HW 2, #2

How far away could a supernova be, yet still appear as a neutrino source for Ice Cube?

a) Sukhbold et al., ApJ 821, 38 (2016) show total energy emitted by SNe in neutrinos as

$$E_{\nu, tot} \approx 3 \times 10^{53} \text{ erg}$$

b) If all that energy is in the form of 10 MeV neutrinos, then

$$N_\nu = \frac{E_{\nu, tot}}{10 \text{ MeV}}$$

$$= \frac{3 \times 10^{53} \text{ erg} * \frac{1 \text{ eV}}{1.6 \times 10^{-12} \text{ erg}}}{10^7 \text{ eV}}$$

$$= 1.9 \times 10^{58} \text{ neutrinos}$$

c) How many electrons in Ice Cube? Assuming it is pure water ice, note that in H_2O, the mass is mostly neutrons and protons

$$2H = 2p^+$$
$$1O = 8p^+ + 8n$$
$$\overline{\quad 10p^+ + 8n \quad} \text{ per molecule}$$

So the number of protons is $\frac{10}{18}$ of the total number of nucleons, and the mass of all the protons will be $\frac{10}{18}$ of the total mass of all the ice. So first, we compute the number of protons in all the ice.

p2

$$\text{Mass of ice} = (1000\text{ m})^3 \cdot (970\text{ kg/m}^3)$$

$$= 9.7\times 10^{11}\text{ kg}$$

$$\#\text{ protons} = \left(\frac{\text{Mass of ice}}{\text{Mass of proton}}\right) * \frac{10}{18}$$

$$= 3.2\times 10^{38}\text{ protons}$$

And

$$\#\text{ electrons} = \#\text{ protons} = 3.2\times 10^{38}\text{ electrons}$$

d) Total cross section for $e^- - \nu$ collisions is

$$\text{area } A = (\#\text{ electrons})(\text{cross-section})$$

$$= (3.2\times 10^{38})(9\times 10^{-48}\text{ m}^2)$$

$$= 2.9\times 10^{-9}\text{ m}^2$$

e) The number of interactions with a pulse of neutrinos will be

$$N = (\text{flux of neutrinos}) * (\text{total cross section})$$

$$= \left(\frac{N_\nu}{4\pi d^2}\right)\cdot A$$

where "d" is the distance to the explosion. →

p3

Rearrange to solve for the distance.

$$d = \sqrt{\frac{N_\nu \cdot A}{4\pi \cdot N}}$$

$$= \sqrt{\frac{(1.9 \times 10^{58})(2.9 \times 10^{-9}\, m^2)}{4\pi \cdot 10}}$$

$$= 6.6 \times 10^{23}\ m * \frac{1\ pc}{3.08 \times 10^{16}\ m}$$

$$\cong 2.1 \times 10^{7}\ pc \approx 21\ Mpc$$

This is roughly the same as the distance to the Virgo Cluster, so <u>maybe</u> we could a supernova in that cluster.