Binary Radio Pulsars
ASP Conference Series, Vol. 328, 2005
F. A. Rasio and I. H. Stairs

GBT Observations of Very Low-Mass Binary Millisecond Pulsars: A Search for Eclipses

David J. Nice

Physics Department, Princeton University, Princeton, NJ 08544, USA

Ingrid H. Stairs

Department of Physics and Astronomy, U. B. C., 6224 Agricultural Road, Vancouver BC, V6T 1Z1, Canada

Zaven Arzoumanian

USRA, LHEA, NASA-GSFC, Greenbelt, MD 20771, USA

Abstract. We present a search for eclipses of two millisecond pulsars, PSR J1807−2459 and PSR B1908+00. These pulsars are in very low-mass binary systems with orbital parameters similar to those of eclipsing binaries. Observations were made with the GBT at frequencies as low as 575 MHz. No eclipses were detected in either system. Observations of well-established eclipsing binary J2051−0827 found eclipses to be substantially weaker than previously seen, with the pulsar detected throughout the eclipse region at 575 MHz and with an electron column density an order of magnitude smaller than previously measured.

1. Introduction

Very low-mass eclipsing binary millisecond pulsars occupy a unique niche in pulsar parameter space, between accreting X-ray binaries and isolated neutron stars. In these systems, mass loss in the secondary is driven either by Roche Lobe overflow or by winds induced by heating of the secondary by pulsar irradiation. The resulting mass flow eclipses the pulsar signal at inferior conjunction.

At this conference, the results of two observational studies related to eclipsing binary pulsars were given. First, multifrequency observations of orbital and pulse-phase variability of eclipsing binary pulsars B1744−24A and B1957+20 were presented. This work will be published elsewhere. Second, a search for eclipses in very low-mass pulsar binaries not previously seen to eclipse was described. This paper summarizes the findings of the latter experiment.

2. Motivation

There are more than a dozen known very low-mass eclipsing binary pulsar systems. There are also several pulsar binaries with similar orbital characteristics but in which no eclipses have been detected (see Table 1 of Freire, in this volume). The mass functions of the non-eclipsing systems are moderately smaller than those of the eclipsing systems. The question arises: why do these systems not exhibit eclipses? There are three possibilities:

1. These systems are qualitatively different from eclipsing binaries. Perhaps the pulsar irradiation is insufficient to drive mass loss in the secondaries. (The spin-down luminosities of this project's target pulsars are not known.) Or perhaps the low mass functions indicate low secondary star masses which, for whatever reason, are less prone to mass loss.

2. These systems are similar to eclipsing systems, with secondaries nearly filling their Roche lobes, but mass flow is "turned off" at the present epoch. In this scenario, eclipsing systems can become non-eclipsing systems, and vice versa, perhaps on a timescale of years. Orbital elements of eclipsing systems exhibit small perturbations on timescales of years, but it is hard to see how they would influence the mass flow.

3. These systems are not different than eclipsing systems, but our viewing geometry is not favorable for detecting eclipses. Their orbital inclinations are much less than 90°, i.e., they are not viewed "edge on." This is consistent with the low mass functions of these binaries if there is a relatively narrow range of secondary masses among the low-mass binaries. (See the discussion by Freire, in this volume.)

It is a common property of very low mass eclipsing systems that the eclipse characteristics depend on frequency. For example, the eclipse lengths, ΔT, of PSRs B1744−24A and B1957+20 scale inversely with frequency, ν, as $\Delta T \propto \nu^\beta$, where $\beta = -0.63 \pm 0.18$ and -0.41 ± 0.09, respectively (Nice et al. 1990; Fruchter et al. 1990). Since eclipses observed at low frequencies are extended along the orbital plane, it is reasonable to suppose that they are extended off the orbital plane as well, so that, for lines of sight far from the plane (i.e., at low inclination) eclipses might be detectable only at low frequencies.

Observations of eclipsing binary PSR J2051−0827 provide further evidence that eclipses are more dramatic, and hence easier to detect, at low radio frequencies. Past observations of this pulsar found no change in flux density, and only small dispersion delays, at 1400 MHz at inferior conjunction, while the system was completely eclipsed at 660 MHz (Stappers et al. 1996; but see below).

3. Observations

We made low-frequency observations of very low-mass binary pulsars PSR J1807 −2459 and PSR B1908+00. Their orbital periods are 1.7 and 3.4 hours, respectively, and companion masses are around 0.01 and 0.02 $M_\odot$ under conventional assumptions. Previous observations of these systems at 1400 MHz did not show eclipses (D'Amico et al. 2001; Deich et al. 1993; Ransom et al. 2001). Observations of eclipsing binary pulsar PSR J2051−0827 were made at some of the same epochs as the other pulsars. While not originally a target of the eclipse-search project, these data are relevant to it (see below).

The pulsars were observed with the 100 m Robert C. Byrd Green Bank Telescope (GBT) at numerous frequencies between 575 MHz and 1660 MHz. The superior gain, frequency agility, and tracking ability of this telescope make it ideal for low-frequency observations of compact binary pulsars. In a typical session, a pulsar would be continuously observed for several hours—often a complete orbit or longer. Data were collected by the Spectral Processor, a Fourier transform spectrometer. Spectra were folded on-line modulo the pulse period over intervals of 0.5 to 5.0 minutes. Off-line, the folded spectral data were de-dispersed, and pulse times of arrival were extracted using conventional techniques.

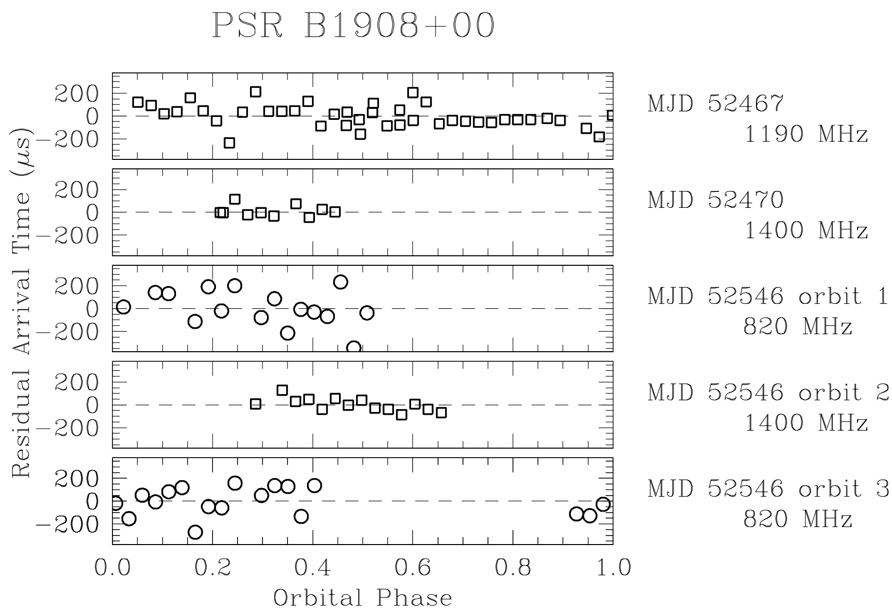

Figure 1. Residual pulse arrival times of PSR B1908+00, measured over five orbits on three separate days. Observing frequencies are indicated in the figure. A partial eclipse would be indicated by arrival time delays, or complete lack of signal, at orbital phase 0.25. All GBT observations of this source are shown in the figure. Gaps and partial coverage of some orbits are the result of telescope scheduling and/or instrumental difficulties.

4. Results

We found no evidence for eclipses of PSR J1807−2459 or PSR B1980+00. Eclipses would have been detected either by absence or systematic reduction in flux around inferior conjunction or, in case of partial eclipses, by systematic delays of the pulsed signal as it passed through the ionized eclipsing medium. Neither of these observational signatures was detected.

The data are shown in Figures 1 and 2. Residual pulse arrival times are shown after subtracting a model for the orbit. The ascending node is at orbital phase $\phi = 0$; eclipses would be at $\phi = 0.25$. Both pulsars are visible at $\phi = 0.25$, at frequencies as low as 575 MHz (J1807−2459) and 820 MHz (B1908+00).

Limits on the electron column density of ionized eclipsing material can be derived from limits on the pulse time of arrival delays, Δt, at $\phi = 0.25$. For J1807−2459, we estimate that $\Delta t \lesssim 20\,\mu$s, at 800 MHz at conjunction, so the maximum excess column density is $\Delta\mathrm{DM} = 0.003\,\mathrm{pc\,cm^{-3}} = 1.0 \times 10^{16}\,\mathrm{cm^{-2}}$. For B1908+00, $\Delta t \lesssim 200\,\mu$s at 820 MHz yields $\Delta\mathrm{DM} = 0.03\,\mathrm{pc\,cm^{-3}} = 1.0 \times 10^{17}\,\mathrm{cm^{-2}}$. These are both smaller than, for example, the past eclipses of J2051−0827, for which $\Delta\mathrm{DM} \approx 3 \times 10^{17}\,\mathrm{cm^{-2}}$ (Stappers et al. 1996, 2001).

But PSR J2051−0827 presents a puzzle. Its eclipses are known to be variable, but it has always shown complete eclipses at low frequency at some point near conjunction

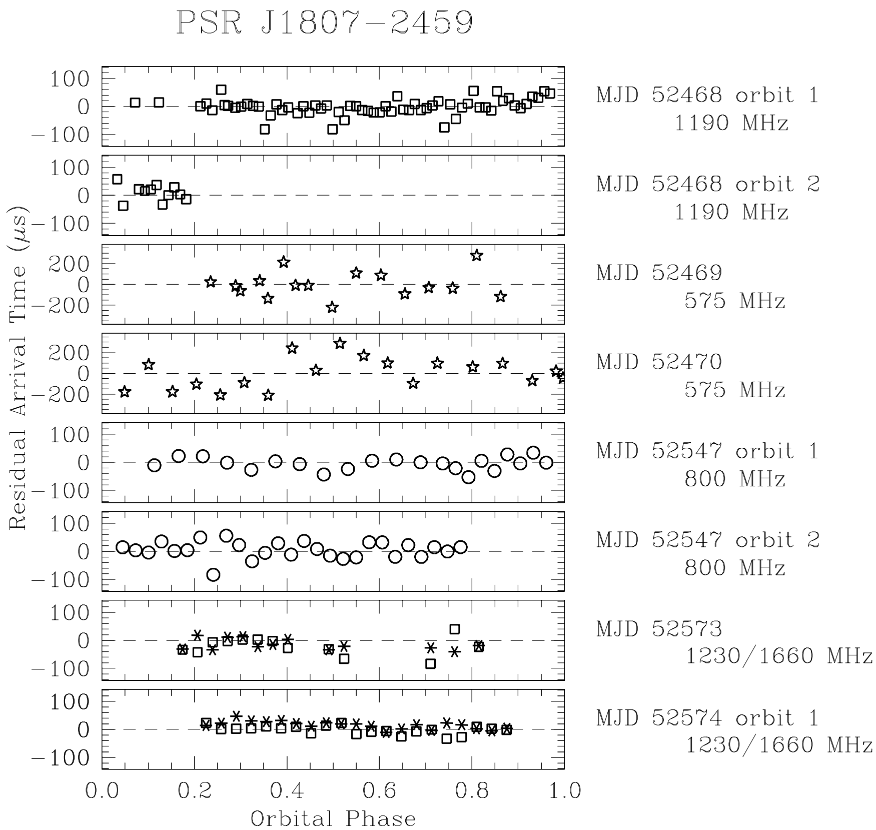

Figure 2. Residual pulse arrival times of PSR J1807−2459 measured over eight orbits on six separate days. Observing frequencies are indicated in the figure; simultaneous dual-frequency observations on MJDs 52573 and 52574 are indicated by squares (1230 MHz) and asterisks (1660 MHz).

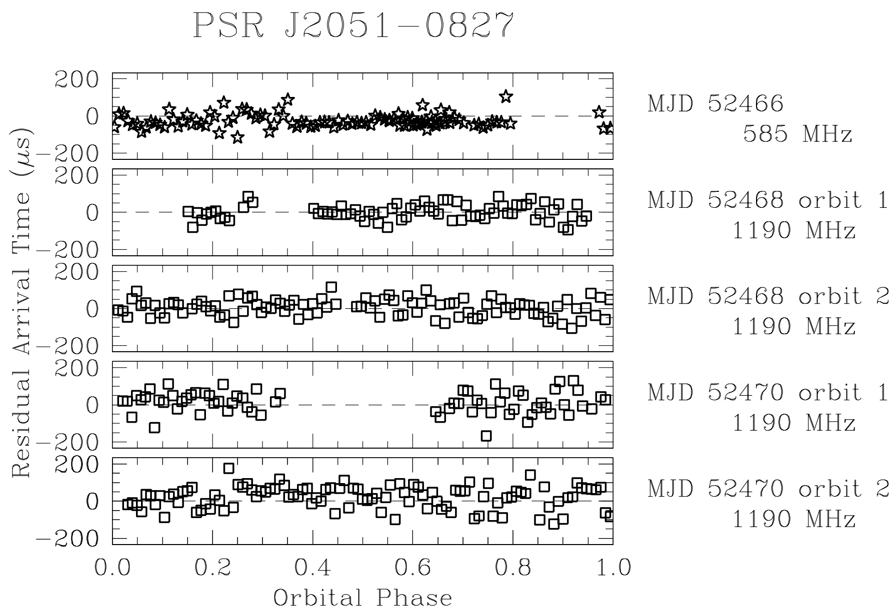

Figure 3. Residual pulse arrival times of PSR J2051−0827, measured over five orbits on three separate days. Observing frequencies are indicated in the figure. Gaps in data indicate breaks in data collection; they are *not* indicative of eclipses.

(Stappers et al. 2001). Observations of this pulsar with the GBT are shown in Figures 3 and 4. Surprisingly, it is visible throughout the eclipse region, albeit attenuated as much as 80−90%. Further, the maximum time delay at conjunction is no more than $\Delta t \sim 50\,\mu$s at 585 MHz, which gives a column density of $\Delta \mathrm{DM} \sim 1\times10^{16}\,\mathrm{cm}^{-2}$, an order of magnitude less than earlier measurements. Clearly the eclipses are much weaker than previously observed.

5. Conclusion

Neither of the target pulsars exhibited eclipses. The question of whether the lack of eclipses is intrinsic to the binaries or whether it is a geometric effect remains open. The surprisingly weak eclipses in binary J2051−0827, with at least an order of magnitude less ionized material around the secondary than seen in previous observations, adds to the mystery. While there is no evidence that these systems completely "turn off" (as in scenario 2 above), it is clear that the eclipse depths can vary greatly.

Acknowledgments. We thank Scott Ransom for discussing previous observations of some target pulsars. This work was supported by NSF grant 0206205 and by an NSERC UFA and Discovery Grant. The GBT/NRAO is a facility of the NSF, operated by Associated Universities, Inc.

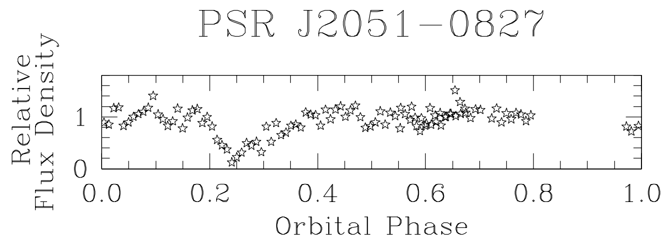

Figure 4. Relative flux density of PSR J2051−0827 over the course of the 585 MHz observations on MJD 52466. In mid-eclipse, the flux density dipped as low as 10−20% of its mean value, but it never went to zero (i.e., the pulsar was always visible.)

References

D'Amico, N., Lyne, A. G., Manchester, R. N., Possenti, A., and Camilo, F. 2001, ApJ, 548, L171

Deich, W. T. S., Middleditch, J., Anderson, S. B., Kulkarni, S. R., Prince, T. A., and Wolszczan, A. 1993, ApJ, 410, L95

Fruchter, A. S., et al. 1990, ApJ, 351, 642

Nice, D. J., Thorsett, S. E., Taylor, J. H., and Fruchter, A. S. 1990, ApJ, 361, L61

Ransom, S. M., et al. 2001, ApJ, 546, L25

Stappers, B. W., et al. 1996, ApJ, 465, L119

Stappers, B. W., et al. 2001, MNRAS, 321, 576