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Pushing the VHE Frontier: LST-1's Inaugural Detection of the Distant Quasar OP 313

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In December 2023, the Flat Spectrum Radio Quasar OP 313 experienced an extraordinary very-high-energy (VHE, E > 100 GeV) gamma-ray flare, reaching an integral flux of 0.3 Crab Units above 100 GeV. This event marked the first VHE detection of OP 313 by the first Large-Sized Telescope (LST-1) at the Northern site of the Cherenkov Telescope Array Observatory, delivering its inaugural scientific result and establishing OP 313 as the most distant blazar detected in this energy regime (z = 0.997). Coordinated observations with LST-1, the MAGIC telescopes, and *Fermi*-LAT enabled us to capture the detailed spectral and temporal evolution of the flare, which we compared with a low-emission state observed in January 2024. A complementary multi-wavelength campaign — from radio through X-rays — enabled us to construct and model the broad-band spectral energy distribution within a two-zone leptonic framework. In this scenario, synchrotron and external Compton processes, involving seed photons from the dusty torus and broad-line region, account for the observed emission, although several combinations of photon fields remain plausible. Furthermore, the broad energy coverage provided by our observations allowed us to probe the attenuation of VHE gamma-rays by the Extragalactic Background Light, yielding competitive upper limits on its intensity. This work not only demonstrates the breakthrough capabilities of LST-1 in VHE gamma-ray astronomy but also provides fresh insights into the complex radiative mechanisms of high-redshift blazars, paving the way for future studies of extreme extragalactic sources.

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1. Introduction

Active Galactic Nuclei (AGNs) are among the most luminous and variable sources in the Universe. A fraction of these AGNs are able to launch relativistic jets with non-thermal emission that spans from radio frequencies to very-high-energy (VHE, E > 100 GeV) gamma rays. Jetted AGNs are the most populous class of sources in the extragalactic VHE sky. The majority of the VHE AGNs is characterized by relativistic jets closely aligned with the line of sight, a condition which indentifies the blazar subclass.

Blazars are often sub-classified in BL Lacertae objects (BL Lacs) and Flat Spectrum Radio Quasars (FSRQs). The former have weak or no optical emission lines in their spectrum, while the latter have strong emission lines and more complex radiation fields [1].

The multi-wavelength Spectral Energy Distribution (SED) of blazars typically shows a characteristic double-peaked shape. The low-energy emission — from radio to optical or X-rays — is explained as synchrotron radiation of relativistic electrons accelerated by the magnetic field within the relativistic jet [2]. However, the origin of the high-energy emission is under debate. One scenario considers leptonic processes with Inverse Compton (IC) scattering, and the other scenario proposes hadronic processes. Detecting more VHE blazars at different energies and distances is crucial to a better understanding of their emission mechanisms.

OP 313 is an FSRQ with redshift z = 0.997 [3]. Past observations by the Major Atmospheric Gamma-ray Imaging Cherenkov (MAGIC) telescopes on this source resulted in upper limits [4]. The object showed **a** high emission state observed in optical [5] and high-energy (HE, E >100 MeV) gamma rays [6] from November 2023. Based on the daily analysis of the *Fermi*-LAT data using the FLaapLUC pipeline [7], the object was observed by the first Large-Sized Telescope (LST-1) from December 10, 2023, resulting in the detection of the source in the VHE energy [8]. OP 313 is the tenth FSRQ ever detected at VHE gamma rays and the most distant AGN in this energy range to date. In addition to LST-1, observations from MAGIC were also performed from December 10, 2023, following the high state detected by *Fermi*-LAT.

2. Observations

LST-1 is one of the four LSTs that will be part of the Cherenkov Telescope Array Observatory (CTAO) at the northern site located on ~2200 m above sea level at the Roque de los Muchachos Observatory on the Canary island of La Palma, Spain [9]. LST-1 is an Imaging Atmospheric Cherenkov Telescope (IACT) equipped with a 23-m diameter mirror dish and a camera composed of 1855 high-quantum-efficiency photomultipliers. These characteristics provide LST-1 with a large collection area and high sensitivity, allowing the detection of gamma-ray events down to energies of ~20 GeV [10]. This makes LST-1 an ideal instrument for the observation of distant VHE gamma-ray emitters.

LST-1 observed OP 313 in December 2023 following optical and high-energy gamma-ray alerts [5, 6], leading to the detection of the source after four nights of observations [8]. LST-1 accumulated a total of ≃15 hours of data after quality cuts between December 10th and December 19th (MJD 60288 to MJD 60297). About 5 additional hours of data were also collected during

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January 2024, when the source was found to be in a lower emission state. The observations were performed in dark conditions at zenith angles ranging from ~10° to ~55°.

The MAGIC telescopes consist of two 17-m diameter IACTs located on the Roque de los Muchachos Observatory. MAGIC observed OP 313 between December 10 and 19 for a total of ~10 hours after data quality cuts based on atmospheric transmission. Additional observations were made in January 2024, resulting in ~4 hours of data after data quality cuts.

We also collected observational data from *Fermi*-LAT, *Swift*-XRT, *Swift*-UVOT, as well as from other telescopes operating in the optical and radio bands. The results of the data analysis will be reported and discussed in an upcoming journal article.

3. Data analysis

LST-1 data analysis was performed with the software `cta-lstchain` [11], following the standard source-independent analysis described in [10]. The high-level data analysis of the selected gamma-ray events was performed with the `Gammapy` python package [12, 13]. The squared angular distance of the reconstructed gamma-ray directions to the nominal location of the source (θ^2 plot) is shown in Fig. 1 (top). OP 313 was clearly detected during the high state of December 2023 with a statistical significance of 12.9σ up to an energy of ~250 GeV with a signal region of $\theta^2 < 0.04$. The significance of the signals are calculated using Eq. (17) of [14]. The source was not significantly detected during January 2024. The average integral photon flux above 100 GeV during the high state period of December 2023 is around 0.3 Crab Units.

MAGIC data were processed using the `MARS` (MAGIC Analysis and Reconstruction Software [15, 16]) software package, following the standard data analysis procedure. Fig. 1 (bottom) shows the θ^2 plot for the December 2023 observations. The significance of the source detection was calculated with a signal region of $\theta^2 < 0.02$, the standard cut in the MAGIC analysis for the lowest energies. The source was detected with a significance of 6.0σ. For January 2024 observations, the source was not significantly detected.

4. Summary

We detected significant VHE gamma-ray emission from the FSRQ OP 313 for the first time. The source became the tenth FSRQ and the farthest AGN confirmed as a VHE gamma-ray emitter. This result represents the first scientific discovery made with LST-1, owing to its lower energy threshold and increased sensitivity at a few GeV compared to previous-generation IACTs. These data also allow us to evaluate the EBL attenuation by scanning the EBL intensity on the gamma-ray spectrum, and to study the multi-wavelength emission and interpret the broadband SED in the framework of blazar radiative models including the thermal contributions from the dusty torus and broad-line region. These results will be shown in an upcoming journal article.

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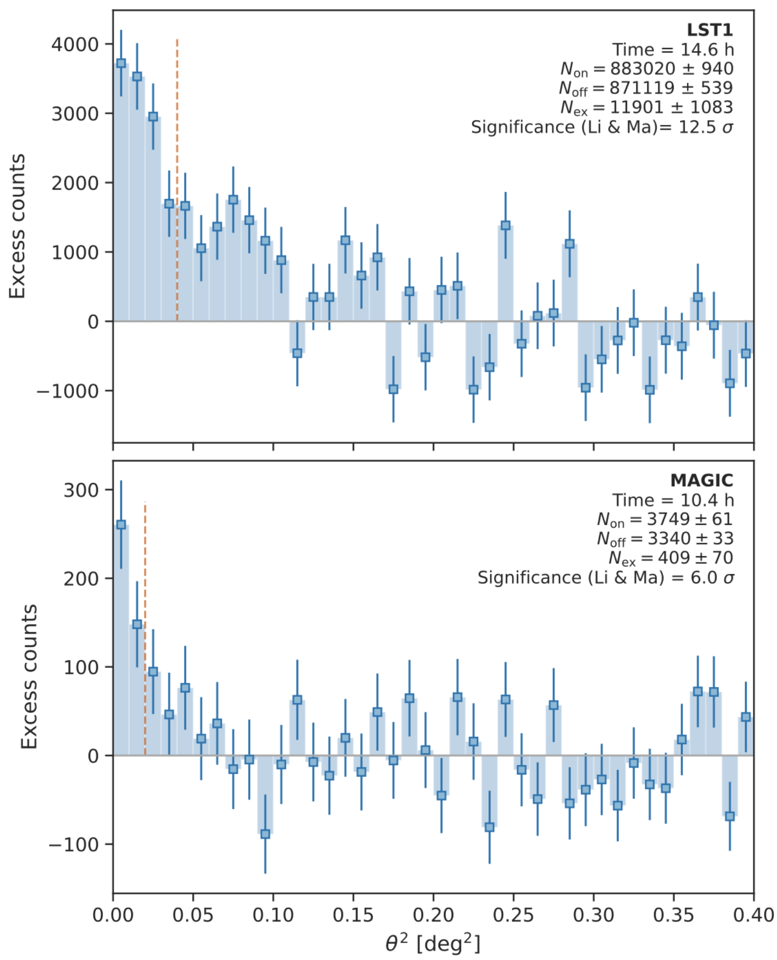

Figure 1: Distributions of the squared angular distance between the reconstructed gamma-ray directions and the location of OP 313 during December 2023, derived from the excess gamma-ray events. *Top*: LST-1. *Bottom*: MAGIC. In the case of LST-1, we obtained the distribution for energies below 250 GeV. The dashed line shows the region where events are considered to calculate the detection significance.

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