ON THE NATURE OF THE OUTFLOW FROM NOVA STARS OCCURRING IMMEDIATELY AFTER EJECTION OF AN ENVELOPE

V.G. Gorbatsky

Leningrad University Observatory

According to modern conceptions the cause of nova outbursts is a thermal runaway (TR) taking place in the deep layers of the accreted envelope of a white dwarf (WD), component of a close binary system. The theory of TR was considered by many authors and, especially, has been developed in detail by Starrfield et al. (1974, 1984). It has been shown that when the pressure at some level in the envelope reaches a critical value P_{cr}, the thermonuclear reactions of the "hot" CNO cycle become very fast, and after a time interval of several tenths seconds the temperature at this level rises to $(2 \div 3) \times 10^8$ K. If the CNO abundances are high enough, the total outburst energy may exceed 10^{47} ergs. As a consequence of TR, a considerable fraction of the envelope mass (20% ÷ 50%) must be torn off by shock waves. As suggested by Starrfield et al. (1974), the remaining matter forms an extended atmosphere ($R \simeq 10^{11}$ cm) and the star transforms itself into a supergiant having a luminosity $L_* \lesssim L_{edd}$ during several months.

The model of explosion considered by Starrfield et al. (1974) is not fully self consistent near the star surface. Firstly, the WD is suggested to remain unaffected by the explosion - inward propagation of energy was not taken into account. Secondly, the hydrostatic equilibrium on the star surface is strongly disturbed after a sudden loss of a considerable amount of gas and therefore there must be an outflow of matter into the lobe between the star and the expanding envelope. These circumstances manifest themselves as peculiarities of the nova outburst, such as spectral variations and also as abundance anomalies. As indicated by the observations, the expanding envelope in the nebular stage is enriched with heavy elements (Truran and Livio 1988). The estimations given below demonstrate that when modelling a nova outburst, the outflow of matter from the star surface in vacuum must be taken into account.

EFFECTS OF THE EXPLOSION ON THE WHITE DWARF. The value of the density in the region where the explosion takes place is $\rho_0 \sim 10^4$ g cm^{-3}, and the electron gas is degenerate. Therefore the pressure P is determined by the expression:

$$P = 10^{13} (\rho_0 / \mu_e)^{5/3} \qquad (1)$$

According to Starrfield et al (1984), $P_{cr} \simeq 2 \times 10^{19}$ dyn cm^{-2}. As a consequence of the TR the temperature increases and the pressure becomes several times larger than P_{cr}. It is well known that, if $T \geq T_0$, where:

$$T_0 = 4.35 \times 10^{-11} n_e^{2/3} \qquad (2)$$

the degeneration is lifted. In such a way, the gas in the exploding region becomes non-degenerate. However, the temperature increases in the surface layers of the WD also. The fraction α of explosion energy E_0 penetrates into the WD by means of thermal waves and, possibly, forms shock waves.

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Let us estimate the mass ΔM of the layer heated to such degree that degeneration is lifted. Using the expression:

$$(3/2)\ (R_*/\mu)\ \bar{T}\Delta M = \alpha E_0 + E_F \qquad (3)$$

where $\bar{T}$ is the mean value of temperature and E_F is the Fermi energy, and taking as the mean value of density $\bar{\rho} \sim 2\rho_0 \sim 2\text{x}10^4$ g cm^{-3} (because the thickness of heated layer ΔR is very small in comparison to the stellar radius R_*) one has from (2): $T_0 = 1.4\text{x}10^8$ K. Assuming $T = T_0$, $E_0 = 10^{42}$ ergs, $\alpha = 1/2$ we obtain the value $\Delta M \sim 4\text{x}10^{30}$ g. The thickness of the heated layer R can be found from the evident equality:

$$\Delta M = 4\ \pi\ R_*^2\ \Delta R \qquad (4)$$

which, for $R_* = 8\text{x}10^8$ cm, gives $\Delta R \sim 0{,}02\ R_*$.

The estimations above show that the surface layer of the WD may be considered after explosion as consisting of non-degenerate gas.

EXPANSION OF GAS IN VACUUM. To study the expansion of a non-degenerate gas in vacuum one can use the known hydrodynamical methods. The problem of outflow of gas from the star surface was considered some time ago by Gorbatzky (1974a). Assuming the expanding gas to be homogeneous in density and temperature at the initial moment, one can use the well known expression to determine the expansion velocity:

$$V_{exp} = 3\ [\ \gamma(R_*/\mu)\ \bar{T}\ ]^{1/2} \qquad (5)$$

If $\bar{T} \sim 10^8$ K the value V_{exp} is two-three times greater than the velocity of motion of the main envelope. There is a velocity gradient in the expanding gas and therefore only some part of the heated outflowing gas can leave the star. The remaining gas had given up its energy to the front layers. An expressions was derived by Gorbatzky (1974a) which allows to calculate the value E_0 and the total mass of heated gas from observational data - the velocity of the main envelope, its mass and the velocity of outflowing gas. It was found for five novae that $E_0 = 3\text{x}10^{46} - 10^{47}$ ergs and $\Delta M \sim 10^{30}$ g. This value of the explosion energy turned out to be in good agreement with the estimations obtained from IR observations and from theory (Starrfield et al. 1984). The value ΔM is of the same order of that obtained in the previous paragraph. In such a way one can draw the conclusion that considerable part of energy E_0 is spent to heat the WD surface layers. The star loses 20% - 30% of all heated gas immediately after outburst. If the luminosity remains close to L_{Edd} the outflow will be continued and consequently an extended envelope will be formed. Such situation has taken place for example, during the transition stage of V 603 Aql when the luminosity was equal approximately to 10^{40} erg s^{-1} (Gorbatzky 1974b).

GAS OUTFLOW FROM THE SECONDARY STAR DUE TO ITS IRRADIATION. The effects of radiation from the WD on the secondary star after a nova outburst were discussed recently by Kovetz et al. (1988). These authors reached the conclusion that the radius of the secondary star changes due to its irradiation and this effect may be the cause of variations of gas stream flowing from the Lagrangian point L_1. The problem of surplus mass loss by the secondary star induced by its irradiation had been considered much earlier by Gorbatzky (1974b) and Basko and Sunayev (1973). As shown for X-ray binaries by Basko and

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Sunayev (1973) and for novae by Gorbatzky (1974b), heating of the secondary star surface by absorbed radiation must result in gas outflow from this star.

In the case of nova outbursts at the depth corresponding to column densities of order of 10^4 g cm^{-2} the temperature may reach the value of 10^5 K.

The outflow velocity may be determined according to Gorbatzky (1974b). If the distance between the star's surface and the critical Roche surface is not very small in comparison to the radius of the secondary star, the lost of the outer layer does not lead to substantial changes of the stellar structure.

According to Gorbatzky (1974b) the mass loss by the secondary star must take place in the form of discrete repeating ejections because of screening effects of the outflowing matter on radiation from the WD. Heating of the secondary star resumes only after dissipation of the gas that has been ejected earlier. The estimations made in by Gorbatzky (1974b) have shown that mass loss from the secondary star due to its irradiation may reach $\sim 10^{30}$ g. Therefore a cold star may serve as an important source of matter containing in the envelope of binary system after nova outburst.

ON THE ABUNDANCES IN THE NOVA ENVELOPES. As shown by Starrfield et al. (1974) an excess of the C,N,O abundances in accreting on WD matter is necessary to give the observed energy output during outburst. The possibility of mixing the accreted gas with matter from the WD was pointed out also by Truran and Livio (1988). While discussing the abundances in the expanding envelopes of novae one must take into account three sources of matter in the envelope during the nebular stage: 1) gas accreted on the WD having experienced nuclear explosion; 2) gas from the outer layers of the WD; 3) gas lost by the secondary star due to its irradiation. The abundances in these components are different and it is difficult to make definite conclusions on their contribution based only on observed spectra.

An important fact concerning the influence of strong magnetic fields on accretion must be taken into account. If the field strength is high enough ($\beta \gtrsim 10^6$ G), accretion occurs preferably in the regions of the magnetic poles. Apparently, this is the case of V 1500 Cyg Kaluzny and Chelebowsky 1988). In the polar regions the conditions for TR and the consequent heating of the WD matter are more favourable and there must be more intensive outflow of matter from these regions. In such a way "polar caps" may be formed in the nova envelopes. The abundances in "caps" may be different from the ones in the "equatorial belt". The prevailing part of gas containing in this belt must belong to a circumstellar envelope which was situated in the orbital plane of the binary system before outburst.

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