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Research Article

A STUDY OF SPIN DOWN PARAMETERS OF FREQUENTLY GLITCHING PULSARS

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ABSTRACT: *In this work, the spin down parameters of frequently glitching pulsars are investigated on a large scale. 301 glitches from 27 pulsars were assembled and the glitches were separated according to the various manifestations of neutron stars in order to investigate their similarities and differences. We analyzed the glitch parameters to see how they correlate and if possible, to predict one from the other. Pulsar's characteristic age - glitch events correlation was also investigated. The results showed that Radio Pulsars contributed 87% of the glitches. Pulsars of age bracket 10^3 to 10^6 years dominated the glitch events. The glitch size also depends on pulsars' characteristic age, though some are due to generic factors. A correlation coefficient 0.78 was obtained for the variation of log $\Delta\nu$ and log $\Delta\dot{\nu}$ indicating that large frequency spin-up is generally associated with large frequency derivative jump. That of log $\Delta\dot{\nu}/\dot{\nu}$ and log $\Delta\nu/\nu$ shows moderate correlation (r = 0.50), though the result is an indication that they have a form of power law relationship. The result for Glitch Activity is in line with literature. Moreover, it is observed that the glitch events in the pulsar PSR J0537-6910 has a continuous distribution unlike many other pulsars. Glitches from PSR J1740-3015 appeared in group suggesting that two glitch mechanisms are working at a regular interval in this pulsar. Finally, due to the frequency of glitch in some pulsars and the glitch sizes, the plausible mechanisms for glitch still remains those involving the transfer of angular momentum.*

KEYWORDS: *Glitches, Neutron Star, Pulsars, Spin Down parameters.*

1. INTRODUCTION

A pulsar is a fast-spinning neutron star with a strong magnetic field that generates powerful broad-band electromagnetic radiation. Pulsars are fast revolving neutron stars known for their extremely consistent rotation speeds[3,6]. Young pulsars, on the other hand, typically display glitches (sudden jumps in spin frequency), which give information into pulsar innards and structure as well as timing noise (a smooth stochastic wander of the pulse phase over long time periods). The measurement of the braking index – a parameter that relates the observable spin frequency of the pulsar with the slowing down torque acting on the neutron star – provides a window into the physics that govern pulsar spin down in the youngest pulsars. As the pulsar spins around the rotation axis, radiation beams are emitted along the magnetic dipole axis. When the emission beam sweeps over the planet, much like a lighthouse may be seen when it is aimed in the direction of an observer, the emitted radiations can be seen [8]. Pulsars, which are basically revolving magnets, generate electromagnetic radiation, particularly magnetic dipole radiation [5]. From high-energy gamma rays to low-energy radio waves, these pulsed emissions have been detected and studied across the electromagnetic spectrum [9,10].

Pulsars are thought to be born in supernova explosions of massive stars $10M_{\odot}$ (where $M_{\odot}$ the mass of the sun which is ~ 2×10^{30}kg) which occur when the stellar core collapses [6]. After the black hole, neutron stars are among the most compact objects, retaining the majority of the progenitor's angular momentum as they revolve. As a result, the pulse rotation speed is significantly accelerated [8] .The mass of a typical radio pulsar is estimated to be between ~1.40 to 2.0 $M_{\odot}$ based on timing studies of binary pulsars [11,12]. A magnetosphere is a zone of plasma and magnetic field that surrounds a neutron star and extends up to the distance where the co-rotation velocity exceeds the speed of light. $R_{Lc} - cP/2\pi$ is the radius of the imaginary light cylinder, where P is the pulsar rotation period and c is the light speed [8]. Over the last four decades, pulsar astronomy has advanced tremendously and has become a major crossroads for a diverse group of researchers.

Since it was originally found in 1967, the research has unquestionably remained one of the fastest developing disciplines of science, as evidenced by the rate of various publications in the field [4]. The detection of rotational discontinuities in the pulse spin times has improved significantly the information gained from researching the inner structure and dynamics of neutron stars.

The spin-down parameters of regularly glitching pulsars are studied on a wide scale in this paper. Over the last four decades, the basic enhanced spin down parameters of radio pulsars in the current sample have been supplied and documented. This is part of an effort to better understand and characterize the phenomenology of glitch occurrences and their consequences on radio pulsars' inherent spin down characteristics.

2. MATERIALS

The glitch data used in this study comes from the Jodrell Bank Observatory Pulsar Glitch Catalogue. There are 537 glitches in 192 pulsars included by the database. The data includes all known glitch dating back over five decades. Those pulsars that have glitched five times or more were chosen from the sample and discussed in further depth. Radio pulsars are responsible for 215 of the 301 known total glitches in 27 pulsars, anomalous X-ray pulsars for 82, and millisecond pulsars for four. Because of the amount of glitches in these pulsars and the impact of number on the statistical method used in this study, they were given special attention. They have individually glitched more than five times, accounting for 56.05 percent of all glitches in the population. The sample was not kept separate from the others. When the individual behaviors of pulsars were required, it was given the highest priority. When the behavior of the complete population of 192 pulsars was required, the full population of 192 pulsars was employed, or, on many occasions, pulsars that met certain specific requirements required for the research activity were used. The Australian Telescope National Facility provided the spin frequency, frequency derivative (spin-down rate), surface magnetic field, and characteristic age used in the analysis (ATNF). Pulsar website available at the website http://www.atnf.csiro.au/research/pulsar/psrcat.

2.1 Method of Data Analysis

The simple regression approach, which is a statistical procedure that indicates the strength of the association between pairs of variables, was used in the statistical analysis of this data. It's also used to figure out which of the independent variables is related to the dependent variable and to investigate the types of correlations between them.

This method allows you to determine the correlation coefficient (r), which indicates the degree of correlation between variables. Glitch size, frequency, frequency spin-down rate, fractional spin-down rate, surface magnetic field, and characteristic age were all used in the analysis. The distributions of the observed parameters are used in our study, as well as simple regression analysis. The parameters, mean, median, and range of observed data are all plotted as histograms. Scatter plots and parameter correlation are also used in the study, which are important for determining the level of dependence between various sets of parameters that investigate different physical phenomena.

3.0 RESULTS AND DISCUSSION

3.1 Distributions of Glitch Sizes

The histograms of fractional glitch sizes and the accompanying fractional spin-down rate are presented to study how the glitches are dispersed. Figures 4.1a and 4.1b below show the outcome.

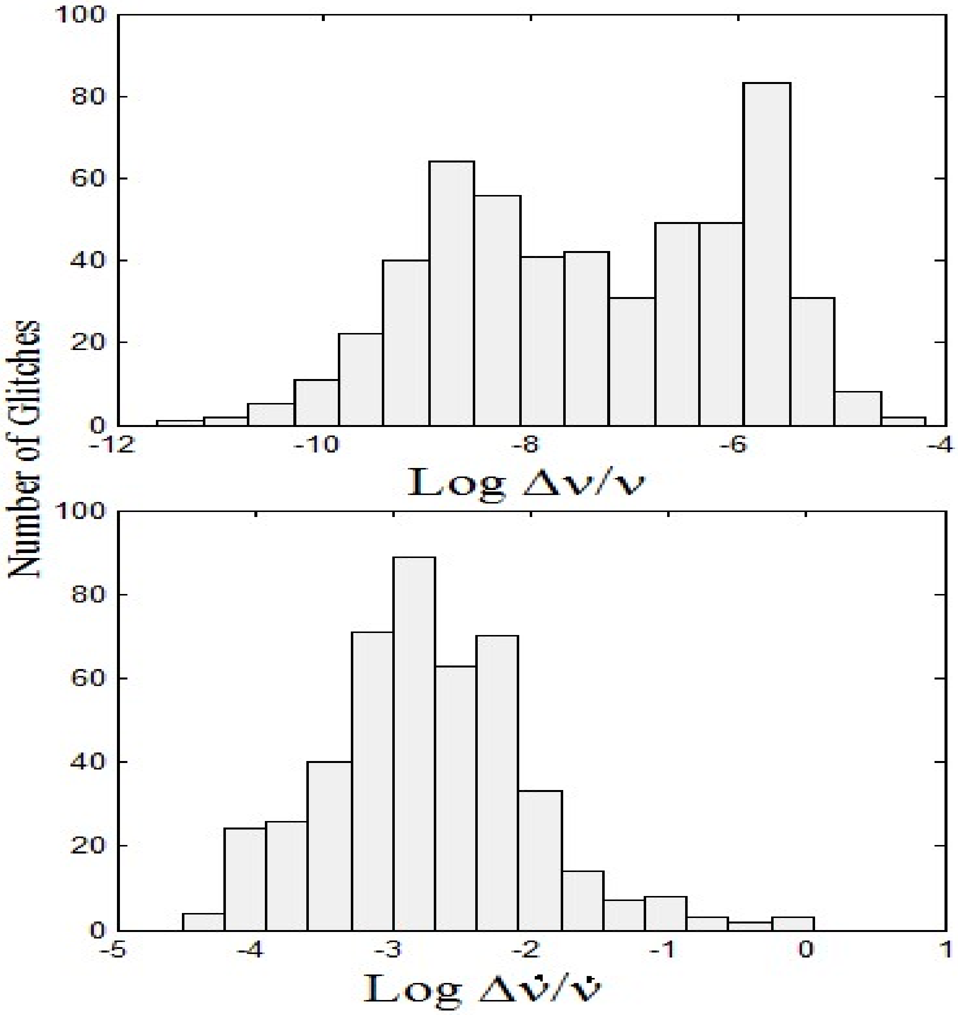

Fig. 1.1: Histogram Distributions of (a) Fractional glitch sizes (b) Fractional change in spin-down rate

Fractional glitch size has logarithmic values ranging from -11.00 to -4.00, with an average of -7.80, indicating that the glitches are evenly distributed around the mean value. In bimodal arrangements, the distribution is clearly continuous and skews negatively, with most pulsars having fractional glitch sizes below -6.

Figure 1.1 also shows the distribution of the fractional change in spin-down rate (Bottom panel). The Fractional change in spin-down rate has a logarithmic range of -4.5 to 0.00, with an average value of -2.79. In unimodal configurations, the distribution is lopsided, with most pulsars having fractional spin-down rates of less than -2.00 with 95% confidence.

3.2 Distributions of Pulsar Spin Properties

We generated a histogram plot of each of the characteristics to explore the distribution pattern and dispersion of the spin properties of the pulsars in our sample. The logarithms of these parameters were utilized as a preferable choice due to the vast variation (three orders of magnitude) in their values. Figures 1.2 and 1.3 illustrate histogram distributions of pulsar characteristic age and surface magnetic field. It ranges from $10^{3.10}$ to $10^{6.10}$ for the typical age, with a mean of ~ $10^{4.10}$and a max of $10^{4.25}$.. This indicates that about ~ 23 (~ 85%) of the pulsars in the sample have a typical age of less than $10^{4.0}$

However, in the case of surface magnetic field, the values are from $10^{11.70}$to $10^{14.65}$ with mean value of ~$10^{12.60}$ and modal value of $10^{12.52}$ with majority of the pulsars havingsurface magnetic fieldvalues less than the mean value.

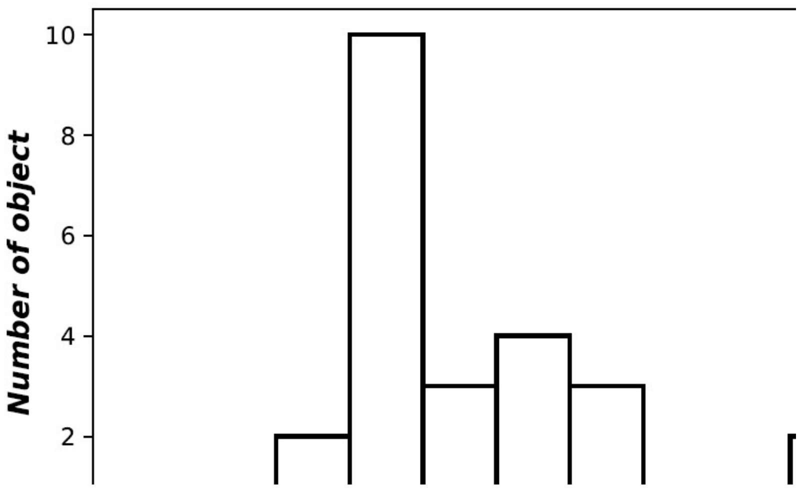

Fig. 1.2: Histogram Distribution of characteristic age of 27 pulsars

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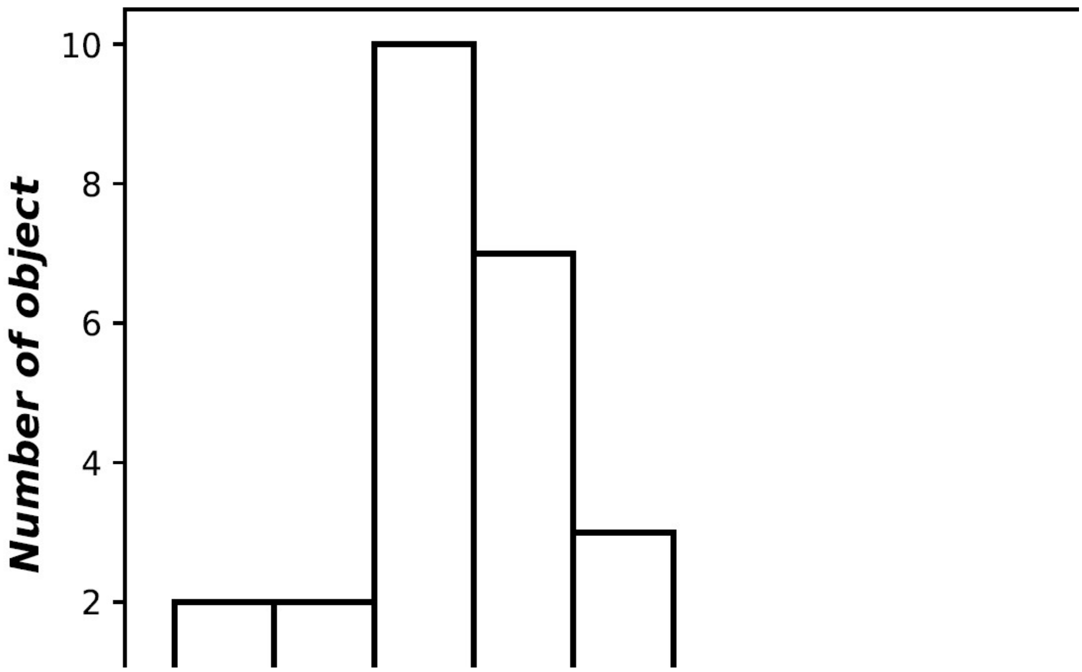


Fig. 1.3: Histogram Distribution of Surface Magnetic Field of 27 pulsars

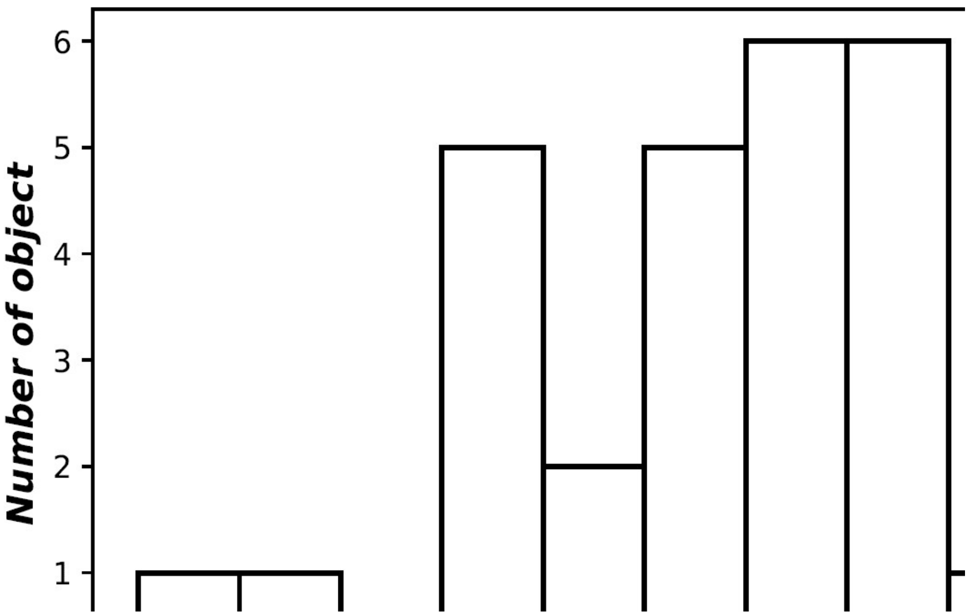


Fig. 1.4: Histogram Distribution of pulsar spin frequency of 27 pulsar

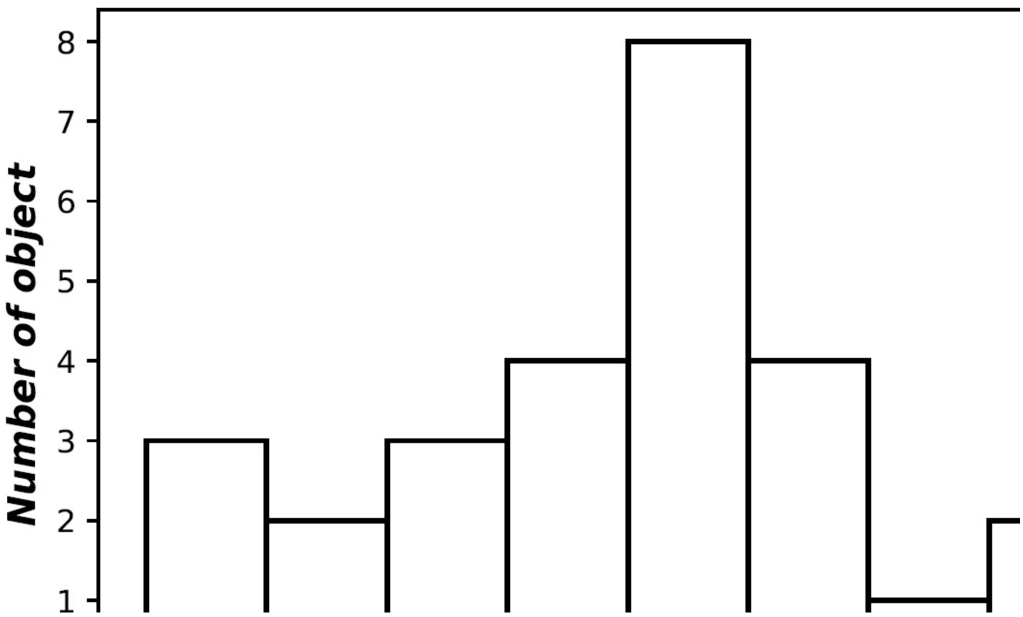


Fig. 1.5: Histogram Distribution of pulsar spin frequency derivative of 27 pulsars.

Figures 1.4 and 1.5 are the distributions of pulsar spin frequency and its first time derivative. The spin frequency ranges from $10^{-0.98}$ to $10^{1.70}$ with mean value of $\sim 10^{0.80}$ (~ 54 %) having spin frequency below the mean value. For the spin frequency first time derivative, it ranges from $10^{-13.80}$ to $10^{-10.50}$ with mean value of $\sim 10^{-12.40}$ in a unimodal distribution and skews to the left with many pulsars (~ 78 %) having values less than the mean value.

3.3 Correlations of Glitch across Pulsar Period and Characteristic age

The scatter plots of the fractional glitch size against the spin period (top panel) and characteristic age (bottom panel) are shown in Figures 1.6. It can be seen from the figure (top panel) that pulsars of $10^{-2} < P < 1$ seconds have mixture of glitch sizes. Pulsars of $8 < P < 2$ mostly have large glitch sizes (bottom panel). These are mostly magnetars. Across the pulsar characteristic age (bottom panel) the distribution is skewed to the left side suggesting that glitch is more rampant in young pulsars. With respect to the glitch number density, pulsars of characteristic age 10^3 years to 10^4 years have more glitches than other. This implies that our sample consist of young energetic pulsars. A simple regression_analysis of our data shows that fractional glitch size is correlated with pulsars characteristic age with correlation coefficient value of 0.63.

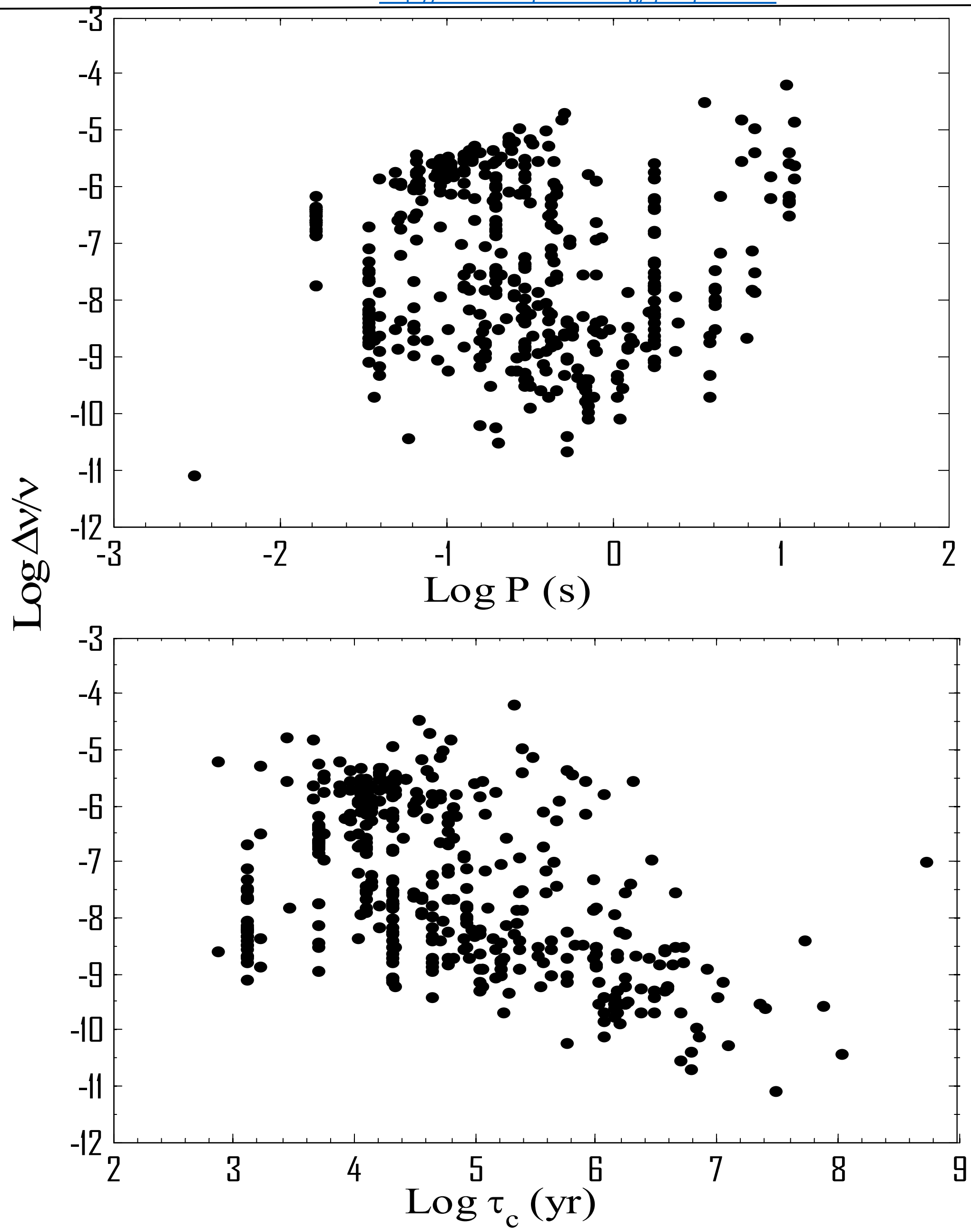


Fig. 1.6: Scatter plot of: Fractional glitch sizes against pulsar spin period (a) Fractional glitch size against (b) characteristic age

3.4 Glitch Events and Pulsar Star Age

The glitch frequency of the 27 pulsars that have glitched five times and above are obtained in the ATNF pulsar catalogue partly shown in table 1.1. The table 1.1 also shows the ages of the number of pulsars and it can be seen from the table that most glitching pulsars have a characteristic age less than 10^5 and this implies that the pulsars in our sample are young, energetic pulsars.

TABLE 1.1 GLITCH FREQUENCY AND CHARACTERISTIC AGE

Age (years)	Number of Pulsars	Number of Glitches	Number of Glitch per Pulsar	Percentage of Glitch in each age group	Number of Glitches in Last Decade	Percentage of Glitch in each age group in last decade
10^3	4	87	21.75	14.82	56	28.87
10^4	18	183	10.16	66.67	118	60.82
10^5	3	20	6.67	11.11	12	6.19
10^6	2	11	5.50	7.40	8	4.12
Sum	27	301	44.08	100	194	100.0

4.5 Relationship Between Fractional glitch size and Fractional Spin down rate

In order to determine the correlation between the changes in pulsar spin parameters as a result of the glitches, we look for a form of relationship between the two parameters. The scatter plot of the fractional glitch size against the fractional change in spin down rate on logarithmic scales is plotted as shown in Figure 1.7. Obviously, it is observed from the plot that there is an upward sloping trend going from bottom left side to the upper right side. A simple regression analysis of our data sample indicates fairly correlation between the two parameters with a correlation coefficient $r= 0.57$. This is an indication that the two quantities have a form of power relation.

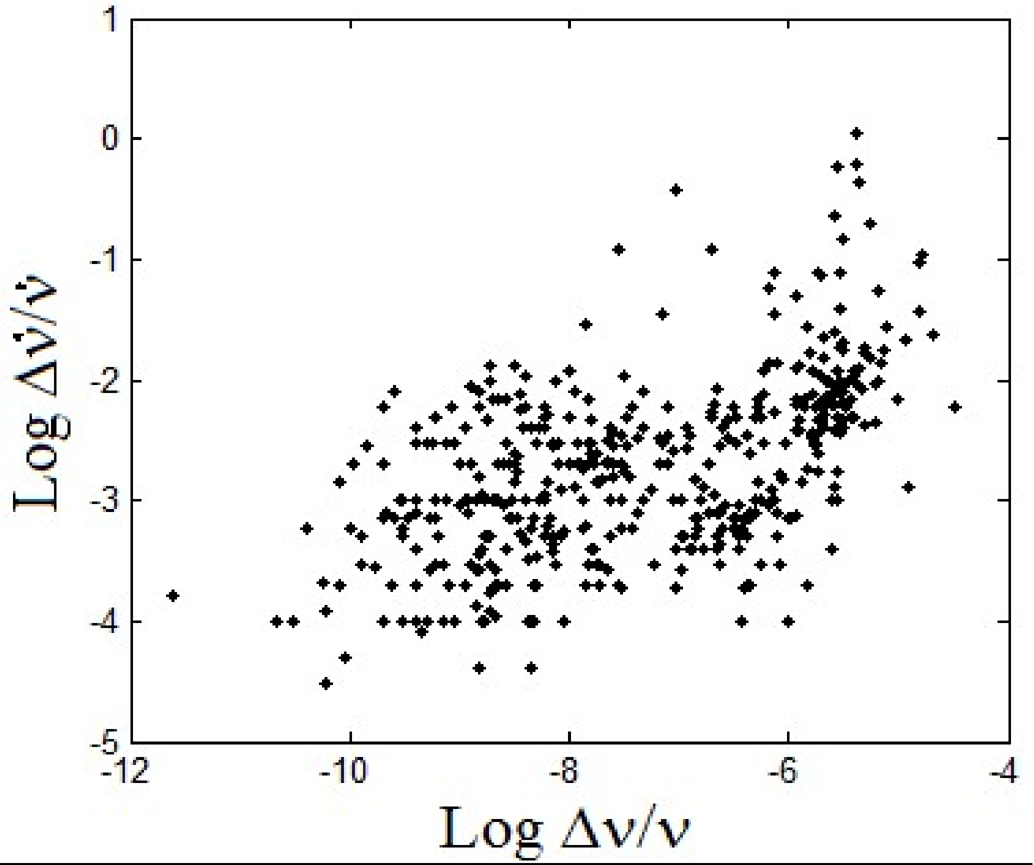
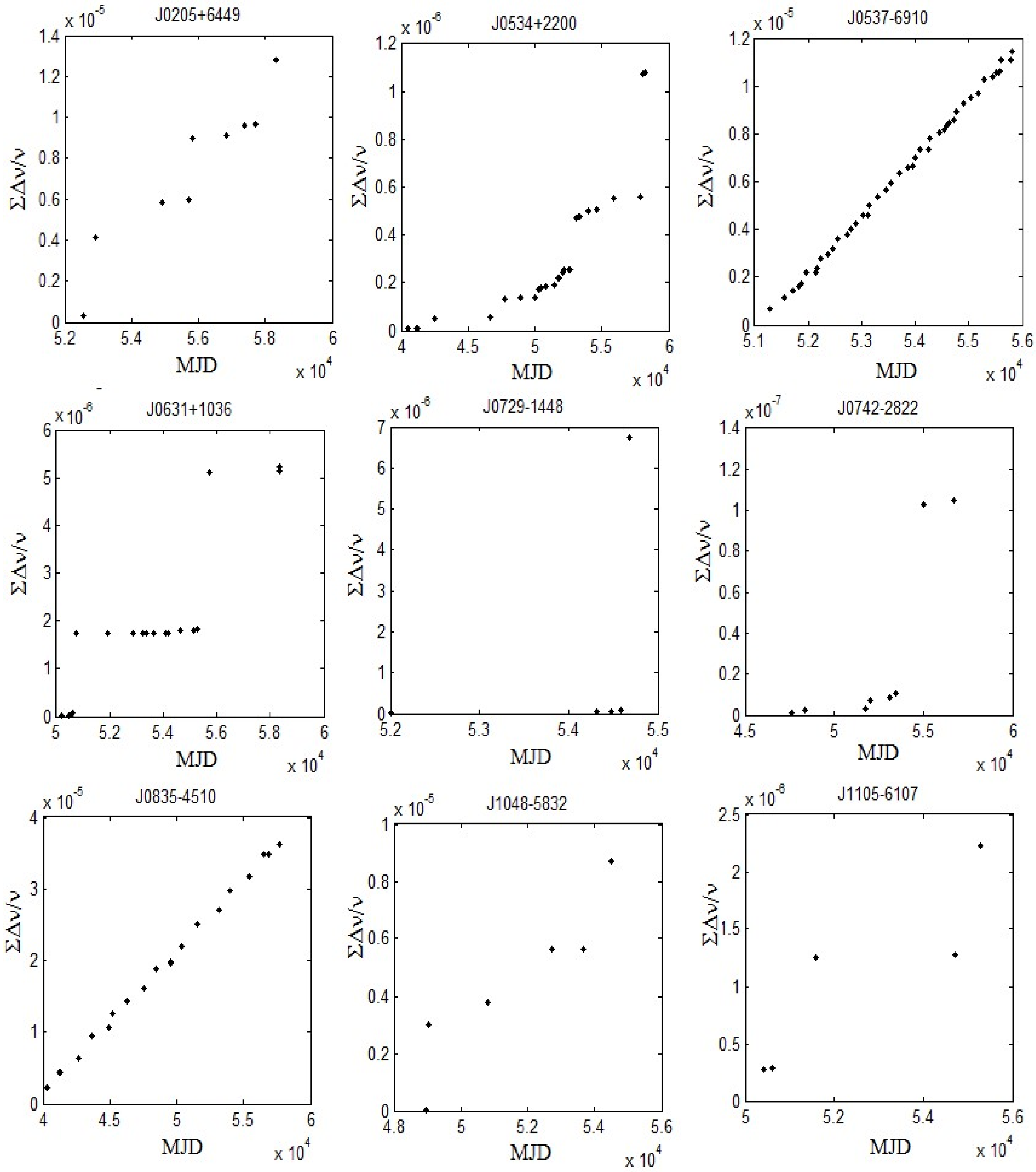


Fig. 1.7 Scatter plot of fractional glitch sizes against corresponding fractional change in spin-down rate.

3.6 Linearity of Glitch Size with Time

Cumulative distribution of the Glitch size can be used to study whether an individual pulsar tends to exhibit specific glitch sizes [1]. Thus, from this observation and that of the result obtained, we plotted the cumulative distributions of glitch magnitude ($\Delta\nu/\nu$) of the 27 pulsars that have five glitches and above to see if these pulsars exhibit specific glitch sizes. The reason for using pulsars with five glitches and above is that the results of the distribution are presented using ten bins in the histogram. The six pulsars J0537-6910, J0835-4510, J1420-6048, J1740-3015, J1801-2451, and J1801-2304 showed a specific_pattern in their cumulative glitch sizes distributions, signifying regular pattern in transfer of angular momentum within the components of the star. The results are shown in Figure 1.8 (a-c).



igure 1.8a Cumulative glitch size as a function of time from first glitch.

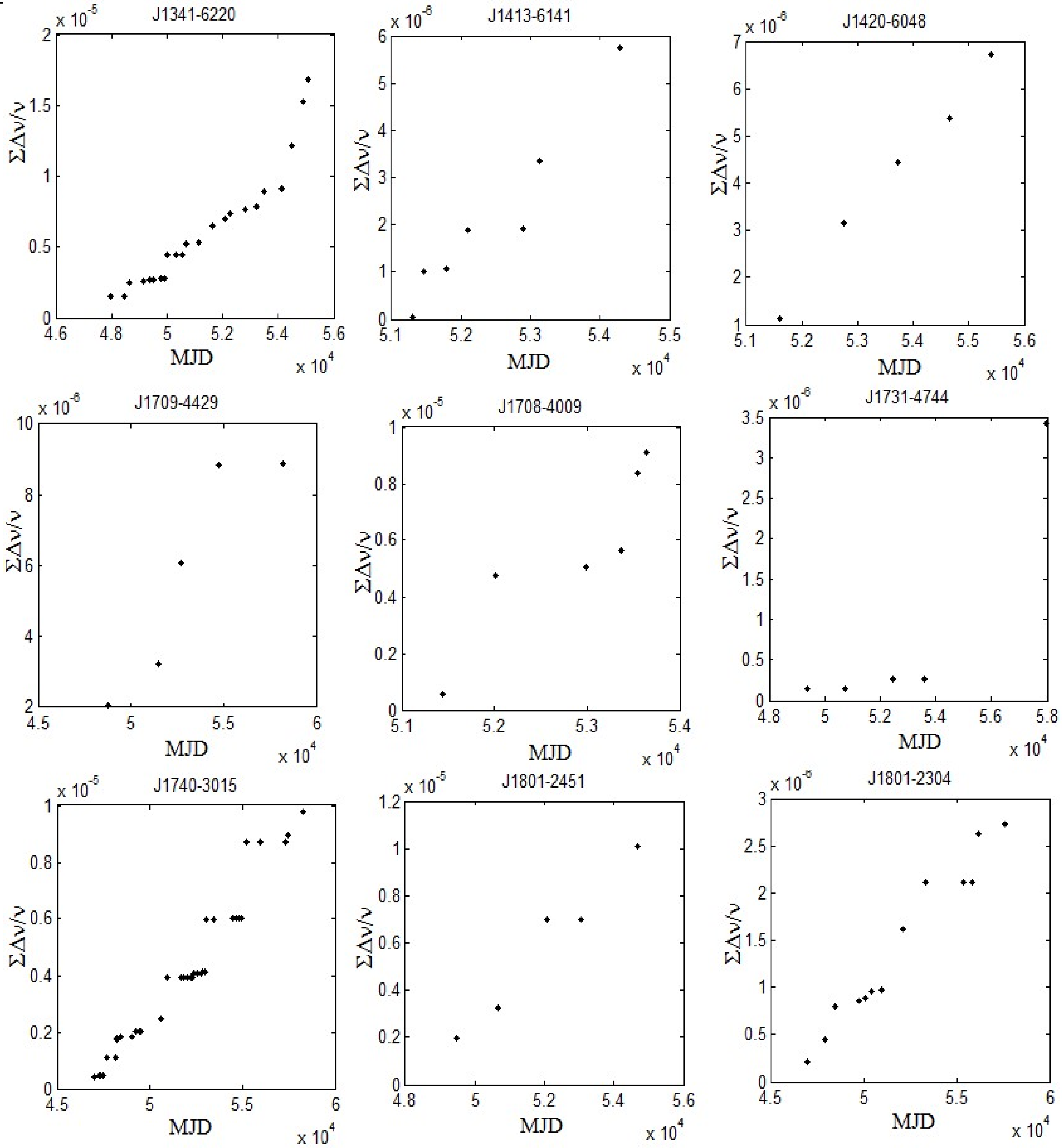


Figure 1.8bCumulative glitch size as a function of time from first glitch (continues)

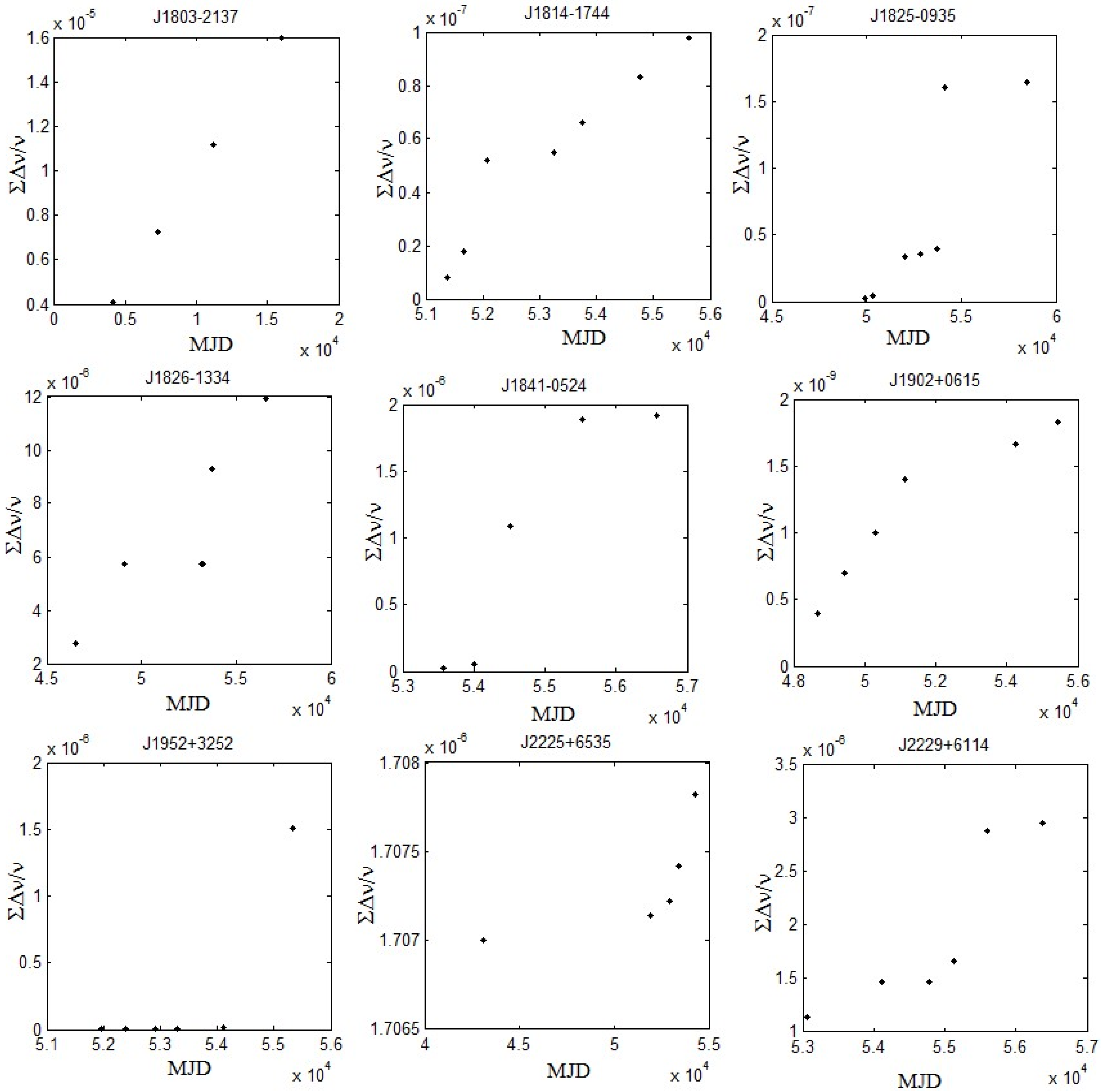


Figure 1.8c Cumulative glitch size as a function of time from first glitch

4.1 SUMMARY

The spin parameters of regularly glitching pulsars are statistically analyzed and provided for a total of 301 glitches in 27 pulsars. The process that causes glitches in glitching pulsars has been the topic of previous research. While some writers claimed that all glitches are the result of a single glitch mechanism [2][, others proposed a dual glitch mechanism [2].As a result of our findings, we may conclude that the frequency of pulsar glitches is mostly determined by the characteristic age, spin frequency, and amplitude of the surface magnetic field. Table 1.1 shows that pulsars with a typical age of 10^3 to 10^4 years produced 81.49 percent of the glitches. The pulsar bracket 10^3 to 10^4 years has the highest average number of glitches per pulsar. Pulsars in this age range are known as "young" pulsars [13].

The frequency distribution of glitches with pulsar characteristic age is shown in Figure 1.1. This result is consistent with most glitch models, as young pulsars spin quickly, causing stress in the crust to build up more frequently than older pulsars. When this stress is discharged, a problem arises. Furthermore, the previous decade alone accounted for more than 42% of all known glitches (194).Due to increased monitoring of active pulsars and the employment of more sensitive instruments than in the past, this is unavoidable. The juvenile pulsars continue to dominate the glitch events at this time scale. Furthermore, the pulsar's magnetosphere's field intensity plays a part in glitching processes.The spin-down rate, which is caused by the pulsar's magnetosphere interacting with the ambient magnetic field, can cause glitch more frequently in pulsars with a high surface magnetic field strength than those with a low surface magnetic field intensity. This is because the magnetosphere's interaction with the surrounding environment will be greater than in a star with a low surface magnetic field intensity.

The result is a high rate of differential rotation in a star with a strong surface magnetic field. As a result, frequent tension builds up, resulting in glitches in such stars. We discovered that stress is the actual source of glitch in some pulsars based on the findings. Those whose interiors can be said to be more homogeneous than others. Because there is significant evidence of regular angular momentum transfer with the star component for the glitch magnitude to follow a precise pattern with time, this is the case.

It also revealed that the interiors of these stars are nearly thermally balanced with the bottom crust. The temperature difference between the layers of the star that causes the problem is insufficient. This allows for periodic unpinning and repinning of the vortex. The pulsars J0537-6910, J0835-4510, J1420-6048, J1740-3015, J1801-2451, and J1801-2304 displayed a continuous distribution and specific glitch pattern in the study of cumulative magnitude distribution of these pulsars, as shown in Fig 1.8. (a-c).Other pulsars, on the other hand, did not display a continuous distribution or a distinctive glitch pattern. However, the pulsar PSR J1341-cumulative 6220's glitch magnitude followed an exponential curve. The most likely explanation is that these stars' core and lower crust have a significant temperature difference. These stars cool exponentially as a result of this. This means that vortex creep, which is temperature_dependent, is fully operational in these pulsars.As the pulsars cool faster, more areas in the lower crust become available for vortex pinning, increasing the magnitude of stress in the crust exponentially between glitches. When this stress is discharged in this way, the amount of glitches increases exponentially.

5. CONCLUSION.

The spin-down rate of a well-matured neutron star is expected to be quick. The malfunctions that have been noticed in many of the pulsars provide significant evidence for this. The basic premise of most glitch models is that as the neutron star crust spins down due to the emission of electromagnetic radiation and particles, the superfluid component lags behind until a critical point is reached, at which point angular momentum is transferred from the superfluid to the crust (due to vortices rearrangement), causing the glitch or star quakes. The vortex creep model is well-known for accurately describing glitch relaxation.

Furthermore, certain pulsars have a distinctive property that cannot be explained by either a linear or a curve equation.

The glitches from this star appear to occur in groups, as can be seen. The interior of this star is inhomogeneous and not in thermal equilibrium, based on its behavior. There may still be a series of phase transitions involving matter contained within the star's contents. This implies that there are two or more types of mechanisms causing glitches in this pulsar.The tiny size glitches from this pulsar can be attributed to starquake, whereas the large glitches can be attributed to vortex unpinning and pinning, particularly Link and Epstein's thermal driving mechanism [7]. The transfer of angular momentum mechanism occurs at regular intervals in this figure as well, with star quakes occurring in between.

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