GIANT RADIO SOURCES

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Abstract

Giant radio sources (GRSs), defined to be those with a projected linear size greater than approximately 1 Mpc, are the largest single objects in the Universe, and are useful for probing a number of astrophysical questions. In this paper we present the results of a multifrequency study of a sample of moderate-redshift giants with the Giant Metrewave Radio Telescope (GMRT) and the Very Large Array (VLA). From spectral index studies, we have estimated the ages and velocities of advancement for a few sources, and identified possible sites of reacceleration. In the GRSs, inverse-Compton losses with the cosmic microwave background radiation dominate over synchrotron radiative losses which could affect the identification of giants at large redshifts. We also show that the prominence of the bridge emission decreases with increasing redshift, possibly due to inverse-Compton losses, and estimate the expected X-ray flux from some of the objects in our sample.

1 INTRODUCTION

Giant radio sources (GRSs) are defined to be those with a projected linear size greater than approximately 1 Mpc ($H_\circ$=71 km s^{-1} Mpc^{-1}, Ω_m=0.27, Ω_{vac}=0.73). These are useful for studying many astrophysical problems such as the late stages of evolution of radio sources, constraining the orientation-dependent unification schemes, probing the intergalactic medium (IGM) and effects of the cosmic microwave background radiation (CMBR) on the extended lobes of radio emission at different redshifts. Although the locations of giants in the luminosity-linear size diagram are broadly consistent with models of evolution of radio sources [1, 2], there is a dearth of giants larger than ∼2 Mpc and at cosmologically interesting redshifts $\gtrsim$1 [3]. At high redshifts, the diffuse bridges of emission are likey to be significantly affected by inverse-Compton (IC) losses against the cosmic microwave background radiation (CMBR), which would affect the appearance and identification of giants at these redshifts. For almost all GRSs the equipartition magnetic field is less than the equivalent magnetic field of the CMBR, B$_{ic}$, defined as $U_{CMBR} = B_{ic}^2/8\pi$ [3], and there is some evidence of the prominence of bridge emission decreasing with redshift, as expected, due to increased IC losses [4].

In this paper we present some of the results from a study of a sample of giant radio sources with the GMRT and the VLA to determine the structure and spectra of the lobes, examine effects of radiative losses and estimate their spectral ages. We also present estimates of the expected X-ray flux in the 0.5−8 keV range due to IC scattering for a few high-redshift giant sources.

2 RADIO STRUCTURES AND SPECTRAL AGEING ANALYSIS

These observations have helped clarify the radio structures of a number of giant radio sources. We present the radio images of a couple of these sources along with an analysis of their spectral ages. The spectral age, defined to be the time elapsed since the plasma particles were last accelerated, is estimated from the observed steepening in the radio spectrum

[5, 6, 7], as the radiating particles diffuse from the hotspot to form the extended lobes of emission. In this analysis it has been assumed that (i) the magnetic field in each lobe is constant and equal to the equipartition value, B_{eq}, (ii) the particles are injected into the lobe with a constant power-law energy spectrum, (iii) they are isotropised on time-scales shorter than their radiative lifetime (JP model)[8], (iv) the radiative lifetime of the synchrotron particles in the plasma are significantly longer than the spectral ages to be determined and (v) each segment or slice of lobe may be regarded as a discrete element of plasma and there is no mixing between the slices. The equipartition magnetic field strength in the lobes, B_{eq}, has been calculated by integrating the total radio luminosity from 10 MHz to 100 GHz, assuming a filling factor of unity and also proton to electron ratio of unity[9]. The predictions of the JP model are fitted to the resultant spectrum of each slice of the lobes with an injection spectral index, α_{inj}, which has been estimated from a model fit to the integrated flux densities of the entire lobe to which the slice belongs. This has been done using the SYNAGE software[10].

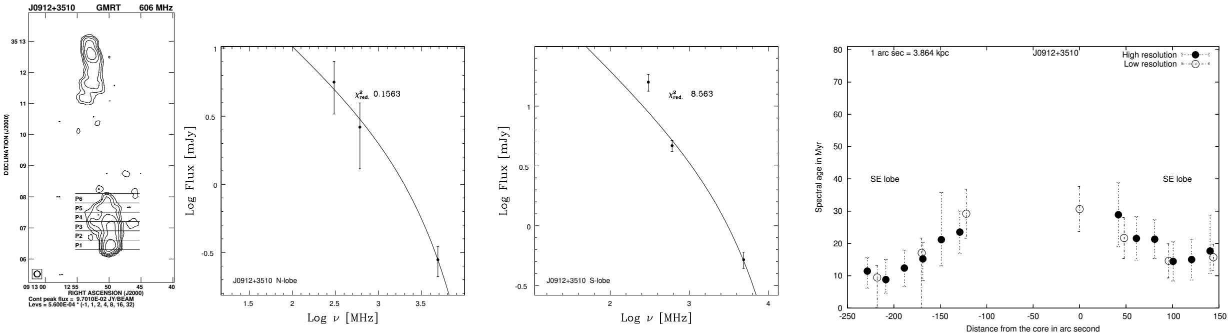

Figure 1: Left panel: 606-MHz GMRT map of the source J0912+3510. Middle panel: JP model fits to the spectra of the slices farthest from the hotspot for each lobe. Right panel: A plot of spectral age vs. distance from the core.

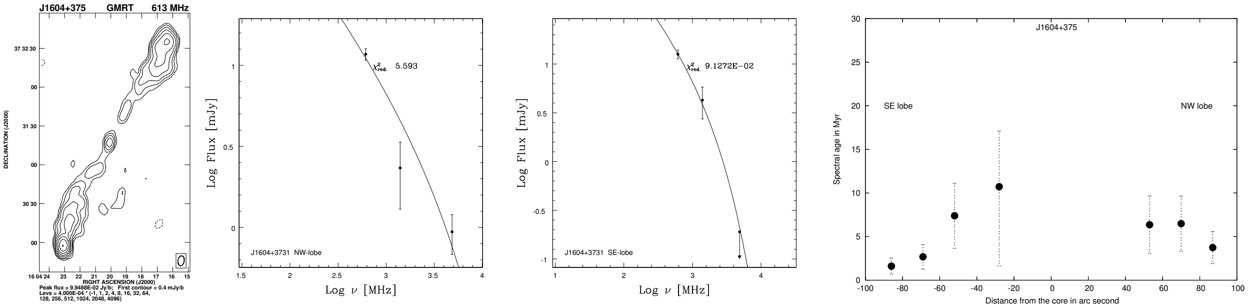

Figure 2: Left panel: 613-MHz GMRT map of the source J1604+3731. Middle panel: JP model fits to the spectra of the slices farthest from the hotspot for each lobe. Right panel: A plot of spectral age vs. distance from the core.

We illustrate our analysis using two of the sources in our sample. In Fig. 1, the GMRT image of the GRS J0912+3510 at 606 MHz with an angular resolution of ∼12 arcsec is shown in the left panel. J0912+3510 is at a redshift of 0.2489 so that its largest angular size of 375 arcsec corresponds to a projected linear size of 1449 kpc. Fits to the spectra were obtained in different slices which are marked in the Fig. 1 using the JP model. Two of these plots corresponding to the slices which are farthest from the hotspots are shown in the middle panel. A 'break frequency' for each spectrum, ν_{br}, determined from the fits, corresponds to a spectral age given by

$$\tau_{rad} = 1.61 \times 10^3 \frac{B^{0.5}}{(B^2 + B_{ic}^2)(\nu_{br}(1+z))^{0.5}}$$

where τ_{rad} is in Myr, B is in μG, ν_{br} is in GHz and B_{ic}=3.18$(1+z)^2$ μG. The resultant values of τ_{rad} for J0912+3510 as a function of projected angular distance from the radio core are shown in the right panel of Fig. 1. Although the spectral indices within a distance of ∼195 kpc from the hotspots do not seem to vary significantly, either due to in situ acceleration or turbulent backflow from the hotspots, they steepen as distance increases from the hotspots. The ages in the farthest regions visible in our images are ∼30 Myr.

Table 1: Injection spectral indices and spectral ages

Source name	Z	LAS (kpc)	$S_{1.4}$ mJy	Comp	α_{inj}	Maximum age of the componemt (Myr)
J0912+3510	0.2489	1449	156	N	0.560	29
				S	0.628	24
J0927+3510	0.55	2206	88	NW	0.750	12
				SE	0.700	13
J1604+3731	0.814	1346	120	NW	0.765	6
				SE	0.775	11

A similar analysis for the GRS J1604+3731 which is at a redshift of 0.814, indicating that its projected linear size is 1346 kpc, is shown in Fig. 2. The GMRT image at 606 MHz with an angular resolution of $\sim$6 arcsec suggests an S-shaped structure which could be due to precession of the central ejection axis. The age estimated in a similar way for the farthest region is $\sim$11 Myr. The results for these two sources as well as for J0927+3510 are summarised in Table 1. The variation of age with linear separation of the slices gives a mean separation velocity between the hotspot and the radiating plasma of about $0.1-0.2$c. Our estimates are consistent with previous results[11, 12, 13, 14, 15].

3 INVERSE-COMPTON SCATTERING

The dominance of inverse Compton losses ($B_{eq} < B_{ic}$) is likely to severely affect the appearance and identification of GRSs at high redshifts due to the suppression of bridge emission by inverse-Compton losses against the CMBR, which increases sharply with redshift. This could lead to 'tail-less' hotspots leading to their classification as independent radio sources. In order to develop strategies for indentifying GRSs at high redshifts we investigate the prominence of bridge emission, $\mathrm{f_{bridge}}$, defined as the ratio of emission from the bridge to that of the total emission, as a function of redshift. The bridge emission has been estimated by subtracting the hotspot flux densities from images with a uniform linear resolution of $\sim$70 kpc. A plot of $\mathrm{f_{bridge}}$ at an emitted frequency of 1.4 GHz against redshift (Fig. 3) clearly shows an inverse correlation, with a Spearman rank correlation coefficient of 0.52, corresponding to a confidence level of >95 per cent[4]. For a few of the GRSs in our sample, we have calculated the expected IC-scattered flux at X-ray wavelengths (Table 2) and plan to observe these with the CHANDRA telescope.

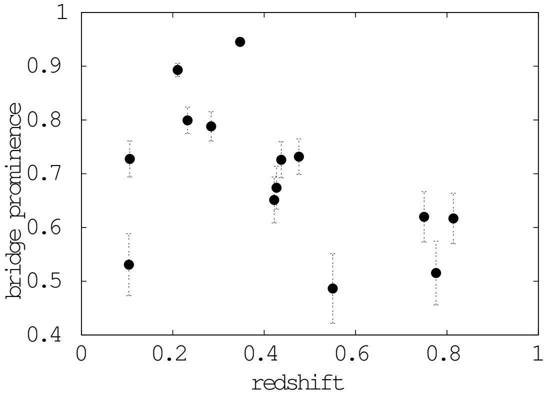

Figure 3: The fraction of bridge emission, $\mathrm{f_{bridge}}$ at an emitted frequency of 1.4 GHz plotted against the redshift.

Table 2: Predicted X-ray flux for a few GRSs

Source name	Z	Comp	$F^s_{\nu_o}$ (Radio) ν_o (mJy)	ν_o (Radio) (MHz)	$F^X_{intrinsic}$ in 0.5−8 keV (10^{-18} W m^{-2})	Expected counts per second in ACIS-I	Expected counts per second in ACIS-S
J0657+4808	0.776	W	40	1425	10.8	9.93E-04	1.42E-03
		E	29	1425	7.8	7.20E-04	1.03E-03
J0908+3932	1.883	NW	182	1400	8.2	8.17E-04	1.22E-03
		SE	48	1400	2.6	2.59E-04	3.85E-04
J1432+1548	1.005	NW	167	617	0.56	5.63E-05	8.41E-05
		SE	146	617	0.55	5.56E-05	8.31E-05
J1604+3731	0.814	N	111	613	4.0	4.03E-04	6.03E-04
		S	142	613	11.3	1.14E-03	1.70E-03
J1637+4146	0.867	N	14	1425	19.9	2.02E-03	3.02E-03
		S	34	1425	32.9	3.34E-03	5.01E-03

4 CONCLUDING REMARKS

Our multifrequency study of GRSs with the GMRT and the VLA have helped clarify the structures of a number of sources, identify possible sites of re-acceleration in the lobes and have shown that typical ages of the lobes range up to $\sim$30 Myr. GRSs are the more evolved counterparts of the normal double-lobed sources, but there appears to be a dearth of objects $\gtrsim$2 Mpc and with redshifts $\gtrsim$1. To identify high-redshift objects we have examined the effect of IC scattering with the CMBR on the observed structures. It is known that in GRSs IC losses dominate so that $B_{ic} > B_{eq}$. We have estimated the observed X-ray flux for some of the sources, and have shown that the prominence of the bridge emission decreases with redshift, possibly due to inverse-Compton losses. This would affect the appearance and identification of GRSs at large redshifts.

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