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BROADBAND OPTICAL OBSERVATIONS OF BL LACERTAE DURING THE 1997 OUTBURST

James R. Webb,[1] Ian Freedman,[1,2] Emily Howard,[1] Feng Ma,[3] Michelle Belfort,[1] Heather Rave,[1,2] Ken Rumstay,[4] Susan Nicol,[2,4] Jessica Krick,[2,4] Terry D. Oswalt,[5] Daniel Marshall,[2,5] and Tim Robishaw[2,5]

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ABSTRACT

We present *BVRI* observations of BL Lacertae during its recent outburst. These observations, made during a 3 month period, cover a significant portion of the optical flare. The reduced data are displayed as light curves and broadband spectra. Changes in the spectral index are analyzed, and the results are compared with previous BL Lac observations. We find that the variations are simultaneous in the optical bands, but the higher frequency bands show a higher amplitude of variability. The spectral index is variable during the active period, and there is marginal evidence that the spectrum flattens as the source gets brighter.

Key words: BL Lacertae objects: general

1. INTRODUCTION

The blazar BL Lacertae underwent an optical outburst during the summer of 1997 (T. J. Balonek 1997, private communication). This source has a history of rapid, high-amplitude flares (Webb 1996) that generally occur on timescales of weeks. The 1997 flare, however, is unique in that it lasted for several months and attained an extremely bright magnitude. BL Lac is regularly observed at the SARA Observatory as part of an ongoing blazar-monitoring program, so data presented here extend back to 1996 June. In response to the 1997 flare, BL Lac was observed in *B*, *V*, *R*, and *I* at the SARA Observatory and at the McDonald Observatory as often as the schedule and weather permitted.

The SARA data are CCD images taken through the 0.91 m telescope at Kitt Peak using the Axiom/Apogee 16 bit 2048 × 2048 CCD camera with a Kodak KAF-4200 grade 0 chip. The images were stored in FITS format and reduced in IRAF using the standard CCD reduction and aperture photometry programs. The filters were standard Johnson and Cousins *BVRI* filter sets made for the CCD.

The McDonald data utilized the 0.76 m telescope and CCD with standard *BVRI* filters. IRAF aperture photometry was used to reduce those images as well. The instrumental magnitudes from both sets of data were then calibrated using four of the standard stars in the BL Lac field given in Smith et al. (1985).

2. ANALYSIS

The *R*-band light curve of BL Lac is plotted in Figure 1. The data in Figure 1 are a combination of observations presented here and data from IAU Circulars (Noble et al. 1997; T. J. Balonek 1997, private communication). Figure 1 shows the multipeaked nature of the outburst from 1996 June through 1997 August, similar to other BL Lac outbursts (Pollock 1982). The 1997 June observations represented the brightest BL Lac had ever been measured, although subsequent observations (T. J. Balonek 1997, private communication) showed that the outburst continued and became even brighter after our observations ended. Table 1 lists the Julian Date, the site where the observations were made, and the *B*, *V*, *R*, and *I* magnitudes. BL Lac routinely shows microvariability in the optical (Carini 1990) and exhibited significant microvariability during this outburst (Mattei 1997); thus, combining observations taken even hours apart adds error, since the source could have varied by several hundredths or a tenth of a magnitude during that time. Whenever we did combine images taken on the same night, they were never more than 15 minutes apart, and the standard deviation of the individual image magnitudes was added to the error for each image in quadrature to account for possible microvariability during the averaging period. Light curves for the bands *B*, *V*, *R*, and *I* are shown in Figure 2. The variations seen in the light curves are consistent with no time delays between the spectral bands.

We converted the calibrated magnitudes to flux using a reddening of $E(B-V) = 0.36$. The fluxes were also corrected for the underlying galaxy, considering aperture size and color system, using the derived flux densities of the host galaxy of BL Lac given by Brown et al. (1989). Figure 3 shows the corrected broadband spectra of BL Lac from JD 2,450,627 through 2,450,652. A close examination of the spectra implies that the spectrum apparently flattens as the brightness of the source increases. Table 2 lists the dates, the *R* fluxes, and the slopes and errors calculated for each of the spectra for which we had *BVR* and *I* observations. A tremendous amount of variability is evident in the plots. The spectral indices range from 0.2 ± 0.2 to -0.8 ± 0.13, with a mean of -0.48 (16 spectra). A study by Brown et al. (1989) showed the spectral index of BL Lac in the optical ranged from -1.6 ± 0.2 to -2.2 ± 0.2 with a median of -2.0 (four spectra). Multicolor data from Smith (1986) were reanalyzed here, consistently with the new data; the resulting spectral indices had an average of -1.21, with maximum

[1] Department of Physics, Florida International University, Miami, FL 33199, and the SARA Observatory; webbj@servax.fiu.edu.

[2] Visiting Observer at the SARA Observatory on Kitt Peak, which is owned and operated by the Southeastern Association for Research in Astronomy.

[3] Department of Astronomy, RLM 15.308, University of Texas at Austin, Austin, TX 78712.

[4] Department of Physics, Astronomy, and Geosciences, Valdosta State University, Valdosta, GA 31698; and the SARA Observatory.

[5] Astronomy Group, Department of Physics and Space Sciences, Florida Institute of Technology, Melbourne, FL 32901-6988; and the SARA Observatory.

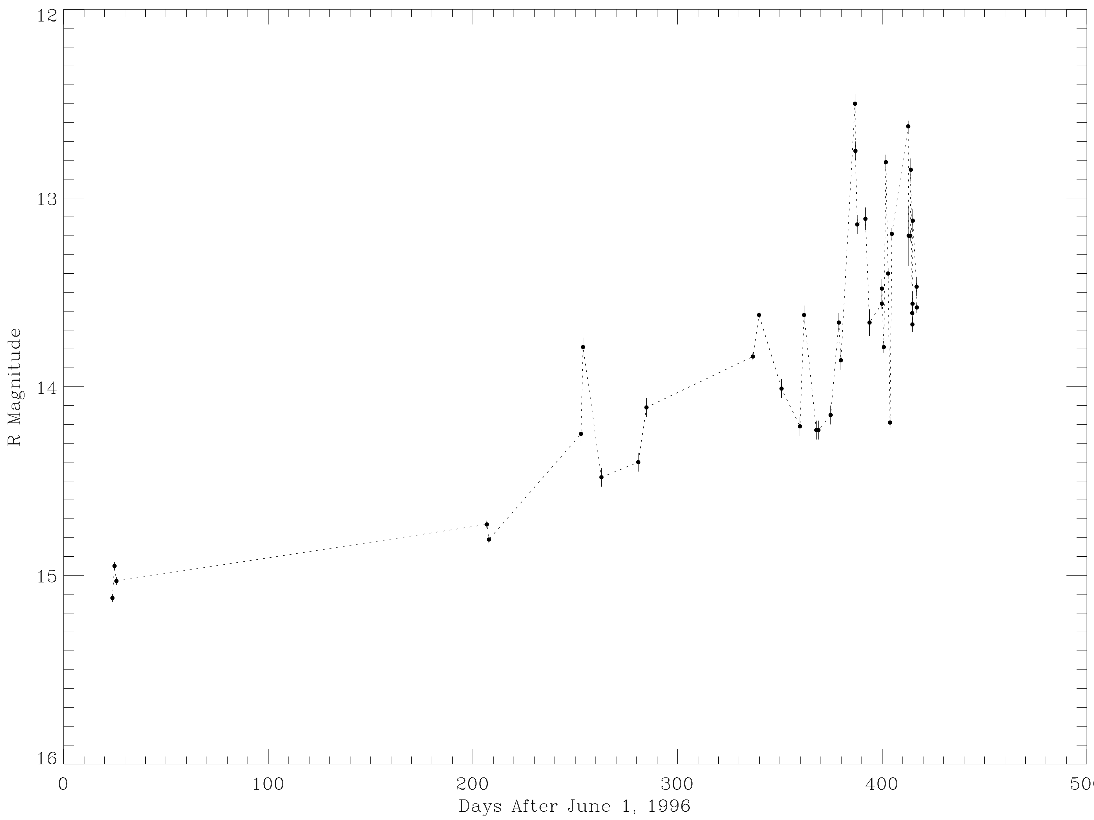

FIG. 1.—*R*-band light curve of BL Lac

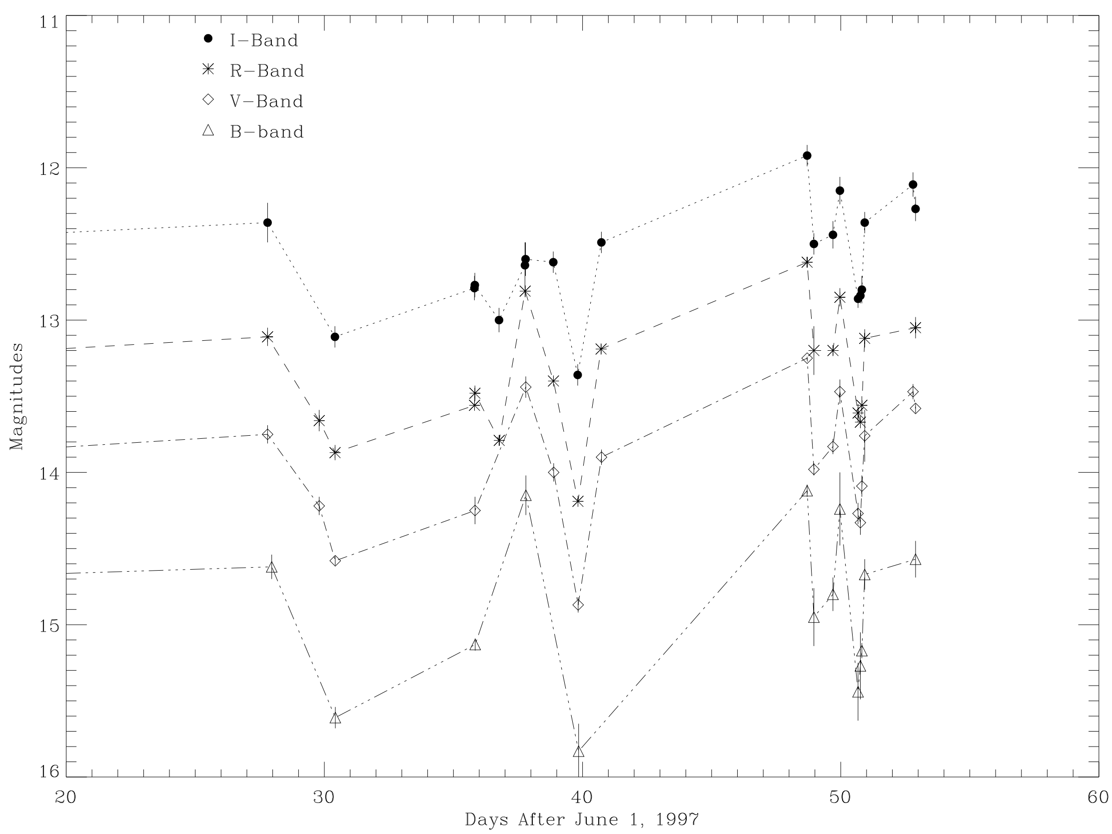

FIG. 2.—*BVRI* light curves of BL Lac during the 1997 outburst

TABLE 1

PHOTOMETRIC OBSERVATIONS OF BL LACERTAE

JD (2,400,000+)	*B*	*V*	*R*	*I*
SARA:				
50,259.850......	...	15.87 (0.02)	15.12 (0.02)	14.26 (0.03)
50,260.880......	16.60 (0.03)	15.61 (0.02)	14.95 (0.02)	14.04 (0.03)
50,261.800......	...	15.74 (0.02)	15.03 (0.02)	14.24 (0.03)
50,442.800......	...	...	14.73 (0.02)	14.24 (0.03)
50,443.800......	...	...	14.81 (0.02)	13.98 (0.03)
50,444.800......	...	...	...	14.00 (0.03)
50,572.800......	...	14.52 (0.02)	13.84 (0.02)	12.78 (0.03)
50,575.800......	...	14.30 (0.02)	13.62 (0.02)	12.79 (0.03)
50,627.800......	14.62 (0.08)	13.75 (0.04)	13.11 (0.06)	12.36 (0.13)
50,629.800......	...	14.22 (0.06)	13.66 (0.07)	...
50,635.811......	...	...	...	12.79 (0.08)
50,635.815......	...	...	13.56 (0.3)	...
50,635.827......	...	...	...	12.77 (0.08)
50,635.832......	...	...	13.48 (0.05)	...
50,635.837......	...	14.25 (0.09)	...	...
50,635.842......	15.13 (0.04)	...	...	...
50,636.767......	...	...	...	13.00 (0.08)
50,636.773......	...	...	13.79 (0.03)	...
50,637.771......	...	...	...	12.64 (0.15)
50,637.776......	...	...	12.81 (0.04)	...
50,637.794......	...	...	...	12.60 (0.11)
50,637.801......	...	13.44 (0.07)	...	...
50,637.803......	14.15 (0.13)	...	...	...
50,638.868......	...	...	...	12.62 (0.07)
50,638.874......	...	...	13.40 (0.03)	...
50,638.881......	...	14.00 (0.06)	...	...
50,639.814......	...	...	...	13.36 (0.07)
50,639.823......	...	...	14.19 (0.03)	...
50,639.831......	...	14.87 (0.05)	...	...
50,639.847......	15.83 (0.18)	...	...	...
50,640.720......	...	...	13.19 (0.03)	...
50,640.730......	...	...	...	12.49 (0.07)
50,640.736......	...	13.90 (0.05)	...	...
McDonald:				
50,648.700......	14.12 (0.04)	13.25 (0.01)	12.62 (0.03)	11.92 (0.07)
50,648.960......	14.95 (0.19)	13.98 (0.04)	13.20 (0.16)	12.50 (0.07)
50,649.700......	14.80 (0.11)	13.83 (0.05)	13.20 (0.03)	12.44 (0.09)
50,649.970......	14.24 (0.24)	13.47 (0.08)	12.85 (0.09)	12.15 (0.09)
50,650.670......	15.44 (0.19)	14.27 (0.07)	13.61 (0.06)	12.86 (0.06)
50,650.760......	15.27 (0.22)	14.33 (0.08)	13.67 (0.04)	12.84 (0.05)
50,650.820......	15.17 (0.05)	14.09 (0.07)	13.56 (0.06)	12.80 (0.09)
50,650.930......	14.67 (0.10)	13.76 (0.17)	13.12 (0.06)	12.36 (0.07)
50,652.800......	...	13.47 (0.05)	...	12.11 (0.08)

TABLE 2

R-BAND FLUX AND SPECTRAL INDICES

JD (2,400,000+)	log Flux[a]	Spectral Index
50,260.0......	−25.312	−0.67 (0.04)
50,522.0......	−24.809	−0.79 (0.17)
50,627.0......	−24.486	−0.47 (0.15)
50,630.0......	−24.809	−0.79 (0.13)
50,635.0......	−24.658	−0.69 (0.11)
50,637.0......	−24.362	+0.21 (0.19)
50,639.0......	−24.950	−0.48 (0.14)
50,648.7......	−24.283	−0.37 (0.09)
50,648.9......	−24.524	−0.62 (0.16)
50,649.7......	−24.524	−0.44 (0.14)
50,649.9......	−24.378	−0.28 (0.21)
50,650.6......	−24.697	−0.57 (0.14)
50,650.7......	−24.723	−0.67 (0.15)
50,650.8......	−24.674	−0.67 (0.11)
50,650.9......	−24.490	−0.63 (0.16)
50,652.9......	−24.461	−0.26 (0.13)

[a] Flux in ergs s^{-1} cm^{-2} Hz^{-1}.

near −0.79 and minimum of −1.64 (17 spectra). The spectrum is apparently flatter during the current outburst than in either the Smith or the Brown et al. observations. Figure 4 shows the spectral distributions for the Smith data. The spectral slope is plotted versus *R* magnitude in Figure 5. There is an apparent correlation in the sense that as the object brightens, the spectrum becomes flatter, but statistically the effect is not significant. The slope of a fitted line is 0.27 ± 0.06, but the formal correlation coefficient is only 0.6. A similar correlation study using the Smith data yielded an even smaller correlation coefficient (0.4) and a slope of −1.0 ± 1.9. There is considerable curvature present in the outburst data, which is not seen in the Brown et al. data and only marginally present in the Smith data. The excess emission is in the *V* band.

3. DISCUSSION

The data presented here show that the optical slope varies, because the amplitude for variability is larger toward

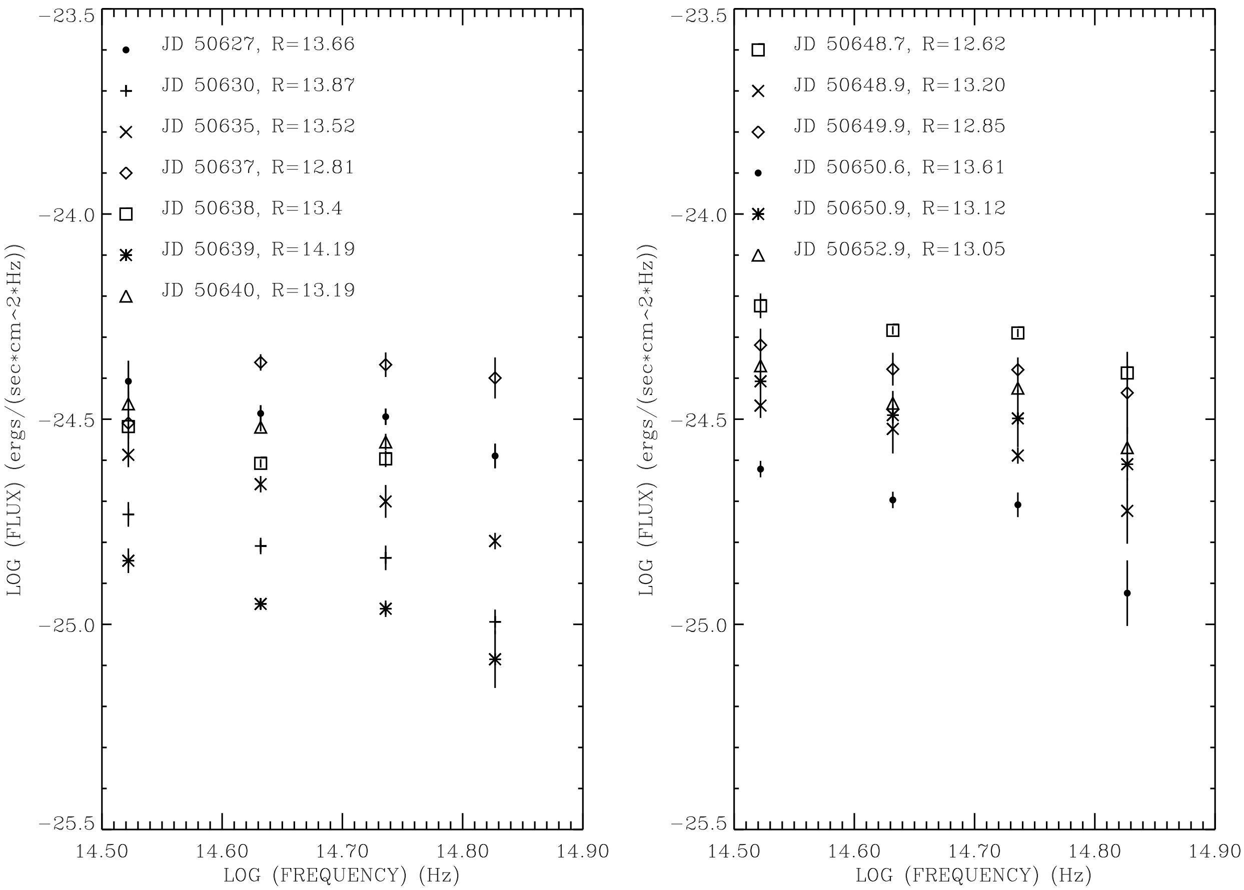

FIG. 3.—Broadband spectra of BL Lac during the 1997 outburst

the blue end of the spectrum than the red. Since we have taken out the nonvariable galactic component, and polarization measurements rule out a strong thermal accretion disk component (Smith 1986), there remain three possible physical explanations for the wavelength-dependent variability. If the nonthermal continuum emission is due to a synchrotron source, then either the electron spectral distribution changes slope, the turnover frequency is variable and located in the optical, or there is more than one variable synchrotron component, each contributing to the optical continuum and varying separately. Adequate characterization of the synchrotron spectrum and determination of the turnover and break frequencies require a much larger spectral distribution than is presented here, so we are not able to distinguish between these possible models without inclusion of IR, radio, and millimeter data.

During this well-observed outburst, several satellite observatories including the *Rossi X-Ray Timing Explorer*, the *Compton Gamma Ray Observatory*, and *ROSAT* observed BL Lac. Flux measurements from EGRET indicated that BL Lac was brighter in gamma rays than seen in previous observations. Bloom et al. (1997) report a flux level of 1.7×10^{-6} photons cm^{-2} s^{-1} over a 2.3 day period, peaking around July 19. This flux is at least a factor of 4.0 brighter than all previous EGRET observations. BL Lac was also detected by OSSE (Grove & Johnson 1997) and was 4 times brighter than its previous high state in X-rays (Madejski, Jaffe, & Sikora 1997; Makino et al. 1997). As can easily be seen in Figure 1, the optical activity is very complex, with a major peak occurring in June and another in July. This "multipeak" morphology is a characteristic of many BL Lac optical flares and makes it extremely difficult to associate particular optical peaks with corresponding X-ray or gamma-ray peaks. If the optical peak on July 20 ($R = 12.62$) is causally associated with the gamma-ray peak on July 19, then there is apparently less than a day's delay, with the gamma-ray peak possibly leading the optical peak (Bloom et al. 1997). The gamma-ray spectrum apparently hardened during the outburst, similarly in character to the optical spectrum, which is consistent with the gamma rays being produced as a result of Compton scattering off of the same synchrotron components present in the optical.

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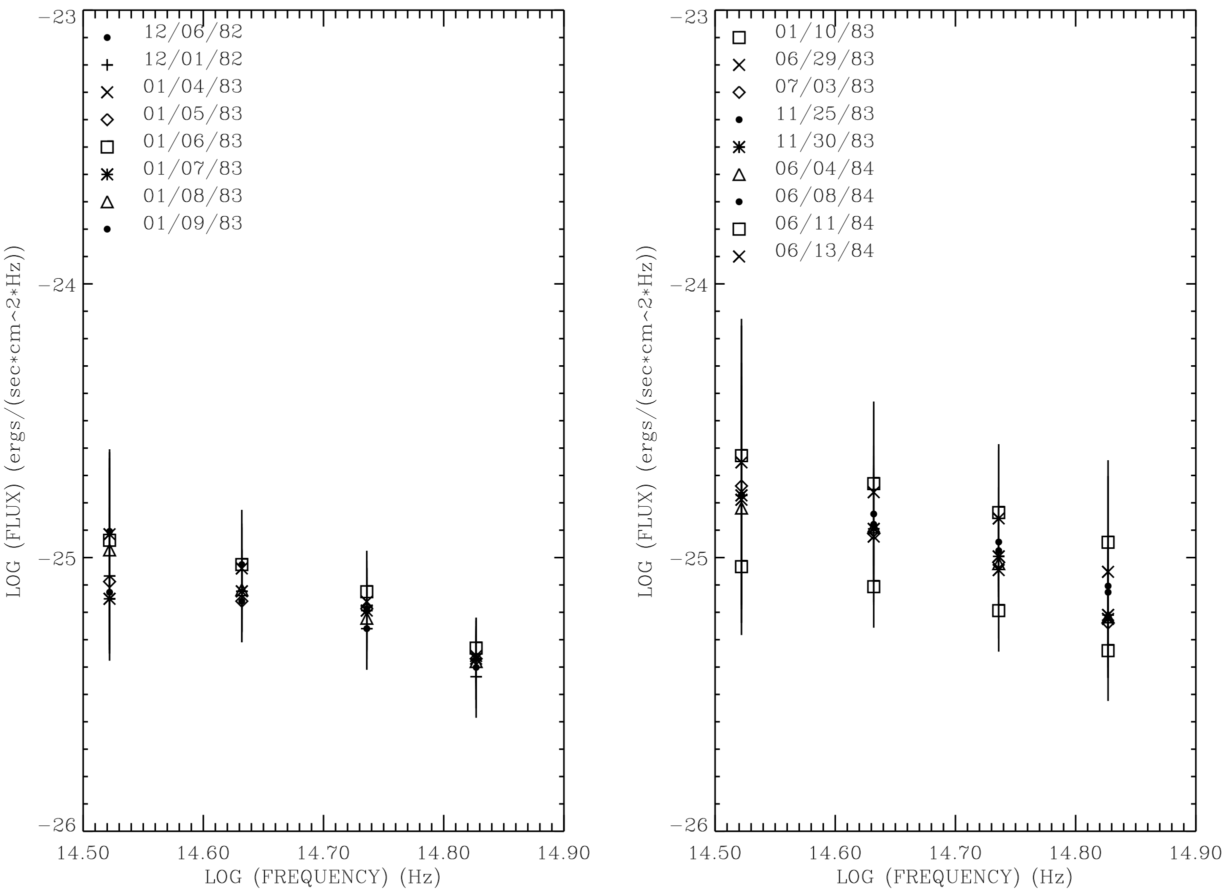

Fig. 4.—Broadband spectra of BL Lac in 1982 and 1983 from Smith (1986)

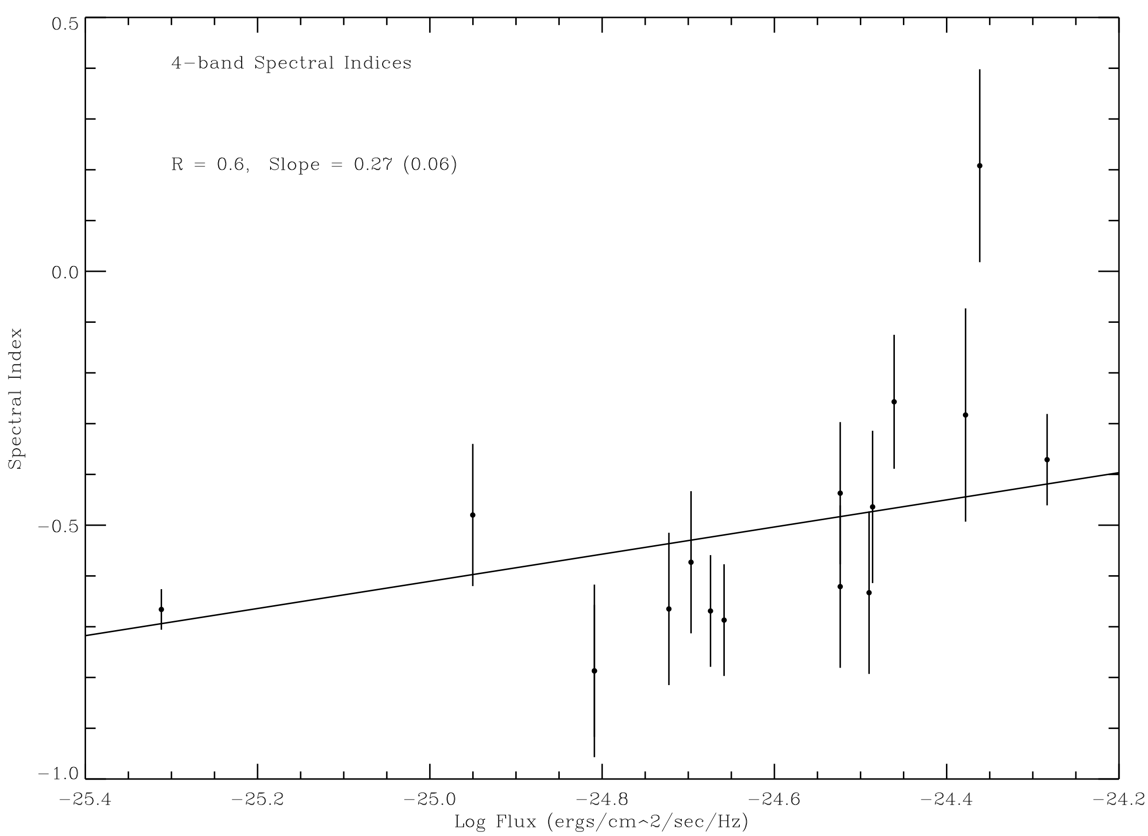

Fig. 5.—Spectral index vs. log (flux)

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