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Space radiation environment and space dosimetry

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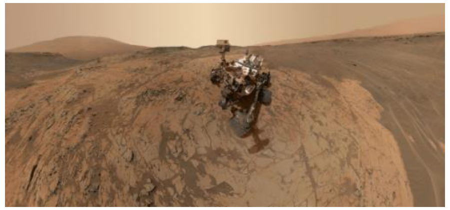
BVS ABR Space Radiation Workshop

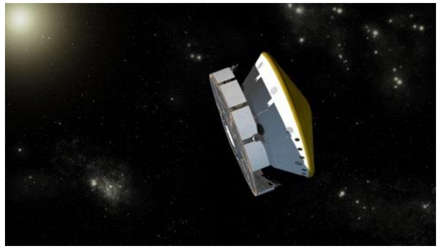
Ionizing radiation is important health risk in space

- Earth
  - 0.1 μSv/h
  - 1 mSv over 1 year on earth

- International Space Station
  - 20 μSv/h
  - 100 mSv over 6 months in ISS



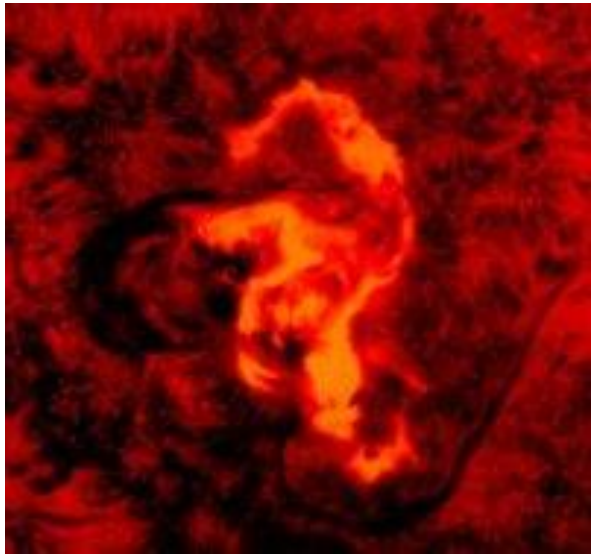
- Mars surface
  - 25 μSv/h
  - 300 mSv over 500 days on mars surface



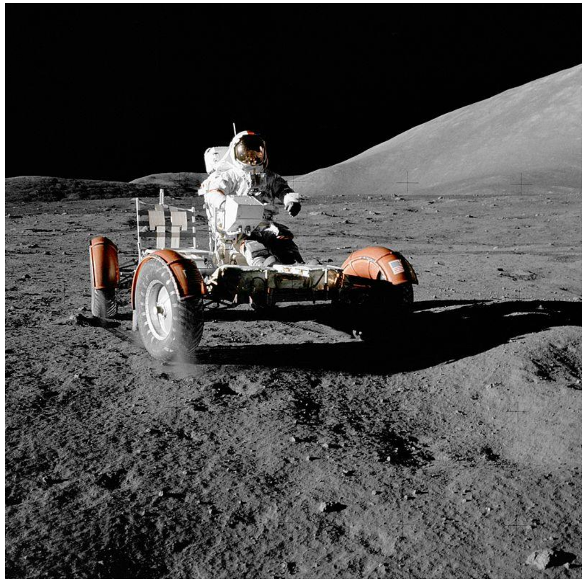
- Deep space
  - 75 μSv/h
  - 300 mSv over 180 days transit to mars

Ionizing radiation is important health risk in space

April 1972: Apollo 16



August 1972: Serious solar storm



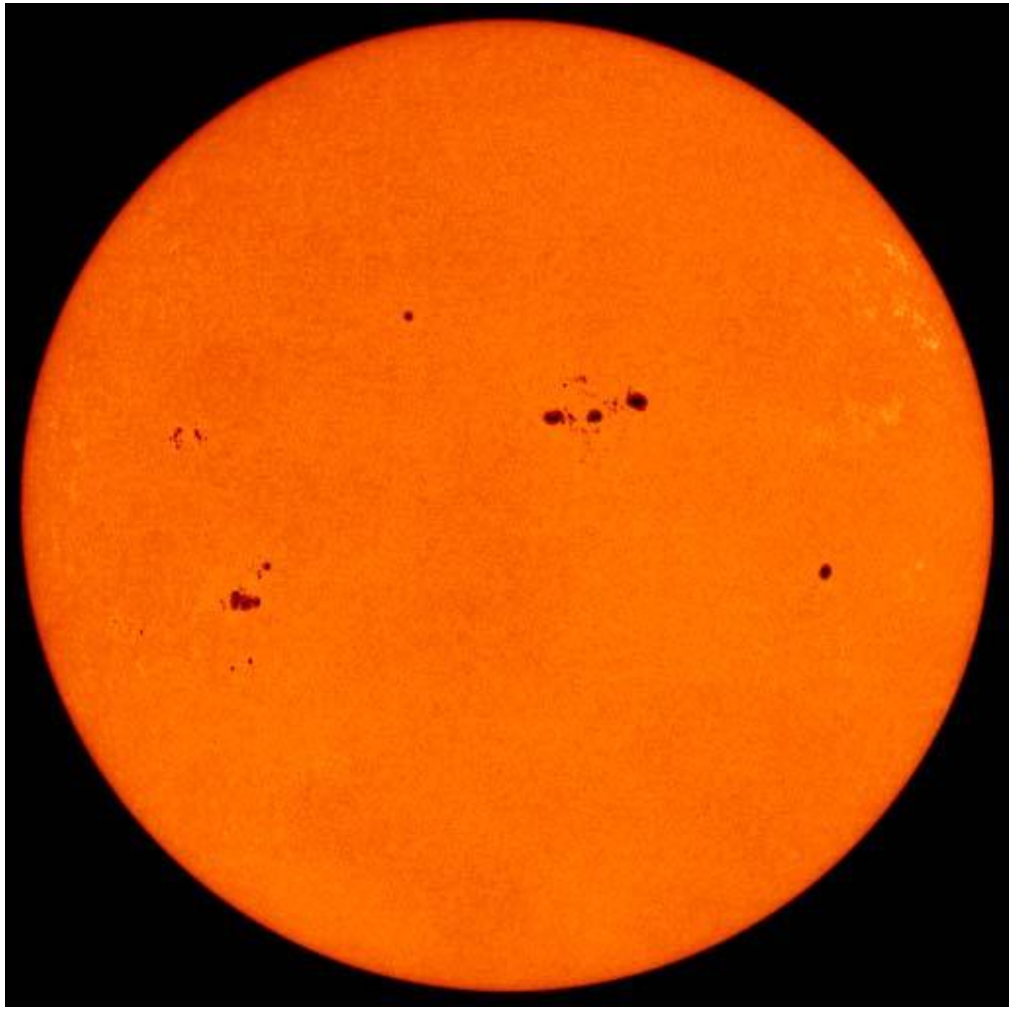
December 1972: Apollo 17

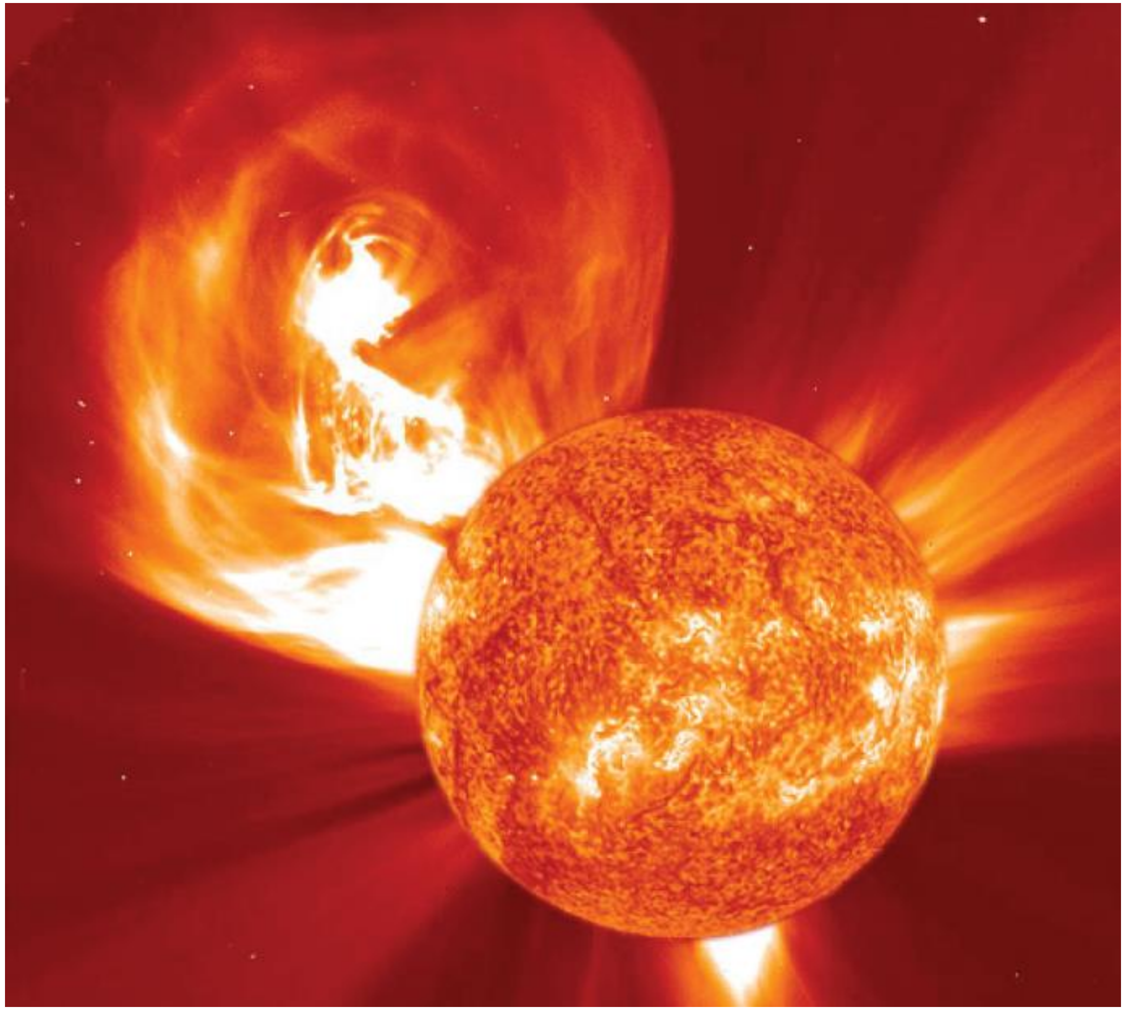
Content

- What are the cosmic radiation sources?
- How does cosmic radiation interact with materials?
- What are the effects of cosmic radiation on the health?
- How can we quantify the cosmic radiation dose?
- How can we determine the cosmic radiation dose?

What are the cosmic radiation sources?

Radiation from the sun

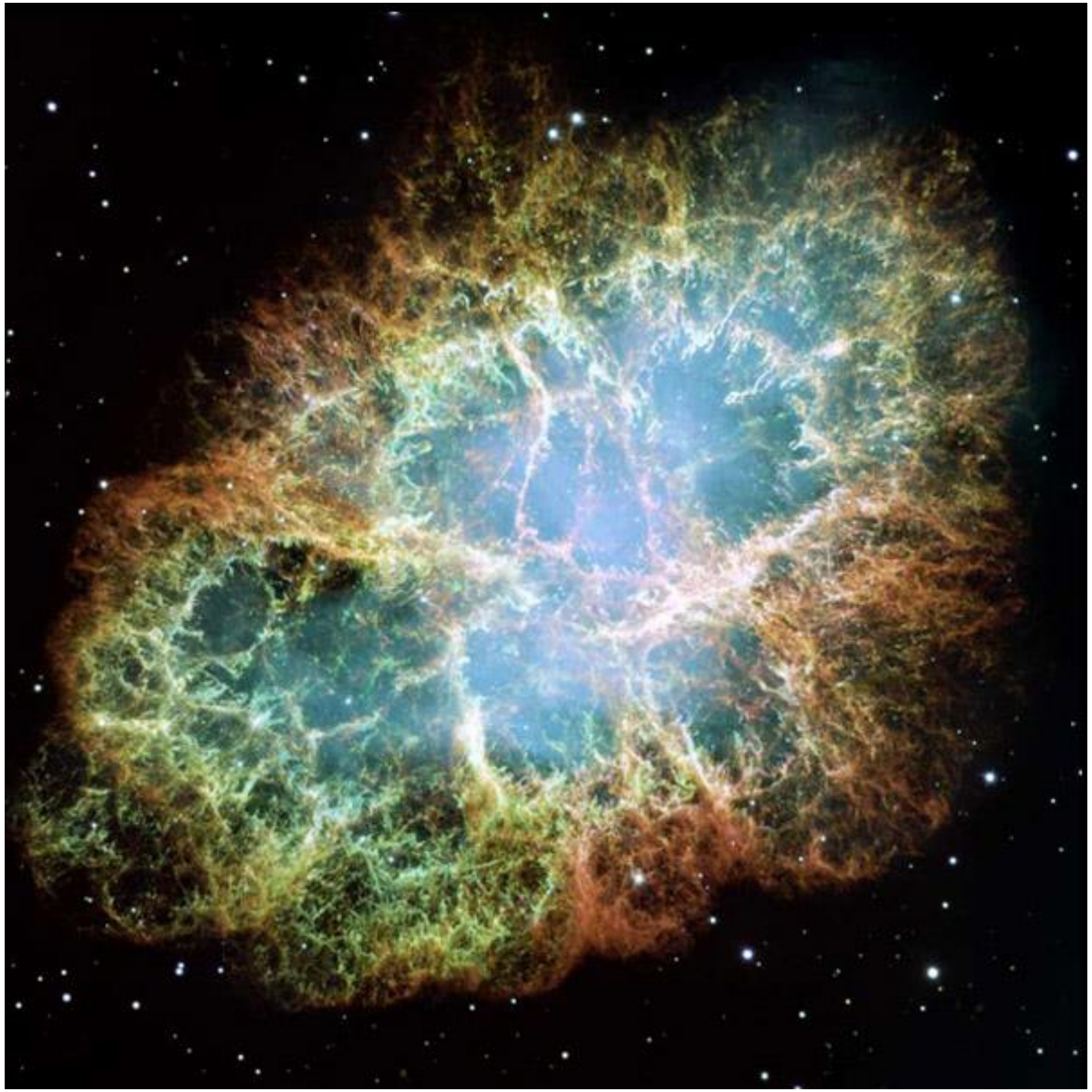




Radiation from the sun

- Charged particles emitted by the solar surface
- Mostly protons and electrons
- Limited amount of nuclei
- Relatively low energies up to typically 100 MeV
- Concentrated during Solar Particle Events (SPE’s)
- SPE probability proportional with to solar activity
- Very difficult to predict
- Limited dose contribution in ISS
- Very high doses in short time further from earth without shielding

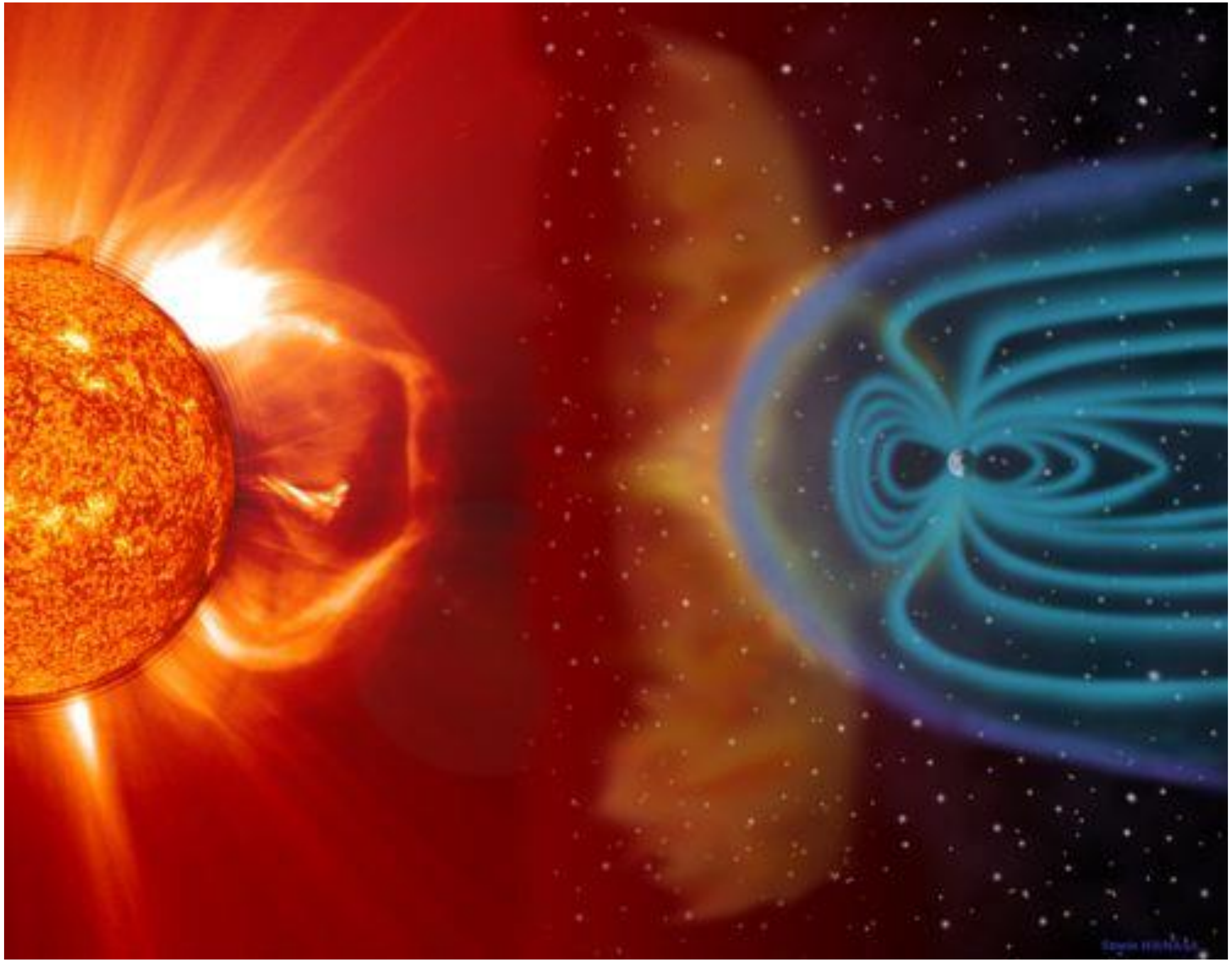
Galactic radiation



Galactic radiation

- Charged particles accelerated by supernova remnants
- Mostly protons and helium nuclei
- Limited amount of heavier nuclei, electrons and positrons
- Extremely high energies up to 10^{12} MeV with peak around 1 GeV
- Continuous fluence from all directions
- Fluence inversely proportional to solar activity due to shielding by magnetic field created by solar wind
- Easier to predict
- 75% of the radiation dose in ISS
- Continuous difficult to shield radiation source further from earth

Geomagnetic fields



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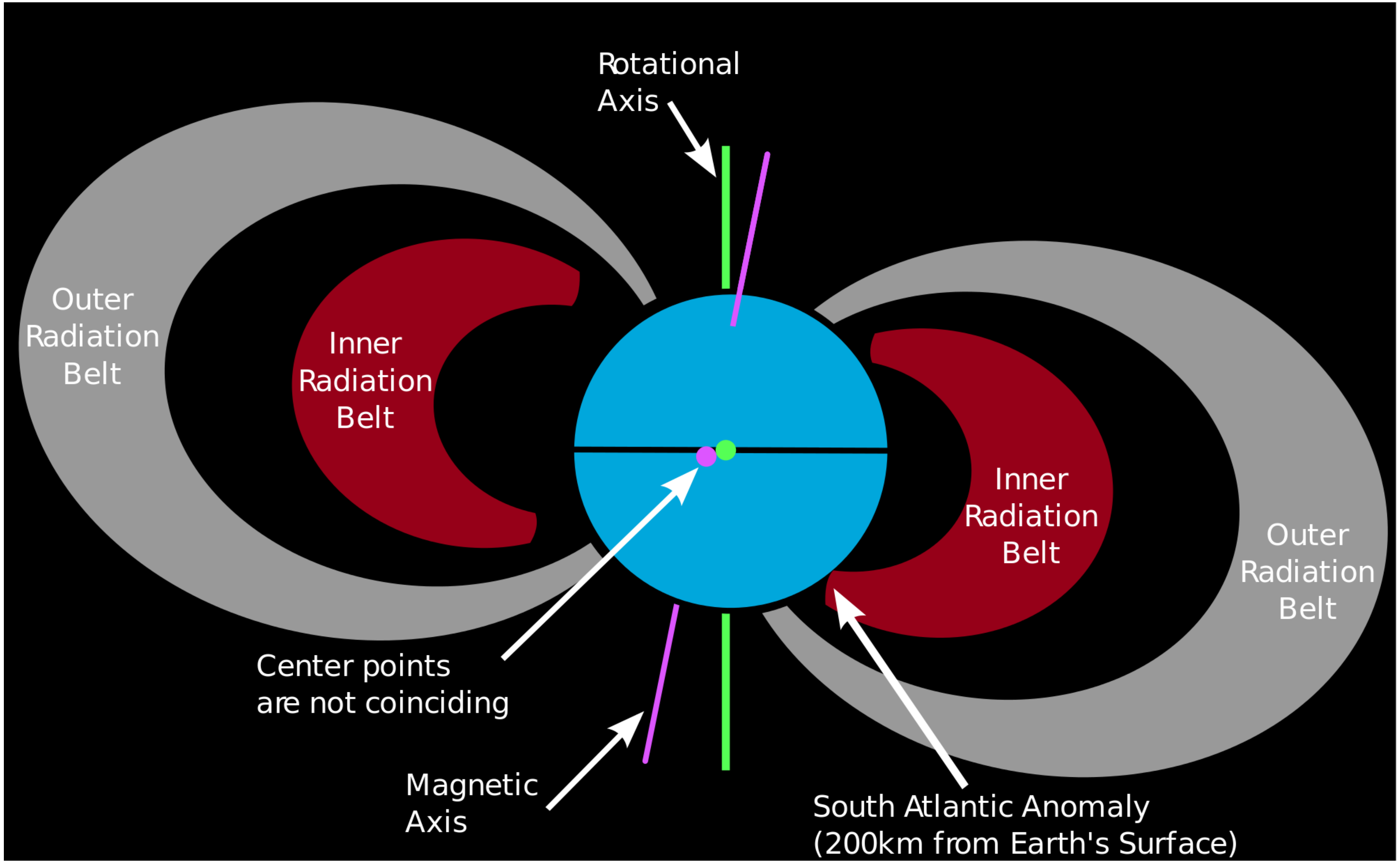
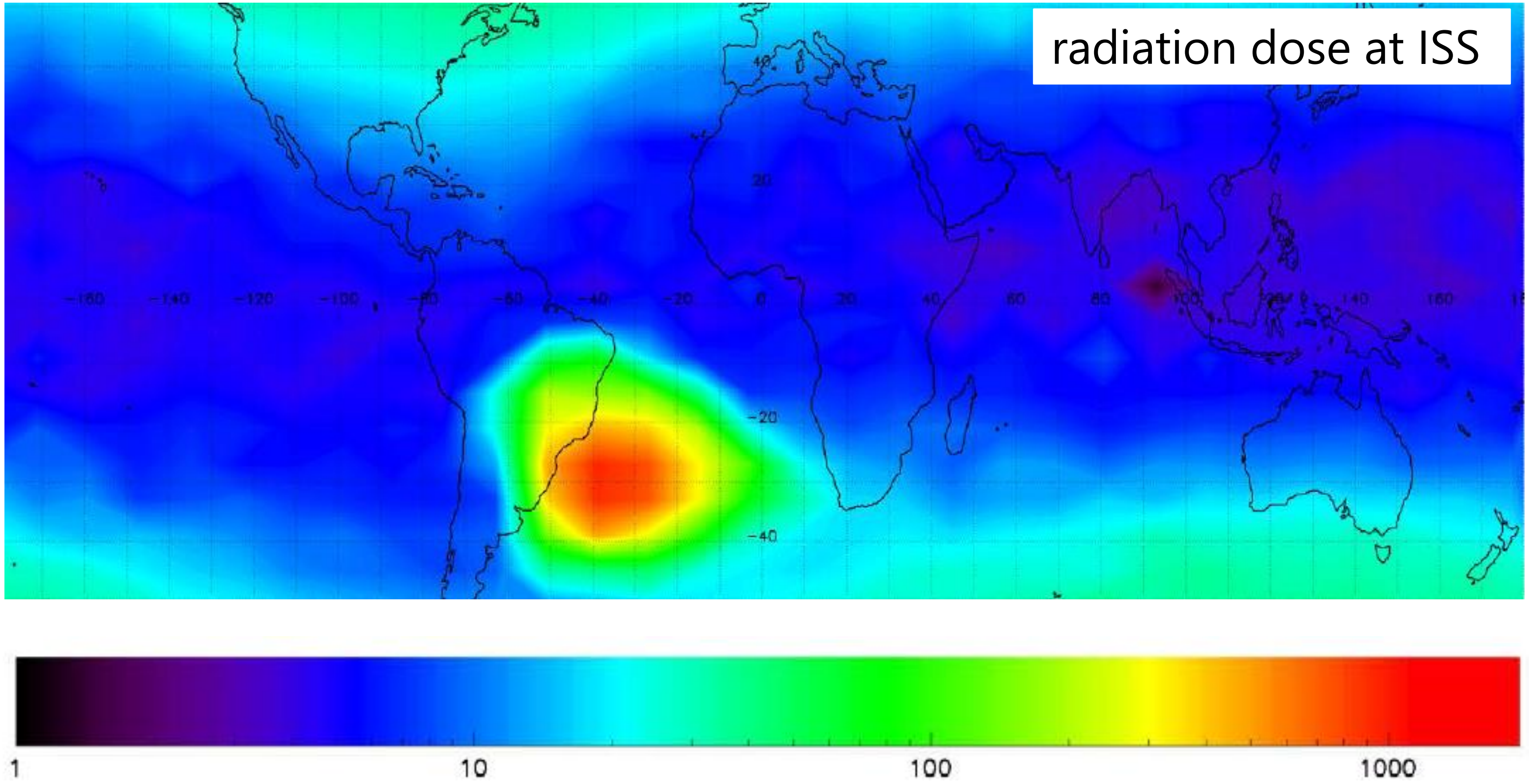
Geomagnetic fields

- Geomagnetic field shields earth largely from cosmic radiation
- Only most energetic particles reach the atmosphere
- Polar areas are less protected
- No significant magnetic field on the moon or mars
- Capture of energetic charged particles in Van Allen radiation belts

Van Allen radiation belts



Van Allen radiation belts



Van Allen radiation belts

- Charged particles captured by the geomagnetic field

- Inner belt
  - Centre around 3000 km above the earth's surface
  - Electrons with energies < 5 MeV and protons with energies < 700 MeV
  - Lowered to 200 km in the South Atlantic Anomaly (SAA)
  - Intensity and size inversely proportional to solar activity

- Outer belt
  - Centre around 22 000 km above the earth's surface
  - Electrons with energies < 7 MeV
  - Intensity and size proportional to solar activity

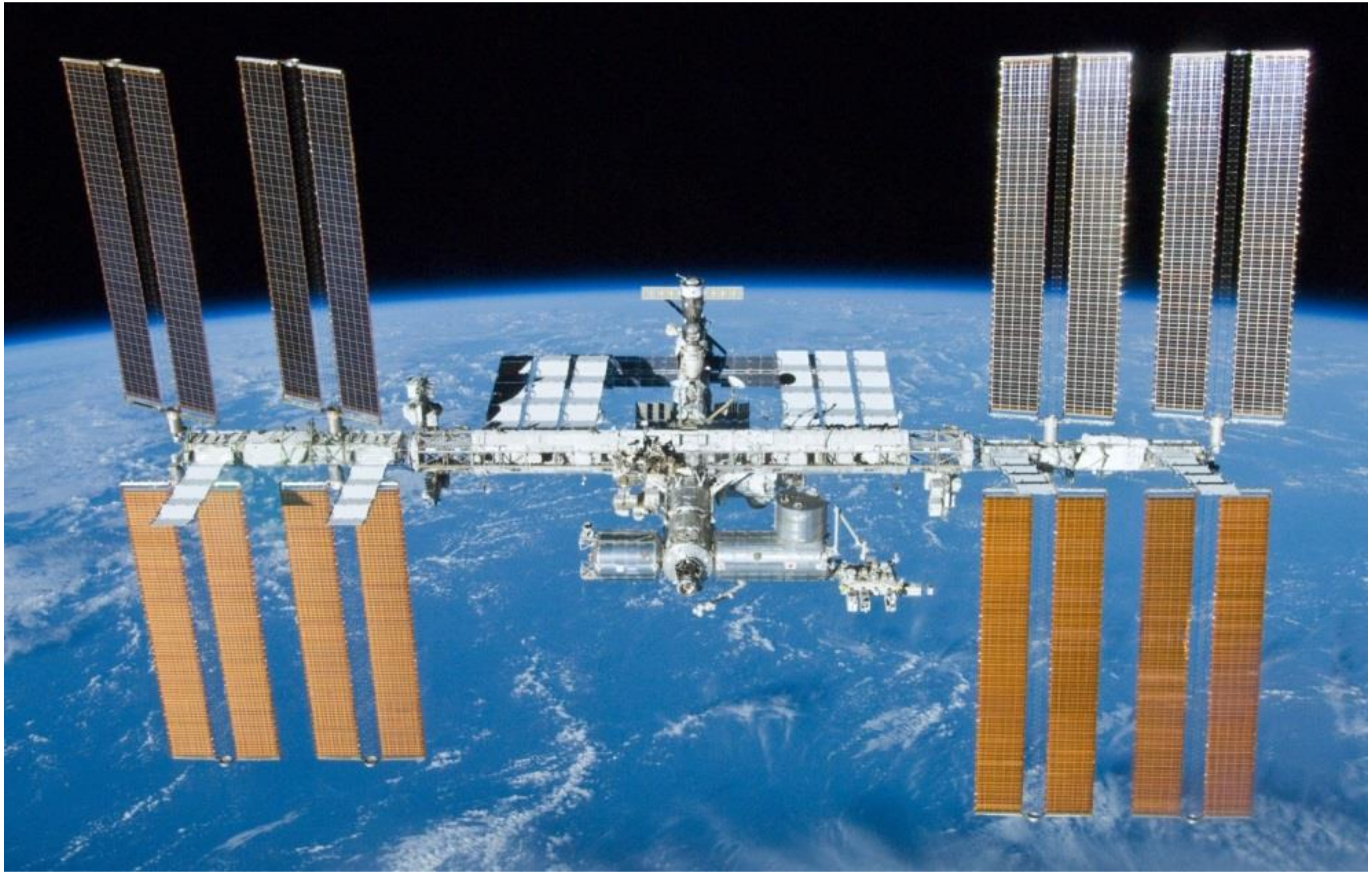
- 25% of radiation dose in ISS due passage through SAA

How does cosmic radiation interact with materials?

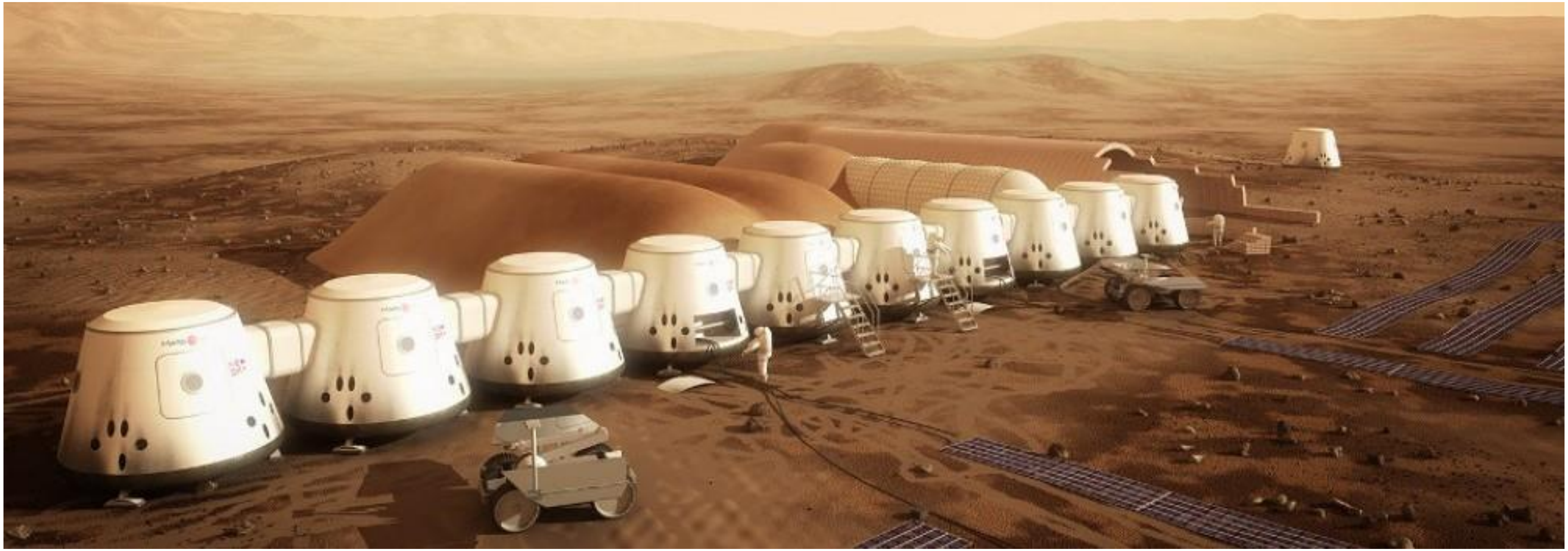
Secondary cosmic radiation

- Nuclear reactions between primary radiation and matter
- Creation of secondary radiation: neutrons, protons, heavier nuclei, pions, muons, gammas, electrons
- Secondary radiation depends strongly on material composition
- Secondary radiation can be more dangerous than primary radiation
- Light materials are best for shielding cosmic radiation (hydrogenous materials such as water, polyethylene, …)

Shielding from cosmic radiation



Shielding from cosmic radiation



Shielding from cosmic radiation

- Extra shielded compartments give good protection against SPE's

- Galactic radiation is very difficult to stop due to high energy
  - Requires several meters of material
  - Not realistic for spacecraft
  - More realistic for habitats on moon and mars

What are effects of cosmic radiation on the health?

Cosmic radiation health effects

- SPE’s can cause deterministic effects

- Long term galactic radiation exposure can cause stochastic effects

- Risk assessment for cosmic radiation is very challenging
  - Limited data for effect of energetic nuclei
  - Limited knowledge on late non-cancer effects
    - Central nervous system
    - Cardiovascular system
    - Immune system
    - Cataract
    - …

How can we quantify the cosmic radiation dose?

Dose quantities for cosmic radiation

- For radiation protection on earth
  - Organ equivalent dose for deterministic effects
  - Effective dose for stochastic effects

- For astronauts a more sophisticated and individualized dose assessment
  - Direct estimation of the risks
  - Based on estimation of organ absorbed doses and quality factors

Risks for manned moon or mars missions

TABLE 1-4 Estimated REID with 95 Percent Confidence Interval (CI) for Sample Exploration Missions

	Solar Minimum		Solar Maximum	
	REID (%)		REID (%)	
Sample Mission	Point Estimate	CI [lower, upper]	Point Estimate	CI [lower, upper]
Long lunar mission, 6 days in deep space, 84 days on surface				
Male	0.28	[0.09, .95]	0.36	[0.12, 1.2]
Female	0.34	[0.11, 1.2]	0.43	[0.13, 1.4]
Mars swing-by, 600 days in deep space				
Male	3.2	[1.0, 10.4]	2.0	[0.60, 6.8]
Female	3.9	[1.2, 12.7]	2.5	[0.76, 8.3]
Mars surface mission, 400 days in deep space, 600 days on surface				
Male	3.4	[1.1, 10.8]	2.4	[0.76, 7.8]
Female	4.1	[1.3, 13.3]	2.9	[0.89, 9.5]

NOTE: Assumes 20 g/cm^2 aluminum shielding and 40-year-old astronauts. Solar maximum includes an August 1972 event in addition to GCR during deep-space portion. REID, risk of exposure induced death. SOURCE: Cucinotta et al., 2005.

How can we determine the cosmic radiation dose?

Determining the cosmic radiation risk

- Estimation of the risk before the mission
  - Models of GCR and SPE
  - Simulation of interaction with geomagnetic field and shielding
  - Simulation of organ absorbed doses and radiation type
  - Understanding of the biological effects of different radiation types

- Personal monitoring with a personal dosimeter

- Ambient monitoring with sophisticated ambient detectors

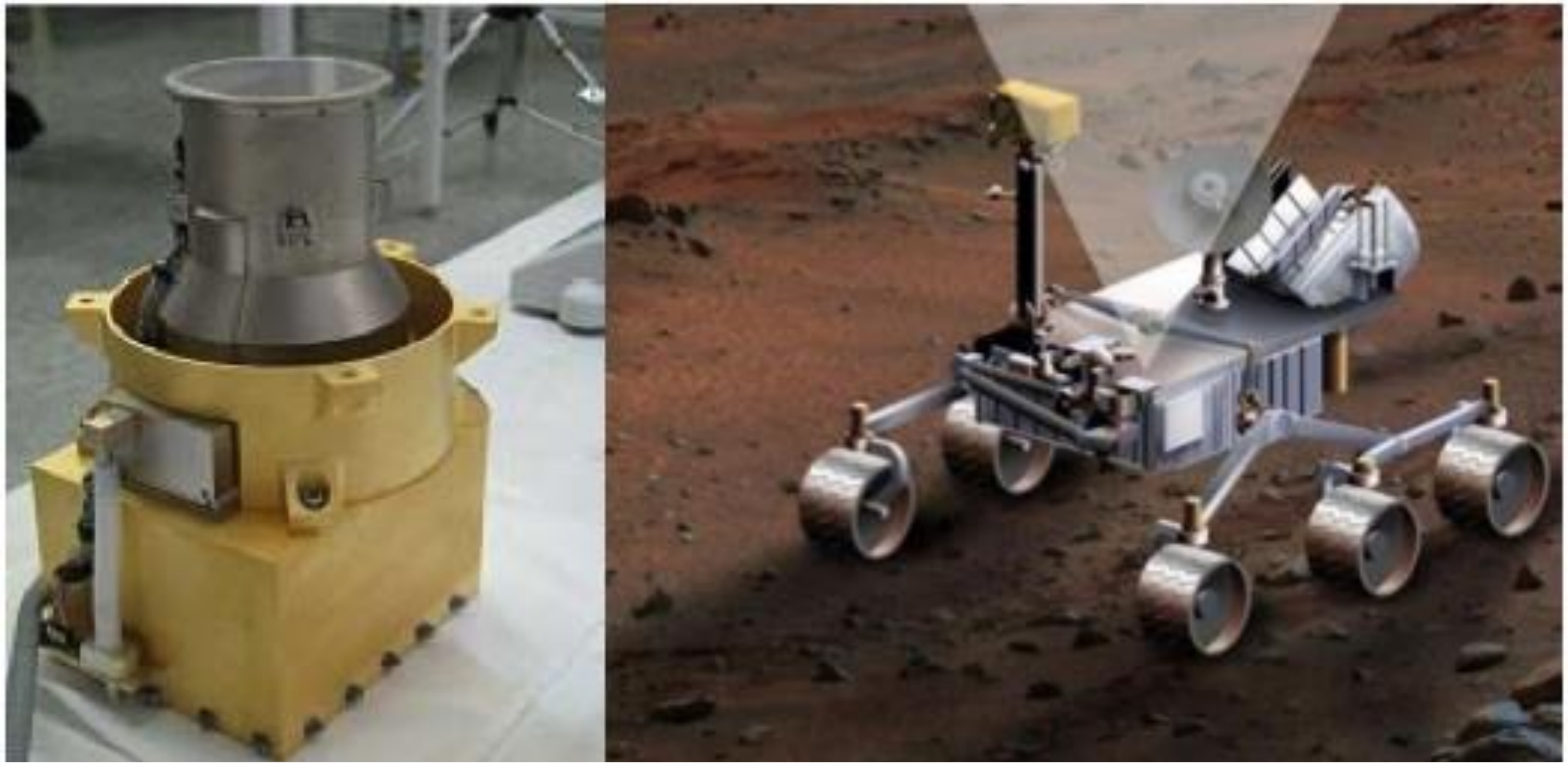
Tissue Equivalent Proportional Counter (TEPC)

IV-TEPC onboard the ISS

Semiconductor telescope

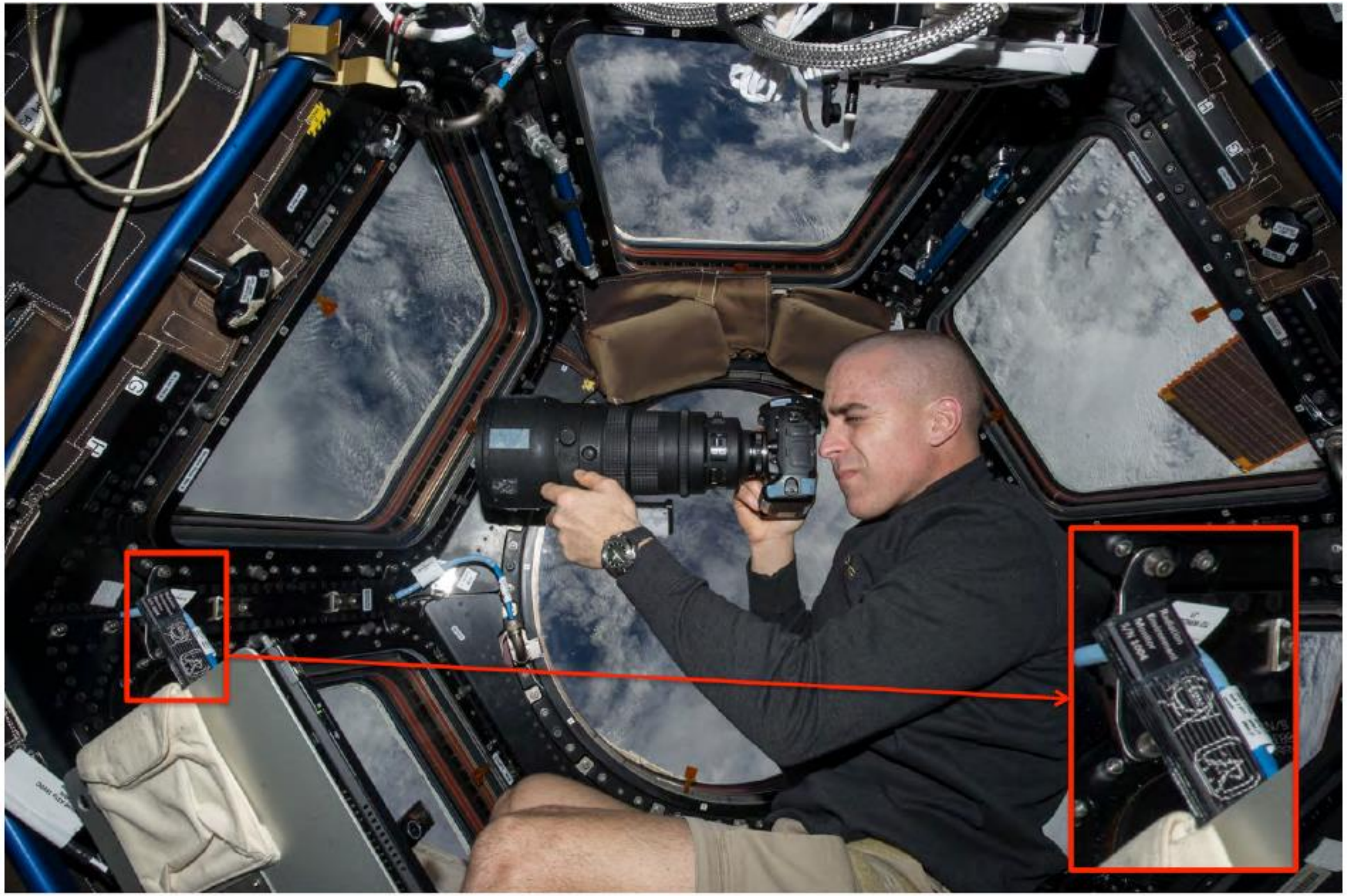
DOSimetry TELescope (DOSTEL) onboard the ISS

Semiconductor and scintillator telescope

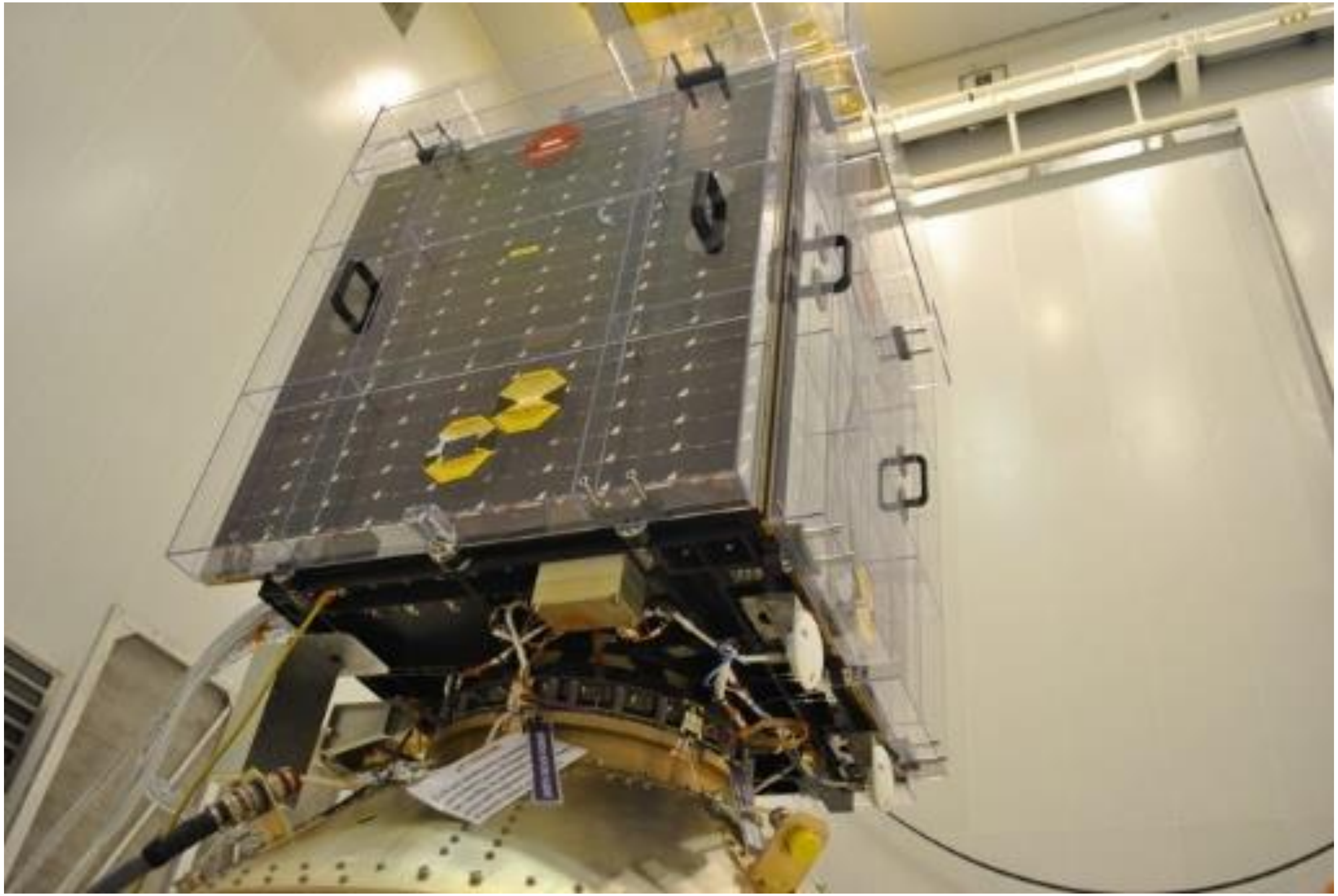


MSL-RAD onboard the mars rover Curiosity

Timepix at ISS

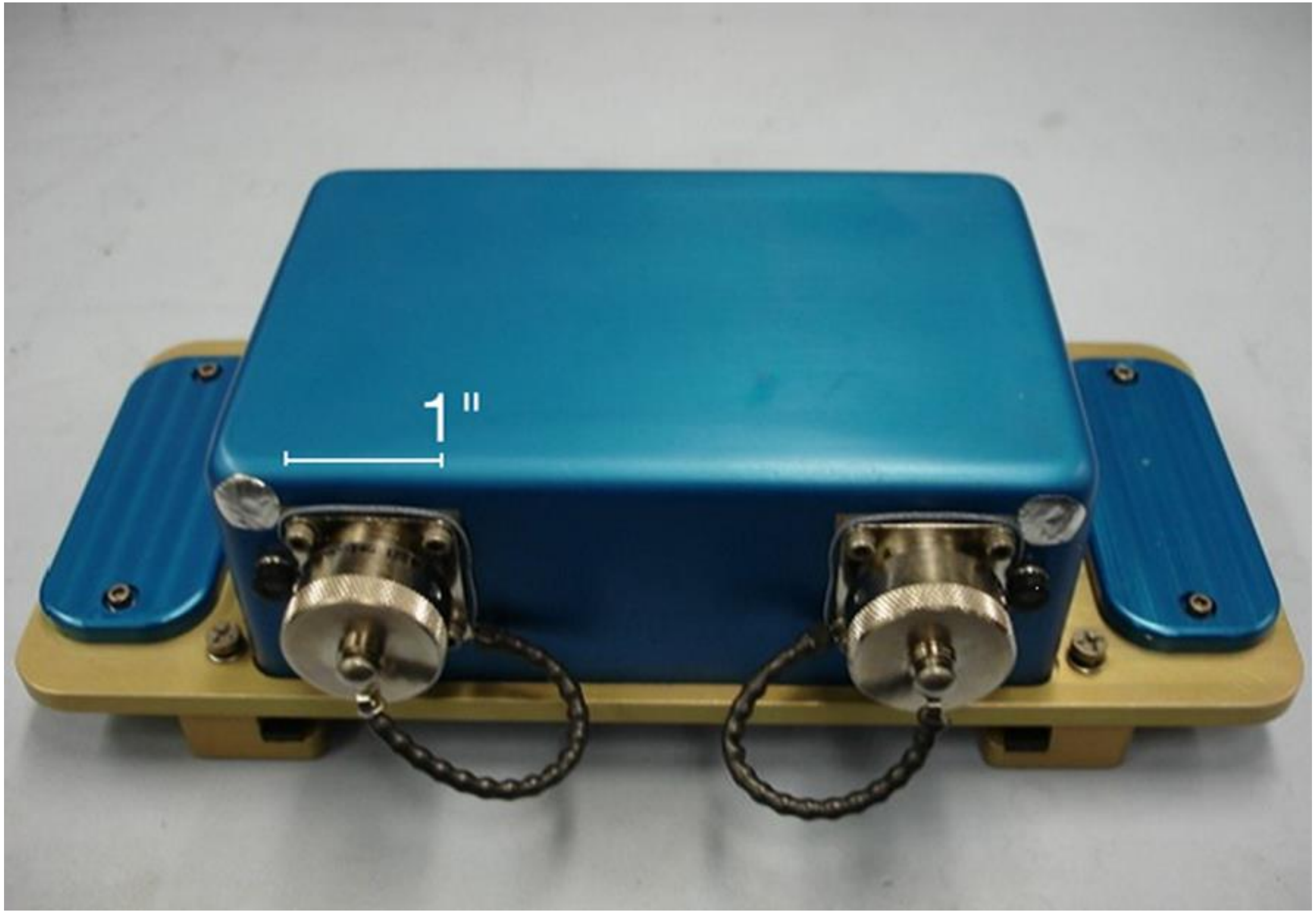


Timepix at Proba V satellite

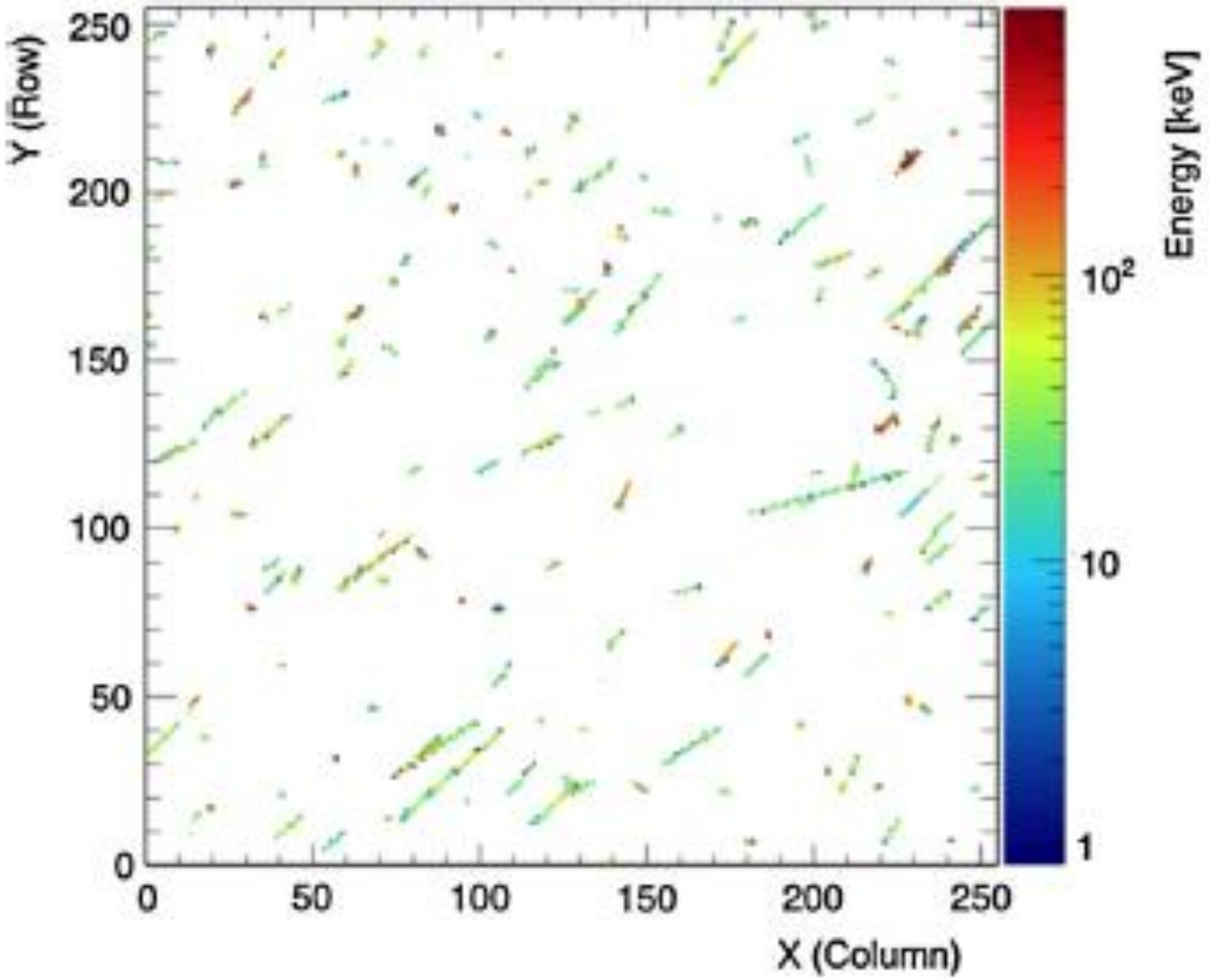


Timepix for Orion missions

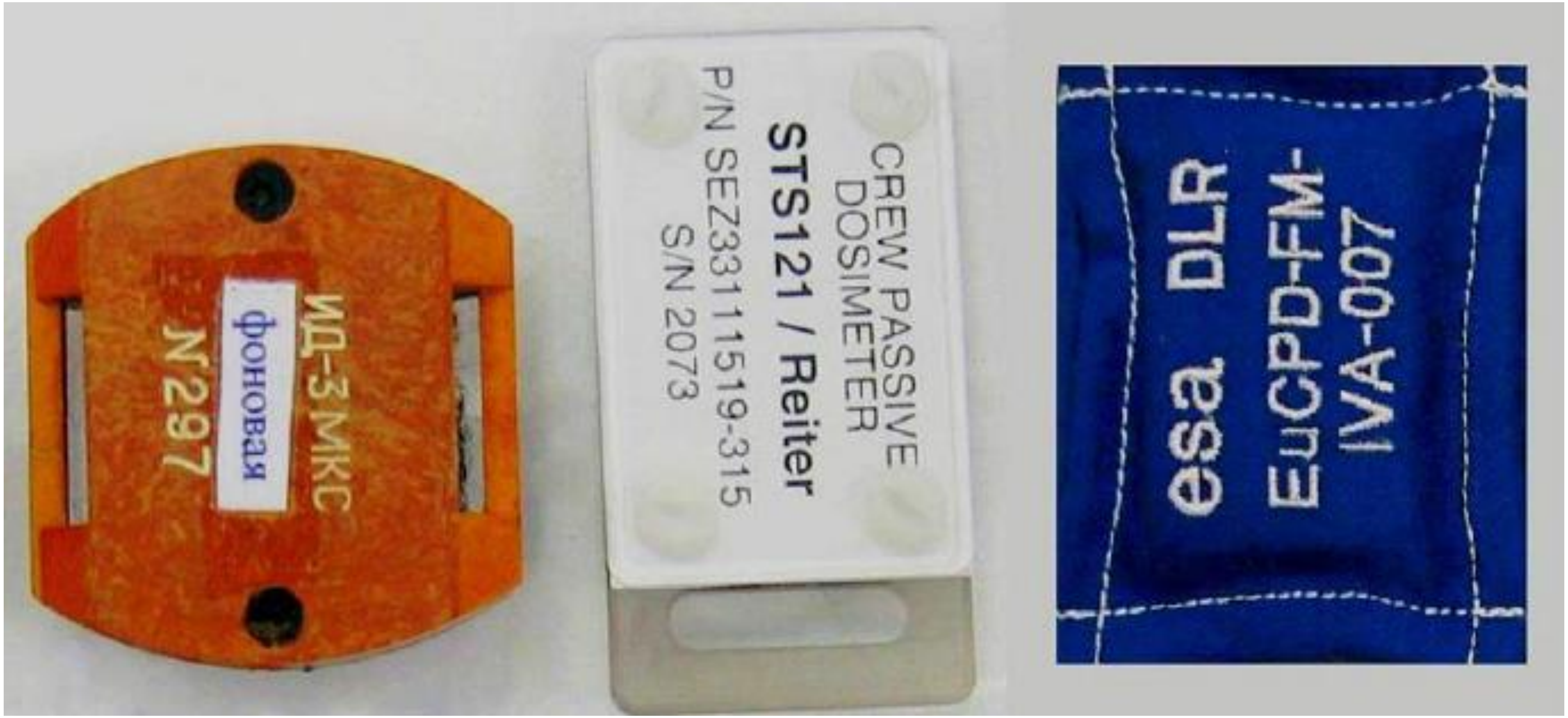
Timepix for Orion missions



Timepix based technology

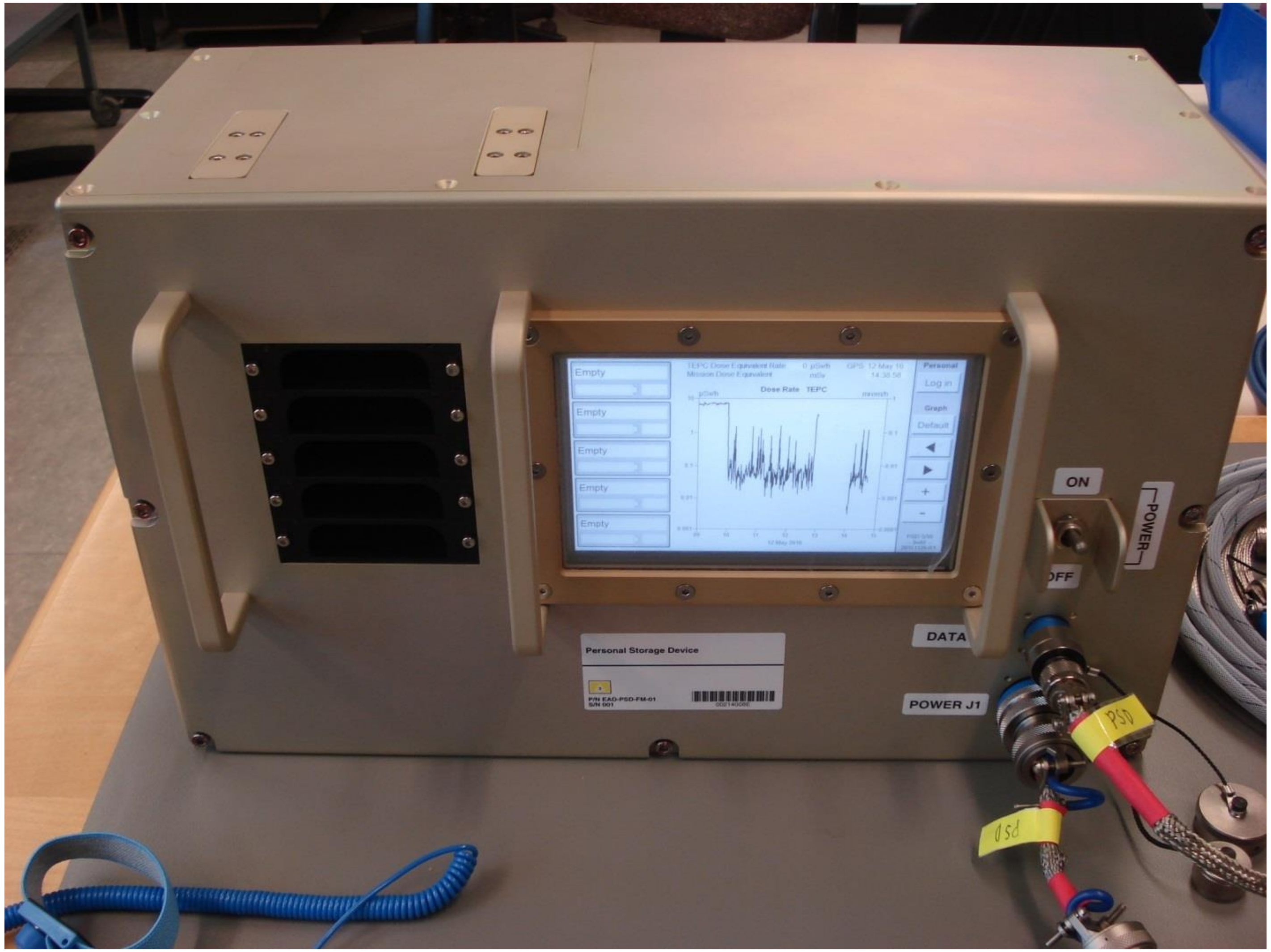


Passive personal dosimeter for astronauts



Passive personal dosimeter for astronauts

EU-CPAD Active personal dosimeter:
Silicon diode and Direct ion storage detectors



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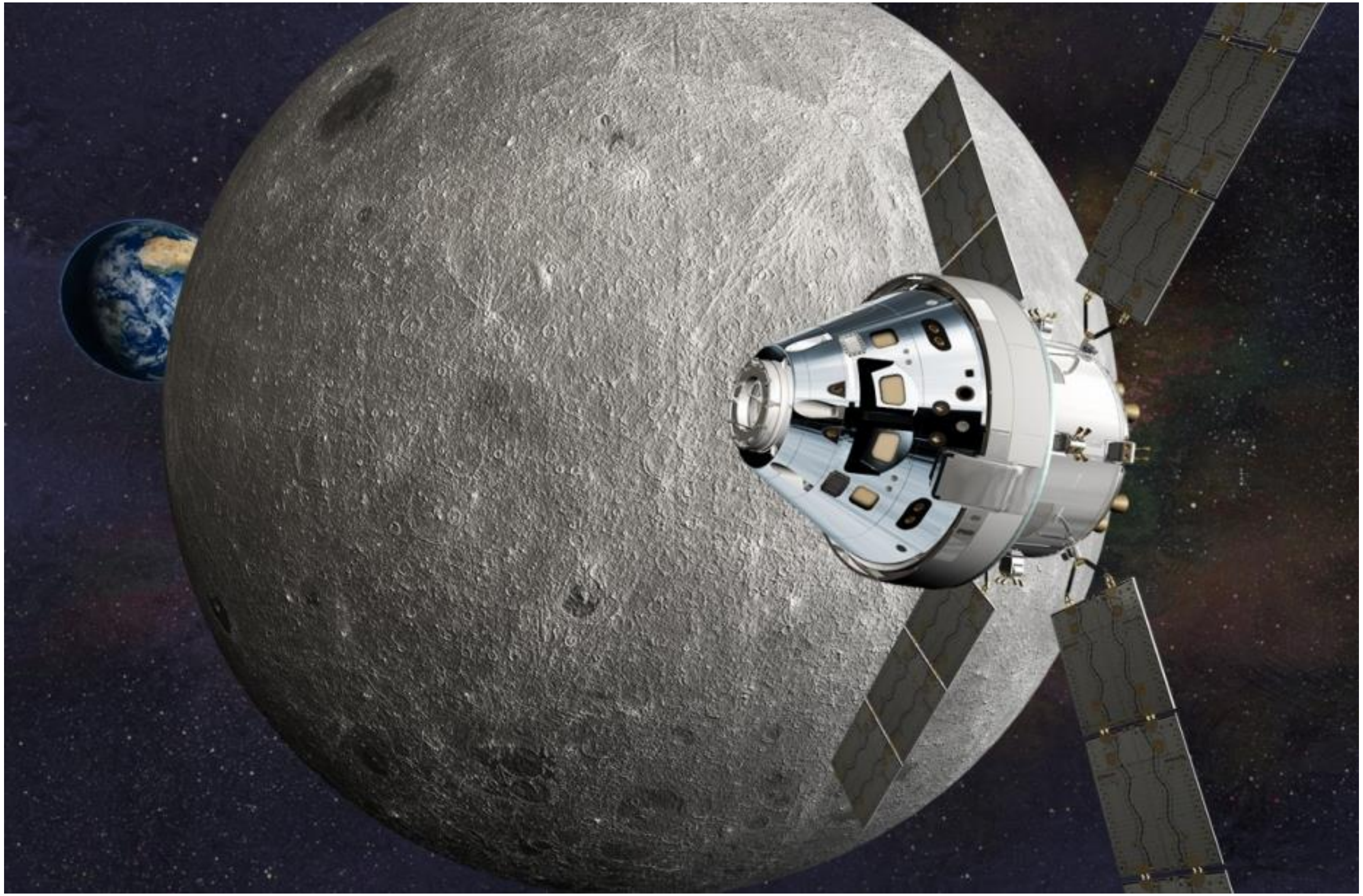
EU-CPAD Active personal dosimeter: Silicon diode and Direct ion storage detectors

Bubble detector

- Small droplets of superheated liquid in transparent polymer
- Formation of gas bubbles by densely ionizing radiation
- Mainly for detection of neutrons
- Addition of ^{6}Li to measure thermal neutrons

Spectroscopic bubble detector measurements in ISS

Matroshka AstroRad Radiation Experiment on Orion EM-1



Matroshka AstroRad Radiation Experiment on Orion EM-1

Matroshka AstroRad Radiation Experiment on Orion EM-1

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