Spectral Ages of Giant Radio Sources

C. Konar, D. J. Saikia, M. Jamrozy, and J. Machalski

1 IUCAA, Pune University Campus, Pune 411007, India
2 National Centre for Radio Astrophysics, TIFR, Pune 411007, India
3 Jagiellonian University, 30244 Krakow, Poland

Abstract. Multifrequency observations with the GMRT and the VLA are used to determine the spectral breaks in consecutive strips along the lobes of a sample of selected giant radio sources (GRSs) in order to estimate their spectral ages. The maximum spectral ages estimated for the detected radio emission in the lobes of our sample of ten sources has a median value of \sim 20 Myr. The spectral ages of these GRSs are significantly older than smaller sources. In all but one source (J1313+6937) the spectral age gradually increases with distance from the hotspot regions, confirming that acceleration of the particles mainly occurs in the hotspots. Most of the GRSs do not exhibit zero spectral ages in the hotspots. This is likely to be largely due to contamination by more extended emission due to relatively modest resolutions. The injection spectral indices range from \sim 0.55 to 0.88 with a median value of \sim 0.6. We show that the injection spectral index appears to be correlated with luminosity and/or redshift as well as with linear size.

1. Introduction

The radio continuum spectra in different parts of an extended radio source contain important information about the various energy losses and gains of the radiating particles during the lifetime of the source. Giant radio sources (GRSs defined to be larger than \sim 1 Mpc, $H_0 = 71$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.27$, $\Omega_{\text{vac}} = 0.73$) are suitable for classical spectral-ageing analysis due to their large angular extent which can be covered by a significant number of resolution elements.

However, while estimating spectral ages, caveats related to the evolution of the local magnetic field in the lobes need to be borne in mind (e.g. Rudnick, Katz-Stone, & Anderson 1994; Jones, Ryu, & Engel 1999; Blundell & Rawlings 2000). Also, while Kaiser (2000) has suggested that spectral and dynamical ages are comparable if bulk backflow and both radiative and adiabatic losses are taken into account in a self-consistent manner, Blundell & Rawlings (2000) suggest that this may be so only in the young sources with ages much less than 10 Myr. A comparison of the dynamical and spectral ages show the dynamical ages to be approximately a few times the maximum synchrotron ages of the emitting particles (Machalski, Jamrozy, & Saikia 2009 and references therein).

We have made multifrequency observations with the GMRT and the VLA, and estimated the spectral ages of ten GRSs (Konar et al. 2004, 2008; Jamrozy et al. 2008). In this paper we summarise the results for two of these sources and
Figure 1. GMRT images of J1313+6937 and J1702+4217 at ~600 MHz with an angular resolution of ~6 and 7 arcsec respectively. The + sign indicates the position of the optical host galaxy of the source. The ellipse at one of the corners indicates the resolution element. The middle and lower panels show the spectral-index map, flux-density profiles, and the spectral age distributions. The spectral ages have been estimated using the SYNAGE package (Murgia 1996; Murgia et al. 1999), and magnetic field values determined using the Beck & Krause (2005) formalism (filled circles and with error bars) and the classical (e.g. Miley 1980) formalism (open circles without error bars). For further details see Konar et al. (2008) and Jamrozy et al. (2008).
Figure 2. The spectral age as a function of the largest linear size.

discuss the dependence of spectral age on size, and the relationships between the injection spectral index, $\alpha_{\text{inj}} (S \propto \nu^{-\alpha})$, and luminosity and linear size.

2. Spectral Ages of J1313+6937 and J1702+4217

**J1313+6937:** This source is at a redshift of 0.106 and has an overall linear size of 745 kpc, somewhat smaller than 1 Mpc. The GMRT image shows the prominent bridge of emission (Figure 1). The spectral-index map and the intensity profiles along the source axis suggest that the synchrotron radiation observed in separate strips of this GRS may be related to a mixture of emitting particles which were injected or accelerated at different epochs. The SE lobe of this GRS is the only one, among the other lobes studied in this piece of work in which the synchrotron ages determined do not more or less gradually increase with distance from the hotspot area to the core. Here $\alpha_{\text{inj}}$ is 0.61 and the spectral age of both the lobes using the classical equipartition magnetic field is $\sim 35$ Myr.

**J1702+4217:** The GRS J1702+4217 is at a redshift of 0.476 and has a largest projected size of 1160 kpc. The GMRT 602-MHz image shows a prominent bridge with several peaks of emission (Figure 1). Although there are peaks of emission visible in the lobe emission, especially at the lower frequency, the spectral age increases smoothly with distance from the hotspots. The spectral ages of the lobes, estimated for an injection spectral index of 0.59 are $\sim 16$ and 18 Myr for the north-eastern and south-western lobes respectively.

2.1. Spectral Age–Linear Size Relation

The maximum spectral ages estimated for the detected radio emission in the lobes of our sources range from $\sim 6$ to 46 Myr with a median of $\sim 23$ Myr using the classical equipartition fields. Using the magnetic field estimates from the Beck & Krause formalism the spectral ages range from $\sim 5$ to 58 Myr with a median of $\sim 24$ Myr. The median linear size of these large sources is $\sim 1300$ kpc. For a sample of extended 3CR sources with a median size of 342 kpc (Leahy, Muxlow, & Stephens 1989), the spectral ages range from $\sim 5$ to 58 Myr with a median value of $\sim 8$ Myr. In the case of 14 compact 3CR sources with a median size of 103 kpc (Liu, Pooley, & Riley 1992) the values range from $\sim 0.3$ to 5.3 Myr with a median value of $\sim 1.7$ Myr. Considering these different samples, there is a trend for the spectral ages to increase with linear size (Figure 2) as
has been noted earlier in the literature (e.g. Parma et al. 1999; Murgia et al. 1999). The relative speeds of the lobe material range from $\sim 0.03$ to $0.2c$ with a median of $\sim 0.1c$ for the Liu et al. sample. The values for our GRSs are similar.

3. Injection Spectral Indices

The injection spectral indices range from 0.55 to 0.88 with a median value of $\sim 0.6$. Our estimates for the GRSs are marginally smaller than those estimated for smaller sources by Leahy et al. (1989) and Liu et al. (1992). Reliable low-frequency measurements of the lobes using instruments such as GMRT, LWA and LOFAR are required to get more reliable estimates of the injection spectral indices. We have explored possible correlations of $\alpha_{\text{inj}}$ with other physical parameters and find that it appears to increase with luminosity and/or redshift, but shows an inverse correlation with linear size (Figure 3).

References

Beck, R., & Krause, M. 2005, Astron. Nachr., 6, 414
Blundell, K. M., & Rawlings, S. 2000, AJ, 119, 1111
Jamrozy, M., Konar, C., Machalski, J., & Saikia, D. J. 2008, MNRAS, 385, 1286
Jones, T. W., Ryu, D., & Engel, A. 1999, ApJ, 512, 105
Kaiser, C. R. 2000, A&A, 362, 447
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
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., Jamrozy, M., & Saikia, D. J. 2009, MNRAS, in press (arXiv:0902.0577)
Miley, G. K. 1980, ARA&A, 18, 185
Murgia, M., Fanti, C., Fanti, R., Gregorini, L., Klein, U., Mack, K.-H., & Vigotti, M. 1999, A&A, 345, 769
Parma, P., Murgia, M., Morganti, R., Capetti, A., de Ruiter, H.R., & Fanti, R. 1999, A&A, 344, 7
Rudnick, L., Katz-Stone, D., & Anderson, M. 1994, ApJS, 90, 955