

# Punting Pulsars: Big Kicks from Little Physics<sup>1</sup>

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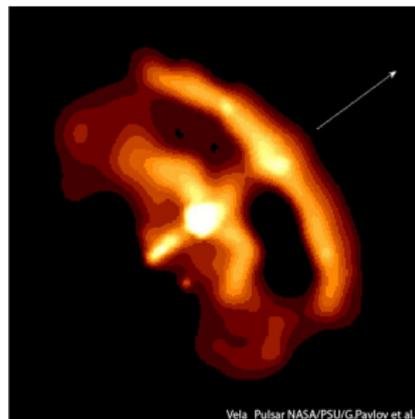
<sup>1</sup>Charbonneau, Hoffman and Heyl, *Large Pulsar Kicks from Topological Currents*. [arXiv:0912.3822] (2009)

# Pulsars have large kicks that we can't explain

Pulsars move much faster than their progenitors, they have been kicked.

- The typical pulsar velocity is 400 km/s
- 15% of pulsars have velocities over 1000 km/s.

Large kicks do not have a suitable explanation.

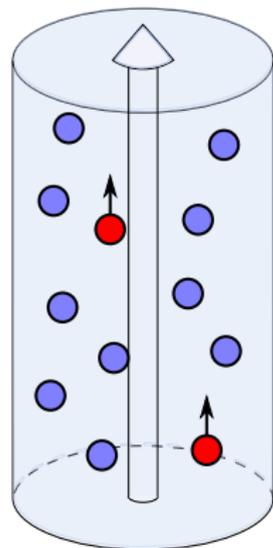
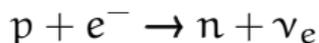
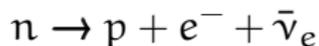


# Topological Vector Currents<sup>2</sup>

Topological vector currents carry electrons along magnetic flux lines in dense matter.

The currents appear in dense stars because

- the electrons have large Fermi momentum.
- the lowest Landau level only admits spin down electrons.
- the Urca processes violate parity,



 magnetic flux  $\Phi$

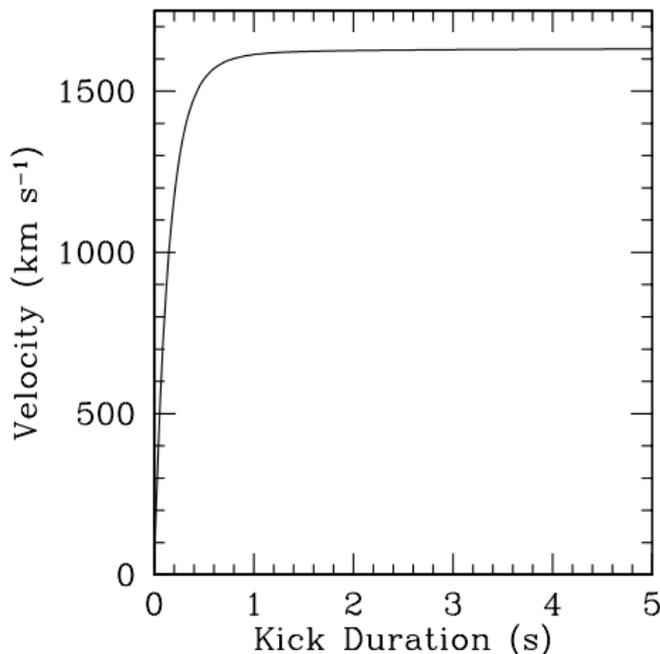
 background electrons  
(zero average helicity)

 excess left-handed  
electrons

<sup>2</sup>Charbonneau and Zhitnitsky [arXiv:0903.4450] (2009)

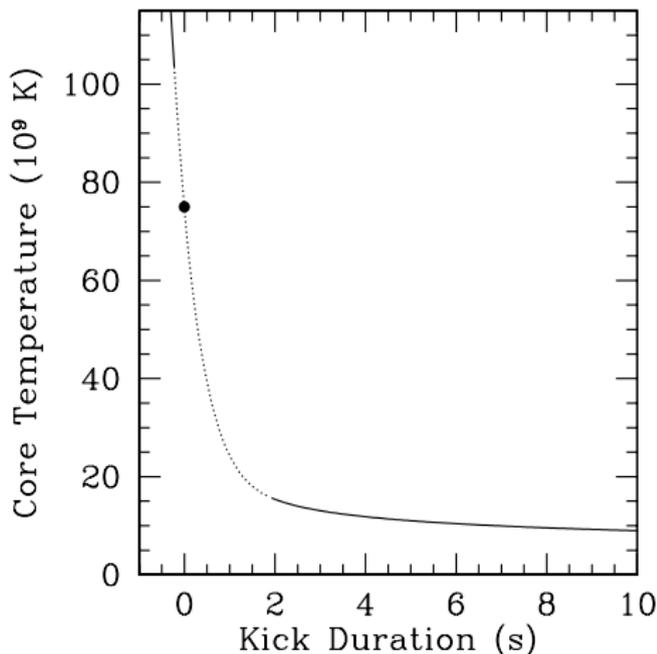
# Kicks from Topological Currents

1. Current carries electrons to the surface of the star.
2. Electrons transfer momentum.
  - electron rocket!
  - bremsstrahlung.
  - quark stars only.
3. Mechanism generates kicks  $> 1000$  km/s.



# Pulsar cooling and magnetic field

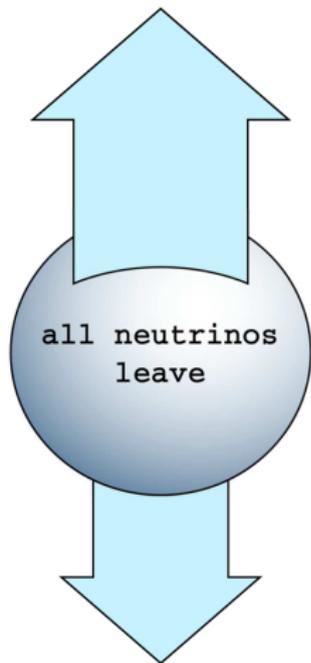
1. Current proportional on temperature and magnetic field.
2. We construct a realistic cooling curve.
  - Haensel et al. (1991)
  - Page & Usov (2002)
3. Virial theorem indicates internal field of  $10^{14}$  G.



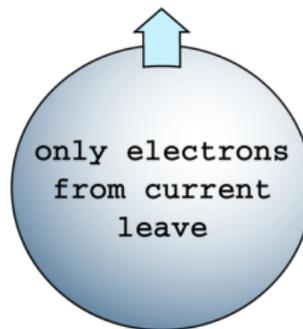
# Doesn't the current affect the cooling?

Neutrino Cooling

Electron Cooling

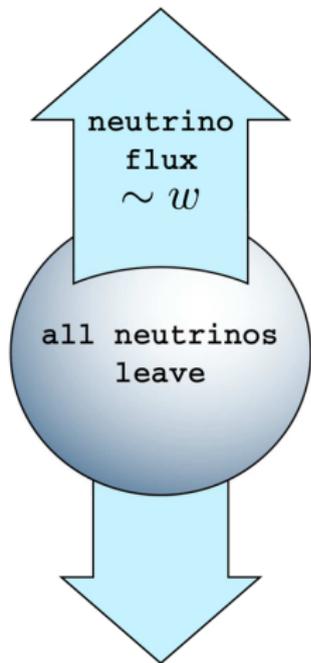


Urca process  
occurs at  
rate  $W$



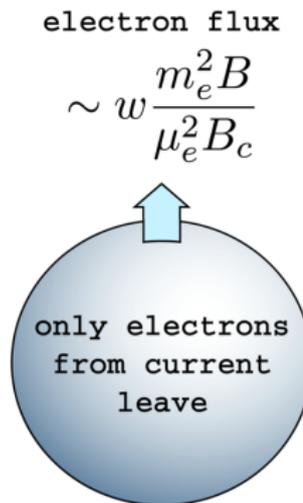
# Doesn't the current affect the cooling?

## Neutrino Cooling



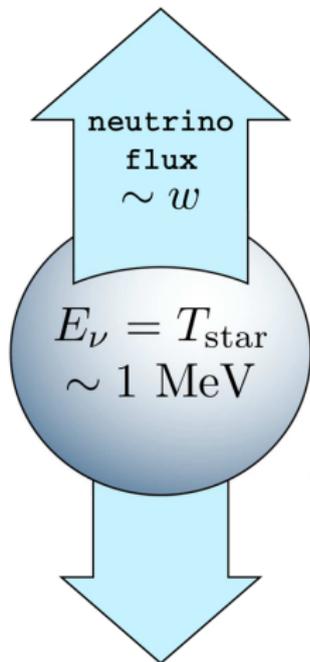
Urca process  
occurs at  
rate  $w$

## Electron Cooling



# Doesn't the current affect the cooling?

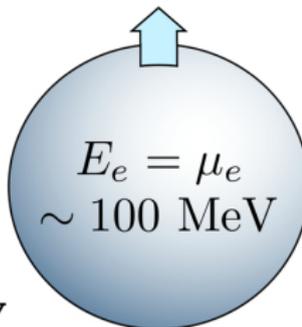
## Neutrino Cooling



## Electron Cooling

electron flux

$$\sim w \frac{m_e^2 B}{\mu_e^2 B_c}$$

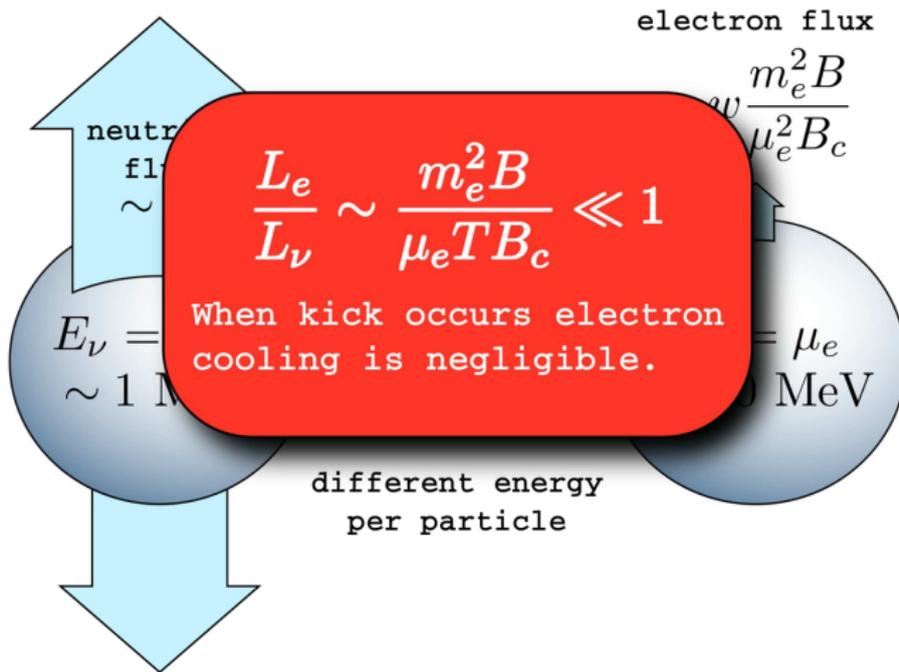


Urca process  
occurs at  
rate  $w$

different energy  
per particle

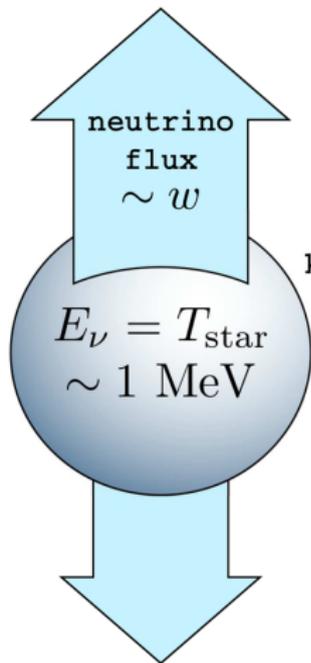
# Doesn't the current affect the cooling?

Neutrino Cooling      Electron Cooling



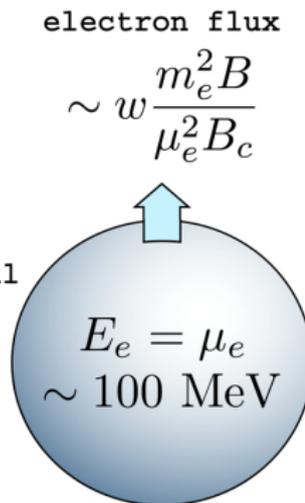
# So why is the electron kick bigger?

## Neutrino Kick



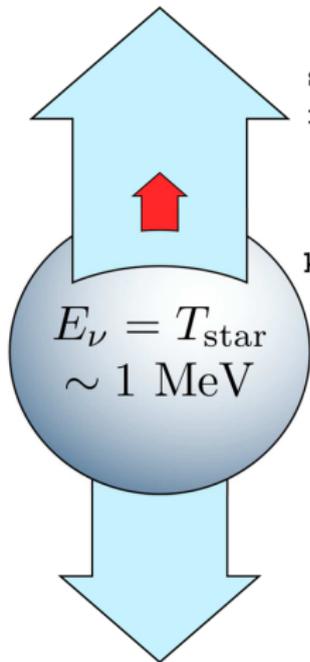
kick proportional  
to flux  
and energy

## Electron Kick



# So why is the electron kick bigger?

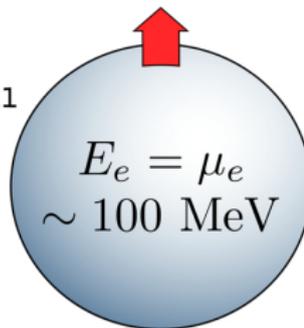
## Neutrino Kick



same flux asymmetry  
from Landau levels  $\sim w \frac{m_e^2 B}{\mu_e^2 B_c}$

kick proportional  
to flux  
and energy

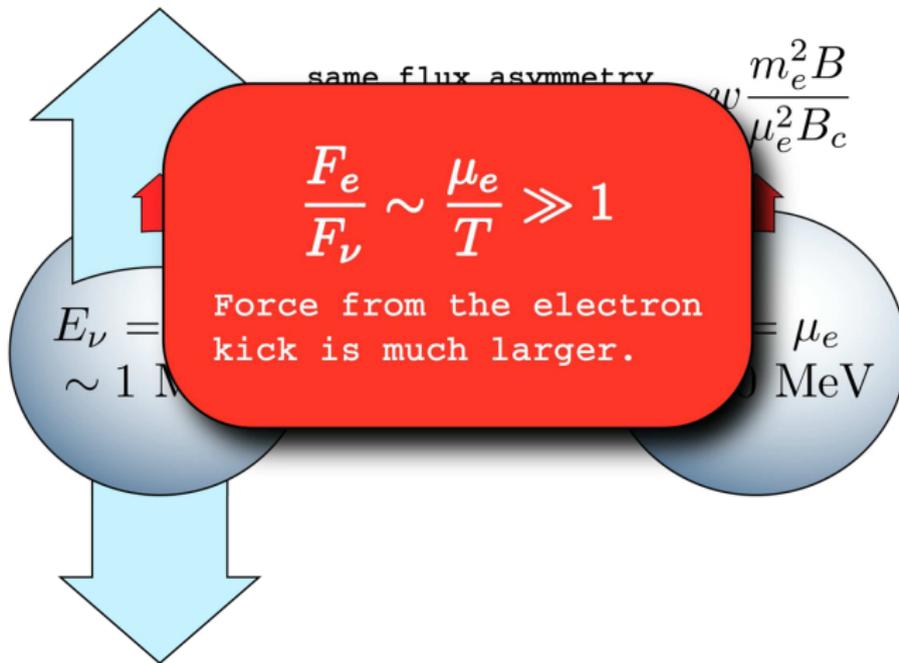
## Electron Kick



# So why is the electron kick bigger?

Neutrino Kick

Electron Kick



Topological currents can generate large kicks.

1. We use a realistic cooling model and reasonable magnetic field strengths to estimate the kick.
2. Current dominates cooling later in life.
3. Leads to the conjecture that pulsars with large kicks are quark stars.