
# Briefing to NAC HEO/SMD Joint Committee Meeting

## *"Mars Radiation Environment – what have we learned?"*

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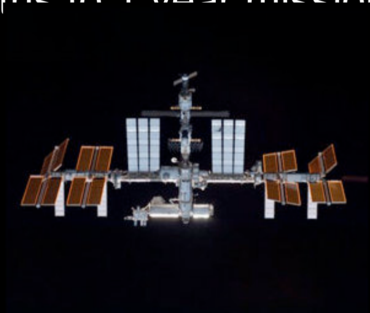
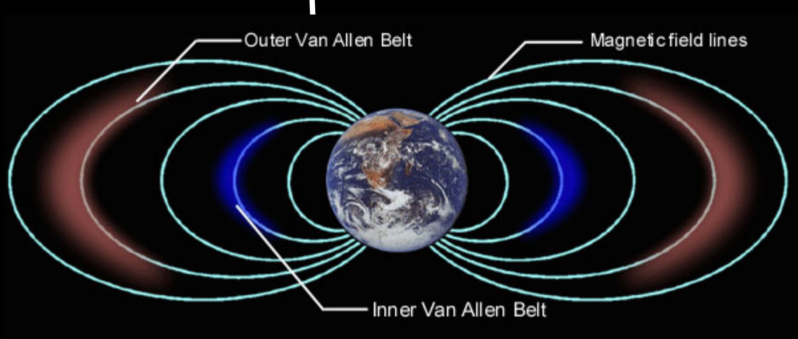
# Space Radiation Environmental Considerations

ISS Low-Earth Orbit
Protection from Magnetosphere
SPE (except high energy tail)
Low energy GCR
Exposure from Trapped Radiation
Total Dose rate similar to Mars Surface

6 months to 1 year mission

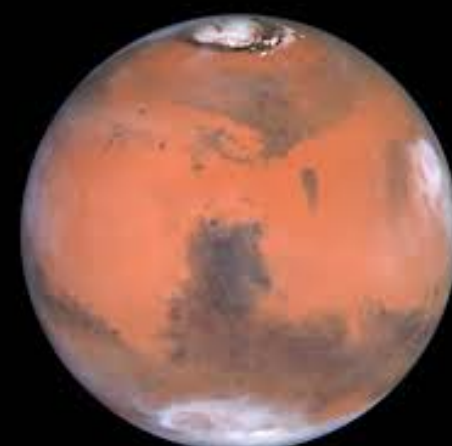





Deep Space
No protection from SPE
No protection from GCR
Dose rate approximately 3 times ISS

Mars Surface
Protection from Mars atmosphere
Protection from planetary shielding
Total Dose rate similar to ISS

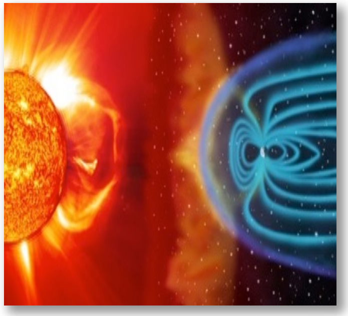
2 to 3 years mission



# Space Radiation Environment

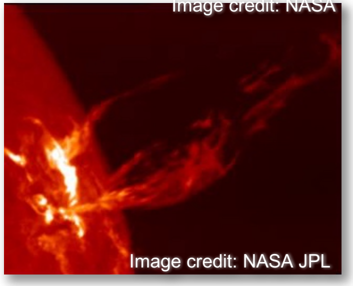
**Low Earth Orbit/ISS:** *HEOMD/SMD*

- ~60% exposure from GCR; ~40% SAA trapped protons
- Dosimetry, operations, & EVA planning used to minimize exposures



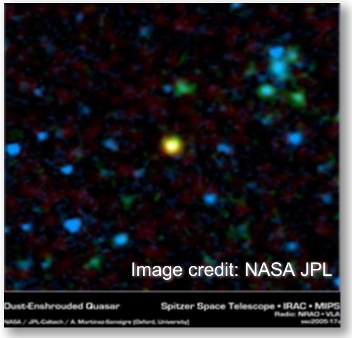

**Solar Particle Events (SPE):** *SMD*

- Intermittent exposure with peak activity during solar max
- Consist of medium to high energy protons from coronal mass ejections
- Real time dosimetry and shielding are effective to prevent acute exposure




**Galactic Cosmic Rays (GCR):** *SMD*

- Chronic exposure from continuous flux of particles, varies with solar cycle
- Consist of penetrating protons and heavy nuclei from outside the Solar System with broad energy spectra (~10's to 10,000 MeV/n)
- Not effectively shielded (fragment into lighter, penetrating species)




**Planetary Surface:** *SMD/HEOMD MSL RAD*

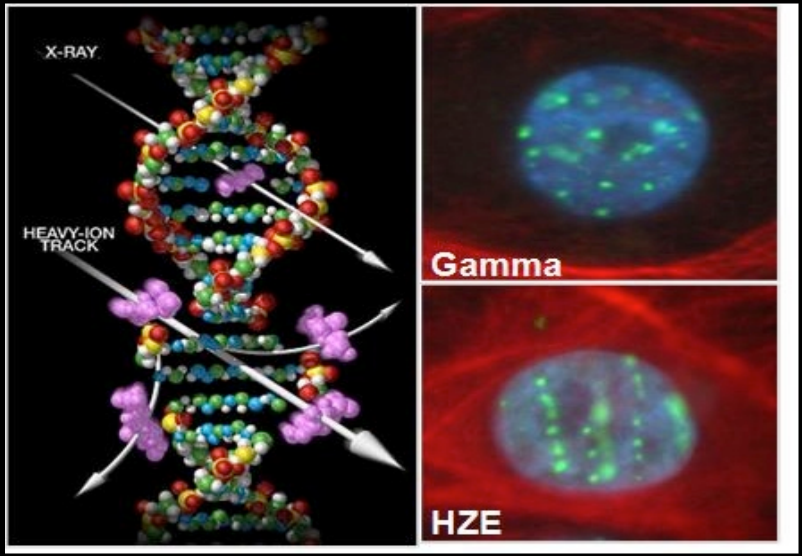
- Mixed field chronic low-dose rate exposure
- Consists of primary GCR and secondary particles generated in the atmosphere and back scattered from surface
- Precursor missions important to characterizing environment

# Space Radiation Challenge

- **Space radiation produces potential increased health risks of cancer, cardiovascular disease, CNS effects, and acute radiation syndromes**
  - Damage to cells is different from terrestrial sources of radiation
  - Translating experimental data to humans

- **Understanding Individual Radiation Sensitivity**
  - Small Crew Population

- **SMD and HEOMD measurements to accurately characterize the space radiation environment are needed to optimize mitigation strategies**

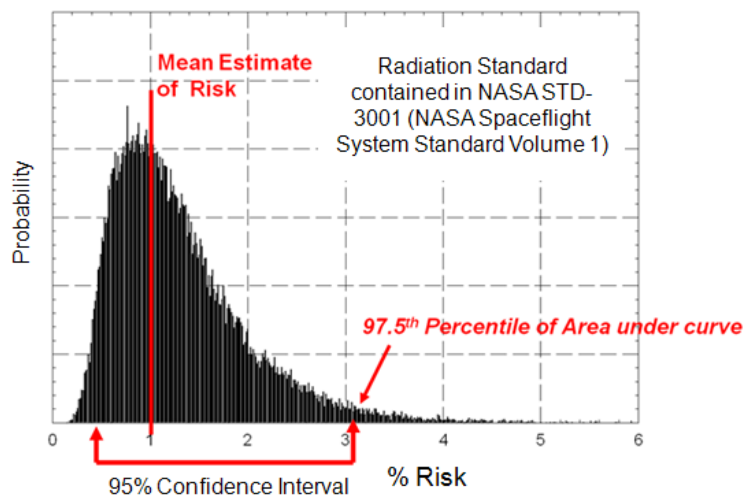




*DNA Damage in Cells: Space radiation (HZE) dense ionizing particle track*

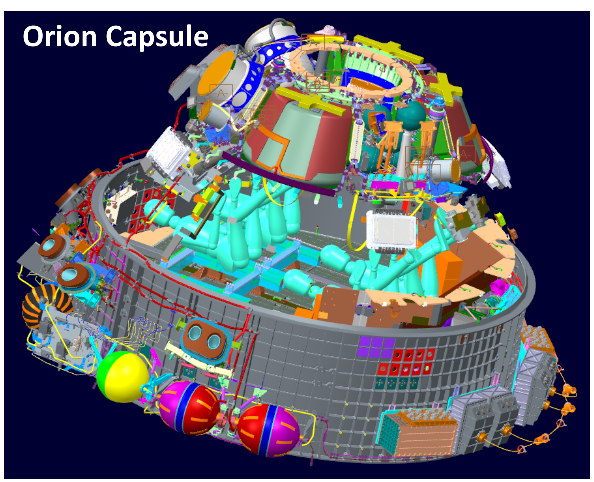
# Significance of Environmental Data

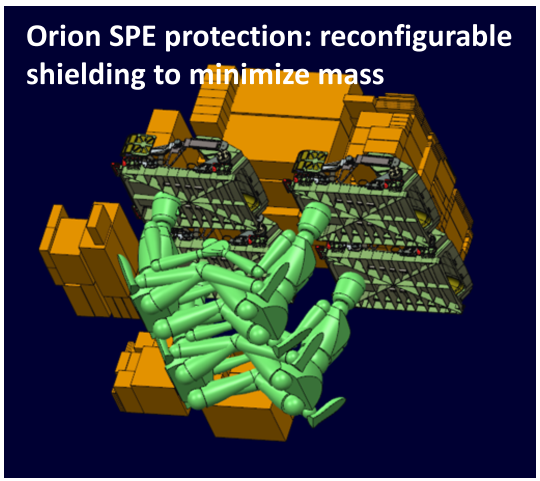
## Supports Optimization and Validation of Radiation Mitigations Strategies

- Risk Model updates and calculation of Permissible Exposure Limits
- Shield Optimization & Verification of Exposure Requirements
- Definition of GCR Simulator requirements for ground-based radiation health research
- Validation of biological countermeasures




*NASA-STD-3001, Volume 1, Appendix F*



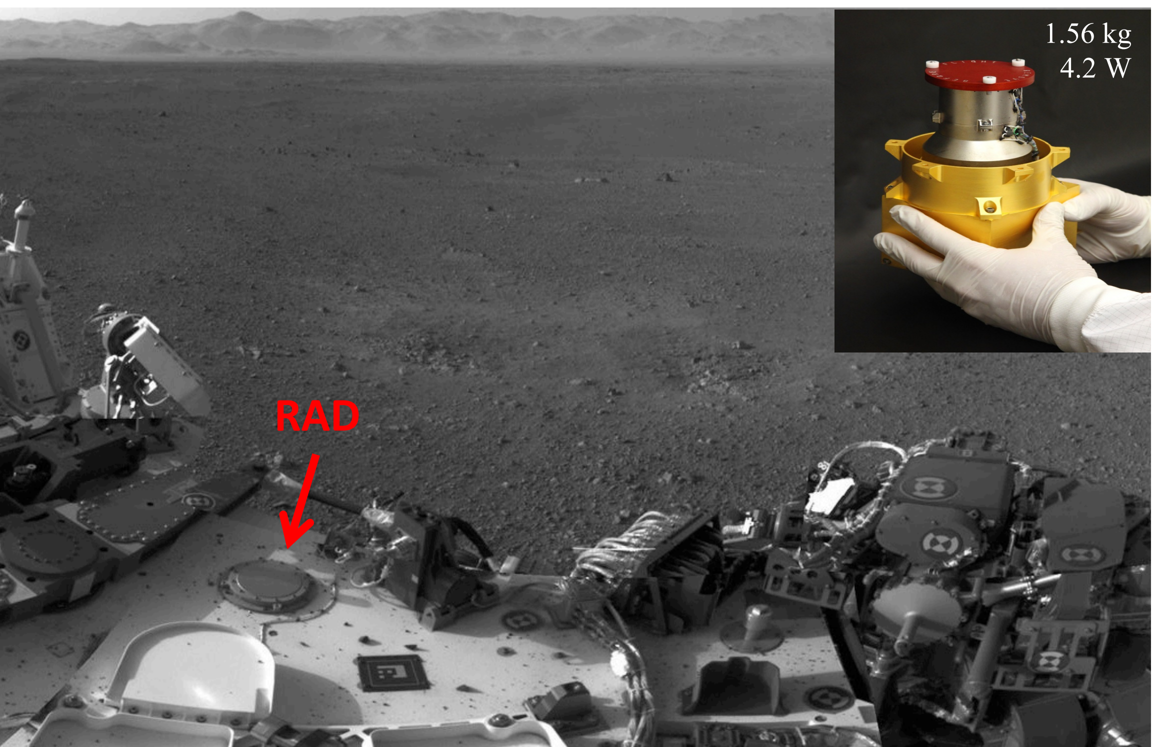

# MSL Radiation Assessment Detector (RAD): working asset on the Mars surface

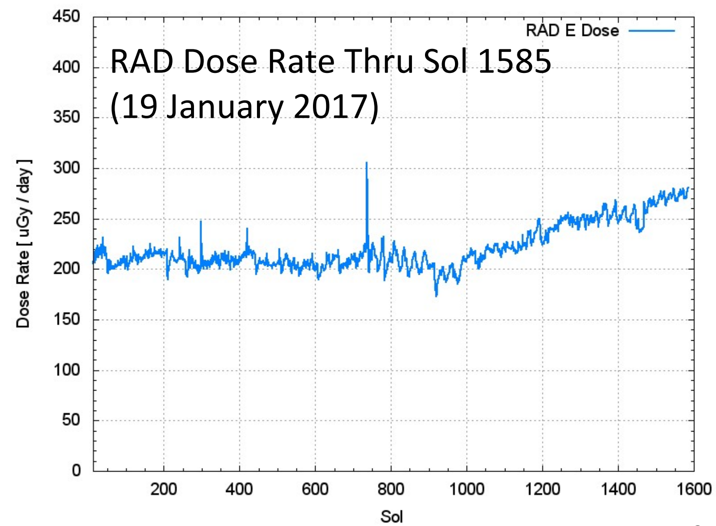
**MSL-RAD is a joint SMD-HEOMD project**

- Operating successfully on Mars since touchdown on 6 Aug 2012.

**First radiation environment measurements on Mars**

- Characterizing the changing Radiation Environment on Mars over the Solar Cycle, due to Galactic Cosmic Rays (GCRs) and Solar Energetic Particles (SEPs)

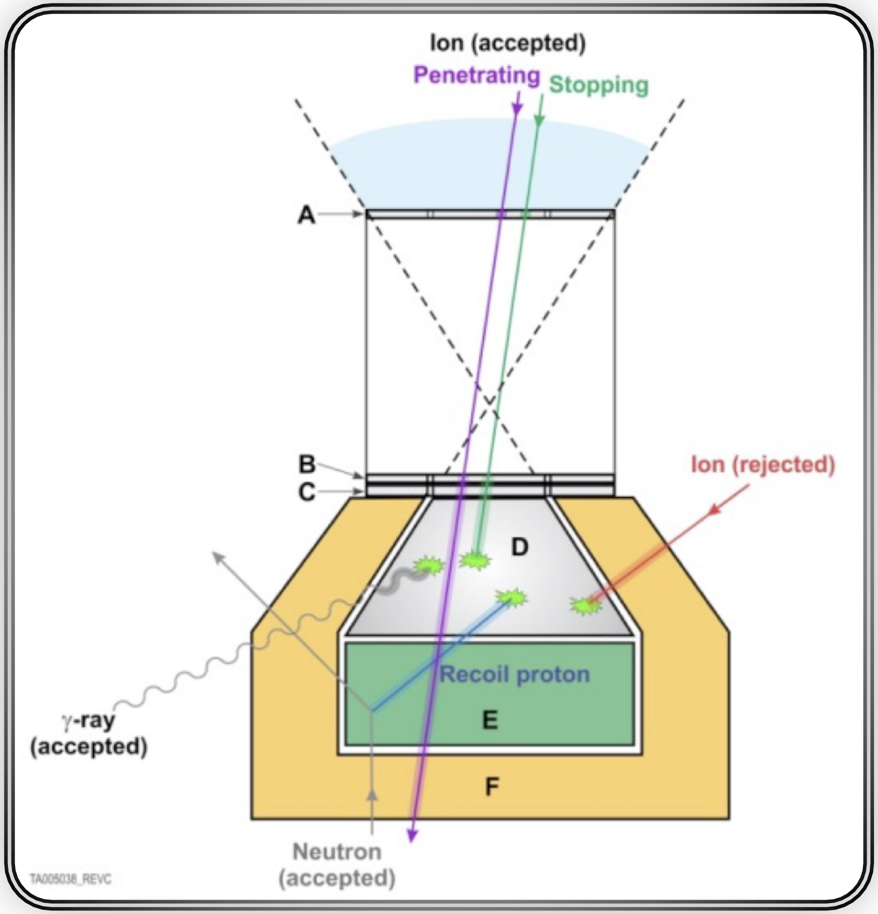



# MSL-RAD Sensor Head Overview

- **B and E detectors record radiation doses in silicon and plastic, respectively**

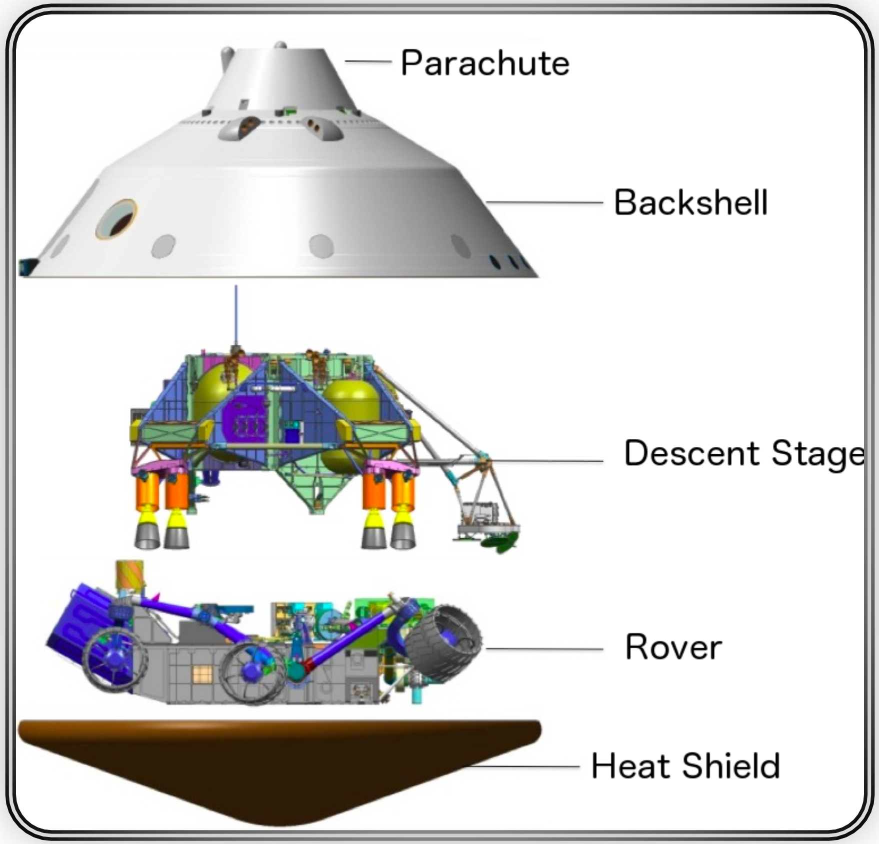
- **Coincidence events in A*B field of view used to perform charged particle identification**

- **Neutral particle detectors D and E → neutron and $\gamma$-ray spectra**



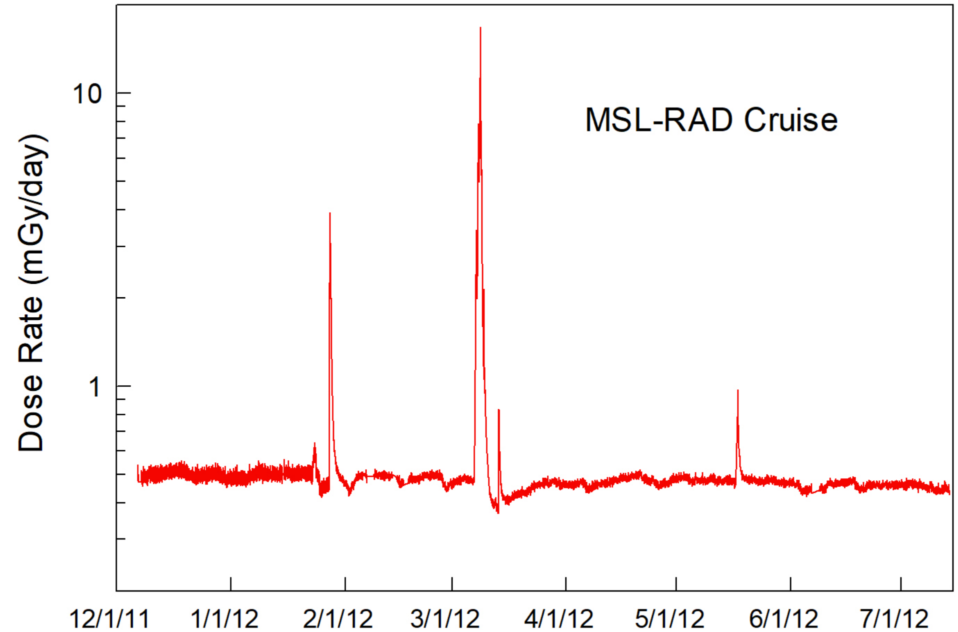
# MSL's Transit to Mars

- **Complex shielding around RAD from descent vehicle include fuel tanks**
- **Average shielding depth was 16 g cm$^{-2}$, likely similar to crewed vehicle**
- **Measured background from RTG at the Cape pre-launch in flight configuration**



# Dose Rates on Cruise to Mars

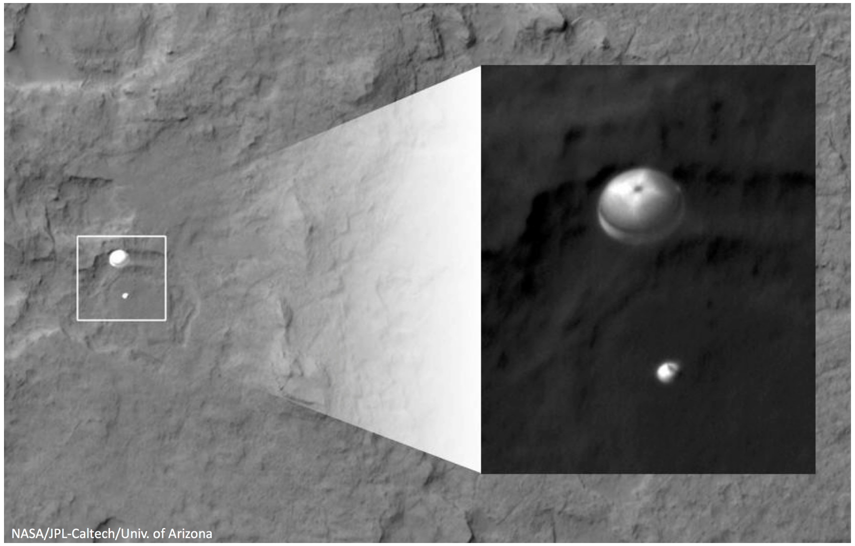
- **Near-constant GCR + five SEP events seen**
- **Dose rates spike by factors of 10 to 100 during SEP events, but contribution to total dose equivalent over cruise is only ~ 5%**
- **Average GCR absorbed dose rate 0.45 mGy/day***
- **RAD measured Radiation "quality factor" Q of 3.7 → 1.7 mSv/day***

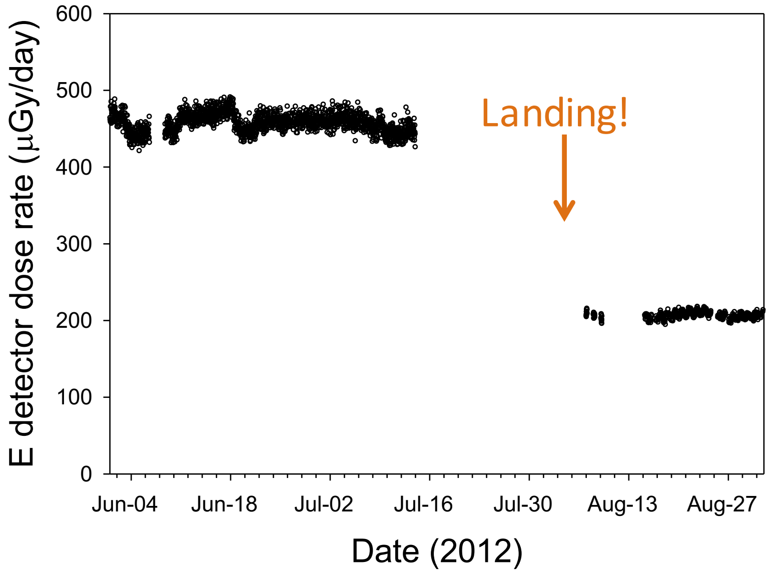



***Radiation Units***

- *mGy is the physical absorbed dose*
- *mSv takes into account the nature of the radiation and proportional cancer risk from that radiation*
- *Radiation "quality factor" Q scales between the two radiation units*
- *Terrestrial radiation sources (x-rays) have a Q=1, space radiation GCR have higher values of Q*

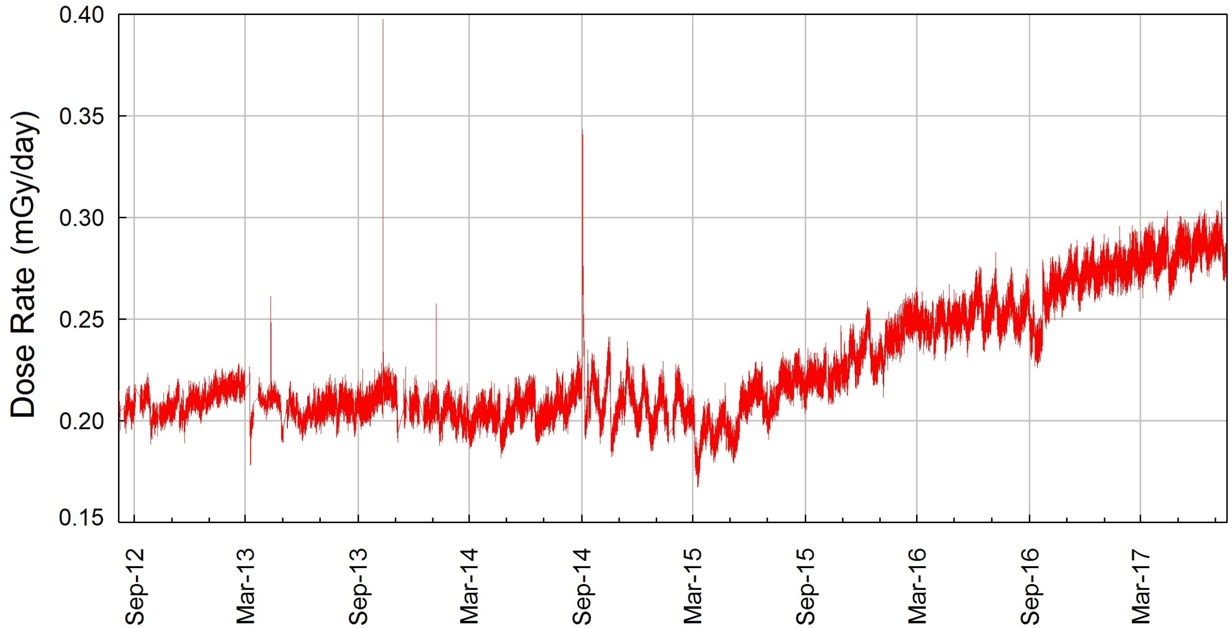
# First Surface Observations




- **Dose rate dropped by factor of 2.5**
  - Expect factor of 2 on airless body
- **Atmosphere shielding > cruise shielding**
  - $CO_2$ column depth averages 23 g $cm^{-2}$ in Gale
- **Diurnal effect due to atmospheric “thermal tide”**
  - Small effect, +-3% dose variations

# Dose Rates on Mars



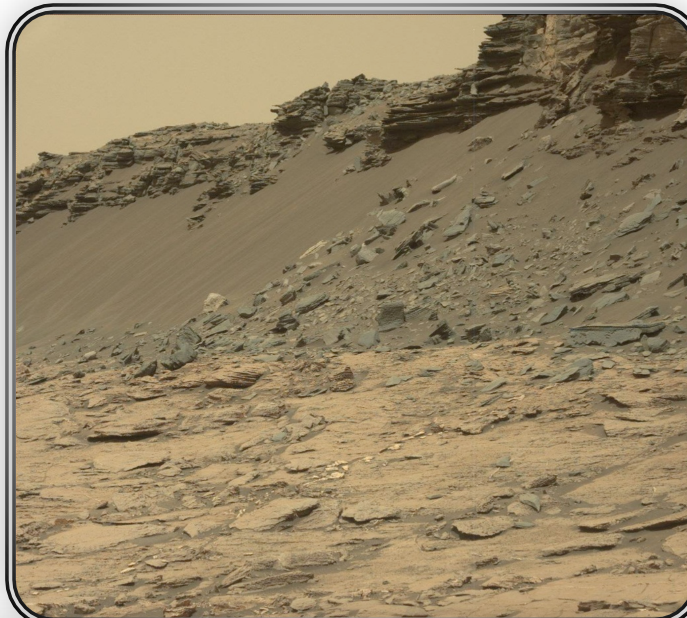

- **Four small SPE's seen – Sun is quiet, Gale floor is well shielded by atmosphere**
- **Heading towards solar minimum → significant increase in GCR flux & dose rate**
- **Radiation "quality factor" Q measured on Mars surface is smaller than in cruise due to atmospheric shielding, averages 2.6 vs. 3.7 in cruise**

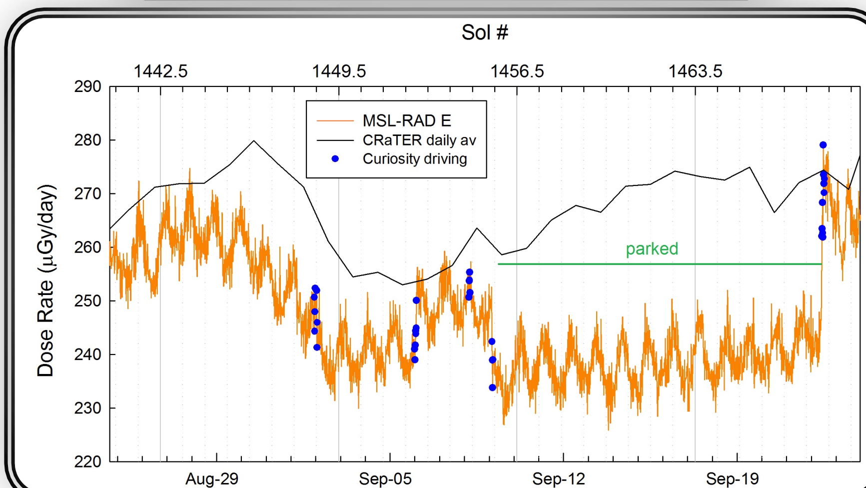
# Shielding from Local Terrain

- **During drive through Murray Buttes, dose rate dropped noticeably while Curiosity was parked near a cliff**

- **Working to quantify in terms of % dose change vs. % of sky blocked**
  - ~ 10% effect seen when comparing to CRaTER (LRO)

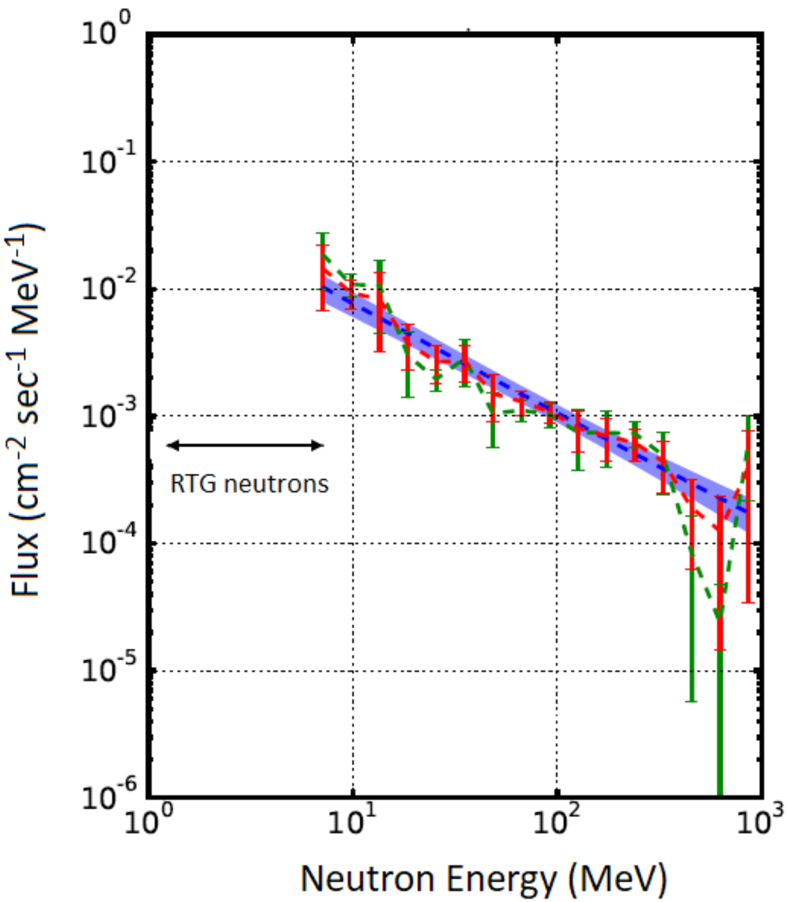
- **Up against a cliff = good spot for habitat**





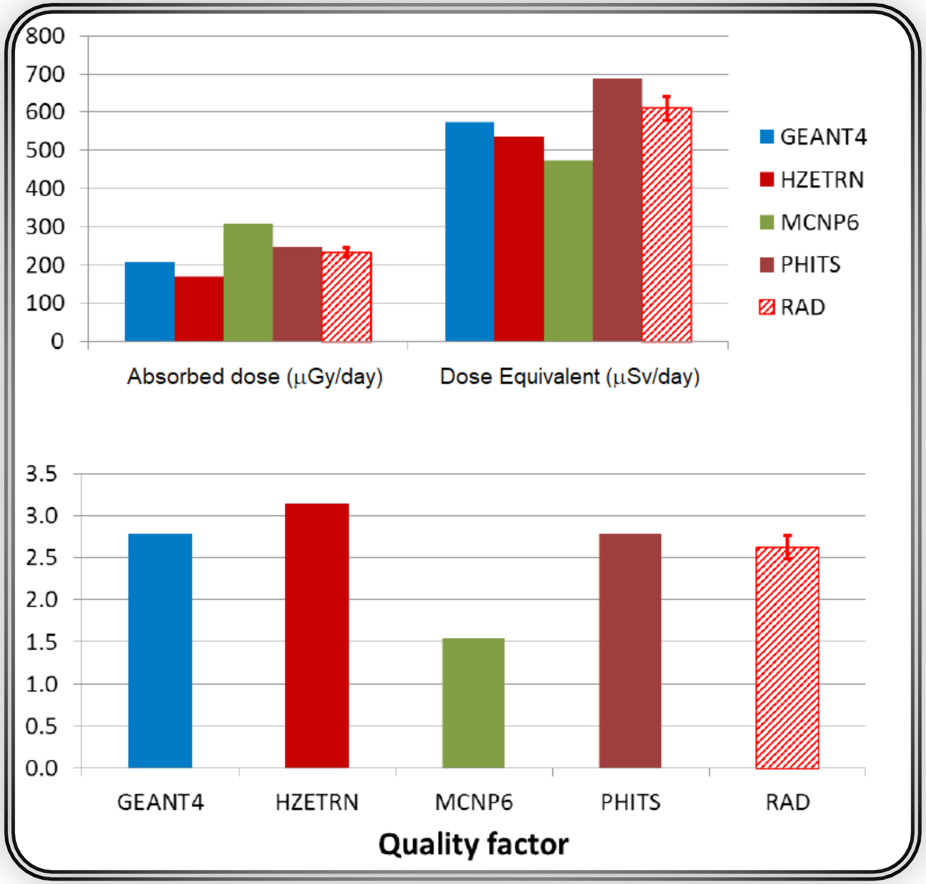
# Surface Environment: High-energy Neutrons

- **MSL RAD represents the first opportunity to measure the neutron exposure**
- **Neutrons are potentially a contributor to overall radiation exposure**
- **Measurement limited to E > 8 MeV (cannot measure entire spectrum)**
- **RTG is not a significant contributor to neutron dose rate in measured range**
- **Dose equivalent rate = 24 ± 4 μSv/day**
  - 5% of total



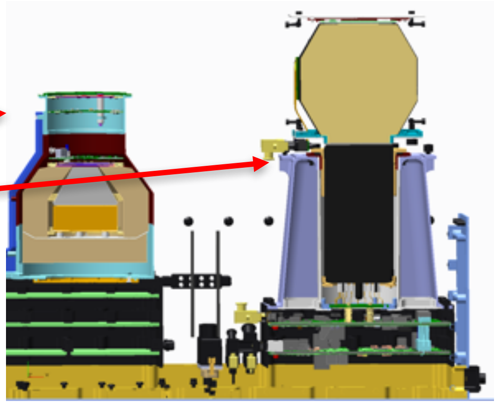
# MSL-RAD Workshop

- **MSL-RAD science team and radiation transport modeling experts met in June 2016**
  - International participation
- **MSL-RAD data is the gold standard for the Mars radiation environment and is used to validate radiation transport models that will support future exploration missions**
- **Modelers attempted to reproduce measurements using current state-of-the-art codes including HZETRN used by NASA**
- **Special issue of *Life Sciences in Space Research* out soon**



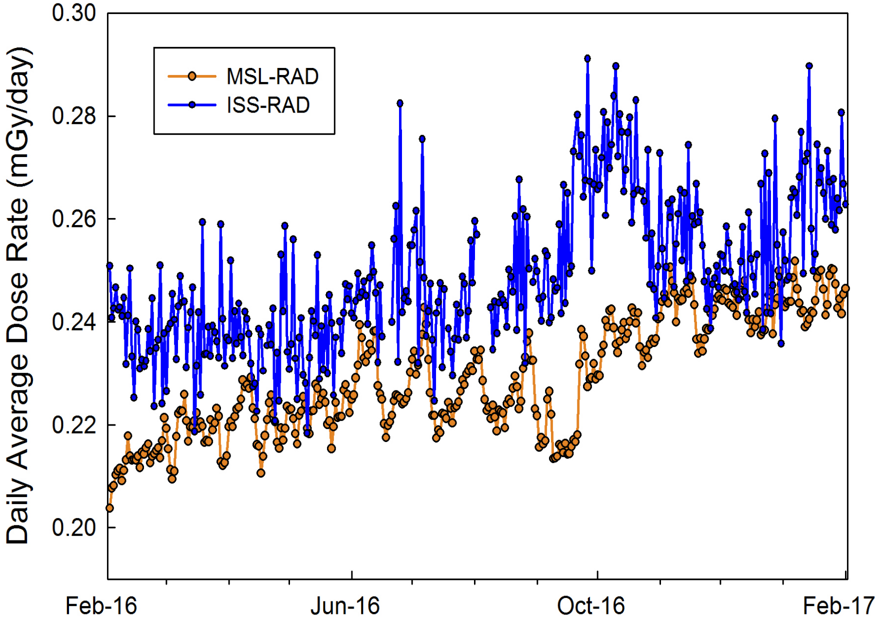
# Mars Surface & ISS Radiation Dose Rates are Similar

- **ISS-RAD Deployed in US Lab with Two Sensor Heads**
  - MSL-RAD Like
  - Fast Neutron Detector (FND)



- **ISS and Mars have Different Radiation Environments**
  - ISS Trapped Radiation (SAA)
  - Mars Atmospheric Shielding
- **Interestingly, Mars Surface and ISS Radiation Dose Rates are Similar**

| Quantity | MSL-RAD | ISS-RAD |
|---|---|---|
| Omnidirectional charged flux (pfu) | 0.41 | 0.45 GCR<br>2.45 SAA |
| Vertical Charged flux (pfu) | 0.65 | 0.61 GCR<br>2.27 SAA |
| **Dose rate (mGy/day)** | 0.213 | 0.240 total<br>(0.181 GCR<br>0.059 SAA) |




*Mars Surface and ISS Dose Rates Over Time*

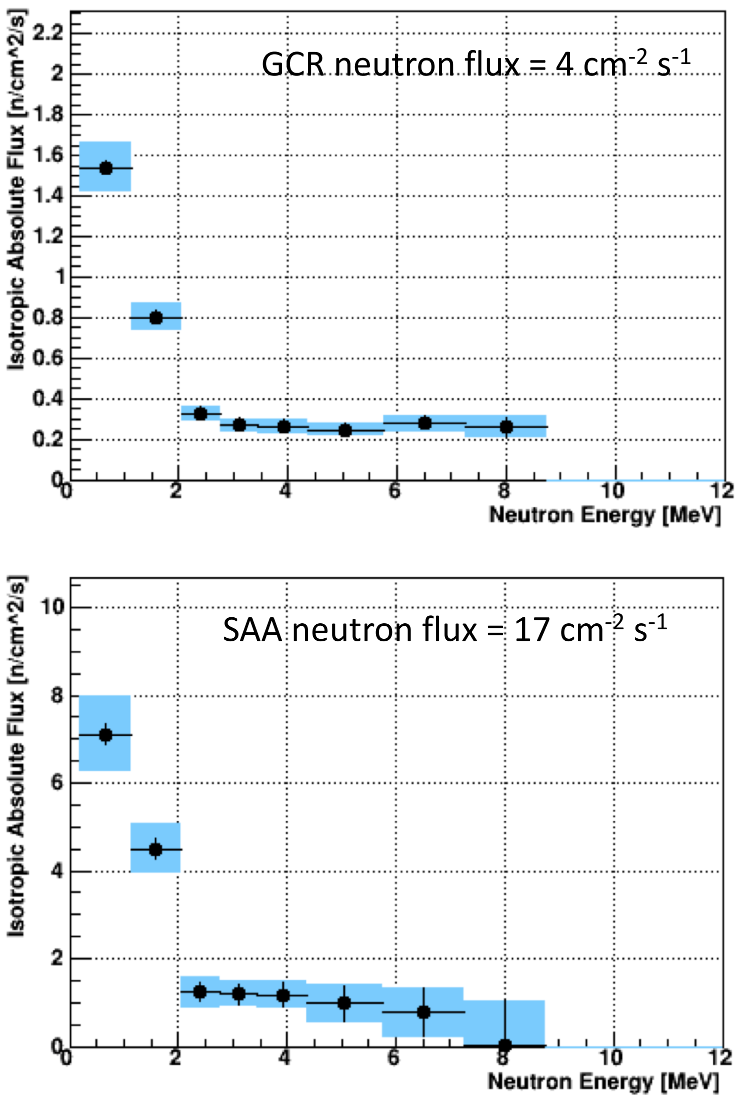
# ISS Neutron Measurements

- **Neutron contribution on ISS found to be 20-30% of total dose equivalent**
  - Measuring lower energies using FND
  - Neutron unfolding technique developed by M. Leitgab, JSC SRAG

- **Neutron dose equivalent rates**
  - 134 μSv/day GCR
  - 17 μSv/day SAA

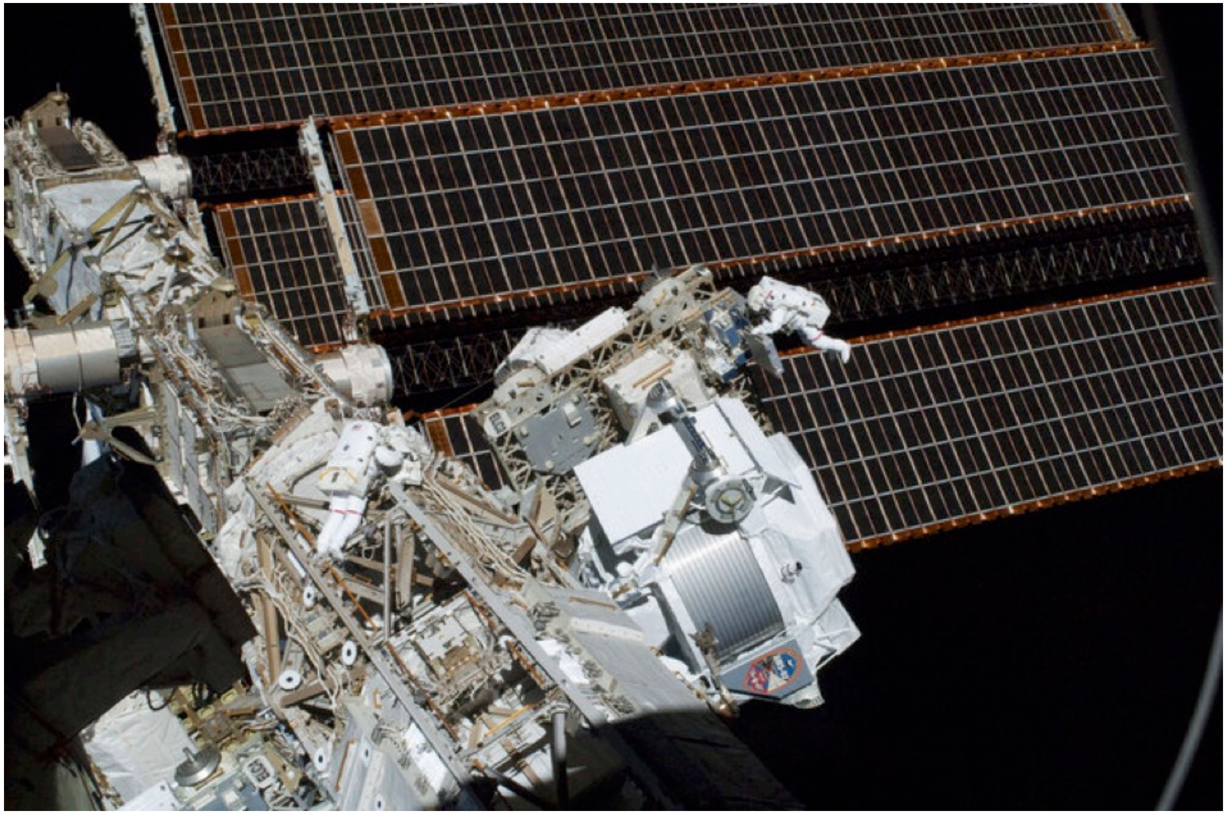
- **Charged particle dose equivalent rates**
  - 300 μSv/day GCR
  - 50 μSv/day SAA

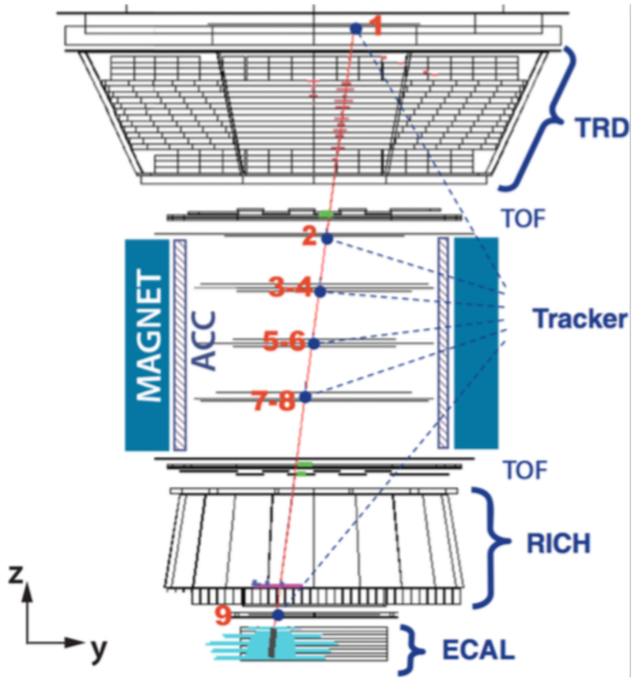
Isotropic Neutron Flux [n/cm^2/s]



# The Alpha Magnetic Spectrometer (AMS-02)

- **Full-blown high-energy physics experiment mounted on starboard truss of ISS**
- **Built for antimatter & dark matter studies, also provides precision measurements of radiation environment outside ISS**



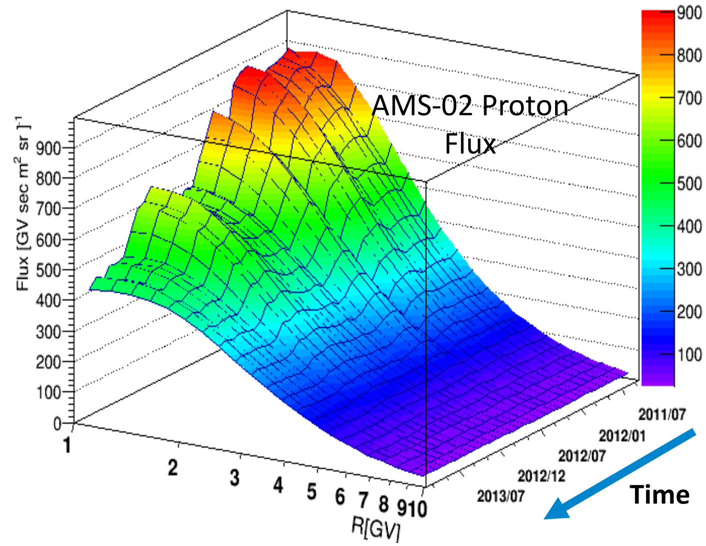



*Alpha Magnetic Spectrometer (AMS): Launched to ISS on STS-134, May 2011*

# AMS-02 Data

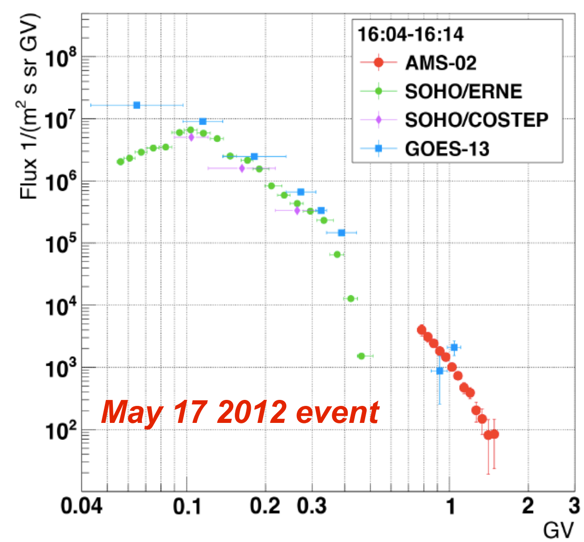
**First-ever continuous measurement of GCR protons (and alphas) over an extended time period and energy range of importance to human space flight**

- GCR protons (and alphas) make up a substantial portion of the overall astronaut exposure behind shielding




*University of Hawaii, Veronica Bindi*

- **Provides detailed insight into the high-energy region of space radiation unavailable from other satellites**
  - Peak (high flux) primary proton spectra measurements are in an important energy range of interest for human protection



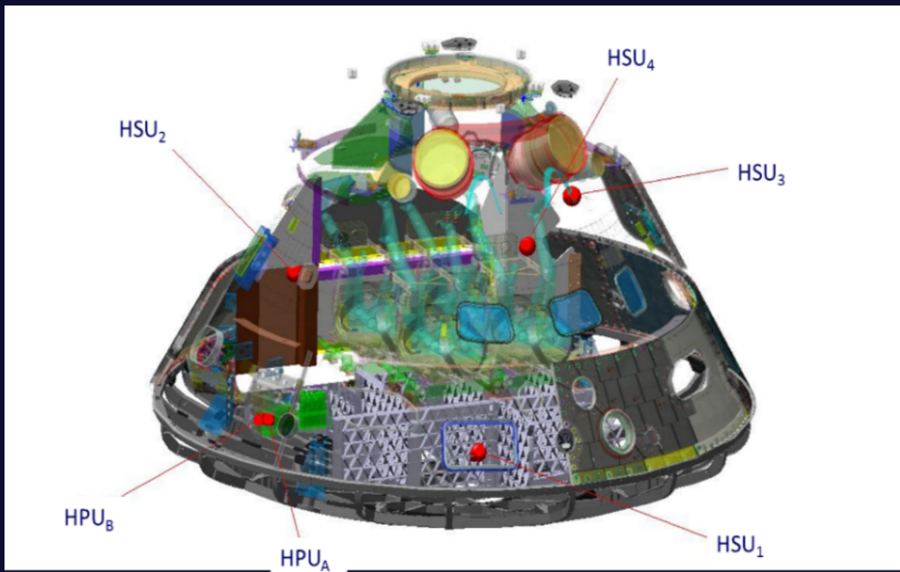

*Energy range is unavailable from other satellites*

- **Measures specific cosmic particle fluxes with unprecedented uncertainty and accuracy providing Gold Standard Data**

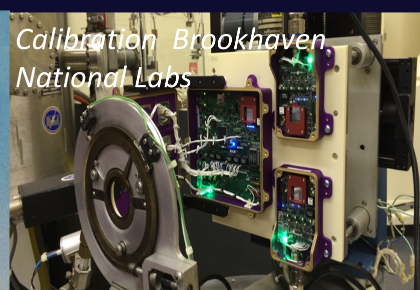
- **Improvement in data quality will provide new scientific insights in cosmic ray and solar activity research**

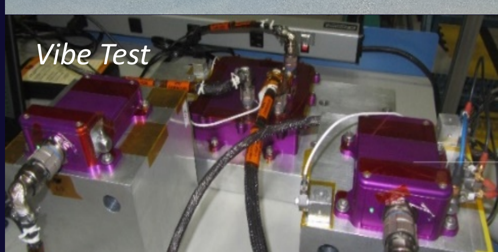
# Real-Time Radiation Monitoring for Protection of Astronauts

*HERA Radiation Monitoring Locations in Orion*



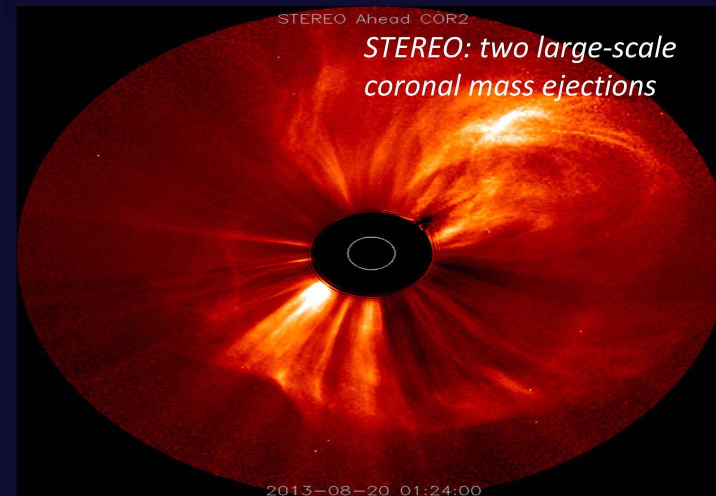






*SMD Assets Used: ACE, DSCVR, SDO, STEREO*





# Current and Future Human Space Missions

## International Space Station

- 6-person crews for 6 months; 2-person crews for 12 months
- 6 mo.: 50-100 mSv depending on altitude & time in solar cycle

## Gateway Missions

- 20 to 40 days in deep space; SPE protection provided
- Doses on order of 35-70 mSv during solar min

## Deep Space Transport: Cis-lunar missions*

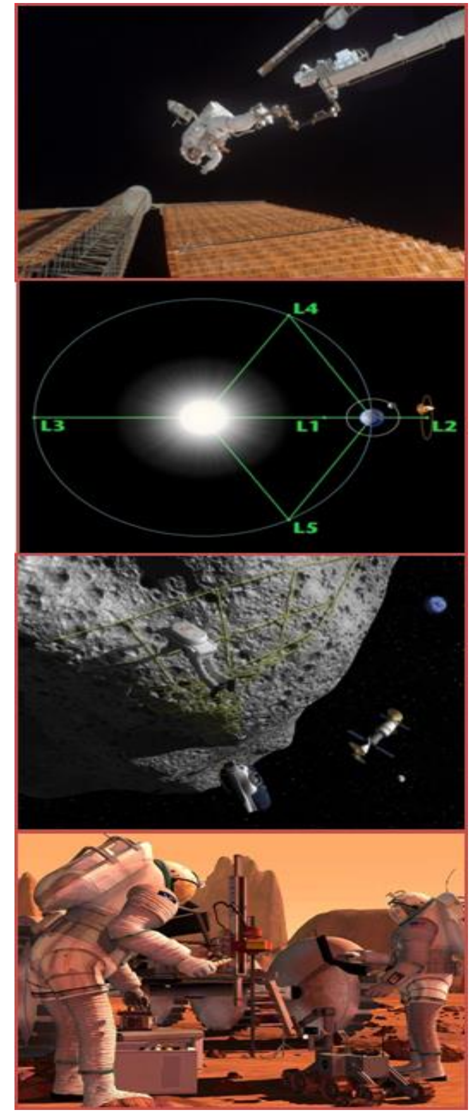
- 200 days to 400 days; SPE protection provided
- Outside Earth's magnetosphere in free space; GCR risks major concern; Doses of 350 to 700 mSv during solar min

## Flyby and Mars Surface**

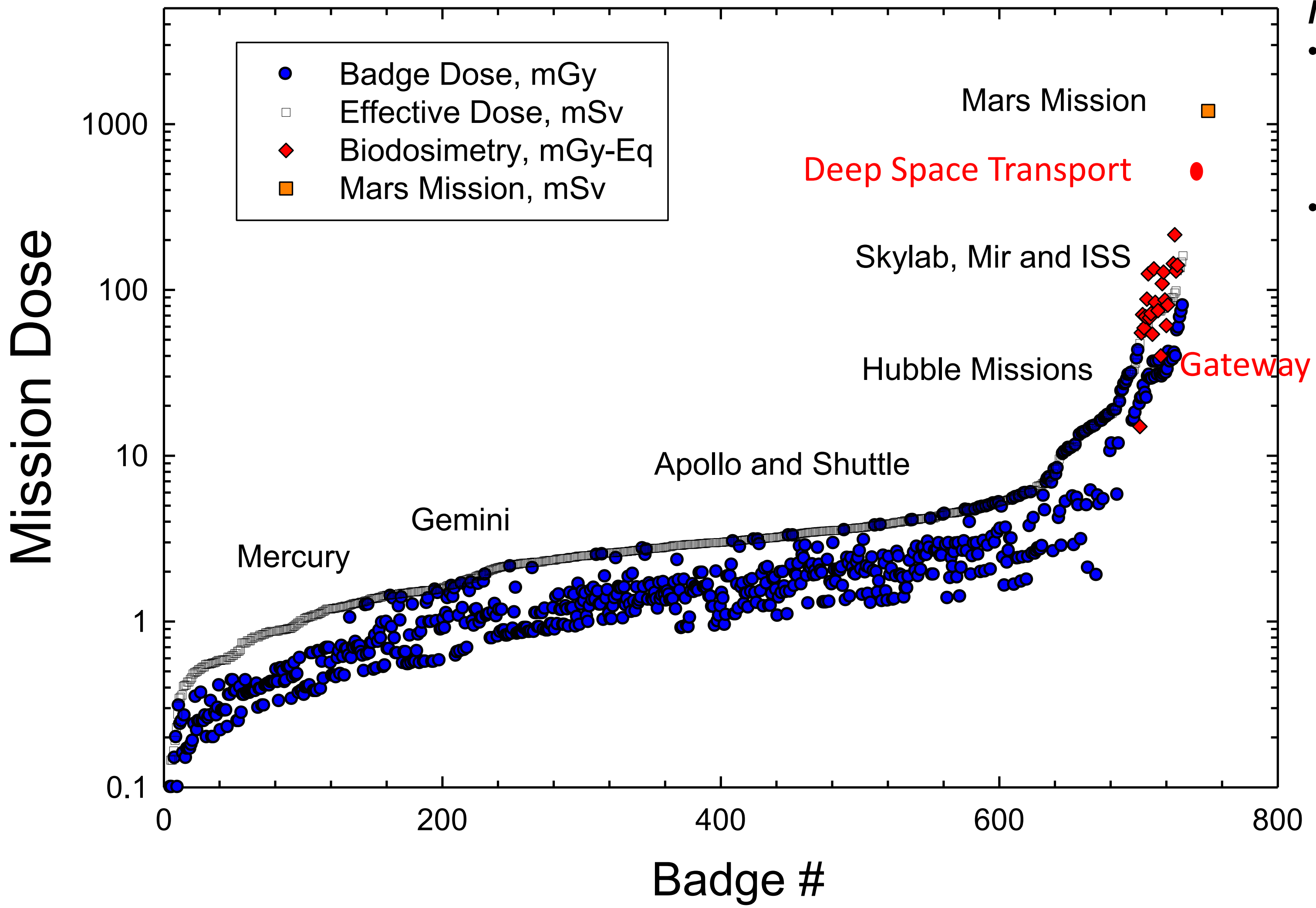
- 4-person crew; up to 3 yrs.
- Long deep space transit times; Mixed field environment on Mars
- Flyby Opposition/Short Stay & Conjunction/Long Stay missions have similar exposure estimates of 1000-1300 mSv during solar min

** Limited number of crew will meet current radiation standards – depends on time in solar cycle*

*** Mars dose estimates above permissible exposure limits for cancer and concern for other non-cancer effects*



# NASA Crew Mission Doses




***NASA Experience*:**

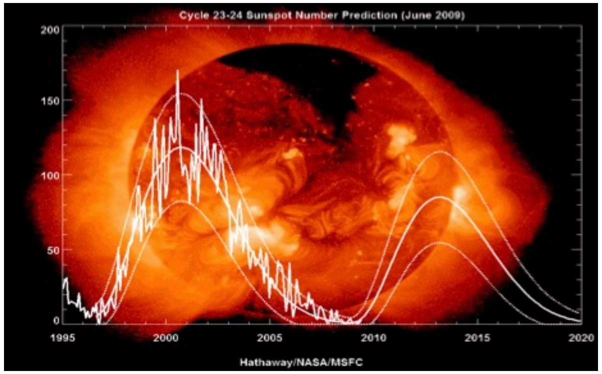
- *Single ISS mission approximately 1/10 of Mars mission exposure*
- *Many crew with multiple missions have accumulated 1/3 of Mars exposure risk*

*Update from Cucinotta et al. Radiat Res (2008)*

# Protection and Mitigation Approaches

- **Space Radiation Environment Characterization including SEP real-time monitoring, MSL RAD, ISS RAD, and LRO-CRaTER measurements**
- **Mars Mission Design including time in solar cycle to minimize GCR exposure by up to half at solar max**
- **Research to inform and validate Exposure Standards for crew protection**
- **Pre-/Post-Mission Medical Approaches including individual sensitivities and early detection/surveillance using biomarkers**
- **In-mission Biological Countermeasures (nutritional, radioprotectors, mitigators)**
- **Spacecraft Shielding, Real-time Dosimetry and Storm Shelters**

*Variation of Solar Activity*




*Shield Design and Optimization*

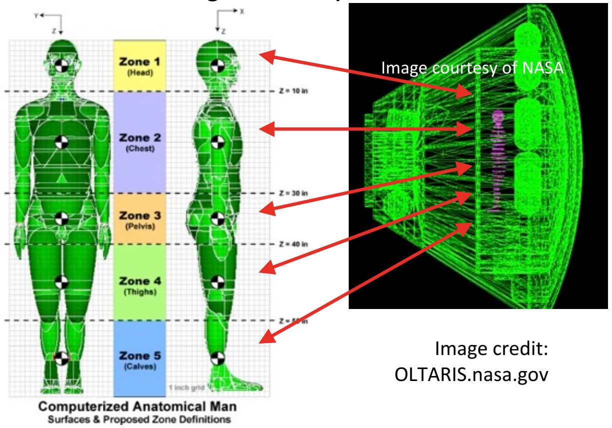
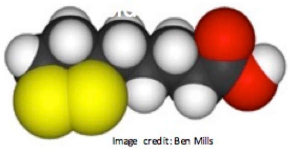



Image credit: OLTARIS.nasa.gov

α-lipoic acid





*BCM Pharmaceuticals*

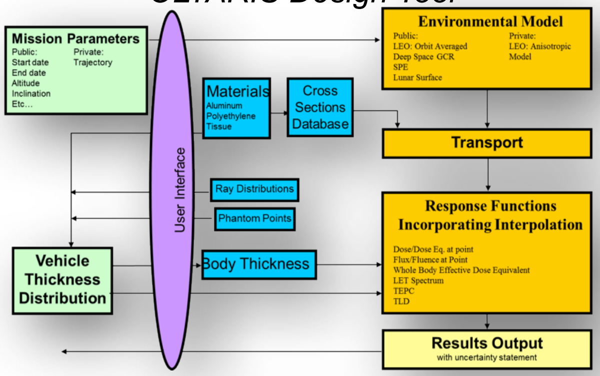
# Optimization of Radiation Protection

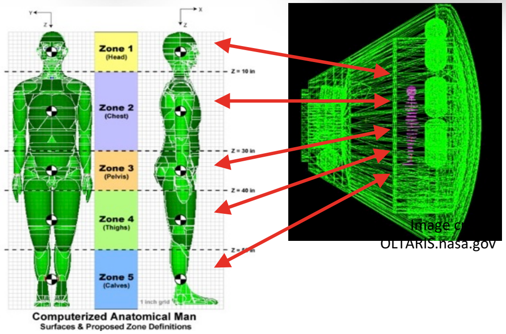
## Environmental Data Supports the Modeling, Analysis, and Design of Exploration Spacecraft

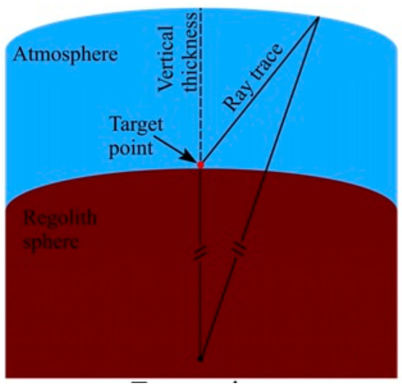
### Vehicle and Habitat Design

- Mission modeling and computational capabilities support the rapid evaluation of astronaut exposure for multiple vehicle configurations through all design phases
- Spacecraft requiring minimal parasitic mass for radiation protection can be designed through the optimal placement of vehicle systems, cargo, & consumables
- Mars surface habitat design, including materials selection and thickness, requires understanding of secondary radiation production in the Mars atmosphere and on the surface

*OLTARIS Design Tool*




*Mars surface and atmospheric protection*

# Solar Particle Event Protection

**Minimal Mass Storm Shelter Concepts**

- Design concepts utilizing onboard mass (water, equipment, consumables, waste, etc.) to minimize parasitic shielding
  - Water walls/pantries around crew quarters
  - Reconfigurable logistics concepts
  - Wearable vests and blankets
- Fabrication of prototypes and operational assessments to determine feasibility

**EM-1 Radiation Vest Assessment**

- AstroRad is an international experiment (ISA/DLR/NASA) that will measure the effectiveness of a radiation vest during the EM-1 mission

*Reconfigurable Logistics*

*Water Walls*

*Radiation Vests and Blankets*

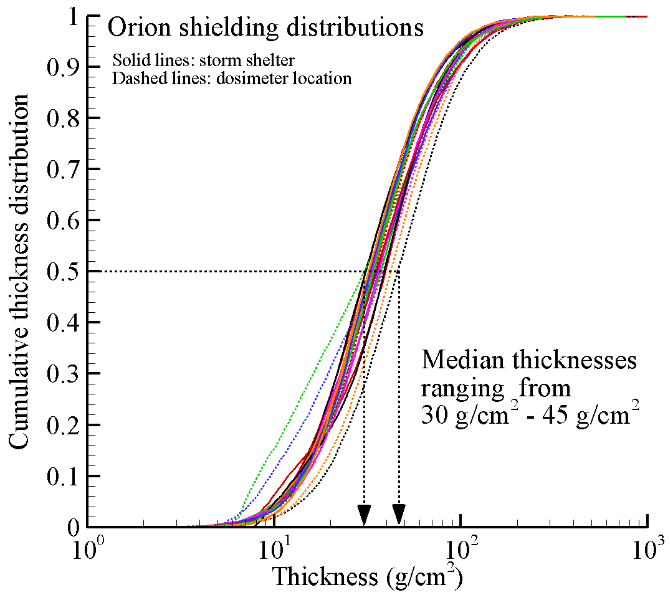
# Shift in GCR Shielding Paradigm

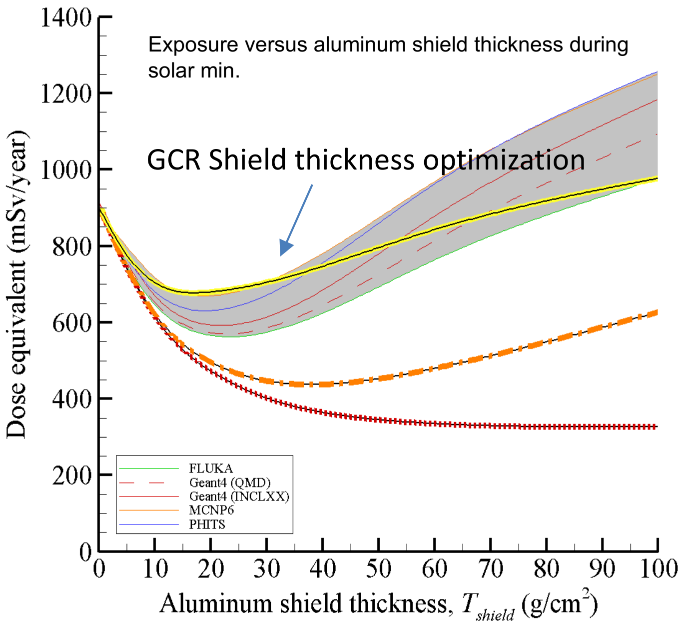
**New Radiation Transport Code Approach Includes transport of additional particle types (HZETRN)**

- More shielding may not reduce risk – optimum shield thickness takes shielding out of larger trade space
- Once minimum exposure is achieved, remaining risk must be reduced by mission duration, biological countermeasures, or acceptance

**Validation Uses Radiation Environmental Data**

- Comparisons to measurements in Earth's atmosphere, MSL RAD, and ISS RAD as well as with Monte Carlo transport models
- STMD Thick Shield Project beam experiments underway at NSRL

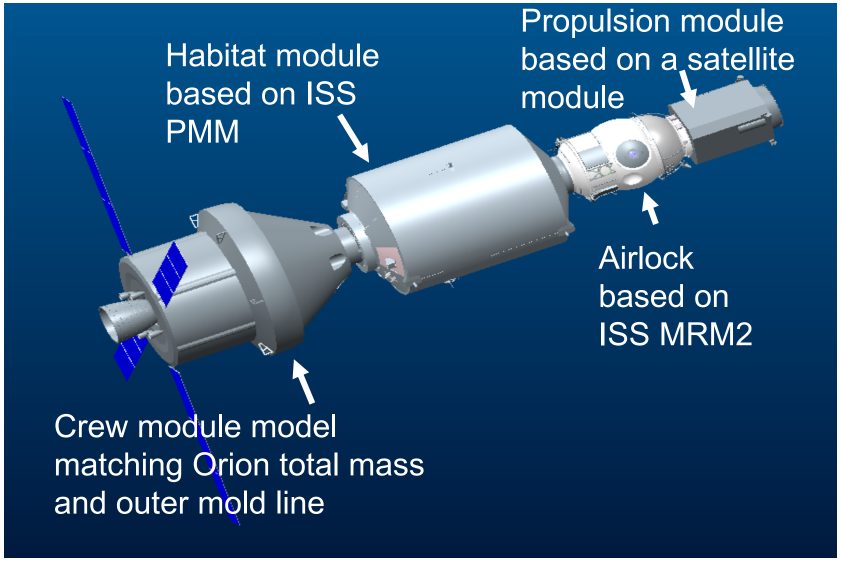


# Exploration Spacecraft

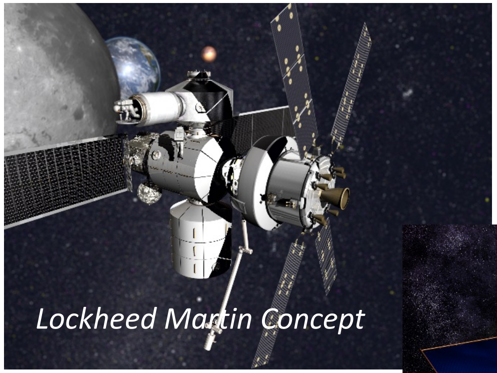
## Deep Space Gateway

- NASA is analyzing the space radiation shielding protection for a fully outfitted Deep Space Gateway
- Incorporating vehicle systems, equipment, and supplies as shield options
- Verifying whether enough materials onboard during a 30-day mission to provide adequate SPE shielding without adding parasitic mass




## NextSTEP Habitat Development

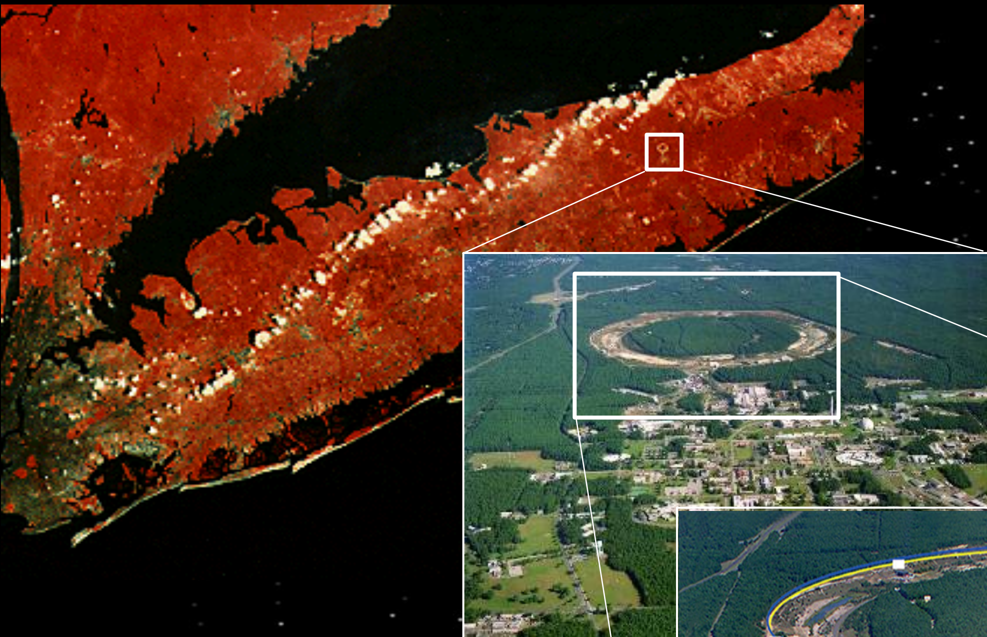
- NASA is supporting partner companies in understanding radiation protection requirements, performing radiation exposure assessments, and supporting design trade studies

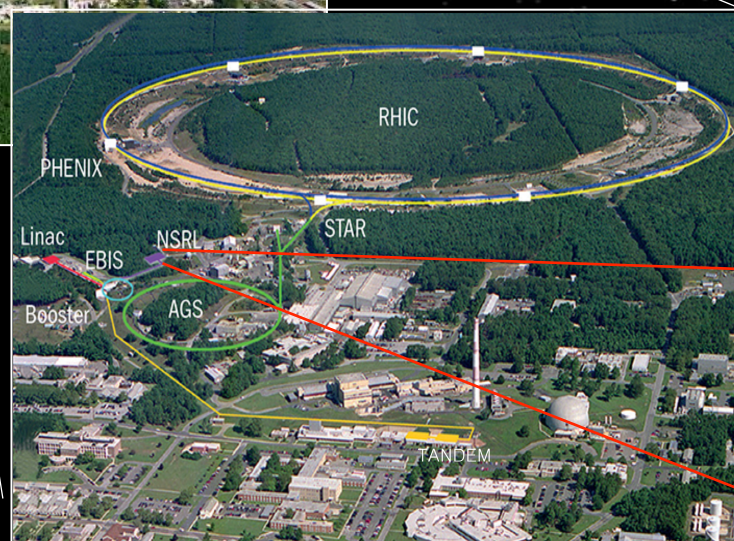



# NASA Space Radiation Laboratory (NSRL) at Brookhaven National Lab

**Galactic Cosmic Ray Simulator**

- Space Radiation Environmental Data Used to Develop Requirements
- Simulation of the GCR primary and secondary environment with a mixed field, high-energy capability
- NSRL upgrades completed to enable GCR simulator capability






**NSRL Beam Line**

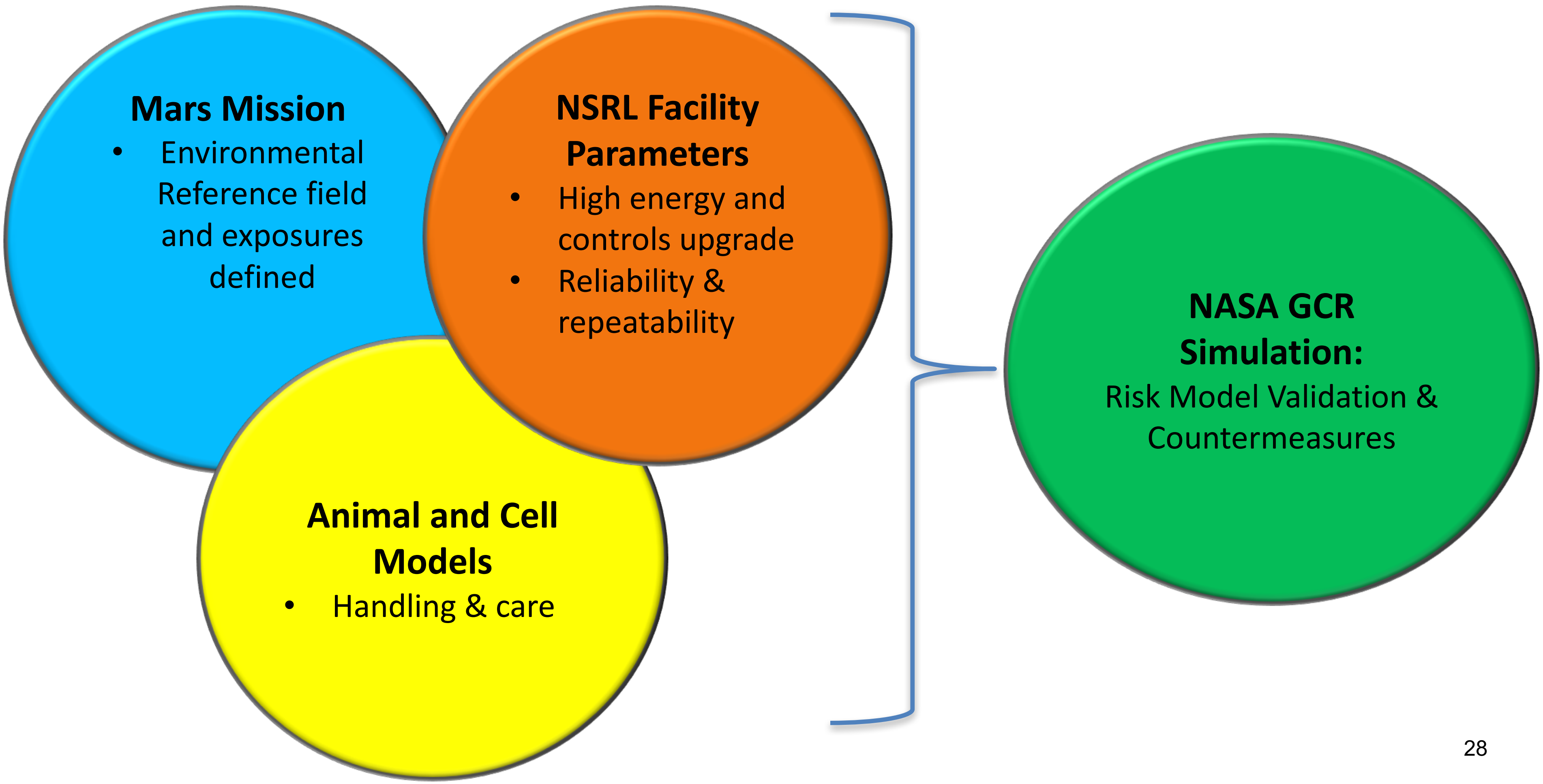
Images courtesy of BNL


**NSRL**

# Mars Mission GCR Simulation

## NSRL Deep Space Radiation Simulation Challenges

- Delivery of Mixed Ion Species to approximate environmental data
- Dose Rate and Duration to better simulate deep space environment
- Translation to Humans – Appropriate Animal or Cell Models to address health risks



# Summary

- Environmental data sets are used to define ground based radiobiology studies, update NASA Health Risk Models, as well as, to design and optimize shielding for NextSTEP, Gateway and Deep Space Transport Habitats
- Environmental monitoring, operational dosimetry, and storm shelter shielding are the collective mitigations to prevent in-mission health risks
- Quantification of radiation environment on Mars and within spacecraft are important for informing radiation mitigation strategies
    - MSL RAD to fully characterize Mars radiation environment
    - ISS RAD to measure neutron contribution to exposure
- Assessment of space weather monitoring and forecast architectures will support future human and robotic exploration of deep space (SMD/HEOMD)
    - Accurate space weather forecasting will enhance exploration mission operational flexibility and planning