A FULL CYCLE IN THE EVOLUTION OF A CLASSICAL NOVA

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ABSTRACT

A classical nova model was evolved through a complete cycle, i.e. accretion leading to outburst, mass loss and again accretion, ending in another outburst, by means of an implicit Lagrangian hydrodynamic code, which included diffusion (concentration, pressure and thermal terms), as well as an extensive nuclear reactions network between 28 isotopes of C, N, O, F, Ne, Na, Mg and Al. The initial model was a 1.25 $M_\odot$ C-O white dwarf (WD) and the accretion rate assumed was 10^{-11} $M_\odot$/yr. For more details of this calculation, see Prialnik (1986).

The accreted matter was assumed to have normal composition (X=0.70, Z=0.03). Nevertheless, due to diffusion and convection, a significant amount of core material was mixed into the accreted matter, raising Z by a factor of 10. The model's evolution closely resembled that of a fast nova eruption, with a peak bolometric luminosity of 2.9×10^5 $L_\odot$, a time of decline by 3^m of 25 days, an ejected mass of 6.5×10^{-6} $M_\odot$ and a maximum velocity of 3800 km/sec.

Mass loss occured in three stages. Shortly after the outburst a shell was ejected, having been accelerated by a shock wave. A period of continuous mass loss at a decreasing rate ensued. The relationship between mass loss rate and

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envelope mass obtained was $\dot{M} \propto \Delta m_{env}^{1.6}$, which agrees well with the results of analytic steady-state wind models, yielding $\dot{M} \propto \Delta m_{env}^{1.5}$ (Kato, 1983). The analytic solution, however, cannot provide the time scale of progression through the sequence of steady-state models. In order to circumvent this difficulty, arbitrary assumptions on $\dot{M}(t)$ have been proposed in the literature. Hartwick and Hutchings (1978) assumed $\dot{M} \propto 1/R(t)$ with the radius $R(t)= R_{initial} + vt$, which amounts essentially to $\dot{M} \propto t^{-1}$. Kwok (1983) found a reasonable fit to observations for $\dot{M} \propto t^{-2}$. The calculations described here provided $\dot{M}(t)$, which may be approximated by $\dot{M} \propto t^{-2.6}$. Finally, the parent star, with a remnant helium-rich envelope (representing 3% of the total envelope mass), contracted, leaving behind an additional, slowly expanding thin nebula. Thus, the entire accreted mass was ejected, as well as a small amount of the underlying WD core.

The decline of the remnant's bolometric luminosity to a value below the luminosity expected from accretion in typical nova systems, i.e. the return to pre-nova appearance, occured within 10 years after the outburst, in good agreement with observations. The nova remnant continued to cool for a few hundred years, when it regained its pre-nova structure, but for the composition of the surface layers. Thus, a typical configuration at the onset of accretion, which leads eventually to an outburst, is not a bare WD, but one coated with a thin helium layer.This layer does not interfere with the penetration of hydrogen into the C-O core; it only raises to some extent the helium abundance of the ejected matter. The composition of the ejecta is in very good agreement with the abundances observed in nova shells with a similar estimated Z (e.g. Nova Cyg 1975 and Nova Cyg 1978), as shown in Table 1. Other characteristics of the model are compared with those of Nova Cyg 1978 (Stickland et. al.,1981) in Table 2. The ejected mass resulting from the evolutionary calculations seems very small. However, ejected shells of the same order of magnitude have been

TABLE 1

ABUNDANCES

NUMBER OF ATOMS PER 1000 ATOMS OF He

Object	H	He	C	N	O	Z
Sun	10000	1000	5	1	8	.02
V1500Cyg (1975)	10000	1000	110	100	150	.28
V1668Cyg (1978)	8000	1000	70	180	140	.31
DQ Her (1934)	7000	1000	180	340	370	.53
Nova Aql (1982)	2500	1000	120	320	180	.58
Model	9200	1000	80	140	140	.29

TABLE 2

COMPARISON OF COMPUTED MODEL WITH NOVA CYGNI 1978

Characteristic	Model	Nova Cygni 1978
t_3(days)	25	30
M_V(max)	-6.4	-6.7
v_{max}(km/sec)	3800	1400
$\Delta m_{ejecta}/M_\odot$	6.5×10^{-6}	5.5×10^{-5}
X	.49	.47
Y	.22	.22
X(C)	.06	.04
X(N)	.11	.14
X(O)	.12	.13

obtained, for example, for Nova Aql 1982: 6×10^{-6} $M_\odot$ (Snidjers et. al.,1984) and for Nova DQ Her 1934: 7×10^{-6} $M_\odot$ (Pottash, 1959), although a more recent estimate of the latter yields 5×10^{-5} $M_\odot$ (Ferland et. al.,1984).

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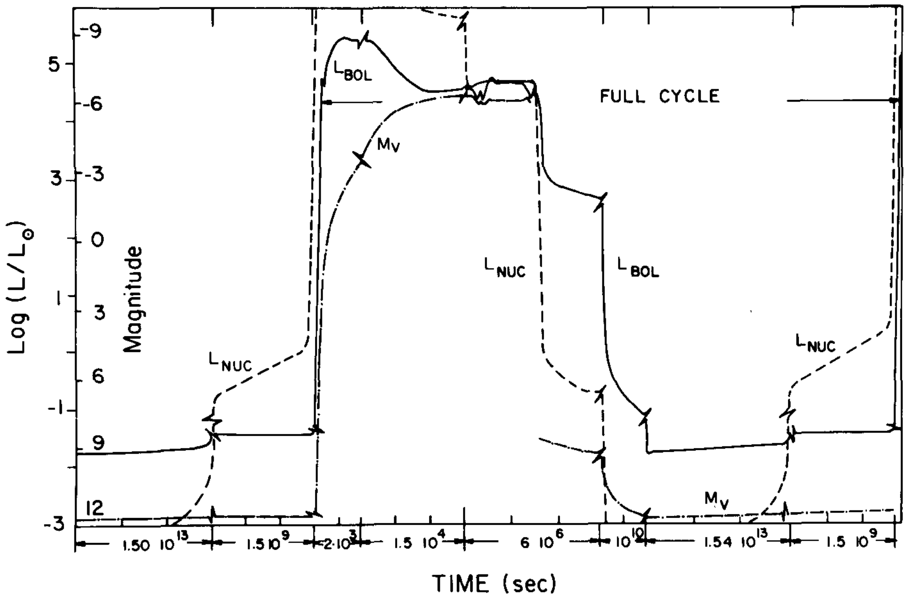

Fig.1 Evolution of bolometric luminosity (solid line), nuclear luminosity (dashed line) and visual magnitude (dash-dot line). The time axis is divided into intervals corresponding to phases of different evolutionary time scales.

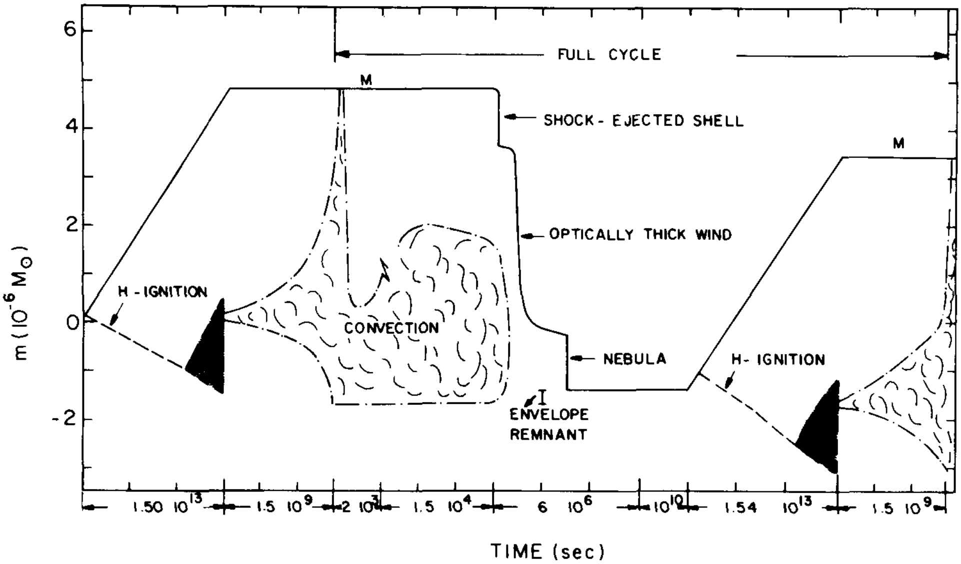

Fig.2 History of the envelope's structure. The ordinate is the mass above the original WD core (m>0) and below it (m<0) . The full line marked M shows the change in stellar mass. Hatched areas indicate burning shells (before onset of convection), where the nuclear energy generation rate exceeds 1000 erg $gm^{-1}s^{-1}$.

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In conclusion, the effect of the outburst on the nova progenitor was transient. Its traces faded away during the quiescent phase between eruptions and, therefore, the two successive outbursts were very similar. The entire evolutionary course of the model is illustrated in Fig.1 and Fig.2. The former shows the model's light-curve and the resulting visual magnitude; in the latter the change in total mass due to accretion and mass loss is shown, as well as the development of burning shells and convective zones.

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