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## Article

# Multiwavelength Picture of the Blazar S5 0716+714 during Its Brightest Outburst

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**Abstract:** S5 0716+714 is a well known BL Lac object, and one of the brightest and most active blazars. The discovery in the Very High Energy band (VHE,  $E > 100$  GeV) by MAGIC happened in 2008. In January 2015, the source went through the brightest optical state ever observed, triggering MAGIC follow-up and a VHE detection with  $\sim 13\sigma$  significance (ATel #6999). Rich multiwavelength coverage of the flare allowed us to construct the broad-band spectral energy distribution of S5 0716+714 during its brightest outburst. In this work, we will present the preliminary analysis of MAGIC and *Fermi*-LAT data of the flaring activity in January and February 2015 for the HE ( $0.1 < E < 300$  GeV) and VHE band, together with radio (Metsähovi, OVRO, VLBA, Effelsberg), sub-millimeter (SMA), optical (Tuorla, Perkins, Steward, AZT-8+ST7, LX-200, Kanata),

X-ray and UV (*Swift*-XRT and UVOT), in the same time-window and discuss the time variability of the multiwavelength light curves during this impressive outburst.

**Keywords:** BL Lacertae objects; individual: S5 0716+714; Galaxies: active; gamma-rays: galaxies

## 1. Introduction

The BL Lac object S5 0716+714 is among the brightest and most active blazars [1]. Because of the featureless optical continuum, it is hard to estimate its redshift. A value of  $z = 0.31 \pm 0.08$  is derived from the photometric detection of the host galaxy [2]. It was detected in VHE for the first time by MAGIC in 2008 [3]. Because of its extreme variability, S5 0716+714 has been the subject of several optical monitoring campaigns (e.g., [1,4–7] and references therein). S5 0716+714 is also among the bright blazars in the *Fermi*-LAT (Large Area Telescope) Bright AGN Sample (LBAS) [8], whose GeV spectra are governed by a broken power law. The combined GeV–TeV spectrum of the source displays absorption-like features in 10–100 GeV energy range [9]. The blazar S5 0716+714 was observed in an unprecedented outburst phase during January 2015. The source was detected at its historic high brightness at optical and IR bands. In January 2015, MAGIC, triggered by the high optical state and by high energy photons detected by *Fermi*-LAT, detected the source with a significance of  $\sim 13\sigma$  [10].

## 2. Instruments Involved

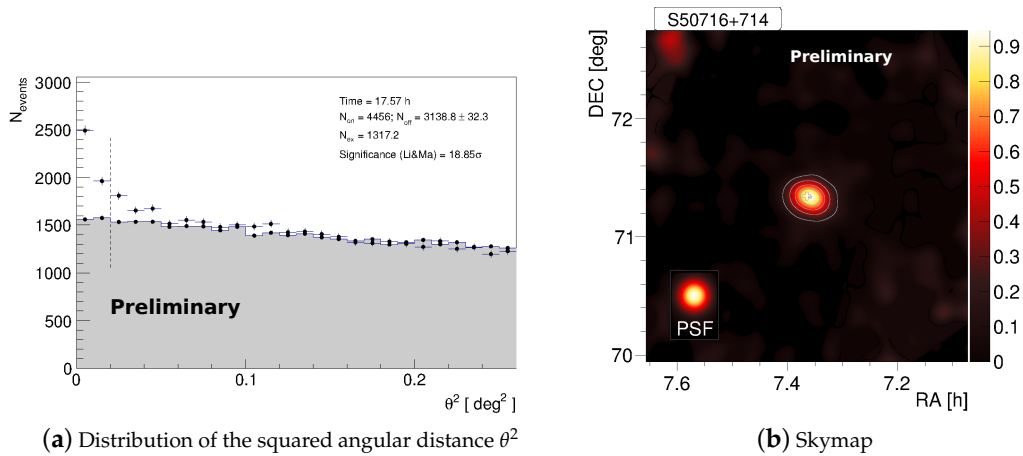
MAGIC is a stereoscopic system consisting of two 17 m diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatorio del Roque de los Muchachos, on the Canary Island of La Palma (Spain). The current integral sensitivity for the zenith range  $35^\circ < z_d < 50^\circ$  above 100 GeV is  $1.76\% \pm 0.03\%$  of the Crab Nebula's flux in 50 h. The Field of View (FoV) of MAGIC is  $3.5^\circ$  [11]. The Large Area Telescope (LAT) on board of *Fermi* is an imaging high-energy  $\gamma$ -ray telescope in the energy range from about 20 MeV to more than 300 GeV [12]. The LAT's Field of View covers about 20% of the sky at any time, and it scans continuously, covering the whole sky every three hours. Multiwavelength observations were performed collecting data from a large number of instruments. Our dataset includes data from *Swift*-XRT [13] in the X-ray and *Swift*-UVOT [14] in optical-UV; for the optical band we show data from the Tuorla Blazar monitoring program (<http://users.utu.fi/kani/1m>), the 1.8 m Perkins telescope (<https://lowell.edu/research/research-facilities/1-8-meter-perkins/>), the Steward Observatory (<http://www.bu.edu/blazars/>), the 70-cm AZT-8 reflector of the Crimean Astrophysical Observatory (<http://crao.cimea.ru/ru>), the 40-cm LX-200 telescope in St. Petersburg, Russia, [15] and Kanata telescope at the Hiroshima Observatory (<http://hasc.hiroshima-u.ac.jp/telescope/kanatatel-e.html>); radio band was covered by Metsähovi [16], the Owens Valley Radio Observatory (OVRO) 40 m telescope [17] and the Effelsberg 100 m radio telescope (<http://www.mpifr-bonn.mpg.de/en/effelsberg>). Radio data at 230 GHz band are obtained using the Submillimeter Array (<http://sma1.sma.hawaii.edu/>) (SMA).

## 3. Observations and Results

### 3.1. MAGIC Analysis

MAGIC started to observe S5 0716+714 on 19 January 2015. Unfortunately, the following two nights of strong wind during the S5 0716+714 visibility window prevented observation of the source, which was resumed on 23 January. From that day, the flux constantly increased up to the maximum flux ever observed in the VHE range for this source, on 27 January. The next activity of S5 0716+714 in the VHE was detected by MAGIC on the 13 February, and this time lasting three days only, up to the 16 February. In the present work, we will refer to January data (from MJD 57040 to MJD 57050) as phase A and to February data (from MJD 57066 to MJD

57069) as phase B. The observations were performed in wobble mode with a 0.4 deg offset and four symmetric positions with respect to the camera center. The observations were performed in 12 nights in January and February 2015 for a total duration of 17.57 h at the zenith range of  $40^\circ < z_d < 50^\circ$ . The corresponding distribution of the squared angular distance  $\theta^2$  between the reconstructed source position and the nominal source position (points) or the background estimation position (shaded area) for the whole period of observation is shown in Figure 1a. The vertical dashed line shows the value of  $\theta^2$  up to which the number of excess events and significance are integrated. The cuts used are optimized for steep spectra and low energy thresholds. The analysis energy threshold is  $\sim 65$  GeV, measured as the peak of the energy distribution of a sample of Monte Carlo simulated events for a source with the spectral shape of S5 0716+714. The analysis of the data collected was performed within the standard MAGIC analysis framework MARS [11,18].



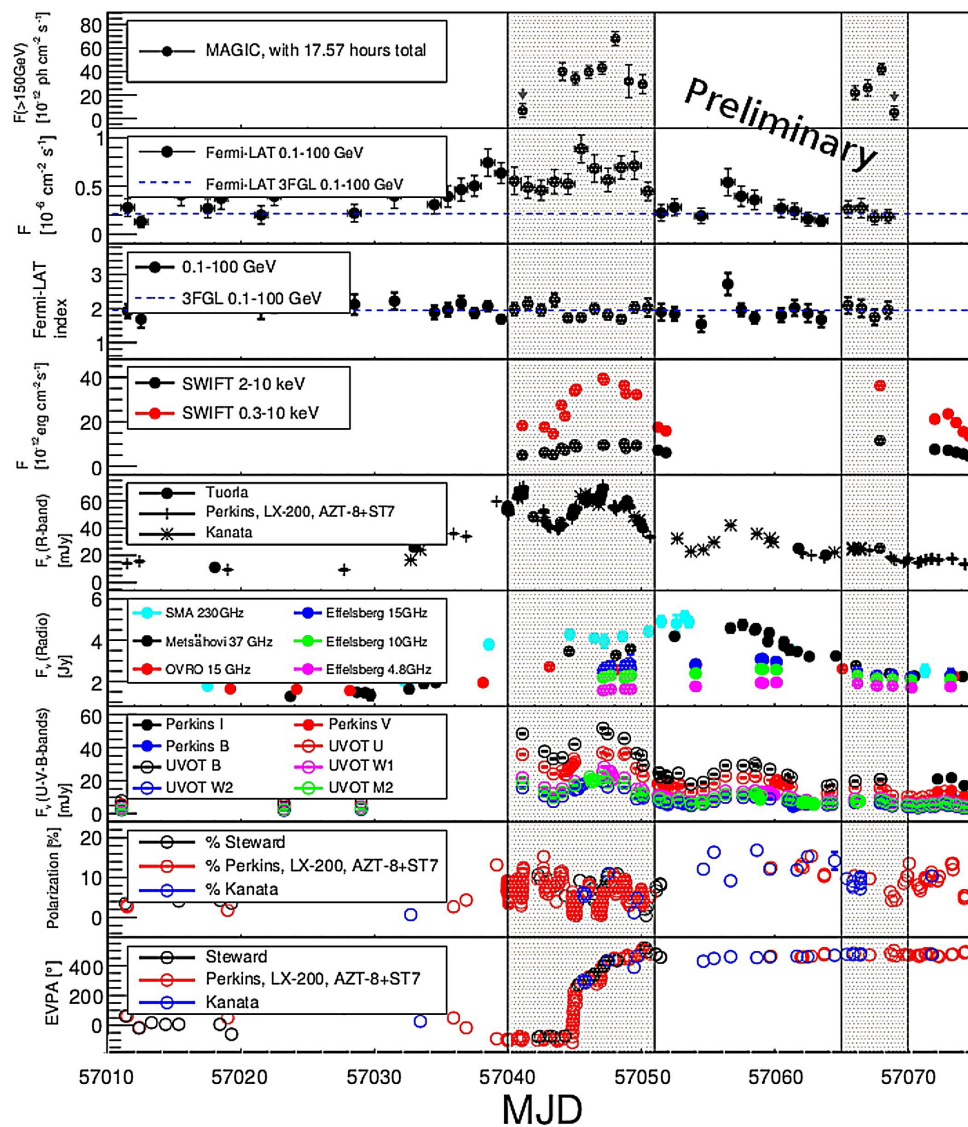
**Figure 1.** Distribution of the squared angular distance  $\theta^2$  between the reconstructed source position and the nominal source position (points) or the background estimation position (shaded area) for S5 0716+714 (a) and VHE skymap of the source (b). The color bar indicates the relative flux. The contours indicate significance in steps of  $5\sigma$ .

### 3.2. Fermi-LAT Analysis

The HE  $\gamma$ -ray (0.1–300 GeV) observations were obtained in a survey mode by the *Fermi*-LAT Large Area Telescope. The LAT data were analyzed using the standard ScienceTools (software version v10.01.01) and instrument response function CALDB. Photons in the source event class were selected for the analysis. We analyzed a region of interest of  $10^\circ$  in radius centred at the position of S5 0716+714 using a maximum-likelihood algorithm [19]. We included all the 54 sources of the 3FGL catalogue [20] within  $10^\circ$  in the unbinned likelihood analysis. Model parameters for sources within 5 degrees of the ROI are kept free, while we kept the model parameters for the rest fixed to their catalogue values.

### 3.3. Multiwavelength Light Curves

The unprecedented outburst of S5 0716+714 was covered in all the wavelengths: such a rich collection of simultaneous data allows us to study with great precision the broadband spectral energy distribution of the source, deeply investigating its nature. Multiwavelength flux light curves of S5 0716+714 during the period from MJD 57010 to MJD 57075 are shown in Figure 2. The top panel shows the MAGIC light curves: in the VHE band, the no-variability hypothesis has been discarded because it resulted in a  $\chi^2/ndf = 67/7$  for January and  $\chi^2/ndf = 22/3$  for the February data for a constant fit. Intranight variability in VHE was not detected. The shadowed areas indicate Phase A (from MJD 57040 to MJD 57050) and Phase B (from MJD 57066 to MJD 57069), the two high states in VHE, and the corresponding activity in the other bands.



**Figure 2.** Multiwavelength light curves of S5 0716+714. Shaded areas indicate Phase A (from MJD 57040 to MJD 57050) and Phase B (from MJD 57066 to MJD 57069) and the respective activities in all the energy bands. *Fermi*-LAT panels (second and third from the top) show the 3FGL averaged flux and spectral index from the 3FGL Catalog [20], respectively, as blue dashed lines.

When MAGIC discovered S5 0716+714 in 2008 ([3]) the radio band was in a quiescent level, while here, even if delayed with respect to the optical peak, it is possible to discern a response in the radio frequency. The VHE integral flux measured in 2008 by MAGIC was 10 and six times lower with respect to the one detected during the phase A and phase B outbursts, respectively. The two phases show quite different behavior: phase A is characterized by a high state of the source clearly visible in every energy band, especially in optical where the highest flux ever detected for S5 0716+714 is reported. HE and optical curves show a double peaked structure and the polarization angle undergoes a fast change between the two optical peaks. After an intermediate time period when activity is limited to the radio band, phase B is characterized by VHE and X-ray high flux, while the other bands reached a lower state after the outburst of phase A. The fractional variability of both phases shows an increasing trend with the energy. The phase B flare is clearly visible in the VHE and X-ray band only. Such differences in behaviour between the two activity states is very interesting to study, and together with the jet analysis of the source and the modeling of the broadband spectral

energy distribution, which will be presented in [21], it will improve our understanding of the BL Lac emission mechanism [22].

#### 4. Discussion

The unprecedented outburst of the BL Lac object S5 0716+714 in January 2015 was observed in all the wavebands. The MAGIC detection of the source, together with simultaneous data in the HE range from *Fermi*-LAT, will allow us to constrain the Inverse Compton part of the broadband spectrum. The rich multiwavelength coverage presented here is part of a more comprehensive study of the source in preparation [21]. The impressive activity in phase A was followed by some days of decreasing flux, and then a new high-state was observed in the VHE and X-ray bands (phase B). The structure of the light curve in phase A showed a double-peaked shape, and the electric vector position angle (EVPA) of the linearly polarized optical emission rotated by  $\sim 360^\circ$  in between the two peaks. Such swings in EVPA have been frequently observed in connection with  $\gamma$ -ray flaring epochs (e.g., [23–25]). A detailed correlation study and modelling of the spectral energy distribution are in progress.

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**Author Contributions:** Marina Manganaro, Giovanna Pedalletti and Mireia Nieves performed the MAGIC analysis of the source. Bindu Rani, Denis Bastieri, Dario Gasparrini took care of the *Fermi*-LAT analysis. This proceeding is part of a joint MAGIC-*Fermi*-LAT work involving also other multiwavelength authors. The preliminary results here included will be part of a paper in preparation which is led by Marina Manganaro, Marlene Doert and Bindu Rani. All the other authors listed provided the analysis of their data and participated in the discussion of the multiwavelength curve. Elina Lindfors is the PI of the MAGIC program of ToO observations of flaring AGNs based on optical, X-ray and  $\gamma$ -ray triggers. Marina Manganaro wrote this proceeding.

**Conflicts of Interest:** The authors declare no conflict of interest.

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