THE RADIO STRUCTURE OF COMPACT STEEP SPECTRUM RADIO SOURCES

C.Fanti[1,2], R.Fanti[1,2], P.Parma[2], R.Nan[3,6], R.T.Schilizzi[3], R.E.Spencer[4], W.J.M van Breugel[5], T.Venturi[1]

1) Dipartimento di Astronomia - Universita' di Bologna - ITALY
2) Istituto di Radioastronomia del CNR - Bologna - ITALY
3) Radiosterrenwacht - Dwingeloo - The Netherlands
4) The Nuffield Radio Astronomy Laboratories - Jodrell Bank - UK
5) Radio Astronomy Laboratory, University of California - Berkeley - USA
6) Beijing Astronomical Observatory - Beijing - CHINA

1. Introduction

Compact Steep Spectrum (CSS) radio sources are defined as having straight steep spectra typical of extended double-lobed radio sources and structures unresolved by conventional interferometers (Peacock and Wall 1982; van Breugel et al., 1984; Fanti et al., 1985). Their spectra remain straight up to quite high frequencies, indicating that no dominant core is present. Sometimes the spectrum bends at frequencies lower than 1 GHz. The angular sizes imply projected linear sizes generally < 10 kpc.

The number of CSS radio sources is not negligible, and varies from ~15% in catalogues compiled at low frequencies (e.g. 3CR, Laing et al., 1983) to ~30% in high frequency samples (e.g. Peacock and Wall, 1982).

If we assume that the extended radio sources in the 3CR catalogue are randomly oriented we can evaluate statistically the number of objects which appear of small size because they are oriented close to the line of sight and hence are shortened by projection. It is found (Fanti and Fanti, 1987) that the expected number of small angular sizes is much smaller than actually observed implying that the vast majority of the CSS radio sources are then physically small objects of sub-galactic dimensions.

2. The source sample

For some years now we have been studying a sample of CSS radio sources from the 3CR catalogue based on the 5 GHz maps made with the Cambridge 5 km radiotelescope (Jenkins et al., 1977). We define a source as CSS if it has at least 80% of its flux density at 5 GHz in a steep spectrum (α >0.5 above ~400 MHz; $S \propto \nu^{-\alpha}$) component, optically identified, and of projected linear size $\leq$10 kpc (Ho=100) (Fanti et al., 1985). These criteria are necessarily somewhat arbitrary, but were adopted to compile a sample which emphasizes the most important

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characteristics of the CSS radio sources. We also limit our analysis to powerful objects (Log P(178) >26 W/Hz), since the weaker ones might be governed by different mechanisms.

The sample includes 26 radio sources (15 QSS, 11 galaxies). VLBI maps at 18 cm exist for ~80% of the sample and for about 30% at 6 cm. MERLIN 18 cm and VLA data at 6 cm and 2 cm are also available for most objects.

3. The radio structure

An accurate morphological classification is not easy since it depends on the resolving power, frequency and sensitivity used. At high frequencies a weak core may show up. High sensitivity is important to establish whether any low brightness emission exists associated with the main component and hence to determine to what extent these objects are indeed small. Optical positions with high accuracy would also be of great importance for the identification of the true core among the source components.

The classification reported here is essentially based on the 18 cm VLBI data. Maps of the sources used as examples can be found in Fanti et al., 1985, unless differently specified. We divide the objects into:

- -doubles : two well separated components, occasionally with a weak core in between (which we refer to as "small doubles");
- -triples : doubles with a strong core;
- -jet-like: straight or bent, sometimes with a well visible core;
- -complex : any object which does not fit in any of the previous classes.

Small doubles (e.g. 3C343.1, 3C237) and triples are similar to the larger doubles, several tens of kpc in extent. They often show high brightness regions inside the lobes, which we may identify with "hot spots", and occasionally weak cores visible at high frequencies with the VLA (van Breugel et al., in prep.). They are also similar to the "compact doubles" of Phillips and Mutel (these proc.) of which they could be an evolved stage. Occasionally the two components may be very asymmetric in brightness (e.g. 3C49, 3C67, 3C268.3) compared to the wide doubles. The ratio of component size to separation is typically 1 to 10, as for their larger cousins, indicating that they are very unlikely to be extended doubles shortened by projection effects. The two or three point spectra of individual components tend to be equal and steep.

The core-jet like sources have significant similarities with those found in flat spectrum sources. Sometimes they are straight (e.g. 3C138, Geldzhaler et al., 1984) but may also show extreme examples of curved structure (e.g. 3C119, Nan et al., these proc.).

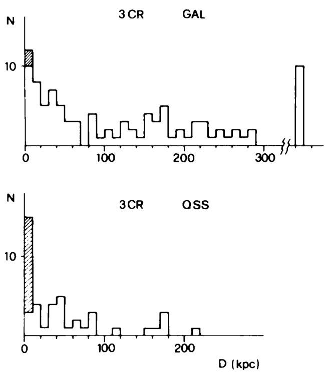
The complex sources may be core-jets very much wound up or with considerably distorted low brightness features (e.g. 3C380, Wilkinson et al., 1984a,1986; 3C287, Nan et al. these proc.) or, possibly, seen end on. But there are also cases like 3C343 (Nan et al. these proc.) which are very difficult to interpret.

The subdivision of 3C sources into morphological classes is summarized as follows:

-9/11 of galaxies are double with weak cores and no visible jets. The only exceptions are: 3C299 which could be core-jet like and 3C346 which has a rather bright core, and possibly a jet, embedded in a very diffuse low brightness region (van Breugel et al., in prep.);
-11/15 of the QSS's are either core-jet or complex;
- 4/15 of the QSS's are triple, i.e. double with a strong core.

Such a morphological segregation is independent of radio luminosity since weak quasars in our sample are still complex and powerful radio galaxies are still double. This marked structural difference was reported by Wilkinson et al., 1984b and Fanti et al., 1985. Here we strengthen those results, with higher resolution data.

Not only double structure is present in galaxies on all scales, but also the distribution of sizes for the galaxies of the entire 3C sample shows good continuity between our "small doubles" and the larger doubles (fig.1). This points to a single class of object undergoing the same evolutionary pattern.



The relation between size and structure is more complex in quasars. With a few exceptions small quasars have complex morphologies with highly curved jet-like features. The distribution of quasar radio sizes in the total 3C sample shows an excess in the small size bin (fig.1) which is mainly due to compact distorted structures (dashed). The structure however seems to develop towards the double morphology as the overall size progressively increases. Quasars larger than 10 kpc are usually double.

Steep spectrum quasars have on average a much brighter core than radio galaxies. However, if we consider galaxies and QSS's together, after appropriate normalization, (Fanti and Fanti, 1987), we find that the distribution of the ratio of core-to-extended emission in CSS radio sources is consistent with that of the classical doubles in the 3CR sample. This tells us two things:
- it confirms that the large majority of CSS sources are randomly oriented, otherwise we would observe doppler-boosted radio cores;
- the radio cores in CSS radio sources have the same relative power as in the more extended objects.

4. Discussion

We have reported three arguments to support the idea that CSS radio sources are mostly intrinsically small objects: i) diameter statistics; ii) separation/component-size ratio; iii) core/extended emission ratio.

If CSS radio sources are mostly randomly oriented, we cannot ascribe the large observed distortions to enhancement by projection of small intrinsic bends. To explain their morphology it is tempting to invoke interactions with an ambient gas, as is known to occur in nearby

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CSS radio galaxies (e.g. 3C305, Heckman et al., 1982). Ordered motions (e.g. 3C119, Fanti et al., 1986; Nan et al., in prep.), random motions and shocks (e.g. 3C380, Wilkinson et al., 1986) or a combination of these (van Breugel et al., these proc.) may play a role. In this scheme double and triple radio sources are either sources whose parent optical object has no turbulent medium or sources which have already escaped from such a medium.

The morphologies we find point to the first possibility for radio galaxies, since they have a double structure from the very beginning. The structure-size trend for quasars instead indicates the existence of a dense turbulent medium over scales of some kpc, strongly perturbing the radio structure. Only if (or when) the radio emitting material emerges from such a region the double structure can be formed. This is furthur discussed by van Breugel et al. (these proc.).

A number of objections can be brought against this simple scheme. For instance if optical boosting were present, as suggested by some authors, galaxies could be turned into quasars, and the diameter statistics we present would be wrong for such objects. It would however be difficult to reconcile this with the fact that we do not observe boosted radio cores (unless more ad hoc assumptions are introduced, e.g. weaker cores in CSS quasars, boosting occurring in both core and extended regions, etc.).

We conclude that the hypothesis that CSS radio sources are physically small objects, randomly oriented in the sky, is still the one requiring the minimum number of assumptions.

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