PSR J1744-3922: a puzzle for standard binary pulsar evolution

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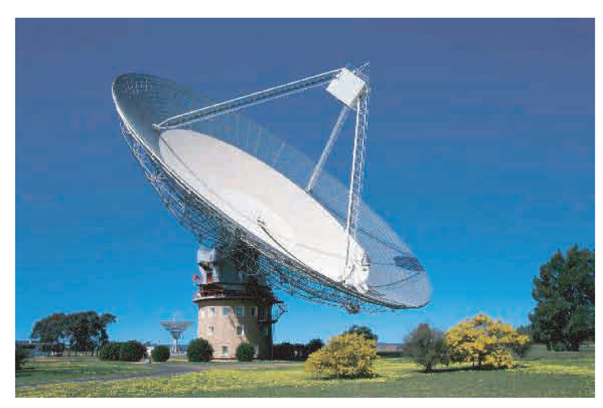
Abstract

We report on the study of PSR J1744-3922 , a binary pulsar exhibiting a strange combination of characteristics in comparison with other apparently recycled pulsars: a long spin period (172 ms), a high magnetic field (1.7×10^{10} G), a short orbital period (4.6 h) and a light companion ($M_{min} = 0.08\ M_{sun}$). Interestingly, PSR J1744-3922 also experiences sporadic and dramatic radio flux variations, first thought to be an intrinsic phenomenon (Faulkner et al. 2004); however we show here a possible correlation between the modulation and orbital phase. Altogether, these properties are not explained by any of the standard evolution models and this suggests that PSR J1744-3922 underwent a peculiar evolution history. A close examination of the binary pulsar population reveals evidence of a few other systems having similar orbital and spin characteristics, which we identify as a possible new class of binary pulsars. We discuss some plausible evolution channels leading to their atypical properties.

Introduction

PSR J1744-3922 is a pulsar having a low-mass companion in a circular orbit. We observed it using the 64-meter Parkes telescope and the 100-meter Green Bank telescope in order to demystify its odd evolution and flux behaviour.

- The pulsed flux emission from the pulsar is varying on timescales of ~1-10 minutes. Often the pulsar was undetectable for hours.
- Interstellar scintillation cannot explain the flickering.
- Faulkner et al. (2004) proposed that "nulling" is the probable source of fluctuations. This effect is a broad band sporadic interruption of the radio emission seen in some old, isolated pulsars.



The Parkes 64-meter telescope
Credit: CSRIO Parkes Observatory

Flux Analysis

Our simultaneous and non-simultaneous multi-frequency observations demonstrate a frequency dependence of this behaviour (Table 1). This argues against the standard "nulling" scenario.

We analysed the flickering using the 1400 MHz Parkes data. The average pulsed flux intensity (Fig. 1) is suggestive of a marginal orbital correlation at the 0.0186 confidence level. This value is based on a Monte-Carlo simulation and is therefore independent of the error estimate in the data.

PSR J1744-3922 has similar properties to PSR B1718-19 which is eclipsed by what is probably the wind material of its companion (Lyne et al. 1993).

Table 1. Percent of observations without detection of the pulsar

Frequency MHz	Parkes %		GBT %		Both %	
680[a]	100	(5)	-	(0)	100	(5)
820	-	(0)	75.0	(4)	75.0	(4)
1400	33.3	(72)	31.6	(19)	33.0	(91)
2200	-	(0)	0.0	(4)	0.0	(4)
2900[a]	50.0	(4)	-	(0)	50.0	(4)
Total	38.3	(81)	33.3	(27)	37.0	(108)

Note. — Numbers in parentheses represent the total number of observations for each band.

[a]Observations at 680 MHz and 2900 MHz have been done simultaneously. Excessive RFI contaminations prevent us using one of the 2900 MHz observations.

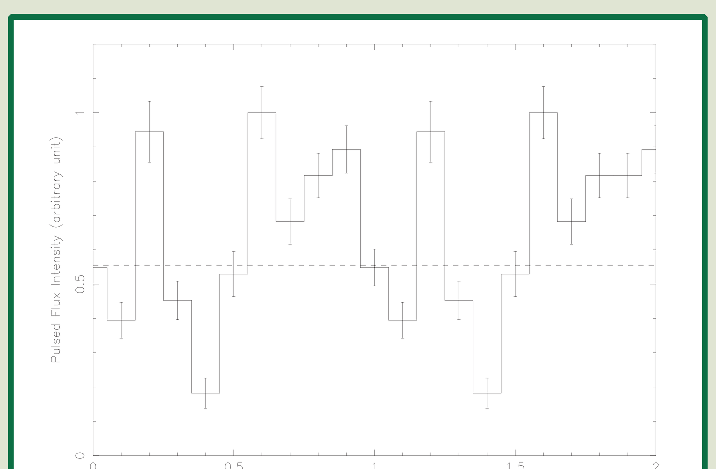


Fig. 1.— Average pulsed flux intensity as a function of the orbital phase. The dashed line is the best-fit for a constant flux model. Orbital phases are defined so that 0.0 is when the companion is in front of the pulsar.

Binary evolution: A Brief Review

Binary radio pulsars are generally "recycled" in that they have undergone an extended period of mass accretion from their companions, which usually involves transfer of angular momentum and resulting spinning up of the pulsar.

Case A evolution: The pulsar is spun up to short periods ($P < 8$ ms) after accreting matter from a low-mass star during a long and steady Roche-lobe overflow phase. This lowers the B-field to $\sim 10^{8\text{-}9}$ G. The companion is a He WD.

Case B evolution: The pulsar is partly spun up ($P > 8$ ms) by accreting from an intermediate-mass star evolving in a short-duration common envelope phase. The B-field suppression is less efficient ($\sim 10^{9\text{-}10}$ G) and the remaining companion is a CO or ONeMg WD ($M > 0.45\ M_{sun}$).

PSR J1744-3922's evolution: Does not fall in either of the above.

- This object appears to have a light companion ($M_{min} = 0.08\ M_{sun}$) in a tight and nearly circular orbit suggesting it is fully recycled ("Case A" channel).
- The relatively long spin period and modest B-field strength are typical of mildly recycled pulsars. These pulsars experienced the "Case B" formation channel.

A New Binary Pulsar Class

PSR J1744-3922 is not the only pulsar to have properties that are difficult to explain using conventional binary evolution theory (see Table 2 below). These pulsars are located in a region of the P-B-M_2-P_{orb} parameter space inaccessible to the standard models (Fig. 2).

We propose to define a new binary pulsar class having the following properties:

1) low eccentricity orbit
2) relatively long spin period
3) moderate B-field ($\sim 10^{10\text{-}11}$ G)
4) low-mass companion ($\sim 0.08\text{-}0.3\ M_{sol}$)
5) short orbital period

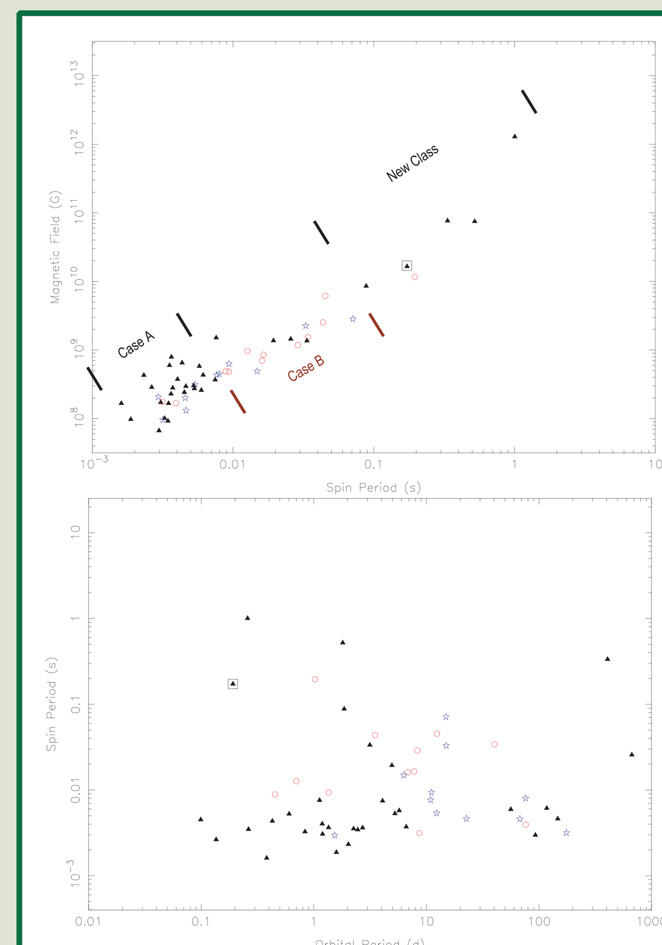


Fig. 2.— Surface dipole magnetic field strength versus spin period (upper panel) and spin period versus orbital period (lower panel) for binary pulsars in circular orbit ($e < 0.01$). Symbols indicate the companion minimum mass: $M_2 \leq 0.2 M_\odot$, $0.2 M_\odot < M_2 \leq 0.3 M_\odot$ and $M_2 > 0.3 M_\odot$ are fille[redacted]

Possible Evolutionary Scenarios

We consider three possible mechanisms for creating members of this class:

1) Standard "Case A" evolution but the accreting neutron star has a magnetar-like B-field. A rescaling of the problem could thus explain a higher-than-usual B-field.

2) Common envelope phase evolution with a low-mass star which becomes a He WD. Systems having orbital periods of a few hours could lose orbital angular momentum through gravitational wave radiation and become ultra-compact X-ray binary progenitors.

3) The accretion induced collapse (AIC) of a massive ONeMg WD to a neutron star. In this case, the companion does not have to be a WD but could be a bloated MS star as Janssen & van Kerkwijk (2005) reported for PSR B1718-19.

Table 2. Characteristics of partly recycled binary pulsars ($P_s > 8$ ms) in low-eccentricity orbit ($e < 0.01$) and having low-mass companions ($M_{min} < 0.2 M_\odot$)

Name	P_s ms	$\log B_s$ G	P_B days	M_{min}[a] $M_\odot$	Type
Case A	$\lesssim 8$	8-9	-	$\lesssim 0.45$	He WD
Case B	$\gtrsim 8$	8.5-10	-	$\gtrsim 0.45$	CO WD
PSR J1744-3922	172.44	10.22	0.19	0.08	?
PSR B1718-19	1004.03	12.11	0.25	0.12	Bloated MS[b]
PSR B1831-00	520.95	10.87	1.81	0.06	?
PSR J1232-6501	88.28	9.93	1.86	0.14	?
PSR J1614-2318	33.50	9.14	3.15	0.08	?
PSR J1745-0952	19.37	9.51	4.94	0.11	?
PSR B1800-27	334.41	10.88	406.78	0.14	?
PSR J0407+1607	25.70	9.16	669.07	0.19	?

[a]M_{min} refers to the minimum mass of the companion, assuming a mass for the pulsar of $1.4 M_\odot$

[b]Janssen & van Kerkwijk (2005)

Conclusions

- We show the pulsed flux modulation is frequency dependent, in disagreement with it being classical "nulling".
- We find a possible correlation of the pulsed flux modulation, again in disagreement with the "nulling" hypothesis.
- We note similarities with other binary pulsars having peculiar properties and propose a new class of binary pulsars.
- Determining the nature of the companion through optical observations would shed light on their evolution.

References

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