Wide Band Gap Radiation Detectors for Deep Space Science

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Outline

- SmallSat Platform Technology Challenges
- GRC Technology R&D
- Benefits of WBG Detectors
- SPAGHETI: Deep-Space CubeSat
- WBG LET Detectors
- Future Concept: CFIDS
- Summary
- Acknowledgements

Metri sunt necesse malum

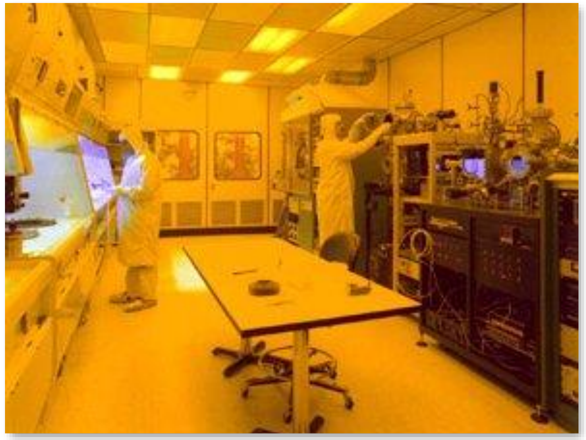
"Measurements are necessary evils"

SmallSat Platform Technology Challenges

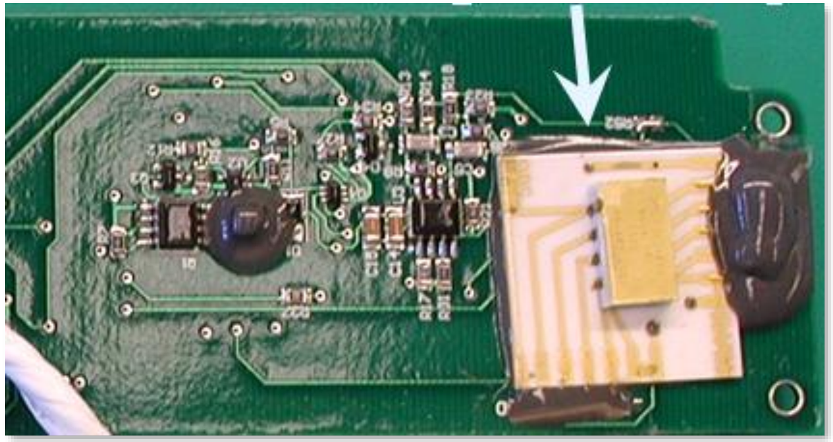
- Need to develop a radiation detector system to fly on small satellite platforms (such as CubeSats) to reduce cost, development time of missions
  - Design point: 1U CubeSat volume, mass for detector system (10 cm x 10 cm x 10 cm, 1 kg) on a deep space platform
  - CubeSats currently flown LEO applications, but future is in Deep Space
- High radiation particle influx from multiple directions (spherical 4π solid angle)
  - Current radiation detector technologies need temperature compensation
  - SmallSat platform size (<100 kg), power limits instrumentation systems
  - More complex systems require new technology
- Solution is the development of new robust, low power, thermally stable solid state radiation detector technology for omni-directional measurements in a compact space radiation detector system
  - Wide band gap (WBG) semiconductors, micro-optics technologies

GRC Advanced Radiation Detector Technology Research and Development

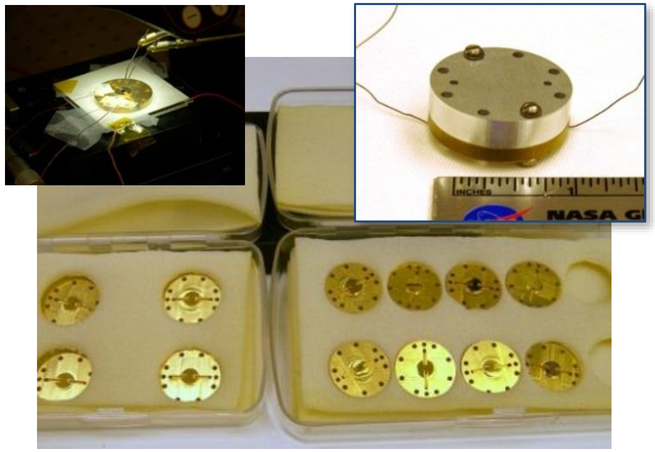
- GRC Expertise and Facilities in:
  - Harsh Environment Thin Films
  - SiC Devices & Harsh Environment Packaging
  - Micro-Optics
  - Space-Based Instrumentation
- These strengths are combined into an in-house Radiation Instrumentation Research effort



In-House Microsystems Fabrication



MISSE 7 SiC JFET & Ceramic Packaging (arrow) on a Rad-Hard Electronics Board for ISS flight

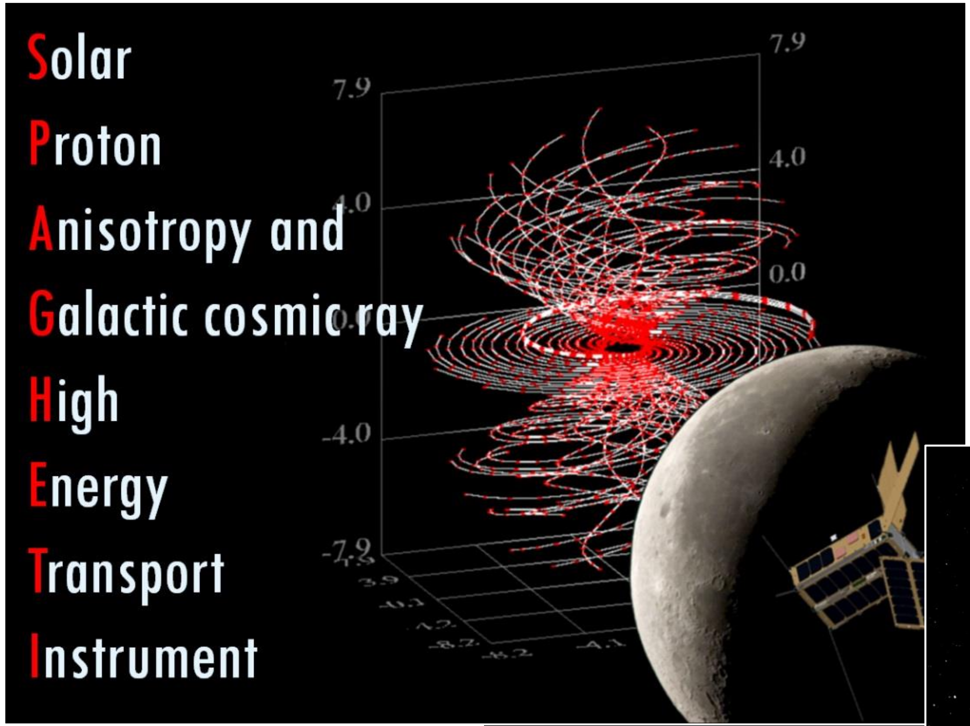


CERES Thin Film Microbolometer Testing and Packaging

Benefits of WBG Detectors: Lower Power and More Robust

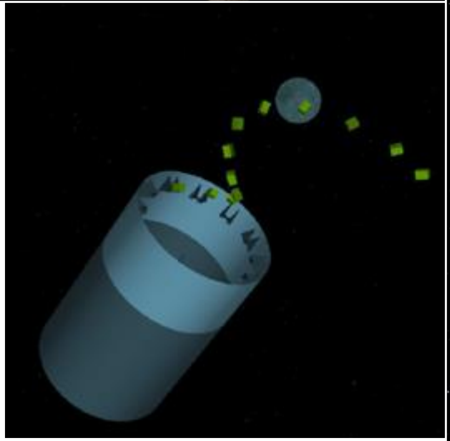
Detector	Active Area	Mass	Volume	Voltage	Dark Current	Minimum Power Draw	Amplitude Signal to Noise	Maximum Operating Tempera-ture	Temperature Sensitivity of Dark Current
LET:									
SOA: Si PIN	1 cm²	0.5 g	185 mm³	100 V	5 nA	0.5 µW	$1x10^5$	60°C	20%/°C
SOA: Si(Li)	30 cm²	35 g	15 cm³	300 V	5 µA	1.5 mW	$8x10^3$	60°C	30%/°C
Proposed: SiC	2 cm²	0.5 g	113 mm³	100 V	5 nA	0.5 µW	$1x10^5$	120°C	0.1%/°C
Scintillator Coincidence/Anticoincidence:									
SOA: PMT	20 cm²	170 g	180 cm³	1000 V	5 nA	5 µW	$4x10^5$	50°C	0.2%/°C
SOA: APD	9 mm²	3 g	200 mm³	30 V	5 nA	0.15 µW	$8x10^4$	85°C	30%/°C
Proposed: GaP	4.8 mm²	5 g	170 mm³	5 V	20 pA	0.1 nW	$3x10^5$	125°C	0.5%/°C
Cherenkov Detector:									
SOA: PMT	20 cm²	170 g	180 cm³	1000 V	5 nA	5 µW	$4x10^5$	50°C	0.2%/°C
Proposed: ZnO	2 mm²	11 g	0.80 cm³	10 V	5 nA	0.05 µW	$4x10^4$	125°C	0.05%/°C

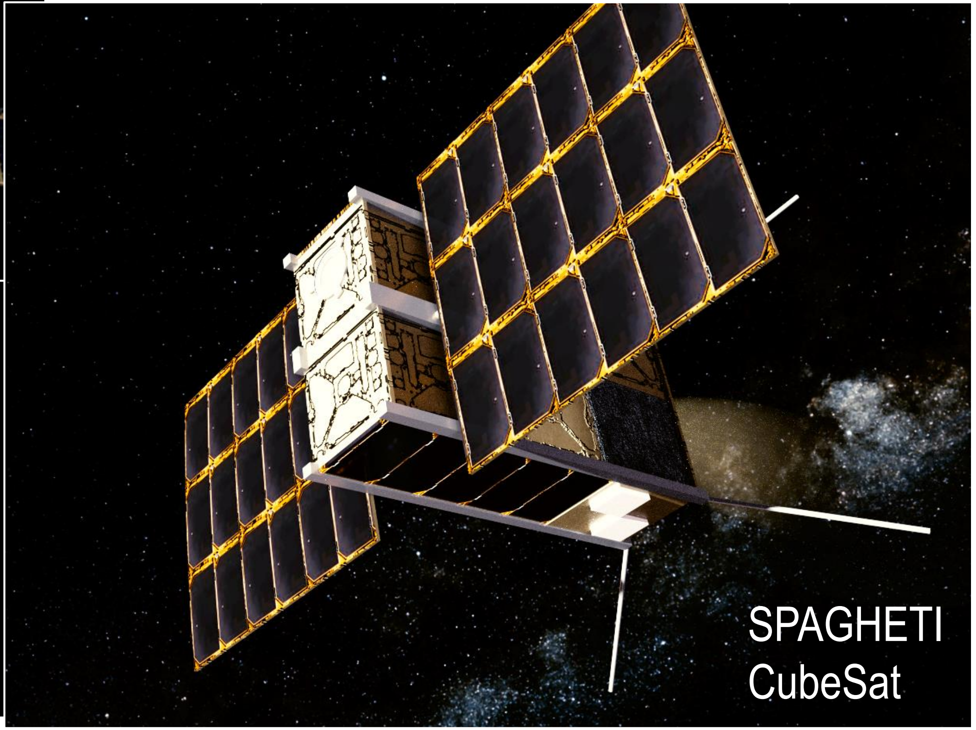
SPAGHETI: Deep-Space CubeSat



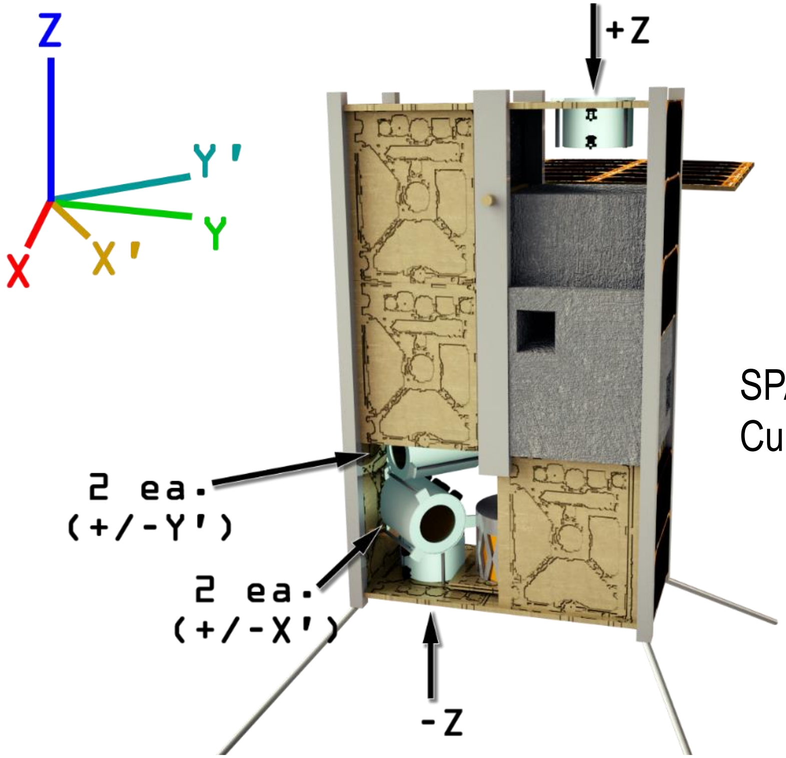
- SPAGHETI would explore the transient variations in ion flux anisotropy in deep space and near the lunar surface

- SPAGHETI was a proposed SmallSat mission for an Artemis 1 launch on a 6U CubeSat bus



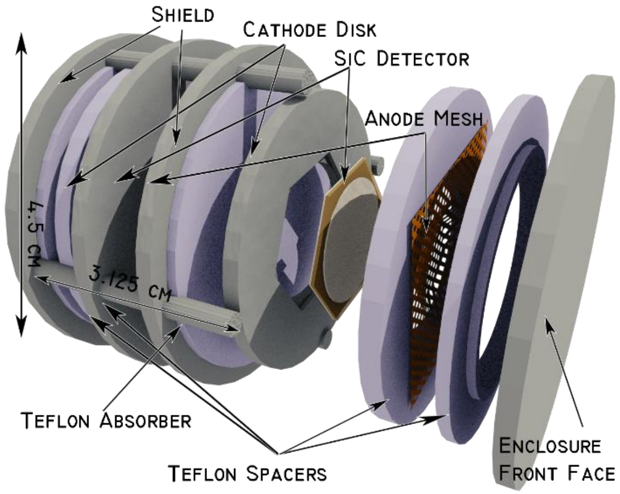


SPAGHETI: Deep-Space CubeSat



SPAGHETI CubeSat

- SPAGHETI would contain 6 packages of WBG LET detector stacks, arranged to provide simultaneous multidirectional measurements

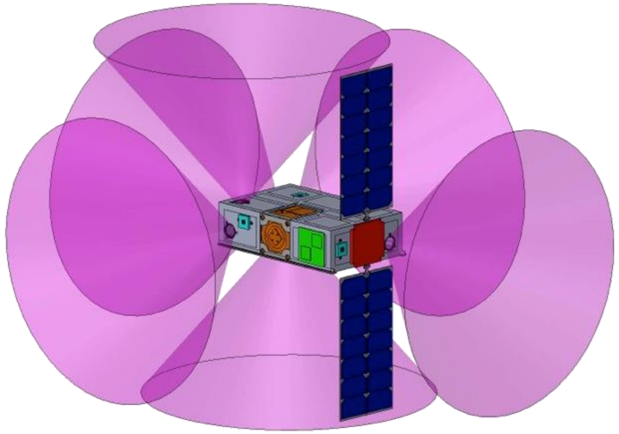


WBG LET Detector Stacks (Charged Particle Telescope)

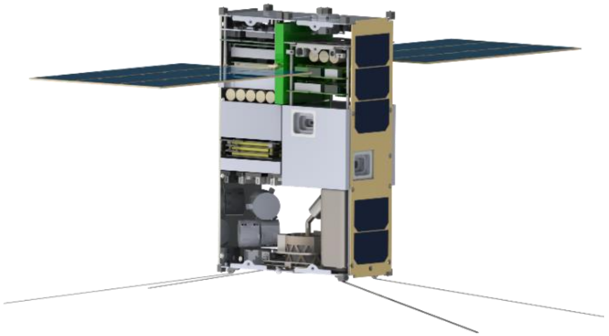
- Each stack would have 2 LET detectors separated by a moderator to allow energy and ion species resolution
- Each detector stack would be directionally sensitive with an 80° field of view and a geometric factor of 0.84 $cm^2 \cdot sr$
- Detector insensitivity to temperature changes would allow compact, low-power operation

SPAGHETI: Deep-Space CubeSat

- GRC-led proposal to Heliophysics Technology and Instrument Development for Science (HTIDeS) program
  - Low lunar orbit (2086×1779 km) using Iodine Ion thruster for corroboration with LRO/CRaTER data
  - Accelerated Technology Development to Flight for High-Payoff Science
- NASA GSFC / Catholic University of America, University of New Hampshire as Science Team
- Morehead State University selected as CubeSat bus provider via pre-proposal competitive process
  - The Aerospace Corporation, Busek as subsystem providers
- Pre-proposal COMPASS review sessions at GRC with partners to ensure technical awareness of risks
- Ultimately SPAGHETI as-proposed was not funded for flight
  - Technology development could proceed at a less-fevered pace



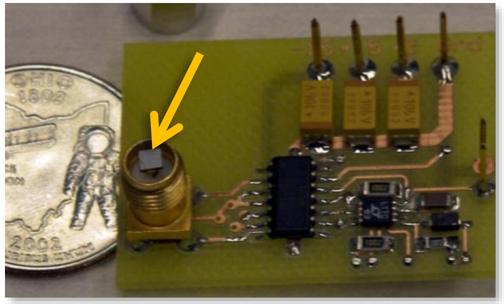
COMPASS SPAGHETI Study



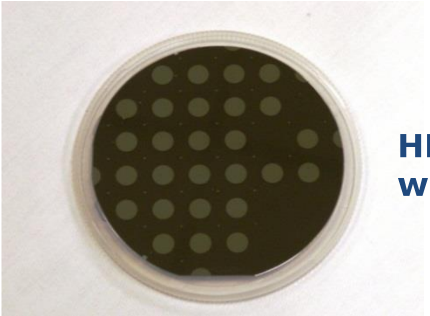
Morehead State U. SPAGHETI Bus as-proposed

WBG LET Detectors

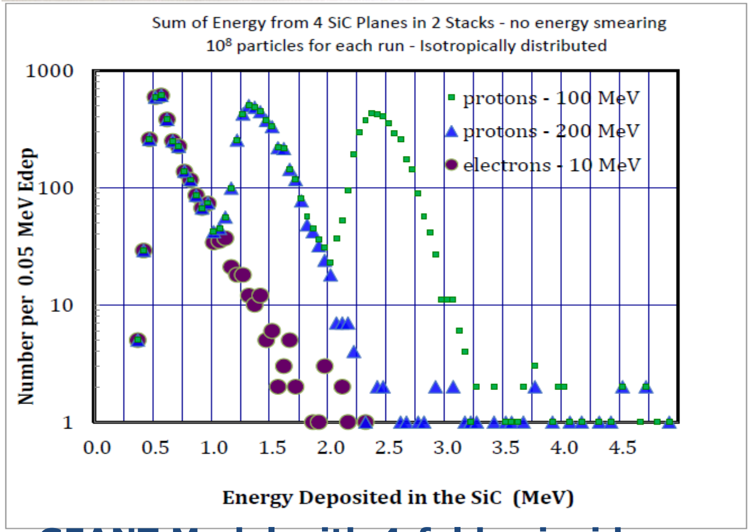
- Typically silicon-based PIN diodes or lithium-drifted silicon wafers (Si(Li)), high bias voltage, thermally sensitive
- <u>Goal</u>: Replace silicon detectors with more robust, temperature-stable low-noise silicon carbide detectors
- Smaller SiC detectors studied as part of AEVA (2005-2007) and ETDP/D (2009-2011), AES (2012) for dosimetry
- Large-area detectors (2 cm^2, 350 µm thick) using high-purity, semi-insulating (HPSI) SiC wafers with low-Z FEP absorber between detectors
- GEANT models show a 4-fold coincidence can resolve LET for high energy protons and electrons



Prototype Dosimeter with SiC detector (arrow)



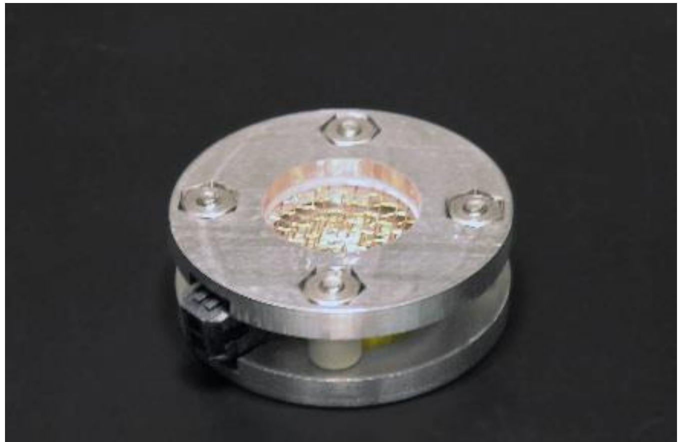
HPSI 4H-SiC wafer with device pads



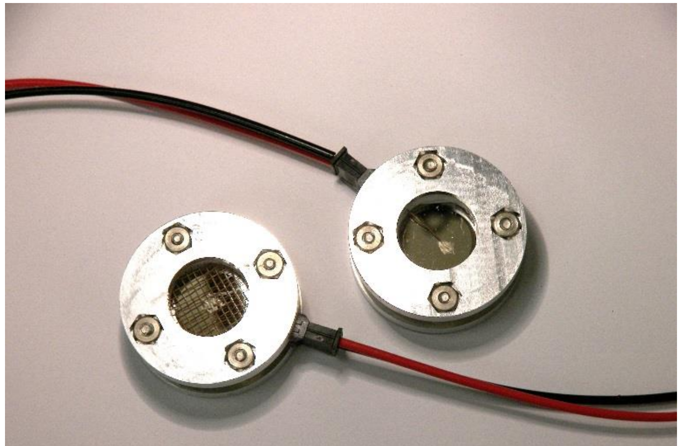
GEANT Model with 4-fold coincidence

WBG LET Detectors

- Proof-of-concept SiC LET detectors developed under a Center Innovation Fund (CIF) award competed through NASA STMD
- As-Built Detector Specs:
  - High Purity Semi-Insulating (HPSI) 4H-SiC
  - Active Area: 200 mm^2
  - Active Thickness: 0.348 mm
  - Top Contact (Anode): 2000 Å Pt/Ti
  - Bottom Contact (Cathode): 7000 Å Pt/TaSi/Ti
  - Die Size: 325 mm^2 square
  - Package Size: 4.13 cm dia. x 1.25 cm
  - Capacitance: 65±5 pF
  - Leakage: 4.5 nA at 100 VDC bias



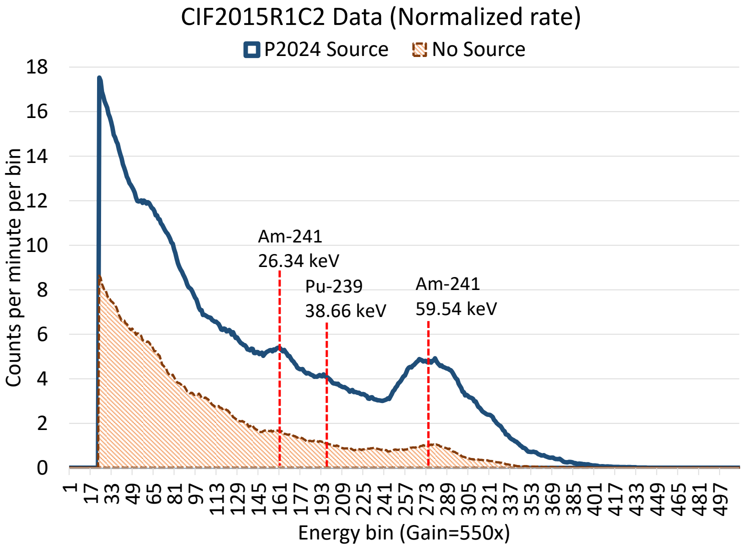
SiC LET Detector Prototype

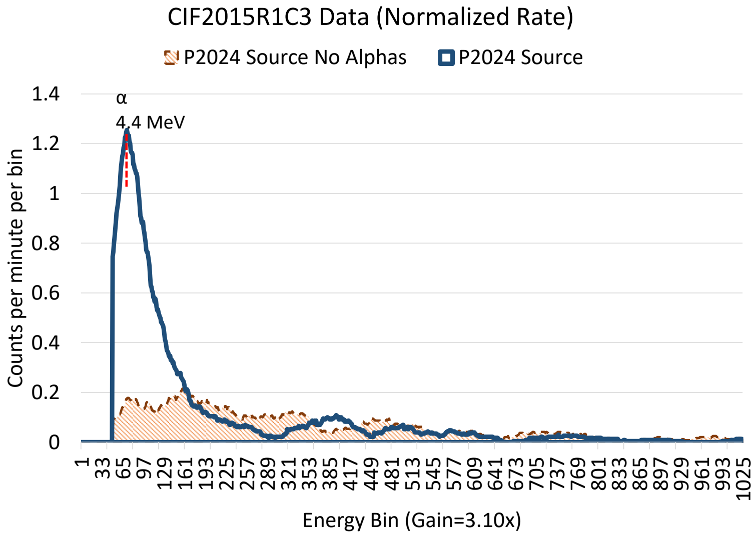


SiC LET Detector Prototypes

WBG LET Detectors

- Checked response at high gain and low gain on multichannel analyzer for gamma, alpha (He-4) peaks of Pu-239 sources
  - Response time limited to 36 counts per second (27.78 ms/count)
  - Should stop 8 MeV/u ions and less; measure E, calculate LET (=E/x)
  - Observed peaks down to 26.3 keV or LET ≥ 75.7 eV/µm
  - Noise floor ≈ 60 eV/µm (20.7 keV), Uncertainty ±30 eV/µm, dE/E = 20% in air
  - Estimate of minimally ionizing proton (3 GeV p) LET = 543 eV/µm in SiC (detectable)
- Characteristic Proof of Concept – validation of key parameters

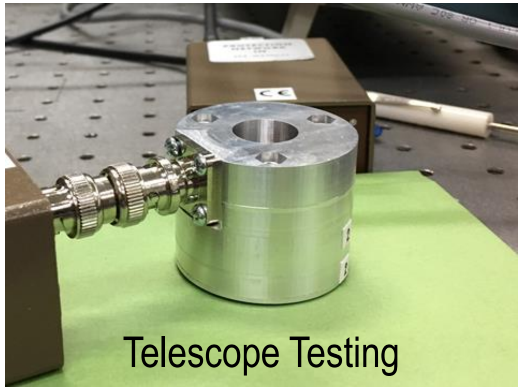


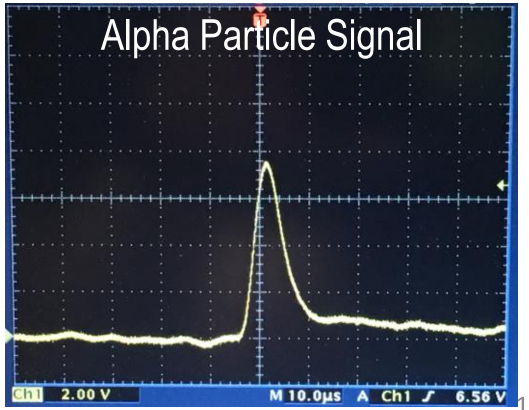


WBG LET Detectors

- Improvements to the detector design currently underway through Individual Research and Development (IRAD) effort
  - Goal is to clean up signal, demonstrate functionality as a SiC Charged Particle Telescope
  - Phase I designed, fabricated, packaged and tested four LET detectors singly and configured as telescope pairs, documenting improved performance and stable operation of the telescope design
  - Phase II currently underway to accommodate smaller connectors and measure a spectra
- Phase I Telescope Specs:
  - Telescope Size: 4.375 cm dia. x 3.50 cm tall
  - Aperture Size: 200 mm^2
  - Geometric Factor: 0.5 $sr \cdot cm^2$
  - Field of View: 62°
  - Detector: HPSI 4H-SiC, 1000Å Pt/Ti (anode), 1000Å Ni/Ti (cathode)
  - Die Size: 1.778 cm x 1.778 cm square
  - Capacitance: 56.7 ± 1.5 pF
- Future plans beyond Phase II include integrating charge amplifiers into the package and accelerator beam line tests


SiC Charged Particle Telescope


Telescope Testing



Alpha Particle Signal

Future Concept: Compact Full-Field Ion Detector System (CFIDS)

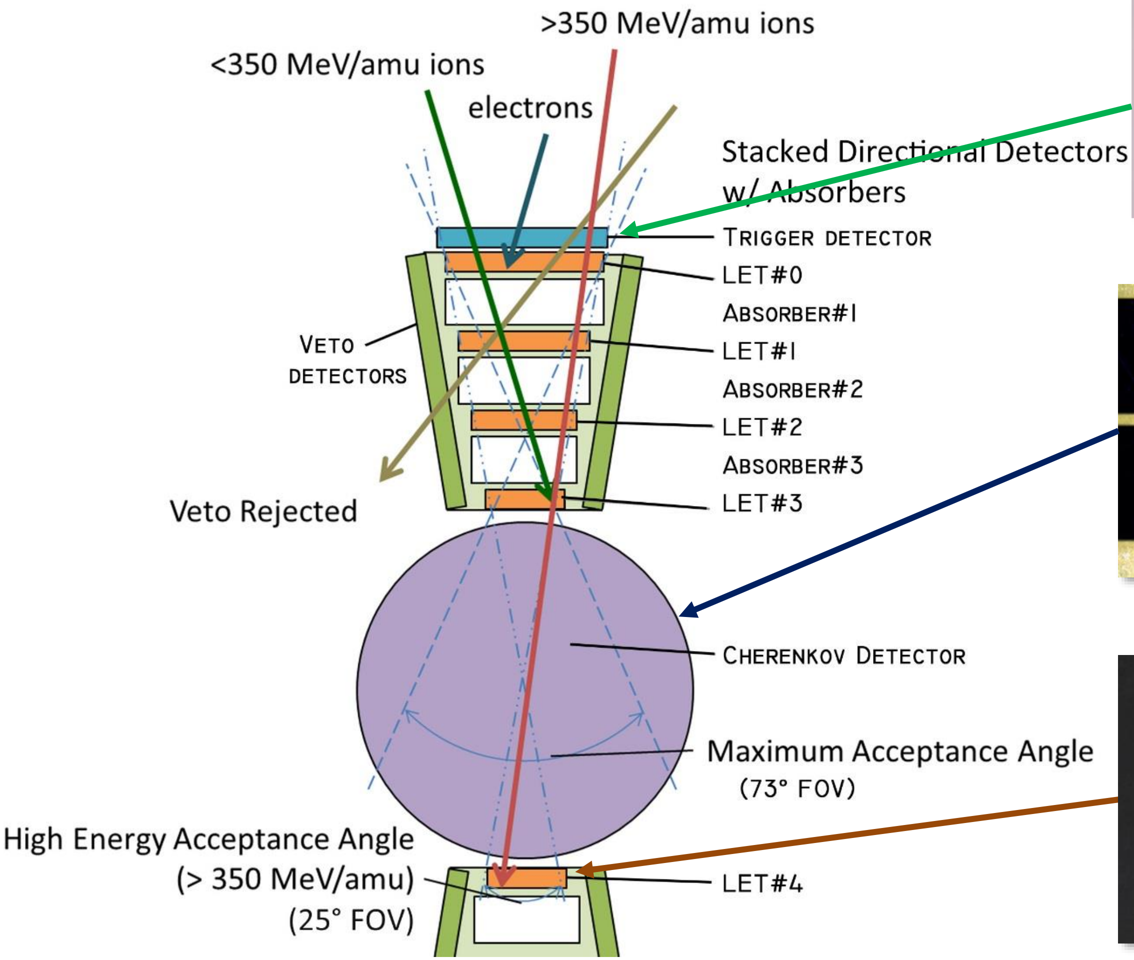
- Mapping of heavy ions > 100 MeV/amu
  - Integrated system with solid-state Cherenkov detector and large area detectors in surrounding wedges
- High radiation flux rates for 10+ year missions
  - Precision rad-hard, thermally stable wide band gap detectors used
- Low noise, multi-directional measurements at single locations
  - Compact, spherical detector system

Space radiation detector with spherical geometry

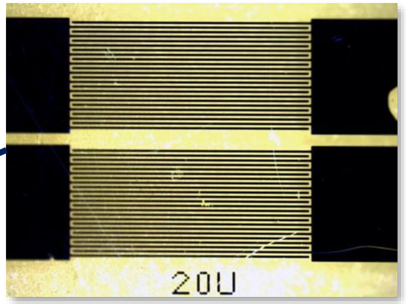
- Technology covered by U.S. Patents 7,872,750 (January 18, 2011) and 8,159,669 (April 17, 2012)

Concept illustration of the CFIDS detector assembly (cables, electronics not shown)

Future Concept: Compact Full-Field Ion Detector System (CFIDS)



GaP Diode for Solid-State Trigger/Veto Detectors (U.S. Patent 10,429,521)



ZnO UV Sensor for Solid-State Cherenkov Detector (U.S. Patent 10,054,691)

Large Area SiC LET Detectors

- CFIDS comprised of a spherical Cherenkov detector surrounded by stacked LET detectors with absorbers, Coincidence/Anticoincidence detectors

Summary

- NASA GRC is leveraging expertise in harsh environment thin films, SiC devices & harsh environment packaging, micro-optics, and space-based instrumentation to advance radiation detector technology
- SPAGHETI was proposed using wide-band gap radiation instrumentation in a Deep Space CubeSat to allow in-situ studies of SEP and GCR interactions in lunar environments
- Large-area radiation detectors based on wide-band gap silicon carbide are under development and have been demonstrated bench tests
- Application of wide band gap semiconductors as radiation detectors holds the promise of improved low-power, robust detectors for a Compact Full-Field Ion Detector System for Deep Space CubeSats

Acknowledgements

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  - GRC Space Science Projects Office (Tibor Kremic, Carol Tolbert)
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  - GRC Innovation and Integration Office (Mark Kilkenny (retired), Gary Horsham)
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  - Elizabeth McQuaid (GRC), José Gonzalez, W. Trevor John (HX5)
- SPAGHETI Collaboration Team:
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