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Supercritical accretion in the evolution of neutron star binaries and its implications

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Abstract

Recently $\sim 2M_{\odot}$ neutron stars PSR J1614-2230 and PSR J0348+0432 have been observed in neutron star-white dwarf binaries. These observations ruled out many neutron star equations of states with which the maximum neutron star mass becomes less than $2M_{\odot}$. On the other hand, all well-measured neutron star masses in double neutron star binaries are still less than $1.5M_{\odot}$. In this article we suggest that $2M_{\odot}$ neutron stars in neutron star-white dwarf binaries are the result of the supercritical accretion onto the first-born neutron star during the evolution of the binary progenitors.

Keywords: Neutron star; Black hole; Supercritical accretion; Binary evolution

1. Introduction

A neutron star is one of the best objects to test the physics of dense matter. Especially in the cores of neutron stars many exotic states are expected to be formed but the information from the central parts of neutron stars is hidden in the macroscopic properties such as neutron star masses and radii.

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Bethe and Brown [1] suggested that the double neutron star binaries are formed only when the mass difference in the progenitors is less than 4% so that the first-born neutron star does not have enough time to accrete. They also suggested that, if the mass difference in the progenitors is bigger than 4%, the first-born neutron star might have the supercritical (super-Eddington) accretion beyond the Eddington limit and collapse into a black hole forming a neutron star-black hole binary. Their argument is based on the observations that all well-measured neutron star masses in double neutron star binaries are less than $1.5M_{\odot}$ [2,3]. Based on the soft neutron star equations of state which predict the maximum neutron star mass to be $\sim 1.5M_{\odot}$, they claimed that the first-born neutron star with the supercritical accretion collapsed into a black hole.

On the other hand, Lee et al. [4] suggested that the mass distribution of neutron stars in double neutron star binaries is the result of the Fe core evolution of neutron star progenitors, which is rather independent of the neutron star equations of states. They claimed that the observed neutron star masses in double neutron star binaries do not indicate the maximum neutron star mass and the maximum neutron star mass can be significantly higher than $1.5M_{\odot}$, which is consistent with the recent observations of $\sim 2M_{\odot}$ neutron stars, PSR J1614-2230 [5] and PSR J0348+0432 [6], in neutron star-white dwarf binaries. These observations ruled out many neutron star equations of state with which the maximum neutron star mass becomes less than $2M_{\odot}$.

The detailed mechanism of the supercritical accretion in the evolution of neutron star binaries is still an open question. However Lee et al. [7] developed an evolution model for soft X-ray black hole binaries, in which the black holes with evolved companions went through the supercritical accretion. As a by-product, they predicted a correlation between the binary orbital period and black hole spin. Their prediction was supported by the measurements of black hole spins [8] and its implications were further carried out by Moreno Méndez et al. [9–12]. In this work, by extending the work by Lee et al. [4], we suggest that $2M_{\odot}$ neutron stars observed in neutron star-white dwarf binaries are the result of the supercritical accretion onto the first-born neutron star during the evolution of the binary progenitors.[2] We also discuss the possibilities of the existence of neutron star binaries with high-mass neutron star or black hole companions.

This article is organized as follows. In Section 2 we discuss the current status of neutron star mass measurements and their implications. In Section 3 the possibilities of the supercritical accretion in the evolution of neutron star binaries are summarized. In Section 4 distributions of neutron star masses in various types of neutron star binaries are discussed in connection with the supercritical accretion. In Section 5 the prospects and final discussion are given.

2. Neutron star masses: Observations

Neutron star mass measurements are done mainly in binaries. There are many different types of neutron star binaries that can provide information on the neutron star masses [2,3]. Typical radii of neutron stars are $\mathcal{O}(10$ km), much smaller than the orbital separation, and the radio pulsar signals from double neutron star binaries are relatively clean compared to those from other types of neutron star binaries which we discuss below. Hence the accurate measurements of neutron star masses have been done mainly in double neutron star binaries by analyzing the binary motion and the radio pulsar signals. All well-measured neutron star masses in double neutron star binaries are less than $1.5M_{\odot}$ [2,3]. On the other hand higher mass neutron stars PSR J1614-2230 and PSR J0348+0432 with $\sim 2M_{\odot}$ have been confirmed in neutron star-white dwarf

[2] Note that one cannot rule out the possibility that these neutron stars were born massive [6]. This possibility, if confirmed, could eliminate the observational support for supercritical accretion.