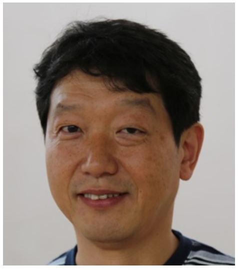
【Grant-in-Aid for Scientific Research (S)】

Broad Section B



Title of Project： r-process nucleosynthesis and role of deformed nuclei

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Research Project Number: 20H05648 Researcher Number：90272137
Keyword：neutron-rich nuclei, nucleosynthesis, β decay, mass, machine learning, neutron merger, supernovae

【Purpose and Background of the Research】

About half of the elements heavier than iron are originated from r-process nucleosynthesis at promising sites such as supernova explosions and binary neutron star collisions. Simultaneous observation of gravitational waves and electromagnetic radiation phenomenon (kilonova) enabled us to identify the binary neutron star collision (GW170817), and confirmed near-infrared light, indicating an evidence of lanthanoid nucleosynthesis. On the other hand, there is no evidence that gold / platinum and uranium were synthesized. The lanthanoid synthesized by the r-process has characteristic peak structure near the mass number A = 165 (Fig. 1-a). However, the mechanism of this peak formation is shrouded in mystery.

There are two hypotheses in lanthanoid nucleosynthesis: the “Nuclear Deformation Cause Theory (NDCT)”[1] and the “Actinide Asymmetric Fission Cause Theory (AAFCT)”[2]. This study focuses on the confirmation of the NDCT and collects data on the masses and β decays of lanthanoid nuclei. The obtained data will be applied to the combined theory with neutral network and deep learning method to search for anomalies. Large scale nuclear data constructed through the cooperation of experiments and theory will be put into calculation for heavy element synthesis calculation. By coordinating the above research systems, we aim to verify lanthanoid nucleosynthesis focusing on the nuclear deformation effect, and to understand comprehensive heavy element nucleosynthesis including gold and platinum associated with neutron magic number N = 126.

【Research Methods】

Uncertainties regarding neutron separation energies (masses), half-lives, and delayed neutron emissions of neutron-rich nuclei are major barriers to quantitative estimation of the r-process. Using spallation reactions of uranium and platinum at the high-intensity heavy ion accelerator facility RIBF, key neutron-rich nuclei in lanthanoid nucleosynthesis will be produced (Fig. 1-b). In order to efficiently collect information on the masses and β decays of the produced rare isotopes, we will introduce a large gas cell device and β decay measuring device. Deep learning method is incorporated into the nuclear theory that takes into account the behavior of the nuclear structure. The deformation magic of the nucleus will be investigated by the systematics and correlation among these nuclear properties. Furthermore, we will construct large-scale nuclear data expanded to unknown nuclear regions together with the uncertainties. The amount of heavy elements synthesized such as lanthanoids, gold and platinum largely depends on the strength of the r-process (electron fraction Ye). Considering the environment of binary neutron stars and supernova explosions, we will verify the lanthanoid nucleosynthesis that incorporates the constructed large-scale nuclear data.

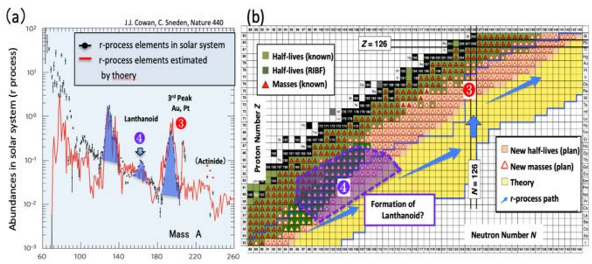

Figure 1 (a) Solar abundance, (b) r-process nuclei

【Expected Research Achievements and Scientific Significance】

The proposed verification of lanthanoid nucleosynthesis is different from the conventional r-process study with neutron magic number N = 50, 82, and 126. The key point is to investigate the anomaly in β decay and neutron separation energies associated with the deformation of nuclei. Although the research strategy focuses on the NDCT, there is a possibility that the hypothesis cannot be confirmed. In that case, the results suggest the AAFCT and indirect evidence of the synthesis of gold, platinum and uranium in GW170817. In this case, quantitative heavy element synthesis including gold and platinum will be studied.

【Publications Relevant to the Project】

・ [1] R. Surman et al., Phys. Rev. Lett. **79** (1997) 1809.
・ [2] S. Goriely et al., Phys. Rev. Lett. **111**, 242502 (2013).

【Term of Project】 FY2020- 2024

【Budget Allocation】 146,400 Thousand Yen

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