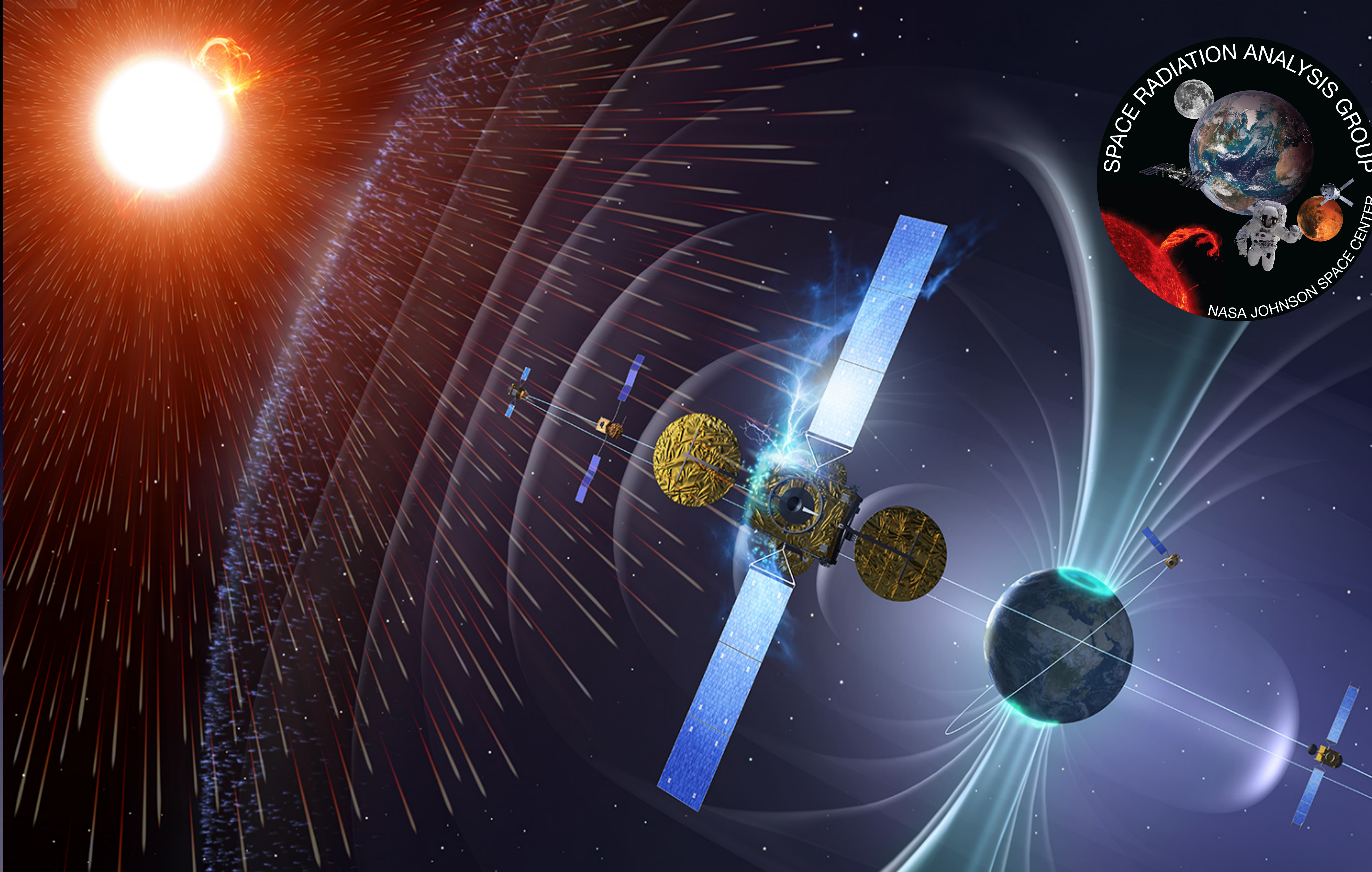


Space Radiation Why Do We Care ?

A. Firan, Ph.D.

Summary

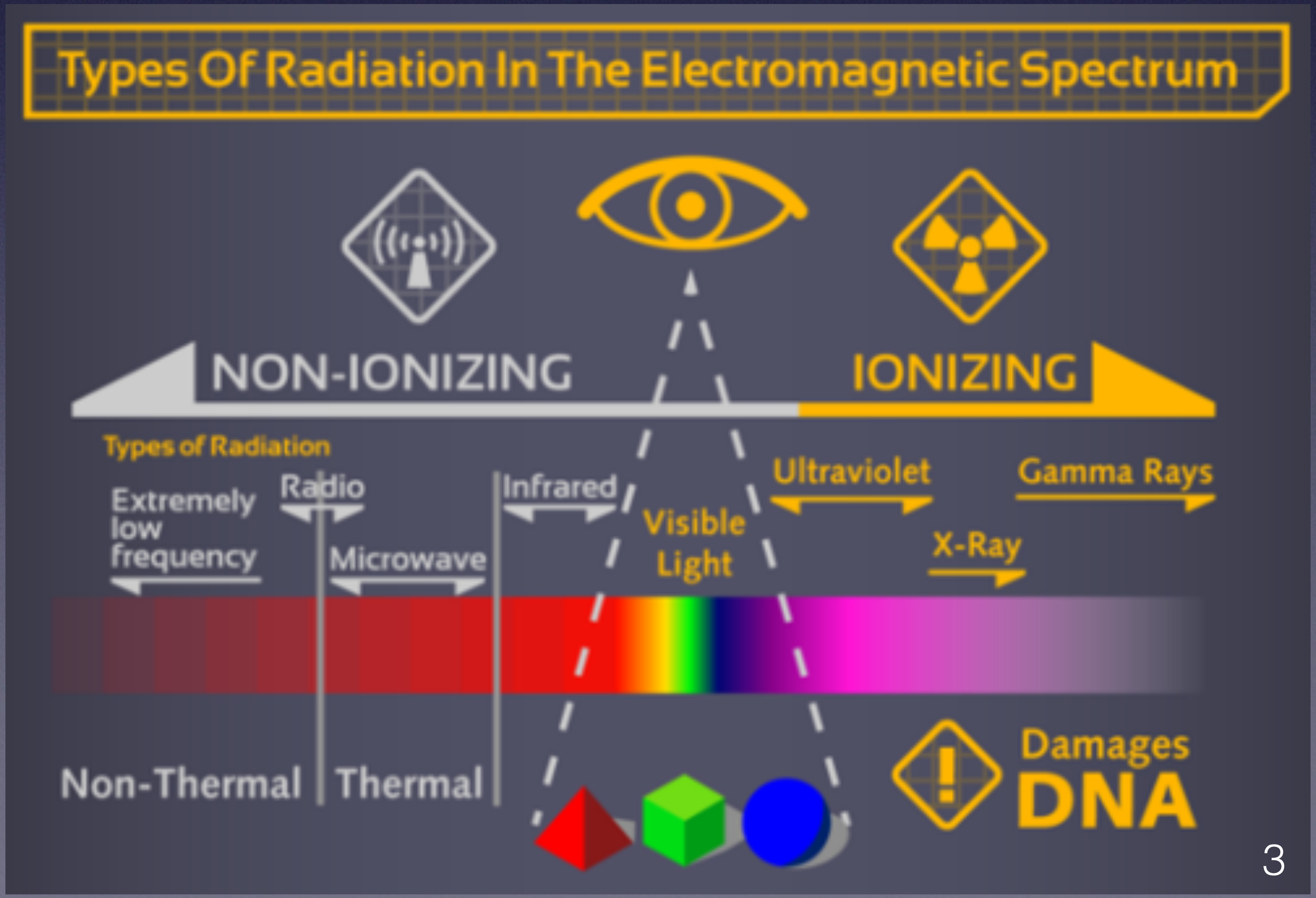
1. Introduction
2. Sources of radiation in space
3. Interaction of radiation with mater
4. Measuring radiation/Detectors
5. Exploration

What is space radiation?

Radiation may be defined as the emmision of energy energy in form of high-speed particles and electromagnetic waves.

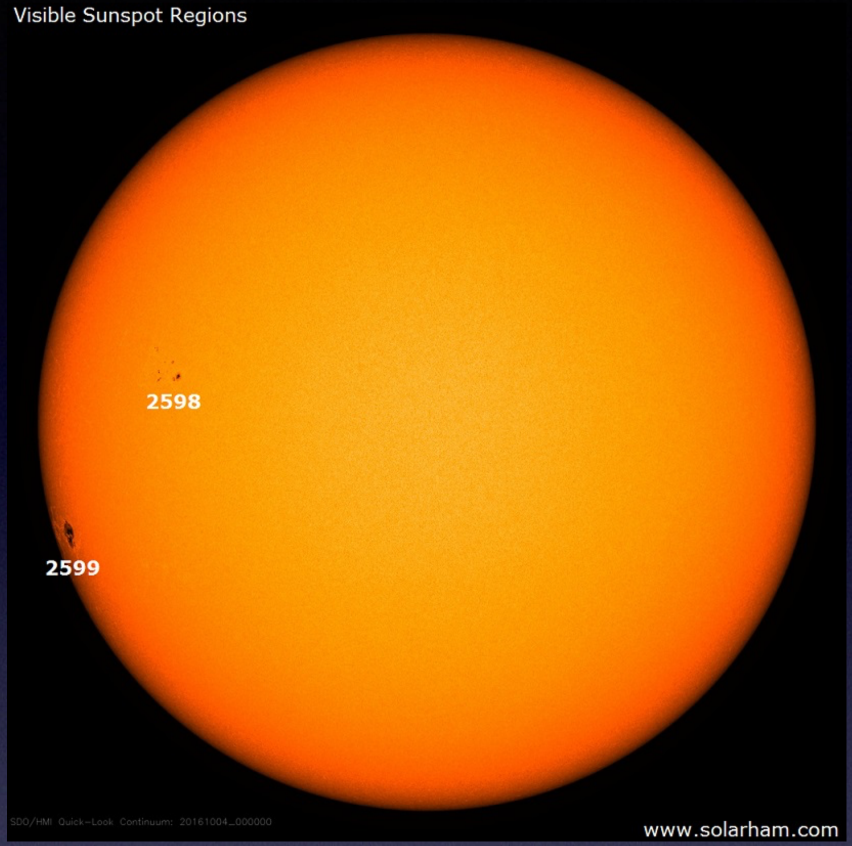
- **Ionizing radiation** is radiation with sufficient energy to remove electrons from the orbits of atoms resulting in charged particles, and it is this type of radiation that is evaluated for purposes of radiation protection(gamma rays, protons, and neutrons).

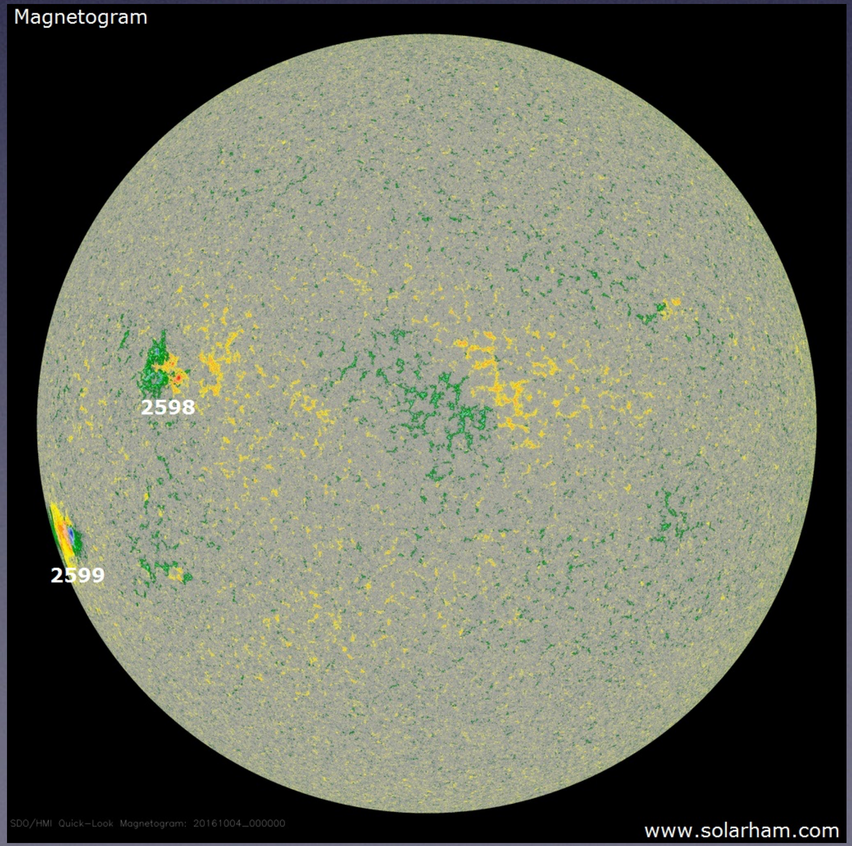
- **Non-ionizing radiation** is radiation without sufficient energy to remove electrons from their orbits (microwaves, radio waves, and visible light).



Source of radiation: Solar activity

4 October 2016

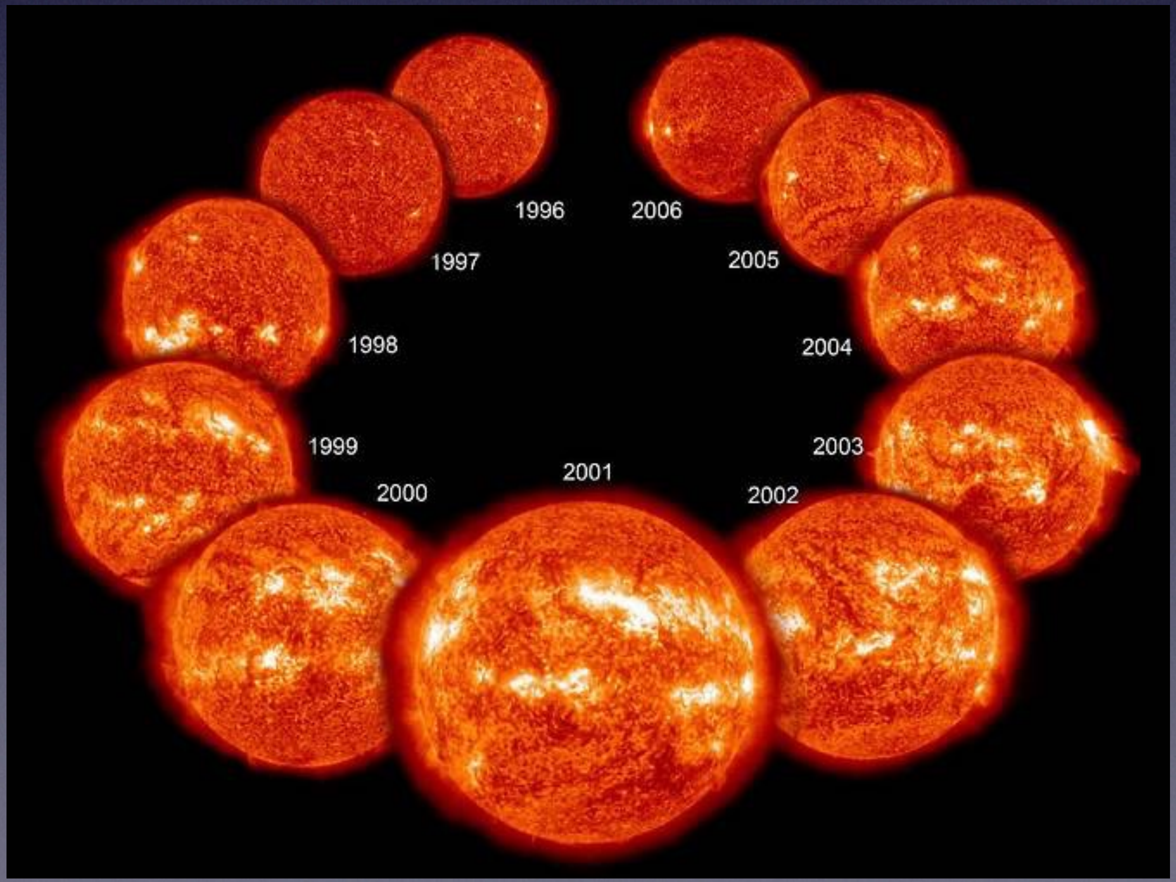




Sunspots are temporary phenomena on the photosphere of the Sun that appear as dark spots due to reduced surface temperature caused by concentrations of magnetic field flux that inhibit convection.

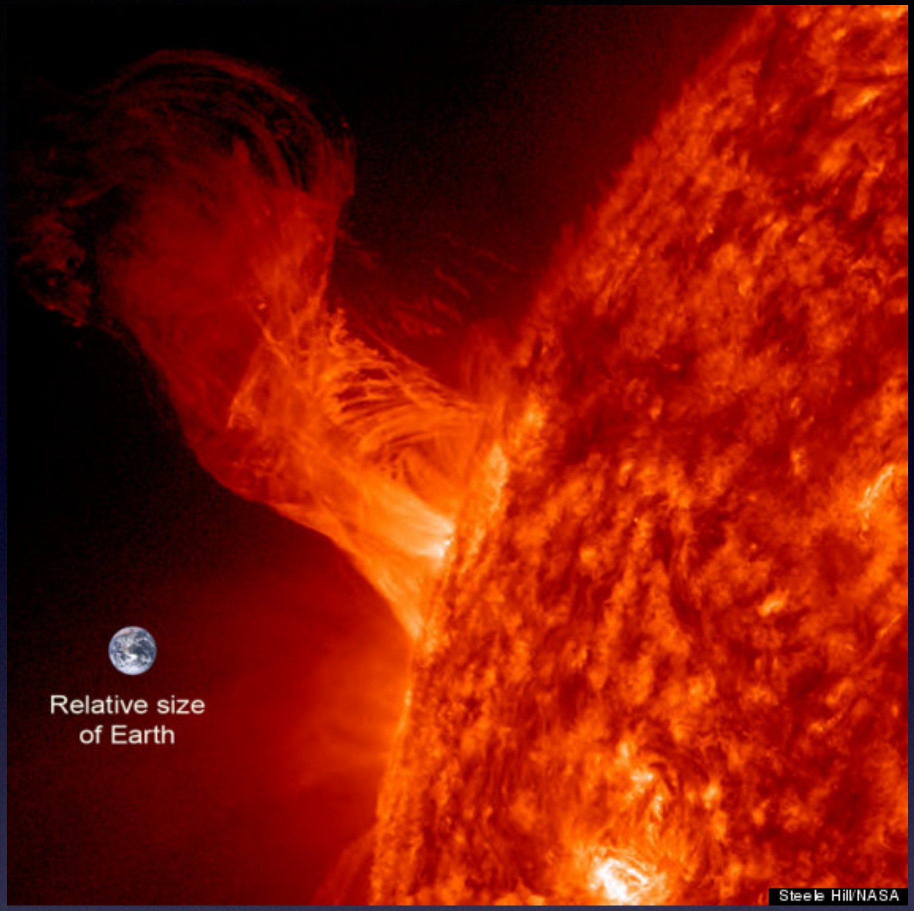
Sunspots usually appear in pairs of opposite magnetic polarity.

Most solar **flares** and **coronal mass ejections** originate in magnetically active regions around visible sunspot groupings.

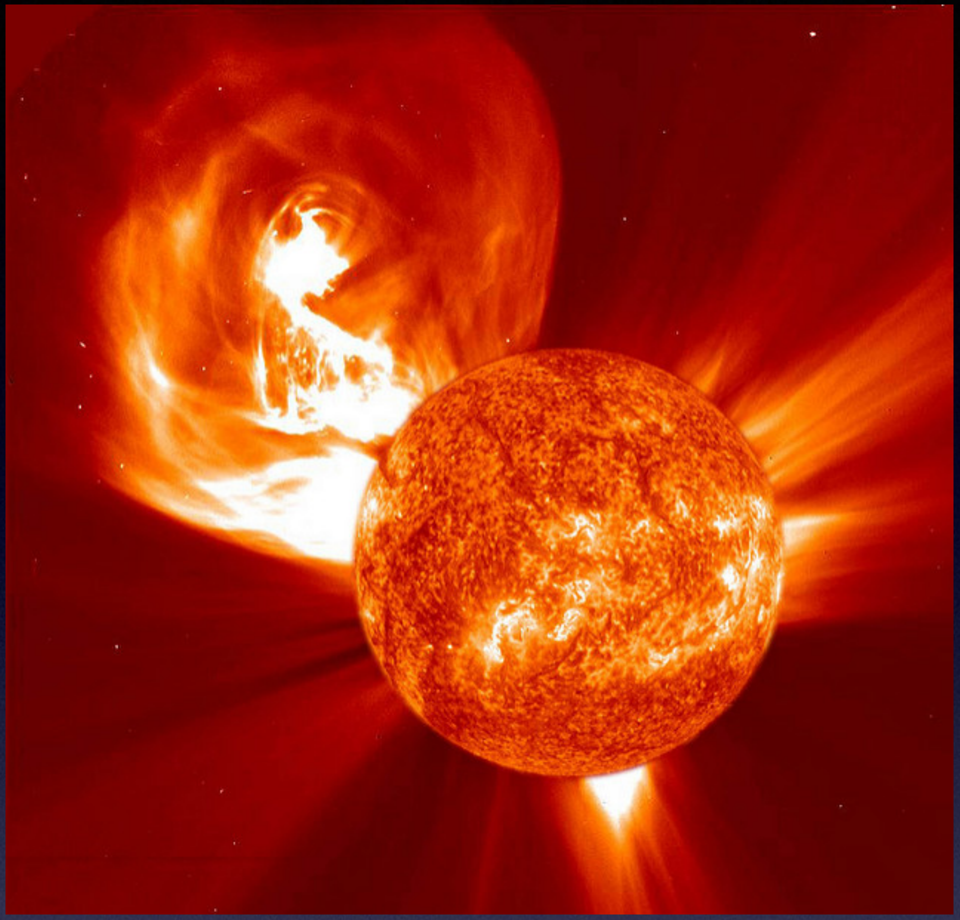


Eleven years in the life of the Sun, spanning most of solar cycle 23, as it progressed from solar minimum (upper left) to maximum conditions and back to minimum (upper right) again

Solar Flares



Coronal Mass Ejections

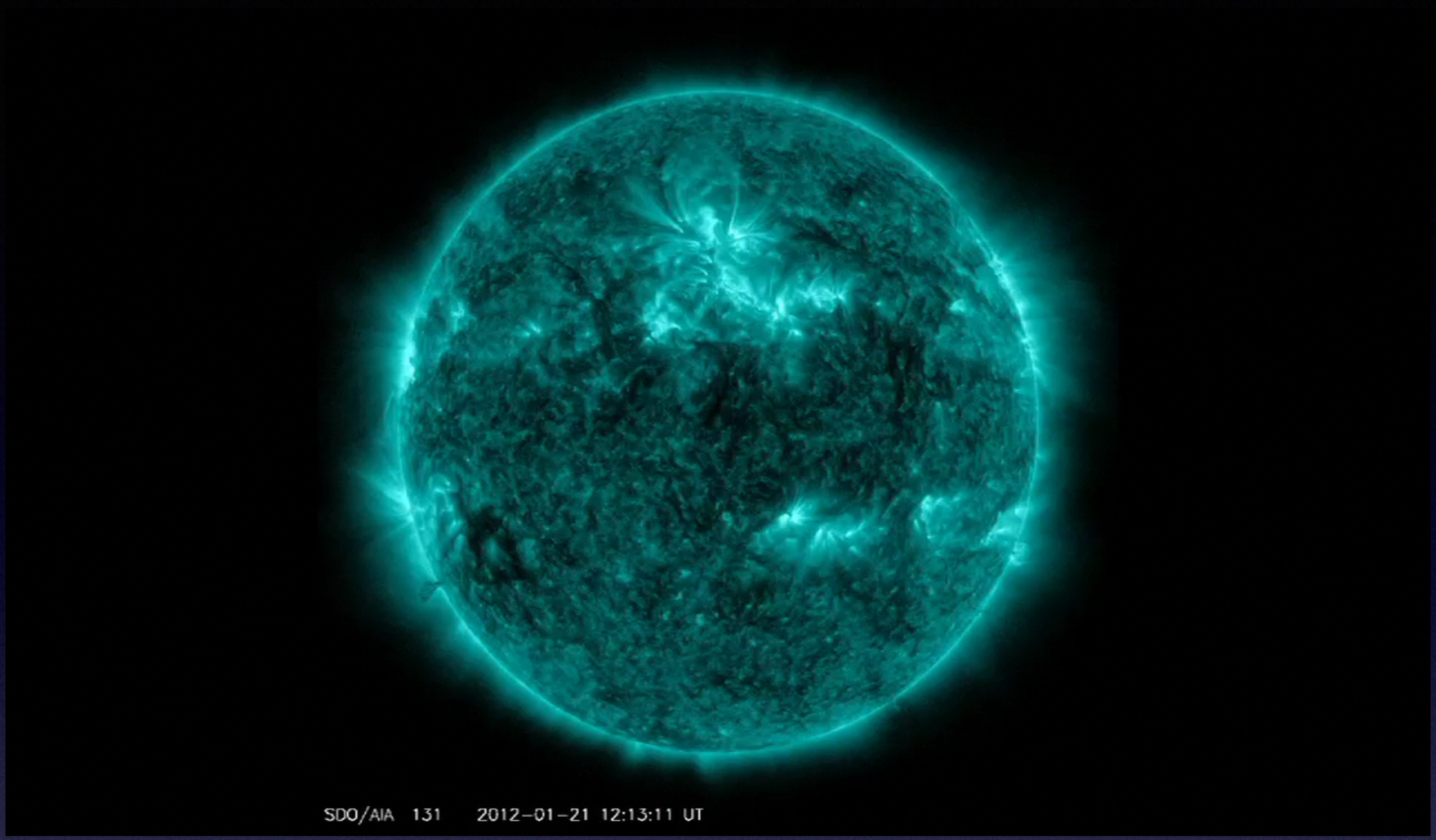


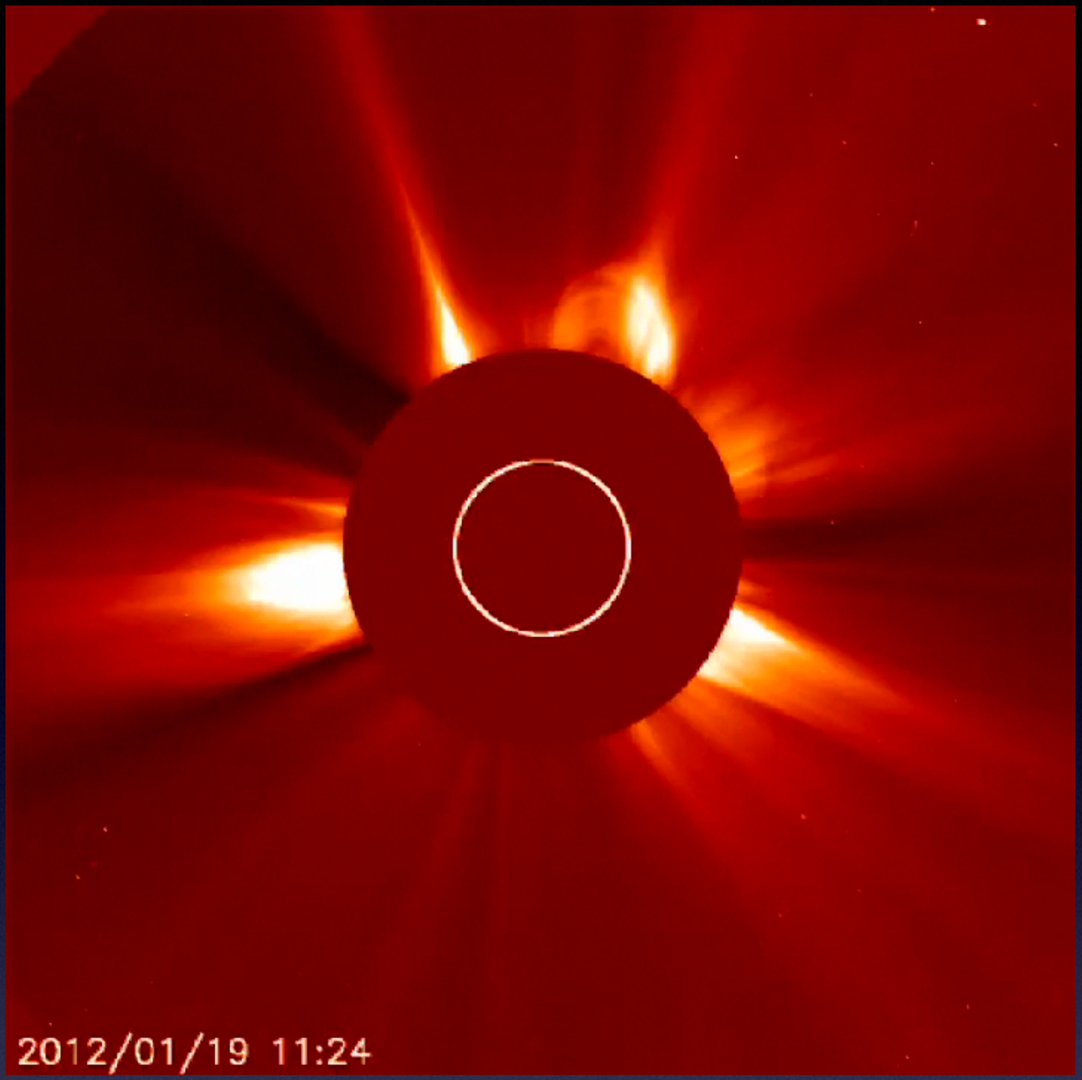
- Solar flares are characterized by a highly concentrated, explosive release of energy, usually in the form of *X-rays* (low flux).

These are huge bubbles of plasma (*ionized atomic matter with high kinetic energy*) threaded with magnetic field lines that are ejected from the Sun's corona (*outer atmosphere*).

- The movement of the shock waves associated with CMEs and solar flares can give rise to magnetic storms.

- The magnetic field generated perturbs the Earth's main magnetic field, allowing particles to reach previously unattainable altitudes and inclinations(enhanced displays of the Aurora Borealis and Aurora Australis). These lights are created by collisions between the particles and atmospheric gases.





- **Solar Dynamics Observatory** captured the flare (teal as that is the color typically used to show light in the 131 angstrom wavelength)
- The flare began at 10:38 PM ET on Jan. 22 2012, peaked at 10:59 PM and ended at 11:34 PM.

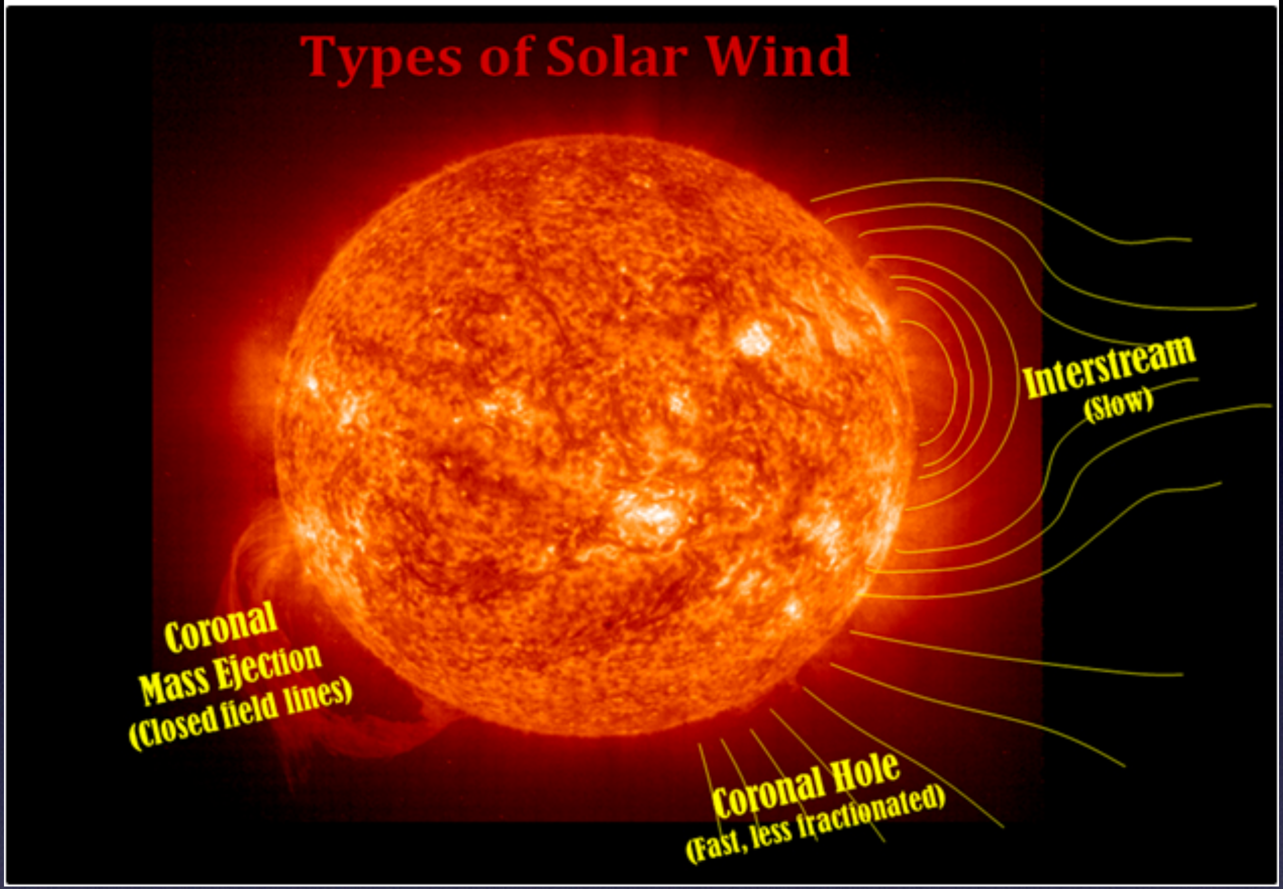
- The **Solar Heliospheric Observatory** captured the coronal mass ejection (CME) in this video (red/orange as that is the color typically used to show light in the 304 angstrom wavelengt)
- Shows the sun's activity from January 19 to January 23 2012.

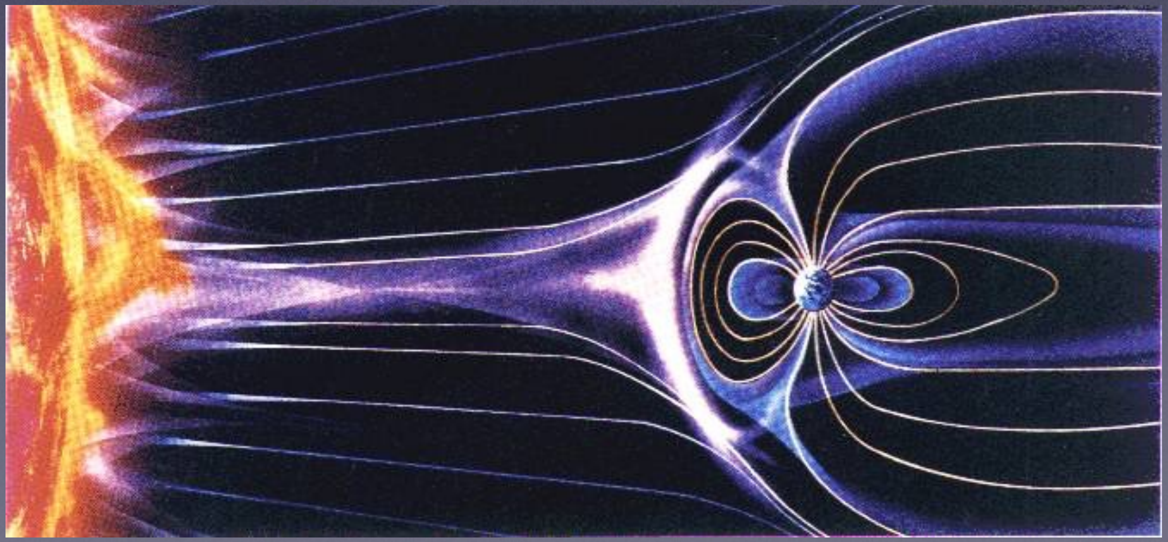
Source of radiation: Solar Wind

The solar wind is a stream of energized, charged particles, primarily electrons and protons, flowing outward from the Sun, through the solar system.

It differs based on where on the sun ii originates:

- Fast wind originates in **coronal holes** and reaches speeds up to 500 mi/s or 800 km/s.
- Slow wind originate at the **coronal streamer belt** around the equator, and travels more slowly, at around 200 mi/s or 300 km/s.





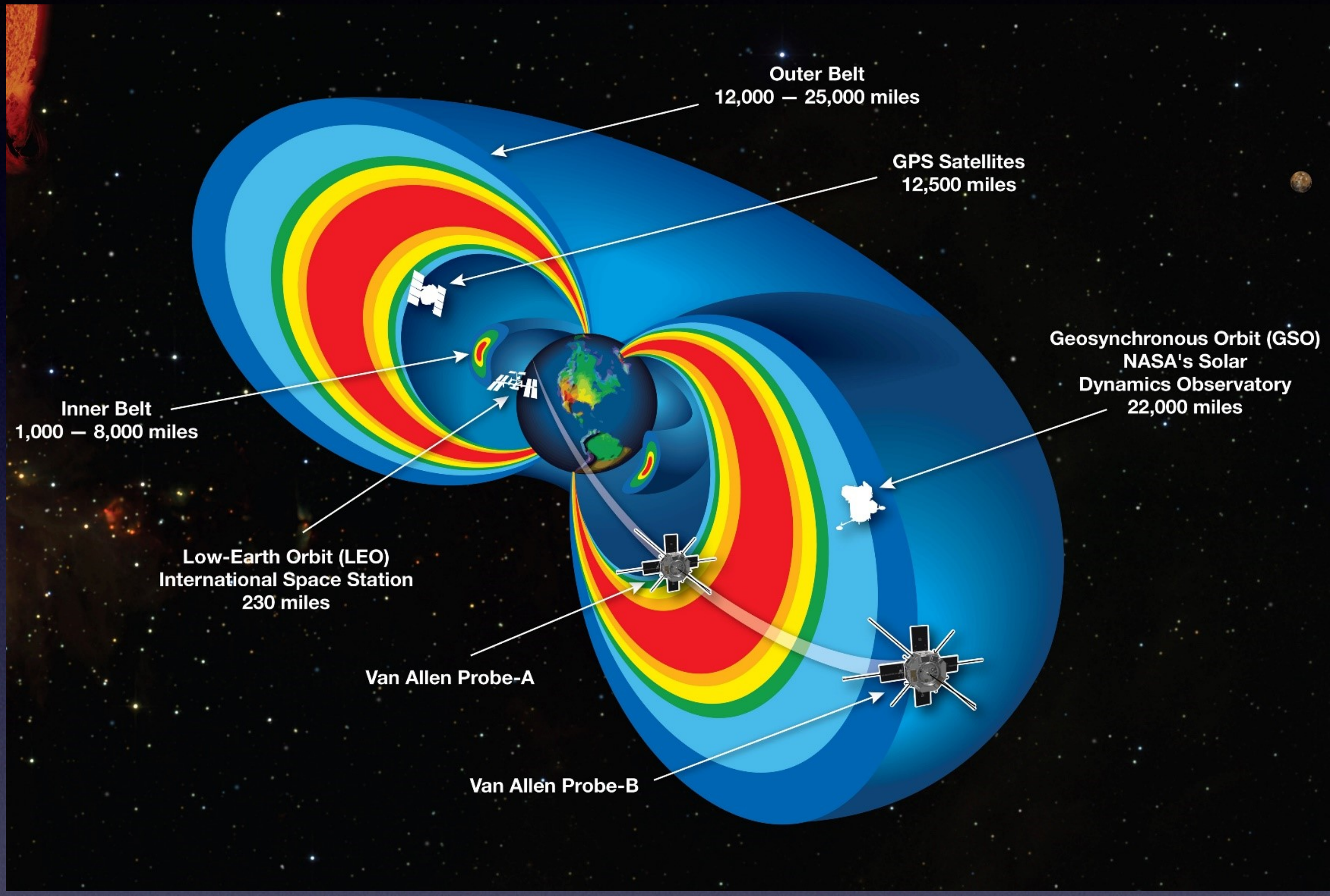
- **It compresses and confines the Earth's magnetic field on the side toward the Sun and stretches it out into a long tail on the night side (magnetosphere).**

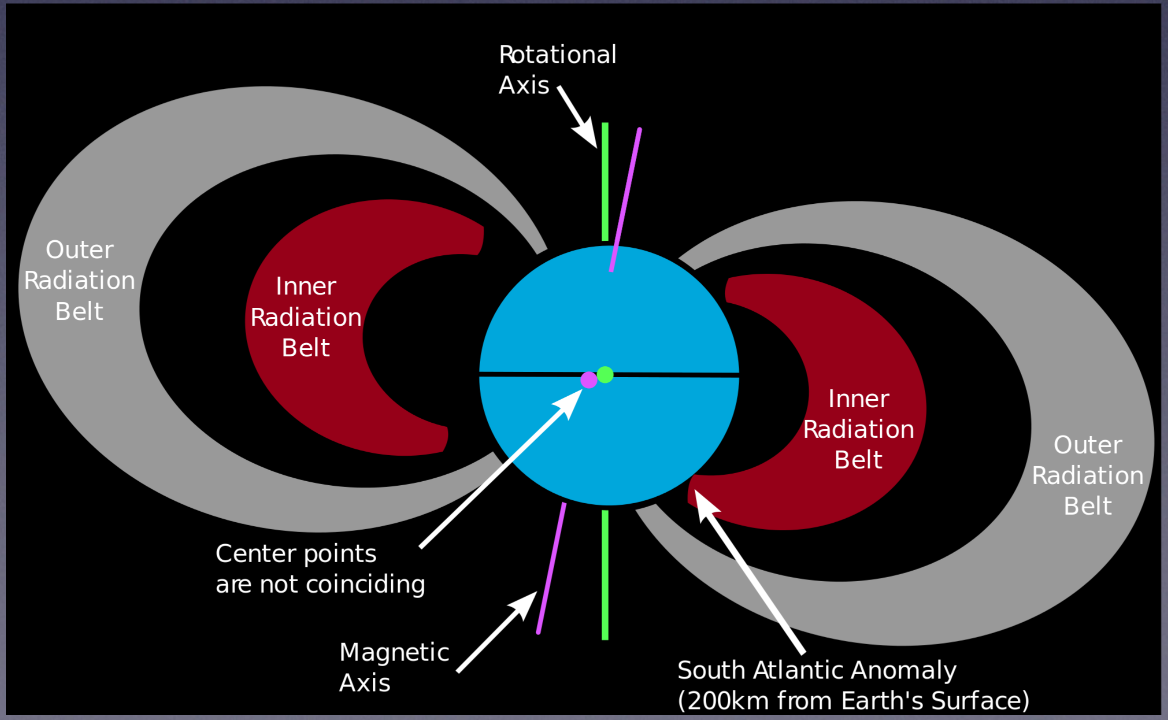
Source of radiation: Trapped particles

- Some particles become trapped in the Earth's magnetic field.

- These particles are contained in one of two doughnut-shaped magnetic rings surrounding the Earth called the Van Allen radiation belts.
    - The inner belt contains protons with energies exceeding 10 MeV (400-6000 mi)

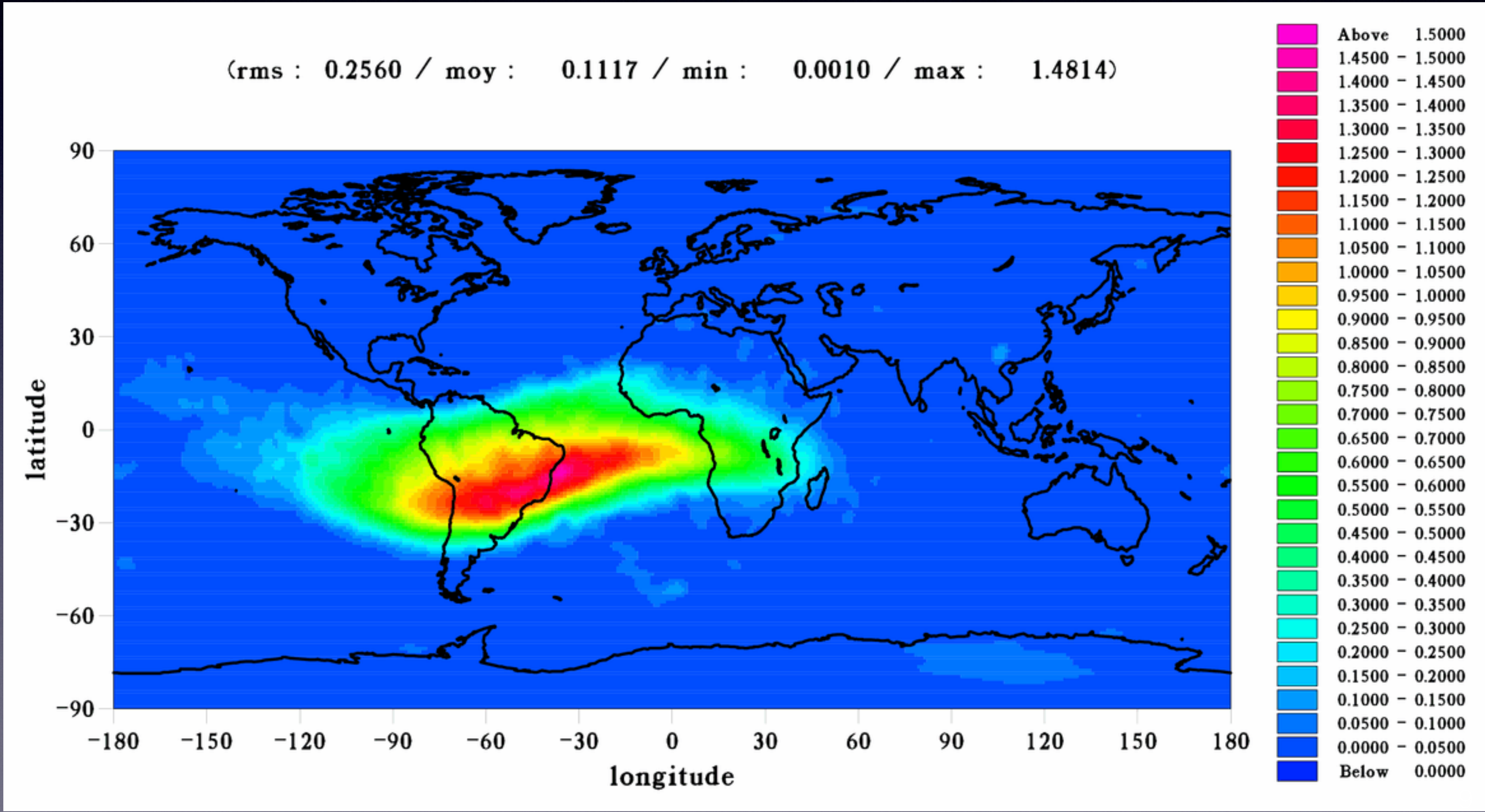
    - The outer belt contains mainly electrons with energies up to 10 MeV (8400-3600 mi).



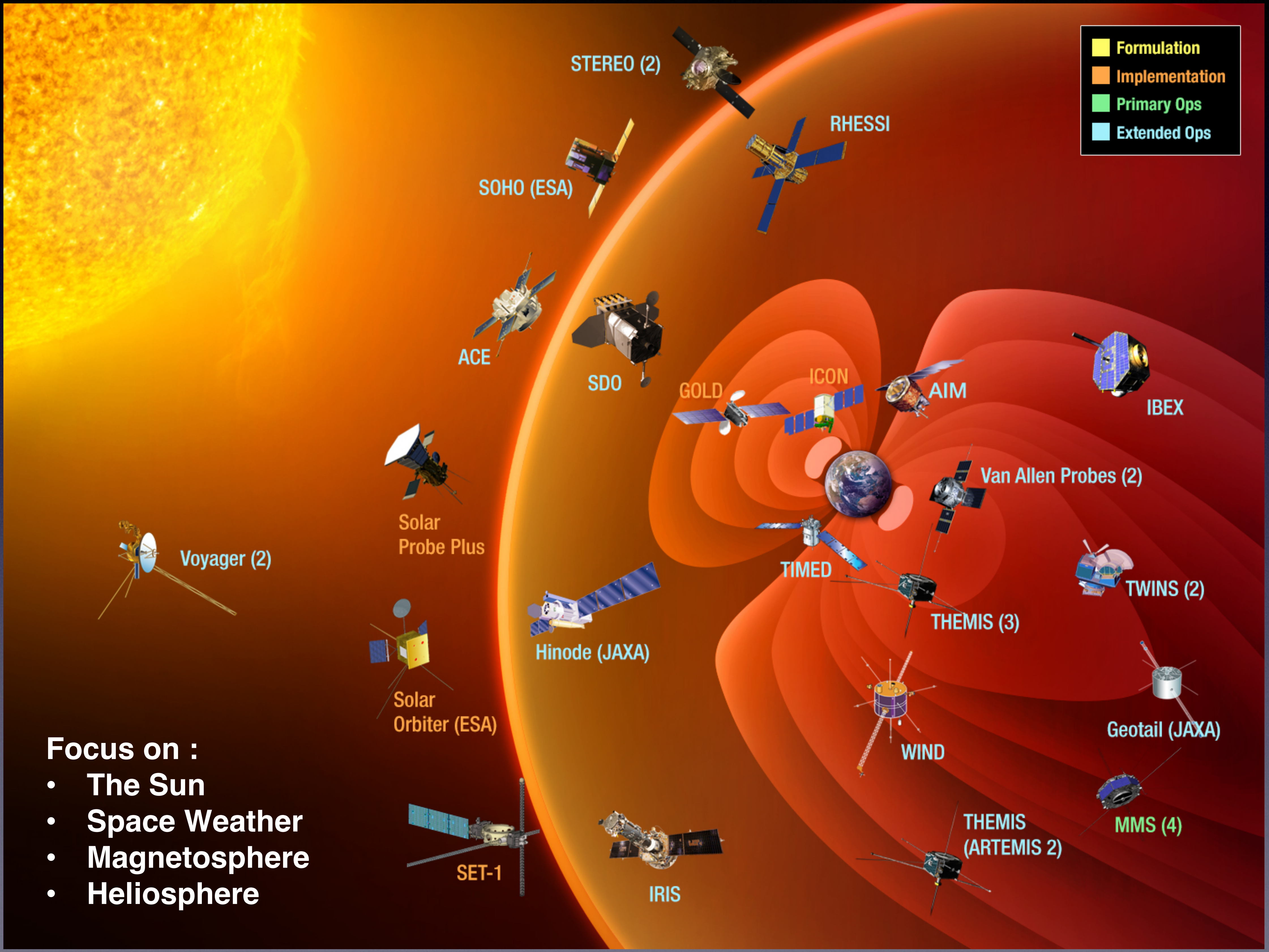


- There is a dip results from the fact that the magnetic axis of the Earth is tilted approximately 11 degrees from the spin axis, and the center of the magnetic field is offset from the geographical center of the Earth by 280 miles(South Atlantic Anomaly Anomaly reaching 120 mi).

Source of radiation: Trapped particles



Heliophysics Mission Fleet Chart



Focus on :

- The Sun
- Space Weather
- Magnetosphere
- Heliosphere

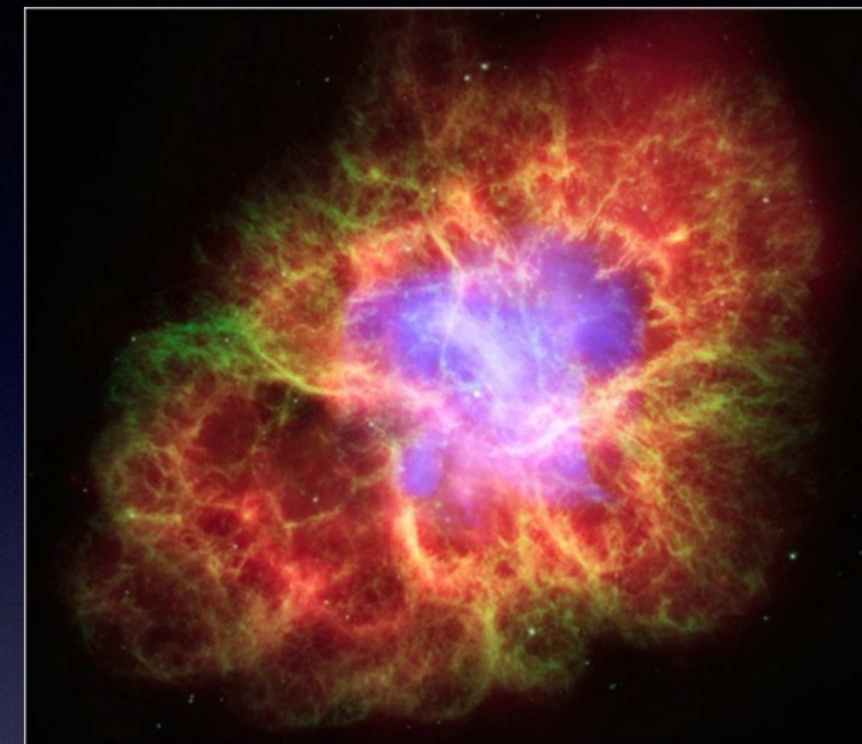
Source of radiation: Galactic Cosmic Rays

- Discovered on Aug. 7, 1912, physicist Victor Hess

- Galactic cosmic radiation is tought to originates outside the solar system but whithin the Milky Way.

- It consists of ionized atoms ranging from a single proton up to an uranium nucleus.

- It travel very close to the speed of light, and because it has a heavy elements componentsuch as iron, it produces intense ionization as they pass through matter..



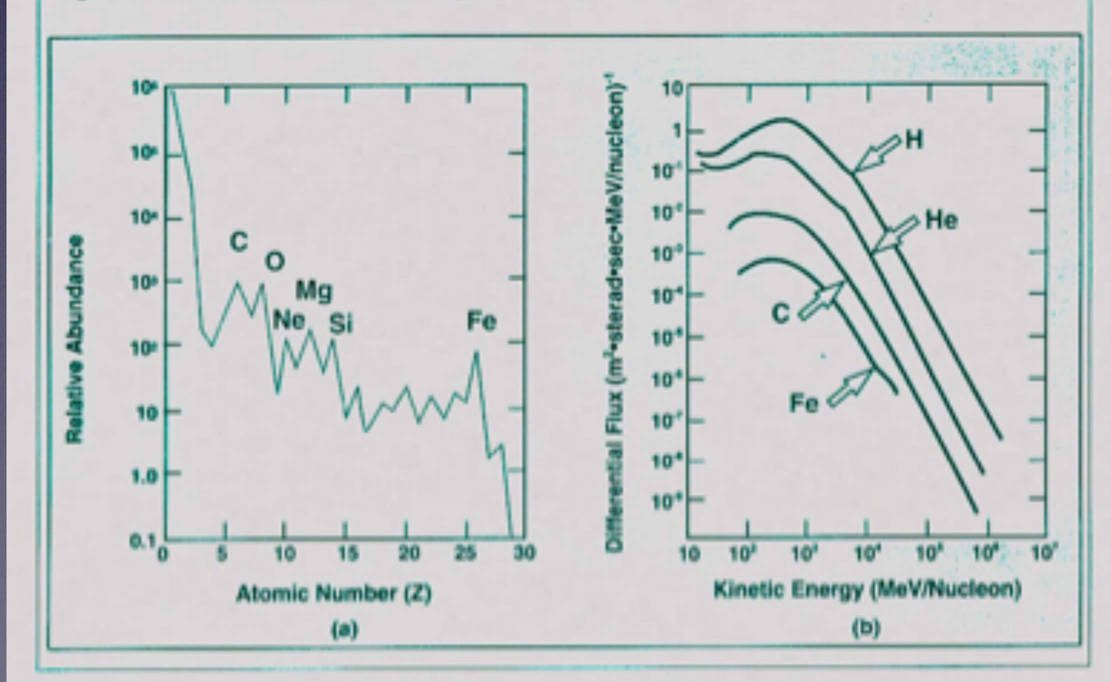
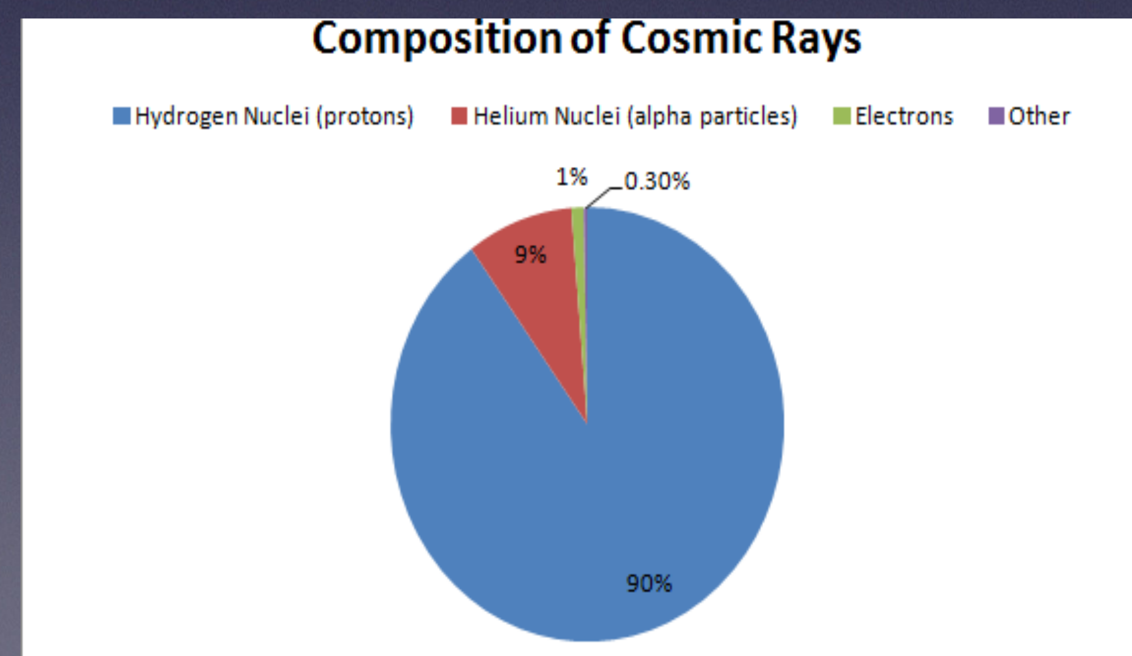
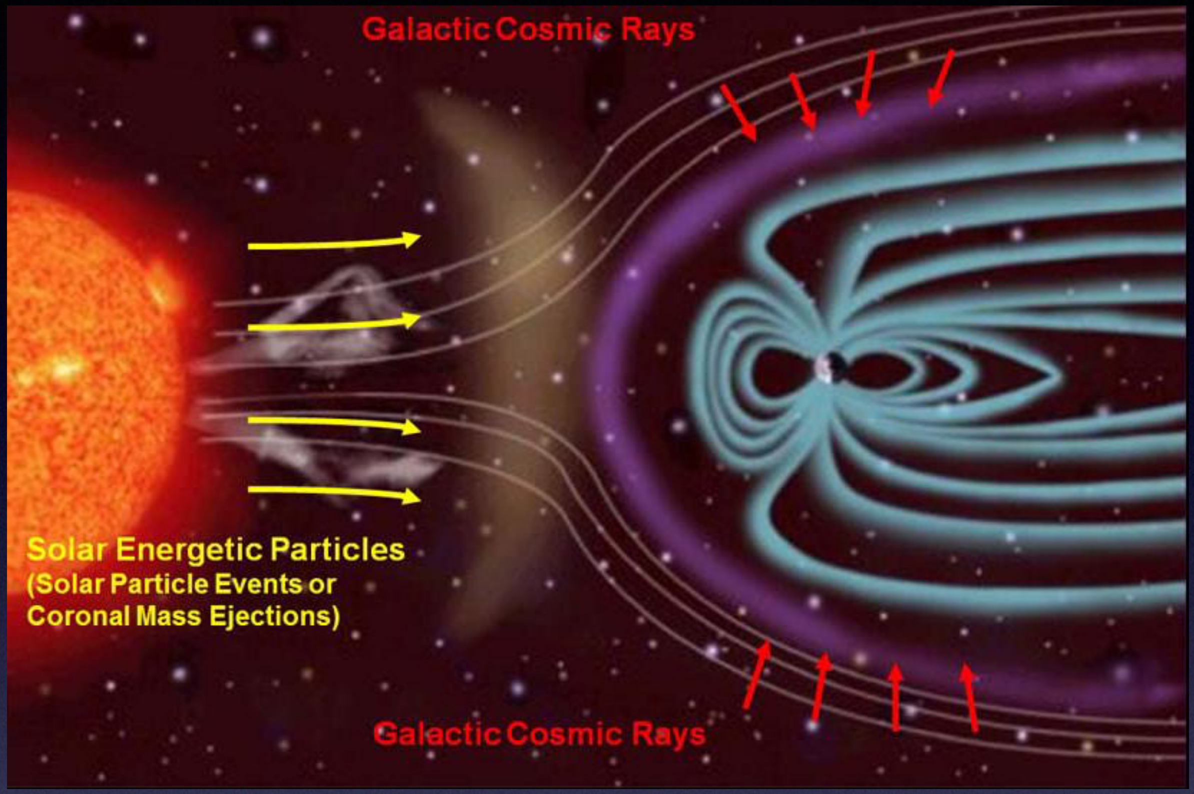
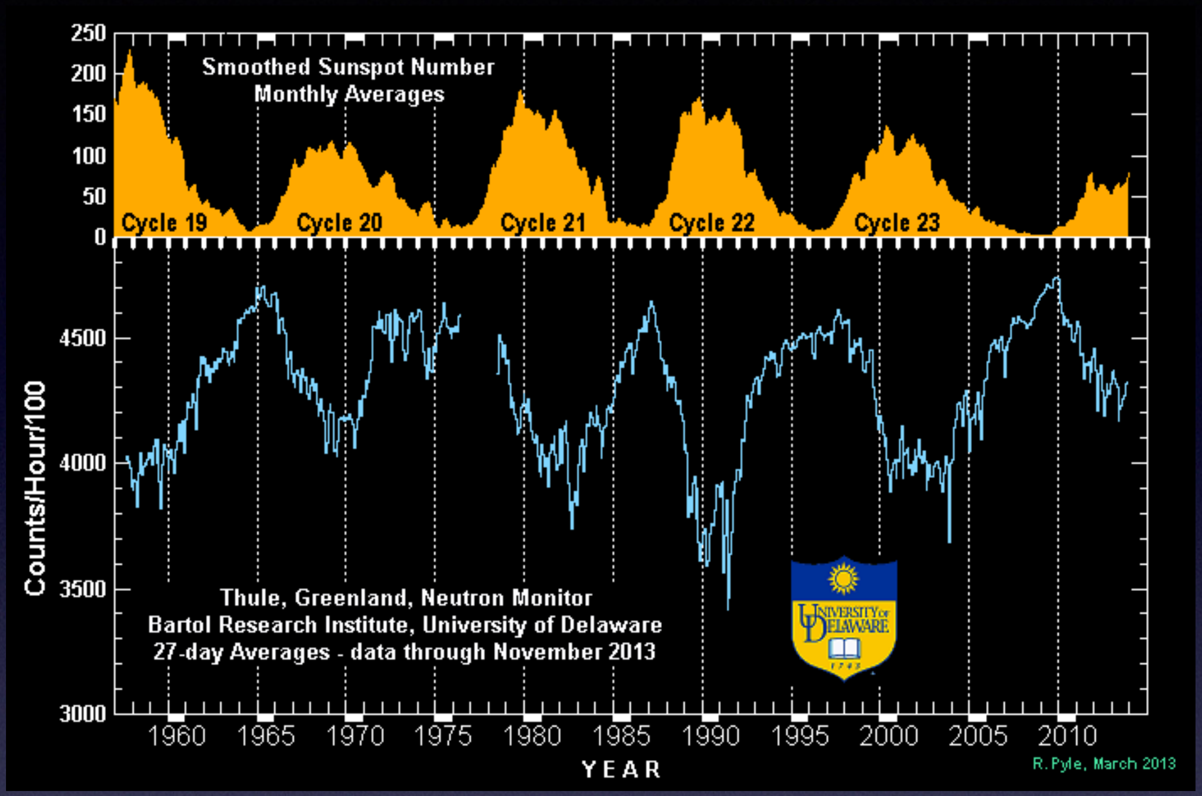


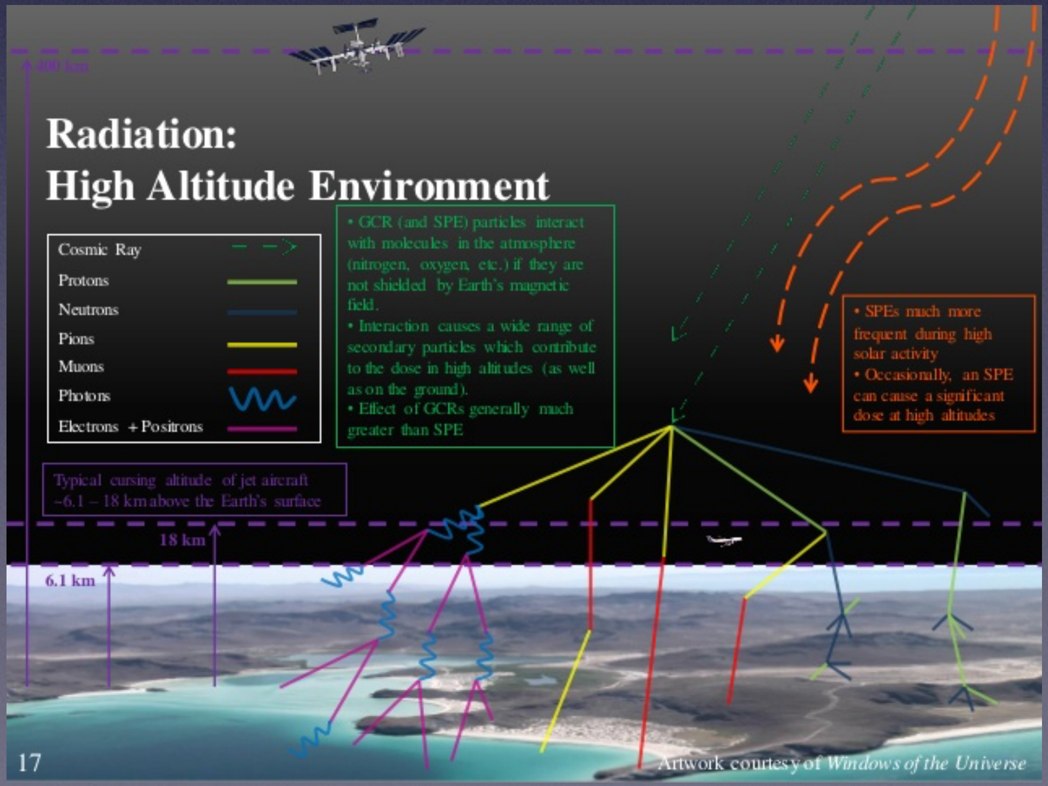
Figure D.1. Abundances (a) and Energy Spectra (b) of GCR



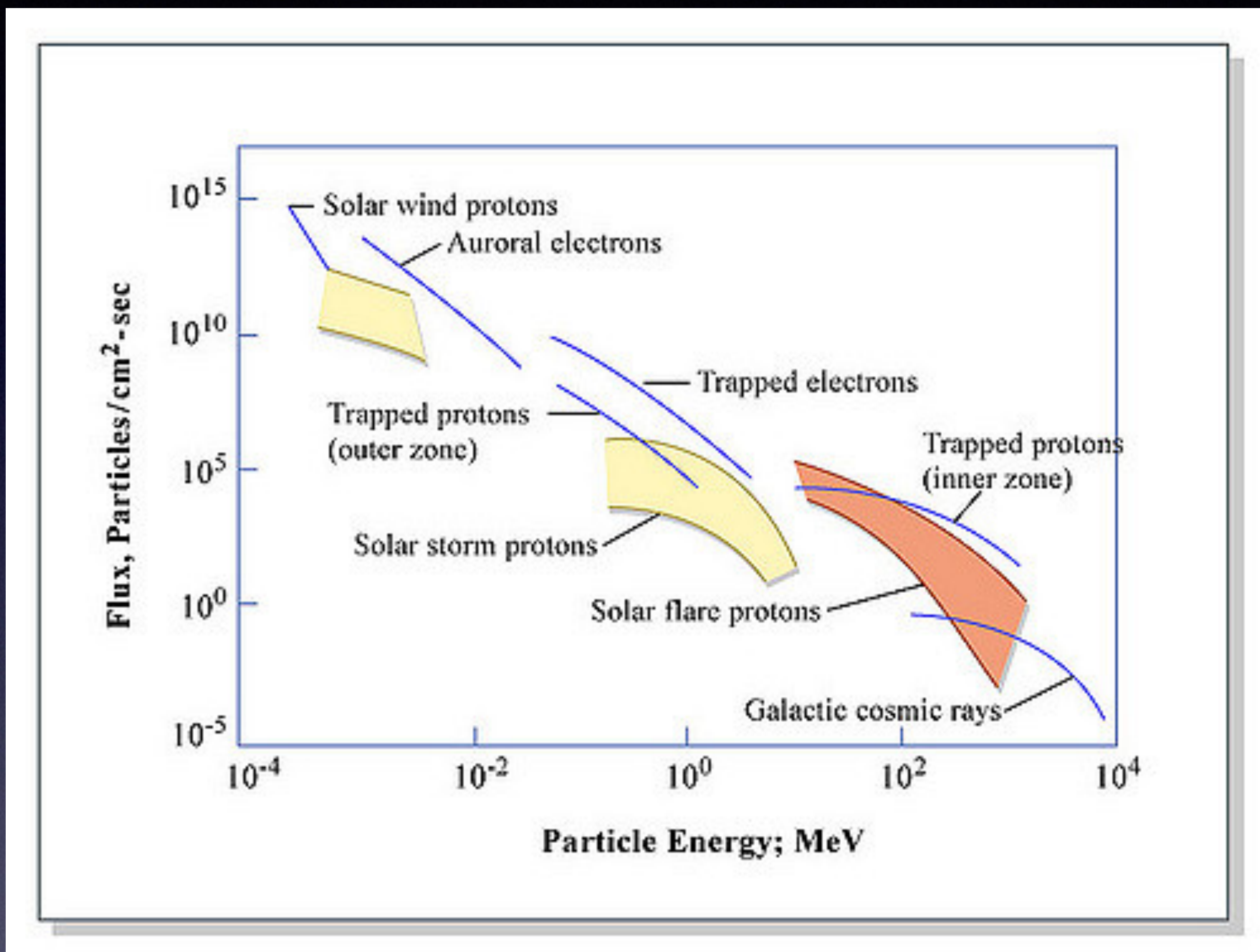
Source of radiation: The Big Picture

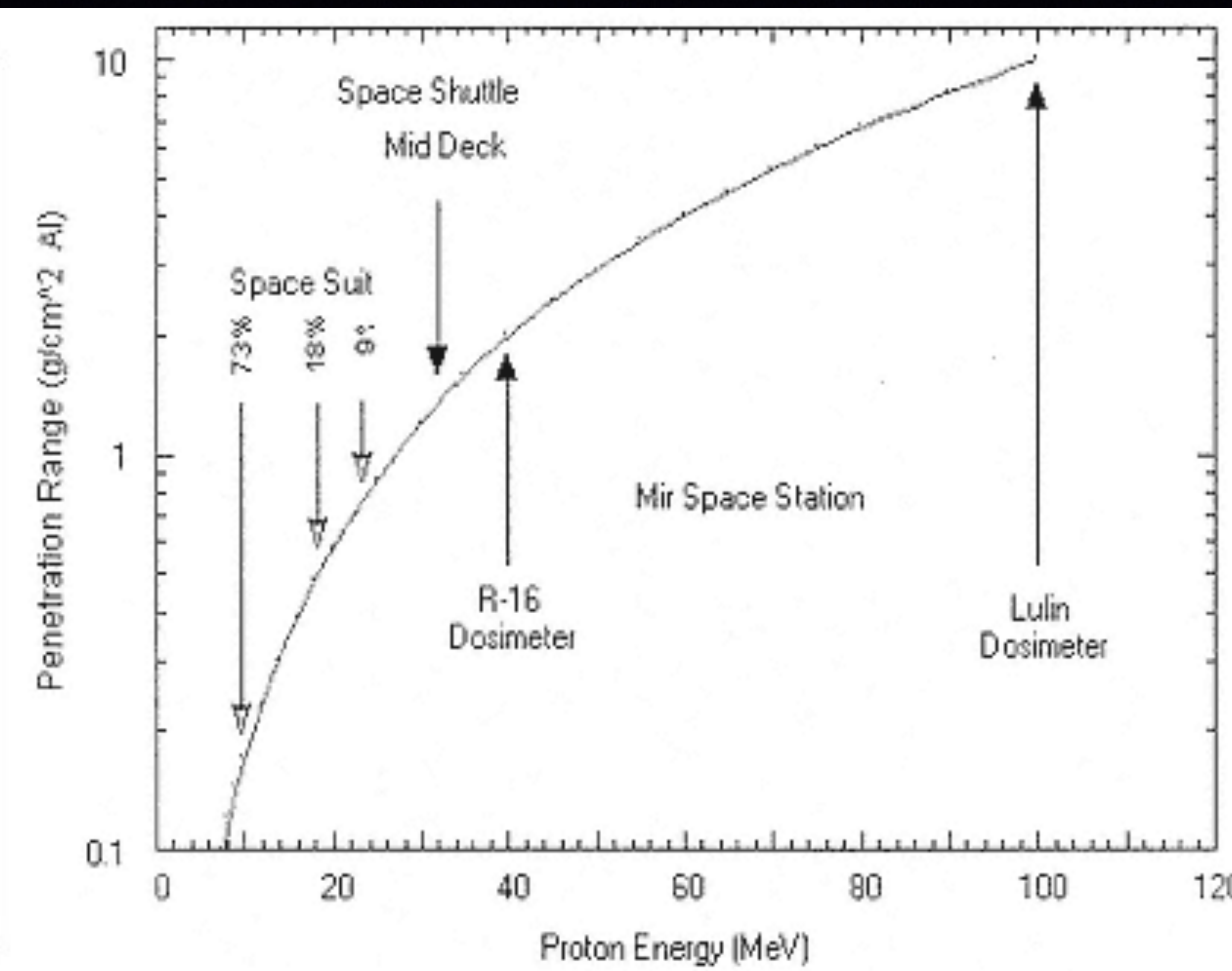




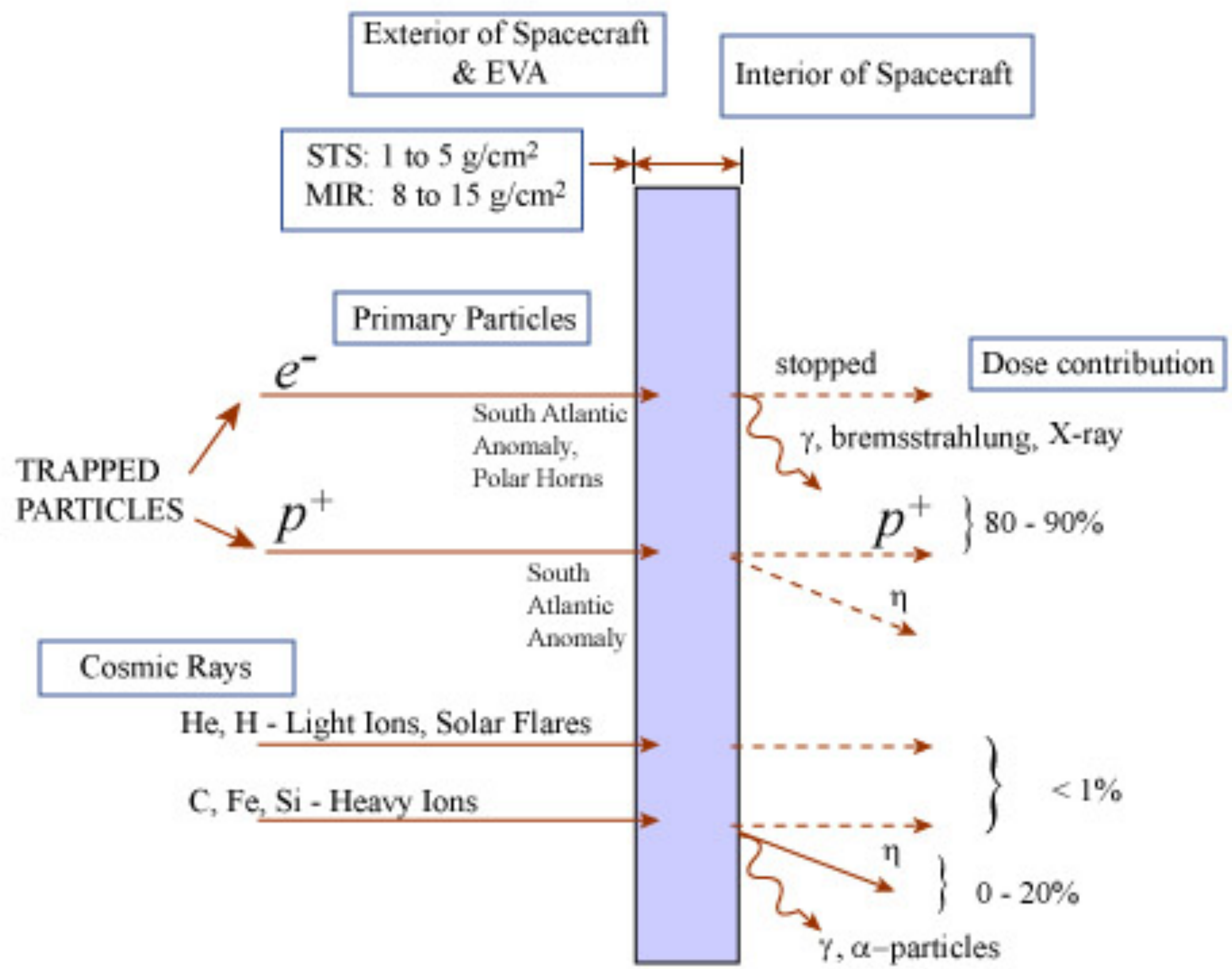


Source of radiation





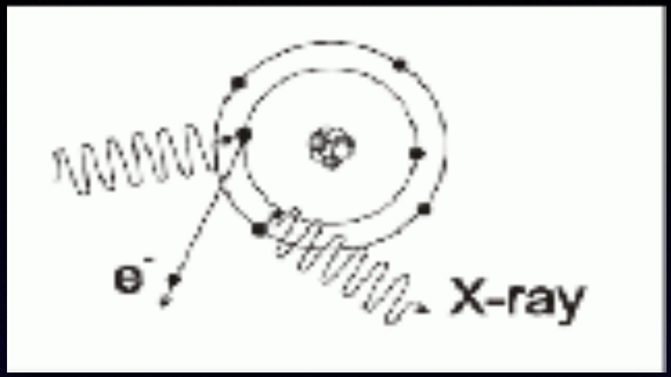
Source of radiation



Space radiation environment inside and outside spacecraft

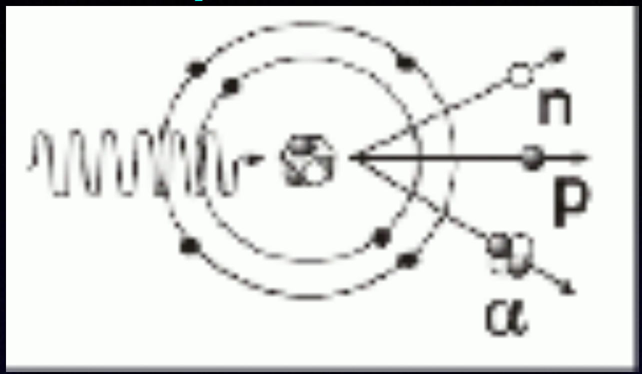
Photon interactions

Photoelectric effect



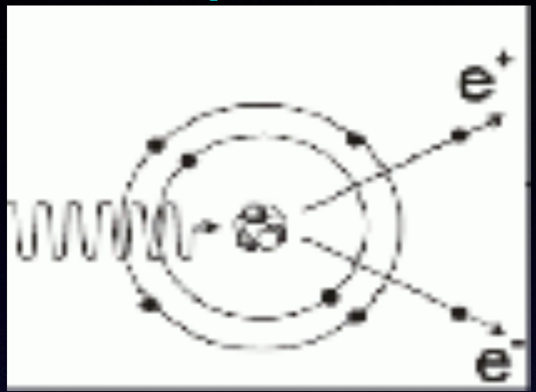
A photon (few eV) interacts with a bound electron in an atom.

Nuclear photoelectric effect



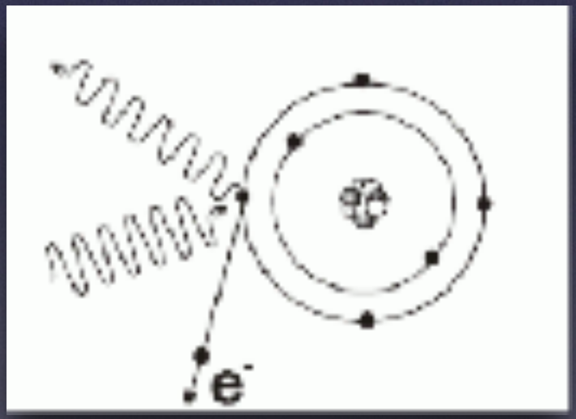
A photon (few MeV) interacts with nucleon in an atom

Pair production



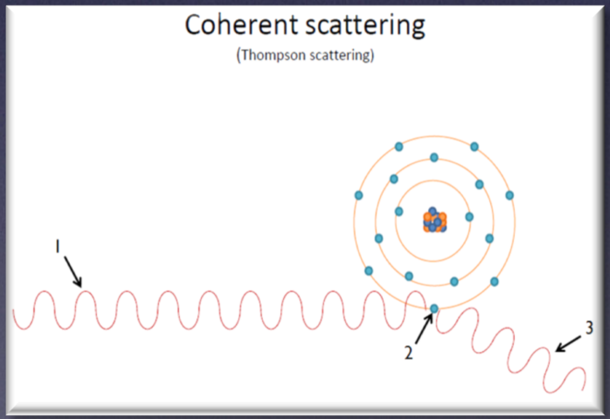
In pair-production effect, a high-energy photon near a nucleus gives up its energy to produce an electron-positron pair

Compton inelastic scattering



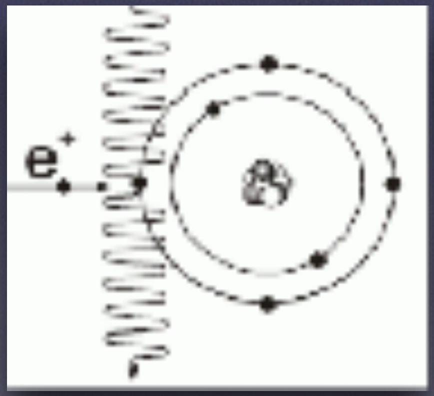
The Compton effect is essentially a collision between a photon and an electron

Thomson elastic scattering



Thomson scattering is the elastic scattering of electromagnetic radiation by charged particle

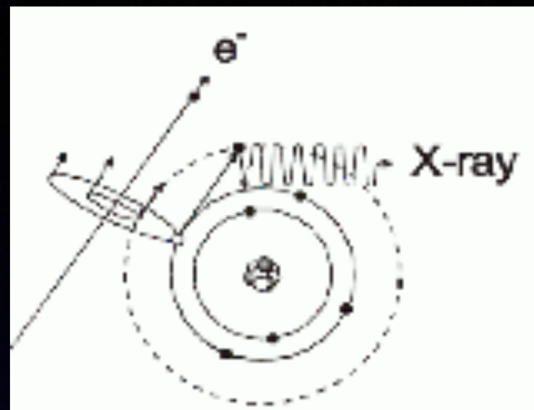
Annihilation



Interaction of particle and antiparticle with photon creation

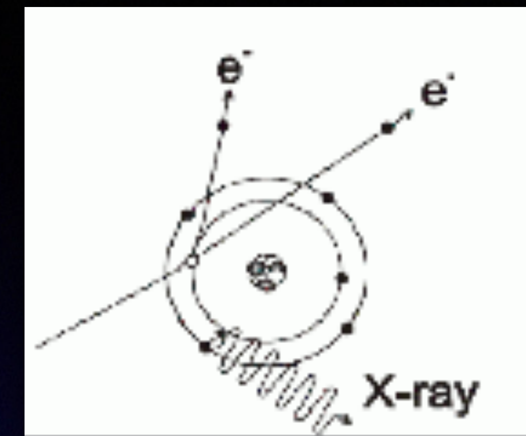
Electrons and ions

Excitation



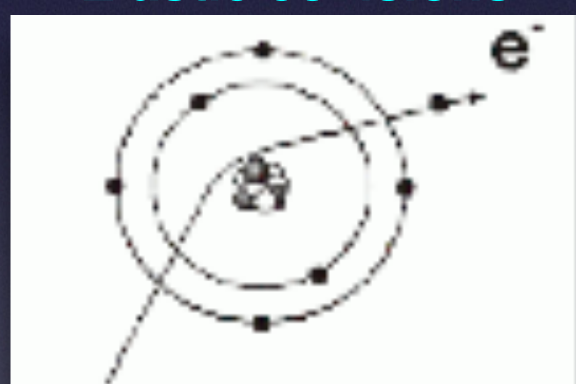
A bound electron is promoted from its atomic orbital *nl* to a less tightly bound orbital n'l', and the incident electron loses energy

Ionization



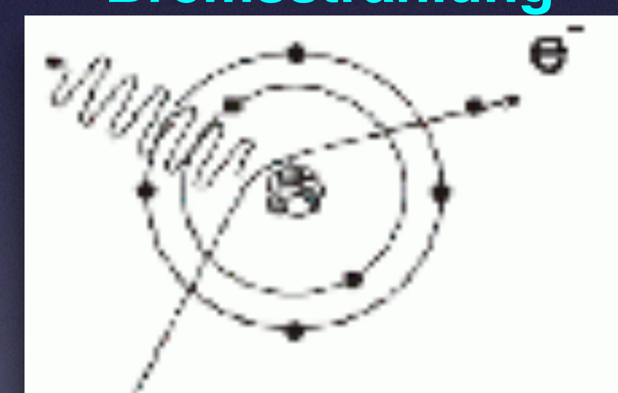
A bound electron is ejected from the atom

Elastic collisions



An electron interacts with the atom or its nucleus as a whole. The energy/momentum are redistributed, but no ionization or excitation occurs

Bremsstrahlung

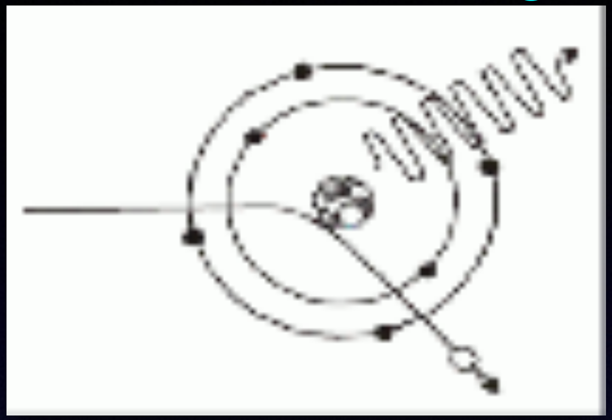


An electron emits radiation as it accelerates/decelerated within the atom or solid, according to the Maxwell equations.

Cerenkov radiation: electromagnetic radiation emitted when a charged particle passes through an insulator at a speed greater than the speed of light in that medium. The characteristic "blue glow" of nuclear reactors is due to Čerenkov radiation.

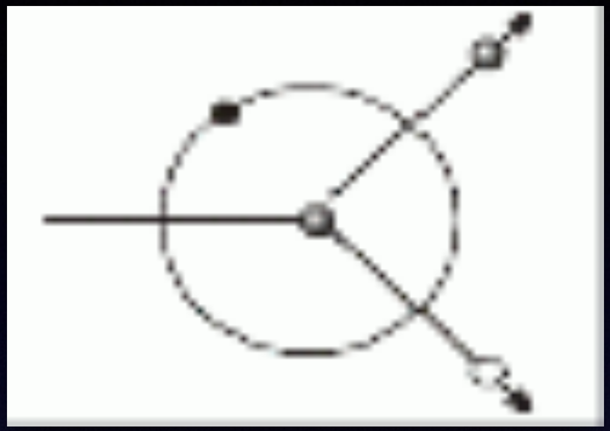
Neutrons interactions

Inelastic scattering



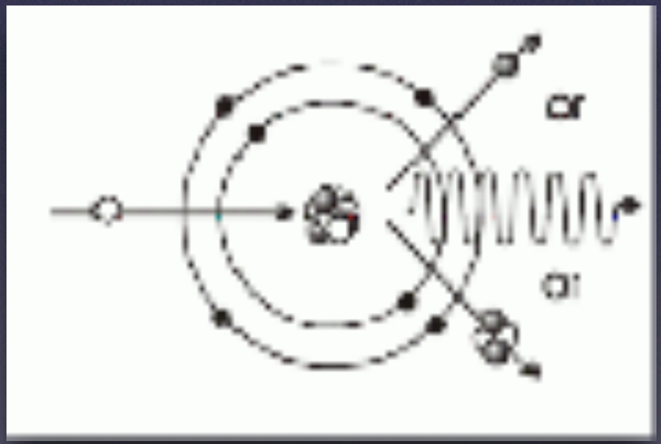
The nucleus is excited which is followed by the emission of radiation.

Elastic scattering



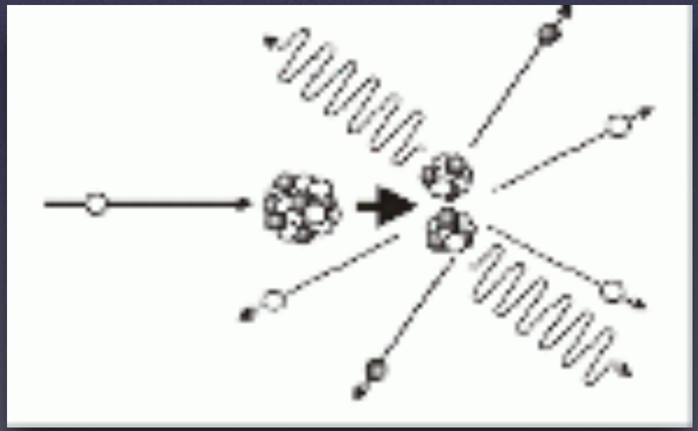
No internal excitation of the nucleus occur, takes place mostly between fast neutrons and low atomic number elements (“billiard ball effect”)

Radiative capture



The incident neutron is absorbed into the nucleus

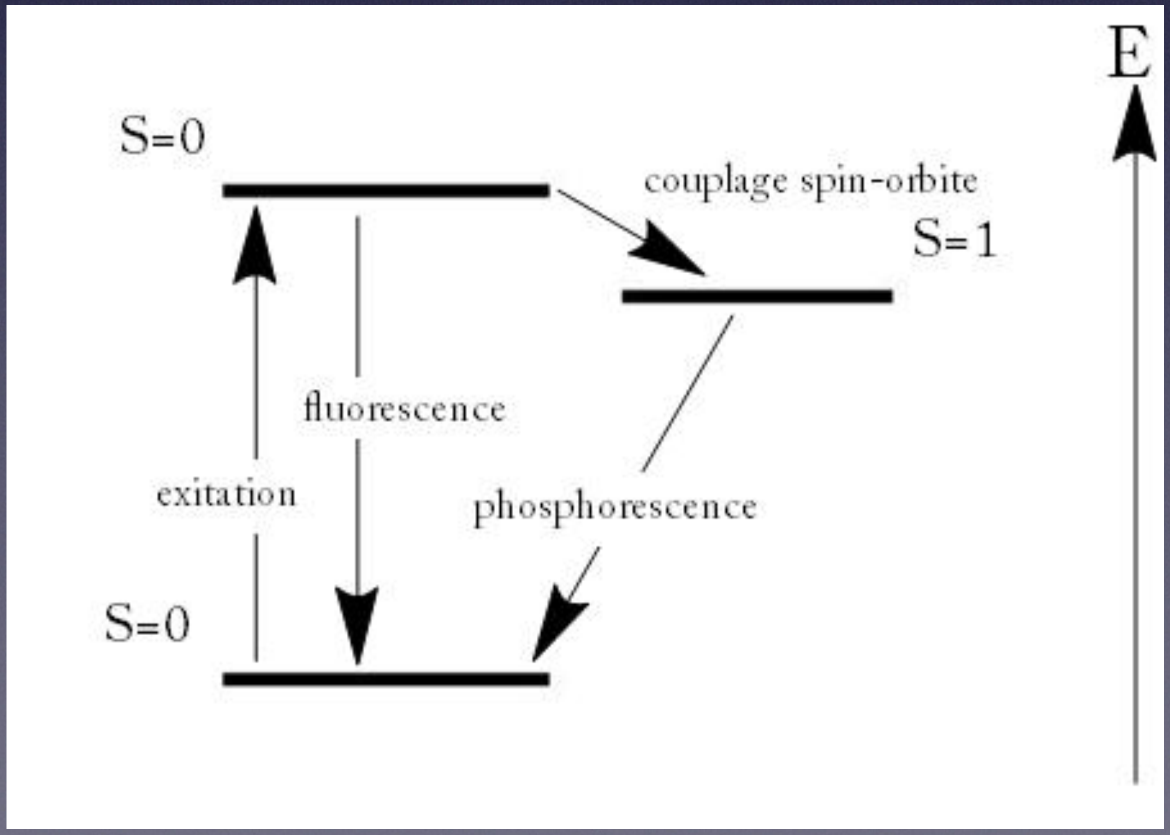
Fission

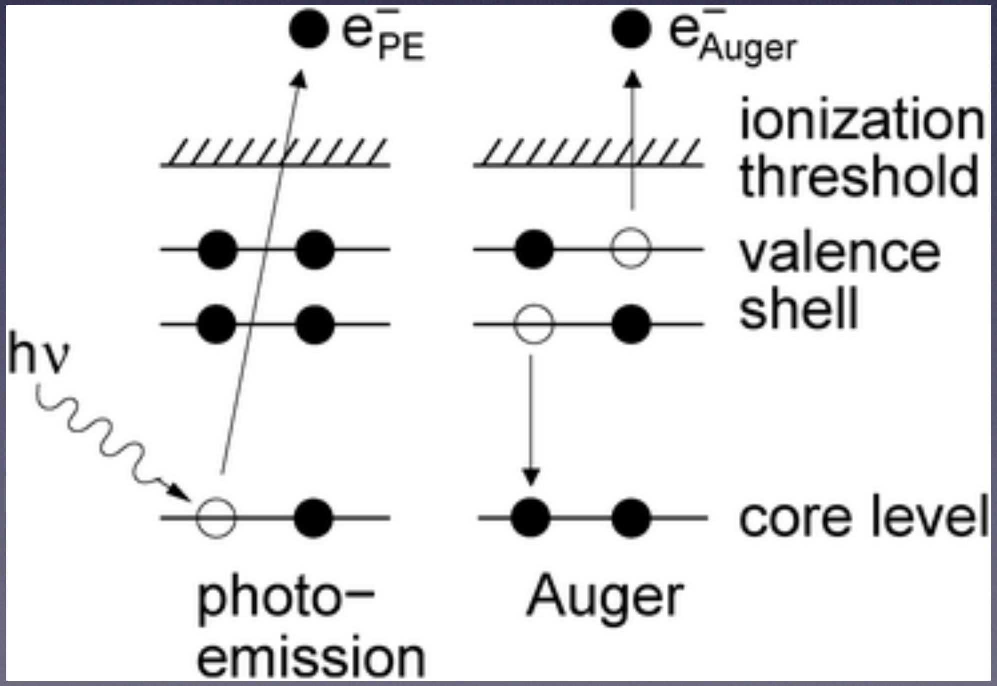


Dissipation of energy in the fission reaction can cause ionization of the medium

Radioactive decay

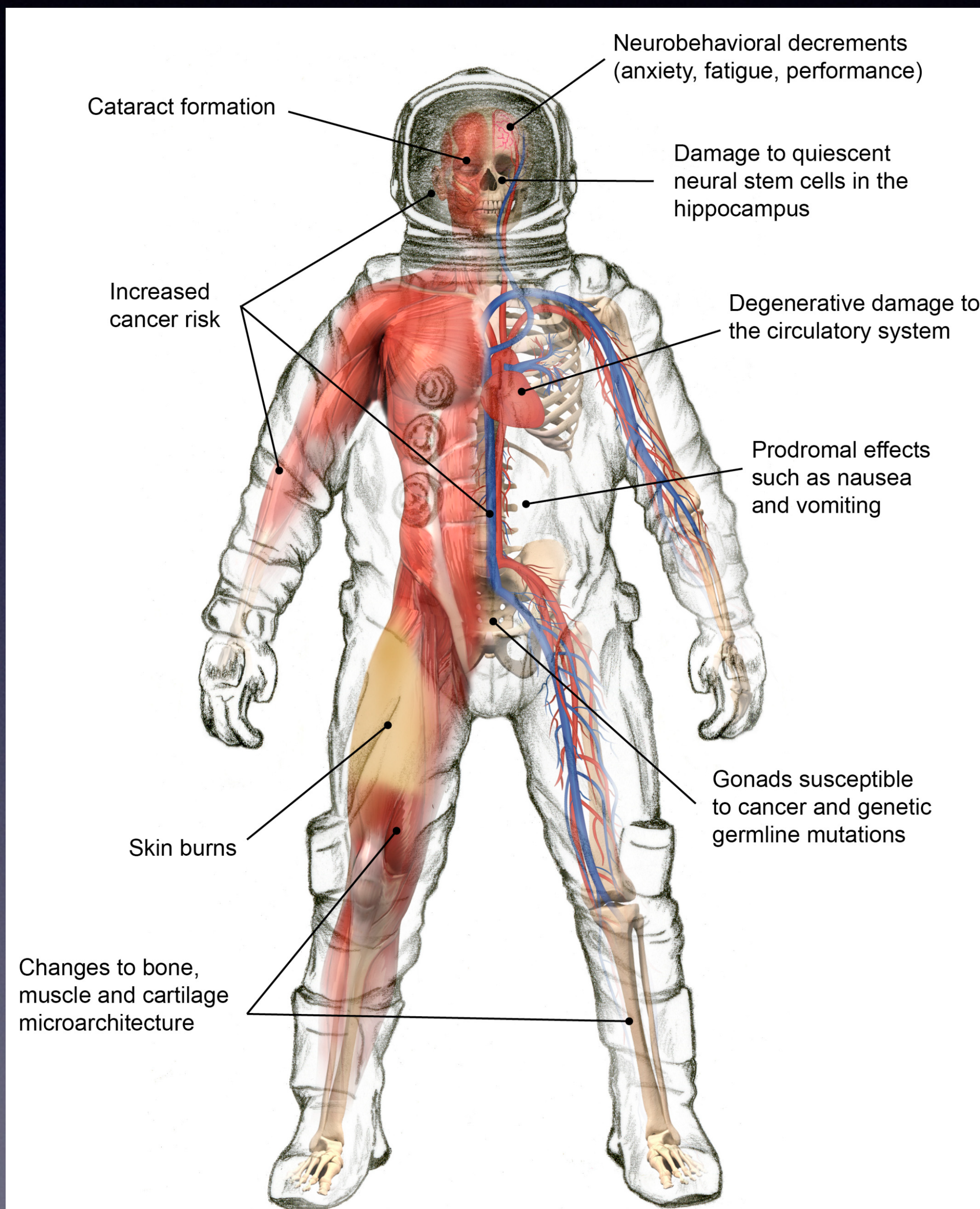
- The processes described above often leave the atom or ion in an excited state
- Radiatiove decay are fluorescence (fast) and phosphorescence (slow), that involve relaxation of the excited state by other means, so that the energy of the emitted photon can be much smaller than of the primary photon or other ionizing particle
- Auger processes release additional electrons from the system. Auger processes can occur in cascades, where the system decays step-by-step to lower energy states, in each step the inner-shell holes move towards outer shell and additional electrons are emitted.





Measuring radiation effects : dose

1 **Absorbed dose** is the concentration of energy deposited in tissue as a result of an exposure to ionizing radiation

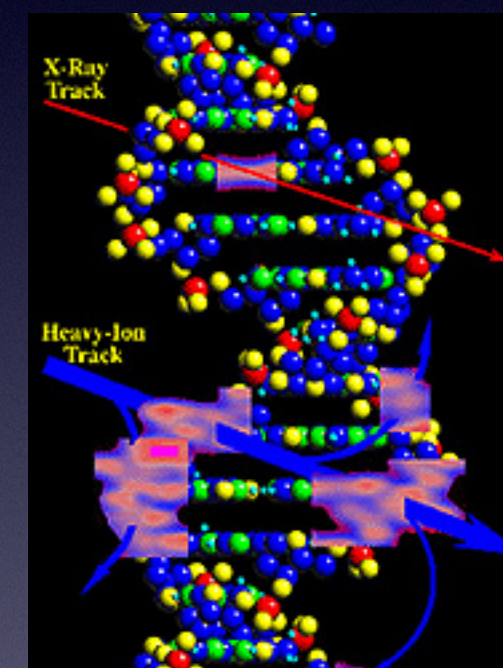


$$\dot{D} = \frac{\varphi A(-d\dot{E}/dx)\Delta x}{\rho A \Delta x} = \dot{\varphi}(-\frac{dE}{\rho dx})$$

- D – dose
- ϕ –fluence
- ρ- density
- A -area

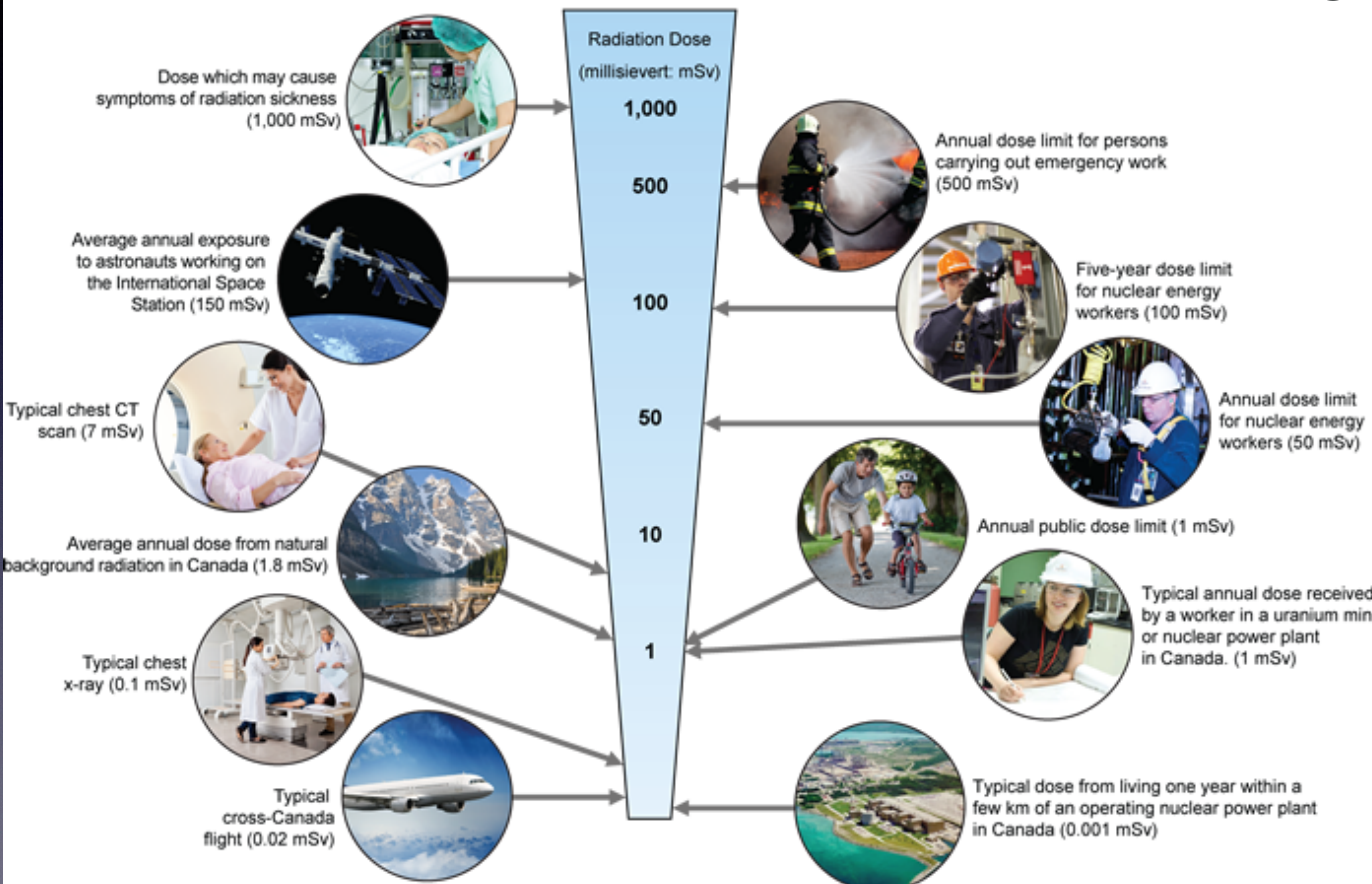
$D_{t,Si} = \frac{1}{m_{sensor}} \cdot \sum_{p_i}$

2. **Equivalent dose** is used to assess how much biological damage is expected from the absorbed dose. (Different types of radiation have different damaging properties.)



3. **Effective dose** is a calculated value, measured in mSv, that takes three factors into account:
   - the absorbed dose to all organs of the body,
   - the relative harm level of the radiation, and
   - the sensitivities of each organ to radiation.

Radiation Dose Examples



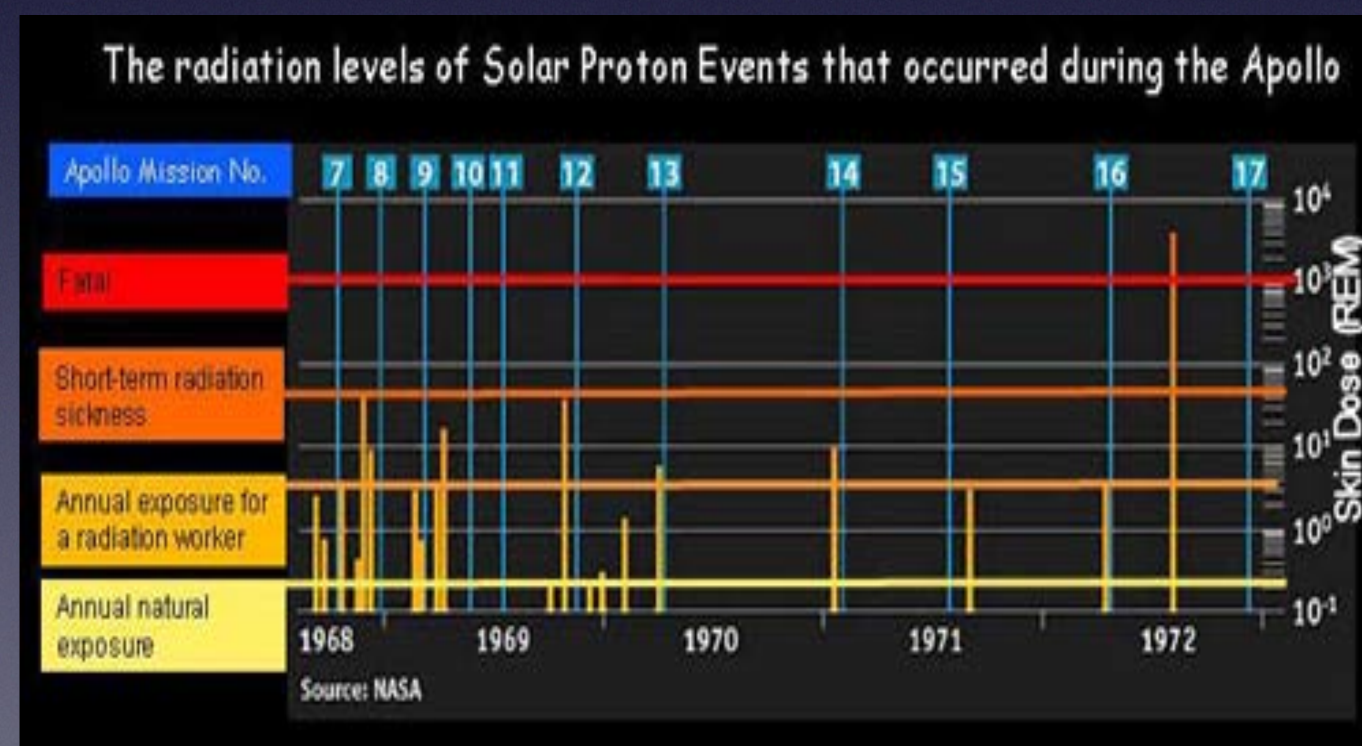
Astronauts Protection

- Astronauts receive the highest occupational radiation exposure

- Effective protection needed to ensure the safety of the astronauts on long duration missions.

- NASA's manned spaceflight missions have taken place within the Earth's magnetosphere(except for the Apollo missions to the Moon.

- Between the Apollo 16 and 17 missions(August 1972 : the crew of Apollo 16 had returned to Earth in April and the crew of Apollo 17 was preparing for a moon landing in December), one of the largest solar proton events ever recorded occurred, and it produced radiation levels of sufficient energy for the astronauts outside of the Earth's magnetosphere to absorb lethal doses within 10 hours after the start of the event.



- **Radiation protection for crew members remains one of the key technological issues which must be resolved.**

Astronauts Protection

- A number of parameters affect astronaut exposure to radiation.

1. the structure of the spacecraft,
2. the materials used to construct the vehicle,
3. the altitude and inclination of the spacecraft,
4. the status of outer zone electron belts,
5. the interplanetary proton flux,
6. geomagnetic field conditions,
7. solar cycle position,
8. EVA start time and duration.

SRAG considers all of these parameters in order to ensure that radiation exposures received by the astronauts remain below established safety limits. Specific components of this responsibility include:

(Console Operators Group)

- Providing radiological support during missions.
- Projecting pre-flight and extra-vehicular activity (EVA) crew exposures
- Evaluating radiological safety with respect to exposure to isotopes and radiation producing equipment carried on the spacecraft

(Physics Group)

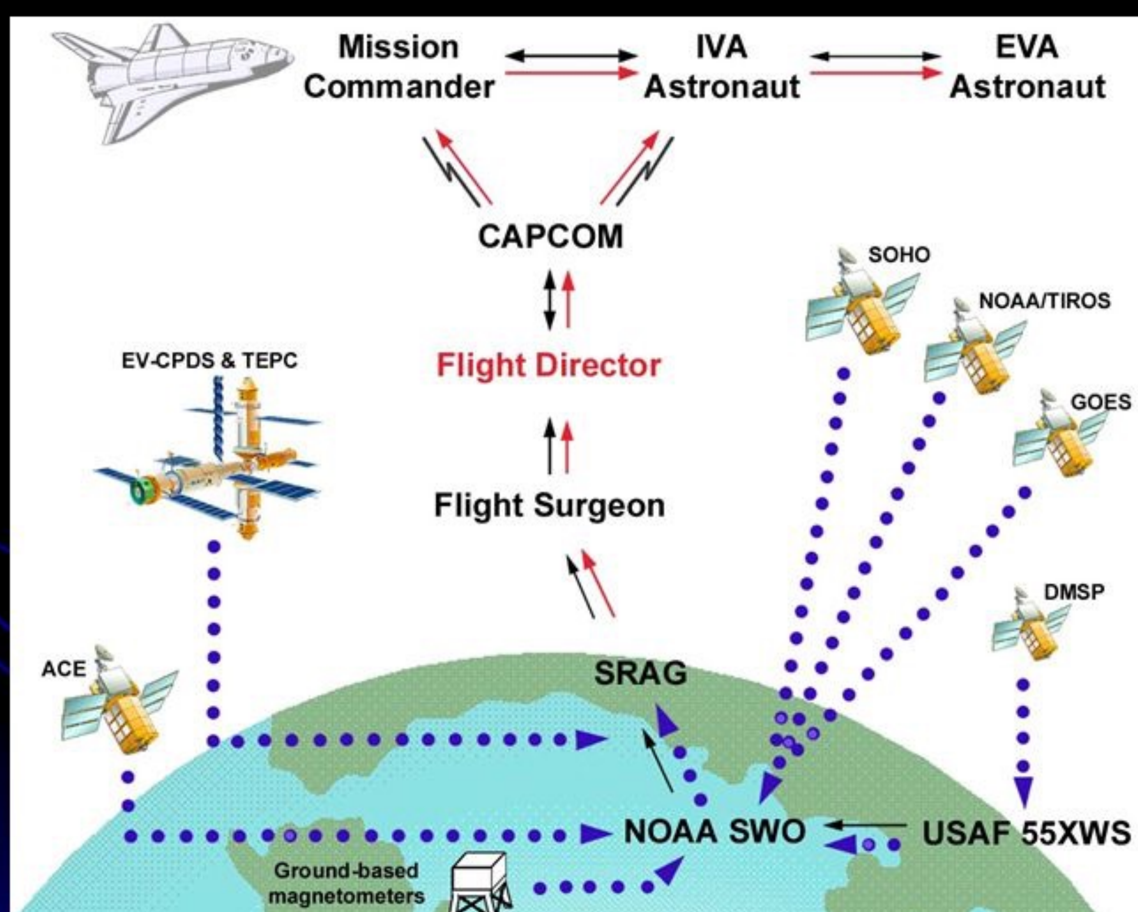
- Maintaining comprehensive crew exposure modeling capability.
- Providing radiation instruments to characterize and quantify the radiation environment inside and outside the spacecraft

Astronauts Protection

Console Operations Support

- 24 hours Contingency Support
- 4 hour/day Nominal Support

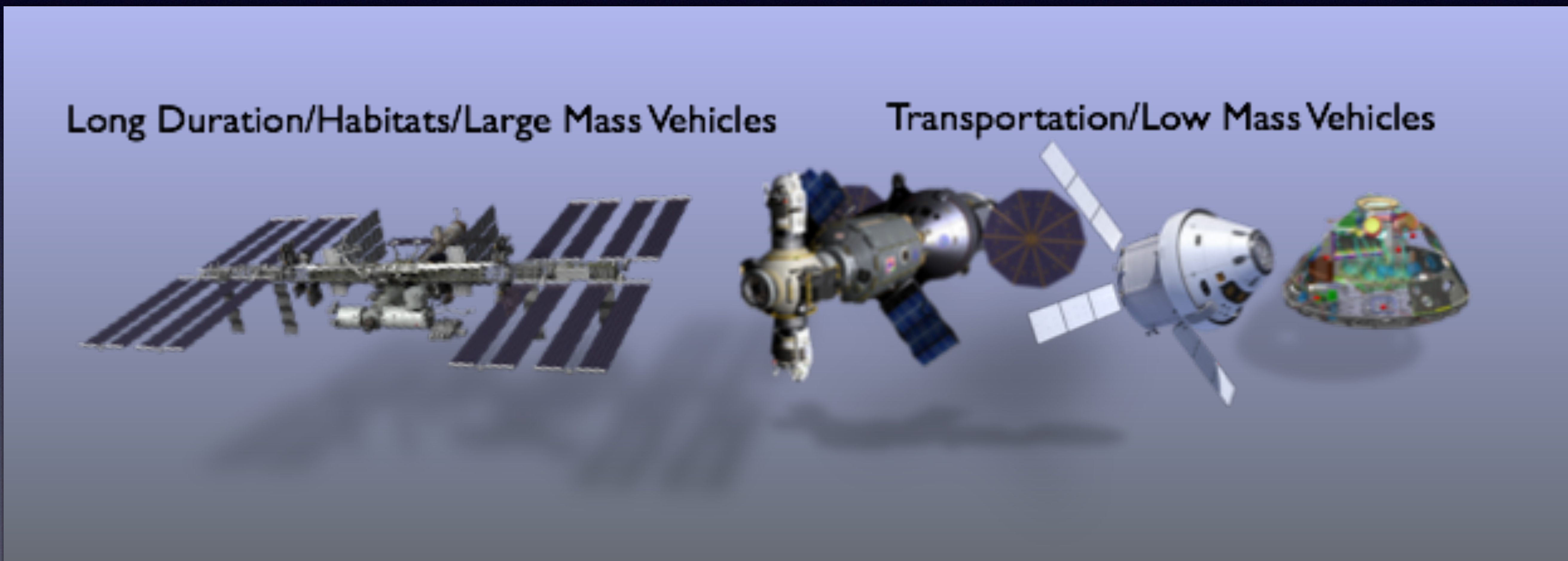
Operational Space Weather
Information Flow



Providing radiological support during missions:

- Projecting pre-flight and extra-vehicular activity (EVA) crew exposures
- Evaluating radiological safety with respect to exposure to isotopes and radiation producing equipment carried on the spacecraft

The vehicles



TECHNOLOGY FOR DOSIMETRY & SPECTROSCOPY

Dosimetry

IV-TEPC: Intra-Vehicle Tissue Equivalent Proportional Counter

- Broad sensitivity micro-dosimeter
- Made of A150 tissue equivalent plastic spheres(3 mm) filled with tissue equivalent gas (low density propane)
- Main alerting instrument on ISS

RAM: *Radiation Area Monitor*

- Planned for EM-1, but not for EM-2
- Each RAM consists of a small Lexan holder with 24 wells to accommodate the standard commercial TLD chip

CPD: Crew Passive Dosimeter

- Uses same technology as RAM;
- Will not be required for low mass vehicles
- May be replaced with CPAD for ISS

CPAD: Crew Personal Active Dosimeter

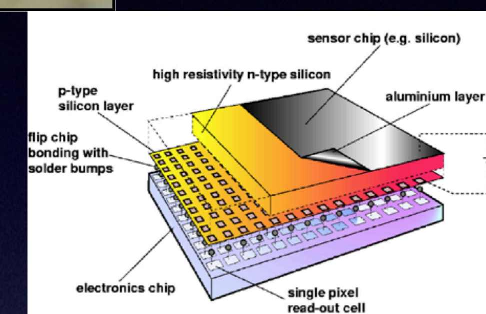
- Dose only, will test on ISS and use on EM-2
- p-n Si junction diode without external bias. Radiation creates electron-hole pairs in depletion layer

TECHNOLOGY FOR DOSIMETRY & SPECTROSCOPY

Spectrometers

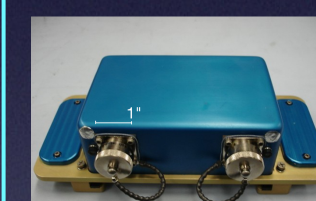
REM: *Radiation Event Monitor*

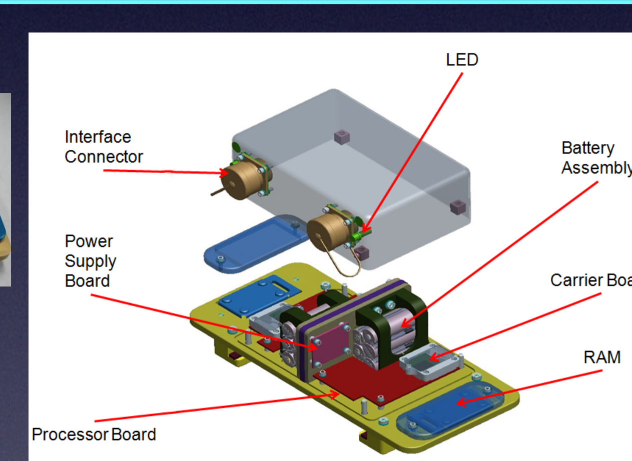
- limited particle + dosimetry
- uses Medipix technology with the expectations of creating the first personal space radiation dosimeter
- current radiation sensors must be returned to Earth for analysis, but the REM could provide dosage data more quickly.
- instruments provide high-spatial/contrast measurements for energy deposition along a particle's track;



BIRD: *Battery-operated Independent Radiation Detector*

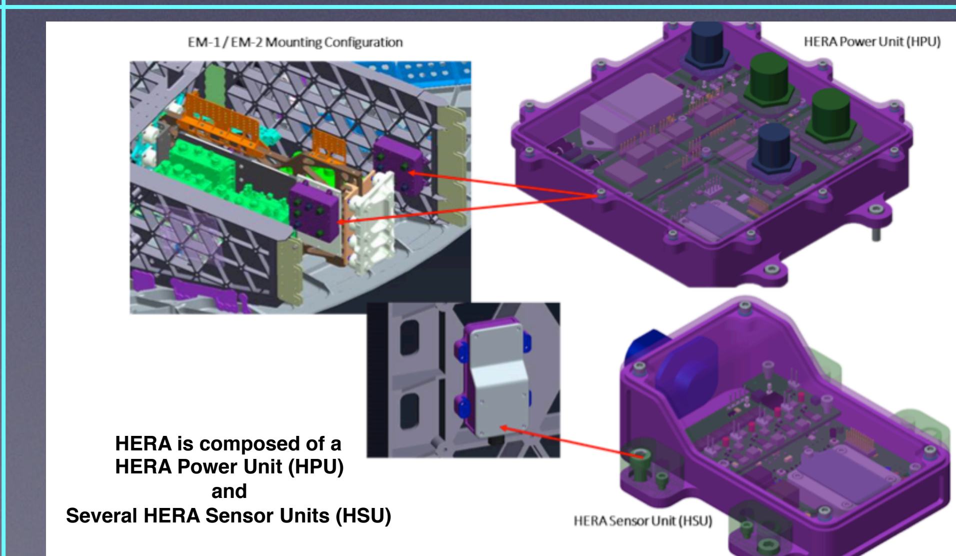
- limited particle + dosimetry;
- the Timepix assembly is mounted permanently to the carrier board
- first in-house built Timepix-based detector;
- successfully flown on EFT-1(december 2014)





HERA: *Hybrid Electronic Radiation Assessor*

- limited particle + dosimetry
- based on timepix technology and REM heritage
- will be integrated into vehicle
- will provide real-time data



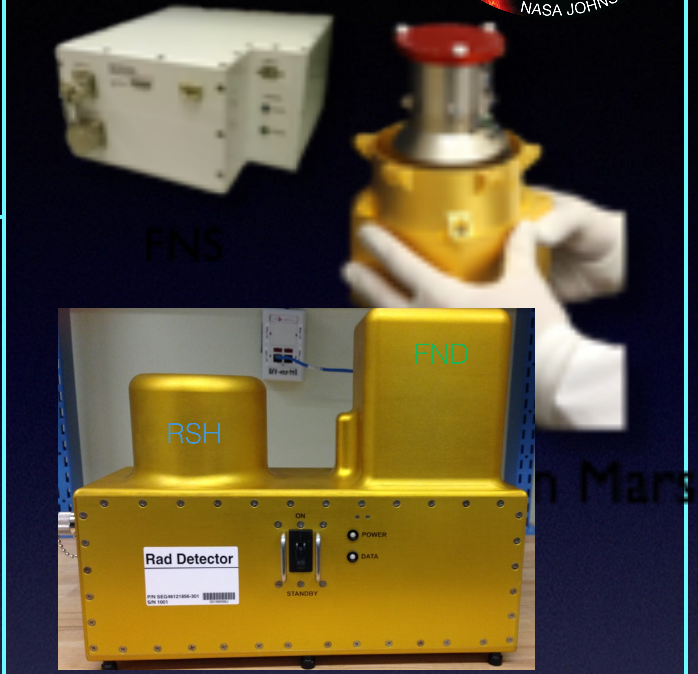
TECHNOLOGY FOR DOSIMETRY & SPECTROSCOPY

Spectrometers

Particle ID

CPS: *Charged Particle Spectrometer*

- current technology is ISS-Radiation Assessment Detector (RAD);
- is heritage-design from Mars Science Lab/RAD



NS: *Neutron Spectrometers*

- ISS-RAD:Fast Neutron detector - FND (natural boron loaded scintilator),
- Fast Neutron Spectrometer –FNS (uses special glass fibers loaded with Lithium to absorb the slowed neutrons and produce a small flash of light unique to the neutron capture process);
- technology from both will mature for future habitat

MPT: *Miniaturized Particle Telescope*

- low mass/power/volume particle spectrometer;
- stack of two-sensor TimePix detector capable of:

detecting protons and higher Z ions at energies from a few to >100 MeV/n and measuring the angular dependence of detected ions

- will fly on ISS as a payload Q2 FY17;
- potential to become new CPS

AMS-02: *Alpha Magnetic Spectrometer*

- State-of-the-art particle physics detector designed to operate on ISS;
- performs high-precision measurements of cosmic rays composition and flux

AMS-02

Data Usage for Model Improvements

Instrument	Impact
 AMS-02	Flux measurements will be used in updating GCR model. - Reduces uncertainty.
 MSL/RAD (on Mars)	Flux measurements used to benchmark transport of GCR through Mars surface. - Helps identify source of differences in transport codes.
 BIRD (EFT-1)	dE/dx spectra to be help improve AP9/AE9. - Reduces uncertainty.
 ISS-RAD	Flux measurements to help renormalize model and/or identify model discrepancies. - Reduces physics uncertainty in risk assessment.

Data Usage for Model Improvements

Thick GCR Shielding Project	Impact
	Beam measurements and multi-code benchmarks used to identify an optimal shield thickness for vehicle optimization and quantify uncertainty in thick shield transport calculations. - Helps identify source of data-model differences for ISS.

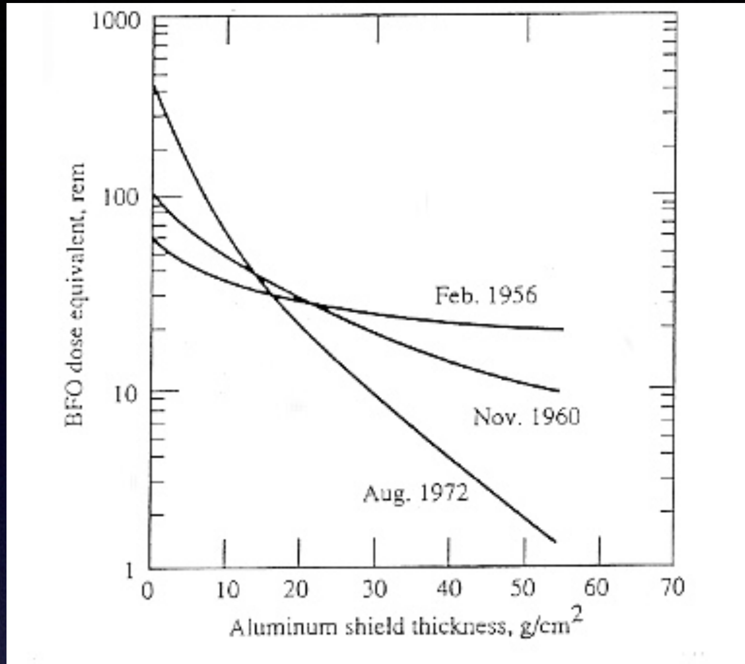


Figure 9. Shielding effectiveness for three of the largest solar proton events.

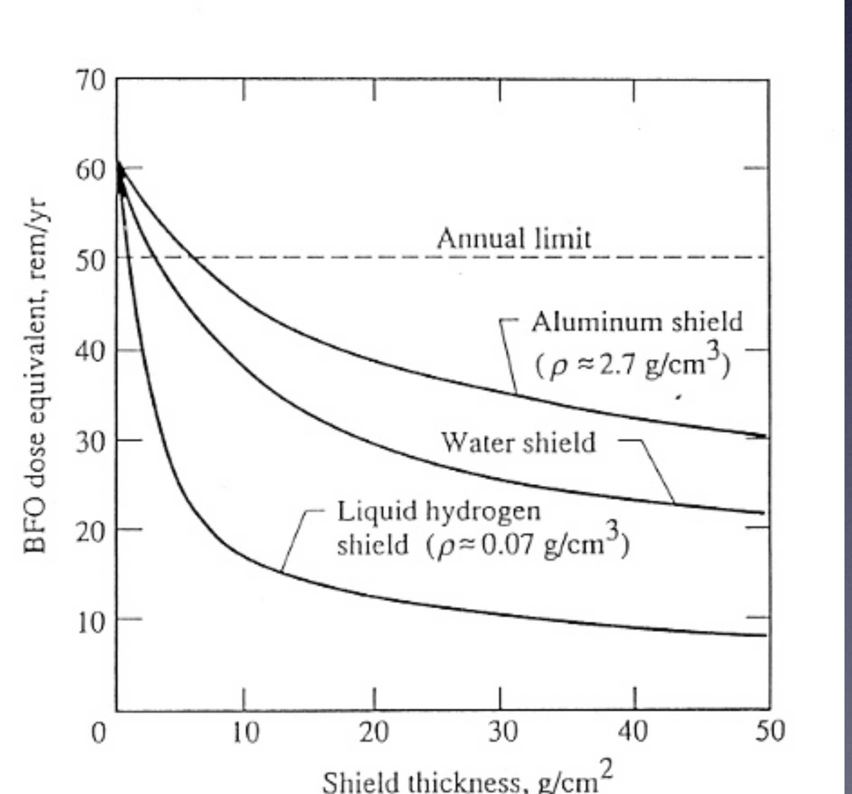
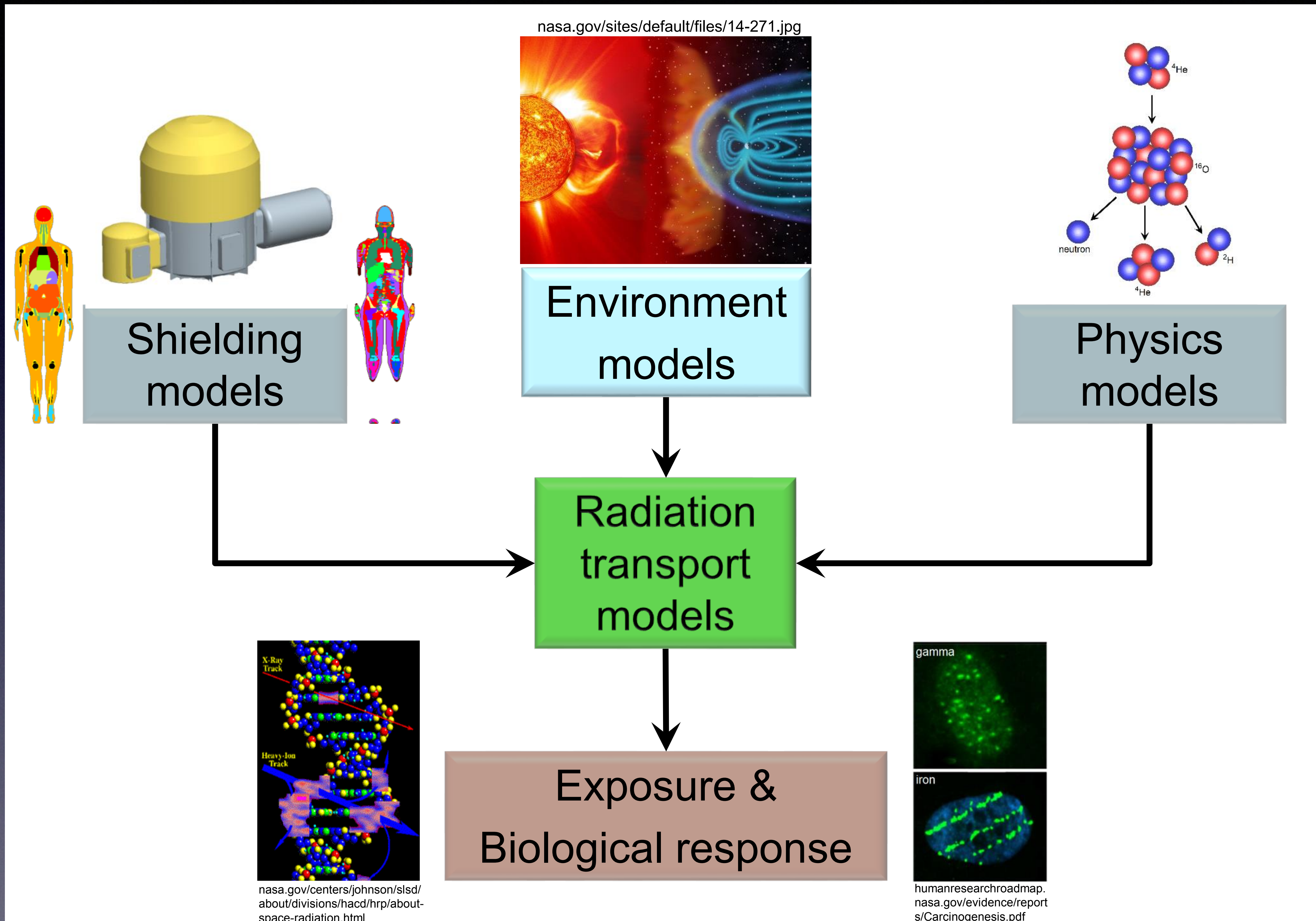


Figure 6. Shielding effectiveness of GCR at solar minimum.

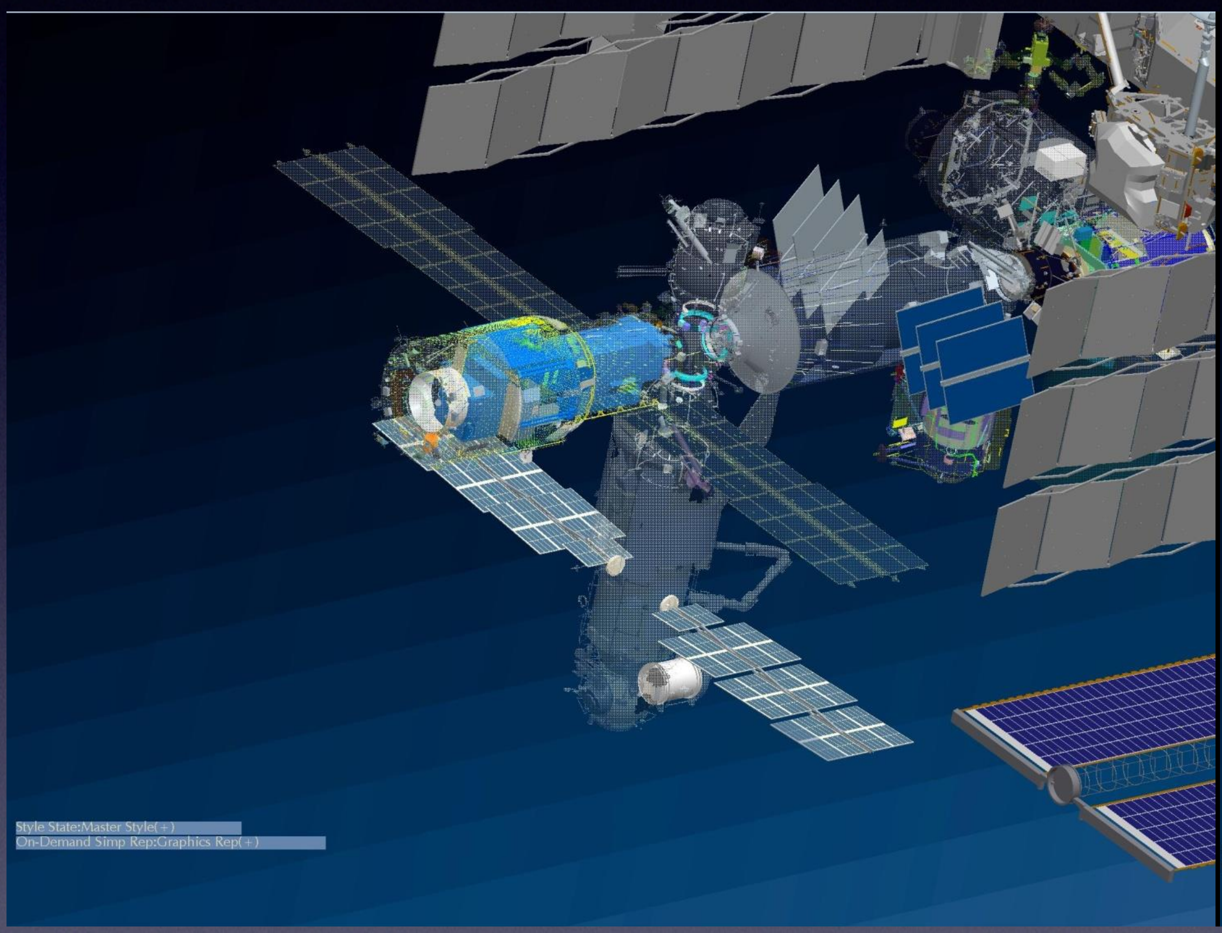
mailto:https://srag.jsc.nasa.gov/Publications/TM104782/techmemo.htm

The experimentalist places a small calibration ion chamber in the center of the NSRL beam. When the beam particles hit it, the signal from the ion chamber will be used to calibrate the radiation dose delivered to the targets.

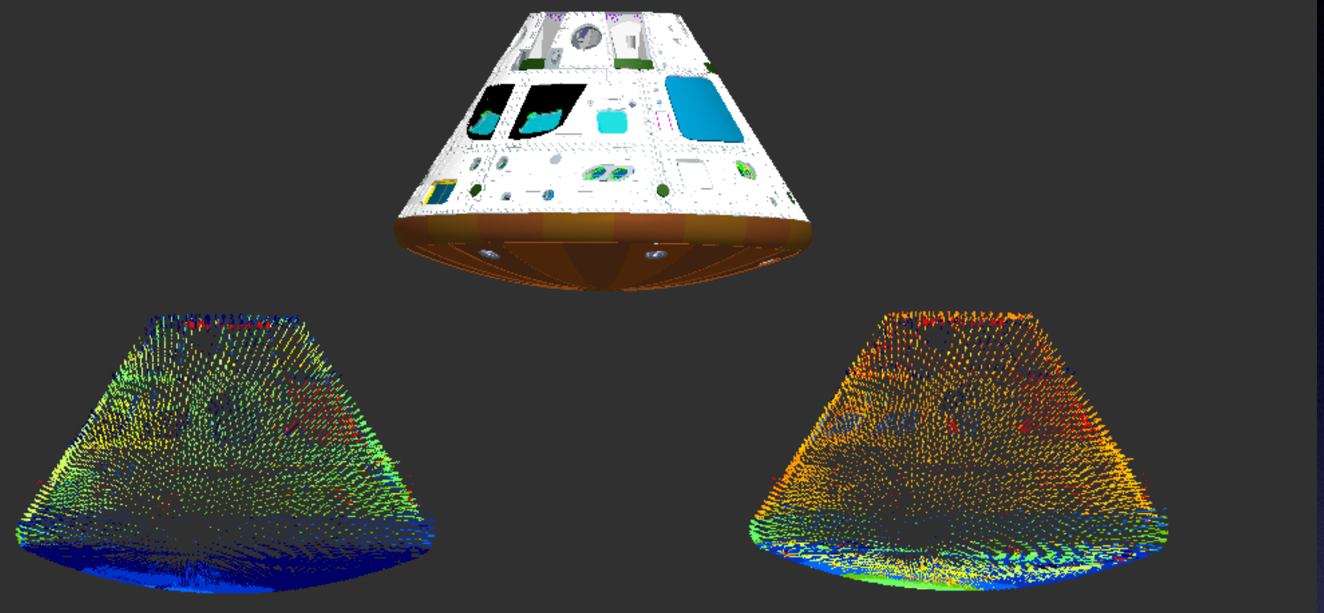
Vehicle/Habitat Radiation Exposure Analysis



Vehicle/Habitat Radiation Exposure Analysis

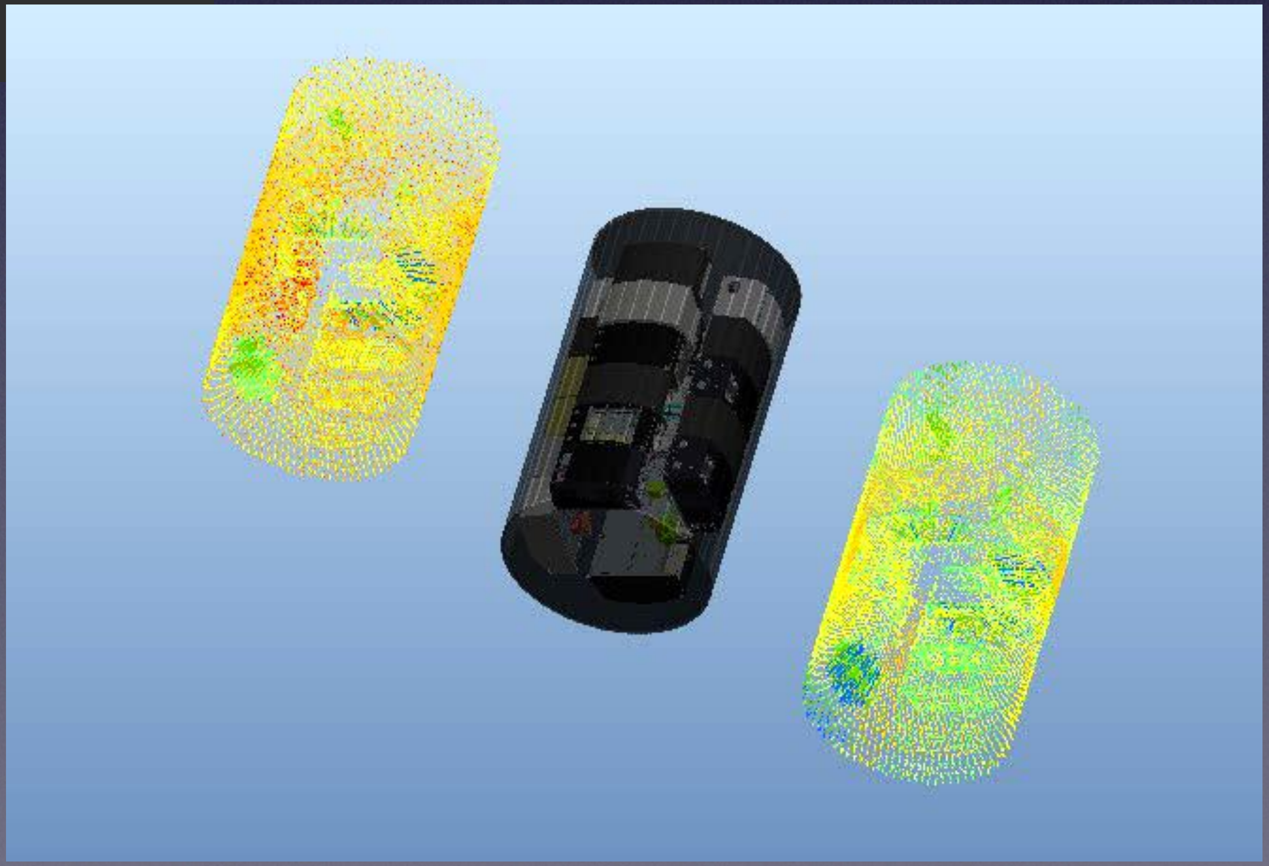


Vehicle/Habitat Radiation Exposure Analysis



ORION Crew Exploration Vehicle

Iss US lab



Why do we need so many instruments?

There is no single low mass/volume/power instrument that does everything:

- **TEPC and IV-TEPC** - They provide dosimetry and measure lineal energy transfer

- Our newer instruments are developed for particle detection/spectroscopy.
    - **Timepix-based** - used for dosimetry and dE/dx.

    - **MSL/RAD and ISS-RAD** - The use of energy deposition in different layers can be used to provide LET (deposited energy per unit path-length), and dosimetry in different layers.
    - - Gamma and neutron spectroscopy can be performed by use of detector response functions and advanced software;

    - ISS-RAD features an additional neutron detector for lower energy ranges.

- Shielding in a vehicle especially one as large as ISS is constantly changing and non-uniform;
- On ISS, dosimetry can vary by a factor of two over the entire station for a single point in time;
- Flux can vary by more than a factor of two at a single location by just pointing in a different direction

How does data improve modeling?

Measurements on Mars and inside ISS identify problems in the models that NASA uses for design and ultimately in risk assessment.

Mars has a thin atmosphere and a thick regolith;

- MSL/RAD is minimally shielded by the Curiosity rover.
- Data-model discrepancies in flux measurements and dosimetry can be caused by the GCR model or transport.

ISS has a very complex structure and the environment is composed of GCR and trapped/SAA.
Data-model discrepancies in flux measurements and dosimetry can be caused by the GCR model, trapped model, shielding, and/or transport.

- Minimally obstructed measurements help correct/improve environment models.

AMS-02 data will be used to correct local interstellar spectra in GCR models.

BIRD data will be used to help improve models on the trapped proton/electron models.
This helps understand the LEO environment better.
Measurements from the **thick target project** help resolve physics issues in transport.

Enviroment Models

Atmosphere models [info]

Density and Temperature Models

- Exospheric H Model [info, ftp]
- NRLMSISE-00 Model [info, **RUN** ftp, link]
- MSISE-90 Model [info, ftp, **RUN**]
- MSIS-86 Model [info, ftp]
- MET Model [info, ftp]
- CIRA: Thermosphere [info]
- CIRA: 0 km to 120 km [info, ftp]
- OLDER MODELS (pre-1985)

Wind Models

- Horizontal Wind Model (HWM) [info, ftp]

Ionosphere Models [info]

General Models

- Incoherent Scatter Radar Models [info]
- IRI [info, ftp, **RUN**]

Electron Density Models

- PIM Model [info]
- FAIM Model [info]
- SLIM Model [info]
- OLDER MODELS (pre-1985)

F2-Peak Models and Applications

- WBMOD Ionospheric Scintillation Model [info, link]
- URSI foF2 Model Maps [info]
- OLDER MODELS (pre-1985)

Electron Temperature Models

- Hinotori Model [info]
- Intercosmos Model [info]
- OLDER MODELS (pre-1985)

Ion Composition and Drift Models

- Intercosmos Ion Composition Model [info]
- OLDER MODELS (pre-1985)

Electric Convection Field Models

- Heppner-Maynard-Rich Electric Field Model [info, ftp]
- IZMIRAN Electrodynamic Model (IZMEM) [info, link]
- Utah Electric Convection Field Model [info]
- OLDER MODELS (pre-1985)

Auroral Precipitation and Conductivity Models

- AFGL Ion Precipitation Model [info]
- AFGL Electron Precipitation Model [info]
- Rice Electron Precipitation Model [info]

Miscellaneous Auroral Models

- Auroral Absorption Model [info]
- Auroral Oval Representation [info, ftp]

Plasmasphere Models

- Akebono Model [info]
- IMAGE Model [info]
- IZMIRAN/SMI Model [info]
- GPID Model [info]
- GCPM Model [info] link

Trapped Particle Models [info]

- VAMPOLA PROGRAMS [info]
- SHIELDOSE [info, ftp, link]
- RADBELT [info, ftp, **RUN**]
- AE/AP Trapped Particle Flux Maps [info, ftp]
- OLDER MODELS (pre-1985)

Gravitation/Geopotential Models

- Earth Gravitational Model 2008 (EGM2008) [info, link]

Geomagnetic(Main) Field Models [info]

General Models

- IGRF Model [ftp, info, link, **RUN**]

Miscellaneous Geomagnetic Field Models

- USGS Model Coefficients for Continental U.S. and Hawaii [info]
- GSFC Model Coefficients: All [ftp], (11/87) [info], (12/83) [info], (9/80) [info], (12/66) [info], (9/65) [info]
- Summary Table
- OLDER MODELS

Magnetospheric Field Models [info]

- Toffoletto-Hill Magnetosphere Model [link]
- Xu-Li Neutral Sheet Model [info, ftp]
- User-Oriented Service Based on External and Internal Geomagnetic Field Models [RUN]
- Tsyganenko Magnetic Field Models and GEOPACK routines [info, link, url]
- OLDER MODELS (pre-1979)

Solar and Interplanetary Space Models

Solar Reference Spectra

- Solar2000 Model [link]
- OLDER REFERENCE SPECTRA

Solar Energetic Particle Models

- Nymmik Solar Energetic Particles Model [link]
- JPL Proton Model [info]
- SOLPRO Model [info, ftp]

Cosmic Rays and Related Software

- Geomagnetic Cutoff Rigidity [info, ftp]
- Spacecraft Anomaly Data Base [info]
- CREME Programs [info, link]

Planetary Models [info]

General Models

- EPIC general circulation model [link]

Venus Models

- PV Ionosphere Model [info, ftp]
- PV Thermosphere Model [info, ftp]

Mars Models

- Mars General Circulation Model (GCM). [link]

Jupiter Models

- Galileo Interim Radiation Environment (GIRE) model [link]

Other Model Related Sites

- NASA's Community Coordinated Modeling Center (CCMC) [link]
- ESA's SPace ENVironment Information System (SPENVIS) [link]
- Open Channel/COSMIC software depository [link]
- Rice University Space Weather page [link]
- URSI'99 Session on Ionospheric Data and Models on the WWW [link]

Older Models:

Older Atmospheric models [info]

Density and Temperature Models

- U.S. Standard Atmosphere [info]
- Jacchia Reference Atmosphere [info, ftp]
- Atmospheric Handbook [info, link]

Older Ionosphere Models [info]

Electron Density Models

- Chiu Ionospheric Model [info, ftp]
- Bent Ionospheric Model [info]
- Penn State Mk III Model [info]

F2-Peak Models and Applications

- CCIR foF2 and M(3000)F2 Model Maps [info]
- ISS-b foF2 Maps [info]
- MINIMUF/QSTMUF Model [info]
- IONCAP Model [info]

Electron Temperature Models

- Density Dependent Electron Temperature Model [info]
- AEROS Electron Temperature Model [info]
- AE/ISIS Electron Temperature Models [info]

Ion Composition and Drift Models

Older Trapped Particle Models [info]

- MODEL Program [info]
- FLOUT Transformation [info]
- SOFIP [info]

Older Gravitation/Geopotential Models

- Older Earth Gravitational Models Earth Gravitational Model 1996 (EGM96) [info],

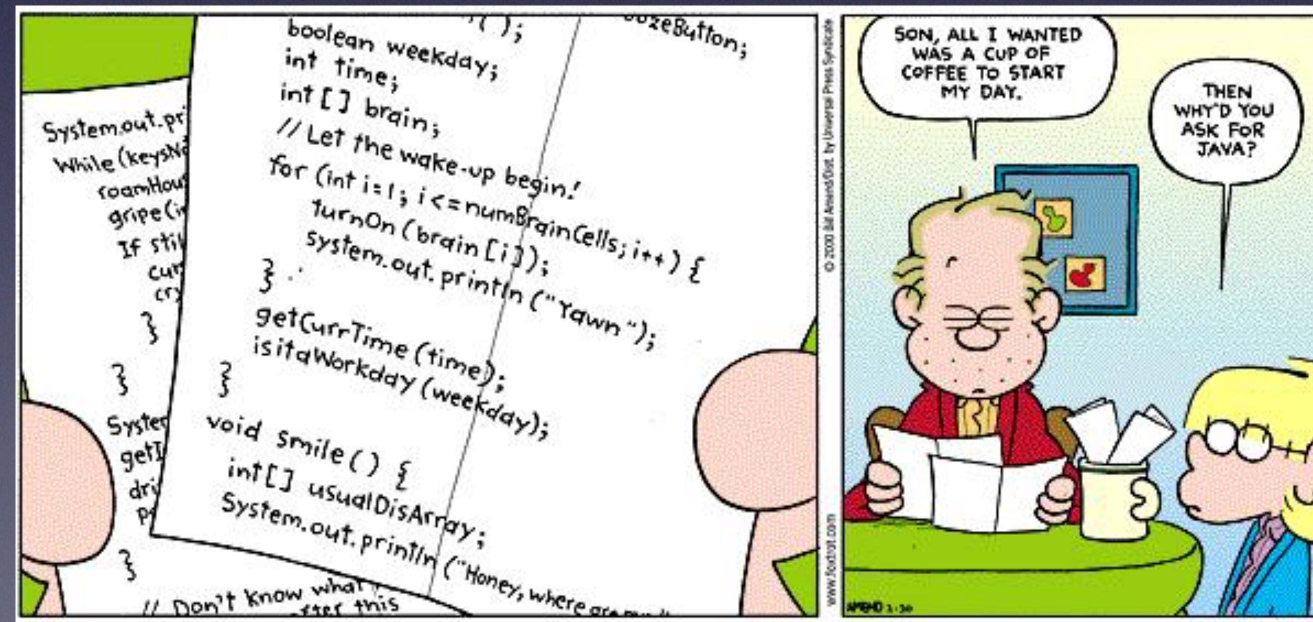
Older Geomagnetic(Main) Field Models [info]

Miscellaneous Geomagnetic Field Models

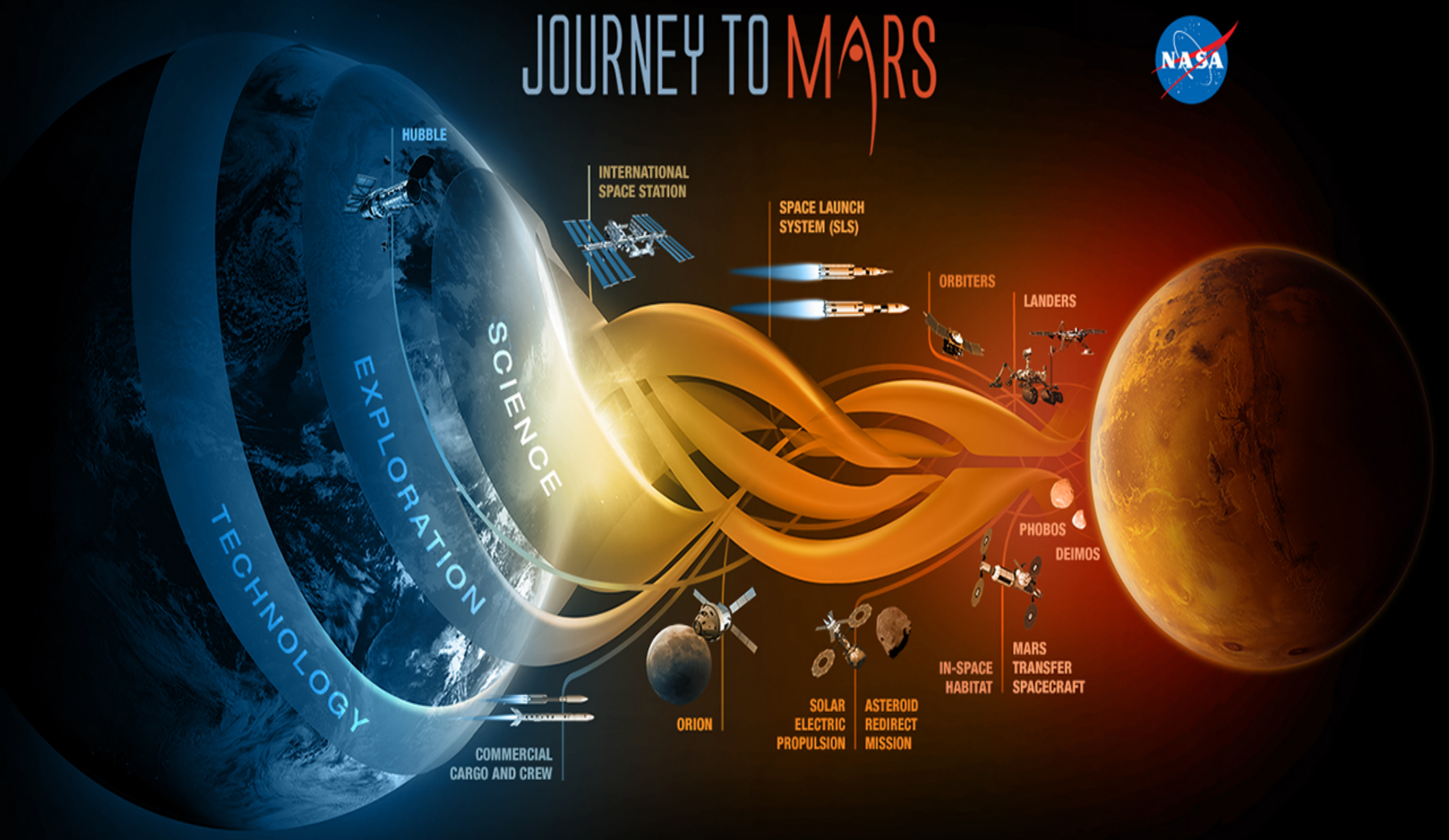
- Jensen-Cain Model Coefficients [info, ftp]
- POGO Model Coefficients: (3/68) [info], (10/68) [info], (8/69) [info], (8/71) [info]
- AWC (75) Model Coefficients [info]
- IGS (75) Model Coefficients [info]
- MGST Model Coefficients All [ftp], (6/80) [info], (4/81) [info]

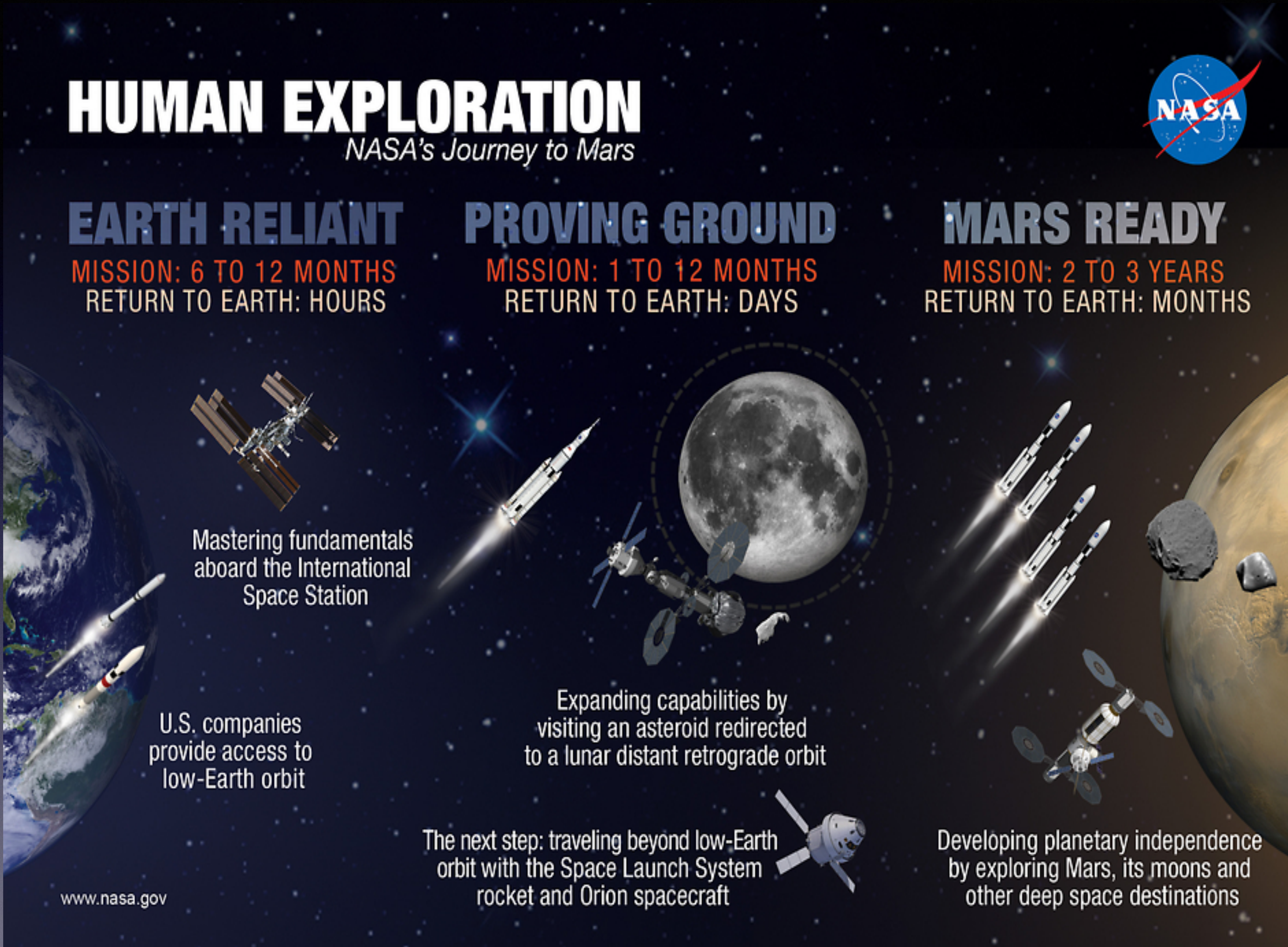
Older Magnetospheric Field Models [info]

- Olson-Pfitzer Field Model [info]
- Mead-Fairfield Field Model [info]
- Geotail Field Model [info]



http://ccmc.gsfc.nasa.gov/modelweb/

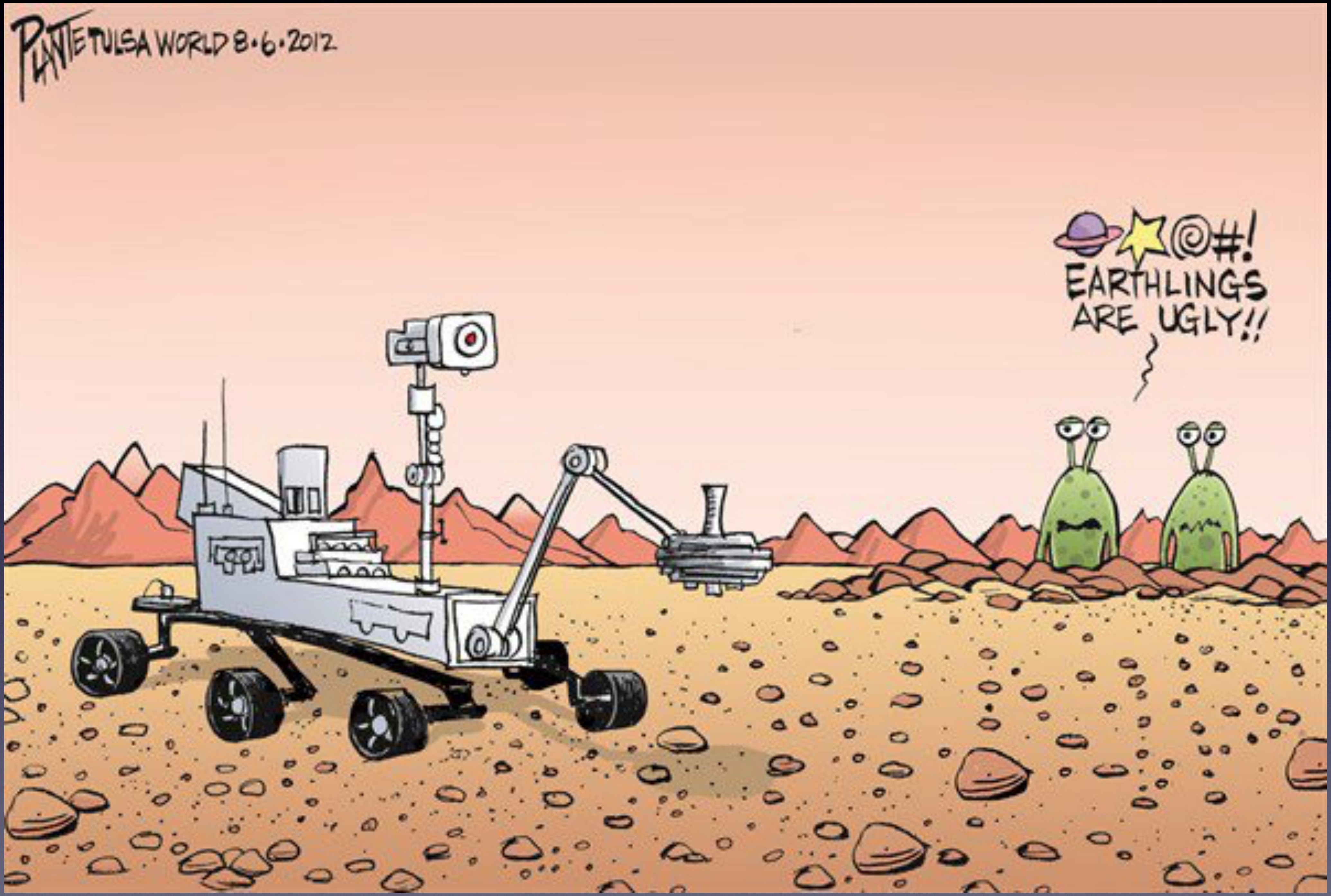

JOURNEY TO MARS
NASA
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
MARS TRANSFER SPACECRAFT
IN-SPACE HABITAT
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
ORION
COMMERCIAL CARGO AND CREW


HUMAN EXPLORATION
NASA's Journey to Mars
NASA
EARTH RELIANT
MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS
PROVING GROUND
MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS
MARS READY
MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS
Mastering fundamentals aboard the International Space Station
U.S. companies provide access to low-Earth orbit
Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit
The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft
Developing planetary independence by exploring Mars, its moons and other deep space destinations
www.nasa.gov

PROVING GROUND

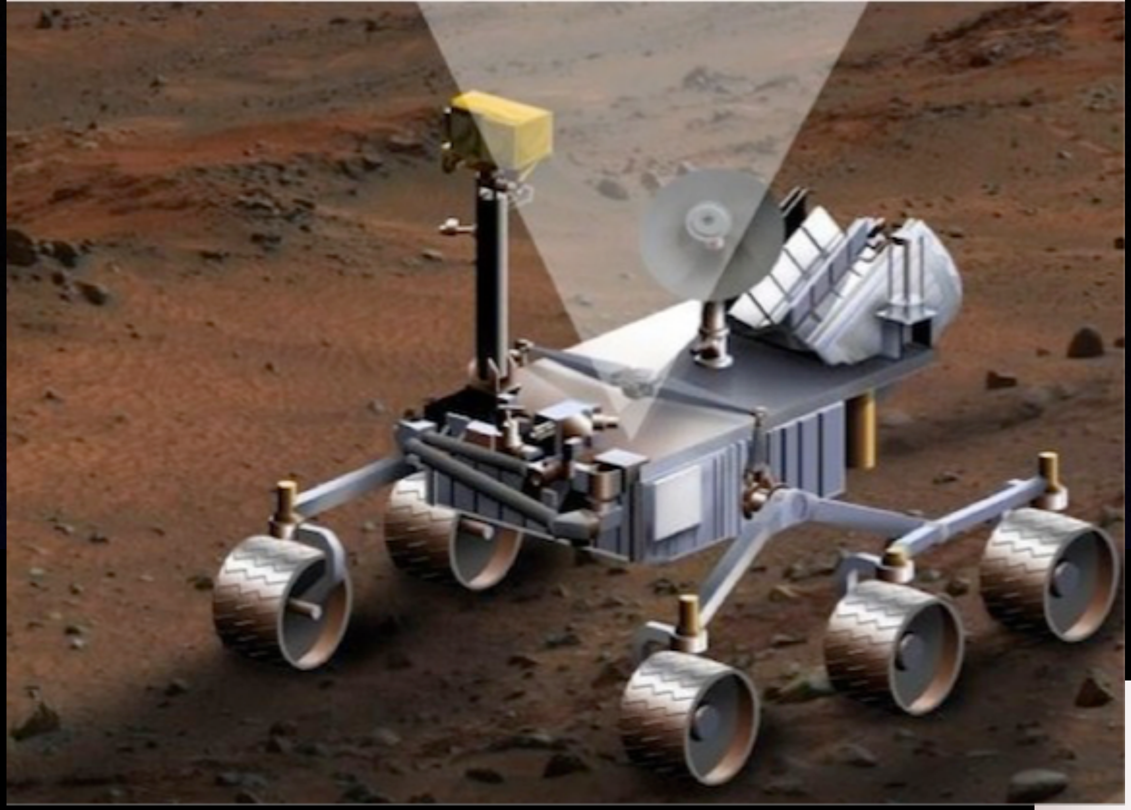
2018 - 2030

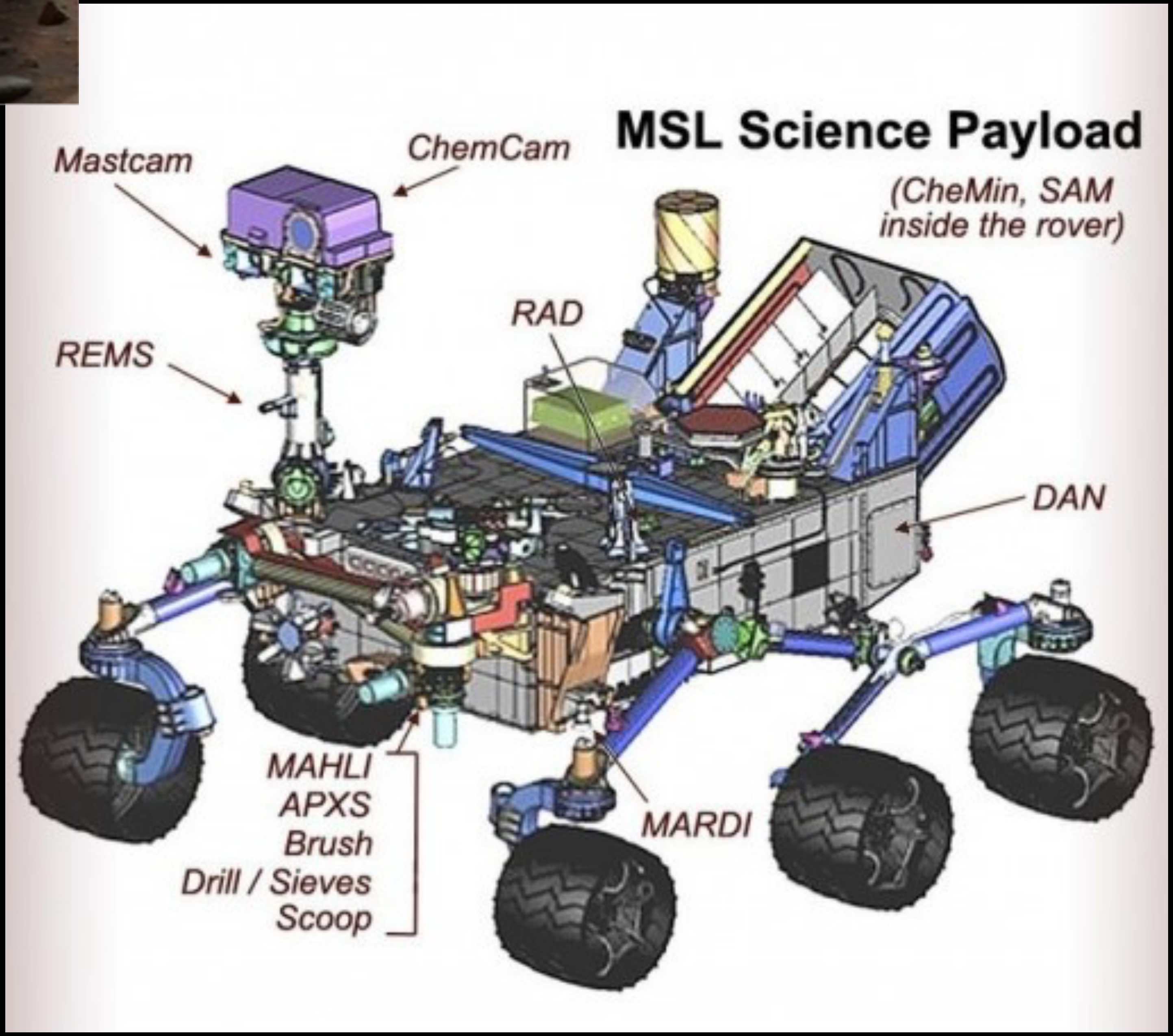
- Regular crewed missions and spacewalks in cislunar space.
- Verify deep space habitation and conduct a yearlong mission to validate readiness for Mars.
- Demonstrate integrated human and robotic operations by redirecting and sampling an asteroid boulder.


PLANTE TULSA WORLD 8·6·2012
@#!
EARTHLINGS ARE UGLY!!

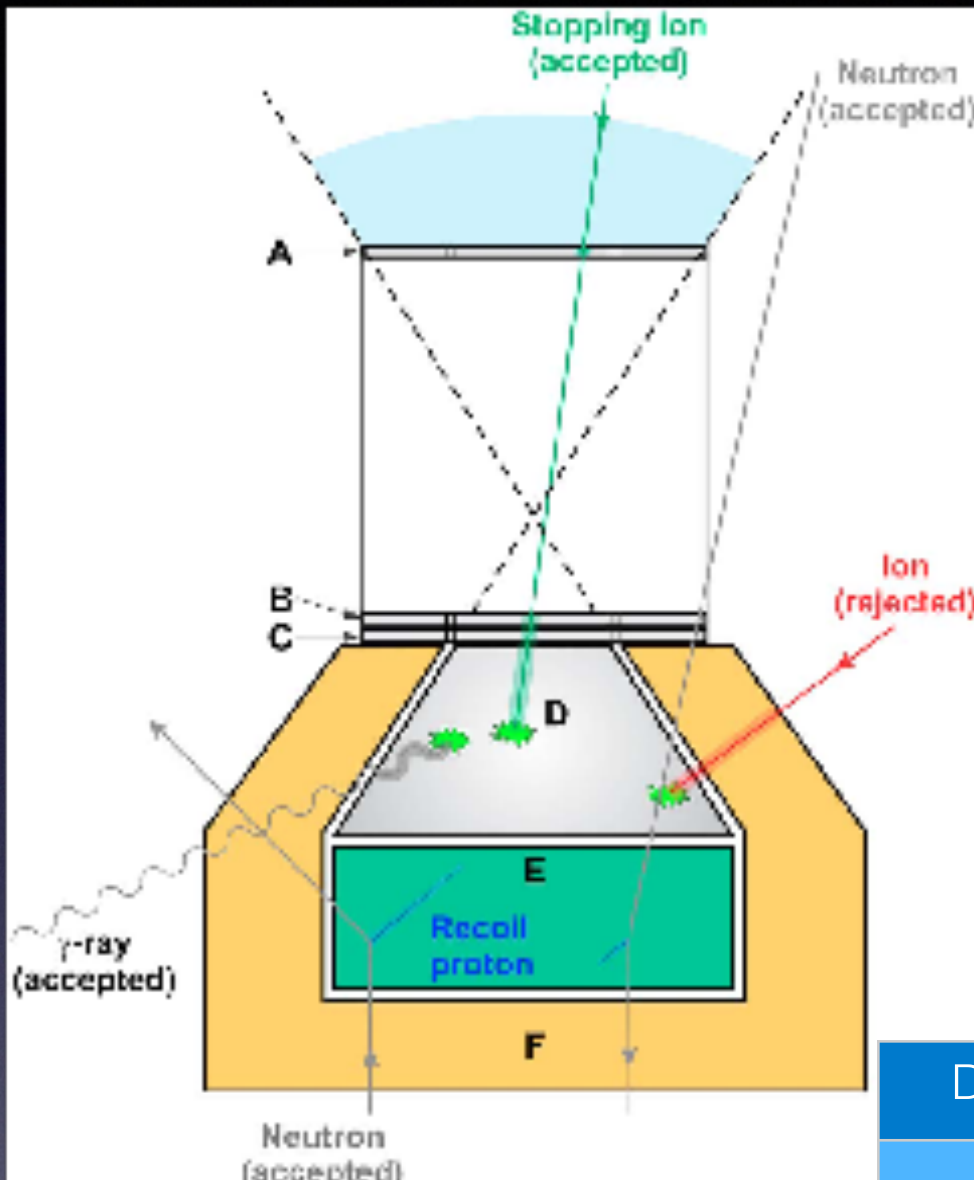
Curiosity Rover

Curiosity Rover





MSL-RAD detector



The Radiation Assessment Detector (RAD) is a particle analyzer designed to characterize the full spectrum of energetic particle radiation, including galactic cosmic rays (GCRs), solar energetic particles (SEPs), secondary neutrons and other particles created both in the atmosphere and in the Martian regolith.

Detector	Material	Type	Purpose
A,B[1],C	Si	SSD; 300µm	Charged particle spectroscopy
D	CsI(TI)	Scintillating Calorimeter	Energy resolving detector
E[1]	Plastic scintillator	Scintillator	High-Energy particle measurements
F	Plastic scintillator	Scintillating anti-coincidence	Anti-coincidence counter

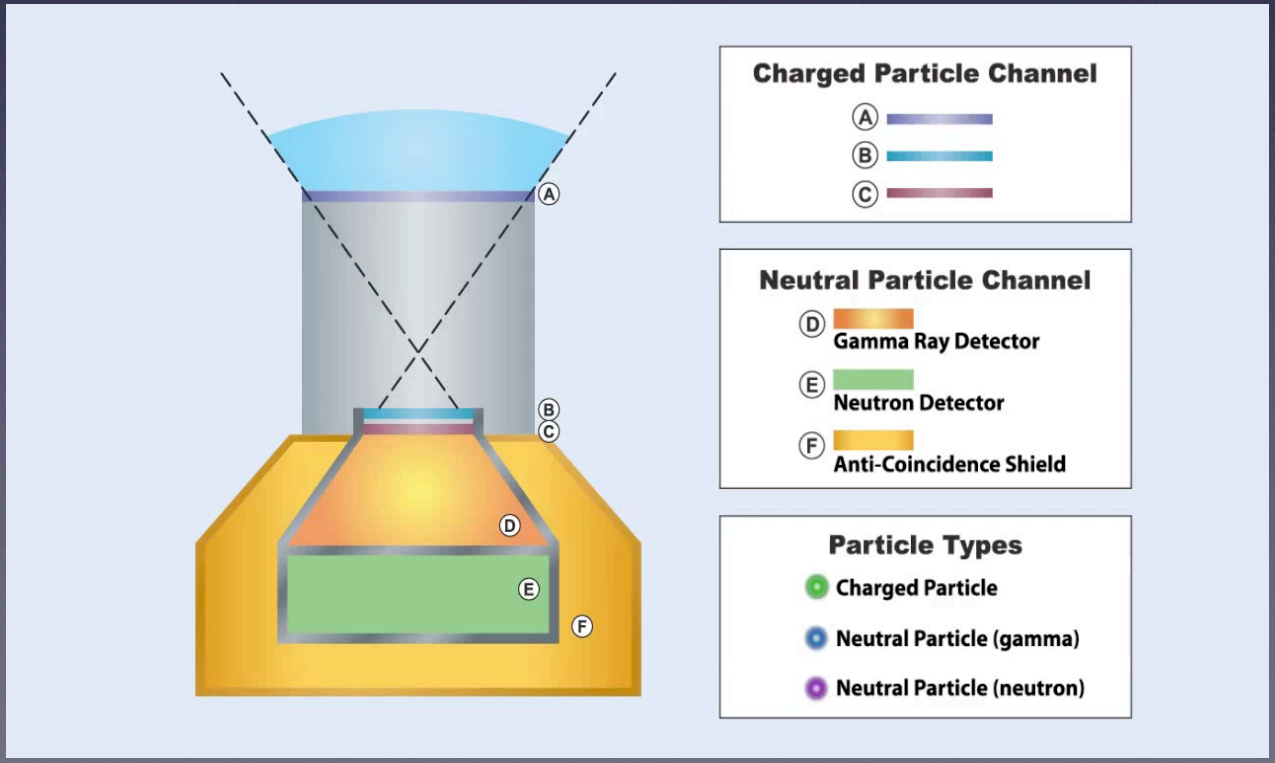
MSL-RAD detector

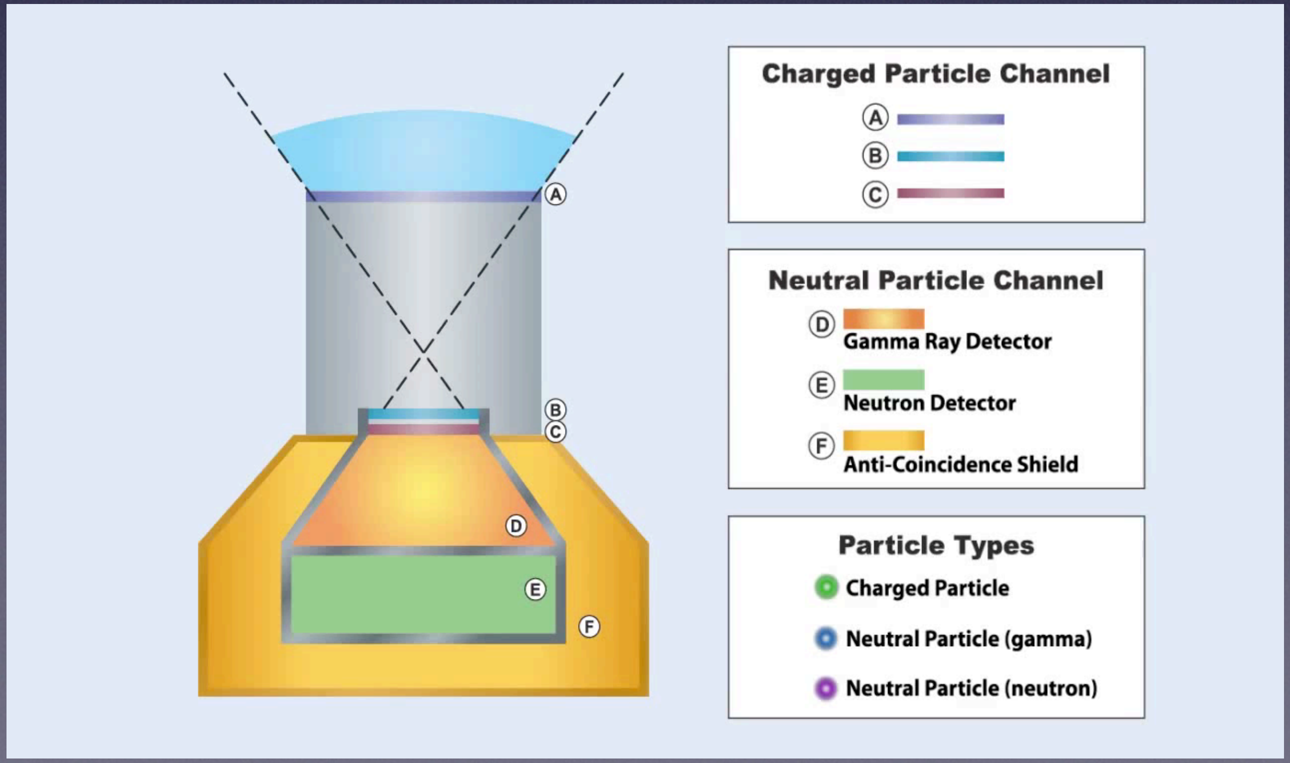
Charged Particles

- Charged particles entering RAD from the top deposit energy in solid-state detectors A, B, and C.
- Valid charged particle events occur in a view cone of about 65 degrees (full angle), defined by the A and B detector telescope geometry (see animation below).

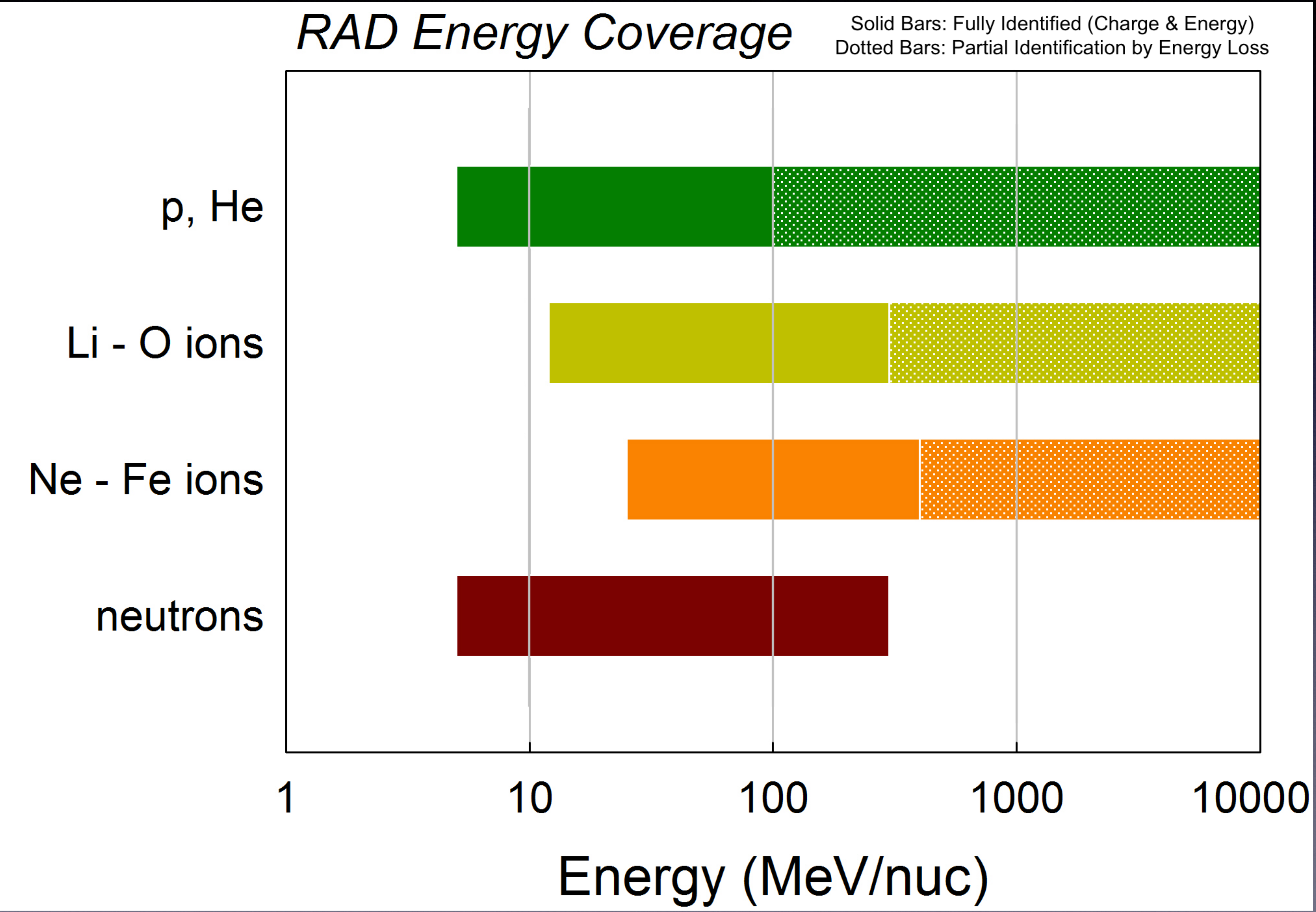
Neutral Particles

- Neutral particles are detected when energy is deposited only in the D and/or E detectors.
- An anticoincidence shield (F) surrounds the D and E detectors to discriminate valid neutral particle events and charged particle events which deposit energy in F as well as D and/or E .

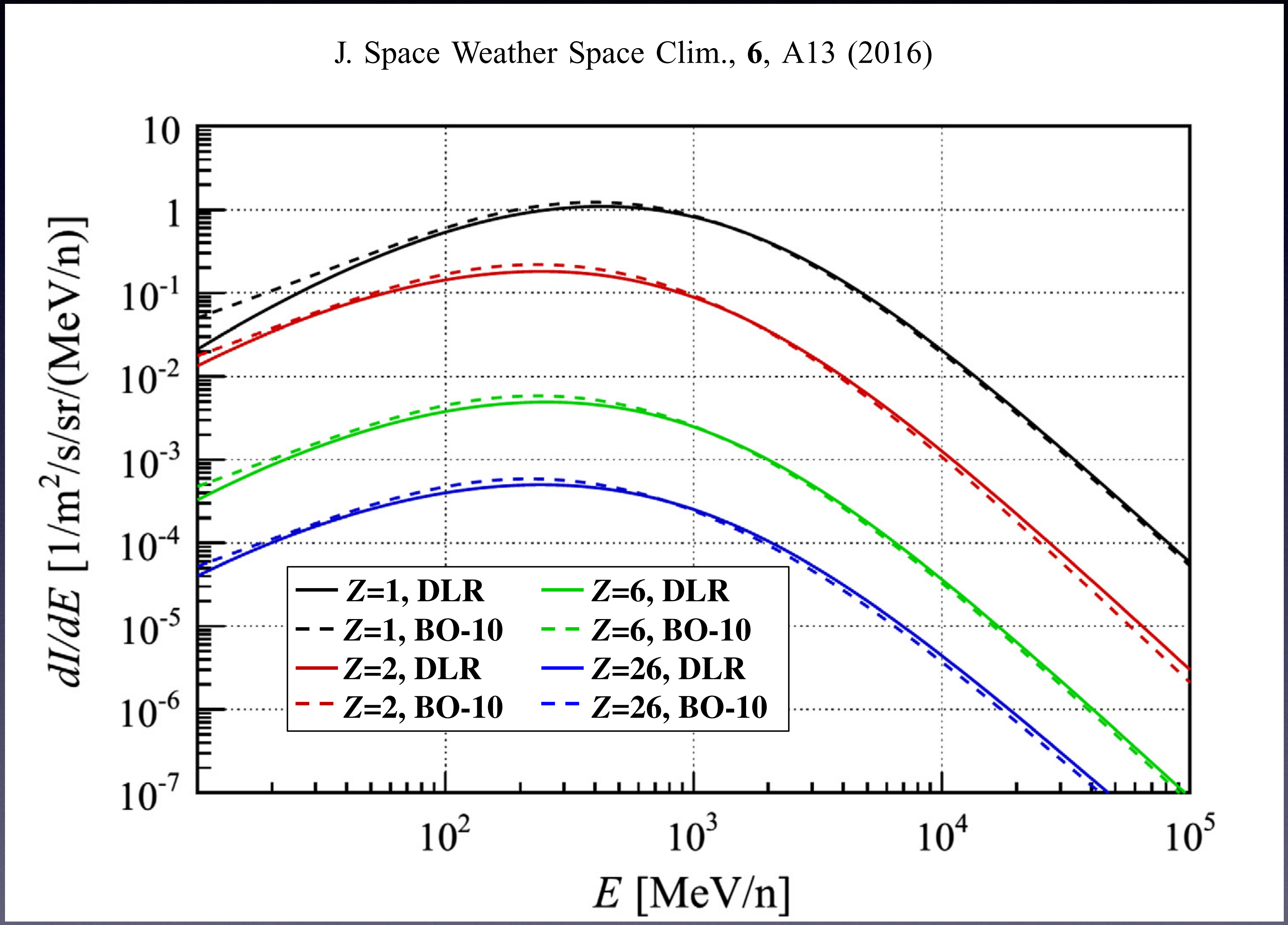




MSL-RAD detector



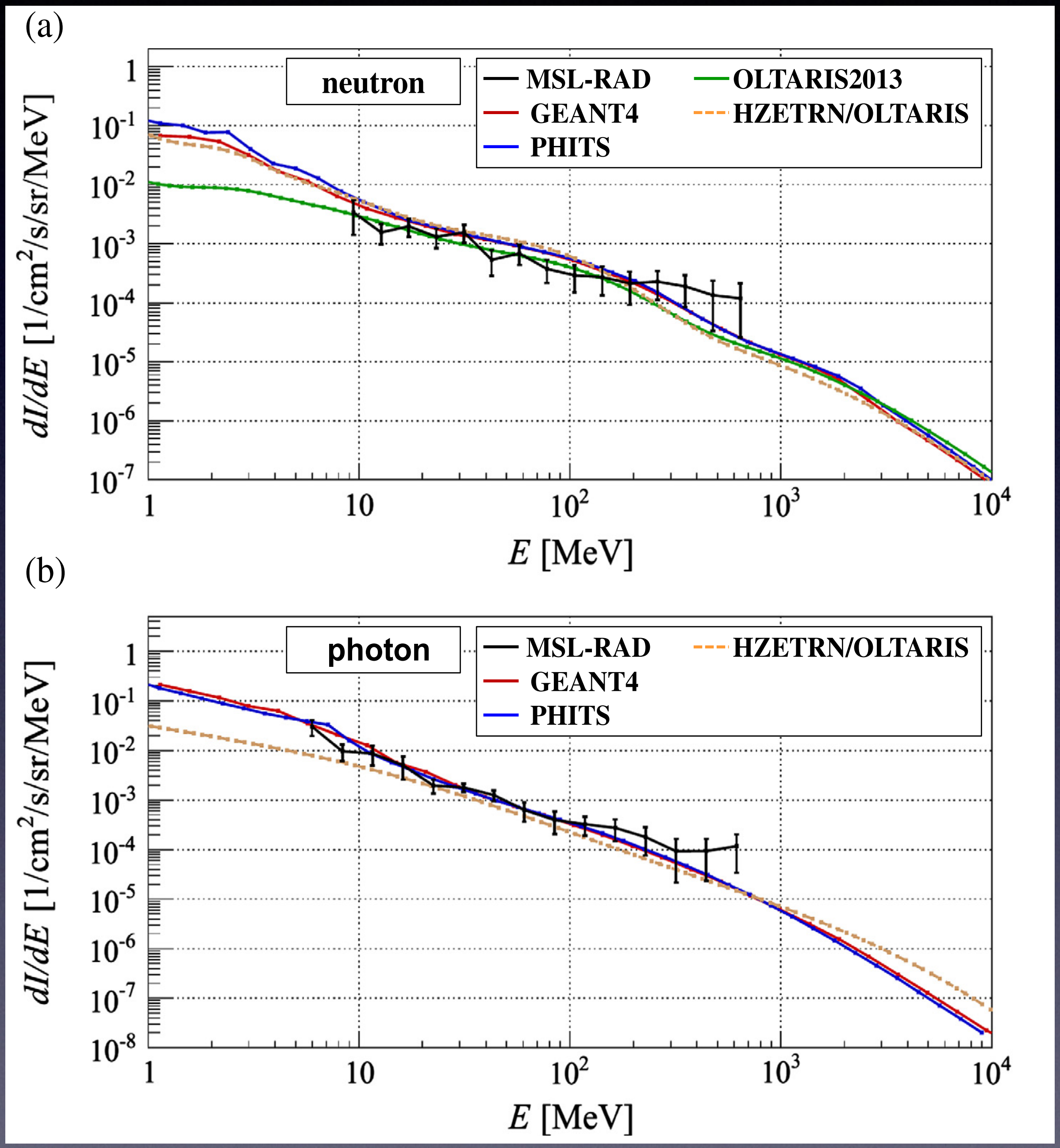
MSL-RAD detector: data vs models

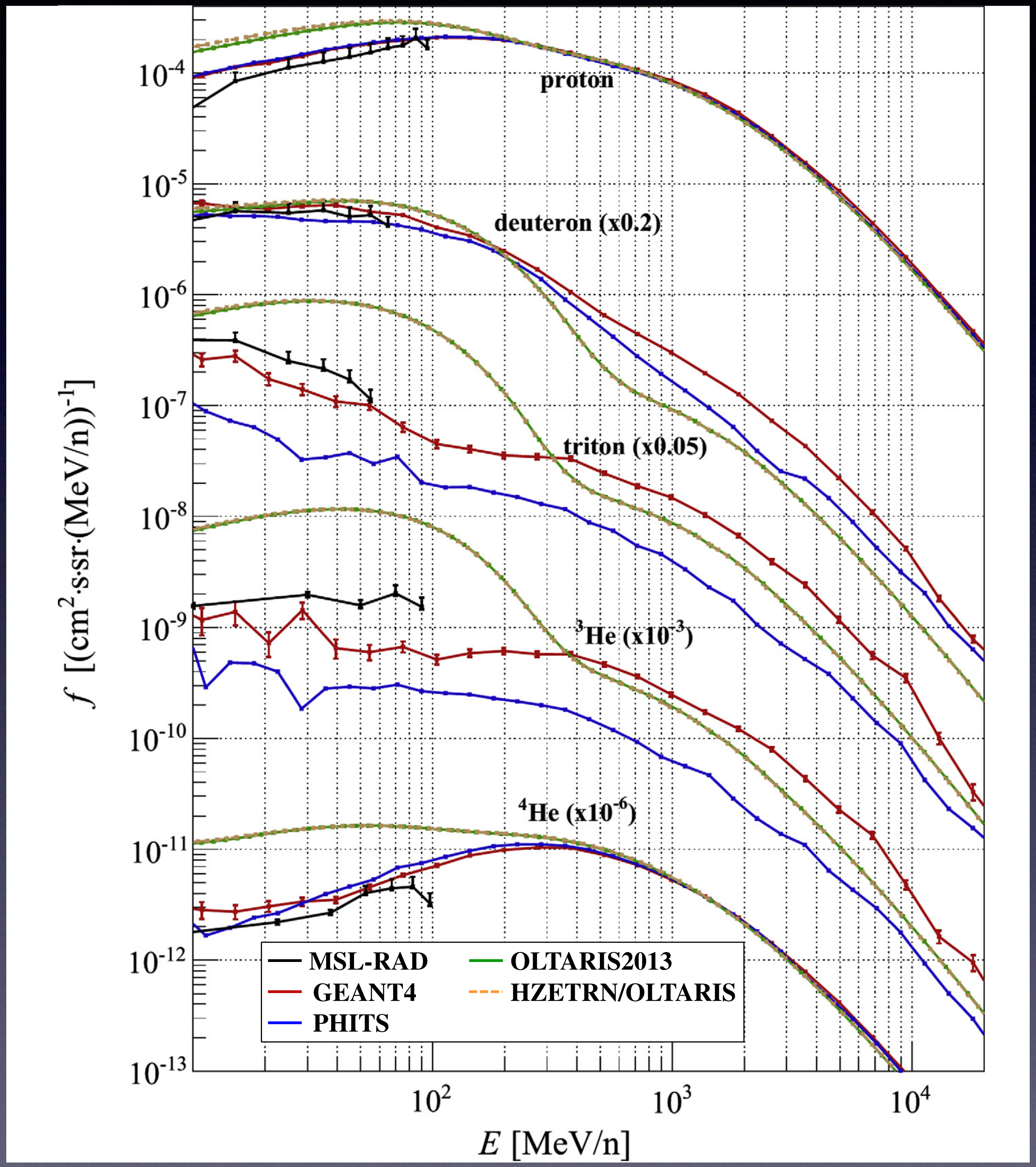


Primary GCR spectra, exemplarily for hydrogen (Z = 1), helium (Z = 2), carbon (Z = 6), and iron (Z = 26), for the time between August 2012 and January 2013 as described by the DLR (Matthiä et al. 2013) and Badhwar/O'Neill 2010 (BO-10) (O'Neill 2010) models.

D. Matthiä et al.: The Martian Surface Radiation Environment – Models and Measurements; J. Space Weather Space Clim., 6, A13 (2016) DOI: 10.1051/swsc/2016008

MSL-RAD detector: data vs models



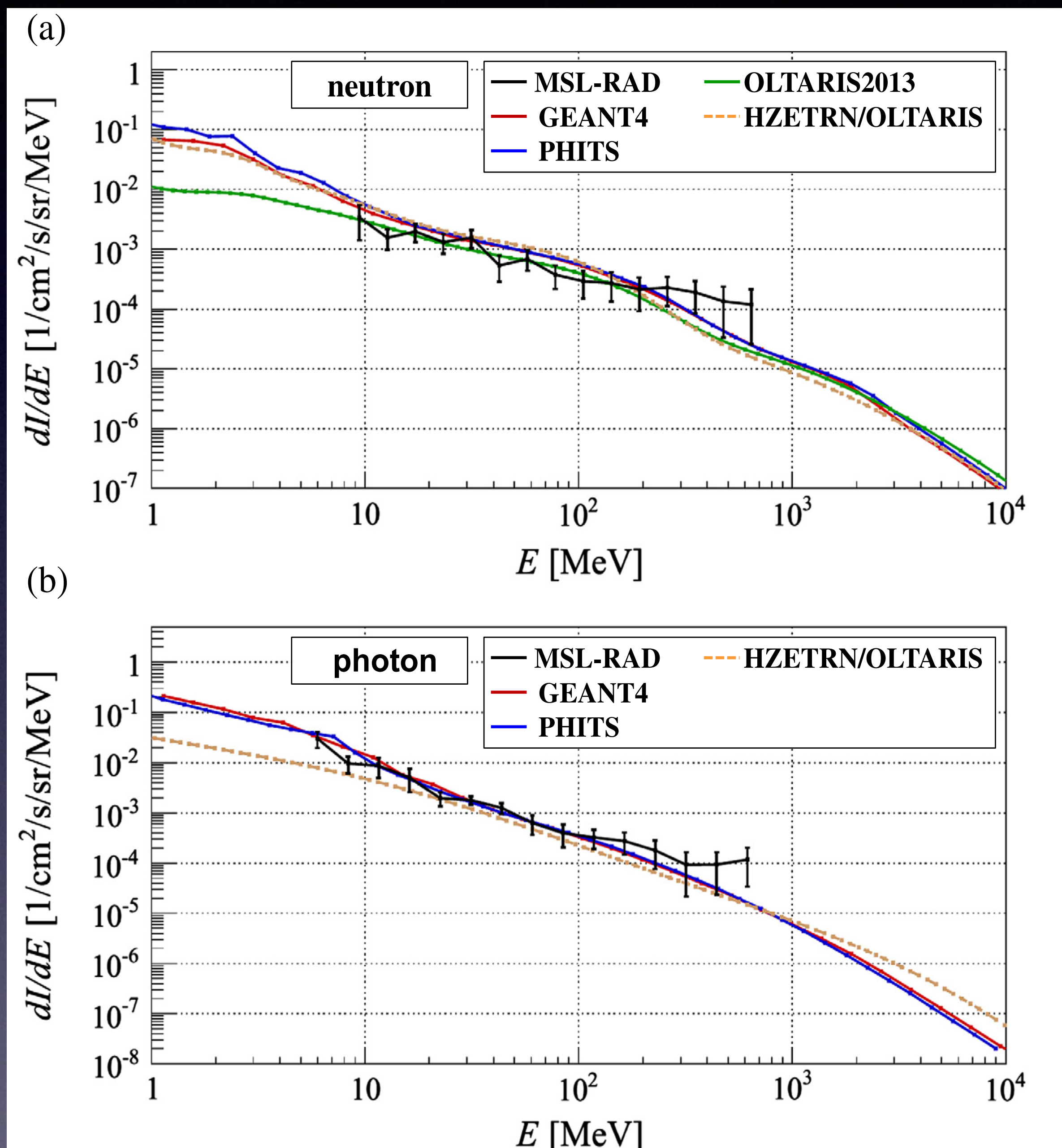


Neutral particle spectra (all incident angles) on the Martian surface measured between 19 August 2012 and 17 February 2013 compared to different simulation results.

Data for zenith angles smaller than 30° on the Martian surface measured between 19 August 2012 and 17 February 2013 compared to different simulation results.

D. Matthiä et al.: The Martian Surface Radiation Environment – Models and Measurements; J. Space Weather Space Clim., 6, A13 (2016) DOI: 10.1051/swsc/2016008

MSL-RAD detector: data vs models



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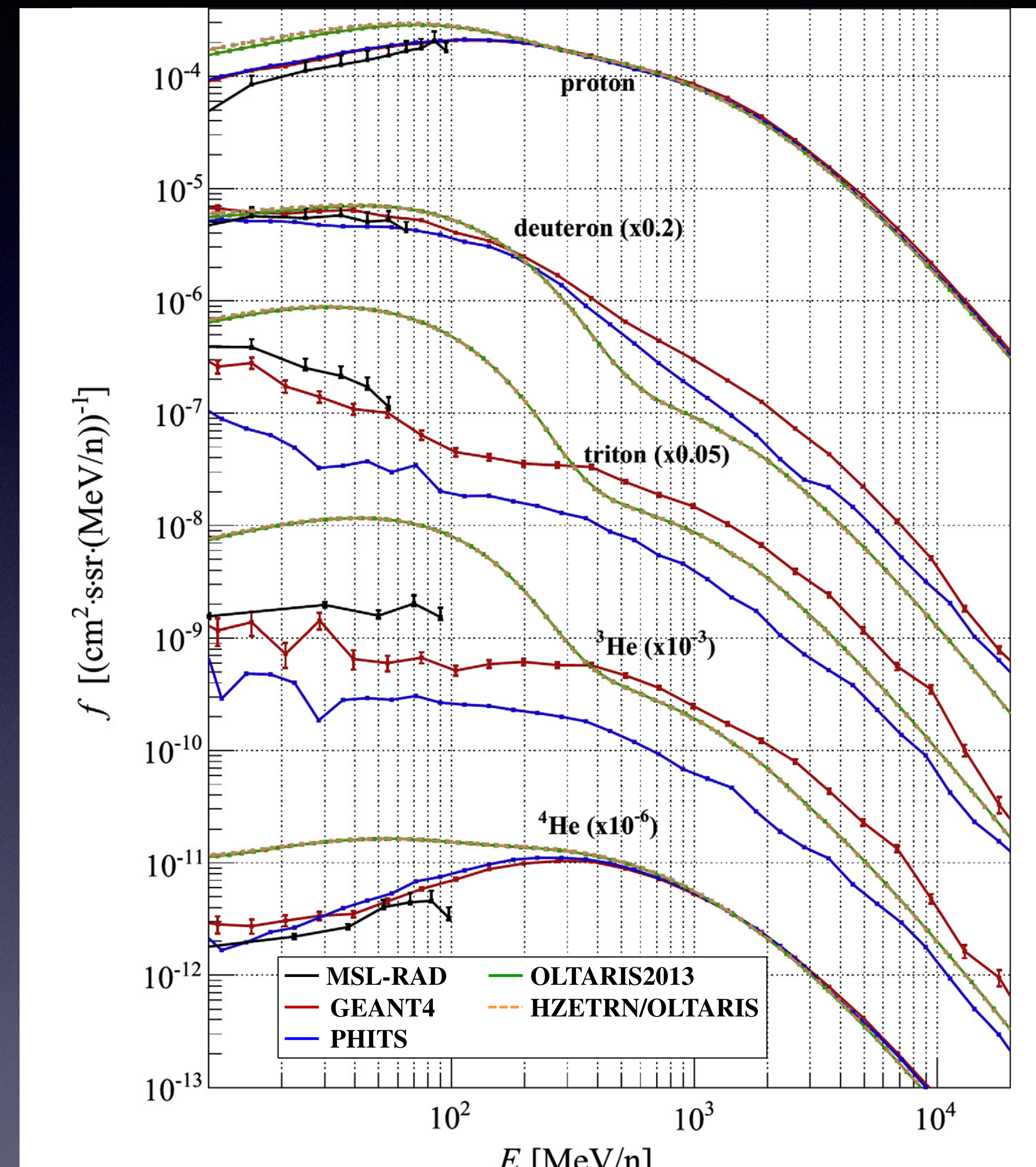
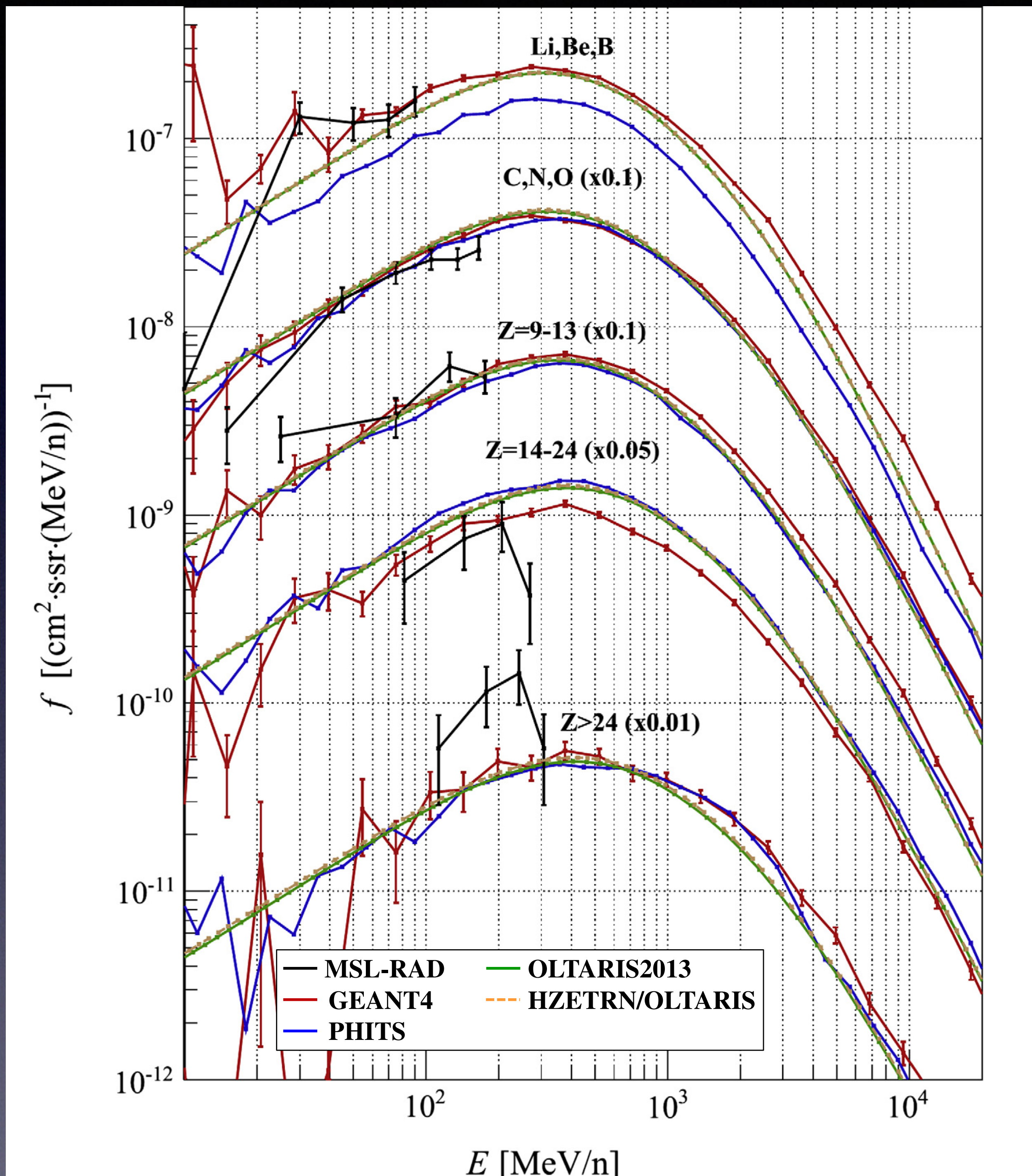
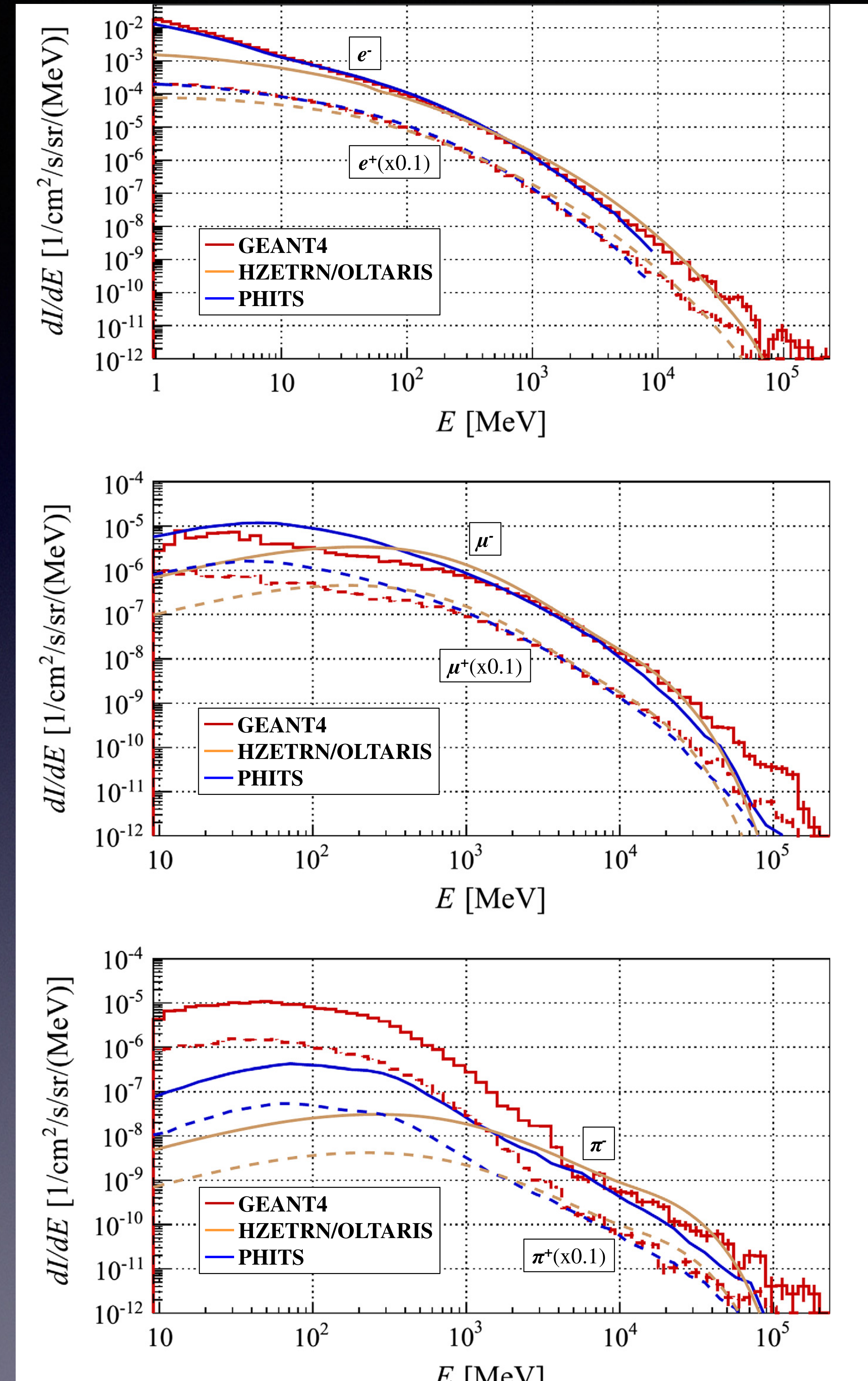


Data for zenith angles smaller than 30° on the Martian surface measured between 19 August 2012 and 17 February 2013 compared to different simulation results.

D. Matthiä et al.: The Martian Surface Radiation Environment – Models and Measurements; J. Space Weather Space Clim., 6, A13 (2016) DOI: 10.1051/swsc/2016008

MSL-RAD detector: data

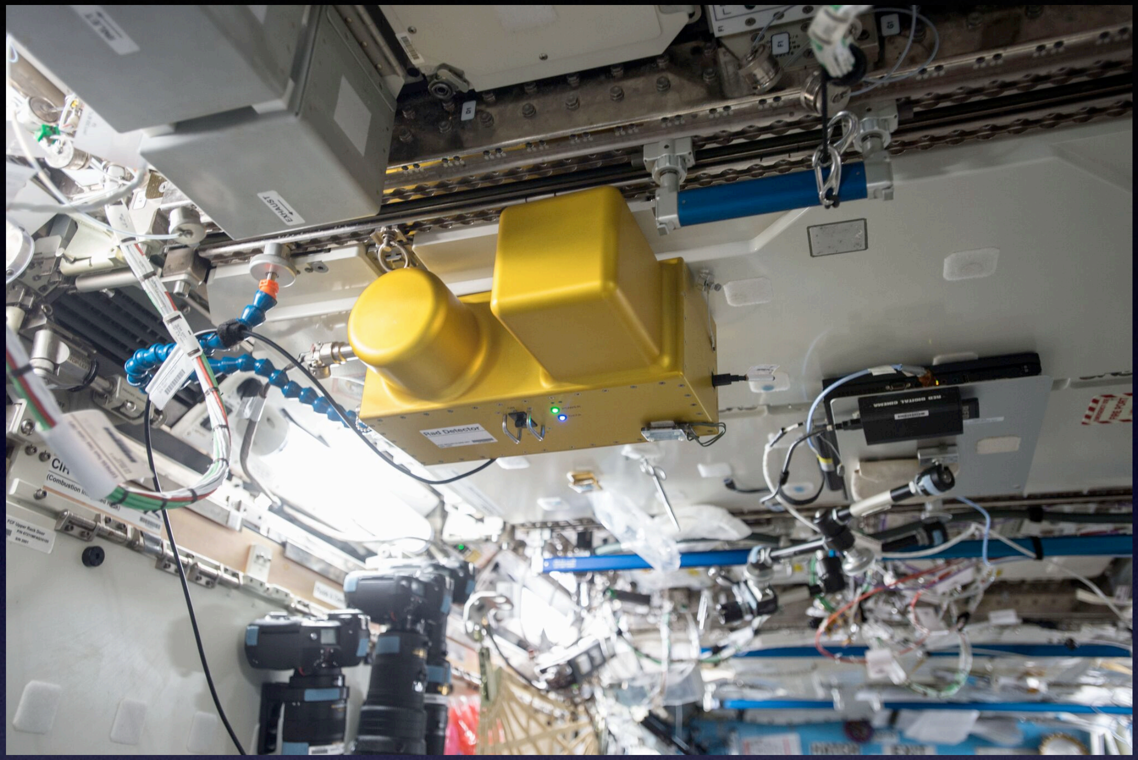


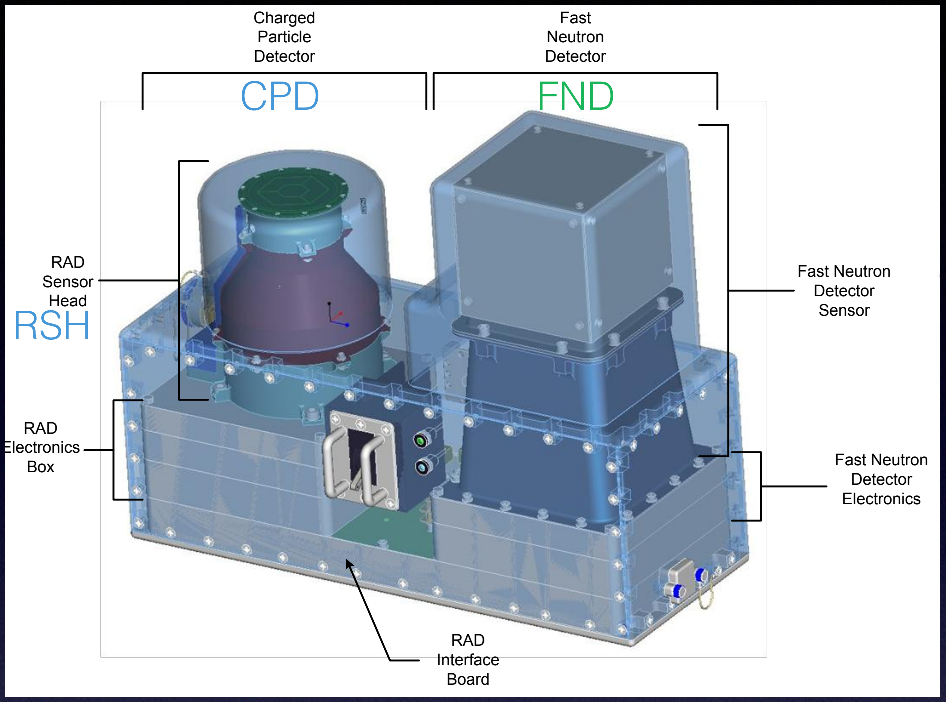


Particle spectra for zenith angles smaller than 30° on the Martian surface measured between 19 August 2012 and 17 February 2013 and calculated for the same period by different simulation tools.

D. Matthiä et al.: The Martian Surface Radiation Environment – Models and Measurements
J. Space Weather Space Clim., 6, A13 (2016) DOI: 10.1051/swsc/2016008

ISS-RAD detector





CPD - similar design to MSL-RAD

FND - a dedicated neutron detector.

Started collecting data on 1 Feb. 2016.

Detector	Material	Type	Purpose
A, B[1], C	Si	SSD; 300μm thick	Charged particle spectroscopy
D	BGO[2]	Scintillating Calorimeter	Energy resolving detector
E[1]	EJ260XL[3]	Scintillator	High-energy particle measurements
F	EJ260XL[3]	Scintillating Anti-coincidence	Anti-coincidence counter

1. B/E - cyclic, omnidirectional charged particle dosimetry
2. Bismuth Germanium Oxide.
3. Plastic scintillator.

Conclusion and Future considerations

- Johnson Space Center is the focal point within NASA for crew radiation health protection.
- JSC engineers and scientists are working together on a variety of topics ranging from measuring biological effects to physical environmental model development
- The goal is to improve the quantitative understanding of risks to astronauts due to radiation exposure during spaceflight.

- Special instrumentation provide the means to quantify crew doses.
- Operational support for current missions and projected support for future exploration class mission will continue to be the function of the Spaceflight Radiation Health Protection Program at Johnson Space Center