Neutron captures and the r-process

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Based on the early description of the electric dipole (E1) strength function of Kadmenskii et al. [1], in a more recent paper Goriely [2] has studied the possible relevance of the existence of a "pygmy" dipole resonance (PDR) in the low-energy tail of the giant dipole resonance (GDR) for neutron-capture cross-section ($\sigma_{n,\gamma}$) calculations. Under certain conditions, i.e. for nuclei where the PDR lies close to the neutron separation energy (S_n), the author predicts local enhancements of the Hauser-Feshbach cross sections by more than a factor 100. If confirmed experimentally, this would result in pronounced consequences for the r-abundance distribution.

To our knowledge, for the first time results from an experiment aimed on the determination of the GDR and the low-lying E1 PDR on medium-heavy, neutron-rich isotopes have been obtained at the LAND-FRS facility of GSI [3]. With respect to possible astrophysical consequences, the measured position of the PDR in ^{130}Sn and ^{132}Sn is of major interest, because some earlier models have predicted considerably lower energies of the PDR in neutron-rich nuclei, in the vicinity of their S_n values. With the known E(PDR)=9.8 MeV and S_n=7.3 MeV in ^{132}Sn, we now can conclude that at least for this isotope, and presumably for the whole A≃130 mass region of astrophysical interest, there will be no significant enhancement of the $\sigma_{n,\gamma}$ value due to the PDR. This is in contrast to what one would extract from e.g. Fig. 3 of [2]. Moreover, we are unable to reproduce the r-abundance calculations shown in Fig. 6a of [2] by any combination of realistic nuclear and astrophysical parameters.

In order to investigate the actual impact of altered $\sigma_{n,\gamma}$ values of r-process nuclei, we have performed a series of full dynamic network r-process calculations in the model of an adiabatically expanding hot entropy bubble [4, 5]. For the calculations shown below, the seed abundances for the r-process were obtained from an α-rich freeze-out of a charged-particle network. For the subsequent r-process, an almost instantaneous (n,γ)–(γ,n) equilibrium is established at the onset of the r-process. Therefore, only late-time neutron captures are important, which are then expected to mainly modify the abundances around the r-process peaks at A≃130 and 195.

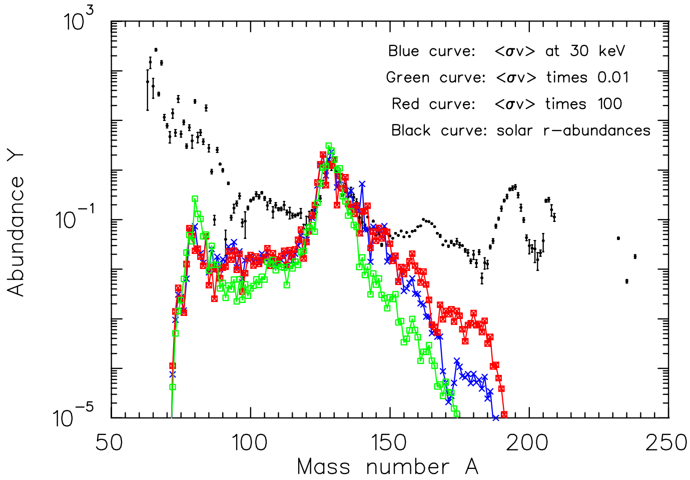

Figure 1: Decayed final abundances of the S=196-entropy component. The neutron capture rates are changed in a range of 4 orders of magnitude.

Fig. 1 shows a snapshot for a parameter combination of Y_e=0.45, S=196 and an expansion time scale of 35 ms, which is representative for the formation of the A≃130 r-abundance peak. In order to take into account considerable uncertainties in the $\sigma_{n,\gamma}$ values, we have scaled the "standard" rates of [6] up and down by a factor 100. Fig. 2 shows the corresponding curves for the development of the neutron number densities as a function of time, again for the above three asumptions on the capture rates. As is clearly evident from Fig. 1, even these large variations in the $\sigma_{n,\gamma}$ values do not affect the final r-abundances in the A≃130 peak region, despite the different – but still "fast" – freeze-out behavior shown in Fig. 2. However, components with high entropies, which synthesize heavier r-process nuclei (A>140), tend to freeze out slower. Here, late-time neutron captures on nuclei near stability – and not on isotopes in the initial r-process path – can modify the final abundance pattern, in particular around the A≃195 peak [5].

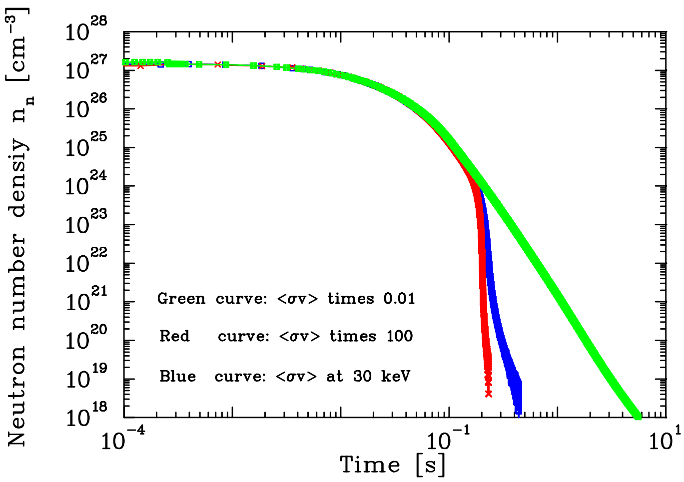

Figure 2: Time evolution of the neutron number density. For $n_n \leq 10^{17}$ ($<\sigma v>$) and $n_n \leq 10^{18}$ ($<\sigma v>\times 100$), the available neutrons are completely exhausted.

References

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