Radio Frequency Studies of the Pulsar Binary PSR J1614-2318

Klim Mikhailov

(U. Amsterdam + ASTRON)

K. Mikhailov, M. Roberts, S. Ransom, J. Hessels, J. van Leeuwen, G. Janssen, R. Breton
(in prep.)

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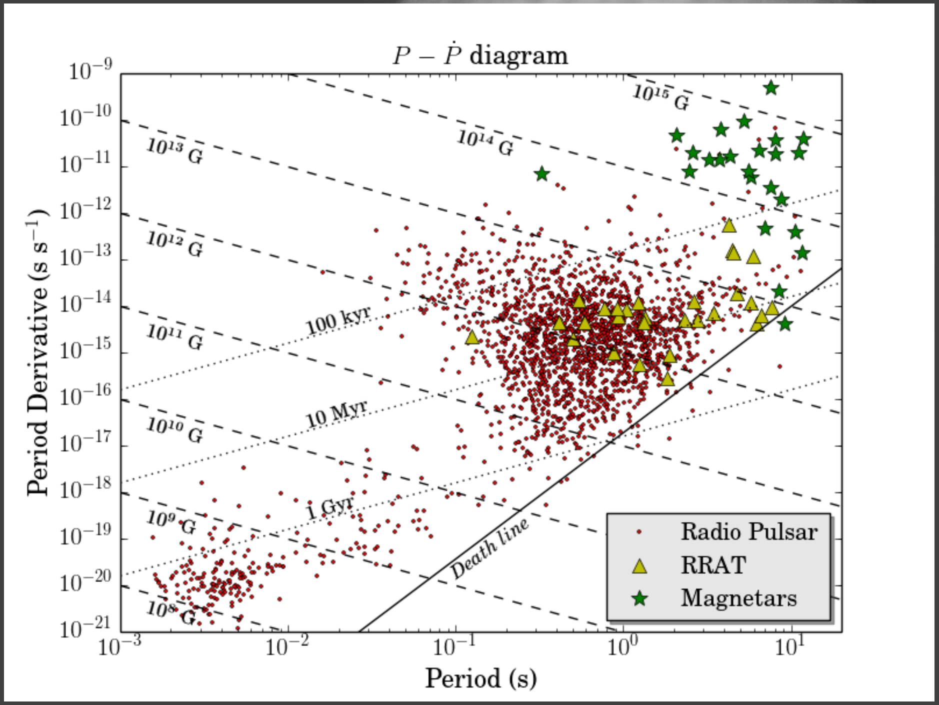
Physics of Neutron Stars, 50 years after – 10-07-17

Introduction

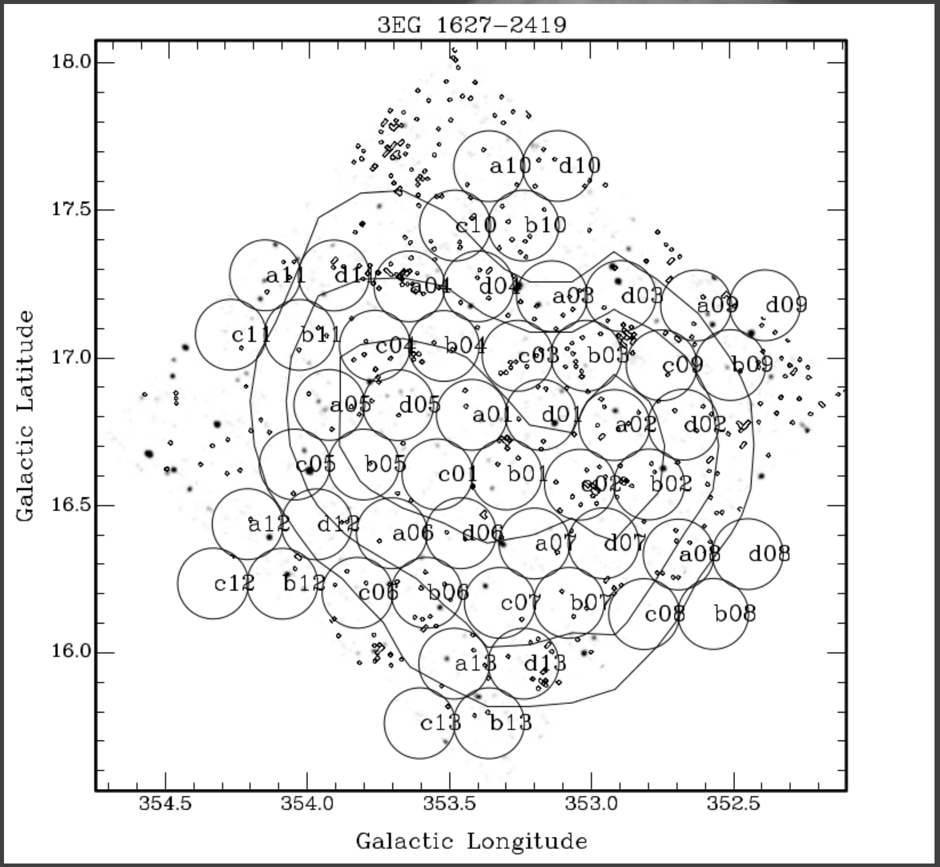
- *Normal pulsars → born in supernovae, spin down*
- *Millisecond pulsars → can spin up, coupled with companions in binary systems*
- *RRATs → sporadic radio emission*
- *Magnetars → magnetic field decay powers radiation*



ATNF Pulsar Catalogue v. 1.56

Introduction

- ***Millisecond pulsars in globular clusters → intense binary interaction***
- ***J1614−2318 discovery: Parkes survey of 56 mid-latitude EGRET error boxes for radio pulsars***
  - *140 sq. degrees of the sky*
  - *5° < |b| < 73°*



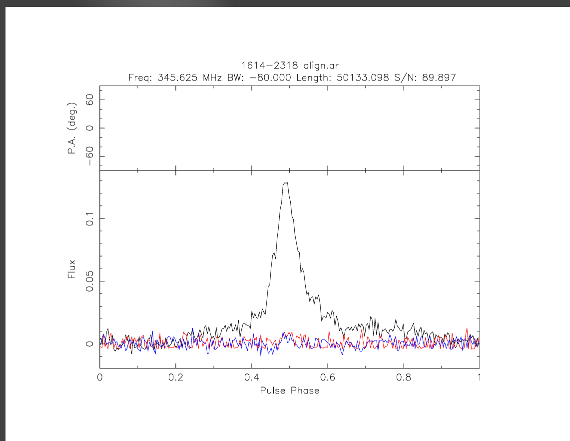
Crawford et al., 2006

Radio Observations and Analysis

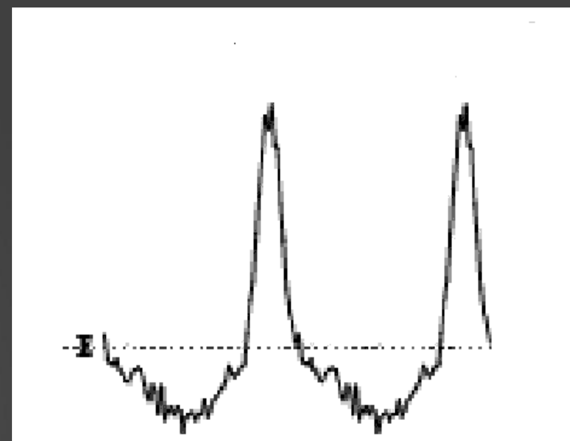
Telescope (Backend)	Central Freq. (MHz)	MJD Range	N_{TOAs}
Parkes (AFB/DFB)	680, 1374, 1390, 1518	52469 – 53104	67
GBT (BCPM)	350, 820, 1400, 1420, 1450, 1850	52734 – 53232	93
GBT (SPIGOT)	350, 820, 1220, 1620, 1820	53119 – 53982	44
GBT (GUPPI)	350, 820	55504 – 56947	16
WSRT (PuMa II)	345, 1380	54154 – 57166	16
LOFAR (COBALT)	150	57403 – 57411	–

- ***Telescopes: Parkes, GBT, WSRT, LOFAR***
- ***Frequency range: 150 MHz – 2 GHz***

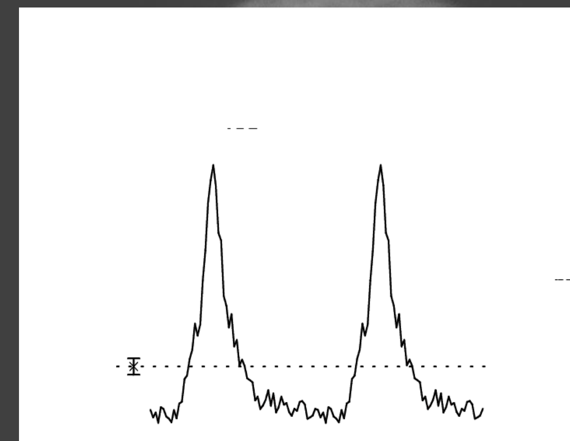
Pulse profiles



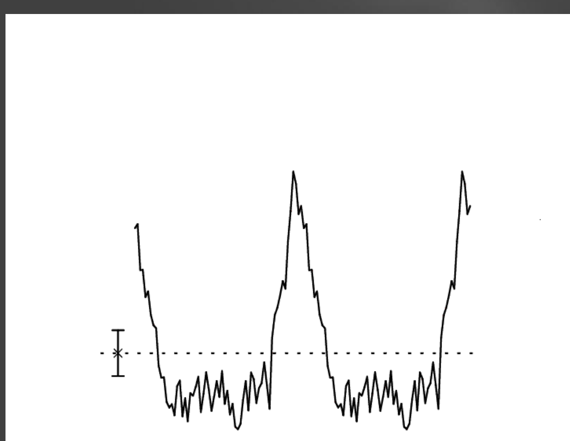
WSRT (345 MHz)



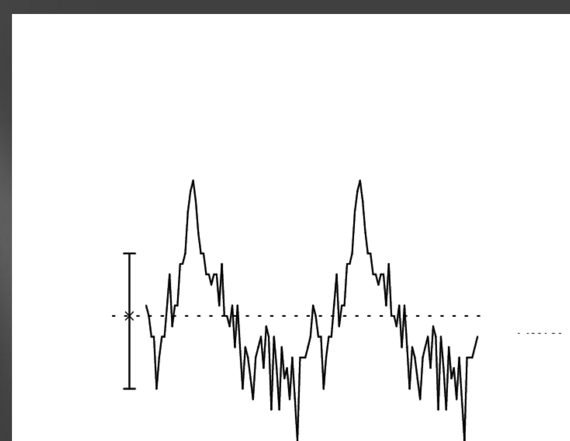
GBT (350 MHz)



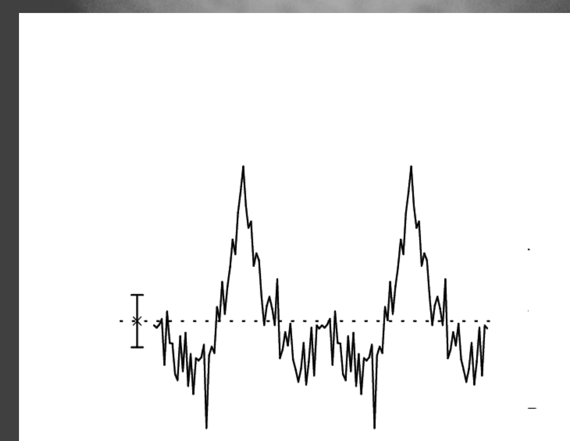
GBT (820 MHz)



Parkes (1.4 GHz)

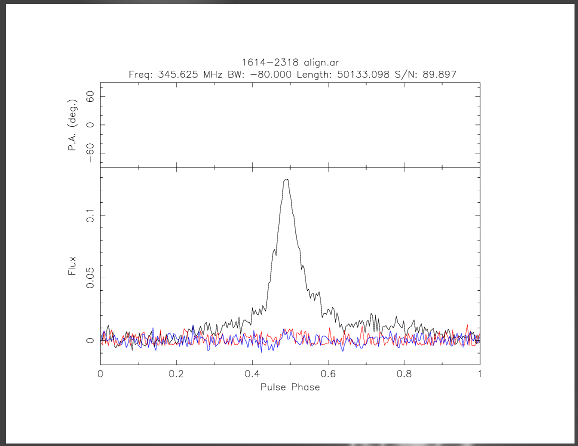


GBT (1.5 GHz)

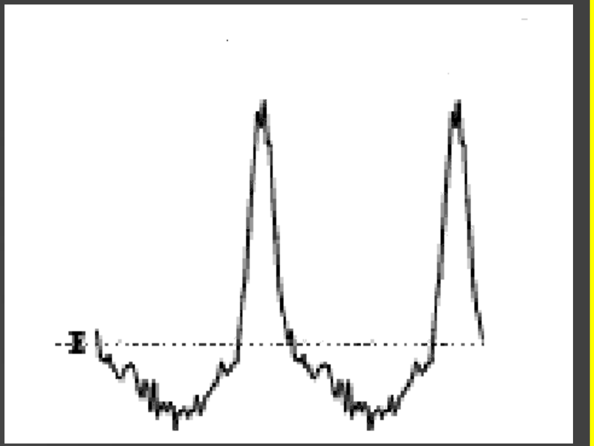


GBT (1.95 GHz)

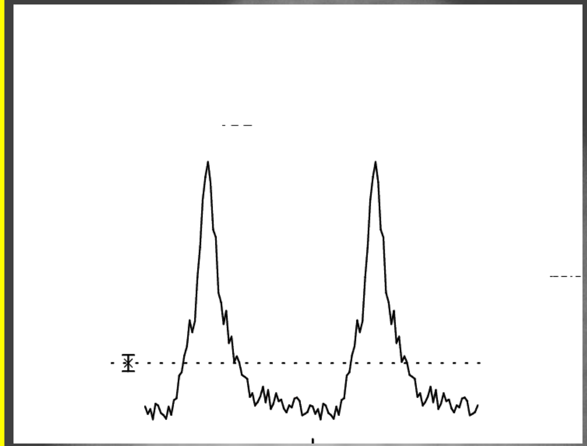
Pulse profiles



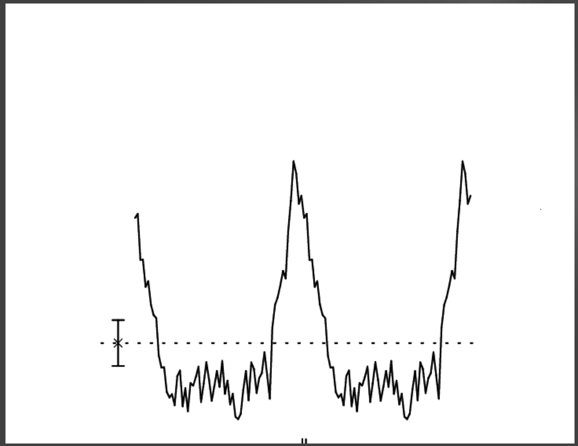
WSRT (345 MHz)



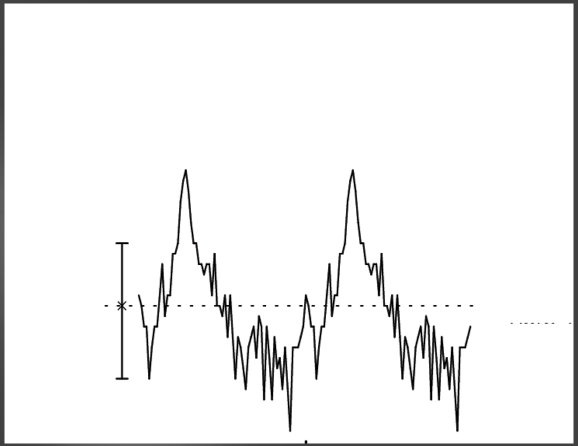
GBT (350 MHz)



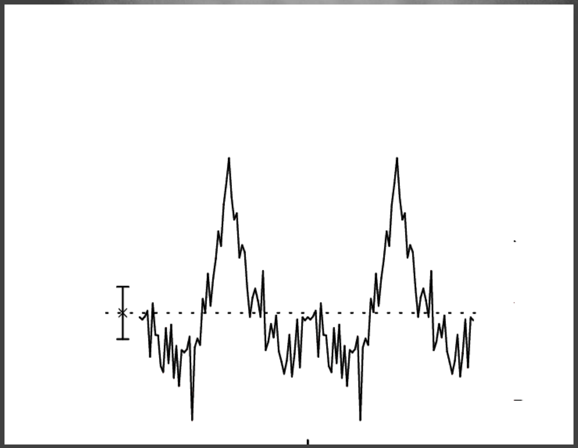
GBT (820 MHz)



Parkes (1.4 GHz)

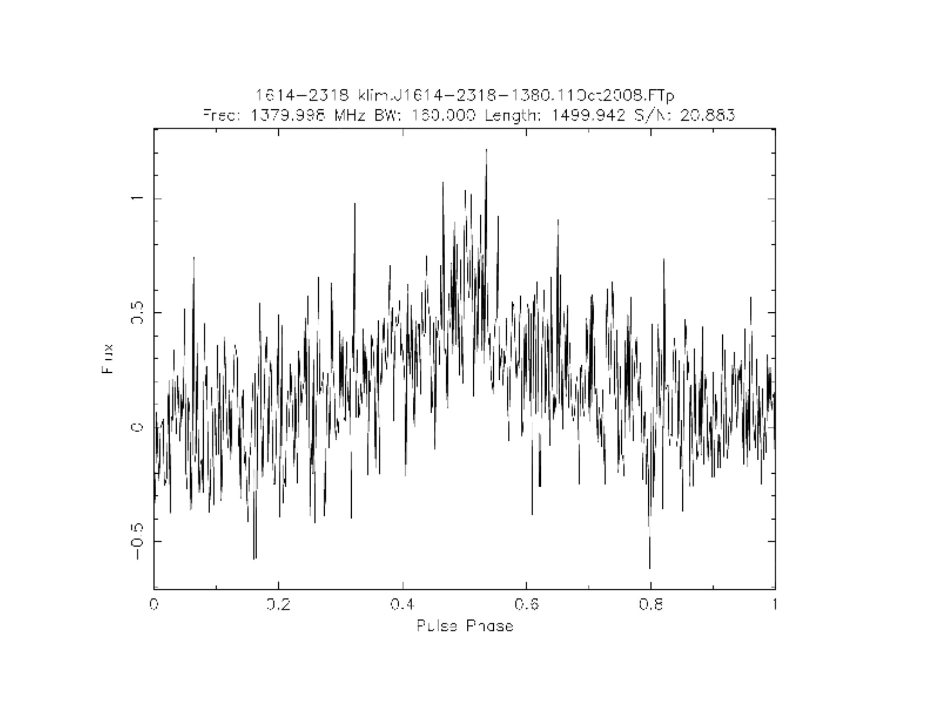


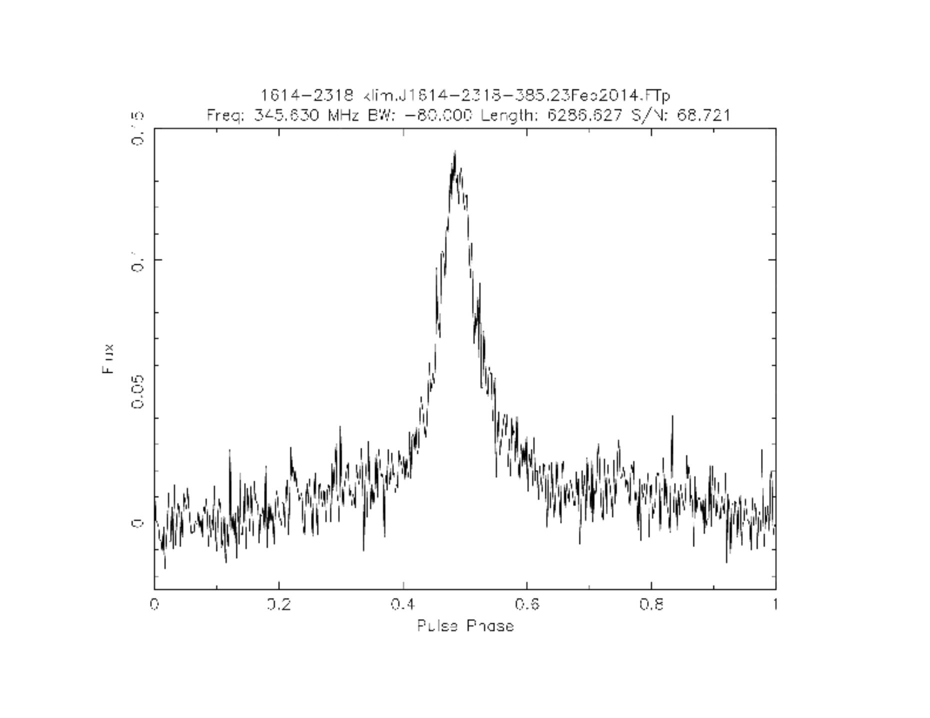
GBT (1.5 GHz)



GBT (1.95 GHz)

WSRT observations





(a) WSRT L-band (1380 MHz)

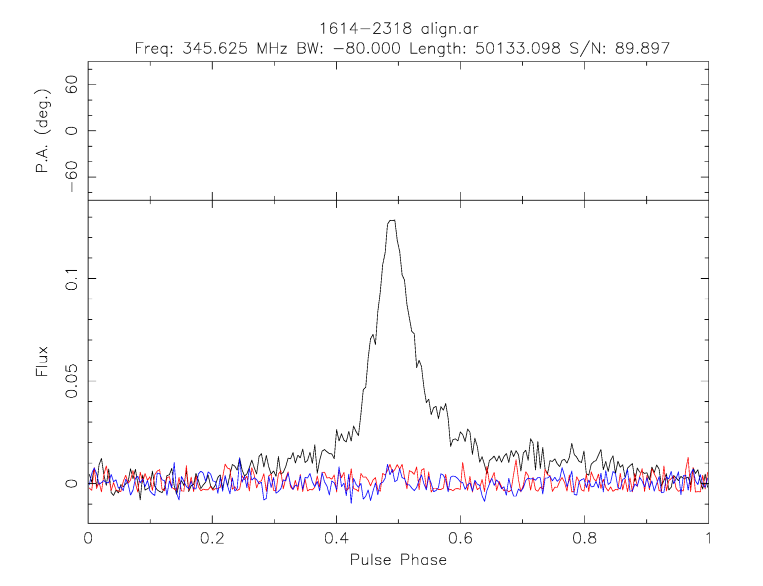
$\Delta\nu$ = 160 MHz, T_{int} = 0.4 h, S/N = 20σ

(b) WSRT B-band (345 MHz)

$\Delta\nu$ = 80 MHz, T_{int} = 1.75 h, S/N = 70σ

Polarization studies

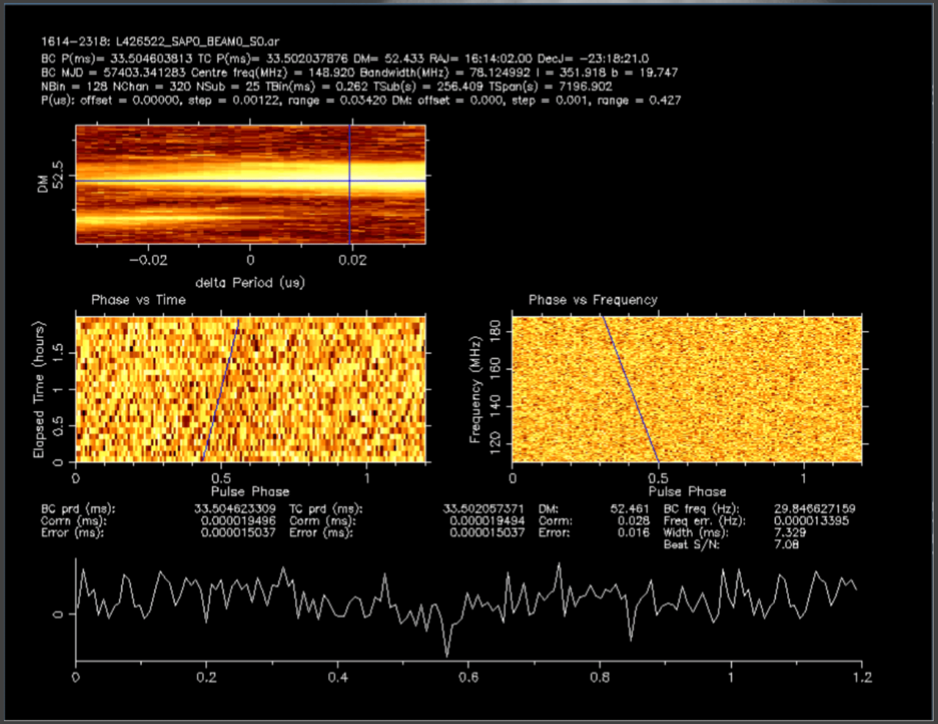
- *Parkes / GBT → no decisive polarization measurements*
- *WSRT → pulsar must be very weakly polarized*



WSRT (345 MHz, 15 h + 90σ S/N)

LOFAR non-detection

- most pulsar fluxes peak at 150 MHz (Stappers et al., 2011)
- 23 LOFAR HBA
  - 3 x 2 h observations
  - $\Delta\nu \sim 80$ MHz
  - $t_{samp} \sim 150$ µsec
  - $S_{min} \sim 0.1$ mJy



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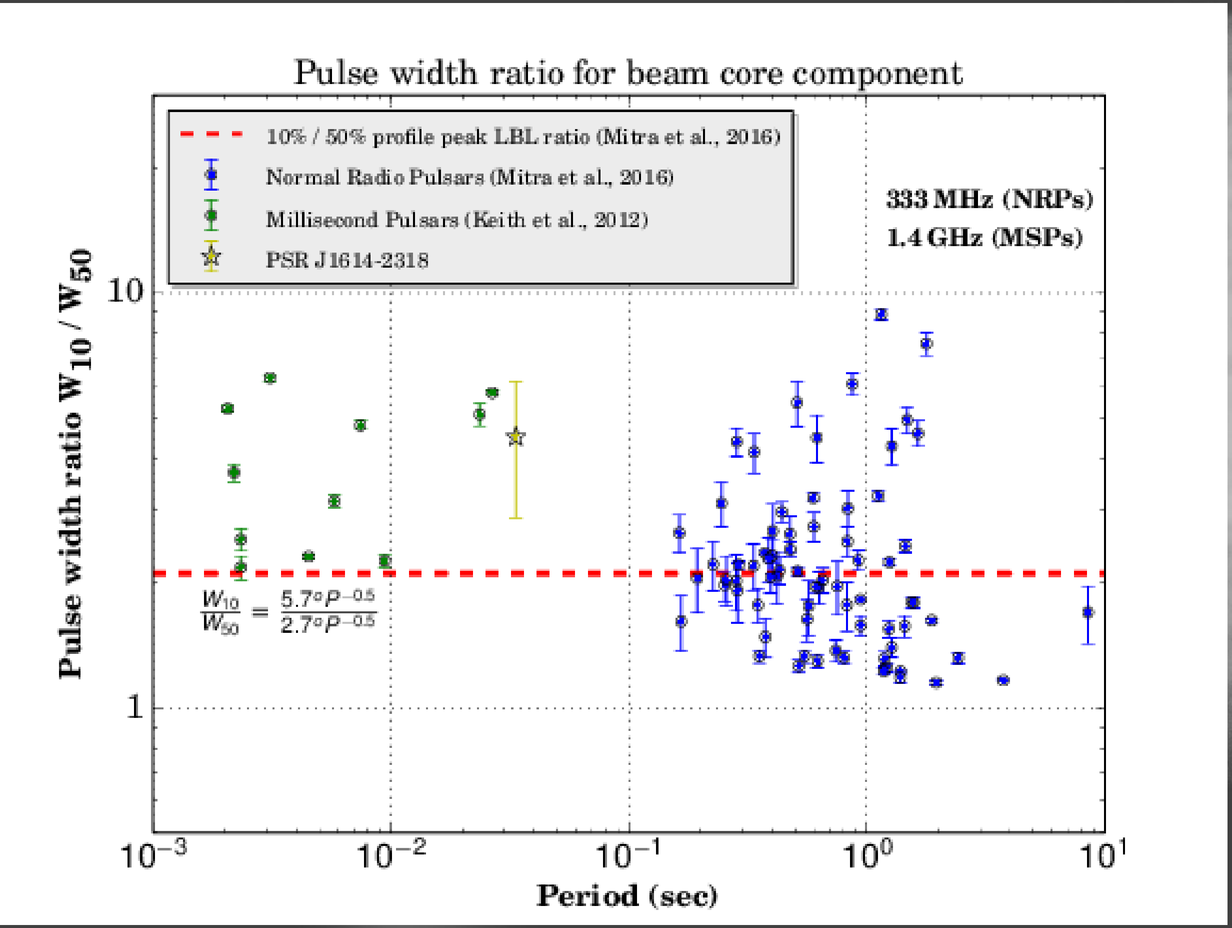
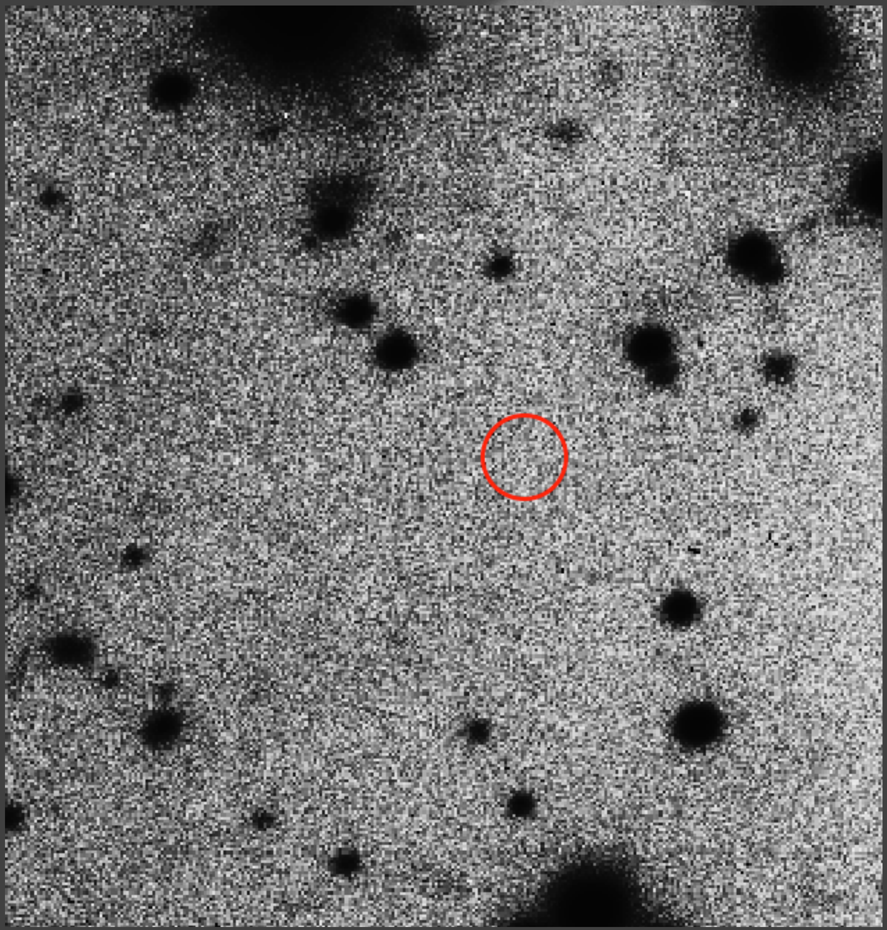
Beam components



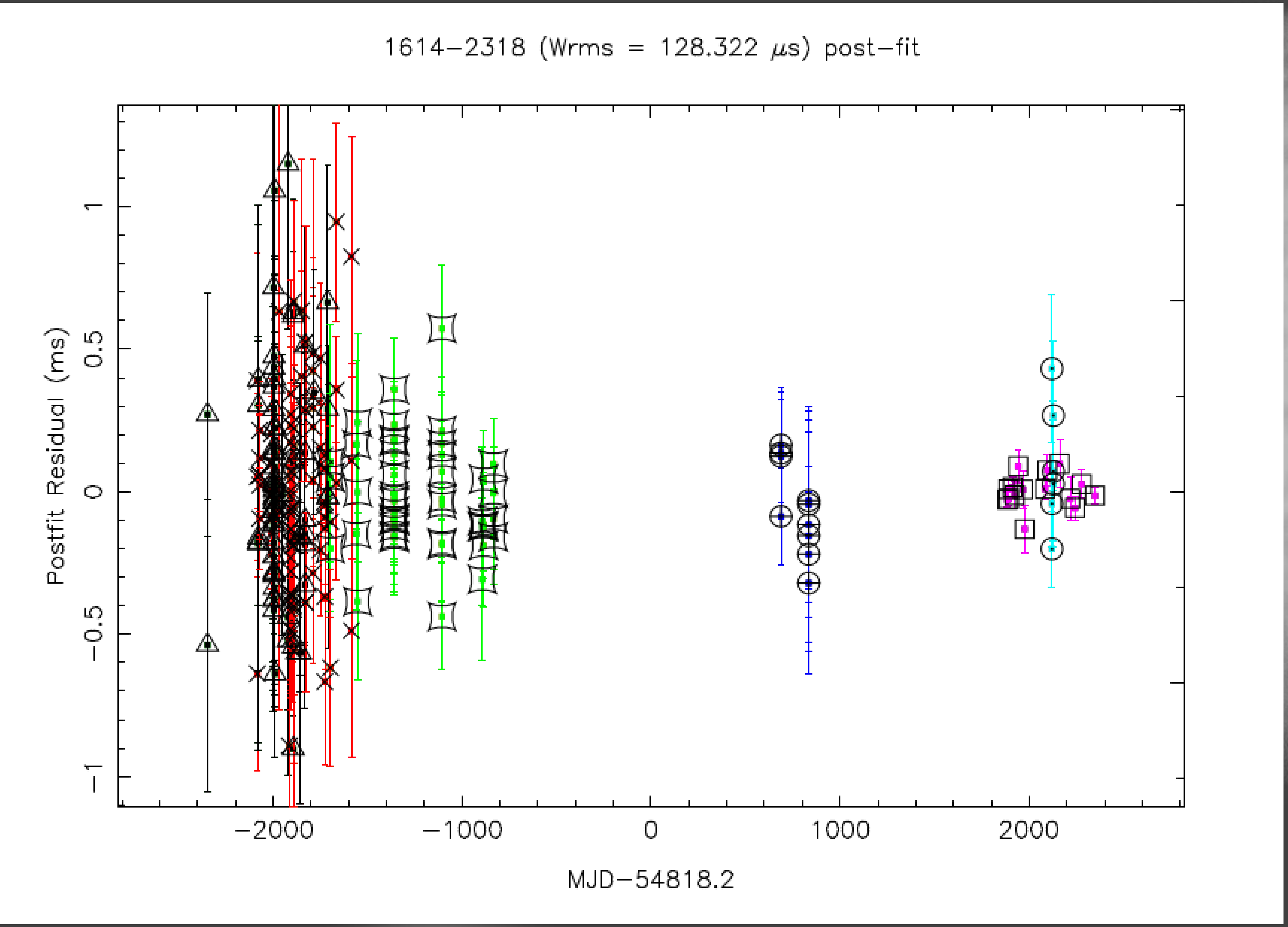
PSR J1614−2318 is consistent with empirical Low Boundary Line (LBL) relation for both core and conal components

Optical follow-up

- SOAR: r' band
  - 15 × 60 s exposures
  - 0.8'' seeing
- No counterpart was seen
  - $m_{r'} > 25$ (5σ)
  - insignificant extinction
  - old, cold He WD



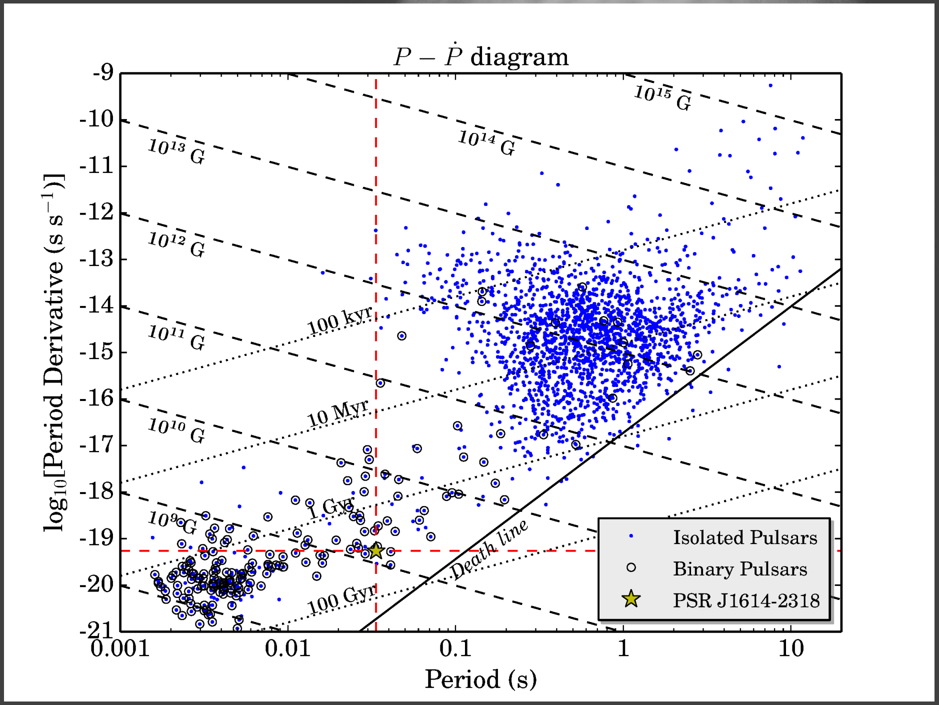
Timing solution



timing parameters are in consistence with the discovery paper (Hessels et al. 2005)

P – Pdot position

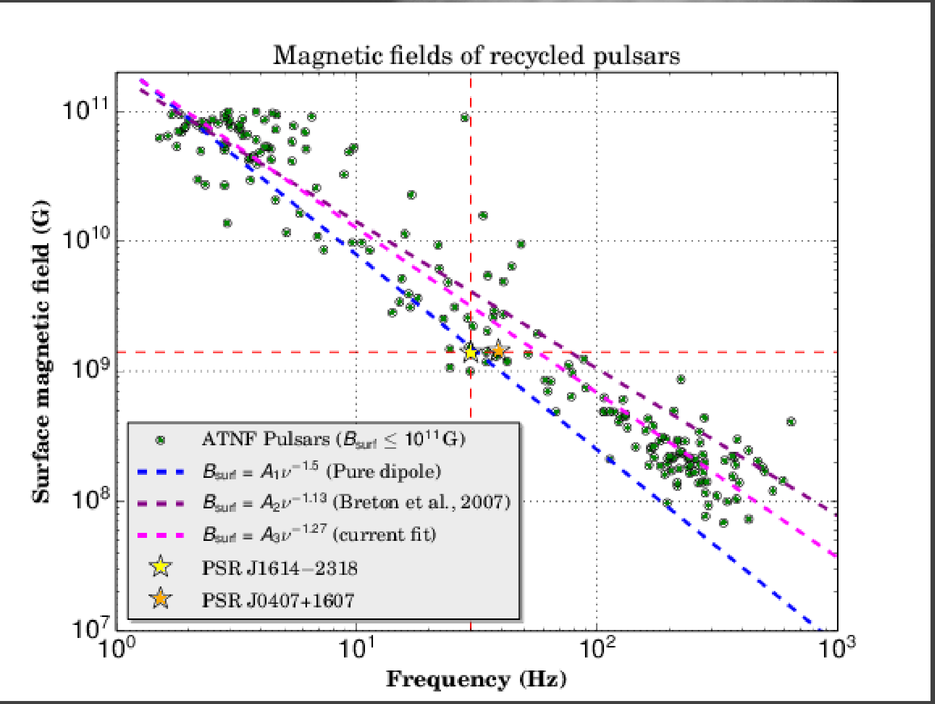
- Spin period: $P_{spin} \approx 33.5$ ms
- Spin-down: Pdot ≈ 5.4×10^{-20} s/s
- Characteristic age: t ≈ 10 Gyr
- Orbital period: $P_{orb} \approx 3.2$ days
- DM ≈ 52.4 pc/cc → d ≈ 1.8 kpcs (NE2001); d ≈ 3 kpcs (YMW16)



Mikhailov et al., 2017

Magnetic field

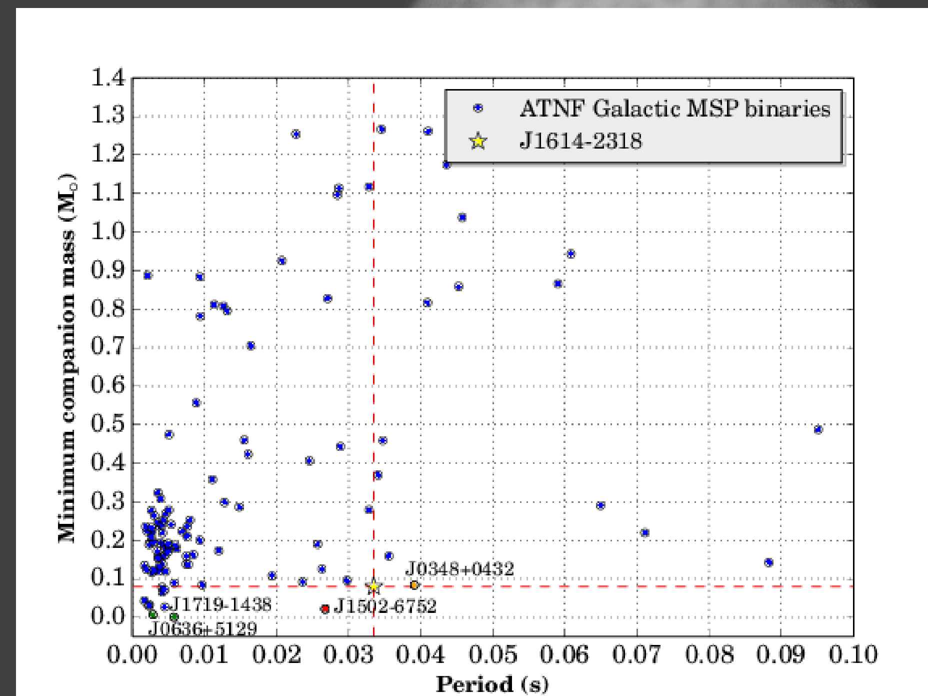
- *Magnetic field: B ≈ 1.4 × 10^9 G*
- *Spin-down energy: Edot ≈ 6.3 × 10^{31} erg/s*



Mikhailov et al., 2017

Timing solution

- *Spin period: $P_{spin} \approx 33.5$ ms*
- *Companion mass: $M_c \approx 0.08\ M_{solar}$*



Mikhailov et al., 2017

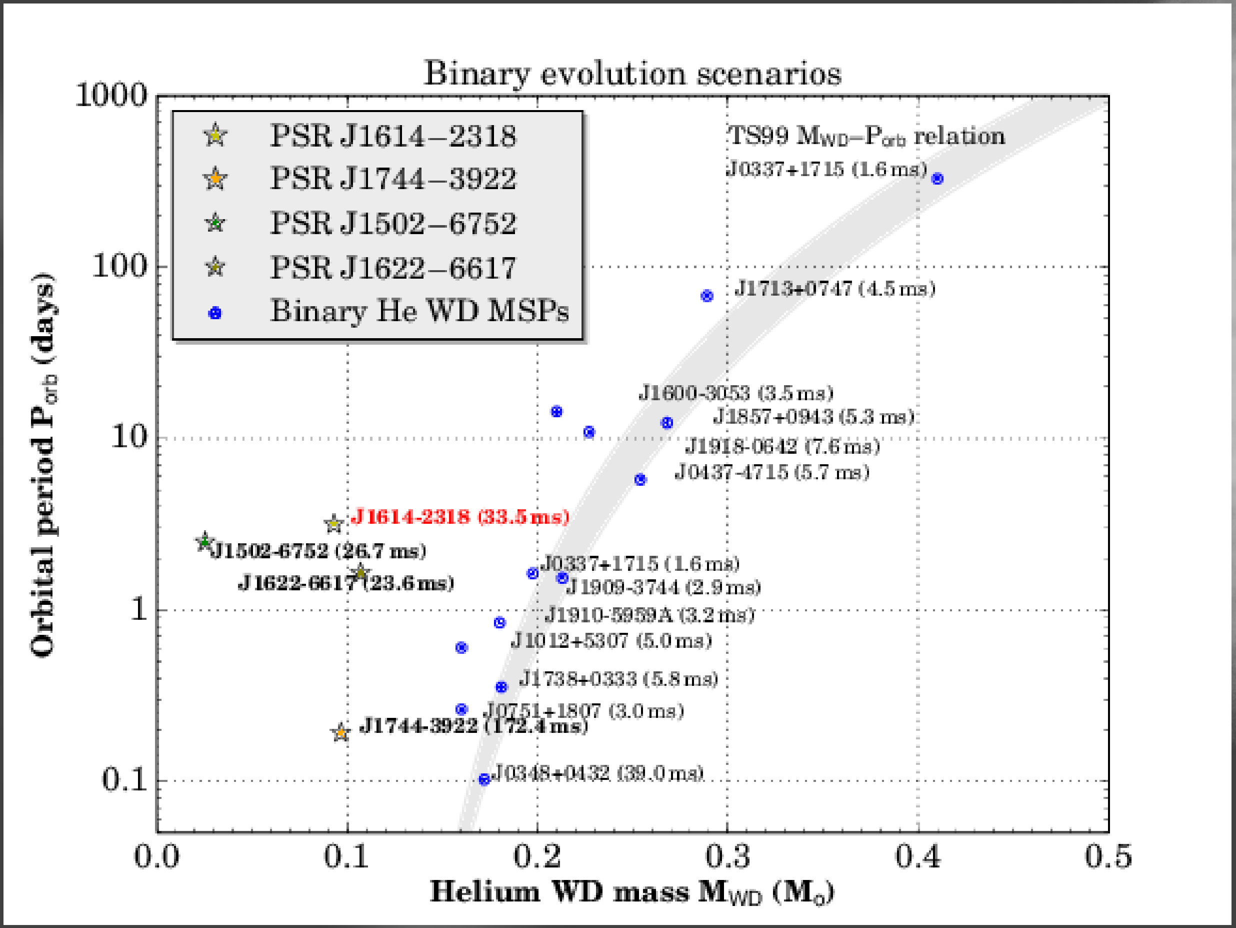
Comparison to J1502–6752

- Spin period: P_{spin} ≈ 26.7 ms
- Spin-down: Pdot ≈ 3.2 x 10^{-19} s/s
- Orbital period: P_{orb} ≈ 2.5 days
- Characteristic age: t ≈ 1.5 Gyr
- Companion mass: M_c ≈ 0.022 M_{solar}
- Magnetic field: B ≈ 2.8 x 10^{10} G
- Spin-down energy: Edot ≈ 5.9 × 10^{32} erg/s
- DM ≈ 151.7 pc/cc → d ≈ 4.2 kpcs

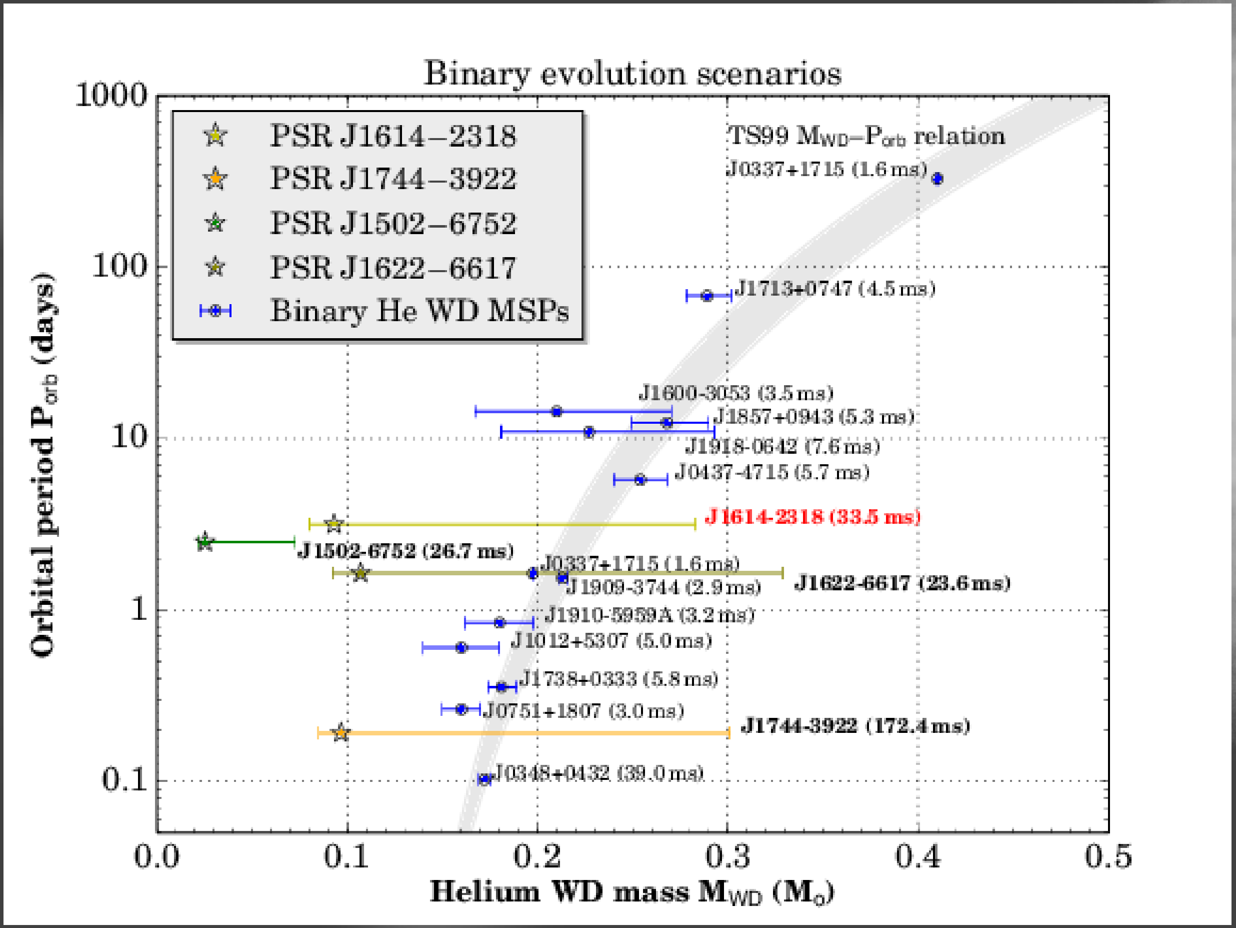
Parameter	J1502–6752
RA, α (J2000)	15:02:18.610(4)
Dec., δ (J2000)	−67:52:16.78(2)
l (°)	314.80
b (°)	−8.07
Pulse frequency, ν (s^{-1})	37.390 971 9910(4)
Frequency derivative, $\dot{\nu}$ (s^{-2})	$-4.0(3)\times 10^{-16}$
Epoch of model (MJD)	55421.2
Dispersion measure, DM (cm^{-3}pc)	151.75
Binary model	ELL1
Orbital period, P_b (d)	2.484 4570(5)
Projected semi-major axis, $a\sin i$ (light-second)	0.317 56(3)
Epoch of ascending node, T_{asc} (MJD)	55421.21202(4)
$e\cos\omega$	$-5.3(125)\times 10^{-5}$
$e\sin\omega$	$-3.9(144)\times 10^{-5}$
Inferred eccentricity, e	$<2 \times 10^{-4}$
Minimum companion mass, $m_{c,min}$ ($M_\odot$)	0.022
Fit time-span (MJD)	55360.4–55757.5
rms of residuals (μs)	67.9
Reduced χ^2	0.7
Mean flux density, S_{1400} (mJy)	0.68
Pulse width at 50 per cent of peak, W_{50} (°)	40
Pulse width at 10 per cent of peak, W_{10} (°)	–
Spin-down energy loss rate, $\dot{E}$ (erg s^{-1})	5.9×10^{32}
Characteristic age, t_c (yr)	1.5×10^{9}
Dipole magnetic field strength, B_{surf} (G)	2.8×10^{9}
DM-derived distance, d (kpc)*	4.2
$\dot{E}^{1/2}/d^2$ ($\times 10^{10}$ $erg^{1/2}$ pc^{-2} $s^{-1/2}$)	0.2

Keith et al. 2012

Binary evolution scenarios



Binary evolution scenarios



M_c > 0.22 M_{solar} → i < 23^o → 8% probability for a randomly oriented orbit

Binary evolution scenarios

- *Why slow spinning?*
  - *Inefficient accretion onto the pulsar*

    - Initially weak field still ends up at 10^9G

    - Insufficient spin up due to relatively weak accretion channel

- *Accretion induced collapse of ONeMg WD*

  $10\ d \leq P_{orb} \leq 60\ d$

- *He WD → HeCO WD*

Conclusion

- Relatively low spin-down → no association with unidentified EGRET γ-ray sources
- Pulse profile: additional wings → different emission components?
- Interesting evolution → magnetic field suppression, aligned rotation?