Impact of uncertainties in nuclear reaction cross sections on nucleosynthesis beyond iron

T. Rauscher

Department of Physics, Univ. of Basel, 4056 Basel, Switzerland
Centre for Astrophysics Research, Univ. of Hertfordshire, Hatfield AL10 9AB, United Kingdom

Low-energy reaction cross sections are required to determine astrophysical reaction rates and to constrain the production of nuclides in various astrophysical environments. Even along stability not all rates can be constrained experimentally and combinations of experimental data and nuclear theory have to be used. Furthermore, off stability only theoretically predicted reaction rates are used in nucleosynthesis calculations, both for neutron-rich and proton-rich nuclides. In the first part of my talk I will very briefly outline some open problems in theoretical predictions for neutron-, proton-, and alpha-induced reactions on intermediate and heavy nuclei, close to and off stability, and impacting nucleosynthesis beyond Fe.

In the main part of the talk I will address an important question in the context of astrophysical applications: how uncertainties in nuclear cross sections and rates propagate into the final isotopic abundances obtained in nucleosynthesis models. This information is important for astronomers to interpret their observation data, for groups studying the enrichment of the Galaxy over time with heavy elements, and in general for disentangling uncertainties in nuclear physics from those in the astrophysical modelling. We developed a new method based on a Monte Carlo (MC) method to allow large-scale studies of the impact of nuclear uncertainties on nucleosynthesis. The MC framework “PizBuin” can perform postprocessing with large reaction networks of trajectories obtained from a variety of nucleosynthesis sites. Temperature-dependent rate uncertainties combining realistic experimental and theoretical uncertainties are used. This is necessary because experiments can only constrain ground state contributions to the stellar rates. From detailed statistical analyses uncertainties on the final abundances are derived as probability density distributions. Furthermore, based on rate and abundance correlations an automated procedure to identify the most important reactions in complex flow patterns from superposition of many zones or tracers is used. This method is superior to visual inspection of flows and manual variation of limited rate sets.

The method so far was already applied to a number of processes: the gamma-process in core-collapse supernovae, the production of p-nuclei in white dwarfs exploding as thermonuclear (type Ia) supernovae, the weak s-process in massive stars, the main s-process in AGB stars, and the neutrino-p process for a large range of conditions in various sites. Especially the studies of nucleosynthesis in thermonuclear supernovae and for the neutrino-p process were computationally very demanding and necessitated the use of the HPC system DiRAC in the UK. The full reaction network containing about 3000 nuclides had to be run several 10^7 times. Highlights from these results and from those for the other processes will be presented, demonstrating the impact of current nuclear rate uncertainties on astrophysical simulations.