The disk vanishes

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ABSTRACT

Recently published observations of VY Scl stars in their low, long-intermediate and high states confirm our model (Hameury & Lasota 2002) according to which accretion disks in such systems must vanish when their temperature corresponds to thermally unstable configurations. An observational confirmation of the hypothesis that the disk disappearance is caused by magnetic effects would have important consequences for cataclysmic variable evolution models.

Subject headings: accretion, accretion disks – novae, cataclysmic variables – stars: individual (TT Ari, MV Lyr, DW UMa) – ultraviolet: stars – white dwarfs

1. INTRODUCTION

VY Scl stars are a subclass of Nova-Like (NL) Cataclysmic Variables (CVs) which show in their long-term light curves the presence of long low states (see e.g. Warner 1995). The brightness variations are generally attributed to variations in the rate at which the secondary star loses matter accreted by the primary white dwarf. Similar luminosity variations are observed in highly magnetized AM Her stars – since these CVs do not have disks these can be only due to mass-transfer variations. On the other hand, in contrast with AM Her stars, all VY Scl stars have orbital periods between ~3 and ~4 hours.

In their high states VY Scl stars (in which accretion disks are clearly observed) are among the brightest stationary CVs but their descent to low states brings them into the range of absolute magnitudes typical of Dwarf Novae (DN) – CVs undergoing more or less regular outbursts – yet no DN-type outburst from VY Scl stars has been observed.

There are therefore two VY Scl puzzles. First, the cause of the observed mass-transfer variations. Second, the reason for the absence of dwarf-nova type outbursts in the regime of physical parameters where they are expected. In this article we address only the second, showing that the solution proposed by Hameury & Lasota (2002, hereafter HL02) has been strongly confirmed by observations (Gänsicke et al. 1999; Linnell et al. 2005; Stanishev et al. 2004). The first puzzle is still unsolved and is part of the larger puzzle of CV evolution.

2. No disk, no outburst

Dwarf nova outbursts are clearly related (Smak 1983) to a thermal instability occurring when the effective temperature of the accretion disk corresponds to partial hydrogen ionization, i.e. $T_{\text{eff}} \approx 5800 - 7200$ K (see e.g. Lasota 2001). Outside this instability strip, accretion disks are either in hot or cold stable equilibria. In such (constant accretion rate) disks the effective temperature decreases with radius (e.g. the celebrated “$r^{-3/4}$ law” for hot disks). Therefore, for a given mass transfer rate, a disk truncated at an inner radius corresponding to effective temperature $\lesssim 5800$ K will be cold and stable (Lasota et al. 1995). Hence the idea that the absence of outbursts during the low states of VY Scl stars is due to such truncation. Leach et al. (1999) assumed that truncation is due to irradiation of the inner disk by the hot white dwarf. HL02 showed that such a model is not viable because it could work only for low-mass and very-hot white dwarfs, contrary to observations that do not show such a selection. Instead, HL02
showed that truncation by the magnetic field of the white dwarf could explain the absence of dwarf nova outbursts during VY Scl low states. However, HL02 pointed out that the magnetic moment required to explain the absence of outbursts in the low state is not sufficient to prevent outbursts during long intermediate states when VY Scl stars fall to or rise from the low state. No outbursts are observed during intermediate states. As explained by HL02, when the characteristic time of mass-transfer rate variations is longer than the disk’s viscous time, the disk structure follows a sequence of quasi-equilibrium states and outbursts are unavoidable if the disk temperature corresponds to the instability strip. The only way to prevent outbursts is to get rid of the disk: no disk, no outbursts. Or, at least no dwarf-nova outbursts. The disk must vanish at the latest when it would enter the instability strip.

HL02 assumed in their calculations that the cause for the disk disappearance is magnetic: it vanishes when the white dwarf’s magnetospheric radius is approximately equal to the circularization radius. Numerical simulations give a typical value of the required magnetic moment as \( \gtrsim 7 \times 10^{32} \text{G cm}^3 \).

To summarize: HL02 predict the absence of accretion disks in VY Scl during the low state and during a substantial fraction of the intermediate states; when entering the hot stable regime of mass-transfer rates the disk is gradually re-formed until it gets back to its full extent in the high state. All these predictions have been confirmed by observations.

3. Confrontation with observations

Günsicke et al. (1999) found that the spectra of the VY Scl star TT Ari observed during a low state show (“virtually”) no signs of an accretion disk. A similar conclusion was arrived to by Linnell et al. (2005) who found that if the disk were present during the low state of MV Lyr its effective temperature would have to be less than 2500 K. This is of course compatible with an absence of a disk and thus confirms the HL02 predictions. Somewhat paradoxically Linnell et al. (2005) claim that their conclusion is “in conflict” with HL02. This is because they compare their interpretation of IUE archival observations with the model HL02 use to show that disc truncation is not sufficient to prevent outbursts during long intermediate states of VY Scl stars. Since MV Lyr is a very slow riser (few hundred days) this model is not supposed to apply to these system and there is not contradiction whatsoever between Linnell et al. (2005) and HL02.

Indeed they also observed MV Lyr in an intermediate state and found that the spectra can be well represented by a disk extending only out to half of the tidal truncation radius. A similar conclusion was reached by Stanishev et al. (2004) who observed the eclipsing VY Scl star DW UMa in an intermediate state. Using eclipse mapping techniques they found that the luminosity difference between the intermediate and the high states is almost entirely due to the increase of the disk radius from \( \sim 0.5 \) to \( \sim 0.75 \) of the distance from the white dwarf to the Roche L1 point. These two observational results are also in a very good agreement with the HL02 model (Hameury & Lasota 2005a,b).

The Linnell et al. (2005) intermediate-state model is isothermal and truncated at 1.7 of the white dwarf radius. This radius is much too small compared to the requirement of HL02 but since according to the authors the contribution to the flux from innermost annuli is small this is not very constraining. One should also note that Linnell et al. (2005) do not take into account the accretion luminosity of the matter falling onto the white dwarf.

4. Conclusions

The properties of VY Scl stars that according to HL02 are required to avoid dwarf-nova outbursts during low and long intermediate states have been found in at least three binaries of this type.

HL02 assumed that the disk vanishing is due to the magnetic field of the white dwarf. The direct evidence of magnetic moments \( \gtrsim 10^{32} \text{G cm}^3 \) in VY Scl stars is still missing. As explained in HL02 this evidence is not easy to find. The current lower limit for detection of magnetic fields in CVs is \( \sim 7 \times 10^6 \) G (Wikramasinghe & Ferrario 2000), which for parameters of MV Lyr, say, would correspond to \( \sim 2.5 \times 10^{33} \text{G cm}^3 \). Confirmation of the magnetic nature of the VY Scl stars would have important consequences for models of CV evolu-
tion since it would increase the fraction of magnetic systems among the CVs and change the observed distributions of magnetic vs non-magnetic cataclysmic binaries (see G"ansicke 2005). It could support the suggestion of Reg"os & Tout (1995) that CV primaries are more magnetic than isolated white dwarfs because they went through a common envelope phase. In any case there is growing evidence that binaries containing white dwarfs with fields \(< 7 \times 10^6 \) G may constitute the dominant fraction of the apparently “non-magnetic” CVs (see e.g. Warner 2004).

If the quest for magnetic moments in VY Scl stars fails, one would have to look for other reasons of the disk vanishing. Accretion disks cannot be present during most of the intermediate state duration. If they were they would go into outburst. Not because of the prediction of the disk instability model (see Lasota 2001, for a review), but because CVs with very similar binary parameter do so when they have the corresponding absolute magnitudes.

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