Rich-Cluster and Non-Cluster Radio Galaxies & The (P,D) Diagram for a Large Number of FR I and FR II Sources

M.J. Ledlow\textsuperscript{a,1}, F.N. Owen\textsuperscript{b}, J.A. Eilek\textsuperscript{c}

\textsuperscript{a}Institute for Astrophysics, Dept. of Physics & Astronomy, University of New Mexico, 800 Yale Blvd. NE, Albuquerque, NM 87131
\textsuperscript{b}National Radio Astronomy Observatory, P.O. Box 0, 1003 Lopezville Road, Socorro, NM 87801\textsuperscript{2}
\textsuperscript{c}Astrophysics Research Center, Dept. of Physics, New Mexico Institute of Mining & Technology, Socorro, NM 87801

Abstract

We present a comparison of the optical and radio properties of radio sources inside and outside the cores of rich clusters from combined samples of more than 380 radio sources. We also examine the nature of FR I and FR II host galaxies, and in particular, we illustrate the importance of selection effects in propagating the misconception that FR I’s and FR II’s are found in hosts of very different optical luminosity. Given the large sample size, we also discuss the power-size $(P,D)$ distributions as a function of optical luminosity.

1 Introduction

The primary goal of this work is to compare radio sources in and out of the rich cluster environment to look for differences in either the host galaxies or the distribution of sources in radio luminosity, size, or morphology. The surprising result that the amplitude and shape of the radio luminosity function (RLF) is identical inside and outside the cores of rich clusters (Ledlow & Owen 1996, Fanti et al. 1984), is puzzling given what we know about the X-ray properties of galaxy clusters and groups. While poor clusters may simply

\textsuperscript{1} E-mail: mledlow@wombat.phys.unm.edu
\textsuperscript{2} The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.
be a lower-mass extension of rich clusters, given the differences in both ambient external density and local velocity dispersion, one might expect a significantly different rate of galaxy interactions, a higher frequency of gas-rich neighbors, and a lower density medium to confine the radio sources. The similarity of the RLF in and out of clusters suggests that the same frequency of elliptical galaxies are radio emitting (also with a similar distribution in radio powers). It does not, however, rule out a different relation in either the radio power-size \((P,D)\) plane or the relationship between radio and optical luminosity and the FR I/II division (de Ruiter et al. 1990, Ledlow & Owen 1995b).

In order to study these effects, we have put together the largest available samples of radio sources to date, including 259 rich-cluster radio galaxies (Ledlow & Owen 1995b, Ledlow & Owen 1996) and 124 radio sources not found within 1 Abell radius (\(\sim 2h^{-1} \text{Mpc}\)) of an Abell cluster. The non-cluster samples are based on the Bologna B2 Survey (Fanti et al. 1987) and a subset of the all-sky 2.7GHz survey from Wall & Peacock (1985)(WP). We include here analysis of new optical (R-band) observations of all 124 non-cluster radio sources, which were analyzed identically to our rich cluster survey (Ledlow & Owen 1995b). We have also used the NRAO VLA D-Array Sky-Survey (NVSS) to measure source fluxes (and in some cases sizes) for the B2 and WP samples. Radio sizes for the rich-cluster radio galaxies are from Eilek et al. (2000).

### 2 Selection Effects

Before we can compare our two samples (cluster & non-cluster), we need to explore the effects of the selection function on the various samples. The B2 sample has traditionally been divided into B2-Near (Colla et al. 1975) and B2-Far (Fanti et al. 1978) subsamples, each with a different selection function. The near-sample has a magnitude-limit of \(m_{pg} < 15.7\) \(m_{R_{24.5}} \lesssim 14\). The far-sample has a magnitude cutoff of \(m_v = 16.5\) \(m_{R_{24.5}} \lesssim 15.9\). Both subsamples essentially have the same radio flux-limit of \(P_{408 MHz} = 200\) mJy \((\approx 100\) mJy assuming \(F_{v} \propto \nu^{-0.7}\)). The WP sample has no magnitude cutoff, but has a high flux-limit of \(P_{2.7GHz} = 2\) Jy \((P_{1400MHz} \geq 3.2\) Jy, also for \(\alpha = 0.7\)).

The effect of these selection functions is illustrated in Fig. 1 where we have shown the 75th percentile values of \(M_{R_{24.5}}\) and \(P_{1400}\) for each of the samples (75% of the objects are to the right of the vertical lines and above the horizontal lines). Because of the magnitude-limits of the B2 sample, the part of the optical/radio luminosity plane fainter than \(M_R^* = -22\) and \(P_{1400} < 10^{24}\) is essentially unsampled. This net effect of these selection functions is to preferentially pick out FR I radio sources with optical luminosities \(\gg L^*\). It is for these reasons that FR I's have mistakenly been identified with only the brighter ellipticals, consistent with brightest cluster galax-
functions for $M < \cdots$ are: FR I=1’s, FR II=2’s, and Fat-Double=F. The solid-line indicates the fiducial $M$ these same selections explain why FR II’s have always been associated with $M^*$ ellipticals. Given the steep slope of both the optical and radio luminosity functions for $M < -23$ and $P_{1400} > 10^{25}$ and the small search volumes, all detected FR II’s are likely to cluster near the survey-limits in optical luminosity (near $M^*$). It should be noted, however, that it is difficult to separate out the effects of redshift evolution with a limited search volume.

3 Rich Cluster vs. Non Rich-Cluster Radio Galaxies

In order to compare our rich cluster radio sources to these other samples, we have therefore applied the B2 selection function (both $M_{opt}$ and $P_{20cm}$ constraints) to our rich cluster survey, including an upper-redshift cutoff of $z=0.24$ to better match the two samples. We have compared a number of parameters from both the optical analysis as well as the radio properties between these two samples. See Ledlow, Owen, & Eilek (2000) for a complete presentation of these results.

For the optical properties, we compared the distribution of ellipticities, surface-brightness profile shape (via a power-law exponent and $r^{1/4}$-law fits), depar-
measure from elliptical isophotes (A4,B4 parameters), the Kormendy relation ($\mu_e$ vs. $r_e$ slope), and the luminosity-size ($M_{24.5}$ vs. $r_{24.5}$) relationships for both the cluster and non-cluster samples. Measured at the same optical luminosity ($M_{24.5}$), we find no discernable differences between the two samples.

We also compared the optical properties of the FR I and FR II host galaxies (combining cluster and non-cluster sources together). From the median of the optical magnitude distributions, we find: $M_{24.5}(FRI) = -22.85 \pm 0.04$ and $M_{24.5}(FRII) = -22.58 \pm 0.10$. Thus, the FR I’s are found in only slightly brighter galaxies, and significantly less luminous on average than BCG’s ($M_{24.5} < -23.5$). Additionally, we found no differences in the host galaxy properties listed above between the FR I and FR II hosts, at least in their broadband photometric properties.

Our radio comparison between cluster and non-cluster sources included the size-distributions (at the same radio power), the distribution in the radio/optical luminosity plane, and the FR I/II division. We find no evidence for differences in either of these properties between the two samples. We do however note the following observations: 1) The size-distribution is somewhat broader outside of clusters, and 2) We do not see a population of FR II’s with $P_{20cm} \gtrsim 25.5$ in the rich cluster sample. However, these differences are minor, and argue for very similar environments (at least the aspect of the environment which most influences the evolution of radio sources) inside/outside the cores of rich clusters. All three samples are plotted together in Fig.1 and Fig. 2.

### 4 The (P,D) Diagram

Given that we find no significant differences in our cluster/non-cluster samples, we have combined them in order to improve the statistics. In Fig. 2, we show the radio-power/size ($P, D$) distributions in several ways. In the bottom diagram we separate the three samples by point-type to show their intrinsic distributions. In the middle plot we show the sample divided into FR I, FR II, and Fat-double classes. For the FR I’s, we find a fit (log-log) of the form: $Size(FRI) \propto P_{20cm}^{0.31\pm0.03}$ (ignoring unresolved sources with only size upper-limits). For the FR II’s, we find essentially no dependence between power and size ($Size(FRII) \propto P_{20cm}^{0.08\pm0.09}$). Note, however, that at the same radio power, both FR I and FR II sources have the same distribution in source-sizes.

The top plot in Fig. 2 shows the median size as a function of radio power and optical luminosity (lower numbers represent bins of lower optical luminosity). One sees from the plot that the trend is for optically fainter galaxies to have larger radio sources. In bins of constant optical magnitude, we find that for fits of the form: $Size \propto P_{20cm}^x$, $x$ decreases with increasing $L_{opt}$ (from 0.36-
Fig. 2. (middle) \((P, D)\) diagram for combined cluster/non-cluster samples with a cutoff of \(z=0.24\). The solid-lines show the fit for the FR I’s with and without the size upper- limits for the unresolved sources. The dashed-line is the fit for the FR II’s. (bottom) Same as middle, where the point types reflect the sample from which the sources were taken (see legend on plot). (top) Median values of the radio size in radio power bins as a function of optical magnitude \((\Delta M=0.75 \text{ mag})\); centered on \(1=-21.38\), \(2=-22.13\), \(3=-22.88\), \(4=-23.63\), \(5=-24.38\).

We also find that the size distributions for \(M \gtrsim M^*\) and \(M \lesssim -23\) are different at the 98\% level. It thus appears that optically brighter galaxies tend to have smaller sizes when measured at the same radio power. Is this result a consequence of environment (the brighter galaxies being in a higher-density environment or near the bottom of the local gravitational potential) or initial conditions (the physics near the black hole and the jet initial conditions)? We plan to address these issues by comparing our observed distributions in \((M_{\text{opt}}, P_{20\text{cm}}, \text{Size})\) with model predictions. It is clear, however, that we may need a new/more-detailed model for FR I sources (see Eilek et al. (2000) these proceedings) in order to understand these results.
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