PLASMON DECAY TO A NEUTRINO PAIR VIA NEUTRINO ELECTROMAGNETIC MOMENTS IN A STRONGLY MAGNETIZED MEDIUM

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We calculate the neutrino luminosity of a degenerate electron gas in a strong magnetic field via plasmon decay to a neutrino pair due to neutrino electromagnetic moments and obtain the relative upper bounds on the effective neutrino magnetic moment.

The recent review:

C. Broggini, C. Giunti, A. Studenikin,
Electromagnetic Properties of Neutrinos,
Adv. High Energy Phys. **2012**, 459526 (2012)
[arXiv:1207.3980 [hep-ph]].

The considered process:

$$\gamma \to \nu\bar{\nu} \quad \text{(em)}$$

The leading processes:

$$\gamma \to \nu\bar{\nu} \quad \text{(weak)}$$

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

$$\gamma e^{\pm} \to e^{\pm}\nu\bar{\nu}$$

$$\gamma\gamma \to \nu\bar{\nu}$$

Conditions:

$$T \ll \mu - m_e \quad \text{(degenerate electron gas)}$$

$$H > \frac{\mu^2 - m_e^2}{2e} \quad \text{(electrons occupy only the ground Landau level)}$$

$$\mu \simeq \mu(T=0) \equiv \varepsilon_{\mathrm{F}} = \sqrt{m_e^2 + p_{\mathrm{F}}^2}$$

Under these conditions the Fermi momentum:

$$p_{\mathrm{F}} = \frac{2\pi^2 n_e}{eH}$$

The $\gamma\nu\nu$-vertex:

$$V^{\alpha}(k) = \mu_{\rm B}\, \sigma^{\alpha\beta} k_{\beta} \left[f_{2\nu}(k^2) + i\gamma^5 g_{2\nu}(k^2) \right]$$

Solar neutrinos [C. Arpesella et al. (Borexino Collab.), Phys. Rev. Lett. **101**, 091302 (2008)]:

$$\mu_{\nu} < 5.4 \times 10^{-11} \mu_{\rm B} \quad ({\rm CL} = 90\%)$$

Reactor (anti)neutrinos [GEMMA experiment:
A. G. Beda, V. B. Brudanin, V. G. Egorov et al., Adv. High Energy Phys., **2012**, 350150 (2012)]
(see D. Medvedev's talk, this conference, 23 Aug)

$$\mu_{\bar{\nu}_e} < 2.9 \times 10^{-11} \mu_{\rm B} \quad ({\rm CL} = 90\%)$$

The polarization vectors:

$$\epsilon_\alpha^{(2)} = \frac{\tilde{F}_{\alpha\beta}k^\beta}{H\sqrt{k_\parallel^2}}, \quad \epsilon_\alpha^{(3)} = \frac{F_{\alpha\beta}k^\beta}{H\sqrt{k_\perp^2}}$$

The dispersion law (for mode 2):

$$k^2 = k_0^2 - k_z^2 - k_\perp^2 = \omega_p^2$$

The plasma frequency:

$$\omega_p = k_0(\mathbf{k} = 0) = \left(\frac{2\alpha}{\pi}\frac{H}{H_0}\frac{p_F}{\varepsilon_F}\right)^{1/2} m_e$$

$H_0 = m_e^2/e = 4.41 \times 10^{13}$ G

General expression for neutrino luminosity:

$$Q_{\rm em} = \int \frac{d^3k d^3q d^3q'}{2^3(2\pi)^9 k_0 q_0 q_0'}(2\pi)^4 \delta^{(4)}(q+q'-k)|M|^2 k_0 n_B\,(k_0)$$

$$Q_{\rm em} = \frac{\bar{\mu}_\nu^2 \omega_p^4}{48\pi^3}\int\limits_0^\infty \frac{k^2 dk}{e^{\frac{1}{T}\sqrt{\omega_p^2+k^2}}-1}$$

$$\bar{\mu}_\nu^2 = \mu_{\rm B}^2(f_{2\nu}^2+g_{2\nu}^2) = \mu_\nu^2 + d_\nu^2$$

The asymptotic cases

$$\omega_p \ll T :$$

$$Q_{\mathrm{em}} = \frac{\zeta(3)}{24\pi^2}\,\alpha\hat{\mu}_\nu^2 \frac{\omega_p^4 T^3}{m_e^2}$$

$$\omega_p \gg T :$$

$$Q_{\mathrm{em}} = \frac{\alpha\hat{\mu}_\nu^2}{3\cdot 2^{9/2}\pi^{3/2}} \frac{\omega_p^{11/2} T^{3/2}}{m_e^2}\, e^{-\frac{\omega_p}{T}}$$

$$\hat{\mu}_\nu = \frac{\bar{\mu}_\nu}{\mu_{\mathrm{B}}}$$

The *relative* upper bound on $\hat{\mu}_\nu$ (from $Q_{\rm em} < Q_{\rm weak}$):

$$\hat{\mu}_\nu < \frac{G_F m_e}{\sqrt{2}\pi\alpha} T F(p); \qquad p = \frac{\omega_p}{T}$$

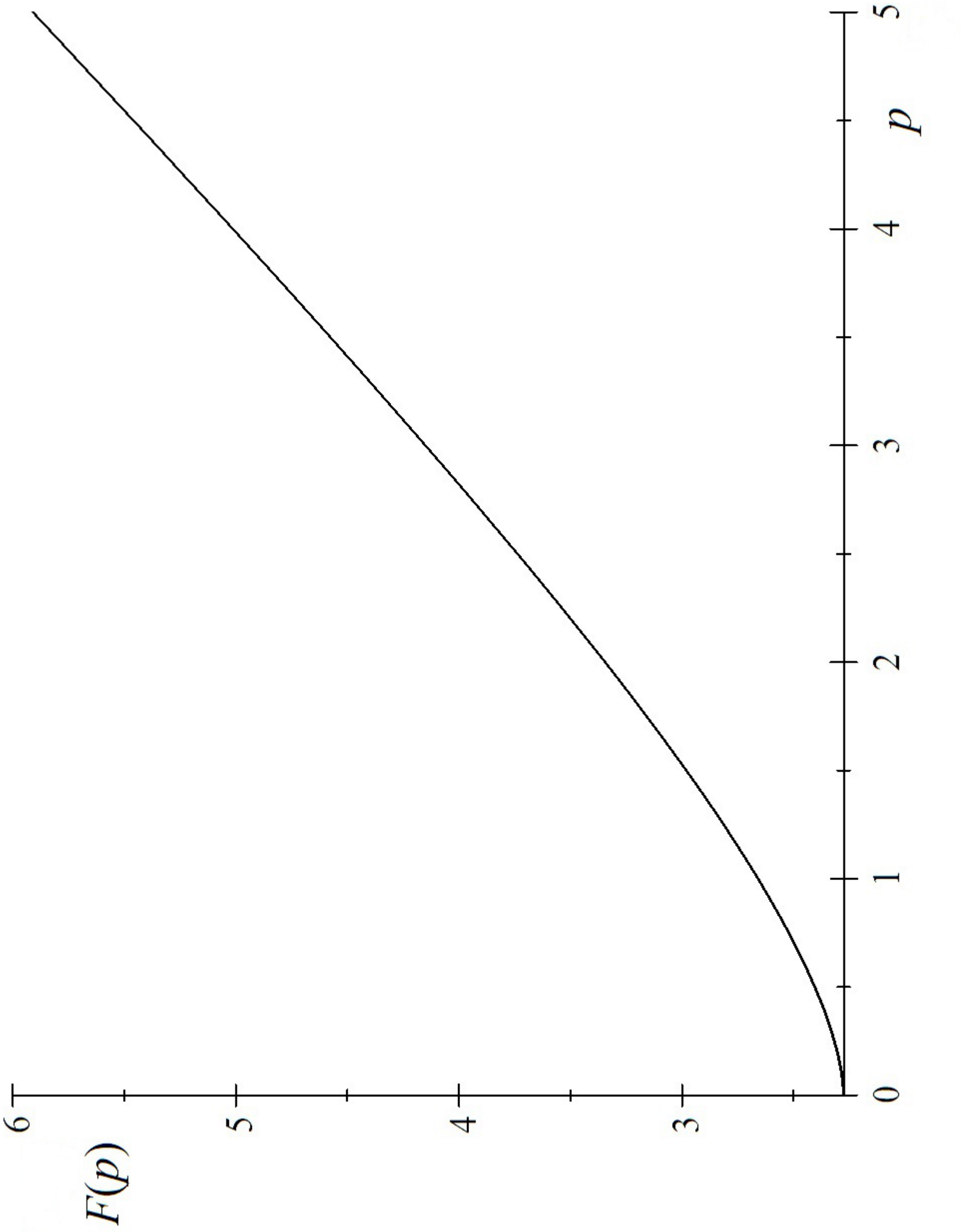
$$F(p) = p \left[\bar{g}_V^2 + \frac{2}{3}\,\bar{g}_A^2 \frac{B_4(p)}{B_2(p)} \right]^{1/2};$$

$$B_n(p) = \int_0^\infty \frac{x^n dx}{\exp(p\sqrt{1+x^2}) - 1}$$

$$\bar{g}_V^2 = \sum_{\ell=e,\mu,\tau} g_V^2(\ell) \simeq 0.929, \quad \bar{g}_A^2 = \sum_{\ell=e,\mu,\tau} g_A^2(\ell) = 3/4.$$

$$F(p) \geq F(0) = 2[2\zeta(5)/\zeta(3)]^{1/2}\bar{g}_A \simeq 2.275$$

$$F(p) \simeq \bar{g}_V p \simeq 0.964p, \qquad p \gg 1$$


F(p)
p
6
5
4
3
0
1
2
3
4
5

The upper bounds in astrophysical form

For $\omega_p \ll T$:

$$\hat{\mu}_\nu < 3.6 \times 10^{-12}\, T_8$$

$$T_8 = T/(10^8 \text{ K})$$

For $T_8 = 2$:

$$\hat{\mu}_\nu < 7.2 \times 10^{-12}$$

For $\omega_p \gg T$:

$$\hat{\mu}_\nu < 2.94 \times 10^{-12} \left(1 + 0.44 H_{13}^2 \rho_6^{-2}\right)^{-1/4} H_{13}^{1/2}$$

$$H_{13} = H/(10^{13}\ \text{Гс}), \quad \rho_6 = \rho/(10^6\ \text{г/см}^3)$$

(for the neutron star crust: $n_e \simeq 0.5\rho/m_p$)

For $p_{\mathrm{F}} \ll m_e$ $(H_{13}/\rho_6 \gg 1)$:

$$\hat{\mu}_\nu < 3.61 \times 10^{-12} \rho_6^{1/2}$$

For $p_{\mathrm{F}} \gg m_e$ $(H_{13}/\rho_6 \ll 1)$:

$$\hat{\mu}_\nu < 2.94 \times 10^{-12} H_{13}^{1/2}$$

$$H_{13} = 300: \qquad \hat{\mu}_\nu < 5.1 \times 10^{-11}$$

The obtained relative upper bounds:

$$\hat{\mu}_\nu < 3.6 \times 10^{-12}\, T_8\,, \qquad \omega_p \ll T$$

$$\hat{\mu}_\nu < 3.61 \times 10^{-12}\, \rho_6^{1/2}\,, \qquad \omega_p \gg T\,, \quad p_{\rm F} \ll m_e$$

$$\hat{\mu}_\nu < 2.94 \times 10^{-12}\, H_{13}^{1/2}\,, \qquad \omega_p \gg T\,, \quad p_{\rm F} \gg m_e$$

Solar neutrinos (Borexino):

$$\hat{\mu}_\nu < 5.4 \times 10^{-11}$$

Reactor antineutrinos (GEMMA):

$$\hat{\mu}_\nu < 2.9 \times 10^{-11}$$

The plasmon decay plays a significant role in the cooling of strongly magnetized neutron stars and is the dominant mechanism of their energy losses in a broad parameter range [M. V. Chistyakov and D. A. Rumyantsev, Zh. Eksp. Teor. Fiz. **134**, 627 (2008)].

Relative bounds on the effective magnetic moment of the neutrino determine the range of its values where the weak channel of the plasmon decay is more effective than the electromagnetic one.