Novae Crossing the Thermal Stability Line

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Abstract

A method, based on the disc instability model, for testing the thermal stability of Cataclysmic Variables (CVs), is presented. It is shown that the border line between thermal stability and instability is crossed during some nova outbursts and decays, however it is not clear whether this is the general behaviour. We suggest two new evolutionary scenarios for short orbital period CVs. One of them is the analogy for the ‘modified hibernation scenario’ and the other is an extension of the ideas of Mukai & Naylor (1993) for long orbital period CVs. We conclude that the observations have not favoured one of the two models. Finally, we speculate the existence of a new type of nova - an AM CVn like nova.

1. Introduction

Osaki (1996) schematically divided the \((P_{\text{orb}}, \dot{M})\) plane into four regions. Long orbital period CVs (nova-likes and U Gem systems) are tidally stable, while short period systems (SU UMa and permanent superhump systems) are tidally unstable. CVs above his critical line (nova-likes and permanent superhumpers) are thermally stable, while the accretion discs of systems below this line (U Gem and SU UMa systems) are thermally unstable. Are these limits crossed? It is clear that the tidal stability limit is hard to cross. In order to do so, the binary period has to be changed. However, a change in the mass transfer rate through the disc (\(\dot{M}\)) is much easier. Only an outburst is required for increasing \(\dot{M}\). Indeed SU UMa systems are thermally unstable in quiescence, but the appearance of superhumps in their light curves seems to be evidence that they become quasi stable during superoutbursts. In this work, we concentrate on a different way of crossing this line - by outbursts (and decays) of non-magnetic classical novae.
2. Models for CVs Evolution

The spectrum of a typical old nova shows a strong continuum and emission lines. Nova-likes have similar features. Novae, nova-likes and dwarf novae share a similar binary configuration, namely a white dwarf and a red dwarf. It was thus suggested that these subclasses of CVs are evolutionarily connected. The 'hibernation scenario' (Shara 1989 for review) suggests that dwarf novae → nova-likes → novae → nova-likes → dwarf novae → hibernation → dwarf novae etc. However, it is now believed that the hibernation stage ($\dot{M}=0$) might not exist at all (Livio 1989), thus dwarf novae → nova-likes → novae → nova-likes → dwarf novae... The typical time scales for the transitions were estimated as a few centuries.

There is some observational evidence that supports this model. Livio (1989) listed a few old novae, which probably experienced dwarf nova outbursts a few decades before the nova event. However, Robinson (1975) compared the magnitudes of 18 old novae with the values of their progenitors. He found no significant difference between these numbers, and concluded that all novae return to their pre-outburst luminosities. Although there are many light sources in old novae, it seems that their accretion discs are above the line (see section 4 and Warner 1995a). Since old novae are usually indistinguishable from nova-likes, it means that the outburst does not alter the thermal stability at all, at least at the order of a few decades. Robinson also pointed out the peculiarities of Nova V446 Her 1960. It is the only clear case of a classical nova that performed dwarf nova outbursts a few decades before the nova eruption and afterwards (Honeycutt et al. 1998). According to the 'modified hibernation scenario' V446 Her is different from other novae only by the time scales of the evolutionary processes.

An alternative view to the 'hibernation scenario' was presented by Mukai and Naylor (1993). They suggested that nova-likes and dwarf novae constitute different classes of pre-nova systems. Therefore, there are two possibilities:
1. nova-likes → novae → nova-likes...
2. dwarf novae → novae → dwarf novae...
Nova-likes should have more frequent nova outbursts than dwarf novae because their mass transfer rates are larger than those of dwarf novae, so the critical mass for the thermonuclear runaway is achieved much faster. In the first option the thermal stability line is not crossed at all, while dwarf novae can cross the limit in the rare occasion of a nova outburst. It seems that the observations of old novae have not been able to judge between the 'modified hibernation scenario' and the different view.
3. A Method for Testing the Thermal Stability

Retter and Leibowitz (1998) presented a very simple way to determine the thermal status of CVs, and particularly of old novae. We briefly summarize here this work. The equation for the thermal stability border-line is taken from Osaki (1996). It is assumed that the accretion disc is the dominant light source in the V band. The bolometric correction \( \frac{L_V}{L_{bol}} \) is estimated from models of stationary accretion discs (laDous 1989). A classical relation between the mass and radius of the white dwarf and typical white dwarf values are used for eliminating the radius of the white dwarf from the equations. The resulting two expressions are:

An equation for the critical V magnitude for crossing the thermal stability line:

\[
(m_V)_{crit} = 2.16 - 4.25\log(P_{orb}) - 3.33\log(M_{wd}/M_\odot) + 5\log(d) + A_V
\]  

(1)

An equation for estimating the mass transfer rate:

\[
\dot{M}/(10^{17} \text{gr/sec}) = (10^{\frac{m_V-A_V-0.69}{2.5}}) \frac{d^2}{(M_{wd}/M_\odot)^{4/3}}
\]  

(2)

where \( P_{orb} \) is the orbital period, \( M_{wd} \) - the white dwarf mass, \( M_\odot \) - the solar mass, \( d \) - the distance to the binary system and \( A_V \) is the interstellar reddening in the V band.

4. The Early Presence of the Accretion Disc in Young Novae

Even if the starting point of a pre-nova is in the lower, thermal instability zone as a dwarf nova, it is not clear that the nova eruption would carry the system into thermal stability, because the presence of an accretion disc is required. It was believed that the nova outburst destroys the disc, and that it takes only a few decades for the accretion disc to reform. However, observations of a few young novae, carried out at Wise Observatory, showed that in three cases the typical time scale for the re-establishment of the disc is weeks to very few years (Leibowitz et al. 1992; Retter, Leibowitz & Ofek 1997; Retter, Leibowitz & Kovo-Kariti 1998). It is therefore probable that the accretion disc even survives the nova event. Anyway, if a pre-nova is thermally unstable, the time scale for crossing the thermal stability limit can be very short.

5. New Evolutionary Scenarios for Short Orbital Period CVs

We focus now on short orbital period CVs. So far there are only two non-magnetic novae below the period gap - CP Pup 1942 and V1974 Cyg 1992. Both perform permanent superhumps in their light curves (Retter et al. 1997; Patterson
& Warner 1998). To these systems, we naturally add V603 Aql 1918, the third permanent superhump nova (Patterson et al. 1997), whose binary period extends to the other side of the gap. (We note in passing that the division between tidally stable and unstable CVs is probably a little above the period gap).

Since all three systems are permanent superhumpers, there is no doubt that their accretion discs are thermally stable, and indeed a calculation, based on the equations presented above, confirms it. However, when we compare the pre-outburst luminosities with the post nova values, various types of behaviour are discovered. V603 Aql seems to have returned exactly to its pre-outburst magnitude. The upper limit on the brightness of the progenitor of CP Pup (Warner 1995b) shows that it was fainter than its post outburst value, but prevents a precise decision concerning the thermal stability of the pre-nova. V1974 Cyg is the most interesting case among the three novae. It is relatively a young nova, which might still be decaying towards quiescence. Retter & Leibowitz (1998) showed that the pre-nova was thermally unstable. It is thus the only clear case of a classical nova that changed its thermal stability state. Retter & Leibowitz also anticipated two possible scenarios for the future status of the nova. It will either stay above a certain brightness level, keeping its permanent superhump state, or if decays below this limit, it will become thermally unstable again, turning into a regular SU UMa system. Such a transition has never been observed in any nova.

Retter & Leibowitz also suggested that permanent superhump systems might be ex-novae. Observational evidence for this idea comes for the possible identification of BK Lyn, a permanent superhump system (Skillman & Patterson 1993), with a Chinese guest star, erupted in 101 (Hertzog 1986). We also note that two SW Sex candidates are old novae (Hoard 1998). Since permanent superhumps have been revealed in many SW Sex systems (Patterson 1998), we regard this fact as another supportive evidence for this notion.

We further propose that evolutionary scenarios, similar to those offered for the long orbital period CVs, are applicable to the short orbital period systems, too. The nova outburst is suggested as a mechanism for taking the accretion discs of SU UMa systems from the thermal instability zone into the stable part of the plane. After a few decades-millenia, the systems may decay back to their pre-outburst state. This scenario (SU UMa systems → permanent superhump systems → novae → permanent superhumpers → SU UMa systems...) resembles the 'modified hibernation scenario'. A different view, as mentioned in section 2, is that permanent superhump systems experience nova outbursts more often than SU UMa systems do. The two options are:
1. permanent superhump systems → novae → permanent superhump systems...
2. SU UMa systems → novae → permanent superhumpers → SU UMa systems...
6. Predicting the Presence of a New Type of Nova

Classical novae are believed to occur on a binary system, that consists of a white dwarf and a red dwarf. In this section we speculate on the existence of a different kind of nova - a helium AM CVn like nova, which consists of two degenerate helium white dwarfs.

The orbital periods of AM CVn systems are very short (\(P_{\text{orb}} = 17 - 50\) min.). Their spectra are rich in helium lines, but lack hydrogen lines. The standard model for these objects is that they consist of two degenerate helium white dwarfs, orbiting around each other in a very close orbit (Warner 1995b). During the last few years, superhumps have been found in five of the six known AM CVn members (Patterson 1998). Two systems are now believed to be in a permanent superhump state, while the other three are considered as helium dwarf novae. The disc instability model was successfully applied to these systems by Tsugawa & Osaki (1997).

We continue the analogy between long and short orbital period CVs and apply it to the ultra-short period AM CVn systems. We propose that the two AM CVn permanent superhumpers are thermally stable as regular permanent superhump systems and nova-likes, and that the three helium dwarf novae are the equivalents of SU UMa and U Gem systems, whose accretion discs are thermally unstable. We thus suggest that helium dwarf novae evolve through nova eruptions into the AM CVn permanent superhumpers. The proposed evolutionary link is cyclic. Alternatively, AM CVn permanent superhump systems experience more frequent nova events than helium dwarf novae. In both models, the presence of the new type of nova, an AM CVn-like nova, is unavoidable.

7. Summary

- Nova progenitors are usually thermally stable during the few decades preceding and following their outbursts, but there are a few exceptions.

- Observations show that the thermal stability line is indeed crossed during some nova outbursts and decays. It is not clear whether this transition occurs in all non-magnetic novae or just a small part of the population.

- In a few cases the thermal stability line is crossed very shortly after the nova eruption.

- The time scales for crossing the line from top towards bottom is probably of the order of a few decades to a few millenia. It is also possible that in some
or most cases the novae stay thermally stable during all the time interval between successive nova outbursts.

- Two evolutionary scenarios for short and ultra short orbital period CVs have been offered. They are similar to the scenarios for long orbital period CVs.
- Based on the similarities between the different superhumping subclasses of CVs, the presence of a new type of nova, an AM CVn-like nova, is suggested.

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