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LETTER

Letter to the Editor

Intraday variability of BL Lacertae in the great 1997 outburst

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Abstract. We report intranight observations performed during the Summer 1997 outburst of BL Lac, in the B, V, R_c and I_c bands. The source was never found to be stable, but always showed a variability of at least 0.04 mag/hour, often with superimposed fast fluctuations on time scales of about an hour and with amplitudes of about 0.1 mag. The amplitude of the flux variations was always larger at shorter wavelengths. No time lag between different bands could be unambiguously detected.

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

1. Introduction

Rapid variability is one of the defining properties of blazars and of Lacertids in particular. Episodes in which large changes of luminosity (about 1 mag) occur over short time scales (less than 1 day) have been rarely detected in the past history of BL Lacertae (see e.g. Carini et al 1992, and references therein) and could be related to the onset of unusual physical conditions generating shocks or other strong instabilities (see e.g., Wagner & Witzel 1995). This source is also known to exibit a strong microvariability with rates of about 0.1 mag/hour (Racine 1970; Miller, Carini and Goodrich 1989).

In June 1997 Noble et al. (1997) observed BL Lacertae in the brightest state since several years. The permanence of this active state was later confirmed by Maesano et al. (1997a) who observed a change of up to 1.5 mag in a day. This famous source has therefore been the target of multifrequency campaings (Bloom et al. 1997, Makino et al. 1997). During the outburst, and particularly the EGRET pointing, we performed several photometric runs to study in detail the structure of the light curve and to measure the variability time scales. In this letter we present the results of these observations and discuss possible implications on the emission processes.

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Table 1. Observation log

Date	Filter (Tel.)	ΔMag	σ
July 14	V (VA)	0.70	0.02
July 15	B (VA)	0.45	0.04
July 16	V (VA)	0.55	0.02
July 19	V (VA), R (PG)	0.35 (V), 0.30 (R)	0.02
July 21	B,I (VA)	0.60 (B), 0.45 (I)	0.04, 0.02
July 22	V,I (VA), R (PG)	0.30 (V), 0.20 (I)	0.02, 0.02
July 26	R (VA)	0.28	0.02
July 27	R (VA)	0.32	0.02
July 29	V (VA), V(PG)	0.50	0.02

2. Observations and data analysis

Photometry was carried out with the 0.5 - m telescope of the Astronomical Station of Vallinfreda (Roma) and the 0.4 - m automatic telescope of the University of Perugia (Tosti, Pascolini & Fiorucci 1996). Both telescopes are equipped with CCD cameras and standard B, V (Johnson) and R, I (Cousins) filters. Data reduction was performed with IRAF-DAOphot (Roma) and with a home-developed software (Perugia). The consistency of the instrumental setups and reduction procedures has already been checked with previous cooperative observing runs on several sources (e.g. Tosti et al. 1997). Comparison stars were taken from Fiorucci and Tosti (1996) for the V, R and I bands, while for the B band we adopted the values by Bertaud et al. (1969).

On a few occasions we performed simultaneous observations with both telescopes, each one operating in one filter, in order to achieve a tight time sampling in the monitoring of the light curve. The observation log is given in Table 1, where for each night of observation we report the filter used by each telescope (VA is for Vallinfreda and PG is for Perugia), the overall variation in each band and the corresponding standard deviations of the reference stars.

3. The light curves

In the following we describe the light curves for each day. For ease of comparison all figures cover the same magnitude range (0.8 mag) and the same time span (7 hours).

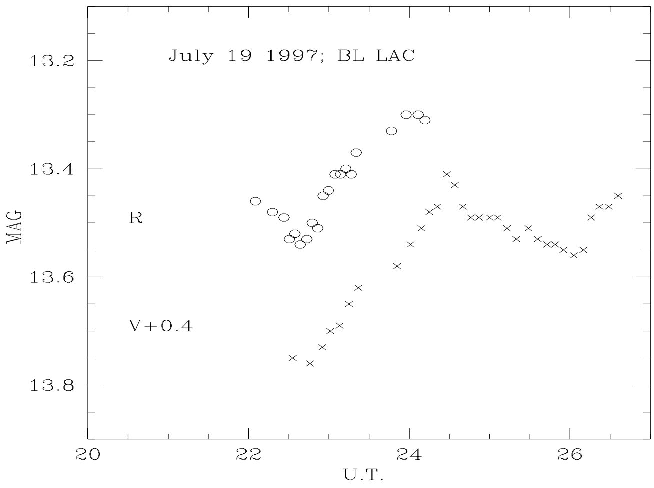

Fig. 1. July 19 light curve: crosses are V magnitudes shifted by 0.4 and circles are R mag

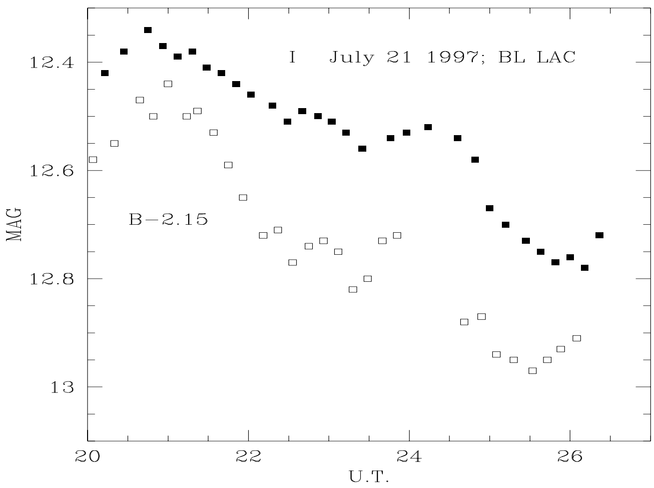

Fig. 2. July 21 light curve. The mag scale is for the I filter (crosses). Open squares are B mag shifted by 2.15.

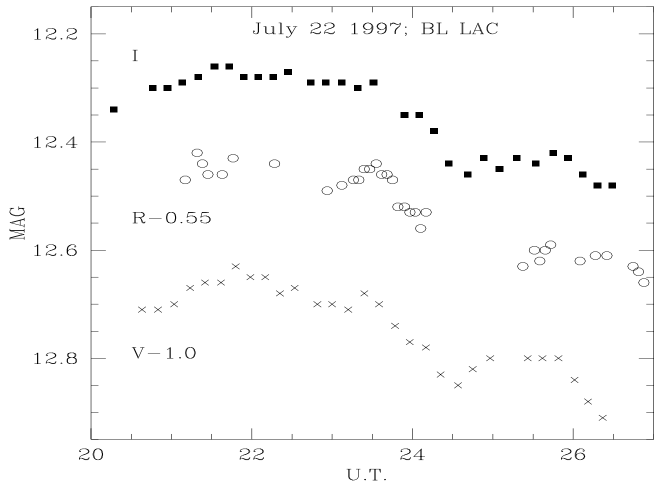

Fig. 3. July 22 light curve: crosses are V magnitudes shifted by 1 mag, circles are R mag shifted by 0.55 mag and filled squares are I mag

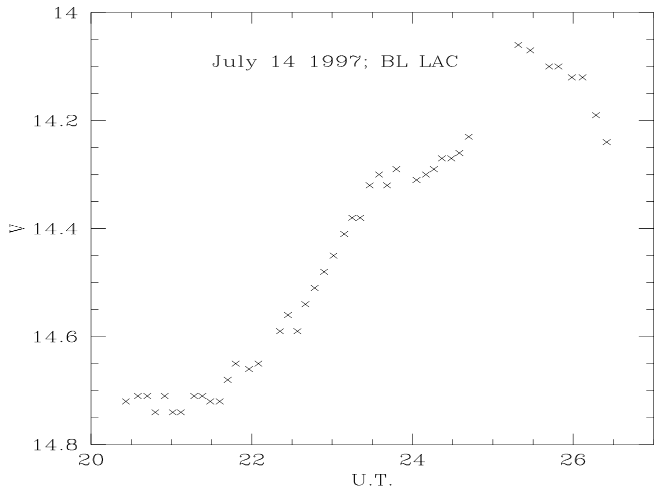

Fig. 4. July 14: V filter light curve

Fig. 1 shows the light curve of July 19 ($JD = 2445649$): the existence of a local minimum is well defined by the R data, while the following maximum is better evident in the V data. We evaluated the rates of magnitude variation from the rising branches of these light curves and found 0.20 mag/hour in V and 0.16 mag/hour in R with a 10% accuracy, suggestive of a colour effect. No time lag between the two filters can be unambigously detected at an accuracy level of about 15 minutes between the two filters.

Fig. 2 shows the light curve of July 21: a general decreasing trend is apparent starting from a local maximum in the I and B curves. The full Moon light and the poor photometric conditions lowered the accuracy in the B band. Again no time lag between the two bands can be safely detected. Neglecting the small amplitude fluctuations, the mean declining rates were equal to 0.08 mag/hour in I and 0.11 mag/hour in B with a 10% accuracy, again in the sense of a larger variation rate at shorter wavelength.

In Fig. 3 is reported the behaviour on July 22. A maximum at the beginning of the night is followed by a slow decrease, which has an average value of 0.20 mag in 4 hours. Once more the amplitude of the variation is larger at shorter wavelength.

Next we present the single filter observations. In Fig. 4 we show the largest amplitude intranight variation detected in our monitoring: 0.7 V mag in $\sim$4 hours. A maximum likely occurred at about UT 25 h, followed by a very steep decline. The following day (Fig. 5) the source was decreasing, but showed an outburst event with similar rising and falling slopes. On July 16 (Fig. 6) we observed a rising branch with an oscillating behaviour overimposed, recalling a sinusoidal damped pattern. The average rate of climb (0.08 mag/hour) is nearly half of that shown in Fig. 4 (July 14).

We do not report the curve of July 26, because we observed the source for only two hours, during which it showed a monotonic decrease of 0.26 mag down to R=13.44. The following day we could get a full intranight observation (Fig. 7) showing first a decreasing branch (average slope 0.08 mag/hour), followed

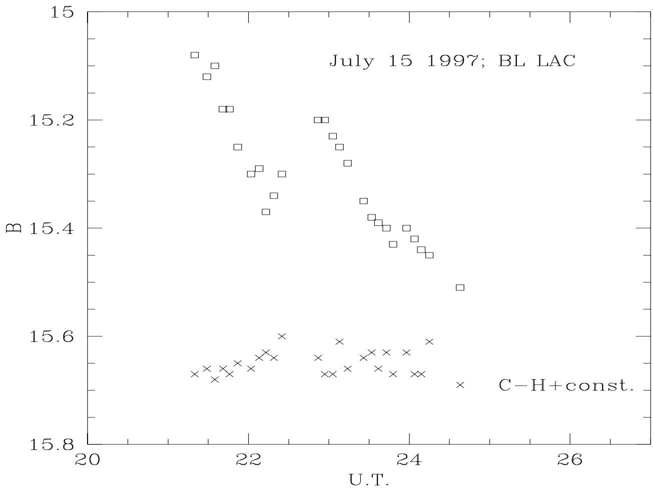

Fig. 5. July 15: B filter light curve. The mag. difference between two reference stars is also reported.

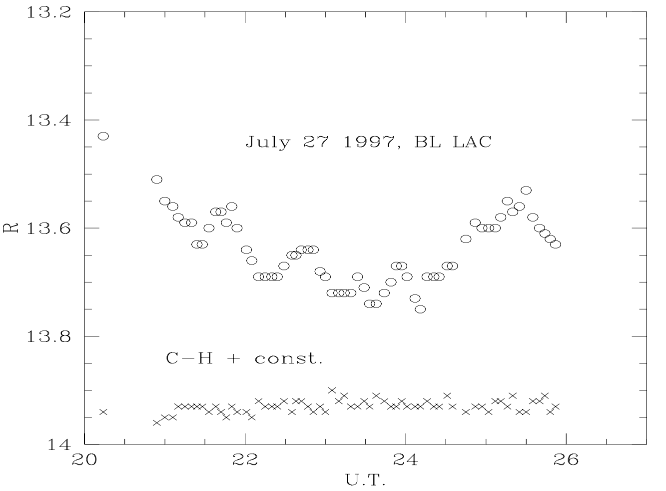

Fig. 7. July 27: R filter light curve. The mag. difference between two reference stars is also reported

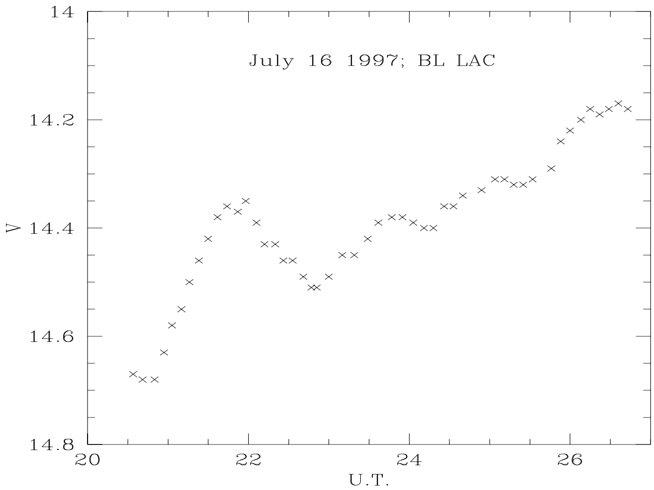

Fig. 6. July 16: V filter light curve

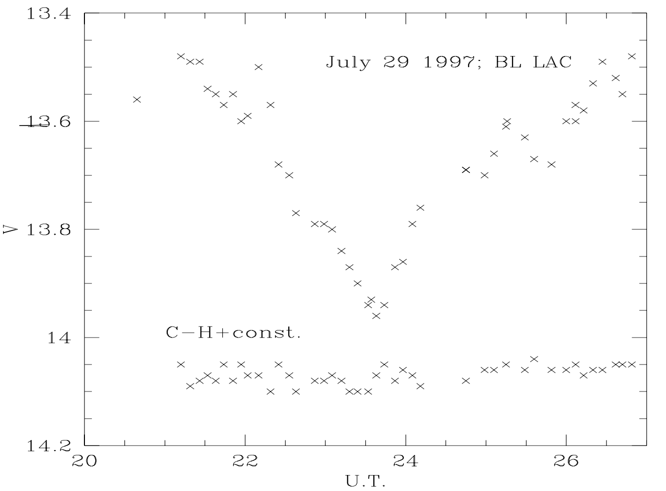

Fig. 8. July 29: V filter light curve. The mag. difference between two reference stars is also reported

by a steeper increase lasting about 1.5 hours (0.12 mag/hour); a superposed oscillating pattern with amplitude 0.07 mag, on a typical scale of one hour is also apparent. Two days later (Fig. 8) BL Lac showed a steep decrease toward a well defined minimum (0.5 mag in 2.5 hours), suddenly followed by an equally steep increase, without any quiescent phase in between. The slope became flatter (0.08 mag/hour) at about 24.5 UT and the source reached the same brightness level as the beginning of the night. Again a marked rippled pattern with typical amplitude of 0.1 mag and ∼1 - hour time scale is evident at the end of this night.

4. Discussion

These intranight observations show that during the very active phase of July 1997, BL Lac had continuous changes of brightness over quite short time scales. These changes are characterized by rather regular trends to which a smaller amplitude oscillating behaviour is frequently superposed. Typical time scales of these oscillations are of 1–2 hours with similar rising and falling slopes, and typical amplitudes are of ∼0.1 mag, but can reach ∼0.3 mag, as shown in the light curve of Fig. 6. Such oscillations were also previously detected by Carini et al. (1992) when the source was substantially fainter.

The slope of the average intra-night trend is inverted in different nights (see, for instance, the plots of Figs. 4, 5 and 6) suggesting that these curves may be just segments of greater oscillations spanning time-scales of over a day.

Our simultaneous multiband light curves also show that the BL Lac flux variations are *not achromatic*: the amplitude of the variations is systematically larger at higher frequency (see Table 1), indicating that the spectrum becomes steeper when the flux decreases and flatter when it increases. This result confirms the first finding by Racine (1970) and the more recent data by Maesano et al. (1997b), who monitored BL Lac (on longer time scales) in the years 1993-95, when the source was in a much fainter state. This color effect is still more evident when the infrared bands are considered as shown by Massaro et al. (1998).

Such effect was also found in other blazars at IR-optical wavelengths on time scales ranging from days to years (e.g. OJ 287: Gear, Robson & Brown 1986; PKS 0422+004: Massaro et al. 1996; S5 0716+714: Ghisellini et al. 1997).

This complex behaviour can hardly be explained in the framework of simple homogeneous models. An interpretation of the decay time scales in terms of pure radiative cooling of a relativistic electron population emitting by synchrotron mechanism seems quite unlikely. In fact one should admit a fine match between the acceleration time and the radiative lifetime because the corresponding raising and decaying portions of light curves span about equal durations.

The occurence of oscillating modes, with characteristic time scales increasing with amplitude, recalls some kind of turbulent process. Among the possible scenarios in which rapid variability can be produced in such disordered conditions, we find particularly appealing a model in which the ambient magnetic field has a turbulent structure with a spectrum covering quite a wide range of wavelengths. A bunch of relativistic electrons moving across this field would emit synchrotron radiation whose intensity depends on the local field strength, so that the oscillating behaviour of the light-curve on different time scales would essentially reflect the spatial distribution of the turbulence spectrum. Indeed, in the regions where the magnetic field decreases, a given frequency is emitted by electrons of higher energy (and vice versa), so the spectral changes are explained by the fact that we are observing different intervals of the particle energy spectrum. The spectral hardening and softening observed when the source flux increases or decreases can then be related to a smooth steepening of the particle spectrum toward higher energies. Alternatively, the same effect could be produced by small variations of the beaming factor, again assuming a steepening of the radiation spectral distribution. More detailed and quantitative models are necessary to study the full consistency of these scenarios with the data.

Finally, we wish to stress the relevance of establishing a network of small, possibly automatic, telescopes to improve the blazar monitoring, especially during episodes of violent activity and concurrent with high energy observations from space.

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