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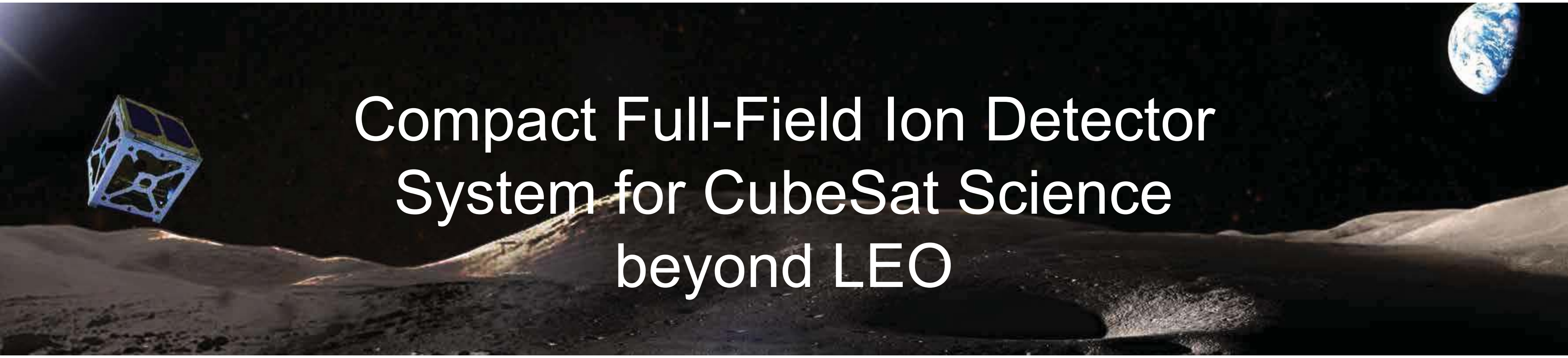

Compact Full-Field Ion Detector System for CubeSat Science beyond LEO

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The Next Frontier: CubeSats for Deep Space

3rd International Workshop on LunarCubes

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Outline

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- Application Concept System
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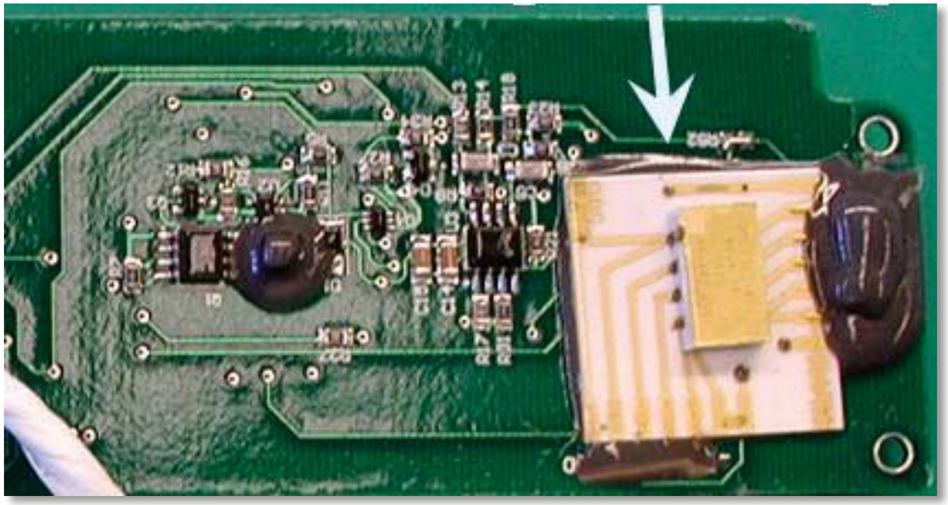
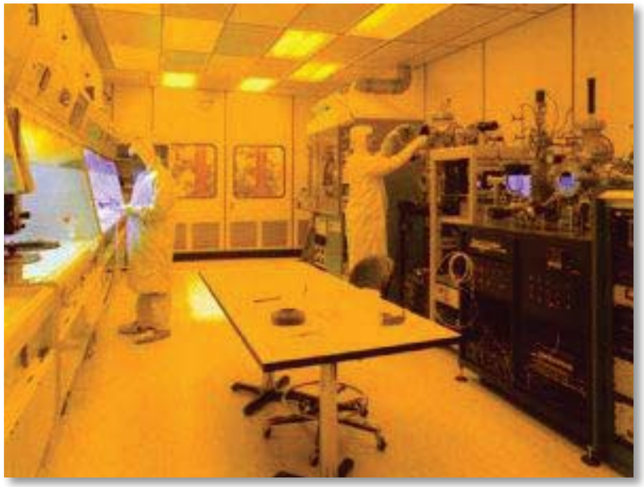
GRC Advanced Radiation Detector Technology Research and Development

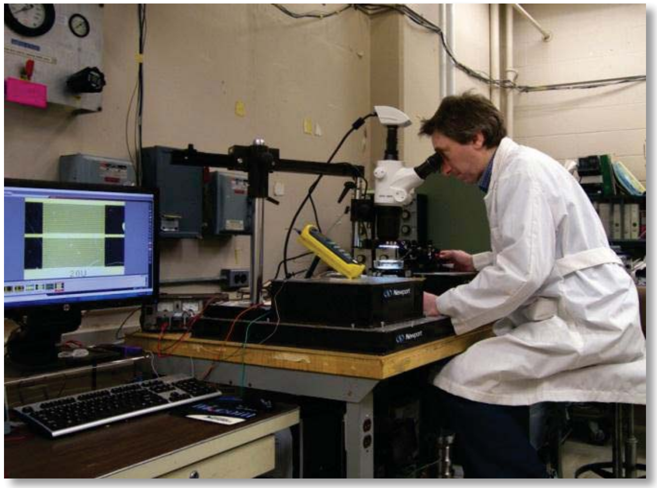
- GRC Expertise and Facilities in:
  - Harsh Environment Thin Films
  - SiC Devices & Harsh Environment Packaging
  - Micro-Optics
  - Space-Based Instrumentation
- These strengths are combined into an in-house Radiation Instrumentation Research effort



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



In-House Microsystems Fabrication



Thin Film Characterization

AEVA SiC Radiation Detector

Technology Challenges and Solutions

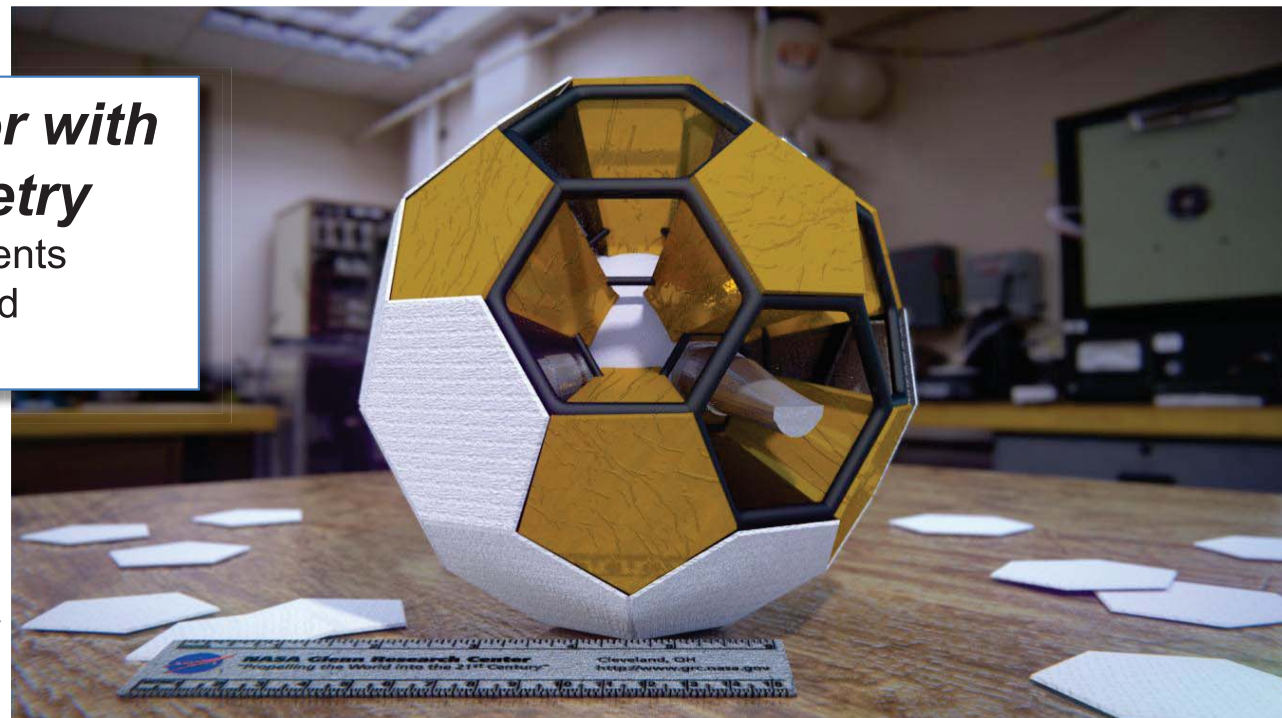
- Goal is to develop a radiation detector system to fly on small satellite platforms (such as CubeSats) to reduce cost, development time of missions
  - Design point: 1U CubeSat volume, mass for detector system (10 cm x 10 cm x 10 cm, 1 kg)
- CubeSats currently flown LEO applications, but future is in Deep Space
  - High radiation particle influx from multiple directions (spherical 4π solid angle)
- Current radiation detector technologies need temperature compensation
  - CubeSat platform size, 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

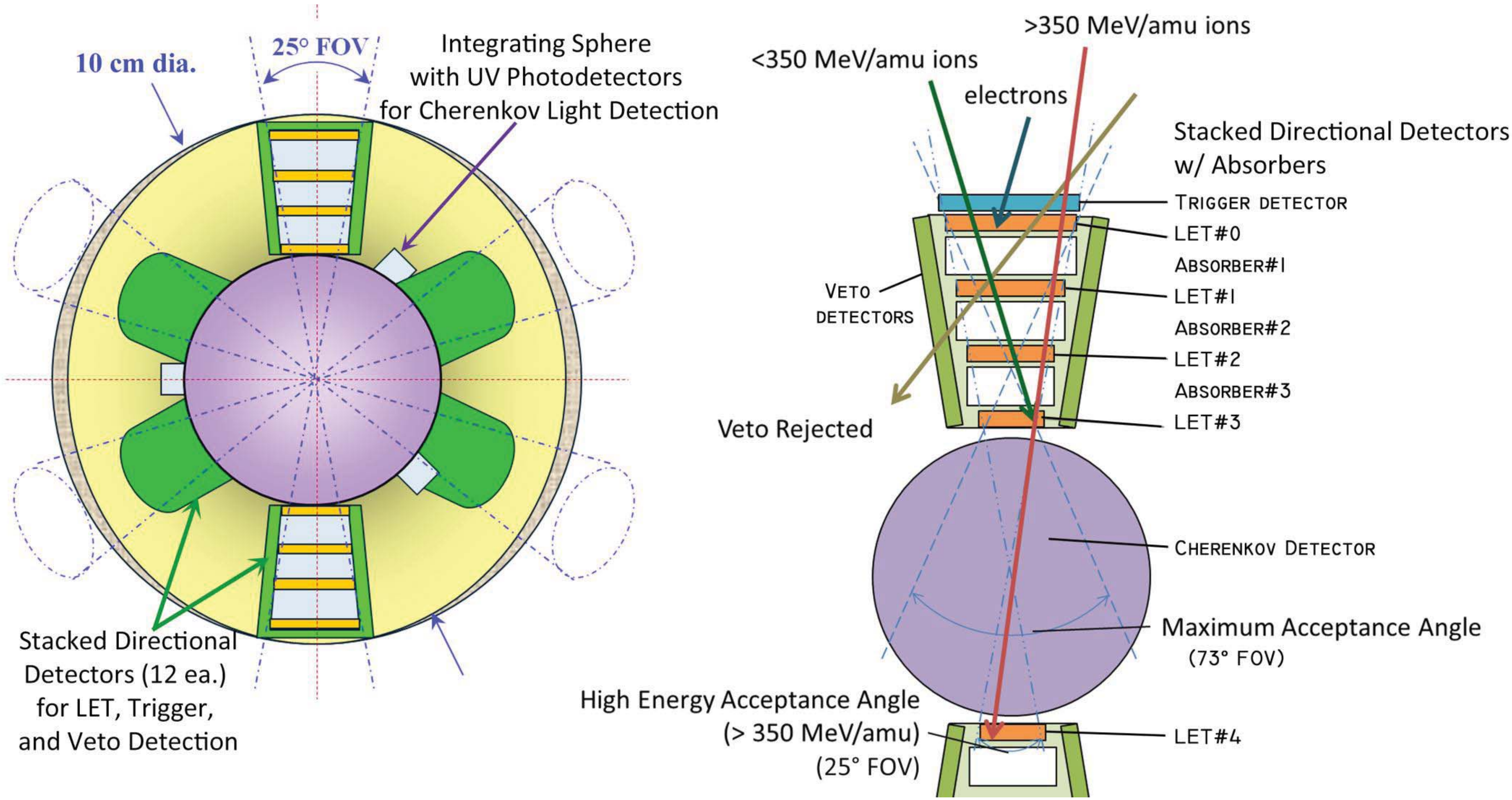
Space radiation detector with spherical geometry

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



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

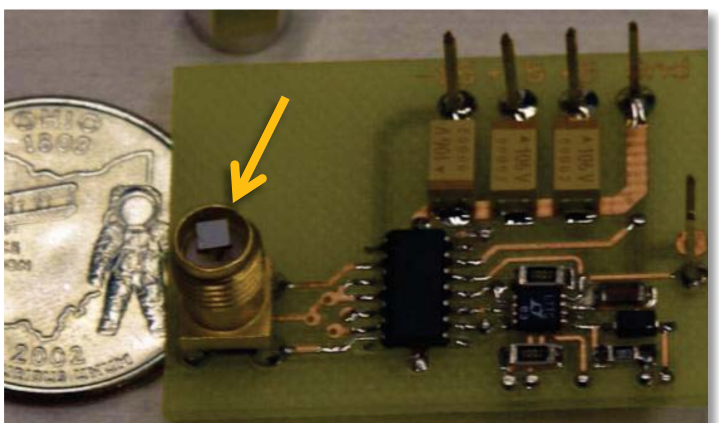
Application Concept: Compact Full-Field Ion Detector System (CFIDS)



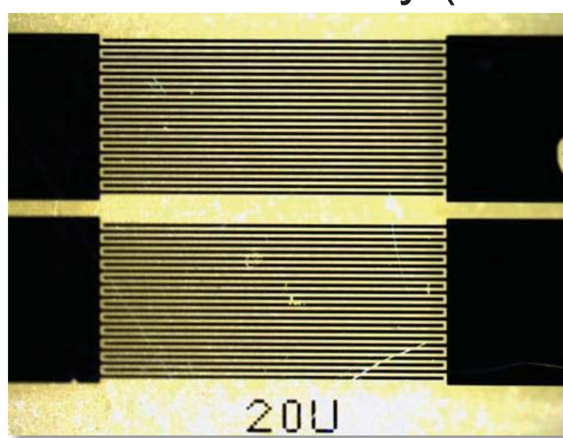
- CFIDS comprised of a spherical Cherenkov detector surrounded by stacked LET detectors with absorbers, Trigger and Veto detectors

GRC Advanced Radiation Detector Technology R&D Timeline

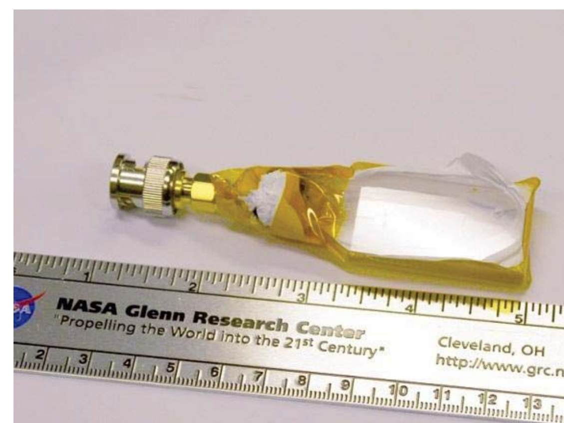
- AEVA Power, Communications, Avionics, Informatics (2005-2007)
  - Study of SiC radiation detectors
- ETDP/D Life Support & Habitation Systems/Radiation Protection (2009-2011), AES Radiation Protection (2012)
  - Demonstration of dosimeter based on SiC diode detector element
- OCT/STMD Center Innovation Fund (three 10-week efforts)
  - Design and fabrication of Proof-of-Concept ZnO Detector for UV Cherenkov light detection (2011, 2012) (patent pend.)
  - Low-Power Scintillator-Diode Detector study (2013)



ETDP dosimeter based on AEVA SiC diode detector element (arrow)



OCT ZnO UV Detector (20 μm electrode spacing)



STMD Low-power scintillator paddle counter

Background: Sampling of Space Radiation Detector Systems in Flight

Detector System	Originator	Platform/Date	Detectors	Use
IVCPDS/EVCPDS /MARIE	JSC (SwRI is current keeper of this heritage)	ISS/2000 Mars Odyssey/2002	Si, 1mm thick, 1x1 cm square anode	Low-to-Mid energy ions: LET, trigger
			Si, 300μm thick, 24x24 array of 1 mm^2 diodes	Low-to-Mid energy ions: LET, position tracking
			Si(Li), 5 mm thick, 2.5 mm dia.	Mid-to-High energy ions (low LET)
			5 cm dia. PMT w/ 1 cm thick glass disk Cherenkov Detector	High energy ions (200-500 MeV/amu)
CRaTER	BU/MIT/SwRI	LRO/2005	Pairs of 140μm and 1mm thick Si detectors 35mm diameter	Sort heavy ions from zenith, compare from surface (bi-directional)
RAD	SwRI/JPL	Curiosity/2011	Si detectors; avalanche photodiodes w/ CsI, “Bicron” 432 scintillators	General dose measurement: Neutron, gamma, proton, alpha
PEPSSI /JEDI	APL	New Horizons/2006 JUNO/2011	Segmented TOF detector w/ solid state detectors and multichannel plates	< 1 MeV ions, electrons; 10 years for development to flight (TRL 3 to 6)

Background: State of the Art (SOA)

- Cherenkov Detectors: UV-sensitive photomultiplier tubes (PMTs) on a UV-transparent radiator material
  - PMT Size: 5 cm dia., 10-12 cm long, 180 cm^3 (without radiator)
  - Power: 1000 V, 5 nA dark current
- LET Detectors: Surface-effect detectors made from diodes (Si PIN) or lithium-drifted silicon (Si(Li))
  - Si PIN Size: 1 mm^2 to 1 cm^2 active area
  - Si(Li) Size: 30 cm^2 x 5 mm thick active volume
  - Power: 100-300 V, 5 nA (PIN) to 5 μA (Si(Li)) dark current
  - Performance: operates 0°C – 60°C, 100°C typical Li drifting temperature; dark current temperature sensitive
- Scintillator Trigger/Veto Detectors: Bulk scintillator (<50°C) on either photomultiplier tubes (PMTs) or avalanche photodiode arrays (APDs; i.e. silicon photomultipliers):
  - APD Size: 9 mm^2 active area (arrays)
  - Power: 30 V, >5 nA dark current, >0.150 μW
  - Performance: operates -20°C – 40°C; temperature sensitivity of dark current requires active temperature compensation
- Wide band gap (WBG) detectors promise to be lower power, more robust

Advantages of WBG Detectors: Lower Power and More Robust

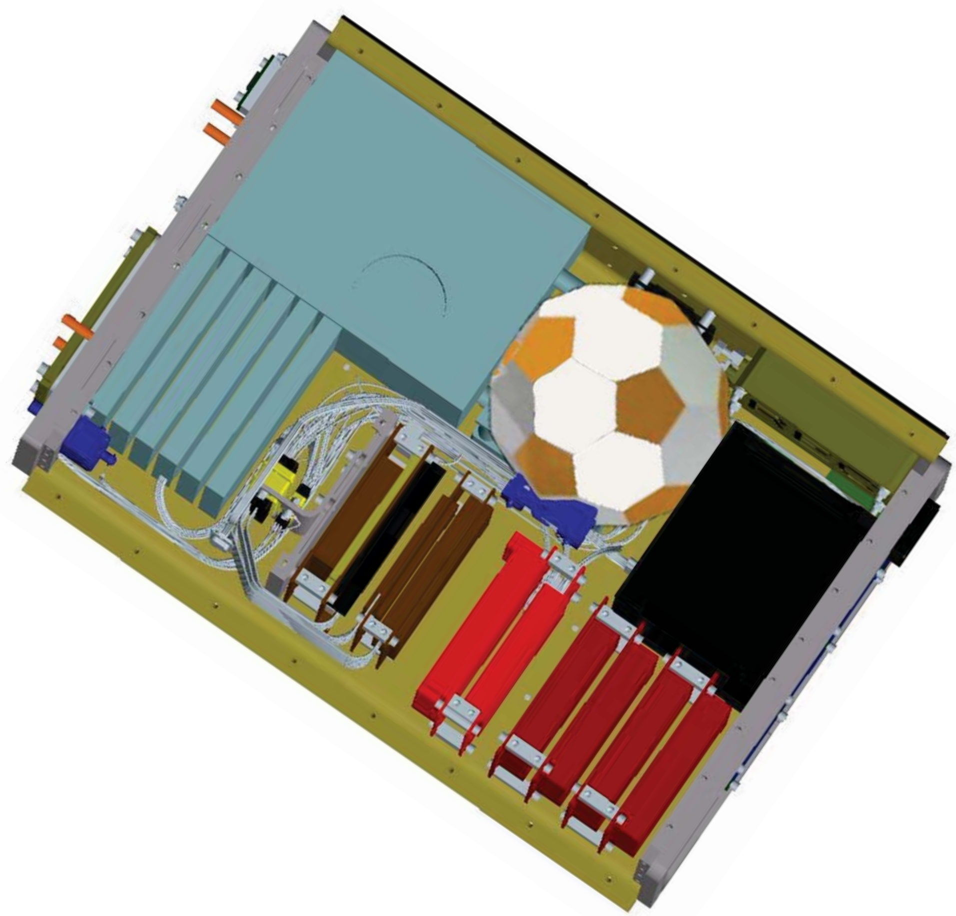
Detector	Active Area	Mass	Volume	Voltage	Dark Current	Minimum Power Draw	Maximum Signal to Noise	Maximum Operating Tempera-ture	Temperature Sensitivity of Dark Current
Cherenkov Detector:									
SOA: PMT	20 cm^2	170 g	180 cm^3	1000 V	5 nA	5 μW	$4x10^4$	50°C	0.2%/°C
Proposed: ZnO	2 mm^2	11 g	0.80 cm^3	10 V	5 nA	0.05 μW	$4x10^4$	125°C	0.05%/°C
LET:									
SOA: Si PIN	1 cm^2	0.5 g	185 mm^3	100 V	5 nA	0.5 μW	$1x10^5$	60°C	20%/°C
SOA: Si(Li)	30 cm^2	35 g	15 cm^3	300 V	5 μA	1.5 mW	$2x10^4$	60°C	30%/°C
Proposed: SiC	1 cm^2	0.3 g	90 mm^3	5 V	50 pA	0.250 nW	$2x10^5$	120°C	0.1%/°C
Scintillator Trigger/Veto:									
SOA: PMT	20 cm^2	170 g	180 cm^3	1000 V	5 nA	5 μW	$4x10^4$	50°C	0.2%/°C
SOA: APD	9 mm^2	3 g	200 mm^3	30 V	5 nA	0.15 μW	$8x10^4$	85°C	30%/°C
Proposed: GaP	4.8 mm^2	5 g	170 mm^3	5 V	20 pA	0.1 nW	$4x10^5$	125°C	0.5%/°C

CFIDS Technology Challenges

Component	Technology Challenge	Approach
Fast Cherenkov Detector	ZnO UV detector packaging	GRC Harsh Environment Packaging expertise; Examine SiC diode back-up
Trigger/Veto Scintillator Counters	GaP photodiodes with fiber scintillators	Compare COTS to custom packaging
Large Area WGB LET Detectors	SiC Diode array	GRC Harsh Environment Packaging expertise; Examine single-crystal option
Signal Conditioning Electronics	Space available	GRC Space Electronics expertise
Detector Integration	Mass limit	More reliance on lower density metals (Al, Ti); Higher fidelity models

CFIDS Application for Deep Space CubeSats

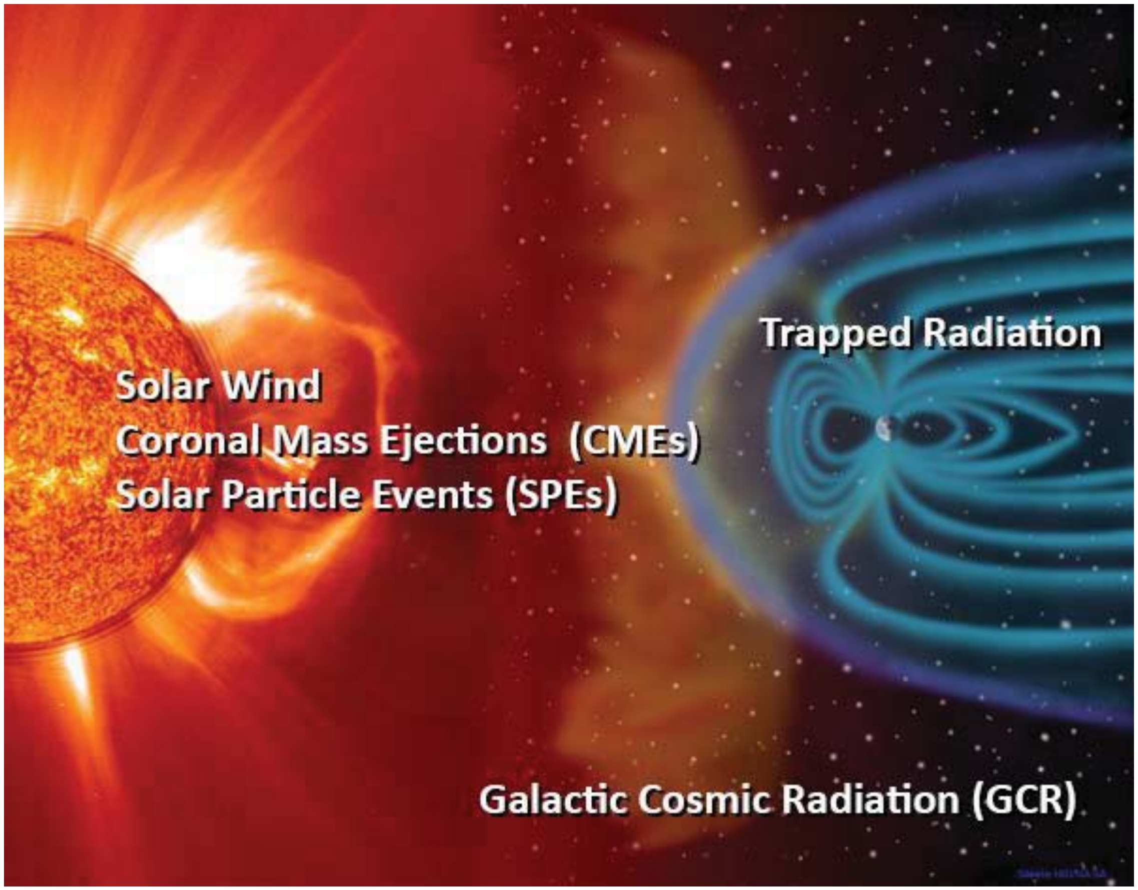
- Detector assembly design point of 1U volume (10x10x10 cm^3)
- Signal conditioning electronics an additional ½U volume
  - Charge Integration, ADC, Power Regulation, Data Formatting
  - Dependent on CubeSat bus Command and Data Handling (C&DH)
- Easily adaptable to 3U, 6U layouts for operation beyond LEO
- Allows new possibilities for unique Deep Space Science on a CubeSat platform



Concept drawing of CFIDS adapted to GSFC/WFF 6U Interplanetary CubeSat Design

Space Radiation Environment in Deep Space

- Outside the Magnetosphere, the space environment contains a variety of sources of radiation that affects spacecraft as well as planets, moons and asteroids:



- Solar Wind
  - Stream of H^+, He^+ from Sun
  - ~1 keV/u peak
  - ~3×10^8 particles/cm²/sec @ 1 AU
- Coronal Mass Ejections (CMEs)
  - Pulses of H^+, He^+
  - ~30 keV/u peak
  - ~1×10^9 particles/cm²/sec @ 1 AU
- Solar Particle Events (SPE)
  - Pulses of H^+, He^+
  - ~100 MeV/u peak
  - ~3×10^4 particles/cm²/sec @ 1 AU
- Galactic Cosmic Radiation (GCR)
  - Stream of H^+ to Fe^+ ($Z=1 \rightarrow 26$)
  - ~300 MeV/u broad peak
  - ~$0.1/u^2$ particles/cm²/sec

Planetary Effects of Space Radiation

- Dynamic changes in planetary magnetospheres
  - Higher the flux, mass and energy, the more penetrating the radiation through the magnetic field to the planetary body
  - CMEs biggest affect on magnetospheres, but even GCR is not minor (4%-8%)
  - Penetrating radiation will modify planetary surfaces and atmospheres
- In Earth atmosphere, heavy GCR ions linked to
  - Aerosol production
  - Unstable isotope production as well as ozone depletion
  - Lightning triggers
  - Lower-troposphere cloudiness and long-term climate change
- Elsewhere, GCR ions linked to
  - Neutron generation in Martian atmosphere
  - Space weathering of moons, asteroids and spacecraft surfaces
- Direct measurements in-situ lacking…. Models abound

Lunar Science Opportunity

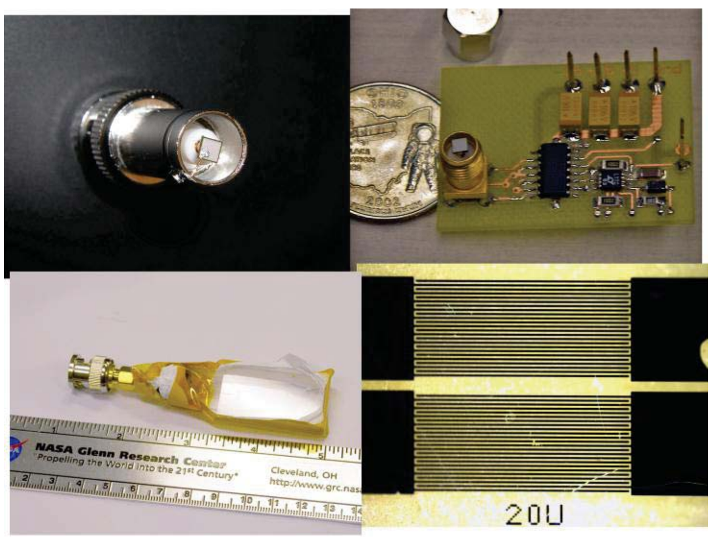
- Moon has no substantial magnetic field or atmosphere
- High Z, high energy (HZE) GCR ions have enough energy to significantly change composition, disrupt molecular structure, cause loss of molecular hydrogen, and cause chemical reactions, including the polymerization of organics, and potentially be linked to formation Fe^0-rich coatings on silicate grains
- These processes are implicated, though not yet directly measured, for many rocky or icy bodies with meager to no atmospheres lacking magnetospheres
- Direct measurements in-situ either in orbit or on the lunar surface will identify specific processes and quantify the effects

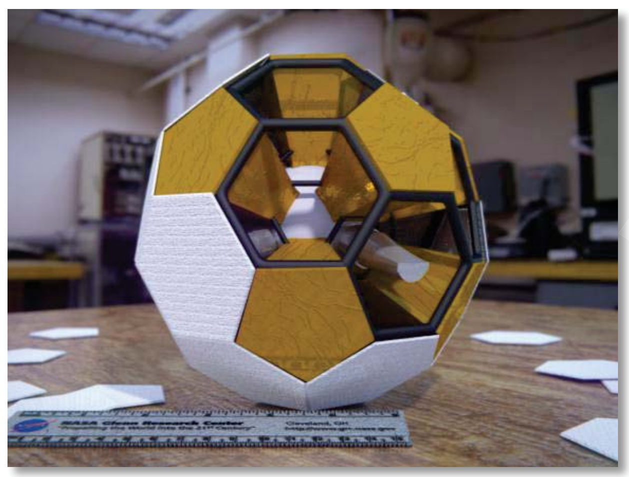
Metri sunt necesse malum

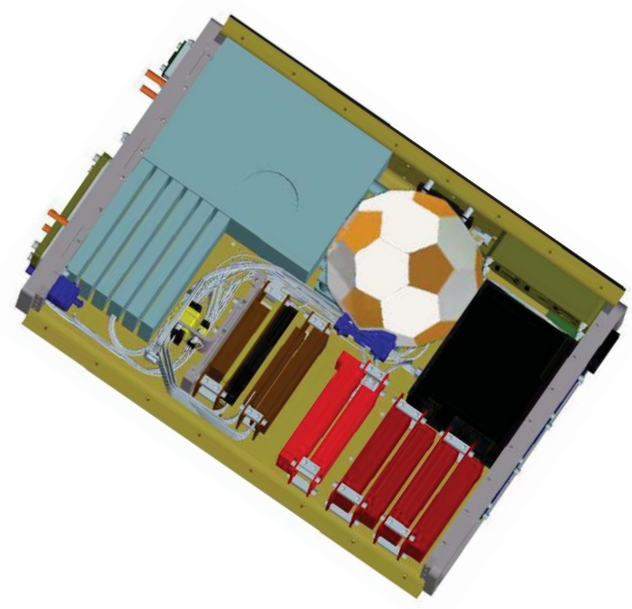
"Measurements are necessary evils"

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
- CFIDS radiation instrumentation system in a Deep Space CubeSat will allow in-situ studies of HZE GCR interactions in lunar environments







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