

The eclipses of black widow pulsar J1810+1744

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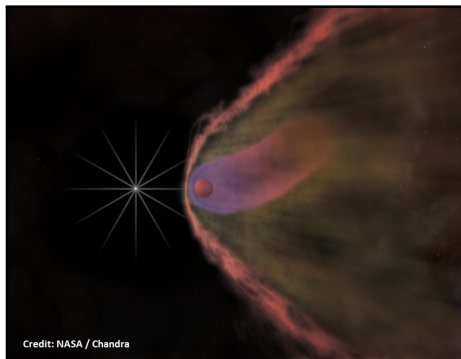
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June 19, 2017



Black widow pulsars

- ~ 30 known systems^a
- Tight orbits
 - ▶ $P_b < 1$ day
 - ▶ Separation \sim few solar radii!
- $M_c = 0.01 - 0.05 M_\odot$
- Strong irradiation of tidally locked companion
 - ▶ Heated & bloated companion
 - ▶ Ablation of material from surface
 - ▶ **Full evaporation of companion?**

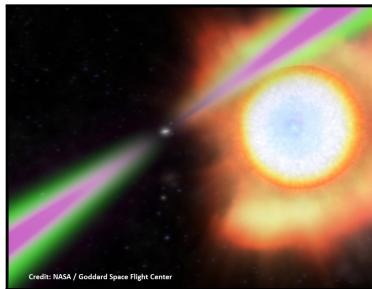


Credit: NASA / Chandra

^a original discovery Fruchter et al., 1988

Eclipses

- Observed in many BWs
- *Pulsed* radio emission diminished or fully eclipsed for some orbital phases
 - ▶ Dependent on observing frequency
- Centred near companion inferior conjunction
 - ▶ Duration implies medium larger than companion Roche lobe
 - ▶ Thus, eclipse medium not gravitationally bound to companion
- **In-depth eclipse analysis for only a handful of black widows**



Why study black widows?

- General
 - ▶ Further understand physical mechanism responsible for eclipses
 - ▶ Infer mass-loss rate from companions
 - ▶ Identify the nature of the irradiated companions
 - ▶ Probe into the pulsar wind
- Why low frequencies?
 - ▶ BW pulsar radio emission usually brighter with decreasing frequency^a
 - ▶ Sensitive to small variations in eclipsing medium
 - ▶ Rarely studied before!

^a Intema et al., 2017; Murphy et al., 2017

J1810+1744

- Pulsar:

P_{orbital} (hours)	P (ms)	DM (pc cm^{-3})	Binary Separation
3.6	1.66	39.66	$1.33 R_{\odot}$ ^a

- Data:

Telescope	Type	Freq	Orbital coverage
LOFAR	Imaging & beamform	110 - 188 MHz	1x full eclipse 4x egress
WSRT	Beamform	310 - 380 MHz	1x full eclipse

^a Breton et al., 2013

Dispersion measure & scattering

- Dispersion measure \propto electron column density along line-of-sight
 - ▶ Probe into density of material near eclipse
 - ▶ Measurable as frequency dependent delays,

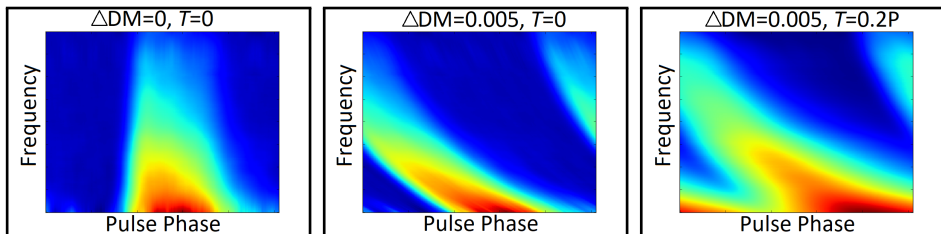
$$\Delta t \propto DM \nu^{-2}$$

- Additional scattering of radio pulse near eclipse
 - ▶ Probe into structure of material and eclipse mechanism
 - ▶ Time delays in pulse well approximated by convolution with exponential function,

$$\text{Pulse} * \frac{1}{\tau} \exp^{-\phi/\tau},$$
$$\tau \propto \nu^{-4}$$

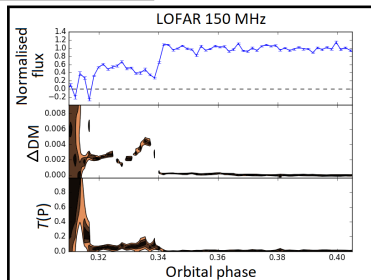
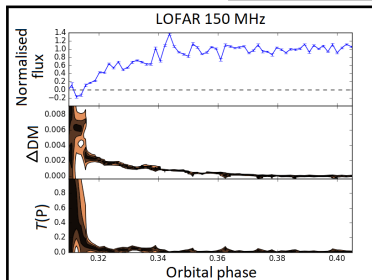
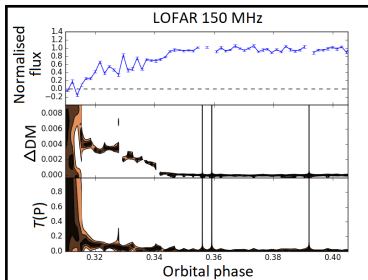
Dispersion measure & scattering

- Created 2-D template (frequency vs pulse phase) from out-of-eclipse observations
- Generated array of templates for a range of DM & τ

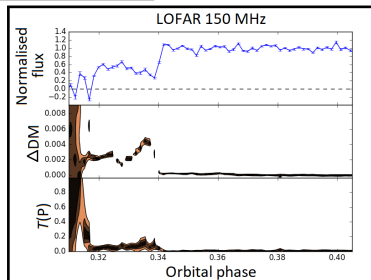
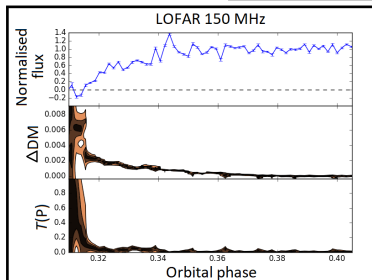
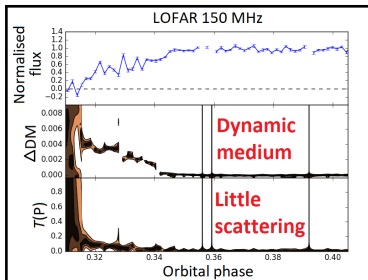


- For each time interval of data, fit template baseline and scale factor

Dispersion measure & scattering



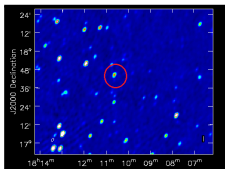
Dispersion measure & scattering



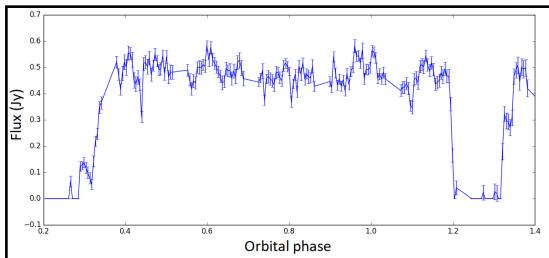
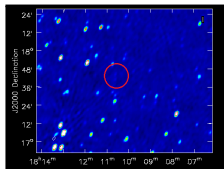
Imaging

- Calibrated using standard LOFAR software and imaged with CASA, using 1 minute time intervals
- Flux extracted with PyBDSF

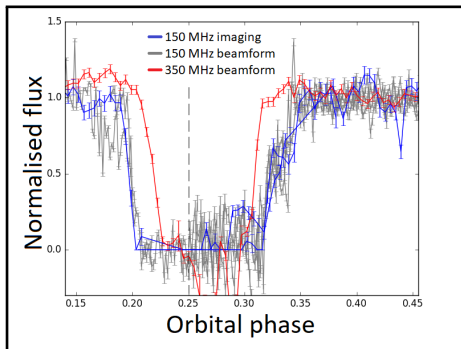
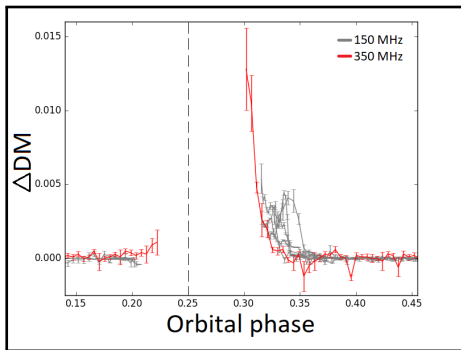
Non-eclipse



Eclipse



Combined results



- Clear asymmetry
- Higher frequency - higher density

- Continuum eclipse = pulsed eclipse
- Duration $\propto \nu^{-0.43 \pm 0.12}$

Summary

- Variable outer edges of eclipse medium
- No steep scattering trends
- Continuum eclipse = pulsed eclipse
 - ▶ Likely absorption mechanism
- Clear frequency dependence
 - ▶ Eclipse duration $\propto \nu^{-0.43 \pm 0.12}$
 - ▶ Consistent with J2215+5135^a & B1957+20^b, with cyclo/synchrotron absorption favoured mechanism^c
- Clear asymmetry of both eclipse and DM
 - ▶ Centred after inferior conjunction of companion
 - ▶ Medium swept back due to orbital motion?^b

^a Broderick et al., 2013

^b Fruchter et al., 1990

^c Thompson et al., 1994; Khechinashvili et al., 2000