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The eclipses of the black widow pulsar J1810+1744 at low radio frequencies

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Abstract. Here we present a study of the radio frequency eclipses of the black widow pulsar J1810+1744 at low frequencies, where we are most sensitive to small deviations in the effects of material along the line of sight. Utilising the simultaneous dual beamforming and interferometric (imaging) mode of LOFAR High Band Antenna, pulsar flux variations throughout the orbit are compared for the two observing techniques to test for the presence of scattering and absorption at eclipse orbital phases. Dispersion measure and scattering variations are used as a sensitive probe into outermost edges of the eclipsing material surrounding the companion star. We find the eclipsing medium to be variable on timescales shorter than the 3.6 hr orbital period, and propose cyclotron-synchrotron absorption as the most likely primary eclipse mechanism.

Keywords. (stars:) pulsars: individual (J1810+1744), eclipses, (stars:) binaries: eclipsing, scattering, plasmas

1. Introduction

Black widow (BW) pulsars reside in incredibly tight orbits with low mass companions. The close proximity to the pulsar leads to heavy irradiation of the companion, driving material from its surface. This ablated material is thought to surround the companion, extending well beyond the Roche lobe, and cause eclipsing of the radio frequency pulsar emission through mechanisms which thus far remain a mystery (Thompson *et al.* 1994).

Only a handful of BW eclipses have been analysed at radio frequencies (e.g. Fruchter *et al.* 1990; Stappers *et al.* 2001; Bhattacharyya *et al.* 2013), and even less at frequencies < 300 MHz. Low frequency observations are highly sensitive to deviations in dispersion measure (DM) and scattering (τ), and thus provide an unparalleled probe into the diffuse outer edges of ablated material.

We have observed and analysed the eclipses of PSR J1810+1744, a 1.66 ms BW pulsar in a tight, 3.6 hr orbit with a $\sim 0.045 M_{\odot}$ irradiated companion (Breton *et al.* 2013). Using observations between 2011 − 2015 from the Low Frequency Array (LOFAR) at 149 MHz, with an additional observation at 345 MHz with the Westerbork Synthesis Radio Telescope (WSRT), we detect variations in flux, DM and scattering around eclipse.

2. Results

Fig. 1 shows the detected pulsar flux and deviation in DM as a function of orbital phase for multiple eclipses. There is clear asymmetry in ingress and egress flux, and eclipses are centred after companion inferior conjunction (orbital phase 0.25). The DM shows little increase before eclipse, whereas large and variable ΔDMs are detected in egress. The asymmetric and jagged nature of the DM curves are suggestive of a clumpy, swept-back

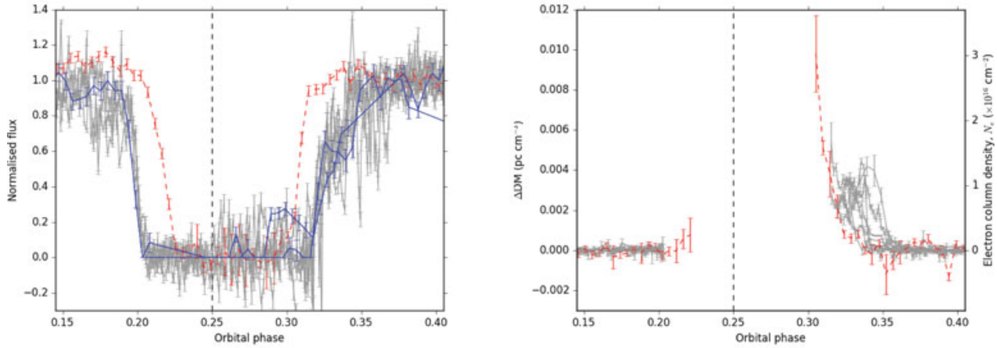

Figure 1. *Left:* Measured pulsar flux, with the out-of-eclipse mean normalised to unity, for two full eclipses, three ingresses and five egresses. *Right:* Dispersion measure, proportional to the electron column density along the line of sight, relative to the out-of-eclipse mean. In both figures, the light grey curves represent beamformed LOFAR data, the red dashed curve represents 345 MHz WSRT data and the dark blue curves represent interferometric (imaged) LOFAR flux. The vertical dashed line at phase 0.25 corresponds to companion inferior conjunction.

tail of material resulting from the orbital motion (c.f. Fruchter *et al.* 1990). Should the material reside at the orbit of the companion, eclipse durations suggest that the medium extends out to many Roche lobe radii of the companion. Splitting the LOFAR and WSRT observations into smaller frequency sub-bands revealed the eclipse duration, $\Delta\phi$, to be well fit by a power-law function of frequency, $\Delta\phi \propto \nu^{-0.41\pm0.03}$; consistent with that seen in PSRs B1957+20 (Fruchter *et al.* 1990) and J2215+5135 (Broderick *et al.* 2016).

Following the analyses in Thompson *et al.* (1994) for PSR B1957+20, the observed eclipse properties have been compared to those expected from theoretical models with differing fundamental mechanisms. The necessity to make strong assumptions for the models mean that the results for a single system are not conclusive. However, disappearance of both total flux in imaging observations and pulsed flux in beamformed observations rule out small-angle scattering and pulse smearing as eclipse mechanisms. The apparent clumpy nature of the medium suggests that refraction of the pulsar radio waves could occur, however the measured frequency dependence of the eclipse duration is not in agreement with this as a primary eclipse mechanism. With the data available, the most promising primary eclipse mechanism is cyclotron-synchrotron absorption in a magnetic field provided by either the pulsar wind or the companion star.

Further studies of this, and other BW systems, at radio frequencies are planned in order to further constrain the eclipse mechanisms and the nature of mass-loss from the companion star.

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