# Multi-Frequency Observations of Gamma-Ray Blazar 1633+382

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**Abstract.** We perform monthly monitoring of the quasar 1633+382 (4C+38.41) within a sample of $\gamma$-ray blazars with the VLBA at 43 GHz along with optical photometric and polarimetric observations. We construct the $\gamma$-ray light curve of 1633+382 using data obtained by the Fermi LAT. We find that a high $\gamma$-ray state of the quasar starting in 2009 September is simultaneous with an increase of the flux in the mm-wave VLBI core. We resolve a superluminal feature on the VLBA images that appears to be responsible for the mm-wave flux increase. We find a strong correlation between optical and $\gamma$-ray light curves with a delay of $\gamma$-ray variations of 5±3 days, as well as a strong correlation between optical flux and degree of polarization during the high $\gamma$-ray state. Comparison between the optical polarization position angle and that in the VLBI core supports the idea that in the quasar 1633+382 a high $\gamma$-ray state is connected with processes originating near the mm-VLBI core.

*Key words.* Gamma-rays—quasars: 1633+382(4C+38.41)—radio jets—polarization.

## 1. Introduction

Blazars are the most numerous objects in the $\gamma$-ray sky (Abdo *et al.* 2010). They show dramatic variability across the electromagnetic spectrum (e.g., Jorstad *et al.* 2010; Marscher *et al.* 2010). Both these properties (strong $\gamma$-ray emission and variability) are tightly connected with relativistic jets, although the localization of the high energy emission is a topic of hot debate. Currently, there are arguments in favor of the $\gamma$-ray origin as close as $<0.1$ pc (e.g., Poutanen & Stern 2010) and as far as $>10$ pc (e.g., Marscher *et al.* 2010) from the central engine. The most direct way to determine where the $\gamma$-ray emission originates is multifrequency monitoring of $\gamma$-ray blazars along with Very Long Baseline Array (VLBA) imaging. In this paper, we will analyze such data for the quasar 1633+382 (4C+38.41) and discuss the correlations and relations which we find.

## 2. Observations and data reduction

The quasar 1633+382 ($z = 1.814$) is one of the brightest $\gamma$-ray blazars that we monitor monthly with the VLBA at 43 GHz (7 mm).[1] We have also carried out a 2-week campaign in April 2010 with 3 VLBA epochs within the campaign. The quasar is monitored as well at 37 GHz (8 mm) at Metsähovi Radio Observatory (Finland). We perform optical photometric and polarimetric monitoring of the blazars using

- the Perkins telescope at Lowell Observatory (Flagstaff, AZ);
- the 1.54-m Kuiper and the 2.3-m Bok telescopes at Steward Observatory;[2]
- the 2.2-m telescope at Calar Alto Observatory (Almería, Spain);[3]
- the 70-cm telescope at the Crimean Astrophysical Observatory; and
- the 40-cm telescope at St. Petersburg State University (Russia).

All optical telescopes possess polarization capabilities. We observed the quasar daily with the RXTE at 2.4–10 keV during the campaign in 2010 April and used XRT measurements of the quasar provided by the Swift archive. We have calculated the $\gamma$-ray light curve of 1633+382 at 0.1–200 GeV with weekly binning of the Fermi LAT data using the software and following the Analysis Threads provided by the FSSC. Figure 1 presents the light curves of the quasar obtained at different frequencies.

## 3. Gamma-ray behaviour and jet kinematics of 1633+382

Figure 1 reveals a relatively quiescent state in $\gamma$-rays, at optical and mm-waves, and in the VLBI core from 2008 September to 2009 June. In September 2009 (RJD $\sim$5000, where RJD = JD-2450000), an increase of the $\gamma$-ray emission by a factor of $\sim$10 coincided with the optical flare and there was a gradual increase in the VLBI core flux. A possible rise of X-ray activity at the same time may occur. A high $\gamma$-ray state appears to last for $\sim$1 yr. The VLBA images show two moving knots in the jet, K1 and K2 (Fig. 1b), which have a similar apparent speed ($\sim$7.5 c). The extrapolation of motion of K2 back in time implies that the interaction of the knot with the core ($T_0 = 5076 \pm 44$ RJD) coincides with the first peak of the $\gamma$-ray high state in the autumn of 2009.

We performed a discrete correlation analysis (DCF) between $\gamma$-ray and optical plus $\gamma$-ray and 37 GHz light curves (Edelson & Krolik 1988) and investigated the significance of the derived correlation coefficients using 5000 simulations of each light curve for different power-law slopes of power spectral densities, PSD $\propto f^{-a}$ (Chatterjee *et al.* 2008) with $a_\gamma = 1.5$, 1.7 (Abdo *et al.* 2010); $a_{37} = 1.5$, 2.0 and 2.5; and $a_{\rm opt} = 1$, 1.2, 1.5, 1.7 and 2.0. In the case of the $\gamma$-ray and 37 GHz light curves the correlation is not significantly independent of the value of $a$. For $\gamma$-ray/optical variations, if $a_{\rm opt} \leq 1.5$, the DCF peak (0.68) at a lag of 5±3 days (optical variations lead) is significant at 99.7% confidence level. The peak of the optical polarization (p = 18.5±1.0% at position angle $\chi = 54° \pm 2°$) is observed at RJD 5040.3 (Fig. 2a).

[1] http://www.bu.edu/blazars/VLBAproject.html
[2] http://james.as.arizona.edu/~psmith/Fermi
[3] http://www.iaa.es/~iagudo/research/MAPCAT/

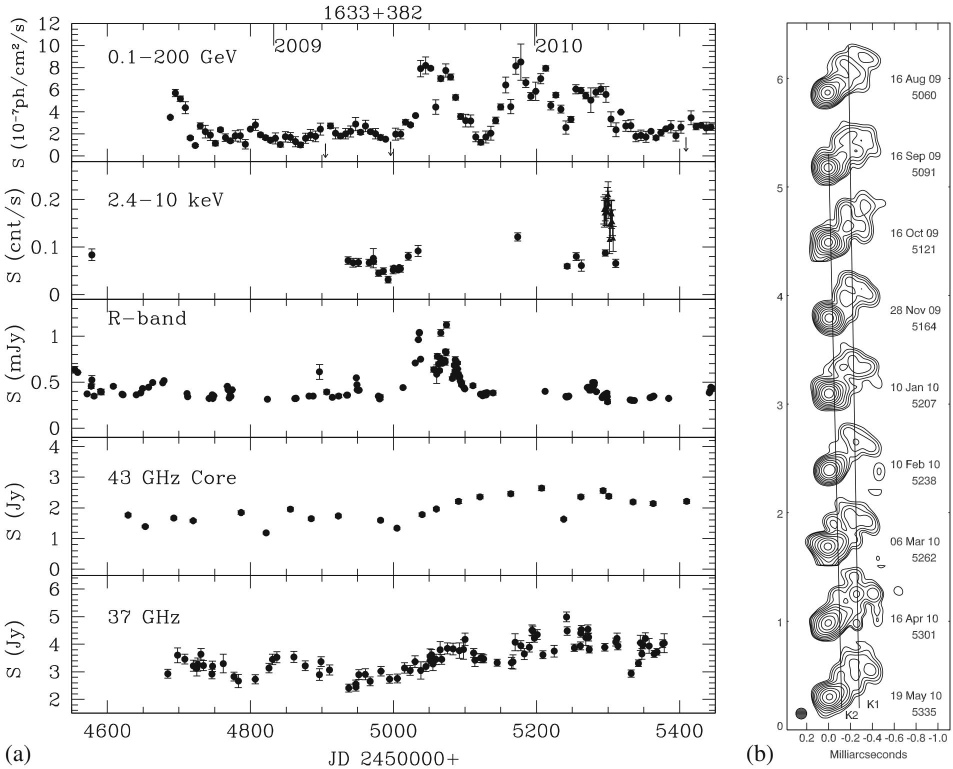


**Figure 1.** (**a**) Gamma-ray, X-ray, optical, 43 GHz VLBI core and 37 GHz light curves of the quasar 1633+382. (**b**) VLBA images at 43 GHz with convolving beam 0.1·0.1 mas, $S_{\rm peak} = 2.45$ Jy/beam, and contours representing 0.25, 0.5, . . . , 64% of the peak.

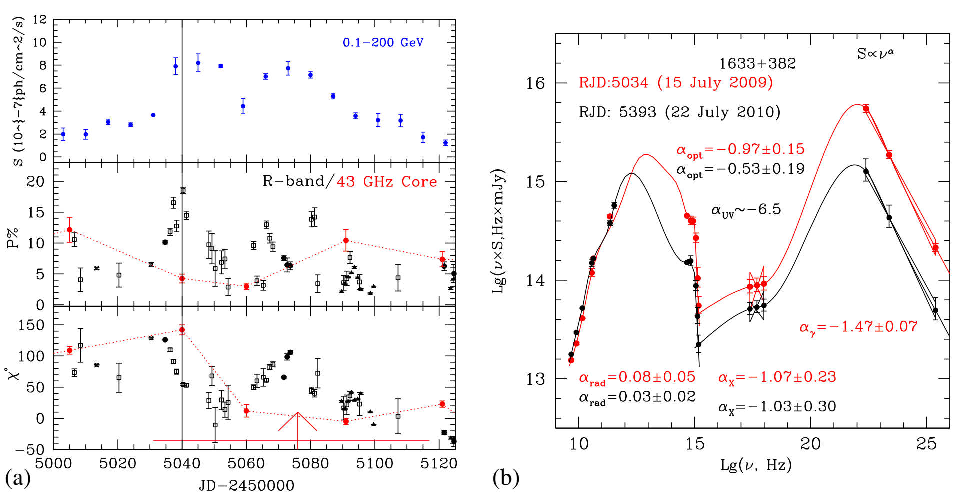


**Figure 2.** (**a**) Gamma-ray light curve, degree of optical and 43 GHz core polarization, and optical position angle of polarization plus EVPA in 43 GHz VLBI core. The arrow shows the time of ejection of K2. (**b**) Spectral energy distributions of 1633+382.

The VLBI core polarization at the same date (RJD 5040.5) is very low with EVPA transverse to $\chi_{opt}$ ($p_{43} = 1.4 \pm 0.4\%$ and $\chi_{43} = 142° \pm 8°$). This implies that at RJD 5040 the VLBI core is optically thick while at previous (RJD 5005) and later (RJD 5060) epochs the optical and core polarization parameters are similar (Fig. 2). This indicates that the core is optically thin. This can be explained by the passage of knot K2 through the core, which agrees with the kinematics of K2, whose ejection time from the core is at RJD 5076±44. The polarization behaviour and passage of K2 through the core coincide with the highest $\gamma$-ray state. Figure 2(b) shows the spectral energy distribution (SED) of the quasar during high (RJD 5034) and low (RJD 5393) $\gamma$-ray states. The SEDs suggest that in the low state the synchrotron and inverse Compton luminosities of the quasar are similar ($L_{syn} \sim L_{IC} \approx 3 \times 10^{47}$ erg/s) and in the high state $L_{IC}$ ($1.3 \times 10^{48}$erg/s) slightly exceeds $L_{syn}$ ($5 \times 10^{47}$erg/s).

## 4. Summary

The analysis of the multifrequency light curves along with polarization information and high resolution VLBA images shows that a high $\gamma$-ray state in the quasar 1633+382 is connected with a disturbance propagating down the jet. The $\gamma$-ray variations are delayed by 5±3 days with respect to the optical synchrotron variations if PSD of optical variations has a similar or flatter slope with respect to that of $\gamma$-rays. Comparison of optical and 43 GHz VLBI core polarization along with analysis of the jet kinematics implies that an interaction between a disturbance and the core causes $\gamma$-ray flaring. The delay of $\gamma$-ray variations with respect to optical variations by several days and a relatively low ratio $L_{IC}/L_{syn} < 3$ suggest that the synchrotron-self-Compton mechanism might be the primary mechanism for $\gamma$-ray production in the quasar 1633+382.

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