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SUPERSOFT X-RAY SOURCES: A REVIEW STUDY

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Abstract: Following their discovery by the Einstein satellite, supersoft X-ray sources (SSXS) are presently considered to be an important new class of X-ray binaries, with characteristic X-ray luminosities $\sim 10^{38}$ erg s^{-1} and spectral peaks occuring in 15–80 eV. More than 100 SSXS have been discovered so far in the Milky Way, the Magellanic Clouds and $\sim$ 20 other nearby galaxies. Interstellar extinction of soft X-rays plays a major role in determining the number of SSXS being observed in a particular galaxy. Originally, because of the similarity in the SSXS spectra with those of LMXBs, near-Eddington accretion onto neutron stars was thought to be the model for SSXS. However, because of later detailed computations following their luminosities and temperatures, it has been demonstrated that accreting white dwarf with steady nuclear burning is a more suitable model for SSXS, as is currently considered. The sustainability of an SSXS has been shown to depend on three possible regimes of nuclear burning, demonstrating the existence of a narrow range of mass accretion rate between $1-4\times10^{7}\ M_{\odot}\ yr^{-1}$ wherein the nuclear fuel burns steadily. Other accretion rates are shown to explain transient SSXS and those with an accompanying stellar wind. Such a window of mass accretion leads to the identification of possible companions to the white dwarf in an SSXS, further leading to a classification scheme, with close binary supersoft sources (CBSS), symbiotic systems (SS) and cataclysmic variables (CV) being the dominant binary systems manifesting as SSXS. The CBSS subclass of SSXS assumes special significance because it has been shown that they are strong candidates as progenitors for supernovae of Type Ia because they provide the mass accretion rates appropriate for a sub-Chandrasekhar double detonation, which is an off-centre model for type Ia supernovae at sub-Chandrasekhar masses. To obtain an estimate of spectral parameters of the SSXS, the fitting of its observed spectrum to a model spectrum is crucial. The investigation of high-resolution X-ray spectra of SSXS reveals detailed rich spectral features due to high gravity white dwarfs as also P Cygni profiles which are characteristic of the presence of stellar winds. Fitting of such spectra require multiple model components. In particular, for a particular SSXS named RX J0925.7-4758, we have been able to obtain, at an initial stage, an unprecedented good fit using a multi-component model and further study is presently under way.

Keywords: x-ray astronomy; supersoft X-ray source; mass accretion; white dwarf; cataclysmic variable; close binary supersoft source; symbiotic system; type Ia supernovae

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1. X-ray Astronomy:

Extraterrestrial X-rays were first detected in 1949 when photon counters on-board a V-2 rocket revealed the presence of solar X-rays, followed by the detection of X-ray radiation in the night sky by Geiger counters carried by an Aerobee rocket in 1962 [1,2]. These events are generally considered to be the birth of *X-ray astronomy*. Ever since, X-rays have been detected from sources within as well as outside the solar system.

X-ray astronomy is today recognized as a mature and important branch of astronomy. Observations made in the X-ray window enable us to understand many high-energy events in the Milky Way and other galaxies. The physics of such events have improved our understanding of stellar and galactic evolution. Since our atmosphere is opaque to X-rays, observations in this band need to be carried out from outer space. Starting with the Uhuru in 1970, a series of satellites with X-ray telescopes have been launched, leading to the discovery of new and exotic classes of X-ray sources.

In X-ray astronomy, the principle mode of measurement is to detect individual photons so as to determine four properties [3]:

1. arrival direction (leading to X-ray imagery)
2. energy
3. time of arrival
4. polarization angle

The initial X-ray detectors were proportional counters and scintillation counters. With the introduction of focusing and imaging X-ray optics, the Wolter telescope, together with imaging detectors in the focal plane allowed the capture of 2D X-ray imagery. An imaging telescope was first used by the Röntgen Satellite (ROSAT) to perform the first all-sky X-ray survey in 1991-92 [4] – which led to more than 125 X-ray sources being detected. Today, the pioneering X-ray satellites, namely Chandra and XMM-Newton, have actively cooled pixelized solid-state detectors as their standard focal plane detector, providing higher energy resolution and wider energy range than proportional counters.In addition to imaging telescopes, high-resolution grating spectrometers, which have very high spectral resolution and large throughput, are also used in the Chandra and XMM-Newton missions.

These X-ray observatories have been gathering voluminous data, which are currently available in the public domain for data analysis using software such as HEAsoft, SAS and CIAO. Astrosat, India's first dedicated multi-wavelength space observatory launched by ISRO in September 2015, is expected to add more valuable data in the analysis of data from X-ray sources.

2. Supersoft X-ray sources:

Luminous supersoft X-ray sources (SSXS) were first identified as an important new class of intrinsically bright X-ray sources by Trümper *et al.* [5], Greiner *et al.* [6] and Kahabka *et al.* [7]. SSXS are now classified as sources with X-ray luminosities of the order of the Eddington limit ($\sim 10^{38}$ erg s^{-1}), and with extremely soft spectra peaking in the energy range 15–80 eV – corresponding to a blackbody temperature of $\sim$300,000–500,000 K (Kababka *et al.*)[8].

The first SSXS were observed by the low-resolution proportional counters on board the Einstein and ROSAT satellites. Presently, high-resolution X-ray spectra have been obtained by Chandra and XMM-Newton for a number of SSXS, some of the most remarkable ones include RX J0925.7-4758 [9, 10], CAL 83 [11], CAL 87 [12] and RX J0019.8+2156 [13].

By 2005, more than 100 SSXS have been reported in $\sim$20 external galaxies, the Magellanic Clouds (MCs) and our galaxy, the Milky Way (MW) [14]. As per the catalog by Greiner [15, 16], the number of SSXS detected have the following break-up:

- In the Milky Way – 10 SSXS
- In the Large Magellanic Cloud – 8 SSXS
- In the Small Magellanic Cloud – 4 SSXS
- In the Andromeda Galaxy – 34 SSXS

The reason for the observation of lesser number of SSXS within our galaxy, as compared to other galaxies, could be the very large interstellar extinction of soft X-rays. Since we lie at the edge of the Milky Way and on the galactic plane, the soft X-rays from galactic SSXS may be undergoing heavy interstellar extinction. It has been suggested that SSXS within the plane of our galaxy must be at a distance of less than $\sim$ 1 kpc so as to be observable, else at larger distances, interstellar absorption would extinguish them (van den Heuvel *et al.*)[17].

The currently accepted model for luminous SSXS is that, with a few exceptions, these sources are accreting white dwarfs (WDs) within a binary system, "which are burning hydrogen within their envelopes in a steady or intermittent manner" [17].

2.1. A new class of luminous X-ray sources:

Even though four of the first luminous SSXS to be discovered, were first detected with the Einstein satellite [18, 19], because of the limited spectral range and resolution of the Einstein satellite, they were not initially recognised as a separate class. The sources CAL 83 and CAL 87 were, at first, thought to be black holes in binary systems, for instance by Smale *et al.* [20] and Wang *et al.* [21], because black hole sources often exhibit soft spectra.

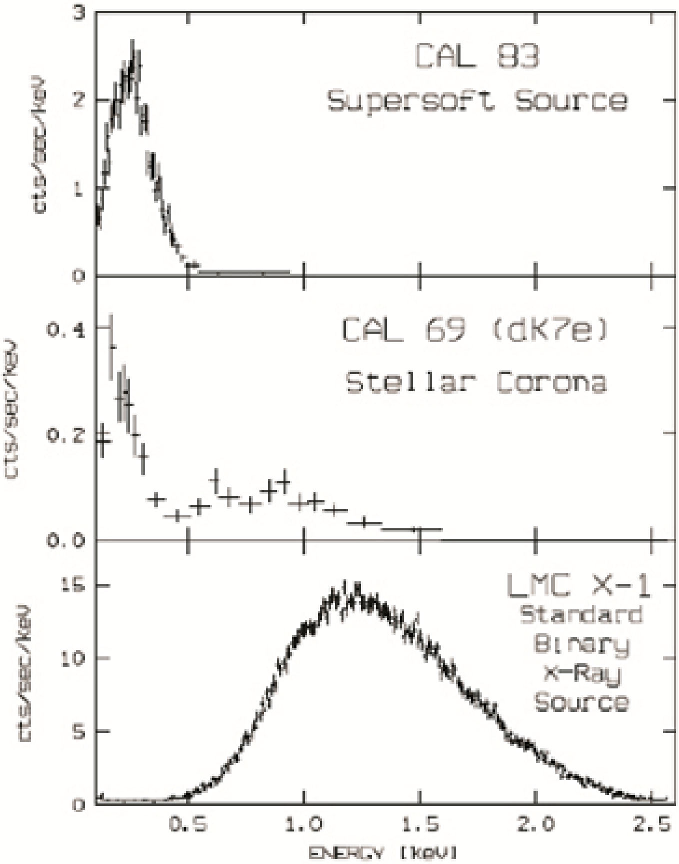

Figure 1: Distinct spectral energy distribution for supersoft X-ray sources (e.g. CAL 83), as compared with a soft X-ray source (dK7e foreground star CAL 69) and a hard X-ray source (black hole candidate LMC X-1) [8].

As depicted in figure , supersoft X-ray sources can be easily distinguished from the X-ray emission of coronae of nearby solar type stars and classical hard X-ray sources (e.g. accreting neutron stars and black holes in binaries). One can easily note that supersoft X-ray sources can be recognized as a distinct class of objects emitting extremely soft spectra.

Owing to the enhanced spectral range and resolution of the ROSAT, the SSXS were later distinguished as a class of sources different from classical strong-point X-ray sources, such as accreting neutron stars or black holes in binaries. SSXS have been observed to have a distinctive peak around 15–80 eV, corresponding to blackbody temperatures that are around 2 orders of magnitude lower than that of classical strong point X-ray sources.

2.2. Currently accepted model: nuclear burning on the surface of a white dwarf:

The optical spectra of the Magellanic Cloud SSXS bear similarity with those of low-mass X-ray binaries, for example the presence of the stron emission He$_{II}$ line at 4686 Åas well as the Balmer lines of hydrogen. Detailed numerical calculations by Kylafis *et al* demonstrated SSXS to be explained as the result of near-Eddington accretion onto neutron stars [22]. However, later calculations indicate the presence of a white dwarf instead of a neutron star which lead to the emission of supersoft X-rays.

If the luminosity and effective temperature of a star are known, using the *Stefan-Boltzmann's law*, one can derive its radius as follows

$$L = 4\pi R^2 \sigma T^4 \tag{1}$$

yielding

$$R = 9 \times 10^8 (L_{37.5})^{1/2} (T_e/40\,\mathrm{eV})^{-2}\,\mathrm{cm}, \tag{2}$$

where $L_{37.5}$ is the X-ray luminosity in units of $10^{37.5}$ erg/s, and T_e is the effective temperature in electron volts.

Using the characteristic values for SSXS, namely $L_{37.5} = 1$ and $T_e = 40$ in equation (2), we obtain that the radius of the emitting object is around 9000 km, *which is similar to that of a white dwarf*. Analogous to accreting neutron stars and black holes in classical X-ray binaries, this suggests that supersoft X-rays are generated by the accretion of matter onto a white dwarf.

It has been argued by van den Heuvel [17] that for white dwarf masses in the range $0.7 - 1.4\,M_\odot$ and with mass accretion rates in the range $\sim 1 - 5 \times 10^{-7}\,M_\odot\,yr^{-1}$, supersoft X-rays are produced (here $M_\odot$ refers to solar mass). In such models, it is assumed that the mass-accretor is the white dwarf, and the companion star is a main-sequence star with a mass in the range $1.4 - 1.5\,M_\odot$ or a post-main-sequence star with a mass in the range $1.5 - 2\,M_\odot$. Theoretically, the mass-transfer rates by Roche-lobe overflow for these companion masses were derived to be $\sim 10^{-7}\,M_\odot\,yr^{-1}$ and $\sim 4 \times 10^{-7}\,M_\odot\,yr^{-1}$ respectively. The X-ray lifetimes were determined to be $\sim 10^7$ years.

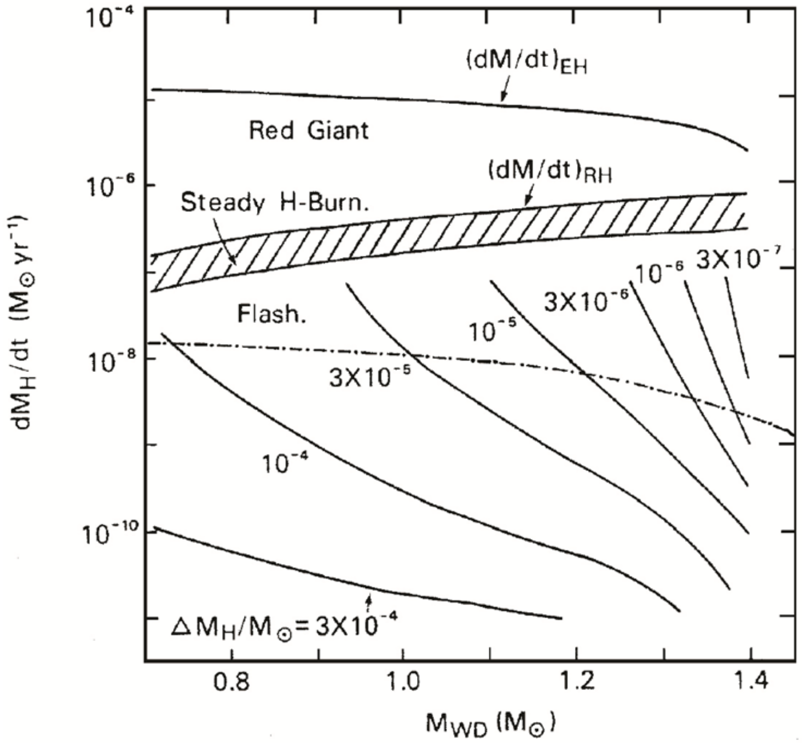

Figure 2: The regimes of nuclear burning in the surface layers of a white dwarf [23].

The conditions for different types of nuclear burning due to mass accretion on a white dwarf has been the subject of independent study by many different groups, some of the notable ones are by Paczyński & Zytkow [24], Prialnik *et al.* [25], Sion *et al.* [26], Sienkiewicz [27], Nomoto [23], Fujimoto [28, 29], Iben [30] and Prialnik & Kovetz [31]. The specific mechanism of the nuclear burning depends on the thermal history of the white dwarf [28-32].

The ignition of nuclear burning, in an envelope of H-rich matter accreted on a white dwarf, takes place if a critical mass of the envelope ΔM_{crit} has been attained which can sustain the necessary high temperature ($\sim 10^8$ K) and pressure ($\gtrsim 10^{18}$–10^{20} g cm $^{-1}$ s^{-2}) for nuclear burning by the CNO cycle.

For a mass accretion rate $\dot{M} \geq 10^{-10}\,M_\odot$ year^{-1} and a white dwarf temperature of 10^7 K, ΔM_{crit} is given as [33]

$$\log\left(\frac{\Delta M_{crit}}{M_\odot}\right) \sim A + B\left(\frac{M_{WD}}{M_\odot}\right)^{-1.436} \ln\left(1.429 - \frac{M_{WD}}{M_\odot}\right) + C\left(\log\left(\frac{\dot{M}}{M_\odot\ \text{year}^{-1}}\right) + 10\right)^{1.484}$$

where $A = -2.862$, $B = 1.542$, and $C = -0.197$. The higher the accretion rate, the lower is the strength of the outburst. A steady state is attained when the accretion rate is similar to the nuclear burning rate. The early calculations of the steady state accretion rate were done by Paczyński and Rudak [34] and Iben [30]. For a hydrogen content, the steady state accretion rate was given by Hachisu and Kato [35] as

$$\dot{M}_{steady} \sim 3.7 \times 10^{-7}\left(\frac{M_{WD}}{M_\odot} - 0.4\right)\ M_\odot\ \text{year}^{-1}$$

As supplemented by Nomoto [23], there are 3 possible regimes of nuclear burning in the surface layers of a white dwarf (depicted in Figure), depending on the accretion rate and the white dwarf mass. These regimes are summarized as follows, for a white dwarf with solar mass:

1. When the mass accretion rate lies in the narrow range $1 - 4 \times 10^{-7}\ M_\odot\ yr^{-1}$, the accreted hydrogen burns steadily, without any significant radius expansion of the white dwarf.
2. For mass accretion rates below the range of steady burning, the accreted matter burns in flashes, i.e. intermittently. With decreasing accretion rates, the frequency of the flashes decreases and the flashes themselves become more violent.
3. For mass accretion rates above the range of steady burning, the radius expands to red giant dimensions, and the matter continues to burn steadily within a thin shell around the white dwarf. This, incidentally, corresponds to the growth rate of the degenerate core in red giant stars due to the hydrogen shell burning.

Calculations made by Hachisu *et al.* [36] show that when the mass accretion rates are very high, much beyond the steady-burning range, a stellar wind solution replaces the static envelope solution. This stellar wind flows out from the white dwarfs at high speeds ($\sim$ 5000 km/s). Since this stellar wind is opaque to soft X-rays, such radiation do not escape.

As long as the accretion rate remains within steady-burning range, the white dwarf will be observed as a steady, luminous SSXS. According to Hachisu *et al.* [36], the white dwarf steadily burns hydrogen and accretes helium, thereby increasing its mass up to $1.38\, M_\odot$ and then explode as a Type Ia supernova. Therefore, here we have a suggestion that *SSXS could be a possible progenitor for a Type Ia supernova.*

2.3. Viable companion to the white dwarf in SSXS:

Since there is a narrow window of mass accretion rates that can eventually give rise to the nuclear burning on a white dwarf, there are limited possibilities with regard to a suitable companion for a white dwarf that can provide the right accretion rate. These possibilities are discussed further in this section.

2.3.1. Close binary supersoft sources:

A white dwarf with a companion star whose mass is larger than about $1.3\, M_\odot$ and has a radiative envelope, provides the simplest binary configuration that can become a luminous SSXS. In such a system, once the donor star overflows its *Roche lobe*, mass transfer (on a thermal time scale) to the white dwarf starts, causing its orbit to shrink. The reason behind this is that mass transfer from the more massive to the less massive component of a binary leads to orbit shrinkage, whereas the thermal equilibrium radius of a star with an evolved He-rich core does not decrease when mass is removed from its envelope. The donor becomes thermally unstable and it will continue transferring mass until it becomes less massive of the two and further mass transfer leads to the orbit expansion [37, 38]. For a star in the vicinity of the main sequence, the thermal time-scale is given by [8]

$$t_{Th} = 3 \times 10^7 \Big/ \left(\frac{M}{M_\odot}\right)^2 \text{ years}$$

From this one can derive the mass transfer rate as:

$$\dot{M} \simeq \frac{M}{t_{Th}} = \frac{1}{3}\left(\frac{M}{M_\odot}\right)^3 \times 10^{-7}\ M_\odot/\mathrm{year}$$

For $M \gtrsim 1.3M_\odot$, we obtain $\dot{M} \gtrsim 10^{-7}\ M_\odot/\mathrm{year}$; similarly $M \lesssim 2.3M_\odot$ gives $\dot{M} \lesssim 4 \times 10^{-7}\ M_\odot/\mathrm{year}$.

Therefore, near-main-sequence companion stars which have mass in the range 1.3–2.3$M_\odot$ can provide the requisite accretion rate for SSXS. Such systems are called *close-binary supersoft sources* (CBSS). Nine such CBSS have been identified by Greiner [15, 16].

2.3.2. Symbiotic systems:

Symbiotic systems are identified as binaries consisting of a red giant star and a white dwarf [39, 40]. Sion *et al.* [41] first showed that a system consisting a red-giant star and a white dwarf is another class of binary systems which can sustain the mass accretion rates necessary for producing supersoft X-rays. Two types of red-giant companions may be expected, providing different modes of mass-transfer.

1. 1 $M_\odot$ red-giant, less massive than the white dwarf. Such a companion overflows its Roche lobe with an orbital period of at least 125 days. The red-giant has a degenerate He core, and its nuclear evolution drives the mass transfer. The expected accretion rate is given by

   $$\dot{M} \approx (P_0/12.5d)10^{-8}\, M_\odot\, yr^{-1}$$

   where P_0 is the orbital period at the onset of mass transfer. This equation shows that for orbital periods longer than about 125 days the accretion rate is sufficiently large for steady nuclear burning on the surface layers of the white dwarf.

2. The red-giant is on the aymptotic giant branch (AGB) and is not filling its Roche lobe, however there is a very strong stellar wind. With mass loss rates from the AGB of the order $10^{-5}\, M_\odot\, yr^{-1}$ and stellar wind velocities of around 30 km/s, the aggregate accretion rate can become as large as of the order $10^{-7}\, M_\odot\, yr^{-1}$ on a white dwarf, which is sufficient to create a luminous SSXS.

2.3.3. Cataclysmic Variables:

The name *cataclysmic variable* is given to an interacting binary in which the compact object is a white dwarf which accretes matter from a low-temperature late-type companion star in a short period of time ($\sim$ hours) [42]. The importance of CVs in astronomy is emphasized by the fact that the visible light is dominated by process of accretion of matter onto the white dwarf. Also, these are numerous in our galaxy, with several hundred of them catalogued to within a few hundred parsecs. Because of their proximity, the interstellar extinction is less, and hence their spectra can be studied over a wide range of wavelengths. Hence CVs allow the observation of accretion physics in great detail.

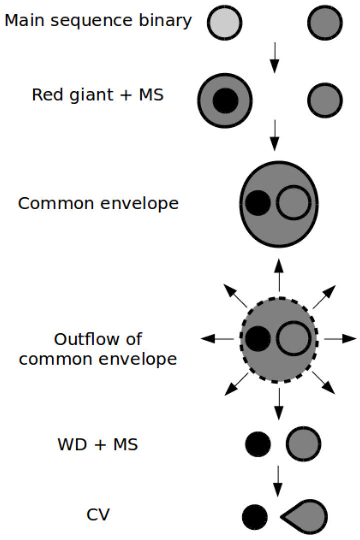

Figure 3: Evolution of a CV from a pair of main-sequence stars [43].

As described in figure [43], the evolution of a CV starts from a pair of main-sequence stars. The more massive star burns its fuel at a faster rate and eventuall reaches the red-giant phase. If the expansion is so large that the atmosphere of the red-giant envelopes the other star, which then spirals in towards the core of the red giant as a result of the atmospheric drag. This envelope, being tenuous, dissipates rapidly as a consequence of the spiral-in. As a result, a short period binary is formed, with the companion star and the white dwarf orbiting each other. Gradually the companion star evolves to fill its own Roche lobe. Finally, with the beginning of mass transfer onto the white dwarf, a cataclysmic variable is formed.

The X-ray emission from CVs arise from the regions close to the white dwarf, and is due to a combination of radiation from plasma at a range of temperatures. The observed spectrum is controlled by the geometry of the accretion process. Comparing the spectra of a number of different types of CVs obtained by Chandra, Mukai classified the X-ray spectra from CVs into two classes [44]:

1. Spectra with strong H, He-like lines of O, Ne, Mg, Al, Si and S, plus the entire Fe L complex of lines from ions XVII to XXIV. Such spectra are well-fitted by a multi-temperature plasma model.
2. Spectra which show a strong, hard power-law component. These require a photoionisation model in order to obtain a goot fit.

The mass accretion rate for a CV in outburst is 100 times smaller that that of a luminous SSXS. Van den Heuvel *et al.* proposed that for a binary mass ratio $\sim$1, unstable mass transfer will occur onto the white dwarf [17]. As discussed in figure , this phase is short-lived and would last only a few times in 10^7 years for a $\sim 1\ M_\odot$ companion star.

3. Classification scheme for supersoft X-ray sources:

As per current knowledge, various binary systems may manifest themselves ar supersoft X-ray sources. Di Stefano *et al.* [45] showed that binary systems that appear as luminous SSXS may be classified on the basis of the mass transfer mechanism from the main star to the white dwarf. This leads to different systems with varying mass accretion rates and associated orbital periods. Also, the emission of supersoft X-rays may be steady or recurrent. This is summarised in table as follows:
In the table above, [A] only those systems are considered in which H-rich material is accreting on the surface of a C-O white dwarf. Here CV = cataclysmic variable, CBSS = close-binary supersoft source and WBSS = wide-binary supersoft source. [B] Two prominent mass transfer mechanisms are mb = magnetic braking and gr = gravitational radiation. [C] $\dot{M}$ is the mass accretion rate on the surface layers of the white dwarf. [D] P_{orb} refers to the orbital period of the binary. [D] When $\dot{M}$ is in the correct range (about $>\sim\ 10^{-7}\ M_\odot\ yr^{-1}$), the source burns nuclear fuel more or less steadily (S); for smaller values of $\dot{M}$, hydrogen burns sporadically (R).

Table 1: Classification of binary systems that may manifest as SSXS.

[A] **System Type**	[B] **Mass Transfer Mechanism**	[C] **Mass Accretion Rate** $\dot{M}$ ($M_\odot\ yr^{-1}$)	[D] **Orbital Period** P_{orb} **(days)**	[E] **Steady or Recurrent**
CVs	mb and/or gr	$<\sim 10^{-8}$	$<\sim 0.2$	R
CBSSs	thermal time scale readjustment of donor	$>\sim 10^{-7}$	$\sim 0.2 - 3.0$	S
		$<\sim 10^{-7}$	$\sim 0.2 - \mathcal{O}(10^2)$	R
WBSSs	nuclear evolution of donor	$>\sim 10^{-7}$	$\sim 3.0 - \mathcal{O}(10^2)$	S
		$<\sim 10^{-7}$	$\sim 3.0 - \mathcal{O}(10^2)$	R
Symbiotics (Wind-driven)	stellar winds from evolved donor	$>\sim 10^{-7}$	$\mathcal{O}(10^2)$	S
		$<\sim 10^{-7}$	$\mathcal{O}(10^2)$	R

4. Derivations from white dwarf atmospheres:

The fitting of the supersoft spectrum to viable models enable one to obtain the luminosities and temperatures for the binary. Generally, the simplest assumption for a spectrum is a blackbody distribution. However, for hot white dwarfs, this provides a poor approximation [46]. With local thermodynamic equilibrium (LTE) atmosphere models for a white dwarf, the flux distributions for SSXS RX J0925.7-4758 and CAL 87 were found to show absorption edges due to heavier elements. With such models, bolometric luminosities which are much lower than those obtained from blackbody approximations, are obtained. These bolometric X-ray luminosities are then found to be of the order of the Eddington limit, and at the same time providing a good fit to models for stable nuclear burning on the surface of a white dwarf.

5. As progenitors of type Ia supernovae:

The widely accepted proposition for type Ia supernovae (SN Ia) is the thermonuclear explosions of mass accreting co-orbiting white dwarfs [47, 48], with the source of accretion being any of the following three possibilities:

a. Stellar wind from the donor
b. Roche lobe overflow
c. Coalescence of two white dwarfs

Even though the exploding white dwarf in an SN Ia is generally assumed to be near the Chandrasekhar limit ($\sim$1.4 $M_\odot$), explosions at sub-Chandrasekhar mass are also possible. Also, the off-centre detonations of accreted He (produced by earlier shell burning of H) on co-orbiting white dwarfs may trigger explosions which are similar to SN Ia. This is known as the *double detonation model* [49, 50].

Prior to the discovery of SSXS, there were two major candidates for near-Chandrasekhar mass SN Ia:

1. The merger of a close pair of co-orbiting white dwarfs due to orbital decay, following the loss of gravitational radiation [51].
2. Symbiotic stars [52]. Yungelson *et al.* showed that symbiotics might produce around $^1\!/_3{}^{\mathrm{rd}}$ of the SN Ia population, if sub-Chandrasekhar double detonation models indeed produce SN Ia [53].

After their discovery, SSXS were suggested to be a new class of potential SN Ia progenitors [36, 45, 48]. The CBSS subclass is considered to be most promising as a progenitor. In the CV subclass, the accrected mass is ejected violently in nova explosions, while the symbiotic subclass yields too low a mass accretion rate for SN Ia.

In CBSS, the mass accretion is sufficient to lead to a sub-Chandrasekhar double detonation. A population of $\sim 1 - 4 \times 10^3$ CBSS in the Milky Way [45], increasing approximately by $\sim 0.2\,M_\odot$ in $\sim 10^6$ years, leads to double detonation rate of $\sim 1 - 2 \times 10^{-3}$ year^{-1} [48], which is almost as high as the SN Ia rate in spiral galaxies.

6. Supersoft spectra:

For steadily nuclear-burning cold white dwarfs ($< 10^7$ K) with cooling ages in the range 1–3×10^8 years [54] and white dwarf mass $M_{WD} \sim (0.7 - 1.3)\, M_{\odot}$, the maximum atmospheric temperature is given by [30, 55]

$$T_{max} \approx 1.4 \times 10^6 \left(0.107 + \left(\frac{M_{WD}}{M_{\odot}} - 0.6\right)^{1.7}\right)$$

Knowing the temperature, the white dwarf mass can be calculated. The white dwarf mass can also be estimated from the bolometric luminosity during the plateau phase of the HR diagram [30]. However, it is the temperature which is considered to be a more accurate indicator of the white dwarf mass. The reason for this is that the luminosity of the binary may be reduced due to absorption or scattering.

In order to derive the effective temperatures and bolometric luminosities, one needs to first fit the observed SSXS spectrum to a viable model. Various different models have been used to fit spectra from different SSXS. Models such as blackbody, LTE and NLTE white dwarf model atmospheres have been applied to the spectra of SSXS observed by ROSAT [56], ASCA [57, 58] and BeppoSAX [59-61]. Applying blanketed LTE white dwarf model atmospheres to 10 SSXS observed by ROSAT, Ibragomov *et al.* derived the spectral parameters for hot and cold white dwarf approximation [62]. Detailed spectral investigations showed that most of the SSXS are either in the regime of stable nuclear burning or are consistent with cooling white dwarfs [55].

The spectral analysis of the interesting SSXS RX J0925.7-4758 using data obtained by Chandra [9] and XMM-Newton [10] reveals the presence of rich spectral features, especially the emission lines of highly ionized metals, such as O_{VIII} and Fe_{XVII}, due to high gravity white dwarfs. The spectral lines are also observed to exhibit P Cygni profiles which is characteristic of the presence of stellar wind. As per present literature, it is not possible to obtain a fit for the spectrum of this particular source using NLTE models. However, the current work undertaken by us using a novel model has shown encouraging results in this direction. Detailed study is under way in this regard. Figure shows a fit obtained for a 2^{nd} order spectrum of RX J0925.7-4758 from the RGS equipment on board the XMM-Newton. The reduced χ^2, which measures the goodness of the fit, was obtained to be 1.48, which is unprecented using a multi-component model for this particular source.

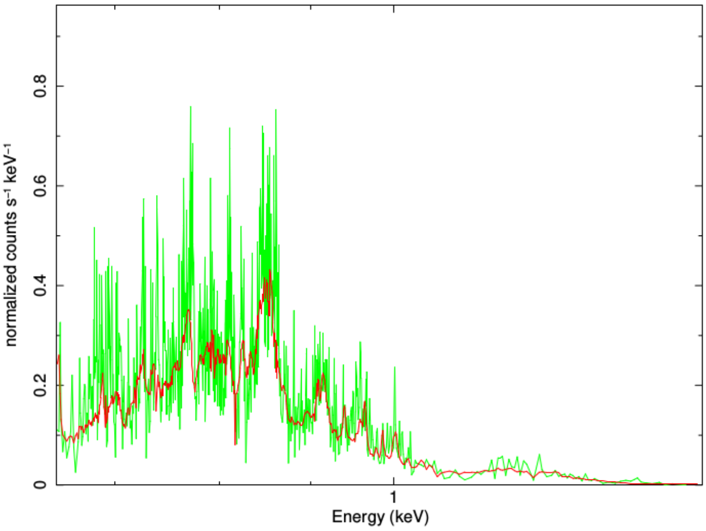

Figure 4: Fitting of the 2^{nd} order RGS spectrum of RX J0925.7-4758 using a novel model.

7. Summary:

From a mere curio, the study of supersoft sources is today considered crucial to the understanding of the evolution of X-ray binaries. Apart from the Milky Way, SSXS have been discovered in the Magellanic Clouds and in about 20 nearby galaxies. A large proportion of the SSXS discovered so far are transient. Supersoft transients seem to be classical and symbiotic novae having a supersoft phase and also systems with no known nova outburst but exhibit supersoft X-ray ”on” and ”off” states.

Although the evolution of SN Ia has not been fully solved as yet, keeping in mind their calculated numbers and birth rates, merging double degerate white dwarfs and CBSS are considered to be the two most promising progenitor candidates for SN Ia.

The SSXS spectra for several sources obtained with high-resolution grating spectrometers reveal the dominance of several spectral features, including P Cygni profiles. Obtaining a proper fit for such spectra has been challenging so far, but crucial in order to be able to derive the parameters of the SSXS under study.

References:

[1] H. Friedman, S. Lichtman, and E. Byram, Photon counter measurements of solar X-rays and extreme ultraviolet light, *Physical Review*, vol. 83, no. 5, pp. 1025–1030, 1951.
[2] R. Giacconi, H. Gursky, F. Paolini, and B. Rossi, Evidence for X-rays from sources outside the solar system, *Physical Review Letters*, vol. 9, no. 11, pp. 439–443, 1962.
[3] R. Staubert and J. Trümper, Overview, in *The Universe in X-rays* (J. Trümper and G. Hasinger, eds.), ch. 1, pp. 3–4, Springer Science & Business Media, 2008.
[4] W. Voges, The ROSAT All-Sky X-ray Survey, *Environment Observation and Climate Modelling Through International Space Projects*, July 1992.
[5] J. Trümper, G. Hasinger, B. Aschenbach, H. Braeuninger, U. Briel, W. Burkert, H. Fink, E. Pfeffermann, W. Pietsch, P. Predehl, J. Schmitt, W. Voges, U. Zimmermann, and K. Beuermann, X-ray survey of the Large Magellanic Cloud by ROSAT, *Nature*, vol. 349, pp. 579–583, February 1991.
[6] J. Greiner, G. Hasinger, and P. Kahabka, ROSAT observation of two supersoft sources in the Large Magellanic Cloud, *Astronomy and Astrophysics*, vol. 246, pp. L17–L20, April 1991.
[7] P. Kahabka and E. van den Heuvel, Super-soft sources, in *Compact Stellar X-Ray Sources*, ch. 11, pp. 461–474, Cambridge University Press, 2006.
[8] P. Kahabka and E. van den Heuvel, Luminous Supersoft X-ray Sources, *Annual Review of Astronomy and Astrophysics*, vol. 35, pp. 342–351, 1997.
[9] H. Bearda, W. Hartmann, K. Ebisawa, J. Heise, J. Kaastra, R. van der Meer, F. Verbunt, and C. Motch, The complex X-ray spectrum of the supersoft source MR Vel, *Astronomy and Astrophysics*, vol. 385, pp. 511– 516, 2002.
[10] C. Motch, H. Bearda, and C. Neiner, XMM-Newton observations of MR Vel/RX J0925.7-4758, *Astronomy and Astrophysics*, vol. 393, pp. 913–920, 2002.
[11] T. Lanz, G. A. Telis, M. Audard, F. Paerels, A. P. Rasmussen, and I. Hubeny, Non-LTE model atmosphere analysis of the Large Magellanic Cloud supersoft X-ray source CAL 83, *The Astrophysical Journal*, vol. 619, no. 1, p. 517, 2005.
[12] M. Orio, K. Ebisawa, J. Heise, and W. Hartmann, A new view of the supersoft X-ray source CAL 87 observed with XMM-Newton, *arXiv preprint astro-ph/0402040*, 2004.
[13] R. Schwarz and K. Reinsch, XMM-Newton observations of the galactic supersoft X-ray source QR And, *Astronomische Nachrichten Supplement*, vol. 325, p. 107, 2004.
[14] P. Kahabka, Supersoft X-ray Sources, *Advances in Space Research*, vol. 38, pp. 2836–2839, November 2006.
[15] J. Greiner, Catalog of supersoft X-ray sources, *New Astronomy*, vol. 5, no. 3, pp. 137–141, 2000.
[16] J. Greiner, Catalog of supersoft X-ray sources. `http://www.mpe.mpg.de/?jcg/sss/ssscat.html`, 2000. [Online; accessed June 2016].
[17] E. van den Heuvel, D. Bhattacharya, K. Nomoto, and S. Rappaport, Accreting white dwarf models for CAL 83, CAL 87 and other ultrasoft X-ray sources in the LMC, *Astronomy and Astrophysics*, vol. 262, pp. 97–105, 1992.
[18] K. S. Long, D. J. Helfand, and D. A. Grabelsky, A soft X-ray study of the Large Magellanic Cloud, *The Astrophysical Journal*, vol. 248, pp. 925–944, 1981.
[19] F. Seward and M. Mitchell, X-ray survey of the Small Magellanic Cloud, *The Astrophysical Journal*, vol. 243, pp. 736–743, 1981.
[20] A. Smale, R. Corbet, P. Charles, S. Ilovaisky, K. Mason, C. Motch, K. Mukai, T. Naylor, A. Parmar, M. van der Klis, et al., CAL 83: a 1-day period low-mass X-ray binary in the LMC, *Monthly Notices of the Royal Astronomical Society*, vol. 233, no. 1, pp. 51–63, 1988.
[21] Q. Wang and X. Wu, A comprehensive X-ray study of the Small Magellanic Cloud, *The Astrophysical Journal Supplement Series*, vol. 78, pp. 391–401, 1992.

[22] N. Kylafis and E. Xilouris, Low-mass X-ray binary models for the supersoft X-ray sources CAL 83, CAL 87 and RX J0527.8-6954 in the Large Magellanic Cloud, *Astronomy and Astrophysics*, vol. 278, pp. L43–L46, 1993.

[23] K. Nomoto, Accreting white dwarf models for type I supernovae. I-Presupernova evolution and triggering mechanisms, *The Astrophysical Journal*, vol. 253, pp. 798–810, 1982.

[24] B. Paczynski and A. Zytkow, Hydrogen shell flashes in a white dwarf with mass accretion, *The Astrophysical Journal*, vol. 222, pp. 604–611, 1978.

[25] D. Prialnik, M. Shara, and G. Shaviv, The evolution of a slow nova model with a Z=0.03 envelope from pre-explosion to extinction, *Astronomy and Astrophysics*, vol. 62, pp. 339–348, 1978.

[26] E. Sion, M. Acierno, and S. Tomczyk, Hydrogen shell flashes in massive accreting white dwarfs, *The Astrophysical Journal*, vol. 230, pp. 832–838, 1979.

[27] R. Sienkiewicz, Stability of white dwarfs undergoing spherically symmetric steady-state accretion, *Astronomy and Astrophysics*, vol. 85, pp. 295–301, 1980.

[28] M. Fujimoto, A Theory of Hydrogen Shell Flashes on Accreting White Dwarfs. I. Their Progress and the Expansion of the Envelope, *The Astrophysical Journal*, vol. 257, pp. 752–766, 1982.

[29] M. Fujimoto, A Theory of Hydrogen Shell Flashes on Accreting White Dwarfs. II. The Stable Shell Burning and the Recurrence Period of Shell Flashes, *The Astrophysical Journal*, vol. 257, pp. 767–779, 1982.

[30] I. Iben Jr, Hot accreting white dwarfs in the quasi-static approximation, *The Astrophysical Journal*, vol. 259, pp. 244–266, 1982.

[31] D. Prialnik and A. Kovetz, An extended grid of multicycle nova evolution models, *The Astrophysical Journal*, vol. 445, pp. 789–810, 1995.

[32] J. MacDonald, CNO abundances and the strengths of nova outbursts and hydrogen flashes on accreting white dwarfs, *The Astrophysical Journal*, vol. 267, pp. 732–746, 1983.

[33] D. M. Townsley and L. Bildsten, Theoretical modeling of the thermal state of accreting white dwarfs undergoing classical nova cycles, *The Astrophysical Journal*, vol. 600, no. 1, p. 390, 2004.

[34] B. Paczynski and B. Rudak, Symbiotic stars: Evolutionary considerations, *Astronomy and Astrophysics*, vol. 82, pp. 349–351, 1980.

[35] I. Hachisu and M. Kato, Recurrent novae as a progenitor system of type Ia supernovae. I. RS Ophiuchi subclass: systems with a red giant companion, *The Astrophysical Journal*, vol. 558, no. 1, 2001.

[36] I. Hachisu, M. Kato, and K. Nomoto, A new model for progenitor systems of Type Ia supernovae, *The Astrophysical Journal Letters*, vol. 470, no. 2, p. L97, 1996.

[37] B. Paczynski, Evolutionary processes in close binary systems, *Annual Review of Astronomy and Astrophysics*, vol. 9, p. 183, 1971.

[38] E. van den Heuvel, Interacting Binaries, 1994.

[39] S. Kenyon, The Symbiotic Stars, 1986.

[40] M. Friedjung, J. Mikolajewska, S. J. Kenyon, and R. Viotti, The symbiotic phenomenon, in *IAU Colloq. 103: The Symbiotic Phenomenon*, vol. 145, 1988.

[41] E. M. Sion and S. G. Starrfield, Evolutionary sequences of very hot, low-mass, accreting white dwarfs with application to symbiotic variables and ultrasoft/supersoft low-luminosity X-ray sources, *The Astrophysical Journal*, vol. 421, pp. 261–268, 1994.

[42] F. D. Seward and P. A. Charles, Cataclysmic variable stars, in *Exploring the X-ray Universe*, ch. 10, pp. 143–170, Cambridge University Press, 2 ed., 2010.

[43] T. R. Marsh, Observations of Cataclysmic Variable and Double Degenerate Stars, in *Binary Stars: Selected Topics on Observations and Physical Processes*, pp. 151–202, Springer, 2001.

[44] K. Mukai, X-ray Spectroscopy of Cataclysmic Variables, *Advances in Space Research*, vol. 32, no. 10, pp. 2067–2076, 2003.

[45] R. di Stefano and L. Nelson, On the evolution, numbers and characteristics of close-binary supersoft sources, in *Supersoft X-Ray Sources* (J. Greiner, ed.), pp. 3–14, Springer, 1996.

[46] J. Heise, A. Van Teeseling, and P. Kahabka, The spectra and luminosity of super-soft X-ray sources, *Astronomy and Astrophysics*, vol. 288, 1994.

[47] W. D. Arnett, A possible model of supernovae: detonation of 12 C, *Astrophysics and Space Science*, vol. 5, no. 2, pp. 180–212, 1969.

[48] D. Branch, M. Livio, L. Yungelson, F. R. Boffi, and E. Baron, In search of the progenitors of type IA supernovae, *Publications of the Astronomical Society of the Pacific*, pp. 1019–1029, 1995.

[49] E. Livne, Successive detonations in accreting white dwarfs as an alternative mechanism for type I supernovae, *The Astrophysical Journal*, vol. 354, pp. L53–L55, 1990.

[50] M. Limongi and A. Tornamb, He stars and He-accreting CO white dwarfs, *The Astrophysical Journal*, vol. 371, pp. 317–331, 1991.

[51] R. Webbink, Double white dwarfs as progenitors of R Coronae Borealis stars and Type I supernovae, *The Astrophysical Journal*, vol. 277, pp. 355–360, 1984.

[52] U. Munari and A. Renzini, Are symbiotic stars the precursors of type IA supernovae?, *The Astrophysical Journal*, vol. 397, pp. L87–L90, 1992.

[53] L. Yungelson, M. Livio, A. Tutukov, and S. Kenyon, A model for the galactic population of symbiotic stars with white dwarf accretors, *The Astrophysical Journal*, vol. 447, 1995.

[54] L. Yungelson, M. Livio, J. Truran, A. Tutukov, and A. Fedorova, A model for the Galactic population of binary supersoft X-ray sources, *The Astrophysical Journal*, vol. 466, 1996.

[55] V. Suleimanov and A. Ibragimov, Supersoft X-ray sources: Basic parameters, *Astronomy Reports*, vol. 47, no. 3, pp. 197–205, 2003.

[56] S. Balman, J. Krautter, and H. Oegelman, The X-ray spectral evolution of classical nova V1974 Cygni 1992: A reanalysis of the ROSAT data, *The Astrophysical Journal*, vol. 499, no. 1, p. 395, 1998.

[57] K. Asai, T. Dotani, F. Nagase, K. Ebisawa, K. Mukai, A. Smale, and T. Kotani, ASCA observation of the supersoft X-ray source CAL 87, *The Astrophysical Journal Letters*, vol. 503, no. 2, 1998.

[58] K. Ebisawa, K. Mukai, T. Kotani, K. Asai, T. Dotani, F. Nagase, H. Hartmann, J. Heise, P. Kahabka, and A. Van Teeseling, X-Ray Energy Spectra of the Supersoft X-Ray Sources CAL 87 and RX J0925.7-4758 Observed with ASCA, *The Astrophysical Journal*, vol. 550, no. 2, 2001.

[59] A. Parmar, P. Kahabka, H. Hartmann, J. Heise, D. Martin, M. Bavdaz, and T. Mineo, A BeppoSAX observation of the super-soft source CAL87, *arXiv preprint astro-ph/9706008*, 1997.

[60] H. Hartmann, J. Heise, P. Kahabka, C. Motch, and A. Parmar, Constraining the spectral parameters of RXJ0925.7-4758 with the BeppoSAX LECS, *arXiv preprint astro-ph/9903243*, 1999.

[61] M. Orio, A. Parmar, J. Greiner, H. gelman, S. Starrfield, and E. Trussoni, The X-ray emission from Nova V382 VelorumII. the super-soft component observed with BeppoSAX, *Monthly Notices of the Royal Astronomical Society*, vol. 333, no. 1, pp. L11–L15, 2002.

[62] A. Ibragimov, V. Suleimanov, A. Vikhlinin, and N. Sakhibullin, Supersoft X-ray sources: parameters of stellar atmospheres, *Astronomy Reports*, vol. 47, no. 3, pp. 186–196, 2003.