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Impact of Neutrino Collective Oscillation on Supernova Nucleosynthesis and Mass Hierarchy

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Binary neutron-star mergers (NSMs) and core-collapse supernovae (CCSNe, both neutrino-driven winds; ν-wind SNe and magneto-hydrodynamic jets; MHD Jet-SNe) are viable candidate astrophysical sites for the heavy r-process elements. In particular, the observed optical and near-infrared emissions from GW170817 are consistent with those from radiative decays of r-process nuclei which are predicted theoretically. However, specific r-process elements have not yet been identified directly in either NSMs or CCSNe, and it is still under the theoretical debate if the "universality"for heavy nuclides above the 2nd peak to actinides is explained by only the NSM r-process, SN r-process, or both [1,2].

In this paper, we would like to propose an alternative approach to the "universality" especially on the 1st peak. The elements whose masses are in the range of A = 80-100 near the 1st r-process peak have several possible nucleosynthetic processes such as r-, s-, rp-, γ-, νp-processes, etc. Although the ν-wind SNe are presumed to be the leading candidate astrophysical site for the 1st r-process peak elements like As-Se-Br, an required neutron-rich condition (Ye < 0.5) has been put into question by failures of robust models for SNe if one assumes only the neutrino heating source to trigger a successful explosion. However, we find that the νp-process operates strongly with amounts of free neutrons being supplied continuously in the proton-rich (Ye > 0.5) materials via p(νe, e-)n reactions when one takes account of the effects of collective neutrino oscillations in coherent self-interacting neutrino scatterings (collective νp-process) [3]. We then find that the nuclear reaction flows can reach the production of abundant p-nuclei like 92Mo, 96Ru, etc. for the mass region of A < 100, which are in reasonable agreement with the observed abundance ratios of the solar-system p-nuclei. This nucleosynthetic method turns out to be a unique probe indicating the still unknown neutrino-mass hierarchy [3]. We currently study extensively if our proposed collective νp-process and the r-process in CCSNe and NSMs can explain the "universality".

[1] S. Shibagaki, T. Kajino, G. J. Mathews et al., ApJ 816 (2016), 79.
[2] T. Kajino & G. J. Mathews, Rep. Prog. Phys. 80 (2017), 084901.
[3] H. Sasaki, T. Kajino, T. Takiwaki et al., Phys. Rev. D96 (2017), 043013.

Summary

We propose a new nucleosynthesis process called "collective νp-process" by taking account of the effects of collective neutrino oscillations in coherent self-interacting neutrino scatterings. In our new method the universality of the three r-process abundance peaks is explained by the core-collapse supernova and the neutron star merger nucleosynthesis. This can be used as probe to distinguish the still unknown neutrino-mass hierarchy.

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