Canadian Association of Physicists

Association canadienne des physiciens et physiciennes

Contribution ID: **429** Type: **Oral Competition (Graduate Student) / Compétition orale (Étudiant(e) du 2e ou 3e cycle)**

(G*) Statistical studies of astrophysical reaction network calculations with correlated uncertainties of nuclear observables

Thursday, June 10, 2021 12:20 PM (10 minutes)

The rapid neutron capture process (r-process) is a complex nucleosynthesis mechanism for heavy nuclei, which occurs under extreme astrophysical environments, such as binary neutron star mergers and core-collapse supernovae. It involves thousands of neutron-rich isotopes and the vast majority of them are not yet experimentally accessible. Therefore, the r-process abundance calculations have to rely on theoretical values of nuclear observables to determine various reaction rates. The choice of the nuclear physics models, as well as the uncertainty within the models themselves, can induce large uncertainties on the calculated abundance pattern. Mumpower *et al.* (2016, 2017) have opened up a way to perform a series of statistical studies on the r-process including uncertainty quantification, sensitivity analysis, and reverse engineering of the nuclear observables. In their work, a constant size of uncertainty on the baseline mass model was propagated by recalculating the nuclear reaction rates for each set of perturbed masses. This assumes no uncertainties on the reaction rate calculations, and in general, uncertainties on nuclear models are not available.

In this work, we develop a method to incorporate such uncertainties, especially in the presence of correlated observables, into various statistical inference tasks. Specifically, we estimate and explicitly model the uncertainties on the masses and β-decay half-lives, and their correlations in the rare-earth region ($A = 150$-180), based on an ensemble of theoretical frameworks, including Skyrme-QRPA, relativistic QRPA, and pnFAM. Theoretical β-decay half-lives are calculated for a range of Q_β-values and their distributions are modelled with Gaussian processes. We then use these distributions to perform Monte Carlo uncertainty estimation for the r-process abundance pattern and variance-based global sensitivity analysis. Furthermore, we discuss emulation of the reaction network calculation code PRISM using artificial neural networks, which greatly reduces the computational cost. This is an essential tool for performing the reverse engineering of nuclear observables without constraining the form of the solutions. Applicability of this method for other reaction rates will also be discussed.

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Session Classification: R1-5 Theory II (DNP) / Théorie II (DPN)

Track Classification: Nuclear Physics / Physique nucléaire (DNP-DPN)