Angular-Momentum Transfer and Superfluid Coupling in Neutron Stars: A Glitch–Spin-Down–FMI Framework

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Abstract

Pulsar glitches—sudden and discrete jumps in the rotational frequency of neutron stars—are important observational tools for studying matter at supranuclear densities. In this work, we present an updated analysis of glitch mechanisms and their implications for understanding the internal structure of neutron stars. We focus on the dynamics of vortex unpinning in the superfluid interior and the stresses present in the crustal lattice. Using current glitch catalogs, we investigate the relationship between the sizes of glitches, spin-down rates, and the Fractional Moment of Inertia (FMI) related to angular momentum transfer. Our findings reveal a strong correlation between long-term glitch activity and the secular spin-down torque, which allows us to better constrain the FMI of the neutron star's superfluid component. These constraints provide insights into crust-core coupling and offer meaningful observational tests for competing models of dense-matter equations of state.

Introduction

Pulsar glitches - sudden increase in spin frequency (ν) of pulsar. Glitch size is **Δν.**

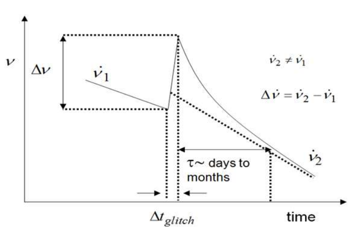

Fig 1: a plot of spin frequency of pulsar as a function of time.

The mechanism that derives glitch is within the pulsars interior, as such, glitches provide one of the few direct observational windows into the superfluid interior of neutron stars.

Aim

- To derive the appropriate relationship between the angular moment transferred from the neutron star interior and the observed glitch size.
- To derive the relationship between the pulsar spin-down rate and the momentum reservoir.
- To ascertain the relationship among the pulsar spin-down rate, glitch activity, and FMI.

Source Data

Pulsar spin parameters are from ATNF pulsar catalog, while Pulsar Glitches are from JBO pulsar glitch catalog.

Theory

- The interior of a neutron star contains superfluid (SF) neutrons. The motion of this SF is not affected by the electromagnetic braking toque on the crust. As such, the SF and the crust rotate differentially (rotation lag).
- The SF rotates via array of pinned vortices.
- The reservoir stores angular momentum due to he lag.
- Anytime the vortices unpin, angular momentum is transferred to the crust, the crust spins up, while the SF spins down = glitch. Fig 2.

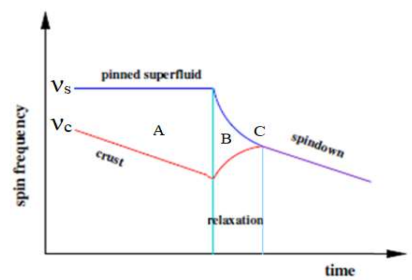

Fig. 2: Relative motion of the superfluid and crust. Panel 'A' = before glitch. 'B' = during glitch, and 'C' = after glitch.

Angular Momentum Transfer

The transferred angular momentum (L) and glitch size are related as

$$L_i = 2\pi I_c \Delta\nu_i, \qquad (1)$$

While the rate of occurrence is

$$\dot{L} = 2\pi I_c \sum_1^n \frac{\Delta\nu_i}{t_i}, \qquad (2)$$

Angular Momentum Reservoir.

Momentum is stored due to rotation lag **(ω)** is of the form.

$$\omega(t) = 2\pi[\nu_{\rm res} - \nu_c(t)] \qquad (3)$$

while the total angular momentum is given by

$$L_{\rm Tot} = 2\pi[I_{\rm res}\nu_{\rm res} + I_c\nu_c(t)] \qquad (4)$$

The size of the reservoir is

$$L_{\rm res} = I_{\rm res}\,\omega(t) \qquad (5)$$

While the rate the reservoir accumulate momentum is

$$\dot{L} = -2\pi I_{\rm res}\dot{\nu}_c(t) \qquad (6)$$

Glitch Activity

Is given

$$A_g = \frac{1}{t_g}\sum_1^n \frac{\Delta\nu}{\nu} \qquad (7)$$

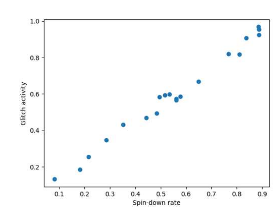

Fig 3: Glitch activity as a function of pulsar spin down rate.

Fractional Moment of Inertia

At a critical lag, the time it took the reservoir to accumulate transferable momentum equals the time interval preceding the glitch, As such Equations (2) and (6) give the FMI

$$\frac{I_{\rm res}}{I_c} = -\sum_1^n \frac{1}{\dot{\nu}_c}\frac{\Delta\nu_i}{t_i} \qquad (8)$$

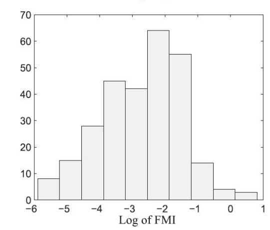

Fig4: Distribution of FMI of the observed glitches

Connecting Glitch activity and FMI

From Equation (7) and (8), we have

$$FMI = -A_g \frac{\nu}{\dot{\nu}_c} \qquad (9)$$

Conclusion

With pulsar spin-down rate, one can estimate the glitch activity.

With pulsar spin frequency and glitch activity, one can estimate the FMI.

The angular momentum reservoir is located in a region approximately 10 percent of the interior structure of neutron star.

Further Reading

https://iopscience.iop.org/article/10.3847/1538-4357/aa6b55#apjaa6b55s2