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A Statistical Study on Double Neutron Star Masses† ⋆

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Abstract By statistically analyzing the masses of twelve double neutron star (DNS) systems, it is concluded that the weighted mean value of DNS masses is (1.339±0.042) $M_{\odot}$, where the weighted mean masses of the primary and companion stars are respectively (1.439±0.036) $M_{\odot}$ and (1.239±0.020) $M_{\odot}$. The mean value of the masses of primary stars is higher than that of companion stars, which indicates that the primary star may increase its mass by accretion, or the mass of its progenitor star is higher. Therefore, the physical process of supernova explosion through which the high-mass stars become NSs can be investigated hereby. Also it is found that the total masses of the DNSs span a narrow range of 2.5∼2.8 $M_{\odot}$, implying that the companion stars might impact on the mass formation of DNSs. Moreover, the mass ratios of the DNSs (primaries to companions) approximate 1 (slightly larger than 1), indicating that the masses of the progenitors of primary stars are approximately equal to the masses of the progenitors of companion stars. By analyzing the distribution of the 12 DNSs in the surface magnetic field strength versus spin period (B-$P_{\rm s}$) diagram, it is found that the surface magnetic field strength in the primary stars of the DNSs is $\sim 10^{10}$ Gs, and the spin period is $\sim$ 50 ms; while the two pulsars, i.e. PSR J1906+0746 and PSR J0737-3039B, are located in the region of normal pulsars in the B-$P_{\rm s}$ diagram, their surface magnetic field strength is $\sim 10^{12}$ Gs, suggesting that they might not be accelerated through accretion.

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1. INTRODUCTION

Double neutron star (DNS) was first detected by Hulse and Taylor in 1975[1], sofar totally 13 pairs of DNSs have been found (the masses of 12 pairs of DNSs have been measured). The measurement on the mass of a neutron star (NS) depends on the measurement of the parameters of the DNS system. The masses of NSs are of important significance for studying the strong gravitational field, general relativistic effect, and gravitational radiation in DNSs[2]. Secondly, not only the study on the mass distribution of NSs can reveal the components, structures, and the state equation of the interior nuclear matter of compact objects[3−5], but also these compact objects with a superhigh density provide a favorable natural laboratory for studying nuclear physics[6−8]. Finally, the analysis on the masses of NSs can be used to study the process of supernova explosion and the formation mechanism of NSs, as well as the evolution of NSs under the action of binary stars[9].

The observation on the first pair of detected DNS system PSR B1913+16 shows that because of the high eccentricity and relatively small orbital period of its own, the relativistic effect becomes more obvious, the observation has obtained the post-Kepler (PK) parameters, the procession of periastron, as well as the orbital shrink and Shapiro delay, and its orbital motion accords with the prediction based on gravitational waves[10].

The study of Schwab et al.[11] shows that the masses of DNSs exhibit a double-peaked distribution, and the peak values are mainly concentrated at 1.246 $M_{\odot}$ and 1.345 $M_{\odot}$. They suggested that these peak values have shown a specific formation mechanism of DNSs: the low-mass NS forms by through the electron capture12,13], and the high-mass NS is mainly originated from the collapse of iron core[14]. Zhang et al.[15] statistically analyzed the data of 10 pairs of DNSs, and obtained their averaged mass M=1.32±0.14 $M_{\odot}$, which is lower than the typical mass of a pulsar accelerated by accretion, it means that the mass formation or evolutionary history of a DNS system may differ from that of other binary star systems. Özel et al.[16] found by statistics that the averaged mass of DNSs is 1.33 $M_{\odot}$, and that the mass distribution of DNSs deduced by using the Bayesian statistics may contain an entirely different evolutionary history. Kiziltan et al.[17] found a double-peaked distribution of the masses of NSs, and the two peak values of the masses of two kinds of NSs are respectively concentrated at 1.33 $M_{\odot}$ and 1.55 $M_{\odot}$. They accordantly suggested that the masses of NSs reflect the different formation mechanisms, and provide important information for understanding the evolutionary history of NSs.

Based on the studies of the mass distribution of DNSs, there have been already many results about the evolution of binary stars. The study of Menezes et al.[18] shows that the composition of nuclear matter in the NSs with a larger mass may be different; in the process of accretion, there is a phase change of matter from a "soft" state to a "hard" state, even it is possible that the matter transits from neutrons to quarks. Lorimer suggested that the