PROCEEDINGS OF SCIENCE

Multi-wavelength view of 3C 279 during the 2017 EHT campaign

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Spinning super-massive black holes at the centers of galaxies can launch powerful magnetized jets. When these jets are oriented within a few degrees of our line of sight, they are called blazars, active galactic nuclei that exhibit variable, non-thermal emission across the entire electromagnetic spectrum, from radio waves to gamma rays. 3C 279 is an archetypal blazar with a prominent radio jet that undergoes broadband flux density variations. In April 2017 and April 2018, the Event Horizon Telescope (EHT) observed 3C 279 with an unprecedented angular resolution of 20 micro-arcseconds. In parallel, an extensive quasi-simultaneous multi-wavelength (MWL) campaign was conducted using both ground- and space-based observatories, covering frequencies from radio wavelengths to the TeV energy range. We present here initial findings from the first EHT-MWL observational campaign, which captured a gamma-ray flaring event. A detailed analysis of the complete 2017 dataset, along with results from the 2018 campaign and their modelling, will be provided in an upcoming publication.

39th International Cosmic Ray Conference (ICRC2025)
15–24 July 2025
Geneva, Switzerland

ICRC 2025
The Astroparticle Physics Conference
Geneva July 15-24, 2025

*Speaker

PoS(ICRC2025)814

1. Introduction

Accreting black holes are thought to convert their rotational energy into Poynting flux, which escapes along their spin axes and powers tightly collimated jets. Recent observations of the active galactic nucleus (AGN) M87 by the Event Horizon Telescope (EHT) provide strong support for this scenario [1, 2], although the first EHT images of M87 do not yet provide a direct connection between the SMBH and the large-scale jet. Understanding the mechanisms behind jet launching, collimation, and evolution — as well as how particles are accelerated to gamma-ray energies in such extreme environments — remains a central challenge in modern astrophysics, see [3] for a review.

Flat Spectrum Radio Quasars (FSRQs) are a subclass of blazars which constitute the most powerful class of AGNs, presenting one of the jets closely aligned with the line of sight of the observer at the Earth. Blazars emit broadband, non-thermal radiation spanning the entire electromagnetic spectrum — from radio waves to very-high-energy gamma rays (VHE; E > 100 GeV). Their radio and optical emission is highly polarized and exhibits strong variability across a wide range of timescales, from minutes to years [4]. 3C 279 is a FSRQ and one of the more distant gamma-ray emitters, situated at a redshift of z = 0.536 [5]. At the core of its host galaxy lies a supermassive black hole (SMBH) with a mass estimate of about $8{\times}10^8$ solar masses [6].

The source was first observed during a four-day campaign in April 2017 as one of the primary calibrators for the EHT observations of M87 and Sgr A* at 230 GHz [7]. The achieved ultra-high angular resolution of 20 μas corresponds, at a redshift of $z = 0.536$ and assuming a black hole mass of $M_{\rm BH} = 8 \times 10^8\, M_\odot$, to a spatial scale of 0.13 pc (∼1700 Schwarzschild radii). EHT observations unveiled a complex, multicomponent structure in the innermost region of the jet, with the northernmost feature appearing elongated perpendicular to the jet's large-scale direction as seen at longer wavelengths. This structure may represent either a broad, resolved jet base or a jet that is spatially bent. Notably, the source morphology exhibits significant day-to-day changes, indicating a systematic structural evolution. Two inner jet components show non-radial motion with superluminal apparent velocities of approximately 15–20c, consistent with the presence of propagating shocks or instabilities within a bent and potentially rotating jet. The source was subsequently observed during the 2018 EHT campaign, and the corresponding results are forthcoming.

3C 279 presents broadband emission from radio up to VHE gamma-rays [8, 9], with the high-energy component typically dominating over the synchrotron emission [10]. The source exhibits strong variability across the entire electromagnetic spectrum (e.g., Hayashida et al. [11]), with its γ-ray flux fluctuating by more than two orders of magnitude — from approximately 10^{-7} to 10^{-5} photons cm^{-2} s^{-1} above 100 MeV (see e.g. [4]). Multi-wavelength (MWL) monitoring during a 2009 γ-ray flare revealed a correlated change in optical polarization, highlighting a direct connection between high-energy activity and jet magnetic field dynamics [12].

The source is characterised by intense and very rapid gamma-ray flaring episodes. In particular, on 2015 June 16, the the Large Area Telescope (LAT) on board the *Fermi Gamma-ray Space Telescope* observed a giant outburst presenting minutes-scale variabilty, with flux doubling times less than 5 min [4]. The observed minute-scale variability suggests a very compact emission region at hundreds of Schwarzschild radii from the central engine in conical jet models. Moreover, during June 2015 flare VHE gamma rays were detected by H.E.S.S. supporting the scenario in which the emission region is located at $r > 1.7 \times 10^{17}$ cm from the black hole, that is beyond the assumed distance of the broad-line region. Similarly, *Fermi*-LAT observations in April 2018 revealed a distinctive double-peaked gamma-ray variability pattern on minute time scales, consistent with expectations from relativistic magnetic reconnection as the underlying acceleration mechanism. Furthermore, the lack of significant $\gamma\gamma$ pair attenuation suggests that the particle acceleration occurs at distances of ~10,000 gravitational radii from the black hole, where plasma turbulence is likely driven by fluid dynamical kink instabilities [13].

Similar to the MWL campaigns conducted for EHT observations of M87 [14, 15], coordinated quasi-simultaneous MWL observations of 3C 279 were carried out during the 2017 and 2018 EHT observing runs. This dataset enables in-depth investigation of jet physics and particle acceleration mechanisms, aids in the interpretation and modeling of the observations, and serves as a valuable legacy resource for the broader astronomical community.

In this proceeding, we focus on the 2017 EHT-MWL observations of 3C 279, while a comprehensive presentation of the full results from the 2017 and 2018 EHT-MWL campaigns will be provided in a forthcoming publication.

2. Observations

3C 279 was observed during the first EHT observational campaign from April 5 to 11, 2017. During the 2018 campaign, observations took place between April 21 and 25. Accompanying MWL observations were taken around both the EHT campaigns (performed in April 2017 and April 2018) and spanning a wide range of frequencies, from 1.7 GHz with RadioAstron up to VHE gamma rays with H.E.S.S. and MAGIC.

More than a dozen observational facilities contributed to the MWL campaign on 3C 279. Figure 1 provides a schematic overview of the observations conducted between March and April 2017 as part of the first EHT-MWL campaign. In addition to instruments involved in the observations during March–April 2017, shown in the figure, our study includes also preliminary cumulative flux estimates from RadioAstron observations at 1.7 and 5 GHz, covering the period from 2016 to 2018.

At radio frequencies, the participating instruments include RadioAstron (1.7 and 5 GHz), the VLBA (15 and 43 GHz), KVN (22, 43, 86, and 129 GHz), GMVA in combination with ALMA (86 GHz), SMA (221 GHz), standalone ALMA (91, 103, and 343 GHz), and the EHT (230 GHz). In the infrared to ultraviolet bands, optical observations were conducted with the Kanata and Perkins telescopes, with the latter employing B, V, and I filters. Additional UV data were obtained with *Swift*-UVOT using the V, B, U, UVW1, UVM2, and UVW2 filters. At X-ray energies, *Swift*-XRT provided coverage in the 0.3–10 keV range. Finally, in the gamma-ray regime, *Fermi*-LAT observed 3C 279 over the 0.1–1000 GeV energy range, while H.E.S.S. and MAGIC provided observations from approximately 80 GeV to above 300 GeV.

3. Preliminary Results of the 2017 EHT-MWL campaign

In this section, we present a few preliminary results from the 2017 EHT and MWL observational campaign on 3C 279.

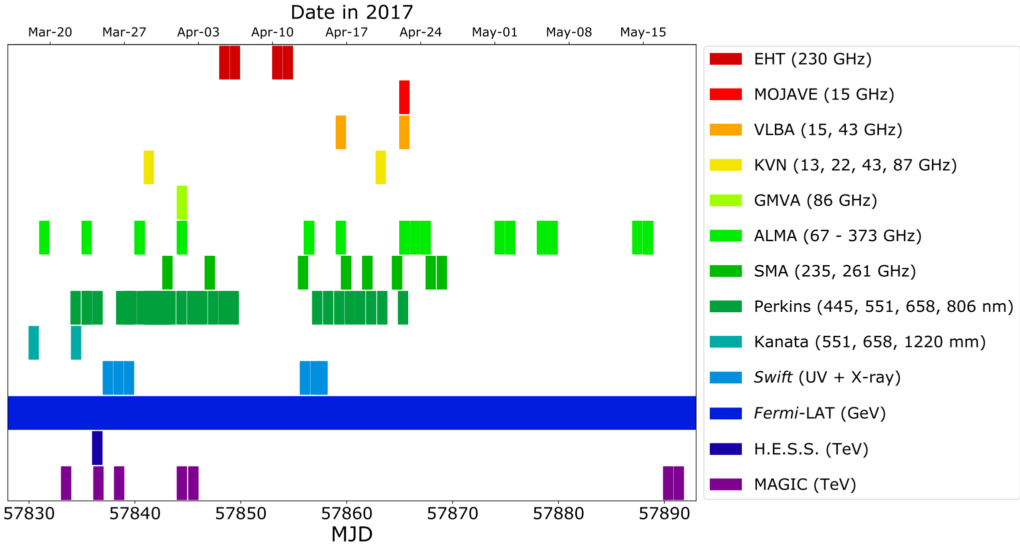

Figure 1: Instrument coverage summary of the 2017 3C 279 MWL campaign, covering MJD range 57830-57870.

3.1 Radio observations results

Figure 2 presents the jet structure of 3C 279 in April 2017 at frequencies of 43, 86, and 230 GHz. The 43 and 86 GHz images, obtained from quasi-simultaneous observations by the VLBA-BU-BLAZAR program [16] and the GMVA blazar monitoring program [1], respectively, are included to illustrate the larger-scale jet morphology. The elongation observed with the EHT at 230 GHz is oriented nearly perpendicular to the long-term jet direction seen on larger scales.

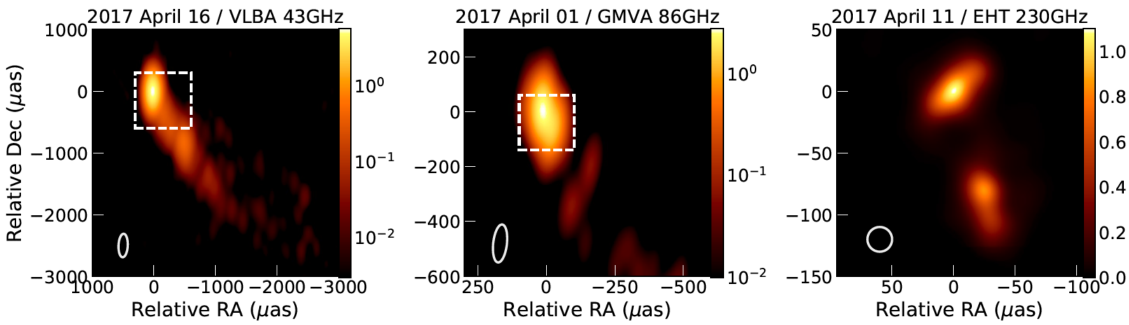

Figure 2: Multi-frequency radio images of 3C 279 obtained in April 2017. From left to right, the panels show observations with the VLBA at 43 GHz, the GMVA at 86 GHz, and the EHT at 230 GHz. The white circles in the lower left corners represent the convolving beam sizes, while white dashed boxes indicate the regions imaged at higher frequencies, shown in the adjacent plot to the right. Figure taken from [7].

The EHT observed 3C 279 on four separate days: April 5, 6, 10, and 11, 2017. Across all epochs, the data consistently reveal an elongated core structure. The northern feature is interpreted as the VLBI "core," while the overall morphology may represent either a broadened, resolved jet

[1] https://www.bu.edu/blazars/vlbi3mm/index.html

base or a spatially bent jet. Notably, the EHT data show significant structural variability on daily timescales, pointing to systematic changes in the inner jet. Two compact components are observed moving non-radially at apparent superluminal speeds of approximately 15 c and 20 c. These motions, together with inferred Doppler factors of 10–20, support a scenario involving traveling shocks or instabilities within a bent and possibly rotating jet. The observed apparent speeds are consistent with those measured at longer (centimeter) wavelengths, indicating that no substantial jet acceleration occurs between the 1.3 mm VLBI core and the outer jet regions.

3.2 Multi-wavelength variability

In Fig. 3 we show the preliminary short-term (March-April 2017) MWL light curve behaviour of 3C 279 with the observations collected by the instruments participating in the coordinated EHT-MWL campaign in 2017.

While no significant flux variability is detected at either centimeter or millimeter radio frequencies, the source exhibits pronounced flaring activity in the UV–optical band, with a peak flux observed around March 22–23. Additionally, the optical polarisation shows substantial variability, with the polarisation degree ranging from 5% to 25%, and the polarisation angle varying between 20° and 80° following a similar temporal trend.

In the gamma-ray band, the source undergoes intense flaring episodes, with *Fermi*-LAT 3-hour binned fluxes reaching up to ten times the long-term average reported over 14 years. For reference, the integrated flux from the 4FGL-DR4 catalog is $\phi_{E>100\,\mathrm{MeV}} \sim 5 \times 10^{-7}$ ph cm^{-2} s^{-1} [17]. In particular, during the EHT observing window (April 5–11), the source displays an average flux of $\phi_{E>100\,\mathrm{MeV}} = (2.07 \pm 0.07) \times 10^{-6}$ ph cm^{-2} s^{-1}. At VHE gamma rays, however, no significant detection is reported by H.E.S.S. and MAGIC during this period.

3.3 Multi-wavelength Spectrum

Figure 4 shows the 2017 MWL broadband SED of 3C 279, a legacy data set with near-simultaneous results collected over a broad range between a frequency of ∼ 1.7 GHz and photon energy of about 1 TeV.

As shown in Sect. 3.1, high-resolution VLBI observations spatially resolve the source structure, whereas at higher frequencies the source appears point-like due to limited angular resolution. In the SED plot, we also indicate the corresponding spatial scales associated with the total emission for the highest-resolution observations. All flux points are based on statistically significant detections ($> 3\sigma$) and provided with uncertainties equivalent to the 1σ confidence level. Upper limits on flux are given at the 2σ confidence level.

4. Summary

We present here preliminary results from one of the most extensive and high angular resolution broadband observational campaigns on 3C 279, conducted in conjunction with the first EHT observations of the source in April 2017 [7]. This comprehensive, quasi-simultaneous campaign aims to establish a valuable legacy dataset for the broader astrophysical community, facilitating robust modeling efforts and serving as a benchmark for theoretical studies. The EHT observations reveal an elongated core structure and a bent jet, exhibiting significant structural variability on

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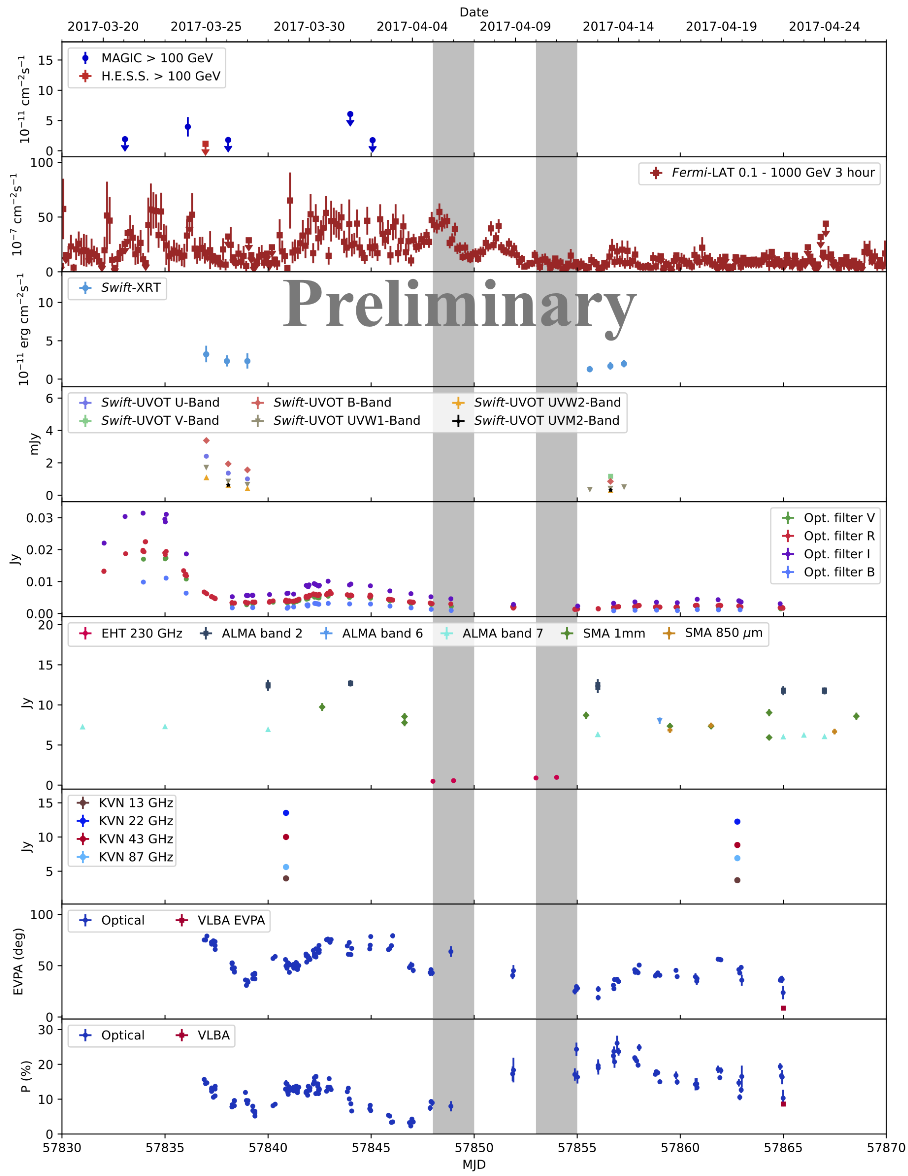

Figure 3: Preliminary MWL light curves of 3C 279 taken during the observational campaign covering MJD range 57830–57870. The grey bands mark the period when the EHT observations took place.

daily timescales, which is indicative of systematic changes occurring in the innermost jet regions. Preliminary results from the MWL campaign show pronounced variability in both the optical and gamma-ray bands, with flaring episodes occurring close in time to the EHT observations. Additionally, the optical polarisation displays variability in both degree and angle.

Acknowledgments

We acknowledge ISCRA for awarding this project access to the LEONARDO supercomputer, owned by the EuroHPC Joint Undertaking, hosted by CINECA (Italy). G.P. acknowledge also

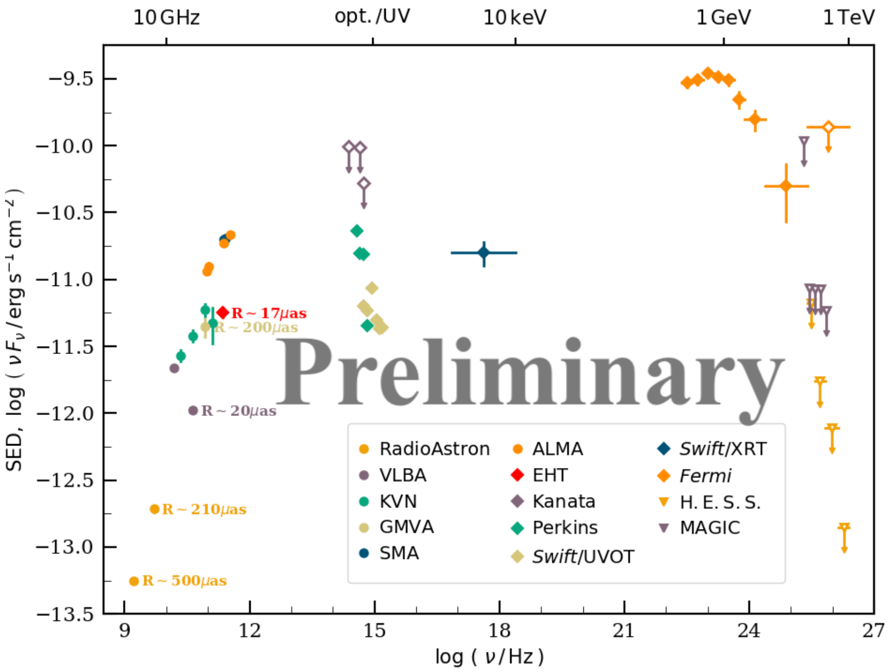

Figure 4: Preliminary MWL broadband spectrum of 3C 279 taken around the EHT observational campaign covering MJD range 57836-57861, with except of RadioAstron for which integrated results on cumulative observations between 2016 and 2018 are reported. The fluxes were measured by various instruments, and they are highlighted with different colours and markers. For the radio/millimetre VLBI and interferometric data the upper limits on emission size (radius) for several representative frequencies, are labelled to clarify.

partial support by ICSC – Centro Nazionale di Ricerca in High Performance Computing, Big Data and Quantum Computing, funded by European Union – NextGenerationEU. We refer to a similar EHT-MWL publication [15] for complete acknowledgments.

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