【Grant-in-Aid for Specially Promoted Research】

Spectroscopy of unknown actinide nuclei to elucidate the origin of uranium

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Purpose and Background of the Research

●Outline of the Research

What is the origin of elements in nature? It is one of the fundamental questions of natural science. The element is determined by the number of protons (atomic number) in the atomic nucleus, which exists at the center of the atom. Nuclei in stars cause fusion with other nuclei, or absorption of neutrons followed by beta decay, synthesizing elements with higher atomic numbers. Furthermore, in an explosive celestial environment with extremely high temperatures and a high neutron density, nuclei repeatedly absorb multiple neutrons and undergo beta decay, synthesizing elements with atomic numbers higher than uranium in just a few seconds. It is called the rapid neutron capture process (r-process), and is the only process that is the origin of uranium and thorium. Gravitational collapse supernovae, and binary neutron star mergers are considered candidates for r-process astronomical sites. In order to identify the physical environment and celestial sites of the r-process, interdisciplinary research involving astronomy, astrophysics, and nuclear physics is required (Figure 1). Most of nuclei involved in the r-process, which proceeds by synthesizing nuclei with an extremely large excess of neutrons, are unknown, and predictions of their mass and lifetime using theoretical models are crucial for simulations of r-process nucleosynthesis. Uncertainties exist in the predicted values, which also creates uncertainties in nucleosynthesis simulations. In neutron-rich nuclei, where the number of neutrons is much larger than that of protons, evaluation of the symmetry energy caused by the difference in the number of protons and neutrons is significant for its stability. In this research, we will acquire nuclear spectroscopic data for a wide range of neutron-rich actinide nuclei, reduce theoretical uncertainties in evaluating symmetry energies and understanding nuclear structure, and develop more reliable nuclear models in order to achieve comprehensive understanding of r-process nucleosynthesis.

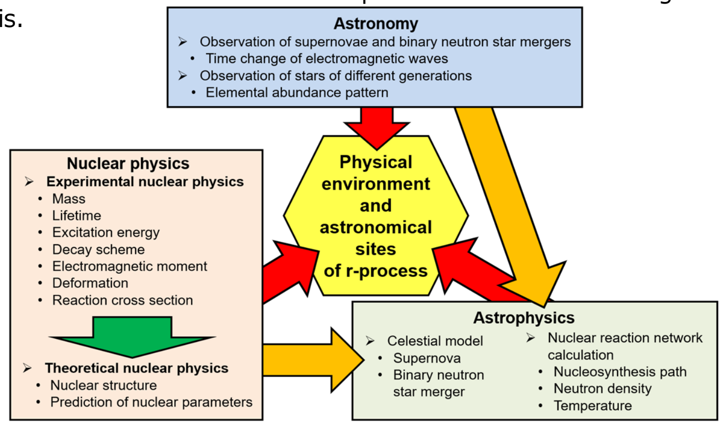

Figure 1. Image of the elucidation of r-process nucleosynthesis through this research

Expected Research Achievements

Neutron-rich actinide nuclei are synthesized by multinucleon transfer (MNT) reactions. Accelerated heavy ions are irradiated onto a target, causing two nuclei to collide with each other at low energy, and neutrons and protons are exchanged between them. Because various kinds of nuclei are synthesized simultaneously, and they are emitted from the target at low energy and specific angles, and have a wide energy and angle distribution, it is difficult to use MNT reactions for spectroscopic experiments. In this research, we will overcome this difficulty by constructing a device called KISS-1.5, shown in Figure 2, in the RIKEN RIBF facility. We have developed a device called KISS, which collects radioactive isotopes (RIs) synthesized through MNT reactions in argon gas, converts them into neutral atoms, element-selectively ionizes them by irradiating them with lasers, and mass-separated them by a dipole magnet for their high-purity nuclear spectroscopy. In KISS-1.5, RIs synthesized through MNT reactions are collected as ions in helium gas and extracted swiftly using electric fields. The extracted reaction products can be precisely mass measured using a multi-reflection time-of-flight mass spectrometer (MRTOF-MS), and ions in a specific mass range can be transported through a variable mass-range separator for their precise mass measurements by MRTOF-MS, or their decay nuclear spectroscopy after identifying them by precise mass measurements. Figure 3 is a part of the nuclear chart showing the years of discovery of neutron-rich isotopes from bismuth (Bi) to berkelium (Bk). No neutron-rich isotopes of elements from thorium (Th) to berkelium have been discovered since 1999. We discovered ^{241}U with KISS and succeeded in measuring the masses of ^{241}U and ^{242}U for the first time. KISS-1.5 will aim at efficacy 100 to 1000 times that of KISS, and will synthesize more than 80 species of new neutron-rich actinide nuclei in the area surrounded by the dotted line in Figure 2 to perform their mass spectroscopy and decay spectroscopy for the refinement of the nuclear models toward the elucidation of r-process nucleosynthesis.

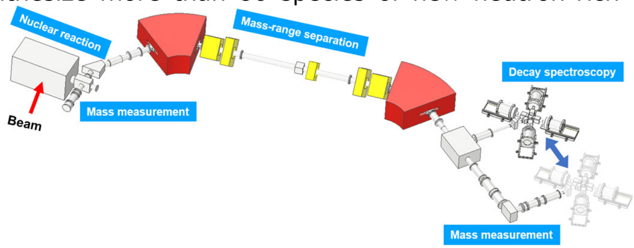

Figure 2. Schematic view of KISS-1.5

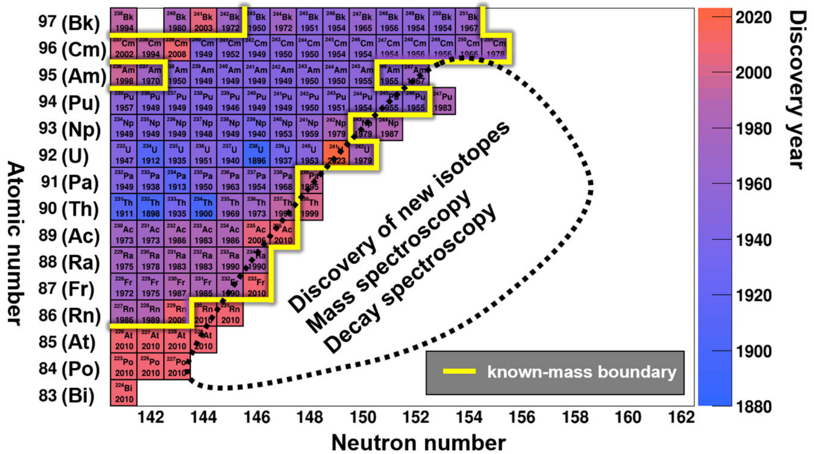

Figure 3. Discovery years of neutron-rich actinides and area of interest in this research

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