III. Chemical and Dynamical Structures of Exploding Stars

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CLASSICAL NOVAE - BEFORE AND AFTER OUTBURST

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I Introduction

Classical nova (CN) and dwarf nova (DN) systems have the same binary components (a low-mass main sequence star and a white dwarf) and the same orbital periods. An important question that therefore arises is : are these systems really different ? (and if so, what is the fundamental difference ?) or, are these the same systems, metamorphosing from one class to the other ?

The first thing to note in this respect is that the white dwarfs in DN systems are believed to accrete continuously (both at quiescence and during eruptions). At the same time, both analytic (e.g. Fujimoto 1982) and numerical calculations show, that when sufficient mass accumulates on the white dwarf, a thermonuclear runaway (TNR) is obtained and a nova outburst ensues (see e.g. reviews by Gallagher and Starrfield 1978, Truran 1982). It is thus only natural, to ask the question, <u>is the fact that we have not seen a DN undergo a CN outburst (in about 50 years of almost complete coverage) consistent with observations of DN systems</u> ? In an attempt to answer this question, we have calculated the probability for a nova outburst <u>not</u> to occur (in 50 years) in 86 DN systems (for which at least some of the orbital parameters are known).
The data and assumptions used were :
1) White dwarf masses were taken from Ritter's Catalogue of Cataclysmic Binaries (1987, and references therein). When the mass was not known, we took the average of known masses above or below the period gap, depending on the system's orbital period.
2) Accretion rates were taken from Patterson (1984) and Verbunt and Wade (1984). When the accretion rate was not known, we used Patterson's accretion rate-orbital period relation.
3) We used the fact that a TNR occurs when the pressure at the base of the accreted envelope reaches a critical value, $P_{crit} \simeq 2x10^{19}$

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dyne cm^{-2} (Truran and Livio 1986, Livio 1987) to calculate the recurrence timescale of CN outbursts for each system.

4) We used a mass-radius relation for white dwarfs. Based on (1)-(4) we found that the probability for a nova not to occur in 50 years in these systems is 0.78-0.84, with the range resulting from differences in mass radius relations. We therefore find, that the fact that a nova outburst has not been observed in these systems is not surprising and does not imply that DN and CN systems are different. Incidentally, the systems found most likely to undergo a CN outburst in the near future were : RU Peg, RX And, SS Cyg and possibly V Sge (V1017 Sgr may also erupt for other reasons, see Webbink et al. 1987).

We have thus established that (in principle at least) DN can metamorphose into CN. The remaining question is therefore, do CN become DN during some phases of their evolution ? Before attempting to answer this question, we shall examine some problems with the mass accretion rates deduced from observations of CN systems.

II Problems with the Accretion Rates in CN systems.

Patterson (1984) and Warner (1987) attempted to deduce the mass accretion rates, $\dot{M}$, in CN systems. The values which they obtained present some problems, which we shall now briefly discuss.

a) $\dot{M}$ deduced from observations is too high to produce strong nova outbursts.
Both numerical and analytical calculations have shown that in order to obtain strong TNRS on the surface of $1M_{\odot}$ white dwarfs, the accretion rate must be lower than $\sim 10^{-9} M_{\odot}/yr$ (Kutter and Sparks 1980, Prialnik et al. 1982, Fujimoto 1982). For higher accretion rates, strong compressional heating leads to ignition under only mildly degenerate conditions, thus producing weak outbursts. Yet, observations seem to imply $\dot{M} \geq 10^{-8} M_{\odot}/yr$.

Possible solutions

The deduced values of $\dot{M}$ are higher than the real ones or the calculations of TNR development have to be modified, or

$\dot{M}$ changes as a function of time, assuming lower values during at least a part of the interoutburst period.

b) A number of CN systems were found to exhibit occasionally DN eruptions.
The class of such systems includes V446 Her, Q Cyg, V3830 Sgr, Nova Vul (1979), WY Sge, GK Per, BV Cen and V1017 Sgr (Livio 1987 and references therein). The problem with this observation lies in the fact that in the disk instability model for DN eruptions (Meyer and Meyer-Hofmeister 1983, Faulkner, Lin and Papaloizou 1983, Cannizzo and Wheeler 1984, Mineshige

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and Osaki 1983), for mass accretion rates above a certain critical value, $\dot{M}_{crit}$, no eruptions are expected to occur. This is a consequence of the fact that for high accretion rates the disk lies on the hot, stable branch of the effective temperature -surface density curve. All CN systems (except for the very long period ones, e.g. GK Per), were found to have accretion rates above $\dot{M}_{crit}$ (Warner 1987) and thus, are not expected to undergo DN eruptions.

<u>Possible solutions</u>

The predictions of the disk instability model (or the model itself) could be uncertain, or

<u>$\dot{M}$ changes as a function of time, assuming lower values during at least a part of the interoutburst period</u>.

c) <u>Observations of the oldest recovered novae imply lower accretion rates.</u>

Observations of CK Vul (1670) found it in a state of very low $\dot{M}$ ($\dot{M} < 10^{-11.5} M_{\odot}$/yr, Shara, Moffat and Webbink 1985). In addition, WY Sge (1783) is fainter by at least a factor 10 than normal CN (Shara et al. 1984). The nova RR Pic (1925) was observed to decrease in brightness by ~0.25 mag in 1975 (Warner 1986).

<u>Possible explanations</u>

These old novae are unusual, or

<u>$\dot{M}$ changes as a function of time, assuming lower values during at least a part of the interoutburst period</u>.

d) <u>The spread in the values of $\dot{M}$ at a given orbital period</u>.

The most fashionable theories of cataclysmic variables evolution assume that mass transfer above the period gap is driven by magnetic braking (e.g. Lamb and Melia 1987, Hameury et al. 1987). Available magnetic braking laws give accretion rates that are dependent on the orbital period but are quite insensitive to other parameters of the binary system (Verbunt and Zwaan 1981, Mestel and Spruit 1987). In particular, the spread in the values of $\dot{M}$ observed at a given orbital period (Warner 1987), is significantly wider than predicted by the theory.

<u>Possible solutions</u>

The predictions of magnetic braking models (or the model itself) could be uncertain, or <u>$\dot{M}$ changes as a function of time</u> so that the spread is introduced by the time variability of $\dot{M}$.

III <u>The "Cyclic Evolution" Scenario</u>.

Points (a)-(d) in section II clearly suggest the possibility that the accretion rates in CN systems are reduced to lower values (than the ones deduced presently from observations) for at least a part of the

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time between outbursts. We would like to note that it is not impossible that in fact all of the other proposed solutions (or different solutions) should apply, since many uncertainties are associated with all of the models involved. However, the variable $\dot{M}$ offers a somewhat simpler solution.

One scenario in the context of which $\dot{M}$ changes between outbursts is the "hibernation" scenario (Shara et al. 1986, Livio and Shara 1987). In this scenario, it has been suggested that $\dot{M}$ decreases a few hundred years following the nova outburst (by a factor 10-100) and then returns slowly to its initial value. The mechanism responsible for the reduction in $\dot{M}$ in the original model, was the increase in the binary separation, resulting from mass loss during the outburst. Such an increase has indeed been observed in BT Mon (Schaefer and Patterson 1983). The model assumed that the separation increase causes the secondary to underfill its Roche lobe, thus reducing the mass transfer. The model further suggested that the system stays bright for 50-200 years following the outburst, due to the presence of the hot white dwarf, which both produces reprocessed light and induces mass transfer from the secondary by irradiation (Livio and Shara 1987, Kovetz et al. 1987). Mass transfer was assumed to increase slowly (after the reduction) through the action of magnetic braking.

We note, however, the following possible difficulty with the original "hibernation" scenario. If the secondary's atmosphere is isothermal (due to irradiation by the WD), then it can be expected that the mass transfer rate will be reduced by a factor 10-100 depending on $\Delta a/H$, where Δa is the change in the separation and H is the (constant) scaleheight (Livio and Shara 1987). If, however, the secondary's atmosphere is convective, then $\dot{M} \sim (\Delta R)^3$, where ΔR is the distance by which the Roche lobe is overfilled. In such a case, an increase in the separation by $\Delta a/a \sim 10^{-4}$ will result in a decrease in $\dot{M}$ by at most a factor 2 (Edwards and Pringle 1987). Thus, it is not clear at all whether an increased separation can produce a significant decrease in $\dot{M}$.

We would like to propose here a modified "cyclic evolution" scenario, which does not require any special mechanism for the reduction in $\dot{M}$. This is based on the idea that <u>many CN systems are brighter both after and before the outburst</u>. The fact that post outburst systems stay (for a few tens to ~ 200 years) brighter than their real quiescent values is more or less established. It is sufficient to note that a number of systems, such as V1229 Aql, IV Cep, HR Del, FH Ser, V1500 Cyg and CP Pup did not return

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to their pre-outburst magnitude (Robinson 1975, Warner 1985). The idea that CN systems experience a pre-outburst brightening (for perhaps a few tens of years before the outburst) is suggested first of all by observations of V533 Her, LV Vul, Nova Vul (1979), CP Lac and GK Per (Robinson 1975 and references therein). The question is of course, what causes this pre-outburst brightening. We suggest that this could result from the increase in the bolometric luminosity of the white dwarf, due to nuclear burning prior to the TNR. The radiation is reprocessed (in the accretion disk and the secondary) and perhaps also induces an increased mass transfer. Recent calculations have shown that the increase in L_{BOL} prior to the TNR can be quite gradual, especially if the white dwarf is relatively hot and not too massive (Livio, Shankar and Truran, unpublished). Similar results were obtained in the quasi-static calculations of Iben (1982).

The picture of cyclic evolution that therefore emerges is one, in which the mass transfer rate in many CN systems, is the same as in DN with the same orbital period throughout most of the time between outbursts. The system then undergoes DN eruptions. A few tens of years prior to the outburst, the bolometric luminosity of the white dwarf starts increasing, producing a brightening of the system (the accretion disk is stabilized then, by heating or increased mass transfer). Following the outburst the system stays bright due to the presence of the hot white dwarf and then returns gradually to its quiescent, low accretion rate phase. The period of reduced $\dot{M}$ ensures that a strong TNR will ensue (Livio, Shankar and Truran 1988).

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