Effects of Irradiation on the Evolution of Ultracompact X-Ray Binaries

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Abstract

Using the Modules for Experiments in Stellar Astrophysics code, we investigate the influences of irradiation on ultracompact X-ray binary (UCXB) evolution. Although the persistent UCXBs have short orbital periods that result in high irradiation flux, the irradiation hardly affects the evolution of persistent sources because the white dwarfs (WDs) in these binaries have large masses that lead to very low irradiation depth. The irradiation has a significant effect on the transient sources during outburst phase. At the beginning of the outburst, high X-ray luminosity produces high radiation flux, which results in the significant expansion of WDs. Then, the irradiation triggers high mass-transfer rates, which can last several days for the transient sources with WDs whose masses are larger than \( \sim 0.015 M_\odot \) or several hundred years for those sources with WDs whose masses are less than \( \sim 0.012 M_\odot \). The observed three persistent UCXBs, XTE J0929-314, 4U 1916-05, and SWIFT J1756.9-2508, may belong to the latter.

Key words: binaries: close – stars: evolution – X-rays: binaries

1. Introduction

Ultracompact X-ray binaries (UCXBs) are a subclass of low-mass X-ray binaries (LMXBs). They are characterized by an orbital period of less than 60 minutes, in which a neutron star (NS) or black hole is accreting matter from its companion star. This indicates that the companion star must fill its Roche lobe. Therefore, due to the short orbital period, the donor stars in UCXBs must be hydrogen deficient, such as white dwarfs (WDs) or helium stars (Paczynski & Sienkiewicz 1981; Nelson et al. 1986). Up to now, there are about 30 known UCXBs or candidates, and 13 of them have observed orbital periods (in’t Zand et al. 2007; Liu et al. 2007; Nelemans & Jonker 2010). UCXBs may be produced by tidal captures or direct collisions in the globular clusters (e.g., Verbunt 1987; Ivanova et al. 2010), or may originate from binary systems that undergo complex interactions such as mass exchange, common envelope evolution, and gravitational radiation (e.g., Yungelson et al. 2002; Belczynski & Taam 2004; Zhu et al. 2012). Recently, Chen & Podsiadlowski (2016) suggested that UCXBs may originate from intermediate-mass X-ray binaries driven by magnetic braking of stars with a strong magnetic field (100–10000 G).

Yungelson (2008) and van Haaften et al. (2012a) described the details for the evolution of UCXBs with helium stars and WDs, respectively. They obtained similar results: with the evolution of UCXBs, the donors’ masses and the mass accretion rates of compact objects become lower and lower, while their orbital periods widen. Finally, UCXBs become binaries with low mass ratios and orbital periods of \( \sim 70–80 \) minutes (van Haaften et al. 2012a). Having used data from the RXTE All-Sky Monitor, van Haaften et al. (2012b) studied the long-term X-ray luminosity behavior of 14 UCXBs. They found that the UCXBs with orbital periods longer than about 50 minutes are much brighter than theoretically estimated values in van Haaften et al. (2012a). Very recently, Sengar et al. (2017) obtained similar results. A possible explanation is that these pulsars irradiate their low-mass companion stars (van Haaften et al. 2012b). The influences of irradiation in semidetached compact binaries have been discussed in the literature (e.g., Podsiadlowski 1991; Hameury et al. 1993; Büning & Ritter 2004). One of the important influences is that the irradiation drives higher mass transfer. However, these works focus on main-sequence stars or subgiant stars as irradiated stars. To our knowledge, irradiated WDs in UCXBs are seldom referred to.

In this work, we investigate the effects of irradiation on WDs in UCXBs and discuss the evolution of UCXBs.

2. Model

UCXBs are composed of an NS and a WD. In our work, NS is a mass point with 1.4 \( M_\odot \), and we do not simulate its evolution. We focus on the effects of the irradiation on WDs and all the consequences for UCXBs. In this work, we use the Modules for Experiments in Stellar Astrophysics code (MESA; see Paxton et al. 2011, 2013, 2015, for details) to simulate the evolution of irradiated WDs in UCXBs.

2.1. WD Model

The donors in UCXBs may be helium stars or WDs. Yungelson (2008) investigated the evolution of low-mass helium stars in semidetached binaries and showed that their evolution is similar to those of WDs after these helium stars undergo a phase of high mass transfer (see also van Haaften et al. 2012b). The compositions of these WDs may be rich in helium or carbon–oxygen. Van Haaften et al. (2012b) gave the compositions of the donors in 10 UCXBs. About half of these donors are rich in helium. In all known radio pulsars, there are 120 pulsars with WDs as their companion stars (Manchester et al. 2005). Figure 1 gives the distributions of WDs’ masses for these pulsars. Among them, about 77% are He WDs, and their masses are \( \sim 0.2 M_\odot \). Although the majority of these binaries cannot evolve into UCXBs in Hubble time, WDs’ masses and compositions may be similar to those in progenitors of UCXBs. Therefore, for simplicity, in this work, we only focus on He WDs as donors in UCXBs. Hereafter, WD means He WD unless noted.

Although WDs are the remnants of low-mass stars, they also have evolutionary tracks. Figure 2 shows the evolution of the effective temperature \( (T_{\text{eff}}) \), radius \( (R) \), central temperature \( (T_c) \),
and central degeneracy \((n_e)\) for WDs with different masses. For the evolution of UCXBs, the WD’s radius is a critical factor. Deloye & Bildsten (2003) investigated the mass–radius relation of WD donors in UCXBs and found that this relation depends on the central temperatures of WDs. In Figure 2, \(T_c\) of a WD whose mass is higher than 0.02 \(M_\odot\) hardly cools down lower than 10^6 K within 13 Gyr. However, the WDs in UCXBs are undergoing mass loss and have different evolutionary tracks.

![Figure 1](image1.png)

**Figure 1.** Distributions of WDs’ masses for 120 pulsars with WDs as their companion stars. He and CO mean that WD is rich in helium and carbon–oxygen, respectively. The median companion mass, assuming \(i = 60^\circ\), is taken as WD mass. Data come from Manchester et al. (2005).

![Figure 2](image2.png)

**Figure 2.** Evolution of the effective temperature \(T_{\text{eff}}\), radius \(R\), central temperature \(T_c\), and central degeneracy \((n_e)\) calculated by MESA, for single WDs with different masses in Hubble time. The solid, dashed, dashed–dotted, dotted, and triple-dot-dashed lines represent the WDs with masses of 0.2, 0.1, 0.05, 0.02, and 0.01 \(M_\odot\), respectively.

![Figure 3](image3.png)

**Figure 3.** Evolution of the central temperature \(T_c\) of a 0.1 \(M_\odot\) WD with different mass-loss rates. Solid, dashed, and dashed–dotted lines represent the mass-loss rates of 10^{-3}, 10^{-5}, and 10^{-10} \(M_\odot\) yr^{-1}, respectively. The dotted lines are the evolution of \(T_c\) for different-mass WDs. From the top to the bottom, the WDs’ masses are 0.1, 0.08, 0.06, 0.04, 0.02, and 0.01 \(M_\odot\), respectively.

Figure 3 gives the evolution of \(T_c\) for a 0.1 \(M_\odot\) WD with different mass-loss rates. Obviously, \(T_c\) rapidly decreases with WD mass, reducing in a timescale much shorter than the Hubble time. The main reason is as follows: mass loss results in the decrease of gravitational potential. The thermal energy leads to the expansion of WD, which gives rise to the fall of \(T_c\).

Figure 4 gives the mass–radius relations of 0.1 \(M_\odot\) WDs with different mass-loss rates. Obviously, with the WD mass reducing, its radius approaches the radius of a zero-temperature WD. Therefore, \(T_c\) of WD only determines the beginning of a UCXB, and it mainly depends on the mass-loss rates of WDs in UCXBs. Here, the mass–radius relation of zero-temperature WDs can be approximated by

\[
R_{\text{WD}} = 0.0115 \left(\frac{M_{\text{CH}}}{M_{\text{WD}}}\right)^{2/3} - \left(\frac{M_{\text{WD}}}{M_{\text{CH}}}\right)^{2/3},
\]

where \(M_{\text{WD}}\) is the mass of a WD and \(M_{\text{CH}} = 1.44 M_\odot\) is the Chandrasekhar mass (Tout et al. 1997). Equation (1) is an approximate fitting formula. For a sufficiently cool WD \(kT_c \ll\) degenerate energy), Tout et al. (1997) used Peter Eggletton’s stellar evolution code to calculate the radii of WDs and finally gave Equation (1) by fitting these WDs’ radii and masses. Because Equation (1) does not depend on temperature, we call it the mass–radius relation of zero-temperature WDs. In fact, the radius of WDs depends on mass, temperature, and composition. In our work, the radii of WDs may be lower than the zero-temperature line for certain WD masses.

### 2.2. Evolution of Orbital Angular Momentum and Mass Transfer

The change of orbital angular momentum is the key to understanding the evolution of UCXBs. In binary systems, mass variations (including mass loss, mass transfer), tide, gravitational radiation, and magnetic braking can change...
Figure 4. Mass–radius relations of WDs. The circles represent the radii of WDs after 13 Gyr cooling, which is calculated by the MESA code. Solid, dashed, and dashed–dotted lines represent the radii’s evolution of 0.1 Mₜ WDs with mass-loss rates of $10^{-8}$, $10^{-9}$, and $10^{-10}$ Mₜ yr⁻¹, respectively. The dotted line shows the mass–radius relation of zero-temperature WDs by Equation (1).

The above three mass-transfer rates depend on ΔR_L via exponent, power, and logarithm functions, respectively. Based on mathematic knowledge, Equation (2) gives the highest sensibility for the mass-transfer rate depending on ΔR_L, while Equation (5) gives the lowest one. In order to discuss the effects of the different mass-transfer rates on the evolution of UCXBs, we use Equations (2) and (5) to calculate MRL, respectively.

Similarly, the accretion efficiency, β = M/Ṁ, is also hardly determined owing to the strong magnetic fields of NSs and the radiation pressure of X-ray luminosity. Furthermore, the orbital angular momentum carried by the lost matter also is unclear, which mainly is relative to the vicinity of the mass lost (Tauris & van den Heuvel 2006). Following Podsiałowski et al. (2002), we take β = 0.5 and assume that the mass is lost from the vicinity of the accreting NS.

### 2.3. Irradiation Model

In the close binaries, irradiation can affect the evolution of donors, even binary systems. Podsiałowski (1991) investigated that the irradiation drives the mass transfer in LMXBs. King et al. (1995) and Bünning & Ritter (2004) developed the irradiation feedback model for compact binaries, and they found that the mass-transfer rates become unstable and these binaries experience mass-transfer cycles. MESA uses the irradiation model provided by Guillot (2010), in which an analytical approach is used to simulate stellar atmospheres. In MESA, the irradiation flux (f_0) and the irradiation column depth (τ_irr) are important input parameters. The former can be given by

\[
f_0 = \frac{L_X}{4\pi a^2},
\]

where \( a \) is the binary separation. In LMXBs, \( a \sim 0.01–0.1 \) (Stevens et al. 1992; Bünning & Ritter 2004; Benvenuto et al. 2012). In this work, \( a \sim 0.01 \).

The \( L_X \) is determined by not only the mass-accretion rate but also the thermal disk instability. The latter divides the UCXBs into persistent and transient sources, which depends on the mass-accretion rate. A UCXB is a transient X-ray source if the mass-accretion rate is lower than a certain critical value, \( M_{\text{crit}} \), or else it is a persistent source. Following Zhu et al. (2015), we use the formula in Dubus et al. (1999) and Menou et al. (2002) to calculate \( M_{\text{crit}} \) for the hydrogen-rich and heavier-element disks, respectively. For the persistent X-ray sources, \( L_X \) can be

PPE code in this work), Han et al. (2002) calculated it by

\[
M_{\text{RL}} = C_{\text{max}} \left\{ 0, \left( \frac{\Delta R_L}{R_L} \right)^3 \right\},
\]

where \( C \) is a constant, and it is taken as 1000 Mₜ yr⁻¹.

In a rapid binary star evolutionary (BSE) code, Hurley et al. (2002) calculated \( M_{\text{RL}} \) by

\[
M_{\text{RL}} = 3 \times 10^{-6} \left[ \min(5, M_{\text{donor}}) \right]^2 \left[ \ln(R_{\text{donor}}/R_L) \right]^3 M_\odot \text{yr}^{-1}.
\]

De Mink et al. (2013) used the above formula to calculate the mass-transfer rates in the binary systems.
approximated by

\[
L_X = \eta M c^2 \simeq 5.7 \times 10^{35} \left( \frac{\eta}{0.1} \right) \left( \frac{\dot{M}}{10^{-10} M_\odot \text{yr}^{-1}} \right) \text{erg s}^{-1},
\]

where \( \eta = 0.1 \) is the efficiency of converting accreted mass into X-ray photons. For the transient X-ray sources, following Belczynski et al. (2008), we assume that \( L_X = 0 \) during the quiet phase and \( L_X = 0.1L_{\text{Edd}} \) during the outburst phase, where \( L_{\text{Edd}} \) is the Eddington luminosity.

The latter (\( r_{\text{int}} \)) is the penetrating depth of \( f_{\text{int}} \) below the photosphere. It depends on the irradiation spectra and the local physical and chemical conditions of the WD donor. For simplicity, we assume that \( f_{\text{int}} \) penetrating in the star decreases exponentially as \( f_{\text{int}}^0 e^{-f_{\text{int}} \rho dr} \), where \( \kappa \) and \( \rho \) are the local opacity and mass density of WD, respectively, and \( r \) is the distance from the WD center. Simultaneously, we also assume that \( r_{\text{int}} = r \), where \( f_{\text{int}} = f_{\text{int}}(r) \), with \( f_{\text{int}} \) being the intrinsic flux and equal to \( \frac{L_{\text{Edd}}}{\text{erg s}^{-1}} \). Here, \( L_{\text{Edd}} \) is the intrinsic luminosity of WDs at \( r \). Thus, it can be seen that \( r_{\text{int}} \) is mainly determined by \(-\int \kappa \rho dr \). Figure 5 gives the values of \( \log \kappa \) and \( \kappa \rho dr \) around the stellar surface for the WDs with different masses. Obviously, \( f_{\text{int}} \) can only penetrate into a very thin layer around the WD surface. The larger the WD mass is, the more difficult the penetration is. Therefore, the irradiation only results in the heating and radial expansion of low-mass WDs.

3. Results

Based on the assumptions in the previous section, we simulate the evolution of a binary system composed of an NS with \( 1.4 M_\odot \) and a WD with \( 0.1 M_\odot \). Because most of the progenitors of UCXBs undergo common envelope evolution, it is reasonable to assume a circular orbit. The orbital period is 3 hr when the WD is born in this system. After the cooling of 2 Gyr, the WD fills its Roche lobe owing to the gravitational wave radiation. The binary system evolves into a UCXB.

3.1. Evolution of UCXBs

Figure 6 shows the evolution of this binary system as a UCXB with different mass-transfer rates. The mass transfer in the model with the mass-transfer rate calculated by Equation (2) from Ritter (1988) can occur even if the WD is just close to its Roche lobe. Therefore, compared with the model with the mass-transfer rate calculated by Equation (5) (Hurley et al. 2002), it has a longer orbital period at the beginning of the UCXB phase. For the same orbital period, the mass-transfer rate in the former is higher than the one in the latter. When matter transfers from a WD to an NS, the orbital period becomes wider and wider. The mass-transfer rate calculated by Equation (2) rapidly decreases at \( P \sim 57 \) minutes because the widening of orbital period produced by high mass-transfer rate exceeds the expansion of the WD due to its mass decreases. Based on the X-ray luminosities of UCXBs in Cartwright et al. (2013), Heinke et al. (2013) estimated their mass-transfer rates, which are shown by the squares in Figure 6. To be exact, these estimated values should be the mass-accretion rates of NSs. Although the mass-transfer rate of Equation (5) agrees with the observational values and Equation (2) gives a higher mass-transfer rate, we cannot conclude which is better because the efficiency of mass accretion, \( \beta \), is unclear.

Van Haaften et al. (2012b) calculated the orbital period threshold for the thermal viscous instability of helium accretion disks in UCXBs and found that the threshold is about 28 minutes. Sengar et al. (2017) also computed this threshold.
It is about 22 minutes for the helium accretion disk under X-ray heating. According to Menou et al. (2002) and considering that a mass-transfer rate corresponds to an orbital period in UCXBs, we calculate the orbital period thresholds with different mass-transfer rates (Equations (2) and (5)), which are represented by thick and thin dashed lines in Figure 6, respectively. Based on the formula in Menou et al. (2002), the longer the orbital period is, the higher the critical mass-transfer rate is. Therefore, the orbital period threshold for the thermal disk instability from Equation (2) is longer than that from Equation (5). Correspondingly, the critical mass-transfer rate in the former is also higher than that in the latter. Our results are consistent with previous works.

On the observations, UCXBs whose orbital periods are shorter than 30 minutes are persistent, which is consistent with theoretical estimates. However, there are some persistent sources (XTE J0929-314, 4U 1916-05, and SWIFT J1756.9-2508) for UCXBs with orbital periods between 40 and 60 minutes. Theoretically, they should be transient. Van Haatient al. (2012b) suggested that the WDs in these UCXBs are heated by the irradiation from X-rays emitted by accreting NSs. Sengar et al. (2017) considered that these systems may be LMXBs that are evolving into UCXBs. However, these LMXBs have mass-transfer rates lower than those of UCXBs (see Figure 2 in Sengar et al. 2017).

### 3.2. Influences of Irradiation on UCXBs’ Evolution

The most remarkable feature of UCXBs are short orbital periods. The X-rays produced by accreting NSs strongly irradiate WDs. This work focuses on the influence of irradiation on UCXBs’ evolution. The conditions of irradiation in the persistent and the transient UCXBs are different. In our work, the orbital period thresholds for the thermal viscous instability of helium accretion disks are about 22 and 28 minutes for the mass-transfer rates of Equations (5) and (2), respectively. They are given by thin and thick dashed lines in Figure 6. Correspondingly, the masses of WDs in the persistent UCXBs are larger than $\sim 0.025$ and $\sim 0.018 M_\odot$, respectively. For simplicity, in the present paper we assume that WDs in the persistent UCXBs have masses larger than 0.02 $M_\odot$.

### Table 1: Physical Parameters for the Irradiation Model

| $M_{WD}(M_\odot)$ | $R_{WD}(R_\odot)$ | $P_{orb}$(Min) | Log $M_{INL} (M_\odot \cdot \text{yr}^{-1})$ | $L_X$ (erg s$^{-1}$) | $f_{\text{irr}}^0$ (erg s$^{-1}$ cm$^{-2}$) | $r_{\text{irr}}$(cm) |
|------------------|------------------|---------------|-------------------------------|----------------|----------------|-------------|
| Persistent        |                  |               |                               |                 |                |             |
| 0.1              | 0.034            | 10            | −7.6                          | $7.2 \times 10^{37}$ | $3.0 \times 10^{44}$ | 10          |
| 0.08             | 0.035            | 12            | −7.9                          | $4.0 \times 10^{37}$ | $1.7 \times 10^{44}$ | 20          |
| 0.06             | 0.036            | 14            | −8.2                          | $1.6 \times 10^{37}$ | $5.3 \times 10^{33}$ | 50          |
| 0.05             | 0.037            | 17            | −8.5                          | $8.7 \times 10^{36}$ | $2.3 \times 10^{33}$ | 80          |
| 0.04             | 0.039            | 20            | −8.9                          | $3.8 \times 10^{36}$ | $8.0 \times 10^{32}$ | 100         |
| Transient        |                  |               |                               |                 |                |             |
| 0.02             | 0.042            | 32            | −9.9                          | $1.0 \times 10^{37}$ | $1.2 \times 10^{43}$ | $9.0 \times 10^5$ |
| 0.018            | 0.043            | 34            | −10.0                         | $1.0 \times 10^{37}$ | $1.1 \times 10^{43}$ | $1.3 \times 10^4$ |
| 0.015            | 0.044            | 40            | −10.2                         | $1.0 \times 10^{37}$ | $9.5 \times 10^{42}$ | $2.0 \times 10^4$ |
| 0.012            | 0.045            | 44            | −10.5                         | $1.0 \times 10^{37}$ | $7.6 \times 10^{42}$ | $2.5 \times 10^4$ |
| 0.01             | 0.047            | 55            | −10.8                         | $1.0 \times 10^{37}$ | $6.4 \times 10^{42}$ | $2.7 \times 10^4$ |

Note. The first and second columns give the masses and radii of WDs, respectively. The third column shows the orbital periods. The fourth column gives the mass-transfer rates, and the X-ray luminosities produced by the accretion NSs are given in the fifth column. The irradiation flux on the surfaces of WDs and the irradiation depth are given in the sixth and seventh columns, respectively.

Table 1 gives the physical parameters for the irradiation model. Figure 7 shows the varieties of the effective temperature ($T_{\text{eff}}$) and the relative radius ($\Delta R/R$) after WDs are irradiated. For the persistent UCXBs ($M_{WD} > 0.02 M_\odot$), WDs rapidly reach a new thermodynamic equilibrium within less than 1 s ($M_{WD} = 0.1 M_\odot$) and about 100 days ($M_{WD} = 0.04 M_\odot$) owing to high irradiation flux ($f_{\text{irr}}^0$) and small irradiation depth ($r_{\text{irr}}$). However, the increase of WD radius is too small to affect UCXB evolution even though we increase $f_{\text{irr}}^0$ via varying $r_{\text{irr}}$ from 0.01 to 0.1, the increase of WD radius is very small owing to small $r_{\text{irr}}$.

For the transient UCXBs ($M_{WD} < 0.02 M_\odot$), X-ray luminosity of the accreting NS does not depend on the mass-transfer rate. During the quiet phase, X-ray luminosity ($\sim 10^{31} – 10^{32}$ erg s$^{-1}$) is very low, and we do not consider the irradiation effect. During the outburst, X-ray luminosity can rise to about $0.1 L_{\text{edd}}$, which is taken as $10^{37}$ erg s$^{-1}$ in this work (See Table 1). As shown in Table 1 and Figure 7, compared with the WDs in the persistent UCXBs, WDs in the transient UCXBs have larger irradiation depth. Therefore, the timescale of a WD reaching a new thermodynamic equilibrium becomes long and the variety of relative radius increases.

The red lines in Figure 6 represent the effects of irradiation on the transient UCXBs. Obviously, the radiation results in a great enhancement of mass-transfer rate. The duration of the enhancement for the transient UCXBs with 0.02, 0.018, and 0.015 $M_\odot$ WDs is only several months and even several days, which is similar to the timescale of an irradiated WD reaching a new thermodynamic equilibrium. For UCXB transients, the timescale outburst is uncertain. The outburst duration of XTE J1751-305 is about 15 days (Markwardt et al. 2002), and it is about 100 days for XTE J1807-294 (Falanga et al. 2005), while the decrease in the bolometric X-ray flux of 4U 1626-67 has lasted for about 30 yr (Krauss et al. 2007). The outburst of UCXB transients originates from the thermal disk instability, and theoretically it can last several months (e.g., Lasota 2001). During the outburst, WDs are irradiated by high X-ray luminosity. This irradiation can trigger a great enhancement of mass-transfer rate. For UCXBs with 0.02, 0.018, and 0.015 $M_\odot$ WDs, the duration of this enhancement is comparable to the timescale of the outburst, even shorter than the...
latter. Therefore, the effects of the irradiation on these UCXBs are covered in the outburst and are not significant on observations. However, it can last hundreds of years for the transient UCXBs with 0.012 and 0.01 M\textsubscript{\textit{E}} WDs, which are longer than the theoretical and observational durations of outbursts. Therefore, from the perspective of observers, they are persistent sources. If we increase $f_{\text{irr}}^0$ via varying $\alpha_{\text{irr}}$ from 0.01 to 0.1, the mass-transfer rates are enhanced more highly. The duration of the outburst will shorten because the high mass-transfer rate results in the orbit period widening more rapidly.

The positions of the three persistent UCXBs (XTE J0929-314, 4U 1916-05, and SWIFT J1756.9-2508) in Figure 6 are consistent with the transient sources. However, the observations of long-term X-ray luminosity behavior for UCXBs have lasted about 20 yr (van Haften et al. 2012b). This is not long enough to judge transient sources with outbursts of hundreds of years. We consider that, due to irradiation, the outbursts of the transient UCXBs are lengthened to hundreds of years. From observations, a transient UCXB becomes a persistent source.

4. Conclusions

We investigate the influences of irradiation on UCXBs’ evolution. The irradiation hardly affects the evolution of persistent sources and the transient sources during the quiet phase. However, it can trigger high mass-transfer rates in the transient sources during the outburst phase. Especially for those sources with WDs whose masses are less than ~0.012 M\textsubscript{\textit{E}}, the high mass-transfer rates can last hundreds of years. The three UCXBs, XTE J0929-314, 4U 1916-05, and SWIFT J1756.9-2508, have orbital periods of 40–60 minutes. Theoretically, they should be transient sources, while they are persistent sources during observations of about 20 yr. Based on the positions of UCXBs’ evolution, we suggest that the three persistent UCXBs should be transient sources, and their outburst can last hundreds of years owing to the irradiation of high X-ray luminosity ($10^{37}$ erg s\textsuperscript{-1}) on the extremely low mass WD ($\leq$0.012 M\textsubscript{\textit{E}}).

This work was supported by the National Natural Science Foundation of China under grant Nos. 11473024, 11363005, 11763007, 11503008, and 11365022 and the Xinjiang Science Fund for Distinguished Young Scholars under grant No. QN2016YX0049.

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Figure 7. Varieties of the effective temperatures ($T_{\text{eff}}$) and the relative radii ($\Delta R/R$) for irradiated WDs. The “Time” of the x-coordinate means the time since the start of irradiation. The different line styles represent WDs with different masses, which are noted in the middle zone of the left panel.
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