

Research Note

Small Magellanic Cloud 13 type supersoft sources

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Abstract. It is proposed that the observational data for the supersoft X-ray source 1E0035.4-7230 in the SMC may be explained in the framework of the standard cataclysmic variable evolution. The fulfilling of several conditions are needed: (1) The white dwarf has a low mass ($\approx 0.6 - 0.7 M_{\odot}$) and rather thick helium buffer layer on top of the C-O core. (2) After the common envelope phase and before the accretion stage the white dwarf has cooled down ($t_c \approx 10^8 - 10^9$ years). (3) After Roche lobe filling when the binary evolution is driven by magnetic braking, the mass accretion rate is $\approx 10^{-8} - 10^{-9} M_{\odot}/\text{yr}$, the accumulation of the matter at the surface of the cold white dwarf leads to nova outbursts and all accreted matter will be ejected. (4) The accretion will gradually heat up the cool white dwarf and after reaching a steady state equilibrium higher temperature, flashes have become more mild and no longer all accreted matter is lost in the flash. At the current stage we are observing this system after a mild (due to the hot white dwarf condition) hydrogen flash in the phase of residual hydrogen burning. We would like to call this new type of objects *SMC 13 type supersoft sources*.

Key words: stars: evolution – X-rays: stars – stars:individual 1E 0035.4-7230 (SMC) – Magellanic Clouds

($kT \sim 4.5 \times 10^5$ K) nature of the source. A bolometric black-body luminosity of $\sim 10^{37}$ erg s⁻¹ has been deduced (Kahabka, Pietsch & Hasinger 1994). Orio et al. (1994) identified the X-ray source with a blue variable star with a strong UV excess. This indicates the presence of a bright accretion disk with high mass transfer rates (cf. Schmidtke et al. 1996). Schmidtke et al. (1994) discovered a 0.1719 day orbital period in optical data with a mean visual magnitude of $V=20.2$. Kahabka (1996) discovered orbital modulation in X-rays at about the same period and Schmidtke et al. (1996) combined optical and X-ray data in order to refine the orbital period. They derive (one solution) a relative phase shift of ~ 0.25 between the optical and X-ray light curve. They discuss an extended scattering accretion disk corona (ADC) occulted by structure at the rim of the accretion disk as origin of the X-ray modulation. Only the HeII λ 4686 line has been clearly observed in emission (Schmidtke et al. 1996). The line is stated to be variable. There has not been found a high velocity ($\sim 1000-5000$ km/sec) component from a broad base of the HeII λ 4686 line as e.g. in RX J0513.9-6951 (Crampton et al. 1996) and in Nova Cyg 1992 (Krautter et al. 1996).

Recently Schmidtke & Cowley (1996) reported the optical identification of RXJ0439.8-6809 in the LMC. Based on periodogram analysis, the suggested periods are 0.1403 and 0.1637 days. The shape of the folded light curve for RXJ0439.8-6809 closely resembles that for the SSS 1E0035.4-7230. RXJ0439.8-6809 may have a similar evolutionary history as 1E0035.4-7230.

1. Introduction

1E0035.4-7230 (=SMC 13, Schmidtke et al. 1996) is possibly one of the most puzzling supersoft sources (SSS). It has been discovered during *Einstein* observations of the SMC as an extremely soft ($kT \leq 4. \times 10^5$ K) and luminous ($\sim 10^{37}$ erg s⁻¹ in the *Einstein* band) source (Seward & Mitchell 1981, Wang & Wu 1992). At that time the source has been characterized as a black hole candidate. *ROSAT* observations confirmed the soft

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2. Evolution of a CV containing a lower mass white dwarf and the proposed evolutionary scenario for 1E0035.4-7230

The current theoretical model by van den Heuvel et al. (1992) includes the steady hydrogen burning on the surface of a massive white dwarf. This steady hydrogen burning model requires high mass accretion rates ($\approx (1 - 4) \times 10^{-7} M_{\odot}/\text{yr}$) which may be easily explained if the donor star is more massive than the white dwarf and the Roche lobe filling takes place when the orbital

period is larger than ~ 8 hours. The short orbital period of 0.1719 days (4.1 hours) for 1E0035.4-7230 places this system outside the regime of the stable mass transfer ($(1 - 4) \times 10^{-7} M_{\odot}/\text{yr}$) and hence the steady state hydrogen burning stage.

Kahabka (1995a,b) has first discussed this source as a recently nuclear burning and low mass ($M_{\text{wd}} \sim 0.5 - 0.7 M_{\odot}$) white dwarf accreting at the rate $\sim 10^{-8} - 10^{-9} M_{\odot}/\text{yr}$.

In short communication we try to explain the observational data for this system in the frame of the following evolutionary scenario. After the common envelope phase a system consisting of a low mass white dwarf ($0.6 - 0.7 M_{\odot}$) and low mass red dwarf ($0.7 - 1.0 M_{\odot}$) was formed (standard CV formation picture proposed by Paczynski (1976)). Let the secondary fill its Roche lobe after $10^8 - 10^9$ years. During this time the white dwarf has cooled down ($\log L/L_{\odot} \approx -2$ to -3 , Iben & Tutukov, 1984). It is also necessary to point out that the low mass C-O white dwarf has a rather thick helium layer left on top of the C-O core ($M_{\text{He}} \approx 0.026 M_{\odot}$ according to Iben & Tutukov, 1984). Depending on the initial orbital period and initial donor mass the secondary fills its Roche lobe and the active CV phase starts. Standard mass accretion rates driven by magnetic braking are in the range $10^{-8} - 10^{-9} M_{\odot}/\text{yr}$.

According to Prialnik & Kovetz (1995) the critical pressure for the outburst is $\approx 10^{18} \text{ dyn cm}^{-2}$. If we use the simple one-zone model proposed by Ergma & Tutukov (1980) for the investigation of the thermal evolution of the accreted layer at the neutron star and white dwarf surface we can estimate from the hydrostatic equilibrium equation

$$P \approx \frac{GM_{\text{WD}}\Delta M}{4\pi R_{\text{WD}}^4} \quad (1)$$

and the white dwarf mass-radius relation (Savonije 1983)

$$R_{\text{WD}}/R_{\odot} = 0.013(1 + X)^{5/3}(M_{\text{WD}}/M_{\odot})^{-1/3} \quad (2)$$

that the critical accreted envelope mass for ignition is:

$$\Delta M/M_{\odot} \approx 3.1 \times 10^{-23} \times (M_{\text{WD}}/M_{\odot})^{-7/3} (\Delta M/M_{\odot})(1 + X)^{20/3}. \quad (3)$$

For $M_{\text{WD}} = 0.6 M_{\odot}$, $X=0$, $\Delta M/M_{\odot} \approx 10^{-4}$. So for the "cold" phase the novae recurrence time scale is $\approx 10^6$ yrs and during the "cold phase" there have been ~ 100 flashes with all accreted envelope to be ejected (Prialnik & Kovetz, 1995). Between thermonuclear outbursts heat is released internally in consequence of compression and gradually the thermal structure between outbursts approaches a steady state equilibrium. For $M \sim 10^{-8} M_{\odot}/\text{yr}$ the equilibrium value of internal temperature of $\sim 5 \times 10^7 \text{ K}$ is achieved in $\sim 10^6$ yrs (Iben, Fujimoto & MacDonald, 1992). With decreasing mass accretion rate the recurrence time scale becomes longer ($\approx 10^5$ yrs for $M \approx 10^{-9} M_{\odot}/\text{yr}$, $\Delta M \approx 10^{-4} M_{\odot}$). Since the CNO abundances of the accreted matter are lower (reduced by a factor of up to ~ 10 , as believed in the SMC cf. Haynes & Milne, 1991) and the thick buffer helium layer prevents the mixing between freshly accreted matter and the C-O core then in hot

low mass white dwarfs the outburst is not so violent and during the outburst not all accreted matter would be lost. The residual hydrogen will burn quasistatically having a high luminosity and surface temperature. So we propose that the observed SSS 1E0035.4-7230 is in the phase after a mild hydrogen flash and it is now in the residual hydrogen burning stage which will last several hundred years.

3. Discussion

From X-ray observations it has been found, that the white dwarf in 1E0035.4-7230 is hot ($\sim 5.5 \times 10^5 \text{ K}$) and luminous ($0.4 - 1.3 \times 10^{37} \text{ erg s}^{-1}$) assuming a white dwarf atmosphere spectral distribution (van Teeseling et al. 1996a). The true luminosity may be larger by a factor 2-3 in case an accretion disk shields half of the X-ray flux from the white dwarf (one hemisphere) and a hot wind (from the white dwarf and the inner accretion disk) scatters part of the X-ray flux. Such a scenario might be required in order to describe the strong modulation seen in X-rays and correlated with the binary orbit. A luminosity of $\sim 10^{37} \text{ erg s}^{-1}$ and a temperature of $\sim 5.5 \times 10^5 \text{ K}$ are consistent with the appearance of a steadily nuclear burning and lower mass ($\sim 0.6 - 0.7 M_{\odot}$) white dwarf after a nuclear flash and during the plateau phase (cf. Sion and Starrfield 1994). But the source most probably is observed after having experienced a large number (a few 1000) of flashes with a recurrence period of $10^5 - 10^6$ years. An important question is, whether during the nuclear flashes mass ejection occurs and what is the fraction of the envelope mass being ejected. According to the recent work of Prialnik and Kovetz (1995) this fraction might be close to 1 for a white dwarf mass of $0.7 M_{\odot}$ and for accretion rates of $\sim 1 \cdot 10^{-8} M_{\odot} \text{ yr}^{-1}$ with less ejection for their hotter sequences. Also the helium buffer zone which prevents the mixing between the core mass and freshly accreted hydrogen will reduce the flash strength and hence the fraction of ejected envelope mass.

The optical magnitude of the star ($M_V \sim +1.4$, assuming SMC membership) is consistent with accretion rates expected from magnetic braking above the period gap as e.g. found in LMXBs (cf. Schmidtke et al. 1996). Additional support for a SMC membership comes from measurements of the radial velocity of the H_{β} emission line (van Teeseling et al. 1996b). A broad base has not been detected in the HeII $\lambda 4686$ emission line in contrast to the supersoft LMC transient RX J0513.9-6951 (Pakull et al. 1993, Crampton et al. 1996) and in Nova Cyg 1992 (Krautter et al. 1996). This argues against either very high mass transfer rates through a disk and/or against a high mass nature of the white dwarf. It may also mean, that radiation pressure is less strong due to reduced nuclear burning being presently active (interflash state).

An interesting question is, why just one (maybe two) such systems are observed and why in the Magellanic Clouds. This could be due to the mass ejection histories through which the systems passed during their several thousand flashes. The strength of a flash is determined by the primordial CNO abundance (Prialnik, 1993 and references therein). In the Magellanic Clouds the metal abundance is reduced by a factor of up to ~ 10 .

Also a thick buffer zone on the top of low mass white dwarf does not allow the mixing between the C-O core and the envelope. This may severely affect the mass ejection of such a nova. A smaller fraction of the envelope mass is expected to be ejected and a longer steady burning phase (plateau phase) will occur.

We suppose that the SSS 1E0035.4-7230 (and also RXJ0439.8-6809) is similar to symbiotic nova systems which also show up as SSS (e.g. RR Tel, AG Dra and SMC 3). The difference between these sources is connected with a different evolutionary history. If in first case we have stationary Roche lobe overflow (CV type evolution) then for the second case the secondary does not fill its Roche lobe but the red giant is losing the mass at a very high rate ($\sim 10^{-5} - 10^{-6} M_{\odot}/\text{yr}$) part of it will be captured by the white dwarf. Since the symbiotic novae observed as SSS have a low mass white dwarf as the accretor (M_{WD} (RR Tel) $\sim 0.7 M_{\odot}$, M_{WD} (AG Dra) $\sim 0.53 M_{\odot}$, Mikolajewska & Kenyon, 1992) then if they capture a fraction 0.001 - 0.01 of the stellar wind they will enter unstable hydrogen burning condition very similar which has been observed for 1E0035.4-7230. Also there is a difference between the time scales since the CV like evolutionary time scale is much longer compared to the symbiotic binary stage. We would like to introduce the term *SMC 13 type supersoft sources* for this new type of objects.

4. Conclusion

We have proposed that the SSS 1E0035.4-7230 located in the SMC is a CV type binary with a low mass white dwarf ($\sim 0.6 M_{\odot}$) accreting from a red dwarf (of mass $\sim 0.4 M_{\odot}$ with the accretion rate $\sim 10^{-8} - 10^{-9} M_{\odot}/\text{yr}$). The C-O white dwarf will have a rather thick helium layer on the top of the core which prevents the mixing between the core and freshly accreted hydrogen. In the accretion phase the initially cold white dwarf will heat up. The reduced CNO abundances in the SMC, buffer helium zone and "hot white dwarf" conditions make the flashes less violent and allow not all matter to be expelled during the flash.

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