Pulsar glitch in a strangeon star model

Xiaoyu Lai 来小禹

Hubei University of Education 湖北第二师范学院

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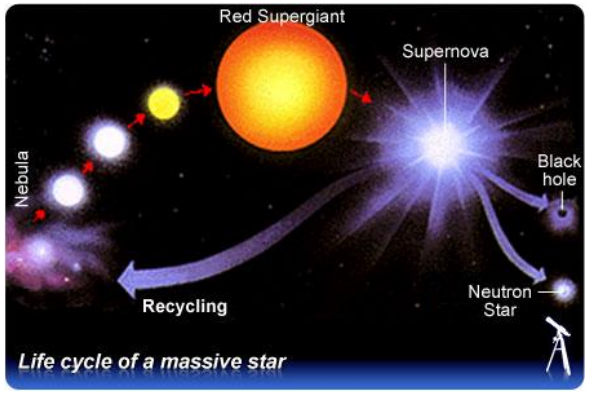
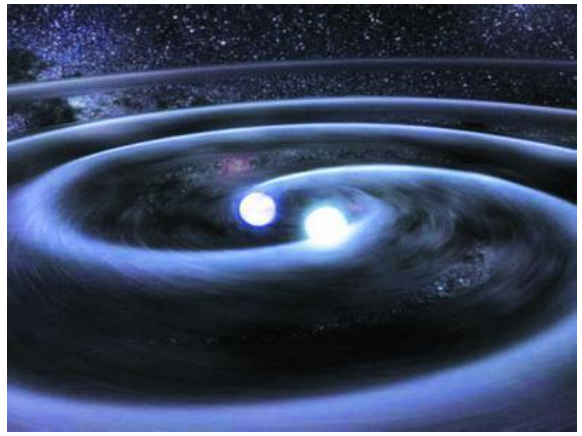
Outline

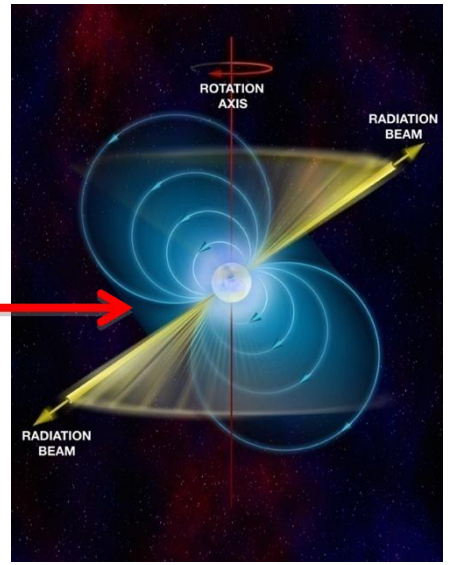
- Pulsars: strangeon stars ?
- Strangeon stars: glitch and recovery
- Summary

“Neutron stars”: a general name of pulsar-like compact stars





$M \sim M_{\odot}$, R~10 km

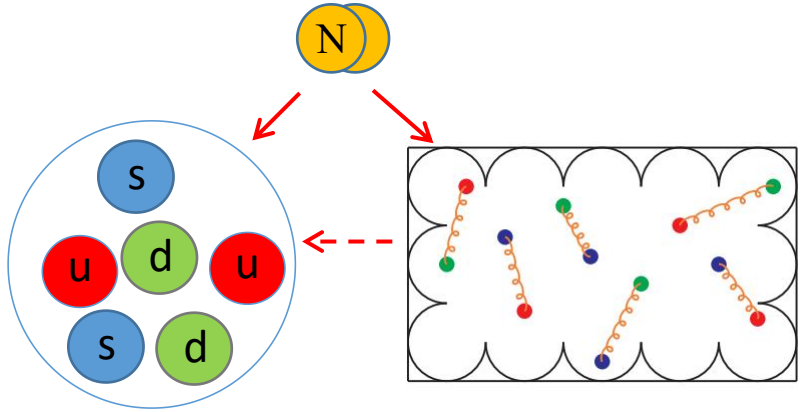


$$\bar{\rho} = \frac{M}{4\pi R^3 / 3} \simeq 2.4\rho_0$$

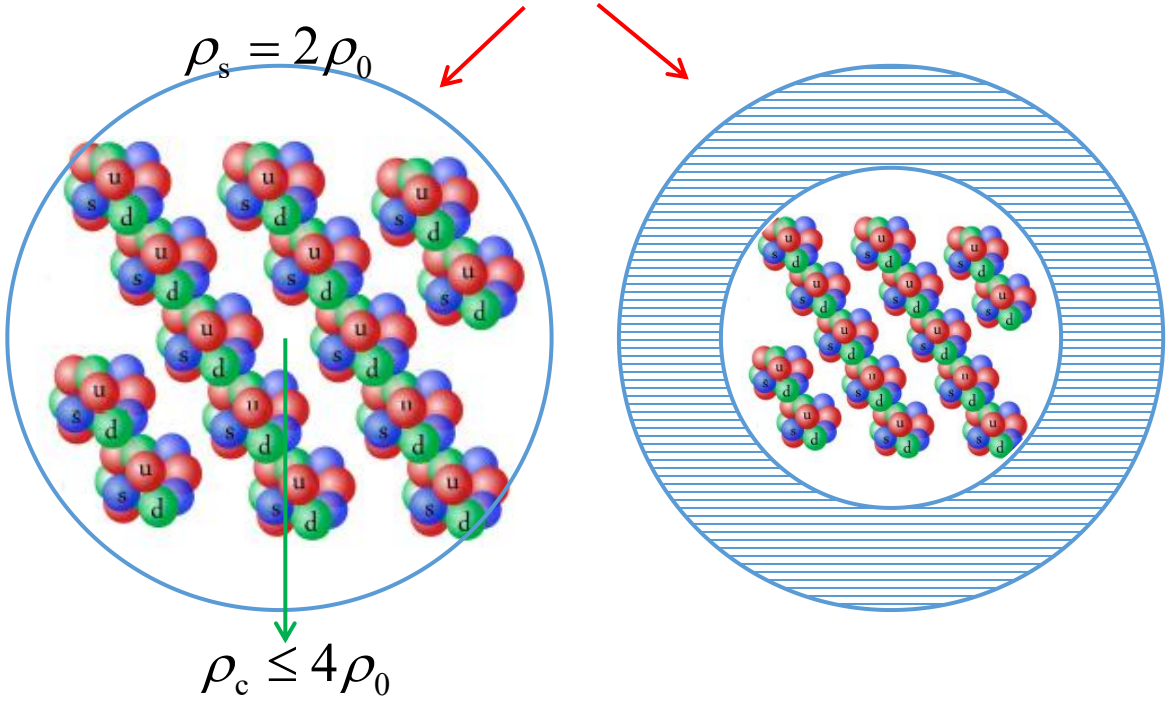
($\rho_0 \approx 2.8\times10^{14}$ g/cm^3: saturated nuclear matter density)

$$\bar{\rho} = \frac{M}{4\pi R^3 / 3} \simeq 2.4\rho_0$$

- **Overlap of neucleons**
- **Energy scale：** $E \sim 400$ **MeV**
  - **Strongly coupled**
  - **Strange quarks**
- **“Strangeon” = strange nucleon**
- **Strangeon stars**

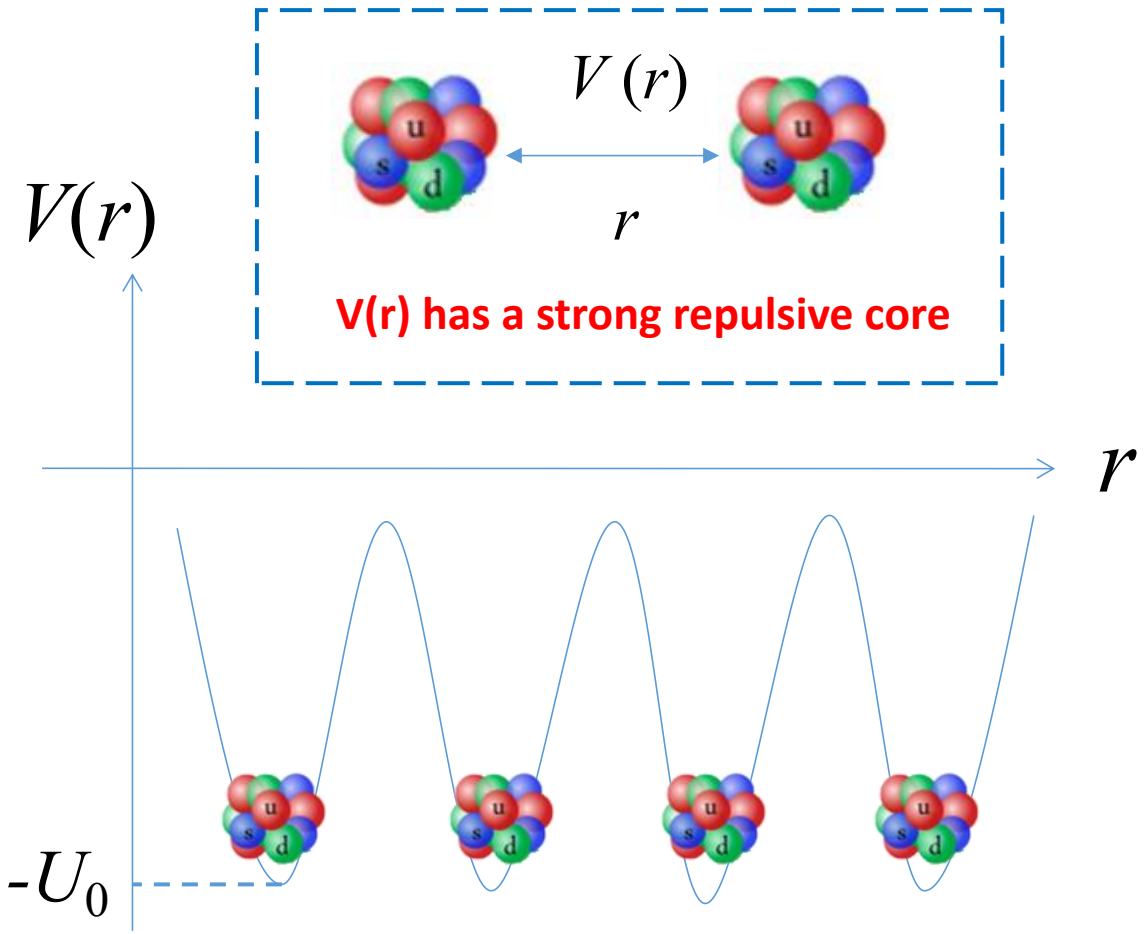


strangeon
(quark-cluster)



N_q = ?
(3, 6, 9, 12, 18, …)

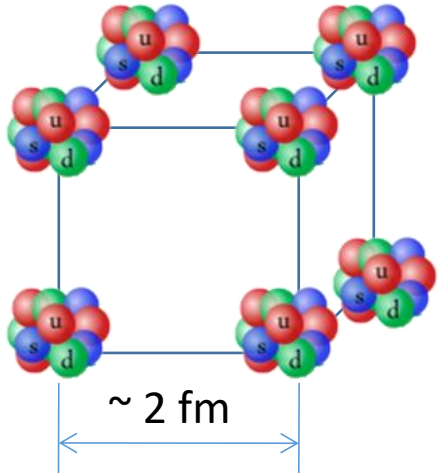
Solid strangeon stars



$$\begin{cases} \Gamma = U_0 / kT \sim 200 \\ U_0 \sim 100\ \mathrm{MeV} \end{cases}$$

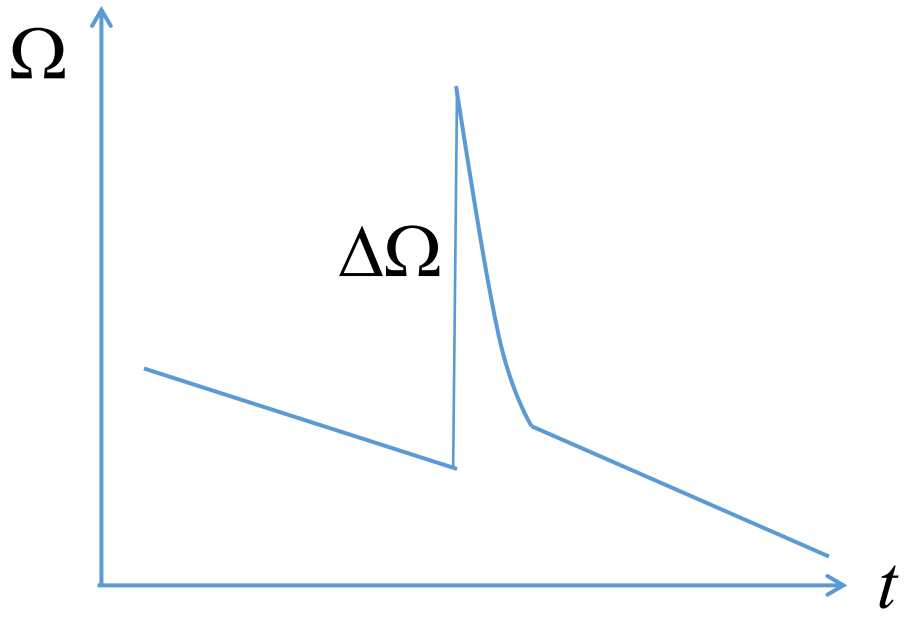
→ Melting temperature

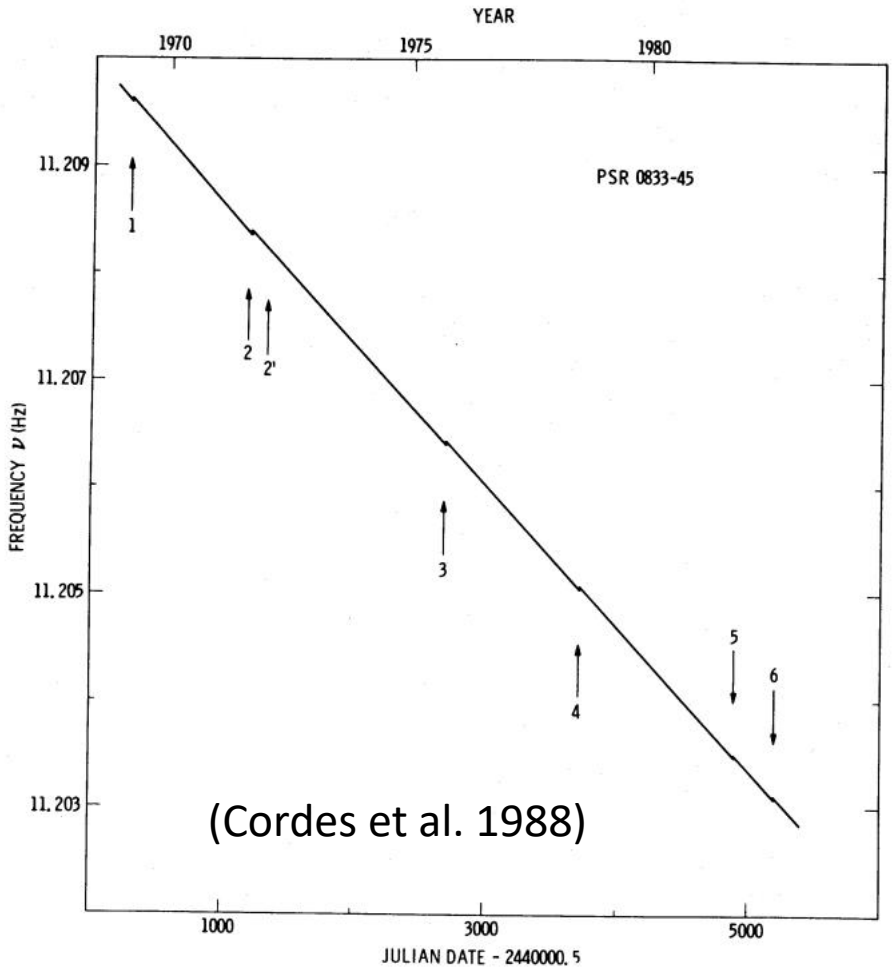
$$kT \sim 0.5\ \mathrm{MeV}$$



Pulsar glitches

- A pulsar glitch is an impulsive spin-up, followed by a quasi-exponential recovery towards the steady spin-down.
- This kind of timing irregularity is widely accepted as a window into the interior structure of pulsars.





(Cordes et al. 1988)

glitch magnitude:

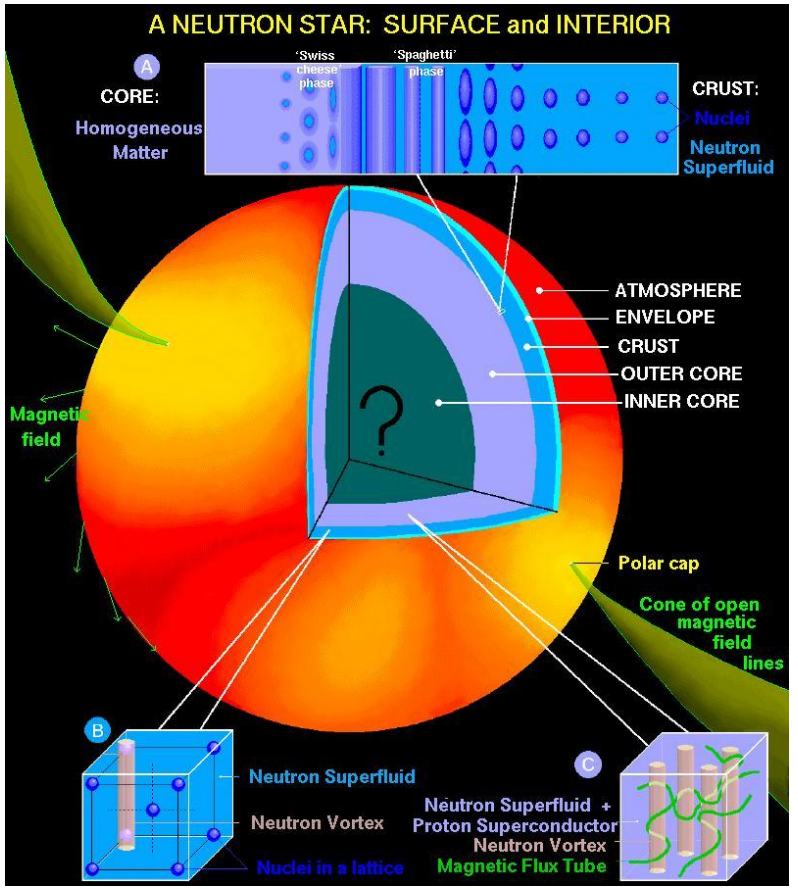
$$\Delta\Omega/\Omega \sim 10^{-10} \text{ to } 10^{-5}$$

Glitches of neutron stars

Rapid transfer of angular momentum from superfluid to the crust

- Superfluid in the crust is not enough ?

$\Delta\Omega / \Omega$ is too large ?



(Anderson & Itoh 1975, Alpar et al. 1984, Andersson et al. 2012)

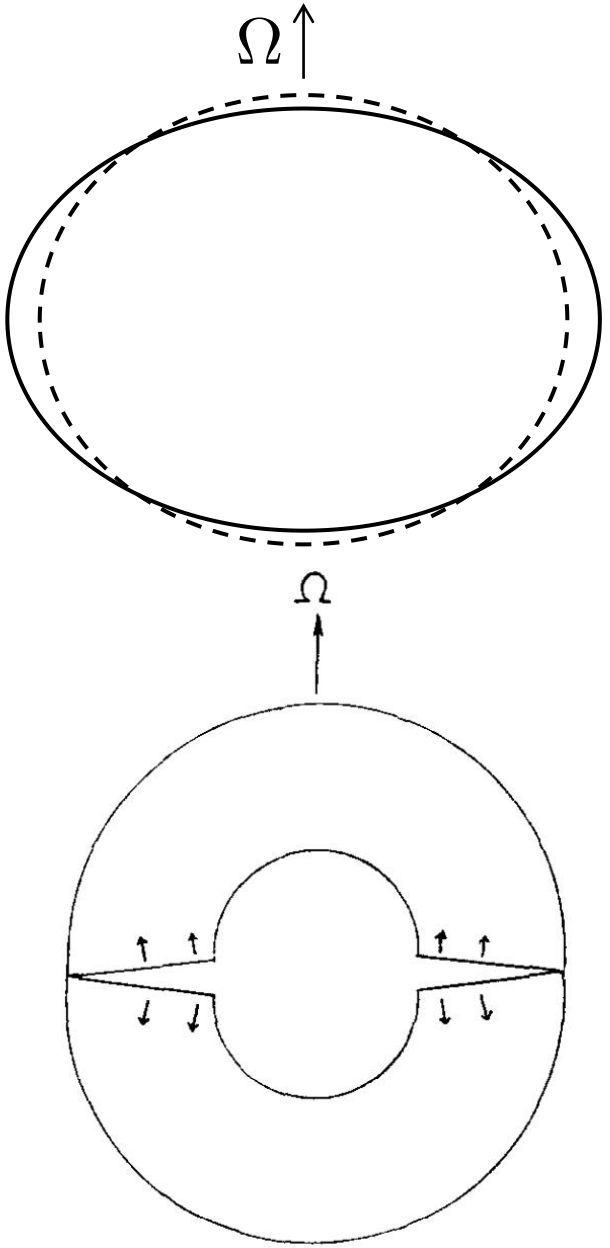
Glitches of neutron stars

Starquake produced by rearrangements of an oblate crust

- There is not enough time to build up the required strain between events

(Baym et al. 1969, Baym & Pines 1971)

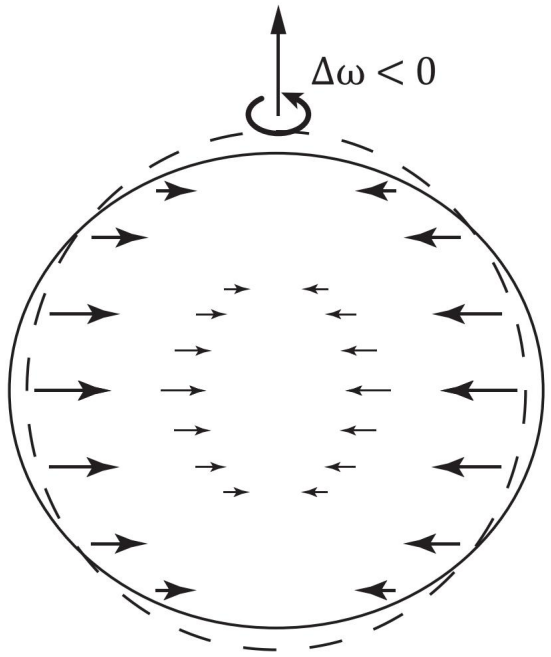
- Crab $\Delta\Omega / \Omega \sim 10^{-9}$ 
- Vela $\Delta\Omega / \Omega \sim 10^{-6}$ 



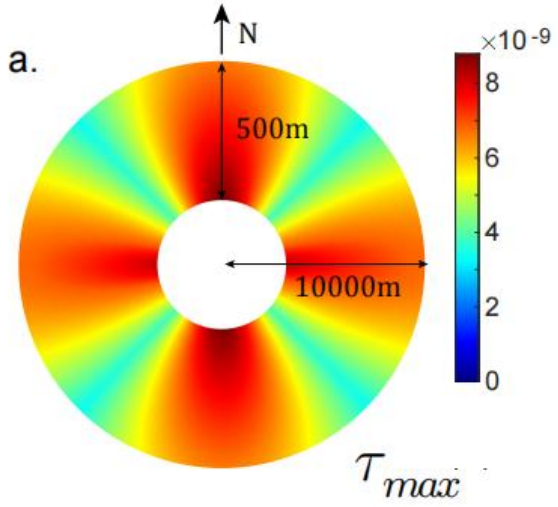
(Baym & Pines 1971)

The starquake of solid strangeon stars

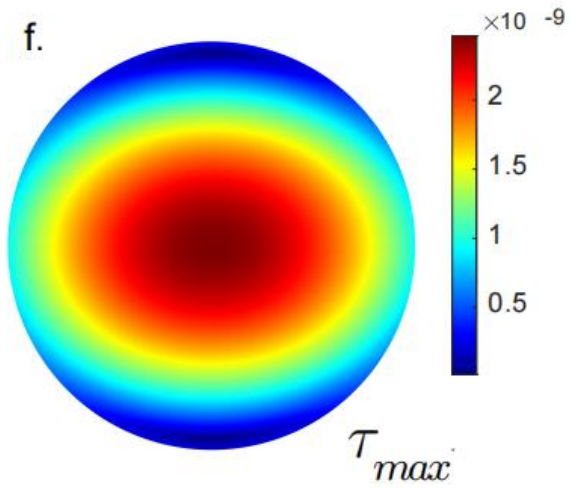
- Shear stress accumulation is significant
  - at both the equator and the poles for NSs
  - at the equator for SSs



Neutron stars



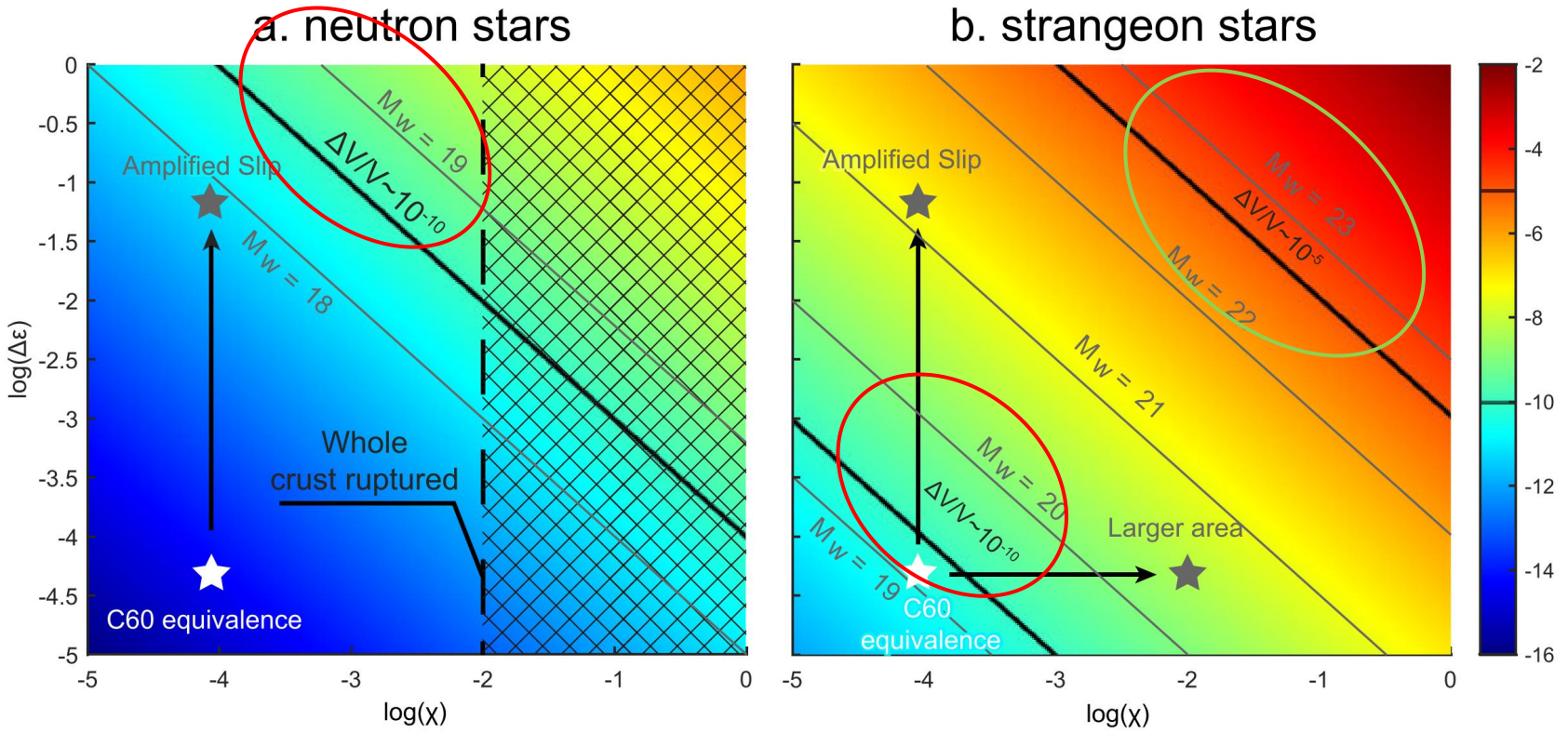
Strangeon stars



(Lu et al. 2023)

Glitch magnitude

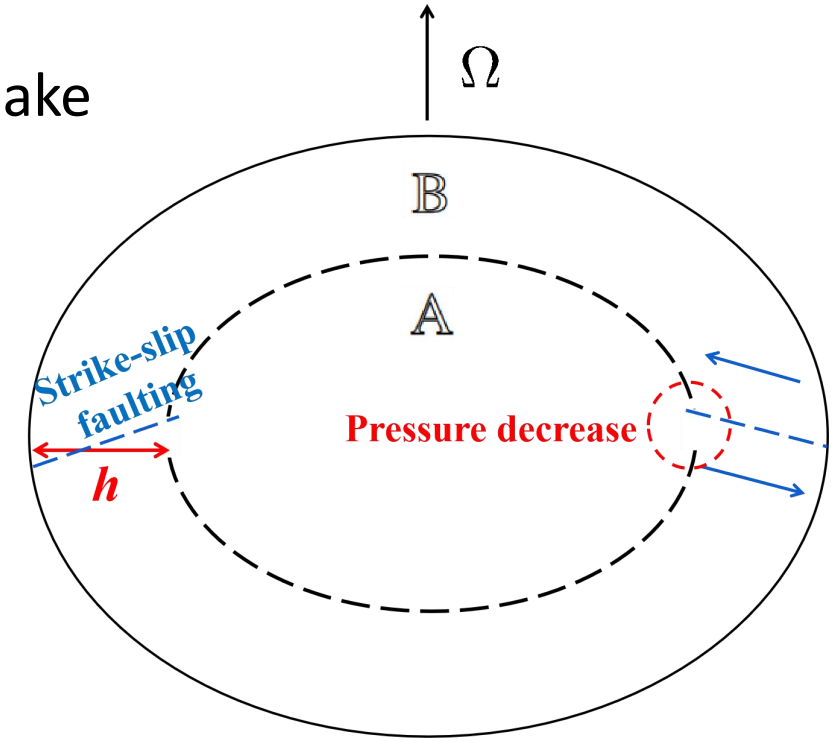
- The whole body of solid SSs can contribute to the change of I (moment of inertia), so $\Delta\Omega/\Omega = -\Delta I/I$ can be larger than that of NSs.



(Lu et al. 2023)

Glitches of strangeon stars

- Starquake

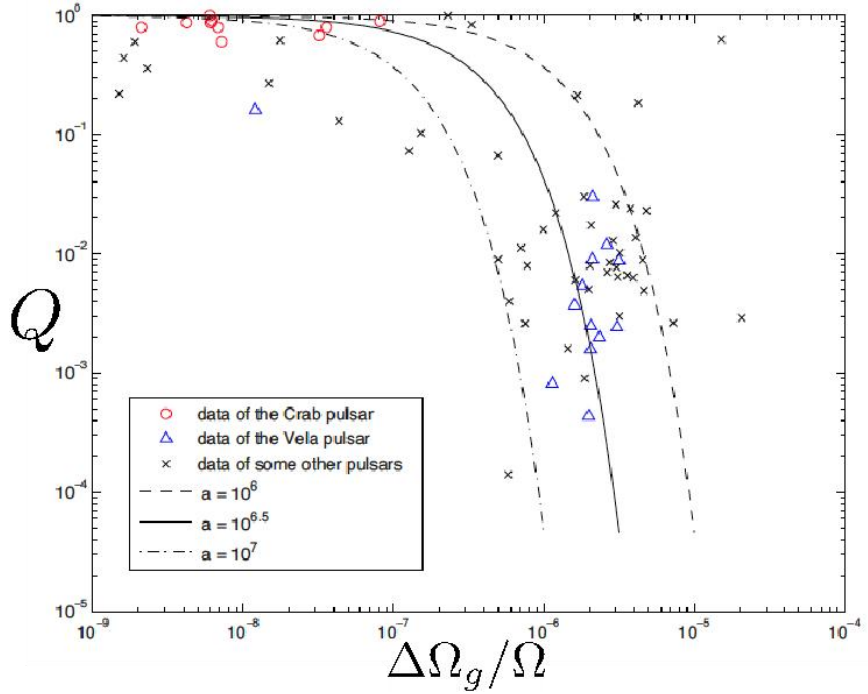


The rupture type in SSs is characterized by strike-slip faulting

change of I_A + change of I_B

recover ***does not recover***

(Lai et al. 2018)



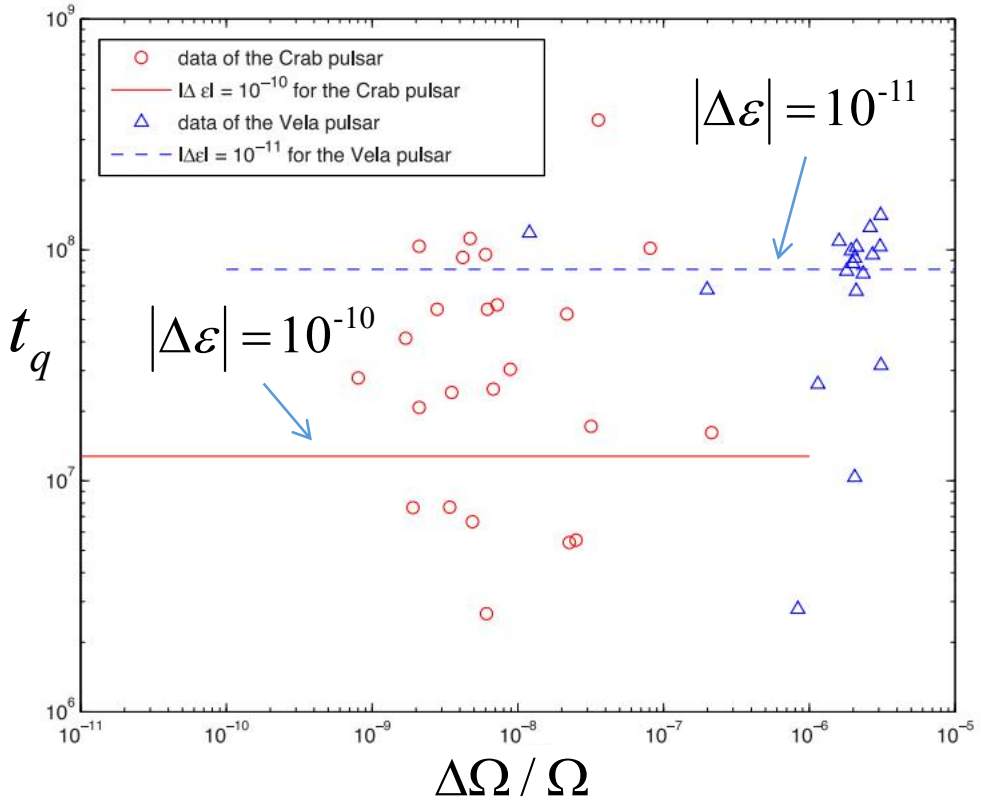
Time interval between two successive glitches t_q

$$I = I_0(1+\epsilon)(1+\eta)$$

$$\frac{\Delta I}{I} = \Delta\epsilon + \Delta\eta$$

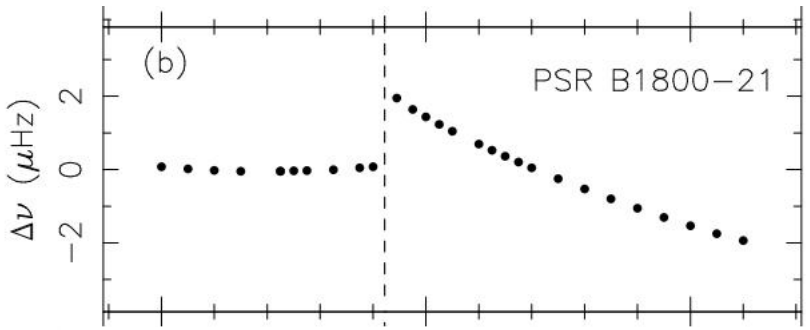
$$\frac{\Delta\Omega}{\Omega} = \left|\frac{\Delta I}{I}\right| = |\Delta\epsilon| + |\Delta\eta|$$

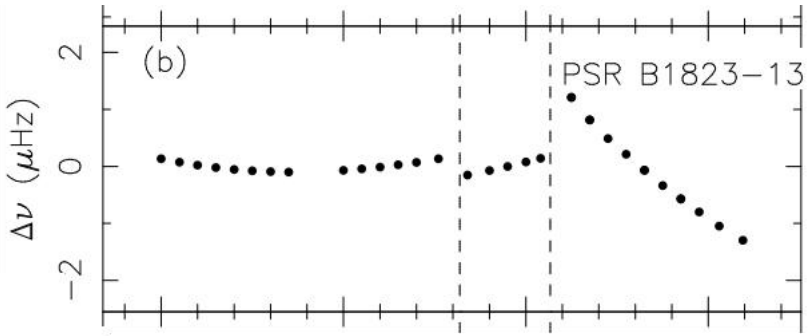
$$t_q \simeq \frac{|\Delta\sigma|}{\dot{\sigma}} = \frac{2A(A+B)}{B I_0}\frac{|\Delta\epsilon|}{\Omega\dot{\Omega}}$$

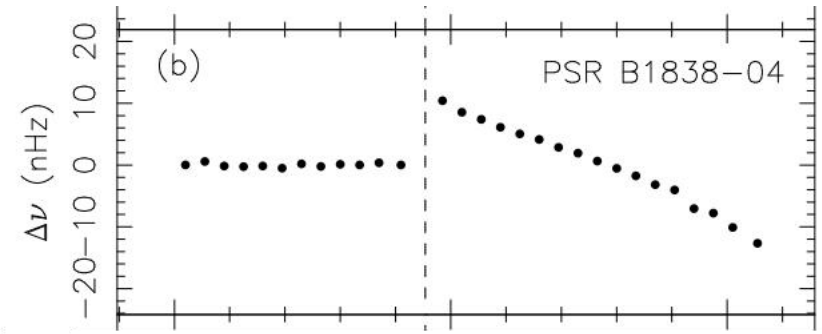


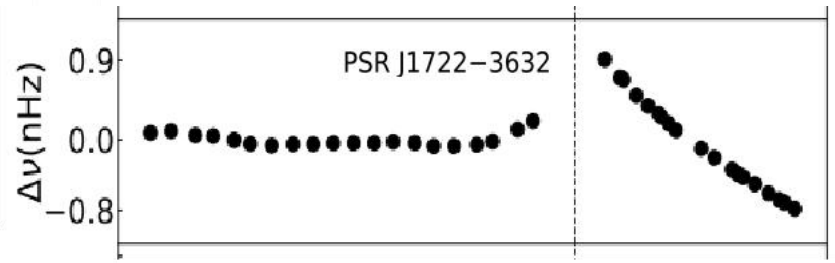
(Lai et al. 2018)

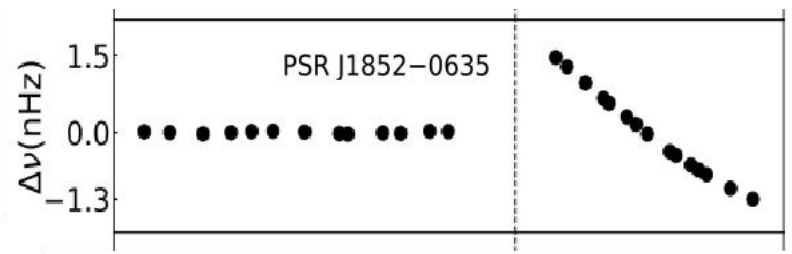
Glitch recovery











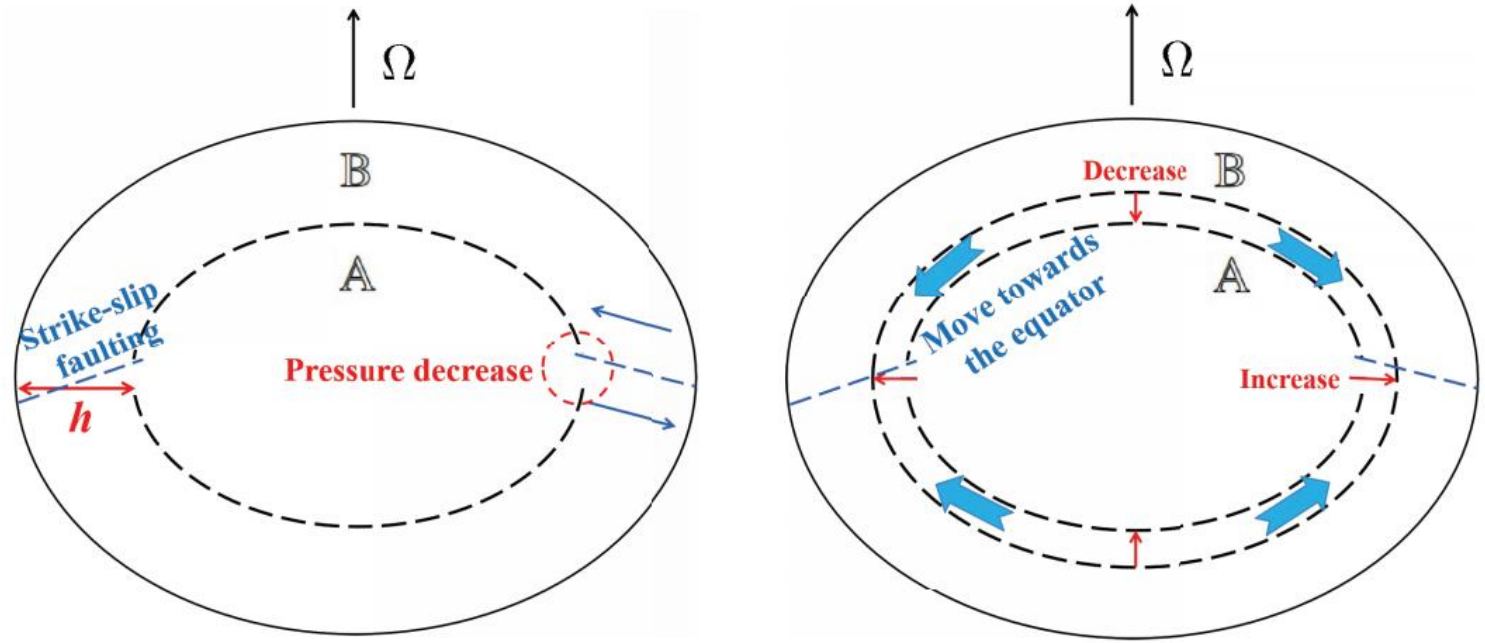
Yuan et al. 2010

Dang et al. 2020

Why a glitch will recover ?

- The cracking would reduce the tangential pressure in the equatorial plane

➡ The matter in the interface (the dashed line) would move towards the cracking place



How to quantitatively describe the recovery ?

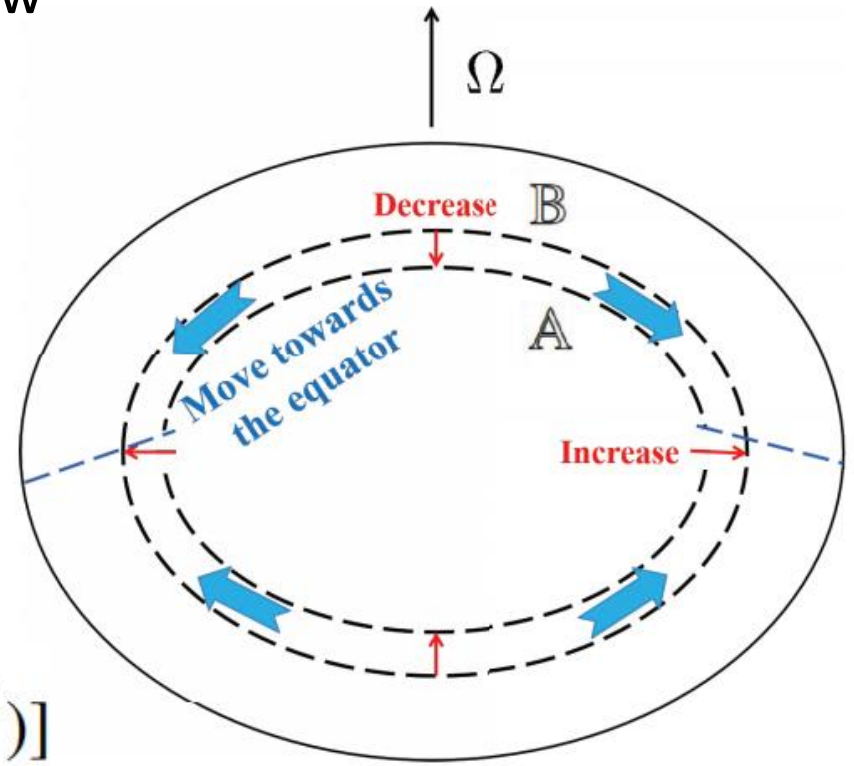
- The outflow in equator is like a “viscous flow”

$$\upsilon = \upsilon_0 \cdot \exp(-t/\tau)$$

$$\epsilon = \frac{2\upsilon_0\tau}{R}(1 - e^{-\frac{t}{\tau}}) + \epsilon_0$$

$$\Delta\epsilon = (\epsilon - \epsilon_0)_{t\to\infty} = 2\upsilon_0\tau/R$$

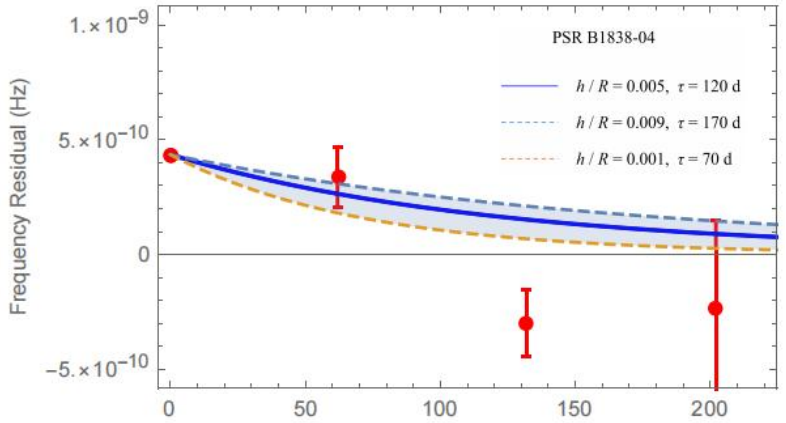
$$I_{\mathbb{A}} = \frac{I_{\mathbb{A}0}}{1 + \epsilon_0}[1 + \epsilon_0 + \Delta\epsilon(1 - e^{-\frac{t}{\tau}})]$$

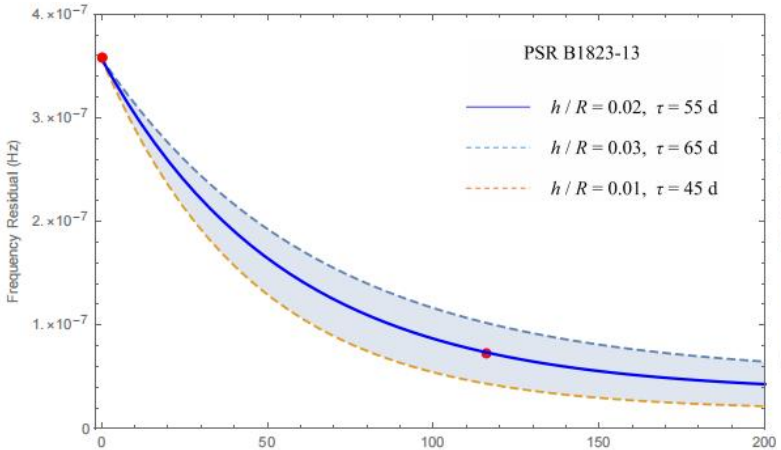


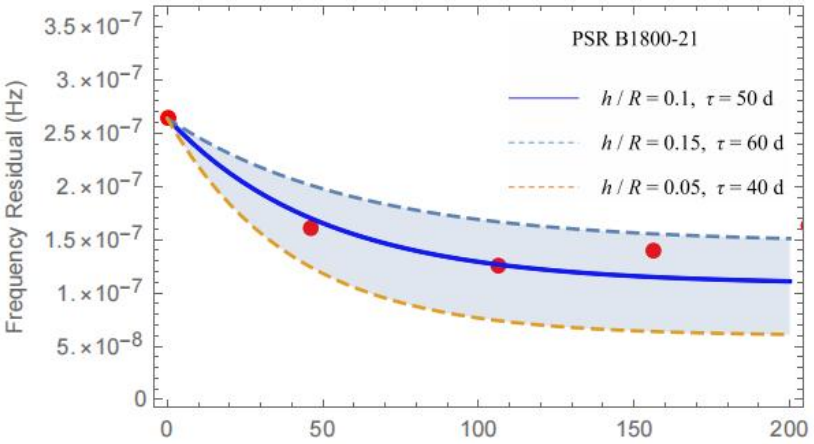
Compare with observations

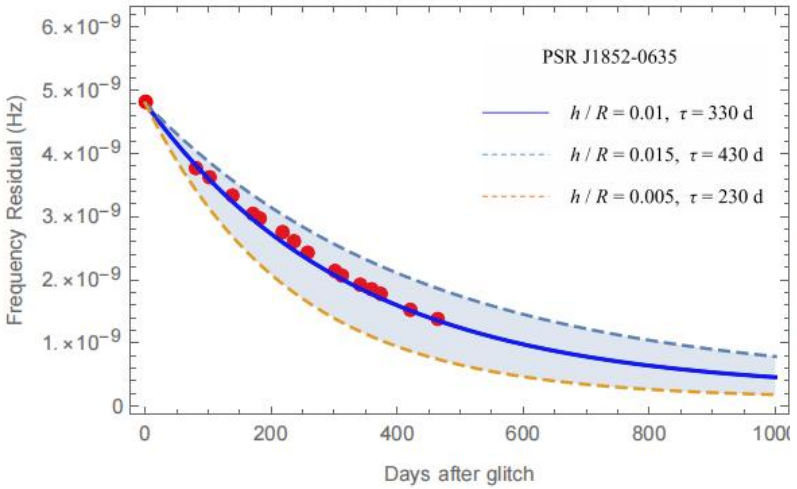
Parameters:

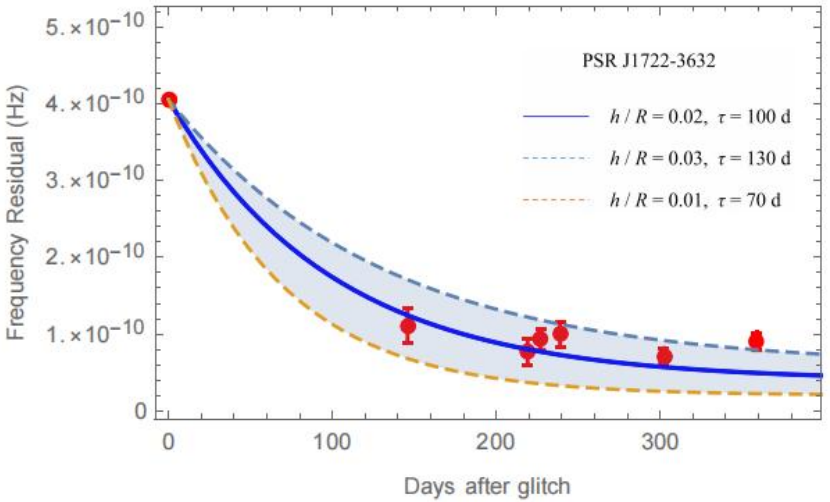
h/R and τ







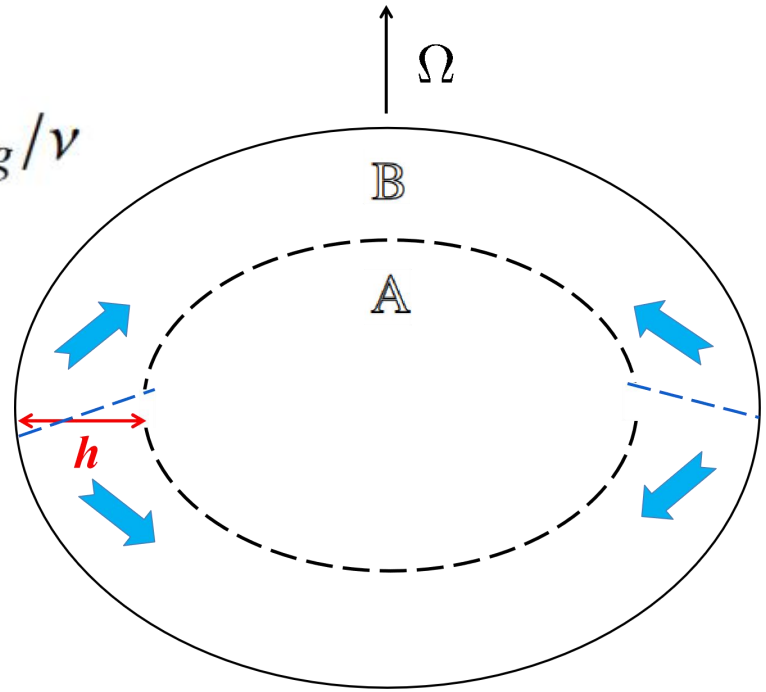




Lai et al. 2023

PSRs	h/R	$\tau\,(d)$	$\tau_d\,(d)$	$\Delta\nu_g/\nu\,(10^{-9})$
B1838-04	0.005	120	80	579
J1852-0635	0.01	330	400	1144
B1823-13	0.02	55	75	2416
J1722-3632	0.02	100	240	2702
B1800-21	0.1	50	120	3910

h/R is positively correlated with $\Delta\nu_g/\nu$



Summary

- Pulars: strangeon stars?
- Starquakes of solid strangeon stars: glitch & recovery

Thank you !