32ND INTERNATIONAL COSMIC RAY CONFERENCE, BEIJING 2011

First results on mirror design for CTA at Irfu-Saclay

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DOI: 10.7529/ICRC2011/V09/0706

Abstract: The Cherenkov Telescope Array (CTA), as the future ground based γ-ray astronomy facility, is currently in a very advanced design phase. CTA will comprise several tens of large Imaging Atmospheric Cherenkov Telescopes of several different sizes. The total reflective surface needed is about 10,000 m^2 requiring unprecedented technological efforts, mainly towards cost reduction. In this paper we present a new mirror concept for CTA specially developed by the IRFU group and intended to fulfill the technical and optical specifications established by the Consortium. Lightweight, reliability and cost-effectiveness were sought with this design. The mirrors consist of a thin glass layer glued to a sandwiched honeycomb structure by pressure against a dedicated spherical mould. The first series of nominal size mirrors have been built and, with this series, the technique and different materials (carbon fiber, glass fiber, aluminum) were evaluated. The results of this evaluation are discussed in this paper, together with current and future mirror testing activities.

Keywords: Cherenkov Telescopes Array, mirrors.

1 Introduction

Because of its large size, the reflector of a Cherenkov telescope is composed of many individual mirror facets. A hexagonal shape was chosen, with a panel size of 1 - 2.5 m^2 area. More precisely, the baseline idea for the Middle Size Telescope (MST) is to use hexagonal mirrors of 1.2 m (flat to flat) diameter, with a spherical shape of about 32 m of radius of curvature. The criteria to evaluate the performance of the facets are equivalent to those of current instruments with regard to the spot size, to the reflectivity and to the long-term durability. 80% of the incident light to the mirror should be reflected in a 1 mrad diameter spot within the wavelength range of 300 - 600 nm, and facets must be robust against aging when exposed to the environment at the chosen site for several years [1][2]. Weight reduction is also an important goal but should not come at the expense of optical quality. About 20 - 30 kg/m^2 is acceptable. Also mirror deformation under gravity must be small enough to maintain the specifications for the PSF and the alignment. Is most likely that CTA will be placed on a site with high temperature amplitude implying that mirrors should resist temperature changes from -15°C to +50°C and keep their optical properties between -10°C to +30°C.

Finally, maybe the most critical point is long-term stability of the reflectivity under the expected environmental conditions. Due to the large mirror surface in CTA, it is intended to maximize the time interval between two re-coating process, demanding a better protection than is currently used on Cherenkov telescopes mirrors.

In order to account for all these requirements, the IRFU team has worked on the development of mirrors facets, particularly using the cold-slumping technique [3] (see Fig. 1). This is a two steps technique. At first, a thin sheet of glass, which is intended to receive the reflective coating at a further step, is shaped with a high precision spherical mould by applying a uniform pressure on it. In a second step a stiff back panel is fixed behind the glass to maintain its spherical shape. The back panel is required to be lightweight, cost efficient and to be assembled easily . Several material combinations have been tested and the design is now converging to its final stage.

This paper reports on the various steps that led to our current best-guess designs for MST mirrors. The test procedures both optical and mechanical for the prototypes are presented, as well as the results for the best specimens. Eventually the perspectives for mass-production and extrapolation of the technique to Large-Scale telescope (LST) mirrors and Small-Scale telescope (SST) mirrors are discussed. The paper is organized as follow: section 2 is dedicated to the evolution on the design of the first series of prototype mirrors. In section 3 the thermal behavior of the mirrors is discussed while in section 4 their optical properties are evaluated. Finally we present the next steps on the development of a final design in section 5 and the conclusions in section 6.

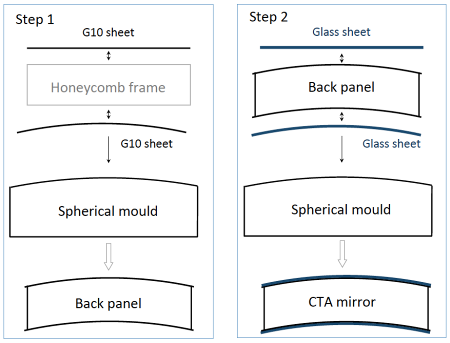

Figure 1: Basic concept of Saclay cold-slumped mirrors.

2 Prototypes description

The very first prototypes were realized with a 50cm x 50cm spherical mould. Many types of back panels have been produced with it. They include pre-formed foam panel, injected foam, and honeycomb both commercial and custom-made. These preliminary prototypes allowed us to learn about the geometries of the back panel, the different materials behavior and the properties of several types of glue.

Mirrors with foam back panels have been ruled out essentially due to their bad thermal behavior. Indeed, the average sag of the mirrors (measured with a basic mechanical sensor) can change significantly and permanently after the mirrors have been submitted to temperatures not higher than 50°C.

We then focused on honeycomb custom-made structures, made of aluminum, carbon fiber or glass fiber, as well as commercial aluminum honeycomb. The results obtained with our reduced-size mould convinced us to purchase a high precision 1.2 m flat-to-flat hexagonal mould of spherical shape. Its radius of curvature is 33.6 m, which matched previous specifications for CTA MST mirrors (32.14 m is the current demanded radius).

The custom-made structure is made of strips of a given material for which one edge is cut according the desired spherical shape. The strips are assembled by hand and the structure is sandwiched between two sheets of material. The structure is glued applying pressure on the rear face and keeping it against a dedicated mould (see Fig. 2). The commercial aluminum honeycomb is not previously milled and is also sandwiched between two sheets of material. The shape is therefore maintained by the glue, which is active on a very large surface thanks to the large number of honeycomb cells (see Fig. 3). As a second step, thin glass sheets are glued on both faces while the structure is maintained against the mould with pressure.

Note that out of the number of prototype mirrors that have been built, not all of them received high quality aluminization. Indeed almost all of them have a glass that is aluminized on its rear face. That allows getting a rough estimate of the optical quality of the mirror without proceeding to a rather expensive front-side aluminization. For some of

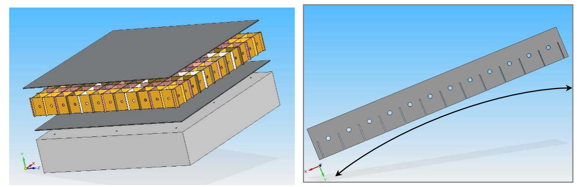

Figure 2: *Left*: Back panel principle with custom made honeycomb sandwich. *Right*: pre-shaped strip with the given radius.

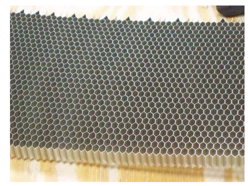

Figure 3: Commercial Aluminum honeycomb which is sandwiched by two plates to get the final mirror structure.

the prototype mirrors, the mechanical measurements and the geometrical quality inferred from the optical estimate were very promising and the mirrors have been sent to industry to receive a real front-side reflecting coating. The reflectivity has been measured for those ones.

In Table 1 the main characteristics of prototypes are given and some of them are shown on Fig. 4.

Figure 4: Some of the nominal size prototype mirrors built at Saclay. The different materials used can be distinguished.

3 Thermal Behavior

As already mentioned above, one important point to study is the stability and durability of the geometry of our mirrors with time and with different environmental conditions. Using a facility installed at Saclay, we exposed the prototypes to different temperature changes, from 0 °C to 36°C, and we mechanically measured the deviation from the nominal spherical shape suffered in each temperature step. As the different materials (aluminum, glass, carbon) have different thermal expansion coefficients and they are glued

Mirror	Sandwich plates	Inner structure	Reflective Surface	Glue type
1	Al (1mm)	Al strips (1mm)	2mm glass sheet[2]	Araldite
2	Al (1.5mm)	Al strips (1.5mm)	2mm glass sheet[2]	Araldite + Optical Gel
3	G10 (1.5mm)	G10 strips (1.5mm)	2mm glass sheet[2] + front coating[3]	Araldite + F50
4	G10 (1mm)	G10 strips (1mm)	2mm glass sheet[2]+ front coating[3]	Araldite + F50
5[1]	G10 (1.5mm)	G10 strips (1.5mm)	2mm glass sheet[2]	Araldite AW 106 + F50
6	G10 (1.5mm)	commercial Al honeycomb [4]	2mm glass sheet[2]	Araldite AW 106 + F50
7	G10 (1.5mm)	commercial Al honeycomb	2mm glass sheet[2]	Araldite AW 106 + F50
8[1]	G10 (1.5mm)	G10 strips (1.5mm)	2mm glass sheet[2]	Araldite AW 106 + F50
9	G10 (1.5mm)	Carbon fiber strips (1.6mm)	2mm glass sheet[2]	Araldite AW 106 + F50
10	Al (1mm)	commercial Al honeycomb	2mm glass sheet[2]	Araldite AW 106 + F50
11	G10 (1.5mm)	commercial Al honeycomb[4]	2mm glass sheet[2] + front coating[3]	Araldite AW 106 + F50
12	3mm glass sheet	commercial Al honeycomb[4]	none	Araldite AW 106
13	2mm glass sheet	commercial Al honeycomb[4]	front coating[3]	Araldite AW 106

Table 1: Prototype mirrors main characteristics. 1) 1.5 mm thick G10 side walls. 2) Rear metalized. 3) Aluminization + 100 nm of SiO_2. 4) 19 mm cell and 8 cm height.

to each other with an epoxy resin, different stresses may appear when the temperature varies and produce a global deformation of the mirror. As CTA will most likely be installed on a desert site, the temperature difference between day and night can play an important role even if the temperature can be relatively stable during the observation time. The two important features are: the magnitude of this deformation and the capacity of the mirror to recover its original shape. In Fig. 5 the behavior with temperature of six of our mirrors is shown. We can see from these results that the amplitude of the deformation for three of them (prototypes 1, 7 and 10, mainly made of Aluminum) is quite important. A rough explanation of this behavior is the following: as the temperature drops, the mirrors tend to become flatter because the Aluminum sandwich behind the glass sheet tends to contract. On the contrary, when temperature rise, the dilatation of the Aluminum allow the structure to reach higher curvatures.

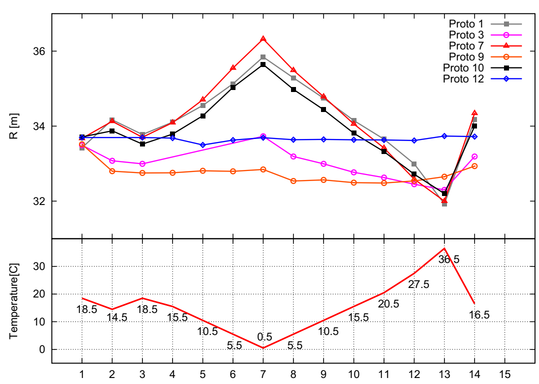

Figure 5: Thermal behavior of some of the prototypes. See table 1 for details on the mirrors.

Concerning the carbon fiber structure (prototype 9), its behavior is quite stable with temperature variation even though the original curvature was not completely recovered. The glass fiber mirror tends to follow the same trend as the Aluminum ones but the amplitude of the deformation is smaller. Finally, the one which seems to experiment no transformation with temperature is the one representative of the final concept of our mirrors (symmetric mirror: same material at two faces). The older prototypes were built without the rear glass sheet, which correspond to the previous asymmetrical design.

4 Optical properties

In order to characterize the prototypes and evaluate them according to the CTA Consortium specifications, we have built a test facility dedicated to measure three important parameters of the mirrors: the Point Spread Function (PSF), the effective reflectivity and the focal distance. Using the 2f (twice the focal distance) test bench sketched on Fig.6 we determined the optical properties of the first series of mirrors. The results for the front-side coated mirrors are presented in Table 2. The mirror is uniformly illuminated by a LED type light source with a strong blue component. As a first approximation, we use two filters (V and B) to get the reflectivity at the relevant wavelengths for Cherenkov detectors. The light flux arriving to the mirror and that reflected in the spot at 2f are measured by planar diffused Silicon photodiodes with 611 mm^2 active area. The PSF is the angular size of the spot produced on a screen (Fig. 6). Images of this screen are taken with a CCD camera (ATIK_4000M) and analyzed offline to get the size of the region that contains 80% and 90% of the reflected light.

The improvement on the reflectivity and the PSF from the first prototypes to the last one is due, basically, to the progress on the control of the technique. Problems related to the deviation from nominal curvature at the edges of the mirrors were found analyzing the images at 2f. As the mirrors have no flexural constrains on the sides, the radius at the edges tended to be larger, generating a large directional dispersion of the light as one can see on the *top/left* panel of Fig. 7. In order minimize this dispersive effect, thick side walls were added to the mirrors to prevent the

Prototype	ρ (B)*	ρ (V)*	PSF size (mrad)
3	77 ± 2 %	75 ± 2 %	~ 1.1
4	78 ± 2 %	78 ± 2 %	~ 1.1
11	84 ± 2 %	81 ± 2 %	~ 1

Table 2: Prototype mirrors optical performance.* ρ is the % of incident light reflected on the 611 mm^2 area photodiode placed at 2f.

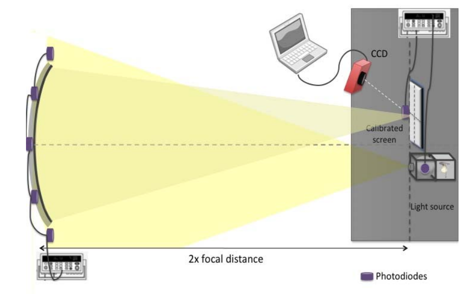

Figure 6: Schematics of Saclay Test Bench setup.

edges to bend as is shown on the *bottom/right* image of Fig. 7. The final result is a clean concentration of the light as the *top/right* panel of Fig. 7 shows.

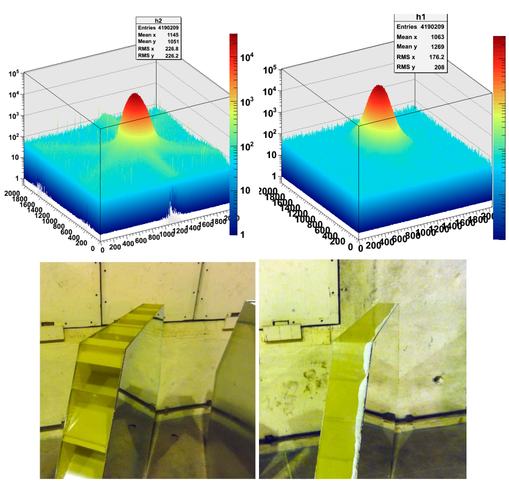

Figure 7: *Left*: image obtained with prototype N° 3 (*Bottom/Left*) at twice the focal distance and a point like source. The light dispersion on six directions perpendicular to the flat sides can be seen on logarithmic scale. *Right*: image obtained with a G10 mirror with a side wall added (*Bottom/Right*).

5 Next steps

With the assumption that the construction of the CTA array will start as early as 2013, completing the design during the next year and launching the production subsequently are required. Our current effort focuses on finishing all the necessary analysis to validate what we believe to be a competitive design for the MST mirrors with the aim to establish an industrial process for manufacturing them. Future tests such as shape measurements, the influence of temperature and humidity and aging of coating will be carried out in collaboration with other parties of the Consortium.

The next step will be the production of a mini-series of about 20 facets and will be done in partnership with local industry. These mirrors will be installed on the MST prototype that is already under construction in Berlin by the Consortium. Basically, the stability and durability of different back panel combinations will be monitored under "real" environmental conditions. The integration and installation of the facets should also be tested and improved from this prototype.

6 Conclusions

The first series of nominal size mirrors facets for CTA telescopes have been built by the IRFU team. The results of the first technical and optical tests are encouraging. We have studied their behavior under thermal variations finding that some of the prototypes are not good enough for CTA requirements while others keep being competitive in this sense. However, this is a preliminary test and the results should be confirmed by more precise measurements in a controlled (temperature and humidity) environment. The most promising prototypes were aluminized and protected by a layer of $Si0_2$. The optical response of these mirrors fulfill the specifications of the CTA consortium for the first prototype mirrors. Based on the experience gained with these mirrors, the production of a small series of 20 mirrors will start soon. The final stage of characterization and evaluation of our mirrors will be finished after their installation on the Middle Size Telescope prototype.

Acknowledgements We gratefully acknowledge support from the agencies and organizations listed in this page: http://www.cta-observatory.org/?q=node/22.

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