Multi-band Intra-night Variability of the Blazar CTA 102 During its December 2016 Outburst

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Introduction

The blazar class of active galactic nuclei (AGNs) involves BL Lac objects and flat-spectrum radio-quasars (FSRQs). Violent variability across the electromagnetic spectrum is among their main characteristics. In particular, the variability time scales could provide valuable information about the emitting region parameters.

The FSRQ CTA 102 (z = 1.037) underwent an unprecedented outburst in Dec. 2016 reaching an R-band magnitude of 10.82 ± 0.04 thus becoming the brightest AGN ever observed. This triggered a GASP-WEBT monitoring campaign which results were published in Raiteri et al. (2017).

We perform temporal analysis of the multi-band intra-night variations of CTA 102 during the outburst with the aim to derive the size and physical parameters of the emitting regions.

Observations and Photometry

We monitored CTA 102 in *BVRI* on Dec. 3rd, 4th, and 5th, 2016 for about 12 hours in total using the 50/70-cm Schmidt telescope of the Rozhen NAO, Bulgaria, and the FLI PL18603 CCD camera.

The aperture photometry of the source, a control star (a field star of compatible brightness), and a couple of GASP-WEBT suggested reference stars was performed by means of DAOPHOT run under IDL. The aperture radii were set to 2 or 3 times the frame FWHM. The light curves for the nights of monitoring are shown in Fig. 1.

Results

The object showed brightness variations in the range 0.1–0.2 mag. They are achromatic for the first night. For the other two nights a “bluer-when-brighter” trend was found (Fig. 2). Then single fast flares were observed. Below we shall consider only the second and third night.

We searched for a time lag, τ, between the emission in the individual bands (*BV* with respect to *I*) using the z-transformed discrete correlation function (zDCF, Alexander 1997). The largest lag is (11.2 ± 4.6) min, estimated by means of a Gaussian fit to the correlation function peak (Fig. 3). The lag values for the other band and nights are positive as well. All detected lags, however, are less than three times the data spacing (which equals 9.4 min for the *BVI* data points), so, we shall consider them not meaningful after Carini et al. (2011).

The flares were approximated with a double exponential law (Abdo et al. 2010). We estimated the time scales of the flux *rise* and *decay*. Unfortunately, the flares were not fully sampled during the nights, so, the accurate estimate of both time scales for each night turned out to be hard: the rise scale was determined for the second night flare, and the decay one for the third night flare. For both nights we showed the fits with the lowest reduced χ^2 (Figs. 4 & 5). The corresponding rise and decay time scales are (10.4 ± 6.2) min and (28.3 ± 17.2) min, respectively.

We calculated the relative spectral energy distribution (SED) of the variable component following Hagen-Thorn & Yakovleva (2008). The flux-flux relations used to build the SED were linear with correlation coefficients larger than 0.98. The SED was approximated with a homogeneous synchrotron source with a spectral index $\alpha = -0.923 \pm 0.002$ and a critical frequency $\nu_C = 1.4\times10^{15}$ Hz (Fig. 6).

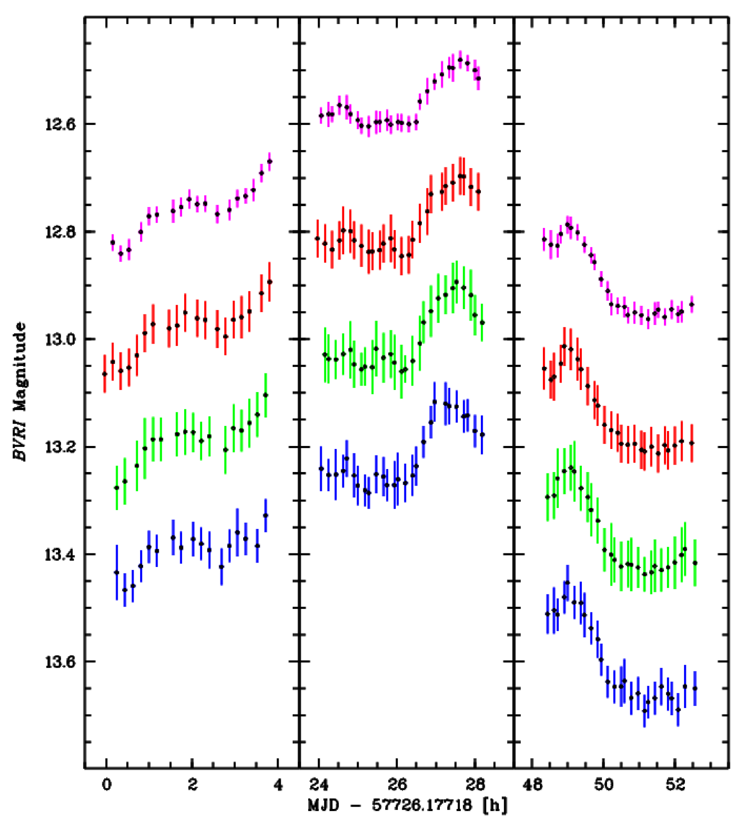

Fig. 1: BVRI light curves (from bottom to top) for the nights of monitoring.

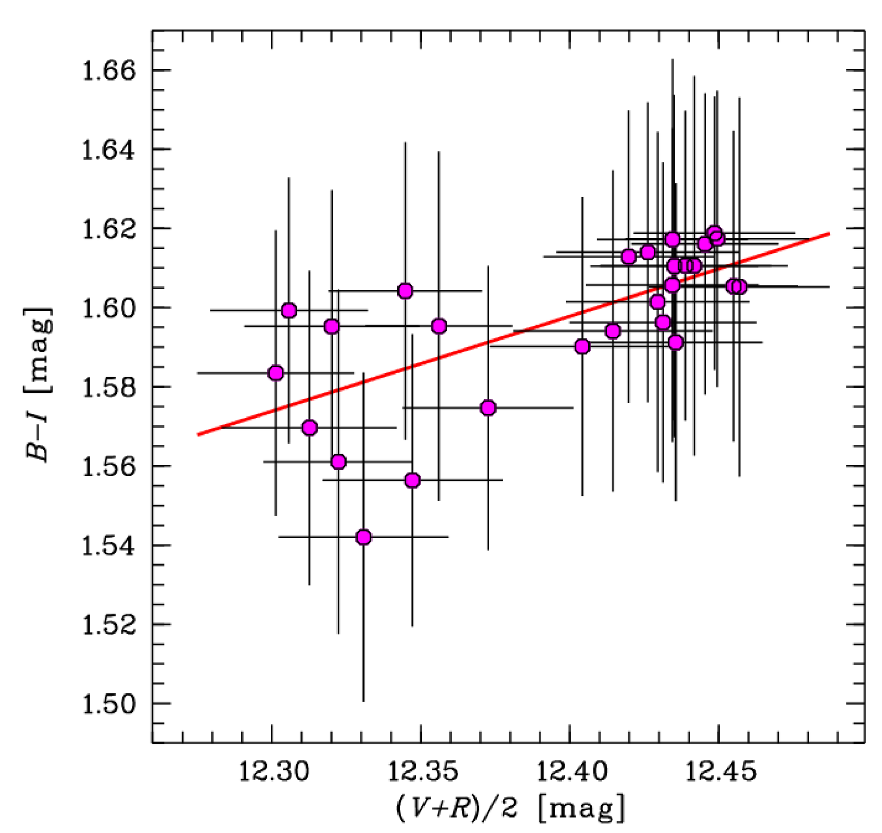

Fig. 2: Colour-magnitude diagram with a weighted linear fit of slope 0.2 ± 0.1 overplotted for Dec. 4th.

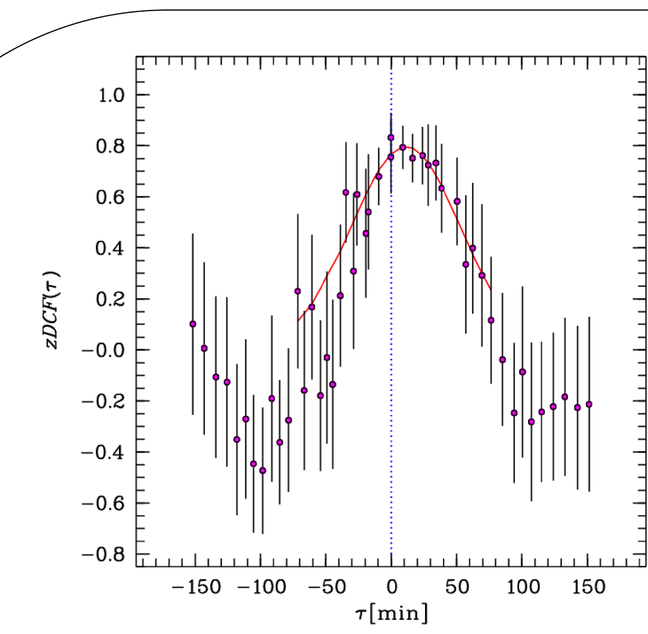

Fig. 3: zDCF of the B and I light curves for Dec. 4th with a weighted Gaussian fit overplotted.

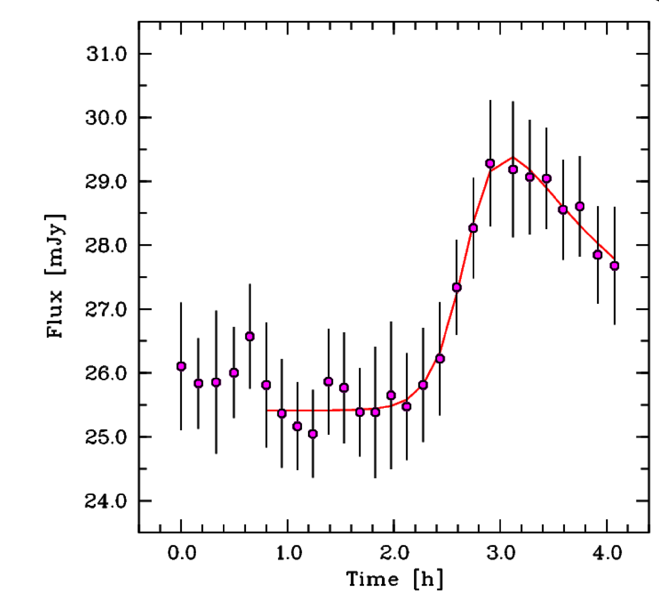

Fig. 4: Double exponential fit to the B band light curve for Dec. 4th.

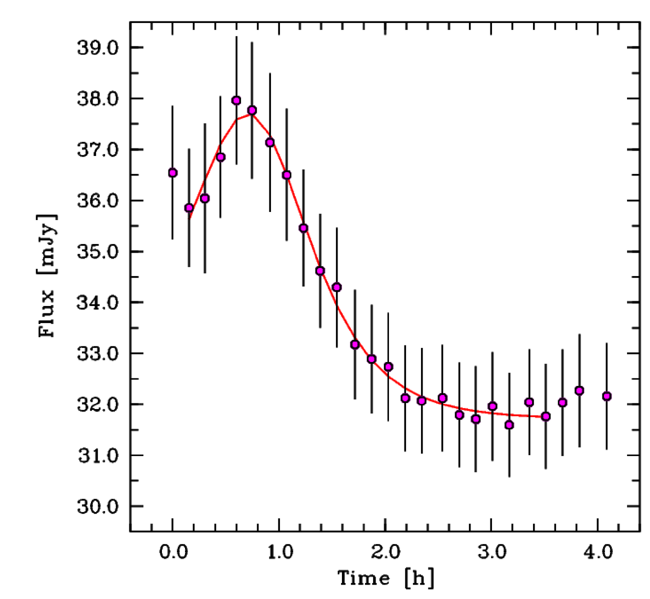

Fig. 5: Double exponential fit to the R band light curve for Dec. 5th.

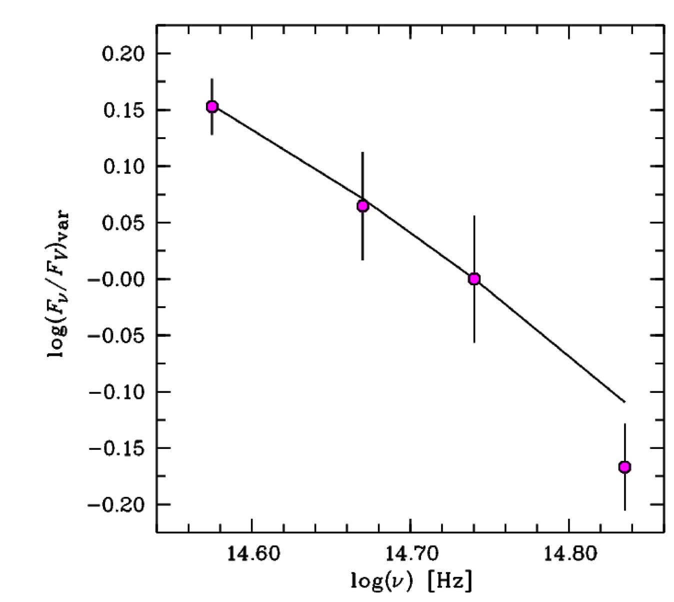

Fig. 6: Relative SED of the variable source for Dec. 5th. Overplotted is the homogeneous synchrotron source spectrum.

Discussion

We presented results from the multi-band intra-night monitoring of the FSRQ CTA102 during its Dec. 2016 outburst in three consecutive nights. The achromatic flux variations in the first night prompt for geometric effects. For the other two nights a “bluer-when-brighter” trend was observed. This could be an indication that the fast flares are produced by shocked plasma cells (the so called “shock-in-jet” model). The shock-in-jet model predicts inter-band time lags with the shorter bands leading longer ones. All zDCFs of ours showed asymmetry towards positive lags, i.e., as expected, however, not significant enough.

The rise time scale constrains the size of the emitting region (e.g., Danforth et al. 2013). The Doppler factor, δ, was roughly estimated using a one-zone SSC model (Tramacere et al. 2009). We got δ = 36.6 for Dec. 4th. This results in an upper limit for the size of the emitting region of 3.4×10^{14} cm (or 22.5 AU). It is in good agreement with the size of the turbulent cells estimated on the base of the numerical shock-in-jet modeling of blazar microvariability light curves (e.g., Bhatta et al. 2013). The authors found that the sizes of most of the cells are less than 40 AU.

The decay time scale constrains the cooling scale (e.g., Ghisellini et al. 1997, Danforth et al. 2013), thus obtaining the following limits: magnetic field strength $\gtrsim$1.1 G and Lorentz factor of the electrons (in the R band) $\lesssim 2.6\times10^3$. The Doppler factor for Dec. 5th is δ = 33.8.

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