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Doppler-shifted X-ray line emission from SS433

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Summary. We present the results from a series of X-ray observations of SS433 made with the *EXOSAT* Observatory in 1983–85 which show that strong iron line emission is present in its X-ray spectrum and displays large energy shifts which vary as a function of the 164-day precession phase. These energy shifts are entirely consistent with the Doppler shifts predicted in the kinematic model for the relativistic jets in SS433. The implication is that the X-ray emitting material is physically associated with the jets. The line energy in the rest-frame is 6.7 keV, suggesting a thermal origin for the line emission. Changes in the visibility of the lines which occur as function of 164-day phase are interpreted as being due to obscuration by a precessing accretion disc. We use this new result to provide additional constraints on the system geometry, and the physical conditions in the jets, and to derive a lower limit to the mass outflow rate. We also discuss the implications for the jet acceleration mechanism.

1 Introduction

SS433 is a galactic binary system with a 13-day period which has achieved notoriety principally because of the enormous Doppler shifts shown by the emission lines in its optical spectrum (see Margon 1984 and references therein). This phenomenon is now basically understood – the Doppler shifts arise in material ejected from SS433 at 0.26 *c* in two highly collimated, opposed jets which are precessing about a fixed axis in space with a 164-day period. Extensive optical monitoring of the 'moving' emission lines, together with radio observations of the changing structure on small angular scales, have provided accurate values for the parameters which describe the jet geometry (e.g. Margon 1984). There is strong evidence that SS433 is a semi-detached binary system containing an accreting compact object surrounded by an accretion disc which also precesses at the 164-day period. In this picture the jets are produced near the compact object and are accelerated in directions normal to the disc.

At X-ray wavelengths SS433 is a relatively weak, undistinguished hard X-ray source with a 2–10 keV X-ray luminosity of $\sim 10^{36}$ erg s^{-1} at the assumed distance of 5 kpc (Warwick *et al.* 1981). Both *HEA0-1* (Marshall *et al.* 1979) and *Ariel 6* (Ricketts *et al.* 1981) measurements showed a continuum spectrum which could be adequately fitted by either a power law or thermal model with an iron emission line near 7 keV. The spectrum obtained with the *Einstein Observatory* Solid State Spectrometer (SSS) showed none of the emission lines (e.g. Si XIII and Si XIV) expected from a thermal plasma at a temperature of a few keV (Grindlay *et al.* 1984). An extensive study by Grindlay *et al.* (1984) based on 34 observations with the *Einstein Observatory* Monitor Proportional Counter (MPC) made over a 1.5-yr period demonstrated that both the X-ray spectrum and intensity were variable on time-scales from hours to months, and indicated that a power law fitted the X-ray spectrum better than thermal models. No evidence was found for variability on time-scales less than ~300 s, suggesting an extended X-ray source. Clear evidence was found in the MPC data for an orbital phase dependence of both X-ray intensity and spectrum, with a suggestion of a partial X-ray eclipse at phase 0.25. The X-ray properties of SS433 almost certainly also vary with 164-day precession phase (as was indicated by *Ariel 5* measurements, Ricketts *et al.* 1981), but the MPC observations had insufficient phase coverage to confirm this.

2 *EXOSAT* observations and results

A total of 15 separate observations of SS433 have been carried out with the *EXOSAT* Observatory in the period 1983 October–1985 October with observation times ranging from 3 to 12 hr. This programme includes seven observations made in 1984 September (with coordinated optical photometry) which cover one complete binary cycle; full details of these will be published elsewhere (Stewart *et al.* 1986). SS433 was detected at flux levels ranging from ~ 1.4 to 3.4×10^{-10} erg cm^{-2} s^{-1} (2–10 keV) in the Medium Energy (ME) and Gas Scintillation Proportional Counter (GSPC) detectors which are sensitive in the ~2–20 keV range, and was also detected as an unresolved point source in the Low Energy telescope with Channel Multiplier Array (CMA; ~0.04–2 keV) detector at count rates of 0.005 to 0.01 count s^{-1}. Details of the *EXOSAT* Observatory and scientific instruments can be found in Turner, Smith & Zimmerman (1981), Peacock *et al.* (1981) and Taylor *et al.* (1981).

We have derived the time-averaged ME and GSPC X-ray spectra for SS433 for each of the 15 observations, and have fitted the spectra with a variety of trial models using standard techniques. Representative GSPC spectra are shown in Fig. 1. The X-ray spectrum is complex, requiring, for most of the observations, at least two continuum components plus an emission line to obtain an adequate fit to the data. (Note the CMA count rate observed is entirely consistent with an extrapolation of the continuum observed at higher energies with an interstellar column density $N_H \approx 1.5\times 10^{22}$ cm^{-2}, similar to values reported in previous studies of SS433 – e.g. see Watson *et al.* 1983.) The quality of the X-ray spectra derived for SS433 is lower than that normally achieved with *EXOSAT*, both because of background subtraction problems for the ME data above ~8 keV (believed to arise in contamination of the background measurement by a strong source 'leaking' through the side of the detector assembly), and because SS433 is near the threshold for obtaining a good X-ray spectrum in the GSPC. Accordingly we defer a full analysis of the continuum spectrum to a later paper, and here concentrate on the determination of the emission-line parameters. These parameters are not significantly affected either by the choice of fitted continuum, or by the background subtraction problems. For different continuum fits the derived line energy changes by <0.1 keV, well within the statistical errors.

In Table 1 we give the line parameters derived from the GSPC spectra for five out of the 15 observations with the highest data quality. (The ME data give completely consistent values.) These line parameters have been derived assuming the same continuum spectral form for each

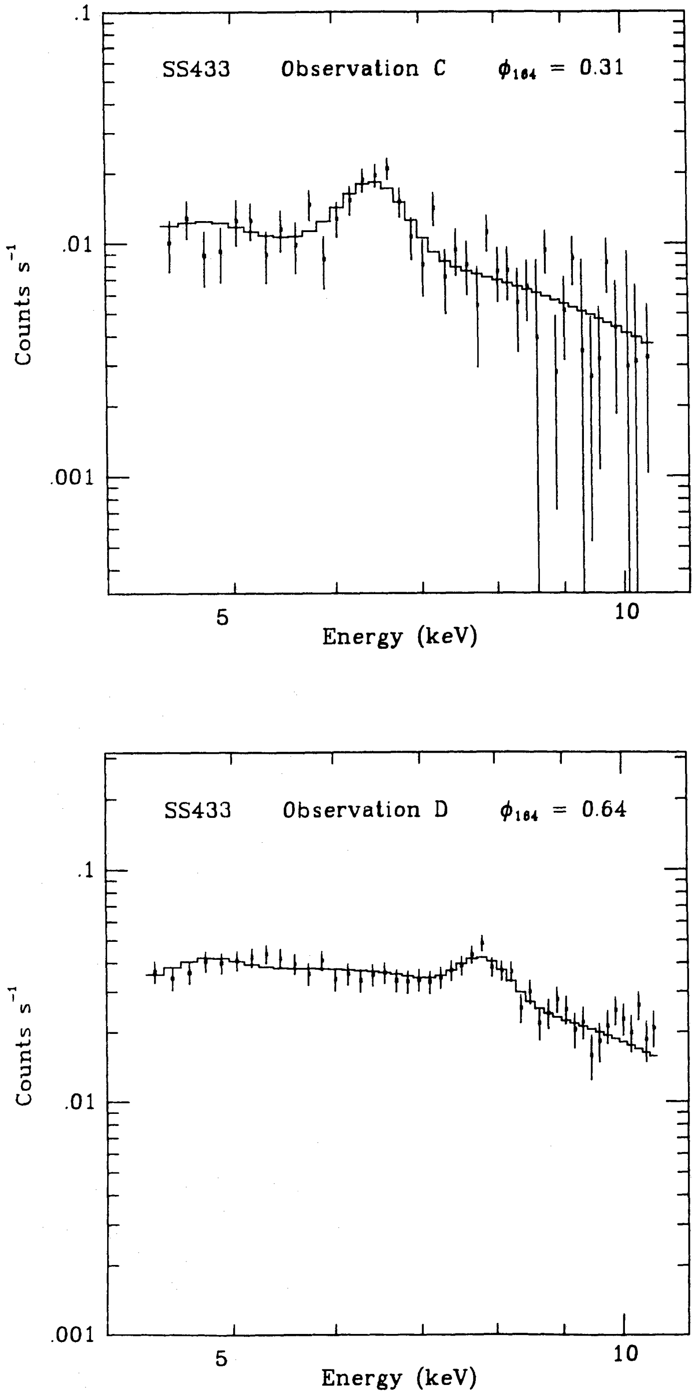

Figure 1. *EXOSAT* GSPC X-ray spectra of SS433 at two different 164-day phases. The histogram shows the best-fit spectrum which consists of a two-component continuum plus emission line (see text). Error bars shown are $\pm 1\sigma$. Spectra are labelled as in Table 1.

observation, namely a two-component model consisting of a blackbody plus optically thin bremsstrahlung. This model provides a good fit to all the GSPC and ME observations with both blackbody and bremsstrahlung temperatures ≈2 keV. There is little change in the continuum-model parameters between observations. The interpretation of the two components is not necessarily physical, as is discussed in Section 4.1. Fitting a single thermal bremsstrahlung model yields a significantly higher temperature (T~10 keV).

Table 1. *EXOSAT* observations of SS433: X-ray emission-line parameters.

Obs	Date [MJD]	ϕ_{164} [1]	E_{line} [2] (keV)	error (keV)	Width [2] (keV)	F_{line} [2]	F_x [3]	EW [2] (keV)
A	45621.2	0.67	7.68	+0.10, -0.18	0.19	1.2	1.3	0.8
B	45964.7	0.78	7.32	+0.20, -0.20	0.19	3.4	2.0	1.2
C	46213.1	0.31	6.49	+0.18, -0.20	0.21	1.4	1.0	1.1
D	46267.0	0.64	7.81	+0.20, -0.20	0.16	1.5	1.4	0.6
E	46343.5	0.11	6.66	+0.17, -0.20	0.78	2.5	1.0	1.8

Notes to Table 1

(1) Assuming the ephemeris of Margon (1984).

(2) Line energy, width and strength and equivalent width are taken from GS measurements assuming the continuum spectral fit to the combined GSPC and ME data. Errors quoted for the line energy are 90% confidence limits. The width quoted is the σ of the fitted Gaussian profile. The line strength F_{line} is in units of 10^{-11} erg cm^{-2} s^{-1}. Typical errors (90% limits) for line width and strength are $\pm$ 0.2 keV and $\pm$ 5 x 10^{-12} erg cm^{-2} s^{-1} respectively. Typical error on the equivalent width (EW) is 30 - 50 %.

(3) The X-ray intensity F_X is taken from the ME data and is in units of 10^{-10} erg cm^{-2} s^{-1} [2-6 keV]. Error on F_X is $\lesssim$ 10 %.

The most striking result is the large variation in the energy of the emission line. The line energy varies from ~6.5 to 7.8 keV, whilst the line strength and width are fairly constant (but see comments in Section 4.2). The obvious explanation for this unprecedented behaviour of an X-ray emission line is that it arises from the changing Doppler shifts of a line with a rest-frame energy near 7 keV. Fig. 2 shows the line energy as a function of 164-day precession phase for those observations where an accurate value can be determined. This clearly demonstrates that the line energy follows the Doppler shift expected in the kinematic model of the jets i.e. it follows the same Doppler curve as that seen in the optical 'moving lines'. A good fit between the expected and measured line energies is achieved if we adopt the parameters of Margon (1984) with a rest energy for the emission line of 6.7±0.1 keV. The line energies derived from the other observations not quoted in Table 1 are entirely consistent with the Doppler curve. We have not presented these data since they do not provide any further constraints on the fit, either because the errors are too large, or because the observations were made close in time to observations A and B and thus do not provide any additional 164-day phase coverage. Further confirmation of this result comes from an observation with the *Tenma* satellite in 1983 September (at 164-day phase 0.41, see Fig. 2) which shows an emission line at 6.70±0.1 keV (Matsuoka *et al.* 1986), very close to the expected value. The largest discrepancy between observed and predicted line energies occurs for the two observations made between phase 0.6 and 0.7 (A & D, see Fig. 2). The magnitude of the discrepancy is not, however, significantly larger than that seen, at times, for the optical lines (e.g.

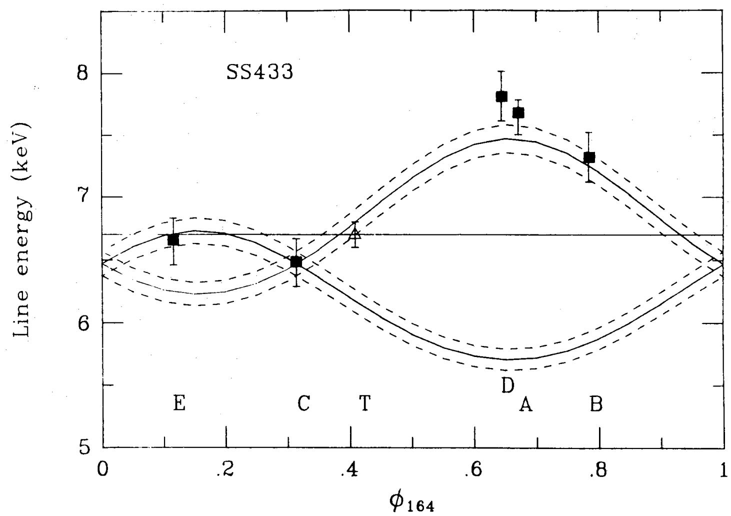

Figure 2. Energy of the X-ray emission line in SS433 as a function of 164-day phase. Individual observations are labelled as in Fig. 1 and Table 1. The point labelled 'T' is a measurement by the *Tenma* satellite (Matsuoka *et al.* 1986 – see text). The solid curve shows the predicted line energy in the kinematic model for an assumed rest line energy of 6.7 keV (marked with horizontal line). The dashed curves correspond to rest line energies of 6.6 and 6.8 keV.

Margon 1985). Only *one* emission line is ever seen, however, in the X-ray spectrum, even though both components would easily be resolved in the GSPC at most 164-day phases. Over most of the phase range the visible line is the component that is normally blueshifted (i.e. the 'blue' component), but at phase 0.11 (observation E) the other, normally redshifted, component (the 'red' component) becomes visible whilst the 'blue' component is absent. In other words the line visible in the X-ray spectrum is always the one associated with the jet which is pointing towards the observer.

3 Interpretation

3.1 ORIGIN OF THE LINE AND CONTINUUM EMISSION

The natural interpretation of these results is that the X-ray emission line in SS433 must originate in the relativistic jets. The rest energy of the line is 6.7±0.1 keV, strongly suggesting thermal emission with Fe XXV dominating. The *EXOSAT* data are also consistent with the X-ray continuum spectrum being predominantly thermal. The measured equivalent width of the line is compatible (within a factor $\lesssim 2$) with that expected for an X-ray plasma with a temperature of a few keV for material with cosmic abundances. This then requires that most ($\gtrsim 50$ per cent) of the continuum flux must also originate in the jets, and also be thermal bremsstrahlung. The only way to avoid this conclusion is to assume that the line and continuum are formed in physically distinct regions; this would then imply that the jet material was significantly overabundant in iron, and that the equivalent width of the iron line was a complete coincidence. This possibility seems unlikely, especially given the lack of any significant change in the equivalent width of the line during the partial X-ray eclipse seen at binary phase 0.25 (Stewart *et al.* 1986) which strongly supports the presence of only one emission region (but see comments in Section 4.1).

3.2 VISIBILITY OF LINES: GEOMETRICAL CONSTRAINTS

The strength of the emission lines is subject to a strong modulation [$\propto 1/(1+z)^3$: 'Doppler boosting'] with changing Doppler shift. Although this effect might possibly explain the absence of the 'red' component around phase 0.65 where the predicted ratio of 'blue' to 'red' line strengths >2, only one component is observed at other phases where the predicted ratio is much smaller. Thus the absence of the 'red' component over most of the 164-day phase covered by the present observations, and its presence at phase 0.11 when the 'blue' component disappears, is most likely explained by geometrical obscuration of the X-ray emitting region in one or other of the jets by some stable component in the system, presumably the accretion disc. We have investigated the geometrical constraints imposed by our data using a simple model of the system in which the X-ray line emission arises entirely from two identical jets with uniform emissivity over their length l_x (and neglible diameter) which are perpendicular to a disc with radius r_d with rim height h_d (see Fig. 3). Obscuration of the jets by the precessing disc (assumed to be opaque) then produces a phase-dependent modulation of the emission-line strengths of the 'blue' and 'red' components.

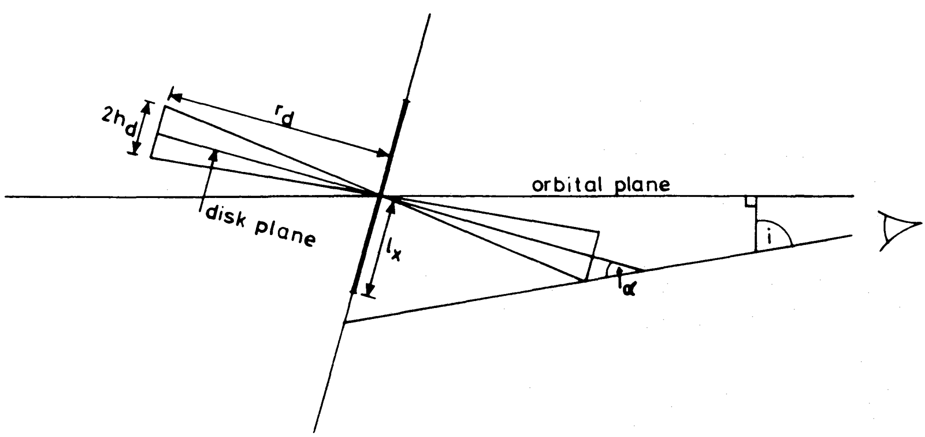

Figure 3. Schematic geometry of the SS433 system indicating geometrical obscuration of the jets by the disc.

The non-detection of the 'blue' component at phase 0.11 places the strongest upper limit on l_x, whilst the detection of at least one line (perhaps both) at phase 0.3 (at this phase we are close to viewing the disc edge-on, and the components cannot be resolved) provides a lower limit to l_x providing h_d is known. Assuming the geometrical parameters of the kinematic model (Margon 1984), i.e. the orbital inclination i (=78°.2), precession cone angle θ(=19°.8), and phase zero ϕ_0, we obtain the following overall constraints:

$$h_d < l_x < h_d + r_d \tan \alpha \tag{1}$$

where α is the effective angle between the line-of-sight and the disc plane. For $\phi=0.11$ this gives:

$$h_d < l_x < h_d + 0.16 r_d. \tag{2}$$

The orbital parameters for the SS433 system are highly uncertain, but assuming a 'reasonable' total system mass $\leqslant 50\ M_\odot$ (e.g. Crampton & Hutchings 1981; van den Heuvel, Ostriker & Peterson 1980), the orbital separation, $a \leqslant 6\times10^{12}$ cm. Assuming a mass ratio $Q(=M_x/M_{opt})\leqslant 1$, this then gives $(r_d/a)\leqslant 0.5$. Taking into account all the uncertainties, we adopt:

$$l_x \leqslant 10^{12}\ \text{cm}. \tag{3}$$

This is a firm upper limit, since any other means of obscuring the jets will almost certainly involve smaller scale structures within the system. On the other hand, this analysis does not provide a useful lower limit, because of uncertainties in the disc geometry. For example, if the thickest part of the disc were located at a radius $r \ll r_d$ (as envisaged in some super-critical accretion models), as opposed to the disc periphery as assumed above, the jets could be much smaller. Further confirmation of our estimate in equation (3) comes from the fact that the X-ray emission region is only partially eclipsed at binary phase 0.25 (Stewart *et al.* 1986). As Stewart *et al.* demonstrate, this also implies a size for the X-ray emission region $l_x \approx 10^{12}$ cm.

3.3 PHYSICAL PROPERTIES OF THE JETS

The geometrical constraints derived above show that the X-ray emission originates in a region in the jets which extends at most to $\sim 10^{12}$ cm from the accreting compact object. In contrast the optical lines are thought to be associated with jet material at much larger distances ($\sim 10^{14}$–10^{15} cm) from the compact object (e.g. Begelman *et al.* 1980). What then limits the size of the X-ray jets? Unless the material in the X-ray jets is continually re-heated by some external energy source, their length simply shows how long the X-ray emitting gas takes to cool under the effects of adiabatic expansion and/or radiative cooling. Assuming the jets expand conically, the ratio of the radiative cooling time t_{rad} to the flow time-scale t_{flow} ($\approx t_{exp}$, the adiabatic expansion time-scale) is given by

$$t_{rad}/t_{flow} = 3/2\left(1 + \frac{AR^{1/3}}{b}\right) \tag{4}$$

where R is the radial distance from compact object, the parameter b depends on the density and flow velocity, and A is an arbitrary constant. Our estimate of the length of the jets thus implies

$$t_{rad} \gtrsim t_{flow}(R = 10^{12}\ \text{cm}) \approx 100\ \text{s}. \tag{5}$$

Assuming a temperature of $10^{7.5}$ K for the X-ray plasma, the value of t_{rad} then gives an estimate of the number density n_e:

$$n_e \lesssim 10^{13}\ \text{cm}^{-3}. \tag{6}$$

This, combined with the total observed X-ray luminosity ($\sim 10^{36}$ erg s^{-1}), then gives an estimate of the emitting volume V (with $n_e = 10^{13} n_{13}$):

$$V \gtrsim 7.5 \times 10^{32} f^{-1} n_{13}^{-2} D_5^2\ \text{cm}^3, \tag{7}$$

where D_5 is the distance in units of 5 kpc, and f is the volume filling factor. The implied cylindrical radius r_x of the X-ray jets is thus:

$$r_x \gtrsim 1.5 \times 10^{10} f^{-0.5} n_{13}^{-1} D_5\ \text{cm} \tag{8}$$

giving an estimated mass outflow rate $\dot{M}$ and kinetic luminosity L_{jet}:

$$\dot{M} \gtrsim 1.6 \times 10^{-6} f^{-1} n_{13}^{-1} D_5^2\ M_\odot\ \text{yr}^{-1}, \tag{9}$$

$$L_{jet} \gtrsim 3 \times 10^{39} f^{-1} n_{13}^{-1} D_5^2\ \text{erg s}^{-1}. \tag{10}$$

Thus the implied luminosity in the mass outflow alone is highly super-Eddington for a 1 $M_\odot$ compact object, but this is completely compatible with the values derived, less directly, from the properties of the 'moving' optical lines (e.g. Milgrom 1981; Begelmann *et al.* 1980), the X-ray lobes (Watson *et al.* 1983), or the supernova remnant W50 which surrounds SS433 (e.g. Zealey, Dopita & Malin 1980). The distance to SS433 is well established (e.g. Hjellming & Johnston 1981), thus the only way to reduce the estimate of $\dot{M}$ substantially below that given by (9) is to make $n_e \gg 10^{13}$ cm^{-3} and appeal to some unknown mechanism to keep the gas at X-ray temperatures for $R \lesssim 10^{12}$ cm. This cannot be the central luminosity, as the Thomson optical depth along the jet exceeds 1 for $n_e \gtrsim 10^{13}$cm^{-3}.

The filling factor, f, for the X-ray emitting region in the jets is difficult to estimate. Optical studies suggest that the jet material at radii$\sim10^{14}$–10^{15} cm is strongly clumped. Clearly, if the material at smaller radii is also clumpy (implying $f \ll 1$), the implied kinetic luminosity in the jets [equation (10)] becomes even more extreme than the value derived above. The clumpiness at larger radii may, however, be due to instabilities in the flow, or variations in the mass ejection rate on time-scales long compared with the X-ray jet transit time [equation (5)]. In this case the filling factor for the X-ray jets could be close to unity.

4 Discussion

4.1 NATURE OF THE X-RAY CONTINUUM

The earlier *Einstein* MPC observations of SS433 (e.g. Grindlay *et al.* 1984) were interpreted in terms of non-thermal X-ray production processes. This view was based on the apparently power-law MPC X-ray spectrum, the lack of lines in the *Einstein* SSS spectrum, and the observation of coincident radio and X-ray flares (Seaquist *et al.* 1982), and led to the development of detailed non-thermal models for SS433 (Grindlay *et al.* 1984; Band & Grindlay 1984, 1985). The present *EXOSAT* results, in contrast, provide strong support for a *thermal* origin for a large fraction of the total X-ray emission. In particular the complex form of the X-ray spectrum measured with *EXOSAT* is fully consistent with that expected from the thermal plasma in the jets, given that each observation is much longer than the radiative cooling time, and hence integrates over spectra with a range of bremsstrahlung tempertures.

The average flux seen by *EXOSAT* is, however, ~50 per cent higher than that detected by the MPC, and the source appears now to be less variable overall. In particular there are no X-ray flare events, and substantially less spectral variability in the *EXOSAT* data, despite the similar total coverage to that achieved with *Einstein*. (The difference in the degree of spectral variability may be, in part, a consequence of the shorter integration times of the MPC observations – see Stewart *et al.* 1986.) It may therefore, be that there has been an overall change in the properties of SS433 over the last five years, i.e. in the balance between thermal and non-thermal components. Nevertheless, with the exception of periods when the source is flaring, we believe that the earlier X-ray observations may be equally consistent with the X-ray emission from SS433 being predominantly thermal.

4.2 CONTINUUM AND LINE VARIABILITY

Our interpretation of the *EXOSAT* results, that the X-ray emission originates in the inner part of the relativistic jets, allows us to predict the 164-day modulation of the X-ray light curve arising from the combination of geometrical obscuration by the precessing accretion disc and Doppler boosting. Unfortunately the quality of the existing observations is not high enough to make this a realistic exercise, particularly since there are clearly other components to the overall variability of SS433 such as the 13-day orbital modulation and the X-ray flares (Grindlay *et al.* 1984; Stewart *et al.* 1986).

In our simple interpretation of SS433, there is no reason to expect significant changes in the emission-line parameters, other than strength, as a function of 164-day phase. The one parameter which does appear to alter is the line width (see Table 1). Whereas most of our observations are consistent with a 'narrow' line with width ≤ 0.45 keV, the observation at 164-day phase 0.11 (observation E) shows a significantly broader line with a width ≈ 0.8 keV. A broad line was also seen during the *Tenma* observation at 164-day phase 0.41 (Matsuoka *et al.* 1985). One possible explanation for this effect may be Compton-broadening of the line by a hot corona to the accretion disc which would be most evident when the line-of-sight was closest to being parallel to the accretion disc.

4.3 ACCELERATION MECHANISMS

The most promising mechanism for the acceleration of the jet material to $0.26c$ in SS433 is 'line-locking', as was first suggested by Milgrom (1979), and which has been investigated in some detail by Shapiro, Milgrom & Rees (1986). The mechanism involves acceleration of the jet material by radiation pressure from a luminous continuum source. Shapiro *et al.* show that, assuming the transfer of momentum takes place predominantly in the Lyman-alpha line of a hydrogenic species, the acceleration continues until the frequency of the Lyman line of the atoms in the jets is 'tuned' by the Doppler shift to the frequency of the Lyman-alpha edge assumed to exist in the continuum-source spectrum. The limiting velocity obtained in this way is close to the value of $0.26c$ observed, and the line-locking mechanism also has the merit of reproducing the observed overall constancy of the jet velocity. Shapiro *et al.* demonstrate that, in order for 'line-locking' to work at all, the interaction cross-section must be high. This means in practice that H and He are the only serious candidates for material with cosmic abundances. Iron is a serious candidate only if large overabundances ($\gtrsim 100$) are allowed.

Our results provide an important constraint on possible 'line-locking' mechanisms since they demonstrate that the Fe emission observed from the jets has an equivalent width close to the expected value for material with normal cosmic abundances. Unless the line and continuum emission are completely unrelated (see above), this would seem to completely rule out the possibility that the acceleration is controlled by line-locking in the Fe Lyman-alpha line. On the other hand our results also show that the jet material close to the compact object is at X-ray temperatures. Is the jet material already at X-ray temperatures even closer to the compact object before it is accelerated? If this were the case, line-locking could not take place, given that Fe is ruled out, because both H and He would be completely ionized. There are two further objections to H or He as the line-locking agents: (i) the flow is not accelerated to the required velocity until radii much greater than the size of the X-ray jets derived here; (ii) a high degree of clumping is required which would then imply enormously high mass-outflow rates (see Section 3.3).

If line-locking is the jet acceleration control mechanism, this must then imply that the jet material starts off cold, is then accelerated by line-locking in the H or He Lyman-alpha lines, and is then heated to X-ray temperatures within a radius 10^{11} cm, substantially smaller than the radii at which any of the flows considered by Shapiro *et al.* achieve the required terminal velocity. An alternative to line-locking may thus be required to explain how the velocity of the jets in SS433 is regulated.

5 Conclusions

The *EXOSAT* study of SS433 has shown that the bulk of the X-ray emission, particularly the Fe line emission, must originate in the relativistic jets and be thermal in nature. Variations in the strength of the 'red' and 'blue' emission-line components with 164-day precession phase are entirely consistent with geometrical obscuration of the X-ray emission regions in the jets by a large accretion disc in the system. The size of the X-ray jets obtained in this way matches the estimate derived from the presence of only a partial X-ray eclipse at phase 0.25 of the 13-day binary period. Assuming the X-ray jets are not re-heated, this size estimate then leads quite directly to a firm lower limit to the kinematic luminosity of the jets:

$L_{\rm jet} \gtrsim 3\times10^{39}$ erg s^{-1}.

If the system is powered by accretion, it is difficult to envisage a mechanism which could produce this enormous kinematic luminosity without also producing a comparable, or indeed much larger, radiative luminosity. (This is necessarily true if the outflow is due to radiation pressure.) Thus, because the kinematic luminosity alone is well above the Eddington limit for a 1 $M_\odot$ compact object (assuming spherical accretion), it is difficult to avoid the conclusion that the accreting object has a mass >10 $M_\odot$.

There is strong, if indirect, evidence from optical and IR studies that the optical star is early-type (e.g. Murdin, Clark & Martin 1980; van den Heuvel *et al.* 1980) with a mass $\geqslant 10$ $M_\odot$. Optical studies (e.g. Crampton & Hutchings 1981; Leibowitz *et al.* 1984; Leibowitz 1984), and the observation of a partial, broad X-ray eclipse (Grindlay *et al.* 1984; Stewart *et al.* 1986), require that the mass ratio for the SS433 system is close to unity, thus implying a massive compact object. The present mass estimate suggested by X-ray results thus seems to add some weight to this argument.

Our interpretation of the *EXOSAT* results has also allowed us to determine the physical properties of the jet material close to the compact object. The density, temperature and dimensions derived place strong constraints on viable jet acceleration mechanisms, and will also have important implications for our understanding of the properties of the cooler, optically emitting, jet material at larger radii from the compact object.

Acknowledgments

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