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Population synthesis of ultra-compact X-ray binaries *

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Abstract Ultra-compact X-ray binaries (UCXBs) are very interesting and important objects. By taking the population synthesis approach to the evolution of binaries, we carry out a detailed study of UCXBs. We estimate that there are $\sim$ 5000–10 000 UCXBs in the Galaxy, and their birthrates are $\sim$ 2.6–7.5×10^{-4} yr^{-1}. Most UCXBs are transient X-ray sources, but their X-ray luminosities are much lower than those of persistent sources. Therefore, the majority of observed UCXBs should be persistent sources. About 40% – 70% of neutron stars (NSs) in UCXBs form via an accretion-induced collapse from an accreting ONe white dwarf (WD), 1%–10% of NSs in UCXBs form via core-collapse supernovae and others form via the evolution-induced collapse of a naked helium star. About 50% – 80% of UCXBs have naked helium star donors, 5% – 10% of UCXBs have HeWD donors, 15% – 40% of UCXBs have COWD donors and UCXBs with ONeWD donors are negligible. Our investigation indicates that the uncertainty mainly comes from evolution of the common-envelope which develops in these systems.

Key words: binaries: close — stars: neutron — X-rays: binaries

1 INTRODUCTION

Low-mass X-ray binaries (LMXBs) are systems that transfer mass from a low-mass donor to its companion, a compact object accretor (a black hole or a neutron star (NS)). Up to now, there are $\sim$ 200 LMXBs known in the Galaxy (Liu et al. 2007). Of special interest are ultra-compact X-ray binaries (UCXBs), whose orbital periods are shorter than one hour. In such short orbital period binaries, the components must be so close to each other that donors cannot be ordinary hydrogen-rich stars (Nelson et al. 1986). The donors could be white dwarfs (WDs) or naked helium stars (Hes). UCXBs are very important and interesting objects for the following reasons: (i) UCXBs are strong gravitational-wave sources in the low-frequency regime ($\sim 10^{-3}$–10^{-4} Hz) where the *Laser Interferometer Space Antennae* will be sensitive. (ii) UCXBs are important labs for the theory of binary evolution, in particular for studying the evolution of a common envelope (CE). (iii) UCXBs are candidate progenitors of radio millisecond pulsars.

Up to now, there are about 30 UCXBs and candidates known (in't Zand et al. 2007). About one-third of the presently known UCXBs are in globular clusters. It was recognized 30 years ago that the total number of LMXBs observed in globular clusters clearly indicate a dynamical origin, with formation rates exceeding those in field populations by several orders of magnitude (Clark 1975).

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UCXBs in globular clusters probably originate from dynamical collisions (Verbunt 2005). However, dynamical collisions are not important in the Galactic field. UCXBs in the Galactic field generally involve CE evolution to form tight NS+WD or NS+He binaries. The orbital periods of these systems decay to the ultrashort regime via gravitational wave radiation or magnetic braking. Ma & Li (2009) proposed an alternative scenario for the formation of UCXBs through circumbinary disk-driven mass transfer between an NS and a main sequence (MS) companion.

In this work, we focus on the formation channels of UCXBs in the Galactic field and investigate their X-ray luminosities. In Sections 2 and 3 the model is described. Results and conclusions are given in Sections 4 and 5, respectively.

2 FORMATION OF ULTRA-COMPACT X-RAY BINARIES

UCXBs have such short orbital periods that they must have undergone at least one CE phase. Both stars in UCXBs are remnants that have lost their envelopes. So UCXBs have gone through two phases of interaction for a tight orbit, including the effects of having a CE. In our work, UCXBs consist of an accreting NS and a WD or an He star which fills its Roche lobe. The basic features of the scenario for the formation of WD+NS systems which can evolve into UCXBs may be summarized as follows (see e.g. Tutukov & Yungel'Son 1993; Iben et al. 1995 for details). Their formation, starting from a zero-age main sequence binary, involves a supernova for the formation of an NS.

2.1 Scenarios for the Formation of Neutron Stars

NSs can be formed via a supernova. There are three channels (e.g., Ivanova et al. 2008; Kiel et al. 2008): (i) core-collapse supernova (CCSN) for a star with an initial mass $M/M_\odot \geq 11$; (ii) evolution-induced collapse (EIC) of a helium star with a mass between 1.4 and $2.5\ M_\odot$ in which the collapse is triggered by electron capture on ^{20}Ne and ^{24}Mg (Miyaji et al. 1980); (iii) accretion-induced collapse (AIC) for an accreting ONeMg WD whose mass reaches the Chandrasekhar limit. The response of accreting ONeMg WDs is treated in the same way as the evolution of a CO WD (for details see Lü et al. 2009).

A nascent NS receives additional velocity ("kick") due to some still unclear processes that disrupt the spherical symmetry during the collapse or from the later dichotomous nature of kicks, which was suggested quite early by Katz (1975). Observationally, the kick is not well constrained due to numerous selection effects. Currently, high ($\sim 100\,\mathrm{km\ s^{-1}}$) kicks are associated with an NS originating from CCSN, while low kicks ($\sim 10\,\mathrm{km\ s^{-1}}$) with an NS born in EIC and AIC (Pfahl et al. 2002).

We apply the core-collapse NS Maxwellian distribution of kick velocity v_k

$$P(v_\mathrm{k}) = \sqrt{\frac{2}{\pi}}\frac{v_\mathrm{k}^2}{\sigma_\mathrm{k}^3}\mathrm{e}^{-v_\mathrm{k}^2/2\sigma_\mathrm{k}^2}\,, \tag{1}$$

where $\sigma_\mathrm{k} = 190$ or 400 km s^{-1} in different simulations for CCSN. For both EIC and AIC, we adopt similar distributions but with $\sigma_\mathrm{k}^* = 20$ or 10 km s^{-1} in the different simulations.

2.2 Common Envelope Evolution

The progenitors of UCXBs undergo CE evolution. The formation of CE involves a dynamically unstable mass transfer from a giant star to its companion. Although many efforts have been devoted to understanding the evolution of the CE (e.g., Ricker & Taam 2008; Ge et al. 2010; Deloye & Taam 2010), detailed knowledge about this process is still poor. It is generally assumed that the orbital energy of the binary is used to expel the envelope from the donor with an efficiency α_ce, which is called the α-algorithm. Nelemans et al. (2000) suggested describing the CE evolution by an algorithm based on the equation for the balance of orbital angular momentum in the system, which implicitly assumes there is conservation of energy (Webbink 1984); this process is called the γ-algorithm. Following Lü et al. (2006), for CE evolution in different simulations, we use $\alpha_{\rm ce}\lambda_{\rm ce} = 1.0$ in the α-algorithm and $\gamma = 1.5$ in the γ-algorithm. Here $\lambda_{\rm ce}$ is a structural parameter which depends on the evolutionary stage of the donor.

After the formation of NS+WD or NS+He systems, the orbital behavior of the binary systems changes via gravitational radiation and magnetic braking. Details are in Section 2.4 of Hurley et al. (2002). In this work, we do not consider the model of circumbinary disk-driven mass transfer proposed by Ma & Li (2009).

3 X-RAY LUMINOSITIES OF ULTRA-COMPACT X-RAY BINARIES

The X-ray luminosity of the accreting NS can be approximated by

$$L_{\rm bol} = \eta \dot{M}_{\rm NS} c^2 \simeq 5.7\times 10^{35}\ {\rm erg\ s^{-1}} \left(\frac{\eta}{0.1}\right)\left(\frac{\dot{M}_{\rm NS}}{10^{-10}\ M_\odot\ {\rm yr}^{-1}}\right), \qquad (2)$$

where $\eta \simeq 0.1$ is the efficiency of accretion onto the NS and $\dot{M}_{\rm NS}$ is the mass-accretion rate of the NS. Super-Eddington accretion rates may be important in the formation of LMXBs and millisecond pulsars (Webbink & Kalogera 1997). We assume that $\dot{M}_{\rm NS} = \min(\dot{M}_{\rm NS}, \eta_{\rm Edd}\times \dot{M}_{\rm Edd})$, where $\dot{M}_{\rm Edd}$ is the Eddington limit given by

$$\dot{M}_{\rm Edd} = 2.08\times 10^{-3}(1+X)^{-1} R_{\rm NS}\ M_\odot\ {\rm yr}^{-1}. \qquad (3)$$

Here, X is the hydrogen mass fraction. $\eta_{\rm Edd}$ is the factor that allows super-Eddington luminosities, taken to be five (Begelman 2002; Zuo & Li 2011). To transform the bolometric luminosity into the X-ray luminosity, a bolometric correction factor $\eta_{\rm bol}$ is introduced by $L_{\rm X} = \eta_{\rm bol} L_{\rm bol}$. Following Belczynski et al. (2008), we take $\eta_{\rm bol} = 0.55$.

However, WDs and He stars in UCXBs fill their Roche lobes. Roche overflow-fed systems are subject to a thermal disk instability and may appear either as persistent or transient X-ray sources depending on the mass transfer rate. A system becomes a transient X-ray source when the mass-transfer rate falls below a certain critical value, $\dot{M}_{\rm crit}$. For disks with heavy elements, we use the work of Menou et al. (2002):

$$\dot{M}_{\rm crit} = \begin{cases} 5.9\times 10^{16} M_{\rm NS}^{-0.87} R_{\rm d}^{2.62} \alpha_{0.1}^{0.44}\ \ {\rm g\ s^{-1}},\ \text{He rich} \\ 1.2\times 10^{16} M_{\rm NS}^{-0.74} R_{\rm d}^{2.21} \alpha_{0.1}^{0.42}\ \ {\rm g\ s^{-1}},\ \text{C rich} \\ 5.0\times 10^{16} M_{\rm NS}^{-0.68} R_{\rm d}^{2.05} \alpha_{0.1}^{0.45}\ \ {\rm g\ s^{-1}},\ \text{O rich} \end{cases} \qquad (4)$$

where $R_{\rm d}$ is a maximum disk radius (2/3 of the accretor's Roche lobe radius) in 10^{10} cm and $\alpha_{0.1} = \alpha/0.1$ in which $\alpha = 0.1$ is a viscosity parameter.

If $\dot{M}_{\rm NS} > \dot{M}_{\rm crit}$, the system is a persistent X-ray source whose X-ray luminosity is determined by Equation (2). If $\dot{M}_{\rm NS} < \dot{M}_{\rm crit}$, the system is a transient source. For transient UCXBs, their X-ray luminosity is given by

$$L_{\rm X} = \begin{cases} 10^{31} - 10^{32} & \text{all quiescent UCXBs transients;} \\ \eta_{\rm bol}\eta_{\rm out} L_{\rm Edd} & \text{outburst UCXBs transients}, \end{cases} \qquad (5)$$

where $\eta_{\rm out}$ is the correction factor to an X-ray luminosity at outburst and $L_{\rm Edd}$ is the Eddington luminosity. In this work, we take $\eta_{\rm out} = 0.1$ (Belczynski et al. 2008). The Eddington luminosity is given by

$$L_{\rm Edd} = \frac{4\pi R_{\rm NS}^2 c g}{\kappa}, \qquad (6)$$

where κ is the opacity of the accreted matter, c is the speed of light, g is the gravitational acceleration at the surface of the NS and $R_{\rm NS}$ is the radius of the NS.

We must know whether a given transient system is in an outburst state or a quiescent state. However, the theory of disk instability cannot provide a reliable estimate of the disk's duty cycle ($\rm DC_{disk}$), which is the fraction of time that a given system spends in the outburst. Following Belczynski et al. (2008), $\rm DC_{disk} = 1\%$.

4 RESULTS

In order to investigate the formation of UCXBs, we performed binary population synthesis studies. In the simulations, we use the initial mass function from Miller & Scalo (1979) for the primary components, a flat distribution of mass ratios (Kraicheva et al. 1989; Goldberg & Mazeh 1994). We assume that all binaries initially have circular orbits. Like in the main case considered in our study of symbiotic stars with WD components (Lü et al. 2006), the distribution of separations is given by $\log a = 5X + 1$, where X is a random variable uniformly distributed in the range [0,1] and a is in $R_\odot$. After a supernova explosion, new parameters of the orbit are derived using standard formulae (e.g., Hurley et al. 2002). The model is normalized to the formation of one binary with $M_1 \geq 0.8\ M_\odot$ per year (Yungelson et al. 1993). We use 2×10^7 binary systems in the Monte-Carlo simulations. In this work, a binary is considered to be a UCXB if its associated LMXB has an orbital period less than 80 minutes (Belczynski & Taam 2004).

4.1 Birthrates and Size of the UCXB Population

In Table 1, we give the input parameters for different simulations. Table 4.1 gives the birthrates and numbers for UCXB populations with different donors via different formation channels. The total birthrate and number of UCXBs in the Galaxy are $\sim 2.6 \times 10^{-4}$–7.5×10^{-4} yr^{-1} and ~ 5000–10000, respectively. The majority of UCXBs are transient sources. However, UCXBs during a quiescent phase are hardly observed because of low X-ray luminosities. Considering the disk duty cycle ($\rm DC_{disk} = 1\%$), the expected number of transient UCXBs that we can observe should be ~ 100. Therefore, most observed UCXBs should be persistent sources. Nelemans et al. (2010) showed that 75% of UCXB candidates are persistent sources, which agrees with our results. In the following sections, UCXBs always mean persistent sources except when we emphasize that they are transient sources.

The input parameter $\sigma_{\rm k}$ has a strong effect on UCXBs via CCSN. The higher $\sigma_{\rm k}$ is, the more difficulty a binary system has of surviving after a supernova. $\sigma_{\rm k}$ changed from 190 in case 1 to 400 km s^{-1} in case 2, which introduces an uncertainty up to a factor of about three. Input parameter $\sigma^*_{\rm k}$ has a weak effect on UCXBs via AIC and EIC. CE evolution strongly affects UCXBs. In general, under the assumptions of the α-algorithm, binary separations after CE evolution shorten by up to $\sim 1\%$ compared to those before CE evolution. However, under the γ-algorithm assumption, binary separations after CE evolution are approximately equal to those before CE evolution. Therefore, the γ-algorithm is unfavorable for the formation of UCXBs.

About 40% (case 4) – 70% (case 2) of NSs in UCXBs form via AIC, about 30% (case 2) – 50% (case 4) of NSs in UCXBs form via EIC, and 1% (case 2)–10% (case 4) of NSs in UCXBs form via CCSN. In order to form ultrashort orbital periods, UCXBs usually undergo a CE evolution after their supernovae. This means that there are enough wide orbits in NS+MS systems so that MSs can evolve to the giant branch. The higher the kick velocity is, the more difficult it is for binaries with wide orbits to survive after their supernovae occur. The kick velocity in AIC and EIC is much lower than that in CCSN. Therefore, most of the NSs in UCXBs form via AIC and EIC. An intriguing fact is that three of the six known accreting millisecond pulsars are UCXBs (e.g., Markwardt et al. 2002). This means that NSs in UCXBs are good candidates for millisecond pulsars, although 4U

Table 1 Input Parameters in Different Simulations for the Population of UCXBs

Cases	$\sigma_{\rm k}$ (km s^{-1})	$\sigma_{\rm k}^*$ (km s^{-1})	CE
case 1	190	20	$\alpha_{\rm ce}\lambda_{\rm ce} = 1.0$
case 2	400	20	$\alpha_{\rm ce}\lambda_{\rm ce} = 1.0$
case 3	190	10	$\alpha_{\rm ce}\lambda_{\rm ce} = 1.0$
case 4	190	20	$\gamma = 1.5$

Table 2 Different Models of the UCXB Population

Cases	NS+He		NS+HeWD		NS+COWD		Total	
	Bir	Num	Bir	Num	Bir	Num	Bir	Num
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Persistent (Transient) UCXBs via CCSN								
case 1	3.0×10^{-5}	110	$4.3 \times 10^{-6}(3.7 \times 10^{-6})$	10(350)	4.9×10^{-6}	40	$3.9 \times 10^{-5}(3.7 \times 10^{-6})$	150(350)
case 2	3.6×10^{-6}	20	$2.7 \times 10^{-6}(1.5 \times 10^{-6})$	20(170)	9.2×10^{-7}	20	$7.2 \times 10^{-6}(1.5 \times 10^{-6})$	60(170)
case 3	3.0×10^{-5}	110	$4.3 \times 10^{-6}(3.7 \times 10^{-6})$	10(350)	4.9×10^{-6}	40	$3.9 \times 10^{-5}(3.7 \times 10^{-6})$	150(350)
case 4	7.3×10^{-6}	50	$1.3 \times 10^{-6}(1.3 \times 10^{-6})$	$<$ 10(120)	5.8×10^{-6}	50	$1.4 \times 10^{-6}(1.3 \times 10^{-6})$	100(120)
Persistent (Transient) UCXBs via AIC								
case 1	3.3×10^{-4}	1700	$8.4 \times 10^{-5}(7.4 \times 10^{-5})$	130(6900)	9.3×10^{-5}	250	$5.1 \times 10^{-4}(7.4 \times 10^{-5})$	2100(6900)
case 2	3.3×10^{-4}	1700	$8.4 \times 10^{-5}(7.4 \times 10^{-5})$	130(6900)	9.3×10^{-5}	250	$5.1 \times 10^{-4}(7.4 \times 10^{-5})$	2100(6900)
case 3	3.3×10^{-4}	1800	$8.5 \times 10^{-5}(7.5 \times 10^{-5})$	140(7000)	9.3×10^{-5}	250	$5.1 \times 10^{-4}(7.5 \times 10^{-5})$	2100(7000)
case 4	5.9×10^{-5}	280	$1.5 \times 10^{-5}(1.3 \times 10^{-5})$	60(1170)	5.1×10^{-5}	210	$1.3 \times 10^{-4}(1.3 \times 10^{-5})$	550(1200)
Persistent (Transient) UCXBs via EIC								
case 1	9.0×10^{-5}	440	$1.6 \times 10^{-5}(1.5 \times 10^{-5})$	80(1340)	8.5×10^{-6}	110	$1.1 \times 10^{-4}(1.5 \times 10^{-5})$	630(1300)
case 2	9.0×10^{-5}	440	$1.6 \times 10^{-5}(1.5 \times 10^{-5})$	80(1340)	8.5×10^{-6}	110	$1.1 \times 10^{-4}(1.5 \times 10^{-5})$	630(1300)
case 3	8.2×10^{-5}	440	$1.6 \times 10^{-5}(1.3 \times 10^{-5})$	90(1200)	1.0×10^{-5}	100	$1.1 \times 10^{-4}(1.3 \times 10^{-5})$	630(1200)
case 4	6.2×10^{-5}	450	$1.3 \times 10^{-5}(1.4 \times 10^{-5})$	10(1300)	2.8×10^{-5}	320	$1.0 \times 10^{-4}(1.4 \times 10^{-5})$	780(1300)

Notes: The first column gives the model number according to Table 1. Cols. (2) to (7) give birthrates (yr^{-1}) and numbers of UCXBs with different kinds of donors. The total birthrates and numbers are shown in Cols. (8) and (9), respectively. NS + He means that an accreting NS has a naked helium star donor, and NS + HeWD (COWD) represents that an accreting NS has an He (CO) WD donor. UCXBs with ONeWD donors are negligible. The numbers in parentheses in Cols. (4), (5), (8) and (9) are birthrates and numbers of transient UCXBs which are negligible in other columns.

1626-67 has a young NS with a 7-second spin period. Hurley et al. (2010) suggested that binary millisecond pulsars via AIC are comparable to or can exceed those for CCSN, which is consistent with our findings.

About 50% (case 4) – 80% (case 2) of UCXBs have He donors, 5% (case 4) – 10% (case 2) of UCXBs have HeWD donors, and 40% (case 4) – 10% (case 2) of UCXBs have COWD donors. The ONeWD originates from an MS (its initial mass is between $\sim 6\ M_\odot$ and $8\ M_\odot$), which evolves to a giant with a massive core. The formation of an ONeWD in an NS+MS system needs a very wide orbit. These NS+MS systems hardly ever form. Therefore, UCXBs with ONeWD donors are negligible. in't Zand et al. (2005) suggested that in most UCXBs, the matter which accumulates on the NS is helium. This is consistent with our results. In our simulation, according to Section 3, the transient UCXBs usually have wider orbits and lower mass-accretion rates. WDs are degenerate. The smaller their masses are, the larger their radii can be and the wider the orbits of UCXBs with these WDs are. Han & Webbink (1999) investigated mass transfer in double WD binaries. According to their results, the smaller a WD's mass is, the lower the mass-transfer rate is. Usually, an HeWD's mass is lower than a COWD's mass at their birth. Therefore, all transient UCXBs have HeWD donors.

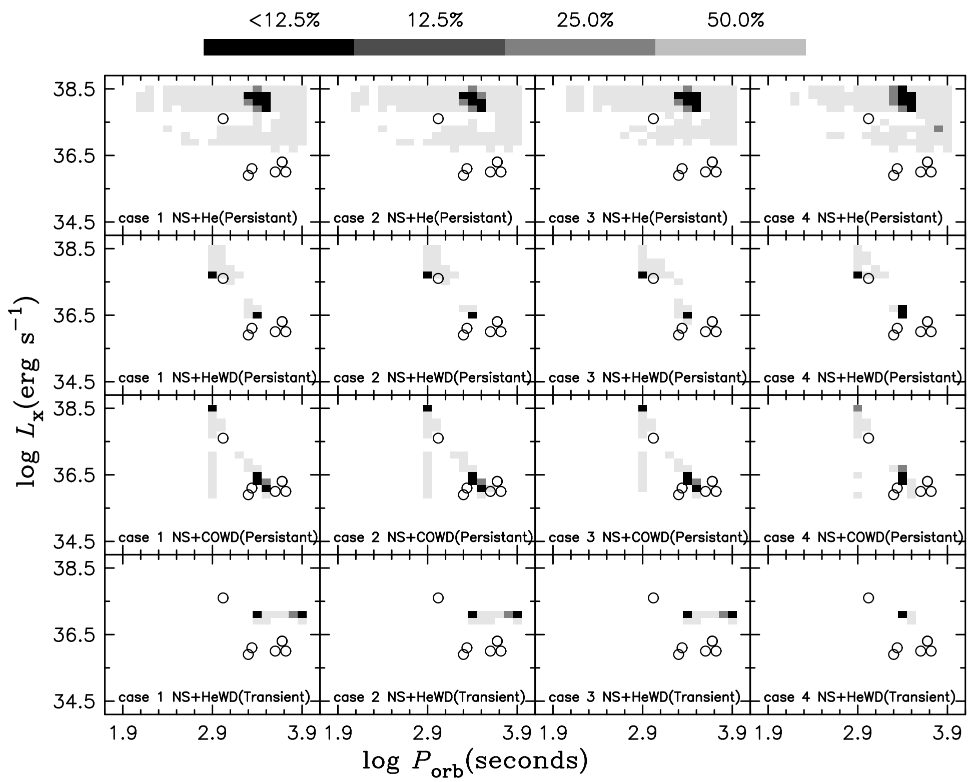

Fig. 1 Distributions of the orbital periods vs. the X-ray luminosities in UCXBs. The gradations of gray-scale correspond to the regions where the number density of the systems is, respectively, within 1 – 1/2, 1/2 – 1/4, 1/4 – 1/8, and 1/8 – 0 of the maximum for $\frac{\partial^2 N}{\partial \log P_{\rm orb} \partial \log L_{\rm x}}$. The number in every panel is normalized to 1. Circles represent observed UCXBs from Nelemans et al. (2010).

4.2 Properties of UCXBs

The orbital periods and the X-ray luminosities of UCXBs are the most important properties. The evolution of orbital periods in UCXBs depends on the magnetic braking and the gravitational wave radiation which drive mass transfer in UCXBs. Figure 1 gives the distributions of the orbital periods and the X-ray luminosities of UCXBs with different donors.

In UCXBs with He donors, the orbital period's evolution and the mass transfer are driven by the magnetic braking and the gravitational wave radiation. The naked He stars usually have convective envelopes. According to Hurley et al. (2002), the magnetic braking is much more efficient than the gravitational wave radiation in driving the mass transfer. Therefore, UCXBs with He donors have high mass transfer rates with $\sim 10^{-7}\ M_\odot$ yr^{-1}. In our work, UCXBs with He donors have high X-ray luminosities. Their orbital periods have wide distributions between $\sim$ 1 – 80 minutes, and the peak is at $\sim$ 40 minutes.

WDs are fully degenerate and have no convective envelopes. In UCXBs with WD donors, the orbital period's evolution and the mass transfer are only driven by the gravitational wave radiation. Compared with UCXBs with He donors, UCXBs with WD donors have lower X-ray luminosities.

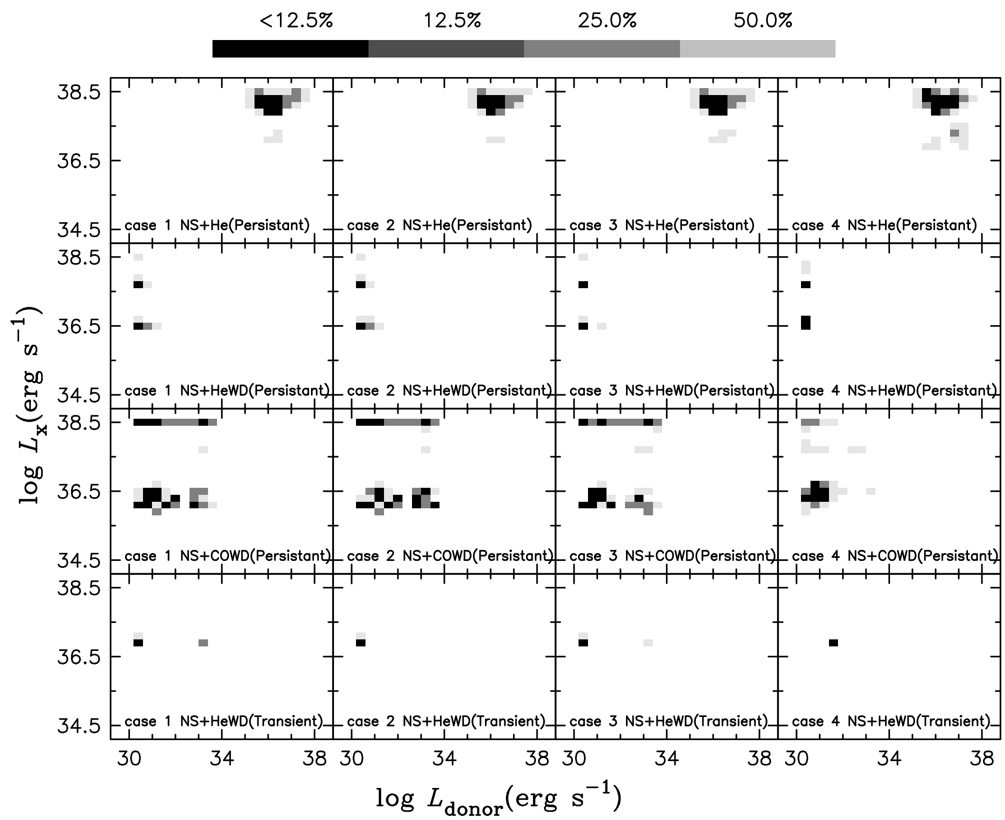

Fig. 2 Similar to Fig. 1, but for distributions of donors' luminosities vs. the X-ray luminosities in UCXBs.

In Figure 1, UCXBs with HeWD and COWD donors are mainly in two regions. In the middle-upper region, these UCXBs have short orbital periods and high X-ray luminosities. In the right-bottom region, these UCXBs have long orbital periods and low X-ray luminosities. In the close binaries, the higher the WD donors' masses are, the higher the mass transfer rates become. The donors in the middle-upper region have higher masses than those in the right-bottom region.

The X-ray luminosities of transient UCXBs during the outburst phase are shown in the bottom panels of Figure 1. Usually, the mass transfer rates in a transient UCXB are very low ($\leq 10^{-12}\ M_\odot$ yr^{-1}). This means that the donor for transient UCXB has low mass ($\leq 0.01\ M_\odot$) and large radius. Therefore, the orbital periods of transient UCXB are the widest among all UCXBs. In Nelemans et al. (2010), there are three transient UCXBs (XTE J1807–294, XTE J1751–305 and XTE J0929–314). Their orbital periods are 40, 42 and 44 minutes, respectively, which are within the range of our results.

Six observed UCXBs are plotted in Figure 1. They represent UCXBs with COWD donors. However, we must note the following.

(i) There is a large uncertainty when we estimate X-ray luminosity by the mass-transfer rate $\eta_{\rm bol}$. Generally, its value is $\sim$ 0.1–0.55. Zuo & Li (2011) took $\eta_{\rm bol} = 0.1$. Therefore, we might overestimate the X-ray luminosities of UCXBs.

(ii) In our work we assume that NSs accrete all matter transferred from their donors via the Roche lobe. However, the interaction between NSs and materials around them is very complex. The matter transfer may not be conservative. We might overestimate the mass accretion rates of NSs in UCXBs.

In this case, we would overestimate the X-ray luminosities of UCXBs. If we decrease the X-ray luminosities of UCXBs, our result could fully cover the observations.

Figure 2 gives the distributions of donors' luminosities and the X-ray luminosities in UCXBs. The luminosities of He donors are much higher than those of WD donors. The naked helium stars may be subdwarf B stars. Han et al. (2002) and Han et al. (2003) investigated the subdwarf B stars formed from binaries. Compared with WDs, the subdwarf B stars have higher luminosities and effective temperatures. This difference may be a way that we can distinguish He donors from WD donors.

5 CONCLUSIONS

We perform a detailed study of UCXBs, employing the population synthesis approach to the evolution of binaries. In our simulations, the kick velocity of nascent NS and CE evolution has strong effects on the Galactic birthrate and number of UCXBs, and results in an uncertainty with a factor of ~ 3. The mass transfer in UCXBs with He donors is mainly driven by magnetic braking, and these UCXBs have very high X-ray luminosities. The mass transfer with WD donors is driven by the gravitational wave radiation. Therefore, kick velocity, CE evolution, magnetic braking and gravitational wave radiation are all very important for understanding UCXBs.

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