BL Lac object 1ES 0647+250, a decade of MWL observations

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on behalf of the MAGIC and *Fermi*-LAT Collaborations and MWL partners

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1ES 0647+250

1ES 0647+250 is a high synchrotron peak (HBL) BL Lac object of unknown redshift. Tentative values have been proposed in the past (e.g. z=0.41 [1]) and a lower limit of z>0.29 was estimated [2]. It is also one of the few distant blazars detected at very-high-energy (VHE, E > 100 GeV) γ rays during a non-flaring state. It was first detected by MAGIC between 2009 and 2011, displaying an average of ~2% of the Crab Nebula flux above 100 GeV.

Since then, it has shown several flaring episodes, detected in the VHE band by MAGIC in 2014, 2019 and 2020. These high states were accompanied by an enhancement of its X-ray activity. We present the MAGIC and multiwavelength (MWL) analysis of 11 years of data of 1ES 0647+250 in order to characterize the long term evolution of this blazar.

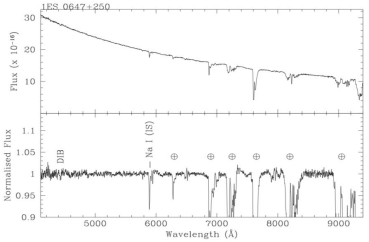

Fig. 1: Optical spectrum of 1ES 0647+250 presented by Paiano et al. (2017) for constraining the redshift lower limit of the source [2].

MAGIC telescopes

The MAGIC (Major Atmospheric Gamma-ray Imaging Cherenkov) telescopes are a stereoscopic system of two 17 m Imaging Atmospheric Cherenkov Telescopes (IACTs) located at the Canary island of La Palma, Spain, at the Roque de los Muchachos Observatory, at an altitude of ~2200 m.

They operate in an energy range between 50 GeV and several TeV, with a sensitivity above 0.1 TeV of about 1.5% of the Crab Nebula flux after a 50-h long observation (see Table A.5 in [3]).

Fig. 2: MAGIC Telescopes at the Roque de los Muchachos Observatory, La Palma, Spain. (*Credit: Daniel López/IAC*).

MWL data set

We collected MWL data from different ground- and space-based observatories and instruments from radio to γ rays: HE γ rays (*Fermi*-LAT), X rays (*Swift*-XRT), UV and optical (*Swift*-UVOT), optical R band (Tuorla-KVA, Las Cumbres, PIRATE and Liverpool Telescope) and radio 15 GHz (OVRO). The figure below shows the long-term radio (15 GHz), optical (R band) and HE γ-ray light curves of 1ES 0647+250:

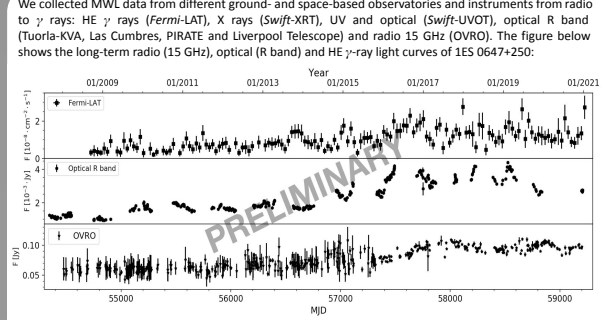

Fig. 3: Long-term light curves of 1ES 0647+250. *Top:* HE γ rays (*Fermi*-LAT). *Middle:* Optical R band (Tuorla blazar monitoring program, Las Cumbres, PIRATE and LT). *Bottom:* Radio (OVRO). All the optical data except from the observations of Dec. 2020 were taken by Tuorla (KVA).

Detection in VHE

The source was observed for a total of 45.42 h and detected in four different periods. The significances of the detection (Li & Ma [4]) are:

- 2009-2011 (26.71 h): 5.5σ
- 2014 (2.22 h): 5.3σ
- 2019 (2.67 h): 6.1σ
- 2020 (13.48 h): 22.9σ

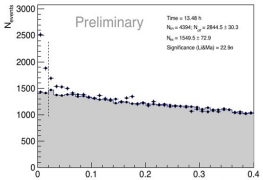

Fig. 4: θ^2 plot for the MAGIC detection of the 2020 flaring state of 1ES 0647+250.

Results

We characterized the emission and the VHE γ-ray spectrum for the different periods. A power law function ($dN/dE = f_0 \cdot (E/E_0)^{\alpha}$) was used to fit the spectra from 2009-11, 2014 and 2019. Moreover, the spectrum of the high state from December 2020 was preferably fitted with a log-parabola function ($dN/dE = f_0 \cdot (E/E_0)^{\alpha+\beta \cdot \log(E/E_0)}$), with a 3$\sigma$ preference over the power law.

	F (E > 100 GeV) [% Crab Units]	Spectral parameters	
		E_0 [GeV]	Spec. index
2009-2011	2.0 ± 0.5	190	α = -3.1 ± 0.4
2014	3.4 ± 1.6	100	α = -3.3 ± 0.7
2019	8.0 ± 1.8	100	α = -3.7 ± 0.6
2020	15.0 ± 1.0	100	α = -3.2 ± 0.2 β = -1.9 ± 0.7

Table 1: Integral flux above 100 GeV and spectral parameters of 1ES 0647+250 for the different campaigns.

We performed an estimation of the redshift using the SED from 2020 and following the empirical relation derived by Prandini et al. 2010 [5]. An upper limit was also determined from the joint fit of the *Fermi*-LAT and MAGIC SEDs assuming that the latter is softer following the method in [6].

Estimated redshift, z_{est}	z_{UL} [95% C.L.]
0.45 ± 0.05	0.81

Table 2: Results of the redshift estimation. z_{est} is the estimated value through the empirical relation derived by Prandini et al. 2010. z_{UL} is the upper limit at 95% C.L. from the joint HE and VHE spectra.

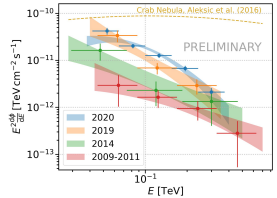

Fig. 5: Observed VHE γ-ray spectral energy distributions (SEDs) of 1ES 0647+250 for the different campaigns.

11 years of MWL data were collected in order to study the long-term behaviour and evolution of this blazar. A deeper analysis of these data will be published soon in a dedicated paper by the MAGIC Collaboration.

Summary and conclusions

- Distant HBL of unknown redshift (z > 0.29), first detected in VHE γ rays during low state
- Detected during several enhanced states in VHE, with a flux increase up to ~7.5 times the low state flux
- 11 years of MWL data were collected for the long-term analysis of the evolution of the source. Further details about the results will be presented soon in a dedicated paper by the MAGIC Collaboration:
  - Variability studies for the different wavelengths will be performed
  - Long- and short-term correlations between bands will be analyzed
  - X-ray and γ-ray spectral analysis will be presented
- Redshift value of z=0.45 ± 0.05 estimated from the HE and VHE spectra, in agreement with previous measurements

References

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Acknowledgements

We acknowledge the support from the agencies and organizations listed here:
https://magic.mpp.mpg.de/acknowledgments_ICRC2021