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Suppression of superfluidity in neutron-star crusts

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Formed in the aftermath of gravitational core-collapse supernova explosions, neutron stars contain matter crushed at densities exceeding that found inside the heaviest atomic nuclei under conditions so extreme that they cannot be reproduced on Earth. Neutron stars are therefore unique laboratories for exploring phases of matter not observed in any other celestial bodies. As early as 1959, the inner crust and the outer core of a neutron star were predicted by Arkhady Migdal to exhibit neutron superfluidity at temperatures below $\sim 10^{10}$ K. Since then, neutron superfluidity has found strong support from radio-timing observations of pulsar frequency glitches, and more recently from the rapid decline of luminosity of the youngest known neutron star in the supernova remnant of Cassiopeia A [1].

In a similar way to laboratory superfluidity of atomic gases in optical lattices, neutron superfluidity in the inner crust of neutron stars is partially suppressed due to the presence of neutron-proton clusters [2]. The reduction of the neutron superfluid density implies that the neutron superfluid cannot flow completely freely despite the absence of viscous drag. Due to this entrainment effect, clusters move with an effective mass and collective excitations of the superfluid are mixed with those of the crust. The extent to which neutron superfluidity is suppressed depends on whether the crust is crystalline or disordered [3]. Recent fully 3D neutron band-structure calculations taking BCS pairing into account will be presented. Astrophysical implications will be discussed.

[1] N. Chamel, J. Astrophys. Astr. 38, 43 (2017).
[2] N. Chamel, J. Low Temp. Phys. 189, 328 (2017).
[3] J. A. Sauls, N. Chamel, M. A. Alpar, eprint arXiv:2001.09959

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