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Extragalactic Sources with very Asymmetric Radio Structure: VLA and MERLIN Observations

D. J. Saikia *University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Cheshire SK11 9DL, England* and *Tata Institute of Fundamental Research, P.O. Box 1234, Bangalore 560012*

P. Shastri *Tata Institute of Fundamental Research, P.O. Box 1234, Bangalore 560012*

T. J. Cornwell *National Radio Astronomy Observatory, Post Box O, Socorro, New Mexico 87801, USA*

W. Junor *Istituto di Radioastronomia, Via Irnerio 46, I-40126 Bologna, Italy*

T. W. B. Muxlow *University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Cheshire SK11 9DL, England*

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Abstract. As part of our study to understand the nature of extragalactic radio sources which are very asymmetric in the surface brightness of the two lobes, often with radio emission on only one side of the nucleus, we have observed a large number of them with high angular resolution and good surface brightness sensitivity at radio frequencies. In this paper we present VLA and MERLIN observations of 15 such sources. We discuss their observed structures and spectra, and possible explanations for their morphologies. We report evidence of a possible correlation between the hot-spot brightness ratio and the degree of core prominence, used as a statistical measure of source orientation, suggesting that relativistic beaming of the hot-spot emission does play a significant role in the observed brightness asymmetry. To explain the apparently one-sided sources within the relativistic beaming framework, the velocities required are in the range of 0.2 to 0.8 *c*. We discuss the possibility that the lobe which is seen to the south of the jet in 3C273 is the counter-lobe seen in projection. We also draw attention to a number of one-sided sources with very weak cores, and discuss their possible nature.

Key words: radio sources, extragalactic—radio sources, structure—relativistic beaming

1. Introduction

The majority of high-luminosity ($P_{178} \geqslant 2 \times 10^{25}$ W Hz^{-1} sr^{-1}) extragalactic radio sources selected at a low frequency ($\leqslant 1$ GHz), have outer lobes which are reasonably symmetric in both brightness and location relative to the active nucleus. However, a significant fraction of them appear to be very asymmetric, sometimes with radio emission on only one side of the parent galaxy. The one-sided sources are often referred to as of the D2 type (*cf.* Miley 1971) or C-type (*cf.* Readhead *et al.* 1978). From a systematic search of the literature, Kapahi (1981; hereinafter referred to as K81) compiled a list of suspected one-sided sources and compared some of their observed properties with those of the more symmetric double-lobed sources. More recent lists or maps of such highly asymmetric sources can be found, for example, in the papers by Perley, Fomalont & Johnston (1982), Browne *et al.* (1982), Hintzen, Ulvestad & Owen (1983, hereinafter referred to as HUO), Saikia *et al.* (1984), Rogora, Padrielli & de Ruiter (1986, 1987), Barthel *et al.* (1988), Hutchings, Price & Gower (1988) and O'Dea, Barvainis & Challis (1988, hereinafter referred to as OBC). Classification of the structures by K81 and HUO was often based on observations which by today's standards are of relatively poor resolution and surface brightness sensitivity. To check their classification and make a systematic study of their properties, we have observed many of these suspected one-sided sources with the VLA and MERLIN. In Paper 1 of this series we presented VLA C-array observations of 17 such sources (Saikia *et al.* 1984), while in Paper 2 we described detailed observations of the interesting one-sided radio source B2 1320+299, and discussed its possible nature (Cornwell *et al.* 1986).

In this paper we present VLA and MERLIN observations of 15 sources, most of which have been chosen from either the K81 or HUO lists. For the VLA maps we present both total-intensity and linear-polarization information. The sources are listed in Table 1, which is arranged as follows. Columns 1 and 2: The source name and an alternative name. Column 3: Optical identification (Q: quasar, G: galaxy, RO: red object, BL: BL Lac and U: unidentified). Columns 4, 5 and 6: Position of the optical object (epoch 1950) and a reference for the position. Column 7: Redshift. The values are from either Hewitt & Burbidge (1980, 1987) or Véron-Cetty & Véron (1987). Column 8: The largest angular size (LAS) of the radio structure in arcsec. In this column U implies that the source is either unresolved or only slightly resolved. The LAS has been estimated from the maps presented in this paper, except for the sources 0309+411 and 1055+018. The angular size of 0309+411 is from a high dynamic range Westerbork map made by de Bruyn (1989), while that of 1055+018 is from Murphy (1988, hereinafter referred to as M88) who detects two lobes from more sensitive observations of lower angular resolution.

2. Observations and analyses

2.1 *VLA Observations*

The VLA observations were made while the array was in either the A or B configurations (*cf.* Thompson *et al.* 1980). The B-array observations were made on 1982 August 11 and September 7 while the A-array ones were made on 1983 November 25 and 1985 February 10.

During the B-array observations most of the sources were observed at only λ6 cm (4885 MHz), while 0309+411 was observed at λ20 cm (1465 MHz) and 2041−149 at both λ6 and 20 cm. Polarization calibration was done only at λ6 cm. The A-array observations were made at λ20, 6 and 2 cm (1465, 4885 and 14965 MHz respectively), and polarization calibration was done at all three frequencies.

Table 1. The list of sources.

Source	Alt. name	Opt. Id.	Optical position (B1950) R.A. h	m	s	Dec. °	′	″	Ref.	Redshift	LAS ″
0115+027	4C02.04	Q	01	15	43.61	02	42	19.7	1	0.672	13.1
0307+444	4C44.07	Q	03	07	09.02	44	24	27.1	2	1.165	4.3
0309+411	NRAO128	G	03	09	44.81	41	08	48.9	3	0.136	570
0814+201	OTL	RO	08	14	12.25	20	08	04.4	4		U
0836+710	4C71.07	Q	08	36	21.56	71	04	22.1	5	2.170	1.4
1055+018	4C01.28	Q	10	55	55.33	01	50	03.4	5	0.888	30.3
1136−135	PKS	Q	11	36	38.51	−13	34	05.9	7	0.554	15.8
1221+809	S5	BL	12	21	47.55	80	56	40.9	6		11.2
1433+177	4C17.59	Q	14	33	36.12	17	42	36.5	8	1.203	10.0
1637+574	OS562	Q	16	37	17.33	57	26	16.2	2	0.745	~5
1741+279	4C27.38	Q	17	41	57.95	27	54	04.3	5	0.372	9.4
1842+681	GC	Q	18	42	43.32	68	06	19.3	5	0.475	~8
2041−149	OTL	U?	20	41	29.17	−14	56	32.8	9		31.0
2251+134	4C13.85	Q	22	51	51.93	13	25	49.1	10	0.673	6.7
2325+269	4C27.52	Q	23	25	28.60	26	59	23.0	7	0.875	7.4

References
1. Clements (1983)
2. Cohen *et al.* (1977)
3. Edwards, Kronberg & Menard (1975)
4. Subrahmanya & Gopal-Krishna (1979)
5. Hewitt & Burbidge (1987)
6. Kühr *et al.* (1987)
7. Miley & Hartsuijker (1978)
8. Wills, Wills & Douglas (1973)
9. Singal, Gopal-Krishna & Venugopal (1979)
10. Wills (1979)

In all the observing sessions the bandwidth was 50 MHz and the primary flux density and polarization calibrator was 3C286. The flux densities are on the BGPW scale (Baars *et al.* 1977). Each source was observed in only one scan lasting about 5–10 minutes at any given frequency. A secondary calibrator was observed before and after each scan on a source. The data were edited and calibrated using the standard DEC10 programs available at the VLA and further processed using the NRAO AIPS package. All maps presented here have been made from self-calibrated data (Schwab 1980).

2.2 *MERLIN Observations*

The MERLIN system has been described in some detail by Thomasson (1986). The MERLIN observations were made in different sessions between 1980 and 1987 (see Table 2). The calibrators and their estimated flux densities for the different sources are as follows: the calibrator used for 0836+710 was BL Lac with an estimated flux density of 2.42 Jy at λ18 cm (1666 MHz). The flux density calibration was checked using data for 3C48 which was observed during the same session. The data for 1221 +809 at both λ73 (408 MHz) and 18 cm (1666 MHz) were also calibrated with BL Lac whose flux densities at the two wavelengths were estimated to be 2.57 and 6.0 Jy respectively. The flux density at λ73 cm is from the Bologna monitoring program (*e.g.* Fanti *et al.* 1981) while at λ18 cm it has been estimated from the observations of Waltman *et al.* (1986). The λ18 cm (1662 MHz) data for 2251+134 were calibrated with 0552+398 whose flux density was estimated to be 2.22 Jy (*cf.* Rudnick & Jones 1983). The data were processed using the Jodrell Bank OLAF package developed by R. Noble.

3. Observational results

Some of the observational parameters and observed properties of individual sources are given in Table 2, which is arranged as follows. Column 1: The source name. Columns 2 and 3: Date and wavelength of observations. For the MERLIN observations, the wavelength is preceded by the letter M. Column 4: Half-power beamwidth and orientation of the elliptical Gaussian restoring beam. The major and minor axes are in arcsec while the position angle (PA) is in degrees. Column 5: An estimate of the rms noise in the total-intensity map, σ_{tp} in units of mJy/beam. Column 6: The values of the polarization noise $\sigma_{pol}=\sqrt{\sigma_Q^2+\sigma_U^2}$, where σ_Q and σ_U are the rms noises on blank sky in the distributions of the Stokes parameters Q and U. Columns 7, 8 and 9: Component designation and the right ascension and declination of the corresponding radio intensity peaks. For components with a superscript '*g*', the positions have been estimated from two-dimensional Gaussian fits. Columns 10 and 11: Peak brightness in units of mJy/beam and the total flux density in mJy. For components with a superscript '*g*' in column 7, these values have been estimated from Gaussian fits. For the rest they have been estimated by specifying boxes around the components. Columns 12 and 13: The percentage polarization and the PA of the *E*-vector at the peak of the total-intensity distribution. The polarized intensity images have not been noise corrected, but the values used while estimating the percentage polarization are usually $\geqslant 4\sigma$ and hence the corrections are negligible.

Table 2. Observational parameters and observed properties of individual sources.

Source	Observational parameters							Observed properties										
	Obs. date	Obs. λ cm	Beam size maj. $''$	Beam size min. $''$	Beam size PA $^\circ$	σ_t mJy/b	σ_p mJy/b	Comp.	Radio position (B1950) R.A. h	R.A. m	R.A. s	Dec. $^\circ$	Dec. $'$	Dec. $''$	Flux density peak mJy/b	Flux density total mJy	Polarization %	Polarization PA $^\circ$
(1)	(2)	(3)	(4)			(5)	(6)	(7)	(8)			(9)			(10)	(11)	(12)	(13)
0115+027	1982 Aug 11	6	1.35	1.32	138	0.22	0.20	W1	01	15	43.30	02	42	17.9	49		17	11
								W2			43.50			17.9	50		1.5	47
								W1+W2							50	215		
								C			43.63			19.4	140		2.6	175
								E1			43.90			21.4	24		7	171
								E2			44.13			21.9	58		2.0	6
								E1+E2							58	205		
								Total							140	587		
0307+444	1985 Feb 10	6	0.41	0.34	155	0.13	0.10	W							10	60	⩽3.3	
								C^g							192	199	3.2	45
								Jet							10	28	21	179
								E							196	330	0.8	125
								Total							196	625		
0309+411	1982 Aug 11	20	5.94	3.84	94	0.72		C^g	03	09	44.78	41	08	49.2	289	304		
								NW			43.00		09	06.0	8	13		
0814+201	1983 Nov 25	20	1.36	1.26	175	0.13	0.12	C^g	08	14	11.51	20	08	01.9	281	284	0.4	124
	1983 Nov 25	6	0.39	0.36	170	0.18	0.22	C	08	14	11.51	20	08	01.9	180	187	1.4	100
0836+710	1982 Oct 21	M18	0.25	0.25		0.62		S							32	181		
								C^g							3434	3407		
								Total							3430	3597		

Table 2. Continued.

Source	Observational parameters					Observed properties													
	Obs. date	Obs. λ cm	Beam size maj. ″	Beam size min. ″	Beam size PA °	σ_t mJy/b	σ_p mJy/b	Comp.	Radio position (B1950) R.A. h	R.A. m	R.A. s	Dec. °	Dec. ′	Dec. ″	Flux density peak mJy/b	Flux density total mJy	Polarization %	Polarization PA °
(1)	(2)	(3)	(4)			(5)	(6)	(7)	(8)			(9)			(10)	(11)	(12)	(13)
1055+018	1983 Nov 25	6	0.45	0.40	162	0.50	0.21	C^g	10	55	55.32	01	50	03.5	2671	2681	4.1	109
	1983 Nov 25	2	0.16	0.13	168	1.18	1.18	C	10	55	55.32	01	50	03.5	4125	4130	4.3	134
1136−135	1983 Nov 25	6	0.56	0.38	10	0.45	0.15	W	11	36	37.90	−13	34	01.1	129	529	7.8	31
								C^g			38.52			06.0	446	461	1.8	13
								E			38.81			07.8	22	640	22.2	101
								Total							444	1629		
1221+809	1981 Jul 21	M73	1.00	1.00		0.52		S1							7	26		
								S2							201	270		
								C+Jet							468	570		
								N1							8	14		
								N2							11	25		
								Total							468	905		
	1980 Dec 27	M18	0.30	0.30		0.59		S							32	103		
								C							456	463		
								Jet							9	31		
								Total							456	600		
1433+177	1982 Sep 07	6	2.02	1.93	48	0.29	0.20	N	14	33	36.09	17	42	42.0	18	27	10	21
								C			36.08			36.8	302		5	61
								S			36.19			32.5	192	246	4	89
								Total							302	597		
	1983 Nov 25	6	0.41	0.41	139	0.24	0.21	N	14	33	36.09	17	42	42.1	11	27	10.1	12
								C			36.09			36.7	228		3.3	46
								S			36.20			32.2	92	251	1.7	124
								Total							228	536		

1637+574	1982 Aug 11	6	1.54	1.36	121	0.64	0.25	C^g	16	37	17.43	57	26	15.9	1604	1639	3.4	111
								Total							1605	1678		
	1982 Sep 07	6	1.86	1.58	126	1.30	0.60	C	16	37	17.43	57	26	15.9	1610		3.5	110
								Total							1610	1699		
1741+279	1983 Nov 25	6	0.58	0.40	102	0.25	0.22	N	17	41	57.91	27	54	10.2	17	93	8.6	142
								C			57.90			04.8	178	196	6.4	71
								S			58.03			0.90	3	28	≤20	
								Total							178	327		
1842+681	1983 Nov 25	20	2.50	1.21	99	0.33	0.19	C^g	18	42	43.49	68	06	19.6	631	652	1.7	92
								Total							636	725		
	1983 Nov 25	6	0.75	0.37	100	0.33	0.21	C	18	42	43.49	68	06	19.6	1318	1329	1.4	37
2041−149	1982 Aug 11	20	5.68	3.92	178	0.69		W	20	41	29.11	−14	56	33.3	186	280		
								E			31.07			42.3	125	200		
								Total							186	480		
	1982 Aug 11	6	1.56	1.23	159	0.13	0.15	W	20	41	29.07	−14	56	33.8	47	79	1.6	131
								E			31.11			43.3	21	61	15.9	18
								Total							47	147		
2251+134	1982 Aug 11	6	1.30	1.25	172	0.50	0.20	SW	22	51	51.68	13	25	46.0	84	170	3.7	66
								C			51.87			49.1	397		1.7	85
								NE			51.99			50.9	112	180	1.6	60
								Total							397	798		
	1987 Jan 24	M18	0.30	0.30		0.37		W							60	220		
								Jet							20	79		
								C^g							549	549		
								E							92	256		
								Total							550	1104		
2325+269	1982 Sep 07	6	1.29	1.21	35	0.25	0.20	NW	23	25	28.41	26	59	24.8	198	331	~1	30
								C			28.54			21.4	53		≤1	
								SE			28.68			18.3	22	85	≤3	
								Total							198	508		

The maps of the sources are presented in Figs 1 to 13. For sources with polarization information, the fractional linear-polarization vectors are shown superposed on the total-intensity contours. No maps are shown for sources with single unresolved or partially resolved components.

4. Spectra

The integrated spectra for the sources together with spectra of the components, wherever possible, are presented in Fig. 14. The spectrum of 0309+411 was shown in Paper 1 and is not repeated here. The total flux densities have been compiled largely from the catalogues listed by Kühr *et al.* (1979, 1981). Estimates from aperture synthesis observations have sometimes been included to provide information at frequencies for which single-dish measurements are not available. These values are either the correlated flux densities at the shortest spacings or the sum of component flux densities. The errors on the component flux densities have been assumed to be 10 per cent unless the quoted value is higher.

A linear fit has been made to the spectrum unless it appears significantly curved, in which case a spectrum of the form $\log S = a + b \log \nu + c \log^2 \nu$ has been fitted. These fits were made using programs from the MPIfR NOD2 package (Haslam 1974).

5. Notes on individual sources

0115+027

The source 0115+027, which appeared to be one-sided in the Westerbork observations reported by Miley & Hartsuijker (1978, hereinafter MH78) has radio emission on both sides of the nucleus with suggestions of a radio jet towards the eastern component (Fig. 1). The outer components are somewhat asymmetrically located; the ratio of their separations from the core, R_θ, is about 1.4.

The source has a steep spectrum with a spectral index, α, defined as $S \propto \nu^{-\alpha}$, of 0.90 $\pm$0.01. Using the peak flux densities of the radio core in our map and the VLA A-array λ20 cm map of HUO, we find $\alpha_c \sim 0.1$. The spectral indices of the western and eastern components are about 1 and 0.9 respectively. VLBI observations have also been reported of the radio core. The correlated flux density with a fringe spacing of about 2.5 mas at 2290 MHz is 60 $\pm$ 10 mJy (Wehrle, Morabito & Preston 1984). The position of the VLBI component determined by Morabito *et al.* (1982) at 2290 MHz agrees with that of the optical quasar (Clements 1983).

The integrated rotation measure (RM) of the source has been reported to be 9.8 $\pm$2.4 rad m^{-2} with an intrinsic position angle (IPA) of 8 $\pm$ 6° by Tabara & Inoue (1980, hereinafter referred to as TI80) and 9 $\pm$ 11 rad m^{-2} with an IPA of 6 $\pm$ 5° by Simard-Normandin, Kronberg & Button (1981, hereinafter referred to as SKB). The low values of RM suggest that the *E*-vectors shown in Fig. 1 are close to the intrinsic values.

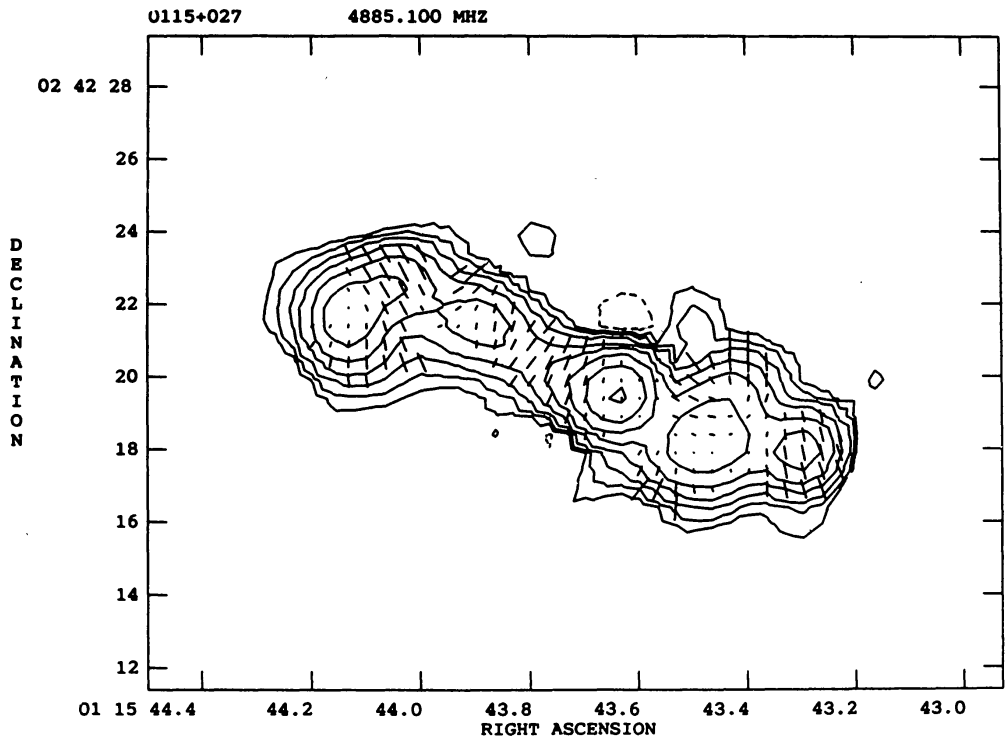

Figure 1. 0115+027 at λ6 cm. Peak brightness: 140.5 mJy/beam. Contours: −1, 1, 2, 4, 8, 16, 32, 64, 128 mJy/beam. Polarization: 1 arcsec = 40 per cent.

0307+444

A VLA map of this source published by HUO shows radio emission on only one side of the nucleus. Our observations of this source (Fig. 2) reveal a weaker complex lobe on the western side, while the eastern lobe is connected to the radio core by a jet-like feature. The source has a straight spectrum between about 0.178 and 5 GHz with a spectral index of 0.53 ± 0.04. The ratio of the peak brightnesses on opposite sides of the core is about 20, while the ratio of their separations from the core, R_θ, is about 1.6.

0309+411

Westerbork observations of this source by Kapahi (1979) showed that it consists of a prominent, compact core coincident with an 18 mag galaxy and a somewhat diffuse component extending about 1.5 arcmin towards the north-west. Gisler & Miley (1979) also mapped this source while observing the Perseus cluster, and classified it as a possible head-tail source.

In our earlier VLA C-array λ6 cm observations of this source, reported in Paper 1, we detected only the core component. O'Dea & Owen (1985) have presented a tapered VLA A-array λ20 cm map which shows that the core has a north-western extension in the direction of a blob which is at a distance of $\sim$25 arcsec from the core. In our present observations (Fig. 3), we detect the core and the secondary blob whose peak

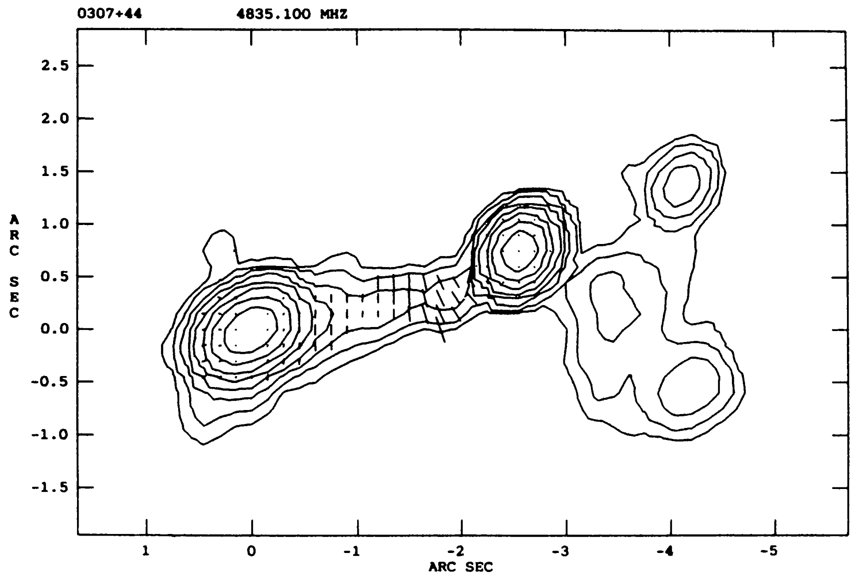

Figure 2. 0307 + 444 at λ6 cm. Peak brightness: 196.3 mJy/beam. Contours: 0.8 × (−1, 1, 2, 4, 8, 16, 32, 64, 128) mJy/beam. Polarization: 0.1 arcsec = 26.7 per cent.

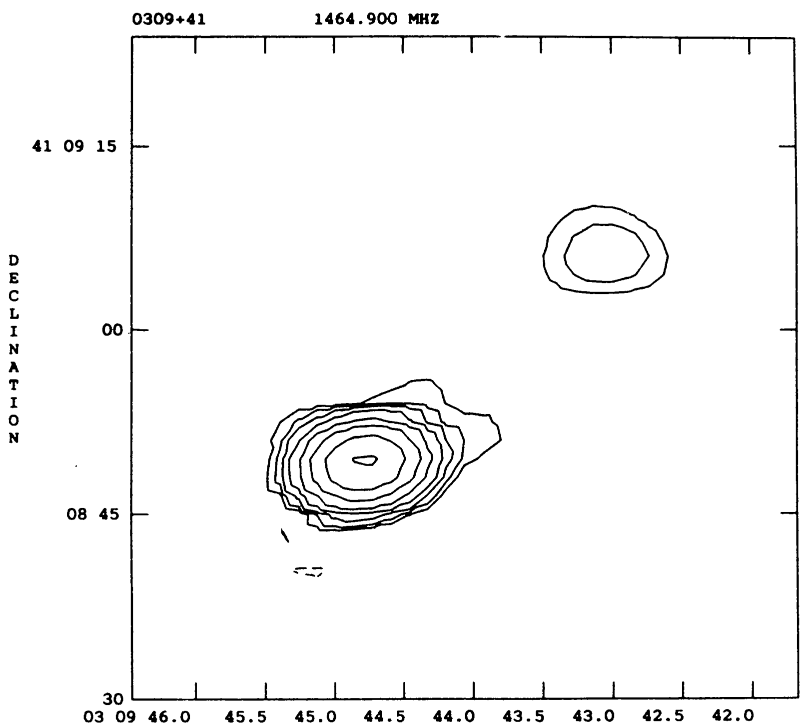

Figure 3. 0309 + 411 at λ20 cm. Peak brightness: 274.7 mJy/beam. Contours: 2 × (−1, 1, 2, 4, 8, 16, 32, 64, 128) mJy/beam.

brightness in our map is ~8 mJy/beam. A deep Westerbork map at 327 MHz has shown that this source is two-sided but the brightnesses of the two lobes are very different (de Bruyn 1989). Its overall angular size is ~570 arcsec. de Bruyn has measured its redshift to be 0.136, which implies that its projected linear size is about

1.8 Mpc in an Einstein-de-Sitter universe with $H_0 = 50$ km s^{-1} Mpc^{-1}. VLBI observations of this source would be extremely interesting for investigating constraints on relativistic beaming models. As shown in Paper 1, the source has an inverted spectrum above a few hundred MHz, and is perhaps variable in both total intensity and linear polarization.

0814+201

Brightness profiles of this source obtained from lunar occultation observations at 327 MHz (Subrahmanya & Gopal-Krishna 1979) show the source to be double-lobed with the eastern component coincident with a red object visible on Palomar Sky Survey prints. In our observations, we detect only the western component which has a spectral index of ~ 0.35 between $\lambda 20$ and 6 cm, a value similar to that of 0.40 ± 0.07 for the integrated spectrum of the source. The reality of the eastern component and hence of the identification needs to be verified from a more sensitive map. The source is in the direction of the Cancer cluster (Valentijn 1980).

0836+710

The large-scale structure of this source has been mapped with the VLA by Perley, Fomalont & Johnston (1980) and Perley (1982) who find the source to be one-sided

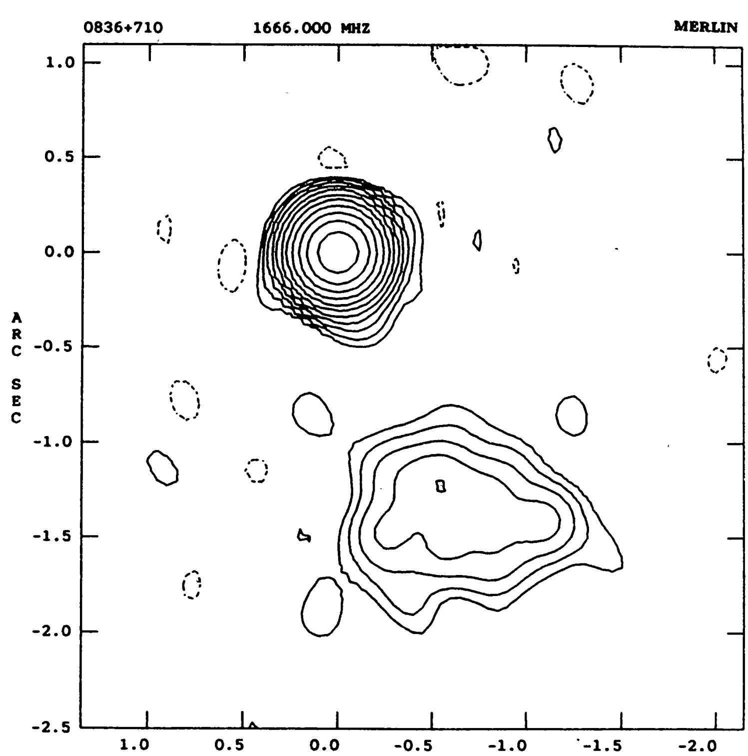

Figure 4. 0836+710 at $\lambda 18$ cm. Peak brightness: 3430 mJy/beam. Contours: -2, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048 mJy/beam.

with a single secondary component ~1.3 arcsec away from the nucleus along a PA ~ 200°. This source has been observed with MERLIN at λ73 and 18 cm. The λ73 cm map made by Muxlow shows the source to be one-sided to a limit of ~180:1. In this paper we present the λ18 cm MERLIN map (Fig. 4) which shows the core with a slight extension along a PA of ~200° and the secondary component whose peak is at a PA of ~204°. VLBI observations of this source reveal 4 components which are lined up at a PA of ~214° (Eckart *et al.* 1986, 1987).

1055+018

This source is a well-known low-frequency variable (Fanti *et al.* 1981; Spangler & Cotton 1981; see Singal & Gopal-Krishna 1985 for a detailed light curve) in which a strong outburst was found by Slee (1984). The source is also variable at high frequencies (*e.g.* Wardle, Bridle & Kesteven 1981). The radio observations reported by Perley (1982) showed a jet-like extension to the south along a PA ~ 180°. Murphy (1988) detects two lobes on opposite sides of the radio core separated by ~30 arcsec. Our observations detect only the radio core, which appears to be about 4 per cent polarized at both λ6 and 2 cm along PAs of 109° and 134° respectively. VLBI observations of the source by Romney *et al.* (1984) show extensions both to the north-east and north-west. The source has a flat spectrum with $\alpha \sim 0.08$.

1136−135

The source was listed as being one-sided by both K81 and HUO, based on the Westerbork observations by Miley & Hartsuijker (1978). Our VLA observations (Fig. 5) clearly show that the source is a triple with an LAS ~16 arcsec and $R_\theta \sim 1.8$. The integrated spectrum of the source is straight with $\alpha \sim 0.70 \pm 0.03$. The RM has been reported to be -25.6 ± 2.1 rad m^{-2} with an IPA of $49 \pm 5°$ by TI80 and -26 ± 1 rad m^{-2} with an IPA ~ $51 \pm 2°$ by SKB. Hence the PAs of the *E*-vectors at λ6 cm (Fig. 5) should be within about 5° of the intrinsic value.

1221+809

Early VLA maps of this source have been published by Perley, Fomalont & Johnston (1980). It was also observed by Perley (1982). Perley noted that there is an extended component along PA 205° at a distance of 2.1 arcsec from the nucleus. In Figs 6a and b we present the MERLIN maps of the source at 408 and 1666 MHz. The 1666 MHz map shows the structure reported by Perley, but in addition there appears to be a disembodied jet towards the north. At 408 MHz, we detect extended blobs of emission further out from the nucleus in both directions. The separation ratio R_θ estimated using the outermost components is about 1.6.

1433+177

This is a slightly misaligned triple source with a flux density ratio of ~9:1 at 5 GHz for the outer components. Our VLA B- and A-array maps are shown in Figs 7a and b

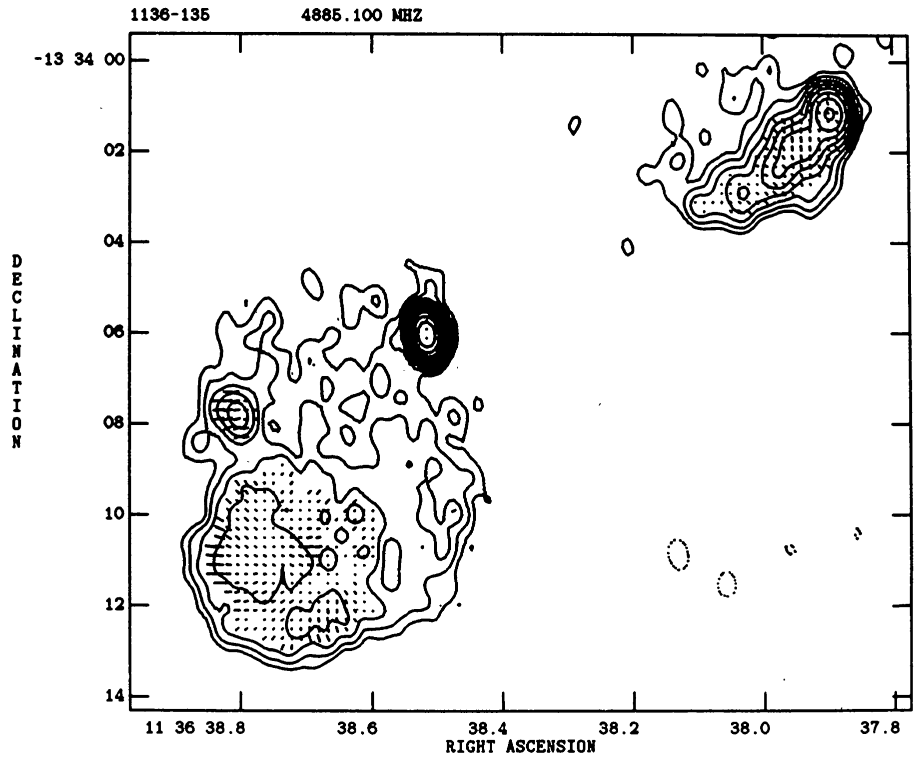

Figure 5. 1136 – 135 at λ6 cm. Peak brightness: 443.7 mJy/beam. Contours: 0.9 × (– 1, 1, 2, 4, 8, 16, 32, 64, 128, 256) mJy/beam. Polarization: 0.1 arcsec = 16.7 per cent.

respectively. The weaker northern component was not detected by Wills (1979) and hence the source was listed as possibly one-sided by K81. The integrated spectrum of the source is steep with $\alpha = 0.70 \pm 0.04$, while the spectral indices of the southern and northern components are about 0.8 and 0.7 respectively. The core spectrum appears to turn over around 4 GHz.

1637+574

Observations with the NRAO interferometer at λ11 cm suggested that the source consists of a core and a secondary component about 9 arcsec south-west of the core (Owen, Porcas & Neff 1978). We do not detect this secondary component but find evidence of weak extended emission towards the north and north-west (Fig. 8). The structure is consistent with the observations of Perley (1982), Rudnick & Jones (1983) and M88. The source has a complex spectrum. There is a large spread in the flux density values at frequencies where multiple measurements are available, indicating that the source is strongly variable. Seielstad, Pearson & Readhead (1983) have monitored the source at 10.8 GHz and found it to be variable. From the VLA observations at λ20, 18, 6 and 2 cm reported by Rudnick & Jones (1983), the RM of the compact component is about 13 ± 5 rad m^{-2}.

1741+279

This source appeared to be one-sided in the observations by Potash & Wardle (1979) who detected only the brighter northern component. The present observations (Fig. 9)

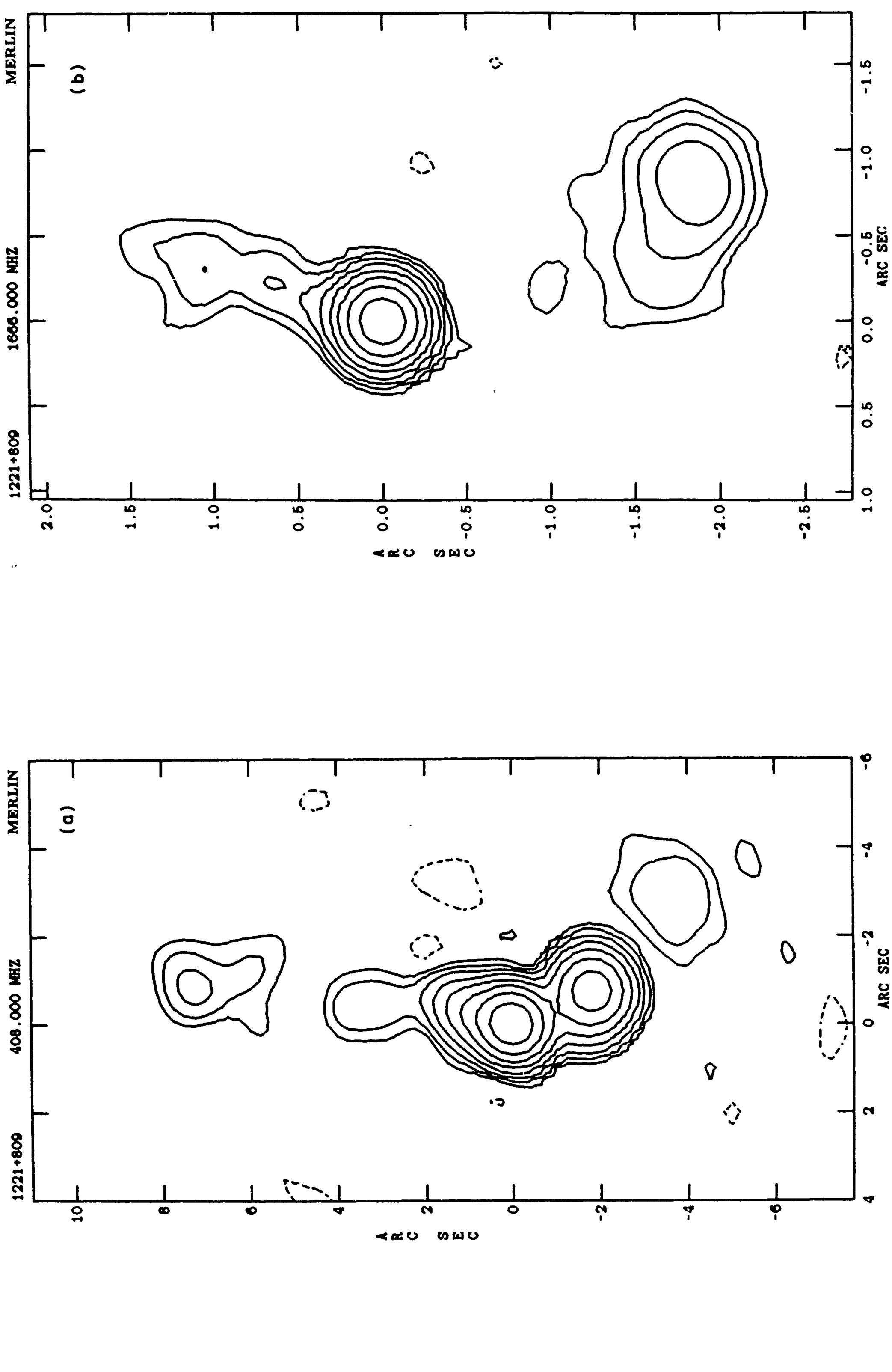

Figure 6. (a) 1221+809 at λ73 cm. Peak brightness: 468.5 mJy/beam. Contours: $2\times(-1, 1, 2, 8, 16, 32, 64, 128)$ mJy/beam. (b) 1221+809 at λ18 cm. Peak brightness: 456.2 mJy/beam. Contours: $2\times(-1, 1, 2, 4, 8, 16, 32, 64, 128)$ mJy/beam.

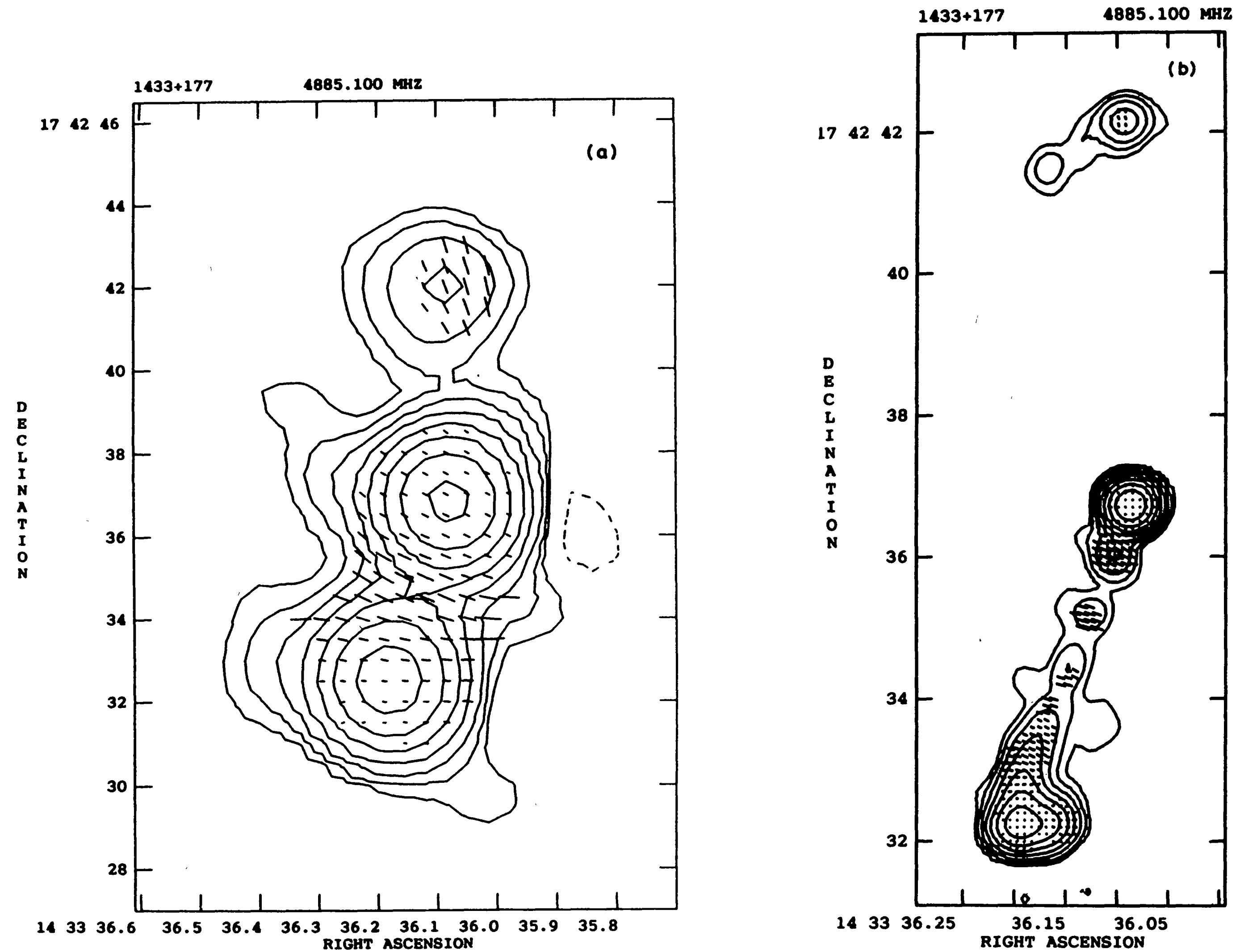

Figure 7. (a) 1433 + 177 at λ6 cm. Peak brightness: 301.9 mJy/beam. Contours: 2 × (−1, 1, 2, 4, 8, 16, 32, 64, 128) mJy/beam. Polarization: 1 arcsec = 28.6 per cent. (b) 1433 + 177 at λ6 cm. Peak brightness: 227.8 mJy/beam. Contours: 0.9 × (−1, 1, 2, 4, 8, 16, 32, 64, 128) mJy/beam. Polarization: 0.1 arcsec = 33.3 per cent.

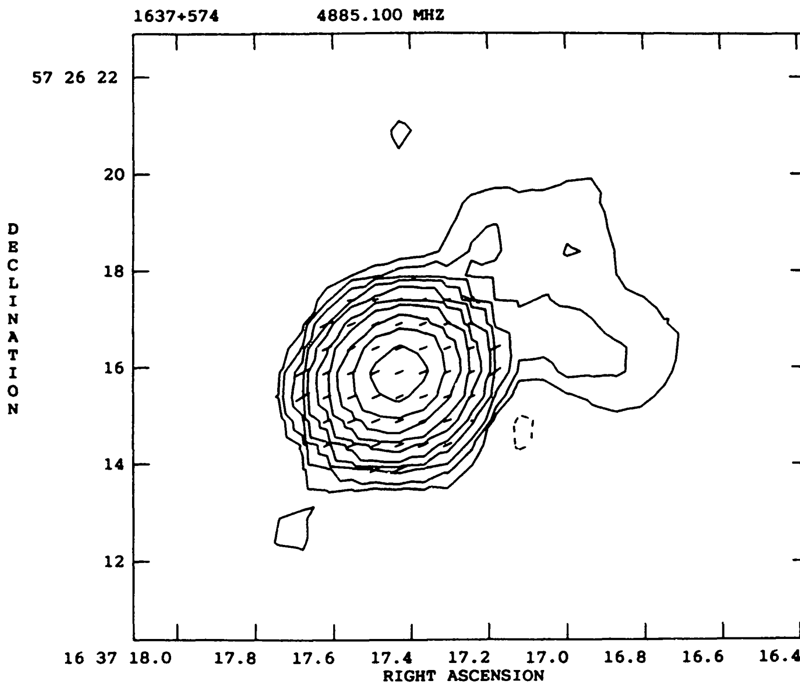

Figure 8. 1637+574 at λ6 cm. Peak brightness: 1605 mJy/beam. Contours: $2\times(-1, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512)$ mJy/beam. Polarization: 1 arcsec = 20.0 per cent.

show a weak southern component. The brightness ratio of the two components is about 5 while the separation ratio of the components from the nucleus is about 1.3. The integrated spectrum of the source is straight between 0.178 and 15 GHz with $\alpha = 0.67 \pm 0.02$. Using our measurements and those of HUO the spectral indices for the northern, core and southern components are $\sim$0.6, 0.7 and 0.8 respectively.

1842+681

This source was included in the K81 list on the basis of NRAO interferometer observations reported by Owen, Porcas & Neff (1978). Our VLA map at λ20 cm (Fig. 10) shows weak diffuse emission to the north and west of the prominent flat-spectrum nucleus. However, the limit on the brightness ratio on opposite sides of the nucleus is only about 4. The straight-line fit to the spectrum (Fig. 14) has a slope of -0.08 ± 0.01.

2041−149

Lunar occultation observations of this source showed it to consist of two components, one of which coincides with a 20.5 mag red object seen on the POSS prints (Singal, Gopal-Krishna & Venugopal 1979). Assuming this object to be the optical identification, the source was classified as being of the one-sided type. The present VLA maps (Figs 11a and b) confirm the radio structure reported earlier, but both the components appear to be morphologically similar to the outer components of a double-lobed

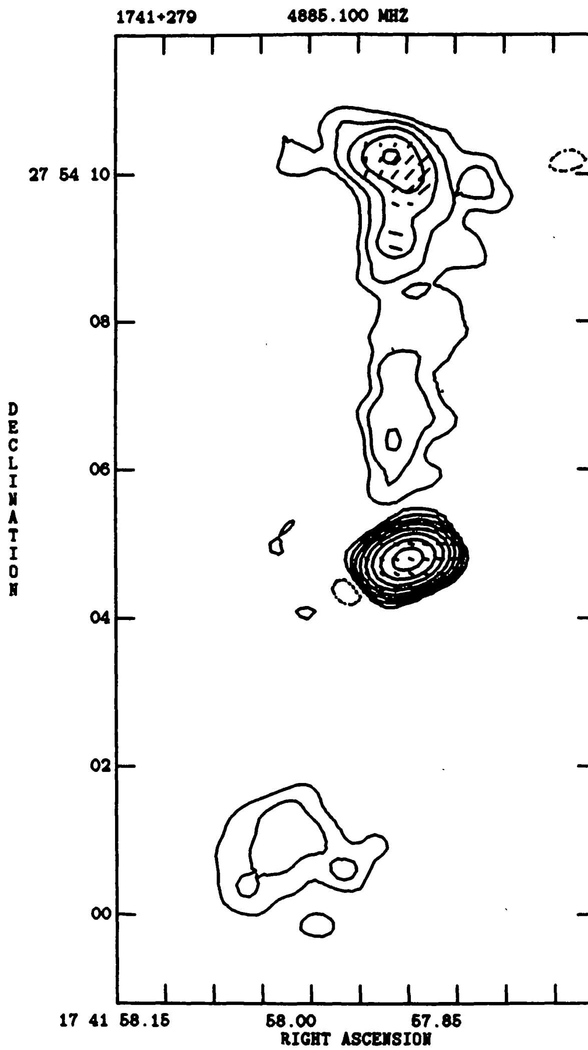

Figure 9. 1741+279 at $\lambda 6$ cm. Peak brightness: 178.0 mJy/beam. Contours: −1, 1, 2, 4, 8, 16, 32, 64, 128 mJy/beam. Polarization: 0.1 arcsec = 10.0 per cent.

source connected by a bridge of radio emission. Moreover, both components have steep spectra with spectral indices of 0.94 ± 0.10 and 0.98 ± 0.01 for the western and eastern components respectively. The integrated spectrum of the source is straight with $\alpha = 0.94 \pm 0.02$. It is possible that the positional agreement of the western component and the red object is a chance coincidence.

2251 + 134

This source was listed as a suspected one-sided source by K81 on the basis of NRAO interferometer observations reported by Wills (1979). It is a triple source with a prominent core and two outer components which are somewhat asymmetrically located with $R_\theta \sim 1.8$. In the VLA B-array map (Fig. 12a) there is a suggestion of a radio jet connecting the radio core to the south-western component. This jet can be

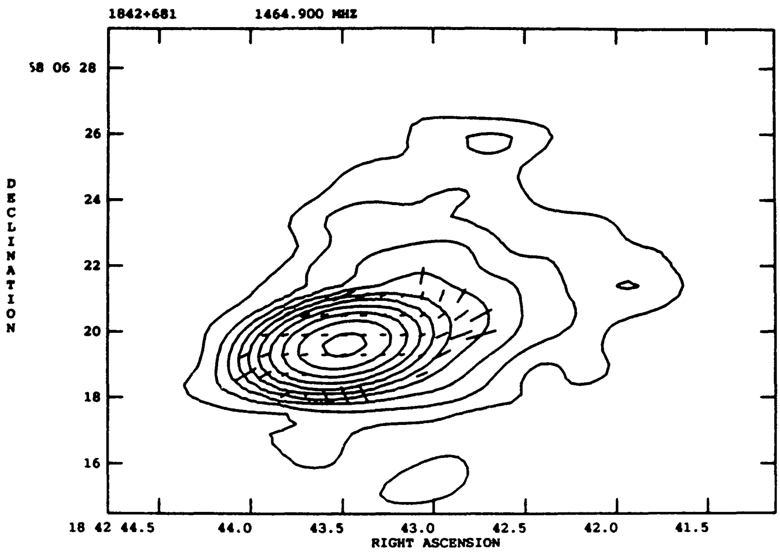

Figure 10. 1842+681 at λ20 cm. Peak brightness: 635.8 mJy/beam. Contours: −1, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512 mJy/beam. Polarization: 1 arcsec = 11.1 per cent.

seen clearly in the MERLIN map shown in Fig. 12b. The source has a steep spectrum below about 5 GHz ($\alpha = 0.61 \pm 0.03$) but tends to flatten towards higher frequencies. The radio core has a flat spectrum with $\alpha = 0.03 \pm 0.04$, while the spectral indices for both the south-western and the north-eastern components are about 0.7.

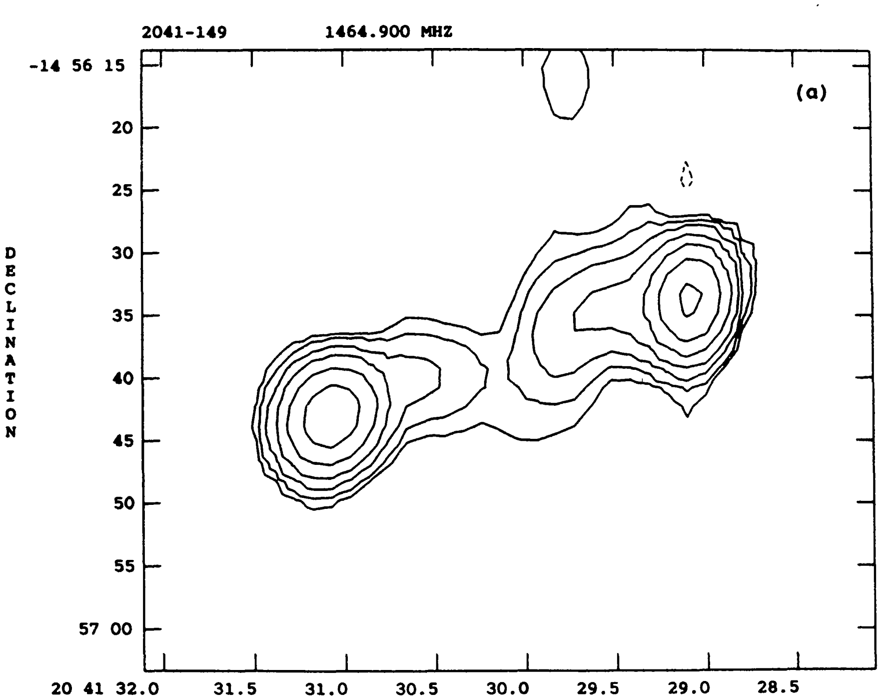

Figure 11. (a) 2041 − 149 at λ20 cm. Peak brightness: 185.8 mJy/beam. Contours: 2.5 × (−1, 1, 2, 4, 8, 16, 32, 64) mJy/beam. (b) 2041 − 149 at λ6 cm. Peak brightness: 46.8 mJy/beam. Contours: 0.6 × (−1, 1, 2, 4, 8, 16, 32, 64) mJy/beam. Polarization: 1 arcsec = 40.0 per cent.

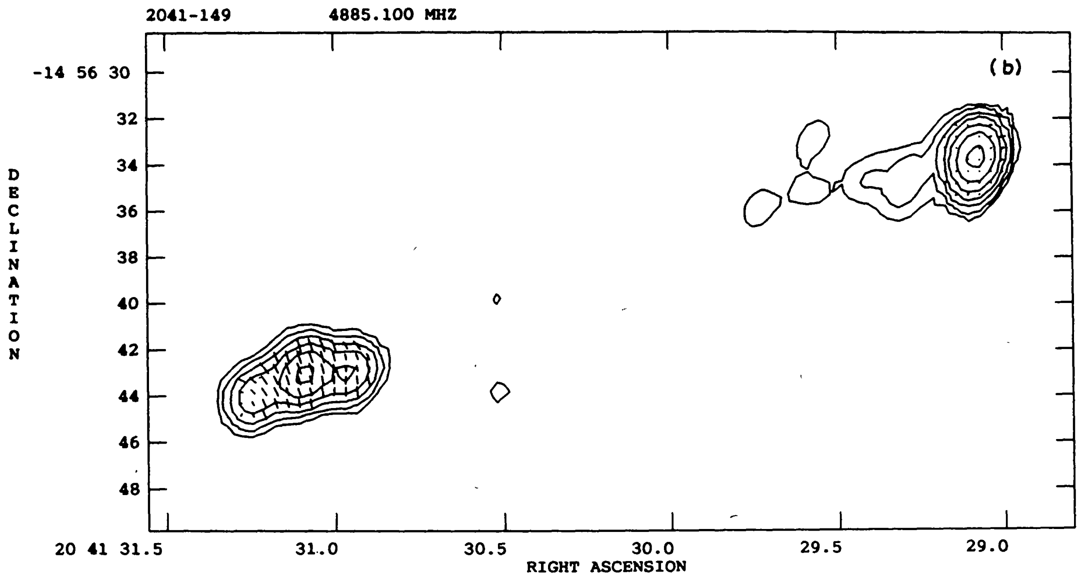

Figure 11. Continued

2325+269

This source appeared to be one-sided in the observations of MH78 but was found to be triple with a central component coincident with the optical quasar by Potash & Wardle (1979). The ratio of the peak surface brightness of the outer components in the

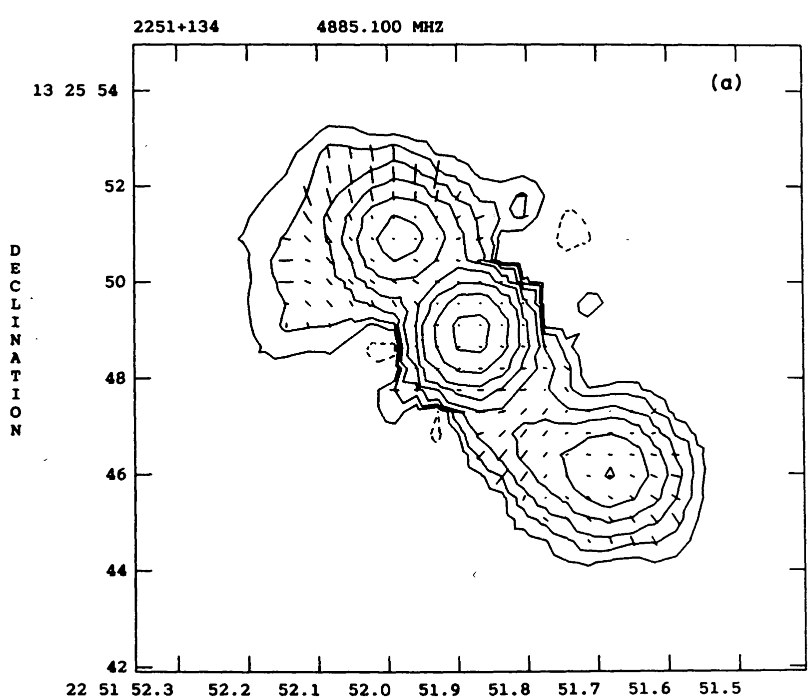

Figure 12. (a) 2251 + 134 at $\lambda 6$ cm. Peak brightness: 396.7 mJy/beam. Contours: $2.5 \times (-1, 1, 2, 4, 8, 16, 32, 64, 128)$ mJy/beam. Polarization: 1 arcsec = 44.4 per cent. (b) 2251 + 134 at $\lambda 18$ cm. Peak brightness: 550 mJy/beam. Contours: $1.83 \times (-1, 1, 2, 4, 8, 16, 32, 64, 128, 256)$ mJy/beam.

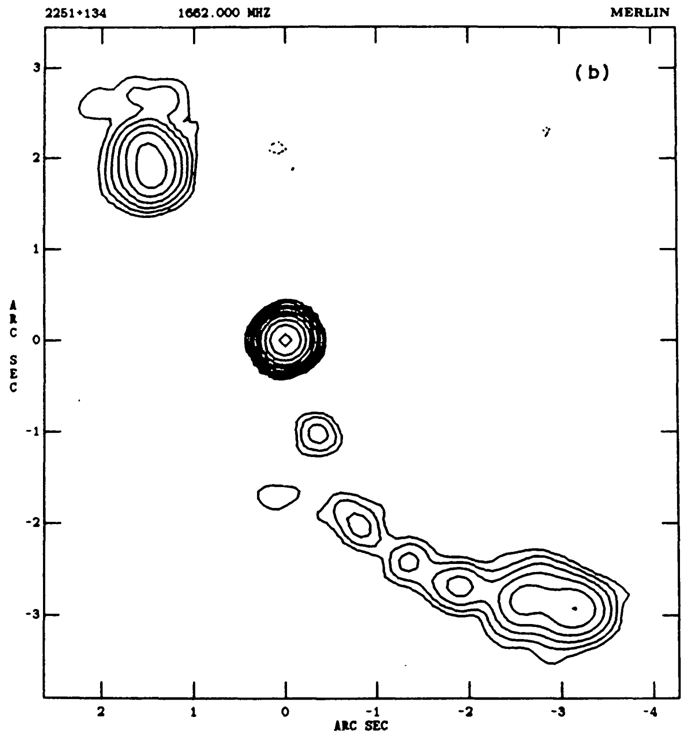

Figure 12. Continued

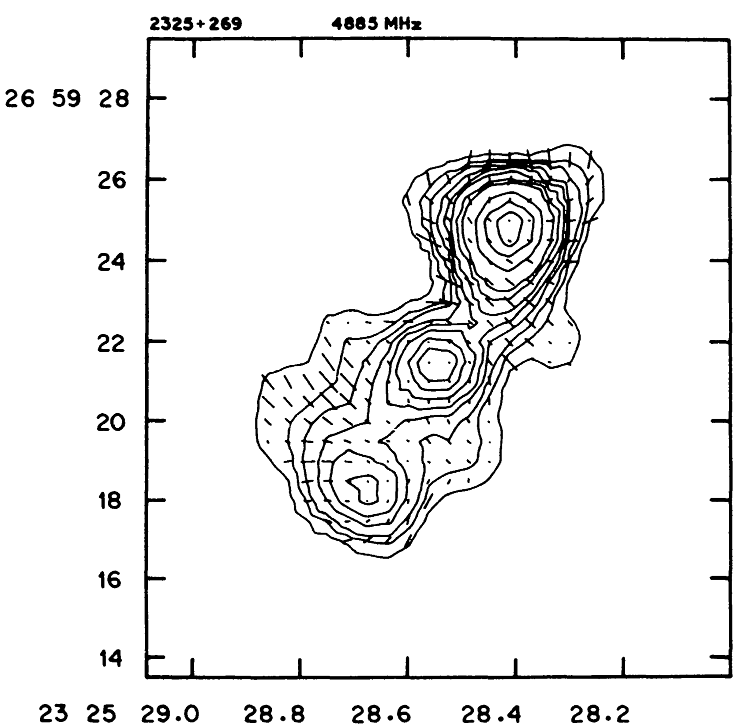

Figure 13. 2325+269 at $\lambda 6$ cm. Peak brightness: 198.0 mJy/beam. Contours: $1.98 \times (-1, 1, 2, 3, 5, 7, 10, 15, 20, 40, 60, 80)$ mJy/beam. Polarization: 1 arcsec = 51.5 per cent.

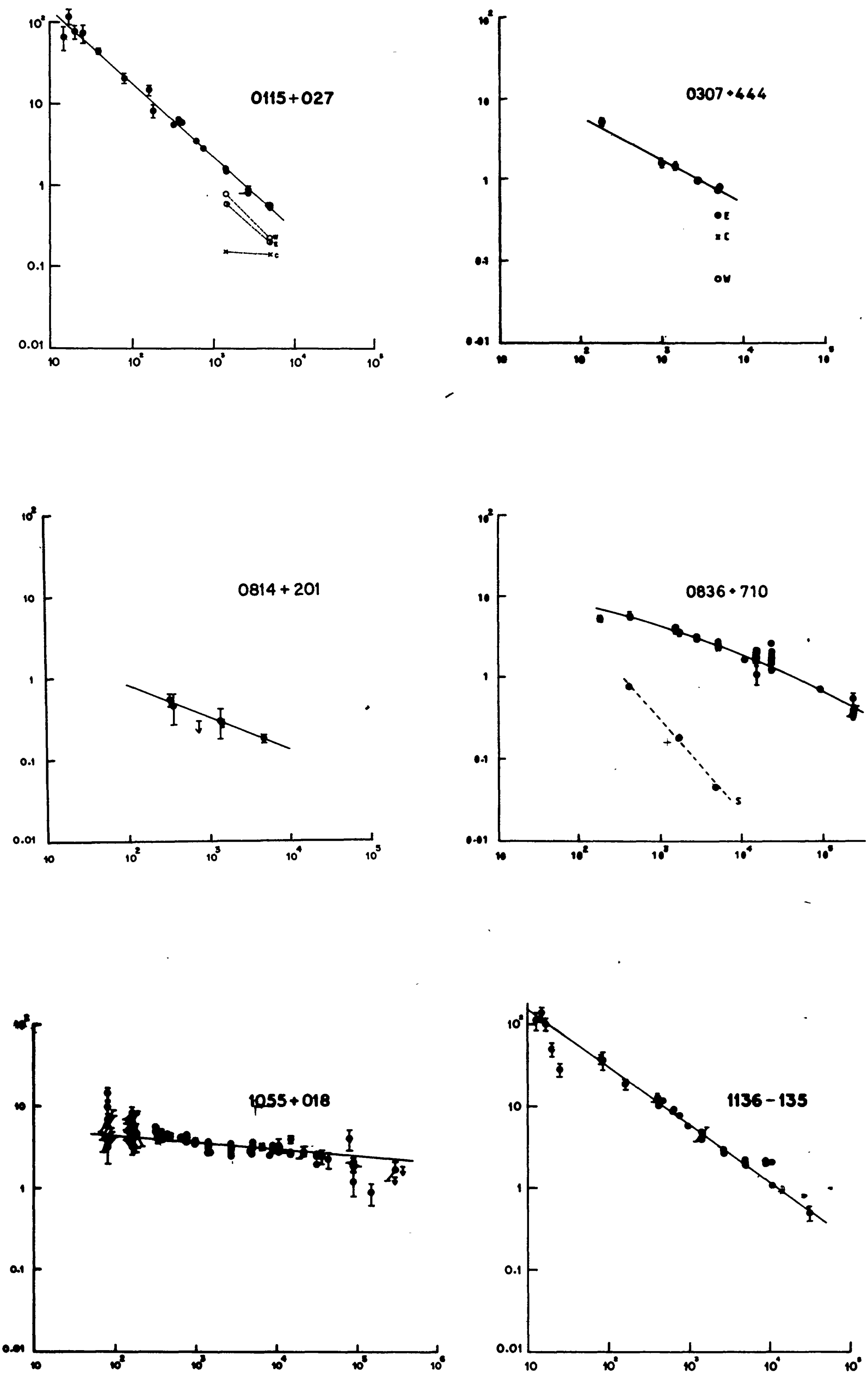

Figure 14. The spectra of the entire source and of the individual radio components. The frequency values are in MHz while the flux densities are in Jy. The filled circles represent the total flux density measurements, and the solid lines the best fit to these points. The spectra of the individual components are shown by broken lines.

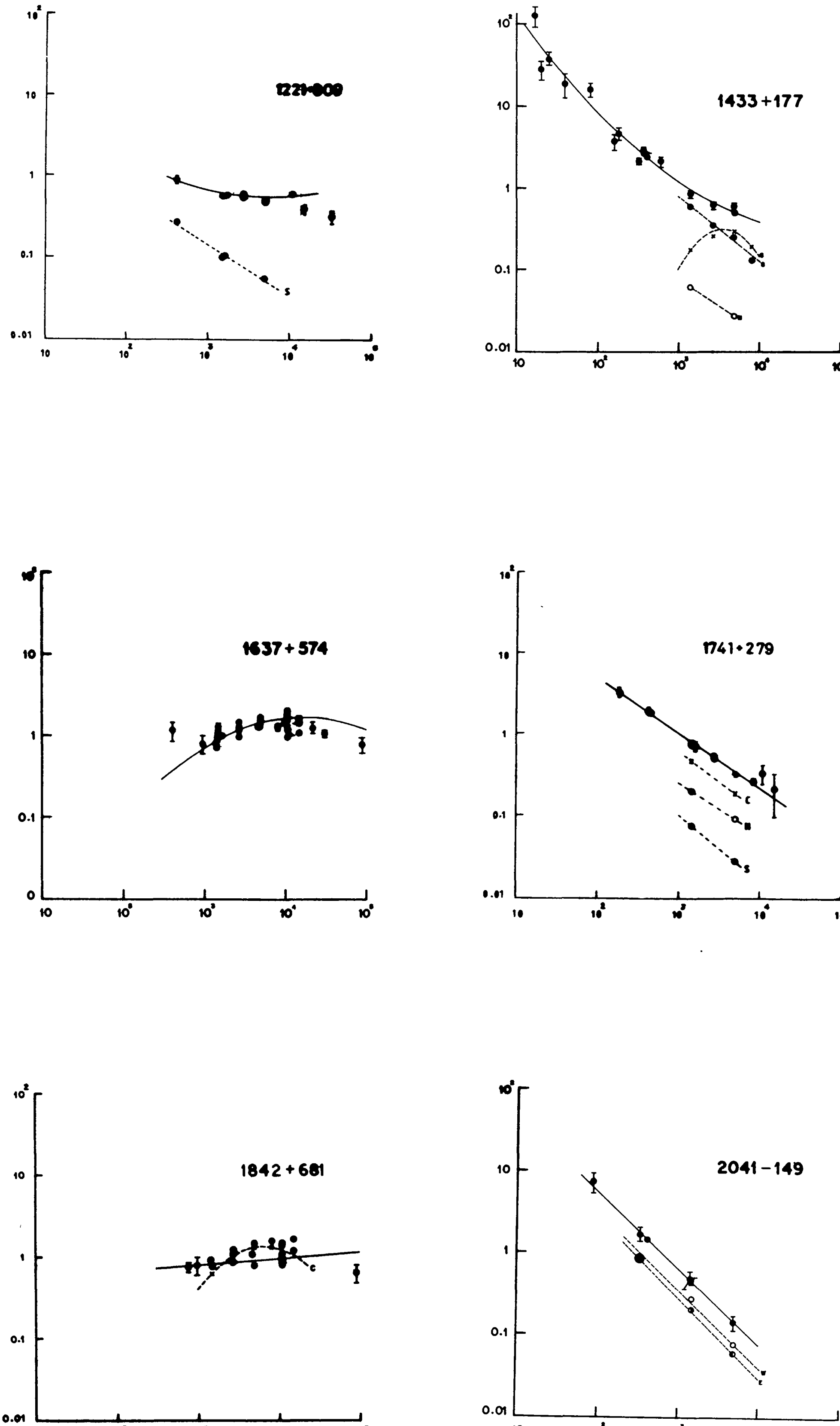

Figure 14. Continued.

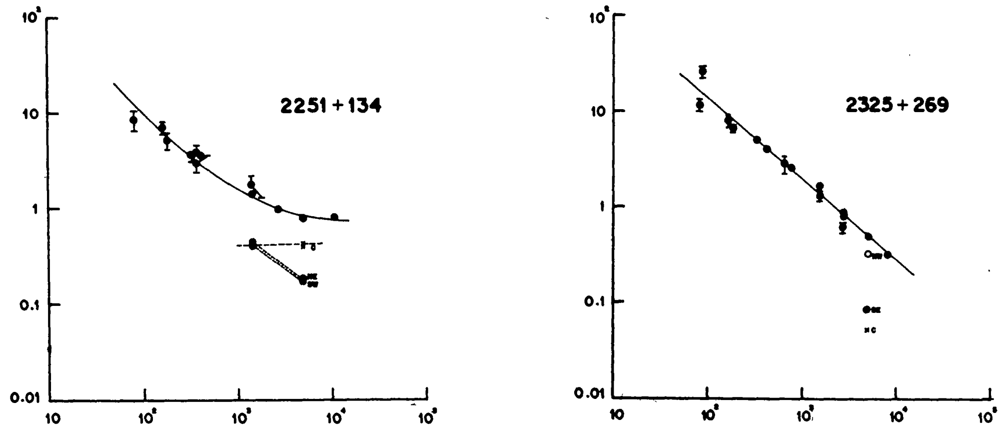

Figure 14. Continued

present VLA map (Fig. 13) is about 9, and the morphology is suggestive of an S-shaped structure. The source has a steep spectrum with $\alpha=0.84\pm0.02$.

6. Discussion and results

6.1 *Occurrence of One-Sided Sources*

The results of our observations, as well as those by other authors, show that the vast majority of sources which were suspected of being one-sided have radio emission on both sides of the nucleus. In many of these sources, one of the components was not detected earlier due to either its low surface brightness or its relatively small separation from the radio core, or a combination of both these effects.

From a search of the literature, K81 compiled a list of 49 suspected one-sided radio sources to make a statistical study of their properties. Since very few of the core-dominated radio sources had been mapped with high angular resolution and sensitivity at that time, the bulk of the sources in his list were selected from low-frequency surveys. Of the initial 49 only 15 still appear one-sided. These sources are listed in Table 3, which is arranged as follows: Columns 1, 2 and 3 are self-explanatory. Column 4: The ratio of the peak brightness of the lobe to three times the rms noise on the opposite side. This parameter gives a quantitative estimate of the lower limit on the degree of asymmetry in the source. Column 5: The fraction of radio emission from the core at an emitted frequency of 8 GHz. For the two sources without a measured redshift a value of 1 was assumed. Column 6: References for the radio structures. Excluding 3C273 and 1729+501, which we discuss in Sections 6.3 and 6.4, the limits on the lobe to counter-lobe brightness ratio for these sources range from about 4 for 1842+681 to about 180 for 0836+710, the median value of the distribution being about 35.

More recent lists of suspected one-sided sources selected from low-frequency surveys have been compiled by HUO and Barthel *et al.* (1988). HUO have listed the radio structures of quasars selected from the Hewitt & Burbidge (1980) catalogue. They include all quasars selected from the 3C, 3CR, 4C and the two Molonglo surveys MC2 and MC3, plus a few with known extended emission selected from the Ohio,

Table 3. One-sided sources from the K81 list.

Source	Alt. name	Redshift	$S_{peak}/3\sigma$	f_c	Ref.
0051+291	4C29.01	1.828	19	0.42	2; 3
0241+622	4U	0.044	47	0.96	6; 7
0742+376	4C37.19		33	0.28	10
0836+710	4C71.07	2.170	183	0.96	8; 9; 15
0945+408	4C40.24	1.252	6	0.95	12; 13; 15
1226+023	3C273	0.158	3800	0.89	1; 15; 16
1320+299	B2		15	0.95	17
1347+539	4C53.28	0.976	7	0.80	5
1415+463	4C46.29	1.552	40	0.79	5; 7; 12; 13
1636+473	4C47.44	0.740	80	0.75	10; 18
1637+574	OS562	0.745	15	0.95	8; 20
1729+501	4C50.43	1.107	485	0.07	5; 10; 12; 13
1842+681	GC	0.475	4	0.90	8
2037+511	3C418	1.686	46	0.82	21; 22
2251+158	3C454.3	0.859	100	0.96	16; 18; 19; 20

References
1. Davis, Muxlow & Conway (1985)
2. Swarup *et al.* (1986)
3. Barthel *et al.* (1988)
5. Owen & Puschell (1984)
6. Hutchings *et al.* (1982)
7. Saikia *et al.* (1989, in preparation)
8. Present paper
9. MERLIN 408 MHz map made by Muxlow
10. Saikia *et al.* (1984)
12. Reid (1987)
13. Shone (1985)
15. Perley, Fomalont & Johnston (1980)
16. Perley, Fomalont & Johnston (1982)
17. Cornwell *et al.* (1986)
18. Browne *et al.* (1982)
19. de Bruyn & Schilizzi (1986)
20. Murphy (1988)
21. Muxlow *et al.* (1989, in preparation)
22. O'Dea, Barvainis & Challis (1988)

Parkes or Bologna surveys. Many of the sources in the HUO lists have since been observed with better resolution and sensitivity either by us or other authors. In Table 4 we summarize more recent structural information on all sources which were classified as being either one-sided (OS) or possibly one-sided (OS?) by HUO. Columns 1 to 6 in the Table are self-explanatory. In column 7, TS implies that the source has been found to be two-sided, while a number denotes a limit on the lobe to counter-lobe brightness ratio for sources still found to be one-sided. A blank in this column denotes that the source has not been re-observed. We are presently mapping most of these sources using MERLIN. It is striking that from about 220 almost entirely low-frequency selected quasars which were classified to have extended lobe emission by HUO, only 6 still appear to be one-sided from better quality data (see Table 4). These 6 were also included in the K81 list and hence also appear in Table 3.

Only about 3 per cent of the low-frequency selected quasars with extended lobe emission, as listed by HUO, appear to be one-sided. This number could be somewhat higher if either many of the suspected one-sided sources which have not been reobserved recently (Table 4, column 7) are found to be one-sided, or there is a higher fraction of one-sided sources among those listed as "single" by HUO. We also note that the one-sided sources may occur more frequently at higher redshifts. The ratios are 2/26 (about 8 per cent) for the high-redshift ($z \geqslant 1.5$) group compared to 4/193 (about 2 per cent) for the lower-redshift group. Although these numbers are based on small sample statistics, coupled with incomplete structural information for the entire

Table 4. Updated classification of the possible one-sided sources from HUO.

Source	Alt. name	Redshift	HUO Class.	Ref.	New Class.	Ref.
0051+291	4C29.01	1.828	OS	1	~20	2; 3
0300−004	4C−00.14	0.693	OS?	4		
0307+444	4C44.07	1.165	OS	5	TS	7
0405−123	PKS	0.574	OS?	6		
0736−019	3C185	1.033	OS	5		
0808+289	B2	1.910	OS	8	TS	9
0812+020	4C02.23	0.402	OS	5	TS	10
0836+195	4C19.31	1.691	OS	11	TS	12
1012+232	4C23.24	0.565	OS	5	TS	13
1055+201	4C20.24	1.110	OS	5	TS	15; 16
1132+303	3C261	0.614	OS	1	TS	13
1136−135	PKS	0.554	OS	6	TS	7
1226+023	3C273	0.158	OS	6	~4000	14; 17; 18
1351+267	B2	0.310	OS	8	TS	9
1354+195	4C19.44	0.720	OS	6	TS	12; 15
1415+463	4C46.29	1.552	OS	20	~40	13; 21; 22; 24
1602−001	4C−00.63	1.625	OS	4	TS	23
1634+589	4C58.32	0.985	OS	5		
1637+574	OS562	0.745	OS	20	~15	7; 15
1641+399	3C345	0.595	OS	25	TS	15; 19; 27
1658+575	4C57.29	2.173	OS	20	TS	21; 22
1725+107	MC2	0.833	OS?	5		
1729+501	4C50.43	1.107	OS	5	~485	12; 21; 22; 24
1800+440	OU401	0.660	OS?	20	TS	21; 28
2248+192	4C19.74	1.806	OS	4		
2251+158	3C454.3	0.859	OS	25	~100	15; 26; 28

References
1. Potash & Wardle (1979)
2. Swarup *et al.* (1986)
3. Barthel *et al.* (1988)
4. Wills (1979)
5. Hintzen, Ulvestad & Owen (1983)
6. Miley & Hartsuijker (1978)
7. Present paper
8. Fanti *et al.* (1977)
9. Rogora, Padrielli & de Ruiter (1986)
10. Wyckoff *et al.* (1983)
11. Jenkins, Pooley & Riley (1977)
12. Saikia *et al.* (1984)
13. Saikia *et al.* (1989, in preparation)
14. Perley, Fomalont & Johnston (1980)
15. Murphy (1988)
16. Hintzen (private communication)
17. Davis, Muxlow & Conway (1985)
18. Perley (1986)
19. Schilizzi & de Bruyn (1983)
20. Owen, Porcas & Neff (1978)
21. Reid (1987)
22. Shone (1985)
23. Swarup, Sinha & Hilldrup (1984)
24. Owen & Puschell (1984)
25. Davis, Stannard & Conway (1978)
26. de Bruyn & Schilizzi (1986)
27. Lythgoe (private communication)
28. Browne *et al.* (1982)

sample, a similar result was reported by Barthel & Miley (1988). Of the 54 quasars in their low-redshift sample ($z \leqslant 1.5$), only one, namely 1132+303, which we have recently found to be two-sided, has been classified to be one-sided. On the other hand, in the high-redshift group, 11 of the 80 quasars have been classified to be one-sided. It should however be noted that for a number of these it is important to check from multi-frequency observations that the component close to the optical quasar is indeed the radio core rather than being the other component of a small double-lobed radio source.

We have concentrated so far on samples of sources selected at a low frequency. In high-frequency selected samples most sources are dominated by compact cores and hence very high dynamic range maps are required to achieve high limits on the lobe to counter-lobe brightness ratio. Several authors have mapped samples of core-dominated objects with both the VLA (*e.g.* Perley, Fomalont & Johnston 1982; Perley 1982; Browne & Perley 1986; OBC; M88) and MERLIN (*e.g.* Browne *et al.* 1982). The median values of the lobe to counter-lobe brightness ratio or their limits for core-dominated sources which were known previously to have some extended structure is about 10 (*cf.* OBC; Perley, Fomalont & Johnston 1982), but could be significantly higher for an unbiased sample of flat-spectrum objects (M88).

6.2 *Possible Explanations*

With the bulk of the previously suspected one-sided sources exhibiting radio emission on both sides of the nucleus, it is perhaps important to enquire whether there are any genuine one-sided radio sources at all. Obviously this question is related intimately to an understanding of the brightness asymmetry in these sources. The suggested explanations include an intrinsic source asymmetry, either in the central engine, in the external environment or in the degree of collimation of the oppositely directed jets, or that the sources are intrinsically symmetric but appear asymmetric because of relativistic motion (*cf.* Blandford & Königl 1979; Scheuer & Readhead 1979). In the latter scenario the flux density of the approaching component is significantly Doppler boosted while that of the receding component is diminished. For an intrinsically symmetric source, the brightness ratio of the hot-spots R_s is given by

$$R_s = \{(1+\beta\cos\phi)/(1-\beta\cos\phi)\}^{2+\alpha}$$

where $v=\beta c$ is the velocity of advance of the hot-spots, ϕ is the angle of inclination to the line of sight and α is the spectral index of the extended emission, which is often close to about 1 for these high-luminosity sources. A third possible explanation for the one-sided sources is provided by the "flip-flop" model (Rudnick & Edgar 1984). In this, energy is supplied alternately on opposite sides of the nucleus, but averaged over its lifetime, the source appears reasonably symmetric. In this situation, a source may appear one-sided if we are witnessing only the first "flip" before the "flop".

We initially concentrate on the relativistic beaming scenario and examine the evidence in favour of this possibility. The occurrence of one-sided or very asymmetric radio structure, coupled with large misalignments between the VLBI and large-scale structure in a number of classic flat-spectrum superluminal sources was noticed more than a decade ago (Davis, Stannard & Conway 1978; Readhead *et al.* 1978). This was in striking contrast to the VLBI observations of cores in reasonably symmetric lobe-dominated sources (*e.g.* Readhead *et al.* 1978). These results raised the interesting possibility that the observed asymmetry of the large-scale structure in the flat-spectrum sources may also be due to relativistic motion of hot-spots in sources inclined at small angles to the line of sight. Subsequently, both VLA and MERLIN observations of flat-spectrum, core-dominated objects (*e.g.* Perley & Johnston 1979; Perley, Fomalont & Johnston 1980; Moore *et al.* 1981) showed that many of them had one-sided extended radio emission, providing additional support to the relativistic beaming scenario. Kapahi (1981) compiled a sample of one-sided sources, largely from low-frequency surveys, and attempted to investigate whether the one-sided sources are the relativistically beamed counterparts of the more symmetric double-lobed ones. He compared among other parameters, the degree of core prominence, f_c, used as a statistical measure of orientation, and the projected linear sizes, l, with those for a sample of two-sided quasars, which was being compiled to study whether the core-dominated quasars are the beamed counterparts of the lobe-dominated ones (Kapahi & Saikia 1981, 1982), a scheme similar to that suggested by Orr & Browne (1982). The one-sided sources were found to have small projected sizes and prominent cores, consistent with an f_c–l anticorrelation expected in the beaming models (Kapahi 1981; Kapahi & Saikia 1982; Hough & Readhead 1988).

Since most sources appear to be two-sided when observed with adequate resolution and sensitivity, we shall address ourselves to the broader question of the importance of relativistic motion in understanding the asymmetry of the oppositely-directed radio lobes. Also, since the brightness or flux ratio, R_s, of the components moving outwards depends more strongly on orientation than does the ratio of the separations of the two lobes from the nucleus, R_θ, ($R_s = R_\theta^{2+\alpha}$), we concentrate on R_s in this paper. If relativistic beaming is really responsible for the observed asymmetry, then one might expect a correlation between the flux density ratio R_s of the hot-spots which are traversing outwards and the fraction of radio emission from the core, f_c. Since hot-spot flux densities are often either unavailable or unreliable, Kapahi & Saikia (1982) looked for a correlation of the lobe flux density ratio with f_c for their sample of quasars but found no evidence for it. We have repeated the exercise using all the 3CR and HUO quasars which are both bigger than 3 arcsec and have been observed with at least 3 resolution elements along their main axes (Fig. 15). Again we do not find evidence of a significant correlation. This may be due to a number of reasons. Possibly, the most important of these is the errors in estimating the hot-spot flux densities. It is important to separate the hot-spot radio emission, since only the hot-spot is advancing outwards while the rest of the lobe emission is largely backflow from the hot-spots. Other reasons which could decrease the significance of any possible correlation are the evolution of the individual components with age, as well as interaction of the outer components with an asymmetric external environment.

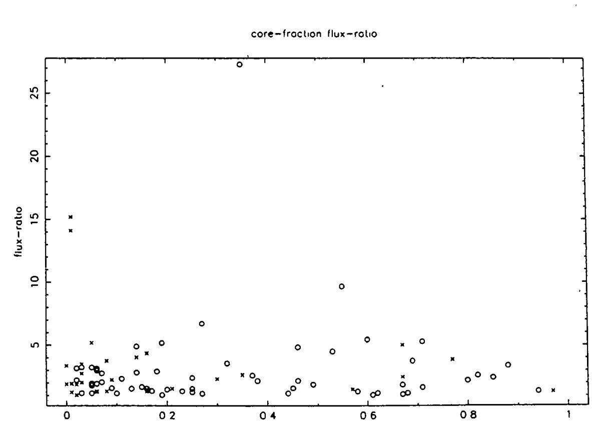

Figure 15. The flux density ratio of the lobes plotted against f_c, the fraction of emission from the core, for the 3CR (×) and HUO (o) quasars.

In order to make a more thorough investigation of whether the flux ratio of the hot-spots correlates with core prominence, one needs a homogeneous set of observations of high angular resolution for a large sample of sources covering a wide range of core prominence. Preferably, the luminosity of the extended emission should be similar. In the absence of such observations we attempt to compare the ratio of the peak flux densities of the outer components for four samples which have all been observed with the VLA A-array at $\lambda 6$ cm and have statistically different degrees of core prominence. These are the observations of the large angular-sized, weak-cored 3CR and 4C quasars by Swarup, Sinha & Hilldrup (1984), our observations during 1983 November of suspected one-sided sources which yield a sample of moderately core-dominated and smaller-sized sources, and the samples of core-dominated objects observed by Perley, Fomalont & Johnston (1982) and OBC. Unlike the other samples, the sources from our observations have not been selected independently of their large-scale asymmetry but have, nevertheless, been included here to show how they compare with the other three samples. For the four samples, the median values of the distributions of the ratio of the peak flux densities on opposite sides of the nucleus, including the limits for one-sided sources, are ~ 2.3, 8.5, 10 and 10 respectively. The corresponding values of f_c are 0.08, 0.5, 0.9 and 0.95 respectively. This trend suggests that relativistic beaming does play a significant role in understanding source asymmetry, but it would be naïve to assume that this is the entire story. For example, one of the most asymmetric quasars in the 3CR sample, 3C68.1, has a very weak radio core and lies on the upper envelope of the angular size-redshift diagram (*e.g.* Hooley, Longair & Riley 1978), suggesting that it is indeed inclined at a large angle to the line of sight.

In order to appreciate the importance of using peak flux density, expected to be a closer approximation to the hot-spot flux density, rather than the total lobe flux density, we show in Fig. 16 the distributions of both the ratios for the sources we have observed in 1983 November with the VLA A-array at $\lambda 6$ cm. The values for the different sources are listed in Table 5. It is clear that the two distributions are very different with the distribution of the lobe flux density ratio having a significantly lower median value than the peak flux density ratio.

Having suggested that orientation-dependent effects play an important role in understanding source asymmetry, we comment on the range of hot-spot speeds required to explain the observed asymmetry in the one-sided sources. Later, we focus on the archetypal one-sided source 3C273 (1226+023), and also identify a possible class of weak-cored one-sided sources. The distribution of the limit on the lobe to counter-lobe brightness ratio for all the sources which still appear to be one-sided from the K81, HUO and Barthel *et al.* (1988) lists requires speeds of about 0.2 to 0.8 c for an inclination angle of 20 degrees. This range is similar to that suggested by OBC for a small sample of core-dominated objects. Although speeds as high as $\sim 0.8\,c$ for the hot-spots are not quite consistent with the prevailing folklore, there are no strong reasons to rule them out for these luminous sources. It is important to realise that the velocity estimates of the hot-spots which are often quoted in the literature (*e.g.* Longair & Riley 1979; Banhatti 1980; Swarup & Banhatti 1981; Katgert-Merkelijn, Lari & Padrielli 1980) have been made using the distributions of symmetry parameters of well-resolved sources in low-frequency selected samples, mapped with relatively coarse resolutions. By the very selection process, the small angular-sized core-dominated sources which are likely to be more asymmetric have been excluded. Also, the coarser resolutions tend to yield more symmetric values of the separation and brightness ratios.

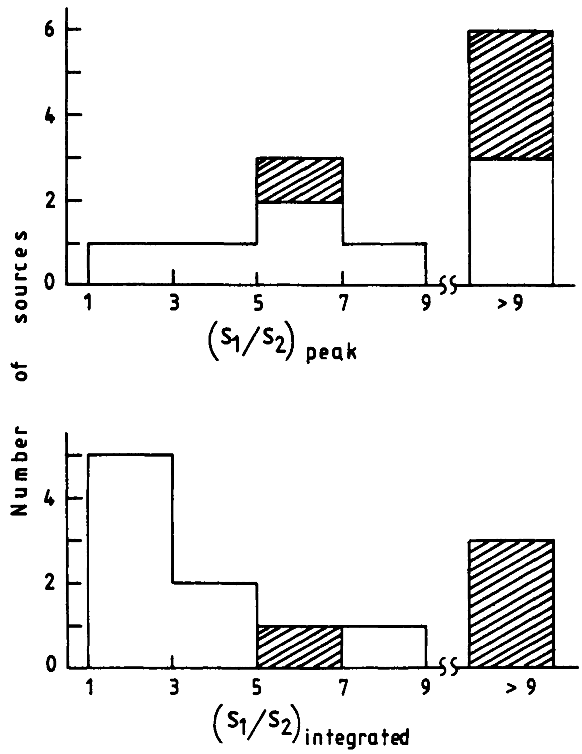

Figure 16. The distributions of the peak and total flux density ratios of the lobes for the sources we have observed with the VLA A-array at λ6 cm during 1983 November. The shaded areas denote limits for the one-sided sources.

Table 5. Flux density ratios of lobes at λ6 cm.

Source	Alt. name	Redshift	S_{peak} ratio	S_{int} ratio	f_c
0241+622	4U	0.044	⩾12.1	⩾12.1	0.96
0919+218	4C21.25	1.421	26.8	3.2	0.08
1012+232	4C23.24	0.565	⩾6.2	⩾6.2	0.83
1040+123	3C245	1.029	18.1	2.5	0.67
1132+303	3C261	0.614	3.4	2.2	0.22
1136−135	PKS	0.557	5.8	1.2	0.30
1203+109	4C10.34	1.088	2.9	2.4	0.30
1222+216	4C21.35	0.435	⩾9.8	⩾9.8	0.72
1415+463	4C46.29	1.552	⩾40.4	⩾40.4	0.79
1433+177	4C17.59	1.203	8.5	7.4	0.35
1509+158	4C15.45	0.828	12.2	2.0	0.18
1741+279	4C27.38	0.372	5.2	3.3	0.58

6.3 *3C273 (1226+023)*

One of the best observed one-sided sources is the well-known quasar 3C273, which has been mapped with very high dynamic range using both the VLA and MERLIN. Davis, Muxlow & Conway (1985) have presented MERLIN 151 and 408 MHz maps of this source with dynamic ranges of $4 \times 10^3:1$ and $10^4:1$ respectively and found no emission on the counter-jet side but discovered an extended region or lobe to the south of the main jet. They have argued that their estimates of the Doppler beaming factors are too small to hide the lobe or the head of a counter-component and have suggested that the jet is intrinsically one-sided. Here, we consider the possibility that the source is two-sided with the lobe south of the main jet being the counter-lobe which appears on the same side as the jet due to projection effects. That such a situation is statistically possible for a small number of sources inclined close to the line of sight has been shown by a number of authors (*cf.* Readhead, Napier & Bignell 1980; Readhead *et al.* 1983; Moore *et al.* 1981). If the lobe south of the main jet is indeed the counter-lobe, then the ratio of peak brightnesses decreases to about 200, implying that the hot-spot speed should be $\sim 0.8\,c$ for a source inclined at about 10 degrees (see Pearson *et al.* 1981; Cohen *et al.* 1987) to the line of sight. The non-detection of a clear hot-spot in this lobe could be due partially to it being beamed away from us. For the above parameters, its brightness would decrease by a factor of 5.

From the present data we find no strong reason to discount this possibility. Higher resolution observations may help clarify whether this feature is related to the jet or is a counter-lobe seen in projection. In the latter case, one might hope to find the lobe appearing as a distinct feature separated from the main body of the jet. Such observations are, however, difficult because of the low surface brightness of this lobe. A possible way of distinguishing between the two alternatives is from depolarization observations. Laing (1988) and Garrington *et al.* (1988) have shown for samples of mostly quasars that the lobe on the counter-jet side is strongly depolarized compared to the one on the jet side. The jet in 3C273 is known to exhibit very little depolarization even at wavelengths as long as $\lambda 73$ cm (Conway 1987). It would be extremely interesting to examine the polarization characteristics of the lobe on the southern side of the jet. If this feature exhibits significant depolarization it would suggest strongly that it is the counter-lobe seen in projection.

6.4 *A New Class of One-Sided Radio Sources?*

In this section we briefly draw attention to a class of one-sided radio sources, which unlike the vast majority of them have very weak cores. From the sources we have observed, examples of sources belonging to this class are 0404+177 and 1629+120 (Barthel *et al.* 1988; Saikia *et al.* in preparation), 1559+173 (Swarup *et al.* 1986; Barthel *et al.* 1988; Saikia *et al.* in preparation) and 1729+501 (Saikia *et al.* 1984; Owen & Puschell 1984; Reid 1987). Unlike the core-dominated sources where most of the dynamic range is "used up" in just detecting the extended emission, high dynamic range observations of these sources can be used to set very high limits on the lobe to counter-lobe brightness ratio. From MERLIN and VLA snap-shot observations the present limits are greater than about 400 for all the four sources. If they are intrinsically symmetric, a hot-spot speed of more than $0.8\,c$ would be required to explain the observed asymmetry. In such a scenario, one of the most intriguing aspects of these sources is their relatively weak cores: the fraction of emission from the radio core, f_c, is less than about 0.15 for each of the four sources. VLBI observations aimed at detecting superluminal motion and studying misalignments between the small- and large-scale structure may help clarify whether they are indeed inclined at small angles to the line of sight. It is also possible that these are perhaps either intrinsically asymmetric one-sided sources or that we are witnessing the first "flip" in a "flip-flop" scenario. In the latter case, the timescale for the energy supply to change direction is at least about 10^5 years.

7. Conclusions

In this paper we have presented VLA and MERLIN observations of 15 sources, selected largely from earlier lists of suspected one-sided radio sources. Our observations, which are of higher resolution and sensitivity than those on which their original classification was based, show most of them to be two-sided. Only a few per cent of low-frequency selected sources appear to be one-sided with a brightness limit of greater than about 20.

We have investigated whether the observed difference in the brightnesses of the two lobes in a radio source could be at least partly due to relativistic beaming. Since only the hot-spots are expected to be moving outwards, we have compared the peak brightness ratios of the hot-spots for samples of quasars observed with similar resolution and spanning a large range in the degree of core prominence, f_c. Here f_c, the ratio of core to total flux density, is being used as a statistical measure of source orientation. We find that the median of the peak brightness ratio increases for the samples with higher values of f_c, suggesting that relativistic beaming plays a significant role in the observed asymmetry of the outer lobes. In order to explain the limits on the lobe to counter-lobe brightness ratio for the one-sided sources, the advance speeds of the hot-spots should be in the range of about 0.2 to 0.8c for a source inclined at about 20 degrees to the line of sight. Although some of the speeds do appear to be quite high there are no strong reasons to rule them out.

We also discuss the possibility that the lobe to the southern side of the jet in the well-known quasar 3C273 is the counter-lobe seen in projection rather than being associated with the jet, and suggest a possible way of distinguishing between the two alternatives. We also draw attention to a possible class of one-sided radio sources which have very weak cores but have limits on lobe to counter-lobe brightness ratio of over several hundred. It is possible that the observed asymmetry in these sources is largely intrinsic rather than being due to relativistic beaming effects.

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