A multifrequency study of possible relic lobes in giant radio sources

Sagar Godambe,1,2★ C. Konar,3★ D. J. Saikia1★ and Paul J. Wiita4,5★

1National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, Post Bag 3, Ganeshkhind, Pune 411007, India
2Department of Physics, The University of Utah, Salt Lake City, UT 84112-0830, USA
3Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411007, India
4Department of Physics and Astronomy, Georgia State University, PO Box 4106, Atlanta, Georgia 30302-4106, USA
5School of Natural Sciences, Institute for Advanced Study, Princeton, New Jersey, 08540, USA

ABSTRACT

We present low-frequency observations with the Giant Metrewave Radio Telescope of three giant radio sources (GRSs: J0139+3957, J0200+4049 and J0807+7400) with relaxed diffuse lobes which show no hotspots and no evidence of jets. The largest of these three, J0200+4049, exhibits a depression in the centre of the western lobe, while J0139+3957 and J0807+7400 have been suggested earlier by Klein et al. and Lara et al., respectively, to be relic radio sources. We estimate the ages of the lobes. We also present Very Large Array observations of the core of J0807+7400, and determine the core radio spectra for all three sources. Although the radio cores suggest that the sources are currently active, we explore the possibility that the lobes in these sources are due to an earlier cycle of activity.

Key words: galaxies: active – galaxies: individual: J0139+3957 – galaxies: individual: J0200+4049 – galaxies: individual: J0807+7400 – galaxies: nuclei – radio continuum: galaxies.

1 INTRODUCTION

Giant radio sources (GRSs) are defined to be those which have a projected linear size $\gtrsim 1$ Mpc ($H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_m = 0.27$, $\Omega_{\Lambda} = 0.73$, Spergel et al. 2003), and provide useful insights towards understanding the late stages of evolution of radio sources and probing the external environment on Mpc scales at different redshifts (e.g. Gopal-Krishna, Wiita & Saripalli 1989; Subrahmanyan & Saripalli 1993; Subrahmanyan, Saripalli & Hunstead 1996; Mack et al. 1998; Blundell, Rawlings & Willott 1999; Kaiser & Alexander 1999; Ishwara-Chandra & Saikia 1999, and references therein; Schoenmakers et al. 2000, 2001; Konar et al. 2004; Machalski et al. 2007; Jamrozy et al. 2008; Konar et al. 2008; Machalski et al. 2008).

There have been many attempts to determine the ages of double-lobed radio sources including the GRSs. Most lobes of GRSs exhibit a steepening in spectral index from the outer peaks towards the nuclear region, allowing an estimate of the spectral age, similar to what has been done for double-lobed radio sources of smaller dimensions. For a sample of GRSs observed with the Giant Metrewave Radio Telescope (GMRT) and the Very Large Array (VLA), Jamrozy et al. (2008) have estimated their median age to be $\sim 20$ Myr while their median size is $\sim 1300$ kpc. The spectral age is likely to be a lower limit since the radio emission is often not seen all the way to the nuclear region, and there could also be re-acceleration of particles in the lobes. For the smaller sources, a large number of studies of spectral ages have been made. For example, for a sample of 3CR sources with a median size of 342 kpc studied by Leahy, Muxlow & Stephens (1989) using the Multi-Element Radio Linked Interferometer Network at 151 MHz and the VLA at 1500 MHz, the spectral age was found to have a median value of $\sim 8$ Myr. Similar gradients in spectral index across the lobes have also been seen in smaller sources such as those studied by Liu, Pooley & Riley (1992) which have a median linear size of 103 kpc and a median age of $\sim 1.7$ Myr. There is a clear trend for the spectral age to increase with size, which is broadly consistent with the expectations of dynamical models of the propagation of jets in an external medium (e.g. Falle 1991; Kaiser & Alexander 1997; Jeyakumar et al. 2005, and references therein).

In the course of our study of GRSs, a number of these objects appeared to have diffuse lobes of emission without any prominent peaks of emission towards the outer edges of the lobes. Unlike Fanaroff–Riley Class I sources, these do not have any jets and the radio emission could be from relic lobes. We have chosen three of these sources, namely J0139+3957, J0200+4049 and J0807+7400, for a detailed investigation using the GMRT. Two of these, J0139+3957 and J0807+7400, have been suggested earlier to be relic radio sources by Klein et al. (1995) and Lara et al. (2001), respectively. In this paper, we present the results of multifrequency observations of these three sources at low frequencies with the GMRT, attempt to estimate their spectral ages and explore the possibility that these lobes might be relics from an earlier cycle.
of activity. We also present the core flux densities of J0807+7400 from archival VLA data, and the core spectra of the three sources.

2 OBSERVATIONS AND ANALYSES

Both the GMRT and the VLA observations were made in the standard fashion, with each target source observation interspersed with observations of the phase calibrator. The primary flux density calibrator was any one of 3C48, 3C147 and 3C286 with all flux densities being on the scale of Baars et al. (1977). The total observing time on each source is a few hours for the GMRT observations while for the VLA observations the time on source ranges up to 10 min. All the data were analysed in the standard fashion using the NRAO AIPS package. All the data were self-calibrated to produce the best possible images.

The observing log for both the GMRT and the VLA observations is given in Table 1 which is arranged as follows. Columns 1 and 2 show the name of the telescope and the array configuration for the VLA observations; column 3 shows the frequency of the observations in MHz, while columns 4 and 5 list the sources observed and the dates of the observations, respectively.

3 OBSERVATIONAL RESULTS

The GMRT images of the three sources, J0139+3957, J0200+4049 and J0807+7400, at the different frequencies are presented in Figs 1–3, respectively, while the observational parameters and some of the observed properties are presented in Table 2, which is arranged as follows. Column 1: name of the source; column 2: frequency of observations in units of MHz; columns 3–5: the major and minor axes of the restoring beam in arcsec and its position angle in degrees; column 6: the rms noise in units of mJy beam−1 and column 7: the integrated flux density of the source in mJy estimated by specifying an area enclosing the entire source. We examined the change in flux density by specifying different areas and found the difference to be within a few per cent. The flux densities at different frequencies have been estimated over similar areas. Columns 8, 11 and 14: component designation, where W, C and E denote the western, core and eastern components, respectively; columns 9 and 10, 12 and 13 and 15 and 16: the peak and total flux densities of each of the components in units of mJy beam−1 and mJy, respectively. The superscript g indicates that the flux densities have been estimated from a two-dimensional Gaussian fit to the core component.

4 DISCUSSION AND RESULTS

The integrated flux densities of the sources from our measurements as well as those from the literature are listed in Table 3, which is self-explanatory, while some of the physical properties of the sources are listed in Table 4 which is arranged as follows. Column 1: source name; column 2: redshift; columns 3 and 4: the largest angular size (LAS) in arcsec and the corresponding projected linear size in kpc; column 5: the luminosity at 1.4 GHz in logarithmic units of W Hz−1; columns 6 and 10: lobe designation where W and E denote the western and eastern lobes, respectively; columns 7 and 11: break frequency, νbr, with errors in units of GHz; columns 8 and 12: magnetic field, B⊥ in units of nT and columns 9 and 13: spectral ages of the lobes with errors in units of Myr. For all the lobes listed in Table 2, we have fitted the observed spectra for the Jaffe & Perola (1973, hereafter JP) model using the SYNAGE package (Murgia 1996; Murgia et al. 1999) to estimate the break frequency listed in columns 7 and 11 of Table 4. Since the integrated spectra at low frequencies are usually determined from a larger number of measurements than those of the individual lobes of emission, we have fixed the value of αinj from a fit to the integrated spectrum using the SYNAGE package. However, because of the very diffuse extended emission in these sources, several measurements even at low frequencies appear to have missed a significant amount of the total flux density. The highly discrepant measurements have not been used in the final fits for estimating αinj, where the typical error in αinj is within about ±0.1. For a sample of GRSs studied earlier (Jamrozy et al. 2008; Konar et al. 2008), the values of αinj estimated for the lobes when possible are similar, within the uncertainties, to those estimated from the integrated spectra. Therefore, this procedure has been adopted for all the three sources considered here. We also examined the spectral index images of the sources, but due to the large diffuse nature of the lobes and different uv coverages at different frequencies, age estimates using the integrated spectra of the lobes were found to be more reliable. While estimating αinj, the core flux density has been subtracted from the total flux density.

The minimum energy magnetic field has been estimated by integrating the spectrum from a frequency corresponding to a minimum Lorentz factor, γmin ∼ 10 for the relativistic electrons to an upper limit of 100 GHz, which corresponds to a Lorentz factor ranging from a few times 104 to 105 depending on the estimated magnetic field strength (see Hardcastle et al. 2004; Croston et al. 2005; Konar et al. 2008). Then, under assumptions that (i) the magnetic field strength in a given lobe is constant throughout the energy-loss process, (ii) the particles injected into the lobe have a constant power-law energy spectrum and (iii) the time-scale of isotropization of the pitch angles of the particles is short compared with their radiative lifetime, the spectral age, τspec, has been estimated from

\[ \tau_{\text{spec}} = \frac{50.3}{B_{\|}^{1/2}} \left( \frac{B_{\perp}^2}{B_{\|} + B_{\perp}^2} \right)^{1/2} \left( \nu_{\text{br}}(1 + z)^{1/2} \right) \text{(Myr)}, \]

where \( B_{\perp} = 0.318(1 + z)^2 \) is the magnetic field strength equivalent to the cosmic microwave background radiation. Here, B, the magnetic field strength of the lobes, and \( B_{\perp} \) are expressed in units of nT, \( \nu_{\text{br}} \) is the spectral break frequency in GHz above which the radio spectrum steepens from the initial power-law spectral index, \( \alpha_{\text{inj}} \), given by \( 5 \propto \nu^{-\alpha_{\text{inj}}} \).

4.1 J0139+3957

The large-scale structure showing the relaxed lobes (Fig. 1) has been reported earlier by a number of authors (e.g. Hine 1979; Vigotti et al. 1989). Klein et al. (1995) presented Effelsberg observations of the source and suggested it to be one with possible relic lobes of emission. Konar et al. (2004) reported GMRT and VLA observations at 1287 at 4841 MHz, respectively, and found that the spectral index of the entire source between 1.3 and 4.8 GHz is 1.34 while that of the core is 0.8. In Fig. 4, we show the fits to the integrated spectra of the entire source as well as the western and eastern lobes using the injection spectral index, \( \alpha_{\text{inj}} = 1.00 \), determined from the fit to the entire source after subtracting the core flux density. The spectral ages for the western and eastern lobes using our measurements have been found to be \( 12^{+29}_{-11}, \) and 5.3±2.2 Myr, respectively (Table 4).

The existence of a possible steep-spectrum core was noted earlier (e.g. Hine 1979; Klein et al. 1995). Similar resolution observations of about 5 arcsec between 1.4 and 5 GHz (Fomalont & Bridle 1978; Gregorini et al. 1988; Bondi et al. 1993; Klein et al. 1995) also yield a core spectral index of ~0.8. This is consistent with the 10.6 GHz
Table 1. Observing log.

| Telescope | Array configuration | Observations frequency (MHz) | Sources | Observations date     |
|-----------|---------------------|-------------------------------|---------|-----------------------|
| GMRT      |                     |                               | J0139+3957 | 2007 June 02          |
| GMRT      |                     |                               | J0139+3957 | 2005 January 28       |
| GMRT      |                     |                               | J0139+3957 | 2007 June 02          |
| GMRT      |                     |                               | J0139+3957 | 2003 August 19        |
| VLA a     | D                   |                               | J0200+4049 | 2007 December 29      |
| GMRT      |                     |                               | J0200+4049 | 2004 December 25      |
| GMRT      |                     |                               | J0200+4049 | 2007 December 29      |
| GMRT      |                     |                               | J0200+4049 | 2004 November 25      |
| GMRT      |                     |                               | J0807+7400 | 2005 January 07       |
| GMRT      |                     |                               | J0807+7400 | 2004 December 07      |
| GMRT      |                     |                               | J0807+7400 | 2005 January 07       |
| GMRT      |                     |                               | J0807+7400 | 2005 January 17       |
| VLA b     | B                   |                               | J0807+7400 | 1995 November 19      |
| VLA b     | D                   |                               | J0807+7400 | 1993 November 01      |
| VLA b     | C                   |                               | J0807+7400 | 1996 February 19      |
| VLA b     | C                   |                               | J0807+7400 | 1996 February 19      |

a Image published by Konar et al. (2004).
b Archival data from the VLA.

Figure 1. GMRT images of J0139+3957 at 239, 334, 605 and 1287 MHz. The image at 1287 MHz has been reproduced from Konar et al. (2004). In this figure as well as in all the other images of the sources, the peak brightness and the contour levels in units of Jy beam$^{-1}$ are given below each image. In all the images, the restoring beams are indicated by ellipses; the values are those listed in Table 2 unless mentioned otherwise in the caption. The ‘+’ sign indicates the position of the optical host galaxy.
Figure 2. GMRT image of J0200+4049 at 333 MHz is shown in the upper panel. The 239-MHz image convolved to a resolution of 45 arcsec and the 605-MHz image convolved to the resolution of the 333-MHz image are shown in the lower panels.
Figure 3. GMRT images of J0807+7400 at 239, 334, 605 and 1289 MHz.
Table 2. The observational parameters and observed properties of the sources from the GMRT images.

| Source       | Frequency (MHz) | Beam size (arcsec) | Component S_p (mJy beam$^{-1}$) | Component S_t (mJy) | Component C_g (mJy) |
|--------------|----------------|-------------------|-------------------------------|-------------------|-------------------|
| J0139+3957   | 239            | 239               | 14.3                         | 12.9              | 278               |
|              | 334            | 334               | 13.9                         | 8.6               | 308               |
|              | 605            | 605               | 6.3                          | 4.9               | 74                |
|              | 1289           | 1289              | 7.0                          | 5.7               | 346               |
| J0200+4049   | 239            | 239               | 20.5                         | 12.6              | 58                |
|              | 333            | 333               | 10.2                         | 8.2               | 68                |
|              | 605            | 605               | 5.4                          | 3.8               | 48               |
|              | 1289           | 1289              | 3.7                          | 2.5               | 33               |
| J0807+7400   | 239            | 239               | 41.8                         | 32.0              | 312               |
|              | 334            | 334               | 18.2                         | 16.5              | 63                |
|              | 605            | 605               | 14.9                         | 12.6              | 346               |
|              | 1289           | 1289              | 7.0                          | 5.7               | 346               |

Notes. C: values of core flux densities listed here have been estimated from images with the resolutions given here. Estimates by mapping with a lower uvcut-off are listed later, along with values from the literature.

Table 3. The total flux densities.

| Source       | Frequency (MHz) | Flux density (mJy) | Error (mJy) | References     |
|--------------|-----------------|-------------------|-------------|----------------|
| J0139+3957   | 26.3            | 64960             | 6086        | 9              |
|              | 74              | 17821             | 2673        | 1              |
|              | 151             | 10800             | 756         | 10             |
|              | 178             | 4773              | 596         | 11             |
|              | 239             | 6415              | 962         | P              |
|              | 325             | 4750              | 100         | P              |
|              | 334             | 5434              | 815         | P              |
|              | 408             | 3890              | 195         | 12             |
|              | 605             | 2643              | 264         | P              |
|              | 1287            | 1201              | 120         | P              |
|              | 1400            | 798               | 16          | 15             |
|              | 1400            | 802               | 80          | 2              |
|              | 1460            | 1037              | 104         | 3              |
|              | 4841            | 203               | 20          | 4              |
|              | 4850            | 262               | 30          | 15             |
|              | 10450           | 106               | 14          | 15             |
|              | 10550           | 115               | 7           | 16, 18         |

Notes. P: present paper. 1: VLSS (http://lwa.nrl.navy.mil/VLSS); 2: NVSS (Condon et al. 1998); 3: Vigotti et al. (1989); 4: Konar et al. (2004); 5: Lara et al. (2001); 6: White & Becker (1992); 7: Becker, White & Edwards (1991); 8: Gregory & Condon (1991); 9: Viner & Erickson (1975); 10: Hales, Baldwin & Warner (1993); 11: Pilkington & Scott (1965); 12: Gower, Scott & Wills (1967); 13: Hales et al. (1995); 14: Hales et al. (1991); 15: Schoenmakers et al. (2000); 16: Mack et al. (1994); 17: Vigotti et al. 1999; 18: Gregorini et al. (1998).
value of $4 \pm 1$ mJy (Mack et al. 1994). Saripalli et al. (1997) find the core to be a compact source with a flux density of $20 \pm 5$ mJy from very long baseline interferometry observations at 1.67 GHz with a resolution of 25 mas. The core flux densities from our low-frequency measurements, by putting a lower limit to minimize any contamination from extended emission, along with values from the literature are listed in Table 5. The spectrum (Fig. 5) shows clearly that while the high-frequency spectrum is steep, it flattens below about a GHz.

### 4.2 J0200+4049

The double-lobed structure has been imaged earlier by a number of authors (Gregorini et al. 1988; Vigotti et al. 1989; Schoenmakers et al. 2000), and some of the diffuse emission is also visible in the NRAO VLA Sky Survey (NVSS) image reproduced by Konar et al. (2004). The latter also report the detection of a radio core at 4.8 GHz with a flux density of 2.6 mJy, and a compact component to the east which is coincident with a faint galaxy seen in the Digital Sky Survey image. Our images (Fig. 2) show evidence of a depression in the centre of the western lobe, which is clearly seen in the 333-MHz image. It is also seen at 239 MHz where the data are of poorer quality, and at 605 MHz which require more short-spacing data to produce a better image. The GMRT image at 1289 MHz is not shown here since only the core and the unrelated compact source to the east (see Konar et al. 2004) were visible.

The flux density of the source appears to have been underestimated in the 74-MHz VLA-Low-frequency Sky Survey image and at 178 MHz in the 4C survey, possibly due to the large extent of the diffuse low-brightness lobes of emission. The values at these frequencies lie significantly below the fit to the integrated spectrum (Fig. 6). For example, the flux density at 178 MHz is only $\sim3$ Jy while it has been estimated to be approximately 12 Jy at 151 MHz. The flux density values at 74 and 178 MHz have not been considered in the fit to the integrated spectrum of the source. The injection spectral index has been estimated to be 0.73. The spectral ages estimated for the western and eastern lobes using our measurements are $143^{+57}_{-28}$ and $151^{+55}_{-27}$ Myr, respectively (Table 4; Fig. 6), which are the largest amongst the three sources discussed here. More accurate measurements of the flux density at both low and high frequencies would help to determine the break frequency more reliably. The lobes are relaxed with a depression in surface brightness in the western lobe. This clearly suggests that the lobes are no longer being fed with energy from the nucleus.

The core flux densities estimated by imaging with lower limit to minimize contamination by extended emission are listed in Table 6. Although the high-frequency spectrum appears to be fairly steep, with a spectral index of $\sim0.8$ between 1289 and 4841 MHz, the spectrum appears to turn over at low frequencies (Fig. 7).

### 4.3 J0807+7400

This source is a giant low-power radio galaxy, the weakest of our three GRs. Observations at 1.4 GHz by Lara et al. (2001) show a compact core component and a weak and extended halo-like emission elongated in the east–west direction with no evidence of either jets or hotspots. At 4.9 GHz, only the core component was visible. Lara et al. (2001) suggested that this object could be a relic Fanaroff–Riley Class II (FR II) radio galaxy where hotspot regions are no longer present. Our GMRT images at low frequencies show the diffuse lobes and bridge of emission. The spectral ages of the lobes using our measurements are $46^{+28}_{-28}$ and $64^{+24}_{-27}$ Myr for the western and eastern lobes, respectively (Table 4; Fig. 8).
A multifrequency study of relic lobes

Figure 4. The fits to the spectra of the entire source after subtracting the contribution of the core (left-hand panel), western (middle panel) and eastern (right-hand panel) lobes of J0139+3957 using the SYNAGE package.

Table 5. Core flux densities of J0139+3957.

| Telescope | Resolution (arcsec) | Date            | Frequency (MHz) | S (mJy)      | References |
|-----------|---------------------|-----------------|-----------------|--------------|------------|
| GMRT      | ∼10                 | 2007 June 02    | 239             | 39.3 ± 6     | P          |
| GMRT      | ∼10                 | 2005 January 28 | 334             | 38.3 ± 6     | P          |
| GMRT      | ∼5                  | 2007 June 02    | 605             | 41.0 ± 4     | P          |
| GMRT      | ∼5                  | 2003 August 19  | 1287            | 35.0 ± 4     | 2          |
| VLA       | ∼5                  | 1982 September  | 1465            | 33.0 ± 3     | 1          |
| Cambridge | ∼5                  | 1977 October    | 2695            | 24.0 ± 2     | 5          |
| VLA       | ∼15                 | 2000 July 24    | 4841            | 12.0 ± 1     | 2          |
| VLA       | 4.9                 | 1989 July       | 4885            | 12.0 ± 1     | 4          |
| VLA       | ∼2                  | 1977 March–May  | 4900            | 13.0 ± 2     | 6          |
| Effelsberg| 69                  | 1990–1991       | 10550           | 4.0 ± 1      | 3          |

Notes: P: present paper; 1: Gregorini et al. (1988); 2: Konar et al. (2004); 3: Mack et al. (1994); 4: Bondi et al. (1993); 5: Hine (1979); 6: Fomalont & Bridle (1978).

Figure 5. The spectrum of the radio core of J0139+3957.

The core has a flat spectral index at high frequencies but appears to have a steep radio spectrum with a spectral index of ∼0.6 at lower frequencies (Fig. 9), possibly due to unresolved jet/lobe structure from more recent activity.

5 CONCLUDING REMARKS

We have presented low-frequency GMRT observations of the lobes of emission of three GRSs, J0139+3957, J0200+4049 and J0807+7400, with diffuse lobes of emission, but no hotspots and no jets from the nuclear region. Klein et al. (1995) had earlier suggested J0139+3957 to consist of relic lobes, while Lara et al. (2001) suggested that J0807+7400 is a relic FR II radio source. We have tried to explore this theme by examining the structure and spectra of all three sources over a large frequency range. Although these three sources do not have hotspots, their structures are not similar to the FR I sources which are characterized by jets that expand to form the diffuse lobes of emission. Also, the luminosities of two of the three sources are above the dividing line for these two classes of sources.

The spectral ages of the lobes estimated from SYNAGE fits to the spectra of the lobes, as well as their integrated spectra, are in the range of ∼5 × 10^6 to 1.5 × 10^8 yr, the upper range being close to time-scales for which the lobes are likely to remain visible if not fed with a fresh supply of energy from the parent galaxy.

The structure and spectra suggest that these lobes are possibly no longer being fed, with one of the lobes in J0200+4049 exhibiting a depression in surface brightness towards the centre of the lobe. However, all three have detected radio cores, two of which, J0139+3957 and J0200+4049, have spectra which flatten at lower frequencies, which could be indicative of an active core, while the core spectrum of J0807+7400 appears steep at low frequencies suggesting unresolved extended emission. The detection of cores suggests that their nuclei are currently active. Although these sources do not belong to the classic double–double radio galaxies, about a dozen or so of which are presently known (e.g. Saikia, Konar &
Figure 6. The fits to the spectra of the entire source after subtracting the contribution of the core (left-hand panel), as well as the western (middle panel) and eastern (right-hand panel) lobes of J0200+4049 using the SYNAGE package.

Table 6. Core flux densities of J0200+4049.

| Telescope | Resolution (arcsec) | Date (YYYY-MM-DD) | Frequency (MHz) | S (mJy) ± ΔS (mJy) | References |
|-----------|---------------------|-------------------|-----------------|---------------------|------------|
| GMRT      | ~11                 | 2007-12-29        | 239             | 7.6 ± 1.1           | P          |
| GMRT      | ~7                  | 2004-12-25        | 333             | 9.5 ± 1.4           | P          |
| GMRT      | ~5                  | 2007-12-29        | 605             | 9.2 ± 0.9           | P          |
| GMRT      | ~3                  | 2004-11-25        | 1289            | 7.9 ± 0.8           | P          |
| VLA       | ~12                 | 2000-07-24        | 4841            | 2.6 ± 0.3           | 1          |

Notes. P: present paper; 1: Konar et al. (2004).

Table 7. Core flux densities of J0807+7400.

| Telescope | Resolution (arcsec) | Date (YYYY-MM-DD) | Frequency (MHz) | S (mJy) ± ΔS (mJy) | References |
|-----------|---------------------|-------------------|-----------------|---------------------|------------|
| GMRT      | ~13                 | 2005-01-07        | 239             | 32.0 ± 5            | P          |
| GMRT      | ~9                  | 2004-12-07        | 334             | 38.4 ± 6            | P          |
| GMRT      | ~5                  | 2005-01-07        | 605             | 19.1 ± 2            | P          |
| GMRT      | ~3                  | 2005-01-17        | 1289            | 12.5 ± 1            | P          |
| VLA-B     | ~6                  | 1995-11-19        | 1385            | 13.4 ± 1            | P          |
| VLA-C     | ~14                 | 1996-02-19        | 1685            | 10.9 ± 1            | P          |
| VLA-D     | ~45                 | 1993-11-01        | 1435            | 10.5 ± 1            | P          |
| VLA-B+C   | ~12                 | 1995-11-19        | 1465            | 14.0 ± 1            | 1          |
| VLA-C     | ~6                  | 1996-02-19        | 4860            | 13.5 ± 1            | P          |

Notes P: present paper; 1: Lara et al. (2001).

Kulkarni 2006), these might also represent sources with evidence of episodic nuclear activity. It would be interesting to determine the structures of the cores from high-resolution radio observations. The relationship between the turnover frequency and source size for GPS objects (O'Dea 1998) shows that the source sizes are ~0.5 to 2 kpc for turnover frequencies of ~1 and 0.4 GHz, respectively (see Figs 5 and 7). Interpreting the cores as more recent activity, the time-scales of episodic activity would range from ~10⁷ to 10⁸ yr.

ACKNOWLEDGMENTS

We thank an anonymous referee for helpful comments. The Giant Metrewave Radio Telescope is a national facility operated by the National Centre for Radio Astrophysics of the Tata Institute.

Figure 7. The spectrum of the radio core of J0200+4049.
A multifrequency study of relic lobes

Figure 8. The fits to the spectra of the entire source after subtracting the contribution of the core (left-hand panel) as well as the western (middle panel) and eastern (right-hand panel) lobes of J0807+7400 using the SYNAGE package.

Figure 9. The spectrum of the radio core of J0807+7400.

of Fundamental Research. We thank the staff for help with the observations. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under co-operative agreement by Associated Universities Inc. We thank the VLA staff for easy access to the archival data base. This research has made use of the NASA/IPAC extragalactic data base (NED) which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the National Aeronautics and Space Administration. We thank numerous contributors to the GNU/Linux group.

REFERENCES

Baars J. W. M., Genzel R., Pauliny-Toth I. I. K., Witzel A., 1977, A&A, 61, 99
Becker R. H., White R. L., Edwards A. L., 1991, ApJS, 75, 1
Blundell K. M., Rawlings S., Willott C. J., 1999, AJ, 117, 677
Bondi M., Gregorini L., Padrielli L., Parma P., 1993, A&A, 101, 431
Condon J. J., Cotton W. D., Greisen E. W., Yin Q. F., Perley R. A., Taylor G. B., Broderick J. J., 1998, AJ, 115, 1693
Croston J. H., Hardcastle M. J., Harris D. E., Belsole E., Birkhanwsh M., Worrall D. M., 2005, ApJ, 626, 733
Falle S. A. E. G., 1991, MNRAS, 250, 581
Fomalont E. B., Bridle A. H., 1978, AJ, 83, 725
Gopal-Krishna, Wiita P. J., Saripalli L., 1989, MNRAS, 239, 173
Gower J. F. R., Scott P. F., Wills D., 1967, Mem. Roy. Astron. Soc., 71, 49
Gregory P. C., Condon J. J., 1991, ApJS, 75, 1011
Gregorini L., Padrielli L., Parma P., Gilmore G., 1988, A&AS, 74, 107
Gregorini L., Vigotti M., Mack K.-H., Zoennehn J., Klein U., 1998, A&AS, 133, 129
Hales S. E. G., Mayer C. J., Warner P. J., Baldwin J. E., 1991, MNRAS, 251, 46
Hales S. E. G., Baldwin J. E., Warner P. J., 1993, MNRAS, 263, 25
Hales S. E. G., Waldram E. M., Rees N., Warner P. J., 1995, MNRAS, 274, 447
Hine R. G., 1979, MNRAS, 189, 527
Hardcastle M. J., Harris D. E., Worrall D. M., Birkhanwsh M., 2004, ApJ, 612, 729
Ishwara-Chandra C. H., Saikia D. J., 1999, MNRAS, 309, 100
Jaffe W. J., Perola G. C., 1973, A&A, 26, 423 (JP)
Jamrozy M., Konar C., Machalski J., Saikia D. J., 2008, MNRAS, 385, 1286
Jeyakumar S., Wiita P. J., Saikia D. J., Hooda J. S., 2005, A&A, 432, 823
Kaiser C. R., Alexander P., 1997, MNRAS, 286, 215
Kaiser C. R., Alexander P., 1999, MNRAS, 302, 515
Klein U., Mack K.-H., Gregorini L., Parma P., 1995, A&A, 303, 427
Konar C., Saikia D. J., Ishwara-Chandra C. H., Kulkarni V. K., 2004, MNRAS, 355, 845
Konar C., Jamrozy M., Saikia D. J., Machalski J., 2008, MNRAS, 383, 525
Lara L., Cotton W. D., Feretti L., Giovannini G., Marcaide J. M., Márquez I., Venturi T., 2001, A&A, 370, 409
Leahy J. P., Muxlow T. W. B., Stephens P. W., 1989, MNRAS, 239, 401
Liu R., Pooley G., Riley J. M., 1992, MNRAS, 257, 545
Machalski J., Chyży K. T., Stawarz L., Koziel D., 2007, A&A, 462, 43
Machalski J., Koziel-Wierzbowska D., Jamrozy M., Saikia D. J., 2008, ApJ, 679, 149
Mack K.-H., Gregorini L., Parma P., Klein U., 1994, A&AS, 103, 157
Mack K.-H., Klein U., O’Dea C. P., Willis A. G., Saripalli L., 1998, A&A, 329, 431
Murgia M., 1996, Laurea thesis, Univ. Bologna
Murgia M., Fanti C., Fanti R., Gregorini L., Klein U., Mack K.-H., Vigotti M., 1999, A&A, 345, 769
O’Dea C. P., 1998, PASP, 110, 493
Pilkington J. D. H., Scott P. F., 1965, Mem. Roy. Astron. Soc., 69, 183
Saikia D. J., Konar C., Kulkarni V. K., 2006, MNRAS, 366, 1391
Saripalli L., Patnaik A. R., Porcas R. W., Graham D. A., 1997, A&A, 328, 78
Schoenmakers A. P., Mack K.-H., de Bruyn A. G., Röttgering H. J. A., Klein U., van der Laan H., 2000, A&AS, 146, 293
Schoenmakers A. P., de Bruyn A. G., Röttgering H. J. A., van der Laan H., 2001, A&A, 374, 861
Spergel D. N. et al., 2003, ApJS, 148, 175
Subrahmanyan R., Saripalli L., 1993, MNRAS, 260, 908
Subrahmanyan R., Saripalli L., Hunstead R. W., 1996, MNRAS, 279, 257
Vigotti M., Gregorini L., Perley R., Clark B. G., Bridle A. H., 1989, AJ, 98, 419
Vigotti M., Gregorini L., Klein U., Mack K.-H., 1999, A&AS, 139, 359
Viner M. R., Erickson W. C., 1975, AJ, 80, 931
White R. L., Becker R. H., 1992, ApJS, 79, 331

This paper has been typeset from a TeX/LATEX file prepared by the author.