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VARIABILITY AND OPTICAL-RADIO PROPERTIES OF BL LACERTAE OBJECTS

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ABSTRACT

The optical variability of new candidates for the BL Lacertae class of objects and of two known members of this class has been examined using the Harvard plate collection. A correlation is indicated between the maximum known range of optical variability and the observed radio spectral index at 5 GHz. Light curves for PKS 0735+17 and 2254+07 (OY 091) are presented.

Subject headings: BL Lacertae objects — galaxies — radio sources, variable

I. INTRODUCTION

A thorough search of the Harvard plate collection was made to determine the optical variability of two known BL Lacertae objects (PKS 0735+17 and B2 0912+29) and nine candidates for that class. Objects of the BL Lacertae class are characterized either by continuous, featureless optical spectra (classified as QC sources or NC galaxies; Usher 1975) or by weak or transient line optical spectra (classified as QW sources or as NW or EW galaxies); other characteristics are flat or centimeter excess radio spectra and optical and radio variability. Light curves are presented for objects with good plate coverage, otherwise only the magnitude range $\Delta B = B_{\max} - B_{\min}$ is given. The values of ΔB, $B_{\max}$ and the radio spectral index $\alpha_{5\ \mathrm{GHz}}$ ($= d \log S / d \log \nu$) for all BL Lacertae objects with well documented optical records are given in Table 1, where photographic magnitudes were converted on the assumption that $B = m_{pg} + 0.2$. These data are plotted in Figure 1 which shows that ΔB increases with increasing α. Hall

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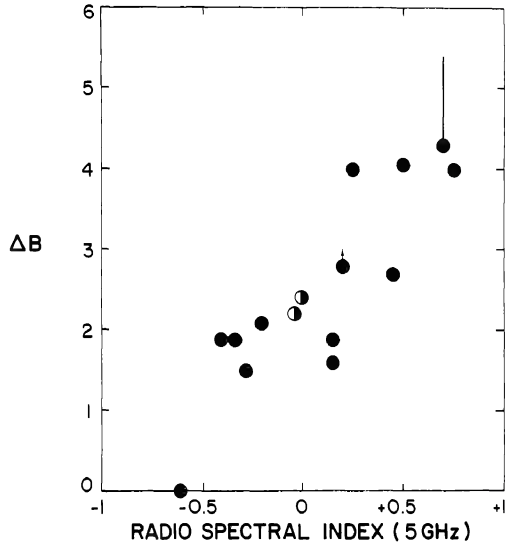

FIG. 1.—Magnitude range versus 5 GHz spectral index for the sources listed in Table 1. *Filled circles*, QC sources. *Half-filled circles*, the weak-line sources PKS 0735+17 (Carswell *et al.* 1974) and PKS 1514−24 (Disney *et al.* 1974).

TABLE 1

OPTICAL MAGNITUDE RANGE AND RADIO SPECTRAL INDEX AT 5 GHz FOR ALL BL LACERTAE OBJECTS HAVING SUBSTANTIAL LONG-TERM OPTICAL RECORDS

Source	Alternate Names	$B_{\max}$	ΔB	Ref.	$\alpha_{5\ \mathrm{GHz}}$	Ref.
PKS 0048−09	...	...	2.7	1	+0.45	*a*
PKS 0537−44	...	>16.9	>4.3	2	+0.7::	*b*
PKS 0735+17	OI+158, VRO 17.07.02	16.7	2.2	3	−0.04	*c*
MA 0829+04	...	16.9	1.9	3	+0.15:	*d*
0851+20	OJ+287, VRO 20.08.01	16.4	4.05	4	+0.5±0.2	*b*
B2 0912+29	...	17.0	1.9	3	−0.35	*b*
UT 0954+556	OK+591, 4C55.77	...	1.5	3	−0.28	*c*
UT 1020−103	OL−133, MSH 10−107	...	<0.2	3	−0.58	*b*
B2 1215+30	ON+325	16.0	2.1	4	−0.2±0.2	*b*
B2 1219+28	ON+231, W COM	17.2	4.0	5	+0.25	*b*
PKS 1514−24	AP LIB	16.4	2.4	4	0.0:	*b*
UT 1538+149	OR+165, 4C14.60	>17.2	>2.8	3	+0.20	*b*
1727+50	I Zw 187, OT+546	16.86	1.86	4, 6	−0.40	*b*
2200+42	VRO 42.22.01, BL LAC	16.6	4.0	4	+0.75	*c*
2254+07	OY+091	17.3	1.6	3	+0.15±0.1	*b*

REFERENCES.—(1) Usher *et al.* 1974. (2) Liller 1974*a*. (3) This paper. (4) Hall and Usher 1973. (5) Pollock *et al.* 1974. (6) Sandage 1967. (*a*) Medd *et al.* 1972. (*b*) Usher 1975. (*c*) Véron *et al.* 1974. (*d*) Brandie and Bridle 1974.

and Usher (1973) and Pollock *et al.* (1974) have suggested that such a relationship might exist on the basis of examination of six BL Lacertae objects; with the present addition of nine more of these objects the relation is now well defined, having a linear correlation coefficient of 0.86 if the apparently nonvariable source UT 1020−103 is included and 0.82 if it is not. Both correlations are highly significant at a significance level of less than 0.001.

The trend in Figure 1 shows that the amount of variability decreases as the spectral index approaches values more characteristic of known radio galaxies and QSSs which in general do not show such a large amplitude of optical variability. This trend suggests a diminution in the strength of the events producing the outbursts and/or an increase in the background which masks the outbursts at low optical flux densities.

II. METHODS

Magnitudes of the objects were determined by visual interpolation between reference stars around the objects. For 2254+07 (OY 091) and UT 1538+149, the reference star magnitudes were determined from the Mount Wilson selected areas by photographic transfer with the Harvard 155-cm reflector and have a standard deviation of ±0.10 mag; for PKS 0735+17 the sequence was determined using the photoelectric *B*-magnitudes of Wing (1973) and the resulting magnitudes have a standard deviation of ±0.05; the sequence for UT 0954+556 was determined from estimated magnitudes on the Palomar Sky Survey prints. For the remaining sources the sequences were established by transfer on good-quality archival plates containing both the object and a Mount Wilson selected area and have a standard deviation of ±0.10 mag. Uncertainties in the visually interpolated magnitudes were examined by comparing, for one object, the magnitudes so obtained with those obtained using the Askania astrophotometer. The magnitudes were found to agree within ±0.20, and for good plates to within ±0.10. Since the amplitude of variability, ΔB, given in Table 1 is the difference between the extreme recorded magnitudes, it is therefore a lower limit on the actual amplitude. In only one case (UT 1538+149) was a lower limit to the faintest magnitude determined by invisibility of the object on the plate. The spectral indices at 5 GHz were obtained from Medd *et al.* (1972), Usher (1975) and Véron, Véron, and Witzel (1974).

III. RESULTS

a) Known BL Lacertae Objects

PKS 0735+17.—The optical counterpart of this source was found to be variable by Wing (1973) and by Carswell *et al.* (1974). Figure 2 shows the major part of the light curve as determined from the Harvard archives, where *B* was found to vary between 14.5 and 16.7. Errors on individual data points are no more than ±0.20 mag. Bertaud (1974) reports that the source has brightened from 16.28 in 1973 to 15.32 in early 1974 and recent Harvard plate material confirms this. These observations suggest the beginning of an active period; and multifrequency observations at this time would be worthwhile, particularly in view of the recent outbursts of the QC source OJ 287 from the optical to radio frequencies (Stein 1974). The optical spectrum contains two magnesium absorption lines (Carswell *et al.* 1974),

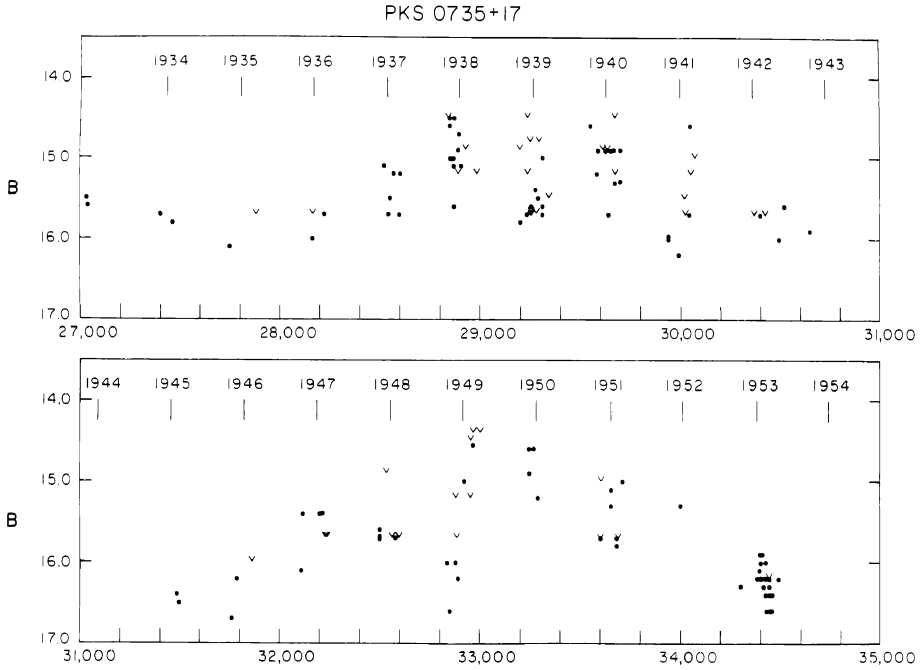

FIG. 2.—Light curve for PKS 0735+17. *Ordinate*, *B* magnitudes; *abscissa*, JD −2,400,000. *V* indicates an upper limit.

and the object is classified by Usher (1975) as a QW source. Few optical spectra of other BL Lacertae type objects have been examined in as much detail as that of PKS 0735+17 with the possible exception of OJ 287 and BL Lac itself; thus some of the fainter QC sources may have spectra containing weak lines which are as yet undetected because of poorer signal-to-noise ratios.

B20912+29.—The optical counterpart was identified as a QC source by Crovisier *et al.* (1974) and, on the basis of 12 plates, was assigned a ΔB of 1.4 mag. Upon examination of additional plate material the object was found to range from 14.9 to 16.8 (m_{pg}) for a revised ΔB of 1.9 $\pm$ 0.20.

b) QC Source Candidates

1. Browne, Crowther, and Adgie (1973) have identified the optical counterparts of 24 Ohio radio sources with stellar objects of neutral color on the Palomar Sky Survey prints, and have suggested that some QC sources may be contained in the list. Those objects brighter than magnitude 18.5 have been examined, although most could be seen on only one or two plates. Three of the sources, 1656+05.3 (OS 094), 2141+17 (OX 169), and 2254+07 (OY 091) were recorded on a reasonably large number of plates.

1656+05.3 and 2141+17.—Neither of these objects was variable to within $\pm$0.20 mag, and it has since been reported that their optical spectra contain emission lines (Strittmatter *et al.* 1974); thus they are not QC sources.

2254+07.—This object was found to vary between 15.5 and 17.1 (m_{pg}), giving a ΔB of 1.6 $\pm$ 0.20, and excellent plate coverage during 1939 revealed the outburst shown in Figure 3. Errors on individual data points are no more than $\pm$0.20 mag. The optical spectrum was found to be continuous (Strittmatter *et al.* 1974), and the object therefore satisfies those criteria necessary to classify it a QC source.

2. Wills and Wills (1974*b*) have examined the optical spectra of 62 objects identified with UTRAO radio sources. Five of the objects with continuous spectra were examined, with results given below. For UT 0548+165, no data were available.

UT 0954+556.—A definite variable with an amplitude of 1.5 $\pm$ 0.30 mag.

UT 1020−103.—This object did not vary within $\pm$0.20 mag despite reasonably extensive plate coverage. Wills and Wills (1974*b*) assign a 95 percent reliability to this identification, and, considering its continuous spectrum, a misidentification is unlikely. Thus it is included in Figure 1, and its position lends support to its being a nonvariable QC source, or conversely that the criteria for the QC class need not include optical variability.

UT 1525+227.—A possible variable, but there was insufficient plate material to be certain.

UT 1538+149.—A definite variable with an amplitude of more than 2.8 $\pm$ 0.20 mag. It is important to note that the actual B_{max} of this object may be significantly larger than the lower limit ($B_{max} > 17.2$) established by invisibility of the object, especially considering that only 15 plates showing a definite image of the object were available.

3. Brandie and Bridle (1974) have identified the optical counterparts of several Michigan radio sources.

MA 0829+04.—This source was identified with a neutral stellar object on the Palomar Sky survey prints. Its spectral index at 5 GHz is about +0.15 (Brandie and Bridle 1974), and it appears to have a continuous optical spectrum (Wills and Wills 1974*a*). Figure 1 suggests an amplitude of variability of 2.7 $\pm$ 0.8 mag. A preliminary examination of the Harvard collection (Liller 1974*b*) gives a ΔB of at least 1.9 mag, thus indicating the possible predictive quality of Figure 1 as applied to BL Lacertae objects.

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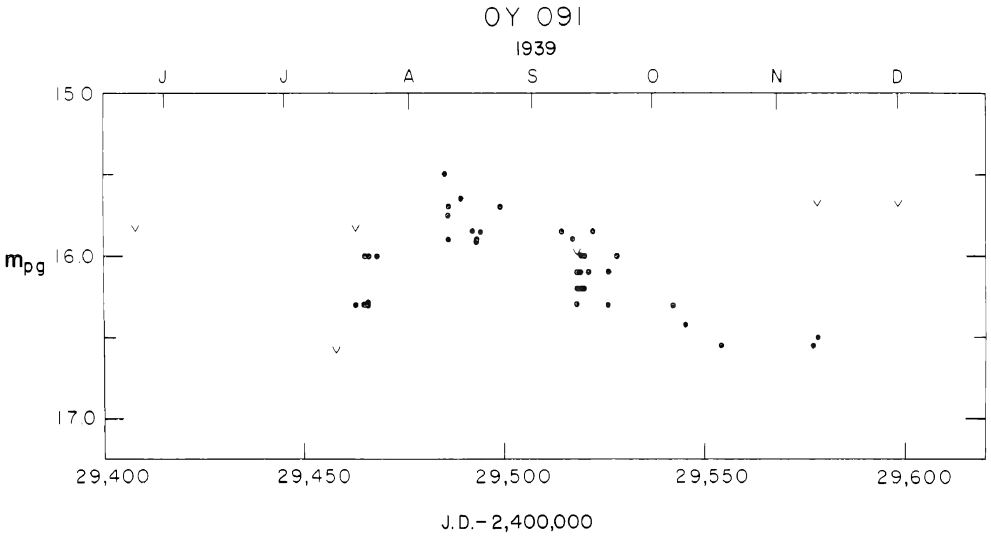

FIG. 3.—Outburst of 2254+07 (OY 091) during 1939. *Ordinate,* m_{pg} magnitudes. *Abscissa,* JD −2,400,000. *V* indicates an upper limit.

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