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New tool for sensitivity studies of r-process nucleosynthesis —a case study of the rare earth peak

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The rapid neutron capture process (r-process) is a complex nucleosynthesis mechanism for the creation of heavy nuclei, which occurs under extreme astrophysical conditions, such as binary neutron star mergers and core-collapse supernovae. Not only are the predictions of the r-process abundance pattern affected by such astrophysical conditions, the calculations also involve thousands of neutron-rich nuclides. While many of the neutron-rich nuclei may become experimentally accessible in the near future, it is important to accurately estimate the influence of each nuclear observable, such as masses, β-decay half lives, neutron capture cross sections, in order to guide the experimental efforts and effectively reduce the nuclear physics uncertainties in the r-process simulations.

In order to achieve such goals, a sensitivity analysis can be employed to assess the influence of the nuclear observables in the nuclear reaction network calculations. We introduce a novel technique called "variance-based sensitivity analysis" method, which not only can provide accurate estimates of interpretable sensitivity indices, but also allows us to gain insights into the dependences of the calculated abundances on the nuclear physics inputs through the inspection of Monte Carlo samples. In this presentation, we point out several limitations of the previously introduced sensitivity analysis methods, and discuss how our method can overcome them and extend the framework to correlated inputs/outputs. We demonstrate our method using experimental β-decay data from the BRIKEN campaign as well as several theoretical models, focusing on the rare-earth peak of the r-process abundance peak at $A \sim 165$. The rare-earth peak is postulated to form during the freeze-out of the r-process nucleosynthesis, when the neutrons in the environment are almost exhausted, and neutron captures and beta-decays operate on similar time scales while the material decays back to stability. Our new sensitivity analysis can be utilized to understand the competition of β-decays and neutron captures with respect to the formation of the rare-earth peak during the freeze-out, by analyzing the Monte Carlo samples generated for the sensitivity analysis.

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