Pulsar Glitches: pinning forces in the snowplow model and dynamical simulations

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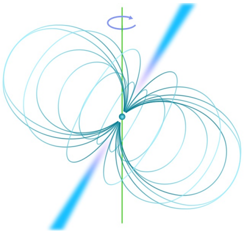
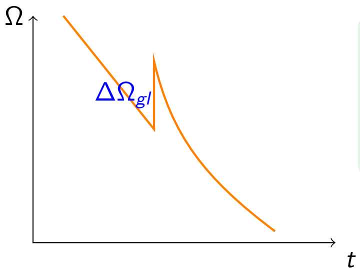


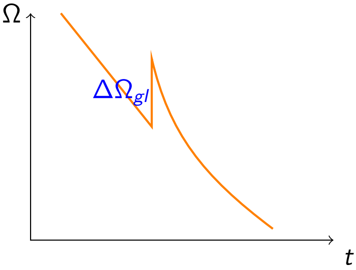
- What are neutron stars?
- Typical values
  - $M \sim 1.4 M_\odot$
  - $R \sim 10$ km
  - $\rho_c \sim (2 \div 10)\rho_0$
  - $P < 10$ s
  - $T \sim 10^8$ K
  - $B \sim 10^{12}$ gauss
- Why should we study them?

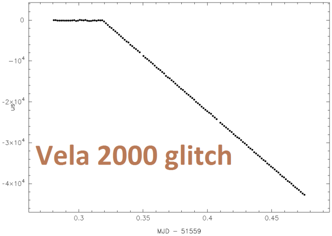


- The crust spins down gradually by electromagnetic emission
- GLITCH = sudden jump in Ω

Typical values $\Longrightarrow$ Vela

- $\Omega \sim 70\ \mathrm{s}^{-1}$
- $\dot{\Omega} \sim 10^{-10}\ \mathrm{s}^{-2}$
- $\Delta\Omega_{gl} \sim 10^{-4}\ \mathrm{s}^{-1} \quad \rightarrow \quad \Delta\Omega_{gl}/\Omega \sim 10^{-6}$
- $t_{gl} \sim 3$ yr (waiting time between two glitches)





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Why we study glitches
...and how to construct a good model

- We work at different levels:
  - MICROPHYSICS inside a neutron star
  - MESOSCOPIC approach
  - MACROSCOPIC model

Glitches
Basic picture

How to explain glitches?

“Starquake” models

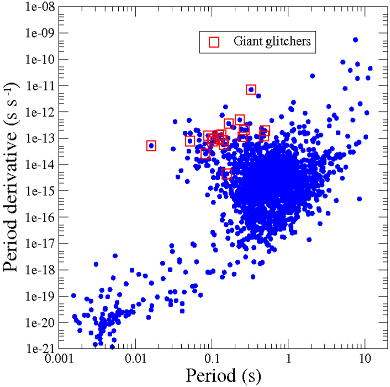
- Reasonable only for small glitches

Bulk superfluidity

- Works well with the “giant” glitches of Vela

$\Downarrow$

- The properties of superfluid matter reflect in a macroscopic behavior



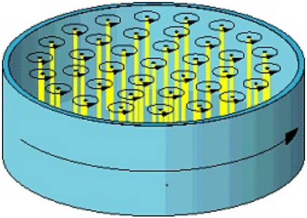
Bulk superfluidity

- Works well with the "giant" glitches of Vela

$\Downarrow$

- The properties of superfluid matter reflect in a macroscopic behavior

- Superfluidity is due to the existence of *pairing gap* Δ due to Cooper pairs
- It is localized in the core and in the inner crust because here we have free n
- In the star we have the normal component and the superfluid one
- A rotating superfluid is organized in vortices



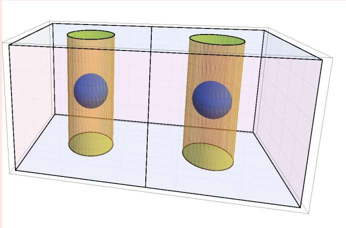
"Macroscopic" properties

- Macroscopic observables are "quantized" in vortices
  - $v(x) = \frac{\hbar}{2m_n}\frac{N(x)}{x}$
  - $\Omega_s(x) = \frac{\hbar}{2m_n}\frac{N(x)}{x^2}$

Basic mechanism
...a qualitative description

Pinning force f_P

- Only in the inner crust
- Interaction between vortices and nuclei of the lattice
- Tend to hold the vortex in its position



Magnus force f_M

- Hydrodynamical lift on vortices
- Tend to move a vortex outward
- Grows as the star slow down

Basic mechanism
...a qualitative description

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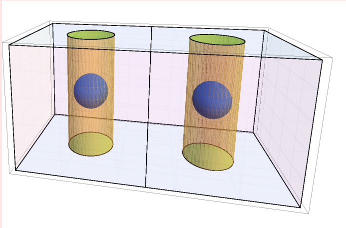

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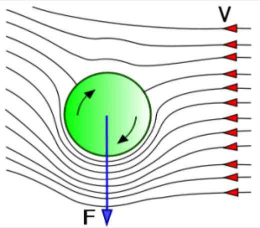
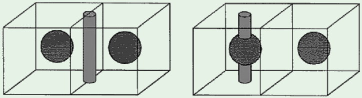


Microscopic level

- Friction and entrainment between normal and superfluid components

- Study of the interaction nucleus–vortex
- Gain in energy when a nucleus is inside the vortex

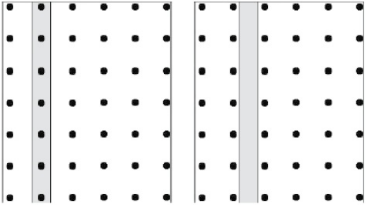


- $\Longrightarrow$ Pinning force per site

Mesoscopic level
The pinning force per unit length

Maximum pinning force

$$F_{max} \approx \frac{\Delta E}{\Delta r}$$

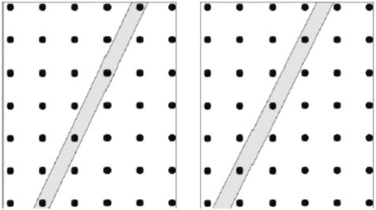


$\Longrightarrow$

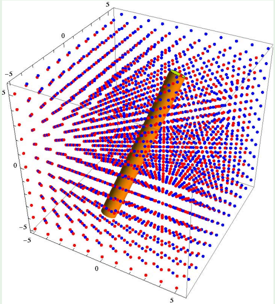
new approach

Realistic case

$$\langle F \rangle \ll F_{max}$$



Mesoscopic level
The pinning force per unit length



- Vortex–nuclei interaction
- $0.2 \div 5$ MeV per interaction
- $R_{ws} \approx 10 \div 40$ fm

Average over all possible orientations:

$$f_p = \langle F \rangle = \frac{1}{4\pi L} \int F(\theta, \phi)\, d\Omega$$

Glitch models

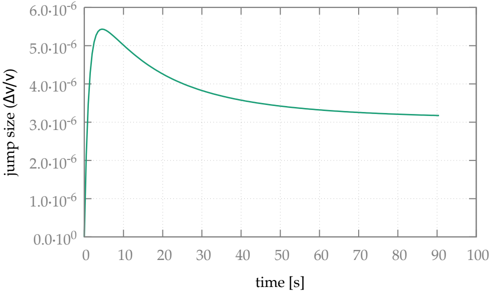
...static approach

The static "SNOWPLOW" model

- Use realistic pinning forces
- Macroscopic properties of superfluids
- Reproduce correctly the orders of magnitude of observational data
  - Jump size
  - Interglitch time

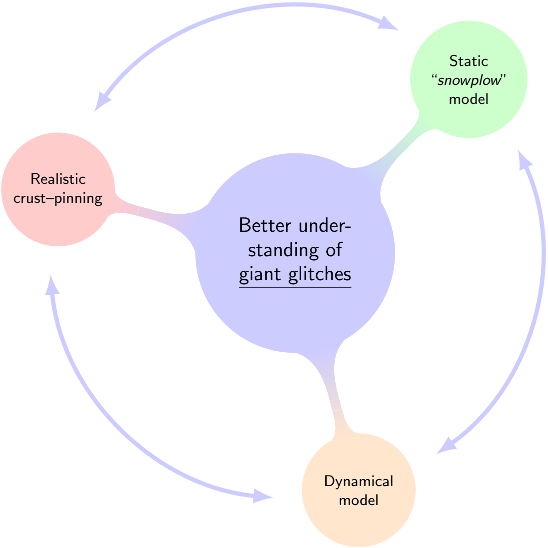
Glitch models
...reproduce a glitch

- Two–fluids model
- Integrate differential equations for neutron and protons



- Follow the whole evolution
- Study and constraint the rise–time and recovery

Conclusions



- Pinning forces in the crust $\sim 10^{15}$ dyn/cm
- Static model that explains observational data
- The dynamical model can follow the whole evolution: rise time and relaxation

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