PROCEEDINGS OF SCIENCE

Inflow *and* outflow from the accretion disc of the microquasar SS 433

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A succession of near-IR spectroscopic observations, taken nightly throughout an entire cycle of SS 433's orbit with UKIRT, reveal (i) the persistent signature of SS 433's accretion disc, having a rotation speed of $\sim$ 500 $\mathrm{km\,s^{-1}}$ and (ii) confirms the presence of the circumbinary disc recently discovered at optical wavelengths by Blundell, Bowler & Schmidtobreick (2008) and (iii) detects a much faster outflow than has previously been measured from the disc wind. Our relatively high spectral resolution at these near-IR wavelengths has enabled us to deconstruct the different components, and their physical origins, that comprise the Brackett-γ line in this binary system.

VII Microquasar Workshop: Microquasars and Beyond
September 1-5 2008
Foca, Izmir, Turkey

`http://pos.sissa.it/`

PoS(MQW7)094

1. Introduction

SS 433 has been extensively studied and monitored since 1978 when it was fully recognised as an interesting system by Clark & Murdin (1978) through spectroscopy (see the comprehensive review by Fabrika, 2004). SS 433's spectrum is characterised by strong interstellar absorption and ubiquitous emission lines from X-ray to IR wavelengths. At near-infrared (near-IR) wavelengths, SS 433 is characterised by a red continuum and bright emission lines from low-ionization species.

Near-IR light can escape high opacity and dusty environments more easily than Hα photons, making it possible to detect heavily obscured line emitting regions. Therefore we carried out a line deblending procedure based on fitting Gaussian profiles to our near-IR spectra, choosing Brγ λ 2.165 μm as the most suitable emission line to model.

The Brγ recombination line has been extensively used in the past to diagnose the presence of accretion discs and outflows (Bandyopadhyay et al., 1997; Shahbaz et al., 1999). In the case of cataclysmic variables (CVs), Dhillon & Marsh (1995) argued that since the Brackett and He I emission lines are so strong in emission and also so broad that they must originate in the accretion disc. In low-mass X-ray binaries (LMXBs) the Brγ line has been detected showing a double-peaked profile characteristic of accretion discs (Bandyopadhyay et al., 1997). Bandyopadhyay et al. (1997) used the distance between the peaks to calculate properties of the orbits in LMXBs, assuming that the compact object accretes via Roche-lobe overflow.

In these proceedings, we present unprecedentedly high signal-to-noise mid-resolution near-IR spectra of SS 433 from UKIRT. We want to study the kinematics of the accretion disc and its outflow. The description of the UKIRT observations and the data reduction will be presented in a future paper (Perez & Blundell *in prep.*). In Section 2 we discuss the results of deconstructing the Brackett-γ emission line in order to identify the different components present in the system. Finally we discuss and give concluding remarks on this work in Section 3.

PoS(MQW7)094

2. Deconstructing the Brackett-γ profile

Decomposition of a line profile as the sum of Gaussian components is a technique widely used to extract information from different parcels of gas in a given composite emission line. Blundell et al. (2008) decomposed the stationary Hα line (observed during a quiescent period in SS 433's behaviour) into primarily 3 components: one broad component ($\sim$ 700 km s^{-1}) whose width decreases with precessional phase so is identified as the accretion disc wind, and two narrower, red and blue-shifted, components alternating in intensity, but stationary in wavelength. The stationary Brγ emission lines show a much more complex profile than the quiescent stationary Hα line studied by Blundell et al. (2008). We came to the realisation that up to six components were needed to account for the complexity of the profile shape in Brγ. Fig. 1 (upper panel) shows an example of a fitted Brγ profile, in which six Gaussians were used for the fit.

Fig. 1 (lower panel) shows the components of the stationary Brγ line as a function of time (vertical axis). It is easy to see that the Brγ complex profile can be decomposed in three main constituents: a very broad wind component present at all times in our dataset; and two sets of narrower but more widely spaced pairs. The broad wind and both narrower pairs show a mean velocity closer than the systemic speed $V_0 \simeq 150$ km s^{-1} (Perez & Blundell *in prep.*).

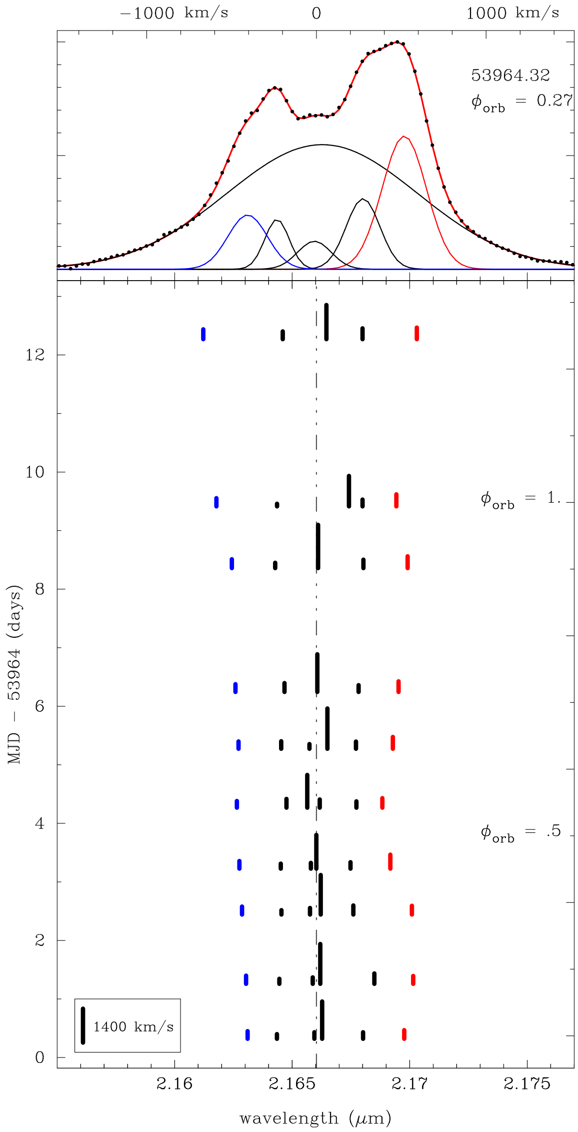

Figure 1: *Upper panel:* Example of the Brγ stationary emission line, observed at orbital phase $\phi_{\rm orb} = 0.27$. *Lower panel:* Tracks of the Gaussian components fitted to our spectra. The modified Julian date (MJD) increases vertically and the height of the tick marks are proportional to the FWHM of each component (see inset in the bottom left corner).

The broad component shows FWHMs from 1300 up to 1500 $\mathrm{km\,s^{-1}}$. The presence of a broad wind component has been reported before from Hα stationary line analysis but with full-widths reaching only up to 800 $\mathrm{km\,s^{-1}}$ (Falomo et al., 1987) and 700 $\mathrm{km\,s^{-1}}$ (Blundell et al., 2008).

The most striking discovery that arises from the Brγ line fitting is the presence of the pair of rapidly rotating narrow components with rotation speed of $\sim$ 500 $\mathrm{km\,s^{-1}}$. An example of these narrower pairs are depicted in red and blue colours in the upper panel of Fig. 1. The speed with which the material spirals in the accretion disc corresponds to half the difference of the speed of those lines, under the assumption that the fitted centroids correspond to the tangent speeds. This pair of lines reveals material that is spiralling in the potential well at speeds of about 500 $\mathrm{km\,s^{-1}}$.

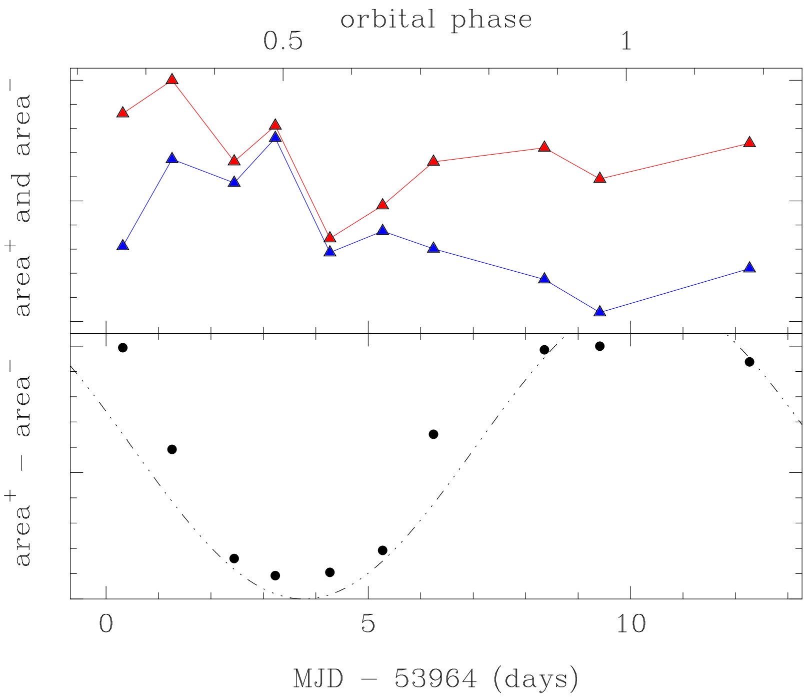

Figure 2: *Upper panel:* Areas (peak×FWHM) of accretion disc emission lines. *Lower panel:* Difference of the areas of the two components (red-blue). Notice the orbital phase dependence (the dashed line is the sinusoidal variation corresponding to the orbital phase).

3. Discussion and Conclusions

A succession of near-IR spectroscopic observations, taken nightly throughout an entire cycle of SS 433's orbit with UKIRT UIST, have enabled us to deconstruct the different components (and their physical origins) that comprise the Brackett-γ line in this binary system. These observations have revealed:

1. the persistent signature of SS 433's accretion disc, having a rotation speed of $\sim$ 500 km s^{-1}. The area of each accretion disc line (i.e., the components moving at $\sim$ 500 km s^{-1}) seem to be correlated (see upper panel in Fig. 2). Also, the difference in the areas of these two lines shows a very clear orbital phase dependence (see lower panel in Fig. 2). This dependence is what we would expect if the material emitting this components comes from the disc, because as the star transits in front of the disc it partially obscures the emitting regions.

2. the presence of the circumbinary disc recently discovered at optical wavelengths by Blundell et al. (2008) by decomposing the Hα line profile in three components (during quiescent state). In the optical this circumbinary ring of material orbits the system at $\sim$ 200 km s^{-1}. It has been proposed that the origin of this glowing material corresponds to overflow of gas from the L2 point, assuming that the system has filled its Roche lobe (Blundell et al., 2008; Filippenko et al., 1988). Our Brγ decomposition is in excellent agreement with the presence of this excretion disc since we see a pair of lines behaving in the same way in the near-IR, and at very similar speeds.

3. a much faster outflow than has previously been measured for the disc wind. With the composite Brγ line dominated throughout our series of observations by the disc wind, and the accretion disc being only a minority ($\lesssim$ 20%) contribution to the total Brγ emission.

Finally, we caution against the use of the unresolved Brackett-γ line intensity as an “accretion signature" in X-ray binaries or microquasars in any quantitative way, since the Brγ emission is telling us about outflow via various different means, not merely accretion onto a compact object.

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