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Highlight results from the MAGIC telescopes

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Summary. — The MAGIC telescopes are a couple of IACT (Imaging Atmospheric Cherenkov Telescopes) located in the Canary island of La Palma. The first telescope, named MAGIC I, has operated since 2004, while the second telescope, MAGIC II, was inaugurated in September 2009. Since then the two instruments have worked simultaneously and have taken data in stereoscopic mode. The telescopes are characterized by a reflective surface of 17 meters of diameter and by an ultra-fast electronics. A key feature of MAGIC is the energy threshold of $\sim 50\,\mathrm{GeV}$, the lowest among the existing IACT. This peculiar threshold allows a superposition of the energy spectra observed by MAGIC with those obtained with gamma-ray satellites, observing up to several hundred GeV. In this contribution we present the main scientific achievements recently obtained by MAGIC in the observation of both galactic and extragalactic objects. The future perspectives are also discussed.

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1. – Introduction

The Very High Energy (VHE) γ-ray domain of the electromagnetic spectrum conventionally includes photons from 100 GeV to some tens of TeV. Only a hundred of celestial objects are known up to now as VHE γ-ray emitters, as shown in fig. 1. These sources are both of galactic and extragalactic origin. Supernova remnants (SNR), pulsars, and pulsar wind nebulae (PWN) belong to the former category and active galactic nuclei (AGN) and starburst galaxies belong to the latter.

These detection have been made possible thanks to the observations of the imaging atmospheric Cherenkov telescopes (IACT). The current generation of such instruments includes MAGIC, H.E.S.S., and VERITAS, IACT located respectively in the Canary islands, Namibia, and Arizona. In this contribution, we present some selected MAGIC results.

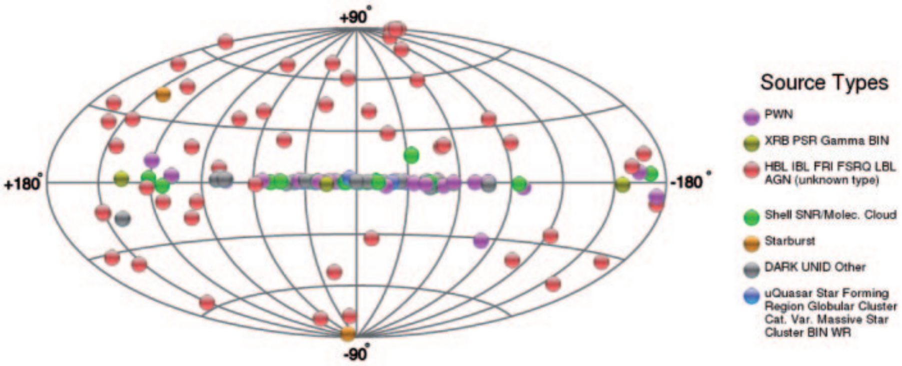

Fig. 1. – Map of known VHE photons emitters, from `http://tevcat.uchicago.edu/`.

1·1. *MAGIC: a low-energy threshold IACT.* – MAGIC (major atmospheric gamma–ray imaging Cherenkov telescopes) is a system of two 17 meters IACT located at the Observatorio del Roque de los Muchachos in the island of La Palma, at 2200 meters above sea level (fig. 2). The first telescope, MAGIC I, has been in operation since 2004 while the stereoscopic system has been operating since 2009. MAGIC cameras and trigger are designed to record data not only during dark nights, but also under moderate light conditions (*i.e.* moderate moon, twilight). The light structure of the telescopes made of ultralight carbon fiber frame allows fast repositioning (less than 20 seconds for a 180° repositioning). This feature is very important for fast follow-up observation of transient objects such as gamma-ray bursts (GRBs), although no TeV emission from GRBs has been detected as of today.

The performances of the MAGIC stereoscopic system are reported in table I [1]. The energy threshold of 50 GeV (or 25 GeV with special trigger setup) is the lowest threshold among the existing IACT, making MAGIC the best instrument to investigate the distant universe. This threshold allows also a partial overlap with *Fermi*/LAT data [2].

The MAGIC scientific program covers different aspects of high-energy astrophysics, that can be synthesized in the following two broad categories:

Fig. 2. – The MAGIC telescopes. Credits R. Wagner.

Table I. – *The MAGIC telescopes main characteristics.*

Energy Threshold	50 GeV
Field of view	3.5°
Energy Resolution ($E > 300\,\mathrm{GeV}$)	16%
Angular Resolution ($E > 300\,\mathrm{GeV}$)	0.07°
Sensitivity ($E > 250\,\mathrm{GeV}$)	0.8% Crab Nebula flux

Source detection and monitoring: one of the main goals of MAGIC is the discovery of new VHE sources (both galactic and extragalactic) aimed to populate the VHE γ-ray sky. In addition, the long-term monitoring of the emission from known sources allows to investigate its origin, in particular when correlated with simultaneous multi-wavelength observations.

Cosmology and fundamental physics: γ-ray propagation in the intergalactic space is tested by MAGIC through the observation of distant sources (*e.g.*, 3C 279). Moreover, fundamental physics, such as the origin of cosmic rays, dark matter searches and the possible tests of Lorentz invariance violations, are also investigated by the MAGIC Collaboration.

2. – Highlights results

In this section we present a brief overview of a selection of important results recently achieved by MAGIC.

2·1. *Galactic objects: the Crab Nebula.* – The Crab nebula PWN was the first VHE source discovered [3] and for this reason is the one of the best studied sources of the γ-ray sky. Despite that, some characteristics, such as the contribution of the various soft radiation fields to its high-energy emission, the strenght of the internal magnetic field, and the maximum energies reached by primary electrons are still largely debated.

MAGIC recorded almost 50 hours of Crab Nebula data in stereoscopic mode between October 2009 and April 2011. Analysis of this data sample using the latest improvements in the MAGIC stereo software provided an unprecedented differential energy spectrum spanning three decades in energy, from 50 GeV up to 45 TeV [4]. The spectral energy distribution (SED) of the high energy domain (*Fermi*/LAT data from [5] together with VHE data) is drawn in fig. 3. In order to estimate the position of the peak we fitted a variable power-law function to our data combined with the *Fermi*/LAT data points. The fit accounts for the correlation in MAGIC data point and considers statistical errors only. The obtained fit peaks at $59 \pm 6\,\mathrm{GeV}$. This is the most precise measurement of the high-energy peak location ever performed for this source.

Since a flaring activity at high energy γ rays (below 100 GeV) was detected by both *Fermi*/LAT and AGILE in September 2010 and April 2011 [5-8], we investigated the flux stability on timescale of days. We have found a stable flux within the systematic uncertainty with a probability of 95%. MAGIC observed the Crab Nebula for one night during the "GeV flare" period, on September 20, 2010. The obtained flux is perfectly compatible with the average flux of all the nights within the statistical error. A preliminary analysis of April 12–14, 2011 data, simultaneous with the second flare detected, also shows no increase in flux.

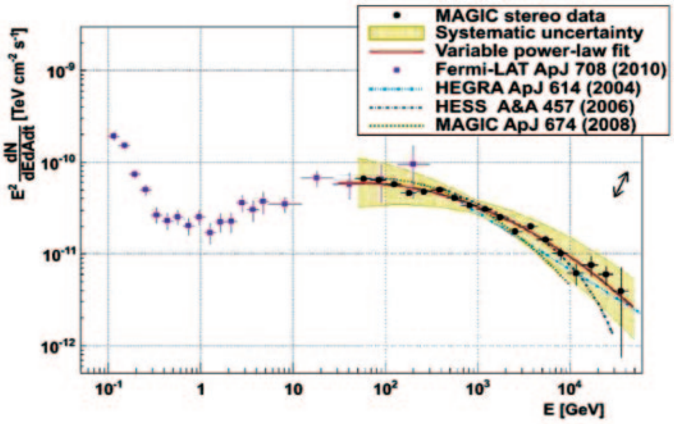

Fig. 3. – Spectral energy distribution of the Crab Nebula obtained with the MAGIC telescopes, together with the results from other γ-ray experiments. The black arrow indicates the systematic uncertainty on the energy scale. Adapted from [4].

2·2. *Extragalactic objects*

2·2.1. The SED of Mkn 421. A second example of the great capabilities of MAGIC is represented by the results obtained during the campaign on Mkn 421. This source is a blazar, *i.e.* an AGN with a jet almost pointing toward the observer. The observed radiation is therefore almost completely dominated by the jet emission, and is largely variable. Given this variability, it is essential to observe the source with simultaneous multi-frequencies campaigns. A multi-frequency campaign, from radio to TeV energies, was organized by the *Fermi*/LAT team from 2009 January 19 to 2009 June 1 [9]. During this campaign, Mrk 421 showed a low activity at all wavebands. The overall SED of Mrk 421 resulting from the observations is drawn in fig. 4, left panel, and represents an unprecedented, complete look at the quiescent SED for this source. The broad band SED was reproduced with a leptonic (one-zone Synchrotron Self-Compton) and a hadronic model (Synchrotron Proton Blazar).

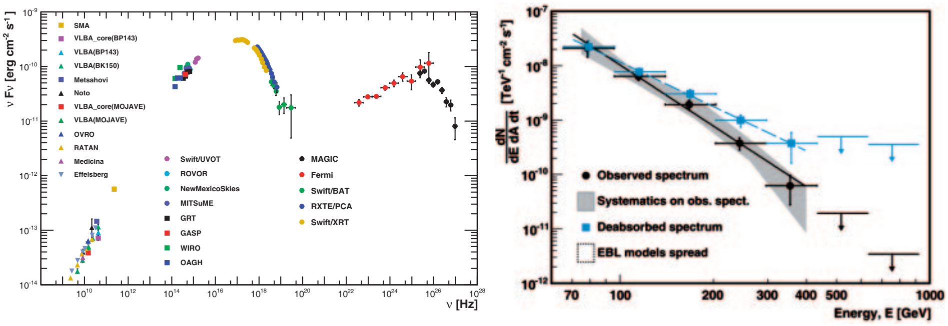

Fig. 4. – Left panel: SED of Mkn 421 during the multi-wavelength campaign from 2009 January 19 to 2009 June 1 [9]. Right Panel: Differential energy spectrum of PKS1222+21 as measured by MAGIC on 2010. From [12].

2˙2.2. Distant FSRQ: 3C 279 and PKS 1222+21. Flat spectrum radio quasars (FSRQ) are distant AGN and therefore can be used to constrain the level of Extragalactic Background Light (EBL), the diffuse light which attenuates the flux of VHE γ-rays [10]. 3C 279, a FSRQ located at $z = 0.536$, is the farthest VHE source detected so far. It was discovered by MAGIC at VHE in 2006 [11] and allowed to place very strong constraints on the density of EBL. A second FSRQ, PKS 1222+21 (4C+21.35, $z = 0.432$), has been recently discovered by MAGIC [12]. The VHE flux varies significantly within the 30 minutes of exposure implying a flux doubling time of about 10 minutes. The short variability timescale suggests a compact emission region near the central engine which is somehow in contradiction with the absence of a spectral cut off. The spectrum, corrected for the absorption by the EBL, can be in fact well described by a single power law (fig. 4 right panel). The absence of the cutoff constrains the γ-ray emission region to lie in an outer region of the jet. This apparent contradiction, confirmed also by recent MAGIC observations of 3C 279 [13], challenges present emission models from jets in FSRQs.

3. – Conclusions and outlook

In conclusion, MAGIC is an instrument that in these 7 years of operations, out of which 3 in stereoscopic mode, obtained significant results both in galactic and extragalactic astrophysics. Regarding the near future, MAGIC is undergoing a major upgrade scheduled to finish in late 2012 and involving the readout system, the camera of the first telescope and the trigger. After the upgrade, we expect an improvement in sensitivity for point sources and significantly better performance for extended sources. In addition we aim at a reduction of the energy threshold. The intervention also aims at making the hardware of both telescopes essentially equal, thereby making the maintenance and operation easier in the future.

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REFERENCES

[1] Aleksić J. *et al.*, *Astropart. Phys.*, **35** (2012) 435.
[2] Atwood W. B. *et al.*, *Astrophys. J.*, **697** (2009) 1071.
[3] Weekes T. C. *et al.*, *Astrophys. J.*, **342** (1989) 379.
[4] Zanin R. *et al.*, preprint arXiv:1110.2987.
[5] Abdo A. *et al.*, *Astrophys. J.*, **708** (2010) 1254.
[6] Tavani M. *et al.*, *Science*, **331** (2011) 736.
[7] Buehler R. *et al.*, *Astrophys. J.*, **749** (2012) 26.

[8] STRIANI E. *et al.*, *Astrophys. J. Lett.*, **741** (2011) L5.
[9] ABDO A. *et al.*, accepted for publication in *Astrophys. J.*, preprint arXiv:11061348.
[10] STECKER F. W., DE JAGER O. C. and SALAMON M. H., *Astrophys. J. Lett.*, **390** (1992) 49.
[11] ALBERT J. *et al.*, *Science*, **320** (2008) 1752.
[12] ALEKSIĆ J. *et al.*, *Astrophys. J. Lett.*, **730** (2011) L8.
[13] ALEKSIĆ J. *et al.*, *Astron. Astrophys.*, **530** (2011) A4.