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

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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;

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

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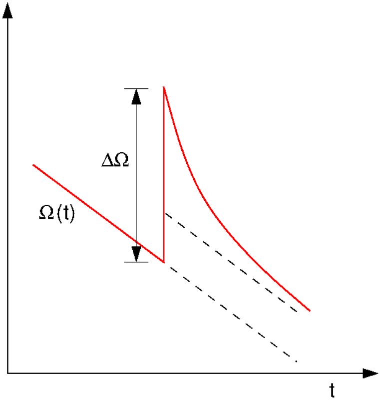
Part I

Introduction

Observational properties

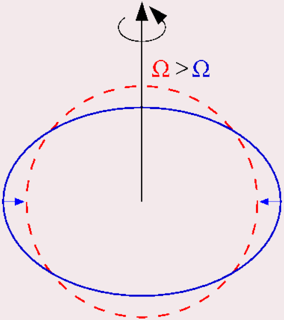
- Glitches observed in over 100 isolated radio pulsars and magnetars;
- Long-term spin-down $\dot{\Omega}_\infty = 10^{-15} - 10^{-10}\,\mathrm{rad\,s^{-2}}$;
- Jumps in angular velocity up to $\Delta\Omega \approx 10^{-4}\,\mathrm{rad\,s^{-1}}$;
- Quasi-exponential relaxation of $\dot{\Omega}(t > t_{\mathrm{gl}})$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



Models to explain glitches:

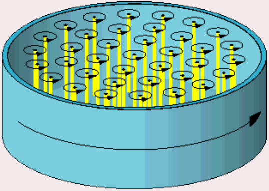
Starquake models:

- Oblate crust deforms toward a spherical shape as the pulsar slows down;
- Sudden crack in the crust, decrease in the moment of inertia;



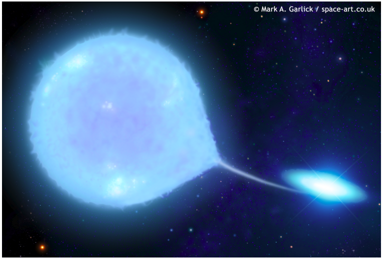
superfluid vortex models (Anderson & Itoh 1975):

- Sudden unpinning of neutron superfluid vortices from lattice nuclei;
- Angular momentum stored in vortices is transferred to the non-superfluid component.



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

- X-ray emission produced by the accretion of matter (wind-fed or accretion disk);
- $t_{spin} = \text{ms to} \approx 10^4$ s;
- 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.



Part II

Glitches and anti-glitches in accreting pulsars

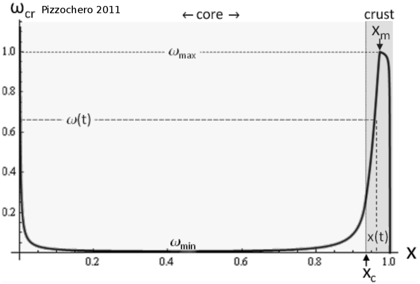
(Ducci et al. 2015; A&A 578, 52)

Aims:

- Conditions under which glitches are more likely to occur in accreting pulsars;
- Expected properties of glitches in these objects.

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 $f_m \approx 10^{15}\,\mathrm{dyn\,cm}^{-1}$ at $\rho \approx 0.2\rho_0$;



- 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; $\Delta\Omega_{\rm gl} \approx 10^{-4}\,\mathrm{rad\,s}^{-1}$.

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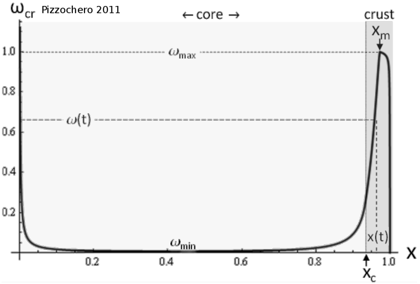

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Anti-glitch scenario

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

anti-glitch:

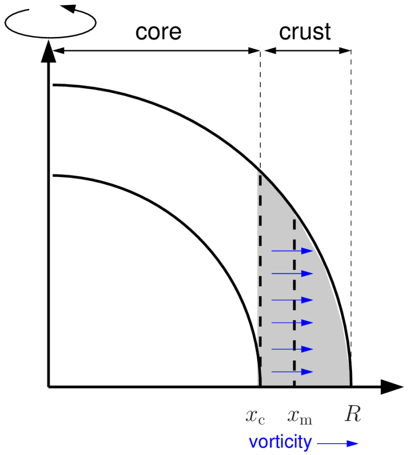
sudden spin-down caused by a mechanism of angular momentum transfer similar to that of glitches (proposed for the first time by Pines+1980).

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

Anti-glitch scenario

Glitch:

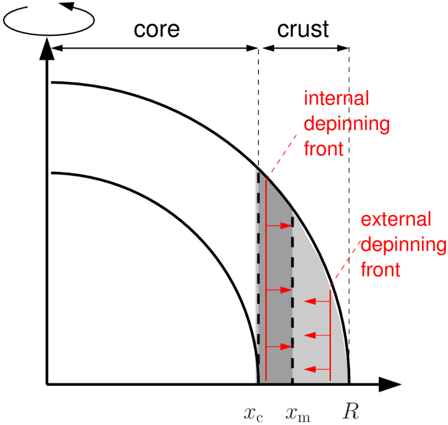
- spin-down of the crust;
- vortices expelled outwards.



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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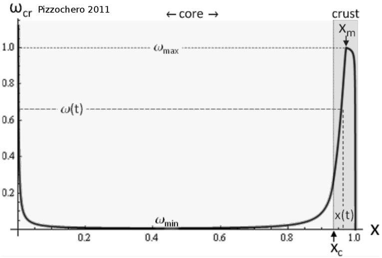
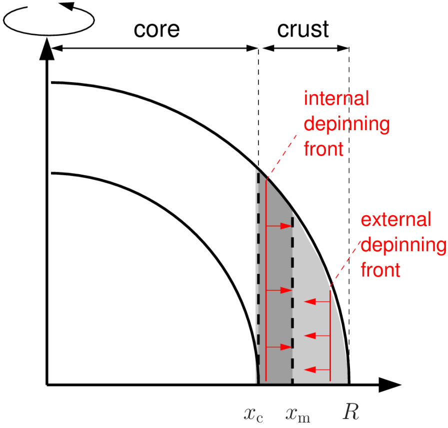
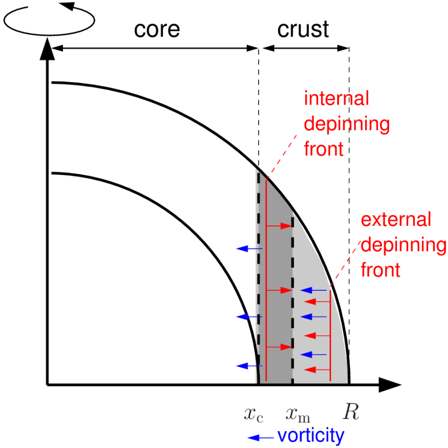




Anti-glitch scenario

Anti-glitch:

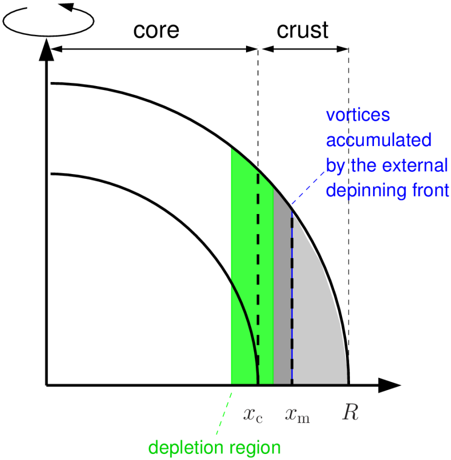
- vorticity moves from R to $x_{\rm m}$;
- vorticity moves from the inner crust to the core;



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);
- radii of the depletion region unknown.
- Vortices accumulated at $x_{\rm m}$ will fill depleted region;
- Transfer of angular momentum will take place in this region.
- $\Delta\Omega_{\rm a-gl} \approx 10^{-5} - 10^{-4}\,{\rm rad\,s^{-1}}$



Anti-glitch scenario

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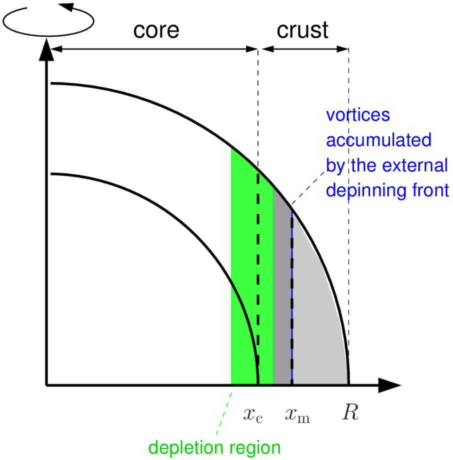

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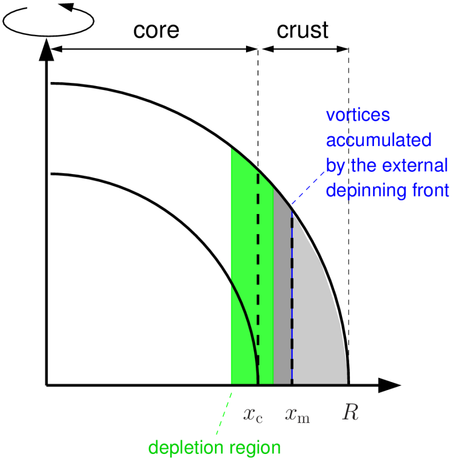
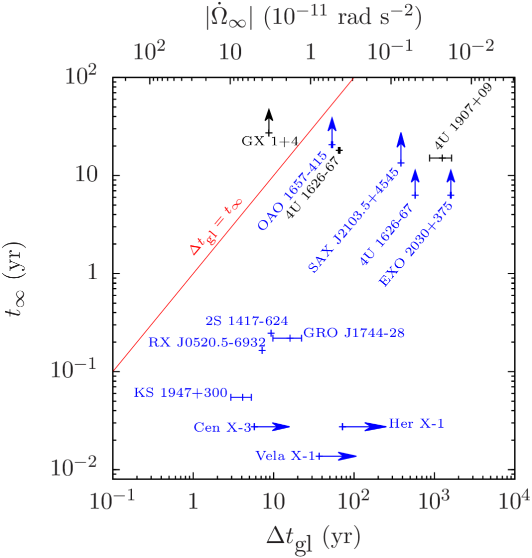


Observability

- 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.

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



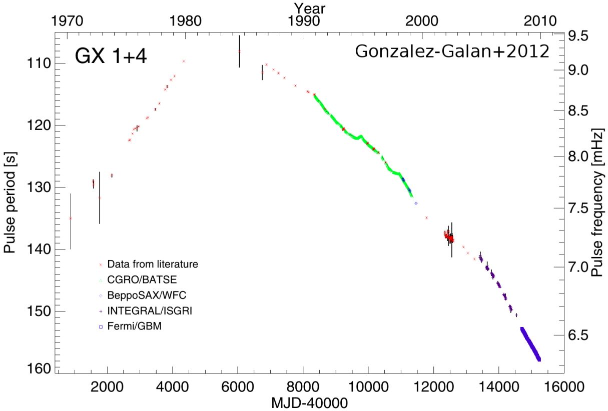
Conclusions

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: possible, can be detected. Unique "laboratory" to study them;
- Anti-glitch ($\dot{\Omega}_\infty > 0$): jump in angular velocity: $\Delta\Omega_{\rm a-gl} \approx 10^{-5} - 10^{-4}\,{\rm rad\,s^{-1}}$
- 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;
  - long recovery timescales;

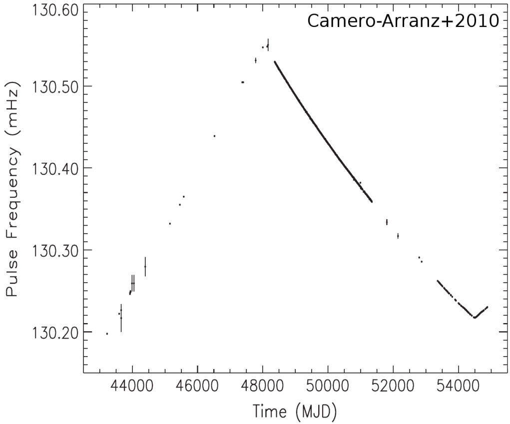
backup slides

Spin period evolution of GX 1+4



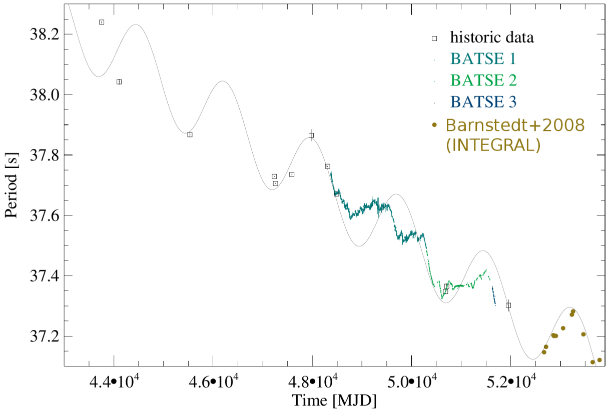
Ω rad s^{-1}	$\dot{\Omega}_\infty$ rad s^{-2}	τ_∞ d	L_x erg s^{-1}
≈ 0.042	-3×10^{-11}	> 9900	$10^{35} - 10^{36}$

Spin period evolution of 4U 1626−67



Ω rad s^{-1}	$\dot{\Omega}_\infty$ rad s^{-2}	τ_∞ d	L_x erg s^{-1}
≈ 0.8	-4.4×10^{-12}	≈ 6600	$\gtrsim 10^{36}$

Spin period evolution of OAO 1657−415



Ω rad s^{-1}	$\dot{\Omega}_\infty$ rad s^{-2}	τ_∞ d	L_x erg s^{-1}
≈ 0.17	-1.3×10^{-11}	≈ 200	$10^{36} - 10^{37}$

Starquake glitch scenario

- Interval between glitches estimated from the magnitude of the preceeding one (Baym & Pines 1971):

$$\Delta t_{\mathrm{q}} = T \frac{2A^2}{BI_0\Omega^2} |\Delta\epsilon|$$

- $T \equiv -\Omega/\dot{\Omega}_{\infty}$;
- $|\Delta\epsilon|$ is the reduction in oblateness ϵ caused by the previous quake;
- A, B, and I_0 depend on the equation of state and on the crust model adopted.
- we use parameters obtained by Pandharipande+1976 and Zdunik+2008 which updated the Baym-Pines model using different EoSs and crust models;
- $\Rightarrow \Delta t_{\mathrm{q}} \gg 10^5$ yr;
- Detection of a glitch produced by a starquake in an accreting pulsar is extremely unlikely.

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;
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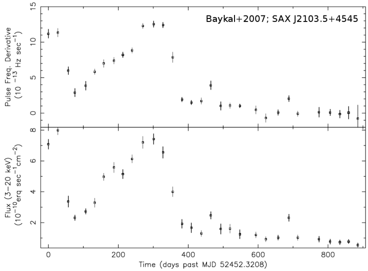

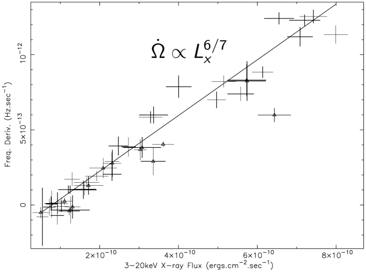

Snowplow model (Pizzochero 2011)

- First physically reasonable model to determine where in the star the vorticity is pinned, how much of it is pinned, and for how long;
- Density profile of the pinning force; maximum value $f_m \approx 10^{15}\,\mathrm{dyn\,cm}^{-1}$ at $\rho \approx 0.2\rho_0$;
- Critical lag for depinning ω_{cr} obtained by equating f_{pin} and f_{Mag};

ω_{cr} as a function of the cylindrical radius

- Vortices from $x < x_\mathrm{m}$ accumulates in a vortex layer at x_m;
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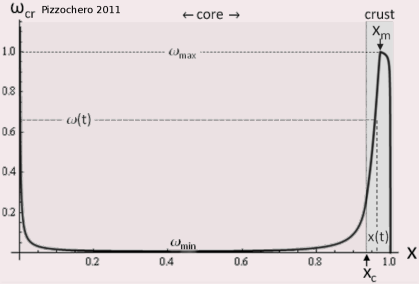

⇒ accreting pulsars ($\dot{\Omega}_\infty < 0$): $\Delta t_\mathrm{gl} \approx 29/\dot{\Omega}_{-11}$ yr; $\Delta\Omega_\mathrm{gl} \approx 10^{-4}\,\mathrm{rad\,s}^{-1}$.

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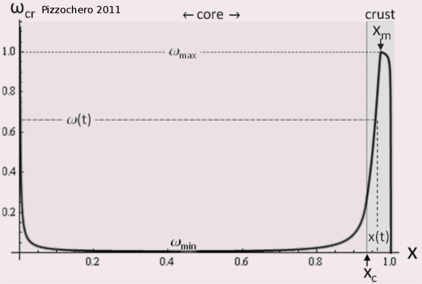

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