SS433 - OBSERVING EVOLUTION IN A PRECESSING, RELATIVISTIC JET

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We commonly refer to the central "object" in extra-galactic radio sources as the "engine" that is the root cause of many radio source characteristics. We frequently ask, COULD "engines" at the cores of extra-galactic sources: (1) be compact objects with accretion disks; (2) eject well-collimated supersonic jets; (3) show relativistic effects in ejected material; (4) produce twin-jets; (5) produce one-sided jets; and (6) initiate highly polarized synchrotron radiation sources? SS433 is a binary star system with radio and optical jets that is relevant because it is a "little engine that could", and does, do all of these things. Further, we can observe changes in SS433 on time scales from hours to several months, and these data allow one to study evolution of jets in a more thorough fashion than is possible for extra-galactic sources.

The SS433 star system (V1343 Aql) has optical emission lines (Margon et. al. 1980) which change wavelength in a manner corresponding to a doppler shift range of 80,000 km/s with a periodicity of 164 days. These emission lines of H I and He I have been interpreted (Margon et. al. 1980) in terms of recombining material in twin-jet flows that have a velocity of 0.26c (c = the speed of light), a jet axis either 80 degrees or 20 degrees to the line of sight, and an ejection vector that rotates around the jet axis every 164 days at an angle of 20 degrees or 80 degrees. SS433 was independently found to be a radio source by Ryle et. al. (1979) and Seaquist et. al. (1979), and as can be seen from the large scale map of Geldzahler et. al. (1980), is a compact radio source inside the 1 degree by 2 degree "supernova remnant" W50. Johnston et. al. (1981) have shown that the relatively steady radio emission from SS433 is combined with flaring events that increase the flux density of the source by up to a factor of two with event time scales of 1-5 days. The radio emission is synchrotron emission from highly relativistic electrons because of the omnipresent non-thermal spectral index of 0.6 and the observation of linear polarization of up to 20% in the jets (Johnston et. al. 1981 and Hjellming and Johnston 1981a). The SS433 radio source was first found to have structure on angular scales of 0.1"-5" by Gilmore and Seaquist (1980). SS433 also shows structures on

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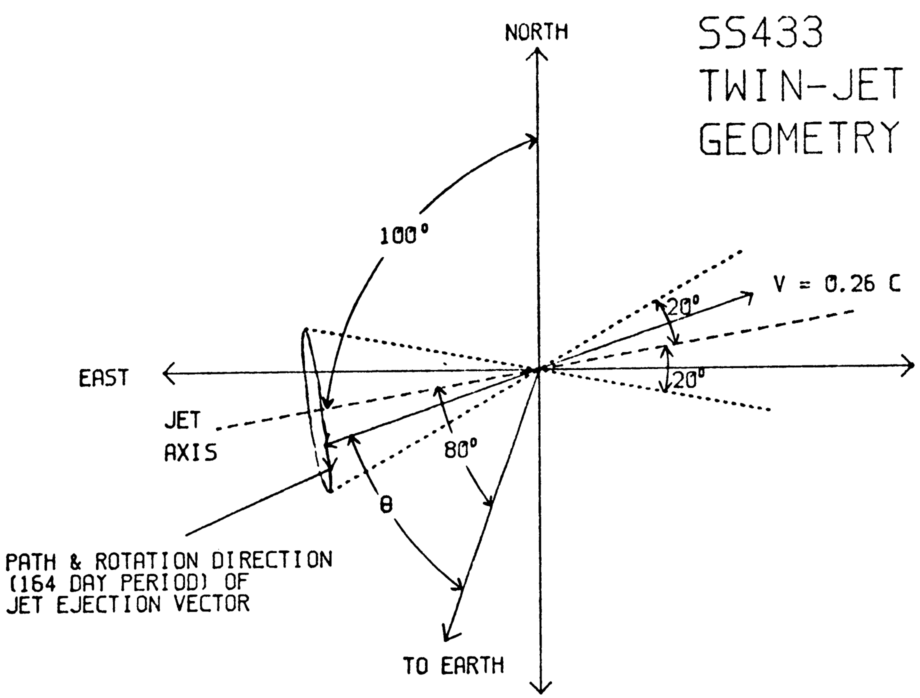

Figure 1. Geometry of the twin-jet ejection vectors for SS433 as determined from radio and optical data.

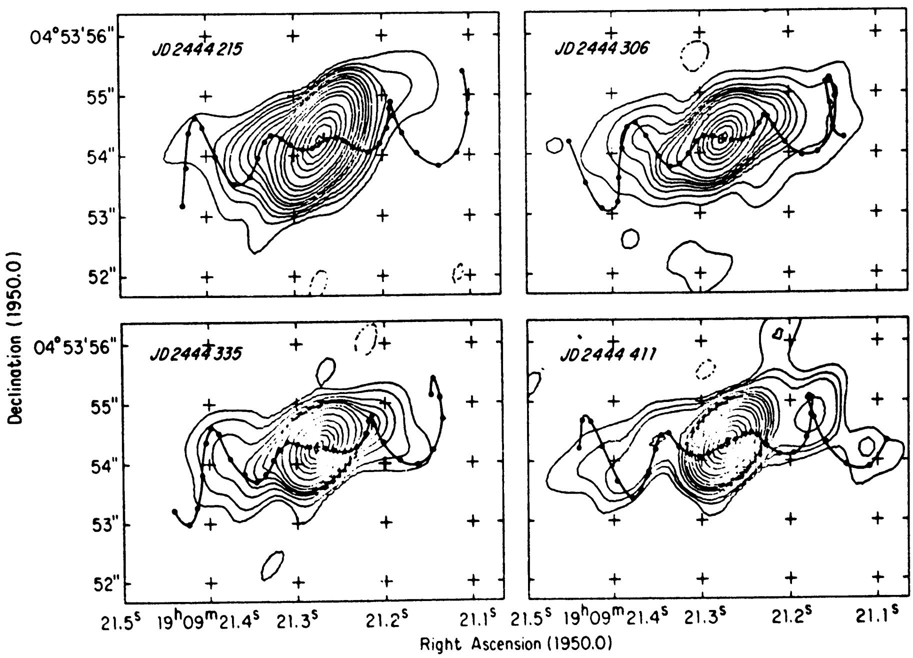

Figure 2. Four epochs of VLA 6 cm maps, with proper motion corkscrews, for SS433. Contours are roughly logarithmic ranging from -0.5% to 90%.

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VLBI size scales of 0.005"-0.3" (Spencer 1979, Schilizzi et. al. 1982, Niell et. al. 1982, Walker et. al. 1981).

Hjellming and Johnston (1981a, 1981b) have shown that the SS433 star system is ejecting radio emitting material in the form of a cork-screw, exactly as one would expect from the twin-jet doppler shift model for the optical emission lines. The parameters of the model that fit both radio and optical data are shown in Figure 1. All of the parameters that could not be determined from the optical data are determined from high resolution VLA radio maps, such as the 6 cm maps shown in Figure 2. In Figure 2 the point source (0.4" X 0.7" HPBW) is located on the position of the star and the remaining structures are due to the ejected material which is found only on the corkscrews superimposed on the maps with filled circles at 20 day intervals in ejection time. As discussed by Hjellming et. al. (1981b), the relativistic time delay effects that can be seen in the corkscrews are used to make an absolute determination of the velocity, which is 0.26c to within 10-20% error. This and the observed proper motion of 3" per year, interpreted with the geometry of Figure 1, show the distance to be 5.5 kpc. This makes W50 violate the surface brightness vs. size relation for supernova remnants by about a factor of two, increasing the probability that W50 has either been caused by or heavily effected by SS433. The radio data also show that the "eastern" jet is the mainly blue-shifted jet in the foreground and the "western" jet is mainly red-shifted and predominately on the far side; it also shows that the sense of rotation is clockwise (left-handed) with respect to the eastern jet axis as shown in Figure 1. These results are borne out by improved 6 cm (0.4" x 0.4" HPBW) and 2 cm (0.13" x 0.13" HPBW) VLA maps made by Hjellming and Johnston (1981c) at 6 epochs between JD 2444579 and JD 2444717. All the extended structures are the accumulated effect of radio source ejection during the roughly 300 days prior to the time the source is observed.

Although to first order the evolution of the radio structures of SS433 is due mainly to the proper motion corkscrews of the twin-jet model, the high resolution VLA radio maps also contain information about the evolution of the radio emitting material as it moves out from the central source. This can be analyzed in two ways. Using maps such as those shown in Figure 2, one can plot the variation of intensity along each corkscrew as a function of time of ejection from the center. In some maps this results in a simple exponential decay with a time constant of 30-40 days. Hjellming and Johnston (1981c) have observed one case corresponding to an ejection at about JD 2444519 that eventually produced a stronger than normal double source with components moving away from the center at a rate of 0.25" per month. When the intensity of each component of this double is plotted as a function of time, a simple exponential decay is found with a time constant of 86 days. When one also considers the 1-5 day decay times for events observed by Johnston et. al. (1981), it is clear that one of the major variable parameters of the radio emitting plasma produced in the central regions of SS433 is the decay time, which is clearly exponential in character for the material with decay times greater than about 20 days - the only material that can contribute significantly to the extended structure in VLA radio maps. There are two obvious ways to obtain simple exponential decays for an evolving radio source: ionization losses due to relativistic electrons interacting with a co-moving thermal plasma, in which case this plasma typically has several electrons per cubic cm; or "catastrophic" losses due to relativistic electrons leaving the radio emitting region, possibly by diffusion across the boundaries of the radio emitting corkscrew. In the latter case the observed decay time would correspond to the diffusion time across the corkscrew.

Although the point source in VLA radio maps of SS433 is unpolarized with typical upper limits of the order of 1%, the extended structure is linearly polarized up to 20%. The linearly polarized intensity maps of Hjellming and Johnston (1981a) are shown in Figure 3 with the proper motion corkscrews of Figure 2 superimposed, and a small plus at the position of the star. Comparing Figures 2 and 3 it is clear that occasional portions of the radio emitting corkscrew are highly polarized and that both geometry and the averaging effects of the synthesized beam strongly affect the observed polarization. The resolution of the VLA maps is not sufficient to clearly show the polarization structure along the corkscrews. In Figure 4 selected linear polarized intensity contours are shown together with linear polarization vectors. In these and other maps it is very noteworthy that whenever a straight section of the corkscrew is seen over a relatively large region, the polarization vectors are roughly perpendicular to the corkscrew. Since the radio emission is optically thin, this means the magnetic field lines are aligned with the corkscrews. This is another indicator that the ejection of radio emitting plasma from the central regions produces contiguous and merged material, since the field lines would not be expected to follow the corkscrew under other circumstances.

If one assumes equipartition of magnetic and relativistic electron energies, one derives magnetic field strengths in the range 0.001-0.1 gauss, and total energies in particles and fields of the order of 10^{42} -10^{43} ergs. However, the short time scale of SS433 phenomena may mean the equipartition assumptions are not valid. If one assumes an electron concentration of several particles per cubic cm, as found from de-polarization across the source at 20 cm, the mass ejection from the central region is roughly 10^{-7} solar masses per year and the kinetic energy "luminosity" is 10^{38} -10^{39} ergs per second.

Because of the extensive amount of optical information about SS433 (Margon 1980) the root causes of the radio and optical jets are almost certainly high velocity (0.26c) well-collimated (roughly 4 degree opening angle) flows perpendicular to a thick accretion disk which is precessing with a period of 164 days, due to the influences of the companion star which is the source of infalling matter at a rate causing super-critical accretion. A schematic diagram illustrating this situation is shown in Figure 5, where the geometry is deliberately

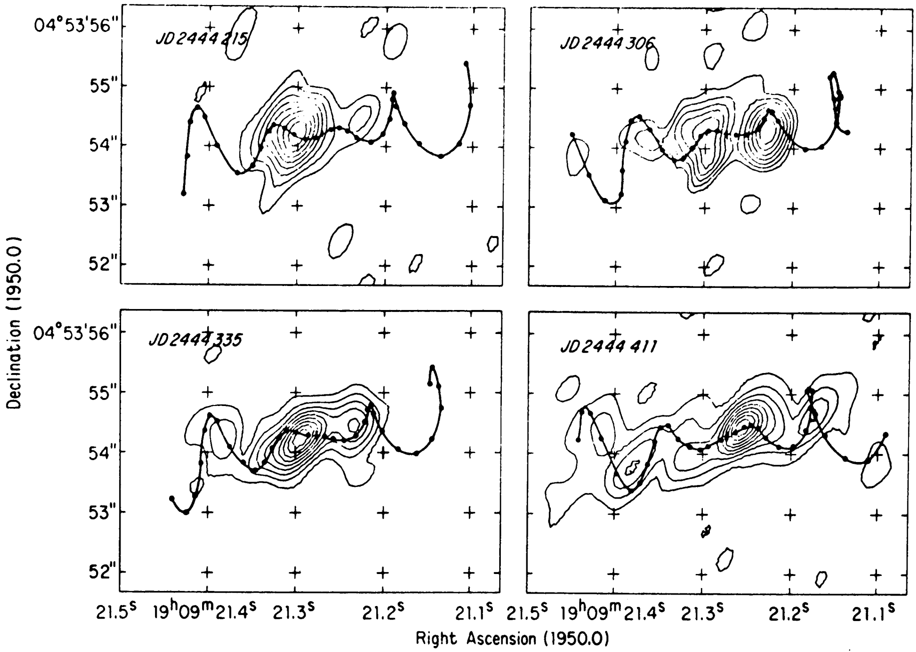

Figure 3. Four epochs of VLA 6 cm linearly polarized intensity maps, with proper motion corkscrews, for SS433. Contour intervals are linear with intervals of 10% starting at 90%.

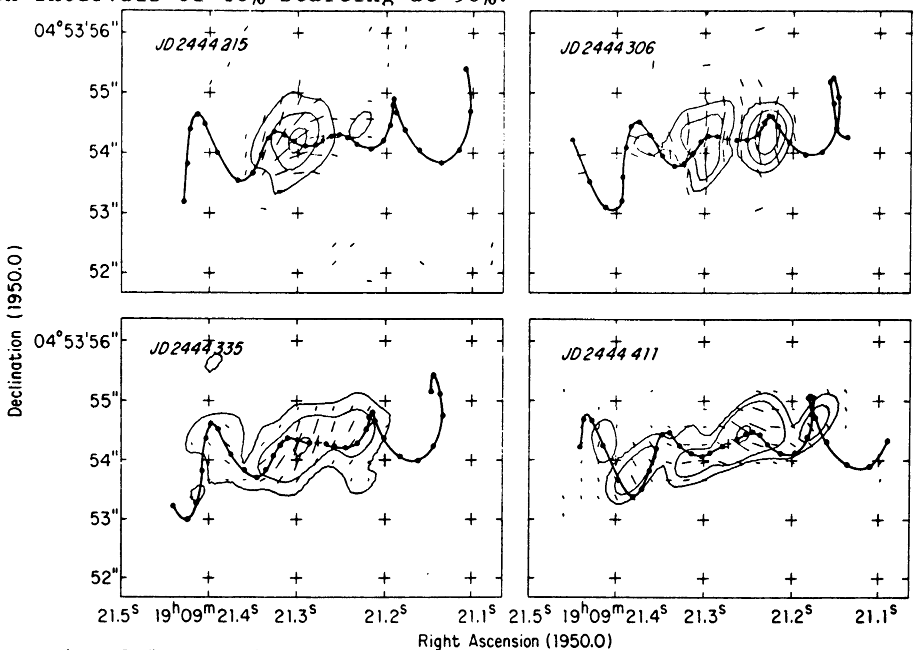

Figure 4. Polarization vectors are shown with selected linearly polarized intensity contours, and proper motion corkscrews, for four epochs of VLA 6 cm maps of SS433.

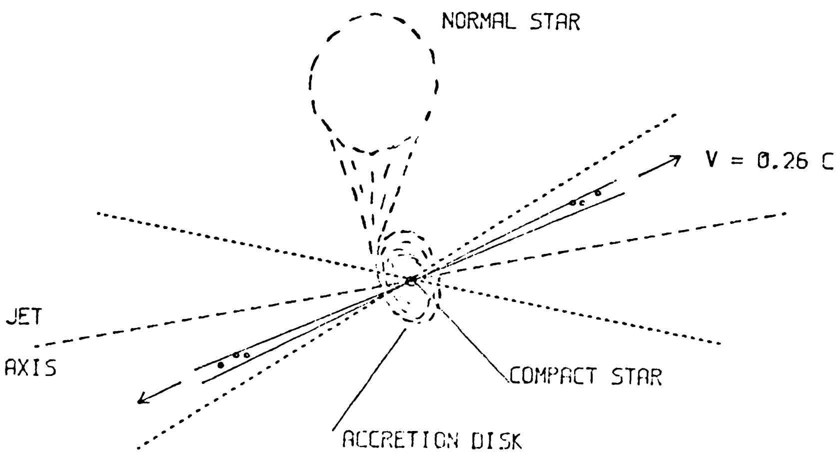

Figure 5. Schematic diagram relating the jet geometry (as in Figure 1) and the SS433 binary system. It also shows the probable origin of the jets in flows perpendicular to a super-critical, thick accretion disk around a neutron star or black hole.

drawn to correspond to the geometry diagram in Figure 1. The compact object which is the accretion target can be either a black hole or a neutron star. In Figure 5 the small circles in the flows schematically illustrate the recombining material producing the observed optical emission lines. The optically emitting regions must arise within a few light days of the compact object although the extended radio structures are observable only in the range 10-400 light days from the center. Both radio and optical emission regions are minor effects occurring in the flows, and SS433 is predominantly producing collimated kinetic energy.

VLBI observations of SS433, such as those presented by Schilizzi et. al. 1981 and Niell et. al. 1981 at this Symposium, provide essential information about the central "engine" for the production of radio emitting material. Because it is almost a certainty that the relativistic particles and magnetic fields are produced in the flows perpendicular to the accretion disk of SS433, the regions from the center to distances of 10-20 light days are where this production occurs, and this is the size scale accessible only to VLBI observations. Similarly, only VLBI observations will have sufficient resolution to show the detailed polarization and magnetic field structure of the SS433 corkscrew.

Because of the extent and type of information that is obtainable for the SS433 radio jets, and the related knowledge of the central "engine", SS433 is certainly the most effective "Rosetta Stone" that one has at the moment for understanding at least some of the physics of supersonic, radio-emitting jets. In this case, we know that a compact object, with an accretion disk and VERY supersonic outflows, is the basic cause of the jets. If these physical phenomena scale to larger masses, and Rees (1982) has argued that they do, the SS433 phenomena will be very important in understanding the physics of extra-galactic jets.

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DISCUSSION

SCHILIZZI: Are the moving blobs in SS433 entities like "plasmons"?

HJELLMING: I would believe that the radio-emitting portions of the "flows" from SS433 have detailed structure, and hence with sufficient resolution as with VLBI observations, you would, and do, see such details. However, there are probably local effects in what are otherwise continuous hydrodynamical flows.

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GOSS: Westerbork Synthesis Radio Telescope observations in the HI 21 cm absorption line have been made of SS433. The derived limits for the distance are 3.7 to 4.7 kpc (Van Gorkom, Goss, Seaquist and Gilmore, MNRAS, in press, 1981).

HJELLMING: Although the 10% error estimate on our distance determination of 5.5 kpc is not significantly outside the 4.7 kpc limit, I would argue that a correction of 0.5-1.0 kpc is needed for the third (observed) arm of the Schmidt model you assumed.

SHERWOOD: I am happy to see the new distance. As Ann Downes et al. 1979 showed that W50 was being depolarized by the HII region, S74, I argued (Montreal IAU) that SS433 must be as far away as S74. I derived a distance of 5.4 kpc for S74 (Pub. Royal Obs. Edinburgh 9, 85, 1974).

HJELLMING: An interesting coincidence, perhaps meaning W50 and S74 are in the same spiral arm.