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SPECTRAL PROPERTIES OF BLAZARS. I. OBJECTS OBSERVED IN THE FAR-ULTRAVIOLET

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ABSTRACT

All blazars (33 objects) observed with *IUE* are considered. For each object, besides the UV flux and slope, radio, IR, optical, and X-ray data are reported. The average energy distribution steepens continuously up to 5×10^{14} Hz. The mean change in slope from IR to UV frequencies is $\Delta\alpha = 0.49 \pm 0.14$. The X-ray flux is on average compatible with an extrapolation from the UV spectrum. The spectral index in the IR band correlates with the ratio of radio to UV flux; the spectral index in the UV band correlates with the ratio of UV to X-ray flux. The spectra of X-ray selected blazars are flatter than average in all bands. The spectral properties of blazars are discussed in terms of the present theoretical models and compared with those of quasars. We argue that the absence of emission lines in BL Lac objects should not, in general, be due to the strength of the optical continuum.

Subject headings: BL Lacertae objects — quasars — radiation mechanisms — spectrophotometry — ultraviolet: spectra — X-rays: sources

I. INTRODUCTION

BL Lac objects, optically violently variables (OVVs), and highly polarized quasars (HPQs) are usually grouped together under the denomination of blazars, which eliminates the somewhat ambiguous issue of the strength of the emission lines as a classification criterion and favors variability and polarization as main distinctive characteristics. However, the problem of whether the different phenomenologies can be understood within a single class of models or require different astrophysical scenarios remains open. In this perspective a detailed study of the energy distribution of blazars is of great importance. In particular, it seems of interest to establish which are the distinctive spectral properties of the class and of possible subclasses beyond those of single objects.

In this paper we address the question considering all the blazars observed in the far-ultraviolet. In fact, the ultraviolet band has, with respect to the optical, the important advantage of a lesser contamination by starlight. This enables a reliable determination of the nonthermal continuum. At the same time the spectra obtained with the *International Ultraviolet Explorer*, though limited to relatively bright sources, $m_v < 16$, constitute a body of data sufficiently large (33 objects) and homogeneous as to allow a systematic analysis.

For most of these objects, spectral information from radio to X-ray frequencies is available, and in many cases simultaneous observations in different frequency domains have been obtained. Thus, detailed spectral data can be collected for the whole sample, i.e., spectral indices in the IR, optical, and UV bands as well as composite indices, derived from the ratios of fluxes at different frequencies. Analogous work was done by Cruz Gonzales and Huchra (1984), starting from a different list of objects and ignoring ultraviolet data.

A detailed description of the sample is given in § II. Most of the UV-observed blazars derive from the list of Angel and Stockman (1980). All six blazars above the completeness threshold (1.5 μJy at 5 keV) of the X-ray survey of Wood *et.al.* (1984), namely 0323+022, 0548−321, 1101−384, 1218+304, 1652+398, and 2155−304 have been observed in the ultraviolet. These will be called X-ray selected in that they have been (four objects) or could have been discovered from X-ray observations. They will be shown to form a well-defined subgroup from the point of view of their spectral properties. This point, which seems to have important implications, is further discussed in Maraschi *et al.* (1986*a*, hereafter Paper II), where a much larger group of X-ray observed blazars (75 objects) is considered.

The results of the analysis of the collected data are presented in § III. In § IV the derived spectral properties are discussed with respect to theoretical models and compared with those of quasars.

Partial accounts of this investigation were given in Maraschi, Tanzi, and Treves (1983, 1984) and Treves *et al.* (1986).

II. BLAZARS OBSERVED IN THE FAR-ULTRAVIOLET

The *IUE* archives up to 1983 December were checked for observations of objects within the blazar lists of Angel and Stockman (1980), Biermann *et al.* (1981), and Schwartz and Ku (1983). Spectra were found, usually covering both wavelength ranges available on *IUE* (short-wavelength 1200–1950 Å, long-wavelength 2000–3000 Å), for 29 objects.

An analysis of the spectra sufficient for our scope, which is that of a uniform definition of spectral indices, was found in the literature for all objects except 0316+41 (NGC 1275),

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TABLE 1

OBSERVATIONAL DATA FOR ULTRAVIOLET-BRIGHT BLAZARS

Coordinates (1)	Name (2)	Comment[a] (3)	z (4)	Ref. (5)	F_r[b] (Jy) (6)	Ref. (7)	F_K[c] (mJy) (8)	Ref. (9)	α_{IR} (10)	Ref. (11)	F_V[d] (mJy) (12)	Ref. (13)	α_{opt} (14)	Ref. (15)	F_{UV}[e] (mJy) (16)	Ref. (17)	α_{UV} (18)	Ref. (19)	F_X[f] (μJy) (20)	Ref. (21)	A_V (22)	Ref. (23)
0215+015......	...		>1.686	1	0.4	2	14.7	3	0.96	3	0.3	4	1.8	4	0.7	5	...		0.052	6	...	
0219+428......	3C 66A		0.444[g]	7	0.52	8	13.1	9	0.7	9	3.6	9	1.3	9	1.3	10	1.6	10	0.08	10	0.15	9
0235+164......	AO		>0.852	2	1.95	8	20	11	1.7	3	6.6	12	2.8	12	0.1	13	...		0.17	14	0.1	15
0316+41.......	NGC 1275	E	0.0172	2	30	2	80	16	...		16.2	17	...		7	18	1.6	19	10	20	0.6	21
0323+022......	PKS	X	0.147	22	0.04	23	...		...		0.92	23	...		0.48	24	1.5	24	2.7	23	...	
0521−365.....	PKS		0.0554	2	9.3	25	9	26	1.5	26	1	26	1.5	26	0.32	26	1.5	26	0.44	6	...	
0537−441......	PKS		0.894	27	4	28	10	3	1.21	3	1.6	29	1.6	29	0.8	30	1.5	30	0.15	30	0.2	30
0548−322......	PKS	X	0.069	2	0.23	11	6.5	11	0.3	31	1.7	31	0.3	31	0.4	32	0.8	32	2.15	32	0.1	31
0617+71.......	...		...		0.65	33	...		...		2.4	33	...		0.17	19	1	19	0.11	33	...	
0735+178......	PKS		>0.424	2	2.1	34	28.5	34	0.9	34	6.9	34	1.27	34	2.8	34	1.4	34	0.17	34	0.15	34
0736+017......	PKS	E	0.191	2	1.8	35	6.1	36	1.4	36	1.9	12	1.1	37	0.63	19	1.0	19	0.32	38	0.3	19
0754+10.......	OI 090.4		...		0.81	9	28	9	1.2	9	4	9	1.1	9	1	9	2.1	9	0.085	39	0.1	9
0829+046......	OJ 049		...		0.47	8	12.7	11	1.1	11	1.4	2	2.2	40	1.75	19	2.1	19	0.095	39	...	
0851+202......	OJ 287		0.306[g]	7	2.2	41	12.6	41	0.75	41	4	41	1	41	1.1	41	1.6	41	0.65	41	0.07	41
0912+297......	OK 222		...		0.3	42	7.4	42	0.6	42	2.7	42	0.9	42	1	42	1.5	42	...		...	
1101+384......	Mrk 421	X	0.03	2	0.56	8	63	43	0.92	43	17.8	43	0.9	43	6	44	1	44	4.3	45	...	
1133+704......	Mrk 180		0.046	7	0.2	2	...		...		2.7	46	0.7	46	0.6	46	0.7	46	2.82	46	...	
1156+295......	Ton 599	E	0.729	2	1.4	47	24.1	47	1.25	47	5.07	47	1.5	47	0.81	47	1.7	47	0.075	48	...	
1215+303......	ON 325		...		0.47	49	10.9	49	0.7	49	3.4	49	2	49	1.0	49	1	49	0.5	49	...	
1218+304......	2A	X	0.13[g]	50	0.05	11	46	51	0.3	50	1.2	51	0.9	50	0.6	52	0.64	52	3.42	45	...	
1219+285......	ON 231		0.102	53	1.9	42	18.6	42	1	42	2.9	42	1.6	42	0.75	42	1.6	42	0.21	42	...	
1308+32.......	B2	E	0.996	7	2.62	8	12	11	0.9	54	1.7	54	1.5	54	0.5	19	0.7	19	0.14	39	...	
1418+54.......	OQ 530		...		1.15	49	10.6	49	1	49	2.4	49	1.8	49	053	49	1.83	49	0.076	55	...	
1514−24.......	ApLiB		0.049	2	2.42	8	16	16	0.85	56	2.9	57	1.5	57	1.9	19	1.7	19	0.22	6	0.16	57
1641+399......	3C 345	E	0.59	2	11.5	58	15.9	58	1.4	58	2.3	58	1.2	58	1.3	58	1.6	58	0.45	58	...	
1652+398......	Mrk 501	X	0.034	2	1.25	46	13.5	46	0.65	46	3.3	46	0.65	10	1.68	10	0.65	10	5.88	10	...	
1727+502......	IZ 187		0.055	2	0.21	59	2.5	59	0.87	59	1.22	59	0.87	59	0.33	59	1	59	1	59	0.08	59
1807+698......	3C 371		0.05	2	2	60	23	60	0.7	60	5.6	60	1.5	60	1.73	60	1.74	60	03	60	0.13	60
1845+797......	3C 390.3	E	0.056	2	0.4	61	4.5	16	...		2.7	62	1.0	62	1.1	62	1.0	62	3	63	0.45	62
2005−489......	PKS		...		1.5	64	...		...		30	64	1.5	64	6.3	64	1.5	64	8	64	...	
2155−304......	PKS	X	0.118	65	0.26	66	31.2	67	0.5	67	17.2	68	0.9	68	16	69	0.72	69	4	69	...	
2200+420......	BL Lac		0.069	9	3.27	8	90	11	1.5	11	5.9	79	2.3	71	1.5	72	3	70	0.53	6	1	71
2223−05.......	3C 446	E	1.404	2	4	72	22	72	1.3	72	2.9	72	2	72	0.7	72	3	72	0.67	73	0.15	72

[a] E, strong emission-line sources; X, X-ray selected objects.
[b] Flux at 5 GHz.
[c] Flux at 2.2 μm.
[d] Flux in the V band.
[e] Flux at 2500 Å.
[f] Flux at 2 keV.
[g] Based on a single line or on the size of the associated nebulosity.

REFERENCES.—(1) Pettini *et al.* 1983. (2) Angel and Stockman 1980. (3) Allen *et al.* 1982. (4) Blades *et al.* 1982. (5) Blades *et al.* 1985. (6) Schwartz and Ku 1983. (7) Miller *et al.* 1978. (8) Weiler and Johnston 1980. (9) Worrall *et al.* 1984*c*. (10) Maccagni *et al.* 1983. (11) Cruz-Gonzales and Huchra 1984. (12) Landau *et al.* 1983. (13) Snijders *et al.* 1982. (14) Owen *et al.* 1981. (15) Pica *et al.* 1980. (16) Heckman *et al.* 1983. (17) Véron 1979. (18) Briggs *et al.* 1982. (19) Our analysis. (20) Branduardi-Raymont *et al.* 1981. (21) Véron 1978. (22) Filippenko and Sargent 1985. (23) Doxsey *et al.* 1983. (24) Urry 1985. (25) Kuhr *et al.* 1981. (26) Danziger *et al.* 1983. (27) Peterson *et al.* 1976. (28) Komesaroff *et al.* 1984. (29) Tanzi *et al.* 1986. (30) Maraschi *et al.* 1985. (31) Weistrop *et al.* 1979. (32) Urry *et al.* 1982. (33) Biermann *et al.* 1981. (34) Bregman *et al.* 1984. (35) Perley 1982. (36) Gear *et al.* 1985. (37) Ennis *et al.* 1982. (38) Ku *et al.* 1982. (39) Madejski and Schwartz 1983. (40) Kinman 1976. (41) Worrall *et al.* 1982. (42) Worrall *et al.* 1986. (43) Maza *et al.* 1978. (44) Ulrich *et al.* 1984. (45) Schwartz *et al.* 1979. (46) Mufson *et al.* 1984. (47) Glassgold *et al.* 1983. (48) McHardy 1985. (49) Worrall *et al.* 1984*b*. (50) Weistrop *et al.* 1981. (51) Ledden *et al.* 1981. (52) Urry *et al.* 1984. (53) Weistrop *et al.* 1985. (54) O'Dell *et al.* 1978. (55) Pollock *et al* 1985. (56) Impey *et al.* 1982. (57) Westerlund *et al.* 1982. (58) Bergman *et al.* 1986*b*. (59) Bregman *et al.* 1982*a*. (60) Worrall *et al.* 1984*a*. (61) Miley *et al.* 1984. (62) Oke and Goodrich 1981. (63) Fabbiano *et al.* 1984. (64) Wall *et al.* 1986. (65) Bowyer *et al.* 1984. (66) Aller *et al.* 1982. (67) Glass 1981. (68) Miller and McAlister 1983. (69) Urry 1984. (70) Bregman *et al.* 1982*b*. (71) O'Dell *et al.* 1977. (72) Bregman *et al.* 1986*a*. (73) Garilli and Tagliaferri 1986.

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0716+71, 0736+017, 0829+046, 1308+32, and 1514−24. For the latter objects the archive spectra were analyzed with the procedure described in Maraschi *et al.* (1986*b*). Spectral indices were obtained by best-fitting the spectrum with a single power law in the combined short-wavelength and long-wavelength ranges whenever both were available. In two cases, 0215+015 and AO 0235+64, no reliable spectral index could be determined because of the weakness of the continuum.

Information on four recently observed sources, 0323+022, 0912+297, 1219+285, and 2005−489, is also included. Two of them, 0323+022 and 2005−489, were identified as BL Lac objects in 1984–1985.

Table 1 lists the UV-observed blazars in order of right ascension together with one of the catalog designations. X-ray selected objects are labeled with an X. Column (4) gives the redshifts. Those based either on a single line or on the size of the associated nebulosity are noted. Those based on absorption lines by presumably intergalactic matter are indicated with >. An E labels objects with relatively strong emission lines, adopting the classification criterion of Angel and Stockman (1980).

In column (6) the 5 GHz flux is reported, in Jy, choosing, in order of priority, (*a*) measurements simultaneous with those in other bands, (*b*) measurements made with the VLA, or (*c*) other available measurements.

In columns (8), (12), and (16) the infrared (2.2 μm), optical (5500 Å), and ultraviolet (2500 Å) fluxes are given in mJy, selecting, when available, measurements simultaneous to those in other bands. In the other cases preference was given to measurements obtained at epochs near to those of the ultraviolet and X-ray observations. The reported fluxes are dereddened with the extinction values reported in column (22). Spectral indices derived from separate power-law fits in each of the three bands are also reported (cols. [10], [14], and [18]). In the optical and IR range, spectral indices and fluxes corrected for the starlight contribution from the host galaxy were chosen, whenever available from the literature. In column (20) the 2 keV flux is given in μJy, as deduced in all cases, except 1156+295 and 1418+54, from observations with the *Einstein Observatory*. References are given for each entry.

III. AVERAGE SPECTRAL ENERGY DISTRIBUTION OF BLAZARS

The distributions of spectral indices in the IR, optical, and UV bands of the 30 blazars observed with *IUE* are shown in Figures 1*a*, 1*b*, and 1*c*, and the mean values are given in Table 2, together with the standard deviation of the mean. Composite spectral indices encompassing different frequency bands are also considered: α_{RU}, connecting the radio (5 GHz) and the UV bands (2500 Å); α_{UX}, connecting the UV (2500 Å) and X-ray (2 keV) bands; and α_{RX}, directly connecting the two extreme frequencies. The composite indices between frequencies ν_1 and ν_2 are defined in the usual way,

$$\alpha_{12} = -\log (F_1/F_2)/\log (\nu_1/\nu_2) .$$

Flux densities are reduced to the source's rest frame by the formula

$$F = F^{\rm obs}(1 + z)^{\alpha - 1} ,$$

where α is the spectral index in the appropriate band. For the radio and X-ray bands we took $\alpha_R = 0$ and $\alpha_X = 1$ respectively, while in the UV we used the values listed in Table 1, or the average value $\langle \alpha_{UV} \rangle = 1.4$ when the measurement was not available. When the redshift is unknown, we use for the *k*-correction the average for the total sample $\langle z \rangle = 0.4$.

The distributions of the broad-band indices are shown in Figures 2*a*, 2*b*, and 2*c*, and the corresponding mean values are given in Table 2.

From Figures 1 and 2 and Table 2 it appears that the overall spectrum of blazars steepens with increasing frequency up to 5×10^{14} Hz. A large change in slope occurs between radio and IR frequencies—compare, for instance, $\langle \alpha_{RU} \rangle = 0.53 \pm 0.02$ with $\langle \alpha_{IR} \rangle = 0.96 \pm 0.07$; however, more data at millimeter and submillimeter frequencies would be needed to better constrain the spectral shape in this frequency domain. The few available observations (Ennis, Neugebauer, and Werner 1982; Landau *et al.* 1983; Gear *et al* 1985) indicate that the change should occur between 3×10^{11} and 10^{13} Hz.

A further significant spectral steepening or "break" occurs on average between the IR and the UV bands with $\langle \alpha_{UV} - \alpha_{IR} \rangle = 0.49 \pm 0.14$. Above 5×10^{14} Hz the steepening is halted: the slopes of the optical and UV bands are comparable. Moreover, since $\langle \alpha_{UX} \rangle$ is consistent with $\langle \alpha_{UV} \rangle$, on average the X-ray flux is compatible with the extrapolation of the UV flux.

Our results compare well with those obtained by Cruz-Gonzales and Huchra (1984) for a group of 25 blazars, of which 17 are in common with ours; except for the optical spectral index, which is somewhat smaller than that given by them ($\alpha_{opt} = 1.89 \pm 0.15$). We believe that this results from the greater weight of the UV data in deconvolving the starlight component.

TABLE 2

MEAN SPECTRAL INDICES AND LUMINOSITIES

Parameter	All	X-Ray Selected	Radio-selected	Strong-Line Objects
α_{IR}	0.94 ± 0.07 (28)	0.51 ± 0.10 (6)	1.06 ± 0.06 (22)	1.25 ± 0.09 (5)
α_O	1.38 ± 0.10 (31)	0.83 ± 0.14 (6)	1.51 ± 0.10 (25)	1.42 ± 0.15 (6)
α_{UV}	1.43 ± 0.11 (31)	0.87 ± 0.12 (6)	1.56 ± 0.11 (25)	1.52 ± 0.28 (7)
α_{RU}	0.52 ± 0.02 (33)	0.39 ± 0.05 (6)	0.55 ± 0.02 (27)	0.59 ± 0.03 (7)
α_{UX}	1.29 ± 0.05 (32)	1.02 ± 0.09 (6)	1.35 ± 0.05 (26)	1.30 ± 0.08 (7)
α_{RX}	0.77 ± 0.02 (32)	0.59 ± 0.03 (6)	0.81 ± 0.02 (26)	0.82 ± 0.03 (7)
α_{UX}^{eff}	$1.11^{+0.05}_{-0.04}$ (32)	$0.94^{+0.06}_{-0.04}$ (6)	$1.19^{+0.06}_{-0.04}$ (26)	$1.19^{+0.11}_{-0.06}$ (7)
log L_R	33.03 ± 0.27 (26)	31.65 ± 0.11 (6)	33.44 ± 0.28 (20)	33.90 ± 0.52 (7)
log L_{UV}	30.16 ± 0.24 (26)	29.57 ± 0.31 (6)	30.34 ± 0.29 (20)	30.74 ± 0.52 (7)
log L_X	26.89 ± 0.17 (26)	26.91 ± 0.22 (6)	26.88 ± 0.22 (20)	27.34 ± 0.35 (7)

NOTE.—Parentheses enclose number of objects used for each entry; cgs units are adopted for monochromatic luminosities.

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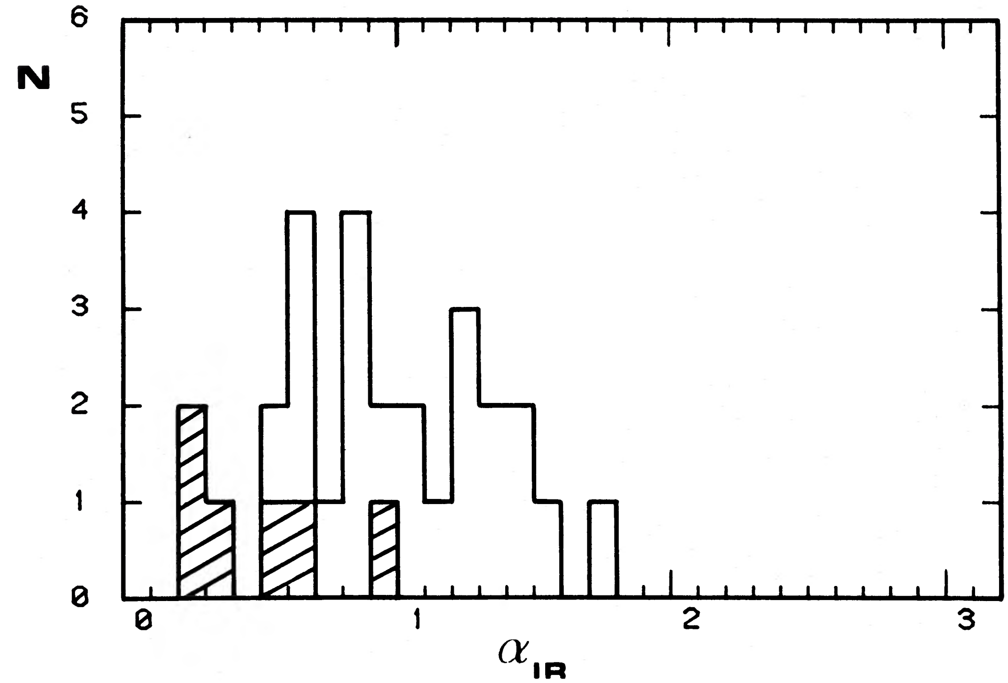

FIG. 1*a*

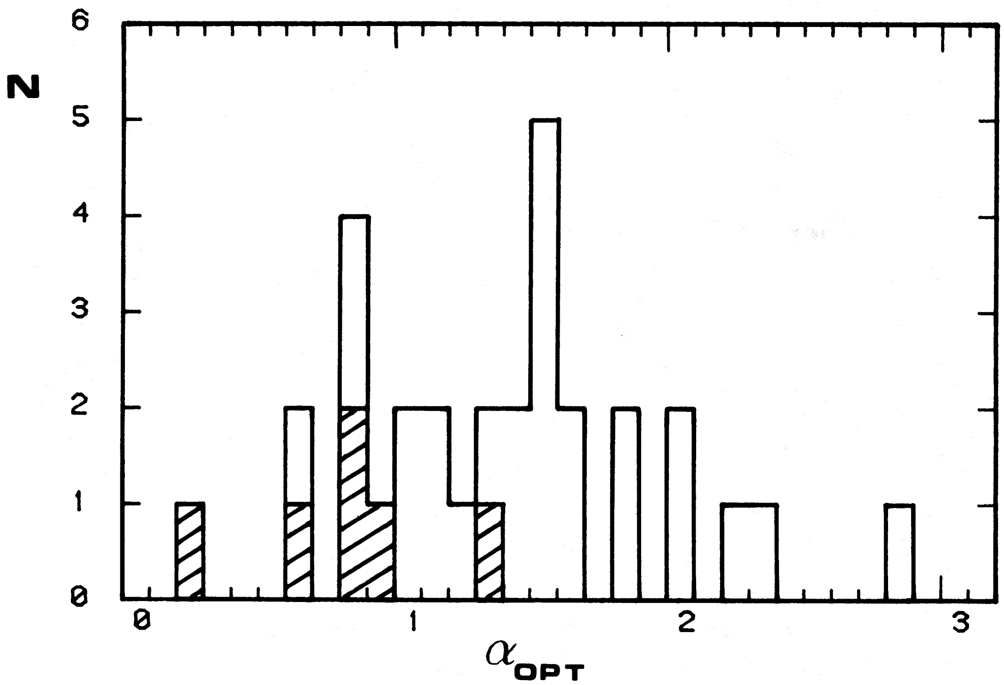

FIG. 1*b*

FIG. 1.—Distributions of spectral indices of UV-bright blazars. Shaded areas correspond to X-ray selected objects. (*a*) Infrared index α_{IR}, (*b*) optical index α_O, (*c*) ultraviolet index α_{UV}.

X-ray selected objects in the sense specified in § I are indicated by shaded areas in the distributions in Figures 1 and 2, and the mean spectral indices are given separately in Table 2 for this subsample and for the rest of the objects in the total group, which are mostly radio-selected. It is noteworthy that X-ray selected objects appear to have significantly flatter spectra than the whole group in each band.

The differences between the average spectral indices of the two subgroups of X-ray selected and otherwise selected objects are $\langle\Delta\alpha_{IR}\rangle = 0.55 \pm 0.1$ and $\langle\Delta\alpha_{UV}\rangle = 0.69 \pm 0.16$ in the IR and UV respectively. The steepening between IR and UV frequencies is present in both subgroups but tends to be less pronounced for the X-ray selected objects. The differences between the composite spectral indices of the two subgroups $\langle\Delta\alpha_{RU}\rangle = 0.16 \pm 0.05$ and $\langle\Delta\alpha_{UX}\rangle = 0.33 \pm 0.12$ are smaller than in the individual bands but still significant. The spectral

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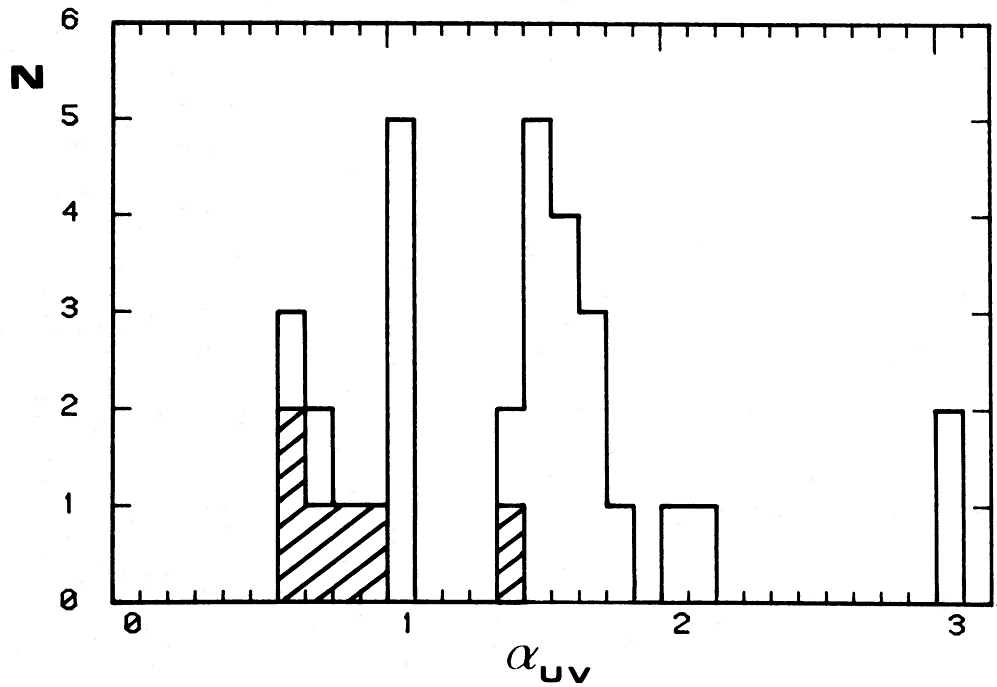

FIG. 1c

indices of X-ray selected objects are systematically lower than those of otherwise selected objects, over wide frequency ranges as well as in individual bands.

In Table 2 average spectral indices are also reported for the subclass of the seven objects with strong emission lines. No significant differences appear with respect to the averages for the whole sample or for the radio-selected group.

The above results indicate that the energy distribution of blazars shows a high degree of coherence, in the sense that the broad-band spectrum seems to be related to the spectral shape in individual bands. This statement can be quantified with a correlation analysis between the various spectral indices. The results of linear regressions are reported in Table 3. The correlations between α_{RU} and α_{IR}, between α_{UX} and α_{UV}, and between α_{UV} and α_{IR} are significant at the 10^{-3} chance probability level. No significant correlation appears between α_{RU} and α_{UV} or between α_{UX} and α_{IR}.

TABLE 3

RESULTS OF LINEAR CORRELATION ANALYSIS BETWEEN SPECTRAL INDICES[a]

y	x	N	m	q	r	P
α_{RU}	α_{IR}	28	0.24	0.30	0.666	$<10^{-3}$
α_{RU}	α_{UV}	31	0.04	0.46	0.186	$\sim 50\%$
α_{UX}	α_{IR}	27	0.26	1.08	0.355	$\sim 10\%$
α_{UX}	α_{UV}	30	0.24	0.93	0.563	$<2 \times 10^{-3}$
α_{RU}	α_{UX}	32	−0.01	0.55	−0.26	$\sim 20\%$
α_O	α_{IR}	28	0.94	0.52	0.629	$<10^{-3}$
α_O	α_{UV}	29	0.56	0.51	0.715	$<10^{-3}$
α_{UV}	α_{IR}	26	0.99	0.58	0.549	$<5 \times 10^{-3}$

NOTE.—The linear correlation is obtained considering x as the independent variable and assuming a relation $y = mx + q$; N is the number of points, r is the correlation coefficient, and P is the chance probability.

IV. DISCUSSION

The results of § III can be summarized as follows. The spectral slope of blazars increases from radio to X-ray frequencies, the major changes occurring between the radio and IR frequencies and in the IR–UV range. The X-ray flux is, on average, consistent with an extrapolation from the UV. Moreover, there is a correlation between α_{RU} and α_{IR} and between α_{UV} and α_{UX}, in the sense that, if the spectrum is flat (steep) in a given band, it tends to be flat (steep) also in the broader band on the same side of the 5×10^{14} Hz break.

The overall shape of the blazar energy distribution from the radio to the X-ray band is extremely smooth, strongly suggesting a single emission mechanism, i.e., synchrotron radiation. In particular, the fact that the 2 keV flux lies on the extrapolation of the UV spectrum indicates that the contribution from inverse Compton scattering at 2 keV should be small. It is worth noting that also in this respect the spectral properties of X-ray selected and radio-selected objects appear to be different. The former tend to have $\alpha_{UX} \geq \alpha_{UV}$, while the latter have $\alpha_{UX} \lesssim \alpha_{UV}$, which suggests that the inverse Compton contribution may be more important in the radio-selected group.

It is widely accepted that the emission of blazars is associated with a stream of relativistic plasma, or jet (e.g., Begelman, Blandford, and Rees 1984). In these models the overall spectrum is determined by the energy spectrum of the electrons as well as by the variation of the physical quantities along the jet.

The spectral change from the radio to the IR region is convincingly ascribed to the transition from partially optically thick to thin synchrotron emission (Marscher 1977; Königl 1981).

The rather definite spectral break between the IR and UV bands indicated by the present analysis is of more ambiguous interpretation. The fact that the average value of the slope change is consistent with 0.5 would be most naturally inter-

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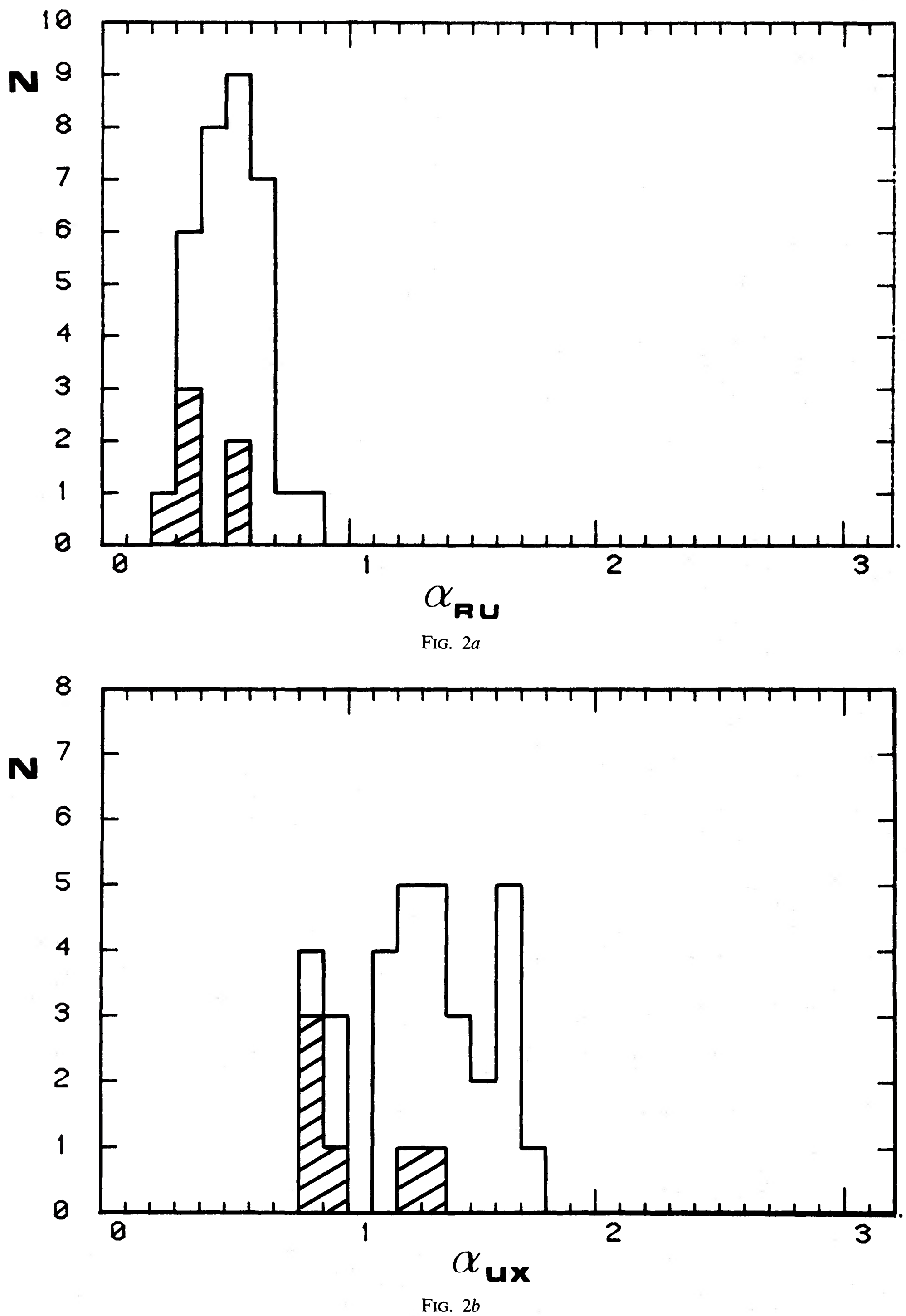

FIG. 2*a*

FIG. 2*b*

FIG. 2.—Distributions of composite spectral indices of UV-bright blazars. Shaded areas correspond to X-ray selected objects. (*a*) Radio (5 GHz) to ultraviolet (2500 Å) index α_{RU}, (*b*) ultraviolet (2500 Å) to X-ray (2 keV) index α_{UX}, (*c*) radio (5 GHz) to X-ray (2 keV) index α_{RX}.

preted as due to radiative losses of continuously injected electrons (Pacholczyk 1970; Cruz-Gonzales and Huchra 1984). This requires that the emission in the 10^{14}–10^{15} Hz interval derives from a single region of the jet (Königl 1981); otherwise the feature would be smeared off in a wider frequency range. On the other hand, the spectral change may also be explained as due to a variation of the maximum synchrotron frequency along the jet (Ghisellini, Maraschi, and Treves 1985). In this case the value of 0.5 is not a natural prediction of the model but can be reproduced by adjusting the parameters. According to the latter scheme, the overall spectrum is essentially determined by the spatial structure of the jet.

It is interesting to compare the spectral properties of blazars with those of QSOs. The latter are given in different papers with emphasis on specific bands. The most remarkable difference regards the shape of the optical–UV continuum. For our

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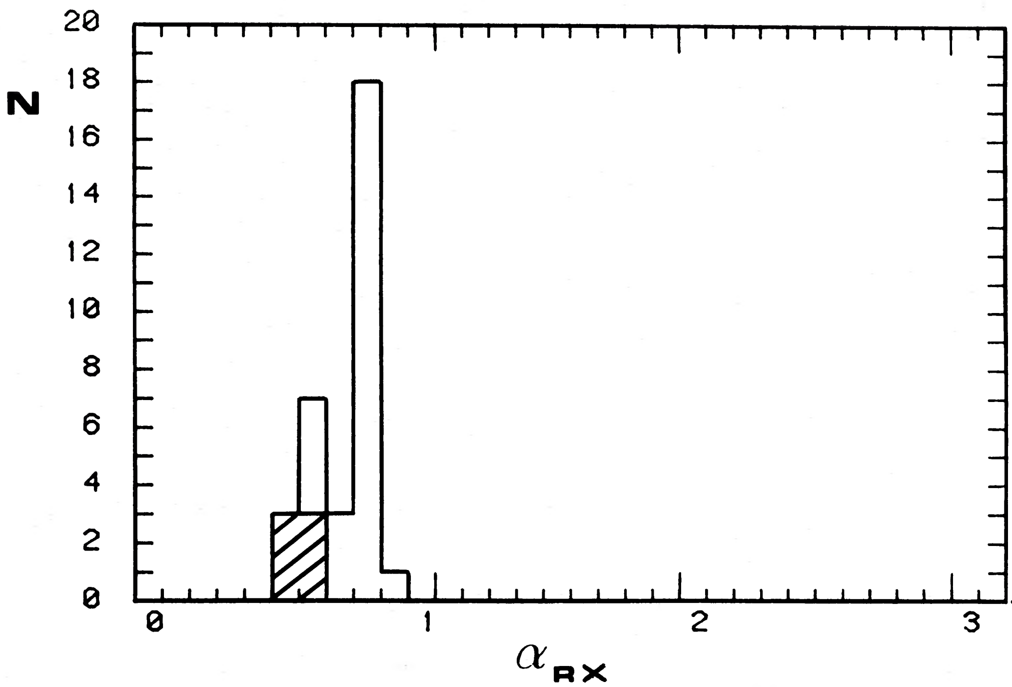

FIG. 2c

sample of 33 blazars we find $\langle \alpha_{UV} \rangle = 1.43 \pm 0.11$ (see Table 2), while Richstone and Schmidt (1980), in their study of 85 QSOs in the optical band, find a much harder spectral shape, $\langle \alpha_{2500} \rangle = 0.6 \pm 0.05$. This is in contrast with the situation in the IR, where we have for blazars $\langle \alpha_{IR} \rangle = 0.94 \pm 0.07$, while from Ennis, Neugebauer, and Werner (1982), for 14 quasars, we derive $\alpha_{IR} = 1.3 \pm 0.1$, i.e., quasar spectra are similar to or steeper than those of blazars. In the 10^{14}–10^{15} Hz range, quasar spectra are concave rather than convex, as is the case for blazars.

For a comparison of the UV to X-ray spectral indices, we refer to the paper of Zamorani *et al.* (1981), who considered a sample of QSOs distinguishing between radio-loud and radio-quiet objects. They define an effective spectral index α_{UX}^{eff}, using the average X-ray to optical flux ratio

$$\alpha_{UX}^{eff} = -\frac{\log \langle F_{2\,keV}/F_{2500} \rangle}{2.605} .$$

Computing the same quantity with the present data we find for our sample $\alpha_{UX}^{eff} = 1.1 \pm 0.05$, while Zamorani *et al.* (1981) give $\alpha_{UX}^{eff} = 1.27 \pm 0.03$ for radio-loud quasars and $\alpha_{UX}^{eff} = 1.46 \pm 0.06$ for radio-quiet quasars. It appears, therefore, that the overall energy distribution of quasars is marginally steeper in the infrared, substantially flatter in the optical, and again steeper in the UV to X-ray range, with respect to the much smoother energy distribution of blazars.

On the whole, the comparative picture of the spectral characteristics of the two classes suggests that the broad-band spectrum of quasars results from two components: one, connecting the IR to the X-rays, may be essentially similar to the average blazar continuum; the second should be strongly peaked at UV frequencies in order to explain the flattening of the continuum in the optical–UV range. It is natural to hypothesize that the latter component is thermal, possibly associated with an accretion disk, while the first one, by analogy with blazars, may be due to nonthermal processes. These arguments based on the average spectral shape support the kind of spectral deconvolutions discussed for specific objects by Malkan and Sargent (1982) and Malkan (1983).

The presence of a different emission component in the optical UV range in quasars could mask the properties of variability and polarization associated with the underlying nonthermal continuum which are apparent in blazars. In this picture, HPQs and OVVs should be those in which the nonthermal component, with steep spectral index, is stronger than the thermal one. This is consistent with the finding of Moore and Stockman (1984), that the average spectral index of their HPQs at 2500 Å is $\alpha_{2500} = 1.5$.

The question of whether blazars without emission lines (BL Lac objects) are those in which the nonthermal continuum is particularly strong, perhaps due to relativistic boosting, still remains. In this respect it is important to mention that in the present sample the average ultraviolet luminosity of objects with strong lines does not differ from that of the whole sample (see Table 2). (Only objects with known redshift are used in the computation of luminosities.) The fact that strong-line objects are not underluminous argues against the idea that the absence of lines in BL Lac objects is due to an unusually enhanced continuum, unless BL Lacs derive from a population intrinsically weaker than HPQs. In the latter case, however, the similarity of the UV luminosities would be coincidental.

The steepness of the optical–ultraviolet continuum seems to be a distinctive property of blazars independent of the presence or absence of emission lines. Since the two groups are indistinguishable also on the basis of the X-ray to UV flux ratio (α_{UX}), it is unlikely that the difference in line strength could be explained by a different ionizing continuum. We conclude that the difference between BL Lac objects and HPQs should be

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attributed to intrinsically different environments around the blazar nucleus.

X-ray selected blazars, which always turn out to be weak-line objects, appear to be anomalous, since their continuum is unusually flat compared to the average of the whole sample. This point motivates the extended analysis presented in Paper II, which leads us to propose a new scheme for interpreting the properties of different types of blazars.

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SPECTRAL PROPERTIES OF BLAZARS. II. AN X-RAY OBSERVED SAMPLE

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ABSTRACT

All the blazars observed in X-rays in various reference lists and all those belonging to X-ray selected samples are considered. It is found that X-ray selected objects have, on average, radio (5 GHz) to ultraviolet (2500 Å) and ultraviolet to X-ray (2 keV) spectral indices significantly flatter than radio-selected objects. The monochromatic luminosity distributions show that X-ray selected and radio-selected blazars have the same average X-ray luminosity, and that the X-ray selected ones are underluminous at ultraviolet and radio frequencies. It is argued that the objects with flat overall spectrum, which may be called radio-weak, discovered from X-ray searches are the dominant members of the blazar population in terms of space density, while radio-loud blazars with the same X-ray luminosity are a minority. The results are interpreted in the framework of a model where the X-ray emission is isotropic, while that at lower frequencies is relativistically beamed. Radio-loud blazars should be those with the beam pointing towards us.

Subject headings: BL Lacertae objects — quasars — radiation mechanisms — spectrophotometry — ultraviolet: spectra — X-rays: sources

I. INTRODUCTION

In the course of an investigation of the detailed spectral properties of blazars, based on a sample observed in the far ultraviolet (Ghisellini *et al.* 1986, hereafter Paper I), it was noticed that sources selected on the basis of their X-ray emission have substantially flatter spectra in the infrared, optical, and ultraviolet bands with respect to otherwise selected sources. The difference in shape appears to extend to the overall energy distribution, in that the composite spectral indices from radio to ultraviolet and from ultraviolet to X-ray frequencies are correlated, respectively, with those in the infrared and ultraviolet bands and are systematically lower for X-ray selected objects. These results were, however, based on only six X-ray selected objects and, in order to make further progress, it appeared of basic importance to extend the analysis to all the X-ray observed objects, relaxing the requirement of far-ultraviolet observations.

In this paper, we discuss a sample of 75 objects, 13 of which can be considered X-ray selected. The criteria adopted in the compilation of the sample are specified in § II. Essentially we consider all the blazars in a few classical reference lists which were observed in X-rays, and all those discovered through their X-ray emission. We use radio (5 GHz), ultraviolet (2500 Å), and X-ray (2 keV) fluxes to construct composite spectral indices and discuss the systematic differences between X-ray selected and otherwise selected objects (§ III). It is confirmed that X-ray selected objects have flatter overall spectra, and are therefore weaker radio emitters relative to their X-ray emission, than otherwise selected objects. No significant spectral differences are found between blazars with weak or strong emission lines. The former are usually defined as BL Lac objects, the latter as highly polarized quasars (HPQs) or optically violently variable quasars.

In § IV we present the monochromatic luminosity distributions at radio, optical, and X-ray frequencies for the 52 objects with known redshift. Here we find what we consider the most important result of the analysis, viz., that X-ray selected blazars have the same average X-ray luminosity as otherwise selected blazars and are underluminous at UV and radio frequencies. This point is crucial, since it implies that X-ray selection should not *a priori* introduce any bias toward flat- or steep-spectrum objects. On this basis it is argued that the radio-weak, X-ray selected BL Lac objects are, in terms of space density, the dominant members of the blazar population.

In § V the results are interpreted in the framework of synchrotron emission models involving relativistic plasma jets. A picture is proposed in which the bulk Lorentz factor Γ increases along the jet, and X-rays are produced near the jet nozzle i.e., quasi-isotropically, while the radio emission derives from regions further away along the jet, with higher values of Γ.

II. BLAZARS OBSERVED IN X-RAYS

Since the class of blazars is not unambiguously defined, we have tried to avoid introducing our own personal prejudices by referring to a few published source lists. The main one is that of the review of Angel and Stockman (1980), which was the first to adopt systematically the blazar classification. We also considered the confirmed HPQs from the survey of Moore and Stockman (1984), excluding the radio-quiet, broad absorption

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line QSO 2225−055, whose polarization is likely to be of different origin. Of the resulting 63 objects, 55 were observed with the *Einstein Observatory* and two with the *EXOSAT* observatory. For 53 of them published results were found, 50 fluxes and three upper limits. For the remaining four objects we were unable to find information, but this uncertainty should not greatly affect our conclusions, due to the small number of objects involved. We treated as reference lists also two X-ray surveys, that of Schwartz and Ku (1983) and that of Biermann *et al.* (1981), and derived nine and five objects respectively. In both cases the authors report a detection rate of 100%. We are therefore confident that X-ray weak objects have not been accidentally neglected.

As far as we know, the only X-ray observed blazars not included in the group defined above are those which appear *only* in the list of Weiler and Johnston (1980). Of these, 13 were observed with *Einstein*, but only for two have we found published fluxes. Due to the large fraction of unknown results we did not include objects from the latter list in our sample.

To the known blazars with sufficient X-ray information we add all the blazars discovered recently from optical identification of X-ray sources. Two of them, PKS 0548−322 and PKS 2155−304, already appear in Angel and Stockman (1980); a third one, 2A 1218+304, appears in Schwartz and Ku (1983). Eight more are added to the sample. They comprise H0323+022, recognized as a BL Lac object by Feigelson *et al.* (1986), four objects discovered in the *Einstein* Medium Sensitivity Survey of Maccacaro *et al.* (1984), and three objects serendipitously discovered by Chanan *et al.* (1982) and Ulmer *et al.* (1983). The entire set of blazars thus assembled comprises 75 objects. It includes 31 of the 33 objects observed in the far-ultraviolet with *IUE* and discussed in Paper I.

We will consider as X-ray selected (XS) not only the sources which were actually discovered from X-ray observations, but also those which appear above the completeness limit in the *HEAO 1* A-1 survey (Wood *et al.* 1984). These are the six objects considered XS in Paper I. Four of them were actually X-ray discovered. The XS group thus contains in all 13 objects.

The other 62 objects of the list were not selected on the basis of their X-ray emission. They all derive from radio surveys except for Mrk 180, I Zw 187, and NGC 1275, which were picked up from optical samples. In the following, we refer to all these objects as otherwise selected, meaning at wavelengths other than X-rays, or, for brevity, as radio-selected (RS), since this is appropriate for 59 of 62 objects.

It is clear that neither the whole group nor the subgroups of XS or RS objects constitute complete samples.

A further distinction between the objects of the entire group is the strength of the emission lines. Those which are reported to have strong emission lines in the Angel and Stockman (1980) catalog and all those deriving from the quasar survey of Moore and Stockman (1984) are considered here as strong-line objects.

III. SPECTRAL PROPERTIES

For the 44 objects not included in Paper I, the relevant information is given here in Table 1 with compilation criteria similar to those adopted for Table 1 of Paper I. Columns (1) and (2) give the coordinate designation and name of the objects. The letter X in column (3) indicates that the object belongs to the X-ray selected group, and the letter E that it has strong emission lines. Column (4) gives the redshift when available.

The flux densities at 5 GHz, at 5500 Å (*V* band), and at 2 keV (in three cases this is an upper limit) are reported in columns (6), (8), and (10). References are given for each entry. Preference was given to measurements simultaneous or close in time to the X-ray observations. In the radio band, VLA measurements were chosen whenever available. In the optical band, values corrected for starlight contribution and for extinction were preferentially taken. The X-ray data derive in all cases from *Einstein* observations.

For uniformity with Paper I and other papers (e.g., Zamorani *et al.* 1981), we use the flux at 2500 Å in the definition of composite spectral indices. This is obtained extrapolating the value measured in the visual band with the average spectral index of blazars in the optical–ultraviolet band derived in Paper I, $\langle \alpha_{UV} \rangle = 1.4$.

Composite spectral indices connecting the radio (5 GHz) and the UV bands (2500 Å), α_{RU}; the UV (2500 Å) and the X-ray (2 keV) bands, α_{UX}; and directly the two extreme frequencies, α_{RX}, are defined as usual (e.g., Paper I). For reducing monochromatic fluxes to the source's rest frame, the average redshift of the whole sample is used, $\langle z \rangle = 0.6$, when the actual redshift is unknown. For the same purpose the spectral indices adopted in the radio, ultraviolet, and X-ray bands are $\alpha_R = 0$, $\alpha_{UV} = 1.4$, and $\alpha_X = 1$.

The observed distributions of the broad-band indices for the entire sample comprising the objects discussed in Paper I are shown in Figure 1, where shaded areas correspond to XS objects. The mean values, neglecting upper limits, are given in Table 2 for the whole group, and separately for the sugroups of XS and RS objects and for the subgroup of strong emission line (E) objects. We have also computed the probability distributions and average values of the spectral indices, taking into account the three upper limits in the way developed by Avni *et al.* (1980). We find that the averages computed in this way do not differ from those of the observed distribution within the errors, and therefore we neglect upper limits in the following.

It clearly appears from both Figure 1 and Table 2 that XS blazars have significantly lower spectral indices than the rest of the sample in the three considered spectral ranges. This confirms for a wider sample the result obtained in Paper I and noted in somewhat different forms by Chanan *et al.* (1982), Stocke *et al.* (1985), and Ledden and O'Dell (1985). The first two papers remark on the radio weakness of XS objects, while the latter choose to define them rather as X-ray strong. In Paper I we showed that the shape of the overall energy distribution is also related to the flatness of the spectrum in the IR–UV range.

It is remarkable that XS objects never have strong emission lines. The average spectral indices of strong emission line objects are larger than those of XS blazars and indistinguishable from those of RS blazars.

The role of selection effects in producing the observed distributions is obviously important: since selected objects are those which are brighter in the selection band, it is expected that radio and X-ray selection may sample different portions of the intrinsic α_{RX} distribution of the blazar population. Nevertheless, the above results contain significant information regarding the original population. For instance, there is no *a priori* reason why radio-bright objects should never have flat overall spectra leading to high X-ray fluxes. The rareness of such objects must be a property of the blazar population. These points are discussed further in § IV on the basis of luminosity distributions.

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TABLE 1

RELEVANT DATA FOR THE X-RAY OBSERVED BLAZARS[a]

Coordinates (1)	Name (2)	Comment[b] (3)	z (4)	Reference (5)	F_R[c] (Jy) (6)	Reference (7)	F_V[d] (mJy) (8)	Reference (9)	F_X[e] (μJy) (10)	Reference (11)
0048−097	OB−081	...	...		0.85	1	0.88	2	0.033	3
0106+013	PKS	E	2.107	4	2.4	5	0.169	6	0.109	7
0109+224	...	...	...		0.45	8	2.42	9	0.125	10
0212+73	...	...	...		2.4	11	0.096	11	0.114	12
0229+341	3C 68.1	E	1.238	13	0.83	14	0.0363	15	<0.025	16
0317+183	...	X	0.19	17	0.012	18	0.198	18	0.57	18
0336−019	CTA 26	E	0.852	6	2.6	14	0.17	15	0.06	10
0338−214	PKS		0.048	19	0.94	19	2.2	20	0.066	21
0403−132	PKS	E	0.571	9	2.8	9	0.505	9	0.148	22
0141+009	...	X	...		0.083	23	1.05	23	1.2	23
0420−014	PKS	E	0.915	9	1.8	9	0.242	9	0.26	7
0422+004	OF 038		...		1.09	1	0.607	1	0.216	10
0454−234	PKS		0.89	24	2.06	5	0.242	20	0.055	21
0454+84	...		...		1.25	11	0.242	11	0.026	11
0458−020	...	E	2.286	6	1.7	5	0.17	6	0.02	25
0528−250	PKS	E	2.76	6	0.94	20	0.183	26	0.081	26
0808+019	...		...		0.66	1	0.96	1	0.18	16
0818−128	OJ 131		...		0.68	1	1.52	1	<0.035	16
0906+015	PKS	E	1.018	6	1.04	5	0.383	6	0.109	7
0906+430	3C 216	E	0.670	6	1.8	5	0.156	6	0.045	16
1147+245	...		...		0.86	1	0.96	1	0.04	16
1207.9+394.........	...	X	0.59	27	0.0061	27	0.086	27	0.097	27
1235+631	...	X	0.297	17	0.007	1	0.14	27	0.116	27
1253−055	3C 279	E	0.538	9	16	9	0.319	9	0.7	28
1400+162	OQ 100		0.244	9	0.16	1	0.505	2	0.05	29
1402+0416	...	X	0.21	30	0.021	27	0.554	27	0.075	27
1408+020	...	X	...		0.001	31	0.105	31	0.071	31
1413+135	PKS		0.26	26	1.23	20	0.038	20	0.033	26
1514+197	...		...		0.5	1	0.61	1	<0.017	29
1522+155	MC 3	E	0.628	9	0.6[f]	14	0.461	9	0.022	6
1538+149	4C 14.60		...		1.14	1	0.483	2	0.075	29
1704+6077	...	X	...		0.004	31	0.066	31	0.0296	31
1749+096	...		...		1.47	1	0.73	5	0.18	16
1803+78	...		...		2.3	11	0.607	11	0.076	11
1921−293	OV 236		0.3525	21	5.05	20	0.383	20	0.285	26
2007+77	...		...		1.5	11	0.607	11	0.053	11
2131−021	4C 2.81		0.056	21	2.12	5	0.127	20	0.054	26
2201+044	4C 04.77		0.028	21	0.3	1	3.19	2	0.165	26
2201+171	...	E	1.08	21	0.7	9	0.116	9	0.051	26
2230+114	CTA 102	E	1.037	6	3.5	9	0.461	9	0.3	21
2234+282	B2	E	0.795	6	1.06	5	0.0096	6	0.03	6
2251+158	3C 454.4	E	0.859	6	10.2	20	1.39	9	0.282	26
2254+074	OY 091		...		0.52	1	1.05	2	0.049	29
2345−167	PKS	E	0.6	9	3.6	9	0.242	9	0.092	7

[a] Those included in Paper I are omitted here.

[b] X, X-ray selected objects; E, strong emission-line sources.

[c] Flux at 5 GHz.

[d] Flux in the V band.

[e] Flux at 2 keV.

[f] Extrapolation from 408 MHz ($\alpha_R = 0$).

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A linear regression analysis shows that α_{RX} is strongly correlated with α_{RU} and α_{UX} for the whole sample (10^{-3} chance probability), for the RS subgroup (2×10^{-3} chance probability) and, with lower significance, for the XS group as well (5×10^{-2} chance probability). Similar results were obtained by Ledden and O'Dell (1985) on the basis of an independent compilation of blazar data. On the other hand, no correlation between α_{UX} and α_{RU} appears for the whole group, while for the two subgroups (XS, RS) separately a correlation of negative sign is indicated. In Table 3 the parameters of the linear regressions and the correlation coefficients are given for the various cases. Since there is an algebraic relation between the three indices, and the sensitivity of radio and X-ray surveys allows only a small interval in α_{RX} to be sampled, selection effects enter into these correlations in a very complicated way. We will not attempt to discuss them further.

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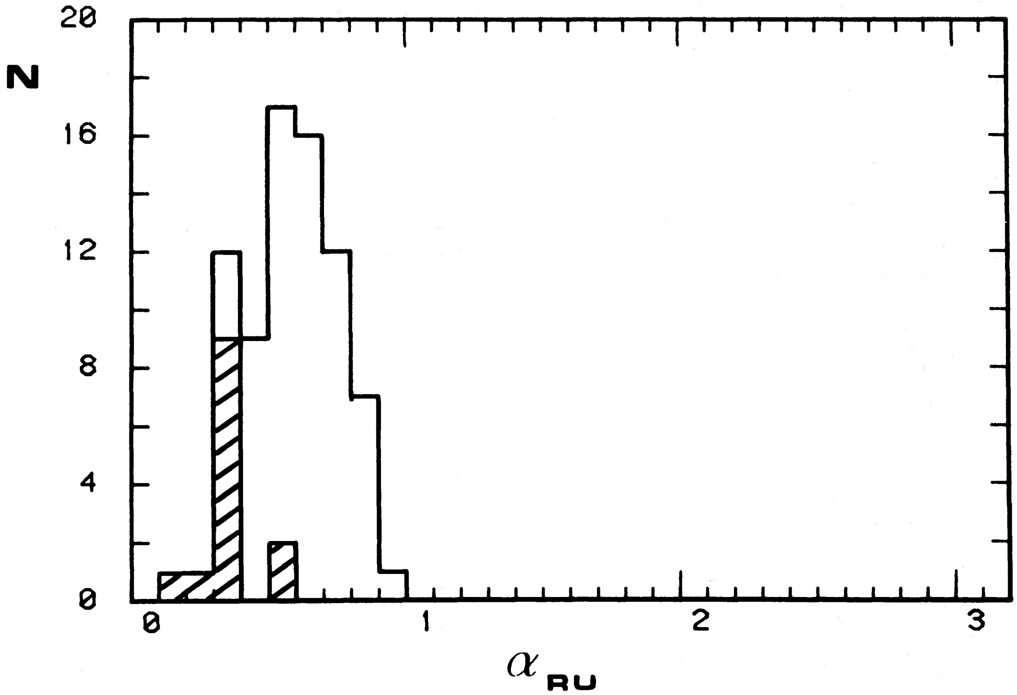

FIG. 1*a*

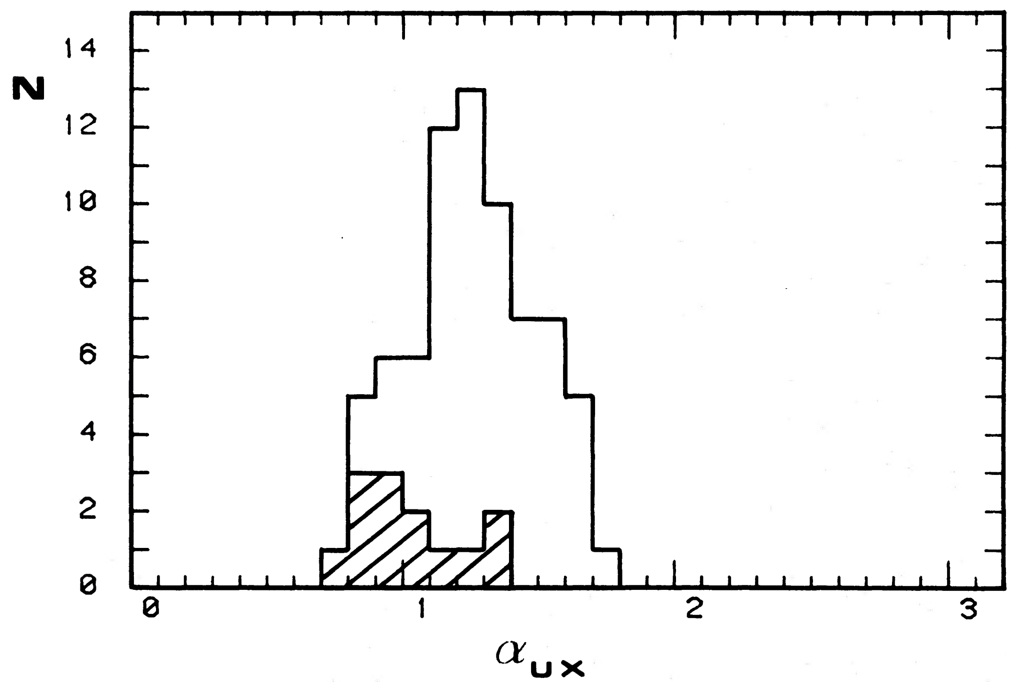

FIG. 1*b*

FIG. 1.—Distributions of composite spectral indices of all X-ray observed blazars. Shaded areas correspond to X-ray selected objects. (*a*) Radio (5 GHz) to ultraviolet (2500 Å) index α_{RV}, (*b*) ultraviolet (2500 Å) to X-ray (2 keV) index α_{VX}, (*c*) radio (5 GHz) to X-ray (2 keV) index α_{RX}.

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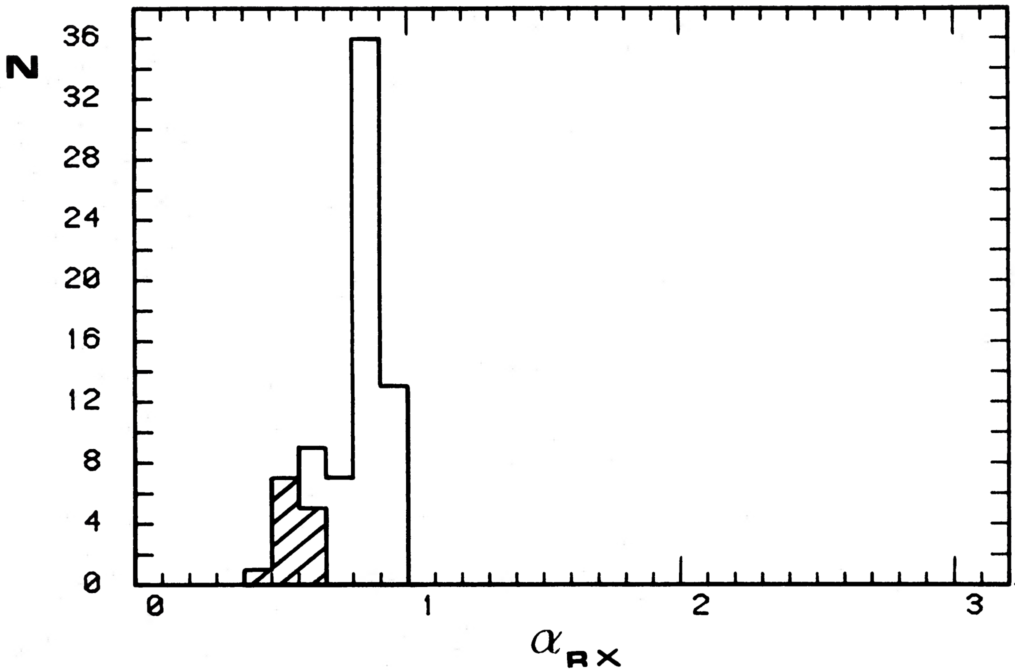

FIG. 1c

TABLE 2

MEAN SPECTRAL INDICES AND LUMINOSITIES

Parameter	All	X-ray Selected	Radio-selected	Strong-Line Objects
α_{RU}	0.59 ± 0.02 (75)	0.37 ± 0.03 (13)	0.63 ± 0.02 (62)	0.69 ± 0.02 (22)
α_{UX}	1.25 ± 0.03 (72)	1.03 ± 0.05 (13)	1.30 ± 0.03 (59)	1.23 ± 0.04 (21)
α_{RX}	0.80 ± 0.01 (72)	0.59 ± 0.02 (13)	0.85 ± 0.01 (59)	0.86 ± 0.01 (21)
α_{UX}^{eff}	$1.11^{+0.03}_{-0.03}$ (72)	$0.96^{+0.04}_{-0.03}$ (13)	$1.18^{+0.04}_{-0.03}$ (59)	$1.14^{+0.07}_{-0.05}$ (21)
log L_R	33.44 ± 0.20 (53)	31.57 ± 0.09 (10)	33.87 ± 0.19 (43)	34.43 ± 0.19 (22)
log L_{UV}	30.19 ± 0.14 (53)	29.51 ± 0.19 (10)	30.35 ± 0.16 (43)	30.71 ± 0.18 (22)
log L_X	27.01 ± 0.13 (52)	26.85 ± 0.16 (10)	27.07 ± 0.16 (42)	27.54 ± 0.15 (21)

NOTE.—Parentheses enclose number of objects used for each entry; cgs units are adopted for monochromatic luminosities.

TABLE 3

RESULTS OF LINEAR CORRELATION ANALYSIS BETWEEN COMPOSITE SPECTRAL INDICES

y	x	N	m	q	r	P
			All			
α_{RU}.........	α_{UX}	72	−0.084	0.689	−0.119	~30%
α_{RX}.........	α_{UX}	72	+0.270	0.465	+0.497	$<10^{-3}$
α_{RX}.........	α_{RU}	72	+0.619	0.440	+0.803	$<10^{-3}$
			X-ray Selected			
α_{RU}.........	α_{UX}	13	−0.254	0.631	−0.504	~10%
α_{RX}.........	α_{UX}	13	+0.155	0.425	+0.466	~10
α_{RX}.........	α_{RU}	13	+0.348	0.457	+0.529	~5
			Radio-selected			
α_{RU}.........	α_{UX}	54	−0.368	1.11	−0.589	$<10^{-3}$
α_{RX}.........	α_{UX}	54	+0.078	0.748	+0.223	~10%
α_{RX}.........	α_{RU}	54	+0.367	0.617	+0.657	$<10^{-3}$

NOTE.—Linear correlation obtained considering x as the independent variable and assuming a relation $y = mx + q$; N is the number of points, r is the correlation coefficient, and P is the chance probability.

IV. LUMINOSITY DISTRIBUTIONS

The distribution of the available redshifts of the objects listed in Table 1 plus those of Paper I is shown in Figure 2. The deficiency of intermediate redshifts, $0.1 < z < 0.4$, may be due to observational difficulties either in finding objects or in determining redshifts in this range, in the absence of strong emission lines. The XS objects have redshifts lower than average.

For the 52 objects with known z it is possible to study the luminosity distributions. Values of $H_0 = 50$ and $q_0 = \frac{1}{2}$ were assumed, and the fluxes were k-corrected as described in Paper I. The distributions of the radio (5 GHz), ultraviolet (2500 Å), and X-ray (2 keV) monochromatic luminosities are shown in Figure 3. It appears from the figures and from the logarithmic averages presented in Table 3 that XS objects have the same X-ray luminosity as otherwise selected objects. On the other hand, they have significantly lower radio and UV luminosities with respect to RS objects. For this reason we call radio-weak the objects with flat overall spectrum ($\alpha_{RX} < 0.7$) and radio-loud those with steep overall spectrum ($\alpha_{RX} > 0.7$), rather than X-ray strong and X-ray normal respectively, as chosen by Ledden and O'Dell (1985). Within the RS group the

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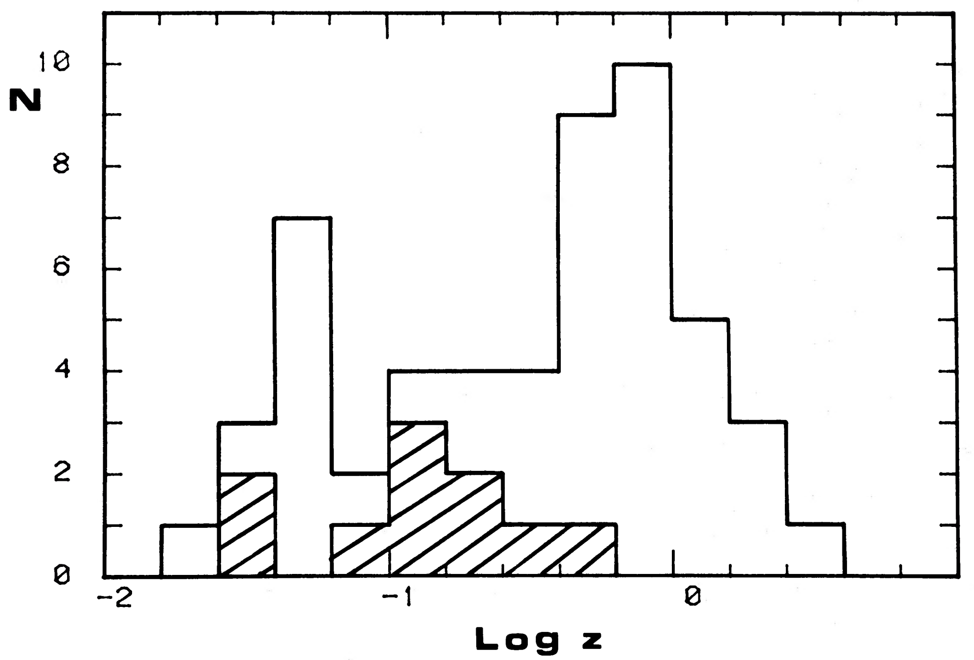

FIG. 2.—Redshift distribution for all X-ray observed blazars. Shaded areas correspond to X-ray selected objects.

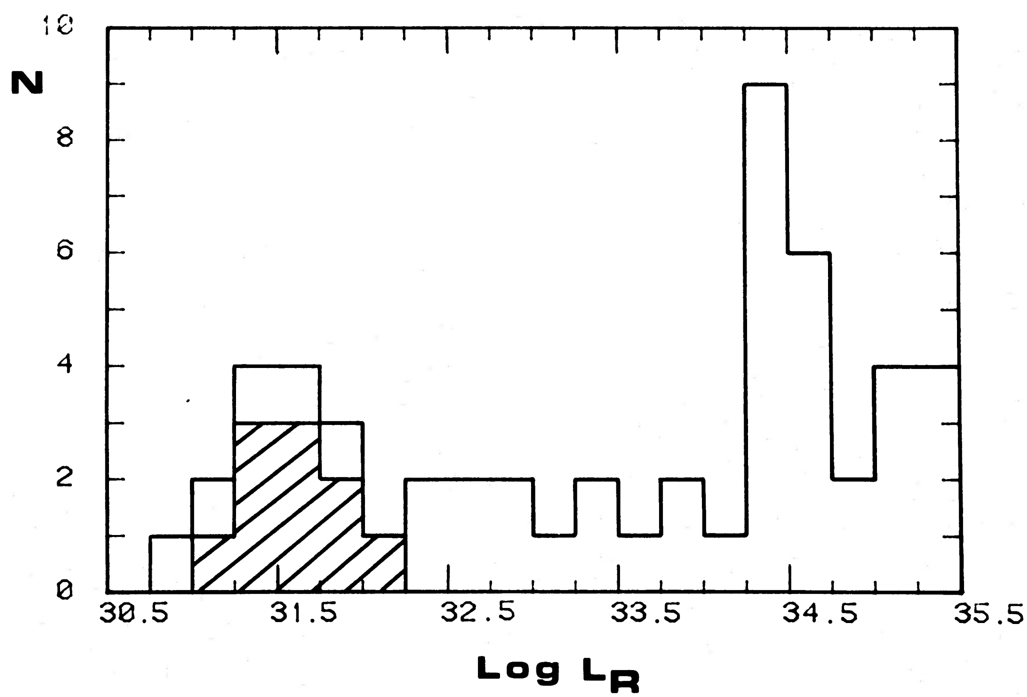

FIG. 3*a*

FIG. 3.—Distribution of monochromatic luminosities in cgs units for all X-ray observed blazars. Shaded areas correspond to X-ray selected objects. (*a*) Distribution of radio (5 GHz) luminosity, (*b*) distribution of ultraviolet (2500 Å) luminosity, (*c*) distribution of X-ray (2 keV) luminosity.

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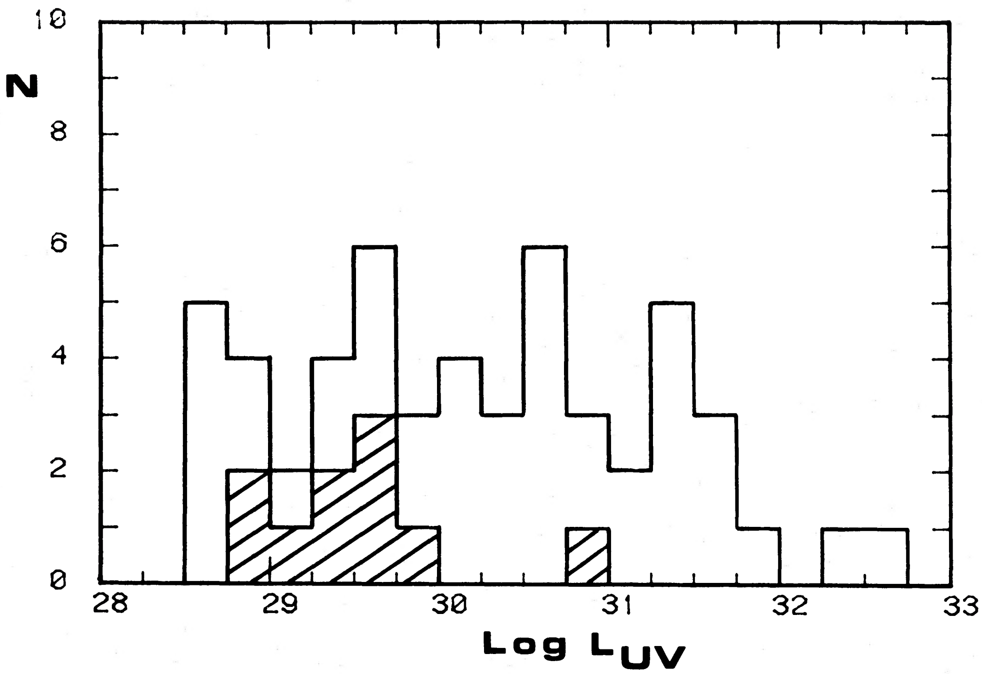

FIG. 3b

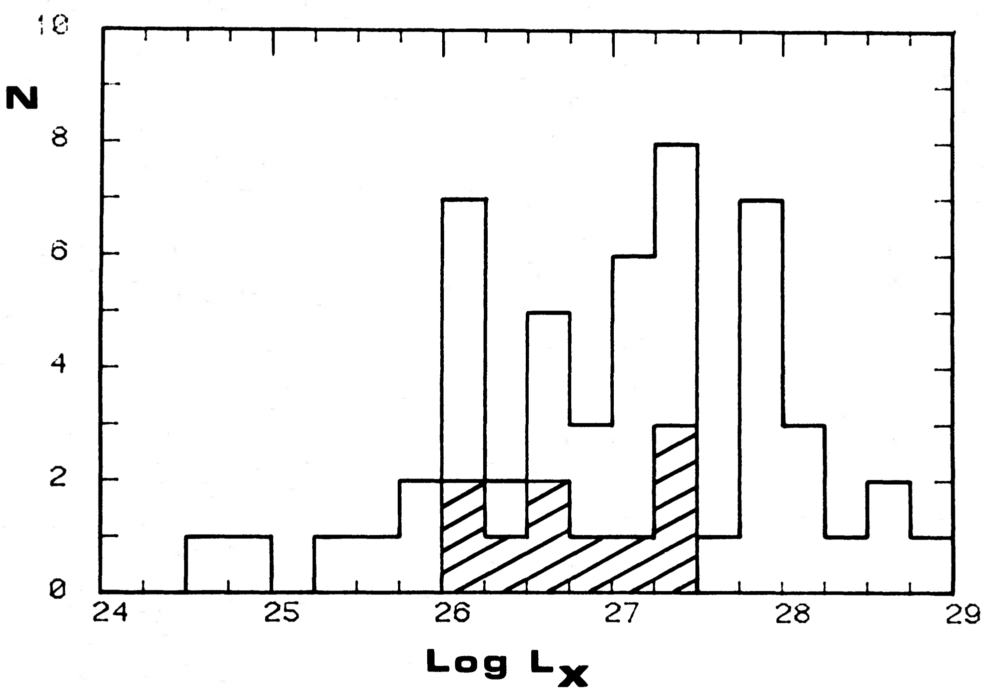

FIG. 3c

objects with strong lines (HPQs) are distinctly more luminous than average at all frequencies, and this is related to a larger value of the average distance.

We consider that the coincidence of the average X-ray luminosity of the XS and RS samples bears important implications. In fact, given that the two subgroups do not differ in X-ray luminosity, X-ray selection should not, in principle, discriminate against radio-loud blazars. Since, on the contrary, all XS blazars are radio-weak, we are forced to conclude that radio-weak objects are intrinsically more abundant than radio-loud objects with the same X-ray luminosity. In other words, the space density of radio-weak blazars is much larger (by at least a factor of 10) than that of radio-loud blazars with the same X-ray luminosity. Note that this does not conflict with the fact that the majority of known blazars are radio-bright, since this reflects simply the mode of formation of blazar lists, which depends heavily on radio selection.

The result obtained here for radio-loud and radio-weak blazars is reminiscent of the situation for radio-loud and radio-quiet quasars.

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V. IMPLICATION FOR EMISSION MODELS

There exists a wide consensus that the electromagnetic spectrum of blazars derives at low frequencies from synchrotron radiation. The correlation found in Paper I between the spectral index in the UV band and α_{UX}, and here between α_{RX} and α_{UX}, indicates that synchrotron emission should extend up to 2 keV.

The proposed models differ in the specification of the spatial structure of the source (homogeneous or inhomogeneous) and in their assumptions about the bulk motion of the emitting relativistic plasma. In particular, the hypothesis that the blazar phenomenon is due to relativistic enhancement of the emitted radiation in the observer's direction, associated with relativistic bulk motion (relativistic beaming) has been under discussion since it was first proposed by Blandford and Rees (1978).

Our main result is that the average X-ray luminosity of objects with widely different broad-band spectra, which have been defined as radio-weak and radio-loud, is essentially the same. This suggests a common mechanism responsible for the X-ray emission and, at the same time, requires us to understand what causes the differentiation in the broad-band spectra. A possible reason for the different overall spectral shapes is simply that the electron spectra are intrinsically different. Since, however, this assumption seems somewhat ad hoc, we propose in the following a more appealing picture, coherent with recent ideas about the structure of these sources.

Consider jet models, in which plasma flows in an elongated region defined by external boundary conditions (e.g., Marscher 1980; Königl 1981). Suppose that the bulk velocity increases along the jet, becoming highly relativistic. In a specific computation Reynolds (1982) has shown that the bulk Lorentz factor Γ can increase along the jet on a scale which may be 100 times the scale of the injection region. Let us further assume that synchrotron X-rays are generated near the injection region (nozzle), while lower frequencies are produced at larger radii (see Ghisellini, Maraschi, and Treves 1985 for a discussion of models of this type). With those hypotheses, X-rays are emitted from plasma with low Γ, i.e., quasi-isotropically, while lower frequencies would be increasingly boosted along the jet axis. The observed spectrum would then depend on the orientation of the jet, with lower frequencies enhanced (steep overall spectra) in the case of alignment of the jet with the line of sight.

We propose that radio-weak blazars are objects with randomly oriented jets, and radio-loud blazars are those in which the jet points to the observer. Since this should occur with a probability $1/(4\Gamma^2_{max})$, one can account at the same time for both the different shape of the overall spectrum and the different space density.

Although the model is only qualitative at the present stage, it has some interesting implications. One is that at low frequencies ($<10^{15}$ Hz), radio-weak objects should be less rapidly variable than radio-loud ones. A second one is that rather small values of Γ_{max} are indicated, $\Gamma_{max} = 5$–3, in order to avoid a too large diminution of the radio flux for the misaligned observer.

These estimates are based on the simple picture of a narrow continuous jet and may be revised if a more realistic model is adopted. In fact, it has been shown (Lind and Blandford 1985) that the dependence of the observed flux on the jet orientation can vary greatly according to which physical conditions are envisaged to produce the emission and the relativistic flow (e.g., discrete plasmoids or shocks propagating in a quasi-stationary medium).

VI. CONCLUSIONS

We have shown that the broad-band spectrum of the available sample of XS blazars is significantly different from that of "classical," RS, blazars. Nevertheless, the average X-ray luminosity of the two subgroups of blazars is the same. If this coincidence is not fortuitous, it implies that X-ray selection should be objective with respect to the radio properties of blazars. The fact that XS blazars happen to be always radio-weak must then be the result of a space density higher than that of radio-loud blazars.

This inference could be directly verified if a complete RS sample of blazars were available. The space density derived from the latter should be compared with that computed by Schwartz and Ku (1983), which is based on the XS objects of the Piccinotti *et al.* (1982) survey and therefore refers essentially to radio-weak objects.

We have also argued that the effects of relativistic beaming may be strong at radio frequencies but not at X-ray frequencies, and that radio-weak blazars may be the parent population of the relativistically enhanced, radio-loud objects.

Observational tests of the model can derive from variability studies at different frequencies or from the comparison of parameters based on the relation between the possibly beamed and unbeamed radiation components, such as the core dominance parameter *R* defined by Antonucci and Ulvestad (1985) in the radio band.

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