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Astroparticle Physics (Physics 711)
Exercise 10

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Problem 1: Inflation (5P)

It seems reasonable that the present features of the universe were determined by initial conditions at some epoch $t = t_i$ when the temperature was very high, say $T \cong 10^{15}$ GeV (the GUT-scale) at around $t \cong 10^{-34}$ s. Estimate the proper distance d_H ('hubble horizon distance') a light signal could have travelled during the time interval [0,t] assuming the universe was radiation dominated. Physical processes could have made the universe homogenous over a sphere of radius d_H at the initial epoch $t = t_i$ (note: a sphere of radius d_H gives an upper limit for homogeneity). If this sphere could expand to encompass the observed universe, then we would have a simple explanation for the observed homogeneity of the universe.

To show that this is not possible in conventional scenarios (without inflation) in which the universe is either radiation or matter dominated do the following calculations:

How large was $d_\mathrm{H}(t_i \cong 10^{-34})$? To what size would it have expanded until today? Compare this to the size of the visible Universe today (i.e. roughly given by the Hubble radius c/H_0) and discuss your results.

Problem 2: Neutrino Scattering Experiments (5P)

a) Calculate the expected flux (Units: $\mathrm{cm}^{-2}\mathrm{s}^{-1}$) of neutrinos from the sun from the pp-cycle

$$4\mathrm{p} + 2\mathrm{e}^- \rightarrow^4 \mathrm{He} + 2\nu_\mathrm{e} + 26.73\ \mathrm{MeV} \quad . \tag{1}$$

The total luminosity of the sun is $L = 3.92 \cdot 10^{26}$ Watts $= 2.4 \cdot 10^{39}$ MeV/s.

b) Calculate the minimum necessary mass of water M that a neutrino detector must have in order to detect about one solar neutrino per day. Use the following assumptions: the detection threshold $E_\nu 10$ MeV reduces the observable flux by 10^4, the cross-section $\sigma_{\nu e}$ is about 10% of the total cross-section and no neutrino oscillations occur. Start by determining the number of target electrons in a detector with a mass of water of M.