Solving the "Stellar ^{62}Ni Problem" with AMS

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The nucleosynthesis of elements heavier than iron can be almost completely ascribed to the *s* process ("slow neutron capture process") and the *r* process ("rapid neutron capture process"). The *s* process can be further divided into a "weak" component (responsible for nuclei up to $A \approx 90$) and a "main" component (for $90 < A < 209$), which occur in different astrophysical scenarios at different temperatures and with different neutron exposures. The weak *s*-process occurs during core He or shell C burning in massive stars. Among the nuclei involved, the long-lived radioactive isotopes ^{63}Ni ($t_{1/2}$= 100.1 yr), ^{79}Se ($t_{1/2} \approx$480000 yr), and ^{83}Kr ($t_{1/2}$= 10.76 yr) assume key positions, because their β^--decay rate becomes comparable to the neutron capture rate ($\lambda_\beta \approx \lambda_n$). The resulting competition leads to branchings in the *s*-process nucleosynthesis path. In the case of ^{63}Ni the split of the reaction path causes part of the reaction flow to bypass ^{64}Zn, whereas at ^{66}Zn both flows merge back. The reaction flow to the higher mass region depends not only on the abundances of the seed nuclei but on their stellar neutron capture cross sections as well. Generally, these cross sections can be determined directly by measuring the prompt γ-rays associated with the neutron capture reaction via the time-of-flight method (TOF). A method to include also the "direct capture" (DC) component of the capture process is to measure the activity of the product nuclei - if unstable - after the irradiation, applying the so called activation method. The determination of neutron cross sections by means of the activation technique represents an important complement to measurements using the TOF method since this independent approach implies different systematic uncertainties. In combination with accelerator mass spectrometry (AMS) the activation technique can be extended to hitherto inaccessible cases, e.g. to reactions producing very long-lived nuclei with very weak or completely missing γ-transitions. The application of AMS counting in stellar neutron reactions has the further advantage of being independent of uncertain γ-ray intensities.

An accurate knowledge of the stellar neutron capture cross sections of ^{62,63}Ni is required since these two cross sections affect the entire weak *s*-process flow towards heavier nuclei. Since almost 20 years there were a lot of discussions and predictions for the ^{62}Ni$(n,\gamma)^{63}$Ni cross section at kT=30 keV. The first measurement via TOF [1] yielded $<\sigma>_{30}$=26.8±5.0 mb. Dependent on how the DC component is calculated, the result can change to 12.5 mb [2] or 35.5 mb [3]. The lower cross section is derived if a subthreshold resonance is subtracted at thermal energies before the DC cross section is extrapolated with *s*-wave behavior into the stellar keV-region [2]. Recent stellar models using $<\sigma>_{30}$=12.5 mb revealed a strong overproduction of ^{62}Ni in postexplosive production factors of supernova type II explosions in a 15 $M_\odot$ star, which intensified the question if this is due to uncertainties in the stellar models or in the nuclear input [4].

The ^{62}Ni(n,γ) cross section has been measured in the last three years repeatedly with both, the TOF method [5,6] and with the activation method plus AMS [7,8] to solve the "^{62}Ni problem". Whereas both TOF measurements deviate (see Fig. 1), the results from the AMS measurements agree. Both activations in [7,8] were carried out with the quasi-stellar neutron spectrum produced by the ^{7}Li$(p,n)^7$Be at the (now closed) 3.7 MV Van de Graaff accelerator at Forschungszentrum Karlsruhe. The ^{63}Ni/^{62}Ni ratio of the first sample was measured at Argonne National Lab [7]. The second measurement consisted of two independently irradiated samples [8], which were measured with the GAMS setup. The (preliminary) result yielded $<\sigma>_{30}$=23.4±4.6 mb, in perfect agreement with the previous AMS measurement.

Further AMS measurements are planned to decrease the statistical error of our measurement, but already now one can say that the "^{62}Ni problem" is solved from the nuclear physics side, and a weighted average of $<\sigma>_{30}$=26±4 mb from [1,6,7,8] can be recommended for future stellar modeling.

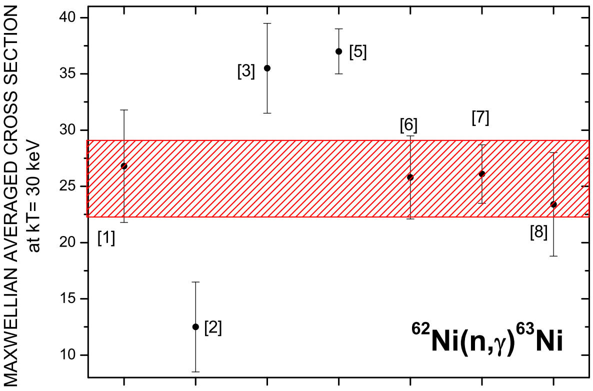

Fig. 1: Comparison of experimental Maxwellian-averaged cross sections at kT= 30 keV. The band shows the weighted average.

References

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