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THE SURFACE BRIGHTNESS OF THE NEBULOSITY IN BL LACERTAE

T. D. KINMAN
Kitt Peak National Observatory*
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ABSTRACT

UBV observations of BL Lac through apertures with diameters in the range 7″–20″ show a surface brightness distribution which is consistent with that expected for a giant elliptical galaxy with redshift 0.07 but not 0.02. The evidence from the change of color with aperture is inconclusive, probably because the assumption that the nonthermal component has a power-law distribution is only correct for the average of many observations. New photographs of the object are given.

Subject headings: BL Lacertae objects — galaxies

Oke and Gunn (1974) have made spectrophotometric observations of BL Lac and the nebulosity around it. They deduced that the nebulosity has a redshift $z = 0.07$ (from absorption features) and an energy distribution like a giant E galaxy, and also that the compact central source has a power-law spectrum with index $\alpha = 1.55$. Later, Baldwin *et al.* (1975) could not find the absorption features in the nebulosity and thought that its energy distribution did not match that of a redshifted E galaxy. In order to gain some more insight into this difficult observational problem, BL Lac was observed through circular apertures of different sizes to obtain *UBV* magnitudes. These broad-band observations by themselves contain too little information to deduce the reddening, redshift, and energy distributions for both the compact and extended components of BL Lac. However, valid models deduced from observations made at higher spectral resolution must be consistent with broad-band observations.

The observations were made on 1974 October 14 and 15 UT, when BL Lac had $V \sim 15.3$, using the computer photometer (Kinman and Mahaffey 1974) at the Kitt Peak 2.1-m telescope. This equipment allows the telescope to be repositioned for each filter to compensate for the effects of atmospheric dispersion which can so easily spoil spectrophotometric results made through small apertures. The comparison star "a" of Bertaud *et al.* (1973), which is 12ˢ48 west and 30″7 north of BL Lac, was concurrently observed through the same apertures; $V = 13.405$, $B - V = 0.583$, and $U - B = 0.236$ were found for this star by comparison with nine stars in selected areas 92, 111, and 112 which had been frequently observed by Landolt (1973). For BL Lac each observation consisted of 12 cycles of 4-, 2-, 2-, and 2-s integrations through the U, B, V, and red-leak filters, respectively, first on the object and then on sky; for the comparison star, eight cycles were used. Table 1 gives the mean values of V, $B - V$, and $U - B$ found for each night for BL Lac with rms errors calculated from the ranges in the observations involved in each mean. The statistical accuracy of the difference between the "star" and "sky" counts ranged from ± 0.018 mag (6″99 aperture) to ± 0.013 mag (19″60 aperture); this appears to be the largest source of random error. The values in table 1 are corrected for the light (ΔV mag) which was observed to be scattered out of the measuring aperture in the case of the comparison star. Unfortunately, two faint stars are included within the 19″60 aperture measurement of this star which, it is estimated, would make it appear 0.030 mag too bright; a correction for this was applied to the values of ΔV given in table 1. No change of color of the comparison star with aperture was found. Two starlike objects occur at radial distances 5″8 and 8″4 from BL Lac at position angles 218 and 205°, respectively (fig. 1 [pl. L3]); they are called O_1 and O_2 by Wlérick, Michet, and Lelièvre (1974). If they are foreground stars with $V \sim 21$, the measurement through the 13″66 diameter aperture will be 0.005 mag too bright, and that through the 19″60 diameter aperture 0.010 mag too bright; no correction has been applied for this.

We now ask whether our magnitudes are consistent with a model of BL Lac which comprises a giant elliptical galaxy and a central point source which has a power-law spectrum. Adams (1974) deduced from *UBV* observations that BL Lac contained a galaxy with an apparent V magnitude 15.3 ± 0.3 (11″ aperture) and a redshift of 0.022. The change of the apparent magnitude of first-ranked E galaxies with measuring aperture size and with redshift has been given by Sandage (1972). With some extrapolation, Sandage's relation would predict a difference of 0.64 in V magnitude between the 10″62 and 19″60 apertures with a redshift of 0.022; this is significantly larger than the observed difference of 0.13 mag. If, however, the galaxy is assumed to have a redshift of 0.07 (which is consistent not only with Oke and Gunn's deduced redshift but also the photometry of Wlérick *et al.*), a satisfactory fit with the present observations can be obtained if the point source had $V = 15.51$ and 15.47 on 1974 October 14 and 15 UT, respectively, and if the galaxy within the 19″60 aperture has $V = 16.52$ (table 1).

If we further adopt an extinction $A_V = 0.85$, $E_{B-V} = 0.28$, and $E_{U-B} = 0.20$, reddened galaxy colors of $B - V = 1.48$ and $U - B = 0.70$, and reddened colors for

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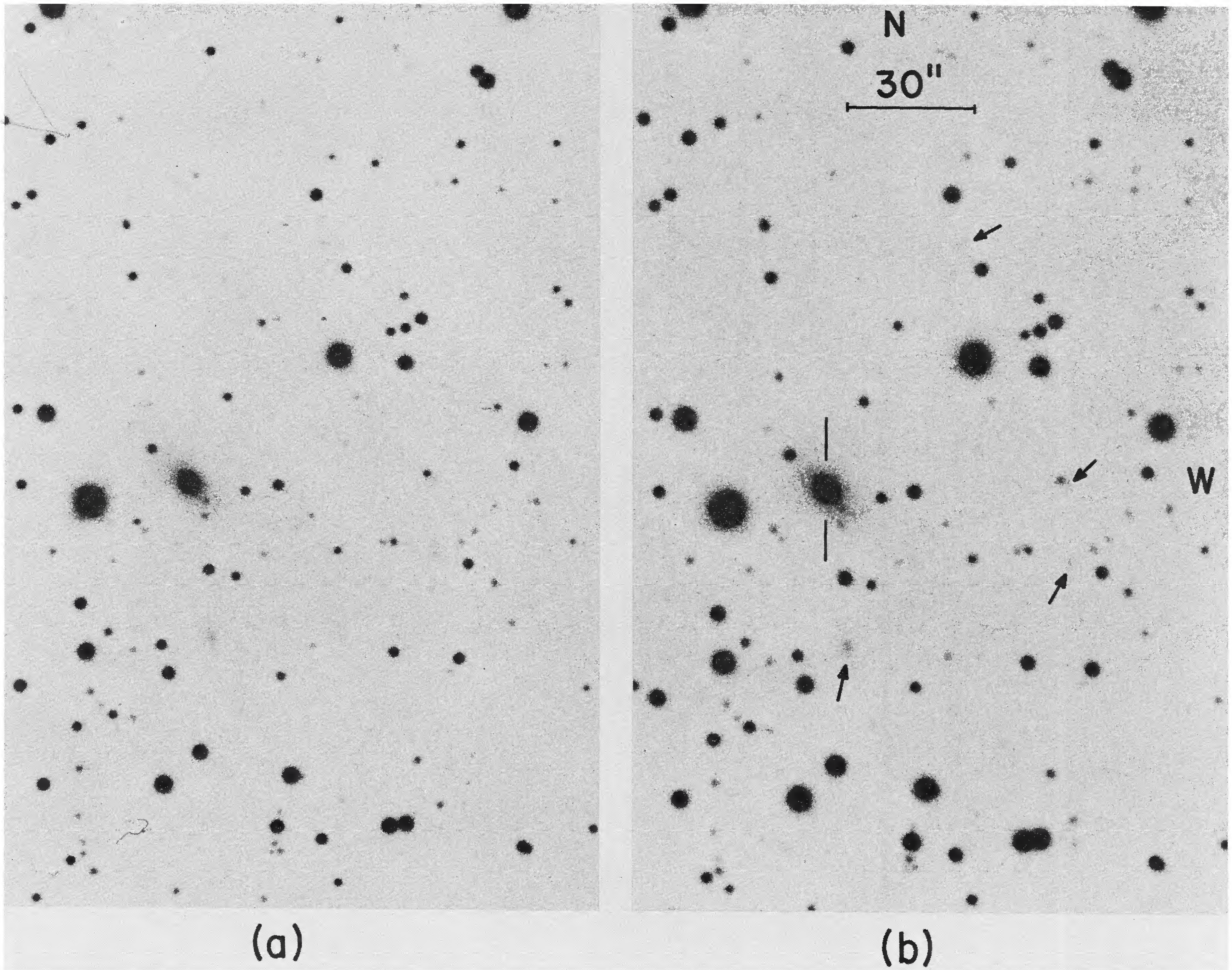

Fig. 1.—The field of BL Lac from 60-min exposures at the prime focus of the Kitt Peak 4-m reflector: (*a*) red-sensitive Kodak 127-02 emulsion with Schott GG-495 filter and Wynne BK-7 corrector, 1974 November 14 UT; (*b*) Kodak IIIa-J emulsion with Schott GG-385 filter and Wynne UBK-7 corrector, 1974 October 18 UT. The object is between the vertical bars, while the arrows denote probable faint galaxies.

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TABLE 1

UBV MEASUREMENTS OF BL LACERTAE THROUGH DIFFERENT APERTURES

DATE AND SPECTRAL REGION	APERTURE DIAMETER (seconds of arc) 6.99	10.62	13.13	19.60
	$n^*=4$	$n^*=4$	...	$n^*=6$
1974 Oct 14 UT:				
V..........	15.300±.006	15.260±.011	...	15.132±.008
$B-V$........	1.010±.006	1.010±.008	...	1.038±.010
$U-B$........	−0.100±.011	−0.062±.014	...	−0.072±.005
Model:				
V..........	15.304	15.244	...	15.149
$B-V$........	0.855	0.880	...	0.920
$U-B$........	−0.292	−0.271	...	−0.239
	$n^*=8$	...	$n^*=5$	$n^*=8$
1974 October 15 UT:				
V..........	15.255±.007	...	15.186±.006	15.121±.005
$B-V$........	1.018±.012	...	1.046±.013	1.022±.003
$U-B$........	−0.102±.005	...	−0.062±.019	−0.028±.016
Model:				
V..........	15.271	...	15.179	15.120
$B-V$........	0.852	...	0.891	0.916
$U-B$........	−0.294	...	−0.263	−0.243
ΔV†.........	−0.025	−0.005	−0.005	0.000

* Number of observations.

† Correction applied for scattered light.

the nonthermal source of $B - V = 0.76$ and $U - B = -0.36$ (which correspond to the model of Oke and Gunn), we obtain the colors for the model of BL Lac in table 1. The mean difference in color (model minus observed) is −0.14 in $B - V$ and −0.20 in $U - B$. Kinman (1975) noted a similar systematic difference between earlier *UBV* observations and those predicted from the Oke-Gunn model. The difference could be largely removed by arbitrarily increasing the reddening to $E_{B-V} = 0.33$ and by assuming a spectral index for the power law of 2.0 instead of 1.55. The observed trend of color with aperture size agrees with the model in $U - B$ but not $B - V$; one can only conclude that the nebulosity is redder than the central source. It is to be noted, however (Kinman 1975), that it is only the time average of the optical energy distribution of rapidly varying continuous spectrum quasars (such as OJ 287) which is a power law; the instantaneous distribution can show significant departures from a power law which are larger at shorter wavelengths. Any analysis of the energy distribution that is based on only a few observations can therefore be misleading. *Thus, whatever the spectral resolution, a relatively large number of observations will be needed to determine the mean spectral index of the nonthermal component.* Also, future observations should be planned to minimize the effect of possible rapid color changes in the nonthermal component.

Figure 2 shows the surface brightness of the BL Lac nebulosity (in V mag per square second of arc) as a function of the logarithm of the radial distance from the central source. The dashed line (*a*) was calculated from the measures of Wlérick *et al.* (1974) along the major axis, while line (*b*) was deduced for the minor axis assuming a ratio of minor-to-major axes of 0.6. The present observations should lie between these lines,

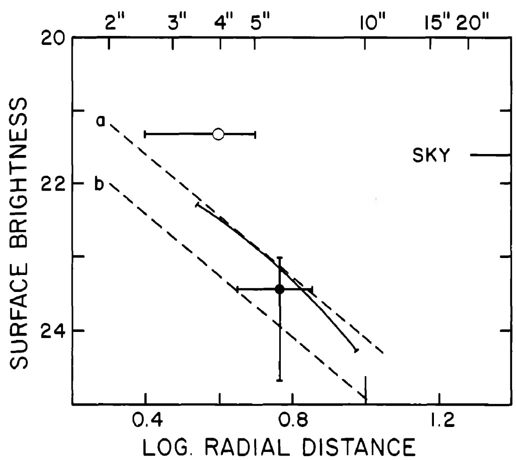

FIG. 2.—The surface brightness of the BL Lac nebulosity (in V-mag per square arcsec) as a function of the logarithm of the radial distance (r) from the central source in sec of arc. The dashed curves (*a*) and (*b*) are deduced from the observations of Wlérick *et al.* for the major and minor axes, respectively. *Filled circle,* the mean value (and the vertical line through it, the range) of the observations of Baldwin *et al. Open circle,* observation of Oke and Gunn. The present observations are shown by the full curve. The horizontal extent of the lines shows the range in r to which the observations refer.

and since both sets of observations have an error ~ ±0.2 mag, their agreement is satisfactory. The mean value calculated from the results of Baldwin *et al.* (1975) (assuming $AB_{5100} - V = 0.4$) refers to the major axis and is also in satisfactory agreement, although the scatter in the individual observations is much larger than expected from their estimated errors. The surface brightness deduced from the observation of Oke and Gunn is, however, significantly brighter than that from the other observers, although BL Lac was apparently quite faint ($V = 15.6$) at that time. Penston and Penston (1973) observed that at 5500 Å about 0.06 mag is scattered out of a 5″ diameter aperture with the instrument used by Oke and Gunn. If this light were scattered into the annulus, it would make the nebulosity appear 0.14 mag too bright, which is insufficient to explain the discrepancy. Apart from this, the observations are generally consistent with the nebulosity of BL Lac having the light distribution of an elliptical galaxy.

Wlérick *et al.* noticed two galaxies (g_1 and g_2) some 3 and 4′ distant from BL Lac and which have about the same angular extent as the BL Lac nebulosity. They suggested that they might form part of a group with BL Lac. In an area of 2300 square minutes of arc around BL Lac, there appears to be roughly one such galaxy per 100–150 square minutes of arc. The concentration around BL Lac is therefore above average, but scarcely enough to demand that these objects must be physically associated with BL Lac. Wlérick *et al.* and Penston and Penston noticed a faint galaxy $0^s.5$ west and 38″ south from BL Lac, which is confirmed on our plates. Several other faint galaxies in the vicinity of BL Lac are shown in figure 1.

More spectrophotometric observations of BL Lac are needed in which adequate attention is paid to proper sky subtraction and the effects of scattered light. Deep photographs (e.g., fig. 1) must be used to find suitable reference "sky" areas. It is also clear that errors in the derived energy distribution will occur when one observes an extended source which has a strong gradient of surface brightness through a small aperture unless steps are taken to remove the effects of atmospheric dispersion. Disney, Peterson, and Rodgers (1974) have shown that AP Lib intermittently shows both emission and absorption lines with a redshift of 0.0486. From its appearance and other properties, BL Lac is probably a similar system which currently has a brighter and more active nonthermal source; conclusive proof of this is, however, still lacking.

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THOMAS D. KINMAN: Kitt Peak National Observatory, P.O. Box 26732, Tucson, AZ 85726