On the Relation Between Radio and Non-Radio Elliptical Galaxies

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Abstract

Empirical evidence suggests that elliptical galaxies hosting a radio source may not be different from normal non-radio ellipticals. To test this possibility, we use Monte Carlo simulations to reproduce the distribution of radio galaxies in the radio-optical luminosity plane. The input parameters of the simulation are the optical luminosity function (LF) of ellipticals and the radio LF of radio galaxies, linked by a function giving the probability for an elliptical to be a radio galaxy.

Simulations reproduce the observations well, supporting unification of radio and non-radio ellipticals, provided that the probability of an elliptical hosting a radio source is proportional to the square of its optical luminosity.

The difference of $\sim 0.5 \, \text{mag}$ in average optical luminosity between FRI and FRII radio galaxies is also explained in this framework.

1 Introduction

Regardless of nuclear activity, all ellipticals lie in the same fundamental plane, have similar ellipticity distributions, isophotal twists, and colors (Homabe & Kormendy 1987; Ledlow & Owen 1995; Govoni et al. 2000; Urry et al. 2000). Furthermore, the presence of massive black holes at the centers of elliptical galaxies is the rule rather than the exception (Ho 1998; Magorrian et al. 1998; Richstone et al. 1998; van der Marel 1999). This suggests all ellipticals have the potential of experiencing a phase of intense nuclear activity.

To test this attractive possibility, we used Monte Carlo simulations to check whether observed samples of radio galaxies can be random selections of elliptical galaxies.

We start from the optical luminosity function (LF) of ellipticals, which in this scenario gives the number of potential radio galaxies as a function of optical magnitude. Then we introduce a probability function for the fraction of galaxy, of a given magnitude, to host a radio source.
2 Calculation

Based on available empirical results for radio galaxies, the following general assumptions are made:

1. The distribution of ellipticals in optical luminosity $L$ is given by a Schechter function, with $M_R^* = -22.8$ mags and $\alpha = +0.2$, as found in the Stromlo-APM experiment (Loveday et al. 1992).

2. All elliptical galaxies of all optical luminosities have the potential of being radio sources, with probability $S(L) = S^*(\frac{L}{L_r})^h$, where $S^*$ sets the overall normalization. From the bivariate LF it is known that $S(L) \propto L^2$ (Ledlow & Owen 1996), so we set $h = 2$ (the results are not very sensitive to the exact value of $h$).

3. Regardless of their optical luminosity, all active ellipticals produce radio sources with total power $P$ distributed following the known radio luminosity function $\frac{dN}{dP} \propto P^\beta$, with $\beta = -2$ (Auriemma et al. 1977; Toffolatti et al. 1987; Urry & Padovani 1995; Ledlow & Owen 1996).

4. In the radio-optical luminosity plane, FR I and FR II are separated by a transition line roughly proportional to $L^2$ (Bicknell 1995).

The number of radio sources per unit volume, having optical luminosity $L$ is the product of the optical LF times the probability $S$ (points 1 and 2):

$$N(L) = \Phi(L)S(L) = \frac{\Phi^*}{L_r}S^*(\frac{L}{L_r})^{\alpha+h}e^{(\frac{L}{L_r})^h}. \tag{1}$$

This is a Schechter function with exponent $(\alpha + h) = 2.2$. The final distribution of radio sources in the radio-optical luminosity plane, as derived in a radio-flux-limited survey, is given by the product of $N(L)$ times the function $\frac{dN}{dP}$, assumed to be the same for all optical luminosities (point 3), times the volume $V(P)$ over which sources of power $P$ can be observed above the flux limit of the survey. Once a random set of galaxies has been generated, sources are divided into FR I and FR II according to point 4.

Given the assumptions, there are essentially no free parameters, but we note the exponent $h$ is not well determined. Also, different groups have found significantly different values of $M^*$ and $\alpha$ (Muriel et al. 1995; Lin et al. 1996, Loveday et al. 1992; Zucca et al. 1997), and there is some freedom in the position of the FR I–II transition power.
Figure 1: Comparison of our simulation with data from Figure 1 of Ledlow & Owen (1996). (For consistency, this figure is computed with $H_0 = 75\ \text{km/s/Mpc}$.)

**Right Panel:** The distribution of radio galaxies (1=FRI and 2=FRII) in the radio-optical luminosity plane, as derived by Ledlow & Owen (1996), plotting data extracted from a complete flux-limited survey, to 0.1 Jy at 1.4 GHz, with no redshift limit. The solid line separating FR I from FR II is the one originally used by Ledlow & Owen.

**Left Panel:** Representative Monte Carlo simulation matched to the Ledlow & Owen (1996) sample. The simulation nicely reproduces the almost uniform coverage of the plane in the region $-25 < M_R < -21$ mag and $23 < \log(P) < 28$ W/Hz, with maximum concentration around the center of this region. Solid squares represent FR II, open squares FR I. The observed distribution occurs because: (1) brighter galaxies are not present because of the upper cutoff in the optical LF; (2) no galaxies are observed fainter than $M_R \sim -21$ mag because the function $N(L)$ decreases rapidly at low optical luminosities; (3) at low radio power, the number of galaxies observed is limited by the radio flux cutoff of the survey and by the small volume over which these faint objects can be discovered. (4) and at high radio power the limit is set by the rapidly decreasing probability of having radio sources of high powers.
Figure 2: Comparison with Figure 3 from Ledlow & Owen (1996). (For consistency, this figure is computed with $H_0 = 75$ km/s/Mpc.) **Left Panel:** Radio and optical luminosity for a sample of 188 radio sources, complete out to $z = 0.09$ down to a radio flux of 0.01 Jy at 1.4 GHz, from Ledlow & Owen (1996). **Right Panel:** Distribution derived from our Monte Carlo simulations. As in the real data, there are no very bright radio sources because of the small volume surveyed. In particular, basically all sources are below the transition line and should be FR I (open squares), as indeed observed by Ledlow & Owen.
Figure 3: **Comparison with data from Govoni et. al. (2000).** (For consistency, this figure is computed with $H_0 = 50 \text{ km/s/Mpc}$.) **Left Panel:** Distribution of radio galaxies studied by Fasano, Falomo & Scarpa (1996), with final results presented by Govoni et al. (2000). The original sample includes all radio galaxies in the redshift range $0.01 < z < 0.12$, down to a flux limit, at 2.7 GHz, of 2 Jy for part of the sample and 0.25 Jy for the rest. **Right Panel:** Result of a Monte Carlo simulation matched to the Govoni et al. sample. The agreement is excellent. We are able to explain nicely the distribution of the sources in the radio-optical luminosity plane, as well as the relative population of FR I (open squares) and FR II (solid squares).
Figure 4: Distributions of optical magnitudes from Govoni et al. (2000) Left Panel: Cumulative distribution of absolute magnitudes for the real (dashed line) and simulated (solid line) data set shown in Fig. 3. Right Panel: Cumulative distribution of absolute magnitudes for FR I (Left) and FR II (Right) radio galaxies separately. The agreement is excellent, explaining the difference in average optical luminosity between FR I and FR II as a subtle selection effect.
3 Results and Discussion

Result shows that under quite general assumption the observed distribution of radio galaxies in the radio-optical luminosity plane is nicely reproduced, as is the observed difference in optical luminosity between FR I and FR II.

The physical basis for our result is that all ellipticals should have a central black hole (van der Marel 1999; Macchetto et al. 1999). Active and non-active galaxies are linked by a probability function, found to be $\propto L^2$. We do not attempt to explain why radio sources are preferentially observed in giant ellipticals, however, the $L^2$ dependence of the probability of radio activity comes from the observed shape of the bivariate radio LF, and is similar to the dependence of the transition power from FR I to FR II. There must be a deeper physical meaning for this.

Once accretion onto the black hole has began, the strength of the radio emission should depend mostly on the accretion rate, which is independent from the galaxy size, justifying assumption 3.

The $\sim L^2$ dependence of the transition power from FR I to FR II imposes that to be an FR II, a bright galaxy must be associated with a very powerful radio source, a very improbable combination given the steepness of both radio and optical LF. Thus, from probability alone, the association FR II – faint galaxies is favored, causing the difference in observed optical luminosity between the two classes. No deeper physical difference between FR I and FR II host galaxies is required.

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