NEUTRINO EMISSION FROM A STRONGLY MAGNETIZED DEGENERATE ELECTRON GAS: THE COMPTON MECHANISM VIA A NEUTRINO MAGNETIC MOMENT

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Abstract. We derive relative upper bounds on the effective magnetic moment of Dirac neutrinos from comparison of the standard weak and electromagnetic mechanisms of the neutrino luminosity due to the Compton-like photoproduction of neutrino pairs in a degenerate gas of electrons on the lowest Landau level in a strong magnetic field. These bounds are close to the known astrophysical and laboratory ones.

1. Neutrino emission is the main source of energy losses of stars in the late stages of their evolution [1]. As is well known, neutron stars (NSs) can have strong magnetic fields $H \gtrsim 10^{12}$ G, the NSs with $H \sim 10^{14} - 10^{16}$ G are called magnetars [2].

In this report, we consider one of the main processes of neutrino emission in the outer regions of NSs (for a review of various neutrino processes, see [3]) that is photoproduction of neutrino pairs ($\gamma e \to e\nu\bar{\nu}$) in a degenerate gas of electrons through two mechanisms: the weak one via standard charged and neutral weak currents and the electromagnetic one via neutrino electromagnetic dipole moments arising in extended versions of the Standard Model [1,4] (for a recent review, see [5]). By comparison of the neutrino luminosities due to these two mechanism, L_w and L_{em}, we derive relative upper bounds on the neutrino effective magnetic moment (NEMM)

$$\bar{\mu}_\nu = (\mu_\nu^2 + d_\nu^2)^{1/2}, \tag{1}$$

restricting ourselves to the case of Dirac neutrinos. Here μ_ν and d_ν are the neutrino magnetic and electric dipole moments, respectively.

2. We assume that the electron gas is degenerate and strongly magnetized:

$$T \ll \mu - m,\ H > ((\mu/m)^2 - 1)H_0/2, \tag{2}$$

where T and $\mu \simeq \mu(T = 0) \equiv \varepsilon_{\rm F} = (m^2 + p_{\rm F}^2)^{1/2}$ are the temperature and chemical potential of the gas, $\varepsilon_{\rm F}$ and $p_{\rm F}$ are the Fermi energy and momentum, $H_0 = m^2/e \simeq 4.41 \times 10^{13}$ G, m and $-e$ are the electron mass and charge (we use the units with $\hbar = c = k_{\rm B} = 1$). Under the conditions (2), electrons occupy only the lowest Landau level in the magnetic field with $p_{\rm F} = 2\pi^2 n_e/(eH)$, where n_e is the electron concentration, and the effective photon mass is generated which

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is equal to the plasmon frequency $\omega_p = ((2\alpha/\pi)(p_{\rm F}/\varepsilon_{\rm F})H/H_0)^{1/2}m$, α is the fine-structure constant.

For the nonrelativistic case, $p_{\rm F} \ll m$ and $\omega_p \ll T$, the neutrino luminosities are expressed as follows:

$$L_w = 3.49 \times 10^2 H_{13}^2 \rho_6^{-1} T_8^9 \ {\rm erg\,cm^{-3}\,s^{-1}}, \qquad (3)$$

$$L_{em} = 4.06 \times 10^{30} (\bar{\mu}_\nu/\mu_{\rm B})^2 \rho_6^2 T_8^3 \ {\rm erg\,cm^{-3}\,s^{-1}}, \qquad (4)$$

where $H_{13} = H/(10^{13}\ {\rm G})$, $\rho_6 = \rho/\left(10^6\ {\rm g/cm^3}\right)$, $T_8 = T/(10^8\ {\rm K})$, and $\mu_{\rm B}$ is the Bohr magneton. Note that Eq. (3) is in agreement with the result of Ref. [6]. Assuming $L_{em} < L_w$, we obtain the upper limit on the NEMM (1): $\bar{\mu}_\nu/\mu_{\rm B} < 9.3 \times 10^{-15} H_{13} \rho_6^{-3/2} T_8^3$, and, for $T = 1.8 \times 10^8$ K, $H = 2.5 \times 10^{12}$ G, $\rho = 5.4 \times 10^4$ g/cm^3, it gives $\bar{\mu}_\nu/\mu_{\rm B} < 1.1 \times 10^{-12}$, which is close to the known astrophysical bounds [7].

For the relativistic case, $p_{\rm F} \gg m$ and $\omega_p \gg T$, we obtain

$$L_w = 2.63 \times 10^{-2} H_{13}^{43/4} \rho_6^{-6} T_8^{3/2} \exp(-1.92 H_{13}^{1/2} T_8^{-1}) \ {\rm erg\,cm^{-3}\,s^{-1}}, \qquad (5)$$

$$L_{em} = 3.02 \times 10^{30} (\bar{\mu}_\nu/\mu_{\rm B})^2 H_{13}^{11/4} T_8^{3/2} \exp(-1.92 H_{13}^{1/2} T_8^{-1}) \ {\rm erg\,cm^{-3}\,s^{-1}}, \qquad (6)$$

and a strong relative bound $\bar{\mu}_\nu/\mu_{\rm B} < 9.3 \times 10^{-17} H_{13}^4 \rho_6^{-3} = 7.6 \times 10^{-16}$ for $H_{13} = 300, \rho_6 = 10^3$. However, under these conditions, the plasmon decay ($\gamma \to \nu\bar{\nu}$) is a much more effective mechanism of neutrino emission [8]. Comparing the corresponding luminosity with that of Eq. (6), we derive a considerably less stringent bound $\bar{\mu}_\nu/\mu_{\rm B} < 1.7 \times 10^{-12} H_{13}^{1/2} = 2.9 \times 10^{-11}$ (for $H_{13} = 300$), which is close to the conservative bound $\mu_\nu < 0.54 \times 10^{-10} \mu_{\rm B}$ [7] and the most stringent laboratory limit $\mu_\nu < 3.2 \times 10^{-11} \mu_{\rm B}$ [9].

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