平成30年度国立天文台滞在型共同研究報告書
Activity Report for NAOJ Visiting Joint Research in FY 2018

2018年06月08日
YYYY／MM／DD

申請者 Applicant	氏　名 Name	Akif Baha BALANTEKIN
	所属・職 Division・position	University of Wisconsin・Eugene P. Wigner Professor
研究課題名 Research Title	超新星元素合成とニュートリノ振動・相対論的電子遮蔽効果 (Effects of neutrino oscillation and relativistic electron screening on supernova nucleosynthesis)	
研究場所 Place	国立天文台三鷹	
共同研究者 氏名・所属・職名 Joint researcher's Name・Institution・Position/Graduate Student year	梶野敏貴・青木和光（准教授）、Michael Famiano・Motohiko Kusakabe (外国人客員教授)、佐々木宏和・森寛治(東大大学院生)、Yamac Pehlivan・Cemsinan Deliduman・Myung-Ki Cheoun (外国人客員)、早川岳人 (国内客員教授)、鈴木俊夫・日高潤・丸山智幸 (特別客員研究員)	

１．研究概要 (Summary of research)

My main research efforts aim to understand the role of neutrinos in astronomy and astrophysics as well as nucleosynthesis in the Big Bang Nucleosynthesis epoch and in the stars including Supernovae. A key development during the last few decades has been the appreciation of the close relationship between neutrinos and nucleosynthesis as physicists and astronomers ascertained the fact that neutrino properties figure prominently in many astrophysical environments. Understanding where and how various nuclei are synthesized during the evolution of the Universe is one of the key questions of modern science. Since copious amounts of neutrinos are present in most nucleosynthesis sites, neutrino physics and neutrino-nucleus interactions are salient components of nucleosynthesis. The site of the r-process nucleosynthesis, driven by a succession of rapid neutron captures on heavy seed nuclei, is still unknown, but the neutrino-driven wind in the core-collapse supernovae and merger of two neutron stars are among the possible sites. Recent observation of the electromagnetic counterpart of gravitational waves from merging neutron stars seems to be consistent with decaying r-process elements. Since our theoretical understanding of core-collapse supernovae is still evolving, it is not possible to rule out the neutrino-driven wind as one of the possible sites. The sheer number of neutrinos emitted from the cooling proto-neutron star following the core collapse necessitates inclusion of neutrino-neutrino interactions in the description of the neutrino transport in supernovae. Unlike the one-body Hamiltonian of the matter-enhanced neutrino oscillations in the Sun and the stars where neutrinos interact with a mean-field (generated by the background particles other than neutrinos), the Hamiltonian describing the many-neutrino gas in a core-collapse should include neutrino-neutrino interaction terms. Studying the impact of these terms in neutrino transport is an integral part of our research activity.

The reaction rates used in astronomical applications need to be corrected for screening due to the electron-positron plasma present in environments. The electrostatic interaction energy between neighboring nuclei could be either small (weak screening) or large (strong screening) compared with the thermal energy. We investigate this intermediate regime.

２.研究成果(Research achievements)

In previous work, exploiting the mathematical similarities between the neutrino-neutrino interaction Hamiltonian in the single angle approximation and the BCS pairing Hamiltonian, we found the conserved quantities associated with the neutrino gas for two and three flavors. At least in the single-angle case, our recognition that the invariants of the exact many-body Hamiltonian reduce to the appropriate constants of motion in the mean field limit suggests that the mean-field approximation appears to capture most of the relevant physics. During the stay sponsored by this visiting award, we formulated a solution around a special class of many-body eigenstates which do not undergo any level crossings as the neutrino self interaction rate decreases while the neutrinos radiate from the supernova. In particular, an initial state which consists of electron neutrinos and antineutrinos of an orthogonal flavor can be entirely decomposed in terms of those eigenstates. Assuming that the conditions are perfectly adiabatic so that the evolution of these eigenstates follow their variation with the interaction rate, we show that this initial state develops a spectral split at exactly the same energy predicted by the mean field formulation. A resulting paper was submitted for publication [1]. Extensive study is being currently carried out [2].

As described above the reaction rates used in astronomical applications need to be corrected for screening due to the electron-positron plasma present in environments. Starting with Salpeter electron screening has been well investigated when various ad hoc prescriptions are given to treat the intermediate regime, but no systematic treatment exists. With the aid of modern computational tools a systematic treatment of the intermediate screening regime is possible and we continued to investigate such a systematics. Together with the other visiting professors, we continued exploring screening effects in core-collapse SN II [2], and also in particular for a homogenous carbon plasma relevant to SN Ia [3].

Finally, we continued our analysis of supernova detection using carbon-based scintillators. Such scintillators include not only ^{12}C, but also about one percent of ^{13}C, necessitating a knowledge of neutrino cross sections for both isotopes [4].

Selected References:

[1] S. Birol, Y. Pehlivan, A.B. Balantekin and T. Kajino, *Neutrino Spectral Split in the Exact Many Body Formalism,* arXiv:1805.11767 [astro-ph.HE], submitted to Phys. Rev. D (2018).

[2] T. Kajino, W. Aoki, A.B. Balantekin, R. Diehl, M.A. Famiano and G.J. Mathews, *Current status of r-process nucleosynthesis*, to be submitted to Rep. of Prog. Phys. (2018).

[3] K. Mori, T. Kajino, A.B. Balantekin and M. Famiano, *Electron screening effects on ignition of SN Ia*, to be submitted to Astrophys. J. (2018).

[4] T. Suzuki, H. Sasaki, T. Kajino and A.B. Balantekin, *Nuclear structure for the detection of supernova neutrinos*, to be submitted to Phys. Rev. C (2018).

３．本制度に対する意見、要望など【申請者記載欄】
(Any comments on this program【For applicant】)

This is an excellent program and I would not make any significant changes in its operation. I t works very well.

４.本制度に対する意見、要望など【本事業で来訪した共同研究者記載欄】
(Any comments on this program【For joint researcher】)

We could proceed very fruitful discussions in several on-going projects as described above by combining this program with several NAOJ functions for Visiting Scholars. (T. Kajino wrote o n behalf of collaborators; Wako Aoki, M. Famiano, M. Kusakabe, H. Sasaki, K. Mori, Y. Pehli van, C. Deliduman, M.K. Cheoun, T. Hayakawa, T. Suzuki, J. Hidaka, and T. Maruyama.

５.共同研究者の滞在日程(Joint research period)

氏名・所属 （Name・Institution）	A. Baha BALANTEKIN, University of Wisconsin, Madison
滞在日程（Period of stay）	日数(days)
2018年 5月 7 日 ～ 2018年 5月 30日 YYYY/MM/DD ～ YYYY/MM/DD	24 日間(days)
年 月 日 ～ 年 月 日 YYYY/MM/DD ～ YYYY/MM/DD	日間(days)
合 計 (Total)	24 日間(days)