12th NASA Space Exploration & Space Weather Workshop

Virtual
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Coordination of Space Weather Technology Investment Planning: STMD/HEOMD/SMD

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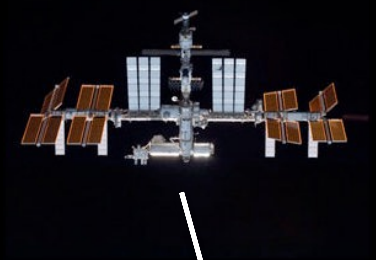
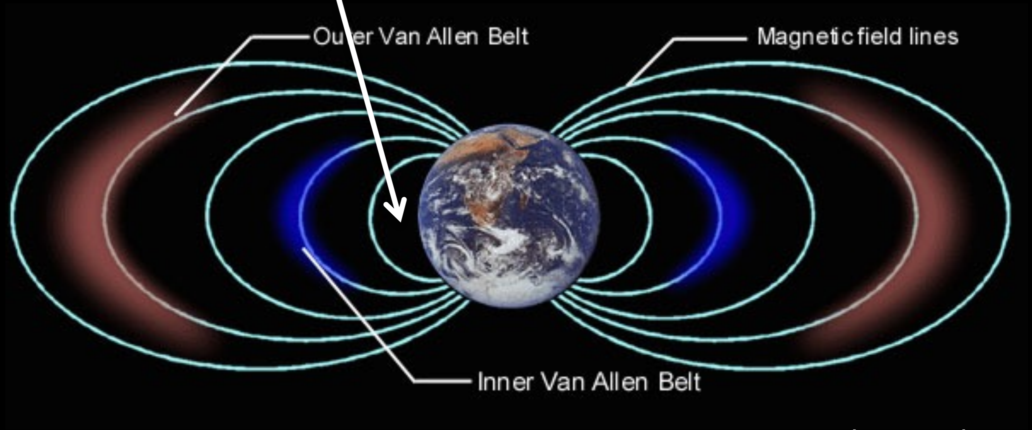
Exploration Considerations

LEO Magnetosphere:
Protection from SPE except high energy
Some protection from GCR low energy
Trapped Radiation
Orbital debris and micro-meteoroid environment
Sun and reflected energy from the earth
6 months to 1 year crew exposure
Large spacecraft mass





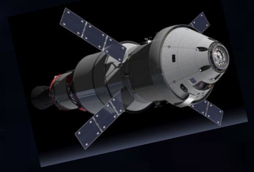
Beyond LEO:
No protection from SPE
No protection from GCR
Lunar EVA: Space Weather Response Time
Micro-meteoroid environment
Energy from sun only
1 to 3 years crew exposure
Less spacecraft mass

Comparison of Shielded Radiation Human Exposures

ISS Low Earth Orbit
Magnetosphere offers protection
6 months (50 – 100 mSv)
1 yr missions (100 – 200 mSv)

Terrestrial Exposures
Round trip LA to Paris: < ~0.1 mSv
Adult chest x-ray: ~0.1 mSv
Computed Tomography of brain: 1.6 mSv
Background from natural radiation: 3 mSv/yr

Deep Space – Gateway and Transit
Dose eq. rate: 2 to 3 x's ISS



Lunar Mission
Artemis sorties (30 day): 40 - 55 mSv
Planetary body offers protection
Surface Dose-rate ~1.5x ISS
Increased neutrons
1-year missions: 300 – 400 mSv

Mars Mission
~ 800-day mission w/30 days on surface ~1 to 1.3 Sv

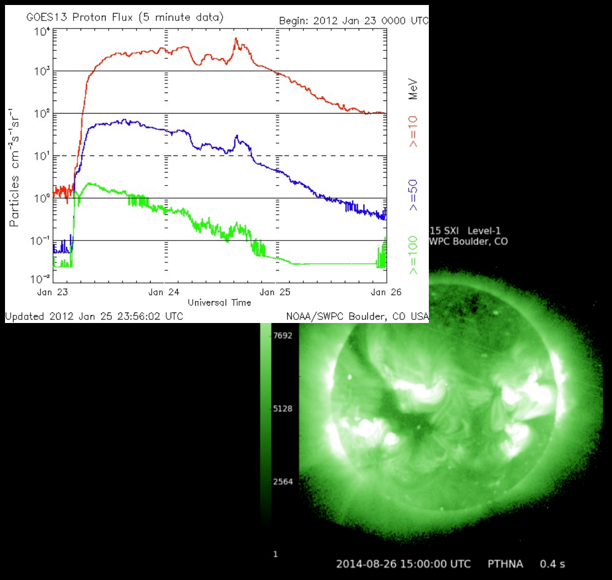
Mars Surface
Protection via atmosphere & planetary shielding
Dose eq. rate similar to ISS

Large Solar Particle Events
Shield to < 250 mSv
Venus swing-by increased exposure risk

1 Rem = 10 mSv

Space Weather Mission Operations

ISS SEP Operations: SRAG and NOAA



Response evolves over numerous hours with international coordination.

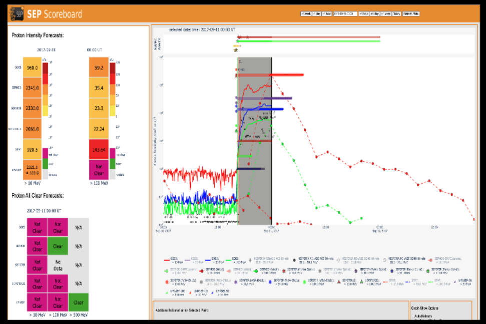
Beyond low Earth orbit missions require this process to be much faster– *SEPs can reach peak flux levels in < 5 hours.*

Gateway-Lunar Surface

NONREIMBURSABLE INTERAGENCY AGREEMENT
BETWEEN
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

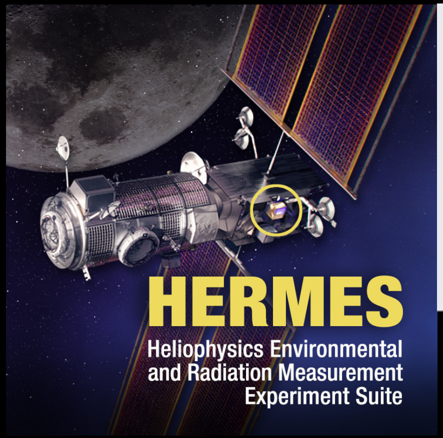
AND UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

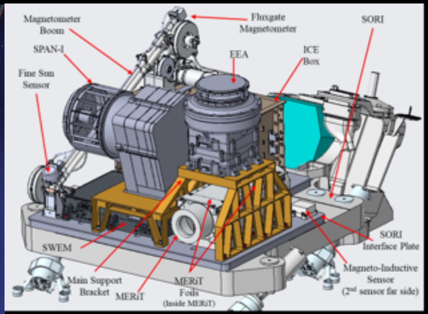
FOR SPACE RADIATION ENVIRONMENT SUPPORT TO NASA



M2M Analysis: SEP Model Scoreboard

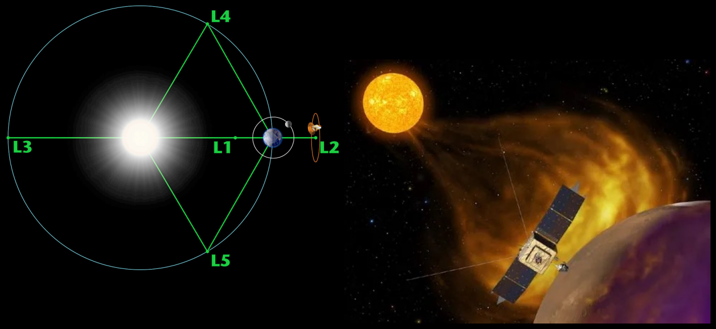
Mars Monitoring/Alert System





Electron Electrostatic Analyzer (EEA), Solar Probe ANalyzer – Ion (SPAN-I), Miniaturized Electron pRoton Telescope (MERiT), Magnetometer Instrument (NEMISIS)

Lunar Testbed/Mars Onboard System

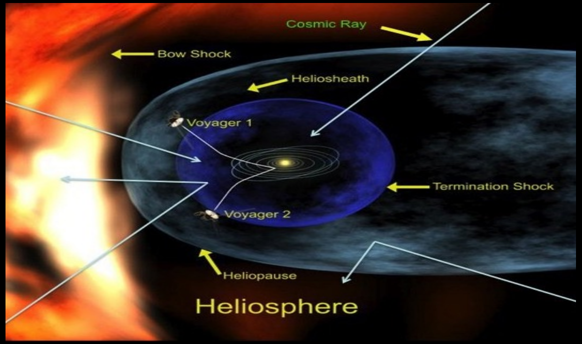


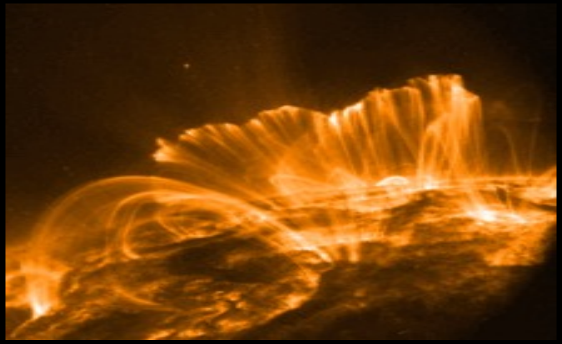
Mars Missions Centric
Space Weather Observation

Space Radiation Health Risks

Dynamic Complex field comprised primarily of charged particles spanning energies over many orders of magnitude

Galactic cosmic rays (GCR) – penetrating protons and heavy nuclei



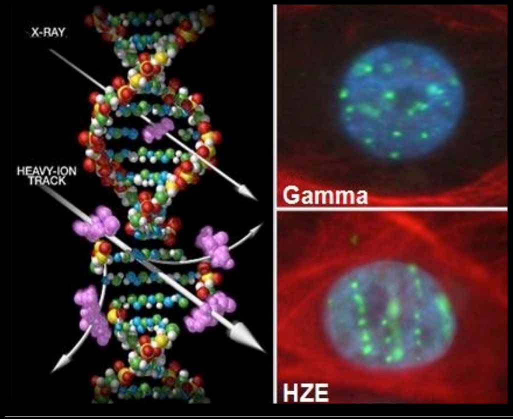


Solar Particle Events (SPE) – low to medium energy protons with high energy tail

What are the levels of radiation in deep space and how does it change with time? → How much radiation is inside the spacecraft, on Mars surface, and in the human body? → What are the health risks associated with radiation exposure?

<u>**Space Radiation Health Risks**</u>

- **Acute Radiation Syndromes due to Solar Particle Events**
- **In-flight & Late Central Nervous System Effects**
- **Radiation Carcinogenesis**
- **Cardiovascular Disease & Other Degenerative Tissue Effects**



DNA Damage in Cells: Space radiation (HZE) dense ionizing particle track

(Cucinotta & Saganti, Patel & Huff, NASA)

How do we mitigate Space Radiation Health Risks?

A combination of vehicle/mission design, SW monitoring/forecasting, SRAG operations, medical countermeasures, crew selection, and post mission health care.

Pre - Mission

Mission and Shielding Design

Risk Models

Radiation Standards

Crew Selection

Individual Susceptibility*

In - Mission

SRAG Mission Operations (NOAA Forecasting, M2M Model Analysis) on Solar Events (All-Clear, Active)

Storm Shelter Shielding

Space Weather Monitoring & Dosimetry

Medical Countermeasures and Biomarkers/Inflight Monitoring*

Post - Mission

Occupational Health Care

Early disease detection

Advances in Terrestrial Treatments*

**long-term development*

STMD Question: What radiation protection technologies are needed to support mitigation of risk to exploration crewmembers?

Starting Point: Radiation Protection Capability Breakdown

State of the Art: Mature spacecraft shielding design tools–reconfigurable SPE storm shelters, limited GCR protection; ISS and Orion-HERA crew radiation monitoring and alert systems; NOAA space weather monitoring using Earth-based assets and SRAG ISS mission operations; mature environmental models–low energy neutron measurements

Existing Development: NOAA/NASA Interagency Agreement on Space Radiation Forecasting, Lunar and M2M Radiation Environment Analysis Capability (HEO/SMD); Heliophysics R2O studies (SMD); SPE forecasting machine learning (STMD); HERMES Gateway instrument suite (SMD/HEO); Radiation monitoring systems: Orion-HERA system, EVA-ARD system, Gateway/HLS-ARES system; Closeout of Active Electrostatic shielding modeling study; ISS radiation flight projects: ISS-RAD and Advanced Neutron Spectrometer; OLTARIS Design Tools/HZETRN transport code (AES); MERA health risk models (HRP); Countermeasure and biomarker research (HRP); Biodosimetry Polaris Proposal (AES)

SCLT Priorities:

- Vehicle and EVA radiation monitoring systems (HERA, ARES, ARD);
- Radiation Monitoring & Mitigation (Next Gen Neutron Spectrometer, Active Shield Study);
- Space Weather Forecasting (forecasting scoreboard and all-clear capability);
- Operational Space Weather Instrument Suite;
- Semi-Autonomous Crew Space Weather Monitoring Capability (HERMES / Moon 2 Mars)

Potential Infusion Targets:

- Active shielding systems level concept design study
- Earth-independent Advanced sensor development, miniaturization, & spaceflight validation of components for Lunar surface demo and Mars transit
- Expansion of NSRL capacity for electronic component/system testing/HLS infusion
- High energy neutron detectors
- Miniaturized radiation biomarker surveillance technologies
- Active personal dosimetry for Lunar EVA

How do we organize Radiation Protection technologies within the STMD Strategic Framework to identify gaps and support investment decisions?

Go
Land
Live
Explore

Thrusts — *Broad categories of strategic impact*

Strategic Outcomes — *High level goals under each Thrust*

Strategic Capabilities → **Capability Areas** — *Groups of technology gaps*

Technology Gaps — *A capability needed for an application that is not available now*

Technology Investments — Investments that represent quantifiable work to close gap

TX06 Advanced Habitation Systems

Alignment with Space Radiation Protection

Strategic Outcome: Enable long-duration human exploration

Capability Areas: Space Radiation Protection

- Space Weather Analysis
- Radiation Monitoring
- Shielding
- Predictive Models of Crew Health Risks
- Biomedical Countermeasures & Surveillance

Advanced Habitation Systems – Capability Areas

LIFE SUPPORT
- Atmosphere Management
- Water Management
- Waste Management

ENVIRONMENTAL MONITORING
- Pressure O_2 & N_2
- Moisture
- Particles
- Microbes
- Chemicals
- Sound

FIRE SAFETY
- Detection
- Protection
- Suppression
- Cleanup

LOGISTICS
- Tracking
- Relocating
- Clothing
- Packaging
- Trash

EVA PHYSIOLOGY
- Crew Required Capabilities
- Suit Design
- Physiological Inputs and Outputs
- ConOps
- Informatics
- Injury & Risk Mitigation
- Exploration Atmosphere/Prebreathe

COUNTERMEASURES
- Exercise Systems
- Sensorimotor Systems
- Physiology Monitoring
- Countermeasure & Performance Informatics

RADIATION PROTECTION
- Space Weather Forecasting
- Shielding
- Monitoring
- Health Risk Models
- Biomedical CM

EXPLORATION MEDICAL
- Diagnostic
- Treatment
- Imaging
- Pharmacy

FOOD & NUTRITION
- Pre-packaged Food
- Food Storage
- Food Resources
- Dietary Tracking
- Health & Performance

06 Advanced Habitation Systems

Space Radiation Protection

TX06.X.X: NASA OCT Technology Taxonomy

Gap type:
K- knowledge, requires scientific research
D – development (TRL 1-4)
T – Technology (TRL 5-9)
E – engineering (TRL 5-9 mission specific)

Gap Description
State of the Art
Key perf. parameters
Lunar/Mars enabling

Physical Mitigation Technologies

(TX06.5.4) 1.1 Space Weather Forecasting

- (D) SPE analysis tools
- (D) Earth – independent alert system
- (K) GCR forecasts: Predictive models of solar cycle modulation

(TX06.5.5) 1.2 Radiation Monitoring

- (E) On-board dosimetry systems
- (T) Adv. space radiation env. characterization systems
- <TBD>: *In-situ* env. monitoring

(TX06.5.3) 1.3 Effective Shielding

- (E) SPE shielding
- (T) Combined GCR/SPE shielding - active
- (T) GCR shielding - passive
- <TBD>: Vehicle analysis tool sets

Biological Mitigation

(TX06.5.1) 1.4 Predictive Models of Crew Health Risks

- (K) Probabilistic health risk models
- <TBD>: Radiobiology Effects Database

(TX06.5.2) 1.5 Biomedical Countermeasures and Surveillance

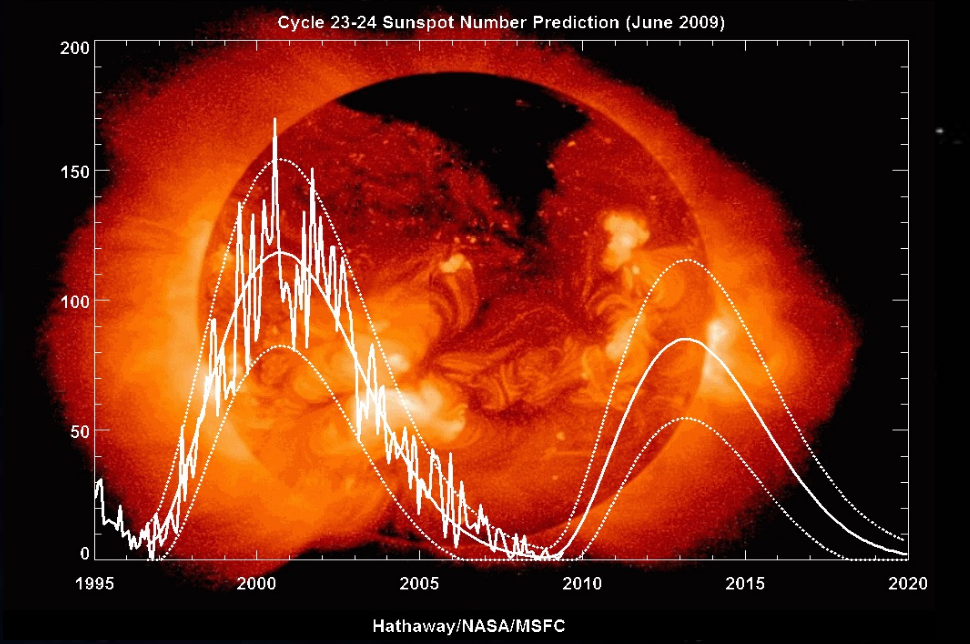
- (K) Biomedical countermeasures
- **<in work>: (K)** Personalized crew protection & biomarker surveillance
- <TBD>: Intelligent human system technologies for mission operations

Major Assets: *Space Weather architecture and NASA Space Radiation Laboratory*

The Physical Perspective - Technology Challenges

Accurate real-time operational forecasting of solar particle events

- Increase warning times in advance of storm – 24 hrs
- Reliable predictions of peak flux, duration, magnitude and time evolution of event – over hours to >7 days
- All-clear periods



Earth-independent monitoring and forecasting

- Miniaturized onboard instrument suite for space weather observation
- Possibility of new space weather architecture platforms along Sun-Mars Line
- Autonomous analysis & warning software

Prediction of solar cycle durations

- Measurements and models supporting predictions >10 years in advance

Advanced space radiation environment characterization

- High energy neutron detectors for >100 MeV neutrons up to 1 GeV neutrons with reduced mass, power, and volume while maintaining sufficient resolution

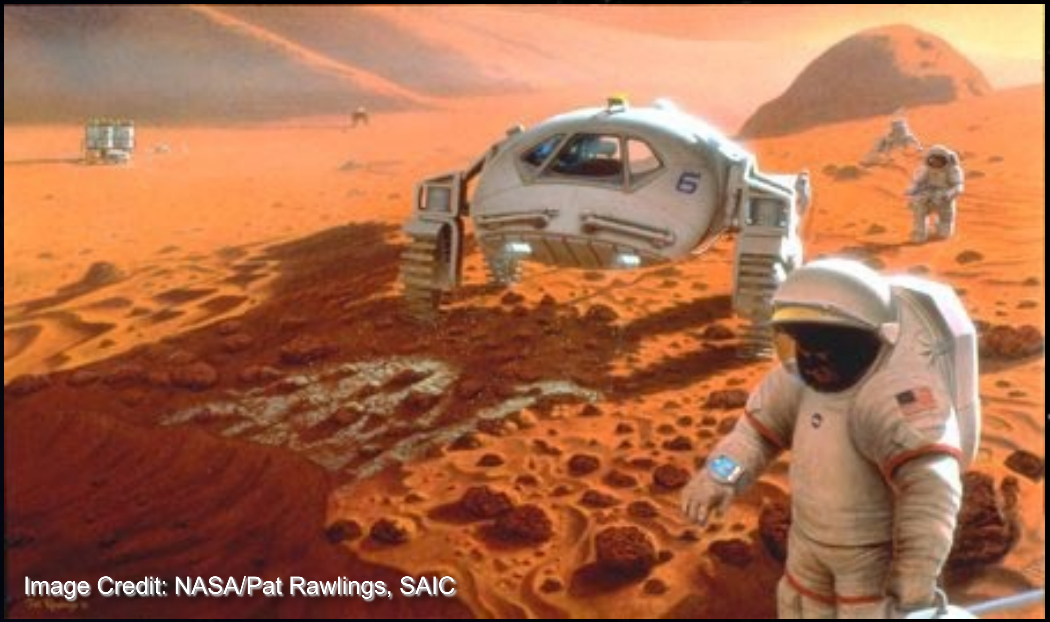
Effective GCR Shielding – Passive and Active

- Advancement & integration of lightweight, multifunctional materials - mass solutions with ~20% reduction
- Systems study of active systems compared with passive, high reliability

Envisioned Future

Integrated radiation protection technologies* to increase permissible mission duration by a factor of two (~400 days to >800 days) within acceptable mission constraints.

**GCR/SPE shielding, advanced monitoring/environmental characterization, precision medical approaches, countermeasures, predictive health models*



Accurate SPE forecasting to minimize crew exposure levels (increase reliability of 24-hour SPE predications by a factor of ~2) and optimize mission operations (increase reliability of 7-day SPE forecast by a factor of ~5).

For Mars spacecraft, compact Earth-independent, on-board space environment observation system that is potentially as accurate as current Earth-based assets.