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A jet in the nucleus of the giant quasar 4C 74.26

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ABSTRACT

An image of the nucleus of the giant quasar 4C 74.26 made using very long baseline interferometry at a frequency of 5 GHz shows a one-sided, parsec-scale jet that is well aligned with the 400-kpc jet seen in VLA images. If the jet asymmetry is due to Doppler boosting, the axis of the source cannot lie close to the plane of the sky. The radio spectrum of the nucleus, measured with the VLA, has a peak at about 8 GHz.

Key words: galaxies: jets – quasars: general – quasars: individual: 4C 74.26 – radio continuum: galaxies.

1 INTRODUCTION

The double-lobed radio source 4C 74.26 or 2043 + 74.9 (Riley et al. 1988) is identified with a 14.8-mag quasar of redshift $z = 0.104$. The angular extent of 10 arcmin corresponds to a projected linear size of 0.8 h^{-1} Mpc (assuming $H_0 = 100\ h$ km s^{-1} Mpc^{-1}, $q_0 = 0.5$), making 4C 74.26 one of the largest known sources associated with a quasar. An image with 15-arcsec resolution made with the VLA at 1.46 GHz (Riley & Warner 1990) shows an unresolved nucleus of 230 mJy from which a single jet extends at least 150 arcsec (200 h^{-1} kpc) in PA 160° toward a bright hotspot in the southern lobe. This hotspot is much brighter and more compact than that in the northern lobe.

If radio-selected quasars are an unbiased sample of a randomly oriented population, the quasars with largest projected size are not expected to show rapid superluminal expansion. This is because apparent superluminal expansion is attributed to relativistic motion along an axis close to the observer's line of sight, and on average the axes of the largest quasars will be almost perpendicular to the line of sight. The detection of superluminal motion in another large quasar, 4C 34.47 (Barthel 1987; Barthel et al. 1989) was thus a surprise, and has led to a re-examination of our assumptions. Rapid superluminal expansion in the nucleus of a large double-lobed quasar could indicate, for example, that the motion in the nucleus is closer to the line of sight than is the axis of the double-lobed source. An alternative and attractive possibility is that a powerful double-lobed radio source appears as a quasar when its axis lies close to the line of sight and as a radio galaxy otherwise (e.g. Readhead et al. 1978; Peacock 1987; Scheuer 1987; Barthel 1989).

We report here first-epoch VLBI observations of the nucleus of 4C 74.26 which show a one-sided parsec-scale jet that is well aligned with the kiloparsec-scale jet. Future observations may provide an expansion speed for features in this jet. We have also used the VLA to measure the radio spectrum of the nucleus.

2 OBSERVATIONS

2.1 VLBI observations

The observations were made on 1988 November 14, using eight antennas of the European VLBI Network and the United States VLBI Network.[1] The source 4C 74.26 was observed for approximately 6 h. Two calibration sources were also observed: 1739 + 52.2 in two 20-min scans and 2200 + 42.0 (BL Lacertae) in one 20-min scan. The observing frequency was 4991 MHz, the bandwidth 1.8 MHz, the polarization left-circular, and the recording system Mark II. The data were cross-correlated using the JPL/Caltech Block-II Interferometry Processor at the California Institute of Technology, and residual delays and fringe rates were determined using a global fringe-fitting algorithm (Schwab & Cotton 1983) as implemented in the AIPS package of the National Radio Astronomy Observatory (task CALIB).

Amplitude calibration was based on measured system temperatures and antenna gains, and on the observations of

[1] MPIfR, Effelsberg, Germany (diameter 100 m); Istituto di Radioastronomia, Medicina, Italy (32 m); Jodrell Bank, England (26 m); Onsala Space Observatory, Onsala, Sweden (25 m); NEROC Haystack Observatory, Westford, MA (37 m); NRAO, Green Bank, WV (43 m); NRAO, Pie Town, NM (25 m, one antenna of the partially completed Very Long Baseline Array); NRAO VLA, Socorro, NM (for part of the observations all 27 antennas were used as a phased array; for the remainder a single 25-m antenna was used). Observations at Westerbork (the Netherlands) and OVRO (California) were unsuccessful.

the calibration source 1739+52.2. The highly variable radio source 1739+52.2 has been only barely resolved in previous observations (Pearson & Readhead 1988), but self-calibration of the present observations showed that it could be modelled with an unresolved component of 1.1 Jy plus a 0.7-Jy halo of size 0.0015 arcsec (FWHM of equivalent Gaussian brightness distribution) slightly displaced from the unresolved component. The amplitude correction factors, accurate to a few per cent, derived from the self-calibration of 1739+52.2 were applied to the data for 2043+74.9. The other calibration source, 2200+42.0, was heavily resolved at the time of these observations. Self-calibration showed that it was extended about 0.006 arcsec in PA 10°, consistent with previous observations (Mutel et al. 1990).

An image of 2043+74.9 was obtained with an iterative self-calibration algorithm (Pearson & Readhead 1984). In each iteration, a model image was used to estimate complex gain corrections for each antenna, and the corrected data were used to estimate a new image for the next iteration. The gain corrections were estimated by using an implementation of the CORTEL algorithm (Cornwell & Wilkinson 1981); the images were estimated from the corrected visibility data using both CLEAN and a maximum entropy algorithm, which provide alternative methods of enforcing the positivity constraint.

2.2 VLA observations

The core of 4C 74.26 was observed at 0.3, 1.4, 5, 8 and 15 GHz with the A-configuration of the VLA on 1988 November 16, to investigate its spectrum. One 15-min snapshot was made at each frequency; the flux density calibrator was 3C 48. The data were calibrated at the VLA by standard procedures. Subsequent reduction was carried out using the AIPS package on a Sparcstation at MRAO. After initial mapping and cleaning, the data were self-calibrated for phase. The core flux densities were measured from these maps by fitting a Gaussian, zero offset and slope with the AIPS task IMFIT.

3 RESULTS

The flux density of the nucleus of 4C 74.26 detected in the VLBI observation was 0.30 ± 0.03 Jy, and it was clear from the visibilities that ~ 0.1 Jy was due to an unresolved component (<0.5 mas), while the remainder was due to an elongated feature. Fig. 1 shows two images made from the same data. The first, a conventional 'clean' image, is convolved with an elliptical Gaussian representing the effective synthesized beam. The second is a maximum entropy image, which can be regarded as a deconvolution of

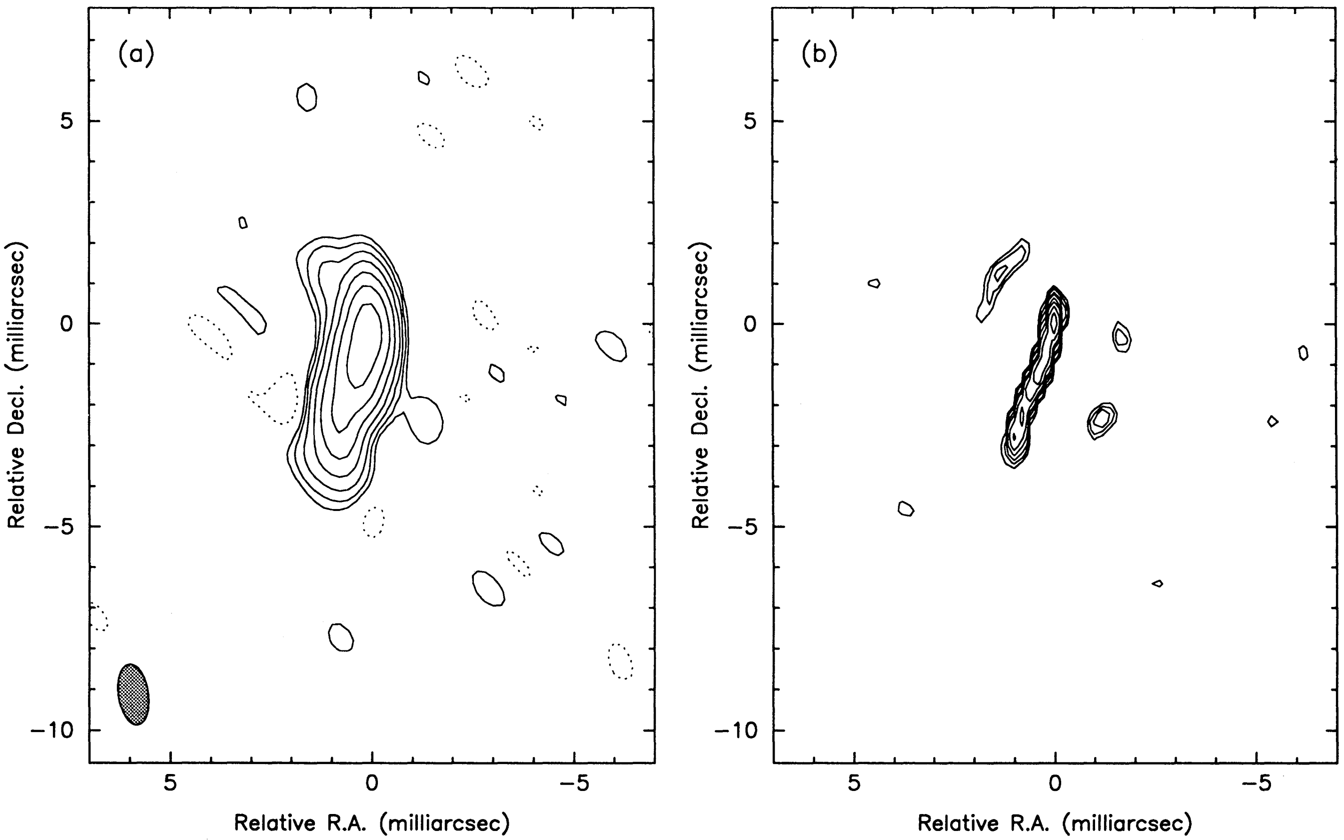

Figure 1. VLBI images of the nucleus of 4C 74.26 at 4.99 GHz. The linear scale is 1 mas = 1.3 h^{-1} pc. (a) Conventional 'clean' image. The image has been convolved with an elliptical Gaussian restoring beam of FWHM 1.5×0.75 mas^2, with the major axis in PA 9° (hatched ellipse). The logarithmically spaced contour levels are ± 1, ± 2, 4, 8, 16, 32 and 64 per cent of the peak, which has brightness 0.14 Jy per beam. The lowest contour is at 2.3 times the rms noise level (0.6 mJy per beam). The spurious low-level extension to the north-east is due to a residual calibration error. (b) Maximum entropy image made from the same visibility data. The contour levels are 0.5, 1, 2, 4, 8, 16, 32 and 64 per cent of the maximum. The detached, low-brightness features are almost certainly due to residual calibration errors. If this image is convolved with the elliptical Gaussian used in (a), a very similar image results.

the clean image. The images show that: (i) the emission region is highly elongated in PA 160° (B1950.0), the same position angle as that of the inner part of the large-scale jet (Riley & Warner 1990); it extends for 4.5 mas (6 h^{-1} pc) in this direction and is unresolved (< 0.5 mas, < 0.6 h^{-1} pc) in the perpendicular direction; (ii) the brightest point is close to the northern end, and the brightness decreases smoothly toward the south. Such elongated brightness features are commonly called 'jets' (Bridle & Perley 1984); in this source, the parsec-scale jet is presumably connected to the kiloparsec-scale jet seen in the VLA image, and it is likely that its southward extent in the VLBI image is limited by the sensitivity of the observations.

The flux density of the core measured on the shortest VLBI baselines agrees very well with that obtained from the VLA map at 4885 MHz (328 mJy), and all the flux detected with the VLA is accounted for on the VLBI maps shown in Fig. 1. The core flux density is variable at 5 GHz (Riley et al. 1988) but, as the VLBI and VLA observations were made only two days apart, this should present no problems when comparing these values. Only a very small amount of the VLA core flux (< 20 mJy) can arise from scales larger than 4 mas. Despite this, however, limits on the surface brightness of any continuation of the parsec-scale jet are still considerably higher than that of the kiloparsec-scale jet (Riley & Warner 1990).

It is not clear whether there is a counter-jet directed towards the northern lobe. If the centre of activity is assumed to be at the brightest point then there is no evidence for a counter-jet, and a lower limit of ~ 50 : 1 can be placed on the jet/counter-jet brightness ratio close to the centre. In order to confirm, though, that the brightest point does represent the centre of activity, observations at another frequency are required to show that it has the flat spectrum characteristic of such 'cores'. The integrated flux densities of the core obtained from the VLA maps were: 70 ± 6 mJy (0.327 GHz); 184 ± 3 mJy (1.46 GHz); 328 ± 1 mJy (4.88 GHz); 333 ± 1 mJy (8.4 GHz); 306 ± 2 mJy (14.9 GHz). Thus the integrated spectrum of the core (Fig. 2 and Riley et al. 1988) shows that some part of the core has an inverted spectrum up to about 10 GHz and has emission in the millimetre region. In this context, however, it is clear from Fig. 2 that, since the parsec-scale jet contributes about two-thirds of the flux at 5 GHz, all or part of it must be self-absorbed and have a flat spectrum below this frequency. The question of the true 'core' will only be answered by higher frequency VLBI observations. Thus the VLBI observations do not resolve the question of whether there is a northern jet at present, or whether it is hidden by Doppler beaming. If it is assumed that the asymmetry is entirely due to Doppler beaming with jet flow speed βc at an angle to the line of sight θ, the brightness ratio of > 50 : 1 requires that $\beta \cos\theta > 0.65$ and hence that $\theta \lesssim 49°$ (Bridle & Perley 1984; the jet spectral index has been taken as $\alpha = -0.5$, $S \propto \nu^{\alpha}$). This suggests that the axis of the double radio source is not close to the plane of the sky and implies that the deprojected size of the parsec-scale jet is ≥ 8 h^{-1} pc and that the whole source is ≥ 1.1 h^{-1} Mpc in extent.

Unfortunately, the parsec-scale jet is smooth, and shows no brightness peaks or 'knots' that could be monitored to measure an apparent jet speed. The total flux density of the core at 4995 MHz decreased from 0.42 to 0.31 Jy between 1986 and 1988 (though from the present VLA observations there is no evidence for further changes), and in other sources flux outbursts are often associated with the ejection of knots into the jet. Knots might also be detectable in observations with higher dynamic range.

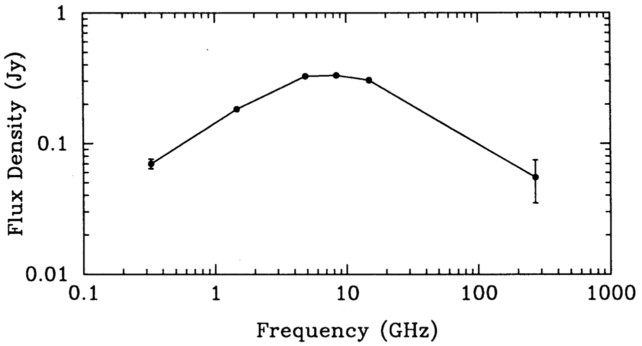

Figure 2. Spectrum of the nucleus of 4C 74.26. The data from 0.3 to 15 GHz were measured with the VLA on 1988 November 16 (see Section 2.2). The point at 270 GHz is from Riley et al. (1988).

4 CONCLUSIONS

The nucleus of 4C 74.26 contains a radio jet of length at least 6 h^{-1} pc which is well aligned with the 200 h^{-1} kpc jet seen in a VLA image. There is at present no evidence for a counter-jet. If the asymmetry of the parsec-scale jet is attributed to Doppler boosting, the axis of the source must lie $\lesssim 49°$ from the line of sight. Unfortunately, there are no clear 'features' such as discrete brightness peaks that could be used to estimate an expansion velocity. Observations with higher resolution or higher surface brightness sensitivity will be needed to detect such features.

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