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NO EVIDENCE FOR RADIO-QUIET BL LACERTAE OBJECTS[1]

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ABSTRACT

Using a large, flux-limited sample of faint X-ray sources, a search has been conducted for radio-quiet BL Lacertae objects. None has been found. Thirty-two X-ray–selected BL Lac objects and BL Lac candidates have been found within the sources of the *Einstein* Medium Sensitivity Survey (EMSS). Thirty-one of these have been observed with the VLA and all have been detected at 5 GHz, albeit with modest radio fluxes (1–50 mJy). While the optical magnitudes of the EMSS BL Lac objects range from 17 to 20.8, their radio-to-optical spectral indices occupy a very small range ($\alpha_{ro} = 0.30$–0.51). The very bright X-ray–selected BL Lac objects like PKS 2155−304 and Markarian 501 have similar α_{ro} values.

Therefore, unlike the clear dichotomy between radio-loud quasars and radio-quiet QSOs, there is no evidence for two populations of Lacertids distinguished by radio loudness.

Subject headings: BL Lacertae objects — radio sources: galaxies

I. INTRODUCTION

Historically, BL Lacertae objects have been discovered almost exclusively by their radio emission (Burbidge and Hewitt 1987). But recently it has become apparent that X-ray emission offers a new, efficient method for finding these rare objects (Stocke *et al.* 1988; Giommi *et al.* 1989). Not only did the early X-ray sky surveys rediscover a few of the brightest BL Lac objects like Markarian 421 and 501, but also a small number of new ones like 2A 1218+308 and H0323+022 were discovered (e.g., Feigelson *et al.* 1986). Pointed observations of known BL Lac objects made with the *Einstein Observatory* imaging proportional counter (IPC) established that BL Lac objects, as a class, are luminous X-ray emitters ($L_X = 10^{43-46}$ ergs s^{-1} in the 0.3–3.5 keV band; Schwartz and Ku 1983; Maccagni and Tarenghi 1981). Further, the very soft X-ray spectra of the X-ray brightest BL Lac objects like PKS 2155−304 (Urry and Muchotzky 1982) led to the expectation that the *Einstein* IPC would be even more efficient at finding new BL Lac objects.

So it was surprising when the several programs (Maccacaro *et al.* 1982; Margon, Downes, and Chanan 1985; Reichert *et al.* 1982) of optical identifications of "serendipitous" X-ray sources found by the *Einstein* IPC failed to find large numbers of X-ray–selected BL Lac objects (XBLs hereafter, in contrast to radio-selected BL Lac objects; RBLs). For example, among the 112 completely identified sources of the *Einstein* Medium Sensitivity Survey (MSS), only four XBLs were found (Stocke *et al.* 1983; Gioia *et al.* 1984; Stocke *et al.* 1985). Through the continuation and extension of the MSS, called the *Einstein* Extended Medium Sensitivity Survey (EMSS), we are in the process of identifying 835 X-ray sources found in numerous IPC fields at high Galactic latitudes ($|b| > 20°$) which are unrelated to the target of the IPC observation (Gioia *et al.* 1989). At the present time (1989 February) 736 of these sources have been optically identified and 32 XBLs and XBL candidates have been found. A subset of 348 sources bounded by f_X (0.3–3.5 keV)$\geq 5 \times 10^{-13}$ ergs s^{-1} cm^{-2} and declination $\geq -20°$ have been virtually completely identified (some uncertainties remain for four sources). This subset includes 22 BL Lacertae objects. Based upon the EMSS identifications, it is now clear that the small number of XBLs found previously by the above-mentioned X-ray surveys is due to a substantial flattening in the slope of the surface density of XBLs which occurs near $f_X \sim 10^{-12}$ ergs s^{-1} cm^{-2} (see Maccacaro *et al.* [1989] for a detailed discussion of this effect and its possible interpretations). That is, because the initial identification studies of serendipitous *Einstein* sources utilized a very limited sky coverage, only a few bright sources were included in these surveys and so only a few BL Lac objects were found. With its much larger sky coverage (780 square degrees), the EMSS contains $\sim$200 sources with $f_X \geq 10^{-12}$, of which $\sim$10% are BL Lac objects. This efficiency for finding BL Lac objects is comparable to that of the high-frequency radio surveys (e.g., Kuhr *et al.* 1981). Based upon the high fraction of bright EMSS sources which are XBLs, we predict that the *ROSAT* all-sky X-ray survey will find large numbers of BL Lac objects and XBLs will soon far outnumber RBLs (see Stocke *et al.* 1989 for an efficient search strategy).

II. THE EMSS BL LACERTAE SAMPLE

The following observational criteria were used to identify the sample of XBLs from the EMSS:

1. The X-ray emission must be pointlike in the IPC. While

[1] This paper uses data obtained at the Multiple Mirror Telescope Observatory (MMTO) which is a joint facility of the Smithsonian Institute and the University of Arizona. Also observations were partially made at Palomar Observatory as part of a collaborative agreement between the California Institute of Technology and the Carnegie Institution of Washington, DC.

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we identify BL Lac objects only with sources which are pointlike based upon IPC observations (see Gioia *et al.* 1989 for details), we have not excluded *a priori* those sources which are extended from containing BL Lac objects. But we have not found yet a single example of an XBL associated with X-ray emission that is unequivocally extended.

2. The optical spectrum must be featureless in the following senses: (*a*) no emission lines present with $W_\lambda \geq 5$ Å; (*b*) if a Ca II H and K break is present due to starlight from the underlying galaxy, then it must have a contrast (i.e., relative flux depression blueward) of $\leq 25\%$ ensuring that a substantial featureless component is present (Stocke *et al.* 1989). Presently these spectroscopic criteria are limited to the wavelength range 3400 Å to 6000 Å at 7 Å spectral resolution but are being extended to 8500 Å using spectra obtained with the double spectrograph at the Palomar 5 m telescope; (*c*) if a redshift is obtained, $z > 0$ excluding galactic objects.

An XBL *candidate* is an X-ray source which meets criterion no. 1 and whose current optical spectrum qualitatively meets criterion no. 2 but is not of sufficient signal-to-noise ratio (S/N) to apply criterion no. 2 strictly at greater than 3 σ confidence level in the wavelength range 3400–6000 Å. The nine candidate XBLs listed in Table 1 have S/N imposed limits on emission or absorption lines which are 50%–100% higher than those required by criterion no. 2.

Unlike most RBLs, moderate S/N optical spectra of EMSS XBLs often reveal the presence of a late-type stellar spectrum diluted by the featureless continuum (Stocke *et al.* 1989) requiring that criterion no. 2*b* be applied. Currently these weak stellar features allow redshift determinations for over 50% of the XBLs in the complete sample of 22 mentioned above. The optical spectroscopy of these EMSS XBLs will be published later.

Out of ~400 active galactic nuclei (AGN) and ~130 cluster and "normal" galaxy X-ray sources identified spectroscopically in the EMSS as of 1989 February, there are only two sources whose optical spectra do not meet criterion no. 2 above but which are close enough to the suggested limits to warrant consideration as XBLs. The object 1E 0815.6+5233 was presented as an XBL candidate in Stocke *et al.* (1989) and Maccacaro *et al.* (1989) on the basis of very weak ($W_\lambda = 5$ Å) Mg II emission but a subsequent red spectrogram obtained at Palomar showed Hβ emission ($W_\lambda = 35$ Å) which easily exceeds the limits of criterion 2a and so we now classify this object as an AGN. This object has a limit on its maximum polarization percentage of less than 0.5% based upon three observations (Jannuzi *et al.* 1989). The object 1E 0815.6+5233 is also a weak radio emitter ($\alpha_{ro} = 0.29$) so its inclusion as an XBL would not alter our conclusions herein. The object 1E 1704.9+6046 was discovered by Chanan *et al.* (1982) and identified as a BL Lac object on the basis of an *Einstein* high-resolution imager (HRI) position and a "featureless" spectrum. Two spectrograms of this object obtained using the MMT "Big Blue" spectrograph and the Palomar 5

TABLE 1

BASIC PROPERTIES OF EMSS BL LACERTAE OBJECTS

Object Name (1E)	X-Ray Flux (ergs s^{-1} cm^{-2} × 10^{-13})	Radio Flux (mJy)	V Mag	α_{RO}	α_{OX}
0122+0903 C	7.42	1.4	19.98	0.34	0.91
0158+0019 C	86.92	11.3	17.96	0.36	0.83
0205+3509 C	5.24	3.6	19.24	0.36	1.07
0257+3429 C	12.32	10.0	18.53	0.40	1.02
0317+1834 C	123.74	17.0	18.12	0.41	0.71
0350−3712 ?	27.92	16.8	18.5::	0.45	0.89
0419+1943 C	25.47	8.0	20.26	0.51	0.62
0607+7108 C	13.04	18.2	18.5:	0.37	0.91
0622−5256 ?	3.71	not obs.	19.0::	...	1.17
0737+7441 C	97.51	24.0	16.89	0.34	0.97
0922+7459 C	10.79	3.3	19.74	0.31	1.09
0950+4929 C	20.75	3.3	19.30	0.36	0.87
1133+1618	3.55	9.0	20.04	0.50	1.04
1207+3945 C	14.80	5.8	19.12	0.39	0.94
1221+2452 C	12.49	26.4	17.65	0.41	1.20
1229+6430 C	33.73	42.0	16.89	0.39	1.15
1235+6315 C	18.64	7.0	18.59	0.37	0.99
1256+0151 ?	2.46	8.0	20.0:	0.49	1.11
1258+6401 ?	3.96	12.0	19.50	0.48	1.11
1312−4221 ?	168.69	18.5	17.0::	0.33	0.84
1402+0416 C	11.19	20.8	17.08	0.34	1.31
1407+5954 C	19.83	16.5	19.67	0.52	0.81
1443+6349 C	15.97	11.6	19.65	0.52	0.81
1458+2249 C	10.50	29.8	16.79	0.36	1.35
1534+0148 C	20.59	34.0	18.70	0.51	0.94
1552+2020 C	43.02	37.5	17.70	0.44	0.97
1704+6046 ?	4.89	1.8	19.12	0.30	1.13
1757+7034 C	23.44	7.2	18.27	0.35	0.99
2143+0704 C	22.17	50.0	18.04	0.49	1.03
2336+0517 ?	4.65	4.9	20.3:	0.47	0.93
2342−1531 ?	4.93	2.3	19.22	0.33	1.11
2347+1924 ?	4.79	3.2	20.78	0.47	0.86

NOTES.—C = XBL in complete sample ($f_x \geq 5 \times 10^{-13}$ ergs s^{-1} cm^{-2} and Decl. $\geq -20°$); ? = XBL Candidate; : = V band magnitude accurate to 0.3 mag from CCD photometry; :: = V band magnitude estimated from sky survey prints (±0.5 mag).

m + double spectrograph clearly show a Ca II break whose strength exceeds the limits of criterion 2b above. In three observations it has remained optically unpolarized (<3%; Jannuzi, Smith, and Elston 1989). Despite our concerns about the classification of this object (e.g., the X-ray emission could be due to diffuse cluster emission which is highly centrally concentrated as in the "cooling flow" clusters), we retain 1E 1704.9 + 6046 as an XBL candidate but note that a substantial correction must be made to its radio-to-optical flux ratio to account for the presence of the starlight.

Although optical polarization and variability were not used to select the EMSS XBL sample, these observations have now been made for a majority of the sample and largely confirm the BL Lacertae classification. Optical photometry is now available for 25 XBLs, all of which are seen to vary. Based upon irregularly spaced sampling of between four and 60 epochs depending upon the object, the maximum observed variations are modest by RBL standards (Stein, O'Dell, and Strittmatter 1976); 0.20–0.86 magnitudes. Twenty-two of the EMSS XBLs have been observed for optical polarization in white light (Jannuzi, Smith, and Elston 1989; Elston, Jannuzi, and Smith 1989). Fifteen have maximum observed polarizations between 2.4 and 10.5%, three are unpolarized thus far with 3 σ limits of less than 3%, and four have as yet inconclusive limits ($\geq$3%). The maximum percentage of polarization and/or the percentage of time spent in a highly polarized state appear to be lower for XBLs than for RBLs (Jannuzi, Smith, and Elston 1989; Schwartz *et al.* 1989), although more polarimetry is needed to confirm this difference. There is also a tendency for several of the XBLs to possess a preferred position angle of polarization ($\pm 6°$–$25°$; Jannuzi, Smith, and Elston 1989).

While the observable properties of XBLs differ somewhat from the RBLs, there are sufficient similarities to leave little doubt that BL Lac is the correct designation for these objects (Stocke *et al.* 1985, 1989; Burbidge and Hewitt 1987).

III. OBSERVATIONS

Thirty-one of the 32 XBLs and XBL candidates listed in Table 1 were observed during several observing sessions at the Very Large Array (VLA) of the National Radio Astronomy Observatory (NRAO). The remaining object (1E 0622.2 − 5255) is too far south to be observed with the VLA. All of these observations were made at 5 GHz with a 50 MHz bandwidth and most were made with the VLA in its standard C-configuration. The C-configuration observations plus some additional observations primarily of southern sources (Decl. $< -20°$) made in a B/C/D hybrid configuration were part of a "snapshot" survey of all extragalactic sources in the EMSS visible from the VLA. These observations were typically of 3–5 minutes duration, have a positional accuracy of $\sim 1''$, and a 5 σ detection limit of $\sim$1 mJy. These survey observations usually did not spatially resolve the radio structure for the XBLs so that only total fluxes at 5 GHz were obtained. Some of these observations have been reported previously (Stocke *et al.* 1985).

After these survey observations were made, a few EMSS XBLs and candidates either had (1) radio observations with poor upper limits (1E 1704.9 + 6046; Chanan *et al.* 1982), (2) nearby sources confusing the BL Lac identification (1E 0922.4 + 7456 and 1E 1133.6 + 1618) or were as yet undetected at <1 mJy (1E 1603.6 + 2600). These few EMSS XBLs and candidate XBLs were reobserved at 5 GHz on 1987 October 24 with the VLA in its standard A/B hybrid configuration. Each of these XBL candidates was detected *except* 1603.6 + 2600 which remained undetected at 0.30 mJy (5 σ).

Because 1E 1603.6 + 2600 is so faint optically (V magnitude varies between 19 and 20), our original MMT spectrograph classification spectrum was of modest S/N but sufficient to make this object an XBL candidate. Due to the very low upper limit on radio flux from this object, 1E 1603.6 + 2600 was reobserved spectroscopically on 1988 August 9 with the double spectrograph on the 5 m Hale Telescope. The resulting spectrum showed weak emission lines of He II 4686 Å ($W_\lambda = 6.7$ Å) and Hα ($W_\lambda = 10.0$ Å) and even weaker absorption lines of He I *at rest*. With the identification of 1E 1603.6 + 2600 as a weak-lined galactic binary system, all XBLs and candidates in the EMSS are now detected radio emitters. A detailed discussion of 1E 1603.6 + 2600 will be presented elsewhere.

Table 1 presents the basic radio, optical, and X-ray data for the present sample of 32 EMSS XBLs and candidates. In Table 1 the X-ray flux is taken from Gioia *et al.* (1989) and is the IPC flux in the 0.3–3.5 keV band computed using an assumed energy index of $\alpha = 1.0$ (appropriate for these XBLs; Maccacaro *et al.* 1988); the radio flux is at 5 GHz and has been tied to the flux scale of Baars *et al.* (1977) through observations of 3C 286 and 3C 48; the optical V band magnitudes are either from CCD observations made with the Mount Hopkins 24 inch (61 cm) telescope (two significant figure accuracy and errors of 0.1 mag or less) or have been estimated from the Palomar or ESO Sky Survey prints. Entries with a double colon indicate estimated magnitudes from the sky surveys (accuracy ± 0.5 mag); entries with a single colon indicate CCD magnitudes which are poorly determined (± 0.3 mag). Recent CCD measurements have updated the magnitude entries for three sources in Table 1 (0419 + 1943, 0607 + 7108, 2347 + 1924) from the values quoted by Maccacaro *et al.* (1989). Where several epochs of photometry are available to measure optical variability, a mean magnitude appears in Table 1. And in no case has the presence of starlight been subtracted from the tabulated magnitudes.

The two-point X-ray-to-optical (α_{ox}) and radio-to-optical (α_{ro}) spectral indices are as defined in Stocke *et al.* (1985) and Tananbaum *et al.* (1979): $\alpha_{ro} = \log(S_{5\,\mathrm{GHz}}/S_{2500\,\mathrm{Å}})/5.38$; $\alpha_{ox} = -\log(S_{2\,\mathrm{keV}}/S_{2500\,\mathrm{Å}})/2.605$.

IV. DISCUSSION

Not only are all of the XBLs in Table 1 detected by the VLA, but their ratios of radio-to-optical flux (represented here by α_{ro}) are all very similar to each other and to the α_{ro} values for the bright XBLs found in the all-sky surveys. Similar values of α_{ro} have also been found by Giommi *et al.* (1989) for XBLs discovered in the *EXOSAT* "high galactic latitude" survey and by Schwartz *et al.* (1989) for XBLs found in the *HEAO* 1 A-3 survey. So, all known XBLs fall within the rather narrow range of α_{ro} values shown in Table 1 and displayed in Figure 1.

It is worth noting that the XBLs are all detected well above the 5 σ radio detection limit for the VLA survey of EMSS sources of $\sim$1 mJy. Although an optically faint XBL ($V > 20$) could have remained undetected by our VLA survey if it had an α_{ro} value at the very low end of the XBL range, our procedure for discovering XBLs would have previously identified it as a candidate despite its radio nondetection. In fact, no such source has been found to date.

The object 1E 1704.9 + 6046 had been proposed by Chanan *et al.* (1982) as a radio-quiet BL Lac object but, based upon our detection of this object at $f_r = 1.8$ mJy, its α_{ro} value now is very

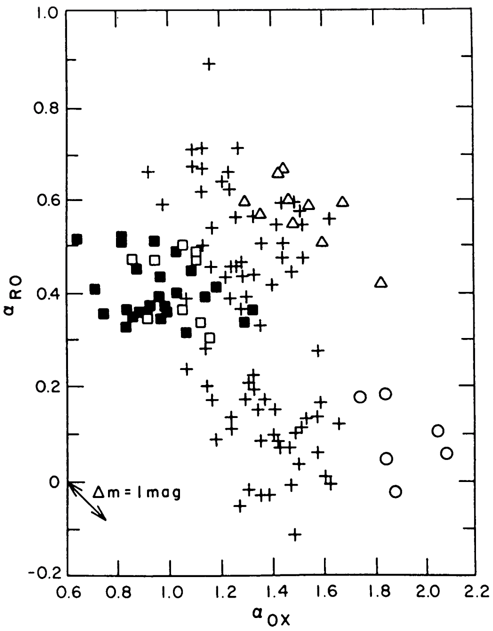

FIG. 1.—The overall energy distributions for several classes of extragalactic objects. The axes are the two point X-ray-to-optical and radio-to-optical spectral indices as defined in the text. The boxes are X-ray–selected BL Lacs (EMSS + *HEAO* 1 A-2; filled boxes $f_X > 10^{-12}$ ergs s^{-1} cm^{-2}; open boxes $f_X < 10^{-12}$); the triangles are radio-selected BL Lac objects with X-ray observations; the plus signs are X-ray–selected AGN from the EMSS; and the open circles are EMSS "normal" galaxies. Only those AGN with radio detections are shown; approximately 275 more EMSS AGN have VLA upper limits of ~1 mJy, which place them below $\alpha_{ro} = 0.25$ in this figure.

similar to that of PKS 0548−322 or PKS 2155−304 and to many EMSS XBLs. While it is true that 1E 1704.9+6046 has the lowest α_{ro} value in Table 1, this object also requires the largest correction by far to its optical flux to account for a substantial starlight contribution ($\Delta\alpha_{ro} \sim +0.15$). Because this correction is much smaller for the other XBLs, then, if this correction were made, 1E 1704.9+6046 would no longer be extreme in its ratio of radio-to-optical flux. The other radio-quiet BL Lac candidate proposed by Chanan *et al.* (1408+020) was later shown to be a Seyfert galaxy (Margon *et al.* 1986). So, to our knowledge, no BL Lac object has a ratio of radio-to-optical flux outside the distribution shown in Figure 1.

If BL Lac objects exist with α_{ro} values significantly less than the EMSS XBLs, they are either extremely rare (i.e., ≤ 0.004 per square degree because we have yet to find such an object in the EMSS) or they are both X-ray and radio quiet.

Figure 1 is an "$\alpha_{ox} - \alpha_{ro}$ diagram" showing the overall energy distributions seen in various classes of extragalactic objects. Besides the XBLs which are shown as boxes in Figure 1, points have been plotted for X-ray–selected AGN (*plus signs*) and "normal" galaxies (*open circles*) from the EMSS and for the small number of RBLs with *Einstein* IPC detections (*triangles*). Only those AGN and galaxies detected with the VLA ($f_r \geq 1$ mJy) are plotted. Approximately 275 more "radio-quiet" AGN have VLA upper limits of ~1 mJy which place then below $\alpha_{ro} = 0.25$ in Figure 1.

XBLs possess the largest ratios of X-ray-to-optical flux (smallest α_{ox}) of any class of extragalactic object. Although the RBLs occupy a different area of the (α_{ox}, α_{ro}) diagram, the separation between the RBLs and XBLs is in the direction expected from the differing methods by which they were selected. As Stocke *et al.* (1985) and Schwartz *et al.* (1989) have shown, RBLs like PKS 2155−304 and PKS 0548−322 are found in the XBL area of Figure 1 when they are in an X-ray bright state (i.e., as discovered in the *HEAO* 1 A-2 or A3 surveys). Schwartz *et al.* (1989) have also shown that BL Lac objects that are both radio and X-ray–selected (i.e., present in flux-limited samples of bright radio and X-ray sources) occupy a region in Figure 1 between the boxes and the triangles.

From the perspective of the relativistic beaming hypothesis for BL Lac objects (e.g., Urry and Shafer 1984), XBLs and RBLs may be the same type of object viewed from different angles relative to a beaming axis. Evidence for this suggestion include the larger starlight fraction and the smaller amounts of optical variability, polarization, and polarization variability seen in XBLs compared to RBLs. These systematic differences between XBLs and RBLs suggest that we are viewing XBLs off the optical (and radio) beaming axis so that the X-ray emission is less beamed than the optical and radio emission. If the XBLs were to have their emission boosted by Doppler beaming (radio boosted by a factor of ~200; optical by ~30), the XBL boxes would move into the area of the RBL triangles in Figure 1. From this hypothesis we would predict that higher resolution and sensitivity radio observations of XBLs will reveal extended radio structure morphologically similar to the Fanaroff and Riley (FR; 1974) type 1 radio galaxies but with no evidence for a Doppler-boosted core source as in the RBLs (Wardle, Moore, and Angel 1984). The few known radio luminosities of EMSS XBLs (see below) are consistent with this hypothesis. Unfortunately, at this time few XBLs have been observed at the resolution and sensitivity needed to test this hypothesis.

Despite the marked separation in α_{ox} between RBLs and XBLs, these two selection techniques locate objects whose radio properties largely overlap. Until more complete redshift information is available for both RBLs and XBLs, the most consistent way to compare the "radio loudness" of these BL Lac objects is to use a nearly distance-independent parameter like α_{ro} as first advocated by Chanan *et al.* (1982). Chanan *et al.* (1982) also were the first to notice the inverse correlation between X-ray flux and α_{ro} described in more detail herein. Figure 2 is a histogram of α_{ro} values for RBLs, XBLs, and X-ray–selected AGN. The XBL and X-ray AGN objects are the same as plotted in Figure 1. The RBL data are taken from the compilation of Weiler and Johnston (1980), although we have used only those RBLs whose optical spectra meet criterion no. 2 of § II. That is, sources traditionally labeled optically violently variable quasars (OVVs) or highly polarized quasars (HPQs) have *not* been included in Figure 2. This dichotomy follows the suggestion of Burbidge and Hewitt (1987) and Worrall and Wilkes (1989) that the HPQs and BL Lac objects should not be considered as a single class. Many more RBLs are plotted in Figure 2 than in Figure 1 because an X-ray detection is not required.

Notice in Figure 2 (and also in Fig. 1) that here is a clear division between the "radio-loud" and "radio-quiet" AGN populations at $\alpha_{ro} = 0.25$–0.35 (which corresponds to a ratio of radio to optical flux of log $R^* = 1.3$–1.8; Sramek and Weedman 1980). But there is no evidence for two populations of BL Lacertae objects. Although the XBLs are biased toward lower α_{ro} values than the RBLs, the distributions clearly overlap (1 σ dispersions overlap). In fact, Figure 2 shows that the full BL Lac population (XBLs + RBLs) spans the same range in α_{ro} as does the radio-loud AGN population. But if

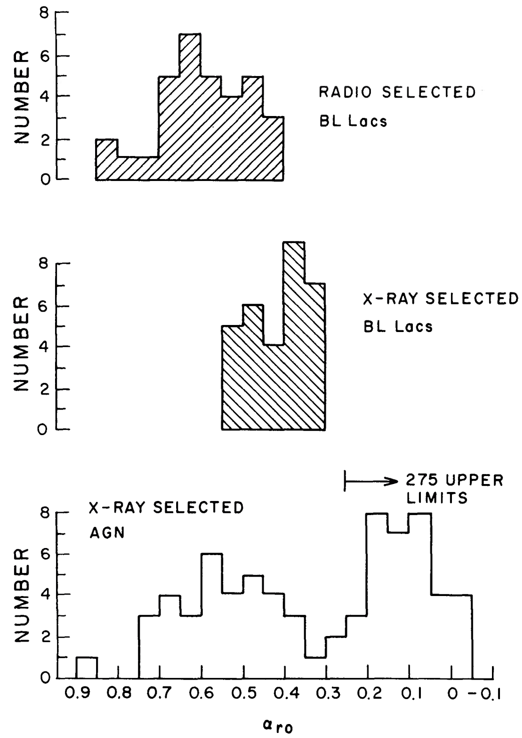

FIG. 2.—A histogram of α_{ro} values for radio (RBLs) and X-ray (XBLs)–selected BL Lac objects and for X-ray–selected AGN. Data for the RBLs are taken from the compilation of Weiler and Johnston (1980) but only those RBLs satisfying the more restrictive definition of a BL Lac proposed in § II of this paper have been included.

only X-ray–selected objects are considered, the spread in α_{ro} for the BL Lac objects is considerably narrower than for either of the two classes of AGN, suggesting a tighter relationship between the radio and optical continuum in these objects than in the AGN. Moreover, the actual intrinsic dispersion in α_{ro} for XBLs may be significantly less than is shown in Figures 1 and 2 because (1) the radio and optical fluxes were not obtained simultaneously and these objects are known to vary in the optical, if not in the radio as well; and (2) many of the EMSS XBLs show evidence in their optical spectrum for starlight due to the underlying galaxy (Stocke *et al.* 1985; Stocke *et al.* 1989) which has not been subtracted from the optical flux. Underlying galaxy subtraction will be undertaken once high-quality optical spectroscopy is in hand for the entire sample and will systematically change the ordinate for a few objects by $\alpha_{ro} \leq +0.1$.

If we attempt to adopt the point of view that the EMSS XBLs are the radio-quiet (or should we say radio-modest) BL Lac population, then because the α_{ro} values for EMSS XBLs and for the brighter XBLs like PKS 2155−304 or Markarian 421 (B2 1101+304) are so similar, these latter objects must be considered "radio-quiet" as well. Since redshifts have now been measured for several of the EMSS XBLs, total 5 GHz radio luminosities can be computed. Assuming a flat spectrum in the radio (Stocke *et al.* 1985), the corresponding 408 MHz mean luminosity of the sample is $\sim 10^{24.5}$ watts Hz^{-1}. This value is over an order of magnitude higher than the suggested lower limit for a "strong" radio galaxy (Miley 1980) and is typical of the radio power for an FR 1 radio galaxy. This radio power level is also at least two orders of magnitude higher than the radio luminosity for a typical radio-quiet QSO or Seyfert galaxy (Condon 1989). Therefore, XBLs are radio-loud.

V. CONCLUSIONS

The conclusion that there is no sizable population of radio-quiet BL Lacertae objects, analogous to the large population of radio-quiet QSOs, is based primarily upon the XBL sample from the EMSS. But XBLs discovered thus far in the other three major X-ray surveys (*HEAO* 1 A-2, Piccinotti *et al.* 1982; *HEAO* 1 A-3, Schwartz *et al.* 1989; and *EXOSAT*, Giommi *et al.* 1989) share the radio properties of the EMSS XBLs and so also support this conclusion. Within the EMSS the absence of radio-quiet BL Lac objects is based upon (1) 22 XBLs which are all detected at 5 GHz and are a complete sample of XBLs selected from a virtually completely identified, flux-limited sub sample of the EMSS. Because this subsample is nearly completely identified, there can be no sizable population of radio-quiet BL Lac objects hidden among its unidentified sources; (2) an additional 10 XBLs and candidates from the largely, but not completely, identified entire sample of 835 EMSS sources which are also radio-detected.

From Figures 1 and 2 it is clear that the EMSS finds large numbers of radio-quiet AGN. So, although there is evidence for a statistical relationship between radio and X-ray emission (Zamorani *et al.* 1981), X-ray selection does not exclude finding radio-quiet objects in large numbers. And yet no radio-quiet BL Lac objects have been found.

There is, as yet, no efficient method for discovering BL Lac objects by optical means. A few BL Lac objects were discovered in the PG UVX survey (primarily previously known RBLs; Schmidt and Green 1983) and a very few BL Lac candidates have turned up in other optical surveys such as the APM quasar survey (e.g., Foltz *et al.* 1987) and the CFHT quasar survey (Crampton, Cowley, and Hartwick 1987). However, objective prism/grism/grens surveys and color surveys (unless several very widely spaced colors are used) will confuse the large numbers of weak-lined white dwarfs and subdwarfs with BL Lac objects. Optical spectroscopy of a quality sufficient to apply criterion no. 2 (see § II) is needed to define a list of optically selected BL Lac candidates. In general, the needs of the quasar surveyors usually preclude high S/N spectra on "featureless" objects (the Foltz *et al.* [1987] work is a exception) so that no optically selected BL Lac sample is presently available.

Optical polarimetry and photometry have yet to discover a single BL Lac (since the original few like BL Lac itself) although new surveys are in progress (Jannuzi and Green 1989; McGraw *et al.* 1988). No other wavelength region (e.g., infrared) has been used to search for BL Lac objects. So for now, the search for radio-quiet BL Lac objects can be conducted only with X-ray–selected objects, as we have done.

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