ICRC'07 Mérida, México

The reflecting surface of the MAGIC-II Telescope

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Abstract: The MAGIC Collaboration is building a clone, MAGIC II, of the current MAGIC Telescope. MAGIC II is being built at $85\,\mathrm{m}$ of distance from MAGIC I, and will also feature a huge reflecting surface of $\sim 240\,\mathrm{m}^2$ of area. Unlike the former telescope, the mirrors for the new one are lighter and larger, being square of $1\,\mathrm{m}$ of side and weighting around $15\,\mathrm{kg}$. For the development and production of the new mirrors, two different techniques, both reliable and affordable in price, were tested. We present a description of these two techniques and the performance of the resulting mirrors.

Introduction

MAGIC the *Major Atmospheric Gamma Imaging Cherenkov* Telescope, was designed to be *the* Cherenkov telescope with the lowest envisaged energy threshold. It was built by an international collaboration at the Roque de Los Muchachos ($2,200\,\mathrm{m}$ of altitude), a volcano rim in the island of La Palma, Canaries. Many technical developments were necessary to lower the energy threshold, but the expected scientific outcome was widely repaying the burdens of the construction.

There exists in fact an observational gap in the electromagnetic spectrum: celestial bodies are studied using both satellite-borne detectors and instruments well rooted to the Earth surface. On the one hand, satellite-detectors have to clash with the poor statistics of high-energy events or, equivalently, with the limited amount of weight available to calorimetric identification. Their upper limit is $\sim$ 10 GeV, set by EGRET on-board CGRO, and will be pushed somewhat up with the oncoming launches of AGILE and GLAST.

On the other hand, for *ground-based* experiments, things behave differently: gamma rays interact with the atmosphere fragmenting into many particles, mainly electrons and positrons, making up an *atmospheric shower*. Most of the particles of the shower have enough energy ($\gamma = \frac{E}{mc^2} \approx 80$ @10 km asl) to emit the so-called *Cherenkov light*.

Ground-based experiments can detect either secondary particles making up the shower or the Cherenkov emission, but in either case their effective area is not the actual detector size (for satellite: $\sim 1\ \mathrm{m}^2$), but the cross-area of the whole shower ($10^{4\div5}\ \mathrm{m}^2$). Nevertheless, they are limited by the capability to recognise showers developing from gamma-rays among the overwhelming number of hadronic showers. Older ground-based experiments could not detect gamma rays below 300 GeV of energy.

The two limits set by satellite and ground-based experiments left an unobserved energy window between 10 and $300\,\mathrm{GeV}$, but the 270 different sources seen by EGRET below 10 GeV, compared with the handful of sources detected above 300 GeV, give us a hint that most of the physics lies in this window. The goal to be achieved is to close this energy gap and, from the ground-based detector side, this means lowering the energy threshold. Among the new ground-based detectors, Cherenkov telescopes like MAGIC itself, HESS, CANGAROO III and VERITAS, were able to decrease the energy threshold, while still maintaining a reasonable flux sensitivity. In fact, in their energy band, they can detect in 50 hours emission of the order of few percent of the *Crab Nebula*, the standard electromagnetic source from radio waves to 50 TeV-gamma rays.

The key to lower the energy threshold is increasing the area of the reflecting surface, as well as designing a trigger able to stand the high rate of the so called *Night Sky Background*, likely to increase itself rapidly as more light is collected by the reflecting surface. This is the reason why the MAGIC Telescope features the bigger reflecting surface ($236\,\mathrm{m}^2$) among other similar experiments.

In order to benefit from all the advantages of stereoscopic vision, the MAGIC Collaboration agreed on building MAGIC II[1], a new telescope, a *clone*, at 85 m of distance from the old one. The reflecting surface of MAGIC II is similar to the one of the older MAGIC, but with the experience gained in assembling mirrors for MAGIC I (square, with a side of 50 cm), we preferred to assemble larger mirrors for MAGIC II (still square, but with a side of 1 m).

The huge reflector will still have an overall parabolic shape, which allows detected photons to keep the correct timing information, and is segmented into 236 smaller elements ($1\,\mathrm{m}\times 1\,\mathrm{m}$), each machined to spherical shape with the curvature radius that better fits the required parabolic shape. Each element is an aluminium honeycomb core *sandwiched* between two outer Al-layers using laminating adhesives. The sandwich, called *raw blank*, is later worked and polished with milling machines. Details can be found in sec. 2, while the optical properties of the mirrors can also be found in sec. 3.

The Mirrors

MAGIC II mirrors are a composite structure made up by a layer of AlMgSi1.0 $F = 30$, an aluminum honeycomb and an outer aluminum box all glued together in a high pressure tank making up the so-called *raw blank*. Raw blanks are pre-shaped to spherical shape and then polished with a milling tool equipped with a diamond tip of *large* (~ 1 m) curvature radius. The final curvature radius is the one that better matches the parabolic shape of MAGIC-II dish ($34.125 \div 36.625\,\mathrm{m}$). After diamond milling, front plates are coated with a hard, transparent protective layer against scratches and aging and the produced mirrors weight around $15\,\mathrm{kg}$. Each mirror will be probably equipped with a heating system to prevent ice and dew formation.

Pre-shaping was first attempted for MAGIC-I mirrors in view of the construction of MAGIC-II mirrors. MAGIC-I mirrors, in fact, are made up with a thicker slab of flat aluminium that is later premilled with an accuracy of better than $\frac{1}{10}$ mm. Using pre-shaped raw-blanks, two major issues could be improved even for the smaller MAGIC-I mirrors:

- the thickness of the Al slab, needed for the milling, was reduced from 5 to $1 \div 2$ mm;
- *premilling* could be skipped.

Pre-shaped mirrors are assembled, as the old one, in an *autoclave* environment, but are lay onto a curved mould, that shapes the final raw blank with the requested curvature radius, between 34 and 36 m.

Let us remind that, in this range, the *sagittae* vary ~ 0.5 mm. Therefore, we can produce all pre-shaped raw-blanks with just one *gross* curvature radius and let the diamond milling machine refine them by removing just a minimal amount of material. This results in a faster, and less expensive, overall procedure.

Working with thinner, but pre-shaped, Al-plates also makes the assembling and machining of larger

ICRC 2007 Proceedings - Pre-Conference Edition

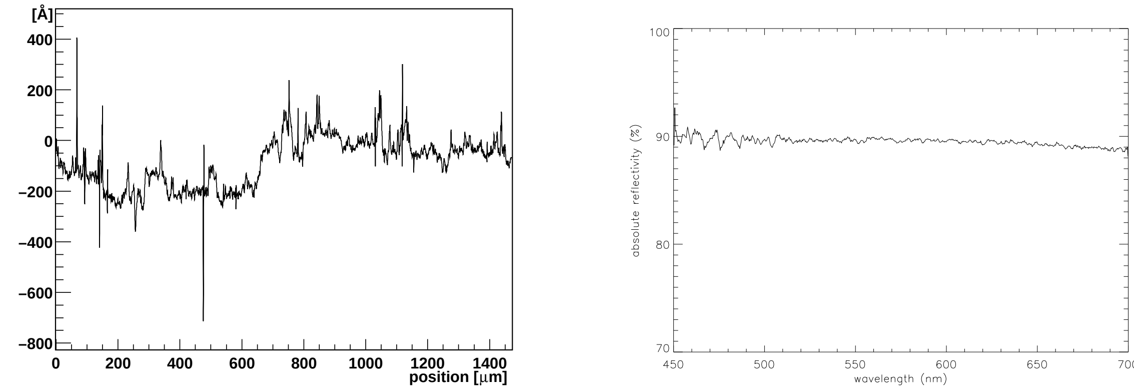

Figure 1: *(Left)* Roughness of a sample taken from a MAGIC mirror after milling and coating. In the roughness diagram, the actual profile (measured in Ångstrom) is plotted against the position (in millimeters). *(Right)* The typical reflectivity of a small portion of mirror before coating.

mirrors easier: in fact, a $1\,\mathrm{m} \times 1\,\mathrm{m}$ spherical mirror of $\sim 34\mathrm{m}$ of curvature radius requests that $\sim 4\mathrm{mm}$ of material would have to be removed from its centre if it were assembled with a flat plate, whereas virtually no material at all is removed from preshaped mirrors. Moreover, as MAGIC currently uses panels hosting four fixed mirrors each for active optics, increasing the mirror size also eliminates the necessity to use back-panels, as the mirrors themselves could be controlled with minor refinements to the actual active optics device.

Larger mirrors have nevertheless some drawbacks. In fact, MAGIC is made up with many small spherical mirrors that best fit the desired overall parabolic shape: increasing mirror size makes the fit harder, at least for the outer mirrors, where the requested paraboloid differs more from a sphere. Astigmatic mirrors can adapt better to parabolic shapes, but their production can be quite difficult, and for MAGIC-II, if machining of astigmatic mirrors does not prove to be feasible via the diamond milling technique, it could be envisaged the construction of a mixed-size surface, with 1-m mirrors in the inner rings and 50-cm ones outside.

Coming back to raw blanks, they are composed of a 2-mm thick Al 3003 box, containing the Al 5052 honeycomb of $6.0\,\mathrm{cm}$ of thickness and sealed with the AlMgSi1.0 layer. Three small aluminum plates, 12-mm thick, are embedded into the honeycomb and glued to the outer box. They host four screws each, to fix the finished mirror to the Active Mirror Control system of the telescope. Final assembly of the raw blank parts is done using two layers of 3M glue foils between box, honeycomb and front plate. The gluing procedure consists of a curing process at $120°$ and $5\ \mathrm{atm}$ of pressure.

The diamond milling of the surface is done by the LT Ultra company (Aftholderberg, Germany). After diamond milling, the roughness of the surface is well below $10\mathrm{nm}\,rms$, as can be seen in fig. 1 for a typical profile analysed with a commercial surface roughness tester. From the same picture one can also see one *step* of the milling machine, that can follow the desired profile at a level of the micrometer. Related to the roughness, the local reflectivity, lying between 85% and 90% in the visible band.

Optical quality checks of the mirrors

To check the optical quality, we use an ultrabright blue LED that is reflected by the mirror under study onto a white screen: the reflected image, the *spot*, is analysed with a CCD camera. The centre of the screen and the LED are at a distance of $\sim\ 10\ \mathrm{cm}$, and are symmetric with respect to the mirror axis. The distance between the mirror and the LED (and between the mirror and the screen) is equal to the nominal curvature radius (or twice the focal length) of the mirror itself, in such a way that a point image is reflected again into a point image.

For the quality check we compute the R_{90}, that is the radius of the circle, taken from the centre of

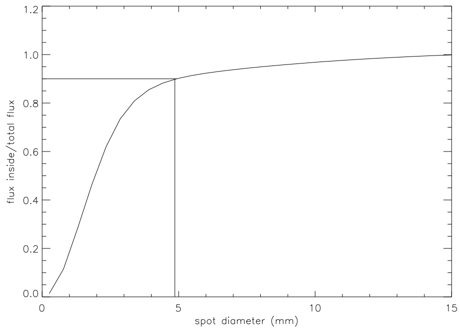

Figure 2: *(Left) Spot* appearance of a produced mirrors on the focal plane. *(Right)* The distribution of the enclosed energy inside the *spot*.

gravity of the spot, containing 90% of the total, reflected light. As the picture is taken at twice the focal, when focusing light-rays coming from *infinity* the spot is actually half the size of the measured one. Looking at fig. 2, the result is that 90% of the light from a parallel beam will be focused, on average, within a circle of $0.5\,\mathrm{cm}$ of diameter, or less than $\frac{1}{4}$ of the MAGIC pixel size (PMTs of 1”$\varnothing$).

The effective radius of curvature is defined operatively as the distance between the spot and the mirror where the R_{90} is minimum. It is the effective radius of curvature that is taken into account for the correct positioning of the mirror onto the parabolic dish, having to match the local mean curvature radius of the paraboloid.

Acknowledgements

The production of the reflecting surface of the MAGIC Telescope was made possible by the financial contributions of the Italian INFN and INAF, the German BMBF, the Universitat Autònoma de Barcelona and the Tuorla Observatory to whom goes our grateful acknowledgement. Acknowledgements is also due to the LT Ultra company of Alt Holderberg for all their dedication in developing new technologies for the mirror production. Finally, we would also like to thank the IAC for the excellent working conditions provided at El Roque de los Muchachos.

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