Status and results of the MAGIC telescope

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Abstract. The MAGIC telescope is an imaging air Cherenkov telescope for very high energy gamma-ray astronomy. The scientific outcome of MAGIC at the end of its second cycle of observations includes outstanding results in both galactic and extragalactic physics. Among them the observation of periodic gamma-ray emission from the galactic binary system LSI+61, an unprecedented fast variability in the flux of the active galaxy Mrk 501 and the discovery of several new gamma-ray sources. The status and ongoing upgrades of the experiment, and a review of the main physics results are presented.

1. Introduction
The field of very high energy (VHE) $\gamma$-ray astrophysics has experienced an extraordinary boost in recent years. With the upcoming of a new generation of imaging air Cherenkov telescopes (IACT) like MAGIC, HESS and CANGAROO, the number of detected sources has increased from less than 10 in 2003 to more than 70 by July 07 [1]. The improved sensitivity of these new instruments not only allows the detection of fainter sources but also a more detailed study of flux and spectrum variability, and of the source morphology. In the following sections the current status and future upgrade plans of MAGIC, as well as a few highlights of the contribution of the MAGIC collaboration to the field of VHE astrophysics are presented.

2. MAGIC
The MAGIC telescope is a single-dish IACT. It is located in the Roque de Los Muchachos observatory on the Canary Islands at 2200m a.s.l. It became operational in October 2003 and started regular observations in early 2005. Now it is starting its third observation cycle.

2.1. Status
With a 17m composite reflector and a camera with 577 high QE PMTs, MAGIC is suited for astrophysical observations in the VHE domain with an energy threshold of about 50 GeV at trigger level. The camera and PMT design allows observations under moderate moonlight, increasing the observation time of the telescope by 50%. The reflector and camera are mounted in a light carbon fibre frame that allows an average slewing time between two arbitrary sky positions below 42s. The data collected in the camera are transferred using analog optical fibers to the readout system in the control house, where they are digitized and stored. In February 2007 the DAQ system was upgraded from a 300 MSamples/s to a novel 2GSamples/s FADC [2].
2.2. MAGIC II
A second telescope will be operational by late 2008 [3]. It will run together with the first telescope in stereoscopic mode for enhanced background suppression. Improvements with respect to the first telescope include a major redesign of the camera, the use of higher QE PMTs, a larger trigger area, improved optics and a redesigned readout system that will also use 2 GSamples/s FADC. With the new telescope we expect an improvement of the sensitivity of a factor 2.

2.3. Shower arrival time in data analysis
The MAGIC readout system not only extracts the pixel charge information for each pixel, but also the arrival time of the signal. With the recent FADC upgrade the time extraction resolution has been improved down to 390 ps. New image parameters that make use of time have been defined and used in the data analysis to help in the discrimination of the hadronic background images. This leads to a sensitivity improvement of about 40% in the whole energy range [4].

3. Review of the results of the physics programs
In this section selected results of the different physics programs in the MAGIC collaboration are presented. For a complete list of publications, see [5].

3.1. Galactic sources
Crab Nebula  The Crab Nebula is the standard candle for VHE astrophysics and one of the most widely studied objects. MAGIC observations of the Crab Nebula [6] benefit from the low energy threshold to reveal the curvature of the spectral energy distribution. This feature is consistent with the Self Synchrotron Compton emission models, with the Inverse Compton (IC) peak located at $77 \pm 47$ GeV.

LS I +61 303  The emission of VHE $\gamma$-rays from the binary system LS I +61 303 was discovered by MAGIC [7]. The whole orbit has been covered by the observations, which amount to about 170h and include data taken with moderate moonlight. The emission has been found to be variable with a maximum around orbital phases 0.5 to 0.8 but also with some high flux episodes outside this range [8]. The periodicity of this emission is still under study.

3.2. Extragalactic sources
Mkn 501  Episodes of intense VHE activity of Mkn 501 were detected in June and July 2005 [9], with rapid flux variations with doubling times as short as 2 minutes. A study on the different flux levels showed a clear correlation between the object luminosity and the position of the IC peak. The light curve for one of the high flux episodes showed also a time lag of 4 minutes between the arrival time of the high energy and the low energy $\gamma$-rays. This effect is compatible with a time delay depending linearly on the energy.

BL Lacertae  This is the first low-peaked BL Lac (LBL) object detected in the VHE regime. LBLs are a subclass of Active Galactic Nuclei disfavoured for having VHE $\gamma$-ray emission. MAGIC detected it during the 2005 campaign coincident with an optical high state [10]. No signal was detected in 2006 observations during a low optical state, suggesting a variability.

High redshift sources  VHE $\gamma$-rays are absorbed by the Extragalactic Background Light (EBL) as they traverse the universe. The observations of high redshift sources can help us determine the not well known EBL density [11]. MAGIC has recently added two new high redshift sources to the VHE catalog: 1ES 1011+496 [12] with $z=0.212$, and 3c279 [13] with $z=0.536$. The discovery of 3c279 opens a window to the detection of other distant sources.
3.3. **Gamma Ray Bursts**  
The fast repositioning and the low energy threshold system makes MAGIC the best suited IACT for the observation of prompt Gamma Ray Burst (GRB) VHE $\gamma$-ray emission. In the first two years of operation we have pointed at 23 GRB candidates, 2 of them in prompt emission phase, and published upper limits on 9 of these objects [14].

3.4. **Other programs**  
Other observational programs include the search for pulsed $\gamma$-rays, the indirect search for dark matter looking for neutralino annihilation signatures [15, 16], a viability study of a special observation mode for indirect detection of $\nu_\tau$ [17, 18], and the use of fast variability episodes of distant $\gamma$-ray sources to constraint the quantum gravity scale [19].

4. **Target of Opportunity observations**  
MAGIC target of opportunity (ToO) observations can be externally triggered. Reciprocal agreements exist with instruments in the optical, X-ray and VHE $\gamma$-ray bands. Trigger conditions based on the flux level are defined for a list of monitored sources. The ToO program has proven to be very successful. The discovery of two new VHE sources, Mkn180 [20] and 1ES 1011+496 [12], has been triggered by optical high states [21]. A possible correlation between the optical and the VHE bands is still to be proven.

5. **conclusions**  
The MAGIC telescope has been taking data for more than two years. The scientific outcome produced in this period has established it as a main actor in the field of VHE astrophysics. With the use of the recently developed analysis techniques and the future hardware upgrades, we expect to increase its scientific output in forthcoming years.

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