Pulsar Kick Induced by Asymmetric Emission of Supernova Neutrinos[1]

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We studied the supernova neutrino scattering and absorption processes in strongly magnetized proto-neutron stars at finite temperature and density. We used a fully relativistic mean field theory [2] for the hadronic sector of the equation of state including hyperons. We solved the Dirac equations for all constituent particles, p, n, Λ, e, and ν, for a poloidal magnetic field with $B \sim 10^{17}$ G. We then applied the solutions to obtain a quantitative estimate of the asymmetry that emerges from the neutrino-baryon collision processes. We included the effects of distortion of the Fermi spheres made by magnetic field that implies asymmetric neutrino scattering and absorption cross-sections.

We found that the differential neutrino scattering cross sections are slightly enhanced in the arctic direction parallel to the poloidal magnetic field B in both cases with and without Λ's (Fig. 1a, c), while the differential absorption cross-sections are suppressed (Fig. 1b, d). The differential cross-sections were integrated over the momenta of the final electrons for absorption, and over the momenta of initial neutrinos for the scattering, respectively. Quantitatively, when $B = 2 \times 10^{17}$ G, the reduction for the absorption process results in about 2 %, and the enhancement for the scattering process about 1 % in the forward direction along the direction of B.

Using these cross-sections, we calculated the neutrino mean-free-paths (MFPs), and then applied to a calculation of pulsar-kicks in core-collapse supernovae. We solved the Boltzmann equation using a one-dimensional attenuation method. Our estimated pulsar-kick velocities are $v_{kick} = 610\,\mathrm{km\,s^{-1}}$ or $580\,\mathrm{km\,s^{-1}}$ with or without Λ's, at $T = 20$ MeV. These values are in reasonable agreement with the observed average pulsar-kick velocity of $v_{kick} = 400\,\mathrm{km\,s^{-1}}$.

Realistic 3D simulation [3] of rotational magnetized proto-neutron star suggests that not only poloidal but toroidal magnetic fields are induced. We currently study the effect of of neutrino-asymmetry in spin-down phenomena of the proto-neutron star [4].

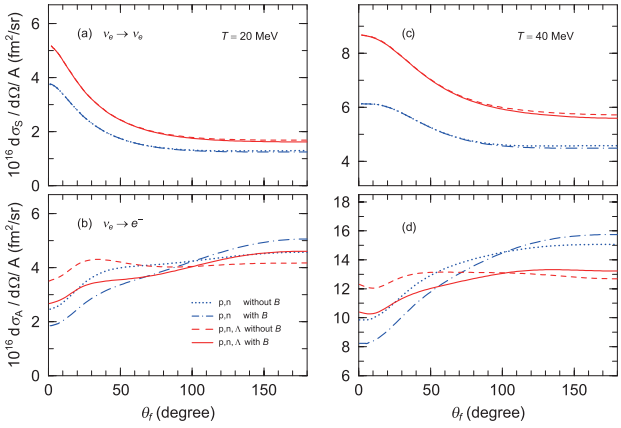

Figure 1: Effects of magnetic fields on the differential cross sections $d\sigma = d\Omega = A$ for neutrino scattering $\nu_e \to \nu_e$ (a and c), and for neutrino absorption $\nu_e \to e^-$ (b and d). Each line is for the different case as indicated.

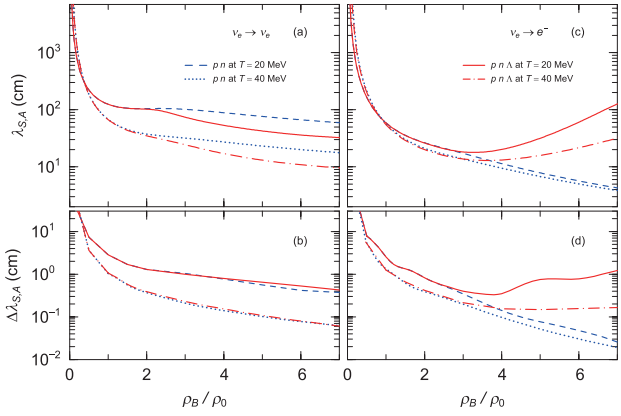

Figure 1: Upper panels show the neutrino MFP for scattering (a) and absorption (c) without magnetic field. Lower panels (b) and (d) show the magnetic contribution to the MFP for scattering (b) and absorption (d). Each line is for the different case as indicated.

References

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[3] Takiwaki, T., Katake, K., Sato, K.: 2009, *ApJ*, **691**, 1360.: Kuroda, T., Umeda, H.: 2010, *ApJS*, **191**, 439.
[4] Maruyama, T., et al.: 2013, submitted.