Alternatives to Hibernation

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Abstract. I outline the evidence pertinent to the connection between the nova explosion and mass transfer rates in CVs. I conclude that there is still insufficient evidence to decide whether or not such a connection exists.

THE PROBLEM

Systems in which classical nova explosions have been observed are structurally indistinguishable from other cataclysmic variables (CVs). They all consist of a low-mass late-type, normally main-sequence star losing mass via Roche-lobe overflow to a white dwarf. The magnetic field of the white dwarf can cause differences in the detail of how the accretion flow reaches the white dwarf. A strong magnetic field will channel the accretion flow straight onto the white dwarf (a “polar” or AM Her star) whilst a weak field will allow an accretion disc to form, with intermediate cases occurring when the inner disc alone is disrupted by the field (an “intermediate polar” or DQ Her star). However, it should be emphasized that all these sub-classes occur amongst both classical novae and other CVs, again arguing for a close relationship between the two. The obvious conclusion to draw is that all CVs eventually undergo a nova explosion, and that those we classify as old novae, happen to have had an explosion in the recent past.

One of the outstanding problems in understanding CVs is the large range of mass transfer rates they have. If we concentrate on the non-magnetic systems, where the problem is best understood, we find a range of about a factor of 100, even if we restrict ourselves to systems with similar orbital periods. Part of the non-magnetic CV classification system is based on this difference, with the high mass transfer rate systems being classified as UX UMa stars, the intermediate ones as VY ScI and Z Cam stars, and the low mass transfer rate systems as dwarf novae.

THE SOLUTIONS

Shara and collaborators [1] suggested that nova explosions may hold the key to explaining the differences in mass transfer rate. In essence their idea is that the explosion coincides with a period of high mass transfer rate, and centuries after the explosion the mass transfer decreases, and finally ceases altogether. The detached binary then “hibernates”, until angular momentum loss brings the system back into contact, mass transfer begins again, laying down on the white the material for the next nova explosion.
The attraction of what became known as the “hibernation scenario” was twofold. First, at the date it was proposed, it appeared that the observed mass transfer rates in CVs were much higher than those which the models required for a nova explosion to occur \[2\]. However, whilst the models of Starrfield, Sparks & Truran still require low mass transfer rates \[3\], the Prialnik & Kovetz models [e.g. 4] do undergo explosions for mass transfer rates similar to those observed in CVs. The second attractive feature was that a host of evidence seemed to imply that old novae continued to fade for at least two hundred years after outburst, as though their mass transfer rates were declining and the binary heading towards “hibernation”. The evidence for this decline was questioned by myself and others \[5\], leading us to suggest that the evidence is perfectly consistent with the idea that the nova explosion is unconnected with the mass transfer rate in the binary \[6\]. Thus if a system was a dwarf nova before the classical nova outburst, it will be so again immediately afterwards, and continue to be so for many nova explosion cycles. For the purposes of contrast, I will refer to this as the “constant mass transfer model” or simply CMT.

That two apparently orthogonal theories can be consistent with the observational evidence is, perhaps, surprising. In this paper I aim to review the current evidence for links between mass transfer rate and the time of nova outburst. I shall begin by discussing the evidence for the systems with long orbital periods, i.e. greater than 0.2 days.

ARE ALL NOVAE UX UMA STARS?

A few years after the nova explosion, virtually all classical novae appear to be high mass transfer rate cataclysmic variables. In the case of the non-magnetic systems, this means they are UX UMa stars. Furthermore, their very similar magnitudes before and after the explosion \[7\], implies that they were also at high mass transfer rates before the explosion. Whilst this may, at first sight, appear to support the idea that there is a mass transfer cycle, at the peak of which the system explodes as a classical nova, in fact it probably simply tells us that low mass transfer rate systems only rarely have nova outbursts. The reason is that it will take them longer to build up the layer of material required for the runaway [e.g. 8]. Further evidence that this is the correct interpretation was provided by the discovery that Nova Her 1960 (V446 Her) is a dwarf nova \[9\], and the data of \[7\] imply it was probably a dwarf nova before its nova outburst.

THE POST NOVA DECLINE

In the first hundred years after the nova outburst the system luminosity declines by around 2 magnitudes. This was first shown by correlating the age of each nova with its current brightness [10], but later also by following individual systems [11]. Whilst such a decline could be caused by a decline in mass transfer rate, it could also be due to irradiation of the disc and secondary star by the white dwarf, which is hot as a result of the nova explosion, and is cooling. Support for this idea came first from observations of Nova Cyg 1975 (V1500 Cyg) [12]. The observations show that the inner face of the
secondary star is heated by the white dwarf, and that the degree of heating is declining with time. The data can be modeled to deduce the temperature of the white dwarf, which is found to be falling at the rate expected by theory. This suggests that it is not actually light from the white dwarf itself which is responsible for the post-nova decline, but the decline in flux which is reprocessed by the secondary star and accretion disc. There are calculations of the reprocessing from the disc alone, which suggest this is correct [13].

If white dwarf cooling is the reason for the post-nova decline, more observations are explained. First, there is evidence that the decline in magnitude ceases after about 100 years, as the white dwarf cooling models predict. Nova Sge 1783 (WY Sge) is now 200 years old, but the binary still has the magnitude expected for high mass transfer rate system [14, 15]. Secondly, old novae sometimes seem to undergo low amplitude dwarf nova-like outbursts. It seems these can be explained by the white dwarf irradiation maintaining the inner disc in the viscous state, whilst an outer annulus undergoes dwarf nova outbursts [16]. The small region of the disc participating in the outburst explains its low amplitude.

CONCLUSIONS FOR LONG PERIOD SYSTEMS

The real problem here is that the predictions of hibernation and CMT have converged. The hibernation model predicts that the decline in mass transfer will drive a decline in luminosity after the nova outburst. Presumably this is already happening in Nova Her 1960, and will happen for Nova Sge 1783, if we wait long enough. A CMT model accepts there is a decline in luminosity caused by the falling irradiation from the white dwarf, but asserts this stops after about a hundred years. In the CMT view, those old novae which show mass transfer rates below the mean are the few low mass transfer rate systems we expect to find. Thus the discovery by [17] that Nova Sco 1860 (T Sco) lies at a brightness level suggesting a long period dwarf nova, is consistent with either model.

SHORT PERIOD SYSTEMS

Whatever view one takes of the post-nova decline, until very recently all the evidence supported the idea that mass transfer rate is broadly the same before and after the explosion. Again both theories accept this, as the hibernation models bring the CV up to the high mass transfer state before the explosion, and the CMT model requires it. Such a picture, though, was built up when all old novae with reliably determined orbital periods had periods longer than about 0.2 days. This has now begun to change, and as new systems are being discovered, there are signs that the picture presented above may not apply to short period systems.

Perhaps the most important point to make first is that high mass transfer rate, short orbital period systems simply should not exist. Figure 1 shows the usual way of classifying non-magnetic CVs, in a plot of mass transfer rate against period [19]. For short periods the only angular momentum loss mechanism available is gravitational radiation, which cannot support (at least in the long term) the high mass transfer rates observed
FIGURE 1. The orbital period vs mass transfer rate plane for cataclysmic variables. The two dotted vertical lines mark the approximate limits of the period gap. The lines marked MB and GR show the expected mass transfer rates for magnetic braking and gravitational radiation respectively, and the unlabeled line divides high mass accretion rate (stable) discs from low mass accretion rate ones. The points for CP Pup and V1794 Cyg are marked. Adapted from [18].

in the old novae CP Pup and V1974 Cyg. Retter and I [18] pointed out that these two systems (which are the best studied ones below the period gap), appear brighter after the nova outburst than they were before it – in contrast to the behaviour of the long period systems. Duerbeck [20] suggests that this effect may be more widespread, including systems with periods above the period gap, but less than 0.2 days.

Retter argues that these results suggest that mass transfer rates below the period gap are driven by the nova explosion. After the nova explosion the mass transfer rate is high, before dropping decades or centuries later. Although this is broadly a “weak hibernation scenario”, one should note a crucial difference – the system is faint immediately before the nova outburst, whilst in the normal hibernation models it is bright. If mass transfer rates do vary in this way, it would explain why there are some systems well above the mass transfer rate allowed by gravitational radiation; they are only there for a short while as a result of the nova event, and will eventually fall back to their original level. I have my own reservations. First, there is no good physical theory of how the cycles would work since simple mass loss cannot drive them [21], nor can irradiation [22]. Secondly, due to their small orbital separation, these short period systems are the ones we would expect to show the greatest effects of irradiation. Thus systems which were probably dwarf novae before their nova explosions, like Nova Cyg 1992 (V1974 Cyg), will find their discs being held in the bright state by irradiation for a relatively long time by the mechanism outlined in [16]. Clearly one solution to this debate is to wait, and see if as the irradiation declines, V1974 Cyg begins to show dwarf nova outbursts. However, as the white dwarf takes decades to cool, quicker resolutions would clearly be preferable.
CONCLUSIONS

For the long orbital period systems (>0.2 days), it is clear we see considerable irradiation from the white dwarf in the decades after outburst, which certainly raises the overall luminosity. Whether when this phase is over, the binary simply returns to its pre-outburst state, or mass transfer then declines into “hibernation” remains an open question. For the systems with orbital periods below 0.2 days, there is emerging evidence that they are fainter before outburst than afterwards. This may simply be because most of them are low mass transfer rate systems (dwarf novae) whose post outburst luminosity is held high for a few decades by intense irradiation. Alternatively short period systems may have mass transfer cycles driven by the explosion. Discovering which of these scenarios is correct is crucial to our understanding not only of classical novae, but also of CVs in general.

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