Radboud Universiteit Nijmegen
Afdeling Sterrenkunde
Jörg R. Hörandel

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Problem 27 Sources of extragalactic cosmic rays

Estimate the number of sources (AGN) which are required to sustain the observed flux of extragalactic cosmic rays.

The energy density of extragalactic cosmic rays amounts to about $\rho_E = 3.7 \cdot 10^{-7}$ eV/cm^3. Calculate the total cosmic-ray power in a sphere with a radius of $r = 75$ Mpc. This is the volume visible by the Pierre Auger Observatory at the highest energies (GZK radius). The typical power in the jets of AGN is of the order of 10^{44} to 10^{46} erg/s. Assume about 10% of this power is converted into cosmic rays. Use the Hubble time (10^{10} a) as upper limit for the residence time of the cosmic rays in the volume.

Use these quantities to estimate the number of AGNs required to produce the observed cosmic-ray power.

Problem 28 GZK Cutoff

High-energy cosmic rays (protons) interact with the photons of the 3 K microwave background if the protons exceed a minimum energy E_{GZK}. High-energy pions are produced via the interactions

$$p + \gamma_{3K} \rightarrow \Delta^+ \rightarrow p + \pi^0$$

or

$$p + \gamma_{3K} \rightarrow \Delta^+ \rightarrow n + \pi^+.$$

These interactions take place if the energy of the 3 K photons exceeds $m_\Delta\ c^2 = 1232$ MeV in the rest frame system of the protons.

Calculate the threshold energy E_{GZK}.

The energy of the photons is given as $\epsilon_\gamma \approx 2.5$ meV.

This effect has been recognized 1965 by the physicists Greisen, Zatsepin and Kuz'min. Hence, the name GZK effect.

The density of the 3 K photons is $n_\gamma = 411$ photons/cm^3, the cross section for the above mentioned interactions is $\sigma_{p\gamma} = 300\ \mu$b (1 b=$10^{-24}$cm^2).

Calculate the mean free path of the protons and use the unit [Mpc].

Student assistant: Johannes Schulz j.schulz@astro.ru.nl
Lecture web site: http://particle.astro.ru.nl/goto.html?astropart1314