High-mass X-ray Binaries: Illuminating the Passage from Massive Binaries to Merging Compact Objects
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ONe WD+He star systems as the progenitors of IMBPs

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Abstract. Previous theoretical studies can only explain part of the observed intermediate-mass binary pulsars (IMBPs) with short orbital periods. Note that an ONe white dwarf (WD) accreting mass from a He star may experience the accretion-induced collapse process and eventually form IMBPs, known as the ONe WD+He star scenario. By investigating the evolution of a large number of ONe WD+He star binaries, we found that the ONe WD+He star scenario can form IMBPs including pulsars with $5-340$ ms spin periods, and the orbital periods range from 0.04 to 900 d. Compared with the observed IMBPs, this scenario can cover almost all of the IMBPs with short orbital periods. Thus, we suggest that the ONe WD+He star channel is responsible for the formation of IMBPs with short orbital periods.

Keywords. binaries: close – stars: evolution – white dwarfs – stars: neutron

1. Introduction

In the observations, intermediate-mass binary pulsars (IMBPs) are composed of a pulsar with a spin period of about 10−200 ms and a heavy ($M_{\rm WD} > 0.4\,{\rm M}_\odot$) carbon-oxygen (CO) or oxygen-neon (ONe WD) (Camilo *et al.* 1996, 2001; Edwards & Bailes 2001). However, the progenitors of these IMBPs are still not understood. Generally, it has been suggested that most IMBPs originate from the intermediate-mass X-ray binaries (IMXBs) including a neutron star (NS) and a $2.0-10.0\,{\rm M}_\odot$ H-rich donor star (e.g. van den heuvel 1975). However, this channel cannot produce IMBPs with orbital periods shorter than 3 d (see Tauris, van den Heuvel & Savonije 2000). Chen & Liu (2013) suggested that the NS+He star channel can explain the formation of 4 IMBPs with short orbital periods.

However, these models can only explain part of IMBPs with orbital periods shorter than 3 d (e.g. Chen & Liu 2013). Another formation channel for IMBPs is the ONe WD+He star scenario, in which an ONe WD accreting mass from a H star will experience the accretion-induced collapse process when the WD mass approaches the Chandrasekhar mass limit, and can eventually form an IMBP when the He star turns to be a WD (see Tauris *et al.* 2013). However, Tauris *et al.* (2013) only considered the case with the initial mass of the primary ONe WDs $M^{\rm i}_{\rm WD} = 1.2\,{\rm M}_\odot$. In this work, we evolve a large number of ONe WD+He star systems for the formation of IMBPs with $M^{\rm i}_{\rm WD} = 1.0, 1.1, 1.2$ and $1.3\,{\rm M}_\odot$, and found that almost all of the observed IMBPs with short orbital periods can be explained by the ONe WD+He star scenario.

2. Model and Results

In order to obtain the parameter space of IMBPs from the ONe WD+He star scenario, we employed the Eggelton stellar evolution code (Eggleton 1973), and carried

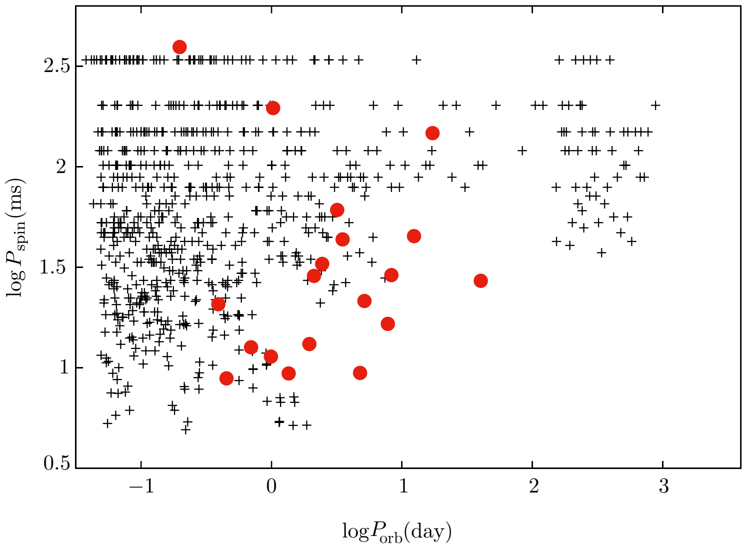

Figure 1. Parameter space of the formed IMBPs in the orbital period−spin period (log $P_{\rm orb}-P_{\rm spin}$) plane. The orbital periods are measured at the formation moment of IMBPs. The plus symbols denote the predicted IMBPs by our simulation, and the filled circles represent the observed IMBPs (see Manchester *et al.* 2005). Source: Liu *et al.* (2018).

out a number of detailed binary evolution calculations for ONe WD+He star systems that would experience the accretion-induced collapse process and eventually produce IMBPs. We then provided the parameter space for the formed IMBPs in the orbital period−spin period plane, and compared with the observed IMBPs taken from the ATNF Pulsar Catalogue in 2017 October (Manchester *et al.* 2005; see http://www.atnf.csiro.au/research/pulsar/psrcat).

In Fig. 1, we present the parameter space of the predicted IMBPs in the orbital period−spin period plane (i.e. the Corbet diagram; Corbet 1984). In this figure, the spin periods of recycled NSs are in the range of $\sim 5-340$ ms, and the orbital periods are distributed in the range of ∼0.04−900 d. In this figure, we also plot the 19 observed IMBPs by filled circles. We found that the orbital periods and spin periods of 13 observed IMBPs can be covered by the ONe WD+He star scenario, and almost all the observed IMBPs with orbital periods shorter than 3 d can be covered.

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