Spatial distribution of luminous X-ray binaries in spiral galaxies

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Accepted 2008 January 15. Received 2008 January 15; in original form 2007 August 8

ABSTRACT

We have modelled the spatial distribution of luminous X-ray binaries (XRBs) in spiral galaxies that are like the Milky Way using an evolutionary population synthesis code. In agreement with previous theoretical expectations and observations, we find that both high- and low-mass XRBs show clear concentrations towards the galactic plane and bulge. We also compare XRB distributions under the galactic potential with a dark matter halo and the modified Newtonian dynamics potential, and we suggest that the difference may serve as potential evidence to discriminate between these two types of model.

Key words: binaries: close – stars: evolution – galaxies: individual: Milky Way – galaxies: luminosity function, mass function – galaxies: starburst – X-rays: binaries.

1 INTRODUCTION

X-ray binaries (XRBs) contain a neutron star (NS) or a black hole (BH) accreting from a normal companion star. They are conventionally divided into low-mass X-ray binaries (LMXBs) and high-mass X-ray binaries (HMXBs), according to the masses of the optical companions (e.g. Verbunt & van den Heuvel 1994). In HMXBs, the evolved (super)giant companions, generally $M_{\text{optical}} \gtrsim 10 M_{\odot}$, have strong stellar wind mass loss to power a bright X-ray source for $\sim 10^{5} - 10^{6}$ yr. LMXBs, in which $M_{\text{optical}} \lesssim 1.5 M_{\odot}$, experience mass transfer via Roche lobe overflow (RLOF) at a rate of $10^{-10} - 10^{-8} M_{\odot}$ yr$^{-1}$. Between these are intermediate-mass X-ray binaries (IMXBs), in which the masses of the companion stars are in the range $\sim 2 - 10 M_{\odot}$ (van den Heuvel 1975). Mass transfer in these binaries often occurs on a (sub)thermal time-scale of $\sim 10^{5} - 10^{7}$ yr through RLOF.

Using distance estimates and the angular distribution of LMXBs, van Paradijs & White (1995) and White & van Paradijs (1996) investigated the spatial distribution of NS and BH LMXBs in our Galaxy, and suggested that the compact objects had received a kick during the supernova (SN) explosions. More recent work by Grimm, Gilfanov & Sunyaev (2002) using RXTE data showed that HMXBs were concentrated towards the Galactic plane with a vertical scaleheight of $\sim 150$ pc, while the vertical distributions of LMXBs were significantly broader with a scaleheight of $\sim 410$ pc, and the radial distribution of LMXBs peaked strongly at the Galactic bulge. However, this sample suffers from some incompleteness of the optical identifications/distance measurements at large distances from the Sun (Jonker & Nelemans 2004). Fortunately, today’s sensitive, high-resolution X-ray observations allow the study of luminous XRBs in galaxies even beyond the Local Group, and make it possible to examine XRB populations in a wide range of galactic environments with different star formation histories. For example, XMM–Newton and Chandra observations of NGC 891, a nearby edge-on spiral galaxy that is very similar in many respects to our own Galaxy, present a straightforward look from the outside (Temple, Raychaudhury & Stevens 2005). The spatial distribution of luminous discrete point sources in this galaxy also shows clear concentrations towards the galactic plane and bulge. From the locations of 154 discrete non-nuclear ultraluminous X-ray sources (ULXs) identified in 82 galaxies observed with Chandra, Swartz et al. (2004) found that the ULXs in their host galaxies were strongly peaked toward their galaxy centres. Statistical analysis of the X-ray point sources from the ROSAT High-Resolution Imager (HRI) survey of nearby galaxies by Liu, Bregman & Irwin (2006) has shown that there is a significant concentration of ULXs towards the galactic centre in late-type galaxies. From a luminosity function (LF) study, they also suggested that regular ULXs are likely to be a high-luminosity extension of the ordinary HMXB/LMXB population in late-type galaxies.

The spatial distribution of XRBs in a galaxy is determined by the initial kick velocity due to any asymmetry in the SN explosion at the birth of a NS/BH, the galactic gravitational potential and the mass transfer process in a binary. In the present work, we investigated the dynamical consequences of XRBs in spiral galaxies like the Milky Way from a theoretical point of view. We used an evolutionary population synthesis (EPS) code to calculate the expected number and luminosity distributions of XRBs in the galaxies. Then, following the approach of Paczyński (1990), we calculated the spatial distribution of XRBs with luminosities $> 10^{37}$ erg s$^{-1}$. For the galactic gravitational potential, we adopted both the standard cold dark matter (CDM) model and the modified Newtonian dynamics (MOND) model. The objective of this study is to present an integrated
picture of XRB distribution in spiral galaxies under the two types of galactic potential model. We also aim to explore the difference in the predicted spatial distributions, which can be done by comparing future high-resolution observations of XRB distributions in nearby galaxies. A recent related work uses the detection of LMXBs in the Sculptor dwarf spheroidal galaxy to probe the dark matter halo (Dehnen & King 2006).

This paper is organized as follows. In Section 2 we describe the population synthesis method and the input physics for XRBs in our model. The calculated results are presented in Section 3, and our discussion and conclusions are in Section 4.

2 MODEL

2.1 Assumptions and input parameters

We have used the EPS code developed by Hurley, Pols & Tout (2000) and Hurley, Tout & Pols (2002) to calculate the expected numbers for various types of XRB population. This code incorporates the evolution of single stars with binary–star interactions, such as mass transfer, mass accretion, common envelope (CE) evolution, SN kicks, tidal friction and angular momentum loss mechanics (i.e. mass loss, magnetic braking and gravitational radiation). Besides the modifications made to the original code by Liu & Li (2007), we have reduced the helium star wind strength by a factor of 0.6, according to the modifications made to the original code by Liu & Li (2007), we have reduced the helium star wind strength by a factor of 0.6, according to Kiel & Hurley (2006), in modelling the formation processes of BH LMXBs.

We assume that the host spiral galaxies are similar to our Galaxy, and we adopt the cylindrical coordinate system \( (R, \phi, z) \) centred at the galactic centre. For stars born in the bulge, we simply assume that they were distributed uniformly between \( R_{\text{min}} = 0 \) and \( R_{\text{max}} = 2 \) kpc, while the star formation rate (SFR) in the disc varies exponentially with \( R \) [i.e. \( \exp(-R/R_{\text{exp}}) \)] from \( R_{\text{min}} = 2 \) out to \( R_{\text{max}} = 15 \) kpc.

Considering different star formation processes in the galactic disc and bulge (described in Section 3.1), we have calculated the populations of X-ray sources in the bulge and disc separately. According to Ballero et al. (2007), we assume that stars in the bulge formed at the age of 0.4 Gyr with a metallicity of 0.001 and an initial mass function (IMF) more skewed towards high mass than in the solar neighbourhood. We neglect the magnetic braking effect for main-sequence (MS) stars of mass 0.8–1.25 \( M_\odot \), as metal-poor MS stars in this mass range do not have an outer convective zone (e.g. Ivanova 2006). For the disc, we take a fixed SFR over the lifetime of the galaxy and solar metallicity. The values of the other adopted parameters are the same as the default parameters used in Hurley et al. (2002) if not mentioned. The IMF of Kroupa, Tout & Gilmore (1993) is taken for the mass of the primary (\( M_1 \)) distribution. For the secondary stars (\( M_2 \)), we use a uniform distribution of the mass ratio \( M_2/M_1 \) between 0 and 1 and of the logarithm of the orbital separation \( \ln a \). The tidal effect is considered to remove any eccentricity induced in a post-SN binary prior to the onset of mass transfer.

When a binary survives a SN explosion, it receives a velocity kick as a result of any asymmetry in the explosion (Lyne & Lorimer 1994). The kick velocity \( v_k \) is assumed to be imparted on the newborn NS with a Maxwellian distribution

\[
P(v_k) = \frac{2}{\sigma^3} \frac{v_k^2}{\pi^2} \exp \left( -\frac{v_k^2}{2\sigma^2} \right),
\]

where \( \sigma = 265 \text{ km s}^{-1} \) (Hobbs et al. 2005) or 190 \text{ km s}^{-1} (Hansen & Phinney 1997). The direction of the initial velocity vector is chosen randomly. Together with the local circular motion in our Galaxy (Burton & Gordon 1978), this gives the initial velocity vectors \( v_x \), \( v_y \) and \( v_z \). After evolving for a period, the binary will turn on X-rays and can be observed if it is luminous enough.

In the mean time, the motion of the binary can be calculated if the galactic potential is known. In our control model, we adopt the Galactic gravitational potential proposed by Johnston, Spiergal & Hernquist (1995), which consists of one Hernquist bulge (Hernquist 1990), one Miyamoto–Nagai disc (Miyamoto & Nagai 1975) and one isothermal DM halo potential. For the MOND potential, we use the model of Shan et al. (2008), which applies a MOND correction to a Kuzmin–Hernquist bulge–disc model in order to study orbits in the axisymmetric potential. The potential can be constructed as

\[
\Phi_N(R, z) = \frac{-GM}{\sqrt{R^2 + (a + |z|)^2 + h}}
\]

where \( G \) is the gravitational constant, \( a \) is the Kuzmin length, \( h \) is the Hernquist length and \( M \) is the total mass of the lens system. In our calculations, we adopt \( M = 1.2 \times 10^{11} M_\odot \), \( a = 4.5 \) kpc (Binney & Tremaine 1987) and \( h = 0.7 \) kpc (Hernquist 1990). Note that when \( h → 0 \), equation (2) recovers to the thin Kuzmin disc model with the Newtonian potential given by Binney & Tremaine (1987); when \( a → 0 \), it becomes the Hernquist model (Hernquist 1990). The modified gravity is then \( g = g_N + \sqrt{g_N}a_0 \) (3) where \( g_N \) is calculated from equation (2) and \( a_0 = 1.2 \times 10^{-8} \text{ cm s}^{-2} \) (Milgrom 1983; McGaugh 2004). For comparison, we also performed calculations with the Kuzmin model presented by Read & Moore (2005).

Because of the cylindrical symmetry of the galactic potential, two space coordinates \( R \) and \( z \) are sufficient to describe the XRB distributions. We integrate the motion equations (i.e. equations 1 and 2 in Paczyński 1990) with a fourth-order Runge–Kutta method to calculate the trajectories of the binary systems and to collect the space parameters of current XRBs. In our calculations, the accuracy of the integral is set to be \( 10^{-6} \) and is controlled by the energy integral.

2.2 X-ray luminosity and source type

In our study, XRBs are simply divided into LMXBs and H/IMXBs according to the mass of the optical companion, and we use the mass of the secondary, \( M_2 \), of 2 \( M_\odot \) to separate these. Typically, the donor star is a MS star but giant and white dwarf (WD) donors are also possible. For every accreting system, the bolometric luminosity (\( L_{\text{bol}} \)) is calculated based on the average mass accretion rate (\( \dot{m} \)) as \( L_{\text{bol}} = \eta \dot{m} L_{\text{Edd}} \), where \( \eta \) is the efficiency for energy conversion and \( c \) is the velocity of light. For persistent XRBs, we adopt \( L_{\text{bol}} = \min(L_{\text{bol}}, L_{\text{Edd}}) \), where \( L_{\text{Edd}} \) is the ‘Eddington factor’ (Rappaport, Podsiadlowski & Pfahl 2004), to allow super-Eddington luminosities, and the critical Eddington luminosity \( L_{\text{Edd}} \) is \( 4GMm_1/c^2 \) \( = 1.3 \times 10^{38} m_1 \text{ erg s}^{-1} \) (where \( m_1 \) is the proton mass and \( m_1 \) is the accretor mass in the units of solar mass). We assume \( \eta_{\text{Edd}} = 1 \) and \( 10 \) for accreting NSs and BHs, respectively. For transient sources, the luminosities in outbursts are taken to be a fraction (\( \eta_{\text{out}} \)) of the Eddington
luminosity. For NS systems, we assume $\eta_{\text{bol}} = 0.1$ and 1 if the orbital period $P_{\text{orb}}$ is less and longer than 1 d, respectively; for BH systems, we adopt $\eta_{\text{bol}} = P_{\text{orb}}/24$ h and we do not allow the maximum peak luminosity to exceed $3L_{\text{Edd}}$ (Chen, Shrader & Livio 1997; Belczynski & Taam 2003; Garcia et al. 2003). The X-ray duty cycle (DC) is taken to be 0.01 empirically (e.g. Taam, King & Ritter 2000).

Finally, a bolometric correction factor $\eta_{\text{bol}}$ is introduced to convert the bolometric luminosity to the X-ray luminosity in the 2–10 keV energy range (Belczynski & Taam 2003). Generally, the correction factor is $\sim 0.1$–0.5 for different types of XRB, and here we adopt $\eta_{\text{bol}} = 0.3$ as our standard value. So, we can obtain the simulated X-ray luminosity form as follows:

$$L_{\text{X,2–10keV}} = \begin{cases} 
\eta_{\text{bol}} \eta_{\text{bol}} L_{\text{Edd}} & \text{transients in outbursts} \\
\eta_{\text{bol}} \min(L_{\text{bol}}, \eta_{\text{bol}} L_{\text{Edd}}) & \text{persistent systems.}
\end{cases}$$

(4)

To discriminate transient (t) and persistent (p) sources, we adopt the criteria of van Paradijs (1996) for MS and red giant donors, and of Ivanova & Kalogera (2006) for WD donors, respectively.

3 RESULTS

3.1 X-ray luminosity functions

First, we consider the XRBs in our Galaxy. For disc sources, from a SFR $\sim 0.25 M_{\odot}$ yr$^{-1}$ for stars more massive than 5 $M_{\odot}$ in Grimm, Gilfanov & Sunyaev (2003), we derive the total SFR in the Galaxy following Liu & Li (2007). For the binary star population, we obtain a specific SFR of $S_{\text{b}} = 1.028$ yr$^{-1}$ for a binary fraction $f = 0.5$. For bulge sources, we construct a phenomenological function of SFR(t) according to fig. 2 in Ballero et al. (2007), and we assume a binary fraction $f = 0.05$ (Ivanova et al. 2005). Fig. 1 shows the simulated cumulative X-ray luminosity functions (XLFs) of H/IMXBs (left) and LMXBs (middle) in the Galaxy with $\alpha_{\text{CE}} = 0.15$ (Dewi & Tauris 2000). Note that the XLF of H/IMXBs is significantly flatter than that of LMXBs, as indicated in the observed XLFs derived by Grimm et al. (2002). The breaks between $\sim 10^{37}$ and $10^{38}$ erg s$^{-1}$ in both XLFs are related to the maximum Eddington luminosities of various types of accreting source (persistent NS H/IMXBs and transient LMXBs) calculated using equation (4).

Grimm et al. (2002) also combined the XLF of star-forming galaxies in their sample (M82, Antennae, Circinus, NGC 4579 and 4736) with a completeness limit lower than 2 $\times$ $10^{38}$ erg s$^{-1}$. These galaxies have a total SFR of $\sim 16 M_{\odot}$ yr$^{-1}$, which exceeds the Galaxy SFR ($\sim 0.25 M_{\odot}$ yr$^{-1}$) by a factor of $\sim 65$. They found that the XLFs of Galactic and Small Magellanic Cloud (SMC) HMXBs agree well with an extrapolation of the combined LF of the starburst galaxies. We factitiously reset a SFR of 16.25 $M_{\odot}$ yr$^{-1}$ in our population calculations in order to examine the effect of the SFR. The star formation history (SFH) is assumed to be the same as in the Galaxy ($\sim 12$ Gyr). We show the cumulative XLFs in late-type spiral galaxies in the right panel of Fig. 1. Note that H/IMXBs (dashed line) and LMXBs (dotted line) dominate at relatively high ($> 10^{39}$ erg s$^{-1}$) and low ($< 10^{39}$ erg s$^{-1}$) luminosities in the XLF, respectively.

3.2 Spatial distribution of XRBs in the CDM potential

With the XLF constructed, we now calculate the spatial distribution of H/IMXBs and LMXBs at the age of 12 Gyr. We should point out that we only consider the dynamical consequence of field binaries. XRBs formed in globular clusters have a different dynamical origin and are not included in this study. The results are described as follows.

Fig. 2 shows the radial distributions of luminous H/IMXBs (left) and LMXBs (middle) in a galaxy like the Milky Way. As the figure shows, both H/IMXBs and LMXBs have a strong concentration in the direction of the galactic centre along the galactic plane, while there is a void of H/IMXBs in the galactic bulge. This is in rough agreement with the observed distribution in our Galaxy, considering that we have ignored the signatures of the Galactic spiral structure. Note that H/IMXBs are dominated by disc sources because sources in the bulge have all died early, while for LMXBs, both bulge (dashed line) and disc (dotted line) sources contribute to the population.

Fig. 2 also shows the radial distributions of luminous XRBs in late-type spiral galaxies with an enhanced SFR of 16.25 $M_{\odot}$ yr$^{-1}$. We only include sources with luminosities $> 10^{38}$ erg s$^{-1}$. As the figure shows, the radial distributions also mainly cluster towards the galactic centre region and decline along the galactic plane, while there is a marked scarcity in the galactic bulge. These features can be compared with the results of Liu et al. (2006). They find that for late-type galaxies, the radial distribution of detected ULXs shows a peak around 0.5 $R_{\text{25}}$ (where $R_{\text{25}}$ is the elliptical radius of the $D_{\text{25}}$ isophote), and the surface number density of ULXs decreases with radii until it flattens outside the $D_{\text{25}}$ isophotes.

Figure 1. Cumulative LF of H/IMXBs (left) and LMXBs (middle) in the Milky Way and luminous XRBs in late-type spiral galaxies (right). The SFR of late-type spiral galaxies is 65 times of that of the Milky Way. Note that H/IMXBs (left) dominate by persistent sources, both NS (dashed line) and BH (dotted line) persistent sources. In the middle panel, the dashed and dotted lines represent the disc and bulge sources, respectively. In the right panel, the thick solid line is the combined LF of both LMXBs (dotted line) and H/IMXBs (dashed line). Note that H/IMXBs dominate at a relatively high ($> 10^{39}$ erg s$^{-1}$) luminosity while LMXBs dominate at a relatively low ($< 10^{39}$ erg s$^{-1}$) luminosity in the XLF.
Figure 2. Radial distributions of H/IMXBs (left) and LMXBs (middle) in the Milky Way. Only sources with luminosity $L_x > 10^{37}$ erg s$^{-1}$ are plotted. The right panel shows the radial distribution of late-type spiral galaxies ($L_x > 10^{38}$–$10^{39}$ erg s$^{-1}$). The origin of the coordinate is at the Galactic Centre, and $R$ is the distance from the Galactic Centre.

Figure 3. Vertical distributions of LMXBs (solid line) and H/IMXBs (dotted line) in the luminosity intervals $\log(L_{x, 2-10\text{keV}}) = [37, 38]$ (left) and $[38, 39]$ (right) in the Milky Way.

Figure 4. Left: vertical distribution of LMXBs with BH (solid line) and NS (dotted line) accretors in the Milky Way. Right: variation of the ratio $R_x(|z|)$ for H/IMXBs in luminosity intervals $\log(L_{x, 2-10\text{keV}}) = [37, 38]$ (solid line) and $[38, 39]$ (dotted line) with $z_0$ in the Milky Way.

Fig. 3 shows the vertical distributions of H/IMXBs (dotted line) and LMXBs (solid line) in the luminosity intervals $10^{37}$–$10^{38}$ erg s$^{-1}$ (left panel) and $10^{38}$–$10^{39}$ erg s$^{-1}$ (right panel), respectively. Obviously H/IMXBs are more concentrated towards the galactic plane than LMXBs. This is in general accordance with Grimm et al. (2002), who suggested that the tail of high-z LMXBs in the Galaxy cannot be solely a result of the globular cluster component, because only three out of nine sources at $|z| > 2$ kpc are located in globular clusters.

The left panel of Fig. 4 shows the vertical distributions of NS and BH LMXBs. These seem to be very similar, which is in general agreement with those obtained by Jonker & Nelemans (2004).
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Figure 5. Spatial distribution of luminous XRBs in the Milky Way in the CDM potential. The origin of the coordinate is at the Galactic Centre. $R$ and $z$ are the horizontal distance from the Galactic Centre and vertical distance from the Galactic plane in units of kpc. The colour bar represents the normalized number of XRBs.

In order to make a more accurate comparison, we define $R_X(|z|) = N_X(0 < |z| \leq 10)/N_X(0 < |z| \leq 10)$ to represent the ratio of the number with $z_0 < |z| \leq 10$ kpc to the total number between $|z| = 0$ and $|z| = 10$ kpc for a certain type (X) of XRB. The right panel of Fig. 4 shows the ratio $R_X(|z|)$ of H/IMXBs against $z_0$. The solid and dotted lines correspond to sources in the luminosity intervals $10^{37} - 10^{38}$ and $10^{38} - 10^{39}$ erg s$^{-1}$, respectively. As shown in this figure, the more luminous the XRBs are, the more concentrated they are towards the Galactic plane, as expected. This can be easily understood as follows. For a companion of mass $M$, the X-ray lifetime $T \propto M/L_X$. The higher $L_X$ is, the shorter $T$ is, and the smaller the displacement from the original position.

Fig. 5 shows a schematic side view of the XRB distribution in the galaxy. The colour bar represents the normalized number ratio of XRBs in the $R$–$z$ plane. Unfortunately, because of the uncertainties in determining the distance to XRBs in the Galaxy (e.g. Jonker & Nelemans 2004), it is difficult to numerically compare the theoretical expectations with observations of bright XRBs in our Galaxy. Observationally, Temple et al. (2005) present an outside view in X-rays of the nearby edge-on spiral galaxy NGC 891. The spatial distribution of luminous discrete point sources in this galaxy also shows clear concentrations towards the galactic plane and galactic bulge.

We have performed calculations with varied key input parameters to investigate their effect on the spatial distributions. The number of HMXBs does not depend on the SFH in late-type galaxies as it is much longer than the total duration for the formation and evolution of HMXBs ($\lesssim 10^7$ yr). According to Liu & Li (2007), for young populations, the binary formation rate and the factor of the super-Eddington accretion rate allowed can affect the XLFs most prominently. Obviously H/IMXBs always follow the initial spatial distributions of their progenitor stars (i.e. close to the disc) because of their relatively short lifetimes. Another important parameter in the evolution of close binaries is the CE efficiency $\alpha_{\text{CE}}$. Our calculations reveal that a change in the value of $\alpha_{\text{CE}}$ does not significantly affect the number of H/IMXBs, but it does have a strong influence on the LMXB population. For small values of $\alpha_{\text{CE}}$, the orbital motion of a low-mass companion during the spiral-in process may be unable to drive off the envelope of the massive BH/NS progenitor, resulting in coalescence rather a compact binary. Variations in the CE efficiency can change the relative numbers of various types of X-ray binaries, but the main feature of XRB distribution is determined by the dynamical processes during the formation of a BH/NS and the galactic potential adopted. Fig. 6 shows the radial (left) and vertical (right) distributions of LMXBs in the Milky Way with different kick velocity dispersions. It is obvious that there is no strong dependence of the overall spatial distribution on the kick velocity dispersion, although it can affect the outcome of binary evolution and the relative numbers of various types of XRBs.

3.3 Spatial distribution of XRBs in the MOND potential

We made similar calculations of XRB trajectories within the MOND potential. In Fig. 7, we compare the radial distributions of XRBs in a galaxy like the Milky Way in both MOND and CDM potentials.
Radial distributions of XRBs with $L_x > 10^{37}$ erg s$^{-1}$ in the Milky Way in the MOND and CDM potentials. The solid, dotted and thick short-dashed lines represent the results in the Shan–Zhao, Kuzmin and CDM models, respectively.

The solid, dotted and thick short-dashed lines represent those in the Shan–Zhao, Kuzmin and CDM models, respectively. Note that LMXBs in MOND potentials also show clear concentrations towards the Galactic bulge as in the CDM model, but they are peaked at $\sim 1–4$ kpc from the galactic centre. This feature can be seen clearly in the schematic side view (Fig. 8) of the distributions of XRBs in the galaxy. In the Shan–Zhao model (left panel) the distribution shows a peak $\sim 2–3$ kpc from the galactic centre, while in the Kuzmin model (right panel) it peaks at $\sim 3–4$ kpc from the galactic centre. The remarkable scarcity of XRBs within the galactic bulge may provide interesting clues to discriminate one of these models by comparing XRB distributions with predictions from the CDM and MOND potentials.

We note that the difference between these models is mainly a result of the potential discrepancy, especially the contribution from the bulge component. The CDM model contains three components: one Hernquist bulge, one Miyamoto–Nagai disc and one isothermal DM halo potential. It is the bulge potential that leads to the peaked distribution of XRBs in the galactic centre. The Kuzmin model has only one disc component, which results in few XRBs within the galactic bulge. In the Shan–Zhao model, the auxiliary point potential in the Kuzmin model is replaced with an auxiliary Hernquist potential, that is to say, this model contains not only the Kuzmin disc potential but also the Hernquist bulge component. This bulge potential causes the distribution peak to move inwards to the bulge. We also find that in the CDM model there is a more extended radial distribution for XRBs than in the MOND model. This is mainly caused by the potential of the DM halo, which is thought to reside beyond 10 kpc from the galactic centre to account for the missing mass.

4 CONCLUDING REMARKS

This study shows that with our current understanding of binary evolutions and galactic structure, it is possible to investigate both the LF and spatial distribution of luminous XRBs in nearby galaxies, although the results are subject to many uncertainties and simplified treatments. For example, in our calculations, only primordial binaries were considered, while in dense environments such as the galactic bulge, dynamical formation channels, such as tidal capture, exchange encounters and direct collisions, may play an important role in binary formation and change the distribution of the XRBs (Voss & Gilfanov 2007). Additionally, we adopted a simplified radial distribution of newborn binaries in the disc and in the bulge. The actual initial distribution is related to the structure of the spiral arms, the distribution and evolution of the giant H II regions and warm CO clouds, about which our knowledge is still poor. Finally, a recent dynamical encounter of galaxies may also lead to the prevalence of a ULX population and have a great influence on their spatial distributions (e.g. Fabbiano, Zezas & Murray 2001; Wölter & Trinchieri 2003; Belczynski et al. 2004; Colbert & Miller 2005; Fabbiano & White 2006). Although a detailed comparison between observations and theoretical predictions is not available at present, rough agreement can be obtained. In particular, our calculations show that XRBs in the CDM and MOND potentials may have distinct radial distributions around the galactic bulge, suggesting a new way to constrain the nature of DM and to test the law of gravity. Our work motivates
further efforts to explore the origin of the spatial distributions of luminous XRBs around galactic centre regions.

ACKNOWLEDGMENTS

We would like to thank Hong-sheng Zhao and Huan-yuan Shan for valuable discussions on the MOND potential. We also thank Hailang Dai, Wen-cong Chen and Jian-xia Cheng for useful comments and discussions. We are also very grateful to an anonymous referee whose comments and suggestions greatly improved the clarity of this paper. This work was supported by the Natural Science Foundation of China under grant numbers 10573010 and 10221001.

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