THE WESTERBORK SURVEY OF RICH CLUSTERS OF GALAXIES

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1. INTRODUCTION

In the Westerbork Survey of Rich Clusters of galaxies (WSRC), seven nearby and *rich* clusters of galaxies have been observed with the Westerbork Synthesis Radio Telescope. The results obtained at different frequencies are published in several papers of a series, and Table 1 serves as a general reference to these publications. In these papers, both discussions on individual radio sources and the presentation of cluster radio luminosity functions (RLF) are given. Here we summarize some of the results of the WSRC which, from a statistical point of view, impose some constraints on the rate of the radio activity of galaxies and on the influence of the galaxy environments on their activity. The rate of radio activity of a sample of galaxies in a cluster can be described by the integral RLF of the cluster, which represents the fraction of galaxies that emit in the radio domain above a certain power. When it is presented as a function of the optical luminosities of the cluster galaxies, it is called the bivariate radio luminosity function (BRLF). The BRLFs are most suitable for representing in an unbiased way the rate of activity of a sample of galaxies, since they are presented in absolute parameters and are normalized to the optical luminosity function (or distribution) of the galaxy samples. This is important since, both inside and outside clusters, it has been shown that the RLF depends strongly on the optical luminosities.

For detailed descriptions of the identification procedures, the optical and radio completeness limits, the technique of deriving RLFs, the used optical information, etc., we refer to the original papers of the series. Here we summarize the over-all results of the RLFs of elliptical plus SO (E+SO, Section 2) and spiral plus irregular galaxies (S+I, Section 3) separately.

In addition, in Section 4 some statistical results on the morphologies of head-tail radio galaxies are presented.

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Table 1

References of the Westerbork Survey
of Rich Clusters of galaxies

	Frequency (MHz)		
	4995	1415	610
A1367	--	VII, VIII	VII, VIII
A1656 (Coma)	0	0, I, II	III, IV, VI
A2147	--	I, II	IX
A2151 (Hercules)	0, V	0, I, II, V	V, IX
A2197	--	I, II	XII
A2199	0	0, I, II	XII
Cancer	--	--	XI, XIII

0	Jaffe and Perola, 1974
I	Jaffe and Perola, 1975
II	Jaffe and Perola, 1976
III	Jaffe et al. 1976
IV	Valentijn et al. 1977
V	Valentijn and Perola, 1978
VI	Valentijn, 1978
VII	Gavazzi, 1978
VIII	Gavazzi, 1979
IX	Perola and Valentijn, 1979
XI	Perola et al. 1980
XII	Gavazzi and Perola, 1980
XIII	Valentijn, 1980

A value of the Hubble constant $H_0 = 100$ km•s^{-1} Mpc^{-1} has been used throughout this series.

2. THE RADIO LUMINOSITY FUNCTION OF E+SO GALAXIES

Auriemma et al. (1977) have presented the local ($z < 0.1$) BRLF at 1415 MHz of a sample of (E+SO) galaxies *merely located outside rich clusters* (Fig. 1). In the construction of their function, a total of ∿ 145 detections were used, and this adequately describes the integral BRLF in the power range $10^{20.4}$-10^{26} W•Hz^{-1}for galaxies with an absolute photographic magnitude M_p between -18 and -22. For all the individual clusters observed in the WRSC, the BRLFs of the E+SO galaxies were not found to be significantly different (within a factor of 2 in detection rate) from the one presented by Auriemma et al. (1977). The largest discrepancy was found for the bright ellipticals ($M_p < -20$) in A2197, where four out of four galaxies were detected ($P_{610} > 10^{21.6}$), while a fraction of 40% was expected from the BRLF of Auriemma et al. (1977). This result is, however, of marginal statistical significance.

In addition we mention that also the peculiar X-ray cluster A2256, which contains five to seven head-tail radio sources and probably diffuse radio emission, has a RLF that is not significantly different (see Bridle et al. 1980) from the function of Auriemma et al. (1977).

The results of the BRLF of the E+SO galaxies seem to imply that the rate of the radio activity of these galaxies is not dependent (or is only weakly so) on the galaxy environment. So the different circumstances outside and inside rich clusters, such as galaxy density, galaxy velocity dispersions, and the presence of an intracluster medium, seem to have only a weak influence on the rate of the individual galaxy radio activity of E+SO galaxies.

3. THE RADIO LUMINOSITY FUNCTION OF S+I GALAXIES

With respect to the S+I galaxies (hereafter called spirals) the results are more diverse. In Figure 2 the values of the integral RLF at $P_{610} > 10^{21.76}$ W•Hz^{-1} are plotted as a function of the absolute magnitudes. We have used a sample of *'field'* spirals studied by Camaron (1971a and b) for comparison. A magnitude correction of 0.6^m was introduced to the Cameron data in order to have its magnitude scale consistent with the Zwicky-Herzog scale we are using in this survey. The A2197 and Cancer cluster spirals have a BRLF very similar to the field spirals (Fig. 2a) with a pronounced dependence on the optical magnitudes. However, the optically bright spirals in the Hercules supercluster (A2151+A2147) seem to be underluminous (∿ 5σ difference) in the radio when compared to the Cameron sample (Fig. 2b), while A1367 has an intermediate position. In Coma the results are reverse (Fig. 2c). Here the optically faint spirals are overluminous (∿ 2σ difference) in radio, and the dependence of the RLF on optical luminosity is completely absent. The RLF of

A2199 shows the same trend, but it is less pronounced. We do not yet have an explanation for these data, but there is an indication that the rate of radio activity of spiral galaxies is correlated to the presence of optical emission lines: in Coma, 90% of the detected spirals show emission lines, while ∿ 50-65% of all the Coma cluster spirals have emission lines. For the other clusters we do not have complete information, but for those galaxies surveyed for emission lines we generally find that 90-100% of the radio detected spirals have emission lines. Complete measurements of the optical spectra of cluster spirals are urgently needed in order to investigate the possible correlation between the presence of emission lines and their radio behaviour, and to reveal in which way the spiral radio activity is possibly influenced by their local conditions.

4. HEAD-TAIL GALAXIES

Using ∿ 15 observations of head-tail radio galaxies from the WSRC and adding all those published elsewhere, a sample of 44 head-tail galaxies was constructed (Valentijn, 1979). This sample is optically unbiased since all head-tail radio sources are identified with galaxies with magnitudes well above the plate limit of the PSS. Figure 3 shows the sample distribution of the absolute magnitudes (M_p) versus the radio power at 610 MHz (P_{610}) while different symbols are adopted for different opening angles (χ) of the radio tails. The opening angle is defined as the angle between the galaxy core and the two furthest displaced radio components, which are generally ∿ 100 kpc away from the galaxy centre.

The expected average M_p of an optically complete sample of elliptical galaxies as predicted from the RLF by Auriemma et al.(1977) is indicated in Fig. 3 by the dashed line. From this figure it can be seen that the wide-angle tails (WATs $\chi > 60^\circ$) seem to have the largest radio power while they are also associated with the optically brightest galaxies (see also Owen et al.,1977; Simon,1978). In fact, the WATs have a $\langle M_p \rangle \sim 0.7^m$ brighter than expected for normal radio galaxies of similar radio power.

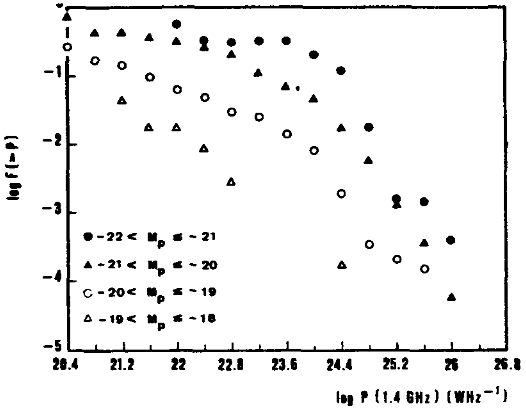
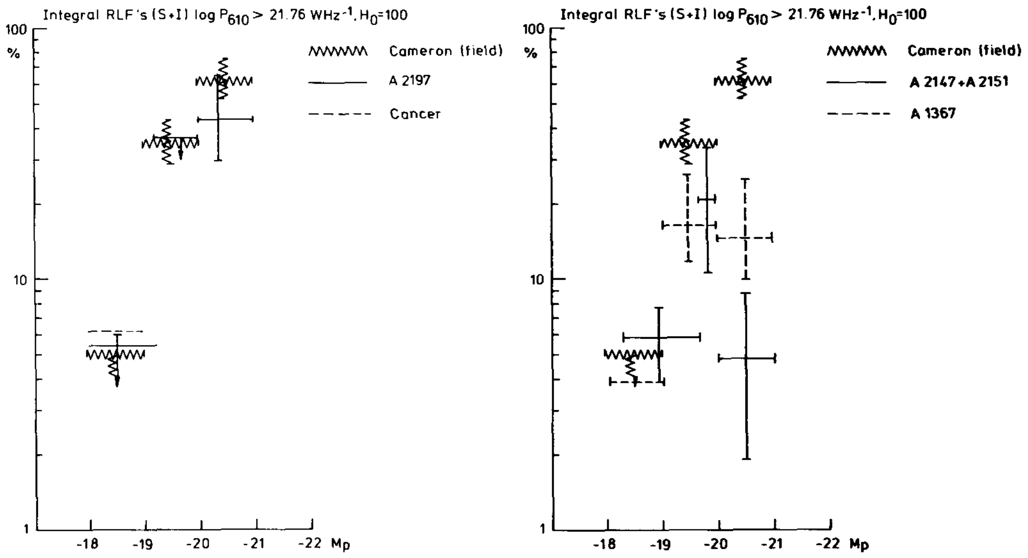


Figure 1. The integral bivariate RLF of elliptical + SO galaxies from Auriemma et al. (1977).



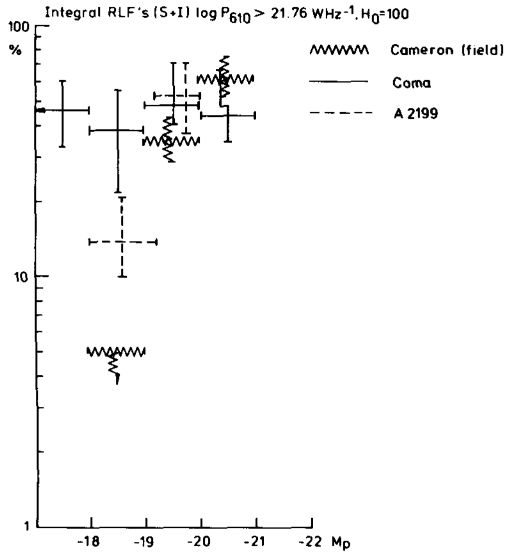


Figure 2. The values of the integral RLF of spiral and irregular galaxies at $P_{610} > 10^{21.76}$ $W \cdot Hz^{-1}$.

This is related to the fact that WATs are often associated with dominant cluster galaxies. Most strikingly, the radio power where NATs and WATs seem to segregate is close to P*, where the break in the RLF of Auriemma et al. (1977) occurs and where also type DI and DII double radio sources separate (Faranoff and Riley, 1974).

For a more extensive discussion on these data we refer to Valentijn (1979). Here we summarize shortly the interpretation given there. It is interesting to realize that the double radio sources ($\chi \equiv 180°$) do not follow the correlation between χ, P_{610}, and M_p found for head-tail sources ($\chi < 180°$), and that they are found (Lari and Perola, 1978) to be generally located outside clusters. In the independent blob model of Jaffe and Perola (1973), the over-all morphology of radio sources as described by χ is related to the stopping distance, determined by the mass of the ejected blobs and the density of the surrounding medium, and to both the galaxy speed and blob ejection velocity. Outside clusters, where a gas density of a factor of 100 less than inside clusters can be expected, the stopping distances are hence a factor of 10 longer, allowing radio sources to produce their apparent double structures irrespective of other parameters. Inside clusters, the stopping distances are much shorter so that the relation of χ to the other parameters enters the scope of the observational samples.

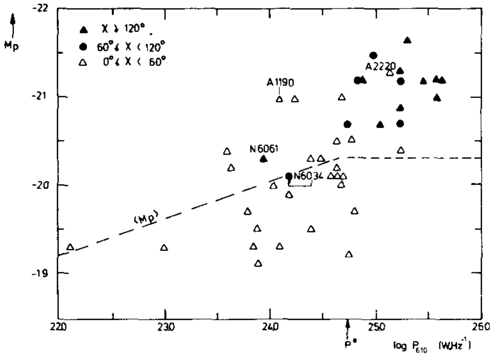


Figure 3. The absolute photographic magnitude (M_p) versus radio power at 610 MHz for head-tail radio sources in three intervals of the opening angle (χ).

The interesting point of such an interpretation is that it allows a similar origin mechanism for all types of radio morphologies with comparable masses of the ejecta and ejection velocities, which is also suggested by the generality of the RLF of elliptical galaxies, while it can describe the *different over-all morphologies* of radio sources as being due to local circumstances (i.e. low gas densities and low galaxy velocities outside clusters).

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