G-SWEPT:
Lunar Gateway SWeeping Energetic Particle Telescope

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UNIVERSITY OF ALBERTA

FACULTY OF ENGINEERING
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Prof. Robert Fedosejevs – Principal Investigator
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Mr. David Barona – Project Manager
Mr. Bo Yu – Research Assistant
Mr. Jonathan Gan – Electronics Engineer

Honeywell Aerospace – Collaborator (Subcontract)

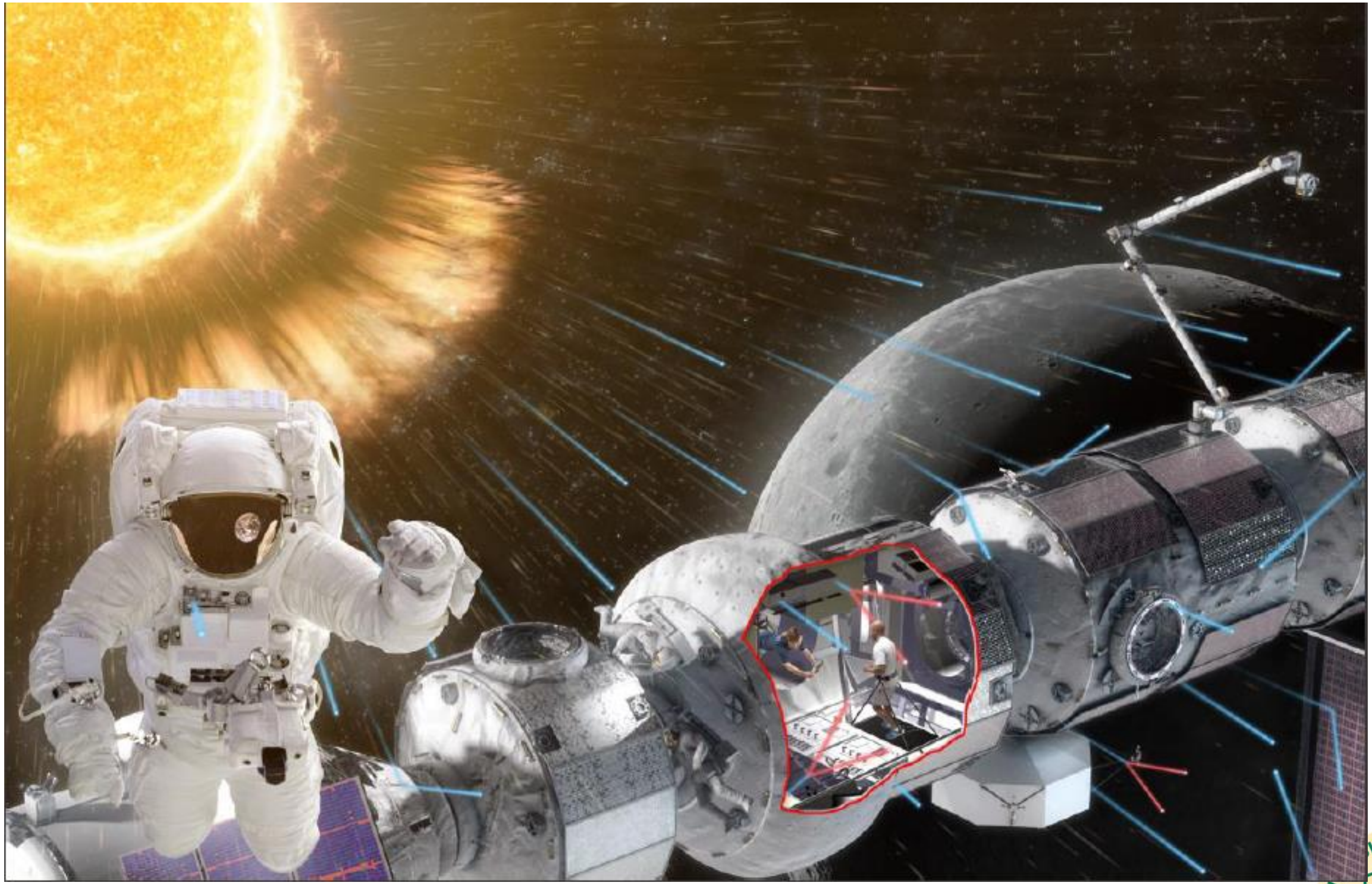
Dr. Neil Rowlands – Missions, Instruments and Payloads

Mr. Dwight Caldwell – Mechanical Systems Engineer
Mr. Ken Smith – Electronics Engineer
Mr. Sahal Belhimer – Electronics Engineer
Mr. Muhammad Amjad – Electronics Engineer

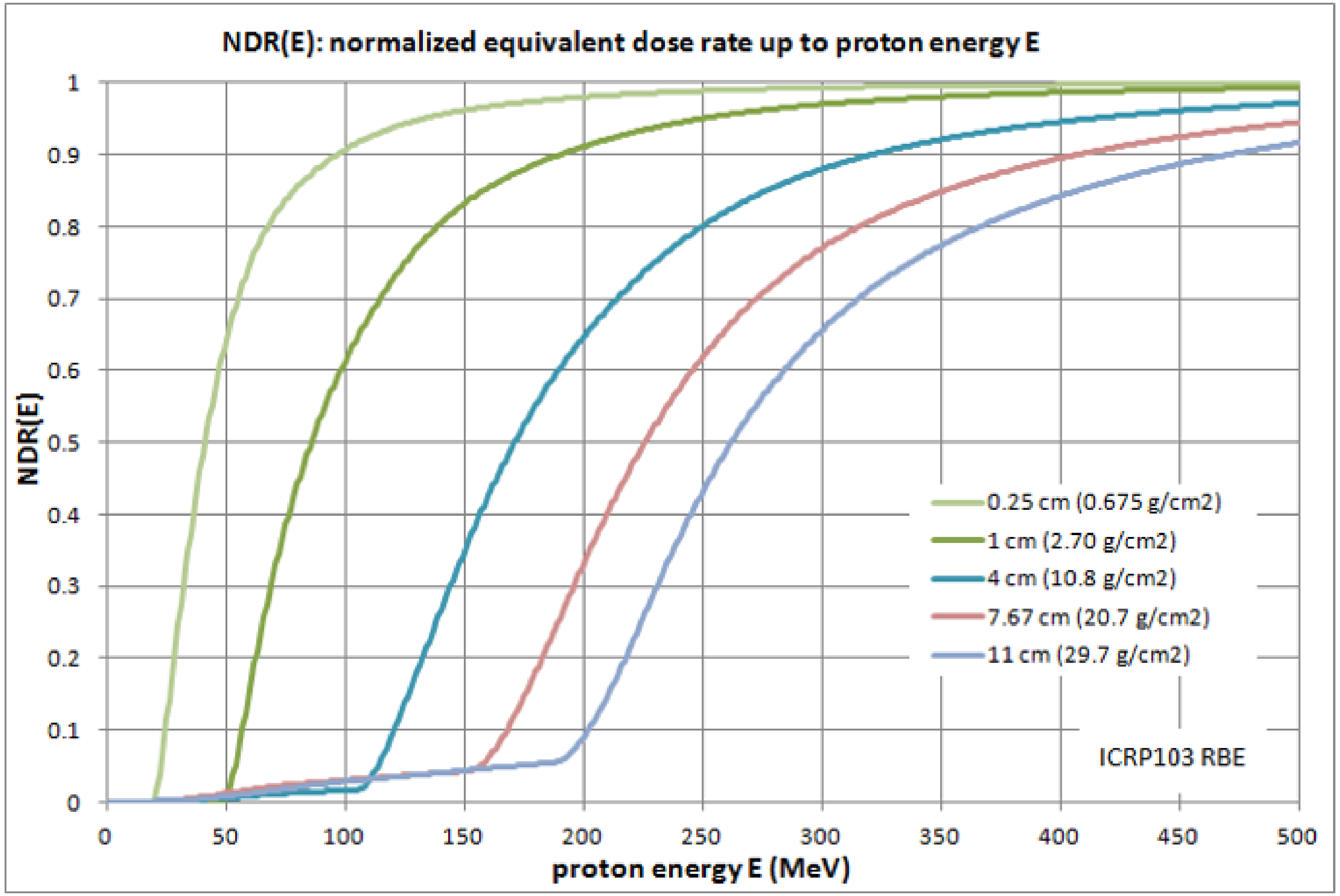
MOTIVATION

G-SWEPT: Deployment of the Canadian Space Radiation Telescope for Lunar Exploration

- Astronauts and critical equipment will be threatened by high radiation fluxes form SEPs
- High energy protons generate significant secondary radiation (neutrons) penetrating through shielding
- High energy electrons can be used as an early warning precursor of an SEP event
- More data is required on directionality and energy spectra of high energy radiation flux during SEP events



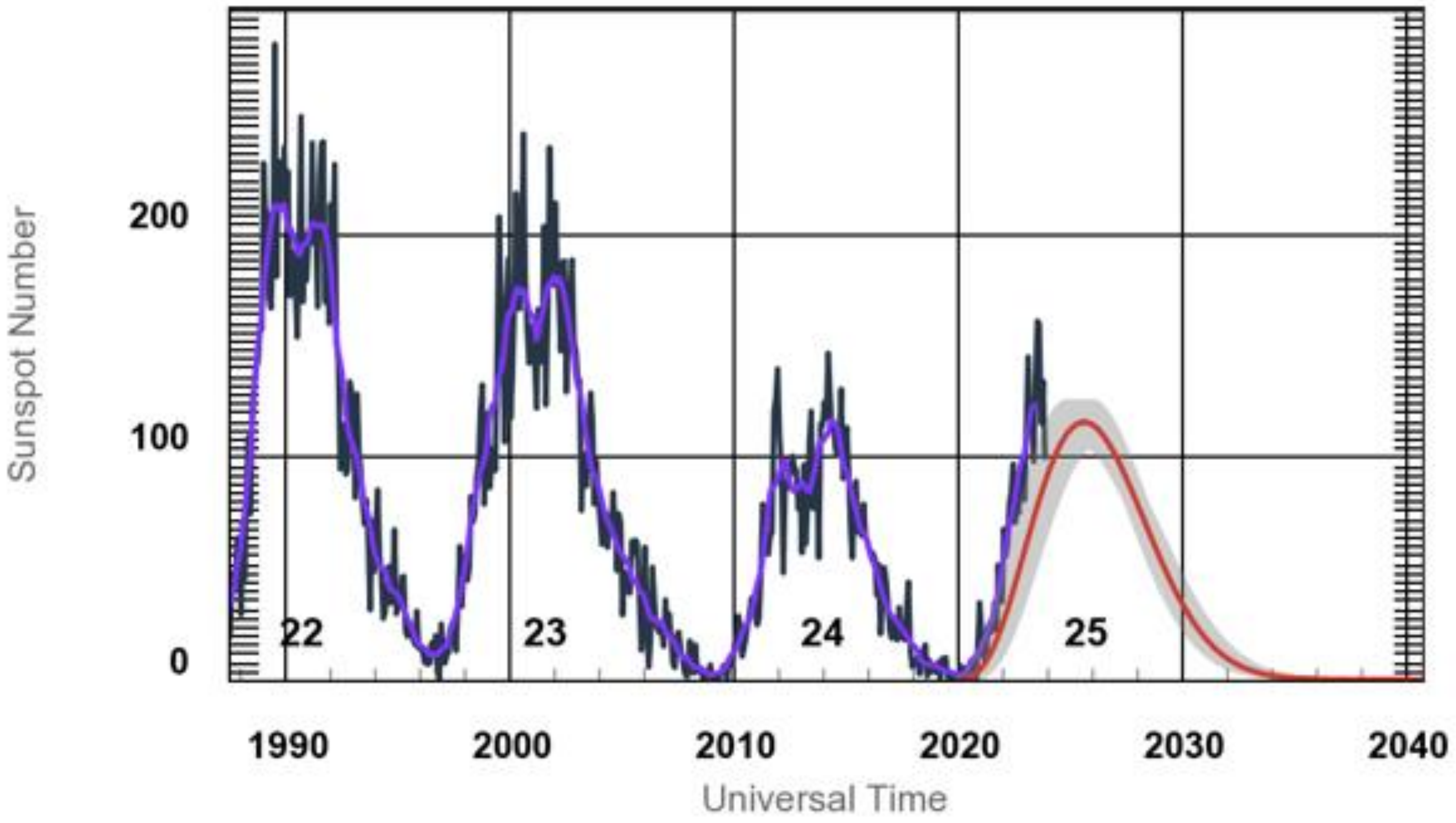
Main Radiation Dose Through 0.25 - 4 cm Al Shielding from 20 - 300 MeV Protons



Based on 60 kg hollow sphere phantom of A-150 human tissue equivalent plastic (GEANT4 simulations)

Predicted Occurrence of Next Solar Max

- No SEP events occurred during the Apollo missions
- Astronauts due to return to the moon in ~2026
- In ~2025 the SEP occurrence rate may be near a maximum, posing the greatest radiation risks
- Our analysis indicates 15 SEP events per year will occur near solar max

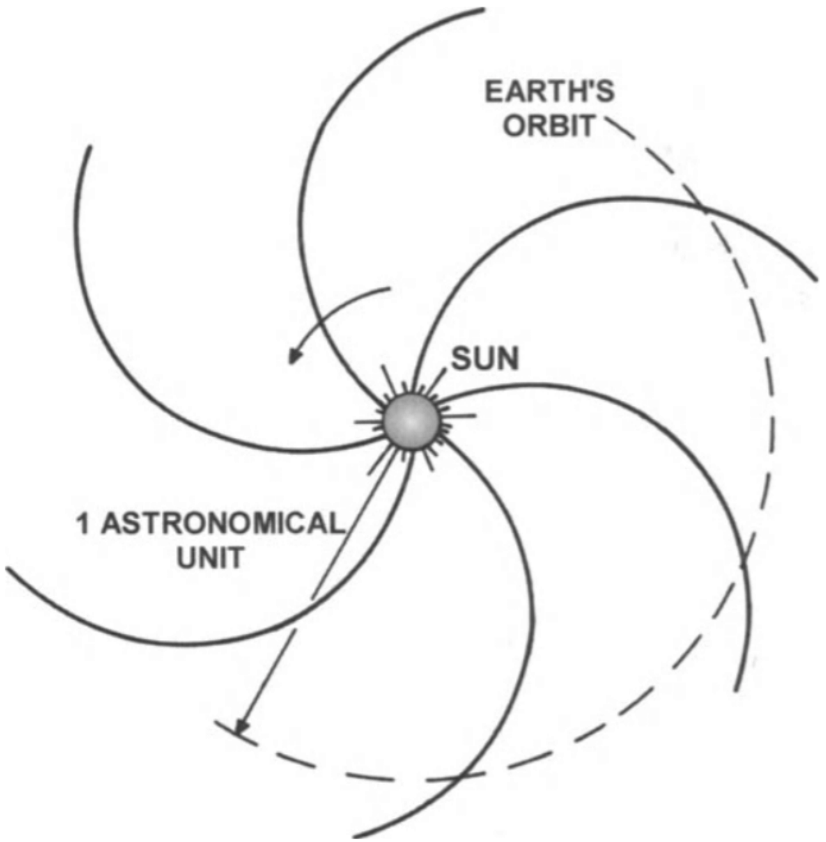


Electron Precursor - Travel Times Along the Parker Spiral

- SEP electrons & protons travel along the IMF Parker spiral

- Due to the lighter mass the electrons are relativistic and travel faster than the protons

- SEP electrons arrive at Earth orbit (1 AU) well before the SEP protons



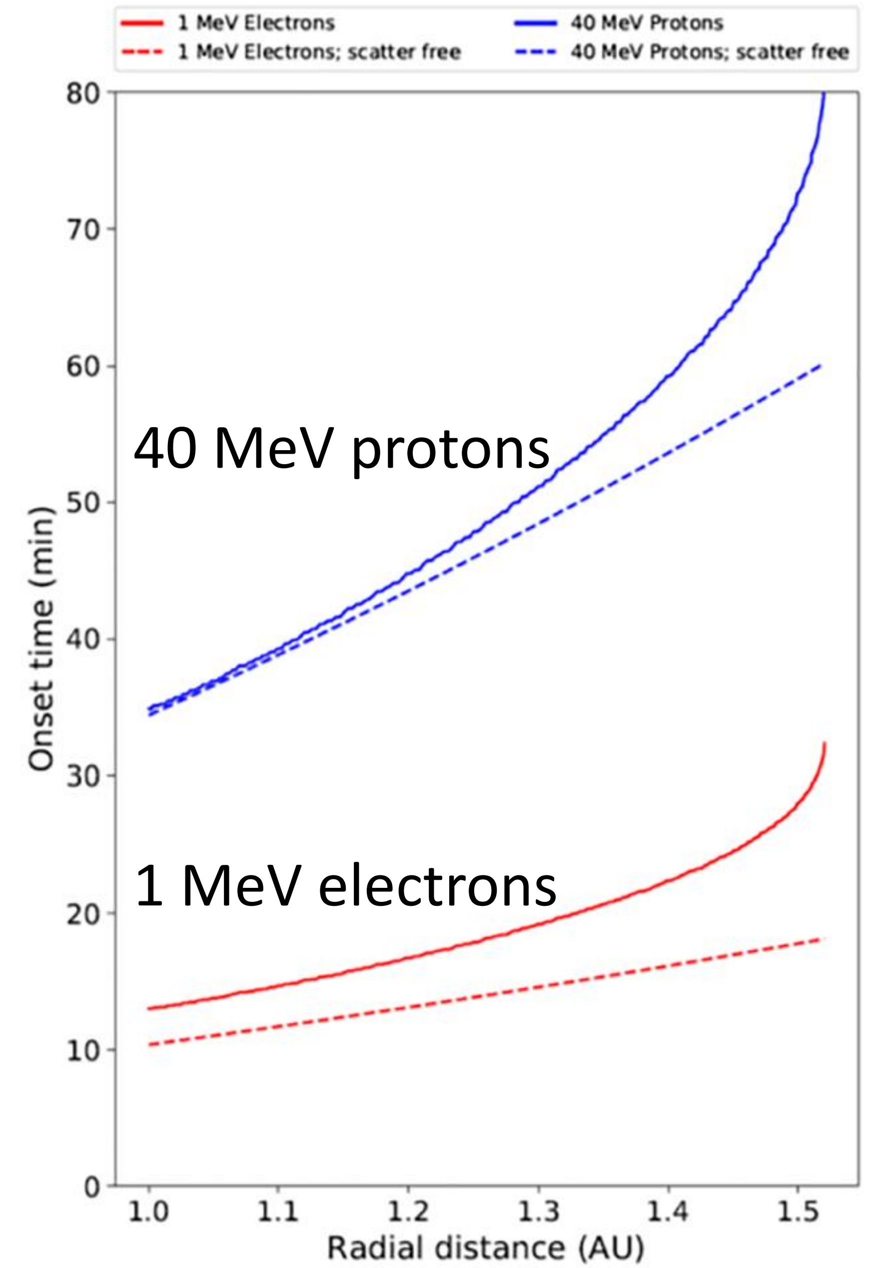
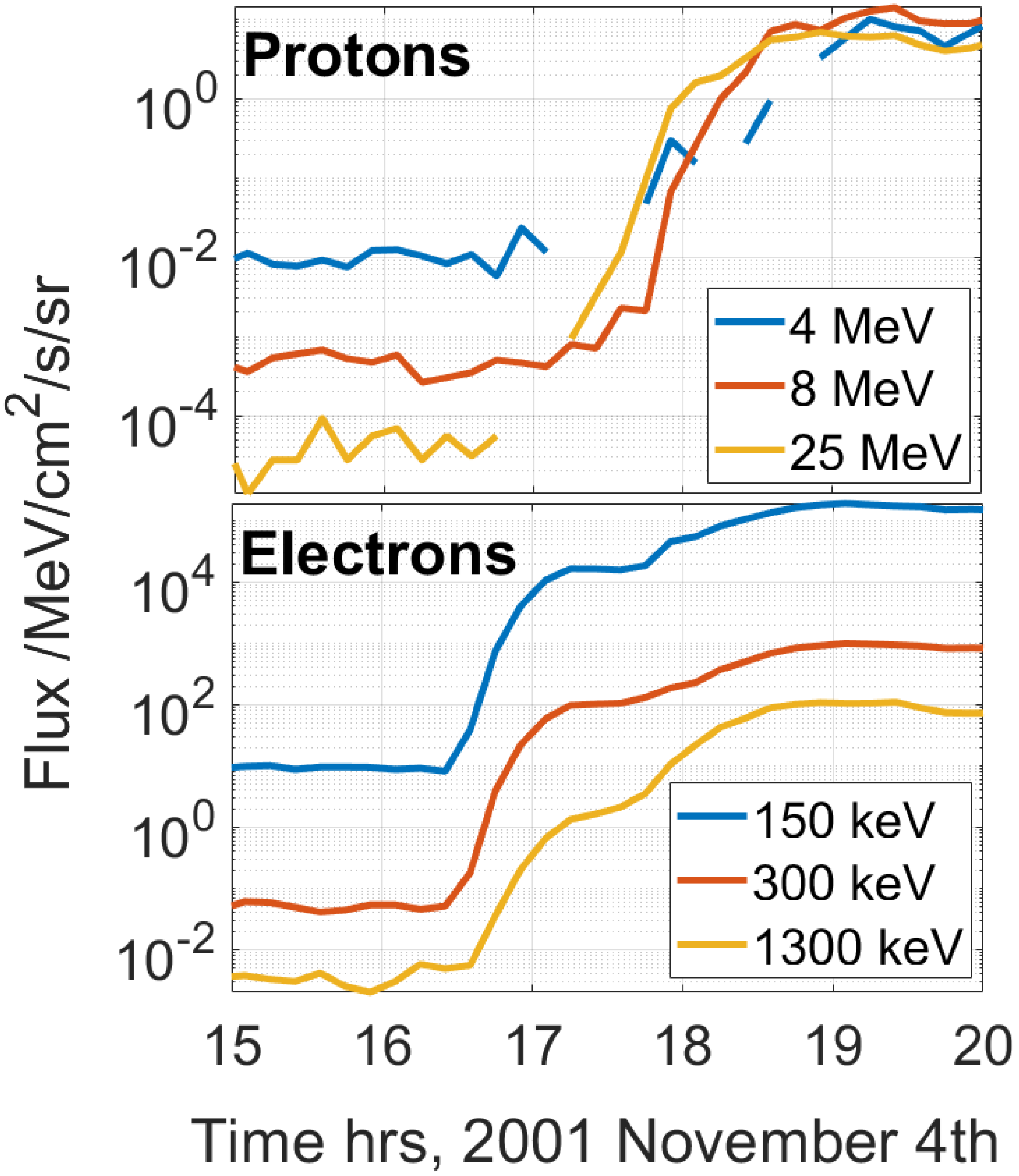


Fig. from *Posner et al. (2020)*

Electron Flux as an SEP Precursor

- We have collected all proton & electron data from the SOHO s/c to examine electron SEP precursors
- Example of electron precursor shown for event on Nov. 4, 2011
- Proton flux enhances ~17:30 UT
- Electron flux enhances ~16:30 UT
- At these energies, the electrons provide a ~ 1 hour warning of enhanced SEP proton radiation



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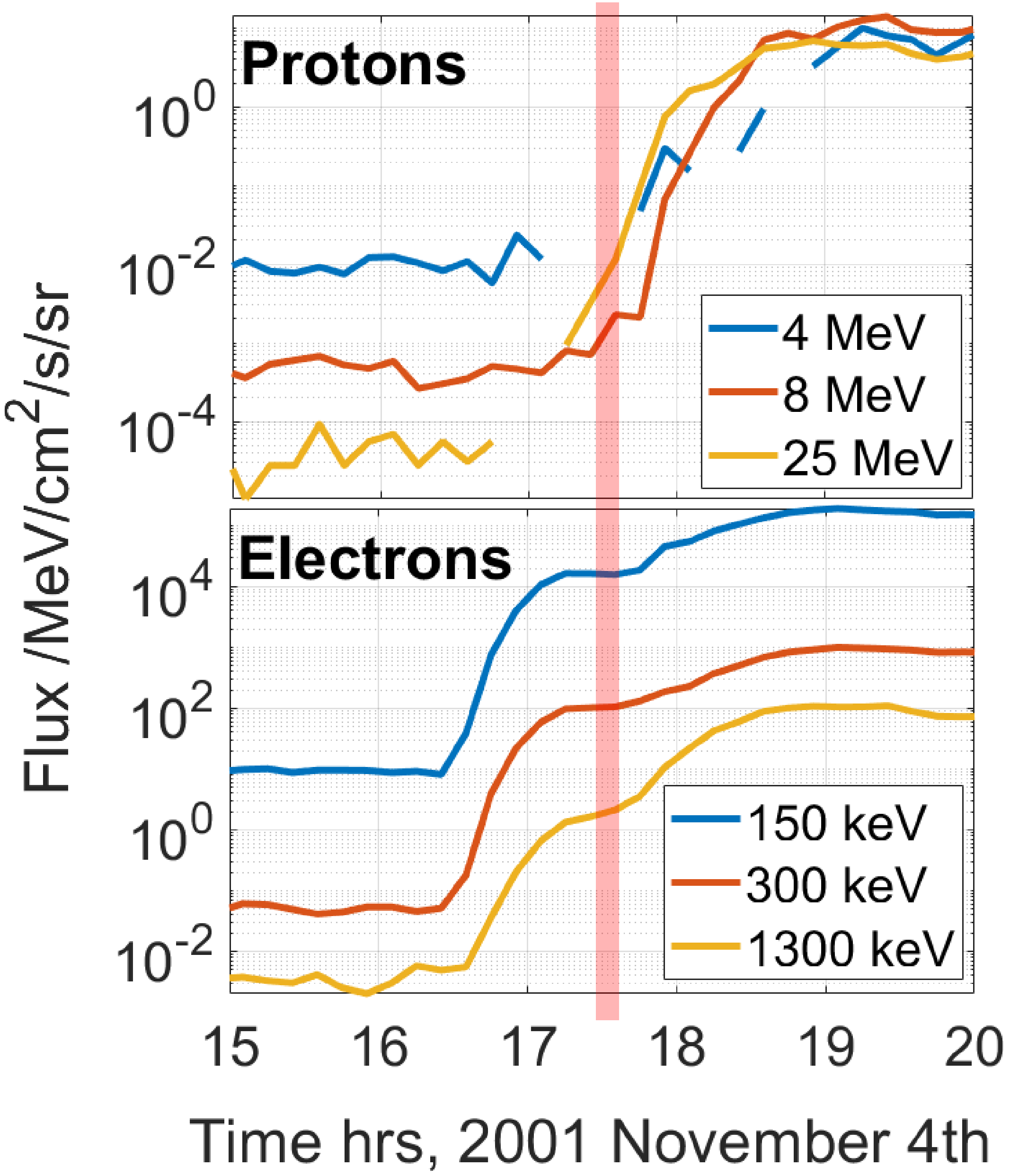

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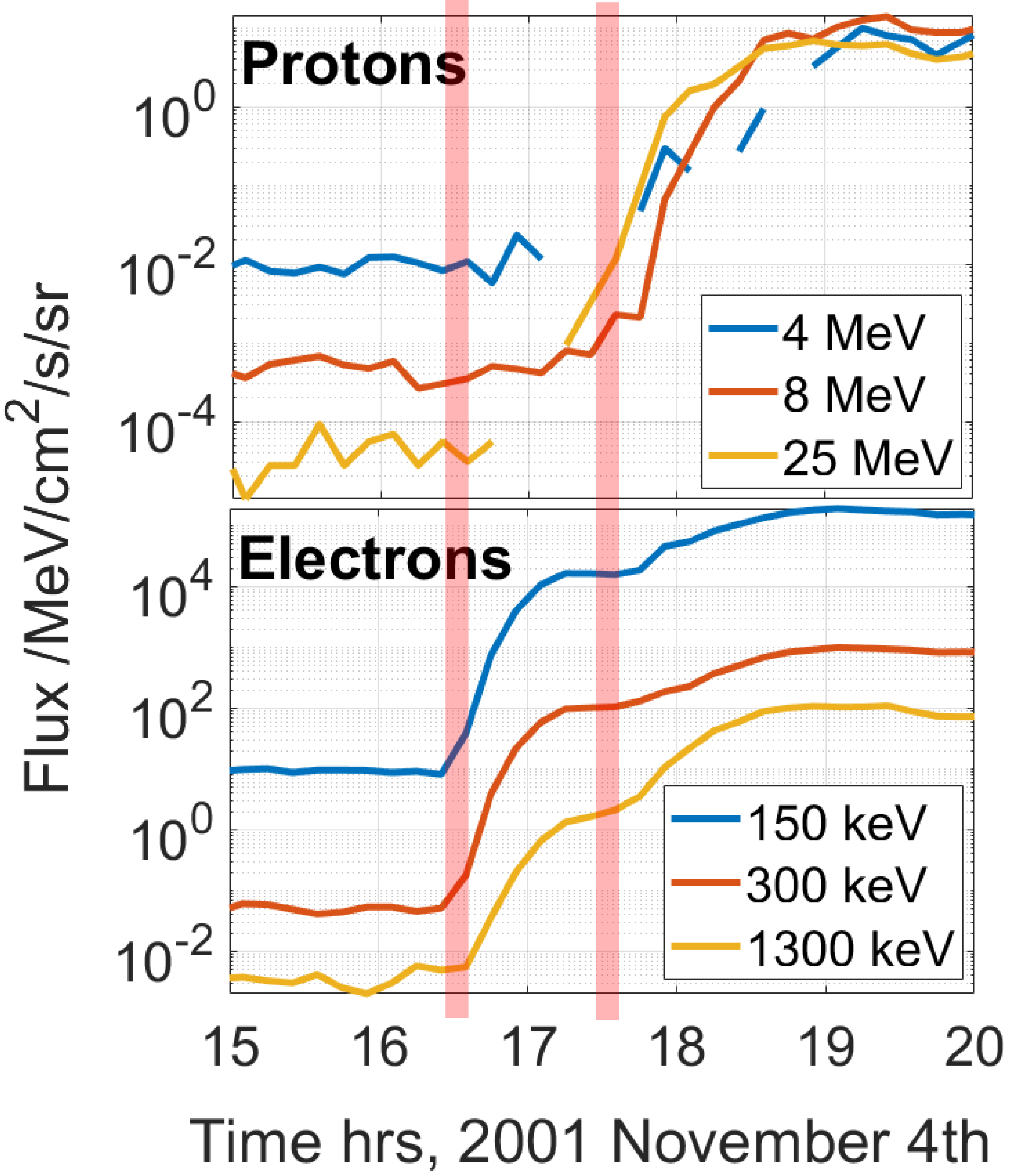
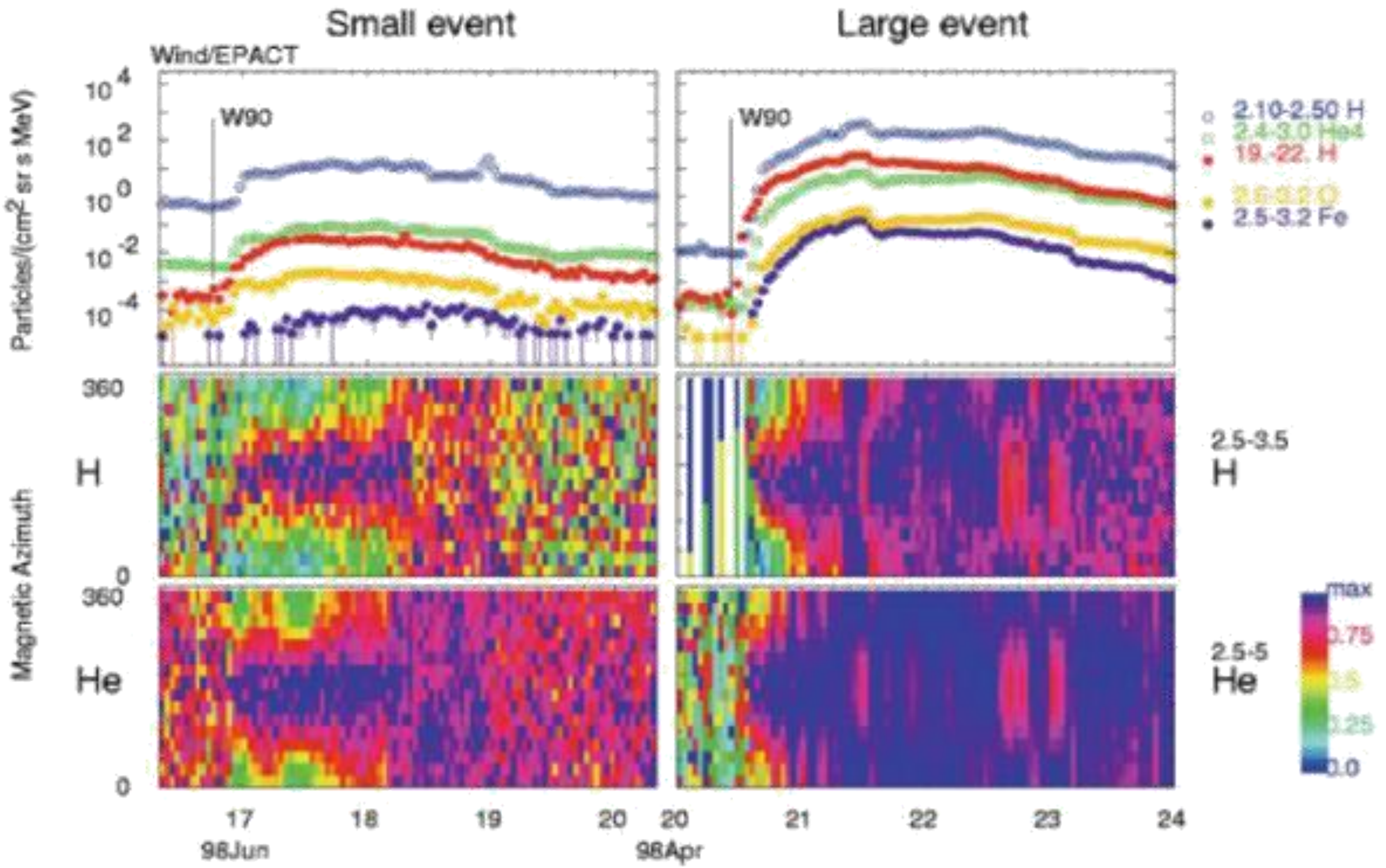


The Directionality of SEPs – Large Events Become Isotropic

SWEPT is unique in being able to measure the SEP directionality.

Important for determining the acceleration process and radiation risks

MERiT (NASA instrument planned for Lunar Gateway) is unable to measure the directionality of SEP particles.



From Reames et al., 2001

CSA has Supported Development of SWEPT for Over a Decade

2012 SWEPT Concept Study to detect Earth's radiation belt electrons, SEPs and GCRs from the ISS

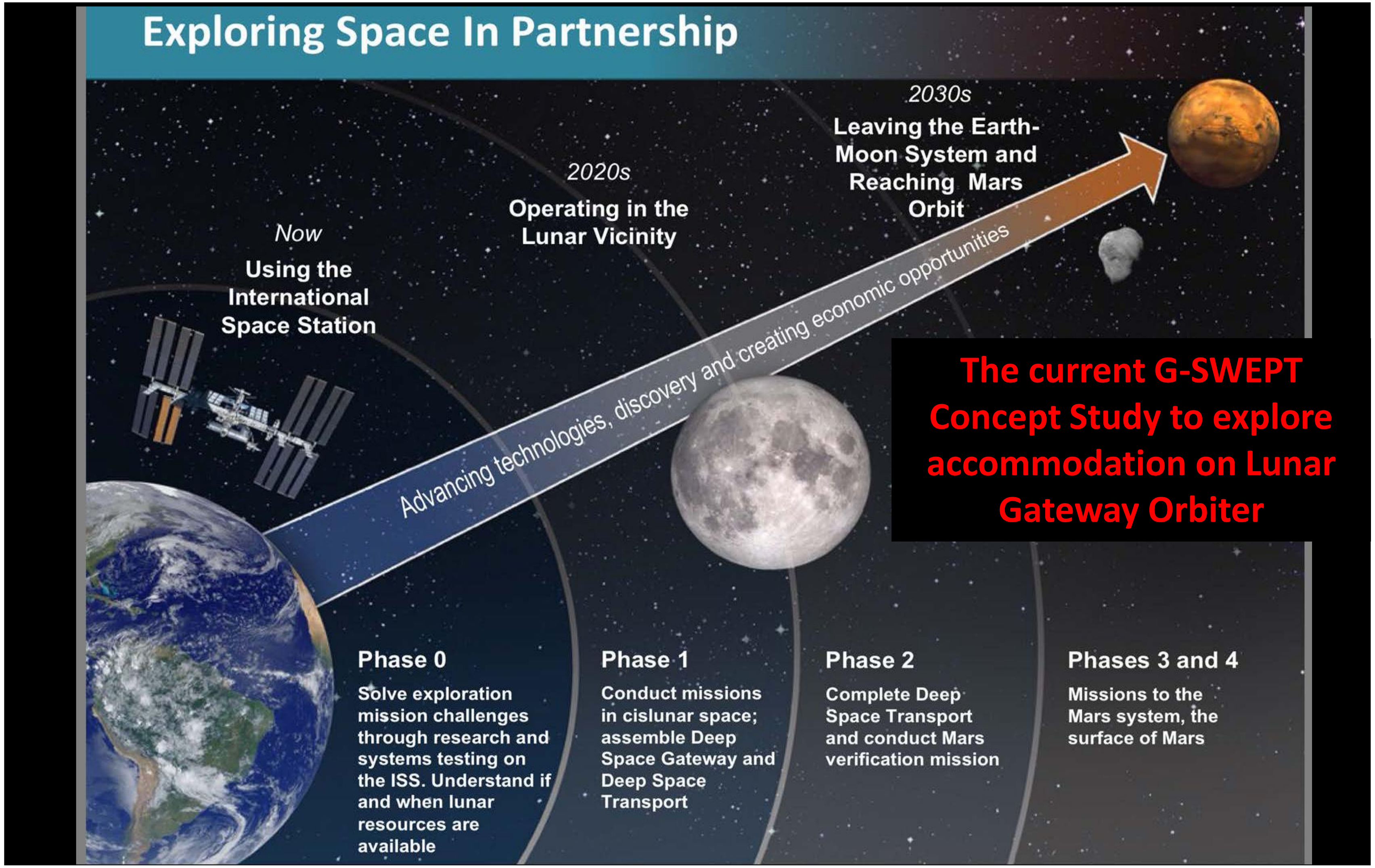
2018 SUPER-SWEPT Science Maturation Study and **SWEPT2 Concept Study** focused on detecting SEPs and GCRs from LOP-G (Gateway).

2020 LL-SWEPT Phase 0 Science Instruments to detect SEPs, GCRs & albedo particles from the lunar surface

2021 P-SWEPT STDP focused on raising technical readiness to TRL5

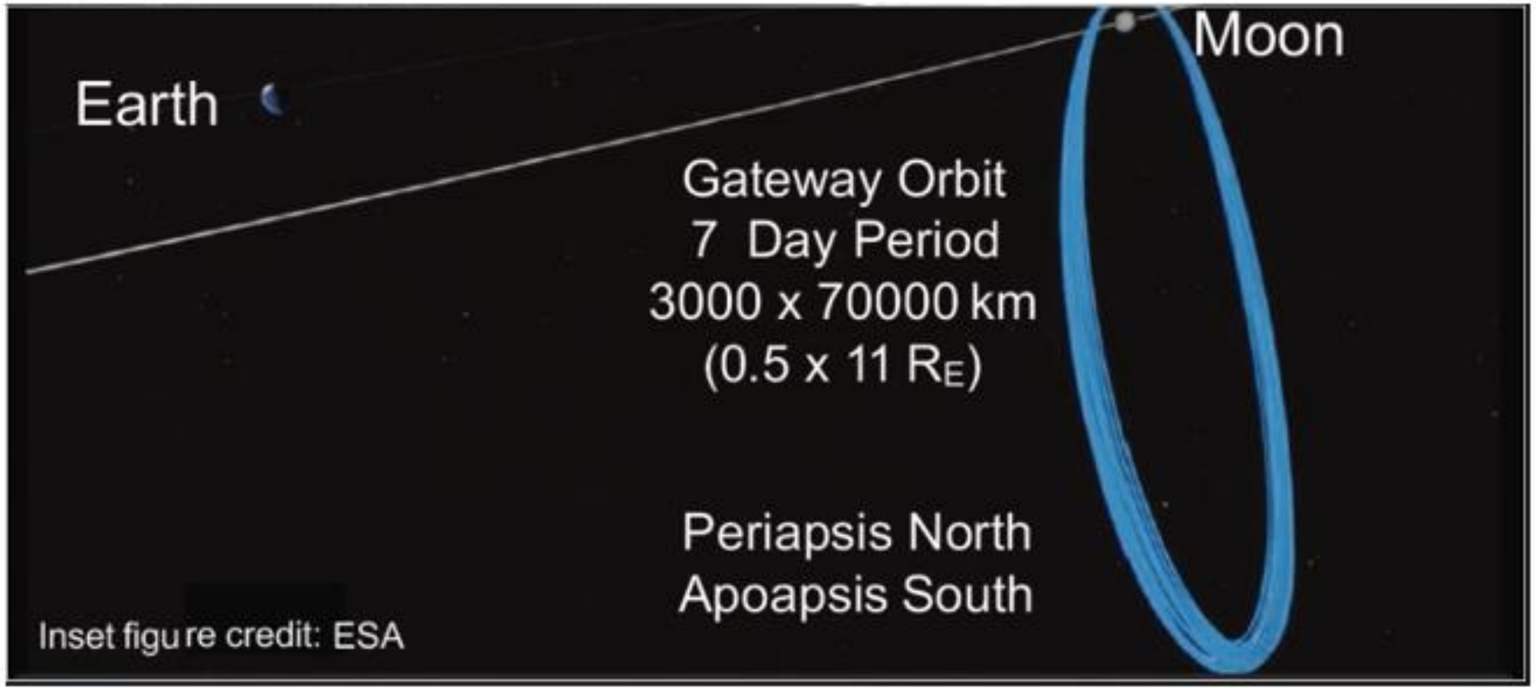
The current G-SWEPT Concept Study to study deployment on Lunar Gateway Orbiter

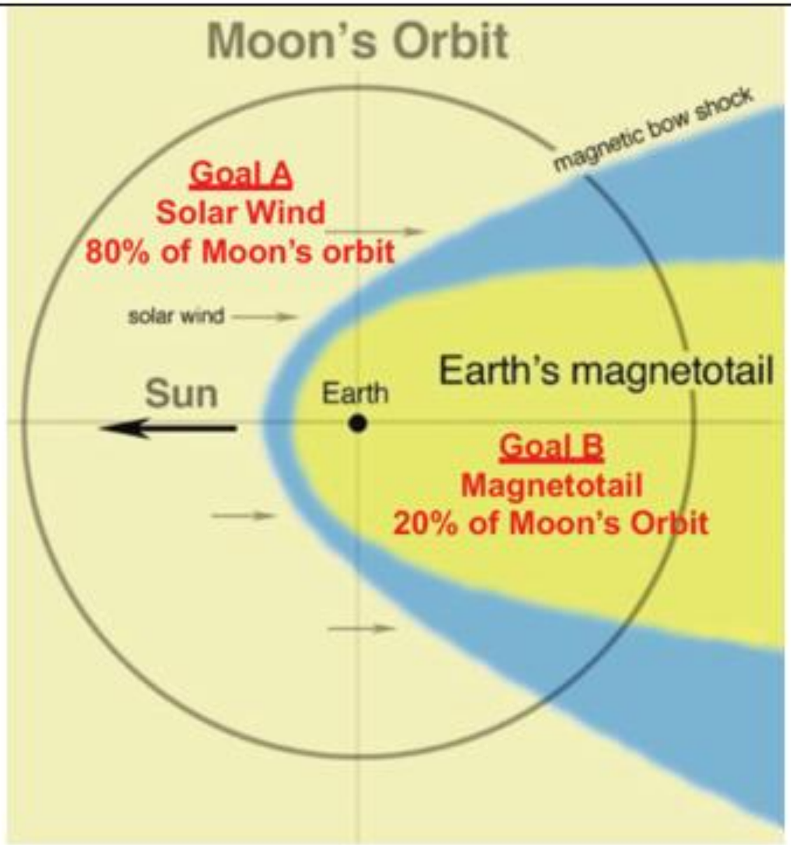
Part of the Global Canadian Space Exploration and Radiation Monitoring Roadmap



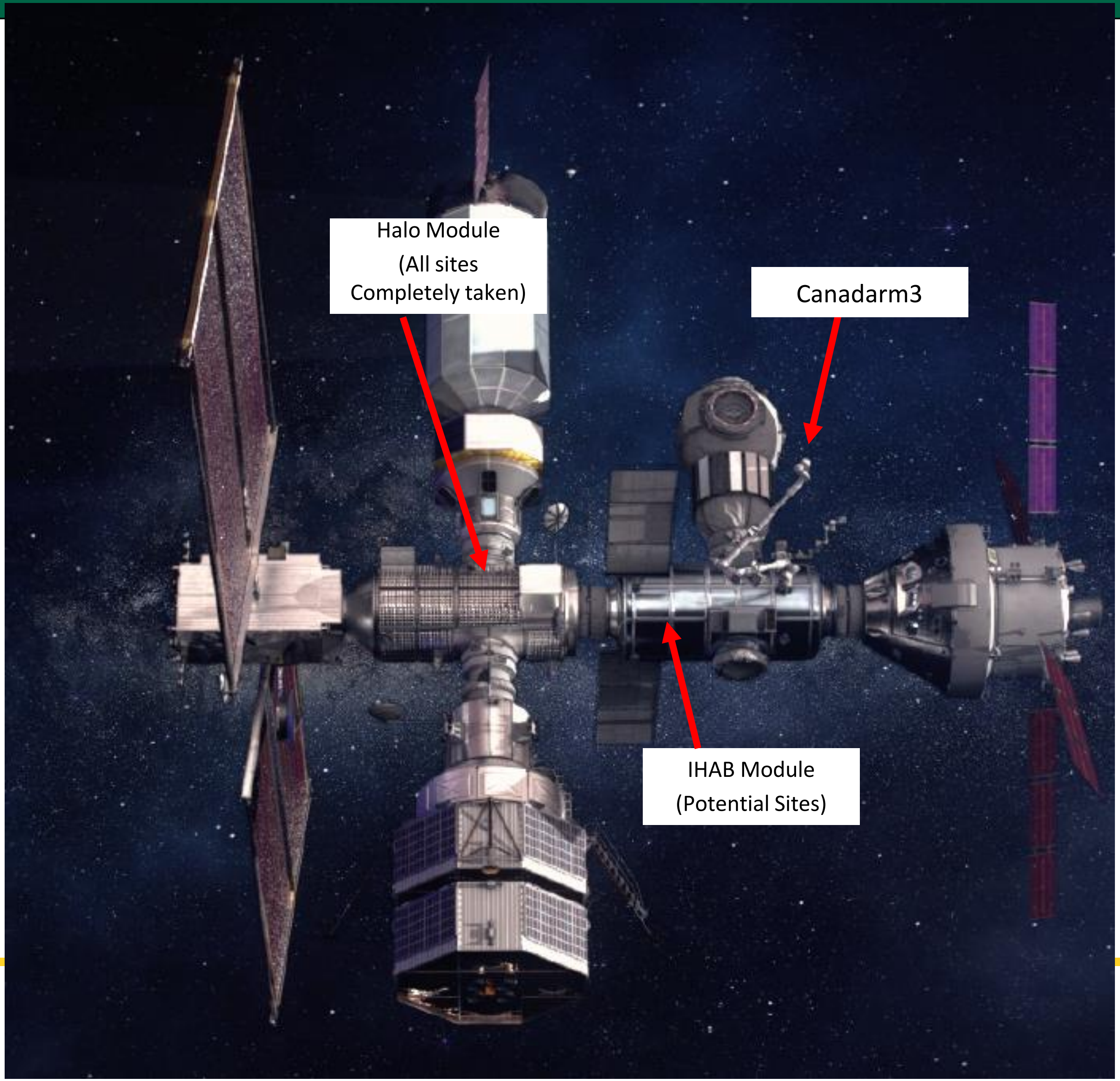
LUNAR GATEWAY ORBIT

Near-rectilinear halo orbit (NRHO)





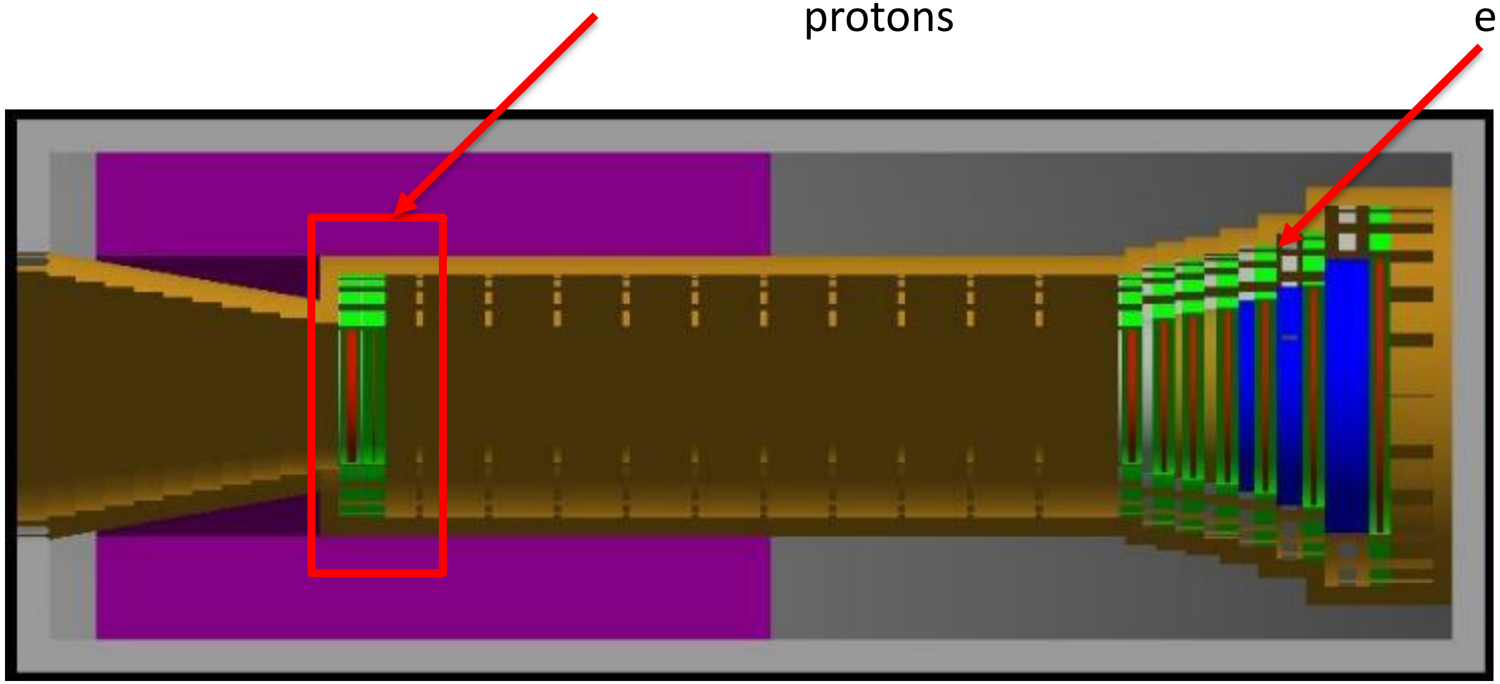
POSSIBLE LOCATIONS ON LUNAR GATEWAY



G-SWEPT Baseline Design: GF = 0.113 cm^2sr

Front detectors to detect electrons and directionality for protons

Silicon detector stack to measure dE/dx energy deposition form energetic particles



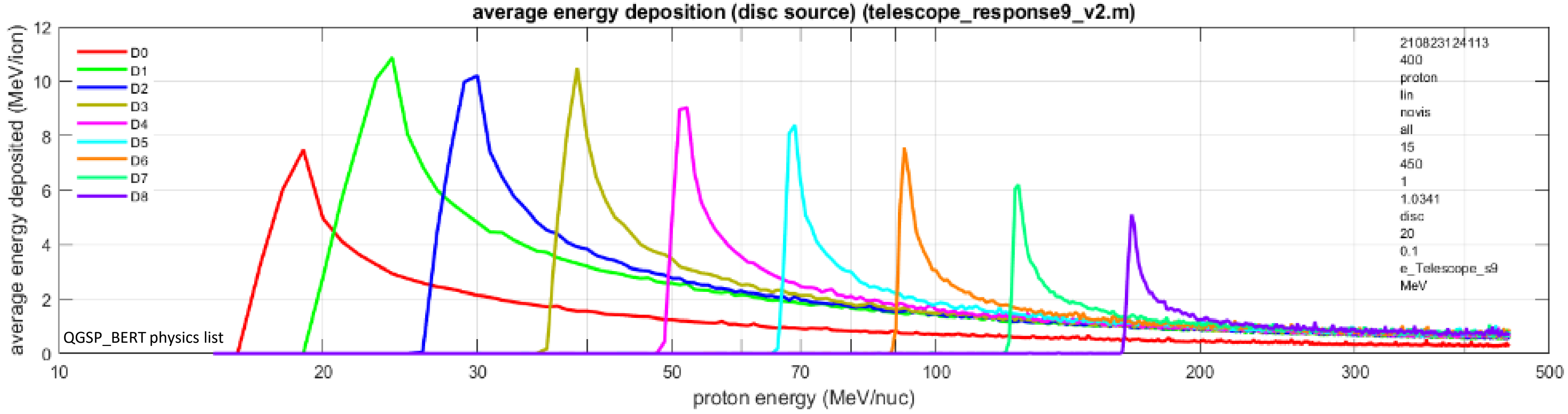
A Cross section of P-SWEPT's 0.113 str GF Initial Concept Geometry in GEANT4

Number of Detectors	9		**Total mass**	4.88	kg
Geometric Factor	0.113	str	**PCB mass (CBE)**	0.49	kg
Telescope width	10.13	cm	**Telescope length**	26.94	cm
Total Side Shielding	60	MeV	**Total Back Shielding**	100	MeV

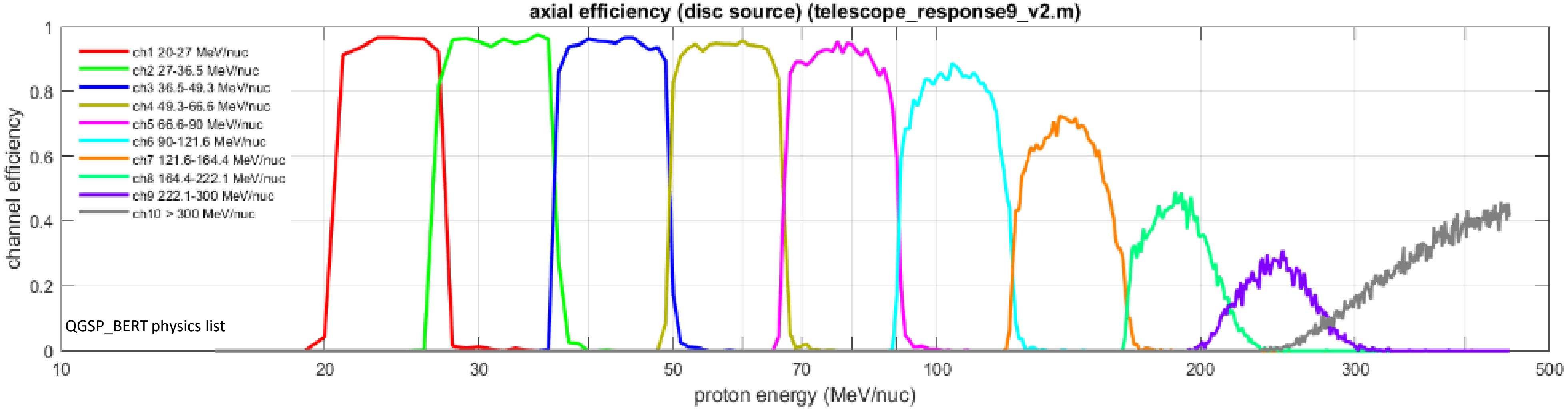
Red: Silicon Detector **Blue:** Tungsten Degrader **Orange:** Copper Degrader **Silver:** Aluminum Degrader **Purple:** Electronics (placeholder).

GEANT4 Simulation of Axial Proton Response.

Energy Deposition in each detector element versus incident energy.

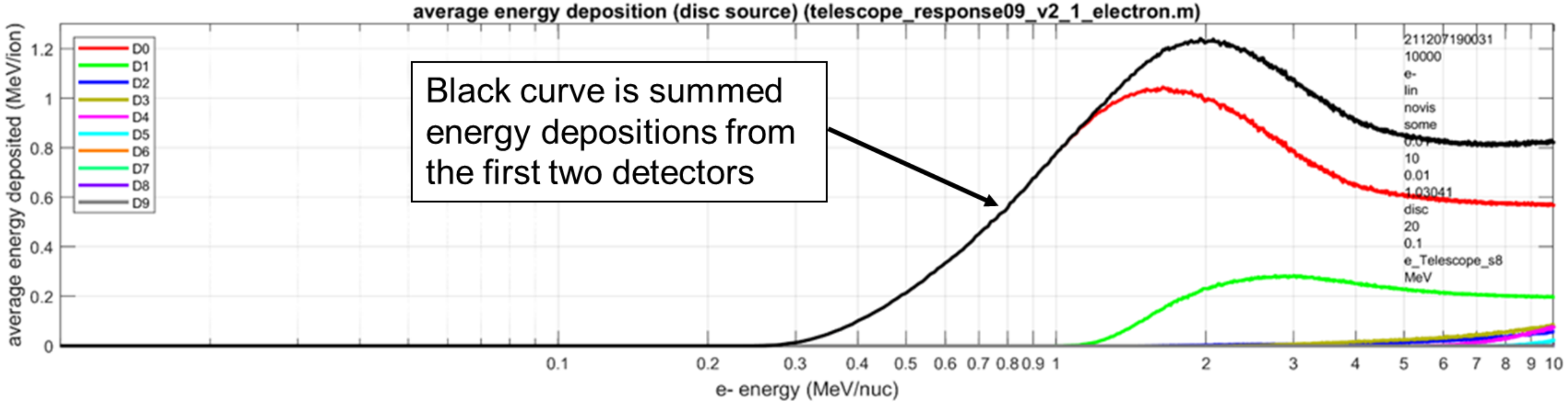


Assignment to Energy Channels based on detector energy signals



GEANT4 Simulation of Axial Electron Response

Energy Deposition in each detector element versus incident energy.



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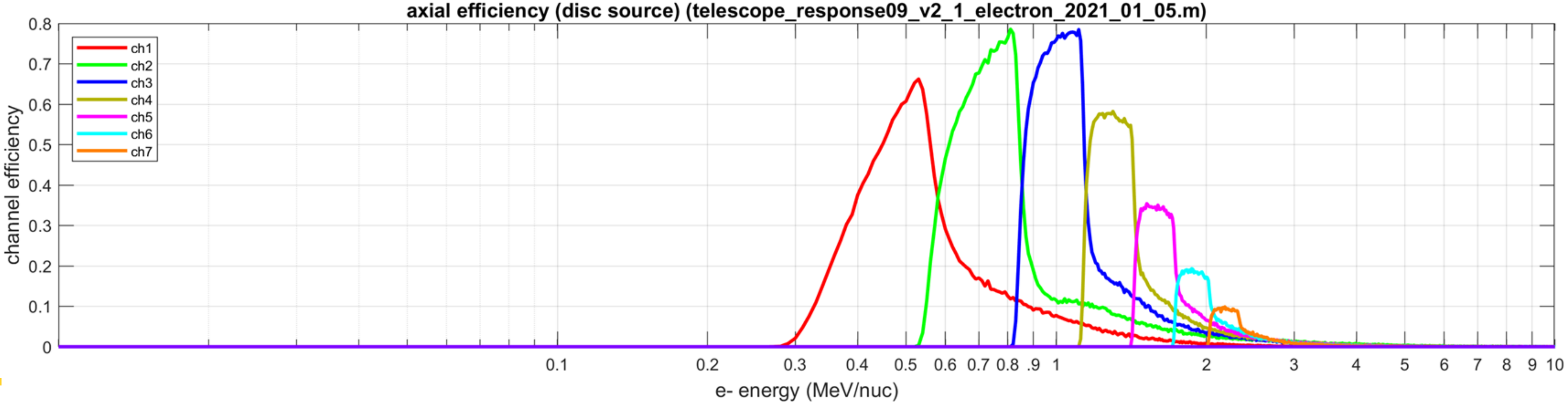
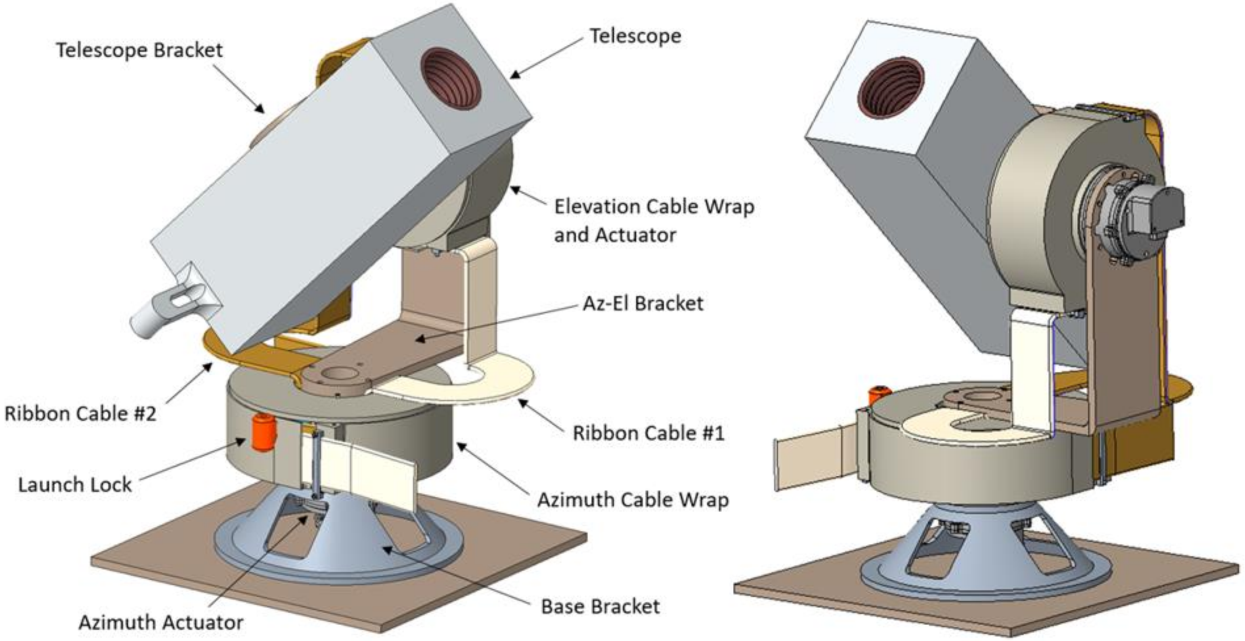


Physical Model of Previous P-SWEPT Detector Design

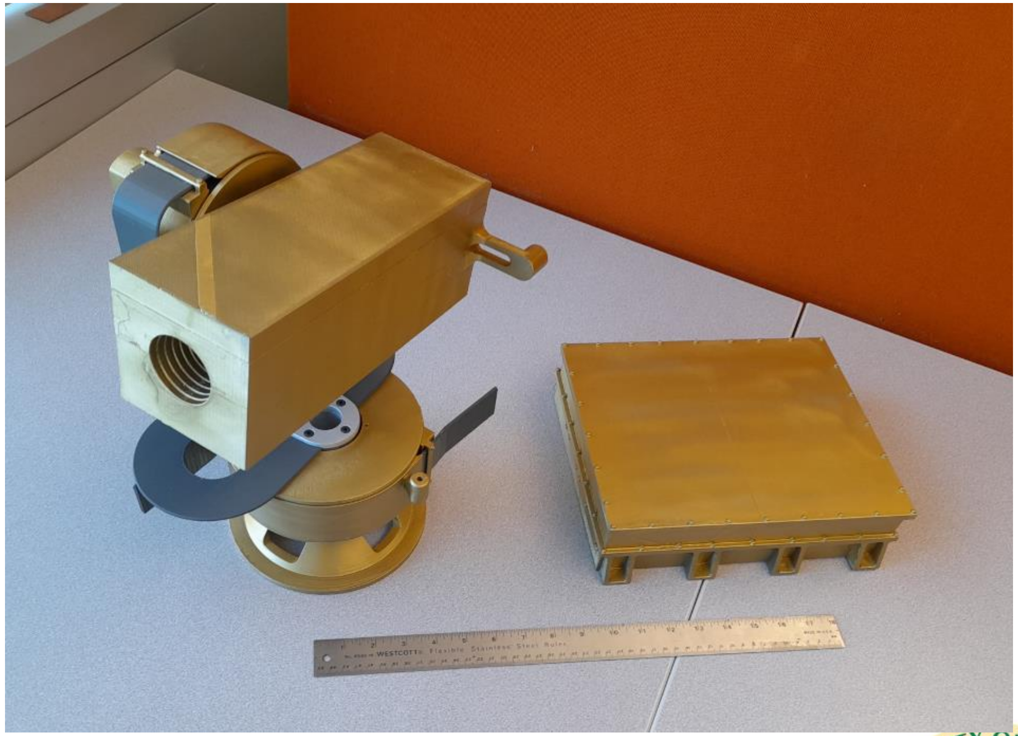
Equivalent mass and volume models of the detector head and electronics

Concept Design

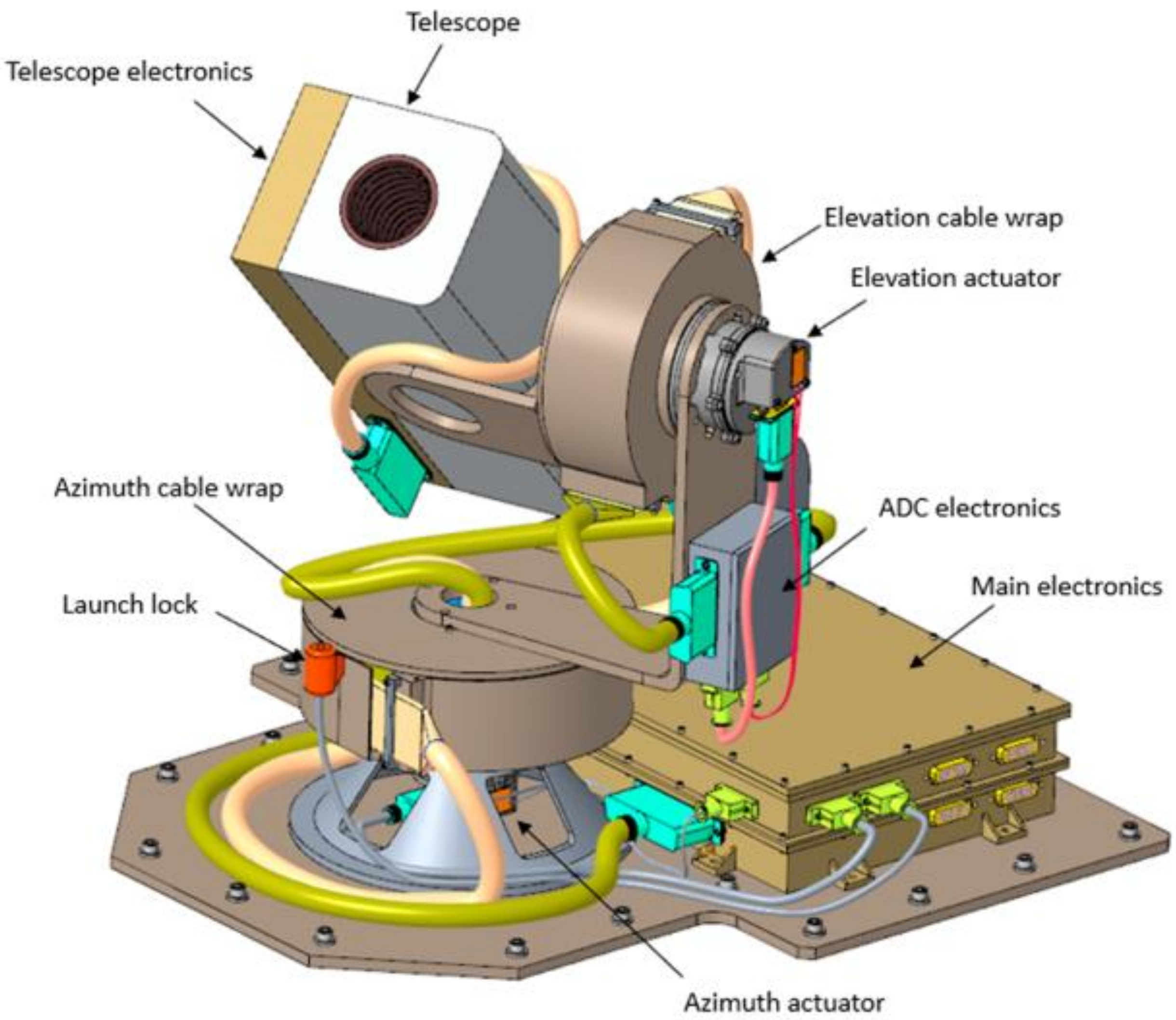


Detector Head Assembly (8.4kg)

Electronics module (3.1 kg)



Models of G-SWEPT Detector Mounted on Lunar Gateway Robotic Platform



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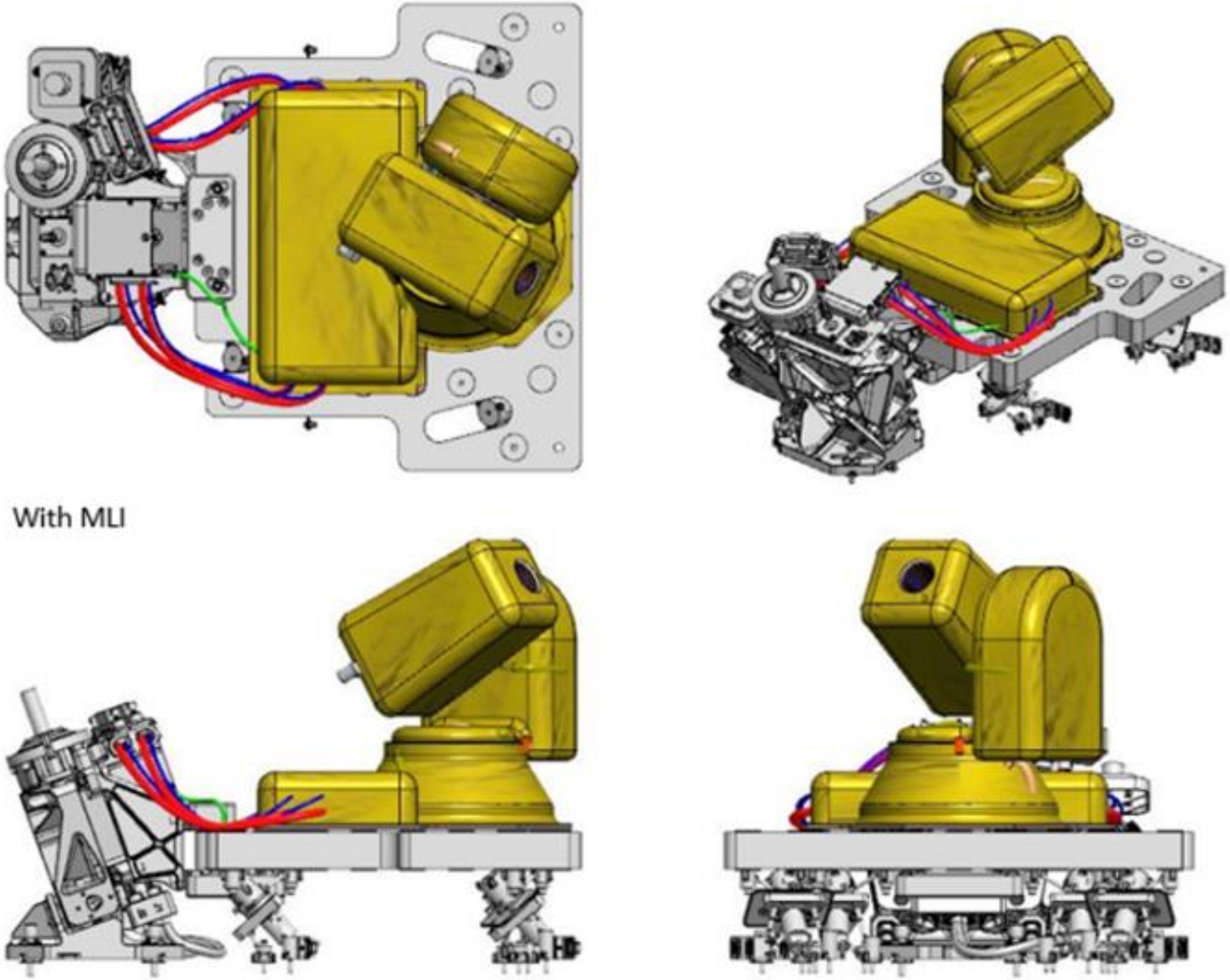


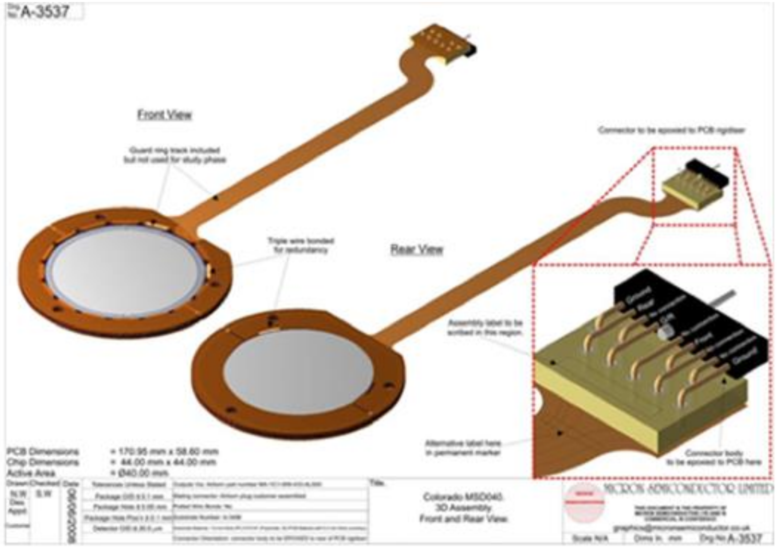
Instrument covered with MLI thermal insulation

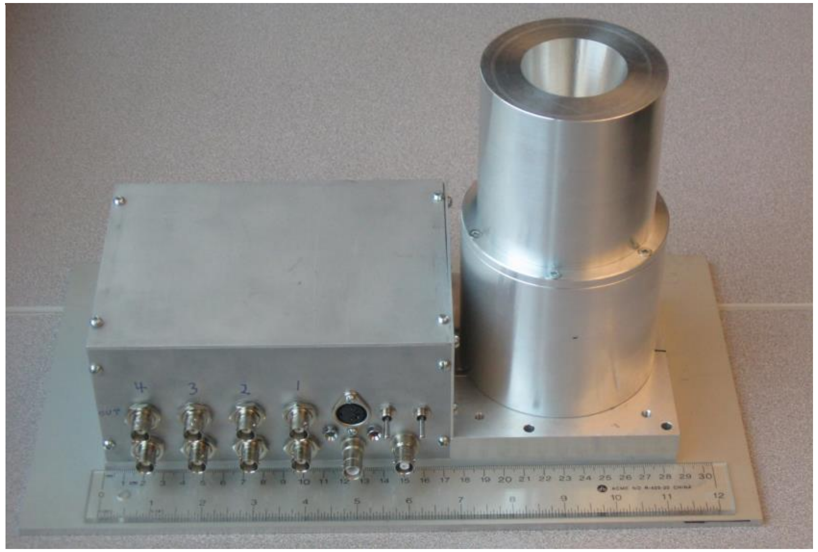
Testing of Silicon Stack Detector at TRIUMF Proton Accelerator: ORBITALS HEPT and SWEPT Projects

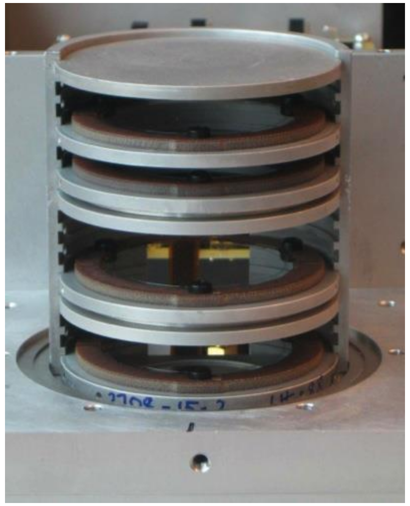
Use dE/dx approach in a detector stack

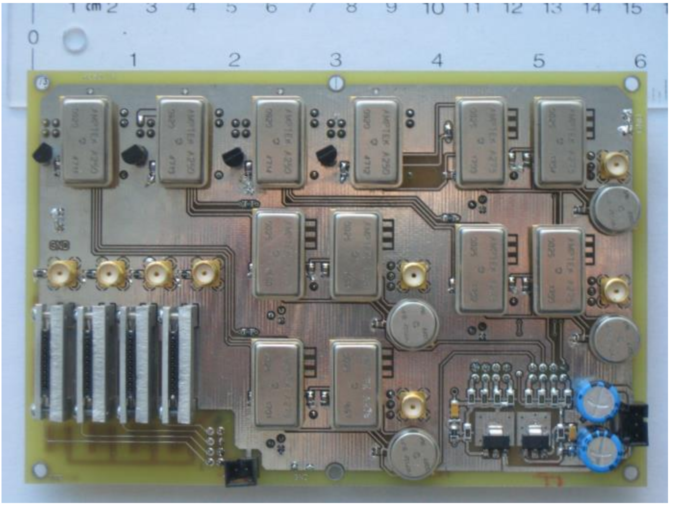
4 detector prototype telescope tested at TRIUMF proton accelerator beamline

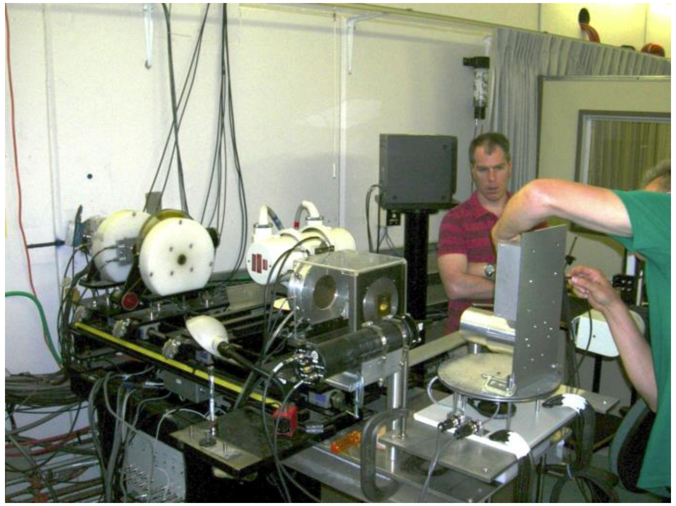
- Variable intermediate degraders
- 5 mm Al and 10 mm Cu or W-Ni-Cu side shield
- Amptek charge amplifier and pulse shaping electronics



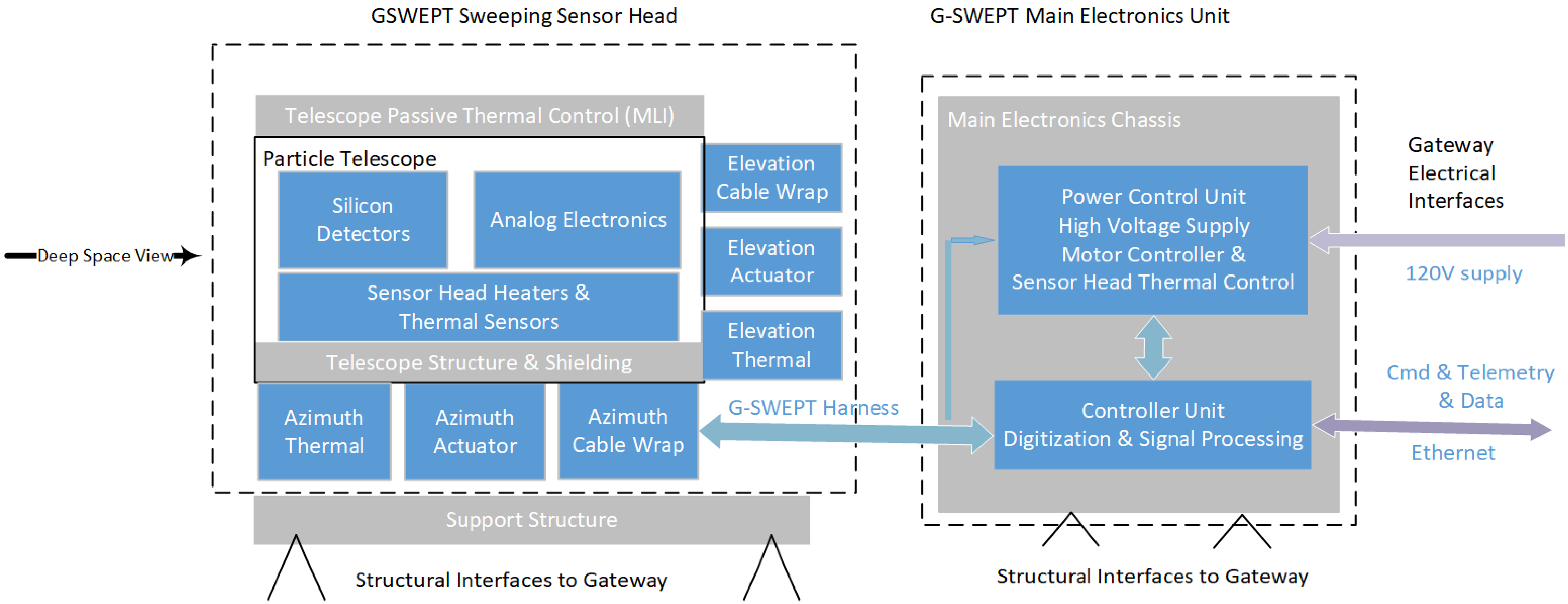






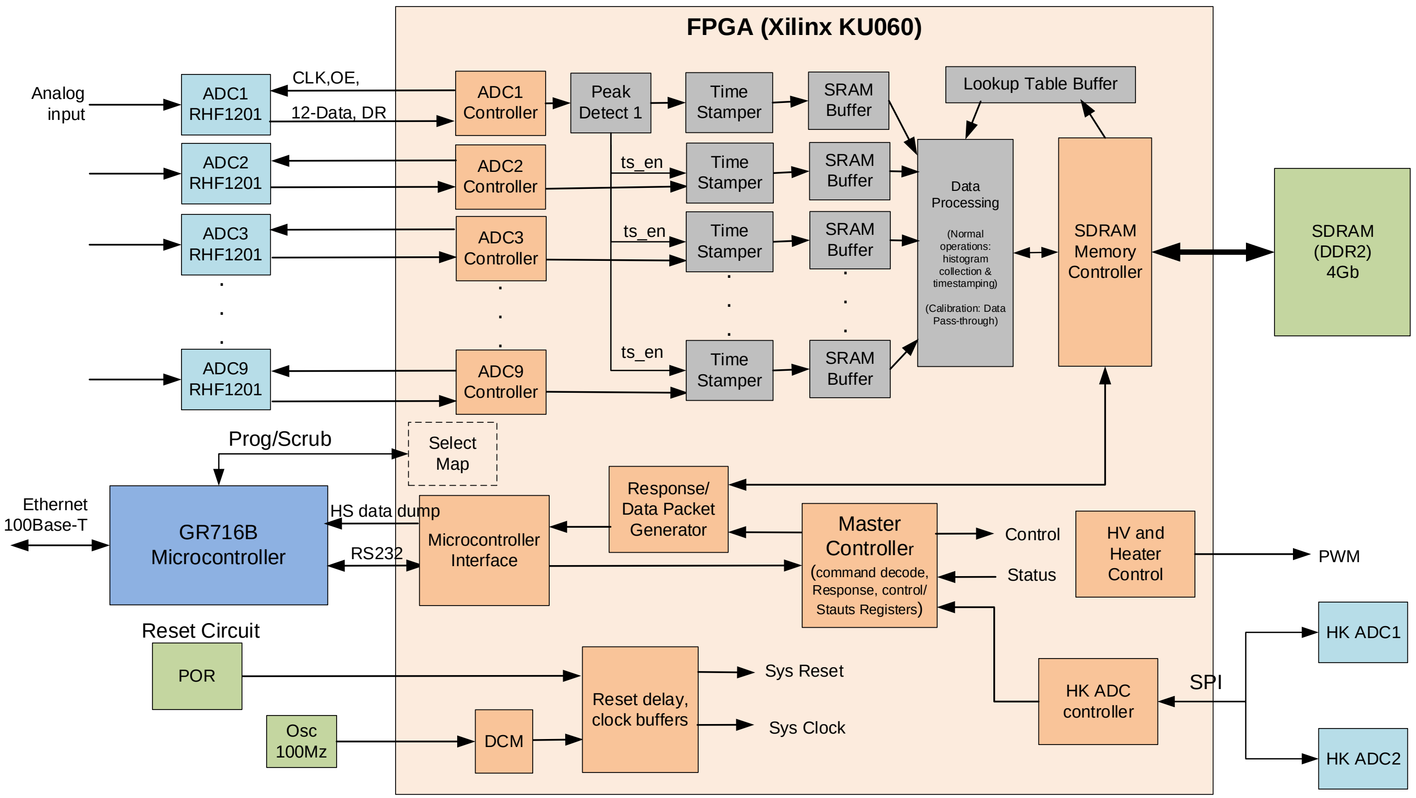


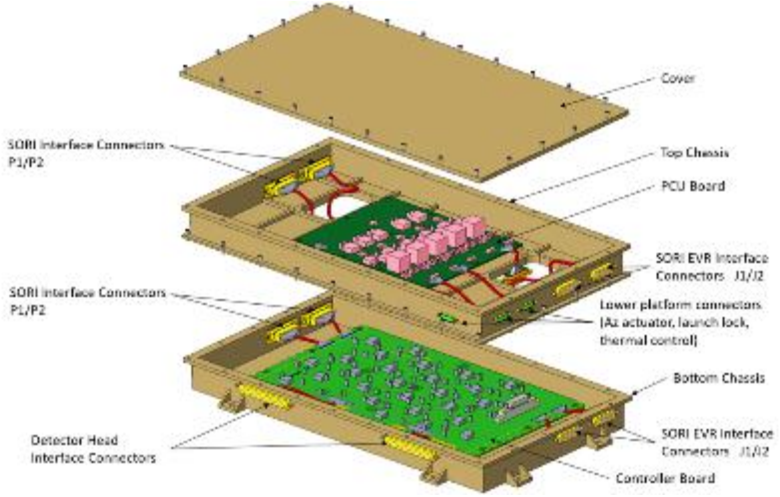
Overall Detector Block Diagram



FPGA Signal Processing and Electronics Box Design

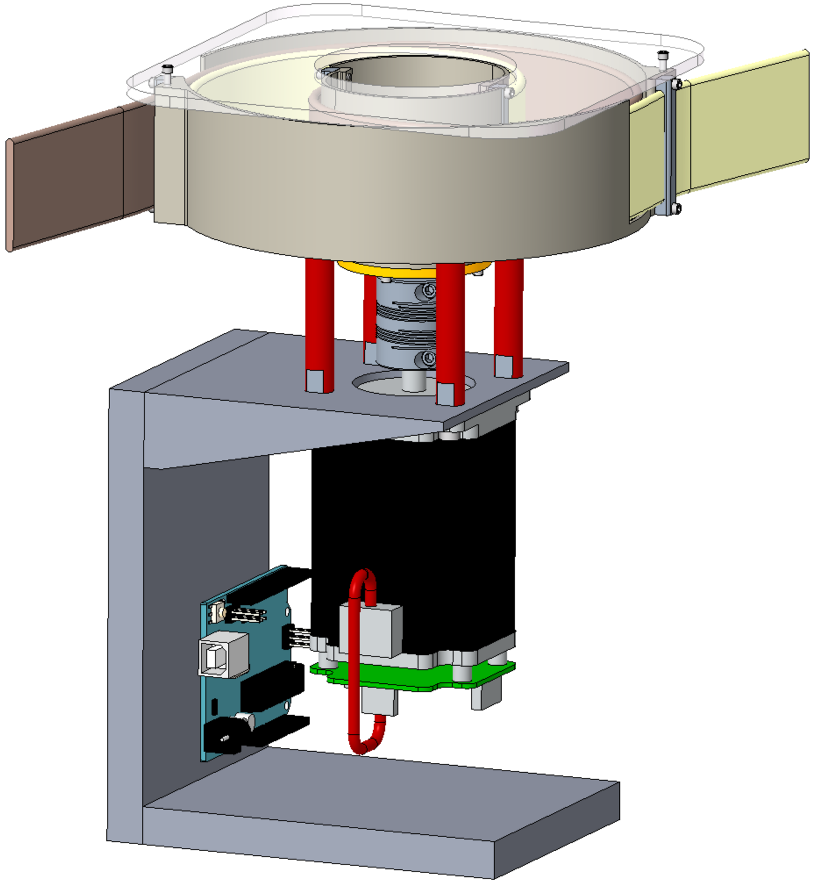
G-SWEPT Flight FPGA Architecture

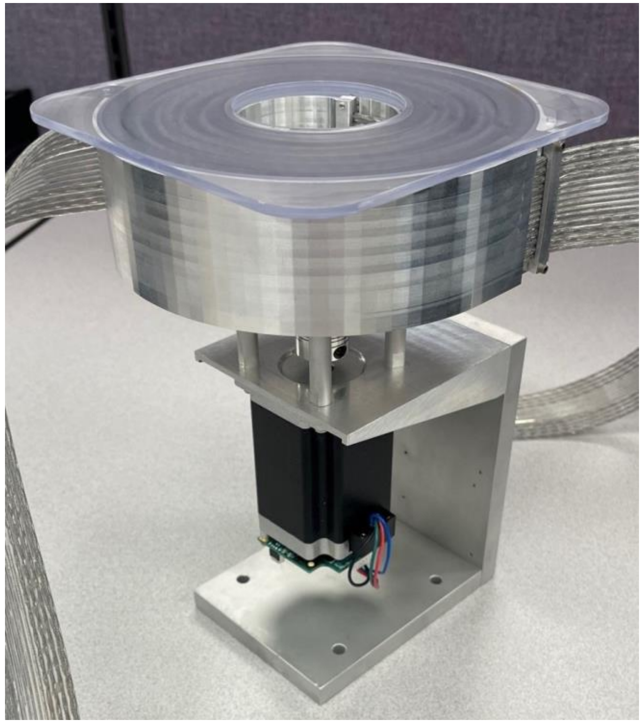




Clock-spring cable wrap – Honeywell Technology

- Dual cable wrap size verified with a 1:1 mock-up
- Life tested to 75,000 rotations (> 11 year lifetime)





G-SWEPT PROPOSED CONCEPT OF OPERATION

Scan Modes:

- Preprogrammed slow scan (GCR background) (60 min per 10^o angular step)
- SEP S2 level event-triggered rapid scan (10 min per 10^o angular step)
- SEP S3 level event-triggered rapid scan (1 min per 10^o angular step)
- Ground instructed scan pattern

Data Products (preliminary specs):

- Electron Spectra (50^o FOV, 10^o scanning steps, 1-60 min cadence)
    - 0.3 – 4 MeV (7 channels)
- Proton Energy Spectra (20^o FOV, 10^o scanning steps, 1-60 min cadence)
    - 20 – 300 MeV (10 channels)
- Alpha Energy Spectra (20^o FOV, 10^o scanning steps, 1-10 min cadence)
    - 80 – 1200 MeV (10 channels)
- SEP Early Warning (triggered by 10x electron threshold count rate)

CONCLUSIONS

Understanding SEP flux is Critical for Upcoming Lunar and Planetary Missions

- Knowing the directionality and energy spectrum are critical for design of optimum shielding
- Impacts astronaut safety and survivability of key electronics systems
- Current proposed instruments do not have the angular sweeping capability of G-SWEPT

TRL Level of G-SWEPT is currently at TRL 5

- Complete design based on space-proven radiation hard components
- Full FPGA signal processing at 200 kcps demonstrated in electrical and accelerator tests
- Low risk path to TRL 6 is now clear

G-SWEPT Ready to Deploy on Lunar Gateway

- A number of External mounting sites possible on Lunar Gateway Orbiter (location TBD)
- Operation directly on Canadarm-3 also possible
- Complements proposed fixed NASA and ESA radiation measurements
- Future planetary missions could follow

END