THE EVOLUTION OF A SLOW NOVA MODEL WITH A Z = .03 ENVELOPE FROM PRE-EXPLOSION TO EXTINCTION

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ABSTRACT

A model for slow nova explosions is presented. The model consists of a 0.8 $M_\odot$ C/O core and an envelope of 10^{-4} $M_\odot$ with solar composition. The envelope is assumed to have been accreted from a companion. The nuclear runaway produces luminosity close to the Eddington luminosity; this ejects 95% of the envelope. We find

I CNO equilibrium burning on a timescale of $10^{5.5}$ seconds produces enough energy for mass ejection.

II The rise in luminosity stops close to the Eddington limit and the outer envelope layers accelerate via the continuous action of radiation pressure.

III The mass outflow has two phases: a gentle outflow at the beginning and then a rapid outflow. In both phases we find $\dot{m} \simeq$ const., or equivalently, steady state outflow.

IV The nova's "shut-off" mechanism is the exhaustion of the envelope's mass. In this "slow nova" model it took about 200 days for 95% of the envelope to be ejected and to leave behing a hot white dwarf.

V The isotope ratios C^{12}/C^{13}, N^{14}/N^{15} and O^{16}/O^{17} are in good agreement with observations.

VI The behaviour of $L_{BOL}(t)$ agrees well with observations. Several additional consequences are discussed.

INTRODUCTION

The hydrodynamic calculations of Starrfield, Sparks and Truran (1974) (SST) are the most detailed nova simulations to date. In these calculations the assumed initial model is a degenerate carbon core of $1M_\odot$ with a hydrogen-rich envelope. This envelope, which is also degenerate, has a mass of $1.25 - 1.7 \times 10^{-3}$ $M_\odot$ and is assumed to have been accreted from a binary companion. SST follow the hydrodynamic and nuclear evolution of this initial model. Their results, which are only partially consistent with observations, raise several important problems. In particular, those models that produce the characteristic energies for the nova phenomenon, do not have any natural mechanism to "turn themselves off" within several months. This is contrary to long-standing results in the visual part of the spectrum (Payne - Gaposhkin, 1957). In order to obtain mass ejection from their models, SST enrich the bottom layers of the envelopes in CNO isotopes. They require $Z \geq .3$ for ejection to occur. These problems connected with SST's work have prompted us to reconsider the initial model of SST. Our most important modification is to lower the initial mass of the hydrogen rich envelope and to avoid any CNO enrichment above Population I abundances. We have been able to produce a model which agrees well with the visual luminosity time dependence of a moderately slow nova, as well as with the estimations of the N^{14}/N^{15} and C^{12}/C^{13} ratios by Sneden and Lambert (1975). These are > 1, although the observations they are based on seem to indicate C^{13}/C^{12} and N^{15}/N^{14} enrichments. Most of the model's luminosity is radiated in the UV part of the spectrum, in agreement with Gallagher and Code's (1974) observations of FH SER.

Details of the computer code, the nuclear reactions network and the treatment of convection that we use are given in Prialnik, Shara and Shaviv (1977) (PSS). In the present abridged version of PSS (1977) we restrict ourselves to a discussion of the evolution of a slow nova model with a $Z = .03$ envelope.

II. THE INITIAL MODEL.

Our fundamental assumption is that hydrogen rich material, accreted onto a degenerate carbon-oxygen core, causes a thermonuclear runaway that ejects the envelope and shows up as a nova. We chose a core of $0.8\ M_\odot$. Its composition is 50% C^{12} and 50% O^{16} (by mass); these are the abundances generally assumed to result from helium burning. No enhanced CNO abundances are assumed in our model. We start with $Z = .03$ (C^{12} , N^{14} and O^{16} abundances by mass of 0.006, 0.006 and 0.018, respectively). In our calculations we assume $m_{env} = 10^{-4}\ M_\odot$ and we find the time needed to reach the nuclear flash to be $\sim 5.8 \times 10^{11}$ sec. Our choise of a $10^{-4}\ M_\odot$ envelope which does not accrete mass while it flashes, but which can lose mass during and after its flash, is consistent with accretion rate considerations. The main features of our initial model (on both sides of the core-envelope interface) are given in fig. 1 (curves labelled (a)). This is about 5000 years before the flash. The temperature at the base of the envelope equals that of the core's boundary, namely 1.5×10^7 °K. We thus imply that any mismatch between the entropy densities of the accreted matter and the outer layers of the core has disappeared on a time scale similar to, or shorter than, the time needed to accrete $10^{-4}\ M_\odot$.

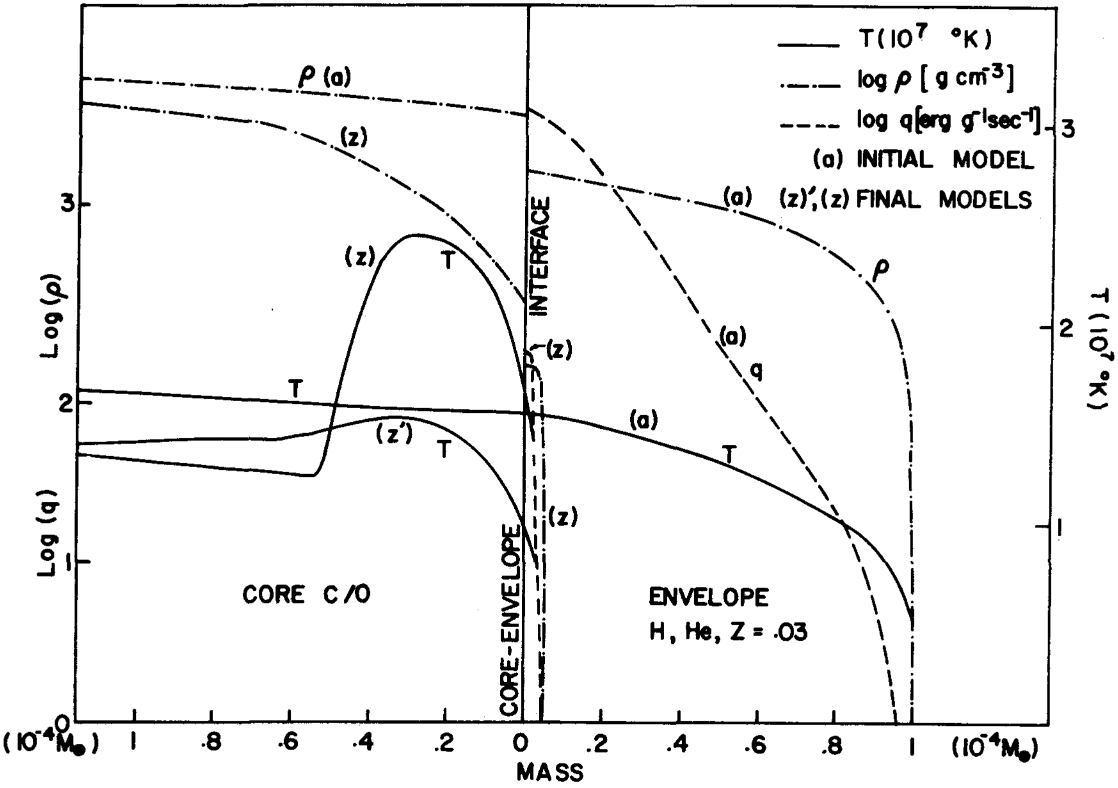

Fig. 1: Temperature, density and energy generation rate profiles around the core - envelope interface at: (a) ∿ 5000 years before the flash; (z) ∿ 40 years after the flash; and the temperature profile (z)' ∿ 1000 years after the flash. The mass ordinate increases outwards and inwards from the interface.

III. THE EVOLUTION OF THE NOVA.

Our initial model is in hydrostatic equilibrium and in quasi-thermal equilibrium. By quasi-thermal equilibrium we mean that the energy produced by p-p reactions in the envelope whose hottest point is at 1.5×10^7 °K, is $\sim$ all radiated away. Only a negligible part is absorbed by the envelope; this goes into work done against gravitation. The average energy generation rate at the envelope's base of about 10^3 erg gm^{-1} sec^{-1} yields a luminosity of 2×10^{-2} $L_{\odot}$ (close to the luminosity of the core) and a nuclear time-scale of 5×10^8 years.

The instability of the configuration finds expression in drastic changes of the evolutionary time scale of, for example, the temperature's history. Even at the beginning of the model's evolution the increase in temperature occurs on a time scale shorter than the nuclear one. The temperature at the envelope base reaches 4.4×10^7 °K in 1.8×10^4 yr. and 8.3×10^7 °K only 3.5×10^6 seconds later. The acceleration of the runaway increases suddenly (cf. Fig. 2) and the envelope base temperature jumps to 1.5×10^8 °K - the peak flash temperature - in less than 6.1×10^4 sec. The temperature histories of eight representative mass shells are given in Fig. 2 starting from the time when the envelope base temperature is 4.4×10^7 °K. Generally speaking, the spikes in the temperature resemble the features found in shell instabilities.

The curve marked 4 in Fig. 2 represents the deepest shell in the hydrogen-rich envelope, where most of the nova's energy is generated. The peak temerature of this shell is 1.5×10^8 °K and the peak energy generation rate is $q = 5.4 \times 10^{13}$ erg gm^{-1} sec^{-1}, when the reaction $N^{13}(p,\gamma)\ O^{14}\ (e^+\nu)\ N^{15}$, which is unimportant below 10^8 °K, is neglected, and $q = 2.7 \times 10^{14}$ erg gm^{-1} sec^{-1} when it is taken into account. Other main features of the flash are not affected by this refinement, nor is the post-flash evolution. The time spent by this shell at a temperature greater than 10^8 °K is 3×10^5 sec. *The computed model does not develop a shock wave in this shell or in any other at any time.*

That this is physically reasonable can be seen as follows. The hydrodynamic timescale t_H of the deepest layers of the envelope is approximately

$$t_H \sim \frac{446}{\sqrt{\rho}} \sim 40 \text{ seconds}$$

where $\rho = 1.4 \times 10^2$ gm cm^{-3} is the density at the envelope base. The total nuclear energy release during the hydrodynamic time scale is smaller than the internal energy, i.e.

$$E\, t_H \sim 10^{16} \text{ erg gm}^{-1} < \frac{3}{2} \frac{k}{\mu} T N_A \sim 2.5 \times 10^{16} \text{ erg gm}^{-1}$$

and it is clearly less than the binding energy (1.6×10^{17} erg gm^{-1}). Consequently the process of energy release can be considered as sufficiently slow as to allow hydrostatic adjustment; shock waves are not necessary.

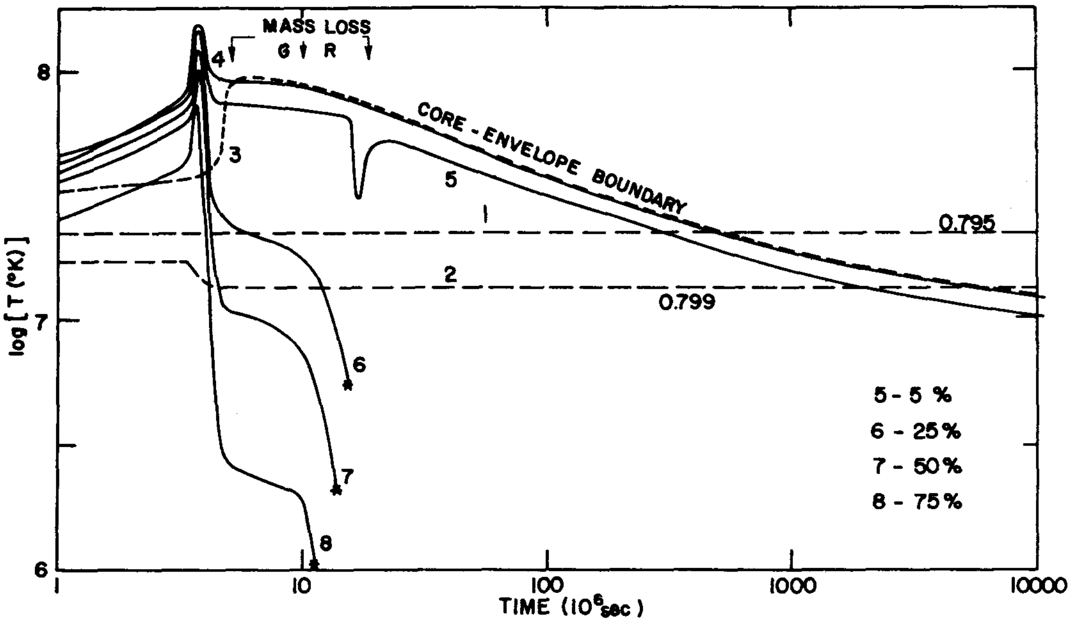

Fig. 2: Temperature history for various mass-shells in the core at: (1) M = 0.795 $M_\odot$; (2) M = 0.799 $M_\odot$ (3) M = 0.800 $M_\odot$ and in the envelope close to the interface (4) and at (5) 5%; (6) 25%; (7) 50% and (8) 75% of the envelope's mass. Asterisks indicate ejection of the corresponding shells. (G - gentle mass loss; R - rapid mass loss).

Curve 3 in figure 2 represents the temperature history of the outermost shell of the C-O core. The shell's temperature increases very slowly from 3.2×10^7 °K to 3.5×10^7 °K while the envelope base jumps from 4.4×10^7 °K to 8.3×10^7 °K. This shell's temperature then rapidly increases, becoming virtually identical to the envelope's base temperature at $\sim 1.5 \times 10^6$ seconds after the flash peak. Thereafter the outermost core shell remains slightly hotter than the innermost envelope shell as both cool together. One year after the flash the shells reach $\sim 5.6 \times 10^7$ °K, and ten years after the flash they have cooled to $\sim 2.5 \times 10^7$ °K. The temperature differences between the shells are too small to be noticed in the figure.

Curve 2 in Fig. 2 represents the deepest core shell which showed any discernable reaction to the envelope's thermonuclear runaway. The effect of the decrease in the pressure on the boundary is noticed on a hydrodynamic time scale while the time scale for re-heating this shell is long. The practically adiabatic expansion lowers the temperature from 1.7×10^7 °K to 1.4×10^7 °K. Note that this shell is just 10^{-3} M_Θ away from the core-envelope boundary. Curve 1, the temperature at a depth of 5×10^{-3} M_Θ under the core boundary shows no temperature variation at all.

The curves marked 5, 6, 7 and 8 in Fig. 2 represent different shells in the envelope. The percentages given in the figure refer to the masses of these shells, counted from the base, as fractions of the mass of the envelope. The temperature history is generally similar to that of the base except for a lower peak in the temperature and a greater fall immediately after the peak. The curves stop at an asterisk. We will return to this point shortly.

The bolometric and nuclear-energy generation luminosities, L_{BOL} and L_{NUC}, respectively are given as functions of time in Fig. 3, starting 2.5×10^6 sec. before the flash, when L_{nuc} is 2.5×10^4 L_Θ. L_{nuc} has reached this value gradually during the preceding 5.8×10^{11} sec. (1.8×10^4 years). During the flash L_{NUC} rises from about 10^5 L_Θ to 5.5×10^8 L_Θ and drops back again to 10^5 L_Θ on a timescale of 1.7×10^6 sec. Meanwhile L_{BOL} rises abruptly by six orders of magnitude to a value of $\sim 1.6 \times 10^4 L_\Theta$, and remains virtually constant for about six months. During this period L_{NUC} is slightly above and then below L_{BOL}. Two years after the flash L_{BOL} has dropped to $10^3 L_\Theta$ while L_{NUC} is only 40 L_Θ; after thirty more years $L_{BOL} \sim 10 L_\Theta$ and L_{NUC} has become negligible, (less than 0.1 L_Θ)

Mass loss occurs during the period of constant bolometric luminosity. L_{BOL} always stays close to 70% of the Eddington critical lumonisity (L_{CRIT}). Continuous mass loss driven by radiation pressure is expected under these circumstances (Finzi and Wolf (1971), Finzi, Finzi and Shaviv (1976)).

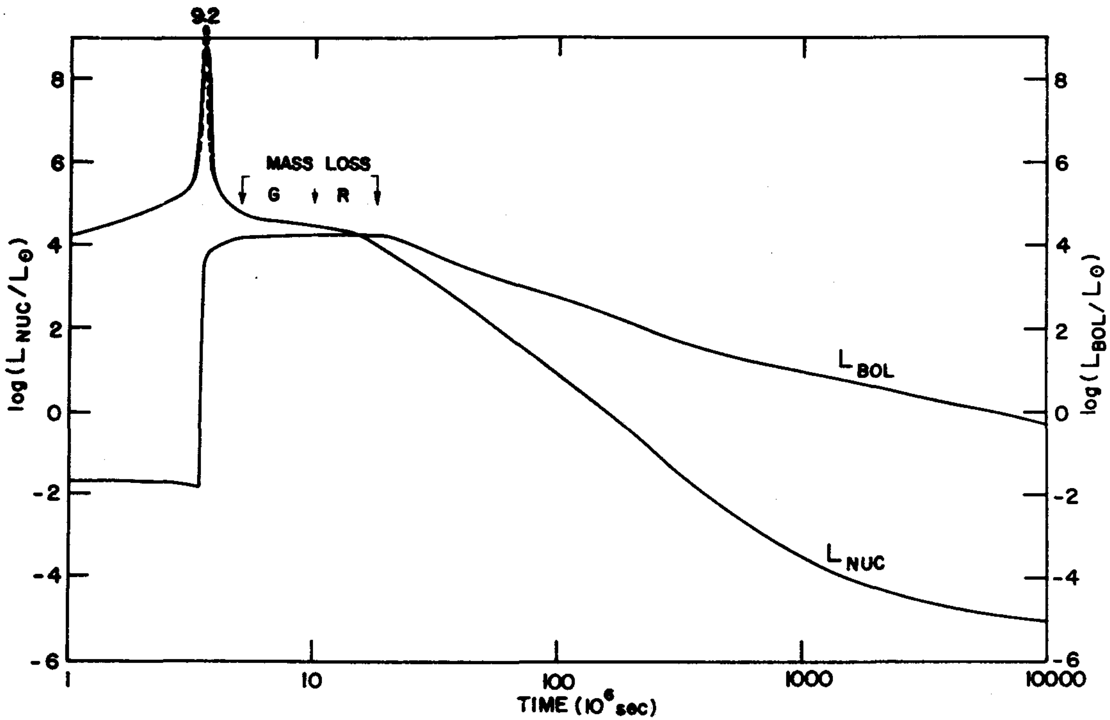

Fig. 3: Evolution of the bolometric luminosity L_{BOL} and nuclear luminosity L_{NUC}. Symbols G and R as in Fig. 2. The broken line indicates the results obtained when the reactions $N^{13}(p,\gamma)\ O^{14}(e^{+}\nu)\ N^{15}(p,\gamma)\ O^{16}$ were included.

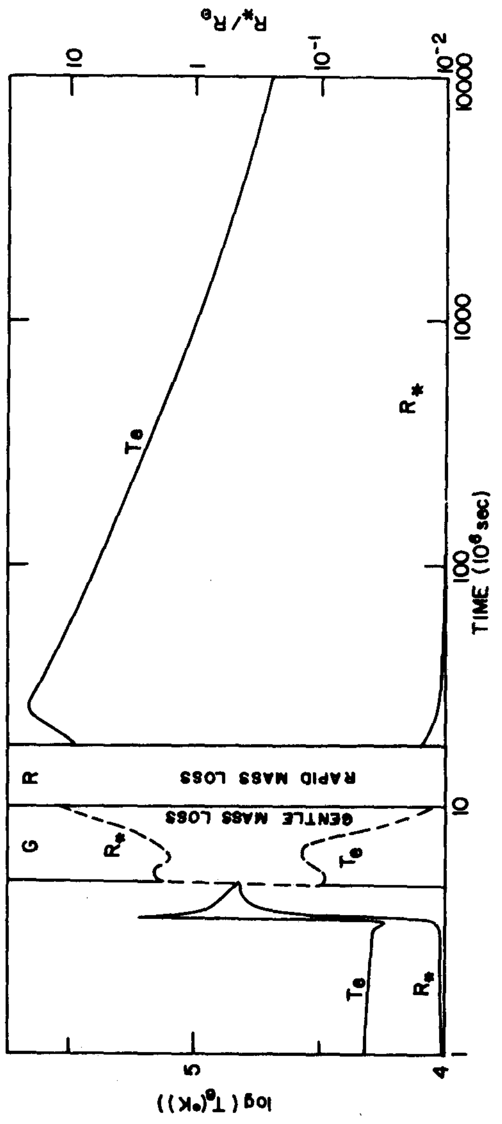

Fig. 4: Variation in time of the effective temperature Te and the radius at the atmosphere base R. The curves are interrupted during the period of rapid mass-loss since the computed values are inaccurate for this period.

Mass loss can be followed by the present lagrangian programme with the provisions given below. As the outer mass shells expand, their evolutionary time scales become shorter. A large discrepancy between the timescales at the base of the envelope and in the outer shells arises. To circumvent this difficulty we adopted the following procedure to simulate mass loss. One or more outer spherical mass shells, with a total mass of about 10^{-6} $M_{\odot}$ (about 10^{-2} of the envelope mass), are artificially removed whenever all the following conditions are fulfilled simultaneously.

(a) The outward acceleration is greater than several times the local acceleration of gravity.

(b) The average velocity of the outgoing matter ($\sim 10^3$ km sec^{-1}) is greater than the local escape velocity and well above the local speed of sound ($\sim$ 100 km sec^{-1}).

(c) The total optical depth of the shells is $\sim$ 1, so that they are optically thin.

The first condition implies that the equation of motion becomes

$$- \frac{1}{p} \frac{dP}{dr} = \ddot{r} \qquad (8)$$

i.e. free expansion of the gas without gravitation.

When these conditions are satisfied the dynamic evolutionary timescale decreases quickly to seconds and less, implying a highly supersonic flow. The removal of the mass at this stage is justified by the fact that the flow is *supersonic* and the mass removed is *downstream*. Hence the removal should have no effect on the flow at any lagrangian mass point internal to the removal point. We checked the physical conditions in the mass shell immediately below the ejected ones and, indeed, found that they were practically unchanged by the removal of the shells above. Nor was the radiation outflow, since the removed shells were optically thin. A simple test of the method was conducted. The runaway shell was divided into several smaller shells and the same procedure was applied. The total mass loss as well as the total time scale for mass loss and the average ejection velocities were identical. Another test was to apply the same procedure to a stable atmosphere, namely, an atmosphere which does not expand outwards. When a small mass-shell was removed from such an atmosphere no significant acceleration or mass loss were found. The model expanded slowly to its original radius, as expected.

In Fig. 5 we give the velocity histories of two mass shells. We start when the velocities are negligible compared to the local escape velocities and end when the shells are removed. Note that the time scales for expansion and removal are directly proportional to the shell's mass, i.e. $\dot{m}$ = *constant* or steady state outflow.

Curves 6, 7 and 8 in Fig. 2 were terminated with an asterisk when their corresponding mass-shells were removed.

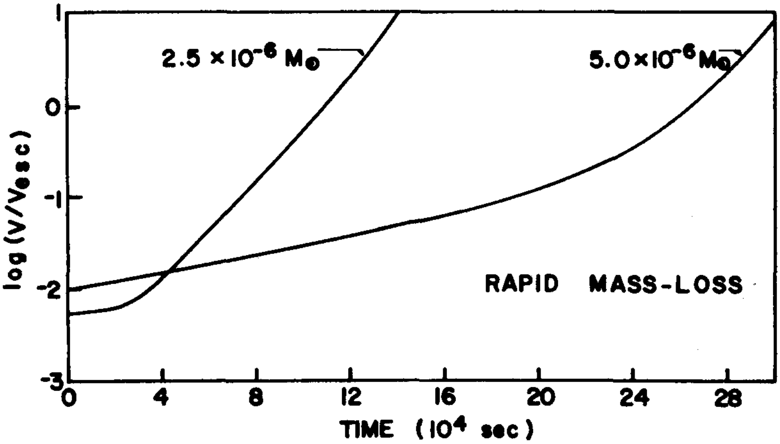

Fig. 5: Progress of the ratio of the average velocity to the local escape velocity prior to ejection for two different mass-shells, one of thickness 2.5 x 10^{-6} $M_\odot$ located at 90% of the envelope mass and the other of thickness 5 x 10^{-6} at 75% of the envelope mass. The given evolution of the two shells is not simultaneous. Time is set zero arbitrarily when $v/v_{esc} \lesssim 10^{-2}$.

Perhaps the most convincing argument of our mass-loss simulation is supplied by curve 5 of Fig. 2. It represents the outer shell of the innermost 5% of the envelope. About 1.5 x 10^7 seconds after the flash, when 95% of the envelope mass has escaped, the shell is expanding in the same way as did the shells above it, which have been finally removed. Its temperature drops to 3 x 10^7 °K and the shell attains a radius of 5.6 x 10^{-2} $R_\odot$ (in terms of the white dwarf's potential well, this is ∿ 80% of the way to infinity). The shell then contracts and heats up again, achieving hydrostatic and quasi-thermal equilibrium about 1.8 x 10^7 seconds after the flash peak. The shell's temperature has returned to 6 x 10^7 °K and the envelope radius has shrunk back to ∿ 10^{-2} $R_\odot$. This ends the episode of mass loss. All of the envelope (and outer core) shells cool as shown in Fig. 2, and the white dwarf contracts steadily.

The convective and mass-loss histories of the model are given in Fig. 6. Convection begins 3.2 x 10^9 seconds before the flash peak, and extends from just above the envelope's base (from the 5% lagrangian mass fraction) almost to the surface. (Hereafter percentages refer to lagrangian mass fractions of the initial envelope mass measured outward from the core.) The convective region then slowly eats its way out to the envelope's surface during the next 100 years. During the last 10^6 seconds before the flash peak the convective region expands inward. *From 2 x 10^5 seconds before, until 13 x 10^5 seconds after the flash peak, the entire envelope is convective.* This will be a critical point when we compare our predicted isotopic abundance ratios with the observations.

At 1.3 x 10^6 seconds after the flash peak the outer 60% and the inner 1% of the envelope cease being convective. At the same time "slow" mass ejection begins, with a mass loss rate of ∿ 10^{21} gram $\sec^{-1}$. About 4.5 x 10^6 seconds after the flash peak the convective region again starts to contract inward from the 40% mass level. It has receded to the 20% level when violent mass loss begins. The convective region shrinks steadily for another 2.5 x 10^6 seconds (by which time 30% of the envelope has been ejected) and then vanishes. *At no time is there convective mixing between the C/O core and the envelope.* The evolutionary timescales involved are always much greater than the turnover times for convection - about 10^3 seconds, so that convection has enough time to become adiabatic.

The fraction of the initial envelope mass remaining bound on the white dwarf's surface as a function of time is given by the broken curve in Fig. 6. The period of rapid mass loss which follows the gentle mass loss lasts 8.5 x 10^6 seconds, (∿ 100 days) and is characterized by an ejection rate of ∿ 2.2 x 10^{22} gm $\sec^{-1}$ = 3.5 x 10^{-4} $M_\odot$ yr^{-1}. We do not discern large fluctuations in the mass ejection rate as the envelope is being lost. However our atmospheric approximation is not accurate enough to predict variations in the mass loss rate of less than a factor of about two, and these cannot be ruled out. The constant slope of the curve m_{envel} (t) means that $\dot{m}$ = constant during both phases of mass ejection,

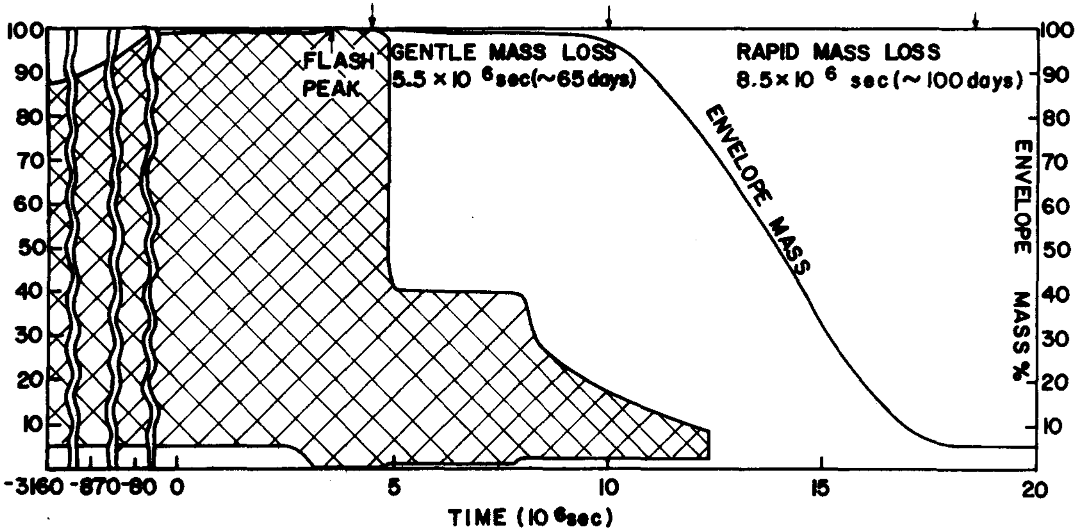

Fig. 6: Envelope mass as a function of time and the variation of the convective zone (shaded area) in the envelope before and during mass loss.

i.e. the gentle and rapid phases. This vindicates the assumption of Bath and Shaviv (1976) of steady state mass ejection. Starting 100 years after the flash peak and after mass ejection has ceased, the outer 3.25×10^{-6} $M_\odot$ of the core become convective. The temperature gradient between the outer core and the envelope remnants is always much smaller than the adiabatic temperature gradient and hence convection does not occur between them during the post-nova cooling phase. Moreover, the constant density drop by a factor of 2.09 at the interface - due to the jump in mean molecular weight - is more than the change in density over one mixing length. Thus the density barrier will not allow any convective overshoot at this stage. A typical structure at a time $\sim$ 40 years and at $\sim$ 1000 years after the flash and after the end of mass ejection is shown in Fig. 1 (by the curves labelled (Z) and (Z)').

The effective temperature and the radius of the white dwarf photosphere are plotted in Fig. 4. At the time of the flash T_e jumps to 1.7×10^5 ^{o}K and then starts to drop as R_* starts to expand. When T_e is down to 3×10^4 ^{o}K and R_* has reached $\sim 10R_\odot$ the envelope begins ejecting mass and our computed T_e and R_* are no longer meaningful. During the five months period of mass loss we expect much of the nova's energy to be radiated in the ultraviolet as its T_e will be $\sim 10^5$ ^{o}K. Another possibility is the formation of carbonaceous dust grains in the ejecta which convert much of the nova's UV luminosity into infrared radiation (Clayton and Hoyle, 1976). This effect is not included in this calculation.

After the end of mass loss the envelope contracts sharply, forcing up T_e (as L is virtually constant). T_e rises steadily to a maximum of 4.6×10^5 ^{o}K, which occurs $\sim$ 90 days after the end of mass loss, and then starts to drop. As the rise in T_e takes place the nova's flux is shifted further and further into the UV. It takes 30 days for the effective temperature to cool down to 10^5 ^{o}K, though by then the old nova's luminosity is $\sim 10L_\odot$.

IV. COMPARISON WITH RESULTS OF STARRFIELD ET AL.

The details of our model's evolution during and after the thermonuclear runaway are different from the published results of SST (1974), more than required by the fact that theirs is a fast nova model, while ours is a slow nova. Mass ejection was induced by a shock wave and completed by β-decay energy in SST's study, while the low CNO abundances and envelope mass assumed here yielded continuous mass-loss driven by radiation pressure.

The total nuclear energy released by our nova model is 3.28×10^{46} ergs, the integrated radiative losses, $\int L_{BOL}\,dt$, are 2.87×10^{45} ergs and the kinetic energy of the ejected mass is $\sim 10^{45}$ ergs. All of this is accomplished by burning only 2.5% of the initial envelope's hydrogen. About 90% of the nuclear energy generated is used to eject the envelope. Once the envelope is gone energy production ceases. The radiated energy as well as the kinetic energy of the ejected mass are in good agreement with the UV, visual and infrared observations' values of nova luminosities and expansion velocities, and in agreement with the results of SST. The difference is that in the models calculated by SST the peak energy generation rate is about one hundred times higher than in our case, but its duration is shorter by the same factor. Therefore, although the same amount of energy is released and the net mass ejected is about the same, the ejection mechanisms are basically different.

This difference leads to a second one. During the 2×10^5 seconds of flash peak in the present model the CNO elements isotopic ratios are able to reach roughly equilibrium abundances (except for O^{16}/O^{17}). The chemical composition of the ejecta is given in Table 1 and the isotope ratios, compared with observations and SST, are given in Table 2. Convection between the envelope base and the rest of the envelope occurred for more than enough time (see Fig. 6) for roughly equilibrium burning ratios to be established throughout the ejected envelope. In SST's case, the more violent flash yielded far from equilibrium isotopic abundance ratios. In light of the analysis of R. Williams, elsewhere in this volume, all previous abundance determinations must be viewed with considerable scepticism. The results in Table 2 are presented for comparison with future, more reliable, abundance determinations.

Finally, our most important result is, perhaps, the envelope depletion "shut-down" mechanism ending a period of 5 - 6 months of constant luminosity. The models computed by SST eject only $\sim$ 10% of their envelopes and end up as high luminosity stars.

Table 1. Composition of matter ejected by the nova model. These results are obtained without taking into account the N^{13} (p,γ) $O^{14}(e^+,\upsilon)$ N^{15}(p,γ) O^{16} reactions. Although most of the nucleosynthesis takes place at temperatures below 10^8 °K, these results may still be in error by 10%.

	%	H^1	He^4	He^3	C^{12}	C^{13}	N^{14}	N^{15}	O^{16}	O^{17}
				x 10^6	x 10^4	x 10^4	x 10^2	x 10^7	x 10^2	x 10^6
TIME	5	.676	.294	.999	5.88	1.95	1.66	4.75	1.31	2.34
	5	"	"	1.05	6.12	2.04	1.65	4.68	1.31	2.74
	52.25	"	"	1.15	6.59	2.24	1.65	4.39	1.31	3.59
	4.25	"	"	1.35	7.15	2.61	1.63	4.30	1.32	4.52
	10.0	"	.293	1.41	7.39	2.79	1.62	4.24	1.32	4.87
	12.5	"	"	1.78	8.00	3.06	1.62	4.08	1.32	4.82
	2.5	"	"	2.34	8.91	3.46	1.61	3.83	1.33	4.75
	3.5	"	"	3.95	1.16	4.48	1.59	2.16	1.34	4.21
AVERAGE FOR	95%	.676	.294	1.39	7.07	2.51	1.64	4.30	1.31	3.87

Table 2. Observations and theoretical predictions for CNO elements and isotope ratios in novae.

Author	Work	$C/C_\odot$	$N/N_\odot$	$O/O_\odot$	C^{12}/C^{13}	N^{14}/N^{13}	O^{16}/O^{17}
Pottasch (1959)	Ejecta of 5 Novae (observations)	$1 \pm .5$	45 ± 15	$5 \pm {}^{15}_{4}$	-	-	-
SST (1974)	Nova Model (prediction)	4	60	3	$\frac{1}{2} - \frac{1}{7}$	$\frac{2}{3}$	4
Present Work	Nova Model (prediction)	.3	18	1.8	2.8	3.8×10^4	3.3×10^3
Sneden & Lambert (1975)	DQ Her (1934) (observations)	-	-	-	$\gtrsim 1.5$	$\gtrsim 2$	-

V. SUMMARY.

We have followed the evolution of a 10^{-4} $M_\odot$ envelope of $X = .7$, $Y = .27$ and $Z = .03$ matter on the surface of a cold 0.8 $M_\odot$ white dwarf. The envelope's base took part in a thermonuclear runaway in which a peak temperature of 1.5×10^8 °K was achieved, and energy was being generated at a rate of 2×10^{14} erg $gm^{-1}s^{-1}$. The entire envelope was convective for 1.3×10^6 seconds following the flash, and roughly equilibrium CNO abundances of carbon and nitrogen isotopes were deposited throughout the envelope. Shortly after the flash the envelope began ejecting mass continuously. The rate of mass loss was a) constant, thus implying a steady state outflow and b) had two phases, initially gentle and later rapid mass loss. During the ensuing six or so months 95% of the original envelope mass was ejected. The white dwarf's photophere then contracted back sharply and its effective temperature rose to 4.6×10^5 °K, before cooling took over. Convection between the envelope and the core never occurred.

We compared our results with those of SST and with observations of novae. Our results either agree or are consistent with the luminosities and changes seen in ultraviolet, visible, infrared and x-ray observations of moderate or fast novae (the only cases measured at all wavelengths). Our model, however, is one of a slow nova and our computed timescales are typically an order of magnitude longer than those observed in the fast novae. Our predicted isotopic abundance ratios are in agreement with observations.

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DISCUSSION of Paper by PRIALNIK, SHARA and SHAVIV:

KIPPENHAHN: I would like to ask a more general question. Can theorists get away by presenting theories which either explain novae (including recurrent novae) or dwarf novae? Historically after one learned about recurrent novae Parenago found his relation which links novae to dwarf novae (I am not sure what the latest stage about this relation is, whether it is still valid or not). Then one found that novae as well as dwarf novae are binaries which all have very similar properties (a white dwarf-like primary with a yellow star filling its critical Roche lobe). Wouldn't it be a miracle if the same type of mass exchanging situation have two qualitatively different mechanisms for outburst?

SHAVIV: I am afraid it is too early. I really don't know. However, you have many free parameters and one which was not mentioned is the distance, stage of evolution, mass, rotation, etc. of the companion. So we are far from having a full picture.

ZIOLKOWSKI: I think there is a basic difference between the novae and dwarf novae type phenomena. While there is no reason to believe that nuclear burning plays any role in dwarf nova outburst (just because of the amount of the energy which is released), there are good reasons to believe that nuclear burning is very important for nova type outburst. So we might have the kind of miracle, you have mentioned.

WEBBINK: Regarding Dr. Kippenhahn's remark, I think that any model which purports to explain both dwarf nova and classical nova outbursts by the same mechanism will have great difficulty in explaining how the old nova GK Persei (1901) has displayed half a dozen distinctly dwarf-nova-like outbursts within the past ten years.

I would like to know in what direction one must go, in terms of core and envelope masses, to produce a fast nova. How fast a nova have you succeeded in producing?

SHAVIV: We have at the moment only preliminary results which must be checked out and verified before publication. So "not for quoting", if you take a $1.25 M_\odot$ with $10^{-5} M_\odot$ we get a fast nova with a decline time of a day. Let me mention that we have so far not been able to exhaust the M_{core}, M_{env} space.

H.C. THOMAS: Can you indicate, why interpolating from the results of Starrfield et al. their models would show no ejection while yours do?

SHAVIV: There are several reasons; let me point out one of them. The mass ejected versus mass envelope has a threshold, a plateau and later it goes down! The mass is too high for the nuclear runaway to eject mass. The parameters of SST correspond to the post plateau region.

SHARA: I would like to answer Dr. Thomas' question as to why Starrfield et al. (1974) did not obtain mass ejection with $Z = 0.3$ models, while we did. Starrfield et al.'s initial models had envelopes of $10^{-3} M_\odot$; our model's envelope had $10^{-4} M_\odot$. The larger mass envelope assumed by SST "smothered" the runaway they obtained, by expanding to about $10R_{\odot}$ without ejecting mass. Our $10^{-4}M_{\odot}$ envelope was ejected during about 6 months, simulating a slow nova.

PAPALOIZOU: How sensitive are your results to the precise way you remove mass? What does your code do if you just let it go with no artificial mass removal?

SHAVIV: We have tried several tests, like taking away the mass at smaller chunks, we have tried not to remove mass at all (and then it continued supersonic), etc., and we found that the final results are insensitive to this mode of mass removal. However, the Te and R are in greater error if you remove the mass too fast. If you do not remove the mass the code produces a Lagrangian treatment of a supersonic flow.

TEMESVARY: Why do you assume low Z?

SHAVIV: The high Z is an ansatz on the basis of the observations. We were uncertain about the compositions, as you heard yesterday from the very interesting talk by Williams which I enjoyed very much! At this point I will say a word about the composition we got. We find $C/C_{\odot} = 0.3$ $N/N_{\odot} = 18$ $O/O_{\odot} = 1.8$ due to reprocessing of C into N and O. If you compare our $C^{13}/C^{12}, N^{15}/N^{14}$ results, they agree well with those deduced by Sneden and Lambert.

Next, I would like to say that due to convection, which has a peculiar history in the envelope, the ejected material should not have a uniform composition, but it will vary in time. This poses a serious question with regard to what you measure, where, etc.

APPENZELLER: Since you showed us some calculated nova light curves predicted from the theory, I would like to ask you whether you can also explain one feature of the light curves which (as far as I know) has never been explained in the theory. This feature is the slow pre-outburst increase in the brightness observed in Nova Cyg 1975 (c.f., Wolf's paper yesterday) which started several weeks before the rapid "normal" increase to maximum brightness?

SHAVIV: We do get a pre-maximum halt. So far, we have not tried to fit a model to a case with a very long (in time) pre-maximum halt. However, I suppose we have enough freedom with our parameter to obtain such a case.

WOLF: In the case of Nova Cyg 1975, a pre-outburst brightening of about 5 mag has been observed already on August 5, about three weeks before the outburst. Is there any possibility to explain this in the scope of your theory?

SHAVIV: In principle we think there is. However, we are at the moment far from exhausting all the possible combinations of parameters. I have shown the curve of flash strength and mass loss as a function of M_{env}. I have not shown how L_{bol} and L_{vis} vary with M_{env}, let alone rotation, rate of mass accretion, etc.