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Multiwavelength Monitoring of the Gamma-Bright Blazar Mkn 421

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Abstract: We present the results of photo-polarimetric monitoring observations of the blazar Markarian 421 carried out with different telescopes (the 0.4 m telescopes of St. Petersburg State University and the Pulkovo Observatory, the 0.7 m telescope of the Crimean Astrophysical Observatory) during 2008–2015. We analyse the optical data as well as gamma-ray ligh t curves obtained with the Fermi Large Area Telescope. The multiwavelength flux variations are discussed.

Keywords: blazars; monitoring observations; color variations

1. Introduction

Mkn 421 is the closest (z = 0.031) and the most well studied TeV blazar. It is classified as a high synchrotron peaked blazar [1] based on its spectral energy distribution (HSP). It was the first blazar detected at TeV energies [2]. Mkn 421 exhibits large variations in the TeV, GeV, X-ray, and optical wavebands [3–5], with correlated TeV and X-ray variations [6].

Here we present results of a color variation analysis of the blazar Mkn 421 during 2008–2015.

2. Observations and Data Reduction

The photometric observations in B, V, R, I bands were carried out with several telescopes: 70-cm of Crimean Observatory (AZT-8), 40-cm of the Astronomical Institute of St. Petersburg State University (LX-200) and 40-cm of Pulkovo Observatory of the Russian Academy of Sciences (LX-200). The observing and reduction techniques are described in [7].

Figure 1 presents the Fermi Large Area Telescope γ-ray light curve (red vectors correspond to upper limits) and the B, V, R, I-bands optical light curves of Mkn 421 during 2008–2015.

We derive γ-ray flux densities at 0.1–200 GeV by analyzing data from the Fermi Large Area Telescope (LAT), provided by the Fermi Science Space Center using the standard software [8]. We have constructed γ-ray light curves with 4-day binning, with a detection criterion that the maximum-likelihood test statistic (TS) should exceed 10.0.

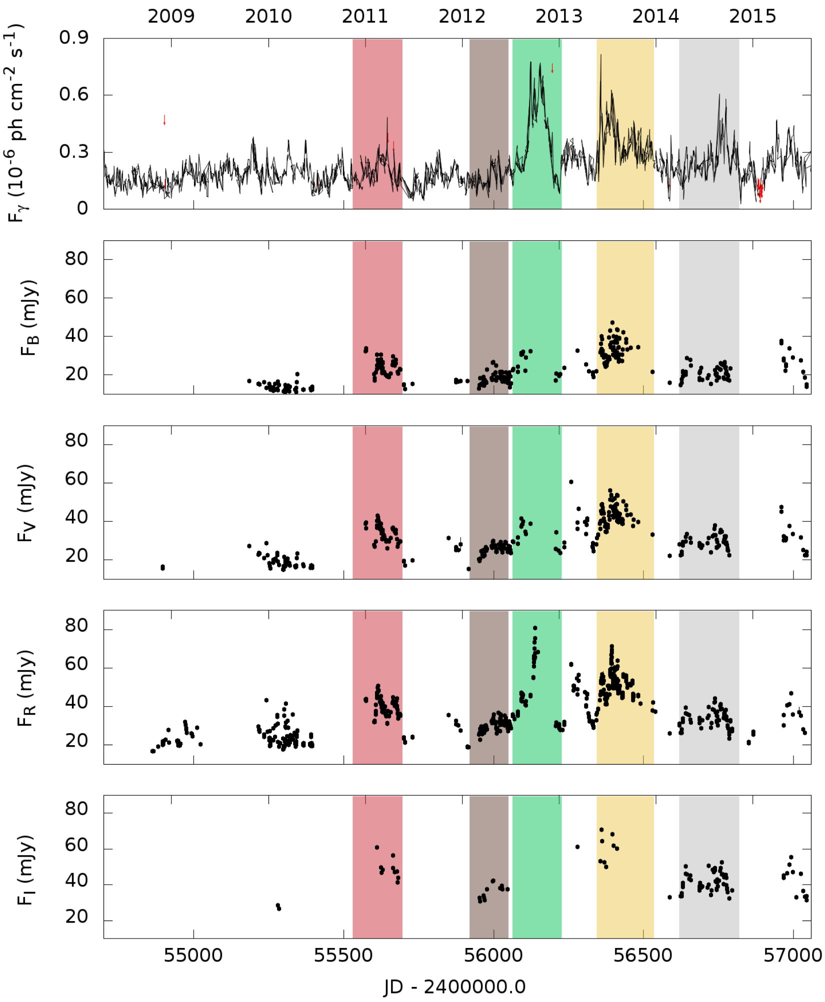


Figure 1. From top to bottom: γ-ray and the B, V, R, I-band optical light curves of Mkn 421 during 2008–2015.

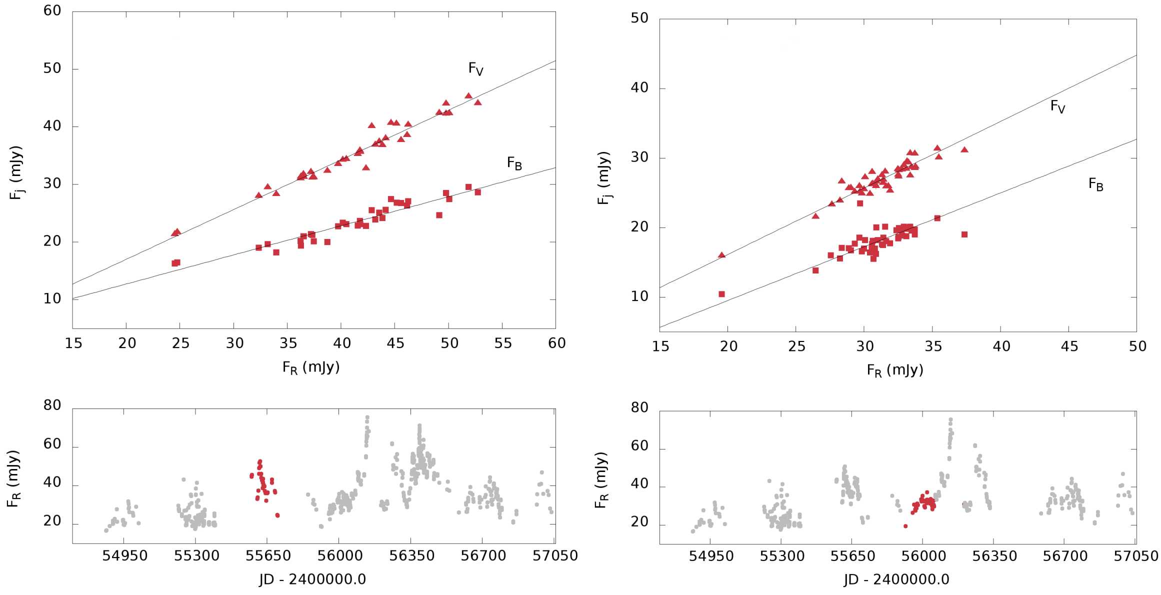
3. Results and Discussion

Color analysis is an important tool to investigate the spectral behavior of the source and, in turn, the nature of its emission.

The technique that was used in our analysis of the color variations is described in [9]. It assumes the presence of two components in the radiation: one constant and one variable, with the latter responsible for the source activity.

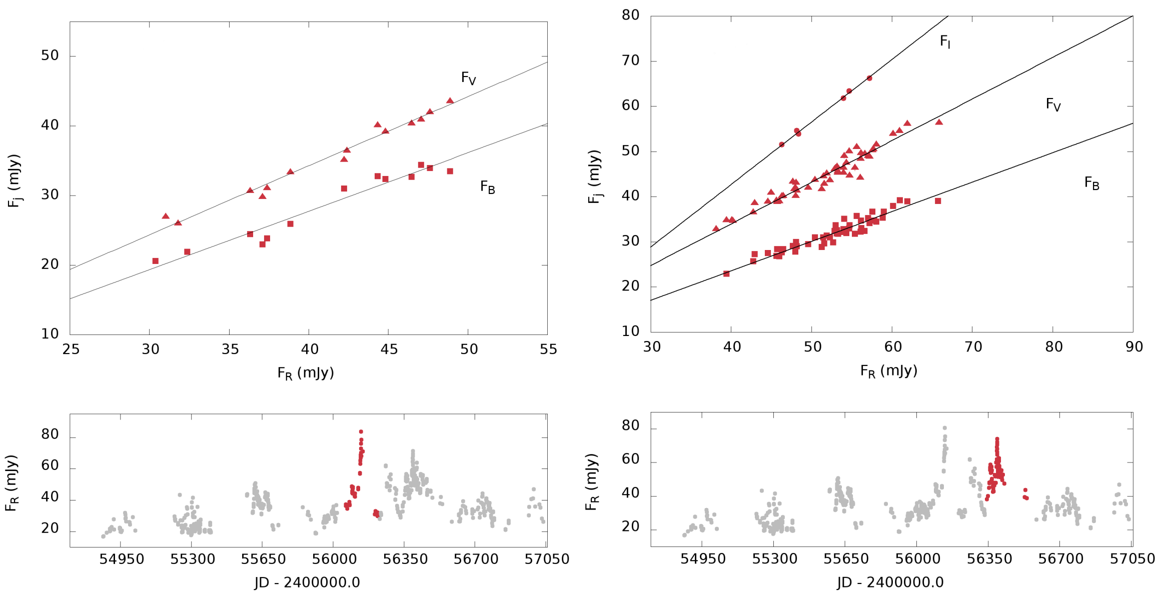
This technique, which has been used to analyze color variations of blazars many times (see, for instance [7]), is based on plotting "flux-flux" diagrams for two bands. The data for simultaneous observations lie along straight lines in such diagrams if the color characteristics of the variable component remain unchanged during the studied time interval; the slopes of these lines yield the flux ratios for the variable component in the analyzed bands. Thus, multicolor variability observations can provide the relative spectral energy distribution (SED) of the variable component.

We have plotted the observed flux density F_B, F_V, F_I as function of F_R (Figure 2–4a) for various intervals of the light curve. These intervals are marked with the multicolor rectangles in Figure 1. For 2012 the analysis was made for the outburst and its close neighborhood. As can be seen, the data points are best-fitted by a straight lines and the slopes of these lines are different for various intervals. Note that the flux density F_I is given only for 2013, because we do not have a sufficient number of data points in I band.



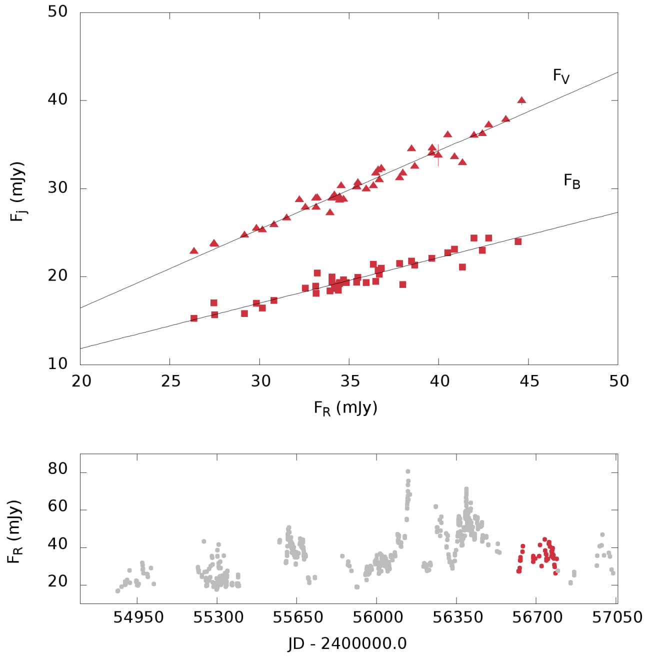
(**a**) (**b**)

Figure 2. (**a**) Flux-flux diagrams for the interval of 2011; (**b**) Flux-flux diagrams for the interval of 2012.

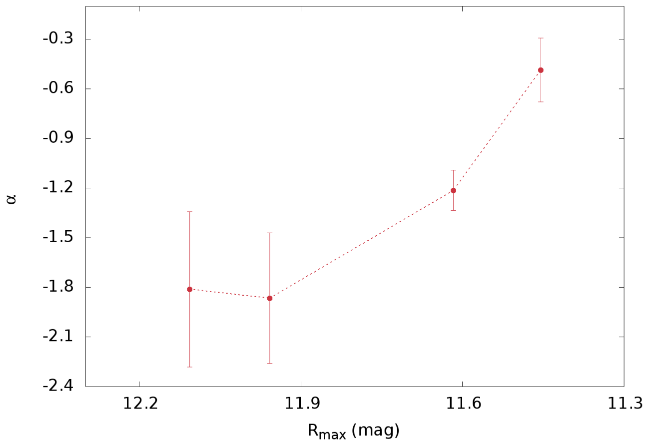


(**a**) (**b**)

Figure 3. (**a**) Flux-flux diagrams for the outburst of 2012; (**b**) Flux-flux diagrams for the interval of 2013.



(**a**)



(**b**)

Figure 4. (**a**) Flux-flux diagrams for the interval of 2014; (**b**) The change of the spectral index with the brightness of the outburst.

The SEDs follow the power law $F_\nu \propto \nu^\alpha$ (where α is spectral index). The least-square fit gives the spectral indices. The relative SEDs for these intervals, corrected for the interstellar extinction, are given at Table 1:

Table 1. The relative spectral energy distribution (SED) for various intervals.

Intervals	α
2011	-1.865 ± 0.394
2012	-0.705 ± 0.179
2012 flare	-0.049 ± 0.193
2013	-1.214 ± 0.122
2014	-1.812 ± 0.470

The spectral indices are different for the outburst of 2012 and its neighborhood (green and brown rectangles in Figure 1): $\alpha_{2012} = -0.049 \pm 0.193$ and $\alpha_{2011/2012} = -0.705 \pm 0.179$, respectively. The change of the spectral index could be caused by emergence of a new radiant component. The SED of this component is harder compared to the pre-outburst SED. This can be explained by enrichment of the emitting plasma with high-energy electrons. Figure 4b presents the change of the spectral index with the brightness of the outburst. As can be seen, the spectrum is harder when the outburst is brighter. Such "bluer when brighter" behavior was also detected in the blazars OJ 287 and BL Lac [10].

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Conflicts of Interest: The authors declare no conflict of interest.

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