Contribution ID: **51** Type: **not specified**

Gapless superfluidity and neutron stars

Born from gravitational-core collapse supernovae, with initial temperatures as high as $\sim 10^{12}$K, neutron stars cool down to temperatures 10^9 K within a few days, providing a unique opportunity to explore matter under extreme conditions. In particular, neutron stars contain nuclear superfluids whose presence is supported by observations of pulsar frequency glitches, rapid decline in luminosity of the Cassiopeia A remnant, and crust cooling of neutron stars in low-mass X-ray binaries.

Despite the importance of the superfluid dynamics in interpreting these astrophysical phenomena, most microscopic calculations of the nuclear pairing properties have been carried out so far for static situations. We have recently studied the dynamics of hot neutron-proton superfluid mixtures within the time-dependent nuclear energy-density functional theory [1,2].

The disappearance of superfluidity has also been investigated and reveals the presence of a dynamical "gapless" state in which nuclear superfluidity is not destroyed even though the energy spectrum of quasiparticle excitations exhibits no gap. The absence of an energy gap affects considerably the neutron specific heat which becomes very different from that in the classical BCS state (in the absence of superflows) [3]. Implications for the crust cooling of neutron stars in low-mass X-ray binaries will be discussed, as well as the consequences of gapless superfluidity for neutron vortex dynamics [4].

[1] N. Chamel & V. Allard, Phys. Rev. C 100, 065801 (2019).
[2] V. Allard & N. Chamel, Phys. Rev. C 103, 025804 (2021).
[3] V. Allard & N. Chamel, Phys. Rev. C 108, 045801 (2023).
[4] V. Allard & N. Chamel, Phys. Rev. Lett. 132, 181001 (2024)

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