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Afdeling Sterrenkunde
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Astroparticle Physics – 2014/15

Werkcollege 12 – 14.01.2015

Problem 34 Energy production of the Sun

The energy in the Sun is produced through nuclear fusion. The fusion processes can be effectively described as $4p + 2e^- \rightarrow^4 \mathrm{He} + 2\nu_e$. During these processes 26.7 eV energy are released, which are converted almost completely into radiation.

Calculate the total power of the Sun from the radiation received at Earth $L = 1.4\ \mathrm{kW/m^2}$. Use the units W and MeV/s. The distance Earth-Sun amounts to $r = 1.5 \cdot 10^8$ km.

How many fusion processes (as described above) happen per second? How much matter (in kg/s) is converted to energy?

Calculate the neutrino flux (ν_e) at Earth. Neutrinos are neutral particles which can escape from the interior of the Sun. They are radiated off isotropically.

Problem 35 Mean free path of neutrinos

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

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

Calculate the mean free path $l = 1/(\sigma_{\nu-n} n)$, with the number density n for

a) neutrino capture of neutrinos with a lab energy of 1 MeV in the center of the Sun (typical density $\langle\rho\rangle \approx 100\ \mathrm{g/cm^3}$). Compare the result to the radius of the Sun.

b) neutrinos with a lab energy of 10^{15} and 10^{18} eV, respectively in rock (density $\langle\rho\rangle \approx 2.5\ \mathrm{g/cm^3}$, mass number $\langle A\rangle = 22$). Give the result in km.

see reverse side!

Problem 36 SN 1987 A

Neutrinos from supernova SN 1987 A were observed with the Kamiokande detector. The following neutrinos were observed:

event no	t_{obs}	neutrino energy (MeV)
1	0	21.3
2	0.107	14.8
3	0.303	8.9
4	0.324	10.6
5	0.507	14.4
6	1.541	36.9
7	1.728	22.4
8	1.915	21.2

The observation times are given relative to the detection of the first neutrino.

The distance of the supernova is 52 kpc. Calculate the travel time t_0 at the speed of light.

Show that a neutrino with mass m and energy E will take a total time of

$$t_{obs} - t_{em} = t_0 \left(1 + \frac{m^2}{2E^2}\right)$$

to reach the Earth.

According to astrophysical models the neutrinos were emitted within an interval of 2 s. Derive an upper limit for the neutrino mass from the data listed in the table. Assume all neutrinos have the same mass.

(This problem is based on W.D. Arnett and J.L. Rosner Phys. Rev. Lett. 18 (1987) 1906. This method provided at the time of publication one of the best upper limits for the neutrino mass.)

The solutions will be discussed during the tutorial on 14.01.2015 at 8:30 in HG01.054.
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Lecture web site: http://particle.astro.ru.nl/goto.html?astropart1415