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Multiwavelength Observations of 6 FSRQ in 2008–2012

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Abstract. We present results of 4 years of VLBA monitoring along with γ-ray and optical R-band photometric observations of 6 blazars (0420-014, 1156+295, 1222+216, PKS 1510-089, 1633+382 and CTA 102). We have analyzed total intensity images obtained with the VLBA at 43 GHz and investigated kinematic evolution of the pc-scale jets of the sources. For all sources we compare flux variations in the VLBI core and bright superluminal knots with γ-ray and optical light curves. The majority of γ-ray flares are coincident with the appearance of a new superluminal knot and/or a flare in the millimeter-wave core and at optical wavelengths. These results support the conclusion that for many flares in blazars the region of the enhanced γ-ray and optical emission is located in the vicinity or downstream of the mm-wave VLBI core.

Keywords. γ-bright blazars, pc-scale jet kinematics, multiwavelength observations.

1. Introduction

Blazars display high variability over a broad range of frequencies. Their extreme properties are thought to be owing to their relativistic jets pointing toward us. Although blazars comprise only a few percents of the overall AGN population, they represent the most numerous class of objects identified with γ-ray sources. The origin of this high-energy radiation is still not clear, although according to the radio-interferometer observation the γ-ray bright blazars have the most relativistic jets (Kovalev *et al.* 2009). There are a number of studies that reveal a connection between the γ-ray emission and jet properties (e.g. Jorstad *et al.* 2001, Marscher *et al.* 2010, Marscher, Jorstad *et al.* 2008).

2. Observations and data reduction

We use R-band data carried out with the LX200 telescope of St.Petersburg State U. (Russia), AZT-8 telescope of the Crimean Astrophysical Obs. (Ukraine, the data analysis is described in Larionov *et al.*, 2008), the Perkins Telescope of Lowell Obs. (Flagstaff, AZ), Liverpool Telescope (Canary Island, Spain), Calar Alto Telesope (Almería, Spain), and Bok and Kuiper Telescopes of Steward Obs. (Mt. Bigelow and Kitt Peak, AZ). We derive 0.1–200 GeV γ-ray flux densities by analysing data from the Large Area Telescope (LAT) of the Fermi Gamma-ray Space Telescope with the standard software (Atwood *et al.* 2009). We have constructed γ-ray light curves with binning from 1 to 7 days (depending on the source's brightness), with a detection criterion that the maximum-likelihood test statistic (TS) should exceed 10.0. We obtain monthly total and polarized intensity images of the quasars with the Very Long Baseline Array (VLBA) at 43 GHz. The VLBA data have been reduced and modelled in the same manner as described in Jorstad, Marscher *et al.* (2005) assuming that the core is a stationary feature of the parsec-scale jet. We also use data of SMA to construct radio band light curves.

Table 1. Parameters of the knots

Source Knot	β_{app} c	T_{eject} MJD	γ-flare T_{max}, MJD
0420-014			
K1	6.7 ± 0.2	-	-
K2	13.4 ± 3.3	-	-
K3	16.5 ± 1.4	54994 ± 39	55001.5
K4	13.1 ± 1.5	55161 ± 15	55141.5
K5	25.3 ± 0.5	55286 ± 15	-
K6	11.6 ± 0.7	-	-
K7	13.0 ± 1.0	55564 ± 15	-
K8	9.1 ± 0.3	55702 ± 15	55715.5
1156+295			
K1	5.2 ± 0.2	54529 ± 15	-
K2	12.7 ± 1.2	54751 ± 45	-
K3	8.2 ± 0.4	55266 ± 61	55274.5
K4	11.0 ± 1.4	55482 ± 15	55470.5
K5	21.4 ± 0.5	55563 ± 28	55540.5
K6	22.6 ± 0.8	55542 ± 21	55540.5
K7	15.8 ± 0.7	55700 ± 15	55701.5
1222+216			
K1	11.38 ± 0.25	55325 ± 15	55316.5
K2	13.82 ± 0.37	55650 ± 15	55631.5
1510-089			
K1	23.2 ± 0.6	54584 ± 19	-
K2	18.2 ± 0.8	54947 ± 33	54946.5
K3	28.9 ± 1.4	55186 ± 15	55194.5
K4	19.0 ± 0.3	55869 ± 15	55868.5
K5	16.0 ± 3.3	55875 ± 73	55868.5
A3	1.8 ± 0.07	-	-
1633+382			
K1	29.4 ± 1.9	54497 ± 34	-
K2	12.6 ± 0.9	54699 ± 27	54700.5
K3	39.9 ± 4.5	55182 ± 15	55173.5
K4	14.3 ± 0.2	55258 ± 15	55249.5
K5	17.1 ± 1.5	55611 ± 15	55633.5
CTA 102			
K1	21.5 ± 2.4	54876 ± 15	54889.5
K2	21.5 ± 0.9	55005 ± 15	-
K3	15.9 ± 0.3	55266 ± 16	-
K4	23.4 ± 0.7	55883 ± 15	56072.5

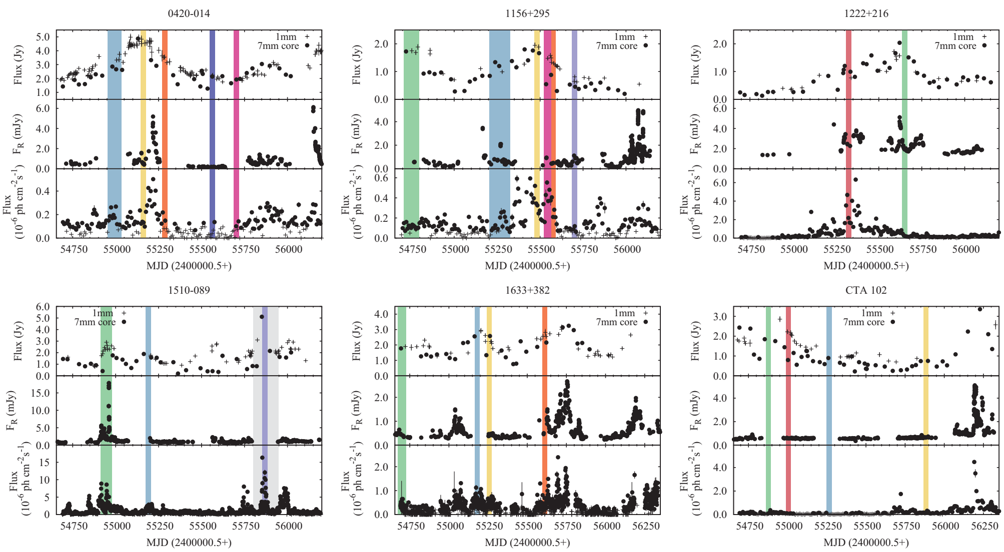

Figure 1. From top to bottom: Radio, optical R-band, and gamma-ray (crosses mark upper limits) light curves during 2008-2012. Vertical bars correspond to the time of the ejection of superluminal knots.

3. Results and Discussion

Figs. 1 present (from top to bottom) the light curves at radio wavelengths (1 mm band, 7 mm VLBA core), the R-band optical light curves, and the Fermi LAT γ-ray light curves (crosses correspond to upper limits) of 6 blazars during the period from 2008 August to 2012 August. We have examined the VLBA images of the sources for both variability of the core and the appearance of superluminal knots ejected between 2008 and 2012. Tab. 1 lists the apparent speed of moving knots, time of separation from the core (T_{eject}), and time of the peak of a γ-ray flare (T_{max}), if the latter occurred within 2σ uncertainty of T_{eject}.

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We have identified 8 superluminal knots (denoted as K1–K8) of the blazar 0420-014. The ejection times of knots K3, K4, and K7 are close to the local peaks of the γ-ray flux. We have identified 7 superluminal knots K1–K7 in the parsec scale jet of the blazar 1156+295, out of which 5 components (K3–K7) emerged from the core during the high γ-ray and optical states. We have detected 2 moving knots in the parsec scale jet of the blazar PKS 1222+216. The ejection of knot K1 coincides with major flares in the γ-ray and optical light curves, and in the core at 7 mm. The knot K2 was ejected during a minor flare in the γ-ray light curve. We have identified 5 moving superluminal knots of the blazar PKS 1510-089, out of which 4 (K2–K5) components were emerged into the jet during the high γ-ray and optical states. The ejection of knot K2 coincides with the major flare in the R-band light curve, a strong flare in the γ-ray light curve (as reported in Marscher *et al.* 2010) and a radio flare at 1 mm. We observe 5 moving knots of the blazar 1633+382 in the parsec scale jet. The components K2 and K5 emerged from the core during the high γ-ray and optical states. The ejection of the knots K3 and K4 coincides with γ-ray flares as well but we have no optical data during this period. We have identified 4 moving knots in the parsec scale jet of the blazar CTA 102. The appearance of knots K1 and K4 was accompanied by minor flares in the γ-ray light curve. We found remarkable similarity between optical and γ-ray behavior of CTA 102 during the large outburst in the fall of 2012 (Larionov *et al.*, 2012), without any time lag between the two light curves, indicating co-spatiality of the optical- and γ-radiating regions (Larionov *et al.*, 2013). This prominent outburst coincides with strong flare in the radio core at 7 mm and ejection of a new component (new component is apparent at the 2 last VLBA epochs, which we possess, that is not sufficient to calculate the ejection time).

4. Conclusions

Over the period from 2008 August to 2012 August, we detected superluminal motion in all 6 objects with the apparent speeds ranging from 1.8 c to 39 c. We find that high levels of the γ-ray activity in all 6 quasars studied coincide with the production of a new superluminal knot and/or a flare in the millimeter-wave core and at radio wavelengths. The majority of these γ-ray flares are associated with optical R-band flares that supports the conclusions that γ-ray and optical flares in blazars are cospatial, and that many of these flares are located in the vicinity or downstream of the mm-wave VLBI core. However, the data do not exclude that some events can take place closer to the central engine.

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