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Observations of a new eclipsing binary millisecond pulsar

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Abstract. We report on the discovery and timing observations of the new eclipsing binary millisecond pulsar J2051–0827. This 4.5ms pulsar is in a 2.4 hour binary orbit with a 0.027 $M_\odot$ companion. The companion and the pulsar are separated by only 1 $R_\odot$. The pulsar is often, but not always, eclipsed for approximately 10% of the orbit at frequencies below 660 MHz. This indicates that the eclipse material extends well beyond the Roche lobe. During a number of observations pulses have been detected throughout the eclipse region at 1.4 GHz and 2.0 GHz. The delays measured with respect to the timing model associated with these observations indicate significant structure and variability in the electron column density in the eclipse region.

1. Introduction

The discovery of the first eclipsing binary millisecond pulsar (Fruchter, Stinebring, & Taylor 1988) seemed to suggest that isolated millisecond pulsars could be the descendents of binary systems where the strength of the pulsar radiation was able to evaporate the companion (Alpar et al. 1982; Rasio, Shapiro, & Teukolsky 1989; Bhattacharya & van den Heuvel 1991). However subsequent observations of the pulse times of arrival at the eclipse boundaries (Fruchter et al. 1990; Ryba & Taylor 1991) and continuum observations (Fruchter & Goss 1992) suggest that sufficient mass loss to evaporate the companion can only occur if the companion almost fills its Roche lobe. As well as being an important evolutionary link, the eclipsing binary pulsars provide a unique opportunity to study the relativistic winds of pulsars as they interact with the extended atmosphere of the companion.

We have discovered a new eclipsing binary millisecond pulsar and have carried out timing observations at a number of frequencies. These observations show that there is structure in the material in the eclipse region and that structure is variable. For more details see the paper by Stappers et al. 1996, of which this is a summary.

2. The timing properties of PSR J2051-0827

The pulsar was discovered during the 436 MHz survey of the entire southern sky carried out at the ATNF's Parkes 64m radio telescope. Timing observations have been made regularly since the discovery with the Parkes telescope and the

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76m Lovell radio telescope at Jodrell Bank. Timing parameters for PSR J2051–0827 are shown in Table 1; the errors shown in the parentheses are twice the formal TEMPO errors (Taylor & Weisberg 1989). The very short orbital period of only 2.38 h makes it the second shortest pulsar orbital period known after PSR B1744-24A (Lyne et al. 1990), and the shortest for pulsar binaries outside globular clusters.

The value of the mass function combined with the canonical neutron star mass, $1.4\,M_\odot$, give a minimum companion mass of $0.027\,M_\odot$. The existence of eclipses implies that the inclination is greater than 60 degrees and hence that the companion mass is within a factor of 1.2 of the minimum. This system is also extremely compact with the two components separated by approximately 1 solar radius.

3. Eclipse characteristics

The radius of the Roche lobe, $R_L \sim 0.13 R_\odot$, of the companion is almost constant for inclinations between 60 and 90 degrees. However, the duration of the eclipse at 436 MHz is approximately 10% of the orbital period which implies a radius for the eclipse region surrounding the companion $r_{eclip} \approx 0.3\,R_\odot$. Thus eclipse material must be constantly be being replenished as seen in other eclipsing binary pulsar systems. This mass loss is most easily achieved if the companion is close to filling its Roche lobe.

Parameters for PSR J2051–0827

Right Ascension (J2000)	$20^h51^m07^s.5118(10)$
Declination (J2000)	$-08°27'37''.78(4)$
Epoch of Period (MJD)	49530.0
Period (s)	0.00450864174335(2)
Period Derivative ($\times 10^{-20}$)	1.3(1)
Dispersion Measure (cm^{-3} pc)	20.741(8)
Orbital Period (days)	0.099110266(4)
Orbital Period Derivative, $\lvert\dot{P}_b\rvert$	$< 25 \times 10^{-12}$
Projected Semi-major Axis (lt-s)	0.045086(10)
Eccentricity	$< 3 \times 10^{-4}$
Epoch of Ascending Node (MJD)	49642.173031(4)
R.M.S. timing residual (μs)	31
Spectral Index	–1.2
Mass function ($M_\odot$)	1.0010×10^{-5}
Minimum Companion mass ($M_\odot$)	0.027

The change in the electron column density (or DM) in the path of the pulsar obtained from the excessive delays relative to the timing model given in Table 1 during observations at 660 MHz and below, indicate that the eclipse mechanism removes photons from the line of sight but does not significantly scatter the pulse. This suggests either absorption or large-angle scattering may

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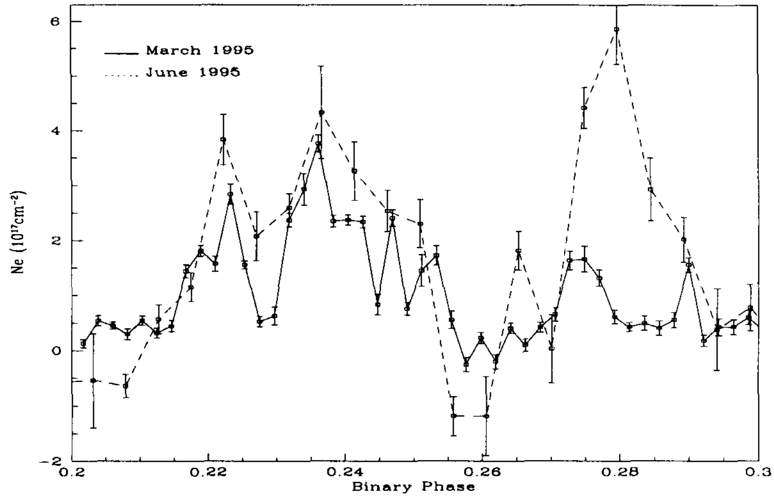

Figure 1. The electron density variation at 2.0 GHz derived from observations made in 1995 March 13 and 1995 June 19, show that the material in the eclipse region contains structure and this structure is variable.

be responsible. During approximately half of the observations made between phases 0.1 and 0.4 at 1.4 GHz the pulsar was detected throughout the low-frequency eclipse region. These detections of the pulsar are again significantly delayed with respect to the timing model and indicate structure in the density of the eclipsing material.

Further observations have been made at 2.0 GHz and during two of these observations shown in Figure 1., the pulsar was bright, allowing us to probe the eclipse region with a significantly improved time resolution of 18 and 40 s. The electron column density implied by the pulse time of arrival delays at these two epochs shows enhancement between phases 0.21 and 0.29 as seen at 1.4 GHz, however the structure is significantly more detailed and different on each occasion. The highly variable nature of the eclipse duration and the electron density structure in the eclipsing region indicate that we are probing a wind zone where there is substantial motion of the eclipse material.

The mass loss rate, as estimated by equating the momentum flux of the wind and the pulsar spin-down, for an assumed mean free electron density in the eclipse region of $10^7\,\mathrm{cm}^3$, is only $\sim 10^{-14}\,M_\odot\,\mathrm{yr}^{-1}$. This is clearly far less than required to completely evaporate the companion on any reasonable timescale.

4. Conclusions

We have discovered a new eclipsing binary millisecond pulsar with a very short orbital period in the galactic disk. The measurement of the pulse time of arrivals at low frequency indicate that the eclipse region is much larger than the Roche lobe and eclipsing material must constantly be being replaced. Observations at frequencies greater than 1 GHz have enabled us to detect the pulsar throughout the eclipse region indicating a complex distribution of electrons. This distribution is also seen to be time variable. Estimates of the mass loss rate due to the impinging pulsar wind suggest that the companion will not be ablated to zero mass on any reasonable timescale.

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References

Alpar, M. A., Cheng, A. F., Ruderman, M. A., & Shaham, J. 1982, Nature, 300, 728.

Bhattacharya, D. & van den Heuvel, E. P. J. 1991, Phys. Rep., 203, 1.

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

Fruchter, A. S. & Goss, W. M. 1992, ApJ, 384, L47.

Fruchter, A. S., Stinebring, D. R., & Taylor, J. H. 1988, Nature, 333, 237.

Lyne, A. G. et al. 1990, Nature, 347, 650.

Ryba, M. F. & Taylor, J. H. 1991, ApJ, 380 557.

Rasio, F. A, Shapiro, S. L., & Teukolsky, S. A. 1989, ApJ, 342, 934.

Stappers, B. W. et al. 1996, ApJ,. In press.

Taylor, J. H. & Weisberg, J. M. 1989, ApJ, 345, 434.

https://doi.org/10.1017/S0252921100042251 Published online by Cambridge University Press