HYDROGEN AND HELIUM BURNING IN THE DEGENERATE ENVELOPES OF C-O DWARFS

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In our previous papers (Tutukov, Ergma, 1979; Ergma and Tutukov, 1979) we have proposed a simple analytical method to investigate the thermal evolution of shells accreted onto the surface of a neutron star. We have used this method for investigation of thermal evolution of shells accreted onto the surface of a carbon-oxygen white dwarf.

Let us suppose that hydrogen (or helium) layer is heating only due to compressional heating of accreted matter. During compression of newly accreted matter the energy E (erg/g) is released

$$E \approx \frac{GM'}{R} \cdot \frac{\Delta R}{R} , \qquad (1)$$

where ΔR is the thickness of the envelope and

$$\Delta R = M_{sh} / 4\pi \rho_{sh} R^2 . \qquad (2)$$

Taking that the envelope is in hydrostatical equilibrium we have

$$M_{sh} = (4\pi R^4 P_{sh}) / (GM') , \qquad (3)$$

where M_{sh} is the envelope mass in g, M' is the dwarf mass in g, R is its radius in cm and P_{sh} is the pressure on the bottom of the layer.

In the stage of accumulation of nuclear fuel on the surface of the dwarf the envelope gains energy with accreted matter at the rate $\alpha c^2 \dot{M}'$, where c is the velocity of light, $\dot{M}'$ is the accretion rate in g/sec and α is part of energy that heats the envelope.

If there are no other sources (when hydrogen burning shell is stationary, α = 0.007) of heat except compressional heating, then according to (1-3), $\alpha = P_{sh} / \rho_{sh} \cdot c^2$.

It is easy to show that during the accretion the nuclear fuel shell is in the thermal equilibrium and its temperature can be estimated by equation

$$\alpha c^2 \dot{M}' = \frac{8\pi ac R^2 T_{sh}^4}{3\kappa \rho_{sh} \Delta R}. \tag{4}$$

Equations (1-4) give

$$T_{sh} = \begin{cases} 10^{9.15} \left(\frac{\kappa \dot{M}}{M}\right)^{1/2} \frac{\rho_{sh}}{\mu}^{1/3} & \text{nondegenerate gas (cold)} \\ 10^{9.75} \left(\frac{\kappa \dot{M}}{M}\right)^{1/3} \left(\frac{\rho_{sh}}{\mu}\right)^{1/3} & \text{nondegenerate gas (hot)} \\ 10^{7.1} \left(\frac{\kappa \dot{M}}{M}\right)^{1/4} \frac{\rho_{sh}^{7/12}}{\mu_e^{5/6}} & \text{degenerate nonrelativistic electron gas (cold)} \\ 10^{8.56} \left(\frac{\kappa \dot{M}}{M}\right)^{1/4} \left(\frac{\rho_{sh}}{\mu_e}\right)^{5/12} & \text{degenerate nonrelativistic electron gas (hot)} \\ 10^{8.1} \left(\frac{\kappa \dot{M}}{M}\right)^{1/4} \frac{sh^{5/12}}{\mu_e^{2/3}} & \text{degenerate relativistic electron gas (cold)} \\ 10^{9.06} \left(\frac{\kappa \dot{M}}{M}\right)^{1/4} \left(\frac{\rho_{sh}}{\mu_e}\right)^{1/3} & \text{degenerate relativistic electron gas (hot)} \end{cases} \tag{5}$$

For the helium layer we may have two regimes: a) "hot" case (see eq. (5)) - if the hydrogen burning shell is stationary, then $\alpha = 7 \cdot 10^{-3}$; b) "cold" case - if compression of matter is the only heat source. The results of our estimates for $M = 1.3 \mathfrak{M}_\odot$ and $R = 10^{8.45}$ cm are presented in Fig. 1 and Table 1.

According to our estimates (see Fig. 1) for the accretion rates $10^{-10} \lesssim \dot{M}$ $(\mathfrak{M}_\odot/yr) \lesssim 10^{-8}$ two regimes are possible. One of them with quasistationary burning hydrogen shell ("hot"), the other with flash burning shell where during the hydrogen flash part of accreted mass unites with the core and part of it may be lost during the flash. Only "cold" regime may be responsible for a nova outburst. In the course of flashes (hydrogen) the helium layer is increased also by mass and for some accretion rates $\dot{M} > 10^{-9} \mathfrak{M}_\odot/yr$ it is possible that a helium flash may be responsible for

TABLE 1

Some Properties of Hydrogen and Helium Flashes in the Degenerate Envelope of C-O Dwarf

$M = 1.3\mathcal{M}_\odot$, $R = 10^{8.45}$ cm, $N_{CNO} / N_P = 10^{-2}$

$\lg \dot{M}$ $M_\odot$/yr	$\lg \rho_{sh}$ g/cm^3	$\lg M_{sh}$ $M_\odot$	$\lg(E_H \cdot 10^{-2})$ erg	$\lg \tau$ $\tau = M_{sh}/\dot{M}$ years	$\lg \rho_{sh}$ g/cm^3	$\lg M_{sh}$ $M_\odot$	$\lg E_{He}$ erg	$\lg \tau$ $\tau = M_{sh}/\dot{M}$ years	Remarks
	hydrogen layer				helium layer				
-8.5					4.5	-4.1	47.2	4.4	hot
-9					4.9	-3.4	47.9	5.6	hot
-10					5.7	-2.2	49.0	7.8	hot
-7	3.4	-6.0	44.2	1.0	5.0	-3.3	48.0	3.7	cold
-8	3.8	-5.2	45.0	2.8	5.8	-1.5	49.3	6.1	cold
-9	4.3	-4.3	45.9	4.7	6.8	0	50.0	9.0	cold
-10	5.0	-3.3	46.9	6.7					

https://doi.org/10.1017/S025292110007603X Published online by Cambridge University Press

enrichment of the outer layer of the dwarf with ^{12}C and ^{16}O elements. The second interesting possibility arises when $\dot{M} < 10^{-9}\ \mathfrak{M}_{\odot}$/yr. For this case the mass of helium layer may be very large ($\sim 0.1\,\mathfrak{M}_{\odot}$). This may lead to a situation when during accretion mass of C-O dwarf increases up to the Chandrasekhar mass limit and in the center carbon ignition condition is reached when central density is high ($\lg \rho_c \sim 10.0$) (Ergma and Tutukov, 1976). As it was shown by Chechetkin et al. (1979) neutron star formation is possible after a supernova explosion if central density is more than $10^{9.8}$ g/cm^3. According to our estimates to explain a recurrent nova by thermonuclear model it requires 1) massive white dwarf, 2) rather high accretion rate $\dot{M} \approx 10^{-7}\,\mathfrak{M}_{\odot}$/yr. To avoid post- flash quiet hydrogen burning, mass loss is required for a recurrent nova.

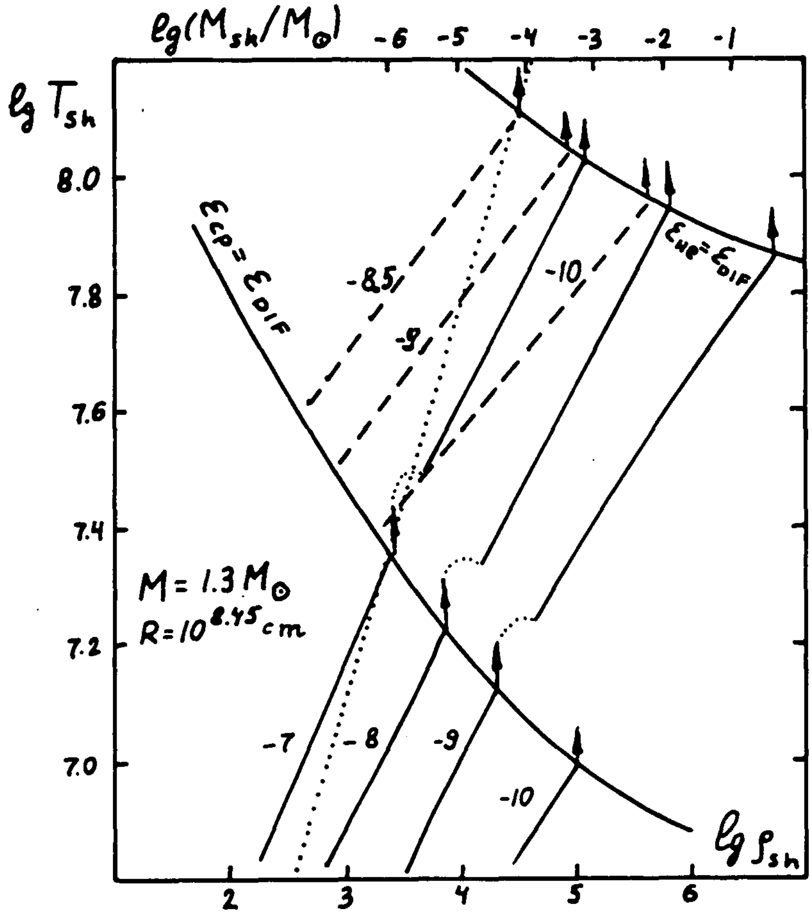

Fig. 1 - Variation of $\lg T_{sh}$ and $\lg \rho_{sh}$ in the envelope of the accreting white dwarf for different accretion rates $\dot{M}$ is given. Numbers along the lines give $\lg \dot{M}$ ($M_{\odot}$/yr). Hydrogen ($C^{12}(p,\gamma)N^{13}$) and helium ($3\alpha \rightarrow C^{12}$) ignition lines are marked by solid line. Dotted line shows the line where degeneracy sets in. Dashed line shows "hot" regime (see the text).

https://doi.org/10.1017/S025292110007603X Published online by Cambridge University Press

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