Asymmetric Neutrino Production in Magnetized Proto-Neutron Stars in Fully Relativistic Mean-Field Theory and Application to Pulsar Kick and Rotational Spin Down

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In our previous works [1,2], we calculated neutrino scattering and absorption cross sections on hot and dense magnetized neutron-star matter including hyperons under a strong magnetic field in a fully relativistic mean field (RMF) theory [3]. The calculated results showed that the magnetic contribution increases the neutrino momentum emitted along the direction parallel to the magnetic field and decreases it along the opposite direction. The enhancement and reduction are conjectured to play a role of increasing the neutrinos emitted to the Arctic area and decreasing them to the Antarctic area when the magnetic field has a poloidal distribution. In the present work [4], as a next step, we consider the neutrino production process though the direct URCA (DU) ($e^- + p \to n(\Lambda) + \nu_e$).

Here we assume that there is uniform magnetic field, and that its strength is weaker than the strong interaction order: $\sqrt{eB} \ll \mu_B$, where μ_B is the baryon chemical potential. We therefore treat the magnetic field in the perturbative way, and approximate the production cross-section as

$$\sigma_{pr} = \sigma_{pr}^0 + \Delta\sigma_{pr} \qquad (1)$$

where σ^0 is independent of B, and $\Delta\sigma$ is proportional to B.

Fig. 1 shows $\Delta\sigma_{pr}/\sigma_{pr}^0$ as a function of the produced neutrino angle θ_f, where the magnetic field is set to be $B = 10^{17}$ G, and the initial neutrino energy is taken to be the chemical potential.

We see that the magnetic-field gives rise to about 8 % asymmetry in the production process at $\rho_B = \rho_0$. As the density increases, the magnetic contribution becomes smaller, particularly in the system with Lambda.

The magnetic field increases emitted neutrinos in the Arctic area and decreases those in the Antarctic area. This magnetic contribution in the production process turns out to be the same as that in the absorption process. Therefore, the asymmetry by the magnetic field becomes about twice by the addition of the production process, and enlarges the pulsar kick [2] and the spin deceleration [4].

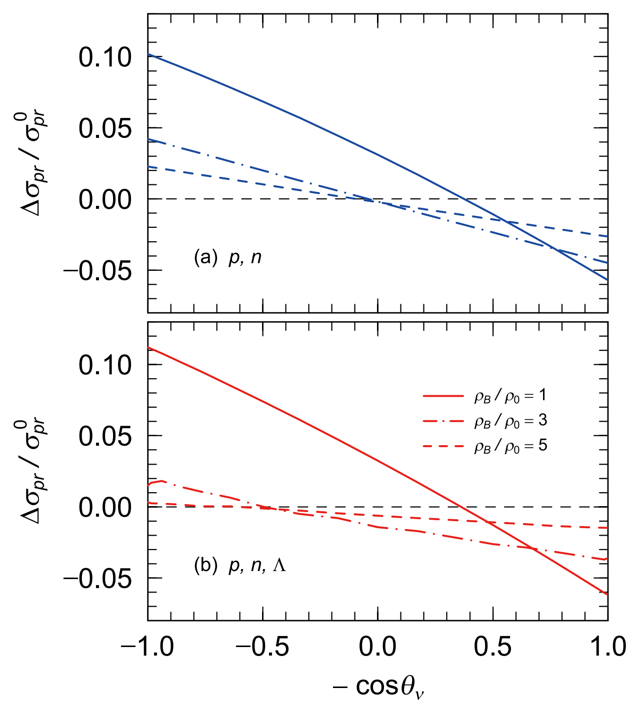

Figure 1: Normalized magnetic part of the total production probability per unit time cross section, $\Delta\sigma_{pr}/\sigma_{pr}^0$, as a function of final neutrino angle θ_f in the system without hyperons (a) and with hyperons (b) for the entropy S/A = 1 under magnetic field of $B = 10^{17}$ G. In each panel dotted, solid, dash-dotted and dashed lines represent the results at $\rho_B = \rho_0$, $3\rho_0$ and $5\rho_0$, respectively.

References

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[4] Maruyama, T., et al.: 2014, *Phys. Rev. C*, **89**, 035801.