A Novel Mechanism for Type-I Superconductivity in Neutron Stars*

James Charbonneau
University of British Columbia
james@phas.ubc.ca

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Abstract

The motivation behind this work is a contradiction between the precession of a neutron star and the model for vortices in a neutron star. This talk will present the contradiction and a possible resolution.

*J. Charbonneau and A. Zhitnitsky, arXiv:astro-ph/0701308

Outline

1. The Trouble with Vortices and Precession[1]

2. A Mechanism for Type-I Superconductivity

3. Conclusion

[1] B. Link, Phys. Rev. Lett. **91**, 101101 (2003)

Neutron Stars have Vortices

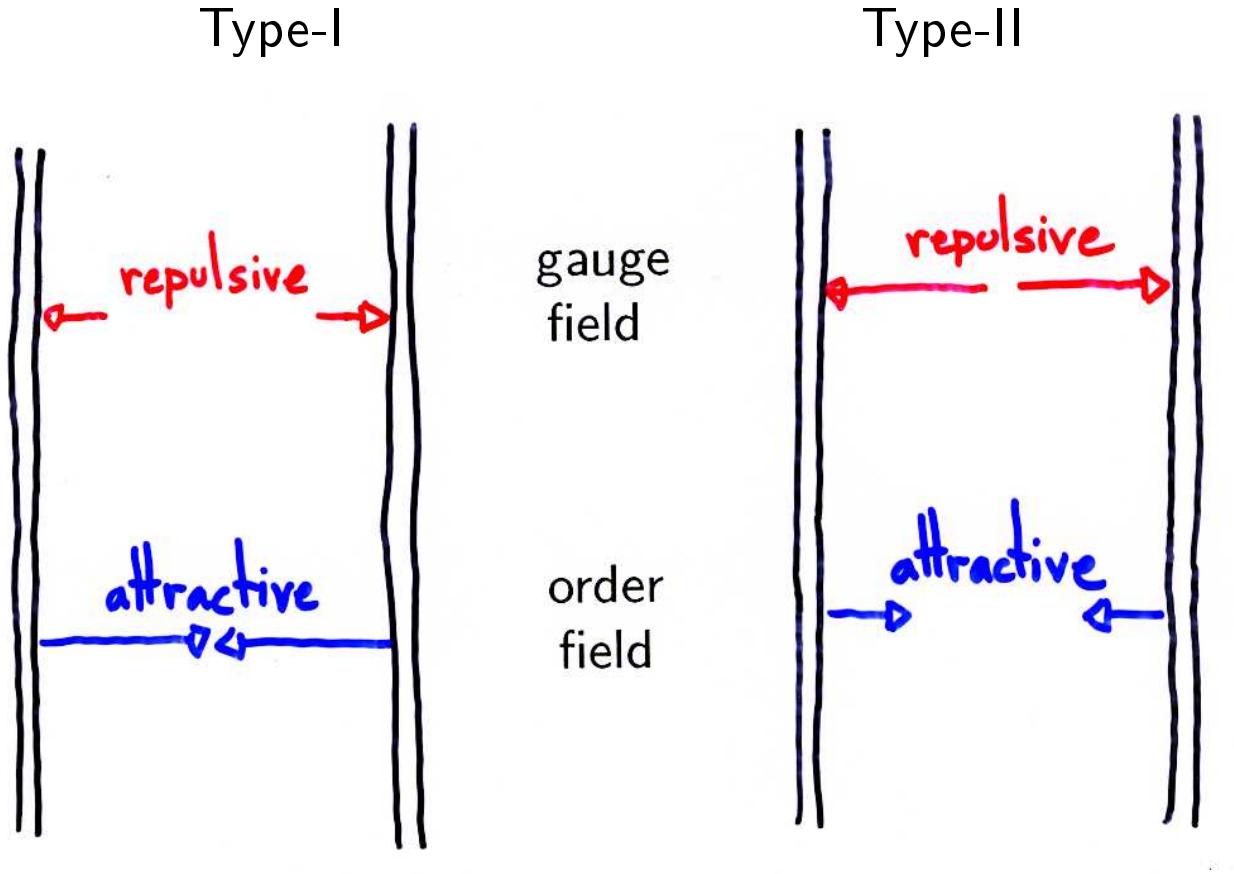
Superfluid Vortices

- the star's rotation $|\mathbf{\Omega}| \sim 10$ rad/s forces the creation of vortices in the direction of $\mathbf{\Omega}$
- circulation is quantized $\Gamma_0 = \frac{2\pi\hbar}{m}$
- form an array, $n \sim 10^{10}$ m^{-2}

Superconducting Vortices

- the star's magnetic field $|\mathbf{B}| \sim 10^{12}$ G forces the creation of vortices in the direction of $\mathbf{B}$
- magnetic flux is quantized $\Phi_0 = \frac{2\pi\hbar c}{q}$
- type-I form domains,
  type-II form an array, $n \sim 10^{16}$ m^{-2}

Types of Superconductivity



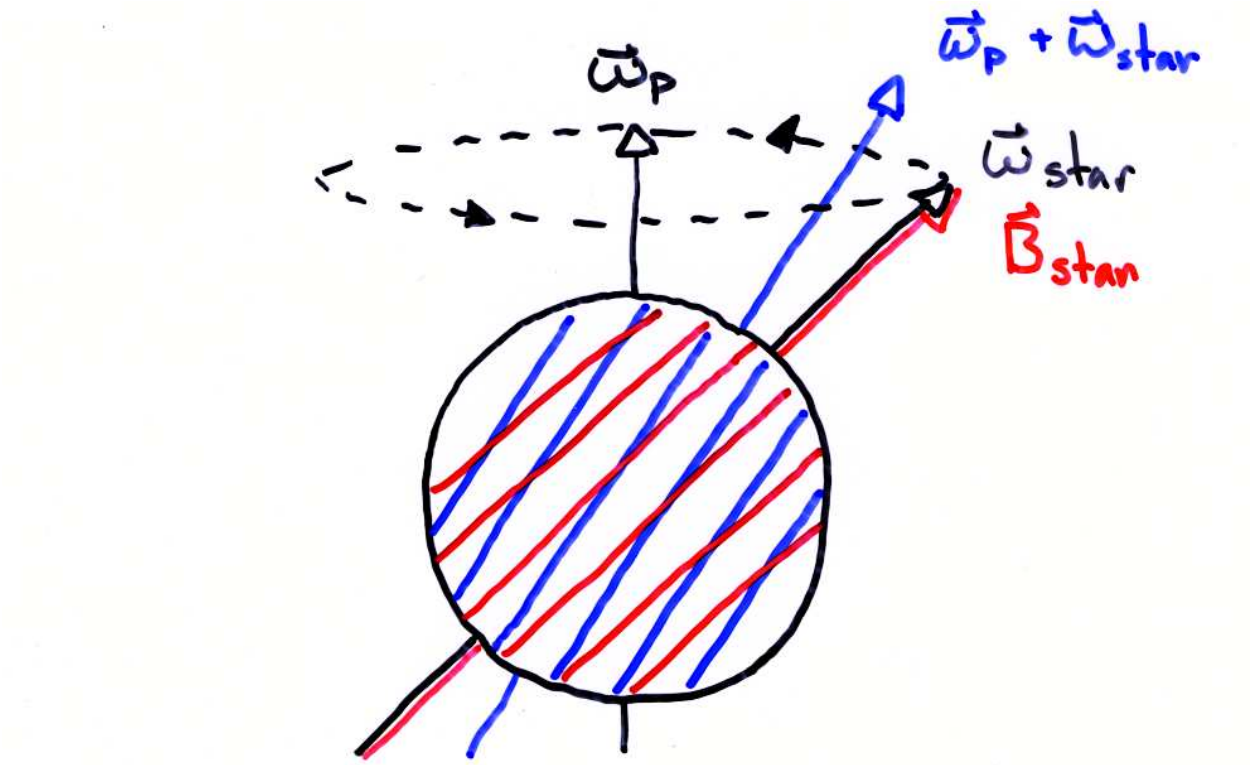
Landau-Ginzburg parameter indicates type-II if

$$\kappa = \frac{\lambda}{\xi} > \frac{1}{\sqrt{2}}$$

where λ is the penetration depth and ξ is the coherence length.

Vortices and Precession

Observations indicate that a neutron star precesses at $\omega \sim 10$ rad/year.



1. The vortices don't pass through each other
   - precession is too quick $\omega \sim 10$ rad/s

2. The vortices do pass through each other
   - highly disspative, the star stops spinning

Conflict!

We must conclude that either

1. proton and neutron condensates do not coexist
   - unlikely from what we know about condensation on Earth

2. proton superconductor is type-I
   - presence of type-I resolves conflict[2]
   - neutron star parameters indicate type-II

$$\kappa = \frac{\lambda}{\xi} \sim \frac{80 \text{ fm}}{30 \text{ fm}} \sim 2.6$$

[2] A. Sedrakian, Phys. Rev. D **71**, 083003 (2005)

Outline

1. The Trouble with Vortices and Precession
2. **A Mechanism for Type-I Superconductivity**
3. Conclusion

Currents along Vortices

Topological currents[3] can exist in neutron stars.

$$j = \frac{q\sqrt{\mu^2 - m^2}}{2\pi^2}\Phi$$

where q is the charge, μ is the chemical potential, m is the particle mass and Φ is the magnetic flux.

Togological current only requires

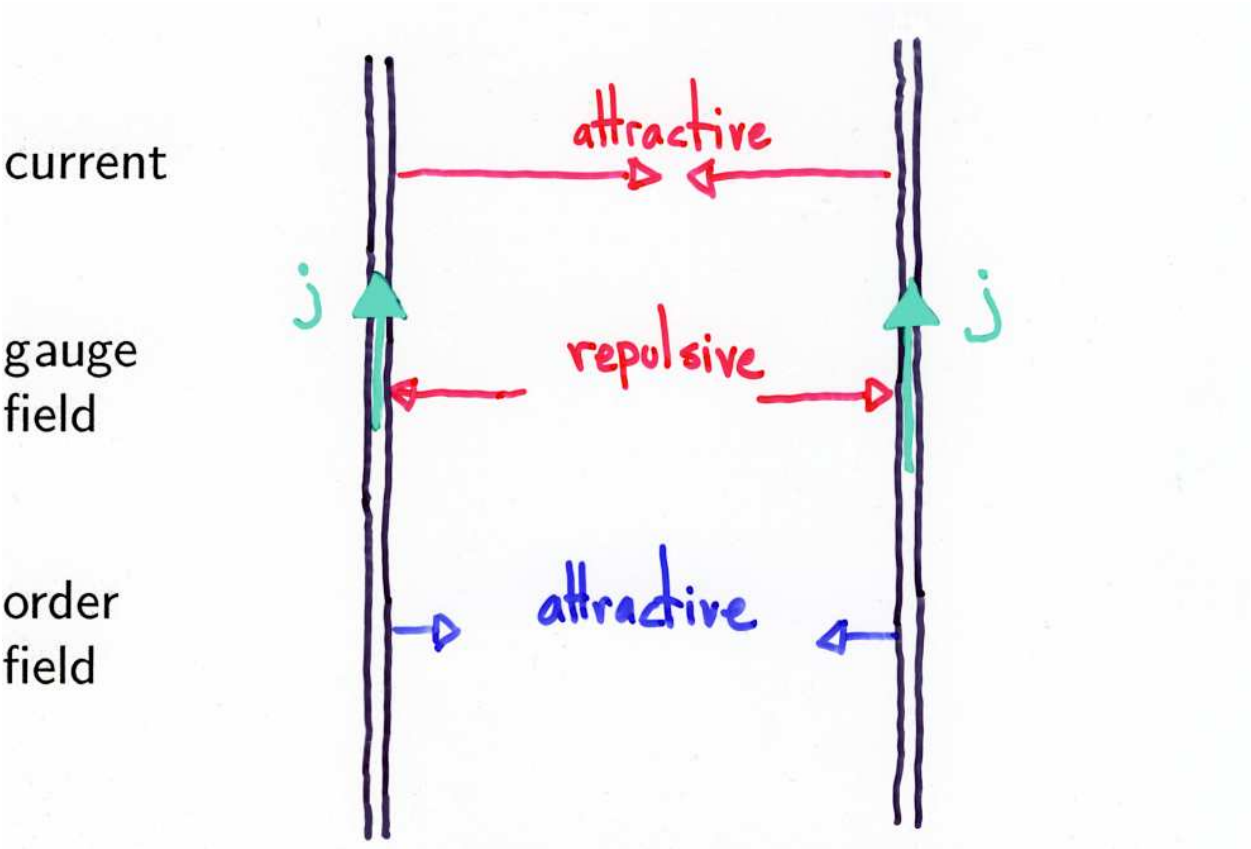
- Dirac fermions
- a topological defect
- a magnetic flux
- parity symmetry must be broken $\mu = \mu_L - \mu_R \neq 0$

An electromagnetic current runs along vortices in neutron stars.

[3] M. Metlitski and A. Zhitnitsky, Phys. Rev. D **72**, 045011 (2005)

How to get type-I superconductivity

Change the interaction between vortices by adding a current.



Attract if $j > \dfrac{\hbar c^2}{q\lambda}$ is satisfied.

Conclusions

- Precession implies a type-I superconductivity must exist in a neutron star.
- Currents are likely to exist in neutron star vortices.
- Currents in vortices can make a superconductor type-I even when it looks like it should be type-II.

Currents in vortices can resolve the contradiction between precession and the vortex structure of a neutron star.

Consequences

1. Toroidal magnetic field
   - Observational and theoretical evidence that one is necessary.

2. Neutron star kicks
   - Current would be expelled from the star at the surface.