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Regularity of pulsar glitches

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ABSTRACT
Glitches are sudden changes (usually increases) of pulsars rotation rates, whose causes are still unknown. Study of glitches and their properties may lead to independent view to the physics of pulsars and to the properties and structure of neutron stars. In this contribution we present preliminary results of our analysis of the inter-glitch intervals. The studied data sample contains 30 pulsars with a number of detected glitches higher than four. Analysis of the data shows that there could exist linear correlation between glitch amplitudes and inter-glitch intervals in the case of 11 pulsars from studied data sample. These results alone may suggests that the global processes may be responsible for glitches.

Keywords: Pulsar – glitches – neutron stars

1 INTRODUCTION

Isolated pulsars are rotating neutron stars characterized by high rotational stability. Nowadays, we can obtain many important informations about astrophysical processes inside neutron stars and in their vicinity. Precise analysis of long-scale pulsar timing shows that rotational frequencies of the pulsars slowly decrease. Moreover, sometimes sudden change (usually increase) of rotational frequency ν may occur and this phenomena is called *glitch*. Relative amplitudes of glitches $\Delta\nu/\nu$ ranges $10^{-11} \leq \Delta\nu/\nu \leq 10^{-5}$ (Espinoza et al., 2011). Since the first glitch detection at the end of 1970's (Vela pulsar, Radhakrishnan and Manchester (1969)), 439 glitches in 213 pulsars have been detected until today[1] (see online database of Jodrell Bank observatory[2] (Espinoza et al., 2011)). Glitches are detected in about one tenth of whole of 2302 discovered pulsars (Manchester et al., 2005).[3] Histogram of glitch amplitudes is shown in the left panel of Fig. 1. We can see two peaks at about $\Delta\nu/\nu \approx 10^{-8}$ and $\Delta\nu/\nu \approx 10^{-6}$. The right panel of Fig. 1 shows all detected glitch amplitudes against characteristic age for all glitching pulsars. We can see that the glitches with large amplitude are occurring mostly in pulsars with characteristic age $\tau \approx 10^4$ years.

[1] October 2013
[2] Actual version of Jodrell bank (JB) online database: http://www.jb.man.ac.uk/pulsar/glitches.html
[3] http://www.atnf.csiro.au/research/pulsar/psrcat/

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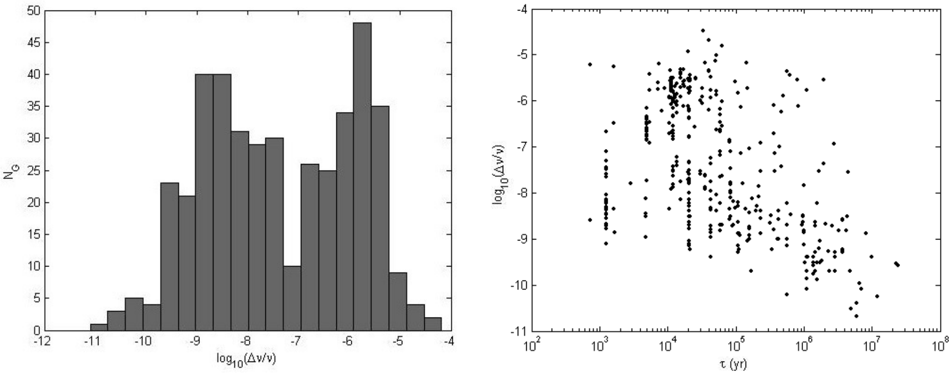

Figure 1. Statistical properties of glitch amplitudes. *Left:* Histogram of glitch amplitudes. *Right:* Relation between glitch amplitudes and characteristic ages of pulsars. The data were taken from on-line databases JB and ATNF.

On the other hand, glitches with amplitudes about $\Delta\nu/\nu \approx 10^{-8}$ (left peak on the left panel of Fig. 1) are occurring at all glitching pulsars independently on their characteristic age.

During the glitch not only the rotational frequency ν but also its time derivative (spin-down rate) $\dot{\nu}$ is changed. Glitches are usually followed by slow relaxation of spin-down rate and frequency to their pre-glitch values. However in some cases, the post-glitch behaviour of ν is more complicated. For example, the J0534+2200 (Crab) pulsar glitches were followed by persistent change of $\dot{\nu}$ (Lyne et al., 1993). Moreover, some glitches of the J0358+5413 pulsar were followed by permanent change of rotational rate ν (Lyne, 1987).

A physical mechanism of glitches is still under discussion (see e.g. a review of a contemporary theories of glitch mechanisms in the bachelor's thesis (Juryšek, 2014) and references there in). However, it is generally accepted that the glitches are caused by variable coupling between neutron star's crust and its superfluid interior (Gosh, 2007). Pulsar glitches are occurring sparsely and the inter-glitch intervals are long. The most glitching pulsars are J0537-6910, J0729-1448, J1740-3015 and J1341-6220 and their mean inter-glitch intervals range from $\lambda \approx 138$ days to $\lambda \approx 272$ days. That is the reason why the total amount of detected glitches increases very slowly and statistical relevance's of obtained results are relatively poor. Despite the weak statistics of glitch data it is very important to study glitches thoroughly, because the glitch behaviours can provide immensely valuable perspective on the properties of the pulsar and consequently on internal structure of neutron stars.

Based on generally accepted models of glitches it is possible to expect the existence of linear correlation between glitch amplitudes $\Delta\nu/\nu$ and inter-glitch intervals (or glitch waiting times) Δt. Almost all previous analysis of glitch waiting times which have been carried out by many authors, see e.g. Wong et al. (2001); Yuan et al. (2010); Wang et al. (2000, 2012), have shown absence of any of the expected correlations, with the exception of two pulsars – J0537-6910 (Middleditch et al., 2006) and J1645-0317 (Shabanova, 2009). Furthermore, several authors (e.g. Wang et al. (2012) and Wong et al. (2001) in the case of the J0534+2200 pulsar or Melatos et al. (2008) using their sample of nine pulsars) have shown that the individual glitches are independent of each other. In the case of correlations between $\Delta\nu/\nu$ and Δt the global processes in the neutron star's crust would be responsible for glitches. On the other hand time independence of glitches may be result of local relaxations of mutually isolated momentum reservoirs.

In our own analysis, we focused on a glitch waiting times and our preliminary results are listed below in Section Data analysis and results, we finish our contribution with Summary and future work.

2 DATA ANALYSIS AND RESULTS

Since last studies of correlations between $\Delta\nu/\nu$ and Δt were published, many new glitches were detected and that is why we repeated analysis of correlation on a large sample of pulsars and glitches. We have chosen 30 pulsars with four or more glitch detections ($N_G \geq 4$) with an effort to use the largest possible sample of pulsars. We have used on-line JB database and the ATNF catalogue as the source of glitch amplitudes and times of arrival.

If origin of glitches is related to process of global character we can expect that larger glitch occurs after longer accumulation of momentum (e.g. in the crust of neutron star) and all accumulated momentum could be released. In this case correlation between glitch amplitudes $\Delta\nu/\nu$ and time interval preceding the glitch Δt_P should exist. Basically, longer time of accumulation of momentum leads to larger glitch amplitude. Additionally, a glitch trigger mechanism may be completely independent on glitches themselves (e.g. accretion of matter or some other external processes). On the other hand, if there is some threshold value that accumulated momentum needs to overcome to trigger the glitch and if only part of the whole momentum reservoir is released during the glitch then correlation between glitch amplitude and waiting time after the glitch Δt_F should exist. This threshold value could be e.g. limit value of difference between rotation velocity of the crust and the interior superfluid. In this case the correlation is because the waiting time till next glitch is affected by the glitch amplitude of the preceding glitch (or equivalently by the amount of momentum from the reservoir that is released during the glitch).

In our study, we search for correlation between $\Delta\nu/\nu$ and time intervals Δt_P and Δt_F on the whole sample of 30 pulsars. Correlations have been quantified using Pearson's correlation coefficients C_{cor}, which have been calculated using 'corrcoef' function implemented in MATLAB (2012) software. The resulting values of correlation coefficients are listed in the Table 1. The most significant correlations are marked using bold typeface. In some cases, high values of $C_{\mathrm{cor}} < 0$ are due to one outlying point in waiting time – glitch amplitude space and after we removed this point the correlation disappeared. Only those pulsars for which this case did not happened are marked in the Table 1. As we can see, there are 11 pulsars with significant correlations between amplitudes and glitch waiting times besides two previously published cases. There are both types of correlations between $\Delta\nu/\nu$ and $\Delta t_P/\Delta t_F$ in the cases of J1731-4744 and J1801-2451 pulsars. Moreover, both dependencies $\Delta\nu/\nu$ on Δt_F are surprisingly giving the $C_{\mathrm{cor}} < 0$. This contradicts the intuitive idea of gradual increase of stress in a global reservoir. Dependency of $\Delta\nu/\nu$ on Δt_P at the J2301+5852 pulsar is also showing $C_{\mathrm{cor}} < 0$.

3 SUMMARY AND FUTURE WORK

Based on our analysis of 30 pulsars with $N_G \geq 4$ we can state that 13 of them show significant correlations between $\Delta t_{P/F}$ and $\Delta\nu/\nu$. These results are surprising in comparison with

Table 1. Correlations between $\Delta t_{P/F}$ and $\Delta\nu/\nu$ at 30 pulsars with $N_G \geq 4$. The most significant correlations are marked using bold typeface.

PSR	N_G	$\Delta t_{P/F}$	$C_{\rm cor}$	PSR	N_G	$\Delta t_{P/F}$	$C_{\rm cor}$
J0205+6449	4	P	-0.3352	J1708-4009	6	P	-0.1101
		F	**0.9902**			F	0.5002
J0358+5413	6	P	-0.2719	**J1731-4744**	4	**P**	**0.9452**
		F	0.9907			**F**	**-0.9144**
J0528+2200	4	**P**	**0.9844**	J1740-3015	33	P	-0.027
		F	0.3780			F	0.4209
J0534+2200	25	P	0.0341	**J1801-2304**	11	P	0.6257
		F	0.0266			**F**	**0.7127**
J0537-6910	23	P	0.0431	**J1801-2451**	5	**P**	**0.8835**
		F	**0.9421**			**F**	**-0.9817**
J0631+1036	15	P	-0.0913	J1803-2137	5	P	0.1490
		F	0.7009			F	0.8901
J0729-1448	5	P	-0.3489	**J1814-1744**	7	P	-0.4347
		F	0.6838			**F**	**0.7564**
J0742-2822	7	P	0.1180	**J1833-1034**	4	**P**	**0.9874**
		F	-0.0818			F	0.1560
J0834-4511	17	P	0.4787	J1825-0935	6	P	-0.2448
		F	0.3724			F	-0.1525
J1048-5832	6	P	-0.4760	**J1826-1334**	5	P	-0.2183
		F	0.5806			**F**	**0.9606**
J1105-6107	5	P	-0.3693	J1902+0615	6	P	-0.3142
		F	0.8685			F	0.4899
J1341-6220	23	P	-0.0818	J1952+3252	6	P	0.8883
		F	0.2931			F	0.7052
J1413-6141	7	P	0.4147	J2225+6535	5	P	-0.3249
		F	**0.8433**			F	0.9983
J1420-6048	5	P	0.6533	**J2229+6114**	5	P	-0.2524
		F	0.2333			**F**	**0.9798**
J1645-0317	7	P	0.2863	**J2301+5852**	4	**P**	**-0.8873**
		F	**0.9888**			F	0.4054

previously published analyses. These results are in agreement with theories suggesting that a global processes in the neutron star's crust play the key role in the glitch mechanisms. In the case of a small number of detected glitches, the statistic reliability of obtained results is essential question and we will focus on this issue in the subsequent work (Juryšek and Urbanec, in prep.). There is need for further analysis in order to distinguish between local and global causes of glitches. At first, it is necessary to investigate mutual independence of individual glitches. We are working on more detailed analysis and we plan to include more significant results in the prepared paper.

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