The Abnormal Glitch Signature of PSR J1119-6127 and the Vortex Creep Model

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TÜBİTAK

This work is supported by Scientific And Technology Research Council of Turkey under the grant 113F354.

CompStar 2015 15-19 June, Budapest

Glitch: sudden increases in the rotation rate of pulsars followed by relaxation towards the pre-glitch state - $\Delta\Omega/\Omega \sim 10^{-10} - 10^{-5}$

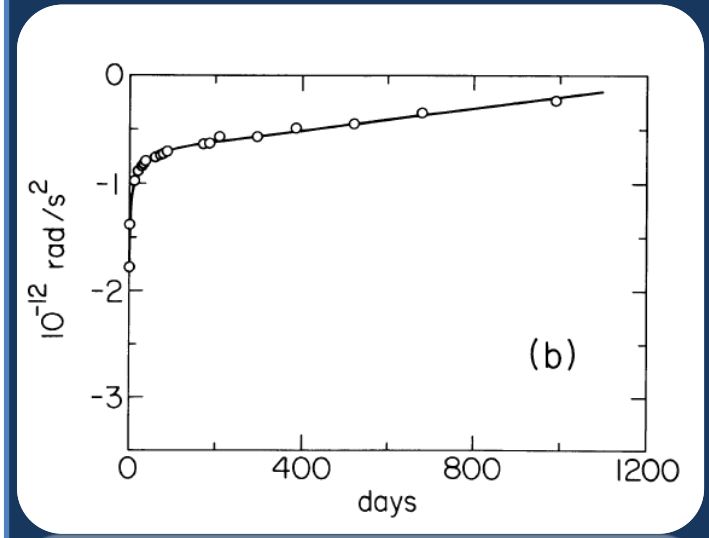
Jump in the spin-down rate $\Delta\dot{\Omega}/\dot{\Omega} \sim 10^{-4} - 10^{-2}$

Standard glitches characterized by:

i. positive step in angular velocity $(\Delta\Omega > 0)$

ii. negative step in the spin-down rate $(\Delta\dot{\Omega} < 0)$

iii. no glitch-associated changes in the electromagnetic signature of rotation- powered pulsars

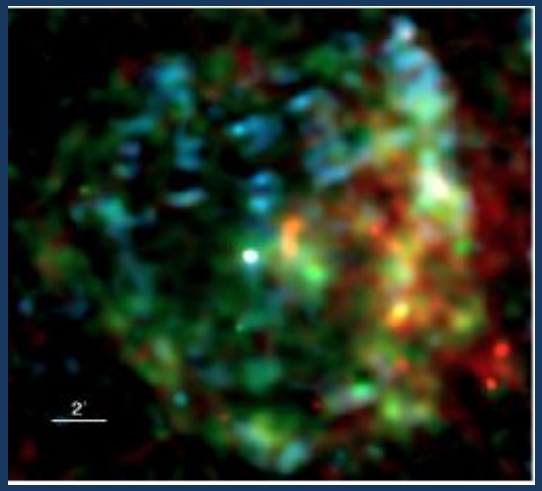


Alpar et al. 1993

PECULIAR GLITCH OF PSR J1119-6127 in 2007 :

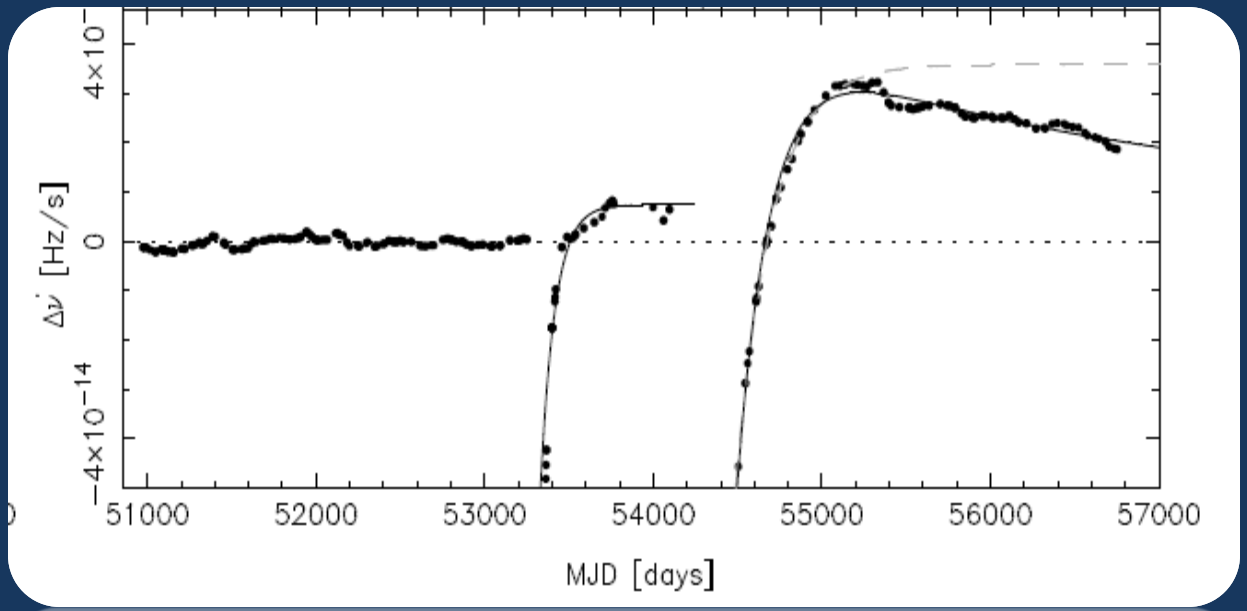
i) $\Delta\dot{\Omega} > 0.$

ii) The radio emission properties display changes (Intermittency and RRAT behaviour for about 3 months) associated with the glitch.



age $\tau_c \approx 1.6$ kyr
$B \approx 4.1 \times 10^{13}$ G (at poles)
Exhibited 3 Glitches

'external' dipole radiation torque must have changed too!



Antonopoulou et al. 2015

The vortex creep model:

Vortex lines can pin to atomic nuclei in the lattice
(thermally activated creep)

↓

$\omega = \Omega_s - \Omega_c$ builds up as the crust spins down under the external pulsar torque.

↓

As this reaches a critical value, a large number of vortices can unpin in an avalanche

↓

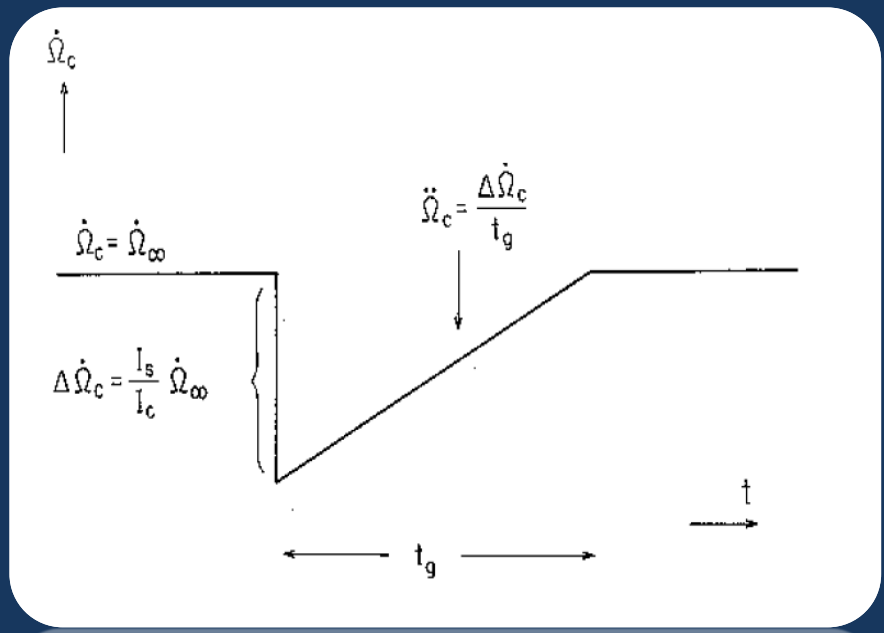
Transfer their angular momentum to the crust

↓

$\Delta\Omega_c > 0$, observed as a **Glitch!**

In the standard vortex unpinning-creep model only outward motion of vortices

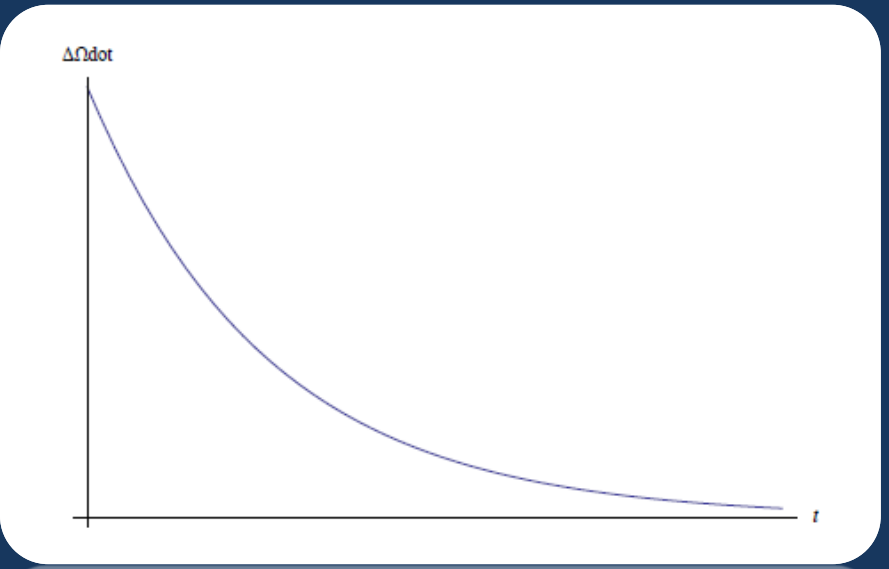
- **The crust spins up**
- **The lag decreases**
- **Coupling decreases**
- **Superfluid decouples**
- **Torque acts on smaller moment of inertia**
- **Spin-down increases**
- **Recovery : superfluid recouples to some other regions of the crust.**



To explain pecularity of PSR J1119-6127's 2007 glitch :

1) Inward vortex motion

2) Glitch associated permanent shift in external torque



$$\Delta\dot{\Omega}_c = -\frac{I_{A'}}{I}|\dot{\Omega}|_\infty \left[1 - \frac{1}{1 + (\mathrm{e}^{-t_0'/\tau_{nl}'} - 1)\mathrm{e}^{-t/\tau_{nl}'}}\right]$$

$\omega = \Omega_s - \Omega_c$ increases

Accelerating creep rather than cutting-off

Increasing rate of angular momentum transfer to crust (spin-up)

Producing a positive change in observed crust spin-down rate.

BUT inward motion of vortices is thermodynamically imposible!
An external effect needed, like **STARQUAKE**

Glitch can be triggered by quake!

moving of crustal plate towards the rotation axis, together with its pinned vortices

↓

At the same time some vortices are unpinned and move outward

↓

Glitch: the angular momentum transfer associated with the sudden outward and inward vortex motions

↓

B-field lines moving with the conducting crustal plate

↓

Change of external torque

↓

Abnormal emission

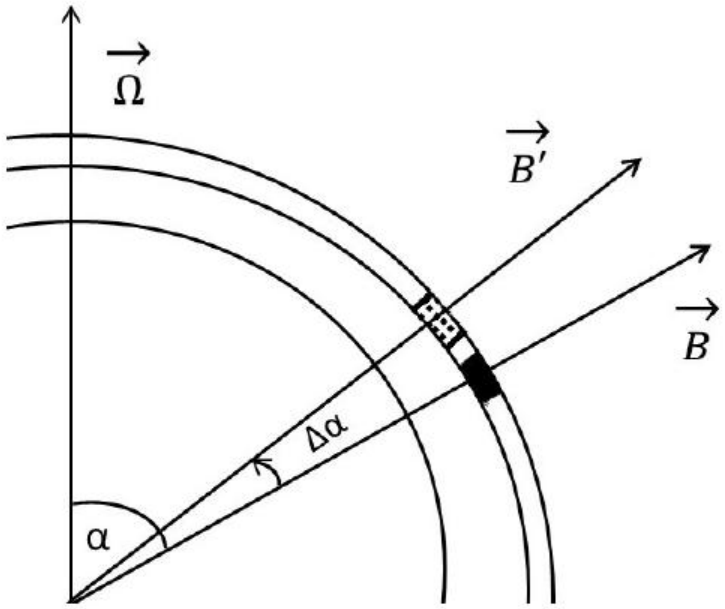
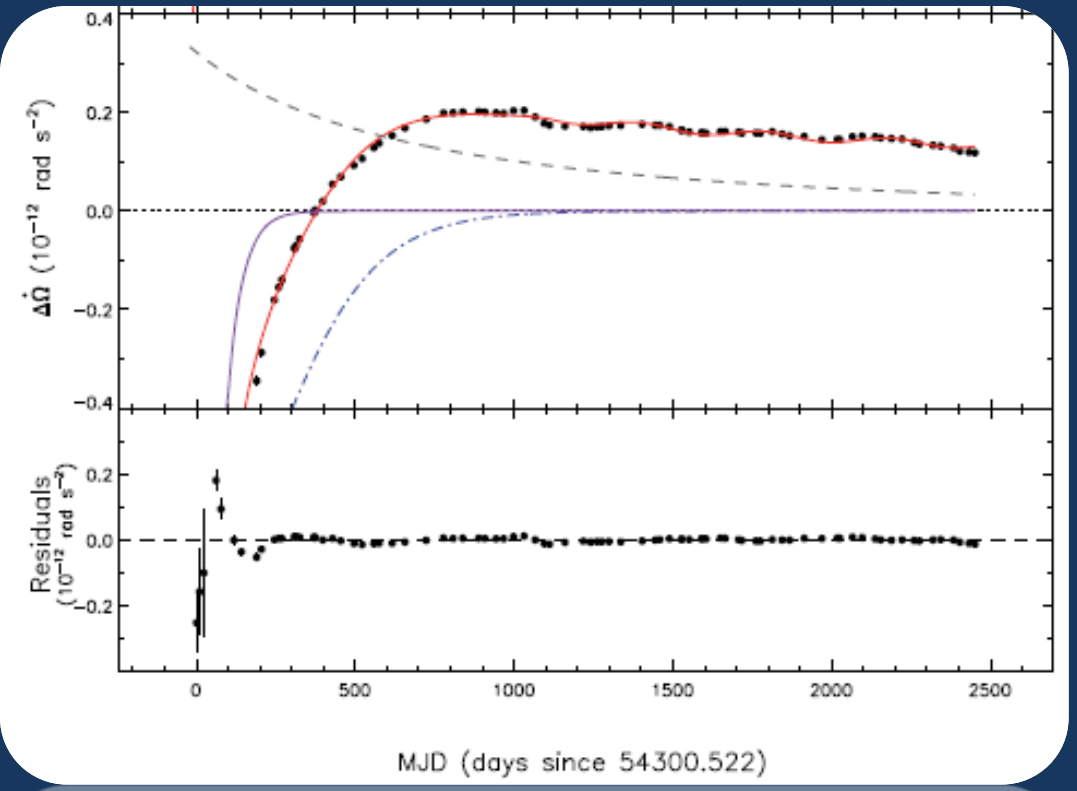


Figure 2. Starquake Model in cross section. The dotted area represents new position of crustal plates (broken ring) after the starquake.

MODEL FITS:

$$\Delta\dot{\Omega}_c(t) = -a_1\left[1-\frac{1}{1+\alpha_1 e^{-(t+\Delta)/\tau_1}}\right] - a_2\left[1-\frac{1}{1+\alpha_2 e^{-(t+\Delta)/\tau_2}}\right] - a_3 e^{-(t+\Delta)/\tau_3} + b. \quad (16)$$



$$a_1 = \frac{I_{A'}}{I}|\dot{\Omega}|_\infty \qquad \alpha_1 = (e^{-t_0'/\tau_1} - 1)$$

$$a_2 = \frac{I_A}{I}|\dot{\Omega}|_\infty \qquad \alpha_2 = (e^{t_0/\tau_2} - 1)$$

$$a_3 = \frac{I_3}{I}\frac{\delta\omega}{\tau_3} \qquad b = (\Delta N_{ext}/N)\dot{\Omega}_\infty$$

Total superfluid moment of inertia affected by Glitch:

$$I_s \gtrsim 0.2I$$

cannot be accommodated by the crust superfluid alone for most neutron star models! (even without entrainment correction) other locations are required to sustain vortex creep.

Contribution from vortex line-toroidal flux line pinning and creep at the outer-core of the neutron star (*Sidery & Alpar 2009*)

The response to a glitch is exponential relaxation
(Gügercinoğlu & Alpar 2014).

$\tau_{tor} \simeq 50$ days $\qquad I_{tor}/I \sim 0.2$

Consistent with our fit results : $\tau_3 \cong 48$ days $\quad I_3/I = 1.74 \times 10^{-1}$

$$I_{s,crust} \sim 3 \times 10^{-2}$$

The glitch associated change in the external torque

a constant offset from the pre-glitch: $b = (\Delta N_{ext}/N)\dot{\Omega}_{\infty}$

$$\frac{\Delta N_{ext}}{N_{ext}} = 3\frac{\Delta\Omega_c}{\Omega_c} + 2\frac{\Delta B_\perp}{B_\perp} \cong 2\frac{\Delta B_\perp}{B_\perp},$$

$$\frac{\Delta B_\perp}{B_\perp} = \frac{\Delta\alpha}{\tan\alpha}.$$

$$\Delta\alpha = \frac{1}{2}\frac{\Delta N_{ext}}{N_{ext}}\ \tan\alpha \cong (-3.3\times10^{-4})\ \tan\alpha$$

≈ 10^{-4} cannot be resolved as an observable glitch associated pulse shape change in the present radio timing data

Intermittent and RRAT behaviour? Effect of the quake on B-field lines which are anchored to the crust.

Twisting and reconnecting field lines can amplify a small shift in the crustal position into a complex and drastic change in the emission pattern.

(*Beloborodov 2009*)

The total numbers of vortices displaced in this glitch:

$$\delta N = 2\pi r^2 \delta\Omega_s/\kappa \cong 2\pi R^2 \delta\Omega_s/\kappa$$

From fit results: $\delta N_{out} \sim 1.3 \times 10^{13}$ $\delta N_{in} \sim 8.4 \times 10^{13}$

common scale, $\sim 10^{13}$

$$I_{A'}/I \cong \frac{4\pi\rho_s R^4 D \sin\alpha \cos^2\alpha}{(2/5)MR^2} \simeq 15/2 \sin\alpha \cos^2\alpha\ (D/R) \sim (2D/R)$$

$$D \sim 6R_6 \text{ m}, \qquad \theta_{\rm cr} \sim 10^{-2} \left(\frac{D}{1\text{ m}}\right) \left(\frac{h}{100\text{ m}}\right)^{-1}$$

compatible with the results of Horowitz & Kadau (2009) for the critical strain angle.

Minimum Glitch Size in Crab: $\Delta\nu \sim 0.05\ \mu\mathrm{Hz}$. *(Espinoza et al. 2014)*

1.3. A ring including many plates and moving inward in cylindrical symmetry ($V = 2\pi RDh$):

$$1.7 \times 10^{-9} = \frac{\Delta I}{I} \cong \left(\frac{\rho_c (2\pi RDh)(2RfD)}{(2/5)MR^2} \right) = 1.6 \times 10^{-6} \left(\frac{D_4^2 \rho_{c,13} h_5 f}{(M/M_S)} \right) \tag{10}$$

$$D \sim 33\ m \left(\frac{(M/M_S)}{\rho_{c,13} h_5 f} \right)^{1/2} \tag{11}$$

Number of vortices pinned to one plate:

$$\delta N = \pi D^2 \frac{2\Omega}{\kappa} \sim 6.5 \times 10^{12} \left(\frac{(M/M_S)}{\rho_{c,13} h_5 f} \right) \tag{12}$$

critical strain angle:

$$\theta_{cr} \sim \frac{D_4 \times 10^4}{h_5 \times 10^5} \sim 3.3 \times 10^{-2} \frac{1}{h_5} \left(\frac{(M/M_S)}{\rho_{c,13} h_5 f} \right)^{1/2} \tag{13}$$

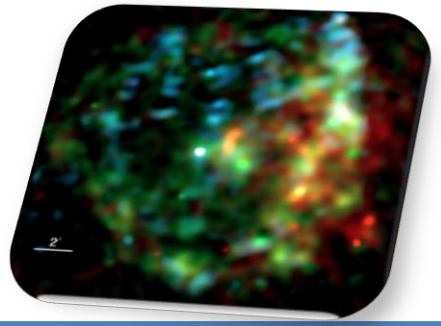
Akbal&Alpar 2015 to be published

Summary:

1) The peculiar glitch of PSR J1119-6127 offers an opportunity to extend the glitch models to account abnormal glitch signatures emission phenomena initiated by a quake

2) Quake both leads to a change in the external torque and triggers the response of the superfluid regions of the neutron star (inward and outward vortex lines motion)

3) The coincidence of the numbers of vortices involved in the last glitch of PSR J1119-6127 with the numbers inferred in Crab and Vela pulsars glitches offers us an explanation in terms of trigger mechanisms for glitches.



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of the
ROYAL ASTRONOMICAL SOCIETY

MNRAS **449,** 933–941 (2015) doi:10.1093/mnras/stv32

Peculiar glitch of PSR J1119−6127 and extension of the vortex creep model

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THANK YOU…