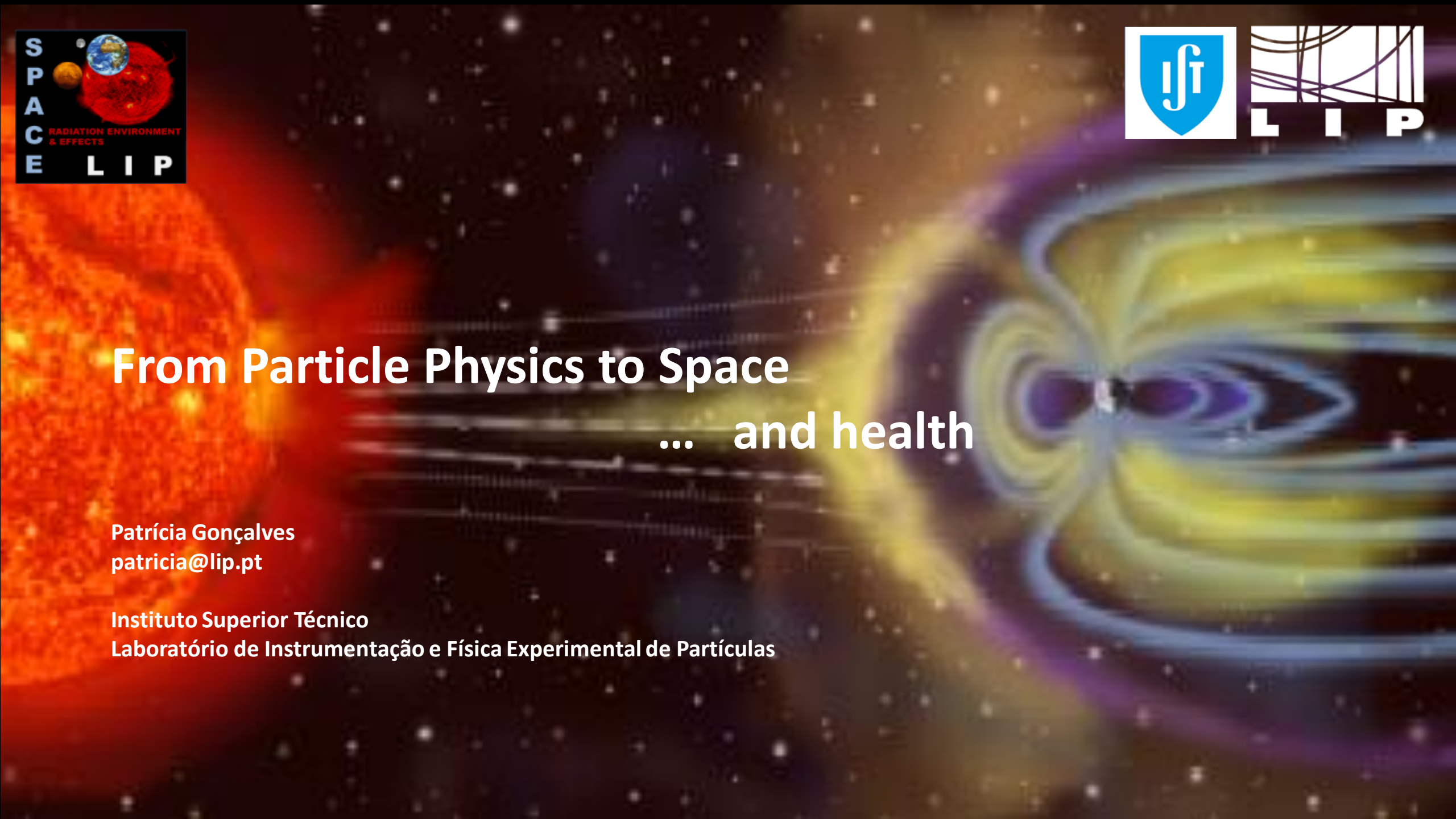

From Particle Physics to Space
… and health

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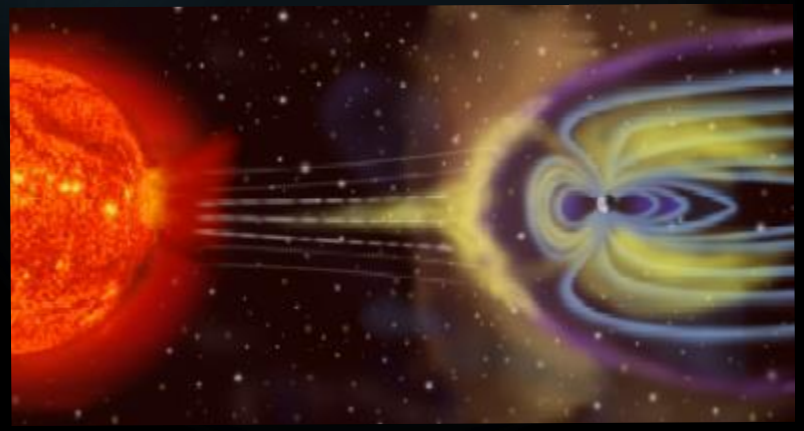
Instituto Superior Técnico
Laboratório de Instrumentação e Física Experimental de Partículas

In space, the radiation environment is responsible for spacecraft system, sub-system and component hazard and damage and it is also responsible by strict constrains on human space exploration.

At Earth's surface, the atmosphere in conjunction with the geomagnetic field provides considerable protection against cosmic rays and solar particle events.



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Radiation Environment in the Solar System

Galactic Cosmic Rays

low flux but highly penetrating

Protons & ions

Solar Particle Events

sporadic, intense & dangerous

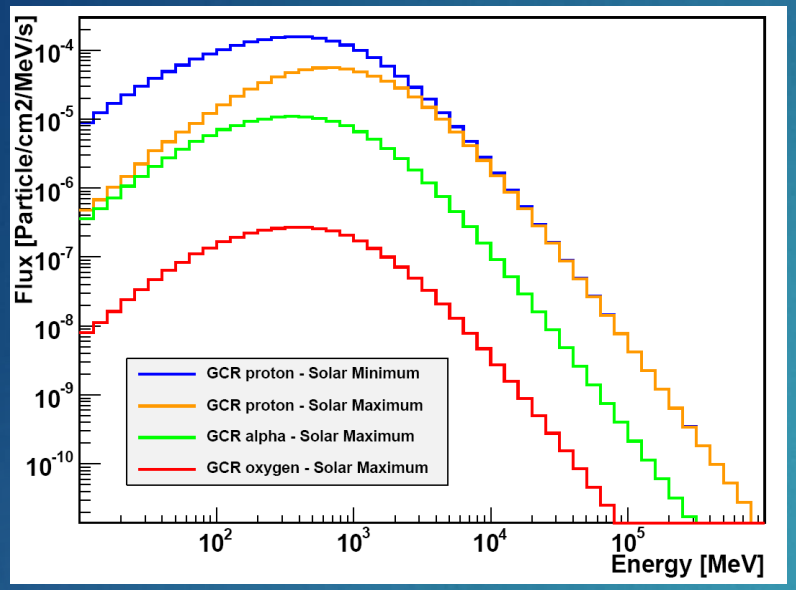
Electrons, protons & ions

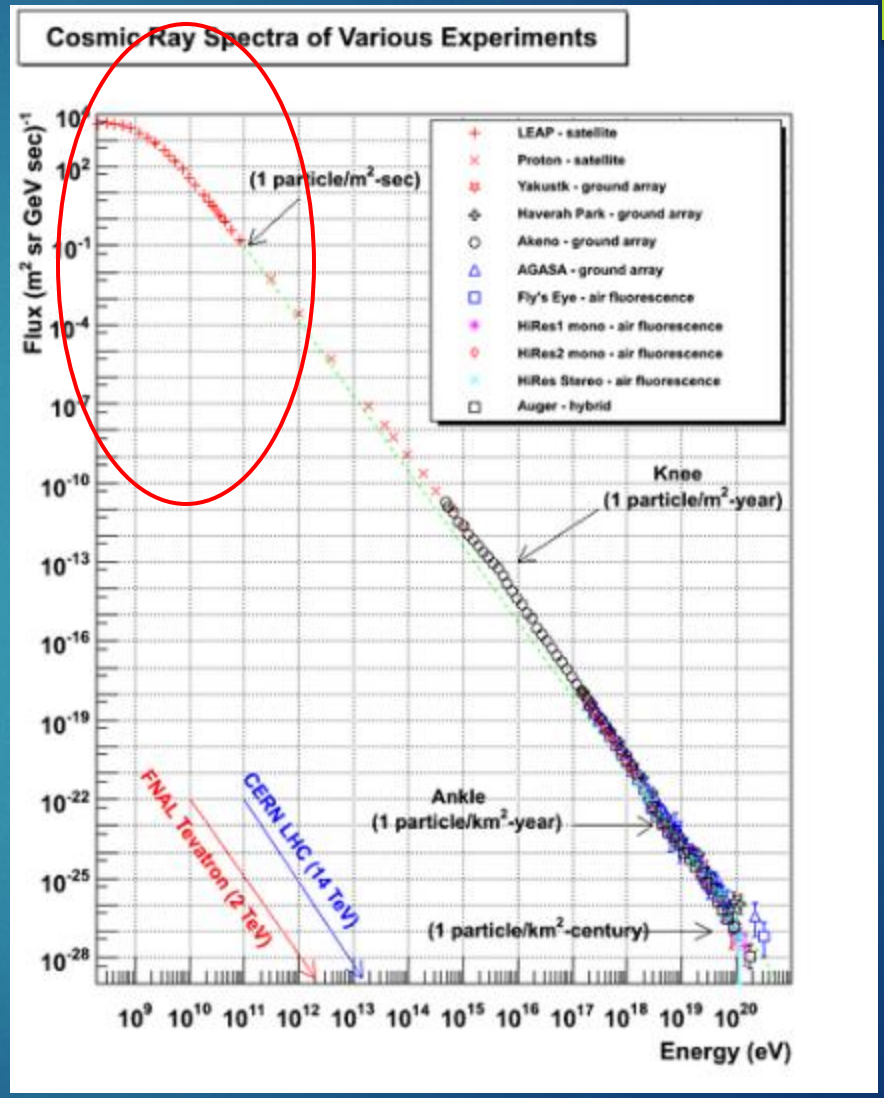
Radiation Belts

high radiation dose

Electrons & protons

Galactic Cosmic Rays (GCR)

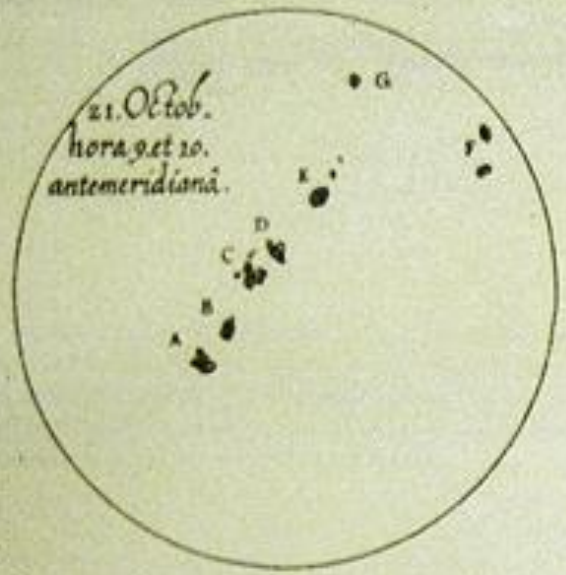


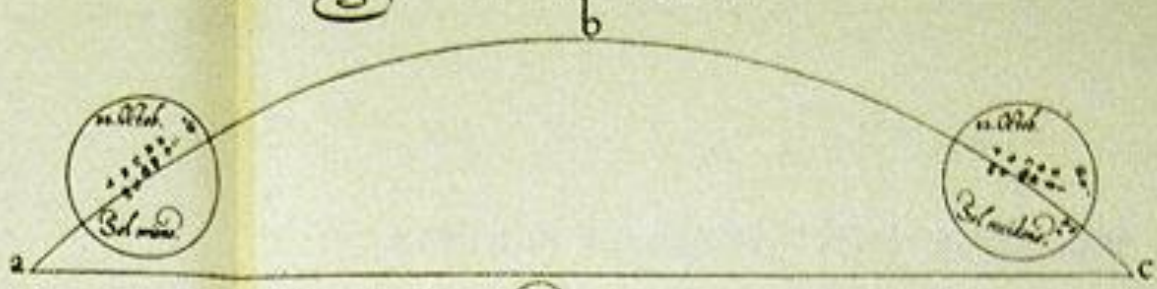


Low flux but highly penetrant

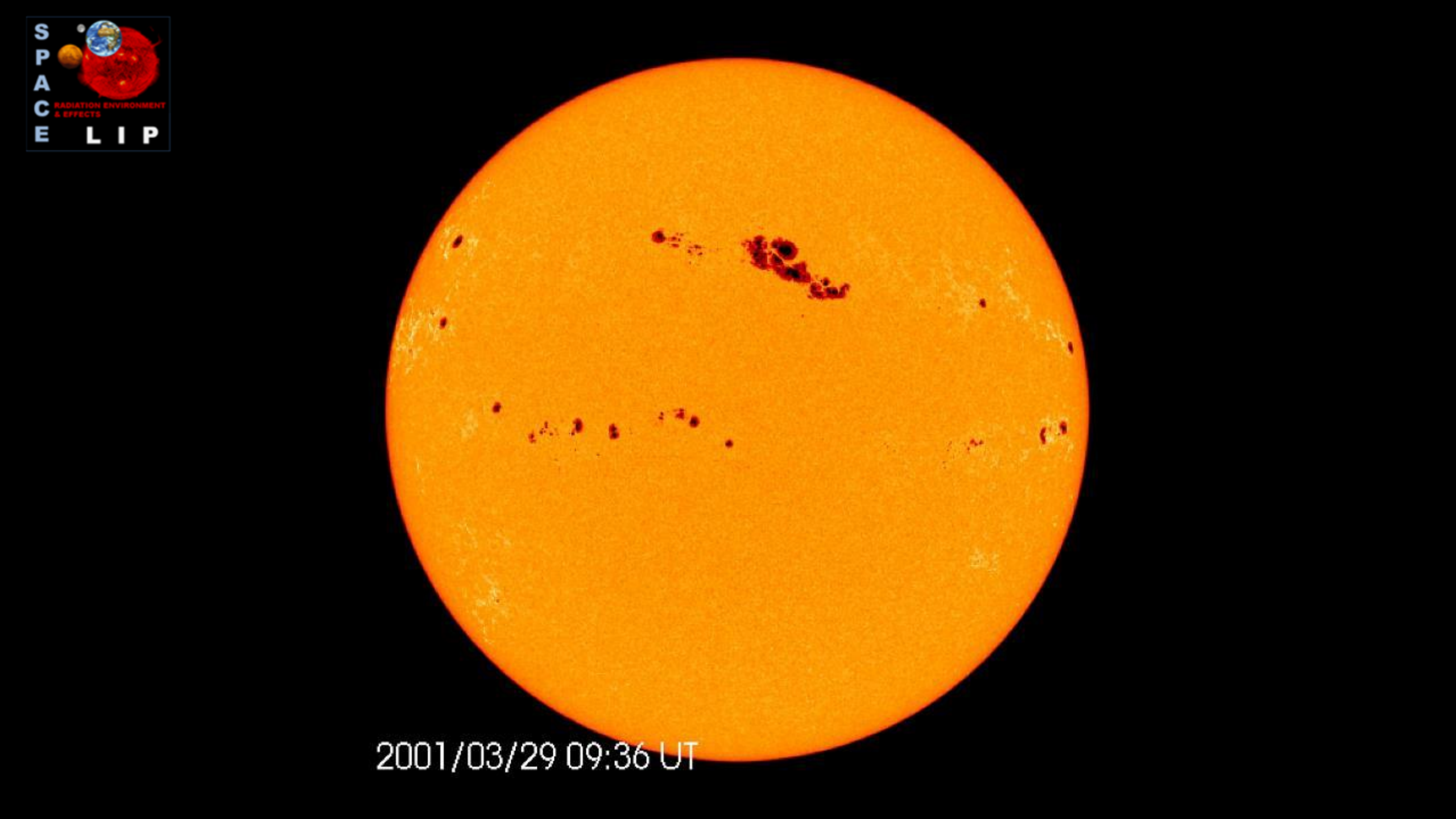
- Protons and nuclei: energy spectra peak at ~1 GeV/n
- Solar cycle modulated flux inversely proportional to solar activity
- E < 1 GeV/n: highly affected by solar activity

MACVLAE IN SOLE APPARENTES, OBSERVATAE anno 1611. ad latitudinem grad. 48. min. 40.





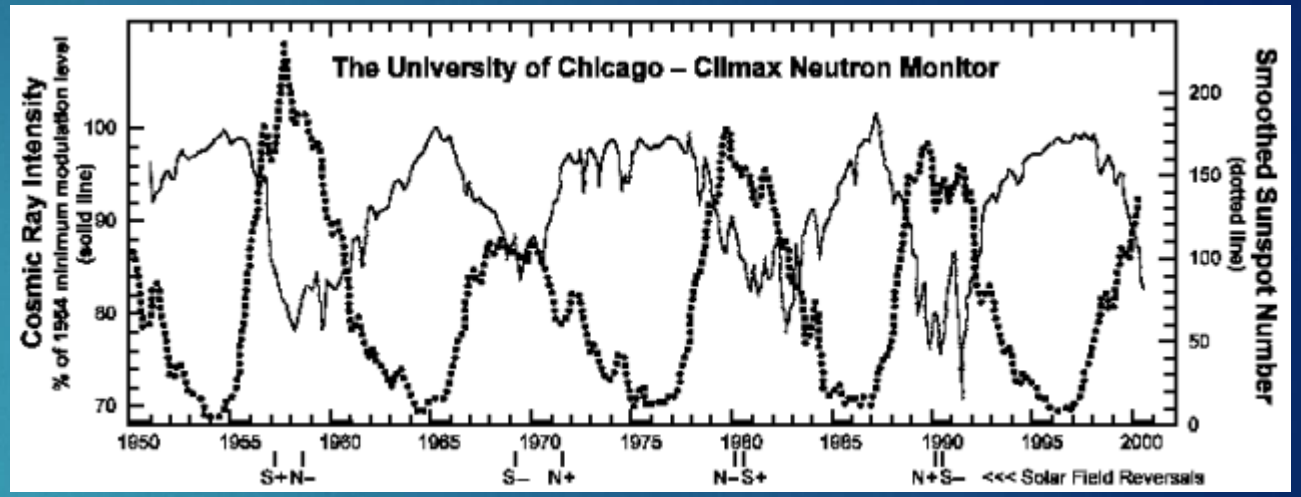
a c, horizon. a b c, arcus solis diurnus. Soloriens ex parte a, maculas exhibet quas vides, occidens verò c, easdem ratione primj motus, nonnihil inuertit. Et hanc matutinam vespertinamq; mutationem, omnes maculæ quotidie subeunt. Quod semel exhibuisse et monuisse, sufficiat.

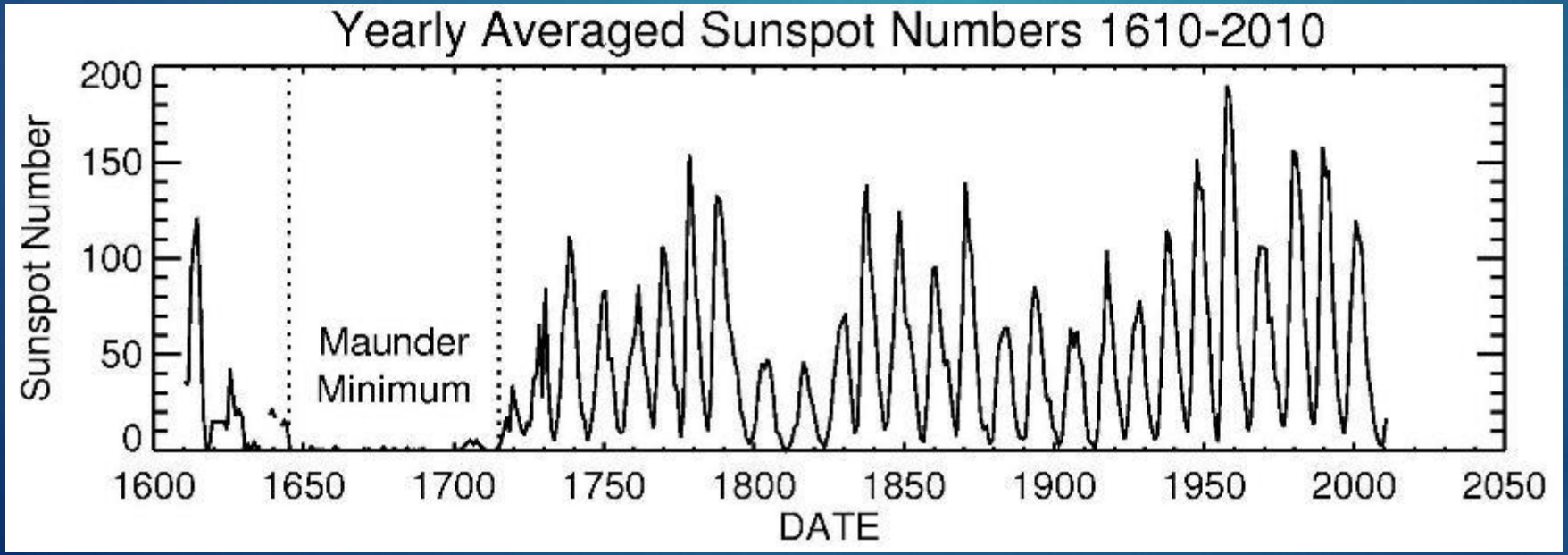

SPACE LIP
RADIATION ENVIRONMENT & EFFECTS
2001/03/29 09:36 UT

11 year Solar Cycle

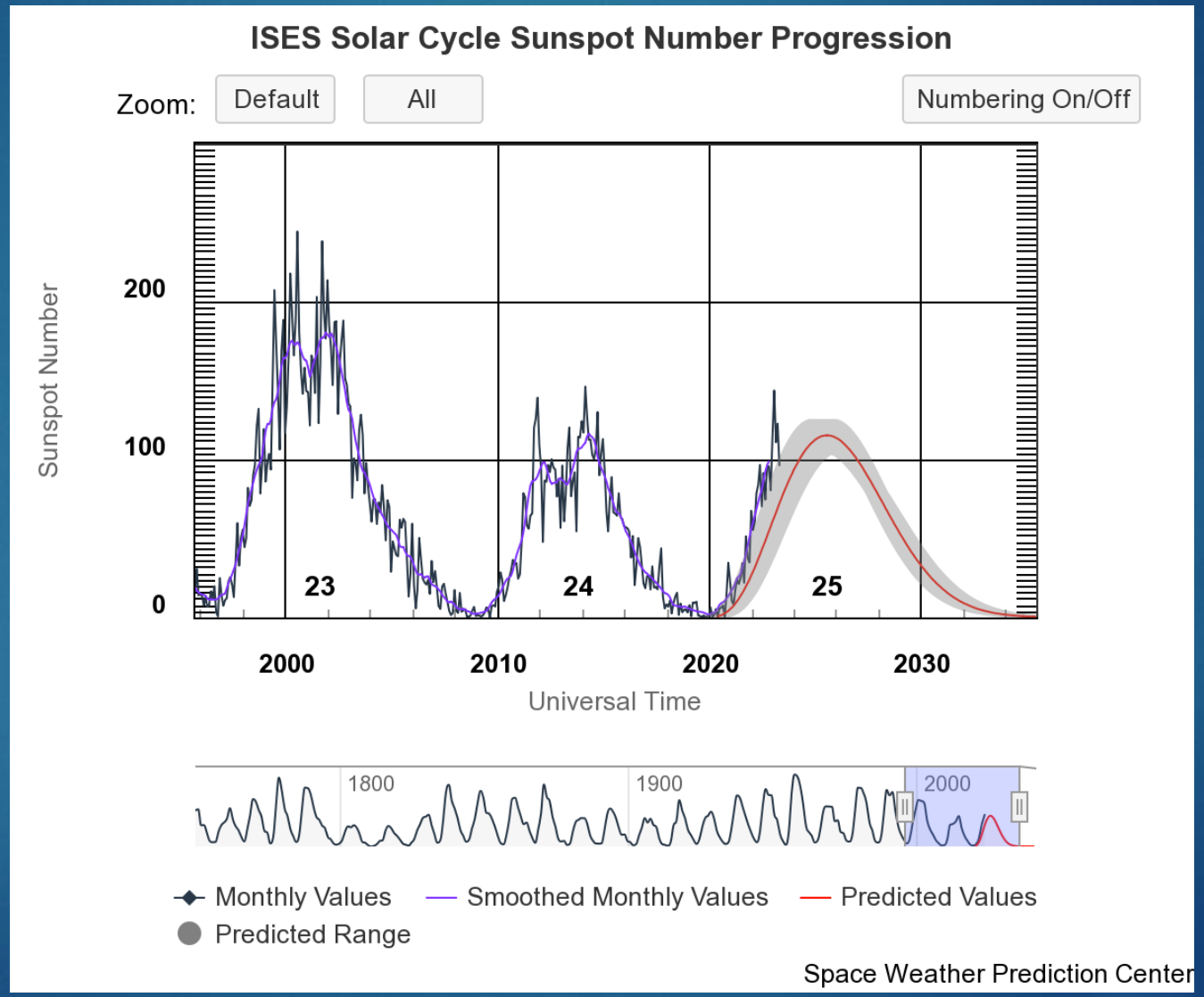
Modulation with solar activity

- ★ Solar Maximum: solar storms and SEP
- ★ Solar Minimum: more GCR



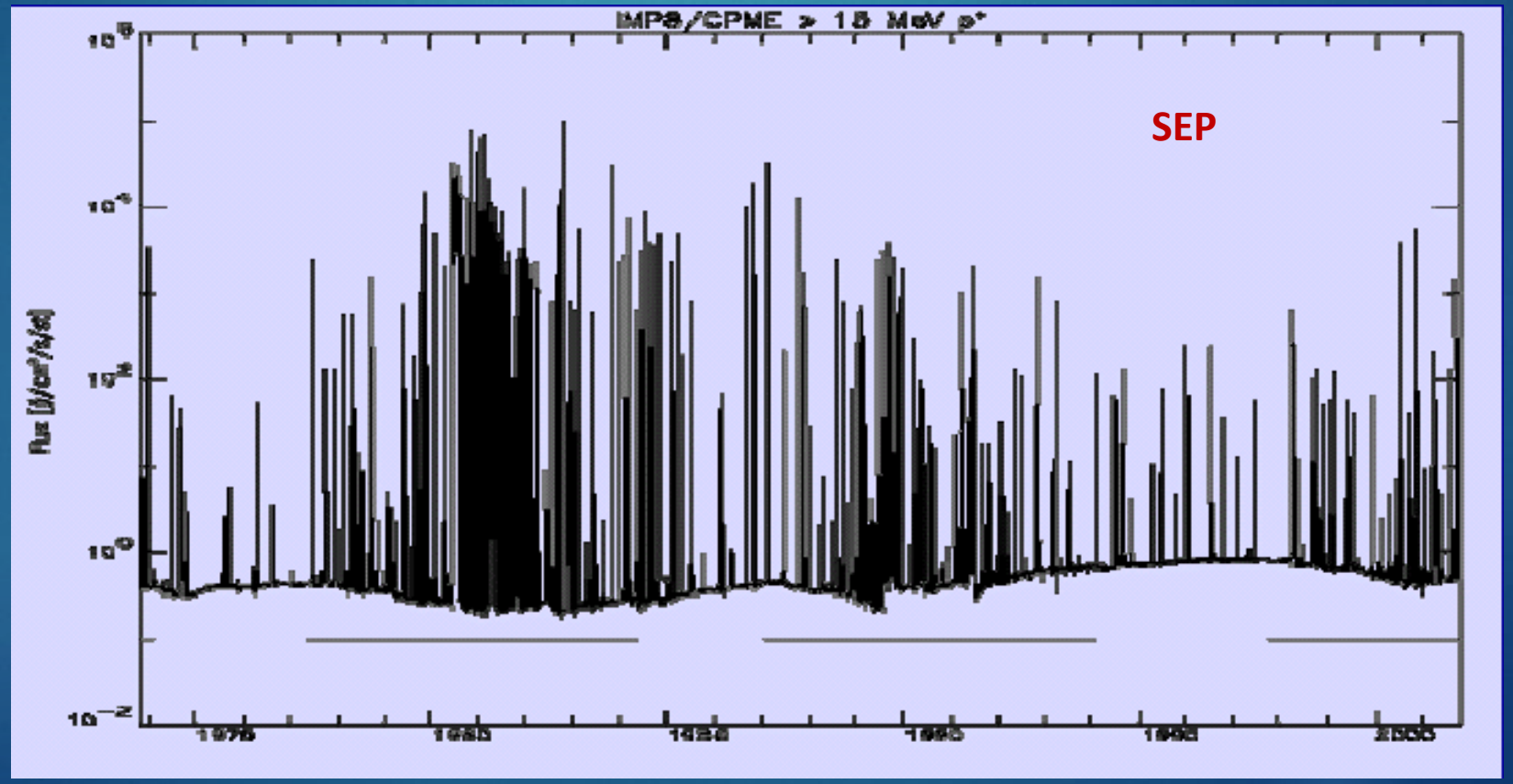


Solar Cycle 25

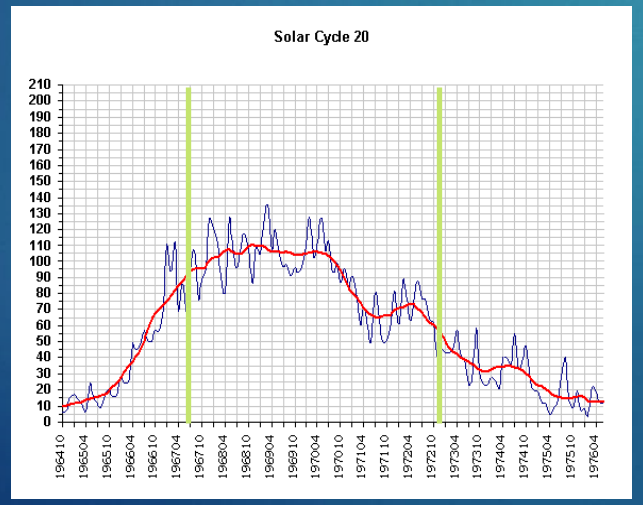


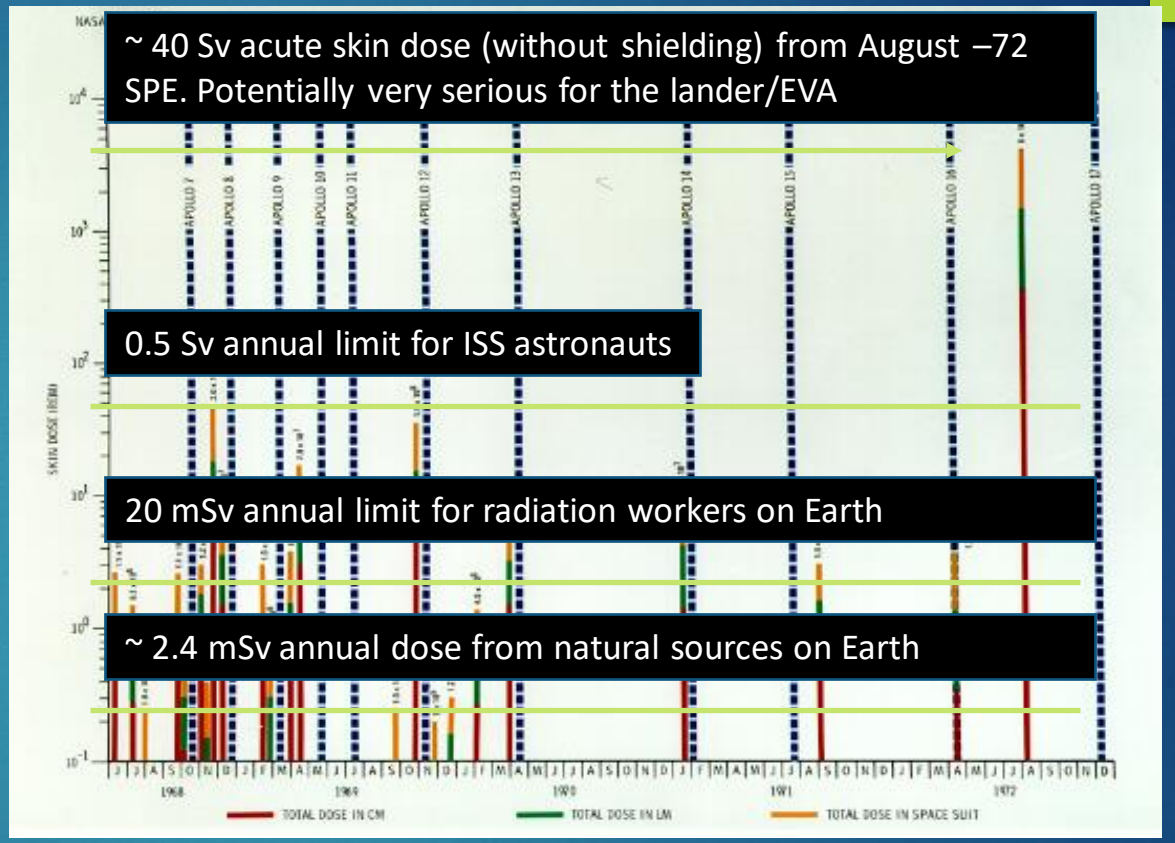
Solar Energetic Particle events

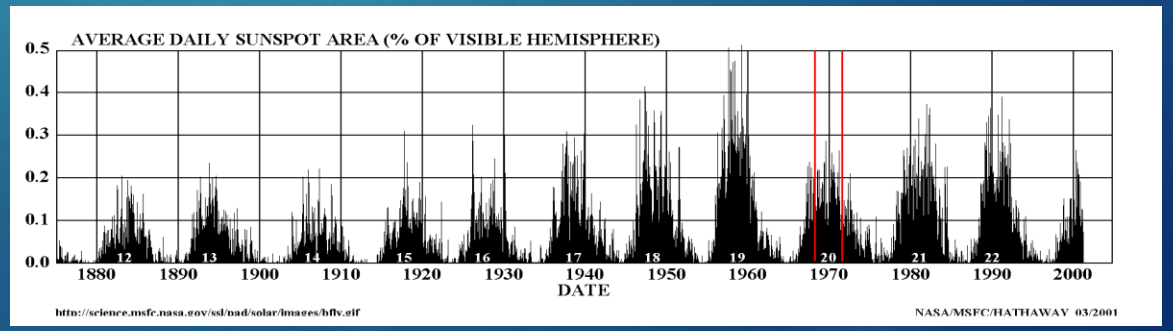
- ★More frequent in “maximum” solar activity years
- ★Highly unpredictable
- ★ Design for by making statistical assessment



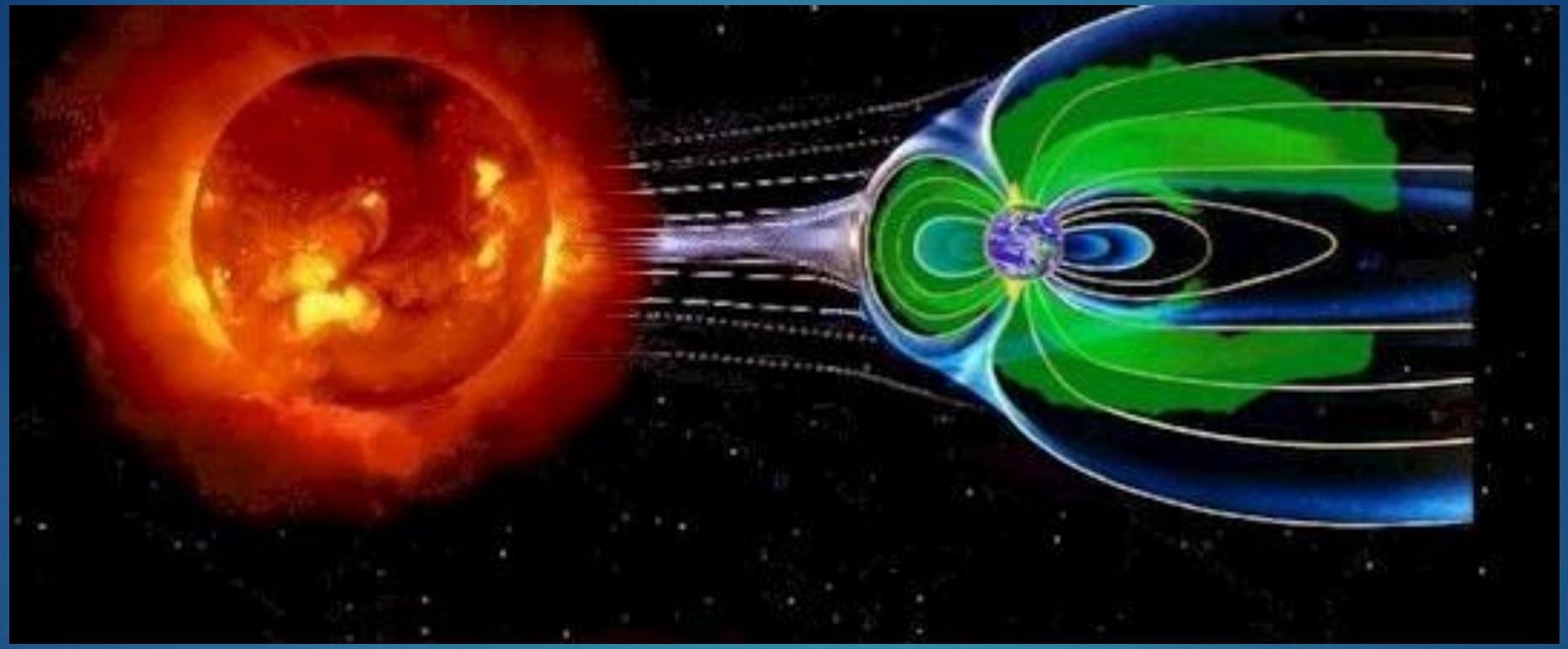
Apollo missions: Solar maximum



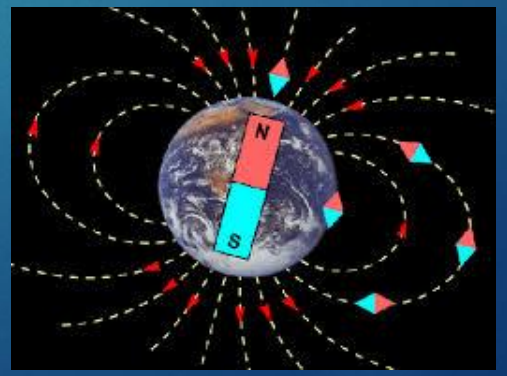




The Magnetosphere: an invisible shield

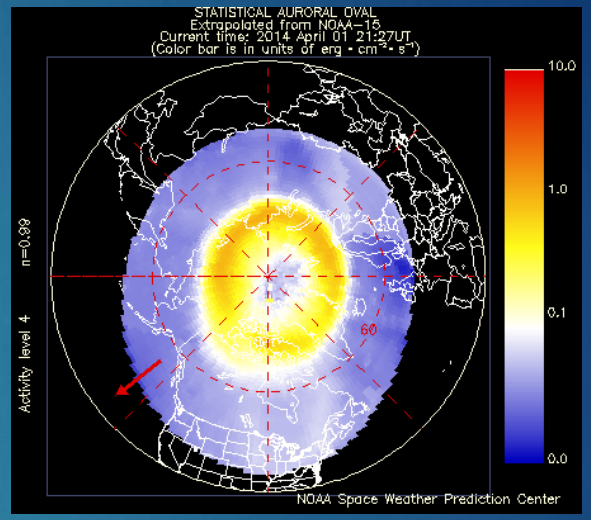


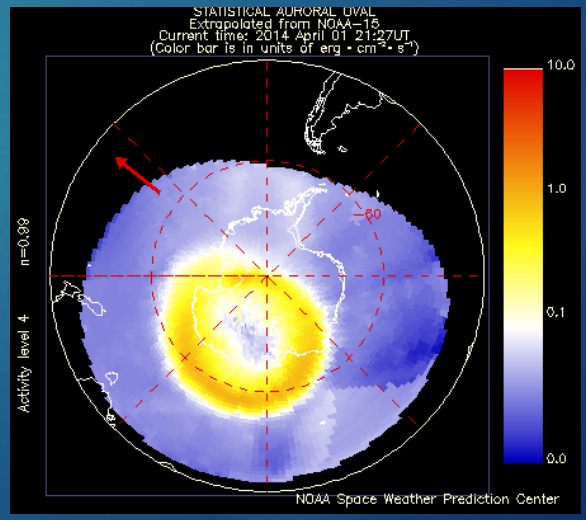
In Earth orbits the radiation belts containing trapped electrons and protons constitute the major radiation source



Auroras

Charged particles captured in the radiation belts excite N2 and O2 molecules that emit visible light while returning to the fundamental state

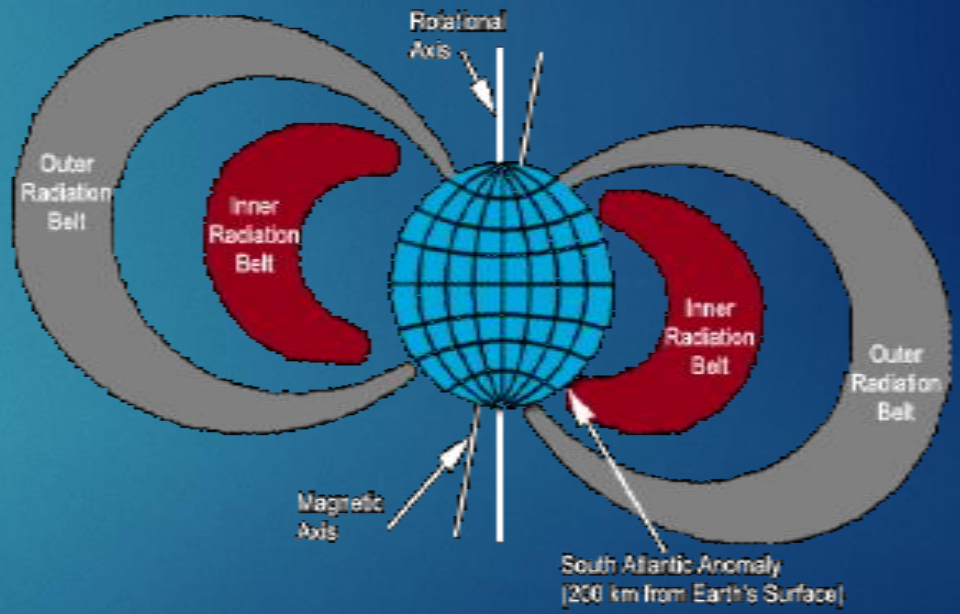




Earth Radiation Belt Regions

High radiation dose, electrons (<10 MeV) & protons (<250 MeV)

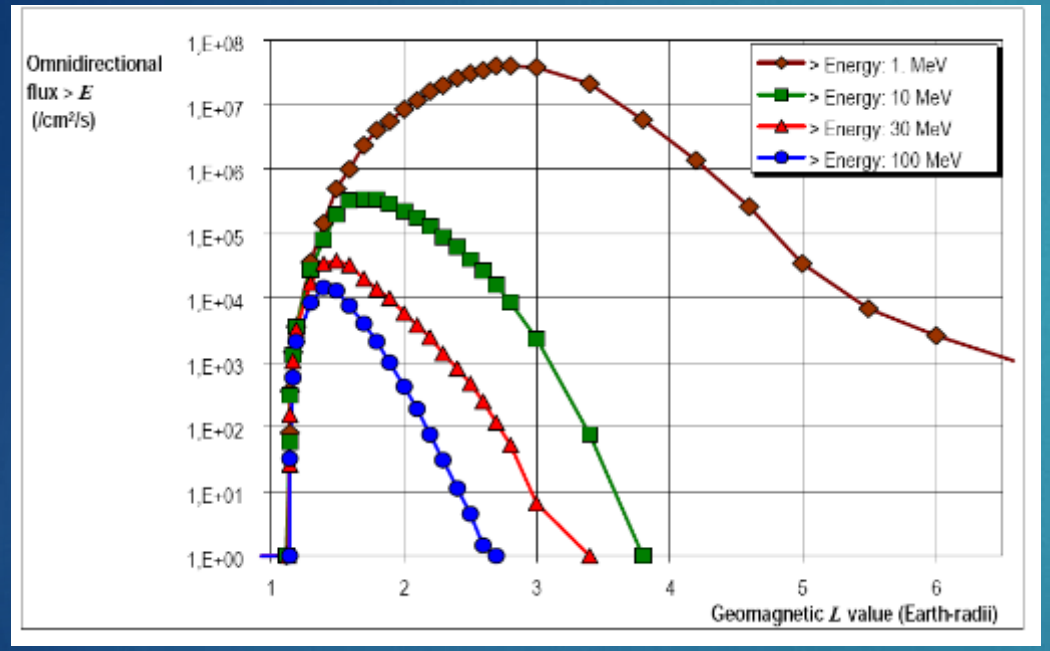
- **Inner belt (700-10000 km)**
  - dominated by protons
  - CRAND = Cosmic Ray Albedo Neutron Decay
  - ~static
  - E~100's MeV
- **Outer belt (~20000-70000 km)**
  - dominated by electrons
  - Controlled by "storms"
  - Very dynamic
  - E~ MeV
- **Slot**
  - low intensities of MeV electrons
  - occasional injections of more particles



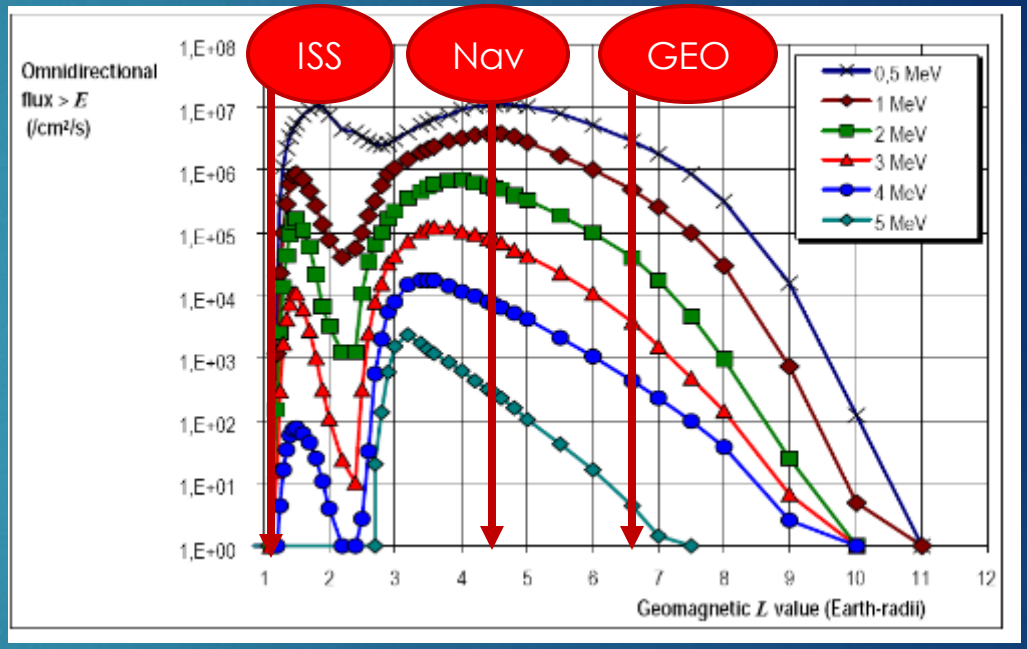
Earth Radiation Belt Models

Examples of ERB Models: AP8,AE8

Protons

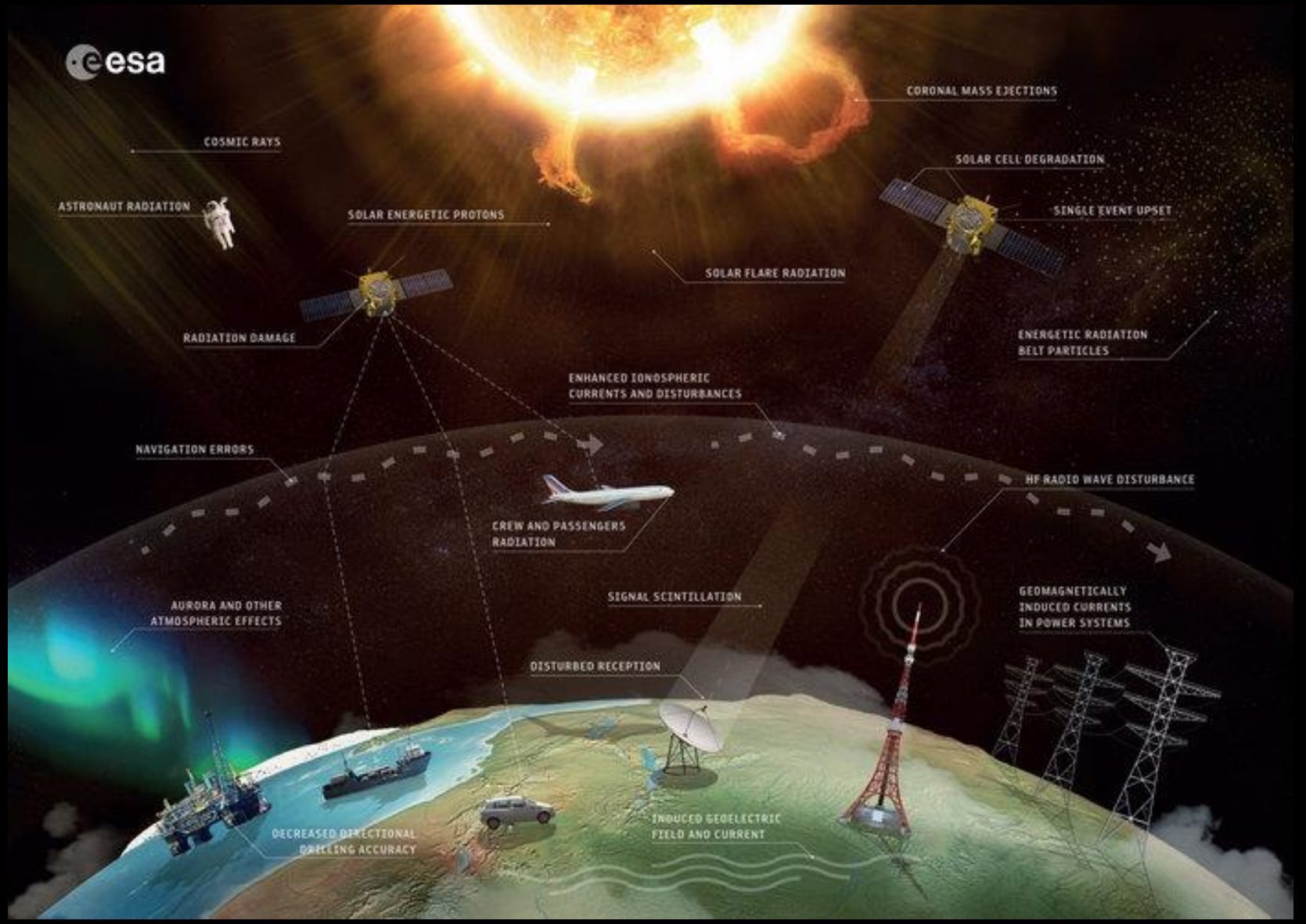


Electrons

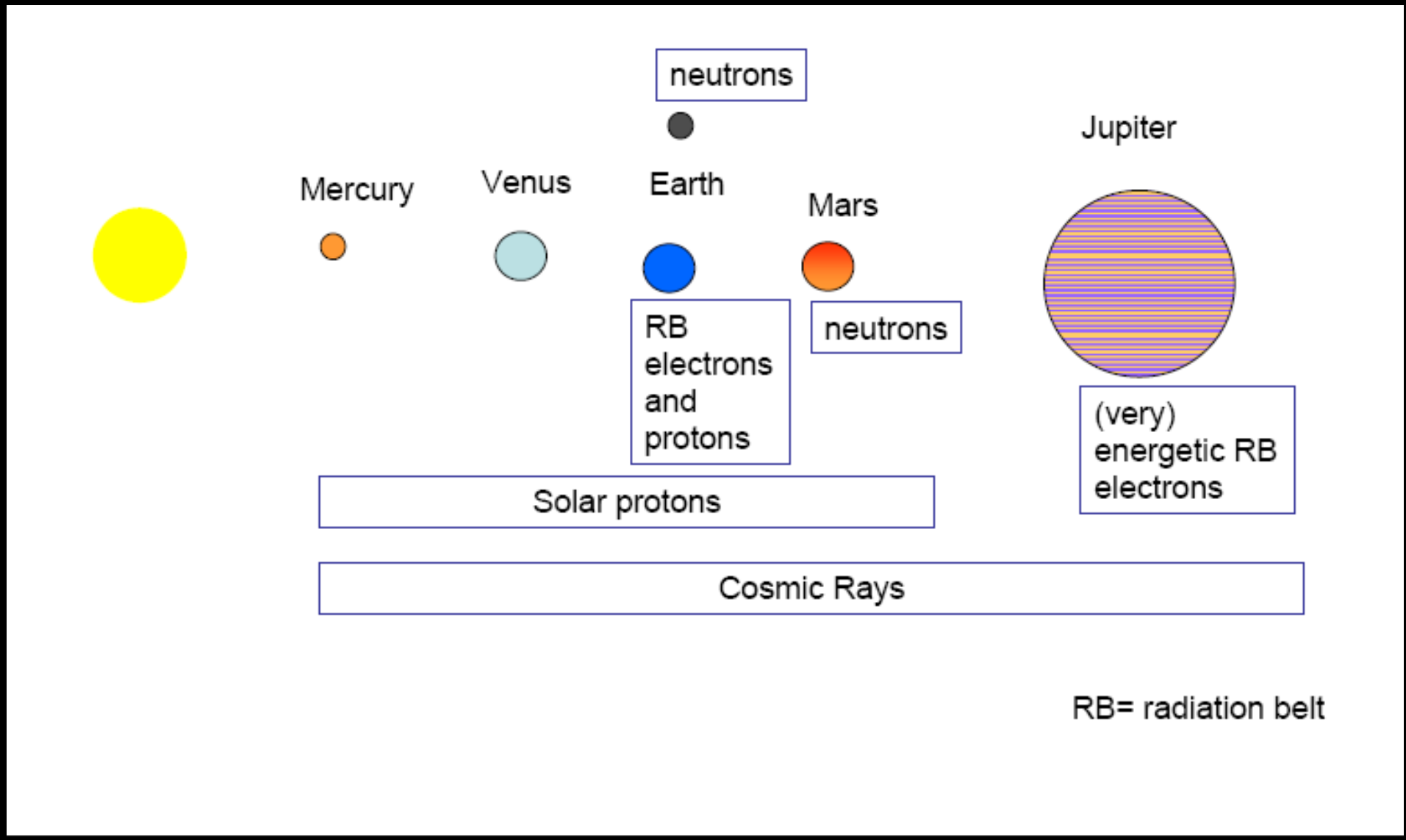


- Based on data from 1960-1970
- Long term averages … but outer belt is very stormy

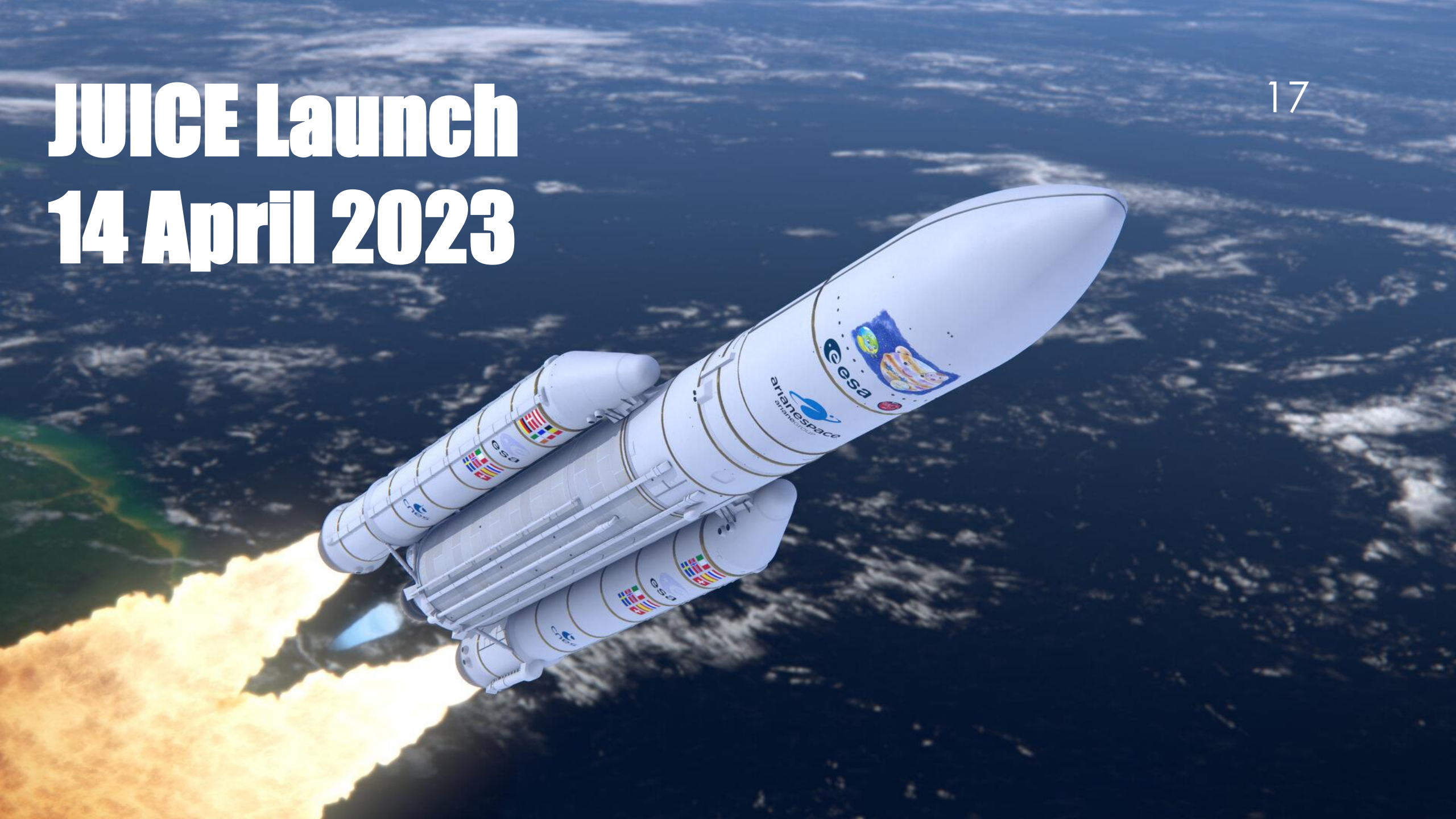
Radiation effects on Earth and in orbit



Radiation Environment in Space



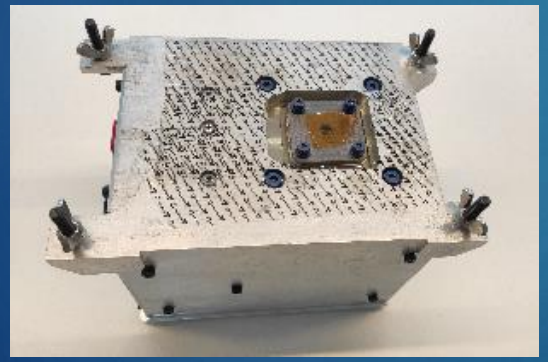
JUICE Launch
14 April 2023

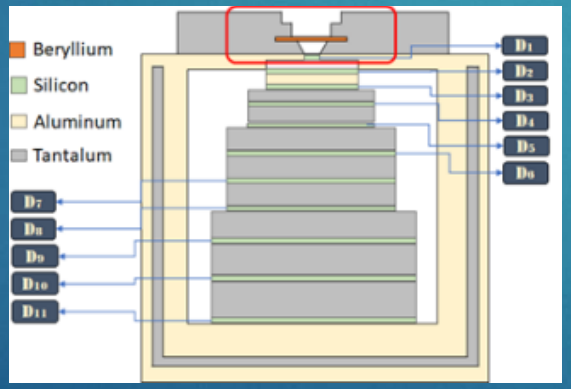


The radiation environment in the solar system: from Mercury to Jupiter

To Mercury – BepiColombo Mission (2018)
BERM – BEpiColombo Radiation Monitor

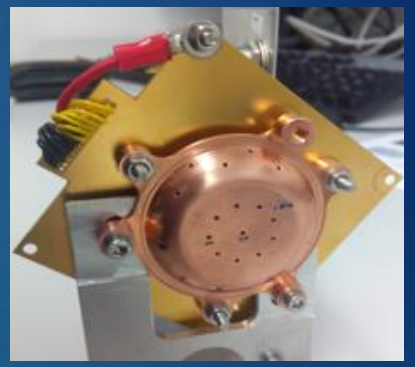
- Measurement
  - electron, proton and ion spectra
- Earth radiation belts measurements in 2021
- Now near Mercury

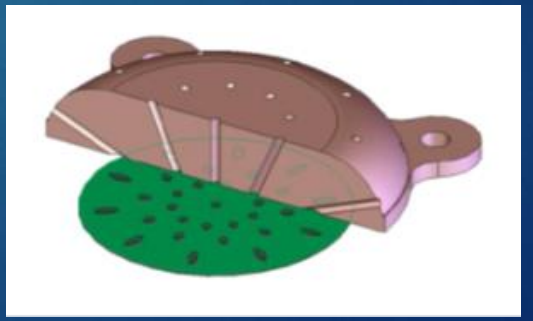




To Jupiter – ESA JUICE Mission (2023)
RADEM – RADiation hard Electron Monitor

- Measurement
  - electron and proton spectra
  - ion LET
  - electron directionality

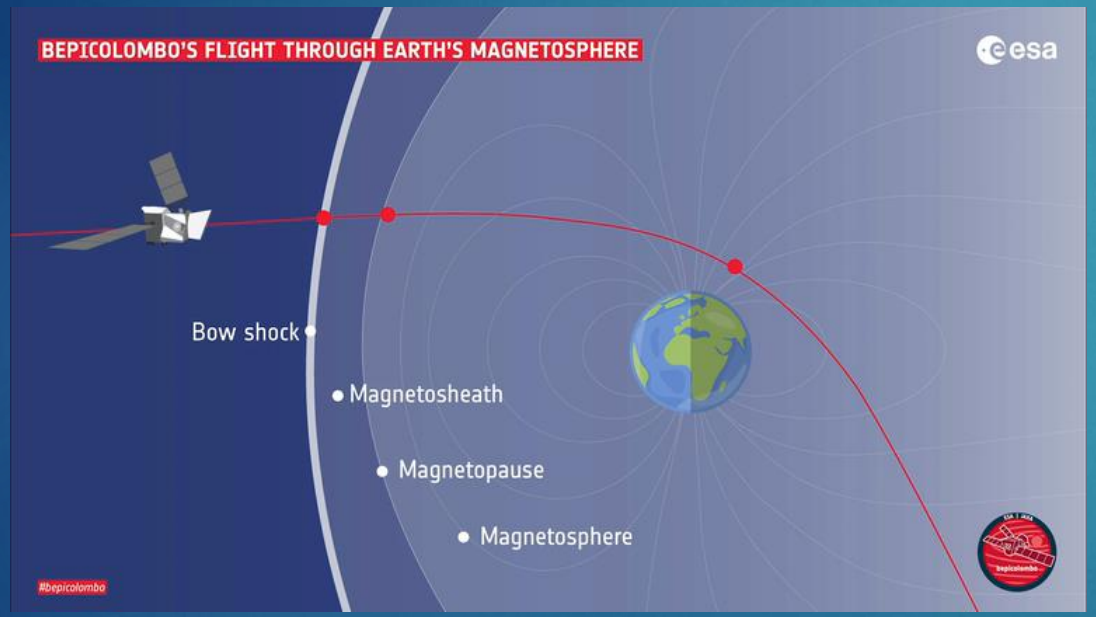




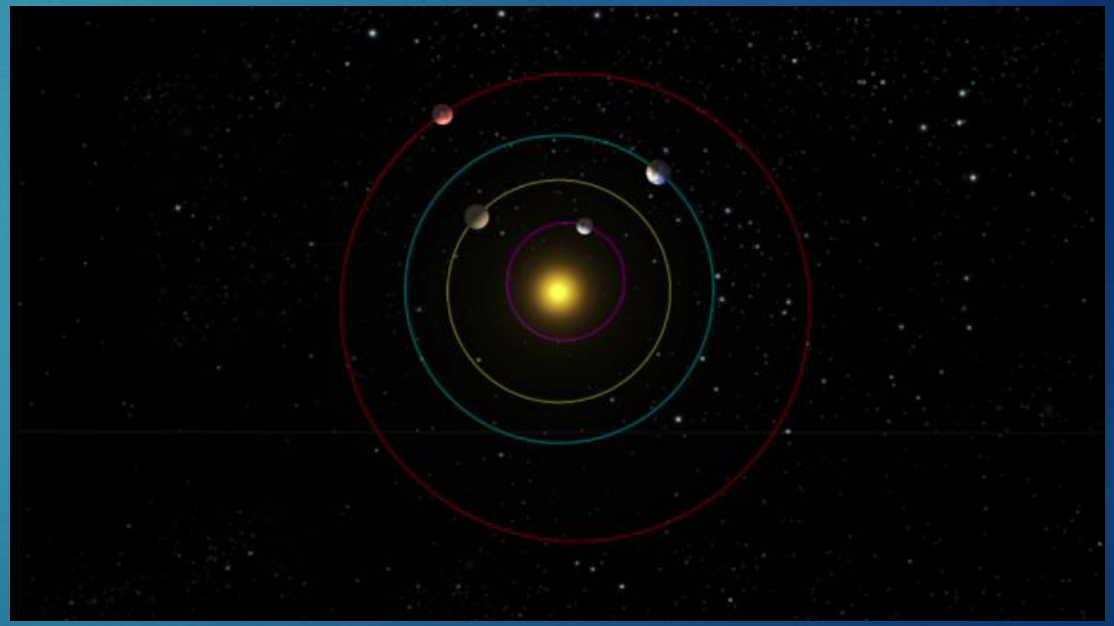
ESA Contract No. 4000137865/22/ES/JD - Expert support to BERM (BepiColombo Environment Radiation Monitor) & RADEM units on board BepiColombo and JUICE spacecraft (LIP,SE2S)
ESA Contact No. 4000110643/13/NL/HB - RADEM Proto-Flight Model (EFACEC, PSI, IDEAS, LIP)

The radiation environment in the solar system: from Mercury to Jupiter

To Mercury – BepiCOlombo Mission (2018)
BERM – BepiColombo Radiation Monitor



To Jupiter – ESA Juice Mission (2023)
RADEM – RADiation hard Electron Monitor



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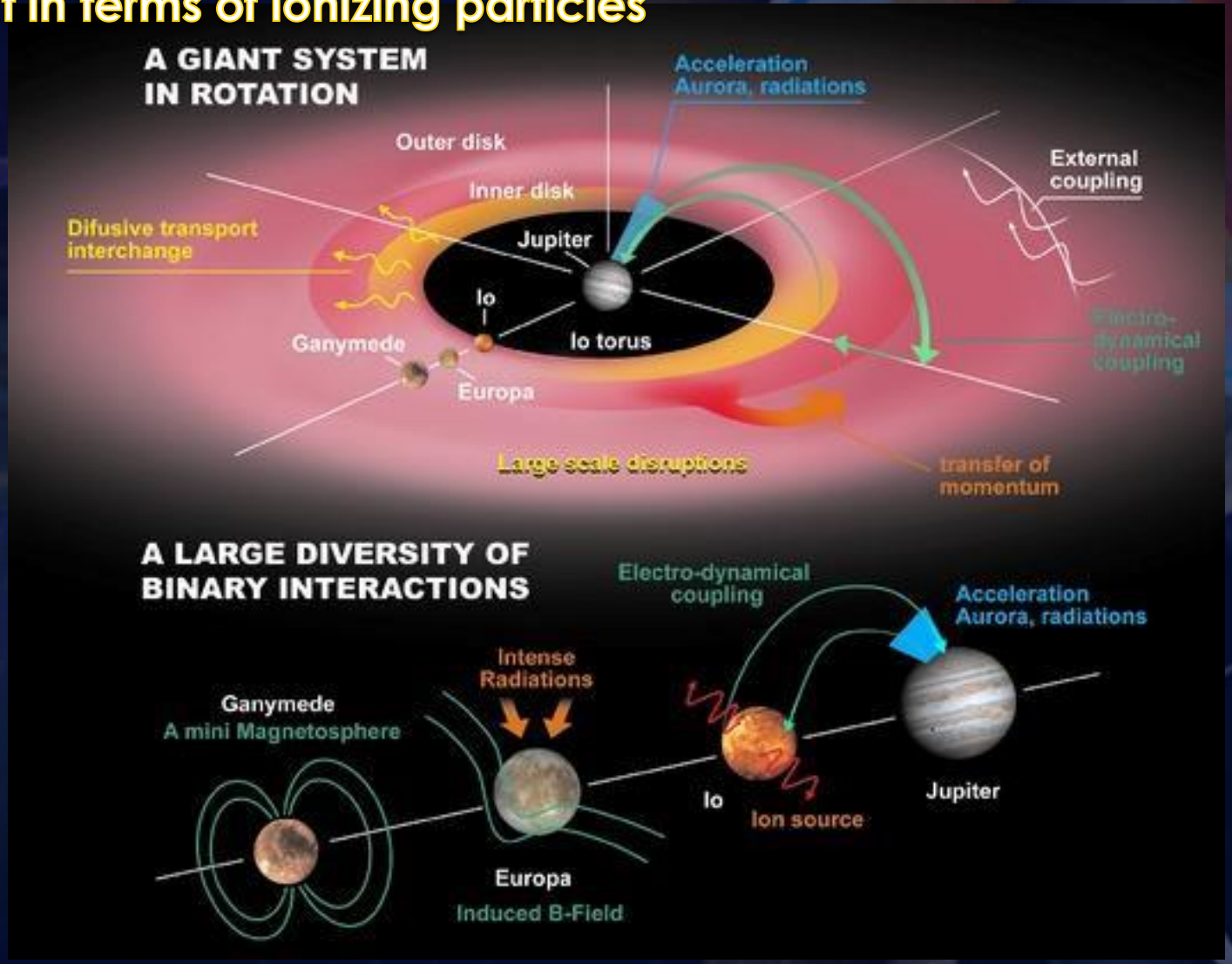
Jovian System

Energetic Particle Environment

Severe environment in terms of ionizing particles

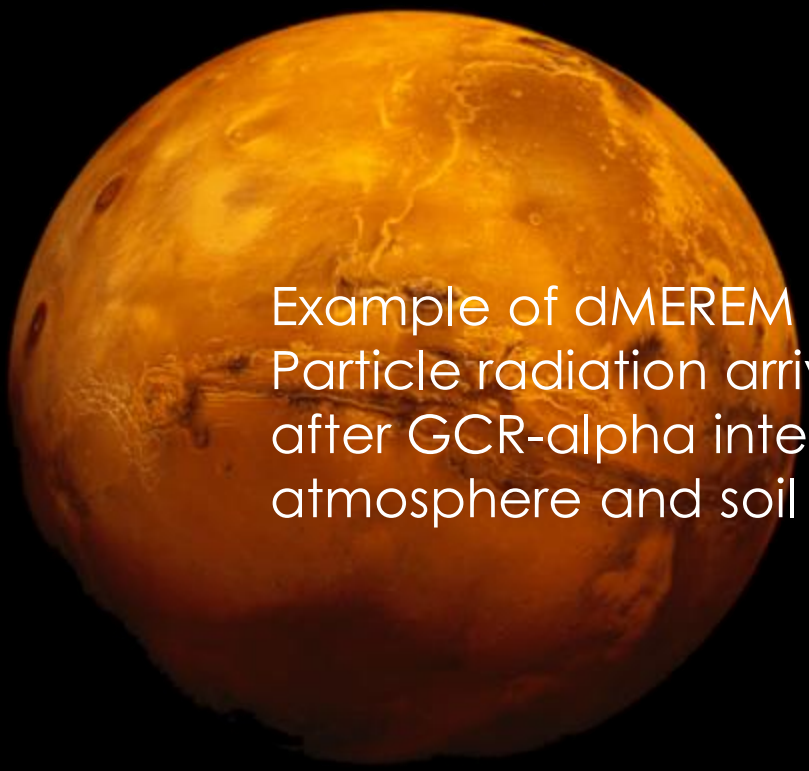


RADIATION ENVIRONMENT MODELING

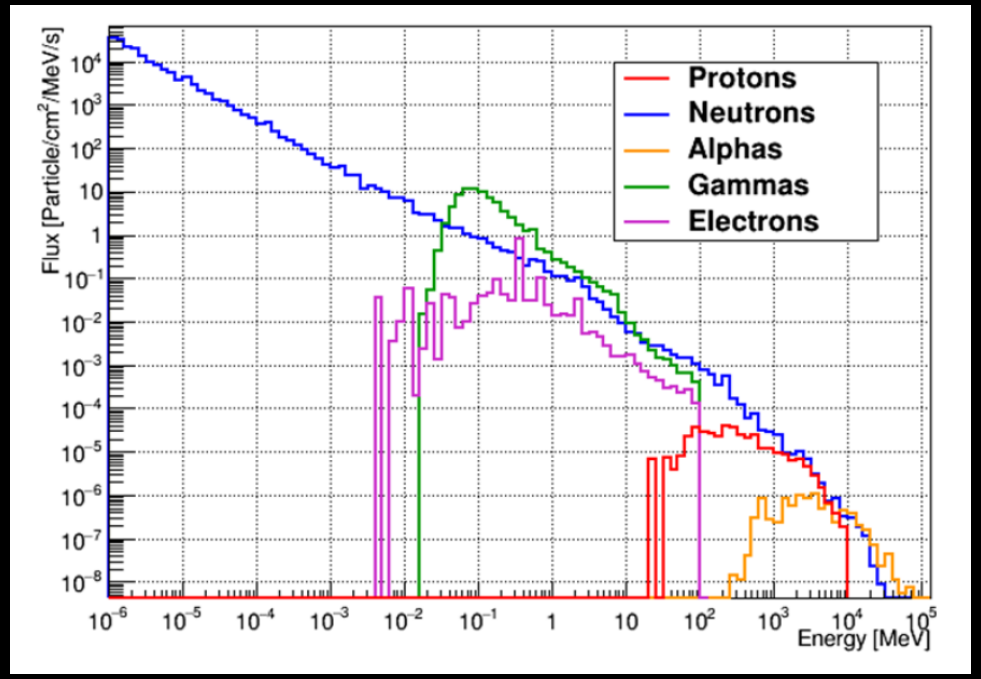
MARSREM: THE MARS ENERGETIC RADIATION ENVIRONMENT MODELS

LIP developed **dMEREM**, a **Geant4 based model for the radiation environment on Mars, Phobos and Deimos**, including local treatment of surface topography and composition,

Inputs given as a function of latitude, longitude, in a 5 x 5 degree grid, and season.



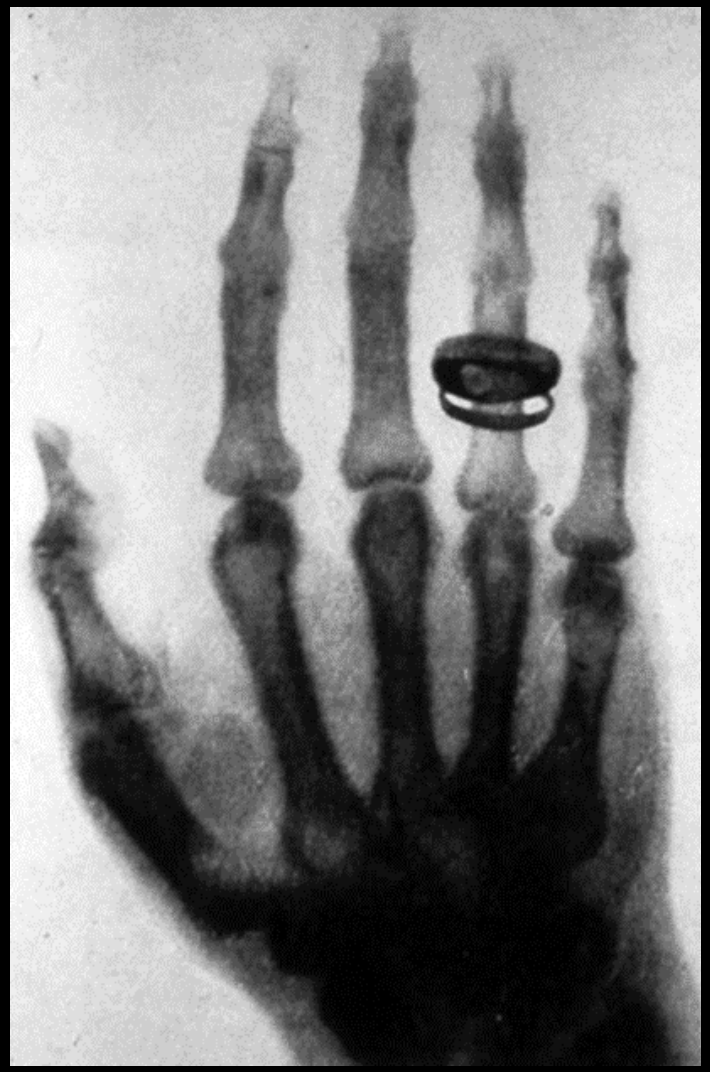
Example of dMEREM results:
Particle radiation arriving on Mars surface after GCR-alpha interaction with atmosphere and soil

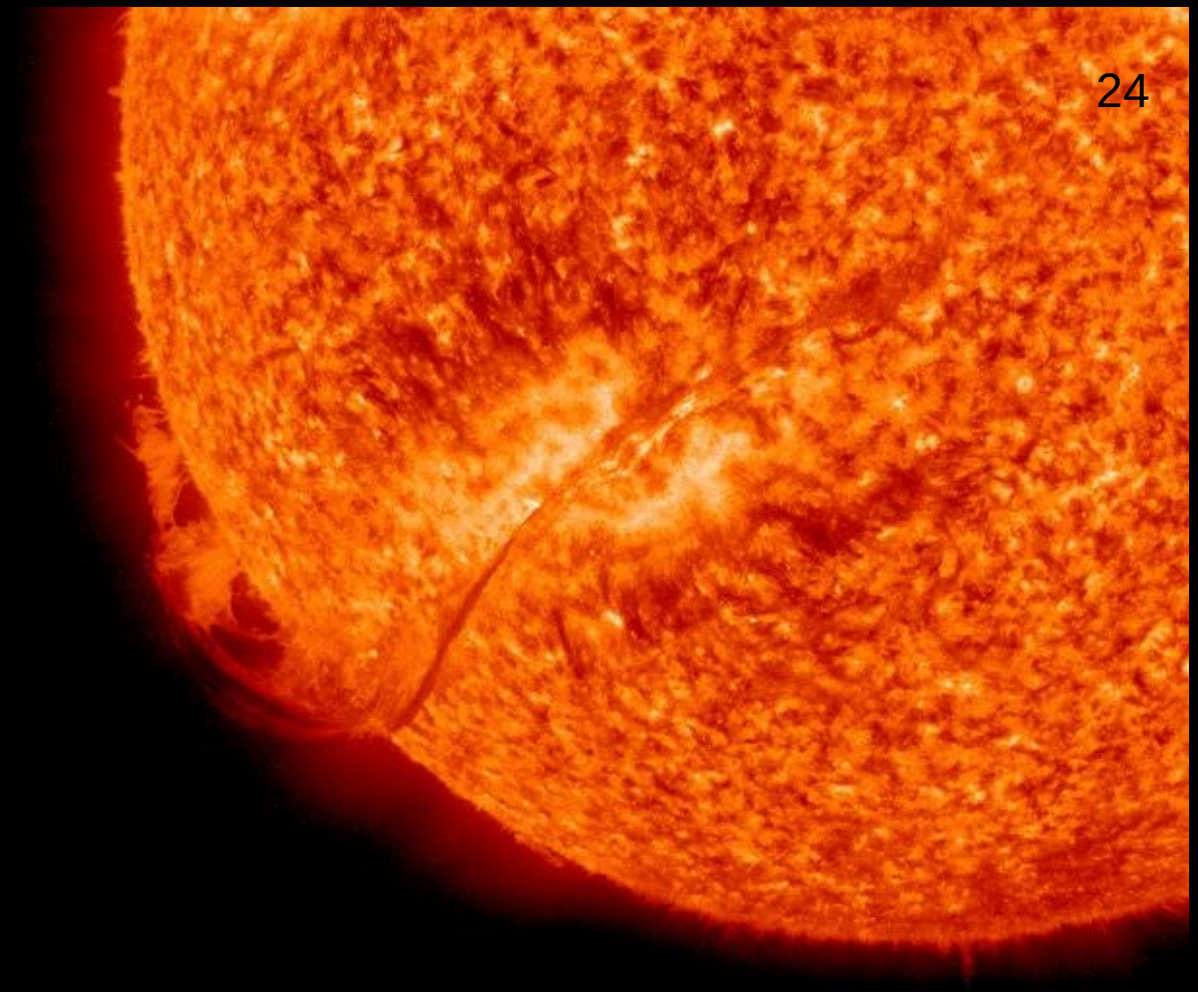


...IT IS POSSIBLE !

What do Space & Health applications have in common?

RADIATION





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http://spaceweather.com/

Human space flight
The danger of the interplanetary travel

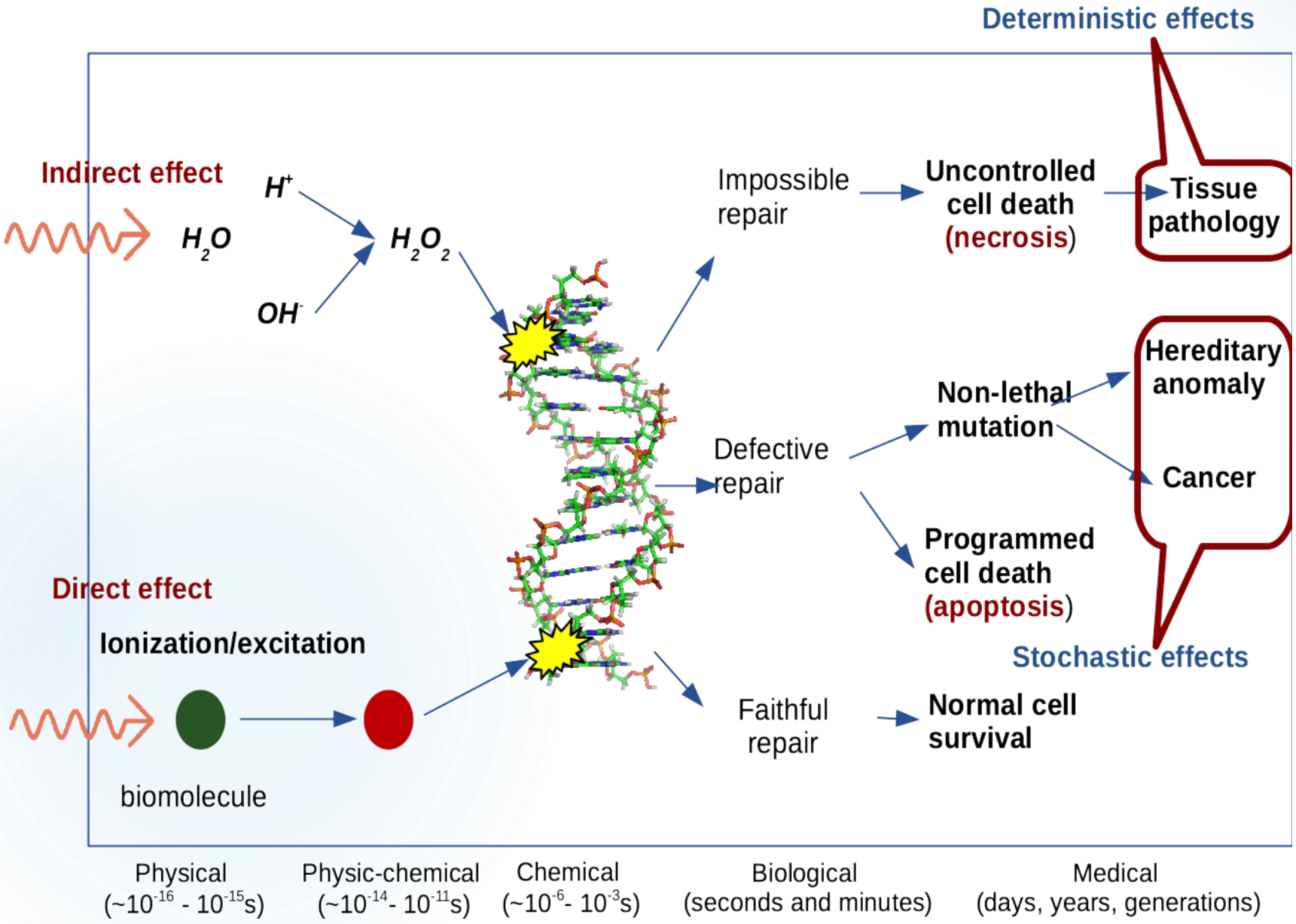
The most dangerous phase while travelling to Mars , from the point of view of the radiation hazard, is the interplanetary travel !

The biggest danger is the possibility of a SEP reaching the mission..

<u>Mitigation Strategies:</u>

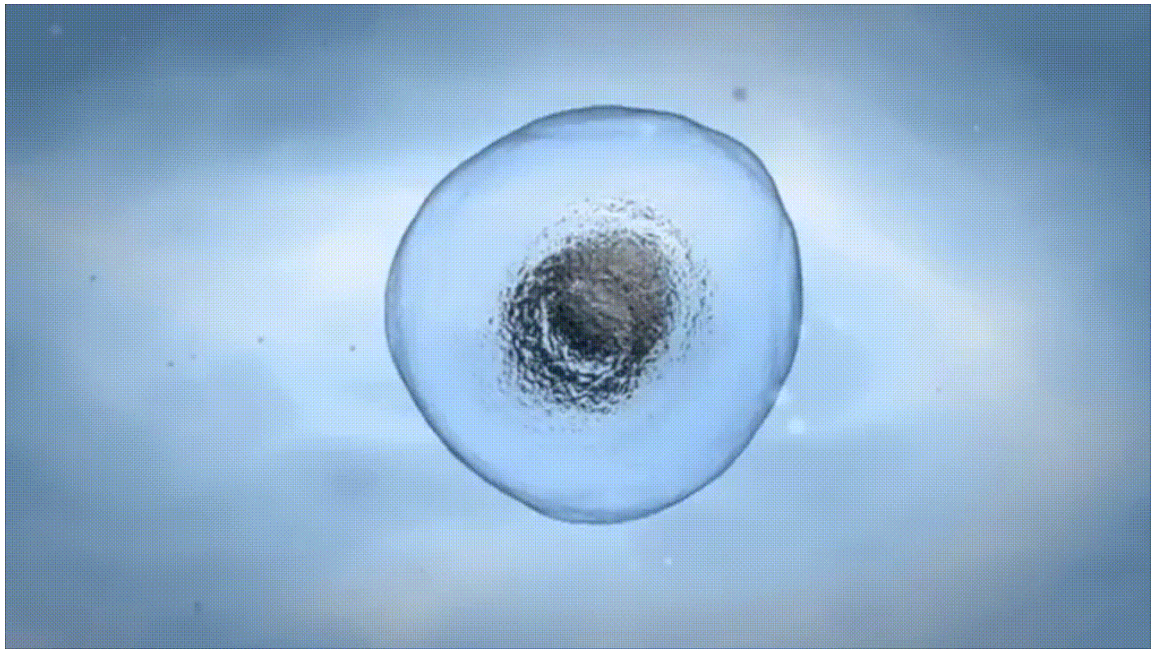
- Shelters inside water compartments or other
- Faster propulsion system
- SEP Forecasting tools and alarms
- Radiopharmaceuticals …

Biological effects of radiation



What is cancer?

Cancer is a group of diseases in which there is an abnormal and uncontrolled proliferation of cells that originated from a "normal" cell that mutated, giving rise to cells that have the ability to continue to multiply, spreading to other tissues and organs beyond those to which the original cell belonged.

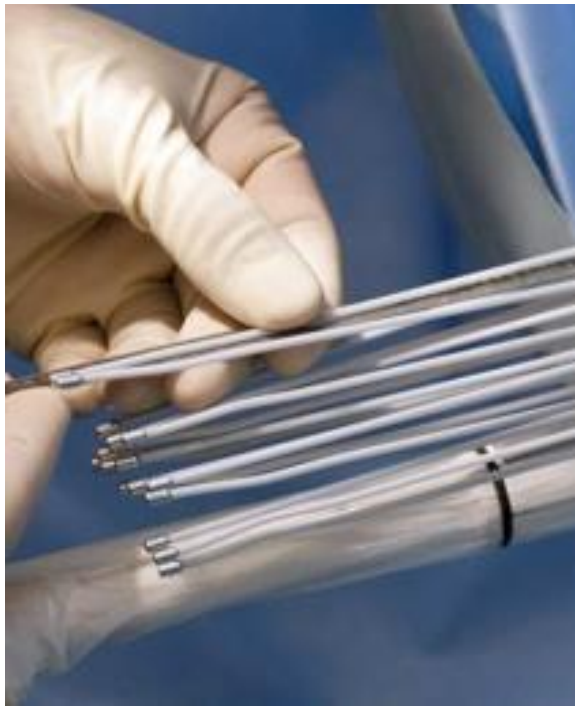


Radiotherapy

Radiotherapy with radioactive sources or internal radiotherapy

- Brachytherapy:

  Photons and electrons released from sources - “seeds” - placed close to the tissue to treat



Radiotherapy

Radiotherapy with external beams

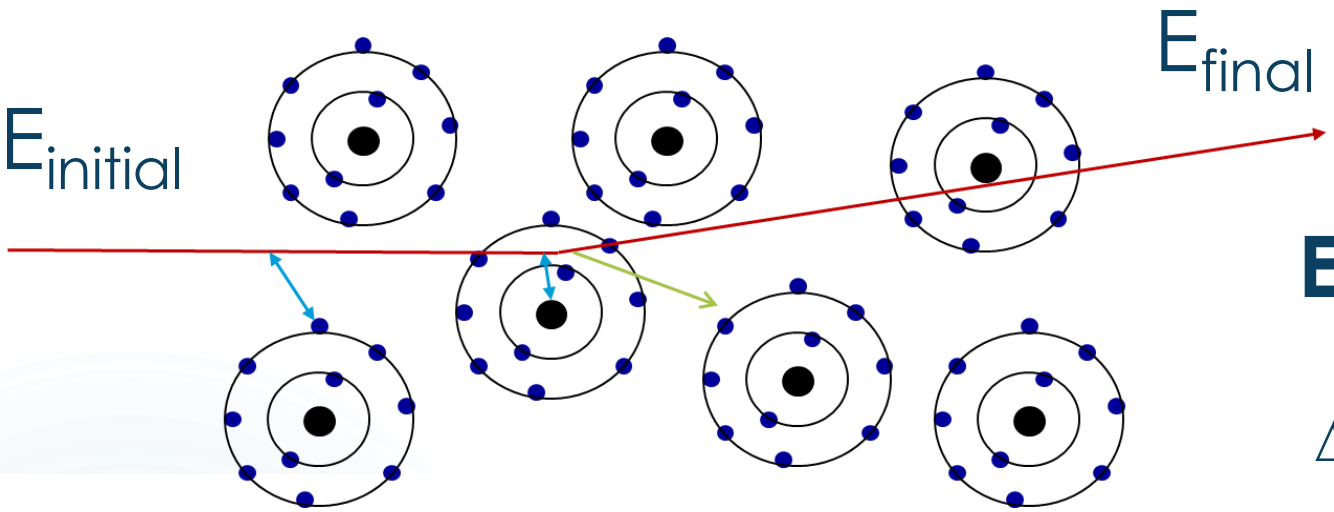
- LINACs

electrons and photons

- Cyclotrons and synchrotrons

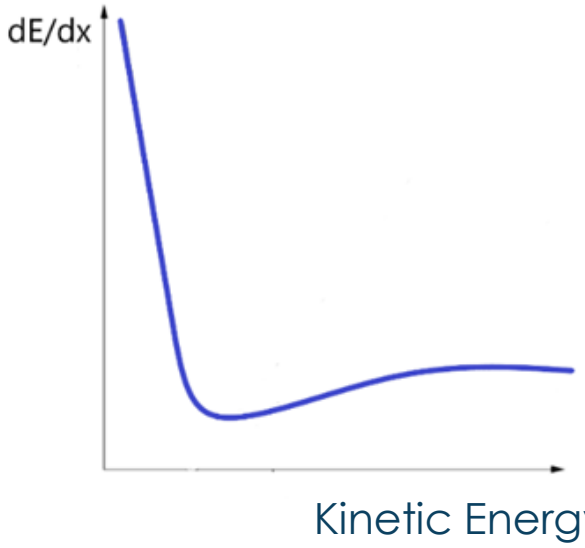
protons and carbon ions

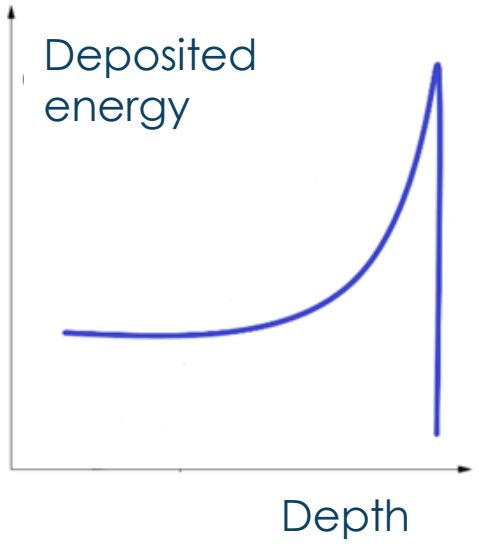
Charged particles



$$E_{final} = E_{initial} - \Delta E$$

ΔE - transferred energy



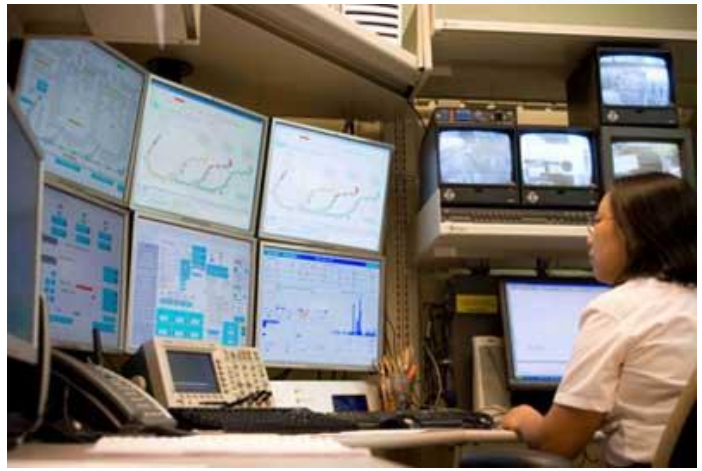


In charged particle therapy the kinetic energy lost by the particles is transferred on to the tissues!

Therapy with hadrons

Proton/ion therapy

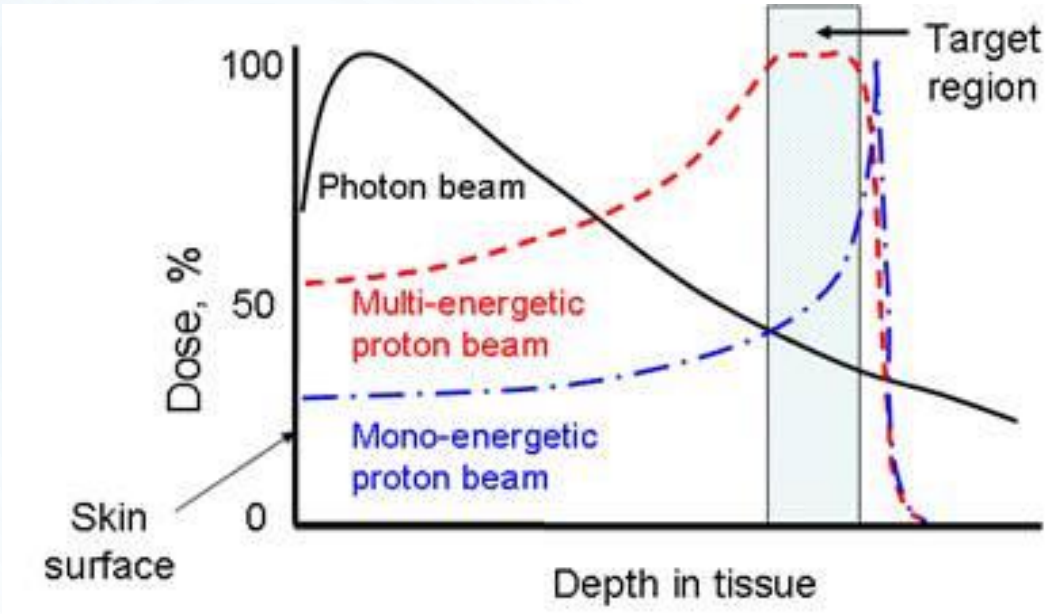
- energetic protons/ions are produced in an accelerator
- energetic protons/ions are directed at the tumor
- Varying the energy of the protons/ions results in good control of the penetration depth
- Beam can be focused to the size of a pin
- less damage to healthy tissue than electron or gamma therapy

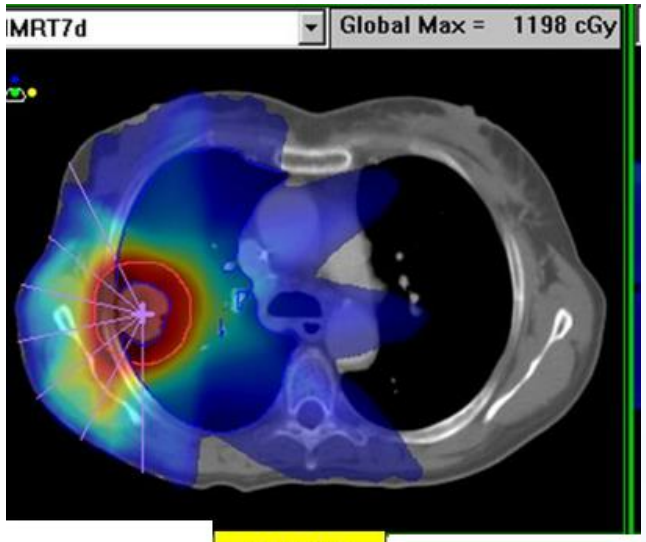


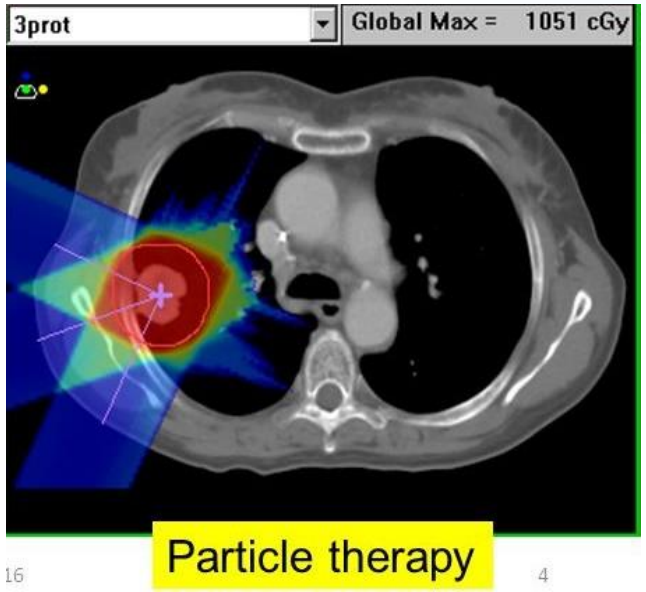
Therapy with hadrons

therapeutic application of accelerators:

particle-based radiotherapy, **including protons and heavy ions**





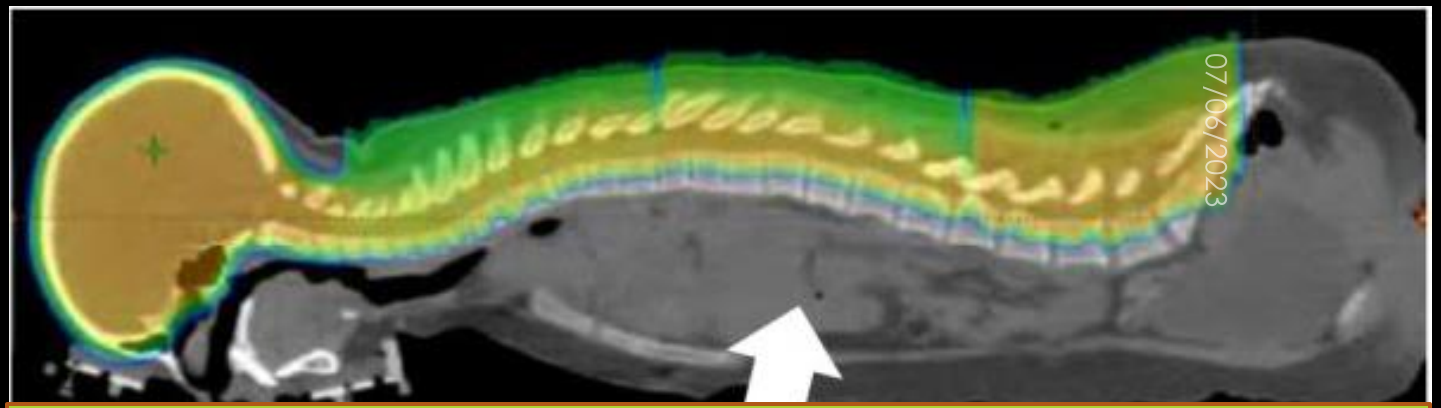


The advantage of protons/ions

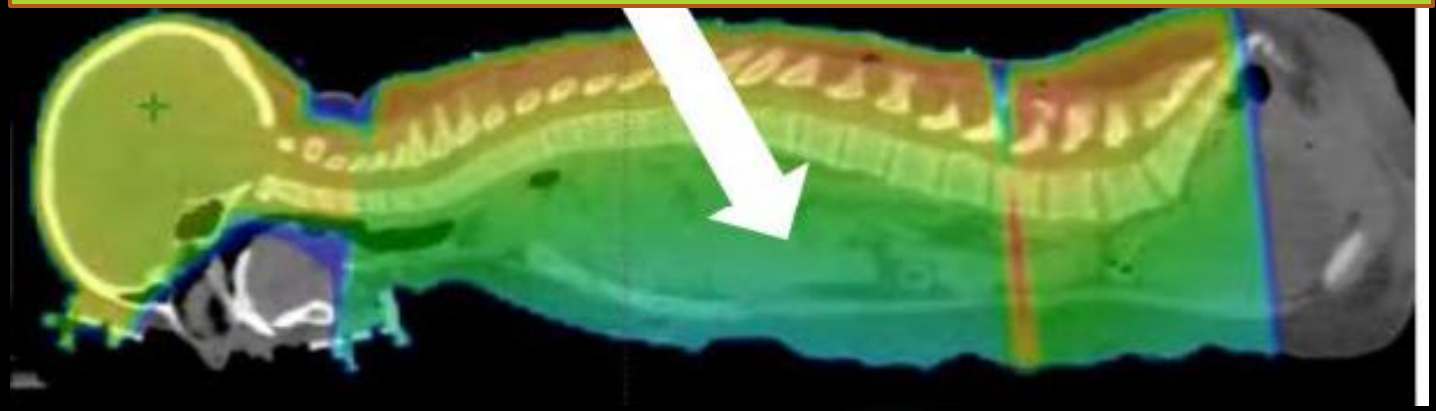
Protons stop!
At a depth that depends on their initial energy

X-rays and gamma rays don´t!
They continue to traverse tissues beyond the region that is being treated

Protons



The use of protons avoids unnecessary irradiation of the heart, lungs and intestines that happens in the case of x-ray radiotherapy



Photons (x-rays / gamma rays)

and there is more…

Questions today
Theses tomorrow