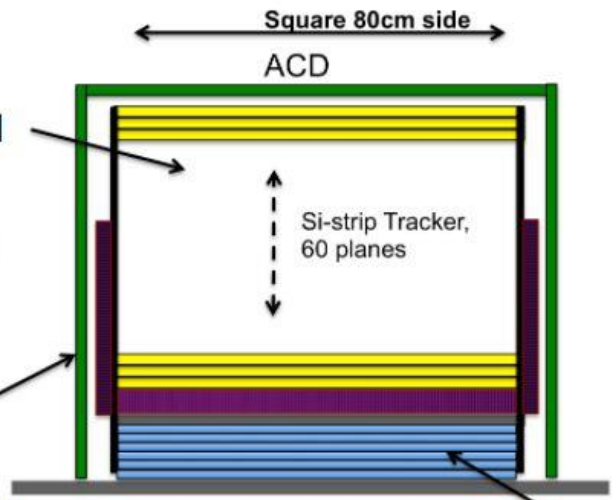


All-Sky Medium Energy γ-Ray Observatory (AMEGO)

- *Medium-energy γ-ray survey mission, NASA probe-class concept*
- *Balloon flight (Ft. Sumner, NM) – Fall 2021*

Tracker: Incoming photon undergoes pair production or Compton scattering. Measure energy and track of electrons and positrons

- 60 layer DSSD, spaced 1 cm, Strip pitch 0.5 mm



CZT Calorimeter: Measure location and energy of Compton scattered photons

- Layer of 0.6 x 0.6 x 2 cm bar CZT

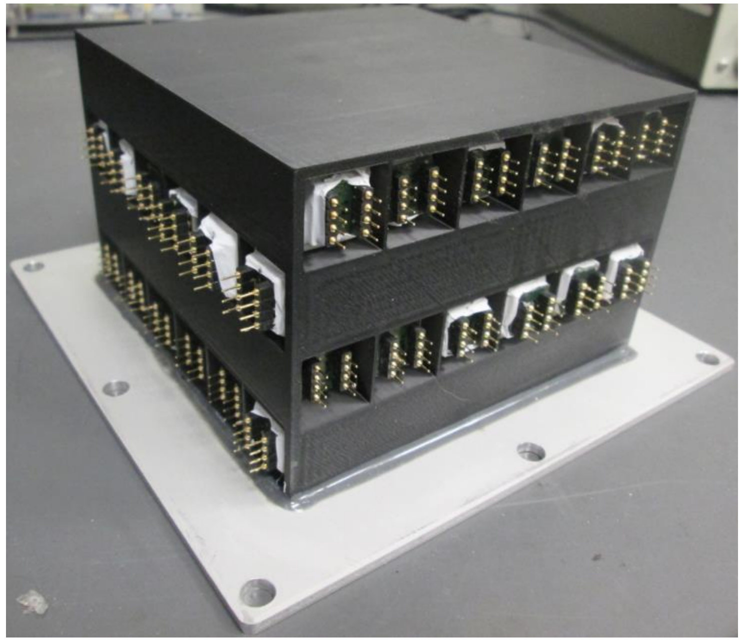
CsI Calorimeter: Extend upper energy range

- 6 planes of 1.5 cm x 1.5 cm bars

PI: Dr. Richard S. Woolf (NRL)

CsI Hodoscope with SiPM Readout

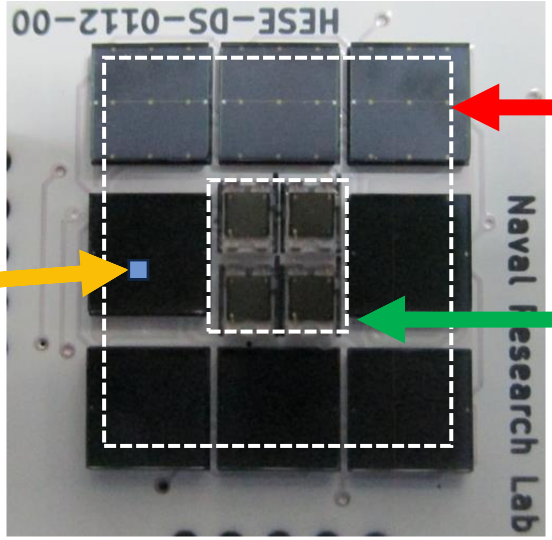
- Testing and balloon-flight prototype shown below
- 17 x 17 x 100 mm^3 CsI(Tl) crystals
- 2 x 2 array of 6-mm J-series SiPM on each end of crystal
- DAQ: IDEAS ROSSPAD
  - 64-channel SiPM ASIC
  - Four 16-channel SIPHRAs



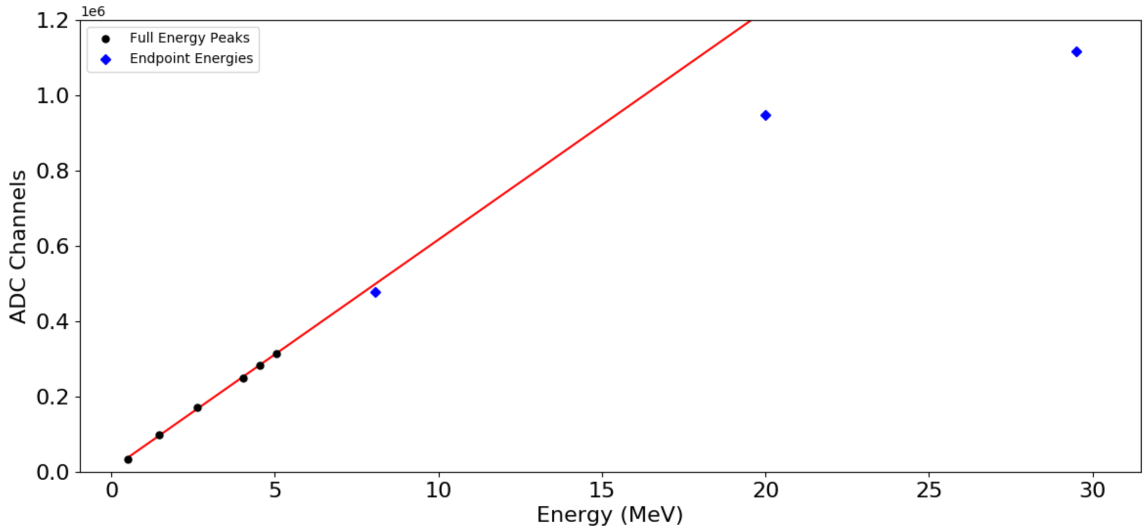
AMEGO

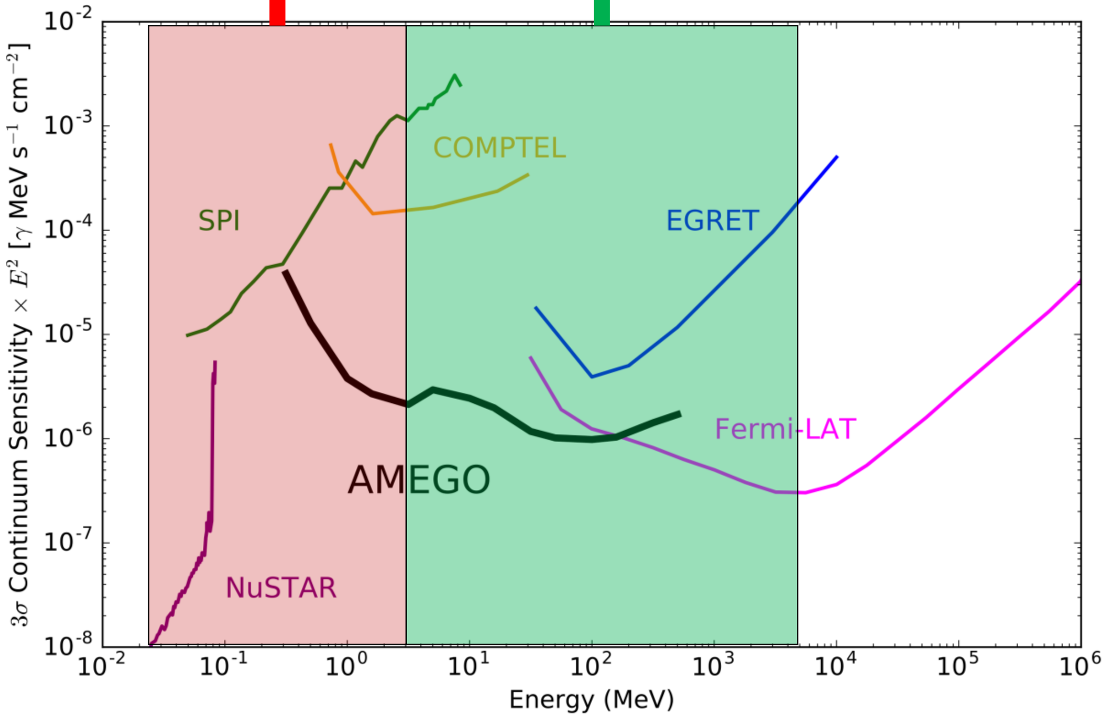
Dual Gain Range SiPM Arrays

Optimize microcell size (10-50 μm) for individual SiPMs to mitigate high-energy non-linearity



Expand dynamic range with small and large SiPM ($1\ mm^2$ to $36\ mm^2$) readouts





Glowbug

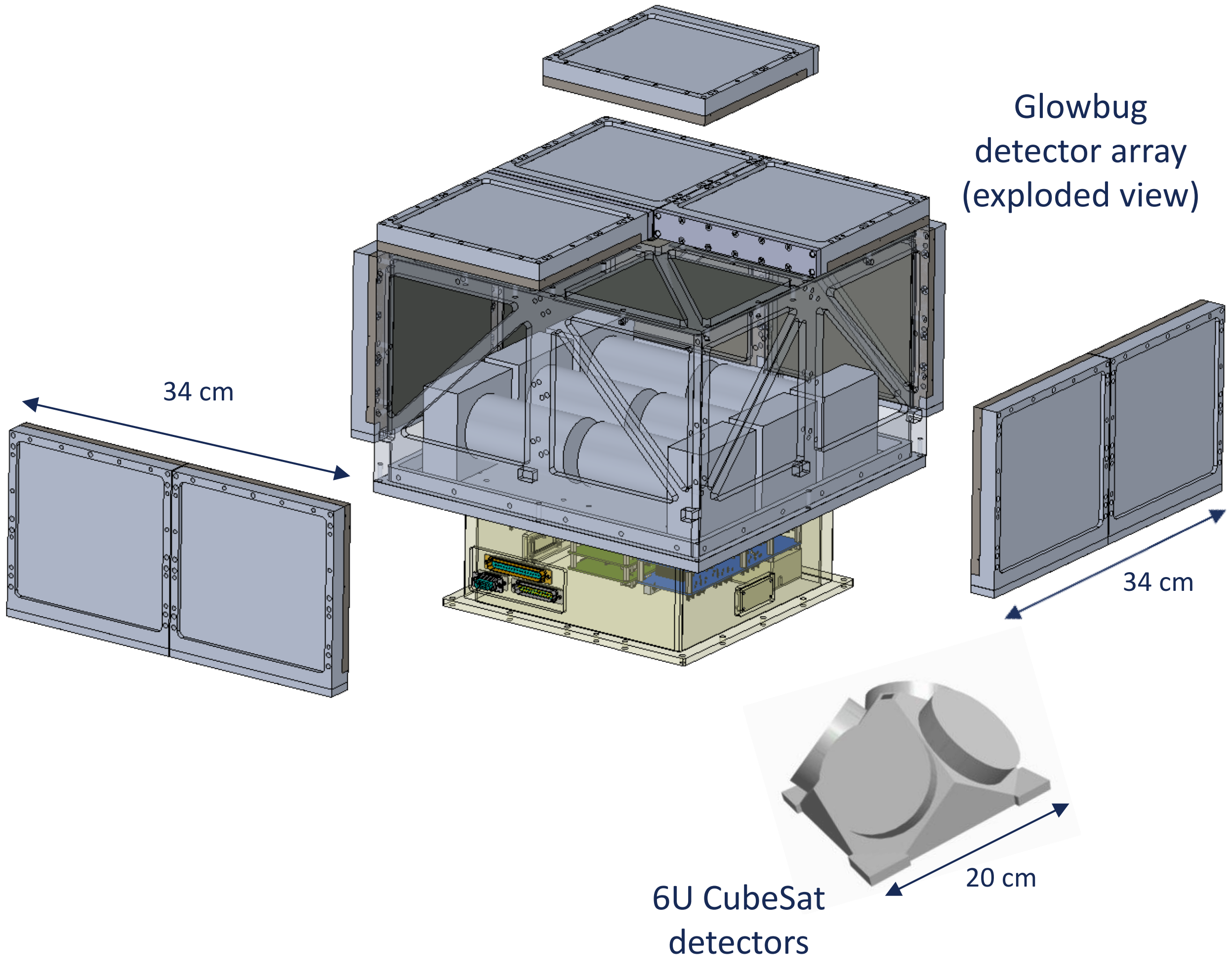
PI: Dr. J. Eric Grove (NRL)

- ***All-sky 30 keV – 2 MeV band transient monitor optimized for GRBs***
- ***Targeting manifest: STP-H9 – early 2020s launch***

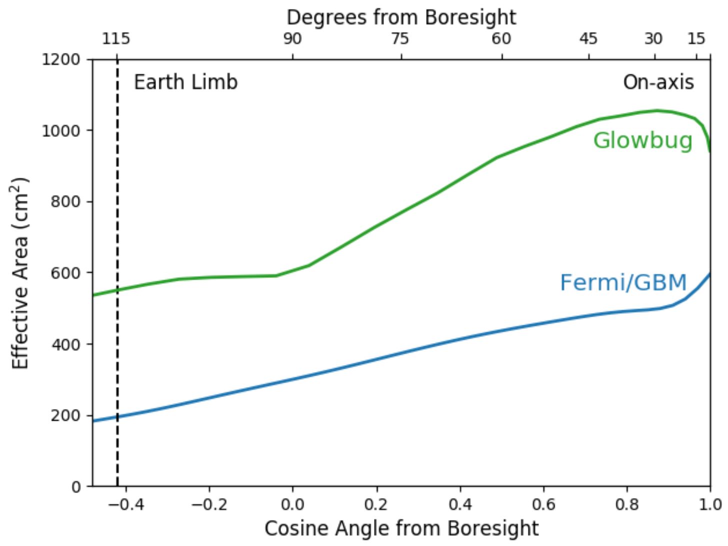
Technology Demonstrator

Low-cost high-sensitivity GRB detector for gravitational wave era

- Large scintillator array
  - CsI(Tl) + SiPM readout (12 detectors, each 15 x 15 x 1 cm^3)
    - Good stopping power; not hygroscopic
    - Low size, weight, and power readout
  - CLLB + SiPM readout (6 detectors, each Ø5 x 10 cm)
    - Additional effective area above 1 MeV
    - Sensitive to both photons and thermal neutrons
  - Front end and DAQ from SIRI-2
    - Low power, space qualified
- Selected by NASA APRA
  - **Funding began March 2019**
- Proposed for STP-H9
  - Launch to International Space Station (ISS) in early 2023



Glowbug

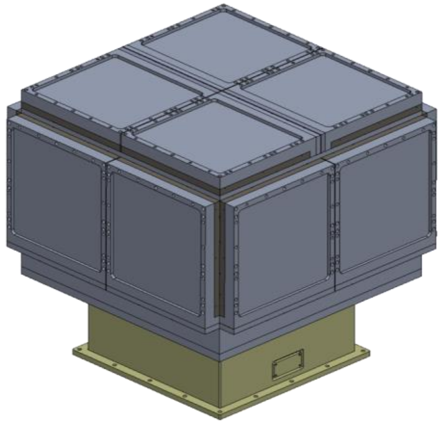


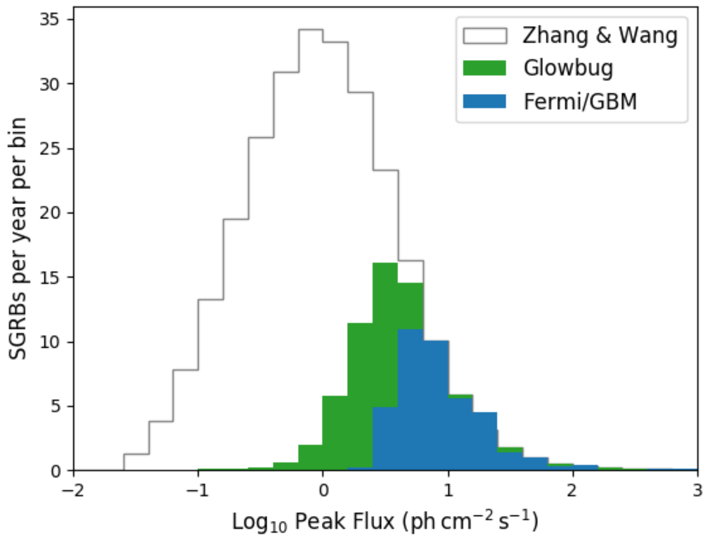
Good sensitivity
at low cost

**Effective area
~2 x Fermi GBM**

Large area scintillators
with SiPM readout

**Attached payload
instrument ~65 kg**



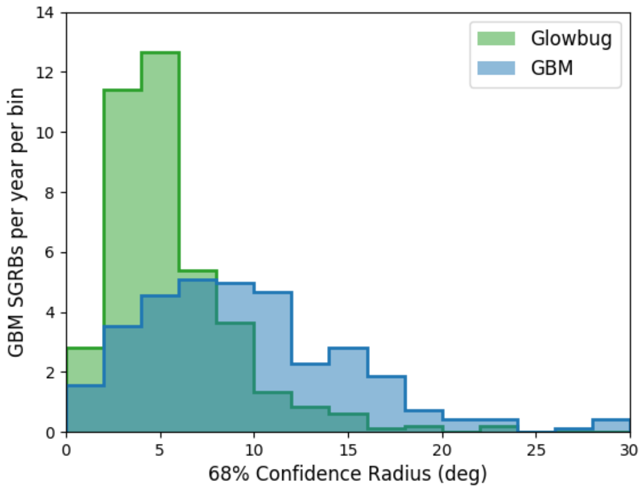


High rate of
GRB detections

**Rate ~ 70 short
GRBs / year**

Modest localization ability

**Comparable
to Fermi GBM**



Conclusion

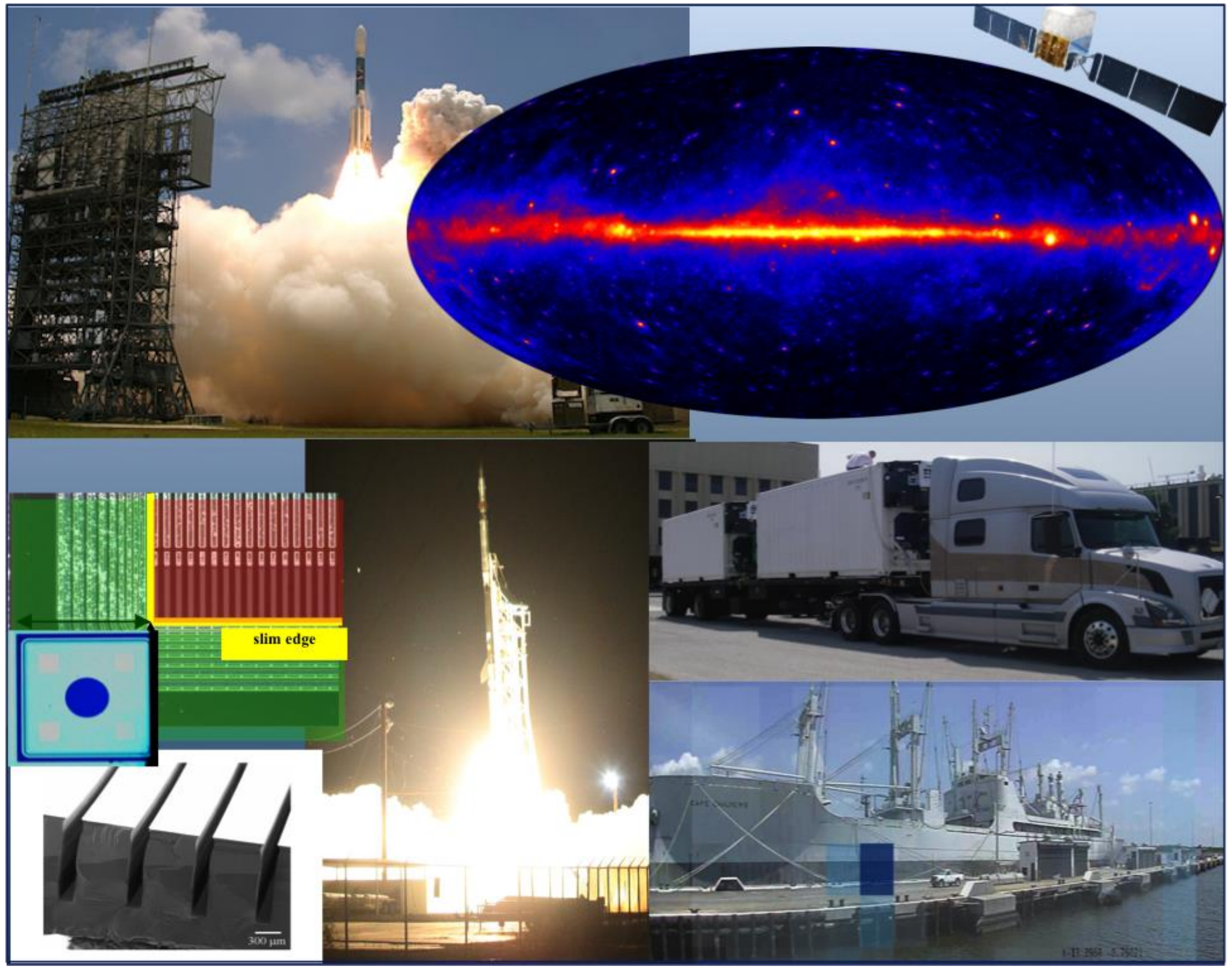
High Energy Space Environment Branch

- Active group with varied interests

- Experience designing, fabricating, and deploying instruments with SiPM arrays in space and terrestrial environments

- Heritage of success in cutting-edge instrumentation and scientific discovery in:
  - high energy astrophysics
  - high energy atmospheric physics
  - security and nonproliferation applications

- We welcome collaboration (and postdocs)!



Conclusion

Instrument Principle Investigators

- Dr. Lee J. Mitchell – lee.mitchell@nrl.navy.mil
  - SIRI-1
  - SIRI-2
  - GARI
- Dr. Richard S. Woolf – richard.woolf@nrl.navy.mil
  - AMEGO CsI calorimeter
- Dr. J. Eric Grove – eric.grove@nrl.navy.mil
  - Glowbug

Acknowledgments

- SIRI-1, SIRI-2, and GARI are supported by the Chief of Naval Research.
- AMEGO and Glowbug are supported by NASA.