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Kinematical models of double radio sources and the unified scheme

II. The database

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Abstract. A large database of 1038 edge-brightened double radio sources has been collected from the literature with special emphasis on finding the best radio map for each source and on obtaining flux information of the extended radio lobes and the core component. The data are collected with two goals in mind. The first goal is to provide the data for our statistical study of double radio source symmetry and the unified scheme in the theoretical framework of Baryshev & Teerikorpi (1995, Paper I). It is also believed that the data are useful to the research community and thus extensive data are given in tabular form[1].

Key words: galaxies: active — jets — radio continuum: galaxies

1. Introduction

The structural properties of "classical" Fanaroff-Riley II radio sources (Fanaroff & Riley 1974) are usually described by a few basic parameters. The first one is the arm length ratio Q, which is defined as the ratio of the hotspot distances from the core in such a way that $Q > 1$ (Fig. 1). Alternatively, a similar parameter $\theta = (Q-1)/(Q+1)$ can be used (e.g. Paper I). The second parameter is the bending angle D which is the complement angle of the angle between the lines connecting the lobes to the core. The third symmetry parameter widely used is the flux ratio F of the two lobes. Together with other information of the sources, such as the relative prominence of the core ($P_{\rm c}/P_{\rm tot}$) and projected linear size (l), these symmetry parameters can be used to constrain the physical conditions in the sources and to test different unification schemes (e.g. Barthel 1989) that seek to explain the differences in source properties by different viewing angles (see e.g. Best et al. 1995).

The author is currently engaged in projects that require symmetry information for a sizable number of FR II radio sources for comparison with theoretical predictions. For this purpose a large database was created by searching the literature for high resolution radio maps and flux data from which the parameters Q, D, F, $P_{\rm c}/P_{\rm tot}$ and l could be extracted. This paper presents the database. In a forthcoming paper (Nilsson et al. 1998, Paper III) the data will be studied in the context of the kinematical double radio source models of Baryshev & Teerikorpi (1995), Paper I). Another possible application of the database is a comparison of the symmetry data to the slingshot simulations of Valtonen et al. (1994).

2. The data

The data are based on the double radio source compilation of Nilsson et al. (1993) with new objects added and some old values renewed using recent studies. To be included in our database the source was required to have FR II type morphology. Thus unresolved sources and sources with complex, FR I or one-sided (D2) morphology were excluded. Special emphasis was given to finding the best published radio maps for unambiguous classification. The small sources with angular sizes of a few arcsec pose a problem since they are sometimes difficult to classify into one-sided and two-sided sources. In these cases the appearance of the radio structure and position of the optical identification with respect to radio emission were used as indicators of the correct classification.

The resulting database contains 1038 sources of which 544 are galaxies, 365 are quasars and 129 have no optical identification. The redshift is known for 334 galaxies and 335 quasars. As a whole the database is quite heterogeneous: part of the data are incomplete, e.g. the sources have not been optically identified or flux information is

[1] Tables 1 and 2 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

missing, and many sources have entered the database from studies in which the sources have not been selected in a systematic manner. However, a statistically complete sample with relatively complete structural information can be extracted from the database.

The complete sample in question contains all double radio sources in the radio source compendium of Herbig & Readhead (1992). This compendium is based on three complete samples, namely 1) the revised 3C sample of Laing et al. (1983, the "LRL sample"), 2) the complete sample of radio sources of Peacock & Wall (1981), the "PW sample" and 3) the complete sample of S4 and S5 sources by Pearson & Readhead (1988), the "PR sample". The first sample is selected to include sources with $S_{178\ \mathrm{MHz}} \geq 10$ Jy and $\delta > 10°$, the second $S_{2.7\ \mathrm{GHz}} \geq 1.5$ Jy and $\delta > 10°$ and the third $S_{5\ \mathrm{GHz}} \geq 1.3$ Jy and $\delta > 35°$. Sources that are closer than 10° to the galactic plane are excluded in all three samples. The statistically complete subsample of the database, hereafter the "HR sample", includes 159 sources of 256 in the Herbig & Readhead (1992) compendium. Of the remaining 97 sources 53 are unresolved, 29 are FR I type, 6 are D2 type, 5 have a complex structure and for 4 sources the radio structure is unknown. The HR sample consists of radio sources that have been observed in greatest detail and thus high quality maps were available for the most part of the sample. Essentially the same sample could have been formed by selecting sources from the LRL sample alone (138 sources in the HR sample come from this sample). This is because the LRL sample is selected at a lower frequency than the the two other samples and thus the lobe dominated sources that have steeper spectra tend to be selected more efficiently. The HR sample contains 110 radio galaxies, 47 radio quasars and two sources with unknown optical identification. The redshift is known for 155 sources (97% of the sample).

A larger subsample with useful amount of flux and structural information can be extracted by selecting all sources in the database with $S_{178\ \mathrm{MHz}} \geq 2.5$ Jy (hereafter the "2.5 Jy sample"). This is close to the 2 Jy limit that was used in forming the 4C sample (Pilkington & Scott 1967; Gower et al. 1967) and the same limit that was used by Hooley et al. (1978) in forming their radio quasar sample. Thus it is not surprising that 75% of the 2.5 Jy sample consists of 3C and 4C sources. Note that the HR sample is a subsample of the 2.5 Jy sample, except for 3 sources in the former that do not occur in the latter. The 2.5 Jy sample contains 722 sources of which 411 are radio galaxies, 234 are radio quasars and 77 have no optical identification. The redshift is known to 501 sources (69% of the sample).

The data are given in Tables 1 and 2. Table 1 contains the sources in the HR and 2.5 Jy samples and Table 2 contains the rest of the sources. When calculating linear sizes and luminosities $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$ has been assumed.

The organization of columns in Table 1 is as follows:

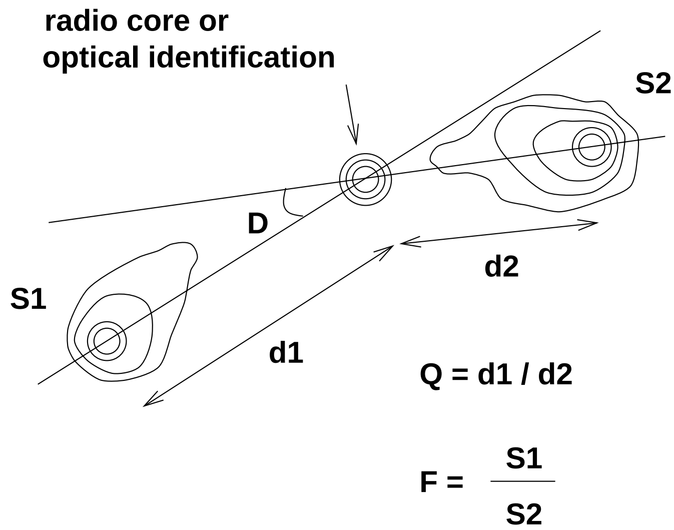

Fig. 1. A schematic radio map showing the definition of symmetry parameters Q, D and F used in this paper

Column (1) – IAU name of the source.

Column (2) – Other name of the source.

Column (3) – Redshift of the optical identification, spectroscopically measured in all cases.

Column (4) – Largest angular size of the radio structure, measured as the angular distance between the outermost hotspots.

Column (5) – Spectral index α between 178 MHz and 5 GHz, calculated from flux data at these frequencies (flux $\propto \nu^{-\alpha}$).

Column (6) – Projected linear size of the source in kpc.

Column (7) – Luminosity between 10 MHz and 10 GHz in the rest frame of the source, calculated from flux data at 178 MHz and 5 GHz and assuming a single power-law spectrum over the whole frequency range. In the rare cases when data were available for one frequency only, the median spectral index of the database $\alpha = 0.8$ was used. Herbig & Readhead (1992) list multifrequency flux data and luminosities that could have been used for the HR sample here, but in order to treat all data in the same manner the single power-law approximation and the formulae in Nilsson et al. (1993) were used in all instances.

Column (8) – Flux of the core component at 5 GHz. In some cases this is estimated from the radio map.

Column (9) – Spectral index of the core near 5 GHz, defined in the same manner as for α above.

Column (10) – The relative strength of the core at 5 GHz, defined here as the radio power of the core divided by the total power of the source. The radio power P is calculated from the expression.

$$P = 4\pi d_\mathrm{l}^2 S (1+z)^{\alpha-1}, \tag{1}$$

where S is the flux density and d_l the luminosity distance of the source. If the core spectral index was not available, $\alpha_\mathrm{core} = 0.1$ was assumed.

Table 3. Summary properties of the two subsamples of the database

sample	$N_{\rm sources}$	$N_{\rm gal}$	$N_{\rm qso}$	$N_{\rm unident.}$	z min/med/max	$(\log L)$ min/med/max	$\alpha_{\rm med}$
HR	159	110	47	2	0.023/0.635/2.510	41.7/44.8/46.2	0.83
2.5 Jy	722	411	234	77	0.003/0.543/4.250	40.1/44.4/47.0	0.84

Column (11) – The arm length ratio Q, defined as the ratio of the distances of the outermost hotspots at opposite sides from the radio core or the optical identification (Fig. 1). $Q > 1$ by definition.

Column (12) – The bending angle D.

Column (13) – The flux ratio F, defined as

$$F = S_1/S_2, \tag{2}$$

where S_1 is the flux density of the lobe farther from the core and S_2 is the flux density of the lobe closer to the core.

Column (14) – The frequency at which S_1 and S_2 were measured (in most cases 5 GHz).

Column (15) – flux %, a value defined as

$$\text{flux\%} = \frac{S_{\rm core} + S_{\rm lobes}}{S_{\rm tot}}, \tag{3}$$

where $S_{\rm core}$ is the flux density of the core, $S_{\rm lobes} = S_1 + S_2$ is the flux density of the lobes and $S_{\rm tot}$ is the total flux density of the source measured with a single dish radio telescope. A value significantly lower than 1.0 is an indication that large-scale flux is missing in the interferometric observations and the F value should be reviewed with caution.

Column (16) – Optical identification: G = galaxy, Q = quasar and - = unidentified.

Column (17) – Reference to the radio map. An asterisk indicates that no radio map was available and the symmetry data were extracted from tabular material.

Column (18) – References.

Column (19) – Sample membership: A = HR sample, B = 2.5 Jy sample.

The organization of Table 2 is similar, except that no column for sample membership (Col. 19) is given.

Table 3 summarizes the properties of the two samples and Fig. 2 shows the position of the sources with known redshift in the redshift – luminosity plane. The redshift distributions of the two samples are very similar; the difference in median redshift in Table 3 is not significant ($p = 0.28$ with the Kolmogorov-Smirnov test), although most of the high redshift sources ($z > 1.5$) belong to the 2.5 Jy sample. The luminosity difference, in contrast, is significant ($p < 0.01$) . Both samples thus probe the redshift space in a similar manner but at each z the 2.5 Jy sample reaches fainter luminosities than the HR sample, which is expected because of the fainter flux threshold.

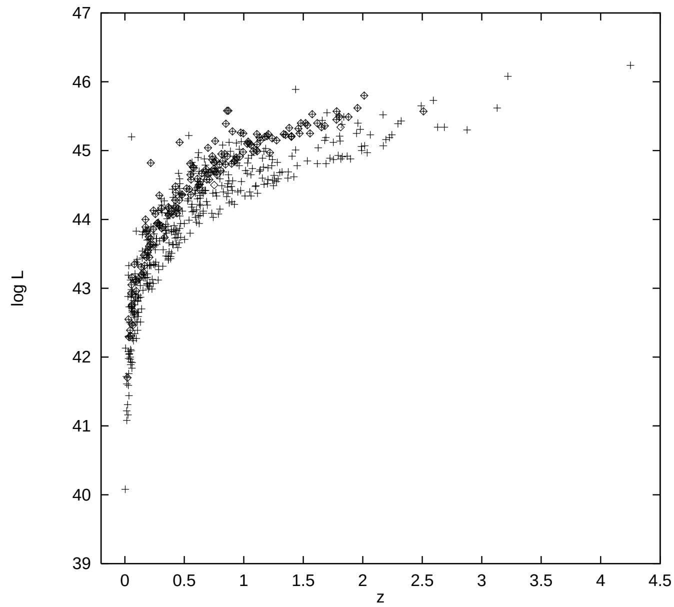

Fig. 2. The redshift – luminosity diagram of the HR sample (diamonds) and the 2.5 Jy sample (plus signs)

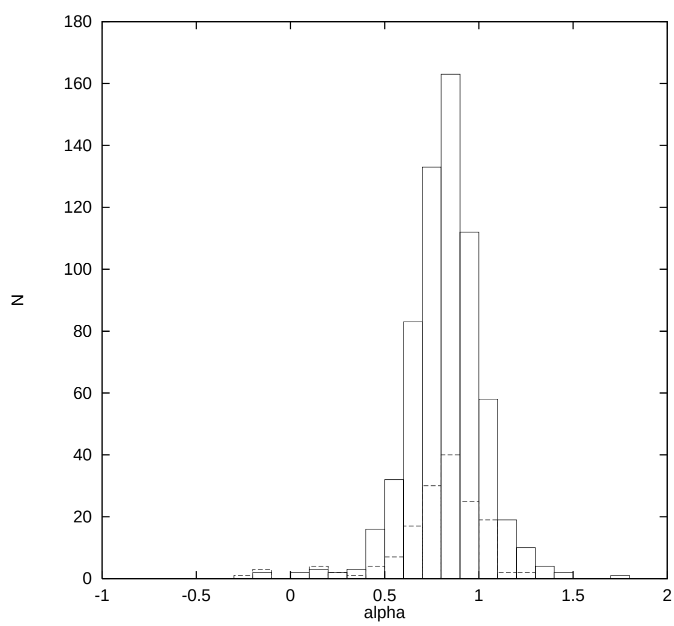

Fig. 3. The distribution of spectral index between 178 MHz and 5000 MHz for the HR sample (dashed line) and 2.5 Jy sample (solid line)

Finally, in Fig. 3 the spectral index α_{178}^{5000} distribution for the HR and 2.5 Jy samples is shown. The spectral index is concentrated around $\alpha = 0.8$, which is expected because both samples contain mainly lobe-dominated FR II sources. There is also a small flat spectrum tail that is caused by triple sources with a very strong core and weak lobes.

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