Eclipse Study of the Double Pulsar System

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Abstract

The double pulsar system PSR J0737-3039 offers an unprecedented opportunity for studying neutron star magnetospheres. The system presents a favourable orbital inclination which makes the faster-spinning pulsar, "A", eclipsed when its slower-spinning companion, "B", passes in front. High time resolution light curves at 820 MHz reveal modulation of the pulsed flux intensity of "A" correlated with the spin phase of "B". We report on preliminary results from a detailed study of the eclipses confirming that modulation also exists at other radio frequencies. We found modulation modes linked to the spin frequency and twice the spin frequency of "B". These features and their spectro-temporal dependence should allow us to probe the magnetosphere of "B" in the plane intersecting our line of sight.

Introduction

PSR J0737-3039 is the only pulsar-pulsar system that has been discovered so far. Luckily, this very tight 2.4-hour system is seen almost perfectly edge-on. This makes the 23 ms pulsar called "A" be eclipsed when its 2.8 s companion ("B") passes in front.

The physical size of the eclipse region is about 30000 km. This is much smaller than the light cylinder radius of pulsar "B" which is 130000 km. Such situation is indicative of a strong interaction between the relativistic wind of "A" and the magnetosphere of "B".

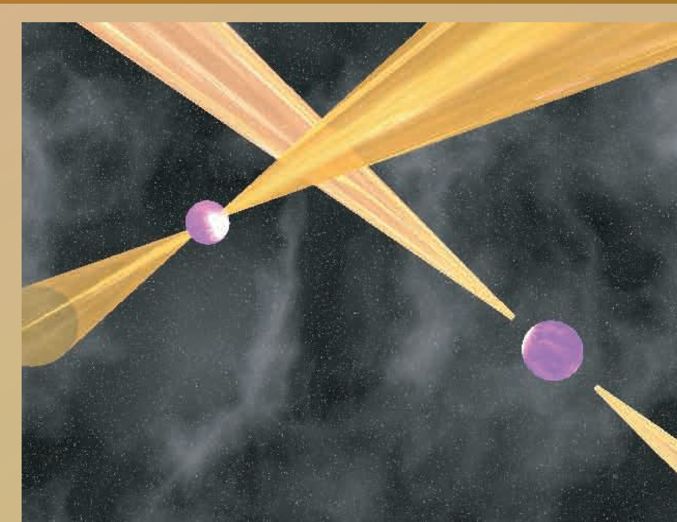

Figure 1. Artist conceptiion of the double pulsar system PSR J0737-3039 (Credit: Michael Kramer, Jodrell Bank Observatory, University of Manchester).

Previous Work

Paper by Kaspi et al. (2004, Ap.J., 613, L137):

- Average eclipse duration of 0.00301 ± 0.00008 orbits.
- Frequency dependence of the eclipse duration. Slope of (-4.52 ± 0.03) x 10^{-7} orbits/MHz (for a linear fit).
- Assymetrical eclipse shape. Ingress ~3.5 times longer than egress.

Paper by McLaughlin et al. (2004, Ap.J., 616, L131):

- At 820 MHz, high time resolution light curves show modulation of the flux during the eclipse.
- Modulations are synchronized with 0.5 and 1.0 times the spin period of "B".
- Eclipse profile dependence on the spin phase of "B". Longer duration when the magnetic axis is parallel to our line of sight.

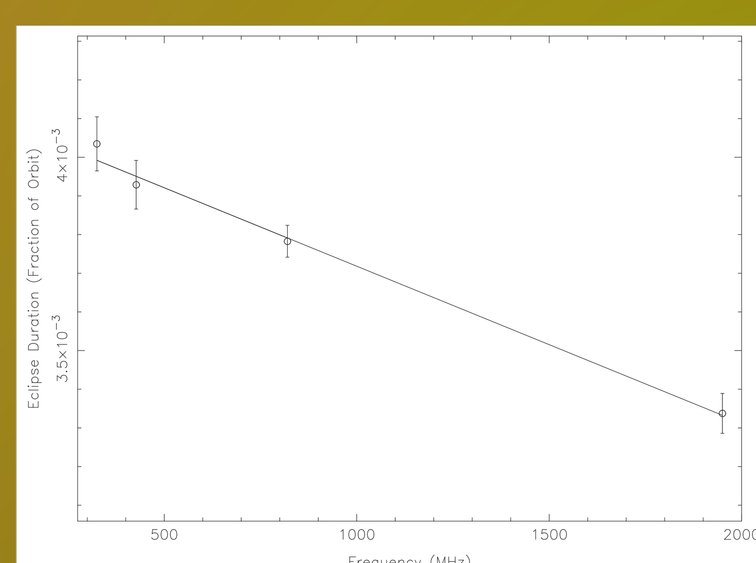

Figure 3. Eclipse duration as a function of radio frequency. The slope of the best fit is (-4.05 ± 0.43) x 10^{-7} orbits/MHz

Observations and Analysis

Data were obtained with the SPIGOT instrument at the Green Bank Telescope at center radio frequencies of 325, 427, 820 and 1950 MHz.

Beside the standard data reduction, the analysis procedure is the following:

- Light curves of the pulsed flux intensity of pulsar "A" are created for all the eclipses.
- Effective time resolution:
  Here: 0.084 s ($3.6xP_B$)
  McLaughlin's: ~0.27 s ($12xP_B$)
  Kaspi's: ~2 s ($\sim 87xP_B$)
- Eclipses can be summed together (at a given epoch and/or frequency) to increase the S/N ratio (see Figure 2):
  Eclipse profiles are shifted up to $\pm 0.5xP_B$ so that the spin phases of "B" are aligned.

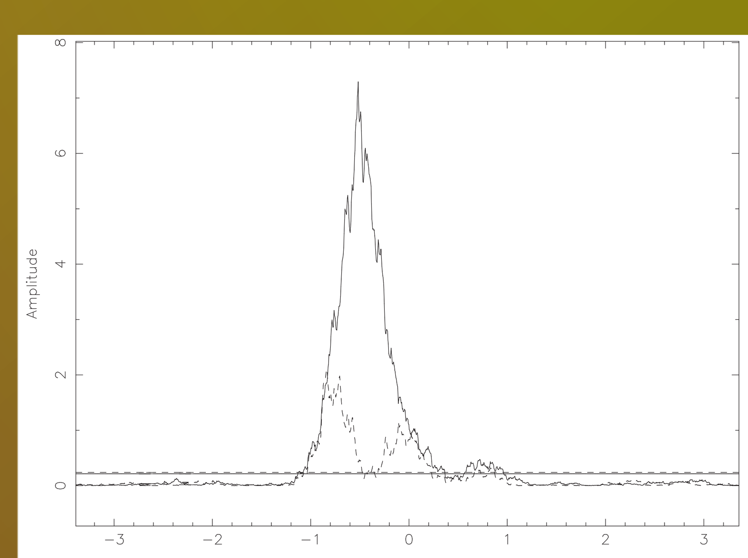

Figure 5. Slices of the dynamic power spectrum shown in Figure 4 centered at the frequency of the ν_B-mode (dashed line) and the $2\nu_B$-mode (plain line). The straight lines are the corresponding 99% confidence levels.

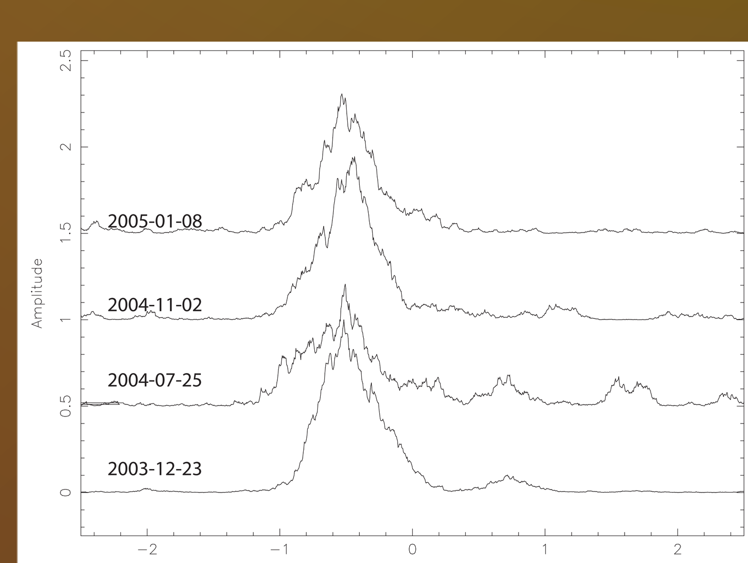

Figure 7. Dynamic power of the $2\nu_B$-mode obtained by averaging all 820 MHz eclipses at a given epoch.

Results: Eclipse Duration

Figure 3 shows the eclipse duration as a function of radio frequency.

- A Fermi function has been fitted for both the ingress and the egress. The duration corresponds to the full width at half maximum.
- Our linear fit is consistent with results reported by Kaspi et al. (2004). (A wider frequency range is covered here and it includes more data.)

Results: Modulation Modes

Dynamic power spectra provide information about the spectral content of the light curves but also their temporal evolution (Figure 4):

- Modulations are exactly related to the fundamental and the first harmonic of pulsar "B" spin frequency.

Figures 5 and 6 show slices corresponding to constant frequency of ν_B and $2\nu_B$.

- Modulations switch from the ν_B-mode to the $2\nu_B$-mode and back to the ν_B-mode.

Results: Mapping the Geometry

Because of geodetic precession, the projected geometry of the system will change. According the theoretical eclipse model of Lyutikov and Thompson (2005, astro-ph/0502333), in which the eclipse is attributed to synchrotron absorption of "A"'s radio emission in the magnetosphere of "B", one should observe a drift of the modulation pattern.

- The ~1 year baseline of our data does not appear to be enough for observing this effect yet (see Figure 7).

The eclipse profile is strongly dependent on the spin phase of "B". Folding light curves at the period of "B" allows us to map out the magnetosphere structure of "B" in the plane intersected by our line of sight (see Figure 8).

- A very narrow window corresponding to "B"'s spin phase 0.25 is almost 100% transparent during the entire eclipse. This effect is independent of radio frequency.

Conclusion

- The eclipse behaviour is radio frequency dependent and "B" spin-phase dependent.
- There is effectively no eclipse at some rotational phases of "B".
- Modulations are characterized by mode switching between frequencies of ν_B and $2\nu_B$.
- No obvious drift in the modulation pattern due to geodetic precession is observed on a 1 year timescale.
- Eclipse profile folding should help testing ecplise models and providing independent estimates of the system's geometry.

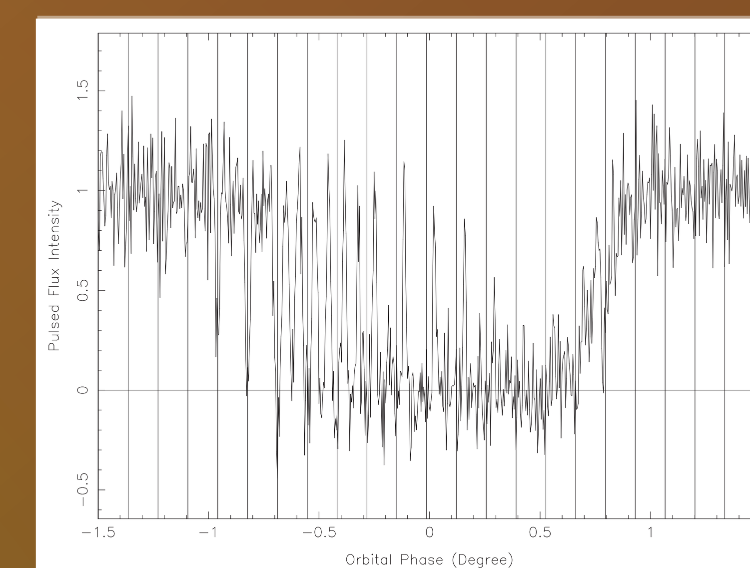

Figure 2. Eclipse light curve of pulsar "A" at 820 MHz. 11 individual eclipses have been added togheter to produce this profile. Vertical lines are the times of arrival of "B" pulses.

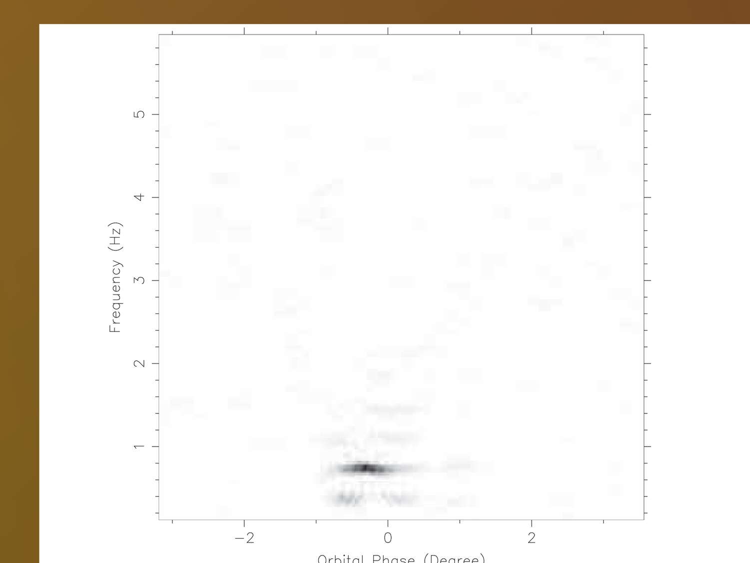

Figure 4. Dynamic power spectrum of the 820 MHz eclipse light curve shown in Figure 2. The two dark horizontal regions are centered at 0.36 Hz and 0.72 Hz, which are ν_B and $2\nu_B$ respectively.

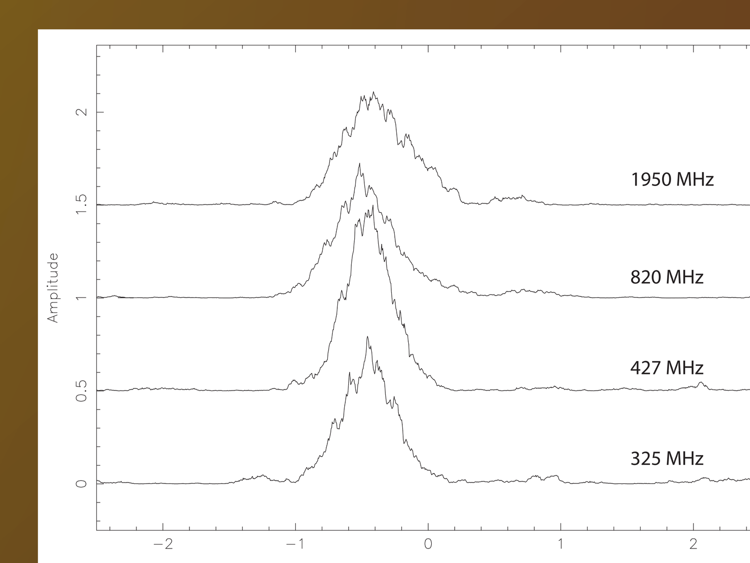

Figure 6. Dynamic power of the $2\nu_B$-mode (as in Figure 5) obtained by averaging all eclipses at a given radio frequency.

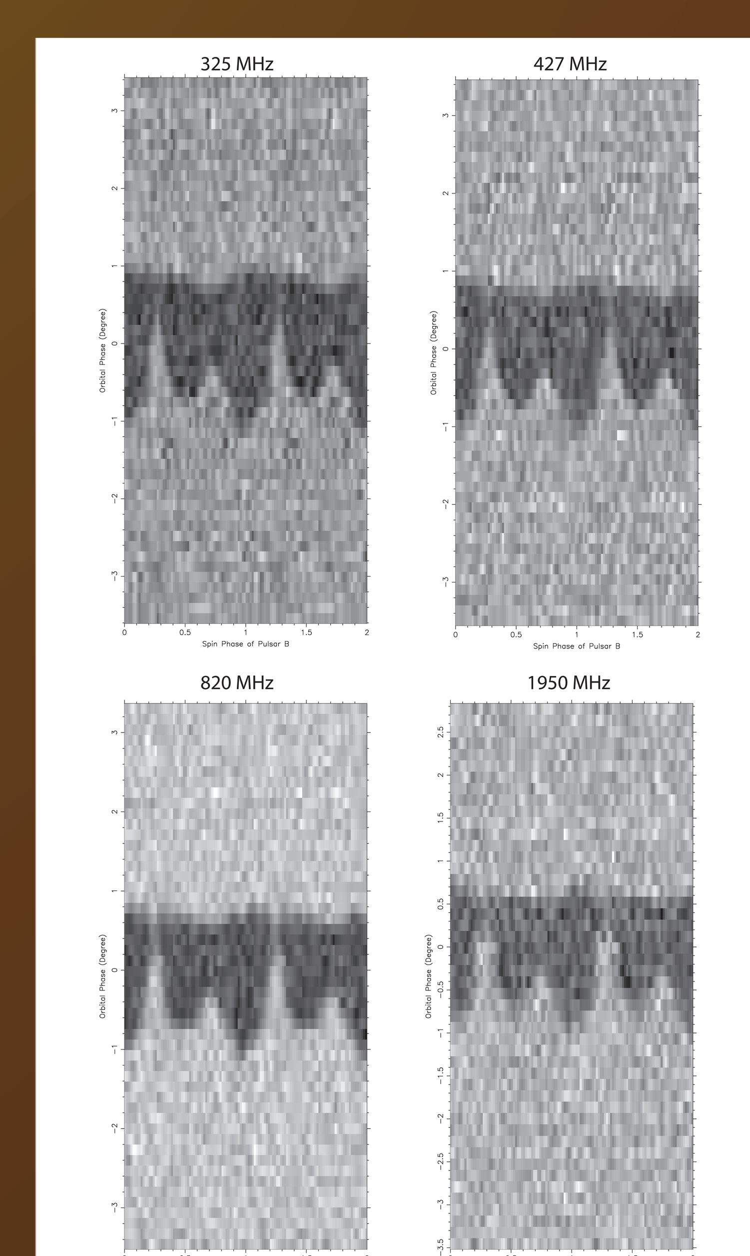

Figure 8. Eclipse light curves of pulsar "A" folded at the spin period of pulsar "B". Each panel is the average of all eclipses at a given frequency.