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Novae versus Dwarf Novae: Energy Sources and Systematics

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SUMMARY

We review observational and theoretical work on classical novae and dwarf novae (U Gem, SS Cyg and Z Cam stars) that bears on the question of why binary systems with very similar component stars and orbits should have such different outburst behaviour. We are able to put together a consistent picture only for certain theories of the outbursts. In this picture, mass transfer occurs continuously at a steady rate from the late-type star towards the degenerate dwarf for all types of cataclysmic systems, most rapidly in the recurrent novae, somewhat slower in the classical novae and most slowly in the dwarf novae. The gas flows into an accretion disk in all cases. For the rapid transfer rates, the disk is always dense enough that viscosity is adequate to transfer angular momentum outwards and allow gas to accrete continuously on to the degenerate dwarf, where it accumulates until it is hot enough and dense enough to undergo nuclear reactions. Gravitational potential energy released during this accretion is the main energy source for classical novae at minimum light, while the mass-losing star (a giant) also contributes appreciably to minimum light in the recurrent novae. For the slowest mass transfer rates, gas accumulates for some time in the outer parts of the disk until a critical density is reached, viscosity increases and accretion occurs rapidly, liberating the available gravitational potential energy. Thus, in the dwarf novae, the main minimum light energy source is the impact of the gas stream from the late-type star hitting the accumulating disk, while the outbursts are caused by the sudden onset of accretion at the rate which is normal for classical novae at minimum light. Some or all of the transferred gas probably stays on the degenerate dwarf, so that an astronomer who waits patiently (about 10^6 yr for a typical system) can expect to see classical nova outbursts from at least some dwarf nova systems.

CHARACTERISTICS OF THE OUTBURSTS AND SYSTEMS

The eruptive or cataclysmic variable stars can be divided into four groups on the basis of their observed outburst behaviour. The four groups are the classical novae (Ne), recurrent novae (RNe), dwarf novae (DNe, with two subgroups, named for prototype stars Z Cam and U Gem, or, sometimes, SS Cyg) and nova-like variables (NL). Recent reviews of one or more of the groups are to be found in Robinson (1976), Warner (1976), Friedjung (1977) and Gallagher & Starrfield (1978).

Classical nova outbursts have characteristic amplitudes between 9 and 14 mag and are rare enough that no true nova has ever been seen to go off more than once. Recent UV and IR data have been combined with visible light curves to provide estimates near 10^{45-46} erg for the total energy of a typical outburst (Warner 1976). The bolometric luminosity remains high (about $10^{4-5}\,L_{\odot}$) for at least 100 day, even though the visible light drops off by several magnitudes in days or weeks. Well-studied novae show evidence for the expulsion of matter during the outburst, in the form of emission lines with velocities well above escape and/or expanding nebulae around the post-outburst star. The average minimum brightness is about $M_{\mathrm{V}} = +4{\cdot}5$ (McLaughlin 1960).

Dwarf nova outbursts are less powerful but more frequent than those of novae. The amplitude of the light curve is only 2–6 mag, and the energy released is 10^{38-39} erg per burst (Robinson 1976). Each system has a characteristic (though somewhat variable) interval between outbursts, which can be as short as 10 day or as long as 30 yr, if we follow Warner (1976) and Paczyński (1977) in demoting WZ Sge from RN to DN on the basis of its low absolute brightness as deduced from proper motions, its non-ejection of material during outbursts, its rapid quasi-periodic light fluctuations, and low mass transfer rate (Robinson, Nather & Patterson 1978). 30–100 day is typical. DNe are considerably fainter ($M_{\mathrm{V}} = +7{\cdot}5$ according to Kraft & Luyten 1965, or even +8–10, Oke 1978, private communication) at minimum light than novae, and in only one case (Z Cam, Warner 1974) is there even indirect evidence for mass being expelled from the system. The outburst normally lasts a day or so, and the infrared (Skody 1977) and X-ray (Gorenstein & Tucker 1976) fluxes decline with the visible light and are never more than 10 per cent of the total (unlike the nova case), for the SS Cyg subgroup. The Z Cam stars sometimes get stuck part of the way down the declining branch of the light curve, at least optically (but again most of the flux is presumably in the blue and UV). Their luminosity at standstill is essentially equal to their average luminosity over a normal cycle of outburst and quiescence (Lortet 1968). This is undoubtedly trying to tell us something, as is the fact that all DNe with recurrence times less than 30 day display either standstills or supermaxima, in which luminosity remains high for 10 day or so (Warner 1976).

Rapid periodic light fluctuations, though first found in the old nova DQ Her ($p = 71$ s) are commoner in DNe than in Ne (Robinson & Nather 1977; Warner 1976). These fluctuations are commonest in, but not restricted to, the Z Cam subtype and the descending branch of the light curve. The oscillation period is anti-correlated with luminosity (Warner & Brickhill 1978; Nevo & Sadeh 1978) for at least some systems and at least on the descending branch of the light curve. If, as Nevo & Sadeh find, that correlation is absent on the ascending branch, this may imply a significant contribution to the total system luminosity from a so-called hot spot, where a gas stream hits an accretion disk. The importance of this seemingly botanical point will become clear in due course. Warner & Brickhill find the correlation on both branches.

The recurrent novae have amplitudes of 7–9 mag, recurrence times (not perfectly periodic) of 10–100 yr, and total outburst energies of 10^{43-44} erg

(Robinson 1976). This has long suggested (Kukarkin & Parenago 1934) a sequence DN–RN–N. This cannot, however, be sustained on closer examination. The amplitudes of the RNe appear smaller than those of the classical novae only because they are brighter at minimum light (Warner 1976). The exception to this rule is T Pyx, which is also much bluer than the others at minimum light. On this basis, and because its spectrum shows no evidence for ejected circumstellar material (unlike, e.g. RS Oph; Catchpole 1969) we suggest it should be demoted to dwarf nova, along with WZ Sge. The recurrent nova supply is thereby reduced to five: U Sco, VY Aqr, T CrB, RS Oph and V1017 Sgr. The available spectroscopic, photometric and orbital data on these systems (Warner 1976; Eachus, Wright & Miller 1976) are consistent with the non-degenerate star being a giant in each case.

The phrase 'nova-like variable' has gradually changed its meaning over the years from signifying (e.g. McLaughlin 1960) a star like P Cyg or Eta Car which brightened significantly at some time, without displaying a typical nova light curve or spectrum, to signifying a close binary system with spectrum, variability and components like those of a nova or dwarf nova between outbursts. We have in mind the latter sense here, so that, although no major outburst has been observed in these systems (some of which, like AE Aqr and UX UMa, are rather well studied), they are apparently part of the same problem, as may be the EUV binaries HZ 43 and F 24 (Shara, Prialnik & Shaviv 1977). The symbiotic stars, on the other hand, having giant components and wider separations than most of the objects so far mentioned, may bear the same relationship to the RNe that the NLs do to the Ne and DNe.

Given these several distinct classes of outburst behaviour, one might expect to find them associated with similarly distinct types of stars. Apart from the RN–giant connection, this is not the case. All the other cataclysmic variables are satisfactorily modelled by a cool star, normally within a magnitude or two of the main sequence, filling its Roche lobe, so that a stream of gas flows from it, making a hot spot as it hits and joins a gaseous disk around a degenerate dwarf. This is truly an all-purpose model – if you allow a neutron star or black hole in place of the degenerate dwarf and mass transfer due to stellar winds as well as Roche lobe overflow, it will also do for a variety of kinds of X-ray sources, including one-shot, nova-like outburst sources with optical identifications, like R Mon, H 1705−25, A 1524−61 and Nova Oph 1977, and recurrent X-ray novae like Aql X-1, 4U 1608−52 and 4U 1630−47 (Grindlay & Liller 1978). Credit for the model should be apportioned among Kuiper (1941), Crawford & Kraft (1956), Smak (1971), Warner & Nather (1971) and probably others as well.

And now comes the unpleasant part: there is no detectable correlation between either orbit periods or masses or spectral types (when observable) of the stars and the type of outburst behaviour displayed, again excepting the presence of giants in some/all RNe, symbiotic stars and a few very slow novae. Thus, any model that aims to deal simultaneously with all cataclysmic variables must not rely heavily on masses, separations or temperatures of the component stars.

Some correlations are reasonably well established. The spectrum of the cooler star is seen only in longer period ($\gtrsim$6 hr) systems, but this means only that the system has to be big enough to accommodate a star that will contribute 10–20 per cent of the total light, and the spectral type of the secondary when seen is not correlated with outburst behaviour. There are probably significant differences in quiescent luminosity among the groups (Warner 1976; Robinson 1976 and references therein; Oke 1978, private communication), with $M_V \sim +7$–10 for the DNe, +4–5 for the Ne and +2–3 for the RNe. These are a result of the dominant light contributions coming from the hot spot in the DNe, the accretion disk in the Ne and the giant star in the RNe (Osaki 1974), but the range in each case is large (and probably overlapping among classes) and the bolometric corrections are neither small nor well known. Some case can perhaps be made for systematic differences in the rate of mass transfer, based on roughly one example in each class (Warner 1976; Robinson *et al.* 1978), $\dot{M} \sim 10^{19}$ g s^{-1} for the Re, 10^{18} for the classical novae, and 10^{16-17} for the DNe, averages over at least one outburst cycle being implied in each case.

We have not even touched on the complexities of cataclysmic variable spectra in and out of outburst. These are discussed by Payne-Gaposchkin (1957), McLaughlin (1960) and Beer (1974). It may be relevant that nova disks typically show lines of higher excitation than do those of dwarf novae, during their respective quiescent stages. The detection of X-rays from the DN SS Cygni outside of outbursts obviously implies the existence of a very hot region, in contradiction to the previous correlation, but (like most prototype objects!) SS Cyg may not be typical. Only it and U Gem have ever been seen as X-ray sources, though there are other DNe that would have been detected if their X-ray to optical luminosity ratios were as high (Cordova 1978, private communication). The nova-like variables come in high and low excitation varieties with roughly equal frequencies, according to Payne-Gaposchkin (1977), who, in a rare act of faith, calls them pre-novae. It would be exceedingly interesting to know if there is a correlation between excitation state and absolute magnitude among the NLs, which might allow us phenomenologically to separate pre-novae from pre-dwarf-novae! There may even be a few pre-transient X-ray sources hiding in the class (Green, Greenstein & Boksenberg 1976, concerning PG 2337+12). It would also be interesting to have pre-outburst spectra of cataclysmic systems which show (or do not show, at some useful level) evidence for neutral gas around the systems.

THEORIES OF THE OUTBURSTS

Hydrogen gas flowing on to the surface of a white dwarf carries with it both nuclear and gravitational potential energy in a ratio of about 50:1, and (perhaps) magnetic energy. At least one model-maker has endeavoured to use each of these sources for each of the kinds of outbursts seen (Bath & Shaviv 1976; Sparks 1977, private communication; Collins & Foltz 1977). But if we try to use the same energy source for all cataclysmic variables, we run into a problem. The 10^7 ratio between DN outburst energy and N outburst energy and the known DN recurrence time would then imply a nova recurrence time of 10^{6-7} yr. Since the rate of discovery of galactic novae (several per year) implies a total rate of 10–100 yr^{-1}, the long recurrence time would require there to be about 10^8 systems in the Milky Way capable of nova outbursts. This is comparable with the number of W Ursa Majoris systems, the commonest known sort of variable star, which would be fine if the W UMa stars were, as has often been suggested, the ancestors of the cataclysmic variables. But they are almost certainly not (Webbink 1976). Thus we are led immmediately to suspect that the nova energy source must be significantly more powerful than that in dwarf novae, so that their recurrence times can be shorter and the total number of systems a good deal smaller than 10^8. This turns out to be the case for the presently dominant theories (and if we are all going the same direction, it must be forward).

The explosive properties of hydrogen deposited on a degenerate dwarf were pointed out by Schatzman (1951) and Mestel (1952), applied to novae by Kraft (1962, 1963), shown to do the right sorts of things by Saslaw (1968) and developed into a full series of nova models by Starrfield, Sparks and Truran (many references, cited by Gallagher & Starrfield 1978), under the assumption that significant amounts of carbon and oxygen are available from the degenerate dwarf. The models are in reasonable accord with* observations of the rising parts of nova bolometric light curves (but the total luminosity of the models stays close to the Eddington limit for much longer than does that of real stars) and are probably capable of ejecting matter with the right mass, velocity and composition to make a nova shell. A competing series of models by Prialnik, Shara & Shaviv (1978) also produces plausible novae, given their particular criteria for ejection, using matter of solar composition. The slow nova models calculated by Sparks *et al.* (1978) using solar CNO abundances apparently eject the outer layers by radiation pressure. The hydrodynamic models of D.Sugimoto (unpublished) are particularly interesting because, in the last time steps calculated, the upper layers are actually going outward with more than the escape velocity.

All published models neglect the entropy and compressional heating of the accreted gas, thus the wide agreement that 10^{-5}–10^{-3} $M_\odot$ (inversely proportional to both mass and luminosity of the degenerate dwarf) must be collected to get an explosion is necessarily somewhat preliminary. It implies recurrence times of 10^{4-5} yr for classical novae.

The compressional heating of accreted gas will allow the explosion to set in sooner (i.e. at smaller accreted mass) than it otherwise would. This effect will be most important for the most rapid transfer rates, those in the recurrent novae. The 'guesstimated' RN transfer rate of 10^{19} g s^{-1} will build up a 10^{-5} $M_\odot$ hydrogen envelope, perhaps enough to explode if the hydrogen accretes rapidly, in about 60 yr, not all that far from typical RN recurrence times. Thus, RNe can plausibly be interpreted as a special case of classical novae, in which extra-rapid mass transfer (driven by the more rapid evolution of the giant star) shrinks the time-scale to a more human one. A smaller envelope also suffices for the RNe because they are likely to have more

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*The authors narrow-mindedly reserve the word 'predict' for theoretical work done in advance of the observations.

massive than average degenerate dwarfs (as is indeed observed to be the case at least for T CrB) according to one model for their evolution. The point is that only an initially wide system can allow the primary to develop a massive degenerate core before mass transfer stops it. Such a massive core results in a high luminosity, loosely bound envelope for the red giant, which is readily driven off by the other star stirring into its envelope (Ostriker & Paczyński 1975). Thus the star does not get very far in before the red giant envelope is gone, and the system is left with a massive degenerate dwarf and relatively large separation, just as required for recurrent novae.

The symbiotic stars can be fitted in by saying (e.g. Warner 1976) that mass transfer in them goes via stellar wind rather than Roche lobe overflow, hence quite slowly, with spherical rather than disk-like accretion on to the compact star, so that we would have to wait 10^5 yr or so to see the nuclear explosion. Sparks, Starrfield & Truran (1978) alternatively suggest that the symbiotic stars have very rapid Roche lobe overflow from the giant which swamps or hides possible explosive behaviour. We suspect this requires shorter orbital periods than are consistent with existing radial velocity data.

The importance of accretion luminosity for dwarf novae was suggested by Crawford & Kraft (1956), made plausible by Smak (1971) and argued convincingly by Bath (1973). All of this year's popular DN models attribute the outbursts to sudden increases in release of gravitational potential energy, unlike the relatively steady release that maintains the minimum-light luminosity of classical novae, etc. Two questions immediately arise from this picture, and we deal with the easier one first: what becomes of the nuclear energy of this accreted gas? Although it is possible to build stable models in which hydrogen burns steadily and non-explosively while accreting on to a degenerate dwarf, provided only that the accretion rate is not too large for the initial luminosity of the accreting star (Vila 1977; Shara *et al.* 1977; Sion, Acierno & Turnshek 1978), the resulting luminosity is much too large for the quiescent state of a DN. Two alternatives remain: either the accreted matter is blown back off in the outburst (10^{-10} M must be expelled, and for temperature and density structures like classical nova outbursts have, would produce an Hβ emission line of less than 0·1 Å equivalent width, comfortably below detectability), or the hydrogen accumulates at the average rate of 10^{16-17} g s^{-1}, giving rise to a classical nova explosion every 10^6 yr or so. We are not aware of anyone who would be desperately unhappy with either alternative.

The second problem is what causes the rapid increase in accretion rate. It also has two possible answers, the supporters of each being exceedingly unhappy with the other. The faucet (tap) that turns the flow on and off can be located either in the cool, mass-losing star or in the outer parts of the accretion disk*. Paczyński (1965) first suggested that the cool star, because of its convective envelope, might be unstable to mass loss on a dynamical time scale, which would eventually turn itself off. He expected this to make a dwarf nova outburst by uncovering hotter, brighter layers of the star, and

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*Right at the first Lagrangian point is another possible location but, short of a Maxwell demon, there does not seem to be any sort of faucet that would function there.

the luminosity would decline as the star adjusted to its new structure. Bath (1969) also originally had in mind changes in the appearance of the cooler star, but later (Bath 1976 and references therein) modified the model so that the dominant effect was the sudden increase in accretion luminosity.

There are several difficulties with this. Firstly, with proper treatment of boundary conditions and non-linear effects, the advertized instability may not, in fact, occur (Paczyński, Ziołkowski & Źytkow 1969; Osaki 1970; Paczyński 1976). Secondly, modellers of the instability disagree on whether it occurs only for deep convection zones (Bath 1976, etc.) or only for shallow ones, corresponding to surface temperatures greater than 5000 K (Wood 1977). Thirdly, there seem to be some divergences between the model and observations. The models require the mass-losing components to be either hotter or cooler (depending on which version you choose) than those of the DNe. Neither is apparently the case, judging from the lack of correlation of outburst behaviour with spectral type of the cool star. In addition, if mass transfer is most rapid during outbursts, one would expect the hot spot where the stream hits the disk to get brighter and/or hotter. It evidently does not (Faulkner 1976; Smak 1971), because the eclipse, due to its being occulted, which is seen during the quiescent phase, disappears during outbursts. There are two ways around this. Firstly, the stream may become so broad that the hot spot covers much of the disk and cannot be eclipsed. This would account for Nevo & Sadeh's (1978) finding that the rising light curve includes an extra light source that masks the period–luminosity relation for the oscillations due to the inner disk. Secondly, the instability may set in and end so rapidly that all the mass is transferred to the disk in a few hours (Pringle 1978, private communication), after which the gas circularizes rapidly and subsequent evolution of the system is controlled largely by viscosity and other processes in the disk itself. In this case, we would simply miss the 'bright hot spot' phase as a rule, and the details of the outburst light curve, periodic oscillations, etc., would result from the same (poorly understood) disk phenomena that we discuss below in connection with the second possible faucet. Finally, at least SS Cyg (Sterne & Campbell 1934), U Gem (Greep 1942) and T Pyx (Steiner 1978) display typical relaxation oscillator behaviour, that is, unusually large outbursts are followed (not preceded) by unusually long inter-burst intervals. This sounds more like a reservoir that has to be filled up to a certain level and then can be emptied by various amounts, rather than material spilling over the top of a gravitational potential barrier. Similar behaviour in the RNe (Steiner 1978) is attributable to the need to refill the reservoir of H on the surface of the degenerate dwarf. The similarity between DNe behaviour and that of the rapid X-ray burster MXB 1730−335 has already been noted by Brecher, Morrison & Sadan (1977).

The other possible faucet site (Smak 1971) is the outer part of the accretion disk itself, as advocated by Osaki (1974) and Paczyński (1977). The idea is that matter is shed at a constant, slow rate from the cool star and accumulates in a toroidal disk until some critical size or density is reached. Syunyaev & Shakura (1978), for instance, suggest that the disk spins down a magnetized white dwarf until the magnetosphere can no longer hold up the disk. The disk suddenly becomes unstable and gas spirals down on to the degenerate dwarf, releasing its gravitational potential energy as the dwarf nova outburst. It is interesting to recall in this connection that the maximum light DN luminosity is comparable with the minimum light nova luminosity, implying that accretion typically occurs at some approximately constant standard rate. The evidence from spectroscopy and eclipse light curves of DNe suggesting that material really does accumulate in the disk between outbursts is discussed by Smak (1976) and Paczyński (1977).

This model also provides answers to the three observational difficulties we found with the unstable star model. Firstly, since the mass transfer rate is a result of a delicate balance among star masses, separations, mass ratio and evolutionary state of the cool component, we expect Ne and DNe to occupy the same range in any one parameter. In the case looked at by Syunyaev & Shakura (1978) an important difference between DNe and Ne would be the stronger surface magnetic field of the degenerate dwarf in the former, the requisite fields being $\lesssim$ present detection limits. Secondly, the hot spot should have the same luminosity at all times and its light should therefore be swamped by that of the inner, accreting disk during outbursts. Finally, after each outburst, the disk will have to build back up to the critical size or density, producing the reported relaxation oscillator behaviour. The model, in addition, is consistent (Madej & Paczyński 1977; Paczyński 1977) with observations bearing on changes of size and temperature of the disk during outbursts, with the known X-ray emission, and with the post-outburst periodic light fluctuations.

An important consequence of the disk-instability model is that, as angular momentum is transported outwards, the outer regions of the disk interact tidally with the stars and return angular momentum from disk rotation back to orbital motion, so that little or no mass is lost to the system. It is therefore a prediction of this model that dwarf nova systems should eventually have classical nova explosions. This will also be the case for the star-instability model provided that either incomplete accretion or a small amount of steady transfer maintain enough material in the outer disk for the tidal interactions to occur.

There are two obvious problems with the disk-instability model. Firstly, the existence of the standstill phase in Z Cam systems indicates that accretion can occur steadily (at least for a little while) at a rate comparable with the average (low) transfer rate in DNe. It may be relevant that such behaviour is found only in systems with short recurrence times, which, in this model, necessarily have higher than average steady transfer rates. The corresponding difficulty for the star-instability model is to explain why the instability occasionally gets stuck in the on position. Secondly, of course, we have no physical understanding of the viscosity in the disk or the sudden change in it that triggers the outburst, unless we invoke Syunyaev & Shakura's (1978) magnetospheric instability; but this is not new. The nature of the viscosity that permits accretion from a disk under any circumstances (cataclysmic binaries, X-ray binaries, black-hole powered QSOs, etc.) is unknown in all cases and concealed in a parameter α. We here merely impose the further condition that α should be a steep function of disk density or size.

Since cataclysmic binaries must have accretion disks of some kind, the star-instability model shares all their difficulties and uncertainties, but it has additional ones connected with the required behaviour of the cool star. Occam's razor undoubtedly plays some part in our preference for the model with only a single set of mysteries.

THE ALL-PURPOSE MODEL REVISITED

Collecting everything together, we can assemble the following unified model. In all cases there is a degenerate dwarf, whose surface we essentially never see (hence the absence of gravitational redshifts remarked upon by Payne-Gaposchkin 1977). It is possible that all the types of systems we have referred to may have subsets or as yet unknown analogues in which the degenerate dwarf has a very strong magnetic field. The only one of these identified so far is the 'polar' group of nova-like variables (Krzemiński & Serkowski 1977), which at present contains at least three objects, AM Her, AN UMa and W Pup (in order of discovery, increasing magnetic field strength and decreasing outburst intensity; these correlations may or may not mean anything).

All systems also contain a relatively late-type star, either more or less massive than the degenerate dwarf, and anywhere from the unevolved main sequence state through sub-giants and giants to (perhaps) completely stripped helium cores. A giant secondary not filling its Roche lobe will transfer some gas to the dwarf via a stellar wind, yielding a symbiotic star. Roche lobe overflow by a giant can give very rapid mass transfer ($\gtrsim 10^{19}$ g s^{-1}) so that an envelope of hydrogen hot enough and dense enough for a nuclear explosion builds up in less than 100 yr. These are the recurrent novae. Between light outbursts, they have two light sources, the giant secondary and the accretion disk around the degenerate dwarf, and are thus noticeably brighter than other kinds of cataclysmic variables.

If the cooler star is a pre- or post-giant and does not fill its Roche lobe, nothing much happens. V471 Tauri and PG 1413+0 are in this state. If it does fill its Roche lobe, then mass transfer will take place at a rate depending in a complicated way on masses, separation, temperature and evolutionary state. In this model, the rate is constant for a given system over the thermal time-scale of the mass-losing star. When that rate is high enough, gas streams from L_1 into an accretion disk whose viscosity is sufficient to keep the gas feeding down onto the degenerate dwarf at the same rate it arrives. Under these circumstances minimum light is due largely to the disk, and, because gas is transferred continuously inward, the rotational structure of the star and the inner disk have come into some sort of happy steady state; this prevents the instability (Bath 1973) or hot spot (Paczyński 1977) which may be responsible for the periodic light fluctuations seen in DNe but not in Ne (except DQ Herc, whose orbital period is notoriously irregular, even as old novae go). At these relative large nova transfer rates, enough hydrogen accumulates to give a nuclear explosion in 10^{4-5} yr. The continuous accretion keeps the receiving surface exceedingly hot, accounting for the high excitation lines that come from the disk, even at minimum light.

If the transfer rate is below some critical value ($\sim 10^{17-18}$ g s^{-1}?), gas builds up in a torus well away from the degenerate dwarf. When some critical disk mass or density is achieved, viscosity increases rapidly and/or a magnetosphere breaks down and accretion sets in at the rate that is continuously maintained in nova disks. Gas from the disk spirals down, and we see a dwarf nova outburst in which the inner disk gets bright enough to swamp the light from the collision hot spot that is responsible for most of the interburst luminosity. The accretion heats up the degenerate dwarf surface, so that photons from it can excite high levels in the atoms of the disk's 'chromosphere', and sloshing of gas and angular momentum back and forth between inner disk and star, perhaps modulated somehow by a magnetic field (Haefner, Schoembs & Vogt 1977), give rise to the quasi-periodic light fluctuations characteristic of the post-outburst phase of DNe. As the outburst dies down, the degenerate dwarf cools off and fails to maintain the high excitation lines. Angular momentum is transferred from the outer disk back to the orbit. This keeps the stars from spiralling together as they would if angular momentum were completely lost to the system, and helps to keep the transfer rate low. Given the low transfer rate, it will take $\sim 10^6$ yr to build up a hydrogen envelope sufficient to yield a nova explosion. Thus, a long-lived astronomer should have about a 3 per cent chance of seeing one of the 300 or so known DNe go off as a classical nova in his lifetime.

From an observational point of view, the difference between disk- and star-instability models of the DN outburst must reduce to the (somehow not so incendiary sounding) question of determining the radial distribution of the generation of luminosity as a function of time through the outburst. Because the short-period oscillations necessarily come from near the degenerate dwarf, further study of their periods and amplitudes as a function of everything else that can be measured are a particularly promising avenue of approach. For instance, in the 'star faucet' case, the initial luminosity increase is due to processes in the outer parts of the disk, to which the oscillations should be quite insensitive, while in the 'disk faucet' case, the outburst begins with accretion onto the star, which ought to trigger or affect the oscillations promptly. In the latter case also, one might expect the luminosity increase to occur first and most rapidly at the shortest (UV or soft X-ray) wavelengths, while in the 'star faucet' case this might not necessarily be so.

Cataclysmic systems caught between outbursts will be seen as nova-like variables, and patience should eventually be rewarded with at least a few DNe, RNe or classical nova explosions among known NL systems. We should be able to predict what sort to expect from the absolute magnitude of the NL system and the excitation state of its spectrum.

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