

Optical imaging and spectroscopy of BL Lac objects^{*}

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Abstract. We present optical images and spectroscopy for a dozen of BL Lac objects. Most of these objects were not previously studied and we give for the first time the properties of their host galaxies. The properties of the new host galaxies are generally consistent with those derived in previous optical studies. We found a case (1101-23) where the external isophotes of the galaxy are clearly boxy.

In addition we gathered spectroscopy for several BL Lac objects with unknown redshift and for companion galaxies. This allowed us to derive a tentative redshift for two new BL Lacs and to investigate the environment around PKS 0829+04. These data complement existing data available in the literature on host galaxies of BL Lacs and their (close) environments.

Key words: galaxies: active – galaxies: BL Lacertae objects: general – galaxies: interactions – galaxies: nuclei – galaxies: photometry – galaxies: structure

1. Introduction

In the past decade BL Lac objects have been actively investigated in direct imaging and spectroscopy using ground based telescopes and HST. The imaging effort has been directed towards detecting the host galaxy, and when possible towards measuring its absolute luminosity and colors and determining its morphological properties. The aim of the spectroscopy has been to measure the redshift of the host or to measure the redshift of companions galaxies in order to assess a possible group or cluster membership.

Apart from studies on individual objects a number of papers have presented optical images for samples or lists of objects.

Twenty three objects have been imaged with the William Herschel Telescope in the R filter and 14 are resolved (Abraham et al. 1991). However due to either unknown redshift or poorly detected nebulosity only for 6 sources absolute quantities are derived. Some cases of disc dominated host galaxies are proposed.

Sixteen objects in the southern sky have been studied by Falomo (1996) using sub-arcsec images obtained at the ESO 3.5m New Technology Telescope (NTT). Eleven sources were resolved and the hosts found to be luminous ellipticals ($M_R \sim -23.5$). For a number of objects close companion galaxies are detected. Due to their small projected distance it is likely that they are associated with the BL Lac but spectroscopy is needed to assess this point.

A larger sample but with poorer average resolution was investigated using the 3.6m CFHT (Wurtz et al. 1996). Fifty objects have been observed and 36 well resolved. For another ten objects the host galaxy has been only marginally detected. No difference of host properties is found between objects discovered in radio surveys (i.e. 1Jy sample) and those derived from X-ray surveys (i.e. EMSS). With very few exceptions all the BL Lac objects investigated are classified as ellipticals based on the surface brightness profiles.

More recently a study of the host galaxies in a large sample of X-ray selected (high frequency peaked) BL Lacs have been presented by (Falomo & Kotilainen 1999). They used high resolution images in the R filter at the Nordic Optical Telescope (NOT) to image 52 targets from EMSS and Einstein Slew samples. All the 45 objects resolved are well represented by elliptical models. On average the hosts are found 1 magnitude more luminous than M^* ($M_R^* \sim -22.5$; Mobasher et al. 1993; assuming $R-K = 2.7$).

In addition to ground based studies several 0.1 arcsec resolution short exposure images have been obtained with WFPC2 camera on board of HST during a snapshot survey (Scarpa et al. 2000; Urry et al. 2000). Objects from various samples, and in the redshift interval $0.05 < z < 1.3$, were observed and 69 out of 110 observed are resolved. The highest redshift host galaxy detected is $z = 0.664$ for 1823+568. For 80% of the resolved host galaxies an elliptical model is clearly preferred over a disc galaxy. The median absolute magnitude of these host galaxies ($M_R \sim -23.7$) is at least one magnitude brighter than M^* . The nuclei are always well centered over the body of the galaxy and have luminosity similar to that of its host galaxy. From the point of view of the optical morphology the hosts of BL Lacs appear indistinguishable from “normal” (non active) ellipticals.

The main aim of all these observations outlined above was to detect the host galaxies and to determine their structural and

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^{*} Based on observations collected at the European Southern Observatory, La Silla, Chile.

Table 1. Journal of the observations.

Name	z	Class ^a	Date	T(int) (sec)	Seeing (arcsec)	A_R
SUSI Imaging R filter						
PKS 0138-097	0.733	LBL	1996 Jan 19	600	1.2	0.14
0301-243	0.26	HBL	1996 Jan 19	1200	0.8	0.10
0338-21	(0.45)	LBL	1996 Jan 19	600	0.6	0.12
REX 0353-36	(0.40)	HBL	1996 Jan 19	600	0.6	0.04
PKS 0735+178	>0.424	LBL	1996 Jan 19	1800	0.7	0.26
PKS 0736+017	0.191	FSRQ	1996 Jan 19	1200	0.55	0.72
PKS 0818-128	...	LBL	1996 Jan 19	600	0.7	0.36
H 1101-23	0.186	HBL	1996 Jan 19	1200	0.9	0.24
MS 1312.1-422	0.108	HBL	1996 Jan 19	600	1.4	0.36
MS 1332.6-293	0.25	HBL	1996 Jan 19	600	1.5	0.22
EMMI spectroscopy						
Name	z	Slit/PA ^b	Date	T(int)		
0301-243	0.26	2off/90	1996 Jan 20	3600		
PKS 0548-322	0.068	2/90	1996 Jan 20	3600		
PKS 0754+10	0.28	2off/0	1996 Jan 20	3600		
PKS 0818-128	...	2/0	1996 Jan 20	1800		
PKS 0829+046	0.18	2off/109	1996 Jan 20	3600		

^a LBL = Low frequency-peaked BL Lacs; HBL = High frequency-peaked BL Lacs; FSRQ = Flat Spectrum Radio Quasars

^b Slit width in arcsec and position angle (degrees). off = offset from the nucleus by $\sim 1''$

photometric properties. The knowledge of the kind of galaxies that host a BL Lac phenomenon in the nucleus is of importance not only for understanding/studying the nuclear activity vs galaxy connection (see e.g. Lawrence 1999) but also as a probe to test unified models of radio loud AGN. In particular if BL Lacs are FR I radio galaxies whose jet is aligned along the line of sight (e.g. Urry & Padovani 1995; Ulrich 1989) their host galaxies should exhibit exactly the same photometrical and morphological properties as the hosts of FR I. The properties of the BL Lacs hosts can also be compared with those of related beamed objects such as FSRQ and HPQ (see e.g. Kotilainen et al. 1998a).

The aim of this work is to complement the existing data on BL Lac host galaxies and close environment with new imaging and spectroscopy for a dozen of (previously not well studied) objects. A general discussion and comparison of the properties of BL Lacs and radio galaxies will be presented elsewhere.

In this paper we therefore present results from optical images of BL Lac objects collected at the NTT with mostly sub-arcsec resolution. Most of the objects presented here were not previously investigated with adequate capabilities. These observations therefore complement the existing data on BL Lac host galaxies.

We also present spectroscopic observations for some of the objects performed with the aim of deriving the redshift of the host galaxies and of some nearby companion galaxies. When no spectroscopic redshift is available we give an estimate of the photometric redshift derived by assuming that the host has $M_R = -23.85$ and $R_e = 9$ kpc (the typical median values found in previous studies of BL Lacs hosts; e.g. Falomo & Kotilainen 1999).

In Sect. 2 we describe the observations and data analysis. Sect. 3 reports the results obtained for each individual objects. Sect. 4 gives a summary of the results and discussion.

2. Observations and data analysis

Optical observations were obtained using the 3.5m New Technology Telescope (NTT) at the European Southern Observatory (ESO), operated via remote control from the ESO headquarters in Garching (Germany). We acquired images using the Superb Seeing Imager (SUSI; Melnick et al. 1992) which is installed at one of the Nasmyth foci of the NTT. Configuration used was R-band filter and a CCD (TK 1024) with $24\mu\text{m}$ pixel size corresponding to $0.13''$ on the sky. Conditions were photometric and seeing was ranging from 0.55 to 1.2 arcsec (FWHM), and in most cases $< 1''$. Observations of standard stars (Landolt 1992) were used to set the photometric zero point.

We obtained images centered on the BL Lac object with exposure times ranging from 10 to 30 min (see Table 1). For many objects we also secured one short (2 minutes) exposure in order to be sure to get unsaturated images of the nucleus of the targets and to enable us to use bright stars in the field to study the PSF.

The images were processed in the standard way (bias subtracted, trimmed, flat fielded, and cleaned of cosmic rays) using the Image Reduction and Analysis Facility (IRAF) procedures. A journal of the observations is given in Table 1.

Spectroscopy of the the objects and/or of galaxies in the field were obtained for some targets in order to determine the redshift of BL Lacs and/or nearby companion galaxies. For this purpose the ESO multi mode instrument EMMI (Melnick et al.

Table 2. Properties of host galaxies and nuclei.

(1) Name	(2) z^a	(3) K_R	(4) R(nucleus)	(5) R(host)	(6) $M_R(\text{nuc})$	(7) $M_R(\text{host})$	(8) $R_e(\text{kpc})$	resolved ^b
PKS0138-097	0.733	1.46	17.64	*	-26.39	*	*	N
0301-24	0.26	0.28	15.96	17.46	-25.36	-24.14	23.1	Y
0338-21	(0.45)	*	16.44	18.86	*	*	*	Y+
REX0353-36	(0.40)	*	18.05	18.92	*	*	*	Y+
PKS0735+17	>0.424	*	15.22	*	*	*	*	N
0736+01	0.191	0.20	16.34	17.08	-24.87	-24.33	12.0	Y
0818-12	?	*	16.17	*	*	*	*	N
1101-23	0.186	0.19	16.80	16.41	-23.87	-24.45	22.3	Y
MS1312-42	0.108	0.10	18.64	16.25	-20.89	-23.38	5.3	Y+
MS1332-29	0.25	0.27	19.44	20.36	-21.92	-21.27	4.2	Y+

^a Photometric redshifts are enclosed within parenthesis (see text)

^b N = not resolved; Y = resolved; Y+ = resolved (first detection)

1992) was used with red arm and grism elements. In general the slit has been oriented in order to obtain in a single observation both the BL Lac object and one or more galaxies around the source.

All the images have been analyzed following the methods and procedure described in Falomo (1996). In particular surface photometry analysis was performed down to the surface brightness magnitude $\mu_R \sim 26 \text{ mag./arcsec}^2$ in order to derive the properties of the host galaxies. A fit of the radial brightness profile was performed assuming a simple two model components: a point source plus a elliptical galaxy described by a de Vaucouleurs law

$$I(r) = I_0 \exp\{-7.67[(r/r_e)^{1/4} - 1]\}$$

where $I(r)$ is the surface brightness and r_e the effective radius. Also disc galaxies models were attempted but in no cases they gave a better fit than the elliptical model. This is consistent with what was found in previous studies on a larger number of sources (Falomo & Kotilainen 1999; Urry et al. 1999; Scarpa et al. 2000).

To obtain absolute quantities we applied correction for Galactic extinction and redshift (K-correction). The former was determined using the Bell Lab Survey of neutral hydrogen N_H converted to E_{B-V} (Stark et al. 1992; Shull & Van Steenberg 1985), while the latter was computed from the model of Coleman et al. (1980) for elliptical galaxies. Throughout this paper, $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $q_0 = 0$ are adopted.

3. Results

In Fig. 1 we report the observed radial brightness profile of the objects together with the best fit with the two components (point source plus elliptical galaxy) for the objects resolved. Parameters of the fit and absolute quantities for host galaxies and the nuclei are given in Table 2. In this table Columns 4–8 we give the results from this paper. The redshift in Column 2 is drawn from literature except that for 0301-24 and two cases where a photometric redshift (given in parenthesis) is derived from the observed host properties. In the following discussion absolute

quantities are given including corrections for galactic extinction and redshift (K-correction). Optical spectra of the BL Lacs or companion galaxies are reported in Fig. 2 together with the main identifications of observed spectral features.

3.1. Comments for individual objects

PKS 0138-097. This object was observed under $1.2''$ seeing and it looks unresolved. Heidt et al. 1996 have presented deep sub-arcsec images of this source that indicate the presence of close companion objects. These could be responsible for the intervening absorption system at $z = 0.501$ (Stickel et al. 1993) seen in the spectrum of the BL Lac object. Our image was taken under relatively poor seeing but nevertheless some evidence of the southern feature at $\sim 1.5''$ from the center of the source is present in our image. This object has also been imaged by HST and found to be unresolved (Scarpa et al. 2000) but the presence of a companion galaxy at $1.5''$ South from the nucleus is clearly apparent.

Recent spectroscopy (Stocke & Rector 1997) detects for the first time the emission-line redshift of $z=0.733$ based upon weak Mg II and [O II] emission features. At this relatively high redshift our image result is consistent with this object being in a luminous (not detected) host galaxy at $z = 0.733$.

0301-243. We took a 20 minute image under good seeing ($0.8''$) of this BL Lac object that clearly shows an extended nebulosity (ellipticity $\varepsilon = 0.3$; $\epsilon = 1 - b/a$) with a complex close environment (see Fig. 3).

The immediate region around the object is rich with faint galaxies and there is a marked enhancement of the galaxy density within $\sim 60''$ from the BL Lac object.

The spectra of two galaxies (G1 and G2; see Fig. 3) at $\sim 6''$ and $20''$ from 0301-243 indicate that they are at $z = 0.263$ suggesting a cluster of galaxies of Abell richness class 0 might be associated with the BL Lac source at this redshift (Pesce et al. 1995). The radial profile is adequately well represented by a point source plus the elliptical model while the fit with an

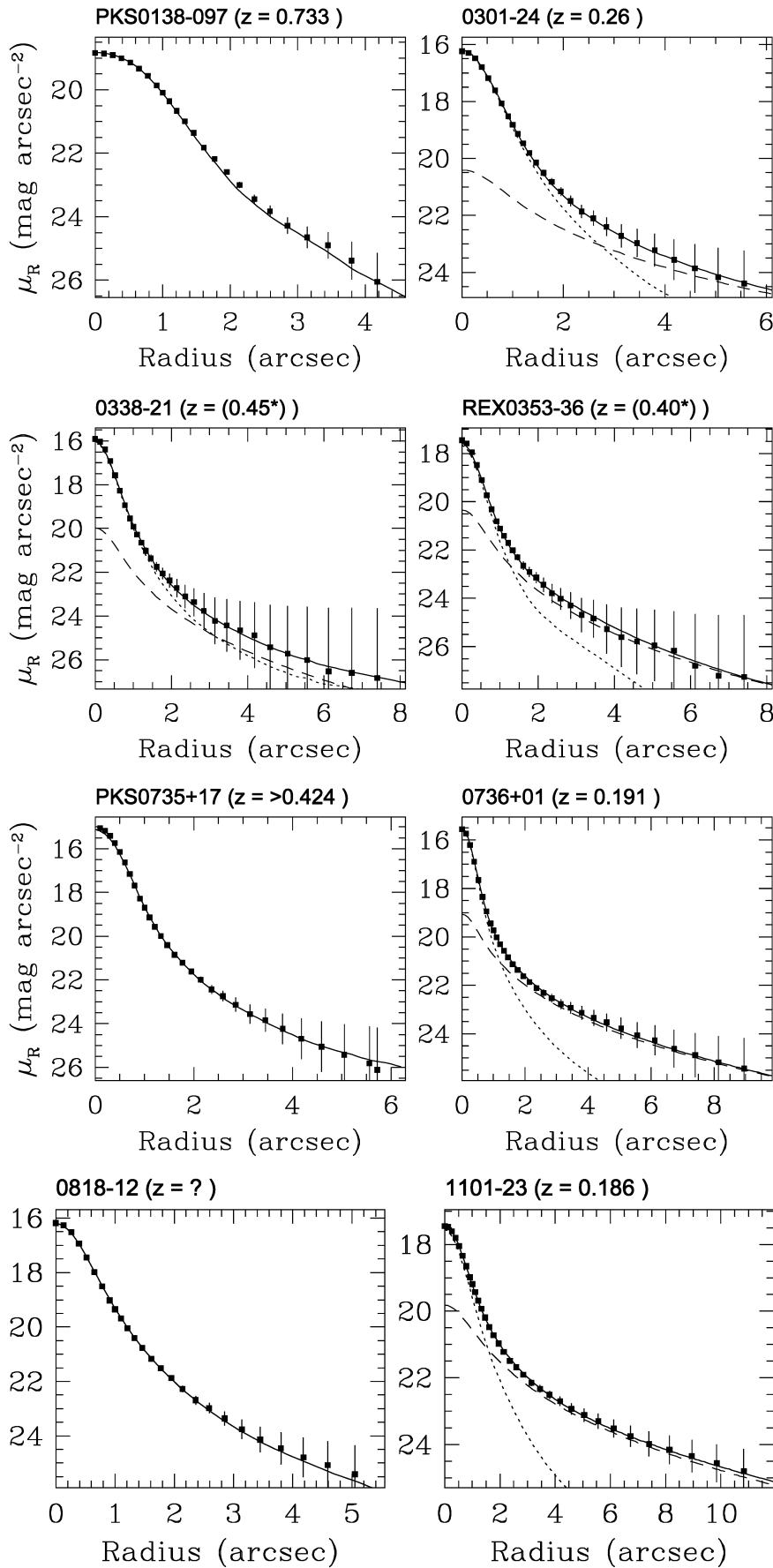


Fig. 1. The observed radial luminosity profiles of each BL Lac object (filled squares), superimposed to the fitted model (solid line) consisting of the PSF (short-dashed line), de Vaucouleurs bulge (medium-dashed line). In the cases of unresolved sources only the scaled PSF profile is shown.

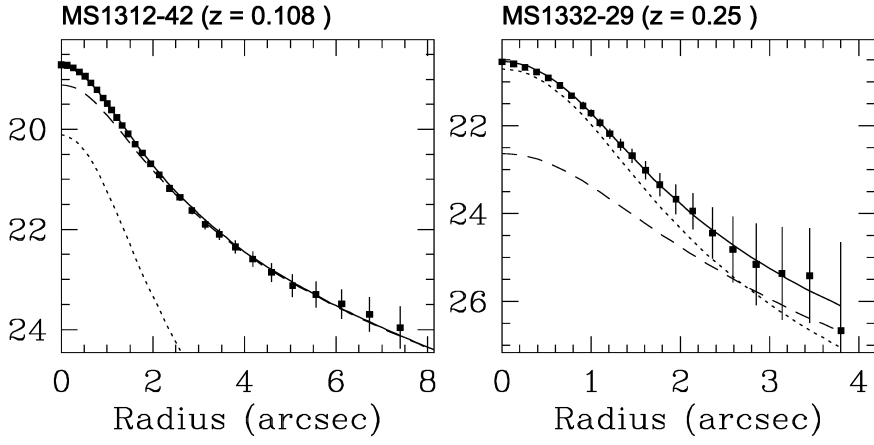


Fig. 1. (continued)

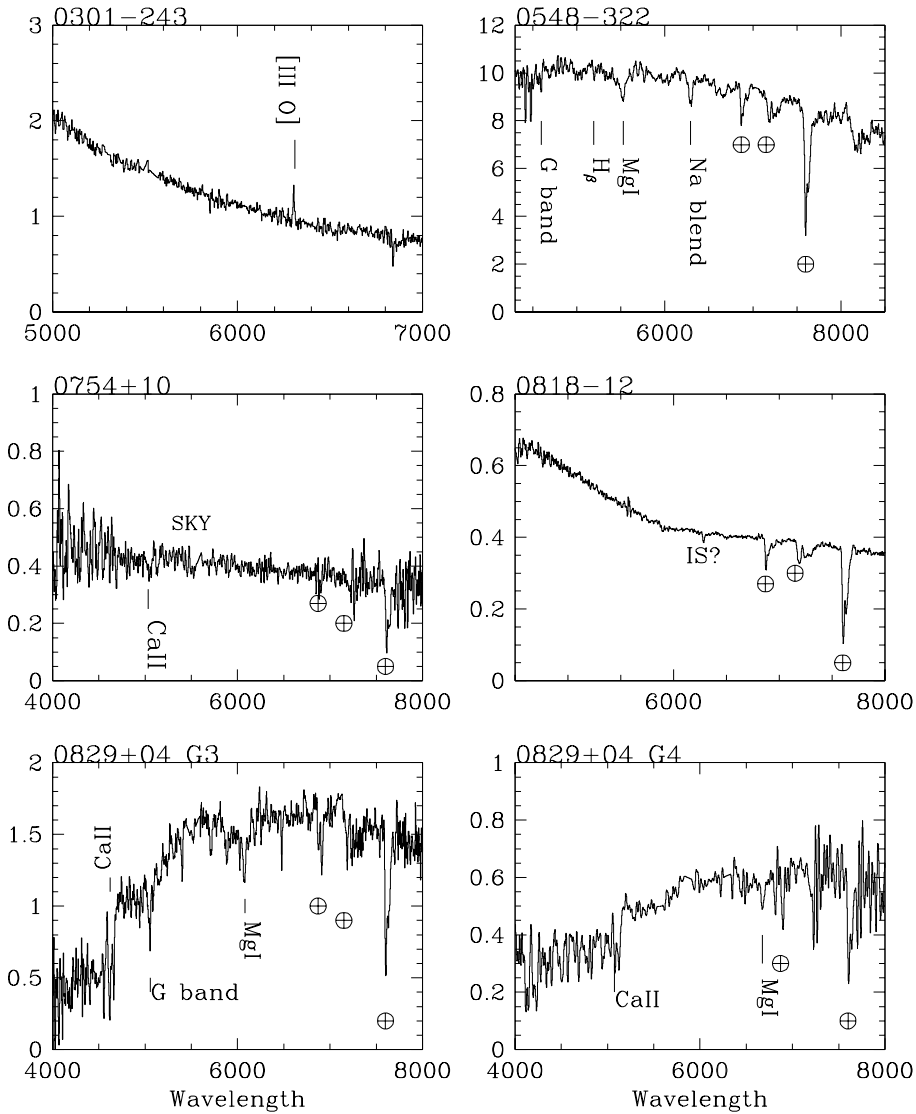


Fig. 2. Optical spectra of BL Lac objects and companion galaxies. Fluxes are in relative units.

exponential disk is not acceptable. Fig. 3 (right panel) shows the field after subtraction of the BL Lac model (nucleus plus host galaxy) revealing the faint galaxy $\sim 3.5''$ South of the nucleus. After masking out the companion from the image we find that

the surrounding nebulosity is very well centered on the nucleus within an accuracy of $0.2''$.

We took three optical spectra of the nebulosity with the slit off the nucleus by $2''$. They are still dominated by the signal from the non-thermal source but all three show one weak emission

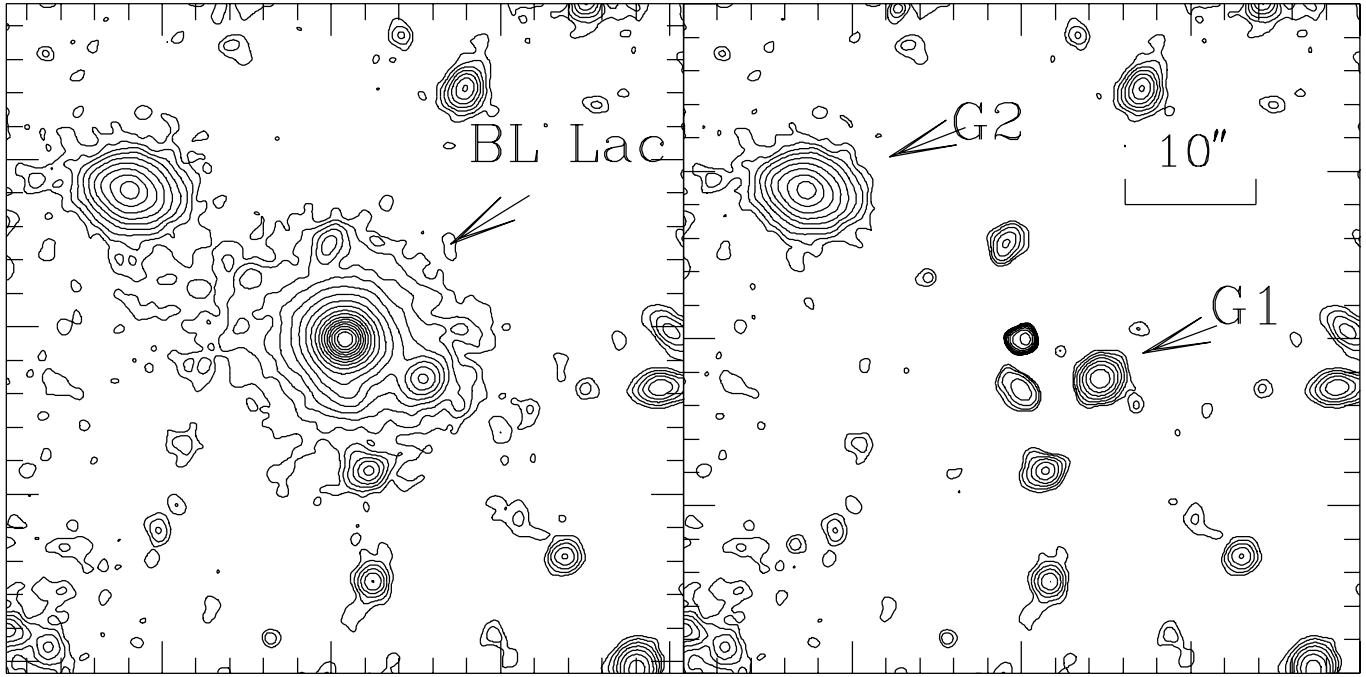


Fig. 3. Contour plot of the central part of 0301-24 before (*left*) and after (*right*) subtraction of a 2D model of the galaxy and the nucleus. After subtraction of the model a faint galaxy $3.5''$ South is visible together with some residual light from the bright nucleus. The spacing between isophotes is 0.5 magnitudes while faintest shown level is $\mu_R = 25.5 \text{ mag arcsec}^{-2}$. Galaxies G1 and G2 are at redshift $z = 0.26$.

line at $\lambda = 6303 \text{ \AA}$ (see Fig. 2). The most plausible identification for this emission is [O III] 5007 \AA that yields a redshift of 0.26. Fainter emissions like [O III] 4959 \AA or H_β could be present at this z but not detectable in our spectrum because the features are lost in the noise. Other possible identifications like MgII 2800 (at $z = 2.25$) are not acceptable because the host galaxy would be too luminous ($M < -30$). The redshift of 0.26 is very similar to the redshift of the companion galaxies G1 and G2 (respectively of $M_R = -20.7$ and $M_R = -22.3$) and supports the idea that the host of the BL Lac is the dominant member of a cluster of galaxies. We note that few other examples have been reported in the literature of BL Lacs in clusters whose membership has been proved spectroscopically. H0414+00 (Falomo et al. 1993a) is in a cluster of Abell class 0; PKS 0548-32 (Falomo et al. 1995) is in a cluster of Abell class 1-2.

At this redshift ($z = 0.26$) the absolute magnitude of the host galaxy of 0301-24 is $M_R = -24.1$

0338-21. Our image obtained with $0.6''$ seeing shows the object to be resolved. This is the first detection of the nebulosity for the source. However its magnitude is not consistent with the redshift of the object published twenty years ago ($z = 0.048$; Wright et al. 1977). The strongest absorption line identified in Wright et al. is indeed a telluric band at 6870 \AA . Subsequent spectroscopy of the source has failed to confirm this redshift and a pure featureless optical spectrum has been observed (Falomo et al. 1994). In fact at this redshift of $z = 0.048$ the nebulosity would correspond to an unreasonably faint and small host galaxy ($M_R \sim -18.5$). Assuming a typical host galaxy (see Sect. 1) we

can well fit the radial brightness profile with a nucleus plus host galaxy obtaining a photometric redshift $z \sim 0.45$.

REX 0353-36. The source was identified as a BL Lac object in the REX survey of AGN (Wolter et al. 1997). Its optical spectrum is featureless (Wolter et al. 1998). We obtained an image under very good seeing (0.6 arcsec) and are able to detect the surrounding nebulosity and measure its luminosity and R_e . This is the first detection of its host. There is no spectroscopic redshift but we can estimate a photometric redshift from the image decomposition assuming the host galaxy has average properties for BL Lacs hosts. The value of the photometric redshift so obtained is $z \sim 0.4$.

PKS 0548-322. This is a very well know BL Lac object at $z = 0.068$ (Fosbury & Disney, 1976) with a very large host galaxy in a rich environment (Falomo et al. 1995). We took one relatively short exposure but good signal-to-noise spectrum centered in the nucleus to search for possible emission lines as have been reported in a number of nearby BL Lacs (e.g. BL Lac itself, Vermeulen et al. 1995). The spectrum, shown in Fig. 2, exhibits a substantial contribution from the stellar population of the host galaxy. The MgI 5175 \AA and Na blend 5892 \AA are well detected with equivalent widths of 12 \AA and 6.5 \AA , respectively. We could not find any emission down to a limit of equivalent width of 2 \AA . This limit corresponds to H_α line luminosity $L(H_\alpha) \sim 5 \times 10^{40} \text{ erg s}^{-1}$ which is about a factor 10 lower than the line detected in BL Lac (Vermeulen et al. 1995).

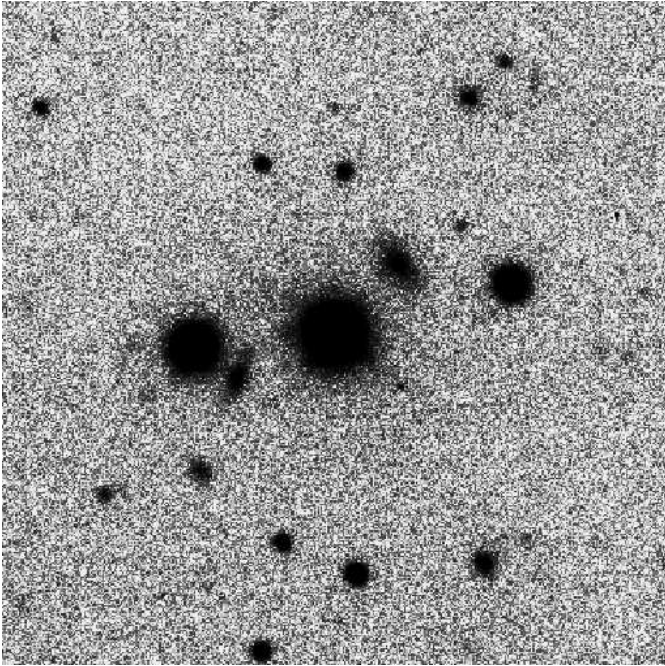


Fig. 4. The BL Lac object PKS 0735+17 (brightest object in the center) imaged by NTT+SUSI (R filter). The two bright objects at both sides of 0735+17 are stars. Field shown is 52 arcsec and North-East is at the top-left side.

PKS 0735+178. This BL Lac object is bright and strongly variable. It has been extensively studied in the radio range and several moving components have been detected in VLBI. The optical spectrum shows the absorption line due to an intervening system at 3980 \AA , which if identified with Mg II gives $z > 0.424$ (Carswell et al. 1974). Our images were obtained under seeing of $0.8''$ but the source remains unresolved. Previous images were presented by Hutchings et al. (1988) who also found this source unresolved. There is no sign in our image (see Fig. 4) that the galaxy $7''$ NW is distorted by interaction with 0735+178 as suggested by previous lower resolution images (Hutchings et al. 1988). The object was also imaged by Stickel et al. (1993) who are not able to detect the surrounding nebulosity. They obtained a spectrum of the galaxy $7''$ NW and found $z = 0.645$. This BL Lac object is unresolved also in a short exposure image obtained with HST (Scarpa et al. 2000). In addition to the two well resolved companion galaxies we detect a faint emission at $\sim 3.5''$ East from the BL Lac (see Fig. 4). Given its projected distance from the BL Lac (25 kpc at $z = 0.424$) it could be related to the intervening absorption at $z = 0.424$ but we cannot exclude that it is just a faint background source.

From our image we can set a lower limit to the redshift (again assuming the typical properties for the host) of $z > 0.5$, consistent with the limit derived from intervening absorption.

PKS 0736+017. The excellent (seeing 0.55 arcsec) image (see Fig. 1) shows the flat spectrum radio quasar PKS 0736+01 ($z = 0.191$) as well as two close resolved faint companions that are embedded in the nebulosity of the object. The radial luminos-

ity profile (see Fig. 1) is very well represented by an elliptical galaxy with a bright point source in the nucleus. It is found that the galaxy has $M_R = -24.3$ and effective radius of $\sim 12 \text{ kpc}$.

This host galaxy was previously detected in the optical with lower resolution by Wright et al. (1998). They derive $M_R = -22.0$, which is substantially fainter than our value. We note that this discrepancy could be due to a problem in the Wright et al. image calibration as their surface brightness goes unbelievably faint. At $5''$ from the nucleus their surface brightness is about $\mu_R = 28$ while our value at the same radius is $\mu_R = 24$.

The object has been also resolved in the NIR by Taylor et al. (1996) who found $M_K = -26.3$, and by Kotilainen et al. (1998a) who found $M_H = -26.2$. The R-H color turns out to be ~ 2.0 , consistent with the range of values reported by Kotilainen et al. 1998b for a number of BL Lacs.

PKS 0754+10. We took two spectra of this BL Lac object for which no firm value of the redshift is available but whose host galaxy had already been detected (Abraham et al. 1991; Falomo 1996). The tentative redshift ($z = 0.66$) proposed by Persic & Salucci (1986) based on inspection of the photographic spectrum reported by Wilkes et al. (1983) is unlikely as the host galaxy would be extremely luminous ($M_R \sim -26 \text{ mag}$). Our spectra were obtained positioning the slit $2''$ from the nucleus in order to reduce the contamination of light from the bright nucleus. Therefore the spectrum (see Fig. 2) is noisy and it is still dominated by the nuclear non thermal emission. We are not able to unambiguously identify spectral lines but some hint of the CaII break signature from the host galaxy is possibly apparent at $\lambda = 5045 \text{ \AA}$ which corresponds to $z = 0.28$. At this redshift the detected surrounding nebulosity would be $M_R \sim -23$. We note that this is consistent with the value of the redshift of the companion galaxy (see Fig. 5) $13.6''$ north-east of the BL Lac object ($z=0.27$; Pesce et al. 1995) and could be another case of a companion galaxy physically associated with a BL Lac object. A definitive redshift determination is however still needed for this BL Lac object.

PKS 0818-128. There is no redshift for this object and its optical spectrum is featureless (Falomo et al. 1994). Our optical images, obtained with seeing of $0.7''$, are not able to detect the host galaxy. The radial brightness profile is well matched by that of a scaled PSF (see Fig. 1). We can set a lower limit to the redshift assuming its nucleus is hosted by a standard luminous ($M_R \sim -23.8$) elliptical. The limit of redshift we found for such a galaxy to be undetected in our image is $z > 0.5$.

In order to search for emission or intervening absorption line we gathered spectra in a wide wavelength range. Our spectrum (see Fig. 2) is still dominated by the non-thermal featureless emission. The only feature (in addition to telluric bands) we can detect is an absorption at 6284 \AA (e.w. 0.7 \AA). The most likely identification of this feature is with an interstellar diffuse absorption band at the same wavelength. This is consistent with the low galactic latitude ($b_{II} \sim 13^\circ$) of the source. Alternatively the absorption line could be identified with MgII 2800 \AA and

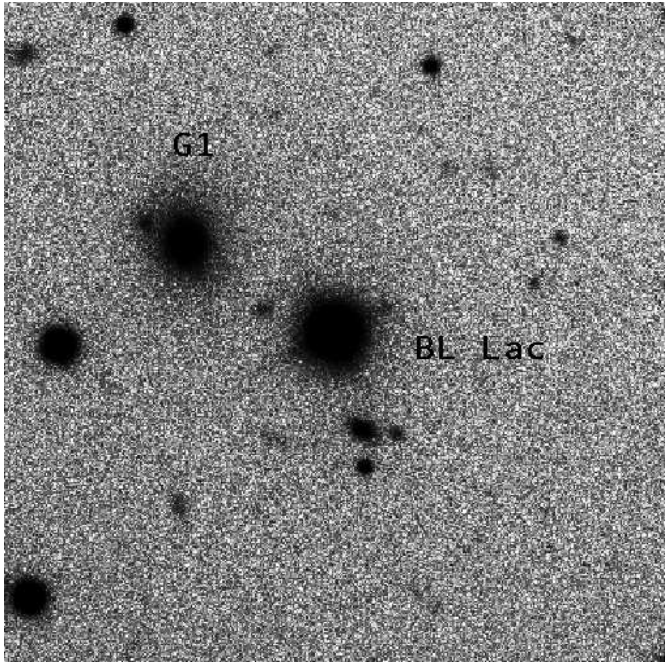


Fig. 5. Image of the BL Lac object (brightest object in the center) PKS 0754+10 obtained with NTT+SUSI (R filter). The galaxy G1 at $13''$ NE is at $z = 0.27$. Field shown is 52 arcsec and North-East is at the top-left corner.

this would yield approximately $z > 1.2$ and, consequentially, the object would be extremely luminous ($M_R < -29$).

PKS 0829+046. Previous images obtained at sub-arcsec resolution showed that the host galaxy ($z = 0.18$) has $M_R \sim -23$ (Falomo 1996). There is also an excess density of galaxies around this object (Pesce et al. 1994). But our spectroscopy shows that only some of them may be physically associated with the BL Lac object. Pesce et al. 1994 obtained the redshifts of galaxies G1 and G2 (see Fig. 6) at respectively $z = 0.24$ and $z = 0.204$. We took additional spectra of two other galaxies (G3 and G4, see Figs. 2 and 6). We found that G4 is at significantly higher redshift ($z = 0.29$) while G3 is at $z = 0.175$, consistent with being associated with PKS 0829+04 at projected distance of ~ 120 kpc. In fact G3 is the only galaxy which is at the same redshift as the BL Lac. On one hand this is another case of similar redshift of a companion galaxy and its BL Lac. On the other hand the environment of 0829+04 must be less rich than what can be estimated from galaxy counts.

H 1101-23. This is a BL Lac discovered from X-ray survey and is surrounded by a conspicuous rather elongated nebulosity (see Fig. 7) at the proposed $z = 0.186$ (Remillard et al. 1989) confirmed by Falomo et al. (1994). The radial brightness profile extends to 15 arcsec along the major axis. We found that the luminosity profile is well fitted by an elliptical galaxy model plus a point source. The luminosity of the host galaxy is very high. The absolute magnitude, $M_R = -24.45$, sets this galaxy among

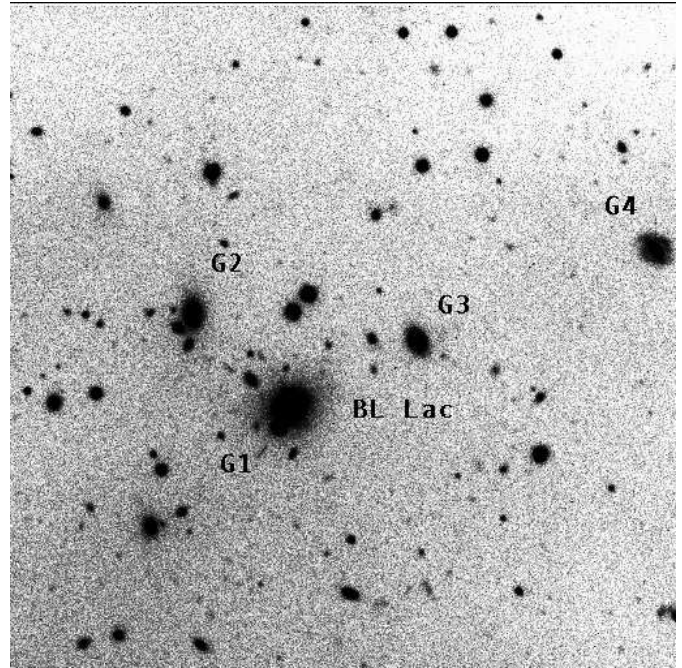


Fig. 6. The field around the BL Lac object PKS 0829+04 obtained with NTT+SUSI (R filter). Field shown is 2.2 arcmin and North-East is at the top-left corner.

the brightest hosts of BL Lac objects (Falomo & Kotilainen 1999).

For this object (see Fig. 8) we performed detailed surface photometry analysis using the AIAP package (Fasano 1990) in order to study the structural properties of the galaxy. From this analysis we derived photometric and structural parameters (surface brightness, ellipticity, position angle and Fourier coefficient C_4 describing the deviation of isophotes from the ellipse) as a function of the equivalent radius $r = a \times (1 - \epsilon)^{1/2}$ where a is the semi-major axis and ϵ is the ellipticity of the ellipse fitting a given isophote. We found the ellipticity profile is increasing from the center outwards up to $\epsilon = 0.45$. The profile of the C_4 (see Fig. 9) shows *disky* (positive C_4) trend in the inner region while the external isophotes are substantially *boxy* (negative C_4), possibly due to merging processes (e.g. Bender et al. 1988). This is the only clear evidence of significantly *boxy* isophotes ever found in a BL Lac host.

Another example of a very luminous host galaxy ($M_R = -24.8$, or -24.45 if de Vaucouleurs law is fitted) was reported by Heidt et al. (1999) for 1ES 1741+196. Also in this case the host galaxy isophotes have high ellipticity (~ 0.35). There is no information, however, about the detailed shape of the isophotes and the amount of possible boxiness.

MS 1312.1-422. This source, drawn from the EMSS of BL Lacs (Maccacaro et al. 1994) was observed during bad seeing conditions (seeing of $1.4''$) but since it is at relatively low redshift ($z = 0.108$; Morris et al. 1991) it is rather well resolved. The host galaxy is indeed dominant with respect to the nuclear source (ratio nucleus/host = 0.1). Our fit of the brightness profile yields

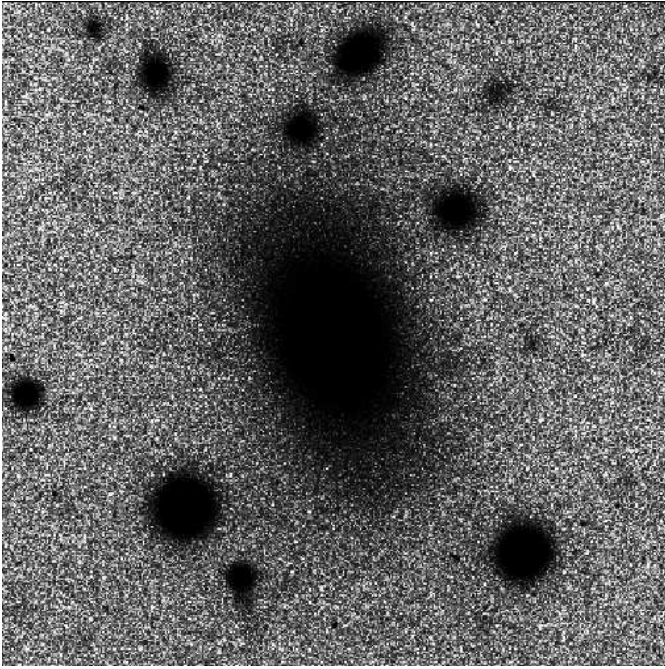


Fig. 7. Central portion ($52'' \times 52''$) of the NTT + SUSI image of the BL Lac object H 1101-23 (brightest object in the center). A *squared* shape of isophotes are well apparent as signature of boxiness. North is up and East to the left

$M_R = -23.4$. No other detection of this host galaxy can be found in the literature.

Note that in the calculation of α_{OX} it is usually the luminosity of the whole object (nucleus + host) which is used in the calculation. Such a procedure if applied to 1312-42 would overestimate the optical flux by a factor ~ 10 .

MS 1332.6-293. The target belongs to the EMSS sample of BL Lacs although its classification is uncertain. Optical spectra showed either emission lines at $z=0.256$ or strong CaII break (Stocke et al. 1991) due to a substantial contribution from stellar emission.

Our image shows this object is only marginally resolved. This is in part due to the bad seeing ($\sim 1.5''$) and also because the host galaxy is substantially under-luminous ($M_R = -21.3$) with respect to the average of the host galaxies of BL Lacs ($M_R = -23.8$ Falomo & Kotilainen 1999).

We note that the same object (1ES1322-297) is listed in the Einstein Slew sample of BL Lacs (Perlman et al. 1996) and has a redshift $z = 0.512$ quite different from the previous finding. Since in neither cases there are spectra published we are not able to make our own judgment of the validity of the redshift values. However, the latter value seems confirmed by another optical spectrum (albeit noisy) reported by Rector (1998). At $z = 0.512$ the host galaxy and point source would be much more luminous ($M_{\text{nuc}} = -23.5$ and $M_{\text{host}} = -23.3$) and well within the averages of these types of objects.

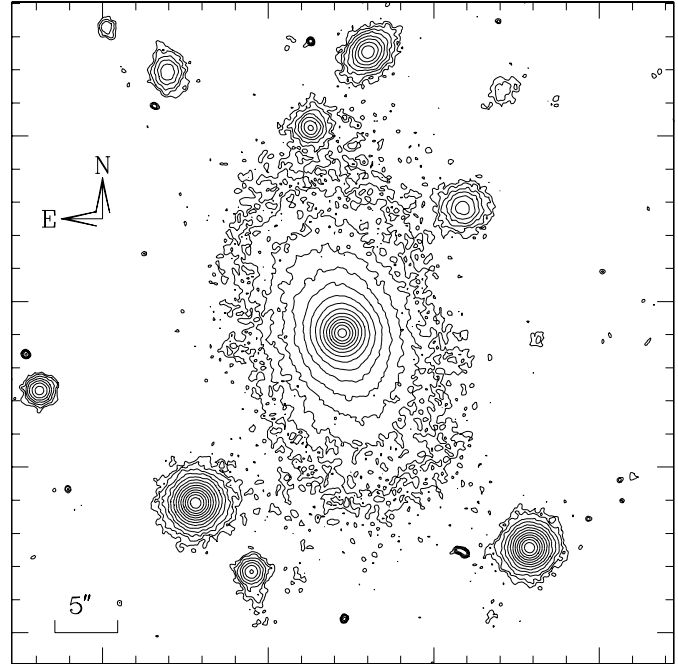


Fig. 8. Contour plot of 1101-23. Faintest isophote is $\mu_R = 25.2$ and spacing between isophotes is 0.5 mag. External isophotes are significantly boxy.

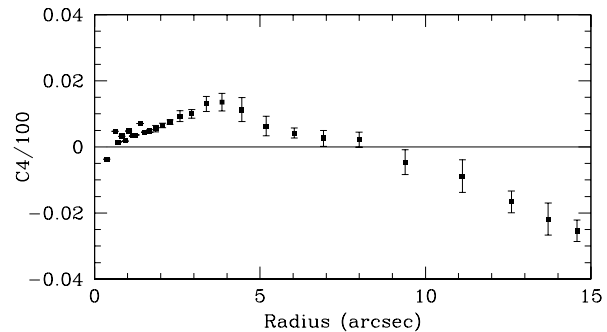


Fig. 9. The amplitude of the Fourier coefficient $C_4/100$ showing the isophotes of the host galaxy of H 1101-23 being *disky* around 3-4 arcsec and substantially *boxy* at larger radii.

4. Summary and conclusions

We have presented optical images of a number of BL Lacs that were not previously well studied. For several of these objects the first detection of the host galaxy is presented here. The properties of the hosts are consistent with them being luminous ellipticals as found in previous similar studies. For two of the resolved objects that have not a spectroscopic redshift we derive a photometric redshift based on the observed properties of the surrounding nebosity.

A bright and boxy elliptical

We find that the external isophotes of the luminous host galaxy of 1101-23 are significantly *boxy* while the inner *disky* region suggests the presence of a small disc component. This is the

first clear example of a *boxy* galaxy hosting a BL Lac object. Boxy isophotes are observed in a fraction of luminous ellipticals (Bender 1988) and could be ascribed to merging events from equal mass galaxies (e.g. Naab et al. 1999). It would be interesting to know what fraction of hosts of BL Lacs exhibit boxy isophotes as compared with non active ellipticals. Very little data are, however, available on isophote shapes of BL Lacs host galaxies because the presence of the bright nucleus and the quality of data often hinder a reliable estimation of this parameter especially at high redshift. For relatively low redshift objects with high resolution images it should be possible to investigate the isophote shape in a systematic way.

The immediate environment of BL Lacs

Our spectroscopy has allowed us to derive a redshift for 0301-24 ($z = 0.26$) and possibly for 0754+10 ($z=0.28$). Both objects have companion galaxies at redshifts very similar to that of the BL Lacs. The companions and the BL Lacs are thus very likely to be gravitationally bound. A third case is PKS 0829+04 for which we took the spectra of two galaxies in the immediate environment and found that one is at the same redshift as the BL Lac object. These spectroscopic results improve the scanty data on redshifts of companion galaxies of BL Lacs. Together with previous findings (Falomo et al. 1993a,b; Pesce et al. 1994,1995; Heidt et al. 1999) our new results yield convincing evidence that galaxies around BL Lacs are (often) gravitationally bound with the BL Lacs. On the other hand only in very few cases do these interactions lead to significantly (observable) disturbed morphology (see e.g. Falomo et al. 1995, Heidt et al. 1999).

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