Mon. Not. R. astr. Soc. (1974) **167**, *Short Communication*, 31P–35P.

THE MORPHOLOGY OF EXTRAGALACTIC RADIO SOURCES OF HIGH AND LOW LUMINOSITY

B. L. Fanaroff and J. M. Riley

(Received 1974 March 6)

SUMMARY

The relative positions of the high and low brightness regions in the extragalactic sources in the 3CR complete sample are found to be correlated with the luminosity of these sources.

It has become clear from recent observations of extended extragalactic radio sources that many consist of fairly compact regions of high brightness (' hot spots ') embedded in more extensive regions of much lower brightness. It is of importance to the models of the origin of the radio emission and of the energy supply to understand the relationship between these regions and other parameters of the radio emission such as luminosity, spectral index and shape. In this note we suggest that there is a definite relationship between the relative positions of the high and low brightness regions of radio sources and their luminosity.

The 199 sources in the 3CR complete sample (Mackay 1971) have been studied with high resolution using the Cambridge One-Mile telescope. All 199 sources were mapped at 1·4 GHz with a resolution of 23″ arc in RA and 23″ cosec δ in Dec. (Macdonald, Kenderdine & Neville 1968; Mackay 1969; Elsmore & Mackay 1970), and 53 of them were observed at 5 GHz with a resolution of $6'' \times 6''$ cosec δ (Mitton 1970a, b, c; Graham 1970; Harris 1972, 1973; Branson *et al.* 1972; Riley 1972, 1973; Riley & Branson 1973; Northover 1973, 1974).

In the investigation described here we have used a sub-sample of the 3CR complete sample, consisting of all those sources which were clearly resolved into two or more components in any of the series of observations mentioned above. The sources were classified using the ratio of the distance between the regions of highest brightness on opposite sides of the central galaxy or quasar, to the total extent of the source measured from the lowest contour; any compact component situated on the central galaxy was not taken into account. Those sources for which this ratio is less than 0·5 were placed in class I; those for which it is greater than 0·5 were placed in class II. In sources for which we have maps of adequate resolution, this is equivalent to having the ' hot spots ' nearer to (Class I) or further away from (Class II) the central bright galaxy or quasar than the regions of diffuse radio emission. The sensitivities of most maps were sufficient for brightness temperatures a few per cent of the peak brightness to have been detected. Those sources for which the sensitivities were not good enough to detect low brightness regions, and those of two or three beamwidths in extent for which classification is impossible, are listed in Table II and have not been included in the analysis.

The results are presented in Table I whose arrangement is as follows:

(i) The luminosity at 178 MHz in W Hz^{-1} sr^{-1} (Hubble's constant = 50 km s^{-1} Mpc^{-1}); the sources are arranged in order of their luminosity.

TABLE I

P_{178}	3C	Type	Class	Size (kpc)	Beam size (kpc)
5×10^{21}	231	C	I	1	0·7
5×10^{22}	272.1	C(D)	I	8	1·9
1×10^{24}	83·1	C(D)	I	250	12
	449	C(D)	I?	270	12
	31	C(D)	I	170	11
	386	C	I?	100	12
	402	C	I?	260	16
3×10^{24}	76·1	D	I	40	21
	264	C	I	190	13
	66	C(D)	I	160	13
	442	C(D)	I	200	17
	274	DC	I	7	2·6
	84	C	I	160	12
1×10^{25}	465	C(D)	I	440	19
	338	DT	I	35	19
	98	DC	II	260	19
	35	C	II	900	43
	285	DT	II	270	50
	382	DC	II	300	10
	192	DT	II	300	11
	277.3	DC	II	60	15
3×10^{25}	390.3	DT	II	320	10
	310	C	I?	360	34
	184.1	DT	II	470	75
	33	D	II	390	11
	388	DT	II	70	16
	314.1	C	?	*600	90
	315	C	?	360	67
	332	DT	II	250	26
	357	DT	II	270	101
	223	DT	II	900	84
1×10^{26}	381	DT	II	250	29
	452	DC	II	500	15
	379.1	DT	II	330	120
	433	C	?	90	19
	323.1	DT	II	340	44
	284	DT	II	750	150
3×10^{26}	46	DT	II	*800	168
	234	DT	II	300	110
	319	DT	II	*300	146
	341	DT	II	370	57
	249.1	D	II	130	57
	219	DT	II	550	30
	351	DT	II	370	60
	274.1	DT	II	*900	180
	79	DT	II?	300	150
	61.1	DT	II	*750	40
	109	DT	II	500	50

TABLE I—*continued*

P_{178}	3C	Type	Class	Size (kpc)	Beam size (kpc)
1×10^{27}	47	DT	II	450	60
	263	DT	II	370	90
	336	D	II	180	100
3×10^{27}	123	DT	II?	*160	50
Unidentified	6.1	DT	II		
	20	DT	II		
	33.1	DT	II		
	268.2	DT	II		
	427.1	D	II		

(ii) The number of the source in the 3C catalogue.

(iii) The morphological description of the source:

D—Double source; each component is barely resolved.

DT—Double source; each component has an extended tail.

DC—Double source; each component is very complex.

C—Complex source with no well-defined axis.

C(D)—Complex source in which the components show a well-defined axis close to the galaxy.

(iv) Class of source:

I—Low brightness regions further from the galaxy than the high brightness regions.

II—High brightness regions further from the galaxy than the low brightness regions. A ? indicates uncertainty in the class.

(v) Approximate size of the source in kpc, defined as the maximum distance between the half-power points of the outermost components; an asterisk indicates that the distance to the source is estimated from the magnitude of the associated galaxy.

(vi) Half-power beamwidth in terms of kpc at the source.

It is clear from Table I that there is a sharp division in luminosity between the two classes; those with luminosities at 178 MHz below $\approx 2 \times 10^{25}$ W Hz^{-1} sr^{-1} (i.e. 3C 231 to 3C 338 in Table I) are nearly all of class I, and those above nearly all class II. The value of the luminosity at which the division occurs is remarkably close to that which divides sources which show strong cosmological evolution (Longair 1971) from those which do not.

The leading (or outermost) edges of the sources in class II are frequently unresolved. In many cases the half-power beam sizes in kpc at these sources are comparable with those in class I sources (see Table I) in which the leading edge is resolved. This being so we can usually rule out the existence in class II sources of low brightness regions of the type seen in class I. Note, however, that the existence of such regions would not necessarily move a source from class II to class I.

It is also apparent (Table I) that the majority of class I sources show very complex structure, but in most of them the structure close to the associated galaxy indicates that material has been ejected in opposite directions, as is presumed to

TABLE II

P_{178}	3C	Size (kpc)	Beam size (kpc)
10^{25}	177	*290	49
	223.1	190	67
	303	*65	25
10^{26}	172	*400	110
	114	*300	150
	300	390	120
	322	*170	150
	401	*66	120
	277.2	*250	170
	173.1	*200	150
	349	*370	160
	277	*680	170
	250	*240	180
	171	40	150
	252	*340	170
	267	*230	170
	244.1	230	180
	215	160	60
	265	*400	170
10^{27}	334	300	270
	175	390	330
	254	100	330
	204	270	400

occur in most of the powerful double sources in class II. Away from the centres of the class I sources there is a great diversity of structure—the components often show considerable changes of curvature along their lengths. Distortion of the components to this degree is not found in most of the class II sources, although the low brightness tails of their components are often significantly inclined to the source axis (Harris 1974).

Despite these differences in their relative positions, the low brightness regions in both classes show similar properties, as do the high brightness regions. The energy densities of the low brightness regions are 10^{-13}–10^{-12} J m^{-3} (see Longair, Ryle & Scheuer 1973) and are such that these regions could be confined by the thermal pressure of a hot intergalactic gas (e.g. Gull & Northover 1973). The spectral indices of these regions are often high ($\alpha \gtrsim 1 \cdot 0$, where $S \propto \nu^{-\alpha}$) (e.g. Riley & Branson 1973; Northover 1973; Hargrave & Ryle 1974), and it is usually assumed that these steep spectra are produced by synchrotron (or inverse Compton) losses; as the equipartition magnetic fields in these regions are very low (~ 1 nT) the periods required to produce such steepening of the spectra are $\sim 10^8$ yr, so the relativistic particles in these regions could be very old. The regions of higher brightness temperature usually have lower spectral indices $\approx 0 \cdot 7$; the energy densities and equipartition field strengths derived for them are often high, indicating that the relativistic particles must be replaced over relatively short timescales (e.g. $\sim 10^4$ yr in Cygnus A; Hargrave & Ryle 1974). This suggests that relativistic particles have recently been deposited or produced in these high brightness regions. The correlation we have found of the positions of these regions with the total luminosity of a source implies that there is a relationship between the way in which the energy is transported and deposited in a source and the total luminosity of that source.

ACKNOWLEDGMENTS

We thank Tony Hooley for supplying us with data on the 3CR complete sample and Dr J. E. Baldwin for helpful discussions. BLF is grateful to St John's College, Cambridge, and to the Cavendish Laboratory for financial support. JMR thanks Newnham College, Cambridge, for a Research Fellowship.

Mullard Radio Astronomy Observatory, Cavendish Laboratory, Cambridge

REFERENCES

Branson, N. J. B. A., Elsmore, B., Pooley, G. G. & Ryle, M., 1972. *Mon. Not. R. astr. Soc.*, **156**, 377.
Elsmore, B. & Mackay, C. D., 1970. *Mon. Not. R. astr. Soc.*, **146**, 361.
Graham, I., 1970. *Mon. Not. R. astr. Soc.*, **149**, 319.
Gull, S. F. & Northover, K. J. E., 1973. *Nature*, **244**, 80.
Hargrave, P. J. & Ryle, M., 1974. *Mon. Not. R. astr. Soc.*, **166**, 305.
Harris, A., 1972. *Mon. Not. R. astr. Soc.*, **158**, 1.
Harris, A., 1973. *Mon. Not. R. astr. Soc.*, **163**, 19P.
Harris, A., 1974. *Mon. Not. R. astr. Soc.*, **166**, 449.
Longair, M. S., 1971. *Rep. Prog. Phys.*, **34**, 1125.
Longair, M. S., Ryle, M. & Scheuer, P. A. G., 1973. *Mon. Not. R. astr. Soc.*, **164**, 234.
Macdonald, G. H., Kenderdine, S. & Neville, A. C., 1968. *Mon. Not. R. astr. Soc.*, **138**, 259.
Mackay, C. D., 1969. *Mon. Not. R. astr. Soc.*, **145**, 31.
Mackay, C. D., 1971. *Mon. Not. R. astr. Soc.*, **154**, 209.
Mitton, S., 1970a. *Astrophys. Lett.*, **5**, 207.
Mitton, S., 1970b. *Astrophys. Lett.*, **6**, 161.
Mitton, S., 1970c. *Mon. Not. R. astr. Soc.*, **149**, 101.
Northover, K. J. E., 1973. *Mon. Not. R. astr. Soc.*, **165**, 369.
Northover, K. J. E., 1974. In preparation.
Riley, J. M., 1972. *Mon. Not. R. astr. Soc.*, **157**, 349.
Riley, J. M., 1973. *Mon. Not. R. astr. Soc.*, **161**, 167.
Riley, J. M. & Branson, N. J. B. A., 1973. *Mon. Not. R. astr. Soc.*, **164**, 271.