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Hiccups in the night: X-ray monitoring of the two Crab-like LMC pulsars

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Abstract.

We are undertaking an extensive X-ray monitoring campaign of the two Crab-like pulsars in the Large Magellanic Clouds, PSR B0540-69 and PSR J0537-6910. We present our current phase-connected timing analysis derived from a set of 50 pointed X-ray observations spanning several years. From our initial 1.2 yr monitoring program of the young 50 ms pulsar PSR B0540-69, we find the first compelling evidence for a glitch in its rotation. This glitch is characterized by $\Delta\nu/\nu = (1.90 \pm 0.05) \times 10^{-9}$ and $\Delta\dot{\nu}/\dot{\nu} = (8.5 \pm 0.5) \times 10^{-5}$. Taking into account the glitch event, we derive a braking index of $n = 1.81 \pm 0.07$, significantly lower than previously reported. For the 16 ms pulsar, PSR J0537-6910, we recorded 6 large glitch events during a period of nearly 3 years, the highest rate of all known Crab-like systems. Despite the extreme timing activity, the long term spin-down of this pulsar continues to average -1.9743×10^{-10} Hz/s.

1. Introduction

A characteristic signature of young rotation-powered pulsars is the phenomena of “glitches”, sudden discontinuous changes in their spin periods (e.g., see Lyne & Graham-Smith 1998). The physical causes of these glitches are not understood. Suggestions include sudden changes in the neutron star (NS) crust configuration (“starquakes”), abrupt reconfiguration of the magnetic field, or perhaps to the sudden unpinning of vortices in the superfluid neutrons in the inner part of the

NS crust. For the latter, the amplitude of the glitch provides an estimate of the fractional part of the moment of inertia carried by superfluid neutrons (Lyne et al. 1996).

The largest glitches have relative amplitudes ($\Delta\nu/\nu$) of several parts per million, but the range of amplitudes covers many orders of magnitude. Often there is a partial recovery back toward the pre-glitch rotation rate on a time scale of ~ 100 days, however, the spin-down rate may be permanently altered. Lyne (1995) noted that the amount of recovery in the rotation rate tends to be inversely proportional to the characteristic age of the pulsar. For some pulsars (e.g. Crab) the glitches are accompanied by a persistent increase in the spin-down rate with a relative amplitude of a few $\times 10^{-4}$. This increase may be caused, for example, by changes in the alignment of the magnetic field because of starquakes (Allen & Horvath 1998; Link et al. 1998).

In this paper we present preliminary results on the first detection of glitches from the two LMC Crab-like pulsars.

2. Observations and Results

All data presented herein were obtained with the PCA instrument on-board the Rossi X-ray Timing Explorer (*RXTE*) for the purpose of monitoring the 16 ms pulsar PSR J0537-6910 (Marshall et al. 1998). However, the 50 ms PSR B0540-69, located $22'$ away, lies well within the *RXTE* 1° (FWHM) field of view and was thus simultaneously observed. The duration and spacing between observations were optimized to phase-link the pulses from PSR J0537-6910 which is more than sufficient to allow a similar analysis for PSR B0540-69, which is both slower and brighter than PSR J0537-6910.

The PCA is sensitive to X-rays in the $2 - 60$ keV band, with a spectral resolution $\delta E/E \sim 18\%$ at 6 keV and a time resolution of $< 100\mu s$. To optimize the pulsar detection, we selected $\sim 2 - 15$ keV photons from the top layer of the PCA only. Photon arrival times were corrected to the solar system barycenter.

Our timing analysis procedure is summarized below (see Zhang et al. 2001 for details). For each observation we folded the arrival times into 20 phase bins over a range of frequencies centered on an initial value found from an FFT of the data set (without accounting for any $\dot{\nu}$). From the folded profile we determined a pulse time-of-arrival (TOA) for each observation in an iterative manner, initially using a linear fit to the TOA's then adding higher order derivative terms as needed.

2.1. The 50 ms LMC Pulsar PSR 0540-69

Using the above prescription we fitted the TOA's for the PSR 0540-69 data sets. A linear fit was used as a quadratic term was not needed to improve the fit. However, we found an apparent timing glitch had occurred, too small to show up directly in a frequency residuals but large enough to be evident in the analysis of the TOAs. An improved fit was obtained by breaking up the data set up into two groups and fitting each separately. Figure 1 presents the pulse arrival times fitted with the ephemerides of Zhang et al. (2001). We determine that the glitch occurred at MJD $51,325 \pm 45$. The glitch at this epoch changed in frequency and frequency derivative $\Delta\nu/\nu = (1.90 \pm 0.05) \times 10^{-9}$ and $\Delta\dot{\nu}/\dot{\nu} = (8.5 \pm 0.5) \times 10^{-5}$,

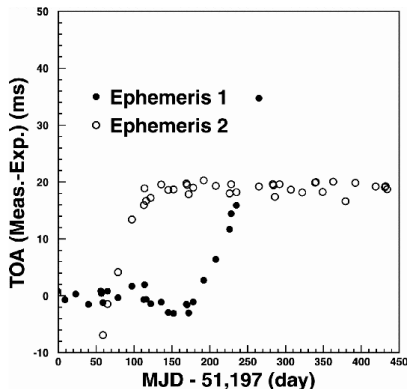


Figure 1. Phase residuals vs. time for PSR 0540-69. The two sets of symbols represent the pulse arrival times computed using two ephemerides, one before and one after the glitch at MJD 51,325 (Zhang et al. 2001).

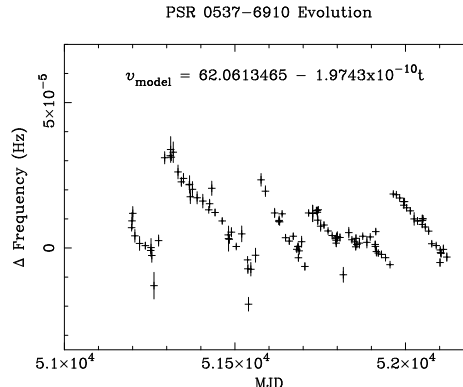


Figure 2. Timing residuals for PSR J0537-6910 based on the monitoring observations presented herein. The data has been fit with the linear ephemeris shown on the plot.

respectively; the magnitude of $\Delta\dot{\nu}$ for this glitch is ~ 3.5 times larger than the one Deeter, Nagase, & Boynton (1999) suggested.

Our timing result for PSR B0540-69 is most consistent with the extrapolated ephemeris of Deeter et al. (1987 to 1991) and agrees to within the uncertainties, while that of Boyd (spanning 1979 to 1993) over-predicts our measured frequencies by tens of micro-hertz. Our braking index of 1.81 ± 0.07 is significantly lower than the values of 2.28 ± 0.02 (Boyd et al. 1995) and 2.0799 ± 0.00027 (Deeter et al. 1999). Eikenberry et al. (1998) found $n = 2.5$ whose errors are dominated by timing noise. However, all previous measurements explicitly assumed that the pulsar had not suffered any glitches during the observation intervals.

Given our new result, and the apparent inconsistent in the reported braking index, it is likely that there may have been many other glitches in the timing history of PSR B0540-69. In particular, when we combine the data points in Table 1 of Boyd et al. (1995) with the frequency measurements of the work presented herein, we obtain a braking index of 2.103 ± 0.005 , significantly lower than 2.28 ± 0.02 . Based on the glitch rates from other Crab-like pulsars, such as PSR J537-6910 (see below) and on Vela (nine glitches in 25 yr; Lyne et al. 1996), it is certainly possible that PSR B0540-69 could have an average glitch rate of one per year. Since our measurements come from phase-linked data sets, they likely provide the most accurate measure of the secular braking index.

2.2. The 16 ms LMC Pulsar PSR 0537-6910

Following a similar analysis as described above, for PSR J0537-6910 we find six large glitches occurred during the first 900 days of our monitoring campaign. The intervals between glitches ranged between ~ 80 to ~ 300 days. The relative increases of the pulse frequency ranged from $\sim 0.14 \times 10^{-6}$ to $\sim 0.68 \times 10^{-6}$, and relative amplitude ranged from $0.15 - 0.68 \times 10^{-6}$ in frequency. Glitches

with amplitudes as small as 0.01×10^{-6} could have easily been detected. Their absence suggests that small glitches are relatively rare in PSR J0537-6910.

With the exception of the Jan 2000 observations, we are able to maintain the cycle-count of the pulse period for all data between the glitches. The long term spindown of the pulsar continues to average -1.9743×10^{-10} Hz/s, i.e., the same value previously reported. With continued monitoring we should be able to determine the braking index, n for PSR J0537-6910; this may allow us to distinguish between possible physical mechanisms contributing to the spindown.

Although PSR J0537-6910 is the oldest and most rapidly rotating Crab-like pulsar, the observed rate of glitching appears to be the highest of all known Crab-like systems. The frequency and size of the glitches are comparable to the extreme values for any pulsar. The pulsars exhibiting the largest known rates of glitches are PSR J1740-3015, for which nine glitches have been observed in 8 years (Shemar & Lyne 1996), and PSR J1341-6220, for which 12 glitches have been seen in 8.2 years (Wang et al. 2000). Most of these glitches were relatively small, however, with typical relative amplitudes of $< 1 \times 10^{-7}$. However, the Vela pulsar has had nine major glitches in 25 years of comparable size as those found for PSR J0537-6910 (Lyne et al. 1996).

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