I Introduction

Since their fortuitous discovery by Jocelyn Bell and Anthony Hewish in 1967, more than 2000 pulsars have been found. Their identification as neutron stars (NSs) and their relevance to type II supernova explosions, was definitively established the next year after the discoveries of pulsars in the Crab and Vela supernova remnants.

II Vortex-mediated glitches

Nuclear superfluidity in neutron stars was predicted and studied even before the discovery of pulsars in 1967 [7]. At temperatures T < Tc, nucleons may form pairs like electrons in superconductors. These pairs are bosons that can be described very well on a large scale - the neutron condensate can thus flow without any viscosity [8].

In particular, the neutron liquid that permeates the inner crust of a neutron star is expected to be superfluid [9], see, e.g. Sec. 8 in Ref. [1].

A rotating superfluid is threaded by an array of vortex lines, each carrying a quantum of angular momentum. Such vortices have been observed in various superfluid systems in laboratory. Similarly a pulsar is expected to contain quantized neutron vortex lines. The number of vortices is proportional to the angular velocity α (nearly 2π/3 for the Vela pulsar).

The neutron superfluid is weakly coupled to the crust by mutual-friction forces [14]. The neutron superfluid in neutron stars is strongly superfluid at the density of unbound neutrons. As a result, the superfluid spins down and, by the conservation of angular momentum, establishes a neutron-star rotation rate that is a fraction of the Keplerian angular velocity at the crust-core transition.

III Crucial entrainment and pulsar glitches

Neutron-diffusion experiments are routinely performed to study crystal structures. Similarly, unbound neutrons in neutron-star crusts can be reflected as the superfluid component driving the crustal rotation. For instance, the strength of vortex pinning, which is one of the most crucial microscopic inputs, has been a controversial issue over the past years [12].

The neutron superfluid is weakly coupled to the crust by mutual-friction forces [14]. This model predicts that the neutron superfluid permeating the inner crust of neutron stars can flow without any viscosity and can behave coherently on a very large scale: T < Tc.

The core transition pressure of neutron superfluidity in neutron stars was predicted and studied even before the discovery of pulsars in the Crab and Vela supernova remnants (see, e.g. Sec. 8 in Ref. [1]).

IV Results and discussion

The ratio appearing in the left-hand side of Eq. (3) can be decomposed as

\[
\frac{\Omega}{\Omega_0} = \frac{\Omega_0}{\Omega} \left(1 + \frac{\pi}{\Omega_0} \sqrt{\frac{\Delta \Omega}{\Omega_0}} \right)
\]

where \(\Omega_0\) is the neutron-star rotation rate (upper curve) and \(\Omega\) is the observed rotation rate (lower curve). The shaded area is excluded if Vela pulsar glitches originate from the neutron superfluid in the crust [15]. Note that any realistic equation of state of dense matter indicates that neutron stars with M > 1.4 Msun have a value of \(\Omega < 0.4\) Hz.

Nuclear superfluid is an important ingredient of the Bragg scattering of free neutrons by the crust, first discussed in Ref. [19].

References


