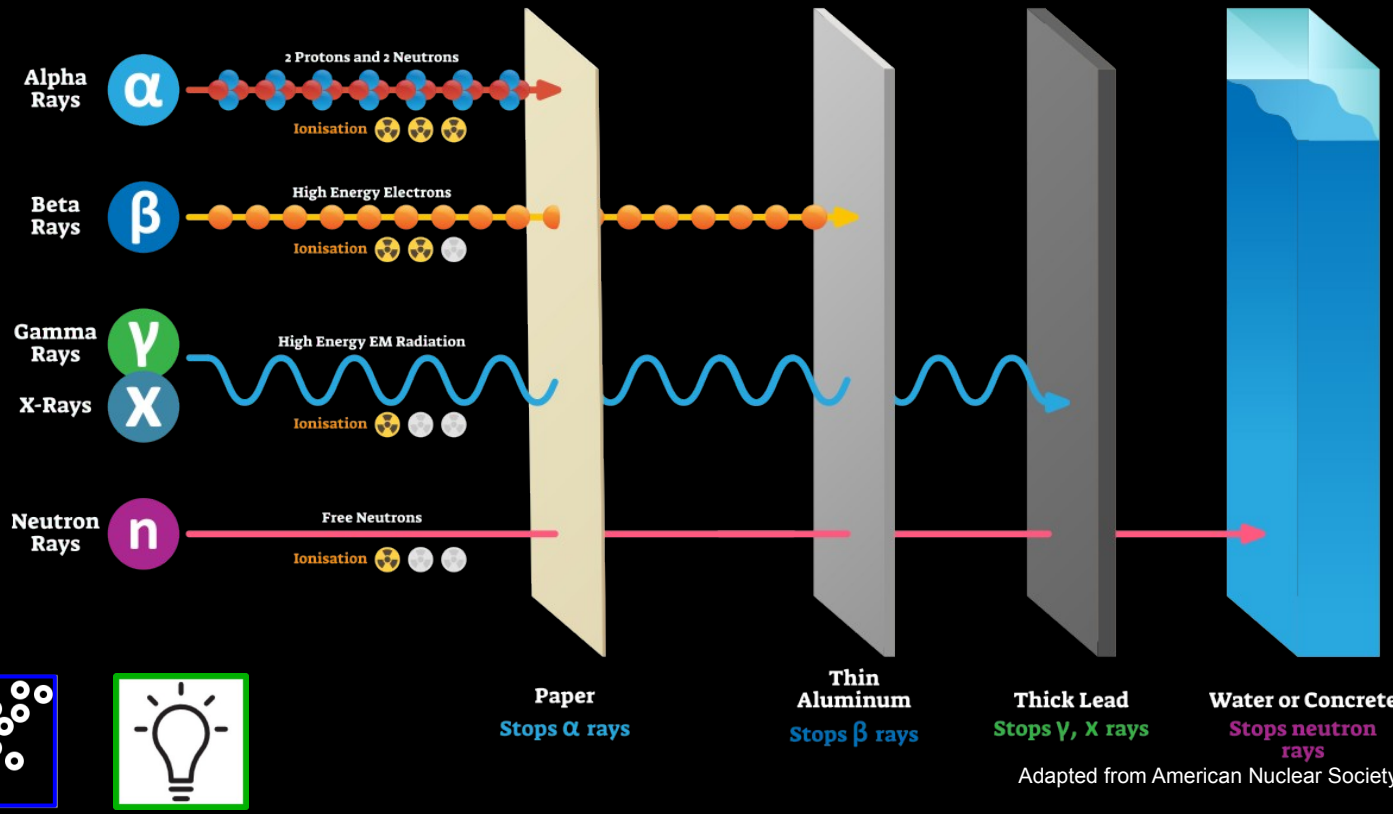
Space Weather Phenomena: Particle Radiation

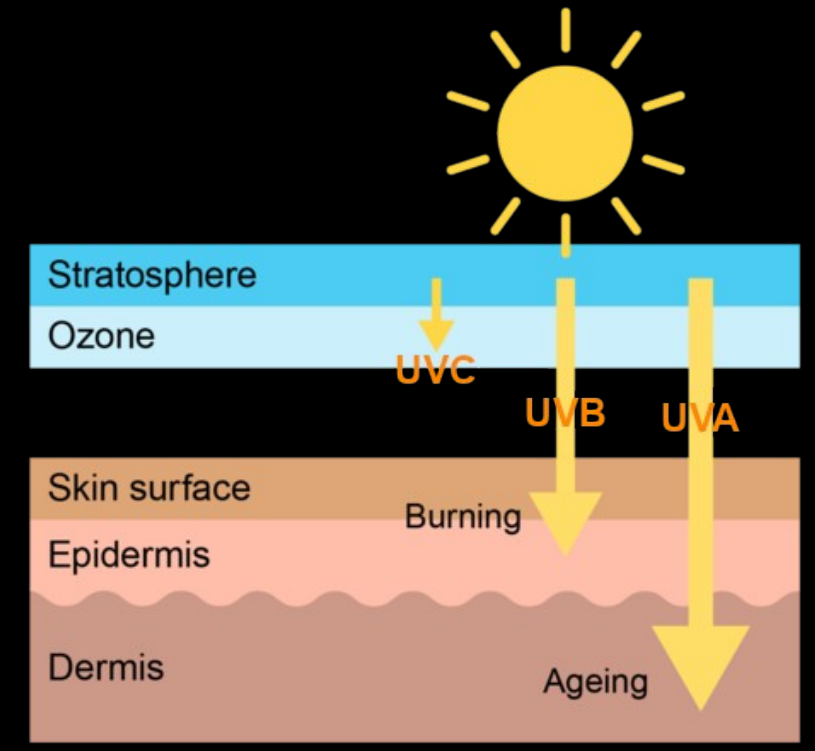
Claudio Corti, Leila Mays, Elana Resnick (CCMC)

What is radiation?

Transfer of energy to materials: objects, human body, etc



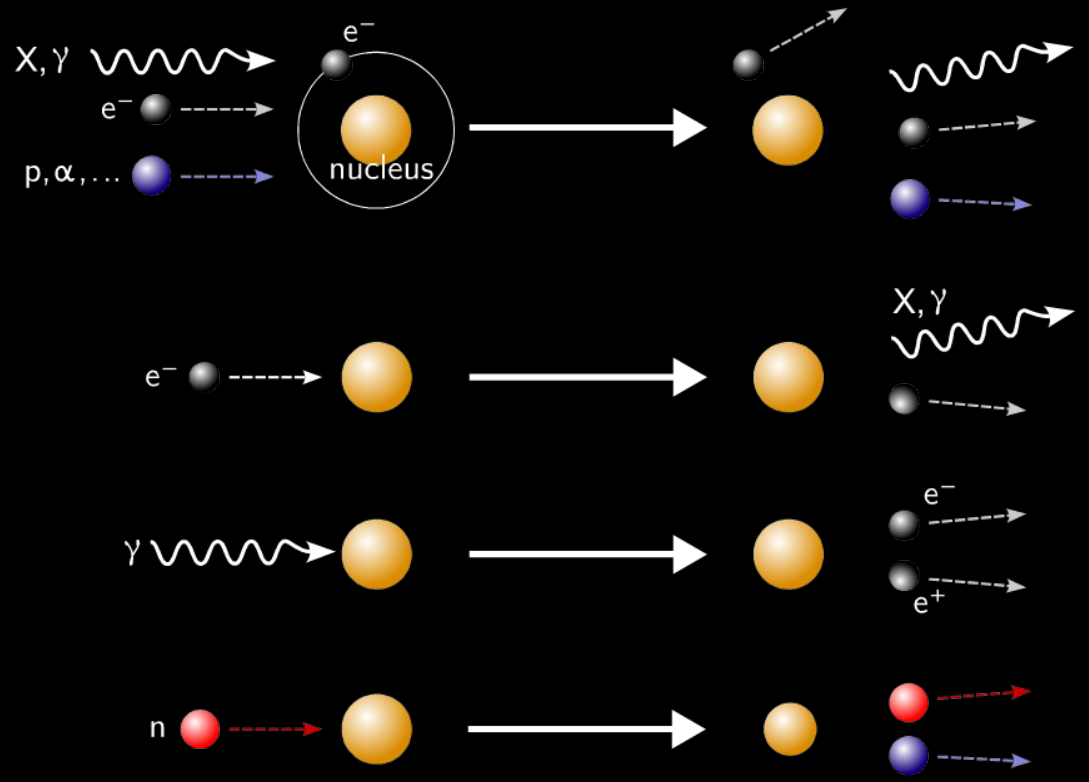
Adapted from American Nuclear Society

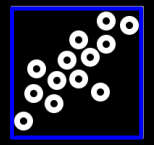


Adapted from Cancer Research UK

How does radiation affect materials?

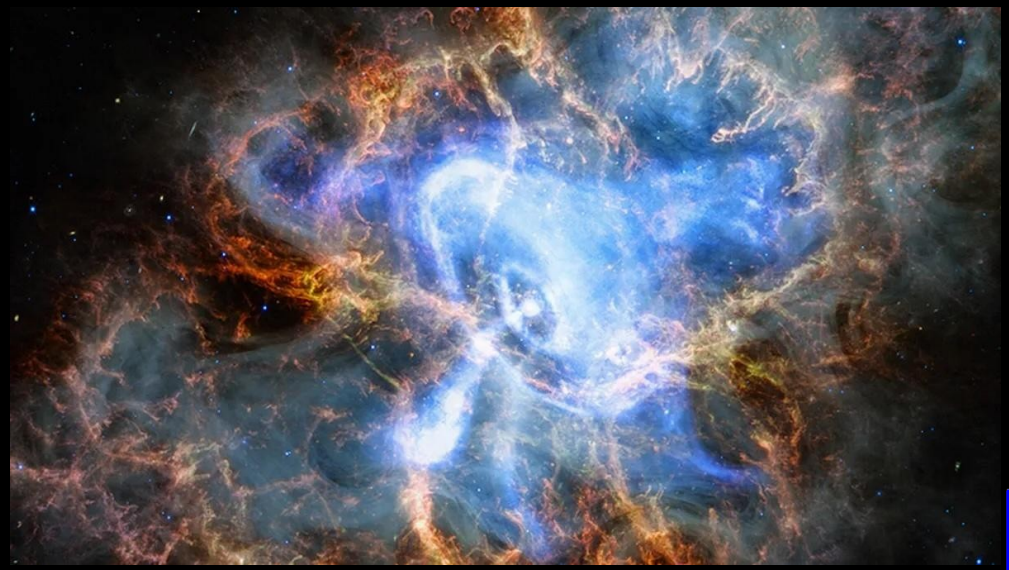
Mostly by ionizing the traversed matter: electrons are stripped out of atoms



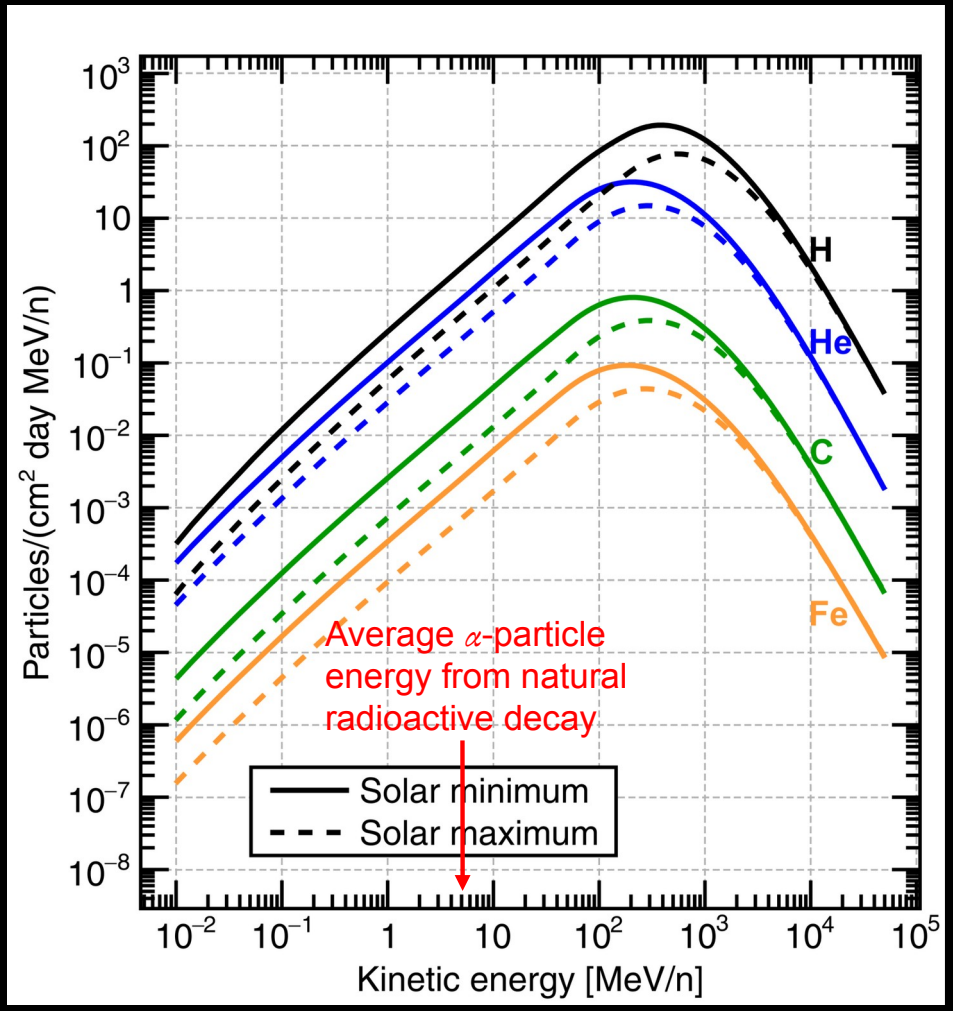


Radiation in space: galactic cosmic rays

Galactic cosmic rays (GCRs) are high-energy charged particles originating outside our solar system, usually in supernova explosions



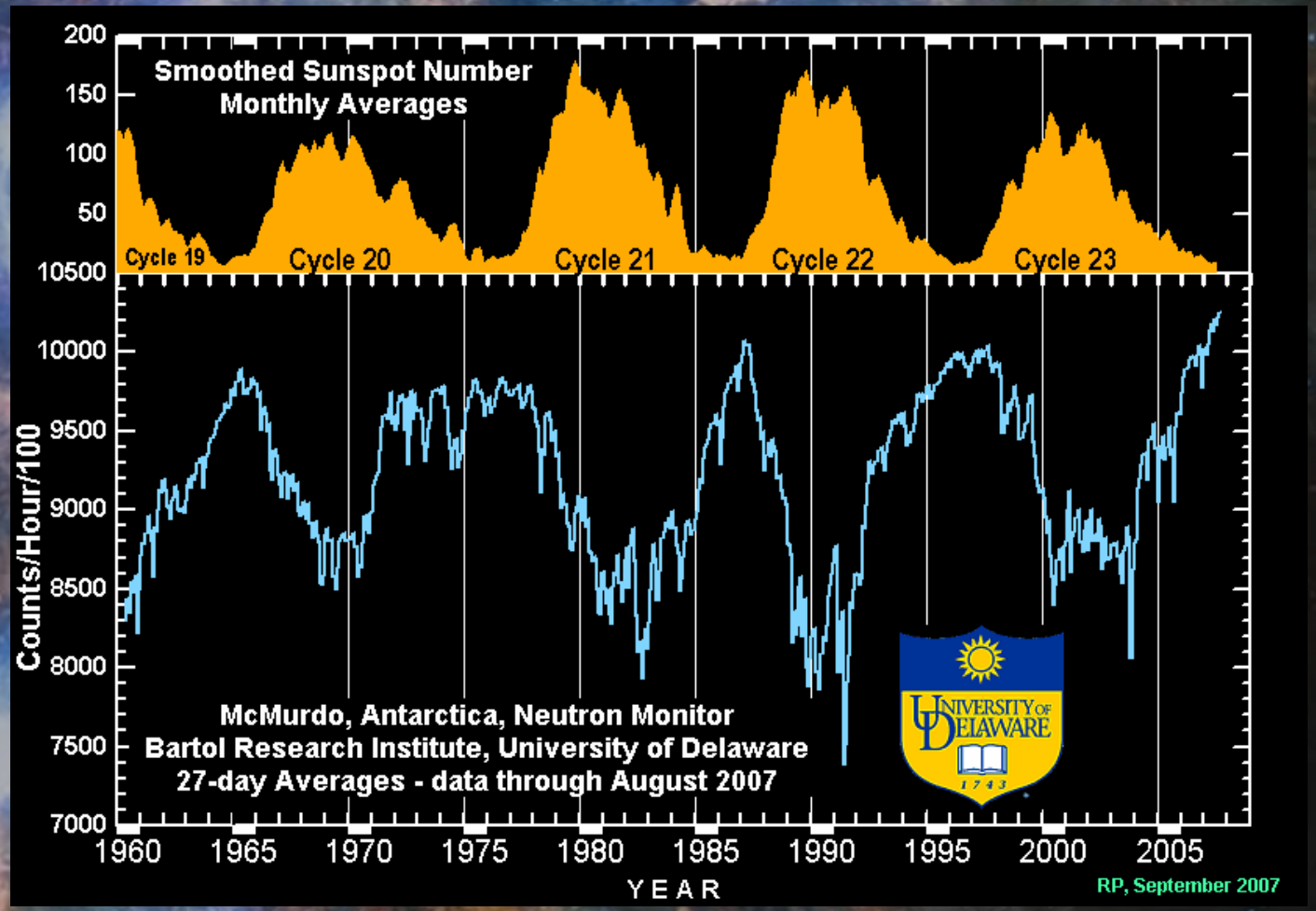
The Crab Nebula, as seen by the James Webb Space Telescope and Chandra X-ray Observatory (Image credit: X-ray, Chandra: NASA/CXC/SAO; Infrared, Webb: NASA/STScI; Image Processing: NASA/CXC/SAO/J. Major)



Radiation in space: galactic cosmic rays

GCR intensity is modulated by the solar activity:

- lower during solar maximum
- higher during solar minimum



Radiation in space: solar energetic particles

Solar energetic particles (SEPs) are accelerated in solar eruptions

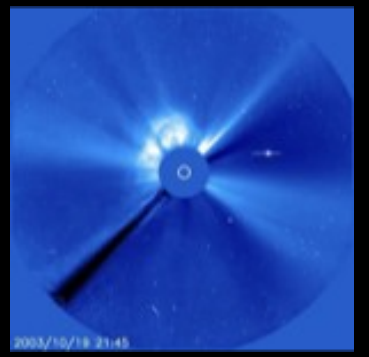
Elemental composition (may vary event by event):

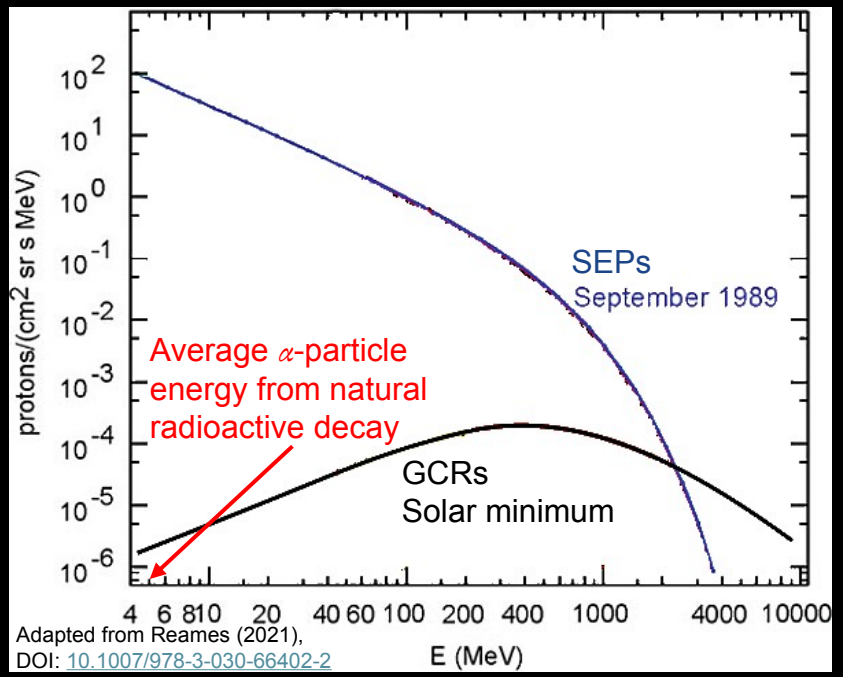
- 96.4% protons
- 3.5% alpha particles
- 0.1% heavier ions (not to be neglected!)

Energies: up to GeV/nucleon

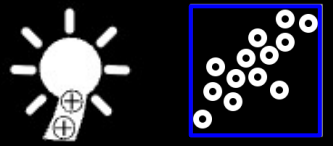
Event magnitude: can be up to 10^5 times higher than GCRs







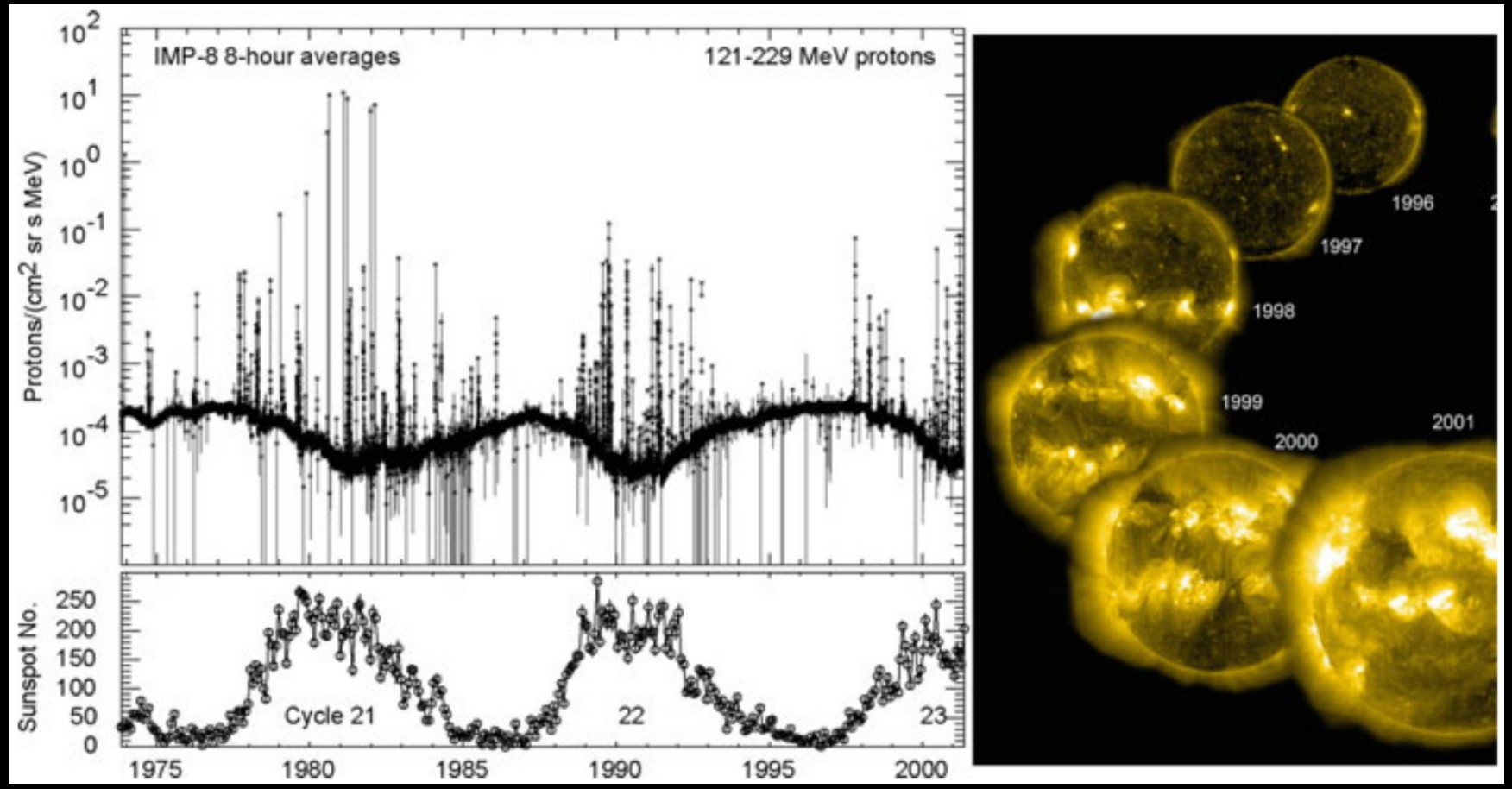
Adapted from Reames (2021), DOI: 10.1007/978-3-030-66402-2



Radiation in space: solar energetic particles

More likely to happen during solar maximum, but can still have large events during solar minimum

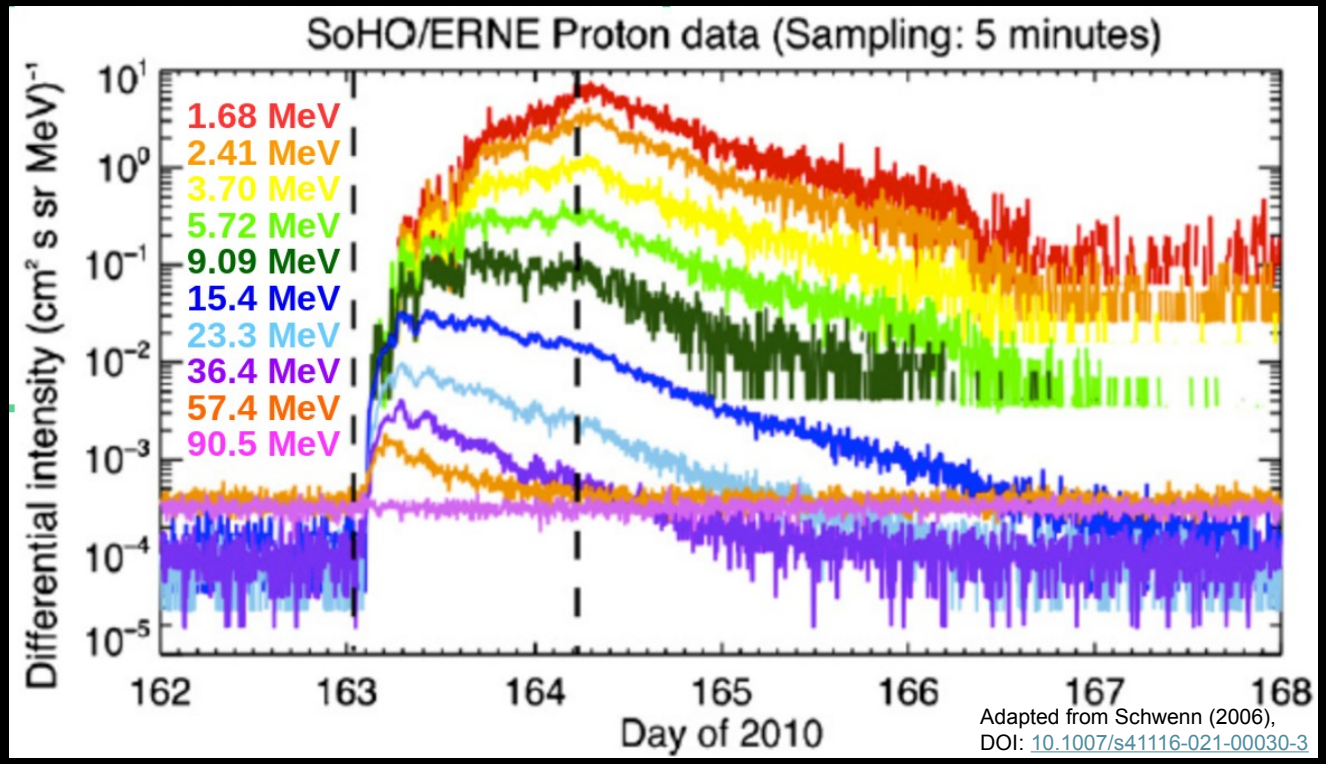
Hard to predict!



Credits: Reames (2021), DOI:10.1007/978-3-030-66402-2

Radiation in space: solar energetic particles

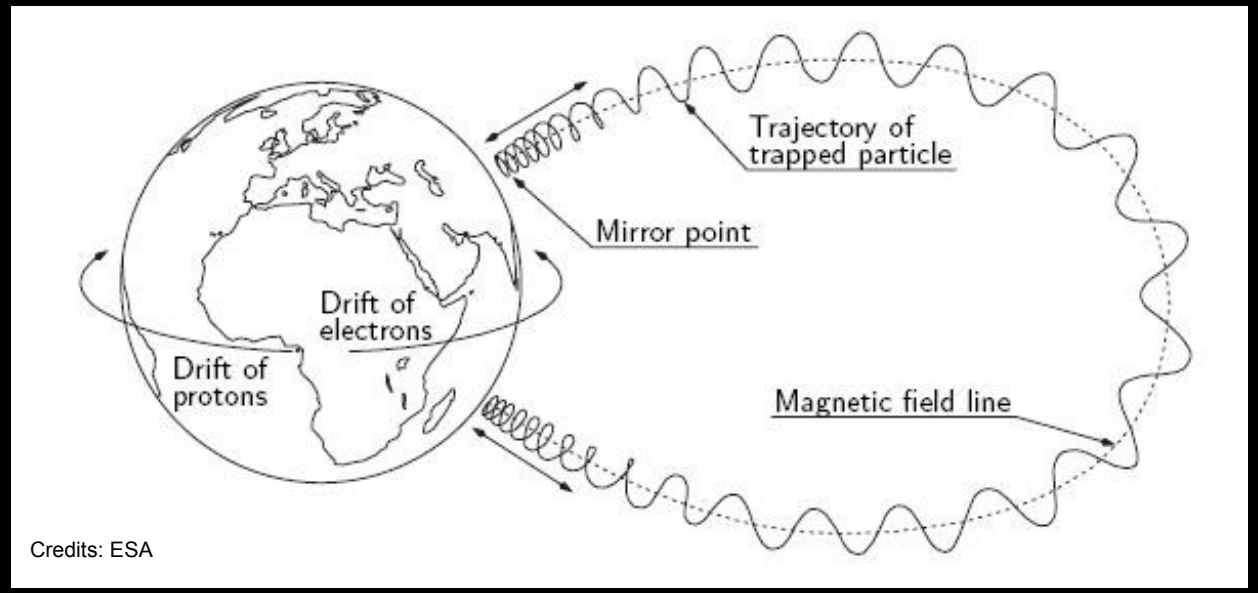
Can last from hours to days



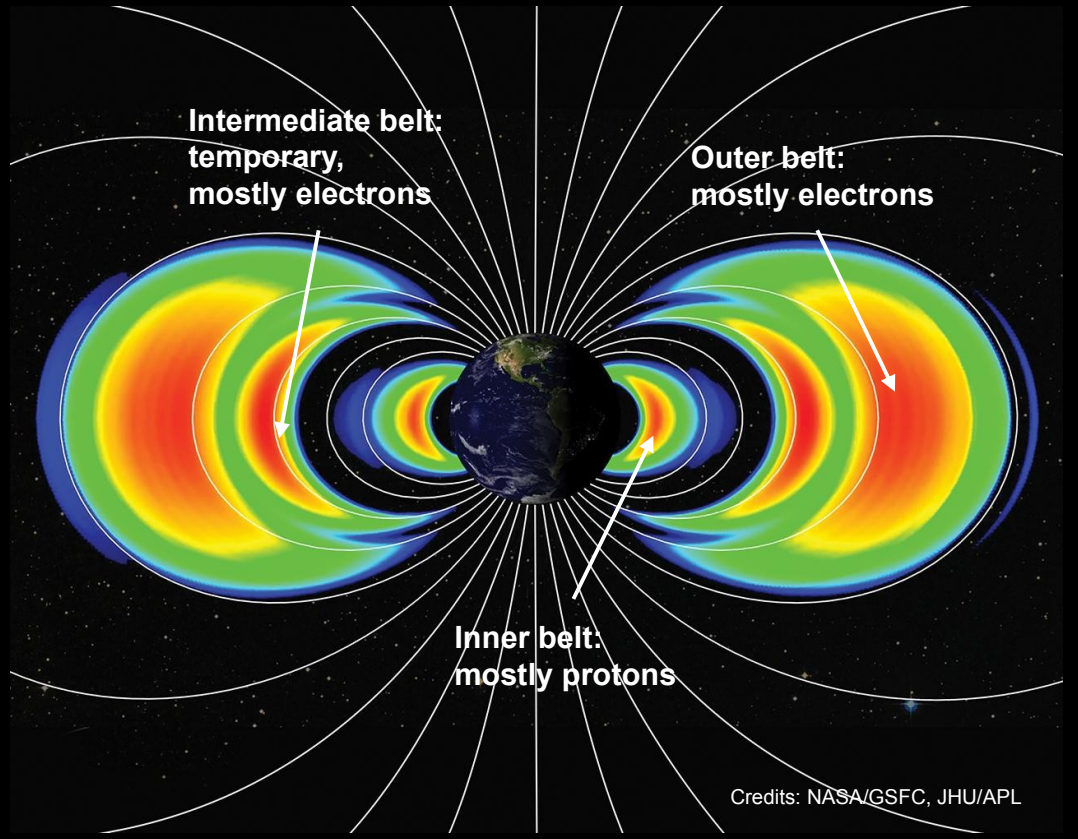
Adapted from Schwenn (2006), DOI: 10.1007/s41116-021-00030-3

Radiation in space: Van Allen belts

Protons (up to GeV) and electrons (300 keV – 10 MeV) trapped in Earth's magnetic field



Credits: ESA

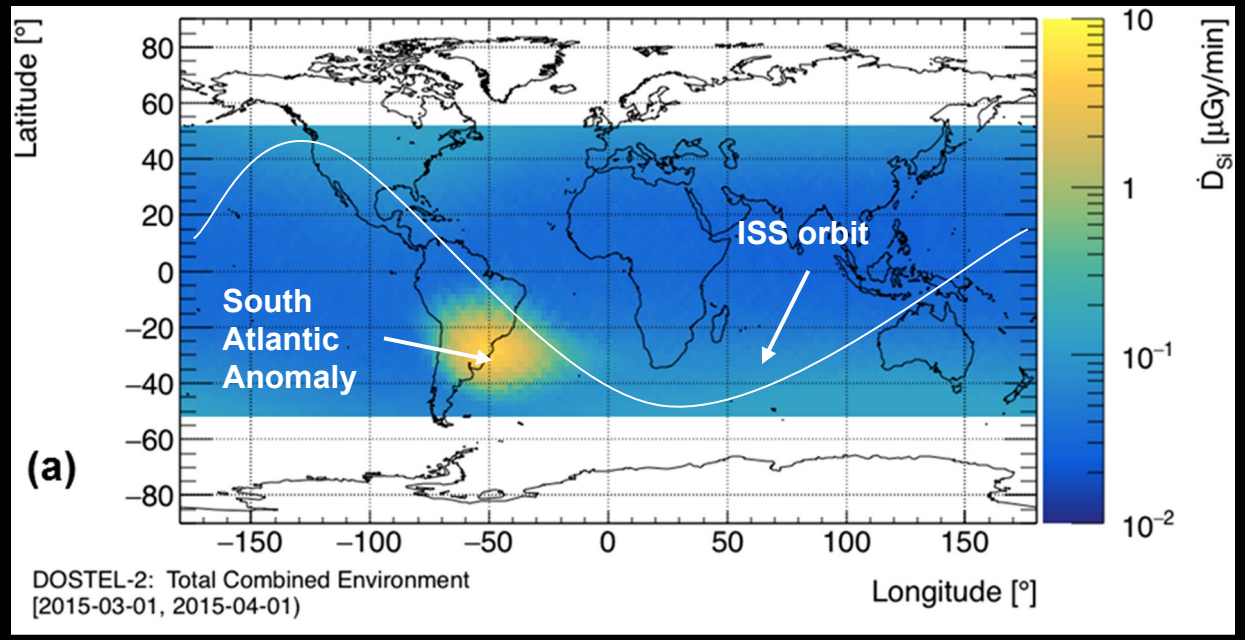


Credits: NASA/GSFC, JHU/APL

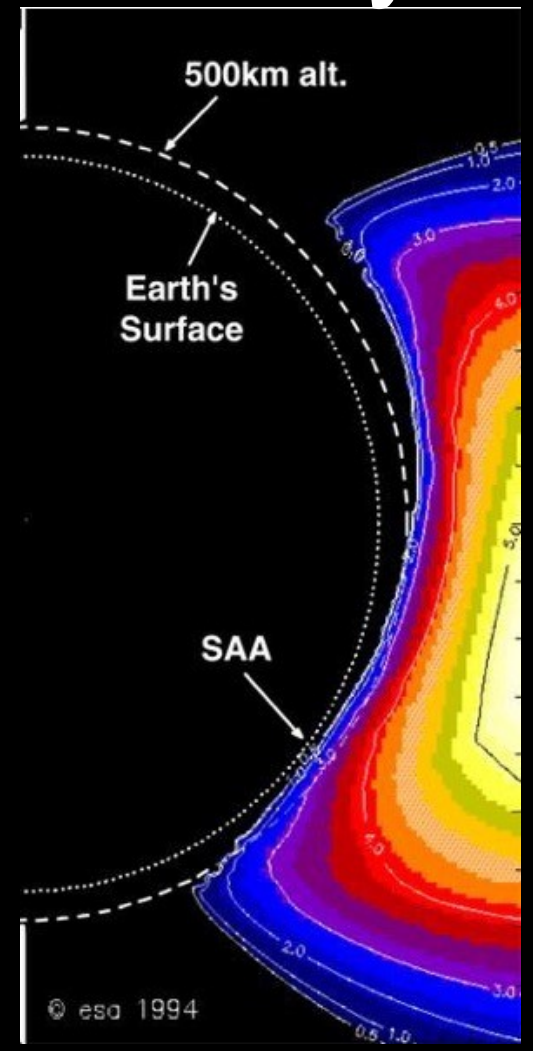
At the same time, Earth's magnetic field can deflect SEPs and GCRs up to 15 GeV/n

Radiation in space: South atlantic anomaly

- SAA dominates the radiation environment below 1000 km
- Caused by tilt and shift of geomagnetic axis relative to rotational axis
- Inner edge of proton belt is at lower altitudes south and east of Brazil

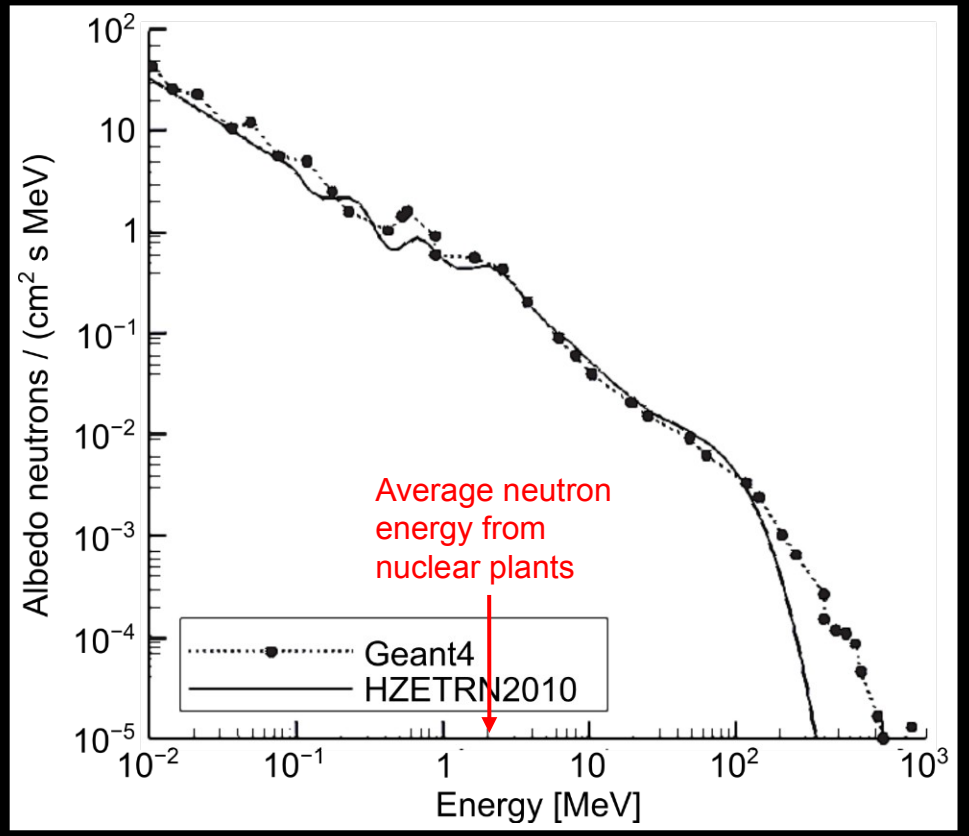


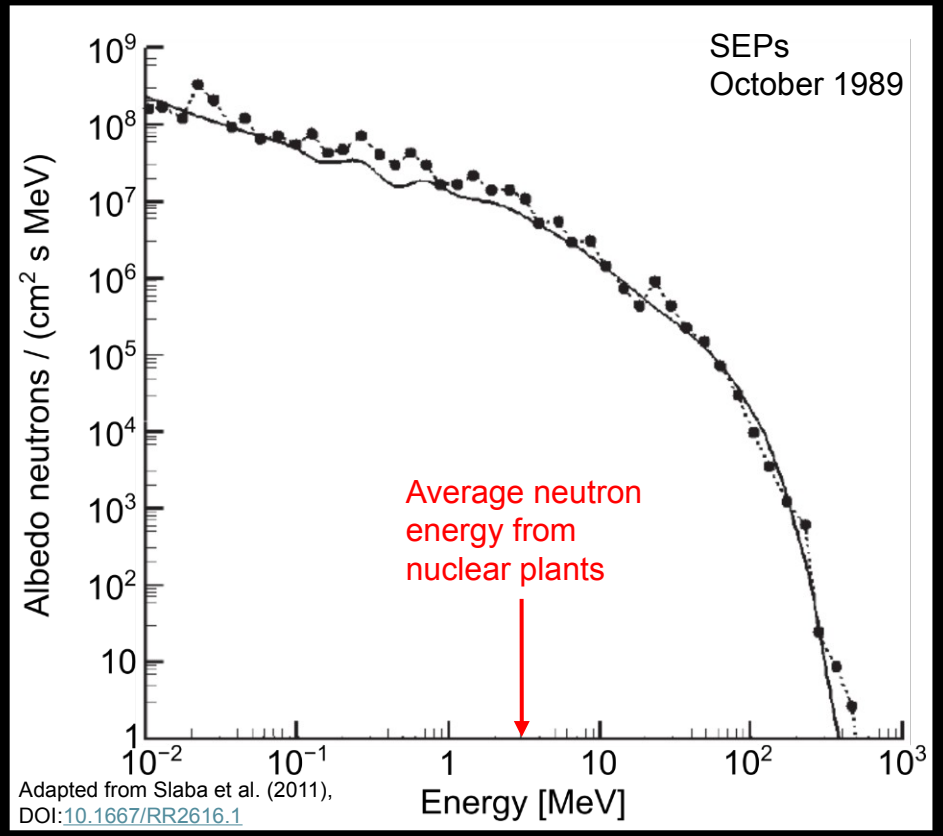
Adapted from Berger et al. (2020), DOI:10.1051/swsc/2020028

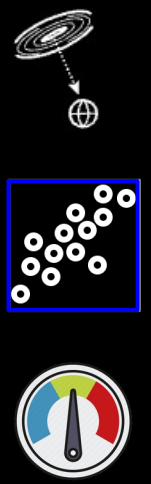


Radiation in space: Moon surface

GCRs and SEPs impinging on the lunar surface eject large amounts of neutrons from the surface with higher energies than what we see on Earth

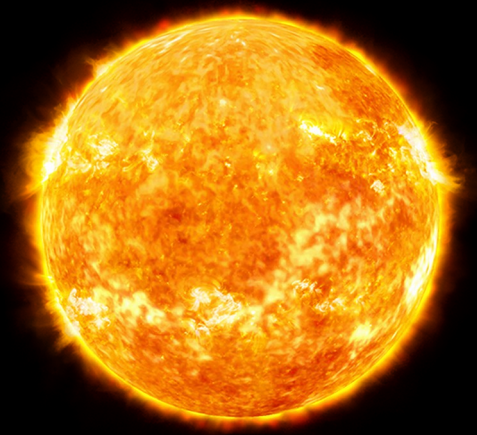


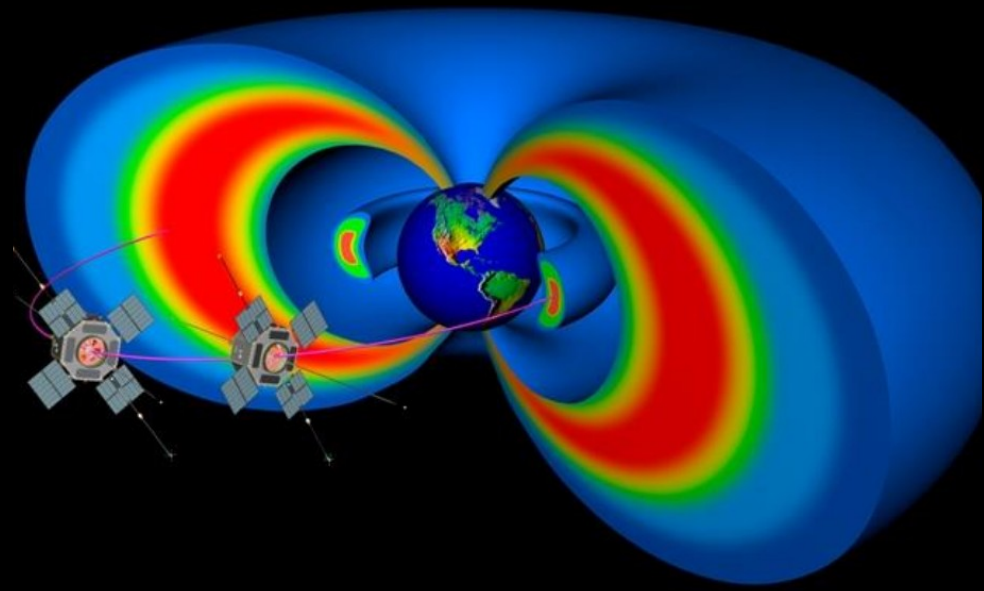




Quiz: which radiation is where?

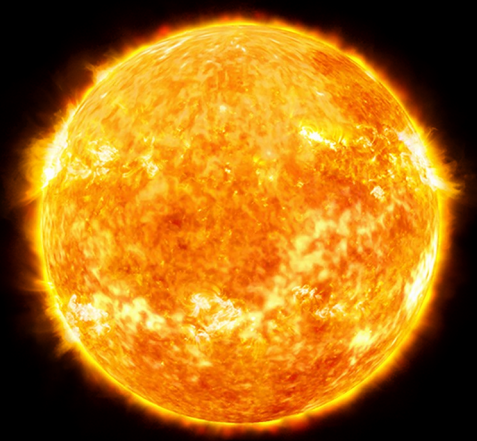
Place the following radiation sources in the appropriate location in space:
SEPs, GCRs, trapped protons, trapped electrons



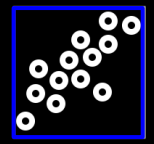


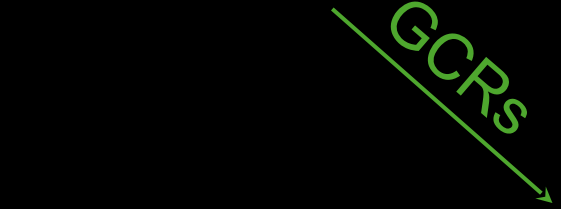
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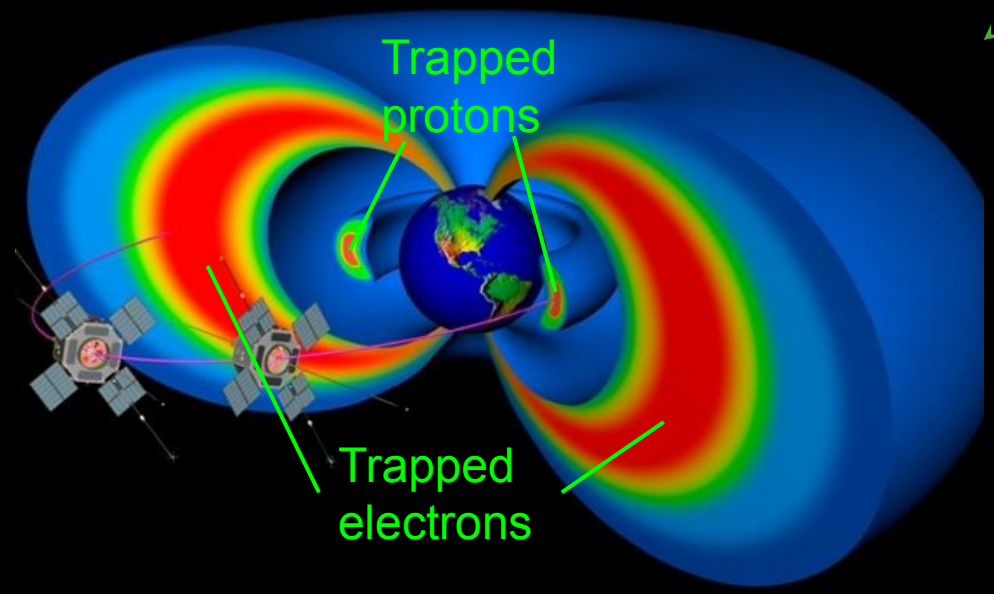














Quantifying radiation effects: particle spectrum

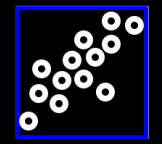
Effects of space radiation depend on:

- particle type (electrons, nuclei with different charge number)
- particle energy (how fast particles move)
- particle intensity (how many particles per unit area and time)

Particle spectrum (intensity vs energy) is a key factor in understanding space radiation effects:

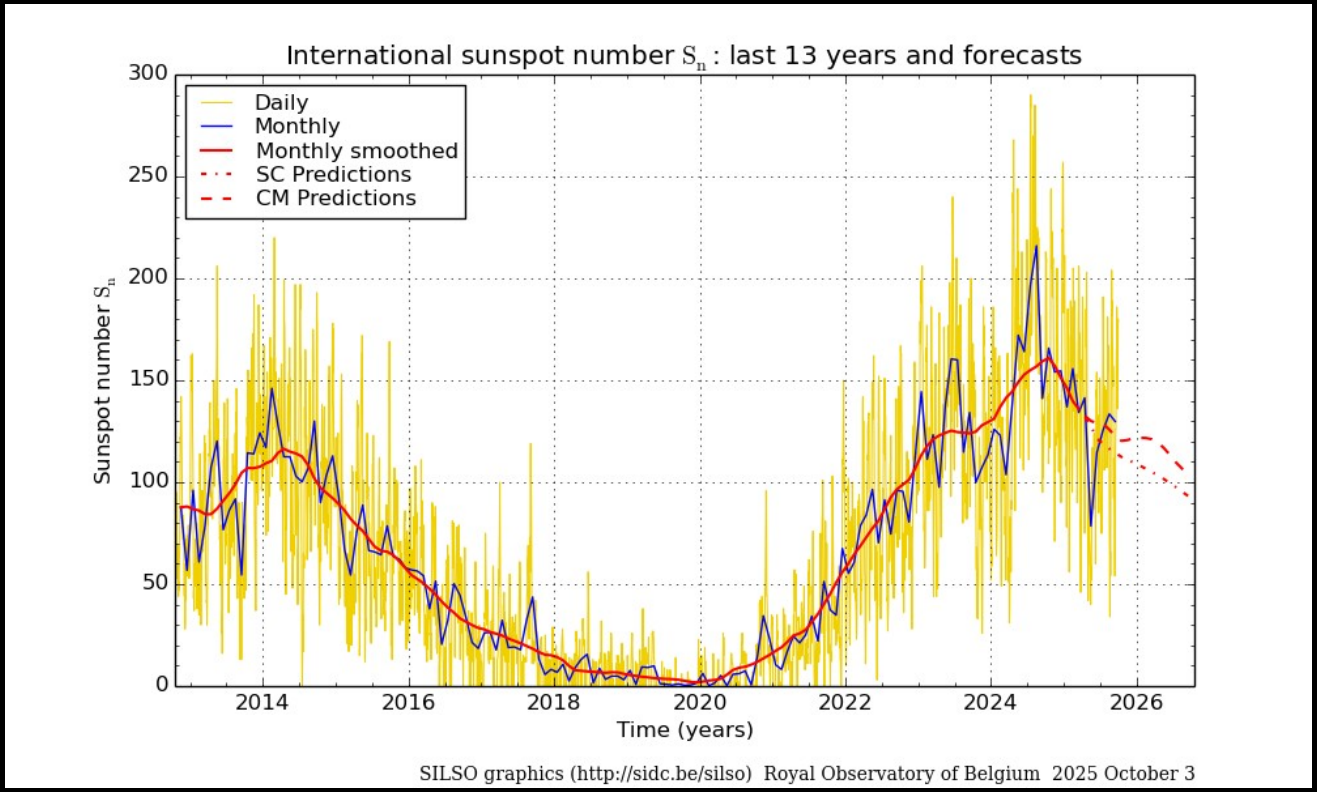
- Soft spectrum: fast decrease of intensity with increasing energy
  ⇒ less particles at high energy
- Hard spectrum: slow decrease of intensity with increasing energy
  ⇒ more particles at high energy





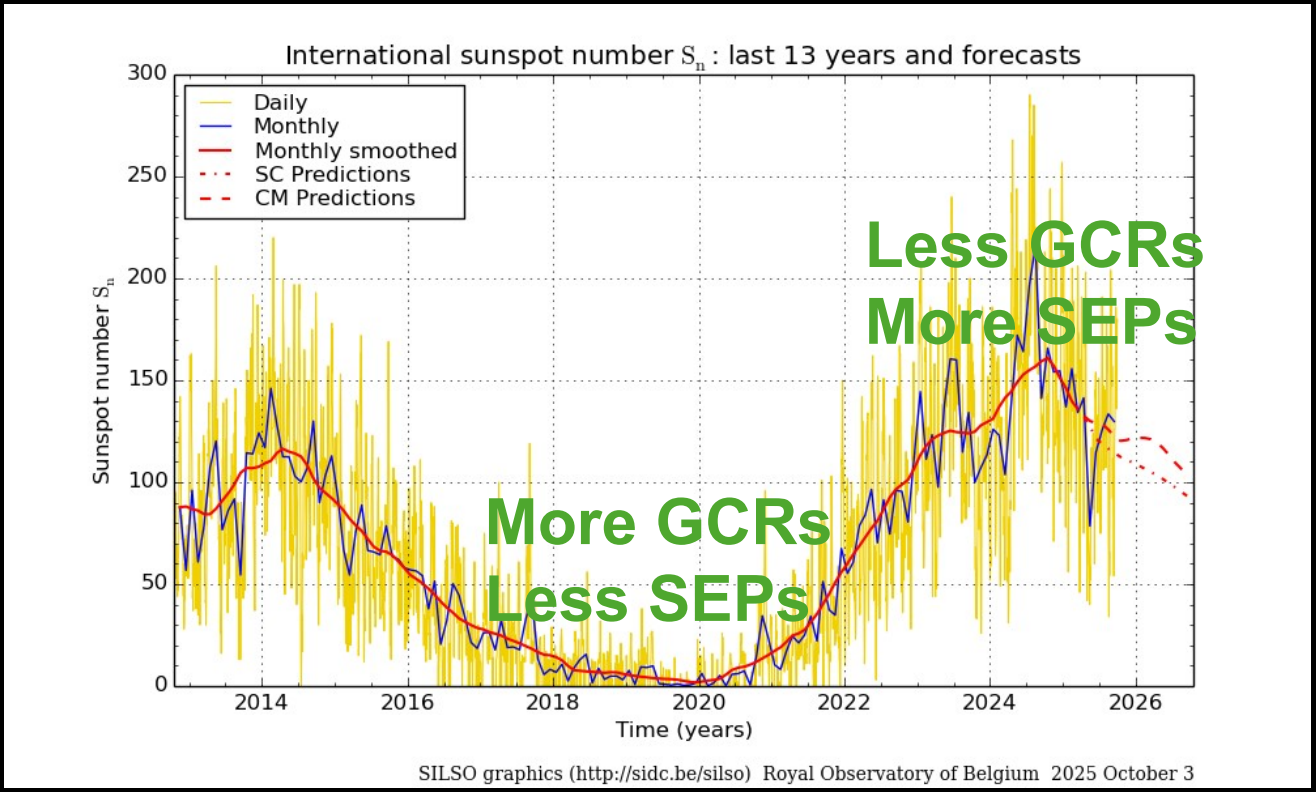
Quiz: When to travel in space?

What is the best period in the solar cycle to launch a deep-space mission?
Hint: which exposure is better to minimize, GCRs or SEPs?



Quiz: When to travel in space?

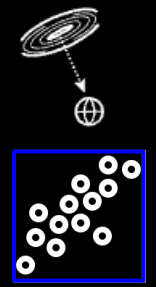
What is the best period in the solar cycle to launch a deep-space mission?



GCRs:
hard spectrum, low intensity

SEPs:
soft spectrum, high intensity

At what point less particles with high energy have the same biological impact of more particles with low energy?

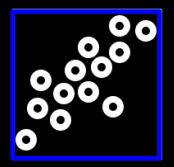


We cannot answer without the concepts of shielding and dose

How do you stop radiation in space?



- Solar UV, electrons (<1 MeV): spacesuit is enough
- Solar X-rays, γ-rays, electrons (>1 MeV): spacecraft is enough, very low intensity

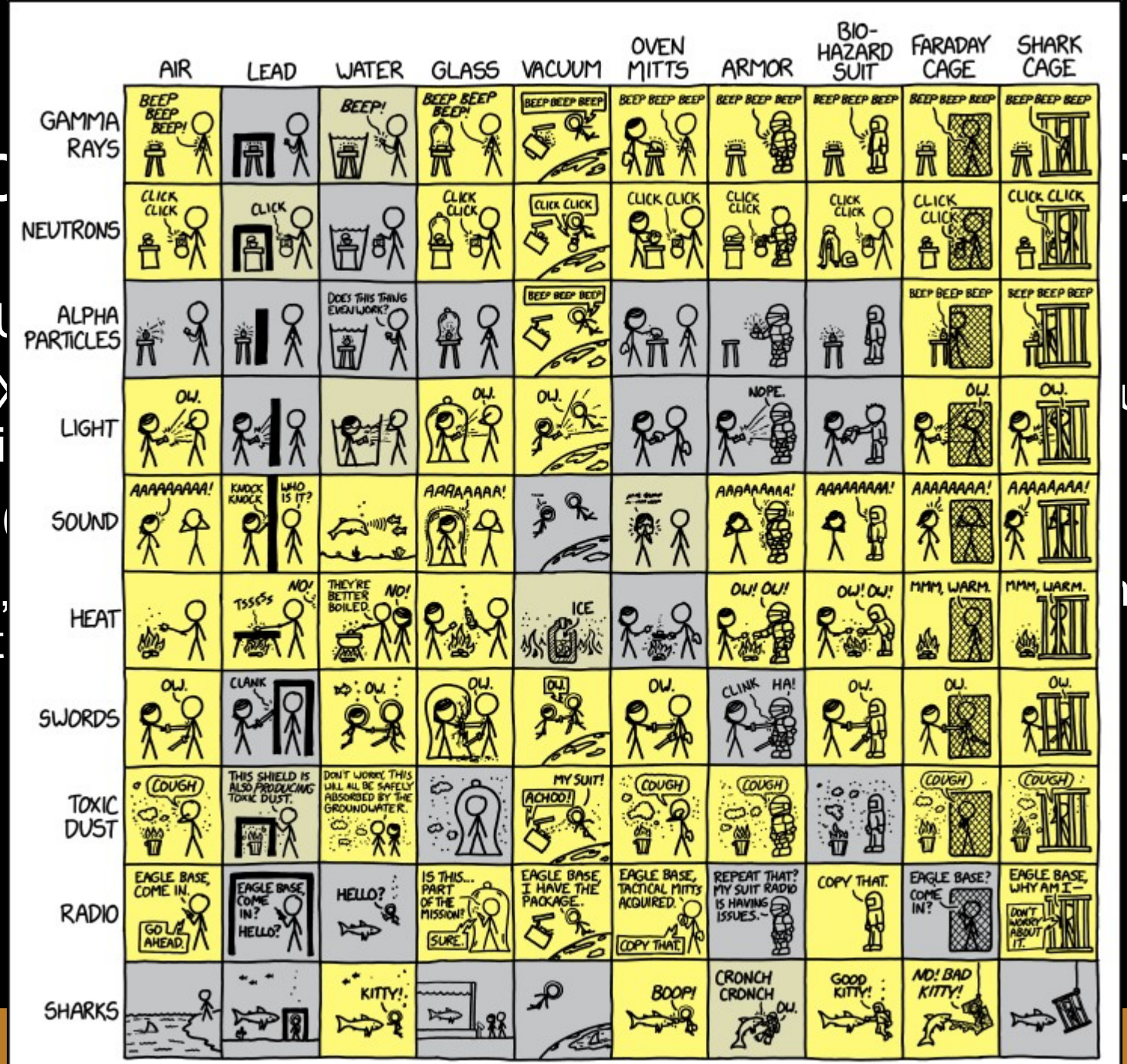


- SEPs (<100 MeV): spacecraft is enough
- GCRs, SEPs (>100 MeV), neutrons: cannot be stopped, only attenuated. More than 3 m of water are needed to stop a 1 GeV proton



Ho…pace?

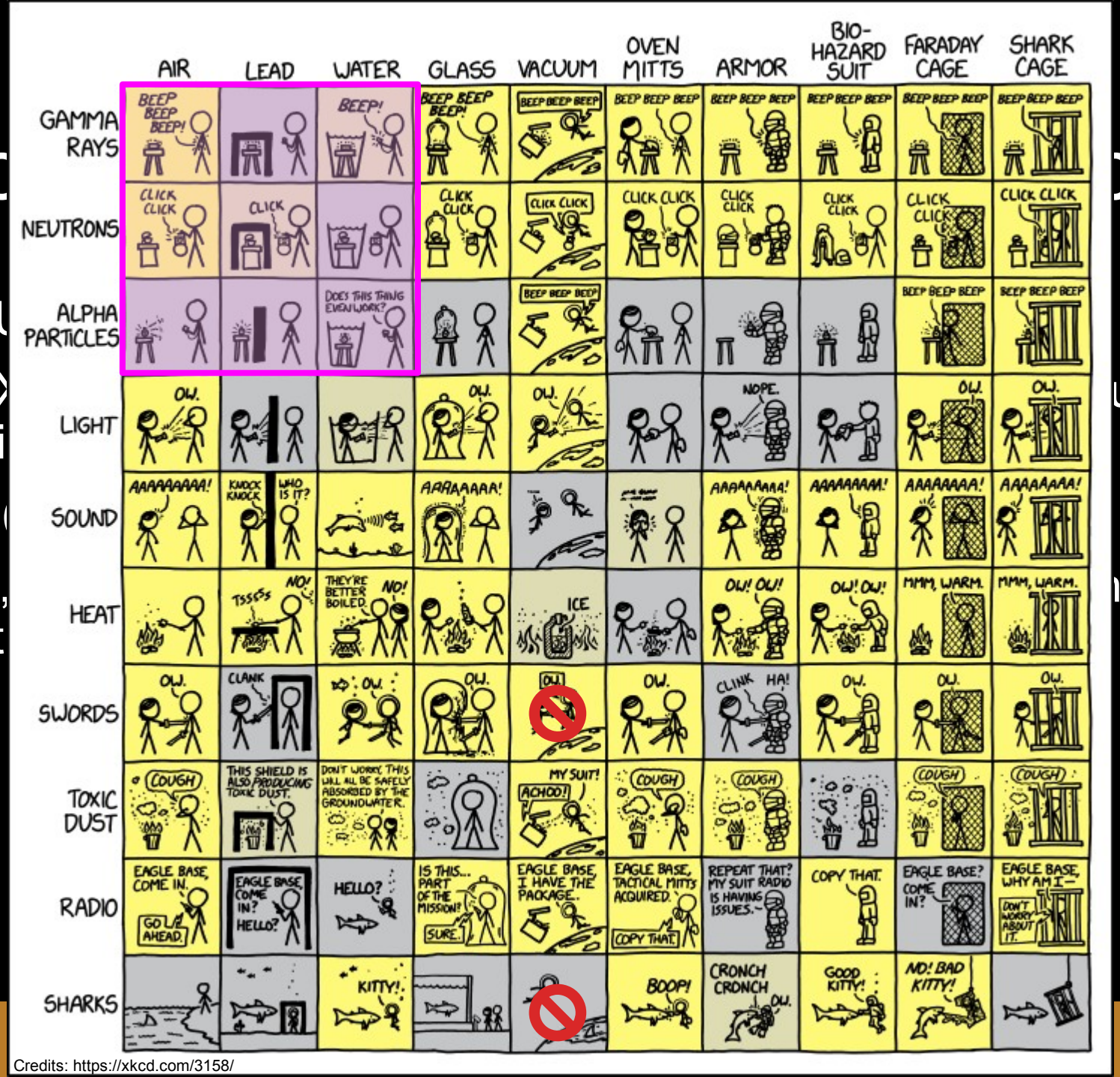
- Solar …
- Solar X… …ugh, very low intensi…
- SEPs …
- GCRs, …ly attenuated. More t…



Credits: https://xkcd.com/3158/

Ho…pace?

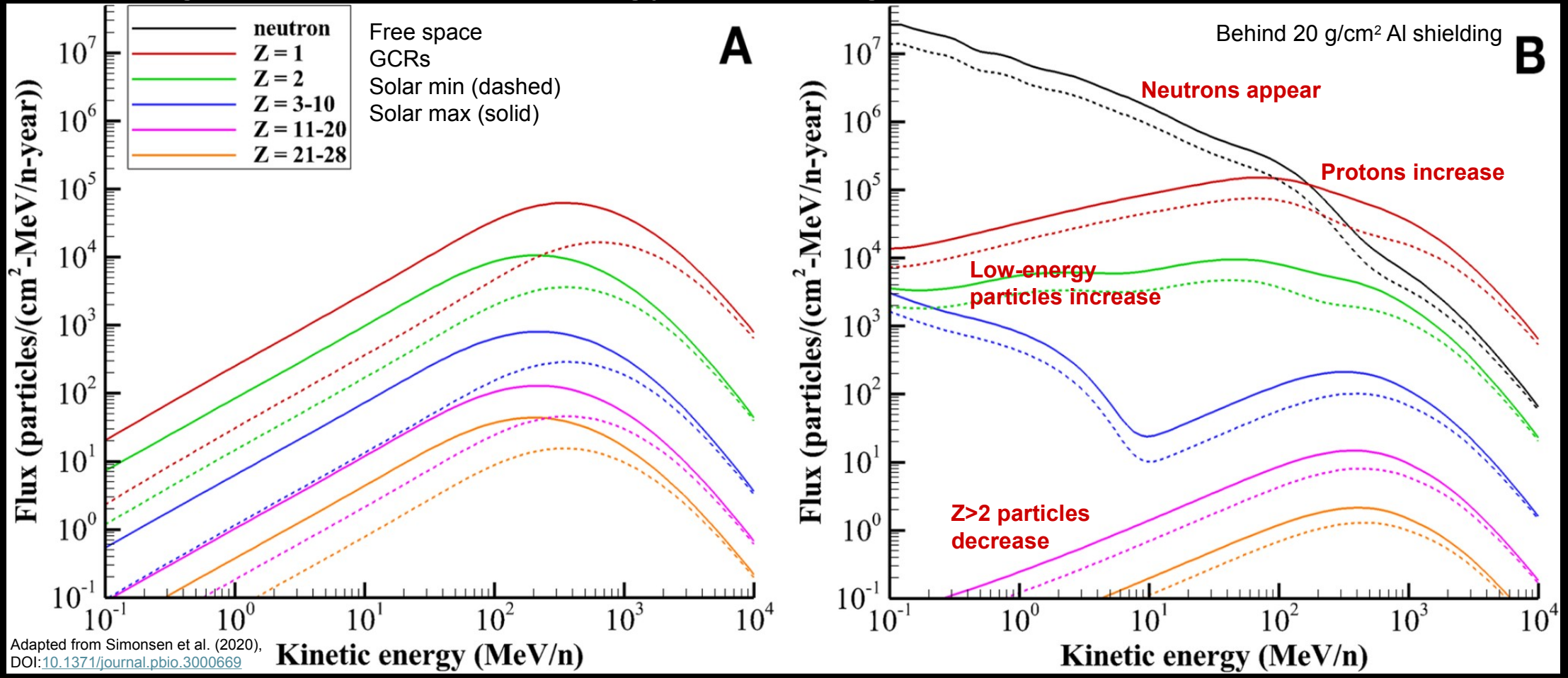
- Solar …ugh, very low intensi…
- SEPs …
- GCRs, …ly attenuated. More t…



Credits: https://xkcd.com/3158/

Radiation shielding: what effects?

Shielding reduces overall energy and charge number of radiation



Adapted from Simonsen et al. (2020), DOI:10.1371/journal.pbio.3000669

Radiation shielding: which materials?

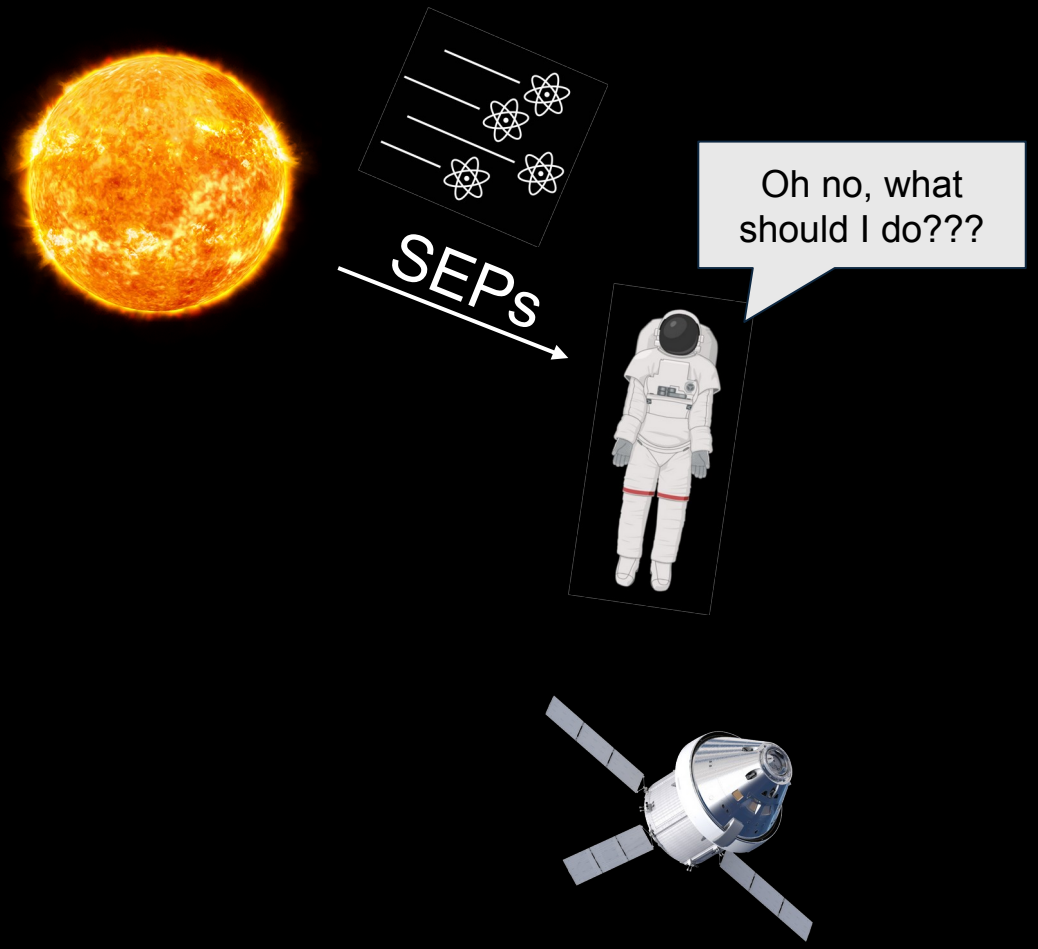
Reference material is Aluminum ($Z = 26$): low weight, very good mechanical and thermal properties

Low charge-number ($Z < 8$) materials lead to less nuclei fragmentation and are more effective at slowing down protons and neutrons, but have worse mechanical properties

Liquid hydrogen ($Z = 1$) minimize nuclei fragmentation and maximize proton and neutron attenuation, but it's highly flammable and can explode when mixed with air

Polyethylene (C_2H_4) can reduce dose from secondary neutrons with respect to Aluminum: reduction factor depends on free space radiation spectrum and shielding thickness

Quiz: What should the astronaut do?



Select the best answer:

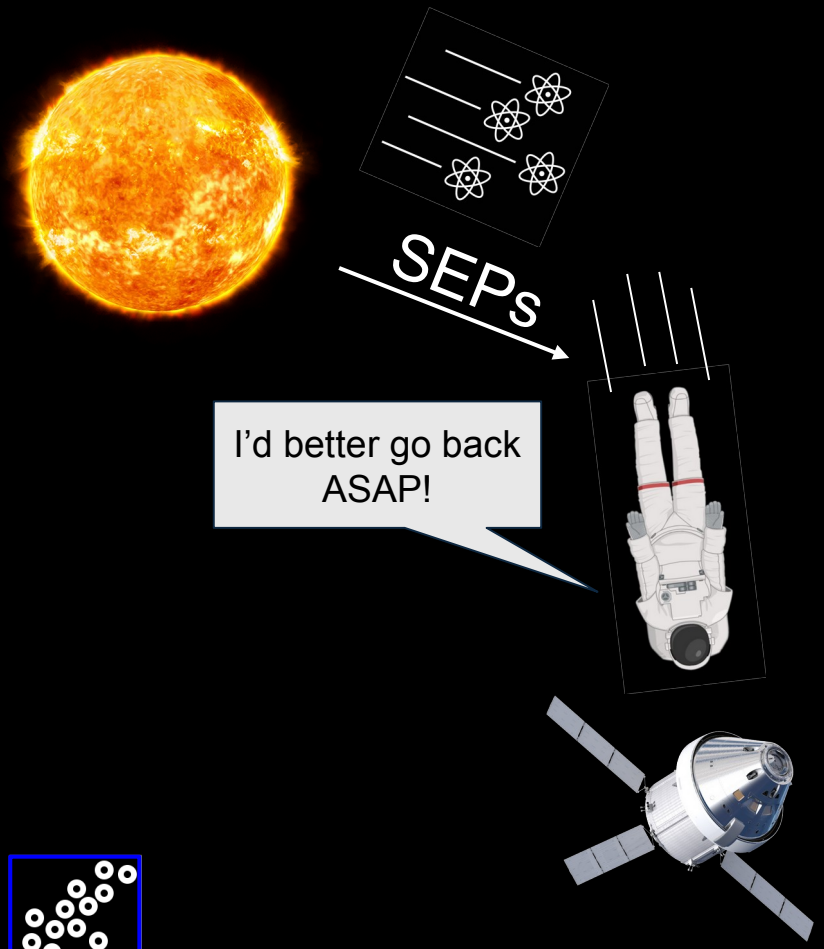
A) Keep floating outside the spacecraft

B) Go back to the spacecraft

C) Go back to the spacecraft and cover with an Aluminum blanket

D) Go back to the spacecraft and cover with a plastic blanket (hint: plastic materials are rich in Carbon)

Quiz: What should the astronaut do?



A) Keep floating outside the spacecraft
Bad: spacesuit shielding is too thin to stop SEPs

B) Go back to the spacecraft
Better! Spacecraft stop most of SEPs; only high energy SEPs (low intensity) can penetrate

C) Go back to the spacecraft and cover with an Aluminum blanket
Even better! Aluminum will provide additional shielding against high energy SEPs

D) Go back to the spacecraft and cover with a plastic blanket
Best! Plastic shields more than Aluminum

Caveat: actual procedures depend on real-time conditions and operational requirements