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 (1.7x10^{10} G), a short orbital period (4.6 h) and a light companion (M_{com} = 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 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 isolated pulsars.

Flux Analysis

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).

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_{com} 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 (~10^{10} G)
4) low-mass companion (~0.08-0.3 M_{sun})
5) short orbital period

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 then 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.

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 ~10^{14} 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 (~10^{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_{com} = 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 moderate B-field strength are typical of mildly recycled pulsars. These pulsars experienced the “Case B” formation channel.

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

Lyne et al., 1993, Nature, 361, 47
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