A Light Redback Companion of PSR J1622–0315 and Irradiation Power in Spider Systems

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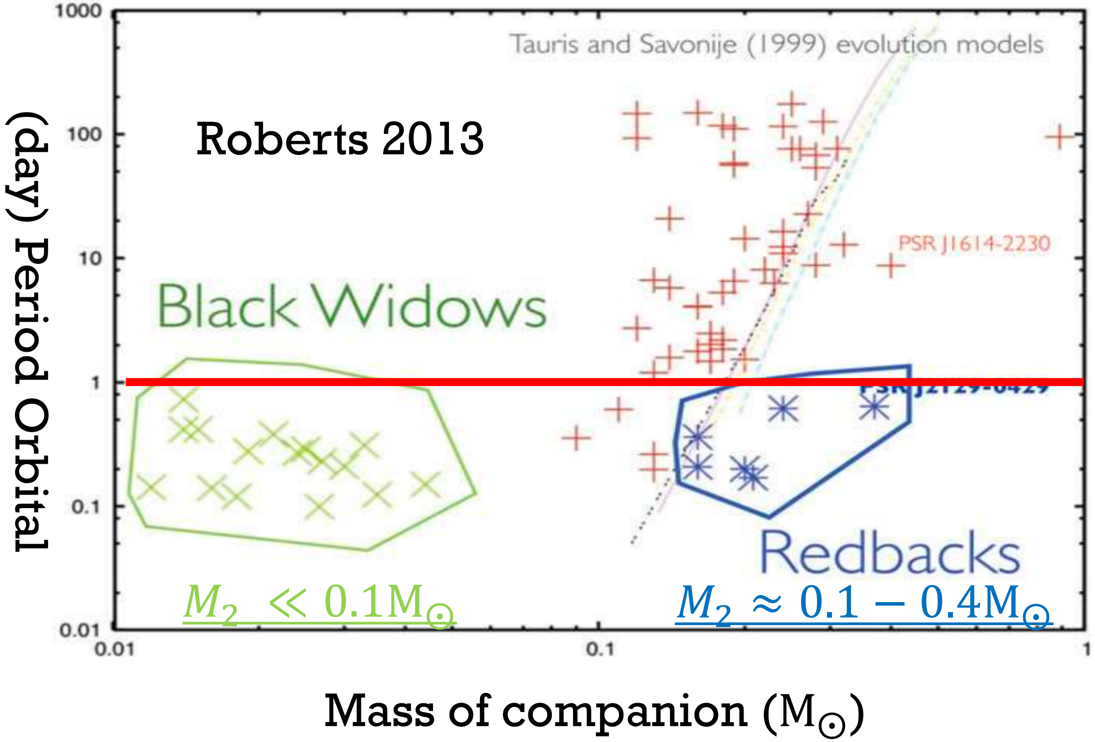
1 Background

Spider binary system

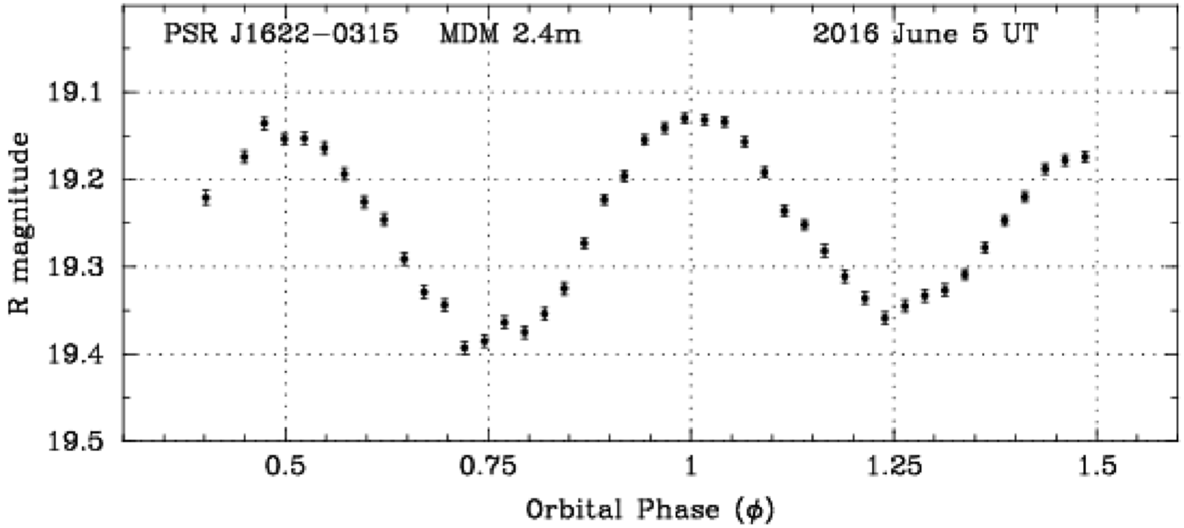
- Compact binaries containing a millisecond pulsar (MSP) with a low-mass companion star, which is ablated away by energetic particles and/or γ-rays produced by the pulsar wind.

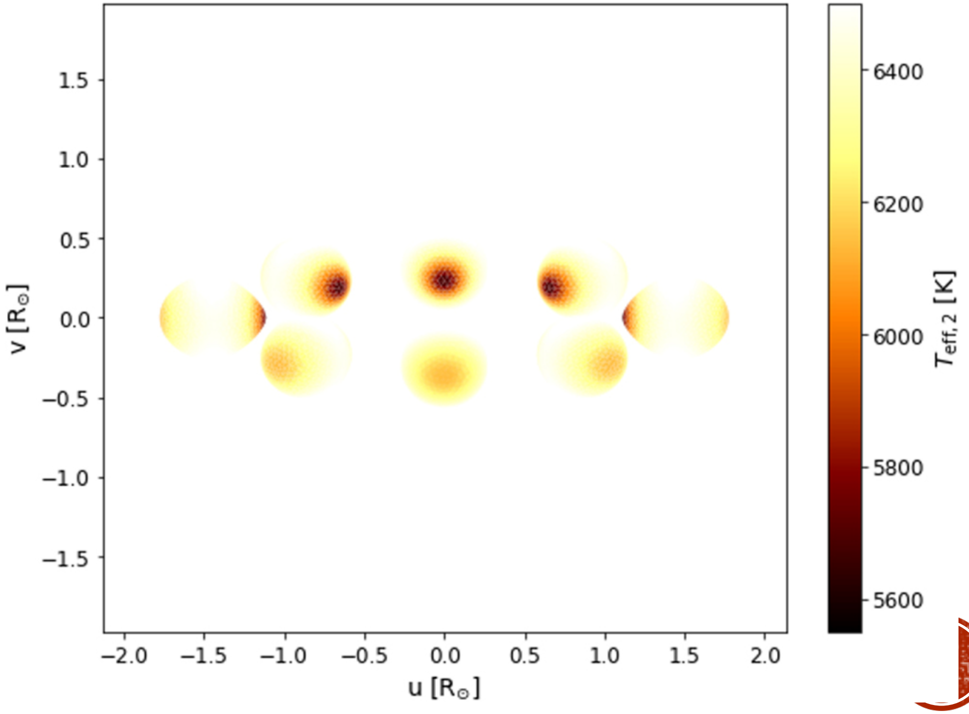


1 Background

PSR J1622–0315

- R.A. = 16:22:59s .6 and decl. = –03:15:37.3 (J2000)
- A binary MSP discovered by Sanpa-Arsa (2016) using the Green Bank Telescope (GBT) and the Nancay telescope.
- Optical counterpart was identified with the MDM Observatory.
- An orbital period of 3.9 hour and the dispersion measure is 21.4 pc cm^{-3} (~20% uncertainties).
- Its light curve exhibits an ellipsoidal variation.
- From the pulsar timing, the mass function was obtained and a companion mass of >0.1 $M_\odot$ was derived, assuming an NS mass of 1.35 $M_\odot$ and an edge-on orbit （Sanpa-Arsa 2016）.
- From the measurements of the companion radial velocity, the NS mass to be constrained to >1.45 $M_\odot$ for an edge-on orbit or, alternatively, constrained the inclination to >64° if the pulsar is less massive than 2.0 $M_\odot$ （Strader et al. 2019）.



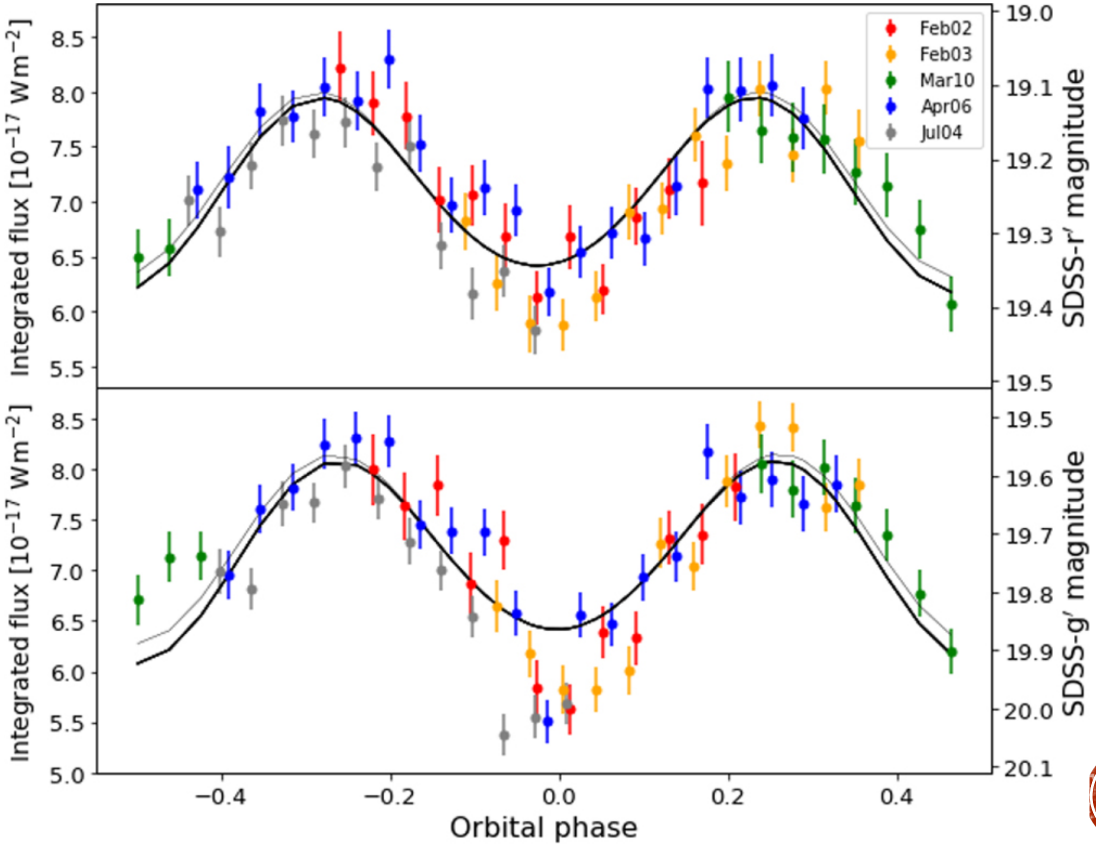


2 Observations

Table 1
Observation Details of MSP J1622–0315

Telescope	Date	Filter (SDSS)	Exposure Time (s)	Duration (minutes)
Lulin 1 m	2019 Feb 2	r', g'	180, 300	120
	2019 Feb 3	r', g'	180, 300	120
	2019 Apr 6	r', g'	180, 300	180
	2021 Jul 4[a]	r', g'	180, 300	36
Lijiang 2.4 m	2019 Mar 10	r', g'	180, 300	80

- Only analyzed the observations that occurred when the weather conditions allowed a seeing better than $FWHM < 3''$.
- Source counts were extracted from circular apertures with 4” radii; background counts from annular regions centered at the positions of the stars, with inner radii of 8” and width of 2” .
- Eight spherical, unsaturated point sources that are relatively isolated, as comparison stars and calculate the average instrumental magnitude.
- Another stable bright star as a reference star and differential magnitudes of it varied less than 0.1 mag among the frames.



3 Light-curve Modeling

PHOEBE v2.3 (Conroy et al. 2020)

MCMC sampling

Table 2

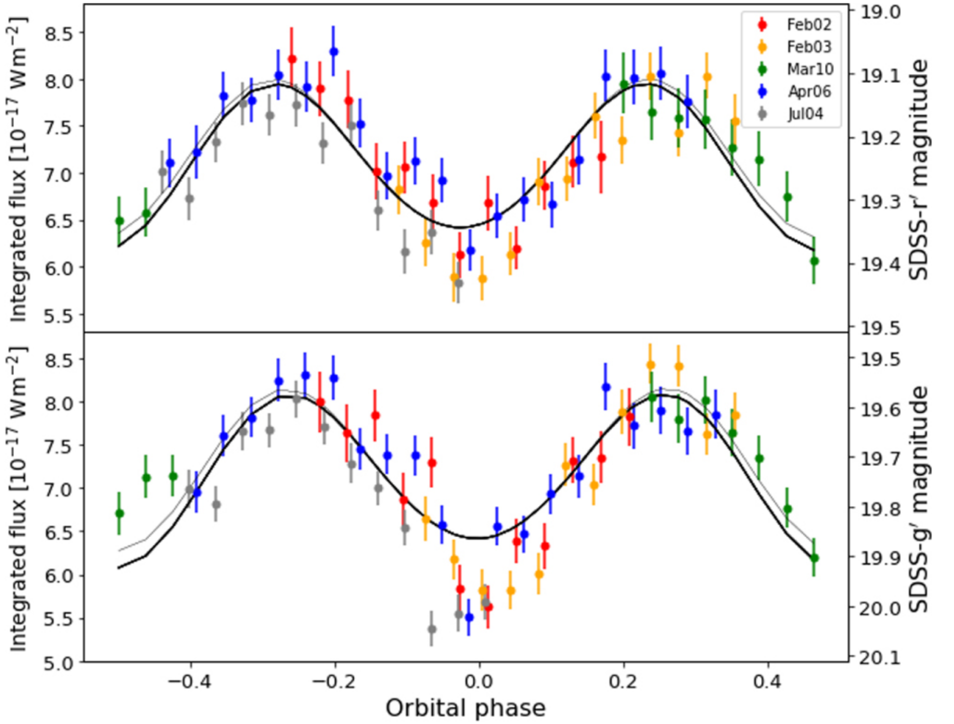
Uniform Priors Are Applied to the Following Fitting Parameters

Lower Limit	Parameter	Upper Limit
0.04	$q_{\rm binary}$	0.12
3500	$T_{\rm eff,2}$ (K)	7000
50	$i_{\rm binary}$ (°)	90
0.7	$A_{\rm V}$ (mag)	0.9
1.664	d (kpc)	7.766

For companion radius, used a Gaussian prior with a mean value of 0.27 $R_\odot$

The PSR J1622–0315 companion is the hottest RB companion known so far.

Fitting Results



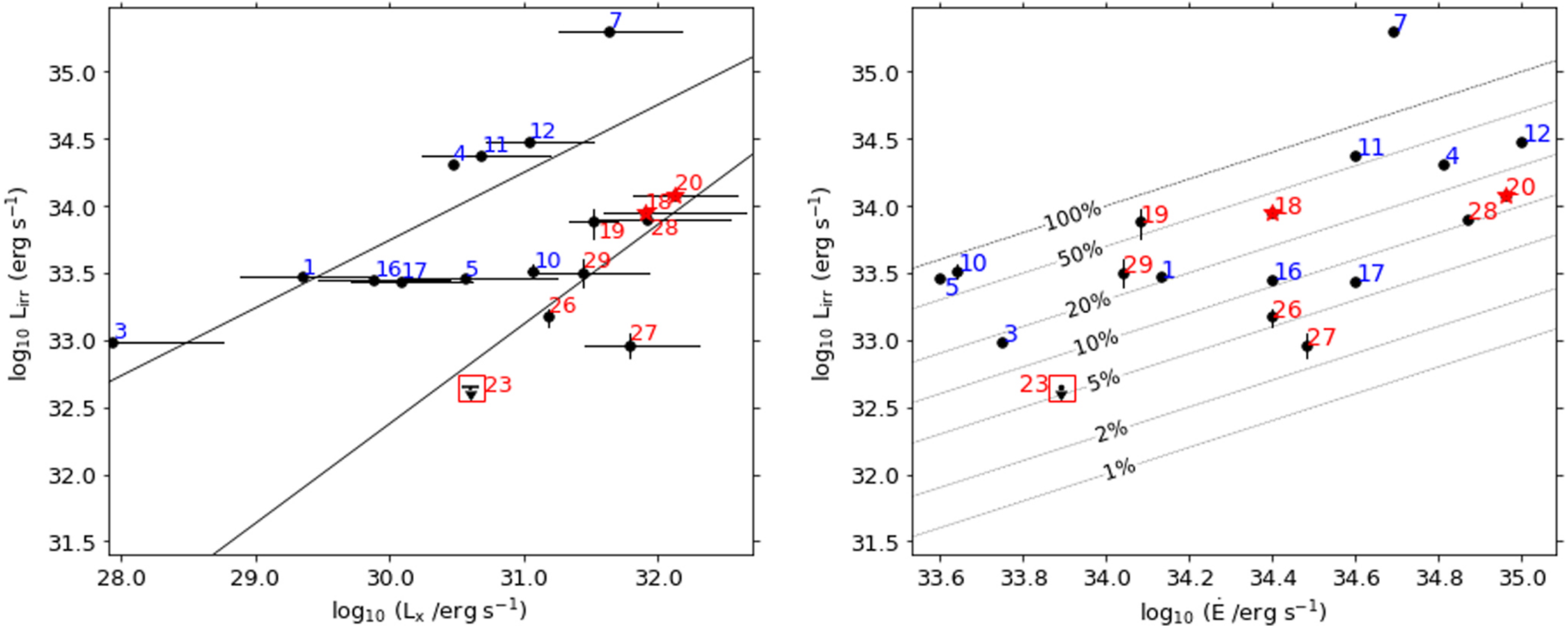
Best-fit Results with 1σ Uncertainties

Fit Parameter(s)	Result(s)
$q_{\rm binary}$ $[M_{\rm comp}/M_{\rm NS}]$	$0.066^{+0.005}_{-0.003}$
$T_{\rm eff,2}$ (K)	6383^{+89}_{-98}
$i_{\rm binary}$ (°)	$78.1^{+7.9}_{-6.9}$
$R_{\rm equiv,2}$ $(R_\odot)$	$0.279^{+0.004}_{-0.004}$
$A_{\rm V}$ (mag)	$0.81^{+0.06}_{-0.07}$
d (kpc)	$2.06^{+0.04}_{-0.04}$
Derived Parameter(s)	
$M_{\rm primary}$ $(M_\odot)$	$1.84^{+0.19}_{-0.19}$
$M_{\rm secondary}$ $(M_\odot)$	$0.122^{+0.007}_{-0.006}$

4 Discussions

The relationship between the irradiation luminosity (L_{irr}), the X-ray luminosity (L_{X}), and the spin-down luminosity ($\dot{E}$)

- Irradiation luminosity is about 2 orders of magnitude higher than the X-ray luminosity, the X-ray emission, regardless of its origin, is unlikely to be the main source of irradiation in these systems.
- The heating mechanism involves some form of reprocessing of the spin-down energy (such as intrabinary shocks).

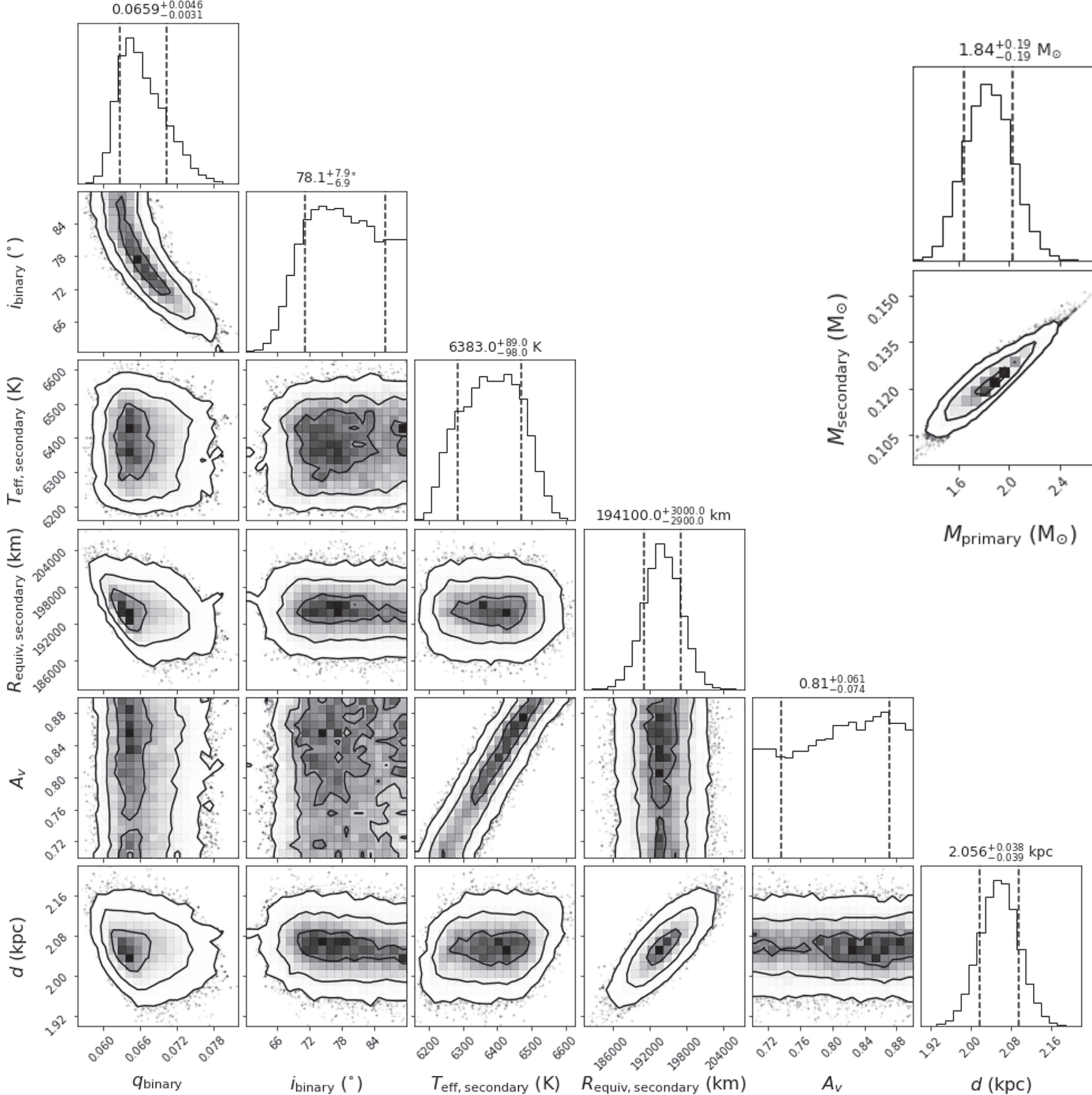


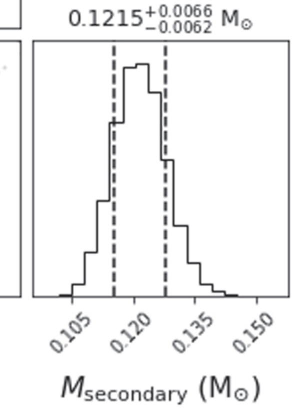
5 Summary

- Based on the new observed light curves of PSR J1622-0315, the physical parameters are derived using PHOEBE through MCMC sampling. And the companion is the hottest RB companion known so far.

- After comparing the relationship between the irradiation luminosity, the X-ray luminosity, and the spin-down luminosity, the X-ray emission is unlikely to be the main source of irradiation in these systems, and the heating mechanism involves some form of reprocessing of the spin-down energy.

THANKS


$0.0659^{+0.0046}_{-0.0031}$
$78.1^{+7.9°}_{-6.9}$
$6383.0^{+89.0}_{-98.0}$ K
$194100.0^{+3000.0}_{-2900.0}$ km
$0.81^{+0.061}_{-0.074}$
$2.056^{+0.038}_{-0.039}$ kpc
$i_{\rm binary}$ (°)
$T_{\rm eff,\,secondary}$ (K)
$R_{\rm equiv,\,secondary}$ (km)
A_v
d (kpc)
$q_{\rm binary}$


$1.84^{+0.19}_{-0.19}$ $M_\odot$
$0.1215^{+0.0066}_{-0.0062}$ $M_\odot$
$M_{\rm secondary}$ ($M_\odot$)
$M_{\rm primary}$ ($M_\odot$)

Item	Designation	BW/RB[a]	P (ms)	$\dot{P}$ ($\times 10^{-21}$ s s^{-1})	Companion Mass ($M_\odot$)	$L_{\rm irr}$ ($\times 10^{34}$ erg s^{-1})	$\log_{10}$ ($L_{\rm x}$/erg s^{-1})	$\log_{10}$ ($\dot{E}$/erg s^{-1})	References
1	PSR J0023+0923	BW (1)	3.05	9.61	$0.018^{+0.002}_{-0.001}$	$0.296^{+0.016}_{-0.013}$	$29.35^{+0.47}_{-0.53}$	34.13	1, 2
2	PSR J0251+2606	BW (1)	2.54	7.57	$0.032^{+0.006}_{-0.003}$	$0.252^{+0.012}_{-0.011}$	…	34.26	1, 4
3	PSR J0636+5128	BW (1)	2.87	3.35	$0.018^{+0.001}_{-0.001}$	$0.097^{+0.001}_{-0.001}$	$27.93^{+1.18}_{-0.82}$	33.75	1, 5
4	PSR J0952–0607	BW (1)	1.41	4.56	$0.029^{+0.001}_{-0.001}$	$2.043^{+0.077}_{-0.076}$	30.47	34.81	1, 7, 8, 9
5	PSR J1124–3653	BW (1)	2.41	1.41	$0.041^{+0.001}_{-0.003}$	$0.286^{+0.008}_{-0.010}$	$30.56^{+0.45}_{-0.68}$	33.60	1
6	PSR J1301+0833	BW (1)	1.84	…	$0.045^{+0.001}_{-0.002}$	$0.697^{+0.046}_{-0.058}$	…	34.82	1, 10
7	PSR J1311–3430	BW (1)	2.56	20.92	$0.016^{+0.001}_{-0.001}$[b]	$\sim$20	$31.63^{+0.37}_{-0.54}$	34.69	11, 12
8	PSR J1544+4937	BW (1)	2.16	2.93	$0.025^{+0.006}_{-0.006}$	$0.161^{+0.035}_{-0.035}$	…	34.06	15, 16
9	PSR J1555–2908	BW (1)	1.79	44.5	$0.060^{+0.005}_{-0.003}$[d]	$9.92^{+0.002}_{-0.002}$[d]	…	35.49	3, 43
10	PSR J1653.6–0158	BW (1)	1.97	2.40	$0.013^{+0.001}_{-0.001}$[e]	$0.333^{+0.039}_{-0.034}$[e]	$31.07^{+0.04}_{-0.04}$	33.64	17, 18, 51
11	PSR J1810+1744	BW (1)	1.66	4.60	$0.071^{+0.027}_{-0.027}$[k]	2.389	$30.68^{+0.44}_{-0.52}$	34.60	19, 2
12	PSR J1959+2048	BW (1)	1.61	10.63	$0.036^{+0.001}_{-0.001}$	$3.01^{+0.036}_{-0.036}$	$31.04^{+0.32}_{-0.48}$	35.00	1, 20, 21
13	PSR J2017–1614	BW (1)	2.31	2.45	…[c]	…	…	33.85	22
14	PSR J2051–0827	BW (1)	4.51	12.13	$\sim$0.04	…	$28.62^{+0.55}_{-0.70}$	33.72	23, 24
15	PSR J2052+1219	BW (1)	1.99	6.70	$0.042^{+0.001}_{-0.001}$	$0.944^{+0.024}_{-0.024}$	…	34.53	1, 25
16	PSR J2241–5236	BW (1)	2.19	6.65	$0.016^{+0.001}_{-0.001}$	$0.282^{+0.005}_{-0.006}$	$29.88^{+0.42}_{-0.57}$	34.40	1, 26
17	PSR J2256–1024	BW (1)	2.29	12.10	>0.030	0.277	$30.08^{+0.37}_{-0.53}$	34.60	2
18	PSR J1023+0038	RB (1)	1.96	11.81	$0.205^{+0.008}_{-0.008}$[j], [f]	0.884	$31.90^{+0.31}_{-0.75}$[i]	34.40	27, 29, 2
19	PSR J1048+2339	RB (1)	4.67	30.37	0.24–0.35	$0.759^{+0.210}_{-0.175}$	$31.52^{+0.18}_{-0.18}$[h]	34.08	30, 31, 32
20	PSR J1227–4853	RB (1)	1.69	11.11	$0.17^{+0.01}_{-0.01}$[j], [f]	$\sim$1.21[f]	$32.12^{+0.31}_{-0.47}$[i]	34.96	27, 33, 34
21	PSR J1306–40	RB (1)	2.20	…	$0.59^{+0.01}_{-0.01}$[g]	$\sim$5.90[g]	31.94	...	35, 36, 47
22	PSR J1431–4715	RB (2)	2.01	14.11	0.13-0.19	…	…	34.83	37, 38
23	PSR J1622–0315	RB (2)	3.85	11.6	$0.122^{+0.007}_{-0.006}$	…	$30.61^{+0.07}_{-0.07}$[h]	33.89	39, 40, 41
24	PSR J1628–3205	RB (2)	3.21	15.06	0.17-0.24	…	$30.96^{+0.33}_{-0.50}$	34.26	10
25	PSR J1723−2837	RB (2)	1.86	7.56	$0.36^{+0.08}_{-0.06}$	…	$31.92^{+0.31}_{-0.48}$	34.67	42, 44, 38
26	PSR J2039−5617	RB (2)	2.65	14.16	0.162-0.18	$0.150^{+0.027}_{-0.018}$	$31.18^{+0.03}_{-0.03}$[h]	34.40	38, 28, 13, 49
27	PSR J2129−0429	RB (2)	7.62	335.6	$0.44^{+0.04}_{-0.04}$	$0.091^{+0.018}_{-0.018}$	$31.79^{+0.34}_{-0.51}$	34.48	45, 46
28	PSR J2215+5135	RB (1)	2.61	33.37	$0.345^{+0.008}_{-0.007}$[k]	0.794	$31.92^{+0.41}_{-0.61}$	34.87	19, 2
29	PSR J2339−0533	RB (1)	2.88	6.68	$0.30^{+0.021}_{-0.02}$[l]	$0.316^{+0.073}_{-0.073}$	$31.44^{+0.33}_{-0.49}$	34.04	48, 50