The MAGIC telescopes: performance, results and future perspectives

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Abstract. MAGIC (Major Atmospheric Gamma–ray Imaging Cherenkov) is a two 17 meter diameter telescope system, located at the Roque de los Muchachos Observatory in the Canarian island La Palma (Spain) at a height of 2240 m.a.s.l., operating in stereoscopic mode since fall 2009. We report on the performance of the instrument and highlight selected recent results from observations. The future perspectives are also illustrated.

1. Performance of the stereo system
The MAGIC telescopes (Fig. 1) are the largest single dish IACTs (Imaging Atmospheric Cherenkov Telescope) built: this permitted to achieve the lowest energy threshold for VHE γ-ray detection, estimated to be \( \sim 50 \text{ GeV} \), closing the gap between space-borne and ground-based instruments. Fig. 2 shows the integral sensitivity of the instrument as a function of energy: it is 0.76% Crab units above 300 GeV (for 50 h integration). With respect to single telescope observations, a factor 2 to 3 improvement in significance is achieved. Stereo observations result in a significant improvement both in angular and spectral resolution. An angular resolution of 0.07° is reached at 300 GeV. The best spectral resolution, \( \Delta E/E \sim 16\% \), is reached at a few hundred GeV. More details about the instrument performance can be found in [1].

Figure 1. A picture of the two MAGIC telescopes at the Roque de los Muchachos observatory.

Figure 2. Integral sensitivity of the MAGIC stereo system.
2. Galactic observations

2.1. Crab Nebula and Pulsar

The improved sensitivity of the instrument and the large stereo data sample, together with the low energy threshold, have allowed us to pinpoint the inverse Compton (IC) peak in the VHE spectrum of the Crab Nebula, considered to be the standard candle of VHE astronomy. Fig. 3 from [2] shows the combined fit of the Fermi/LAT and MAGIC data to a curved power law, along with results from other IACTs. The peak of the IC component is found to occur at $59 \pm 6$ GeV (statistical errors only).

Based on mono data, MAGIC had observed pulsed emission from the Crab pulsar above 25 GeV and a hint for emission above 60 GeV [3]. More recently the analysis of 73 hours of new stereo data have allowed us to detect pulsed emission up to 400 GeV (for details see this Conference Proceedings and [4]).

After recent reports of fast variability at GeV and TeV energies, MAGIC has searched for daily variations of the Crab Nebula flux over the above-mentioned data sample: the flux was found to be steady within statistical errors.

2.2. Extended sources

MAGIC stereo observations allow us to extract relatively high-resolution sky maps with $E \geq 100$ GeV. The emission measured by MAGIC from the field of view of the SNR W51C [5] shows that the bulk of the observed VHE $\gamma$-rays come from where the SNR shell collides with a large molecular cloud (the latter is seen in radio data), thus suggesting that the $\gamma$-ray emission is most likely of hadronic origin.

2.3. $\gamma$-ray Binaries

Thanks to the increased sensitivity of the stereo system, the extensively studied periodic source LS I+61 303 has been detected by MAGIC [6] at a flux of less than 5% of Crab during a low emission state in 2009. MAGIC also detected in 2011, in coincidence with a X-ray outburst, the variable source HESS J0632+057 [7].

![Figure 3. Spectral Energy Distribution of the Crab Nebula obtained with the MAGIC telescopes, together with Fermi/LAT data and previous results from IACTs.](image1)

![Figure 4. Spectral energy distribution of Mrk 421 averaged over all the observations taken during the multifrequency campaign from in 2009.](image2)
3. Extragalactic observations

3.1. Blazars
Blazars constitute the vast majority of extragalactic sources detected at VHE. About 50 blazars have been so far detected in this energy range, 14 of them by MAGIC. During this conference the recent detection of IES0647+250, a BL Lac object of redshift \( z \sim 0.45 \), was announced (a paper is currently in preparation).

MAGIC has organized several multiwavelength observations involving many instruments. Simultaneous broad-band SEDs are key for blazars modeling: this is well illustrated by recent simultaneous observations of Mrk 421 as shown in Fig. 4 from [8].

3.2. Quasars
New classes of VHE active galaxies different from blazars have been established by IACTs. Quasars are distant objects: the flux of \( \gamma \)-rays of GeV to TeV energies is attenuated due to their interaction with the Extragalactic Background Light (EBL). Decreasing the energy threshold then is crucial to detect such distant sources: MAGIC has detected two out of three quasars known to emit at VHE. 3C 279 (\( z=0.536 \)), the farthest VHE source detected so far, was discovered by MAGIC at VHE in 2006 [9] and allowed to place constraints on the EBL density.

A second quasar, PKS 1222+21 (\( z=0.432 \)), has been discovered by MAGIC in 2010 [10]. It shows significant flux variability and no sign of cutoff. The spectrum is shown in Fig. 5, where the correction by EBL absorption using the model [11] has been taken into account. The combined Fermi/LAT and MAGIC data constrain the EBL density in the UV-optical to near-IR range.

![Figure 5. High energy SED of PKS 1222+21 during the flare of June 2010, showing Fermi/LAT (squares) and MAGIC (circles) differential fluxes.](image)

![Figure 6. Spectrum of electrons and positrons measured with MAGIC, along with other measurements from instruments on orbit, balloons and IACTs.](image)

3.3. Radiogalaxies
MAGIC detected three out of four known VHE radiogalaxies, i.e. M 87 [12] [13], NGC 1275 [14], and IC 310 [15], both in the Perseus cluster. The detection of NGC 1275, with its very steep spectrum, was possible thanks to the stereo improved sensitivity at \( E < 200 \) GeV. IC 310 is the only radiogalaxy of the “head-tail” type detected so far.
4. Cosmic rays
IACTs may discriminate showers initiated by electrons or positrons from the background of hadronic cosmic ray showers through the image shape analysis. A sample of 14 hours of extragalactic observations has allowed to measure the combined $e^-/e^+$ spectrum in the energy range between 100 GeV and 3 TeV [16]. Preliminary results are shown in Fig. 6: the spectrum is in good agreement with previous measurements.

Electrons and positrons deflect in opposite directions in the geomagnetic field: their shadows do not coincide, which makes possible to measure the ratio of electrons to positrons in the energy range from 300 - 700 GeV, an energy band not reached by Pamela. MAGIC has carried out such challenging observations in 2010 and 2011 [17].

5. MAGIC Upgrade
The MAGIC telescopes were shut down in Summer 2011 to perform a major hardware intervention: both telescopes will be equipped with a new 2 GSamples/s readout based on DRS4 chip.

In the Spring of 2012 the camera of MAGIC-I will be upgraded to match the camera geometry and trigger area of MAGIC-II, and both telescopes will be equipped with “sumtrigger” covering the total conventional trigger area [18]. We expect an improvement in sensitivity, a better performance for extended sources, and a further reduction of the energy threshold. Moreover, having same hardware on both telescopes will make maintenance and operation easier.

6. Conclusions
The MAGIC telescopes have now been operating for two years in stereoscopic mode. The performance of the instrument has been evaluated: the threshold energy has decreased to 50 GeV, the integral sensitivity at its optimal range above 300 GeV is 0.76% Crab units. After almost two years of operations in stereo mode the system has confirmed its capabilities, being the most sensitive observatory in the range 50 - 200 GeV. A reach harvest of scientific results is expected after the current upgrade of the telescopes is completed in Spring 2012.

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