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The centi-arcsecond structure of 16 low-frequency variable sources at 92 cm

D.R. Altschuler[1], L.I. Gurvits[1–4], W. Alef[5], B. Dennison[6], D. Graham[5], A.S. Trotter[7] and J.E. Carson[8]

[1] National Astronomy and Ionosphere Center, Arecibo Observatory, P.O. Box 995, Arecibo, Puerto Rico, 00613
[2] Joint Institute for *VLBI* in Europe, P.O. Box 2, 7990 AA, Dwingeloo, The Netherlands
[3] Netherlands Foundation for Research in Astronomy P.O. Box 2, 7990 AA, Dwingeloo, The Netherlands
[4] Astro Space Center of P.N. Lebedev Physics Institute, Leninsky pr. 53, Moscow 117924, Russia
[5] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121, Bonn, Germany
[6] Department of Physics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061–0435, U.S.A.
[7] Department of Astronomy, Harvard University, 60 Garden St., Cambridge MA 02138, U.S.A.
[8] Physics Department, Massachusetts Institute of Technology, Cambridge, MA 02139, U.S.A.

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Abstract. — We present results of global Mark 2 *VLBI* snapshot observations at 92 cm of 16 low frequency variable sources. The sample contains 2 radio galaxies, 9 quasars, 4 BL Lac objects, and 1 source with an uncertain identification. The sources were selected from a five-year flux monitoring program using the 305-m radio telescope of the Arecibo Observatory and the 91-m radio telescope of the NRAO (Green Bank) at 1400, 880, 606, 430, and 318 MHz. A comparison of our results with *VLBI* maps at higher frequencies and WSRT, VLA and MERLIN maps provides constraints on models of the structures of these sources. Our data show clear evidence that all sources are resolved at baselines longer than $2-6$ Mλ. The results will enable us to look for possible correlations between flux density variability and source structure, aiming to distinguish between intrinsic variability of extragalactic radio sources and variability due to propagation phenomena. Finally, we identify a few particularly interesting sources for further investigation with higher dynamical range and at various frequencies.

Key words: radio continuum: galaxies — galaxies: nuclei — quasars: general — BL Lacs: general

1. Introduction

The radio flux density variability of extragalactic radio sources has been the subject of a large amount of work since it's discovery by Dent (1965) and Sholomitskii (1965). For a review see Altschuler (1989). The short timescales of variability, presumed to be intrinsic to the radio source, implied that insight into the physics of the central energy source of active nuclei would be obtained from these studies.

The confirmation of variability at low radio frequencies (< 1 GHz, Hunstead 1972) represented a problem for the models which had been elaborated to understand the variability and required a modification of the basic assumption that all variability was intrinsic to the source. Models for variability as a consequence of propagation effects were proposed by Shapirovskaya (1978), and developed in detail by Rickett et al. (1984).

Multifrequency monitoring programs such as that of Mitchell et al. (1994) confirm that at least two mechanisms are responsible for the observed variability. Intrinsic variations manifest themselves at high frequencies (> 1 GHz) and follow the trends expected from the evolution of synchrotron emitting components. Extrinsic variations manifest themselves at low frequencies and agree with the expected behaviour for refractive interstellar scintillation (Rickett 1986).

The theory predicts a strong dependence between source structure and variability properties, which is what lead us to perform the *VLBI* measurements which are the subject of this paper. Results of a study along these lines have been reported by Spangler et al. (1989, 1993), and Mantovani et al. (1990). In particular, the study of Spangler et al. (1993) is based on *VLBI* structures at 608 MHz (Padrielli et al. 1991) for a sample of eleven sources found to be variable at 408 MHz. Our larger sample provides data with the possible advantage that our structural information was obtained at the same frequency as the flux density monitoring, avoiding uncertainties related to frequency dependent structure.

In this paper we present the *VLBI* results for the 16 sources observed. Published *VLBI* maps at 92 cm are

Table 1. The sample for the *VLBI* study of low frequency variable extragalactic radio sources

Source	RA (1950)[a]	Decl. (1950)[a]	Type	$z^{\rm b}$	$S^{\rm c}_{318}$ [Jy]
0116+319 4C31.04	01 16 47.425	+31 55 05.78	G	0.057	4.10
0235+164	02 35 52.619	+16 24 03.88	B	0.940	1.49
0333+321 NRAO140	03 33 22.385	+32 08 36.50	Q	1.263	3.30
0723−008	07 23 17.854	−00 48 55.45	B	0.127	3.43
0735+178	07 35 14.109	+17 49 08.88	B	>0.424	2.17
0851+202 OJ287	08 51 57.311	+20 17 57.34	B	0.306	1.19
1055+018 4C01.28	10 55 55.320	+01 50 00.44	Q	0.888	5.40
1117+146 4C14.41	11 17 50.97	+14 37 21.1	G	0.362[d]	3.91
1422+202	14 22 37.5	+20 13 58	Q	0.871	5.66
1611+343 DA406	16 11 47.916	+34 20 19.8	Q	1.401	3.29
1633+382 4C38.41	16 33 30.625	+38 14 09.98	Q	1.814	2.35
1901+319 3C395	19 01 02.320	+31 55 13.84	Q	0.635	6.41
2050+364 DA529	20 50 54.3	+36 23 58	G	–	3.19
2145+067 4C06.69	21 45 36.566	+06 43 3.18	Q	0.990	3.68
2230+114 CTA102	22 30 07.812	+11 28 22.7	Q	1.037	7.52
2251+158 3C454.3	22 51 29.521	+15 52 54.31	Q	0.859	12.13

[a] Coordinates from Morabito et al. (1982, 1985), and Perley (1982).
[b] Redshifts from Véron-Cetty & Véron (1993).
[c] Flux density at 318 MHz obtained at the Arecibo Observatory in March 1986 (Altschuler et al. 1995).
[d] Redshift from de Vries et al. (1995).

quite scarce, and the present work will more than double the sample of sources mapped to date. Section 2 gives details of the observations and data reduction and Sect. 3 provides detailed descriptions for each source including relevant summaries of previous work. Detailed analysis of any relation between structure and variability will be the topic of a separate paper once the 12 years of monitoring data accumulated to date have been analyzed.

2. Sample selection, observations and data processing

The sample chosen for our study is based on the multifrequency flux density monitoring program reported in Altschuler et al. (1984); Dennison et al. (1984); and Mitchell et al. (1994). This program was designed to study the multifrequency behaviour of 34 extragalactic sources known or suspected of being variable at low frequencies. The *VLBI* sample discussed here is composed of 16 sources from the list of 34 sources, which show higher variability than the remaining 18. The 16 sources and some of their characteristics are presented in Table 1.

Each source was observed on March 22–25, 1986 during at least three 20-minutes scans with the Global *VLBI* network composed of the telescopes listed in Table 2. Scans were distributed over the available observing time to optimize the uv–coverage. A typical uv–coverage is presented in Fig. 1. The achieved angular resolution is in the range 13–30 mas in the East–West direction, and 50–100 mas in the North–South direction. The observations were carried out in left circular polarization using the Mk 2 data recording standard (Clark 1973) with an effective bandwidth of 1.8 MHz.

Table 2. *VLBI* telescopes and their characteristics at λ = 92 cm

Code	Station	Diameter (m)	$T_{\rm sys}$ (K)	Sensitivity (K/Jy)
F	Fort Davis	26	180	0.10
G	Green Bank	43	65	0.27
Ki	Haystack	46	180	0.20
J1	Jodrell Bank	76	100	1.10
N	Maryland Point	26	180	0.10
O	OVRO	40	250	0.24
R	Simeiz	22	200	0.07
Z	Torun	15	220	0.05
W	WSRT[a]	94	160	1.68
Y	VLA[a]	130	100	2.08

[a] WSRT and VLA were used in phased array mode; an equivalent diameter is given.

The data were correlated at the Max-Planck-Institut für Radioastronomie (MPIfR, Bonn, Germany) with the Mk2 correlator with 1 s integration time. Fringe fitting and initial editing were done with the MPIfR *VLBI* data

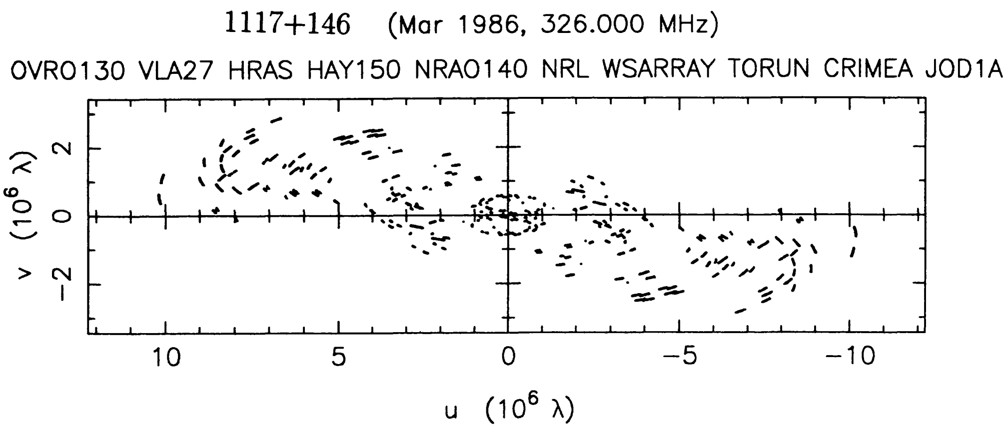

Fig. 1. An example of typical *uv*-coverage. The source is 1117+146, 10 radio telescopes, 3 scans of 20 minutes each

processing software package (Alef 1989). The residual fringe rate and the residual delay resulting from this fringe fit was used to estimate station based residual fringe rates and delays. These "corrected" residuals were used to integrate the data coherently to 30 s. Data was exported to MERGE format suitable for the Caltech *VLBI* data software (Pearson 1995). Further steps of data processing including editing, amplitude calibration, model fitting, and image reconstruction were done using the Caltech *VLBI* package implemented on a Sun workstation operated under UNIX at the Arecibo Observatory. The recently developed DIFMAP program (Shepherd et al. 1994) also was used for most sources.

Amplitude calibration was based on system temperature measurements at all telescopes and either antenna temperature measurements or preobservational measurements of telescope gains, supplied by the corresponding observatories. The consistency of the amplitude calibration was checked by comparing the obtained correlated fluxes at short baselines for all sources. The result of this cross–checking allows us to conclude, that the amplitude calibration is consistent for all telescopes within $\pm 7\%$.

For most sources we used both the modelfitting program MODELFIT and the cycle of programs AMPHI–CLEAN–INVERT for hybrid mapping. All these programs are part of the Caltech *VLBI* software package. We found it useful to cross–check results of both methods with possible exchange of intermediate source models between the two methods in order to achieve the best possible agreement factor between observational data and brightness distribution models. Closure phases and *uv*–cross–points have been used wherever possible, however the limited *uv*–coverage did not allow us to use it widely. We also used the program DIFMAP for re–processing of the data for most sources using the advantage of the interactive properties of DIFMAP and its convenient graphical and halftone output. The achieved dynamical range of the maps is $(50 - 80) : 1$, a typical agreement factor between data and models is $(1.5 - 2.5)\sigma$.

Data for 1422+202, 2050+364, and 2145+067 were not sufficient to produce satisfactory maps, although some conclusions on their structure will be presented below on the basis of the best model fit. Maps for the remaining 13 sources from the sample are presented in Fig. 3 and are discussed in the following section along with other published data.

To formalize the derived structural information we used the program MODELFIT of the Caltech package and the tasks JMFIT and IMFIT of AIPS (Fomalont 1989). We used the simplest assumption that the source structure could be represented by a superposition of elliptical gaussian components. This enables us to present source structures quoting the major and minor axes of these components, their flux densities, position angles of their major axes, and position angles and angular distances from the arbitrary origin of the coordinate frame. These parameters are presented in Table 3. We used three different ways to extract these parameters, depending on the source structure and the level of statistical significance.

The best fit structures of six of the sources, 0723−008, 0851+202, 1611+343, 2230+114, and 2251+158, corresponds to a single gaussian component model. In the analysis we used the programs JMFIT and IMFIT within the NRAO AIPS package to determine the component's size, position angle, and flux density. After ensuring that both programs gave similar results, we used it as a representation of the source sizes.

The same AIPS tasks were also used to analyze the two double sources, 0116+321 and 1117+146. Each of the components was fit to a two-dimensional elliptical gaussian, and the distance and position angle between components listed are the distance and position angle between these two gaussians.

For the sources with more complicated structure, we attempted to fit the data to two or three gaussian

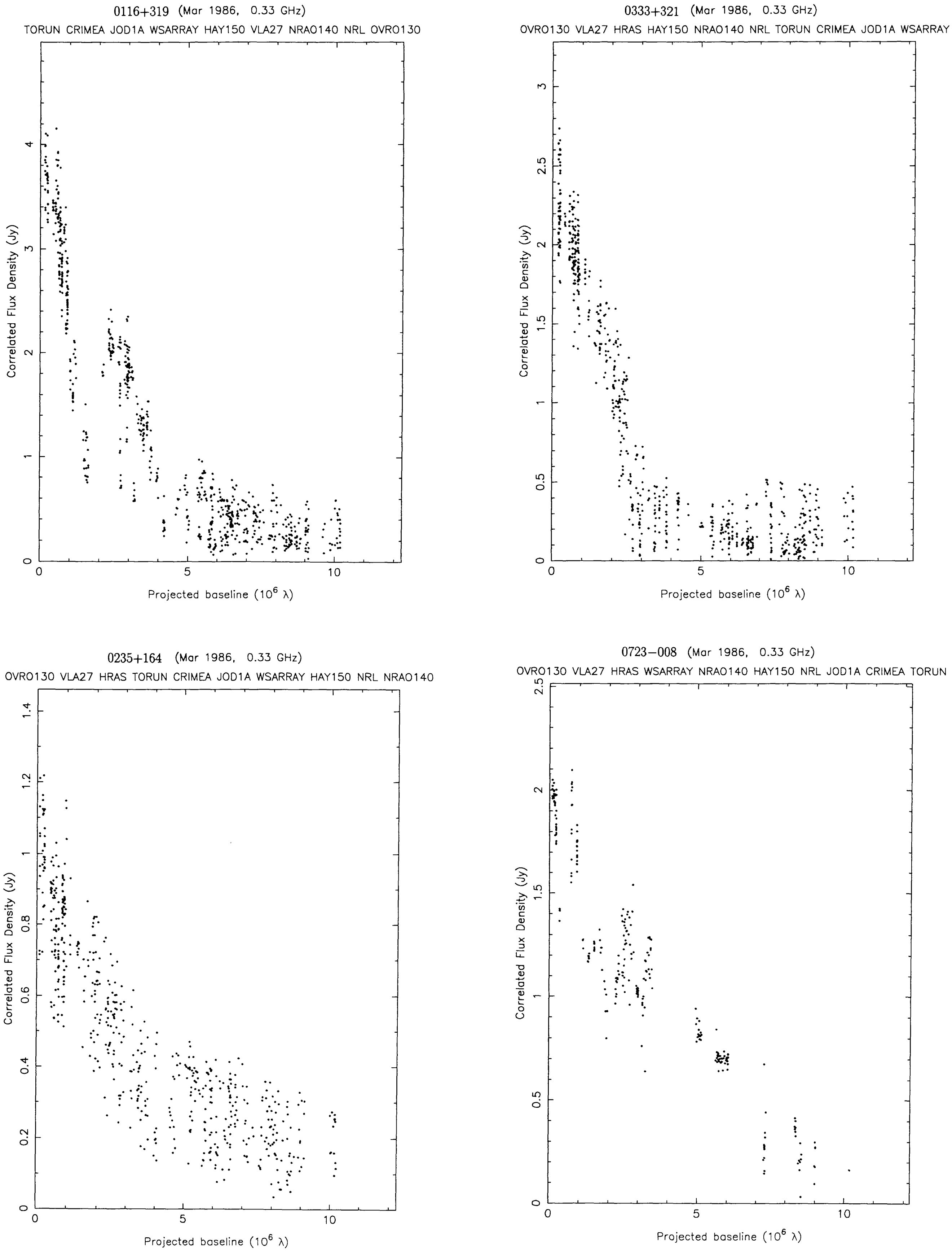

Fig. 2. a-p) Correlated flux density as a function of the projected baseline for the 16 observed sources

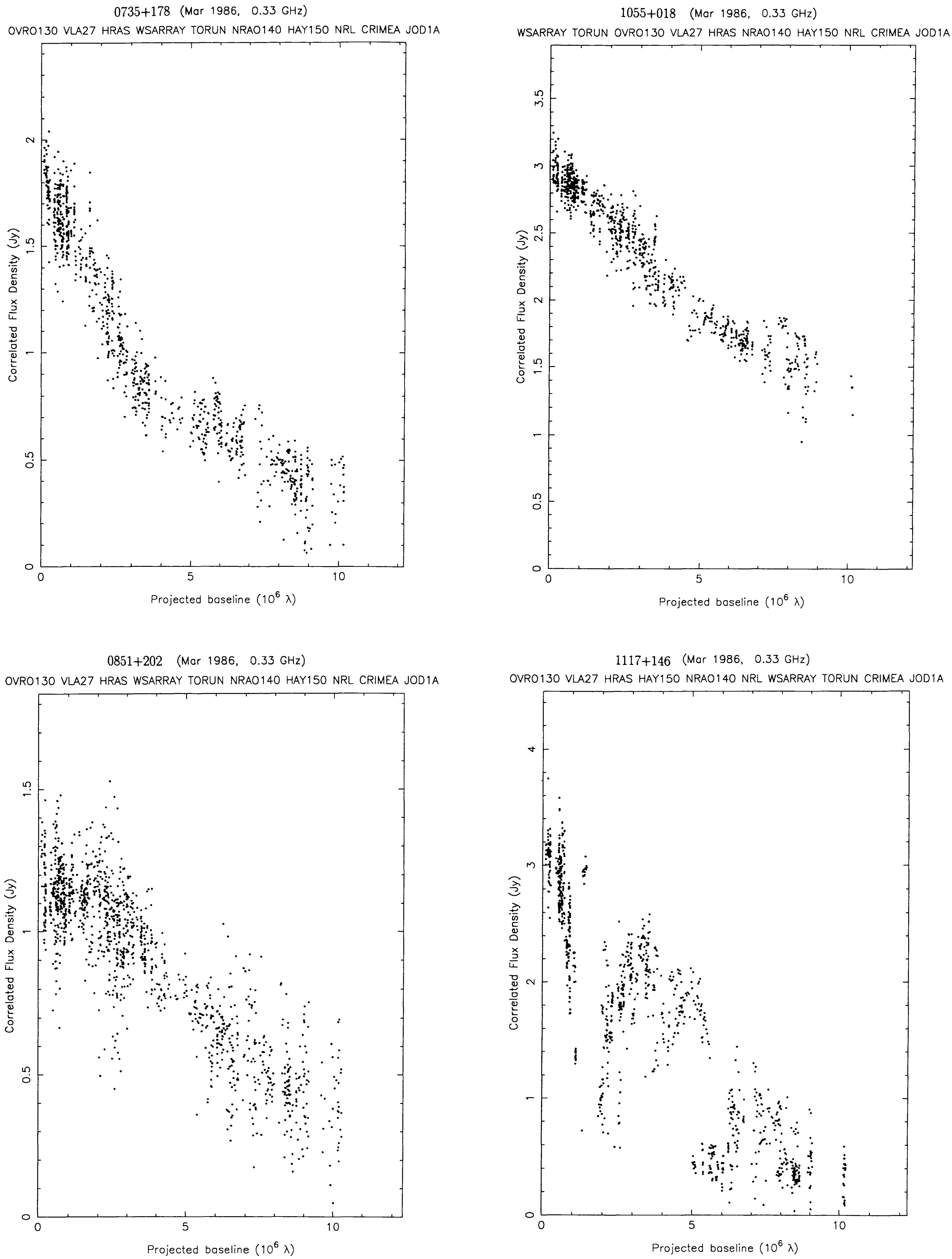

Fig. 2. continued

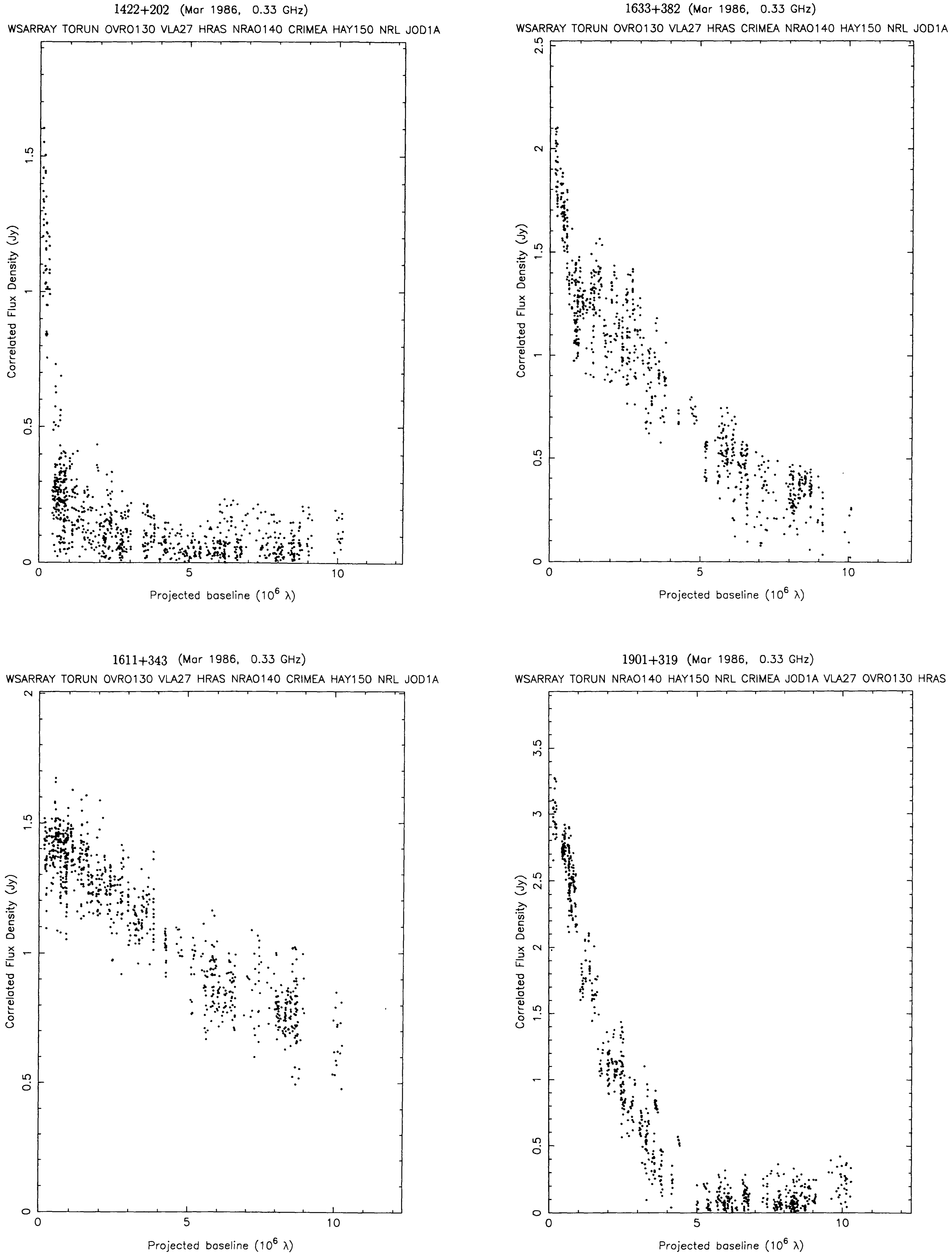

Fig. 2. continued

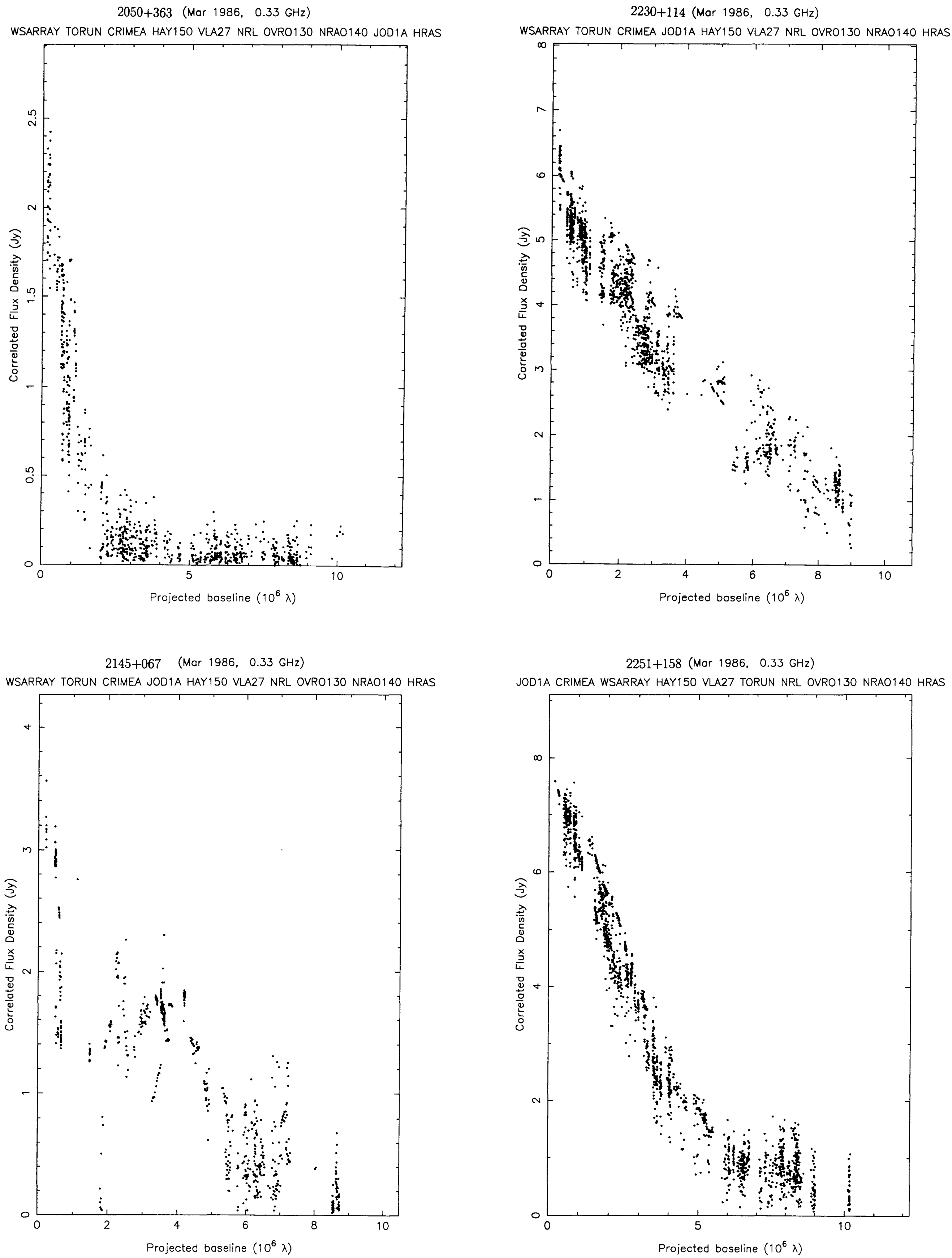

Fig. 2. continued

Table 3. Parameters of the most compact components of *VLBI* structures at 92 cm

Source	Comp	S_{327} (Jy)	Offset from comp A (mas)	PA of offset (deg)	Major axis (mas)	Minor axis (mas)	PA (deg)
0116+321	A	2.13	—	—	32	23	44.5
	B	1.03	69	108	55	23	113.3
0235+164	A	0.52	—	—	19	13	−6.7
	B	0.36	38	22	84	15	−27
0333+321	A	1.20	—	—	58	34	−11
	B	0.73	58	−120	26	21	156
0723−008	—	1.34	—	—	238	22	−10
0735+178	A	1.28	—	—	21	15	1.0
	B	0.40	28	65	9	8	0.0
0851+202	—	1.07	—	—	81	19	−12
1055+018	A	2.23	—	—	34	4	−16
	B	0.68	17	−136	66	13	−12
1117+146	A	2.08	—	—	43	22	158
	B	1.74	70	118	34	16	162
1422+202	—	0.25	—	—	—	30	—
1611+343	—	1.23	—	—	11	8	15
1633+382	A	0.90	—	—	11	10	−22
	B	0.27	26	−35	23	18	−70
1901+319	A	2.32	—	—	48	33	107
	B	0.30	72	102	23	17	30
2050+364	—	1.85	—	—	—	81	—
2145+067	—	1.10	—	—	—	30	—
2230+114	—	4.00	—	—	89	21	−14
2251+158	—	5.40	—	—	74	28	−11

components using the Caltech package program MODELFIT, which finds the best fit to multiple overlapping two-dimensional elliptical gaussians. The sources analyzed using this method were 0235+164, 0333+321, 0735+178, 1055+018, 1633+382 and 1901+319.

Three of the sources, 1422+202, 2050+364, and 2145+06, display significantly resolved images, so that fitting gaussian components to the maps becomes difficult. For these cases, we determined the angular size of the most compact component directly from the dependence of the correlated flux density on the projected baseline (see Fig. 2). This most compact component might be the one relevant for the study of the variability–structure relation.

As a general statement we note, that all the data show clear evidence that the source images at baselines 2 − 6 Mλ and longer are significantly resolved as is clear from plots of the "correlated flux density – projected baseline" shown in Fig. 2.

We note, that the structural components, listed in Table 3 are the strongest compact component in the structure, which are of interest for the "variability versus structure" study. For most of the sources a significant part of the total flux as derived from our monitoring program is not accounted for by the listed compact components, and is related to more extended structures (halo–like) with lower brightness temperatures. Typically these structural features are more than 100 − 200 mas in diameter. A detailed study of these features would require full–track instead of snap–shot observations, with an aperture synthesis system covering the range of baselines 10−1000 km.

3. Notes on individual sources

The *VLBI* images obtained are shown in Fig. 3. In what follows we review briefly for each source the previously known structural information and compare these with our results. Only for 0851+202 and 1117+146 does the flux density contained in our images add up to the total flux of the source at the time of observation. This fact confirms the earlier statement of Vijayanarasimha et al. (1985) based on the study of 57 flat spectrum extragalactic sources at 327 MHz using the interplanetary scintillation (IPS) technique, that on average up to 40% of the total flux density comes from an area larger than ≃ 50 mas.

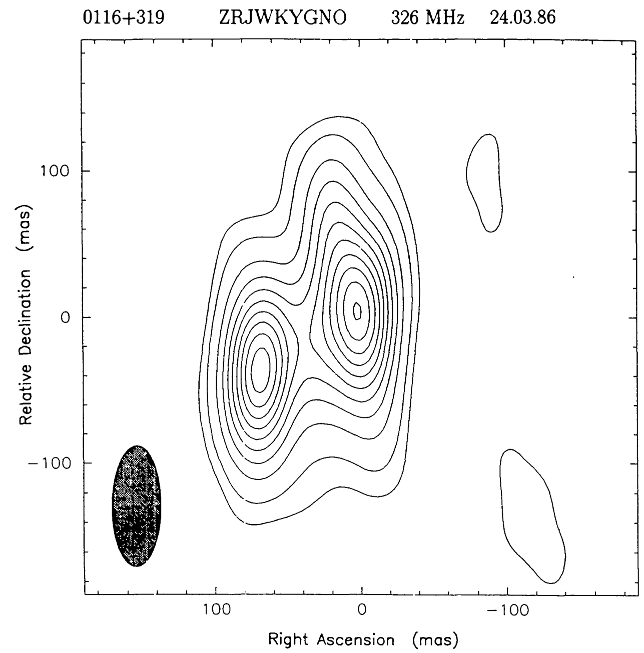

Fig. 3. a) 0116+319: Contour levels are −5, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 99% of the peak brightness of 1.261 Jy/beam; restoring beam is 81.80 × 33.10 mas in PA = −0.5°

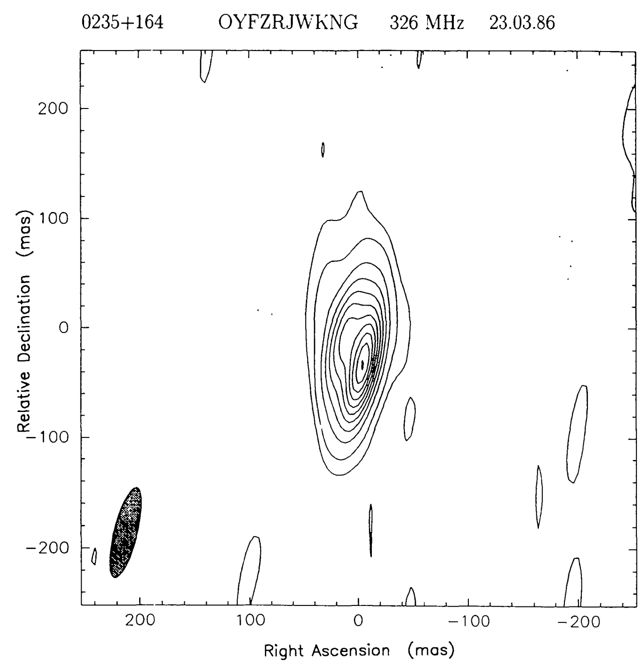

Fig. 3. b) 0235+164: Contour levels are −5, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 99% of the peak brightness of 0.369 Jy/beam; restoring beam is 83.20 × 20.60 mas in PA = −14.1°

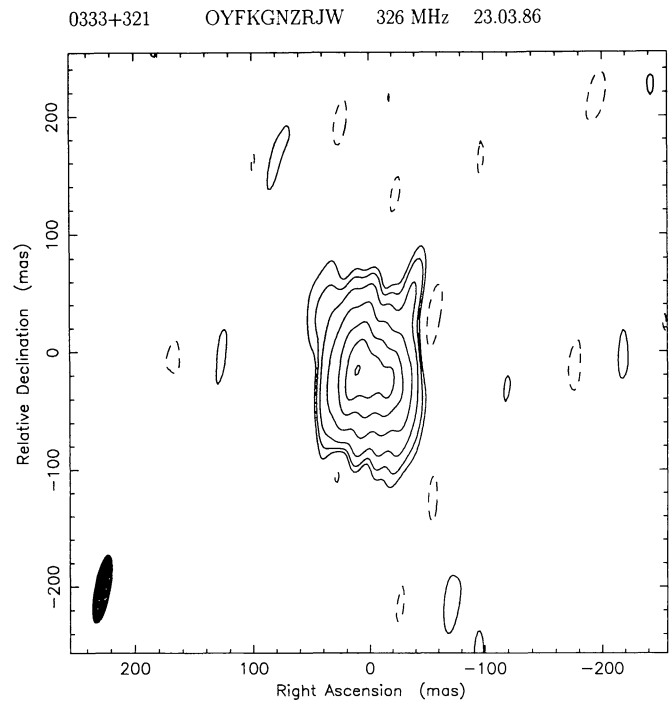

Fig. 3. c) 0333+321: Contour levels are −3, 3, 5, 10, 25, 50, 75, 99% of the peak brightness of 0.416 Jy/beam; restoring beam is 58.79 × 12.65 mas in PA = −10.5°

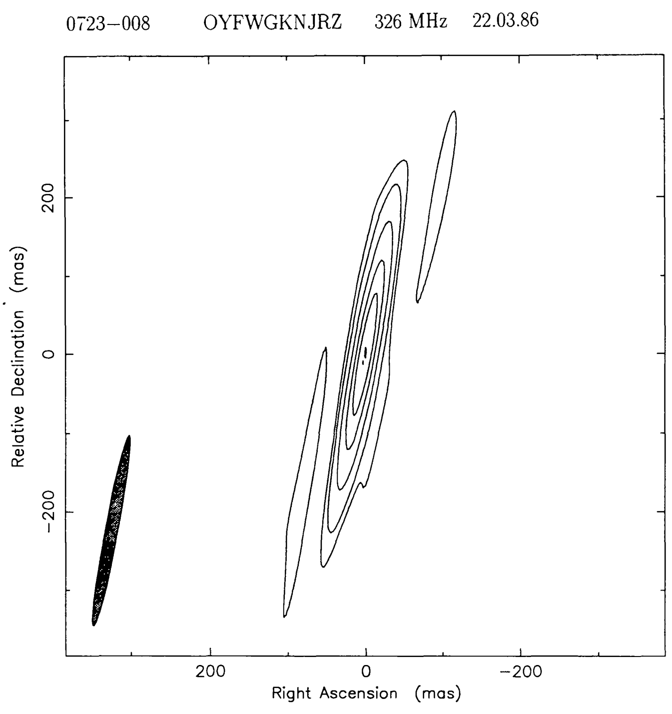

Fig. 3. d) 0723−008: Contour levels are −5, 5, 10, 25, 50, 75, 99% of the peak brightness of 0.978 Jy/beam; restoring beam is 247.25 × 15.62 mas in PA = −10.4°

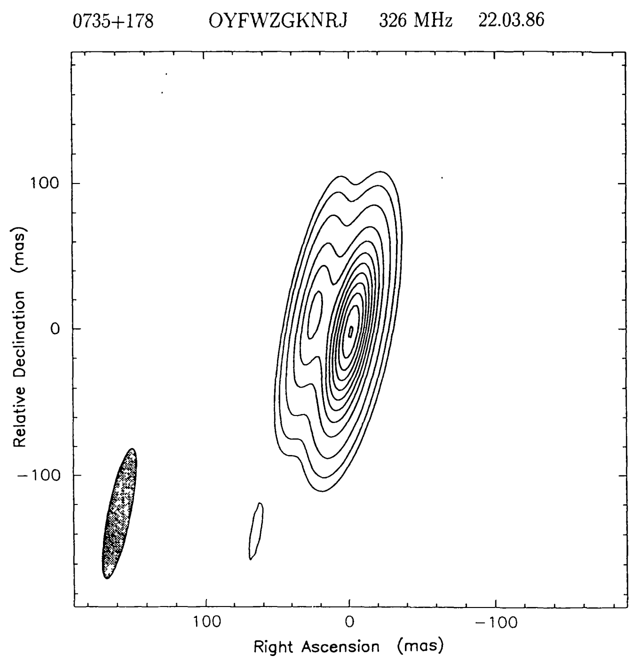

Fig. 3. e) 0735+178: Contour levels are −5, −3, 3, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 99% of the peak brightness of 0.852 Jy/beam; restoring beam is 90.50 × 15.30 mas in PA = −11.6°

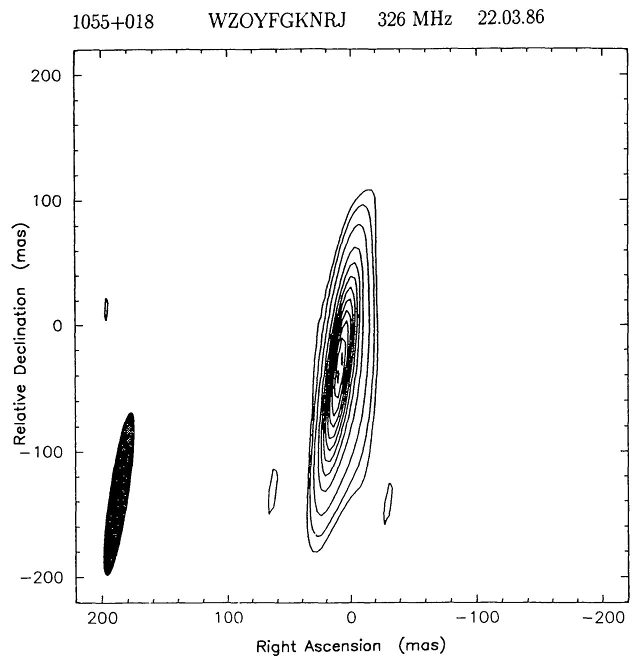

Fig. 3. g) 1055+018: Contour levels are −3, 3, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 99% of the peak brightness of 1.938 Jy/beam; restoring beam is 131.00 × 14.30 mas in PA = −8.3°

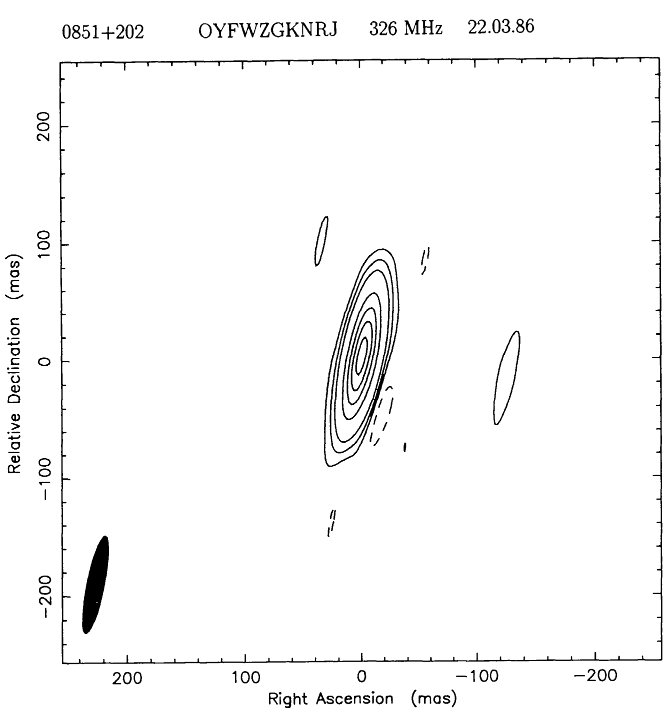

Fig. 3. f) 0851+202: Contour levels are −2, 2, 5, 10, 30, 50, 70, 90% of the peak brightness of 0.823 Jy/beam; restoring beam is 83.35 × 13.97 mas in PA = −11.6°

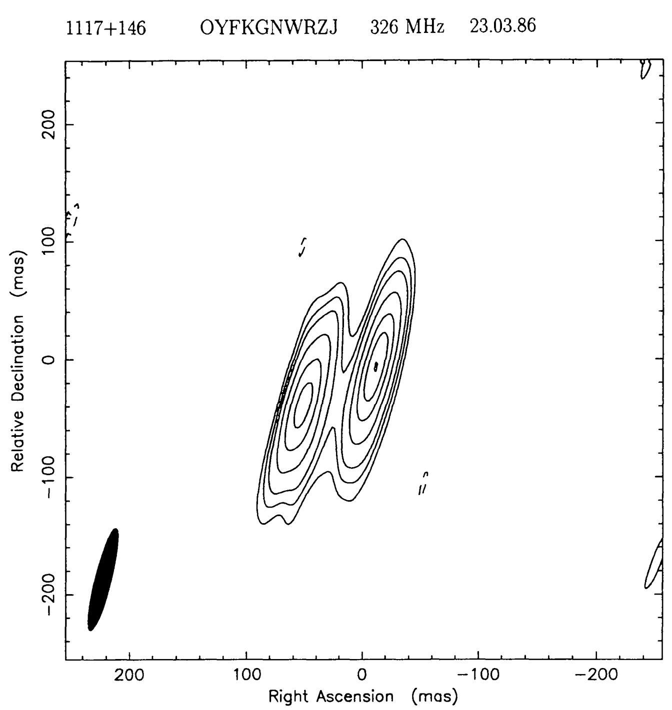

Fig. 3. h) 1117+146: Contour levels are −2, 2, 5, 10, 25, 50, 75, 99% of the peak brightness of 1.005 Jy/beam; restoring beam is 89.68 × 13.34 mas in PA = −14.2°

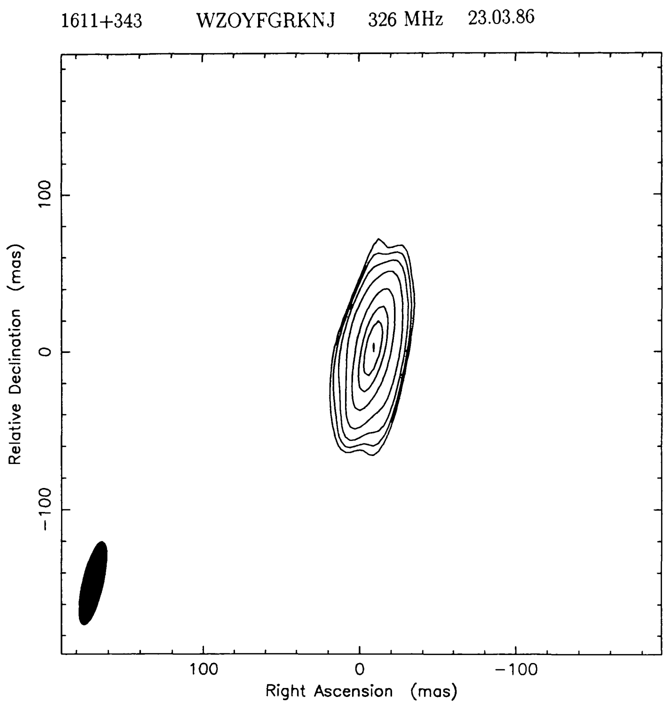

Fig. 3. i) 1611+343: Contour levels are −2, 2, 3, 5, 10, 25, 50, 75, 99% of the peak brightness of 1.034 Jy/beam; restoring beam is 54.11 × 12.72 mas in PA = −12.7°

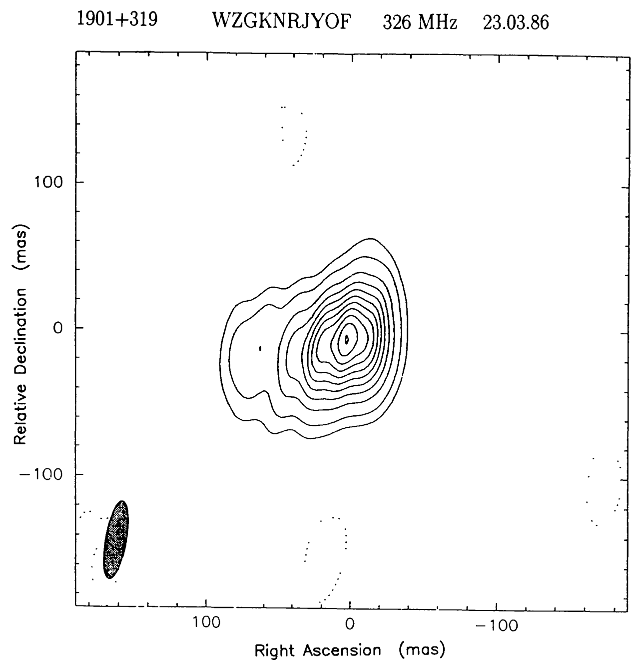

Fig. 3. k) 1901+319: Contour levels are −5, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 99% of the peak brightness of 0.568 Jy/beam; restoring beam is 53.60 × 14.00 mas in PA = −9.7°

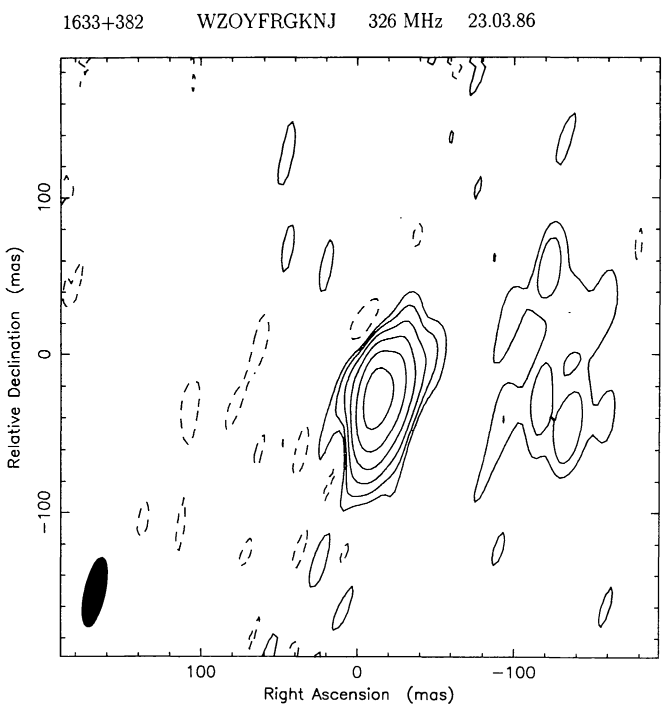

Fig. 3. j) 1633+382: Contour levels are −2, 2, 4, 8, 16, 32, 64% of the peak brightness of 0.673 Jy/beam; restoring beam is 45.42 × 12.95 mas in PA = −11.87°

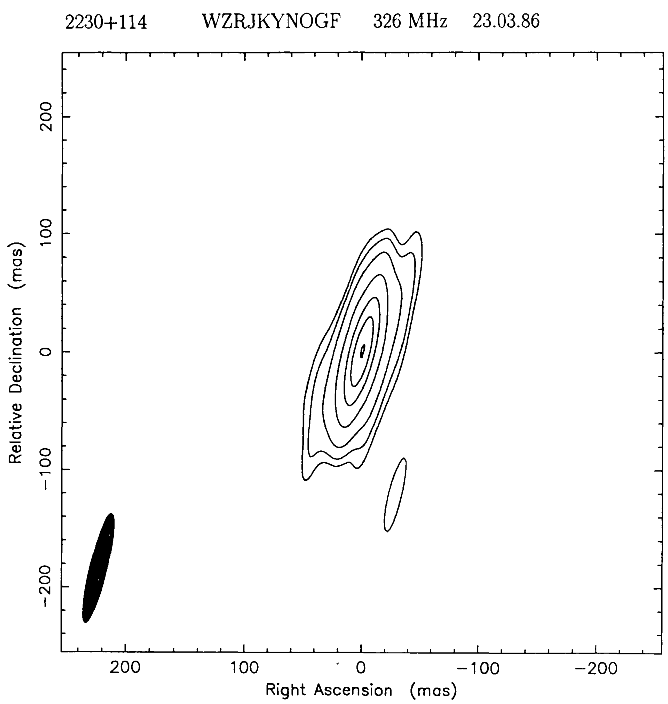

Fig. 3. l) 2230+114: Contour levels are −3, 3, 5, 10, 25, 50, 75, 99% of the peak brightness of 1.261 Jy/beam; restoring beam is 95.22 × 14.00 mas in PA = −13.3°

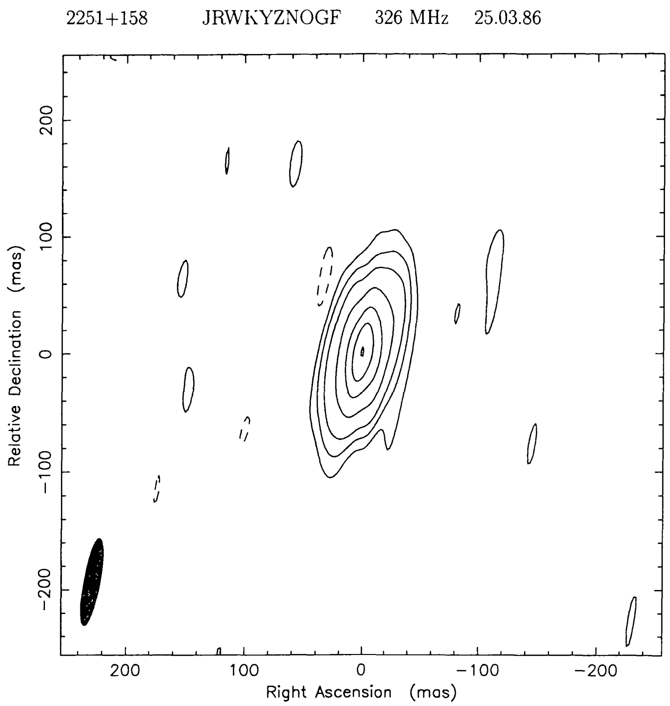

Fig. 3. m) 2251+158: Contour levels are −2, 2, 5, 10, 25, 50, 75, 99% of the peak brightness of 2.896 Jy/beam; restoring beam is 75.33 × 13.27 mas in PA = −10.2°

3.1. *0116+319 (4C31.04)*

The source 0116+319 is identified with the bright elliptical galaxy MCG 5-4-18, $z = 0.057$ (van den Bergh 1970). Spectral classification of the radio source is controversial. Peacock & Wall (1982) classified the source as a steep spectrum one since $\alpha_{11\text{cm}}^{6\text{cm}} < -0.5$. Data of Perley (1982) are not in conflict with this classification, $\alpha_{21\text{cm}}^{6\text{cm}} = -0.42 \pm 0.04$. However, the spectral behavior of the source at higher frequencies $\alpha_{6\text{cm}}^{2\text{cm}} < -0.16\pm0.03$ (van Breugel et al. 1984) along with the cm-wavelength variability excludes 0116+319 from the class of steep spectrum compact extragalactic radio sources (Wrobel & Simon 1986). This last statement suggests the existence of a very compact (substantially less than 40 mas) component, responsible, particularly for the flattening of the radio spectrum at short wavelengths (< 6 cm).

Observations by Wrobel & Simon (1986) at 92 cm reveal a double structure separated by ~70 mas with a dominant elongation position angle of ~ 115° and an error of ~ 10°. Our data are in good agreement with this result. We measure practically the same value of a separation of ~ 69 mas at a position angle of 108°. No apparent relative motion of two components could be detected within the accuracy of measurements. The *VLBI* structure observed in our experiment contains up tp 80% of the total flux density of the source at 92 cm.

3.2. *0235+164*

According to 327 MHz observations with the Ooty radio telescope, there is a scintillating component < 100 mas responsible for ~2/3 of the total flux density of the source, suggesting that the source consists of a core < 100 mas and a halo of a few arcseconds (Gopal-Krishna 1977). The source is unresolved by the VLA at 6 and 20 cm (Ulvestad et al. 1983). A MERLIN map of Stannard & McIlwrath (1982) at 410 MHz shows some extended emission on the arcsecond scale in three directions: northeast, southwest, and northwest. It was suggested that the prominence of the radio core is due to beaming, and the extended emission is a lobe seen at the end of a jet projected toward the observer.

VLBI observations of Bååth et al. (1981) at 5 GHz show some extended structure at several milliarcseconds from the core to the northeast. *VLBI* observations at three different epochs at 6 cm showed the presence of a mas scale jet to the northeast at a position angle that varied significantly between epochs (Bååth 1984). *VLBI* observations at 1.3 cm confirmed the extended structure to the northeast, and suggested that the varying position angle may be caused by rapid precession of the jet (Jones et al. 1984)

Our observations confirm the existence of extended structure on the centi-arcsecond scale to the northeast. We fit two elliptical gaussians to the strongest component and the weaker extension. We also detected some weak emission to the southwest. One interpretation for this emission is that of a lobe seen almost directly in front of the core, as was suggested by Stannard & McIlwrath (1982). This explanation is in a perfect agreement with the classical model of Bl Lacs as AGN with a jet oriented almost directly toward an observer. Indeed, a model to fit the radio flux variability spanning a factor of 50 in frequency was developed in terms of adiabatically cooling synchrotron emission regions in a compact, highly relativistic jet (O'Dell et al. 1988).

In agreement with the above mentioned prediction of Gopal–Krishna (1977), the observed *VLBI* structure at 327 has a charactersitic angular size < 100 mas and contains ~ 60% of the total flux density, detected by the Arecibo telescope at 318 MHz at nearly the same time as the *VLBI* observations.

3.3. *0333+321 (NRAO140)*

Perley (1982) reported a single secondary component 7.6″ away at a position angle of 150° using the VLA at 21 and 6 cm. Westerbork observations at 6 cm indicate two components on either side of the core, the southeastern one 6.9″ away at a position angle of 149° and a nothwestern one 4.1″ away at a position angle of −31° (Schilizzi & de Bruyn 1983). O'Dea et al. (1988) detected only the southeast component at 6 cm, consistent with Perley's (1982) observations.

VLBI observations at 1.7 GHz show a jet extending to 8 mas at a position angle of 132° (Romney et al. 1984). Marscher & Broderick (1985) also find the source to be extended mainly along a position angle of $\sim 130°$.

Our low frequency observations do not follow these high frequency result. The achieved resolution does not allow to check the prediction of Marscher & Broderick (1985) on component sizes smaller than 2.6 mas based on the radio spectrum decomposition. We find some extension to the northeast at a position angle of 56° and more prominent extension at the southwest (component B at the position angle $\sim -120°$), as opposed to the extensions to the southeast which are seen at higher frequencies on both milliarcsecond and arcsecond scales. although claiming the source as unresolved with MERLIN at 18 cm, Pilbratt et al. (1987) nonetheless show a map with some extension at low brightness level to the southwest. This extension has the same size and similar position angle as our component B. The different structures observed at different frequencies are a consequence of the complex spectral properties of the source structure at centiarcsecond scales. Indeed, the observed *VLBI* structure contains $\sim 59\%$ of the total flux density of the source at 92 cm.

3.4. *0723–008*

According to VLA observations at 21 and 6 cm the source is unresolved (Perley 1982). *VLBI* observations at 18 cm give an indication of a jet extending to the north to ~ 20 mas at a position angle of $\sim 24°$ (Romney et al. 1984; Padrielli et al. 1986). Our observations substantially resolve the source. The data obtained allow us to fit the structure with a single component gaussian model, which contains only $\sim 40\%$ of the total flux density of the source. Along with the absence of any VLA–scale structure at 21 cm, as noted above, it may be an indication of the presence of a steep spectrum halo with size $> 0.5''$. The jet, detected with *VLBI* at 18 cm, could be "hidden" in our observations due to the very poor north–south resolution.

3.5. *0735+178*

VLA observations at 6 cm detect a jet with a length of $\sim 2''$ at a position angle of 180° near the core and curving to the southwest (O'Dea et al. 1988). MERLIN data at 6 cm with sub-arcsecond resolution show a strong core and weak extended emission at a position angle of $\sim 160°$ (Zhang & Bååth 1991).

VLBI observations at 1.35 cm show a component $\sim$1.2 mas from the core at a position angle of $\sim 25°$, while at the longer wavelength of 6 cm *VLBI* data show an outer component to the northeast. The outermost component seems to be stationary at a distance of $\sim$4.2 mas from the core at a position angle of $\sim 70°$ (Gabuzda et al. 1989b; Bååth & Zhang 1991; Bååth et al. 1991). The other components between the core and the stationary one are superluminal, and move from the core to the northwest component. Bååth & Zhang (1991) propose a model of the source in which the jet originates at a viewing angle $> 10°$ and bends to the south towards the observer, and the secondary component lies at a zero degree viewing angle.

Our map shows essentially a double component structure. It is responsible for $\sim 77\%$ of the total flux density of the source at 92 cm. The separation between the observed components at 92 cm is much larger than the angular scale of *VLBI* structures at 6 and 1.35 cm. Thus, we can not incorporate our result directly to the model of the precessing jet, mentioned above. However, our map is not in a contradiction with this model.

3.6. *0851+202 (OJ287)*

The source structure is reported as core–jet from *VLBI* obsevations at 6 cm (Roberts et al. 1987; Gabuzda et al. 1989a). The jet position angle is reported to be $\sim -100°$. *VLBI* observations of Bååth et al. (1992) at 3 mm do not resolve the source. These authors suggest that the source is similar to superluminal sources, but with the jet oriented even closer to the line of sight, than the optimal angle for a classical explanation of the superluminal phenomenon (Rees 1967).

In our observations the source is resolved with some extension along the minor axis of the synthesized beam. This could be indicative of the above mentioned jet roughly in the east–west direction. A single component gaussian model of the brightness distribution with parameters presented in Table 3, provides the best fit. We note, that the source is a rare case in our sample with practically all the observed total flux density contained in the *VLBI* structure.

3.7. *1055+018 (4C01.28)*

VLA observations at 20 cm show an unresolved core and a resolved lobe $\sim 2''$ across, $\sim 25''$ north (Hintzen et al. 1983). Later VLA observations at 18 cm show a triple source with a total extent of $\sim 30''$ and a jet extending south of the core (Murphy et al. 1993). Perley (1982) also observed a component to the south along a position angle of 180° at a distance of $4''$.

Observations by Slee (1984) at 180 MHz suggest that $\sim 65\%$ percent of the flux density comes from a component of < 10 mas. *VLBI* observations at 1.7 GHz show elongations on the milliarcsecond scale to the northeast and northwest (Romney et al. 1984). In *VLBI* observations at 608 MHz, Padrielli et al. (1991) find an extension to the west at a position angle of $-60°$. Upon inspection of the arcsecond resolution maps, they suggest that the jet must bend strongly to the south.

Our observations indicate an extension to the southwest at a position angle of −136° on the centiarcsecond scale (component B), as expected if the jet is bending to the south as it extends from milliarcsecond to arcsecond scales. We note also some indication of a possible extension in the northeast direction, which however needs high angular resolution to be confirmed. The *VLBI* structure contains slightly more than a half of the total flux density of the source at 92 cm. This implies structures larger than 200 mas, possibly the lobe, resolved in the above mentioned VLA observations.

3.8. *1117+146 (4C14.41)*

The source 1117+146 is recently reported as an intermediate redshift galaxy ($m_R = 20.1$, de Vries et al. 1995). The source is classified as a gigahertz peaked-spectrum (GPS) radio source (O'Dea et al. 1991).

Padrielli et al. (1991) observed the source with *VLBI* at 608 MHz, and obtained a map with a clear double structure. Our map is in perfect agreement in component separation and position angle with it. With some obvious reservations as to the effect of variability (the difference in epochs of the 327 and 608 MHz observations is 2.2 years), one can estimate the spectral indices of both components as -0.37 ± 0.05 and -0.44 ± 0.06. These numbers barely allow for a steep spectrum classification, as implied by the total flux density of the source. Recent *VLBI* observations at 18 cm (Bondi 1993; Sanghera et al. 1995) show double structure with partially resolved components nearly equal in flux density. The separation between 18 cm components is in agreement with Padrielli's et al. (1991) measurements at 608 MHz and ours at 327 MHz.

However, data of the *VLBI* study at 932 MHz (Bååth 1988) at three published epochs indicates the source structure to be noticeable different from what is observed at lower frequencies. Observed changes in the source structure at 932 MHz are possibly consistent with a hypothesis involving beaming effects (Bååth 1988). Alternatively the observed double structure with relatively flat spectra of the components could be due to gravitational lensing, although this interpretation needs further detailed study. Some indirect confirmation of the gravitational lensing hypothesis could be the fact, that the observed *VLBI* structure contains ~ 97% of the total flux density of the source at 92 cm.

3.9. *1422+202*

Low resolution VLA observations at 6 cm give some indication of a possible core–jet structure (Saikia et al. 1986). Later VLA maps with higher resolution show a structure elongated in the north-south direction with a faint region off-axis east of the southern bright spot (Mantovani et al. 1992). Observations at 408 MHz with arcsecond resolution reveal a similar structure, but a part of the jet extending to the south is not seen (Mantovani et al. 1992).

Our data present a very diffused image of the source. The only available so far *VLBI* image of the source (at 18 cm, Bååth & Mantovani 1991) demonstrates a well resolved structure of about 9″ along the North–South direction. For the purpose of the "variability versus structure" study, we extracted the strongest compact component of the source, whose parameters are presented in Table 3. However, this component contains only ~ 4.5% of the total flux density at 92 cm. Our data show a significant part of the emission to be concentrated within an area of ~ 400 mas in diameter.

3.10. *1611+343 (DA406)*

The source is unresolved by the VLA at 21 and 6 cm (Perley 1982).

VLBI observations at 18 cm GHz (Romney et al. 1984; Padrielli et al. 1986; Waak et al. 1988) did also not resolve the source. *VLBI* observations of Padrielli et al. (1991) report a barely resolved source at 608 MHz. According to our observations, the source is resolved, with no structural details but a diffuse single component. This component contains ~ 37% of the total flux density at 92 cm. As in the case of 0723−008 the combination of this result with the VLA observations of Perley (1982) may indicate that the source has an extended (from a few hundred milliarceseconds to a few arcseconds) steep spectrum halo.

3.11. *1633+382 (4C38.41)*

The source was not resolved by Kapahi (1981) with the WSRT at 6 cm. As reported by Murphy et al. (1993) on the basis of VLA observations, the source has a triple structure with a total angular extent of ~ 12″. VLA data at 6 and 21 cm (Perley 1982) provide an indication of a possible extension of ~ 200 mas to the southeast.

Kellermann et al. (1977) found the *VLBI* structure of the source at 2.8 cm to be consistent with an elliptical gaussian component 0.5 × 0.3 mas extended along the position angle 160°. Marscher & Shafer (1980) found that the best fit for the *VLBI* structure at 18 cm was with a circular Gaussian of 1.2 mas in diameter.

VLBI observations of Pearson & Readhead (1988) at 5 GHz show a structure with three components, with two of them extended toward position angles of 115° (at a distance of 0.34 mas) and −63° (at a distance of 1.08 mas). At 608 MHz (Padrielli et al. 1991) there is a compact core with an extended structure to the west up to 20 mas and some indication of the extension to the east (up to 10 mas).

We find both some extension to the east (< 20 mas) and greater extension to the northwest along a position angle −35°. This latter structural pattern we identify with the component B listed in Table 3. We also note a weak emission from the extended area west from the core at a distance of ~ 130 mas. This feature is responsible for ~ 18% of the *VLBI* flux density of the source. The *VLBI* structure of the source contains ~ 50% of the total flux density of the source. The remaining part may be a "bridge" between the reported VLA structure and the discussed structural patterns within 200 mas from the core. Such a combination of structures at the range of frequencies from 327 MHz to 5 GHz is typical for a core–jet morphology.

3.12. *1901+319 (3C395)*

VLA observations at 2 cm by van Breugel et al. (1984) shows two components: a strong, variable one and a secondary one to the northwest at a distance of 0.7″ and a position angle of −53°.

VLBI observations at 18, 12, and 6 cm of the southern VLA component show a compact double structure; the two components are separated by ~ 15.6 mas at a position angle of ~ 118° (Johnston et al. 1983; Phillips & Mutel 1982; Phillips & Shaffer 1983). Later observations by Waak et al. (1985) reveal a third superluminal component between the two stationary ones, moving from the northwestern to the southeastern component. The extended arcsecond scale emission has been shown to be on the opposite side of the compact flat spectral index component from the steep spectral index component (Johnston et al. 1983). Saikia et al. (1990) propose a model to explain this reversal in which the jet initiates towards the southeast and bends around to the northwest as it approaches the arcsecond scale.

Padrielli et al. (1991) note that their 608 MHz *VLBI* observations are inconsistent with the 6 cm *VLBI* observations, in that they do not find a double structure with similar position angle and flux ratio. They suggest that one of the components fades between 5 and 0.608 GHz, or that extended emission between the two components becomes more prominent.

Our observations show a clear extended structure along a position angle of 102°. This emission is strong and extended enough to cover the area mentioned above as one with the superluminal motion and two stationary components. Our structure confirms the general direction of this kind of activity. Our result also confirms the existance of the emission at a distance of ~ 84 mas, which was first shown in the 608 MHz map by Padrielli et al. 1991.

For the purpose of "structure versus variability" study we fit the brightness distribution with the double component structure listed in Table 3. However, this structure contributes only ~ 40% of the total flux density of the source. The remaining part is contained in a diffuse emission within the map area and possibly in the larger halo.

3.13. *2050+364 (DA529)*

The radio source's optical counterpart is identified with a galaxy of $r = 21.2$ with as yet unknown redshift (Biretta et al. 1985). According to *VLBI* observations of Phillips & Mutel (1982) at 18 cm, the source is a compact double; the two components separated by ~ 61 mas and with slightly different turnover frequencies so that at 90 cm the flux densities are considerably different. Later 6 cm *VLBI* observations confirm that the two components have identical spectral indices (Mutel et al. 1985). However, the detailed structure of each component is very different; the authors suggest that this is due to the different physical conditions in the immediate interstellar environment of each component.

Observations at lower frequencies find intense scattering and broadening of the image of this source (Dennison et al. 1984; Mutel & Hodges 1986; Fey & Mutel, 1993). In fact our measured angular size is in good agreement with an extrapolation of the relationship between angular size and wavelength determined by Mutel & Hodges (1986). Our results present clear evidence of very strong influence of the scattering medium on the apparent structure of the source. All this is not surprising in view of the low galactic latitude of the source, $b = -5°$.

3.14. *2145+067 (4C06.69)*

Analysing VLA data at 21 and 6 cm Perley (1982) reports a two component structure with the secondary component at a distance of 2.5″ and a position angle of 305°.

VLBI observations at 5 GHz show a well-resolved component elongated to the southeast and a secondary diffuse component at a position angle of ~ 140° (Wehrle et al. 1992). The authors note that both components are embedded in a diffuse halo, and therefore it is not possible to determine which component is the core. They also point out that if the stronger *VLBI* component is the core, then the jet must bend by 180° between milliarcsecond and arcsecond scales.

Our observational data are not sufficient to produce a convincing map. However, analyzing the correlated flux density as a function of the projected baseline (Fig. 2n), one can suspect some structural features at distances ~ 48 mas and ~ 200 mas from the core. If so, the most probable direction of these features is along position angles ~ 100° or ~ −80°.

A single component gaussian model, presented in Table 3, was extracted from the data to be used for the "structure versus variablity" study. This component contains ~ 30% of the total flux density of the source.

3.15. *2230+114 (CTA102)*

Perley (1982) reports a double structure at 21 and 6 cm with the secondary component 1.6″ from the core at a position angle of 140°. However, van Breugel et al. (1984)

did not detect the secondary component with the VLA at 2 and 6 cm. Later VLA and MERLIN observations by Spencer et al. (1989) show triple strucure, with the southeast component at a distance and position angle similar to those found by Perley (1982).

VLBI observations by Pearson et al. (1980) at 18 cm are best fit to a two-component model with a compact strong core and a weaker component ~ 7 mas in diameter. This component is located at a distance of ~ 20 mas at a position angle of $\sim -34°$. These results are in agreement with earlier *VLBI* observations of Clarke et al. (1969), Kellermann et al. (1971) and Wilkinson et al. (1979).

A three-component model for the *VLBI* structure was developed on the basis of observations at 932 MHz (Bååth 1987) and at 5 GHz (Wehrle & Cohen 1989). These investigations agree on a general morphology of the source, but give different estimates for the value of apparent superluminal motion in the source.

VLBI observations by Ananthakrishnan et al. (1989) at 327 MHz were fitted to a two-component model in which the secondary component is 17 mas in diameter and displaced by 30 mas at a position angle of 21 degrees, inconsistent with most other observations. However, this model may have some consistency with the low resolution *VLBI* map at 6 cm (Wehrle & Cohen 1989).

The source is well resolved by our observations. Qualitatively one can note agreement with an elongation to the southeast with all above mentioned *VLBI* observations at frequencies higher than 327 MHz. We, nonetheless, cannot confirm the two–component model of Ananthakrishnan et al. (1989) proposed for the 327 MHz structure: our data do not show any peculiarity at the projected baseline ~ 6.6 Mλ, which corresponds to 30 mas (see Fig. 2o).

For the purpose of our study we fit the data to a single component brightness distribution, presented in Table 3. This component contains $\sim 53\%$ of the total flux density.

3.16. *2251+158 (3C454.3)*

Perley (1982) reports VLA observations at 21 and 6 cm which show a two component structure with the secondary component at a distance of 5.4″ and at a position angle of $-42°$. Browne et al. (1982) using MERLIN at 408 MHz find a core with a jet extended $\sim 5''$, ending in a hot spot at a position angle of $\sim -48°$.

The source has often been observed with *VLBI* at various frequencies. The common view of its *VLBI* structure assumes a core–jet morphology (Pauliny–Toth et al. 1987). For example, *VLBI* data at 18 cm show a jet ~ 20 mas long with a position angle of $-65°$ near the core and $-53°$ at its end. The authors also found a 10 mas jet at 6 cm, in agreement with 18 cm observations (Romney et al. 1984; Padrielli et al. 1986), and shorter jets at 2.8 and 1.35 cm. Because of the degree of variability and the measured flux of the core and jet, Pauliny-Toth (1987) suggests that the long-wavelength variations in flux density arise in the milliarcsecond jet and are intrinsic to the source.

Our observations substantially resolve the source. No particular morphological feature can be noted. The best fit to the data corresponds to a single component gaussian with the parameters, listed in Table 3. This *VLBI* structure contains $\sim 45\%$ of the total flux density.

4. Conclusions

1. Radio structures of extragalactic sources at 92 cm are significantly resolved at baselines $2 - 6$ Mλ and longer.
2. All but two sources, 0851+202 and 1117+146, have a significant part of their total flux density at 92 cm in angular scales larger than ~ 200 mas. Therefore, these structures are suitable for studies with an aperture synthesis system covering the range of baselines $10 - 100$ km with reasonably complete $uv-$coverage. A combination of the MERLIN and EVN might be an optimal array for this kind of study.

Detailed analysis of the obtained structural properties versus results of total flux variability will be the subject of a separate paper.

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References

Alef W., 1989, in *VLBI* Technique and Applications. In: Felli M. & Spencer R.E. (eds.). Kluwer Acad. Publ., Dordrecht, p. 97
Altschuler D.R., 1989, Fund. Cosmic Phys. 14, 37
Altschuler D.R., Broderick J.J., Condon J.J., et al., 1984, AJ 89, 1789
Altschuler D.R., Salgado J.F., Ghosh T., et al., 1995 (in preparation)

Ananthakrishnan S., Kulkarni V.K., Ponsonby J.E.B., et al., 1989, MNRAS 237, 341

Bååth L.B., Elgered G., Lindqvist G., et al., 1981, A&A 96, 316

Bååth L.B., 1984, in *VLBI* and Compact Radio Sources, Proceedings of the IAU Symposium No. 110. In: Fanti R., Kellermann K. and Setti S. (eds.). Dordrecht: Reidel, p. 127

Bååth L.B., 1987, in Superluminal Radio Sources. In: Zensus J.A. and Pearson T.J. (eds.). Cambridge: Cambridge University Press, p. 206

Bååth L.B., 1988, in The Impact of *VLBI* on Astrophysics and Geophysics, Proceedings of the IAU Symp. No. 129. In: Reid M.J. and Moran J.M. (eds.). Kluwer Acad. Publ., Dordrecht, p. 117

Bååth L.B., Mantovani F., 1991, in The Radio Interferometry: Theory, Techniques, and Applications. In: Cornwell T.J. and Perley R.A. (eds.). ASP Conf. Ser. 19, 298

Bååth L.B., Zhang F.J., 1991, A&A 243, 328

Bååth L.B., Zhang F.J., Chu H.S., 1991, A&A 250, 50

Bååth L.B., Rogers A.E.E., Inoue M., et al., 1992, A&A 257, 31

Biretta J.A., Schneider D.P., Gunn J.E., 1985, AJ 90, 2508

Bondi M., 1993 (private communication)

Browne I.W.A., Orr M.J.L., Davis R.J., Foley A., Muxlow T.W.B., 1982, MNRAS 198, 673

Clark B.G., 1973, Proc. IEEE 61, 1242

Clarke R.W., Broten N.W., Legg T.H., Locke F.L., Yen F.L., 1969, MNRAS 146, 381

Dennison B., Thomas M., Booth R.S., Brown R.L., Broderick J.J., Condon J.J., 1984, A&A 135, 199

Dent W.A., 1965, Sci 148, 1458

de Vries W.H., Barthel P.D., Hes R., 1995, A&A (submitted)

Fey A.L., Mutel R.L., 1993, ApJ 404, 197

Fomalont E.B., 1989, in Synthesis Imaging in Radio Astronomy. In: Perley R.A., Schwab F.R. and Bridle A.H. (eds.). San Fransisco: Astronomical Society of Pacific, p. 213

Gabuzda D.C., Wardle J.F.C., Roberts D.H., 1989a, ApJ 336, L59

Gabuzda D.C., Wardle J.F.C., Roberts D.H., 1989b, ApJ 338, 743

Gopal-Krishna, 1977, Nat 269, 780

Hintzen P., Ulvestad J., Owen F., 1983, AJ 88, 709

Hunstead R.W., 1972, Ap. Lett. 12, 193

Johnston K.J., Spencer J.H., Witzel A., Fomalont E.B., 1983, ApJ 265, L43

Jones D.L., Bååth L.B., Davis M.M., Unwin S.C., 1984, ApJ 284, 60

Kapahi V.K., 1981, A&AS 43, 381

Kellermann K.I., Jauncey D.L., Cohen M.H., et al., 1971, ApJ 169, 1

Kellermann K.I., Shaffer D.B., Purcell G.H., et al., 1977, ApJ 211, 658

Mantovani F., Fanti R., Gregorini L., Padrielli L., Spangler S., 1990, A&A 233, 535

Mantovani F., Junor W., Fanti R., et al., 1992, MNRAS 257, 353

Marscher A.P., Broderick J.J., 1985, ApJ 290, 735

Marscher A.P., Shaffer D.B., 1980, AJ 85, 668

Mitchell K.J., Dennison B., Condon J.J., 1994, ApJS 93, 441

Morabito D.D., Preston R.A., Slade M.A., Jauncey D.L., 1982, AJ 87, 517

Morabito D.D., Wehrle A.E., Preston R.A., et al., 1985, AJ 90, 590

Murphy D., Browne I.W.A., Perley R.A., 1993, MNRAS 264, 298

Mutel R.L., Hodges M.W., Phillips R.B., 1985, ApJ 290, 86

Mutel R.L., Hodges M.W., 1986, ApJ 307, 472

O'Dea C., Barvanis R., Challis P.M., 1988, AJ 96, 435

O'Dea C.P., Baum S.A., Stanghellini C., 1991, ApJ 380, 66

O'Dell S.L., Dennison B., Broderick J.J., et al., 1988, ApJ 326, 668

Padrielli L., Romney J.D., Bartel N., et al., 1986, A&A 165, 53

Padrielli L., Eastman W., Gregorini L., Mantovani F., Spangler S., 1991, A&A 249, 351

Pauliny-Toth I.I.K., 1987, in Observational Evidence of Activity in Galaxies, Proceedings of the 121st Symposium of the IAU. In: Ye. Khachikyan E., Fricke K.J. and Melnick J. (eds.). Dordrecht: Reidel, P. 295

Pauliny-Toth I.I.K., Porcas R.W., Zensus J.A., et al., 1987, Nat 328, 778

Peacock J.A., Wall J.S., 1982, MNRAS 198, 843

Pearson T.J., 1995, in Very Long Baseline Interferometry, Proceedings of the NRAO 1993 Summer School. In: Diamond P.J. and Zensus A. (eds.). San Fransisco: Astronomical Society of Pacific (in press)

Pearson T.J., Readhead A.C.S., Wilkinson P.N., 1980, ApJ 236, 714

Pearson T.J., Readhead A.C.S., 1988, ApJ 328, 114

Perley R.A., 1982, AJ 87, 859

Phillips R.B., Schaffer D.B., 1983, ApJ 271, 32

Phillips R.B., Mutel R.L., 1982, A&A 106, 21

Pilbratt G., Booth R.S., Porcas R.W., 1987, A&A 173, 12

Rees M., 1967, MNRAS 135, 345

Rickett B.J., Coles W.A., Bourgois G., 1984, A&A 134, 390

Rickett B.J., 1986, ApJ 307, 564

Roberts D.H., Gabuzda D.C., Wardle J.F.C., 1987, ApJ 323, 536

Romney J., Padrielli L., Bartel N., et al., 1984, A&A 135, 289

Saikia D.J., Kulkarni V.K., Porcas R.W., 1986 MNRAS, 219, 719

Saikia D.J., Muxlow T.W.B., Junor W., 1990, MNRAS 245, 503

Sanghera H.S., Saikia D.J., Lüdke E., et al., 1995, A&A (in press)

Schilizzi R.T., de Bruyn A.G., 1983, Nat 303, 26

Shapirovskaya N.Ya., 1978, Soviet Astr. 22, 544

Shepherd M.C., Pearson T.J., Taylor G.B., 1994, BAAS 26, 987

Sholomitskii G.B., 1965, Soviet Astr. 9, 516

Slee O.B., 1984, MNRAS 209, 215

Spangler S., Fanti R., Gregorini L., Padrielli L., 1989, A&A 209, 315

Spangler S., Eastman W.E., Gregorini L., Mantovani F., Padrielli L., 1993, A&A 267, 213

Spencer R.E., McDowell J.C., Charlesworth M., et al., 1989, MNRAS 240, 657

Stannard D., McIlwrath B.K., 1982, Nat 298, 140

Ulvestad J.S., Johnston K.J., Weiler K.W., 1983, ApJ 266, 18

van Breugel W., Miley G., Heckman T., 1984, AJ 89, 5
van den Bergh S., 1970, PASP 82, 1374
Véron-Cetty M.-P., Véron P., 1993, A Catalogue of Quasars and Active Nuclei, ESO Sci. Report No. 13, 6th Edition
Vijayanarasimha U., Ananthakrishnan S., Swarup G., 1985, MNRAS 212, 601
Waak J.A., Spencer J.H., Johnston K.J., Simon R.S., 1985, AJ 90, 1989
Waak J.A., Spencer J.H., Simon R.S., Johnston K.J., 1988, in The Impact of *VLBI* on Astrophysics and Geophysics, Proceedings of the 129th Symposium of the IAU. In: Reid M.J. and Moran J.M. (eds.). Kluwer Acad. Publ., Dordrecht, p. 141
Wehrle A.E., Cohen M.H., 1989, ApJ 346, L69
Wehrle A.E., Cohen M.H., Unwin S.C., et al., 1992, ApJ 391, 589
Wilkinson P.N., Readhead A.C.S., Anderson B., Purcell G.H., 1979, ApJ 232, 365
Wrobel J.M., Simon R.S., 1986, ApJ 309, 593
Zhang F.J., Bååth L.B., 1991, MNRAS 248, 566