Long-term spectral and temporal evolution of 1ES 1959+650

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1ES 1959+650

1ES 1959+650 is a nearby high-frequency peaked (HBL) BL Lac object at redshift z=0.048 [1]. Being one of the steadily brightest blazars in very-high-energy (VHE, E > 100 GeV) gamma rays makes it one of the first TeV sources detected and therefore one of the most extensively studied BL Lac objects at the highest energies since 20 years ago.

In 2016, it underwent an episode of extreme activity reaching ~3 Crab units (CU) [2]. During this flare, intra-night variability was also found.
We present the multiwavelength observations carried out to understand the evolution of its spectral and temporal behaviour allowing us to compare the different flux states of this source.

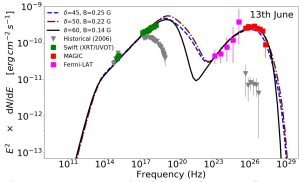

Fig. 1: One-zone SSC model of the SED from 2016 flare [2].

MAGIC telescopes

The Major Atmospheric Gamma-ray Imaging Cherenkov (MAGIC) telescopes observe the sky in VHE gamma rays. They are situated at Roque de los Muchachos Observatory (La Palma, Spain) at an altitude of 2200 m. MAGIC telescopes are operated in the energy range from 50 GeV to several tens of TeV. Its sensitivity above 300 GeV is ~0.7% of the Crab nebula flux for 50 h of mid-zenith angle observations of point-like sources with Crab-like spectra (see Table A.6 in [3]). MAGIC extends its duty cycle by observing under moonlight [4].

Fig. 2: MAGIC Telescopes at the Roque de los Muchachos Observatory, La Palma, Spain. (*Robert Wagner/MAGIC Collaboration*).

The source has been observed by MAGIC since 2015. The preliminary light curve for energies above 300 GeV is depicted in Fig 3.

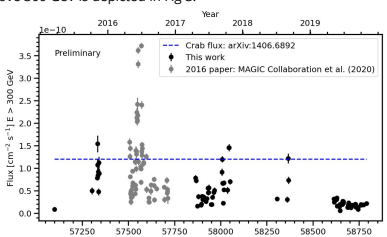

Fig. 3: MAGIC light curve (1-day binning) for energies above 300 GeV. Observations shown here are only those performed under low night sky background. For reference, the Crab nebula flux from [5] is depicted by the blue dashed line. 2016 data points (gray) were taken from [2].

Multiwavelength observations

MWL data were collected from different instruments: radio (OVRO), optical/UV (Tuorla and *Swift*-UVOT), X-ray (*Swift*-XRT), HE gamma rays (*Fermi*-LAT) and VHE gamma rays (FACT). The corresponding light curves are presented in Fig. 4.

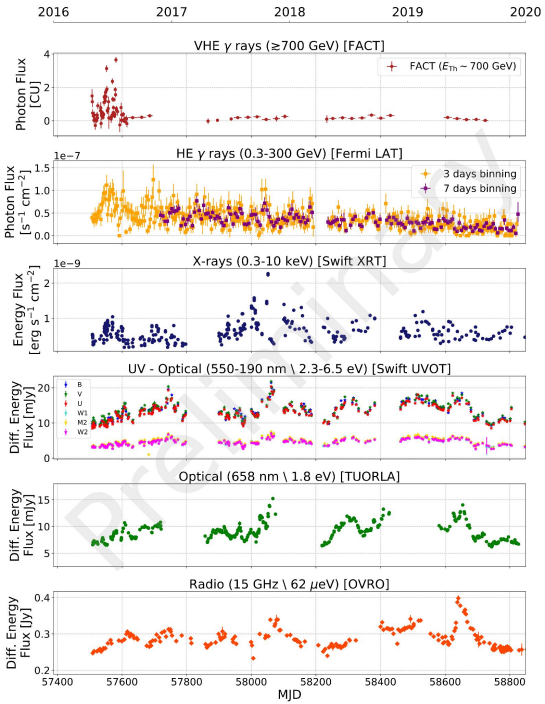

Fig. 4: Long-term multiwavelength light curves of 1ES 1959+650 from 2016 to 2019.

Results

We characterized the integral flux and VHE γ-ray spectrum from August 2019 observations (Table 1). The 2016 flare fitting parameters are also shown for comparison. A power-law fitting function is assumed ($dN/dE = f_0 \cdot (E/E_0)^{\alpha}$).

Table 1: Integral flux above 300 GeV and spectral parameters of 1ES 1959+650 for the different periods from which we extracted the SED. The values reported are preliminary.

Date	Flux (E > 300 GeV) [CU]	f_0 [TeV^{-1} cm^{-2} s^{-1}]	E_0 [GeV]	Spectral index (α)
2016-06-13	3.4 ± 0.1	(1.81 ± 0.05)·10^{-9}	300	-2.00 ± 0.02
August 2019	0.12 ± 0.01	(4.9 ± 0.3)·10^{-11}	400	-2.5 ± 0.1

The broadband SED of each period was modeled with a one-zone synchrotron self-Compton (SSC) leptonic emission model (Fig. 5). The different VHE SEDs were de-absorbed assuming the EBL model from Domínguez et al. 2011 [6].

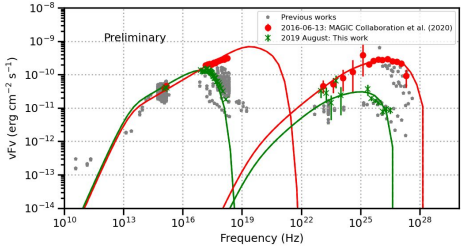

Fig. 5: Broadband SEDs corresponding to each period from Table 1 modeled with a one-zone SSC emission model. Archival observations were compiled from SSDS SED builder (https://tools.ssdc.asi.it/) and references therein.

Summary

- Extreme behavior in 2016 when the source reached ~ 3 CU in VHE gamma-rays.
- VHE flares in 2015, 2017 and 2018 reaching ~ 1 CU.
- 2017 VHE flare accompanied by high states in X-ray, optical/UV, and radio bands.
- Low-flux state (~0.2 CU) in the gamma-ray band during 2019.
- Broadband SEDs modeling of each period assuming a one-zone SSC scenario.
- Study of the variability, cross-band correlations and broadband SED modeling to be reported in MAGIC Collaboration et al., 2021, In prep.

References

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