Asymmetric Neutrino Reaction from Magnetized Proto-Neutron Stars in Fully Relativistic Framework

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Various phases of the hot and dense hadronic matter are interesting topics in nuclear, particle and astro physics. The neutron star is the most possible target to realize these dense matter. Furthermore a new type of neutron stars, called “magnetars”, with a super strong magnetic field have been discovered [1]. In this study only the neutrino emission is the observable information; it also gives us an interesting question as for the dense matter. Neutrino emission as well as GW is the unique observable that provides signals of the change of internal structure of the neutron star [2]. Then, we have calculated scattered and absorbed neutrinos in the hot and dense hadrons with hyperons under strong magnetic field.

Here we assume that there is uniform magnetic field along z-direction as $\vec{B} = B\hat{z}$. Even astronomically strong magnetic field is still weaker than the strong interaction order: $\sqrt{eB} \ll \mu_a$, where μ_a is the chemical potential of the particle a. We therefore treat the magnetic field in the perturbative way, ignore the contribution from the convective current, and thus consider only the spin interaction. In this approximation the cross-section is given as

$$\sigma = \sigma^0 + \Delta\sigma \qquad (1)$$

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

Figure 1 shows $\Delta\sigma$ of the neutrino scattering ($\nu_e \rightarrow \nu_e$) and absorption ($\nu_e \rightarrow e^-$) in the upper and lower panels, respectively, as a function of the incident neutrino angle θ_i, where the magnetic field is set to be $B = 2 \times 10^{17}$ G, and the initial neutrino energy is taken to be the chemical potential. We found that the scattering cross sections is maximum at $\theta_i = 0°$, and that the absorption cross section is minimum at $\theta_i = 0°$. In addition these results are opposite at $\theta_i = 180°$. These results lead to a very interesting phenomena that in the strong poloidal magnetic field, the neutrinos are strongly absorpted in the antarctic areas of the proto neutron-stars. This result implies that the strong magnetic field could influence the pulser-kick of proto neutron stars.

As the next step, we applied the above results to calculations of pulsar-kick in core-collapse supernovae of the proto neutron-star. In these calculations we solved the Boltzmann equation using a one-dimensional attenuation method. Then, we obtain the kick velocity of about 600 km/s for the $M_{NS} = 1.68\, M_\odot$ isothermal model with $T = 20$ MeV when the magnetic field is uniformly poloidal, with its strength $B = 2 \times 10^{17}$ G.

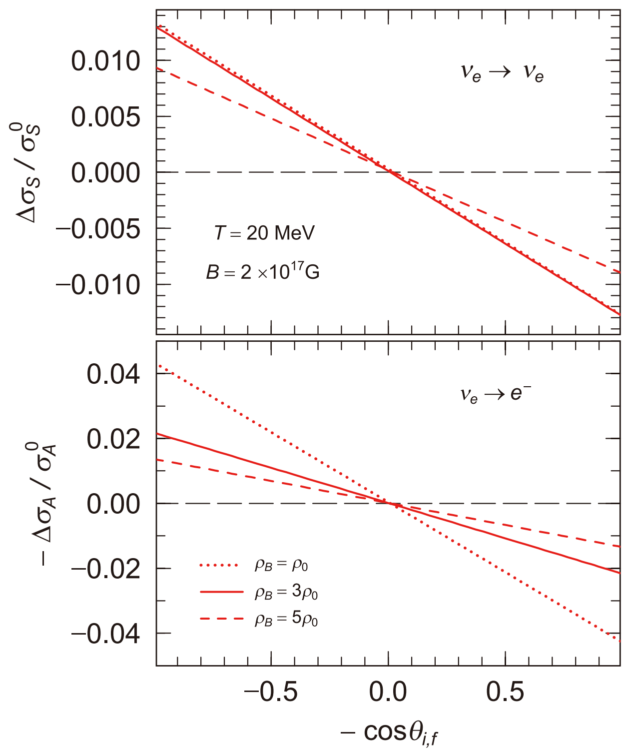

Figure 1: (Color online) Ratios of the magnetic part of the scattering cross-sections $\Delta\sigma_S$ and those of the absorption cross-sections $\Delta\sigma_A$ for $B = 2 \times 10^{17}$ G, to the cross-sections without a magnetic-field $\sigma^0_{S,A}$ at $T = 20$ MeV. Dotted, dashed and solid lines represent the results for densities of $\rho_B = \rho_0$, $3\rho_0$ and $5\rho_0$, respectively.

References

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[3] Maruyama, T., et al.: 2011, *Phys. Rev. D*, **83**, 081303(R).