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BVRI photometry of BL Lacertae in 1993-1995

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Abstract. The results of optical photometry of BL Lac over a time interval of two years in the *B, V, R, I* filters are presented. The source is found for most of the time in a low state. The mean colour indexes are similar to those observed in higher luminosity states, however a flattening of the spectral slope was present during three small amplitude outbursts. A brief comparison with the observations available in the literature and some considerations on the physical conditions driving the appearance of emission lines are made.

Key words: BL Lacertae objects: general — BL Lacertae: individual: BL Lac

1. Introduction

Photometric observations of variable extragalactic sources, like the BL Lac objects, are important to construct their historical light curves and to study their behaviour on different time scales. In the recent years important results have been reached with the development of international collaborations (e.g. the project OJ 94, Sillanpaa et al. 1996), useful to fill the unavoidable observation gaps of a single observer. It is therefore important that homogeneous sets of photometric data be readily published to be accessible to all the researchers active in the field: it is the combination of several observational campaigns spanning a large time interval that will finally bring out a deeper scientific insight.

In this paper we present the results of CCD photometric observations of BL Lac covering a time range of more than two years, from August 1993 to January 1996. The majority of the observations was performed in summer 1995 after the discovery of broad emission lines (Vermeulen et al. 1995).

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2. Optical photometry

The observations were carried out with a 0.5 m reflector telescope of the Astronomical Station of Vallinfreda (Rome) at 850 m a.s.l. (since July 1995, formerly at Oriolo) equipped with a CCD camera and the standard filters B, V (Johnson) and R, I (Cousins). Exposure times were generally 600 s in B and 300 s in the other bands. The scale on our detector is 2.29 arcsec/pixel and we used typically for our aperture photometry a radius of 3 pixels (12 Kpc at $z = 0.07$), so the host galaxy of BL Lac is substantially within our aperture. The apparent magnitude of this galaxy has been estimated $B \sim 18.3$, $V \sim 16.8$ (Brown et al. 1989), one magnitude fainter than the lowest value recorded by us in this period ($V = 15.9$). Data reduction was performed with the APPHOT tasks within the IRAF package, using the comparison stars given by Smith et al. (1985), which were all within our instrument field of view. The $(B - V)$ color indexes of these stars range form 0.8 to 1.3 and are therefore similar to that of BL Lac itself (~ 1.0) The observed magnitudes in the four photometric bands are given in Table 1. No reddening corrections, which for BL Lac are relevant, were applied. Repeated observations in the same night with the same filter were averaged if their difference was less than two standard deviations. Only one case of intranight variability is present in our sample (JD 2449924) with an amplitude of about 0.1 mag. The number of averaged observations is also listed in Table 1.

In the time interval monitored by our observations a significant variability is apparent in all the four bands; since the observations were not always performed in all the bands we cannot compare the variability ranges over the entire time interval. Considering only the epochs in which all the bands were observed we found that the variability range increases from 1.08 mag in I to 1.35 mag in B, confirming that the flux is more variable at higher frequencies, as observed in many other sources of this class.

In the second half of 1993 BL Lac was in a quite low state: our V data of the month of August interpolate very well those reported by Tornikoski et al. (1994) and confirm the good correlation between the optical and radio

light-curve, which indicated a quiescent behaviour at 22 and 37 GHz.

In September and October 1994 the source was in a brighter state and likely had an outburst of a few days duration: in particular, on 1994 Sep. 7 (JD 2449603) the magnitudes $B = 14.85$ and $R = 13.26$ were reached, with an increase of 0.79 mag in B and 0.55 mag in I in three days; about one month after it was found at a level comparable to the initial one. Unfortunately, we were not able to perform a number of observations sufficient to achieve a detailed description of this episode.

In 1995/96 BL Lac was found in a prolonged low state: the brightest level observed (October 16) was only $V \sim 14.9$. We observed the lowest flux ($V \sim 15.9$) at the end of June; our figure is only 0.15 mag fainter than that reported by Jeffries et al. (1995) for 1995 June 4. In that occasion, spectroscopic observations (Vermeulen et al. 1995) showed in the spectrum of this object several emission lines and absorption features, the latter originated by the associated galaxy.

Looking at the light curve we can also find two minor flares around JD 2449933 and 2450007. None of these flares is sufficiently well sampled to derive reliably the rising and falling times in the different bands, and only in the latter case we could observe BL Lac also some days before and after the flare (JD 50003 − 50014) so we can make an estimate of its amplitude (~ 0.8 mag).

The correlation coefficient between R and $(V - I)$ is 0.54, and a smaller $(V-I)$ corresponds to a brighter state. Actually both flares are characterized by a significantly flatter spectral slope ($V - I = 1.47$) while the steepest $(V - I)$ values (1.75) corresponds to local minima in the light curve. Unfortunately we have no V, I data for the peak of the first (and brighter) maximum.

In another occasion an interesting change of the spectral shape was observed between JD 2449957 and 2449958 (1995 Aug. 27-28) around one of the local minima. While the source brightened in V, R and I by, respectively, 0.34, 0.31 and 0.18 mag, it remained constant in B, at variance with the general behaviour of a wider flux variability at shorter wavelengths. This is reminiscent of the peculiar behaviour shown by OJ 287 during the minimum of 1989 (Kidger et al. 1991), when the variation amplitude was not a monotonic function of the wavelength.

3. Discussion

We will not try here to make a complete reconstruction of the historical light curve but just check some of the more recent works to see whether the present low brightness level has already been observed in the past.

Our recorded minimum value is $V = 15.92$ (1995-Jul.-1) and very similar levels were reached on 1995-Jul.-29 ($V = 15.75$), 1995-Aug.-27 ($V = 15.76$), 1995-Oct.-12 ($V = 15.66$) and 1995-Oct.-19 ($V = 15.68$). From our measures the average luminosity of BL Lac was $V = 15.4$ over the last 200 days and we could not find fluctuations greater than half magnitude from the mean level. It would be interesting to merge our data with those of other observers to see if actually there was a lack of strong flares during a so long period.

The average $B - V$ of all our observations is 1.10, with a dispersion of ± 0.12: the most discrepant points are generally found with the source near to the minimum level, when photometric errors are also larger. If we consider only the data of 1994, when the source was brighter, the average value is 1.00. For comparison, in the period (JD 2442930 − 2443845) reported by Cruz-Gonzales & Huchra (1984) the source was at an average value $V \sim 14.8$, i.e. 0.6 mag brighter than in our period, with an average $(B - V) \sim 0.97$, rather similar to our value. In the following, we will assume that the V mag can be simply estimated from B or $m_{\rm pg}$ observations adopting $(B - V) = 1.0$.

Shen & Usher (1970) give the historical light curve of BL Lac up to 1970: only in a few occasions values as low as $B = 16.3$ are reported but there are also a number of rather high upper limits, so it cannot be excluded that it became fainter than $B = 16.3$. In this light curve the minimum value is $B = 16.7$ in the late sixties. Webb et al. (1988) report a long record of observations from 1971 to 1985, somehow continuing the sequence of Shen and Usher: their minimum value is $B = 17.17$ on Jan.-3-1981 and the median value on 1981 is $B \sim 16.5$ very similar to our finding. Also Xie et al. (1987) report B between 16.3 and 17.1 on Sep.-Nov. 1981, while Shokin et al. (1994) found BL Lac at $m_{\rm pg}$ 16.7 on 1992-Aug.-24. The fainter value in the last 15 years was reported by Carini et al. (1992) on 1980-May-13 when BL Lac was observed at $V = 16.73$, but two days after it has already raised to $V = 15.17$. Such a faint level corresponds to the estimated value for the host galaxy (Brown et al. 1989) so that in this case the central engine of BL Lac should have switched off for a while. We conclude therefore that BL Lac attained similarly low levels also in the past, but there is no evidence that it remained for long times at a level substantially fainter than that recorded by us. It may be regarded therefore at an actual minimum of activity and it will be interesting to see how long it will remain in this condition.

A final comment about the onset of the Hα emission detected on May 1995. In their paper, Vermeulen et al. (1995) suggested three possible explanations for this event: i) a decrease of extinction so that a previously hidden BLR became visible; ii) a brightening of the photoionizing continuum; iii) an increase of the number, or of the efficiency, of the emitting clouds.

Our data show that the $(B-V)$ color index of BL Lac has remained very similar to its previous value, or even a bit redder, so there is no indication of a decrease of the extinction. The light-curve indicates that BL Lac has been in a low state since then, and it seems strange that the

Table 1. Observed magnitudes, no reddening correction applied

Date	JD − 2400000	B	V	R	I	aver.
13/08/93	49213.390	16.21 ± 0.10	15.29 ± 0.05			
18/08/93	49218.449		15.25 ± 0.05			
20/08/93	49220.422		15.23 ± 0.05			
21/08/93	49221.473		15.20 ± 0.05			
10/09/93	49241.460		15.49 ± 0.05			
12/10/93	49253.413		15.09 ± 0.03			
01/11/93	49273.472		15.18 ± 0.07	14.43 ± 0.05		
02/08/94	49567.450	16.07 ± 0.17	14.97 ± 0.03	14.25 ± 0.03		
28/08/94	49593.388		14.32 ± 0.03	13.67 ± 0.03		
03/09/94	49599.445	15.47 ± 0.09	14.50 ± 0.03	13.81 ± 0.03	13.01 ± 0.03	2
04/09/94	49600.310	15.64 ± 0.03	14.51 ± 0.03	13.81 ± 0.03		
07/09/94	49603.480	14.88 ± 0.04		13.26 ± 0.03		2
07/10/94	49633.385	15.58 ± 0.03	14.67 ± 0.03	13.96 ± 0.03		
08/10/94	49634.360	15.90 ± 0.10				3
10/10/94	49636.319	15.69 ± 0.03				3
30/06/95	49899.507		15.92 ± 0.06	15.10 ± 0.07	14.18 ± 0.05	
23/07/95	49922.473	16.94 ± 0.20	15.58 ± 0.06	14.85 ± 0.03	13.95 ± 0.05	2
25/07/95	49924.404	16.41 ± 0.10	15.31 ± 0.04	14.60 ± 0.03	13.75 ± 0.04	
	49924.430		15.42 ± 0.03	14.73 ± 0.04	13.83 ± 0.04	
27/07/95	49926.478		15.54 ± 0.03	14.88 ± 0.04	13.97 ± 0.05	
29/07/95	49928.444		15.75 ± 0.06	14.97 ± 0.03	14.11 ± 0.04	
02/08/95	49931.503		15.46 ± 0.14			
03/08/95	49933.500	16.21 ± 0.08	15.14 ± 0.04	14.48 ± 0.03	13.67 ± 0.04	
07/08/95	49936.538	16.48 ± 0.08	15.34 ± 0.04	14.70 ± 0.03	13.73 ± 0.04	
21/08/95	49951.369	16.60 ± 0.11	15.47 ± 0.05	14.60 ± 0.06	13.86 ± 0.05	
27/08/95	49957.394	16.61 ± 0.09	15.76 ± 0.06	15.00 ± 0.06	14.01 ± 0.04	2
28/08/95	49958.483	16.62 ± 0.10	15.42 ± 0.04	14.69 ± 0.07	13.83 ± 0.09	2
29/08/95	49959.416	16.77 ± 0.10	15.57 ± 0.03	14.81 ± 0.04	14.02 ± 0.04	
30/08/95	49960.426		15.53 ± 0.04	14.82 ± 0.05	13.98 ± 0.05	
31/08/95	49961.358				14.02 ± 0.04	
01/09/95	49962.385	16.58 ± 0.07	15.62 ± 0.04	14.86 ± 0.03	14.06 ± 0.05	
21/09/95	49982.339	16.72 ± 0.14	15.53 ± 0.03	14.79 ± 0.03	13.95 ± 0.03	2
22/09/95	49983.365	16.47 ± 0.06	15.41 ± 0.03	14.64 ± 0.04	13.75 ± 0.05	2
27/09/95	49988.400	16.58 ± 0.05	15.43 ± 0.03	14.70 ± 0.04	13.85 ± 0.03	2
12/10/95	50003.284		15.66 ± 0.03	14.98 ± 0.03		
14/10/95	50005.301	16.78 ± 0.05	15.58 ± 0.03	14.82 ± 0.03	14.04 ± 0.03	
15/10/95	50006.283	16.46 ± 0.06	15.39 ± 0.03		13.95 ± 0.03	
16/10/95	50007.351	16.01 ± 0.10	14.90 ± 0.05	14.17 ± 0.05	13.43 ± 0.05	
17/10/95	50008.368		15.30 ± 0.04	14.64 ± 0.03	13.62 ± 0.03	
19/10/95	50010.339		15.64 ± 0.05	14.88 ± 0.03	14.04 ± 0.03	
22/10/95	50013.334	16.69 ± 0.04	15.68 ± 0.03	14.95 ± 0.03	14.09 ± 0.03	
23/10/95	50014.330	16.85 ± 0.10	15.58 ± 0.05	14.87 ± 0.05	14.06 ± 0.05	3
25/10/95	50016.293			14.87 ± 0.03		
21/11/95	50043.235	16.61 ± 0.05	15.53 ± 0.06	14.91 ± 0.03	14.05 ± 0.03	2
11/12/96	50063.265		15.27 ± 0.03	14.58 ± 0.03	13.71 ± 0.03	
08/01/96	50091.222		15.53 ± 0.03	14.81 ± 0.04	14.00 ± 0.03	
16/01/96	50099.255	16.37 ± 0.03	15.23 ± 0.03	14.53 ± 0.03	13.78 ± 0.04	

ionizing (UV) flux has increased while the optical has decreased. The most likely possibility is that some structure modification occurred in the source, linked to the very low level of activity, which allowed larger surrounding region to efficiently emit in the optical lines. In this case, given that BL Lac has been rather faint for a long time, we would expect that the emission lines are still detectable with a comparable intensity. Note that some other BL Lac objects (e.g. 0215 + 015), for which detections of broad emission lines have been reported, are similarly characterized by long term decreasing luminosity trends (Smith & Nair 1995). A spectroscopic monitoring of this object, as well as of other blazars in a low state, would be highly useful to clarify the relation of the line emission with the variations of the ionizing continuum.

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