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Research Note

The sub–arcsecond structure of 4C39.25

N. Jackson[1], I.W.A. Browne[2], A. Alberdi[3], and J.M. Marcaide[4]

[1] Sterrewacht Leiden, Postbus 9513, NL-2300 RA Leiden, The Netherlands
[2] NRAL Jodrell Bank, Macclesfield, Cheshire SK11 9DL
[3] Instituto de Astrofísica de Andalucía, CSIC, Aptdo. de Correos 3004, E-18080 Granada, Spain
[4] Universitat de Valencia, E-46100 Burjassot, Valencia, Spain

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Abstract. We present a new 5 GHz MERLIN image of the superluminal quasar 4C39.25 at a resolution of 70 mas. The major contribution of this new image is that structures within the previously unresolved jet are exposed to view. The presence of a straight–line jet is now more obvious, and the structure of the source, particularly in the region where the jet enters the terminal hotspot, is very similar to that of larger sources. This provides further evidence for basic similarity between sources such as 4C39.25 and larger sources. However, the flux in the jet is not as strong as expected from simple versions of relativistic beaming/orientation unified models, and jet deceleration or bending may have to be invoked to explain the observations.

Key words: galaxies: active – galaxies: quasars: individual: 4C39.25 – galaxies: jets

1. Introduction

4C39.25 = 0923+392 is a quasar at a redshift of 0.699 (Lynds et al. 1966). Its arcsecond radio structure is that of a core–dominated quasar (Browne et al. 1982) and consists of a bright core surrounded by diffuse extended radio emission. A sample of such quasars was used by Browne et al. to argue that core–dominated quasars were intrinsically weak "classical double" lobe–dominated quasars, viewed at such an angle that their cores appeared brighter due to Doppler boosting (Orr & Browne 1982).

General support for this view has been provided by VLBI studies in this object. Early suspicions that the source consisted of just two stationary components (Shaffer et al. 1977) or indeed contained a superluminal *contraction* (Shaffer 1984) were resolved when it was subsequently shown that the milliarcsecond scale structure of the source consisted of a superluminally expanding component moving between two stationary components (Marcaide et al. 1985; Shaffer et al. 1987). This behaviour has been modelled by Marcaide et al. (1989) and Alberdi et al. (1993) in terms of a model in which the stationary components are the places where the relativistic jet bends almost directly into the line of sight, leading to increased Dopppler boosting, and the superluminal component is a moving shock propagating through the jet.

Arcsecond–scale images have not generally been detailed enough hitherto to provide much support for any particular model. Observations with resolutions down to $0\farcs15$ with the VLA at frequencies up to 15GHz have previously been published (Marscher et al. 1991), although the highest–resolution observations tend to resolve out much of the extended structure, and observations of approximately this resolution have also been published from the MERLIN array operating at 1.6GHz (Marcaide et al. 1989). In both cases the structure consists of an extension which runs $2''$ to the east of the core: this extension consists of a bright terminal blob (hereafter called "the hotspot"), emission trailing back from this hotspot and a bright condensation about one–third of the way out from the core to the hotspot (hereafter called "the knot"). There is a lobe on the other side of the core, but this tends to be resolved out on observations of $<0\farcs3$ resolution.

In order to provide better data on this source, we undertook observations with the upgraded MERLIN system, with which we obtained an image at 70 mas resolution. Section 2 describes the observations and section 3 the results and conclusions.

2. MERLIN observations

The observations were performed on 1991 September 7 during the first two months of observations with the upgraded MERLIN system. Six telescopes took part in the observations (Jodrell MkII, Tabley, Darnhall, Knockin, Defford and the new 32m telescope at Cambridge). During this time the observing frequency

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Send offprint requests to: N. Jackson

was 4993 MHz: polarization information was not available, and the bandwidth was limited to 8×1 MHz channels. The theoretical noise level was thus several times the limit of 50 μJy now routinely attained: however, the limiting factor in the map is the residuals due to closure errors from the extremely bright (nearly 10 Jy) central point source.

The data were corrected using a standard gain–elevation curve and reduced to the flux scale of Baars et al. (1977) using an observation of 3C286. A preliminary phase solution was obtained in AIPS using the point source calibrators 2134+004 and OQ208. The reduction was complicated by the need to calibrate non–closing errors as accurately as possible. These errors are baseline–based and cannot be removed by self–calibration, and mostly result from mismatched bandpasses in the correlator. These were removed by the AIPS task BPASS using the point source calibrators, resulting in a nominal straightening to 0.1% across the 8 channels. This baseline calibration was then applied to the 4C39.25 data, which were then edited and mapped (including self–calibration steps) in the Jodrell Bank OLAF package (Noble 1982), followed by a final phase of CLEANing in the NRAO AIPS package. The final map has a high dynamic range considering it has been made with such a long baseline array containing so few telescopes (about 37000:1 peak to RMS and 10000:1 from the peak to the lowest believable contour). There are minor artefacts very close to the core, the most important being the slight extension to the southwest of the core and the trail of emission at the level of the lowest contour to the northwest of the knot 1/3 of the way from the core to the hotspot, but away from the core the noise level is only a factor of 3–4 above the thermal noise. Our conclusion is that the correction for instrumental residual effects in the correlator is possible at the level of 0.1–0.2%. The final map is shown in Fig. 1.

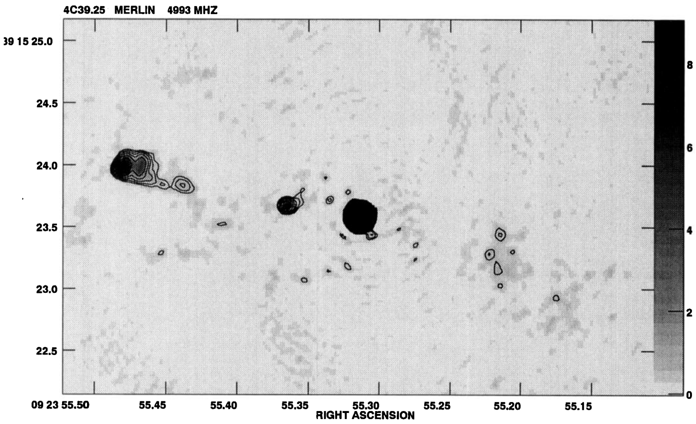

Fig. 1. The new MERLIN map of 4C39.25. Contours are plotted at levels of 0.8 mJy$\times$(1.0, 1.5, 2.25, 3.38, 5.1, 7.6, 11.4, 17.1, 25.6). The grey scale runs from 0 mJy (white level) to 9 mJy (black level)

3. Discussion and conclusions

The new map shows all the features that have been seen at lower resolutions of 150–200 mas (Marcaide et al. 1989; Marscher et al. 1991). The eastern hotspot (containing a flux of 56 mJy), the emission trailing to the west of it ($\simeq$5 mJy) and the knot (12 mJy) are all visible. In addition, the western lobe is just visible. The appearance of these features reinforces our conclusion that the map is basically sound.

However, with the extra factor of 2 in resolution we begin to see further features within the known existing high–brightness structures, and particularly in the terminal hotspot. This appears to consist of a condensation at the eastern end together with a subsidiary ridge to its west. This began to appear on the 2 cm map of Marscher et al. (1991), but the southern side of this structure is more sharply defined, as is the ridge of emission which appears to enter it from the west. This ridge is exactly in a line with the knot and the core. These observations therefore provide much firmer evidence for an arcsecond scale jet. 4C39.25 is one of the few small core–dominated radio quasars in which such evidence is available. The structure of this system is reminiscent both of observations of larger sources (see e.g. Black et al. 1992) and of recent simulations (Cox et al. 1991) in which the radio jet enters one side of the lobe: in this model the rest of the lobe, away from the line of the jet, is composed of old primary hotspots at which the jet is no longer pointing directly, and splatter spots around the periphery of the lobe as the jet deflects off the sides.

One can quantitatively examine the relation between the core–dominated quasar 4C39.25 and other more extended quasars. If we use the relativistic–beaming orientation unified scheme of Orr & Browne (1982) we obtain a prediction for the angle of the radio axis to the line of sight via the ratio of radio core to extended flux at 5 GHz, and by assuming, following Orr & Browne, a bulk Lorentz γ value of 5. In this case we obtain an angle to the line of sight of 7° using the total core–to–extended flux ratio given in the compilation of Browne & Murphy (1987). The linear size of the source when deprojected using this angle is about 1 arcminute, or about 560 kpc (we use H_o = 50kms^{-1}Mpc^{-1}, q_o=0 throughout this paper) which is large but not unreasonable: it lies at the top of the range of linear sizes of 3C quasars at similar redshift and somewhat above the centre of the range of sizes of 3C radio galaxies (e.g. the compilation of Hooimeyer 1991). Moreover, we may underestimate the angle to the line of sight if the "core" flux originates in a region of the jet that is bent towards us as claimed by Marcaide et al. (1989) and Alberdi et al. (1993).

A consistency check can also be performed by comparing the flux of the "jet" that we obtain with fluxes for radio jets in lobe–dominated quasars. We use for this purpose all declination $> 10°$ lobe–dominated quasars with redshifts in the range $0.35<z<1.05$ from the compilation of radio jets of Liu & Xie (1992). Compact steep spectrum sources have been excluded. In each of these sources where suitable radio maps are available, the jet luminosity (defined to include all emission along a line between the core and the lobe including intermediate knots but excluding the core, lobe and hotspot fluxes) has been estimated, either from values given by Liu & Xie or from estimates based on radio maps (Burns 1984; Owen & Puschell 1984; Neff & Brown 1984; Jackson et al. 1990; Saikia et al. 1987; Stocke et al. 1985; Feigelson et al. 1984) or unpublished data.

The 4C39.25 jet luminosity is $10^{25.7}$WHz^{-1}. According to the simple version of the relativistic beaming scheme, its angle to the line of sight is 7° as calculated above. The luminosity of the jets in the comparison sample of the same redshift (and about the same extended radio luminosity) is about $10^{25.6}$WHz^{-1}. However, this comparison sample is subject to a selection effect: within an orientation scheme, objects in which the jets are most prominent and likely to be detected will also be those objects which are as close as possible to the line of sight while still remaining as lobe–dominated quasars. We adopt 25° as a conservative estimate of their average angle to the line of sight.

With these assumptions, and according to the simplest version of the relativistic beaming unified scheme, one would expect the jet in 4C39.25 to be stronger than that of a typical quasar from the Liu & Xie sample with the same extended radio luminosity by about a factor of 40, which reflects the different Doppler boost factors at 7° and 25°. (This number does not change significantly for the scheme in which radio galaxies are included [Scheuer 1987; Barthel 1989]). However, the observed factor, taking account of the scatter in jet luminosities, is $<$10. Thus some additional effect is required to make the observations consistent with the unified scheme. The most likely possibilities are (i) that the jet bends away from the line of sight after leaving the core, thus causing us to overestimate its true Doppler boost factor, (ii) that the jet slows down after leaving the core, or (iii) that some of the extended emission, e.g. the hotspot at the end of the jet, is significantly beamed, causing us to overestimate its intrinsic luminosity. Hence we may be comparing 4C39.25 with lobe dominated objects that are too powerful. We note that the extended emission on the opposite side of the core to the jet is much weaker than on the jet side and since this emission is unlikely to be beamed it may be a better measure of the intrinsic extended luminosity of the source. If further high–resolution observations of core–dominated quasars reveal anomalously low jet fluxes, jet deceleration or hotspot beaming will be needed if the relativistic beaming unified scheme is to be kept consistent with observational data.

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References

Alberdi, A., Marcaide, J. M., Marscher, A. P., Zhang, Y. F., Elósegui, P., Gómez, J. L., & Shaffer, D. B 1993, ApJ, 402, 160
Baars, J. W. M., Genzel, R., Pauliny-Toth, I. I. K., & Witzel, A. 1977, A&A, 61, 99
Barthel, P. D. 1989, ApJ, 366, 606
Black, A. R. S., Baum, S. A., Leahy, J. P., Perley, R. A., Riley, J. M., & Scheuer, P. A. G. 1992, MNRAS, 256, 186
Browne, I. W. A. & Murphy, D. W. 1987, MNRAS, 226, 601
Browne, I. W. A., Orr, M. J. L., Davis, R. J., Foley, A., Muxlow, T. W. B., & Thomasson, P. 1982, MNRAS, 198, 673
Burns, J. O. 1984, in "Physics of Energy Transport in Extragalactic Radio Sources", eds A. H. Bridle and J. A. Eilek, p. 25, NRAO
Cox, C. I., Gull, S. F., & Scheuer, P. A. G. 1991, MNRAS, 252, 558
Feigelson, E. D., Isobe, T., & Kembhavi, A. 1984, AJ, 89, 1464
Hooimeyer, J. R. A. 1991, PhD thesis, University of Leiden
Jackson, N., Browne, I. W. A., Shone, D. L., & Lind, K. R. 1990, MNRAS, 244, 750
Liu, F. K., & Xie, G. Z. 1992, A&AS, 95, 249
Lynds, C. R., Hill, S., Heere, K., & Stockton, A. 1966, ApJ, 144, 1244
Marcaide, J., Alberdi, A., Elosegui, P., Schalinski, C. J., Jackson, N., & Witzel, A. 1989, A&A, 211, L23
Marcaide, J. M., Bartel, N., Gorenstein, M. V., Shapiro, I. I., Corey, B. E., Rogers, A. E. E., Webber, J. C., Clark, T. A., Romney, J. D., & Preston, R. A. 1985, Nature, 314, 424
Marscher, A. P., Zhang, Y. F., Shaffer, D. B., Aller, H. D., & Aller, M. F. 1991, ApJ, 371, 491
Neff, S. G., & Brown, R. L. 1984, AJ, 89, 195
Noble, R. G., 1982, unpublished Jodrell Bank document
Orr, M. J. L. & Browne, I. W. A. 1982, MNRAS 200, 1067
Owen, F. N., & Puschell, J. J. 1984, AJ, 89, 932
Saikia, D. J., Salter, C., Neff, S. G., Gower, A. C., Sinha, R. P., & Swarup, G. 1987, MN, 228, 203
Scheuer, P. A. G., 1987, in "Superluminal Radio Sources", eds. J. A. Zensus and T. Pearson, Cambridge University Press
Shaffer, D. B., Kellerman, K. I., Purcell, G. H., Pauliny-Toth, I. I. K., Preuss, E., Witzel, A., Graham, D., Schilizzi, R. T., Cohen, M. H., Moffet, A. T., Romney, J. D., & Niell, A. E. 1977, ApJ 218, 353
Shaffer, D. B. 1984, in IAU Symposium 110, "VLBI and Compact Radio Sources", eds. Fanti, R., Kellerman, K. I., & Setti, G., Reidel, Dordrecht
Shaffer, D. B., Marscher, A. P., Marcaide, J., & Romney, J. D. 1987, ApJL, 314, L1
Stocke, J. T., Burns, J. O., & Christiansen, W. A. 1985, ApJ, 299, 799

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