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Multifrequency VLBI follow up study of strong γ-ray flares in the blazars 3C273 and 3C279

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Abstract. We present multifrequency VLBI observations of the blazars 3C273 and 3C279 after detecting strong γ-ray flares in both of them. 3C273 exhibited a prominent flare in γ-rays in September 2009 which was followed by a strong flare in the 7 mm VLBI core and emergence of a new feature in the parsec scale jet. We have used time delay between flares in different wavebands together with kinematic analysis to determine that the γ-ray emission zone in 3C273 is located $3.6 - 5.3$ pc upstream from the apparent 7 mm core. We have also analyzed frequency dependent core position to measure a deprojected distance between 7 mm core and the true base of the jet: $1 - 6$ pc for 3C273 and $1 - 3$ pc for 3C279, depending on observing epoch. For 3C279 light curve analysis did not give a robust γ-radio delay because there were too many overlapping flares in this source during considered period.

Keywords. techniques: interferometric, radio continuum: galaxies, (galaxies:) quasars: individual (3C273, 3C279)

1. Introduction

It was shown by many researchers that γ-ray activity in blazars is connected with radio flux density and parsec scale morphology changes (e.g. Kovalev *et al.* 2009, Pushkarev *et al.* 2010, Ghirlanda *et al.* 2011, Jorstad *et al.* 2013). However the location of γ-ray emitting zone is still debated. Usually two scenarios are considered: near site scenario locates γ-rays origin close to the jet nozzle (e.g. Pushkarev *et al.* 2010, Tavecchio *et al.* 2010, Rani *et al.* 2014) while the far site scenario locates γ-rays origin many parsecs away from the jet nozzle (e.g. Marscher *et al.* 2010, Agudo *et al.* 2011, Schinzel *et al.* 2012).

Unfortunately no facility could provide sufficient angular resolution in γ-rays to uniquely locate the γ-ray emission zone. So to distinguish between these two scenarios we have combined advantages of *Fermi*/LAT γ-ray telescope (Atwood *et al.* 2009) and high angular resolution of the VLBA.

2. Observations

We have triggered our multifrequency observational campaign on the VLBA after γ-ray flux of 3C273 had risen by a factor of ≈ 3 above its average level. We have conducted four observations spanning five month period. Our observations were made at 5, 3.6, 2, 1.3 cm and 7 mm wavebands simultaneously. Amplitude calibration accuracy is estimated as 10% at two shorter wavelengths and 5% at other. To extend temporal coverage and improve calibration accuracy we have also used Boston University blazar monitoring 7 mm data and MOJAVE 2 cm VLBA data which are available online.

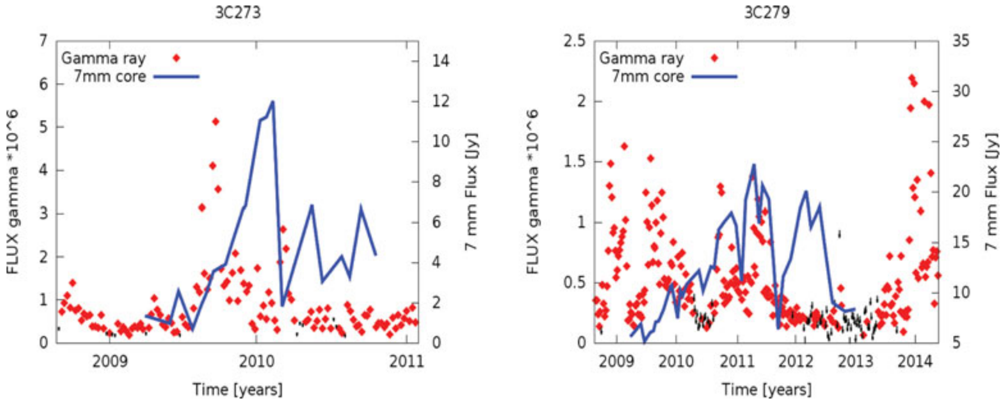

Figure 1. γ-ray flux of 3C273 and 3C279 (symbols) and 7 mm VLBI core flux density (measured data points are connected with a line).

We performed modelfitting in Difmap (Shepherd 1997) aiming to tie up models against both time and wavelength with a preference to circular Gaussian components unless elliptical ones gave much better fit.

3. Lightcurves and kinematics analysis

We have compared variability behavior in γ-rays to changes of the VLBI core flux density at 7 mm for both sources. There was a distinct major flare in 3C273 with peak flux of an order of magnitude higher than an average level which was followed by a flare in 7 mm core (Fig. 1). There were no flares of comparable amplitude during considered time period in 3C273 neither in γ-rays nor in 7 mm radio thus we uniquely cross-associate these flares. Meanwhile 3C279 exhibited four flares of comparable amplitude in 2009–2011 which could not be uniquely associated with the flares in 7 mm core (Fig. 1).

In the case of 3C273 we have estimated peak-to-peak delay between flares in γ-ray and radio to be $145 - 165$ days, γ-rays lead radio.

Major core activity in quasars is usually followed by emergence of a new bright feature in the extended parsec scale structure of the jet (e.g. Jorstad *et al.* 2013, Ramakrishnan *et al.* 2014). We have also found a new component in 3C273 that could be associated with the flare in 7 mm VLBI core. We have tracked it backwards (Fig. 2) and estimated that it had passed the 7 mm core ≈ 113 days after the peak of the γ-ray flare in the assumption that its speed was constant all the way. This agrees well with the time delay measured using lightcurves.

We explain the time delay between γ-ray flare and 7 mm core flare as an effect of synchrotron opacity in the jet medium following Pushkarev *et al.* 2010. If a perturbation occurs somewhere near the true base of the jet it might immediately result in a flare at wavelengths for which jet medium is transparent i.e. in γ-rays. But radio emission is synchrotron self-absorbed and could not escape until the perturbation in its movement downstream reaches a region with optical depth at given frequency $\tau \approx 1$, the so-called VLBI core. Once the perturbation reaches the VLBI core, it triggers a flare and, if prominent enough, could later be observed as a distinct feature moving further downstream the jet. Within an assumption of a constant speed of the perturbation we should expect that the time delay "γ-ray flare – radio core flare" and the time delay "γ-ray flare – newborn feature passage through the core" should be approximately equal.

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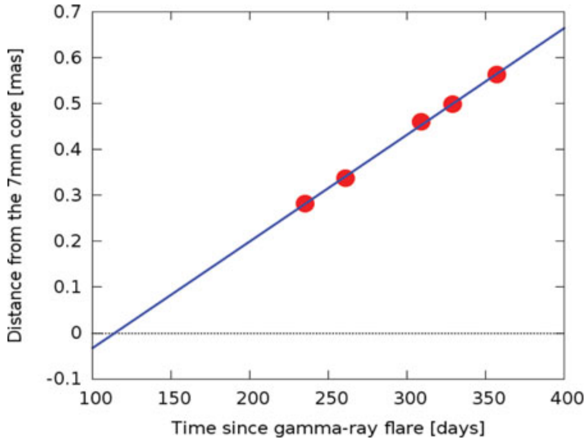

Figure 2. Kinematics of a new emerged component associated with a flare in the 7 mm core in 3C273.

We estimated deprojected distance between γ-ray emission site and 7 mm core of 3C273 using time delay range $113-165$ days and found that former is located $3.6-5.3$ pc upstream from the latter.

4. Frequency dependent core position

We have taken advantage of our multifrequency dataset to perform a frequency dependent core position (coreshift) analysis (e.g. Sokolovsky *et al.* 2011, Pushkarev *et al. et al.* 2012, Lobanov *et al.* 1998). We have used both 2 dimentional cross-correlation of images and optically thin components alignment as described in Kutkin *et al.* (2014). In an assumption that synchrotron opacity is a prevailing absorption mechanism, the coreshift analysis gives an estimate of the distance along the jet between its true base and the apparent VLBI core. For 3C273 the analysis gives a value of deprojected distance between jet nozzle and 7 mm core that varies between 1 and 6 pc during five months covered by our four multifrequency observations. This is consistent with the distance from 7 mm core to the γ-ray emission site estimated in Section 3. Thus for 3C273 γ-ray origin could be robustly placed close to the true base of the jet. In case of 3C279 the analysis is more complicated because of its wide (difficult to modelfit with a set of Gaussians) jet and lack of extended structure at shorter wavelengths. Our early estimates of the 7 mm core to jet nozzle distances give $1-3$ pc, depending on observing epoch.

5. Summary

We have performed comprehensive study of a rich multifrequency and long-term dataset of blazars 3C273 and 3C279 after detecting high γ-ray activity state in them employing flux variations, kinematics and coreshift analysis.

In the case of 3C279 the lightcurves are too overpopulated with flares to allow their unique cross identification. Coreshift analysis gives a value of $1-3$ pc as a distance between 7 mm core and a jet nozzle of 3C279.

For 3C273 it is possible to associate a prominent γ-ray flare in 2009 with a distinct flare in the the apparent 7 mm VLBI core. Time delay between flares and newborn component kinematics allowed us to locate γ-ray emission site ≈ 4 pc upstream from the 7 mm core. At the same time the coreshift analysis based estimates of the distance from 7 mm core to the true base of the jet are $1-6$ pc. Hence the location of a γ-ray emitting zone should be very close to the jet nozzle.

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† http://www.bu.edu/blazars/VLBAproject.html