Machine learning for energy surfaces for neutron star inner crusts

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The neutron star equation of state (EoS) plays a crucial role in determining static and dynamic properties of neutron stars. The latter has recently received significant attention due to the multi-messenger detection of a neutron star merger [1].

An important component of the EoS is its low-density crust. In this, we expect finite nuclei, embedded in an electron gas (the outer crust), or in electron and neutron gases (the inner crust). Determining the proton numbers of the nuclei at different inner crust densities is a longstanding problem in nuclear physics [2], partly because of the computational burden of the calculations. The energy minimizations performed across the density range of the inner crust require significant computational time.

Gaussian Process Emulation (GPE) is a regression method from machine learning, with a wide range of applications in nuclear physics, and in many other scientific domains. We have already successfully applied GPE to an inner crust energy minimization [3, 4], done with nuclear energy density functional calculations. I will present an iterative version of GPE, building on previous work [3–5]. We use here semi-classical calculations with the Thomas-Fermi approximation, including pairing effects at the BCS level. With iterative GPE, we can dramatically reduce the number of calculations needed to determine the composition of the inner crust. This will enable us to expand our investigations into the structure, by including temperature effects and by using fully microscopic calculations.

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[1] B. P. Abbott, et al., Phys. Rev. Lett. **119**, 161101 (2017).

[2] J. W. Negele, D. Vautherin, et al., Nucl. Phys. A **207**, 298 (1973).

[3] A. Pastore, M. Shelley, C. A. Diget, PoS (INPC2016) p 145 (2016).

[4] A. Pastore, M. Shelley, S. Baroni, C. A. Diget, J. Phys. G: Nucl. Part. Phys. **44**, 094003 (2017).

[5] M. Shelley, P. Becker, A. Gration, A. Pastore, arXiv:1811.09130 (2018).