SS433’s accretion disc, wind and jets: before, during and after a major flare

Katherine M. Blundell¹, Linda Schmidtobreick² and Sergei Trushkin³

¹University of Oxford, Astrophysics, Keble Road, Oxford OX1 3RH
²European Southern Observatory, Vitacura, Alonso de Cordova, Santiago, Chile
³Special Astrophysical Observatory RAS, Karachaevo-Cherkassian Republic, Nizhnij Arkhyz 36916, Russia

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ABSTRACT
The Galactic microquasar SS433 occasionally exhibits a major flare when the intensity of its emission increases significantly and rapidly. We present an analysis of high-resolution, almost-nightly optical spectra obtained before, during and after a major flare, whose complex emission lines are deconstructed into single gaussians and demonstrate the different modes of mass loss in the SS433 system. During our monitoring, an initial period of quiescence was followed by increased activity which culminated in a radio flare. In the transition period the accretion disc of SS433 became visible in Hα and He I emission lines and remained so until the observations were terminated; the line-of-sight velocity of the centre of the disc lines during this time behaved as though the binary orbit has significant eccentricity rather than being circular, consistent with three recent lines of evidence. After the accretion disc appeared its rotation speed, as measured by the separation of the Hα disc emission lines, increased steadily from 500 km/s to 700 km/s. The launch speed of the jets first decreased then suddenly increased. At the same time as the jet launch speed increased, the wind from the accretion disc doubled in speed. Two days afterwards, the radio flux exhibited a flare. These data suggest that a massive ejection of material from the companion star loaded the accretion disc and the system responded with mass loss via different modes that together comprise the flare phenomena. We find that archival data reveal similar behaviour, in that when the measured jet launch speed exceeds 0.29c this is invariably simultaneous with, or a few days before, a radio flare. Thus we surmise that a major flare consists of the overloading of the accretion disc, resulting in the speeding up of the H-alpha rotation disc lines, followed by enhanced mass loss not just via its famous jets at higher-than-usual speeds but also directly from its accretion disc’s wind.

Key words: stars: individual: SS433 — stars: winds, outflows — accretion, accretion discs

1 INTRODUCTION
The Galactic microquasar SS433 is famous for its continual ejection of plasma collimated in two oppositely-directed jets launched at speeds that average over time to one quarter of the speed of light. The system is a binary with a period of 13.08 days (Crampton, Cowley & Hutchings 1980) that eclipses at both oppositions (e.g. Goranskii et al. 1998). There is evidence that He II 4486 ˚Å emission has been observed from the base of the jets (Crampton & Hutchings 1981; Fabrika & Bychkova 1990) and C II lines orbiting with the compact object have been detected (Gies et al 2002). The accretion disc is not always revealed by optical observations (although see Falomo et al 1987; Perez & Blundell 2010) but the signature of the accretion disc, namely a widely-separated pair of emission lines, appears to be prominent in the near infra-red (Perez & Blundell 2009). The system is rather massive with the compact object and disc having a mass of ~16 M⊙ and the companion star having ~24 M⊙. See Blundell, Bowler & Schmidtobreick (2008); Fabrika (2004) for a historic review.

In August 2004 a campaign of nightly observations of SS433 was initiated with the NTT 3.5-m telescope on La Silla, Chile. The observations continued until early November. There were few gaps in the coverage and this sequence of nightly observations reveal very rich behaviour in this microquasar. The results obtained on the relativistic jets (Blundell, Bowler & Schmidtobreick 2007) and on the properties of the stationary emission lines during the first half of the series of observations (Blundell, Bowler & Schmidtobreick 2008) have already been published. This paper is concerned with...
the observations during the second half of the series, when SS433 was switching from a quiescent state to a period of activity culminating in a major flare.

1.1 On the physical interpretation of the two types of flare

A number of authors (for example, Seaquist et al. 1983; Fabrika 2004) have suggested that SS433 exhibits two types of radio flare: (1) those where the flux density at all frequencies rises and maintains a constant, although fairly flat spectrum ($S_{\nu} \propto \nu^{-0.2}$) and (2) those where a peak is seen at frequencies of several GHz which then gradually moves to lower frequencies over a timescale of a few days. Time-resolved radio studies (Fiedler et al. 1983; Bonsignori-Pacconi et al. 1986) have revealed clusters of flares separated by periods of quiescent emission, without any indication of significant stable periodicity (see discussion in Sec 5.4).

In observations of the Galactic microquasar Cygnus X-3, a major flaring event in September 2001 was resolved into two distinct peaks in intensity, separated by a couple of days. The first of these (a type-1 flare) has a fairly flat spectrum and, by milli-arcsecond resolution observations with the Very Long Baseline Array (VLBA), is seen to correspond to emission from the nucleus (i.e. core) of this microquasar. The second peak (a type-2 flare) is likely to correspond to the appearance of jet ejecta, specifically their brightening as the bolides expand and transition from being optically thick to optically thin and subsequent fading as the bolides continue (Miller-Jones et al. 2004). Similarly, Vermeulen et al. (1993b), in their combined radio and optical study of SS433 in 1987, found two types of flare: one with a peak flux that is similar over the entire observed range of radio wavelengths coinciding with a brightening of the core component of the system (Vermeulen et al. 1993a) and the second type of flare where a lower peak flux density at high frequency evolves into a higher peak flux density at low frequency and in which the same campaign of Very Long Baseline Interferometry (VLBI) imaging revealed that the flaring takes place some distance away from the nucleus.

Separate flaring of the radio emission from the nucleus (perhaps arising from a disc wind (e.g. Blundell & Kuncic 2007)) and from intense jet ejecta we believe correspond to the two distinct modes of energy and angular momentum output at work, as explored by Nipoti et al. (2005). We remark that Blundell, Bowler & Schmidtobreick (2008) found a persistent fast wind to be rooted in SS433’s accretion disc and that Perez & Blundell (2009) found from infra-red spectroscopy that this wind is the dominant mode of mass-loss in this object.

We emphasize that not all radio emission in microquasars should be interpreted as arising from jets, and that radio emission due to disc winds should be considered especially when there are different spectral characteristics that could be clues to alternative origins (c.f. Fender et al. 2004). A model for nuclear emission in radio-quiet quasars arising from optically-thin bremsstrahlung from (scale-free) accretion disc winds has been presented by Blundell & Kuncic (2007).

2 DATA

Our nightly spectra were taken from Julian Date 2453000+245.5 to +321.5, after which SS433 was not observable from La Silla. Up to Day +274.5 only one observation was missed and during this period SS433 was quiescent (Blundell, Bowler & Schmidtobreick 2007, 2008). Between Days +274.5 and +287.5 there were only two observations (+281.5, +282.5) and there was a gap of two nights after +291.5. After Day +310.5 there is only one observation, Day +321.5. All spectra were taken with the ESO 3.6-m New Technology Telescope with the EMMI instrument (Dekker et al. 1984), using grating 6 and a 0.5-arcsec slit. The resolution was 2.2 Å at 6000 Å and the wavelength range was 5800 to 8700 Å.

IRAF was used for the basic data reduction including overscan subtraction, flat-fielding, and wavelength calibration. No flux calibration was performed. Instead, the spectra have been normalised for the continuum using the program SPLIT written and kindly provided by Jochen Liske. The “moving” Hα jet lines were individually fitted with gaussians for all spectra and subtracted to obtain a clean data set of “stationary” Hα lines. Fig 2 indicates the high signal-to-noise of the gaussians we fitted to the stationary Hα complexes.

We do not refer in this paper to the flux of the spectra because we do not have absolute flux calibration for these data (although the instrumental setup and exposure time were identical for each observation, and the weather conditions were fairly similar). We instead use the term intensity to mean the “area” of an emission line in the spectrum, which is calculated as the height of the fitted gaussian multiplied by its FWHM; for our normalised spectra this value is the same as the equivalent width of the line.

In Fig 2 we show the wavelengths of the centres of the components fitted to the stationary Hα complex. The data displayed start at Day +260.5 and until Day +287.5 most spectra are fitted with a single broad line attributed to the wind (on the basis of our analysis in Blundell, Bowler & Schmidtobreick 2008). (Thus, lines with FWHM greater than 10 Å are shown in black) and a pair of lines showing negligible change in redshift as a function of time (shown in grey) inferred to be the inner rim of the circumbinary disc (Blundell, Bowler & Schmidtobreick 2008, see fig. 1). A striking change occurs at around Day +288.5 when the Hα complex is broadened by the addition of components at comparatively extreme excursions in velocity. These spectra usually comprised a single broad line (FWHM 10 to 20 Å) and two or four lines which are narrow (FWHMs of a few Å only). The same behaviour is seen for the He I lines at 6678 Å and 7065 Å (Schmidtobreick & Blundell 2006). After Day +296 the He I lines and the hydrogen Paschen series develop pronounced P Cygni features and an O I line at 7772 Å exhibits absorption to the blue cutting deep into the continuum. The O I line at 8446 Å does not show any such features. The behaviour of these lines will be described in a forthcoming paper.

3 THE APPEARANCE OF SS433’S ACCRETION DISC IN THE OPTICAL

The data shown in Fig 2 on the extreme blue and red features of SS433’s stationary Hα complex are simply explained as being radiated from a ring or disc orbiting the compact object itself, with a speed in excess of 500 km s$^{-1}$, consistent with the picture seen in infra-red spectroscopy (Perez & Blundell 2009). Bowler (2010) has published a subset of our data showing the behaviour presented here. If the Hα-emitting region of the accretion disc is perpendicular to the jet axis, then the disc is close to edge-on to Earth during these observations. Fig 3 shows the timing of “crossover” of the jet lines: the epoch when the jets are launched in the plane of the sky. This figure shows that variations in the separation of the red and blue jet lines differs from the prediction of the kinematic model. This is a manifestation of the phenomenon analysed and published in Blundell & Bowler (2005) and in
Figure 1. Examples of our observed spectra of the “stationary” Hα feature shown in green from (a) Day +295 and (c) Day +265 with the five and three gaussians with which these emission features were respectively fitted. The superpositions of the gaussians fitted for each spectrum are plotted in purple; the difference between the green and purple curves — the residuals — are shown in (b) and (d) respectively.

Figure 2. Wavelengths of the centroids of the gaussian-fitted components of the sequence of Balmer Hα spectra. Julian date increases vertically. The heights of the lines reflect the widths of the gaussian fits, on a logarithmic scale. The signature of the circumbinary disc is clear in the grey lines before Day +287; a fuller picture of this is in Blundell, Bowler & Schmidtobreick (2008). After Day +287 the accretion disc is revealed; the lines attributed to the red and blue shifted regions are appropriately colour coded. The black lines are broad and associated with the wind from the disc; the mean redshift of these lines jumps about 150 km s$^{-1}$ to the red between Days +291 and +294 and then almost back again, and the same behaviour is seen on Days +301 and +303. The colours are fitted algorithmically, to avoid subjective inference, such that the broad (i.e. wind) line in each spectrum is coloured black, then the outermost lines are coloured red and blue and all remaining lines are grey. The top panel demonstrates clear changes between example spectra from Days +300 and +306.
Blundell, Schmidtobreick & Trushkin (2007): angular variations in the cone angle of rms ~ 3 degrees have been exhibited by this system since its discovery. For example, increasing separation of the jet lines (Blundell & Bowler 2005, eqn 3) indicates a typical instance of the cone angle increasing.

The rotational velocity of the radiating material in the accretion disc is found by taking by half the difference of the redshifts of the two components while the line-of-sight velocity of the centre of the disc is given by the mean of their redshifts, shown in Fig. 4a and Fig. 4b respectively as a function of time. The line-of-sight velocities of the disc material emitting Hα are modulated by the orbital velocity of the compact object about the binary centre of mass, which has been reported to be ~175 km s⁻¹ to ~200 km s⁻¹ (Crampton & Hutchings 1981; Fabrika & Bychkova 1990). Given this explanation it is entirely possible that the extreme blue features observed on Days +273 and 274 are earlier glimpses of the blue rim of the accretion disc. The rotational velocity as derived from the separation of the Hα disc lines (Fig. 4a) is about 500 km s⁻¹ when this structure is first revealed and reaches as much as 700 km s⁻¹ at the end of the sequence of observations. Given the precession phase (see Fig. 3), the disc is believed to be close to edge-on at the epoch of these observations and so no significant fraction of this rotation-speed change can be attributed to changes in the disc orientation.

The centroid of the pair of widely-separated lines which are so marked in both Hα (Fig. 2) and in He I 7065 Å reach a (local) max-
SS433 before, during and after a major flare

### Figure 5

This figure shows the line-of-sight velocities observed when the accretion disc was revealed in the build-up to the flare on a white background, and after the flare when the jet speed ceases to be high on a grey background. The orbital phases of the maximum and minimum line-of-sight velocities are a function of the eccentricity of the orbit and the red dot-dash line indicates the predicted line-of-sight velocity if the eccentricity were zero (i.e. circular orbit) while the blue solid line indicates the predicted line-of-sight velocity if the eccentricity is 0.55. During the flare when there seems to be a good view of the disc the latter is a better description than the former. Both lines are plotted for the semi-major axis of the orbit being aligned along our line-of-sight.

### 3.1 A further signature of SS433’s binary orbit’s eccentricity

If the orbit of the black hole and accretion disc about the companion star were circular then the line-of-sight speed of the disc would be greatest at orbital phase 0.75. The pair reach their most extreme blue position more than half an orbital period later (but then remain at approximately the same wavelength for a few days). After Day +301.5 the pair of widely-separated lines return towards the red. These two lines, swinging together in phase, are separated by over 1000 km s\(^{-1}\). During the period after Day +287 the jets were close to the plane of the sky, making an angle to the line of sight of 80\(^\circ\) initially then 85\(^\circ\) by Day +294; see Blundell, Bowler & Schmidtobreick (2007) and Fig. 3.

In a multiplet of lines emerging from a windy and smoggy system there is bound to be some uncertainty about the proper assignment of lines to the opposite sides of the disc, but we have strictly taken the extreme blue and extreme red components of the H\(\alpha\) complex after Day +287.5 and paired them. It is clear from both Fig. 3 and Fig. 4b that the simple explanation advanced above, while representing very well the data over the first half of the orbital cycle, has inadequacies after Day +298. The lines attributed to the edges of the disc do not return toward the red along a sinusoidal curve but rather hang in the blue for several days before snapping back rather abruptly around Day +303.5. It is also clear that the pattern becomes rather noisy after Day +300. These irregularities cannot be attributed to measurement error (as is evident from Fig. 3 and Fig. 4b) and are unlikely to be due to inadequate modelling of the line profiles. We explore possible explanations for the behaviour after Day +298 in Section 7.

### 3.2 The disruption of the circumbinary disc

In the days that follow the flare, after accounting for a broad component of the H\(\alpha\) complex as wind and the high velocity components as the manifestation of the accretion disc, in most cases there are one or two lines unaccounted for. It seems likely that some of these are the continuation of the signature of the circumbinary disc, in most cases there seems to be a clear signature that the black hole and disc are in an elliptical, not a circular, orbit around the companion star with periastron being at orbital phase 0.5. Fig. 3 shows the predicted line-of-sight velocities for this system if the eccentricity \(e = 0.55\). Photometric monitoring of this binary system in no way precludes the orbit being significantly eccentric but the occurrence of the eclipses at orbital phases 0 and 0.5 (i.e. equally spaced) requires the semi-major axis to be aligned close to the line of sight. There are three other independent indications that the binary orbit of SS433 is eccentric: (i) the peak jet speed of SS433 varies sinusoidally with orbital period (Blundell & Bowler 2005) suggesting that something about the orbit breaks circular symmetry; (ii) Perez & Blundell (2009) find that the constraints on the size of the companion star require the semi-minor axis to be smaller than the semi-major axis; (iii) the precession of the radio ruff of SS433 having a periodicity of as short as \(\sim 42\) orbital periods requires significant eccentricity in the binary orbit (Doolin & Blundell 2009).

Fig. 4 displays the variation of the line-of-sight velocity of the centre of the broad Gaussian representing the wind in the system, established as coming off the accretion disc prior to Day +274.5 (Blundell, Bowler & Schmidtobreick 2008). This centre oscillates in line-of-sight velocity in a similar way to the lines from the periphery of the disc, but suffered a displacement in the mean towards the red between Day +291 and +294 and again between Day +303 and +305. This displacement amounts to approximately 150 km s\(^{-1}\); less than one tenth of the width of the wind lines after Day +294.

Thus although Fig. 3 and Fig. 4 display data that are somewhat erratic, these data are sufficient to establish that the high speed components of the stationary Balmer H\(\alpha\) lines which appear after Day +287.5 are contributed by a ring, or tight spiral, within the accretion disc of SS433. The enhanced wind which appears at the onset of the flare is rooted in the accretion disc, just as in more placid times (Blundell, Bowler & Schmidtobreick 2008, Sec. 2.1).

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4 THE SEQUENCE OF EVENTS IN THIS FLARE HISTORY

Fig. 5 is a schematic illustration of the events that collectively comprise the flare phenomenon. Fig. 3 shows that the moving H\(\alpha\) lines from the jet ejecta appear strongly on Day +294; these continue to be ejected up to Day +297, then largely disappear but appear again on Day +307. This figure shows that the disappearance is total between Days +302 and 305. The optical jet lines reappear, rather more strongly, on Day +307 and +308, before disappearing.
Figure 6. The spectrum from Day +294 is shown with two different intensity scales to illustrate the moving jet lines in Hα and in certain helium lines. The upper panel has solid green and gold lines (same parameters as in Fig. 3) redshifted and blueshifted appropriate for rest-frame Hα; the lower panel shows the same colored lines as dashed for He 5876, dotted for He 6678 and dot-dashed for He 7065. Note that the more redshifted line in each pair of “moving lines”, whether helium or hydrogen, is redshifted further than the simple kinematic model predicts; this increase in mean redshift is a manifestation of the increased jet speed at this time.

In Fig. 8 we display the variation with time of quantities likely to cast light on the nature of this flaring episode. The separation of the extreme components of Hα suddenly increases at Day +288 when the accretion disc is unveiled (see Fig. 8a). The speed of the wind from the disc starts rising about 3 days later and has doubled by Day +294 (Fig. 8b) five days after the disc was revealed.

Figure 7. Upper panel: schematic illustration of the various phenomena involved in the flaring episode. Yellow columns indicate where the companion star eclipses the compact object and inner part of its accretion disc; blue and white alternating columns indicate when the black hole and disc are moving towards Earth; pink and white alternating columns indicate when the black hole and disc are moving away from Earth. The numbers at the top of the columns are Julian Day numbers minus 2453000. Lower panel: illustrations of the relative locations of the accretion disc, the accretion disc wind, the companion star and the jet radius throughout the period of observation, for the orbital and precessional phases appropriate to the dates illustrated. The illustrated diameters of the jets act as a simple visual aid to remind the reader that the faster jet speed observed on Day +294 likely comes from a smaller launch radius, consistent with the increasing rotation speed of the accretion disc observed during these observations.

In fact, the moving He I lines reflect this behaviour too: we observe the same shifts from helium lines with rest wavelengths 5876, 6678 and 7065 (Fig. 6). These helium lines appear on Day +294 as shown in this figure but are somewhat faded on Day +295; they appear with the same shifts as Hα on Day +307 and again on Day +308 when they appear somewhat stronger. (Fig. 6 shows that there is a small peak in jet line intensity around Day +268 but this is due to primary eclipse occurring at this time; this is the extent to which it is likely that the jet line intensity enhancement we observe on Day +294 is due to primary eclipse.) The equivalent widths on Day +294 are significantly greater than those observed during primary eclipses before Day +287. This episode is similar to that observed by Kopylov et al. (1985), where the jet equivalent widths flared from invisibility and then collapsed again. The episode of jet flaring they observed coincided with a photometrically-determined optical flare and also coincided with a primary eclipse; we return to the phasing of flares in Sec 5.4.
The speed of the jets (Blundell, Bowler & Schmidtobreick 2007) drops at about the time the disc was revealed but by Day +294 has risen to a rather high value, $\beta \sim 0.28$, as shown in Fig 8. The flux at 4.8 GHz measured by the RATAN-600 telescope (Trushkin et al. 2007) increased rapidly about 10 days after the disc became visible, i.e. about 5 days after the enhanced wind and jet speeds, as depicted in Fig 8. There is a local maximum in radio flux at Day +299 and a larger flare between Day +300 and +302; it is possible that these two flares could correspond to a type-1 flare (corresponding to optically-thin bremsstrahlung radio emission from the wind) and type-2 flare (synchrotron radio emission from expanding jet bolides) respectively but there is insufficient spectral information to constrain this with any certainty. After Day +302 the radio intensity falls, although there is increased radio emission around Day +310. We note that on Day +294, there are hints of a “precursor dip” or “quench” in radio intensity prior to a steep increase in intensity at the onset of a major flare, similar to the behaviour reported by Vermeulen et al. (1993b) for the 1987 flares. The quench phase may relate to high opacity at radio wavelengths of the jet bolides that appear so intensely at optical wavelengths shown in Fig 8. Such precursor dips or quenches are also observed in the microquasar Cygnus X-3 (e.g. Trushkin et al. 2007). In Fig 8, the intensity of Hα radiated from the wind has a minimum just after Day +294. We do not have absolute photometry with these data but since the instrument setup was kept the same and the weather conditions were similar, we are confident that the intensities of the lines during these days can be meaningfully compared with each other and thus that this dip is a real effect.

5 MORE GENERAL CONCLUSIONS ABOUT FLARES, INCLUDING THOSE OBSERVED BY OTHERS

A priori we should expect that a flare, in the sense of enhanced intensity observed at a particular waveband such as the radio, might be attributable to wind or to jets and not necessarily just due to jet ejection. We have shown in Sec 4 that in major flares, mass-loss via both wind and jets appear to play together. Collectively, the panels in Fig 8 suggest that type-1 and type-2 flares, if as we surmise correspond to (1) enhanced mass-loss from the wind and (2) enhanced mass-loss from the jets respectively, are a characteristic sequence that comprise this flare phenomenon. We now consider whether the phenomena we have observed are consistent with the characteristics of major flares observed by others.

5.1 Generality of wind behaviour during a flare

Dopita & Cherepashchuk (1981) report that an optical outburst in SS433 is correlated with the broadening of the stationary lines and the appearance of P-Cygni profiles. This is consistent with our reporting in Sec 3 of the dramatic broadening of the stationary line because of (i) the hike in wind speed and intensity and (ii) the appearance of the widely-spaced accretion disc lines.

5.2 Is the disappearance of jet lines following a major flare a general characteristic of flares?

Vermeulen et al. (1993c) report a substantial reduction in the intensity of the jet lines just as we depict in Fig 8 (symmetrically in both the east and west jets as simultaneously as it is possible to discern given the time sampling available with existing optical spectroscopy), within one day of an optical flare as observed with V-band photometry by Aslanov et al. (1993). Similarly, Margon et al. (1984) report that particularly strong jet lines (compared with Margon et al.’s > 400 nights of observations) were followed by the disappearance of jet lines (seemingly a ubiquitous flare characteristic) with the moving lines returning the following month. It is remarkable that the SS433 system appears to return to the average behaviour predicted by the kinematic model (Margon et al. 1984) after a cessation from the usual jet launch following major flare activity.

5.3 Are flares associated with elevated jet speeds?

Although there is a tremendous archive of radio data from the Green Bank Interferometer (GBI) spanning the time from Julian
Days 2445463 to 2445509, the overlap of these data with the densely sampled spectroscopic archive recorded by Eikenberry and Collins, as used by Blundell & Bowler (2005) to construct a historical record of jet launch speeds, is unfortunately rather sparse. However, the following may be discerned from these two sets of archival data: whenever the measured jet-speed exceeds 0.29c, this coincides with, or is within a day or two of, a radio flare; there are no exceptions to this in the data currently available. For example, on Julian Day 2444437 the jet speed reached 0.32c; and there is a clear flare recorded by the GBI where the flux density at 2.3 GHz exceeded 1.5 Jy (over a factor of two in excess of the quiescent flux density at this frequency).

Margon et al. (1984) report extreme intensity variability (at least equivalent width variability, which can be tricky to understand since the continuum is varying) in the jet lines of SS 433 as it undergoes a flare in the early 1980s. Figure 8 shows (in the lower panel) the speed increases at this epoch, derived using the technique presented by Blundell & Bowler (2005, eqn 2), and (in the upper panel) radio flux densities at 2 GHz and 8 GHz from the GBI. This figure shows the increase of the jet speeds shortly precedes a radio flare observed at both 2 GHz and 8 GHz and also, as reported by Margon et al, the temporary disappearance of the jet lines. It is curious that following this major flare, there are subsequent radio flares at very similar orbital phases to the first, as observed in the data we present in this paper, as briefly considered in Sec 5.4.

5.4 Clustering, timing and phasing of flares

Fiedler et al. (1987) found the time between clusters of flare peaks is 25±10 days while the time between adjacent clusters is 150±50 days. They suggested that “the clustering of flares observed in the radio lightcurve suggests that the reservoir of material ejected from the binary system is quasi-periodically loaded and dumped. The loading and dumping timescales correspond to the quiescent period between each cluster and the time between flare events in a cluster, respectively.” It is not clear how to reconcile our observations of the major flare we observed on Day +294 followed by its successor one orbital period later, although we note that Fig 9 seems to depict another instance of flares repeating one orbital period apart.

We note that the episode of jet flaring reported by Kopylov et al. (1985) coincided with a primary eclipse just the same phasing as for the flare we present in this paper. Fabrika & Irsamambetov (2003) suggest a dependence of flaring with certain orbital phase and precession phase combinations based on a conglomeration of radio and optical flares. We remark that radio and optical flares in SS433 are not going to be co-temporal because of expansion and opacity effects, as exemplified by the sequence represented in Fig 7. We also point out that radio flaring may be due to wind as well as jets (and we note the profile of the radio curve we show in Fig 7 is consistent with two peaks, resembling the case of Cygnus X-3 (Miller-Jones et al. 2011) where there is a very secure identification of a first peak with wind ejection and a second peak with jet ejection because of contemporaneous images made with VLBI techniques). However, assuming flare stages are reported with accurate time-stamping and a dependence of these on orbital phase is discerned, we remark that this would be circumstantial evidence that there is ellipsity in the binary orbit of SS433, supporting our discussion in Sec 3.1. Chakrabarti et al. (2005) present a study of the variability of SS433’s emission at radio, infra-red and optical wavelengths and report that there is typically a delay of two days between infra-red and radio variability. It seems plausible that this delay arises as type-2 flare peaks move from high radio frequency to low radio frequency as bolides expand and thus transition from being optically thick at a given frequency to optically thin. We suggest that this time delay relates to the time-of-flight in traversing the distance between the nucleus of SS433 and the radio-brightening zone discussed by Vermeulen et al. (1987) and Paragi et al. (1999).

It is unfortunate that there are no VLBA observations of SS433 during the flare sequence that we witnessed. However, the diagnostic power of spectroscopic observations is exemplified throughout the flare episode and we have been able to reconstruct the sequence of events summarized in Figure 7.

6 (HOW) ARE X-RAYS ASSOCIATED WITH FLARES IN SS433?

There are famous examples of a detailed correspondence of dramatic X-ray lightcurve variation associated with jet flaring in some microquasars, e.g. GRS 1915+105 (Mirabel & Rodríguez 1998). In SS433, the relation between flares and X-rays is much less clear. Examination of the RXTE ASM archival database for data observed during our optical monitoring described in Sec 3 reveals that there is no hint of any increase in X-ray luminosity during the flare we describe in this paper. This lack of making any identification of X-ray acknowledgement of the flaring activity may be because at this epoch the jet axis is fairly close to the plane of the sky and hence the innermost regions obscured: Nandi et al. (2005) in fact suggest that the X-rays associated with SS433 arise from the very inner base of the jets. They report double normal flux rates from RXTE when high jet speeds (> 0.3c) occur, possibly at epochs when the jet axis is not aligned with the plane of the sky. However, we emphasize that this conclusion is contingent on Nandi et al correctly identifying the blueshifted FeXXVI and redshifted FeXXV lines.

7 THE NATURE OF THE ACCRETION DISC DURING THE FLARE

The blue accretion disc line is seen to move significantly bluewards in Fig 4 in contrast with the more subtle bluewards movement by the red accretion disc line over the same time range.

2 http://xte.mit.edu/asmlc/ASM.html
One possibility is that for several days after Day +298 obscuring material is progressively unveiling faster regions on the blue side of the accretion disc while tending to cover faster regions on the red side. Another possibility might be interference by a massive stellar wind outflow from the companion. Extreme velocity components of Hα are observed intermittently in data other than ours [Falomo et al 1987; Dopita & Cherepashchuk 1981; Kopylov et al 1985] and the extreme excursions on Day +305 (Fig. 2) are certainly real (and might represent a brief view of regions of the disc further in).

Material from the companion star is feeding the accretion disc and may fall towards the disc from the L1 point. Before the material reaches the disc, it is possible that it is moving faster than the orbital speed and may have to slow down via a shock thus forming a hotspot. If there is a trail of material approaching the (outer) edge of the disc and glowing – like a Katherine wheel – then close to phase 0 this trail could be pointing away from Earth and could give light from a long stream or flow of material moving away from Earth, thus influencing the wavelength at which the material in the disc rotating away from us would be observed.

There is no evidence of the sinusoidal variation in the difference of the areas of the Balmer Hα accretion disc lines, in comparison with the clear sinusoid seen for the areas of the Brackett-γ lines [Perez & Blundell 2009]. Fig. 10 shows (upper panel) the complete lack of any sinusoidal dependence while the lower panel reveals a rather steady normalised difference in line areas (the difference in the intensities of the red and blue jet lines divided by their combined intensities) which indicates no dependence on orbital phase at all, during the interval the accretion disc is revealed by optical, very clearly identified the accretion disc of SS433, although it seems likely that Falomo et al. (1987) had a glimpse in observations made in June 1979. Subsequently, both Dopita & Cherepashchuk [1981] and Kopylov et al [1985] made separate observations of the same flare episode in July 1980. More recently Perez & Blundell (2010) have presented evidence for the accretion disc lines viewed in the optical through the attenuating disc wind while Perez & Blundell (2009) presented infra-red spectroscopy of the of the accretion disc. The centres of both the accretion disc and the wind during the flare episode are orbiting at speeds consistent with 175 km s\(^{-1}\) – 200 km s\(^{-1}\), in agreement with the He II and C II measures of the orbital speed of the compact object about the centre of mass of the system (Crampton & Hutchings 1981; Fabrika & Bychkov 1990). We suggest the flare was initiated by a disturbance of the outer regions of the accretion disc, perhaps a massive ejection from the companion which fed the accretion disc. After some delay the disc responded with a doubling of wind speed, initially reduced jet speed then dominated by a period of higher than usual launch speeds and finally a complex radio flare. Collectively, the panels in Fig. 10 seem to imply that type-1 and type-2 flares, if corresponding to (1) enhanced mass-loss from the wind and (2) enhanced mass-loss from the jets respectively, are a characteristic sequence that comprise the flare phenomenon.

8 Conclusions
This sequence of observations has, for the first time in the optical, very clearly identified the accretion disc of SS433, although it seems likely that Falomo et al. (1987) had a glimpse in observations made in June 1979. Subsequently, both Dopita & Cherepashchuk (1981) and Kopylov et al. (1985) made separate observations of the same flare episode in July 1980. More recently Perez & Blundell (2010) have presented evidence for the accretion disc lines viewed in the near-IR by Perez & Blundell (2009), and so may indicate that a considerable wind was blown off the_star prior to the build-up of the flare itself.

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References
Aslanov, A. A., Cherepashchuk, A. M., Goranskii, V. P., Rakhmov, V. Y., & Vermeulen, R. C. 1993, A&A, 270, 200
Blundell, K. M., & Bowler, M. G. 2005, ApJ, 622, L129
Blundell, K. M., Bowler, M. G., & Schmidtobreick, L. 2007, A&A, 474, 903
Blundell, K. M., Bowler, M. G., & Schmidtobreick, L. 2008, ApJ, 678, L47
Blundell, K. M., & Kuncic, Z. 2007, ApJ, 668, L103
Bowler, M. G. 2010, A&A, 516, A24
Bonsignori-Facondi, S. R., Padrielli, L., Montebognoli, S., & Barberi, R. 1986, A&A, 166, 157
Chanan, G. A., Middleditch, J., & Nelson, J. E. 1976, ApJ, 208, 512
Chakrabarti, S. K., et al. 2005, MNRAS, 362, 957
Cherepashchuk, A. M., et al. 2005, A&A, 437, 561
Cherepashchuk, A. M., et al. 2008 PoS 1 Nov 7th INTEGRAL workshop, arXiv:0811.0069v1
Claret, A. 2004, A&A, 424, 919
Claret, A., & Gimenez, A. 1992, A&AS, 96, 255
Claret, A., & Gimenez, A. 1993, A&A, 277, 487
Crampton, D., Cowley, A. P., & Hutchings, J. B. 1980, ApJ, 235, L131
Crampton, D., & Hutchings, J. B. 1981, ApJ, 251, 604
Dekker, H., Delabre, B. & D’Odorico, S., 1986, SPIE 627, 39
Doolin, S., & Blundell, K. M. 2009, ApJ, 698, L23
Dopita, M. A., & Cherepashchuk, A. M. 1981, Vistas in Astronomy, 25, 51
Eggleton, P. P. 1983, ApJ, 268, 368
Fabrika, S. N., & Bychkova, L. V. 1990, A&A, 240, L5
Fabrika, S. 2004, Astrophysics and Space Physics Reviews, 12, 1
Fabrika S. & Irsambetova T., 2003, New Views on Microquasars, 276
Falomo, R., Boksenberg, A., Tanzi, E. G., Tarenghi, M., & Treves, A. 1987, MNRAS, 224, 323
Fiedler, R. L., et al. 1987, AJ, 94, 1244
Fender, R. P., Belloni, T. M., & Gallo, E. 2004, MNRAS, 355, 1105
Gies, D. R., McSwain, M. V., Riddle, R. L., Wang, Z., Wiita, P. J., & Wingert, D. W. 2002, ApJ, 566, 1069
Goranskii, V. P., Esipov, V. F., & Cherepashchuk, A. M. 1998, Astronomy Reports, 42, 209
Kopylov, I. M. et al (1985) Sov. Astron. 29 186
Kotani, T., et al. 2006, VI Microquasar Workshop: Microquasars and Beyond,
Margon, B., Anderson, S. F., Aller, L. H., Downes, R. A., & Keyes, C. D. 1984, ApJ, 281, 313
Miller-Jones, J. C. A., Blundell, K. M., Rupen, M. P., Mioduszewski, A. J., Duffy, P., & Beasley, A. J. 2004, ApJ, 600, 368
Miller-Jones, J.C.A., Blundell, K.M., Duffy, P., Tammi, J., Podsiadlowski Ph., Mioduszewski A., Rupen M., & Trushkin S., in prep
Mioduszewski, A. J., Rupen, M. P., Walker, R. C., Schillemat, K. M., & Taylor, G. B. 2004, Bulletin of the American Astronomical Society, 36, 967
Mirabel, I. F., & Rodríguez, L. F. 1998, Nat, 392, 673
Nandi, A., Chakrabarti, S. K., Belloni, T., & Goldoni, P. 2005, MNRAS, 359, 629
Nipoti, C., Blundell, K. M., & Binney, J. 2005, MNRAS, 361, 633
Paragi, Z., Vermeulen, R. C., Fejes, I., Schilizzi, R. T., Spencer, R. E., & Stirling, A. M. 1999, A&A, 348, 910
Perez M., S., & Blundell, K. M. 2009, MNRAS, 397, 849
Perez M., S., & Blundell, K. M. 2010, MNRAS, 408, 2
Seaquist, E. R., Gilmore, W. S., Johnston, K. J., & Grindlay, J. E. 1982, ApJ, 260, 220
Schmidtobreick, L., & Blundell, K. 2006, VI Microquasar Workshop: Microquasars and Beyond
Trushkin, S. A., Bursov, N. N., Kotani, T., Nizhelskij, N. A., Namiki, M., Tsuboi, M., & Voitsik, P. A. 2007, ESA Special Publication, 622, 357
Vermeulen R.C., 1989, PhD Thesis, University of Leiden
Vermeulen, R. C., Icke, V., Schilizzi, R. T., Fejes, I., & Spencer, R. E. 1987, Nat, 328, 309
Vermeulen, R. C., Schilizzi, R. T., Spencer, R. E., Romney, J. D., & Fejes, I. 1993a, A&A, 270, 177
Vermeulen, R. C., McAdam, W. B., Trushkin, S. A., Facconi, S. R., Fiedler, R. L., Hjellming, R. M., Johnston, K. J., & Corbin, J. 1993b, A&A, 270, 189
Vermeulen, R. C., et al. 1993c, A&A, 270, 204
