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SS433: THE MICROQUASAR LINK WITH ULXS?

P. A. Charles,[1] A. D. Barnes,[1] J. Casares,[2] J. S. Clark,[3] W. I. Clarkson,[1] E. T. Harlaftis,[4] R. I. Hynes,[5] T. R. Marsh,[1] and D. Steeghs[6]

RESUMEN

SS433 es el microcuasar prototipo de la Galaxia y posiblemente incluso análogo a las fuentes ULX si se tiene en cuenta la energía cinética de los "jets". Sin embargo y a pesar de 20 años de estudio, nuestras restricciones sobre la naturaleza del sistema binario son extremadamente grandes debido a la dificultad de localizar rasgos espectrales capaces de revelar la naturaleza y el movimiento del donador de la masa. Los espectros azules de alta resolución recientemente obtenidos cuando el disco (en precesión) se encuentra de perfil, sugieren que la binaria se halla cerca de la fase de envolvente común, lo cual hace extremadamente difícil obtener las restricciones cinéticas. Sin embargo, encontramos evidencia de un donador masivo como era de esperar para la muy alta tasa de transferencia de masa inferida y comparamos las propiedades de SS433 con las de Cyg X3.

ABSTRACT

SS433 is the prototype *microquasar* in the Galaxy and may even be analogous to the ULX sources if the jets' kinetic energy is taken into account. However, in spite of 20 years of study, our constraints on the nature of the binary system are extremely limited as a result of the difficulty of locating spectral features that can reveal the nature and motion of the mass donor. Newly acquired, high resolution blue spectra taken when the (precessing) disc is edge-on suggest that the binary is close to a common-envelope phase, and hence providing kinematic constraints is extremely difficult. Nevertheless, we do find evidence for a massive donor, as expected for the inferred very high mass transfer rate, and we compare SS433's properties with those of Cyg X-3.

Key Words: **ACCRETION: ACCRETION DISCS — X-RAYS: BINARIES — X-RAYS: STARS**

1. INTRODUCTION

SS433 holds a special place in late 20th century astronomy as the first relativistic jet source discovered in the Galaxy (see Margon 1984), and hence is the prototype *microquasar*. It is remarkable as the only *continuously* emitting microquasar, with its key feature being the 162.5d precession period of the jets (and associated accretion disc) that is revealed by the "moving lines" which have now been observed for more than 2 decades. The radial velocity curves of the moving lines are very well described by the *Kinematic Model* (Margon 1984), thereby revealing key parameters of the jets (v=0.26c; i=79°) and, combined with radio observations of the associated SNR W50, a distance of 4.8kpc. It is observed as a weak ($\sim 10^{36}$erg s^{-1}) X-ray source (X1909+048), which combined with the high orbital inclination (it is eclipsing) suggests that it may be an Accretion Disc Corona (ADC) type of X-ray source. However, it is well established that the kinetic energy in the jets is at least 1,000 times greater than the observed luminosity (Safi-Harb 2003), although the origin of the jet energy is still a matter of debate, and this would place SS433 in the recently defined class of ULX sources (e.g. King 2003). If the intrinsic luminosity were indeed $\geq 10^{39}$erg s^{-1}, then the implied mass-transfer rate would be extremely high ($\dot{M} \sim 10^{-4} M_{\odot} y^{-1}$, see also Fuchs et al 2003).

This has led to King et al (2000) investigating the evolutionary status of SS433 and they show that, given a massive, radiative companion, it is possible for SS433 to avoid the common-envelope phase, by expelling the majority of the transferred material (part of which constitutes the jets). They conclude that the observed X-rays are then likely to almost entirely arise from the jets themselves. Indeed, the X-ray output of SS433 appears to be dominated by the precessing jets, with moving X-ray emission lines and even spatially resolved X-ray structure along the jet axis (Marshall et al 2002; Namiki et al 2003). Recently, however, the RXTE All-Sky Monitor has revealed a long-term modulation in the precessional X-ray lightcurve (Gies et al 2001). The relativistic doppler boosting from jet precession alone is insuffi-

[1]University of Southampton, Southampton, UK
[2]Instituto de Astrofísica de Canarias, La Laguna, Spain.
[3]University College London, UK
[4]National Observatory, Athens, Greece
[5]University of Texas at Austin, USA
[6]Harvard-Smithsonian Center for Astrophysics, Cambridge, USA.

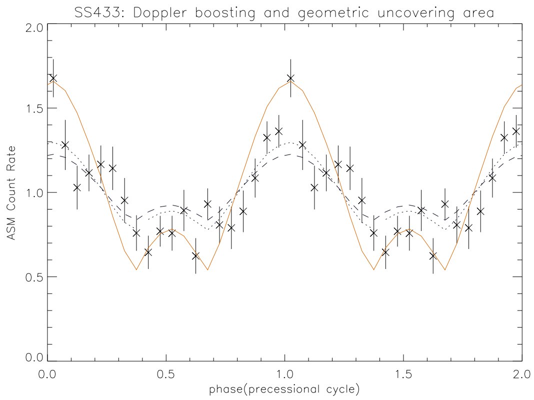

Fig. 1. 7-year X-ray lightcurve of SS 433 obtained with the RXTE/ASM. The dotted and dashed curves represent modulation expected from doppler boosting in the relativistic jets (for the cases of bullets and a continuous stream respectively). An additional geometric modulation is clearly required, modelled here as the modulation of a power-law jet by a precessing accretion disk (dot-dashed line). From Clarkson et al (2004).

cient to produce this modulation, which requires an additional, presumed geometrical component (Clarkson et al 2004). For the established high inclination this can most naturally be provided by structure in the edge-on view of the accretion disk, which may be tilted or warped to produce the apparent asymmetry in the precessional lightcurve.

2. DYNAMICAL CONSTRAINTS

While the binary period (of 13d) is also well-known, the nature of the mass donor (a ∼B star; Crampton & Hutchings 1981) is poorly constrained because of the high reddening in combination with strong disc/jet emission features that obliterate the characteristic (and weak) absorption lines of early-type stars. Consequently, only emission line radial velocity curves have been derived with any confidence (Fabrika & Bychkova 1990), which means that dynamical constraints on the system masses are limited. Indeed, with no evidence for X-ray pulsations or bursts, there is no obvious indication as to the nature of the compact object. And the interpretation of the radial velocity curves requires assumptions about the mass donor, leading to estimates that range from $0.8M_\odot$ (d'Odorico et al 1991) to $62M_\odot$ (Antokhina & Cherepashchuk 1985)!

Nevertheless Fabrika & Bychkova used ∼4 yrs of 6m data taken around precession phase $\Psi \sim 0$ (which minimises the scatter in their radial velocity curve), corresponding to the most open viewing angle of the disc (and hence best view of the hotter inner disc regions). For an assumed e=0 they obtain $f(M_2) \simeq 8M_\odot$, which gives $M_2 \sim 10M_\odot$ for a NS, or $15M_\odot$ for a $6M_\odot$ BH (both are capable of explaining the extremely high $\dot{M}$).

Consequently it has been impossible to add SS433 to the growing list of compact object mass determinations (Charles & Coe 2003) which is so important for a system whose properties link it to both the microquasars and ULX systems.

3. DETECTION OF MASS DONOR IN SS433?

Recognising the need to investigate the nature of the mass donor if progress was to be made in understanding SS433, it became clear to several groups that high S/N, high resolution blue spectra were crucial in order to search for weaker spectral features in absorption (away from the strong disc emission lines). Assuming that the best chance to search for the donor signature would come when the disc had precessed (with the jets) to its maximum opening angle, Gies et al (2002) obtained spectra that suggested weak absorption features similar to those seen in late A supergiants. These did yield a few radial velocity measurements, but could only be used to derive mass constraints in combination with the HeII emission radial velocity curve (see figure 3), from which they obtained $q = M_X/M_2 = 0.6 \pm 0.1$, and $M_X = 11 \pm 5\mathrm{M}_\odot$, $M_2 = 19 \pm 7\mathrm{M}_\odot$. Such an extreme mass ratio would be expected in order to explain the required very high (thermal) mass transfer rate (King et al 2000). However, their extremely limited orbital phase coverage clearly indicated the need for further observations to confirm and extend these results.

In fact, we had been acquiring such blue spectra of SS433 for several years (from AAT, WHT, INT, and Calar Alto), in an attempt to obtain good sampling in both orbital and precessional phases. Our initial aim was to search for any irradiation signature of the donor via the Bowen fluorescence mechanism, as has been so successful in Sco X-1 and other luminous X-ray binaries (see Casares et al, these proceedings). Unfortunately, no such component was visible, only broad Bowen emission, likely from an extended region such as the disc. We had also decided to take a different route to Gies et al when seeking evidence for the donor itself, and therefore examined our spectra obtained around precessional phases ∼0.3–0.7, when the jets are close to perpendicular to our line-of-sight, and correspondingly the accretion disc is seen close to edge-on. Since the strong optical variability as a function of precessional phase is already well-established (and indicates a disc contribution at least equal to that of the mass donor), we felt that

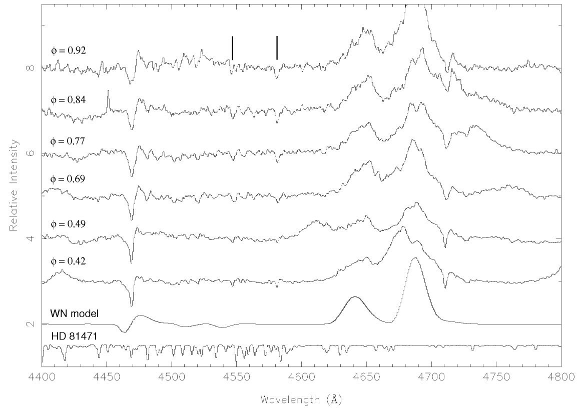

Fig. 2. Blue spectra of SS433 obtained near precession phase ∼0.5, when the disc is closest to edge on. The sharp absorption features between $\lambda\lambda$4500-4600 are characteristic of late B–A spectral types and we associate these with the mass donor. The bottom two spectra show (upper) the similarity of the gross SS433 emission features to that of a high mass-loss WN star and (lower) an A7I template star HD 81471.

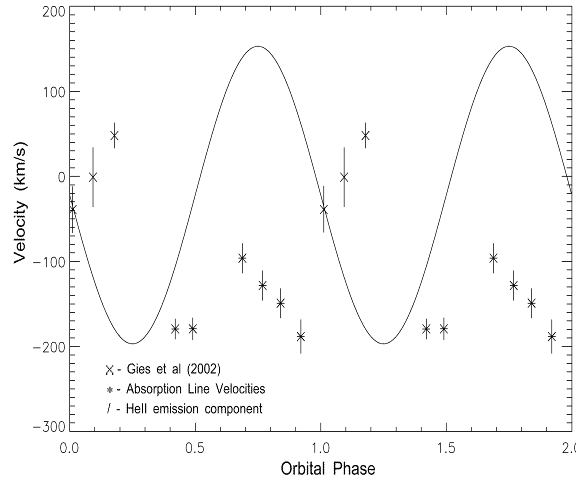

Fig. 3. Absorption line radial velocity measurements of SS433 obtained by us (*) and Gies et al 2002 (x), together with the Fabrika & Bychkova 1990 fit to their HeII emission velocities which were presumed to represent the disc/compact object.

it was important to minimise the disc component by observing when the disc was edge-on. Our best spectra obtained at these phases are shown in figure 2. Of particular interest are the weak, but narrow, absorption features in the $\lambda\lambda$4500-4600 region. These are mostly FeII transitions and are typically seen in early-type (late B - A) spectra. This includes the spectral type suggested by Gies et al, but we could not detect the transitions they reported. However, we have now clearly detected such features in SS433, and these are marked in figure 2, and are strong in the A7 template (HD81471) plotted at the bottom.

What was more remarkable was the radial velocity curve of these absorption features (see figure 3). While the velocity around orbital phase 0.75 is close to that expected from Gies et al's values for their mass ratio, the subsequent velocities (approaching phase 1.0) move in the *opposite* direction! This only makes sense if the secondary is embedded in a dense outflowing disc wind, although we might expect these lines to then show P Cyg behaviour under such circumstances, and the velocities around phase 0.4–0.5 are even more anomalous. Nevertheless, with this orbital phase behaviour, it becomes extremely difficult to justify a keplerian interpretation of the observed velocities, and hence any resulting masses would be subject to major systematic effects. And support for the concept of a major disc plane (equatorial) mass outflow has already been obtained via the radio detection of extended emission in a direction that is *perpendicular* to the main jet outflow (Blundell et al 2001). Furthermore, the overall SS433 spectrum is remarkably similar to models of WN spectra (e.g. 2nd from bottom plot of figure 2 from Clark & Porter 2004 which is a model for the WN9 star WR105 with parameters of T = 32,500K, $\dot{M}$= $1.2\times10^{-5} M_{\odot} y^{-1}$ and v_{∞} = 700 km s^{-1}), and represents a dense outflow in which an ionising source is embedded. We are not claiming that SS433 is a W-R star, but simply point out that it makes little difference whether a hot star or powerful X-ray source is the source of that ionisation, both of which are of course present in Cyg X-3 (Fuchs et al 2003), which may even be the end result of the evolution of systems like SS433.

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