MAGIC latest results and multiwavelength observations of FSRQs: 3C 279 and PKS 1510-089

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Abstract: Flat spectrum radio quasars (FSRQs), a subclass of blazars, are characterized by a steep γ-ray spectrum which makes their detection in the very high energy domain (VHE, >100 GeV) challenging. Up to Feb 2013 there are only three FSRQs unambiguously discovered in this energy regime, all three detected at least once by MAGIC, a stereoscopic system of two Imaging Atmospheric Cherenkov Telescopes located on La Palma, Canary islands. Here we present the latest MAGIC results together with simultaneous multiwavelength observations on two out of the three FSRQs, 3C 279 and PKS 1510-089. 3C 279 (z=0.536) was observed by the MAGIC telescopes as part of two distinct campaigns in 2011: regular monitoring between February and April and follow up observations in June after high activity in optical regime and high energy γ rays (HE, 100 MeV-100 GeV). None of the campaigns resulted in a significant detection at VHE, consequently upper limits on the flux in the energy range $125-500$ GeV have been computed. PKS 1510-089 (z=0.36) was observed with the MAGIC telescopes from February to April 2012, as follow up observations after alerts from Fermi-LAT and AGILE collaborations. We detected the source in the VHE regime at >5 sigma significance. We complement MAGIC observations of 3C 279 and PKS 1510-089 with simultaneous multiwavelength observations in high-energy γ rays, X-rays, optical and radio wavelengths and polarization observations. With this study of the spectral and variability features observed from radio to VHE γ rays, we aim at identifying the physical processes responsible for the emission from this class of sources.

Keywords: FSRQs, 3C 279, PKS 1510-089, gamma rays, multiwavelength

1 Introduction

Blazars, active galactic nuclei (AGN) with a relativistic jet pointing towards the observer, represent the vast majority of extragalactic sources of very high energy (VHE, >100 GeV) γ rays. So far $\sim$ 50 blazars have been detected in VHE γ rays[1]. Blazars are divided into two sub-categories, BL Lacertae objects (BL Lacs) and flat spectrum radio quasars (FSRQs). FSRQs, contrary to BL Lacs, show broad and pronounced emission lines in their optical spectra. This indicates that they are surrounded by clouds of dense material, the so-called broad line region (BLR). Only three FSRQs have been detected up to now in VHE γ rays: 3C 279 (redshift z=0.536), PKS 1222+126 (z=0.432) and PKS 1510-089 (z=0.36). The MAGIC experiment [1] detected all three (3C 279:[2, 3], PKS 1222+126:[4],PKS 1510-089: [10, 11]) and here we present our latest results of recent observation campaigns on 3C 279 and PKS 1510-089.

2 3C 279

3C 279 was discovered by the MAGIC experiment during a high activity state in the optical band in 2006 [2]. It was detected again in 2007, always during a high activity state in the optical band [3]. Other episodes of enhanced activity in other wavebands have been measured by various experiments, and in some cases follow-up observations

1. http://tevcat.uchicago.edu/

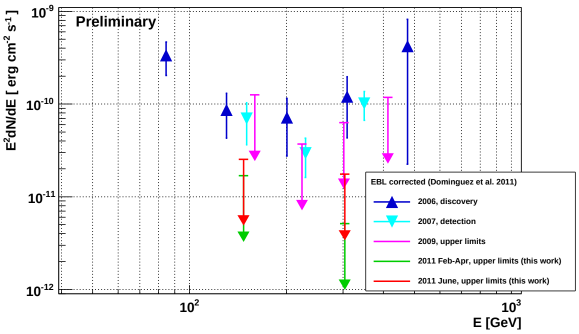

Figure 1: 3C 279 MAGIC observations: 2011 upper limits and historical data [3], all corrected for the absorption of the extragalactic background light using the model proposed in [5].

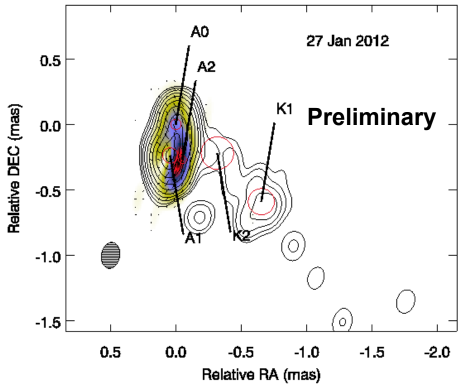

Figure 3: VLBA image of the 43 GHz core. Four bright components are moving within 1 mas from the core (A0), but there is no ejection of new components.

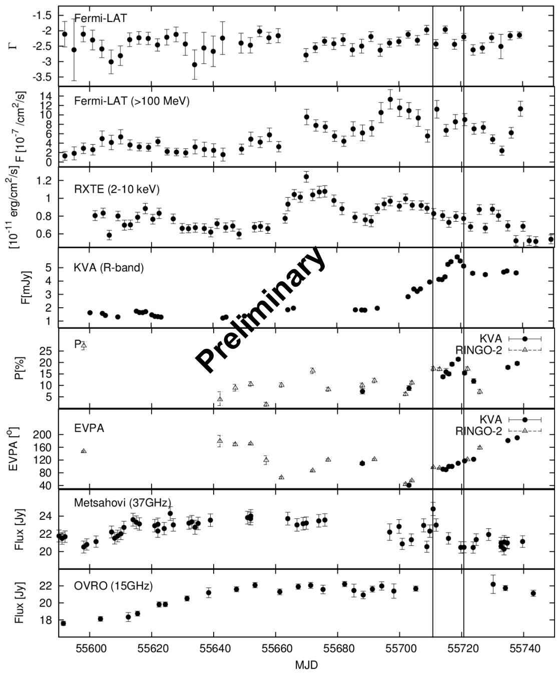

Figure 2: The multiwavelength light curve of 3C 279, from radio to HE γ rays. Vertical lines indicate the MAGIC observing period.

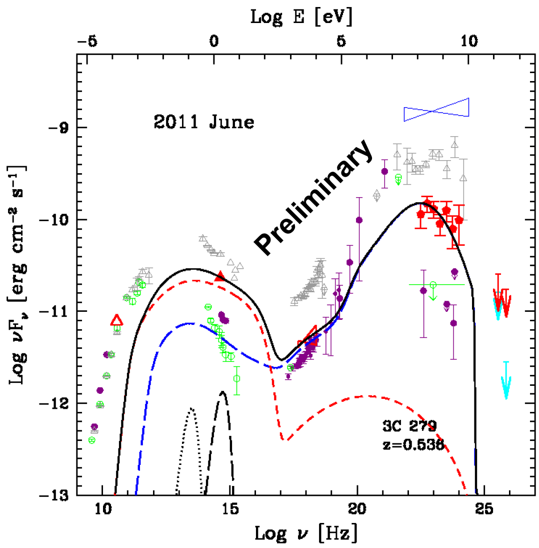

Figure 4: 3C 279 mutiwavelenght spectra energy distribution of June 2011: radio from Metsahovi and OVRO (red open triangles), optical from KVA (red full triangles), X-ray from RXTE (red bowtie), high-energy γ rays from *Fermi*-LAT (red circles) and MAGIC (red arrows: ebl corrected, cyan arrows: observed points). Historical data are also shown [3]. Only points marked in red are considered for the SED fit. The high-energy emission is dominated by the region inside the BLR (blue line) while the synchrotron is dominated by the contribution from the external region, far outside the BLR and IR and therefore only SSC was considered for the second bump. The blackbody radiation from the BLR (dashed) and from the IR torus (dotted) are also shown.

were performed by MAGIC. The observations we present here were performed in 2011, firstly from February to April, as regular monitoring of the source, then in June as follow-up observations after flares in optical and high energy γ-ray (HE, 100 MeV-100 GeV) bands. None of the periods provided a significant detection, and consequently we computed upper limits on the flux. The derived upper limits are below the previous upper limits set by MAGIC from the 2009 campaign [3] and also below the level at which the source was detected by MAGIC in 2006 and 2007 [2, 3], see Fig.1.

The multiwavelength light curve (Fig.2) shows periods of enhanced activity in all the presented energy bands. In HE γ rays there are two subsequent flares, and the same behavior is observed in the X-rays. In the optical band, we have a major flare starting around MJD 55700, with the flux in the R-band increasing during the descending phase of the flares observed at higher energies. Simultaneously with the increase in the photometric flux, there is an increase in the polarized flux accompanied by a smooth rotation of the polarization angle. Enhanced activity is observed also at radio frequencies, but without rotation of the polarization angle and with no ejection of new components from the

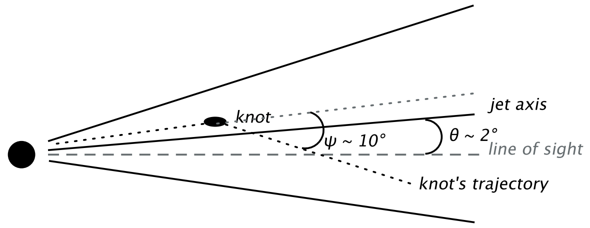

Figure 5: A sketch of the bent trajectory model. The behavior observed in the optical band is interpreted with relativistic aberration and geometric effects due to a bent trajectory of the emission knot.

radio core (Fig.3).

We interpret the multiwavelength features observed in June 2011 using a multi-zone leptonic emission model [6] (Fig.4) and a bent trajectory (Fig.5). In detail, relativistic electrons emit synchrotron radiation responsible for the optical emission and a population of low energy photons (in our case, photons coming from the BLR) is up-scattered via inverse-Compton process, causing the high energy emission (from X-rays to γ rays). The high energy radiation comes from a region close to the central engine. The optical emission is generated far-out (3-5 pc), in a region outside the BLR and the infrared torus. The rotation of the optical polarization angle is interpreted with a bend in the trajectory of the emission knot. The relativistic speed of the plasma ($\Gamma \sim 16$ [7]) and the close alignment of the jet to the line of sight ($\theta \sim 2^\circ$ [7]) will amplify small bends through relativistic aberration. A bend by $\Psi \leq 10^\circ$ will imply a change in the aberrated angle of $\sim 60^\circ$.

3 PKS 1510-089

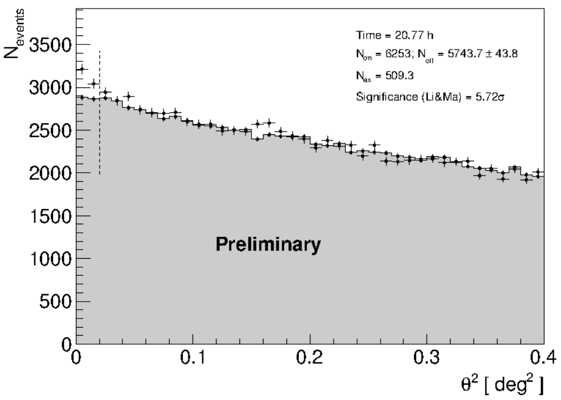

Figure 6: The θ^2 plot and the statistic of the detection of PKS 1510-089. ON-source events (black points), the OFF-source events (grey shaded area) and the region selected for the calculation on the significance of the detection (vertical dashed line) are also shown.

MAGIC observed PKS 1510-089 from February to April 2012, after alerts of flaring state in HE γ rays reported by AGILE [8, 9] and *Fermi*-LAT. During 28 nights, $\sim$ 25 hours of data were taken, resulting in a detection of $> 5\,\sigma$ significance [10, 11]. Fig.6 shows the distribution of the squared angular distance (θ^2) between the source position and the

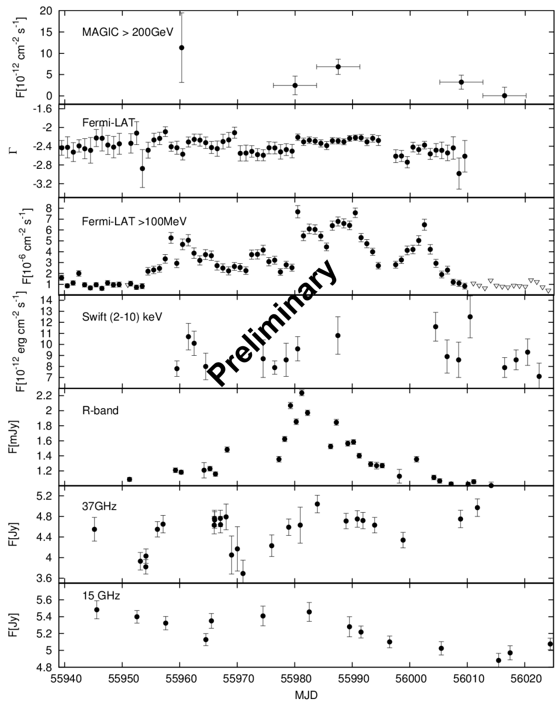

Figure 7: The spring 2012 multiwavelength light curve of PKS 1510-089, from radio to VHE γ rays.

reconstructed γ-ray direction. The weekly light curve above 200 GeV does not indicate variability. A similar behavior has been observed by H.E.S.S. at the time of its discovery [12], in contrast to what was observed for the other two VHE FSRQs (3C 279 [3] and PKS 1222+216[4] have been detected in VHE during single night flares). On the other hand, the multiwavelength light curve during spring 2012, shown in Fig.7, indicates pronounced variability at lower energies. *Fermi*-LAT reports three distinct flares, the first two cleraly detected by the AGILE experiment too (see Fig.8), characterised by different multiwavelength behavior. The first (starting around MJD 55960) and the last one (starting around MJD 56000) have contemporaneous flares in the 37 GHz radio, the first one being also accompanied by a rotation of the optical polarization angle and the emission of a new knot from the 43 GHz VLBA radio core. During the second γ-ray flare (starting around MJD 55980), there is an optical outbursts and a second rotation of the optical polarization angle. In the X-rays the source was showing a behavior similar to the one observed in previous campaign [13].

4 Conclusions

The MAGIC telescopes have observed and detected all three FSRQs known to emit in VHE γ rays. These peculiar sources showed different behaviour not only with respect to the other FSRQs, but also considering distinct flaring episodes from the same object. During 2011, 3C 279 underwent outbursts in HE and optical bands but no signal was found at VHE. The multiwavelength behaviour showed not only similarities (flares in optical and radio) but also differences (absence of rotation of the polarization angle in the radio, no emission of new knot) between different epochs. The case of PKS 1510-089 is different. It had

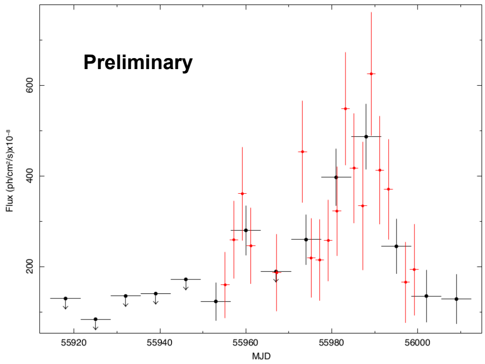

Figure 8: AGILE-GRID light curves of PKS 1510-089, for $E > 100\,\mathrm{MeV}$ with 7-days (black points) and 2-days (red points) binning. There is clear indication of the first two flares detected by the *Fermi*-LAT experiment, while at the time of the third flare measured by *Fermi*-LAT the source was not in the field of view of AGILE.

flares in the optical and HE γ rays, and has been detected at VHE γ rays but no variability can be claimed during this period. What we have learned up to now, is that VHE FSRQs detections happen during high activity states at lower energies (but are not necessarily implied by them) but they show different patterns and different time scales in the activity at all measured energies. Long term observations accompanied by intense multiwavelength campaigns could help us for understanding the origin of the VHE emission of FSRQs and the physical processed taking place in these sources.

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