Topological Vector Currents and Neutron Star Kicks

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Neutron Stars

Basic neutron star properties are,

- radius $R_{\mathrm{star}} \sim 10$ km and mass 1.4 $\mathrm{M}_\odot$.
- large magnetic field $\sim 10^{12}$ G.
- relatively cold $T_{\mathrm{star}} \sim 10^9$ K $\ll T_{\mathrm{Fermi}} \sim 10^{12}$ K.
- spin period of ~ 3 ms.

Neutron stars have been "kicked";

- star before supernova has proper motion ~ 30 km/s.
- neutron star motion ~ 200 km/s, with some > 1000 km/s.

The direction of proper motion, spin axis, and magnetic field are all correlated.

Topological Currents

Topological vector currents are found by

- finding the expectation value of $j^\mu = e\bar{\Psi}\gamma^\mu\Psi$,
- solving the Dirac equation in a magnetic field,
- using the Atiyah-Singer index theorem.

They are non-dissipative, electromagnetic currents, and have the form

$$j = -\Lambda\mu_{\mathrm{e}}\frac{e^2\Phi}{2\pi^2}\,.$$

where Φ is magnetic flux, μ_e is electron chemical potential, and Λ is the helicity expectation value.

Topological Currents in Neutron Stars

In a neutron star

- magnetic field is carried by proton vortices each with flux $\Phi = \frac{2\pi}{e}$.
- electron chemical potential is $\mu_\mathrm{e} \sim 100$ MeV.
- beta decay in the vortex creates electrons with helicity $\Lambda = -0.98$.

In equilibrium the helicity would be washed out.

Current carries electrons out of the star;
the system is not in equilibrium.

Maintaining Nonzero Helicity

Helicity is not washed out

- mean free path of weak interaction is $l_{\mathrm{electron}} \sim 640$ km.
- radius of neutron star $R \sim 10$ km.
- electrons escape before helicity is removed.

The ratio of electrons in vortices to the rest of the star is $\sim 10^{-3}$

- a new "equilibrium" is reached with helicity $\Lambda \sim -0.0001$.

Current in a single proton vortex is

$$j \sim 10^{-5}\ \mathrm{MeV} \sim 1\ \mathrm{mA},$$

which carries electrons to the surface of the star.

The Electron Rocket

In a neutron star $\sim 10^{31}$ vortices means a total current

$$j_{\rm star} \sim 10^{26}\ {\rm MeV}.$$

- Over a short time the current can propel the star to > 1000 km/s.
  - much of the current is likely dissipated in the neutron star's crust.[1]
- Current travels antiparallel to magnetic field; proper motion, spin, and magnetic field are correlated.

[1] J.F. Caron and A. Zhitnitsky

Conclusion

Topological currents are a good candidate for a kick mechanism

- can easily produce kicks greater than 1000 km/s.
- are powered by chemical potential, not temperature.
  - high neutron star temperatures aren't required.
  - helicity isn't washed out as a result of high temperatures.
- explain spin-proper motion correllation.
  - hydrodynamic kicks don't explain this correllation.