Status of the MAGIC Telescope

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Abstract

The status of the 17 m diameter imaging air Cherenkov telescope MAGIC will be reviewed.

1. Introduction

A new window in very high energy (VHE) gamma-ray (γ) astronomy has been opened by the discovery of the first TeV γ-source, the CRAB Nebula, by the Whipple collaboration in 1989 [1]. In the following years a few more VHE γ-sources have been discovered in the 350 GeV - 10 TeV energy range. All discoveries were made by so-called imaging air Cherenkov telescopes (IACT), which had a lower threshold, higher sensitivity and superior γ/hadron (γ/h) separation power compared to other contemporary ground-based detectors. Soon after the observation of the first VHE γ-sources it became evident that better detectors with much lower threshold and higher sensitivity were needed. First ideas for a very large diameter, new technology telescope, dubbed MAGIC (Major atmospheric Gamma Imaging Cherenkov) telescope, were presented in 1995, refs. [2], [3]. Preceding discussions concentrated on either a single very large IACT with a threshold close to 10 GeV or a more conventional solution of a multi-telescope system based on the proven type of 10 m class telescopes, albeit with a higher threshold. A cost and physics comparison led to the conclusion that a single very large diameter (VLD) IACT would be cheaper and would allow for a lower threshold compared to the "conventional" multi-telescope arrangement with 10 m mirror dishes. The single VLD telescope would have a somewhat lower sensitivity at higher energies. It was considered to be too risky to construct already at the beginning an array of the new technology VLD telescopes without having proved the validity of the new technologies.

A collaboration was formed to build at first a single 17 m diameter telescope and it was decided that only after the successful demonstration of the new technologies one would embark on the increase in sensitivity by building a telescope system.

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The new elements proposed for the telescope were:

i) A 17 m diameter mirror mounted on a lightweight space frame made from carbonfiber reinforced tubes.

ii) A tessellated mirror of 940 diamond turned all-aluminum elements, [4], with internal heating in order to reduce weight, production time and cost. The diamond turning technique would allow for ease in generating mirrors of different curvature to achieve an overall parabolic profile, i.e., a profile to minimize timespread of the Cherenkov light flash at the camera level.

iii) A novel active mirror control (AMC) to allow for rapid corrections of residual deformations of the large spaceframe, [5].

iv) A fine pixelized camera using high quantum efficiency (QE), red extended, fast photomultipliers (PMT)

v) Signal transmission to a distant counting house (needed for a later multitelescope system) by means of optical fibers operated in the analog mode in order to achieve very high bandwidth and to replace bulky, low loss coax cables, [6].

vi) A multilevel trigger and a 300 MHz FADC system for pulse digitization.

Further details can be found in [7]. The proposed elements for i), ii), iii), iv), v) and in part for vi) had never been used beforehand in IACTs. Following an outside reviewer's recommendation, the use of the high QE, red-extended PMTs was postponed because the technology of production was not yet mature and the costs for the telescope would have been nearly doubled. Nevertheless, improved PMTs with bialkali cathodes (see below) were to be tried.

Two other design goals were pursued, a) the ability to reposition the telescope within 20 sec to any position in the sky in order to respond quickly on GRBs (this needs a fast alert from satellite borne detectors) and b) the ability to observe during moonshine, albeit with a higher threshold (see below). Observation during moonshine has been successfully demonstrated by the HEGRA collaboration with the so-called prototype CT1 telescope and turned out to be important for the study of rapidly flaring objects. Being able to observe during moonshine will basically double the chances to observe the rare GRBs. The proposal was put forward in 1998, and fundings for the major investments were approved at the end of the year 2000. Construction started immediately afterwards.

2. Physics goals

The full extent of the current physics objectives of MAGIC cannot be discussed here. Therefore, only the main goals are listed:

1) Search for Active Galactic Nuclei (AGN) with a redshift up to z = 2 to 3. These observations should shed light onto intrinsic γ production processes in AGNs, black holes and indirectly about the cosmological infrared (IR) background from γ-absorption processes (γ horizon).

2) Search for recently (up to a few 10^4 years ago) exploded Super Novae. The remnants are considered to be efficient particle accelerators and thus likely to be the origin of the charged CRs.

3) Study of Plerions (Pulsars) which are expected to show in certain energy bands pulsed γ emission, i.e., to test of the validity of the polar cap or the outer gap model. A low telescope threshold, as close as possible to 10 GeV, is essential.

4) Contributing to the identification of the so-called unidentified EGRET sources.

5) Diffuse γ emission from the galactic plane (from charged CRs interacting with the interstellar gas, e.g., information about the gas (dust) density in the galactic plane)

6) Gamma-Ray bursts (GRB) which occur 1–2 times per day and are still in many aspects enigmatic.

7) Search for possible Topological Defects left over from the early universe

8) Search for the lightest supersymmetric particles. γs would be generated in annihilation processes.

9) Tests of quantum gravity effects.

3. Essential telescope parameters and present status.

The main telescope parameters are:

Telescope type, position precision	alt-azimuth, $\approx 0.02\ ^\circ$, augmented by star lock-on
Total weight of moving parts	60 tons
Mirror diameter, area and profile	17 m, 234 m^2, parabolic profile, f/d $\approx$ 1

Mirror elements	940, 49.5x49.5 cm^2, all-aluminum sandwich construction, 4 kg/element, diamond turned surface, quartz coated, integrated heating
Point spread function	typ. 0.03°
Mirror support structure	3-layer space frame made of CF reinforced tubes
Weight of mirror support structure	8.9 tons including camera support masts and declination drive ring
Camera FOV and pixel size	$\approx 4°$ (hexagonal layout) central section with 396 Pixels of 0.1° and outer ring with 200 0.2° pixels
PMTs	Type 9116 A for inner section, and type 9117 A for outer section. PMTs from Electron Tubes
Trigger	3-level trigger using FPGAs allowing for 3,4,5 next-neighbor coincidence and simple pattern selection
DAQ, rate	300 MHz FADCs, aiming for 1 kHz data rate
Costs	4.5 M$ (not including development costs)

Construction of the foundation started in September 2001, and the telescope frame was completed in December 2001. The assembly of the frame took only one month because of a construction based on the so-called tube and knot system of the company MERO. This system allowed assembling the entire frame without any welding. Mirror installation commenced in summer 2002, and up to now 99 m^2 of mirror area has been completed (final completion is foreseen in spring 2003 because the funding profile did not allow to complete mirror production in due time). The AMC proved to be very precise and fast responding although the complete test can only be carried out after the completion of the mirror. The camera will be mated with the telescope in November and hopefully first test data will be taken in December or January. If no unexpected difficulties arise, the data taking with the full telescope will start in mid 2003.

4. Some technical details

One of the challenges in the construction of detectors for γ-astronomy is to increase the photoelectron yield per given shower energy. Besides an increase of the mirror area the photon to photoelectron conversion yield can be optimized.

(i) To operate the PMTs with a rather high voltage between cathode and first dynode to maximize the electron collection efficiency in the PMT front-end.

(ii) A light catcher geometry that maximizes the chances that the photon trajectories pass the semitransparent hemispherical photocathode twice, [8].

(iii) To overcoat the cathode with a wavelength shifter doped, diffuse lacquer [8].

The latter two modifications increase the QE by a factor of ≈ 1.3.

We are testing a new lining of the light catchers with a dielectric mirror foil of a reflectivity close to 98%. This should increase the conversion efficiency by another 15–20%. For the study of intense, variable sources such as flaring AGNs and also to increase the chances to detect GRBs we intend to operate the telescope also during moonshine. Therefore we selected PMTs with only 6 dynodes and operate them at a low gain of $2x10^4$. To make up for the low gain, the PMTs are followed by AC coupled, fast transimpedance amplifiers.

5. Summary

The MAGIC telescope is in its final phase of assembly, and it is expected that operations will start soon. All the new technical components function as expected although some final tests are still missing. In view of the technical progress made over the last years, the originally seemingly bold proposals are now relatively conservative and even better solutions are visible. Therefore an upgrade program is already under discussion concentrating on improving MAGIC I as well as adding an improved MAGIC II to the installation on La Palma, see contribution by R. Mirzoyan to this conference. The addition of more telescopes opens both the possibilities to observe more than one source at a time as well as to carry out more precise measurements in the so-called stereo mode.

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