Uncertainties in γ-process nucleosynthesis from nuclear physics and astrophysics

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The Monte Carlo (MC) code PizBuin was developed to study nuclear uncertainties by post-processing large reaction networks with trajectories obtained from a variety of nucleosynthesis sites and performing large-scale MC variations using temperature-dependent rate uncertainties combining experimental and theoretical uncertainties [1]. Considering temperature-dependent uncertainties is essential especially for explosive nucleosynthesis, where reactions on excited states dominate the reaction rate and experimental ground state cross sections cannot constrain the stellar rates [2,3]. Realistic uncertainties on the final abundances are derived as probability density distributions. Correlations of rates with abundances allow to identify key reactions in complex flow patterns from superposition of many zones or tracers.

Results obtained for the γ-process in exploding massive stars [1] and in thermonuclear supernovae [4] (exploding white dwarfs, SNIa) are presented. For the study of massive stars exploding in a core-collapse supernova (ccSN), more than 100 zones from a modern 1D stellar model experiencing explosive burning were combined. The computationally very demanding study of SNIa combined more than 4600 tracers from a 2D explosion to determine overall uncertainties originating from uncertainties in the nuclear input and the associated key reactions. Comparing the ccSN and SNIa results it is found that the SNIa uncertainties are smaller and fewer key reactions can be identified. This is due to the larger range of conditions encountered in thermonuclear supernovae, causing a multitude of possible flow patterns, avoiding bottlenecks and diminishing the impact of uncertainties in specific, isolated reaction rates.

Astrophysical modelling uncertainties were studied by comparing MC results from two stellar models for ccSN explosions [1]. This comparison showed that the differences can be understood mainly by the different zoning schemes chosen and not by differing details of the stellar evolution or explosion. We also compare the yields of two further ccSN calculations where production of p nuclides proceeds in different regions of the star, due to the details of the applied mixing and assumed explosion [5]. The final abundances of a few p nuclides were found to differ but the underlying reaction paths and thus nuclear physics uncertainties remained similar. Regarding SNIa, despite of the fact that we used a particular 2D model of a white dwarf explosion, separately studying high density and low density regions allowed to draw more general conclusions, also applicable to other explosion models. Again, uncertainties in the SNIa results are smaller due to the already low initial uncertainties and low number of key reactions [4]. This is very relevant as Galactic Chemical Evolution calculations found that SNIa contribute much stronger than ccSN to the total budget of solar p abundances [5].

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