PROCEEDINGS OF SCIENCE

Long term study of the blazar S5 0716+714: investigating a turbulent jet at all wavelengths

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The blazar S5 0716+714 is an intermediate BL Lacertae object remarkable for its variability in many energy bands. It was discovered by MAGIC in the very-high-energy (VHE) gamma-ray range in 2008. Later in 2015 an impressive electric vector polarization angle (EVPA) swing was detected in connection with a multiwavelength flaring event including the VHE gamma-ray band. This generated interest in further studies of the jet of this source and its electromagnetic emission at all wavelengths. Since then, MAGIC has monitored the source in coordination with other observatories and here we present the long-term study using data from 2015 to 2022 in a MWL context. The data set also includes the extraordinary flaring activity of 2017, so far the historical maximum detected for this source in the optical and VHE gamma-ray band.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

*Speaker

PoS(ICRC2023)900

1. Introduction

The blazar S5 0716+714 is an intermediate BL Lac object (IBL) with an unknown redshift which was discovered to emit very-high-energy (VHE, E>100 GeV) gamma rays in 2008, by the MAGIC collaboration [1]. S5 0716+714 is very well known for its impressive variability in all the energy bands. For this reason it has been object of many observational campaigns, in the optical, radio and X-ray bands and more recently also in gamma-rays. Few years after the discovery of VHE gamma-ray emission, the MAGIC telescopes, triggered by the high optical state of the source and by *Fermi*-LAT, performed several observations of the source together with other instruments and detected a bright flare in VHE gamma rays [2]. A multiwavelenght (MWL) campaign was quickly organized in order to collect data from different instruments and study the broadband spectral energy distribution of the source and the emission mechanism. In [2] it was possible to study in detail two phases of the flaring activity, the highest in January 2015 (Phase A) and the lowest one in February 2015 (Phase B), across the entire electromagnetic spectrum. During Phase A also a very fast rotation of the Electric Vector Polarization angle (EVPA) was reported. The modeling of the spectral energy distribution (SED) was not trivial and a two zone model was needed at that time to describe the observational data. The very long baseline interferometry (VLBI) maps revealed that the gamma-ray detection could be associated with the entrance and exit of a superluminal knot in and out of a recollimation shock in the jet. After those interesting results MAGIC decided to monitor the source more closely, in particular to search for EVPA rotations in connection with VHE emission. A long term monitoring campaign was set up involving many telescopes and collaborations, in particular the whole Earth blazar telescope (WEBT) collaboration, the Tuorla observatory and the BU Blazar group for VLBI. Here we present the long term study of S5 0716+714 from 2015 to 2021 which will be reported in detailed in a paper in preparation for the MAGIC collaboration and MWL collaborators [5].

2. Observations

The MAGIC telescopes is an array of two Imaging Atmospheric Cherenkov telescopes (IACTs) operating in stereo mode at the Roque de Los Muchachos Observatory (ORM) in the Canary island of La Palma (Spain). They are sensitive to gamma-rays from ~50 GeV to 10 TeV. Due to their low energy threshold they are very suitable for the observation of distant celestial objects, reaching redshift z=1 [8, 9]. MAGIC is monitoring S5 0716+714 since 2015 in cooperation with other facilities in different energy bands. The dataset, after quality cuts, amounts to 35 hours of data, taken between 2015 to 2021. The source was observed in a medium zenith angle range (40-50 z_d). The weather conditions were monitored with the MAGIC LIDAR, allowing to recover and correct the energy of the events even in the presence of clouds [7]. The dataset was analysed with the MARS software [3, 4]. The source has been detected in a few occasions, in particular in Dec 2017 during a very bright flare which is at the moment corresponding to the historical maximum of the source in the VHE gamma-ray band.

For high-energy (HE) (0.1 GeV<E<100GeV) gamma rays data we used the public data from the Large Area Telescope on board of *Fermi* satellite. The HE gamma ray data were taken from the *Fermi* Light Curve Repository. Light curve was computed using a 30-day time binning across

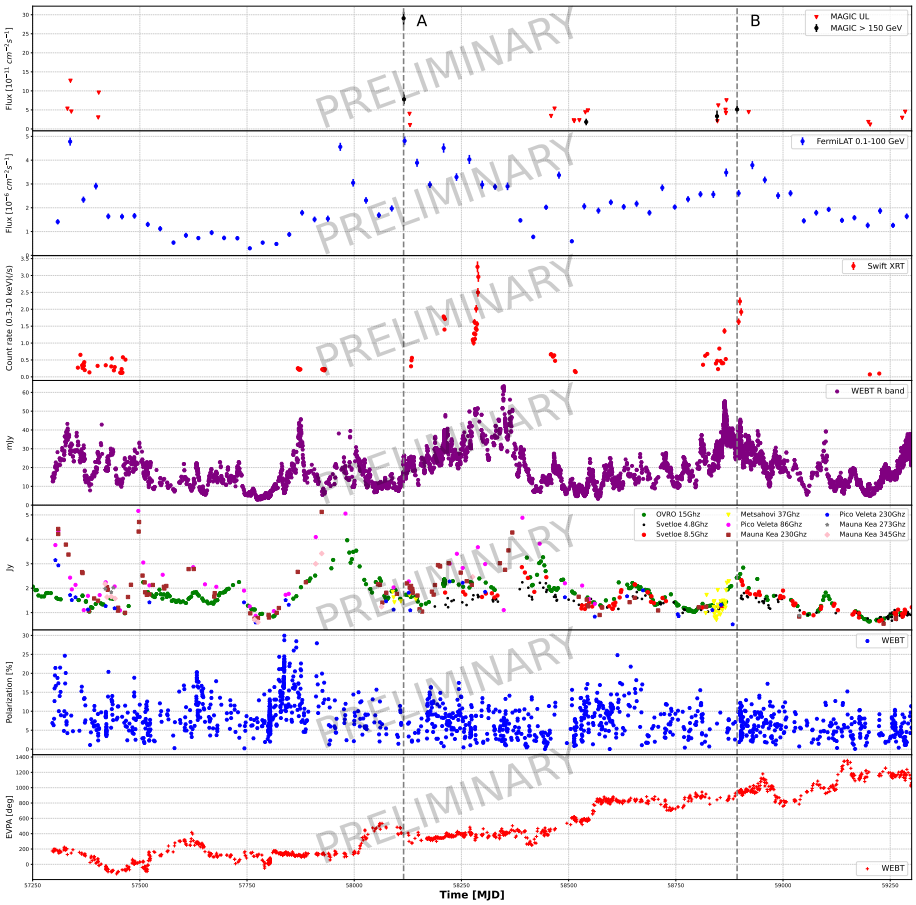

Figure 1: MWL lightcurves of S5 0716+714 in the time period MJD 57250 (16 Aug 2015) to MJD 59300 (27 Mar 2022)

whole period with free photon-index parameter.

Swift-XRT light curve was obtained using online tool called The *Swift*-XRT data products generator[1]. Light curve was generated using photon counting method with the integration time of 1-day time binning.

The very well sampled data from WEBT were published in [6]

[1] https://www.swift.ac.uk/user_objects/docs.php

3. Results

We present the MWL light curves of S5 0716+714 from the period MJD 57250 (16 Aug 2015) to MJD 59300 (27 Mar 2021) as shown in the figure 1. The two vertical dashed lines correspond to the highest activity in VHE gamma rays (A, centered in MJD 58115 - 28 January 2017) and to another flaring activity in optical, gamma rays and X-rays (B, centered in MJD 58892 - 14 February 2020) which is very well covered by many instruments simultaneously. Both nights are used to model the broadband spectral energy distribution that will be shown in the paper in preparation for the MAGIC collaboration and MWL collaborators [5].

4. Summary

The blazar S5 7016+714 has been monitored by MAGIC and a MWL campaign has been held in order to study the source in a broadband context and model the SED. In this work we analyzed MAGIC data between 2015. and 2022. We obtained MWL light curves from radio to VHE, which allows to study variability across the entire spectrum. In December 2017 MAGIC observed S5 706+714 in flaring activity which can also be seen in HE energy from *Fermi* LAT data. The current MWL broadband light curve allows us to make a detail investigation of the broadband properties which we will compare to other existing models.

References

[1] Anderhub H., Antonelli L. A., Antoranz P., Backes M., Baixeras C., Balestra S., Barrio J. A., et al., 2009, ApJL, 704, L129. doi:10.1088/0004-637X/704/2/L129

[2] MAGIC Collaboration, Ahnen M. L., Ansoldi S., Antonelli L. A., Arcaro C., Baack D., Babić A., et al., 2018, A&A, 619, A45. doi:10.1051/0004-6361/201832677

[3] Aleksić J., Ansoldi S., Antonelli L. A., Antoranz P., Babic A., Bangale P., Barceló M., et al., 2016, APh, 72, 76. doi:10.1016/j.astropartphys.2015.02.005

[4] Zanin R., Carmona E., Sitarek, J., et al., 2013, Proc. of the 33th International Cosmic Ray Conference (ICRC) 2-9 July 2013, Rio de Janeiro, Brazil

[5] MAGIC collaboration +MWL collaborators, in preparation, 2023

[6] Weaver Z. R., Jorstad S. G., Marscher A. P., Morozova D. A., Troitsky I. S., Agudo I., Gómez J. L., et al., 2022, ApJS, 260, 12. doi:10.3847/1538-4365/ac589c

[7] Fruck C., Gaug M., Zanin R., Dorner D., Garrido D., Mirzoyan R., Font L., 2014, arXiv, arXiv:1403.3591. doi:10.48550/arXiv.1403.3591

[8] Ahnen M. L., Ansoldi S., Antonelli L. A., Antoranz P., Arcaro C., Babic A., Banerjee B., et al., 2016, A&A, 595, A98. doi:10.1051/0004-6361/201629461

[9] Ahnen M. L., Ansoldi S., Antonelli L. A., Antoranz P., Babic A., Banerjee B., Bangale P., et al., 2015, ApJL, 815, L23. doi:10.1088/2041-8205/815/2/L23

MAGIC acknowledgements

We would like to thank the Instituto de Astrofísica de Canarias for the excellent working conditions at the Observatorio del Roque de los Muchachos in La Palma. The financial support of the German BMBF, MPG and HGF; the Italian INFN and INAF; the Swiss National Fund SNF; the grants PID2019-104114RB-C31, PID2019-104114RB-C32, PID2019-104114RB-C33, PID2019-105510GB-C31, PID2019-107847RB-C41, PID2019-107847RB-C42, PID2019-107847RB-C44, PID2019-107988GB-C22 funded by the Spanish MCIN/AEI/ 10.13039/501100011033; the Indian Department of Atomic Energy; the Japanese ICRR, the University of Tokyo, JSPS, and MEXT; the Bulgarian Ministry of Education and Science, National RI Roadmap Project DO1-400/18.12.2020 and the Academy of Finland grant nr. 320045 is gratefully acknowledged. This work was also been supported by Centros de Excelencia "Severo Ochoa" y Unidades "María de Maeztu" program of the Spanish MCIN/AEI/ 10.13039/501100011033 (SEV-2016-0588, CEX2019-000920-S, CEX2019-000918-M, CEX2021-001131-S, MDM-2015-0509-18-2) and by the CERCA institution of the Generalitat de Catalunya; by the Croatian Science Foundation (HrZZ) Project IP-2016-06-9782 and the University of Rijeka Project uniri-prirod-18-48; by the Deutsche Forschungsgemeinschaft (SFB1491 and SFB876); the Polish Ministry Of Education and Science grant No. 2021/WK/08; and by the Brazilian MCTIC, CNPq and FAPERJ.

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PoS(ICRC2023)900