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Is there a relationship between BL Lacertae objects and flat-spectrum radio quasars?

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SUMMARY

The properties of a complete sample of flat-spectrum radio quasars are analysed and compared to those of radio-selected BL Lacs, studied in a previous paper, to look for any relationship between the two classes. It is shown that microlensing of quasars by stars in foreground galaxies can probably be ruled out as an explanation for the BL Lac phenomenon, while an evolutionary connection between flat-spectrum radio quasars and BL Lacs does not seem to be supported by the present data. The intrinsic properties of the two classes, that is extended radio emission and line luminosities, are significantly different. BL Lacs are not quasars with emission lines swamped by an enhanced optical continuum, but their line luminosities are intrinsically weak. The most probable scenario is one where BL Lacs and flat-spectrum radio quasars represent separate instances of relativistic beaming in low- and high-luminosity radio galaxies respectively.

Key words: BL Lacertae objects: general – galaxies: jets – quasars: general – radio continuum: galaxies.

1 INTRODUCTION

BL Lacertae objects are special types of active galactic nuclei (AGN), characterized by high luminosity, rapid variability, relatively high optical polarization, and weak or absent emission lines. Radio loudness seems to be another of their fundamental properties, as shown by X-ray (Stocke *et al.* 1990) and optical (Hawkins *et al.* 1991) searches. Moreover, all BL Lacs in the 1-Jy sample (the only complete sample of radio-selected BL Lacs: Stickel *et al.* 1991) are core-dominated and all those with multiple-epoch very long baseline interferometry (VLBI) maps are superluminal sources (Urry, Padovani & Stickel 1991). This latter property may, of course, reflect the fact that they have been selected for VLBI observations because they have the brightest cores.

Flat-spectrum radio quasars (FSRQs) are in many ways similar to BL Lacs, and in fact members of the two classes are often grouped together under the blazar category. FSRQs are quasars with spectral index $\alpha \leq 0.5$ ($F_\nu \propto \nu^{-\alpha}$) at a few GHz. Recent studies (Fugmann 1988; Impey & Tapia 1990) have shown that most, if not all, FSRQs are highly polarized and rapidly variable. Moreover, basically all FSRQs in the 2-Jy catalogue (Wall & Peacock 1985) are core-dominated, while all objects with multiple-epoch VLBI maps display superluminal motion (Padovani & Urry 1992). The most striking difference between BL Lacs and FSRQs is the presence of strong emission lines in the latter objects. Although there are undoubtedly some borderline objects, in which emission lines appear when the continuum is in a low state, a rest-frame equivalent width of 5 Å seems to separate quite well the two classes (see discussion in Stickel *et al.* 1991).

The properties of both classes of objects have been explained in terms of relativistic beaming (as first proposed by Blandford & Rees 1978), that is the spectra of BL Lacs and FSRQs are thought to be dominated by emission from a relativistic jet closely aligned with the line of sight. This hypothesis implies the existence of larger numbers of objects, the so-called 'parent populations', intrinsically identical to BL Lacs and FSRQs respectively, but misdirected with respect to us. The most likely candidates consist of the Fanaroff–Riley type I and II (FR I and FR II) radio galaxies. In this picture, BL Lacs are the fraction of FR I (i.e. low luminosity: Fanaroff & Riley 1974) radio galaxies pointing roughly along the line of sight and, similarly, FSRQs are those FR II (i.e. high luminosity) radio galaxies beamed towards us.

The luminosity functions predicted for the beamed objects, given the luminosity function of the parents and taking into account the selection biases due to beaming (Urry

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& Shafer 1984; Urry & Padovani 1991), have been compared to the observational data of BL Lacs in the X-ray, optical, and radio bands (Padovani & Urry 1990, 1991; Urry *et al.* 1991) and to the luminosity function of radio quasars (Padovani & Urry 1992). The comparison showed quite a good agreement between predictions and observations, in support of the beaming model, and constrained the Lorentz factor(s) of the emission in different bands.

Vagnetti, Giallongo & Cavaliere (1991) have recently suggested that there might be no need for two separate unified schemes, namely BL Lacs and FR Is and FSRQs and FR IIs. In their picture, there could be an evolutionary connection between FSRQs and BL Lacs, with strong-lined objects changing with time into weak-lined ones where the optical continuum is dominated by a beamed component which swamps the emission lines. Their conclusions were based on a radio–optical analysis of the evolution of radio quasars and rested on a very small number of BL Lacs.

A completely different explanation for the BL Lac phenomenon, put forward by Ostriker & Vietri (1985, 1990), is gravitational minilensing. In this picture, 'a significant fraction' of BL Lacs are supposed to be gravitationally microlensed optically violently variable (OVV) quasars (i.e. FSRQs), with their continuum emission greatly amplified, relative to the line emission, by stars in a foreground galaxy: hence the low equivalent widths. This is made possible by the fact that the line-emitting regions are too large to be lensed by stars. BL Lacs and FSRQs would then be the same objects, with the former being the latter 'seen' through intervening galaxies.

The purpose of this paper is to use the only recently available complete samples of BL Lacs and FSRQs to study the differences and/or similarities between the two classes. More specifically, the properties of FSRQs will be analysed and compared to those of radio-selected BL Lacs, studied in a previous paper (Padovani 1992; Paper I), to test in a quantitative way if there is any relationship, either evolutionary or through gravitational lensing, between the two classes. To this aim, I will use a complete sample of FSRQs extracted from the 2-Jy catalogue (Wall & Peacock 1985). The analysis will include correlations between luminosities, comparison of effective spectral indices, luminosity functions, and beaming parameters. The structure of the paper is as follows: Section 2 describes the samples used and outlines the statistical analysis, while Section 3 presents the correlation study for the flat-spectrum radio quasars. Section 4 compares the luminosities and spectral indices, Section 5 discusses the results, and in Section 6 the conclusions are presented. Throughout this paper the values $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$ have been used.

2 THE SAMPLES AND THE ANALYSIS

The 1-Jy sample of BL Lacs, studied in Paper I, is the only complete sample of radio-selected BL Lacs (Stickel *et al.* 1991). It contains 34 objects having $F_{5\,\mathrm{GHz}} \geq 1$ Jy, selected from the 1-Jy catalogue (Kühr *et al.* 1981) on the basis of their low radio spectral index ($\alpha \leq 0.5$), optical magnitude (< 20), and rest-frame equivalent width (< 5 Å).

The sample of FSRQs has been derived by Padovani & Urry (1992) from the 2-Jy sample (Wall & Peacock 1985), a complete flux-limited sample including 233 sources with $F_{2.7\,\mathrm{GHz}} \geq 2$ Jy. The redshifts and optical identifications have been updated using the latest version of the 1-Jy catalogue (Stickel & Kühr, in preparation). All sources but three galaxies in the 2-Jy catalogue belong in fact to the 1-Jy catalogue. The sample contains 50 quasars with spectral index $\alpha \leq 0.5$. These are flat-spectrum quasars that were not classified as BL Lacs by Stickel *et al.* (1991) and are therefore known to have a rest-frame equivalent width larger than 5 Å. Radio, optical, and X-ray data for the sample are presented in Table 1, in which R is the ratio of core-to-extended radio emission at 5 GHz. Note that the difference of a factor of ~ 2 in the radio flux limits of the BL Lac and FSRQ samples is not important, as shown by the fact that the mean properties of the 1- and 2-Jy BL Lacs are not significantly different.

To compare the radio properties of FSRQs to those of the 1-Jy BL Lacs, selected at 5 GHz, I have used radio fluxes at 5 GHz for FSRQs as well. These are given by Wall & Peacock (1985). Variability at radio frequencies should not be a problem, since most sources exhibit changes of less than ~ 20 per cent over several years (Urry 1988). In order to study the properties of the compact and extended radio emission, I have collected from the literature estimates of the ratio R of core-to-extended flux on arcsec (i.e. VLA) scales at 5 GHz. All values were K-corrected to 5-GHz rest frequency taking $\alpha_{\mathrm{extended}} - \alpha_{\mathrm{compact}} = 1$.

The optical fluxes, on the other hand, should be 'representative' for each object, given the remarkable optical variability of FSRQs. They were derived where possible, from the Rosemary Hill Observatory monitoring data: Pica *et al.* (1988) and Webb *et al.* (1988) give detailed light curves extending typically over 10–20 years for about 40 per cent of the sample. For the objects studied by Pica *et al.* (1988) I used the published average magnitude, while for those in Webb *et al.* (1988) the mean magnitude was estimated from the light curve. (In a few cases visual magnitudes were derived from the mean B magnitude taking $B - V = 0.4$.) For the remaining objects the magnitudes given by Wall & Peacock were compared to the ones given by Véron-Cetty & Véron (1989) and, if significantly different, were replaced by the mean of the two. Finally, magnitudes were converted to fluxes at 5000 Å assuming an optical spectral index of 1.4 (Ghisellini *et al.* 1986) and correcting for line emission following Véron-Cetty & Véron (1989).

In the X-ray band there is the additional problem of the uncertainties in the spectral indices, especially as measured by different instruments, which will affect the estimated flux at a given energy. For this reason X-ray data were collected at 1 keV, i.e. near the logarithmic mid-point of the *Einstein Observatory* Imaging Proportional Counter (IPC) band. The main source of X-ray data (11 objects) was the study by Worrall & Wilkes (1990), a detailed spectral fitting of IPC data for blazars, analysed in a uniform way. Fluxes at 1 keV for 15 more objects were derived from X-ray data in the literature using the appropriate spectral index, if given, or $\alpha_x = 0.5$ (Worrall & Wilkes 1990). In total, X-ray data are available for more than 50 per cent of the sample. To my knowledge, there is no detailed study of X-ray variability of FSRQs comparable to the one of Giommi *et al.* (1990) for BL Lacs. However, if one assumes that the variability properties are similar, then X-ray variability should not be much of a problem.

Table 1. The sample of flat-spectrum radio quasars.

Object	Other Name(s)	F_{5GHz} Jy	log R	Ref.	$F_{5000Å}$ mJy	Ref.	F_{1keV} μJy	Ref.	z
0133+476	OC 457	3.26	...	...	0.2	P	...	...	0.859
0208−512		3.21	...	...	0.4	WP,VV	...	...	1.003
0212+735		2.20	>3.5	A	0.03	WP,VV	0.2	B1	2.367
0336−019	CTA 26	2.30	1.9	BP	0.3	P	0.06	H	0.852
0403−132	OF −105	3.24	0.7	BM	0.4	WP,VV	7.1	WW	0.571
0405−123	OF −109	1.81	−0.3	WB	1.5	WP,VV	...	...	0.574
0420−014	OF −035	2.14	2.4	BM	0.2	W	0.4	WW	0.915
0438−436		7.00	...	...	0.09	WP	0.1	W2	2.852
0440−003	OF −67, NRAO 190	3.13	1.3	BM	0.2	W	0.2	W2	0.844
0451−282	OF −285	2.50	...	...	0.09	WP	...	...	2.559
0454−463		2.04	...	...	0.2	WP,VV	...	...	0.858
0528+134	OG 147	3.86	1.6	BP	0.05	WP	0.4	B2	2.060
0605−085	OH −10	3.39	1.4	BP	0.1	WP,VV	...	...	0.870
0637−752		5.49	0.1	WB	1.6	WP	1.1	WW	0.654
0736+017	OI 61	2.06	2.1	BM	1.1	P	3.0	WW	0.191
0834−201	OJ −257.5	3.42	...	...	0.06	WP,VV	...	...	2.750
0836+710	4C 71.07	2.57	1.5	BP	0.7	WP	1.5	G	2.160
0859−140	OJ −199	2.29	1.3	BP	0.8	WP	...	...	1.327
0906+430	3C 216	1.78	−0.1	BM	0.1	WP,VV	0.08	B2	0.668
0923+392	4C 39.25	8.90	1.2	BM	0.2	WP	0.4	WW	0.698
0954+556	4C 55.17	2.27	0.9	BP	0.2	WP,VV	...	...	0.901
1055+018	4C 01.28	3.07	1.3	BP	0.2	WP,VV	...	...	0.888
1127−145	OM −146	7.25	1.7	BM	0.6	P	0.1	H	1.187
1148−001	4C −00.47	1.95	1.7	BP	0.4	P	...	...	1.982
1226+023	3C 273	40.00	0.7	BM	22.2	P	11.1	WW	0.158
1253−055	3C 279	16.10	1.1	BM	0.6	P	0.6	WW	0.537
1424−418		2.12	...	...	0.3	WP,VV	...	...	1.524
1504−166	OR −107	1.96	...	...	0.1	WP	0.1	H	0.876
1508−055	4C −05.64, OR −015	2.33	0.1	BP	0.5	WP,VV	...	...	1.188
1510−089	OR −017	3.25	1.5	BM	0.6	P	0.5	WW	0.361
1610−771		5.55	...	...	0.08	WP	...	...	1.710
1611+343	OS 319	2.67	1.4	BM	0.4	P	0.05	H	1.403
1633+382	4C 38.41	4.08	1.8	BP	0.2	WP	0.08	W2	1.814
1641+399	3C 345	10.90	1.5	BM	1.2	W	0.7	WW	0.594
1741−038	OT −68	3.63	...	...	0.1	WP,VV	...	...	1.054
1928+738	4C 73.18	3.34	0.7	HR	1.9	WP	1.8	G	0.302
1954−388		2.00	...	...	0.4	WP,VV	...	...	0.626
2052−474		2.45	...	...	0.1	WP,VV	...	...	1.491
2106−413		2.28	...	...	0.02	WP,VV	...	...	1.055
2128−123	OX −148, PHL 1598	2.00	1.3	WB	2.0	P	0.3	WM	0.501
2134+004	OX 57, PHL 61	12.38	1.9	BP	0.4	P	0.1	W2	1.936
2145+067	4C 06.69	4.57	2.0	BP	0.9	WP,VV	...	...	0.990
2203−188	OY −106	4.24	1.6	BP	0.1	WP,VV	...	...	0.618
2223−052	3C 446	4.31	1.5	BM	0.5	W	1.5	WW	1.404
2230+114	CTA 102	3.50	1.4	BM	0.4	P	0.4	W2	1.037
2243−123	OY −172.6	2.38	2.0	BP	0.6	WP,VV	...	...	0.630
2245−328	OY −376	1.80	...	...	0.08	WP	...	...	2.255
2251+158	3C 454.3	23.26	1.2	BM	0.6	W	1.3	WW	0.859
2326−477		2.46	...	...	0.9	WP,VV	...	...	1.301
2345−167	OZ −176	3.47	1.4	AU	0.3	W	0.1	W2	0.576

Radio structure: A Antonucci *et al.* (1986); AU Antonucci & Ulvestad (1984); BM Browne & Murphy (1987); BP Browne & Perley (1986); HR Hough & Readhead (1987); WB Wills & Browne (1986).

Optical data: P Pica *et al.* (1988); VV Véron-Cetty & Véron (1989); W Webb *et al.* (1988); WP Wall & Peacock (1985).

X-ray data: B1 Biermann *et al.* (1981); B2 Bregman *et al.* (1985); G George (personal communication); H Henriksen *et al.* (1984); W2 Worrall *et al.* (1987); WM Worrall & Marshall (1984); WW Worrall & Wilkes (1990).

The correlation analysis was performed in the same way as in Paper I. I employed multiple and partial correlation analyses, that is I also studied the correlation between two variables excluding the effect of other variables. For example, $r_{ij.klm}$ denotes the correlation coefficient between the two variables *i* and *j* once the effect of *k*, *l*, and *m* has been subtracted (see Paper I for details). The correlation coefficients used for the analysis were the Spearman rank order correlation coefficients derived using a non-parametric or rank correlation analysis (Press *et al.* 1987). The level at which a correlation was taken to be significant was $\gtrsim 95$ per cent. The presence of lower/upper limits (mostly in the BL Lac sample) was properly taken into account using ASURV, the survival analysis package which uses the routines described in Feigelson & Nelson (1985) and Isobe, Feigelson & Nelson (1986). The restriction of the analysis, to the subset of the sample having data in all three bands under consideration, may have some influence on the results. Note, however, that the omission of some objects was not due to an *a priori* choice, and in any case this is the best that can be done at present. The redshift term in the multiple correlation analysis was taken to be proportional to the luminosity distance, i.e. $\log[z(1+z/2)]$ since I have assumed $q_0=0$. Effective spectral indices between two frequencies, i.e. $\alpha_{\rm ro}$, $\alpha_{\rm rx}$ and $\alpha_{\rm ox}$, were defined in the usual way and calculated between the rest-frame frequencies equivalent to 5 GHz, 5000 Å and 1 keV.

3 THE CORRELATION ANALYSIS FOR FSRQs

The sample used included 27 objects, that is all the ones with X-ray data. The correlation matrix is given in Table 2, where it can be seen that there are strong correlations between luminosities and redshift, due to selection and evolutionary effects. The strongest luminosity–luminosity correlation is the one between $L_{\rm r}$ and L_0. However, a partial regression analysis shows that the $L_{\rm r}$–L_0 correlation, subtracting the effect of the other variables, is not significant ($r_{\rm ro.xz}=0.36$, $P\simeq 92$ per cent, where P gives the significance of the correlation). Similarly, no significant correlation is present between $L_{\rm r}$ and $L_{\rm x}$ ($r_{\rm rx.oz}=0.35$, $P\simeq 90.9$ per cent) and $L_{\rm x}$ and $L_{\rm o}$ ($r_{\rm xo.rz}=0.30$, $P\simeq 85.7$ per cent).

Table 2. FSRQs: correlation coefficients for the subsample with X-ray data.

	$L_{\rm r}$	$L_{\rm o}$	$L_{\rm x}$	z
$L_{\rm r}$	1.00	0.81	0.72	0.90
$L_{\rm o}$	...	1.00	0.70	0.73
$L_{\rm x}$	...	...	1.00	0.60
z	...	...	...	1.00

Table 3. FSRQs: correlation coefficients for the subsample with X-ray and radio core data.

	$L_{\rm c}$	$L_{\rm ext}$	$L_{\rm o}$	$L_{\rm x}$	z
$L_{\rm c}$	1.00	0.42	0.80	0.71	0.90
$L_{\rm ext}$	...	1.00	0.52	0.46	0.34
$L_{\rm o}$	...	...	1.00	0.68	0.74
$L_{\rm x}$	...	...	...	1.00	0.61
z	...	...	...	...	1.00

I now split the radio luminosity into a core ($L_{\rm c}$) and an extended ($L_{\rm ext}$) component. 25 objects have R values and X-ray data. The correlation matrix is given in Table 3. As before, there are strong correlations between luminosities and redshift and, as before, there are no significant correlations between luminosities (i.e. $r_{\rm co.xzext}=0.30$, $P\simeq 82.1$ per cent; $r_{\rm cx.ozext}=0.33$, $P\simeq 86.6$ per cent; $r_{\rm ox.czext}=0.19$, $P\simeq 60.2$ per cent).

Restricting the analysis to the 16 high-polarization quasars (HPQs; i.e. the FSRQs with optical polarization $p_{\rm max}>3$ per cent) with data in all three bands under consideration gives only one significant correlation, between $L_{\rm r}$ and $L_{\rm o}$ ($r_{\rm ro.xz}=0.64$, $P\simeq 98.7$ per cent; while $r_{\rm rx.oz}=0.01$, $P\simeq 1.6$ per cent and $r_{\rm xo.rz}=0.46$, $P\simeq 90.5$ per cent). A multiple linear regression fit gives

$$\log L_{\rm r}=(17.13\pm 5.67)+(0.60\pm 0.21)\log L_{\rm o}-(0.03\pm 0.09)\log L_{\rm x}+(0.98\pm 0.27)\log[z(1+z/2)], \qquad (1)$$

where 1σ uncertainties are given. When the radio luminosity is decomposed into core and extended emission, no significant correlation is found for the HPQs having the relevant data. This result should be regarded with caution due to the small number of objects involved.

Low-polarization quasars (LPQs) do not show any significant luminosity–luminosity correlation. This different behaviour could be explained by assuming that the optical luminosity of FSRQs is made up of two components (see e.g. Wills 1989): a polarized synchrotron continuum, which dominates in HPQs and is physically associated with the radio synchrotron emission, as suggested by the radio–optical correlation; and an unpolarized (thermal?) component not related to the radio emission, which prevails in LPQs.

As regards the lack of correlations between the other bands, this is in conflict with various previous studies (e.g. Kembhavi, Feigelson & Singh 1986; Browne & Murphy 1987; Worrall *et al.* 1987), which found strong correlations between radio and X-ray luminosity and X-ray and optical luminosity in FSRQs. It is important to note that *all* previous works used inhomogeneous and incomplete samples of radio quasars with published X-ray data, while here I have used a complete sample of objects. Turning to the single papers, Kembhavi *et al.* made extensive use of partial correlation analysis but they studied the effect of redshift and optical luminosity on the X-ray–radio core correlation separately, while I subtracted both effects at the same time. In any case, even considering the correlation coefficient between $L_{\rm c}$ and $L_{\rm x}$ subtracting only the effect of $L_{\rm o}$, I do not find a significant correlation for the complete sample of FSRQs under study ($r_{\rm cx.o}=0.39$, $P\simeq 93.8$ per cent), at variance with Kembhavi *et al.* ($r_{\rm cx.o}=0.48$, $P>99.9$ per cent). Browne & Murphy checked that the dependence of $L_{\rm x}$ upon redshift was weaker than its dependence on $L_{\rm r}$ (which is also the case for the sample of FSRQs studied in this paper), but did not explicitly say if the correlation between $L_{\rm r}$ and $L_{\rm x}$ was still significant once the common dependence on redshift was subtracted. Finally, Worrall *et al.* used multiple regression analysis to study the dependence of $L_{\rm x}$ on both $L_{\rm o}$ and $L_{\rm r}$, finding significant correlations. This is difficult to understand in the light of the results obtained here. It could be due to the larger number of objects they used (61, as compared with the 27 used here out of a complete sample of 50), although the two samples span a similar range in luminosities.

4 COMPARISON BETWEEN BL LAC AND FSRQ PROPERTIES

Figs 1–3 plot L_r versus L_x, L_r versus L_o, and L_x versus L_o respectively for BL Lacs and FSRQs. Table 4 gives the average properties and the probability for the distribution of a given parameter to be different for the two classes, derived from the KS test or the log-rank, Gehan's, Cox–Mantel, and Peto & Peto's tests in the presence of lower/upper limits (Feigelson & Nelson 1985). A summary of the correlations is given in Table 5.

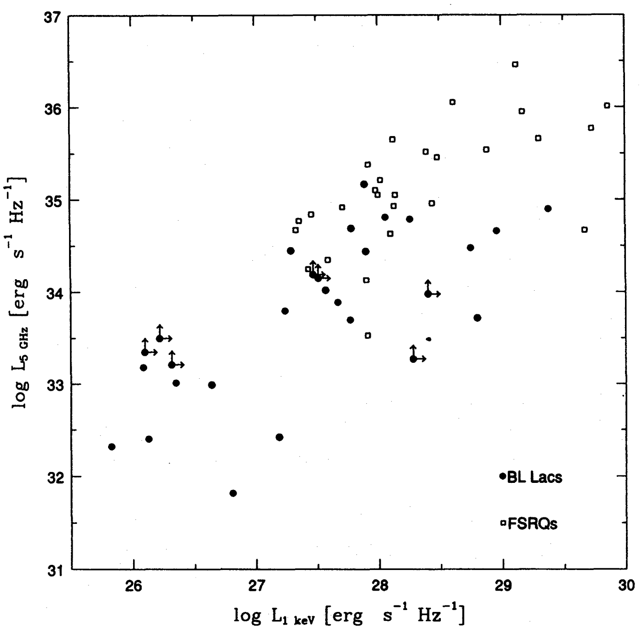

Figure 1. Radio luminosity versus X-ray luminosity for radio-selected BL Lacs (filled points) and flat-spectrum radio quasars (open squares). Lower limits are indicated accordingly.

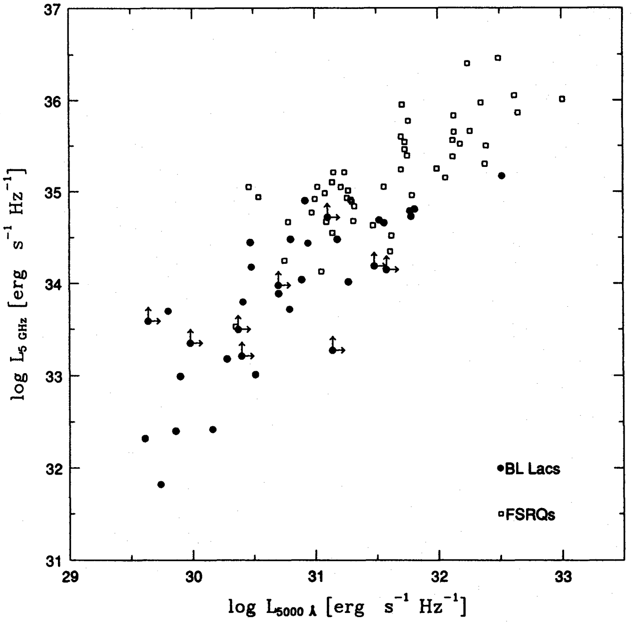

Figure 2. Radio luminosity versus optical luminosity for radio-selected BL Lacs (filled points) and flat-spectrum radio quasars (open squares). Lower limits are indicated accordingly.

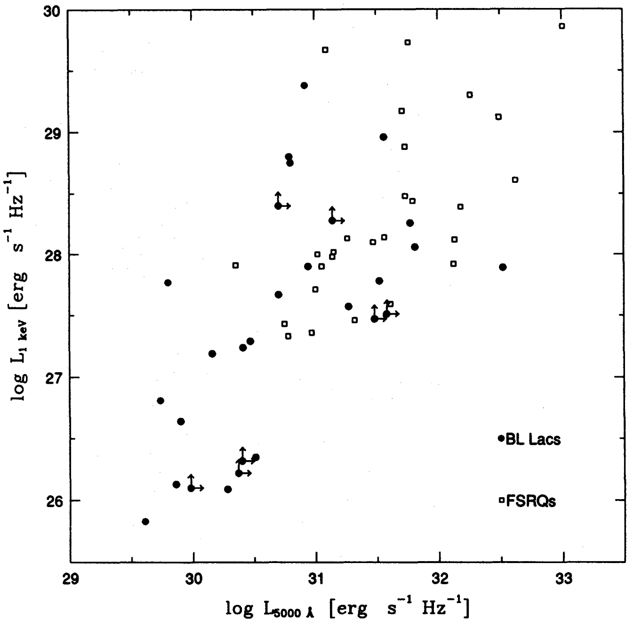

Figure 3. X-ray luminosity versus optical luminosity for radio-selected BL Lacs (filled points) and flat-spectrum radio quasars (open squares). Lower limits are indicated accordingly.

Table 4. Mean properties of the complete samples of FSRQs and BL Lacs.

Parameter	Flat-Spectrum Radio Quasars	Radio Selected BL Lacs	$P_{\rm diff}$
z . . .	1.15±0.10 (50)	0.56±0.06 (34)	>99.9%
$\alpha_{\rm ro}$ . .	0.71±0.01 (50)	0.60±0.02 (34)	>99.9%
$\alpha_{\rm ox}$ . .	1.24±0.05 (27)	1.26±0.06 (28)	60.4%
$\alpha_{\rm rx}$ . .	0.89±0.02 (27)	0.82±0.02 (28)	96.3%
log L_x .	28.32±0.14 (27)	27.74±0.20 (28)	91 - 97%
log L_o .	31.60±0.09 (50)	30.97±0.14 (34)	>98.2%
log L_r .	35.19±0.08 (50)	34.06±0.15 (34)	>99.9%
log L_c .	35.03±0.10 (35)	33.92±0.19 (24)	>99.9%
log $L_{\rm ext}$	33.62±0.14 (35)	31.85±0.25 (24)	>99.9%
log R .	1.40±0.12 (35)	2.07±0.22 (24)	>99.3%
log $L_{\rm OIII}$	43.34±0.19 (14)	41.30±0.11 (8)	>99.9%

Parentheses enclose number of objects used for each parameter. L_c and $L_{\rm ext}$ are the radio core and extended luminosities respectively. $P_{\rm diff}$ is the probability that the distribution of a given parameter is different for the two classes. Continuum luminosities are in units of erg s^{-1} Hz^{-1}, while [O III] luminosities are in units of erg s^{-1}.

Table 5. Summary of correlations of FSRQs, HPQs, and BL Lacs.

Correlation	FSRQs	HPQs	BL Lacs
L_r - L_o	N	Y	Y
L_r - L_x	N	N	N
L_x - L_o	N	N	N
L_c - L_o	N	N	Y
L_c - L_x	N	N	–?

Y indicates positive correlation, N indicates no correlation, ? indicates marginal correlation, – indicates anticorrelation.

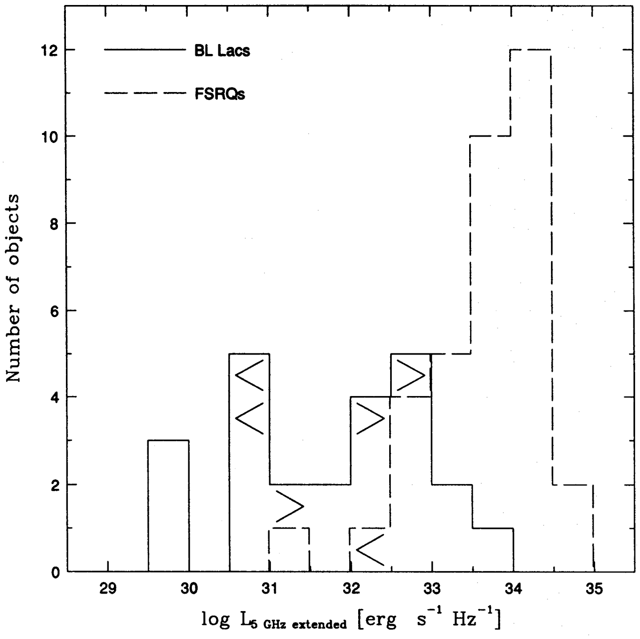

Figure 4. The distribution of extended radio emission at 5 GHz for radio-selected BL Lacs (solid line) and flat-spectrum radio quasars (dashed line). Lower and upper limits are indicated accordingly. The two distributions are significantly different.

FSRQs have larger luminosities than BL Lacs at all wavelengths, ranging from a factor of ~4 in the optical and X-rays, to ~13 in the radio. One of the most interesting properties to compare is the extended radio luminosity. This is thought to be unbeamed and therefore gives important clues about the parent populations. Separation of the radio flux in core and extended emission shows that the difference in radio core luminosity is the same as the difference in total radio luminosity, while the extended radio luminosity is on average a factor of 60 larger for FSRQs.

Fig. 4 shows the distribution of extended radio luminosity for the BL Lac and FSRQ complete samples (radio data on the extended emission are available for about 70 per cent of the objects). The two distributions are clearly different: the application of survival analysis tests, to take into account the lower/upper limits, excludes that the two samples have been drawn from the same parent populations at a >99.99 per cent significance level. Antonucci & Ulvestad (1985), using heterogeneous blazar samples, showed that the distribution of extended radio emission of BL Lacs and OVV/HPQs overlapped with that of FR I and FR II radio galaxies. I showed in Paper I that the distributions of extended radio luminosity for BL Lacs and FR Is are indistinguishable. Moreover, the distribution of extended radio luminosity for FSRQs is also not significantly different from that of FR II radio galaxies in the 2-Jy sample. Therefore, not only are the distributions of extended radio luminosity for BL Lacs and FSRQs different, but the former is similar to that of FR Is while the latter is similar to that of FR IIs: the parent populations of the two classes are then clearly different.

Burbidge & Hewitt (1987, 1989) suggested that there may be two kinds of BL Lacs: those associated with nearby ellipticals, typically at $z \lesssim 0.3$, and the more distant ones with quasar-like spectra. The latter should therefore have FR II type radio structure. This is *not* supported by the data. In fact, the distributions of extended radio power for the two BL Lac subgroups, defined following Burbidge & Hewitt (1989), are statistically indistinguishable. Moreover, the extended radio power properties of the $z > 0.3$ subgroup are different at the >99.99 per cent level from those of FSRQs. The slight overlap between the extended radio luminosities of BL Lacs and FSRQs simply reflects the overlap at 5 GHz between FR Is and FR IIs and therefore cannot be used to indicate that some BL Lacs are associated with FR II radio galaxies.

FSRQs have larger redshifts than BL Lacs, smaller values of the ratio of core-to-extended radio flux and steeper values of $\alpha_{\rm ro}$ and $\alpha_{\rm rx}$. Only the distributions of $\alpha_{\rm ox}$ are similar for the two classes, while for the distributions of $L_{\rm x}$ the application of survival analysis tests gives contradictory results, so no firm conclusion can be drawn. The X-ray (0.1–3.5 keV) spectra are also different, with BL Lacs having $\alpha_{\rm x} \approx 1.0$ and FSRQs (and HPQs) having $\alpha_{\rm x} \approx 0.5$ (Worrall & Wilkes 1990).

As regards line luminosities, which should reflect the intrinsic continuum, they differ by about the same amount as the extended radio luminosities. [O III] luminosities are available for eight 1-Jy BL Lacs (Stickel *et al.* 1991). Due to the limited spectral range, this corresponds to more than 70 per cent of the objects for which [O III] was detectable (i.e. the 11 1-Jy BL Lacs with certain redshift $\lesssim 0.5$). The mean value is $L_{\rm O\,III} \simeq 2 \times 10^{41}$ erg s^{-1} with a spread of less than an order of magnitude. [O III] luminosities were found for 14 2-Jy FSRQs in the literature (Jackson & Browne 1991; Oke, Shields & Korycansky 1984; Blumenthal, Keel & Miller 1982; Steiner 1981; Yee 1980; Neugebauer *et al.* 1979), which basically means about 70 per cent of the objects for which [O III] was detectable. The mean value in this case is $L_{\rm O\,III} \simeq 2 \times 10^{43}$ erg s^{-1}, that is two orders of magnitude larger than for BL Lacs, with a spread of more than two orders of magnitude, and no overlap between the two classes. This is a very important result, since it shows that BL Lacs have *intrinsically* weak lines, and the small equivalent widths are *not* due to the swamping of the lines by the beamed optical continuum. Again, the comparison with FR Is and FR IIs is most instructive. Even in that case, in fact, there is a close correspondence between radio power and emission-line luminosity, with FR IIs having stronger lines than FR Is (see e.g. Rawlings & Saunders 1991; Morganti, Ulrich & Tadhunter 1992).

Regarding luminosity correlations, BL Lacs show significant correlations between $L_{\rm r}$ and $L_{\rm o}$, and $L_{\rm c}$ and $L_{\rm o}$, while they show a marginal anticorrelation between $L_{\rm c}$ and $L_{\rm x}$. FSRQs, on the other hand, do not show any significant correlation between various luminosities, while the radio and optical luminosities of HPQs are correlated.

5 DISCUSSION

5.1 BL Lacs as microlensed quasars?

As discussed in the Introduction, Ostriker & Vietri (1985, 1990) have suggested that BL Lacs objects could actually be gravitationally microlensed radio quasars with continuum emission greatly amplified, relative to the line emission, by stars in a foreground galaxy. Under this hypothesis, the

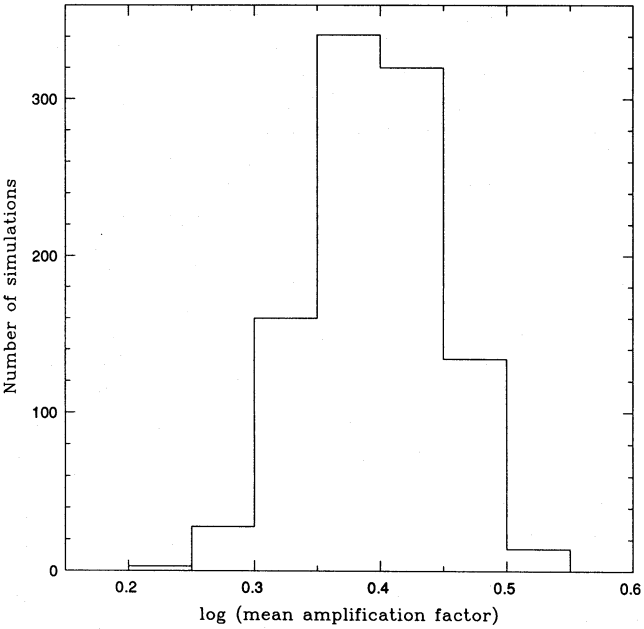

Figure 5. The distribution of mean amplification of the optical flux of BL Lacs derived from numerical simulations under the hypothesis that BL Lacs are microlensed flat-spectrum radio quasars. The hypothesis would require typical amplifications of the order of 10, which are not obtained.

redshift determined by emission or absorption features refers to the lensing galaxy, while the BL Lac object itself is at a larger redshift. Were the microlensing hypothesis correct, BL Lac luminosities would have been wrongly derived in the previous section.

With the complete sample of BL Lacs and FSRQs now available, this hypothesis can be tested on a statistical basis with numerical simulations. To each BL Lac object at redshift z_{bl}, supposed to be related to the lensing galaxy under this hypothesis, was assigned a new redshift z_{q}, picked at random from the FSRQ sample, under the obvious condition $z_{\mathrm{q}} > z_{\mathrm{bl}}$. The same procedure was applied to all BL Lacs in the sample. The ratio between the optical fluxes corresponding to each BL Lac and to the quasar to which the BL Lac had been 'moved', i.e. the BL Lac flux amplification under the lensing hypothesis, was then calculated. Finally, the mean amplification for the whole sample was derived. A total of 1000 simulations were run and the resulting distribution of mean amplifications is shown in Fig. 5. The mean value corresponds to a mean optical amplification $\simeq 2.2$ while the maximum value obtained was $\simeq 3.5$. Taking into account that the optical flux of BL Lacs has a galaxy contribution, these values should be slightly reduced. This means that, under the conditions of the lensing hypothesis, one gets a mean optical amplification of order unity, much smaller than the factor of at least 10 required by Ostriker & Vietri to swamp the emission lines of quasars. Therefore, *microlensing cannot significantly affect the BL Lac population*, although it might be relevant in a few single cases.

Another independent argument indicates that microlensing cannot explain the observed properties of BL Lacs. Ostriker & Vietri (985) calculated the optical number counts of BL Lac objects predicted by the lensing hypothesis (see their fig. 1). These can be compared to the recent number count estimates of Padovani & Urry (1991), complemented by the value $N(B \leq 19) \gtrsim 0.1$ deg^{-2} derived by Hawkins *et al.* (1991). The predictions for the cases of a microlensing amplification of a factor of 100 and 10 are clearly ruled out by the observations, since they would require a flattening of the counts at $B \sim 16$–18 respectively, which is not observed. Again, the inferred amplification is smaller than required by the model. Finally, the supposedly 'strange' redshift distribution of BL Lacs (Ostriker & Vietri 1990) was based on incomplete and inhomogeneous samples. Urry *et al.* (1991) have shown that the redshift distribution of the 1-Jy sample of BL Lacs is fully consistent with the predictions of a relativistic beaming model. Note that the differences in the X-ray spectra of BL Lacs and FSRQs also do not support the microlensing hypothesis (Worrall & Wilkes 1990).

5.2 BL Lacs and quasars within an evolutionary scheme?

Vagnetti *et al.* (1991; VGC) have argued for an evolutionary unified scheme which would connect BL Lacs with FSRQs, claiming a spectral and statistical continuity between the two classes. I shall discuss these two points in turn.

5.2.1 *Spectral continuity*

VGC parametrized the dependence of the ratio between optical and radio luminosities using the form

$$\log(L_{\mathrm{o}}/L_{\mathrm{r}}) = A_L \log L_{\mathrm{r}} + A_z T + A, \qquad (2)$$

where $T(z)$ is the look-back time. They derived the best-fitting parameters for FSRQs and then extrapolated the correlation to low values of redshift and L_{r}, showing this to be in agreement with the observed mean value of $L_{\mathrm{o}}/L_{\mathrm{r}}$ for four BL Lacs. Their arguments were then based on a very small number of BL Lacs. With the two complete samples of BL Lacs and FSRQs studied here, their hypothesis can be tested by deriving the dependence of $L_{\mathrm{o}}/L_{\mathrm{r}}$ directly for the two classes. For the 23 1-Jy BL Lacs with certain redshift determination, a multiple regression fit with the luminosities in units of 10^{33} erg s^{-1} Hz^{-1} (following VGC) gives a significant correlation ($P \simeq 99.6$ per cent) with $A_L = -0.50 \pm 0.32$, $A_z = 1.16 \pm 1.87$, $A = -2.93 \pm 0.29$. For the 50 2-Jy FSRQs, however, the correlation is not significant ($P \simeq 84.2$ per cent). The best-fitting relationship for BL Lacs was then rederived by evaluating L_{o} at 5500 Å, L_{r} at 2.7 GHz and using $q_0 = 0.1$, to allow direct comparison with the results of VGC. The results of the new fit were $A_L = -0.65 \pm 0.30$, $A_z = 1.68 \pm 1.50$, $A = -3.02 \pm 0.30$, to be compared with $A_L = -0.65 \pm 0.09$, $A_z = 1.24 \pm 0.43$, $A = -3.01 \pm 0.16$ found by VGC. (Note that, due to a misprint, the normalizations reported in table 1 of VGC have to be decreased by a factor of 10. This does not affect any of their results.) The two fits agree quite well within the uncertainties. However, a couple of points have to be considered.

(i) A negative value of A_L is to be expected in both cases, since the correlation to be tested is $L_{\mathrm{o}}/L_{\mathrm{r}}$ versus L_{r}; the most interesting parameter is the redshift term A_z, which agrees for the two classes because of the very large uncertainties on this term for BL Lacs, due to the still limited sample size. A_z (BL Lacs) is also consistent with no dependence on look-back time (i.e. $A_z = 0$), and in fact a partial correlation analysis shows that L_o/L_r has no significant dependence on $T(z)$. On the other hand, A_z (FSRQs) is significantly different from zero at the $\sim 3\sigma$ level.

(ii) BL Lacs in this paper are objects with rest-frame equivalent width < 5 Å. The 2-Jy FSRQs used for this study are known to have a larger value of the equivalent width and they do not show a significant correlation between the physical parameters in equation (2). This could be due to the relatively high flux limit of the sample: VGC used five different samples down to 0.1 Jy and they also found no correlation for the 2-Jy sample (Vagnetti, personal communication). However, the problem with their samples is that they are not defined using an equivalent width criterion and so they could include some objects which would have been classified as BL Lacs and therefore would have entered the derivation of the correlation for BL Lacs. (Note that the equivalent width criterion seems to separate objects which are *intrinsically* different, as shown by the comparison of extended radio powers and line luminosities in Section 4.) VGC excluded from their analysis only two BL Lacs, while many more are present according to the equivalent width classification: the 2-Jy sample contains seven 1-Jy BL Lacs out of 57 flat-spectrum quasars; the 1.5-Jy sample (Peacock & Wall 1981) contains 10 1-Jy BL Lacs out of 35 flat-spectrum quasars. Since the possible quasars do not have a redshift estimate and were therefore excluded from the VGC analysis, it turns out that 43 per cent of the so-called FSRQs in the 1.5-Jy sample are really 1-Jy BL Lacs. The 0.5-Jy sample (Peacock 1985) contains one 1-Jy BL Lac out of the seven sources with flux larger than 1 Jy, plus three BL Lac candidates (Dunlop *et al.* 1989) corresponding to 12 per cent of the quasars. Finally, a substantial presence of BL Lacs amongst flat-spectrum sources ($\gtrsim 30$ per cent for $F_{2.7\,\mathrm{GHz}} > 0.1$ Jy) is expected from the luminosity functions and evolution parameters derived by Urry *et al.* (1991) and Padovani & Urry (1992).

In summary, I found a significant relationship between L_o/L_r versus L_r and the look-back time for BL Lacs but not for the 2-Jy FSRQs. The best-fitting parameters for BL Lacs agree within the uncertainties with those found by VGC for samples of flat-spectrum objects. However, this agreement could be due to the large uncertainties of the best-fitting values for the BL Lacs sample. Moreover, and most importantly, the flat-spectrum samples used by VGC contain a significant number of BL Lacs, as defined in this paper by the equivalent width criterion, and that could explain the similar correlations. Larger samples of homogeneously defined objects are required to address the problem further.

5.2.2 *Evolution and luminosity functions*

The evolutionary properties and luminosity functions of BL Lacs and FSRQs are very important for an assessment of the relationship between the two classes. These quantities were derived by Stickel *et al.* (1991) and Padovani & Urry (1992) respectively for 1-Jy BL Lacs and 2-Jy FSRQs.

The question of evolution can be addressed through the V/V_m test (Schmidt 1968), where V is the volume enclosed by an object and V_m is the maximum accessible volume within which an object could have been detected above the flux limit of the sample. In the absence of evolution, the quantity V/V_m has the property of being uniformly distributed between 0 and 1, with a mean value of 0.5. BL Lacs have $\langle V/V_m \rangle = 0.60 \pm 0.05$ (Stickel *et al.* 1991), while FSRQs have $\langle V/V_m \rangle = 0.64 \pm 0.04$ (Padovani & Urry 1992). The two mean values are consistent within 1σ, although the former is indicative of evolution only at the 2σ level, while the latter indicates strong evolution at the 3.5σ level. For a radio luminosity evolution $L(z) = L(0)\exp[T(z)/\tau]$, where $T(z)$ is the look-back time and τ is the time-scale of the evolution in units of the Hubble time, the following values of τ were found: $\tau = 0.32^{+0.27}_{-0.08}$ for BL Lacs and $\tau = 0.23^{+0.07}_{-0.04}$ for FSRQs. Again the values are consistent within 1σ, but the value of τ for BL Lacs does not exclude the case of no evolution ($\tau > 1$).

The local luminosity function of FSRQs at 5 GHz was derived by de-evolving the sample as described in Padovani & Urry (1992). It is compared in Fig. 6 to the local luminosity function of BL Lacs, derived from the 1-Jy sample (Stickel *et al.* 1991) and rebinned here to allow a direct comparison in the common luminosity range $2.5 \times 10^{33} \lesssim L_{5\,\mathrm{GHz}} \lesssim 4.0 \times 10^{34}$ erg s^{-1} Hz^{-1}. Note that BL Lacs go down to 6×10^{31} erg s^{-1} Hz^{-1} in luminosity, a factor of 40 below FSRQs. In the region of overlap, FSRQs are about twice as numerous as BL Lacs. To test the difference between the two luminosity functions, I have performed a χ^2 test, taking σ equal to the sum in quadrature of the errors. The resulting $\chi^2_\nu \simeq 2.7$ implies a difference significant at the 97 per cent level. The derived local luminosity functions are quite sensitive to the value of the evolution parameter τ, especially at high luminosities. If the error bars for the various bins are derived by summing in quadrature the Poisson errors and the variations of the luminosity functions associated with a 1σ change in τ, the latter being dominant, the difference between the two luminosity functions in the range of overlap is no longer significant. However, if the two

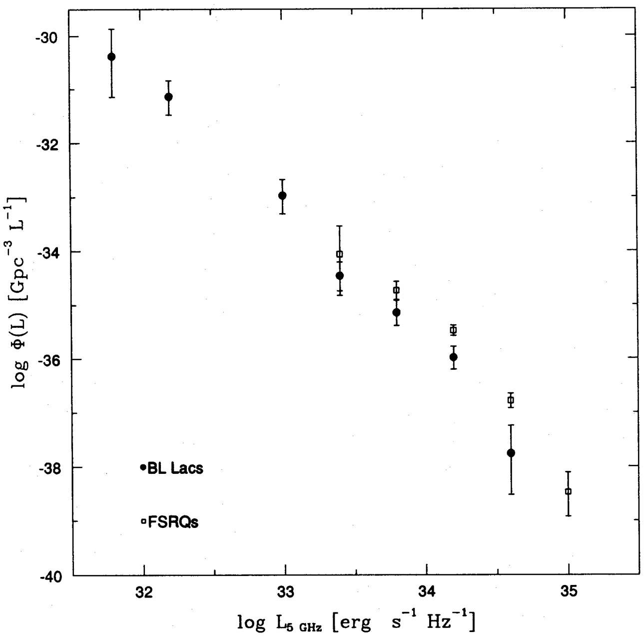

Figure 6. The local luminosity functions at 5 GHz of BL Lacs (filled points) and flat-spectrum radio quasars (open squares). The error bars indicate 1σ errors assuming Poisson statistics (Gehrels 1986).

populations are unified within a common evolutionary scheme, thereby having the same value of the evolution parameter, the changes due to a variation in τ will be the same and the relative difference of the two populations will be independent of τ. If $\tau = 0.23$ for the two populations, then the two luminosity functions are different at the > 99.99 per cent level.

Note that, under the beaming hypothesis, it is not surprising that BL Lacs and FSRQs have roughly comparable number densities in the observed luminosity range. The predictions of beaming models having FR Is and FR IIs as a parent population respectively (Urry *et al.* 1991; Padovani & Urry 1992) happen to overlap somewhat in that range because of the similarity of the luminosity functions of the parents in the corresponding intrinsic luminosity range, and because of the roughly similar beaming parameters (see Section 5.3).

5.2.3 *Intrinsic properties*

The intrinsic properties of BL Lacs and FSRQs do not give support to the picture of an evolutionary connection between the two classes. The difference of a factor of ~ 60 in the extended radio emission between $\langle z \rangle \sim 1.1$ and 0.6 would imply a very strong luminosity evolution, much stronger in fact than any other evolution observed in AGN (for example, optically selected quasars show roughly the same amount of evolution for $0 \lesssim z \lesssim 2.2$: Boyle *et al.* 1990). The same is true for the line luminosities: in this case, the difference is a factor of ~ 100 between $\langle z \rangle \sim 0.5$ and 0.2. Finally, and probably most importantly, the suggestion of VGC, that strong-lined objects change into weak-lined ones because the lines are swamped by a beamed component, does not apply to BL Lacs which have *intrinsically* weak lines, as shown in Section 4.

5.3 The beaming model and the differences between BL Lacs and FSRQs

Some of the observed differences between BL Lacs and FSRQs can be explained by the beaming hypothesis. In the following, I will use the formalism of Urry & Padovani (1991), where the total luminosity of a source is the sum of a jet luminosity and an unbeamed part, i.e. $L_T = L_j + L_u$. It is further assumed that the observed jet luminosity, which is δ^p times the intrinsic jet luminosity, with δ the Doppler factor, is a fraction f of the unbeamed luminosity. It follows that $L_T = (1+R)\,L_u$, with $R = f\delta^p$ the ratio between the beamed (jet) component and the unbeamed one. The main parameters of the model at radio frequencies for the two classes, taken from Urry *et al.* (1991) for BL Lacs and Padovani & Urry (1992) for FSRQs, are similar, as shown in Table 6. The range of Lorentz factors derived from the models is basically the same, as is the ratio between the intrinsic jet luminosity and the extended luminosity. This could suggest that similar physical processes are at work in the production of jets in radio sources of different powers. The distribution of Lorentz factors is more skewed towards low γs for BL Lacs, which seem also to be slightly more pointed towards the observer. The model parameters correctly predict a mean value for R which is larger for BL Lacs than for FSRQs. Deriving the mean value of δ^p in terms of $\langle \gamma \rangle$ and $\langle \cos\theta \rangle$, itself a function of θ_c, the critical angle separating the beamed populations from the parents, and given the definition of R, one obtains a predicted value of $\log[\langle R \rangle(\mathrm{BL})/\langle R \rangle(\mathrm{FS})] = 0.8$, to be compared with an observed value of 0.7 ± 0.3. Despite the smaller value of R, the mean extended luminosity of FSRQs is so much larger than that of BL Lacs that $L_r = (1+R)\,L_{\mathrm{ext}}$ is larger for the former class. Therefore, in a flux-limited sample, FSRQs are observed at higher redshifts.

Table 6. Radio-band beaming model parameters for FSRQs and BL Lacs.

Class	γ_1	γ_2	$\langle\gamma\rangle$	G	f	θ_c
BL Lacs	5	36	7	−4.0	1.0×10^{-2}	10°
FSRQs	5	40	11	−2.3	0.5×10^{-2}	14°

G is the slope of the Lorentz factor distribution, i.e. $n(\gamma) \propto \gamma^G$, extending between γ_1 and γ_2, with mean value $\langle\gamma\rangle$, f is the ratio between the intrinsic jet luminosity and the extended, unbeamed luminosity, while θ_c is the critical angle separating the beamed class from the parent population.

The observed mean effective spectral indices for the two classes depend on the relative ratios of beamed to unbeamed luminosity in the bands under consideration and the effective spectral indices of the parent populations. Considering in fact two frequencies ν_1 and ν_2, it can be shown that

$$\alpha_{12}(\mathrm{BL}) - \alpha_{12}(\mathrm{FS}) = \alpha_{12}(\mathrm{FR\,Is}) - \alpha_{12}(\mathrm{FR\,IIs}) + \frac{1}{\log(\nu_2/\nu_1)} \left[\log\left\{\frac{[1+R_1(\mathrm{BL})]}{[1+R_1(\mathrm{FS})]}\right\} - \log\left\{\frac{[1+R_2(\mathrm{BL})]}{[1+R_2(\mathrm{FS})]}\right\}\right], \qquad (3)$$

with obvious meaning of the symbols.

The values of the ratios of the jet to unbeamed luminosity are known only for the radio band, so that a further test of the beaming model, on which equation (3) is based, cannot be done at present. One can use equation (3), however, to get a rough estimate of these ratios in other bands under the beaming hypothesis, starting from the observed effective indices and the mean R values in the radio. Note that equation (3) assumes that the unbeamed luminosity observed in BL Lacs and FSRQs corresponds to the luminosity observed in FR Is and FR IIs respectively. This is unlikely to be the case in the optical band, where there is also a thermal contribution from the galaxy. Let us then consider the X-ray band and suppose that the X-ray luminosity in radio galaxies represents the unbeamed component in BL Lacs and FSRQs. Using the observed values of α_{rx}, given in Table 2 for the supposedly beamed populations, in Paper I for the FR Is, and derived from the sample of Fabbiano *et al.* (1984) for the FR IIs ($\alpha_{\mathrm{rx}} = 0.95 \pm 0.02$), one obtains that $R_X(\mathrm{BL}) \gtrsim 15\, R_x(\mathrm{FS})$, i.e. the X-ray jet is more dominant in BL Lacs than in FSRQs. This number is uncertain (at least by a factor of 2–3), due to the propagation of the errors in the various quantities entering its derivation, but this difference between BL Lacs and FSRQs could explain the different X-ray spectral slopes. Note that $R_x(\mathrm{BL}) > R_x(\mathrm{FS})$ would not necessarily mean that the X-ray band in BL Lacs is more beamed than in FSRQs, since we have no information about the relative values of f in the X-rays.

The only significant luminosity correlation I have found is the one between radio and optical luminosities for the HPQ subsample of FSRQs. As discussed in Section 3, this could be explained by the presence of an optical component, dominating in HPQs, connected to the radio emission. In Paper I, I found a similar result for BL Lacs, namely a connection between the radio and optical bands only. This could be another suggestion that similar processes are at work in the two classes. One could speculate, drawing a parallel with what seems to be the case in BL Lacs (see Paper I) and assuming that the X-rays are in effect more beamed in BL Lacs than in FSRQs, that FSRQs are also characterized by higher Lorentz factors in the radio and optical bands as compared to the X-rays.

6 CONCLUSIONS

I have studied the differences/similarities between BL Lacs and flat-spectrum radio quasars by analysing the properties of two complete samples. The main objective was to see if there is any relationship between the two classes, in particular either evolutionary, as suggested by Vagnetti *et al.* (1991), or through gravitational microlensing, as proposed by Ostriker & Vietri (1985, 1990). The main conclusions are the following.

(i) *Microlensing cannot be the dominant phenomenon which determines the properties of BL Lacs.* The data rule out optical amplification factors $\gtrsim 10$ and would be consistent with values around 2–3, too low to swamp the emission lines of quasars.

(ii) An evolutionary connection between BL Lacs and flat-spectrum radio quasars is not supported by the available data, although larger complete samples are needed for a definite test. The spectral continuity suggested by Vagnetti *et al.* (1991) can be explained by small statistics and BL Lac contamination of the quasar samples they used. Moreover, a direct comparison seems to show that, in the limited range of overlap, the two local luminosity functions are different by about a factor of 2, although the significance of this difference depends somewhat on the evolutionary properties of the two classes. Roughly comparable number densities for the two classes in the observed range are in any case predicted by the beaming models.

(iii) The distribution of extended radio luminosities of BL Lacs is indistinguishable from that of Fanaroff–Riley I radio galaxies, while that of flat-spectrum radio quasars is not significantly different from that of Fanaroff–Riley II radio galaxies. The extended radio luminosities and line luminosities of the two classes are significantly different, which implies that the parent populations in the beaming hypothesis are different. BL Lacs are *not* quasars with emission lines swamped by the optical continuum: their small equivalent widths are due to the lines being intrinsically weak. There is no evidence in the data for the existence of two separate low- and high-redshift populations of BL Lacs.

(iv) The beaming model parameters for the two classes are not very different, with BL Lacs having on average smaller values of the Lorentz factor. Some of the observed differences between BL Lacs and flat-spectrum radio quasars are explained by the model, while others need more data for the predictions of the model to be tested.

The main conclusion is that the available observational data favour a scenario in which BL Lacs and flat-spectrum radio quasars are examples of similar relativistic phenomena in radio galaxies of different powers, with no direct connection between the two classes.

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