Abstract

Lami SULEIMAN

Dense matter properties and neutron star modelling

Compact stars have a crucial role to play in the understanding of ultra dense and isospin asymmetric matter. Born in the extremely bright explosion of a massive star at the last stage of its life, neutron stars can present masses as high as twice the mass of the Sun, in a radius of around ten kilometers, thus gathering matter in their interior in extreme conditions of density and gravity. The nuclear physics probed by observing neutron stars is complementary in terms of density and isospin asymmetry to any terrestrial experiment. Multi-messenger astronomy is used to extract information on the interior of neutron stars, their structure and their composition. Connecting the observation of macroscopic parameters to the equation of state of neutron star matter requires a solid understanding of gravitation theories and modelling of the star's interior.

In this thesis, three aspects of dense matter modelling that are essential to understand neutron star properties and its macroscopic features are discussed.

The first point discussed is the construction of the equation of state of dense matter for the low and the high density parts of the neutron star interior. A common practice within the astronuclear physicists community consists in treating the core and the crust of the star with different nuclear models. However, this non-unified treatment of the equation of state results in errors on the macroscopic parameter modeling which are not negligible in the face of current and near future observational precision. In this thesis, the role of non-unified equations of state on the modeling of the mass, the radius, the moment of inertia, and the tidal deformability of a cold neutron star is assessed. Moreover, analytical representations of neutron star's equation of state based on the piecewise polytropic parametrization are provided for more than fifty modern and unified nuclear models.

The second subject presented in this thesis concerns the heat sources triggered deep in the crust of accreting neutron stars. The observed thermal relaxation of a few X-ray transients suggests that the standard approximation considering that the crust is entirely made of accreted material may not be valid for neutron stars that have accreted only small amounts of matter. In this manuscript, the equation of state of an accreting neutron star which is partly made of a global equilibrium crust under compression, and partly of accreted material, is calculated. Heat sources in the compressed crust are determined and compared to the heat sources deposited in the fully accreted crust approximation. The impact of the kinetics of the non-equilibrium reactions leading to the crustal heating, which has been neglected in previously established calculations, is calculated for a few shells of the outer layers of accreting crusts. The reaction rate of electron captures leads to the increase of the heat release in the considered shells of the crust.

The final point discussed in this thesis concerns a neutrino emission process in the core of neutron stars, referred to as Modified Urca. Establishing the neutrino emissivity of Urca processes is important to understand the cooling of cold neutron stars, temperature dependent proto-neutron stars or binary merger remnants. Modified Urca combines the weak interaction and the strong interaction. In this thesis, the hadronic part of the Modified Urca process is derived in the framework of Thermal Quantum Field theory for finite temperature neutron star matter. A number of common approximations taken for the distribution of nucleons and the nucleon propagators are alleviated. The suppression of the Modified Urca process above the threshold of the weak interaction driven Direct Urca process is discussed for different regimes of temperature and density.