Accreting White Dwarf as an Emitter of Luminous Super Soft X-Radiation

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Abstract

As a candidate of luminous super soft X-ray sources (LSSS) an accreting binary white dwarf (WD) of mass 1.3M⊙ have been considered . A red giant or a near main sequence star , more massive than the WD , when transfers high mass (~ 10^{-7} M⊙ / year) towards WD , thermonuclear burning will be there on the accreting surface . The accreting matter containing small fraction of heavy nuclei – C, O, Ne, Mg – will capture proton at the high temperature condition leading to   CNOF, NeNa, MgAlSi cyclic reactions. Energy generations due to these cyclic reactions have been studied to examine whether steady state nuclear burning can contribute to emit SS X- radiations. During the steady H-burning for 25 years CNOF , NeNa, MgAlSi cycle generates energy $5.46 * 10^9$, $1.12 * 10^9$, $2.88 * 10^8$ (erg g^{-1} s^{-1}) respectively . Observed luminosities by Einstein , ROSAT, ASCA observatories are found to be explainable due to all these three cyclic operations , operating at the base of the envelope of the accretor . Absorptive and electron-scattering opacities at layers of the envelope and color temperature near the photosphere have been determined.

1 Introduction:

During the last decade , Einstein observatory , Roentgen Satellite (ROSAT) , ASCA observations have discovered dozens of a new class of bright astronomical objects , which is named as luminous super soft X-ray sources (LSSS) (Hasinger , 1994; Di Stefano , 1996; van Teesling etal. 1996). Einstein Observatory was the first one to discover LSSS (Rappaport and Di Stefano , 1996). All-sky X-ray survey carried out by ROSAT has found 7 numbers of LSSS in our own Milky Way Galaxy, 11 in the Large and small Magellanic Clouds (LMC, SMC), 16 in the Andromeda Nebula and 1 in the Local Group Galaxy NGC 55 (Kahabka and van den Heuval, 1997) . But since the SS X-radiation are easily absorbed by the inter stellar matter, actual numbers of the LSSS are expected to be quite high. The main characteristics of these sources are their spectra which peaks at energies in the range of 15-80 eV with luminosities of the order of ~ $10^{36} – 10^{38}$ ergs s^{-1}. Some LSSS are found to be steady while others exhibit variation with time .

To analyse the observed characteristics Astrophysicists have used varieties of treatments and proposed several theoretical models including accreting black holes and neutron stars. But the most promising candidate as first suggested by van den Heuvel (1992) , is an accreting binary WD. Binary WD may be in varied subsystems CVs , CBSS, WBSS and wind driven . In a close binary (CB) system , the companion may be a near main-sequence in the mass range 1.3 – 2.5 M⊙ . During their evolution , when the more massive companion becomes thermally unstable , Roche-lobe overflows amd mass transfer occurs at the rate of $2.4 * 10^{-7}$ M⊙ yr^{-1}

2   WD model

A model for a massive accreting WD suggested by Sion et al (1979) has been considered here and studied whether the system emits super soft X-radiation with the luminosity, 'L' in the observed range. Sion's CB in sequence B system is a C-O core WD with its envelope composition of H mass fraction X=0.7, He

mass fraction $Y=0.27$ and heavy element mass fraction $Z=0.03$. The accreted matter is assumed to have the same composition as the envelopes. Initial heavy elements are C, O, Ne, and Mg ; all are having equal shares. The initial WD model is of mass 1.3 $M_\odot$, log R is 8.679 (R = Radius) , Log $T_{sh}=7.981$ (T_{sh} = Temprature of the H-burning shell), log $_{sh}=1.236$ ($_{sh}$ = density of the shell) and the accreting rate $\notin=2.71 * 10^{-7} M_\odot$ yr^{-1}. At this high temperature of the shell, H will capture heavy seed nuclei C, O, Ne and Mg and consequently CNOF, NeNa, MgAlSi cyclic reactions (Fig 1, 2, 3) will start to operate leading to large amount of energy production. Steady H-burning at the base of the envelope with reaction rate update information (last modified August 6, 1996 , c.f. Internet, Altavista) , have been considered.
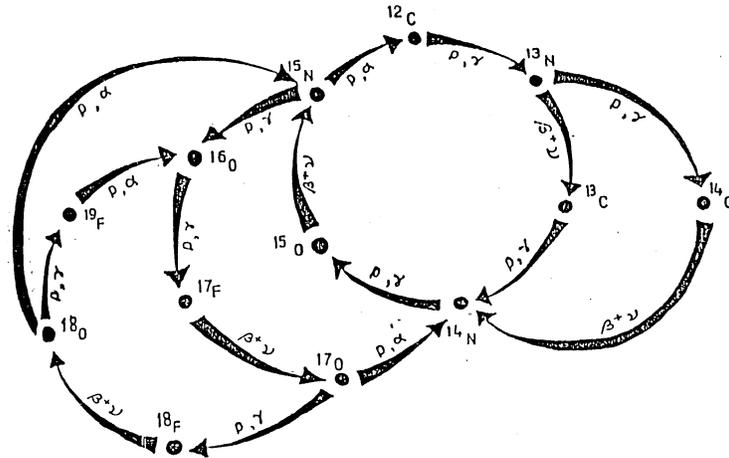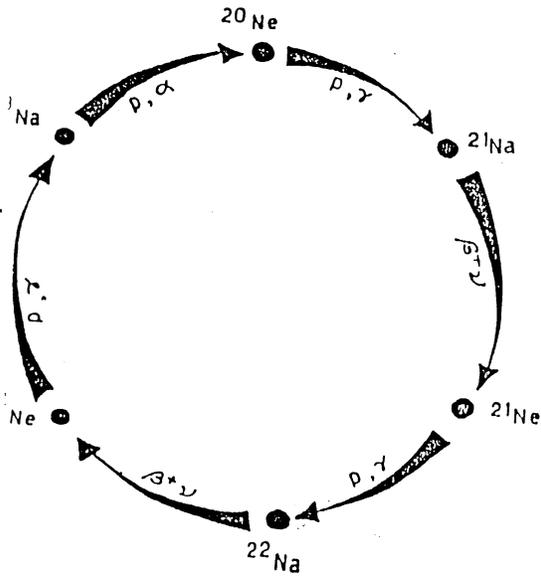

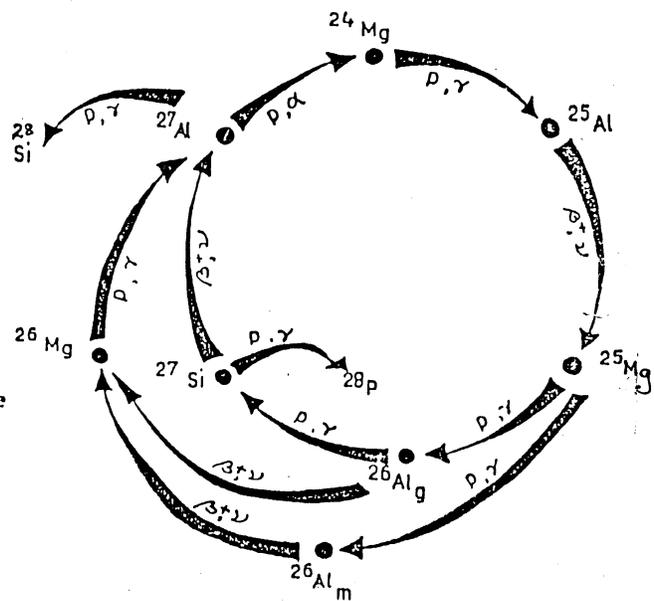Fig. 1. Extended CNOF Cycle.

Fig .2: NeNa Cycle

Fig.3 : MgAlSi Cycle

3. Luminosity and the Effective Temperature :

Life-time 't' for each of the CNOF, NeNa, MgAlSi cyclic reactions have been calculated using equation(1)   .

Life-time , t = [$_{sh}$ X $N_A<\sigma v>$]$^{-1}$ ......…………..   (1)

where, $N_A<\sigma v>$ is the reaction rate (cm^{3}mole^{-1}sec^{-1}) . In the T_{sh} - $_{sh}$ condition , if the slowest reaction rate is R_{12} among all the considered reactions energy generation E_{nuc} is given by,

$$E_{nuc} = \frac{QR_{12}}{_{sh}} = \frac{Q_{sh}N_A}{A_1A_2}[N_A<\sigma v> X Z fs] \text{ erg g}^{-1} \text{ s}^{-1} \ ...……..(2)$$

where Q is the total disintegration energy during processing of 4H into He in the complete cycle, which is ~ 26 MeV (since a part of it is carried away by neutrinos), N_A is the Avogadro's number, A_1, A_2 , are the mass numbers of the reacting nuclei, fs the enhancement factor. $^{16}O(p,r)^{17}F$ being the slowest reactions among the CNOF reactions. Contribution of CNOF towards energy production, E_{nuc} is $5.46*10^9$ erg g^{-1}s^{-1}. In the NeNa[MgAlSi] cycle, $^{20}Ne(p,r)^{21}$ Na[$^{27}Al(p,\alpha)^{24}Mg$] is the slowest one generating energy , $E_{nuc}=1.12*10^9[2.88*10^8]$ erg g^{-1}s^{-1}. Stable nuclear burning is assumed to be there for accretion time tacc of 25 years in steady state with accretion i.e., all the amount of accumulated fuel is burned when ∉ is $1.71*10^{19}$ g s^{-1}. Energy radiated per second is given by -

$$L = E∉ = E_{nnc} * t_{acct} * ∉ \text{ erg s}^{-1} \ …….. (3)$$

Contribution from all the three cycles leads to have total luminosity L = $9.26 * 10^{37}$ ($=7.36*10^{37}+1.51*10^{37}+3.88*10^{36}$) erg s^{-1}. The effective block body temperature , T_{eff} is found to be 74.88eV.

Eddington temperature $T_{e,Edd}$ which is given by (Hoshi, 1998)

$$T_{e,Edd} = \left(\frac{cGM_{ch}}{\kappa_e\sigma R_0^2} \right)^{1/4} \left(\frac{M}{M_{ch}} \right)^{1/4} \left(1- \frac{M}{M_{ch}} \right)^{-1/4} …….... (4)$$

comes out to be $1.31 * 10^6$ K , where K_e the opacity contribution due to electron scattering has been calculated according to Richardson (1982). M_{ch} is the Chandrasekhar limiting mass (1.46 M⊙), $R_0=1*10^9$ cm and the ratio $L/L_{e,Edd} =0.19$

4. Structure of the Envelope and Color Temperature :

Observed properties of LSSS depend on the star's envelope characteristics. Total column mass from the base to the photosphere, m_0 is given by,

$$m_0 = \frac{L_{e,Edd}}{L} \left(\frac{GM}{R^2} \right)^{-1} \frac{aT_{sh}^4}{3} .... (5)$$

which is $1.74*10^8$ gcm^{-2} with envelope thickness $h_0=5.08*10^7$ cm. Taking density near the photosphere to be $1.29*10^{-4}$ gcm^{-3} the column mass 'm' at different height, pressure 'p', temprature 'T' and density ' 'are given in the Table I.

Table I

Variation of column mass m (g cm^{-2}) , pressure p (dyne cm^{-2}) , density   (g cm^{-3}) with variation of envelope thickness h (cm) .

h (cm)	4.27 (8)	3.40 (7)	3.28 (6)	3.25 (5)	3.27 (4)	3.27 (3)
m (g cm^{-2})	1.73 (7.9)	1.73 (7)	1.73 (6)	1.73 (5)	1.73 (4)	1.73 (3)
p (dyne cm^{-2})	1.04 (17)	1.31 (16)	1.31 (15)	1.31 (14)	1.31 (13)	1.31 (12)
(g cm^{-3})	11.95	1.31	1.29 (-1)	1.29 (-2)	1.29 (-3)	1.29 (-4)

The color temperature T_{color} at the optical depth, $\Upsilon=2/3$ depends on κ_e, absorptive opacity κ_a, T, and $L/L_{e,Edd}$. T_{color} is given by,

$$T_{color} = \left(\frac{\kappa_a \kappa_e T^4}{\mu m_H}\right)^{-1/7} \left(\frac{K}{L_{e,Edd}}\right)^{-1/7} \left(\frac{L}{L_{e,Edd}}\right)^{3/7} * \left(1 - \frac{L}{L_{e,Edd}}\right)^{-1/7} \left(\frac{3}{a}\right)^{3/7} \left(\frac{GM}{R^2}\right)^{2/7} \quad \text{.......} (6)$$

κ_e, κ_a near the photosphere is $1.03*10^{24}$, $6.66*10^{11}$ cm^2 g^{-1} respectively. With the radiation density constant 'a' $=7.56*10^{-15}$ erg cm^{-3} K$^{0-4}$, T_{color} is $1.27*10^2$ eV.

5. Conclusion :

A CBWD of mass 1.3 M$\mathbf{o}$, radius $4.77*10^8$ cm, accreting rate $2.71*10^{-7}$ M$\mathbf{o}$ yr^{-1}, yield total luminosity $9.26*10^{37}$ erg s^{-1} and effective temperature T_{eff} 74.88 eV. Comparing these values with the observational datas by different observations, strongly suggest that the considered Sion (1979) model a WD accretor at sequence B can well explain the astronomical datas. Einstein IPC observations have found $T_{eff}<100$eV for the source CAL 87. Comparing luminosity found by ROSAT and Einstein observations of values ~$7*10^{37}$ ergs s^{-1} ($3-20*10^{37}$ ergs s^{-1}) for CAL 83 (for RX J05 278-6954) with our calculated ones, leads to a strong suggestion that LSS Source possibly is a CBWD. Sion's (1979) CBWD model is a good model for this purpose. Constructing the structure of the envelope the total column mass is $1.74*10^8$ gm cm^{-2} leading to have color temperature $T_* = 1.27*10^8$ eV for $L/L_{e,Edd}=0.19$. ASCA observations for RX J0925.7 - 4758 suggests T_* same value as the presently calculated one, when the source is at a distance of ~33 kpc away from us.

Acknowledgment :

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