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Particles and the Cosmos – 2020/21

Werkcollege 11 – Cosmic ray propagation

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Problem 20 Spectra of cosmic-ray nuclei

The energy spectra of cosmic rays observed above the atmosphere are usually described by power laws

$$\frac{dN}{dE} \propto E^{\gamma}$$

at high energies (where solar modulation can be neglected). Compare the energy spectra for Carbon and Boron nuclei.

a. Which one is steeper at high energies?

b. Why?

c. What is the conceptual difference between elements like carbon and elements like boron?

Problem 21 Energy spectra of electrons

The energy spectrum of electrons in cosmic rays can be described by a power law with a spectral index of $\gamma \approx -3.3$.

a. Why is the energy spectrum of electrons steeper as compared to nuclei (typical values $\gamma \approx -2.7$)?

b. Enumerate the processes which occur during the propagation of electrons through the Galaxy.

c. Calculate the synchrotron energy losses for an electron with an energy of 100 GeV in the Galaxy and compare it to the losses by protons. Consider a Galactic magnetic field strength of $B = 3\ \mu$G. Calculate the power radiated as synchrotron radiation for both particle species and give the result in [eV/s].

Hint: the radiated power for a particle with charge e and energy E, moving on a circular trajectory with radius r, amounts to

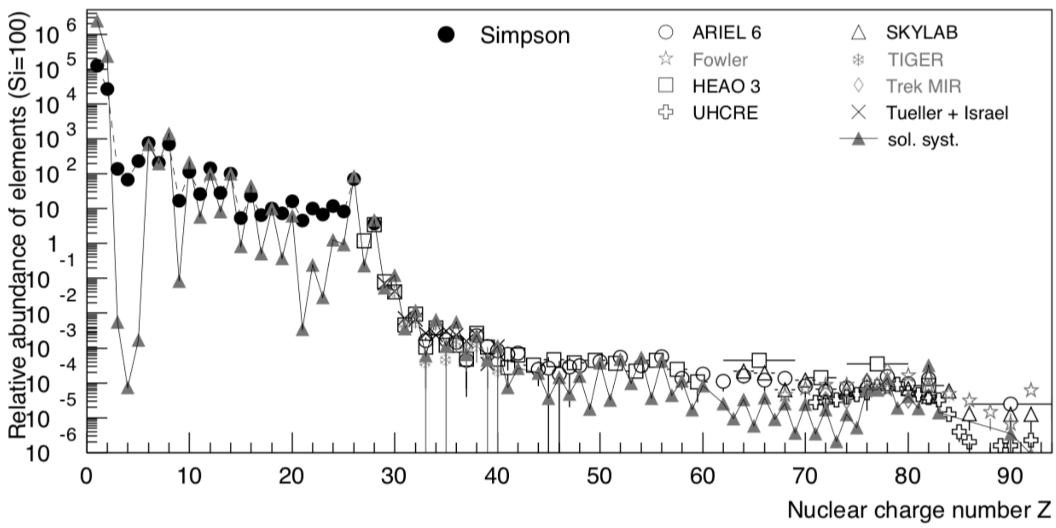
$$P(E,r) = \frac{e^2\ c}{6\pi\epsilon_0 r^2}\left(\frac{E}{m_o\ c^2}\right)^4 \quad .$$

The permittivity of vacuum is given as $\epsilon_0 = 8.85 \cdot 10^{-12}$ A s/V m.

Estimate the time needed until the electrons and protons have radiated their complete energy through synchrotron radiation.

Problem 22 Abundance of elements

The figure shows the abundance of elements in cosmic rays compared to the typical abundance in the solar system.



taken from J.R. Hörandel, Advances in Space Research 41 (2008) 442

Explain the main features of this diagram:

a. p and He are less abundant - why?

b. up and down of elements with even and odd charge numbers

c. why are Li, Be, B more abundant in cosmic rays?

d. why are the sub-iron elements more abundant in cosmic rays?

problem 23 Muons in the atmosphere

In the lecture we discussed the production of pions in the atmosphere. The number of pions in the atmosphere reaches a maximum at an atmospheric depth around 100 to 200 g/cm^2. Some of these pions decay into muons, i.e. the muons are produced at large heights in the atmosphere. The lifetime of a muon is $\tau = 2.2\ \mu$s.

a. How far can a muon travel before it decays?

b. Why do muons travel down to sea level in the atmosphere?

c. Calculate the decay length of a muon with an energy of 10 GeV

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Lecture web site: http://particle.astro.ru.nl/goto.html?partcos2021