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# Astroparticle Physics – 2016/17

## Werkcollege 13 – 08.12.2016

**Problem 48** Energy spectra of TeV gamma rays

Assume hadronic particles (protons and nuclei) are accelerated in a supernova remnant. The remnant is visible in TeV gamma rays through gammas from neutral pion decay.

The energy spectrum of the observed gamma rays has the shape

$$\frac{dN}{dE_\gamma} \propto E_\gamma^\beta \text{ with } \beta = -2.1.$$

What is the shape of the energy spectrum of the corresponding hadronic (mother) particles?

Hint: assume in hadronic interactions 1/3 of the energy is transferred to neutral pions. The latter decay into two photons $\pi^0 \to \gamma\gamma$.

Gamma rays up to energies of 100 TeV have been observed. Estimate the maximum energy of hadrons accelerated in this source.

**Problem 49** Mean free path of solar neutrinos

The cross section for neutrinos with energy $E_{cm}$ (center of mass system) for inelastic interactions with nucleons is given as

$$\sigma_{\nu-n} = 5 \cdot 10^{-44} \left(\frac{E_{cm}}{1 \text{ MeV}}\right)^2 \text{ cm}^2.$$

Calculate the mean free path $\lambda = 1/(\sigma_{\nu-n} n)$, with the number density $n$ for neutrino capture of neutrinos with a lab energy of 1 MeV in the center of the Sun (typical density $\langle\rho\rangle \approx 100$ g/cm$^3$). Compare the result to the radius of the Sun.

**Problem 50** Cosmogenic neutrinos

Neutrinos produced through the interactions of ultra-high-energy cosmic rays (UHECRs) with photons from the cosmic microwave background radiation (CMB) are called "Cosmogenic neutrinos". Due to their low flux and very small interaction cross-section, their detection requires huge detectors with very efficient background suppression.

IceCube is a 1 km$^3$ neutrino detector located at the geographic South Pole and consists of several light detectors buried into the polar ice. The 3.5-km-thick ice layer works both as target material and as shielding against background. When a neutrino interacts in the sensitive region, a cascade of secondary particles is generated and Cherenkov light is then produced. By collecting the Cherenkov photons the properties of the interacting neutrino (energy, flavor, direction) are inferred. On the ice surface, an array of frozen water Cherenkov detectors (called IceTop) have been installed for providing additional background suppression by working as a *veto*. Moreover, IceTop is also able to carry on study of cosmic rays for energies up to $10^{18}$ eV.

**a)** Under the assumption Cosmogenic neutrinos are produced by pion decays following the GZK interaction (see Problem 39)

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

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

compute the typical energy of Cosmogenic neutrinos.

Hint: assume $E_p = 6.4 \cdot 10^{19}$, $E_{\pi^+}$ equal to 15% of $E_p$, and that the neutrino is emitted in the same direction of the pion. Remember that the pion mass is equal to 139.6 MeV/c$^2$ and the muon mass is 105.7 MeV/c$^2$ .

**b)** By assuming the cosmogenic neutrino flux equal to $F_\nu = 3 \cdot 10^{-17}$ cm$^{-2}$ sr$^{-1}$ s$^{-1}$ and the IceCube detector being isotropically sensitive, compute the rate of Cosmogenic neutrinos detected per year by IceCube.

Hint: assume the ice density being equal to $\rho = 1$ g cm$^{-3}$ and use the following nucleon-neutrino cross-section

$$\sigma_{\nu-n} = 7.84 \cdot 10^{-36} \left(\frac{E_\nu}{\text{GeV}}\right)^{0.363}$$

which is valid for $E_\nu > 10^{16}$ eV .

The solutions will be discussed during the werkcollege on 08.12.2016 in HG02.702.
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Lecture web site: http://particle.astro.ru.nl/goto.html?astropart1617