Asymmetric Neutrino Emissions in Relativistic Mean-Field Approach and Observables: Pulsar Kick and Spin Deceleration of Strongly Magnetized Proto-Neutron Stars

T. Maruyama[a)], N. Yasutake[b)], T. Kajino[c)], M.K. Cheoun[d)], C.Y. Ryu[d)] and G.J. Mathews[e)]

a) College of Bioresouce Sciences, Nihon University, Fujisawa 252-8510, Japan

b) Department of Physics, Chiba Institute of Technology, Narashino 275-0023, Japan

c) National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka 181-8588, Japan

d) Department of Physics, Soongsil University, Seoul, 156-743, Korea

e) Center of Astrophysics, University of Notre Dame, Notre Dame, IN 46556, USA

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 as "magnetars", with a super strong magnetic field has been discovered. In this study the neutrino emission is the important observable information; it also gives us an interesting question as for the dense matter.

In this work, then, we have calculate scattered and absorbed neutrino cross-sections in the hot and dense hadron with hyperons under strong magnetic field. We treat the magnetic field with the perturbative way, omit the contribution from the convention current and consider only the spin-interaction. As a result we can get a significant angular dependence of the neutrino absorption part ($\nu_e \to e^-$) [1].

As a next step, we applied the above results to calculations of pulsar-kicks in core-collapse supernovae and spin deceleration of the proto-neutron-star (PNS). 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, and its strength $B = 2 \times 10^{17}$G [2].

When the magnetic field is toroidal, furthermore, we calculate the spin deceleration and obtain $\dot{P}/P \sim 10^{-6}$ when the spin period $P \approx 10ms$. The obtained vale of the spin deceleration is much larger than that predicted with the magnetic dipole radiation, $\dot{P}/P \sim 10^{-7}$ [3].

Furthermore, we recently calculated the neutrino production under the strong magnetic-field and showed that the production process also enhances the asymmetry of the neutrino emissions [4].

[1] T. Maruyama , T. Kajino, N. Yasutake, M.K. Cheoun and C.Y. Ryu, Phys. Rev. **D83**, 081303(R) (2011).

[2] T. Maruyama, N. Yasutake, M.K. Cheoun, J. Hidaka, T. Kajino, G.J. Mathews and C.Y. Ryu, Phys. Rev. D 86 (2012) 123003.

[3] T. Maruyama, J. Hidaka, T. Kajino, N. Yasutake, T. Kuroda, T. Takiwaki, M.K. Cheoun, C.Y. Ryu and G.J. Mathews, Phys. Rev. C 89 (2014) 035801.

[4] T. Maruyama, M.K. Cheoun, J. Hidaka, T. Kajino, T. Kuroda, G.J. Mathews, C.Y. Ryu, T. Takiwaki and N. Yasutake, Phys. Rev. **D** in press.