Basics of Cosmic Rays

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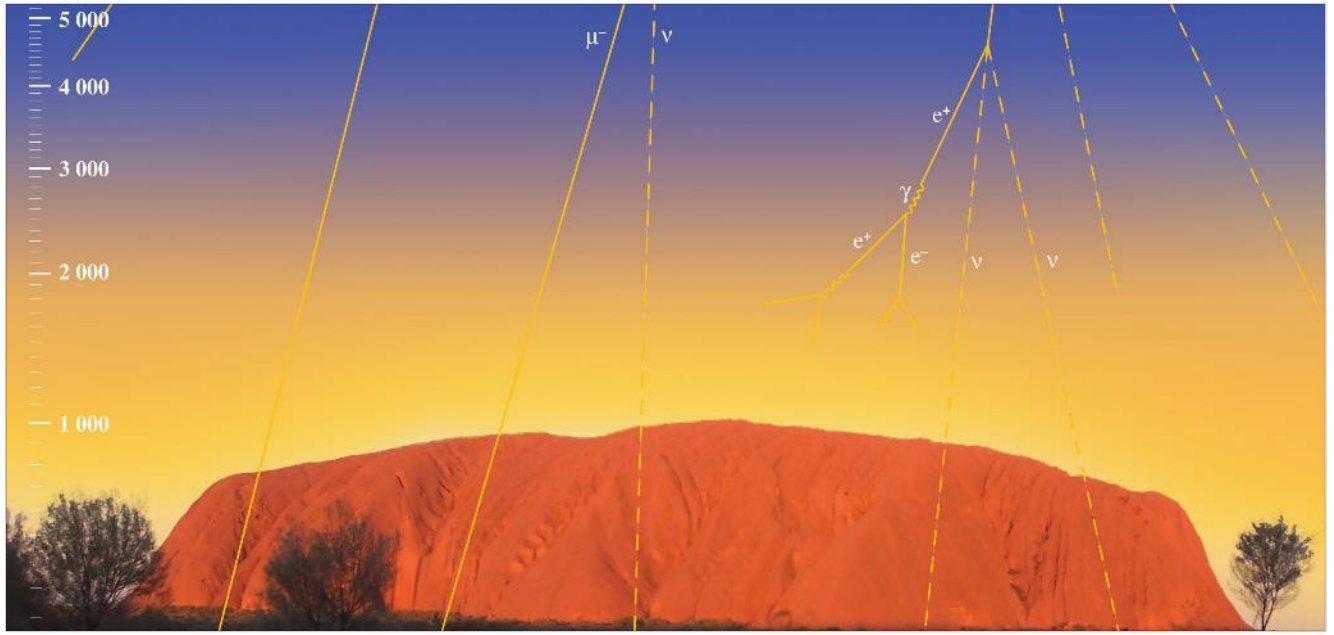
What are cosmic rays?

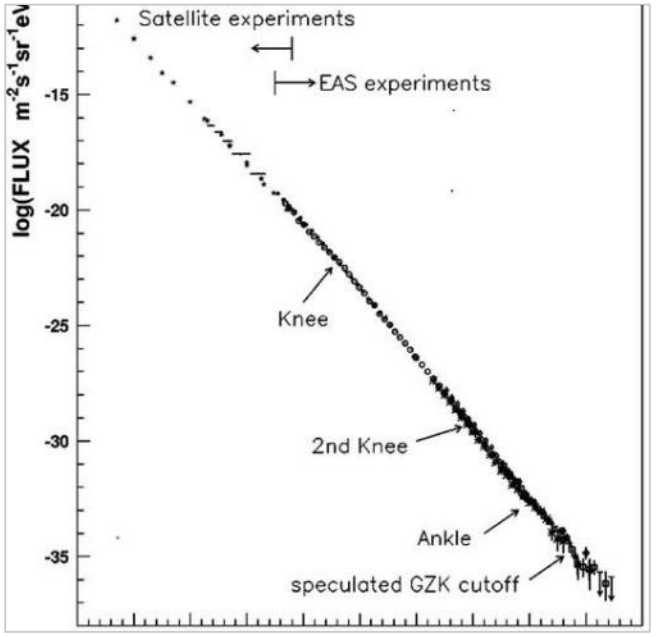


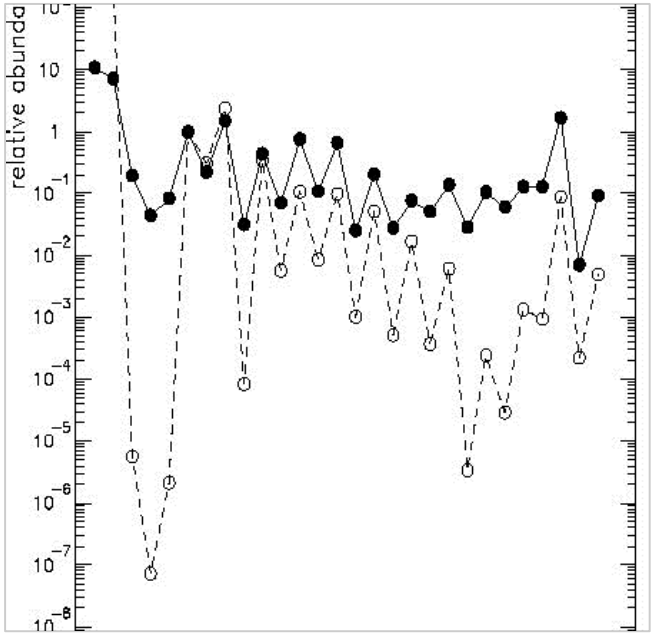
- Cosmic rays are highly energetic particles reaching the Earth from space.
- Cosmic rays come from the sun (solar energetic particles, SEP) and from outside the solar system (galactic and extra galactic cosmic rays). However the term “cosmic ray” is usually used for non-solar cosmic rays.
- Cosmic rays can be classified as
  - Primary cosmic rays – those coming from space
  - Secondary cosmic rays – those produced by the interactions of primary cosmic rays with atoms and molecules in the atmosphere.

Fundamental questions of (extra-solar) cosmic ray research

- What are the source regions of cosmic rays?
- How are cosmic rays accelerated?
- How do cosmic rays propagate in the galaxy?

Properties of cosmic rays





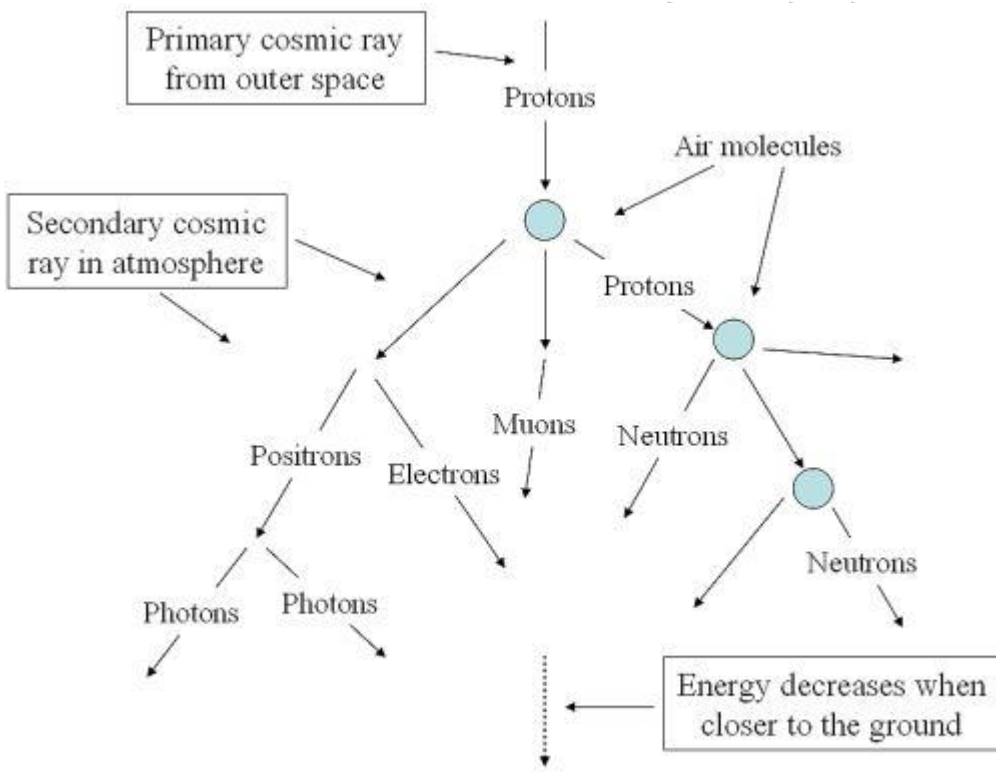
- Energy spectrum
- abundances
- lifetimes/confinement
- isotropy/anisotropy

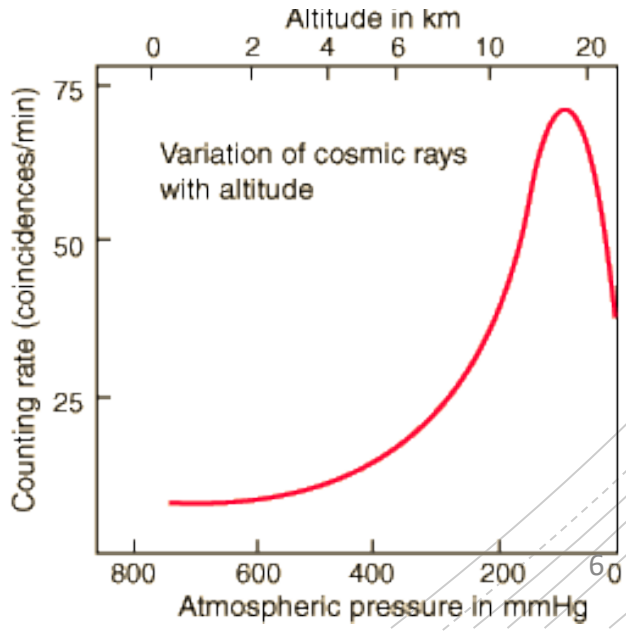
Primary Cosmic Rays

- ~90% protons – hydrogen nuclei
- ~ 9% alpha particles – particles composed of two protons and two neutrons, helium nuclei.
- ~1% electrons, positrons, antiprotons, HZE ions

Secondary Cosmic Rays (air showers)

- x-rays
- muons
- protons
- alpha particles
- charged mesons (pions, kaons)
- electrons
- positrons
- neutrons
- neutrinos





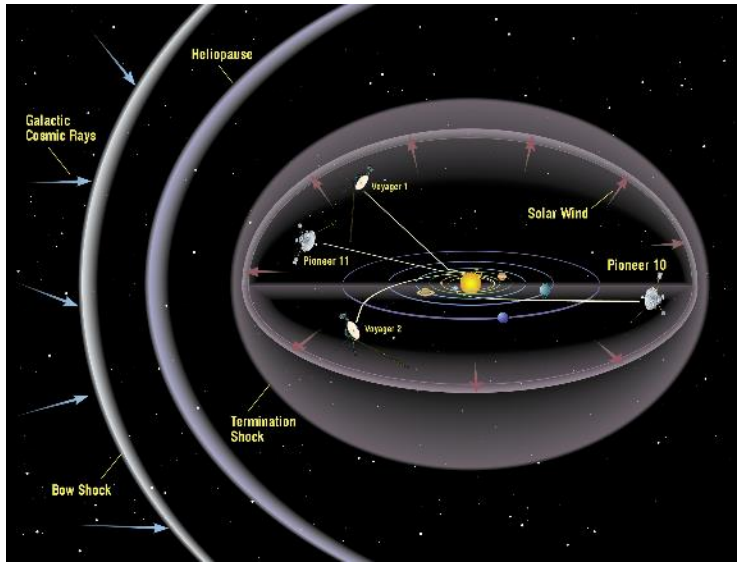
Some muon physics

- Muons are leptons with a mass of $105.7\ MeV/c^2$.
- Most naturally occurring muons are cosmic ray secondaries resulting from pion decay.
- Muons have a lifetime of $2.2\ \mu s$.
- The principal decay channels of muons are:

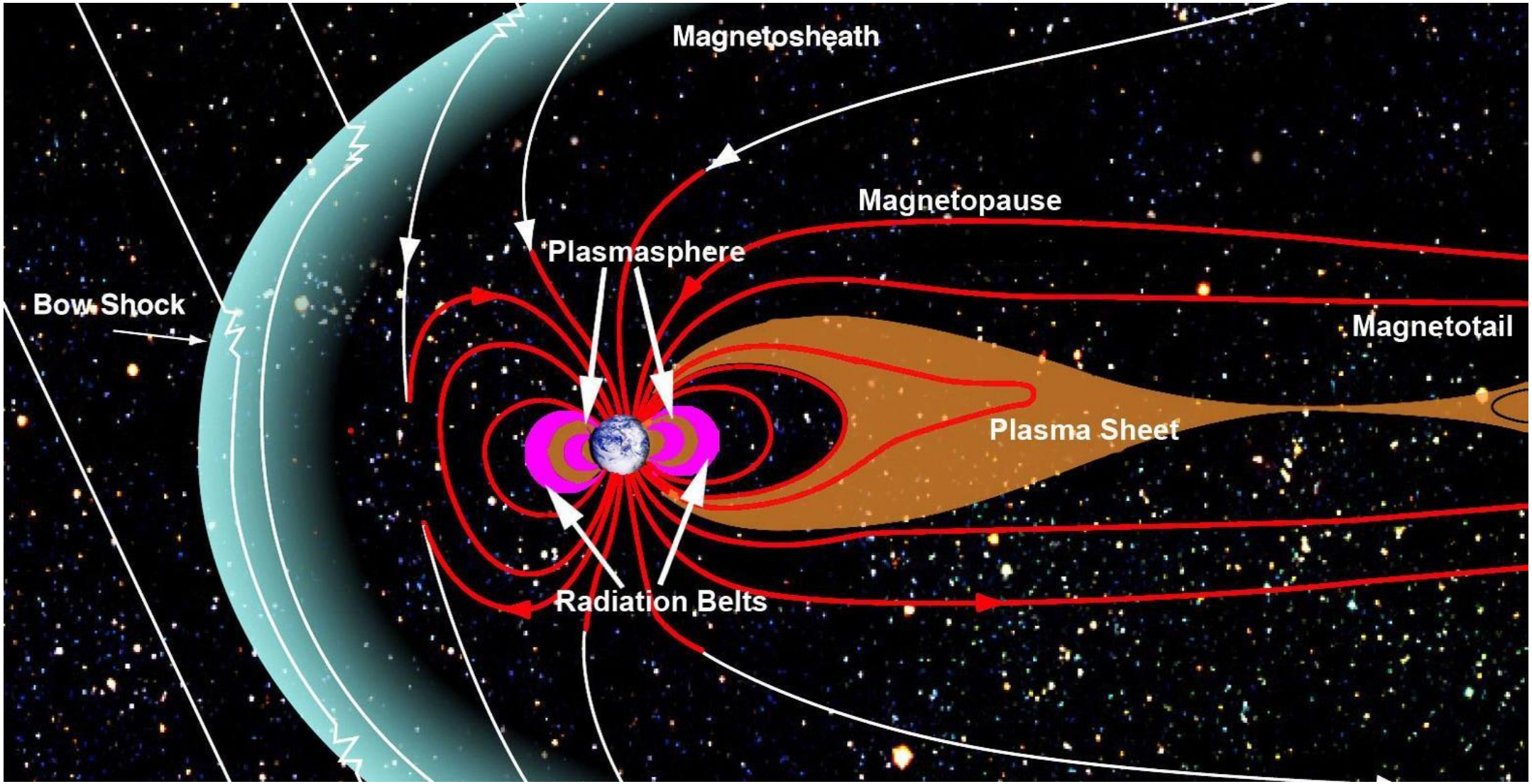
$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

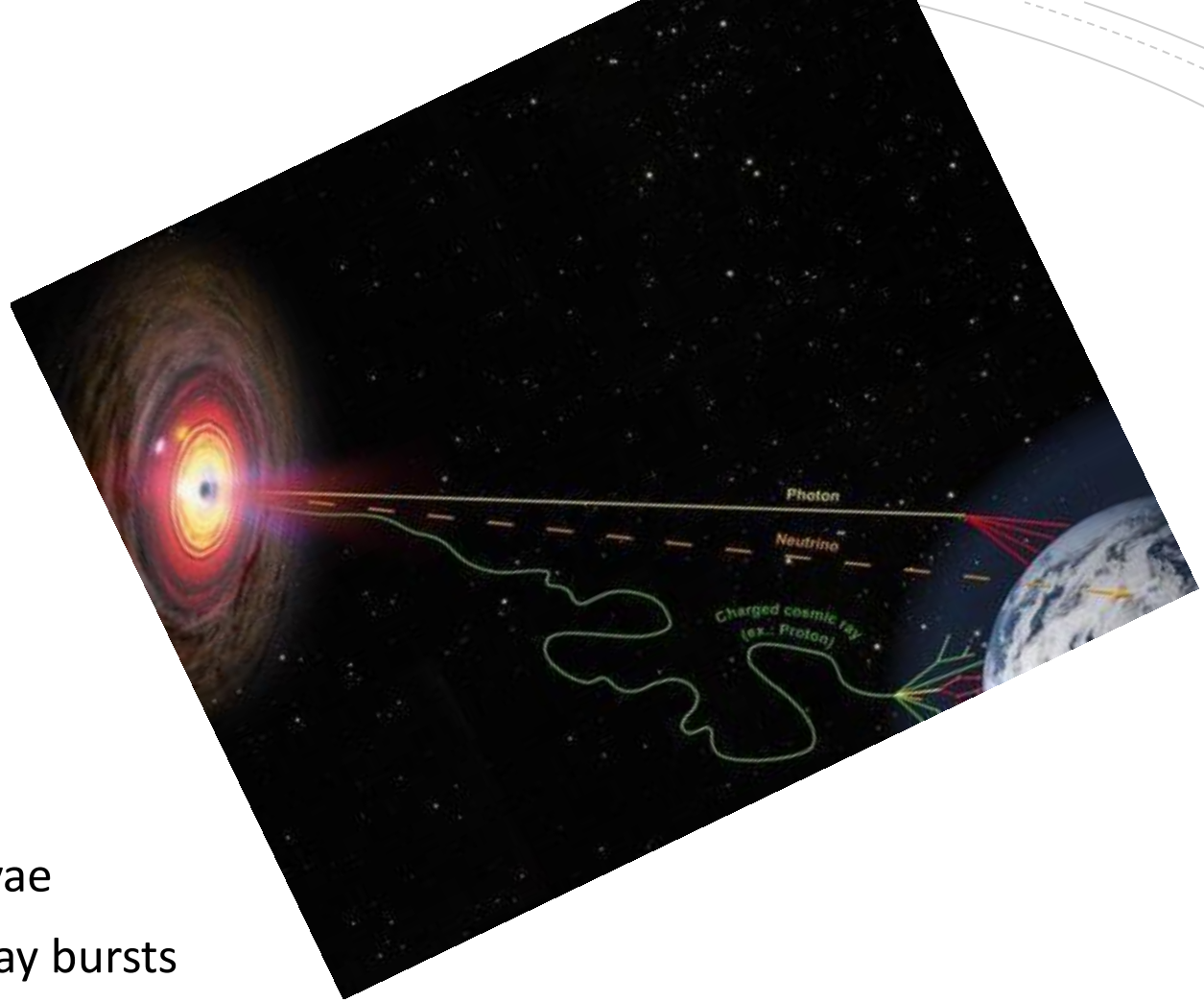
Cosmic Ray Flux



- The flux of incoming cosmic rays depends on the solar wind, the Earth's magnetic field and the energy of the cosmic rays.

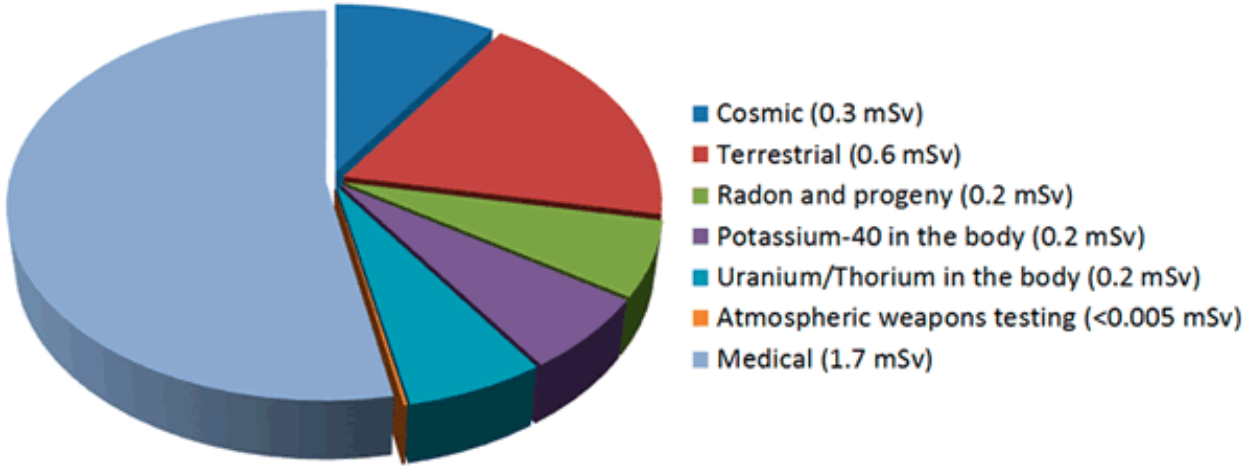

Magnetosheath
Magnetopause
Plasmasphere
Bow Shock
Magnetotail
Plasma Sheet
Radiation Belts

Potential Cosmic Ray Sources



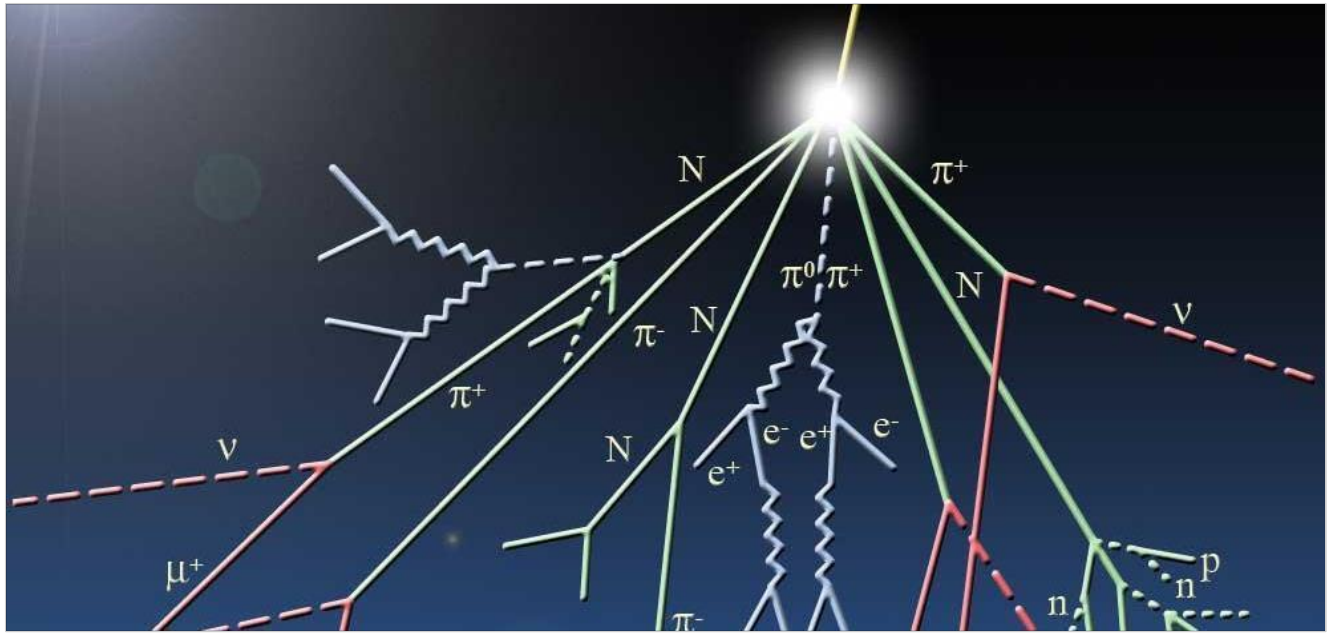
- supernovae
- gamma ray bursts
- active galactic nuclei
- quasars
- dark matter interactions?

Why should people care about cosmic rays?



- The study of cosmic rays has led to important contributions to atmospheric chemistry.
- They are a source of background radiation
- They are a health hazard for interplanetary space travel.
- They have enough energy to affect electronics.
- They may have a role in lightning.
- May play a role in climate change

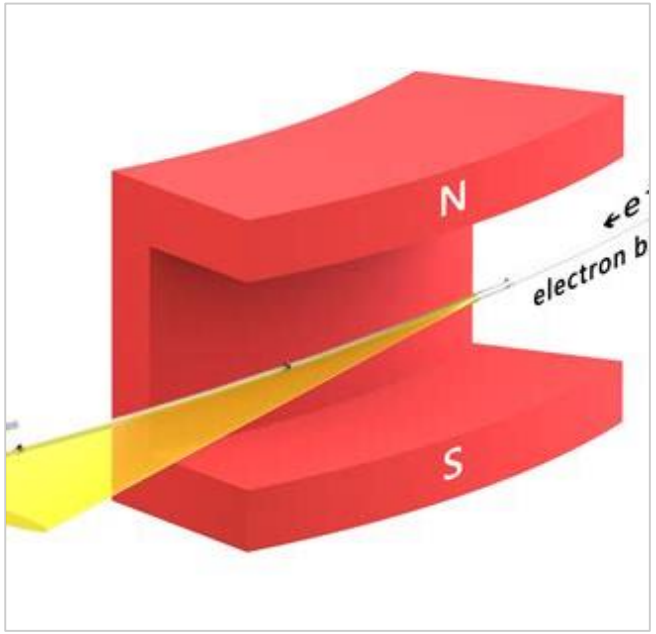
Why should particle physicists care about cosmic rays?



- The maximum energy of cosmic rays is of the order of $10^{20}\ eV$.
- Higher energy cosmic rays induce particle showers in the atmosphere.

- The problem is …
  - There is no experimental control
  - There are no cross-checks
  - Very energetic events are rare

How do we measure cosmic rays?



- synchrotron radiation
- gamma rays
- cloud chambers and bubble chambers
- magnetic spectrometers
- Cherenkov radiation
- scintillation detectors

The Oh-My-God particle

- This was the highest energy cosmic ray detected, by the HiRes detector on October 15, 1991.
- Its energy was estimated as $(3.2 \pm 0.9) \times 10^{20} eV$.
- If it was a proton, it travelled at 99.99999999999999999951% the speed of light.
- Since the first observation, at least 72 similar events have been recorded.

Thanks for listening!