Slow glitches in the pulsar B1822-09

Shabanova T.V.

Astro Space Center of Lebedev Physical Institute, Moscow, Russia

Timing observations.

Timing observations of PSR B1822-09 have been made at the Pushchino Observatory at frequencies 102/112 MHz with the BSA transit radio telescope, using a 32×20 kHz filter bank receiver. Observations have been conducted since 1991 a few times per month. The topocentric arrival times of each observation were calculated by cross-correlating an average pulse profile with a low-noise template and then were corrected to the barycentre of the Solar System using the TEMPO software package and the JPL DE200 ephemeris. A simple spin-down model involving a rotation frequency n and its first derivative $\dot{n}$ was used for fitting to the barycentric arrival times. The differences between the observed times and the times predicted by a best fit model gave the timing residuals used for an analysis of the pulsar's rotation behavior. In order to study variations in the spin-down parameters of the pulsar in more detail, the rotation frequency and frequency first derivative were calculated by performing local fits to the arrival time data over the interval 200 days.

Detected glitches.

The main result of the Pushchino timing observations is a detection of three slow glitches in the spin rate of the pulsar B1822-09. These events can be related to a new type of variations in the pulse rotation rate, which has not been observed in any pulsar before. These slow glitches occurred in June 1995, August 1998 and December 2000. Besides the pulsar suffered one more glitch, which had a typical signature and has preceded the indicated events.

History.

In 1994 September the pulsar suffered a quite small glitch, with the fractional increase of rotation frequency equal to $\Delta n / n \approx 8\times10^{-10}$. This glitch was typical, associated with a sudden increase in the rotation frequency [1].

The first slow glitch occurred about a year later, in June 1995 and Shabanova detected it [1]. This slow glitch was characterized by a gradual increase in the rotation frequency during 620 d, accompanied by a rapid decrease in the magnitude of the frequency first derivative by ~0.4 per cent and a subsequent increase back to its initial value of the same time span.

The second slow glitch occurred in August 1998 and Shabanova & Urama detected it [2]. The authors studied the glitch behavior of the pulsar for the period 1991-1998 at widely separated frequencies of 0.1 and 1.6/2.3 GHz using quasi-simultaneous observations made at the Pushchino Radio Astronomy Observatory (PRAO) and the Hartebeesthock Radio Astronomy Observatory (HartRAO). They showed that the n and $\dot{n}$ changes with time are similar at both observational frequencies and reported a second large decrease in the magnitude of the first frequency derivative by ~2.4 per cent, which occurred in August 1998.

The third slow glitch occurred in December 2000 and Shabanova detected it. This result was published in the paper [3], which summarized the results of the two previous papers, reported a third slow glitch and presented a description of the timing behavior of PSR B1822-09 over the 19-yr data span from 1985 to 2004. The third slow glitch was independently observed by Zou et al. [4]. The good agreement between the results describing the signature of the third slow glitch at different frequencies of 112 and 1540 MHz provides strong evidence for the existence of unusual glitch phenomenon in the pulsar B1822-09.

Signature of the three slow glitches.

We extend the observational interval to 2006 and present a description of the timing behavior of the pulsar over the 21-yr data span from 1985 to 2006. The timing data set analyzed includes the Pushchino data collected for the period 1991—2006 and the HartRAO data collected over the 1985—1998 interval and taken from the previously published paper [2].

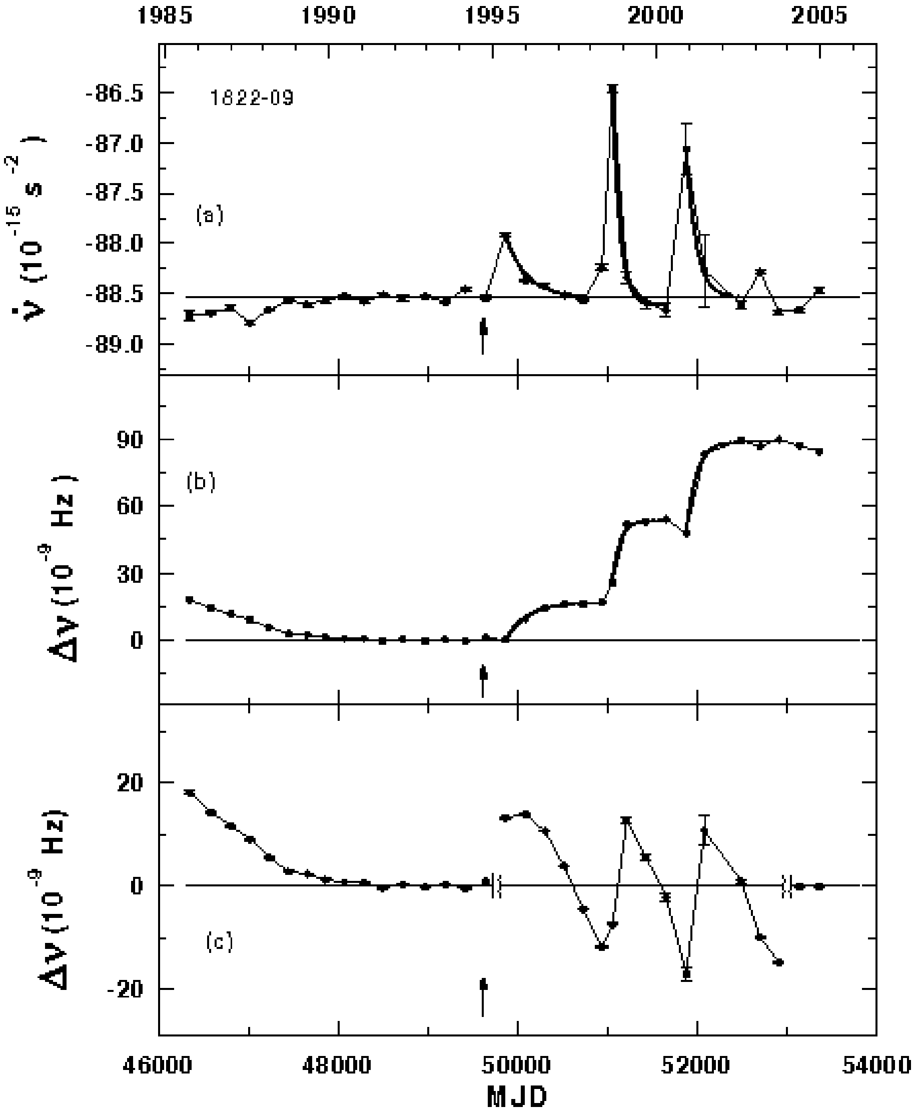


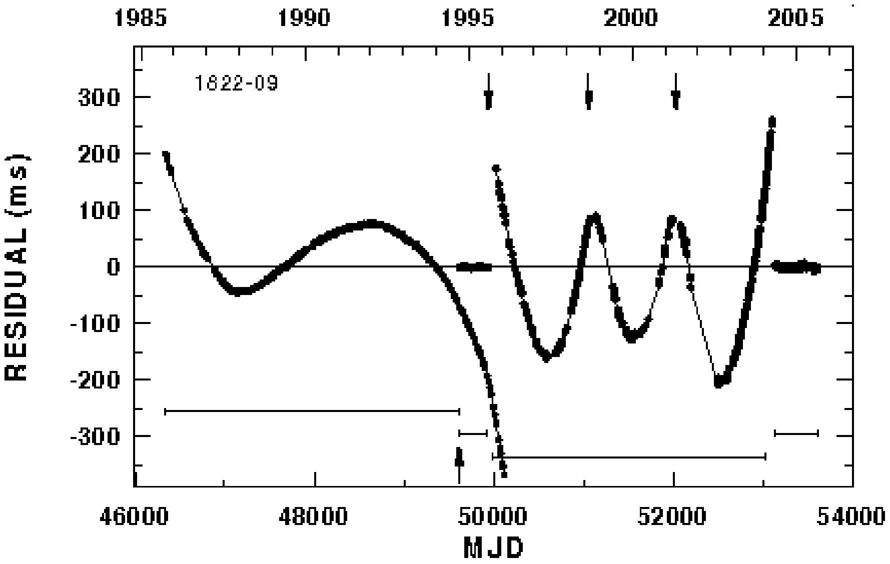
Fig. 1 shows the frequency first derivative $\dot{n}$ and frequency residuals Δn as a function of time over the entire data span of 21 yr from 1985 to 2006. Arrows indicate the time at which the 1994 glitch of typical signature occurred. Three slow glitches during the 1995—2004 interval are clearly seen in the data.

(a) $\dot{n}$ versus time. Three rapid decreases in $\dot{n}$ over the interval 1995—2004 are the effect of the slow glitches. The horizontal line denotes the mean value of $\dot{n}_0$ over the 1991—1994 interval. A fractional decrease of the frequency derivative is about 0.7, 2.7 and 1.7 per cent for the three events, respectively. The form of the subsequent increase back to its initial value is well modeled by an exponential function with the time-scale of 235, 80 and 110 days, respectively.

(b) Δn relative to a fit to the data for the interval 1991—1994. The significant cumulative change in the rotation rate is the effect of the three slow glitches. A gradual growth in rotation frequency n is well described by asymptotic exponential functions with the same time-scale of 235, 80 and 110 days. A fractional increase in frequency of $\Delta n / n_0$ is about 13, 20 and 31×10^{-9} for the three slow glitches, respectively.

(c) As for (b) but with Δn relative to a new fit to the data for the 1995—2004 interval where the slow glitches occurred. It is clearly seen that the rotation frequency of the pulsar relative to a new fit shows oscillatory behavior. The time-scale of this oscillation can be estimated to be ~1000 days. The plot shows that the cyclical changes in the rotation rate were stopped in the middle of 2004.

Timing residuals of the pulsar.



A full picture of the timing residuals for the pulsar over the 21-yr data span between 1985 and 2006 is presented in Fig. 2. Analyses of the entire data set showed that a simple spin-down model could describe not all the arrival times within half the pulsar period because of the presence of several glitches. Therefore, the timing residuals were obtained from four independent polynomial fits for n and $\dot{n}$ over four different intervals indicated in the plot by the horizontal lines. The bottom arrow indicates the epoch at which the 1994 glitch occurred. The three upper arrows indicate the epochs at which the three slow glitches occurred.

For the first interval 1985—1994, the timing residuals relative to a simple spin-down model show a large cubic term that corresponds to a large frequency second derivative $\ddot{n} = 9\times10^{-25} s^{-3}$ that is most likely related to timing noise.

The second interval is a short one-year interval 1994—1995 following the 1994 glitch and preceding the first slow glitch in August 1995. During this interval the pulsar exhibits timing residuals dominated by random deviations at a level of a few milliseconds with a zero mean.

The third interval is a long interval from 1995 to 2004 where the three slow glitches occurred. The plot shows that variations in the pulse arrival times have oscillatory structure with large amplitude of about 150 ms. Three cycles of this structure are caused by the three slow glitches observed for this interval.

The fourth interval 2004—2006 shows that the cyclical changes in the pulse arrival times were stopped in the middle of 2004. The timing residuals for this interval were obtained from a new independent polynomial fit.

Observed properties of the slow glitches.

Characteristic feature of the slow glitches is a gradual exponential increase in the rotation frequency with a long time-scale of 200—300 days. This is accompanied by a rapid initial decrease in the magnitude of the frequency derivative by 1—2 per cent and a subsequent exponential increase back to its initial value with the same time-scale. An obvious relaxation in frequency after a slow glitch is not observed. The size of a slow glitch after a span of a few years is moderate, with a fractional increase of $\Delta n / n \approx 2\times10^{-8}$. The integrated effect of the three slow glitches at the present time is equal to $\Delta n \approx 89\times10^{-9}$ Hz, which gives the total fractional increase in the rotation frequency of $\Delta n / n_0 \approx 7\times10^{-8}$. This means that at the present time the pulsar period is approximately 53 ns less than the expected value from extrapolation of the pre-glitch 1991—1994 model. As a result, the pulsar begins to rotate faster than it would if the slow glitches had not occurred.

Discussion.

It is known that variations in the pulsar rotation rate in the form of glitches and timing noise are common to many pulsars and arise from sudden and irregular transfer of angular momentum between a more rapidly rotating interior superfluid and a solid crust of a neutron star. Pulsar glitches are characterized by a sudden increase in rotation frequency, followed by a post-glitch relaxation. They are accompanied by an increase in the magnitude of $\dot{n}$, which decays after the glitch [5]. The pulsar glitches and post-glitch relaxation reflect changes in the angular momentum distribution inside a neutron star [6].

The signature of slow glitches, as they have been observed in the spin rate of the pulsar B1822-09, is quite different. Characteristic feature of the slow glitches is a gradual exponential increase in the rotation frequency with a long time-scale of 200—300 days. This is accompanied by a rapid initial decrease in the magnitude of the frequency derivative by 1—2 per cent and a subsequent exponential increase back to its initial value with the same time-scale. An obvious relaxation in frequency after a slow glitch is not observed.

The magnitudes of the glitches in the rotation rate and spin-down rate are similar in both types of glitches. The size of a slow glitch after a span of a few years is moderate, with a fractional increase of $\Delta n / n \approx 2\times10^{-8}$. A decrease in the magnitude of the frequency derivative is $\Delta\dot{n} / \dot{n} \approx 10^{-3} - 10^{-2}$.

It seems more likely that significant variations in spin-down rate have to be attributed to variations in braking torque. A decrease in spin-down rate requires a corresponding decrease in torque that brakes rotation of the pulsar crust. Torque variations may be caused by changes in magnetosphere structure, e.g. variations of the polar car size. The measured oscillatory behavior in n on a time-scale of 1000 days reflects the oscillatory changes in torque, which suggests the existence of a long-term oscillation in the polar cap size.

It is likely that the reason of unusual glitch phenomenon in PSR B1822-09 may be related to evolution of the inclination angle between the spin and magnetic axes.

References

[1] Shabanova T. V., 1998, A&A, 337, 723
[2] Shabanova T. V., Urama J. O., 2000, A&A, 354, 960
[3] Shabanova T. V., 2005, MNRAS, 356, 1435
[4] Zou W.Z., Wang N., Wang H.X., Manchester R.N., Wu X.J., Zhang J., 2004, MNRAS, 354, 811
[5] Shemar S. L., Lyne A. G., 1996, MNRAS, 282, 677
[6] Alpar M. A., Chau H. F., Cheng K. S., Pines D., 1993, ApJ, 409, 345