BLACK HOLE MASSES AND THE FUNDAMENTAL PLANE OF BL LACERTAE OBJECTS

R. FALOMO

Istituto Nazionale di Astrofisica, Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, I-35122 Padua, Italy; falomo@pd.astro.it

J. K. KOTILAINEN

Tuorla Observatory, University of Turku, Väisäläntie 20, FIN-21500 Piikkiö, Finland; jarkot@astro.utu.fi

N. CARANGELO

Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF), Sez. di Milano–CNR, Via Bassini, 15, I-20133 Milan, Italy; nicol@mi.iasf.cnr.it

AND

A. TREVES

Università dell'Insubria, Via Valleggio 11, I-22100 Como, Italy; treves@mib.infn.it

Received 2003 February 23; accepted 2003 June 7

ABSTRACT

We report on measurements of the stellar velocity dispersion (σ) from the optical spectra of the host galaxies of four BL Lac objects. Together with our earlier results on seven BL Lac objects (Falomo and co-workers) and with the previously derived photometric and structural properties, these data are used to construct the fundamental plane (FP) of the BL Lac hosts. We find that the BL Lac objects follow the same FP as low-redshift radio galaxies and inactive luminous elliptical galaxies, in agreement with similar results presented by Barth and coworkers. This indicates that the photometric, structural, and kinematical properties of the host galaxies of BL Lac objects are indistinguishable from those of inactive massive elliptical galaxies. Using the correlation between black hole mass ($M_{\rm BH}$) and σ in nearby elliptical galaxies, we derive the masses of the central black hole in BL Lac objects. These masses, in the range from 6×10^7 to 9×10^8 $M_\odot$, are consistent with the values derived from the bulge luminosity and appear to be linearly correlated with the mass of the galaxies ($M_{\rm BH} \approx 0.001 M_{\rm bulge}$).

Subject headings: BL Lacertae objects: general — galaxies: active —
galaxies: elliptical and lenticular, cD — galaxies: kinematics and dynamics —
galaxies: nuclei

1. INTRODUCTION

Imaging studies of the host galaxies of low-redshift BL Lac objects (e.g., Falomo 1996; Wurtz, Stocke, & Yee 1996; Falomo & Kotilainen 1999; Urry et al. 2000) have consistently shown that this kind of nuclear activity is exclusively hosted by luminous elliptical galaxies. Detailed studies of the nearest ($z < 0.2$) objects have indicated that the structural properties of the hosts of these active galactic nuclei (AGNs) are indistinguishable from those of normal unperturbed massive elliptical galaxies (Falomo et al. 2000). Similar studies conducted on a large sample of nearby radio galaxies (Govoni et al. 2000) have shown them to have also photometric and structural global properties close to those of inactive spheroids. These observations lend support to the unified model for radio-loud AGNs (e.g., Urry & Padovani 1995) that interprets BL Lac objects as a subset of radio galaxies with the jet pointing close to our line of sight.

On the other hand, it is also well known that the global properties of early-type galaxies, such as the effective radius r_e, the average surface brightness $\langle \mu_e \rangle$, and the central velocity dispersion σ_c, are linked fairly well through the so-called fundamental plane (FP; Djorgovski & Davis 1987; Dressler et al. 1987). This is in fact what is expected if galaxies are virialized systems, have constant M/L ratio, and are homologous structures.

Indeed, real galaxies deviate from the FP defined by the virial equilibrium under the above hypotheses (e.g., Burstein et al. 1997; Jørgensen, Franx, & Kjaergaard 1996)

and define a plane that is tilted with respect to the virial FP. The differences from the "canonical" FP are interpreted as being due to changes in the M/L ratio (due to different stellar content or differences in the dark matter distribution; Pahre, Djorgovski, & de Carvalho 1995; Mobasher et al. 1999) or to the breakdown of the homology assumption (e.g., kinematic anisotropy; Ciotti, Lanzoni, & Renzini 1996; Busarello et al. 1997).

In the context of the link between galactic properties and the nuclear activity, it is important to understand if active galaxies define the same FP as normal (inactive) elliptical galaxies. A recent study of a large sample of powerful radio galaxies (Bettoni et al. 2001) has provided clear evidence that this is the case. The host galaxies of these radio sources define in fact an FP that is fully consistent with that of inactive elliptical galaxies with the only difference of sampling the most luminous (and massive) objects of the luminosity function of early-type galaxies.

In this paper we present new measurements of the stellar velocity dispersion (σ) in the host galaxies of four BL Lac objects that, together with our earlier results on seven BL Lac objects (Falomo, Kotilainen, & Treves 2002, hereafter FKT02) and with the previous determinations of the global photometric and structural host properties, are used to construct the FP of BL Lac objects and to compare it with that of radio galaxies and normal elliptical galaxies.

In addition, we make use of the correlation relating the central black hole (BH) mass ($M_{\rm BH}$) with σ of the spheroidal component in nearby inactive galaxies (e.g., Gebhardt et al.

TABLE 1
OBSERVATIONS AND RESULTS

Object	z	Setup[a]	Exposure Time (s)	S/N[b]	σ (km s^{-1})
NGC 2986.....................	0.0077	A	600	50	260 ± 10
		B	600	55	275 ± 10
NGC 5831.....................	0.0055	A	600	40	187 ± 15
NGC 7562.....................	0.012	A	600	45	285 ± 12
		B	600	55	280 ± 10
AP Lib	0.049	A	3000	40	250 ± 12
PKS 0521$-$36................	0.055	A	3600	45	249 ± 8
		B	3000	45	261 ± 8
PKS 0548$-$322..............	0.069	A	2400	40	269 ± 10
		B	3000	55	257 ± 10
PKS 2201$+$04	0.027	A	3600	30	165 ± 15

[a] Setup A: range 4400–6300 Å. Setup B: range 6300–8000 Å.
[b] S/N pixel^{-1}.

2000; Ferrarese & Merritt 2000) to infer the M_{BH} of our sample of BL Lac objects, thus expanding our previous study (FKT02). Similar measurements of the velocity dispersion of BL Lac objects (with many objects in common with our sample) have been reported recently by Barth, Ho, & Sargent (2003, hereafter BHS03). Preliminary results of this work are given in Treves et al. (2003) and Falomo et al. (2003a).[1] Hubble constant $H_0 = 50$ km s^{-1} Mpc^{-1} and $\Omega = 0$ are used throughout this paper.

2. OBSERVATIONS AND DATA ANALYSIS

The spectra were obtained in 2001 June using the ESO 3.6 m telescope equipped with EFOSC2. Two grisms were used covering the spectral ranges 4400–6300 Å (setup A) and 6300–8000 Å (setup B) at 0.54 and 1.3 Å pixel^{-1} dispersion, respectively. The absorption lines from the host galaxies that are considered in our analysis are composed of Hβ (4861 Å), Mg I (5175 Å), Ca E band (5269 Å), Na I (5892 Å), and the TiO + Ca I (6178 Å) and TiO + Fe I (6266 Å) blends.

The grisms and a 1$''$ slit yield a spectral resolution of $\sim$60–80 km s^{-1}, which is adequate for the expected range of σ in luminous elliptical galaxies (e.g., Djorgovski & Davis 1987; Bender, Burstein, & Faber 1992) such as the hosts of BL Lac objects. In addition, spectra of bright K I–K III stars that exhibit a low rotational velocity ($V \sin i < 20$ km s^{-1}) were taken to be used as templates of zero velocity dispersion. Furthermore, spectra of the nearby elliptical galaxies NGC 2986, NGC 5831, and NGC 7562 were secured to provide a test of the adopted procedure to derive σ.

During the observations, seeing ranged between 0$''$8 and 1$''$3. The slit was positioned on the nucleus, and the one-dimensional spectrum was extracted from a 3$''$–5$''$ diameter aperture, which was always within the effective radius of the host galaxy in order to minimize aperture corrections. The IRAF[2] package was used for data reduction, including bias subtraction, flat-fielding, wavelength calibration, and extraction of one-dimensional spectra. For each source, two spectra were combined to remove cosmic-ray hits and other occasional spurious signals in the detector. In Table 1 we give the observed sources, the instrumental setup, exposure times, and the signal-to-noise ratio (S/N) of final spectra that are reported in Figure 1 (also for sources studied in FKT02).

The stellar velocity dispersion σ was determined using the Fourier quotient method (e.g., Sargent et al. 1977). The spectra were normalized by subtracting the continuum, converted to a logarithmic scale, and multiplied by a cosine bell function that apodizes 10% of the pixels at each end of the spectrum. For all the new observed objects except PKS 0548$-$32 the optical spectrum shows emission lines (mainly Hβ, Hα, and [O III] λ5007). These features have been removed by a linear interpolation of the adjacent continuum. Finally, the Fourier transforms of the galaxy spectra were divided by the Fourier transforms of template stars, and σ was computed from a χ^2 fit with a Gaussian broadening function (see, e.g., Bertola et al. 1984; Kuijken & Merrifield 1993). The scatter of the σ measurements using different template stars was typically $\sim$10 km s^{-1} and can be considered as the minimum uncertainty. Since early-type galaxies exhibit gradients in velocity dispersion (Davies et al. 1983; Fisher, Illingworth, & Franx 1995), the measured values of σ have been referred to a common aperture adopting the procedure described in Falomo et al. (2002). The observed values of σ and their estimated errors are given in Table 1, and the results for the full sample (including those from FKT02) are given in Table 2. For the three nearby galaxies we find a good agreement with the previously published values of σ (Prugniel et al. 1998).

For three objects we have spectra in both spectral ranges. The resulting values of σ are in all cases in good agreement, with an average difference of 12 km s^{-1}, ensuring sufficient homogeneity of data taken with different grisms and/or resolution. For PKS 2201$+$04 the present results are very similar to those obtained by us at the Nordic Optical Telescope (NOT; FKT02). For the following discussion the average of the pair of measurements was thus used.

2.1. Comparison with BHS03 Results

BHS03 have recently reported measurements of σ for 11 BL Lac objects. Nine of them are in common with our sample, and it is therefore enlightening to directly compare the
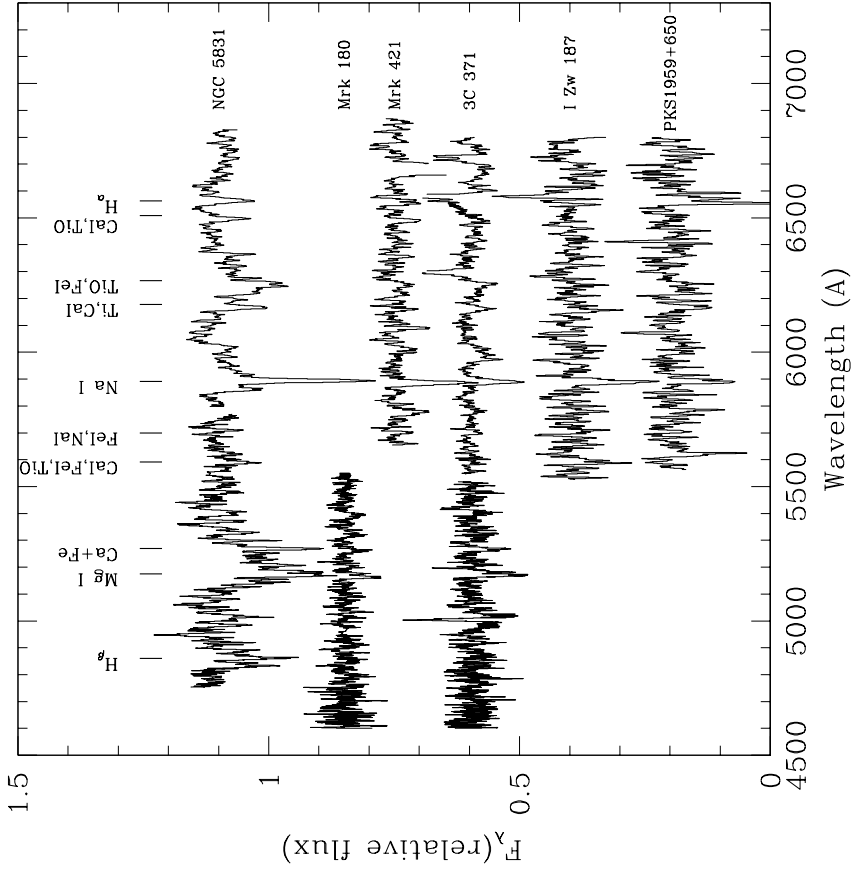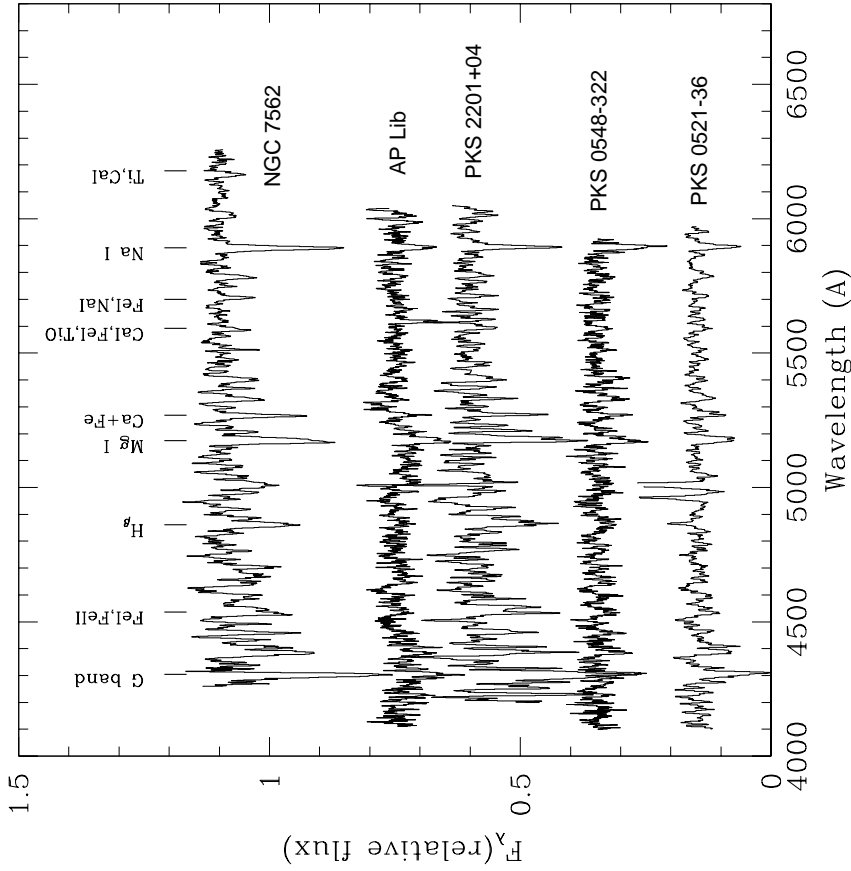
Fig. 1.—(a) Optical rest-frame spectra of the BL Lac objects observed at ESO compared with that of the nearby elliptical galaxy NGC 7562. The spectra (from bottom to top) have been shifted vertically by -0.85, -0.65, -0.4, -0.25, and $+0.1$ units to avoid overlap. Main absorption features are identified. Emission lines are present in the spectrum of all these BL Lac objects except PKS 0548$-$322. These emission features have been removed from the analysis of the stellar velocity dispersion (see text for details). The strongest emission lines have been truncated to avoid superposition of the graphs. (b) Optical spectra of the BL Lac objects (rest frame) observed at the NOT (FKT02) compared with that of the nearby elliptical NGC 5831. The reproduced spectra have been continuum-normalized to unity. The tracings of the spectra (from bottom to top) have been shifted vertically by -0.8, -0.6, -0.4, -0.25, -0.15, and $+0.1$. The strongest emission lines have been truncated to avoid superposition of the graphs. In the case of Mrk 421 the tracing around the telluric B band was also omitted.

TABLE 2
PROPERTIES OF HOST GALAXIES AND BH MASSES OF BL LAC OBJECTS

Object	Type[a]	z	σ^{b} (km s^{-1})	$\log(M_{\text{BH}})_\sigma^{\text{c}}$ ($M_\odot$)	m_R^{d}	M_R^{e}	$R_e^{\text{d,e}}$ (kpc)	$\log(M_{\text{BH}})_b^{\text{f}}$ ($M_\odot$)
Mrk 421	H	0.031	236 ± 10	8.52 ± 0.13	13.17 ± 0.15	-23.21	9.5 ± 3.0	8.61
Mrk 180	H	0.045	244 ± 10	8.59 ± 0.13	14.09 ± 0.14	-23.12	8.6 ± 2.5	8.56
Mrk 501	H	0.034	291 ± 13	8.94 ± 0.15	12.62 ± 0.29	-23.96	12.2 ± 3.9	8.98
I Zw 187[g]	H*	0.055	171 ± 12	7.89 ± 0.17	15.28 ± 0.07	-22.37	5.5 ± 0.5	8.19
3C 371	L*	0.051	284 ± 18	8.89 ± 0.17	13.84 ± 0.05	-23.64	14.5 ± 1.5	8.82
1ES 1959+650...............	H	0.048	195 ± 15	8.15 ± 0.17	14.23 ± 0.16	-23.12	6.6 ± 3.5	8.56
PKS 2201+04	L*	0.027	160 ± 7	7.76 ± 0.13	13.50 ± 0.12	-22.58	5.1 ± 0.5	8.29
PKS 0521−36................	L*	0.055	255 ± 8	8.68 ± 0.12	14.35 ± 0.20	-23.30	5.0 ± 2.5	8.65
PKS 0548−322..............	H	0.069	263 ± 10	8.74 ± 0.13	14.45 ± 0.3	-23.71	14.0 ± 1.5	8.85
AP Lib	H*	0.049	250 ± 12	8.64 ± 0.14	13.81 ± 0.08	-23.58	8.9 ± 1.0	8.79
0706+591[g]	H	0.125	216 ± 23	8.35 ± 0.22	$15.70 \pm \ldots$	-23.81	$9.3 \pm \ldots$	8.90
2344+514[g]	H	0.044	294 ± 24	8.96 ± 0.20	13.36 ± 0.05	-23.80	7.1 ± 1.6	8.90

[a] Type of BL Lac object. L: low frequency peaked BL Lac object; H: high frequency peaked BL Lac object. An asterisk indicates that the spectrum shows emission features.

[b] Central velocity dispersion corrected to a common aperture as in FKT02.

[c] The uncertainty on the BH mass is derived from the combination of the errors on σ and the dispersion of the M_{BH}-σ relation.

[d] Total apparent magnitude of the host galaxy corrected for Galactic extinction. Adopted values are the median of the measurements collected from the literature (see BHS03; Falomo, Pesce, & Treves 1995; Falomo 1996; Falomo & Kotilainen 1999; R. Falomo & J. Kotilainen 2003, in preparation; Heidt et al. 1999; Nilsson et al. 1999, 2003; Pursimo et al. 2002; Scarpa et al. 2000; Stickel, Fried, & Kühr 1993; Wurtz et al. 1996).

[e] Parameters are computed assuming $H_0 = 50$ km s^{-1} Mpc^{-1} and $\Omega = 0$.

[f] BH masses derived from the host galaxy luminosity and eq. (2) in the text.

[g] Values of σ are taken from Barth et al. 2003.

results. For some common objects the σ-values of BHS03 are derived from the near-infrared Ca II triplet lines, while our measurements refer to the visual–red spectral region, including the g band (4304 Å), Mg I (5175 Å), Ca E band (5269 Å), Na I (5892 Å), and the TiO + Ca I (6178 Å) and TiO + Fe I (6266 Å) at rest frame. Moreover, BHS03 use a different method (direct spectral fitting) from ours to derive σ. These differences, as well as the use of different templates, can explain modest (≤ 20 km s^{-1}) differences in σ. Larger differences are more difficult to give reasons for. BHS03 assert that their measurements are more accurate because of higher S/N of their data and the possibility that our measurements are biased by interstellar absorption and metallicity effects. While it is certainly true that BHS03 acquired higher S/N, we believe that the Na I interstellar absorption in the host galaxies has little, even negligible, effect since all the elliptical host galaxies are likely to be gas-poor. In the cases in which we have data in both spectral ranges (including and excluding the Na I line), we find no significant difference in the derived values of σ. Galactic Na I absorption occurs at different wavelength than in the (redshifted) BL Lac hosts and therefore does not contribute to the broadening of the intrinsic Na I line. Moreover, the elimination of emission lines by a linear continuum interpolation has no effect on the Fourier analysis since it introduces low spatial frequencies that are removed in the Gaussian fitting of the real part of the power spectrum. On the other hand, metallicity effects on the strength of the Mg I feature are more challenging to take into account. Note, however, that most of the σ data used to derive the M_{BH}-σ relation for elliptical galaxies were obtained in the visible region (e.g., Davies et al. 1987), including the Mg I feature, and using a method very similar to ours. We believe that to derive BH masses it is paramount to have consistent measurements for the targets and the calibrators.

While a good agreement is found for most objects, some discrepancies remain. The largest differences of σ between BHS03 and this work are for Mrk 501 and I Zw 187, up to 80 km s^{-1} and in opposite directions. For Mrk 501 (see also FKT02), our value of σ is consistent with that expected for the luminosity of the host galaxy and gives consistent results for the BH mass (see Fig. 2). For I Zw 187, we obtained only a relatively poor S/N spectrum and therefore our determination of σ remains more uncertain. The influence of these differences in σ for estimating the BH masses is discussed in the next section.

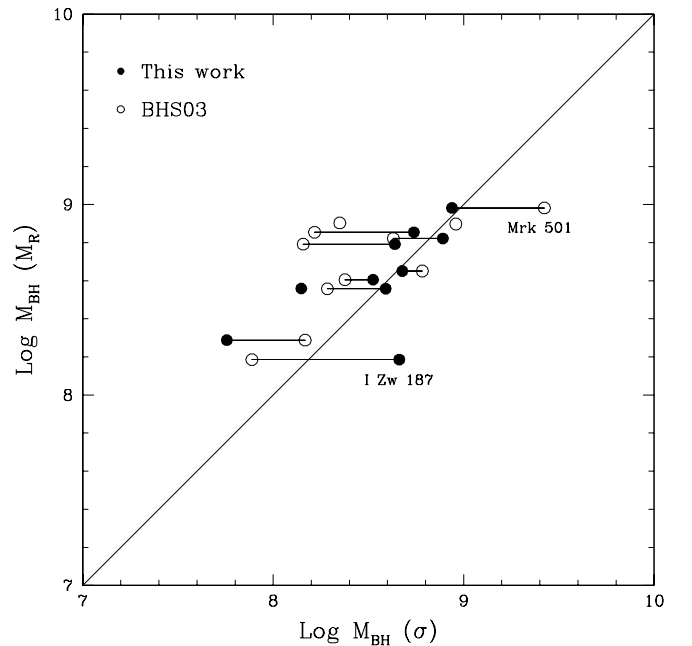FIG. 2.—Comparison between BH masses derived from the M_{BH}-σ and the M_{BH}-M_R(bulge) relations (defined by Bettoni et al. 2003) for the total sample of 12 BL Lac objects with measured σ. Filled circles refer to this paper and FKT02, while open circles refer to BHS03.

3. RESULTS AND DISCUSSION

3.1. *Black Hole Masses of BL Lac Objects*

Unlike most AGNs, BL Lac objects are characterized by the weakness or absence of emission lines. This prevents us from deriving an estimate of the central BH mass from the kinematics of regions that are gravitationally bound to the BH, as in Seyfert galaxies and quasars (e.g., McLure & Dunlop 2001). A powerful (even if indirect) way to obtain BH masses is thus to use the relationship between M_{BH} and σ for nearby early-type galaxies. Since all sources considered here are at $z \simeq 0.1$, we assume that possible cosmological evolution of the M_{BH}-σ relation is negligible. We have adopted the updated relationship (derived only from elliptical galaxies) by Bettoni et al. (2003), who assume the same cosmology used here and the same calibrations for the velocity dispersion and the magnitudes. The relation between M_{BH} and σ is

$$\log\left(\frac{M_{BH}}{M_\odot}\right) = 4.55 \log \sigma - 2.27 . \quad (1)$$

We assume that this relationship is valid also for AGNs (e.g., Merritt & Ferrarese 2001) and in particular for BL Lac objects that have elliptical hosts (e.g., Falomo & Kotilainen 1999; Falomo et al. 2000; Urry et al. 2000). The derived values of M_{BH} are given in Table 2. They are in the range from $\sim 6 \times 10^7$ to $\sim 9 \times 10^8$ $M_\odot$. The typical error (median value) on these estimated BH masses, taking into account the uncertainties in σ and in the M_{BH}-σ relationship given by Bettoni et al. (2003), is ~ 0.15 dex (see Table 2).

The M_{BH} is also correlated with the luminosity of the bulge of the host galaxy (e.g., Kormendy & Gebhardt 2001). The absolute magnitudes M_R of the BL Lac hosts are given in Table 2. M_{BH} was thus calculated following the updated relationship for elliptical galaxies (Bettoni et al. 2003):

$$\log\left(\frac{M_{BH}}{M_\odot}\right) = -0.50 M_R - 3.00 . \quad (2)$$

The resulting values of M_{BH} are given in Table 2. For most sources, the difference of M_{BH} derived from the two methods is within the estimated uncertainty, but for two objects (PKS 2201+04 and EXO 0706.1+5913) the difference is ~ 0.5 dex.

The average values of M_{BH} for the BL Lac objects from the two methods are $\langle \log M_{BH} \rangle_\sigma = 8.57 \pm 0.12$ and $\langle \log M_{BH} \rangle_{bulge} = 8.63 \pm 0.08$ with an average difference of $\langle \Delta \log M_{BH} \rangle = -0.07 \pm 0.09$. On the other hand, if we use the σ-values from BHS03, we find $\langle \log M_{BH} \rangle_\sigma = 8.48 \pm 0.14$ and $\langle \log M_{BH} \rangle_{bulge} = 8.68 \pm 0.08$ with an average difference of $\langle \Delta \log M_{BH} \rangle = -0.21 \pm 0.10$.

In Figure 2 we compare the BH masses derived from the M_{BH}-M(bulge) relation with those obtained from our adopted M_{BH}-σ relation, using both the BHS03 and our values of σ. There is a generally good agreement between the two methods, although the data from BHS03 tend to systematically deviate to lower BH masses. This suggests that some systematic effect may be present in the σ-values obtained by BHS03.

According to the shape of their spectral energy distribution, BL Lac objects are distinguished into two types: low frequency peaked (LBL) and high frequency peaked (HBL; see Padovani & Giommi 1995). Based on BH masses derived from the peak luminosity and its frequency, Wang, Xue, &

Wang (2001) proposed that LBLs have significantly (by ~ 2 dex) smaller BH masses than HBLs. In our sample, there are nine HBLs and only three LBLs (marked as H or L in Table 2). With the caveat of small number statistics, we find no significant difference of M_{BH} in the two types of BL Lac objects. This result is confirmed by the analysis of M_{BH}, derived from host luminosity, for a larger sample of BL Lac objects (Falomo, Carangelo, & Treves 2003b).

The measurements of σ and the effective radii of the host galaxies can be used to estimate the mass of the hosts through the relationship (Bender et al. 1992)

$$M_{host} = \frac{5\sigma^2 r_e}{G} . \quad (3)$$

The two quantities M_{BH} and M_{host} are consistent with a linear relation, and their average ratio is $\langle M_{BH}/M_{host} \rangle = 1.0 \times 10^{-3}$. This is very similar to values found for other types of active and inactive galaxies (e.g., McLure & Dunlop 2002; Bettoni et al. 2003) and indicates that the mass of the spheroid is fundamentally linked to the mass of the central BH.

3.2. *The Fundamental Plane of BL Lac Objects*

The kinematical measurement of the velocity dispersion of the host galaxies of BL Lac objects allows us to construct the FP of these active galaxies and to compare it with that obtained for other active and inactive elliptical galaxies. We use the full sample of 12 BL Lac objects for which σ has been measured (this paper; FKT02; BHS03). Since our spectrum of I Zw 187 has rather low S/N, we prefer to adopt for it the value of σ reported by BHS03.

For all these BL Lac objects, *HST*/WFPC2 and/or ground-based images are available to derive the global properties (luminosity and scale length) of the host galaxies. In Table 2 we report the data for the 12 BL Lac objects used to construct the FP. Note that while the apparent magnitudes of the host galaxies derived from ground-based and *HST* images agree reasonably well, the effective radius may be different by more than a factor of 2. As pointed out also by BHS03, the effective radius estimated from *HST* images tends to be smaller than that obtained from ground-based data. This is likely due to the small field of view of WFPC2 ($\sim 35''$) with respect to the full size ($\sim 30''$–$40''$) of the most nearby objects. In fact, this trend disappears when more distant objects are considered (e.g., Falomo & Kotilainen 1999). For the purpose of this work we have collected all published data reporting both total apparent magnitude (in the R band) and the effective radius. The adopted quantities for each object are derived from the median value of all available data. In Table 2 we report these values together with the rms scatter for the effective radius for all objects with at least two usable measurements. From the apparent magnitudes and the effective radii R_e of the host galaxies we have obtained the average surface brightness $\langle \mu_e \rangle$ within R_e. All magnitude values have then been corrected for Galactic extinction (Schlegel, Finkbeiner, & Davis 1998), k-correction (Poggianti 1997), and cosmological $(1 + z)^4$ dimming of the surface brightness.

In Figure 3 we show the FP of the BL Lac objects compared with that of low-redshift radio galaxies (Bettoni et al. 2001) and normal elliptical galaxies (Jörgensen et al. 1996). This is a homogeneous comparison because all data sets were analyzed identically. We find a remarkable agreement
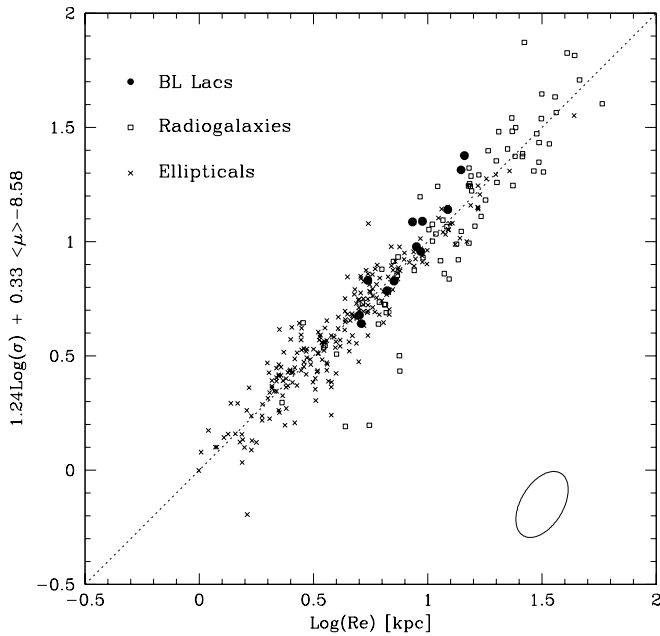
FIG. 3.—FP of BL Lac objects (*filled circles*) compared with low-redshift radio galaxies (*open squares*; Bettoni et al. 2001) and normal elliptical galaxies (*crosses*; Jörgensen et al. 1996). For BL Lac objects, the typical error region is indicated by the ellipse. The sizes of the minor and major axes are derived from the average error on the quantities plotted in the X- and Y-axes, respectively. The error for the Y-axis is derived combining the average uncertainty on σ and $\langle \mu \rangle$. Note that the error of $\langle \mu \rangle$ in addition to the photometric uncertainty ($\sim$0.1 mag) also significantly depends on the error of R_e. The orientation of the major axis of the ellipse is determined by the relation $\langle \mu \rangle \propto 5 \log R_e$.

between the FP defined by normal (inactive) galaxies, radio galaxies, and BL Lac host galaxies. A similar result was also obtained by BHS03, who presented velocity dispersion measurements for most of the objects discussed here. The hosts of BL Lac objects tend to occupy the intermediate region of the FP, in agreement with the fact that the hosts of BL Lac objects are luminous elliptical galaxies but rarely at the bright end of the luminosity function of massive elliptical galaxies (Falomo et al. 2003b). The comparison of the kinematical, photometric, and structural properties of BL Lac hosts with those of radio galaxies and inactive elliptical galaxies over the FP shows that their global properties are indistinguishable. This result strengthens the idea that a

massive elliptical galaxy may undergo a phase of nuclear activity with little (or negligible) effect on its global structure. Moreover, it gives support to the hypothesis that the relations connecting the mass of the central BH with the velocity dispersion and luminosity of nearby inactive elliptical galaxies can be extended to elliptical galaxies with nuclear activity. The similarity of the BH masses obtained with the two techniques for BL Lac objects (previous section) shows that this picture is becoming self-consistent.

For more powerful active galaxies (e.g., radio-loud quasars), there are no kinematical data available, so it is not possible to compare the global properties of their host galaxies in the FP. We note, however, that at least at low redshift the morphology and the photometric properties of quasar hosts agree well with those of luminous inactive elliptical galaxies (e.g., Dunlop et al. 2003).

4. CONCLUSIONS

We have presented kinematical data for a small sample of the host galaxies of nearby BL Lac objects that were previously investigated through images. The combined photometric and spectroscopic data allow us to construct the FP for this class of active galaxies and to compare it with that of other elliptical galaxies.

The main result of this work, together with that by BHS03, shows that the host galaxies of BL Lac objects define an FP that is indistinguishable from that of low-z radio galaxies and normal (inactive) elliptical galaxies. This further strengthens the idea that the nuclear activity may occur in all massive spheroids without producing significant changes in the global structural and kinematical properties of the galaxies.

In addition, and consistently with the above result, we have also shown that the BH mass derived from either the $M_{\rm BH}$-σ or $M_{\rm BH}$-M_R(bulge) relation yields consistent results. The BH mass of the majority of BL Lac objects is contained in the range 10^8–10^9 $M_\odot$ with no difference between HBL and LBL.

REFERENCES

Barth, A., Ho, L. C., & Sargent, W. L. W. 2003, ApJ, 583, 134 (BHS03)
Bender, R., Burstein, D., & Faber, S. M. 1992, ApJ, 399, 462
Bertola, F., Bettoni, D., Rusconi, L., & Sedmak, G. 1984, AJ, 89, 356
Bettoni, D., Falomo, R., Fasano, G., & Govoni, F. 2003, A&A, 399, 869
Bettoni, D., Falomo, R., Fasano, G., Govoni, F., Salvo, M., & Scarpa, R. 2001, A&A, 380, 471
Burstein, D., Bender, R., Faber, S. M., & Nolthenius, R. 1997, AJ, 114, 1365
Busarello, G., Capaccioli, M., Capozziello, S., Longo, G., & Puddu, E. 1997, A&A, 320, 415
Ciotti, L., Lanzoni, B., & Renzini, A. 1996, MNRAS, 282, 1
Davies, R. L., Burstein, D., Dressler, A., Faber, S. M., Lynden-Bell, D., Terlevich, R. J., & Wegner, G. 1987, ApJS, 64, 581
Davies, R. L., Efstathiou, G., Fall, S. M., Illingworth, G., & Schechter, P. L. 1983, ApJ, 266, 41
Djorgovski, S., & Davis, M. 1987, ApJ, 313, 59
Dressler, A., Lynden-Bell, D., Burstein, D., Davies, R. L., Faber, S. M., Terlevich, R., & Wegner, G. 1987, ApJ, 313, 42
Dunlop, J. S., McLure, R. J., Baum, S. A., O'Dea, C. P., & Hughes, D. H. 2003, MNRAS, 340, 1095
Falomo, R. 1996, MNRAS, 283, 241

Falomo, R., Carangelo, N., Kotilainen, J. K., & Treves, A. 2003a, in Coevolution of Black Holes and Galaxies, ed. L. C. Ho (Carnegie Obs. Astrophys. Ser., Vol. 1; Cambridge: Cambridge Univ. Press), in press
Falomo, R., Carangelo, N., & Treves, A. 2003b, MNRAS, 343, 505
Falomo, R., & Kotilainen, J. 1999, A&A, 352, 85
Falomo, R., & Kotilainen, J. K., & Treves, A. 2002, ApJ, 569, L35 (FKT02)
Falomo, R., Pesce, J. E., & Treves, A. 1995, ApJ, 438, L9
Falomo, R., Scarpa, R., Treves, A., & Urry, C. M. 2000, ApJ, 542, 731
Ferrarese, L., & Merritt, D. 2000, ApJ, 539, L9
Fisher, D., Illingworth, G., & Franx, M. 1995, ApJ, 438, 539
Gebhardt, K., et al. 2000, ApJ, 539, L13
Govoni, F., Falomo, R., Fasano, G., & Scarpa, R. 2000, A&A, 353, 507
Heidt, J., Nilsson, K., Sillanpää, A., Takalo, L., & Pursimo, T. 1999, A&A, 341, 683
Jörgensen, I., Franx, M., & Kjaergaard, P. 1996, MNRAS, 280, 167
Kormendy, J., & Gebhardt, K. 2001, in AIP Conf. Proc. 586, 20th Texas Symposium on Relativistic Astrophysics, ed. J. C. Wheeler & H. Martel (New York: AIP), 363
Kuijken, K., & Merrifield, M. R. 1993, MNRAS, 264, 712
McLure, R., & Dunlop, J. 2001, MNRAS, 327, 199
———. 2002, MNRAS, 331, 795

Merritt, D., & Ferrarese, L. 2001, MNRAS, 320, L30
Mobasher, B., Guzman, R., Aragon-Salamanca, A., & Zepf, S. 1999, MNRAS, 304, 225
Nilsson, K., Pursimo, T., Heidt, J., Takalo, L., Sillanpää, A., & Brinkmann, W. 2003, A&A, 400, 95
Nilsson, K., Pursimo, T., Takalo, L., Sillanpää, A., Pietilä, H., & Heidt, J. 1999, PASP, 111, 1223
Padovani, P., & Giommi, P. 1995, ApJ, 444, 567
Pahre, M. A., Djorgovski, S. G., & de Carvalho, R. R. 1995, ApJ, 453, L17
Poggianti, B. M. 1997, A&AS, 122, 399
Prugniel, P., Zasov, A., Busarello, G., & Simien, F. 1998, A&AS, 127, 117
Pursimo, T., Nilsson, K., Takalo, L., Sillanpää, A., Heidt, J., & Pietilä, H. 2002, A&A, 381, 810

Sargent, W. L. W., Schechter, P. L., Boksenberg, A., & Shortridge, K. 1977, ApJ, 212, 326
Scarpa, R., Urry, C. M., Falomo, R., Pesce, J. E., & Treves, A. 2000, ApJ, 532, 740
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Stickel, M., Fried, J. W., & Kühr, H. 1993, BAAS, 98, 393
Treves, A., Carangelo, N., Falomo, R., & Kotilainen, J. 2003, in ASP Conf. Ser. 290, Active Galactic Nuclei: From Central Engine to Host Galaxy, ed. S. Collin, F. Combes, & I. Shlosman (San Francisco: ASP), 621
Urry, C. M., & Padovani, P. 1995, PASP, 107, 803
Urry, C. M., et al. 2000, ApJ, 532, 816
Wang, J. M., Xue, S. J., & Wang, J. C. 2001, preprint (astro-ph/0111209)
Wurtz, R., Stocke, J. T., & Yee, H. K. C. 1996, ApJS, 103, 109