Glitch Observations in Slow Pulsars

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Abstract. We have analyzed 5.5 years of timing observations of 7 “slowly” rotating radio pulsars, made with the Westerbork Synthesis Radio Telescope. We present improved timing solutions and 30, mostly small new glitches. The most interesting results are: 1) The detection of glitches one to two orders of magnitude smaller than ever seen before in slow radio pulsars. 2) Resolving timing-noise looking structures in the residuals of PSR B1951+32 by using a set of small glitches. 3) The detections of three new glitches in PSR J1814−1744, a high-magnetic field pulsar.

In these proceedings we present the most interesting results of our study. For a full coverage, we refer the reader to Janssen & Stappers (2006).

1. Glitches: The basics

Glitches are characterized by a sudden increase of the pulsar rotation frequency (ν), accompanied by a change in spindown rate (˙ν) and sometimes followed by relaxation or exponential decay to the previous rotation state. Typical magnitudes of glitches are from 10−10ν to 10−6ν and steps in slowdown rate are on the order of 10−3ν. Glitches give an unique opportunity to study the internal structure of neutron stars, as they are believed to be caused by sudden and irregular transfer of angular momentum from the superfluid inner parts of the star to the more slowly rotating crust (Ruderman et al. 1998). They are mostly seen in pulsars with characteristic ages (τc) around 10⁴ − 10⁵ yr and can occur up to yearly in some pulsars. Most of the youngest pulsars, with τc ≲ 2000 yr show very little glitch activity. This could be because they are still too hot which allows the transfer of angular momentum to happen more smoothly (McKenna & Lyne 1990).

We have observed our sample of pulsars since 1999 at the Westerbork Synthesis Radio Telescope (WSRT) with the Pulsar Machine (PuMa; Voûte et al. 2002) at multiple frequencies centered at 328, 382, 840 or 1380 MHz as shown in Table 1.

Fig. 1. Residuals for PSR B0355+54. A miniglitch is visible at MJD 53200.

2. Results: Individual pulsars

2.1. PSR B0355+54

This relatively old pulsar (5.6 × 10⁵ yr) has been studied intensively since its discovery (Manchester et al. 1972). It has low timing noise and the only report of glitches in this pulsar is by Lyne (1987) and Shabanova (1990). The

Table 1. Summary of observed frequencies.

| Pulsar Name | 328 MHz | 382 MHz | 840 MHz | 1380 MHz |
|-------------|---------|---------|---------|----------|
| B0355+54   | *       | *       | *       | *        |
| B0525+21   |         | *       | *       | *        |
| B0740−28   |         |         | *       | *        |
| B1737−30   |         |         |         | *        |
| J1814−1744 |         |         |         | *        |
| B1951+32   |         |         |         | *        |
| B2224+65   |         |         |         | *        |
reported glitches are very different, the first happened at MJD 46079 and was quite small with $\Delta \nu/\nu = 5.6 \times 10^{-9}$. The second, at MJD 46496, is one of the largest glitches known, with $\Delta \nu/\nu = 4.4 \times 10^{-6}$.

We have a well-sampled multi-frequency observing data span of almost 6 years for this pulsar. We improve on previously published (Hobbs et al. 2004; Wang et al. 2001) timing solutions. Although a timing solution for our data span including only position parameters and two frequency derivatives already yields a better root-mean-square (rms) of 67 $\mu$s, we find a better solution (47 $\mu$s) including 4 mini-glitches with frequency steps over an order of magnitude smaller than any glitch found to date in a slowly rotating pulsar: $\Delta \nu/\nu$ of $10^{-10}$ to $10^{-11}$. In Fig. 1 one of the small glitches is shown. The residuals show the typical bend-down signature of a glitch.

### 2.2. PSR J1814−1744

The estimated surface dipole magnetic field strength of PSR J1814−1744 is one of the highest known for radio pulsars, $5.5 \times 10^{13}$ G. This is very close to the magnetic field strengths for anomalous X-ray pulsars (AXPs). The spin parameters are very similar as well. However, no X-ray emission was detected for this pulsar (Pivovaroff et al. 2000). Three glitches have been detected in AXPs so far: two in 1RXS J1708−4009 (Dall’Osso et al. 2003; Kaspi & Gavriil 2003), and one in 1E 2259+586 (Kaspi et al. 2003). The steps in frequency in AXP glitches seem at least an order of magnitude smaller than any glitch found to date in a PSR J1814−1744. The typical glitch signatures are $\Delta \nu/\nu$ of $10^{-9}$ to $10^{-8}$. In Fig. 2 glitch detections in the residuals for PSR J1814−1744. The typical glitch signatures are visible around MJDs 51700, 52120 and 53300.

### 2.3. PSR B1951+32

This low-magnetic field pulsar was discovered in 1987 by Kulkarni et al. (1988), and is associated with the CTB 80 supernova remnant (Strom 1987). A small glitch was detected by Foster et al. (1990) in the beginning of March 1988. Because of the high timing activity of this pulsar, it was quite difficult to find a new timing solution for this pulsar when starting from an epoch just before the start of our data span. Only by shifting the epoch a few hundred days at a time and creating new solutions for each next epoch could we generate the present solution with the epoch in the middle of our data set. We found a solution for our data span of 5.5 years consisting of observations at 840 and 1380 MHz. The solution has a rms of 3.2 ms, which is the best timing solution so far found for this pulsar only including the first two frequency derivatives. The residuals show a large timing activity, see the upper plot of Fig. 3.

The pulsar has shown glitching behaviour before, and the cusp-like structures in the residuals are known to be an indication for glitches (Hobbs 2002). Therefore we tried to resolve the variations with glitches. A solution including four glitches results in a much better rms of 0.4 ms for our data span. The glitches we use are of similar magnitude to the one reported by Foster et al. (1994), and the steps in frequency derivative are also comparable. The residuals are shown in the bottom plot of Fig. 3.

### 3. Discussion

#### 3.1. Glitch sizes

We have measured glitch sizes down to $\Delta \nu/\nu = 10^{-11}$, which provides the first evidence that such small glitches occur and can be measured in slowly rotating pulsars. These glitches are then of a similar size to the one reported by Cognard & Backer (2004) in a millisecond pulsar, and thus perhaps provide further evidence for a continuous distribution of glitch sizes. Let us now consider how these small glitches affect the observed glitch size distribution. In Fig. 4 a histogram is shown for all now known glitch sizes. New glitches found in this study are shown added on top of the old glitch distribution. A Kolmogorov-Smirnov test shows that over the whole range, the distribution has only a probability of 0.001% to be consistent with a flat distribution in log space of glitch sizes. But if we consider only the part of the diagram between $10^{-9} < \Delta \nu/\nu < 10^{-5.5}$, where the statistics are better, another KS test shows that the distribution has a 29.8% chance to be drawn from a flat distribution. The increased number of glitches with sizes around $\Delta \nu/\nu \approx 10^{-9}$, now
Fig. 3. Timing residuals for PSR B1951+32. The upper plot shows the residuals to a model including two frequency derivatives. The bottom plot shows the 10 times better solution including 4 small glitches.

comparable to the amount of larger glitches observed, suggests again that the lack of the smallest glitches at the lower end of the distribution is due to observing limits. The lack of glitches at the upper end of the distribution can not be due to observing limits. Apparently there is some physical restriction to the maximum size of a glitch, and we can consider the boundary of $\Delta \nu / \nu \approx 10^{-5}$ as the natural upper limit of glitch sizes.

3.2. Glitches vs. timing noise

Apart from glitches, irregularities in the rotation of the pulsar are usually described as timing noise. Like glitches, timing noise is also seen mostly in the younger pulsars with high spin frequency derivatives.

Fig. 4. Histogram of all known glitch sizes, from the ATNF glitch table (Manchester et al. 2005) and Urama & Okeke (1999). New glitches found in this study are added on top of the known glitches.

To make a better distinction, if possible, between timing noise and glitches, more modelling is needed, both on the expected glitch size distributions, as well as on the exact influence on timing parameters of small glitches and recoveries from large glitches. We have seen that for frequently glitching pulsars, it can be difficult to resolve glitches that occur close together in time. This effect is probably more important for small glitches, as they appear to occur more often and thus are more likely to merge together. There are many manifestations of timing noise and some have a form which clearly cannot be explained as being due to glitches. However, our discovery of small glitches and the way in which we were able to improve a "timing-noise-like" set of residuals for PSR B1951+32 by including glitches in the solution indicates that they may play a role, and that improved sensitivity and more frequent observations may be required to find more such instances.

References

Janssen, G. H. & Stappers, B. W. 2006, A&A (astro-ph/0607260)
Camilo, F., Kaspi, V. M., Lyne, A. G., et al. 2000, ApJ, 541, 367
Cognard, I. & Backer, D. C. 2004, ApJ, 612, L125
Dall’Osso, S., Israel, G. L., Stella, L., Possenti, A., & Perozzi, E. 2003, ApJ, 599, 485
Foster, R. S., Backer, D. C., & Wolszczan, A. 1990, ApJ, 356, 243
Hobbs, G. 2002, PhD thesis, University of Manchester
Hobbs, G., Lyne, A. G., Kramer, M., Martin, C. E., & Jordan, C. 2004, MNRAS, 353, 1311
Kaspi, V. M. & Gavriil, F. P. 2003, ApJ, 596, L71
Kaspi, V. M., Gavriil, F. P., Woods, P. M., et al. 2003, ApJ, 588, L93
Kulkarni, S. R., Clifton, T. R., Backer, D. C., et al. 1988, Nature, 331, 50
Lyne, A. G. 1987, Nature, 326, 569
Manchester, R. N., Hobbs, G. B., Teoh, A., & Hobbs, M. 2005, AJ, 129, 1993
Manchester, R. N., Taylor, J. H., & Huguenin, G. R. 1972, Nature Phys. Sci., 240, 74
McKenna, J. & Lyne, A. G. 1990, Nature, 343, 349
Ruderman, M., Zhu, T., & Chen, K. 1998, ApJ, 492, 267
Shabanova, T. V. 1990, Sov. Astron., 34, 372
Strom, R. G. 1987, ApJ, 319, L103
Urama, J. O. & Okeke, P. N. 1999, MNRAS, 310, 313
Voûte, J. L. L., Kouwenhoven, M. L. A., van Haren, P. C., et al. 2002, A&A, 385, 733
Wang, N., Manchester, R. N., Zhang, J., et al. 2001, MNRAS, 328, 855