Astrophysical Impact of New β-decay Half-lives on *r*-process Nucleosynthesis [1]

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Rapid neutron capture process (*r*-process) is responsible for the origin of approximately half of the elements heavier than iron. Despite of several decades of theoretical studies and observational progress, the astrophysical sites for *r*-process nucleosynthesis are unknown.

Physical conditions for the *r*-process are well constrained. It is evident that the *r*-process occurs via a sequence of rapid neutron captures on neutron-rich isotopes far from stability. The relative abundance of *r*-process elements is then determined by the relative β-decay rates along this *r*-process path, i.e., slower β-decay lifetimes result in higher abundances.

In this context, it is of particular interest that β-decay half-lives of 38 neutron-rich isotopes including ^{100}Kr, $^{103\text{–}105}$Sr, $^{106\text{–}108}$Y, $^{108\text{–}110}$Zr, ^{111,112}Nb, $^{112\text{–}115}$Mo, and ^{116,117}Tc have been measured at the recently commissioned radioactive isotope beam factory (RIBF) facility at the RIKEN Nishina Center [2]. Newly measured lifetimes are an improvement on existing measurements and a number of them were measured for the first time.

We performed nucleosynthesis calculations for ejecta from the MHD supernova model [3] with the three different reaction networks. These are extensions of the basic network described in [3,4]. First, we adopt FRDM theoretical rates [5] from the REACLIB compilation [6] as standard. The other two (RIBF and RIBF+) utilize the new experimental β-decay half-lives and two versions of the theoretical FRDM β-decay rates for the other isotopes. The RIBF network replaces the FRDM rates with the new measured ones where possible. The network (RIBF+) is based on the RIBF network and FRDM rates with modified Q values for (n, γ) for A = 97–115 isotopes based on the new suggested masses.

Figure 1 shows the final abundance distribution with the solar system abundances [7]. The newly measured β-decay rates in this mass region might shift the β-flow equilibrium thereby filling in the low abundances near $A \sim 120$. The abundances in the A = 110–120 region however are only slightly enhanced. Although the new rates provide a little assistance in enhancing the abundances near the valley, they do not alleviate this problem.

We note that the *r*-process ow moved farther away from stability and proceeded faster in the RIBF+ network in which the (n, γ) Q values were systematically enhanced for isotopes with A = 104–115. This helped to fill in the abundances in the higher mass region with $A \geq 115$. Thus, it is important to measure the masses and/or neutron separation energies in this region.

Furthermore, our results suggest that nucleosynthesis in the LEPP (light-element primary process) elements with $A \leq 120$ observed in some ultra-metal-poor stars [8], also is sensitive to the nuclear physics uncertainty from β-decay rates in this region. Hence, further studies on both the nuclear physics and astrophysics of the synthesis of elements with $A \sim 110$–120 are warranted.

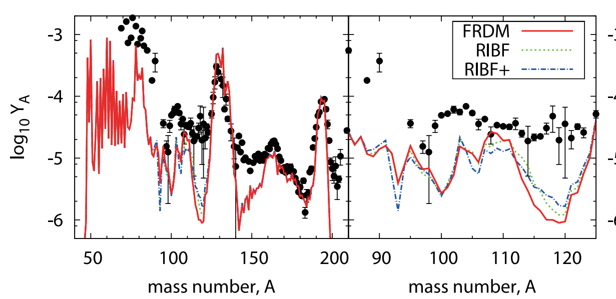

Figure 1: Total final abundance distributions of *r*-process elements from the adopted MHD supernova model with observed solar system abundances (black dots, taken from [7]). Red solid, green dotted, and blue dashed lines correspond to results from using the FRDM (standard), RIBF, and RIBF+ rates, respectively.

References

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