Compact Full-Field Ion Detector System for SmallSats beyond LEO

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Mutri sunt necesse malum

“Measurements are necessary evils”
Technology Roadmap Challenges

• NASA’s Integrated Technology Roadmap (2012): Technology Area (TA) 8.3.1 “In-Situ Instrumentation/Detectors: Particles”
  Challenges:
  – Energy Threshold (resolve to 1 keV for 30 MeV)
  – Environment Tolerance (radiation-hard ion & electron sensors)
  – Data Handling (improved out-of-band rejection)
  – Heliophysics, Planetary Science Missions
  – “Robust sensors capable of operating for long periods in environment of space are needed to measure the radiation at the destination as well as during the journey.”

• TA08 Roadmap Enabling Approaches:
  – Integrated existing detector technologies
  – Radiation hardened electronics
  – Miniature power supplies

• Alternative: New detectors
SmallSat Platform Technology Challenges

• Goal is 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)

• CubeSats currently flown LEO applications, but future is in Deep Space
  – High radiation particle influx from multiple directions
    (spherical $4\pi$ 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 semiconductors, micro-optics technologies
Application 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)
Application Concept: Compact Full-Field Ion Detector System (CFIDS)

- CFIDS comprised of a spherical Cherenkov detector surrounded by stacked LET detectors with absorbers, Trigger and Veto detectors.
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

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

In-House Microsystems Fabrication

CERES Thin Film Microbolometer Testing and Packaging
Solid-State Trigger/Veto Detectors

- Typically scintillator blocks of plastic or iodide crystal mated to a photomultiplier tube (PMT) or a pixelated avalanche photo detector (APD), also referred to as a silicon photomultiplier (SiPM)
- **Goal:** Replace the role of PMTs and SiPMs in these types of detectors with WBG devices, saving on size, weight and required power
- Demonstrated a miniature gallium phosphide (GaP) photodiode “paddle style” radiation detector as part of a 10-week OCT/STMD Center Innovation Fund (CIF) study in 2013 (patent pending).
- Use with acrylic ribbon scintillators for the CFIDS concept
Solid-State Cherenkov Detector

• Typically flat disks or blocks of sapphire or acrylic mounted on PMTs.

• **Goal**: Replace the role of the relatively large PMTs with solid-state devices that do not require temperature control or compensation.

• A fast, large area solid-state UV detector based on single-crystal, undoped zinc oxide (ZnO) was developed at GRC (patent pending) as part of two 10-week OCT/STMD CIF studies (2011, 2012)
  – Active area of 1 mm by 2 mm (2 mm²), designed to have a 1 ns response time with 10 V applied bias voltage
  – In a bridge circuit can detect small, fast pulses of UV light like those required for Cherenkov detectors.
  – Sensitive to UV light at 254 nm, slightly less so at 370 nm, and not sensitive to room lighting (about 430-630 nm).
  – Demonstrated improved sensitivity to UV than commercial SiC and GaP detectors

![OCT ZnO UV Detector (20 μm electrode spacing)]
WBG LET Detectors

• Typically silicon-based PIN diodes or lithium-drifted silicon wafers (Si(Li)), high bias voltage, thermally sensitive

• **Goal**: 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 cm², 350 μm thick) using high-purity, semi-insulating (HPSI) SiC wafers with low-Z FEP absorber between detectors for CFIDS

• GEANT models show a 4-fold coincidence is required to resolve LET for high energy protons and electrons
Benefits of WBG Detectors: Lower Power and More Robust

<table>
<thead>
<tr>
<th>Detector</th>
<th>Active Area</th>
<th>Mass</th>
<th>Volume</th>
<th>Voltage</th>
<th>Dark Current</th>
<th>Minimum Power Draw</th>
<th>Amplitude Signal to Noise</th>
<th>Maximum Operating Temperature</th>
<th>Temperature Sensitivity of Dark Current</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cherenkov Detector:</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SOA: PMT</td>
<td>20 cm²</td>
<td>170 g</td>
<td>180 cm³</td>
<td>1000 V</td>
<td>5 nA</td>
<td>5 μW</td>
<td>4x10⁵</td>
<td>50°C</td>
<td>0.2%/°C</td>
</tr>
<tr>
<td>Proposed: ZnO</td>
<td>2 mm²</td>
<td>11 g</td>
<td>0.80 cm³</td>
<td>10 V</td>
<td>5 nA</td>
<td>0.05 μW</td>
<td>2x10⁴</td>
<td>125°C</td>
<td>0.05%/°C</td>
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<tr>
<td><strong>LET:</strong></td>
<td></td>
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<tr>
<td>SOA: Si PIN</td>
<td>1 cm²</td>
<td>0.5 g</td>
<td>185 mm³</td>
<td>100 V</td>
<td>5 nA</td>
<td>0.5 μW</td>
<td>1x10⁵</td>
<td>60°C</td>
<td>20%/°C</td>
</tr>
<tr>
<td>SOA: Si(Li)</td>
<td>30 cm²</td>
<td>35 g</td>
<td>15 cm³</td>
<td>300 V</td>
<td>5 μA</td>
<td>1.5 mW</td>
<td>8x10³</td>
<td>60°C</td>
<td>30%/°C</td>
</tr>
<tr>
<td>Proposed: SiC</td>
<td>2 cm²</td>
<td>0.5 g</td>
<td>185 mm³</td>
<td>5 V</td>
<td>70 pA</td>
<td>0.350 nW</td>
<td>2x10⁵</td>
<td>120°C</td>
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<tr>
<td><strong>Scintillator Trigger/Veto:</strong></td>
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<tr>
<td>SOA: PMT</td>
<td>20 cm²</td>
<td>170 g</td>
<td>180 cm³</td>
<td>1000 V</td>
<td>5 nA</td>
<td>5 μW</td>
<td>4x10⁵</td>
<td>50°C</td>
<td>0.2%/°C</td>
</tr>
<tr>
<td>SOA: APD</td>
<td>9 mm²</td>
<td>3 g</td>
<td>200 mm³</td>
<td>30 V</td>
<td>5 nA</td>
<td>0.15 μW</td>
<td>8x10⁴</td>
<td>85°C</td>
<td>30%/°C</td>
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<tr>
<td>Proposed: GaP</td>
<td>4.8 mm²</td>
<td>5 g</td>
<td>170 mm³</td>
<td>5 V</td>
<td>20 pA</td>
<td>0.1 nW</td>
<td>3x10⁵</td>
<td>125°C</td>
<td>0.5%/°C</td>
</tr>
</tbody>
</table>
• SPAGHETI is a SmallSat mission for an EM–1-type launch on a 6U CubeSat bus enabled by stacks of WBS LET detectors

• SPAGHETI will explore the transient variations in ion flux anisotropy in deep space and near the lunar surface
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

• Application of wide band gap semiconductors as radiation detectors holds the promise of improved low-power, robust detectors for CFIDS

• SPAGHETTI using CFIDS radiation instrumentation system in a Deep Space CubeSat will allow in-situ studies of SEP and GCR interactions in lunar environments
Acknowledgements

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• Dr. Nathan Schwadron (University of New Hampshire)
  – SPAGHETI collaboration
• Dr. Ben Malphrus (Morehead State University)
  – SPAGHETI CubeSat bus architecture
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