aeronomie·be

Royal Belgian Institute for Space Aeronomy (BIRA-IASB)

Institut royal d'Aéronomie Spatiale de Belgique (IASB)

Koninklijk Belgisch Instituut voor Ruimte-Aeronomie (BIRA)

SWIC: Space Radiation

Space Weather Group - D14

Mark Dierckxsens (Mark.Dierckxsens@aeronomie.be)
Erwin De Donder (Erwin.dedonder@aeronomie.be)

KONINKLIJK BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT ROYAL D'AERONOMIE SPATIALE DE BELGIQUE ROYAL BELGIAN INSTITUTE OF SPACE AERONOMY KONINKLIJK BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT ROYAL D'AERONOMIE SPATIALE DE BELGIQUE ROYAL BELGIAN INSTITUTE OF SPACE AERONOMY KONINKLIJ

SPACE RADIATION in general

Radiation is the transmission of energy through matter and space

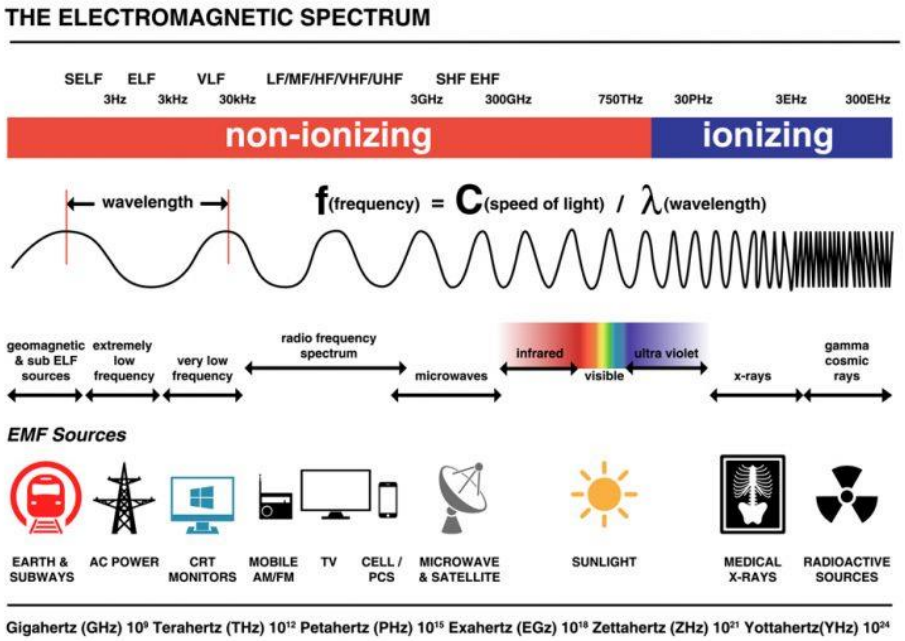
Electromagnetic waves

Particles

SPACE RADIATION in general

ELECTROMAGNETIC RADIATION

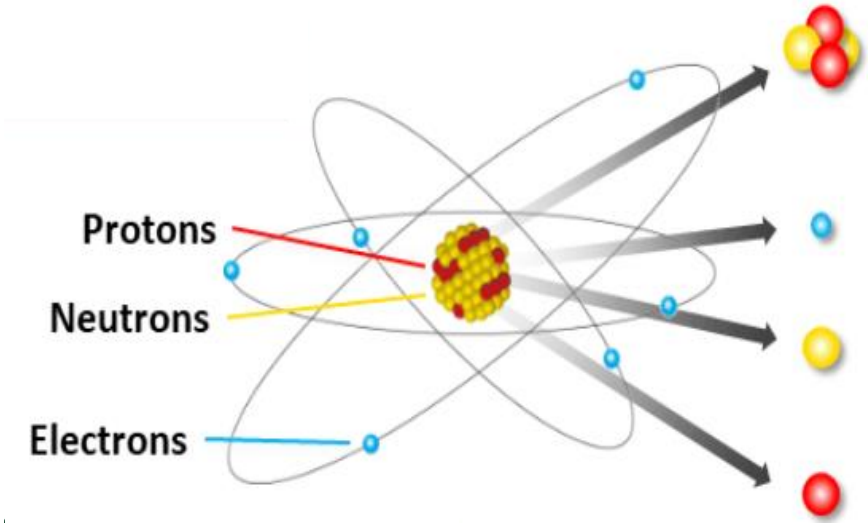
- → Energy transmitted in the form of photons (EM waves)
- → Speed of light (c)
- → Sun emits mostly light from UV to infrared
- → During solar flares: from radio waves up to gamma rays



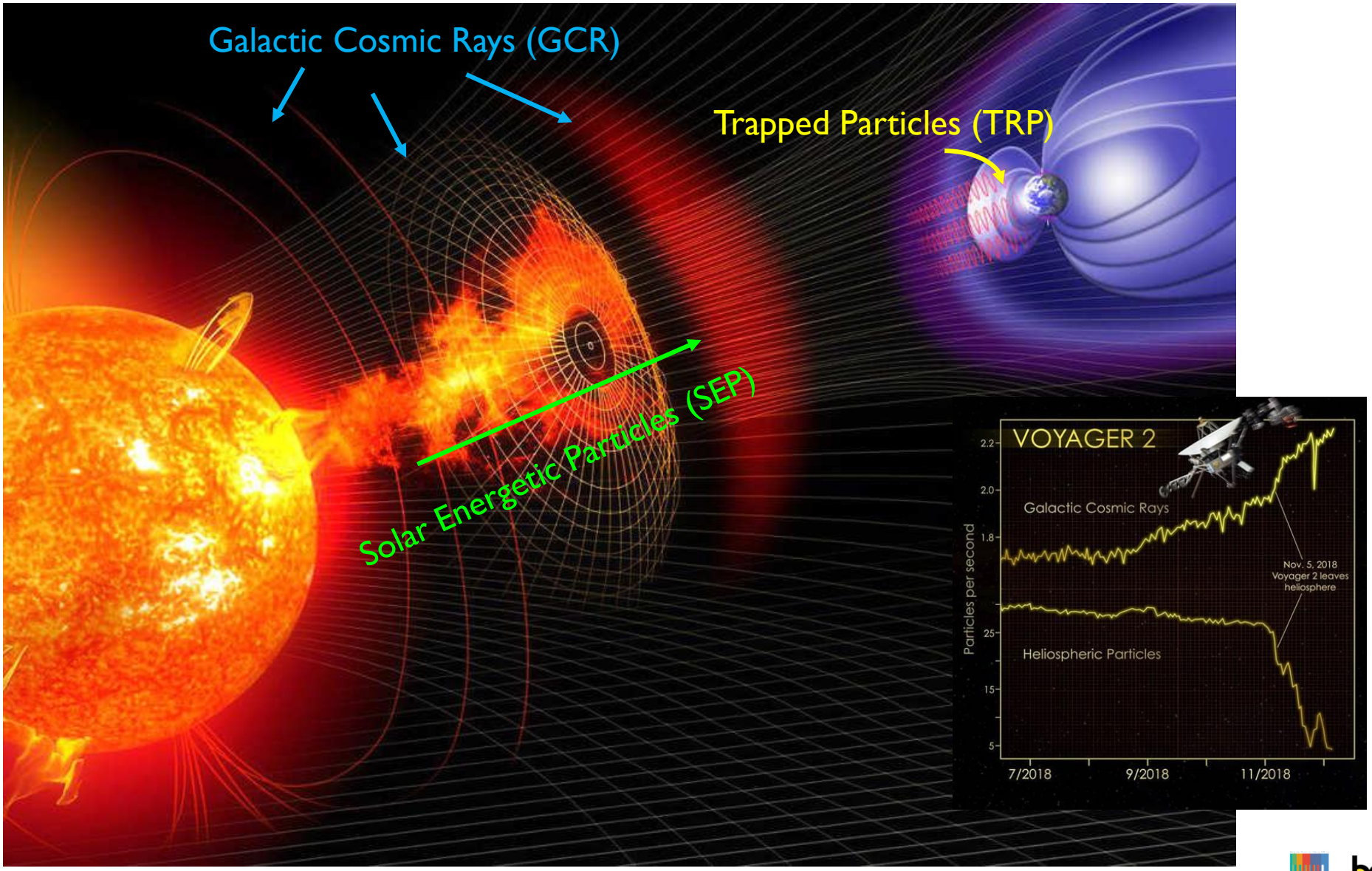
SPACE RADIATION in general

PARTICLE RADIATION

- → Energy transmitted by fast-moving atomic or sub-atomic particles (electrons, protons, alpha particles, etc.)
- → Few m/s up to sizable fraction of c
- → Energy expressed in eV ($1\ eV = 1.602\times10^{-19}\ J$)
- → Space: from keV to >TeV (10^{15} eV)
- → <100 keV : plasma



Energetic Particle Populations in heliosphere



Interplanetary particles

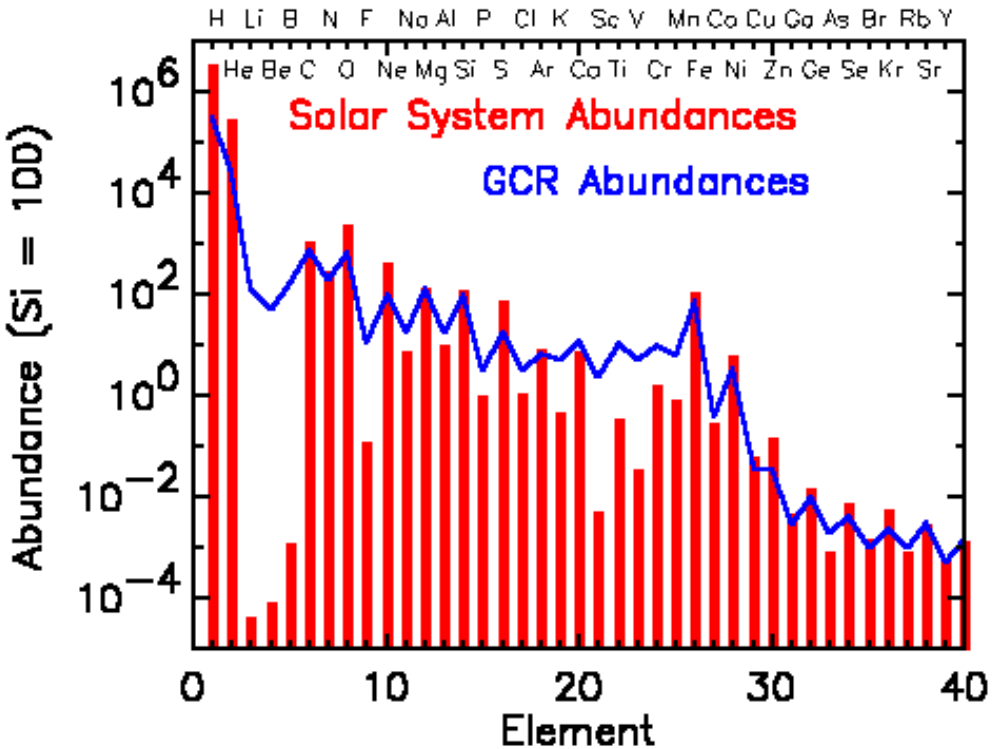
Cosmic Rays (CR):

- Galactic Cosmic Rays (GCR)
- Solar Energetic Particles (SEP)

→ Protons and heavy ions of all the elements of the periodic table

Galactic Cosmic Rays (GCR)

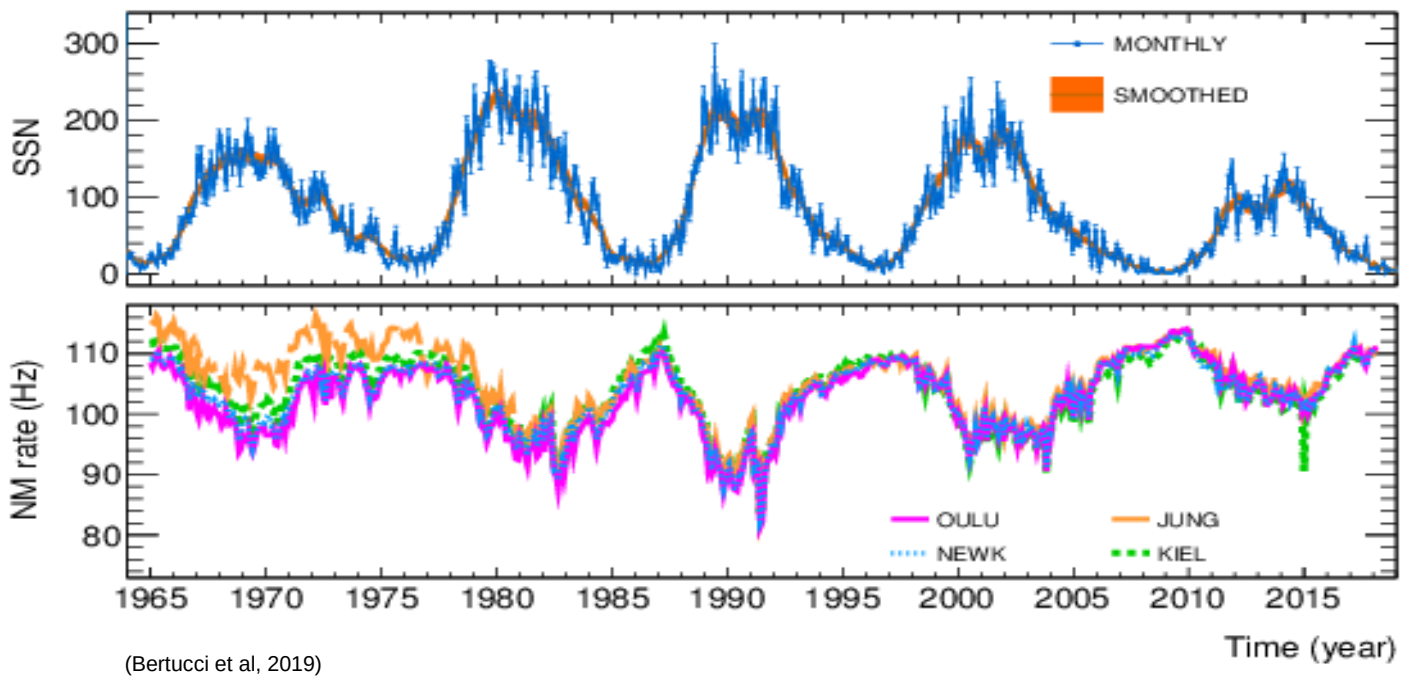
- High-energy charged particles produced outside solar system
  - ~ 83% protons
    ~13% ^{4}He ions (alphas)
    ~3% electrons
    ~1% heavier nuclei
    → "HZE nuclei" (Q>2)
  - E ~ MeV – GeV and even > TeV (extra-galactic)
  - Electrons neglected (density much lower than solar wind)



(https://imagine.gsfc.nasa.gov/Images/science/abund2.gif)

GCR Modulation

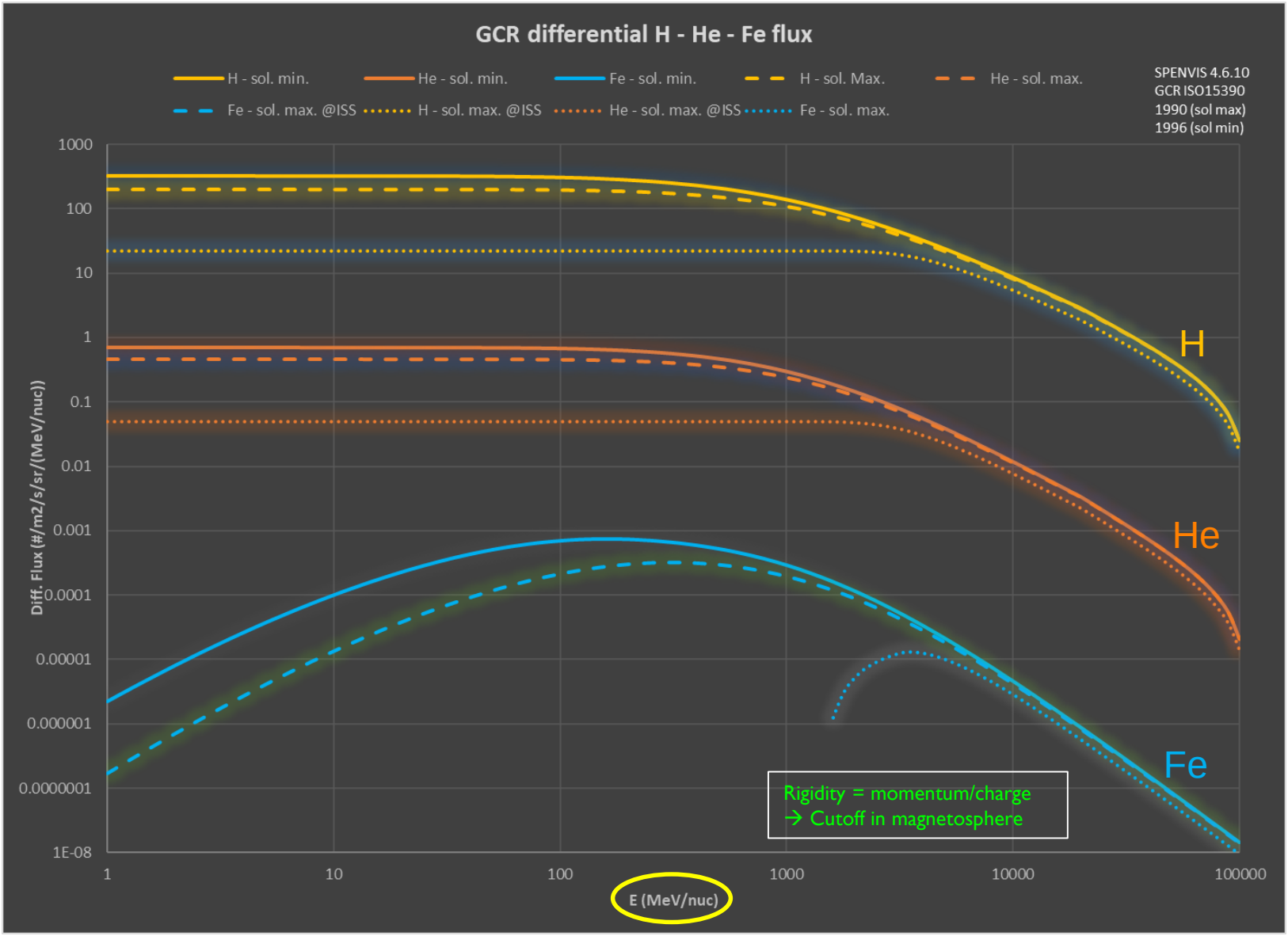
- Omnidirectional flux modulated by solar activity
  - Solar cycle: GCR max (min) @ solar min (max)
  - Coronal Mass Ejection (CME) → Forbush decrease (see later)



(Bertucci et al, 2019)

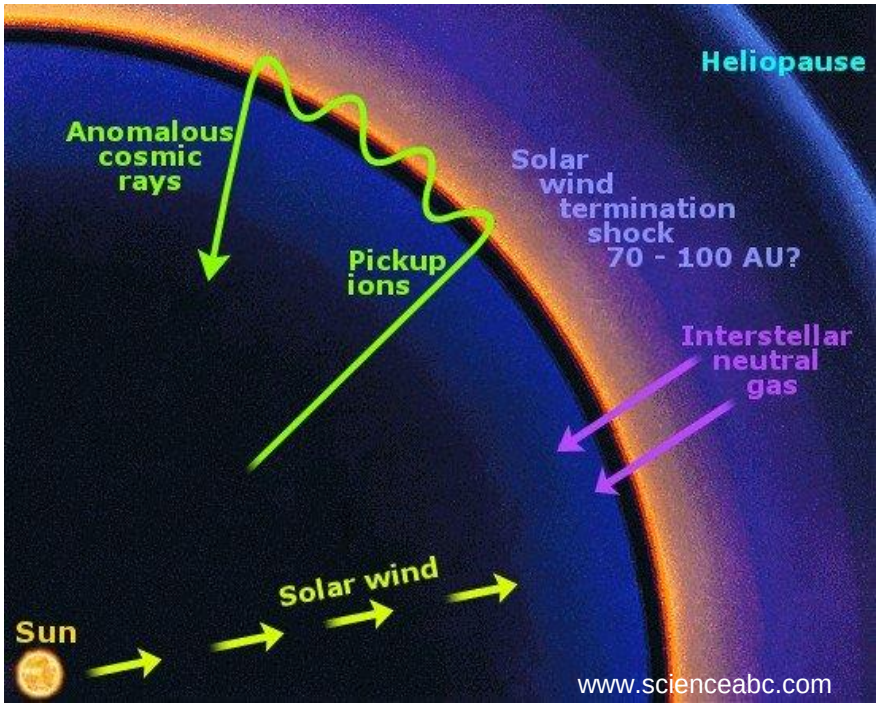
HZE = high (H) atomic number (Z) and energy (E) | SSN = Smoothed Sunspot Number | NM = Neutron Monitor

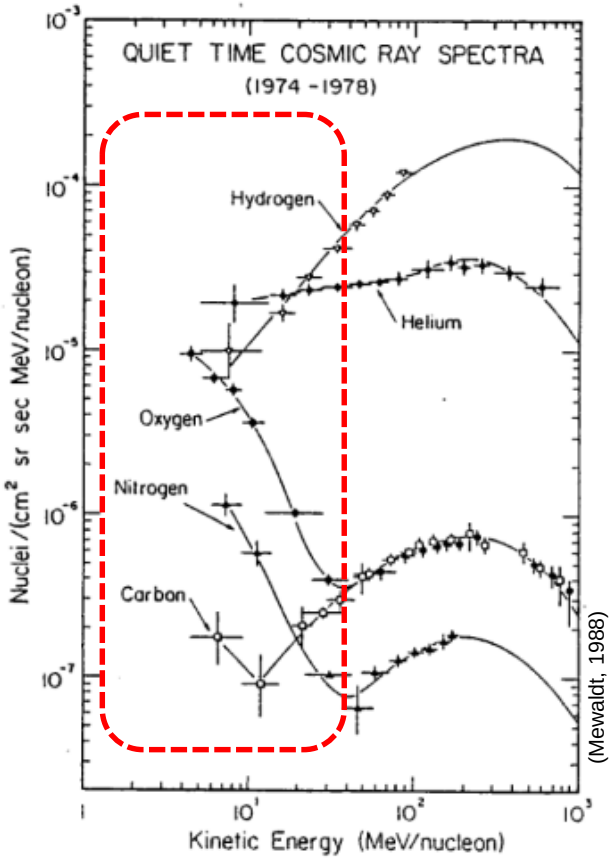
Galactic Cosmic Rays (GCR) (2/2)



Anomalous Cosmic Rays (ACR)

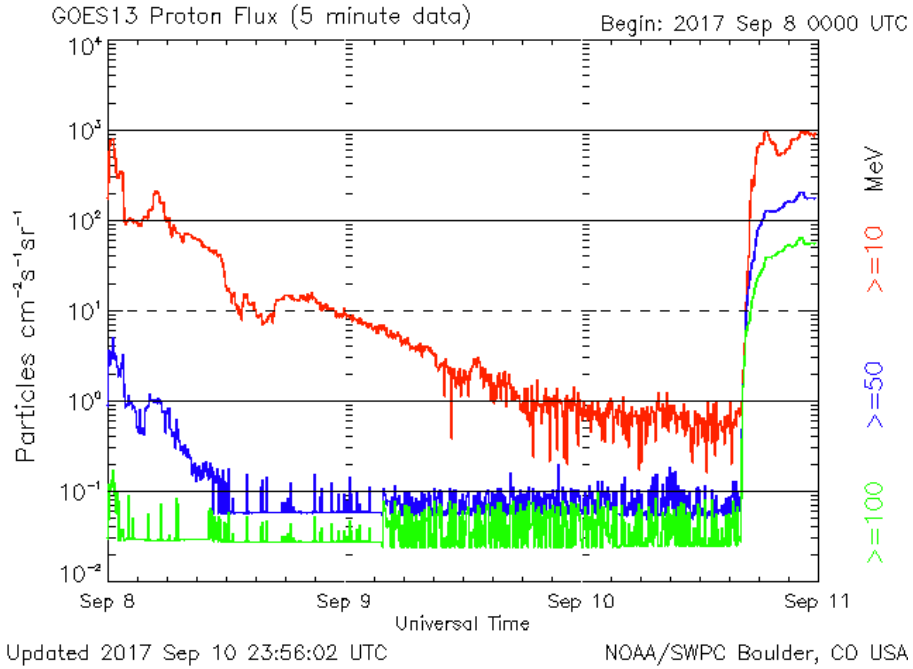
- He and heavier ions with E ~10 -100 MeV/nuc
- Originate in interstellar gas that diffuses into heliosphere
- Single ionised
- Only seen during solar minimum
- Source of heavy ions trapped in Earth's magnetic field (?)

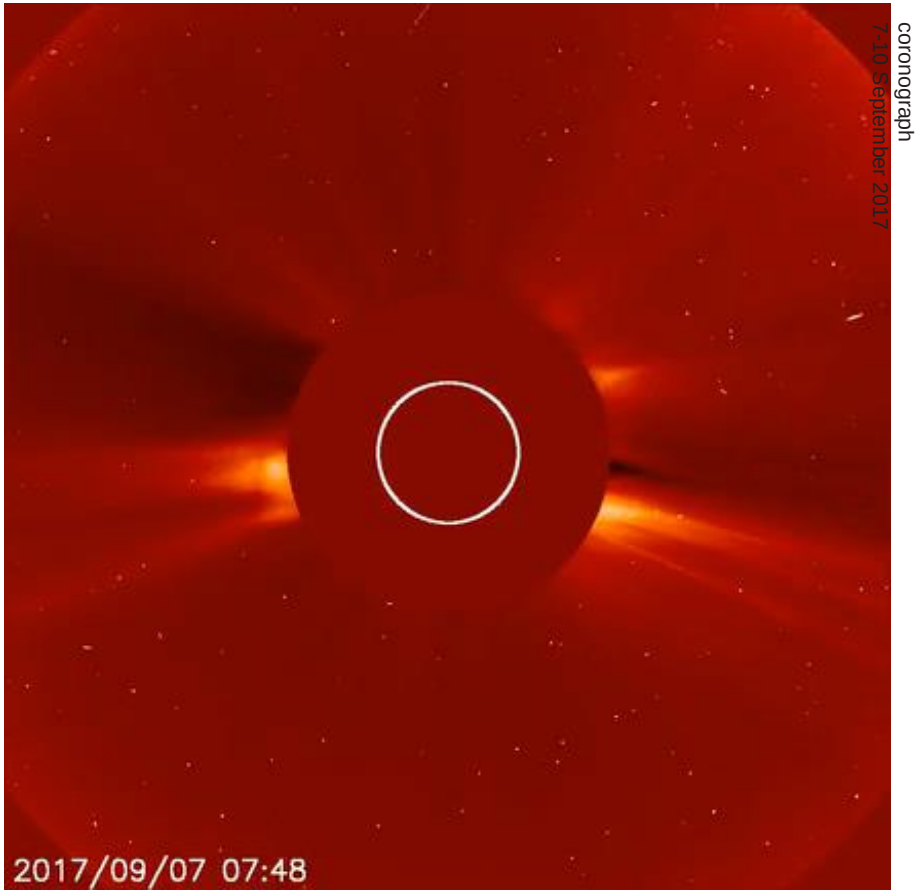




Solar Energetic Particles (SEP)

- Produced in solar flares and by CME driven shocks → SEP events
- >90% protons, electrons, heavy ions (→ composition changes from event to event)
- E ~ keV – GeV
- Solar Proton Event (SPE): >10 pfu at ≥10 MeV



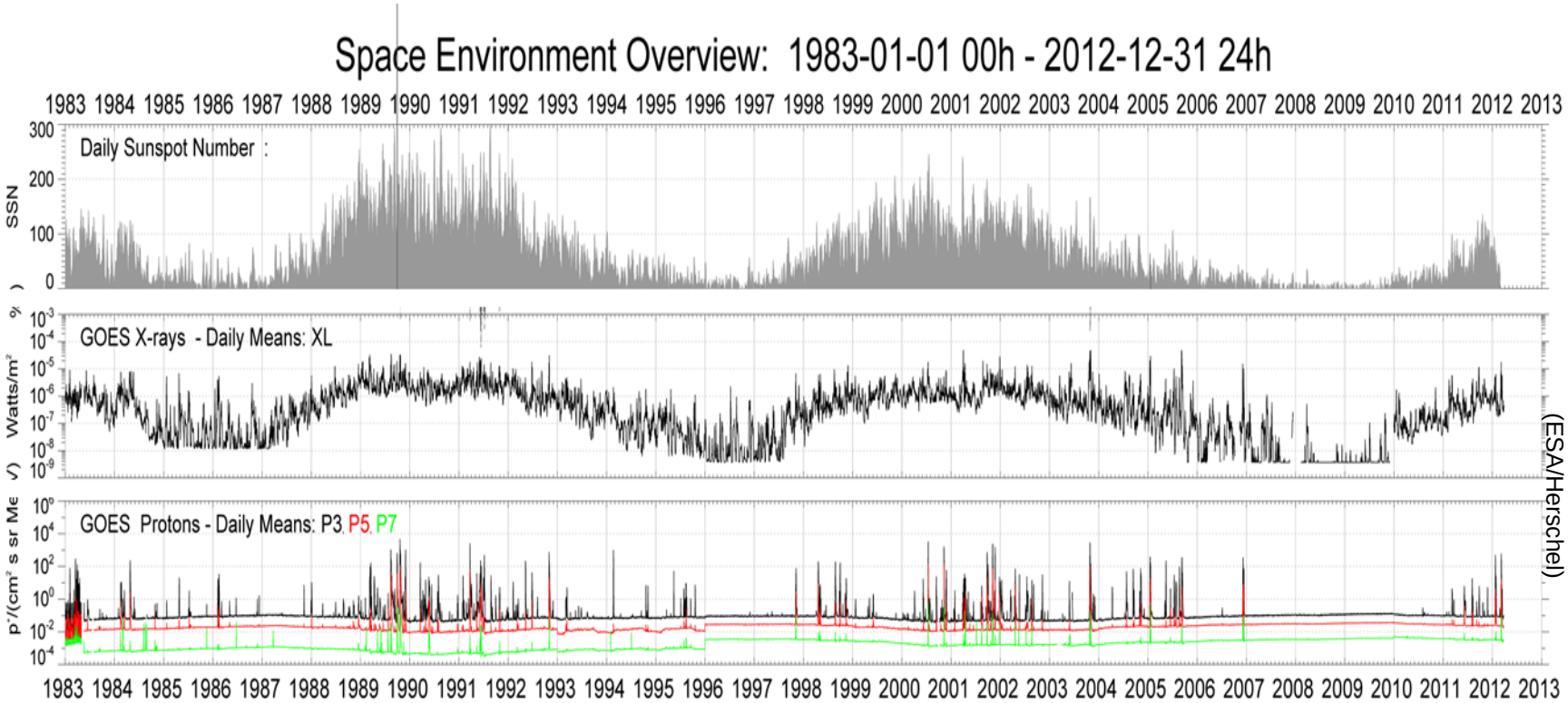


Observations by SOHO/LASCO coronograph
7-10 September 2017

1 proton/cm^2/sr/s = 1 pfu

Solar cycle dependence of SEP events

SEP events are much more frequent during the active phase of the solar cycle, though they are stochastic in nature.

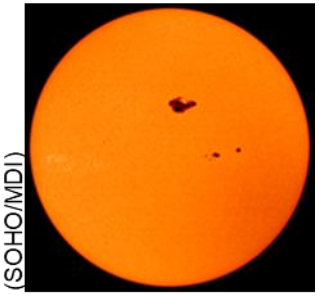


(ESA/Herschel)

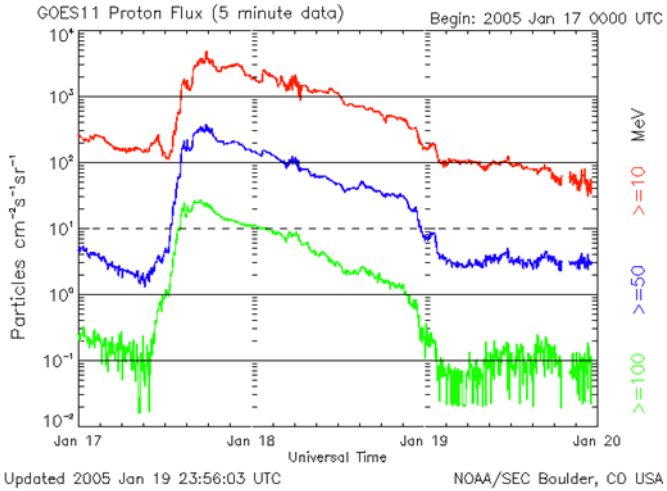
Impulsive vs. gradual SEP events

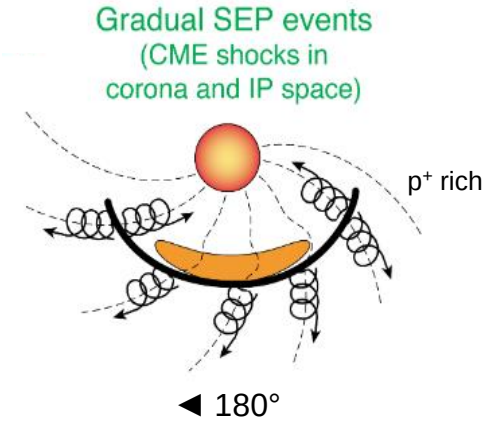
In the week of January 20 2005, active region NOA AR 10720 produced several different types of SEP events.

16-17/01/2005



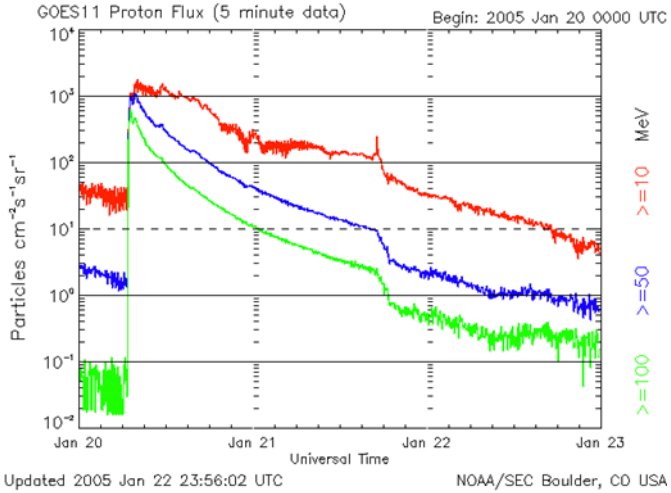
(SOHO/MDI)

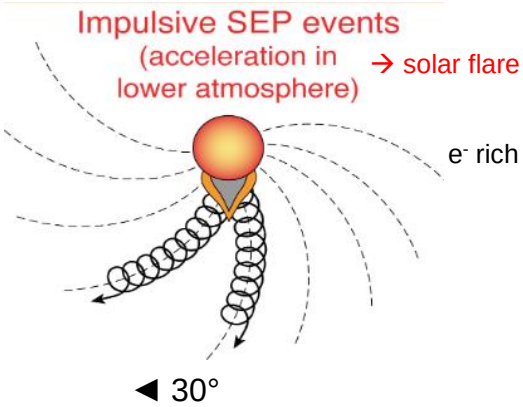




20/01/2005

(SOHO/MDI)

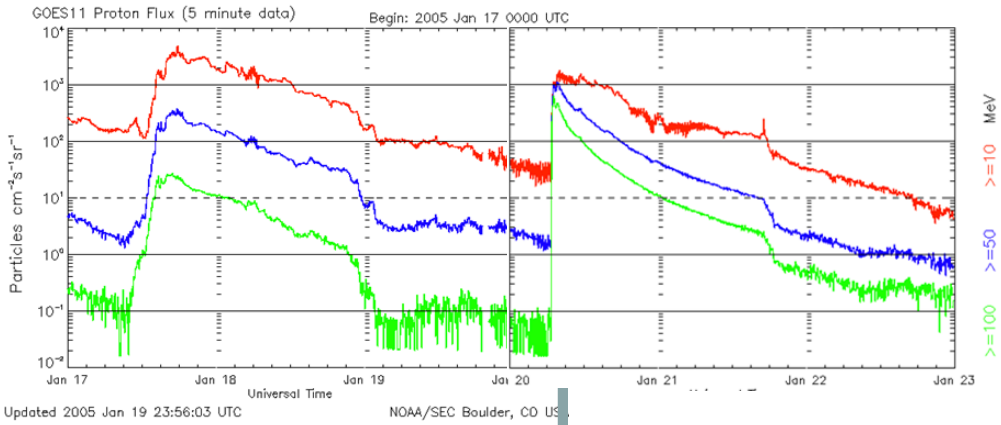




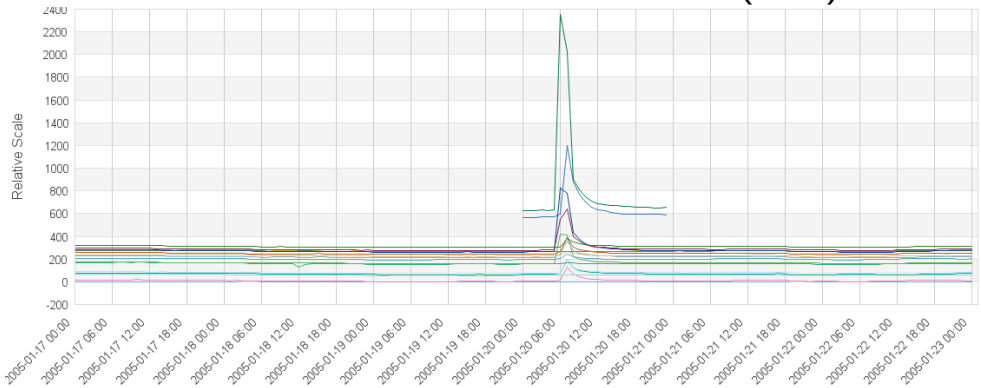
(Reames, 1999)

SEP events and Ground Level Enhancement (GLE)

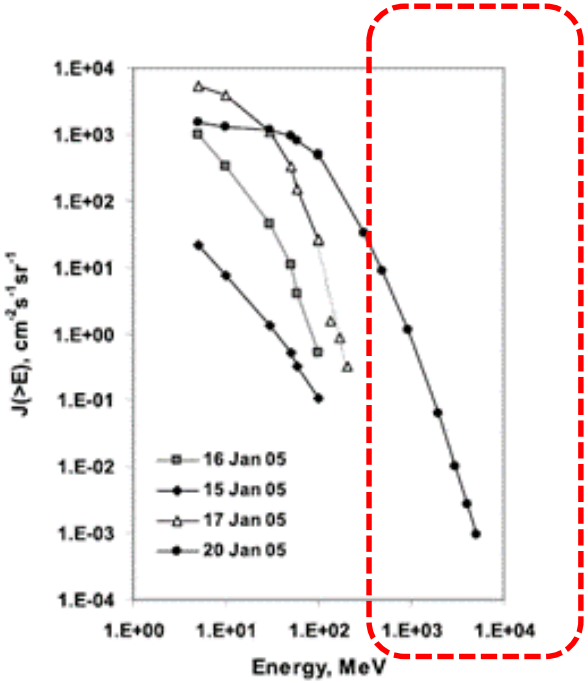
GLE = sudden increases in the cosmic ray intensity recorded by ground based detectors produced by >500 MeV SEPs.



Ground Level Enhancement (GLE)



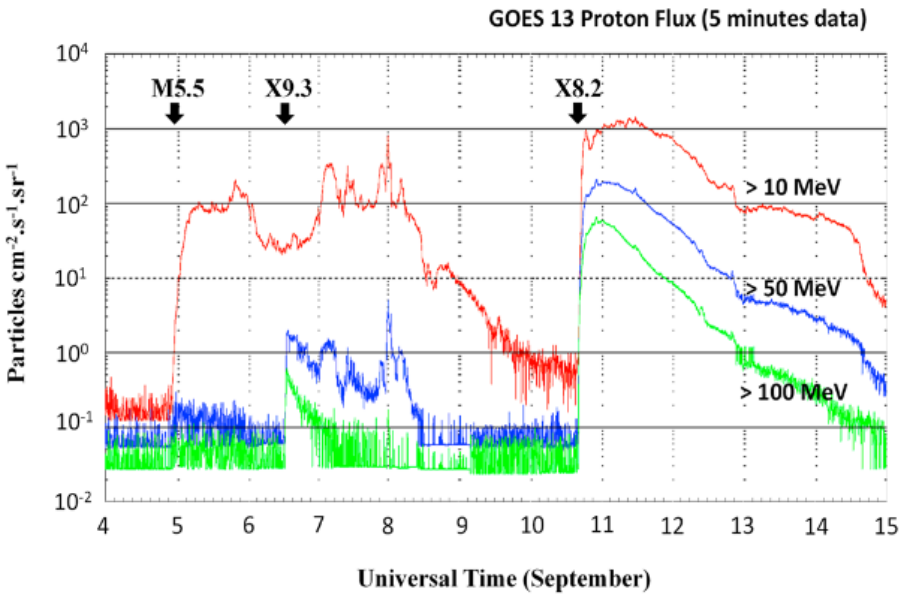
Hard spectrum

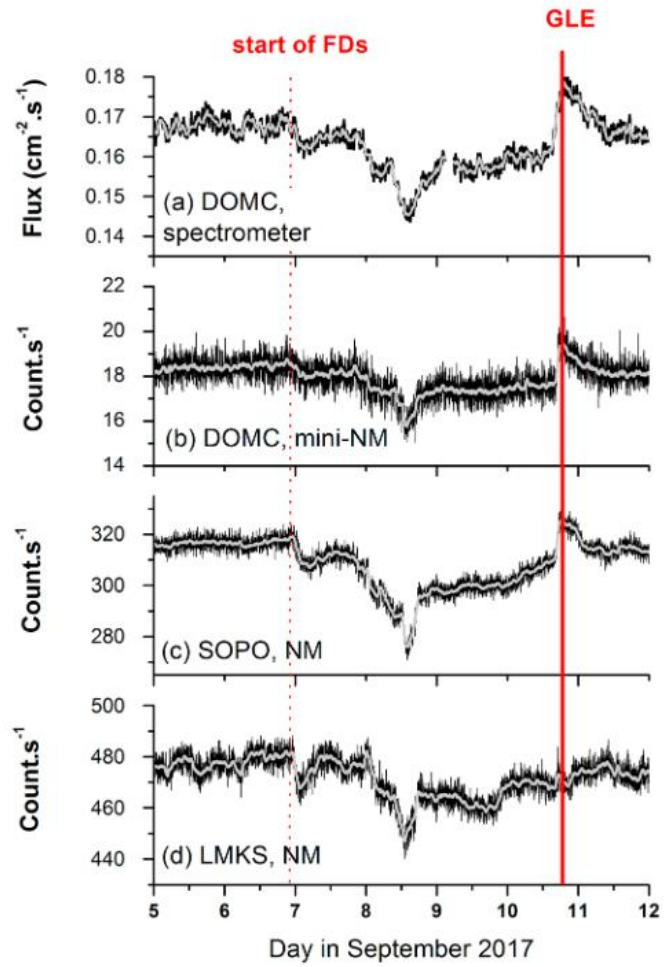


http://swe.ssa.esa.int/web/guest/anemos-federated

SEP events and Forbush Decrease (FD)

FD = Rapid decrease in observed neutron flux on the ground due to enhancement of magnetic fields related to ICMEs and their shock fronts that sweeps GCRs away from Earth.





(Hubert et al., 2017)

Trapped particles

→ Trapped by planetary magnetospheres in belts, including protons, electrons and heavier ions

Trapped particles – Van Allen belts

- Proton, electron fluxes modulated by both long term variations in solar activity and solar storm events
- Trapped electron fluxes seem to be higher during solar max declination phase
- Trapped proton fluxes in LEO reach maximum during solar minimum

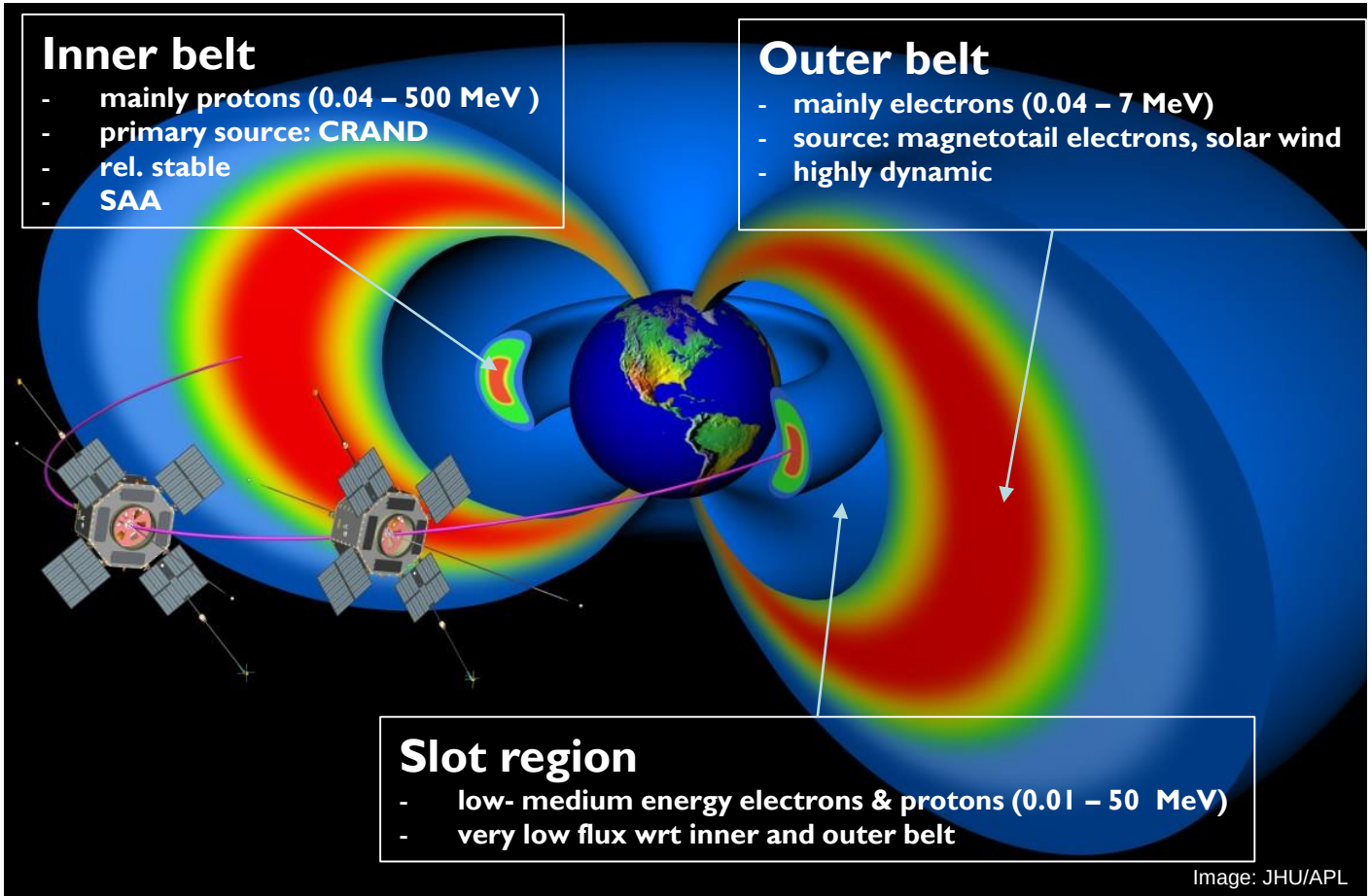
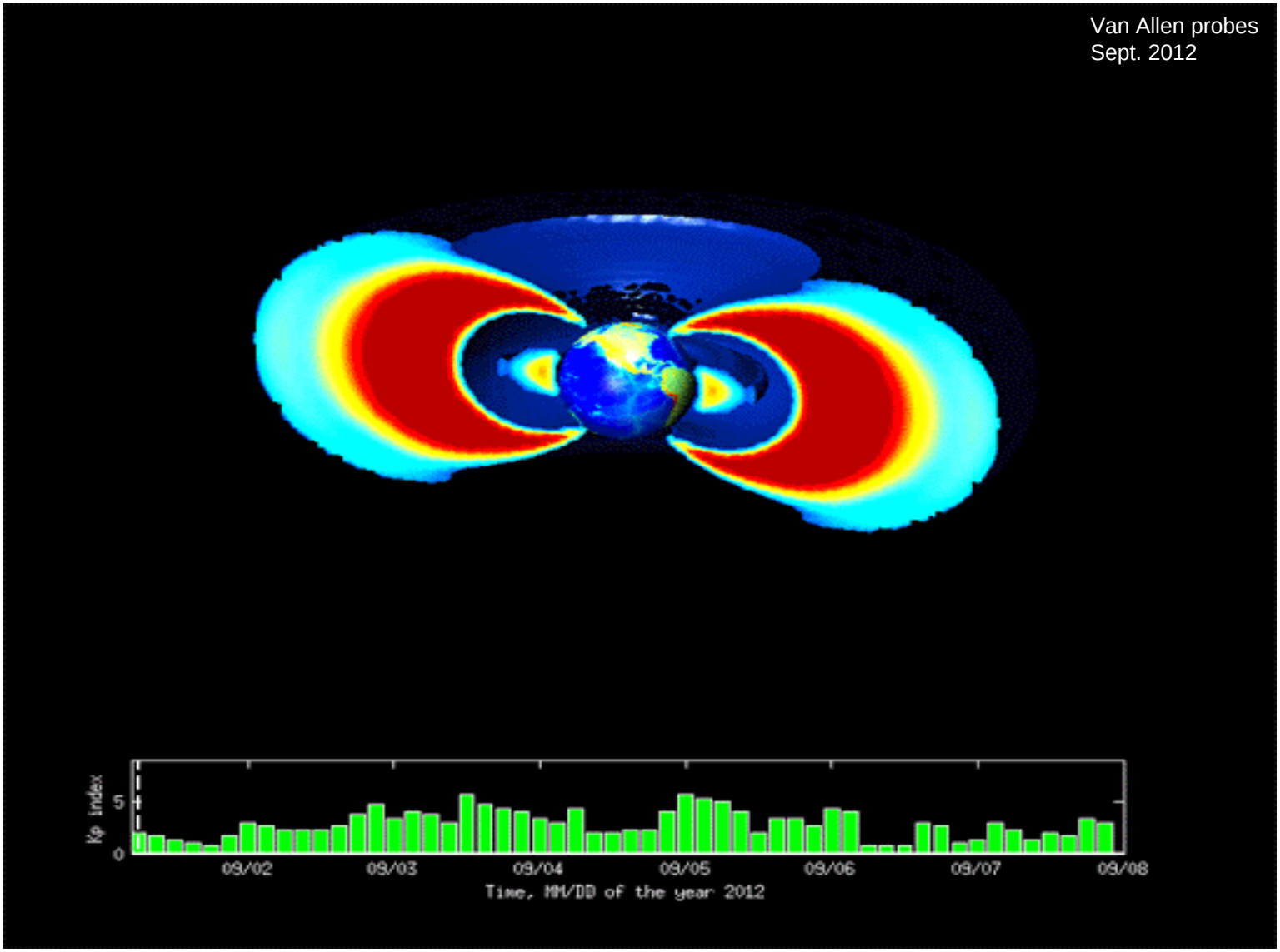


Image: JHU/APL

3rd belt during magnetic storm

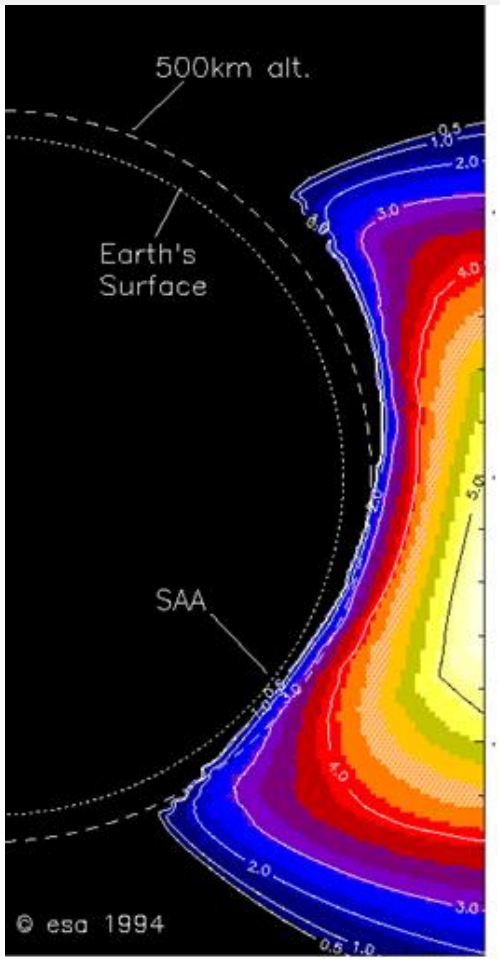


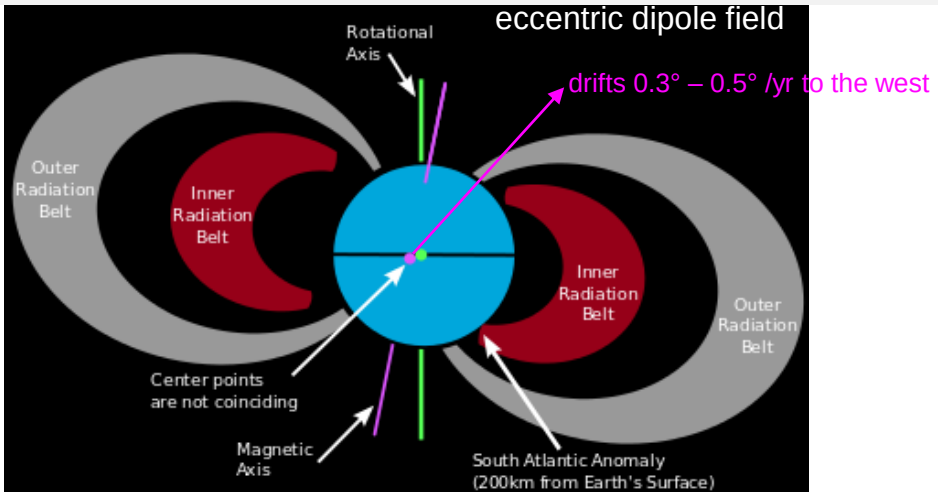
Inner belt – South Atlantic Anomaly (SAA)

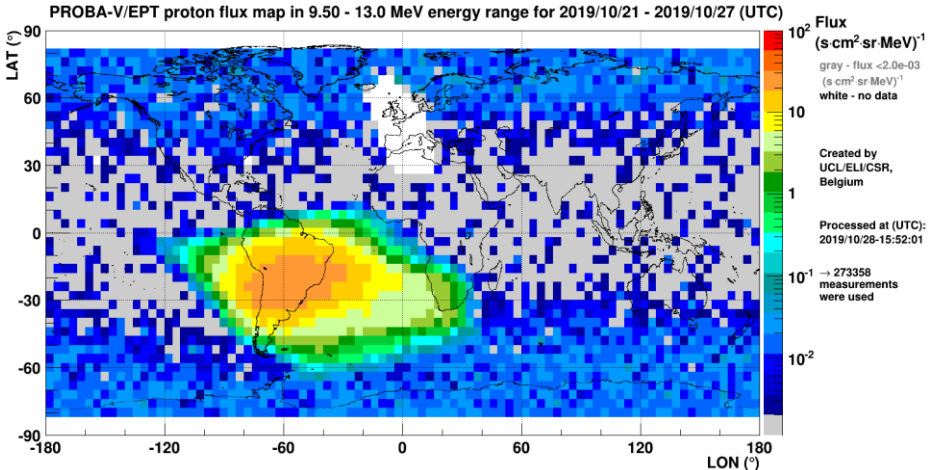
The South Atlantic Anomaly: area where inner Van Allen radiation belt comes closest to the surface to an altitude of 200 km. In this region the proton flux is increased:

→ the ISS (~407 km, 51.6°) requires extra shielding

→ the HST does not take observations while passing through the SAA





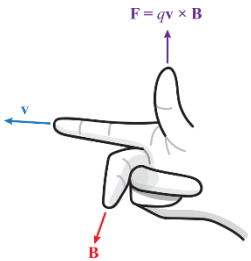


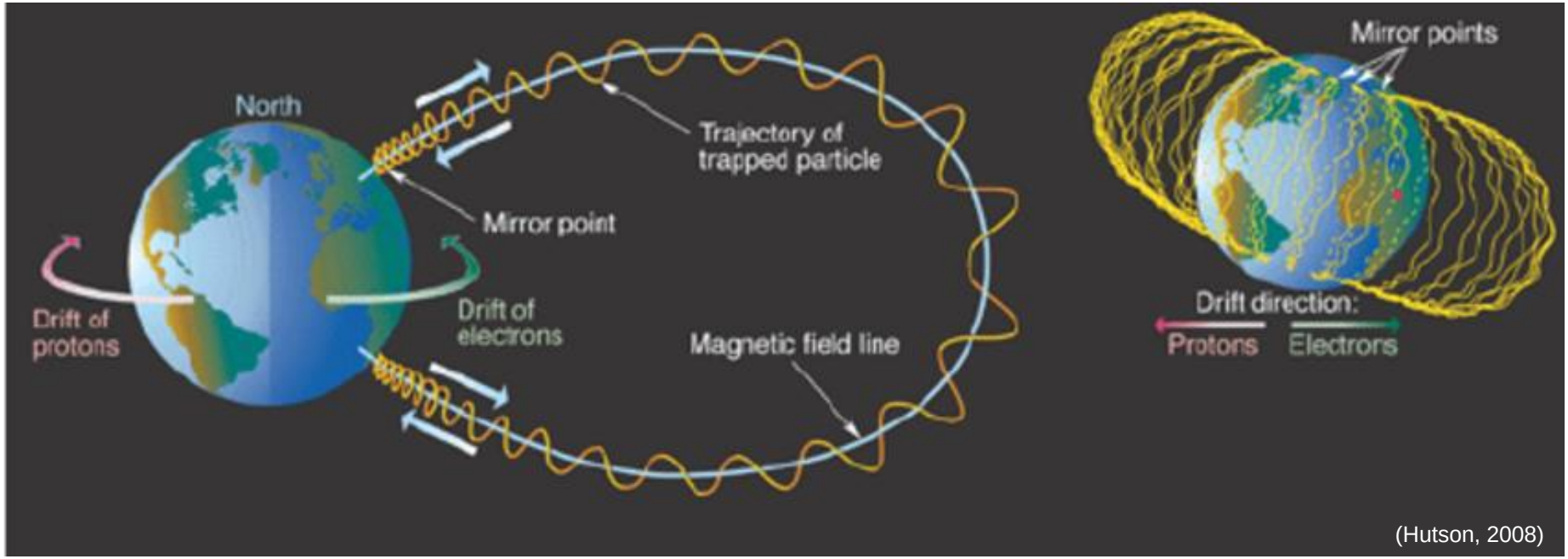
Trapped particle motion

Triple periodic motion of a charged particle in the radiation belts:

- spiral motion (gyration) around field line
- bounce motion between mirror points along the field line
- slow drift around the Earth between the field lines

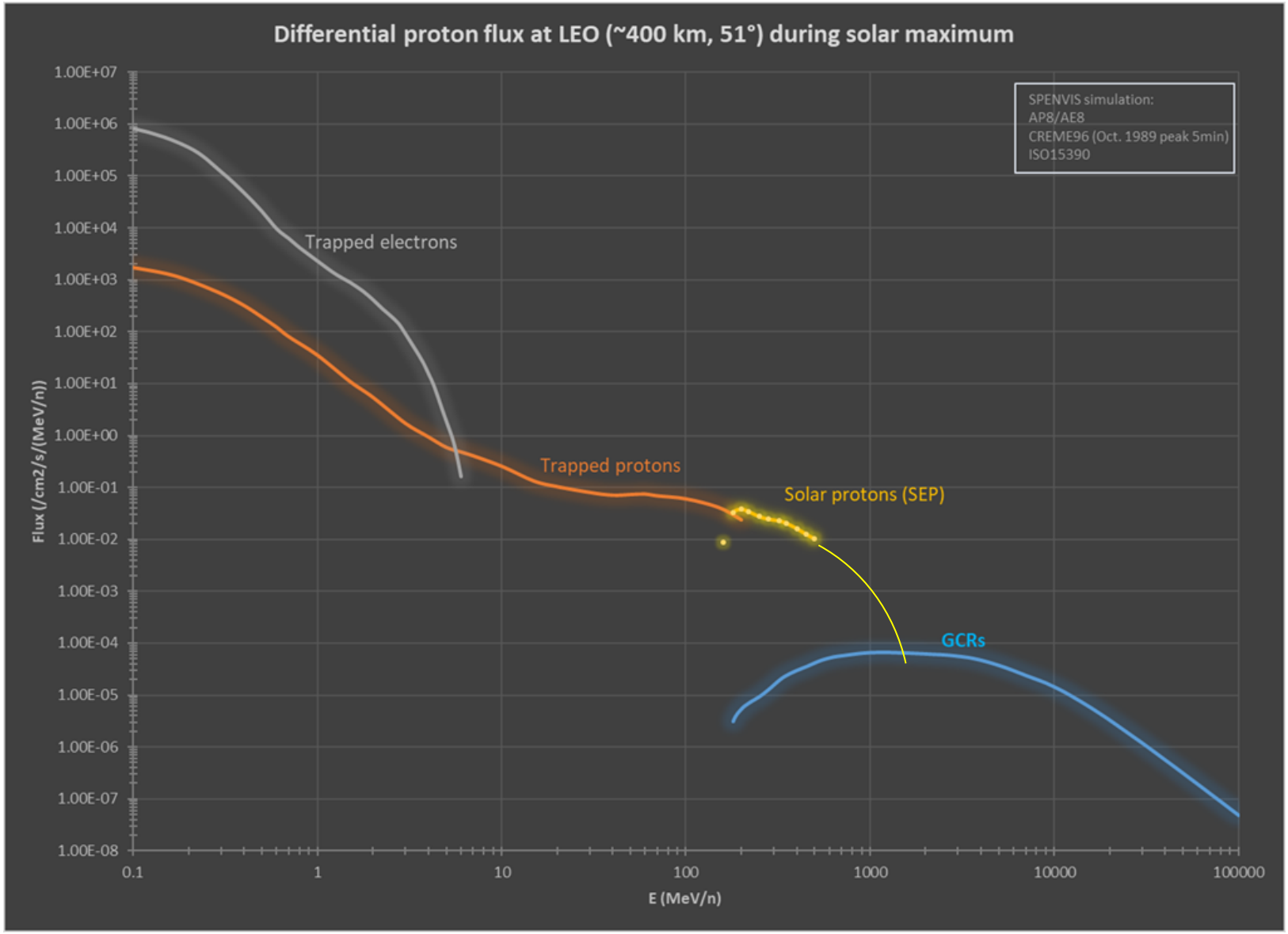
Lorenz force





(Hutson, 2008)

All together

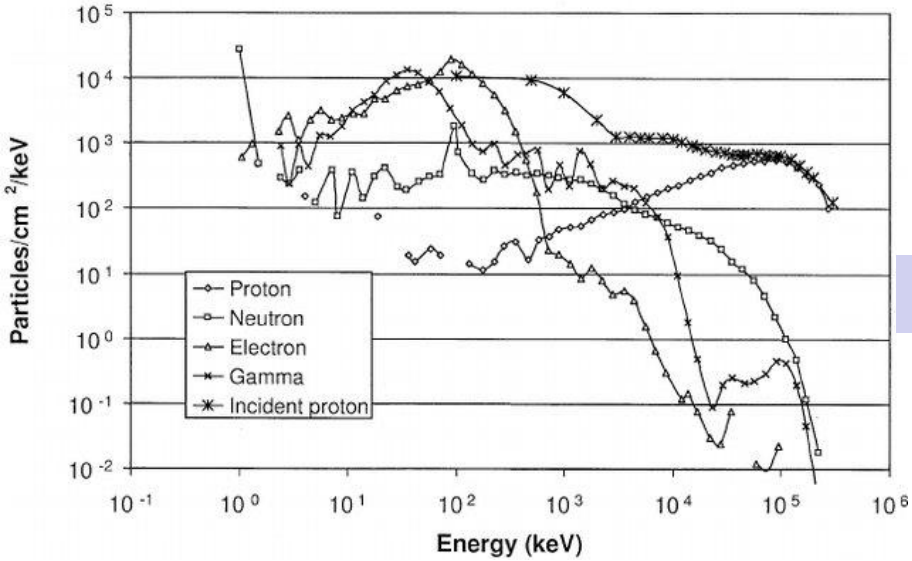


Secondary particles

→ GCR and SEP may interact with shielding material and with the atmosphere of planets producing showers of secondary particles (protons, electrons, neutrons, heavy ions, pions, muons and photons)

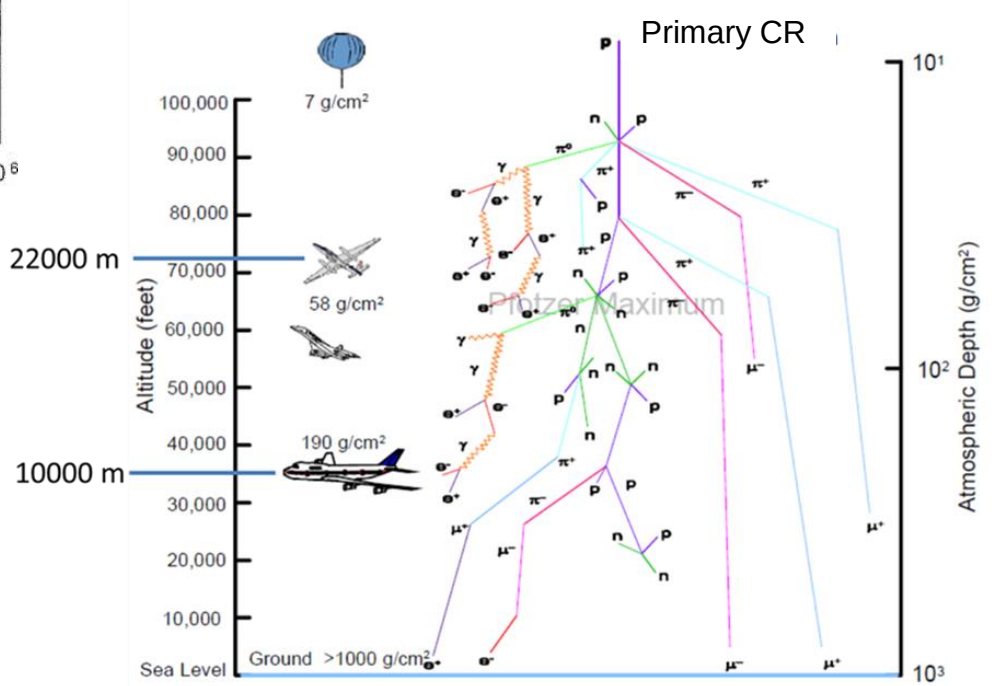
Secondary particles

Al shielding

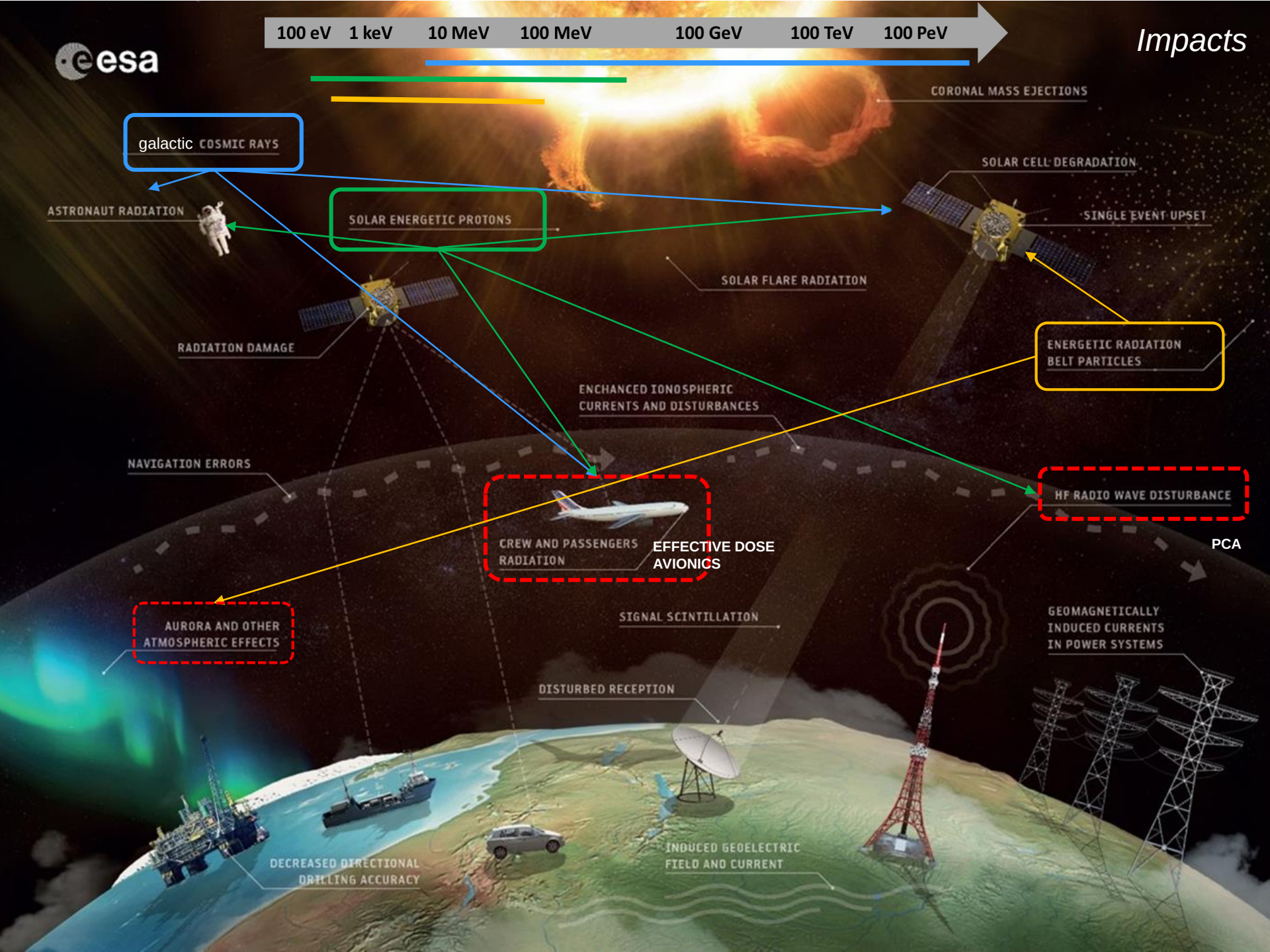


Secondary particle fluence energy spectra after 20-mm aluminum shield, calculated with SPENVIS for an incident trapped proton spectrum accumulated over one year.

Atmosphere



Impacts


100 eV
1 keV
10 MeV
100 MeV
100 GeV
100 TeV
100 PeV
esa
CORONAL MASS EJECTIONS
galactic COSMIC RAYS
SOLAR CELL DEGRADATION
ASTRONAUT RADIATION
SOLAR ENERGETIC PROTONS
SINGLE EVENT UPSET
SOLAR FLARE RADIATION
RADIATION DAMAGE
ENERGETIC RADIATION BELT PARTICLES
ENCHANCED IONOSPHERIC CURRENTS AND DISTURBANCES
NAVIGATION ERRORS
HF RADIO WAVE DISTURBANCE
CREW AND PASSENGERS RADIATION
EFFECTIVE DOSE
AVIONICS
PCA
AURORA AND OTHER ATMOSPHERIC EFFECTS
SIGNAL SCINTILLATION
GEOMAGNETICALLY INDUCED CURRENTS IN POWER SYSTEMS
DISTURBED RECEPTION
DECREASED DIRECTIONAL DRILLING ACCURACY
INDUCED GEOELECTRIC FIELD AND CURRENT

Further reading

esa space situational awareness

http://swe.ssa.esa.int/space-radiation

European Space Agency

ESA SSA SWE NEO SST

About SWE
- What is Space Weather
- SSA Space Weather Activities
- Current Space Weather
- Contact

Service Domains
- Spacecraft Design
- Spacecraft Operation
- Human Spaceflight
- Launch Operation
- Transionospheric Radio Link
- Space Surveillance and Tracking
- Power Systems Operation
- Airlines
- Resource Exploitation System Operation
- Pipeline Operation
- Auroral Tourism Sector
- General Data Service

Expert Service Centres
- ESC Solar Weather
- ESC Heliospheric Weather
- ESC Space Radiation
- ESC Ionospheric Weather
- ESC Geomagnetic Conditions

Other Resources
- Documents
- SWWT
- SWEN NewsLetter
- Upcoming Events

Sign-In
- You are not signed in.
- Sign In
- Request For Registration

Space Radiation Expert Service Centre (R-ESC)

ESC Objectives | Contributions | Contributors

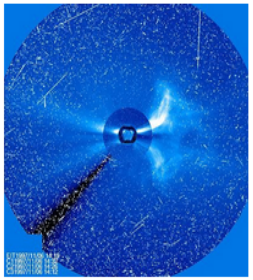
Mission Statement

The mission of the Space Radiation ESC (R-ESC) is to provide and develop the functionalities, capabilities and expertise in the domain of Space Radiation that are needed within the ESA SSA SWE network to achieve as a collaborative enterprise its mission of demonstrating and assessing the influences of Space Weather and informing and supporting end users through the provision of accurate, reliable and timely products and (pre-) operational services, tailored to their requirements. The Space Radiation ESC ensures that the monitoring, modelling and forecasting of space particle radiation (ambient plasma, solar energetic particles, radiation belts, galactic cosmic rays), micron-size particulates (from meteoroids and space debris), as well as all types of phenomena induced effects on technologies and biological systems, are fully covered in regard to the near-Earth space environment.

Space radiation refers to high-energy ionized particles of different origin present in space and affecting spacecraft, components and biological systems. It covers mainly the galactic cosmic ray (GCR) background, solar energetic particle (SEP) events and the Earth's trapped radiation belts. GCRs originate from outside the Solar System and are composed of high-energy protons, alpha particles and heavier nuclei. Their flux is constant and modulated by solar activity. GCRs are a threat to astronauts and spacecraft electronics on interplanetary missions. Life on Earth is protected from GCRs by the Earth's magnetic field and atmosphere. However, GCRs could be a health concern for aircraft crew flying regularly at high altitudes and latitudes.

SEPs consist primarily of protons and electrons accelerated by solar flares or interplanetary shock waves associated with Coronal Mass Ejections (CMEs). Their intensity and occurrence are difficult to predict. SEPs cause similar damage as GCRs. They are also a threat for astronauts during an extravehicular activity (EVA) and a source of solar panel degradation.

Trapped radiation belts surround planets with a substantial magnetic field, such as Earth or Jupiter. The radiation belts are composed mostly of protons and electrons. The dose deposition and non-ionizing energy loss caused by the radiation belt population interacting with spacecraft materials generate degradation in solar panels and other spacecraft components.



SOHO images altered by solar energetic particles (© SOHO - ESA & NASA)