Multifrequency monitoring of the flat spectrum radio quasar PKS 1222+216 in 2008-2015

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Abstract

We analyze the broadband activity of the flat spectrum radio quasar PKS 1222+216 from 2008 to 2015 using multifrequency monitoring which involves gamma-ray data from the FERMI Large Area Telescope, total intensity and linear polarization observations from different optical telescopes in R band, and imaging of the inner jet structure with the VLBA at 43 GHz. During the observations the source has several dramatic flares at gamma rays and optical bands, with the rising branch of a gamma-ray flare accompanied by a rapid rotation of the polarization position angle (EVPA), a fast increase of the degree of polarization in the optical band, brightening of the VLBI core, and appearance of a new superluminal component in the parsec-scale jet. We find a significant correlation between the gamma-rays, optical R band, and 43 GHz variability on a long-term scale and a good general alignment between EVPAs in R band and at 43 GHz, while the correlation between short-term variations is not apparent. Synchronous activity across the bands supports the idea that the emission regions responsible for the flares in gamma-rays and optical band are co-spacial and located in the vicinity of the mm-wave core of the parsec-scale jet. The rapid variability of the optical linear polarization points to strong turbulence in the jet plasma.

Introduction

The flat spectrum radio quasar PKS 1222+216 (4C+21.34; z=0.43) is a highly variable source. Since the 2009 it showed a number of bright flares in the mm- radio band, optical band and gamma-ray band. The PKS 1222+216 was detected in the VHE band by MAGIC during a high activity period in gamma-rays in 2010 [1]. The 43 GHz VLBA imaging shows a compact core and extended unidirectional flow to the north. Apparent velocity of moving knots reaches 22 c. The radio and most part of optical emission have synchrotron origin, which is confirmed by a high fractional polarization in these bands. Several optical flares accompanied by a rapid rotation of the EVPA (over 450 degrees), and fast increase of the fractional linear polarization (time scales down to ~1 day) were observed during the period from late 2009 to midyear 2011 (see Figs. 1). The fractional polarization reached 29% in optical R band on 15 April 2015.

Observations and data reduction

Optical R-band flux densities are obtained from photometric and polarimetric observations with the 0.4 m telescope of St. Petersburg State U. (LX200) and with the 0.7 m telescope of the Crimean Astrophysical Observatory (AZT-8). The data analysis for these telescopes is described in [2]. We also use R-band photometric and polarimetric data obtained with the Perkins Telescope (BU group [3]), Liverpool Telescope, Calar Alto Telescopes [4] and Steward Observatory [5].

We used total and polarized intensity images of the quasar obtained by the Boston U. group at 43 GHz with the VLBA. Each image in Stokes I, Q, and U parameters was fit by a model consisting of a number of components with circular Gaussian brightness distributions to obtain total flux densities, fractional polarization, EVPA, and relative (to the core) positions of the components. The «core» is a stationary feature located at one of the ends of the portion of the jet that is visible at 43 GHz. Identification of components across the epochs is based on analysis of their distance from the core, flux density, position angle and size. We have computed the kinematic parameters of knots (proper motion, apparent velocity and acceleration) by fitting the position of a component over epochs by different polynomials in the same manner as described in [6].

We have derived 0.1-200 GeV gamma-ray flux densities using the data provided by the Large Area Telescope (LAT) of the Fermi Gamma-ray Space Telescope. We used the unbinned likelihood analysis implemented in the standard Fermi Science Tools software [7] for data reduction. The gamma-ray light curve is constructed with 4 day integration times. We used a log-parabola spectral model of the source and a detection criterion that the maximum-likelihood test statistic (TS) should exceed 10 to provide a 3σ detection level.

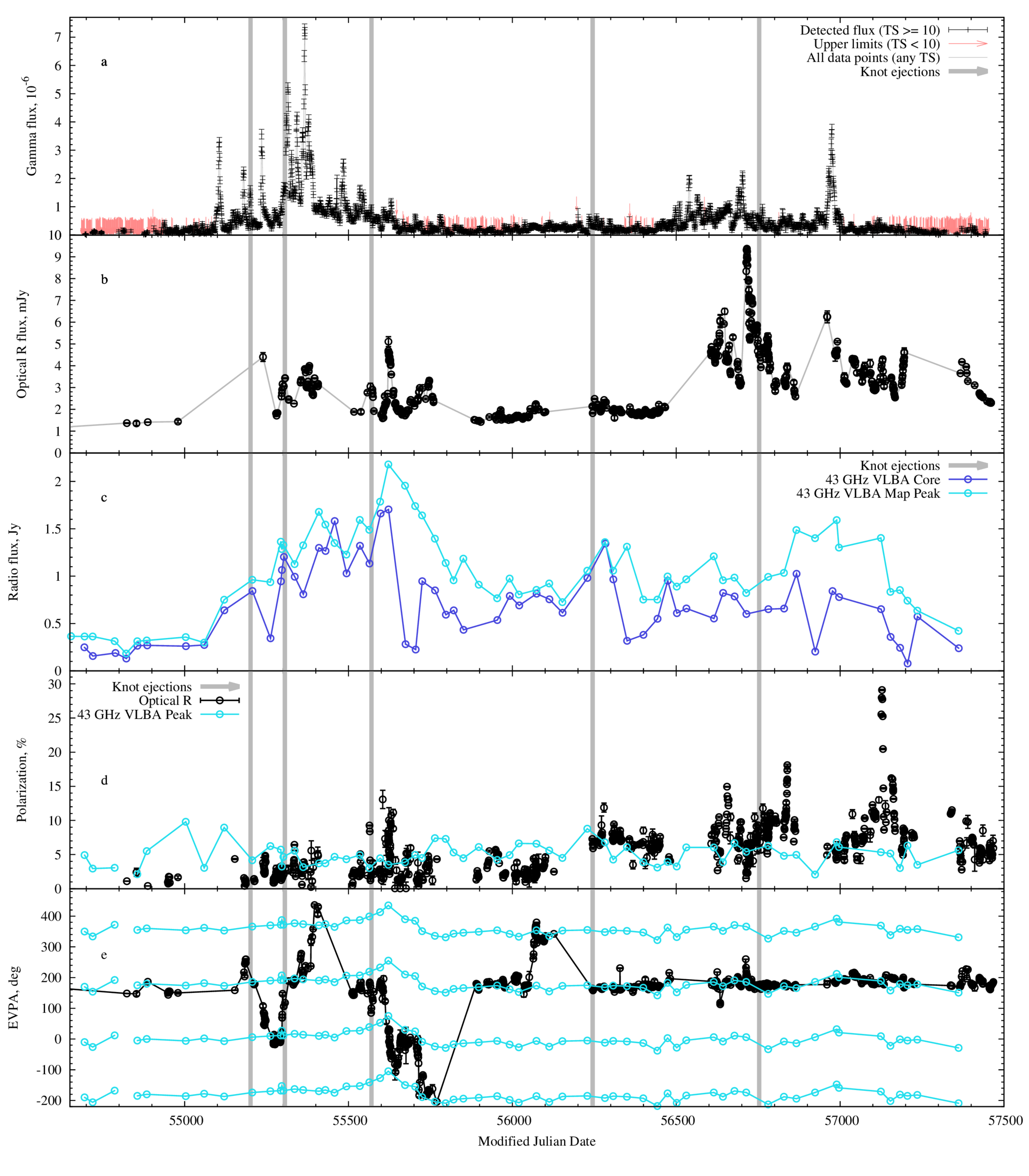

Figure 1. Light curves and polarization parameter curves.

a. Gamma-ray light curve in units of ph·cm^{-2}·s^{-1}. Red arrows mark upper limits.

b. Optical light curve in R band.

c. Light curves in radio band 43 GHz for the VLBA core and VLBA map peak.

d. Degree of polarization of the 43 GHz VLBA map peak, and optical R band

e. EVPA of the 43 GHz VLBA map peak, and optical R band.

Results and Discussion

Light Curves.
During 2008-2015 the quasar PKS 1222+216 demonstrated two phases of high activity with a number of flares in the optical band and gamma-rays separated by continuous relatively quiet state. The light curves and polarization parameters vs. time during the period from August 2008 to December 2015 are presented in Figs. 1.

The first major flare in the gamma-ray band started on MJD 55095 with the rapid increase of flux and sharp peak on MJD 55106. The brightness of the 43 GHz VLBA-core increased up to 0.64 Jy (on MJD 55121) contemporaneously with the optical flare.

A number of gamma-ray and optical flares occurred during the next two years. The light curves in these bands simultaneously demonstrate a series of sharp peaks, but there is no direct accordance between the time and amplitude of individual peaks. The brightness of the 43 GHz VLBA-core also varied dramatically from 0.22 Jy (MJD 55705) to 1.70 Jy (MJD 55622), but more smooth due to higher opacity. An enlarged plot of this period is shown in Fig. 2.

The interval from ~MJD 55800 to ~MJD 56430 is characterized by a minor activity in gamma-ray and optical bands. The light curves in the optical band, gamma-rays and the brightness of the radio core at 43 GHz roughly replicate each other. Highest average flux densities were observed from ~MJD 56200 to ~MJD 56350 in all these bands.

The second phase of high activity consists of increased average flux densities and a number of major flares in the optical band and gamma rays. Larger scale light curves are presented in Fig. 3. Where simultaneous observations are available, the bright optical flares occurred nearby to the bright flares in gamma-rays.

Polarization.
Over the whole presented interval of observations the quasar PKS 1222+216 displays prominent variability of the degree of optical polarization and a fast EVPA rotation.

A series of major gamma-ray flares from MJD 55095 to MJD 55800 were accompanied by a fast increase of polarization degree in the optical R band (Fig. 2) and dramatic EVPA rotations (Figs. 1). Starting from the MJD 55180 EVPA value in the optical R band rotated from 158° to 260° (MJD 55153 and MJD 55187), than rotated to -17° (MJD 55275), and than rotated to 436° (MJD 55396). The optical flare on MJD 55558 is accompanied by the increase of the degree of polarization from 2% to 9% and EVPA rotation from 185° to 85°. The optical flare on ~MJD 55624 is accompanied by the high degree of polarization and rapid rotation of EVPA over 300 degrees. This optical flare corresponds to the observed maximum of VLBA core at 43 GHz.

Since the MJD 56200 only minor EVPA rotations were observed in the optical band. Meanwhile the degree of polarization during the second phase of high activity varied dramatically (Fig. 3). Flares in the gamma-rays and optical band were accompanied by the fast rising of the fractional polarization in the optical R band. During the optical flare on MJD 57128 the degree of the optical polarization reached 29% near the optical flux maximum. Increasing a degree of polarization with an increasing total flux can be explained by the ordering of the magnetic field in the shock in jet model [6, 8].

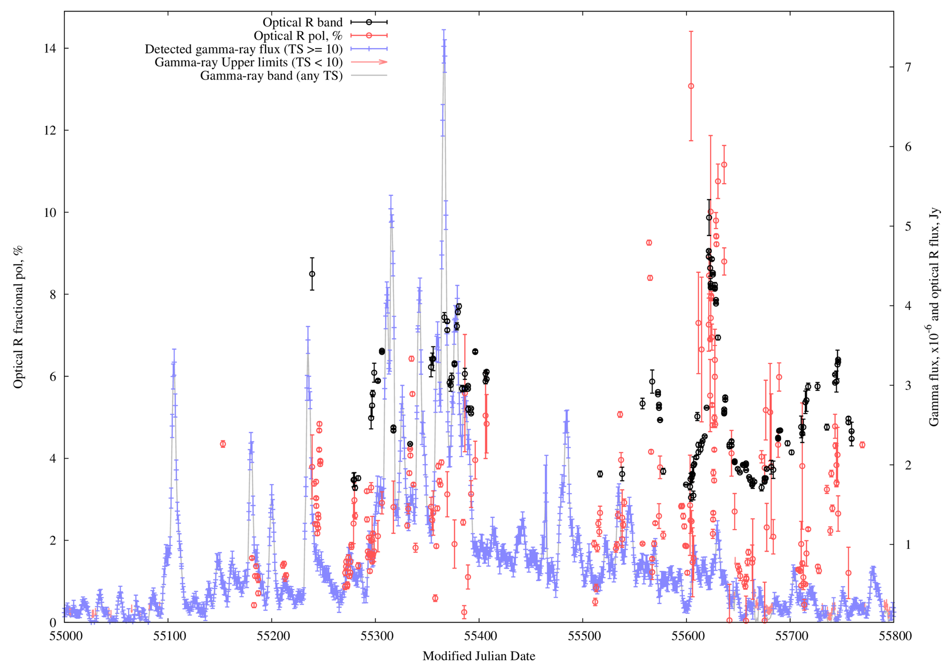

Fig. 2. Light curves in gamma rays, optical R band and fractional polarization in optical R band for the period from MJD 55000 to MJD 55800.

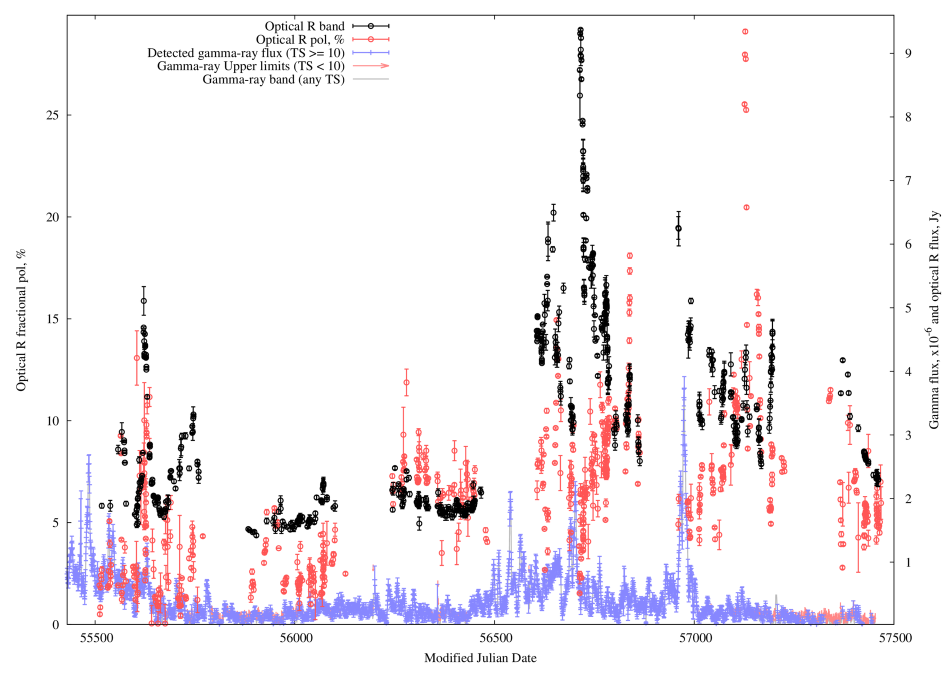

Fig. 3. Light curves in gamma rays, optical R band and fractional polarization in optical R band for the period from MJD 55500 to MJD 57500.

VLBA images.
The 43 GHz radio core was relatively faint (S_core< 0.4 Jy) before the first gamma-ray flare (MJD 55100). Two superluminal knots K1 and K2 were ejected during a series of strong gamma-ray flares and rapid EVPA rotations in the optical R band (~MJD 55201 and ~MJD 55306). The ejection of knot K3 (~MJD 55570) is contemporaneous with the optical flare, an increase of fractional polarization and rotation of EVPA in the optical band. During the relatively 'silent' period only one knot K4 was ejected (~MJD 56245). Nevertheless the appearance of the knot K4 coincided with the increase of flux densities in the gamma-rays and optical band. The knot K5 passed trough the core on ~MJD 56753 after the brightest optical flare and a series of gamma-ray flares. A new knot X6 appeared in the 2015 after the second phase of high activity. Further observations are required to estimate parameters of the knot X6. We also detected a stationary component A1 located 0.14+/-0.04 mas from the core.

Fig. 4 shows the VLBA image at 43 GHz (12 Jul. 2015) with the trajectories of the components overlaid. The direction of the jet changed with time. The position angles of knots K1 and K2 with respect to the core were about +10°. The position angles of knots K3 and K4 were -7° and -4° respectively. The knot K5 appeared with the position angle about +10°. The knot X6 appeared with the position angle ~28° after the second phase of high activity.

The EVPA of optical R band has preferred direction near 0 degrees which coincides with the EVPA values of VLBA map peak at 43 GHz and the jet flow direction (Figs. 1e).

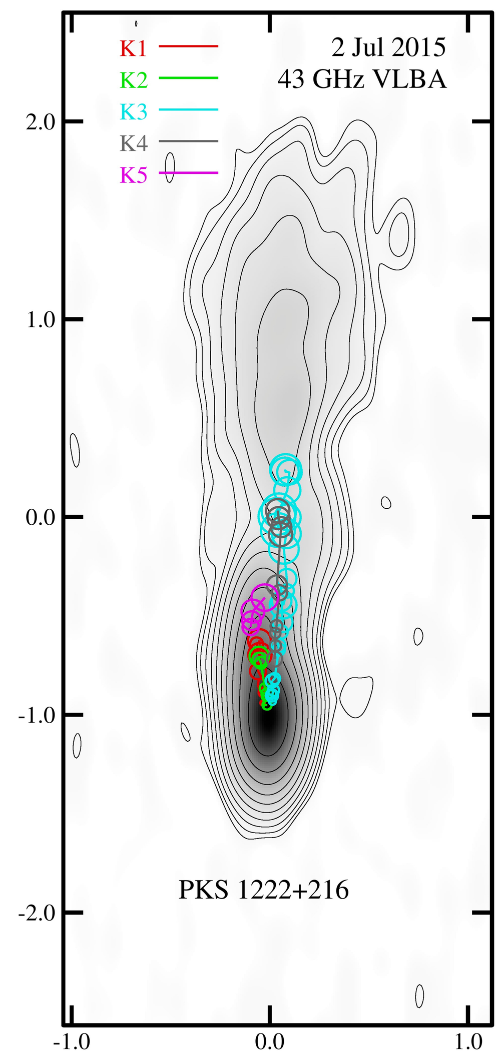

Fig. 4. VLBA map at 43 GHz overlaid with trajectories of the knots for PKS 1222+216

Conclusion

During the period of observations from August 2008 to December 2015 the quasar PKS 1222+216 demonstrated a high activity with a number of flares in the optical and gamma ray bands. The long-term activity is arose from the radio band to the gamma-rays contemporaneously. The fine structure of the light curves did not show detailed correspondence, but many flares (or polarization maxima) in optical band occurred nearby to the bright gamma-rays flares. We have detected 5 superluminal knots in the parsec-scale jet at 43 GHz with apparent speeds ranging from 9 c to 22 c. The ejection times of all knots K1 – K5 are close to the times of gamma-ray and/or optical flares, and to intervals of significant EVPA rotations and variations in fractional polarization in the optical band. The direction of the parsec-scale jet changed from ~10° to -4°..-7° after the first phase of high activity and to ~28° after the second phase of high activity. We also found the preferred direction of EVPA in optical R band near 0 degrees which is close to the EVPA values of VLBA map peak at 43 GHz and the jet flow direction. The presented multi-wavelength behavior of the quasar PKS 1222+216 evidences that many optical and gamma-ray flares originate in the vicinity of the millimeter-wave core of the parsec-scale jet [9]. The rapid variability of the optical linear polarization may be explained by a strong turbulence in the jet plasma [10].

Acknowledgments

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