Chin. J. Astron. Astrophys. Vol. 1, No. 3, (2001) 195–199
(*http://www.chjaa.org* or *http://chjaa.bao.ac.cn*)

Chinese Journal of
Astronomy and
Astrophysics

LETTERS

A Large Glitch in the Crab Pulsar

Na Wang[1,2,3,4] ⋆, Xin-Ji Wu[1,2,4], R. N. Manchester[3], Jin Zhang[2], A. G. Lyne[5] and Aili Yusup[2]

[1] Department of Astronomy, Peking University, Beijing 100871
[2] Urumqi Astronomical Observatory, NAO-CAS, Urumqi 830011
[3] Australia Telescope National Facility, CSIRO, P.O. Box 76, Epping NSW 1710 Australia
[4] Chinese Academy of Sciences - Peking University Beijing Joint Astrophysics Center, Beijing 100871
[5] University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Chesire SK11 9DL, UK

Received 2001 April 9; accepted 2001 April 28

Abstract Using a new pulsar timing system at the 25-m radio telescope of Urumqi Astronomical Observatory, we have detected a large glitch in the Crab pulsar which occurred in 2000 July. The size of the glitch is $\Delta\nu/\nu \sim 2.4 \times 10^{-8}$, with a relative increment in frequency derivative $\Delta\dot{\nu}/\dot{\nu} \sim 5 \times 10^{-3}$. The observing system is introduced and the observed properties of the glitch are discussed.

Key words: Stars:neutron — pulsars:general

1 INTRODUCTION

A pulsar glitch is a phenomenon in which the pulse frequency has a sudden increase, typically with a fractional amplitude $\Delta\nu/\nu$ in the range of $10^{-8} - 10^{-6}$. Glitches are unpredictable but occur at intervals of a few years in many young pulsars. Coincident with the glitch, there is often an increase in the magnitude of the frequency derivative followed by three types of recovery: almost no recovery, partial recovery and total recovery on timescales from days to years. It is believed that the recovery represents a 're-balance' of the neutron star interior superfluid.

The Crab pulsar (PSR B0531+21) was discovered in 1968 and since then it has been monitored closely. It is a fast rotating normal pulsar with period $P \sim 33$ ms, and a very high period derivative $\dot{P} \sim 4.2 \times 10^{-13}$, which implies a strong magnetic field on the pulsar, $B_{\rm s} \sim 4 \times 10^{12}$ G. If we describe the pulsar rotation by $\dot{\nu} = -K\nu^n$, with K a positive constant related to the magnetic field strength, then the braking index n equals 3 for a dipole magnetic field. The characteristic age of the pulsar, given by $\tau = P/[(n-1)\dot{P}] = P/(2\dot{P})$, where $P = 1/\nu$ is the pulsar period, is equal to the actual age if the pulsar was born with a period much less than its present value. With the given period and period derivative, the Crab pulsar has a characteristic

---

⋆ E-mail: wangna@bac.pku.edu.cn

age of 1257 yr, quite close to its true age based on the Chinese record of a 'guest star' in 1054, which was in fact the supernova explosion where the pulsar was born and the Crab Nebula was formed.

The Crab pulsar is characterised by its frequent small glitches with relative sizes in the range 2×10^{-9} to 85×10^{-9} (Lyne et al. 1993; Wong et al. 2001). The post-glitch relaxations are unique, showing a rapid exponential decay in one or two weeks and a persistent and cumulative increase in $|\dot{\nu}|$. After large glitches, there is clearly a permanent change $\Delta\dot{\nu}_{\rm p}$ in $\dot{\nu}$, with $\Delta\dot{\nu}_{\rm p}/\dot{\nu}$ in the range 10^{-5} to 4×10^{-4}. Wong et al. (2001) have shown that the permanent change, $\Delta\dot{\nu}_{\rm p}$, is approximately proportional to the jump in frequency. Because of this, the pulsar is now rotating more slowly than it would have done without the glitches. The cumulative increase in $|\dot{\nu}|$ might imply an angular momentum release from the interior superfluid, a misalignment of rotation and magnetic axis or an increase in the effective dipole magnetic field.

Large and small glitches in the Crab pulsar exhibit rather different properties. Small glitches are often followed by secondary spinups or 'aftershocks' 20–40 days after the main glitch. The amplitudes of these spinups are small and comparable with timing noise. However, Wong et al. (2001) pointed out that this phenomena constitutes another class of timing events. On the other hand, the larger glitches detected in 1989 and 1996 exhibited a gradual spinup for about several hours immediately after the initial jump. These various properties indicate that glitches in the Crab pulsar are random processes, supporting the idea of glitches being local phenomena in neutron stars (Wang et al. 2000).

In the next section we discuss a large Crab glitch which occurred in 2000 July. It was detected by the pulsar timing system developed on the 25-m radio telescope at the Nanshan site of Urumqi Astronomical Observatory (UAO).

2 OBSERVATIONS AND RESULTS

The UAO pulsar timing system has been operating since mid-1999. The center frequency of the room temperature receiver is 1.54 GHz and the system temperature is about 100 K for both circular polarisations. A $2 \times 128 \times 2.5$ MHz filterbank/digitiser system is used to provide the time and frequency resolution. Regular observations for 74 pulsars, including the Crab pulsar, commenced in November 1999, with about one observing session per week. For most observations, the integration time is 16 minutes and the sampling interval is 1 ms. Since January 2001 we have used a sampling interval of 700 μs for the Crab pulsar. Details of the timing project can be found in the recent paper by Wang et al. (2001).

A pulse arrival time (TOA) is obtained from each observation. First, the data are dedispersed relative to the center frequency and summed in time using the program TREDUCE (supported by Swinburne University of Technology and Australia Telescope National Facility) to form a single mean pulse profile. By cross-correlating this mean pulse profile with a standard profile we obtained the Observatory TOA for each observation. These TOAs are reduced to arrival times at infinite observing frequency at the Solar System barycentre using the DM and the JPL Solar system ephemeris DE200 (Standish 1982).

The pulse phase at time t can be predicted by

$$\phi(t) = \phi_0 + \nu_0 t + \frac{1}{2}\dot{\nu}t^2 + \frac{1}{6}\ddot{\nu}t^3 + \cdots, \qquad (1)$$

where t is the time from the reference epoch. Provided the rotation model is sufficiently accurate, the pulse phase at any observed arrival time, $\phi(t_{\rm i})$, will be close to an integer. The difference between the observed and predicted pulse arrival times is known as timing residual. After a glitch, the residuals will deviate greatly from zero.

The time-dependence of the pulsar frequency after a glitch is generally well described by an exponential function:

$$\nu(t) = \nu_0(t) + \Delta\nu_{\rm g}[1 - Q(1 - \exp(-t/\tau_{\rm d})] + \Delta\dot{\nu}_{\rm p}t\,, \tag{2}$$

where $\nu_0(t)$ is the value of ν extrapolated from before the glitch, $\Delta\nu_{\rm g} = \Delta\nu_{\rm d} + \Delta\nu_{\rm p}$ the total frequency change at the time of the glitch ($t = 0$), where $\Delta\nu_{\rm d}$ is the part of the change which decays exponentially and $\Delta\nu_{\rm p}$ is the permanent change in pulse frequency, $Q = \Delta\nu_{\rm d}/\Delta\nu_{\rm g}$, $\tau_{\rm d}$ is the decay time constant and $\Delta\dot{\nu}_{\rm p}$ the permanent change in $\dot{\nu}$ at the time of the glitch.

Observations of the Crab pulsar revealed a glitch during July, 2000. This was also observed at Jodrell Bank Observatory and the pre-glitch ephemeris given in Table 1 is based on Jodrell Bank data. They also determined the glitch epoch to be MJD 51740.8 (2000 July 15). We use these parameters in our analyses, except that $\dddot{\nu} = 0$ was adopted because the time span is too short for a fit to be made.

The data included in this work are from MJD 51547.9 to 51966.6. The residuals relative to the pre-glitch timing model from the UAO timing observations for the Crab pulsar are shown in Fig. 1. The observed variations in frequency and frequency derivative, obtained by fitting short sections of the data, are plotted in Fig. 2. Our observations around the time of the glitch are not sufficiently frequent to determine the decay time constant $\tau_{\rm d}$, and we estimate it to be four days. This value gives phase continuity at the adopted glitch epoch and we keep it fixed in the analyses. Fitting of the glitch model described in Equation (2) using the pulsar timing program TEMPO[a] gives a glitch size $\Delta\nu/\nu \sim 2.4(8) \times 10^{-8}$, an increment in $\Delta\dot{\nu}/\dot{\nu} \sim 5(2) \times 10^{-3}$, where uncertainties in the last quoted digit are given in parentheses. The decay parameter $Q = 0.8(4)$, that is, about 80 per cent of the jump in frequency decays away on the 4-day timescale. As may be seen in Fig. 2, there is a persistent increase in the magnitude of the slow-down rate. Fitting for this in TEMPO gives $\Delta\dot{\nu}_{\rm p}/\dot{\nu} = 1.28(9) \times 10^{-4}$. The rotation parameters for the post-glitch data obtained using TEMPO are given in Table 2.

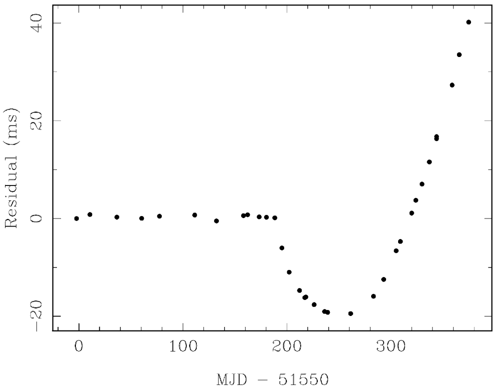

Fig. 1 Timing residuals for the Crab pulsar showing the glitch of 2000 July

Table 1 Pre-glitch Ephemeris of Crab Pulsar

PSR	B0531+21 (J0534+2200)
R.A. (J2000)	$05^{\rm h}34^{\rm m}31^{\rm s}\!.972$
Dec. (J2000)	$22^\circ00'52''\!.07$
Epoch (MJD)	51562.7279
ν (s^{-1})	29.845547780
$\dot{\nu}$ (s^{-2})	$-3.7457341 \times 10^{-10}$
$\ddot{\nu}$ (s^{-3})	1.0161006×10^{-20}
$\dddot{\nu}$ (s^{-4})	-6.0×10^{-31}
DM (cm^{-3} pc)	56.77

---

[a] See http://www. atnf.csiro.au/research/ pulsar/timing/tempo

Table 2 Rotation Parameters after the 2000 July Glitch

Epoch (MJD)	51856.0000
Data span	51745.2–51966.6
ν (s^{-1})	29.836059670(2)
$\dot{\nu}$ (s^{-2})	$-3.743460(3) \times 10^{-10}$
$\ddot{\nu}$ (s^{-3})	$1.17(2) \times 10^{-20}$

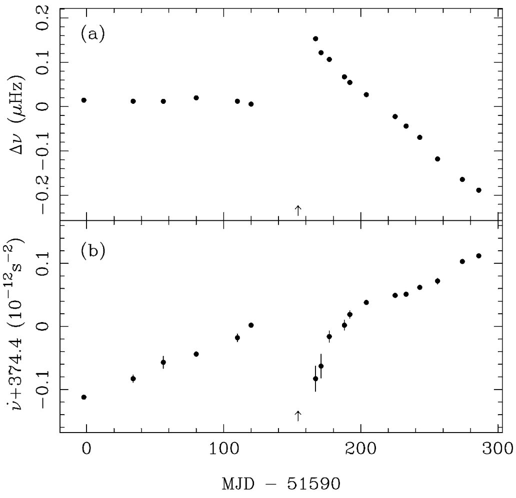

Fig. 2 The glitch of Crab pulsar at epoch MJD 51741 (2000 July 15); (a) frequency residual $\Delta\nu$ relative to the pre-glitch solution and (b) the variation of $\dot{\nu}$. The glitch epoch is indicated by an arrow near the bottom of each plot.

3 DISCUSSION

Lyne, Shemar & Smith (2000) and Wang et al. (2000) showed that the glitch activity reaches its highest level in pulsars with ages of 10^4 to 10^5 years. Pulsars older than this rarely glitch and in younger pulsars, glitches are small or absent. Glitches in the Vela pulsar ($\tau \sim 11$ kyr), for example, have very different characteristics from those in the Crab pulsar in three ways: first, the increase of rotation rate is normally huge with $\Delta\nu/\nu \sim 10^{-6}$, second, only part of the glitch decays ($Q \sim 0.2$), and third, the relaxation is slow with a decay time typically of several hundred days. The Crab pulsar is very young ($\tau \sim 1.3$ kyr) and has small glitches every four years or so on average (Lyne et al. 1993; Wong et al. 2001). In between the Crab pulsar and the giant glitch group are the second and third youngest pulsars, PSRs B0540−69 ($\tau \sim 1.6$ kyr) and B1509−58 ($\tau \sim 1.7$ kyr), which haven't shown any glitches up to now but which have well determined braking indices. As pointed out by Wong et al. (2001), more glitch samples in these young pulsars would provide better constraints on the evolution of the interior structure of neutron stars.

Table 3 presents all known glitches in the Crab pulsar including the one in 2000 July. This is the third largest glitch seen in the Crab pulsar (the two larger ones are $\Delta\nu/\nu \sim 37 \times 10^{-9}$ in 1975 and 85×10^{-9} in 1989). Similar to other large glitches in this pulsar, there is a permanent increase in $|\dot{\nu}|$ with $\Delta\dot{\nu}_{\rm p} \sim -48(3) \times 10^{-15}$ s^{-2}, which is also smaller than in the two larger glitches. The decay time constant $\tau_{\rm d}$ and decay fraction Q are model dependent, but are consistent with values observed in previous glitches of the Crab pulsar (Lyne et al. 1993; Wong et al. 2001). Table 3 also shows that the glitch rate since 1995 is few times higher than that from 1969 to 1992, but the recent glitches are smaller. The glitch activity parameter, defined to be the accumulated frequency jumps $\sum \Delta\nu_{\rm g}$ divided by the data span (McKenna 1990), was $\sim 5.1 \times 10^{-15}$ s^{-2} from 1969 to 1992, but after the latest glitch is $\sim 9.4 \times 10^{-15}$ s^{-2} from 1992 to 2000. Although these values are rather uncertain because of the small number statistics, they indicate an increasing trend in the Crab glitch activity. It remains to be seen if this is a statistical fluctuation or a secular trend.

Table 3 Rotation Parameters for the Detected Glitches

No.	MJD (Date)	$\Delta\nu_{\rm g}$ (10^{-7}s^{-1})	$\tau_{\rm d}$ (d)	Q	$\Delta\nu_{\rm p}$ (10^{-7}s^{-1})	$\Delta\dot{\nu}_{\rm p}$ (10^{-15}s^{-2})	Ref.
1	40494 (690930)	1.2(1)	18.7(16)	0.58	0.5(1)	−1.4(4)	lps93
2	42447.5 (750204)	13.2(2)	18(2)	0.77	10.2(12)	−92(1)	lps93
3	44900 (811023)	···	···	···	2.8	−3.8(7)	lps93
4	46664.4 (860822)	1.23(3)	9.3(2)	1.00	1.1(1)	−7.1(16)	lps93
5	47767.4 (890829)	18.5	18(2)	0.89	23.8(2)	−155(2)	lps93
6	48947.0 (921121)	3.0(4)	2.0(4)	0.87	0.4(1)	−2(1)	wbl01
7	50020.6 (951030)	0.8(2)	3.2(73)	0.80	0.15(15)	−5.7(43)	wbl01
8	50259.93 (960625)	6.6	10.3(15)	0.68	3.1(3)	−83(6)	wbl01
9	50459.15 (970111)	2.3(1)	3.0(11)	0.87	0.32(13)	−18(7)	wbl01
10	50489.0 (970210)	0.2	···	···	0.50(8)	−4.8(18)	wbl01
11	50812.9 (971230)	2.6(7)	2.9(18)	0.92	0.17(5)	−14.2(6)	wbl01
12	51452.3 (991001)	2.9(5)	3.4(5)	0.83	0.4(1)	−6(2)	wbl01
13	51740.8 (000715)	7.3(24)	4.0	0.80	1.43(6)	−48(3)	This work

Acknowledgements Supported by the National Natural Science Foundation of China under No. 10073001 and the National Scaling-the-Heights Project on Fundamental Research.

References

Lyne A. G., Pritchard R. S., Smith F. G., 1993, MNRAS, 265, 1003 (lps93)

Lyne A. G., Shemar S. L., Graham-Smith F., 2000, MNRAS, 315, 534

McKenna K., Lyne A. G., 1990, Nature, 343, 349

Standish E. M., 1982, A&A, 114, 297

Wang N., Manchester R. N., Pace R., Bailes M., Kaspi V. M., Stappers B. W., Lyne A. G., 2000, MNRAS, 317, 843

Wang N., Manchester R. N., Zhang J. et al., 2001, MNRAS, Submitted

Wong T., Backer D. C., Lyne A., 2001, ApJ, 548, 447 (wbl01)