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Heavy-ion collisions and the low-density neutron star equation of state

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The present new and very exciting multi-messenger era for the astronomy, nuclear, gravitational and astrophysics community was set by the detection of gravitational wave signals from the collision of two neutron stars (NS) by the LIGO and Virgo interferometers in 2017, followed up by the detection of the gamma-ray burst GRB170817A and the electromagnetic transient AT2017gfo. Later, in 2019, a second and third signals, GW190425 and GW190814, were detected, the first one a larger system than those of any binary NS known to date, and the latter a system involving the collision of a black hole with a 2.5-2.67 Msun compact object, that has not been ruled out yet to be a NS. The NICER collaboration has published new radius and mass measurements from PSRJ0030+0451 [1], and very recently from PSRJ0740+6620 [2], which have been able to set new constraints in NS matter.

In the near future, the large amount of new data that will be made available by SKA will allow us to determine NS properties with much smaller uncertainties and set strong constraints on the equation of state of stellar matter. Neutron stars will, as a consequence, become a real laboratory to test the nuclear force under extreme conditions of density, proton-neutron asymmetry and temperature.

Light (deuterons, tritons, helions, $\alpha-$particles), and heavy (pasta phases) nuclei exist in nature not only in the inner crust of neutron stars (cold $\beta-$equilibrium matter), but also in core-collapse supernova matter and NS mergers (warm nuclear matter with fixed proton fraction). The appearance of these clusters can modify the neutrino transport, and, therefore, consequences on the dynamical evolution of supernovae and on the cooling of proto-neutron stars are expected. However, a correct estimation of their abundance implies that an in-medium modification of their binding energies is precisely derived.

In this talk, we will address not only from the theoretical point of view how these clusters are calculated for warm stellar matter in the framework of relativistic mean-field models with in-medium effects [3], but also how these models are calibrated to experimental data from heavy-ion collisions [4, 5], measured by the INDRA Collaboration [6]. We show that this in-medium correction, which was not considered in previous analyses from heavy-ion collisions, is necessary, since the observables of the analyzed systems show strong deviations from the expected results for an ideal gas of free clusters. It turns out that the resulting light cluster abundances come out to be in reasonable agreement with constraints at higher density coming from heavy ion collision data. Some comparisons with microscopic calculations are also shown.

References:
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