THE ASTRONOMICAL JOURNAL, 121:90–96, 2001 January

MULTIBAND MICROVARIABILITY OBSERVATIONS OF BL LACERTAE DURING THE OUTBURST OF 1997

S. D. CLEMENTS
Department of Physics and Space Sciences, Florida Institute of Technology, Melbourne, FL 32901; clements@astro.fit.edu

AND

M. T. CARINI
Department of Physics and Astronomy, Western Kentucky University, Bowling Green, KY 42101; carini@wku.edu
Received 2000 August 16; accepted 2000 August 19

ABSTRACT

BL Lac was observed in the V and R bands on 11 nights in 1997 July during a major optical outburst. It varied continuously, exhibiting nightly variations ranging from 0.1 to 0.6 mag. Over the course of the 11 nights, BL Lac was seen to vary by 1.8 R magnitudes. Color variations were also observed, with BL Lac becoming bluer as it brightened. The influence of variable seeing conditions on the observed variations was investigated. No correlation was found between the observed microvariability and the local seeing conditions.

Key words: BL Lacertae objects: general — BL Lacertae objects: individual (BL Lacertae) — galaxies: photometry

On-line material: machine-readable tables

1. INTRODUCTION

1.1. *BL Lacertae*

BL Lacertae is the prototype for a class of active galactic nuclei (AGNs) having nonthermal spectral energy distributions with weak or undetectable emission lines (EW < 5 Å; Stickel, Fried, & Kühr 1993), strong, variable polarized emission, and highly variable continuum emission at all wavelengths (Angel & Stockman 1980). In the spring of 1995, Vermeulen et al. (1995a, 1995b) detected a broad Hα line in BL Lac with EW > 5 Å, confusing its classification. This, however, does not alter its classification as a blazar. Blazars, a class made up of optically violent variable quasars, high-polarization quasars, and BL Lac objects (Impey 1987), share a number of interesting properties. A blazar's highly polarized continuum varies rapidly in flux and polarization (Angel & Stockman 1980; Impey & Neugebaur 1988). In addition, blazars are compact, flat-spectrum radio sources, often exhibiting apparent superluminal motion (Impey 1987). These characteristics are usually attributed to synchrotron emission from a relativistic jet with its jet axis oriented at small angles to the observer's line of sight.

1.2. *Long-Term Light Curve*

Originally classified as a variable star (hence its variable-star moniker), BL Lac has been observed at optical wavelengths for over 100 years. Its long-term optical light curve, compiled by Webb et al. (1988) and, more recently, by Fan et al. (1998), shows very rapid flares of amplitude 1–2 mag occurring repeatedly prior to 1982, at which time it appears to have undergone a marked change in behavior. Since 1982, relatively few flaring events were superposed on its slowly varying light curve. Observations by Bai et al. (1999) and Maesano et al. (1997) showed it to be fairly faint and relatively stable in 1995 and 1996. Then, in 1997 May, BL Lac brightened dramatically (Noble et al. 1997). The plethora of observations that followed showed erratic flaring activity reminiscent of its behavior before 1982. Today, the widespread use of CCD technology allows much more complete temporal coverage of the rapidly varying source at optical wavelengths than was possible before 1982. Numerous observers targeted BL Lac at a variety of wavelengths during the summer (including Bloom et al. 1997; Madejski et al. 1999; Massaro et al. 1998; Nesci et al. 1998; Speziali & Natali 1997; Webb et al. 1998), many monitoring this source for microvariability.

1.3. *Microvariability*

Microvariability, also known as intraday variability, has been defined as rapid flux variations with timescales significantly shorter than a day (Miller, Carini, & Goodrich 1989). These flux variations may be discrete events or part of a longer timescale trend (Carini et al. 1992). Speculation on the mechanism responsible for microvariability has included interstellar scintillation, superluminal microlensing, hot spots on an accretion disk surrounding the nucleus, and various jet models (Gopal-Krishna, Sagar, & Wiita 1993 and references therein).

The presence of microvariability in BL Lac was reported as early as 1970 (Racine 1970; Tritton & Bret 1970), with variations of up to 0.1 mag hr^{-1} reported. Further compelling evidence of microvariability in BL Lac was presented by Miller et al. (1989). In their study, repeated short exposures were made of BL Lac over the course of a night, revealing unmistakable small-amplitude variations of up to ∼ 0.8 mag with timescales of 1–2 hr.

In this paper, multiband (V and R) microvariability observations of BL Lac during the summer of 1997 are examined.

2. OBSERVATIONS

Following initial reports of its outburst, BL Lac was observed on 11 nights in 1997 July. Observations were made at the Newtonian focus of the 0.76 m (30 inch) telescope at the University of Florida's Rosemary Hill Observatory (RHO) in Bronson, Florida. The detector was a Photometrics Star-1 CCD camera. When set up for use with the CCD, the effective focal ratio is f/5.01. BL Lac and four

TABLE 1

INFORMATION FOR THE FOUR COMPARISON STARS OF SMITH ET AL. 1985

Star	Smith et al. 1985 Star	V	ΔV	R	ΔR	$V-R$	$\Delta(V-R)$
C1......	B	12.78	0.04	11.93	0.05	0.87	0.09
C2......	C	14.19	0.03	13.69	0.03	0.50	0.06
C3......	K	15.44	0.03	14.88	0.05	0.56	0.08
C4......	H	14.31	0.05	13.60	0.03	0.71	0.10

comparison stars were imaged simultaneously on the Star-1 camera's 11′50″ × 7′50″ field. Exposures were made alternately through Johnson V and Cousins R filters. In all, 299 exposures were made, 147 in V and 152 in R. Typical exposure times were 180 s through the V filter and 40 s through the R filter. Exposures were longer when BL Lac was fainter, up to 360 s for V exposures and 60 s for R exposures.

3. DATA REDUCTION

After the effects of the bias offset, thermal noise, and the nonuniform sensitivity of the pixels were removed from each CCD frame, magnitudes were measured using the aperture photometry tool of the MIRA AP 5.0 software package. With this tool, the counts within an aperture centered on the object are compared with the counts within an annulus on the sky surrounding the aperture. After testing a number of aperture sizes, we used an aperture with a 5 pixel radius (1 pixel = 1″.23). The sky annulus extended from 5 to 10 pixels from the object centroid.

The four comparison stars of Smith et al. (1985) were used, one as a comparison star for determining the sky value for each exposure, and the other three as check stars to indicate the uncertainty in the measured magnitudes. Table 1 lists the designations used in this paper for these

TABLE 2A

NIGHTLY AND OVERALL MEAN V MAGNITUDES FOR BL LACERTAE AND THE CHECK STARS, WITH THEIR STANDARD DEVIATIONS (σ_V)[a]

		BL LAC				C2		C3		C4	
NIGHT	NUMBER	V	σ_V	V_{min}	V_{max}	V	σ_V	V	σ_V	V	σ_V
Jul 3........	11	14.764	0.054	14.673	14.816	14.157	0.006	15.464	0.026	14.316	0.009
Jul 4........	15	14.809	0.134	14.534	14.966	14.162	0.012	15.486	0.020	14.339	0.010
Jul 10	4	14.676	0.140	14.539	14.869	14.152	0.044	15.518	0.270	14.374	0.178
Jul 14	15	13.929	0.078	13.796	14.054	14.162	0.008	15.489	0.022	14.328	0.011
Jul 15	27	14.433	0.308	14.353	14.490	14.163	0.011	15.482	0.020	14.335	0.011
Jul 16	14	14.202	0.102	14.074	14.397	14.161	0.015	15.452	0.033	14.311	0.012
Jul 23	1	14.085	(0.353)	...	...	14.554	(0.393)	15.945	(0.477)	14.515	(0.190)
Jul 24	13	14.265	0.062	14.065	14.254	14.166	0.016	15.470	0.056	14.327	0.021
Jul 25	9	13.851	0.018	13.826	13.880	14.161	0.011	15.475	0.031	14.318	0.015
Jul 29	38	13.509	0.164	13.304	13.854	14.157	0.013	15.449	0.030	14.320	0.016
All	147	14.129	0.473	13.304	14.966	14.163	0.035	15.473	0.065	14.327	0.035
Good[b]......	142	14.114	0.472	13.304	14.966	14.161	0.012	15.468	0.033	14.325	0.016

[a] Values in parentheses for the check stars are absolute deviations from their overall means. For BL Lac, values in parentheses are the mean absolute deviations of the check stars for the night.

[b] Excludes data from July 10 and 23.

TABLE 2B

NIGHTLY AND OVERALL MEAN R MAGNITUDES FOR BL LACERTAE AND THE CHECK STARS, WITH THEIR STANDARD DEVIATIONS (σ_R)[a]

		BL LAC				C2		C3		C4	
NIGHT	NUMBER	R	σ_R	R_{min}	R_{max}	R	σ_R	R	σ_R	R	σ_R
Jul 3........	13	14.102	0.052	14.008	14.162	13.727	0.024	15.046	0.032	13.675	0.022
Jul 4........	15	14.167	0.131	13.924	14.321	13.738	0.009	15.074	0.026	13.693	0.011
Jul 8........	1	12.508	(0.072)	...	...	13.806	(0.081)	15.117	(0.061)	13.755	(0.074)
Jul 10	5	14.140	0.084	14.054	14.252	13.790	0.135	14.957	0.149	13.760	0.149
Jul 14	15	13.334	0.068	13.210	13.473	13.726	0.013	15.058	0.043	13.678	0.009
Jul 15	27	13.837	0.035	13.770	13.887	13.730	0.013	15.059	0.035	13.696	0.012
Jul 16	14	13.608	0.093	13.474	13.781	13.732	0.017	15.057	0.092	13.674	0.011
Jul 23	1	13.260	(0.010)	...	...	13.726	(0.001)	15.085	(0.029)	13.678	(0.003)
Jul 24	13	13.558	0.054	13.490	13.653	13.729	0.020	15.056	0.055	13.677	0.022
Jul 25	10	13.249	0.030	13.216	13.319	13.718	0.008	15.051	0.046	13.675	0.017
Jul 29	38	12.955	0.154	12.741	13.276	13.712	0.015	15.048	0.046	13.674	0.021
All	152	13.536	0.455	12.508	14.321	13.727	0.031	15.053	0.056	13.684	0.034
Good[b]......	145	13.524	0.443	12.741	14.321	13.725	0.017	15.056	0.048	13.681	0.019

[a] Values in parentheses are described in Table 2A.

[b] Excludes data from July 8, 10, and 23.

stars, along with the Smith et al. (1985) designations, V and R magnitudes, $V-R$ colors, and uncertainties in the magnitudes and colors. The sky value was determined for each observation by requiring the magnitude of the comparison star to be equal to its value as given by Smith et al. (1985). Using this sky value, the magnitudes of BL Lac and the three check stars were then determined. Comparison star C1 was used as the comparison star for determining the sky value, because it was the brightest of the four and thus had the best signal-to-noise ratio (S/N $\sim$ 40 typically). Because of the calibration procedure used, the standard deviation of the comparison star is, by design, equal to zero. The standard deviations of the check stars then give a measure of the uncertainty in the magnitudes obtained for BL Lac. The mean magnitudes and standard deviations for BL Lac and the three check stars are given in Table 2 for each night of observations, as well as for the overall data set. The minimum and maximum magnitudes of BL Lac are also given. Examination of Table 2 indicates that the uncertainty in BL Lac's measured magnitude is typically less than 0.02, though it is somewhat larger (0.02–0.03) when BL Lac is fainter.

4. DATA ANALYSIS AND RESULTS

4.1. *Characteristics of the Light Curve*

The light curve for BL Lac showing the 11 nights of observations is plotted in Figure 1. The tabular form of these data, Table 3, gives the times and the V and R magnitudes of BL Lac and the three check stars. In Figure 1, the V and R magnitudes of BL Lac are shown, as are the V and R magnitudes of check star C2. The scatter of the magnitudes of check star C2, as well as that of the other check stars (see Table 2), gives an indication of the uncertainty in the measured magnitudes of BL Lac.

BL Lac varied each night multiple observations were made through a given filter. For a period of $\sim$1.3 hr on July 29, BL Lac brightened at a rate of 0.294 R mag hr^{-1} (0.297 V mag hr^{-1}). This is among the fastest variations reported for BL Lac. On most nights, complete flaring events were not detected. Instead, BL Lac would either fade throughout the night (July 4 and 14) or brighten throughout the night (July 10, 16, 24, and 25). On two nights (July 3 and 15), BL Lac faded slightly and then brightened. In some cases, small-amplitude events ($\sim$0.1–$\sim$0.2 mag) of short duration ($\sim$0.5–$\sim$1.0 hr) were superposed on the nightly trends (July 4, 14, 15, and 29). During the longest night of observing (July 29), multiple events were detected, with BL Lac brightening at one point to $R = 12.741$ and $V = 13.304$. The faintest state during the observing run occurred on July 4, when BL Lac dimmed to $R = 14.321$ and $V = 14.966$. It was at its brightest observed state on July 8, when it was detected at $R = 12.508$. Unfortunately, on this night the CCD window fogged over and only one observation could be made (the big fish that got away). The measured magnitude for this observation is therefore less reliable than that for other nights. The uncertainty of this observation is estimated to be $\sim$0.1, because the check stars were all within 0.1 mag of their mean R magnitudes.

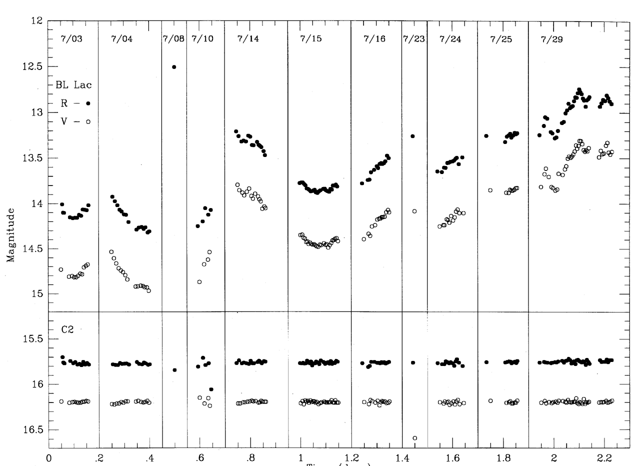

FIG. 1.—Light curves for BL Lac (*top*) and for check star C2 (*bottom*). V magnitudes are shown as open circles, R magnitudes as filled circles. A constant (2.037) has been added to the V and R magnitudes of C2 for display purposes. The scatter in the magnitude of C2 ($\sigma_V = 0.012$, $\sigma_R = 0.017$) is indicative of the uncertainty in the magnitude of BL Lac. The time axis has been compressed to allow small-timescale variations to be seen. Tickmarks along the time axis are 0.05 days, or 1.2 hr, apart.

TABLE 3A

V MAGNITUDES OF BL LAC, THE COMPARISON STAR (C1), AND THE CHECK STARS (C2, C3 AND C4) AS A FUNCTION OF TIME

Day of Year (UT)	V(BL Lac)	V(C1)	V(C2)	V(C3)	V(C4)
184.25486……	14.732	12.780	14.151	15.508	14.315
184.28750……	14.810	12.780	14.166	15.468	14.312
184.29930……	14.803	12.780	14.159	15.458	14.325
184.30764……	14.816	12.780	14.155	15.436	14.313
184.31597……	14.816	12.780	14.161	15.432	14.307

NOTE—Table 3A is presented in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content.

4.2. *Color Variations*

The V and R light curves varied synchronously within the uncertainty in the time. (The time between V and R exposures was, typically, $\sim$5.5 minutes.) However, the amplitudes of the V and R variations were not equal, and thus BL Lac exhibited color variations. Before the $V-R$ colors were computed, the V magnitudes of BL Lac were interpolated (or extrapolated, if the first or last of the night) to the times of the R exposures. Figure 2 shows the colors of BL Lac and check star C2 versus time. The magnitudes of check star C2 are offset in Figure 2 by a constant amount, in order to enable their display with BL Lac's data. The scatter in the colors of the check stars gives an indication of the uncertainty in the computed colors for BL Lac. The mean

TABLE 3B

R MAGNITUDES OF BL LACERTAE, THE COMPARISON STAR (C1), AND THE CHECK STARS (C2, C3 AND C4) AS A FUNCTION OF TIME

Day of Year (UT)	R(BL Lac)	R(C1)	R(C2)	R(C3)	R(C4)
184.26041……	14.008	11.930	13.663	14.986	13.607
184.26458……	14.100	11.930	13.722	15.062	13.678
184.26736……	14.102	11.930	13.732	15.054	13.681
184.29166……	14.151	11.930	13.706	15.060	13.681
184.30277……	14.162	11.930	13.731	15.032	13.694

NOTE—Table 3B is presented in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content.

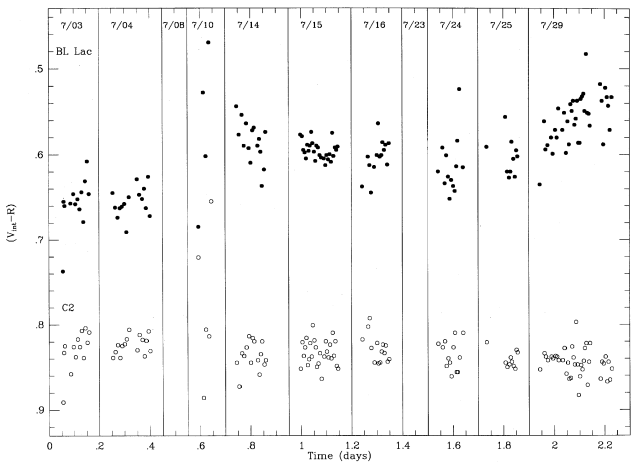

FIG. 2.—The $V-R$ color of BL Lac (*top*) and check star C2 (*bottom*) versus time. A constant (0.4) has been added to the $V-R$ color of C2 for display purposes. The scatter in the color of C2 ($\sigma_{V-R} = 0.017$) is indicative of the uncertainty in the color of BL Lac. $V_{\rm int}$ represents the V magnitudes interpolated (or extrapolated, if the first or last of the night) to the times of the R exposures. The time axis is plotted as in Fig. 1 for ease of comparison with the light curves.

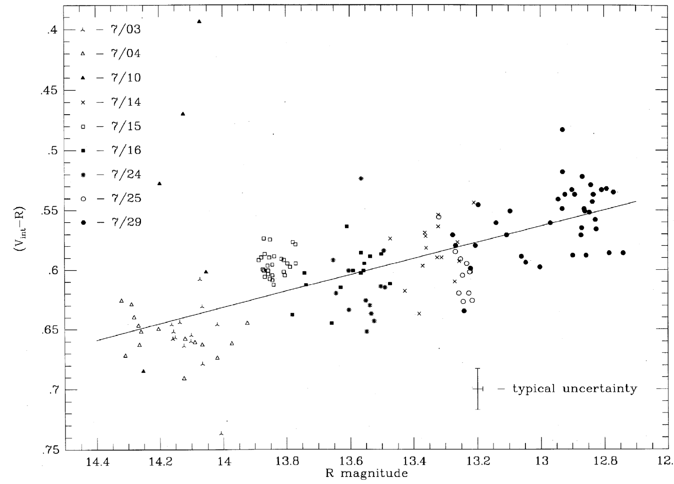

FIG. 3.—The $V-R$ color of BL Lac as a function of its R magnitude. The line represents the unweighted linear least-squares fit to the data excluding data from July 10 ($V_{\rm int}-R = 0.068R - 0.323$ with correlation coefficient = 0.741). A similar relationship is found for $V-R_{\rm int}$ vs. R ($V-R_{\rm int} = 0.070V - 0.388$ with correlation coefficient = 0.732).

colors and the standard deviations in the colors of BL Lac and the three check stars are given in Table 4. The scatter in the magnitudes of check star C2, quantified in Table 4 along with the scatter for the other comparison stars, indicates that the uncertainty in the $V-R$ color of BL Lac is $\sim$0.02 mag. Comparison of the color variations for BL Lac in Figure 2 with the magnitude variations in Figure 1 shows that BL Lac became bluer as it brightened. (Similar results are obtained when $V-R$ colors are computed using R magnitudes interpolated to the times of the V exposures.) This correlation certainly applies to the night-to-night variations, but it also may apply to variations within a given night for some nights. (Note especially the data for July 14 and 29.) On July 14, for example, BL Lac became redder as it faded throughout the night.

Figure 3 illustrates the color-magnitude relationship for BL Lac more directly. Here the $V-R$ color of BL Lac is plotted versus its R magnitude. The line in Figure 3 represents the unweighted linear least-squares fit to the data. With a slope of 0.068 and correlation coefficient 0.741, this linear fit supports the trend, apparent with visual inspection, that BL Lac became bluer as it brightened. (The same result is obtained when the R magnitudes are interpolated to the times of the V exposures and the computed $V-R$ colors are plotted versus V magnitude.) This result is consistent with the contribution of a larger fraction of total light by the underlying galaxy (relatively redder) when the flaring component (relatively bluer) is fainter. It is not clear whether the color of the flaring component varies or not.

4.3. *Contribution of the Host Galaxy to the Microvariability*

Cellone, Romero, & Combi (2000) warn that varying seeing conditions may result in spurious microvariations in the light curve of an AGN embedded in a host galaxy. These spurious variations would be caused by the changing contribution of the host galaxy within the aperture used for photometry as seeing conditions changed. They suggest that the data reduction methods often employed in microvariability studies to eliminate the effects of seeing variations, though validated in a study of MCG +8-11-11 by Carini et al. (1991), may not work in other situations. Cellone et al. have rather convincingly shown that the

TABLE 4

NIGHTLY AND OVERALL MEAN COLORS $V_{\rm int}-R$ FOR BL LACERTAE AND THE CHECK STARS, WITH THEIR STANDARD DEVIATIONS (σ)

		BL LAC		C2		C3		C4	
NIGHT	NUMBER	$V_{\rm int}-R$	σ	$V_{\rm int}-R$	σ	$V_{\rm int}-R$	σ	$V_{\rm int}-R$	σ
Jul 3........	13	0.657	0.030	0.430	0.024	0.418	0.046	0.642	0.023
Jul 4........	15	0.656	0.017	0.424	0.011	0.410	0.034	0.646	0.011
Jul 10	5	0.536	0.113	0.376	0.090	0.690	0.429	0.709	0.218
Jul 14	15	0.585	0.024	0.437	0.016	0.432	0.048	0.648	0.012
Jul 15	27	0.595	0.010	0.433	0.015	0.425	0.035	0.639	0.015
Jul 16	14	0.604	0.021	0.429	0.016	0.396	0.092	0.638	0.018
Jul 24	13	0.613	0.033	0.436	0.017	0.422	0.081	0.652	0.030
Jul 25	10	0.603	0.022	0.441	0.010	0.421	0.045	0.644	0.021
Jul 29	38	0.559	0.029	0.445	0.016	0.401	0.055	0.647	0.025
All..........	150	0.601	0.046	0.437	0.025	0.426	0.102	0.651	0.043
Good[a]......	145	0.599	0.042	0.436	0.017	0.414	0.056	0.644	0.020

[a] Excludes data from July 10.

microvariations they observed for PKS 2316−423 on a nonphotometric night were due to varying seeing conditions, despite the fact that the comparison stars did not exhibit such spurious variations. This conclusion was based on the remarkable similarity of the light curve for the AGN, the light curve of another galaxy in the same field, and the variations as a function of time of the FWHM of the stellar point-spread function (PSF).

They further investigated such seeing-induced variations using computer models of AGN embedded in host galaxies. They found that larger seeing-induced variations were detected when smaller apertures were used for the photometry and when the host was fainter than the AGN. Furthermore, their findings suggest that larger seeing-induced variations are expected when the host is an elliptical, instead of a spiral, galaxy. One of their models showed variations of ∼0.2 mag caused by varying seeing conditions, with the FWHM of the PSF varying from ∼1″.6 to ∼6″.6. The intranight variations observed for BL Lac in 1997 July were of comparable amplitude, ranging from 0.103 to 0.535 mag, and averaging 0.250 mag. It is thus prudent to investigate the contribution of variable seeing conditions to the microvariability detected for BL Lac during these observations.

BL Lac is imbedded in an elliptical host galaxy (Wurtz, Stocke, & Yee 1996) having an integrated magnitude of $R = 15.55 \pm 0.02$ (Scarpa et al. 2000). The embedded point source was found by Scarpa et al. (2000) to have a magnitude of $R = 13.58 \pm 0.05$. The mean R magnitude for BL Lac was found to be $R = 13.54$ for the 1997 July observations reported here. This includes the contribution of the host within a 5 pixel (6″.2) radius aperture. For an AGN that is 2 mag brighter than its host galaxy, Cellone et al. (2000) recommend using an aperture with a radius no smaller than 1″.6 (equal to 2 pixels with their telescope/detector system, and equal to ∼1.3 pixels with ours). Thus, the aperture used in this study is much larger than that recommended by Cellone et al. (2000) to limit seeing-induced spurious variations to less than 0.01 mag for 1″ changes in the FWHM of the PSF. Because spurious variations are reduced with the use of larger apertures in the photometry, they are expected to have an even smaller effect these observations.

An excellent means of determining if seeing conditions influenced the observed microvariations of BL Lac would be to compare observations made during the same time period by observers at different locales, but no such observations were found in the literature. Another excellent test would be to measure the magnitude of another galaxy in the same field, as was done by Cellone et al. (2000) in their study of PKS 2316−423. Unfortunately, no such galaxy shared the CCD frame with BL Lac. Therefore, to examine the influence of variable seeing conditions on the observed microvariability of BL Lac, only the FWHM of the stellar PSF of the check stars could be examined and compared to the light curves of BL Lac.

In Figure 4, the FWHM of the stellar PSF of check star C2 is shown as a function of time. Figure 4 is plotted to the same horizontal scale as Figure 1, allowing comparison of the magnitude variations of BL Lac with the seeing conditions. On most nights, the FWHM of the PSF varied by 1″ or less. (Recall that 1 pixel = 1″.23.) On two nights, the FWHM varied by slightly more than 1″.5. It is interesting to note that the seeing conditions improved (the FWHM decreased) with each night of observations beginning July

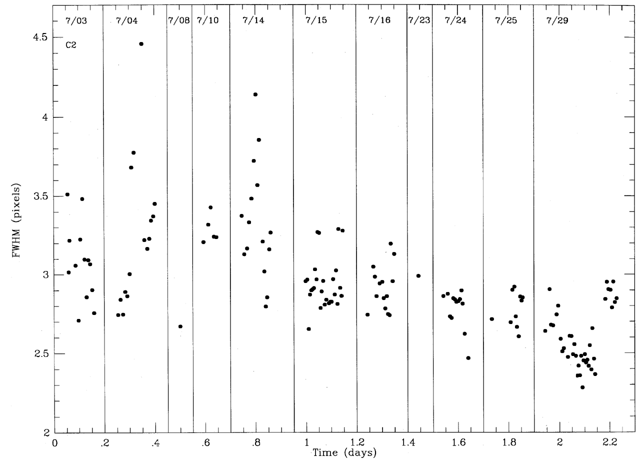

FIG. 4.—FWHM of the stellar PSF for check star C2 as a function of time. The time axis is the same as in Fig. 1, again for ease of comparison with the light curves.

15, while the mean magnitude of BL Lac increased. This is the type of trend that is expected for seeing-induced variations; a smaller PSF will allow a larger contribution of the host galaxy in the aperture for photometry. However, the magnitude varies much more than expected for seeing-induced variations, according to the work of Cellone et al. (2000). (The FWHM decreased by ∼0.5 pixels [∼0″.6] from July 15 to July 29, while the brightness increased by $R = \sim 1.1$ mag.) This trend from night to night is therefore attributed to coincidence. In fact, close inspection reveals that the intranight brightness variations are not correlated with the FWHM variations. For example, on July 3 there is no correlation between the erratically varying FWHM and the smoothly varying brightness of BL Lac.

The R magnitude of BL Lac was plotted as a function of the FWHM of the stellar PSF of comparison star C2 in Figure 5. The relationship noted above is evident in this figure. That is, there appears to be an increase in the brightness of BL Lac as the FWHM of the PSF decreases from one night to another. However, not a single night's data

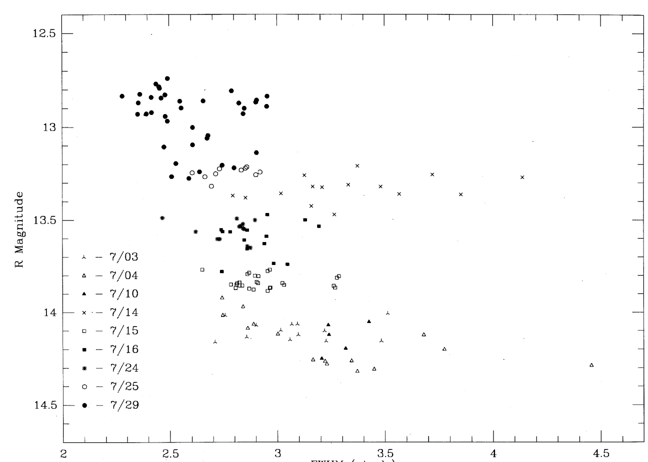

FIG. 5.—R magnitude of BL Lac as a function of the FWHM of check star C2's stellar PSF. A linear fit to the data gives $R = 0.700$ FWHM + 11.490 with correlation coefficient of 0.528. This correlation is attributed to the improvement in seeing conditions from the first part of the month to the later part of the month, over which time BL Lac coincidentally brightened.

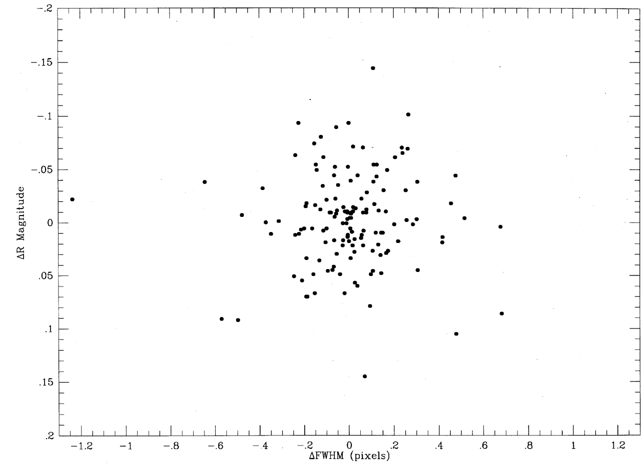

FIG. 6.—Change in the R magnitude of BL Lac as a function of the change in the FWHM of check star C2's stellar PSF. ΔR represents the differences in successive R magnitudes ($\Delta R_i = R_{i+1} - R_i$). Similarly, ΔFWHM represents the differences in successive FWHM values ($\Delta \mathrm{FWHM}_i = \mathrm{FWHM}_{i+1} - \mathrm{FWHM}_i$). Values for ΔR and ΔFWHM that spanned 2 nights of observing were discarded. No correlation is seen ($\Delta R = -0.004\Delta\mathrm{FWHM} - 0.002$, with correlation coefficient $= -0.021$).

follow this trend (note especially the data for July 14). In fact, each individual night's data argue that seeing in no way has affected the computed magnitudes of BL Lac.

As an additional check for a correlation between intranight brightness variations and seeing conditions, the change in the R magnitude of BL Lac from one exposure to the next was plotted in Figure 6 as a function of the change in the FWHM of the stellar PSF from one exposure to the next. Changes from one night of observing to another are

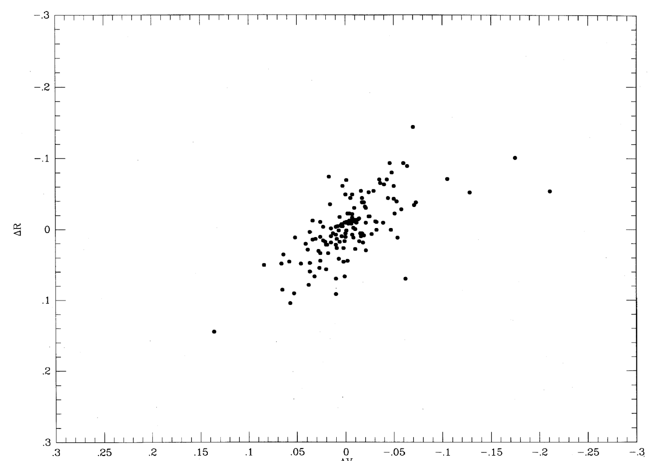

FIG. 7.—Change in the R magnitude as a function of the change in the V magnitude of BL Lac. As in Fig. 6, ΔR represents the differences in successive R magnitudes ($\Delta R_i - R_{i+1} - R_i$). Thus, ΔV represents the differences in successive V magnitudes ($\Delta V_i = V_{i+1} - V_i$). Values for ΔR and ΔV that spanned two nights of observing were discarded. Here, a correlation is seen ($\Delta R = 0.714\Delta V + 0.002$ with correlation coefficient = 0.679).

not included. No correlation is seen in Figure 6 (correlation coefficient $= -0.02$).

For contrast, consider a similar plot looking for a correlation between variations in the R and V magnitudes of BL Lac. In Figure 7, the change in the R magnitude of BL Lac from one exposure to the next is plotted as a function of the change in the V magnitude from one exposure to the next. (The V magnitudes were interpolated to the times of the R exposures before the change in V magnitude was computed.) Here a correlation is evident (correlation coefficient $=0.68$).

5. SUMMARY

BL Lac was observed on 11 nights in 1997 July for microvariability, following a significant outburst. It exhibited nearly constant variability, at one point brightening at a rate of ~ 0.3 mag hr^{-1}. The nightly changes in brightness ranged from ~ 0.1 to ~ 0.5 mag. On a few nights, small-amplitude (~ 0.1–~ 0.2 mag), short-duration (~ 0.5–~ 1.0 hour) events were superposed on the overall nightly trends.

This observed microvariability is intrinsic to the source, as determined by a rigorous check for correlations between variability and seeing conditions. However, a trend was observed for BL Lac to brighten as the seeing conditions improved from night to night, though the amplitude of the brightness variation is much greater than expected for seeing-induced variations based on the models of Cellone et al. (2000). This observed night-to-night trend is therefore attributed to coincidence. (The trend only applies to the observations from July 15 to 29.)

It was further found that BL Lac became bluer as it brightened, consistent with the host galaxy's making a greater relative contribution to the brightness when the AGN is fainter. It is unclear whether the AGN itself exhibits such color variations. In future work, the color of the embedded blazar will be examined for variability after we have carefully assessed the contribution of the underlying galaxy.

The authors wish to thank A. G. Smith for generously allocating observing time at RHO, J. P. Oliver for supplying useful information about the telescope/camera system at RHO, and the University of Florida's department of astronomy for providing access to their computing facilities. In addition, the authors wish to thank J. Noble, B. Nelson, and an anonymous referee for their useful suggestions. This research has made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This work was supported in part by NASA grant NCCW-0085.

REFERENCES

Angel, J. R. P., & Stockman, H. S. 1980, ARA&A, 18, 321
Bai, J. M., Xie, G. Z., Li, K. H., Zhang, X., & Liu, W. W. 1999, A&AS, 136, 455
Bloom, S. D., et al. 1997, ApJ, 490, L145
Carini, M. T., Miller, H. R., Noble, J. C., & Goodrich, B. D. 1992, AJ, 104, 15
Carini, M. T., Miller, H. R., Noble, J. C., & Sadun, A. C. 1991, AJ, 101, 1196
Cellone, S. A., Romero, G. E., & Combi, J. A. 2000, AJ, 119, 1534
Fan, J. H., Xie, G. Z., Pecontal, E., Pecontal, A., & Copin, Y. 1998, ApJ, 507, 173
Gopal-Krishna, Sagar, R., & Wiita, P. J. 1993, MNRAS, 262, 963
Impey, C. 1987, in Superluminal Radio Sources, ed. J. A. Zensus & T. J. Pearson (Cambridge: Cambridge Univ. Press), 233
Impey, C. D., & Neugebaur, G. 1988, AJ, 95, 307

Madejski, G. M., Sikora, M., Jaffe, T., Blazejowski, M., Jahoda, K., & Moderski, R. 1999, ApJ, 521, 145
Maesano, M., Montagni, F., Massaro, E., & Nesci, R. 1997, A&AS, 122, 267
Massaro, E., Nesci, R., Maesano, M., Montagni, F., & D'Alessio, F. 1998, MNRAS, 299, 47
Miller, H. R., Carini, M. T., & Goodrich, B. D. 1989, Nature, 337, 627
Nesci, R., Maesano, M., Massaro, E., Montagni, F., Tosti, G., & Fiorucci, M. 1998, A&A, 332, L1
Noble, J. C., Carini, M. T., Miller, H. R., Balonek, T. J., Whitman, K., & Davis, S. M. 1997, IAU Circ. 6693
Racine, R. 1970, ApJ, 159, L99
Scarpa, R., Urry, C. M., Falomo, R., Pesce, J. E., & Treves, A. 2000, ApJ, 532, 740
Smith, P. S., Balonek, T. J., Heckert, P. A., Elston, R., & Schmidt, G. D. 1985, AJ, 90, 1184
Speziali, R., & Natali, G. 1997, A&A, 339, 382
Stickel, M., Fried, J. W., & Kühr, H. 1993, A&AS, 98, 393
Tritton, K. P., & Brett, R. A. 1970, Observatory, 90, 110
Vermeulen, R. C., Browne, I. W. A., Cohen, M. H., Goodrich, R. W., Ogle, P. M., Readhead, A. C. S., & Tran, H. D. 1995a, IAU Circ. 6176
Vermeulen, R. C., Ogle, P. M., Tran, H. D., Browne, I. W. A., Cohen, M. H., Readhead, A. C. S., Taylor, G. B., & Goodrich, R. W. 1995b, ApJ, 452, L5
Webb, J. R., Smith, A. G., Leacock, R. J., Fitzgibbons, G. L., Gombola, P. P., & Shepherd, D. W. 1988, AJ, 95, 374
Webb, J. R., et al. 1998, AJ, 115, 2244
Wurtz, R., Stocke, J. T., & Yee, H. K. C. 1996, ApJS, 103, 109