1989MNRAS.236P..13R

Mon. Not. R. astr. Soc. (1988) **236,** *Short Communication,* 13P–20P

4C 74.26 – the largest radio source associated with a quasar

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Accepted 1988 September 19. Received 1988 September 16

Summary. Observations of the radio source 4C 74.26 with the Cambridge Low-Frequency Synthesis Telescope have shown it to be a 10-arcmin double. It is identified with a quasar with a redshift of 0.104, measured with the University of Hawaii 88-inch telescope, giving the source a projected linear size of 1.6 Mpc and making it the largest-known radio source associated with a quasar. The optical spectrum and image, radio maps and JCMT millimetre observations are presented here. The radio properties of 4C 74.26 are remarkably similar to those of other giant sources identified with galaxies – despite its very much larger non-stellar optical nuclear luminosity – as well as to those of 4C 34.47, the only other giant source associated with a quasar.

1 Introduction

Surveys with the 6C Telescope (Baldwin *et al.* 1985) and the Cambridge Low-Frequency Synthesis Telescope (CLFST) (Baldwin 1986) at 151 MHz have revealed a number of radio sources with large angular size and low surface-brightness – objects which are difficult to detect with higher-resolution instruments. One of these sources is 4C 74.26, a 10-arcmin double with a total flux density of 9.9 Jy. Observations with the Cambridge 5-km telescope (Ryle 1972) reveal one bright, fairly compact hotspot in the southern lobe and a very bright core whose position is within 0.8 arcsec of that of a stellar object with a magnitude ~ 15.5 on both the red and blue prints of the Palomar Sky Survey. The optical spectrum of this object shows it to be a quasar with redshift 0.104. The projected linear size of the radio source is therefore 1.6 Mpc ($H_0 = 50$ km s^{-1} Mpc^{-1}, $q_0 = 0$), making 4C 74.26 the largest-known source associated with a quasar – more than 30 per cent larger than the only other 'giant' (>1 Mpc) quasar, 4C 34.47 (Barthel 1987). We present the optical spectrum and image, radio maps and millimetre observations of this remarkable object, and briefly discuss its properties.

2 Observations and results

2.1 OPTICAL OBSERVATIONS

A flux-calibrated spectrum and optical image of the identification were obtained in 1986 August using the Cambridge CCD system on the University of Hawaii 88-inch telescope on Mauna Kea; details of the observations are included in the captions to Figs 1 and 2. The spectrum (Fig. 1) is typical of a quasar, featuring strong broad Balmer emission lines (FWHM ~7500 km s^{-1}), narrow forbidden lines of moderate (~10 Å) equivalent width and a strong non-stellar continuum. The redshift, determined from the [O III]4959/5007 doublet and [N II]6583, and corrected for galactic rotation, is 0.104 ± 0.001. The spectrophotometry gives $m_V = 14.8 \pm 0.2$ and $m_B = 15.2 \pm 0.3$ for the continuum (the measurement of m_B required some

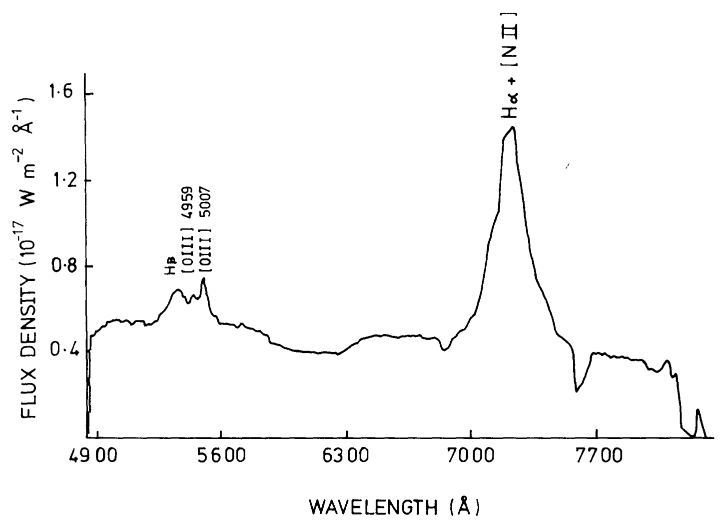

Figure 1. Flux-calibrated optical spectrum of the quasar associated with 4C 74.26, comprising two 5-min exposures. The slit was oriented east–west and was 5 arcsec wide; the spectral resolution was ≃15 Å.

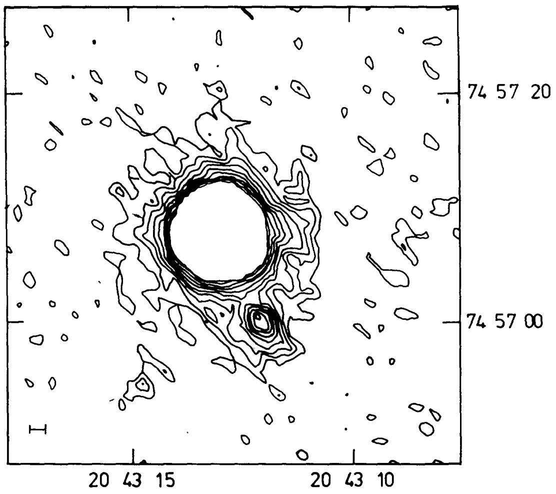

Figure 2. Contour plot of the CCD image of 4C 74.26 showing the outer envelope of the quasar and its companion to the south-west. The plate scale is 1 arcsec pixel^{-1} and the seeing, indicated by the horizontal bar, was 1.5 arcsec (FWHM). The integration time was 10 s; no filter was used but the response of the CCD is approximately $R_c + I_c$ (Cousins 1976). Contours are plotted at intervals of 50 counts pixel^{-1} from 1350–1800 counts pixel^{-1}; the sky level is 1300 ± 40 counts pixel^{-1}. An approximate flux calibration (correct to within a factor of 2) gives 50 counts pixel^{-1} ≃ 1.5×10^{-18} W m^{-2} arcsec^{-2} ≃ 24 mag arcsec^{-2}.

extrapolation of the spectrum to shorter wavelengths), in broad agreement with the estimates from the Sky Survey prints. On the assumption that $A_V \sim 0.5$ and $A_B \sim 0.7$ (Burstein & Heiles 1982) along the quasar's line of sight through the Galaxy ($l = 109^\circ$, $b = 19^\circ.5$), the continuum has absolute magnitudes of $M_V \approx -24.7$ and $M_B \approx -24.5$. The integrated non-stellar continuum is thus sufficient to dominate the starlight of an underlying galaxy in these wavebands – a typical radio galaxy at a redshift of 0.1 has $M_V = -23.1$ and $M_B = -22.1$ (Laing, Riley & Longair 1983; Peacock, Miller & Longair 1986).

The direct image (Plate 1 and Fig. 2) shows that the quasar is surrounded by some low-brightness extended emission; at distances greater than 4 arcsec (10 kpc) from the nucleus the image is appreciably more extended than the other stellar images in the field. About 8 arcsec (20 kpc) to the south-west there is a 19-mag galaxy which may be interacting with the quasar. The low-brightness emission presumably represents the underlying galaxy. Determination of the magnitude and type of this galaxy is made difficult by the fact that the image, which was obtained only as an aid to positioning the slit of the spectrograph, is undersampled and uncalibrated, and the nucleus of 4C 74.26 is burned out. However, the flux calibration was determined to within a factor of 2, using other objects of known magnitude observed at the same time. Comparison of the image of the outer regions of the underlying galaxy with the flux-calibrated images of radio galaxies in approximately the same waveband presented by Baum *et al.* (1988) indicates that it is typical of the giant ellipticals associated with radio sources in both size and luminosity.

2.2 RADIO OBSERVATIONS

Radio observations of 4C 74.26 have been made with the CLFST at 151 MHz, the Cambridge One-Mile telescope (Macdonald, Kenderdine & Neville 1968) at 408 and 1407 MHz, MERLIN (Davies, Anderson & Morison 1981) at 1666 MHz and the Cambridge 5-km telescope at 2695 and 4995 MHz; details are given in Table 1. The 151- and 4995-MHz maps, both cleaned using the Hogböm (1974) algorithm, are presented here. The other observations provide integrated and core-flux densities on the scale of Laing & Peacock (1980), as listed in Table 2; these were estimated from the maps except for the integrated flux densities at 2695

Table 1. The radio observations.

Telescope	Frequency (MHz)	Date	Synthesized HPBW (arcsec) RA x Dec	Shortest baseline (λ)
38-MHz	38	1985.0	1000 x 1040	3
CLFST	151	1985.5	70 x 73	6
OMT	408	1985.5	80 x 83	130
	1407	1985.5	23 x 24	230
MERLIN	1666	1986.9	0.24 x 0.21	33000
5 km	2695	1984.5	3.7 x 3.8	1300
	4995	1986.5	2.0 x 2.1	4700
		1987.5		600
		1988.0		4700

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Table 2. Integrated and core flux densities.

Frequency (MHz)	Flux density (Jy) Integrated	±	Core	±
38	30	9	-	-
151	9.9	1.0	<0.3	-
408	4.0	0.1	<0.16	-
1407	1.63	0.08	0.18	0.02
1666	-	-	0.24	0.02
2695	1.1	0.2	0.34	0.01
4995 (86.5)	-	-	0.42	0.01
(87.5)	0.81	0.2	0.37	0.01
(88.0)	-	-	0.31	0.01
2.7×10^5	-	-	0.055	0.02

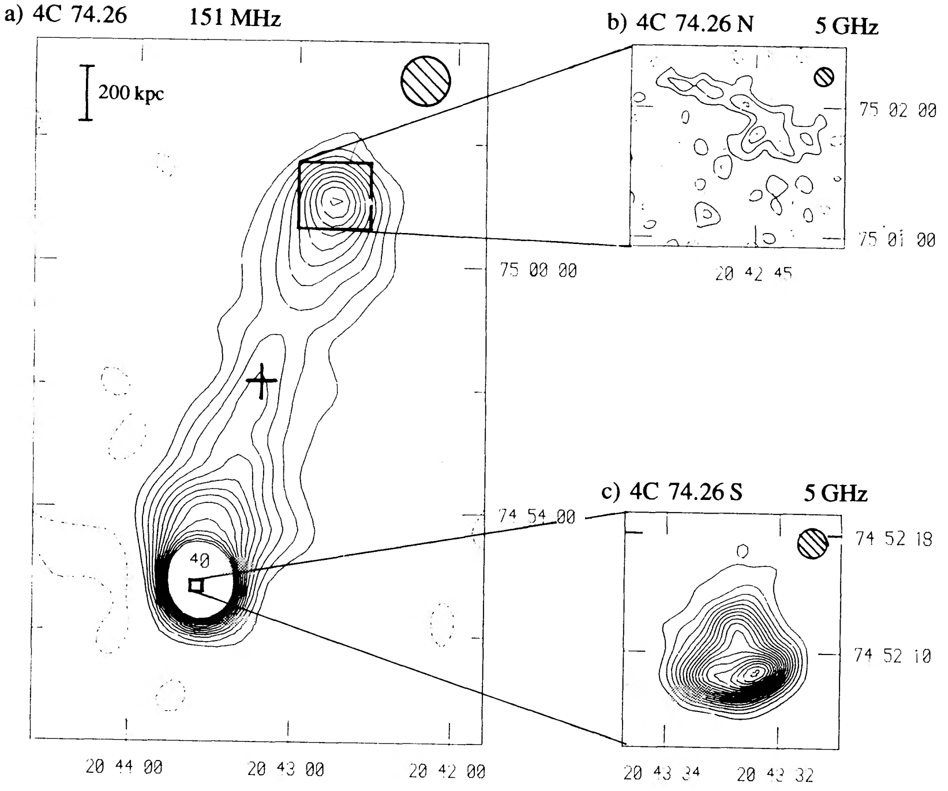

Figure 3. Maps of 4C 74.26 at 151 MHz and 5 GHz. The hatched circles indicate the half-power beamsizes. Negative contours are dashed and there are no zero contours. The coordinates are 1950.0. (a) 151 MHz, half-power beamsize 70 × 73 arcsec^2. The cross indicates the position of the quasar. The contour interval is 70 mJy beam^{-1}. There are 40 contours to the peak in the southern hotspot. (b) 5-GHz map of the northern hotspot, half-power beamsize 7 × 7.3 arcsec^2. The contour interval of 1 mJy beam^{-1} is about 1.5 times the noise level. (c) 5-GHz map of the southern hotspot, half-power beamsize 2 × 2.1 arcsec^2. The contour interval of 1.5 mJy beam^{-1} is about four times the noise level.

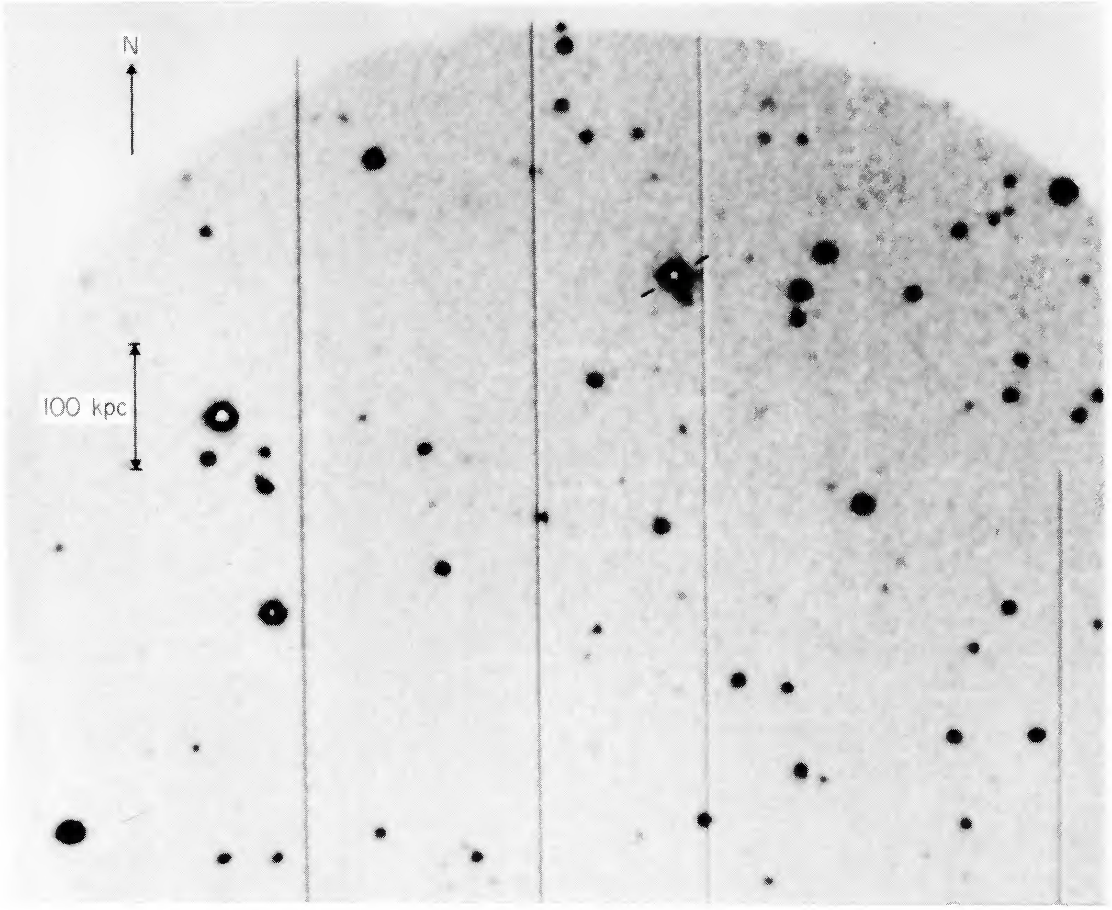

Plate 1. CCD image of the field of 4C 74.26. The vertical bar is 37 arcsec in length and represents 100 kpc at the redshift of the source. The vertical stripes are dud columns in the CCD.

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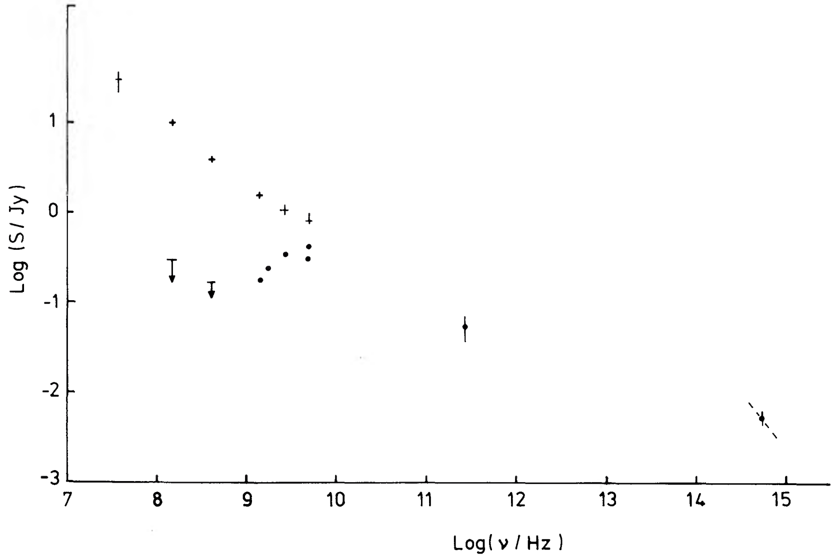

Figure 4. Composite spectrum of 4C 74.26. The integrated radio flux densities are shown by crosses. The flux densities of the radio core, the millimetre component at 270 GHz and the optical continuum at 5×10^{14} Hz (6000 Å) are shown by filled circles, with upper limits at 151 and 408 MHz. The dashed line shows the approximate slope of the optical continuum as determined from the spectrum. The upper point at 4995 MHz is the value at 1986.5 and the lower one the value at 1988.0.

and 4995 MHz which were from the peaks of the smallest-spacing amplitude plots. The 38-MHz value for the integrated flux density was obtained with a new array at Cambridge (Laycock 1987). The 151-MHz map and the 4995-MHz maps of the northern and southern hotspots are shown in Fig. 3(a)–(c). The southern hotspot is roughly 16 kpc in extent with an unresolved southern edge. The northern hotspot is of very low surface-brightness and was not visible on the highest-resolution map; the lower-resolution map in Fig. 3(b) shows that it has the form of a smooth arc ~ 100 kpc in length. No jet has been detected above the noise level on either the full-resolution or smoothed maps. Limits to the surface brightness of any jet within four beamwidths of the core are higher than the nominal noise level by a factor of ~ 4 due to residual side-lobes from the intense core. The core lies at RA $20^h43^m12^s.99$, Dec. $74°57'08''.7$ (1950.0). It has an inverted spectrum below 5 GHz (Fig. 4) and contributed about 50 per cent of the total flux density at 4995 MHz in 1986 July; its 4995-MHz flux density has decreased by about 26 per cent in 18 months, being 0.42 ± 0.01 Jy in 1986 July, 0.37 ± 0.01 Jy in 1987 July and 0.31 ± 0.01 Jy in 1988 January. Both the inverted spectrum and the variability imply that a substantial fraction of the flux is coming from a region less than 1 pc in extent. MERLIN observations at 1666 MHz indicate, as expected, that the core is unresolved with a resolution of 0.2 arsec (0.5 kpc); they also provide a limit on the surface brightness of any jet within 12 arcsec (30 kpc) of the core, there being no other emission above the noise level of 0.6 mJy beam^{-1}.

2.3 MILLIMETRE OBSERVATIONS AND THE SPECTRUM OF THE CORE

The nucleus of 4C 74.26 was observed using the UKT14 detector (Duncan *et al.*, in preparation) at 1100 μm on the James Clerk Maxwell Telescope in Hawaii. The FWHM of the Gaussian beam of the telescope was 20 arcsec and the chop throw 40 arcsec. The nucleus of 4C 74.26 was detected at the 3σ level with a flux density of 55 ± 20 mJy.

The millimetre flux density and that of the optical continuum are plotted in Fig. 4 to show their relationship with the emission from the radio core. The millimetre emission can plausibly be interpreted as synchrotron radiation with the same origin as the radio core emission; for example, a spectral index $\alpha = (S \propto \nu^{-\alpha})$ in the millimetre region and a turnover in the radio region at about 10 GHz would produce the required spectrum. The optical continuum has a fairly steep spectrum ($\alpha \sim 1$) and may arise either from dust or from synchrotron radiation originating in a much smaller volume than the radio core; for either mechanism there must be a cut-off in the sub-millimetre region of the spectrum.

3 Discussion

The radio luminosity of 4C 74.26 at 178 MHz is 4×10^{25} W Hz^{-1} sr^{-1}, placing it on the borderline between classical double (FR II) sources and the more diffuse, relaxed (FR I) sources (Fanaroff & Riley 1974). Its structure is clearly that of an FR II source and is similar to those of other well-known 'giant' FR II sources of comparable luminosity, e.g. 3C 35 (van Breugel & Jägers 1982), DA240 (Tsien 1982), 3C 236 (Barthel *et al.* 1985) and 4C 34.47 (Jägers *et al.* 1982; Barthel 1987). Only one of these, 4C 34.47, is also associated with a quasar; the others are galaxies, with no detectable non-stellar continuum and without broad emission lines. This reflects the fact that the overall radio structure of a source is strongly related to its radio luminosity but is largely independent of the intensity of its non-stellar continuum and broad emission lines.

Despite the overall similarities between the two giant quasars, 4C 74.26 and 4C 34.47, there are two significant differences which may have a consistent explanation in terms of the orientations of their radio axes with respect to the line-of-sight. First, the Hβ line in 4C 74.26 (FWHM ~ 7500 km s^{-1}) is significantly broader than that in 4C 34.47 (FWHM ~ 1800 km s^{-1}) (Miley & Miller 1979; Wills & Browne 1986). Wills & Browne (1986) have found an anticorrelation between broad-line width and the ratio of the strength of the radio core to that of the lobes. They propose that the anticorrelation is expected in relativistic beaming models if the motion of the emission-line gas is predominantly confined to a plane perpendicular to the radio axis; broad-line width could thus be a crude indicator of source orientation, so that 4C 74.26 may make a larger angle to the line-of-sight than 4C 34.47. The second difference – which is worth commenting on here but which may be removed by more sensitive observations of 4C 74.26 – is that 4C 34.47 has a one-sided kpc-scale jet, whilst 4C 74.26 does not. Large-scale jets frequently occur in double-lobed quasars and are invariably one-sided (Bridle 1986). There is evidence that their one-sidedness is a result of their orientation with respect to the line-of-sight and is due to Doppler boosting of the radiation from one of two otherwise fairly symmetrical, oppositely directed jets (Laing 1988). In 4C 74.26, the angle the radio axis makes with the line-of-sight may be too large for significant Doppler boosting to occur.

This comparison of 4C 74.26 with 4C 34.47 indicates the effect that orientation may have on observed quasar activity. Orientation may also play a critical role in determining the observed optical properties of an active galactic nucleus, as may variability of the central continuum source. For example, the nucleus of a quasar whose axis lies close to the plane of the sky may be obscured (Netzer 1985) and it may then 'masquerade' as a galaxy (Scheuer 1987). Both the evidence that the galaxy underlying the quasar in 4C 74.26 is probably a giant elliptical and the fact that its radio properties are so similar to those of the other giants associated with galaxies provide support for such suggestions.

Acknowledgments

We are indebted to all those who operate the telescopes at the Mullard Radio Astronomy Observatory, to the committee responsible for allocating observing time on the University of

Hawaii 88-inch telescope and the telescope staff, and to Dr C. D. Mackay for the use of his CCD system and Dr A. Stockton for the use of his grism spectrometer. We also thank Dr T. Muxlow for analysing the MERLIN data and those responsible for operating MERLIN. The JCMT is operated by the Royal Observatory, Edinburgh, on behalf of the Science and Engineering Research Council of the United Kingdom, the Netherlands Organisation for Pure Research and the National Research Council of Canada.

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