Carnegie Observatories Astrophysics Series, Vol. 1:
Coevolution of Black Holes and Galaxies, 2004
ed. L. C. Ho (Pasadena: Carnegie Observatories,
http://www.ociw.edu/ociw/symposia/series/symposium1/proceedings.html)

Black Hole Masses and the FR I–FR II Dichotomy

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Abstract

Understanding the FRI-FRII dichotomy is key in comprehending the processes connected to the radio jet activity. Our aim is to see if the central black hole mass plays a role in determining the FRI-FRII dichotomy. We present here the preliminary results of the first run of observations dealing with the determination of the black hole masses through the use of the $M_{\rm BH} - \sigma_c$ relation for 5 FRI and 3 FRII radio galaxies. It appears that the FRI-FRII dichotomy does not depend on the black hole mass; however, the statistics are still poor, and additional observations, covering a larger sample, are underway.

1.1 Introduction

The majority of radio galaxies can be morphologically divided into two classes: if most of the radio luminosity is emitted from the central regions of the jet (edge-darkened), the radio galaxy is classified as FRI; if the radio luminosity comes mainly from the outer parts of the jet, in particular from the lobes (edge-brightened), the radio galaxy is an FRII. Interestingly, this morphological classification coincides with a separation based on the total radio power: generally, the FRIs have L_{178} below $\sim 2.5 \times 10^{33} h_{50}^{-2}$ erg s^{-2} Hz^{-1}, where L_{178} is the total radio power at 178 MHz, while the FRIIs have L_{178} above this value (Fanaroff & Riley 1974). Ledlow & Owen (1994) have showed that the separation between FRI and FRII also depends on the optical luminosity of the host galaxy; in particular, the dividing radio luminosity increases with the optical luminosity of the host galaxy (see Fig. 1.1). On the theoretical side, this dichotomy has been interpreted as due to either the different ways in which the radio jet interacts with the ambient medium (Bicknell 1995; Gopal-Krishna & Wiita 2001) and/or the different nuclear intrinsic properties of the accretion and jet formation (Baum et al. 1995; Reynolds et al. 1996; Meier 1999). However, very little observational evidence has been gathered in support of either interpretations. By using the $M_{\rm BH}$-$M_{\rm bulge}$ correlation between the bulge magnitudes and the masses of the supermassive black holes (SBHs) hosted at the galactic centers (Kormendy & Richstone 1995), $M_{\rm BH}$ can be substituted for M_R in the Ledlow & Owen's plot (see Fig. 1.1), thus revealing that, at a given radio luminosity, FRI galaxies appear to host more massive SBHs than FRIIs (Ghisellini & Celotti 2001). Although suggestive, this argument fails to be conclusive, due to the large scatter - a factor of several in $M_{\rm BH}$ (Ferrarese & Merritt 2000) - intrinsic to the $M_{\rm BH}$-$M_{\rm bulge}$ relation.

More recently, it has become possible to obtain more accurate estimates of $M_{\rm BH}$ using the correlation between $M_{\rm BH}$ and the velocity dispersion of the host bulge σ_c (Ferrarese &

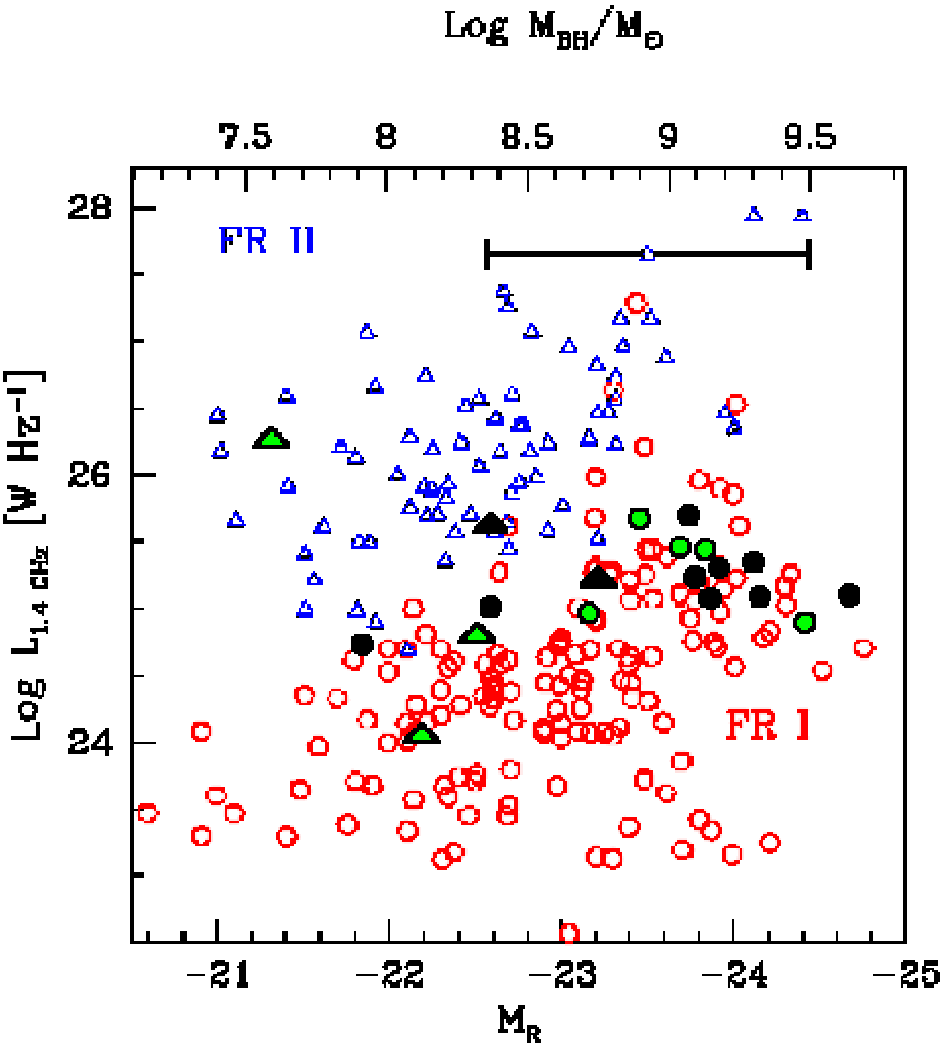


Fig. 1.1. M_R is the R band absolute magnitude of the host galaxy; $L_{1.4\ GHz}$ is the radio power at 1.4 GHz; $M_{\rm BH}$ is the mass of the central black hole obtained by applying the relation $\log M_{\rm BH}/M_{\odot} = -0.62(\pm 0.08) M_R - 5.41(\pm 1.75)$ (McLure & Dunlop 2001); the black bar represents the scatter in the $M_{\rm BH} - M_R$ relation. The filled symbols are the objects in the considered sample selected to have similar $L_{1.4\ GHz}$; the green ones are the already observed sources presented here.

Merritt 2000, Gebhardt et al. 2000). The tightness of this correlation allows to estimate $M_{\rm BH}$ with 30% accuracy; even detailed dynamical models applied to high resolution kinematics can rarely lead to higher precision measurements. By measuring the stellar velocity dispersion for a sample of FRI and FRII radio sources with an accuracy better than 10% we intend to explore what role the black hole mass plays in determining the large scale morphology of the radio jets. Here are presented the preliminary results of the first run of observations.

1.2 Sample, Observations and Data Reduction

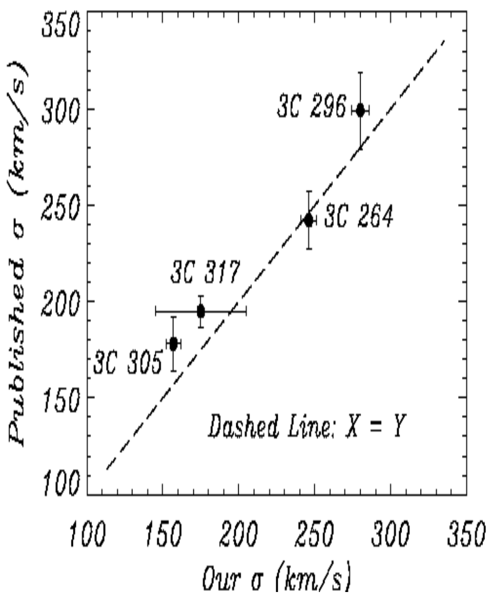
We have selected a sample of 19 nearby (z <0.05) radio galaxies (14 FRIs and 5 FRIIs) which are known, from HST images, to have relaxed and undisturbed morphologies. The selected radio galaxies have similar radio luminosity, in order to see if the FRI-FRII dichotomy depends on the central black hole mass. At present, we have observed 8 of the galaxies in our sample (5 FRIs and 3 FRIIs) using the Mayall 4-m telescope at Kitt Peak (NOAO). To maximize the ratio between stellar light and non-thermal emission from the central AGN, the stellar velocity dispersion was measured from the CaII absorption triplet at 8500 Å. This has the unfortunate consequence of limiting the highest redshift of the observable sources to 0.05, above which the CaII absorption lines are shifted to a region heavily contaminated by atmospheric water vapor. The RC spectrograph was used in the following configuration: slit width 2″; CCD spatial scale 0.43″pxl^{-1}; dispersion 0.47 Å pxl^{-1}, spectral range $\lambda \in$(8200,9200) Å; resolution $\sim$44 km s^{-1}. Integrated exposure times were in the range 2-4 hours depending on the object; the observing conditions have been very good throughout the entire run, with seeing $\sim$1″.

Standard reduction steps have been taken, giving particular attention to wavelength calibration and sky subtraction. The extracted 1-D spectra are characterized by very high signal-to-noise ratio $S/N \sim$ 40-130 per Å(all the galaxies except one have S/N greater than $\sim$100). The stellar velocity dispersions σ_c have been determined with an accuracy better than 5% with the Fourier Correlation Quotient (FCQ) method which is not sensitive to template mismatching (Bender 1990).

1.3 Results

The left panel of Fig. 1.2 shows a comparison between the velocity dispersions measured in this work and those already published in the literature, finding good agreement between the two; there are no previously published velocity dispersions for the other 4 objects. The right panels of Fig. 1.2 demonstrates that a foreground star is super-posed right on the nucleus of the host galaxy of 3CR 386: the star and the nucleus of 3CR 386 are so well superposed that even in HST images the star has been always identified with the nucleus of 3CR 386, making this FRI a clear outsider of any relation involving its nuclear optical luminosity (Chiaberge, Capetti & Celotti 1999, 2000)

The left panel of Fig. 1.3 shows a comparison between the $M_{\rm BH}$ derived from the $M_{\rm BH}$-σ_c and the $M_{\rm BH}$-M_R relations. The advantage in using σ_c, and therefore in the approach undertaken with this study, is immediately apparent: the SBH masses inferred from the latter relation are not accurate enough to reach definitive conclusions, unless very large datasets are addressed. The right panel of Fig. 1.3 shows the distribution in $M_{\rm BH}$ for the 8 galaxies observed as part of this project, plus 3 additional FR Is with $M_{\rm BH}$ determined from dynamical studies (Ferrarese, Ford, & Jaffe 1996; Macchetto et al. 1997; Bower et al. 1998). Our preliminary results seem to indicate that $M_{\rm BH}$ is not a major drive in shaping the FRI-FRII dichotomy. Given our admittedly small sample, SBHs powering FRII sources do not appear to be systematically less massive than those hosted by FRI galaxies; in fact, $< \log M_{\rm BH} >$ for FRIs is equal to $< \log M_{\rm BH} >$ for FRIIs within the errors.



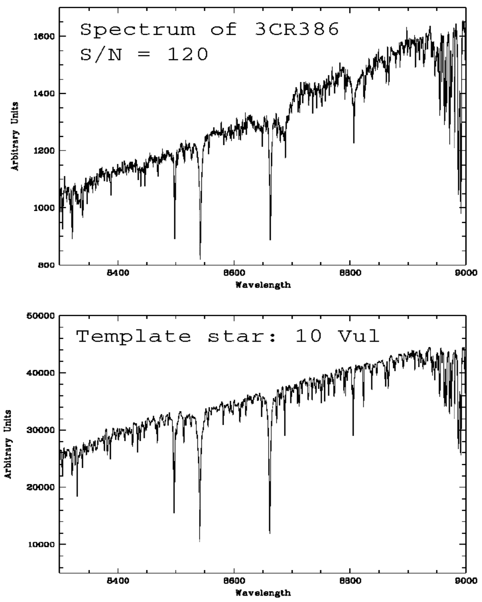


Fig. 1.2. Left: velocity dispersions are from Smith et al. (2000) for the two sources 3CR 264 and 3CR 317; from Heckman et al. (1985) for 3CR 305 and from Tonry & Davis (1981) for 3CR 296. Right: spectrum of 3CR 386 (upper panel) and spectrum of the template star 10 Vul (lower panel); the three most prominent narrow absorption features in both spectra are the absorption lines of the CaII triplet at rest. In the spectrum of 3CR 386 the redshifted broadened CaII triplet absorption lines are clearly visible at $\sim$ 8650, 8700 and 8800Å.

1.4 Conclusions and Future Work

We presented preliminary results from our kinematic survey of the bulges of FRI-FRII hosts. The goal of the project is to assess a possible dependence of the FRI-FRII dichotomy on the mass of the central SBH. Our first findings seem to indicate that this is not the case, since we find that, at a given radio luminosity, FRIs and FRIIs have comparable central black hole masses, within the errors. Our sample is still limited to 8 objects, making statistical conclusions rather uncertain. Our goal for the future is twofold. On one side increase the sample size to obtain better statistics. On the other side, derive an additional estimate of $M_{\rm BH}$ by using the correlation between SBH masses and the light concentration parameter discovered by Graham et al. (2001). The latter point is intended to address potential biases which might still affect the $M_{\rm BH}$-σ_c relation (Merritt & Ferrarese 2001; Tremaine et al. 2002).

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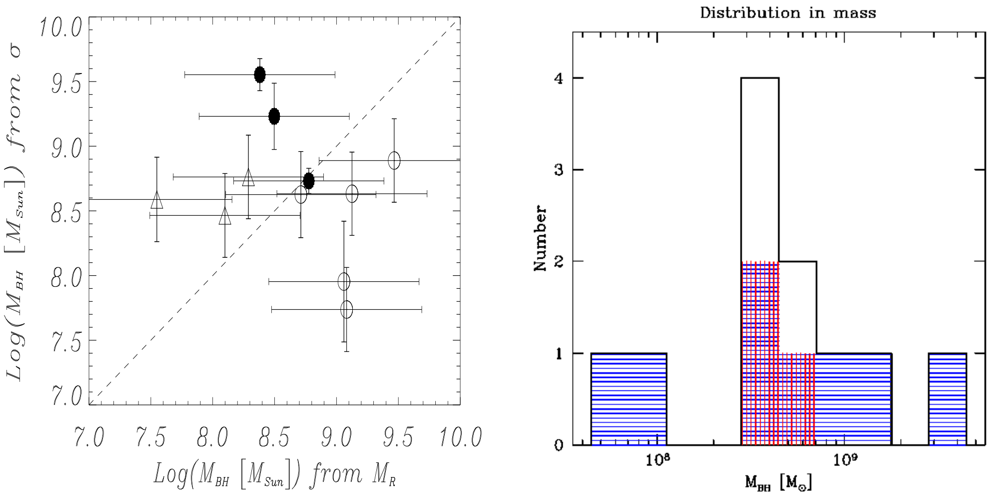

Fig. 1.3. Left: comparison between the two black hole mass estimators - $M_{\rm BH} - \sigma_c$ (this work, relation from Ferrarese 2002) and $M_{\rm BH} - M_R$ (McLure & Dunlop 2001) - for the 8 observed objects (open circles are FRIs while open triangles are FRIIs) and for 3 FRIs with masses from dynamical studies (filled circles). The error bar on $M_{\rm BH}$ from σ_c is the sum in quadrature of the standard propagation error and of the scatter of the relation of 0.32 dex; the error bar on $M_{\rm BH}$ from M_R is the scatter of $\sim$0.6 dex from McLure & Dunlop (2001). Right: $M_{\rm BH}$ distribution (8 objects from this work and 3 with $M_{\rm BH}$ from dynamical studies); the blue area corresponds to FRIs, while the red one to FRIIs.

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