Compact Cosmic Ray Detector for On-orbit Testing of Shielding Materials

Stephen Berkebile, James R. Gaier

NASA Glenn Research Center

Cleveland, OH

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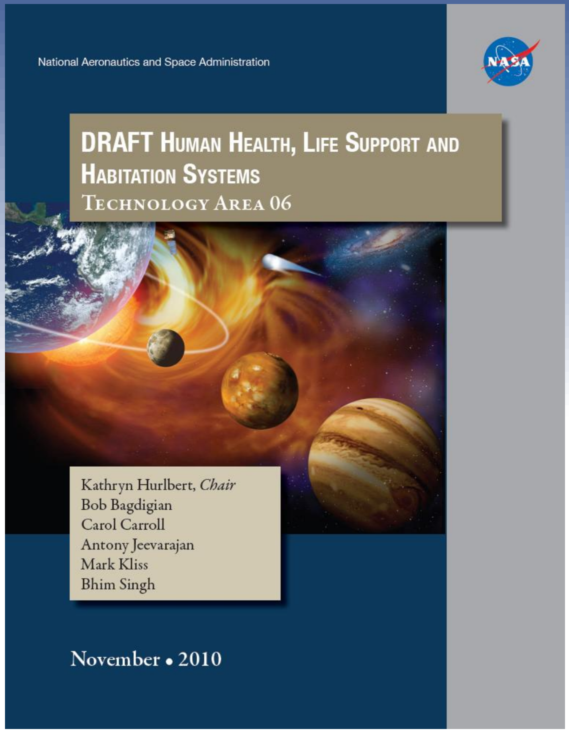
• NASA Materials International Space Station Experiment (MISSE-X)

• NASA ETDD Radiation Protection Project

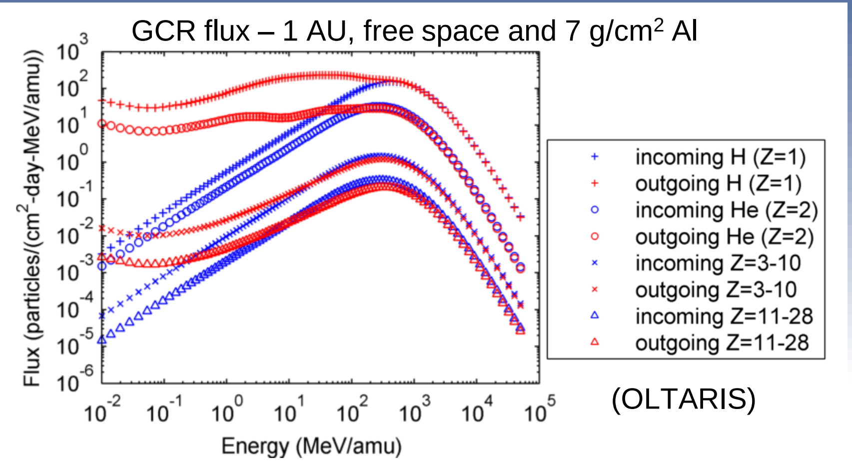
Space Radiation Challenges

- Space Technology Area Roadmap (TA06, 2.5 Radiation)
  - "The radiation area is focused on developing knowledge and technologies … (among other) … to minimize exposures through the use of material shielding systems."
  - "The major technical challenge for future human exploration is determining the best way to protect humans from the high-charge and high-energy galactic cosmic radiation (GCR) permeating interplanetary space."



- Mars mission projections currently 3 – 5 times permissible exposure limit
- Goal: 20-30% reduction in GCR exposure through improvements in shielding

Space Radiation Challenges



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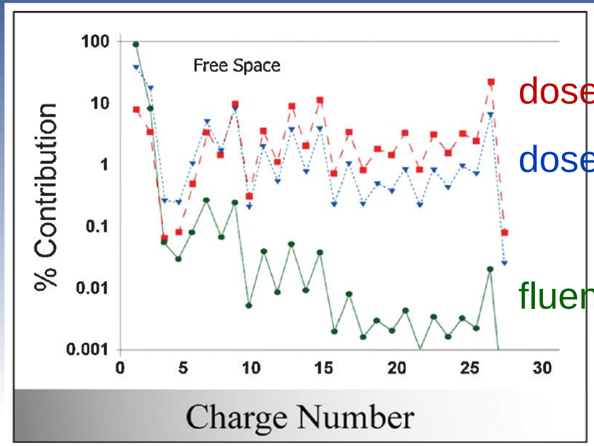
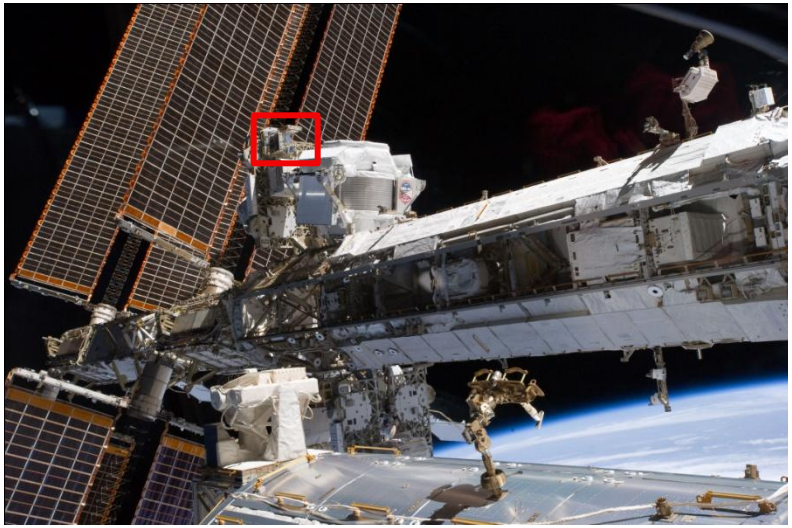


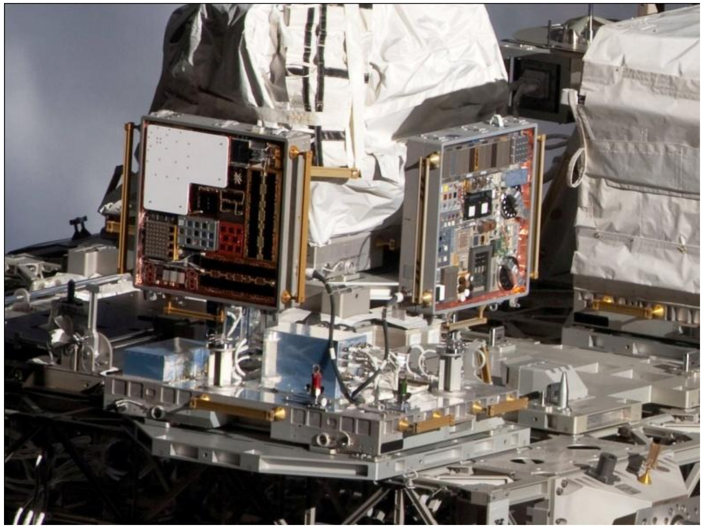
One year behind 5 g/cm² Al (solar min.)
Durante, Cucinotta, Rev. Mod. Phys., 83, p.1245, (2011).

- Dose mostly from HZE (high charge and energy ions)
  - Damage different than terrestrial radiation (x-rays, gamma)
  - Easily penetrates typical shielding (mass constraints)
- Solutions?
  - Hydrogen has highest specific stopping power, but not a structural material!
  - Multifunctional and dual-use materials
  - Novel composite materials
- TRL 6/7: Demonstration in a relevant/space environment

MISSE-X

- Materials International Space Station Experiment
  - Eight previous missions (one currently in space)
  - Test bed for materials, coatings, solar cells, sensors, electronics, etc. attached to outside of ISS
  - Effects of atomic oxygen, UV, sunlight, radiation and extremes of heat and cold
  - Experiment emphasis: passive → active (limited down mass)



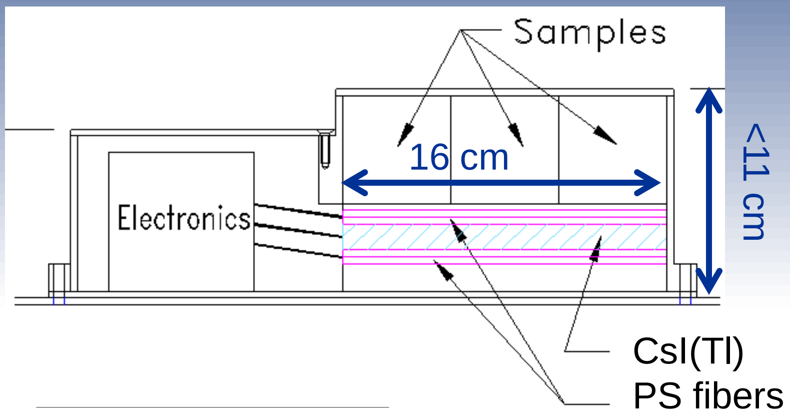


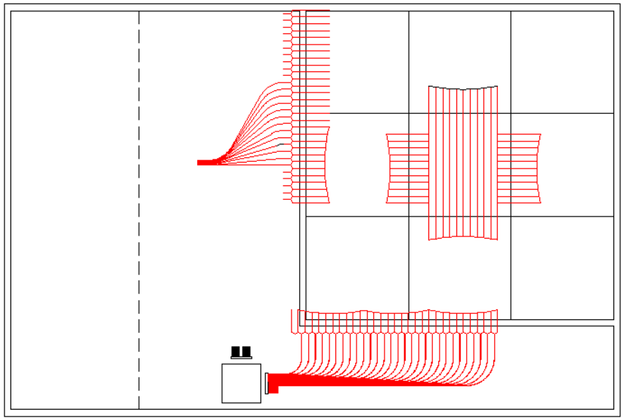
Experimental Concept – MRSMAT

- Existing detectors/experiments
  - Cosmic ray environment
  - Dosimetry, tissue-equivalent dose inside and outside ISS
- Features
  - Side-by-side testing of seven candidate materials
  - Al, polyethylene standards
- Requirements: Discriminate between GCR shield effectiveness of 1 mGr/day
  - Minimum absorption length, identical exposure, S/N ratio >5
  - Discern whether GCR passed through which sample
  - Insensitive to <10 MeV/A, sensitive to 0.1 to 10 GeV/A
- Limitations
  - Low power (<25 W), low voltage, limited space
  - Temperature swings of -60°C to +60°C

Basic Design

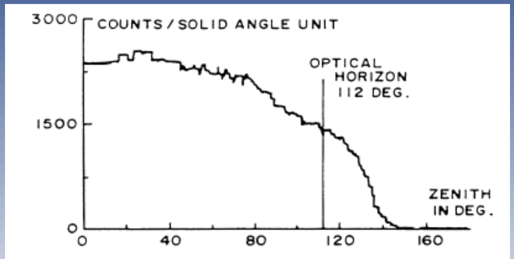
- Scintillating fiber arrays, 3.5 mm polystyrene (PS)
  - MIP: ~300 detectible photons at fiber end
- CsI(Tl)
  - Robust, sensitive to heavy ions
  - Pulse shape discrimination
- Light detection: SiPMs
  - Pros
    - ✓ compact
    - ✓ low voltage, large output signal
    - ✓ insensitive to B-field
    - ✓ high detection efficiency / dynamic range
  - Cons
    - ✓ temperature sensitive gain
    - ✓ dark counts





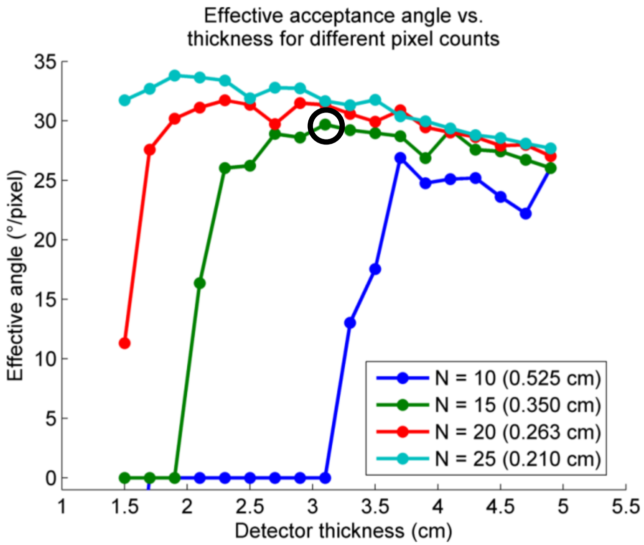
Angular resolution

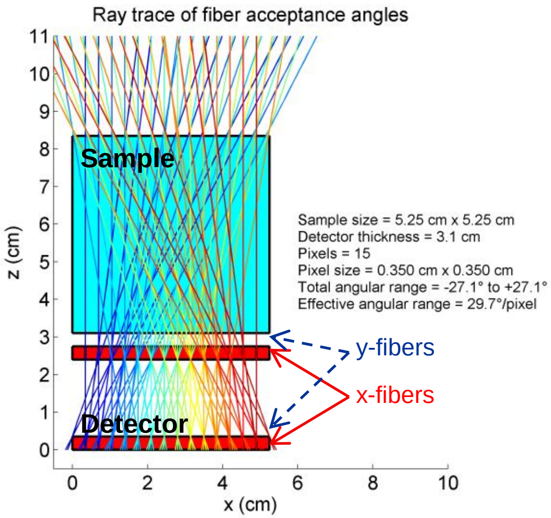
- GCR environment
  - Isotropic in free space
  - LEO nadir protected by Earth



5 GeV cosmic rays, zenith west plane
reproduced in Smart, Adv. Space Res., 36, p.2012, (2005).

- Geometric considerations

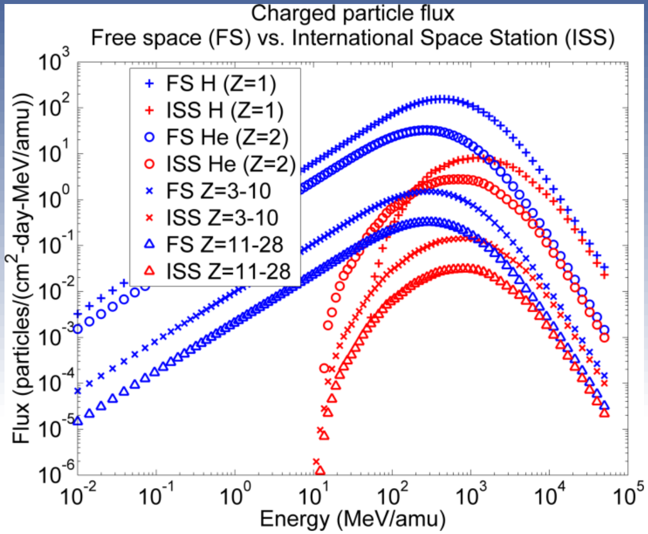




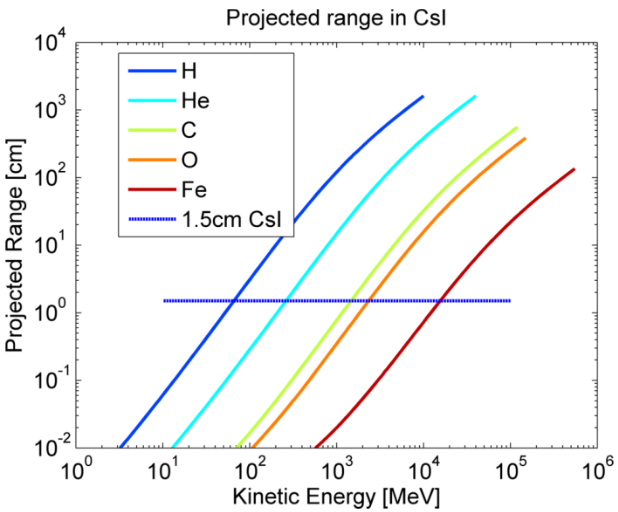
Expected Relevance

- LEO vs. free space
  - Lower flux, but weighted towards greater HZE

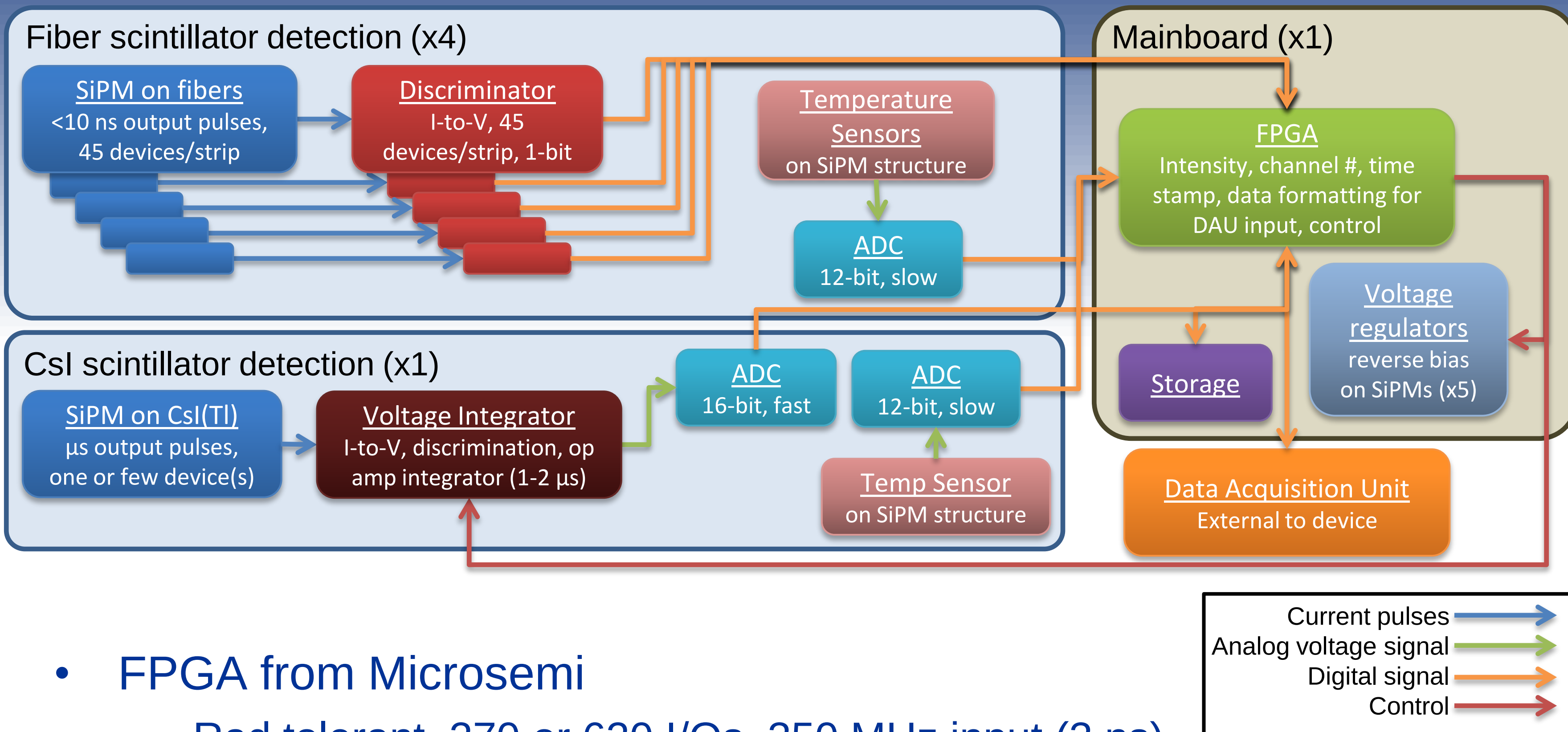
Ion Flux, ion/cm²-s	H	He	Li - Ne	Na – Fe
Deep space	3.72	0.50	0.0261	0.00564
ISS 2010	0.53 (14%)	0.10 (20%)	0.00578 (22%)	0.00126 (22%)



- Poisson statistics $P_r = \frac{\mu^r e^{-\mu}}{r!}$
  - At 100 μs sampling time, 99.3% events will be single particle (excluding nuclear cascades)
- Energy sensitivity
  - Event must trigger all levels
  - H: >65 MeV, Fe: >16 GeV



Electronics



- FPGA from Microsemi
  - Rad tolerant, 270 or 620 I/Os, 350 MHz input (3 ns)
- SiPM directly connected to discriminator on fibers
- Temperature-dependent reverse bias voltage control
- Data rate: 7 to 70 kbs

Summary and Outlook

- MISSE-X
- Scintillation-based detector to determine shielding effectiveness of novel structural materials
  - Low power
  - Compact
  - Robust?
- Near future
  - Monte Carlo simulations
  - Test SiPMs
    - ✓ MIP sensitivity with 3.5 mm fibers
    - ✓ Saturation with CsI(Tl)
    - ✓ Ability to deal with temperature dependence of SiPMs
  - Test candidate electronics for speed

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