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RADIO STRUCTURE AND OPTICAL IDENTIFICATION OF 3C319

A. H. BRIDLE
Queen's University at Kingston, Ontario, Canada K7L 3N6

E. B. FOMALONT
National Radio Astronomy Observatory[a], Charlottesville, Virginia 22901
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ABSTRACT

Maps of 3C319 made with the VLA at 1.48 and 4.89 GHz show the source to have an elongated double structure and a distribution of radio spectral index which support identification of the entire structure with an $18^m.5$ elliptical galaxy located near its radio centroid. A bright radio "head" at the northeastern end of the source is resolved by our 1.3 arcsec beam at 4.89 GHz and the position of its radio peak is ~ 0.7 arcsec from a $\sim 20^m$ diffuse optical object. This object may be a galaxy that is unrelated to 3C319, or it may be optical emission from the northeastern radio lobe.

I. INTRODUCTION

The radio source 1522 + 546 = 3C319 has an elongated structure ~110 arcsec in overall extent that has been mapped at 1.4 GHz with ~23 arcsec resolution by Macdonald *et al.* (1968) and at 2.7 GHz with ~8 by 13 arcsec resolution by Fomalont and Bridle (1978). An $18^m.5$ galaxy, the brightest in a distant cluster, has usually been assumed to be the optical identification (Longair 1965, Wyndham 1966, Smith *et al.* 1976) because of its proximity to the centroid of the radio structure. As part of a program of observations of extended radio sources associated with elliptical galaxies (Bridle and Fomalont 1978), we reappraised this identification and considered it uncertain for the following reasons. First, there is a non-negligible (~3%) probability that the $18^m.5$ galaxy lies within the limits of the radio structure by chance. Second, there are at least three other optical objects (cluster members?) above the print limit of the *Palomar Sky Atlas* within the radio structure which could be considered as possible, though less likely, identification candidates. Third, we consider that the practice of making optical identifications of extended structures on the basis of proximity to their radio centroids should be restricted to sources which are clearly bifurcated along their major axes, in order not to misidentify sources with "head-tail" morphology. The available maps of 3C319 (Macdonald *et al.* 1968, Fomalont and Bridle 1978) did not show a clear bifurcation but instead showed the brightest emission to be near the northeastern end of the radio structure; on this evidence 3C319 could be either a "double" source with a dominant "hot spot" at one end and relatively elongated lobes, or a head-tail candidate.

We attempted (Fomalont and Bridle 1978) to resolve the ambiguities in the structural classification and identification of 3C319 by observing the source at several hour angles with four VLA antennas at 4.9 GHz to search for any small-diameter (<3 arcsec) radio component within the large-scale structure which might mark the location of the correct optical identification. We found a component $\lesssim 2$ arcsec in diameter, containing ~8% of the total intensity of 3C319, at the extreme northeastern end of the structure and detected no small-diameter emission brighter than 4 mJy at the optical position of the $18^m.5$ galaxy that is normally assumed to be the identification.

This observation complicated the assessment of the identification because the detected small-diameter radio feature lay within errors of the optical position of a faint image on the *Palomar Sky Atlas* E print. This image might therefore be the identification of some or all of the radio source, or it might be merely a confusing background object. Furthermore, neither these observations of 3C319 with four VLA antennas nor those by Jenkins *et al.* (1977) with the Cambridge 5-km telescope were adequate to distinguish whether the large-scale structure of the source has a basically double morphology (favoring the centroidal identification) or a head-tail morphology (favoring identification with the faint image near the small radio component).

This paper reports new VLA observations of 3C319 which show that it has several features characteristic of an elongated double radio structure and thus favor the centroidal identification. The new results raise the possibility that the faint image in the northeastern lobe of the source could be optical emission associated with the processes of relativistic particle deposition in the radio lobe.

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II. THE LARGE-SCALE STRUCTURE OF 3C319

The new observations of 3C319 were made with nine antennas of the VLA on 28 March 1978. Important parameters of the observations are listed in Table I. As 15-min scans at 1.48 and 4.89 GHz were alternated, the (u,v) coverage is radially segmented at each frequency, so that the level of radial sidelobes on our maps is higher than normal for continuous synthesis observations made with the VLA in this configuration. The maps therefore contain possibly spurious low-level features on some radial lines emanating from the peak intensity in the northeastern lobe, and we urge caution in their use for purposes other than our immediate goal of classification of the radio structure.

Figure 1 shows (a) a CLEANed (Högbom 1974) 1.48-GHz map at 3.1 by 3.5 arcsec resolution (major axis in p.a. 112°) with a lowest contour of 4.0 mJy/beam and (b) a CLEANed 4.89-GHz map at the same resolution with a lowest contour of 1.7 mJy/beam. The contour levels are chosen so that emission with spectral index $\alpha = 0.7$ [$S(\nu) \propto \nu^{-\alpha}$] between these two frequencies would contour at the same level on each map. Both maps are basically bifurcated around the optical position of the $18\overset{m}{.}5$ galaxy (marked by the bold cross in Fig. 1) and therefore suggest that 3C319 is an elongated double source rather than a head-tail structure.

TABLE I. Parameters of VLA observations of 3C319.

System temperature	50 K
Bandwidth	50 MHz
Calibration source	1526 + 670
Calibration source R.A.[a]	$15^h26^m12\overset{s}{.}05$
Calibration source Dec.[a]	+67° 01′ 16″.5
Source scan length	12 min
Calibrator scan length	3 min
Antenna positions (m):	
West arm (azimuth 236°)	44.85, 484.00, 3188.09, 5222.90, 7659.48, 10472.87
East arm (azimuth 115°)	−80.00, 147.33, 484.00

[a] all coordinates given in this paper are for epoch 1950.0.

The maps are dominated by emission from the barely-resolved "head" near the northeastern end of the source. This head has a peak flux density at this resolution of 103 mJy at 1.49 GHz and 44 mJy at 4.89 GHz; its spectral index is therefore $\alpha \sim 0.71$ between these frequencies. The heads of head-tail sources normally have spectra which rise less steeply than this with decreasing frequency, but such a spectrum is not at all unusual for a bright feature near the end of a lobe in a double source.

The spectral variations over the more diffuse structure are also more consistent with interpreting 3C319 as an elongated double structure. The spectral index of the large-scale emission increases from $\alpha \sim 0.7$ at each end of the structure to $\alpha \sim 1$ towards its center. If the large-scale emission in 3C319 were the extended trail of a head-tail structure, we should expect to find α increasing steadily with distance from the northeastern end of the source, rather than this centrally symmetric spectral variation.

The diffuse emission shows little fine-scale structure. The faint ridges emanating from the head at the northeastern end of the source may not all be real since

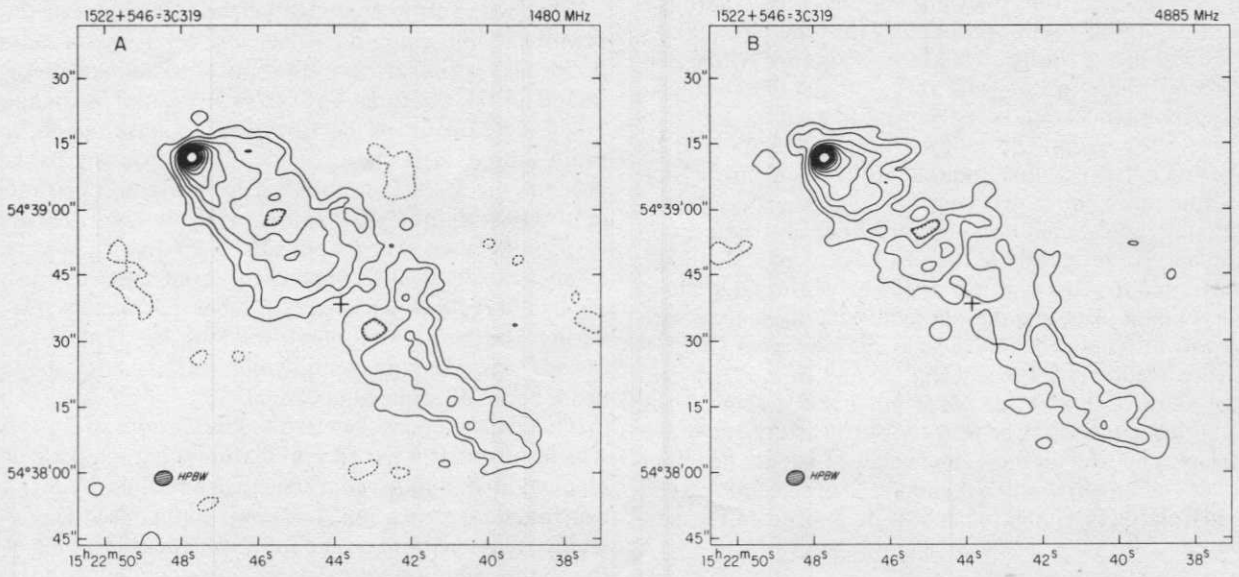

FIG. 1. (a) Map of 3C319 at 1.48 GHz with resolution 3.1 by 3.5 arcsec (major axis in p.a. 112°); the hatched ellipse at lower left shows the FWHM of the beam. Contours are drawn at −4 (dotted), 4, and 8–80 mJy/beam in steps of 8 mJy/beam. The cross marks the position of the $18\overset{m}{.}5$ galaxy that is the probable identification. (b) Map of 3C319 at 4.89 GHz with resolution 3.1 by 3.5 arcsec (major axis in p.a. 112°); the hatched ellipse at lower left shows the FWHM of the beam. Contours are drawn at −1.7 (dotted), 1.7, and 3.4–34 mJy beam in steps of 3.4 mJy/beam. The cross marks the position of the $18\overset{m}{.}5$ galaxy that is the probable identification.

similar radial features are present in the synthesized beam. The northwards curvature of the southwestern lobe near R.A. (1950) = $15^h\ 22^m\ 41^s.5$ is probably real, however; similar deflections of the inner lobes have been documented in the double radio galaxy 3C192 by Högbom (1979).

III. THE STRUCTURE OF 3C319 AT 1.3 ARCSEC RESOLUTION

Figure 2(a) shows a 4.89-GHz map at 1.2 by 1.3 arcsec resolution (major axis in p.a. 1°) of the entire field of Fig. 1; Fig. 2(b) shows detail around the northeastern head at this resolution, on which are superimposed vectors whose lengths are proportional to the linearly-polarized intensity at each point and whose position angles denote the position angle of the E-vector in the incident radiation. Figure 2(a) shows (1) that there is little evidence for brightness ridges along the length of the source as would be expected in a head-tail structure, and (2) that there is little or no emission from the $18^m.5$ galaxy near the source centroid. We can set a new upper limit of 1 mJy to the 4.89 GHz flux density of any unresolved source associated with this galaxy.

The peak intensity of the northeastern head is 21 mJy, and is at 1950.0 position $15^h\ 22^m\ 47^s.73 \pm 0^s.05$, +54° 39′ $11''.7 \pm 0''.5$ at this resolution. The head is clearly broader than the synthesized beam, with a FWHM of 1.8 ± 0.3 arcsec in right ascension and 2.3 ± 0.2 arcsec in declination. The head merges with other more resolved (~4 arcsec) structure to its south and west however, and we suspect that the above parameterization of the head structure is sensitive to telescope resolution. The difference in position between the peak of the head in Fig. 2 and that of $15^h\ 22^m\ 47^s.68 \pm 0^s.05$, +54° 39′ $11''.3 \pm 0''.5$ found by Fomalont and Bridle (1978) is almost certainly due to the improved resolution of the present data.

Figure 2(b) shows that the emission from the head is 16% linearly polarized in p.a. ~60°. This degree of polarization would be unusually large for the head of a head-tail structure but is not exceptional for the fractional polarization in a lobe of a double source.

Assuming that the rotation measure of 5.4 ± 5.7 rad m^{-2} found for the integrated emission from 3C319 by Tabara and Inoue (1978) applies over the region near the bright radio head, there is little Faraday rotation at 4.89 GHz and the magnetic field near the head must therefore be aligned perpendicular to the source major axis. Twelve arcsec south-west of the head the emission is about 25% linearly polarized. The magnetic field around the outer edge of the head follows the ridge lines of the emission. The above polarization properties are typical of radio lobes of double sources.

IV. THE OPTICAL OBJECT NEAR THE RADIO HEAD

All of the above results have suggested that 3C319 is an elongated double source whose optical identification should therefore be found within ~17 arcsec of the radio centroid with ≳90% confidence according to the precepts of Bridle and Fomalont (1978). As the $18^m.5$ galaxy has a <1% probability of being this close to the radio centroid

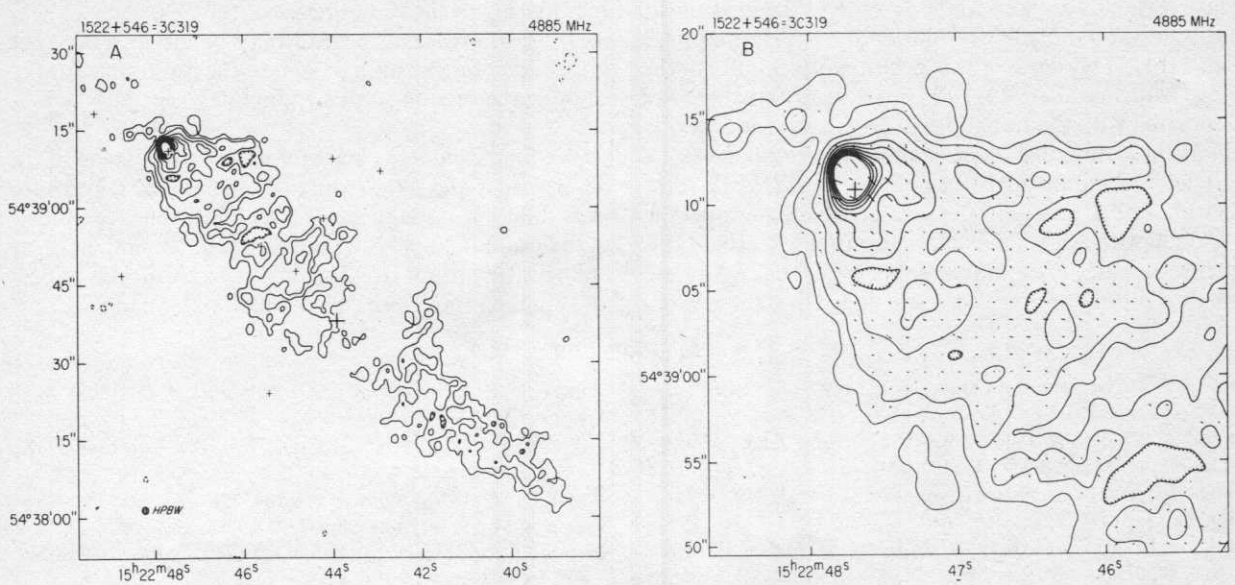

FIG. 2. (a) Map of 3C319 at 4.89 GHz with resolution 1.2 by 1.3 arcsec (major axis in p.a. 1°); the hatched ellipse at lower left shows the FWHM of the beam. Contours are drawn at −0.6, 0.6, and 1.2–12 mJy/beam in steps of 1.2 mJy/beam. The bold cross marks the position of the $18^m.5$ galaxy that is the probable identification. The fainter crosses mark the positions of other diffuse images (galaxies?) in the field, from Table II. (b) The region of the northeastern head from Fig. 2(a). The cross marks the position of the ~20^m diffuse image close to the peak intensity of the head. The vectors show the distribution of the linearly polarized intensity over the source (magnitude and position angle of the E-vectors).

TABLE II. 1950.0 Optical positions (rms errors ~ 0″.4) for galaxies in the region of 3C319.

R.A.	Decl.	Comment
$15^h\ 22^m\ 42^s.92$	54° 39′ 07″.2	
$15^h\ 22^m\ 42^s.28$	54° 39′ 39″.4	
$15^h\ 22^m\ 43^s.90$	54° 38′ 38″.4	Identification galaxy
$15^h\ 22^m\ 43^s.97$	54° 39′ 09″.8	
$15^h\ 22^m\ 44^s.19$	54° 38′ 58″.4	
$15^h\ 22^m\ 44^s.80$	54° 38′ 47″.9	
$15^h\ 22^m\ 45^s.44$	54° 38′ 24″.1	
$15^h\ 22^m\ 45^s.59$	54° 38′ 52″.5	
$15^h\ 22^m\ 47^s.67$	54° 39′ 11″.1	Object near northeastern radio head
$15^h\ 22^m\ 48^s.73$	54° 38′ 47″.0	
$15^h\ 22^m\ 49^s.33$	54° 39′ 18″.3	
$15^h\ 22^m\ 50^s.70$	54° 39′ 11″.3	
$15^h\ 22^m\ 53^s.01$	54° 38′ 14″.2	
$15^h\ 22^m\ 55^s.57$	54° 38′ 15″.4	

by chance, we now consider it a probable identification for the whole structure. What then is the relation, if any, to 3C319 of the optical object near the northeastern radio head?

The bold cross in Fig. 2(b) marks the optical position of this object derived by taking a weighted mean of the optical positions quoted by Jenkins *et al.* (1977), Bridle and Fomalont (1978) and the position given in Table II (rms errors 0″.4) which was measured from two orientations of the *Palomar Sky Survey* E plate with the University of Texas engine by B. J. Wills. These three independently-measured optical positions have been weighted inversely as the squares of their quoted errors to derive the plotted position of $15^h\ 22^m\ 47^s.68$, +54° 39′ 10″.9, whose errors should be ~0″.3 in each coordinate. This position is 0″.4 west and 0″.6 south of the peak of the radio head on our high-resolution 4.89-GHz map [see Fig. 2(b)]. The sense of this position offset adds to the radio evidence that 3C319 is not a head-tail structure associated with the faint optical object, for the object is not at the outer edge of the small radio component.

The object appears diffuse on the *Sky Atlas* E print and may be a galaxy in the cluster which contains the $18^m.5$ identification. The optical positions of other faint diffuse images, presumably galaxies, in the radio field are marked by fainter crosses in Fig. 2(a); the plotted positions (Table II) were also measured from the E plate of the *Palomar Sky Survey* by B. J. Wills. The surface density of such images in this field is such that the object near the radio head may well be a cluster galaxy that is not physically related to the radio structure. The probability that a foreground galactic star lies so close to the radio head is only $\sim 10^{-4}$.

Various groups in recent years (Blanco *et al.* 1975; Kronberg 1976; Simkin 1976, 1978; Kronberg *et al.* 1977a,b; Tyson *et al.* 1977; Saslaw *et al.* 1978) have discussed the possibility that faint optical features located near "interesting" parts of radio-galaxy structures are in fact physically related to them, and have speculated on the astrophysical consequences of such relationships. So far no consistent pattern of "optical properties of radio lobes" has yet emerged from such work, so the reality of the proposed associations remains debatable. The object near the radio head of 3C319 is several magnitudes brighter ($m_V \sim 20^m$) than most of the optical features discussed by these authors, and lies only ~ 0″.1 from the line joining the radio head to the center of the $18^m.5$ galaxy. It is therefore worthy of the attention of optical astronomers seeking evidence for optical emission associated with the processes of particle deposition in the lobes of extended radio sources.

V. CONCLUSION

We conclude that the $18^m.5$ galaxy near the centroid of 3C319 is now the most plausible optical identification for the entire radio source, which has been shown by our observations to have an elongated double structure. The relationship to the radio source of the $\sim 20^m$ object near its bright northeastern head may be either a) chance projection of a cluster galaxy into the radio structure or b) optical emission from a radio lobe.

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