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Radio spectra of intermediate-luminosity broad-line radio galaxies

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Abstract. Within the context of investigating possible differences between the mechanisms at play in Radio Loud AGN and those in Radio Quiet ones, we study the spectral characteristics of a selected sample of Intermediate-Luminosity Broad-Line Radio Galaxies in X-rays, optical, IR and radio. Here, we present the radio spectra acquired with the 100-m radio telescope in Effelsberg between 2.6 and 32 GHz. These measurements reveal a large variety of spectral shapes urging for radio imaging that would disclose the source morphology. Such studies could potentially discriminate between different mechanisms.

Key words. Galaxies: active – Galaxies: nuclei – Radio continuum: galaxies

1. Introduction

A great deal of our current understanding of the processes at play in AGNs is coming from studies of chiefly Radio-Quiet (RQ) objects. In fact, it appears that different mechanisms become important at different luminosities so that the emission from luminous RQ systems is dominated by accretion flow (Haardt & Maraschi 1991), whereas in lower luminosity systems the accretion flow may be radiatively less efficient (Ho 1999).

On the other hand, little is known about the mechanisms determining the behavior of the Radio-Loud (RL) AGNs, mostly because they comprise only a small fraction of the complete AGN population. Studies of the Broad-Line Radio Galaxy (BLRGs) sub-class have been focusing on the brightest and most luminous objects. This rough picture leaves several questions unanswered such as whether there

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Table 1. The used receivers characteristics

Frequency (GHz)	T_{sys} (K)	Sensitivity (K/Jy)	FWHM (arcsec)
2.64	17	1.5	260
4.85	27	1.5	146
8.40	22	1.3	81
10.45	~50	1.3	66
14.60	~50	1.1	50
32.00	77	0.5	25

are differences between the physics of RL and RQ systems. A uniform coverage of the parameter space of the studied AGNs could shed light on many of these issues. In particular, the detailed comparison of RL and RQ AGNs of similar luminosity can provide significant insight.

To make up for the bias towards the most luminous sources we have selected a sample of 6 Intermediate-Luminosity BLRGs (IL-BLRGs) and studied their radio spectrum. The ultimate goal of this attempt would be to determine their Spectral Energy Distribution from radio to X-rays utilizing the XMM-Newton observations that have been performed for these sources (see Sambruna et al. in prep.). That would potentially reveal the relative importance of the various emission mechanisms. Further, radio observations in conjunction with X-ray measurements can provide information about the relative contribution of the disk and the jet and how that depends on luminosity. Here, we present the results of the radio study only.

2. The sample

In its full version, the project currently discussed, focuses on the study of 11 IL-BLRGs with $L_{2-10\mathrm{kev}}$ of the order of $10^{42} - 10^{43}$ erg s^{-1}. These objects are all Radio Loud and have flux densities $F_{1.4GHz} \geq 4$ mJy and lie at $z \leq 0.1$. From cross-correlating the main galaxy catalog from the SDSS Data Release 2 (Abazajian et al. 2004) with the NVSS (Condon et al. 1998) and FIRST catalogs (Becker, White, & Helfand 1995; White et al. 1997), Best et al. (2005) compiled a catalog of 2215 RL objects. From a sub-set of 429 sources with $z \leq 0.1$, Hao et al. (2005) found 11 that show broad Hα lines (FWHM(Hα) $>$ 1200 km s^{-1}). Those comprise the sample under investigation. Here we present the radio data for six of these sources all of which have been observed by both Effelsberg and XMM-Newton (to be presented in Sambruna et al., in prep.).

3. Observations and data reduction

The radio spectra reported here have been measured with the 100-m telescope in Effelsberg quasi-simultaneously on March 28, 2007.

3.1. Observations

The observations were performed with the heterodyne receivers at 2.64, 4.85, 8.35, 10.45, 14.60 and 32.00 GHz, mounted on the secondary focus (see Table 1). The receivers at 4.85, 10.45 GHz are equipped with multiple feeds allowing differential observations. The 32-GHz system is a correlation receiver that is also significantly insensitive to linear atmospheric effects, whereas the others are all single-feed systems. The measurements were conducted with the newly installed adaptive secondary reflector characterized by low surface RMS that induces higher sensitivity (up to 50% increase at 43 GHz). Nevertheless, the limiting factor has been the atmosphere itself. The so-called ”cross-scan” observing technique has been applied. Its essence lies in measuring the response of the antenna as it is slewed over the source position in both azimuthal and elevation direction. The advantage of this method is mainly the fact that it allows the direct detection of cases of confusion and also the correction of pointing offset errors. The individual spectra have been measured quasi-simultaneously within 1 hr to guarantee that they are free of source variability of time-scales longer than that. Let us underline that the beam is large enough to leave the source structure unresolved. This is especially important when the interpretation the radio spectra in terms of source morphology is attempted as we discuss in Section 4.

Table 2. The flux densities measured at Effelsberg along with the NVSS entries. Note that the upper limits are given in terms of three times the rms noise. The SNR is ≥ 3.

Source (NVSS J)	$S^{\dagger}_{1.4}$ (mJy)	$S_{2.64}$ (mJy)	$S_{4.85}$ (mJy)	$S_{8.35}$ (mJy)	$S_{10.45}$ (mJy)	$S_{14.6}$ (mJy)	$S_{32.00}$ (mJy)
023140−011005	11.6±0.6	33.6±0.6	39.8±2	–	37.1±1.4	–	41.8±2.0‡
081040+481230	38.8±1.5	31.3±0.4	20.7±0.6	12.6±0.9	14.9±2.7	–	17.4±3
090624+005758	5.8±0.4	–	8.5±0.6	12.1±2.1	14.0±0.8	16.9±2.1	–
101806+000539	11.5±1.5	8.0±0.5	5.5±0.6	4.2±0.3	≤3·42.3	3.6±0.9	–
125027+001345	54.3±1.7	58.1±1.6	52.6±1.3	57.4±0.9	61.5±2.1	61.7±2.8	62.3±0.4
142041+015931	11.7±0.6	9.7±1.9	8.1±0.6	4.8±0.4	4.2±0.7	–	–

†extracted from the NVSS (Condon et al. 1998)
‡observed in July 2007

3.2. Data Reduction

Considerable effort has been put in applying some necessary post-observation corrections to the raw data: (a) Pointing offset correction, which is meant to account for the power loss caused by the offset between the telescope position and the true source position. (b) Gain correction; The 100-m telescope is designed according to the homology principle that preserves the parabolic shape of the reflector. However, small scale deformations cause an elevation-dependent change of its gain that could also cause power loss. The gain correction accounts for this effect. (c) Opacity correction, which corrects for the atmospheric opacity effect. (d) Finally, the data are subjected to sensitivity correction, which means translating the source antenna temperature into absolute flux density units. It is done by observing standard sources referred to as calibrators (Baars et al. 1977; Ott et al. 1994, and Kraus priv. com.).

4. The spectra

The acquired flux densities along with those from the NVSS catalog (Condon et al. 1998) are summarized in Table 2. The spectra are shown in Fig. 1. Only data with SNR ≥ 3 have been used. Note that in Table 2 the upper limits are given in terms of three times the RMS noise in the scan. It is noteworthy that the majority of the targets are very weak making their measurements exceptionally challenging.

From Fig. 1 it becomes clear that the sources possess a large variety of spectral shapes. Henceforth, the name prefix "NVSS J" is omitted from all the source names. 101806+000539 and 142041+015931 show a steep spectrum indicative of synchrotron jet emission. 081040+481230 behaves similarly below 10 GHz (with $S \sim \nu^{\alpha}$, $\alpha \approx -0.42$). At higher frequencies however, it seems that a flat-spectrum component (possibly a core component) becomes significant. Further observations are necessary to test this idea. 125027+001345 is also a typical case of a flat spectrum source ($\alpha \sim 0.05$) likely core-dominated. On the other hand, 023140−011005 and 090624+005758 appear to be less common. The former seems to be of flat spectrum with a low frequency turnover that could also be caused by source variability (NVSS and Effelsberg measurements are not simultaneous). The latter shows a monotonically increasing spectrum (indicative of a GHz-peaked spectrum source with $\alpha \sim 0.62$) suggesting a self absorbed system in which we observe only the optically thick part of the spectrum. Alternatively, such a spectral shape could be attributed to a flat spectrum source (core-dominated) that undergoes a flaring event. This could only be clarified with additional observations.

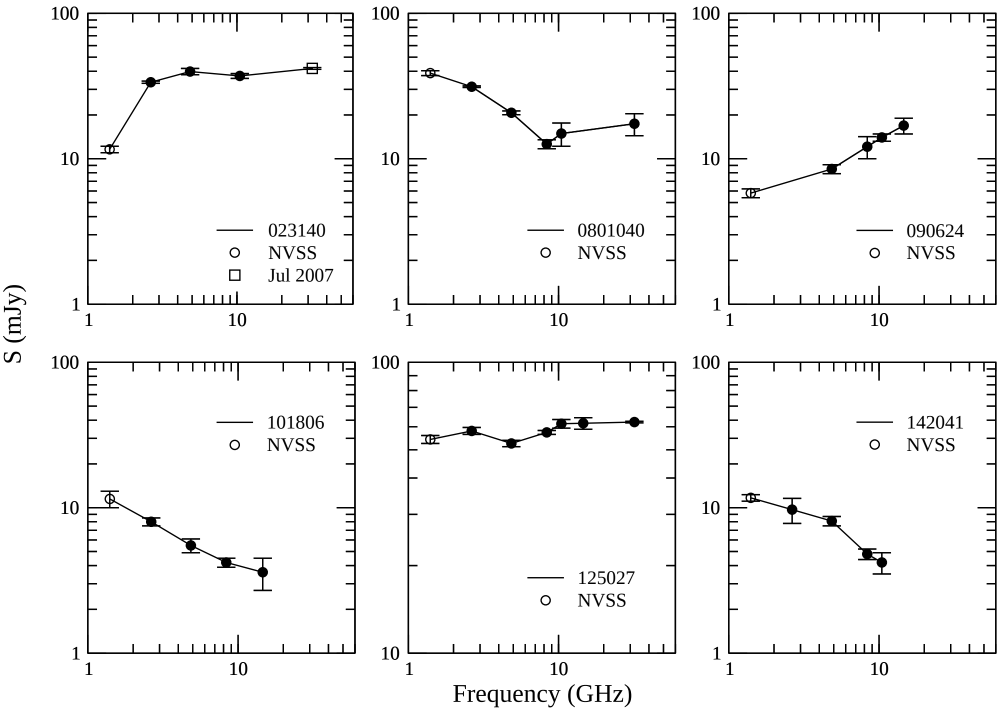

Fig. 1. The measured spectra.

However, our recent re-analysis of the optical spectra showed that two of the sources discussed earlier, namely 090624+005758 and 125027+001345, display optical spectral characteristics that could classify them as NLRGs rather than as BLRGs. Having this solidly confirmed would alter the interpretation of the spectra of those two objects and necessitate the separate study of the two classes.

5. Conclusions

Clearly, the 6 BLRGs discussed here show a variety of radio spectra that could be interpreted in different ways. Interferometric observations would be essential for the correct interpretation of the observed phenomenology. All these results in conjunction with the X-ray and optical data are in preparation for publication (Sambruna et al., in prep.).

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