THE SW SEX PHENOMENON AS AN EVOLUTIONARY STAGE OF CATACLYSMIC VARIABLES

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Abstract. From recent large observing campaigns, one finds that nearly all non- or weakly magnetic cataclysmic variables in the orbital period range between 2.8 and 4 hours are of SW Sex type and as such experience very high mass transfer rates. The evolution of cataclysmic variables as for any interacting binary is driven by angular momentum loss which results in a decrease of the orbital period on evolutionary time scales. In particular, all long-period systems need to cross the SW Sex regime of the orbital period distribution before entering the period gap. This makes the SW Sex phenomenon an evolutionary stage in the life of a cataclysmic variable. Here, I present a short overview of the current state of research on these systems.

Key words: cataclysmic variables - SW Sex phenomenon - binary evolution

1. The evolution of cataclysmic variables

Cataclysmic variables (CVs) are semi-detached binaries comprising a Roche lobe filling low-mass main-sequence star transferring matter onto a white dwarf. The evolution of any CV is determined by the loss of angular momentum it experiences. Without any braking mechanism, the angular momentum is conserved in the binary. Hence, the system will spin up when mass is transferred towards the more massive primary and thus closer to the centre of mass. This will eventually result in the secondary getting detached from its Roche-lobe. To establish a stable mass-transfer, the continuous loss of angular momentum is fundamental. The CVs are thus evolving from longer orbital periods towards shorter orbital periods. The standard model predicts magnetic braking as the dominant source for angular momentum loss for long-period CVs ($P \geq 3$ h) while CVs below the period gap ($P \leq 2$ h) are supposed to lose angular momentum via gravitational radiation only. The special case of CVs that reached the orbital period minimum and in which the secondary becomes degenerate has no impact on the SW Sex phenomenon and is thus no further discussed.
Rappaport et al. (1983) suggested the scenario of disruptive magnetic braking with the assumption that the magnetic braking is efficient as long as the secondary star has a radiative core but becomes negligible when the secondary star is fully convective at about $M_2 \approx 0.25M_\odot$. For a Roche-lobe filling secondary star, this mass corresponds to an orbital period of about $P = 3\,h$, i.e. just at the upper edge of the period gap. The secondary star is driven out of thermal equilibrium due to the large mass loss rate and is therefore oversized for its mass. Once the magnetic braking stops, the mass loss rate drops and the star will relax to its normal size in thermal equilibrium, thus losing the contact with its Roche-lobe. The binary is now detached and not detectable as a CV. It is still evolving towards shorter orbital periods by losing angular momentum via gravitational radiation. At an orbital period of about $2\,h$ the Roche-lobe is sufficiently small that mass transfer will be established again but on a low level driven by gravitational braking only.

Even though it is not yet understood why the magnetic braking would cease when the secondary becomes fully convective, the standard model is widely accepted, not least because there exist several pieces of observational evidence for the disruptive magnetic braking scenario. Patterson et al. (2005) showed from superhump measurements that the donor mass of CVs at the upper edge of the gap seems to be similar to the donor mass of CVs just below the gap. This supports the idea that the period gap is indeed a region in which no mass transfer happens and through which the CVs evolve as detached systems. The second evidence comes from the observations that the donors above the gap are more bloated than donors below the gap indicating that they experience more mass loss which drives them out of thermal equilibrium (Knigge et al., 2011). Third, using the temperature of white dwarfs as a measure for the accretion induced compressional heating Townsley and Gänsicke (2009) could show that the accretion rate above the gap is higher than the one below the gap, and last but not least, Schreiber et al. (2010) showed that the mass distribution of post common envelope binaries is in agreement with the predictions of Politano and Weiler (2006) for disrupted magnetic braking.

Observationally, there is thus no doubt for a discontinuity in the mass transfer rate of CVs around an orbital period of $3\,h$ but the reason for the reduced magnetic braking is still under discussion.
2. SW Sextantis stars

SW Sextantis stars are a group of CVs that were originally defined as eclipsing nova-like stars which show single-peak emission lines, high-velocity emission line wings, strong He II emission but no polarisation, and transient absorption features in the emission lines at an orbital phase of $\phi = 0.5$ (Thorstensen et al. [1991]). They also show orbital phase offsets of 0.2 cycles of the radial velocity curves with respect to the photometric ephemeris and are interpreted as having high mass transfer rates (see e.g. Rodríguez-Gil et al. [2007a]). The idea that these binaries have high mass transfer rates is supported by the study of Townsley and Gänsicke (2009) who show that the white dwarf temperature of these stars exceeds the expected value for accretion governed by an angular momentum loss from standard magnetic braking.

Initially, SW Sex stars were considered as odd objects. However, Gänsicke (2005) showed that they are instead common in the orbital period range between 2.8 and 4 h, i.e. the range just above the period gap. In particular, all the eclipsing nova-like systems in this period range belong to the sub-class of SW Sex stars.

Being an eclipsing system is, however, not an intrinsic physical property of the star but rather depends on the angle under which the binary is observed. It thus appears entirely plausible that all non- or weakly-magnetic CVs just above the period gap are physically SW Sex stars, i.e. experience a very high mass transfer rate.

To test this hypothesis, Rodríguez-Gil et al. (2007b) and Schmidtobreick et al. (in preparation) have conducted a survey and obtained time-series spectroscopy on the non-eclipsing CVs with $V \leq 18$ in the 2.8–4 h period range. They searched for the presence of the defining SW Sex characteristics such as broad line wings with large-amplitude radial velocity variations, single-peaked line profiles with phase-dependent central absorption, and phase lags between the radial velocity modulation in the line cores and wings. They also checked for line flaring, an additional feature that is often observed in SW Sex stars but also in intermediate polars and that is manifested in fast oscillations of the emission line flux and velocity with periods around 10-20 min.

As the main result, they found that indeed the majority of the observed CVs in the 2.8–4 h period range, and all nova-like stars among these are
3. SW Sex stars as an evolutionary state

In the previous sections, I have discussed two statements: (1) CVs evolve from longer orbital periods to shorter ones due to angular momentum loss, and (2) most CVs and i.e. all nova-likes in the period range from 2.8–4 h are of SW Sex type. Combining these two facts one can deduce that those CVs that get into contact at longer orbital periods $P \geq 4$ h have to evolve through

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{figure1.png}
\caption{The orbital period distribution as presented by Gänsicke (2005). The regime of the SW Sex stars and the orbital period gap are marked in different colour shades. The evolutionary path of a CV due to angular momentum loss and the position where the magnetic braking gets reduced are indicated.}
\end{figure}

of SW Sex type. Several of these are showing the line-flaring phenomenon. The detailed results of the campaign are discussed in Rodríguez-Gil et al. (2007b) and Schmidtobreick et al. (in preparation). They conclude that SW Sex stars are not oddballs but present instead the major population of CVs in the period range just above the gap.
the SW Sex regime before they enter the period gap and most likely become an SW Sex star during this phase (see Fig. 1). This implies that the SW Sex phenomenon is actually a state in the evolution of CVs. More importantly, it is the state of a CV just before it enters the period gap, i.e. the state in which a CV is when the magnetic braking stops and the binary becomes detached.

To understand the evolution of CVs and in particular the evolution into the orbital period gap, one needs to understand the SW Sex phenomenon. Models that predict or simulate the evolution of CVs and that make use of the magnetic braking and its disruption, also have to take into account that before the binary becomes detached, the CV is most likely an SW Sex star and as such experiences a high accretion rate that cannot be explained by standard magnetic braking.

A special case in this context represent the two old novae XX Tau and V728 Sco, with orbital periods of 3.3 h and 3.32 h, respectively (Rodríguez-Gil and Torres, 2005; Tappert et al., 2012a). Most old novae are high mass-transfer systems (e.g. Iben et al., 1992), and since their orbital periods place these two objects right within the SW Sex regime, they have double reason to fall into this category as does, e.g., the old nova RR Pic (Schmidtobreick et al., 2003). Instead, spectroscopic observations indicate that XX Tau and V728 Sco have significantly lower mass-transfer rates and share the spectroscopic characteristics of dwarf novae rather than nova-likes (Schmidtobreick et al., 2005; Tappert et al., 2012b). In fact, at least V728 Sco has been observed to undergo dwarf-nova like outbursts (Tappert et al., 2012a). This behaviour might be connected to the nova outburst that these CVs experienced in the past. The presence of low mass-transfer novae in the SW Sex regime could potentially be explained within the context of the hibernation model (Shara et al., 1986; Prialnik and Shara, 1986), but an in-depth analysis of the behaviour of old novae with orbital periods between 2.8 h and 4 h is still pending.

So far, most models do not include the SW Sex phenomenon, simply because SW Sex stars have so far been considered as weird objects among the normal CVs. There was just no need to complicate an evolutionary model only to explain a few outliers. However, Zangrilli et al. (1997) have developed a model for the magnetic braking that could indeed explain the high mass transfer rate for systems just above the period gap. They use two $\alpha-\Omega$ dynamos, one in the convective envelope and one at the boundary layer with
a slowly rotating radiative core. The main difference to other models is the slow rotation of the core which is considered to not be synchronised with the orbital motion. During the evolution of the CV, the core becomes smaller, and its material has to speed up to move with the synchronised convective envelope. This yields an additional braking which becomes stronger towards the fully convective boundary and would explain an increased mass transfer rate for CVs just above the period gap, i.e. the SW Sex stars.

One problem in the understanding of SW Sex stars as a group lies in the fact that only for a few of them, the system parameters like masses or temperature or even mass ratio is known. This is due to their high mass transfer rate and the dominating accretion disc that does not allow a direct observation of either of the binary components. Fortunately, most if not all SW Sex stars sometimes switch into a low state where their brightness drops by several magnitudes. These so-called VY Scl low states are rare and unpredictable but when they occur the mass transfer is strongly reduced or even completely suppressed. Therefore, the disc becomes much fainter or dissolves completely, and the stellar components of the binary become accessible (see Rodríguez-Gil et al. 2011, for a review). During such low states, some information on the system parameters were gathered on TT Ari (Gänsicke et al. 1999), MV Lyr (Hoard et al. 2004), and DW UMa (Knigge et al. 2000; Araujo-Betancor et al. 2003). They all show indication for high temperature white dwarfs consistent with the high mass transfer rates that are expected for these binaries. To increase the knowledge on these nova-likes, a project has been started by Rodríguez-Gil et al. (2011) to monitor the nova-like stars photometrically and to trigger time-resolved spectroscopic observations as soon as they go into a deep low state. First results have been obtained for BB Dor (Rodríguez-Gil et al. 2012; Schmidtobreick et al. 2012), VY Scl (Schmidtobreick et al. in preparation), and HS 0220+0603 (Rodríguez-Gil et al. in preparation).

Summary

I have discussed the two statements that due to angular momentum loss, CVs evolve from longer orbital periods to shorter orbital periods and that almost all CVs with an orbital period between 2.8 h and 4 h are of SW Sex type. Putting both information together, one can conclude that CVs that are born with an orbital period $P \geq 4$ h have to evolve through the 2.8–
4 h period range before entering the period gap. During this phase, they will almost certainly exhibit the SW Sex behaviour. This makes the SW Sex phenomenon an evolutionary state of CVs and in particular the evolutionary state during which the magnetic braking gets disrupted. SW Sex stars thus play an important role in our understanding of CV evolution and should be part of any model that tries to explain or to simulate CV evolution. The presence of non-magnetic old novae with low mass-transfer rates in the SW Sex regime appears somewhat conflicting in this context. However, it is well possible that their current state is a consequence of the nova eruption, as outlined by the hibernation model. To include SW Sex stars into the overall evolutionary tracks of CVs, more observational information is needed for this type of CVs, i.e. the determination of system parameters for a representative amount of these binaries. However, due to the bright accretion disc being the dominating source for emission in these high mass-transfer systems, information on the stellar components can only be obtained during one of the rare low states. Consequently, respective results are still sparse, but since there are a number of projects dedicated to this research, the situation is likely to improve in the not too distant future.

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