Propagation of High Energy Neutrinos in a weakly magnetized environment

Sarira Sahu

ICN, UNAM, Mexico City

with W.-Y.P. Hwang, EPJ-C 08

The coherent forward scattering of low energy neutrinos in a medium give the matter potential

$$V_{\nu_e} = \sqrt{2} G_F \left(N_e - N_{\bar{e}} \right) \quad for \quad q^2 \ll M_W^2$$

This is derived by considering the contact interaction and assuming the momentum transfer smaller than the vector boson mass. For $q^2 \sim M_W^2$ this is no more valid. In this case the energy limit is

$$\nu_e + e^+ \rightarrow W^+ \qquad \bar{\nu}_e + e^- \rightarrow W^-$$

$$E_\nu \simeq M_W^2 / 2 m_e \simeq 10^7 \, GeV$$

$$W_{\mu\nu}(q) = \frac{-g_{\mu\nu}}{\left(q^2 - M_W^2 + i \Gamma_W M_W\right)}$$

Take into account threshold effect

$$W_{\mu\nu}(q) = \frac{-g_{\mu\nu}}{\left(q^2 - M_W^2 + i q^2 \Gamma_W / M_W\right)}$$

Using finite temperature field theory as a tool to calculate the neutrino self energy in a background medium in the presence of a magnetic field, we calculate the neutrino effective potential

Dispersion relation of the neutrino is

$$k_0^2 - K^2 = m_\nu^2 + V_{eff}$$

Neutrino self-energy in the magnetized e+e- medium is given by

$$\Sigma(k) = \frac{g^2}{2} \int \frac{d^4 p}{(2\pi)^4} R \gamma_\mu S_l(p) \gamma_\nu L W^{\mu\nu}(q)$$

$$i S(p) = \int_0^\infty ds\, e^{\phi(p,s)} G(p,s)$$

Schwinger Propagator for fermion

Decomposition of Fermion Self-Energy

$$\Sigma = R \tilde{\Sigma} L = a \gamma_\mu k^\mu + b \gamma_\mu u^\mu + c \gamma_\mu b^\mu$$

¿

$$u^\mu = (1,0), \qquad b^\mu = (0, \hat{b}) \qquad \vec{B} = B \hat{b}$$

¿

The dispersion relation of the neutrino in the background is given by

Is the angle between k and B

$$k_0 - k \simeq b - c\cos\theta$$

$$V_{\nu_e} = V = \left(1 - \frac{1}{2}\frac{eB}{m_e T}\cos\theta\right)\sqrt{2}\,G_F\left(N_e f(s_W) - N_{\bar{e}} f(-s_W)\right)$$

Reduction due to B field, B~0.01me^2/e, T=0.05 me, 10% reduction

Konstandin 06, Sahu 08

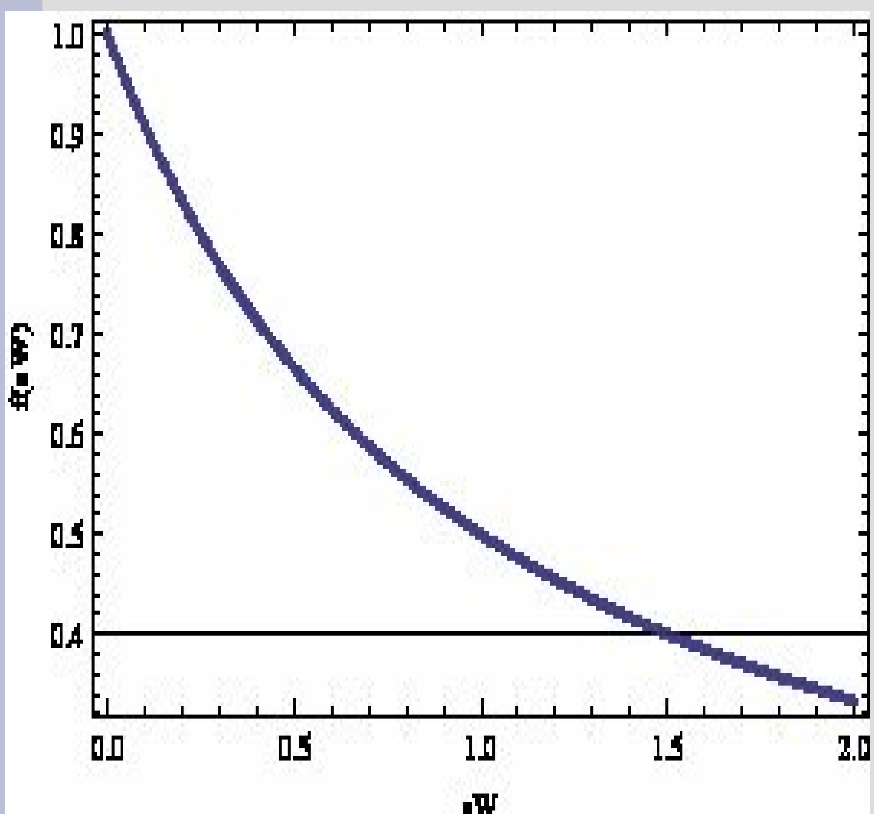
$$f(\pm s_W) = \frac{(1 \pm s_W)}{(1 \pm s_W)^2 + s_W^2 \gamma_W^2} \qquad s_W = 2E_\nu m_e / M_W^2$$

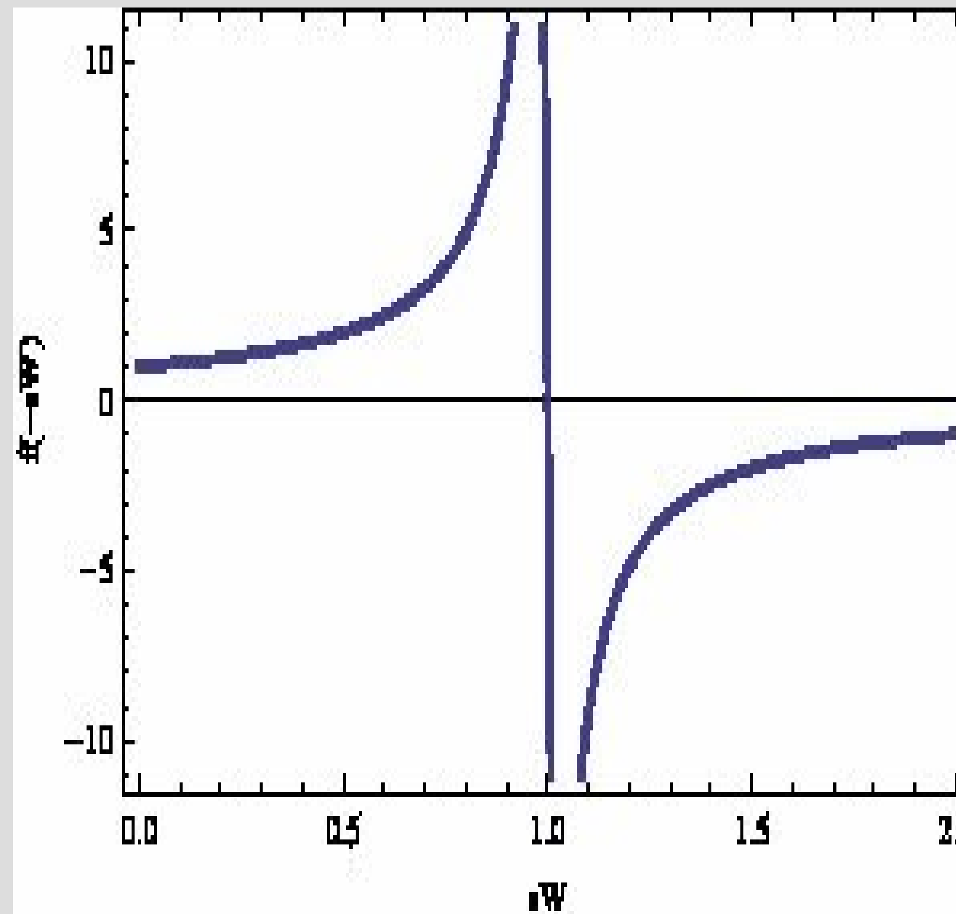
$$\gamma_W = \Gamma_W / M_W \simeq 0.0266$$

The discontinuity in the function f(-sw) at sW=1 corresponds to W-boson production.

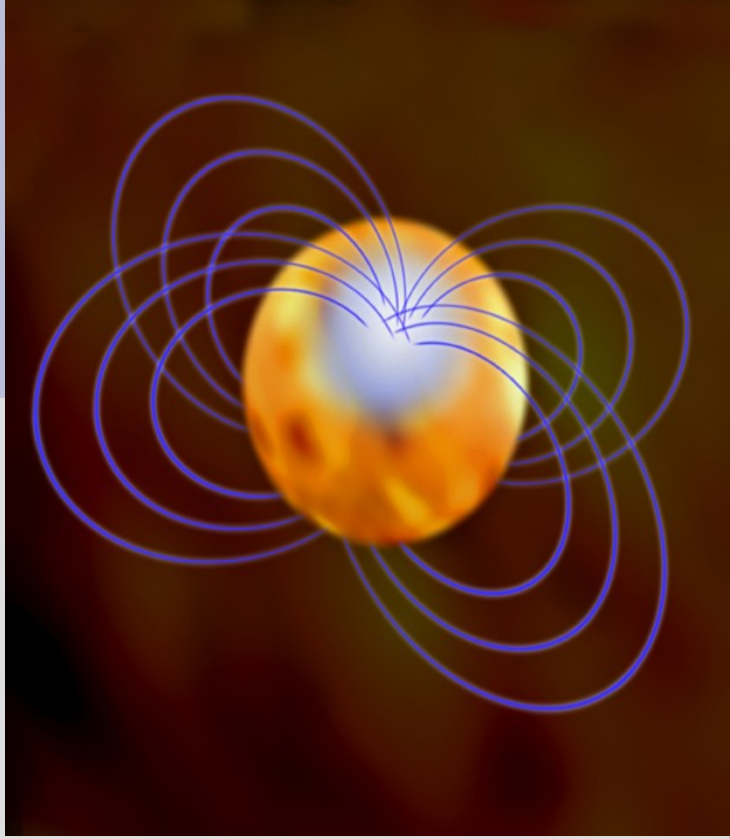
$$\nu_e + e^- \to \nu_e + e^-$$
$$\bar{\nu}_e + e^+ \to \bar{\nu}_e + e^+$$

$$\nu_e + e^+ \to W^+$$
$$\bar{\nu}_e + e^- \to W^-$$





Application to Magnetars



SGR 1806-20

27th of October 2004 in our galaxy
with ~ 15 Kpc distance

$$E_\gamma \simeq 3 \times 10^{46} \;\; erg, \;\; 0.1 \;\; sec$$

$$B \sim 1.6 \times 10^{15} \;\; G$$

Presence of baryons in the fireball are responsible for the production of high energy neutrinos through

$$p\gamma \rightarrow \Delta \rightarrow \;\; n\pi^+ \rightarrow n\nu_\mu e^+ \;\; \nu_e \;\; \bar{\nu}_\mu$$

also pp interaction

TeV-PeV

Zhang.. 03

Neutrino oscillation in magnetar atmosphere

$$\nu_e \longleftrightarrow \nu_{\mu,\tau}$$

$$P(t) = \frac{\Delta^2 \sin^2\theta}{\omega^2} \sin^2\left(\frac{\omega t}{2}\right)$$

$$\omega = \sqrt{V - \Delta \cos 2\theta + \Delta^2 \sin^2 2\theta}$$

$$\Delta = \frac{\Delta m^2}{2 E_\nu}$$

Resonance condition

$$V = \Delta \cos 2\theta$$

At resonance, the length is

$$l_{res} = \frac{2.5\times10^{10}\ E_{\nu,14}\ cm}{\Delta\hat{m}_{\nu}^{2}\sin2\theta}, \qquad E_{\nu,14} = 10^{14}\ eV$$

On the surface of the magnetar, the photon number density is

$$n_{\gamma} \simeq 9.73\times10^{29} L_{47.5} r_{0,6}^{-2}\ cm^{-3}$$

$$T \sim 313\, keV$$

We have to estimate the number density of e+e-pair in the fireball

To create an e+e- pair, the minimum energy of the photon should be

$$h\nu \simeq 2m_e$$

By equating the e+e-annihilation rate to the local expansion rate, the remaining pair is given by

$$N_{\pm} \simeq 6.1\times 10^{44} E_{46.5}^{3/4} r_{0,6}^{-1/2} t_{-1}^{1/4}$$

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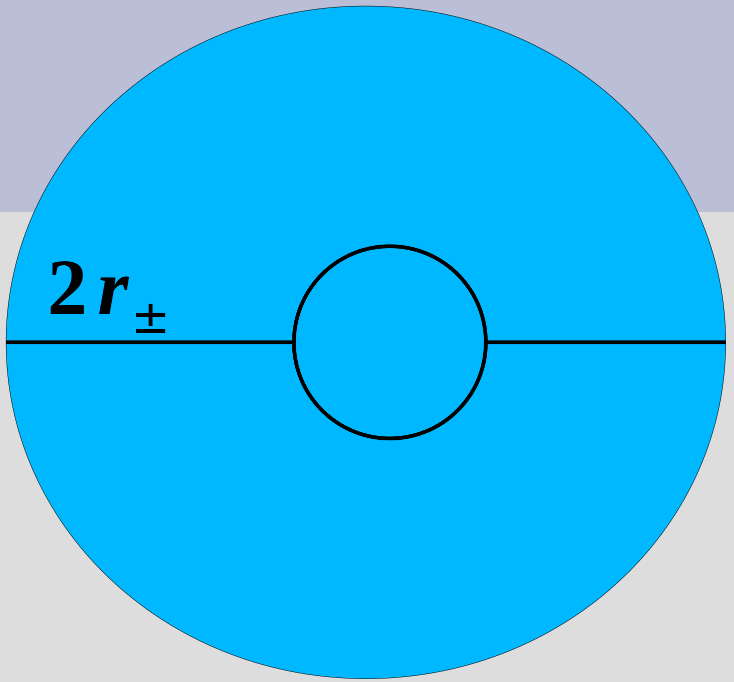
Pair temperature is

$$T \simeq 18\, KeV \quad at \quad a \quad distance \quad r_{\pm} \quad \sim 2.1\times 10^{9} \quad cm$$

Number density of photon at this point is

$$n_\gamma \simeq 1.8 \times 10^{26}\, cm^{-3}$$



Number density of pair is

$$N_e \simeq 2.2 \times 10^{30} \left(\frac{T}{m_e} \right)^{(3/2)} e^{-m_e/T}\, cm^{-3} \simeq 6.8 \times 10^{15}\, cm^{-3}$$

The radius is

$$r_{\pm} \simeq 2.1 \times 10^{9}\, cm$$

$$\Delta \hat{m}^2 \cos 2\theta \simeq 1.7\times 10^{-7}$$

Analysis is done by considering the large and small mixing

Large Mixing range $0.64 \le \sin^2 2\theta \le 0.96$

We get

$$2.8\times 10^{-7}\ eV^2 \le \Delta m_\nu^2 \le 8.5\times 10^{-7} eV^2 \qquad , E_\nu = 10^{14} eV$$

$$3.16\times 10^{16} cm \le l_{res} \le 1.1\times 10^{17} cm$$

Samall Mixing range $2\times 10^{-3} \le \sin^2 2\theta \le 7\times 10^{-3}$

We get

$$\Delta m_\nu^2 \sim 10^{-7} eV^2$$

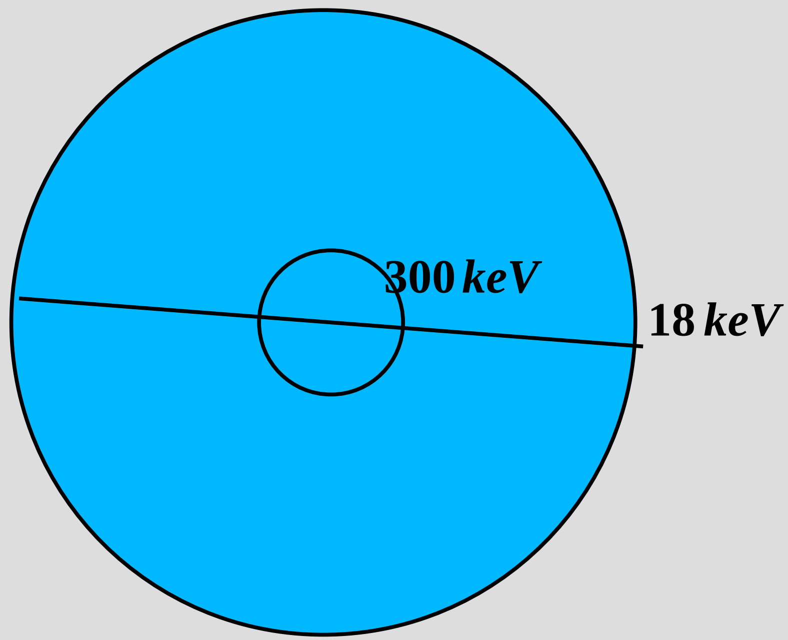
$$l_{res} \sim 10^{18} cm$$

The l_res obtained are much larger than r_(+-) and the Temp also will be very small at l_res. So High Energy Neutrinos will never satisfy the resonance condition and no supression of their flux due to matter and magnetic field effect.

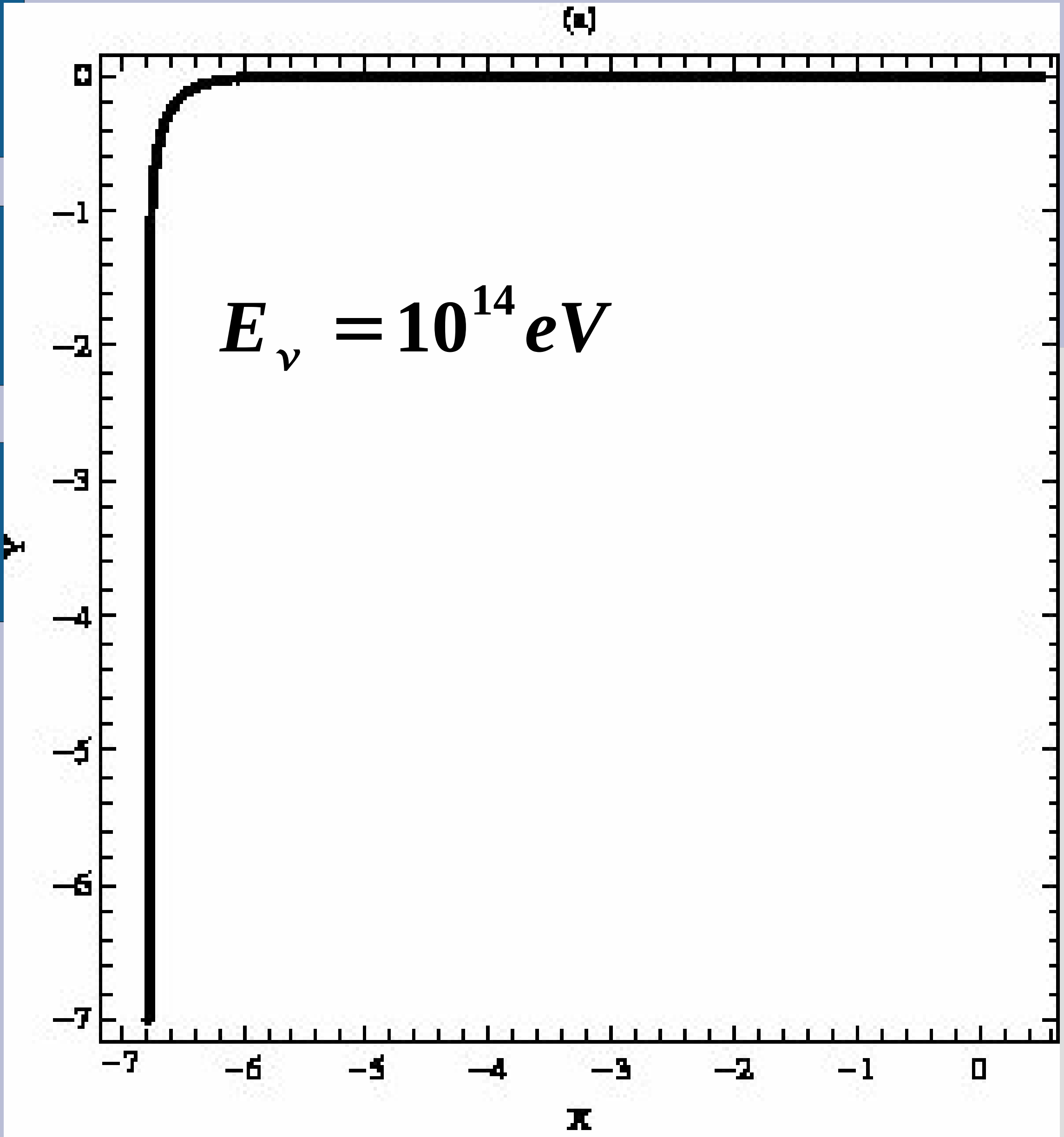
But if the Neutrinos are of GeV energy or less, Temp ~ 50 keV or more
For large mixing we get:

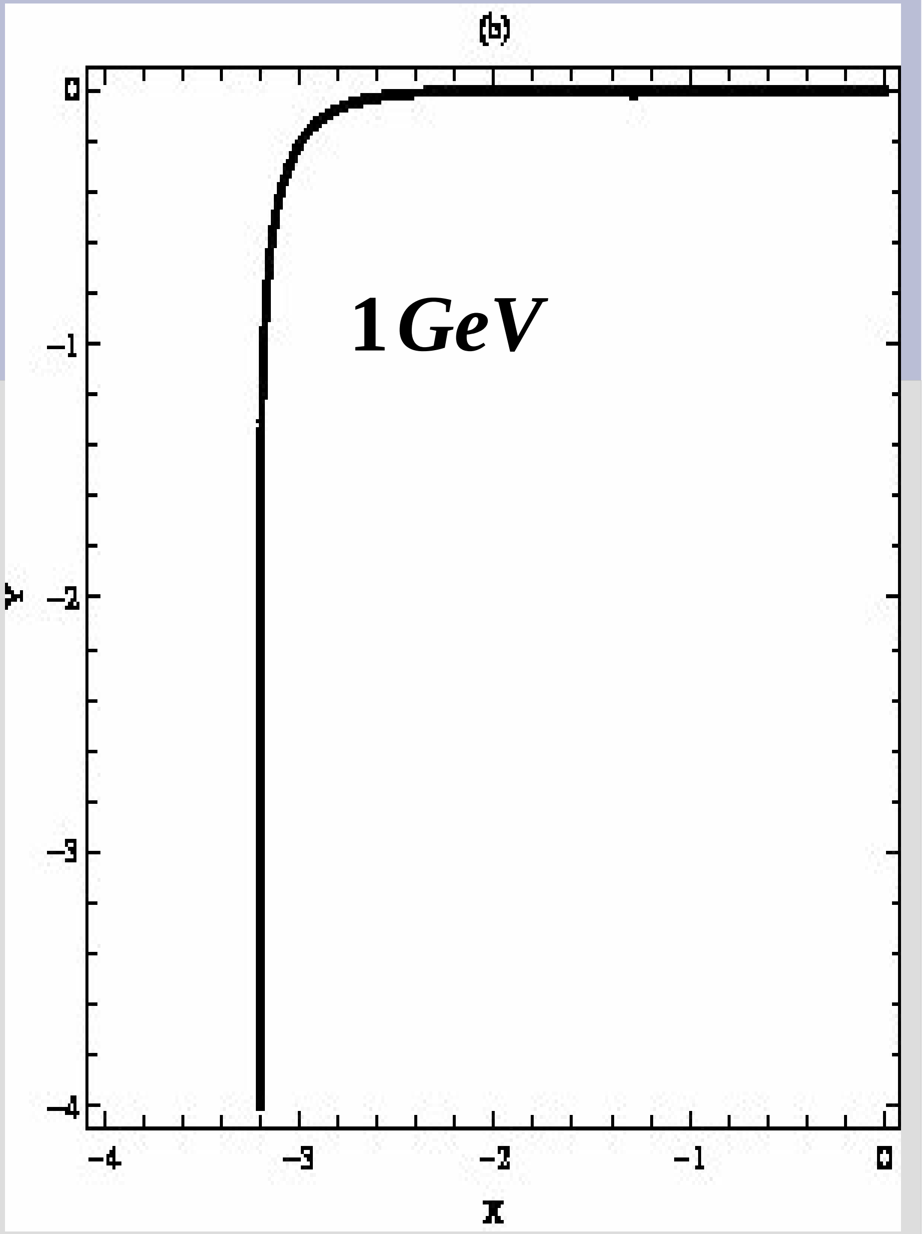
$$10^{-3}\,eV^2 \le \Delta\, m_\nu^2 \;\; 3.1\times 10^{-3}\,eV^2$$

$$\left(6.7\times 10^{7}\,cm \le l_{res} \le 3\times 10^{8}\,cm\right) \quad < \quad r_{\pm}$$



Resonant oscillation is possible if GeV neutrinos are produced deep inside the Magnetar atmosphere where Temperature is of Order 50 keV or so.





$$X = \log[\Delta m_\nu^2], \qquad Y = \log[\sin^2 2\theta]$$

Summary:

We have studied the neutrino propagation in a medium, where we found :

Resonant Oscillation of TeV-PeV neutrinos in the Magnetar Atmosphere is very much supressed.

GeV neutrinos resonant oscillation is possible.