Glitches and anti-glitches in accreting pulsars: expected properties and observability

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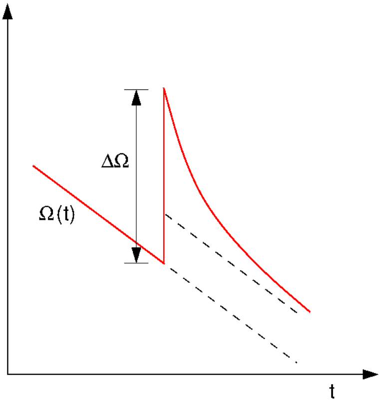
Part I

Introduction

Observational properties

- Glitches observed in over 100 isolated radio pulsars and magnetars;
- Long-term spin-down $\dot{\Omega}_\infty = 10^{-15} - 10^{-10}\,\mathrm{rad\,s^{-2}}$;
- Jumps in angular velocity up to $\Delta\Omega \approx 10^{-4}\,\mathrm{rad\,s^{-1}}$;
- Quasi-exponential relaxation of $\dot{\Omega}(t > t_{\mathrm{gl}})$ to $\dot{\Omega}_\infty$.



Models to explain glitches:

- starquake models (Baym & Pines 1971);
- superfluid vortex models (Anderson & Itoh 1975).

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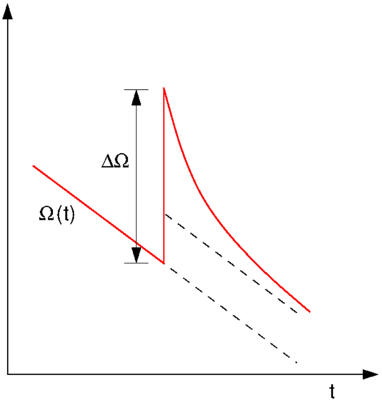

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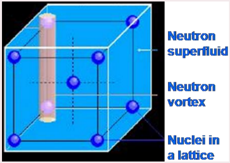
Superfluid vortex model

- matter divided into *(1) neutron superfluid; (2) normal component (that corotates with the pulsar magnetic field)*.
- rotating superfluid organised as array of vortices parallel to the spin axis of the NS.

Vortex pinning

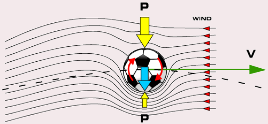
- vortices pinned to the lattice of ions;
- vortices not coupled with the normal component of the star;



- therefore, although the crust spins-down, the superfluid conserves its angular momentum.

Vortex unpinning

- As the NS spins-down, a rotational lag builds up between the superfluid vortices and the normal component $\omega = \Omega_s - \Omega_n$;
- When $\omega = \omega_{cr}$, the *Magnus force* unpins and moves them out.



- transfer of angular momentum to the normal component;
- star surface spins-up $\Rightarrow$ glitch.

Motivation

- Several glitches have been observed in young, isolated pulsars;
- A detection in accretion-powered X-ray pulsars is still lacking;

$\Downarrow$

- Investigate conditions under which glitches are more likely to occur in accreting pulsars;
- Determine the expected properties and observability of glitches;

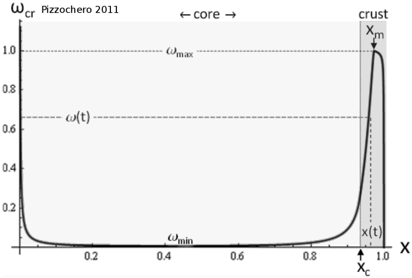
Part II

Glitches and anti-glitches in accreting pulsars

(Ducci et al. 2015; A&A 578, 52)

Snowplow model (Pizzochero 2011)

- Snowplow model can predict three observables: $\Delta t_{\rm gl}$, $\Delta\Omega_{\rm gl}$, $\Delta\dot{\Omega}_{\rm gl}/\dot{\Omega}_\infty$;
- Density profile of the pinning force; maximum value $f_m \approx 10^{15}\,{\rm dyn\,cm}^{-1}$ at $\rho \approx 0.2\rho_0$;
- Critical lag for depinning $\omega_{\rm cr}$ obtained by equating $f_{\rm pin}$ and $f_{\rm Mag}$:



- Vortices from $x < x_{\rm m}$ accumulates in a vortex layer at $x_{\rm m}$;
- When $\omega(x_{\rm m}) = \omega_{\rm max}$, the layer suddenly moves out and exchange the stored angular momentum with the normal component $\Rightarrow$ glitch.

$\Rightarrow$ accreting pulsars ($\dot{\Omega}_\infty < 0$): $\Delta t_{\rm gl} \approx 29/\dot{\Omega}_{-11}$ yr; $\Delta\Omega_{\rm gl} \approx 10^{-4}\,{\rm rad\,s}^{-1}$.

Anti-glitch scenario

Some XRBs show long-term spin-up ⇒ good candidates for anti-glitches.

anti-glitch:

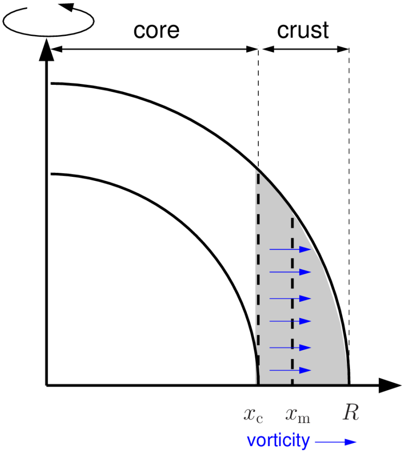
sudden spin-down caused by a mechanism of angular momentum transfer similar to that of glitches (proposed for the first time by Pines+1980).

- We modified the snowplow model of Pizzochero 2011 to calculate $\Delta\Omega_{\mathrm{a-gl}}$;

Anti-glitch scenario

Glitch:

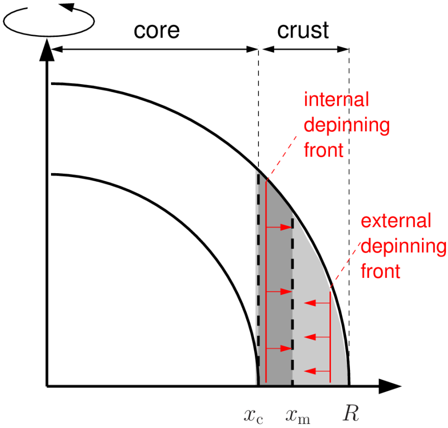
- spin-down of the crust;
- vortices expelled outwards.



Anti-glitch scenario

Anti-glitch:

- the crust accelerates (long-term spin-up);
- new vortices created at R;
- new vortices $x > x_{\rm m}$ accumulated by the external depinning front moving inward;
- internal depinning front moves outwards across the region $x < x_{\rm m}$.



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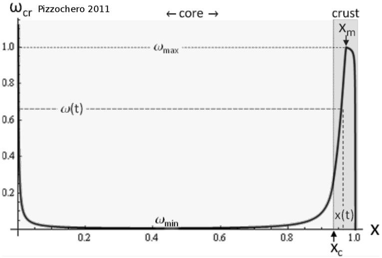
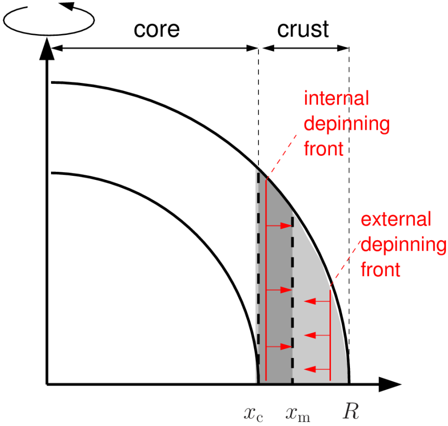


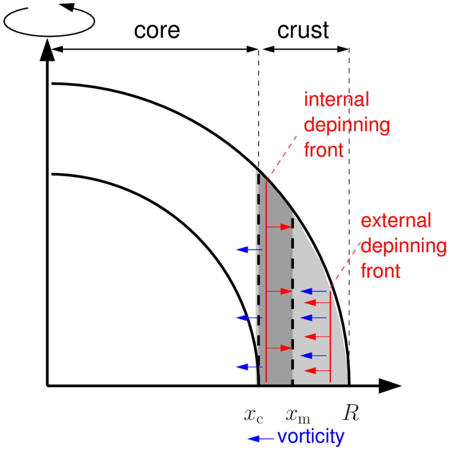


Anti-glitch scenario

Anti-glitch:

- vorticity moves from R to $x_{\rm m}$;
- vorticity moves from the inner crust to the core:

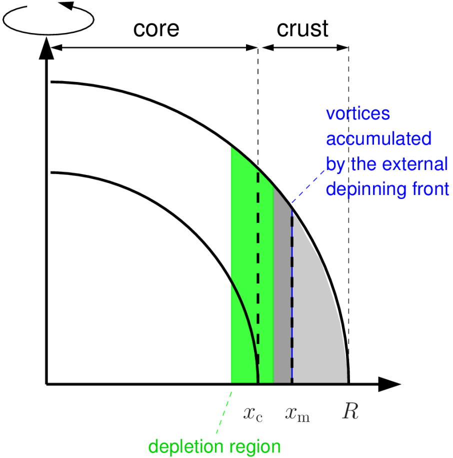
$$\vec{F}_{\rm m} = \kappa\rho_{\rm s}\hat{e}_{\rm z} \times (\vec{v}_{\rm L} - \vec{v}_{\rm s})$$



Anti-glitch scenario

Anti-glitch:

- vortices accumulated at $x_{\rm m}$ by the external depinning front;
- depletion of vortices around $x_{\rm c}$ (regions with lower pinning potential);
- Vortices accumulated at $x_{\rm m}$ will fill depleted region;
- Transfer of angular momentum will take place in this region.
- $\Delta\Omega_{\rm a-gl} \approx 10^{-5} - 10^{-4}\,{\rm rad\,s^{-1}}$



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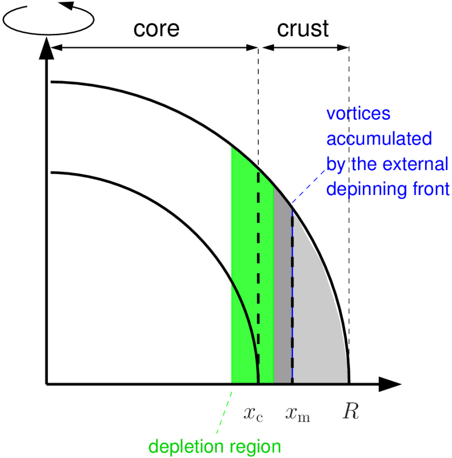

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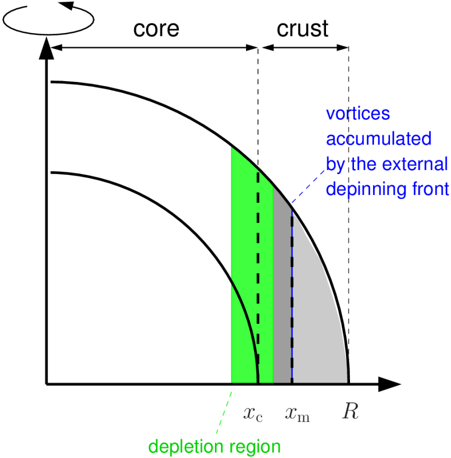
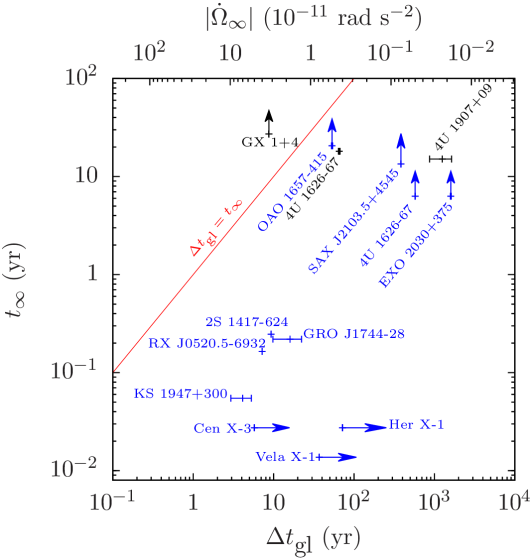


$\Delta t_{\rm gl} - t_\infty$ diagram



Conclusions

We outlined for the first time the expected observational properties of glitches in accreting pulsars.

- Glitches caused by the superfluid: possible, can be detected;
- Anti-glitches in accreting pulsars: XRBs unique laboratory to study them;
- Anti-glitch ($\dot{\Omega}_\infty > 0$): $\Delta\Omega_{\mathrm{a-gl}} \approx 10^{-5} - 10^{-4}\,\mathrm{rad\,s^{-1}}$
- GX 1+4 best candidate for the detection of glitches;
- Other results:
- Glitches caused by starquakes: rare and their detection unlikely;
- Coupling timescale between superfluid and normal component $\tau \propto 1/\Omega$:
  - Glitch (anti-glitch) long rise time: $(10^2 - 10^3)\Omega^{-1}$ s;

backup slides

Observability

- Same size of the jumps in angular velocity observed in magnetars and fluxes show that in principle they can also be detected in XRBs;
- *caveat:* A suitable spacing of the observations is required to detect glitches and distinguish them from other timing irregularities induced by variations in the accretion torque;
- Observations of correlated changes in the source flux (typical of accretion torque) should help to recognize them.

X-ray binaries (NS or BH + donor star)

- X-ray emission produced by the accretion of matter (wind-fed or accretion disk);
- $L_x = 10^{32} - 10^{38}\,\mathrm{erg\,s^{-1}}$; $t_{spin} = \mathrm{ms\ to} \approx 10^4\,\mathrm{s}$;
- how many? few hundreds in our Galaxy (few tens bright accr. pulsars);
- accr. pulsars can experience spin-up and spin-down: caused by the interaction between the accretion flow and the magnetosphere;
- accr. torque $\simeq$ e.m. braking torque in young glitching pulsars;
- rate of glitches $\propto \dot{\Omega}$; $\Rightarrow$ glitches in XRBs more frequent than expected in old pulsars.