Comment on "Constraining Hadronic Superfluidity with Neutron Star Precession"

The timing residuals of some pulsars have been interpreted as evidence for long-period ($\sim$1 yr) precession [1,2], a consequence of a slight misalignment between the spin $\boldsymbol{\omega}$ and total angular momentum $\mathbf{L}$ of the neutron star. In a recent Letter, Link [3] accepts this inference and, with the crucial assumption that the ${}^1S_0$ neutron superfluid of the inner crust has no effect on precession dynamics, has shown that neutron and proton superfluids do not coexist in the liquid core of the neutron star or that the proton superfluid is a type I superconductor. This argument is important because, if correct, it would give a powerful insight into problems otherwise well shielded from experimental observation.

In this Comment we show that the assumption about ${}^1S_0$ superfluid is not sustainable and that if long-period precession were clearly established experimentally, the conclusion would have to be that nuclei and superfluid neutrons do not coexist. This would be inconsistent with the usually assumed properties of matter at subnuclear densities and would certainly be evidence for new physics, possibly quark deconfinement.

Precession is most easily considered in coordinates rotating with the solid component of the neutron star. The Euler equation is $\dot{\mathbf{L}} + \boldsymbol{\omega} \times \mathbf{L} = 0$, where $\mathbf{L} = \mathbf{L}_p^c + \mathbf{L}_p^i + \mathbf{L}_c$. Vortices pinned to crust nuclei or to the type II proton superconductor in the interior of the star are the sources of the components $\mathbf{L}_p^c$ and $\mathbf{L}_p^i$ which are time independent. The crust and components coupled with it have angular momentum $\mathbf{L}_c$ almost parallel with $\boldsymbol{\omega}$. The small misalignment, caused by mechanical or magnetic stress deformation of the star, may be of the appropriate order of magnitude for precession periods $\sim$1 yr. Established precession with a 500 d period [1] would constrain vortex pinning so that $|\mathbf{L}_p^c + \mathbf{L}_p^i| < 10^{-8}L$. Link assumes that $L_p^c = 0$, hence that $L_p^i < 10^{-8}L$, with the consequences described in [3].

The elementary vortex-nucleus pinning force may be attractive or repulsive, and within 1 or 2 orders of magnitude of 0.5 MeV fm^{-1} (see, for example, [4]). Under the assumption made in [3] precession of amplitude θ and angular velocity Ω has superfluid velocity, in rotating coordinates, $v_n = v_n^0 \approx R\Omega\theta$, where R is the neutron star radius: $v_n^0 \approx 7 \times 10^{-3}\ \mathrm{cm\,s^{-1}}$, for PSR B1828-11. Consider, first, interaction with a single isolated nucleus. At small v_n, a nonperturbative calculation of dissipation is essential [5] because in the attractive case, the vortex is trapped for a time $\tau \propto v_n^{-2}$ by the potential minimum and the energy transfer to Kelvin waves is $\propto v_n^{-1}$. There is no trapping in the repulsive case and no divergence in energy transfer. But this distinction does not exist for interaction with a three-dimensional array of nuclei, whether or not disordered and heterogeneous [6]. For either attractive or repulsive elementary forces, any vortex path with velocity $\mathbf{v}(\neq \mathbf{v}_n)$ through such an array defines a potential surface which must have minima causing vortex trapping. Small-v motion is always highly dissipative above the pinning threshold $v = v_p$ [5,7].

The energy of precession is the difference between the inertial frame rotational energy immediately after the event causing precession and the energy, at the same $\mathbf{L}$, for stable rotation about the axis of greatest principal moment. This is $E_p = L\Omega\theta^2/2$ and is very small ($\approx 3 \times 10^{36}$ ergs) for the claimed precession of PSR B1828-11. Its dissipation in one precession period would require a dissipative force per unit length of vortex $f_\parallel \approx (\kappa\Omega E_p)/(4\pi\omega v_n^0 V_{\mathrm{nd}})$, where κ is the neutron superfluid quantum of circulation and V_{nd} is the volume of the neutron-drip region of the crust. For PSR B1828-11, this is $f_\parallel \approx 10^9\ \mathrm{dyn\,cm^{-1}}$. It is 7 orders of magnitude smaller than that obtained from [4]. Also, vortices unpinned in a violent event exciting precession [8] would have repinned [7] at $v_n \approx 10^{6-7} v_n^0$.

The assumption made in [3] is so unlikely to be valid that no conclusions should be based on it. Any precession excited would be heavily overdamped and unobservable. It would be preferable to question whether some poorly understood magnetospheric phenomenon is not being observed [1,2] rather than true Eulerian precession.

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[1] I. H. Stairs, A. G. Lyne, and S. L. Shemar, Nature (London) **406**, 484 (2000).
[2] T. V. Shabanova, A. G. Lyne, and J. O. Urama, Astrophys. J. **552**, 321 (2001).
[3] B. Link, Phys. Rev. Lett. **91**, 101101 (2003)
[4] P. M. Pizzochero, L. Viverit, and R. A. Broglia, Phys. Rev. Lett. **79**, 3347 (1997).
[5] P. B. Jones, Phys. Rev. Lett. **81**, 4560 (1998).
[6] P. B. Jones, Phys. Rev. Lett. **83**, 3589 (1999).
[7] P. B. Jones, Mon. Not. R. Astron. Soc. **340**, 247 (2003).
[8] B. Link and C. Cutler, Mon. Not. R. Astron. Soc. **336**, 211 (2002).

