THE EVOLUTION OF THE COMPACT RADIO STRUCTURE IN SS433 OVER A 16-DAY PERIOD +

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INTRODUCTION

SS433 has been under intensive study for the past five years in almost all wavelength bands of the electromagnetic spectrum. This peculiar object is generally regarded (Beer 1981) as being a binary system composed of a main sequence star losing mass via Roche lobe overflow to a massive accretion disk associated with a compact object, probably a neutron star. The binary period is 13.1 days. Supercritical accretion onto the disk causes about 10^{-6} $M_\odot$/year of ionised matter to be ejected in the form of jets with a relatively constant velocity of 0.26 c along the disk axis. The disk (or the inner part of it) precesses with a period of about 164 days, although there is evidence that this may not be constant. The half angle of the precession cone is ~20° and its axis lies at an angle of ~80° to the line of sight. The main sequence star loses mass at a rate of 10^{-4} to 10^{-6} $M_\odot$/yr into a stellar wind with the result that a relatively dense environment surrounds the binary system.

The jets have been traced by radio means from distances from the centre of the binary system of ~1.5×10^{14} cm (5 milliarcsec) out to ~1.5×10^{17} (3 arcsec) and by X-ray imaging out to ~10^{20} cm (30 arcmin). There is a suggestion that the jets reach the shell structure of W50 which lies 1 degree away from SS433 (Geldzahler et al 1980; Downes et al 1981). (A distance of 5 kpc to SS433 has been assumed). Analysis of data for simultaneous radio and X-ray flares in SS433 by Seaquist et al (1981), as well as long term monitoring of the radio flux density by Johnston et al (1981) and Geldzahler et al (these proceedings) suggests that radio flare generation occurs at distances of 10^{14-15} cm from the central binary, perhaps where the beams or jets encounter inhomogeneities in the stellar wind. This evidence thus suggests that radio emission is detectable only at distances two orders of magnitude larger than the dimensions of the binary system and implies that, in the radio, we are looking at the smoke from SS433 rather than the fire itself.

VLA observations by Hjellming and Johnston (1981a, 1981b) have been crucial in resolving some of the angle ambiguities in the kinematic model of Abell and Margon (1979) which was introduced to explain the movement in the optical emission lines as function of epoch. These radio

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observations also demonstrated that the moving material was, in fact, being expelled with a proper motion of ~9 milli-arcsec/day. More detailed evidence that the radio emitting blobs lie along trajectories predicted by the kinematic model has come from VLBI and MERLIN work (Schilizzi et al 1981, 1982, 1983; Romney et al 1983, Niell et al 1981; Spencer 1979), but a case of non agreement has also come to light (Spencer and Waggett, these proceedings).

SS433 has been of considerable interest to astronomers working in active galactic nuclei because of the similarity of its gross properties to those of extragalactic radio sources (Hjellming and Johnston 1982) - it has an active "nucleus", variable flux density, knotty jets, relativistic motion and polarised extended emission. The fact that at VLBI resolutions we can observe individual blobs of emission affords us the possibility of studying the detailed evolution of these blobs as a function of epoch. This is the subject of this contribution.

OBSERVATIONS

Six epochs of observations at three day intervals were scheduled at 4990 MHz in December 1982 using networks of up to 5 telescopes. Due to combinations of inclement weather, equipment malfunction, short coherence times arising from the use of rubidium oscillators at Westerbork and Jodrell Bank, and a not overly strong source for the Mk II recording system, fringes were not obtained on all baselines. Table 1 summarizes the observations.

Table 1

Date	JD-2445000	Telescopes*	Baselines with fringes detected
6 Dec 82	5310.1	O,E,W,J,G	OE,OW,EW,EJ,WJ
9	5313.1	O,E,W,J,G	OE,OW,EW,EJ
12	5316.1	O,E,W,J,G	OE,OW,EW,EJ
15	5319.1	E,W,N	EW
18	5322.1	E,W,J	EW
21	5325.1	E,W,J	EW,EJ,WJ

* O: Onsala, E: Effelsberg, W: Westerbork, J: Jodrell Bank, G: Green Bank, N: NRL, Maryland Point.

RESULTS AND DISCUSSION

Figure 1 displays the visibility curves for the most sensitive, and shortest, baseline E-W (fringe spacing ~50 mas) for the six epochs. (The full data will be published elsewhere.) It is clear that the first three epochs (6, 9, and 12 December) form a group, and the last three (15, 18 and 21 December) another group, there being a significant injection of energy into the source between 12 and 15 December.

The first group of observations is characterised by a decreasing fringe contrast around 1800 GST indicative of expanding structure. The

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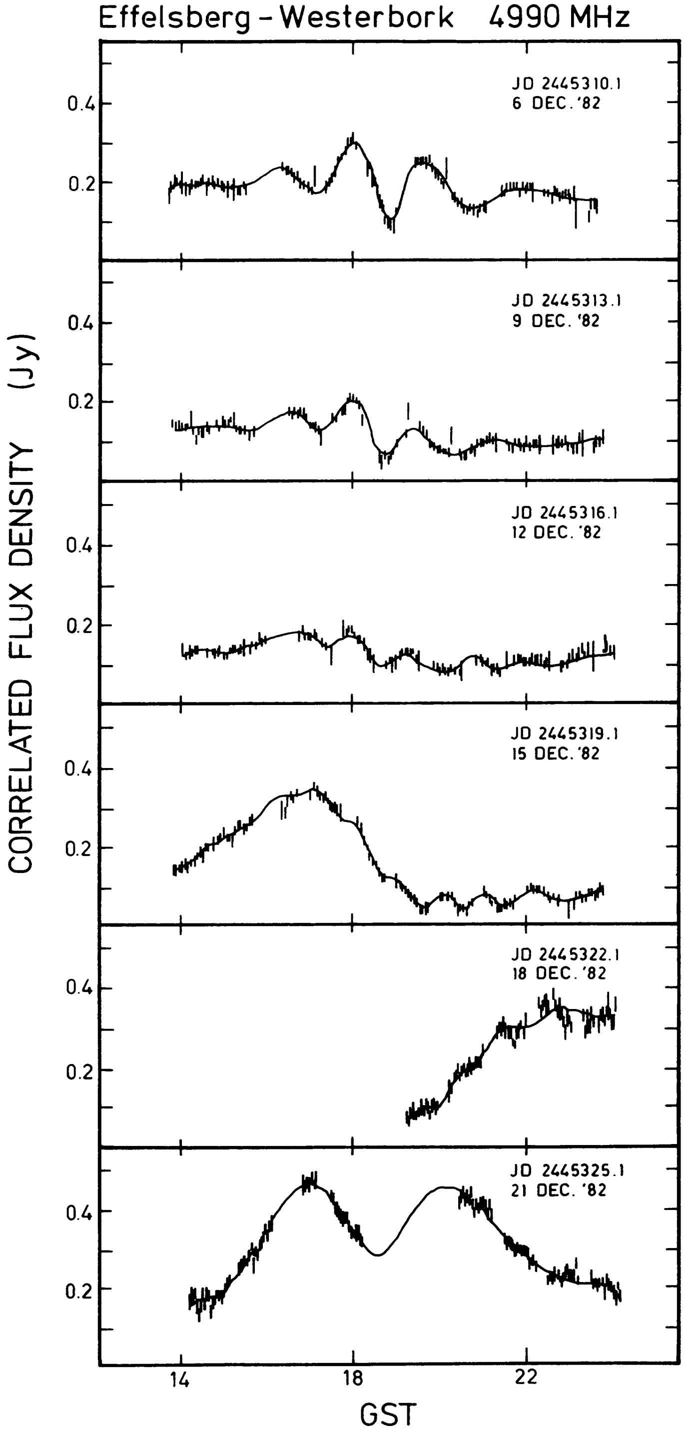

Figure 1 : Correlated flux densities for SS433 at 4990 MHz on the Effelsberg-Westerbork baseline for the 6 epochs of measurement. The curves drawn through the data represent models for the radio structures which have been derived from the whole dataset at each epoch. (see Figure 3 and text).

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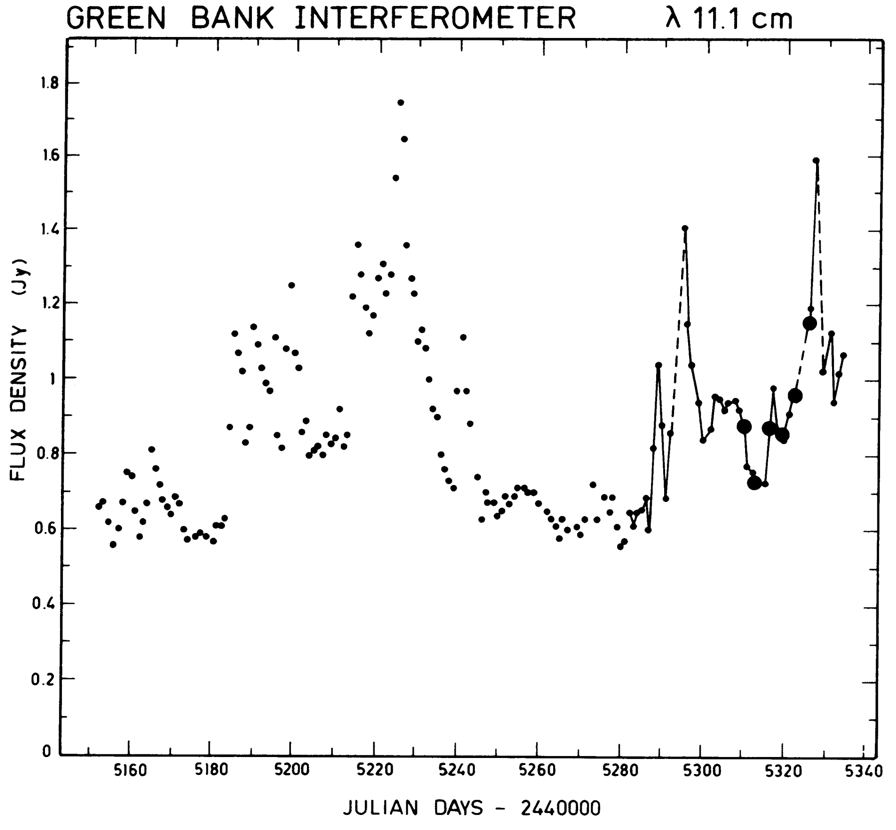

Figure 2: Total flux density for SS433 at λ11.1 cm (Johnston et al, private communication). The large dots indicate when VLBI measurements were made (6,9,12,15,18,21 December 1982). Dashed lines join points spaced at more than 1 day.

correlated amplitudes on the longer baselines E,W to O,J (fringe spacings ~10 milli-arcsec) are consistent with a "core" flux density of ~150 mJy on 6 December decreasing to ~100 mJy on 9 and 12 December. This can also be seen in a similar decrease in the peak correlated flux density on the E-W baseline. The total flux density at 11.1 cm (Johnston et al, private communication, figure 2) decreased from 6 to 9 December and then increased on 12 December to a peak on 13 December. In the period 1400 $\leq$ GST $\leq$ 1600 on both 6 and 9 December there is some evidence for small amplitude oscillations in the data which are not reproduced by the model. If real, these may be related to the oscillations seen in the data for 1900 $\leq$ GST $\leq$ 2400 on 15 and 18 December which can be modelled as an outlying component.

The models derived for the first three epochs (Figure 3) show one-sided emission typical of nuclear structure in extragalactic sources - a compact, relatively bright component (core) with an elongated, lower brightness component (jet) pointing towards an even lower brightness diffuse component. The maps in Figure 3 have been scaled so that the top

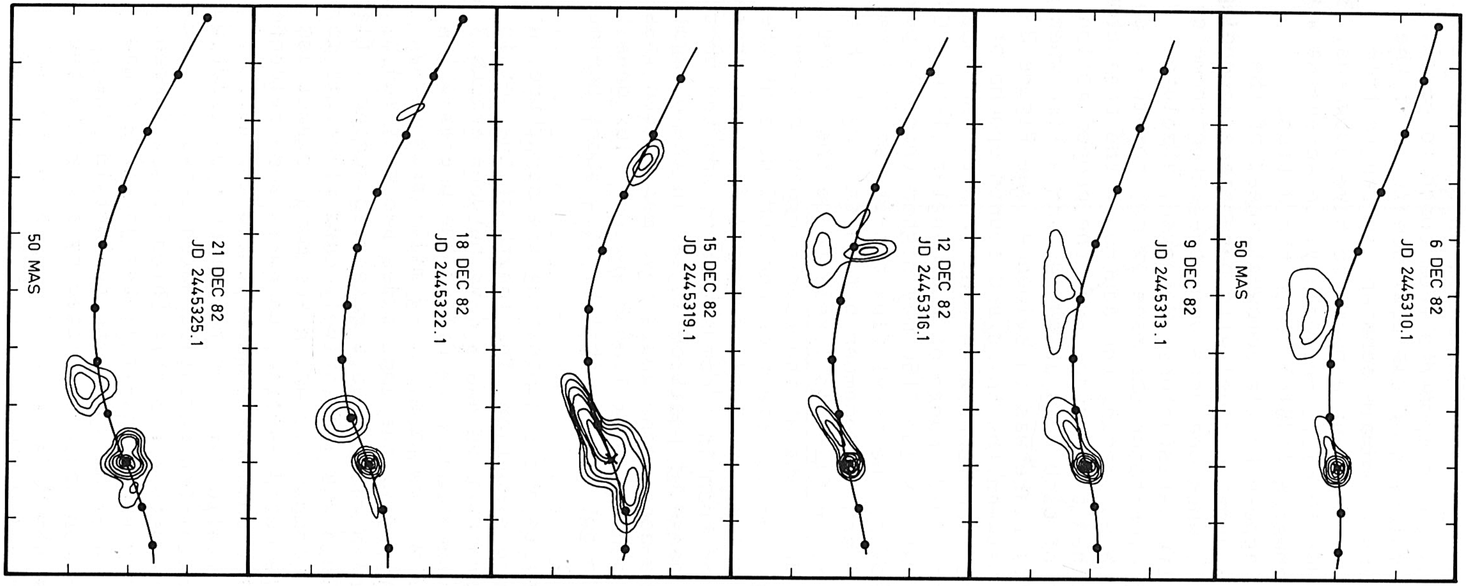

Figure 3: Contour maps of models for SS433 at the 6 epochs of measurement. Contour levels are 2, 5, 10, 20, 50 and 80% of the peak intensity. North is up, east is the left; the beam is 10x10 milli-arcsec. The curves drawn through the structures represent the expected trajectories of blobs on the kinematic model of Abell and Margon (1979) with parameters from Margon et al (1980); the dots are spaced by 6 days. A cross marks the assumed centre of the structure.

contour is 80% of the peak flux density in each map; this masks the change in flux density in individual components from epoch to epoch. However figure 4 displays the evolution of the flux densities of the model components. The jet appears to remain constant in length from December 6 to 9, but the diffuse component appears to move outwards. The proper motion derived is of order 10 milli-arcsec/day, in agreement with the results of Hjellming and Johnston (1981b). Both the diffuse component (blob 2) and the jet appear to lie somewhat ahead of the trajectory predicted from the kinematic model with parameters according to Margon et al (1980). However, when one considers the interferometer resolution the agreement is quite satisfactory. Moreover, absolute registration of the model trajectories on the maps is not possible, so that plausible assumptions, such as placing the centre of the trajectory on the most compact peak, have had to be made. From the proper motion, the most likely date of origin of blob 2 is JD2445295, at a time when a relatively steep spectrum (soft) flare was in evidence (see Figure 2).

Remarkable changes occur between the third and fourth epochs of observation. Figure 1 shows that the correlated flux density increased between December 12 and 15 over a wide range of hour angles (1400 $\lesssim$ GST $\lesssim$ 1900), peaking at GST ~ 1700 at a value ~150 mJy higher than the peak value three days earlier. Moreover, the total flux density at 11.1 cm increased by ~250 mJy between 9 and 13 December before falling back by ~100 mJy by 15 December. This minor flare is likely to be the source of the flux increase seen in the VLBI data at the fourth epoch; however it is not understood why the flare had no effect on the VLBI data at the third epoch. A peak at a particular hour angle suggests flux enhancement in an elongated structure rather than in a compact core, and the broad nature of the peak suggests a range of position angles in the elongated structure. A brightening in the core alone would have manifested itself in a general increase in flux density at all hour angles. Flux density measurements at Westerbork rule out the possibility of a short period flare between 1400 and 1900 GST.

The model in Figure 3 depicts a jet dominating the structure, with a broad component in the reverse direction. The length of the jet is ~30 milli-arcsec, so that it appears that in the 3 days between epochs 3 and 4, the radiating electrons in the flare have filled the pre-existing channel, like air passing down a blow-pipe, at ~9 milli-arcsec/day.

The short period oscillations in the amplitudes are modelled by an outlying component (blob 1) which was probably generated during a flare on day JD2445289 (Figure 2). This was a relatively hard flare; it may be that hard radio flares produce components which are more compact and long lived than soft flares. As noted earlier, there is some evidence for an outlying component in the data for the first two epochs.

There is disappointingly little data for the fifth epoch, but what there is, suggests that the radio structure bifurcated between epochs 4 and 5. The model (Figure 3) shows that a bubble (blob 3) has formed at the end of where the jet was three days earlier; the jet itself has apparently faded, but the data are too sparse to be certain. The oscillations in the amplitudes can again be fitted by including the outlying component, blob 1, in the model.

By the last epoch the correlated amplitudes in the range 2000 $\lesssim$ GST

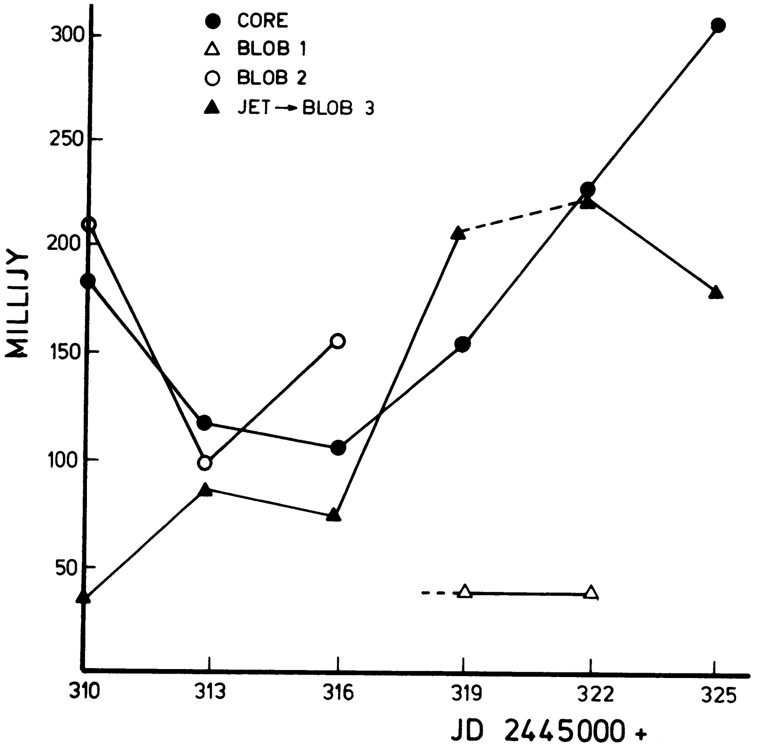

Figure 4: Model component flux densities as a function of epoch.

≲ 2400 have again changed dramatically, and in addition the overall flux density has increased by ~100 mJy consistent with an increase in the core flux as the peak of the JD2445327 flare approaches (Figures 2 and 4). Blob 3 has moved outwards along the trajectory by ~30 milli-arcsec, again consistent with the generally accepted proper motion. A jet to the east has appeared in p.a. ~85° which does not lie on the trajectory. However the position angle is influenced by noisy data on the long baselines E-J, W-J and may not be correct. What is clear is that the strong elongated component to the west at epoch 4 has faded to a mere shadow of its former self by epochs 5 and 6. Note that this one-sided emission is in the same sense as was found at the first three epochs. There is some evidence for the outlying component, blob 1, in short period oscillations in the visibilities, but these are not of sufficient amplitude to require blob 1 in the model.

Figure 4 depicts the variation in model flux density for the major compact radio components in SS433. The core decreases in a regular manner for the first three epochs and then increases in accord with the increasing total flux density going into the flare of JD2445327 (Figure 2). The eastward "jet" and "blob 2" vary up and down in flux density at the first 3 epochs, the magnitude of the variation being a measure of the uncertainty in the value for these rather low brightness extended components. The jet brightens by ~150 mJy between epochs 3 and 4 and remains at the same level after the bubble (blob 3) has been detached from the blow-pipe (i.e. jet) at epoch 5, then decreases by ~50 mJy by the final epoch.

CONCLUSIONS

These can be summarized as follows:

1) the proper motion of individual blobs is clearly seen,
2) the production of blobs is related to flare activity,
3) the evolution of blobs can be very different from one side of the core to the other,
4) the observations suggest that 'hard' radio flares produce blobs which are more compact and long-lived than 'soft'flares,
5) there is evidence of a "blow-pipe effect" in which the energy of a flare is pumped into an elongated cavity (the pipe) via particles moving at 0.26 c until a self contained radio emitting blob (the bubble) is formed and detaches itself to move ballistically away at 0.26 c.

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