The SW Sextantis stars

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Abstract
I review the observational properties of SW Sex stars. I show that they can be explained by an accretion stream overflowing the disc, combined with an accretion disc wind. I suggest that SW Sex behaviour is caused by episodes of very high mass transfer, which are balanced by VY Scl low states.

1. Introduction

Thorstensen et al. (1991a) coined the term “SW Sex stars” to describe a subset of novalike variables which (1) were typically eclipsing systems with orbital periods of 3–4 hrs; (2) showed distorted emission line wings; and (3) had line-core absorption near phase 0.5. Other typical characteristics include (4) single-peaked lines, particularly He\textsuperscript{II} $\lambda$4686; (5) peculiar eclipse profiles in the lines and continuum, and (6) tomograms bright in the lower-left quadrant. The same stars also often show VY Scl low states and superhumps. See Table 1 for a list of certain and likely class members.

In this review I’ll discuss whether each of these features can be explained by the suggested models. I report my own judgement of the state of play, but warn the reader that other authors might have written a very different review (see Horne 1999). Finally, I discuss the SW Sex stars as a whole.

2. Emission line wings

Thorstensen et al.’s (1991a) paper reminded me of EX Hya in outburst (Hellier et al. 1989) where high-velocity H\textalpha wings, crossing from side to side on the orbital cycle, appeared to result from an accretion stream overflowing the initial impact with the disc and re-impacting much further in. Shafter et al. (1986) had already suggested something similar for SW Sex stars and Lubow (1989) had given theoretical backing to the idea. Accordingly, I observed PX And for 7 orbits with the McDonald 82\" telescope — still one of the best SW Sex datasets — and computed the velocities of an overflowing stream to produce synthetic line profiles. By adding emission from the re-impact point (with a velocity at the mean of the free-fall stream and the local disc velocities) I obtained a good match to the phasing and velocity of the observed line wings (Hellier & Robinson 1994; Fig. 1). Subsequent work has produced similar results in V1315 Aql (Hellier 1996) and LS Peg (Taylor, Thorstensen & Patterson 1999).

In some stars one has to reduce the model velocity to match the data (e.g. to 75% of freefall in V1315 Aql; Hellier 1996). Justification for this has subsequently been provided by hydrodynamical modelling of the stream-disc impact (Armitage & Livio 1998), which shows that after passing through the impact at the disc rim the infalling stream has a range of velocities below freefall.

Currently, emission from the stream/disc re-impact appears to be the only viable model for the distorted line wings. Casares et al. (1996) have criticised it, claiming to see two high-velocity components in the
4.19 3.95 3.80 3.74 3.51 3.35 3.34 3.28 3.24 3.35 3.34 3.28 3.24 2.60

Star Period High-vel Phase 0.5 Single-peaked Eclipses VY Sci Superhumps Refs
(hrs) S-wave 0.5 abson lines states

BT Mon 8.01 ✓ ✓ ✓ ✓ ✓ 1
LS Peg 4.19 ✓ ✓ ✓ ✓ ✓ 2
V1776 Cyg 3.95 ✓ ✓ ✓ ✓ ✓ 3
LX Ser 3.80 ✓ ✓ ✓ ✓ ✓ 4
BH Lyn 3.74 ✓ ✓ ✓ ✓ ✓ ✓ 5,6
PX And 3.51 ✓ ✓ ✓ ✓ ✓ ✓ 7,8,9
V1315 Aql 3.35 ✓ ✓ ✓ ✓ ✓ ✓ 10,11
WX Ari 3.34 ✓ ✓ ✓ ✓ ✓ ✓ 12
SW Sex 3.28 ✓ ✓ ✓ ✓ ✓ ✓ 13,14
V795 Her 2.60 ✓ ✓ ✓ ✓ ✓ ✓ 15

Table 1: The SW Sex stars. The † symbol indicates uncertainty. Refs: Ritter & Kolb (1998); Patterson (1999); (1) Smith et al. 1998 (2) Taylor et al. 1999 (3) Garnavich et al. 1990 (4) Young et al. 1981 (5) Thorstensen et al. 1991b (6) Hoard & Szkyd 1997 (7) Thorstensen et al. 1991a (8) Hellier & Robinson 1994 (9) Still et al. 1995 (10) Dhillon et al. 1991 (11) Hellier 1996 (12) Beunemar et al. 1992 (13) Shafter et al. 1998 (14) Dhillon et al. 1994 (15) Dhillon et al. 1997 (16) Casares et al. 1996 (17) Dickinson et al. 1997.

3. The “phase 0.5” absorption

When I first computed model spectra I included emission from the full length of the stream overflowing the disc. This produced an emission S-wave in the usual place for a stream/disc impact. Looking at SW Sex star spectra, however, there is no such feature (e.g. Fig. 1); indeed there appears to be a reduction in flux along the track of such an S-wave (max redshift at phase 0.1–0.2; amplitude \(\sim 400 \text{ km s}^{-1}\)).

I thus computed models with absorption from the free-fall part of the overflowing stream, before the re-impact, and noticed that it could additionally explain the phase 0.5 absorption. The first such models (Hellier & Robinson 1994) gave absorption at all phases, whereas it is observed predominantly in the phase range 0.2–0.6. Hence, I invoked a flared disc, so that most light comes from the rear of the disc in these high-inclination systems. The effect is that the stream absorbs the bright rear disc at phases around 0.5, but has little effect when obscuring the near side of the disc. A simulation with a 4° flare in an 82° inclination system is shown in Fig. 1 (see also Hellier 1998a). I also show the velocity measurements of an absorption-dominated metal line from Thorstensen et al. (1991a). There is an excellent match to the phase range and the velocity trend of the absorption. The velocity amplitude, though, is too large in the model by a factor \(\sim 3\). Note, though, that (1) I am using free-fall velocities, whereas the material will have been slowed in the stream/disc bow shock, and (2) the observed absorption is boxed in by disc and disc-overflow emission, biasing the absorption centroid to the line core. The \(\gamma\)-velocity of the absorption cannot be reliably measured because of the other components in the Balmer lines, and because the metal line measured by Thorstensen et al. is a blend of uncertain composition.
Figure 1: The Hα trailed spectra from PX And (top left) together with a model simulation (top right) and the absorption centroid measured by Thorstensen et al. (1991a) from a metal line (right).

In a lower-inclination system the disc flare will have little effect and the absorption should be seen at all phases. In the non-eclipsing LS Peg, Taylor et al. (1999) see absorption at (nearly) all phases in He i λ6678 (their fig. 10), and compute a tomogram showing absorption in the usual location for a stream/disc impact, both in accordance with the above model.

The alternatives to explaining the absorption by the overflowing stream are to invoke disc bulges (e.g. Hoard & Szkody 1997) or material expelled by a propeller (Horne 1999), but neither idea has yet been developed enough to make a comparison with the data similar to that above.

4. The single-peaked lines

The most straightforward explanation for single-peaked line profiles, as seen particularly in He ii λ4686, is an accretion disc wind (e.g. Honeycutt et al. 1986; Dhillon et al. 1991). Such profiles have been computed theoretically by Hoare (1994). In support of this I have shown that the peak of the He ii λ4686 line of V1315 Aql moves with the white dwarf motion (Hellier 1996; although note that the He ii λ4686 wings also contained a disc-overflow component). The wind component is also present in the Balmer lines, filling in any double-peaked disc emission to produce broad, single-peaked profiles.

The presence of a wind is confirmed by P Cygni profiles in the Balmer lines of V1315 Aql (Hellier 1996; Fig. 2), which are seen at all phases and appear to move with the orbital motion of the white dwarf.
Clear wind signatures in optical lines have also been seen in BZ Cam (Patterson et al. 1996).

5. The Doppler tomograms

Doppler tomograms of SW Sex lines are often brightest in the lower-left quadrant, but at a lower velocity than the trajectory of the stream (a clear example is fig. 13 of Hoard & Szkody 1997, Fig. 3). This discrepancy has been used to argue against the overflow model, and can instead be considered to favour the disc-anchored propeller of Horne (1999). If material is expelled by a propeller, blobs of different density will collide outside the binary, where they would give line emission at the correct velocity and phase to explain the tomogram.

This reasoning, though, assumes that the brightening in the tomogram can be taken at face value. The emission from the overflowing stream will have a large velocity dispersion and a mean velocity well below free-fall (see Armitage & Livio 1998). As pointed out by Hellier & Robinson (1994) and Hellier (1996), the brightest region of the tomogram will occur in the lower-left quadrant where the stream component overlaps with the ring of emission from the disc, but this brightening is not a component in its own right. The emission in the upper-left quadrant is reduced by the absorption discussed above.

One can see this effect directly in the trailed spectra (e.g. Fig. 1). The high-velocity overflow component zigzags across the disc double peaks, causing bright regions where they overlap (phases 0.35 and 0.85). (The crossings at phases 0.1 and 0.6 are reduced by absorption along the track of the usual S-wave.) The relevant region in the tomogram (corresponding to the sinusoidal track from +300 km s\(^{-1}\) at phase 0.85 to –300 km s\(^{-1}\) at 0.35) is bright because it links these regions but there is no discernable component moving along this track. The same effect is seen in all SW Sex spectra with enough S/N to separate components. If the emission were from colliding blobs outside the binary, as in the propeller model, it would be visible at all phases and so would produce a continuous S-wave along the track; thus the trailed spectra do not support the propeller interpretation.

6. The continuum eclipses

The eclipse profiles of the SW Sex stars do not follow the theoretical expectation for a novalike disc. The eclipse bottoms are V-shaped, rather then U-shaped, and when mapped onto a disc produce an inner disc cooler than expected (Rutten et al. 1992). However, if the above ideas are correct, interpreting the eclipse using a flat disc will be inappropriate. Instead, one would have to account for (1) a disc flare; (2) an overflowing, vertically extended stream (which might be brighter or darker than the novalike disc); and (3) a wind removing energy from the inner disc. No study has yet included all these factors.

A pointer can, however, be gained from recent observations of the intermediate polar EX Hya in outburst. These outbursts seem to be mass-transfer events in which an enhanced stream overflows the accretion disc (Hellier et al. 1999). They give us a chance to see an overflowing stream against a faint low-state disc. The observed eclipse profiles are asymmetric V-shapes, with rapid ingress and slower
egress, and they have minima late by 0.02 in phase (compared to inferior conjunction of the secondary).
These features are all reproduced by a model eclipse of a bright stream (Hellier et al. 1999; Fig. 4). The
same characteristics can be seen in the eclipse of SW Sex (fig. 1 of Rutten et al. 1992), although bear in
mind that in SW Sex the stream eclipse is convolved with that of a bright high-state disc.

7. The emission-line eclipses
The He\textsuperscript{II} λ4686 lines are eclipsed to the same extent as the continuum but the Balmer lines are only
partially eclipsed, so that their equivalent widths increase during eclipse (e.g. Dhillon et al. 1991). This is
explained if He\textsuperscript{II} λ4686 consists of wind emission from near the white dwarf where it is deeply eclipsed,
and if the Balmer lines contain a wind component from higher up, where it escapes eclipse. The models
by Hoare (1994), however, predict the opposite, with Balmer emission emerging from closer to the white
dwarf. Thus either the wind models are over-simplified (e.g. no clumpiness) or a different idea is needed.
The other evidence for winds (e.g. the P Cygni profiles) suggests the former.

8. Discussion
I have shown above that the main SW Sex characteristics — distorted line wings, distorted eclipses, phase
0.5 absorption — can be explained if the accretion stream overflows the disc in these stars. The model,
though, is still an outline and needs further development, such as the derivation of line profiles from the
hydrodynamical modelling of Armitage & Livio (1998).
Stream/disc overflow seems to be more widespread than just SW Sex stars. For example, the X-ray
beat-period pulsations in many intermediate polars are probably caused by overflow (e.g. Hellier 1991,
with recent reviews by Buckley, this volume, and Hellier 1998b). Of particular note is FO Aqr, which
shows an X-ray beat period and also an absorption S-wave from an overflowing stream (Hellier et al.
1990), reminiscent of SW Sex absorption.
Such X-ray beat periods are variable and sometimes absent [pointed out by Hellier (1991), but now
best shown by Wheatley’s (1999) dataset on TX Col.] The implication of fluctuating overflow probably
applies to SW Sex stars as well. For instance, SW Sex itself has sometimes appeared much less SW Sexy
than normal (Dhillon et al. 1997). Further, we’d expect there to be novalikes very similar to SW Sex stars,
but with little or no overflow occurring. BP Lyn and UU Aqr (Hoard & Szkody 1996; Hoard et al. 1998)
seem to be such stars, with (in my judgement) insufficient phase 0.5 absorption and/or high-velocity
S-wave to qualify as fully fledged SW Sex stars (although there is unlikely to be a clean divide).
So why does overflow appear preferentially amongst a group of novalikes with 3–4 hr periods? This
is counter to expectations since theoretically it should be easier to overflow a cool low-state disc than a high-state novalike disc (e.g. Hessman 1999), yet overflow has not been reported in quiescent dwarf novae.

The presence in SW Sex stars of both overflow and winds, and their tendency to show superhumps, is circumstantial evidence for very high mass-transfer rates. Further, SW Sex stars occur in the same period range as stars showing VY Scl low states, and in a range containing few dwarf novae (e.g. Shafter 1992). Thus something appears to inhibit mass transfer at medium rates. Several mechanism have been proposed to explain this, including star spots (Livio & Pringle 1994) and irradiation of the secondary star (Wu et al. 1995; King et al. 1996).

Thus if irradiation in a high-$\dot{M}$ novalike leads to even more mass transfer, it can drive the novalike into an SW Sex state (any similar mechanism by which mass transfer feeds back into enhanced mass transfer would also suffice). When the feedback cycle breaks (perhaps through the intervention of star spots or through shielding by the accretion disc) the system plunges into a VY Scl low state. This mechanism would occur preferentially just above the gap, since the orbital separation is less than in other novalikes, hence explaining the period distribution of SW Sex and VY Scl stars.

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