PhD position in theoretical nuclear astrophysics

A unified equation of state for neutron star crusts and supernova matter

Context

After the first gravitational wave (GW) detection from a neutron star merger (GW170817), multi-messenger astronomy including GW, optical and neutrino observations is revolutionizing among others our understanding of the nature of gravity, and the properties of dense matter. We propose here to advance in particular on dense matter, studying the remnant of binary neutron star mergers as Proto-Neutron Stars (PNS), the compact post-bounce objects in a core-collapse supernova. The big questions associated to the field are the following:

(1) To which extent can future GW and neutrino observations constrain the microphysics of nuclear matter, namely the Equation of State (EoS), transport coefficients and neutrino interactions? In particular, can a phase transition in dense matter be detected?

(2) Can EoS effects be disentangled from gravity?

Thesis project

So far, it is not possible to derive the dense matter EoS from first principles over the entire range necessary for describing compact stars, neither for nuclear or hadronic nor for quark matter. Therefore, simplified EoS need to be constructed. We will pursue two different strategies. The first one consists in parameterizing the EoS, putting the least possible number of model assumptions. The parameters are then adjusted applying Bayesian statistics to various probes of dense matter (low-density neutron matter EoS; nuclear properties such as masses, radii, skins, collective modes; relativistic heavy ion collisions; NS masses and radii). This meta-model technique has proven very successful for describing cold neutron stars [1-3], and will be extended to finite temperature as needed for the description of PNS and the merger remnant. The second, more traditional strategy is based on direct modeling of dense matter. It is less flexible than the aforementioned, but has the advantage of addressing specific physical questions, e.g. the particle content. We shall pay particular attention to the description of inhomogeneous matter [4,5] and the crust melting/formation in binary neutron star mergers and during PNS cooling [6].

The research work is at LPC Caen and GANIL. The candidate will also benefit of our tight collaboration with colleagues from IP2I (Lyon), and LUTH (Meudon), and of our international connections through the COST action PHAROS http://www.pharos.ice.csic.es/

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Further reading

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2. T.Carreau, F.Gulminelli, J.Margueron, « Bayesian analysis of the crust-core transition with a compressible liquid-drop model », ArXiv:1902.07032 and Eur.Phys.Journ.A, in press.
3. T.Carreau, F.Gulminelli, J.Margueron, « General predictions for the neutron star crustal moment of inertia», ArXiV:1810.00719 and Phys.Rev.C, in press.
4. Ad.A.Raduta and F.Gulminelli, "Nuclear Statistical Equilibrium equation of state for core collapse", Nuclear Physics A 983 (2019) 252
5. G.Grams, S.Giraud, A.Fantina and F.Gulminelli, « Nuclear distribution from a free energy density in a Wigner-Seitz Cell », Phys. Rev. C 97 (2018) 035807
6. A.Fantina, S.de Ridder, N.Chamel, F.Gulminelli, "Crystallization of the outer crust of a non-accreting neutron star", A&A, in press