

# Kicking Pulsars Hard<sup>1</sup>

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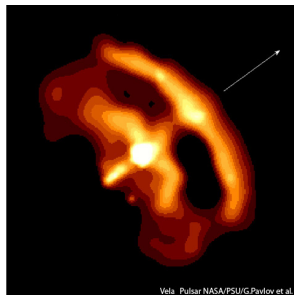
<sup>1</sup>Charbonneau, Hoffman and Heyl, *Large Pulsar Kicks from Topological Currents*. [arXiv:0912.3822] (2009)

# 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.

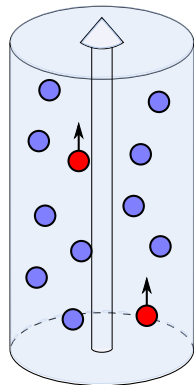
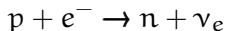
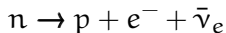


# Topological Vector Currents<sup>2</sup>

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,

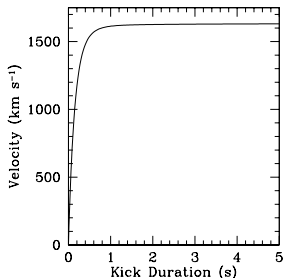
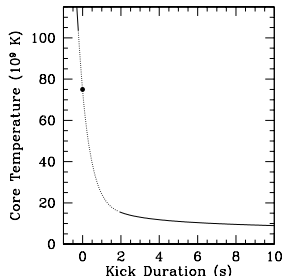


- magnetic flux  $\Phi$
- background electrons (zero average helicity)
- excess left-handed electrons

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

# Kicks from Topological Currents

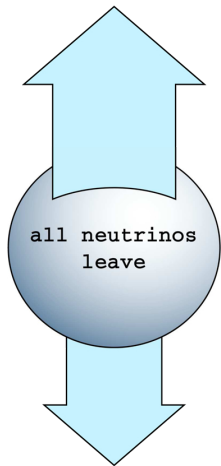
1. Electrons transfer momentum.
  - electron rocket!
  - bremsstrahlung.
  - quark stars only.
2. Current is sensitive to Temperature, need a realistic cooling curve.
  - Haensel et al. (1991)
  - Page & Usov (2002)
3. Mechanism generates large kicks  $> 1000$  km/s.



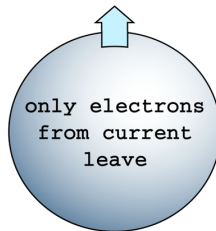
# Doesn't the current affect the cooling?

Neutrino Cooling

Electron Cooling

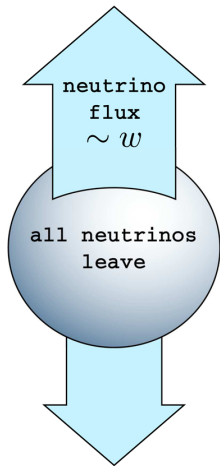


Urca process  
occurs at  
rate  $W$



# Doesn't the current affect the cooling?

## Neutrino Cooling

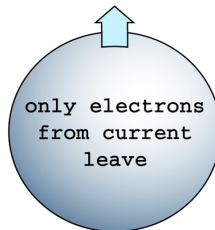


## Electron Cooling

electron flux

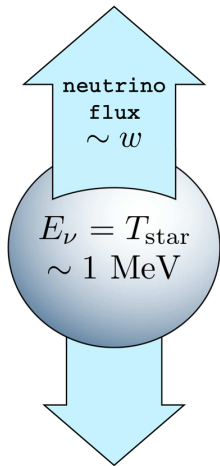
$$\sim w \frac{m_e^2 B}{\mu_e^2 B_c}$$

Urca process  
occurs at  
rate  $w$

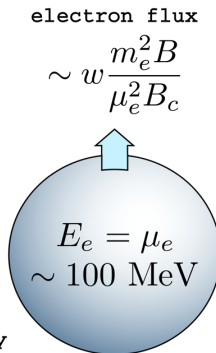


# Doesn't the current affect the cooling?

## Neutrino Cooling



## Electron Cooling

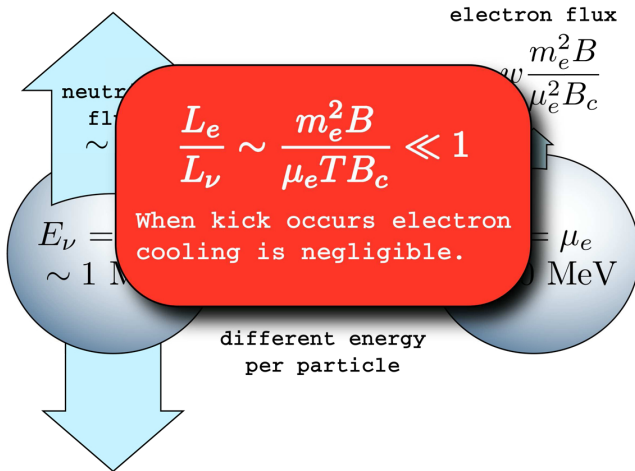


Urca process  
occurs at  
rate  $w$

different energy  
per particle

# Doesn't the current affect the cooling?

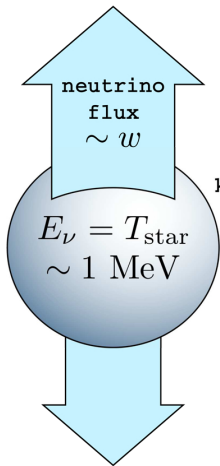
Neutrino Cooling      Electron Cooling





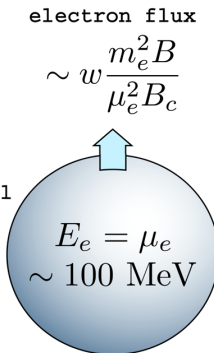
# So why is the electron kick bigger?

## Neutrino Kick



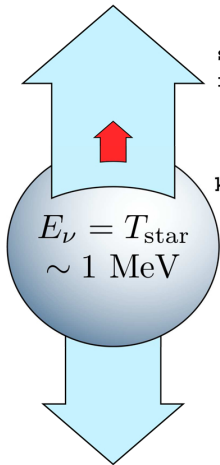
kick proportional  
to flux  
and energy

## Electron Kick



# So why is the electron kick bigger?

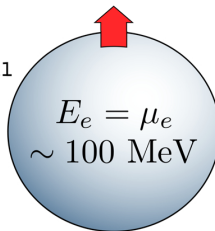
## Neutrino Kick



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

kick proportional  
to flux  
and energy

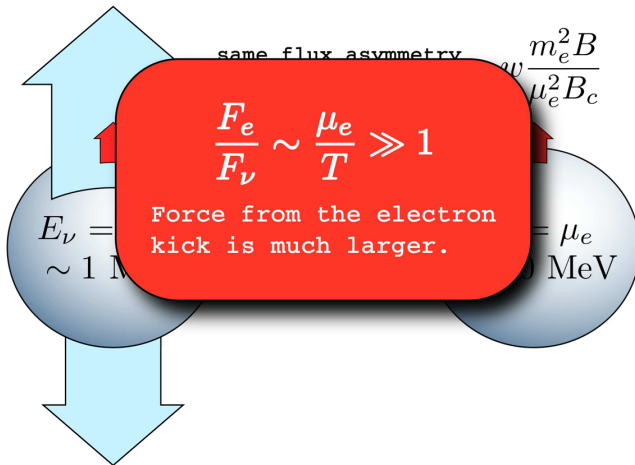
## Electron Kick



# So why is the electron kick bigger?

Neutrino Kick

Electron Kick



Topological currents can generate large kicks.

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