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TWO X-RAY–SELECTED BL LACERTAE OBJECTS OBSERVED WITH THE *HEAO 1* SCANNING MODULATION COLLIMATOR

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ABSTRACT

We have discovered two 16th magnitude BL Lac objects, H1101−232 and H1426+428, during an ongoing program to identify the optical counterparts of X-ray sources from the *HEAO 1* survey. Each is a persistent and relatively bright X-ray source that was also detected by the *Uhuru* and *Ariel 5* surveys. Our classifications are based on the combined observations of featureless optical continua, compact radio emission, and images of the underlying host galaxies. In addition, we have measured 2.7% linear polarization in the optical emission of H1101−232. We have confirmed the X-ray identification of H1426+428 in an observation with *EXOSAT*. The *EXOSAT* X-ray spectrum is well modeled by a power law with an energy index of 1.19. Both BL Lac objects exhibit high f_x/f_{opt} ratios, and they show a distinct resemblance to other X-ray–selected BL Lac objects. The host galaxies are ~18th mag with angular diameters ~20″, and each may be the dominant member of a cluster of galaxies. Additional wide-slit spectroscopy reveals faint absorption features with redshifts of 0.129 for H1426+428 and 0.186 for H1101−232. The implied X-ray and optical luminosities exceed 10^{45} ergs s^{-1} for both BL Lac nuclei, assuming isotropic emission. The optical brightness of H1101−232 faded by 0.3–0.6 mag during most of 1987. The *HEAO 1* survey continues to identify BL Lac objects at a rate ~15% of the total number of active galactic nuclei, in sharp contrast with the statistics of the *Einstein* serendipitous sources at lower X-ray flux. Since the percentage of measurable redshifts is high among *HEAO 1* BL Lacs (14 of 24, currently), the flux-limited subset of *HEAO 1* LASS–MC identifications may clarify this problem by constraining the luminosity function of nearby, X-ray–selected BL Lac objects.

Subject headings: BL Lacertae objects — galaxies: clustering — galaxies: nuclei — X-rays: sources

I. INTRODUCTION

BL Lac objects are a type of active galactic nuclei (AGNs) that are characterized by featureless optical continua, compact radio emission with a flat spectrum, optical (and sometimes radio) polarization, steep X-ray spectra, and emission variability in all spectral regions (Stein, O'Dell, and Strittmatter 1976; Angel and Stockman 1980; Urry, Mushotzky, and Holt 1986). Current theories favor synchroton radiation as the principal radio and optical emission mechanism, with synchrotron or synchrotron self-Compton emission at X-ray frequencies. Jets or relativistic beaming effects have been invoked by many authors to explain various spectral and temporal characteristics. However, a clear description of the nature of BL Lac objects has not been achieved.

The X-ray–selected sample of BL Lac objects has attracted special interest. When the serendipitous sources detected by the *Einstein Observatory* are compared to surveys at higher flux limits (e.g., Piccinotti *et al.* 1982), there is a great deficiency of BL Lac objects relative to other AGNs in the *Einstein* sample (Maccacaro *et al.* 1984; Stocke *et al.* 1985). These statistics force the conclusion that the density evolution of BL Lac objects, as exhibited by their number versus redshift, is markedly different from X-ray–selected QSOs. It has also been suggested that X-ray–selected BL Lac objects differ from radio and optically selected BL Lacs in that the former are less likely to show very large degrees of polarization or "violent" optical variability and more likely to show starlight from the underlying galaxy (Stocke *et al.* 1985; Ledden and O'Dell 1985).

Our group has been working to optically identify the X-ray sources observed with the Scanning Modulation Collimator (MC) during the all-sky survey by experiments flown on the first *High Energy Astronomy Observatory* (*HEAO 1*) satellite. The MC positions for bright extragalactic sources initially helped to establish the BL Lac objects constitute a class of X-ray emitters (Schwartz *et al.* 1979). Another MC identification was the highly variable (in X-rays and optical polarization) BL Lac object H0323+022 (Margon and Jacoby 1984; Feigelson *et al.* 1986). The current MC program, which seeks the identifications of the fainter *HEAO 1* sources, is described by Remillard *et al.* (1986). In this paper we present the observations of two BL Lac objects that have been discovered during this program. A preliminary report of these identifications were given by Schwartz *et al.* (1985).

II. X-RAY POSITIONS AND INDENTIFICATIONS

Both of the X-ray sources were detected in the surveys conducted by *Uhuru* (Forman *et al.* 1978), *Ariel 5* (McHardy *et al.* 1981), and the *HEAO 1* Large Area Sky Survey (LASS; Wood *et al.* 1984). We further constrain the allowed X-ray positions with observations by the *HEAO*–MC, which restricts the source position to one of the multiple, precise (typically 0′.6 by 2′.5) error boxes produced by this experiment (Gursky *et al.*

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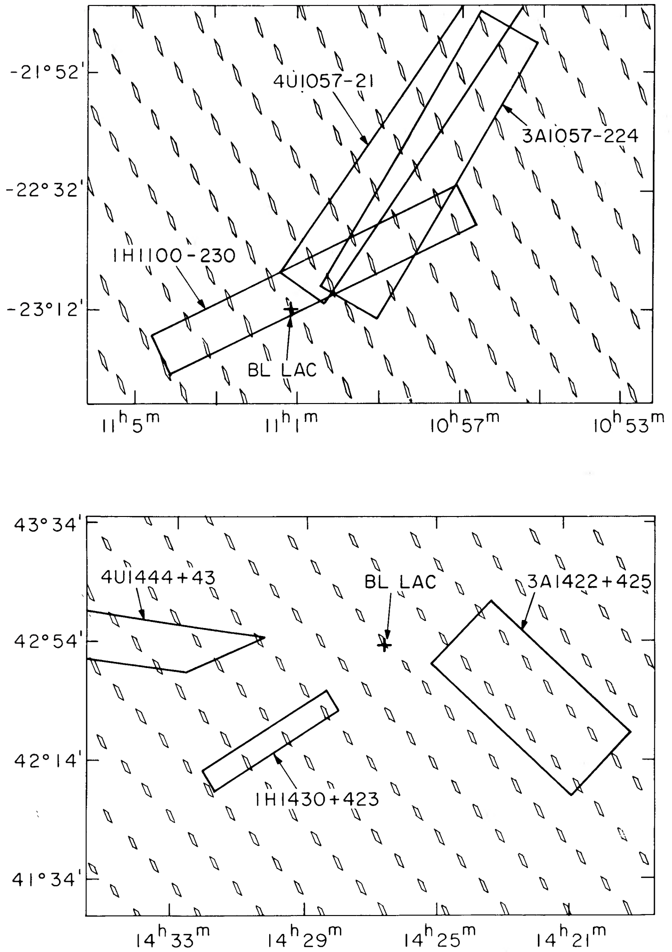

FIG. 1.—The allowed X-ray positions from the *HEAO*–MC (*diamonds*), the *HEAO*–LASS ("1H"; Wood *et al.* 1984), *Uhuru* ("4U"; Forman *et al.* 1978), and the *Ariel 5* survey ("3A"; McHardy *et al.* 1981). The positions of the BL Lac objects, which are the optical counterparts of the X-ray sources, are indicated with a heavy " + " symbol.

1978). The X-ray positions and the locations of the BL Lac objects are displayed in Figure 1.

For both of these X-ray sources, the search for cataloged optical or radio sources within the allowed X-ray positions failed to produce a candidate optical counterpart. Schmidt telescope observations with *U*- and *B*-filtered, double-exposed images (see Remillard *et al.* 1986) were made using the Burrell Schmidt at Kitt Peak and the Curtis Schmidt at CTIO to locate optical candidates on the basis of a strong ultraviolet ($U - B$) color index. In addition, a radio survey of selected MC positions was undertaken at the VLA (Schmelz, Feigelson, and Schwartz 1986). Followup spectroscopy and CCD imaging of two coincident UV object/compact radio sources led to the BL Lac classifications and secured the X-ray identifications. We designate the objects H1101−232 and H1426+428; optical finding charts are provided in Figure 2 (Plate 1) and Figure 3 (Plate 2), respectively. The celestial coordinates are given in Table 1 and also in the figure captions.

The MC positions (diamond error boxes in Fig. 1) are derived from the intersection of transmission bands from two detector systems, MC1 and MC2. In the case of H1101−232, the MC detections (in units of standard deviations, σ, in the detector background flux) are 3.0 σ on MC1 and 2.9 σ in MC2 in the energy range of 2.5–5.5 keV, for the sum of two 7 day scans of the source (1978 June 15–21 and 1978 December 16–22). As seen in Figure 1, the BL Lac object lies in an MC error "diamond" that is within the LASS error box and is just beyond the boundaries (90% confidence) of both the *Ariel 5* and *Uhuru* error boxes. There are no other candidate optical counterparts for this source, and we regard the identification as highly probable. *Einstein* observations of the Abell cluster 1146 (Perrenod and Henry 1981), which is within the *Ariel 5* and *Uhuru* error boxes, show that this cluster is not the counterpart of the X-ray source detected by the survey instruments.

To determine the X-ray flux from the LASS catalog, we use a conversion factor of 0.0027 LASS counts cm^{-2} s^{-1} per 10^{-11} ergs cm^{-2} s^{-1} for BL Lac objects, based on a comparison between the LASS counting rates (Wood *et al.* 1984) and the nearly simultaneous *HEAO 1* A-2 spectral measurements of bright BL Lac objects (Worrall *et al.* 1981). Using this conversion, the LASS measurement of H1101−232 during the first *HEAO 1* scan (1977 December 16–22) implies a 2–10 keV flux of 1.9 ($\pm$0.3) $\times 10^{-11}$ ergs cm^{-2} s^{-1}. However, the flux appears to have risen by 50%–100% during the second and third *HEAO 1* scans, which are the ones contributing to the MC results. The *Ariel 5* and *Uhuru* measurements also indicate higher fluxes, with measurements of 2.9 and 7.0 $\times 10^{-11}$ ergs cm^{-2} s^{-1}, respectively, assuming an X-ray spectrum similar to the Crab nebula ($\alpha_x \sim 1.0$).

The X-ray error boxes for H1426+428 show disjoint positions from LASS, *Uhuru*, and *Ariel 5* that converge near the BL Lac's position (see Fig. 1). In each case the more significant deviation is along the axis that is more poorly determined. In the *HEAO 1* survey, the narrow dimension of the LASS error box is aligned with the movement of the instrument's field of view during satellite rotation, and a source transit in this direction occurs every $\sim$30 minutes. The longer axis of the error box indicates the direction in which the instrument's viewing anulus slowly precesses, and a source transit in this direction takes 6 days or longer, depending on the source's ecliptic latitude. Therefore, the discrepancy between the position of H1426+428 and the LASS error box may be caused by significant X-ray source variability on a time scale of days.

The MC detections are 3.0 σ in MC1 and 3.8 σ in MC2, again in the energy range of 2.5–5.5 keV, for the sum of three 9 day scans of the source region (1977 December 30–1978 January 7, 1978 June 30–July 8, and 1978 December 29–1979 January 5). The LASS count rate for H1426+428 implies a 2–10 keV flux of 3.1 $\times 10^{-11}$ ergs cm^{-2} s^{-1}, using the conversion rate described above. The *Ariel 5* flux is very similar, while the *Uhuru* flux is again greater by a factor of 2.5. The difference in *Ariel 5* versus *Uhuru* fluxes cannot be taken as definitive evidence for variability for these two objects because of the difficulties comparing the different instruments, especially when their own positional errors are so large.

The X-ray source identification for H1426+428 has been confirmed by observations with *EXOSAT*. The *EXOSAT* LE image shows a single point source within its 2° field of view, and the LE and ME flux measurements are consistent with those of the X-ray surveys. The analysis of the *EXOSAT* spectrum is given in § VI.

III. RADIO OBSERVATIONS

Each of the optical counterparts was observed in a 2 minute snapshot by the 27 antennas of the NRAO Very Large Array (VLA) at Socorro, New Mexico. The observations were made

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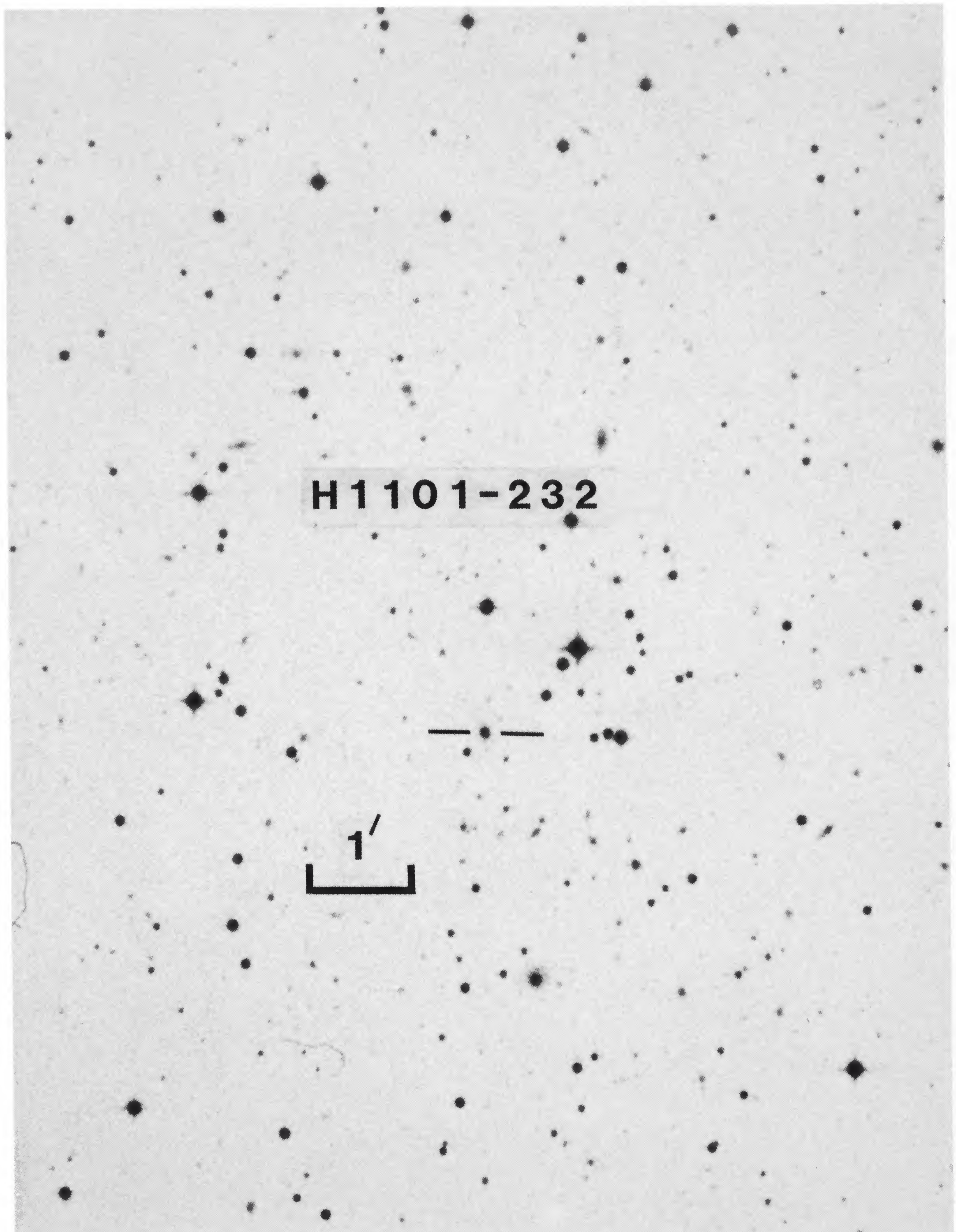

FIG. 2.—Optical finding chart for the BL Lac object, H1101 − 232. East is to the left, and north is toward the top. The celestial coordinates (1950.0) are $11^h01^m11\overset{s}{.}1$, $-23°13'20''$.

REMILLARD *et al.* (*see* **345**, 141)

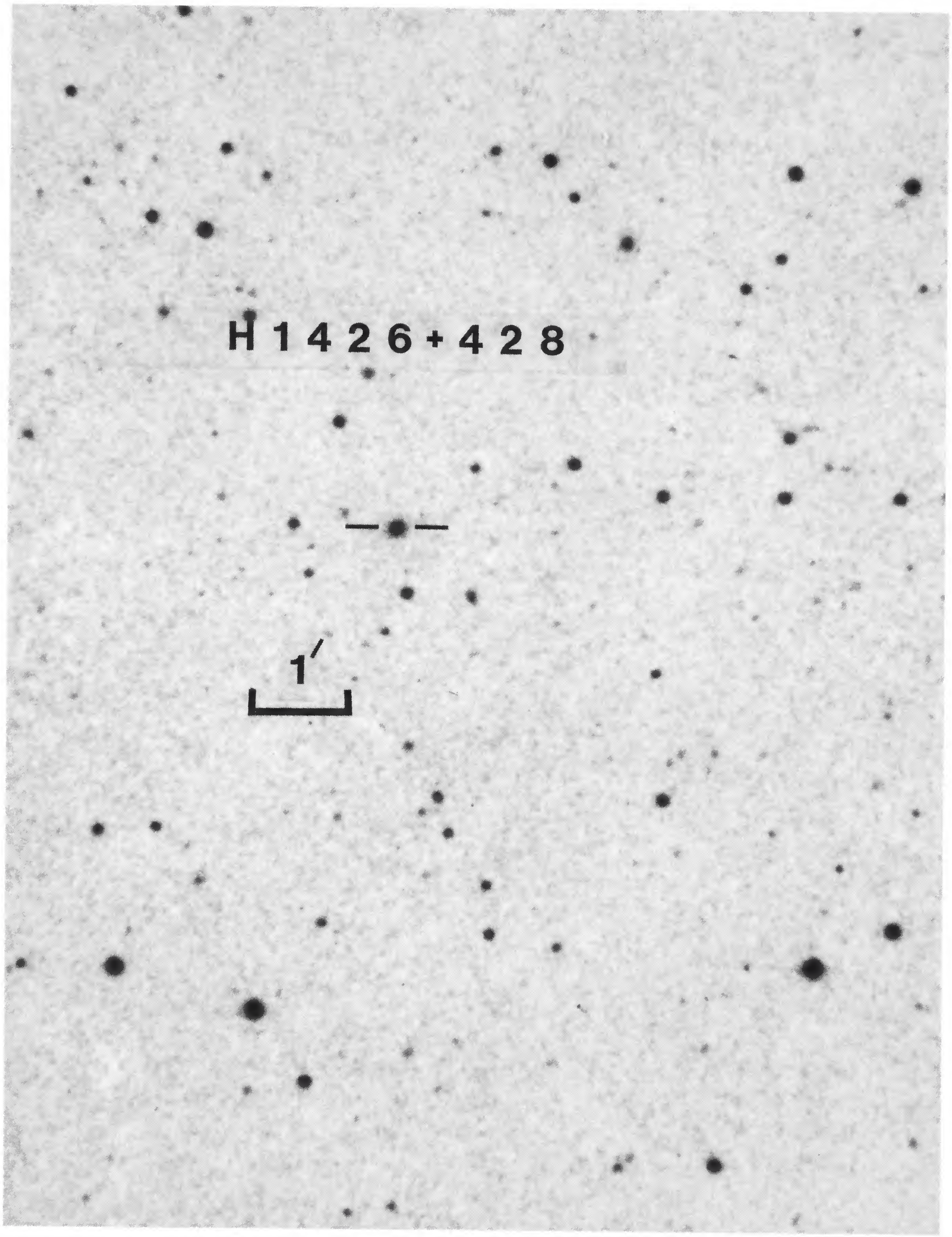

FIG. 3.—Optical finding chart for the BL Lac object, H1426+428. East is to the left, and north is toward the top. The celestial coordinates (1950.0) are $14^h26^m35\overset{s}{.}9$, 42°53′46″.

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TABLE 1

THE BL LAC OBJECTS

	H1426+428	H1101−232
Optical position (±1″.0)	$11^{h}01^{m}11^{s}.1$ −23°13′20″	$14^{h}26^{m}35^{s}.9$ 42°53′46″
Radio position (±2″.0)	$11^{h}01^{m}11^{s}.1$ −23°13′20″	$14^{h}26^{m}35^{s}.9$ 42°53′44″
X-ray flux (10^{-11} ergs cm^{-2} s^{-1}, 2-10 keV)	1.9–3.5	3.3 (±0.3)
Radio flux (mJy at 1.4 GHz)	83.0 (±2.0)	33.7 (±2.0)
Optical magnitudes (±0.05)		
(10″ aperture) V	16.55[a]	16.45
$B-V$	+0.45	+0.50
$U-B$	−0.61	−0.55
$V-R$	+0.60	+0.64
f_x/f_{opt} (2–10 keV vs. 3000–7000 Å)	7.6[a]	8.4
Optical/X-ray index, β_{ox}	0.75	0.72
Index α_{ox} (extrapolated)	0.68	0.64
Radio/optical index, β_{ro}	0.35	0.29
Index α_{ro} (extrapolated)	0.44	0.37
Optical linear polarization	2.7% (±0.3%) at 52°	...
Redshift	0.186	0.129
log L_x (ergs s^{-1} at 2–10 keV)	45.7	45.4
M_v nucleus	−23.9[a]	−22.9
M_v host galaxy	−22.3	−22.1

[a] In this table we use the optical measurements for H1101−232 made during 1984–1985 (see Table 2), i.e., the optical dip during 1987 is regarded as exceptional behavior.

at 20 cm (1.4 GHz) on 1983 May 11, with the VLA in configuration C. Further details regarding the image cleaning and flux calibration can be found in Schmelz *et al.* (1986). The celestial positions obtained from the radio maps are accurate to ±2″, while the spatial resolution (FWHM) of the synthesized beam is 15″, and the overall field of view is 30′.

The radio flux of H1101−232 was 83.0 ± 2.0 mJy, and the flux of H1426+428 was 33.7 ± 2.0 mJy. In each case the radio source was unresolved, with a spatial resolution of ∼2″. The radio positions are included in Table 1, and they are coincident with the optical positions to within the measurement uncertainties.

Deeper multiconfiguration VLA observations have also been obtained of both objects (Feigelson *et al.*, in preparation). H1101−232 shows a core-jet structure with a total extent around 45″. Similar extended structures are found in most radio-selected BL Lac objects (Antonucci and Suvestad 1985). In contrast, H1426+428 has little or no extended radio structure.

IV. OPTICAL SPECTRA OF THE BL LAC NUCLEI AND HOST GALAXIES

Optical spectra were obtained for the celestial objects indicated in Figures 2 and 3, and both exhibit featureless continua. The observations of H1101−232 were first made at the Anglo-Australian Telescope (AAT) on 1984 February 8, using Image Photon Counting System (IPCS) and a long slit (1′) with 2″.0 width. The wavelength coverage was 3400–7200 Å, with ∼10 Å resolution. The spectrum, with 300 s exposure time, exhibits no significant emission or absorption features. We observed H1101−232 for 1000 s with the AAT on 1986 February 6 using a 7″ slit, after it was learned that there was a substantial host galaxy underlying the BL Lac nucleus (see § V). For the second spectrum, we simultaneously used the IPCS and the Faint Object Red Spectrograph (FORS). The latter employs a 584 pixel GEC CCD detector, and the observations were conducted with 20 Å resolution. A dichroic filter was used to separate the incoming beam at ∼5400 Å, and the IPCS and FORS measured the blue and red spectra, respectively. The combined wavelength coverage is 3200–10000 Å. In addition to the standard procedures for normalizing the detector sensitivity, subtracting the sky background, and calibrating the energy flux, the FORS spectra are normalized by observations of bright stars with smooth, continuous spectra to remove the red absorption bands caused by the Earth's atmosphere. The combined IPCS/FORS spectrum of H1101−232 is shown in Figure 4. Individually, there are no absorption features with a high degree of significance; however, there is one set of weak features that correspond to a single redshift ($z \sim 0.184$) of the main absorption lines (viz., Ca H and K, Mg *b*, and Na D) of a typical galaxy composed of late-type stars. To confirm this result, H1101−232 was observed at the AAT for 2000 s on 1988 February 23, using the same IPCS/FORS instrumentation and subsequent data reduction procedures. The FORS result, shown in Figure 5, confirms the locations of the Na I and Mg I absorption lines and also shows Hβ in absorption. This spectrum provides an improved redshift measurement for H1101−232, $z = 0.186 \pm 0.001$. We note that the narrow (2

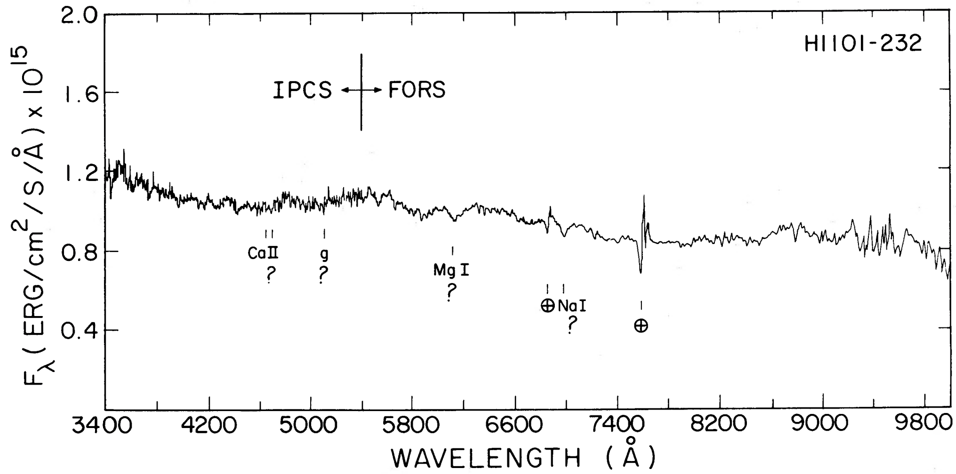

FIG. 4.—The optical spectrum of H1101−232, observed at the AAT on 1986 February 6, with the combined RGO/IPCS and FORS spectrographs and a 7″ entrance slit. The spectrum shows no emission lines, and there is a set of weak features that suggest the prominent absorption lines of a normal galaxy with a redshift of 0.184.

pixel) excess in the spectrum between Hβ and Mg *b* is not O III in emission, but is probably residual counts from a cosmic-ray detection in the CCD spectrograph.

We first observed H1426+428 with the 1.3 m McGraw-Hill telescope at Michigan-Dartmouth–M.I.T. Observatory, using the Mark II spectrograph, which is a 2048 channel, photon-counting, reticon scanner (see Shectman and Hiltner 1976). The wavelength coverage was 3800–7400 Å, with 15 Å resolution. There were no significant emission or absorption features detected in a 1.5 hr observation using a circular aperture with a 5″.6 diameter. H1426+428 was reobserved with the same telescope and spectrograph on 1985 May 19 with a circular aperture of 11.2″ diameter, in an attempt to detect absorption features from the host galaxy. The exposure time was 2.0 hr, and the spectrum is shown in Figure 6. One set of very weak features, none of which is individually significant, indicates an absorption-line redshift ~0.129. This result was confirmed at higher resolution, using the same telescope and the Mark III CCD spectrograph. The Mark III observations were made with a 576 pixel Thompson CCD (10 electron readout noise), a 600 line mm^{-1} grism, and a 5″ entrance slit. The CCD spectrum, shown in Figure 7, consists of 3 hr in total exposure time divided among 12 individual spectral images taken during the nights of 1988 February 6 and 11. The observed wavelength range was 5400–6800 Å, with an effective resolution of 9 Å The reduction procedures include the subtraction of a median-averaged image of the electronic bias, and the spectral extractions and calibrations were accomplished using the IRAF software distributed by NOAO. The weak spectral features suggested in Figure 6 are quite convincing in Figure 7; the host galaxy of H1426+428 contributes absorption lines of Na I and Mg I with a redshift of 0.129 ± 0.001.

V. OPTICAL PHOTOMETRY OF THE BL LAC NUCLEI AND HOST GALAXIES

A number of photometric observations have been made of the two BL Lac objects, using both photoelectric photometers and CCD cameras on several different telescopes. A journal of the observations and results is given in Table 2. During each observation we used standard observatory instruments and

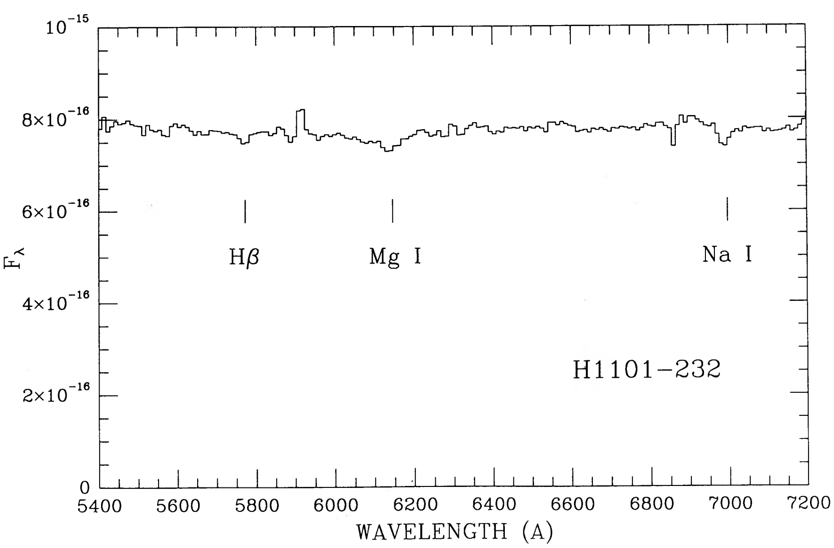

FIG. 5.—A second observation of H1101−232 with the AAT. The spectrum is from the FORS spectrograph, and the observation took place on 1988 February 23. The host galaxy's absorption lines at Hβ, Na I D, and Mg I *b* are confirmed with a redshift of 0.186 ± 0.001.

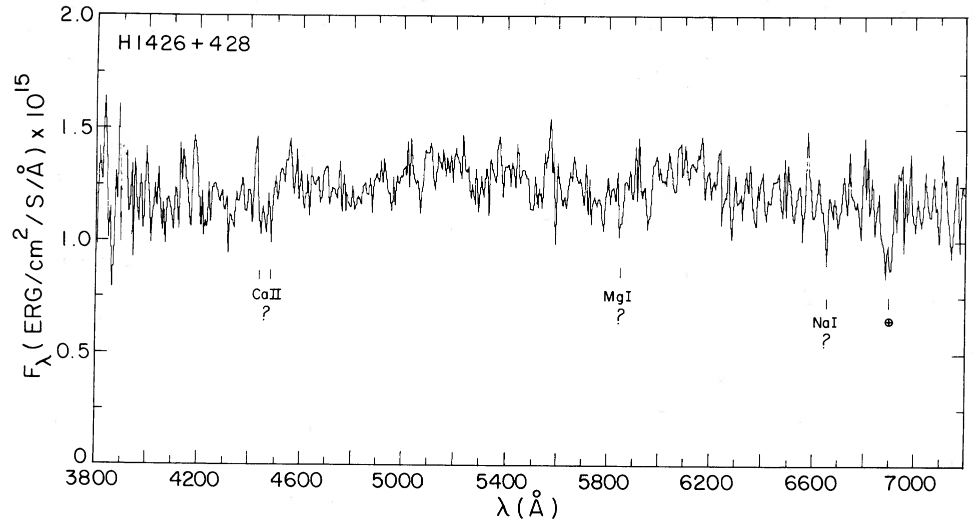

FIG. 6.—The optical spectrum of H1426+428 obtained with the McGraw-Hill 1.3 m telescope on 1985 May 19. We used the Mark II reticon spectrograph with a circular aperture of 11″.2 diameter. The spectrum is essentially featureless, with a hint of absorption features that indicate a possible redshift of 0.129 for the host galaxy.

broad-band filters, and the sky conditions were clear and moonless. Photometric normalizations were accomplished by observing standard stars of Landolt (1983) or Graham (1982). The photometric measurements were made through circular apertures with diameters between 10″ and 12″, and all of the CCD reductions have employed a virtual, square aperture of 10″ width for consistency. We also include spectrophotometric results in Table 2, but only when the observations were made with large apertures, during excellent observing conditions. We have detected only minor evidence of optical variability among the five measurements of H1426+428. However, the nine measurements of H1101−232 indicate a prolonged depression during 1987, when the brightness diminished by more than 0.5 mag.

The CCD images further reveal that both BL Lac objects are the nuclei of substantial (and very similar) nebulosities of low surface brightness. Each host galaxy is evident in *V*-, *R*-, and *I*-filtered images, with a maximum signal to noise in the *R* band. We are able to best describe the host galaxies and deconvolve the flux contributions of the nuclei and starlight by investigating the long exposures obtained with the MASCOT CCD instrument (Ricker *et al.* 1981) and the 2.4 m Hiltner telescope on 1987 January 4. The diameters of the major axes of the host galaxies are ~21″ and 24″ for H1101−232 and H1426+428, respectively, with surface brightness limits of 27.2 R mag. per square arcsec. The position angles (east of north) are ~22° and 118°, respectively.

The deconvolution of the nuclei and the host galaxies can be estimated as follows. The sum of the net counts above the sky background within a large aperture (i.e., ≥24″) effectively measures the total brightness of the nucleus and the host galaxy. Since the host galaxies are much larger than the seeing FWHM (1″.9 for the images under discussion), the brightness profile within the inner 4″ of the nucleus can provide a first-order estimate of the brightness of the isolated nucleus. We fitted the central 4″.2 (6 × 6 pixels) of each BL Lac image to the point-

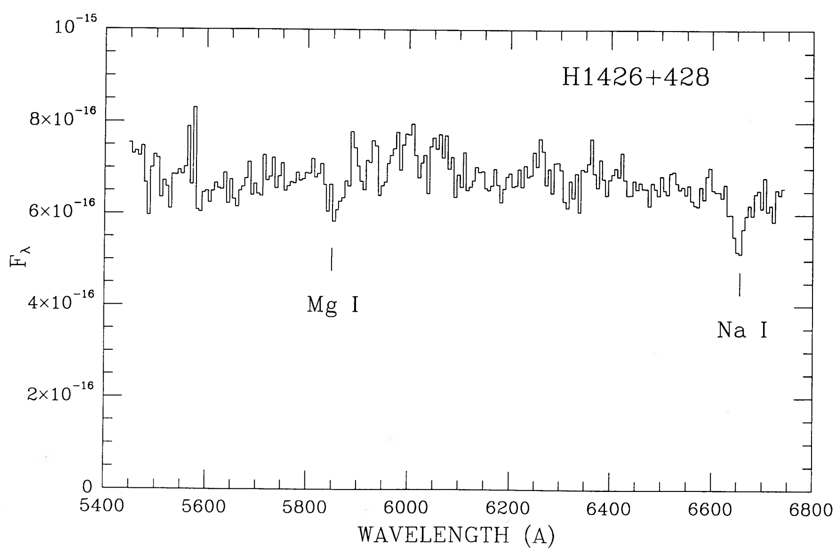

FIG. 7.—A second spectrum of H1426+428 made with the McGraw-Hill 1.3 m telescope and the Mark III CCD spectrograph during 1988 February. Here, the absorption lines of the host galaxy at a redshift of 0.129 are confirmed.

TABLE 2

OPTICAL PHOTOMETRY

UT Date	Telescope	Instrument/Detector	Aperture	V Magnitude
		H1101−232		
1989 Jan 12.5	Hiltner 2.4 m	TI CCD	10″ square	16.76 (±0.02)
1988 Feb 23.7	AAT 3.9 m	IPCS spectrograph	5″ slit	16.69 (±0.10)
1987 May 26.3	ANU 2.3 m	photoelectric	9″ circular	17.19 (±0.04)
1987 Apr 26.0	CTIO 0.9 m	RCA CCD	10″ square	16.83 (±0.04)
1987 Jan 4.5	Hiltner 2.4 m	TI CCD	10″ square	16.94 (±0.02)
1986 Dec 10.4	ANU 2.3 m	photoelectric	9″ circular	17.00 (±0.02)
1986 Feb 6.7	AAT 3.9 m	IPCS spectrograph	7″ slit	16.51 (±0.10)
1985 Jan 17.6	McGraw-Hill 1.3 m	TI CCD	10″ square	16.55 (±0.02)
1984 Feb 4.5	ANU 1.0 m	photoelectric	10″ circular	16.55 (±0.04)
		H1426+428		
1989 Jan 12.6	Hiltner 2.4 m	TI CCD	10″ square	16.54 (±0.02)
1987 Jan 4.6	Hiltner 2.4 m	TI CCD	10″ square	16.42 (±0.02)
1985 May 19.3	McGraw-Hill 1.3 m	Reticon spectrograph	11″ circular	16.2 (±0.1)
1985 Jan 17.6	McGraw-Hill 1.3 m	TI CCD	10″ square	16.44 (±0.02)
1983 Mar 11.5	KPNO 1.0 m	photoelectric	12″ circular	16.42 (±0.02)

spread function represented by a bright field star on the same CCD image. The fit employs a minimum χ^2 solution for an object's location, the local sky background, and the object's brightness relative to the reference star, which is calibrated via the usual, large-aperture photometry. The point-spread function is defined in the manner of "daophot," i.e., we employ a two-dimensional Gaussian function coupled with an empirical correction table that is interpolated with a bivariate cubic spline. For the point-spread fit applied to the BL Lac nuclei, the local background is limited to a 2″ annulus beginning at a radius ~2″ from the BL Lac nucleus. This background area contains surface brightness from the host galaxy, and this method for calculating the nuclear brightness causes an overestimate only to the extent that the host galaxy's gradient within the inner 20% of its radius is significant compared to the brightness of the BL Lac nucleus. We computed the total brightness and the point-spread determination of the nuclear brightness for each BL Lac object from the V-band and R-band images obtained during 1987 January. The deconvolved brightness of the host galaxy of H1101−232 is $V = 18.3$, while the host galaxy of H1426+428 is brighter, at $V = 17.6$. The rms errors for each set of V-band images is 0.05 mag. The host galaxies have similar color indices, $V-R \sim 0.70$ and 0.84 for H1426+428 and H1101−232, respectively.

When the redshifts are considered, the absolute magnitudes of these galaxies are $M_v \sim -22.1$ for H1426+428 and $M_v \sim -22.3$ for H1101−232, assuming $H_0 = 50$ km s^{-1} Mpc^{-1} and galactic A_v values of 0.1 and 0.2 mag, respectively, estimated from the integrated 21 cm measurements of H I in each direction (Stark *et al.* 1989). These large (diameters ≥ 100 kpc) and luminous galaxies are similar to giant ellipticals or to the cD galaxies sometimes found in clusters.

The CCD R-band images of the BL Lac objects further suggest that each host galaxy may be the central member of a cluster or group of galaxies. There appear to be 15–20 marginally resolved objects within 2′ of H1426+428, with a roughly symmetric distribution around the BL Lac object, and a very similar condition (~15 objects) appears in the case of H1101−232 as well. These objects are similar in color to the host galaxies, and the net counts in V-band images imply a brightness range of $22 < V < 20$. Spectroscopic observations are required to confirm that these objects are physically associated. Only a few other BL Lac objects are known to be members of clusters or groups of galaxies (see Weistrop *et al.* 1983).

Polarization measurements of H1101−232 were made using the "Minipol" polarimeter and the 1.0 m telescope at Las Campanas Observatory during 1985 March. The linear polarization in a broad optical bandpass ($CuSO_4$ filter) was 2.7% ± 0.3% with a position angle of 52°, confirming the BL Lac classification. We do not have optical polarization measurements of H1426+428.

VI. EXOSAT OBSERVATIONS OF H1426+428

The BL Lac object H1426+428 was observed with *EXOSAT* between 1985 January 12.89 and January 13.13 UT. The LE detector (0.1–2.0 keV) measured a single point source at the position of the optical/radio source, and the mean count rate was 0.279 ± 0.008 counts s^{-1} through the thin lexan filter. The ME detector halves were swapped during the observation, so that each half observed both the source and background positions in an alternating manner. The net ME spectrum shows significant source counts between argon PHA channels 5 and 33 (1–8 keV). The X-ray background flux appears to be stable during the observation, since all of the argon PHA channels between 34 and 128 and all of the xenon PHA channels show net flux levels that are consistent with the value ~0.0, which is to be expected for faint (1–2 millicrab) X-ray sources. A deadtime correction of 10% was applied to the source fluxes in each of the ME energy channels.

The ME spectrum and LE flux were simultaneously fitted by a power-law model ($F_\nu \alpha \nu^{-\alpha}$, where α is the X-ray energy index), combined with photoelectric absorption due to the column density of material along the line of sight (N_H). The best fit was determined by computing the model parameters that minimize χ^2, and the analysis was accomplished under the auspices of the X-ray group at the University of Leicester, England (see Pounds *et al.* 1984). A reduced χ^2 value of 1.047 (27 degrees of freedom) was obtained for $\alpha = 1.19$ (−0.06, +0.09) and $N_H = 2.7$ (−0.6, +0.9) × 10^{20} cm^{-2}. The uncertainties indicated within parentheses are 90% confidence limits assuming the other spectral parameters remain fixed. The data and the best-fit model are shown in Figure 8.

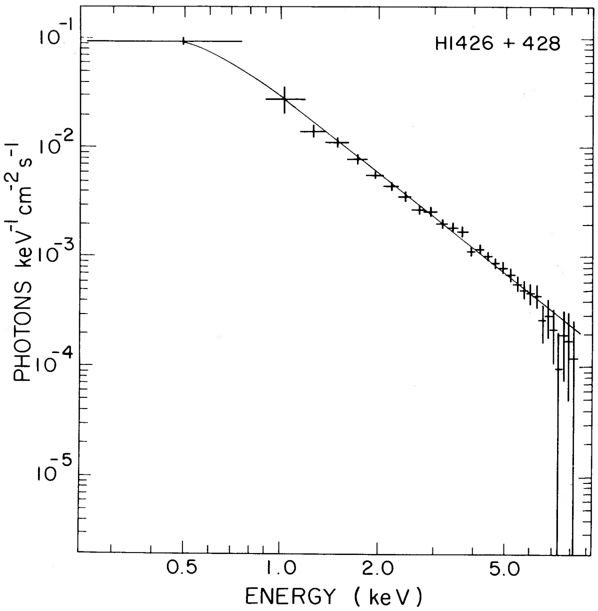

FIG. 8.—The X-ray spectrum of H1426+428 obtained with EXOSAT. The flux-calibrated data points and error bars are drawn along with the best fit (*smooth, solid line*) obtained by minimizing χ^2 for a power-law model with photoelectric absorption by intervening gas. The lowest energy data point is the flux from the LE instrument with the thin lexan filter, and the remaining data points are from the argon energy channels (5–33) of the ME detector. The best fit is obtained for an energy index of 1.2 (equivalent to a photon number slope of 2.2 in the figure), with a column density of 2.7×10^{20} cm^{-2}.

The energy index, $\alpha = 1.19$ (equivalent to a photon number index of 2.19) is typical of BL Lac objects (Worrall *et al.* 1981; Madejski 1985) and is steeper than the value $\alpha = 0.7$ usually obtained for QSOs and Seyfert galaxies of comparable flux levels (Mushotzky *et al.* 1980; Petre *et al.* 1984; Pounds *et al.* 1984). The integrated 2–10 keV X-ray flux from *EXOSAT* is 3.6×10^{-11} ergs cm^{-2} s^{-1}, which is similar to the flux implied by the LASS count rate (see § II). The derived X-ray column density is only slightly above the expected amount of material along the line of sight in the Galaxy, since $\sim 1.5 \times 10^{20}$ cm^{-2} of neutral H is inferred from radio measurements at 21 cm in directions near the position of the BL Lac object (Stark *et al.* 1989).

The ME and LE observations were divided into four sections of ~ 1.4 hr each to investigate X-ray variability within the 5.6 hr observation of the H1426+428 with *EXOSAT*. No variations were found, with upper limits (3 σ) on a 1–2 hr time scale of 20% in the energy range of 0.1–2.0 keV and 15% in the range of 3–8 keV.

An X-ray spectrum is not available for H1101−232, since it was not a target of either *Einstein* or *EXOSAT* observatories.

VII. DISCUSSION

The three most sensitive all-sky surveys at X-ray energies have detected both H1101−232 and H1426+428. Thus the X-ray emission of each BL Lac appears to be persistent, although the flux may vary by a factor of 2. Optical variability has been detected only in the case of H1101−232, with variability time scales of order 1–15 months. We are motivated to compare the average X-ray, optical, and radio flux densities to deduce the overall shape of the BL Lac spectra, and we will avoid the 1987 optical dip of H1101−232 when averaging the optical flux for comparison with the measurements at other frequencies. Table 1 lists the values for some of the commonly used spectral indices in order to compare the two BL Lac objects with others in the literature. The spectral indices describe power-law relations connecting the flux densities between 2 keV and 4000 Å (β_{ox}) and between 4000 Å and 20 cm (β_{ro}), each in the rest frame of the BL Lac object. The calculation of β_{ox} also assumes an X-ray energy index of 1.2 for both sources, and the extinction estimates for the optical fluxes were stated in § V. We extrapolate to the more frequently used indices α_{ox} (2 keV–2500 Å) and α_{ro} (2500 Å–6 cm), assuming an intrinsic optical/UV energy index of 1.7 and a radio index of 0.0. These results are also given in Table 1. The locations of H1101−232 and H1426+428 in the α_{ro}, α_{ox} plane can be compared to others shown in Figure 11 of Stocke *et al.* (1985) or Figure 2 of Ledden and O'Dell (1985; with a slightly different definition of the α indices). The two BL Lac objects are clearly within the subgroup noted for strong X-ray and modest radio flux, relative to the optical flux.

The cases presented here support the contention by Stocke *et al.* (1985), that BL Lac objects in which the host galaxies contribute a substantial fraction of the total optical flux are likely to be powerful X-ray emitters with high values of the flux ratio f_x/f_{opt} (i.e., low values of α_{ox} and β_{ox}). BL Lac objects dominate the group of AGNs with the highest f_x/f_{opt} ratios, as measured by the instruments of the *HEAO 1* survey, although there is a very wide distribution in the flux ratio for the BL Lac class as a whole. The two new identifications appear to be prime examples of X-ray luminous BL Lac objects with very high values in the ratio of f_x/f_{opt}. The values of the spectral index β_{ox} (Table 1) are significantly lower than those derived for a group of emission-line AGNs discovered as *HEAO 1* sources (Remillard *et al.* 1986).

The host galaxies of H1101−232 and H1426+428 appear to be similar to the large elliptical galaxies underlying several luminous and nearby BL Lac objects such as Mrk 421, Mrk 501, and 2A1219+305 (Ulrich *et al.* 1975; Weistrop, Smith, and Reitsema 1979; Weistrop *et al.* 1981). The latter galaxies have absolute magnitudes near $M_v = -22$, and visual diameters ~ 50 kpc (assuming $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$). The host galaxies of H1426+428 and H1101−232 are larger than these elliptical hosts, but they are smaller than the huge galaxy ($M_v \sim -23$) associated with the BL Lac object 1E 1415.6+2557 (Halpern *et al.* 1986).

Thusfar, in our program to identify *HEAO 1* optical counterparts, the numbers of BL Lac objects and other types of AGNs (i.e., QSOs and Seyfert galaxies) are entirely consistent with the statistics (four persistent BL Lacs + 1 flaring case vs. 28 emission-line AGNs) from the complete sample of high-latitude X-ray sources detected by the *HEAO 1* A-2 experiment (Piccinotti *et al.* 1982). The detection limit of the *HEAO 1* LASS survey is about a factor of 6 lower than the flux limit of the Piccinotti sample; as of 1988 December, there are 24 BL Lac objects and 133 emission-line AGNs among the identified portion of the LASS catalog (an incomplete sample, which does include all of the Piccinotti identifications). Therefore, the latest assessment of the *HEAO 1* survey strongly confirms the abundance of BL Lac objects at high X-ray flux levels. We are not beginning to sense the drastic reduction in the space density of BL Lac objects at X-ray fluxes that are lower than the Piccinotti limit by a factor of 10–100 (Schwartz and Ku 1983; Maccacaro *et al.* 1984; Giommi *et al.* 1989). Among the ~ 180 unidentified LASS sources at high galactic latitude

($|b| > 20°$), we estimate there are ~13 BL Lac objects awaiting discovery.

The real interest in the number versus flux discrepancy between BL Lacs and emission-line AGNs is the implication that there are separate evolutionary factors or luminosity distributions governing the space densities of the various AGN types. The *HEAO 1* BL Lacs are especially useful in studying this problem, since so many of them (14 of 24 currently) have measured redshifts. The subset of *HEAO*–LASS sources that constitutes a flux-limited, high-latitude sample (347 sources with 2–10 keV flux > 0.85 millicrab) may provide important constraints on the X-ray luminosity function of nearby BL Lac objects. A casual inspection of the current LASS–MC identifications suggests that the luminosity function ($N \propto L^{-\gamma}$) of BL Lacs appears significantly flatter (i.e., lower γ) than that of broad-line Seyferts and QSOs. A rigorous evaluation will be possible when the optical identification process is nearly complete. The high space density of nearby X-ray–selected BL Lacs has supported the suggestion that their parent population is the class of elliptical radio galaxies with relativistic beams that are not pointed along our line of sight (Browne 1983). With the perspective of recent X-ray identifications, this hypothesis continues to be a viable possibility.

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