

Activity Report of the NAOJ Visiting Scholar Program

Host Project/Division: Division of Science Name of Host Scientist: Kajino, Toshitaka

Name of Visiting Scholar: Akif Baha BALANTEKIN

Title: Visiting Professor

Period: from 2020/01/22 to 2020/03/06

I. Report from the visiting scholar

[i] Achievement during the period of stay (in comparison with the initial plan)

(Collaborative Research)

During the project period, we have made significant progress on all of the topics relevant to our proposed work.

I. Nucleosynthesis in the era of multi-messenger astronomy:

The targets of “multi-messenger astronomy” is to understand the roles of fundamental interactions, i.e. GW (gravity), neutrino (weak force), photon (electromagnetism), and atomic nuclei (strong force) behind various astronomical phenomena. With graduate student Yudong Luo and Visiting Profs. Michael Famiano and Motohiko Kusakabe as well as Prof. Toshitaka Kajino, we explored screening effects arising from a relativistic magnetized plasma in the early Universe, supernovae and neutron-star-mergers which are the targets in “multi-messenger astronomy”. We first studied intensively the effects with applications to big bang nucleosynthesis (BBN) in the early Universe. The screening potential which depends on the thermodynamics of charged particles in the plasma is altered by the magnetic field. We focused on the impact of screening on the electron capture interaction. Taking into account the correction in BBN arising from a homogeneous primordial magnetic field (PMF), we constrained the epoch at which the PMF was generated and its strength during BBN. Considering such screening corrections to the electron capture rates and using up-to-date observations of primordial elemental abundances, we also discussed the possibility of solving the problem of underestimation of the deuterium abundance. We found for certain values of the PMF strength predicted D and He4 abundances are both consistent with the observational constraints. This work has been published in Phys. Rev. D (2020).

II. Relativistic plasma effects in extreme celestial conditions:

With the graduate students Kanji Mori and Yudong Luo as well as Visiting Profs Michael Famiano and Motohiko Kusakabe in addition to Prof. Toshitaka Kajino, we investigated Coulomb screening and weak interactions in a hot, magnetized plasma. We evaluated Coulomb screening in a relativistic thermal plasma in which electrons and positrons are in equilibrium. In high fields, the electron transverse momentum components are quantized into Landau levels. We evaluated changes in the characteristic plasma screening length at high temperatures and at high magnetic fields and estimated changes in weak interaction rates. It was found that high fields can result in increased beta-decay rates as the electron and positron spectra are dominated by Landau levels. We also evaluated these effects in a simple r-process model. It is found that relativistic Coulomb screening has a small effect on the final abundance distribution. While changes in weak interaction rates in strong magnetic fields

can have an effect on the r-process evolution and abundance distribution, we showed that the field strength required to have a significant effect may be larger than what is currently thought to be typical of the r-process environment in collapsar jets or neutron star mergers. This work is now being prepared for publication.

III. New subjects:

In addition to the research subjects listed in the original application, the rich intellectual environment at NAOJ, where many Japanese and international scientists routinely visit and engage in very fruitful discussions in Prof. Kajino's group, led to new projects. With Profs T. Maruyama, M.-K. Cheoun, and G.J. Mathews we studied neutrino-antineutrino pair synchrotron emission from electrons and protons in a relativistic quantum approach. This process occurs only in the presence of a strong magnetic field, and it is considered to be one of effective processes for neutron star cooling. We calculated the luminosity of these pairs emitted from neutron-star-matter with a magnetic field of about 10^{15} G. We found that the energy loss is much larger than that of the modified URCA process. These pair emission processes in strong magnetic fields is expected to contribute significantly to the cooling of the magnetars. This work has been published. With graduate student Kanji Mori and Prof. Famiano we performed simulations of stellar evolution with additional energy losses due to neutrino magnetic moments or extra dimensions and found that they eliminate the blue loops in the evolution of intermediate-mass stars. We then used the existence of Cepheid stars is used to constrain the neutrino magnetic moment and large extra dimensions. This work is now being prepared for publication.

I discussed many subjects on astronomy and nuclear astrophysics with Prof. Kajino's graduate students of the University of Tokyo, Mr. Yuta Yamazaki, Mr. Yudong Luo, Mr. Kanji Mori and Mr. Hirokazu Sasaki. Some of research results with them were published in journal papers as reported below. I also joined in regular DoS (Division of Science) Seminar and COSNAP (COSmology and Nuclear AstroPhysics) Seminar which are organized by Prof. Kajino's group in Division of Science. I had several talks in these seminars on the research subjects as mentioned above. I also made many valuable discussions with post docs, too.

(Others)

I and Prof. Kajino worked with scientists from Japan (Prof. T. Suzuki, Prof. T. Maruyama) as well as with international collaborations of scientists from US (Prof. M. Famiano, Prof. G. J. Mathews), Korea (Prof. M.-K. Cheoun), and China (Prof. M. Kusakabe) and their graduate students.

[ii] Any comments on this program

I appreciate the hospitality of NAOJ during my stay as a Visiting Professor. This program is indeed a very fruitful and multidisciplinary international collaboration program because we can make intensive and extensive discussions with many experts in various research fields. During my stay several senior collaborators inside Japan and from foreign countries visited Prof. Kajino and we could carry out valuable discussions concerning our on-going and new projects. I strongly support this NAOJ program that is an excellent exchange program under the leadership of outstanding scholar like Prof. Kajino.

Unfortunately due to the COVID pandemic return flights back to the US were drastically reduced forcing me to leave one week earlier. I look forward to my next visit.

[iii] List of publications and presentations by the visiting scholar in collaboration with NAOJ staff or graduate students

(Publications)

- (1) T. Maruyama, A. B. Balantekin, M.-K. Cheoun, T. Kajino, and G.J. Mathews, nnbar- Pair Emission in Neutron-Star Matter based on a Relativistic Quantum Approach, Phys. Lett. B **805**, 135413 (2020).
- (2) Y. Luo, M. A. Famiano, T. Kajino, M. Kusakabe, and A. B. Balantekin, Screening corrections to Electron Capture Rates and resulting constraints on Primordial Magnetic Fields, Phys. Rev. D **101**, 083010 (2020).
- (3) T. Suzuki, S. Chiba, T. Yoshida, A. B. Balantekin, T. Kajino, M. Honma, Y. Tsunoda, N. Tsunoda, and N. Shimizu, Nuclear Weak Rates for Astrophysical Processes in Stars, JPS Conf. Proc. **31**, 011039 (2020).
- (4) T. Kajino, W. Aoki, A. B. Balantekin, R. Diehl, M. A. Famiano, G. J. Mathews, Current Status of r-Process Nucleosynthesis, Prog. Part. Nucl. Phys. **107**, 109 (2019).
- (5) T. Suzuki, A. B. Balantekin, T. Kajino, and S. Chiba, Neutrino- ^{13}C cross sections at supernova neutrino energies J. Phys. G: Nucl. Part. Phys. **46**, 075103 (2019).

(Presentations)

- (1) A. B. Balantekin, Entanglement of Supernova Neutrinos, Tohoku University Graduate Program on Physics of the Universe Seminar, February 13, 2020.
- (2) A. B. Balantekin, Collective neutrino oscillations and quantum information science, NAOJ COSNAP Seminar, February 18, 2020.
- (3) A. B. Balantekin, Distinguishing Dirac and Majorana Neutrinos, Kyoto University Physics Colloquium, February 27, 2020.

II. 以下の項目について、受入教員が記入してください。

Report from the host scientist

[iv] 本制度に対する意見、要望など Any comments on this program

This was a fruitful time for research and discussions with Prof. Balantekin and many other scholars. We completed several ongoing projects and started new ones during his stay at NAOJ Mitaka. The opportunity for our graduate students and post docs to interact with him was inspiring for their development as researchers. I sincerely believe that this program will continuously provide substantial enrichment for all scientists at NAOJ.

I have one concern: In the past the program over two different fiscal years was accepted. It is reasonable because fiscal year system in most foreign countries is from September until next August and because foreign scholars have sabbatical leave according to this regulation. Prof. Balantekin's original application was between January 2020 and May 2021, but it was turned down. It is quite a pity that new NAOJ policy is against international standard.