

Spectacular Flares of the Radio Galaxy NGC 1275 measured with MAGIC

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We report on the detection of flaring activity from the prominent Fanaroff-Riley I radio galaxy NGC 1275 located in the Perseus cluster of galaxies in the very-high-energy gamma-ray band. The observations were performed with the MAGIC telescopes between 2016 and 2017 over several months. During this time period, the mean flux above 100 GeV was measured to be roughly ten times brighter than during previous observations. The night-by-night light curve above 100 GeV shows several peaks indicating flux-doubling time-scales of shorter than one day much smaller than the monthly time-scale previously detected by MAGIC. The brightest flux, observed around December 2016 and January 2017, reached 1.75 times the flux from the Crab Nebula, i.e. was about sixty times brighter than the average flux of the previous years. The spectral energy distribution measured up to > 1 TeV shows a curved shape unlike the previously measured simple power-law. The angle between the jet-axis and the line-of sight of NGC 1275 was formerly found to be 30-55 degree in the radio band excluding strong Doppler boosting of the emitted radiation towards the observer. The fast TeV flux variability and the spectral behaviour observed from a non-blazar object challenge current standard theoretical models and therefore, provide new and fascinating insights into the gamma-ray production and emission mechanism of active galactic nuclei. In the conference, we present the observational results and discuss possible physical processes responsible for the flaring events.

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1. Misaligned blazars

The number of extragalactic objects detected in the very-high-energy (VHE, $E > 100$ GeV) range with ground-based gamma-ray instruments has grown rapidly in the last twenty years. Out of these, the majority of objects belongs to the class of active galactic nuclei (AGN). As of summer 2017, ~ 70 AGN were found¹. These objects are radio-loud AGN whose nucleus contains a super-massive black hole and two plasma jets ejected in which particles are believed to be accelerated to relativistic energies and then emit photons through radiative processes. *Blazars* are AGN with a small angle of $\Theta \sim$ few degrees between the jet axis and the line-of-sight defined by the observer. The majority of the VHE detected AGN belong to the class of blazars. A smaller number of AGN, five in total, is believed to have larger angles $\Theta \gtrsim 10$ deg. This angle affects the shift of the frequency of the radiation and the boosting of its luminosity. The latter is the reason why AGN with small angles are naturally easier to be detected with current VHE instruments. In case of small angles the flux gets boosted by a few orders of magnitude while for larger angles the flux might be even de-boosted. A strong Doppler boosting due to a small angle and a high bulk Lorentz factor is used to explain the observational findings of blazars such as the fast flux variability [1, 2]. In this way, one can resolve problems, such as the high opacity due to internal absorption in a tiny emission region, see [3]. However, fast flux variability was also found for the non-blazar objects [4, 5]. They behave in many aspects like blazars and therefore, those objects are often referred to *misaligned blazars*.

In this proceeding, we report on the results obtained from MAGIC observations of the object NGC 1275 during the period between September 2016 and February 2017.

2. NGC 1275

NGC 1275 is a Fanaroff-Riley (FR) I radio galaxy located in the center of the Perseus cluster of galaxies, better known as 3C 84 in the radio band. The classification as FR I is based on its radio morphology [6, 7]. Parsec-scale measurements using the Very-Long-Baseline Interferometry technique indicated a viewing angle of $\Theta = 30^\circ - 55^\circ$ [8] and $\Theta = 65^\circ \pm 16^\circ$ [9]. On sub-parsec scales one particular radio knot (C3) was found to have been ejected ten years ago and it brightens since then [10, 11].

In the optical band, strong nuclear emission lines were found suggesting a Seyfert galaxy [12, 13]. In [14], NGC 1275 was classified as BL Lac type object, a sub-class of blazars, based on the weak emission-line spectrum, the absence of broad hydrogen lines, and the variability and polarization of the nucleus. Flux variability was found basically in all bands, in radio [15], optical [16], and X-rays [17].

NGC 1275 was first identified to be a gamma-ray emitter with the *COS B* satellite [18]. Later on it was detected in the gamma-ray band with *Fermi*-LAT in the energy range $E > 100$ MeV [19]. MAGIC and VERITAS reported the detection at $E > 100$ GeV in [16, 20, 21].

The fastest gamma-ray flux variability was previously found in the LAT data and resulted in time scale of (1.51 ± 0.02) d [22], whereas MAGIC measurements only showed marginal flux

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¹<http://tevcat.uchicago.edu/>

changes on monthly scales above 100 GeV. In October 2016 as well as in January 2017, MAGIC and VERITAS announced the detection of bright flares in the Astronomer’s Telegrams #9689, #9690, #9929, and #9934.

3. Data analysis and results

The observations were performed with the MAGIC (Major Atmospheric Gamma Imaging Cherenkov) telescopes. Those are two 17 m-diameter Imaging Atmospheric Cherenkov Telescopes on the island of La Palma, Spain. The energy range covered by standard MAGIC observations is between 50 GeV and 50 TeV. The data presented here were gathered under the MAGIC Key Observations Proposal for monitoring misaligned blazars.

During the period September 2016 to February 2017 (MJD 57637.1–57811.9), 56 h of observation were performed with the majority of the observations during dark nights and within a zenith distance range of $12^\circ < Z_d < 50^\circ$. For the analysis, we discarded data affected by non-optimal weather conditions and used the standard analysis chain as described in [23].

The analysis of the data resulted in a detection with a significance of 52σ calculated with Eq. 17 in [24], see Fig. 1. Here, we show the square route of the distribution of the angular distance between the reconstructed and the expected source position, called θ^2 , of the signal and background events. We also report for the first time a significant signal from NGC 1275 at energies above 1 TeV with a significance level of 8σ , see Fig. 2.

In the time period from September 2016 and February 2017 (MJD 57637.1–57811.9), a mean flux of $(1.19 \pm 0.03) \times 10^{-10} \text{ cm}^{-2} \text{ s}^{-1}$ above 100 GeV was measured with the MAGIC telescopes. This is seven to nine times higher than during previous observations in 2009–2010 and 2010–2011 reported [16] where a typical flux of $\sim 3\%$ of the Crab Nebula flux was measured. We found a high state in October–November 2016 as reported in the ATel #9689 and again strong flaring activity in December 2016 and January 2017 with one exceptional outburst announced in ATel #9929 with a flux of 1.75 times the Crab Nebula flux above 100 GeV. The latter outburst was 60 times brighter than the low state measured in [16].

4. Discussion

The so-called *shock-in-jet* model is used to explain the production of gamma-rays in AGN. In this model, particles are accelerated to high energies via shock acceleration at shock fronts in the jets of the AGN. The observed radiation is believed to be produced by, e.g., synchrotron-self Compton (SSC) processes [25, 26, 27]. The simplest version of such a model assumes a single spherical component in which synchrotron photons are producing the low energy emission and the same low energy photons are seeds for the inverse-Compton emission observed in the high-energy bands. In case of fast flux variability, the size of the emission region becomes small, and VHE emission can be absorbed via internal $\gamma\gamma$ -pair production. Strong Doppler boosting can solve this problem [3].

In case of NGC 1275, we have investigated the variability time scales and the corresponding Doppler factor necessary to maintain the observed emission. We found that rather moderate

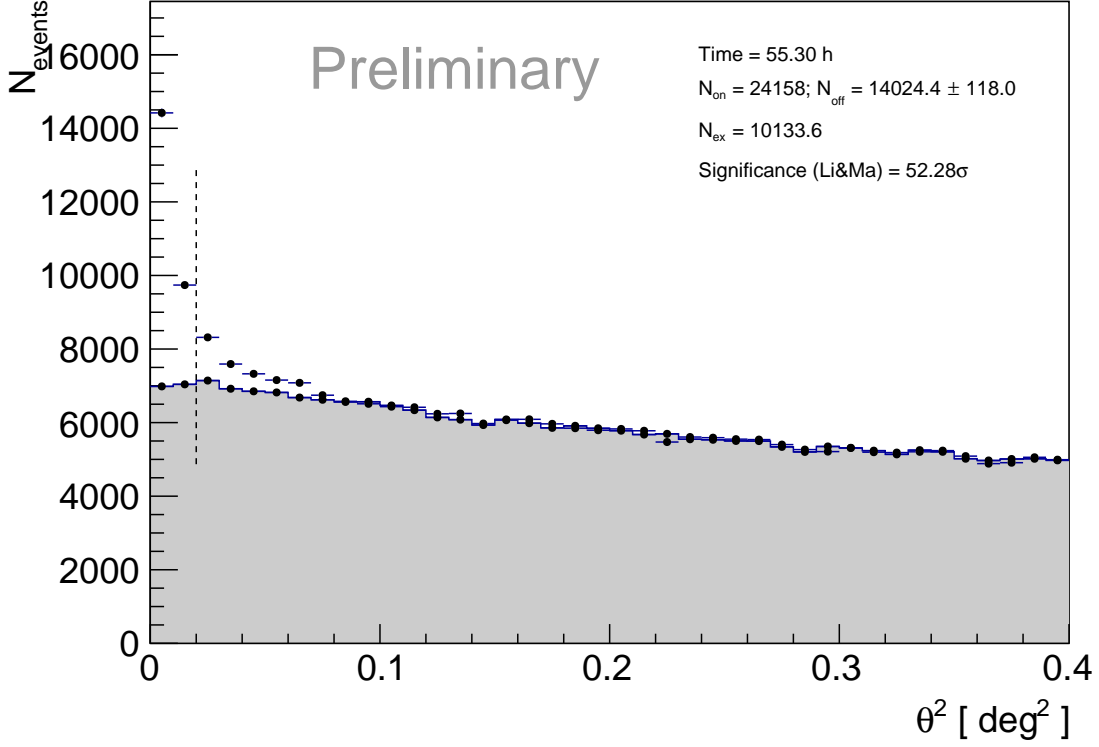


Figure 1: θ^2 distributions of the signal (black points) and background (gray area) estimation performed between September 2016 and February 2017. The significance is calculated for the region between zero and the vertical dashed line.

Doppler factors $\delta \sim \mathcal{O}(10^{0-1})$ are needed which however constrain the viewing angle to be much smaller than the angles yielded in radio observations.

In [28] a spine-layer geometry of the emission zone was used to explain the broad-band radiation of NGC 1275. In this model, a fast spine with $\Gamma_{\text{spine}} = 10 - 20$ in the inner part of the cylindrical jet is surrounded by a slower layer with $\Gamma_{\text{layer}} = 2 - 4$. The VHE emission is produced predominantly by the latter. A limb-brightened structure of the inner parsec-scale jet of NGC 1275 was reported in [29] which indicates such a geometry.

The authors mentioned that TeV emission may not be explained by their model due to strong internal pair-production. As we clearly found a signal at energies greater than 1 TeV, such a model can probably be excluded as explanation for the flaring activity.

Alternative scenarios [30] such as the magnetospheric models [31, 32], star-in-jet interactions [33, 34, 35] or magnetic reconnection [36, 37] would be investigated in the future.

5. Conclusion

More and more gamma-ray observations of misaligned blazars (e.g., fast variability and hard TeV spectra) are reported which are not easy to be explained with our standard models for the gamma-ray production in AGN and therefore, alternative models need to be identified or exploited to

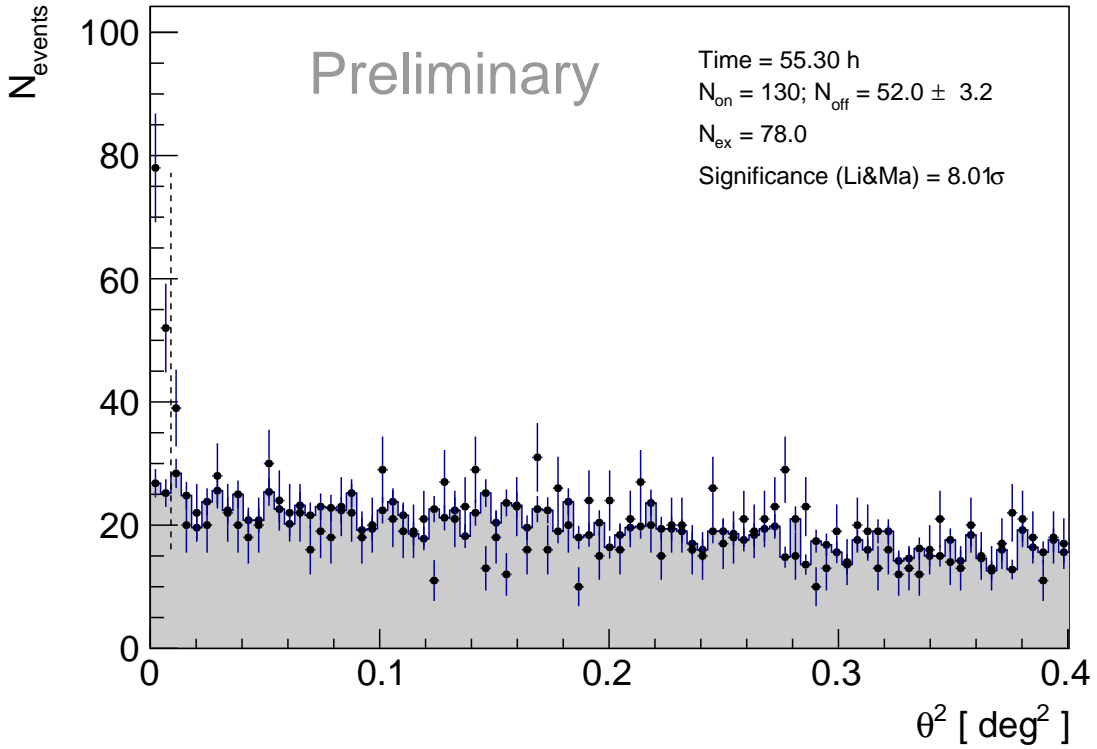


Figure 2: θ^2 distributions of the signal (black points) and background (gray area) estimation above an energy of 1 TeV from observations performed between September 2016 and February 2017. The significance is calculated for the region between zero and the vertical dashed line.

deepen our understanding of the production of gamma-ray emission in AGN. Studying this requires a preferably continuous monitoring with *Fermi*-LAT and the ground-based gamma-ray instruments. This, together with multi-wavelength observations as well as deep VLBI measurements will enlarge our knowledge of the jet structure and the connection between the jet and central black hole and their surroundings.

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