THE LUMINOUS SUPERSOFT X-RAY SOURCE RXJ0925.7-4758 AS A BINARY ACCRETING WHITE DWARF

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Abstract: The luminous super soft X-ray sources (LSSS) are believed to be white dwarf binaries with large mass accretion rates ($\sim 1\times10^{-7}$ - $6\times10^{-7} M_{\Theta}\, yr^{-1}$) and the energy source is the steady nuclear burning on the white dwarf (WD) surface. During such high accretion rates, hydrogen shell burning consumes hydrogen at the same rate as the WD accretes. In the present work, the LSSS RXJ0925.7-4758 has been studied to examine whether steady state nuclear burning can contribute to emit super soft X-radiation. The luminosity and effective temperature of the LSSS RXJ0925.7-4758 are calculated using the model proposed by Nomoto *et.al.*, 2007 and the values of luminosity (8.56×10^{37}erg/sec) and effective temperature (94.19 ev) are found to tally well with the observed ones. Using formulas of Hoshi, 1998, the color temperature of the LSSS RXJ0925.7-4758 is calculated which is found to be 106 ev and it is higher than the effective temperature of the source.

Keywords: white dwarf; super soft X-ray source; color temperature

1. Introduction:

Luminous Super Soft ray sources (LSSSs) are characterized by very soft X-ray radiation of high luminosity, having extremely soft spectra (equivalent black body temperature of 20- 100 ev) and are highly luminous (bolometric luminosity of 10^{36}-10^{38}ergs^{-1})[1] .This corresponds to a blackbody temperature typically of 30,000-5,00,000 K, some two orders of magnitude lower than for that of the classical X-ray binaries which contain neutron stars or black holes[2]. LSSSs are divided into relatively 'Soft' LSSSs with spectra that have the bulk of their flux below 0.5kev and relatively 'hard' LSSSs that emit mainly above 0.5 kev. [3]

Einstein observatory, ROSAT, ASCA, CHANDRA, XMM-Newton, SWIFT, SUZAKU observations in the last four decades have discovered dozens of luminous super soft X-ray sources (LSSSs)[4]. Einstein observatory was the first one to discover LSSS. [2]. Astrophysicists have used varieties of treatments and several theoretical models including accreting black holes and Neutron stars to analyze the observed characteristics of LSSSs. But the most promising candidate as first suggested by Van den Heuvel, E.P.J. *et.al*.,[4][5], is an accreting binary white dwarf (WD) in a close binary (CB) system, the companion may be a near main sequence in the mass range 1.3-2.5M_{Θ} . In the present work in order to explain the observed characteristics of LSSS RXJ0925.7-4758, a steady state model proposed by Nomoto *et.al.*, 2007[6] is considered, in which hydrogen shell burning consumes hydrogen at the same rate as the white dwarf accretes it. Different parameters are taken from the model and are presented in the table 1 to explain the observed characteristics of the considered source. In section 2, luminosity and effective temperature of the LSSS RXJ0925.7-4758 has been calculated. Eddington temperature, Eddington luminosity of source has been calculated in section 3. Study of structure of the envelope and color temperature of the source is presented in section 4.

Table 1: Steady state Hydrogen burning model, WD mass $M=1.35M_{\Theta}$

$\dot{M}$ ($M_{\Theta}yr^{-1}$)	3.5×10^{-7}
$Log_{10}T_H$ (K)	8.05
T_H (K)	$0.11\times10^{+9}$
$Log_{10}\rho_H$ (gm/cm^3)	1.56
ρ_H	36

2. Luminosity and effective temperature:

The values of luminosity and effective temperature of considered LSSS is calculated using the following relations - energy production through a reaction cycle depends on the slowest reaction in the sequence and the nuclear energy generation rate is given by

$$E_{nuc} = QR_{12}/\rho \text{ erg } g^{-1}s^{-1} = Q\, \rho N_A\, [N_A\langle\sigma\, \upsilon\rangle X_H X_Z]\, /A_1A_2 \text{erg } g^{-1}\, s^{-1} \tag{1}$$

Here, R_{12} is the slowest reaction rate and Q is the total disintegration energy in the cycle. N_A is the Avogadro number. A_1 and A_2 are the mass numbers of the reacting nuclei of the slowest reaction rate. Energy radiated per second that is luminosity L is given by

$$L = E_{nuc}\, M \text{ erg } s^{-1} \tag{2}$$

$$M= \dot{M}t_{acc}\,, \tag{3}$$

where $\dot{M}$ is the mass accretion rate and t_{acc} is the time of accretion . The effective temperature is given by

$$T_{eff} = (L/4\pi R^2\sigma)^{1/4} \tag{4}$$

where R is the radius and σ is the Stefan-Boltzmann constant.

From [7] recent reaction rates are taken for mathematical calculations. Calculated values of luminosity and effective temperature are presented in table 2 for the considered source and also the observed values are mentioned in the table for the considered source.

Table 2: T_9 =0.11K, ρ =36 gm/cc, accretion rate=6.97×10^{27}gm/year.

Supersoft X-ray sources	Observed luminosity(L)erg/ sec	Observed Effective temperature (T_{eff}) ev	Calculated luminosity(L)erg/ sec	Calculated Effective temperature (T_{eff}) ev
RXJ0925.7-4758	$5\text{x}10^{37}$	96	$8.56\text{ x}10^{37}$	94.19

3. Eddington Temperature, Eddington luminosity of LSSS:

Eddington temperature $T_{e,EDD}$ which is given by (Hoshi,1998)[8]

$$T_{e,EDD}= (cGM_{ch}/k_e\sigma R_o^2)^{1/4}(M/M_{ch})^{1/4}(1- M/M_{ch})^{-1/4} \tag{5}$$

Resulted to be $1.44*10^6$K, where k_e is the electron scattering opacity which has been calculated according to Bodenheimer 1995[9]. M_{ch} is the Chandrasekhar limiting mass ($1.46M_{\Theta}$), R_o is equal to $1\text{x}10^9$cm .The Eddington luminosity L_{edd} yielded out to be $2.33\text{x}10^{38}$erg/sec. The ratio of L/ L_{edd} is equal to 0.367 for the considered source.

4. Structure of the Envelope and Color Temperature:

Observed properties of the LSSS depend on the star envelope characteristics. The total column mass from the base to the photosphere m_o is given by

$$m_o =(L_{edd}/L)(GM/R^2)^{-1}(aT_H^4/3) \tag{6}$$

which comes out to be $4.22\text{x}10^8$ gm/cm^2 with envelope thickness $4.05\text{x}10^7$ cm.

The temperature (T), pressure (P), density (ρ) and column mass (m) at different heights are given by relations –

$$T = T_1\left(1-\frac{h}{h_0}\right) \quad (7)$$

$$P = P_1\left(1-\frac{h}{h_0}\right)^4 \quad (8)$$

$$\rho = \rho_1\ (1-\frac{h}{ho})^3 \quad (9)$$

The column mass (m) at a height (h) is given by

$$m = h\rho \quad (10)$$

Now, to investigate the structure of the envelope that means how the gas properties change with positions by dividing the envelope thickness h_o in six different envelope heights, using equation (7) to (10), density (ρ), pressure (P), column mass (m) are determined which are shown in Table (3).

Table: 3 Variation of density (ρ), pressure (P), column mass (m) and temperature (T) with envelope height h.

h (cm)	ρ (gm/cc)	P(dyne/cm^2)	m (gm/cm^2)	T(k)
2.025×10^7	5.2	6.25×10^{16}	1.06×10^8	5.50×10^7
2.43×10^7	2.67	2.56×10^{16}	6.49×10^7	4.40×10^7
2.83×10^7	1.13	8.10×10^{15}	3.19×10^7	3.30×10^7
3.24×10^7	0.334	1.6×10^{16}	1.08×10^7	2.20×10^7
3.63×10^7	4.65×10^{-2}	1.16×10^{14}	1.61×10^6	1.14×10^7
4.0095×10^7	4.17×10^{-5}	1.1×10^{10}	1.67×10^3	1.10×10^6

.

Color temperature:

The color temperature is the temperature corresponding to the mean energy of the photons while T_{eff} is the one calculated from the luminosity L and the radius R of a star. [10]

In the layer of optical depth $\tau < 1$, photon flux is transmitted without loss of energy, although individual photons are scattered many times [8]. Hoshi (1998) approximates these layers with $\tau \leq 2/3$ to be isothermal with the temperature T_{color}, the temperature at $\tau = 2/3$. The Color temperature T_{color} is given by the relation

$$T_{color} = (k_e k_o)^{-1/7}\ (k/\mu m_H)^{1/7}\,(L/L_{e,Edd})^{3/7} * (1- L/L_{e,Edd})^{-1/7} (3/a)^{3/7}\,(GM/R^2)^{2/7} \quad (11)$$

where k_e is electron scattering opacity , m_H is the mass of the hydrogen atom and μ is the mean molecular weight respectively, a is the radiation density constant.

$$\text{And } R = R_o\left(1+\frac{h_o}{R_o}\right)\left(1-\frac{M}{M_{ch}}\right)^{1/2} \quad (12)$$

With envelope thickness $h_O = 4.05\times10^7$ cm, R comes out to be 2.8×10^8 cm. Here 'a' is the radiation density constant and has the value 7.56×10^{-15} erg cm^{-3} K^{-4}. K_O is a constant and has the value 2.5×10^{27} cm^{5}g^{-2} k^4. K_e is the electron scattering opacity near the photosphere has been calculated according to Bodenheimer 1995[9]. The value of K_e comes out to be 0.33 cm^2 g^{-1} with hydrogen mass fraction X=0.7.For the LSSS RXJ0925.7 –4758, the ratio $(L/L_{e,Edd})$which is equal to 0.367, the color temperature T_{color} is evaluated. The value of T_{color} becomes 106 ev which is greater than the effective temperature T_{eff} of the considered source.

5. Conclusion:

The luminosity and effective temperature of LSSS RXJ0925.7-4758 have been calculated by using Nomoto (2007)[6] model .Comparing these values with observational data of different observations suggest that the conditions given in the model [6] can explain the LSSS RXJ0925.7-4758 and it can be concluded that this LSSS is an accreting WD of mass $1.35M_O$. Constructing the structure of the envelope the total column mass m_o

is 4.22×10^8 gm/cm^2 with envelope thickness 4.05×10^7 cm leading to have Color temperature T_{color}=106 ev for L/ $L_{e,Edd}$=0.367. ASCA observation for RX JO925.7-4758 tally well with the presently calculated value.[11].

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