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Black Hole Masses and the Fundamental Plane of BL Lac Objects

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Abstract

We present stellar velocity dispersion (σ) measurements of 10 BL Lac objects. From these data we infer the black hole mass (M_{BH}) of BL Lacs using the relationship between M_{BH} and σ obtained from nearby elliptical galaxies. The new kinematical properties BL Lac host galaxies, together with their structural and photometrical data, are then used to construct the fundamental plane (FP) of the hosts of BL Lacs. It is found that BL Lacs and low redshift radiogalaxies are located on the same FP of that defined by non radio ellipticals. As a consequence of having similar host properties BL Lacs and radiogalaxies appear therefore to contain also similar central BHs.

1.1 Introduction

There is a general consensus about the existence of Super- massive Black Holes (SBH) at the center of normal galaxies as well as in the nuclei of active galaxies and quasars (see e.g. review by Ferrarese 2002). It is therefore believed that SBHs, in addition to be a key ingredient for the development of the nuclear activity, play an important role in the formation and evolution of all massive galaxies.

Measuring BH masses is rather challenging for both nearby and distant sources and requires either spectroscopy at high spatial resolution to resolve the sphere of influence of the BH or to map the variations between the emission of the ionizing continuum and that from line emitting regions gravitationally bound to the BH (reverberation mapping).

From dynamical measurements of nearby early type galaxies a significant correlation between the BH mass and the global properties of their host galaxies was discovered. This is translated into empirical relations between the BH mass and the bulge luminosity (e.g. Kormendy & Gebhardt 2001 and references therein) and between the BH mass and the velocity dispersion of the host galaxy (Ferrarese & Merritt 2000; Gebhardt et al. 2000). These relationships, in spite of the significant scatter ($\sim$ 0.4 dex), afford a novel way to determine M_{BH} in active and inactive galaxies, if a reliable measurement of host galaxy luminosity or velocity dispersion is available. For active galaxies with no emission lines as BL Lac objects, the application of these relations represents the most suitable way to derive the central BH mass. Estimates of the BH mass of BL Lacs, derived from the M_{BH} – bulge luminosity relation, are discussed in Treves et al. (2002), Falomo et al. (2003) and Woo & Urry (2002).

Although the velocity dispersion is much harder to measure it can yield better estimates

Table 1.1. *Velocity dispersion and BH masses of BL Lacs*

Object	z	σ km/s	Log(M_{BH})$_\sigma$	Log(M_{BH})$_{host}$	M_R(host)	Re kpc
Mrk421	0.031	236	8.53	8.58	-23.15	3.4
Mrk180	0.045	244	8.59	8.42	-22.84	3.8
Mrk501	0.034	291	8.94	8.96	-23.91	15
Izw187	0.055	253	8.66	8.16	-22.32	4.7
3C371	0.051	284	8.89	8.95	-23.89	2.9
1ES1959	0.048	195	8.15	8.53	-23.06	6.6
pks2201	0.027	160	7.76	8.26	-22.51	5.1
PKS 0521-36	0.055	280	8.86	8.62	-23.24	4.1
PKS 0548-32	0.069	240	8.56	8.82	-23.63	12.8
AP LIBRAE	0.049	220	8.39	8.74	-23.48	4.9

of M_{BH} because of a tighter relation with the BH mass (Gebhardt et al. 2003) and less sensitivity to calibrations and to the choice of cosmological parameters (see discussion in Bettoni et al. 2003). We report here on the measurements of σ from the optical spectra of 10 BL Lac host galaxies. This expands what we presented in Falomo et al (2002). The observed objects were selected from a sample of nearby (z<0.2) BL Lacs for which we obtained optical images either from the ground (Falomo 1996; Falomo & Kotilainen 1999) or with HST+WFPC (Scarpa et al. 2000; Urry et al. 2000). Barth et al (2002, 2003, and these proceedings) measured σ for 12 objects many of them in common with our sample. While there is a general agreement of the results from the two independent observations, there are some significant discrepancies for individual sources, likely due to the different method of analysis, spectral range and spectral templates used. These differences, however, do not affect the main conclusions of this study.

1.2 Observations and Data Analysis

We secured medium resolution (R 3000) optical spectra of BL Lacs using the 2.5m Nordic Optical Telescope (NOT) and the ESO 3.6m telescope equipped with ALFOSC and EFOSC2, respectively. The chosen grisms combined with a 1 arcsec slit yield a spectral resolution for velocity dispersion measurement of 60 – 80 km s-1, which is adequate for the expected range of σ in luminous ellipticals (e.g. Djorgovski & Davis 1987; Bender, Burstein & Faber 1992) such as the hosts of BL Lacs. The spectral range includes Ca II, Mg I (5175 A) , E-band (5269 A) and Na I (5892 A) absorption from the host galaxies). The measurement of the velocity dispersion σ was done with the Fourier Quotient method (e.g. Sargent et al. 1977) using template spectra of late-type stars (G and K spectral type) that exhibit a low rotational velocity (V $\times$ sen(i)$<$ 20 km/s). Furthermore, spectra of the well studied nearby ellipticals were also secured in order to provide a test of the adopted procedure to derive σ. The observed values of σ are normalized to the central velocity dispersion as specified in Falomo et al. (2002). In this work we assume H0=50 Km s-1 Mpc-1 Ω=0.

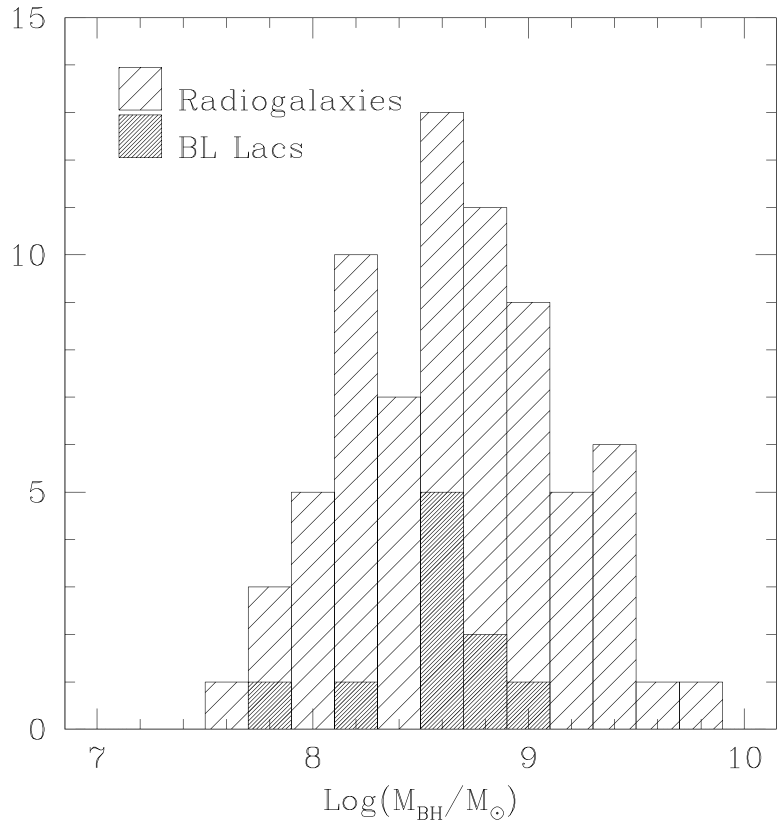

Fig. 1.1. The distribution of the BH mass of our sample of BL Lac objects compared with that of a sample of 73 low redshift radio galaxies (Bettoni et al. 2001). In both cases the BH mass was derived from the stellar velocity dispersion. [eq. (1)]

1.3 Results and Discussion

1.3.1 Black Hole Masses

From the measurements of the velocity dispersion of the hosts of BL Lacs we have derived the BH mass. from the M_{BH} -σ relation (see equation 1). For each object we report in Table 1 the redshift z, the absolute magnitude M_R of the host galaxy (corrected for galactic extinction, evolution and K-corr), effective radius Re, the measured σ, the M_{BH} derived from equations (1 and 2; Bettoni et al. 2003) for 20 nearby inactive ellipticals for which the BH masses were measured.

$$Log(M_{BH}/M_{\odot}) = -0.50 \times M_R - 3.00 \tag{1.1}$$

$$Log(M_{BH}/M_{\odot}) = 4.55 \times Log\,(\sigma) - 2.27, \tag{1.2}$$

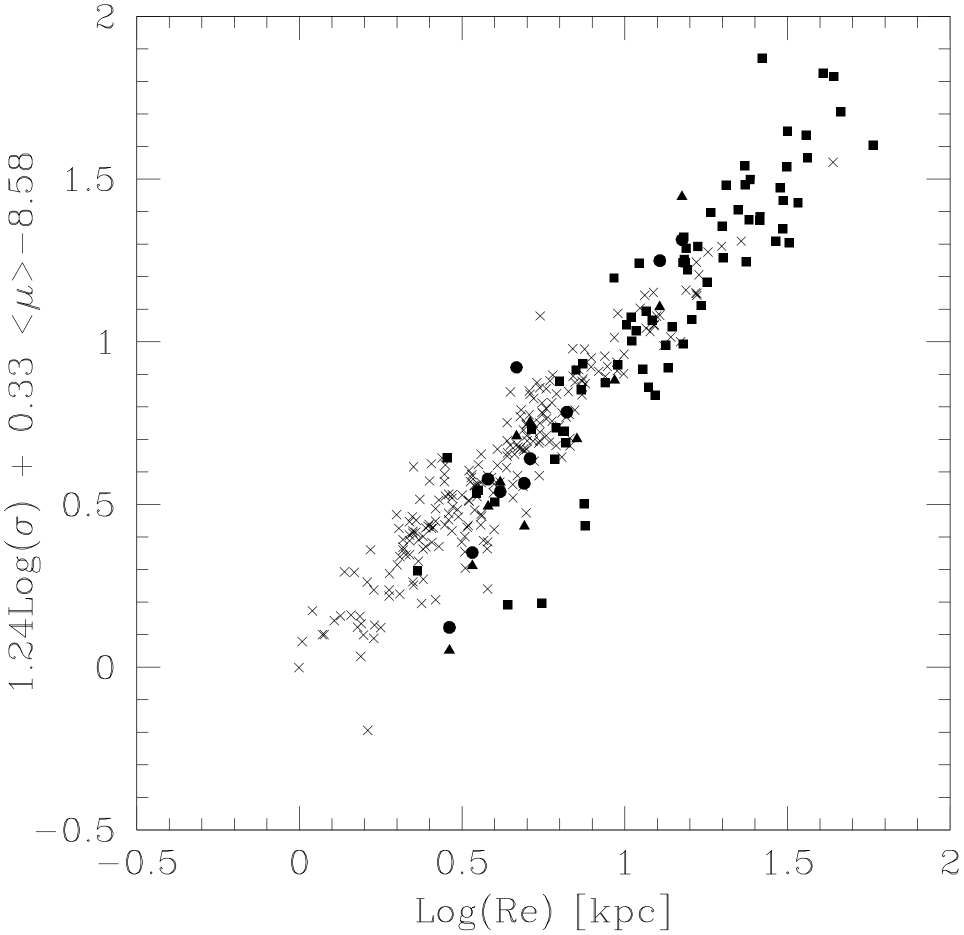

Fig. 1.2. The Fundamental Plane of BL Lac objects (filled circles this work; filled triangles Barth et al 2002) compared with low red-shift Radio Galaxies (filled squares Bettoni et al 2001) and non radio ellipticals (crosses JFK96)

These relations were derived assuming the same definitions and calibrations for σ and the host galaxy luminosities. The average value of the BH masses estimated using the relation (1) is $<\mathrm{Log}(M_{BH}/\mathrm{M}_\odot)>$ =8.5 ± 0.4. Similar values are found using the host luminosity from equation (2): $<\log(M_{BH}/\mathrm{M}_\odot)>$=8.6 ± 0.3. Note, however, that in spite of similar average values, differences of M_{BH} by a factor of two are present for individual objects. In Figure 1.1 we show the distribution of M_{BH} for BL Lacs in our sample compared with that of a large sample of low redshift radiogalaxies (Bettoni et al. 2003). It turns out the the two distribution (even if actually based on a very small sample of BLL) are very similar.

1.3.2 The Fundamental Plane

The new measurements of the velocity dispersion together with the previously determined global properties (effective radius and average surface brightness) of the host galaxies of BL Lacs allow us to construct the fundamental plane (FP) for this class of active galaxies. In Figure 1.2 we compare the Fundamental Plane of BL Lacs with that of radio-galaxies and inactive ellipticals. It turns out that BL Lac hosts are (in this representation) indistinguishable from normal and radio ellipticals. This yields additional support to the unified models of low luminosity radio loud AGNs.

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