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The galactic luminous supersoft X-ray source RXJ0925.7-4758/MR Vel

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Abstract. A steady-state model has been considered to explain the observed properties of the LSSS RXJ0925.7-4748/MR Vel. The steady-state models consist of a C–O core surrounded by a hydrogen-rich envelope of the solar abundances. At the bottom of the envelope, hydrogen is burned at the same rate as the star accreted it. Using the most recent proton capturing reaction rates and β-decay rates, the cyclic reactions have been studied. In the present work, effort has been made to explain the observed characteristics of the source RXJ0925.7-4758/MR Vel considering the above mentioned model. The calculated values of luminosity (8.56×10^{37} erg s^{-1}) and effective temperature (94.19 eV) tally well with the observed one. Photoionisation code CLOUDY has been used to explain the observed absorption edges in the spectrum of RXJ0925.7-4758/MR Vel.

Keywords. White dwarf; luminous supersoft X-ray source; luminosity; absorption edge.

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1. Introduction

For the last few decades, Einstein observatory, Roentgen Satellite (ROSAT), ASCA, CHANDRA, XMM-Newton, SWIFT, SUZAKU and other ingenious devices launched by different space agencies, are exploring the X-ray sky. They have detected different types of celestial X-ray sources with their sophisticated instruments. Luminous supersoft X-ray source (LSSS) [1–11] is one such X-ray source. Data obtained from ROSAT have established the LSSS as a separate class of object that has extremely soft spectra (equivalent black-body temperature of (20–100) eV and is highly luminous (10^{36}–10^{38} erg s^{-1}) [12] . LSSSs are divided into two categories, namely relatively 'soft' LSSSs with spectra that have the bulk of their flux below 0.5 keV and relatively 'hard' LSSSs that emit mainly above 0.5 keV [13]. According to Kahabka and Van den Heuvel [14], LSSSs are classified as: CVs, CBSSs, WBSSs and symbiotic SSs. LSSSs can be explained as an accreting white dwarf (WD) in a close binary (CB) system (first suggested by Van den Heuval (1992)). WD accretes matter from a more massive main-sequence secondary at a rate just sufficient to permit stable nuclear burning near its surface [15].

In the present work, a model for accreting binary WD suggested by Nomoto *et al* [16] has been considered to explain the characteristics of LSSS RXJ0925.7-4758/MR Vel. Nomoto *et al* constructed steady-state models for WD accreting matter of solar composition. The steady-state models consist of a C–O core surrounded by a hydrogen-rich envelope of solar abundances. At the bottom of the envelope, hydrogen is burned at the same rate as the WD accreted it.

Considering the above-mentioned model, luminosity and effective temperature for the considered source has been calculated and the mathematical relations used are discussed in §2. Absorption edges of the source are studied in §3. Section 4 gives the conclusion of the present work.

2. Luminosity and effective temperature

The values of luminosity and effective temperature of the considered LSSS RXJ0925.7-4758/MR Vel are 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

Table 1. $T_9 = 0.11$ K, $\rho = 36$ g/cc, accretion rate $= 6.97 \times 10^{27}$ g/yr.

LSSS	Observed luminosity (L) (erg s^{-1})	Observed effective temperature (T_{eff}) (eV)	Calculated luminosity (L) (erg s^{-1})	Calculated effective temperature (T_{eff}) (eV)
RXJ0925.7-4758/MR Vel	5×10^{37} [22]	96 [23]	8.56×10^{37}	94.19

$$E_{nuc} = QR_{12}/\rho = Q\rho N_A[N_A\langle\sigma\upsilon\rangle X_H X_Z]/A_1A_2 \text{ erg g}^{-1} \text{ s}^{-1}. \text{ [17]} \quad (1)$$

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.

When $\dot{M}$ (erg s^{-1}) is the mass accretion rate and t_{acc} is the time scale of accretion, then total mass of the accreted matter is

$$M = \dot{M}t_{acc}. \text{ [18]} \quad (2)$$

Energy radiated per second, that is luminosity L, is given by

$$L = E_{nuc}M \text{ erg s}^{-1}. \text{ [17]} \quad (3)$$

Effective temperature is given by

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

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

A steady-state model of WD mass $= 1.35M_\odot$, T_H(K) $= 0.11 \times 10^9$ (temperature of the H-burning shell), $\rho_H = 36$ g/cc (density of the H-burning shell) and the mass accretion rate $\dot{M}$ ($M_\odot$ yr^{-1}) $= 3.5 \times 10^{-7}$ is considered for the present study [16].

Under these considered parameters of H-burning shell region, nucleosynthesis processes are studied. Nuclear astrophysics compilation of reaction (NACRE) rates [19–21] are taken for mathematical calculations because more than half of the CF88 (Caughlan and Fowler) rates have been recompiled on the grounds of careful evaluation of experimental data. Calculated values of the luminosity and effective temperature with the considered parameters – temperature, density and accretion rate – are presented in table 1 along with the observed values [22,23] of RXJ0925.7-4758/MR Vel.

3. Absorption edges

The interstellar medium (ISM) can be studied with a new window obtained from high-resolution X-ray observations from the Chandra X-ray observatory and XMM Newton. When X-rays pass through the interstellar medium, it affects X-ray spectra in two ways: photoelectric absorption, particularly at low energies, and scattering by dust grains, producing X-ray halos. Absorption features are from the excitation and ionization of inner-shell (K-shell) electrons at X-ray energies, although for high-Z elements such as iron, L-shell absorption edges are also detectable. The wavelength range available to Chandra and XMM-Newton includes absorption features from carbon through iron. The interaction of X-ray photons from bright point sources such as galactic X-ray binaries with the ISM imprints absorption lines and edges in the spectrum of the source [24].

The absorption edges in the spectrum of LSSS RXJ0925.7-4748/MR Vel was discovered by the ROSAT all sky survey [25]. Beardra *et al* [26] have fitted the observed spectrum of MR Vel with the black body model, LTE model atmosphere and NLTE model atmosphere. The interstellar absorption edges due to Ne1 (at $\lambda = 14.30$ Å) and Fe-L ($\lambda = 17.54$ Å) are recognisable in the models and in the data and confirm that interstellar absorption is appreciable [26]. Motch *et al* [27] reported a long XMM-Newton observation of RXJ0925.7-4758/MR Vel involving the EPSC pn, RGS and OM instruments. They remarked that interstellar 'O' edge is well marked at 23.3 Å and there are clear evidences for the presence of Fe-L and Ne1 edges at 17.54 Å and 14.30 Å.

In order to study the absorption edges of the considered source, the photoionisation code CLOUDY is used. Using CLOUDY [28], we aim to understand the physical conditions around the source by modelling the absorption features with physical parameters. Several models are constructed by varying ionisation parameter (ξ) and abundance. For the simulation by the CLOUDY photoionisation code, the calculated value of effective temperature $T = 1.2 \times 10^6$ K is considered which represent the shape of the incident radiation field.

To study the X-ray spectra of RXJ0925.7-4748/MR Vel, the ROSAT data of LSSS RXJ0925.7-4758/MR Vel have been fitted with black body spectra and column density with $(1-1.9) \times 10^{22}$ cm^{-2} [25]. Bearda *et al* [26] fitted the spectra with $N_H = 1.28 \times 10^{22}$ cm^{-2}. The RGS spectra in the O edge region suggest an absorption of $N_H = 1.5 \times 10^{22}$ cm^{-2} [27].

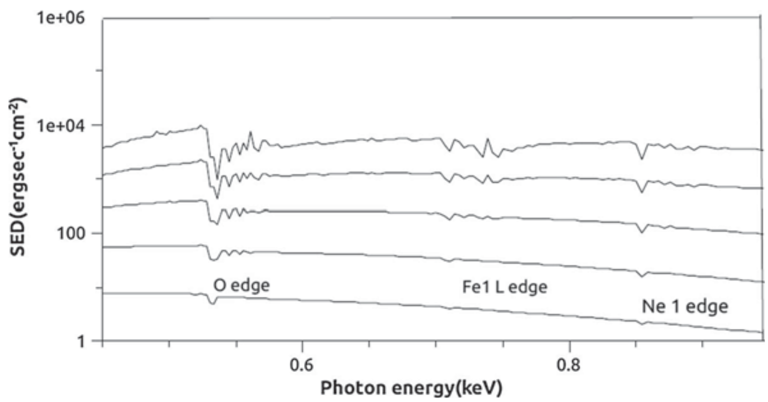

Figure 1. Position of absorption edges for old solar 84 abundance.

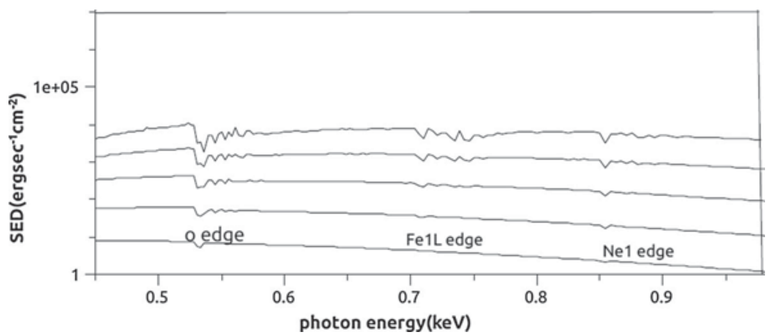

Figure 2. Position of absorption edges for GASS10 abundance.

The column density $N_H = 10^{22}$ cm^{-2} is considered for the study in this line of present work for simulation. We have considered a constant density cloud at a distance $R = 10^{17}$ cm from the source. We have calculated the grid of photoionisation models covering $\log \xi = -3$ to 1 for hydrogen density $= 10^3$ cm^{-3} using old solar abundance. After simulation, absorption edges are obtained at 0.533 keV, 0.71 keV and 0.854 keV in the transmitted spectra through the cloud (figure 1). Then the abundances were changed and GASS10 abundances were taken instead of solar abundance (figure 2). Equivalent width of the absorption edges at different column densities for different ionisation parameters with old solar 84 and GASS10 abundances are calculated and are presented in tables 2 and 3.

4. Result

After simulation, sharp drops are found at 0.534 keV, 0.701 keV and 0.854 keV in the transmitted flux through the cloud. The drops at 0.534 keV and 0.854 keV can be marked as oxygen K edge and Ne1 edge but the drop at 0.701 keV can be predicted as Fe1 (L) edge. In the gas with the ionisation parameters in the range $-3 \leq \log \xi \leq 1$ and solar abundance, absorption edges are formed in the spectrum of the LSSS RXJ0925.7-4758/MR Vel.

5. Conclusion

The luminosity and effective temperature of LSSS RXJ0925.7-4758/MR Vel are calculated using Nomoto (2007) model and values are obtained as 8.56×10^{37} erg s^{-1} and 94.19 eV respectively which are found at par with the observed values [22,23]. By using photoionisation code CLOUDY, with the variation of variables, ionisation parameter and abundance, definite absorption edges are obtained at 0.533 keV, 0.701 keV and 0.854 keV which tally well with the observed values at 0.532 keV, 0.706 keV and 0.860 keV by XMM Newton [27]. But absorption edge at 0.701 keV can be predicted as Fe1 L edge which is observed as Fe L edge. It is seen in the simulation process that higher values of equivalent width of the absorption edges is obtained using old solar 84 abundance than using GASS10 abundance. Since equivalent width is a measure of line strength or total absorption in a line, it can be suggested from the present work that old solar 84 abundance is more preferable in the system for explaining the

Table 2. Equivalent width of the edges for different column densities with old solar 84 abundance.

	Log ξ	Log(N_x) (cm^{-2})	Equivalent width (mÅ)
O edge (keV)			
0.534	−3	17.226	∼64.29
	−2	17.583	∼120.79
	−1	17.856	∼169.41
	0	18.07	∼199.13
	1	18.22	∼265.98
Fe1 L edge (keV)	−3	16.002	∼3.52
0.701	−2	16.335	∼12.20
	−1	16.625	∼30.66
	0	16.848	∼50.61
	1	17.003	∼59.35
Ne1 edge (keV)	−3	16.154	∼4.76
0.845	−2	16.535	∼13.50
	−1	16.859	∼22.63
	0	17.107	∼32.99
	1	17.28	∼44.15

Table 3. Equivalent width of the edges for different column densities with GASS10 abundance.

	Log ξ	Log(N_x) (cm^{-2})	Equivalent width (mÅ)
O edge (keV)			
0.534	−3	17.11	∼51.38
	−2	17.437	∼104.27
	−1	17.706	∼135.57
	0	17.938	∼189.46
	1	18.113	∼217.49
Fe1 L edge (keV)	−3	16.015	∼2.99
0.701	−2	16.358	∼11.59
	−1	16.648	∼30.42
	0	16.884	∼50.09
	1	17.060	∼69.01
Ne1 edge (keV)	−3	16.03	∼3.45
0.845	−2	16.42	∼8.93
	−1	16.74	∼18.42
	0	17.01	∼27.79
	1	17.21	∼37.77

absorption edges. We also suggest that, the absorption edges are formed in the spectrum of LSSS RXJ0925.7-4758/MR Vel because of the presence of a cloud of old solar 84 abundance with ionisation parameters in the range $-3 \leq \log \xi \leq 1$ which is at a distance of 10^{17} cm from the source.

References

[1] K S Long, D J Helfand and D A Grabelsky, *Astrophys. J*. **248**, 925 (1981)
[2] G Hasinger, *Rev. Mod. Astron*. **7**, 129 (1994)
[3] P Kahabka and E P J Van den Heuvel, *Ann. Rev. Astron. Astrophys*. **35**, 69 (1997), in: *Proceedings of the 165th Symposium of the International Astronomical Union* edited by J Paradijs, E P J Van den Heuvel and Eric Kuulkers
[4] M Orio, T Nelson, A Bianchini, F D Mille and D Harbeck, *Astrophys. J*. **717**, 739 (2010)
[5] R DiStefano and A K H Kong, *Astrophys. J*. **609**, 710 (2004)
[6] J Greiner, R DiStefano, A Kong and F Primini, *Astrophys. J*. **610**, 261 (2004)
[7] R DiStefano and A K H Kong, *Astrophys. J*. **592**, 884 (2003)
[8] P Kahabka, *Adv. Space Res*. **38**, 2836 (2006)
[9] P Kahabka, F Haberl, M Pakull, W C Millar, G L White, M D Filipovi and J L Payne, *Astron. Astrophys*. **482**, 237 (2008)

[10] R Distefano, *Astrophys. J*. **712**, 72 (2010)
[11] M Orio, *Bull. Astron. Soc. India* **40**, 333 (2012)
[12] J Greiner, *Lecture notes in physics* (Springer-Verlag, 1996) Vol. 472, ISBN: 978-3-540-61390
[13] H W Hartmann and J Heise, *Astron. Astrophys*. **322**, 591 (1997)
[14] P Kahabka and E P J Van den Heuvel, *Astron. Astrophys*. **35**, 69 (1997)
[15] E P J Van den Heuvel, D Bhattacharya, K Nomoto and S A Rappaport, *Astron. Astrophys*. **262**, 97 (1992)
[16] K Nomoto, H Saio, M Kato and I Hachisu, *Astrophys. J*. **663**, 1269 (2007)
[17] M Wiescher, *Nucl. Part. Astrophys*. edited by J G Hirsch and D Page, *Cambridge Contemporary Astrophys*., Vol. 79 (1998)
[18] K Shen and L Bildsten, *Astrophys. J.* **692**, 324 (2009)
[19] M Aikawa, M Arould, S Goriely, A Jorissen and K Takahashi, *Astron. Astrophys*. **441**, 1195 (2005)
[20] Y Xu, S Goriely, A Gorissen, G Chen and M Arnould, *Astron. Astrophys*. **549**, 106 (2013)
[21] A Jorrissen and S Goriely, *Nucl. Phys. A* **688**, 508 (2001)
[22] P C Schmidtke, A P Cowley, V A Taylor, D Crampton and J B Hutchings, *Astron. J*. **120**, 935 (2000)
[23] K Ebisawa, K Asai, K Mukai, A Smale, T Dotani, H W Hartmann and J Haise, *Lect. Notes Phys*. **472**, 91 (1996)
[24] A M Juett, N S Schulz and D Chakrabarty, *Astrophys. J*. **612**, 308 (2004)
[25] C Motch, G Hasinger and W Peitsch, *Astron. Astrophys*. **284**, 817 (1994)
[26] H Bearda, W Hartmann, K Ebisawa, J Heise, J Kaastra, R van der Meer, F Verbunt and C Motch, *Astron. Astrophys*. **385**, 511 (2002)
[27] C Motch, H Bearda and C Neiner, *Astron. Astrophys*. **393**, 913 (2002)
[28] G J Ferland, R L Porter, P A M van Hoof, R J R Williams, N P Abel, M L Lykins, G Shaw, W J Henney and P C Stancil, *Revista Mexicana de Astronomia Y Astrofisia* **49**, 137 (2013)