Journal Club

J1756-2251 -- a relativistic double neutron star binary system

Huanchen Hu

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Credit: NASA/Dana Berry, Sky Works Digital

Observations

- First discovered by Faulkner et al. (2005) during the Parkes Multibeam Pulsar Survey (Manchester et al. 2001)
- >700 pulsars found
- 13-beam receiver
- Galactic plane ($|b|<5°$, $260°<l<50°$)
- 35 min integration
- Centre frequency: 1374 MHz, 96 channels, BW: 288 MHz

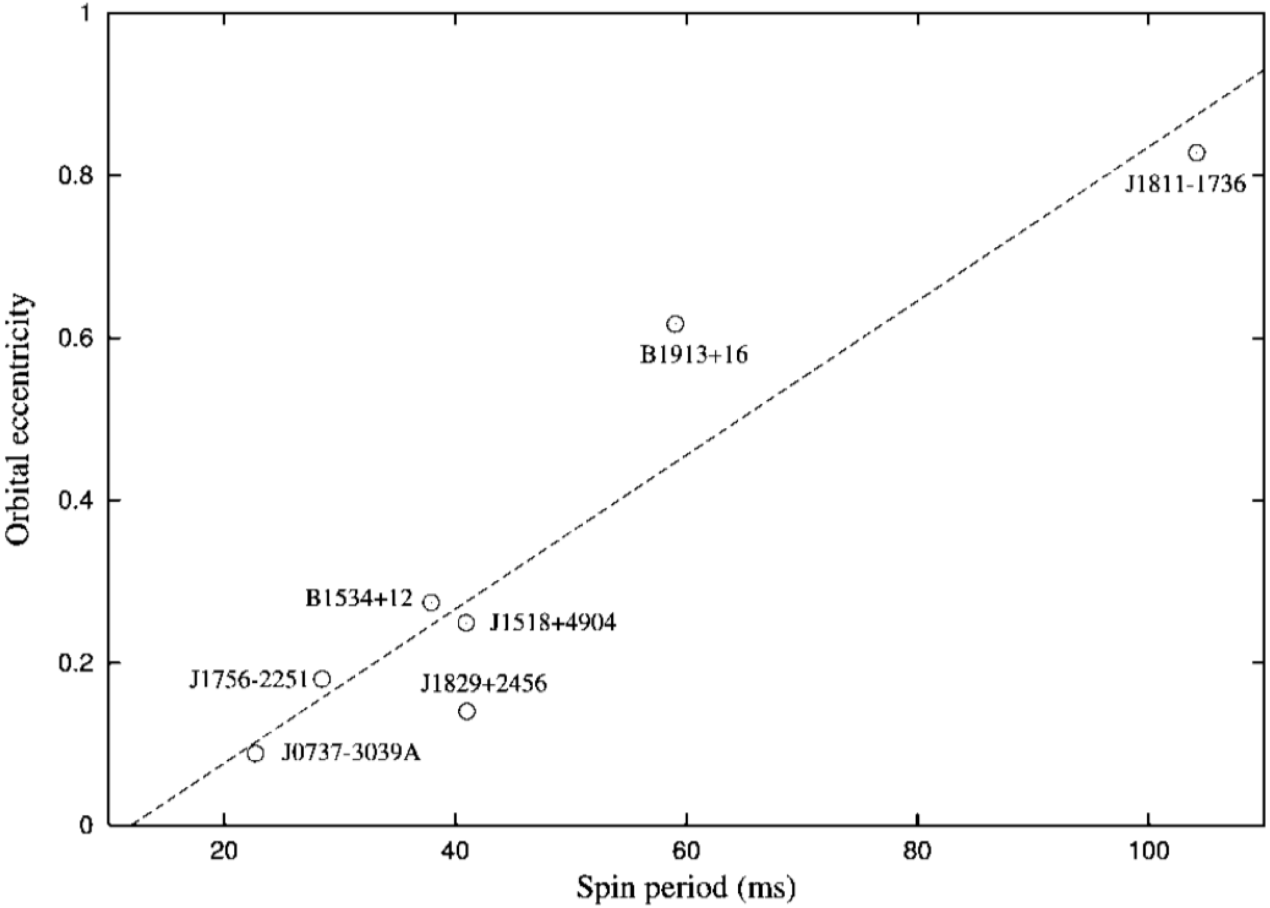
Credit: ATNF

Some Features

- Spin period: 28.5 ms
- orbital period: 7.67hr
- eccentricity: 0.18
- Significant $\dot{\omega} = 2°.585 \pm 0°.002\ \mathrm{yr}^{-1}$
- Total mass: $2.574 \pm 0.003\ M_{\odot}$, similar to J0737-3039
- Coalescence time: ~1.7 Gyr

Strong correlation between *P* and *e*

Faulkner et al. 2005



Follow-up Observations

9 yrs data from 5 telescopes (PK, GB, NC, WB, JB)

Ferdman et al. 2014

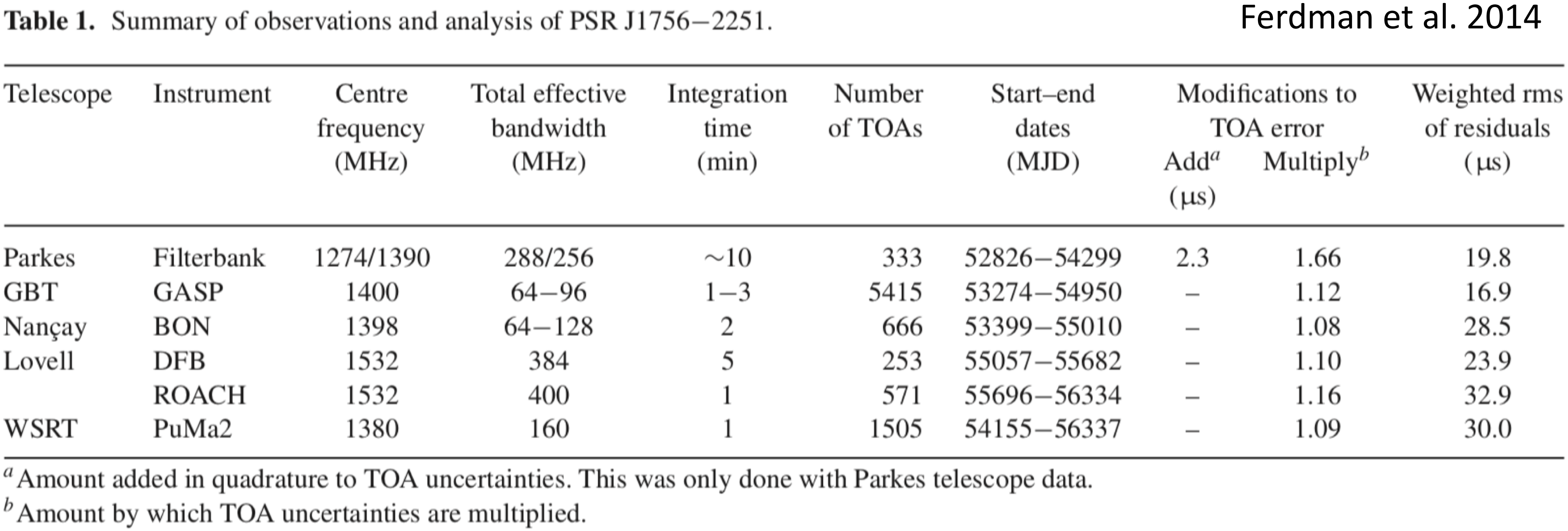


Table 1. Summary of observations and analysis of PSR J1756−2251.

Telescope	Instrument	Centre frequency (MHz)	Total effective bandwidth (MHz)	Integration time (min)	Number of TOAs	Start–end dates (MJD)	Modifications to TOA error Add[a] (μs)	Multiply[b]	Weighted rms of residuals (μs)
Parkes	Filterbank	1274/1390	288/256	∼10	333	52826−54299	2.3	1.66	19.8
GBT	GASP	1400	64−96	1−3	5415	53274−54950	–	1.12	16.9
Nançay	BON	1398	64−128	2	666	53399−55010	–	1.08	28.5
Lovell	DFB	1532	384	5	253	55057−55682	–	1.10	23.9
	ROACH	1532	400	1	571	55696−56334	–	1.16	32.9
WSRT	PuMa2	1380	160	1	1505	54155−56337	–	1.09	30.0

[a] Amount added in quadrature to TOA uncertainties. This was only done with Parkes telescope data.

[b] Amount by which TOA uncertainties are multiplied.

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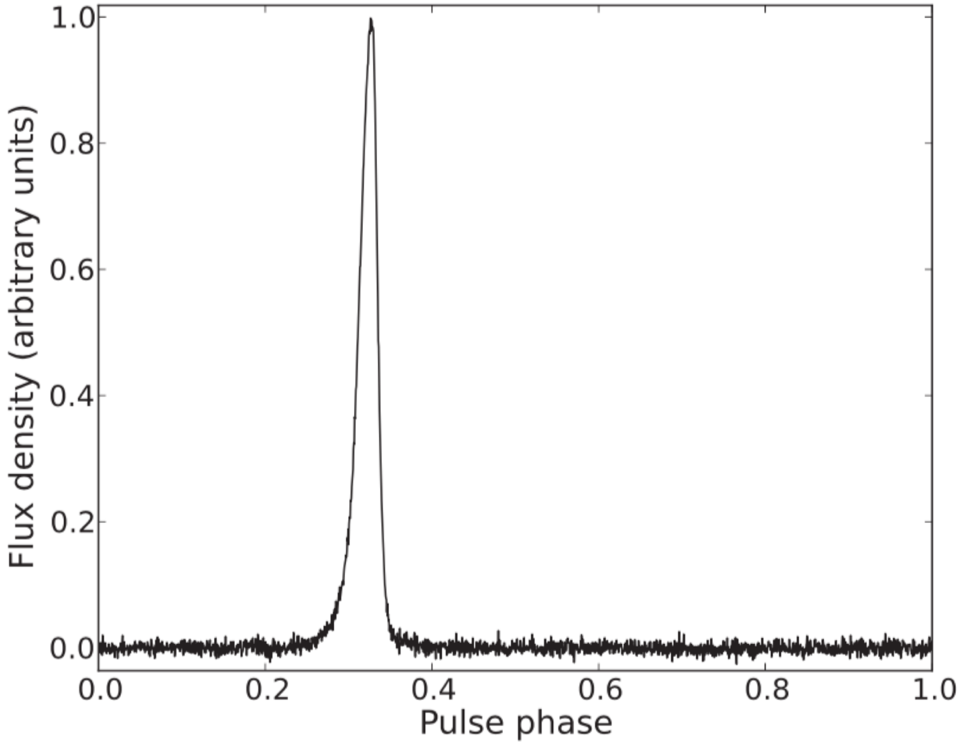


Figure 1. Standard template profile for PSR J1756−2251, constructed from data taken with the GBT using the GASP pulsar backend.

Timing residuals

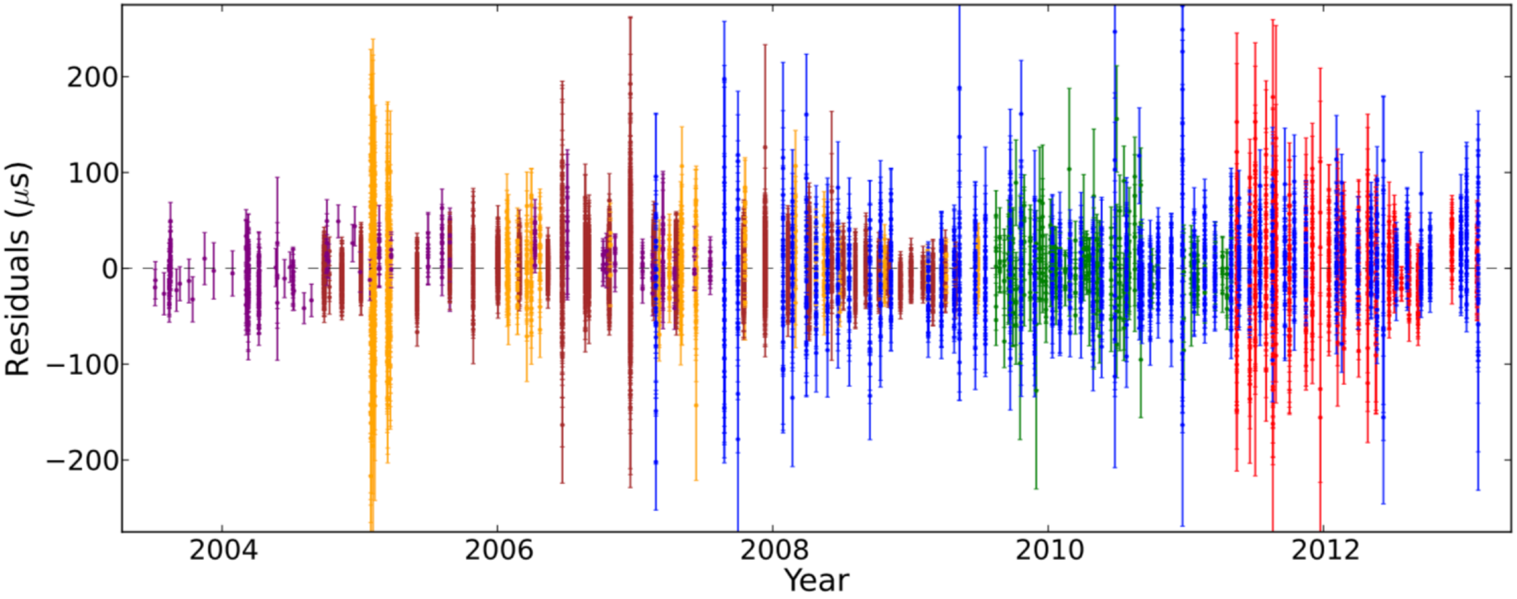
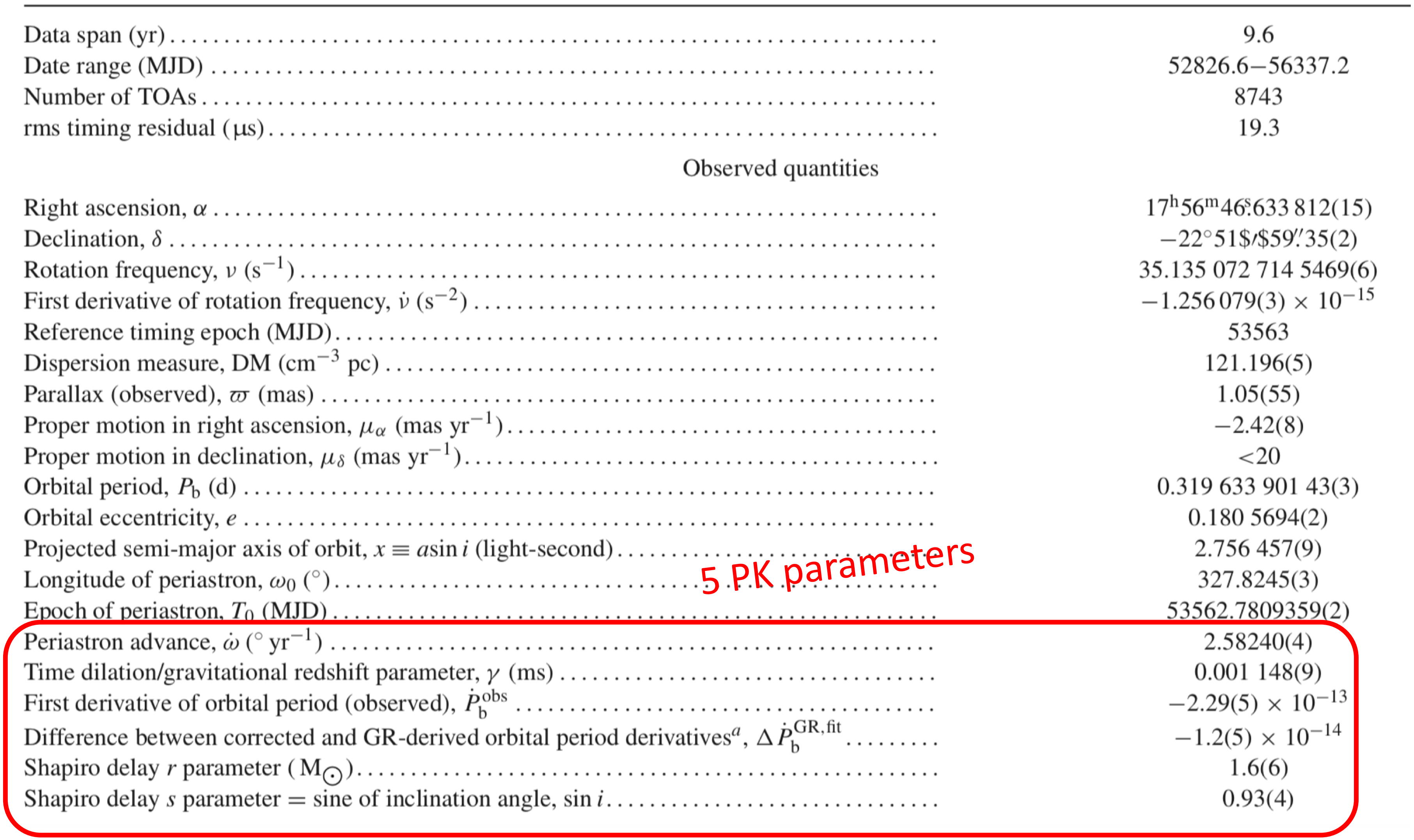


Figure 2. Timing residuals for PSR J1756−2251, after including best-fitting parameters in the timing model. Residuals from each instrument used are represented by different colours as follows: Parkes filterbank – purple; GBT/GASP – dark red; Nançay/BON – orange; Westerbork/PuMa2 – blue; Jodrell Bank (Lovell)/DFB – green; and Jodrell Bank/ROACH – light red.

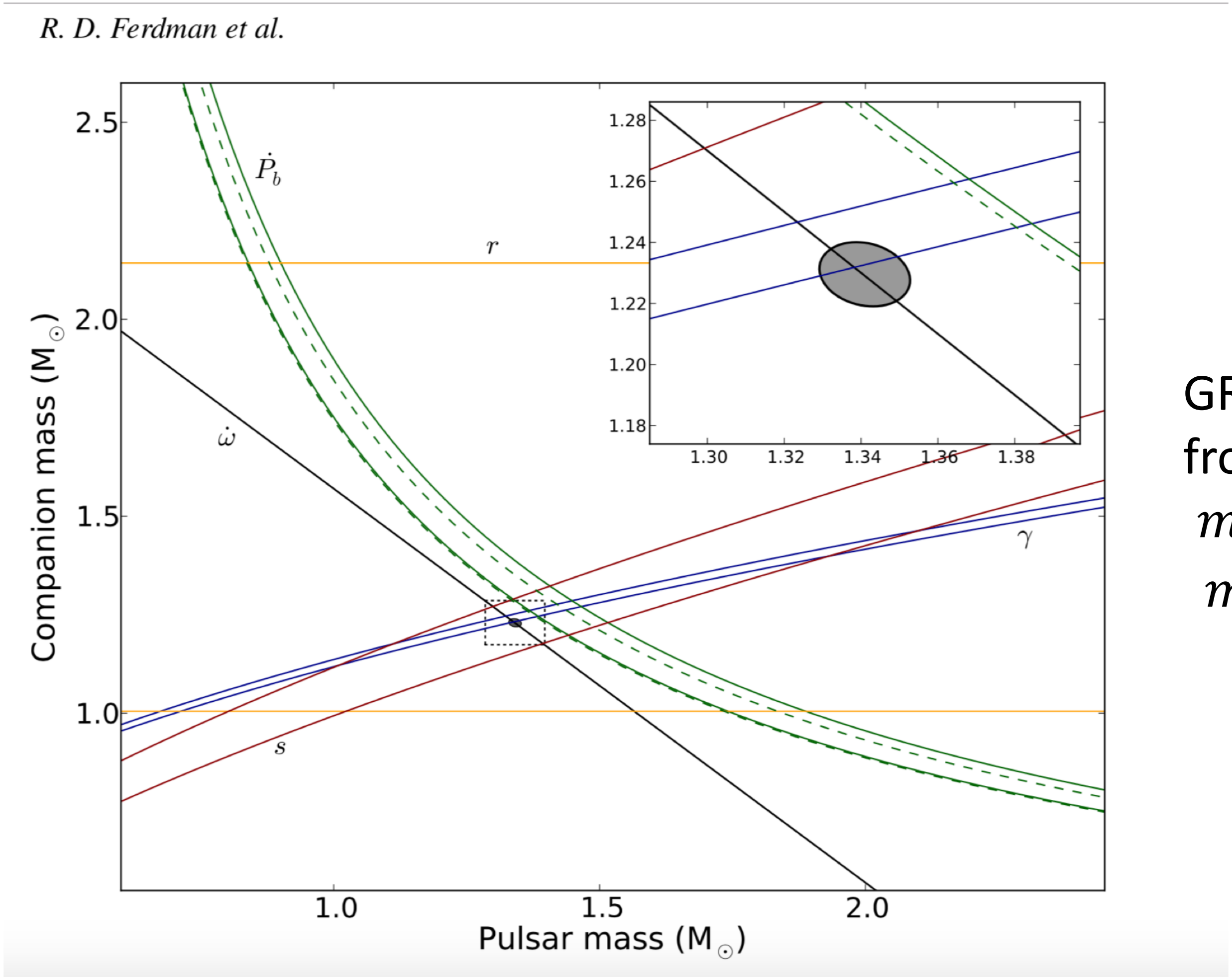
Table 2, Ferdman et al. 2014



Data span (yr)	9.6
Date range (MJD)	52826.6–56337.2
Number of TOAs	8743
rms timing residual (μs)	19.3
Observed quantities	
Right ascension, α	$17^{\mathrm{h}}56^{\mathrm{m}}46^{\mathrm{s}}.633\,812(15)$
Declination, δ	−22°51$/$59″.35(2)
Rotation frequency, ν (s^{-1})	35.135 072 714 5469(6)
First derivative of rotation frequency, $\dot{\nu}$ (s^{-2})	$-1.256\,079(3)\times10^{-15}$
Reference timing epoch (MJD)	53563
Dispersion measure, DM (cm^{-3} pc)	121.196(5)
Parallax (observed), ϖ (mas)	1.05(55)
Proper motion in right ascension, μ_α (mas yr^{-1})	−2.42(8)
Proper motion in declination, μ_δ (mas yr^{-1})	<20
Orbital period, P_b (d)	0.319 633 901 43(3)
Orbital eccentricity, e	0.180 5694(2)
Projected semi-major axis of orbit, $x \equiv a\sin i$ (light-second)	2.756 457(9)
Longitude of periastron, ω_0 (°)	327.8245(3)
Epoch of periastron, T_0 (MJD)	53562.7809359(2)
Periastron advance, $\dot{\omega}$ (° yr^{-1})	2.58240(4)
Time dilation/gravitational redshift parameter, γ (ms)	0.001 148(9)
First derivative of orbital period (observed), $\dot{P}_\mathrm{b}^{\mathrm{obs}}$	$-2.29(5)\times10^{-13}$
Difference between corrected and GR-derived orbital period derivatives[a], $\Delta\dot{P}_\mathrm{b}^{\mathrm{GR,fit}}$	$-1.2(5)\times10^{-14}$
Shapiro delay r parameter ($\mathrm{M}_\odot$)	1.6(6)
Shapiro delay s parameter = sine of inclination angle, $\sin i$	0.93(4)

5 PK parameters

Test of GR


R. D. Ferdman et al.

GR-predicted masses from $\dot{\omega}$ and γ:

$$m_p = 1.341 \pm 0.007 M_\odot$$

$$m_c = 1.230 \pm 0007 M_\odot$$

Test of GR

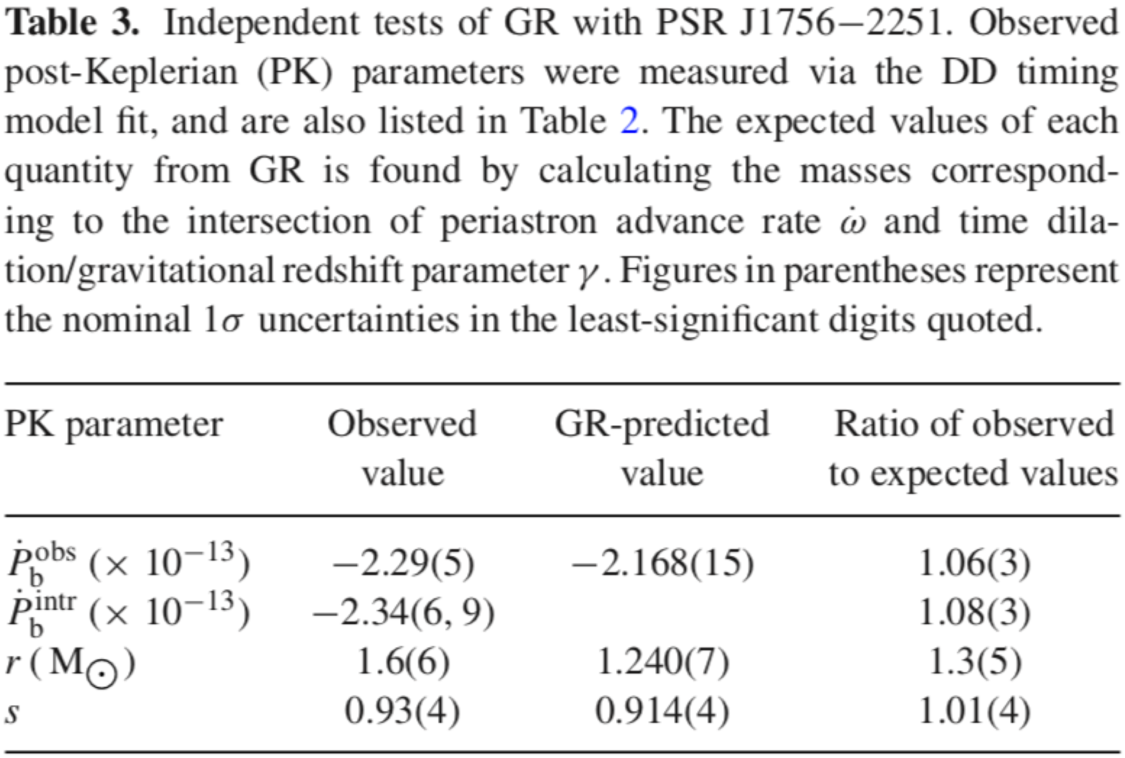


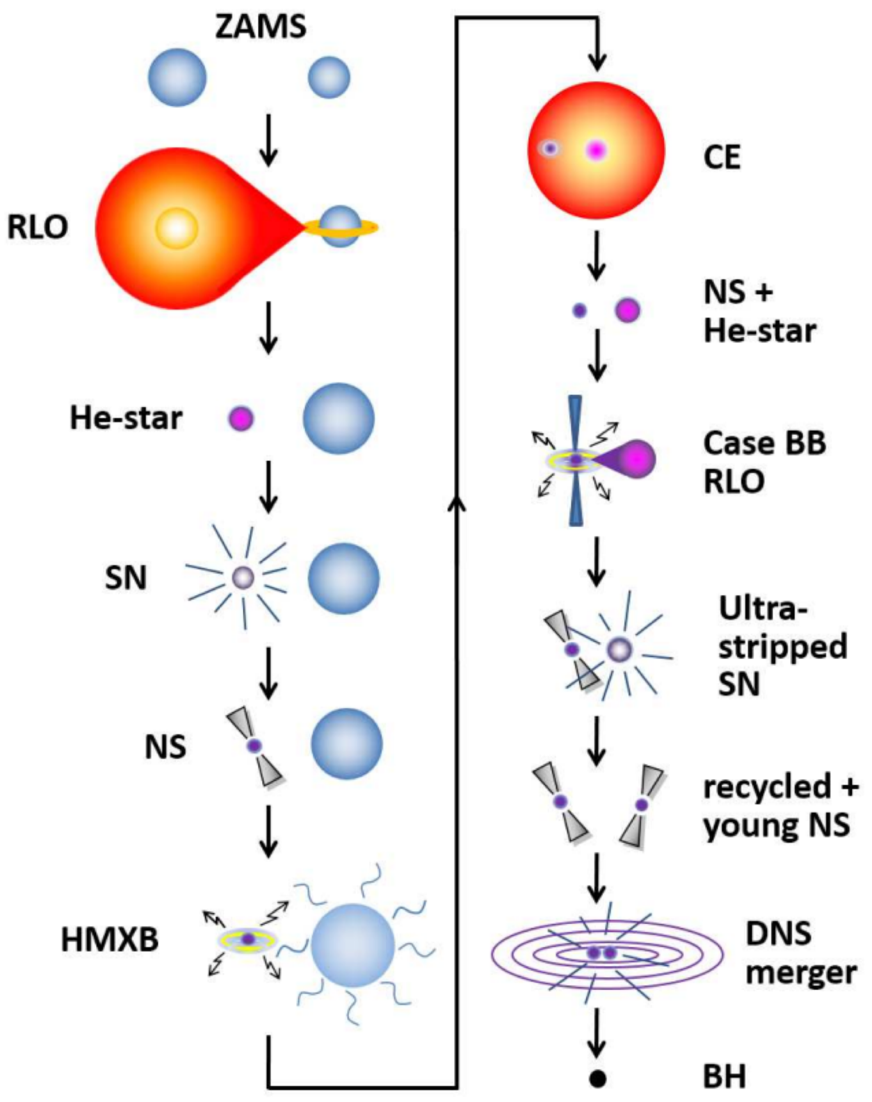
Table 3. Independent tests of GR with PSR J1756−2251. Observed post-Keplerian (PK) parameters were measured via the DD timing model fit, and are also listed in Table 2. The expected values of each quantity from GR is found by calculating the masses corresponding to the intersection of periastron advance rate $\dot{\omega}$ and time dilation/gravitational redshift parameter γ. Figures in parentheses represent the nominal 1σ uncertainties in the least-significant digits quoted.

PK parameter	Observed value	GR-predicted value	Ratio of observed to expected values
$\dot{P}_\mathrm{b}^\mathrm{obs}$ ($\times 10^{-13}$)	−2.29(5)	−2.168(15)	1.06(3)
$\dot{P}_\mathrm{b}^\mathrm{intr}$ ($\times 10^{-13}$)	−2.34(6, 9)		1.08(3)
r ($\mathrm{M}_\odot$)	1.6(6)	1.240(7)	1.3(5)
s	0.93(4)	0.914(4)	1.01(4)

Agreement with GR:
r: 50%
s: 4%

$\dot{P}_\mathrm{b}^\mathrm{obs}$ and $\dot{P}_\mathrm{b}^\mathrm{intr}$ disagree with GR by 2-3σ, likely due to systematic observational biases.

DNS evolution



Tauris et al. 2017, Fig. 1.

Formation of the 2nd NS

1. Asymmetric iron-core-collapse SN (ICCS)
   - substantial natal kick
   - increased eccentricity
   - high space velocity
2. Symmetric – electron capture SNe or Type Ic SNe
   - low-mass
   - small orbital eccentricity
   - low system tangential space velocity

   e~0.18, low mass companion, similar to J0737-3039