INTRA-NIGHT MONITORING OF THE BLAZAR 0716+714: RESULTS FROM THE 2011 CAMPAIGN

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Introduction

Blazars are the most extreme class of Active Galactic Nuclei. They exhibit strong and rapid variability across the electromagnetic spectrum and high and variable polarization from radio to optical wavebands. This extreme behaviour is related to a relativistic jet oriented close to the line of sight.

Among blazars, the BL Lac object S5 0716+714 (z = 0.31±0.08, Nilsson et al. 2008) is one of the brightest and most variable. The brightest optical state of the object up to now was detected on Jan 18, 2015: R = 11.71±0.05 mag (Bachev et al. 2015; Bachev & Strigachev 2015) and R = 11.677±0.005 mag (Chandra et al. 2015). The duty cycle of S5 0716+714 (the fraction of time when an object displays intra-night variability, Romero et al. 1999) is close to 90% (e.g., Agarwal et al. 2016), i.e., the source shows almost permanent flux changes. This fact facilitates the proper characterization of its intra-night variations, which is of utmost importance in order to constrain the physical processes leading to such variations.

We have started a long-term multi-band monitoring programme since 2011 in order to characterize the S5 0716+714 variability on intra-night time scales. Here we report the results of our 2011 monitoring campaign.

Observations and Data Analysis

The observations presented here were performed during six nights in February, March, and November, 2011 using the 50/70 cm Schmidt telescope of the Rozhen National Astronomical Observatory (Bulgaria), equipped with the FLI PL16803 model CCD camera (scale 1.079 arcsec/px) and the Johnson-Cousins *BVRI* set of filters (Kostov 2010). The exposure times varied between 60 and 200 sec depending on the night and passband. The duration of the monitoring was larger than 4 hours during four of the nights and ~2 hours during the other two nights.

The aperture photometry was performed using DAOPHOT (Stetson 1987) with dynamic aperture radius of two or three times FWHM, where FWHM is the mean full width at the half maximum of the frame. The calibration of the *BVR* photometry was done with respect to stars 1-7 from the standard sequence of Villata et al. (1998); the star 1 was not used in the *R* band as it saturates on most of the frames. The *I* band magnitudes were calibrated with respect to stars 2, 3, 5, 6 of Ghisellini et al. (1997); the stars 1, 4, 7, 8 were not calibrated by the authors. For all passbands the star 8 was used as a control star. The final magnitudes of the blazar and of the control star were estimated using a weighted mean zero-point derived from the reference stars. The resulting light curves are shown in Fig. 1.

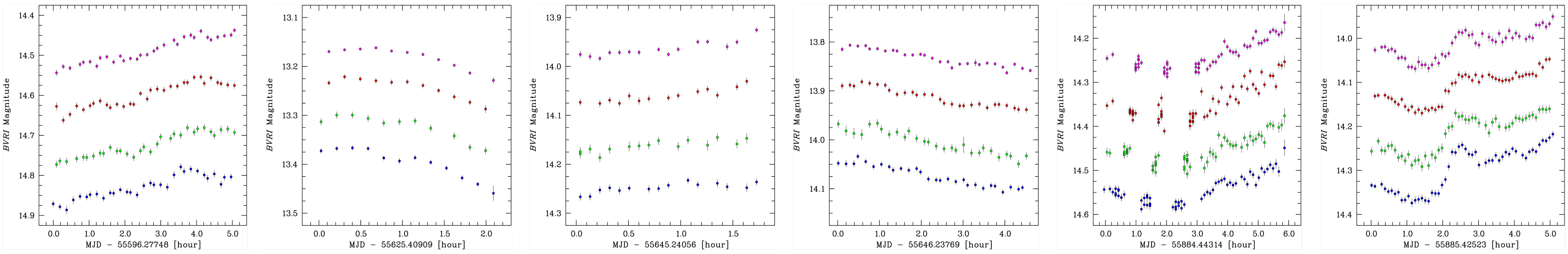

Fig. 1: *Light curves of S5 0716+714 for Feb 03, Mar 04, Mar 24, Mar 25, Nov 18, and Nov 19 (from left to right) in B, V+0.4, R+0.7, and I+1.1 bands (from bottom to top).*

Results and Discussion

To establish the variability status of the source, we applied the *C* criterion and found the blazar to be variable during 5 nights out of 6. The night with no variability detected is Mar 24, but the monitoring duration is less than 2 hours, so, we cannot make a firm conclusion about the variability status of the source for Mar 24. If the blazar is assumed non-variable during this night, then its duty cycle is 93%. Next, we built the *B*-*I* vs *R* colour-magnitude diagrams for the nights with variability detected and found the blazar to show significant bluer-when-brighter trend on Mar 25 and Nov 19. The variability during the other nights could be considered achromatic, i.e., of geometric origin. The light curves of Nov 19 show a prominent flare, which will be analyzed in details below.

Generally, the observed variability pattern of S5 0716+714 could be well described with a low order polynomials (the Nov 19 flare being excluded), which is typical for variability caused by viewing angle changes. On the top of these smooth variations are superimposed fluctuations and flares that could reflect the emission processes taking place behind the shocks moving in a turbulent medium. The light variations are best pronounced in the *B* band and less – in the *I* band.

THE NOV 19 FLARE We applied the *z*-transformed discrete correlation function (ZDCF, Alexander 1997) to search for a time lag between the *B* and *I* band light curves. Approximating the ZDCF peak with a Gaussian, we found a positive time lag, τ = 4.7±1.5 min, i.e, the *B* band variations lead the *I* band ones (Fig. 2). This lag, however, is nearly equal to the time spacing between the *B* and *I* data points, which is about 4 min. Therefore, it cannot be considerd significant; nevertheless, the ZDCF asymmetry towards the positive lags is evident. The detection of a "soft" lag means that the synchrotron cooling of accelerated electrons is the dominant emission mechanism of the flare (Kirk et al. 1998).

We approximated the Nov 19 flare with a double exponential law (Abdo et al. 2010) plus a linear base level. The best fit was obtained for the *B* band (Fig. 3), so, the corresponding results will be used in the further analysis. The rise and decay *e*-folding time scales are Trise = 7.7±1.8 min and Tdecay = 32.2±5.0 min (as measured in the observer frame), so, the flare is asymmetric, which rules out its geometric origin. The estimates of the time scales allows us to compute some parameters of the emitting region.

The upper limit of the region radius could be found as $R \leqq c\ T\text{rise}\ \delta / (1+z)$, where c is the speed of light and δ the Doppler factor. We adopted δ = 31.33 (+13.05/-6.07) from Liodakis et al. (2018) and found $R \leqq (3.3\ +1.6/-1.1)\times10^{14}$ cm or (22.1 +11.0/-7.1) AU. This upper limit is in agreement with the turbulent cell sizes obtained by Bhatta et al. (2013) by means of numerical modeling of S5 0716+714 microvariability.

If we assume that (i) the flare is caused by the synchrotron emission of electrons, which cool after being accelerated at the front of a shock and (ii) the injection of accelerated particles in the emitting region takes place in tame scales less than the light crossing one, then the asymmetry of the Nov 19 flare means that the cooling time scale is longer than the light crossing one, Tcool $\geqq R/c$. Therefore, we can put limits on the magnetic field strength and the electron energy in the flare region (Ghisellini et al. 1997). Under the equapartition assumption we obtained the following limits: $B \leqq$ (2.1 +0.6/-0.3) Gauss and $\gamma_0 \geqq (2.0\ +0.5/-0.2)\times10^3$, where γ_0 is the energy of the electrons (in units of mc^2), emitting in the *B* band. These limits are in good agreement with the median values of these parameters for BL Lac objects estimated by Chen (2018) on the base of broadband spectral energy distributions of a sample of γ-loud blazars.

This research is based on activities partially supported by the Bulgarian National Science Fund under contract DN 18/13-12.12.2017 and within the agreement between the Bulgarian and Serbian academies of sciences for the period 2020 – 2022.

Fig.2: *ZDCF between the Nov 19 B* and *I light curves.*

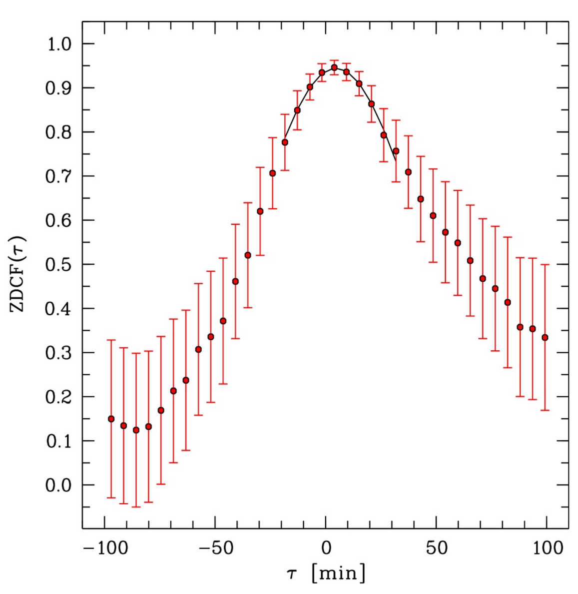

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Fig. 3: *Decomposition of the Nov 19 flare (B band). The flare profile (dashed) is arbitrary shifted for better visibility.*