Pulsar glitches in a strangeon star model

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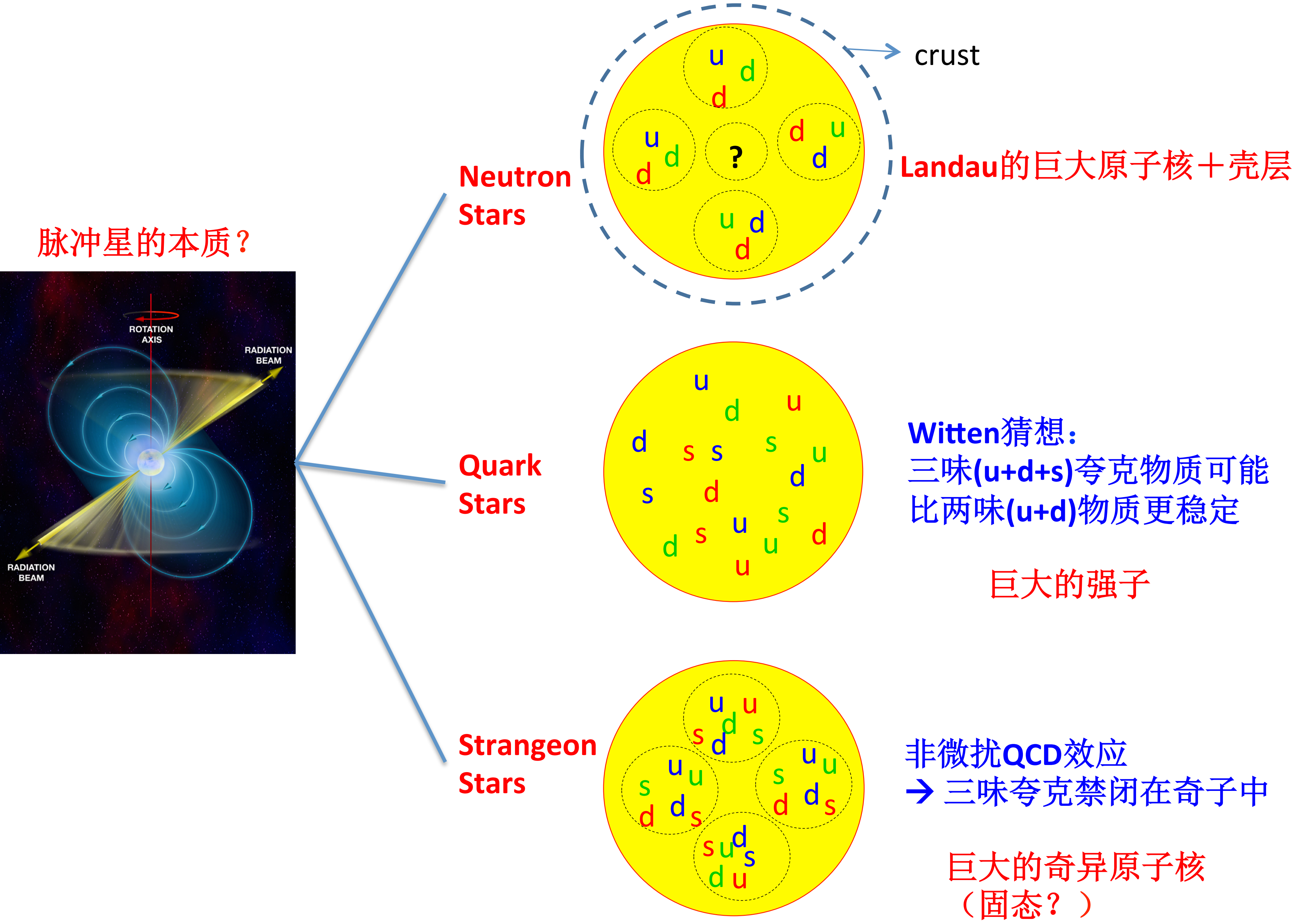
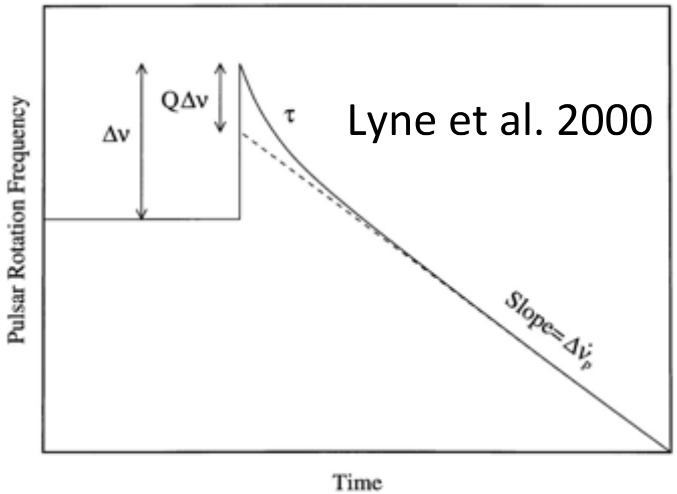
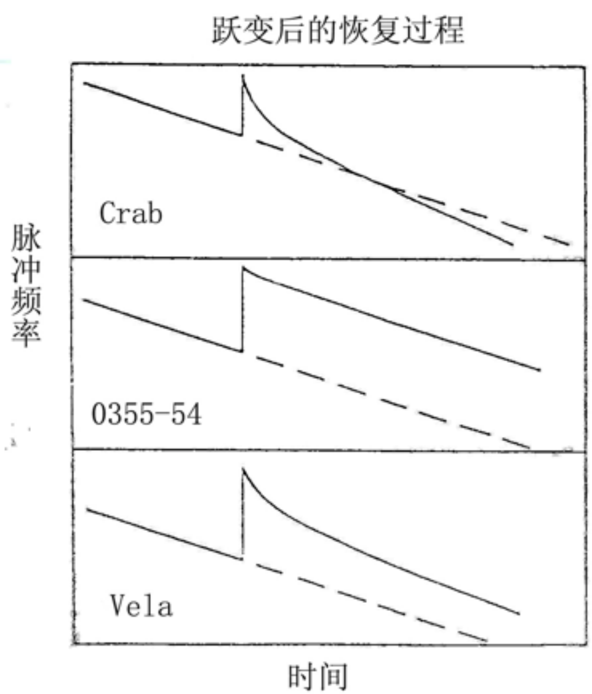
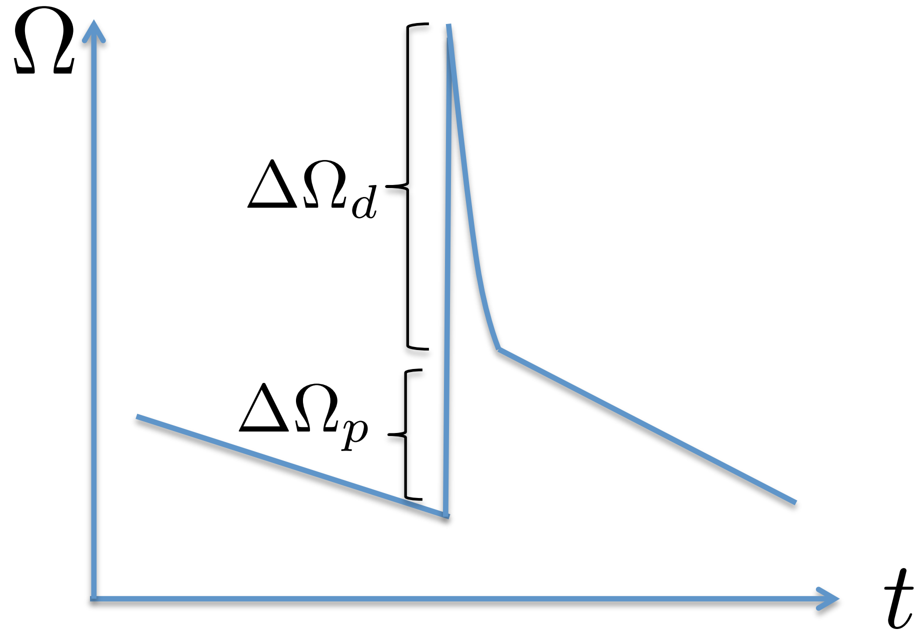

脉冲星的本质？
ROTATION AXIS
RADIATION BEAM
RADIATION BEAM
Neutron Stars
crust
?
Landau的巨大原子核＋壳层
Quark Stars
Witten猜想：
三味(u+d+s)夸克物质可能
比两味(u+d)物质更稳定
巨大的强子
Strangeon Stars
非微扰QCD效应
→ 三味夸克禁闭在奇子中
巨大的奇异原子核
（固态？）

Pulsar glitches



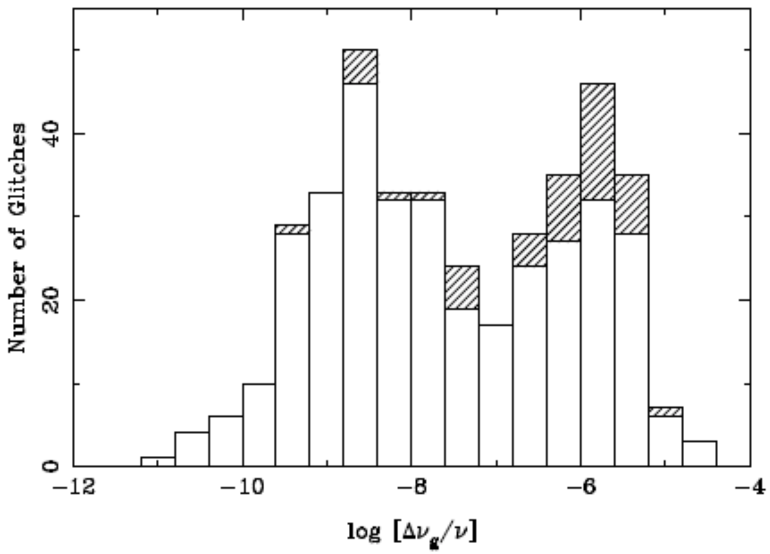


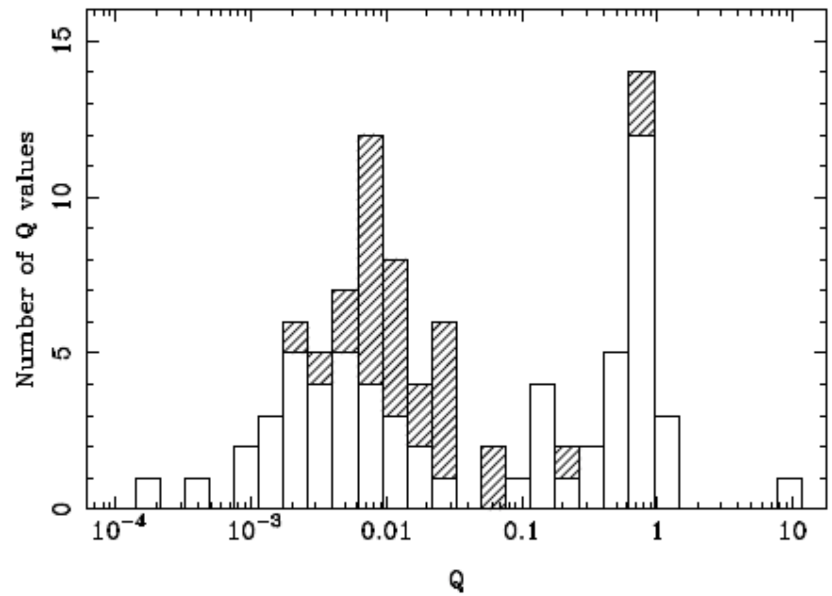


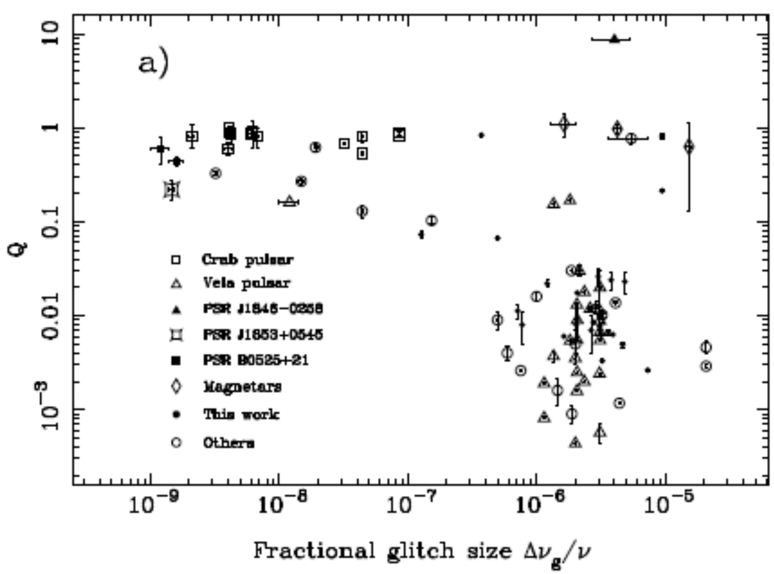
$$\Delta\Omega_g = \Delta\Omega_d + \Delta\Omega_p$$

$$Q = \Delta\Omega_d / \Delta\Omega_g$$

Pulsar glitches







Espinoza et al. 2011
Yu et al. 2013

Glitches of neutron stars

- Starquake produced by rearrangements of an oblate crust (Baym et al. 1969)
- Rapid transfer of angular momentum from inner superfluid to the crust (Anderson & Itoh 1975)

Glitches of strange/quark stars

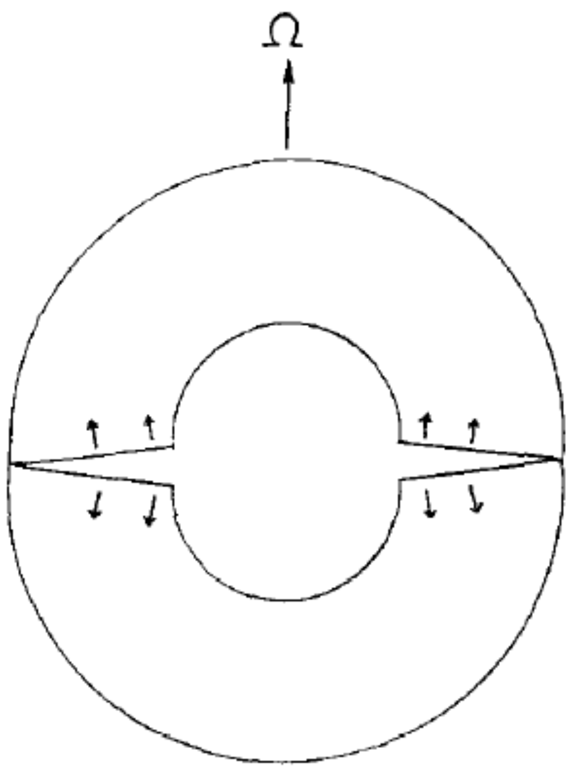
- ?

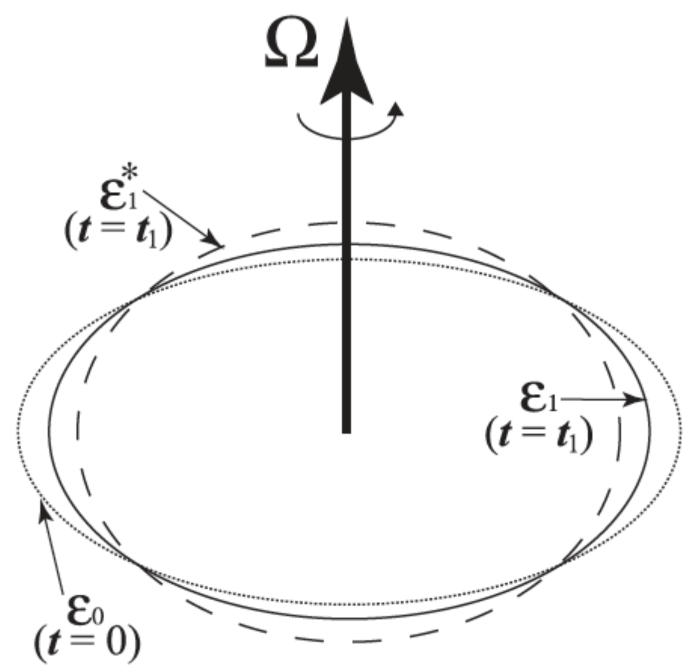
Glitches of strangeon stars

- Solid strangeon stars → starquakes (星震)

The starquake scenario

- For neutron stars
  - Baym & Pines 1971
- For strangeon stars
  - Zhou et al. 2004
  - Peng & Xu 2008
  - Zhou et al. 2014

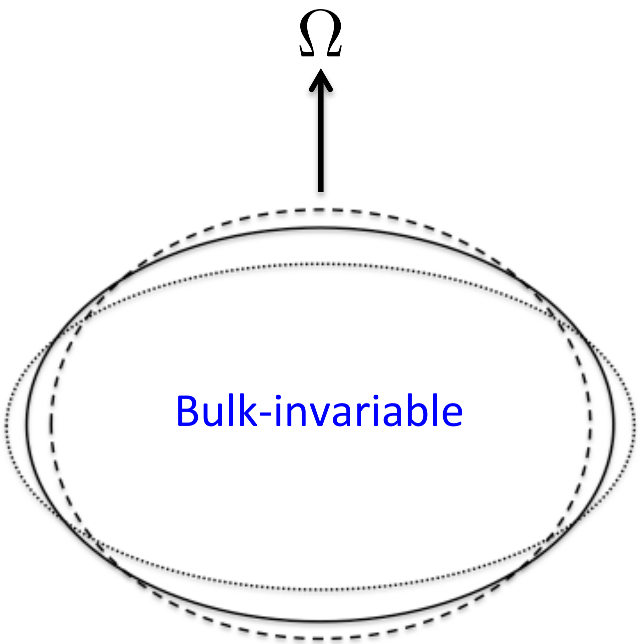




Two types of starquakes

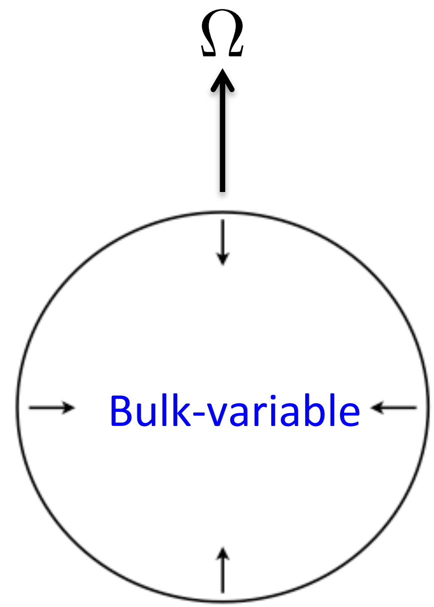
(Zhou et al. 2014)

Two ways to change $I = I_0(1 + \epsilon)$



ϵ changes

No significant energy release



I_0 changes

Significant energy release (AXP/SGRs)

Two types of starquakes

Zhou et al. 2014

- Bulk-invariable

$$\Delta E \sim 4 \times 10^{36}\ \mathrm{erg} \left(\frac{t}{10^6\ \mathrm{s}}\right) \left(\frac{\Delta\Omega}{\Omega}/10^{-6}\right)$$

  – For glitches without significant energy release

- Bulk-variable

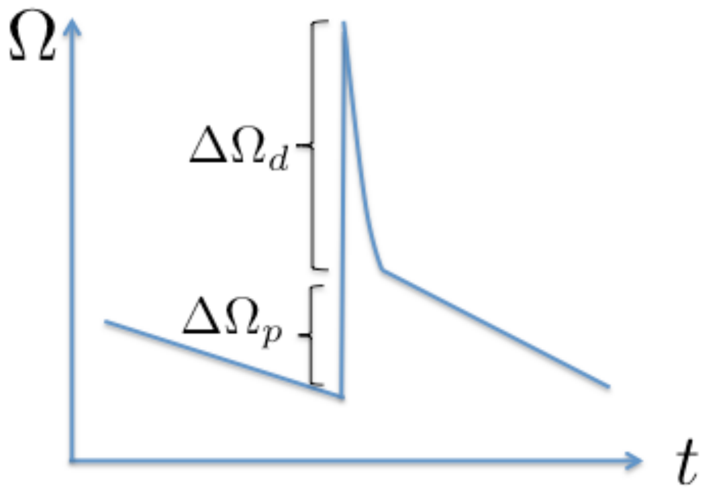
$$\Delta E \sim 10^{47}\ \mathrm{erg} \left(\frac{M}{1.4\ M_\odot}\right)^2 \left(\frac{R}{10^6\ \mathrm{cm}}\right)^{-1} \left(\frac{\Delta\Omega}{\Omega}/10^{-6}\right)$$

  – For glitches in AXP/SGRs

Improvement of bulk-invariable starquakes

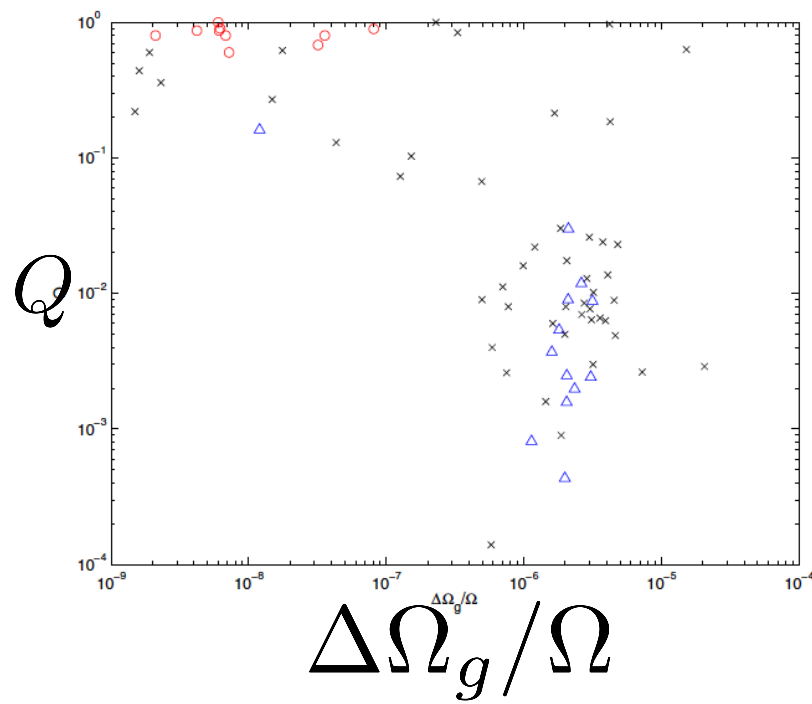
Motivation

- Different values of glitch size $\Delta\Omega_g/\Omega$
- Different values of recovery coefficient Q



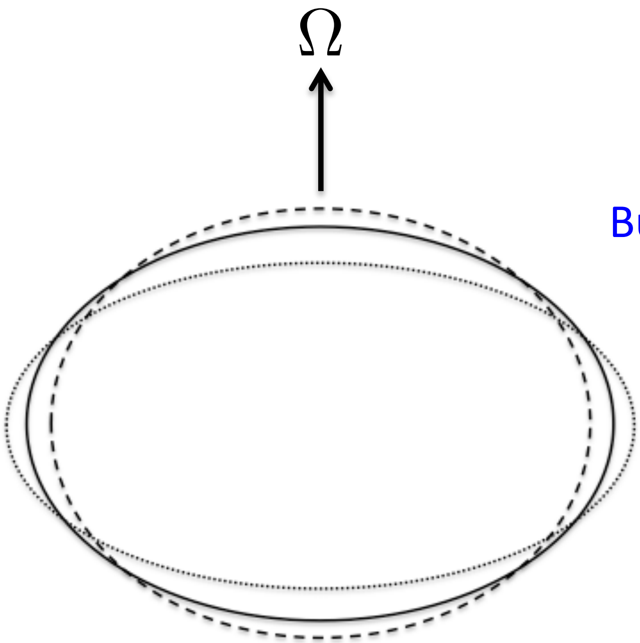
$$\Delta\Omega_g = \Delta\Omega_d + \Delta\Omega_p$$

$$Q = \Delta\Omega_d/\Delta\Omega_g$$

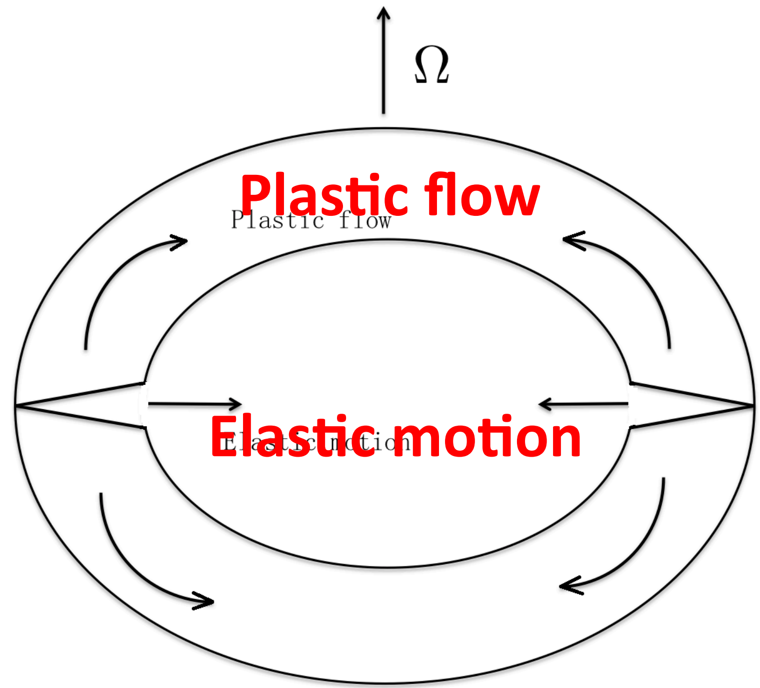


Dada: Jodrell Bank glitch table (without error bars)

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



Bulk-invariable



ϵ changes

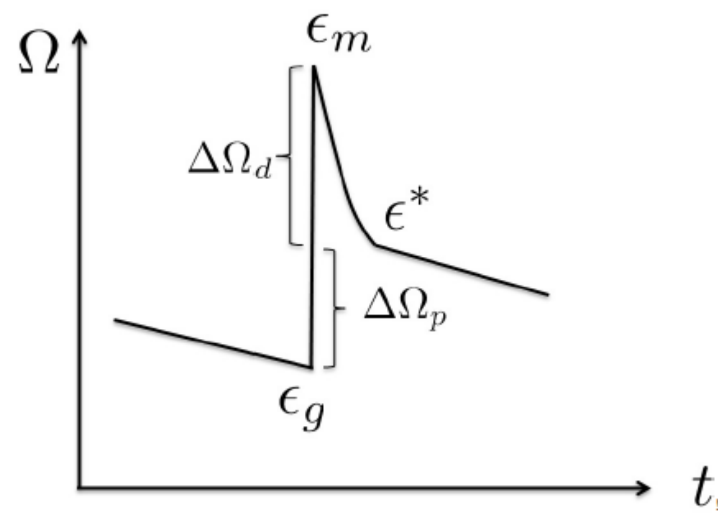
η changes

plastic flow + elastic motion

↓ ↓

does not recovery ***recover***

Recovery coefficient



$$\frac{\Delta\Omega_g}{\Omega} = -(\epsilon_m - \epsilon_g) - \Delta\eta$$

$$\frac{\Delta\Omega_p}{\Omega} = -(\epsilon^* - \epsilon_g) - \Delta\eta$$

$$Q = \Delta\Omega_d / \Delta\Omega_g$$

$$\Rightarrow \quad Q = \frac{\epsilon^* - \epsilon_m}{\Delta\Omega_g / \Omega}$$

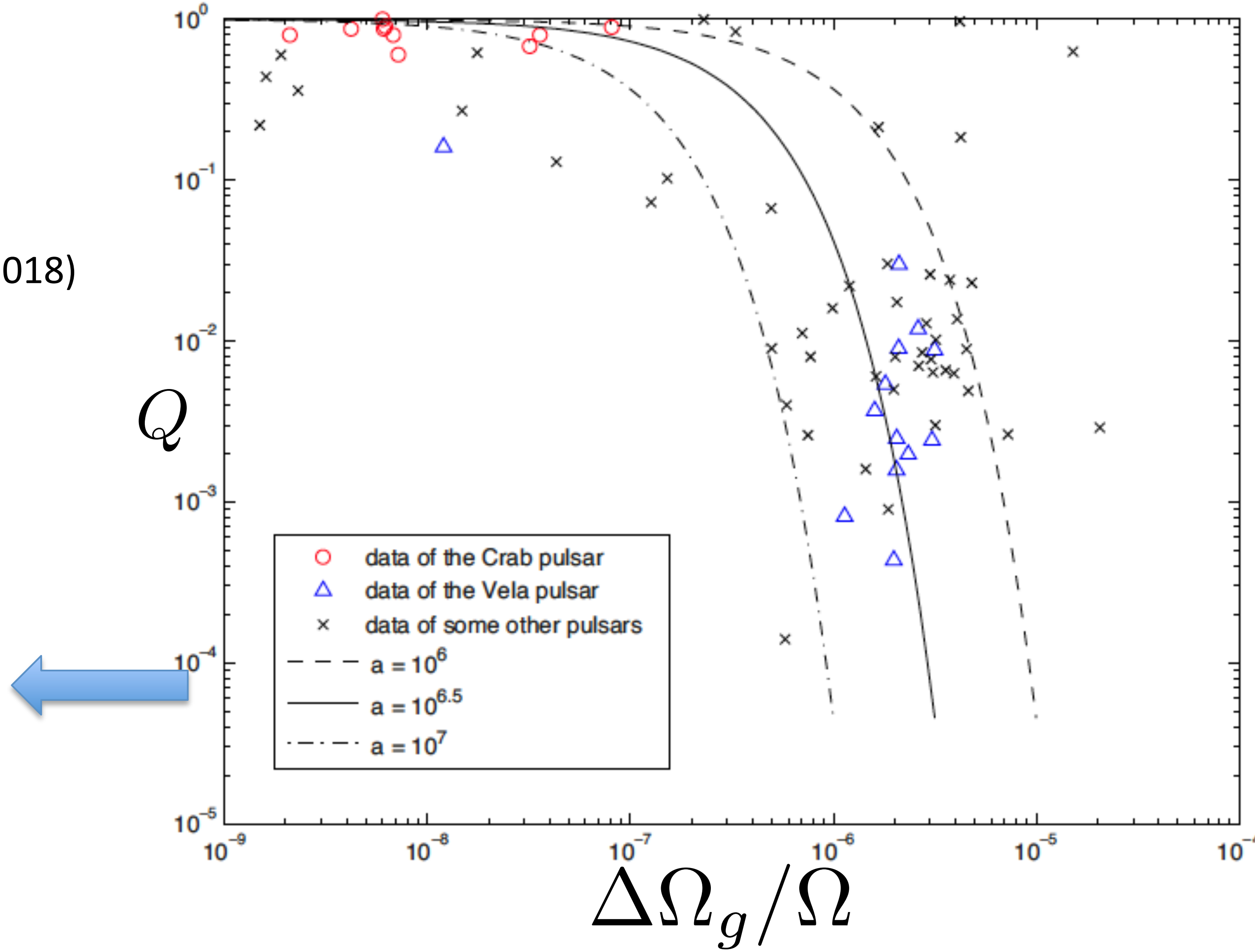
$$\epsilon^* - \epsilon_m = \frac{\Delta\Omega_g}{\Omega} \exp\left(-a \frac{\Delta\Omega_g}{\Omega}\right)$$

$$\Rightarrow \quad Q = \exp\left(-a \frac{\Delta\Omega_g}{\Omega}\right)$$

$$Q = \exp\left(-a\frac{\Delta\Omega_g}{\Omega}\right)$$

(Lai et al. 2018)

$\epsilon \gtrsim 10^{-7}$



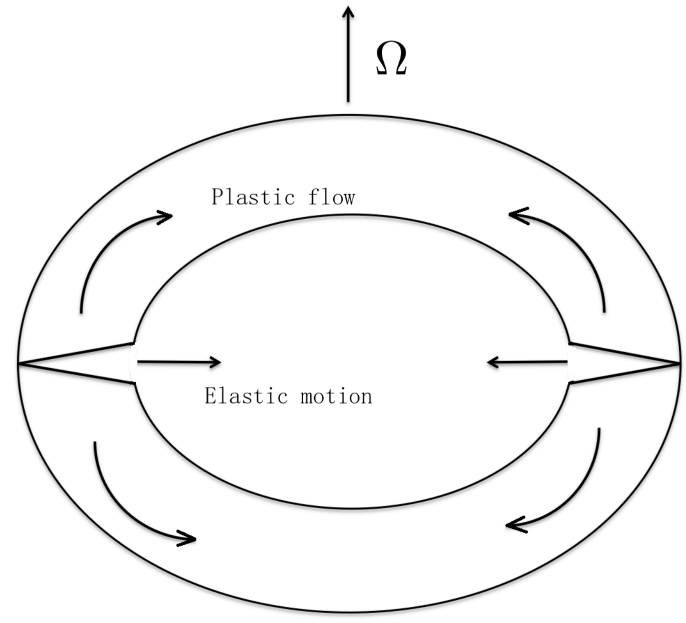
Dada: Jodrell Bank glitch table

Conclusions

- Starquake process:

  plastic flow + **elastic motion**

  does not recover *recovery*



- Recovery coefficient
- $\epsilon \gtrsim 10^{-7}$