SS 433 – Concerning the slaved accretion disk

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Abstract.

The Galactic microquasar SS 433 is a black hole that super-Eddington accretes from a disk fed from a Companion. The famous jets precess about an axis believed to be controlled by the feed; slaved precession. Variations in the polar angle of the precessing jets in SS 433 are negatively correlated with variations in the speed of the jets. This curious correlation has never been explained; here I consider a mechanism involving the effect of flares on the slavery. Recent observations of speed variation of the X-ray jets, with a period of ~ 6 days, have a natural place in this slaved disk scenario.

1. Introduction.

Folklore concerning the unique binary SS 433 has been that the speed of ejection of the opposing jets is remarkably constant at 0.26c. Not constant; the speed fluctuates between about 0.235 and 0.285c. This was first established in analysis of a deep VLA image (Blundell & Bowler 2004) and later (Jeffrey et al 2016) from VLBA images. The same results were obtained from archival optical spectra (Blundell & Bowler 2005) and a succession of images taken over 75 days (Blundell et al 2007).

There is no evidence that the two jets have different speeds at any one time; the Doppler shifts to the red (z^+) and blue (z^-) are remarkably (anti-) symmetric, even down to the details of nutation (or nodding) with a period of 6.28 days (Blundell et al 2007, Kopylov et al 1987). The nutating and precessing central engine acts as a whole; variations in one jet reflected in the other (Blundell & Bowler 2004).

The highest speeds are associated with flares observed in the optical spectra (Blundell et al 2007, 2011) and in radio images (Jeffrey et al 2016). It now seems clear that these flares are the result of eruptions of the Companion donor star, probably filling the Roche lobes, ejecting material from the binary system (Bowler 2021, Waisberg et al 2019). Thus observations suggest that eruptions feed more material to the accretion disk, thereby increasing the speed of ejecta in the jets.

In the optical spectra (Blundell & Bowler 2005) and the more recent data in Blundell et al 2007 there is variation of jet speeds with the orbital period of 13.08 days. This also suggests that variation of the rate of transfer of material to the accretion disk affects the jet speeds; transfer maximised at periastron for an elliptical orbit. The binary orbit is elliptical (Cherepashchuk et al 2021) and the phase of the maximum of the13.08-day component of jet speed advanced by ~ 90° in 25 years (Blundell et al 2007), suggestive of apsidal precession. If the accretion disk is slaved to precession of the donor, a 6-day periodicity in delivery of material might be manifested in observations (Section 3).

2. Jet speeds and the polar angle.

Remarkably, the polar angle of the jet axis relative to the precession axis is anti-correlated with the jet speed; that is, faster jets make a smaller polar angle. This finding (Blundell & Bowler 2005) provided a partial solution to an ancient problem. A plot of the residuals of the redshifts from the approaching jet versus those from that receding would, in the absence of velocity jitter, have a slope of -1; falling from upper left to lower right (Fig.6 in Blundell & Bowler 2005). From the archival data of Eikenberry et al 2001 that slope is in fact - 0.79; requiring velocity jitter (anti-) correlated with the polar angle. Searching for an explanation free of *ad hoc* hypotheses and consistent with complete symmetry, I find that this anti-correlation may have its origin in the effect of flaring on the slaved accretion disk.

3. Slaved accretion disks.

SS 433 is a binary system, one member a compact object (a black hole) and the other a comparatively normal star feeding the accretion disk. In such systems, if that normal star has a significant quadrupole moment and its axis of rotation is not aligned with the axis of the orbit, then the axis of rotation precesses. If this precession is copied by the disk, the disk is said to be slaved to the rotation of the normal star. In the model of Roberts 1974 and of Petterson 1975 (originally devised for Her X-1) the normal star fills its Roche lobe and spills material through the L_1 point, preferentially when the compact object crosses the bulging equator of the normal star, every 6 days. The equatorial material has a component of momentum perpendicular to the orbit. If this is preserved in the fall, the disk created is tilted with respect to the orbital plane; for relatively slow precession the disk axis follows the precessing axis of the normal companion. This transfer to the environs of the compact object is crucial to the slaved disk model; the angular momentum transferred determines the polar angle of the normal to the disk. One application to SS 433 (Leibowitz 1984) successfully reproduces photometric data; a recent observation is Waisberg et al 2019.

4. Source of the correlation.

Periods of flaring - which can last 10s of days - are associated with periods of high jet velocity, implying that more material is then being processed by the central engine. There are other indicators; see Fig.8 of Blundell et al 2011, for example the increase in the speed of the wind, blown from the disk. Such eruptions of the normal star, manifested as flares, will disturb and augment the stream of equatorial material. This seems likely to destroy, or at least dilute, the angular momentum component associated with motion normal to the plane of the orbit, the component responsible for slaving the accretion disk. Thus freed, the normal to the disk plane evolves closer to the normal to the orbital plane. Hence the anti-correlation; higher speeds with reduced polar angle.

There are unresolved issues. First, in the slaved disk model for precession, transfer of stellar material via L_1 should occur preferentially every half period, at least in the absence of flaring. This determines the orientation of the accretion disk but there is no guarantee that the jet speed should exhibit a 6-day modulation. There is in fact no evidence for such periodicity in the speed of the jets in Blundell & Bowler 2005 or in the data of Blundell et al 2007; a periodicity of 13.08 days is clearly observed. The ellipticity of the orbit is only 0.05 (Cherepashchuk et al 2021); it seems questionable that this alone is sufficient to impose the orbital periodicity on the jet speeds, yet it is there, with evidence for apsidal precession. However, the amplitude of this periodic residual is only 2.5% of the average jet speed (Blundell & Bowler 2005, Blundell et al 2007). Finally, the correlation coefficient between excursions in jet speed and excursions in polar angle is -0.62 (Blundell et al 2007); it is not established that the scenario sketched above could account quantitatively for this. Nonetheless, this anti-correlation might be further evidence that precession of the disk is slaved and there is recent evidence for a 6-day period in the speed of X-ray jets.

5. Recent X-ray results.

Optical observations have mostly been made with successive gaps of at least a day. Recent X-ray observations with XRISM covered 6 days, divided into 5 segments each day. Making the usual assumption of jet symmetry, an astonishingly well-defined 6-day sinusoidal variation in jet speed emerged, rising from 0.25c to 0.28c in about 3 days (Sakai et al 2026). This matches half the synodic period; the amplitude is as large or larger than that of the (optical)13-day oscillation.

6. Conclusion.

We have fresh evidence that the accretion disk is slaved, in this explanation for the anti-correlation of speed and polar angle. The new data above (Sakai et al 2026) are a unique sequence, but in accord with expectations from the mechanism of Roberts 1974. Survival of such a signature might – eventually - be useful in understanding production of the jets.

References

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