Low-Power Multi-Aspect Space Radiation Detector System

National Aeronautics and Space Administration

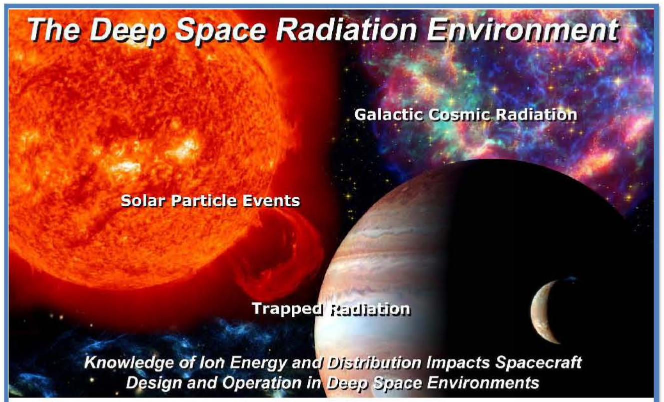
John D. Wrbanek, Susan Y. Wrbanek, Gustave C. Fralick, Jon C. Freeman
NASA Glenn Research Center, Cleveland, OH

Stephen P. Berkebile
Oak Ridge Associated Universities, NASA Glenn Research Center, Cleveland, OH

Abstract

The advanced space radiation detector development team at NASA Glenn Research Center (GRC) has the goal of developing unique, more compact radiation detectors that provide improved real-time data on space radiation. The team has performed studies of different detector designs using a variety of combinations of solid-state detectors, which allow higher sensitivity to radiation in a smaller package and operate at lower voltage than traditional detectors [1-3]. Integration of all of these detector technologies will result in an improved detector system in comparison to existing state-of-the-art (SOA) instruments for the detection and monitoring of the deep space radiation field.

The Deep Space Radiation Environment



Radiation Detector Issues for Exploration

- Improvements of existing models will impact spacecraft design and posturing during mission operations
- Deep space environments and outer planetary radiation belts need improved understanding for localized time and statistical variations of steady state and "storm" conditions
- Current radiation detector technology is limited in lifetime, precision, discrimination, and directional sensitivity for the mass, power, and volume requirements for future missions [4-7]

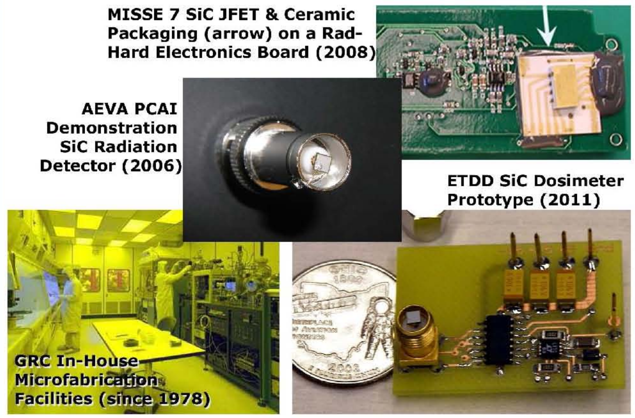
Challenges & Solutions

- Mapping of heavy ions > 200 MeV/amu
  - ✓ *Solution*: Integrated solid-state Cherenkov detector system with large area detectors
- High radiation flux rates for 10+ year missions
  - ✓ *Solution*: Precision rad-hard, thermally stable wide band gap detectors
- Low noise, multi-directional measurements at single locations
  - ✓ *Solution*: Compact, spherical detector system

Approach:

- Develop new robust, low power, thermally stable solid-state technologies as radiation detectors to improve lifetime, power and noise performance
- Demonstrate omni-directional measurements of radiation using novel integrating techniques
- Integrate multiple types of detectors and materials to expand energy range and sensitivity for lower mass, power and volume requirements

Advanced Radiation Detector Technology Research & Development at NASA GRC



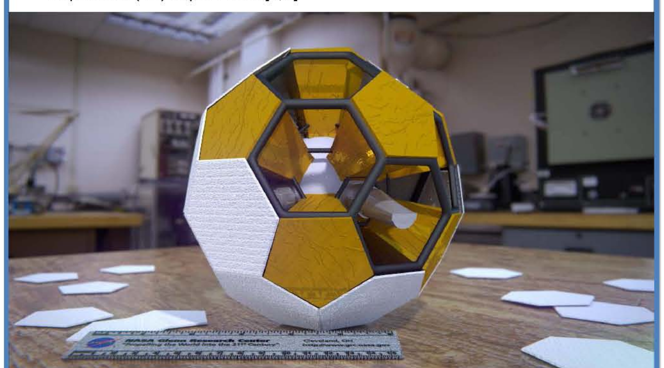
GRC Instrumentation Research Expertise & Capabilities for Space Radiation Environments

Application of GRC Expertise and Facilities in:

- Harsh Environment Thin Films
- Silicon Carbide (SiC) Devices & Harsh Environment Packaging
- Micro-Optics
- Radiation Shielding Materials

Research Objectives

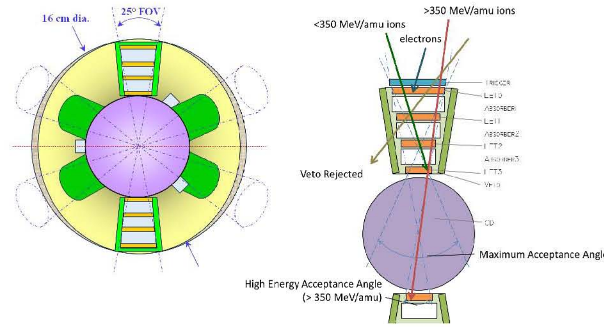
Develop detector technologies to enable a low-power radiation detector system capable of monitoring a wide range of high energy heavy ions (HZE ions) over a spherical (4π) aspect area [8,9]



Design Concept for a Spherical Space Radiation Detector System (cables not shown for clarity)

Acknowledgments: This work was supported at GRC by the NASA ETDP/AES Program with basic sensor development supported by the NASA OCT CIF Program.

Concept System Design



A concept schematic drawing of a spherical detector system comprising a spherical Cherenkov detector, surrounded by various arrays of detector stacks is shown above. Potential improvements over state-of-the-art (SOA) are shown in the table below.

SIS CRM Metric	CRM SOA	Improvement Enablers	Detector System Expected Performance
Energy Range	140 MeV/amu	Integrated Detectors	1,000 MeV/amu
Energy Resolution	±30 keV	Low Noise Detectors	±25 keV
Angle Coverage	0.3 cm²-sr	Spherical Geometry	1 cm²-sr
Angle Resolution	±14°	Solid State Detectors; Spherical Geometry	±12°
Particle Species/Charge	Multiple in multiple detectors	Integrated Detectors	e – Fe
Miniaturization (Mass, Power, & Volume)	Defined by Detectors	Integrated Solid State Detectors	30% SOA

Enables:

- Improved temperature insensitivity to changes induced by transitions from sunlight into shadow (and vise-versa)
- Improved precision with lower mass, power and volume requirements
- Improved radiation discrimination and directional sensitivity
- Unique monitoring of radiation environment of high relevancy for planetary exploration from all directions of the celestial sphere

References:

[1] Wrbanek J.D., Fralick G.C., Wrbanek S.Y., Chen L.Y. (2007) NASA/TM—2007-214674.
[2] Wrbanek J.D., Fralick G.C., Wrbanek S.Y., Chen L.Y. (2005) *Space Resources Roundtable VII: LEAG Conference on Lunar Exploration*, p. 93, LPI Contribution No. 1287.
[3] Wrbanek J.D., Fralick G.C., Wrbanek S.Y. (2005) *Radiation and Micrometeoroid Mitigation Technology Focus Group Meeting*, P-0875.
[4] *Capability Road Map (CRM) 12: Science Instruments and Sensors (SIS) Capability Portfolio*, NASA Science Mission Directorate (2005).
[5] *Managing Space Radiation Risks in the New Era of Space Exploration*, Committee on the Evaluation of Radiation Shielding for Space Exploration, National Research Council (2008).
[6] *Strategic Plan for Space Radiation Health Research*, Life Sciences Division, Office of Life and Microgravity Sciences and Applications (NASA 1998).
[7] *NASA Space Technology Roadmaps and Priorities*, National Research Council (2012).
[8] NASA Tech Briefs (April 2007) p. 7.
[9] Wrbanek J.D., Fralick G.C., Wrbanek S.Y., U.S. Patents 7,872,750 (January 18, 2011), 8,159,669 (April 17, 2012).

LOW-POWER MULTI-ASPECT SPACE RADIATION DETECTOR SYSTEM. J. D. Wrbanek[1,3], S. Y. Wrbanek[1], G. C. Fralick[1], J. C. Freeman[1] and S. P. Berkebile[2], [1]NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH, [2]Oak Ridge Associated Universities, NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135, [3]Email address: John.D.Wrbanek@nasa.gov

Introduction: The advanced space radiation detector development team at NASA Glenn Research Center (GRC) has the goal of developing unique, more compact radiation detectors that provide improved real-time data on space radiation. The team has performed studies of different detector designs using a variety of combinations of solid-state detectors, which allow higher sensitivity to radiation in a smaller package and operate at lower voltage than traditional detectors [1-3]. Integration of all of these detector technologies will result in an improved detector system in comparison to existing state-of-the-art (SOA) instruments for the detection and monitoring of the deep space radiation field.

The goal of this research is to develop a low-power radiation detector system capable of monitoring a wide range of high energy heavy ions (HZE ions) over a spherical (4π) aspect area [4, 5]. The technology applied to this 4π HZE Detector System enables:

- Improved temperature insensitivity to changes induced by transitions from sunlight into shadow (and vise-versa);
- Improved precision with lower mass, power and volume requirements;
- Improved radiation discrimination and directional sensitivity;
- Unique monitoring of radiation environment of high relevancy for planetary exploration from all directions of the celestial sphere.

New Capabilities: New capabilities for radiation measurement in exploration beyond Earth orbit are realized from a variety of low-power detectors. Due to limited resources available for power and space for payloads, miniaturizing and integrating instrumentation is a key aspect to enabling manned and unmanned deep space missions to High Earth Orbit (HEO), Near Earth Objects (NEO), Lunar and Martian orbits and surfaces, and outer planetary systems. New, robust compact detectors allow future instrumentation packages more options in satisfying specific mission goals. Technology limiters are primarily detector size, noise floor and detection geometry. Enabling technology solutions for these limitations are development of low noise, integrated solid state detectors with spherical geometry.

Integrating the variety of detectors will allow measurements of radiation of different types from different directions at once, something that is not available with current state-of-the-art detectors. Space radiation comes in a variety of types, energies, and directions. Current SOA detector technology is large, power consuming, and thus reducing the size and operational power will improve mission affordability. The variety of radiation in space demands a suite of detectors tailored to accurately monitor and analyze the various types. NASA GRC is developing a variety of light weight, low-power solid state detectors that can increase the variety and energies of radiation able to be detected and yet reduce the amount of space and power consumed by current SOA. This will enable more accurate and unique measurements of high relevancy for the radiation environment in missions beyond Earth orbit.

System Development Approach: Advanced instrumentation technology for space radiation applications is specifically called for in the Strategic Program Plan for Space Radiation Health Research [6]. The NASA Space Technology Roadmaps and Priorities [7], the Science Instruments and Sensor Capabilities Road Map [8], and the design goals of existing cosmic ray detectors define the technology requirements [9]. These requirements include particle energy range and resolution, angular coverage and resolution, and the number of sensing elements as important design criteria in trade studies.

A variety of detector types, including low noise, wide band gap (WBG) semiconductors are considered applicable for radiation detectors due to their low ionization energy, high electron mobility, high density and structural rigidity. A concept schematic drawing of a spherical detector system comprising a spherical Cherenkov detector, surrounded by various arrays of detector stacks is shown in Figure 1. Most of the technology in this detector system has been demonstrated at some level, but the challenge is to design and develop unique detection array methods in coordination with advancing these technologies. Some of the specific goals of these instrumentation efforts are:

- Apply scintillator ribbon material where appropriate to detect radiation impinging over large, irregular surfaces where electronic device placement is not feasible. The flexibility of an advanced fiber-based detector system is an attractive option to allow embedded multi-directional radiation characterization and precision trigger/veto functionality.

- Demonstrate a spherical Cherenkov detector that can detect radiation from all directions, amplifying signal through use of integrating sphere properties designed into detector. Current detectors have directional sensitivity along one axis, and this spherical detector increases the directional sensitivity to any direction. Immersed in the space environment, where radiation is omni-directional, measurements sensitive over an entire sphere is a significant improvement from interpolating along discrete axes.
- Develop a variety of stacked detectors with various solid state detectors, absorbers and converters for optimum detection of electrons, neutrons and ions in a small, low-power package. A miniature detector stack will reduce mass, power, and volume requirements as well as improving particle species discrimination and spatial resolution.
- Apply WBG solid state devices as practical large area detectors. WBG semiconductors have the advantages of low ionization energy, high electron mobility, high density and structural rigidity as for use as radiation detectors. WBG semiconductors have negligible sensitivity to temperature changes as well, a direct benefit for space applications.

The realization of the detector system leverages in-house GRC expertise and facilities in 1) harsh environment thin films, 2) silicon carbide (SiC) devices and harsh environment packaging, 3) micro-optics technology, and 4) structural radiation shielding materials. Integration of all of these technologies will result in an improved detector system in comparison to existing state-of-the-art capabilities as summarized in Table 1. As mission needs change, the detector technology integration can be adapted for performance and optimal science benefit.

References: [1] Wrbanek J.D., Fralick G.C., Wrbanek S.Y., Chen L.Y. (2007) NASA/TM—2007-214674. [2] Wrbanek J.D., Fralick G.C., Wrbanek S.Y., Chen L.Y. (2005) *Space Resources Roundtable VII: LEAG Conference on Lunar Exploration*, p. 93, LPI Contribution No. 1287. [3] Wrbanek J.D., Fralick G.C., Wrbanek S.Y. (2005) *Radiation and Micrometeoroid Mitigation Technology Focus Group Meeting*, P-0875. [4] *NASA Tech Briefs* (April 2007) p. 7. [5] Wrbanek J.D., Fralick G.C., Wrbanek S.Y., U.S. Patents 7,872,750, 8,159,669 (January 18, 2011, April 17, 2012). [6] *Strategic Plan for Space Radiation Health Research*, Life Sciences Division, Office of Life and Microgravity Sciences and Applications (NASA 1998). [7] *NASA Space Technology Roadmaps and Priorities*, National Research Council (2012). [8] *Capability Road Map (CRM) 12: Science Instruments and Sensors (SIS) Capability Portfolio*, NASA Science Mission Directorate (2005). [9] *Managing Space Radiation Risks in the New Era of Space Exploration*, Committee on the Evaluation of Radiation Shielding for Space Exploration, National Research Council (2008).

Table 1: Potential improvements to critical metrics for advanced space radiation detection.

SIS CRM Metric	CRM SOA	Improvement Enablers	Detector System Expected Performance
Energy Range	140 MeV/amu	Integrated Detectors	1,000 MeV/amu
Energy Resolution	±30 keV	Low Noise Detectors	±25 keV
Angle Coverage	0.3 cm²-sr	Spherical Geometry	1 cm²-sr
Angle Resolution	±14°	Solid State Detectors; Spherical Geometry	±12°
Particle Species/Charge	Multiple in multiple detectors	Integrated Detectors	e – Fe
Miniaturization (Mass, Power, & Volume)	Defined by Detectors	Integrated Solid State Detectors	30% SOA

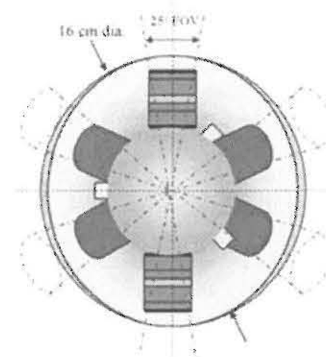


Figure 1: Concept of an Integrated Spherical Space Radiation Detector System [5].