EURICA!

~ Secrets Revealed via Decay Spectroscopy of Exotic Nuclei ~

EURICA: A state-of-the-art decay spectrometer

~ Exploring exotic nuclei with high-efficiency and high-resolution equipment ~

The RIBF in Japan, one of the world’s most powerful radioactive beam facilities, has been providing intense beams of exotic nuclei since 2007. Following the success of the first decay spectroscopy experiments in 2009, which focused on the study of neutron-rich nuclei with masses of around A = 100-117, a world-class decay project called EURICA (Euroball-RIKEN Cluster Array)† was launched owing to the efforts of 190 international collaborators. This state-of-the-art spectrometer, which consists of twelve Euroball HPGe cluster detectors (formerly GSI RISING) and the highly-segmented RIKEN β-ray detector WAS3ABi, markedly improves the performance of high-resolution decay spectroscopy of exotic nuclei with fast radioactive beams. EURICA has been in operation since 2012, and has harvested the decay properties of several hundred exotic nuclei. The lifetimes and level schemes of isotopes produced in BigRIPS can be deduced by measuring the times of flight, trajectories, and energies of the isotopes, and their subsequent β and γ rays emitted in the β-γ decay.

β-decay half-lives and nuclear astrophysics

~ How and where were the heavy elements produced in the universe? ~

The β-decay half-lives of isotopes with production rates as low as several events per day were measured using the EURICA spectrometer. In the fall of 2012, the half-lives of neutron-rich nuclei in the vicinity of ^{78}Ni (Z=28, N=50) were investigated using WAS3ABi, a device that consists of 8 layers of double-sided silicon-strip detectors (shown in the image on the right). The results are summarized in Figure 1. The systematics of the half-lives indicate a sudden decrease beyond N=50 (^{79,80}Ni) and below Z=28 (^{77}Co), thus providing robust evidence for a doubly magic ^{78}Ni.

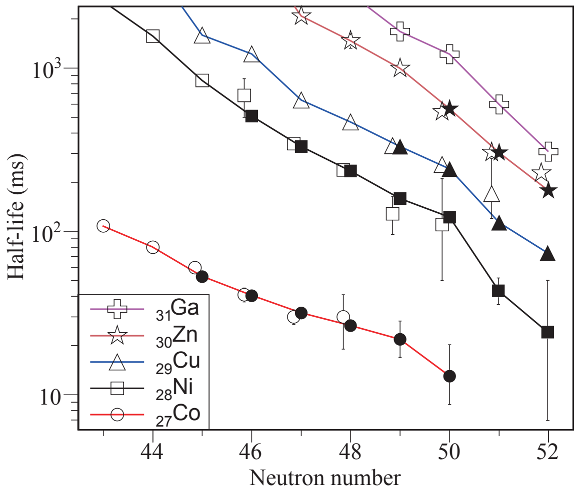

Figure 1: Experimental half-lives as a function of neutron number for the Z=27–31 isotopic chains. The filled and open symbols represent half-lives measured by EURICA and other experimental setups, respectively.

The decay properties of exotic nuclei are also key to uncovering some of the long-standing mysteries of the astrophysical rapid-neutron capture process (r-process), namely, the main astronomical site(s) and its mechanism. The r-process is a sequence of neutron-capture and β-decay processes that is known to be responsible for the synthesis of approximately half of the elements heavier than iron. Nuclear physics inputs, for example, nuclear masses (Q_β), neutron-capture rates, β-decay half-lives, and β-delayed neutron emission probabilities of very neutron-rich nuclei, are expected to play a significant role in the understanding of the mechanism and site(s) of the r-process. Figure 2 summarizes the nuclei surveyed with EURICA at the RIBF. A first attempt to study the universality of the astrophysical r-process was performed by measuring the β-decay half-lives of 110 neutron-rich nuclei around mass A=100-140, where 40 half-lives were measured for the first time. As shown in Figure 3, the reaction-network calculations of supernova nucleosynthesis with the new half-lives indicate that the (n,γ)↔(γ,n) equilibrium is still valid, and reproduces the universality of the elements with $Z > 56$.

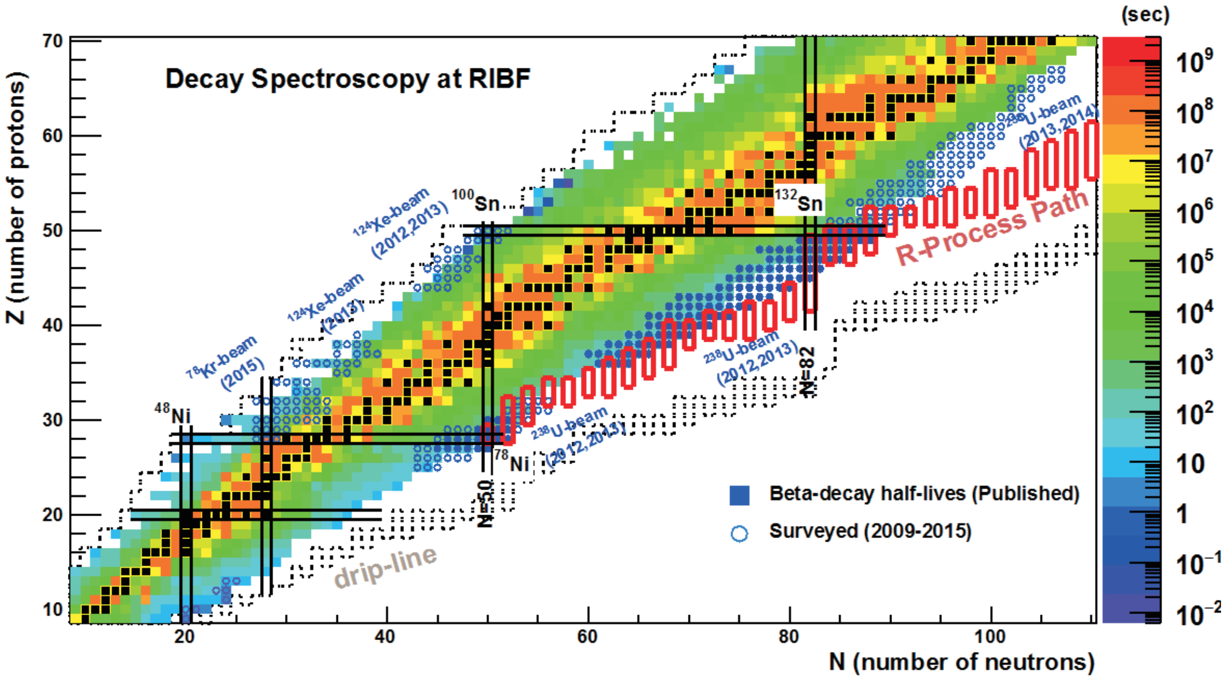

Figure 2: Summary of the nuclei surveyed with EURICA, where known half-lives are presented in color. The open circles indicate the data collected prior to the Kr beam campaign in 2015. The results are presented in S. Nishimura et al. PRL 106, 052502 (2011), Z.Y. Xu et al. PRL 113, 032505 (2014), and G. Lorusso et al. PRL 114, 192501 (2015).

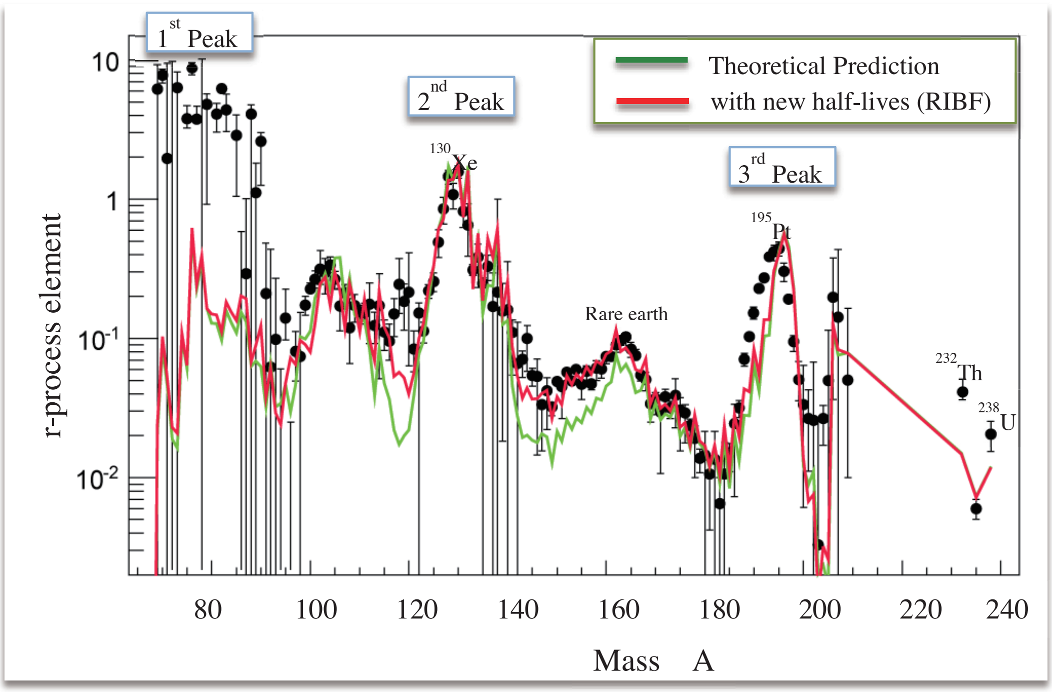

Figure 3: Abundances of r-process elements compared with estimations of reaction-network calculations of supernova nucleosynthesis.

Magicity and deformation

~ The magic numbers 28, 50, and 82, and regions far from the valley of stability ~

Understanding nuclear shell structure and its evolution toward the drip-lines is one of the major topics in nuclear structure research as well as nuclear astrophysics. One of the main goals of EURICA is to study the shell gaps around the doubly magic nuclei ^{78}Ni (Z=28, N=50), ^{132}Sn (Z=50, N=82), and ^{100}Sn (Z=50, N=50), where a possible weakening of the magicity and shell quenching effects have been discussed. Figure 4 provides a compilation of the energies of the first excited states in even-even nuclei obtained via γ rays from isomers and β-delayed γ rays from daughter nuclei. In addition, detailed level schemes were deduced for ^{116,118}Ru, ^{129}In, and ^{131}In via the β-delayed γ rays of ^{116,118}Tc, ^{129}Cd, and ^{131,132}Cd, respectively, and long-lived isomers in ^{126}Pd and ^{131}Cd were identified via internal conversion. Some of the EURICA results from 2012 are related to low-lying states in neutron-rich nuclei that contribute to the formation of the r-process peak around mass A~130. Further systematic studies on shell evolution of both neutron- and proton-rich nuclei have been conducted using β-γ spectroscopy with EURICA at the RIBF and will be reported in the future.

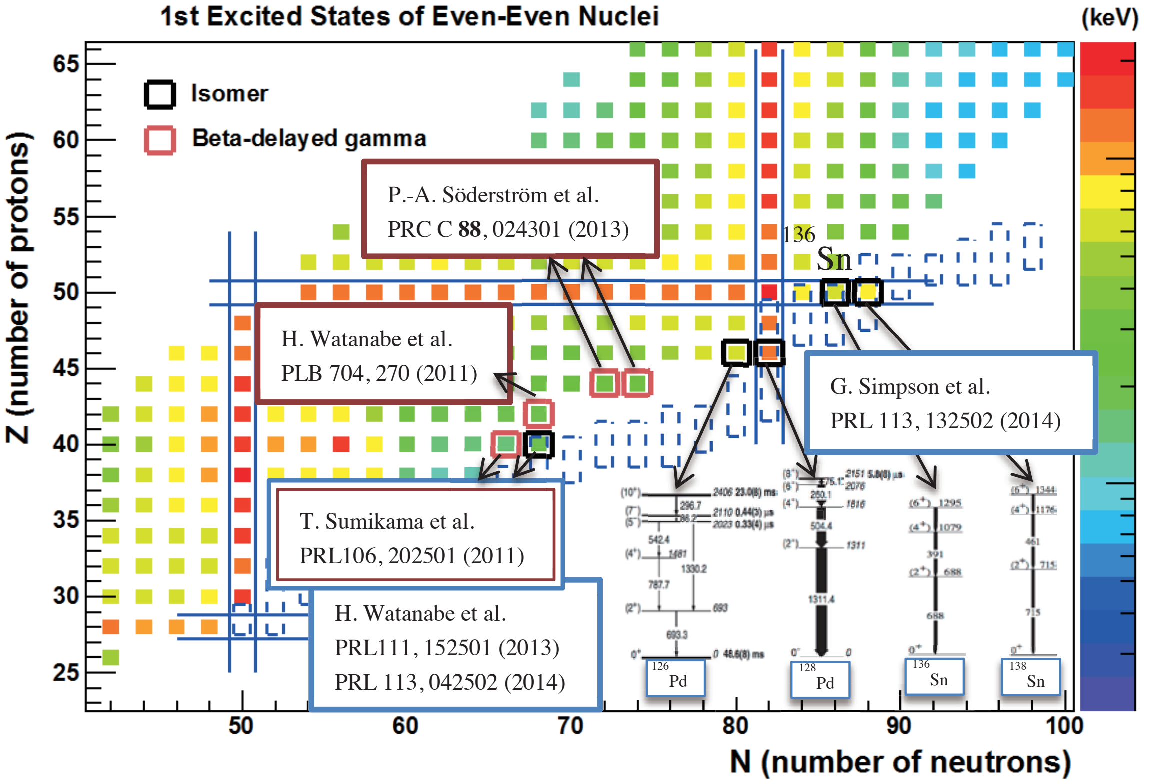

Figure 4: Overview of first excited state energies in even-even nuclei obtained via γ rays from isomers and β-delayed γ rays from daughter nuclei.

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