Pulsar of the week: 6 February 2019

PSR J1757-1854

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Highlights

- 21.49 ms Pulsar in a highly-eccentric (~0.6), 4.4-h orbit with a neutron star (NS) companion.
- Discovered in the HTRU South Low-Lat Survey by Dr. Andrew Cameron.
- Shows highly relativistic effects due to gravitational-wave (GW) damping, with a merger time of 76 Myr.

$$m_p = 1.3384(9)\mathrm{M}_\odot \qquad m_c = 1.3946(9)\mathrm{M}_\odot$$

Discovery

Segment	Amount.	t_{int} (min)	Min. P_{b} (hours)	$\lvert a_{\mathrm{max}} \rvert$ ($\mathrm{m\,s^{-2}}$)
Full	1	72	12	1
Half	2	36	6	200
Quarter	4	18	3	500
Eighth	8	9	1.5	1200

- Initially detected only in the second 36 minute half-segment at an acceleration of -32ms^{-2} with SNR of 13.3.
- Acceleration search on 72 minute data recovered the signal with reduced SNR of 10.6.
- Jerk search on 72 minute observation gave SNR of 21.4.

Discovery Plot

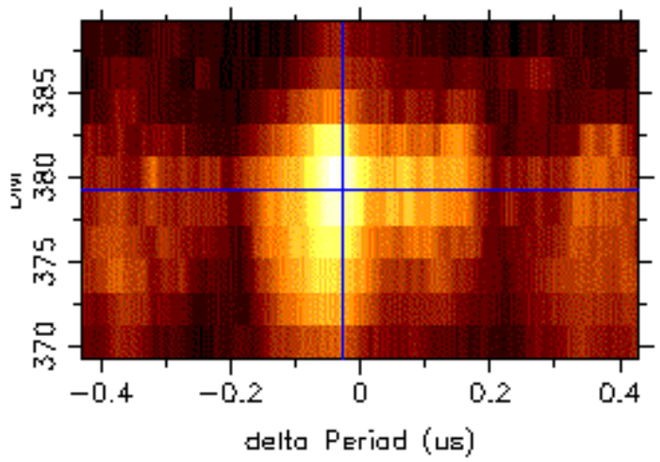
009-F2-S2150-p0: 2012-04-12-16:27:35-03_009-F2-S2150-p0.022-d379.2-a-31.89.ar2

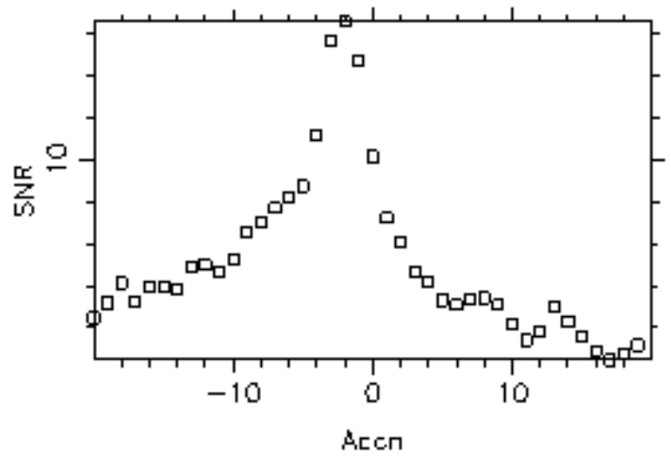
BC P(ms)= 21.504691079 TC P(ms)= 21.502722938 DM= 379.184 RAJ= 17:57:10.80 DecJ= -18:49:34.9

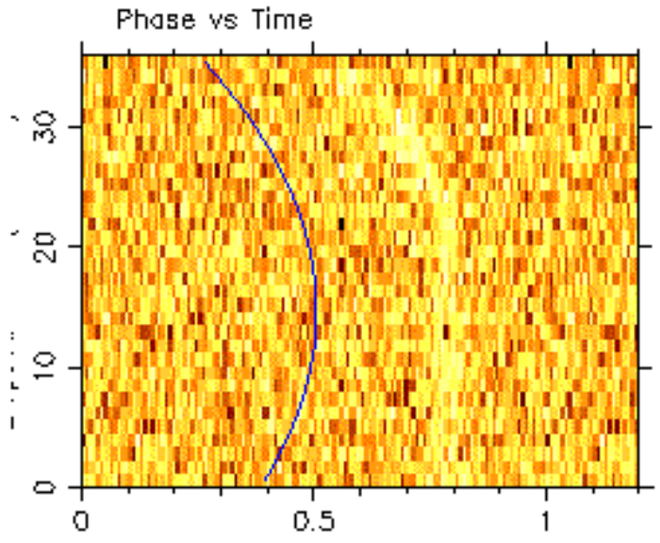
BC MJD = 56029.726282 Centre freq(MHz) = 1382.000 Bandwidth(MHz) = -400 l = 10.045 b = 2.890

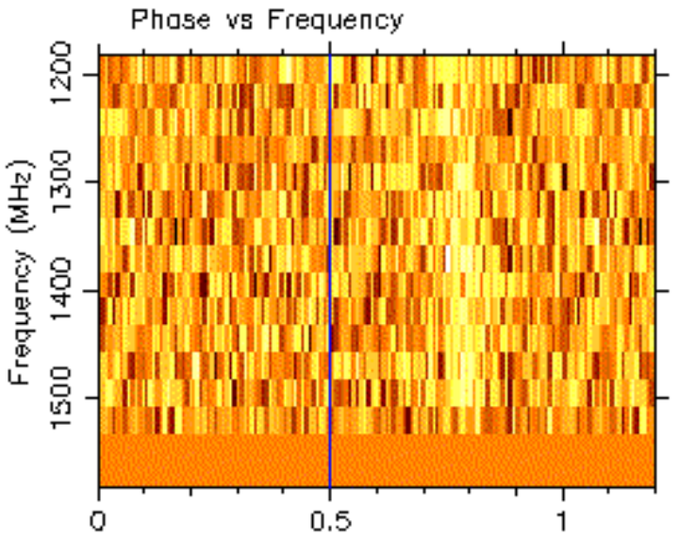
NBin = 128 NChan = 16 NSub = 32 TBin(ms) = 0.168 TSub(s) = 67.439 TSpan(s) = 2160.518

P(us): offset = 0.00000, step = 0.00167, range = 0.43000 DM: offset = 0.000, step = 2.000, range = 10.000

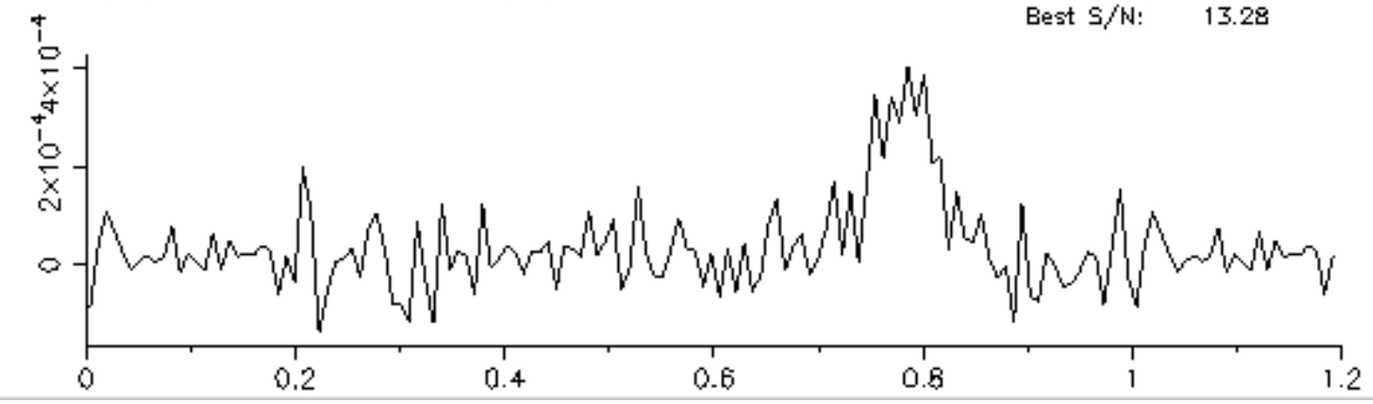




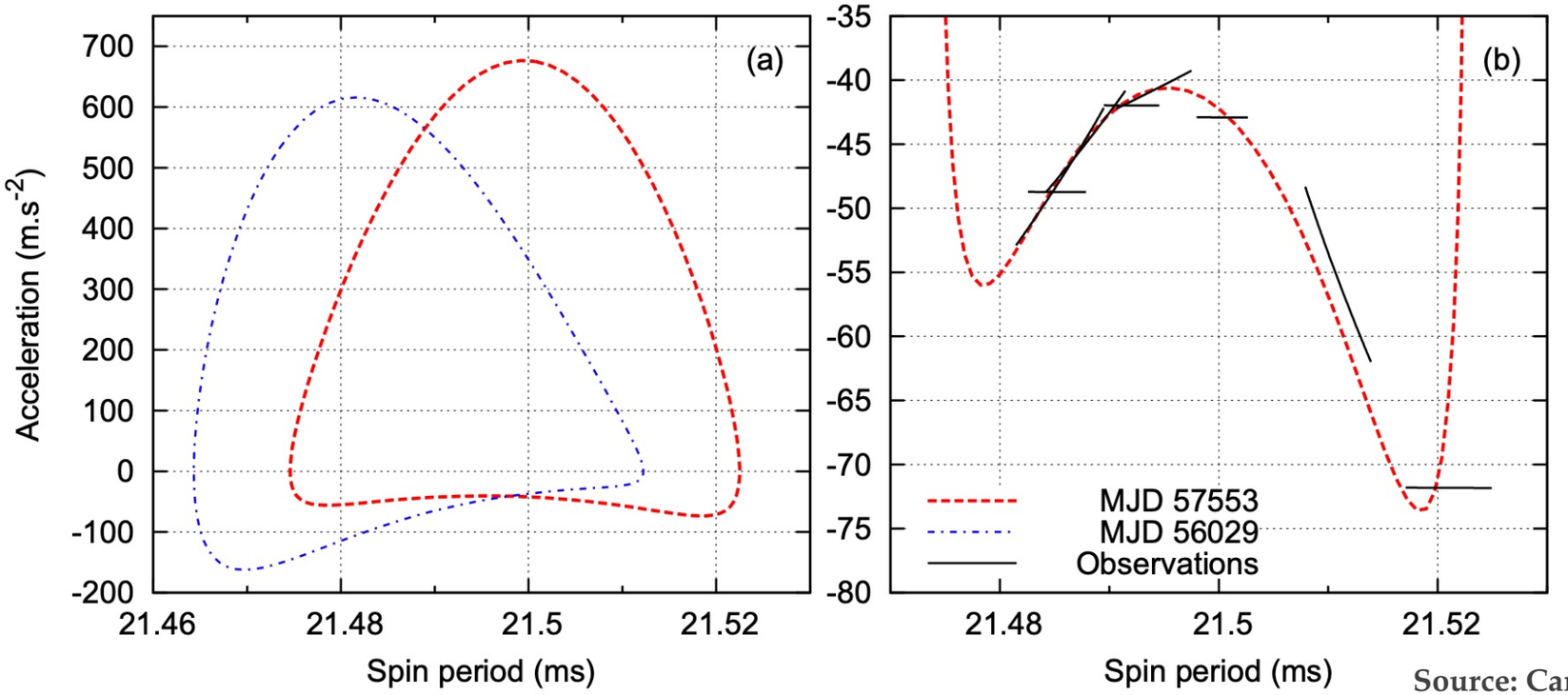




BC prd (ms):	21.504662660	TC prd (ms):	21.502694522	DM:	379.184	BC freq (Hz):	46.501543214
Corrn (ms):	-0.000028419	Corrn (ms):	-0.000028416	Corrn:	0.000	Freq err. (Hz):	0.000007595
Error (ms):	0.000003512	Error (ms):	0.000003512	Error:	0.290	Width (ms):	1.512
						Best S/N:	13.28



Follow-up Observations



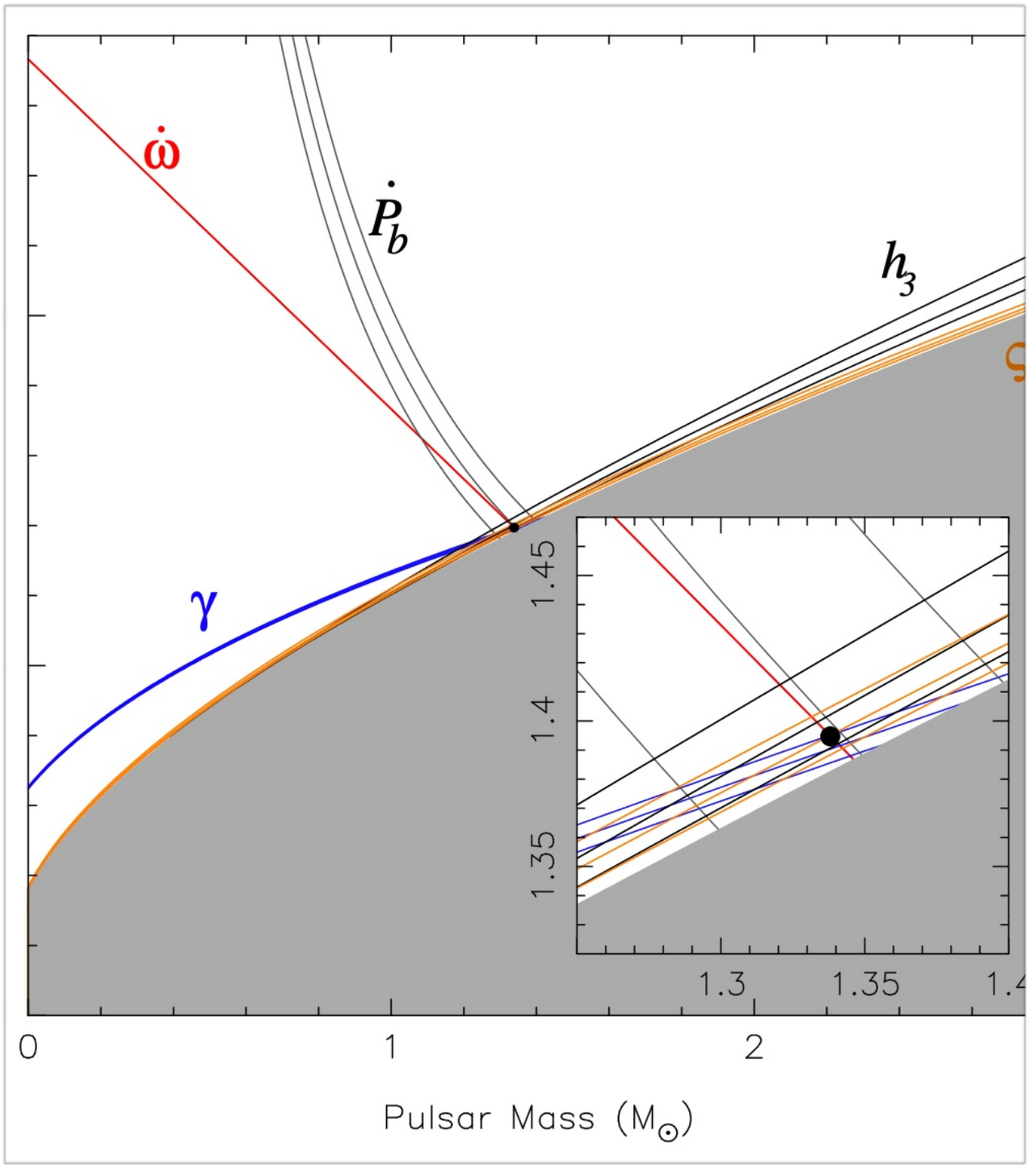
Source: Cameron et al. 2017

- Observations to map the orbit were done at Parkes, Effelsberg and Jodrell Bank telescopes.
- **Interesting Fact**: Pulsar not detected in multiple observations with standard acceleration techniques.
- Later found that observations happened during the orbit's periastron phase. (50-60 minute interval where acceleration value changed from negative values to ~+684 ms^{-2})

Measured parameters and implications

- Characteristic age T_c ~ 130 Myr.
- Surface Magnetic Field B_{surf} ~ 7.61 x 10^9 G
- Five post-keplerian parameters measured.
  - Rate of periastron advance: $\dot{\omega}$
    Einstein delay : γ
    Orbital Period Derivative : $\dot{P}_b$
    Shapiro Parameters. : h_3, ς
- New Records Set:
  - Closest Binary Separation at periastron : $0.749 R_\odot$
  - Highest relative velocity at periastron : $1060 \mathrm{kms}^{-1}$
  - Highest value of $\dot{P}_b$ and $\frac{\dot{P}_b}{P_b} = -3.33 \times 10^{-16} s^{-1}$

Testing General Relativity



Test 1

GR predicts: $\dot{P}_b = -5.2747(6) \times 10^{-12}$

Agrees with relative uncertainty of only 5%

Test 2

GR predicts: $h_3 = 5.37^{+0.72}_{-0.40} \quad \mu s$

Agrees within One Sigma uncertainty

Test 3

GR predicts: $\varsigma = 0.92^{+0.040}_{-0.025}$

Agrees within One Sigma uncertainty

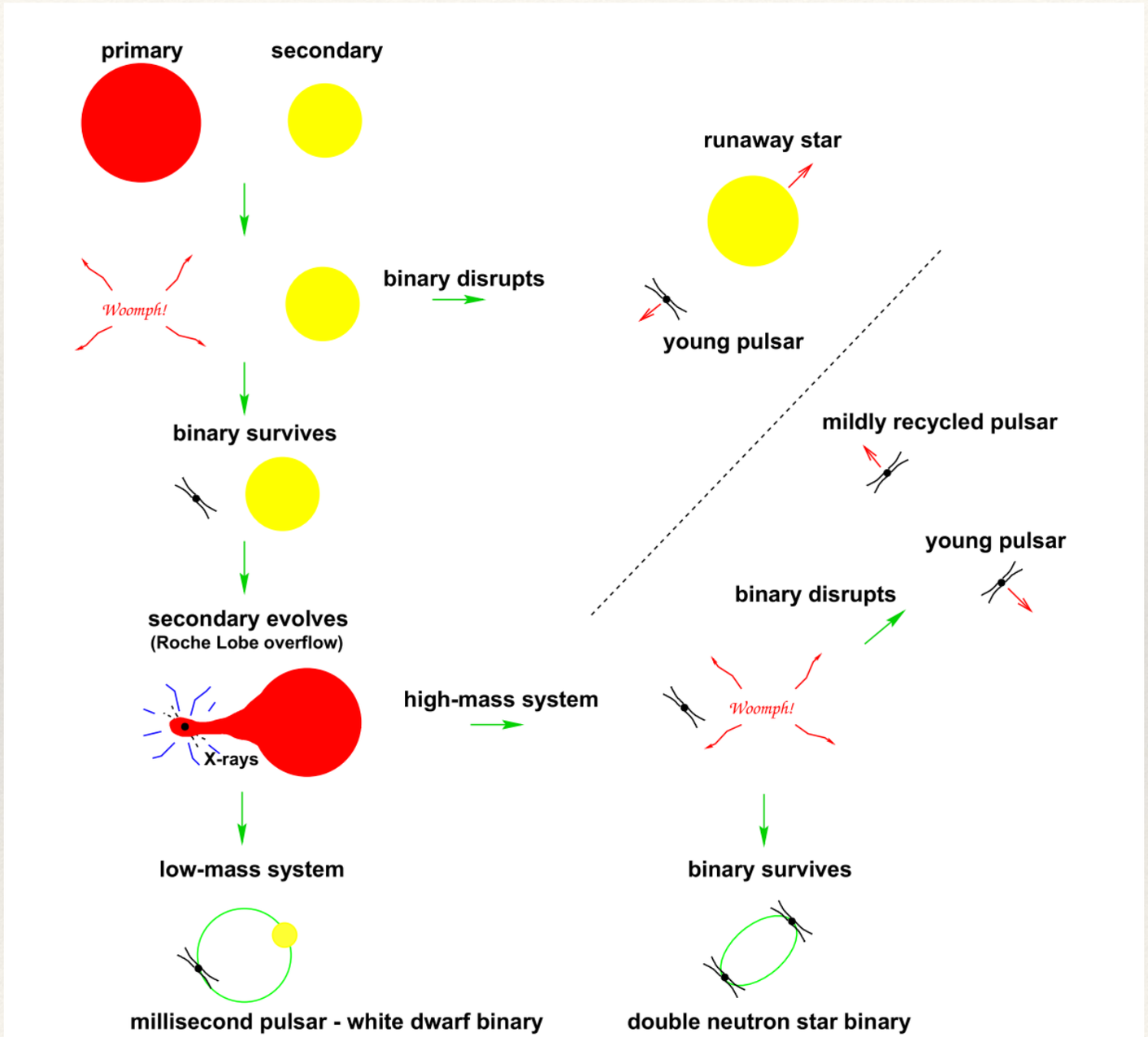
Source: Cameron et al. 2017

Limitations

- Unlikely to employ $\dot{\omega} - \dot{P}_b$ measurement technique as done for PSR J0737−3039.
- Hard to correct for extrinsic acceleration effects due to large distance ~7.4 kpc (NE 2001)

$$\left(\frac{\dot{P}_b}{P_b}\right)^{obs} = \left(\frac{\dot{P}_b}{P_b}\right)^{GR} + \frac{V_{trans}^2}{cD} + \frac{\Delta a_{radial}}{c}$$

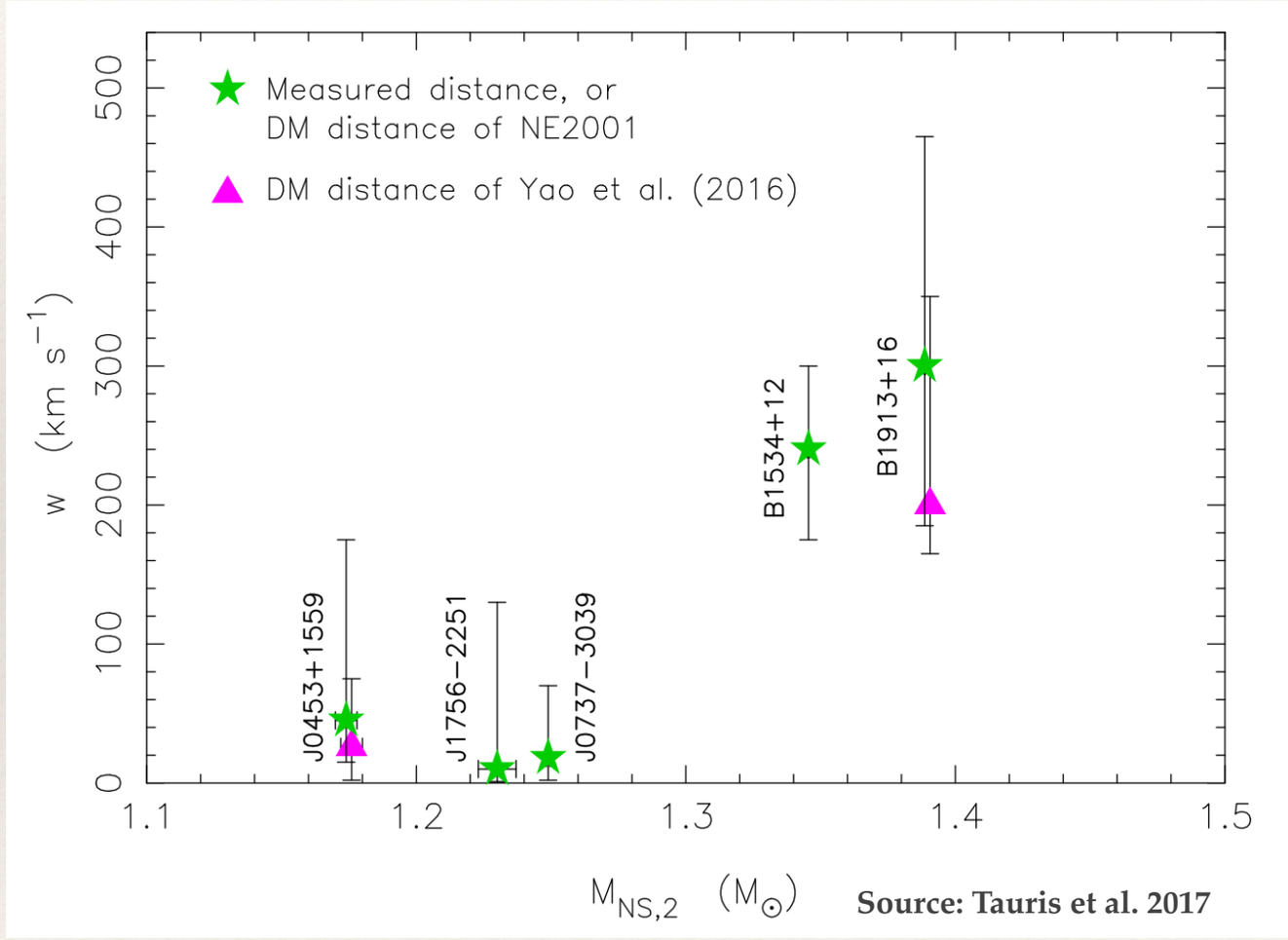
Formation of DNS Systems



Source: Lorimer (2008)

Evolutionary History

- PSR J1757-1854 has a relatively massive young NS companion.
- NS more massive than recycled pulsar. Only other known system showing this property is PSR B1534+12.
- Indicates that a large kick is likely to have been imparted on the young NS at birth.
- Montecarlo simulations show values closed to ~400kms^{-1}



Source: Tauris et al. 2017

Future Prospects

- PSR J1757-1854 is expected to allow for future measurements of Lense-Thirring precession.
- Large misalignment angle between spin vector of pulsar and orbital angular momentum $\approx 25^{\circ}$

$$\dot{x}_{\mathrm{LT}} = x \cot i \left(\frac{\mathrm{d}i}{\mathrm{d}t} \right)_{\mathrm{LT}}$$

- Expect a measurement unto 3 sigma within ~7-8 years.
- Also an ideal system to measure PK parameter which describes relativistic deformation of elliptical orbit.

Future Prospects

- PSR J1757-1854 is also an ideal system to measure PK parameter δ_θ which describes relativistic deformation of elliptical orbit.

$$\Delta_{\delta_\theta} \simeq -\delta_\theta \frac{e^2}{\sqrt{1-e^2}} x \cos\omega \sin u$$

- Has only been measured before in PSR B1913+16 and in and PSR J0737−3039, in both cases with low significances.
- Equation implies that you also need a high change in ω in order to separate the effect of δ_θ from γ $\Delta_\gamma = \gamma \sin u$
- PSR J1757-1854: $\dot{\omega} \simeq 10.37^\circ\,\mathrm{yr}^{-1}$
- 3 sigma measurement expected in ~7-8 years.

Companion Searches

- GBT observations done in coherently de-dispersed time search mode.
- Two methods used to search for companion.
  - Accelsearch with z =50
  - Deconvolve the orbit and do presto periodicity search (as described in Martinez et al. 2015)
- No Detection Yet.

Summary

- PSR J1757-1854 is one of the most relativistic binary pulsar systems detected.
- Has already passed 3 tests of General Relativity with additional precision expected with time.
- Expected to measure Lense-Thirring precision and δ_θ in ~7-8 years.
- No pulsation from companion detected yet.

Ephemeries

Right ascension, α (J2000)	17:57:03.78438(6)
Declination, δ (J2000)	−18:54:03.376(7)
Spin period, P (ms)	21.497231890027(7)
Spin period derivative, $\dot{P}$ (10^{-18})	2.6303(7)
Timing epoch (MJD)	57701
Dispersion measure, DM ($\mathrm{pc\,cm^{-3}}$)	378.203(2)
Binary model	DDH
Orbital period, P_b (d)	0.18353783587(5)
Eccentricity, e	0.6058142(10)
Projected semimajor axis, x (lt-s)	2.237805(5)
Epoch of periastron, T_0 (MJD)	57700.92599420(5)
Longitude of periastron, ω (°)	279.3409(4)
Rate of periastron advance, $\dot{\omega}$ ($^\circ\,\mathrm{yr^{-1}}$)	10.3651(2)
Einstein delay, γ (ms)	3.587(12)
Orbital period derivative, $\dot{P}_\mathrm{b}$ (10^{-12})	−5.3(2)
Orthometric amplitude, h_3 (μs)	4.6(7)
Orthometric ratio, ς	0.90(3)
Mass function, f ($\mathrm{M_\odot}$)	0.35718891(2)
Total system mass, M ($\mathrm{M_\odot}$)	2.73295(9)†
Pulsar mass, m_p ($\mathrm{M_\odot}$)	1.3384(9)†
Companion mass, m_c ($\mathrm{M_\odot}$)	1.3946(9)†
Inclination angle, i (°)	$84.0^{+0.4}_{-0.3}$ or $96.0^{+0.3}_{-0.4}$†
Flux density at 1.4 GHz, S_{1400} (mJy)	0.25(4)
DM distance, d (kpc)	7.4 (NE2001)
	19.6 (YMW16)
Surface magnetic field, B_surf (10^9 G)	7.61
Characteristic age, τ_c (Myr)	130
Spin-down luminosity, $\dot{E}$ ($10^{30}\,\mathrm{ergs\,s^{-1}}$)	10500
Time units	TCB
Solar system ephemeris	DE421
RMS residual (μs)	36

† Parameters derived according to the DDGR model.