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MEASUREMENT OF THE BREAKING INDICES OF FREQUENTLY GHTCHING PULSARS USING INTEGRATION METHOD

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ABSTRACT: *Pulsars are old, stellar objects that emit electromagnetic radiations in a definite time interval, with a predictable smooth spin-down, predisposed to discrete fluctuations/glitches. The rotational frequency of pulsars decays with time as quantified by the breaking index which is now known to have no consequence on other pulsar qualities like obliquity angle evolution or complex high-order multiple structures but rather on its spin proportion. In the canonical model n=3, but observationally n≠3 in numerous cases. Showing that the canonical model requires modification. Using the Australian Telescope National Facility (ATNF). Pulsars catalog, we selected 208 pulsars with 670 glitches. We computed the breaking and observed that the breaking index is smaller for very young pulsars, which usually glitch more frequently than their older, more stable counterpart analysis. They have switched over from time and also account for over 68% of the entire glitches in our population. A regression analysis shows that spin properties of pulsars are ≥ 65% correlated with breaking index (n). Implications of this result are discussed.*

KEYWORDS: Breaking index, Pulsars, Glitch, Glitch Parameters, Characteristic Age, and Frequently.

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INTRODUCTION

A pulsar is a highly magnetized, rapidly spinning neutron star which emits an intense beam of broadband electromagnetic radiation (Gold, 1968, Kramer, 2006) along its magnetic dipole axes as it spins about the radiation axis. Pulsars are essentially rotating magnets and emit pulsed dipole radiations which have been detected and studied over the whole electromagnetic spectrum (Lyne and Smita, 1998). They are presumably born in supernova explosions of massive stars with $\geq 10M_0$ that are created by the collapse of stellar cores (Kramer, 2006) which results in the significant amplification of the pulse rotation speed (Horimer and Kramer, 2005) with the resultant typical radio pulsar masses ranging from □ 1.4-2.0M_0. a neutron star is always surrounded by its magnetosphere which extends up to a distance whose the conotating velocity reaches the speed of light, C with the radius of the imaginary light cylinder, $R_{LC} = C P/2\pi$, where P is the pulsar rotational period (Lorimer and Kramer, 2005).

The spin properties of pulsars include characteristics attained from their birth properties based on the magnetic dipole model and are fundamental properties that unravel their internal structures and dynamics.

They include key derived properties like period P_o and its derivatives P' frequency, ν and its first and second derivatives ύ ϋ, the magnetic field B, the characteristic age τ and breaking index, n.

Pulsar astronomy has evolved tremendously over several decades to become a crossroad for a wide spectrum of researchers; it has also remained one of the fastest-growing fields since it was first discovered in 1964 (Hewish *et al.* (1968)).

LITERATURE REVIEW

Pulsar was discovered by a team of radio astronomers led by Professor Anthony Hewish who constructed an 82 H_2 away of 2048½ dipoles to observe the scintillation of compact radio sources (Hewish *et al.*, 1964). The dipoles were set horizontally several wavelengths above the ground in regular rows that covered an area of about 20,000m^2. Hewish *et al.* (1964) observed rapid fluctuations were a scintillation effect that was produced by the interplanetary medium and is most severe for sources of angular diameter < 1 arc sec and were at lengths > 1m. The effect was also found to be stronger with decreasing angular distance to the sun and the fluctuation rate faster with increasing wavelength. The systematic investigation of these signals showed from a high-speed recording that they consist of a $^1/_3$ second duration with a repetition period of 1.337s that was maintained with astonishing precision; tentatively explained as scintillating white dwarfs or neutron stars (Hewish *et al.*, 1968) or pulsars if their spin periods are > 0.015s.

There are now three generic classes of pulsars which are based on the underlying mechanisms believed to power their observed emission: rotation-powered, magnetars and accretion-powered pulsars (Lorimer and Kramer, 2001; Kaspi *et al.*, 1994; Manchester *et al.*, 1989).

Pulsars are very important and invaluable objects that have a wide range of applications in astrophysics including high precision timing and time-keeping devices, the study of the galaxy and interstellar medium, the study of plasma physics under extreme conditions, the search tool

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for exoplanets, cosmological studies, the test of general relativity, the study of reference frame ties, super-dense matter and neutron stars.

The pulsar magnetosphere plays a key role in its spin down though this fact is not yet quantified and the magnetospheric fluctuations may also be the physical origin of stochastic variations in its rotation rates (Kramer, 2006). The pulsar dipole's nonalignment with its rotation axes generates a broad electromagnetic radiation at the frequency of the pulsar, which accounts for the observed slowdown and acts as the source of the main loss of its rotational energy.

The standard model for radio pulsar spin down is the magnetic dipole model which is based on the classical radiation from a spinning magnetic dipole (Pacini, 1968; Goldreich and Julian, 1968) which approximates a spinning neutron star to a rotating magnetic dipole. The pulsar emission is obtained from the kinetic energy of a rotating neutron star, when the spinning magnetic dipole in a vacuum loses its rotational energy ($E_{rot)}$ at the rate

$$\frac{dE_{rot}}{at} = - B^2r\, R^6\nu^n \sin^2\alpha/6c^3 \qquad \text{\_\_\_ (1)}$$

$$= I\,\Omega\,\Omega \qquad \text{\_\_\_ (2)}$$

Where B_p is the magnetic field strength at the poles, R is the radius of the neutron star, ν is its spin frequency, n is the torque breaking index, and α is the angle between the magnetic and rotational axes, Ω is the rate of change of angular velocity, ν is related to the observed rotation frequency,

$$\Omega = 2\pi^\nu = 2\pi/p \qquad \text{\_\_\_\_ (3)}$$

Equation (3) suggests that all isolated pulsars always spin down in a more or less regular fashion and their spin will decrease steadily with time. This time evolution of the spin frequency of pulsars is defined by a single time derivative, ν due to the magnetic dipole breaking torque process. Pulsars are powered by their rotational kinetic energy with their spin periods increasing according to the spin-down law (Manchester and Taylor, 1977):

$$P' = Kp^{2-n} \qquad \text{\_\_\_\_\_ (4)}$$

Where n is the breaking index and k is an arbitrary positive constant with

$$K = \frac{B^2\, R^6 \sin\alpha}{6\, c^3\, I} \qquad \text{\_\_\_\_\_ (5)}$$

B is the neutron star surface magnetic field, I is its movement of inertia, R is the pulsar radius and c is the speed of light. In its simplest form, the widely used standard vacuum dipole spin-down model, k is taken to be an arbitrary positive constant and n = 3 according to Manchester and Taylor (1977) who showed that'

$$n = 2 - \frac{P''}{p'^2} \qquad \text{\_\_\_\_\_ (6)}$$

Where ρ" is the period second time derivative.

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Hence integrating equation (4) from t = o to t = 7 yields the spin-down age of the pulsar, T (Hyne and Smith, 1988) as

$$T = \frac{P}{(n-1)P'}\left(1 - \frac{P_o}{P}^{\,n-1}\right) \qquad \_\_\_\_\_\_ (7)$$

Where P_o is the spin period of the pulsar at birth. For spin down due to pure magnetic dipole breaking in a vacuum, the breaking index n = 3 and the characteristic age, τ_i of pulsars there reduces to

$$\tau_I = P/(2P') \qquad \_\_\_\_\_\_\_\_\_\_\_\_\_\_ (8)$$

The breaking index n is a value that measures how pulsars gradually slow down with time and it theoretically constrains the different pulsar spin-down models. The differentiation of the spin-down law gives the breaking index as

$$n = \nu\ddot{\upsilon}/\nu^2 \qquad \_\_\_\_\_\_\_\_\_\_\_\_\_\_ (9)$$

Where $\ddot{\upsilon}$ is the frequency second derivative. However, the integration of the same law (as suggested by Johnston and Galloway, 1999) yields another formula of the breaking index in terms of the spin period, P which is irrespective of the spin frequency second derivative as

$$n = 1 + \frac{\nu_1\ddot{\upsilon}_2 - \nu_2\ddot{\upsilon}_1}{\nu_1\nu_2(t_2 - t_1)} \qquad \_\_\_\_\_\_\_\_ (10)$$

$$= 1 + \frac{P_1 P_2 - P_2 P_1}{P_1 P_2 - (t_2 - t_1)} \qquad \_\_\_\_\_\_\_\_ (11)$$

Equation (11) is the integration formula.

In this paper, we have adopted the integration approach in our data analysis.

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DATA ANALYSIS AND RESULTS

Alternative Method of Measuring Frequency Second Time Derivative

The frequency second-time derivative, ϋ of the sample was computed using a theoretical method. This is to analytically estimate the breaking indices of these pulsars. The result is shown in Figure 1.

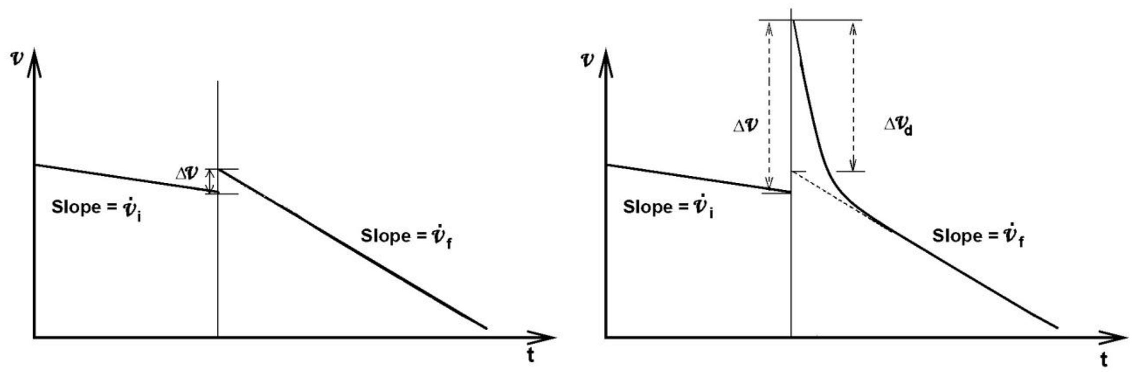

Fig 1**:** A schematic depiction of a Well Resolved Pulsar Glitch (Lorimer & Kramer 2005)

The frequency second-time derivative, ϋ which is known to be analogous to the spin rate, is calculated using the following equation:

$$\ddot{\upsilon} = \frac{\triangle \acute{\upsilon}}{\triangle t} = \frac{\acute{\upsilon}_2 - \acute{\upsilon}_1}{t_2 - t_1} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_} \qquad (12)$$

Where t_1 and t_2 are the first and second epochs of observation (in seconds) with their corresponding frequency derivatives, v_1 v_2 respectively.
The plots data sets with up to five points of v (5^1) against time (2) give a slope that represents the frequency second-time derivatives (ϋ) (5^{-2}) of the sample. Also, the regression analysis for eight pulsars out of the sixteen sub-sample that have glitches up to five times was carryout out. The slopes of plots of the frequency second-time derivatives of the eight pulsars were to calculate the breaking indices of these pulsars.

Table 1 represents the summary of the results of regression analysis for the pulsars.

Name of Pulsar	**v**	**ύ ($x10^{-12}$)**	**Ÿ ($x10^{-23}$)**	**n**
B0531 + 21	5.1420	-6.77	-6 ± 3.00	-3.870
B0740 – 28	4.5000	-4.08	1 ± 0.08	3.120
B1338 – 62	8.0450	-6.27	0.1 ± 20	0.230
B0833 – 45	14.2670	-17.80	-5 ± 40	-2.520
B1758 – 23	2.6430	-24.20	70 ± .020	3.030
B1737 – 30	15.2340	-3.96	-1 ± 0.03	-14.200
B1822 – 09	3.9100	-1.78	-0.1 ± 0.20	-1.430
B1823 – 13	11.1989	-15.60	0.1 ± 0.30	0.059

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Table 1: Results of the regression analysis for the 8 pulsars showing their slopes and breaking indices.

DISCUSSION AND CONCLUSION

Discussion

The result of the statistical analysis of a large sample of spinning down pulsars whose breaking indices were obtained through the indirect method has been presented. Our result yielded 16 pulsars with seemingly significant values, $0 < n \leq 5$, of the breaking indices, many in agreement with those earlier published in the literature (Walterred et al., 2011; Espinoza *et al.*, 2017; Livinptone *et al.*, 2007).

We notice that those 16 pulsars in our sub-sample with significant values 0<n c 5 of breaking indices here periods ranging between 0.04s to 1.27s and period derivatives 10^{-12} to 12^{-6} with characteristic ages between 1ky to 1myr implying that they are predominantly young.

Changes in the breaking index values obtained using the integration method are likely due to differences in epochs of observations as we observed from our analysis of the 16 sub-samples.

CONCLUSION

Using a sample of pulsars from the Australian Telescope National Facility data catalogue, we compiled and performed a statistical study of the spin properties of 208 glittering pulsars and computed their breaking indices.

Hoverer, using a sub-sample of 16 pulsars with the frequency $2.4532Hz \leq \nu \leq 15.824H_2$ and frequency derivatives range $-6.03 \times 10^{-14} \leq \acute{\upsilon} \leq -2.42 \times 10^{-11}$ we determined the values of their characteristic ages, τ_1 to he within the range $10^3 yr \leq \tau_1 \leq 10^6 yr$. our result shows that the breaking indices are a function of the pulsar spin-down rates, the magnetic field of the pulsar and their rotational periods. This result may be due to a number of factors including their recovery from unseen glitches (Epizona *et al.*, 2017), unobserved glitches (Johnston and Galloway, 1977) or other processes yet to be unaccounted for.

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