



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

**Conference Paper****Author(s):**

Podobnik, Franjo; Manganaro, Marina; Jormanainen, Jenni; Lindfors, Elina; Bonnoli, Giacomo; Paoletti, Riccardo; Jorstad, Svetlana G.; Kiehlmann, Sebastian; Agudo, Ivan; Elsässer, Dominik; Lorey, Christyan; Raiteri, Claudia; Villata, Massimo; C. Redhead, Anthony; Marscher, Alan; MAGIC Collaboration; Abe, Hyuga; [Abhir, Jayant](#) ; [Biland, Adrian](#) ; Fukami, Satoshi; et al.

**Publication date:**

2023

**Permanent link:**

<https://doi.org/10.3929/ethz-b-000653308>

**Rights / license:**

[Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International](#)

**Originally published in:**

PoS: Proceedings of Science 444, <https://doi.org/10.22323/1.444.0900>

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

**F. Podobnik,<sup>a,\*</sup> M. Manganaro,<sup>b</sup> J. Jormanainen,<sup>c</sup> E. Lindfors,<sup>c</sup> G. Bonnoli,<sup>d</sup>  
R. Paoletti,<sup>a</sup> S. Jorstad,<sup>l</sup> S. Kiehlmann,<sup>f</sup> I. Agudo,<sup>g</sup> D. Elsasser,<sup>h</sup> C. Lorey,<sup>i</sup>  
C. Raiteri,<sup>j</sup> M. Villata,<sup>j</sup> A.C. Redhead<sup>k</sup> and A. Marscher<sup>l</sup> on behalf of the MAGIC  
collaboration**

<sup>a</sup>Università di Siena and INFN Pisa, Via Roma 56, I-53100 Siena, Italy

<sup>b</sup>Faculty of Physics, University of Rijeka, Radmile Matječić 2, Rijeka, 51000, Croatia

<sup>c</sup>Finnish MAGIC Group: Finnish Centre for Astronomy with ESO, University of Turku, FI-20014 Turku, Finland

<sup>d</sup>National Institute for Astrophysics (INAF), I-00136 Rome, Italy

<sup>e</sup>Institute for Astrophysical Research, Boston University, 725 Commonwealth Avenue, Boston, MA 02215, USA

<sup>f</sup>Institute of Astrophysics, Foundation for Research and Technology-Hellas, GR-71110 Heraklion, Greece

<sup>g</sup>Instituto de Astrofísica de Andalucía-CSIC, Glorieta de la Astronomía, 18008 Granada, Spain

<sup>h</sup>Department of Physics, Otto-Hahn-Str. 4a, 44227, Dortmund, Germany

<sup>i</sup>Hans-Haffner-Sternwarte, Naturwissenschaftliches Labor für Schüler am FKG, Friedrich-Koenig-Gymnasium, D-97082 Würzburg, Germany

<sup>j</sup>INAF, Osservatorio Astrofisico di Torino, via Osservatorio 20, I-10025 Pino Torinese, Italy

<sup>k</sup>Caltech, The Division of Physics, Mathematics and Astronomy, 1200 E California Blvd, Pasadena CA 91125, USA

<sup>l</sup>Institute for Astrophysical Research, Boston University, 725 Commonwealth Avenue, Boston, MA 02215, USA

E-mail: [f.podobnik@student.unisi.it](mailto:f.podobnik@student.unisi.it), [marina.manganaro@uniri.hr](mailto:marina.manganaro@uniri.hr)

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

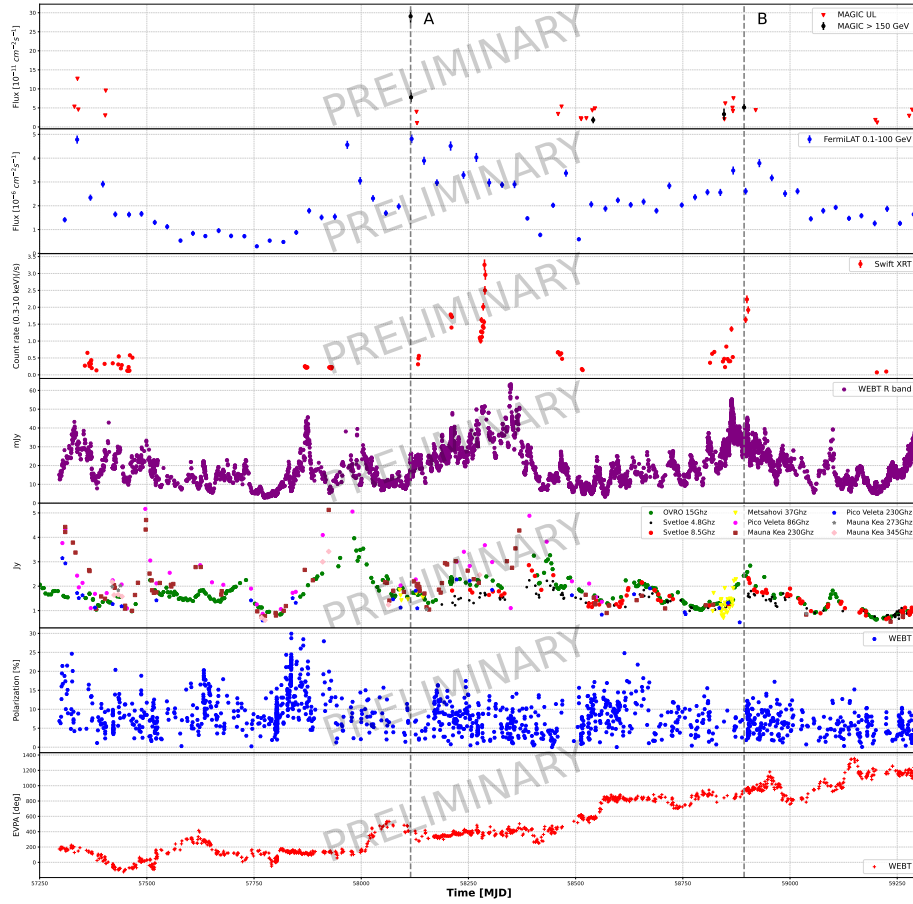
## 1. Introduction

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 multiwavelength (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  $\sim 50$  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) ( $0.1 \text{ GeV} < E < 100 \text{ GeV}$ ) 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



POS (ICRC2023) 900

**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<sup>1</sup>. 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]

<sup>1</sup>[https://www.swift.ac.uk/user\\_objects/docs.php](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., Babić 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., Babić 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., Babić 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.

## Full Authors List: MAGIC Collaboration

H. Abe<sup>1</sup>, S. Abe<sup>1</sup>, J. Abhir<sup>2</sup>, V. A. Acciari<sup>3</sup>, I. Agudo<sup>4</sup>, T. Aniello<sup>5</sup>, S. Ansoldi<sup>6,46</sup>, L. A. Antonelli<sup>5</sup>, A. Arbet Engels<sup>7</sup>, C. Arcaro<sup>8</sup>, M. Artero<sup>9</sup>, K. Asano<sup>1</sup>, D. Baack<sup>10</sup>, A. Babic<sup>11</sup>, A. Baquero<sup>12</sup>, U. Barres de Almeida<sup>13</sup>, J. A. Barrio<sup>12</sup>, I. Batkovic<sup>8</sup>, J. Baxter<sup>1</sup>, J. Becerra González<sup>3</sup>, W. Bednarek<sup>14</sup>, E. Bernardini<sup>8</sup>, M. Bernardos<sup>4</sup>, J. Bernete<sup>15</sup>, A. Berti<sup>7</sup>, J. Besenrieder<sup>7</sup>, C. Bigongiari<sup>5</sup>, A. Biland<sup>2</sup>, O. Blanch<sup>9</sup>, G. Bonnoli<sup>5</sup>, Ž. Bošnjak<sup>11</sup>, I. Burelli<sup>6</sup>, G. Busetto<sup>8</sup>, A. Campoy-Ordaz<sup>16</sup>, A. Carosi<sup>5</sup>, R. Carosi<sup>17</sup>, M. Carretero-Castrillo<sup>18</sup>, A. J. Castro-Tirado<sup>4</sup>, G. Ceribella<sup>7</sup>, Y. Chai<sup>7</sup>, A. Chilingarian<sup>19</sup>, A. Cifuentes<sup>15</sup>, S. Cikota<sup>11</sup>, E. Colombo<sup>3</sup>, J. L. Contreras<sup>12</sup>, J. Cortina<sup>15</sup>, S. Covino<sup>5</sup>, G. D’Amico<sup>20</sup>, V. D’Elia<sup>5</sup>, P. Da Vela<sup>17,47</sup>, F. Dazzi<sup>5</sup>, A. De Angelis<sup>8</sup>, B. De Lotto<sup>6</sup>, A. Del Popolo<sup>21</sup>, M. Delfino<sup>9,48</sup>, J. Delgado<sup>9,48</sup>, C. Delgado Mendez<sup>15</sup>, D. Depaoli<sup>22</sup>, F. Di Pierro<sup>22</sup>, L. Di Venere<sup>23</sup>, D. Dominis Prester<sup>24</sup>, A. Donini<sup>5</sup>, D. Dorner<sup>25</sup>, M. Doro<sup>8</sup>, D. Elsaesser<sup>10</sup>, G. Emery<sup>26</sup>, J. Escudero<sup>4</sup>, L. Fariña<sup>9</sup>, A. Fattorini<sup>10</sup>, L. Foffano<sup>5</sup>, L. Font<sup>16</sup>, S. Fröse<sup>10</sup>, S. Fukami<sup>2</sup>, Y. Fukazawa<sup>27</sup>, R. J. García López<sup>3</sup>, M. Garzcarczyk<sup>28</sup>, S. Gasparyan<sup>29</sup>, M. Gaug<sup>16</sup>, J. G. Giesbrecht Paiva<sup>13</sup>, N. Giglietto<sup>23</sup>, F. Giordano<sup>23</sup>, P. Gliwny<sup>14</sup>, N. Godinović<sup>30</sup>, R. Grau<sup>9</sup>, D. Green<sup>7</sup>, J. G. Green<sup>7</sup>, D. Hadasch<sup>1</sup>, A. Hahn<sup>7</sup>, T. Hassan<sup>15</sup>, L. Heckmann<sup>7,49</sup>, J. Herrera<sup>3</sup>, D. Hrupec<sup>31</sup>, M. Hütten<sup>1</sup>, R. Imazawa<sup>27</sup>, T. Inada<sup>1</sup>, R. Iotov<sup>25</sup>, K. Ishio<sup>14</sup>, I. Jiménez Martínez<sup>15</sup>, J. Jormanainen<sup>32</sup>, D. Kerszberg<sup>9</sup>, G. W. Kluge<sup>20,50</sup>, Y. Kobayashi<sup>1</sup>, P. M. Kouch<sup>32</sup>, H. Kubo<sup>1</sup>, J. Kushida<sup>33</sup>, M. Láinez Lezáun<sup>12</sup>, A. Lamastra<sup>5</sup>, D. Lelas<sup>30</sup>, F. Leone<sup>5</sup>, E. Lindfors<sup>32</sup>, L. Linhoff<sup>10</sup>, S. Lombardi<sup>5</sup>, F. Longo<sup>6,51</sup>, R. López-Coto<sup>4</sup>, M. López-Moya<sup>12</sup>, A. López-Oramas<sup>3</sup>, S. Loporchio<sup>23</sup>, A. Lorini<sup>34</sup>, E. Lyard<sup>26</sup>, B. Machado de Oliveira Fraga<sup>13</sup>, P. Majumdar<sup>35</sup>, M. Makariev<sup>36</sup>, G. Maneva<sup>36</sup>, N. Mang<sup>10</sup>, M. Manganaro<sup>24</sup>, S. Mangano<sup>15</sup>, K. Mannheim<sup>25</sup>, M. Mariotti<sup>8</sup>, M. Martínez<sup>9</sup>, M. Martínez-Chicharro<sup>15</sup>, A. Mas-Aguilar<sup>12</sup>, D. Mazin<sup>1,52</sup>, S. Menchiari<sup>34</sup>, S. Mender<sup>10</sup>, S. Mićanović<sup>24</sup>, D. Miceli<sup>8</sup>, T. Miener<sup>12</sup>, J. M. Miranda<sup>34</sup>, R. Mirzoyan<sup>7</sup>, M. Molero González<sup>3</sup>, E. Molina<sup>3</sup>, H. A. Mondal<sup>35</sup>, A. Moralejo<sup>9</sup>, D. Morcuende<sup>12</sup>, T. Nakamori<sup>37</sup>, C. Nanci<sup>5</sup>, L. Nava<sup>5</sup>, V. Neustroev<sup>38</sup>, L. Nickel<sup>10</sup>, M. Nieves Rosillo<sup>3</sup>, C. Nigro<sup>9</sup>, L. Nikolić<sup>34</sup>, K. Nilsson<sup>32</sup>, K. Nishijima<sup>33</sup>, T. Njoh Ekoume<sup>3</sup>, K. Noda<sup>39</sup>, S. Nozaki<sup>7</sup>, Y. Ohtani<sup>1</sup>, T. Oka<sup>40</sup>, A. Okumura<sup>41</sup>, J. Otero-Santos<sup>3</sup>, S. Paiano<sup>5</sup>, M. Palatiello<sup>6</sup>, D. Paneque<sup>7</sup>, R. Paoletti<sup>34</sup>, J. M. Paredes<sup>18</sup>, L. Pavletić<sup>24</sup>, D. Pavlović<sup>24</sup>, M. Persic<sup>6,53</sup>, M. Pihet<sup>8</sup>, G. Pirola<sup>7</sup>, F. Podobnik<sup>34</sup>, P. G. Prada Moroni<sup>17</sup>, E. Prandini<sup>8</sup>, G. Principe<sup>6</sup>, C. Priyadarshi<sup>9</sup>, C. Raiteri<sup>5</sup>, W. Rhode<sup>10</sup>, M. Ribó<sup>18</sup>, J. Rico<sup>9</sup>, C. Righi<sup>5</sup>, N. Sahakyan<sup>29</sup>, T. Saito<sup>1</sup>, S. Sakurai<sup>1</sup>, K. Satalecka<sup>32</sup>, F. G. Saturni<sup>5</sup>, B. Schleicher<sup>25</sup>, K. Schmidt<sup>10</sup>, F. Schmuckermaier<sup>7</sup>, J. L. Schubert<sup>10</sup>, T. Schweizer<sup>7</sup>, A. Sciacaluga<sup>5</sup>, J. Sitarek<sup>14</sup>, V. Sliusar<sup>26</sup>, D. Sobczynska<sup>14</sup>, A. Spolon<sup>8</sup>, A. Stamerra<sup>5</sup>, J. Strišković<sup>31</sup>, D. Strom<sup>7</sup>, M. Strzys<sup>1</sup>, Y. Suda<sup>27</sup>, T. Suric<sup>42</sup>, S. Suutarinen<sup>32</sup>, H. Tajima<sup>41</sup>, M. Takahashi<sup>41</sup>, R. Takeishi<sup>1</sup>, F. Tavecchio<sup>5</sup>, P. Temnikov<sup>36</sup>, K. Terauchi<sup>40</sup>, T. Terzić<sup>24</sup>, M. Teshima<sup>7,54</sup>, L. Tosti<sup>43</sup>, S. Truzzi<sup>34</sup>, A. Tutone<sup>5</sup>, S. Ubach<sup>16</sup>, J. van Scherpenberg<sup>7</sup>, M. Vazquez Acosta<sup>3</sup>, S. Ventura<sup>34</sup>, V. Verguilov<sup>36</sup>, I. Viale<sup>8</sup>, C. F. Vigorito<sup>22</sup>, V. Vitale<sup>44</sup>, I. Vovk<sup>1</sup>, R. Walter<sup>26</sup>, M. Will<sup>7</sup>, C. Wunderlich<sup>34</sup>, T. Yamamoto<sup>45</sup>

<sup>1</sup> Japanese MAGIC Group: Institute for Cosmic Ray Research (ICRR), The University of Tokyo, Kashiwa, 277-8582 Chiba, Japan <sup>2</sup> ETH Zürich, CH-8093 Zürich, Switzerland

<sup>3</sup> Instituto de Astrofísica de Canarias and Dpto. de Astrofísica, Universidad de La Laguna, E-38200, La Laguna, Tenerife, Spain

<sup>4</sup> Instituto de Astrofísica de Andalucía-CSIC, Glorieta de la Astronomía s/n, 18008, Granada, Spain

<sup>5</sup> National Institute for Astrophysics (INAF), I-00136 Rome, Italy

<sup>6</sup> Università di Udine and INFN Trieste, I-33100 Udine, Italy

<sup>7</sup> Max-Planck-Institut für Physik, D-80805 München, Germany

<sup>8</sup> Università di Padova and INFN, I-35131 Padova, Italy

<sup>9</sup> Institut de Física d’Altes Energies (IFAE), The Barcelona Institute of Science and Technology (BIST), E-08193 Bellaterra (Barcelona), Spain

<sup>10</sup> Technische Universität Dortmund, D-44221 Dortmund, Germany

<sup>11</sup> Croatian MAGIC Group: University of Zagreb, Faculty of Electrical Engineering and Computing (FER), 10000 Zagreb, Croatia

<sup>12</sup> IPARCOS Institute and EMFTEL Department, Universidad Complutense de Madrid, E-28040 Madrid, Spain

<sup>13</sup> Centro Brasileiro de Pesquisas Físicas (CBPF), 22290-180 URCA, Rio de Janeiro (RJ), Brazil

<sup>14</sup> University of Lodz, Faculty of Physics and Applied Informatics, Department of Astrophysics, 90-236 Lodz, Poland

- <sup>15</sup> Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, E-28040 Madrid, Spain
- <sup>16</sup> Departament de Física, and CERES-IEEC, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain
- <sup>17</sup> Università di Pisa and INFN Pisa, I-56126 Pisa, Italy
- <sup>18</sup> Universitat de Barcelona, ICCUB, IEEC-UB, E-08028 Barcelona, Spain
- <sup>19</sup> Armenian MAGIC Group: A. Alikhanyan National Science Laboratory, 0036 Yerevan, Armenia
- <sup>20</sup> Department for Physics and Technology, University of Bergen, Norway
- <sup>21</sup> INFN MAGIC Group: INFN Sezione di Catania and Dipartimento di Fisica e Astronomia, University of Catania, I-95123 Catania, Italy
- <sup>22</sup> INFN MAGIC Group: INFN Sezione di Torino and Università degli Studi di Torino, I-10125 Torino, Italy
- <sup>23</sup> INFN MAGIC Group: INFN Sezione di Bari and Dipartimento Interateneo di Fisica dell'Università e del Politecnico di Bari, I-70125 Bari, Italy
- <sup>24</sup> Croatian MAGIC Group: University of Rijeka, Faculty of Physics, 51000 Rijeka, Croatia
- <sup>25</sup> Universität Würzburg, D-97074 Würzburg, Germany
- <sup>26</sup> University of Geneva, Chemin d'Ecogia 16, CH-1290 Versoix, Switzerland
- <sup>27</sup> Japanese MAGIC Group: Physics Program, Graduate School of Advanced Science and Engineering, Hiroshima University, 739-8526 Hiroshima, Japan
- <sup>28</sup> Deutsches Elektronen-Synchrotron (DESY), D-15738 Zeuthen, Germany
- <sup>29</sup> Armenian MAGIC Group: ICRA Net-Armenia, 0019 Yerevan, Armenia
- <sup>30</sup> Croatian MAGIC Group: University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB), 21000 Split, Croatia
- <sup>31</sup> Croatian MAGIC Group: Josip Juraj Strossmayer University of Osijek, Department of Physics, 31000 Osijek, Croatia
- <sup>32</sup> Finnish MAGIC Group: Finnish Centre for Astronomy with ESO, University of Turku, FI-20014 Turku, Finland
- <sup>33</sup> Japanese MAGIC Group: Department of Physics, Tokai University, Hiratsuka, 259-1292 Kanagawa, Japan
- <sup>34</sup> Università di Siena and INFN Pisa, I-53100 Siena, Italy
- <sup>35</sup> Saha Institute of Nuclear Physics, A CI of Homi Bhabha National Institute, Kolkata 700064, West Bengal, India
- <sup>36</sup> Inst. for Nucl. Research and Nucl. Energy, Bulgarian Academy of Sciences, BG-1784 Sofia, Bulgaria
- <sup>37</sup> Japanese MAGIC Group: Department of Physics, Yamagata University, Yamagata 990-8560, Japan
- <sup>38</sup> Finnish MAGIC Group: Space Physics and Astronomy Research Unit, University of Oulu, FI-90014 Oulu, Finland
- <sup>39</sup> Japanese MAGIC Group: Chiba University, ICEHAP, 263-8522 Chiba, Japan
- <sup>40</sup> Japanese MAGIC Group: Department of Physics, Kyoto University, 606-8502 Kyoto, Japan
- <sup>41</sup> Japanese MAGIC Group: Institute for Space-Earth Environmental Research and Kobayashi-Maskawa Institute for the Origin of Particles and the Universe, Nagoya University, 464-6801 Nagoya, Japan
- <sup>42</sup> Croatian MAGIC Group: Ruđer Bošković Institute, 10000 Zagreb, Croatia
- <sup>43</sup> INFN MAGIC Group: INFN Sezione di Perugia, I-06123 Perugia, Italy
- <sup>44</sup> INFN MAGIC Group: INFN Roma Tor Vergata, I-00133 Roma, Italy
- <sup>45</sup> Japanese MAGIC Group: Department of Physics, Konan University, Kobe, Hyogo 658-8501, Japan
- <sup>46</sup> also at International Center for Relativistic Astrophysics (ICRA), Rome, Italy
- <sup>47</sup> now at Institute for Astro- and Particle Physics, University of Innsbruck, A-6020 Innsbruck, Austria
- <sup>48</sup> also at Port d'Informació Científica (PIC), E-08193 Bellaterra (Barcelona), Spain
- <sup>49</sup> also at Institute for Astro- and Particle Physics, University of Innsbruck, A-6020 Innsbruck, Austria
- <sup>50</sup> also at Department of Physics, University of Oslo, Norway
- <sup>51</sup> also at Dipartimento di Fisica, Università di Trieste, I-34127 Trieste, Italy
- <sup>52</sup> Max-Planck-Institut für Physik, D-80805 München, Germany
- <sup>53</sup> also at INAF Padova
- <sup>54</sup> Japanese MAGIC Group: Institute for Cosmic Ray Research (ICRR), The University of Tokyo, Kashiwa, 277-8582 Chiba, Japan