

# SÉMINAIRE du PÔLE THÉORIE



LABORATOIRE DE PHYSIQUE DES DEUX  
INFINIS IRÈNE JOLIOT-CURIE

*Pôle de Physique Théorique*

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## Nuclear physics in the lab and the stars

Describing matter at the extreme conditions present in neutron stars (NS) within a unified framework is challenging in view of the wide range of densities encountered. On the other hand, nucleosynthesis simulations of rapid neutron-capture processes (or r-process) require detailed knowledge of nuclear reactions and radioactive decay (hence of the nuclear structure properties, in particular, nuclear masses) for a few thousand exotic neutron-rich nuclei. The challenge for nuclear theory is then the construction of a model that accurately describes (i) masses of neutron-rich nuclei present in the crust of neutron stars and (ii) masses of all the neutron-rich nuclei potentially produced during the r-process nucleosynthesis, together with (iii) a stiff enough neutron matter equation of state to explain the most massive observed pulsars. I will present the latest entry of the microscopic nuclear energy density functionals (EDFs) developed at IAA, which aims to provide accurate nuclear physics inputs to astrophysical applications, and progress in the above topics. The Brussels-Skyrme-on-a-Grid (BSkG) are parameterizations of the Skyrme EDF with the advantage of being based on the powerful concept of symmetry breaking, allowing for exotic shapes such as triaxial and octupole deformation during the adjustment process. To compensate for the increase in computational cost, machine learning techniques are employed to optimize the parameter adjustment. Compared to its predecessors, the latest BSkG3 [1] offers a more realistic description of matter at the extreme densities relevant to NS. Furthermore, we include a pairing treatment designed to match the 150 pairing gaps in INM deduced from ab-initio calculations. The latter is particularly important for a reliable description of superfluids in NS. Quantitatively, the model offers lowered root-mean-square deviations on 2457 masses (0.631 MeV), and an unmatched accuracy with respect to 45 primary fission barriers of actinide nuclei (0.33 MeV). To connect nuclear physics with NSs crust, I will also present results of a complementary macroscopic approach to understand the role of different nuclear ingredients to NSs. I will show the impact of neutron matter and symmetric nuclear matter as predicted by chiral Effective Field Theory (EFT) Hamiltonians in contrast to Skyrme effective forces in the inner crust [2]. As a final point, I will show effects of dilute neutron matter predictions for the inner crust making a link with microscopic predictions of pairing gap and the unitary limit of interacting Fermi systems.

[1] G. Grams, W. Ryssens, G. Scamps, S. Goriely, and N. Chamel, *Eur. Phys. J. A* **59**, 270 (2023).

[2] G. Grams, J. Margueron, R. Somasundaram, and S. Reddy, *Eur. Phys. J. A* **58**, 56 (2022).

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