11

Super Soft Sources

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11.1 Introduction

Super Soft Sources (SSS) are characterized by radiation with effective temperatures of \( \sim 10^5 \) to \( \sim 10^6 \) K and luminosities of \( \sim 10^{36} \) to \( \sim 10^{38} \) erg s\(^{-1}\). The first luminous SSS in the Large Magellanic Cloud (LMC) have been discovered around 1980 with the *Einstein* observatory (Long et al. 1981). Optical identifications for both CAL 83 and CAL 87 established the binary nature of these sources (Cowley et al. 1990; Smale et al. 1988). During the *ROSAT* all-sky survey in 1990–1991 in soft X-rays (cf. Trümper et al. 1991) and pointed follow-up observations many SSS have been detected. *BeppoSAX* discovered super-soft X-ray emission from recurrent and classical novae. Deep observations performed with *Chandra* and *XMM-Newton* led to the discovery of SSS in nearby spiral and elliptical galaxies. A catalog of SSS is given in Greiner (2000a). Optical identifications exist for SSS in the Galaxy, the LMC, and the SMC (cf. Tab. 11.1).

Here binary SSS are considered. For 7 systems orbital periods of \( \sim 9^h \) to \( \sim 4^d \) have been determined, in the range predicted for steadily nuclear burning white dwarfs (WDs) in close-binary systems undergoing unstable mass-transfer on a thermal timescale (close-binary SSS, CBSS, DiStefano and Nelson 1996; van den Heuvel et al. 1992). From binary evolutionary calculations follows that such systems may have evolved companions with masses \( \sim (1.3–3.0) M_\odot \) (Rappaport et al. 1994). U Sco is a recurrent nova. A few systems with orbital periods of 1.4\(^h\) to 3.5\(^h\) are classical novae (CV-type SSS): V 1974 Cyg (Krautter et al. 1996), GQ Mus (Ögelman et al. 1993), Nova LMC 1995 (Orio and Greiner 1999), and V 382 Vel (Orio et al. 2002). 1E 0035.4-7230 and RX J0537.7–7034 may have a lower mass WD. The recurrent novae RS Oph, T CrB, V394 CrA, and CI Aql 2000 have a subgiant or low-mass giant donor and modeling of the optical outburst light
### Table 11.1. Catalog of optically identified super-soft sources

| Name         | Alias          | $V$<sup>a</sup> (mag) | $T$<sup>b</sup> (eV) | $L$<sup>c</sup> ($10^{37}$ erg s<sup>-1</sup>) | Type<sup>d</sup> | $P_{\text{orb}}$<sup>e</sup> | $i$<sup>f</sup> (°) | $D$<sup>g</sup> (kpc) | References                  |
|--------------|----------------|------------------------|-----------------------|-----------------------------------------------|---------------|----------------|-----------------|----------------------|--------------------------|
| RX J0019.8+2156 | QR And | 12.4 | 25–37 | ~0.4 | CBSS | 15.85 h | 16–56 | ~2 | 1,2,3,4 |
| RX J0925.7–4758 | MR Vel | 17.1 | 77 | 1–5 | CBSS | 4.03 d | 55±10 | 5–10 | 5,6,7,8 |
| V 382 Vel | N Vel 1999 | 2.8–8.0 | 34–48 | 40–210 | CV-N | 3.5 h | - | 1.7 | 9,10 |
| GQ Mus | N Mus 1983 | 18 | 38–43 | 0.7 | CV-N | 85.5 m | 50–70 | 4.7 | 11,12,13 |
| U Sco | BD–17 4554 | 8–19 | 74–76 | 0.6–24 | RN | 1.23 d | 83±3 | 6–14 | 14,15,16,17 |
| AG Dra | BD+67 922 | 8.3–9.8 | 10–15 | 0.3–1.1 | Sy | 554 d | 30–45 | 1.6–2.5 | 18,19,20,21 |
| V 1974 Cyg | N Cyg 1992 | 4.4–17 | 34–51 | 6–37 | CV-N | 1.95 h | - | 2–3 | 22,23,24 |
| RR Tel | N Tel 1948 | 6.7–11 | 12 | 1.3 | Sy-N | 387 d | - | 3.6 | 25,26,27 |
| CAL 83 | LHG 83 | 16.2–17.1 | 28–60 | 0.6–10 | CBSS | 1.04 d | ~20 | 50 | 28,29 |
| CAL 87 | LHG 87 | 19–21 | 55–76 | 0.3–0.5 | CBSS | 10.6 h | ~78 | 50 | 30,31,4 |
| RX J0513.9–6951 | HV 5682 | 16.5–17.5 | 52 | 9.5 | CBSS | 18.3 h | ~15 | 50 | 32,33,34,4 |
| RX J0527.8–6954 | HV 2554 | - | 18 | - | CBSS ? | 9.4 h | - | 50 | 35,36 |
| RX J0537.7–7034 | - | ~19.7 | 18–30 | >0.6 | CV | 3.5 h | 45–70 | 50 | 37,38 |
| 1E 0035.4–7230 | SMC 13 | 20.1–21.5 | 27–48 | 0.4–1.1 | CV | 4.13 h | 20–50 | 60 | 39,40,41 |

References: 1Cowley et al. (1998); 2Beuermann et al. (1995); 3Becker et al. (1998); 4Meyer-Hofmeister et al. (1997); 5Schmidtke et al. (2000); 6Bearda et al. (2002); 7Schmidtke and Cowley (2001); 8Matsumoto and Mennikent (2000); 9Orio et al. (2002); 10Della Valle et al. (2002); 11Diaz et al. (1995); 12Bahman and Krautter (1991); 13Diaz and Steiner (1994); 14Munari et al. (1999); 15Kahabka et al. (1999a); 16Schafer and Ringwald (1993); 17Thoroughgood et al. (2001); 18Tomov et al. (2000); 19Mikołajewska et al. (1995); 20Greiner et al. (1997); 21Gänsicke et al. (1999); 22Rosino et al. (1996); 23Bahman et al. (1998); 24Krautter et al. (1996); 25Feast et al. (1983); 26Heck and Manfroid (1985); 27Jordan et al. (1994); 28Smale et al. (1988); 29Parmar et al. (1998); 30Hutchings et al. (1998); 31Parmar et al. (1997); 32Crampton et al. (1996); 33Reinsch et al. (1996); 34Alcock et al. (1996); 35Greiner et al. (1991); 36Alcock et al. (1997b); 37Greiner et al. (2000); 38Orio and Ogelman (1993); 39van Teeseling et al. (1998); 40Kahabka et al. (1999b); 41Crampton et al. (1997).

*a*Optical $V$ magnitude; *b*temperature from X-ray spectral fit (for GQ Mus, 9 years after outburst; for RX J0513.9–6951 for the X-ray on-state); *c*bolometric luminosity from X-ray spectral fit (for GQ Mus, 9 years after outburst; for RX J0513.9–6951 for the X-ray on-state); *d*type of the system (CBSS = close-binary SSS; Sy = symbiotic system; N = Nova; RN = recurrent nova; CV = catalyysmic variable); *e*orbital period; *f*binary inclination; *g*source distance.
curve requires a super-soft phase (Hachisu and Kato 2000a,b; 2001a,b). The symbiotic systems with detected super-soft X-ray emission RR Tel (Jordan et al. 1994), AG Dra (Greiner et al. 1997), SMC 3 (Jordan et al. 1996), and Lin 358 (Mürset et al. 1997) have orbital periods of at least a few hundred days (cf. Mikolajewska and Kenyon 1992). There are two transient SSS which have not yet been optically identified, the globular cluster X-ray source 1E 1339.8+2837 (Dotani et al. 1999) and RX J0550.0–7151 (Reinsch et al. 1999). For a review of SSS see Kahabka and van den Heuvel (1997).

### 11.2 Nuclear burning

Nuclear burning is ignited in an envelope of H-rich matter accreted onto a WD, in case a critical envelope mass \( \Delta M_{\text{crit}} \) has been reached which can sustain the high temperature \((\sim 10^8 \text{ K})\) and pressure \((\gtrsim (10^{18} - 10^{20}) \text{ g cm}^{-1} \text{ s}^{-1})\) required for nuclear burning, mainly the CNO cycle (Fujimoto 1982a,b). \( \Delta M_{\text{crit}} \) decreases with increasing WD mass \( M_{\text{WD}} \) and increasing accretion rate \( \dot{M}_{\text{acc}} \) (Prialnik and Kovetz 1995) and is (for a WD temperature \( T_{\text{WD}} = 10^7 \text{ K} \) and for \( \dot{M}_{\text{acc}} \geq 10^{-10} M_{\odot} \text{ yr}^{-1} \)) approximated by

\[
\log \left( \frac{\Delta M_{\text{crit}}}{M_{\odot}} \right) \approx A + B \left( \frac{M_{\text{WD}}}{M_{\odot}} \right)^{-1.436} \ln \left( 1.429 - \frac{M_{\text{WD}}}{M_{\odot}} \right) + C \left( \log \left( \frac{\dot{M}_{\text{acc}}}{M_{\odot}} \text{ yr}^{-1} \right) + 10 \right)^{1.484},
\]

with \( A = -2.862, B = 1.542, \) and \( C = -0.197. \) The accretion rate onto the WD determines the strength of the outburst. Higher accretion rates lead to less violent outbursts. If the accreted envelope remains on the WD, a steady-state can be achieved in case the accretion rate is similar as the nuclear burning rate. The steady-state accretion rate \( \dot{M}_{\text{steady}} \) has been given by Paczyński and Rudak (1980) and Iben (1982). Hachisu and Kato (2001b) give an expression for \( \dot{M}_{\text{steady}} \) which is for a hydrogen content \( X = 0.7 \)

\[
\dot{M}_{\text{steady}} \approx 3.7 \times 10^{-7} \left( \frac{M_{\text{WD}}}{M_{\odot}} - 0.4 \right) M_{\odot} \text{ yr}^{-1}.
\]

\( \dot{M}_{\text{steady}} \approx (1 - 4) \times 10^{-7} M_{\odot} \text{ yr}^{-1} \) for \( M_{\text{WD}} = (0.7 - 1.4) M_{\odot}. \) For accretion rates \( \dot{M}_{\text{acc}} < \dot{M}_{\text{steady}} \) a fraction of the accreted matter is ejected in a nova outburst. Below a threshold \( \dot{M}_{\text{low}} \approx 0.25 \dot{M}_{\text{steady}} \) all accreted matter will be ejected during a nova outburst. A red giant envelope will form for accretion rates above a critical rate \( \dot{M}_{\text{crit}} \approx 2 \dot{M}_{\text{steady}}, \) for which part of the envelope is blown-off by a strong wind (cf. Fig. 11.1).
Fig. 11.1. Regimes of optically thick winds, steady nuclear burning, and flashes in the $M_{\text{WD}} - \dot{M}_{\text{acc}}$ plane (Fig. 2 of Hachisu and Kato 2001b; from Fig. 9 of Nomoto 1982). The $\Delta M$ values indicate envelope masses (for a given accretion rate) at which burning is ignited.

11.3 Timescales

In case a steady-state is sustained nuclear burning can last up to $\sim 10^6$ years (the thermal timescale of the donor, Yungelson et al. 1996). For CAL 83 an ionization nebula has been detected which can be explained by illumination of the local interstellar medium for $\sim 10^5$ years by the super-soft X-ray emission (Remillard et al. 1995). For $\dot{M}_{\text{acc}} < \dot{M}_{\text{steady}}$ nuclear burning is recurrent and can last for $\sim 1$ month to thousands of years (Prihnik and Kovetz 1995; Kahabka 1995; Kato 1997, 1999). The timescale of expansion and contraction of the WD envelope due to a variable accretion rate close to $\dot{M}_{\text{crit}}$ is given by the Kelvin-Helmholtz time $\tau_{\text{KH}} \approx 3100 M_{\text{WD}} m_{\text{env}}^{-5} (R_{\text{WD}} L_{\text{WD}}^{37})^{-1}$ days, with mass $M_{\text{WD}}$ ($M_\odot$), envelope mass $m_{\text{env}}^{-5}$ ($10^{-5} M_\odot$), radius $R_{\text{WD}}$ ($10^9$ cm), and luminosity $L_{\text{WD}}^{37}$ ($10^{37}$ erg s$^{-1}$) of the WD. There are two SSS for which alternating X-ray on and off-states have been discovered, RX J0513.9−6951 (Pakull et al. 1993; Reinsch et al. 1996) and CAL 83 (Alcock et al. 1997a; Kahabka 1998; Greiner and DiStefano 2002). The flux pattern in both sources could be established in the optical due to the multi-year observational Macho campaign. For RX J0513.9−6951 X-ray on-states of duration $\sim 30$ days occur during optical dips of similar duration while X-ray off-states occur during optical high-states. The on/off pattern has a recurrence time
of \( \sim (100 - 200) \) days (Southwell et al. 1996). CAL 83, for which only two off-states have been observed, shows an irregular behavior in the optical with switching form high to low and intermediate states, interrupted by dipping with timescales of a few 10 days. A limit-cycle has been proposed for RX J0513.9−6951 in which expansion of the WD atmosphere (due to an increase in the mass-accretion rate) enhances the irradiation of the accretion disk and the mass-flow through the disk (Reinsch et al. 2000). The involved timescale is the viscous time of the disk. No external mechanism is required to cause transitions between on and off-states. It has been proposed that the on/off pattern of CAL 83 is due to episodic mass-loss due to star spot activity of the donor (cf. Alcock et al. 1997a). An alternative explanation is an irradiation-driven instability of the outer layer of the donor (cf. Šimon and Mattei 1999). Other known stellar cycles are due to Mira type pulsations which have cycle lengths of \( \sim (300 - 500) \) days. AG Dra has a bright giant variable with a pulsational period of \( \sim 355 \) days (Gális et al. 1999), and the symbiotic nova RR Tel has an AGB Mira variable with a period of \( \sim (350 - 410) \) days (Heck and Manfroid 1985). The similarity in the optical variability of several unusual CVs, V Sagittae, T Pyxidis, WX Centauri, and V 751 Cygni, with RX J0513.9−6951, let to propose that these systems belong to the class of SSS (Patterson et al. 1998; Greiner 2000b).

### 11.4 Super-soft X-ray spectra

The maximum atmospheric temperature \( T_{\text{max}} \) of steadily nuclear burning cold \( (<10^7 \text{ K}) \) WDs which have cooling ages \( \gtrsim (1 - 3) \times 10^8 \) yr (Yungelson et al. 1996) is for \( M_{\text{WD}} \sim (0.7 - 1.3) \, M_\odot \) (from Iben 1982)

\[
T_{\text{max}} \approx 1.4 \times 10^6 \left( 0.107 + \left( \frac{M_{\text{WD}}}{M_\odot} - 0.6 \right)^{1.7} \right) \text{ K.} \tag{11.3}
\]

Sion and Starrfield (1994) have calculated evolutionary models for low-mass \((M_{\text{WD}} < 0.7 \, M_\odot)\) hot WDs accreting at rates \( \sim 10^{-8} \, M_\odot \, \text{yr}^{-1} \) over thousands of years. The WD is heated up during the evolution due to steady nuclear burning and reaches a surface temperature \( T_{\text{eff}} \sim 3.25 \times 10^5 \) K. Mac Donald (1996) gives the maximum temperature for a WD after a nova outburst and before turn-off. The WD mass can also be estimated from the bolometric luminosity during the plateau phase of the Hertzsprung-Russel diagram (Iben 1982). The temperature is a better indicator of the WD mass as the luminosity can be reduced due to absorption and scattering. Effective temperatures in the range \( \sim 20 \) to \( \sim 80 \) eV and bolometric luminosities \( \sim 3 \times 10^{36} \) to \( \sim 3 \times 10^{38} \) erg s\(^{-1}\) (cf. Tab. 11.1), have been derived by fitting
blackbody, LTE and non-LTE WD model atmospheres (e.g. Hartmann and Heise 1997) to the X-ray spectra of SSS measured with ROSAT (van Teeseling et al. 1994; Balman et al. 1998), ASCA (Asai et al. 1998; Ebisawa et al. 2001) and BeppoSAX (Parmar et al. 1997, 1998; Hartmann et al. 1999; Kahabka et al. 1999a, b; Orio et al. 2002). The highly resolved spectrum of CAL 83 measured with XMM-Newton (Paerels et al. 2001) is dominated by numerous absorption or emission features. The Chandra (Bearda et al. 2002) and XMM-Newton (Motch et al. 2002) spectra of RX J0925.7−4758 show a wealth of spectral features with emission lines of highly ionized metals (e.g. O viii and Fe xvii) which show P Cygni wind profiles. For a few SSS the neutral hydrogen absorbing column which is required for the spectral modeling is available from UV measurements (Gänside et al. 1998).

11.5 The accretion disk

Super-soft X-ray emission is reprocessed by the accretion disk into UV and optical light (Fukue and Matsumoto 2001; Suleimanov et al. 1999). Modeling of the optical orbital light curve of CAL 87, RX J0019.8+2156, 1E 0035.4−7230, and CAL 83 has been performed by Schandl et al. (1997); Meyer-Hofmeister et al. (1997); Kitabatake and Fukue (2002). A variation of the disk rim height with orbital phase is explained by the intersection of the gas stream with the accretion disk which causes a bulge (spray) on the disk rim. For the He ii λ4686, H α, and H β emission lines blue- and redshifted satellites (bipolar jets) have been found in the optical spectra of RX J0019.8+2156, RX J0513.9−6951, and RX J0925.7−4758, which correspond to Doppler velocities $v_{\text{bipolar}} \sim 885$, $\sim 3800$, and $\sim 5200$ km s$^{-1}$ (Tomov et al. 1998; Becker et al. 1998; Southwell et al. 1996; Motch et al. 1998). These lines are transient on timescales of months. One can compare these velocities with the terminal velocity of a line driven wind, $v^{LD}_{\infty} = 3 v_{\text{esc}}$, with the escape velocity $v_{\text{esc}} \approx 5160 \sqrt{M_{\text{WD}}(M_\odot)/R_{\text{d}}(10^9 \text{ cm})}$ km s$^{-1}$ (Cassinelli 1979) and of a radiation driven wind from an accretion disk surrounding a WD, $v^{rd}_{\infty} = 0.42 v_{\text{esc}}$ (Hachiya et al. 1998; Fukue and Hachiya 1999). In luminous SSS the gaseous envelope is highly ionized and radiation driven winds are dominating. For $M_{\text{WD}} \approx 0.6$ to $1.4 M_\odot$ one derives in case of radiation driven winds (from the inner disk with radius $R_{\text{d}}$) terminal velocities of 1700 to 5700 km s$^{-1}$, consistent with the observed velocities of bipolar outflows. Bearda et al. (2002) found in the complex Chandra HETGS spectrum of RX J0925.7−4758 P Cygni structure in the line profiles of O viii (Ly β) and Fe xvii. The highest absorption velocities of $\sim 1500$ km s$^{-1}$ are consistent with radiation driven winds from the inner disk of a massive WD.
11.6 The donor star

In CBSS the donor is assumed to be slightly evolved, between the zero-age main sequence and the terminal-age main sequence (TAMS) or even beyond (subgiant), and to nearly fill its Roche lobe. For stars at the TAMS with $M_{\text{don}} \gtrsim 1.2 \, M_{\odot}$, $\langle \rho \rangle \approx 20.9 \, (10^{M_{\text{don}}})^{-1.54} + 0.0457 \, (10^{M_{\text{don}}})^{-0.045} \, \text{g cm}^{-3}$, assuming a mass-radius relation for solar metallicity stars (Schaller et al. 1992). For CAL 83, assuming a Roche lobe filling donor and $M_{\text{WD}} \approx 1.0 \, M_{\odot}$, the mean density is $\langle \rho \rangle \approx 0.15 \, \text{g cm}^{-3}$, consistent with $M_{\text{don}} \gtrsim 1.5 \, M_{\odot}$ below the TAMS (cf. van den Heuvel et al. 1992). In case a significant amount of matter has been transferred during the evolution of the system this mass estimate may not be valid. A commonly used method to constrain $M_{\text{don}}$ is by radial velocity emission line diagnostics of the He$\Pi \lambda 4686$ line, assuming the line originates predominantly in the accretion disk (Thoroughgood et al. 2001; Matsumoto and Mennickent 2000; Becker et al. 1998). In case the He$\Pi \lambda 4686$ line emission is strongly dominated by the mass-flow from the donor (cf. Cowley et al. 2002), then the inferred donor mass can be underestimated. The location of the He$\Pi \lambda 4686$ line in the binary system can be inferred from Doppler maps (cf. Deufel et al. 1999). The optical spectra of CBSS are dominated by the emission of the bright accretion disk. The donor has a minor contribution to the optical spectrum ($\sim 10\%$), the spectral type can in most cases not be determined. An exception are SSS with optical faint states like recurrent novae: The accretion disk has a minor contribution to the overall spectrum, irradiation is strongly reduced, and the donor dominates the optical spectrum. Pritchett and van den Bergh (1977) give for spectral features Mg$\upi$+Mg H, Fe$\upi$+Ca I, Na$\upi$+TiO the line equivalent width as a function of spectral type (for giant and main-sequence stars). Anupama and Dewangan (2000) have measured the Mg$\upi$b and Fe$\upi$+Ca I absorption features in the spectrum of the 1999 outburst of U Sco and have determined the spectral type as K2 V. Matsumoto and Mennickent (2000) constrained from the non-detection of Si$\upi$III $\lambda 4525$ and Mg$\upi$ $\lambda 4481$ in the optical spectrum of RX J0925.7$-$4758 the spectral type of the donor. For an inclination $i \sim 50^\circ$, $M_{\text{don}} \sim 3.5 \, M_{\odot}$, lower than for a nearly Roche-lobe filling solar metallicity star at the TAMS, but consistent with a subgiant.

11.7 Evolution

The evolution of CBSS undergoing unstable mass-transfer ($M_{\text{don}} > M_{\text{WD}}$) has been considered by Rappaport et al. (1994); Yungelson et al. (1996), and Langer et al. (2000). An estimate of the mean mass-transfer rate in CBSS is $\dot{M} \approx M_{\text{don}}/t_{\text{th}}$, with $t_{\text{th}} = 3 \times 10^7 \, (M_{\text{don}}/M_{\odot})^{-2} \, \text{yr}$, the thermal
timescale of the donor (van den Heuvel 1994). For initial donor masses $M_{\text{don}} \sim (1.5 - 2.5) M_\odot$ mass-transfer rates $\dot{M} \approx (1 - 5) \times 10^{-7} M_\odot \text{yr}^{-1}$ are derived. There have been proposed alternative evolutionary scenarii for CBSS, i.e. irradiation-driven mass-transfer (van Teeseling and King 1998) which could account for systems in the short period ($\lesssim 4^h$) regime (see also Ritter 2000). CO WDs which have masses $< 1.2 M_\odot$ and which grow in mass by accretion towards the Chandrasekhar mass ($\sim 1.38 M_\odot$) have been proposed as candidate progenitors for Type Ia supernovae. The large accretion rates required for steady nuclear burning can be supplied either by slightly evolved main sequence stars or by low-mass red giants. The realization frequency can be as large as $(1 - 3) \times 10^{-3} \text{yr}^{-1}$ and close to the galactic supernova Ia rate of $\sim 3 \times 10^{-3} \text{yr}^{-1}$ (Nomoto et al. 2000; Hachisu et al. 1996; Li and van den Heuvel 1997; Yungelson and Livio 1998).

11.8 SSS in nearby galaxies

During the ROSAT survey of M31 15 SSS and the recurrent super-soft transient RX J0045.4+4154 have been detected (Supper et al. 1997; White et al. 1995). One transient SSS (RX J0044.0+4118) has been optically identified with a classical nova in M31 (Nedialkov et al. 2002). The detected sources have luminosities $> 2 \times 10^{37} \text{erg s}^{-1}$ and may be connected to massive ($> 0.9 M_\odot$) steadily nuclear burning WDs (Kahabka 1999). During recent surveys performed with Chandra and XMM-Newton SSS were detected to considerably lower luminosities of $\lesssim 2 \times 10^{36} \text{erg s}^{-1}$. Two sources, XMM J004308.5+411820 (Shirey 2001) and XMM J004414.0+412204 (Trudolyubov et al. 2002), are transients. In addition the first super-soft pulsator (865 s) has been discovered with XMM-Newton (XMM J004319.4+411759), which is transient and more luminous (Osborne et al. 2001; Trudolyubov et al. 2001). This period is below the orbital period of accreting main-sequence star binaries. An explanation as a double-degenerate system is unlikely, but a super-soft intermediate polar (M31PSS) appears to be possible (King et al. 2002). 3 of the 5 SSS observed after ROSAT are transients. Such a high fraction of transient SSS is consistent with the numbers derived from population synthesis calculations (Yungelson et al. 1996). In M33 7 SSS were detected (Haberl and Pietsch 2001). 8 SSS have been discovered with Chandra in the Sb spiral galaxy M 81, distance 3.6 Mpc (Swartz et al. 2002). The sources have bolometric luminosities of $\sim 2 \times 10^{36} \text{to} \lesssim 3 \times 10^{38} \text{erg s}^{-1}$. 4 of the sources are located in the bulge and 3 sources coincide with spiral arms. The brightest source (N1) is a bulge source with a luminosity $\gtrsim 3 \times 10^{38} \text{erg s}^{-1}$ and effective temperature $\sim (70-90) \text{eV}$. The large luminosity would require
a massive WD, in a state of luminous outflow. From the age of the bulge population (>8 Gyr), a mass <1 \( M_\odot \) is inferred for the stellar companion. The system could be a helium Algol (Iben and Tutukov 1994). Two further bright sources N2 and N3 with effective temperatures (7.9 – 8.5) \( 10^5 \) K and (5.4 – 7.5) \( 10^5 \) K are consistent with massive WDs. 10 SSS have been discovered with Chandra in the Scd spiral galaxy M101, distance 7.2 Mpc (Pence et al. 2001). The 3 brighter sources have luminosities \( \sim 10^{38} \) erg s\(^{-1}\) and effective temperatures \( \sim (7 – 11) \) \( 10^5 \) K. 7 fainter sources have effective temperatures \( \sim (5.5 \pm 0.2) \) \( 10^5 \) K. Most SSS correlate with spiral arms, one source is located in an interarm region, and another source correlates within 2″ with a globular cluster. In NGC 55, NGC 300, and NGC 1291 one SSS has been detected (Schlegel et al. 1997; Read and Pietsch 2001; Irwin et al. 2002). Sarazin et al. (2001) discovered with Chandra the first three SSS in an elliptical galaxy, NGC 4697. At a distance of \( \sim 16 \) Mpc these sources must be luminous \( (\gtrsim 5 \times 10^{37} \) erg s\(^{-1}\)) to be detectable. To evolve towards the TAMS within the age of the elliptical a stellar mass \( \sim 1.0 \) \( M_\odot \) is required, below the lower limit mass for CBSS. These sources may be CV-type SSS.

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