R-process Nucleosynthesis in the MHD+neutrino-heated Collapsar Jet

NAKAMURA, Ko (Waseda University)
KAJINO, Toshitaka, SATO, Susumu, HARIKAE, Seiji (NAOJ/University of Tokyo)
MATEHWS, Grant J. (University of Notre Dame)

Nucleosynthesis by a process of rapid neutron-capture (the r-process) accounts for about a half of the abundance of nuclei heavier than iron. Two possible astrophysical sites of r-process production, supernovae and neutronstar mergers, have been discussed by many researchers. In the case of supernovae, neutrino-driven wind from a central proto-neutronstar was XXX. Recent state-of-the-art numerical simulations, however, do not produce high-entropy and neutron-rich conditions necessary for r-process. For neutronstar merger models, the low rate and the long time delay of binary mergers are incompatible with the history of Galactic chemical evolution deduced from observations of r-process elements in metal-poor stars.

In this article [1], we consider long-duration gamma-ray bursts (LGRBs) as another astrophysical site for the r-process. The collapsar model [2] is a favored model for the formation of observed LGRBs. In the collapsar model, the central core of a rotating massive star collapses to a black hole and forms an accretion disk around the black hole. Harikae et al. [3] simulated LGRB evolution based on the collapsar scenario and found that a relativistic jet along the polar axis can be launched, mainly powered by heating from the pair annihilation of thermally generated neutrinos emanating from this accretion disk. In order to follow the evolution of mass elements in the jet, we have employed 20,000 tracer particles moving with the material. We have followed the time evolution of temperature, density, and electron fraction (Y_e) for the tracer particles and calculated nucleosynthesis by means of a large nuclear network involving about 5,000 nuclei.

Of the 20,000 tracer particles, 1289 of them were determined to be participating in the jet. About a half of them have high electron fraction ($Y_e > 0.4$) and r-process is unlikely. On the other hand, some particles show very neutron-rich composition ($Y_e \sim 0.1$). They also present a wide variety of entropy per baryon in unit of the Boltzmann constant (S/k_B) from ~ 10 to more than 1,000.

Figure 1 shows the final isotopic abundance distribution for all 1289 particles emitted in the jet. Here, we can see that this collapsar simulation produces elements up to the mass number A = 195 r-process peak. We found that particles with very high entropy per baryon ($S/k_B \sim 1,000$) can produce heavy elements up to the third r-process abundance peak and even beyond to the actinides. On the other hand, particles with relatively low entropy per baryon ($S/k_B \sim 100$) only produce light elements up to the 2nd r-process peak as is evident in Figure 1. The elemental abundances with $140 < A < 180$ is referred to the *universality* region and approximately reproduced by our calculations.

Our results, however, includes some problems such as the r-process peaks appearing at slightly higher mass numbers. Further investigation is necessary to evaluate the role of LGRBs in r-process nucleosynthesis.

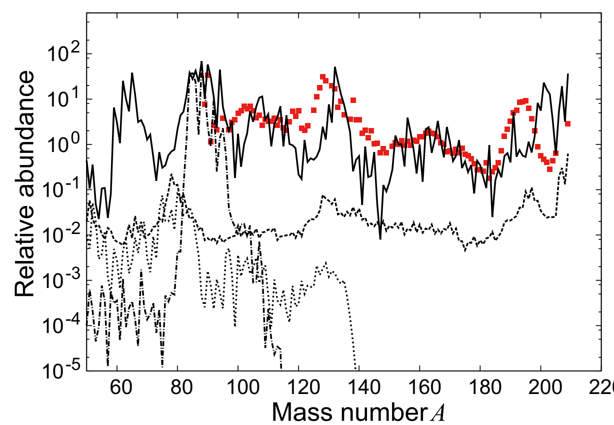

Figure 1: Calculated r-process abundance pattern (solid line) in long-duration gamma-ray bursts, compared with solar-system r-process abundances (red). Yields are normalized to ^{153}Eu. Dotted, dashed and dot-dashed lines display respectively the abundance yields for the typical flows of high (S/k_B = 1000), intermediate (100) and low (25) initial entropy/baryons.

References

[1] Nakamura, K., et al.: 2015, *A&A*, **582**, A34.
[2] Woosley, S. E.: 1993, *ApJ*, **405**, 273.
[3] Harikae, S., Takiwaki, T., Kotake, K.: 2009, *ApJ*, **704**, 354.