The B3-VLA CSS sample

VI. VLA images at 2 cm[★]

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Received 29 July 2005 / Accepted 9 November 2005

ABSTRACT

Aims. New radio observations are presented for a sample of 56 Compact Steep Spectrum (CSS) radio sources from the B3-VLA CSS sample.

Methods. We used the VLA A-configuration observation at 2 cm to obtain high-frequency, high-resolution data.

Results. The majority (85%) of sources have a double morphology with a number of them showing a large asymmetry in terms of their component flux densities and/or component arm ratio. These new data have revealed 27 cores and core candidates. Three of the sources have a core-jet morphology and the morphologies of a few objects ($\leq 10\%$) are still ambiguous. The integrated radio spectra, over a frequency range from 0.16 to 15 GHz, show good agreement with a “continuous injection model” for $\geq 85\%$ of the sources.

Key words. galaxies: active – galaxies: nuclei – radio continuum: galaxies – galaxies: quasars: general

1. Introduction

This is the sixth of a series of papers reporting on the morphological and spectral properties of the B3-VLA CSS sample comprising 87 Compact Steep-Spectrum (CSS) sources and Gigahertz Peaked-Spectrum (GPS) sources (Paper I, Fanti et al. 2001) defined as those radio sources with linear size $< 20 h^{-1} \text{ kpc}$ and high frequency spectral index $\alpha \gtrsim 0.5$ ($S_\nu \propto \nu^{-\alpha}$) extracted from the B3-VLA catalogue (Vigotti et al. 1989). The aim has been to increase significantly the statistics on sources with Linear Size (LS) in the range $0.4 h^{-1} \leq \text{LS(kpc)} \leq 20 h^{-1}$ when compared with the classical CSS samples from the 3CR (Laing et al. 1983) and the PW (Peacock & Wall 1982) catalogues.

This paper reports on the results of observations at 15 GHz with the VLA in A configuration of a sub-sample of 56 radio sources identified as double/triple in the VLA observations presented in Paper I. Improved core detectability is expected at this high resolution and high frequency owing to the increased contrast in surface brightness between the core (compact with a probably flat or inverted spectrum) and the lobes (extended and steep spectrum).

The B3-VLA CSSs were first observed at 4.9 and 8.5 GHz with the VLA in A configuration in both total intensity and

polarization (Paper I; Paper IV). These observations provided detailed images of good quality for sources with angular size $\geq 1''$. In $\sim 10\%$ of cases a radio core was detected. Subsequently, twenty-eight sources which were unresolved (or dominated by an unresolved component) and eighteen sources which were slightly resolved at the higher resolution ($\sim 0''.2$) were re-observed at 1.7 GHz with the VLBA and with the EVN+MERLIN respectively (Paper II; Paper III). Good quality, high-resolution images were produced. For the eighteen most compact sources (Largest Angular Size $\leq 0''.2$) VLBA observations at 4.9 and/or 8.5 GHz were also carried out (Paper V), resulting in the detection of the source core in $\sim 40\%$ of the cases.

In order to investigate further the cores in the remaining sources, VLA-A observations have been undertaken for most of them at 15 GHz, this frequency providing a best compromise between good resolution and sensitivity for those sources well resolved in Paper I. Table 1 lists the fifty-six objects observed with some relevant data. The observations and the data reduction procedures are presented in Sect. 2. In Sect. 3 we comment on individual sources. Discussion and Conclusions are given in Sects. 4 and 5 respectively.

2. Observations and data reduction

The observations were carried out in 3 different runs on May 31st 2003, June 3rd 2003 and July 27th 2003 with the

[★] Tables 1, 2 and Fig. 1 are only available in electronic form at <http://www.edpsciences.org>

¹ $H_0 = 100 h \text{ km s}^{-1} \text{ Mpc}^{-1}$, $q_0 = 0.5$.

VLA in A configuration, with two 50 MHz IFs at a mean frequency of 14965 MHz. This provided a typical resolution of $\sim 0''.12$. Each source was observed in snap-shot mode for a total integration time ranging from 2 to 30 min, depending upon the expected peak flux density and structure of the source, as estimated from the VLA-A configuration data at 4.9 and 8.5 GHz (Paper I). The shortest baseline was ~ 34 k λ , implying that sub-structures larger than $\sim 2''$ would be poorly sampled/imaged. The target sources were interleaved with appropriate phase and amplitude calibrator sources, the latter being observed for 3 min approximately 4 times per hour.

The whole data reduction was performed in AIPS (Astronomical Image Processing System). As the primary flux density calibrators, 3C 286 and 3C 48, were partially resolved at 15 GHz, clean component models from the FITS format images found at: <http://www.aoc.nrao.edu/~cchandle/cal/cal.html> were used. The tropospheric phase stability was quite poor and, based on the gain variations during the three runs, the flux density calibration achieved for the VLA-A 15 GHz observations has been estimated to be accurate within $\sim 7\%$.

After the a priori phase and amplitude calibration, images were produced from a number of phase self-calibration and clean-restore iterations. The rms noise levels in the images (1σ), measured in regions away from the sources, range from ~ 0.05 mJy/beam to ~ 0.15 mJy/beam, in agreement with the expected thermal noise.

The 2 cm images are presented as thick contours in Fig. 1, with the 3.6 cm (thin contours) from Paper I superimposed. A typical first contour in the 3.6 cm images (3σ) is 0.2 mJy/beam (i.e. components with a peak flux density less than 0.2 mJy/beam are not seen in our 8.5 GHz images). Image registration, achieved using the KARMA package, has been generally straightforward. As only a comparison between the structures at 8.5 and 15 GHz is required, a detailed spectral index distribution is not of interest in this paper and a particularly accurate registration is therefore unnecessary. Component flux densities and sizes are given in Table 2, which also lists the 4.9 and 8.5 GHz flux densities from Paper I. At all the frequencies the sources were split into the smallest meaningful number of components visible in the overall structure, although at 15 GHz a larger number of features was usually found to be necessary because of the higher resolution. Compact components were taken into account only if they had a peak brightness $\geq 3\sigma$. Extended sub-components were taken into account only if they contribute more than $\sim 10\%$ to the main component flux density.

For the simplest structures one/two Gaussian component fits were performed using the AIPS task JMFIT, which provided component positions, total flux densities, deconvolved (half maximum) sizes (major and minor axis) and the major axis position angles (PA). For more diffuse features (not reliably fitted by a multiple-Gaussian model) flux densities were determined by means of TVSTAT and angular sizes were measured from the lowest reliable contour in the image (an “*” in Table 2 marks such cases). For the few cases (“ext” in Table 2) in which diffuse structure surrounded compact components, the flux densities were derived by subtracting the compact

Fig. 2. Comparison between the VLA 15 GHz integrate flux densities and those extrapolated from the data in Paper I. The line has a slope of one.

components (flux densities obtained using JMFIT) from the source integrated flux density. The sizes were estimated from the lowest reliable contours in the images. Finally, in order to better identify the same component at both low and high frequencies, an over-resolved image at 8.5 GHz (“*” in Table 2) was used in some cases. It was obtained by imaging the 8.5 GHz data using the sampling of the 15 GHz data and restoring the δ -components with the 15 GHz beam. The new images allowed us to find 27 ($\approx 50\%$) cores or core candidates (“Core” in Table 2). This will be discussed in Sect. 4.2.

A comparison of the integrated 15 GHz flux densities in our images, S_{meas} , (Col. 7, line “T”, of Table 2) with an extrapolation to 15 GHz from the VLA data at 4.9 and 8.5 GHz from Paper I has been made. The result is shown in Fig. 2.

There is a good agreement between the two sets of data. In 70% of the cases the two flux densities differ by $\leq 20\%$. The sources with the largest deviations, discussed in detail in Sect. 3, are characterized by low surface brightness extended features which have probably been poorly sampled at 15 GHz. Furthermore, two sources (1027+392 and 2311+469) have bright radio nuclei and it is possible that the differences between their extrapolated fluxes and the measured ones (ratio of 1.24 and 0.7 respectively) are caused by core variability. Excluding ten more discrepant radio sources, the average value of $S_{\text{ext}}/S_{\text{meas}}$ is 1.03 ± 0.02 with a dispersion of 0.12. Such a dispersion can be largely accounted for by the combined uncertainties in both the measured and extrapolated flux densities.

3. Notes on individual sources

Here we comment on most of the observed sources; in particular, we highlight the presence of a core or core candidate.

0003+387 – The radio structure is double and the two components are well separated. No extended emission around or between them is seen even at the lower VLA frequencies. This is one of the few sources whose integrated spectrum is definitely fitted by the JP model (see Sect. 4.4.2).

0034+444 – The spectrum of C1 seems to flatten above 8.5 GHz. If this component were, or contained the core, this would be a double source with a very asymmetric brightness distribution.

0039+391 – The core candidate (component C in Fig. 1) is derived from a comparison between the 15 GHz image and the 8.5 GHz over-resolved (not shown) one.

0039+398 – The integrated radio spectrum flattens below ≈ 0.4 GHz. The core candidate suggested in Paper I has been rejected as a new core candidate component (C2 in Fig. 1, not seen in the previous low frequency images) has appeared in the 15 GHz image.

0039+412 – The spectrum of the southern component appears to be very steep owing to missing flux density at 15 GHz. Component Cc turns out to be the source core.

0049+379 – A core candidate (component C in Fig. 1) appears in the 15 GHz image within the extended emission to the north of the southern component.

0110+401 – The source is dominated by a bright inverted spectrum core ($\alpha_{8.5}^{15} \sim -0.31$) and a one-sided jet. There is no evidence for a counter-jet. Extended low surface brightness emission, resolved out at 15 GHz, surrounds the main structures. It is likely that the source is being seen projected at a small angle to the line of sight.

0120+405 – A core candidate is visible between the East and West components: it is not visible at lower frequencies and its spectrum is likely to be inverted.

0123+402 – The source has been imaged at 1.7 GHz by MERLIN and EVN with resolutions of ≈ 160 and ≈ 40 mas respectively (Paper III). In the 4.8 and 8.5 GHz VLA images this object has the same very unequal triple structure as in the MERLIN ones. In our 15 GHz image the northern component has been completely resolved out.

0128+394 – The core candidate suggested in Paper I has not been confirmed.

0137+401 – Component C has been confirmed as the core component. At 15 GHz it is the brightest feature and accounts for 64% of the total flux density.

0140+387 – This is one of the few sources whose integrated spectrum is definitely fitted by the JP model (see Sect. 4.4.2). None of the components visible at 15 GHz can be considered a “bona fide” core.

0144+432 – The bright northern component has $\alpha_{8.5}^{15} = 0.40$, but we do not consider it as a core since it is strongly polarized (15%) at 8.5 GHz.

0213+412 – The central component is clearly extended at 15 GHz, but its high frequency spectrum is definitely flat. We interpret its structure as the superposition of the true core plus a short jet. The integrated spectrum of the whole source may turn over at ≈ 150 MHz.

0222+422 – If all the flux density measurements are considered, the integrated spectrum is better fitted by a JP model, (see Sect. 4.4.2) but this is probably an artifact arising from missing flux density in the southern lobe. Therefore, the 15 GHz data have not been included in the model fit. The weak (peak < 0.2 mJy/beam) component, centrally located between the two lobes in the image shown in Paper I, and which has

been suggested as the candidate core, has not been detected at 15 GHz.

0254+406 – The source has a very bright hot-spot in the S lobe. There is no evidence for a hot-spot in the NW lobe. The core candidate (peak < 0.2 mJy/beam) suggested in Paper I is not confirmed.

0701+392 – The core (component C in Fig. 1) is clearly detected at 15 GHz and has an inverted spectral index between 8.5 and 15 GHz. The integrated spectrum may turn over at ≈ 150 MHz.

0722+393 – The integrated spectrum turns over at ≈ 200 MHz. The source could be either a double source with a very asymmetric brightness distribution or a core-jet source, with the core not yet resolved from the jet by our observations.

0729+437 – The core candidate (component C in Fig. 1) is visible at 15 GHz, but is not seen in the over-resolved 8.5 GHz image, suggesting that it has an inverted spectrum.

0744+464 – A core candidate (component C in Fig. 1) shows up at 15 GHz.

0805+406 – The source is dominated by a bright flat spectrum core (component W in Fig. 1 as in Paper I) and a knotty (knots C and E) one-sided jet. The integrated (optically-thin) spectrum is straight up to 30 GHz. All this structure is embedded in low surface brightness extended emission. In the 4.9 and 8.5 GHz images (see Paper I) there is a steep-spectrum extended structure to the North-West which is not detected in our 15 GHz image. We have assumed that this diffuse component is an unrelated source, although the hypothesis that it is a second lobe cannot be discarded.

0809+404 – This is a very asymmetric double. The brightest component is compact. A 1.7 GHz VLBA image in Paper II shows it to have a very amorphous structure with a low brightness feature which seems to point toward the fainter component. The integrated spectrum may turn over below ≈ 150 MHz.

0814+441 – Component C (Fig. 1), which we identify as the core, has a flat spectrum between 4.9 and 8.5 GHz ($\alpha_{4.9}^{8.5} = 0.23$), and seems to steepen between 8.5 and 15 GHz ($\alpha_{8.5}^{15} = 1.4$). However, variability cannot be excluded. Some flux density may be missing at 15 GHz in component W because of resolution and the diffuse emission which surrounds it has been resolved almost totally.

0856+406 – At the lower frequencies this source has a double structure with flux density ratio $\approx 1.7/1$. At 15 GHz the fainter component (W) is not detected. The integrated spectrum is better fitted by the JP model (see Sect. 4.4.2).

0930+389 – Both lobes show two hot-spots. The core candidate suggested in Paper I is not confirmed/detected.

0935+428 – A core candidate (component C in Fig. 1) is detected between the East and West components.

0951+422 – The core candidate suggested in Paper I is not confirmed. The central component is in fact resolved into two nearly identical knots separated by $0''.21$.

0955+390 – The extended low surface brightness emission of the lobes is mostly resolved out at 15 GHz. Component C in Fig. 1 is the core.

1025+390 – The core (C in Fig. 1) is very bright and dominates the source spectrum at high frequencies. The extended

emission is rather amorphous with some indication of a hot-spot in the South component. The morphology seems to be of FRI type and could be reminiscent of a Wide Angle Tail (WAT) often found at the center of galaxy clusters. The core subtracted spectrum is well fitted by the CI model (see Sect. 4.4.2).

1027+392 – Component C1 (Fig. 1), visible at 15 GHz only, is the core candidate. The integrated spectrum may turn over at ≈ 150 MHz.

1044+454 – It is a very asymmetric double with flux density ratio of $\approx 20/1$. At the resolution of the 1.7 GHz VLBA image (Paper II), the brightest and more compact component is again double and asymmetric along the same PA, but on a six-times smaller scale. The source could be either a core jet or a very unequal CSO.

1055+404 – In our 4.9 and 8.5 GHz images the source is clearly a core-jet with the flat spectrum core placed in the N edge of the source structure. In the 15 GHz image the core has disappeared indicating a case of extreme variability of the core.

1128+455 – This source was imaged with MERLIN and EVN at 1.7 GHz (Paper III). It was interpreted as a possible very small WAT radio source. The integrated spectrum may turn over at ≈ 150 MHz.

1136+420 – This is a very asymmetric double. The fainter component is more diffuse and has a steeper radio spectrum than the dominant one. At the resolution of the 1.7 GHz image in Paper II the brighter and more compact component displays a very amorphous structure.

1157+460 – Although the source could have a triple structure, we consider it to be a double with component W being an unrelated source, as also suggested in Paper III. The core candidate is deduced from a comparison with an over-resolved 8.5 GHz image and is undetected in the 1.7 GHz EVN+MERLIN (Paper III).

1201+394 – The central component, C, (Fig. 1) is a candidate core. The flux density from the extended emission is substantially less than would be expected at 15 GHz, primarily because of resolution.

1204+401 – The northern component is mostly resolved at 15 GHz with a consequent loss of flux density. No core candidate can be found.

1216+402 – The northern component is mostly resolved, which probably accounts for much of the missing flux density at 15 GHz. No core candidate can be found.

1217+427 – This is one of the few cases where the radio emission seems to come from hot-spots only, with little lobe emission, if any, at all the frequencies studied by our group. At first sight this source may appear to be a gravitational lens as the ratios of the fluxes of the two components are almost identical at 4.9 and 8.5 GHz. However, at 15 GHz the flux density of the southern component is somewhat less than it should be when compared with the northern one. The X band polarization data in Paper IV also shows the southern component to have a higher fractional polarization ($m = 3.26\%$) than the northern component ($m = 0.56\%$). This indicates the presence of two separate components, which allows us to discard the hypothesis of a gravitational lens.

1220+408 – The low surface brightness, northern component is mostly resolved, which probably accounts for the missing flux density at 15 GHz. The component C1 in Fig. 1 is the source core.

1350+432 – The northern component, which is the only one detected at all the three frequencies, has a radio spectrum which flattens at the high frequencies ($\alpha_{8.5}^{15} = 0.64$ against $\alpha_{4.9}^{8.5} = 1.5$). The overall structure resembles that of a one-sided core-jet with the core embedded in the northern component.

1458+433 – The source has a very bright radio core (component C in Fig. 1). The discrepancy between the measured total flux density exceeding the extrapolated one could be the result of core variability, or to the fact that the contribution from the flat spectrum core becomes relevant at 15 GHz.

2301+443 – The core candidate (S2 in Fig. 1) is derived from a comparison with an over-resolved 8.5 GHz image.

2302+402 – The core candidate (C in Fig. 1) is derived from a comparison with an over-resolved 8.5 GHz image.

2311+469 – The source has a very bright core (C in Fig. 1). After the subtraction of the core flux density, the integrated spectrum is well fitted by the CI model (see Sect. 4.4.2). The difference between the measured total flux density and the extrapolated one (lower) could well be because of core variability.

2322+403 – The core candidate (C in Fig. 1) is derived from a comparison with an over-resolved 8.5 GHz image.

2349+410 – The core (C in Fig. 1) is derived from a comparison with an over-resolved 8.5 GHz image.

4. Discussion

4.1. Radio morphology

A majority of the sources show a “Double/Triple” structure with the radio emission dominated by extended components which can be interpreted as radio lobes. The present discussion is restricted to the fifty-one sources with angular sizes $\geq 0''.6$, i.e. at least five times larger than the VLA resolution at 15 GHz, corresponding to $LLS \sim 1 h^{-1}$ kpc. The morphological classification is based on the data presented in this paper as well as that available in the literature. Twenty-one objects have a detected or candidate core (see Sect. 4.2) with extended emission on both sides of it. According to the definition of Readhead et al. (1996) we classify them as Medium Symmetric Objects (MSOs). Nineteen other sources show a double morphology similar to the above and, although the core is not detected, they are also considered to be MSOs. Approximately 55% of these forty sources have similar hot-spots on both sides and in four of them (0003+387, 0729+437, 1143+456, 1217+427) the lobe emission is much weaker than the hot-spot luminosity and is sometimes undetected at cm wavelengths.

Approximately 35% show a dominant hot-spot plus a fainter or more diffuse one in the other lobe. For the remaining 10% the hot-spots are not clearly identified.

Four of the remaining 11 sources (0123+402, 0809+404, 1044+454, 1136+420) have a double structure with very asymmetric flux densities in the two components (see Sect. 4.3). The brighter component is also the more compact one. One of them (0123+402) has been imaged with MERLIN+EVN and

Table 3. Core parameters.

Source	C	core type	h	Ra m	s	°	Dec '	''	S_{15} mJy
(1)	(2)	(3)		(4)			(5)		(6)
0039+391	C	<i>b</i>	00	41	54.980	39	25	21.23	1.2
0039+398	C2	<i>b</i>	00	42	17.625	40	09	49.08	0.7
0039+412	C _c	<i>a</i>	00	42	18.707	41	29	26.30	8.5
0049+379	C	<i>b</i>	00	52	16.926	38	15	28.52	0.5
0110+405c-j	S	<i>a</i>	01	13	17.760	40	26	12.63	44.2
0120+405	C	<i>b</i>	01	23	25.996	40	46	59.16	0.8
0137+401	C	<i>a</i>	01	40	33.755	40	24	13.88	21.3
0213+412	C	<i>a</i>	02	16	30.364	41	31	50.88	63.7
0701+392	C	<i>a</i>	07	04	31.365	39	11	23.14	2.2
0729+437	C	<i>b</i>	07	32	43.705	43	35	40.39	0.7
0744+464	C	<i>b</i>	07	47	43.566	46	18	57.44	1.2
0805+406c-j	W	<i>a</i>	08	09	03.135	40	32	56.22	43.5
0814+441	C	<i>a</i>	08	17	35.419	43	59	34.63	3.5
0935+428	C	<i>b</i>	09	38	16.525	42	38	34.85	0.6
0955+390	C	<i>a</i>	09	58	44.280	38	48	21.88	3.4
1025+390	C	<i>a</i>	10	28	44.275	38	44	36.84	151.4
1027+392	C	<i>a</i>	10	30	16.573	38	57	53.90	34.9
1055+404c-j	N	<i>a</i>	10	58	00.452	40	10	19.78	<0.4
1157+460	C	<i>b</i>	12	00	31.159	45	48	42.52	3.7
1201+394	C	<i>b</i>	12	04	06.830	39	12	18.25	1.0
1220+408	C1	<i>a</i>	12	22	35.240	40	36	21.12	5.2
1458+433	C	<i>a</i>	15	00	29.964	43	09	51.54	10.5
2301+443	S2	<i>b</i>	23	03	45.351	44	39	06.15	4.1
2302+402	C	<i>b</i>	23	04	54.646	40	28	53.50	2.9
2311+469	C	<i>a</i>	23	13	48.165	47	12	14.94	108.0
2322+403	C	<i>b</i>	23	24	48.561	40	40	22.27	1.0
2349+410	C	<i>a</i>	23	51	52.88	41	21	14.8	3.7

Note. Column 1: source name. Core-jet morphologies are indicated as c-j; Col. 2: core component from Fig. 1; Col. 3: core class defined as in Sect. 4.2; Col. 4: right Ascension (J2000); Col. 5: declination (J2000); Col. 6: core flux density at 15 GHz from Fig. 1.

appears to be an asymmetric triple. The other three still have a somewhat uncertain nature (see notes).

The source 1055+406 definitely has a one-sided core-jet structure and 0110+401 and 0805+406 are dominated by one-sided core-jet structures embedded in low brightness extended emission. Finally, 0034+444, 1027+392, 1128+455 and 1350+432 have uncertain morphologies (see Sect. 3), which are difficult to fit into any of the above classifications. At our resolution and sensitivity jets are rarely seen.

The five sources with angular sizes $\leq 0''.6$ have been well imaged at higher resolution with MERLIN+EVN and, although their cores are not detected, their overall morphologies are of the MSO type.

4.2. Core detection and “Core dominance”

The *radio core* (“Core” in Table 2) is generally defined as an unresolved (or slightly resolved) component with a “flat” or inverted spectrum. We take as core candidates components which are unresolved in our A configuration data at 15 GHz

and have $S_{15} \geq 5\sigma$. An additional constraint is that they must not be more than a few percent ($\sim 3\%$) polarized at 8.5 GHz.

We classify them as:

- *a* – bona fide cores: components which are well resolved from the more diffuse emission at both 15 and 8.5 GHz and have a flat spectrum ($\alpha < 0.5$);
- *b* – candidate cores: components which are only visible at 15 GHz and whose spectra, from conservative limits on the 8.5 GHz flux densities, are presumably flat or inverted.

Of the fifty-one radio sources with angular size $\geq 0''.6$, fifteen have a core and ten a core candidate. Amongst the five sources with smaller angular size, two (0039+391 and 2301+443) have a core candidate. Core parameters are given in Table 3.

In a number of cases the necessary spectral information has been obtained from the over-resolved image at 8.5 GHz. Comments are given in Sect. 3.

In some cases the observed spectrum is steeper than expected because of the inclusion of extended or jet emission at frequencies less than 15 GHz.

On the basis of the flat (or almost flat) spectrum between 4.9 and 8.5 GHz, nine cores have already been proposed

Fig. 3. Core dominance distribution for the B3-VLA sources (filled circles) and 3CR sources (open circles).

in Paper I. These we classify as *a*-cores. Six other objects, previously proposed as core candidates in Paper I because of their compactness and location within the source structure, have been rejected by the present observations. This emphasises the fact that compactness and central location within a source structure do not guarantee a secure core identification.

For CSS sources with angular sizes $\geq 0''.6$ we have analysed the *core dominance* (*c.d.*) distribution, defined as the *k*-corrected ratio of the 15 GHz core flux density (S_c^{15}) to that of the 4.9 GHz flux density of the extended structure ($S_{\text{ext}}^{4.9}$). The fractional integral distribution, i.e. the fraction of sources with *c.d.* exceeding a given value, is shown in Fig. 3 (filled circles). It has been computed after taking into account the upper limits for the undetected cores using a technique generally referred to as “*survival analysis*”, originally described by Avni (1980). If no core is detected, the core flux density is assumed to be the 5σ average noise (i.e. ≈ 0.5 mJy), except when the core detectability rises to higher levels because of diffuse emission. The *c.d.* distribution can be recovered reliably down to a value of *c.d.* ≈ 0.003 , above which we reach $\approx 50\%$ of the total. The quasars have larger values of *c.d.*, three of them (one with a core-jet structure) having values above 0.1. The two other core-jets (empty fields) also have a higher core dominance.

Exclusion of the quasars does not appreciably change the median *c.d.* of the remaining objects (galaxies and empty fields).

No obvious correlation has been found between *core dominance* and *LS*. Figure 3 also shows a comparison between the B3-VLA CSS *c.d.* (filled circles) and the *c.d.* distribution for the 3CR sources (open circles; data from Giovannini priv. comm.), which have the same range of luminosity as the B3-VLA sample, but with $LS > 20 h^{-1}$ kpc: the two distributions have the same shape within the errors. This result seems to contradict what is expected from the classical evolution model, since larger sources at the same observed radio power are

expected to have brighter cores than the compact ones. Further studies are therefore necessary to explain this result.

It is known (see e.g. Saikia & Gupta 2003) that CSSs tend to be much more asymmetric in flux density, arm ratio, spectral index and polarization than ordinary large radio sources. This is simply explained if one considers that CSSs evolve in the interstellar medium which is much more inhomogeneous than the intracluster/intergalactic medium into which large radio source lobes expand. The inhomogeneities will mostly affect source properties such as morphology, individual component size, emissivity and polarization, which will therefore result in asymmetries.

4.3. Asymmetries

In order to study the (a)-symmetry properties of the sample we have analysed the distribution of the two component flux density ratio ($S_R = S_+/S_-$, where the symbols + and – refer to the stronger and the weaker components respectively) for all the forty-four sources with angular sizes $\geq 0''.6$ that in Sect. 4.1 have been classified as MSOs or double sources with an asymmetric brightness distribution. For the twenty-one double sources with detected (candidate) cores we have also analysed the arm-ratio ($d_R = d_+/d_-$) distribution, where *d* is the core distance of the largest knot in the lobe, assumed to be the hot-spot.

To carry out the study of the asymmetries, we have used a “low resolution” approach, summing back the sub-components into a major component on each side of the source “center” or core. In the presence of a (candidate) core this is trivial. In other cases the source sub-division is quite obvious. Table 4 lists the forty-four double sources and their parameters with the quoted flux densities being those of the “re-summed” components. From a comparison with Table 2, it is possible to see how each source has been re-summed into a double structure. In two cases (2322+403, 2349+410) one of the components at 4.9 GHz includes the core, which cannot be separated from the more extended structure in the current observations, but is visible and well-isolated at the higher frequency. The 4.9 GHz flux densities for these components have been determined by subtracting estimated values for the cores from the total flux densities. Flux densities obtained in such way are marked with $\star$ in Table 4. Candidate cores showing up only at 15 GHz are assumed to have inverted spectra and their contributions at lower frequencies have been neglected.

4.3.1. Flux density ratio (S_R)

Figure 4a shows the distribution of the flux density ratio of the strongest to the weakest component. Approximately 45% of the sources have $S_R < 2$ and can be considered roughly symmetric in flux density. Five of those remaining have $S_R \gg 10$.

In Fig. 4b we plot S_R vs. *L**LS*. The plot shows that the dispersion in S_R is smaller above ~ 9 kpc, i.e. the larger radio sources appear to be more symmetric (see also Fig. 4a). Among radio sources with $L*LS* > 9 kpc only 1/17 has $S_R > 4$ compared with the 10/27 of the small objects. The probability that this effect is due to random fluctuations is $\approx 1\%$. Double$

Table 4. Relevant parameters for double sources.

Source	C	$S_{4.9}$ mJy	$S_{8.5}$ mJy	S_{15} mJy	α	arm-length h^{-1} kpc
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0003+387	N	53.5	22.7	7.5	[1.77]	
	S	51.9	22.8	10.2	1.46	
0039+398	E	11.0	4.9	2.7	[1.26]	6.27
	W	214.1	111.9	59.4	1.15	9.55
0039+412	N	90.1	48.8	26.3	1.11	3.83
	S	14.8	7.7	2.2	[1.72]	4.67
0041+425	N	53.7	26.6	11.9	1.36	
	S	88.5	48.0	30.7	[0.95]	
0049+379	N	124.6	56.7	28.1	1.34	4.57
	S	50.2	19.7	8.6	1.58	1.55
0120+405	E	133.8	68.1	33.2	1.25	5.79
	W	35.5	19.7	9.9	1.15	4.43
0123+402	N	2.6	1.6	<0.3	0.90	
	S	34.9	18.1	8.1	1.31	
0128+394	N	44.5	19.7	14.5	[1.00]	
	S	36.6	17.9	4.0	[2.00]	
0137+401	N	19.9	9.2	2.4	[1.91]	8.69
	S	36.0	19.9	9.4	1.21	8.95
0140+387	N	41.6	11.8	5.5	[1.81]	
	S	35.5	14.2	4.2	[1.92]	
0144+432	S	67.3	34.9	17.6	1.20	
	N	32.7	19.8	15.7	[0.66]	
0213+412	N	30.0	14.0	5.6	1.51	3.86
	S	55.1	27.7	12.2	1.36	3.91
0222+422	N	46.6	22.1	7.7	[1.62]	
	S	19.1	9.9	3.6	[1.50]	
0228+409	E	24.1	13.8	8.0	0.99	
	W	76.0	40.8	20.1	1.20	
0254+406	N	44.0	21.0	8.6	1.47	
	S	103.1	58.9	36.8	0.93	
0255+460	E	75.3	39.9	11.4	[1.70]	
	W+C	167.2	93.3	57.6	0.96	
0701+392	E	32.5	20.7	7.4	[1.34]	4.03
	W	144.3	85.2	47.7	1.00	3.73
0729+437	N	22.4	14.4	5.8	[1.22]	4.17
	S	111.4	67.5	42.7	0.86	1.49
0744+464	E	18.5	9.1	3.6	1.47	3.36
	W	124.9	71.5	43.5	0.95	1.77
0809+404	E	407.6	263.3	156.7	0.86	
	W	4.2	3.5	2.0	[0.67]	
0810+460	S	144.8	83.2	46.4	1.02	
	N	140.3	73.5	28.0	1.45	
0814+441	E	40.2	22.3	7.7	[1.49]	3.15
	W	22.7	11.5	2.6	[1.96]	3.87
0856+406	E	24.6	9.6	4.7	[1.49]	
	W	13.7	5.7	<0.2	1.63	

Table 4. continued.

Source	C	$S_{4.9}$ mJy	$S_{8.5}$ mJy	S_{15} mJy	α	arm-length h^{-1} kpc
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0930+389	N	32.6	18.5	7.3	[1.35]	
	S	37.4	21.0	12.8	0.96	
0935+428	E	63.3	34.6	24.3	[0.86]	3.04
	W	57.9	32.8	12.1	[1.41]	2.75
0951+422	N	70.5	45.5	22.1	[1.05]	
	S	28.5	14.7	4.8	[1.61]	
0955+390	E	63.8	38.0	14.0	1.11	8.49
	W	85.3	51.8	26.9	[1.97]	6.40
1025+390	N	50.5	32.0	13.7	[1.18]	2.44
	S	89.1	53.5	25.3	[1.13]	2.82
1044+454	N	86.2	39.6	21.4	[1.25]	
	S	3.3	1.3	1.3	[0.83]	
1136+420	E	9.0	4.5	<1.4	1.29	
	W	164.5	105.3	61.0	0.89	
1143+456	N	20.8	9.2	4.0	1.48	
	S	116.7	55.7	27.7	1.29	
1157+460	N	218.3	127.4	61.5	1.14	0.80
	S	118.1	59.3	17.4	[1.73]	1.29
1201+394	N	54.2	32.9	9.3	[1.59]	4.54
	S	104.9	65.9	28.5	[1.17]	3.84
1204+401	N	39.9	23.0	3.4	[2.23]	
	S	18.5	9.0	6.8	[0.90]	
1216+402	N	42.3	23.5	8.7	[1.43]	
	S	63.6	37.6	13.4	[1.40]	
1217+427	N	57.7	33.6	22.7	[0.84]	
	S	31.5	18.4	8.5	[1.18]	
1220+408	N	28.0	16.7	4.4	[1.67]	11.20
	Se	73.0	39.5	15.5	[1.40]	6.47
1233+418	N	55.7	38.9	24.4	0.74	
	S	141.5	98.4	64.8	0.70	
1241+411	E	37.7	24.7	10.8	[1.13]	
	W	119.7	82.1	48.1	0.82	
1458+433	N	77.2	45.8	22.7	1.10	1.99
	S	37.5	22.1	9.2	[1.27]	5.14
2302+402	N	375.5	194.0	95.1	1.23	1.23
	S	71.9	35.7	24.1	[0.98]	1.21
2311+469	N	422.5	255.0	170.5	0.81	6.09
	S	221.7	111.6	63.2	1.13	3.36
2322+403	N	24.0	12.7	7.1	1.09	6.00
	S	★72.1	36.2	17.8	1.26	4.00
2349+410	E	★78.4	42.4	30.2	[0.85]	1.57
	W+Wo	39.7	17.2	4.6	[1.94]	1.76

Sub-components from Table 2 have been summed into major “lobes”. Column 1: source name; Col. 2: component; Col. 3: 4.9 GHz flux density; Col. 4: 8.5 GHz flux density; Col. 5: 15 GHz flux density; Col. 6: three-frequency spectral index; Col. 7: hot-spot component distance from the core.

sources with a core (or core candidate) are evenly distributed amongst large and small size radio sources, indicating that the presence of a core does not affect the flux density ratio. This implies that the core detection is not strictly related to

Fig. 4. **a)** *Top*: distribution of S_R for $LLS < 9$ kpc (+45° shaded) and $LLS \geq 9$ kpc (-45° shaded). The last bin includes the five sources (0039+398, 0123+402, 0809+404, 1044+454, 1136+420) with $S_R > 10$. **b)** *Bottom*: S_R plotted as a function of LLS . Circles mark the sources with a (candidate) core; crosses are double sources. The broken curve roughly indicates the upper envelope of the distribution for $S_R \leq 10$.

orientation effects. This will be further discussed in the Sect. 4.3.2. The similarity in the distribution of S_R for sources with and without a (candidate) core also suggests that the assumption that all the sources of Table 4 are doubles (even if we see just their lobes) is basically correct.

4.3.2. Arm ratio (d_R)

Relativistic Doppler boosting and travel time delay may be responsible for flux density and arm length asymmetries. These, assuming the simplified hypothesis that a source is intrinsically symmetric, lead to the relationship $S_R = d_R^{3+\alpha}$ between flux density ratio (S_R) and arm ratio (d_R) where α is the source spectral index.

A plot of S_R vs. d_R^4 for the sources with a (candidate) core is shown in Fig. 5. No correlation is found between d_R^4 and the flux density ratio (Fig. 5).

Fig. 5. Flux density ratio (S_R) of the stronger to the weaker component vs. d_R^4 . Filled and open triangles are sources with $LLS < 9$ kpc and $LLS \geq 9$ kpc respectively.

However, there is a slight indication in Fig. 5 ($\sim 2\sigma$) that sources smaller than 9 kpc (filled triangles) have $d_R < 1$, i.e. the stronger component is closer to the core than the weaker one.

A conservative view would be that the distribution in Fig. 5 implies that the stronger component may be located randomly on either the receding or the approaching side of the core and that the arm ratio asymmetries are not due to orientation effects. This is consistent with the result of the previous section that the radio sources with a core are not any smaller in size than the others.

Therefore the asymmetries must be the result of inhomogeneities in the interstellar medium and the present source sample is a good one to investigate this phenomenology further.

4.4. Spectra

In order to study the spectral properties of our sample two approaches have been adopted:

- we have determined the spectra of the major source components using our own VLA data;
- the integrated spectra of the sources have been obtained using the best available data from the literature in addition to our own VLA data.

4.4.1. Component spectra

Whenever possible the spectral indices of a source's major sub-components (defined as in Sect. 4.3) have been computed between 4.9 and 15 GHz from the three data points using a weighted interpolation with a power law. In $\approx 50\%$ of cases, such fits are good ($\chi^2 \lesssim 4$, i.e. $\geq 95\%$ confidence level). When a linear fit is not a good enough approximation, the spectral indices in Table 4 are in square brackets. In $\approx 80\%$ of the cases in which this occurs, the spectrum is steeper in the range 8.5 to 15 GHz than in the lower frequency interval.

Table 5. References for B3-VLA CSS source flux densities used for the spectral analysis.

Frequency MHz	Reference	Data	%
(1)	(2)	(3)	(4)
151	Hales et al. (1988)	6C Survey	98
327	Rengelink et al. (1997)	WENSS	100
408	Ficarra et al. (1985)	B3 Survey	100
1465	Condon et al. (1998)	NVSS	100
4850	Kulkarni et al. (1990)	Effelsberg	
	Gregory et al. (1996)	GB6	100
4860	Fanti et al. (2001)	VLA	100
8460	Fanti et al. (2001)	VLA	100
10 550	Gregorini et al. (1998)	Effelsberg	100
14 940	this article	VLA	67
32 000	Mack (private communication)	Effelsberg	14
230 000	Klein et al. (1996)	IRAM	24

Note. Column 1: observed frequency; Col. 2: reference; Col. 3: data; Col. 4: percentage of the observed B3-VLA CSS sample. The percentage refers to the sample of 84 sources (see Sect. 4.4.2).

The mean value of the spectral indices is $\alpha_{4.9}^{15} = 1.28 \pm 0.04$ and the mean curvature is $\Delta\alpha = \alpha_{8.5}^{15} - \alpha_{4.9}^{8.5} = 0.21 \pm 0.07$.

We have also determined the mean radio spectra of the components as a function of the flux density asymmetry parameter S_R . The mean values of α for the stronger and for the weaker components are: $\alpha_+ = 1.18 \pm 0.05$ and $\alpha_- = 1.34 \pm 0.06$. So, there is some indication at the 2σ level that the fainter components have a steeper high frequency spectrum.

4.4.2. Integrated spectra

The integrated radio spectra of most of the sources (obtained from data using the references listed in Table 5) show significant deviations from a power law as they become steeper at high frequencies.

Only in a few cases (see Sect. 3) is there a high frequency flattening and this appears to be related to the presence of a strong, possibly variable core. The steepening is interpreted as being caused by radiation losses from the more energetic electrons.

Two synchrotron spectrum models have been used to fit the radio spectra:

- a Continuous Injection power law spectrum (spectral index α_{inj}) in a constant magnetic field without re-acceleration processes or expansion losses (CI model, Kardashev 1962);
- a passive evolution of a power law energy distribution of the electron population in a constant magnetic field without any input of fresh particles, or re-acceleration processes or expansion losses, (JP model, Jaffe & Perola 1973).

In both models there is a spectral steepening at frequencies greater than a critical value dependent on the magnetic field strength and the source radiative age, $\nu_{br} \propto B^{-3} \tau_{syn}^{-2}$, but in the first model (CI) the spectral index increases as $\alpha = \alpha_{inj} + 0.5$, while in the second model the steepening is more dramatic.

Preliminary fits of the spectra of the 84 B3-VLA CSS sources with $LAS < 0''.6$ have been carried out by Zappacosta (degree thesis) using both models. Our new observations, providing further high frequency data, allow us to better reproduce the spectral steepening for the 56-source sub-sample. In sources with a strong core component, the measured core flux density has been subtracted at 4.9, 8.5 and 15 GHz, assuming it to have a flat spectrum. For sources in which diffuse components have been partially or wholly resolved at 15 GHz, (see Sect. 3) our values have been discarded. The fifty-six sources in our sample can be classified into two different groups dependent upon the accuracy of the fit to the spectrum: forty-two objects have been fitted with $\chi_{red}^2 \leq 2.5$, and amongst these only two sources (0003+387, 0856+406) are definitely better fitted by a JP model; the other sources except one (1044+454 with $\chi_{red}^2 \sim 10$) have $2.5 \leq \chi_{red}^2 \leq 6$ and amongst them only one (0140+387) is definitely better fitted by the JP model. Some examples are shown in Fig. 6.

It has to be stressed that a given spectrum may be well fitted by both models if the change in slope occurs at relatively high frequencies where there are few or no measurements. In practice a moderate spectral steepening within our explored frequency range (0.16 to 15 GHz) could be fitted by a CI model with a break frequency in that range, or by a JP model with a much higher break frequency, typically at the upper edge of or outside our frequency range. The two fits might not be significantly different. Only when there is a large steepening is it possible to discriminate between the two models. In our data this happens when the slope change is at a frequency $\nu \lesssim 4$ GHz; i.e. for $\approx 45\%$ of the sample. In this latter sub-sample only two sources out of twenty-two seem to have a JP spectrum. Sources for which the JP model would have been a better fit, would not recently have been supplied with fresh particles. However, they are not necessarily dying sources, as the nuclear activity could be intermittent, with active phases followed by quiescent ones. Murgia (2003) has discussed the temporal behavior of the radio spectrum in this scenario. When the active phase stops, a high-frequency exponential break occurs and drifts to lower frequencies. However this extreme break quickly disappears following the onset of a new active phase and the ordinary CI spectral shape is recovered.

The distribution of α_{inj} shows a peak at ≈ 0.55 but is skewed toward higher values up to one. Figure 7 shows the distributions of the injection spectra (α_{inj}) and the rest frame break frequencies (ν_{br}) as a function of LS .

In order to derive the source rest frame break frequency, the mean red-shift value of the sample, $z \approx 1.22$, has been assumed for empty fields. There appears to be a correlation (Fig. 7) between the source rest frame break frequency (ν_{br}) and the linear size. The larger (and therefore the older) is the source, the lower is its break frequency. Therefore, the break frequency appears to be an effective clock indicating the source age, although its dispersion is quite large.

Assuming equipartition magnetic fields (typically few hundred μG) the typical ages are in the range from 10^3 to $10^5 h^{-3/7} yr$ and are well correlated with LS , as can be seen in Fig. 8. This correlation is definitely not an artifact introduced

Fig. 6. Spectral fit. *The top panels* refer to the source 0003+387, which results better fitted by a JP model. *The bottom panels* are the same for the source 1350+432, better fitted by a CI model.

Fig. 7. a) *Left:* injection spectral index distribution versus source linear size. Circles are for objects presented in this paper, squares for objects without the 15 GHz data (Zappacosta degree thesis). Filled symbols are for α_{inj} obtained from a CI model and open ones from a JP model. There is no correlation. **b)** *Right:* source rest frame break frequency versus linear size. Symbols are as in **a**).

Fig. 8. Radiative ages distribution as function of the source linear size. Symbols are as in Fig. 7.

by the assumption of equipartition ($B_{\text{eq}} \propto LS^{-6/7}$ implies $\tau_{\text{syn}} \propto LS^{9/7}$).

5. Conclusions

We have presented the results of new VLA observations at 15 GHz for 56 sources of the B3-VLA CSS sample from Fanti et al. (2001). The main conclusions that can be drawn from the data are the following:

- Out of the fifty-six sources, fifteen have a core (a compact component with a flat spectrum) and twelve have a core candidate (a component identified at 15 GHz only and whose spectrum is presumably flat or inverted);
- ~85% of the sources have a double morphology and the radio emission is dominated by extended lobe components. Twenty-one of these have been classified as MSOs as they have a detected core or core candidate and show extended emission on both sides of it. Nineteen have a double structure but no detected core emission and have therefore been classified as possible MSOs. Four sources show a double structure, highly asymmetric in terms of flux density distribution between the two components. The brighter component is also the more compact. One source definitely has a one-sided core-jet structure and two others are dominated by a core-jet structure embedded in a low brightness extended emission. Finally, four sources have uncertain morphology.
- Amongst the double sources, a large fraction (~45%) are symmetric in terms of their component brightness and arm length. No evidence for Doppler boosting has been found. The larger sources are also more symmetric, implying that the asymmetries are caused by inhomogeneities in the interstellar medium rather than orientation effects;
- there is a slight indication that the fainter components of double sources have steeper spectral indices;
- the integrated radio spectra can usually be described by a continuous particle injection model. Only a few sources

are better fitted by a single injection event and a passive spectral evolution. It is only possible to clearly discriminate between the CI and JP models when the spectrum steepens at frequencies ≤ 4 GHz, i.e. for 45% of the sample;

- assuming equipartition magnetic fields, the estimated ages are in the range 10^3 to $10^5 h^{-3/7}$ yr and are well correlated with the source linear size.

Acknowledgements. The VLA is operated by the US National Radio Astronomy Observatory which is operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation. We are very grateful to an anonymous referee for very helpful comments and suggestions and for a careful reading of the manuscript of this paper.

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Online Material

Table 1. The source sample.

Name	Id	m_V	z	$S_{0.4}$ Jy	L_{AS} "	L_{LS} h^{-1} kpc	$\text{Log } P_{0.4}$ $h^{-2} \text{ W Hz}^{-1}$	Morph.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0003+387	G	23.7	1.47	1.36	1.3	5.5	27.65	D
0034+444	G	22.8	2.79	2.25	3.2	11.9	28.53	U
0039+391	G		1.01	1.02	0.38	1.6	27.19	Dc
0039+398	E			1.98	3.7	16	>26.8	Dc
0039+412	E			0.91	2.0	8.5	>26.4	Dc
0041+425	E			1.26	1.0	4.1	>26.6	D
0049+379	G		1.7K	2.55	1.45	6.1	28.10	Dc
0110+401	Q	20.0	1.479	1.08	3.9	16.7	27.44	cJ
0120+405	G		0.84	1.68	2.4	10.1	27.20	Dc
0123+402	G	23.8		0.81	1.22	5.2	>26.4	Ta
0128+394	G	22.9	1.6K	0.92	2.7	11.5	27.53	D
0137+401	Q	18.5	1.62	0.82	4.2	17.6	27.48	Dc
0140+387	G		2.9K	1.81	1.1	4.1	28.55	D
0144+432	Q	21.0	1.26	0.82	4.0	17.2	27.21	D
0213+412	G	21.4	0.515	1.26	2.0	7.3	26.58	Dc
0222+422A	G		3.5K	0.81	3.4	11.9	28.24	D
0228+409A	E			0.90	3.8	16.2	>26.4	D
0254+406	G	24.0	1.224	1.43	4.5	18.9	27.49	D
0255+460	Q	20.5	1.21	1.74	0.75	3.2	27.51	D
0701+392	Q	18.7	1.238	1.17	1.8	7.8	27.35	Dc
0722+393A	E			2.91	0.25	1.0	>26.9	U
0729+437	E			0.90	1.3	5.6	>26.4	Dc
0744+464	G		2.926	1.66	1.4	5.1	28.46	Dc
0805+406	E			1.33	2.5	10.7	>26.6	cJ
0809+404	G		0.551	2.31	1.2	4.5	26.9	Da
0810+460B	G	20.3	0.33R	4.08	1.03	3.0	26.74	D
0814+441	E			0.84	4.0	17.0	>26.4	Dc
0856+406	G	24.3	2.28	1.07	0.8	3.2	28.10	D
0902+416	E			0.93	0.34	1.4	>26.4	D
0930+389	G		2.395	0.92	3.7	14.4	27.97	D
0935+428A	G	24.0	1.291	1.35	1.3	5.5	27.54	Dc
0951+422	Q	20.5	1.783	1.08	2.0	8.3	27.64	D
0955+390	E			1.05	4.8	19.2	>26.5	Dc
1025+390B	G	18.7	0.361	1.54	3.2	9.7	26.36	Dc
1027+392	E			0.83	1.6	6.9	>26.4	Uc
1044+454	G	24.8	4.1K	1.67	1.0	3.2	28.82	Da
1055+404A	E			0.94	2.8	12.1	>26.5	cJ
1128+455	G	18.7	0.40	4.37	0.9	2.9	26.98	U
1136+420	E	21.7	0.829	0.84	1.0	4.3	>26.5	Da
1143+456	G	24.0	0.762	2.26	0.8	3.3	27.26	D
1157+460	G	21.3	0.742	2.88	0.62	2.5	27.29	Dc
1201+394	G	19.0	0.445	1.11	2.1	7.2	26.40	Dc

Table 1. continued.

Name	Id	m_V	z	$S_{0.4}$ Jy	LAS "	LLS h^{-1} kpc	$\text{Log } P_{0.4}$ $h^{-2} \text{ W Hz}^{-1}$	Morph.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1204+401	G	23.0	2.066	1.00	1.6	6.7	27.94	D
1212+380	G	24.0	1.5K	1.08	0.47	2.0	27.63	D
1216+402	G	22.1	0.756	1.00	3.8	15.5	26.88	D
1217+427	E			0.87	2.7	11.7	>26.5	D
1220+408	G	23.2		1.50	4.1	17.6	>26.7	Dc
1233+418	G	18.4	0.25R	1.47	2.2	5.3	26.00	D
1241+411	G	17.7	0.259	0.80	1.0	2.6	25.72	D
1350+432	G	22.1	2.149	0.83	1.6	6.5	28.00	U
1458+433	G	22.3	0.927	1.08	1.6	6.9	27.08	Dc
2301+443	G		1.7K	4.04	0.5	2.1	28.34	Dc
2302+402	E			2.53	0.6	2.6	>26.8	Dc
2311+469	Q	17.5	0.745	4.34	2.4	9.6	27.44	Dc
2322+403	E			0.85	3.2	14.0	>26.4	Dc
2349+410	Q	19.2	2.046	1.38	0.82	3.3	27.99	Dc

Notes. Column 1: source name; Col. 2: optical identification; Col. 3: optical magnitude; Col. 4: red-shift; K and R indicate a photometric red-shift from K or R magnitude (Paper I); Col. 5: flux density at 0.4 GHz; Col. 6: largest angular size; Col. 7: largest linear size computed assuming $z = 1.05$ for sources without z (Paper I); Col. 8: Log of radio luminosity at 0.4 GHz; lower limits have been computed for $z = 0.5$ Paper I; Col. 9: morphological classification: D = double; T = triple; U = uncertain; c = core; cJ = core-Jet; a = asymmetric. Data are from Paper I; Paper IV.

Fig. 1. VLA images. Thick contours: 15 GHz isophotes. First contour is three times the average rms noise level on the images (0.3 mJy/beam); contour levels increase by a factor of 2. Peak flux density is at 15 GHz. Thin contours: 8.5 GHz isophotes. First contour is three times the average rms noise level on the image (0.2 mJy/beam); contour levels increase by a factor of 8. The beams are almost circular with sizes $0''.12 \times 0''.12$.

Fig. 1. continued.

Fig. 1. continued.

Fig. 1. continued.

Fig. 1. continued.

Fig. 1. continued.

Fig. 1. continued.

Fig. 1. continued.

Fig. 1. continued.

Fig. 1. continued.

Table 2. Source parameters derived from images in Fig. 1.

Source	c	$S_{4.9}$ mJy	sc	$S_{8.5}$ mJy	sc	S_{15} mJy	θ_1 mas	θ_2 mas	PA °
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0003+387	T	105.4		45.5		17.7	1300		
	N	53.5		22.7		7.5	82.6	49.7	104
	S	51.9		22.8		10.2	*560	*400	
0034+444	T	183.5		92.2		46.9	1400		
	N	164.5		84.1	N_c	26.4	101.3	58.7	151
					N_{ext}	14.8	*670	*510	
	C1	7.9		4.8		5.7	*510	*160	
	C2	5.1		1.9		<0.3			
	S	6.0		1.4		<0.3			
0039+391	T	75.3		34.8		19.7	340		
	N	10.2	N_c^o	4.7		1.0	77.8	43.0	40
			C_{Core}^o	1.5		1.2	57.4	38.1	133
0039+398	S	65.1	S^o	28.6		17.5	18.1	10.0	122
	T	225.8		117.2		62.8	3700		
	E	11.0		4.9		2.7	266.3	125.8	73
	C1	<0.7		0.4		<0.3			
		...		...	$C2_{Core}$	0.7	9.5	4.7	145
	W	214.1		111.9		59.4	48.7	10.1	68
0039+412	T	131.1		73.5		39.1	2000		
	N	90.1	N_c^o	28.8		15.9	127.4	9.4	17
			N_{ext}^o	20.0		10.4	*680	*360	
	C	26.2	C_{Core}^o	9.9		8.5	17.3	13.2	122
			C_{ext}^o	7.1		2.1	*500	*210	
	S	14.8	S^o	7.7		2.2	203.9	122.8	64
0041+425	T	142.2		74.6		42.6	1000		
	N	53.7		26.6	N_c	5.7	43.3	25.0	73
					N_{ext}	6.2	*510	*300	
	S	88.5		48.0		30.7	71.5	43.3	176
	T	174.8		76.4		36.7	1450		
	N	124.62		56.7		28.1	99.8	35.5	82
0049+379	S	50.2		19.7		8.1	84.6	49.6	12
					C_{Core}	0.5	<45.5	<41.5	62
	T	263.9		184.1		134.5	~680		
0110+401	N	239.9	N_{ext}^o	25.9		52.3	*440	*390	
			N_c^o	63.4		15.3	13.7	12.2	150
			C^o	37.0		22.7	167.7	27.8	29
			S_{Core}^o	36.9		44.2	32.0	8.2	161
	T	169.3		87.8		43.9	2400		
	E	133.8		68.1	E_c	19.7	68.3	30.9	178
					E_{ext}	13.5	*590	*420	
	W	35.5		19.7		9.9	123.9	64.0	49
		...		...	C_{Core}	0.8	<32	<32	

Table 2. continued.

Source	c	$S_{4.9}$ mJy	sc	$S_{8.5}$ mJy	sc	S_{15} mJy	θ_1 mas	θ_2 mas	PA °
(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)	
0123+402	T	74.7		38.1		17.6	590		
	N	2.6		1.6		<0.3			
	C	37.2		18.5		9.5	28.8	27.2	92
	S	34.9		18.1	S	4.1	99.8	21.9	134
					B_{ext}	4.0	*270	*200	
0128+394	T	81.1		39.8		18.5	2700		
	N	44.5	$N1^\circ$	17.1		13.1	32.2	6.0	110
			$N2^\circ$	2.6		1.4	98.0	34.9	97
	S	36.6		17.9	$S1$	3.1	122.7	86.1	50
					$S2$	0.9	53.1	45.9	119
0137+401	T	95.0		55.7		33.1	4200		
	N	19.9		9.2		2.4	193.9	104.2	140
	C_{Core}	39.1		26.6		21.3	53.4	47.3	17
	$S1$	22.4		12.3	S_{ext}	9.4	*1150	*440	
	$S2$	13.6		7.6					
0140+387	T	77.1		28.0		9.7	700		
	N	41.6	N°	11.8		5.5	57.7	23.3	53
	S	35.5	C°	4.7		2.0	73.5	30.8	93
			S°	9.5		2.2	41.9	27.6	98
0144+432	T	111.2		60.6		34.5	~4000		
	N	32.7		19.8		15.7	50.3	23.3	99
	C	11.2		5.9	$C1$	1.2	142.6	106.0	38
	S	67.3		34.9		17.6	*1390	*710	
0213+412	T	221.7		141.0		90.3	2000		
	N	30.0		14.0	$N1$	4.0	133.1	108.7	25
					$N2$	1.6	73.8	52.6	178
	C	136.6	C_{Core}°	73.3		63.7	151.4	16.6	112
			C_{ext}°	25.9		8.8	*660	*380	
	S	55.1		27.7		12.2	*680	*470	
0222+422	T	65.7		32.0		11.3	3400		
	N	46.6		22.1	N_c	6.2	146.4	82.9	133
					N_{ext}	1.5	*560	*370	
	S	19.1		9.9		3.6	*800	*590	
0228+409	T	100.2		54.6		28.1	3800		
	E	24.1		13.8		8.0	*860	*420	
	W	76.0		40.8	W_c	8.5	82.1	73.6	71
					W_{ext}	11.6	*1100	*550	
0254+406	T	149.8		83.3		46.6	~4500		
	N	44.0		21.0		8.6	*520	*400	
	C	0.4		0.3		<0.3			
	S	103.1	S_c	39.8		27.9	152.8	64.5	93
			S_{ext}	19.1		8.9	450.7	344.1	83

Table 2. continued.

Source	c	$S_{4.9}$ mJy	sc	$S_{8.5}$ mJy	sc	S_{15} mJy	θ_1 mas	θ_2 mas	PA °
(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)	
0255+460	T	242.5		133.2		68.8	660		
	E	75.3	E_c^o	18.4		11.4	110.2	91.5	164
			E_{ext}^o	21.5		<0.3			
	W	167.2	W_c^o	75.7		42.3	77.8	32.5	114
			W_{ext}^o	17.6		14.5	176.1	42.4	100
		...		...	C	0.8	123.4	98.6	55
0701+392	T	176.8		105.9		57.3	1800		
	E	32.5	E_c^o	10.0		7.4	95.8	84.6	61
			E_{ext}^o	10.7		<0.3			
		...	C_{Core}^o	0.3		2.2	46.7	34.3	85
	W	144.3	W_c^o	70.3		44.5	69.2	45.0	14
			W_{ext}^o	14.9		3.2	*440	*370	
0722+393	T	252.9		125.6		62.2	250		
			N	116.7		54.1	50.8	26.1	14
			S	8.9		8.1	140.0	60.2	1
0729+437	T	133.8		81.9		49.2	1300		
	N	22.4		14.4		5.8	76.3	47.7	176
	S	111.4		67.5	S_c	25.3	29.7	8.5	22
					S_{ext}	17.4	*440	*290	
					C_{Core}	0.7	43.1	38.3	22
0744+464	T	146.3		83.1		48.3	1400		
	E	18.5		9.1		3.6	35.3	20.8	16
	C	2.9		2.6	$C1_{\text{Core}}$	1.2	103.7	44.2	74
	W	124.9		71.5		43.5	58.0	35.1	37
0805+406	T	171.6		124.9		85.2	1100		
	E	59.9		38.9		16.6	122.6	79.1	58
	C	41.9		25.9		13.2	26.2	10.4	97
	W_{Core}	29.8		30.1		33.8	26.7	25.2	67
	Ext	~40		~30		21.6	~1100		
0809+404	T	411.8		266.8		158.7	1200		
	E	407.6		263.3		156.7	45.4	40.8	75
	W	4.2		3.5		2.0	162.2	36.4	22
0810+460	T	285.1		156.7		74.4	630		
	N	140.3	N^o	73.5		28.0	110.9	34.3	75
	S	144.8	$S1^o$	59.8		34.6	62.3	16.0	48
			$S2^o$	23.4		11.8	192.9	79.0	50
0814+441	T	71.6		41.5		14.0	2280		
	E	40.2		22.3		7.7	*818	*386	
	C_{Core}	8.7		7.7		3.5	61.6	25.4	68
	W	22.7		11.5		2.6	*682	*455	

Table 2. continued.

Source	c	$S_{4.9}$ mJy	sc	$S_{8.5}$ mJy	sc	S_{15} mJy	θ_1 mas	θ_2 mas	PA °
(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)	
0856+406	T	38.3		15.3		4.7	800		
	E	24.6		9.6		4.7	<29	<29	
	W	13.7		5.7		< 0.2			
0902+416	T	198.3		131.1		85.6	340		
			N^0	17.4		10.9	85.8	19.4	66
			S^0	113.7		74.7	78.5	10.7	173
0930+389	T	70.9		40.2		19.8	3700		
	N1	28.6		15.5		5.4	63.5	17.4	35
	N2	3.3		2.1		1.6	<39	<39	
	N3	0.7		0.9		<0.3			
	C	0.9		0.7		<0.3			
	S	37.4	S1	12.6		6.7	<41	<41	
0935+428			S2	8.4		6.1	160.7	83.8	52
	T	121.2		67.4		37.0	1300		
	E	63.3	$E1^0$	30.2		21.1	40.9	10.9	85
			$E2^0$	4.4		3.2	285.7	40.5	73
		...		...	C_{Core}	0.6	<52.6	< 40.0	38
	W	57.9	$W1^0$	21.1		6.7	52.3	16.2	177
0951+422			$W2^0$	11.7		5.4	89.9	15.6	64
	T	161.4		107.1		57.1	2000		
	N	70.5	N_c^0	18.3		15.8	152.8	74.3	164
			N_{ext}^0	27.2		6.3	*590	*340	
	C	62.5	$C1^0$	25.1		15.9	42.8	18.9	39
			$C2^0$	21.7		14.3	56.8	24.9	57
0955+390	S	28.5		14.7		4.8	325.9	39.6	173
	T	152.8		93.4		43.3	~4800		
	E	63.8		38.0	E_{ext}	14.0	*1000	*500	
	C_{Core}	3.7		3.6		1.8	< 40.0	< 40.0	
1025+390	W	85.3		51.8	W_{ext}	26.9	*1000	*500	
	T	310.9		226.2		190.4	~3200		
	N	50.5		32.0		13.7	~1430		
	C_{Core}	171.3		140.7		151.4	37.7	18.4	160
1027+392	S	89.1		53.5		25.3	~1110		
	T	158.0		104.0		55.7	~1600		
	C	127.0	$C1_{\text{Core}}^0$	38.5		34.9	72.4	53.5	135
			$C2^0$	15.8		6.6	66.1	19.2	70
1044+454	Ext	31.0		49.7		14.2	*960	*380	
	T	89.5		40.9		22.7	1000		
	N	86.2		39.6		21.4	88.7	17.5	37
	S	3.3		1.3		1.3	179.2	46.4	64

Table 2. continued.

Source	c	$S_{4.9}$ mJy	sc	$S_{8.5}$ mJy	sc	S_{15} mJy	θ_1 mas	θ_2 mas	PA °
(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)	
1055+404	T	121.3		72.8		42.8	2800		
	N_{Core}	4.1		4.5		<0.4			
	C	103.0		60.6	C_{c}	26.1	78.3	23.6	62
					C_{ext}	11.4	*740	*530	
	S	14.3		7.7		5.3	*530	*470	
1128+455	T	665.4		403.8		209.4	~900		
			N	142.5		62.6	118.2	18.9	143
			S	246.4		134.2	56.1	37.2	141
			Ext	14.9		12.6	*420	*320	
1136+420	T	173.5		109.8		62.5	1000		
	E	9.0		4.5		<0.9			
	W	164.5		105.3		61.0	49.3	32.9	74
1143+456	T	137.5		64.9		31.7	800		
	N	20.8		9.2		4.0	136.4	27.0	39
	S	116.7		55.7		27.7	36.0	35.5	106
1157+460	T	363.8		200.5		88.0	~800		
	N	218.3		127.4	N_{I}	61.5	32.1	17.6	173
					C_{Core}	3.7	90.0	32.5	9
	S	118.1		59.3		17.4	78.1	33.2	10
	W	27.4		13.8		5.4	65.9	20.5	59
1201+394	T	159.1		98.8		38.4	2100		
	N	54.2		32.9	N_{ext}	9.3	~1030		
	...		$C_{\text{Core}}^{\text{o}}$	1.4		1.0	<80		
	S	104.9	S_{c}^{o}	27.6		20.7	91.8	44.6	41
			$S_{\text{ext}}^{\text{o}}$	38.3		7.8	*610	*410	
1204+401	T	58.4		32.0		10.2	1600		
	N	39.9		23.0		3.4	*370	*220	
	S	18.5		9.0		6.8	36.2	21.5	92
1212+380	T	63.8		33.3		12.8	300		
	N	36.5		20.1		9.5	36.7	8.1	113
	S	27.3		13.2		3.3	108.6	32.8	136
1216+402	T	105.9		61.1		22.1	3800		
	N	42.3		23.5		8.7	*1300	*600	
	S	63.6	S_{c}	18.6		5.8	65.2	10.2	47
			S_{ext}	19.0		7.6	*900	*660	
1217+427	T	89.2		52.0		31.2	2700		
	N	57.7		33.6		22.7	32.1	30.0	115
	S	31.5		18.4		8.5	59.4	27.4	102
1220+408	T	114.1		64.6		26.9	4100		
	N	28.0		16.7	N_{ext}	4.4	~2000		
	C	13.1	$C1_{\text{Core}}^{\text{o}}$	5.6		5.2	41.2	14.7	125
			$C2_{\text{ext}}^{\text{o}}$	2.8	$C2_{\text{c}}$	1.7	51.3	18.8	66
	S_{ext}	73.0		39.5		15.5	~1520		

Table 2. continued.

Source	c	$S_{4.9}$ mJy	sc	$S_{8.5}$ mJy	sc	S_{15} mJy	θ_1 mas	θ_2 mas	PA °
(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)	
1233+418	T	271.0		184.1		108.6	~2200		
	N	55.7		38.9		24.4	340.2	240.8	52
	C	41.8		28.8		16.4	128.7	77.1	29
	S	141.5		98.4	S_1	59.2	92.3	63.6	148
					S_2	5.6	60.5	27.1	8
	Ext	~32		~18		~3	*650	*380	
1241+411	T	157.4		106.8		58.9	~1000		
	E	37.7		24.7		10.8	148.8	113.7	116
	W	119.7		82.1		48.1	41.6	17.5	41
1350+432	T	28.6		12.4		5.4	1600		
	N_{Core}	18.2		7.8		5.4	80.4	26.8	99
	S	10.4		4.6		<0.3			
1458+433	T	147.0		89.4		45.1	1600		
	N	77.2	N^o	45.8		22.7	223.9	193.0	161
	NW	~2.5		~0.3		<0.3			
	C	23.3	C_{Core}^o	17.2		10.5	24.9	12.3	120
	S	37.5	S^o	22.1		9.2	114.5	18.4	45
2301+443	T	261.1		114.5		55.0	500		
	N	50.5	N^o	18.6		7.7	76.6	50.2	59
			B^o	5.5		2.1	198.8	43.7	61
					$S_{2\text{Core}}$	4.1	58.8	27.4	57
	S	210.6	S_1^o	90.4		41.1	25.9	26.7	159
2302+402	T	447.4		229.7		122.1	600		
	N	375.5	N	194.0		95.1	40.6	14.4	149
					C_{Core}	2.9	86.3	34.3	105
	S	71.9	S	35.7		24.1	102.8	85.8	154
2311+469	T	702.9		412.8		341.7	2400		
	N	422.5	N_c^o	217.8		153.7	91.9	64.6	91
			N_{ext}^o	37.2		16.8	*630	*310	
	C_{Core}	58.7		46.2		108.0	18.7	5.1	141
	S	221.7		111.6		63.2	*740	*630	
2322+403	T	96.1		48.3		25.9	3200		
	N	24.0	N^o	12.7		7.1	*900	*320	
			C_{Core}^o	0.4		1.0	56.3	52.1	154
	S	72.1	S_c^o	19.2		11.9	85.1	52.6	160
			S_{ext}	17.0		5.9	*720	*450	
2349+410	T	125.5		64.6		38.5	1200		
	E	85.8	E^o	42.4		30.2	54.4	23.9	123
			C_{Core}^o	5.0		3.7	51.3	47.3	71
	W	39.7	W^o	17.2		4.6	90.3	59.4	73

Notes. Column 1: source name; Cols. 2 and 3: component label and flux density at 4.9 GHz (Paper I; Paper IV) [T, N, S, E, W = Total, North, South, East, West]; “ext” = extended component; “c” = compact component; “Core” = core component; “...” = undetected; Cols. 4 and 5: sub-component label and flux density at 8.5 GHz (Paper I; Paper IV). “ext”, “c”, “Core” & “...” as in Cols. 2; “ o ” = over-resolved component; Cols. 6 and 7: sub-component label and flux density for the present 15 GHz images; “ext”, “c” & “Core” as in Cols. 2; Col. 8: component deconvolved angular size of major and minor axis and position angle of the major axis from JMFIT at 15 GHz. For diffuse components (marked by an “*”) linear sizes are derived from the images.