A radio study of the double-double radio galaxy 3C293

S. A. Joshi1, S. Nandi2, D.J. Saikia1, C.H. Ishwara-Chandra1 and C. Konar3

1 National Centre for Radio Astrophysics, TIFR, Pune University Campus, Post Bag 3, Pune 411 007, India
2 Aryabhatta Research Institute of Observational Sciences, Manora Peak, Nainital 263 129, India
3 Institute of Astronomy and Astrophysics, Academia Sinica, P.O. Box 23-141, Taipei 10617, Taiwan, R.O.C.

ABSTRACT
We present radio continuum observations at frequencies ranging from $\sim$150 to 5000 MHz of the misaligned double-double radio galaxy, DDRG, 3C293 (J1352+3126) using the Giant Metrewave Radio Telescope (GMRT) and the Very Large Array (VLA). The spectra of the outer lobes and the central source are consistent with being straight, indicating spectral ages of $\lesssim 17-23$ Myr for the outer lobes, and $\lesssim 0.1$ Myr for the central source. The north-western lobe has a prominent hotspot suggesting that the interruption of jet activity is $\lesssim 0.1$ Myr, consistent with the age of the inner double. The time scale of interruption of jet activity appears significantly smaller than observed in most other DDRGs which are often associated with giant radio sources. These observations suggest that there is a wide range of time scales of interruption of jet activity in active galaxies.

Key words: galaxies: active – galaxies: nuclei – galaxies: individual: 3C293 – radio continuum: galaxies

1 INTRODUCTION
An important aspect in our understanding of active galactic nuclei (AGN) is whether their nuclear activity is episodic and if so, the duration of their active phases, and the implications of such episodic activity. The extended radio emission in radio galaxies and quasars contains an imprint of the history of nuclear jet activity. The structure and spectra of their lobes of radio emission provide us with an opportunity of studying the time scales of episodic nuclear activity. A striking example of episodic nuclear activity is when new pairs of radio lobes are seen closer to the nucleus before the ‘old’ and more distant radio lobes have faded (e.g. Subrahmanyan, Saripalli & Hunstead 1996; Lara et al. 1999). The ones with two pairs of radio lobes are usually referred to as ‘double-double’ radio galaxies (DDRGs; Schoenmakers et al. 2000a); while an example of one with three pairs of radio lobes has also been reported (Brocksopp et al. 2007). Presently, close to about two dozen good cases of AGN with episodic nuclear activity have been identified from either radio and/or X-ray observations (Saikia & Jamrozy 2009, for a review).

Although in most DDRGs, the outer double appears reasonably well aligned with the inner one (e.g. Saikia, Konar & Kulkarni 2006), 3C293 is a striking example of a DDRG where the inner double is misaligned from the outer one, the misalignment angle being $\sim 35^\circ$. The radio galaxy 3C293 is at a redshift of 0.0450 (Fouque et al. 1992) so that 1 arcsec corresponds to 0.874 kpc in a Universe with $H_0=71$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m=0.27$ and $\Omega_{\Lambda}=0.73$. The optical host galaxy, VV5-33-12, is peculiar with compact knots and multiple dust lanes (van Breugel et al. 1984; Martel et al. 1999; de Koff et al. 2000; Capetti et al. 2000), and appears to be a merger remnant. It has a small companion galaxy situated $\sim 37$ arcsec ($\sim 30$ kpc) towards the south-west (Heckman et al. 1985; Evans et al. 1999; Beswick et al. 2004). Hubble Space Telescope (HST) observations have detected an optical/infrared (IR) jet within the central kiloparsec emitting synchrotron emission at these wavelengths (Leahy, Sparks & Jackson 1999; Floyd et al. 2006). Emonts et al. (2005) have reported evidence of jet-induced outflow of warm gas in 3C293. Broad neutral hydrogen (H I) absorption was observed by Baan & Haschick (1981) using the Arecibo telescope, and has since been studied with a wide range of angular resolutions revealing the complex gas distribution seen in absorption towards the different radio components of the central source (Shostak et al. 1983; Haschick & Baan 1985; Beswick et al. 2002, 2004; Morganti et al. 2003). Evans et al. (2005) have found CO(1-0) gas in both emission and absorption within the central few kiloparsecs. The CO emission appears to be largely distributed in an asymmetric disc rotating about the AGN.
The large- and small-scale structure of 3C293 have been imaged by a number of authors. The outer double-lobed structure has a projected linear size of \(\sim 190 \text{ kpc}\), and resembles an FRII radio galaxy. However, the two lobes are highly asymmetric in intensity. The north-western component has a hotspot which is brighter than the peak of emission at the outer extremities of the southern lobe by a factor of \(\sim 10\) (e.g. Bridle, Fomalont & Cornwell 1981; Beswick et al. 2004). The prominent central source has a steep radio spectrum, and when observed with high angular resolution resembles a compact double-lobed source with multiple components and a flat-spectrum radio core (Akujor et al. 1996; Beswick et al. 2004, and references therein; Giovannini et al. 2005). The projected linear separation of the two prominent peaks on opposite sides of the nucleus is \(\sim 1.7 \text{ kpc}\), and has been interpreted to represent a more recent cycle of AGN activity, reminiscent of 3C236. However, 3C293 has a relatively small overall projected linear size compared with most DDRGs which are over approximately a Mpc in size. Also, the inner double of 3C293 has diffuse extended emission beyond the two prominent peaks; the total extent of the inner source including the extended emission is \(\sim 4.2 \text{ kpc}\). Akujor
et al. (1996) find the diffuse extended emission to have significantly steeper spectra than the inner components and have considered the possibility that this might represent yet another cycle of activity. Similar resolution data over a larger frequency range would be useful to further explore this possibility.

In this paper, we present the results of low-frequency observations made with the Giant Metrewave Radio Telescope (GMRT) at 154, 240 and 614 MHz, as well as Very Large Array (VLA) observations at 4860 MHz made from archival data. These observations do not resolve the different components of the central source seen in the high-resolution images. We have determined the spectra of the outer and inner lobes over a large frequency range, estimated their spectral ages and discuss the constraints on time scale of episodic activity. The observations and data reduction are described in Section 2. The observational results, including the radio maps and spectra are presented in Section 3. The results are presented in Section 4, while the concluding remarks are given in Section 5.

2 OBSERVATIONS AND DATA REDUCTION

The analysis presented in this paper is based on radio observations made with the GMRT, and as well as on VLA archival data. The observing log for both the GMRT and VLA observations is listed in Table 1.

2.1 GMRT observations

The GMRT observations were made in the standard manner, with each observation of the target-source interpersed with observations of the phase calibrator. 3C286 was observed as the flux density and bandpass calibrator, and all flux densities are on the Baars et al. (1977) scale using the latest VLA values. At each frequency the source was observed in a full-synthesis run of approximately 9 hours including calibration overheads. The data were calibrated and reduced in the standard way using the NRAO AIPS package. Several rounds of self calibration were done to improve the quality of the images.

3 OBSERVATIONAL RESULTS

The observational results on 3C293 are described here. A catalogue of sources detected at 154 MHz within 2.2° of the phase centre, i.e. the position of 3C293, was made (HPBW=3.1°). Those with angular sizes larger than 45 arcsec were compared with the NRAO VLA Sky Survey (NVSS; Condon et al. 1998) images to examine evidence of any steep-spectrum relic emission not detected in the NVSS images at 1400 MHz. No such relic emission was seen in the 154-MHz images, consistent with earlier studies (e.g. Sirothia et al. 2009a), while a possible relic and a couple of extended sources, all seen in the NVSS images, are described briefly in the Appendix. The catalogue of sources detected at 154 MHz with an angular resolution of 15×12.5 arcsec² along PA 73° is available electronically as on-line supplementary material. A total of 320 sources, including 3C293, which have a peak flux density >7-σ have been listed. The value of σ, the primary beam corrected local rms noise, varies from 8.6 mJy beam⁻¹ near 3C293 to typical values of 3–4 mJy beam⁻¹ in regions without a strong source. All but three of the weaker sources, namely, J1352+3059, J1352+3039 and J1357+3111, are seen in the NVSS images at 1400 MHz. Using 5 times the rms noise in the NVSS images yields spectral indices steeper than ~1.2 for these three sources.

3.1 Overall structure of 3C293

The observational parameters and the flux densities estimated from these images are presented in Table 2. These have been estimated from the images made by tapering and weighting the data and convolving the images to match the resolution of the GMRT image at 154 MHz. The flux densities have been estimated by specifying a similar area around the components at the different frequencies. We have examined the variation in flux density while varying the size of the area around the component. Considering these fluctuations as well as calibration errors, the error in the flux density has been estimated to be approximately 15 per cent at 150 and 240 MHz, 7 per cent at 610 MHz and 5 per cent at 4860 MHz.

The source is quite asymmetric in both brightness and location of the outer components. The ratio of separations from the core of the brighter north-western component to the weaker south-eastern one is ∼0.6. The peak brightness of the north-western component is larger by a factor of ≥10, while the ratio of the total flux densities lies between a factor of ∼5 and 7, depending on the frequency of observations (see Table 2). The central source is also highly asymmetric in location, with the ratio of separations from the core of the eastern component to the western one being ∼3. However, the flux densities are more symmetric with the peak brightness ratio being within a factor of ∼2, and the ratio of total flux densities varying between ∼1.2 and 1.6 (cf. Akujor et al. 1996; Beswick et al. 2004). Such asymmetries are often seen in compact steep-spectrum radio sources (cf. Saikia et al. 1995), and the asymmetries observed in 3C293 are likely to be due to a combination of the effects of both orientation and relativistic motion (cf. Jeyakumar et al. 2005).

| Telescope | Array Conf. | Obs. Freq. (MHz) | Bandwidth (MHz) | Primary beam (arcmin) | Obs. Date |
|-----------|-------------|------------------|----------------|-----------------------|-----------|
| GMRT      |             | 154              | 6              | 186                   | 2009 Jan 27 |
| GMRT      |             | 240              | 6              | 114                   | 2008 Dec 22 |
| GMRT      |             | 614              | 6              | 43                    | 2008 Dec 22 |
| VLA       | C           | 4860             | 50             | 9                     | 1984 Oct 04 |

*: VLA archival data.
Table 2. The observational parameters and flux densities. Column 1: frequency of observations in MHz, with the letter G or V representing either GMRT or VLA observations; columns 2–4: the major and minor axes of the restoring beam in arcsec and its PA in degrees; column 5: the rms noise in units of mJy beam$^{-1}$; column 6: component designation, where Cent refers to the central source including the radio core; columns 7 and 8: the peak and total flux densities of the source.

| Freq. | Beam size | rms | Cmp. | $S_p$ | $S_t$ |
|-------|-----------|-----|------|-------|-------|
| MHz   | (")      | (")| (°)  | (mJy) | (mJy) |
| NW    | SE        | Tot |
| NW    | SE        | Tot |
| NW    | SE        | Tot |

3.2 Spectra

The integrated spectrum of 3C293 using the data from Laing & Peacock (1980) and Kühr et al. (1981) and our measurements is shown in Fig. 2. All the flux densities are consistent with the scale of Baars et al. (1977). Excluding the points below 50 MHz which have large uncertainties and the measurement at 178 MHz which is significantly lower than expected from the measurements at 154 and 160 MHz, the spectral index, $\alpha$ ($S \propto \nu^{-\alpha}$), of the source is $0.71 \pm 0.01$.

In Fig. 3 we present the spectra of the north-western, central (middle) and south-eastern (lower) components respectively. For the central component, the core flux density has been subtracted for measurements above $\sim 1400$ MHz, as described in the text.

Using our measurements alone yields the same value for the spectral index.
frequencies of ~1400 MHz and above using the values listed by Bridle et al. (1981), Akujor et al. (1996) and Beswick et al. (2004). The core is relatively weak, even at ~15000 MHz, and has made no significant difference to the spectra. The flux densities of the extended lobes have not been listed by Bridle et al. (1981). The flux densities of all the three components are consistent with straight spectra, the spectral indices being 0.72±0.02 for the central component, and 0.80±0.02 and 0.91±0.03 for the north-western and south-eastern components respectively. The spectral index of the central component, which contributes over 70 per cent of the total flux density of the source, is consistent with the integrated spectral index.

4 DISCUSSION

4.1 Spectral ages

The spectra of the outer components using the total flux densities between 150 and 4860 MHz and that of the inner double using measurements between 150 and 15000 MHz are consistent with a single power-law. We have fitted the spectrum of the inner double after subtracting the core flux density for the Jaffe & Perola (1973; JP), Kardashev-Pacholczyk (KP, Kardashev 1962; Pacholczyk 1970) and the continuous injection (CI, Pacholczyk 1970) models using the SYNAGUE package (Murgia et al. 1999). The break frequency obtained from these fits are rather large (≥7×10^5 GHz) and have huge uncertainties because the spectra are practically straight. We have adopted conservative lower limits to the break frequency to be the highest frequency of our observations.

In order to estimate the spectral ages, we have to estimate the magnetic field strength, which was done in a similar way to that of 3C46 and 3C452 (Nandi et al. 2010). The magnetic field strength has been estimated by integrating the spectrum from a frequency corresponding to a minimum Lorentz factor, γ_min ~10 for the relativistic electrons to an upper limit of 100 GHz, which corresponds to a Lorentz factor ranging from a few times 10^4 to 10^5 depending on the estimated magnetic field strength (see Hardcastle et al. 2004; Croston et al. 2005; Konar et al. 2008, 2009). It has also been assumed that the filling factors of the lobes are unity, and the energetically dominant particles are the radiating particles only, neglecting the contribution of the protons. A cylindrical geometry has been assumed for both the lobes, and the central source, and their sizes have been estimated more reliably from the available higher-resolution images (e.g. Bridle et al. 1981; Akujor et al. 1996). The deconvolved size of the central source estimated from our observations is consistent with that estimated from the higher-resolution image of Akujor et al. (1996).

The equipartition magnetic field estimate for the inner double is 16.92±1.67 nT, indicating that for a conservative break frequency ≥16 GHz, the inferred spectral age is <0.18 Myr. For the extended lobes, where reliable measurements of the total flux density are available up to ~5 GHz, the magnetic field strengths are 1.12±0.11 and 0.88±0.09 nT for the north-western and south-eastern lobes respectively, while the corresponding spectral ages are ≥16.9 and 23.0 Myr respectively for a break frequency ≥5 GHz. For a break frequency of ≥100 GHz, as was adopted by Nandi et al. (2010), the spectral ages are ≥0.07, 3.77 and 5.13 Myr respectively for the central source, and the north-western and south-eastern components respectively. Machalski et al. (2007) have examined the dynamical ages of FRII radio sources and find that these agree with the spectral ages for objects less than 10 Myr, while for a sample of giant radio galaxies the ratio of dynamical age to the spectral age of the lobes lies between ~1 and 5 (Machalski, Jamrozy & Saikia 2009). Lower limits to the dynamical age may be estimated by assuming the velocity of advancement to be c, and an inclination of the source axis to the line of sight to be ~45°. This yields ages of ≥0.3 Myr for the outer north-western hot-spot, and ≥0.006 Myr for the more distant eastern hot-spot of the central source in 3C293.

4.2 Recurrent activity time scale

In addition to the age estimates, one can also constrain the time scale of interruption of jet activity from the presence of a hot-spot in the north-western lobe of 3C293. Hot-spots in the outer lobes have been seen in other sources with evidence of episodic jet activity, although the outer doubles are often diffuse as for example in J1453+3308 (Schoenmakers et al. 2000a; Konar et al. 2006). Examples of sources with hot-spots are the northern lobe of B1834+620 (Schoenmakers et al. 2000b), and the western outer lobe of 4C02.27 (Jamrozy, Saikia & Konar 2009). The hot-spots have typical sizes of ≤10 kpc (e.g. Jeyakumar & Saikia 2000), and are expected to fade in ~10^4 to 10^5 yr after the energy supply has been cut off (e.g. Kaiser, Schoenmakers & Rottgering 2000). This is usually smaller than the time it takes for the material to reach the hot-spots from the radio core, and hence it is reasonable to assume that the hot-spot fades soon after the last jet material has passed through it.

For 3C293, the fraction of emission from the core, f_c, at an emitted frequency of 8 GHz, which is often used as a statistical indicator of the orientation of the jet axis to the line of sight, is ~0.017. The corresponding median value of f_c for galaxies is ~0.002 while for quasars it is ~0.05 (e.g. Saikia & Kulkarni 1994), suggesting that the orientation of the nuclear jet is close to the dividing line between radio galaxies and quasars. We adopt an orientation angle of ~45° to the line of sight. The hot-spot in the north-western lobe implies that it still receives jet material. For an inclination angle, φ~45° and a jet velocity of c, the travel time from the core to the hot-spot is ~0.35 Myr. However, this will be affected by light-travel time effects due to the orientation of the source axis. The high brightness asymmetry and the observed levels of polarization (cf. Bridle et al. 1981) suggest that the north-western lobe is approaching us, indicating that the observed time difference between the ejection of the last material and its arrival at the approaching hot-spot is ~0.1 Myr. To be able to see the hot-spot as well as the inner structure, the interruption of jet activity must be less than ~0.1 Myr, within which period of time the inner double must also form. The estimated spectral age of the inner double assuming a break frequency of ~100 GHz is consistent with this scenario.
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CONCLUDING REMARKS

Estimation of the time scales of recurrent activity is important to constrain models of such activity (e.g. Kaiser, Schoenmakers & Röttgering 2000; Brocksopp et al., 2011), as well as understand possible effects on the host galaxy and its evolution. GMRT and VLA observations of this highly misaligned DDRG have shown that the spectral age of the inner double is likely to be $\lesssim 0.1$ Myr, which is similar to the time scale of interruption of jet activity. The overall linear size of $\sim 190$ kpc, is much smaller than most DDRGs which are known to be over a Mpc in size. For example in the well-studied DDRG J1453+3308, the dynamical and spectral ages of the diffuse outer lobes of are $\sim 215$ and 50 Myr, while that of the inner double is only $\sim 2$ Myr, suggesting a much longer time-scale of interruption (Kaiser et al. 2000; Konar et al. 2006). Reliable identification of signs of episodic activity in sources of different sizes is required to explore the entire range of time scales of episodic activity. For example in the compact steep-spectrum source CTA 21, a compact double-lobed structure with a size of $\sim 12$ mas (Jones 1984; Kellermann et al. 1998), and diffuse emission on scales extending to $\sim 300$ mas (Dallacasa et al. 1995), led Salter et al. (2010) to suggest that CTA 21 may be undergoing repeated cycles of activity. This is consistent with the suggestion of (Reynolds & Begelman 1997) that jet activity in compact sources may be intermittent on time scales of $10^5$ to $10^7$ yr. Objects such as 3C293 help us explore the implications of the intermediate range of time scales of episodic nuclear activity. For example the model by Kaiser et al. (2000) where long time-scales of $\sim 10^7$ yr is required for the dispersion of the clouds of entrained material would not be applicable here. Here, given the small size of the inner double, the hotspots are likely to have formed by interaction of the jets with the interstellar medium of the host galaxy.

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APPENDIX

The images of three of the extended sources detected at 154 MHz are shown here, along with an extract from the catalogue of 320 sources detected at this frequency in the image with an angular resolution of 15×12.5 arcsec² along PA 73°. The catalogue consists of sources with a peak flux density ≥7 times the local rms noise value. The full table is available as on-line supplementary material. Amongst the extended sources detected at this frequency, Fig. 4 shows a wide-angle tailed (WAT) source associated with a galaxy at a redshift of 0.061. This was detected ~2.5° north of the phase centre. A lower resolution image of the source shows diffuse emission towards the south-east which has been estimated to have a spectral index of ~1.02 between 154 and 1400 MHz using the NVSS image, while the WAT has a spectral index of ~0.91. The diffuse blob has a tail extending approximately in the direction of the WAT host galaxy, and is likely to be related to the WAT source. There is no known optical counterpart for this source.

Approximately 2.5° to the south-east of the phase centre we detect the large radio galaxy J1400+3019 (Fig. 5, upper panel), which is associated with a galaxy at a redshift of 0.206, and has an overall angular size of 649 arcsec, indicating a projected linear size of 2170 kpc (Parma et al. 1996; Ishwara-Chandra & Saikia 1999). The spectral index of this source between 154 and 1400 MHz is ~1.01.

Approximately 30 arcmin towards the west of 3C293, the 154-MHz image shows an FRI galaxy, J1356+3126 (Fig. 5, lower panel), which resembles the morphology of 3C31. There are three galaxies in the vicinity of the centroid, of which the one closest to the peak, SDSS J135620.77+312627.3 with a redshift of 0.151 is likely to be the identification. The nearby companion SDSS J135621.36+312631.7 is only ~8.7 arcsec towards the north-east. Although its redshift has not been measured, its separation would be ~23 kpc at a redshift of 0.151 and could be a companion galaxy. It may be relevant to note that NGC383, the galaxy associated with 3C31 has a nearby companion and is a member of a chain of galaxies Arp 331 (e.g. Strom et al. 1983). The overall angular size of the radio source J1356+3126 is ~120 arcsec which corresponds to a projected linear size of ~310 kpc. Its spectral index is 0.6 between 154 and 1400 MHz.

Table 3. The first 15 sources from the list of sources detected at 154 MHz within 2.2° of the phase centre (HPBW~3.1°). Sources with a peak flux density ≥7σ, where σ is the primary beam corrected local rms noise in units of mJy beam⁻¹ have been listed. There are a total of 320 sources. Columns 1 and 2: The right ascension (h:m:s) and declination (d:m:s) in J2000 co-ordinates; columns 3 and 4: the peak and integrated flux densities in units of mJy beam⁻¹ and mJy respectively estimated from the primary beam corrected image; column 5: the angular size of the source in arcsec where U denotes an unresolved source. The flux densities and source sizes have been estimated as described in Sirothia et al. (2009b).

| RA (h:m:s) | Dec (d:m:s) | Speak mJy/beam | Sint mJy | Size arcsec |
|-----------|-------------|----------------|----------|------------|
| 13:42:08.04 | 31:19:32.6 | 172.1 | 330.4 | 30.7 |
| 13:42:31.58 | 32:03:29.1 | 36.6 | 36.6 | U |
| 13:42:51.04 | 31:37:56.4 | 67.2 | 67.2 | U |
| 13:42:51.39 | 31:11:04.6 | 204.3 | 518.0 | 95.4 |
| 13:43:03.02 | 31:43:50.0 | 2341.9 | 3961.1 | 59.5 |
| 13:43:07.66 | 31:27:50.3 | 319.2 | 497.4 | 44.2 |
| 13:43:08.30 | 30:31:10.7 | 34.0 | 34.9 | U |
| 13:43:13.10 | 32:08:01.0 | 33.0 | 33.0 | U |
| 13:43:28.67 | 31:16:30.0 | 61.2 | 61.2 | U |
| 13:43:53.47 | 32:43:28.5 | 36.0 | 36.6 | U |
| 13:44:00.76 | 32:11:27.3 | 148.1 | 148.1 | U |
| 13:44:26.84 | 31:34:51.7 | 424.3 | 934.2 | 39.5 |
| 13:44:36.79 | 31:04:25.1 | 179.3 | 221.8 | 12.6 |
| 13:44:39.72 | 32:01:23.1 | 1519.7 | 2003.7 | 61.6 |
| 13:44:54.55 | 31:51:43.5 | 34.0 | 34.0 | U |

The double-double radio galaxy 3C293
Figure 4. A WAT source associated a galaxy at a redshift of 0.061 along with evidence of diffuse emission. The upper panel shows the higher resolution GMRT image at 154 MHz with a restoring beam of $15 \times 12.5$ arcsec$^2$ along PA $73^\circ$, while in the middle panel the restoring beam is $41 \times 39$ arcsec$^2$ along PA $159^\circ$. The lower panel shows the NVSS image at 1400 MHz. Crosses mark the position of the optical galaxy.

Figure 5. A known giant radio galaxy with an FRII-type structure (upper panel) and an FRI-type galaxy resembling the morphology of 3C 31 (lower panel). Crosses in the images mark the positions of the optical galaxies. The restoring beam for the giant radio galaxy, J1400+3019, is $41 \times 39$ arcsec$^2$ along a PA=$159^\circ$, while for the FRI galaxy, J1356+3126, it is $15 \times 12.5$ arcsec$^2$ along PA=$73^\circ$. 
The double-double radio galaxy 3C293

Table 4. Sources within 2.2° of the phase centre of the GMRT observations at 154 MHz (HPBW~3.1°). All sources with a peak flux density ≥7σ, where σ is the primary beam corrected local rms noise in units of mJy beam⁻¹ are listed. The values of σ range from 8.6 mJy beam⁻¹ near 3C293 to typical values of 3~4 mJy beam⁻¹ in regions without strong sources. There are a total of 320 sources. All but three of the weaker sources (J1352+3039, J1352+3039 and J1357+3111) are seen in the NVSS images at 1400 MHz. Using 5 times the rms noise in the NVSS images yields spectral indices steeper than ~1.2 for these three sources. Columns 1 and 2: The right ascension (h:m:s) and declination (d:m:s) in J2000 co-ordinates; columns 3 and 4: the peak and integrated flux densities in units of mJy beam⁻¹ and mJy respectively; column 5: the angular size of the source in arcsec where U denotes an unresolved source. The flux densities and source sizes have been estimated as described in Sirothia et al. (2009b).

| RA (h:m:s)   | Dec (d:m:s) | S_{peak} mJy beam⁻¹ | S_{int} mJy | Size '' |
|--------------|-------------|----------------------|-------------|---------|
| 13:42:08.04  | 31:19:32.6  | 172.1 330.4 30.7    |             |         |
| 13:42:31.58  | 32:03:29.1  | 36.6 36.0 U         |             |         |
| 13:42:51.04  | 31:37:56.4  | 67.2 67.2 U         |             |         |
| 13:42:51.39  | 31:11:04.6  | 204.3 518.0 95.4    |             |         |
| 13:43:03.02  | 31:43:50.0  | 2341.9 3961.1 59.5  |             |         |
| 13:43:07.66  | 31:27:50.3  | 319.2 497.4 44.2    |             |         |
| 13:43:08.30  | 30:31:10.7  | 34.0 34.0 U         |             |         |
| 13:43:13.10  | 32:08:01.0  | 33.0 33.0 U         |             |         |
| 13:43:28.67  | 31:16:30.0  | 61.2 61.2 U         |             |         |
| 13:43:53.47  | 32:43:28.5  | 36.6 36.6 U         |             |         |
| 13:44:00.76  | 32:11:27.3  | 148.1 148.1 U       |             |         |
| 13:44:26.84  | 31:34:51.7  | 424.3 934.2 39.5    |             |         |
| 13:44:36.79  | 31:04:25.1  | 179.3 221.8 12.6    |             |         |
| 13:44:39.72  | 32:01:23.1  | 1519.7 2003.7 61.6  |             |         |
| 13:44:54.55  | 31:51:43.5  | 34.0 34.0 U         |             |         |
| 13:44:58.49  | 30:15:53.1  | 334.6 699.0 85.5    |             |         |
| 13:45:10.70  | 32:10:53.7  | 404.8 674.3 23.6    |             |         |
| 13:45:29.69  | 32:27:06.8  | 44.6 44.6 U         |             |         |
| 13:45:38.98  | 30:59:15.5  | 41.2 41.2 U         |             |         |
| 13:45:41.18  | 30:08:35.9  | 36.0 36.0 U         |             |         |
| 13:45:41.63  | 31:24:05.6  | 181.1 336.2 31.1    |             |         |
| 13:45:43.02  | 31:33:41.6  | 102.2 125.4 14.6    |             |         |
| 13:45:48.10  | 32:32:28.0  | 35.6 35.6 U         |             |         |
| 13:45:49.14  | 31:41:19.9  | 32.2 32.2 U         |             |         |
| 13:45:49.56  | 32:07:57.9  | 34.4 34.4 U         |             |         |

RA (h:m:s) Dec (d:m:s) S_{peak} S_{int} Size
| RA (h:m:s) | Dec (d:m:s) | $S_{\text{peak}}$ | $S_{\text{int}}$ | Size |
|------------|-------------|-------------------|-----------------|------|
| 13:48:17.11 31:03:10.1 | 34.3 | 70.4 | 48.5 |
| 13:48:18.18 33:05:55.3 | 33.8 | 33.8 | U |
| 13:48:20.32 30:20:02.9 | 117.3 | 320.7 | 134.8 |
| 13:48:20.71 32:22:14.0 | 24.1 | 24.1 | U |
| 13:48:30.41 32:54:58.8 | 46.9 | 46.9 | U |
| 13:48:31.84 30:39:25.4 | 40.1 | 40.1 | U |
| 13:48:42.13 31:33:04.7 | 163.5 | 191.0 | 26.7 |
| 13:48:42.32 33:10:18.4 | 60.1 | 60.1 | U |
| 13:48:48.02 29:39:18.9 | 2048.4 | 4951.0 | 44.3 |
| 13:48:49.83 31:10:18.5 | 110.0 | 155.3 | 28.8 |
| 13:48:51.08 32:02:28.4 | 63.9 | 121.7 | 48.6 |
| 13:48:52.13 30:29:05.3 | 25.8 | 25.8 | U |
| 13:48:55.10 31:57:32.4 | 394.0 | 502.4 | 41.4 |
| 13:48:56.82 33:17:10.4 | 140.2 | 193.0 | 16.5 |
| 13:48:57.33 29:28:53.7 | 45.7 | 45.7 | U |
| 13:48:59.60 32:59:47.6 | 44.3 | 44.3 | U |
| 13:49:03.00 31:40:09.4 | 34.4 | 34.4 | U |
| 13:49:04.19 32:18:32.2 | 42.0 | 75.4 | 29.0 |
| 13:49:08.61 30:50:52.0 | 43.5 | 43.5 | U |
| 13:49:11.10 31:32:07.2 | 59.7 | 59.7 | U |
| 13:49:11.48 31:40:31.6 | 32.8 | 32.8 | U |
| 13:49:11.68 31:33:49.2 | 30.5 | 30.5 | U |
| 13:49:14.00 33:03:16.9 | 71.7 | 71.7 | U |
| 13:49:29.28 31:22:54.0 | 53.6 | 53.6 | U |
| 13:49:34.12 30:04:34.0 | 39.9 | 39.9 | U |
| 13:49:37.94 31:44:47.2 | 65.5 | 65.5 | U |
| 13:49:39.76 30:08:48.8 | 76.0 | 76.0 | U |
| 13:49:48.26 31:01:54.9 | 86.9 | 164.8 | 29.3 |
| 13:49:50.51 29:35:37.5 | 74.0 | 74.0 | U |
| 13:49:52.63 30:15:22.9 | 55.7 | 185.5 | 118.2 |
| 13:49:58.59 31:04:13.1 | 23.8 | 23.8 | U |
| 13:49:58.52 32:49:56.1 | 72.2 | 133.4 | 54.4 |
| 13:50:00.33 30:04:15.2 | 124.7 | 197.0 | 16.6 |
| 13:50:06.10 31:03:54.3 | 23.8 | 23.8 | U |
| 13:50:11.22 29:42:54.0 | 49.2 | 49.2 | U |
| 13:50:11.84 31:32:34.9 | 24.0 | 24.0 | U |
| 13:50:11.97 30:22:44.8 | 705.9 | 1274.6 | 89.3 |
| 13:50:16.38 32:36:59.4 | 36.2 | 36.2 | U |
| 13:50:18.36 30:37:39.1 | 72.5 | 171.0 | 73.6 |
| 13:50:19.39 32:22:39.8 | 72.7 | 72.7 | U |
| 13:50:20.80 30:32:05.0 | 191.3 | 249.3 | 27.7 |
| 13:50:31.47 30:57:24.9 | 191.2 | 282.2 | 72.7 |
| 13:50:31.90 33:01:34.2 | 49.0 | 215.7 | 118.6 |
| 13:50:32.50 30:10:47.9 | 39.7 | 39.7 | U |
| 13:50:33.48 30:07:51.7 | 28.8 | 60.2 | 32.2 |
| 13:50:35.43 30:40:17.3 | 53.8 | 53.8 | U |
| 13:50:36.64 30:37:30.0 | 79.0 | 79.0 | U |
| 13:50:39.43 29:31:05.9 | 39.9 | 39.9 | U |
| 13:50:45.65 31:28:33.1 | 136.6 | 237.7 | 32.0 |
| 13:50:46.59 30:13:25.7 | 101.8 | 101.8 | U |
| 13:50:47.83 33:07:30.7 | 139.8 | 159.8 | 13.0 |
| 13:50:48.29 33:12:12.3 | 626.9 | 1269.2 | 64.2 |
| 13:50:49.26 33:05:31.0 | 70.4 | 70.4 | U |
| 13:50:49.94 29:42:51.3 | 45.0 | 45.0 | U |
| 13:50:50.05 30:09:12.3 | 244.4 | 319.4 | 26.6 |
| 13:50:52.54 30:34:52.8 | 289.5 | 370.7 | 48.0 |
| 13:50:56.90 33:16:46.3 | 179.0 | 443.3 | 32.7 |
| 13:51:01.11 30:42:44.1 | 33.4 | 33.4 | U |
| 13:51:01.97 32:43:35.9 | 51.7 | 51.7 | U |
| 13:51:02.66 31:14:28.3 | 108.5 | 108.5 | U |
| 13:51:03.14 30:53:56.1 | 387.8 | 674.5 | 57.1 |
| 13:51:11.21 33:17:38.2 | 44.5 | 44.5 | U |
| 13:51:12.55 33:21:57.1 | 127.0 | 249.6 | 37.0 |
| RA (h:m:s) | Dec (d:m:s) | S_{peak} | S_{int} | Size |
|------------|-------------|----------|---------|------|
| 13:54:15.39 | 30:34:06.6 | 53.4 | 53.4 | U |
| 13:54:16.46 | 30:42:05.8 | 35.5 | 35.5 | U |
| 13:54:25.97 | 31:52:17.8 | 37.4 | 37.4 | U |
| 13:54:26.35 | 30:05:35.3 | 79.0 | 100.7 | 19.1 |
| 13:54:30.62 | 33:13:45.1 | 39.3 | 39.3 | U |
| 13:54:32.01 | 32:03:30.6 | 847.1 | 1703.2 | 106.2 |
| 13:54:33.34 | 30:56:04.0 | 225.9 | 267.9 | 47.2 |
| 13:54:33.74 | 29:57:32.4 | 416.0 | 512.7 | 52.1 |
| 13:54:37.29 | 31:44:21.1 | 65.2 | 120.9 | 44.1 |
| 13:54:39.32 | 31:51:51.9 | 36.4 | 36.4 | U |
| 13:54:48.26 | 29:21:05.0 | 104.4 | 157.3 | 20.8 |
| 13:54:50.43 | 33:24:15.3 | 51.1 | 243.0 | 59.3 |
| 13:54:51.32 | 32:47:24.5 | 175.8 | 229.7 | 56.9 |
| 13:54:51.43 | 32:31:58.1 | 89.2 | 89.2 | U |
| 13:54:59.24 | 30:36:07.1 | 714.5 | 764.2 | 13.1 |
| 13:55:01.25 | 29:43:17.1 | 592.9 | 714.8 | 10.9 |
| 13:55:01.36 | 33:06:27.1 | 54.9 | 54.9 | U |
| 13:55:04.58 | 31:32:12.6 | 31.3 | 31.3 | U |
| 13:55:06.00 | 30:34:59.2 | 165.5 | 243.1 | 47.0 |
| 13:55:06.07 | 31:51:31.1 | 90.8 | 90.8 | U |
| 13:55:11.79 | 32:57:42.8 | 134.3 | 134.3 | U |
| 13:55:11.91 | 32:56:12.7 | 109.1 | 109.1 | U |
| 13:55:12.94 | 32:17:35.9 | 379.1 | 750.8 | 54.1 |
| 13:55:13.15 | 32:51:59.0 | 33.1 | 33.1 | U |
| 13:55:14.91 | 31:56:26.7 | 204.1 | 204.1 | U |
| 13:55:16.45 | 29:21:54.3 | 102.7 | 366.0 | 91.2 |
| 13:55:19.29 | 29:25:34.7 | 90.2 | 187.7 | 36.9 |
| 13:55:21.78 | 31:44:39.2 | 240.3 | 869.9 | 64.8 |
| 13:55:21.79 | 31:28:15.9 | 88.8 | 88.8 | U |
| 13:55:22.69 | 30:34:32.2 | 89.8 | 89.8 | U |
| 13:55:25.45 | 29:33:11.6 | 700.6 | 817.4 | 77.4 |
| 13:55:26.94 | 32:34:58.6 | 92.0 | 92.0 | U |
| 13:55:28.65 | 32:19:52.2 | 47.9 | 47.9 | U |
| 13:55:30.13 | 30:31:30.2 | 175.9 | 195.2 | 13.9 |
| 13:55:30.30 | 31:12:36.5 | 108.4 | 108.4 | U |
| 13:55:31.93 | 32:48:28.1 | 44.8 | 44.8 | U |
| 13:55:35.14 | 30:33:21.7 | 53.8 | 79.4 | 25.1 |
| 13:55:35.89 | 29:55:00.8 | 131.7 | 131.7 | U |
| 13:55:37.65 | 32:29:15.3 | 60.9 | 60.9 | U |
| 13:55:39.20 | 32:39:19.6 | 77.7 | 77.7 | U |
| 13:55:41.11 | 30:24:15.1 | 174.0 | 174.0 | U |
| 13:55:46.12 | 32:38:04.6 | 566.6 | 649.8 | 20.2 |
| 13:55:51.35 | 31:37:34.9 | 33.3 | 33.3 | U |
| 13:55:56.72 | 33:29:06.5 | 46.8 | 46.8 | U |
| 13:55:58.28 | 31:08:32.9 | 52.2 | 52.2 | U |
| 13:55:58.79 | 31:19:39.7 | 172.3 | 192.9 | 15.1 |
| 13:56:03.56 | 30:59:00.6 | 34.1 | 34.1 | U |
| 13:56:04.82 | 31:45:07.6 | 107.7 | 107.7 | U |
| 13:56:07.51 | 30:04:55.0 | 105.1 | 172.2 | 21.2 |
| 13:56:08.03 | 31:53:05.3 | 792.1 | 846.2 | 9.9 |
| 13:56:15.53 | 30:52:20.2 | 1037.0 | 1459.4 | 60.0 |
| 13:56:15.66 | 30:06:40.4 | 114.0 | 114.0 | U |
| 13:56:17.08 | 32:21:14.6 | 211.0 | 211.0 | U |
| 13:56:19.79 | 32:03:55.3 | 58.8 | 58.8 | U |
| 13:56:19.96 | 32:26:28.0 | 97.9 | 436.7 | 85.6 |
| 13:56:24.73 | 31:17:06.4 | 173.5 | 282.7 | 39.5 |
| 13:56:29.14 | 30:11:24.3 | 42.7 | 42.7 | U |
| 13:56:30.33 | 28:41:19.8 | 811.5 | 1007.1 | 71.3 |
| 13:56:36.64 | 30:36:17.5 | 29.5 | 29.5 | U |
| 13:56:38.89 | 30:22:30.2 | 212.3 | 212.3 | U |
| 13:56:39.46 | 30:16:51.3 | 57.2 | 57.2 | U |
| 13:56:44.86 | 32:19:46.2 | 2869.4 | 8854.4 | 161.2 |
| 13:56:46.56 | 32:53:48.0 | 51.0 | 51.0 | U |
| 13:56:48.06 | 30:22:40.1 | 338.8 | 619.2 | 95.6 |

The double-double radio galaxy 3C293

RA (h:m:s) Dec (d:m:s) S_{peak} S_{int} Size