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Multimessenger astrophysics at LNS from a nuclear physics point of view

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The detection of the gravitational event GW170817 is a turning point in nuclear astrophysics. Its observation triggered the investigation of the bright optical transient AT2017gfo using a broad number of diagnostic tools, opening the era of multimessenger astronomy. In particular, the follow-up of the lightcurve evolution made it possible to pinpoint the contribution from freshly synthesized heavy elements to the heating rate and opacity. From a nuclear physics perspective, this event is the first record of the in-situ operation of the rapid neutron-capture process (r-process), responsible of the production of about 50% of elements heavier than iron. The kilonova associated with GW170817 proved that neutron star (NS) mergers are primary sites for the production of heavy elements, thanks to the large neutron densities leading to the production of neutron-rich isotopes far from the beta-stability valley.
This very brief overview shows the large number of nuclear and atomic physics input necessary to model the blast and its subsequent evolution. Among these, a primary role is played by the nuclear equation of state necessary for the description of NS structure and dynamical properties, and ruling the dynamics of binary NS mergers. Indeed, one of the main novelty offered by the binary NS merger event detection is the possibility to access NS tidal polarizability and, from that, NS radii and EOS of neutron rich matter.
The other fundamental ingredients to understand the blast followup are r-process yields (fixing the heating term of the light curve) and opacities (fixing the optical properties of the expanding plasma). In turn, r-process yields are strongly influenced by neutron capture cross sections, beta-decays and in particular those followed by neutron emission, and fission rates.
Besides constraints from observations, the comparison of predicted and experimental r-process yields is a fundamental tool to understand the explosion conditions. At present, the tighter constraints on r-process nucleosynthesis is based on solar system heavy-element abundances, once the calculated slow neutron-capture process (s-process) yields have been subtracted. Therefore, accurate modelling of the s-process is pivotal to the understanding of the r-process as well.
The Laboratori Nazionali del Sud of INFN are a unique place for the investigation of multimessenger astrophysics from a nuclear physics point of view, thanks to the expertise and the presently available and forthcoming experimental setups focused on the study of these many ingredients necessary to the understanding of the physics of the explosion and of its time evolution.
While the CHIRONE experiment studies the nuclear EOS at both low densities, using reactions among heavy nuclei with different N/Z ratios at Fermi energies available at LNS, and high densities, carrying out dedicated experiments at GSI to constrain NS radii, to be compared with the astrophysical ones, the nToF and ASFIN experiments measure n-capture and n-producing reaction cross sections, for both the r- and the s-process, the latter using mainly indirect methods to cover energies of astrophysical interest. ASFIN and PANDORA experiments will measure beta decays under different conditions: the former experiment will focus on beta-delayed neutron emissions, while the latter is the only facility that will measure beta decays in plasmas, where atoms are ionized as under stellar conditions leading to significant changes in lifetime for some isotopes of astrophysical interest. PANDORA is also undertaking a program of measurement of opacities of plasmas under temperature and densities similar to those characterizing kilonova ejecta, that would be one of its kind as well.
Special attention has been also devoted to the investigation of those reactions influencing the evolution of the NS progenitors and constraining their physical properties (such as masses and number), e.g., the 12C+12C fusion and the reactions leading to 26Al production and destruction. The ASFIN collaboration applied indirect methods to cast light on these related topics.
In this presentation I will briefly report on recent results these experiments have achieved towards a better understanding of multimessenger astronomy.

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