The host galaxies of BL Lac objects in the near–infrared

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Abstract. We present near–infrared imaging of 11 BL Lac objects. The host galaxy is resolved in 7 low redshift (z≤0.24) BL Lacs, while the 4 unresolved BL Lacs have either high (z≥0.5) or unknown redshift. The host galaxies of low redshift BL Lacs are luminous (average M(H) = –25.8±0.5), i.e. slightly brighter than L* galaxies, but slightly fainter than brightest cluster galaxies. The optical/near–infrared colour and colour gradient of the BL Lac hosts (R–H = 2.2±0.5; Δ(R–H)/Δ(log r) = –0.09±0.04) are consistent with those of normal ellipticals, indicating that the nuclear activity has only a marginal effect on the properties of the hosts. Comparison with the properties of FSRQ and RG is briefly discussed.

1. Introduction

Blazars (BL Lac objects and flat spectrum radio quasars [FSRQ]) exhibit strong and variable luminosity and polarization, core–dominated radio emission and very often superluminal motion (Kollgaard et al. 1992). The clearest difference between them is that FSRQs have strong broad emission lines, which are weak or absent in BL Lacs. Blazar emission is usually explained by a synchrotron–emitting relativistic jet oriented close to our line–of–sight (Blandford & Rees 1978). This beaming model implies the existence of identical parent objects which have their jet directed away from us. In the current unified model (see e.g. the review by Urry & Padovani 1995), BL Lacs are identified with low luminosity (F–R I) radio galaxies (RG), and FSRQs with high luminosity (F–R II) RGs. To directly test the unified model, we need to compare orientation–independent properties of blazars, e.g. extended radio emission, host galaxies and environments, with those of the parents,

Optical imaging (e.g. Falomo 1996; Wurtz et al. 1996) has shown that the host galaxies of nearby (z≤0.5) BL Lacs are predominantly giant ellipticals with similar magnitude to F–R I RGs. The extended radio power and optical environment of BL Lacs are also consistent with those of F–R I RGs, but suggest a contribution to the parent population from F–R IIs (Kollgaard et al. 1992; Wurtz et al. 1997). Very little near–infrared (NIR) imaging exists on BL Lacs, although NIR offers some advantages. The luminosity of the massive old stellar population peaks in the NIR, leading to a minimum nucleus/host ratio there. One also needs to apply much smaller K–correction in the NIR than in the optical. Here we present NIR H–band (1.65 μm) images of 11 BL Lacs. All the low redshift BL Lacs have been imaged in the optical by us (Falomo 1996, Falomo & Kotilainen, in prep.). Identical analysis of the two datasets allows us a homogeneous investigation of the R–H colour of the hosts. We decompose the luminosity profiles of BL Lacs into nuclear and galaxy components, and compare the NIR properties of the hosts with those of FSRQs and RGs. $H_0 = 50$ km s^-1 Mpc^-1 and $q_0 = 0$ are used. A full account of the results is given in Kotilainen et al. (1998b).

2. Observations, data reduction and analysis

NIR H band (1.65μm) images were obtained of the BL Lacs with IRAC2 (pixel scale = $0.278''$ px^{-1}, field of view = $71''^2$) on the 2.2m telescope at ESO. Data reduction consisted of bad pixel correction, median sky subtraction, flat-fielding, and alignment and combination of images. We estimate photometric accuracy of $\sim$0.1 mag. K–correction was applied to the host galaxy magnitudes following the method of Neugebauer et al. (1985) for a first-ranked elliptical galaxy.

Radial luminosity profiles of the BL Lacs were extracted down to μ(H) $\sim$22–23 mag arcsec^{-2}. The luminosity profiles were iteratively least-squares fitted into point source and bulge (de Vaucouleurs) components. For low redshift BL Lacs, we attempted also exponential disc model but in no case did this model give a better fit. We estimate the uncertainty of the derived host galaxy magnitudes to be $\sim\pm$0.3 mag.

3. Results and discussion

The host galaxy is well resolved in all the low redshift (z$\leq$0.24) BL Lacs. In the unresolved cases, the redshift is either high (z$\geq$0.5) or unknown but probably high. The derived properties of the host galaxies are given in Table 1. The average R–H host colour of our BL Lac sample, R–H = 2.2$\pm$0.5, is consistent with that found for local giant ellipticals (R–H $\sim$2.5). It also agrees with evolutionary population synthesis models, which predict for low redshift ellipticals R–H$\sim$2.2 (Poggianti 1997) and R–H$\sim$2.4 (Fioc & Rocca-Volmerange 1997).

Table 1. Near-infrared properties of the host galaxies.

Name	z	R(e) kpc	M(H,nuc)	M(H,gal)	R-H	Δ(R-H)/Δ(log r)	Note
PKS 0048–097	$\geq$0.5(?)		$\leq$-29.2				U
PKS 0118–272	$\geq$0.557		$\leq$-30.1				U
PKS 0521–365	0.055	3.8	-25.8	-25.4	2.3	-0.08	R
PKS 0537–441	(0.896)		(-32.0)				U
PKS 0548–322	0.069	8.3	-23.0	-25.7	2.1	-0.06	R
PKS 1514–241	0.048	3.3	-24.1	-25.1	2.1	-0.12	R
PKS 1538+149	0.605		-28.7				U
PKS 2005–489	0.071	3.1	-26.6	-26.3	2.7	-0.15	R
MS 2143.4+070	0.237	5.5	-24.7	-25.9	2.5	-0.04	R
PKS 2155–305	0.116	5.0	-28.5	-26.8	2.4		R
PKS 2254+074	0.190	32.5:	-26.5:	-25.6:	1.8:	0.10:	R

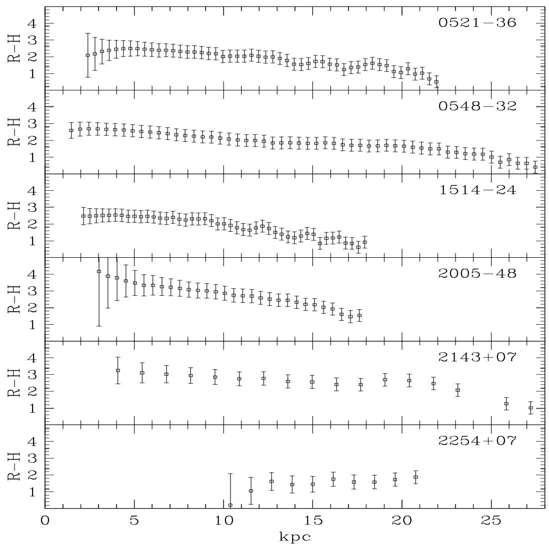

Figure 1. R–H colour vs. radius for the BL Lac hosts.

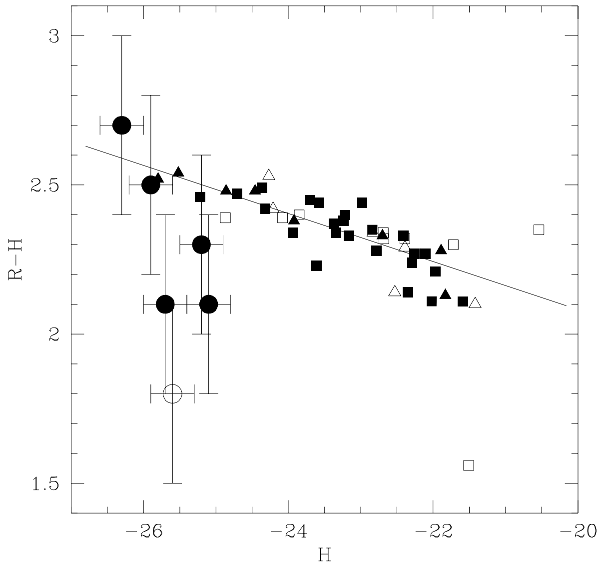

Figure 2. The R–H vs. H colour–magnitude diagram for the BL Lac hosts (filled circles), elliptical galaxies in the Virgo (filled triangles) and Coma (filled squares) clusters, and S0 galaxies in the Virgo (open triangles) and Coma (open squares) clusters (Bower et al. 1992). The uncertain value for PKS 2254+074 is indicated as an open circle. The solid line shows the best–fit for Virgo and Coma (Bower et al. 1992).

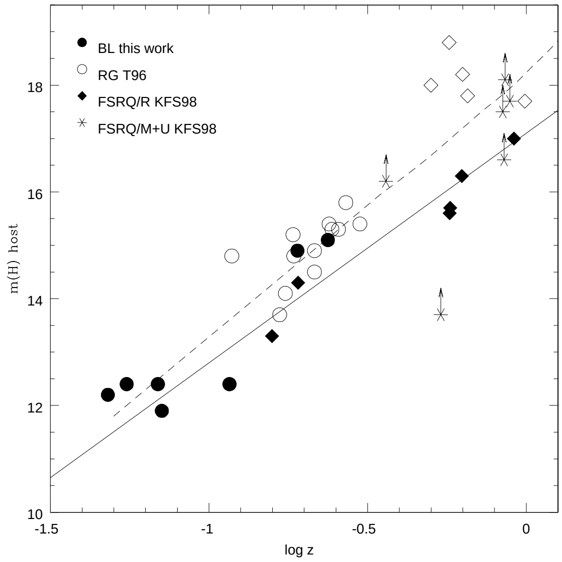

Figure 3. The apparent H magnitude of the host galaxies of BL Lacs (filled circles), FSRQs (Kotilainen et al. 1998a; filled diamonds [resolved hosts], asterisks [marginally resolved and unresolved hosts]), and RGs (Taylor et al. (1996), open circles). The solid line is the relation for RGs derived by Eales et al. 1997), and the dashed line is the passive stellar evolutionary model for elliptical galaxies (Bressan et al. 1994).

The R–H colour profiles for six BL Lacs are shown in Fig. 1. The ensuing R–H colour gradient of the host galaxies is given in Table 1, column (7). With the exception of PKS 2254+074, all BL Lacs have a modest colour gradient (average Δ(R–H)/Δ(log r) = –0.09±0.04) that makes the galaxies bluer in the outer regions. This behaviour is similar to that found in normal ellipticals (Peletier et al. 1990; Schombert et al. 1993). In Fig. 2 we show the colour–magnitude diagram of the BL Lac host galaxies. With the exceptions of PKS 0548–322 and PKS 2254+074, the BL Lac hosts follow reasonably well the established relation for elliptical galaxies in clusters (Bower et al. 1992).

There is increasing evidence that the properties of elliptical galaxies (at least in nearby clusters) can be explained by a single burst of star formation followed by passive stellar evolution (Stanford et al. 1998). The similarity of the colours and colour gradients of BL Lac hosts to those of normal ellipticals thus indicates that nuclear activity has only marginal effect on the overall properties of the host galaxy. For example, galaxy interactions and mergers, often invoked to explain AGN phenomena (Heckman 1990), do not seem to induce strong star formation in BL Lac hosts. Either gas density is low in the host and/or in the interacting galaxy, or the timescales of star formation and nuclear activity are different.

In Fig. 3 we show the H band host galaxy apparent magnitude vs. redshift (Hubble) diagram for the BL Lacs, FSRQs (Kotilainen et al. 1998a) and F–R II RGs (Taylor et al. 1996). The resolved BL Lac hosts lie quite well on the

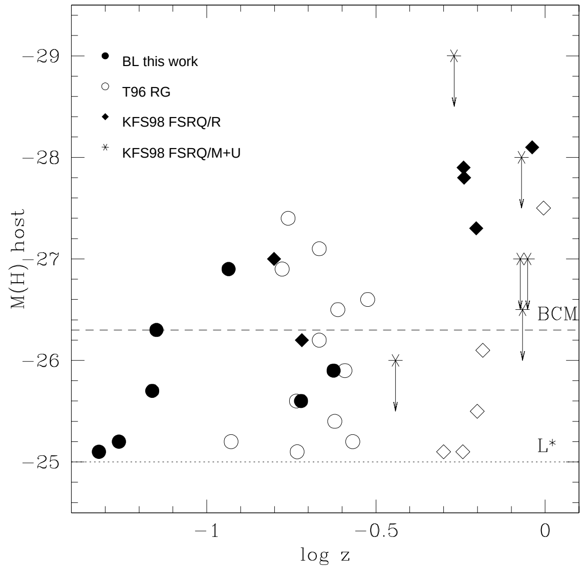

Figure 4. The absolute H band magnitude of the host galaxies vs. redshift. For symbols, see Fig. 3. The dotted and dashed lines are the luminosities of L* and brightest cluster member galaxies (BCM), respectively.

established H–z relation for RGs (Eales et al. 1997). In Fig. 4, we show the H–band host galaxy absolute magnitude vs. redshift diagram for the BL Lacs, FSRQs and RGs. The average H–band absolute magnitude of the seven resolved low redshift BL Lac hosts is M(H) = –25.8±0.5. The host galaxies are therefore slightly more luminous than an L* galaxy (M(H) = –25.0±0.2; Mobasher et al. 1993). As found in the optical by Wurtz et al. (1996), the BL Lac hosts have slightly, but not significantly lower NIR luminosities than nearby brightest cluster member galaxies (BCM; z = 0.07±0.03; M(H) = –26.3±0.3; Thuan & Puschell 1989).

The luminosity of the BL Lac hosts in this study is very similar to that found in previous optical studies of low redshift BL Lacs, if normal colors are assumed. Interestingly, there is good agreement between the BL Lac hosts and the F-R II RGs of Taylor et al. (1996), the only RG sample studied in the NIR and thus almost free from colour uncertainty. The lack of direct comparison sample of F-R I RGs, however, prevents us from discussing the issue of the parent population of BL Lacs further.

Kotilainen et al. (1998a) found for clearly resolved FSRQ hosts at z∼0.7 M(H) = –27.8±0.3, while the value adding their marginally resolved hosts is M(H) = –26.7±1.2. Because not all FSRQs were resolved, it is possible that the average host luminosity of FSRQs is fainter. Moreover, given the large redshift difference between the BL Lac and FSRQ samples, it is possible that the remaining difference in host luminosity is due to cosmological evolution in the stellar population of an elliptical galaxy that makes it fade by ∼0.8 mag between z$\sim$1 and z$\sim$0 (e.g. Bressan et al. 1994). Indeed, there is increasing evidence for significant evolution in the colours and luminosity of elliptical galaxies (Aragon-Salamanca et al. 1998). Thus, while the present data suggests that BL Lac hosts are less luminous than those of FSRQs, additional homogeneous observations of high redshift BL Lacs are needed to reach a firm conclusion.

4. Conclusions

We have presented a NIR imaging study of 11 BL Lac objects, for most of which the host galaxy is clearly resolved. Consistently with optical studies, we find that the host galaxies of low redshift BL Lacs are luminous (average M(H) = –25.8$\pm$0.5); more luminous than L* galaxies (by $\sim$1 mag) but of similar luminosity to or slightly fainter than the brightest cluster galaxies. The average R–H colour and colour gradient of the BL Lac hosts are consistent with those of non-active elliptical galaxies, suggesting that the nuclear activity has little effect on the properties of the host galaxies.

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