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ACCRETION ONTO HOT WHITE DWARFS IN RELATION TO SYMBIOTIC NOVAE

MARIO LIVIO
Department of Physics, Technion, Haifa; and Department of Astronomy, University of Illinois, Urbana

DINA PRIALNIK
Racah Institute of Physics, The Hebrew University of Jerusalem; and Department of Geophysics and Planetary Sciences, Tel Aviv University

AND

ODED REGEV
Department of Astronomy, Columbia University; and Department of Physics, Technion, Haifa
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ABSTRACT

The hydrodynamic evolution of a hot 1 $M_\odot$ white dwarf, accreting hydrogen-rich matter at rates in the range 10^{-8}–10^{-6} $M_\odot$ yr^{-1} (i.e., above those expected to result in classical nova outbursts), is investigated. Three types of behavior are encountered: (*a*) For $\dot{M} \sim 10^{-8}$ $M_\odot$ yr^{-1}, nova-type outbursts of long duration ($\sim$20 yr) occur at intervals of $\sim$1500 yr; at each outburst half of the accreted envelope is ejected with velocities up to 40 km s^{-1}. The light-curve resembles closely those of the symbiotic novae RR Tel and RT Ser. (*b*) For $\dot{M} \sim 10^{-7}$ $M_\odot$ yr^{-1}, the star spends comparable periods of time at a high plateau luminosity (close to the Eddington limit) and giant dimensions, and at a low luminosity (equal to the accretion luminosity) and white dwarf dimensions, successively. No mass is ejected in this case. (*c*) For $\dot{M} \sim 10^{-6}$ $M_\odot$ yr^{-1}, equilibrium is achieved with steady hydrogen burning supplying a typical red giant luminosity. We conclude that: (1) symbiotic novae (which undergo outbursts similar to those of very slow novae) are more likely to occur in detached systems (D-type), involving wind accretors, in agreement with observations; and (2) the contribution of symbiotic stars to the frequency of Type I supernovae is severely constrained, although the occurrence of supernovae in symbiotic systems cannot be ruled out.

Subject headings: stars: accretion — stars: binaries — stars: evolution — stars: novae — stars: symbiotic — stars: white dwarfs

I. INTRODUCTION

Accretion of hydrogen-rich matter onto a white dwarf (WD) leads to three different classes of events delimited by two critical accretion rates (Fujimoto 1982; Iben 1982): $\dot{M}_{\rm nova}$ and $\dot{M}_{\rm RG}$ ($>\dot{M}_{\rm nova}$). Low accretion rates, $\dot{M} < \dot{M}_{\rm nova}$, produce nova outbursts; accretion at high rates, $\dot{M} > M_{\rm RG}$, results in the formation of a red giant, which burns hydrogen continuously (or, eventually, experiences AGB–type helium shell flashes). In the intermediate range $\dot{M}_{\rm nova} < \dot{M} < \dot{M}_{\rm RG}$, hydrogen flashes are still encountered, but they are relatively mild and recur at short intervals of time. According to numerical calculations of nova evolution (Prialnik *et al.* 1982), the maximal accretion rate for nova outbursts is a few 10^{-9} $M_\odot$ yr^{-1} (as long as the WD mass is not close to the Chandrasekhar limit). A lower value is obtained when some of the accretion energy is assumed to be absorbed by the WD rather than be radiated prior to infall (Prialnik, Kovetz, and Shara 1989). Thus, probably, $\dot{M}_{\rm nova} \leq 10^{-9}$ $M_\odot$ yr^{-1}. The other critical accretion rate, which constitutes the upper limit of the intermediate range, may be roughly estimated as follows. The luminosity of a red giant is related to the core mass $M_{\rm core}$ by (Paczyński 1970; Uus 1970):

$$L = 5.9 \times 10^4 (M_{\rm core} - 0.48)\, L_\odot\ . \qquad (1)$$

The source of energy is essentially hydrogen burning and hence the nuclear luminosity is

$$L_{\rm nuc} = \dot{M}_{\rm core} X Q_{\rm H}\ , \qquad (2)$$

where X is the hydrogen mass fraction in the burning shell and $Q_{\rm H}$ is the energy liberated per gram of hydrogen. Subsequent burning of helium into C—O provides only $\sim$10% of the energy and is irrelevant to the present crude estimate. Equating equations (1) and (2) and substituting $M_{\rm core} = M_{\rm WD}$, we obtain the minimum accretion rate that would enable stable hydrogen burning:

$$\dot{M}_{\rm RG} = 5.9 \times 10^4 (M_{\rm WD} - 0.48)/XQ_{\rm H}$$
$$= 4.6 \times 10^{-7}\ M_\odot\ {\rm yr}^{-1} \qquad (3)$$

(for $M_{\rm WD} = 1$ $M_\odot$ and $X = 0.7$). Both critical accretion rates depend to some extent on the WD mass and on its temperature (luminosity).

The intermediate range of accretion rates is relevant to the subclass of symbiotic stars known collectively as the "symbiotic novae." The group includes such objects as RT Ser and RR Tel (the slowest novae in the classification of Payne-Gaposchkin 1957), AG Peg, AS 239, V1016 Cyg, V1329 Cyg, HM Sge (Allen 1980; Kenyon and Truran 1983) and PU Vul (Liller and Liller 1979). Sometimes V1017 Sgr is also included (e.g., Garcia 1986). The particular feature which singles out these objects among the general group of symbiotic stars is that they undergo long outbursts that are believed to be powered by thermonuclear runaways (TNRs) on the surface of accreting WDs (for a recent review, see Viotti 1988). It has been suggested by Paczyński and Rudak (1980), following the results of Paczyński and Żytkow (1978), that a subsequent subdivision may be identified within the class of symbiotic novae, according to the conditions under which the TNR occurs: nondegerate (Type I) or degenerate (Type II). In the first case the WD expands only moderately during the outburst and thus remains very hot. It produces a high-velocity wind, similar to that emitted by the hot central stars of planetary nebulae (e.g., Kwok 1982; Kahn 1983). In the second case, the WD expands to become an A-F type supergiant, similar to classical novae at maximum (e.g., Gallagher and Starrfield 1978).

As the compact object in symbiotic stars is characterized by high effective temperatures—of order 10^5 K—accretion at a moderate rate onto hot WDs is most likely to lead to outbursts of the symbiotic nova type. The evolution of hot WDs which accrete hydrogen-rich matter at relatively high rates ($\dot{M} > \dot{M}_{nova}$) has been investigated in the *quasi-static* or in the *steady-burning* approximations by Paczyński and Żytkow (1978); Sion *et al.* (1979), Iben (1982), and Sion and Starrfield (1986). In the present work we carry out *full hydrodynamic* calculations of accretion onto a hot (luminous) WD. We shall thus be able to examine in detail the dynamical properties of the phase following the development of a TNR, including eventual mass loss. The calculations and the results are described in § II. We then discuss (in § III) the possible relation between different TNR models and different types of binary systems (detached or semidetached). We conclude by examining the possible role of symbiotics as Type I supernova progenitors.

II. RESULTS OF NUMERICAL CALCULATIONS

a) Input Physics and Initial Parameters

The initial model chosen for our calculations is a hot 1 $M_\odot$ C—O WD with an initial luminosity $L_{WD} = 7\ L_\odot$, a radius $R_{WD} = 8.4 \times 10^{-3}\ R_\odot$, and an effective temperature of 10^5 K. At the center, the temperature is 10^8 K and the density is 3×10^7 g cm^{-3}. The WD interior is cooled by a neutrino flux of 40 $L_\odot$. A thin hydrogen-rich layer of $1.1 \times 10^{-7}\ M_\odot$ is assumed to exist above the C—O WD core; at the base of this layer, the temperature is 1.1×10^7 K and the pressure, 2.4×10^{16} dyn cm^{-2}.

Three evolutionary sequences, labeled M8, M7, and M6, were run, corresponding to constant accretion rates $\dot{M} = 10^{-8}$, 10^{-7}, and $10^{-6}\ M_\odot$ yr^{-1}, respectively. They all started from the same initial configuration, so as to make possible a conclusive comparison between the consequences of different accretion rates. The composition of the accreted matter was $X = 0.7$ and $Z = 0.03$. Half of the free-fall energy was assumed to be gained by the accreting star, the other half having been presumably radiated, either in the accretion disk (if one existed) or outward from the stand-off shock (in the case of radial accretion). Thus the rate of energy gain, by accretion, was

$$L_{acc} = \frac{1}{2}\frac{GM_{WD}\dot{M}}{R_{WD}} = 18\,\frac{\dot{M}}{10^{-8}\ M_\odot\ yr^{-1}}\,L_\odot\ , \qquad (4)$$

larger than L_{WD} for all the accretion rates considered. Consequently, the outer layers of the WD were hotter than in models where this energy is neglected. However, since the WD's interior was hot in our case, no temperature inversion arose below the surface, as obtained in case of accretion onto a cold WD (Prialnik, Kovetz, and Shara 1989).

The hydrodynamic one-dimensional evolution code used was described in some detail by Prialnik (1986) and the accretion algorithm by Prialnik and Livio 1986). We should mention that hydrostatic equilibrium was nowhere assumed (even when velocities were small). The effect of diffusion across the boundary between WD core and accreted matter was ignored. It should be negligible on the short evolutionary time scales imposed by the relatively high accretion rates adopted (see, e.g., Kovetz and Prialnik 1985).

TABLE 1

OUTBURST CHARACTERISTICS OF MODEL M8

Property	First Flash	Second Flash
T_{max} (K)[a]	1.38×10^8	1.51×10^8
v_{max} (km s^{-1})[b]	39	36
$M_H/M_\odot$[c]	1.76×10^{-5}	1.71×10^{-5}
$\Delta m_{ej}/M_\odot$[d]	8.0×10^{-6}	8.3×10^{-6}
$\Delta m_{H\to He}/M_\odot$[e]	7.3×10^{-6}	6.1×10^{-6}
τ_{on} (yr)	20	17
τ_{off} (yr)	1475	1510
$L_{on}/L_\odot$	3.2×10^4	3.2×10^4
$L_{off}/L_\odot$	26	26
ΔM_{bol}	$7^m_.7$	$7^m_.7$

[a] T_{max}: maximal temperature attained in burning shell.
[b] v_{max}: maximal ejection velocity.
[c] M_H: mass of hydrogen-rich envelope at the onset of the flash.
[d] Δm_{ej}: ejected mass.
[e] $\Delta m_{H\to He}$: mass layer throughout which hydrogen was converted to helium.

b) Model M8

The evolution of model M8 was followed through three hydrogen flashes. This amounts to *two full cycles*, if we disregard the first accretion episode, which is affected to some degree by the (arbitrary) initial conditions. The evolution of the nuclear luminosity L_{nuc} and the bolometric luminosity L_{bol} is shown in Figure 1, top and bottom panels, respectively. The time interval corresponding to the second flash is blown-up and shown in Figure 2; L_{bol} and L_{nuc}, in the upper panel, and the effective temperature T_{eff}, in the lower one. Characteristic properties of this model are given in Table 1. We find that, typically, the duration of the quiescent accretion phase is $\tau_{off} \simeq 1500$ yr, while the high-luminosity phase lasts for $\tau_{on} \simeq 20$ yr. The bolometric luminosity is essentially a two-value function: $L_{off} \simeq L_{acc} + L_{WD} = 26\ L_\odot$ during the "off" phase and $L_{on} \simeq 3.2 \times 10^4\ L_\odot \simeq L_{Edd}$ during the "on" phase. The outbursts amplitude is thus $7^m_.7$.

A TNR develops when the mass of the hydrogen-rich envelope reaches $1.7 \times 10^{-5}\ M_\odot$. At the first flash, the envelope is composed entirely of accreted matter, at the later two flashes, the accreted matter accumulates on top of a hydrogen-rich (unburnt) layer, left over from the previous outburst. This is one reason for the longer duration of the first accretion phase. Another is the colder configuration it starts from: while the temperature at the bottom of the hydrogen-rich envelope is initially 1.1×10^7 K, it has a minimum of 2.3×10^7 K between flashes. The latter temperature is a result of downward heat diffusion occurring during a flash, which affects the outer few $10^{-4}\ M_\odot$ of the WD core.

About half of the hydrogen-rich envelope ($\sim 8 \times 10^{-6}\ M_\odot$) is ejected during each outburst. Two-thirds of the remnant half are burnt before the star contracts back to its initial radius. Then hydrogen burning continues slowly, i.e., at a rate which is smaller than the accretion rate. Ejection velocities do not exceed 40 km s^{-1}. Thus the mass is lost as a stellar wind, at a rate of $\sim 10^{-6}\ M_\odot$ yr^{-1}, while the star is in thermal equilibrium, at an effective temperature of ~ 8500 K. Therefore the star contracts, maintaining thermal equilibrium for a while, with L_{bol} and L_{nuc} both declining. Later, L_{nuc} drops to ~ 0.01

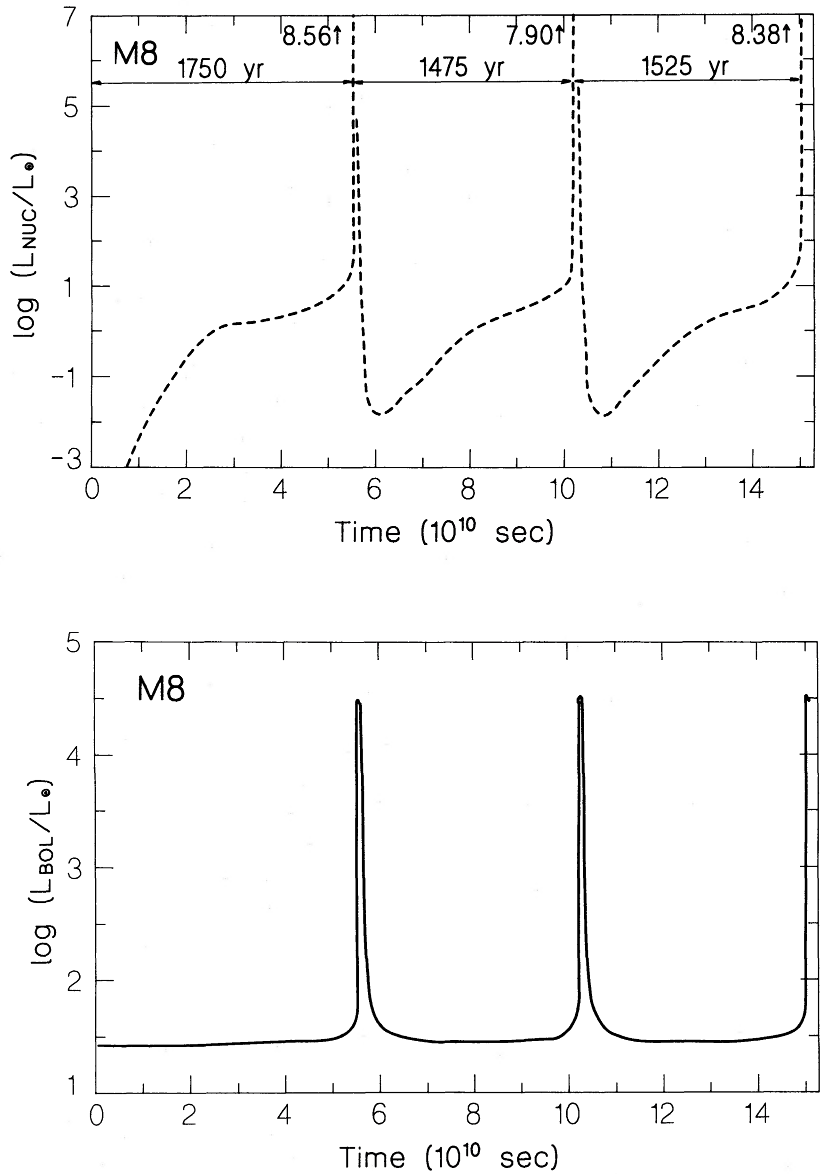

FIG. 1

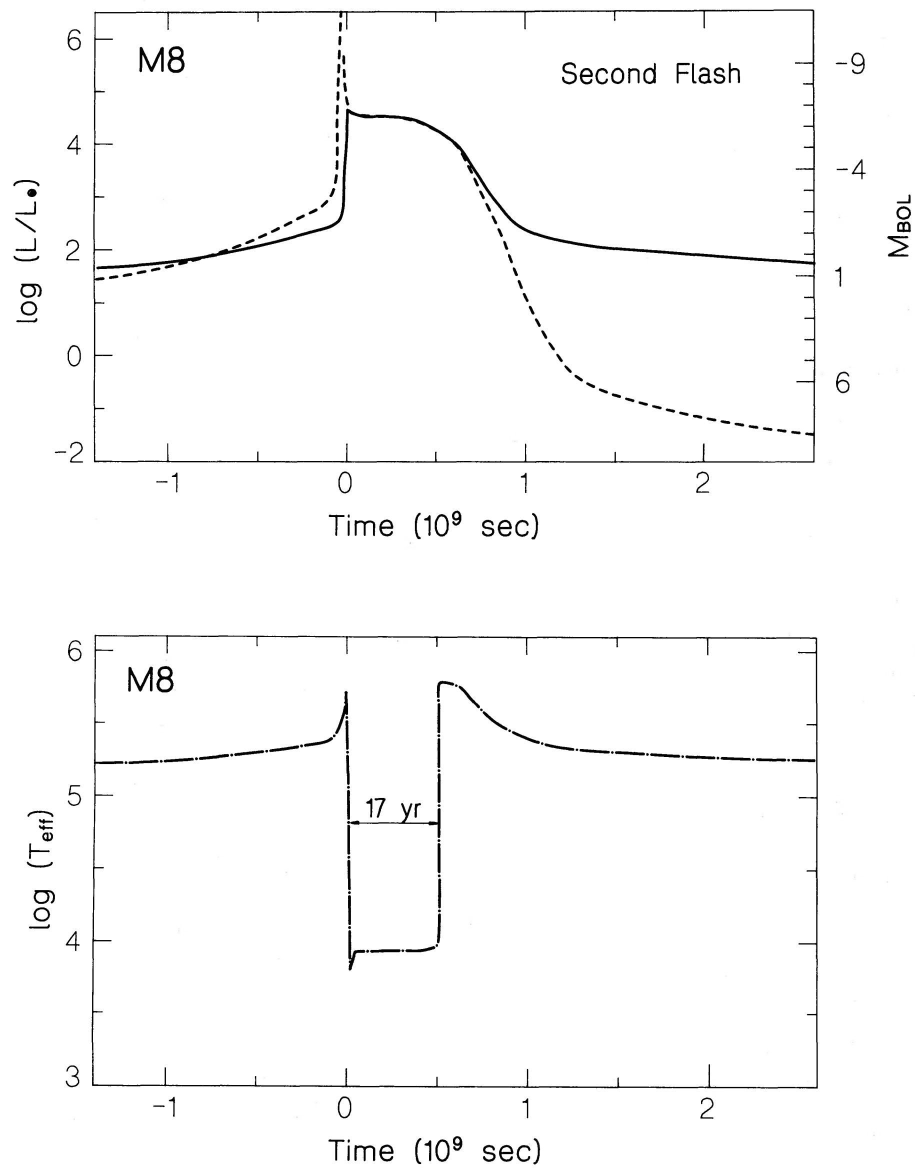

FIG. 2

FIG. 1.—Nuclear luminosity L_{nuc} (*top*) and bolometric luminosity L_{bol} (*bottom*) as a function of time for model M8 ($\dot{M} = 10^{-8}\ M_{\odot}\ yr^{-1}$). The time elapsed between outbursts and the maximal values of L_{nuc} attained at each flash are indicated by arrows.

FIG. 2.—*Top*: nuclear luminosity L_{nuc} (*dashed line*) and bolometric luminosity L_{bol} or absolute magnitude M_{bol} (*solid line*), and *bottom*: effective temperature (*dash-dotted line*) as a function of time, during the second flash of model M8 (as in Fig. 1). The time is (arbitrarily) set zero at the peak of the flash.

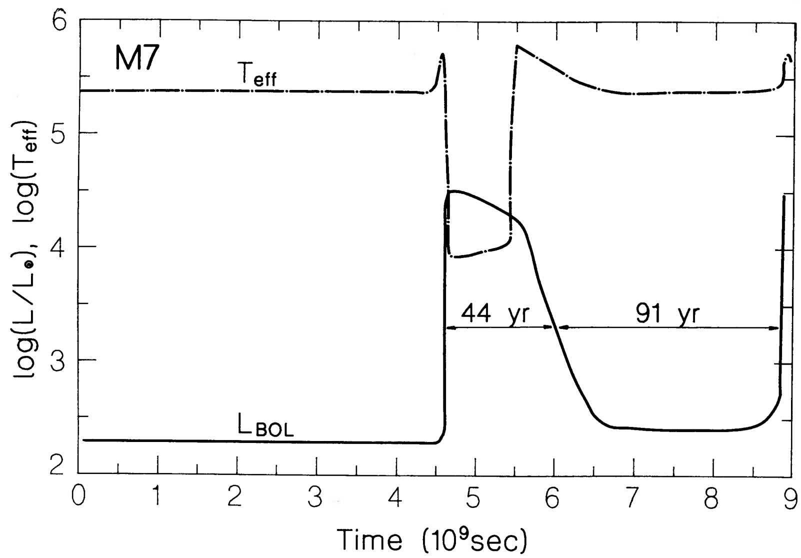

FIG. 3.—Bolometric luminosity L_{bol} (*solid line*) and effective temperature T_{eff} (*dash-dotted line*) as a function of time for model M7 ($\dot{M} = 10^{-7}\ M_\odot\ yr^{-1}$) during one full cycle. The durations of the flash and of the interflash phase are indicated.

$L_\odot$, whereas L_{bol} returns to its plateau value $L_{off} \gg L_{nuc}$, sustained by the accretion luminosity.

The characteristics of this model are very similar to those of the slowest novae (classified also as symbiotic novae), RR Tel and RT Ser (see next section). Its long-term evolution should result in a build-up of a helium-rich envelope, at a rate $\leq 5 \times 10^{-9}\ M_\odot\ yr^{-1}$, or possibly less (see § III).

c) Model M7

We followed the evolution of model M7 through one complete cycle (two outbursts), since we expect—as in the previous case—subsequent cycles to be similar. Characteristics may change slowly over a large number of cycles (e.g., Iben 1982), but hydrodynamical calculations that would reveal such changes should be extremely expensive and not sufficiently rewarding.

The evolution of the bolometric luminosity and the effective temperature is shown in Figure 3. The high value of the bolometric luminosity (L_{on}) is the same as for the previous model, the low value (L_{off}) is one order of magnitude higher, as expected ($\dot{M}$ is one order of magnitude higher). Therefore, the outburst's amplitude is reduced, amounting now to $\sim 5^m.5$. The effective temperature in quiescence is also higher. 2.3×10^5 K, instead of the former 1.4×10^5 K. A striking difference between this model and M8 is the high ratio $\tau_{on}/\tau_{off} \sim 0.5$, as compared with the previous one, of order 0.01. But the most important difference between this model and M8 is that *no mass is ejected*, although the star expands to $\sim 82\ R_\odot$. Velocities do not exceed a few km s^{-1} and *the envelope contracts back to its preoutburst radius* when almost all the accreted hydrogen has been burnt into helium. Thus a helium envelope accumulates on top of the C—O core at a rate of $10^{-7}\ M_\odot\ yr^{-1}$, 50 times faster than in the previous case.

d) Model M6

The accretion rate adopted in this case is higher than $\dot{M}_{RG}$, and hence this model was expected to reach a steady state configuration. The purpose of the calculation was, in fact, to confirm this expected result by hydrodynamical computations, which do not suppress instabilities. A red giant type, seemingly stationary configuration was indeed obtained after an initial accretion phase of ~ 7 yr, followed by a mild flash. During the flash the star expanded, the luminosity increased from $\sim 2 \times 10^3$ to $\sim 3 \times 10^4\ L_\odot$ and equilibrium was achieved with L_{bol} and L_{nuc} in balance, as illustrated in Figure 4. After evolving the star further for a period of time equal to the initial accretion period—during which thermal equilibrium was maintained unchanged—we terminated the calculations. We should mention that the evolution of a model star having an extended envelope of very low mass requires prohibitively small time steps.

We note that at the end of our calculations the helium layer above the C—O core is growing at a rate equal to about half the accretion rate. Hence the hydrogen-rich outer envelope is also growing in mass at roughly the same rate. Eventually, the star should run into the double-shell instability and undergo helium shell flashes. This should be accompanied by mass ejection. Hence in this case it is not clear if and at what rate is the accreting star's mass growing.

e) Comparison with Previous Calculations

It is generally accepted that accretion of hydrogen-rich matter onto a WD at a rate $\dot{M} < \dot{M}_{RG}$ results in hydrogen flashes of duration τ_{on} (of order years to decades), separated by quiet accretion periods of length τ_{off} (of order hundreds to thousands of years). According to our numerical results $10^{-7} < \dot{M}_{RG} < 10^{-6}$. This range is close to the order of magnitude estimate given in § I and is consistent with the results of Iben (1982), who found that a red giant is obtained for $\dot{M} > \dot{M}_{steady} \sim 1.3 \times 10^{-7}(M_{WD}/M_\odot)^{3.57}\ M_\odot\ yr^{-1}$, and with those of Nomoto, Nariai, and Sugimoto (1979), who obtained hydrogen flashes for $\dot{M} < 0.4\dot{M}_{RG} \sim 3.3 \times 10^{-7}(M_{WD}/M_\odot - 0.52)\ M_\odot\ yr^{-1}$. The values of τ_{on} and τ_{off} obtained here from hydrodynamical calculations are quite similar to those of quasi-static calculations (Iben 1982; Sion and Starrfield 1986). There is, however, a (small) qualitative difference. Since a hydrogen flash is triggered when the envelope mass reaches a critical value which depends mainly on M_{WD}, τ_{off} increases roughly as

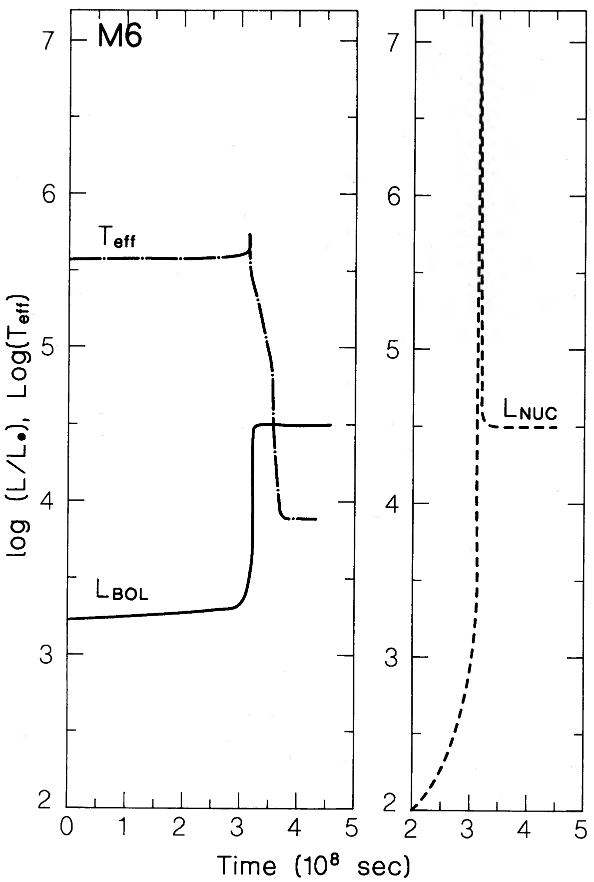

FIG. 4.—*Left*: bolometric luminosity L_{bol} (*solid line*) and effective temperature T_{eff} (*dash-dotted line*), and *right*: nuclear luminosity L_{nuc} (*dashed line*) as a function of time for model M6 ($\dot{M} = 10^{-6}\ M_\odot\ yr^{-1}$) until thermal equilibrium ($L_{bol} = L_{nuc}$) is reached and maintained for a relatively long period of time.

$\dot{M}^{-1}$. If mass ejection is disregarded, τ_{on} is roughly the same for a given WD, regardless of the accretion rate (or, as found by Iben, loc. cit., decreases slightly with increasing $\dot{M}$). According to more realistic models, which allow for mass ejection, the lower the accretion rate the stronger is the outburst and, as a result, more mass is ejected more rapidly. As $\dot{M}$ increases, the TNR becomes less powerful and mass is lost slowly, as an optically thick wind; moreover, the ejected mass may amount to only a small (even negligible) fraction of the accreted envelope. Consequently, τ_{on} *increases with increasing* $\dot{M}$. Hence the ratio $\tau_{on}/\tau_{off} \propto \dot{M}^n$ with $n > 1$.

f) *Comparison with Observations*

The light curves corresponding to the outbursts of models M8 and M7 resemble quite remarkably those of RR Tel (one of the slowest classical novae, recognized now as a symbiotic star) and those of RT Ser, a typical symbiotic nova. We note, in particular, the following points.

1. The rise time, which is very short for classical nova models (several hours), is here of the order of 1 yr. The rise time of RR Tel was somewhat less than 1 yr; that of RT Ser was ~14 yr.

2. The amplitudes obtained were $\sim 7^m.7$ for M8 and $\sim 5^m.5$ for M7. They are to be considered lower limits for the visual magnitude amplitudes. Most symbiotic novae have amplitudes in the range 4–8^m; for RT Ser $\Delta m = 7$ and for RR Tel $\Delta m_{pg} = 7$, in good agreement with our results.

3. The effective temperature at maximum was ~8000 K for both models, only slightly higher than that corresponding to RR Tel, whose spectrum at maximum light resembled that of an F supergiant. Optical spectra of RT Ser at maximum visual light also resembled the A8-F0 supergiant spectrum (typical of symbiotic and classical novae).

4. Model M8 maintained constant luminosity for ~15 yr, after which L_{bol} declined slowly. We note that this behavior is very different from that encountered in classical nova models (lower $\dot{M}$ and colder WDs), in which the initial decline is very rapid and begins as soon as the mass-loss phase is over (e.g., Prialnik 1986). It agrees very well with the behavior of symbiotic novae: in the case of RR Tel, the system remained nearly constant for ~5 yr and then began a slow decline.

5. Finally, model M8 returned to within 1^m of its minimum brightness on a time scale of 100 yr. RR Tel has not yet returned to its preoutburst brightness. Therefore the total decline time will be greater than 44 yr.

III. DISCUSSION

The main goals of our study have been (1) to identify what causes the differences between symbiotic novae and classical novae, (2) to characterize a possible distinction among symbiotic systems, based on the TNR model for the outbursts, and (3) to examine the question of mass loss and the viability of symbiotic systems as progenitors of Type I supernovae. In what follows we shall discuss successively these three general topics.

It is by now well established that accretion at low rates ($\dot{M} \leq 10^{-9}\ M_\odot\ yr^{-1}$) onto relatively cold WDs results in a TNR under degenerate conditions, which produces a classical nova outburst (e.g., Prialnik *et al.* 1982; MacDonald 1983). Therefore, in our attempt to simulate outbursts of the symbiotic nova kind, we concentrated on relatively high accretion rates ($\dot{M} \geq 10^{-8}\ M_\odot\ yr^{-1}$) onto a relatively hot WD ($L_{WD} \simeq 10\ L_\odot$). Our results identify three types of behavior.

Type a.—For $\dot{M} \sim 10^{-8}\ M_\odot\ yr^{-1}$ the recurrence time scale satisfies $\tau_{off} \gg \tau_{on}$ and the outburst is very similar to that of the slowest novae. One important difference between these outbursts (occurring at high $\dot{M}$ and L_{WD}) and those of faster novae (lower $\dot{M}$ and L_{WD}) is that in the former, only about half of the accreted material is ejected as a direct consequence of the TNR (although this may be a lower limit—see below), while in the latter, the entire accreted envelope *and* some of the WD mass are ejected.

Type b.—For $\dot{M} \sim 10^{-7}\ M_\odot\ yr^{-1}$ we obtain $\tau_{off} \sim \tau_{on}$. The WD expands to moderate giant dimensions, but no mass is ejected in this case (again, as a direct consequence of the TNR).

Type c.—For $\dot{M} \sim 10^{-6}\ M_\odot\ yr^{-1}$ a stable red giant is obtained, i.e., $\tau_{off} = 0$. Therefore, such accretion rates cannot produce symbiotic systems.

As already mentioned, these results are consistent with previous calculations (e.g., Nomoto *et al.* 1979; Iben 1982).

The companion of the hot compact star in a symbiotic system is a red giant. It is therefore of interest to estimate the rates of accretion onto a WD that would be obtained from the wind of a giant companion. These accretion rates are given by (e.g., Livio *et al.* 1986):

$$\dot{M}_{acc} \simeq 0.02\left(\frac{M_{WD}}{M_\odot}\right)^2\left(\frac{V_{rel}}{6\times 10^6\ cm\ s^{-1}}\right)^{-3} \times\left(\frac{V_W}{5\times 10^6\ cm\ s^{-1}}\right)^{-1}\left(\frac{a}{400\ R_\odot}\right)^{-2}\dot{M}_W\ , \quad (5)$$

where $\dot{M}_W$ is the rate of mass loss from the giant, a is the separation, V_W is the wind velocity and V_{rel} is the relative velocity between the WD and the wind. Typical mass-loss rates in winds can be as high as $\sim 10^{-6}\ M_\odot\ yr^{-1}$ (e.g., Cassinelli 1979), especially in D-type symbiotics containing Mira variables (Gehrz and Woolf 1971). Thus accretion rates of $\sim 10^{-8}\ M_\odot\ yr^{-1}$ *at most* may be expected in the case of wind accretors. In fact, lower accretion rates will be obtained in many such sustems, for example Mira B (Livio and Warner 1984), AG Dra (Garcia 1986), Z And (Fernandez-Castro *et al.* 1988). Consequently, *outbursts resembling those of slow novae—case a above—are more likely to occur in systems involving wind accretors.* Higher accretion rates (as in cases *b* and *c* above) may be obtained (in principle, at least) when the giant companion fills its Roche lobe (e.g., Webbink 1976; Livio, Truran, and Webbink 1986). We may therefore conclude that symbiotic novae undergoing degenerate flashes *should be found more frequently in detached systems.* In general, D-type systems with long orbital periods can be expected to become symbiotic novae at some stage of their evolution.

A classification of symbiotic novae according to whether or not the giant fills its Roche lobe was attempted by Garcia (1986). However, it should not be regarded as certain, because in most cases the orbital period is unknown (e.g., Viotti 1988). It is interesting to note that, in agreement with our conclusions, all symbiotic novae that appear in his table (RR Tel, V1016 Cyg, HM Sge, and AG Peg) *are classified as detached systems.* Of the systems classified as semidetached, some are believed to contain accreting main-sequence stars, such as CH Cyg and CI Cyg (Kenyon and Webbink 1984) and, possibly, T CrB and RS Oph (Livio, Truran, and Webbink 1986, Webbink *et al.* 1987). One system, which is very probably semidetached and which does experience nova-like outbursts is V1017 Sgr. This system is normally classified as a recurrent nova, but it has been recently shown by Webbink *et al.* (1987) that it is almost certainly a classical nova, which also experienced two dwarf nova eruptions. It has, very probably, a much shorter orbital period—2 to 20 days—than regular symbiotics. Another system classified as semidetached by Garcia is RW Hya. However, more recently, Kenyon and Fernandez-Castro (1987) have shown that the observations are consistent with a wind accretor. The system apparently consists of a hot WD ($L_{WD} \sim 200\ L_\odot$), accreting mass at a rate of $\sim 10^{-8}\ M_\odot\ yr^{-1}$ from the wind of an M giant (which loses mass at a rate of $\sim 8 \times 10^{-8}\ M_\odot\ yr^{-1}$). Therefore this system may be expected to undergo a symbiotic nova-type outburst in the future (for such a hot WD, $\tau_{off} \sim$ a few hundred years).

Finally, we would like to discuss the symbiotic novae in relation to Type I supernovae. Iben and Tutukov (1984) have estimated—using a Salpeter-type birth rate function—that Type I supernovae can result from wind-accreting WDs with a frequency of $\nu_{SNI} \sim 4 \times 10^{-3}\ yr^{-1}$. This is in agreement with Kenyon's (1986) estimate $\nu_{SNI} \sim 5 \times 10^{-3}\ yr^{-1}$. However, both these estimates assume that none of the accreted matter is ejected by the WD. According to our results, this assumption is incorrect, at least for relatively low accretion rates ($\sim 10^{-8}\ M_\odot\ yr^{-1}$). Moreover, in a recent work, Kato and Hachisu (1988) have studied mass loss via an optically thick wind, following hydrogen shell flashes and found that even during the weakest flashes $\sim 70\%$ of the envelope mass is blown off. It seems, therefore, that the contribution of symbiotic stars to ν_{SNI} should be reduced significantly. First, the D-type systems, which undergo shell flashes, should be discarded as Type I SN progenitors. They constitute $\sim 20\%$ of all known symbiotics (e.g., Kenyon 1986). Second, as the results of the present work indicate, in order to avoid shell flashes, but secure symbiotic system characteristics, the accretion rate should be confined to a very narrow range. Hence only for $10^{-7}\ M_\odot\ yr^{-1} \leq \dot{M} \leq 3 \times 10^{-7}\ M_\odot\ yr^{-1}$ could symbiotic systems serve as progenitors of Type I SNs. This conclusion confirms previous results, obtained in the quasi-static or steady burning approximations: Paczyński and Żytkow (1978), Sion *et al.* (1979), Iben (1982), Sion and Starrfield (1986). Furthermore, since the symbiotic lifetime is of order 10^6 yr, only relatively massive WDs would be able to produce carbon deflagration SNs. All these constraints regarding the contribution of symbiotic systems to ν_{SNI} make the necessity of finding other scenarios leading to Type I SNs, such as merging WDs, even more pressing. Nevertheless, we should mention that at least two symbiotic (or symbiotic like) systems very probably contain neutron stars V2116 Oph (= GX1+4; Doty, Hoffman, and Lewin 1981) and HD 157491 (= 2A174+241; Garcia *et al.* 1983). Supernova explosions thus surely occurred in these systems. While in principle these could have been Type II SNs, the presence of pulsations in GX1+4 (e.g., Elsner *et al.* 1985) suggests that the magnetic field of the neutron star has not decayed. This tends to favor a (relatively recent) Type I SN as the mechanism producing the neutron star. Thus the occurrence of SNs in symbiotic systems cannot be entirely ruled out.

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REFERENCES

Allen, D. A. 1980, *M.N.R.A.S.*, **192**, 521.
Cassinelli, J. P. 1979, *Ann. Rev. Astr. Ap.*, **17**, 275.
Doty, J. A., Hoffman, J. A., and Lewin, W. H. G. 1981, *Ap. J.*, **243**, 257.
Elsner, R. F., Weisskopf, M. C., Apparao, K. M. V., Darbro, W., Ramsey, B. D., Williams, A. C., Grindlay, J. E., and Sutherland, P. G. 1985, *Ap. J.*, **297**, 188.
Fernandez-Castro, T., Cassatella, A., Gimenez, A., and Viotti, R. 1988, *Ap. J.*, **324**, 1016.
Fujimoto, M. 1982, *Ap. J.*, **257**, 752.
Gallagher, J. S., and Starrfield, S. 1978, *Ann. Rev. Astr. Ap.*, **16**, 171.
Garcia, M. R. 1986, *A.J.*, **91**, 1400.
Garcia, M. R., Baliunas, S. L., Doxey, R., Elvis, M., Fabbiano, G., Koenigsberger, G., Patterson, J., Schwartz, D., Swank, J., and Watson, M. G. 1983, *Ap. J.*, **267**, 291.
Gehrz, R. D., and Woolf, N. J. 1971, *Ap. J.*, **165**, 285.
Iben, I. Jr. 1982, *Ap. J.*, **259**, 244.
Iben, I., Jr., and Tutukov, A. V. 1984, *Ap. J. Suppl.*, **54**, 335.
Kahn, F. D. 1983, in *IAU Symposium 103, Planetary Nebulae*, ed. D. R. Flower (Dordrecht: Reidel), p. 305.
Kato, M., and Hachisu, I. 1988, *Ap. J.*, **329**, 808.
Kenyon, S. J. 1986, *The Symbiotic Stars* (Cambridge: Cambridge University Press), p. 126.
Kenyon, S. J., and Fernandez-Castro, T. 1987, *Ap. J.*, **316**, 427.
Kenyon, S. J., and Webbink, R. F. 1984, *Ap. J.*, **279**, 252.
Kovetz, A., and Prialnik, D. 1985, *Ap. J.*, **291**, 812.
Kwok, S. 1982, *Ap. J.*, **258**, 280.
Liller, M. H., and Liller, W. 1979, *A.J.*, **84**, 1357.
Livio, M., and Warner, B. 1984, *Observatory*, **104**, 152.
Livio, M., Soker, N., deKool, M., and Savonje, G. J. 1986, *M.N.R.A.S.*, **222**, 235.
Livio, M., Truran, J. W., and Webbink, R. F. 1986, *Ap. J.*, **308**, 736.
MacDonald, J. 1983, *Ap. J.*, **267**, 732.
Nomoto, K., Nariai, K., and Sugimoto, D. 1979, *Pub. Astr. Soc. Japan*, **31**, 287.
Paczyński, B. 1970, *Acta Astr.*, **20**, 47.
Paczyński, B., and Rudak, B. 1980, *Astr. Ap.*, **82**, 349.
Paczyński, B., and Żytkow, A. 1978, *Ap. J.*, **222**, 604.
Payne-Gaposchkin, C. 1957, *The Galactic Novae* (Amsterdam: North Holland).
Prialnik, D. 1986, *Ap. J.*, **310**, 222.

Prialnik, D., and Livio, M. 1985, *M.N.R.A.S.*, **216**, 37.
Prialnik, D., Livio, M., Shaviv, G., and Kovetz, A. 1982, *Ap. J.*, **257**, 312.
Prialnik, D., Kovetz, A., and Shara, M. M. 1989, *Ap. J.*, **339**, 1013.
Sion, E. M., Acierno, M. J., and Tomcszyk, S. 1979, *Ap. J.*, **230**, 832.
Sion, E. M., and Starrfield, S. 1986, *Ap. J.*, **303**, 130.
Uus, U. 1970, *Scientific Inf. Acad. Sci. USSR*, **17**, 32.
Viotti, R. 1988, in *Symbiotic Phenomenon*, ed. J. Mikolajevska, M. Friedjung, S. J. Kenyon, and R. Viotti (Dordrecht: Kluwer), p. 269.
Webbink, R. F. 1976, *Nature*, **262**, 271.
Webbink, R. F., Livio, M., Truran, J. W., and Orio, M. 1987, *Ap. J.*, **314**, 653.

Mario Livio: Department of Physics, Technion, Israel Institute of Technology, Haifa 32000, Israel

Dina Prialnik: Department of Geophysics and Planetary Sciences, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Ramat Aviv 69978, Israel

Oded Regev: Department of Astronomy, Columbia University, New York, NY 10027