APR13-2013-001023

Abstract for an Invited Paper
for the APR13 Meeting of
the American Physical Society

Superfluidity in the Core of Neutron Stars

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The year (1958) after the publication of the BCS theory, Bohr, Mottelson & Pines showed that nuclei should also contain superfluid neutrons and superconducting protons. In 1959, A. Migdal proposed that neutron superfluidity should also occur in the interior of neutron stars. Pairing in nuclei forms Cooper pairs with zero spin, but the relevant component of the nuclear interaction becomes repulsive at densities larger than the nuclear matter density. It has been proposed that neutron-neutron interaction in the spin-triplet state, and $L = 1$ orbital angular momentum, that is known to be attractive from laboratory experiments, may result in a new form of neutron superfluidity in the neutron star interior. I will review our present understanding of the structure of neutron stars and describe how superfluidity strongly affects their thermal evolution. I will show how a "Minimal Model" that excludes the presence of "exotic" matter (Bose condensates, quarks, etc.) is compatible with most observations of the surface temperatures of young isolated neutron stars in the case this neutron superfluid exists. Compared to the case of isotropic spin-zero Cooper pairs, the formation of anisotropic spin-one Cooper pairs results in a strong neutrino emission that leads to an enhanced cooling of neutron stars after the onset of the pairing phase transition and allows the Minimal Cooling scenario to be compatible with most observations. In the case the pairing critical temperature T_c is less than about 6×10^8 K, the resulting rapid cooling of the neutron star may be observable. It was recently reported that 10 years of Chandra observations of the 333 year young neutron star in the Cassiopeia A supernova remnant revealed that its temperature has dropped by about 5%. This result indicates that neutrons in this star are presently becoming superfluid and, if confirmed, provides us with the first direct observational evidence for neutron superfluidity at supra-nuclear densities.

[1]Work in collaboration with M. Prakash, J.M. Lattimer and A.W. Steiner