NOVAE BETWEEN OUTBURSTS

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ABSTRACT

The paper is divided into two parts. In the first part, the common envelope phase that follows a nova outburst is discussed. It is shown that this phase leads to mass loss, preferentially in the orbital plane. It is argued, that the common envelope can explain the rapid appearance of a nebular spectrum in novae and the shaping of the nebula.

In the second part, the present status of the cyclic-evolution ("hibernation") scenario is reviewed. It is argued that novae and dwarf novae are the same systems, transforming from one class to the other. Observational and theoretical evidence is presented, that shows that both the accretion rates and the white dwarf masses in observed nova systems should be higher than the average. Novae should therefore not be regarded as "typical" cataclysmic variables. Some critical observations that can provide observational tests are suggested.

I.INTRODUCTION

This talk will be divided into two parts. In the first part (Section II), I shall discuss the common envelope phase that follows a nova outburst. In the second part (Section III), I shall discuss the present status of the cyclic evolution ("Hibernation") scenario of classical novae. Conclusions follow in Section IV and some critical observations are outlined in Section V.

II. THE COMMON ENVELOPE PHASE

The following three facts are true essentially for all novae:

(1) The orbital periods of classical novae are typically of the order of hours, these imply orbital separations of

$$a \simeq 1.3 R_\odot \left(\frac{M_{WD} + M_2}{M_\odot}\right)^{1/3} \left(\frac{P_{\rm orb}}{4hr}\right)^{2/3} \qquad (1)$$

(2) Novae at visual maximum are characterized by near (or super) Eddington luminosities. Typically they obey the Paczynski (1971) core-mass luminosity relation. These two luminosities

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are given by

$$L_{EDD} \simeq 3.8 \times 10^4 L_\odot (M_{WD}/M_\odot) \quad (2)$$

$$L_{PAC} \simeq 5.925 \times 10^4 L_\odot (M_{WD}/M_\odot - 0.522)\ , \quad (3)$$

and they imply luminosities of order $(2-5) \times 10^4 L_\odot$ for white dwarf masses in the range $1.0 - 1.3 M_\odot$.

(3) At the above luminosities and with an effective temperature $T_e \lesssim 10^4 K$, we obtain photospheric radii of order

$$R_{\rm phot} \gtrsim 4 \times 10^{12} {\rm cm} \sim 60 R_\odot\ . \quad (4)$$

We thus find (from (1)–(3)), that the secondary star is necessarily engulfed in the expanding nova envelope.

Now, the visual light curves of classical novae (for which orbital periods are known) indicate that some novae remain in a common envelope configuration for a timescale of months (examples are: DQ Her, T Aur, RR Pic, HR Del). In addition, the appearance of a nebular spectrum a year or less following the outburst (e.g. Williams, this volume) argues for a rapid ejection of the envelope (which exposes a hot, small, ionizing source). As we shall see, this fact also demonstrates the potential role of a common envelope phase. The importance of the common envelope was first noted by MacDonald (1980, 1986, see also MacDonald et al. 1985).

In view of the above, a preliminary, two-dimensional hydrodynamical caluclation of the common envelope phase has been carried out (Livio, Shankar, Burkert and Truran 1989, and see also Shankar et al., this volume). In the calculation, a binary consisting of a $1M_\odot$ white dwarf and a $0.5M_\odot$ secondary, at a separation of 7×10^{10}cm, were allowed to revolve inside a $10^{-5}M_\odot$ common envelope. The density and temperature profiles in the envelope were taken from a slowly expanding phase in the evolution of a spherically symmetric nova model. In this preliminary calculation, the envelope was assumed to be at rest. A typical velocity field that was obtained after 3.12×10^5sec is shown in Fig 1. The two main things to note are: (i) Ejection velocities of the order of 1000 km/sec are obtained. (ii) Most ejection takes place preferentially in the orbital plane, within an opening angle of $\sim 15^\circ$. Mass loss rates of the order of $2 \times 10^{-6} M_\odot/yr$ were obtained for this particular case in the final stages. Higher mass loss rates (up to $3 \times 10^{-5} M_\odot/yr$) were obtained in the initial phase. The common envelope phase, which involves the deposition of frictional energy by the binary may thus have important implications for the following processes and topics:

(1) Mass loss (speeding up the appearance of a nebular spectrum, as mentioned above).
(2) Shaping of the nebula.
(3) The evolution of orbital parameters.
(4) Symbiotic novae.

Here, I shall discuss briefly only points (2) and (4) and I refer the reader to a detailed discussion in Livio et al. (1989). The potential role of the common envelope (CE) in shaping, can be best understood in terms of the "interacting winds" model, proposed originally for planetary nebulae (Kwok 1982, Kahn 1983). In the planetary nebula (PN) case, the AGB star's envelope is ejected at relatively low velocities. Once the hot central star is exposed, it emits a hot, fast wind which catches up with the slowly moving material, shocks it and generates a snowplow effect. Soker and Livio (1989) have shown, following a suggestion by Balick (1987), that this can lead in the case of PNe with binary nuclei, to shapes that are consistent with the observed ones (Bond and Livio 1989). In the nova case, the hot fast wind runs into material ejected in the CE (and previous) phase. Since the latter material is more concentrated towards the orbital plane, the fast wind penetrates more easily in the polar direction, generating polar "blobs", while it

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compresses a ring in the equatorial direction. Thus, a prolate morphology is obtained. This is very consistent with the observed morphology in the case of DQ Her, GK Per, T Aur (e.g. Wade, this volume) and RR Pic (Duerbeck 1987).

The fourth point above (symbiotic novae), is meant in the negative sense. Namely, because the orbital periods in the case of symbiotic novae are of the order of years (e.g. Garcia 1986), we do not expect a common envelope phase to occur in this case. This may be part of the reason why the time development of the outbursts of these objects is extremely slow, extending over decades, since mass loss via the CE cannot occur. The slow development of the thermonuclear runaway itself can be explained in terms of a high accretion rate onto relatively hot white dwarfs (Livio, Prialnik and Regev 1989, Kenyon and Truran 1983).

The role of the CE in coupling between the white dwarf and the secondary (spinning up the white dwarf) in the case of V 1500 Cyg has been described by Stockman (this volume, see also Stockman, Schmidt and Lamb 1988). We thus find that the CE probably plays an important role in the post thermonuclear runaway evolution of classical novae.

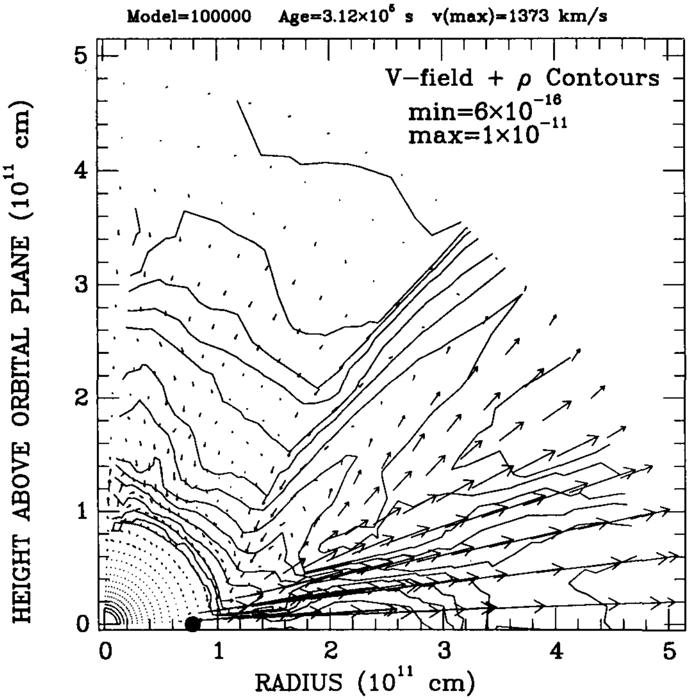

Fig. 1 The velocity field and density contours in the common envelope. The density contours are logarithmically spaced, with a spacing of 0.3. The black circle denotes the secondary star.

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III. THE CYCLIC EVOLUTION ("HIBERNATION") SCENARIO

It has been known for some time that the deduced mass accretion rates in classical nova systems (Patterson 1984, Warner 1987), $\dot{M} \gtrsim 10^{-8} M_{\odot}/yr$, present some problems. I shall now discuss some of these problems briefly (see also Livio 1987, 1988).

(a) A number of classical novae (CNe) exhibit dwarf nova eruptions at some stage. These are: V 446 Her, Q Cyg, V 3890 Sgr, Nova Vul (1979), WY Sge, GK Per, BV Cen and V 1017 Sgr (see Tyable 1). The problem posed by this observation, lies in the fact that the deduced accretion rates for CNe are above the critical rate at which a disk instability can occur (e.g. Cannizzo and Wheeler 1984, Meyer and Meyer- Hofmeister 1983). The deduced accretion rates put CNe on the hot, stable branch in the temperature-surface density curve (except GK Per, because of its long orbital period).

(b) The values of $\dot{M}$ deduced from observations are too high to produce strong (mass ejecting) outbursts. While the exact value above which only weak flashes are obtained is not known, because of differences in the results of different workers (e.g. MacDonald 1983, Fujimoto 1982, Prialnik et al. 1982, Kutter and Sparks 1980), all groups agree, that for accretion rates in excess of $10^{-8} M_{\odot}/yr$, only weak outbursts are obtained (as long as the white dwarf is not close to the Chandrasekhar mass). This is a consequence of strong compressional heating, which leads to ignition under only mildly degenerate conditions.

(c) If the scatter in the accretion rates for a given orbital period (Paterson 1984, Warner 1987) is real and constant (in time), then we can expect no sharp period gap. This point was noted by Hameury, King and Lasota (1989, see also Verbunt 1984). This is a consequence of the fact that for a high $\dot{M}$ (short accretion timescale), the mass losing star is expected to be much out of thermal equilibrium (since $\tau_{\dot{M}} < \tau_{KH}$) and this will tend to produce a wide gap (upon cessation of magnetic braking). On the other hand, for low $\dot{M}$ ($\tau_{\dot{M}} > \tau_{KH}$), the star can adjust to thermal equillibrium, a situation which will result in no gap at all (Rappaport, Verbunt and Joss 1983). Thus, the mere existence of a well defined gap tells us that the scatter in $\dot{M}$ (if real) represents fluctuations around some mean value, rather than actual constant values.

(d) Observations of the oldest recovered novae, WY Sge (Nova 1783, Shara and Moffat 1983) and CK Vul (Nova 1670, Shara and Moffat 1982), show them to be in a state of low accretion rates (some doubts whether CK Vul was actually a nova exist, Duerbeck, this volume).

(e) There may exist a discrepancy between the space density of cataclysmic variables ($D_{CV} \sim 10^{-6} pc^{-3}$, Patterson 1984) found in galactic surveys and that deduced from nova theory ($D_{CV} \sim 10^{-4} pc^{-3}$, Bath and Shaviv 1976). However, recent determinations seem to indicate $D_{CV} \sim 10^{-4} pc^{-3}$ (Shara and Moffat, this volume).

All the points (a) - (e) above suggest that the accretion rate in nova systems changes as a function of time (see also Livio 1988).

In this respect we note the following:

(i) Novae after outburst remain bright due to the presence of the hot white dwarf. Mass loss is enhanced due to irradiation of the secondary (e.g. Kovetz et al. 1988, Sarna 1989) for a period of 50 - 300 years (Livio and Shara 1987). This is evidenced, first of all, from the fact that a number of systems (e.g. V 1229 Aql, IV Cep, HR Del, FH Ser, V 1500 Cyg, CP Pup) did not return for a long time to their preoutburst brightness (Robinson 1975, Warner 1985). Secondly, Vogt (1989) has demonstrated recently that post outburst novae decline in brightness at an average rate of $2^m.1 \pm 0.6$ per century. This decline reflects the decrease in $\dot{M}$ towards the mean value.

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(ii) Changes in $\dot{M}$ (of unknown origin) are observed in many systems. For example, AM Her, VV Pup and AN UMa are found for months or more to be 3 - 5 magnitudes less bright than their maximum (Liebert ans Stockman 1985). TT Ari, MV Lyr and VZ Scl have known transitory low states (Warner 1987). An attractive possibility for the origin of these fluctuations is long term magnetic cycles in the secondary star (see also Bianchini, this volume). The following important point should be noted: in the presence of large fluctuations in $\dot{M}$ (for whatever reason) the thermonuclear runaway is likely to occur during a high mass transfer (see also Paczynski 1988) phase (besides the purely probabilistic aspect of this statement, increased compressional heating will also speed-up the runaway). This means that typically, novae have a high $\dot{M}$ also before the outburst (this of course is not expected to be true for a given individual system). This is supported by Vogt's (1989) tentative finding that on the average, novae before the outburst increase in brightness at a rate of $0^m.05$ per year.

The emerging cyclic evolution ("hibernation") picture is therefore the following: Novae and dwarf novae are the same systems (this is true for systems which have disks and therefore AM Her systems are typically excluded). Following the outburst, $\dot{M}$ is higher than the secular mean, due to irradiation of the secondary. Before the outburst $\dot{M}$ is also probably higher, due to fluctuations in $\dot{M}$ (for a short time before the outburst the system may be brighter also due to reprocessed radiation from the increasing bolometric luminosity of the white dwarf). During the phases in which $\dot{M}$ is close to the secular mean (or possibly much lower, due to fluctuations), the system appears as a dwarf nova. Thus, $\dot{M}$ is generally higher in the "nova phase" than in the "dwarf nova phase".

I would like to explain now, the difference between the picture presented above and the original "hibernation" scenario (Shara, Livio, Moffat and Orio 1986). In the original scenario, it has been assumed that a specific mechanism is required, in order to decrease $\dot{M}$ from its post-outburst value. It was suggested that an increase in the binary separation, due to mass ejection in the nova eruption, results in the secondary underfilling its Roche lobe. However, while a small increase in the separation does probably occur in many systems (in particular for longer orbital periods), as observations of BT Mon indeed show (Schaefer and Patterson 1983), this increase can reduce $\dot{M}$ by a factor of a few at most (unless it operates in a way we do not understand, Livio and Shara 1987, Ritter 1988). This is essentially a consequence of the fact that the separation increase is typically not larger than a scaleheight in the secondary's atmosphere.

In the present scenario, no specific mechanism is required to reduce $\dot{M}$ from the value it has shortly after the nova eruption. As I explained above, the post-outburst value is considerably higher than the secular mean due to irradiation. It decreases to the secular mean once the white dwarf cools (and then fluctuates about the mean).

The principal consequence of the cyclic evolution ("hibernation") picture is the fact that novae and dwarf novae can transform from one class into the other.

Now, while it seems quite clear that once the white dwarf in a dwarf nova system accretes sufficient mass it will undergo a nova outburst (if it is sufficiently massive), one may ask if it is not surprising that we have not seen some systems do this already. I want first to point out that in fact three systems, V 446 Her (nova of 1960), V 3890 Sgr (nova of 1962) and Nova Vul (1979) have exhibited dwarf nova type eruptions prior to their nova outburst. In addition, using available data on masses and accretion rates and theoretical recurrence timescales (e.g. Truran and Livio 1986), it can be shown that the probability for a nova not to have occurred in the last 50 years among known dwarf nova systems is about 0.8 (Livio 1988). Incidentally, the dwarf novae most likely to undergo a nova outburst in the relatively near future are RU Peg, RX And and SS Cyg. In the case of SS Cyg, there may even exist an indication that the mass transfer rate is increasing, from the fact that the average recurrence interval in the first half of the period

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1896 - 1985 was $T_{rec} = 51.0$ days, while in the second half it was $T_{rec} = 47.6$ days (Mattei et al. 1986).

Having pointed out that the accretion rates in cataclysmic variable systems in their "novae phase" are higher than the average, I would like also to point out that the white dwarf masses in observed nova systems are also expected to be higher tha the average. This is suggested mainly by the following facts (and see also Truran and Livio 1989 for discussion):

(i) The dynamical behaviour of novae (39 out of 65 are "fast", high expansion velocities) suggests low envelope masses and therefore massive white dwarfs.

(ii) Abundance determinations in novae show an average enriched fraction of 0.38 (see Truran, this volume) with about a quarter of all observed novae containing a (massive) O-Ne-Mg white dwarf.

(iii) Frequency of occurrence arguments predict an average white dwarf mass in observed nova systems of the order of 1.0 - 1.2 $M_\odot$ (e.g. Politano, Livio, Truran and Webbink, this volume).

TABLE 1

Classical nova systems that exhibited dwarf nova eruptions.

System	DN Eruptions	References
V 446 Her (1960)	Had DN-type eruptions prior to the nova outburst. No DN eruptions after the outburst.	1 - 3
Q Cyg (1876)	Eruptions with 0.6 - 1 mag amplitude and 7 - 10 days duration were detected about 100 years after the nova outburst.	4
V 3890 Sgr (1962)	DN-type eruptions were detected 22 and 23 years prior to the nova outburst	5
Nova Vul (1979)	Some mini-eruptions found prior to the nova outburst, best observed in 1926	6
WY Sge (1783)	A DN eruption was detected on June 17, 1982	7
GK Per (1901)	DN eruptions were observed in the period 1948 - 1983	8
BV Cen	Normally classified as a dwarf nova, but recently re-classified as a post outburst classical nova	9
V 1017 Sgr	Normally classified as a recurrent nova but recently re-classified as a possible classical nova with two DN eruptions.	10

References: (1) Stienon 1963. (2) Stienon 1971. (3) Robinson 1975. (4) Shugarov 1982. (5) Dinerstein 1973. (6) Liller and Liller 1979. (7) Shara et al. 1984. (8) Sabbadin and Bianchini 1983. (9) Menzies et al. 1986. (10) Webbink et al. 1987.

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IV. CONCLUSIONS

From the discussion in Sections II and III the following conclusions can be drawn:

(1) The common envelope phase that follows a nova outburst plays an important role in the ejection of mass, in the shaping of the nebula and possibly in the binary system's evolution. The common envelope is particularly important in very slow, slow and perhaps to some degree moderately fast novae.

(2) Classical novae (not strongly magnetized) and dwarf novae are probably the same systems, undergoing a cyclic evolution (modified "hibernation" scenario). In their "classical nova phase", the systems have on the average a higher accretion rate than the secular mean. This is certainly true after the outburst, and probably in many cases also before the outburst.

(3) The average white dwarf mass in classical nova systems that were observed to erupt, should be higher than both the average mass of single white dwarfs and the average white dwarf mass in cataclysmic variables. The average value should be in the range 1.0 - 1.2 $M_\odot$.

(4) As a consequence of points (2) and (3) above, observed classical novae are not typical cataclysmic variables (have a higher $\dot{M}$ and a higher M_{WD}) and thus, they should not be used to determine general average properties.

V. CRITICAL OBSERVATIONS

Some critical observations can be performed, in order to clarify some of the topics discussed in the present work and provide some observational tests. Among these are:

(1) More determinations of the white dwarf masses in novae systems are required (clearly not an easy task), in order to check the prediction of a high average mass. Particularly interesting will be the very fast novae CP Pup, V 1500 Cyg, V 603 Aql and GK Per (all of which, incidentally, are probably magnetic) and the moderately fast novae DI Lac, T Aur, PW Vul and RR Pic.

(2) Period determinations to six significant figures are required, in order to determine the importance of frictional angular momentum loss in the common envelope phase, in systems likely to erupt in the near future. The group of such systems obviously includes the recurrent novae T Pyx, U Sco and V 394 Cr A but also the dwarf novae RU Peg and RX And and a number of nova like systems (see Warner, this volume, for a list of candidates).

(3) It is important to continue to monitor systems which did not return to their pre-outburst brightness, for a luminosity decrease, which will confirm the effect of irradiation. In this group are V 1500 Cyg, CP Pup, FH Ser, HR Del, IV Cep and V 1229 Aql (see Section III).

(4) If the cyclic evolution picture is correct, then novae (non magnetic) should experience dwarf nova eruptions when the accretion rate drops below the critical value. This leads to the prediction that novae that were very faint prior to their outburst (and thus presumably had a low $\dot{M}$, this of course depending on their distance) should have either exhibited dwarf nova eruptions or they are magnetic. This prediction applies for example to: V 4077 Sgr, GQ Mus, V 693 Cr A and RW UMi. Thus, it is extremely important to determine whether any of these systems has undergone dwarf nova eruptions in the past, or whether they are indeed magnetic (see also Warner, this volume, about GQ Mus). Incidentally, V 1500 Cyg would have belonged to the same group (and probably CP Pup) and indeed it has been identified as an AM Her object.

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The discovery of more systems which have undergone dwarf nova eruptions some tens to a hundred years prior to their nova outburst (using archival material) would also lend support to the cyclic evolution picture.

(5) It would be extremely interesting to obtain images (e.g. CCD, speckle, radio) of the nebular shells of symbiotic novae (for example RR Tel, RT Ser, AG Peg, V 1016 Cyg, HM Sge) and see if they have a different morphology than the prolate one of CN shells. Since these systems do not experience a common envelope phase, they are not subject to the same type of shaping process (the interacting winds probably operate in this case too, however the configuration may be more spherically symmetrical).

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