CLASSICAL NOVAE: PROPERTIES BETWEEN OUTBURSTS

Brian Warner

Department of Astronomy, University of Cape Town

With the recent publication of *Classical Novae*, edited by Bode and Evans, there is no need for me to give a list of novae or their overall characteristics. Furthermore, probably the most interesting developments in the past few years in studies of novae during quiescence have been in those areas (magnetic systems, long term brightness variations) which are reviewed separately at this conference. So that leaves me with the task of making some general comments about recent trends in the more mundane aspects of quiescent novae. However, what may at first sight seem mundane often has importance to theoretical interpretation.

The orbital period distribution

Probably the two most important extensions to our knowledge of nova orbital periods are the recognition of novae *below* the period gap and *in* the period gap. Only a few years ago one of the peculiarities of the nova period distribution that distinguished novae from other subclasses of cataclysmic variables was the restriction of all known novae to above the gap (Robinson 1983; Vogt 1989). The discovery of orbital periods of 88.5 mins in CP Pup (Warner 1985b; Bianchini *et al.* 1985; O'Donoghue *et al.* 1989) and of 85.5 mins in GQ Mus (Diaz & Steiner 1989) not only changes the statistics, it adds further support to notions that all subclasses of cataclysmic variable are able to interchange amongst themselves (Vogt 1982, 1989; Shara *et al.* 1986).

The discovery that V Per has an orbital period of 154 mins (Shafter & Abbott 1989), which places it in the middle of the period gap, is paralleled in other subclasses where the nova-like variable V795 Her appears to have an orbital period of 167 mins (Mironov *et al.* 1983; Rosen *et al.* 1989; Shafter *et al.* 1989), the recurrent nova T Pyx may have a period of 142 mins (Shaefer, Landolt & Warner 1989), and the probable intermediate polar 1H 0709-360 has a period of 147 mins (Tuohy *et al.* 1989).

https://doi.org/10.1017/S0252921100068263 Published online by Cambridge University Press

A list of known orbital periods for classical novae is given in Table 1.

Table 1

Orbital Periods of Classical Novae

Star	P_{orb}(d)	Nova	Star	P_{orb}(d)	Nova
GK Per	1.997	1901	WY Sge	0.154	1783
DI Lac	0.544	1910	RR Pic	0.145	1925
V1668 Cyg	0.439	1978	V1500 Cyg	0.140	1975
BT Mon	0.334	1939	V603 Aql	0.139	1918
V533 Her	0.210	1963	V Per	0.107	1887
HR Del	0.214	1967	CP Pup	0.0614	1942
T Aur	0.240	1891	GQ Mus	0.0594	1983
DQ Her	0.194	1934			

In the period gap

The existence of one or more objects in the previously empty period gap does not call into question all of the theory developed to explain the gap. There is no doubt that the low space density of objects observed to have 2.1 hrs < P_{orb} < 2.8 hrs is statistically significant. In the scheme of angular momentum loss through magnetic braking (Verbunt 1984), stars can evolve through the 2-3 hr orbital period region without becoming detached if they have on average experienced a low rate of mass transfer, $\dot{M}$. This is the conclusion reached by Shafter & Abbott (1989), to explain the present state of V Per. However, this would mean a reversion to the problem of the "hidden parameter" (Warner 1987a) which determines the mean $\dot{M}$ for different systems. In the absence of any direct evidence that such a parameter actually exists, the principle of uniformitarianism, as expoused in the nova hibernation model (Shara *et al.* 1986) or other interchange schemes (Vogt 1982), seems more attractive. V Per and the other gap-filling objects therefore acquire a special interest as exceptions that we may hope will "prove the rule". This can only be achieved if an explanation other than low secular $\dot{M}$ is readily found.

One possibility is that the gap-filling systems have evolved secondaries. Already one piece of evidence may point in that direction: Bailey (1989) finds from the eclipse width that the nova-like variable

https://doi.org/10.1017/S0252921100068263 Published online by Cambridge University Press

1H0709-360 must have a mass ratio $M_2/M_1 > 0.6$. If the secondary obeys the usual main sequence mass-radius relationship, then $M_2 = 0.21\ M_\odot$ and $M_1 \leq 0.35\ M_\odot$. However, if the secondary originally evolved before becoming a semi-detached CV system, and on being stripped of sufficient mass the outer convection zone reached the helium core, it may have mixed to become a helium-rich main sequence star. Such objects have larger masses for a given radius (see Figure 2 of Faulkner *et al.* 1972), which is in the correct direction to explain the anomalously high mass ratio in 1H0709-360.

Extant calculations (Pylyser & Savonije 1988) indicate that the secondary must expand to its Roche lobe *before* developing a substantial helium core if subsequent evolution is to be towards shorter orbital periods. However, these calculations were mostly made for the conservative case; exploration of orbital evolution for the case where regular nova explosions remove mass and angular momentum from the system are required in order to see whether it is possible to get evolved stars to orbital periods ~ 3 hours.

Irrespective of the outcome of this particular suggestion, V Per and its gap-filling conspirators promise to open new windows on CV evolution and demand intensive observational study.

Below the period gap

Below the orbital period gap CVs have in the past been separable into three distinct types (Warner 1985a): the polars (which account for about one third of the objects); the SU UMa stars, which constitute most of the remainder; and two intermediate polars, EX Hya and SW UMa, of which the latter is simultaneously an SU UMa star (Shafter *et al.* 1988). Now that we know two classical novae (CP Pup and GQ Mus) below the period gap (Warner 1985b; Diaz & Steiner 1989), it is natural to ask whether these constitute another separate class, or whether they develop from the explosion of one or more of the existing classes. What is notable is that, unlike the situation above the period gap, there is not a populous group of non-eruptive, non-magnetic nova-like systems that can be identified as pre- or postnovae.

Neither CP Pup nor GQ Mus were known as dwarf novae before their nova explosions. Both had very faint prenova magnitudes (>17 for CP Pup: Gaposchkin 1946, and 19-20 for GQ Mus: Beuermann 1983), but may well have been discovered as SU UMa stars if they had had superoutbursts. From the fact that CP Pup and V1500 Cyg have both settled down to postnova brightnesses considerably brighter than those before outburst (Warner 1985b) we suspect that they, and by analogy GQ Mus as well, were in states of anomalously low $\dot{M}$ prior to eruption. Their postnova quiescent absolute magnitudes of $M_v \sim 5$ (Warner 1985b) place them brighter than what is required to trigger dwarf nova outbursts (Warner 1987a).

For all three objects - V1500 Cyg, CP Pup and GQ Mus - these observations are compatible with them being polars or intermediate polars rather than dwarf novae. V1500 Cyg is now known to be a polar (Stockman *et al*. 1988), albeit temporarily desynchronized, and CP Pup shows evidence for multiple periods (O'Donoghue *et al*. 1989 and this conference) but no circular polarization, implying that if it has a magnetic field it is lower than most polars (but it could be similar to V2051 Oph which appears to be a low-field polar (Warner & O'Donoghue 1987). The light curve of GQ Mus now resembles that of a polar (Diaz & Steiner 1989) and the absence of circular polarization earlier in the outburst decline (Cropper 1986), when it will have been diluted by other contributors, is probably no argument against a strong magnetic field.

The evidence so far, therefore, is that the two known novae discovered below the orbital period gap developed from magnetic systems rather than SU UMa stars.

Masses of white dwarfs in Novae

The topic of masses of CVs is one where we have probably lost more ground than gained in the past decade. In principle, the fact that all CVs possess Roche geometry should aid the determination of masses - the fact that the mean density of the secondary star is accurately determined by the orbital period is the starting point; an empirical mass-radius relationship for lower main sequence stars then gives the secondary mass (Patterson 1984). Again in principle, the white dwarf mass is then obtainable if its radial velocity amplitude, K_1, and the inclination of the orbit are known.

The weak points of this approach are (i) the use of an assumed M-R relationship when theoretically it is expected that the secondaries will be out of thermal equilibrium - although Patterson (1984) has shown that the M-R relationship for CV secondaries does not noticeably depart from the empirical relationship for single stars - and, more importantly, (ii) the determination of K_1 from disc emission lines. It was pointed out by

Robinson (1983) that observers rarely agreed on measurements of K_1, and Wade (1985) has catalogued the anomalies observed in radial velocity curves of emission lines from CVs. The two principal difficulties are that K_1 depends (by a factor of up to 2) on where in the emission line profile the velocities are measured, and that unexplained phase shifts between radial velocity and photometric phases occur. The first of these factors clears up most of the apparent differences between observers. As the mass function contains a factor K_1^3, any errors are greatly magnified in the mass determination. From a statistical discussion of eclipsing CVs, Bailey (1989) has shown that in many CVs K_1 is typically overestimated by a factor ~1.5 to 2.

Before discussing some more satisfactory results for novae masses, more general remarks on CV masses are necessary. If we accept the nova hibernation model (Shava *et al.* 1986), or any other scheme which results in interchange between all CV subtypes, then measurement of *any* masses - for dwarf novae, nova-like variables, polars, etc. - are relevant to the novae. However, there are strong selection effects to be considered - if nova frequency is a strong function of white dwarf mass (Livio & Soker 1984) then those novae that we have observed in the last century or so will preferentially have come from the high mass end of the distribution. These effects have been considered in detail by Ritter & Burkett (1986), who show that there is also a strong tendency to discover preferentially the dwarf novae with higher masses.

Rejecting mass determinations based on K_1 measurements leaves only the longer orbital period systems where the secondaries are bright enough to be seen despite the brightness of the nova disc. Here we have the fortunate circumstance that the secondary will be more readily detected in systems of high inclination, where the disc is viewed edge-on. Thus the eclipsing systems, where a sufficiently accurate estimate of inclination is simultaneously available, provide the optimum situation for measurement of nova masses. Yet none of the four relatively bright eclipsing novae (T Aur, DQ Her, BT Mon, V Per) has been observed in this way.

Instead, we have results for two non-eclipsing novae: GK Per and V1500 Cyg. In GK Per (Crampton *et al.* 1986) the secondary has a velocity amplitude $K_2 = 34 \pm 5$ km s^{-1} from its absorption lines, but this cannot be combined with a M-R relationship because the secondary is evolved. With the additional uncertainty in the inclination, no good determination of masses is yet possible; Crampton *et al.* give a most probable mass of 0.9 $M_\odot$ for the white dwarf.

In V1500 Cyg (Horne & Schneider 1989) spectra taken in 1981 show narrow emission components phased with the motion of the secondary. These are interpreted as resulting from irradiation by the primary, which necessitates modelling of their intensity distribution over the illuminated hemisphere of the secondary. Horne & Schneider deduce a minimum mass of 0.9 $M_\odot$ for the white dwarf in V1500 Cyg, in accordance with theoretical requirements for a high mass white dwarf in a nova with such a large amplitude and rapid decay.

Discovery of novae with high inclinations should be relatively easy if use is made of the tight correlation between the equivalent width and inclination (Figure 8 of Warner 1987a): any novae with $W(H\alpha) \geq 25$Å are candidates for eclipsing systems. In particular, note that the value $W(H\alpha) \simeq 42$Å in V Per (Shafter & Abbott 1989) leads to $i \sim 82^\circ$, in agreement with its eclipsing nature.

Curiously, a more secure result on the mean mass ratios and mean white dwarf masses in CVs has come from abandoning spectroscopic measurements in favour of photometry. Bailey (1989) shows from the frequency distribution of eclipse widths that below the orbital period gap the average $q = M_2/M_1 = 0.13 \pm 0.03$, whereas above the gap $q = 0.65 \pm 0.12$: but the latter value is subject to selection effects and should possibly be nearer to 0.9. In addition, for the short period group Bailey finds $M_1 \sim 0.6$ $M_\odot$ from the recognizable eclipse features of the white dwarf components. As this group does not contain any nova remnants, it does not contain systems biassed towards high masses. Given enough eclipsing nova systems, Bailey's technique could be used to prove the higher mass tendency of novae. Similar results for q and M_1 are obtained from detailed modelling of the light curves, assuming only that the bright spot lies along single particle stream trajectories (Wood 1987). Bailey's results for the short period systems are in agreement with current theoretical work on evolution with mass loss through nova outbursts (Hameury *et al.* 1989).

Observed ranges of classical novae

As I have previously pointed out (Warner (1987a), much of the dispersion in the Amplitude-Rate of Decline relationship for novae is caused by the different inclinations of the accretion discs at minimum light. Thus DQ Her is about 4 magnitudes fainter than it would appear if seen face on, and the newly identified eclipsing system V Per is about 3 magnitudes fainter than face on. I have given a list of 10 novae that fall significantly off of the general relationship (Table 8 of Warner 1987a), all appearing 2 to 4 magnitudes brighter than other nova remnants. The recent work of Duerbeck (Bode *et al.* 1989) has resulted in removal of at least six of these "problem stars": in four cases the identification of the remnant was incorrect and in one case a much brighter maximum magnitude is suspected. No doubt the remaining stars, AR Cir, HS Sgr, V1016 Sgr,and FS Sct, will also be found more consistent with the other novae, with the result that mean absolute magnitudes of novae in quiescence will remain remarkably uniform (Table 2: Warner 1987a)

Table 2

Mean range and absolute magnitudes of novae at quiescence

Speed Class	Mean Absolute	Mean Range Magnitude
VF	4.4	13.2
F	3.7	11.3
MF	4.4	10.9
S, VS	4.1	9.6
VVS	5.2:	9.4:

This result of course only has implications for the uniformity of mass transfer into the discs of novae; the white dwarfs themselves may have a variety of properties.

The prenova-nova transition

If it had been possible to carry out an all-sky survey for ultraviolet-rich objects in the year 1900 the results would have been very little different from what we find today. But if such a survey had led to the intensive investigation of all such objects brighter than V = 14.5 we would have had detailed knowledge of 5 objects before they became novae - namely GK Per (V ~ 14), V603 Aql (12.0), RR Pic (11.9), DQ Her (14.5) and HR Del (12.1), which became novae in 1901, 1918, 1925, 1934 and 1967 respectively.

Clearly the time is approaching when we may see another nova arising from an object brighter than 14.5, so we should attempt to have good observational studies of all potential candidates. Although not all nova-like objects with V < 14.5 are yet known (especially in the southern hemisphere), a list of the presently known objects is likely to contain the expected nova. As it is now known that the magnetic cataclysmic variables are capable of producing novae, to the list of nova-like variables must be added those magnetic systems - all intermediate polars - that have luminosities comparable to prenovae. The list is given in Table 3.

Table 3

Bright Nova-like variables

IX Vel	9.6	V795 Her	13.0	PG 2133 +115	14.0
V3885 Sgr	10.4	HS Vir	13.0	V751 Cyg	14.0
RW Sex	10.8	RW Tri	13.2	V363 Aur	14.2
TT Ari	11.1	VY Scl	13.2	LX Ser	14.4
CL Sco	11.2	V1223 Sgr	13.2	V825 Her	14.4
QU Car	11.4	LB 1800	13.3	RX LMi	14.4
V426 Oph	12.4	AO Psc	13.3	V1315 Aql	14.4
MV Lyr	12.5	CM Del	13.4	V794 Aql	14.5
V442 Oph	12.6	KR Aur	13.5	V425 Cas	14.5
V592 Cas	12.8	TV Col	13.5	BG CMi	14.5
UX Uma	12.8	FO Aqr	13.5	V380 Oph	14.5
KQ Mon	13.0	AC Cnc	13.8	DW UMa	14.5

Included in this list must be a number of remnants of novae that exploded in the nineteenth century and perhaps even earlier. Our predecessors were not assiduous in discovering novae: only one (CK Vul: 1670) was found in the seventeenth century and one (WY Sge: 1783) in the eighteenth. Even in the nineteenth century the first nova was not discovered until V841 Oph in 1848.

If there are ~6 objects per century that leave nova remnants with V < 14.5, and these remain at such brightnesses for up to 200 years on average, and we furthermore assume that we know all such objects that have occurred in the twentieth century, then only about 6 of the objects in Table 3 are nineteenth century postnovae and the remaining ~30 are probable prenovae.

https://doi.org/10.1017/S0252921100068263 Published online by Cambridge University Press

As I have pointed out elsewhere (Warner 1987b), monitoring nova-like varibles is an area where the amateur variable star observers can extend their already invaluable contributions. Apart from the potential of providing the earliest possible notice of a nova on the rise, there is the opportunity of an earlier warning of a nova outburst: Robinson (1975) has drawn attention to the fact that some prenovae have brightened by up to two magnitudes during the year or so prior to explosion. Any nova-like variables showing such a steady rise would be worthy of the closest attention.

References

Bailey, J., 1989. *Mon. Not. R. astr. Soc.*, in press.
Beuermann, K., 1983. *I.A.U. Circ.*, No. 3768.
Bianchini, A., Friedjung,M. & Sabbadin, F., 1985. *Inf. Bull Var. Stars*, No. 2650
Bode, M.F., Duerbeck, H.W. & Evans, A., 1989. In *Classical Novae* eds. M.F. Bode & A. Evans, Wiley, p. 249.
Crampton, D., Cowley, A.P., & Fisher, W.A., 1986. *Astrophys. J.*, *300*, 788.
Cropper, M.S., 1986. *Mon. Not. R. astr. Soc.*, *222*, 225.
Diaz, M.P. & Steiner, J.E., 1989. *Astrophys. J.*, *339*, L41.
Faulkner, J., Flannery, B.P. & Warner, B., 1972. *Astrophys. J.*, *175*, L79.
Gaposchkin, S., 1946. *Harv. Bull.* No. 918.
Hameury, J.M., King, A.R., Lasota, J.P. & Livio, M., 1989. *Mon. Not. R. astr. Soc.*, *237*, 835.
Horne, K. & Schneider, D.P., 1989. *Astrophys. J.*, in press.
Livio, M. & Soker, N., 1984. *Mon. Not. R. astr. Soc.*, *208*, 783.
Mironov, A.V., Moshkalev, V.G. & Shugarov, S. Yu., 1983. *Inf. Bull. Var. Stars*, No. 2438.
O'Donoghue, D., Warner, B., Wargau, W. & Grauer, A.D., 1989. *Mon. Not. R. astr. Soc.*, in press.
Patterson, J., 1984. *Astrophys. J. Supp.*, *54*, 443.
Pylyser, E. & Savonije, G.J., 1988. *Astr. Astrophys.*, *191*, 57.
Ritter, H. & Burkert, A., 1986. *Astr. Astrophys.*, *158*, 161.
Robinson, E.L., 1975. *Astr. J.* , *80*, 515.
Robinson, E.L., 1983. In *Cataclysmic Variables & Related Objects*, eds. M. Livio, & G. Shaviv, p. 1.
Rosen, D.R., Branduardi-Raymont, G., Mason, K.O. & Murdin, P.G., 1989. *Mon. Not. R. astr. Soc.*, *237*, 1037.
Schaefer, B., Landolt, A. & Warner, B., 1989. Unpublished.
Shafter, A.W. & Abbott, T.M.C., 1989. *Astrophys. J.*, *339*, L75.
Shafter, A.W., Szkody, P. & Thorstensen, J.R., 1986. *Astrophys. J.*, *308*, 765.
Shafter, A.W., Robinson, E.L., Crampton, D., Warner, B. & Prestage, R., 1989. In preparation.
Shara, M.M., Livio, M., Moffat, A.F.J. & Orio, M., 1986. *Astrophys. J.*, *311* , 163.
Stockman, H.S., Schmidt, G.D. & Lamb, D.Q., 1988. *Astrophys. J.*, *332*, 282.
Tuohy, I.R., Remillard, R.A., Brissendon, R.J.V., Bradt, H.V. & Schwartz, D.A., 1989. In preparation.

Verbunt, F., 1984. Mon. *Not. R. astr. Soc.*, *209*, 227.
Vogt, N., 1982. *Mitt. Astr. Ges.* *57* , 79.
Vogt, N., 1989. In *Classical Novae*, eds. M.F. Bode & A. Evans, Wiley, p. 225.
Wade, R.A., 1985. In *Interacting Binaries*, eds. P.P. Eggleton & J.E. Pringle, Reidel, Dordrecht, p. 289.
Warner, B., 1985a. In *Interacting Binaries*, eds. P.P. Eggleton & J.E. Pringle. Reidel, Dordrecht, p.367.
Warner, B., 1985b. *Mon. Not. R. astr. Soc.*, *217*, 1P.
Warner, B., 1987a. *Mon. Not. R. astr. Soc.*, *227*, 23.
Warner, B., 1987b. *J. Amer. Assoc. Var. Star Obs.* *15*, 163.
Warner, B. & O'Donoghue, D., 1987. *Mon. Not. R. astr. Soc.*, *224*, 733.
Wood, J., 1987. *Astr. Sp. Sci.* *130*, 81.