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The results of simultaneous TESS and multiband photometric observations of BL Lac during a high activity

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Abstract. For the blazar BL Lac, we analyze data from TESS and multiband observations that were obtained using the MTM-500 telescope of the Crimean Astrophysical Observatory from 1.09.2022 to 30.09.2022. During this period, BL Lac showed strong variability, both accompanied and unaccompanied by changes in spectral index. The shortest characteristic variability times are mainly in the range from 0.2 to 1 day and do not depend on the object brightness, the spectral index, and the average amplitude of the variability within the corresponding intervals of the light curve. It indicates that the mechanisms of short-term variability are characterized by two or more independent parameters.

Keywords: radiation mechanisms: non-thermal; relativistic processes; techniques: photometric; BL Lacertae objects: individual (BL Lac); galaxies: jets

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1 Introduction

The blazar BL Lac was in a highly active state like never before during 05.2021–12.2023. It was very bright and showed a large amplitude of brightness fluctuations (Bachev et al. 2023). To compile a complete picture of the processes that led to such violent variability, the observations in different spectral ranges and on different time scales are necessary. Earth's daily rotation complicates observations of micro-variability. However, during 01.09.2022–30.09.2022 BL Lac was in the field of view of the TESS space mission (Ricker et al. 2015), conducting almost continuous optical monitoring of a section of the sky for 27 days with high temporal resolution. Supplementing these data with the results of simultaneous multiband photometric observations performed on the MTM-500 telescope of the CrAO RAS, we got the opportunity to investigate the correlation between the temporal and spectral properties of the BL Lac variability on time scales from several hours to several days.

2 Observations and data analysis

Intraday B-, V,-R-, I-observations of BL Lac were performed by the telescope MTM-500 (Rublevski & Kiselev 2019)

As a result of the nested ANOVA test, intraday variability was detected on 15 out of 23 nights according to MTM-500 data. Figure 1 shows the light curves for the entire observation period and the night MJD=59840. Converting magnitudes to the radiation flux (Mead et al. 1990), we determined the spectral index α under the assumption of a power-law spectrum $F \propto \nu^{\alpha}$ (Fig. 2). We calculated the uncertainty of the α value arising from errors in flux measures according to the method described by Gorbachev et al. (2024).

Due to the dense stellar environment near BL Lac, its relatively weak brightness, and the large pixel size ($21''$), TESS does not provide automatic processing results for this source. It leads us to the need to perform our photometric processing of TESS full-frame image cuts summed up by 10. There is an acceptable agreement with the MTM-500 data (Fig. 1). However, there are some differences, in particular, the difference in the amplitude of the variability ($\Delta m_{\text{MTM-500}} = 1.225$ and $\Delta m_{\text{TESS}} = 1.102$). We attribute this fact to the change in the spectral index with variability, as well as the wide bandwidth of the TESS filter (600–1000 nm).

If one process is responsible for variability on small time scales, its parameters may change over time. Or this process can be replaced by another one. Then, we can expect a change in the shortest characteristic variability time τ. Assuming that a single process dominates the variability at some time interval, we define τ using the structure function (SF) for consecutive intervals on the light curve using TESS

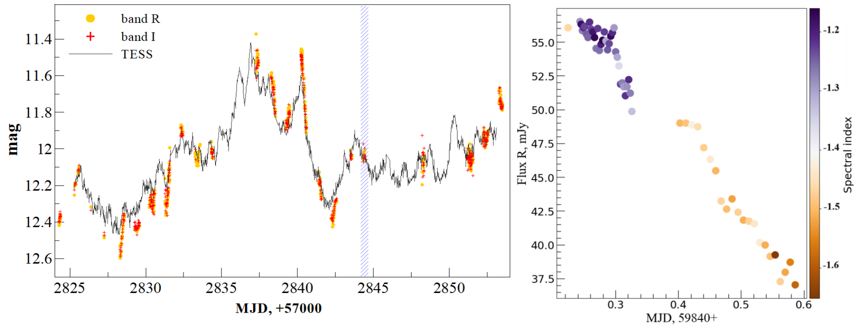

Fig. 1. The left panel shows combined BL Lac light curve according to MTM-500 and TESS data. For better clarity of the light curves, the values in the R and I bands were reduced by 1.1 and 0.36 magnitude, respectively. The shaded area marks the night, the light curve of which is shown on the right panel.

telescope data (for more details, see Butuzova 2021). Figure 3 shows the absence of explicit dependencies of τ on the square of the average variability amplitude (SF_{max}), defined as the value of the SF maximum, the maximum brightness change, and the average brightness at the corresponding intervals.

The evolution of the spectral index and τ demonstrates different behavior: curves show both correlation and anticorrelation intervals as well as significant changes in τ with α constant (Fig. 2).

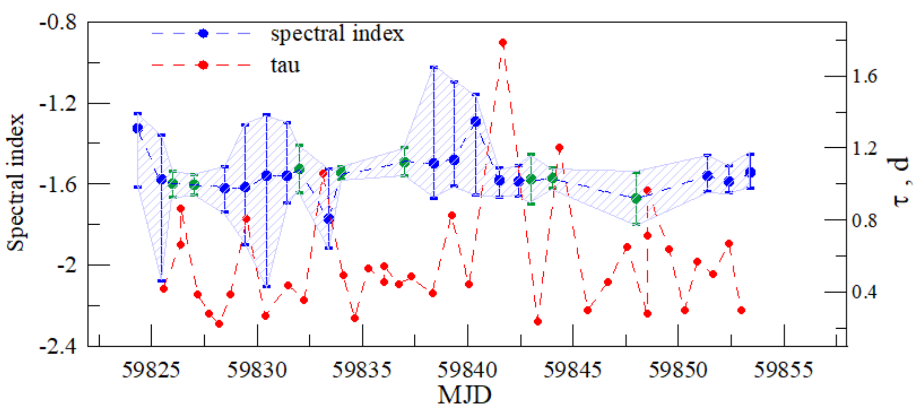

Fig. 2. Evolution of the BL Lac spectral index and the shortest characteristic variability time τ. The blue and green symbols mark the median values of α for nights with and without detected intra-day variability, respectively. The error bars show the maximum change in α during the night. The shortest characteristic variability time τ is highlighted in red.

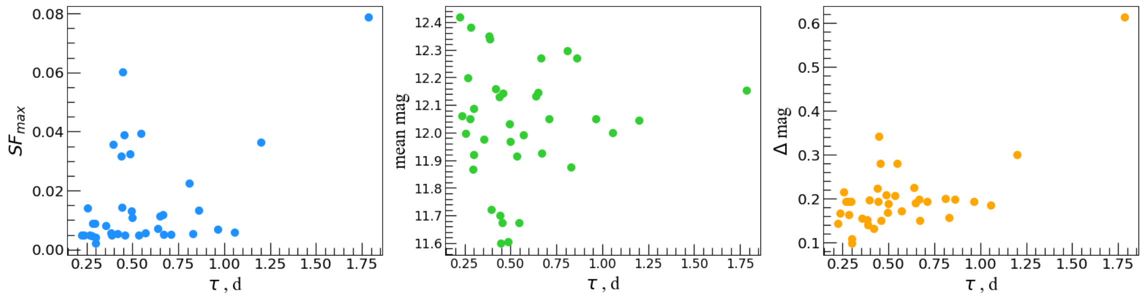

Fig. 3. The dependence of micro-variability parameters (SF_{max}, <mag> and Δmag) on τ.

3 Summary

Intra-day variability of BL Lac was detected on 15 of the 23 nights, with 7 nights showing changes in spectral index. For the first time, we prove that the difference in the variability amplitude in TESS and ground-based telescope data is caused by a change in α at a wide TESS bandwidth. The shortest characteristic variability times are mainly in the range from 0.2 to 1 day. No correlation was found between the temporal and spectral variability characteristics. It indicates that the mechanisms of short-term variability are characterized by two or more independent parameters.

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