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Review

Highlights of the Magic Florian Goebel Telescopes in the Study of Active Galactic Nuclei

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Abstract: The MAGIC (Major Atmospheric Gamma-ray Imaging Cherenkov) Florian Goebel telescopes are a system of two Cherenkov telescopes located on the Canary island of La Palma (Spain), at the Roque de Los Muchachos Observatory, and operating in stereo mode since 2009. Their low energy threshold (reaching 15 GeV) allows the study of Active Galactic Nuclei (AGNs) in the very-high-energy gamma ray range with an impressive sensitivity up to the redshift limit of the existing IACT systems. MAGIC has collected many discoveries and comprehensive studies of different kinds of galaxies and their AGNs, also in a multi-wavelength context, expanding the knowledge of our Universe. Here we report the highlights which have been achieved by the MAGIC collaboration since the beginning of the operations.

Keywords: γ-ray astrophysics; Active Galactic Nuclei; very-high-energy gamma rays; non-thermal; high energy astrophysics

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1. Introduction

The main targets of extragalactic astrophysics in the high-energy range are Active Galactic Nuclei (AGNs), galaxies powered by a central supermassive black hole ($M_\bullet \gtrsim 10^6\ M_\odot$) and emitting non-thermal photons across the electromagnetic spectrum. AGNs whose radiation reaches the gamma-ray energy range are only 10% of the AGNs observed in our Universe, and they show collimated jets of relativistic plasma. The presence of the jet is strongly connected to the gamma-ray emission, and when such a jet is oriented in the direction of the observer, AGNs are called blazars and commonly further subdivided in BL Lac type objects (BL Lacs) and Flat Spectrum Radio Quasars (FSRQs). AGNs can show variability in all energy bands, and because of the many studies and observations conducted in the various single bands, the categorization of them can be very complex. An effective recent categorization consists in dividing AGNs in two main classes, jetted and not-jetted AGNs [1]. This approach is very powerful since disentangles the study of AGNs from characteristics attributed to a single energy band and is more projected in a multi-wavelength (MWL) and multi-messenger (MM) context. When AGNs emit from the radio to the VHE (very-high-energy, E $>$ 100 GeV) gamma-ray band, they present a double-peaked spectral energy distribution (SED) [2], which can be studied in order to identify and predict the emission mechanism of the radiation. The first bump, which extends between radio and X-ray energies, is universally attributed to synchrotron radiation process by a population of electrons rotating in the magnetic field of the AGN, while the second bump, which can reach VHE gamma-ray energies, can be explained, depending on the position and on its shape, by different theoretical models which can be completely leptonic or including an hadronic component. Is then of primary importance to collect simultaenous data in a MWL context, in order to be able to infer a theoretical interpretation of the dataset and shed light on the emission scenarios of AGNs. For this reason the observation of AGNs has always been one of the priorities in the physics program of the MAGIC Florian Goebel telescopes. The IACT technique is extensively described in [3–5]. In this work, Sec. 2 will be devoted to the MAGIC strategies in observing AGNs, first presenting the peculiarities and characteristic of the MAGIC system (see 2.1) and then the observational strategies adopted (see 2.2). Sec. 3 collects the highlights from the MAGIC telescopes concerning the study of AGNs and Sec. 4 discuss the results presented and the future perspectives of VHE gamma-ray astrophysics.

2. MAGIC strategies in observing AGNs

2.1. MAGIC characteristics

The MAGIC collaboration started its activity and datataking with a single telescope, now named MAGIC I, which is operational since 2004 at the Observatory of the Roque de Los Muchachos on the Canary Island of La Palma. Since 2009, a second telescope, MAGIC II, is part of the system and the two telescopes operate simultaneously (stereo mode). MAGIC telescopes are IACTs, ground based instruments which detect VHE gamma-rays thanks to the extensive air showers they produce in the atmosphere. The Cherenkov light emitted by the charged particles belonging to the extensive air showers is collected by the segmented mirror dishes of IACTs and imaged in their cameras. The MAGIC Florian Goebel telescopes were constructed with the specific goal of decreasing the energy threshold for VHE gamma-rays detection, in order to explore more distant sources in such energy range and consequently probe earlier parts of the Universe. A lower energy threshold was also necessary to close the gap towards HE gamma-ray detectors, since the latter ones reach the energy of a few tenth of GeV. Being able to connect with High Energy (HE, $100\,MeV E > 10\,GeV$) gamma-rays data constraints the HE bump of the broadband SEDs, allowing to effectively determine the emission scenarios of jetted AGNs. This goal was reached successfully, making MAGIC the IACT (Imaging Atmospheric Cherenkov Telescope) system with lower energy threshold, namely 50 GeV but able to reach 15 GeV with the use of a specific stereoscopic analog trigger [SumTriggerII, see 6], as in the recent work performed on Geminga observations of MAGIC [7]. In the development and construction of the telescopes, major innovations were introduced with respect to the other IACTs, exploiting techniques known in accelerator particle physics experiments, such as fast electronics and automatic controls of the devices and computers and networks able to record and reconstruct large volumes of data and perform interrelations. The main characteristics of MAGIC telescopes are the following:

- Active mirror surface of $236\,m^2$, made of square elements 49.5×49.5 cm or 99×99 cm; f/D [1] = 1.03;
- Support frame of carbon fibre made for minimum weight and maximum stiffness;
- Approximately hexagonal camera of 1.05 m diameter, with 1039 PMTs of 1" (or 0.1 degree) diameter each; all PMTs have an effective quantum efficiency of 25 to 35%, depending on wavelength; The camera is kept as light as possible, held by an aluminium support arc, stiffened by a web of thin steel cables;
- The maximum repositioning speed is more than 7 degrees per second, meaning the telescopes can be pointed to any point on the observable sky in less than 25 seconds (due to a weight of only around 60 tons);
- Analog signals are transmitted from the camera to the counting house via optical fibres; only the amplifiers and laser diode modulators for transmission are inside the camera housing;
- Digitization is achieved by the Domino Ring Sampler (DRS4) chip with a sampling frequency of 1.64 GHz, to make use of the timing information in the pulse.

The performance of the MAGIC Florian Goebel telescopes is described in detail in [8,9].

[1] focal length to diameter ratio

Figure 1. The MAGIC Florian Goebel telescopes at the Roque de Los Muchachos Observatory, Spain. Image Credit: Chiara Righi.

2.2. Observational strategies

In order to maximise the efficient use of available observing time with MAGIC telescopes, that must accommodate for different sources and projects, sophisticated observing strategies are applied, taking in account various factors. AGNs show intrinsic variability, gamma-rays from them are attenuated by the Extragalactic Background Light (EBL), and observed Cherenkov showers are affected by variable transmission of the Earth's atmosphere. Most of the AGNs observed by the MAGIC telescopes are not detectable in VHE during their quiet states, but only during flaring states, due to EBL absorption. Higher the redshift, and higher the energy, stronger EBL absorption effects occur (see Sec. 3.2). In order to understand AGN emission mechanisms, we need to calculate the SED. For this purpose, MAGIC observations coordinated with instruments sensitive to other energy ranges of electromagnetic spectrum are performed using MWL observational strategy. Target of Opportunity (ToO) observations are triggered using observations in other energy ranges, mainly by optical telescopes, and Fermi-LAT space telescope sensitive in HE gamma rays. Some AGNs that show long-term variability in VHE, or are of special interest, are observed using monitoring observational strategy (i.e. see Sec. 3.8), over longer period of time with regular observations separated typically by the order of few days or weeks. In some cases, MWL observing campaigns are organised in advance coordinated with instruments sensitive in other energy bands, yielding contemporaneous observations. As some AGNs show fast intra-night variability, flexible observing time can be activated during the observing night through so-called "self-triggers". Snapshots of the order of 40-60 min can be prolonged in case of detection hint (i.e. signal exceeding 3 σ of significance during the observations). The Earth's atmosphere plays an important role for Cherenkov telescopes, being an actual part of the detector. The atmosphere above La Palma is often covered by thin cirrus clouds that allow observations by MAGIC, but decrease atmospheric transmission and scatter Cherenkov light. Sand from Sahara (Calima) also decreases atmospheric transmission in similar way, at lower altitudes. This leads to decrease in energy resolution and angular resolution, especially at energies below 1 TeV, and therefore increases energy threshold for detection [10]. In order to reduce systematic uncertainties originating from the atmospheric conditions, the MAGIC collaboration operates an elastic LIDAR (Light Detection And Ranging) system on the observing site [11]. This enables data corrections using the atmospheric transmission profiles [12].

3. Results

3.1. MAGIC discoveries in the VHE gamma-ray range

Since the beginning of the operations, MAGIC has discovered many AGNs emitters in the VHE gamma-ray range, 26 BL Lacs, 6 FSRQs (see Sec. 3.3), one radio galaxy (see Sec. 3.6), 3 blazars (not definitive classification yet).

The subdivision of blazars in the subclasses BL Lacs and FSRQs is based on the lack or presence of emission/absorption lines in their optical spectra, respectively. BL Lacs present very weak lines while the optical spectra of FSRQs have strong resolved lines which can be measured providing a value of the luminosity and consequently of the mass of their black-hole [13]. BL Lacs can be further categorized depending on the position of the peak of their synchrotron bump, which can be measured from their broadband SED. They are defined as LBL (low-energy peaked), HBL (high-energy peaked) or IBL (intermediate) when their synchrotron peaks are placed in the submillimeter to infrared energy bands, ultraviolet to X-ray energy bands, or intermediate between the previous two cases, respectively. In Table 1 the AGNs discovered by MAGIC are reported, ordered by their redshift.

Table 1. List of the jetted AGNs which were discovered to emit VHE gamma rays by the MAGIC telescopes. Data retrieved from TeVCat[1].

Name	type	redshift	Date of announcement	References
RGB J2042+244	HBL	0.104	2019.11	[14]
Markarian 180	HBL	0.045	2006.09	[15]
TXS 0210+515	HBL	0.049	2019.01	[14]
1ES 2037+521	HBL	0.053	2016.10	[14]
1ES 1727+502	HBL	0.055	2011.11	[16]
2WHSP J073326.7+515354	HBL	0.065	2018.04	[17]
1ES 1741+196	HBL	0.084	2011.08	[18]
B2 1811+31	IBL	0.117	2020.10	[19]
B3 2247+381	HBL	0.1187	2010.10	[20]
TXS 1515-273	HBL	0.1284	2019.02	[21]
1ES 1215+303	HBL	0.131	2011.01	[22]
RX J1136.5+6737	HBL	0.1342	2014.04	[23]
1RXS J081201.8+023735	HBL	0.1721	2021.02	
MAGIC J2001+435	IBL	0.1739	2010.07	[24]
1ES 1218+304	HBL	0.182	2006.05	[25]
IC 310		0.0189	2010.03	[26]
RBS 0723	HBL	0.198	2014.01	[14]
1ES 1011+496	HBL	0.212	2007.09	[27–30]
MS 1221.8+2452	HBL	0.218	2013.05	[31]
RGB J0136+391	HBL	> 0.27	2012.07	[]
H 1722+119	HBL		2013.05	[32]
1ES 0647+250	HBL	> 0.29	2010.07	[33]
PKS 1413+135	Blazar	$0.247 > z < 0.5$[34]	2022.01	[35]
S5 0716+714	IBL	0.31?	2008.04	[36,37]
OT 081	LBL	0.322	2016.07	[]
TXS 0506+056	Blazar	0.3365	2017.10	[38,39]
S2 0109+22	IBL	0.36	2015.07	[40]
S4 0954+65	Blazar	0.3694	2015.02	[41]
PKS 1222+216	FSRQ	0.432	2010.06	[42]
1ES 0033+595	HBL	0.467	2011.10	[43]
GB6 J1058+2817	BL Lac(class unclear)	0.4793[44]	2021.04	[45]
3C 279	FSRQ	0.5362	2008.06	[46–48]
B2 1420+32	FSRQ	0.682	2020.01	[49]
TON 0599	FSRQ	0.7247	2017.12	[50]
PKS 1441+25	FSRQ	0.939	2015.04	[51]
QSO B0218+357	FSRQ	0.954	2014.07	[52,53]

[1] The TeVCat online source catalog, http://tevcat.uchicago.edu

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3.2. Sources at high redshift and EBL studies

VHE gamma rays can interact with the EBL photons by pair production. This process results in an attenuation of the flux of VHE photons which becomes more relevant at higher distances. For this reason, IACTs have a limit on the redshift they could reach, which is depending on the EBL characteristics and on the energy of the VHE gamma rays emitted from the source under study. This limit is represented by the so-called Gamma Ray Horizon, described in detail in [54,55]. Theoretical predictions conducted in [54] were clearly indicating the importance of a low energy threshold for IACTs in order to reach sources more distant as possible taking into account the EBL attenuation. Considering those predictions and the precise measurements of the EBL obtained by UV to the mid-infrared telescopes [56], the detection of AGNs close to redshift 1 were considered extremely challenging. Nevertheless, the MAGIC telescopes, thanks to their particularly low energy threshold, managed to detect in the VHE gamma range two AGNs very close to redshift 1, pushing the limits of the Gamma Ray Horizon. Those two discoveries were particularly important to probe the EBL with IACTs. Both sources were detected in 2014 and they were both FSRQs. The first one, QSO B0218+357, also at a redshift of z=0.94, was also the first gravitationally lensed blazar to be detected in the VHE gamma ray range, triggered by enhanced activity in the HE gamma-ray range. Its detection by MAGIC happened during the arrival time of the delayed component of the emission [52]. The MWL SED was challenging a simple leptonic model and in that occasion a two-zone leptonic model with an external component (emission region located inside or outside the broad line region) was used to interpret the broadband emission, as in the third scenario proposed in [57]. Following this peculiar detection, a MWL campaign was organized in order to collect more information on the emission scenario even if during a quiescent state and also in this case, a model with an external Compton component and two zones was necessary to interpret the data [53]. It is interesting to note the different MWL SEDs observed in the case of the first detection (Panel a) of Figure 2 and for the monitoring in quiescent state (Panel b) of Figure 2).

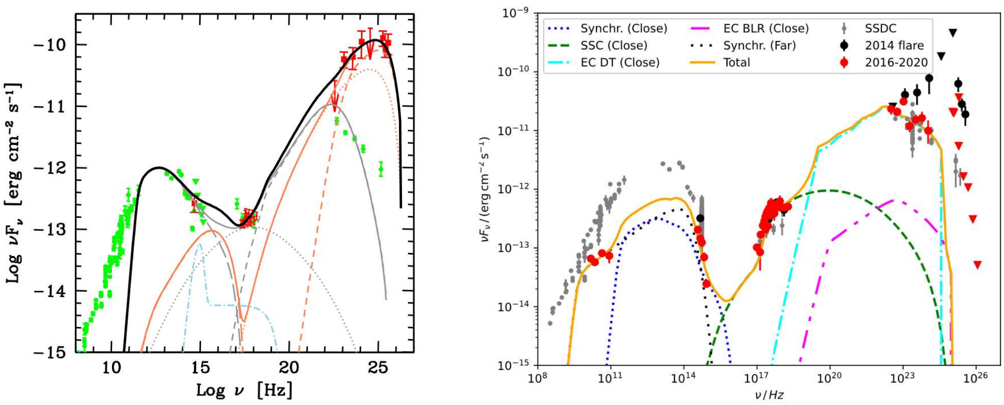

Figure 2. (**a**) Broadband SED of QSO B0218+357 during the 2014 flare. From [52]. Permission asked. (**b**) MWL SED of QSO B0218+357 during the monitoring campaign (red markers) compared to the 2014 flare (black markers). Reprinted from [53] (Figure 11).

The second one, PKS 1441+25, is a FSRQ located at a redshift of z=0.94 and was detected by MAGIC during a flaring state [51], triggered by high activity in the HE gamma-ray range. Its MWL SED was also not possible to be interpreted by a simple leptonic model and an external Compton was considered, with the location of the emitting region explained as originating in the jet outside the broad line region. With those distant sources it was possible to probe and measure the EBL for the first time at such an high redshift with VHE gamma-ray data, as reported in [58].

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3.3. Flat Spectrum Radio quasars

FSRQs are highly luminous blazars which show strong emission lines in their optical spectra. This feature indicates the presence of a radiatively efficient accretion disk [59]. The first classification of blazars based also on their gamma emission, in which one of the properties of FSRQs is their soft gamma index ($\Gamma > 2$ is the notorious blazar sequence concept introduced in [60]. The discoveries which followed in the VHE gamma-ray range provided more material to investigate the classification of blazars and consolidate aspects of the blazar sequence while revisiting and expanding critically some of the initial considerations. A complete review on those topics is in [61]. In the VHE gamma-ray range, there are only 9 FSRQs firmly detected, and 6 of them were discovered (in the VHE gamma-ray range) by MAGIC. MAGIC detected the absolute first FSRQs in VHE energy, 3C 279, located at a redshift of z=0.53 in 2006 [46,47]. This result was of primary importance because demonstrated the capability of IACTs in accessing region of the Universe in which the EBL attenuation is not negligible. Moreover, the emission of FSRQs in the VHE gamma-ray range results in a MWL SED which possess an high Compton Dominance (CD, ratio between so-called IC peak and the synchrotron peak), and then need a different and often more challenging modelling approach with respect to BL Lacs. This feature than is now clearly observed in the FSRQs detected in VHE gamma rays, was explored for the first time in detail with 3C 279. As shown in Figure 3, the MWL SED presents and high CD and to describe the dataset models including an external component were necessary[47].

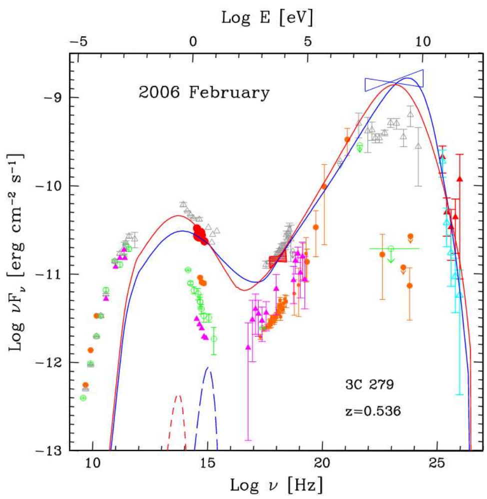

Figure 3. MWL SED of 3C 279 in 23/02/2006. The dashed lines correspond as external components of the emission the blackbody radiation from the torus (red) and the broad line region (blue) respectively. From [47]. Asked for permission.

The second FSRQ detected by MAGIC was PKS 1222+216 in 2010 [42]. The VHE gamma-ray emission was found to be variable on the timescale of 10 minutes: this was an important result which allowed to constrain the size of the emission region. The detection of PKS 1222+216 by MAGIC challenged the jet emission models and opened the discussion between different possible scenarios (far dissipation, [62]; recollimation, [63]; small compact emission regions in the jet ,[64]; reconfinement shocks [65]; relativistic filamentation [66]. The farthest AGNs detected by MAGIC were already mentioned in 3.2 and detected in 2014 (QSO B0218+357) and 2015 (PKS 1441+25). After them, MAGIC detected another FSRQ in 2017, TON 0599, located at redshift 0.72[50]. Also this source presents a MWL SED of complex interpretation which is object of a paper in preparation for the MAGIC collaboration. More recently, in 2020, MAGIC detected a new FSRQ, B2 1420+32 [49], adding another piece of the puzzle of the interpretation of such rare and powerful sources in the VHE gamma-ray sky.

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3.4. Transitional blazars

In some cases the usual categorization of blazars based on the property of their optical spectra is complicated. BL Lacs are supposed to present an optical spectra with very weak or absent emission lines. Instead in some cases (even for BL Lacertae) optical spectra measured in different states of activity can vary, leaving the categorization uncertain. Some blazars can be detected in the VHE gamma-ray range also when they are in quiescent state, while others only in flaring states of activity. It happens then that some sources which were categorized as BL Lacs because of their optical spectra, in a flaring state suddenly show a strong VHE gamma-ray emission which can not be explained by the most simple leptonic models, often enough precise to describe the MWL emission from BL Lacs. Another categorization is connected to the position of the synchrotron peak, which can also vary depending on the activity of the source. Those sources could be indicated as transitional [67], even if is not clear if their behaviour is simply linked to an exceptional activity in gamma rays or connected to a real change of properties in time. In order to understand better those transitional AGNs it is important to obtain a long term dataset in MWL. MAGIC observed and detected for the first time in the VHE gamma-ray range two AGNs which were categorized as BL Lacs, but from the MWL dataset collected simultaneously to the MAGIC observations they resulted to have characteristics close to FSRQs. The first one, S4 0954+65, was observed by MAGIC in 2015 and studied in a MWL context in [41]. The MWL SED of S4 0954+65 was found to be reproduced by a leptonic model typical of FSRQs, with an external Compton component (dusty torus). Very similarly, the blazar OT 081, observed and detected by MAGIC in 2016, presents many characteristic of FSRQs rather than BL Lacs, in particular the high CD [68].

3.5. Extreme sources

The BL Lacs whose possess a synchrotron peak at unusually high energies, above 10^{17} Hz, belong to the EHBL class (extreme HBLs, [69]). EHBLs are expected to be very faint in the VHE gamma-ray range and very difficult to be detected by IACTs. Nevertheless their study is appealing because they can be used for testing the gamma-ray propagation at high energy and in particular to probe EBL and derive limits on the IGMF (inter galactic magnetic field, see [70] for a review). [71] reports in the detail the progress in the study of such AGNs. MAGIC has devoted many observations to the hunting and study of EHBLs. In 2018 MAGIC observed and detected for the first time in VHE gamma-rays the EHBL 2WHSP J073326.7+515354 [17]. The observations were scheduled as part of the hunting strategy of MAGIC for such extreme sources, and this source was selected primarily because of the high synchrotron peak frequency ($\nu_{synch} = 10^{17.9}\,Hz$). The successful strategy resulted in the VHE detection and in a deep study of the MWL charateristics of the SED. The theoretical interpretation of the broadband emission was challenging as expected for this kind of AGNs, and four different theoretical models were used to test this particular case. The scenario which better described the dataset was a spine-layer two-zone leptonic model as in [72]. Many other EHBLs were observed by MAGIC within the EHBL hunting program, and they are collected in [14]. This work includes also the the archetypal EHBL 1ES 0229+20 and the results obtained observing it from 2013 to 2017. Included in this paper are also three EHBLs detected for the first time in the VHE gamma-ray range, 1ES 2037+521, RBS 0723, and TXS 0210+515. This work confirms and highlights the existence of two different kinds of EHBLs: extreme-synchrotron sources (synchrotron peak energy $= h\nu_{synch} \geq 1\,keV (2.4 \times 10^{17}\,Hz)$; extreme-TeV sources (gamma-ray peak energy $= h\nu_{\gamma} \geq 1\,TeV (2.4 \times 10^{26}\,Hz)$. This corresponds to a hard spectrum in the soft X-ray band (photon index $\Gamma_{X-ray} < 2$, or in the TeV band ($\Gamma_{\gamma} < 2$). Blazars which belong to the HBL class, can acquire extreme characteristics and show extreme behaviour. This was noted in two occasions by MAGIC observations, for Mrk 501 [73] and for 1ES 2344+514[74,75]. As mentioned before, EHBLs and in particular extreme-TeV sources are perfect candidates for the study of IGMF. In fact their high energy emission and their hard spectrum can be used to constrain the presence of cascades in the IGMF. For this reason a deep study was performed using gamma-ray observations (by MAGIC, H.E.S.S., VERITAS and the *Fermi*-LAT telescopes) from the archetipal EHBL

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1ES 0229+20 with the specific goal of detecting or constraining the IGMF-dependent secondary flux generated during the propagation of TeV gamma rays through the intergalactic medium. The results, presented in [76], place robust limits which consist in a lower bound of $B > 1.8 \times 10^{-17}\,G$ for the long-correlation-length IGMF and $B > 10^{-14}\,G$ for an IGMF of cosmological origin.

3.6. Black-hole lightening: IC310

A very interesting result obtained by MAGIC regards the radio galaxy IC 310, powered by a supermassive black hole ($M = 3 \times 10^{8} M_{\odot}$). In 2012, an impressive high activity of the source was observed in the VHE gamma-rays, characterized by a very fast variability (doubling time scales faster than 4.8 min). This result was challenging the existing theoretical models of variability and suggested a new interpretation of the sub-horizon scale variability, consisting in a pulsar-like particle acceleration by the electric field across a magnetospheric gap at the base of the radio jet [77]. This interpretation is represented in Figure 4.

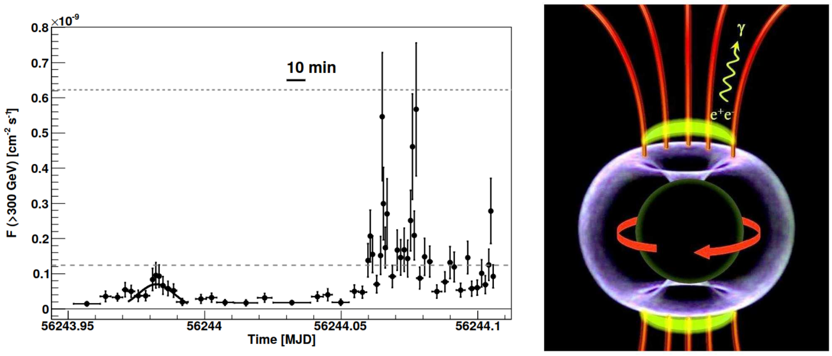

Figure 4. (**a**) Light curve of IC 310 observed by the MAGIC telescopes the 12th and 13th November 2012. From [77], Figure S4. (**b**) Emission scenario for the origin of the very variable gamma-ray emission observed in IC 310 during the activity of 2012: the black sphere represents the rotating black hole with its event horizon. The apple-shaped blue ergosphere surrounding the black hole accretes plasma from the center of IC 310. The magnetosphere is represented in red and its polar vacuum gap regions in yellow. In the gaps, the electric field of the magnetosphere has a component parallel to the magnetic field accelerating particles to ultra-relativistic energies. Inverse-Compton scattering and copious pair production due to interactions with low-energy thermal photons from the plasma accreted by the black hole leads to the observed gamma rays. From [77], Figure S5.

3.7. Neighbour accelerators: Markarians at VHE gamma-rays

Two Markarians emitting in the VHE gamma-ray range, Mrk 421 and Mrk 501, have been monitored by MAGIC since the beginning of the operations. Those neighbour blazars (redshift z=0.031 and z=0.034 respectively) are perfect to study the mechanism of acceleration and broadband emission of blazars for many reasons: their vicinity implies a negligible effect of the EBL absorption on their VHE gamma-ray spectra and also very precise VLBI (Very Large Baseline Interferometry) studies which can be used to constrain the emission scenarios; their brightness allows a monitoring in different states of activities (quiescent, flaring and intermediate states) and consequently a study of the temporal evolution of their broadband SEDs; their variability can be used to break degeneracies between emission models.

Many MWL campaigns were organized in order to acquire simultaneous MWL data of both Mrk 421 and Mrk 501. This resulted in many works which describe the broadband emission of such powerful blazars over the years, accompanied by detailed studies of the broadband correlations and variability in different states of activity.

All the publications by MAGIC (collaborating with many other instruments) on Mrk 421 and Mrk 501, together with the main results obtained and the corresponding references, are listed in Table 2 and 3. Another Markarian, Mrk 180, was discovered in the VHE gamma-rays by MAGIC in 2006 [15] during an optical outburst. This source is tough very faint and was detected by MAGIC so far only in that occasion.

Table 2. List of the main results obtained by MAGIC on Mrk 421.

Mrk 421			
Time	Main results	Theor. model	Ref.
Nov 2004 – Apr 2005	γ-ray/X-ray corr., IC peak $\sim$100 GeV	one-zone SSC	[78]
22-30 Apr + 14 Jun 2006	intra-night var. (29 Apr, $\sim$36 min.)	leptonic	[79]
5 Aug 2008-12 Mar 2010	MWL SED in a quiescent state characterization	one-zone SCC, proton-synch	[80]
Mar 2010	γ-ray/X-ray corr., γ-ray and X-ray var.	one-zone SCC, two-zones SSC	[81]
Jan-Jun 2009	quiescent state characterization, X-ray harder-when-brighter, γ-ray/X-ray corr., optical/X-ray anti-corr.	one-zone SCC	[82]
Jan-Mar 2013	γ-ray/X-ray corr., double-bumped frac. var., low state characterization	one-zone SCC, suggestion of multi-zone leptonic	[83]
Mar 2007-Jun 2009	X-ray/soft X-ray corr., frac. var. increasing with energy, different levels of activity	suggested SSC, or generic hadronic scenarios	[84]
28 Apr-4 May 2014	X-ray spectrum variability	one-zone SSC	[85]
Nov 2014-Jun 2016	X-ray and γ-ray harder-when brighter, double-bumped frac. var., X-ray/γ-ray/ corr., VHE intra-night var. (27 Jan + 12 Mar 2015)	suggesting that the emission is powered by a multiplicative process	[86]
11-19 Apr 2013	intra-night var. of X-ray and VHE γ-ray bands, VHE γ-ray/X-ray corr.	magnetic reconnection in a multi-zone scenario	[87]
Feb 2010	limits on the Doppler factor and size of the emission region, time-lagged corr. optical/VHE	one-zone SSC excluded	[88]
Dec 2016-Jun 2017	VHE/X-ray corr., orphan γ-ray activity, intra-night VHE var., UV/X-ray anti-corr.	two-zone leptonic	[89]
Dec 2007-Feb 2009	upper limits on extended emission	possible constraints on EGMF	[90]

Table 3. List of the main results obtained by MAGIC on Mrk 501.

Mrk 501			
Time	Main results	Theor. model	Ref.
May-Jul 2005	VHE intra-night var., spectra hardening when increasing flux, var. increasing with energy	one-zone SSC	[91]
Jul 2006	low state in VHE steep VHE photon index spectral hardening with flux (VHE)	one-zone SSC	[92]
15 Mar-1 Aug 2009	low activity characterization	one-zone SSC	[93]
Mar 2009	quiescent state characterization, X-ray peak shift of two orders of magnitude	one-zone SSC	[94]
1 Apr-10 Aug 2013	hard X-ray var. on hour timescales, 5 MWL SEDs	one-zone SSC	[95]
March-May 2008	low state characterization, hint of X-ray-to-VHE correlation	one-zone SSC	[96]
15 Mar-1 Aug 2009	frac. var. increasing with energy, flaring activity coincident with EVPA rotation (1 May)	two-zones SSC	[97]
Mar-Jul 2012	hard X-ray and VHE spectral indexes, extreme behaviour, VHE/X-ray corr., frac. var. increasing with energy	one-zone SSC	[73]
16-31 Jul 2014	frac. var. increasing with energy, VHE/X-ray corr., narrow feature in the VHE spectrum at 3 TeV (19 Jul)		[98]
Feb 2017-Dec 2020	X-ray/VHE corr., HE/radio corr.,	one-zone leptonic, two-zone leptonic, but also hadronic and lepto-hadronic are considered	[99]
May and Apr 2008	upper limits on extended emission	possible constraints on EGMF	[90]

3.8. Long-term Monitoring campaigns

The long-term monitoring of peculiar sources was a successful strategy which brought many interesting results. For instance the giant radio galaxy M 87 was studied by MAGIC over the years allowing a deep characterisation of quiescent states [100,101], as well as the study of flaring activity[102, 103]. Being M 87 a very important target of radio observation, a collaboration in MWL with many telescopes including EHT allowed a deep MWL study of this close radiogalaxy. [101,104]. The blazar PG 1553+113 was also the object of long monitoring campaigns in MAGIC. This blazar was monitored by MAGIC from the beginning of the operations, in mono mode [105,106], and as part of MWL monitorings campaign. In [107] 5 years of observations and related results are reported. Recently this source, already well known for its variability in different energy bands, was find to possess a quasi-periodicity in gamma-rays [108–110], which makes its monitoring even more important in order to shed light on its complex MWL emission mechanism. The BL Lac object 1ES 0647+250 was

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discovered to emit VHE gamma-rays in 2012 [111] by MAGIC. Following this result, a monitoring campaign was set up in order to collect MWL data and deeply study this HBL. The campaign resulted in a deep study of the correlations between waveband and characterization of the broadband emission in four different states of activity [33]. In the X-ray and VHE gamma-rays band long-term variability was detected, as well as correlations between radio, optical and HE gamma-ray fluxes. The blazar 1ES 1959+650 was detected by MAGIC in 2004 [112]. 1ES 1959+650 is a nearby AGN (z=0.048) and a HBL, which in 2015 entered an high state of activity in different energy bands, especially in optical, but also in gamma-rays. The results of MAGIC and MWL monitoring of this source in the recent years are gathered in [113]. They include the detection of intra-night variability in the VHE gamma-ray range and the interpretation of the broadband emission in the frame of one-zone SSC model.

3.9. Multi-messenger studies

The first MM event which included simultaneous detection of photons and neutrinos from an astrophysical source is the famous explosion of the supernova 1987A [114]. In the following years, the development of neutrino experiments made easier to detect neutrinos from astrophysical objects and to identify their origin, allowing a complex system of alerts in collaboration with other observatory and telescopes at different pothon energies. The efforts of the astronomical communite were paid back when in 2018 the blazar TXS 0506+056 was found to be flaring in many wavelenghts in coincidence with the neutrino event IceCube-170922A. This important detection was made possible by the coordination between instruments and by the prompt response to the IceCube alert. MAGIC was part of the MM observations and of this discovery, which is reported in [38]. Several theoretical models were tested to explain the MM SED and in [39] the dataset is interpreted with a one-zone lepto-hadronic scenario, where the gamma-ray emission is produced by the Inverse Compton up-scattering of external photons (see Figure 5).

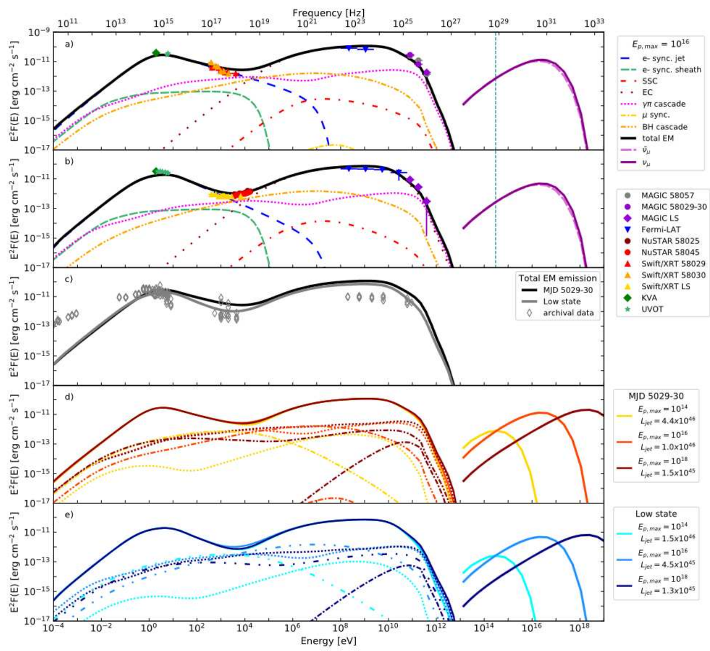

Figure 5. MM SEDs of the blazar TXS 0506+056. In panel a) it is shown the MM SED for the enhanced VHE gamma-ray state, while in panel b) the one corresponding to the lower state. Panel c) shows a comparison with archival data, while panel d) and e) results for different values of the maximum proton energy. From [39]. Asked for permission.

Thanks to the close collaboration between neutrino experiments and other instruments across the electromagnetic spectrum, MM observations are regularly performed waiting for the next MM event from a blazar.

4. Conclusions

The study of extragalactic sources has been one of the main targets of the MAGIC Florian Goebel telescopes from 20 years, since the beginning of their operations. The low energy threshold, which was the main goal behind their constructions, allowed to closely connect to the other gamma-ray experiments and smoothly describe the high-energy bump of the MWL SEDs from many celestial objects. MAGIC discovered in the VHE gamma-ray range many extragalactic sources and over the years characterized in detail many types of AGNs, with a focus on MWL and MM studies, of paramount importance in the identification of the braodband emission scenario. The results obtained by MAGIC during their long time of operation will be certainly complemented and extended by the new generation of IACTs, the CTAO (Cherenkov Telescope Array Observatory [115]).

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
AGN	Active Galactic Nucleus
AGNs	Active Galactic Nuclei
EBL	Extragalactic Background Light
LIDAR	LIght Detection And Ranging
MAGIC	Major Atmospheric Gamma-ray Imaging Cherenkov (telescopes)
IACTs	Imaging Atmospheric Cherenkov Telescopes
HE	High-energy
VHE	Very-high-energy
MWL	Multi-wavelength
MM	Multi-messenger
SED	Spectral Energy Distribution
FSRQ	Flat Spectrum Radio Quasar
BL Lacs	BL Lacertae type objects
f.o.v	Field of view
MJD	Modified Julian Date
ToO	Target of Opportunity
SSC	Synchrotron self-Compton

References

1. Padovani, P. On the two main classes of active galactic nuclei. *Nature Astronomy* **2017**, *1*, 0194, [arXiv:astro-ph.GA/1707.08069]. doi:10.1038/s41550-017-0194.
2. Ghisellini, G.; Righi, C.; Costamante, L.; Tavecchio, F. The Fermi blazar sequence. **2017**, *469*, 255–266, [arXiv:astro-ph.HE/1702.02571]. doi:10.1093/mnras/stx806.
3. Bose, D.; Chitnis, V.R.; Majumdar, P.; Acharya, B.S. Ground-based gamma-ray astronomy: history and development of techniques. *European Physical Journal Special Topics* **2022**, *231*, 3–26, [arXiv:astro-ph.IM/2201.04719]. doi:10.1140/epjs/s11734-021-00396-3.
4. de Naurois, M.; Mazin, D. Ground-based detectors in very-high-energy gamma-ray astronomy. *Comptes Rendus Physique* **2015**, *16*, 610–627, [arXiv:astro-ph.IM/1511.00463]. doi:10.1016/j.crhy.2015.08.011.

5. Aharonian, F.; Buckley, J.; Kifune, T.; Sinnis, G. High energy astrophysics with ground-based gamma ray detectors. *Reports on Progress in Physics* **2008**, *71*, 096901. doi:10.1088/0034-4885/71/9/096901.
6. Dazzi, F.; Schweizer, T.; Ceribella, G.; Corti, D.; Dettlaff, A.; Garcia, J.R.; Hafner, D.; Herranz, D.; Lopez-Moya, M.; Mariotti, M.; et al. The Stereoscopic Analog Trigger of the MAGIC Telescopes. *IEEE Transactions on Nuclear Science* **2021**, *68*, 1473–1486. doi:10.1109/TNS.2021.3079262.
7. MAGIC Collaboration.; Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Asano, K.; Baack, D.; Babić, A.; Baquero, A.; Barres de Almeida, U.; et al. Detection of the Geminga pulsar with MAGIC hints at a power-law tail emission beyond 15 GeV. **2020**, *643*, L14, [arXiv:astro-ph.HE/2011.10412]. doi:10.1051/0004-6361/202039131.
8. Aleksić, J.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Bangale, P.; Barceló, M.; Barrio, J.A.; Becerra González, J.; Bednarek, W.; et al. The major upgrade of the MAGIC telescopes, Part II: A performance study using observations of the Crab Nebula. *Astroparticle Physics* **2016**, *72*, 76–94, [arXiv:astro-ph.IM/1409.5594]. doi:10.1016/j.astropartphys.2015.02.005.
9. Aleksić, J.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Bangale, P.; Barceló, M.; Barrio, J.A.; Becerra González, J.; Bednarek, W.; et al. The major upgrade of the MAGIC telescopes, Part I: The hardware improvements and the commissioning of the system. *Astroparticle Physics* **2016**, *72*, 61–75, [arXiv:astro-ph.IM/1409.6073]. doi:10.1016/j.astropartphys.2015.04.004.
10. Pecimotika, M.; Dominis Prester, D.; Hrupec, D.; Mićanović, S.; Pavletić, L.; Sitarek, J. Performance and systematic uncertainties of CTA-North in conditions of reduced atmospheric transmission. **2023**, *2023*, 011, [arXiv:astro-ph.IM/2302.02211]. doi:10.1088/1475-7516/2023/06/011.
11. Fruck, C.; Gaug, M.; Hahn, A.; Acciari, V.; Besenrieder, J.; Dominis Prester, D.; Dorner, D.; Fink, D.; Font, L.; Mićanović, S.; et al. Characterizing the aerosol atmosphere above the Observatorio del Roque de los Muchachos by analysing seven years of data taken with an GaAsP HPD-readout, absolutely calibrated elastic LIDAR. **2022**, *515*, 4520–4550, [arXiv:astro-ph.IM/2202.09561]. doi:10.1093/mnras/stac1563.
12. Schmuckermaier, F.; Gaug, M.; Fruck, C.; Moralejo, A.; Hahn, A.; Dominis Prester, D.; Dorner, D.; Font, L.; Mićanović, S.; Mirzoyan, R.; et al. Correcting Imaging Atmospheric Cherenkov Telescope data with atmospheric profiles obtained with an elastic light detecting and ranging system. **2023**, *673*, A2, [arXiv:astro-ph.IM/2302.12072]. doi:10.1051/0004-6361/202245787.
13. Vestergaard, M.; Peterson, B.M. Determining Central Black Hole Masses in Distant Active Galaxies and Quasars. II. Improved Optical and UV Scaling Relationships. **2006**, *641*, 689–709, [arXiv:astro-ph/astro-ph/0601303]. doi:10.1086/500572.
14. Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Engels, A.A.; Asano, K.; Baack, D.; Babić, A.; Banerjee, B.; Barres de Almeida, U.; Barrio, J.A.; et al. New Hard-TeV Extreme Blazars Detected with the MAGIC Telescopes. **2020**, *247*, 16, [arXiv:astro-ph.HE/1911.06680]. doi:10.3847/1538-4365/ab5b98.
15. Albert, J.; Aliu, E.; Anderhub, H.; Antoranz, P.; Armada, A.; Asensio, M.; Baixeras, C.; Barrio, J.A.; Bartko, H.; Bastieri, D.; et al. Discovery of Very High Energy γ-Rays from Markarian 180 Triggered by an Optical Outburst. **2006**, *648*, L105–L108, [arXiv:astro-ph/astro-ph/0606630]. doi:10.1086/508020.
16. Aleksić, J.; Antonelli, L.A.; Antoranz, P.; Asensio, M.; Backes, M.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; Bednarek, W.; Berger, K.; et al. Discovery of very high energy gamma-ray emission from the blazar 1ES 1727+502 with the MAGIC Telescopes. **2014**, *563*, A90, [arXiv:astro-ph.HE/1302.6140]. doi:10.1051/0004-6361/201321360.
17. MAGIC Collaboration.; Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Baack, D.; Babić.; , A.; Banerjee, B.; Barres de Almeida, U.; Barrio, J.A.; et al. Testing emission models on the extreme blazar 2WHSP J073326.7+515354 detected at very high energies with the MAGIC telescopes. **2019**, *490*, 2284–2299, [arXiv:astro-ph.HE/1909.11621]. doi:10.1093/mnras/stz2725.
18. Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Arcaro, C.; Babic, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; et al. MAGIC detection of very high energy γ-ray emission from the low-luminosity blazar 1ES 1741+196. **2017**, *468*, 1534–1541, [arXiv:astro-ph.HE/1702.06795]. doi:10.1093/mnras/stx472.
19. Blanch, O. Detection of very-high-energy gamma-ray emission from B2 1811+31 with the MAGIC telescopes. *The Astronomer's Telegram* **2020**, *14090*, 1.
20. Aleksić, J.; Alvarez, E.A.; Antonelli, L.A.; Antoranz, P.; Asensio, M.; Backes, M.; Barrio, J.A.; Bastieri, D.; Becerra González, J.; Bednarek, W.; et al. Discovery of VHE γ-ray emission from the BL Lacertae

object B3 2247+381 with the MAGIC telescopes. **2012**, *539*, A118, [arXiv:astro-ph.HE/1201.2634]. doi:10.1051/0004-6361/201117967.

21. Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Artero, M.; Asano, K.; Baack, D.; Babić, A.; Baquero, A.; Barres de Almeida, U.; et al. First detection of VHE gamma-ray emission from TXS 1515-273, study of its X-ray variability and spectral energy distribution. **2021**, *507*, 1528–1545, [arXiv:astro-ph.HE/2107.09413]. doi:10.1093/mnras/stab1994.
22. Aleksić, J.; Alvarez, E.A.; Antonelli, L.A.; Antoranz, P.; Ansoldi, S.; Asensio, M.; Backes, M.; Barres de Almeida, U.; Barrio, J.A.; Bastieri, D.; et al. Discovery of VHE γ-rays from the blazar 1ES 1215+303 with the MAGIC telescopes and simultaneous multi-wavelength observations. **2012**, *544*, A142, [arXiv:astro-ph.HE/1203.0490]. doi:10.1051/0004-6361/201219133.
23. Mirzoyan, R. Discovery of Very High Energy Gamma-Ray Emission from BL Lac object RX J1136.5+6737 by the MAGIC Telescopes. *The Astronomer's Telegram* **2014**, *6062*, 1.
24. Aleksić, J.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. First broadband characterization and redshift determination of the VHE blazar MAGIC J2001+439. **2014**, *572*, A121, [arXiv:astro-ph.HE/1409.3389]. doi:10.1051/0004-6361/201424254.
25. Albert, J.; Aliu, E.; Anderhub, H.; Antoranz, P.; Armada, A.; Asensio, M.; Baixeras, C.; Barrio, J.A.; Bartelt, M.; Bartko, H.; et al. Discovery of Very High Energy Gamma Rays from 1ES 1218+30.4. **2006**, *642*, L119–L122, [arXiv:astro-ph/astro-ph/0603529]. doi:10.1086/504845.
26. Aleksić, J.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; Bednarek, W.; Berger, K.; Bernardini, E.; et al. Rapid and multiband variability of the TeV bright active nucleus of the galaxy IC 310. **2014**, *563*, A91, [arXiv:astro-ph.HE/1305.5147]. doi:10.1051/0004-6361/201321938.
27. Albert, J.; Aliu, E.; Anderhub, H.; Antoranz, P.; Armada, A.; Baixeras, C.; Barrio, J.A.; Bartko, H.; Bastieri, D.; Becker, J.K.; et al. Discovery of Very High Energy γ-Rays from 1ES 1011+496 at z = 0.212. **2007**, *667*, L21–L24, [arXiv:astro-ph/0706.4435]. doi:10.1086/521982.
28. Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. MAGIC observations of the February 2014 flare of 1ES 1011+496 and ensuing constraint of the EBL density. **2016**, *590*, A24, [arXiv:astro-ph.HE/1602.05239]. doi:10.1051/0004-6361/201527256.
29. Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. Multiwavelength observations of the blazar 1ES 1011+496 in Spring 2008. **2016**, *459*, 2286–2298, [arXiv:astro-ph.HE/1603.07308]. doi:10.1093/mnras/stw710.
30. Aleksić, J.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Arcaro, C.; Babic, A.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. Insights into the emission of the blazar 1ES 1011+496 through unprecedented broadband observations during 2011 and 2012. **2016**, *591*, A10, [arXiv:astro-ph.HE/1603.06776]. doi:10.1051/0004-6361/201527176.
31. Cortina, J. Discovery of Very High Energy Gamma-Ray Emission from MS1221.8+2452 with the MAGIC telescopes. *The Astronomer's Telegram* **2013**, *5038*, 1.
32. Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. Investigating the peculiar emission from the new VHE gamma-ray source H1722+119. **2016**, *459*, 3271–3281, [arXiv:astro-ph.HE/1603.06523]. doi:10.1093/mnras/stw689.
33. MAGIC Collaboration.; Acciari, V.A.; Aniello, T.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Arcaro, C.; Artero, M.; Asano, K.; Baack, D.; et al. Long-term multi-wavelength study of 1ES 0647+250. **2023**, *670*, A49, [arXiv:astro-ph.HE/2211.13268]. doi:10.1051/0004-6361/202244477.
34. Readhead, A.C.S.; Ravi, V.; Liodakis, I.; Lister, M.L.; Singh, V.; Aller, M.F.; Blandford, R.D.; Browne, I.W.A.; Gorjian, V.; Grainge, K.J.B.; et al. The Relativistic Jet Orientation and Host Galaxy of the Peculiar Blazar PKS 1413+135. **2021**, *907*, 61, [arXiv:astro-ph.GA/2012.04045]. doi:10.3847/1538-4357/abd08c.
35. Blanch, O.; Sitarek, J.; Striskovic, J. First detection of very-high-energy gamma-ray emission from PKS1413+135 with the MAGIC telescopes. *The Astronomer's Telegram* **2022**, *15161*, 1.

36. Anderhub, H.; Antonelli, L.A.; Antoranz, P.; Backes, M.; Baixeras, C.; Balestra, S.; Barrio, J.A.; Bastieri, D.; Becerra González, J.; Becker, J.K.; et al. Discovery of very High Energy γ-Rays from the Blazar S5 0716+714. **2009**, *704*, L129–L133, [arXiv:astro-ph.CO/0907.2386]. doi:10.1088/0004-637X/704/2/L129.
37. MAGIC Collaboration.; Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Arcaro, C.; Baack, D.; Babić, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; et al. Multi-wavelength characterization of the blazar S5 0716+714 during an unprecedented outburst phase. **2018**, *619*, A45, [arXiv:astro-ph.HE/1807.00413]. doi:10.1051/0004-6361/201832677.
38. IceCube Collaboration.; Aartsen, M.G.; Ackermann, M.; Adams, J.; Aguilar, J.A.; Ahlers, M.; Ahrens, M.; Al Samarai, I.; Altmann, D.; Andeen, K.; et al. Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A. *Science* **2018**, *361*, eaat1378, [arXiv:astro-ph.HE/1807.08816]. doi:10.1126/science.aat1378.
39. Ansoldi, S.; Antonelli, L.A.; Arcaro, C.; Baack, D.; Babić, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. The Blazar TXS 0506+056 Associated with a High-energy Neutrino: Insights into Extragalactic Jets and Cosmic-Ray Acceleration. **2018**, *863*, L10, [arXiv:astro-ph.HE/1807.04300]. doi:10.3847/2041-8213/aad083.
40. MAGIC Collaboration.; Ansoldi, S.; Antonelli, L.A.; Arcaro, C.; Baack, D.; Babić.; , A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; et al. The broad-band properties of the intermediate synchrotron peaked BL Lac S2 0109+22 from radio to VHE gamma-rays. **2018**, *480*, 879–892, [arXiv:astro-ph.HE/1807.02095]. doi:10.1093/mnras/sty1753.
41. MAGIC Collaboration.; Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Arcaro, C.; Baack, D.; Babić, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; et al. Detection of the blazar S4 0954+65 at very-high-energy with the MAGIC telescopes during an exceptionally high optical state. **2018**, *617*, A30, [arXiv:astro-ph.HE/1801.04138]. doi:10.1051/0004-6361/201832624.
42. Aleksić, J.; Antonelli, L.A.; Antoranz, P.; Backes, M.; Barrio, J.A.; Bastieri, D.; Becerra González, J.; Bednarek, W.; Berdyugin, A.; Berger, K.; et al. MAGIC Discovery of Very High Energy Emission from the FSRQ PKS 1222+21. **2011**, *730*, L8, [arXiv:astro-ph.HE/1101.4645]. doi:10.1088/2041-8205/730/1/L8.
43. Aleksić, J.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; Bednarek, W.; et al. Discovery of very high energy γ-ray emission from the blazar 1ES 0033+595 by the MAGIC telescopes. **2015**, *446*, 217–225, [arXiv:astro-ph.HE/1410.7059]. doi:10.1093/mnras/stu2024.
44. Massaro, F.; Masetti, N.; D'Abrusco, R.; Paggi, A.; Funk, S. Optical Spectroscopic Observations of Blazars and γ-Ray Blazar Candidates in the Sloan Digital Sky Survey Data Release Nine. **2014**, *148*, 66, [arXiv:astro-ph.HE/1503.03868]. doi:10.1088/0004-6256/148/4/66.
45. Blanch, O. Detection of very-high-energy gamma-ray emission from GB6 J1058+2817 with the MAGIC telescopes. *The Astronomer's Telegram* **2021**, *14506*, 1.
46. MAGIC Collaboration.; Albert, J.; Aliu, E.; Anderhub, H.; Antonelli, L.A.; Antoranz, P.; Backes, M.; Baixeras, C.; Barrio, J.A.; Bartko, H.; et al. Very-High-Energy gamma rays from a Distant Quasar: How Transparent Is the Universe? *Science* **2008**, *320*, 1752, [arXiv:astro-ph/0807.2822]. doi:10.1126/science.1157087.
47. Aleksić, J.; Antonelli, L.A.; Antoranz, P.; Backes, M.; Barrio, J.A.; Bastieri, D.; Becerra González, J.; Bednarek, W.; Berdyugin, A.; Berger, K.; et al. MAGIC Observations and multiwavelength properties of the quasar 3C 279 in 2007 and 2009. **2011**, *530*, A4, [arXiv:astro-ph.CO/1101.2522]. doi:10.1051/0004-6361/201116497.
48. Aleksić, J.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; Bednarek, W.; et al. MAGIC observations and multifrequency properties of the flat spectrum radio quasar <ASTROBJ>3C 279</ASTROBJ> in 2011. **2014**, *567*, A41, [arXiv:astro-ph.HE/1311.2833]. doi:10.1051/0004-6361/201323036.
49. MAGIC Collaboration.; Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Artero, M.; Asano, K.; Baack, D.; Babić, A.; Baquero, A.; Barres de Almeida, U.; et al. VHE gamma-ray detection of FSRQ QSO B1420+326 and modeling of its enhanced broadband state in 2020. **2021**, *647*, A163, [arXiv:astro-ph.HE/2012.11380]. doi:10.1051/0004-6361/202039687.
50. Mirzoyan, R. Detection of very-high-energy gamma-ray emission from the FSRQ Ton 0599 with the MAGIC telescopes. *The Astronomer's Telegram* **2017**, *11061*, 1.
51. Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Bednarek, W.; et al. Very High Energy γ-Rays from the Universe's Middle Age:

Detection of the z = 0.940 Blazar PKS 1441+25 with MAGIC. **2015**, *815*, L23, [arXiv:astro-ph.GA/1512.04435]. doi:10.1088/2041-8205/815/2/L23.
52. Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Arcaro, C.; Babic, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; et al. Detection of very high energy gamma-ray emission from the gravitationally lensed blazar QSO B0218+357 with the MAGIC telescopes. **2016**, *595*, A98, [arXiv:astro-ph.HE/1609.01095]. doi:10.1051/0004-6361/201629461.
53. Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Artero, M.; Asano, K.; Baack, D.; Babić, A.; Baquero, A.; Barres de Almeida, U.; et al. Multiwavelength study of the gravitationally lensed blazar QSO B0218+357 between 2016 and 2020. **2022**, *510*, 2344–2362, [arXiv:astro-ph.HE/2111.12926]. doi:10.1093/mnras/stab3454.
54. Blanch, O.; Martinez, M. Exploring the gamma ray horizon with the next generation of gamma ray telescopes. Part 1: Theoretical predictions. *Astroparticle Physics* **2005**, *23*, 588–597, [arXiv:astro-ph/astro-ph/0107582]. doi:10.1016/j.astropartphys.2005.03.008.
55. Blanch, O.; Martinez, M. Exploring the gamma-ray horizon with the next generation of gamma-ray telescopes. Part 2: Extracting cosmological parameters from the observation of gamma-ray sources. *Astroparticle Physics* **2005**, *23*, 598–607, [arXiv:astro-ph/astro-ph/0406061]. doi:10.1016/j.astropartphys.2005.03.009.
56. Domínguez, A.; Primack, J.R.; Rosario, D.J.; Prada, F.; Gilmore, R.C.; Faber, S.M.; Koo, D.C.; Somerville, R.S.; Pérez-Torres, M.A.; Pérez-González, P.; et al. Extragalactic background light inferred from AEGIS galaxy-SED-type fractions. **2011**, *410*, 2556–2578, [arXiv:astro-ph.CO/1007.1459]. doi:10.1111/j.1365-2966.2010.17631.x.
57. Tavecchio, F.; Becerra-Gonzalez, J.; Ghisellini, G.; Stamerra, A.; Bonnoli, G.; Foschini, L.; Maraschi, L. On the origin of the γ-ray emission from the flaring blazar PKS 1222+216. **2011**, *534*, A86, [arXiv:astro-ph.HE/1104.0048]. doi:10.1051/0004-6361/201117204.
58. Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Baack, D.; Babić.; , A.; Banerjee, B.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. Measurement of the extragalactic background light using MAGIC and Fermi-LAT gamma-ray observations of blazars up to z = 1. **2019**, *486*, 4233–4251, [arXiv:astro-ph.HE/1904.00134]. doi:10.1093/mnras/stz943.
59. Madejski, G.G.; Sikora, M. Gamma-Ray Observations of Active Galactic Nuclei. **2016**, *54*, 725–760. doi:10.1146/annurev-astro-081913-040044.
60. Fossati, G.; Maraschi, L.; Celotti, A.; Comastri, A.; Ghisellini, G. A unifying view of the spectral energy distributions of blazars. **1998**, *299*, 433–448, [arXiv:astro-ph/astro-ph/9804103]. doi:10.1046/j.1365-8711.1998.01828.x.
61. Prandini, E.; Ghisellini, G. The Blazar Sequence and Its Physical Understanding. *Galaxies* **2022**, *10*, 35, [arXiv:astro-ph.HE/2202.07490]. doi:10.3390/galaxies10010035.
62. Tavecchio, F.; Ghisellini, G.; Bonnoli, G.; Ghirlanda, G. Constraining the location of the emitting region in Fermi blazars through rapid γ-ray variability. **2010**, *405*, L94–L98, [arXiv:astro-ph.CO/1003.3475]. doi:10.1111/j.1745-3933.2010.00867.x.
63. Marscher, A.P. Relativistic jets and the continuum emission in QSOs. **1980**, *235*, 386–391. doi:10.1086/157642.
64. Ghisellini, G.; Tavecchio, F. Rapid variability in TeV blazars: the case of PKS2155-304. **2008**, *386*, L28–L32, [arXiv:astro-ph/0801.2569]. doi:10.1111/j.1745-3933.2008.00454.x.
65. Nalewajko, K.; Sikora, M. A structure and energy dissipation efficiency of relativistic reconfinement shocks. **2009**, *392*, 1205–1210, [arXiv:astro-ph/0810.3912]. doi:10.1111/j.1365-2966.2008.14123.x.
66. Frederiksen, J.T.; Haugbølle, T.; Medvedev, M.V.; Nordlund, Å. Radiation Spectral Synthesis of Relativistic Filamentation. **2010**, *722*, L114–L119, [arXiv:astro-ph.HE/1003.1140]. doi:10.1088/2041-8205/722/1/L114.
67. Ghisellini, G.; Tavecchio, F.; Foschini, L.; Ghirlanda, G. The transition between BL Lac objects and flat spectrum radio quasars. **2011**, *414*, 2674–2689, [arXiv:astro-ph.CO/1012.0308]. doi:10.1111/j.1365-2966.2011.18578.x.
68. Manganaro, M.; Seglar-Arroyo, M.; Becerra-González, J.; Sanchez, D.; Cerruti, M.; Tavecchio, F.; Fallah-Ramazani, V.; Agudo, I.; Ciprini, S.; Filippenko, A.V.; et al. MAGIC and H.E.S.S. detect VHE gamma rays from the blazar OT081 for the first time: a deep multiwavelength study. 37th International Cosmic Ray Conference. 12-23 July 2021. Berlin, 2022, p. 815.

69. Costamante, L.; Ghisellini, G.; Giommi, P.; Tagliaferri, G.; Celotti, A.; Chiaberge, M.; Fossati, G.; Maraschi, L.; Tavecchio, F.; Treves, A.; Wolter, A. Extreme synchrotron BL Lac objects. Stretching the blazar sequence. **2001**, *371*, 512–526, [arXiv:astro-ph/astro-ph/0103343]. doi:10.1051/0004-6361:20010412.
70. Durrer, R.; Neronov, A. Cosmological magnetic fields: their generation, evolution and observation. **2013**, *21*, 62, [arXiv:astro-ph.CO/1303.7121]. doi:10.1007/s00159-013-0062-7.
71. Biteau, J.; Prandini, E.; Costamante, L.; Lemoine, M.; Padovani, P.; Pueschel, E.; Resconi, E.; Tavecchio, F.; Taylor, A.; Zech, A. Progress in unveiling extreme particle acceleration in persistent astrophysical jets. *Nature Astronomy* **2020**, *4*, 124–131, [arXiv:astro-ph.HE/2001.09222]. doi:10.1038/s41550-019-0988-4.
72. Ghisellini, G.; Tavecchio, F.; Chiaberge, M. Structured jets in TeV BL Lac objects and radiogalaxies. Implications for the observed properties. **2005**, *432*, 401–410, [arXiv:astro-ph/astro-ph/0406093]. doi:10.1051/0004-6361:20041404.
73. Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Arcaro, C.; Babić, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. Extreme HBL behavior of Markarian 501 during 2012. **2018**, *620*, A181, [arXiv:astro-ph.HE/1808.04300]. doi:10.1051/0004-6361/201833704.
74. MAGIC Collaboration.; Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Babić, A.; Banerjee, B.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. An intermittent extreme BL Lac: MWL study of 1ES 2344+514 in an enhanced state. **2020**, *496*, 3912–3928, [arXiv:astro-ph.HE/2006.06796]. doi:10.1093/mnras/staa1702.
75. Abe, H.; Abe, S.; Acciari, V.A.; Agudo, I.; Aniello, T.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Arcaro, C.; Artero, M.; et al. Multi-year characterisation of the broad-band emission from the intermittent extreme BL Lac 1ES~2344+514. *arXiv e-prints* **2023**, p. arXiv:2310.03922, [arXiv:astro-ph.HE/2310.03922]. doi:10.48550/arXiv.2310.03922.
76. Acciari, V.A.; Agudo, I.; Aniello, T.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Artero, M.; Asano, K.; Baack, D.; Babić, A.; et al. A lower bound on intergalactic magnetic fields from time variability of 1ES 0229+200 from MAGIC and Fermi/LAT observations. **2023**, *670*, A145, [arXiv:astro-ph.HE/2210.03321]. doi:10.1051/0004-6361/202244126.
77. Aleksić, J.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Bangale, P.; Barrio, J.A.; González, J.B.; Bednarek, W.; Bernardini, E.; et al. Black hole lightning due to particle acceleration at subhorizon scales. *Science* **2014**, *346*, 1080–1084, [arXiv:astro-ph.HE/1412.4936]. doi:10.1126/science.1256183.
78. Albert, J.; Aliu, E.; Anderhub, H.; Antoranz, P.; Armada, A.; Asensio, M.; Baixeras, C.; Barrio, J.A.; Bartko, H.; Bastieri, D.; et al. Observations of Markarian 421 with the MAGIC Telescope. **2007**, *663*, 125–138, [arXiv:astro-ph/astro-ph/0603478]. doi:10.1086/518221.
79. Aleksić, J.; Anderhub, H.; Antonelli, L.A.; Antoranz, P.; Backes, M.; Baixeras, C.; Balestra, S.; Barrio, J.A.; Bastieri, D.; Becerra González, J.; et al. MAGIC TeV gamma-ray observations of Markarian 421 during multiwavelength campaigns in 2006. **2010**, *519*, A32, [arXiv:astro-ph.CO/1001.1291]. doi:10.1051/0004-6361/200913945.
80. Abdo, A.A.; Ackermann, M.; Ajello, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; Berenji, B.; et al. Fermi Large Area Telescope Observations of Markarian 421: The Missing Piece of its Spectral Energy Distribution. **2011**, *736*, 131, [arXiv:astro-ph.HE/1106.1348]. doi:10.1088/0004-637X/736/2/131.
81. Aleksić, J.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; Bednarek, W.; et al. Unprecedented study of the broadband emission of Mrk 421 during flaring activity in March 2010. **2015**, *578*, A22, [arXiv:astro-ph.HE/1412.3576]. doi:10.1051/0004-6361/201424811.
82. Aleksić, J.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. The 2009 multiwavelength campaign on Mrk 421: Variability and correlation studies. **2015**, *576*, A126, [arXiv:astro-ph.HE/1502.02650]. doi:10.1051/0004-6361/201424216.
83. Baloković, M.; Paneque, D.; Madejski, G.; Furniss, A.; Chiang, J.; Ajello, M.; Alexander, D.M.; Barret, D.; Blandford, R.D.; Boggs, S.E.; et al. Multiwavelength Study of Quiescent States of Mrk 421 with Unprecedented Hard X-Ray Coverage Provided by NuSTAR in 2013. **2016**, *819*, 156, [arXiv:astro-ph.HE/1512.02235]. doi:10.3847/0004-637X/819/2/156.
84. Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. Long-term multi-wavelength variability and

correlation study of Markarian 421 from 2007 to 2009. **2016**, *593*, A91, [arXiv:astro-ph.GA/1605.09017]. doi:10.1051/0004-6361/201628447.
85. Abeysekara, A.U.; Archambault, S.; Archer, A.; Benbow, W.; Bird, R.; Buchovecky, M.; Buckley, J.H.; Bugaev, V.; Cardenzana, J.V.; Cerruti, M.; et al. A Search for Spectral Hysteresis and Energy-dependent Time Lags from X-Ray and TeV Gamma-Ray Observations of Mrk 421. **2017**, *834*, 2, [arXiv:astro-ph.HE/1611.04626]. doi:10.3847/1538-4357/834/1/2.
86. Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Asano, K.; Babić, A.; Banerjee, B.; Baquero, A.; de Almeida, U.B.; Barrio, J.A.; Becerra González, J.; et al. Multiwavelength variability and correlation studies of Mrk 421 during historically low X-ray and γ-ray activity in 2015-2016. **2021**, *504*, 1427–1451, [arXiv:astro-ph.HE/2012.01348]. doi:10.1093/mnras/staa3727.
87. Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Baack, D.; Babić, A.; Banerjee, B.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. Unraveling the Complex Behavior of Mrk 421 with Simultaneous X-Ray and VHE Observations during an Extreme Flaring Activity in 2013 April. **2020**, *248*, 29, [arXiv:astro-ph.HE/2001.08678]. doi:10.3847/1538-4365/ab89b5.
88. Abeysekara, A.U.; Benbow, W.; Bird, R.; Brill, A.; Brose, R.; Buchovecky, M.; Buckley, J.H.; Christiansen, J.L.; Chromey, A.J.; Daniel, M.K.; et al. The Great Markarian 421 Flare of 2010 February: Multiwavelength Variability and Correlation Studies. **2020**, *890*, 97, [arXiv:astro-ph.HE/2002.03567]. doi:10.3847/1538-4357/ab6612.
89. MAGIC Collaboration.; Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Artero, M.; Asano, K.; Babić, A.; Baquero, A.; Barres de Almeida, U.; et al. Investigation of the correlation patterns and the Compton dominance variability of Mrk 421 in 2017. **2021**, *655*, A89, [arXiv:astro-ph.HE/2106.05516]. doi:10.1051/0004-6361/202141004.
90. Aleksić, J.; Antonelli, L.A.; Antoranz, P.; Backes, M.; Baixeras, C.; Barrio, J.A.; Bastieri, D.; Becerra González, J.; Bednarek, W.; Berdyugin, A.; et al. Search for an extended VHE γ-ray emission from Mrk 421 and Mrk 501 with the MAGIC Telescope. **2010**, *524*, A77, [arXiv:astro-ph.HE/1004.1093]. doi:10.1051/0004-6361/201014747.
91. Albert, J.; Aliu, E.; Anderhub, H.; Antoranz, P.; Armada, A.; Baixeras, C.; Barrio, J.A.; Bartko, H.; Bastieri, D.; Becker, J.K.; et al. Variable Very High Energy γ-Ray Emission from Markarian 501. **2007**, *669*, 862–883, [arXiv:astro-ph/astro-ph/0702008]. doi:10.1086/521382.
92. Anderhub, H.; Antonelli, L.A.; Antoranz, P.; Backes, M.; Baixeras, C.; Balestra, S.; Barrio, J.A.; Bastieri, D.; Becerra González, J.; Becker, J.K.; et al. Simultaneous Multiwavelength Observation of Mkn 501 in a Low State in 2006. **2009**, *705*, 1624–1631, [arXiv:astro-ph.HE/0910.2093]. doi:10.1088/0004-637X/705/2/1624.
93. Abdo, A.A.; Ackermann, M.; Ajello, M.; Allafort, A.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M.G.; Bastieri, D.; Bechtol, K.; et al. Insights into the High-energy γ-ray Emission of Markarian 501 from Extensive Multifrequency Observations in the Fermi Era. **2011**, *727*, 129, [arXiv:astro-ph.HE/1011.5260]. doi:10.1088/0004-637X/727/2/129.
94. Acciari, V.A.; Arlen, T.; Aune, T.; Beilicke, M.; Benbow, W.; Böttcher, M.; Boltuch, D.; Bradbury, S.M.; Buckley, J.H.; Bugaev, V.; et al. Spectral Energy Distribution of Markarian 501: Quiescent State Versus Extreme Outburst. **2011**, *729*, 2, [arXiv:astro-ph.HE/1012.2200]. doi:10.1088/0004-637X/729/1/2.
95. Furniss, A.; Noda, K.; Boggs, S.; Chiang, J.; Christensen, F.; Craig, W.; Giommi, P.; Hailey, C.; Harisson, F.; Madejski, G.; et al. First NuSTAR Observations of Mrk 501 within a Radio to TeV Multi-Instrument Campaign. **2015**, *812*, 65, [arXiv:astro-ph.HE/1509.04936]. doi:10.1088/0004-637X/812/1/65.
96. Aleksić, J.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; Bednarek, W.; et al. Multiwavelength observations of Mrk 501 in 2008. **2015**, *573*, A50, [arXiv:astro-ph.HE/1410.6391]. doi:10.1051/0004-6361/201322906.
97. Ahnen, M.L.; Ansoldi, S.; Antonelli, L.A.; Antoranz, P.; Babic, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; et al. Multiband variability studies and novel broadband SED modeling of Mrk 501 in 2009. **2017**, *603*, A31, [arXiv:astro-ph.HE/1612.09472]. doi:10.1051/0004-6361/201629540.
98. MAGIC Collaboration.; Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Babić, A.; Banerjee, B.; Barres de Almeida, U.; Barrio, J.A.; Becerra González, J.; Bednarek, W.; et al. Study of the variable broadband emission of Markarian 501 during the most extreme Swift X-ray activity. **2020**, *637*, A86, [arXiv:astro-ph.HE/2001.07729]. doi:10.1051/0004-6361/201834603.

99. Abe, H.; Abe, S.; Acciari, V.A.; Agudo, I.; Aniello, T.; Ansoldi, S.; Antonelli, L.A.; Arbet-Engels, A.; Arcaro, C.; Artero, M.; et al. Multimessenger Characterization of Markarian 501 during Historically Low X-Ray and γ-Ray Activity. **2023**, *266*, 37, [arXiv:astro-ph.HE/2210.02547]. doi:10.3847/1538-4365/acc181.
100. Aleksić, J.; Alvarez, E.A.; Antonelli, L.A.; Antoranz, P.; Asensio, M.; Backes, M.; Barrio, J.A.; Bastieri, D.; Becerra González, J.; Bednarek, W.; et al. MAGIC observations of the giant radio galaxy M 87 in a low-emission state between 2005 and 2007. **2012**, *544*, A96, [arXiv:astro-ph.HE/1207.2147]. doi:10.1051/0004-6361/201117827.
101. MAGIC Collaboration.; Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Arcaro, C.; Baack, D.; Babić, A.; Banerjee, B.; Bangale, P.; et al. Monitoring of the radio galaxy M 87 during a low-emission state from 2012 to 2015 with MAGIC. **2020**, *492*, 5354–5365, [arXiv:astro-ph.HE/2001.01643]. doi:10.1093/mnras/staa014.
102. Albert, J.; Aliu, E.; Anderhub, H.; Antonelli, L.A.; Antoranz, P.; Backes, M.; Baixeras, C.; Barrio, J.A.; Bartko, H.; Bastieri, D.; et al. Very High Energy Gamma-Ray Observations of Strong Flaring Activity in M87 in 2008 February. **2008**, *685*, L23, [arXiv:astro-ph/0806.0988]. doi:10.1086/592348.
103. Abramowski, A.; Acero, F.; Aharonian, F.; Akhperjanian, A.G.; Anton, G.; Balzer, A.; Barnacka, A.; Barres de Almeida, U.; Becherini, Y.; Becker, J.; et al. The 2010 Very High Energy γ-Ray Flare and 10 Years of Multi-wavelength Observations of M 87. **2012**, *746*, 151, [arXiv:astro-ph.CO/1111.5341]. doi:10.1088/0004-637X/746/2/151.
104. EHT MWL Science Working Group.; Algaba, J.C.; Anczarski, J.; Asada, K.; Baloković, M.; Chandra, S.; Cui, Y.Z.; Falcone, A.D.; Giroletti, M.; Goddi, C.; et al. Broadband Multi-wavelength Properties of M87 during the 2017 Event Horizon Telescope Campaign. **2021**, *911*, L11, [arXiv:astro-ph.HE/2104.06855]. doi:10.3847/2041-8213/abef71.
105. Albert, J.; Aliu, E.; Anderhub, H.; Antoranz, P.; Baixeras, C.; Barrio, J.A.; Bartko, H.; Bastieri, D.; Becker, J.K.; Bednarek, W.; et al. MAGIC observations of PG 1553+113 during a multiwavelength campaign in July 2006. **2009**, *493*, 467–469, [arXiv:astro-ph/0812.3037]. doi:10.1051/0004-6361:20079048.
106. Aleksić, J.; Anderhub, H.; Antonelli, L.A.; Antoranz, P.; Backes, M.; Baixeras, C.; Balestra, S.; Barrio, J.A.; Bastieri, D.; Becerra González, J.; et al. Simultaneous multi-frequency observation of the unknown redshift blazar PG 1553+113 in March-April 2008. **2010**, *515*, A76, [arXiv:astro-ph.HE/0911.1088]. doi:10.1051/0004-6361/200913607.
107. Aleksić, J.; Alvarez, E.A.; Antonelli, L.A.; Antoranz, P.; Asensio, M.; Backes, M.; Barrio, J.A.; Bastieri, D.; Becerra González, J.; Bednarek, W.; et al. PG 1553+113: Five Years of Observations with MAGIC. **2012**, *748*, 46, [arXiv:astro-ph.CO/1101.2764]. doi:10.1088/0004-637X/748/1/46.
108. Ackermann, M.; Ajello, M.; Albert, A.; Atwood, W.B.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Becerra Gonzalez, J.; Bellazzini, R.; et al. Multiwavelength Evidence for Quasi-periodic Modulation in the Gamma-Ray Blazar PG 1553+113. **2015**, *813*, L41, [arXiv:astro-ph.HE/1509.02063]. doi:10.1088/2041-8205/813/2/L41.
109. Covino, S.; Landoni, M.; Sandrinelli, A.; Treves, A. Looking at Blazar Light-curve Periodicities with Gaussian Processes. **2020**, *895*, 122, [arXiv:astro-ph.HE/2004.10763]. doi:10.3847/1538-4357/ab8bd4.
110. Peñil, P.; Domínguez, A.; Buson, S.; Ajello, M.; Otero-Santos, J.; Barrio, J.A.; Nemmen, R.; Cutini, S.; Rani, B.; Franckowiak, A.; et al. Systematic Search for γ-Ray Periodicity in Active Galactic Nuclei Detected by the Fermi Large Area Telescope. **2020**, *896*, 134, [arXiv:astro-ph.HE/2002.00805]. doi:10.3847/1538-4357/ab910d.
111. De Lotto, B.; Magic Collaboration. The MAGIC telescopes: performance, results and future perspectives. Journal of Physics Conference Series, 2012, Vol. 375, *Journal of Physics Conference Series*, p. 052021. doi:10.1088/1742-6596/375/1/052021.
112. Albert, J.; Aliu, E.; Anderhub, H.; Antoranz, P.; Armada, A.; Asensio, M.; Baixeras, C.; Barrio, J.A.; Bartko, H.; Bastieri, D.; et al. Observation of Very High Energy Gamma-Ray Emission from the Active Galactic Nucleus 1ES 1959+650 Using the MAGIC Telescope. **2006**, *639*, 761–765, [arXiv:astro-ph/astro-ph/0508543]. doi:10.1086/499421.
113. MAGIC Collaboration.; Acciari, V.A.; Ansoldi, S.; Antonelli, L.A.; Arbet Engels, A.; Baack, D.; Babić, A.; Banerjee, B.; Barres de Almeida, U.; Barrio, J.A.; et al. Broadband characterisation of the very intense TeV flares of the blazar 1ES 1959+650 in 2016. **2020**, *638*, A14, [arXiv:astro-ph.HE/2002.00129]. doi:10.1051/0004-6361/201935450.

114. Bionta, R.M.; Blewitt, G.; Bratton, C.B.; Casper, D.; Ciocio, A.; Claus, R.; Cortez, B.; Crouch, M.; Dye, S.T.; Errede, S.; et al. Observation of a neutrino burst in coincidence with supernova 1987A in the Large Magellanic Cloud. **1987**, *58*, 1494–1496. doi:10.1103/PhysRevLett.58.1494.
115. Actis, M.; Agnetta, G.; Aharonian, F.; Akhperjanian, A.; Aleksić, J.; Aliu, E.; Allan, D.; Allekotte, I.; Antico, F.; Antonelli, L.A.; et al. Design concepts for the Cherenkov Telescope Array CTA: an advanced facility for ground-based high-energy gamma-ray astronomy. *Experimental Astronomy* **2011**, *32*, 193–316, [arXiv:astro-ph.IM/1008.3703]. doi:10.1007/s10686-011-9247-0.