The Binary Nature of PSR J2032+4127

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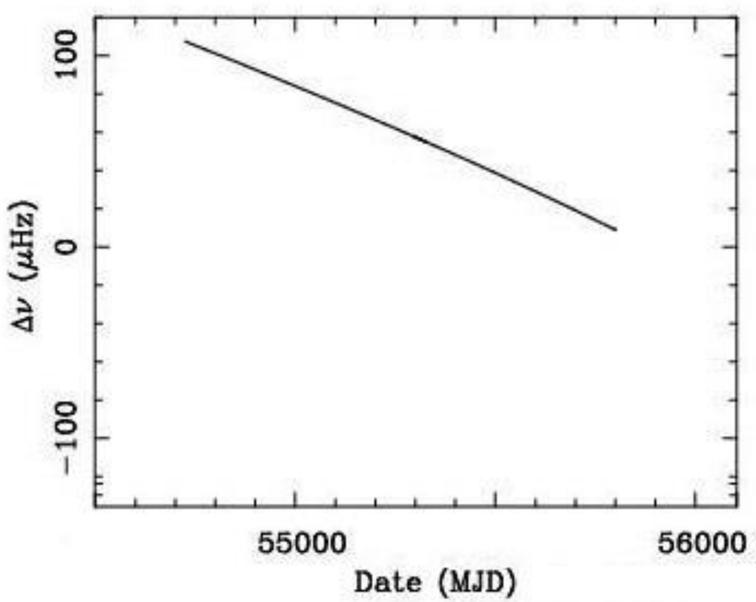
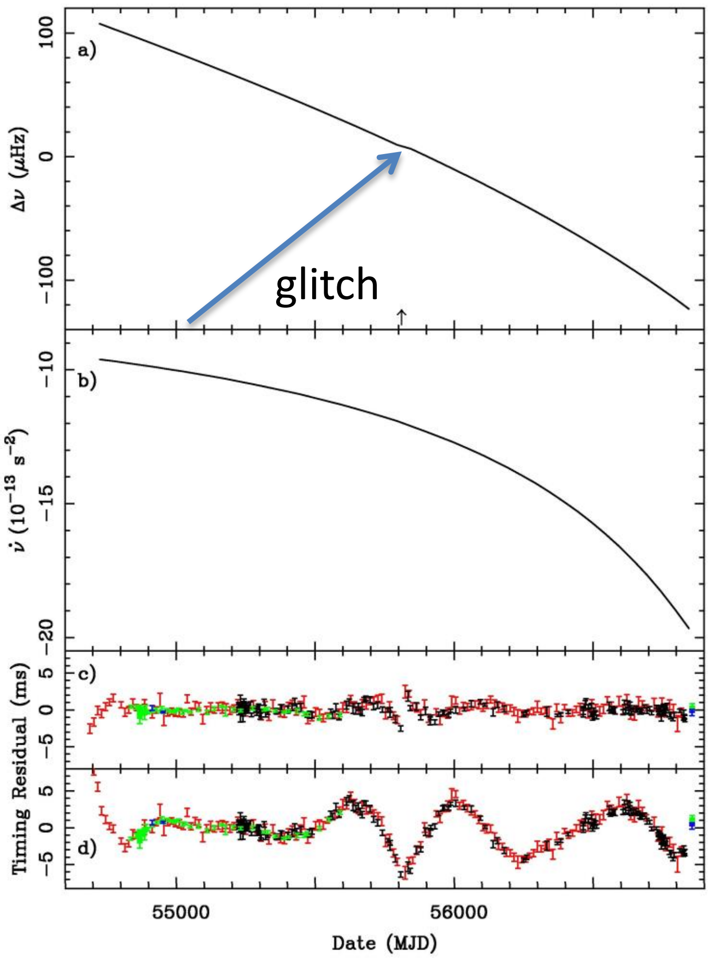
Introduction

- 143-ms gamma-ray pulsar discovered by the Fermi LAT (Abdo et al. 2009)
- Detected in radio by Camilo et al. (2009)
- Initial timing suggested high spin-down rate → young pulsar, $\tau \sim 10\text{ky}$



- Projected position lies close to a Be star in Cyg OB2
- Lack of orbital modulation suggested not associated
- Nearby extended X-ray nebula detected by Chandra/XMM
- Also a TeV gamma-ray nebula

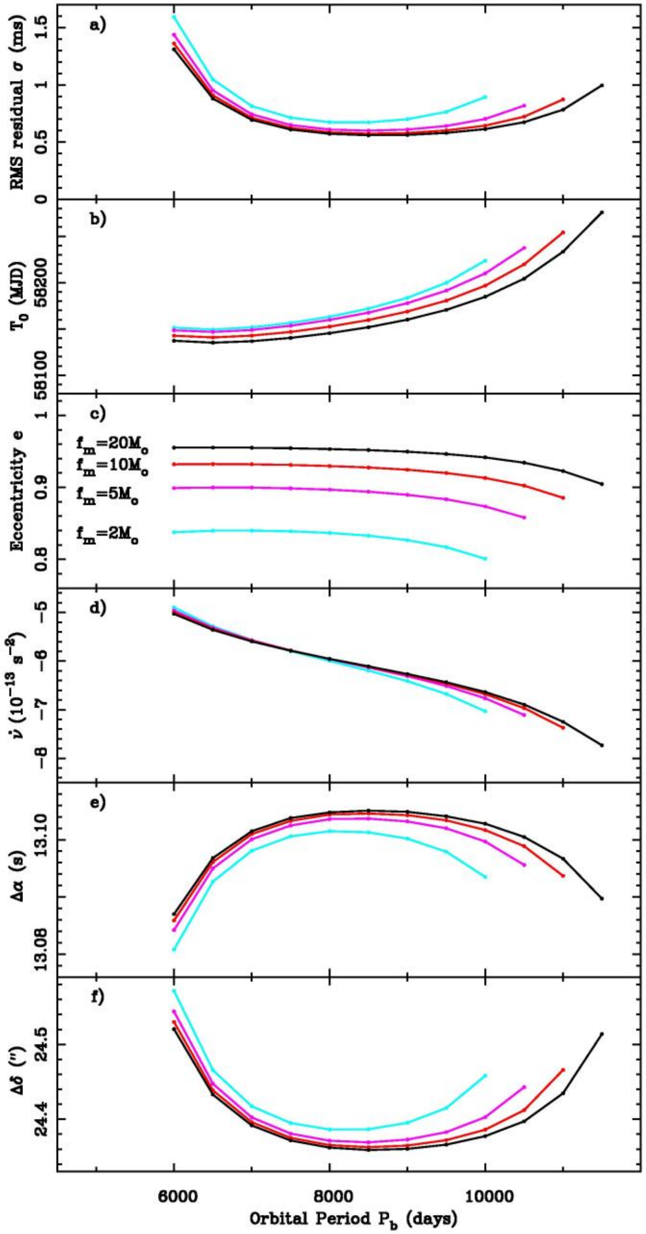
The spin-frequency history of PSR J2032+4127



6-yr timing observations with JBO, GBT, Fermi

- Spin- frequency offset Δν from 6.98083 Hz, measured over 150-day intervals, showing the monotonic spin-down of the pulsar.
- Spin-frequency first derivative $\dot{\nu}$ determined over the same time intervals as showing a doubling of the magnitude.
- Timing residuals relative to a 7-derivative noise model
- Timing residuals relative to a 6-derivative noise model

Binary Fits



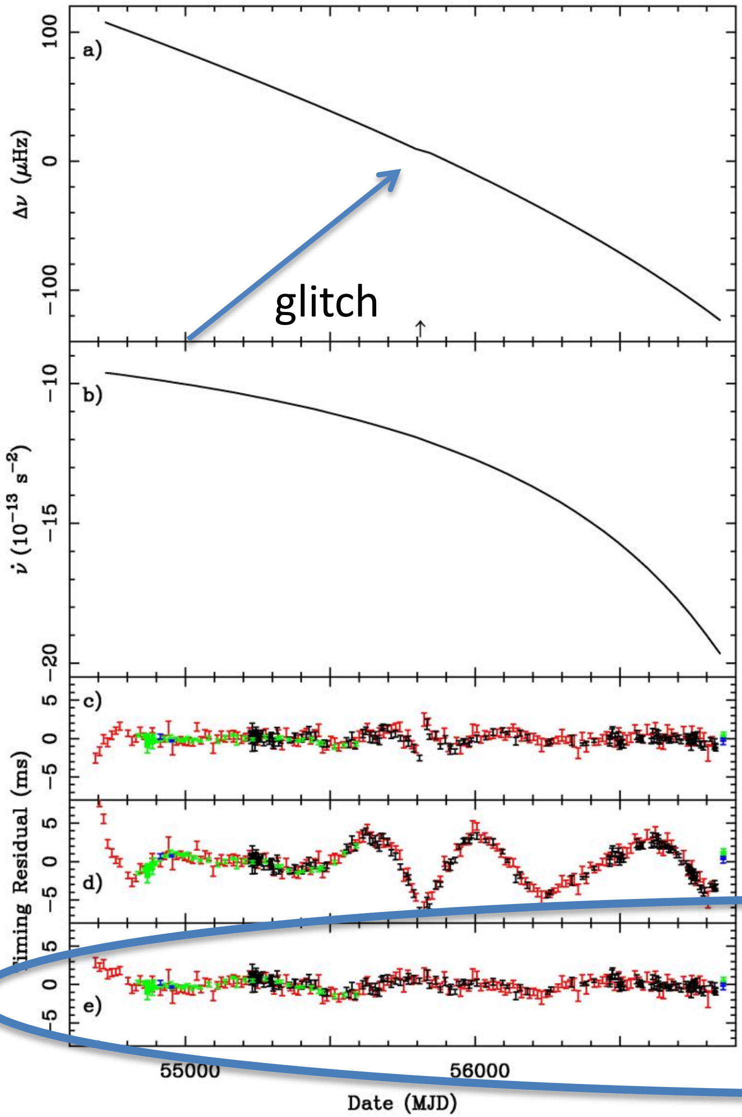
- The only plausible origin of such a large variation in the observed slowdown rate of a pulsar lies in the Doppler effects of binary motion with another star.

- There are strong covariances between some of the fitted parameters, arising from the small orbital phase range of the available data.

- We explored the quality of fits to the TOAs of a number of binary models having different fixed values of orbital period P_b and mass function f_m.

The results

The spin-frequency history of PSR J2032+4127



Timing Observations at JBO, GBT, Fermi

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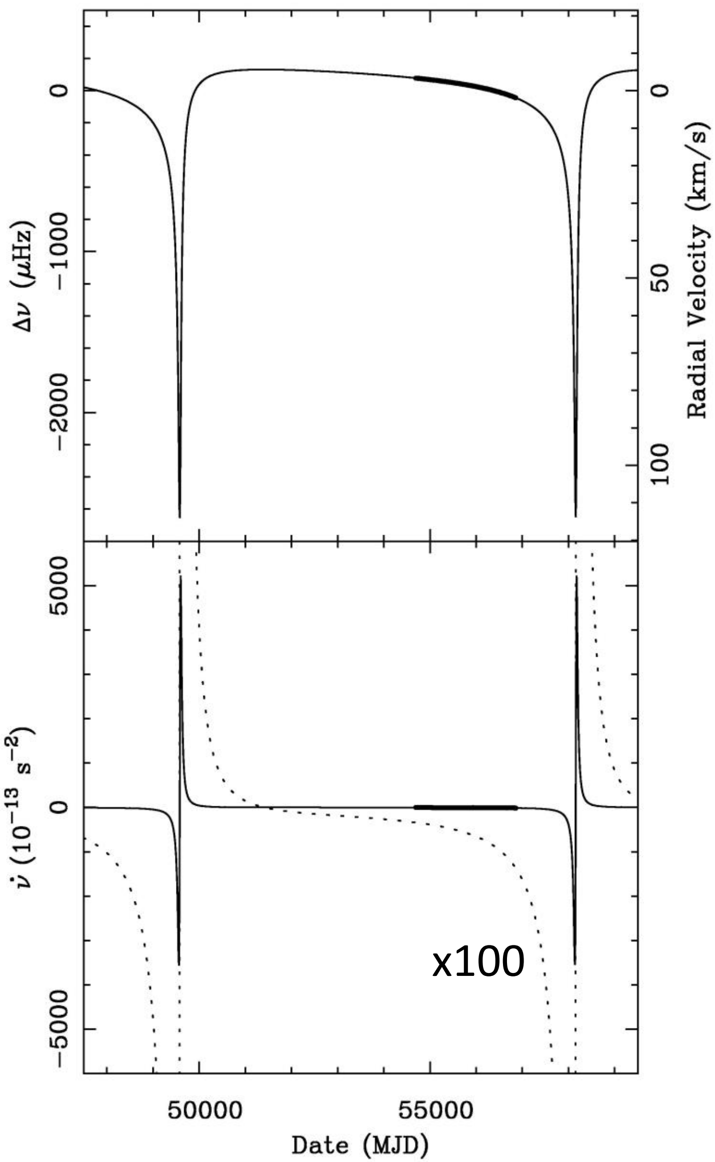
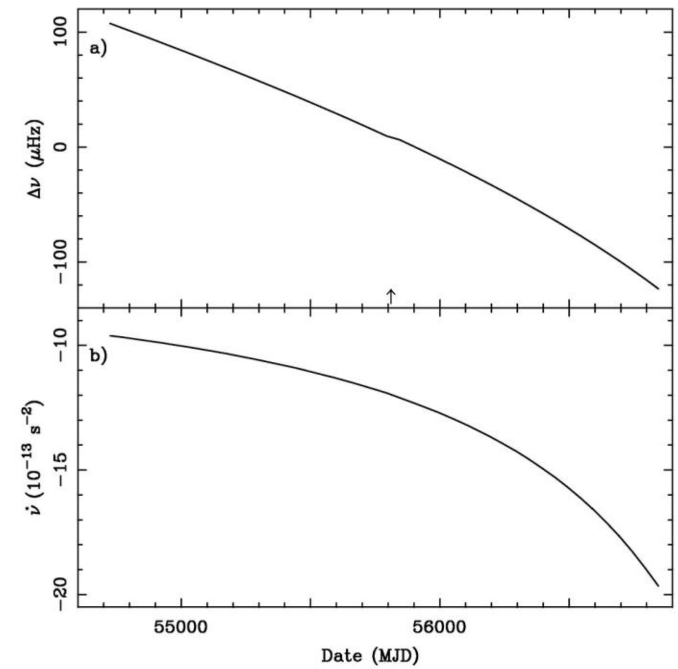
- Timing residuals relative to the best-fit "binary" model, P_b = 8578 d and mass function f_m = 10 $M_\odot$

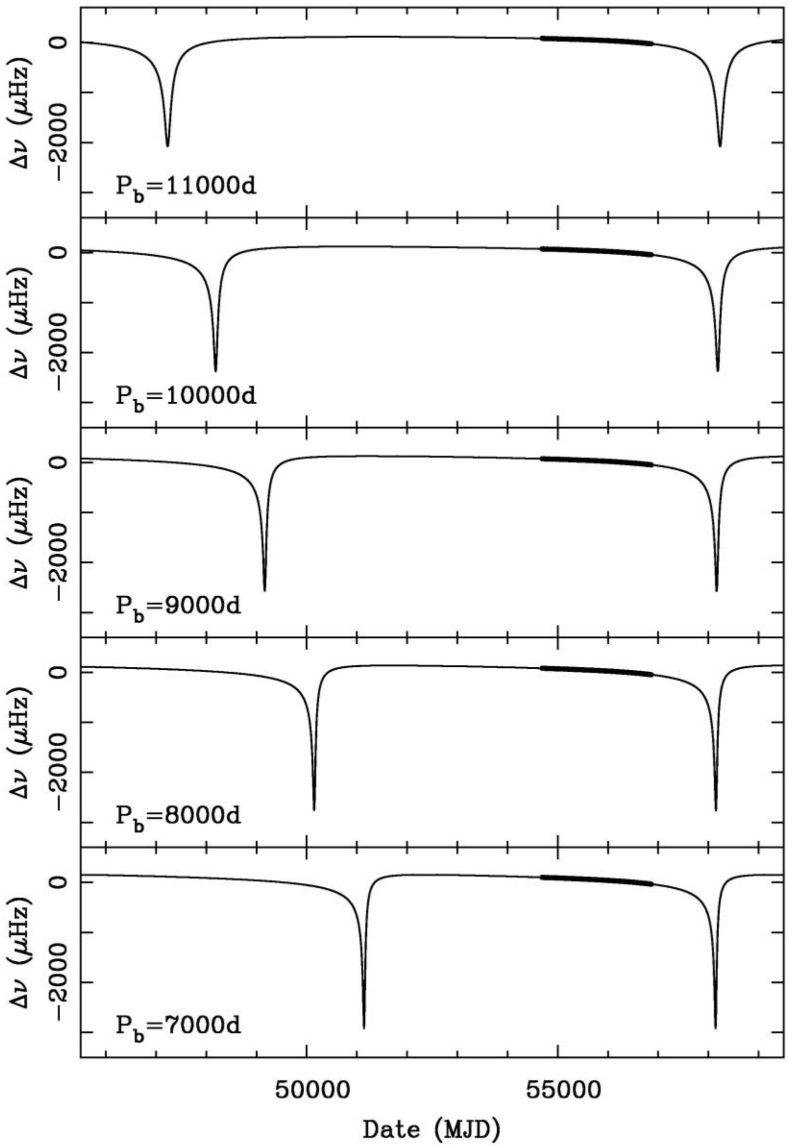
PSR J2032+4127 – Best binary fit

Orbital Period P_b = 8578 day
Mass function $f_m = 10\ M_\odot$





J2032+4127 – Possible binary orbits



Mass function $f_m = 10\ M_\odot$

Epoch of Periastron

T_o=MJD 58175±25

(Feb/Mar 2018)

Pulsar

Characteristic Age

~20kyr

The Companion

- Pulsar is within 0.4” of MT91 213, a 12^m Be star
- Spectral type B0V
- Mass of B0V stars =$15.0\pm 2.8\ M_\odot$ (Hohle et al 2010)
- If $M_p = 1.35\ M_\odot$ and $i=60^o$, expected mass-function

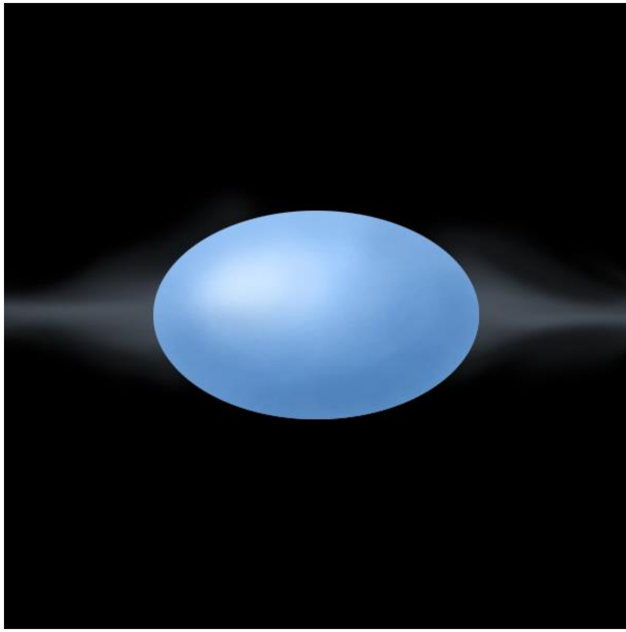
$f_m = (M_c \sin i)^3/(M_p+M_c)^2 = 8.2\ M_\odot$

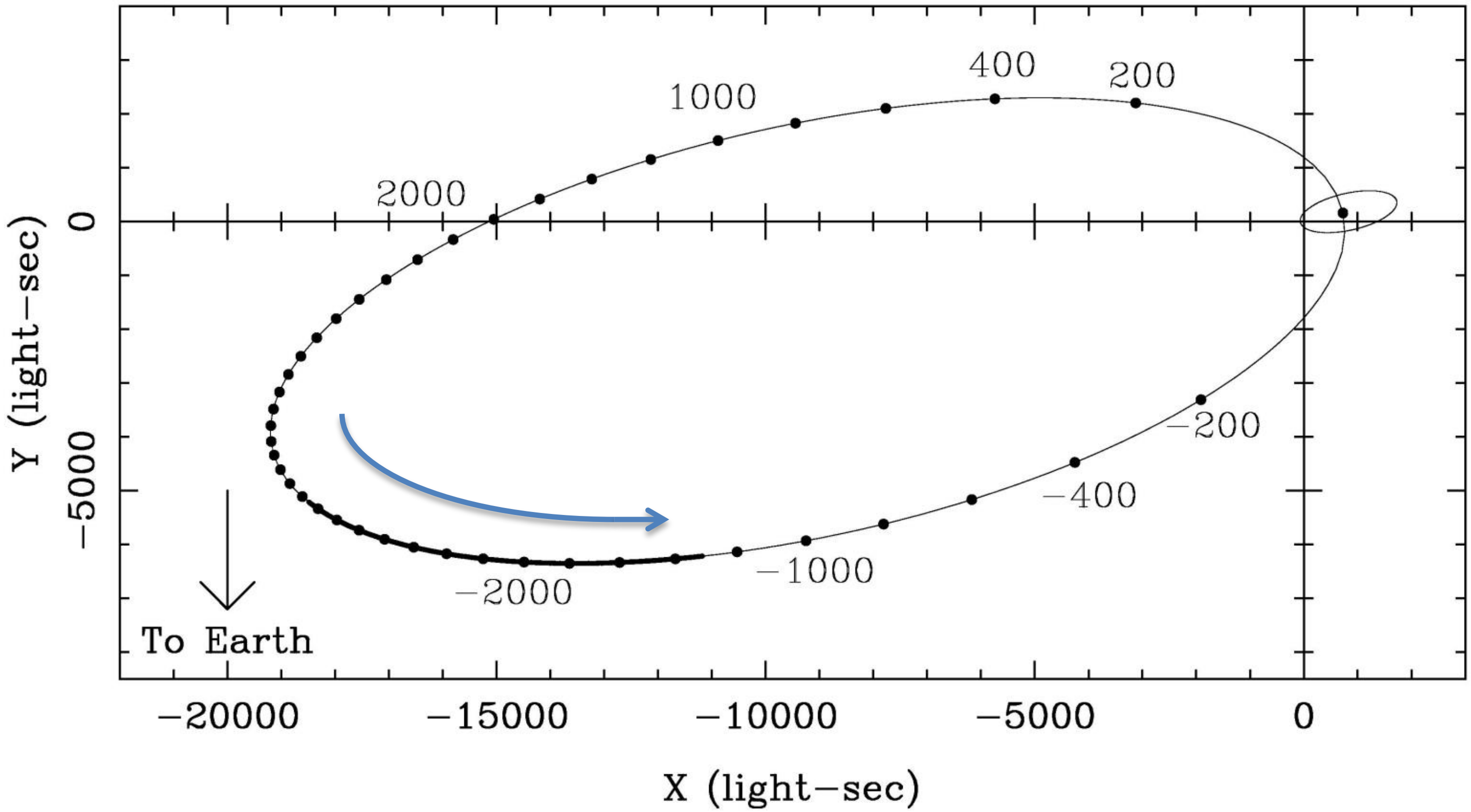
i.e. within the measured range

- Two other Be-NS binaries known

PSR B1259-63 and PSR J1638-4725

- Be stars – properties due to large angular mmtm –> spin + disk





Schematic diagram showing the orbital motions of PSR J2032+4127 and its Be-star companion MT91 213 about their common centre of mass for fm = 10 $M_{\odot}$, projected onto the plane containing the line-of-sight and the major axis of the orbit. The inclinaton i of the plane of the orbit to the plane of the sky is assumed to be 60°. The markers are at 200-day intervals and indicate the time from periastron. The thick line shows the portion of the pulsar orbit covered by the observations reported here. The pulsar is currently (MJD 56912) on the near side of the Be star and is about 1300 days before periastron passage. Note that the orbital velocity is proportional to the separation of the markers, a 1000-light-sec separation indicating a velocity of about 18 km s−1. The small ellipse near the origin shows the orbit of Be star, assuming that it has a mass of 17.5 $M_{\odot}$ and that the pulsar has a mass of 1.35 $M_{\odot}$.

Conclusions

- PSR J2032+4127 is in a binary system.
- Companion is most likely MT91 213, a Be-star.
- NS orbit has largest size, period and companion mass.
- Orbital period between 20-30 years & mass function 5-15 $M_{\odot}$.
- DM/RM variations expected around periastron.
- Study the wind and disk of the companion star.
- HE emission probably not PWN emission but from circumstellar and/or intra-binary shocks.
- Variability in high energy emission likely.
- We should get ready for periastron in Feb/Mar 2018!

Fit Results

Errors derived using a Monte Carlo method

Parameter	Noise Model	Parameter	Binary $f_m = 10 M_\odot$	Binary $f_m = 20 M_\odot$
Right Ascension, α (J2000.0)	$20^h32^m13.^s111(8)$		$20^h32^m13.^s107(8)$	$20^h32^m13.^s105(8)$
Declination, δ (J2000.0)	$41°27'24.17(10)$		$41°27'24''.36(10)$	$41°27'24''.36(10)$
Epoch of frequency, t_0 (MJD)	55714.0		55700.0	55700.0
Freq, ν_0 (Hz)	6.9808479486(10)		6.980808(12)	6.980806(12)
Freq 1st deriv, $\dot{\nu}_0$ (10^{-12}s^{-2})	$-1.16583(12)$		$-0.61(5)$	$-0.61(5)$
Glitch Epoch, T_g (MJD)	55810.51(2)		55810.76(7)	55810.76(7)
Freq, $\Delta\nu_g$ (10^{-6} Hz)	1.907(2)		1.907(2)	1.907(2)
Freq 1st deriv, $\Delta\dot{\nu}_g$ (10^{-16}s^{-2})	$-4(3)$		$-10(2)$	$-10(2)$
DM (pc cm^{-3})	114.66(3)		114.65(3)	114.65(3)
DM deriv, DM1 (pc cm^{-3}y^{-1})	0.00(1)		0.00(1)	0.00(1)
Timing noise parameters:		Binary parameters:		
Freq 2nd deriv, $\ddot{\nu}_0$ (10^{-20}s^{-3})	$-0.3651(7)$	Orbital period, P_b (d)	8578(1200)	8625(1200)
Freq 3rd deriv, $f3$ (10^{-28}s^{-4})	$-0.439(2)$	Epoch of Periastron, T_0 (MJD)	58161(31)	58153(31)
Freq 4th deriv, $f4$ (10^{-36}s^{-5})	$-0.690(14)$	Proj. semi-major axis, x (lt-s)	8819(1250)	11151(1250)
Freq 5th deriv, $f5$ (10^{-44}s^{-6})	$-1.26(9)$	Eccentricity, e	0.93(3)	0.95(3)
Freq 6th deriv, $f6$ (10^{-52}s^{-7})	$-6.2(3)$	Long. of Periastron ω (deg)	12(4)	10(4)
Freq 7th deriv, $f7$ (10^{-60}s^{-8})	$-27(3)$			
RMS timing residual, σ (ms)	0.53		0.57	0.56