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Universality of abundances in r-process nucleosynthesis

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The abundance of about half of the stable nuclei heavier than iron via the rapid neutron capture process or r-process is intimately related to the competition between neutron capture and β-decay rates, which ultimately depends on the binding energy of neutron-rich nuclei. The well-known Bethe-Weizsäcker semi-empirical mass formula describes the binding energy of ground states – i.e. nuclei with temperatures of T≈0 MeV – with the symmetry energy parameter converging between 23–27 MeV for heavy nuclei. In this work, we find an unexpected enhancement of the symmetry energy at higher temperatures, T≈0.7–1.0 MeV, from the available data of giant dipole resonances built on excited states. Although these are likely the temperatures where seed elements are created – during the cooling down of the ejecta following neutron-star mergers or collapsars– the fact that the symmetry energy remains constant between T≈0.7–1.0 MeV, suggests a similar trend down to T≈0.5 MeV, where neutron-capture may start occurring. Calculations using this relatively larger symmetry energy yield a reduction of the binding energy per nucleon for heavy neutron-rich nuclei and inhibits radiative neutron-capture rates. This results in a substantial close in of the neutron dripline – where nuclei become unbound – which elucidates the long sought universality of heavy-element abundances through the r-process; as inferred from the similar abundances found in extremely metal-poor stars and the Sun [1].

[1] José Nicolás Orce, Balaram Dey, Cebo Ngwetsheni, Srijit Bhattacharya, Deepak Pandit, Brenden Lesch, and Andile Zulu, submitted to Phys. Lett. B (2022) https://arxiv.org/abs/2110.00713

Auteur principal: ORCE, Nico (University of the Western Cape)

Orateur: ORCE, Nico (University of the Western Cape)

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