THE THEORY OF NOVAE AND NOVA-LIKE SYSTEMS*

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Abstract. Recent observational and theoretical developments in the study of novae, particularly dwarf novae, are discussed. Mechanisms promoting mass transfer include (i) nuclear evolution or (ii) envelope instability of the red star and (iii) gravitational radiation of orbital angular momentum. Growing observational evidence against (ii) is supported by recent theoretical work on the medium and long term response of stellar radii to mass loss. Mechanisms (i) and (iii) may operate alone or in concert, depending on the circumstances.

1. Introduction

In the limited time at my disposal, it is impossible to review all the relevant recent work that falls within the scope of my title. I hope I may therefore be forgiven for personal bias in selecting points that seem to be of particular interest.

One must first face the problem that counter-examples exist to almost any statement one tries to make about these systems. Furthermore, although one can attempt to contrast and distinguish between the four types: classical novae, recurrent novae, dwarf novae and nova-like variables, the distressing fact is that in many of their properties there is considerable overlap. Nowhere are these points better illustrated than by the virtually ubiquitous property of membership in a short-period binary system with period substantially less than a day. A glance at a compilation of spectroscopic binaries among these variables (Mumford, 1967) reveals that the recurrent nova T CrB stands out with a period of $227\overset{d}{.}6$; while the hope that some correlation might exist between type and binary period is dashed by the observation that there is an example of each type among the four shortest periods shown in the same table. One must perforce conclude that apart from the obvious, and defining characteristics (e.g. magnitude and frequency of outbursts – see Table I), these systems are differentiated by some underlying physical phenomena for which we possess inadequate observational handles.

Much of the recent detailed theoretical work has concentrated on studying runaway thermonuclear explanations for outbursts at or near the upper end of the logarithmic range of observed outburst energies, e.g. Rose (1968), Starrfield (1971a, 1971b) Rose and Smith (1972), and Starrfield *et al.* (1972). The latter work in many respects seems to put the theory of classical novae *per se* on a fairly sound theoretical footing, but at the same time raises awkward evolutionary questions. In what follows, I shall in fact concentrate more on the puzzles raised by the dwarf novae in particular, where the situation is even murkier. The term 'novae' will however be used to denote any of the four (or more) types unless a careful distinction needs to be drawn.

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2. The Binary Model

A little over a decade ago, classical work by Kraft (e.g. Kraft, 1963, and references contained therein) established by a variety of means that novae were binary systems: Some are double-lined spectroscopic binaries, some single-lined, while some show regular eclipses. This direct evidence is available for so many of the known novae that one can reasonably draw two inferences:

(1) All novae are binaries, with direct evidence absent in some instances only because of unfavourable orientation of the orbit.

(2) Furthermore, the components must be 'close', that is to say at least one member has dimensions comparable to the separation.

Spectroscopically, a hot blue component is generally present in emission. Excluding T CrB (which, in agreement with point (2) above, at least shows a giant spectrum), the longer period systems are seen to contain red dwarf or subdwarf members. There is a systematic tendency for these to become later and fainter as the periods decrease until, for periods shorter than about six hours, no late-type component can be seen. However, eclipses by relatively dark components can still occur, thereby revealing the presence of what are probably dwarf M's.

In response to these observations, a model has emerged over the last decade. The model (see Figure 1) consists of a late-type, essentially main sequence component filling its Roche lobe and spilling matter towards a white dwarf companion (evidence for the existence of the latter is summarized in the next section). The resulting model has much in common with that first proposed for the nova-like variable UX UMa by Walker and Herbig (1954). In its latest refinements (Smak, 1971; Warner and Nather, 1971), the stream of infalling material creates a ring or disk surrounding the white dwarf. The disk contains a luminous 'hot spot' where fresh infalling material collides with the disk, which is itself the debris from many previous collisions. Thus 'the medium is the wreckage'. With three possible light centres in the system (or at least two, with one of them, the hot spot, variable and permanently displaced from either main mass concentration), it becomes possible to explain many of the otherwise puzzling features of the periodic systems, e.g. eclipse asymmetries, the 'humps' prior to primary eclipse, the disappearance of 'flickering' during eclipse, and so on.

With simple assumptions, the period-spectral type correlation and the disappearance of late-type components at about six hours can be understood, lending further support to the model. Assume that the late components are sufficiently like main-sequence stars that the radius-mass relationship is essentially undisturbed. Assume also that the white dwarf mass is comparable to, or greater than its companion. Then (Faulkner *et al.*, 1972) a $P\sqrt{\varrho}$ relationship exists between the period P and the density, ϱ of the lobe-filling late component which is, to an accuracy of $\sim 3\%$, independent of the white dwarf mass. This relationship,

$$P\sqrt{\varrho} \sim 3.8 \times 10^4 \text{ s}$$

coupled with a crude representation of the lower main sequence (i.e. $R \propto M$) yields

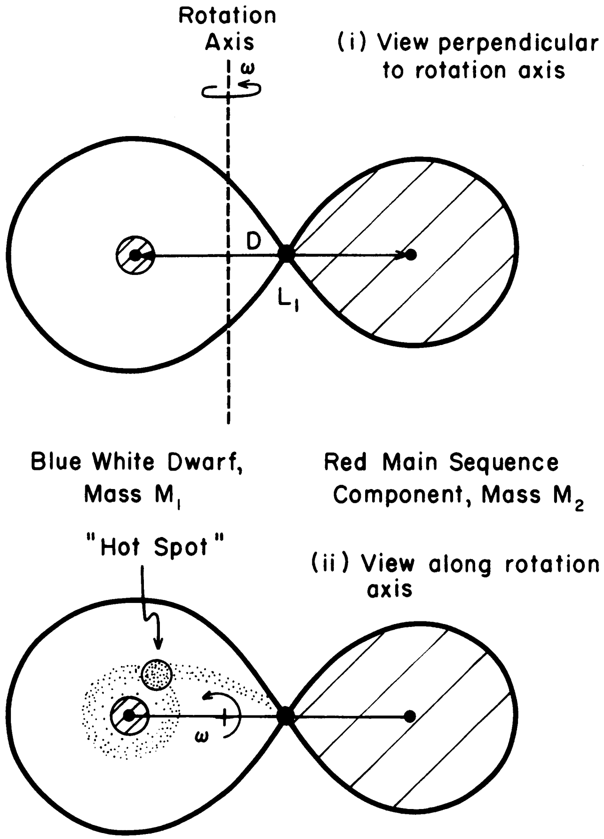

Fig. 1. The typical nova configuration. However, as pointed out in the text, the central parts of the red component may be fairly well evolved. In later stages as suggested for HZ 29 (Faulkner *et al.*, 1972), the main sequence component may be replaced by a degenerate, receding system, mass transfer still proceeding as shown.

$P \propto M$ (Faulkner, 1971) and thence, by appropriate specification of spectral types, the observed correlation and disappearance.

The restriction of the $P\sqrt{\varrho}$ relationship to situations where the lobe-filling mass contains less than half the mass of the system is not, in practice, a serious deficiency. If the lobe filling mass fraction were to exceed a critical value of order 0.5, mass transfer would occur first on extremely short term dynamical time scales followed by medium term thermal time scales before settling down to the ultimate long term time scales which presumably characterize the bulk of these variables. This long term time scale is, of course, intimately related both to the actual mass transfer mechanism and to the precise seat of the quasi-periodic outbursts. In contrast with the general agreement on the model described above, both of these points have remained bones of contention, as has the nature of the progenitors. We shall return to these points later.

We conclude our discussion of the binary model by remarking that the above considerations mean that in practice we may turn the $P\sqrt{\varrho}$ relationship around and use

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it to deduce candidates, possibly in a variety of evolutionary stages of development, for the lobe-filling component. This is illustrated in Figure 2, where a number of interesting and relevant radius-mass relationships for such lobe-filling stars are crossed by lines indicating the associated orbital period. In the most extreme example to which this has been applied, i.e. HZ 29, it has been shown that the extremely short period of this nova-like variable ($\sim$17.5 min) suggests a most natural model in which an unobserved but eclipsing low mass ($\sim$0.04 $M_\odot$) lobe-filling degenerate helium star orbits a more massive and observable white dwarf (Warner and Robinson, 1972b; Faulkner

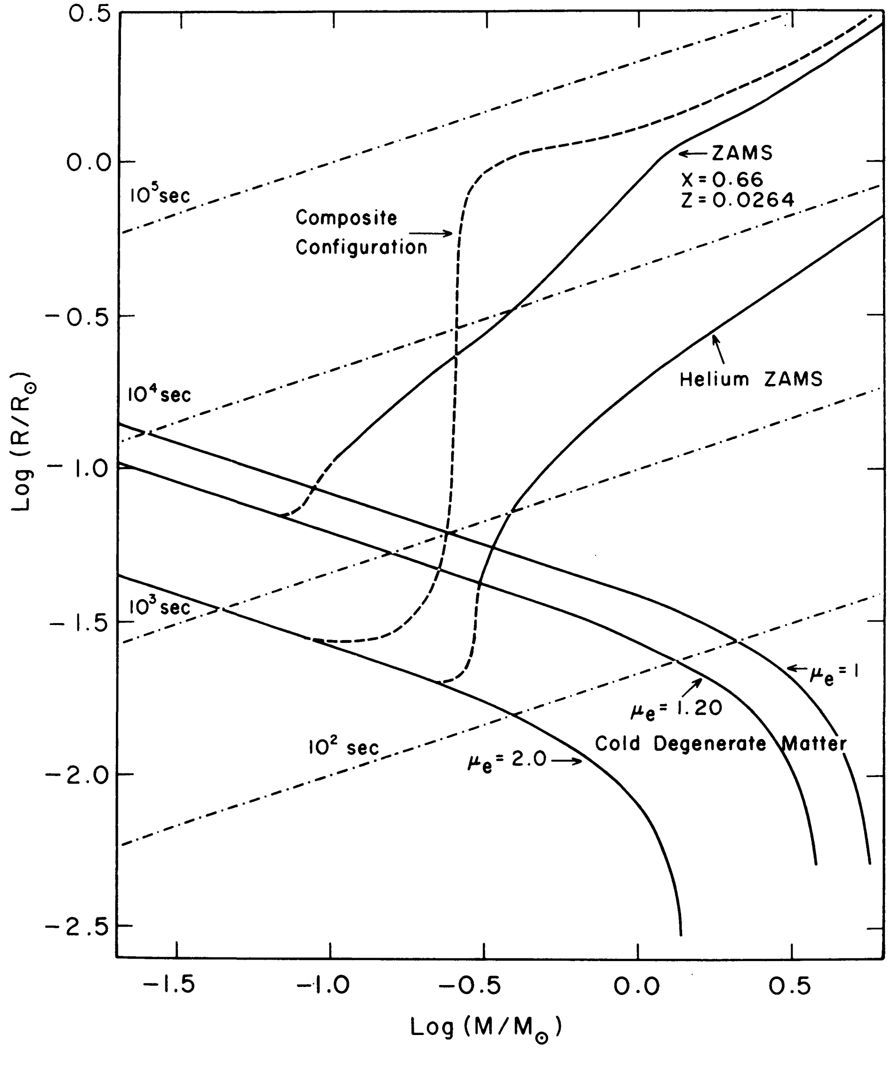

Fig. 2. Lines of given orbital period are shown for lobe-filling secondaries, together with typical hydrogen- or helium-burning zero-age main sequences, and a schematic representation of the possible relationship for a composite configuration. Because of mass loss, evolution proceeds to the left along any given sequence, until a transition ultimately occurs to the appropriate degenerate sequence.

et al., 1972). The small separation of these two degenerate stars ($\lesssim 0.25\ R_\odot$) demands an explanation which must, presumably, arise as a logically possible outcome of nova or nova-like evolution.

3. Evidence for the White Dwarf

Following Kraft, white dwarfs are assumed to be present in all these systems, although until recently WZ Sge was the only certain case because a typical DB spectrum was observed. It was also supposed that the 71s pulsations of DQ Her (Walker, 1956) were associated with a white dwarf. Were these radial pulsations, they would imply a very low mass. However, Warner *et al.* (1972) have shown that a phase shift of $+360°$ which occurs during eclipse may be interpreted as evidence for non-radial modes of pulsation in a more massive white dwarf.

Within the past year, a most dramatic order-of-magnitude increase has occurred in the number of suspected non-radially pulsating white dwarfs. These discoveries have been made mainly, but not exclusively, among the dwarf novae. Iben has reported earlier that Warner discussed many additional examples at the I.A.U. Symposium No. 59. These presumably included Z Cam, CN Ori, UX UMa, AH Her and AM CVn (i.e. HZ 29) with periods near 17, 24, 29, 31 and 115 s respectively (Warner and Robinson, 1972a), SY Cnc and KT Per (25 and 27s; Robinson, 1973c), CD $-42°$ 14462 (29s; Warner, 1973b), Z Cha (28s; Warner, 1974) and VW Hyi ($\sim$28–34s; Warner and Harwood, 1973; Warner and Brickhill, 1974). With one or two exceptions, the amplitudes are very small (in the range of $\sim 0\overset{m}{.}01$ to $0\overset{m}{.}001$ or less) and the periods are usually found by combinations of power spectrum and periodogram analysis. In some cases, during lengthy observing runs (duration of hours or days) systematic and possibly quantized monotonic changes of period have been seen, the changes being positive for one object and negative for others. In CN Ori, a 'phase transition' was actually observed. In AH Her (Robinson, 1973b) the pulsations have been shown to be absent at several points on the rising branch of an outburst and during minimum light, in contrast with the situation at and just after maximum light in AH Her, Z Cam and CN Ori (Warner and Robinson, 1972a). The inference has been drawn that one is seeing non-radial pulsations in the white dwarf as a consequence of an outburst in the latter, the amplitudes being small because the outburst has caused the inner parts of the accreting disk to brighten up considerably and dominate the optical output. The lack of pulsations leading up to the outburst is seen (Starrfield *et al.*, 1974) as evidence for the picture in which a major role is assigned to the release of energy in the disk by β^+ – unstable nuclei following non-equilibrium nuclear burning among possibly enhanced abundances of carbon and oxygen. Starrfield *et al.* claim that the build up of pulsations would be seen in the models of Rose and Smith.

Against the euphoria engendered by these brilliant observational triumphs, one should perhaps set the growing suspicions that one may not actually be seeing white dwarf pulsations at all! Thus Bath *et al.* (1974) have suggested that hot spots from accretion funneling onto a rapidly rotating magnetic white dwarf might be responsible for the DQ Her observations. The sign of their phase shift is however almost certainly negative. While this agrees with a $-360°$ phase shift recently observed in UX UMa pulsations during eclipse (Nather and Robinson, 1974), it appears that one should be looking for an explanation capable of producing $\pm 360°$ phase shifts with equal facility. The positive sign would demand white dwarf rotation in the opposite sense to the orbit, which seems unlikely. In another approach, Bath (1973) proposes that transient hot spots in the orbiting disk close to the white dwarf are responsible for the pulsations seen. This would seem once again to produce only negative phase-shifts. This is perhaps the most serious objection to Bath's proposal, although in all other respects it satisfies four summary criteria for any explanation of the behaviour of UX UMa, as compiled by Nather and Robinson. The latter authors incidentally remark that the $l=2$, $m=0$ pulsation mode of Warner *et al.* (1972) fails two criteria, the hot spot funneling of Bath *et al.* three. Nather and Robinson suggest instead $l=2$, $m=\pm 2$ pulsations (only the m value is really important), but then cast doubt on the whole idea of seeing white dwarf pulsations directly by noting serious discrepancies between several estimates of the blue star radius in UX UMa. Recent pulsation models (Osaki and Hansen, 1973) imply a radius certainly less than $\sim 0.05\ R_{\odot}$; on the other hand, both the eclipse solutions for UX UMa and the duration of the phase shift seen suggest a radius probably in the range of $\sim 0.3\ R_{\odot}$ to $\sim 1.0\ R_{\odot}$. Their tentative way out of this dilemma is that the hot surrounding disk may somehow act as an extension of the white dwarf envelope, creating for some purposes a large apparent photosphere. It becomes imperative to test whether the broad H and He I lines seen in UX UMa are due to rotational Doppler broadening in the disk or to Stark broadening on the white dwarf surface.

The suspicion that the glowing disk may play a far more important and obscuring role than hitherto assigned also occurred apparently independently and simultaneously to Warner (1974) and Starrfield *et al.* (1974). One may summarise by saying that all the models proposed to explain the pulsations contain at heart a stellar mass at least as compact as a white dwarf, and that on the issue of the proved existence of white dwarfs in these systems, there is room for cautious, if confused, optimism.

4. Proposed Outburst Mechanisms and Evolutionary Scenarios

Variants of at least four basic mechanisms have been proposed for nova outbursts. Briefly, they may be characterized as follows:

(i) Nuclear evolution of the red component causes it to swell, overflowing the surrounding Roche lobe (Crawford and Kraft, 1956). That portion of the hydrogen-rich material released which subsequently reaches the white dwarf via the accretion disk ultimately undergoes violent, unstable nuclear burning.

(ii) A thermal instability or relaxation oscillation occurs in the convective envelope of the red component. As a result the thermal energy of the envelope is released, manifesting itself as an outburst (Paczyński, 1965; Bath, 1969, 1972). Osaki (1970) produced a variant in which shear turbulence in the surface layers strongly modifies energy transport and induces mild outbursts.

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(iii) Gravitational radiation inexorably removes energy and angular momentum from the system so that the Roche lobe continuously encroaches upon the surface of the red component. Mass must necessarily be transferred (Kraft, 1966) and, taking account of stellar structure requirements, the self-consistent rate of transfer can be calculated (Paczyński, 1967; Faulkner, 1971). The outburst follows as in (i) above.

(iv) The X-mechanism (Ostriker, 1973). By analogy with a model produced for self-excited binary X-ray sources (Davidson and Ostriker, 1973), intense radiation from the hot spot and accretion disk induces continued mass loss from the cool red component. The seat of the ultimate outburst would again seem to be the white dwarf. The suggestion is however largely unexplored.

Before discussing how these mechanisms fare against recent observations, it is convenient to draw up a table summarising the energy requirements of nova models (Table I). The table makes no attempt to be complete (indeed, our lack of knowledge precludes it), but it illustrates properties generally attributed to some of the more 'typical' examples of each class.

TABLE I

Energy requirements of nova models

	Classical novae	Recurrent novae	Dwarf novae
Outburst range (magnitude)	~ 10–12	~ 6–8	~ 2–5
Outburst energy, E(ergs)	~ 10^{45} or more	~ 10^{43}–10^{45}	~ 10^{38}–10^{39}
Time interval, T(years)	(300–1000??) (great uncertainty)	25–50	~ 0.05–1
Mass ejected, M_{ej} (gms)	~ 10^{28}–10^{29}	~ 10^{28}	?
M_{ej}/T ($M_\odot$ yr^{-1})	??	~ 10^{-7}	~ 10^{-9}?? (one example)
$E/(0.007c^2\,T)$ ($M_\odot$ yr^{-1})	??	~ 10^{-10}	~ 10^{-12}–10^{-11}
*M_{burnt}/M_{ej} (nuclear explanation)	??	~ 10^{-3}	?

*$M_{burnt} = E/(0.007c^2)$, the amount of hydrogen burnt on the nuclear explanation to produce the outburst energy E.

The major question which one might hope to resolve, thereby distinguishing between the above possibilities, is the rate of mass transfer and/or ejection. There are those who favour a canonical figure of ~$10^{-7}\,M_\odot$ yr^{-1} on the grounds that (a) such an ejection rate has been observed, for example in the recurrent nova RS Oph (Pottasch, 1967); (b) it might also hold for classical novae which eject ~10–30 times as much mass but at intervals suspected to be ~10–30 times less frequent (Pottasch, 1959; Boyarchuk* 1970); (c) orbital period changes of order 1 part in 10^7 per annum are taking place for example in the classical nova DQ Her (Nather and Warner, 1969). However, as Smak (1972) has pointed out, the orbital periods are known to both in-

* Note that the shell mass for RS Oph 1958 (Folkart *et al.*, 1964) as quoted in Boyarchuk's Table I is incorrect. It should read $2 \times 10^{-6}\,M_\odot$ (not 2×10^{-7}). This value was however revised upwards by a factor of 3 (Pottasch, 1967).

crease and decrease, sometimes in a cyclical manner. Recent examples include the $\sim$29 yr variation of UX UMa (Krzeminski and Walker, 1963; Mandel, 1965, Nather and Robinson, 1974), the $\sim$2 yr variation of HZ 29 (Krzeminski, 1972), and similar effects in RW Tri (Mandel, 1965) and U Gem. Explanations in terms of third bodies for all these systems seem a little unlikely, and the effect may occur because disks can act as temporary reservoirs of mass and angular momentum. In any event, we feel with Smak, that one should be cautious in interpreting observed rates of orbital period change as evidence for long term mass transfer at comparable relative rates.

For at least one dwarf nova it appears possible that the mass transfer or ejection rate may be significantly less than the 'canonical' figure. Robinson has derived values of $\sim 3 \times 10^{-9}\ M_\odot\ \mathrm{yr}^{-1}$ (Robinson, 1973a) and $\sim 2 \times 10^{-9}\ M_\odot\ \mathrm{yr}^{-1}$ (Robinson, 1973d) for Z Cam. While these are admittedly lower limits, it hardly seems likely that they are underestimates by factors of 30 or 100.

What rate of mass transfer might one expect according to competing theories? The answers are surprisingly incomplete, or they depend upon a better knowledge of the circumstances than we possess. If a system had become of the envisaged contact type relatively recently and if the red component were more massive than the white dwarf at this stage, as seems likely to be the case, then a period of thermal readjustment involving timescales of $\sim 10^6$ or 10^7 years would indeed be appropriate.

Following this stage, there are two ways in which nuclear evolution timescales might determine the subsequent events. The white dwarf mass may have been built up through sufficient retention of added material that its companion, now of comparable mass, is able to evolve in a reasonable length of time. This could well be the case for Z Cam where the masses are: white dwarf $\sim$1.0–1.3 $M_\odot$, red component $\sim$0.8–1.0 $M_\odot$ (Faulkner, 1971; Warner, 1973a). Incidentally, it is unfortunate (to say the least!) that the author chose to illustrate mechanism (iii) by applying it to Z Cam. The temptation to apply the theory to a system about which much was known was irresistible. However, as we shall discuss later, it was a borderline case for application, and it appears from Robinson's observations that Z Cam's red component is indeed currently a frustrated main-sequence leavetaker. One other way in which nuclear timescales could still be important would arise if the red component's core was already sufficiently far evolved when the system arrived at the standard configuration. In this case, the previous stripping of the red component's envelope during the thermal readjustment era might leave it, even though of very low mass, poised for its fruitless attempt to depart the main sequence. That this, or something like it, must be a possibility is hinted at by the model for HZ 29 (Faulkner *et al.*, 1972), although the critical point where nuclear evolution ceases to be relevant is not yet known.

Finally we come to a stage with a timescale which is unavoidable if Einstein's theory of gravity, or anything like it, is correct, i.e. mechanism (iii) above. Where this takes over from nuclear evolution as the dominant mechanism will depend upon the previous evolutionary history of the red component. If the latter is truly like a pristine main sequence star, evolution via gravitational radiation could be more important than nuclear evolution for stars as massive as $\sim 1\ M_\odot$ in systems of total mass $\sim 2\ M_\odot$

(Faulkner, 1971). The more evolved the interior of the red component, the lower the mass at which gravitational evolution will dominate – but it certainly seems likely that systems with binary periods shorter than ~ 5 hours containing white dwarfs more massive than the red components (themselves $\leqslant 0.7\ M_\odot$) will be so dominated. According to the theory (with its imperfections, based as it is on zero-age main sequence approximations), the rate of mass transfer is very well determined and lies in the range ~ 0.5–$2.0 \times 10^{-10}\ M_\odot\ \mathrm{yr}^{-1}$. These transfer rates lead, in the absence of other mechanisms, to timescales of the order of a few to ten billion years. They have a comfortable margin in hand to satisfy the energy requirements of Table I.

The scenarios presented above have suggested ways in which high mass transfer rates and mechanisms (i) and (iii) might be relevant at different times, even in the same system. We have not discussed mechanism (ii) because we believe it is almost certainly ruled out by recent observational and theoretical developments. It is to these developments that we now turn.

5. The Seat of the Outburst; Observations and Theory

The precise seat of the outburst has been a matter of some controversy during the past decade. Krzeminski (1965) showed that in U Gem, the primary eclipse present at minimum light remained approximately constant in intensity units during outburst. As a result, it was essentially absent (in magnitude) at maximum light. Assuming that the white dwarf was obscured during primary eclipse, Krzeminski concluded that it had nothing to do with the outburst itself. The outburst was therefore associated with the red, or secondary component. It was in response to these observations that Paczyński (1965) developed the theoretical 'secondary hypothesis'.

The secondary hypothesis was challenged by Walker and Chincarini (1968) who, observing SS Cyg during a rise to maximum, found that the outburst was associated with the blue component. However, according to Smak (1969), uncertainties in the elements of the SS Cyg velocity variations permitted a solution in which the contrary conclusion would be valid. Subsequently, Walker and Reagan (1971) checked the orbital period of SS Cyg once again, essentially confirming the value used by Walker and Chincarini. Although some disquieting phase shift seems to have intervened also, the results of Walker and Reagan nevertheless support the contention that the outburst originates in the blue, hot component.

A way of avoiding Krzeminski's conclusion was independently proposed by Warner and Nather (1971) and Smak (1971), namely the 'hot spot' model we have discussed throughout. It is the hot spot which is eclipsed, and it remains of essentially constant brightness during outburst. Smak in particular shows how Krzeminski's observations may be interpreted as evidence for the outburst occurring somewhere near the central parts of the accreting disk. Nowever, this explanation requires us to be in a particularly favourable direction with respect to the orbital plane of U Gem: able to see the white dwarf and central disk regions satisfactorily, but having the hot spot periodically obscured by the secondary. It thus became imperative to search for further evidence to test the model. Robinson (1973a) made observations of Z Cam which indicated that the central disk regions brightened during outburst. However, the matter appears to have been clinched by Warner's observations (Warner, 1974) of the southern eclipsing dwarf nova Z Cha. The eclipse, which is total, shows a disappearance both of the white dwarf primary and the hot spot. During outburst the eclipses become (a) wider and (b) partial, apparently establishing with certainty that the outburst is centred on the primary. At maximum light, the eclipses show that the whole disk around the primary has brightened up, whereas the hot spot remains of constant intensity.

After many years, this observationally disposes of the red star as the seat of the outburst. But Bath (1973), resourceful as ever, maintains that it may still be the red star, undergoing his envelope oscillations, which sends matter towards the white dwarf, the outbursts occurring in direct response to each burst of mass transfer. While we think the behaviour of the bright spot (Warner, 1974) makes this unlikely, other stellar structure considerations cast more doubt on the whole envelope mechanism. This brings us to our final topic.

6. The Response of Stellar Radii to Mass Loss

According to Bath (1972), any stellar model corresponding essentially to stars in or to the red side of the instability strip and its extensions in the HR diagram will be unstable to mass loss if confined by a Roche lobe. This conclusion is, we feel, suspect on at least two grounds: (a) the changing size of the Roche lobe is ignored, and even more importantly, (b) the long term consequences of mass loss for the underlying star are ignored. For, whatever the behaviour of the models on the short timescales studied by Bath, surely the important question if one wishes to understand say dwarf novae, is what happens to the underlying star given mass loss on timescales of 10^7, 10^8, 10^9... years? Should conditions in the underlying star differ significantly from those initially assumed, the calculations will not be relevant to the long term situation.

Accordingly, we and colleagues have investigated the response of stellar radii to mass loss in the surprisingly neglected region of the lower main sequence (Eggleton *et al.*, 1974). Such simple models have been studied because (a) they are thought to be relevant to the short binary period novae, (b) they provide a *reductio ad absurdum* disproof of the contention that the envelope instability hypothesis can work independently of the state of evolution of the underlying star and (c) no one seems to have done it previously!

The models exhibit both transient and long-term effects because of the thermal imbalance which necessarily accompanies long-term mass loss. Models above and below a critical mass ($\sim 0.75\ M_{\odot}$) initially shrink more or less rapidly than the main-sequence relationship would suggest. At sufficiently high rates of mass loss, the models of lowest mass investigated (0.5 and 0.25 $M_{\odot}$) do experience transient expansion. However, it is clear that for models appropriate to many of the observed dwarf and other novae, the greater the rate of mass loss, the faster the star shrinks. For the shortest period, lowest secondary mass systems (which must surely be transferring to more massive white dwarfs), the transfer rates would have to be so great to induce expansion which could overcome the increasing size of the swelling Roche lobe, that there would be no chance of observing them. In short, the tail cannot wag the dog following amputation.

We conservatively conclude that the secondary mechanism cannot be a prime theoretical cause, although it may in some fashion modulate the rates implied by some other mode of mass transfer.

7. Summary and Wild Speculations

We have suggested in Section 4 a scenario in which mechanisms (i) and (iii) might play roles of varying importance. Although it is certainly not clear that the various types of novae need be connected in any evolutionary sense, nevertheless we have concluded that if they are, a good, if unconventional case may be made for the dwarf novae to be later and associated with the most massive white dwarfs. This contention indeed receives strong support from Warner's study (Warner, 1973a) of the masses of the components of ten short period cataclysmic variables, predominantly dwarf novae. The white dwarf primaries, with one exception, lie in the narrow range of $\sim 1.2 \pm \pm 0.2\ M_{\odot}$. The exception, interestingly enough, is U Gem, with a primary of only $\sim 0.65\ M_{\odot}$ and a more massive secondary, which may explain the relatively short term thermal timescales associated with its period variations mentioned above. Is it possible that dwarf novae explanations are bimodal? Whether this is the case or not, the suggestive proximity of Warner's primary masses to the Chandrasekhar limit may help explain the mild outbursts and short repetition times associated with the dwarf novae. The surface gravitational fields may be so large, and the non-degenerate layers so thin, that an extremely small addition of fresh nuclear fuel can trigger outbursts at very frequent intervals. The thermal history of the white dwarf, completely ignored above, may also be an important factor.

We have throughout avoided the problem of the progenitors. We feel, with Kraft (1967), that W UMa systems are the most likely although others (e.g. Giannone, 1973) are of the opinion that close but not contact systems appropriate to 'case A' of mass exchange may be relevant. Vilhu will speak on some of these points later (Vilhu, 1974). Whichever close systems one favours for the progenitors, one thing seems perfectly clear: the white dwarf masses obtained when a semi-detached system is first formed rarely exceed $\sim 0.3\ M_{\odot}$, a far cry from Warner's observations, and demanding subsequent build up.

Looking back over the past decade, we have, it seems, come a long way, if not by a direct route. Much work remains to be done, however, before we can confirm Kraft's provocative suggestion that gravitational radiation might ultimately be responsible for the behaviour of some dwarf novae; a suggestion made on a similar occasion (Hamburg, 1964) and published (Kraft, 1966) in proceedings as widely ignored by relativists as these may be.

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