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Optical R band photometry of selected HBLs

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Abstract. This paper presents the highlights of optical *R* band photometry of high-energy selected BL Lacertae objects performed at 70 cm meniscus type telescope of Abastumani Astrophysical Observatory, Georgia. Most of the targets exhibit long-term variability with 1-5 yr timescales and overall brightness variations with up to 2.4 stellar magnitudes. 1ES 0229+200 do not show clear long-term variability despite the removal the host galaxy contribution but some short-term bursts. The later are found at all brightness states of the targets, giving rise to an idea that the variety of hypothetic mechanisms should be responsible for such variations but the interactions between shock waves and jet inhomogeneities. No periodical variations are found. 1ES 1028+511 changes nearly periodically but there are no enough data points in order to consider this result as a credible one. Two-peak maxima in the historical light curves, indicating the existence of reverse shock waves along with the forward ones, are detected for several sources. The fact that no intra-night variations are found for the sample, is in agreement with the conclusions of some authors that high energy selected BL Lacs are intrinsically less variable than low-energy selected ones. The targets show intra-day changes being mainly in association with short-term bursts.

Key words. galaxies: active – BL Lacertae objects: photometry-optical

1. Introduction

BL Lacertae (BL Lacs) objects are the most extreme representatives of active galactic nuclei (AGNs) with strong radio emission, smooth spectra (featureless or with very week lines), violent variability over the whole electromagnetic spectrum and high polarization. This properties are generally interpreted as being the signature of a relativistic jet pointed towards us. Along with flat-spectrum radio quasars (FSRQs), BL Lacs are included in blazar class. Their spectral energy distributions (SED) reveal two different components: a low-energy one peaking at infrared-soft X-ray wavelenghts, and considered to be the result of synchrotron radiation of relativistic electrons, while High-energy component is thought to originate from inverse Compton scattering of low energy photons at ultrarelativistic particles (Padovani 2007).

One of the key blazar characteristics is a flux variability at different timescales: from ultrafast TeV flares up to long-term variations of a few years in optical domain (Cellone, Romero, & Araudo 2007). This feature is an important tool to investigate blazar innermost structure by means to light-travel argument. It is currently widely accepted that long-term variability should be in association with ultra-relativistic shock waves propagat-

Send offprint requests to: B. Kapanadze ing through the jet (Marscher, &Gear 1985). The interaction of the shocks with jet turbulent medium can trigger short-term variations (Cellone, Romero, & Araudo 2007). This publication reports the results of long-term optical monitoring of eleven BL Lacerate objects, selected from the catalogue *Einstein Slew Survey* (Table 1, (Elvis et al. 1992)).

The targets belong to HBLs (high-energy peaked BL Lacertae objects), with low-energy peaks in the UV/X-ray bands. This blazar subclass was found to have optical variability patterns different from those of low-energy peaked BL Lacs (LBLs, (Heidt, &Wagner 1996). Romero, Cellone, & Combi (1999) found lower duty cycles and variability amplitudes for XBLs in their sample. These differences were attributed to the stronger magnetic fields in high-energy peaked BL Lacs which prevents the formation of small-scale jet inhomogeneities in these objects. However, these results were based on small number targets and and we need more observations in order to make up some statistically significant conclusions.

This publication is organized as follows. In Section 2, I describe the observational technique and data reduction methods; in Section 3, the highlights of the results of long-term photometry are provided. Section 4 gives some remarks concerning the obtained results and future investigations.

2. Observations and data reductions

The observations were carried out during 1997-2007 in in *R* band of Johnson-Cousins system with 70 cm meniscus type telescope of Abastumani Astrophysical Observatory,Georgia. The data are obtained by means of ST-6 (1997-2006) and APOGEE-6 CCD (since September 2006) cameras, attached to the Newtonian and prime focuses, respectively. Image processing was made using standard routines of IRAF. Photometric reductions were performed by means of DAOPHOT II software. Aperture photometry was carried out with concentric apertures. The usual way to select the suitable aperture radius is the construction of growth curves.

Blazar variability at different timescales are investigated by generation of historical light curves using either stellar magnitudes or linear fluxes. We can convert *R* magnitudes into linear *F* flux and vise versa using the equation provided by Nilsson et al. (2007). I selected the comparison stars from Fiorucci, Tosti, & Rizzi (1999), Villata, Raiteri, & Lanteri (1998), Nilsson et al. (2007), Monet et al. (1998) or they were chosen among field stars matching closely the target in the magnitude and position. *R* magnitudes were corrected on galactic absorption according to Schlegel, Finkbeiner, & Davis (1998) (for each target, the derived values of galactic absorption are presented in the last column of table 1).

One of he best ways to determine any variability timescale in the case of unevenly sampled data sets (as it is customary for astronomical observations!) is a structure function (SF) analysis developed by Simonetti, Cordes, & Heeschen (1985). Furthermore, the variability durations were corrected on object's red-shift (see (Romero, Cellone, & Combi 1999).

Some of the targets (1ES 0229+200, 1426+428, 1959+650, 2344+514) are hosted by bright elliptical galaxies, which add significant fluxes into measurement aperture and dilute intrinsic flux variations. This contamination is especially great for 1ES 2344+514 amounting up to 90% of total flux. In that cases, the *R* magnitudes were first converted into linear fluxes and then the respective values of hosts' *R* band fluxes (see Nilsson et al. (2007)) were subtracted. I converted the corrected fluxes back into stellar magnitudes, which were then de-reddened.

3. Results

3.1. Long-term variability

During ten years of optical R-band monitoring, most of the targets showed long-term variability (i.e. flares with timescales from several months to several years). 1ES 0229+200 do not exhibit clear long-term changes but some short-term bursts, despite the removal of

Table 1. List of targets

Target	*RA*	*Dec*	z $A_{\rm r}$	
1ES 0229 + 200	02 : 32 : 48	+20 : 17 : 17	0.139	0.36
1ES 0323 + 022	02 : 26 : 14	+02 : 25 : 17	0.149	0.30
1ES 0414 + 022	04 : 16 : 52	+01 : 05 : 24	0.287	0.316
1ES 0502 + 675	05 : 07 : 56	+67 : 37 : 24	> 0.314	0.406
1ES 0647 + 250	06 : 50 : 47	+25 : 03 : 00	0.30	0.263
1ES 0806 + 524	08 : 09 : 49	+52 : 18 : 58	0.138	0.118
1ES 1028 + 511	10 : 31 : 19	+50 : 53 : 36	0.361	0.033
1ES 1426 + 428	14 : 28 : 32	+42 : 40 : 29	0.129	0.033
1ES 1517 + 656	15 : 17 : 48	+65 : 25 : 23	> 0.7	0.068
1ES 1959 + 650	19 : 59 : 59	+65 : 08 : 55	0.047	0.473
1ES 2344 + 514	19 : 59 : 59	+51 : 42 : 18	0.044	0.577

host contribution. The timescales of long-term trends, corrected on red-shifts, cover a wide range of 0.7-5 yr (see Fig.3). 1ES 0323+022, 0502+675, 0806+524, 1426+428, 1959+650, 2344+514 do not exhibit any indication of the periodicity (see e.g. Fig. 1-2). The greatest observed amplitude of 1.5 mag is recorded for 1ES 2344+514 (after the removal of host contribution although with uncertainties amounting up 0.2 magnitude in that case. Otherwise, the amplitude did not exceed 0.3 mag.). 1ES 1959+650 is the most luminous among the targets with a maximum brightness of 13.95 mag (corrected on galactic absorption and host contribution) and amplitudes ranging from 0.65 up to 1.4 mag. As a rule, both variability amplitudes and durations was changing from one flare to other.1ES 1028+511 varied nearly periodically but there are few data during one of the flares and even a few additional points might change the variability character essentially. Hence, the further monitoring for periodicity confirmation and period derivation is needful. As to the rest of the sources, it is impossible to make reasonable conclusions in this respect due to some observational gaps. Note that the *B* band light curve of 1ES 0414+009, constructed by Pica et al. (1988), exhibits non-periodical behavior. Hence, one may expect the same situation in R band too. The overall *B* magnitude change for this object of 2.18 mag is twice grater than the same in the *R* band. The same should say for 1ES 0323+022 in the case of of *R* and *V* magnitudes ((Jannuzi, Smith, & Elston 1993)). Unfortunately, we have not got enough information for other targets in this regard in order to say whether this trend is common for our sample.

There are some indications that the base level of the flux undergo the changes of decades order probably due to the instabilities occurring in blazar accretion discs.

According to the calculations of Sokolov, & Marscher (2004), the collision of the shock wave with Mach disc can lead to the formation of a doubly structured emission region consisting of two zones, confined between forward and reverse shocks. Emission from each zone can produce a flare and the resulted variability will be a combination of two flares. This event should be reflected in double-peak maxima in historical light curve of the blazar. The maxima with two broad peaks are observed for 1ES 0502+675, 0647+250, 0806+524, 1517+656, 1959+650, 2344+514 (see e.g. fig. 1, between $JD - 2450000 = 2500 - -3500$). The appearance of such structures are predicted on basis of binary BH model for blazars too, if the secondary BH hits the accretion disc of the primary before and after pericenter passage (see e.g. (**?**)). But it is hard to apply this hypothesis to our targets since they do not vary quasi-periodically. Thus, the suggestion

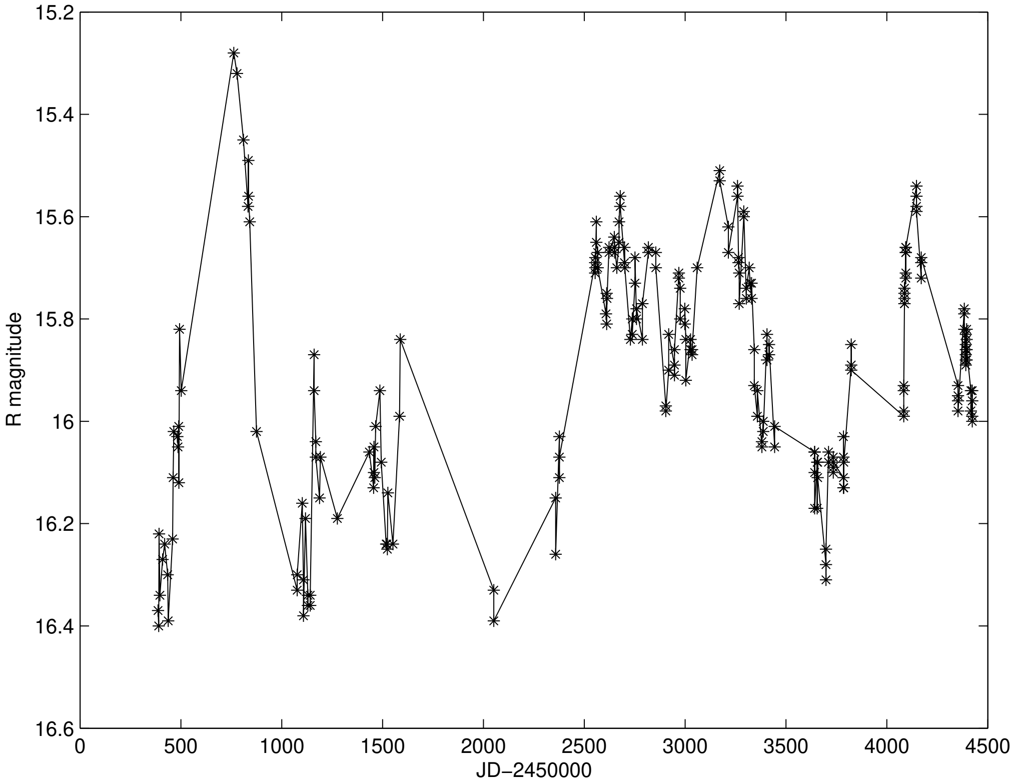

Fig. 1. Historical R band light curve of 1ES 0502+675 (corrected on galactic reddening).

of Sokolov, & Marscher (2004) seems to be much reasonable in that case.

I examined the correlation of characteristic timescales (i.e. averaged per different flaring cycles, Smith et al. (1993)) of long-term flares and targets' redshifts, but no positive result was obtained in this respect (see Fig.4).

3.2. Short-term bursts and intra-day variability

Due to the very high Reynolds number in a relativistic jet, the jet plasma should be quite turbulent (Marscher 1996). Therefore, one should expect the existence of such structures in the blazar jets as Mach discs and oblique shocks. Collisions of shock waves with them can produce short-term bursts (with duration from a few weeks up to several months)(see e.g. Sokolov, & Marscher (2004)).

Numbers os short-term bursts, lasting up to 120 days, were seen for most of the targets (see e.g. Fig.5). Their amplitudes sometimes exceeded 0.5 mag. They emerged at all stages of brightness. This fact gives rise to the hypothesis that other mechanisms along with the interactions between shocks and jet inhomogeneities should be at work. 1ES 1426+428 exhibited these features only during the flare states. 1ES 0647+250 show the smoothest light curve without any short-term bursts.

Intra-day variability (with timescales of days order, see Romero, Cellone, & Combi (1999)) with the rate of up to 0.1 mag per day are customary for our targets. They mainly occurred during short-term bursts. The exception

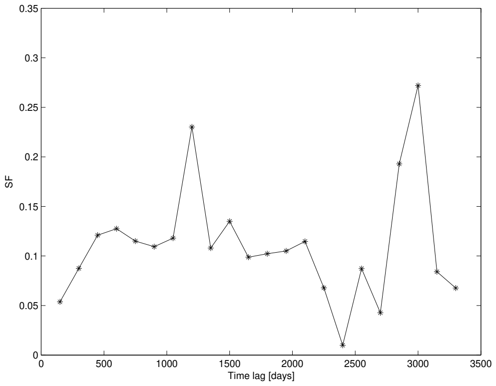

Fig. 2. Structure function for 1ES 0502+675.

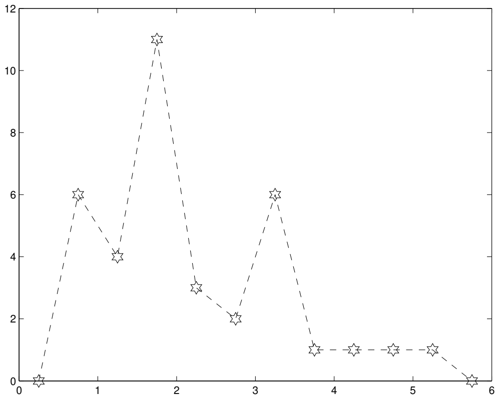

Fig. 3. Statistics of the flares for the sample (number of flares versus duration).

is 1ES 0647+250 which is inactive in this regard too.

3.3. Microvariability

Romero, Cellone, & Combi (1999) defined intra-night optical variability (INOV) or microvariability as strictly intra-night flux changes with timescales from minutes to a few hours. This kind of the flux variations is very important to investigate the fine structure of blazar optical jets. Up to now, remarkably large intra-night fluctuations, amounting to several tenths of a magnitude in a few hours, are firmly established for dozens of blazars (see e.g. (Cellone, Romero, & Araudo 2007)).

The targets were examined for microvariability. No positive results were obtained in this respect (after taking into account all the possible effects causing a spurious microvariability). The C parameter, introduced by Romero, Cellone, & Combi (1999), was always less than 2.576 (99% confidence level).

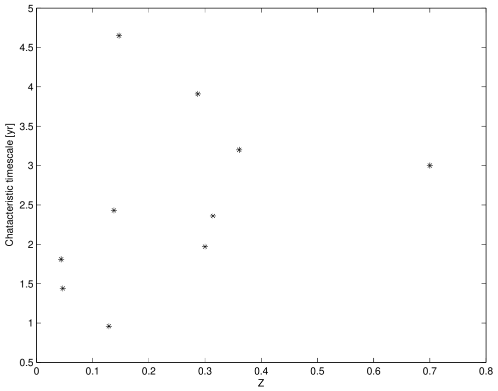

Fig. 4. Characteristic timescales of Long-term variability versus redshift.

4. Concluding remarks

The paper presents the highlights of the optical monitoring of selected XBLs at Abastumani Observatory, Georgia. This observations make an valuable contribution in the study of optical properties of these blazars , whose optical observations were performed rarely in the past. Along with the data of other observational

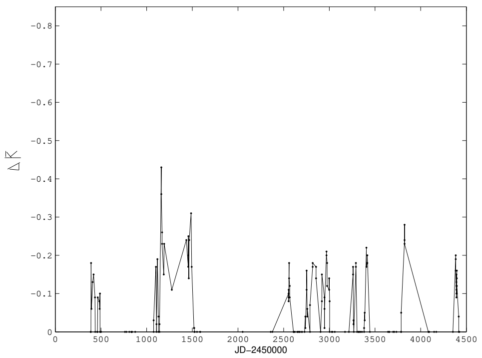

Fig. 5. Short-term bursts in 1ES O502+675.

campaigns in different spectral bands, our results can be used to establish spectral energy distributions and study the physical processes responsible for blazar features.

Despite some observational gaps, the characteristics of the *R* band variabilities are derived. For some targets, no periodical flares are found and we need further monitoring for other ones in order to establish the character of their variability. Future investigations, in cooperation with other observatories, are necessary to establish whether the changes of the decades are intrinsic for these objects, which can give an important clue in understanding of the instable processes inherent to blazar accretions discs.

As remarked above, short-term burst are found both at blazar flaring and quiet stages, that is we have to search for a variety of hypothetic mechanisms causing such instable processes in addition to relativistic shock-jet inhomogeneity interactions.

The fact that our sample do not reveal microvariability, is in agreement with the suggestion that HBLs are intrinsically less variable than LBLs (as it is shown in Cellone, Romero, & Araudo (2007) and Kapanadze (2009), some claims concerning violent microvariabilities in some XBLs (see e.g. (Bai et al. 1998)) should be the artefact of unsuitable choice of the reference stars used for differential photometry). Nevertheless, it seems quite possible to discover these variabilities (see above provided maximum rate of intra-day changes) and it is necessary to carry out intensive observations to have a progress in this direction.

5. DISCUSSION

JIM BEALL: What was the source that had no observed variability? Can you expand your comments on this?

BIDZINA KAPANADZE: Such a source is 1ES 0229+200, which a TeV object. It is embedded in bright host galaxy. Despite the attempt to remove host contribution, no long-term variability was found but some short-term fluctuations. Nevertheless this object show clear long-term flares in X-rays, according to RXTE observations. The basic hypothesis explaining blazar long-term variability resorts to the evolution of shock waves propagating through the jet. If this is the case, the shocks should suffer strong dilution in 1ES 0229+200 until reaching the jet region where the optical photons predominantly originate.

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