Contribution ID: **272**

Type: **Invited Review Talk**

Exploring dense matter physics with gravitational wave detections of neutron stars

Friday 20 June 2025 11:00 (30 minutes)

Highly dense and isospin asymmetric matter is partly out of the reach of nuclear laboratories on Earth. Our theoretical understanding of strong and nuclear forces at high density and relatively low temperatures is also limited such that the equation of state and properties of dense matter remains a mystery. However, this particular type of matter comprises the deepest shells of the highly compact astrophysical objects that are neutron stars. An entire field of nuclear astrophysics is devoted to exploring dense matter physics with multi-messenger observations of neutron stars throughout their lifetime. A boost to this field recently occurred with the construction of several gravitational wave detectors that can observe the ripples of space time originating from the coalescence of compact objects.

In this talk, we discuss the advances made on the subject of dense matter physics thanks to the detection of the gravitational waves emitted by neutron star mergers. First, we present our current network of gravitational wave detectors, comprised of LIGO Hanford, LIGO Livingston, Virgo and KAGRA ground based interferometers. We then present the key sources gathered in the recent catalog GWTC-3 of the LIGO-Virgo-KAGRA collaboration and discuss in detail the link between dense matter and the deformation of neutron stars, and its imprint on the gravitational waveform. Particular attention is paid to the most informative source to date, GW170817, and how it has constrained the equation of state of dense matter. We quickly expand on the ability of binary coalescences to help us understand heavy-element nucleosynthesis, using the example of the mass-gap event that occurred during the fourth observing run of the LIGO-Virgo-KAGRA collaboration. Finally, we present what to expect from future observations and the next generation of ground based gravitational wave detectors (Cosmic Explorer and Einstein Telescope) and discuss some of the challenges we shall face in an era of high precision gravitational waves detections.

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Session Classification: Gravitational Waves and Nuclear Astrophysics