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MERLIN observations of the unusual superluminal quasar 3C395

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SUMMARY

We present MERLIN observations at 73, 18 and 6 cm of the quasar 3C395 (1901 + 319) which has a superluminal component moving towards a stationary knot located at a distance of 15.8 mas from the VLBI core. The observations help to clarify the radio structure of 3C395 on scales ranging from a few tens to a few hundreds of milliarcsec. They show evidence of a highly curved jet-like structure extending beyond the stationary VLBI component. The radio images of 3C395 are consistent with a two-sided structure inclined at a small angle to the line-of-sight, with the approaching jet being decelerated and distorted within ~ 15 mas of the nucleus. The approaching emission appears to be on the same side as the receding one at distances ≳ few hundred milliarcsec from the nucleus, largely due to projection effects. We suggest that the large superluminal speed of 3C395 compared to sources of similar core prominence is due to bends in the jet in the vicinity of the nucleus.

1 INTRODUCTION

The radio source 3C395 (1901 + 319), which is associated with a 17-mag quasar at a redshift of 0.635 (Hewitt & Burbidge 1987), has been observed with the VLA by a number of authors. It has been mapped at 1.4 and 5 GHz by Perley, Fomalont & Johnston (1980) and Perley (1982), at 5 GHz by Pearson, Perley & Readhead (1985), and at 5 and 15 GHz by van Breugel, Miley & Heckman (1984). These observations all show that the source consists of a prominent core and an extended component to the north-west separated from it by ~ 0.7 arcsec along PA ~ 310°. The radio structure of 3C395, with one-sided extended emission, is thus similar to those observed for many other core-dominated objects (e.g. Perley *et al.* 1980; Perley 1982; Browne *et al.* 1982).

Early VLBI observations of 3C395 which were made at 1.67 GHz by Phillips & Mutel (1980), at 2.3 GHz by Phillips & Shaffer (1983) and at 5 GHz by Johnston *et al.* (1983), showed that the core consists of two components, namely the VLBI core and a steep-spectrum feature towards the south-east which is separated from the core by 15.8 mas along PA ~ 118°, and is thus on the opposite side of the core to that of the extended arcsec-scale steep-spectrum lobe (cf. Johnston *et al.* 1983). This made 3C395 one of the most asymmetric sources known with the ratio of separations of the outer components from the nucleus ~ 40 : 1. Waak *et al.* (1985) made further VLBI observations and found evidence of superluminal motion in a new component located between the two VLBI components discussed earlier. This has been confirmed recently by Simon *et al.* (1988a), who also showed that the VLBI component at a distance of 15.8 mas has no apparent motion nor variation in brightness over a 6-yr period. Thus the superluminal component in 3C395 is located between two stationary VLBI components. From observations at a later epoch however, Simon, Johnston & Spencer (1988b) found no evidence of significant relative motion between the superluminal component and the VLBI core between 1985.4 and 1986.9, but they noted that this could be due to either deceleration of the component or ejection of a new component from the nucleus.

The structure of the quasar beyond the stationary VLBI component has so far remained unclear, although Waak *et al.* noted the possible presence of low-brightness emission about 20 mas north-east of the nucleus along PA ~ 50°. An understanding of the structure on the tens of milliarcsec scales might help to clarify the unusual occurrence of a superluminal component between two stationary components, and to understand the larger scale radio structure of the source. With these objectives in mind we present MERLIN observations of the source at 73, 18 and 6 cm (408, 1666 and 4995 MHz, respectively).

2 OBSERVATIONS

The MERLIN system has been described by Thomasson (1986). The observations at 73, 18 and 6 cm were made on 1987 April 28, 1980 November 8 and 1983 September 3, respectively. The 73-cm observations were made with an 18-m dish at the Mullard Radio Astronomy Observatory, Cambridge as part of the full MERLIN system, while the 18- and 6-cm observations were made with only five telescopes, the former without Darnhall and the latter without Wardle. The data at the three wavelengths were calibrated using 0429+415, 2200+420 and 0316+413, respectively, the flux densities of the calibrators were estimated to be 15.8, 4.47 and 59.0 Jy, respectively. The data were reduced using the Jodrell Bank OLAF package development by R. Noble, and the NRAO AIPS package.

3 RESULTS

The MERLIN 73-cm map made with an angular resolution of 0.5 × 0.5 arcsec^2 is not presented here since it shows only the two dominant components, namely the radio core and the north-western lobe. These features can be seen clearly in our 18-cm image (Fig. 1) as well as the published VLA maps mentioned earlier. The peak brightnesses of the two components at 73 cm are 3530 and ~800 mJy/beam, respectively, while the total flux density in the map estimated by specifying a box around the source is 5060 mJy. The 18-cm image restored with an angular resolution of 0.25 × 0.25 arcsec^2 (Fig. 1) shows evidence of extended emission separated by ~0.4–1 arcsec from the nucleus along a PA of ~275°, in addition to the two dominant components mentioned earlier. The rms noise in the map far from the source of emission is 0.38 mJy/beam. The peak brightnesses of the core and the prominent north-western component are 2039 and 200 mJy/beam, respectively, while the corresponding value for the weaker feature 0.4 arcsec west of the nucleus is ~20 mJy/beam. The total flux density estimated by specifying a box around the source is 2570 mJy.

In Fig. 2(a) and (b) we show the 6-cm images restored with angular resolutions of 100 × 100 and 50 × 50 mas^2, respectively, the latter image being 'super-resolved'. The rms noise in the two maps is 0.24 and 0.25 mJy/beam, respectively. The flux densities of the components estimated from the lower resolution map are as follows. The peak and integrated values for the north-western component which has a secondary peak in addition to the prominent hotspot are 57 mJy/beam and 97 mJy. The peak brightness of the nucleus is 1168 mJy/beam and its integrated value including the extension to the east is 1255 mJy. The flux density of the collimated structure north of the nucleus, which could possibly be a continuation of the extension to the east from the nucleus, is ~12 mJy, while the total flux density of the source estimated by specifying a box around it is 1375 mJy. It is difficult to get reliable spectral indices of the components from these maps since the UV coverages for the three frequencies are very different, but the data show that the core has a flat spectrum with a spectral index $\alpha \sim 0.4$ ($S \propto \nu^{-\alpha}$), while for the extended emission $\alpha \sim 0.8$. The spectral index of the core has been estimated using the peak brightness values of the core, and that of the extended emission by subtracting the peak brightness of the core from the total emission in the map.

4 DISCUSSION AND CONCLUSIONS

The 6-cm images (Fig. 2a and b) show the core to be extended to the east, with evidence of this jet-like structure,

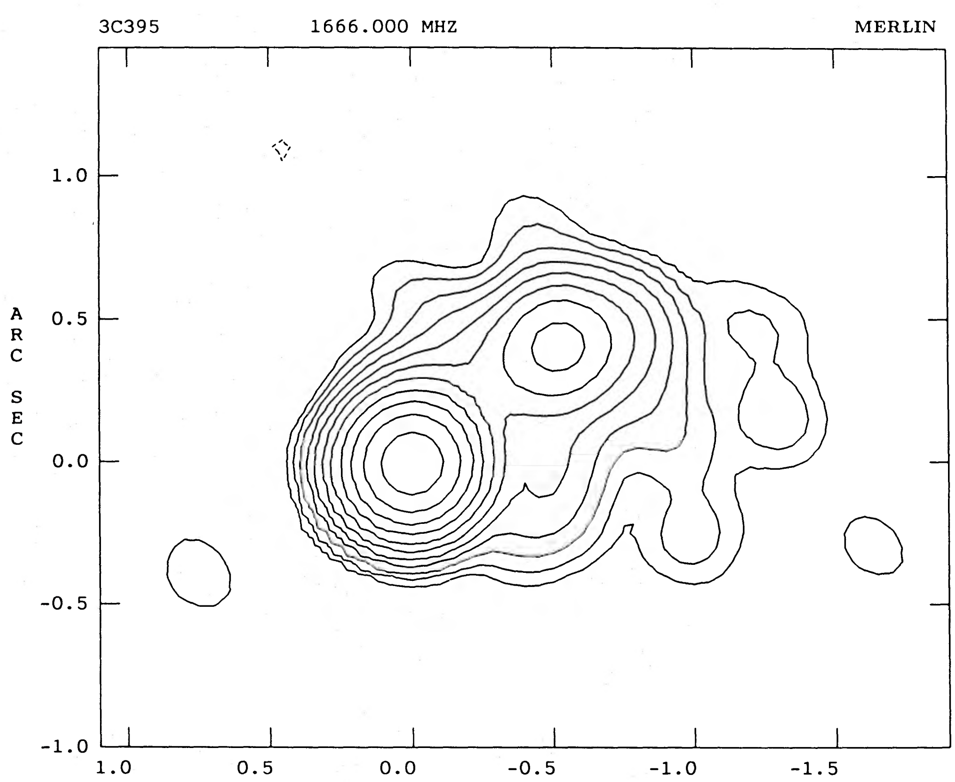

Figure 1. The 18-cm image of 3C395 with an angular resolution of 0.25 × 0.25 arcsec^2. Peak brightness: 2039 mJy/beam. Contours: 1.2 × (−1, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512 and 1024) mJy/beam. Negative contours are shown dashed.

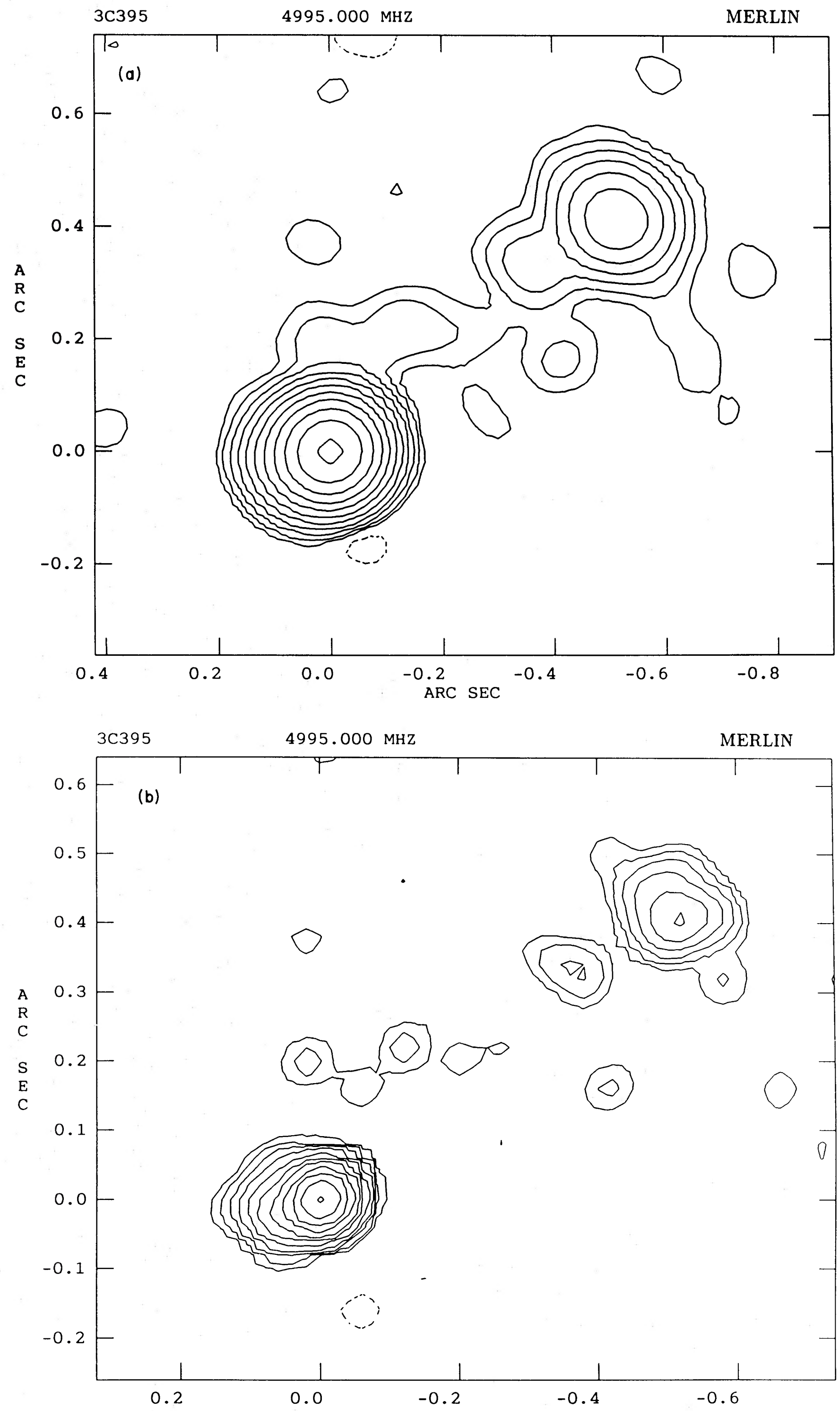

Figure 2. (a) The 6-cm map of 3C395 restored with a beam of 100×100 mas^2. Peak brightness: 1168 mJy/beam. Contours: -1, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512 and 1024 mJy/beam. (b) The 6-cm map of 3C395 with an angular resolution of 50×50 mas^2. Peak brightness: 1107 mJy/beam. Contours: -1, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512 and 1024 mJy/beam.

possibly extending to the north and north-west. The outermost region of the extension towards the east is along PA ~ 96°. A possible model for 3C395 based on the VLBI and MERLIN observations is schematically illustrated in Fig. 3. The VLBI components, namely the nucleus, the stationary hotspot and the superluminal component are enclosed by the dashed circle and have been labelled 1, 2 and 3, respectively. The dashed line traces the path of the jet, while A and B are the outer hotspots. Our observations, together with the VLBI results discussed earlier, demonstrate the presence of a strongly curved jet-like structure extending beyond the stationary, steep-spectrum VLBI component (2 in Fig. 3).

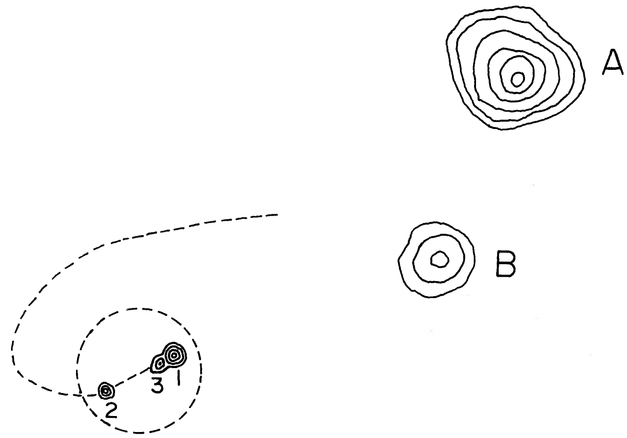

Figure 3. Schematic illustration of a possible model for 3C395. The VLBI components, namely the nucleus, the stationary hotspot and the superluminal component are enclosed by the dashed circle and have been labelled 1, 2 and 3, respectively. The dashed line traces the path of the jet, while A and B are the outer hotspots discussed in the text.

Such structures can be reproduced by precessing jets in sources inclined at small angles to the line-of-sight, as has been demonstrated by Gower *et al.* (1982). However, the occurrence of the stationary VLBI component suggests a change in the physical properties of the jet at the location of the stationary hotspot (2 in Fig. 3), perhaps caused by interaction with dense gas in the external medium. The jet appears distorted and bent, the intrinsic distortion being possibly amplified by projection effects since the source is inclined at a small angle to the line-of-sight as suggested by the apparent motion of the superluminal component. It is difficult to be certain from the present observations whether the jet is connected to the prominent hotspot (A in Fig. 3) located at about 0.7 arcsec from the nucleus or the weaker more extended emission on the west (B in Fig. 3). The latter would suggest significant dissipation of energy along the jet as it interacts with a dense, clumpy external medium. In this case the prominent hotspot on the western side, namely A, could be the receding component of the source; the approaching emission appearing on the same side due to projection effects. To distinguish between the two possibilities a low-frequency map with an angular resolution of ~50 mas to trace the entire length of the jet would be very useful. Also, depolarization observations may be a useful diagnostic since lobe depolarization has been shown to be strongly correlated with jet sidedness (Laing 1988; Garrington *et al.* 1988).

Another interesting aspect of 3C395 is the large apparent velocity, $v_{app}=\beta_{app}c$, of the superluminal component. Its value of $\beta_{app}h\sim 13$ for a Hubble constant $H_0=100h$ km s^{-1} Mpc^{-1} in an Einstein–de Sitter universe is amongst the highest known for all sources, and much higher than for sources of comparable core dominance as can also be seen in Browne (1987). In recent lists of superluminal sources (e.g. Porcas 1987 and Zensus & Pearson 1988) the only other source to have a higher value is CTA102 with $\beta_{app}h\sim 18$ (Bååth 1987), but higher resolution observations of this source by Wehrle & Cohen (1989) have not confirmed such high velocities. The projected linear size of 3C395 is only $\sim 2.9h^{-1}$ kpc which is amongst the smallest for all known superluminals (see also Browne 1987).

To explain these characteristics of 3C395, one possibility is that the channel for ejection of radio plasma from the active nucleus is not straight, but bent from a somewhat larger to a smaller angle towards the line-of-sight very close to the nucleus such that $\beta_{app}=\beta\sin\phi/(1-\beta\cos\phi)$ is maximized. Here $v=\beta c$ is the true velocity and ϕ is the angle of inclination to the line-of-sight. This could account for a larger superluminal speed of 3C395 compared to other sources of similar core prominence. Bends in the nozzle on VLBI scales have been suggested earlier (e.g. Marscher 1987). This idea has been used recently by Marcaide *et al.* (1989) to explain the VLBI strucutre of 4C39.25 which also has a superluminal component between two stationary components. We attribute the small size of 3C395 to both projection and a dense clumpy environment which also possibly causes the strong curvature at ~15 milliarcsec from the nucleus. Some evidence for such an environment may be provided by the rotation measure (RM) of the source. Aizu *et al.* (1990) have recently determined the RM of 3C395 to be 179 ± 2 rad m^{-2} and the intrinsic position angle (IPA) to be $30.4\pm 0.9°$, which is close to the values of RM$=169\pm 1$ rad m^{-2} and IPA$=31\pm 1°$ listed by Simard-Normandin, Kronberg & Button (1981). Although 3C395 with $l=63.0°$ and $b=+11.8°$ is only just outside one of the regions of large RM determined by Simard-Normandin & Kronberg (1980), the RM of the nearby source 3C399.1 ($l=62.7°$ and $b=+8.5°$) is only 60 ± 1 rad m^{-2} (Simard-Normandin, Kronberg & Button 1981). Clearly, observations of more sources in the immediate vicinity of 3C395 are required to estimate reliably the foreground galactic contribution to its RM. On the VLBI scales it is obviously important to monitor 3C395 regularly and study the kinematics and evolution of the superluminal component as it approaches the stationary VLBI component at a distance of 15.8 mas. Also, higher resolution VLBI observations would be useful for clarifying the structure closer to the nucleus.

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