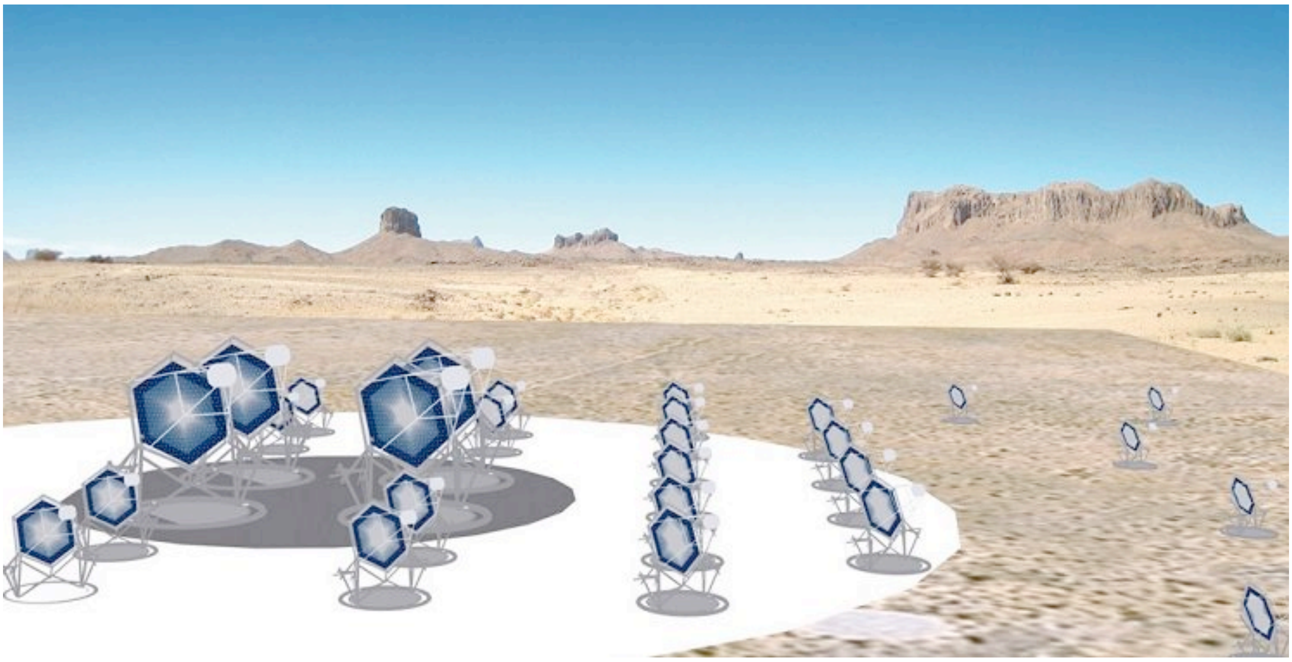
PROGESS REPORT ON THE DEVELOPMENT OF THE MANUFACTURING TECHNOLOGY FOR THE M1 MIRROR SEGMENTS



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DOCUMENT HISTORY

Version	Date	Modification
1	21-12-2011	first version

LIST OF ACRONYMS

ASTRI	Astrofisica con Specchi a Tecnologia Replicante Italiana
CTA	Cherenkov Telescope Array
FEA	Finite Element Analysis
IACT	Imaging Atmospheric Cherenkov Telescope
INAF	Istituto Nazionale di AstroFisica
IRD	Industrial Research and Develop
KOM	Kick Off Meeting
MAGIC	Major Atmospheric Gamma-ray Imaging Cherenkov telescope
OAB	Osservatorio Astronomico di Brera
PDR	Preliminary Design Review
PV	Peak to Valley
rms	root mean square
SC	Schwarzschild-Couder
SST	Small Size Telescope
WBS	Work package Breakdown Structure
WP	Work Package

APPLICABLE DOCUMENTS

[AD1] ASTRI Governance document

[AD2] CTA-TC_PR1-110331 *“Level A: Preliminary CTA System Performance Requirements”*

REFERENCE DOCUMENTS

[RD1] ASTRI-IR-OAB-3100-009, Canestrari R. et al *"The optical layout of the ASTRI prototype: 4 meter Schwarzschild-Couder Cherenkov telescope for CTA with 10 degrees of field of view"*

[RD2] SST-STR_review Greenshaw T. et al *"Summary report of the SST-STR working group activities"*, Chapter 4.1 (The ASTRI end-to-end prototype)

[RD3] ASTRI-SPEC-OAB-3100-002 Canestrari R. et al *"Error Budget Tree for the ASTRI prototype: structure and mirrors"*

[RD4] MAN-PO/111118 *"Review of the CTA Small Size Telescopes"*, Chapter 5

[RD5] wp_mir_report Foerster A. et al *"Summary of the Activities of CTA WP MIR"*, Chapter 1.1 (Cold slumped glass mirrors)

[RD6] ASTRI-ES-BCV-3120-009 (aka BCV_P9785_rep_1_draft1) BCV progetti srl *"Glass facesheets stress evaluation in case of cold shaping"*

[RD7] ASTRI-ES-BCV-3120-010 (aka BCV_P2652_rep_2_Rev_0) BCV progetti srl *"Stresses and elastic distortions induced by gravity, wind loads, temperature gradient. A parametric analysis"*

[RD8] SST-STR_review Greenshaw T. et al *"Summary report of the SST-STR working group activities"*, Chapter 5.2 (Hot-slumped with cold-adjusted-shape glass mirrors)

[RD9] Canestrari R., et al *"Investigation of a novel slumping technique for the manufacturing of stiff and lightweight optical mirrors"*, Proc. SPIE 7018, 70180D (2008)

[RD10] Canestrari R., et al *"Techniques for the manufacturing of stiff and lightweight optical mirror panels based on slumping of glass sheets: concepts and results"*, Proc. SPIE 7437, 743711 (2009)

[RD11] ASTRI-SPEC-OAB-3100-003 Canestrari R. *"ASTRI SST design loads"*

[RD12] ASTRI-SOW-OAB-3100-003 Canestrari R. et al *"Statement of the Work for the engineering designs of mechanical subsystems for a dual-mirror Cherenkov telescope prototype for the ASTRI project"*

[RD13] ASTRI-MIN-OAB-3100-011 Fiorini M. *"Kick-Off meeting per la struttura e la meccanica del prototipo di SST-2M"*

1. INTRODUCTION

This document is the deliverable R3 required by the ASTRI governance document [AD1].

The aim of this document is to provide the state of the art of all the activities related to the design of the mirror segments of the primary mirror M1 and the development of a suitable manufacturing technology. The activities here reported are mainly related to the WP 3120 of the ASTRI WBS.

2. THE MIRROR SEGMENTS PRELIMINARY DESIGN

As reported in [RD1], the M1 mirror surface can be described with the following polynomial equation:

$$z = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + \sum_{i=1}^{N} \alpha_i r^{2i}$$

where *z* is the surface profile, *r* the surface radial coordinate, *c* the curvature (the reciprocal of the radius of curvature), *k* the conical constant, α_i the coefficients of the asphere (see Tab. 1 and Fig. 1).

PARAMETER	VALUE
r	[0-4300] mm
c	-1.2161e-4 1/mm
k	0

COEFFICIENT	VALUE
α_1	0.00
α_2	9.61060e-013
α_3	-5.65501e-020
α_4	6.77984e-027
α_5	3.89558e-033
α_6	5.28038e-040
α_7	-2.99107e-047
α_8	-4.39153e-053
α_9	-6.17433e-060
α_{10}	2.73586e-066

Tab. 1: Parameters and coefficients used to describe the primary mirror M1 surface profile.

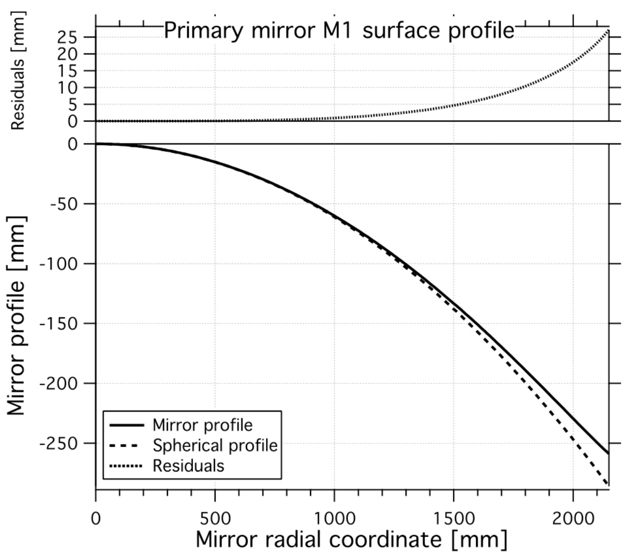
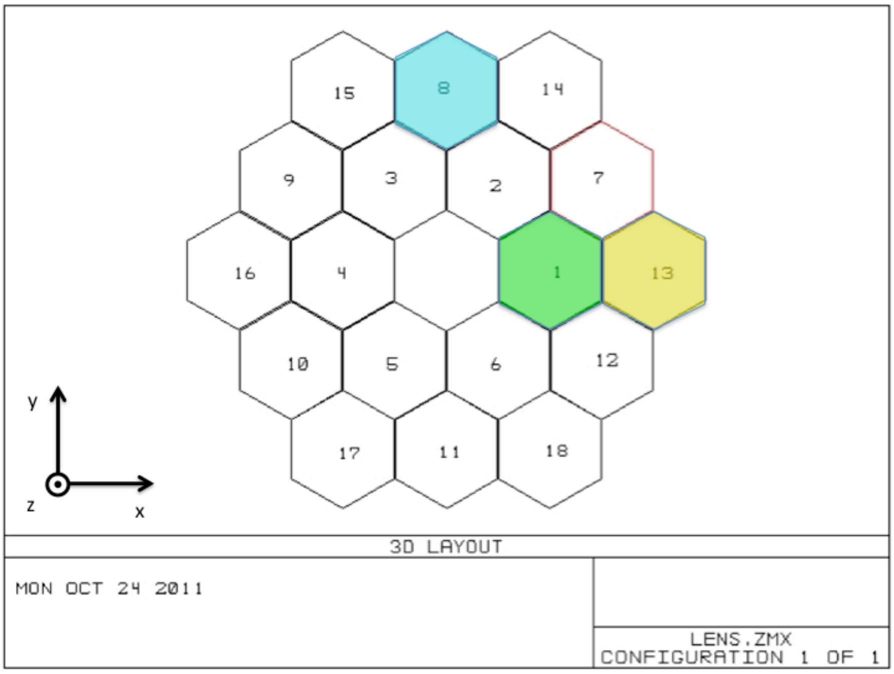


Fig. 1: Radial profile of the primary mirror M1 and the residuals with respect to the best sphere.

The primary mirror is segmented into 18 tiles; the central tile position is not used because it is completely obstructed by the secondary mirror. A schematic representation of the M1 arrangement is shown in Fig. 2 (top panel). The segmentation requires three types of segments having different surface profiles (see Fig. 2, bottom panels):

- the green segments, inner corona
- the light blue segments, central corona
- the yellow segments, outer corona



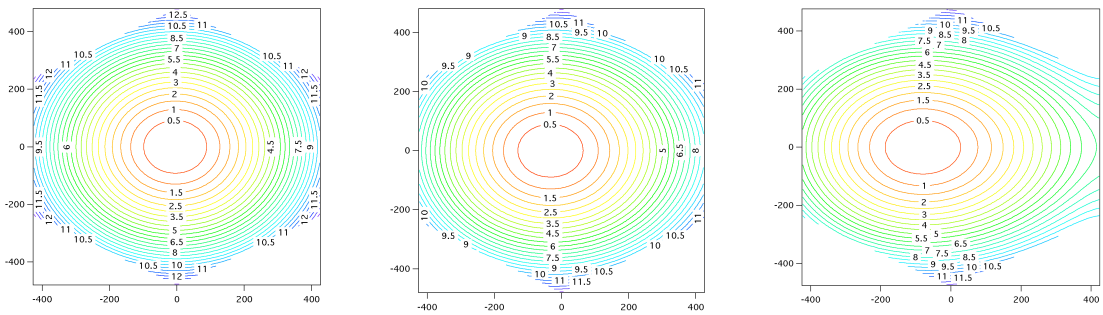


Fig. 2: (top) arrangement and nomenclature adopted for the M1 primary mirror segments.

(bottom) From left to right, the contour plots of the green, blue and yellow M1 mirror segments. The aspherical component is much pronounced for those ones placed at larger radial distance.

The segments have hexagonal shape with an aperture of 849 mm face-to-face. There is a gap of about 10 mm between panels for mounting and alignment purposes. Each segment will be equipped with two actuators plus one fixed point for alignment. Only tilt misplacements will be corrected; the piston correction will be available for the primary mirror segments, but not motorized. For further details about the support and control system and the mounting/dismounting procedure refer to [RD2].

2.1 The Error Budget Tree

A detailed error budget has been compiled and is reported in [RD3]. This document is a living document. This means that the numbers adopted for each parameter can be subject of changes depending from the outcomes of the structural analyses and/or technological developments.

The analysis has been performed in such a way the global effect of all contributions keeps the energy concentration (ensquared energy) better then (or equal to) 70%.

This can be translated in a PV error budget equal to 120 μm and slope error budget equal to 60'' rms.

It worth to be noted that the release of this document was also suggested by the CTA-SST review committee as reported in [RD4].

3. THE MANUFACTURING TECHNOLOGY

The manufacturing technology should be able to provide mirrors compliant with the desired optical performance together with lightweightness, robustness and economicity. These characteristics are particularly important when a project, such as CTA, foresees the implementation of a large number of identical telescopes and where reliability is essential to increase the duty cycle of the array. For such reasons we think that manufacturing technologies that exploit the concept of replication of a master shape are best suited.

A recent project at the INAF-OAB was dedicated to a manufacturing process optimized for large spherical mirror facets for IACTs. The process is called cold-glass slumping. It has been adopted at the world's largest Cherenkov telescope: the 17 m MAGIC II telescope. The chosen substrate has a sandwich-type mechanical structure that confers stiffness and low areal density. A thin glass sheet is bent and is made to adhere to a mold having a highly precise shape. The complete panel is assembled by gluing a reinforcing core structure and a second thin glass sheet. After the glue is polymerized, the panel can be released and properly coated. The coating provides adequate reflectivity and protection against reflectivity losses and scratches. More details can be found in [RD5]. In Fig. 3 are shown the manufacturing phases of the cold-glass slumping technique (left panel) and a picture of on the mirror segments realized for the MAGIC II telescope (right panel).

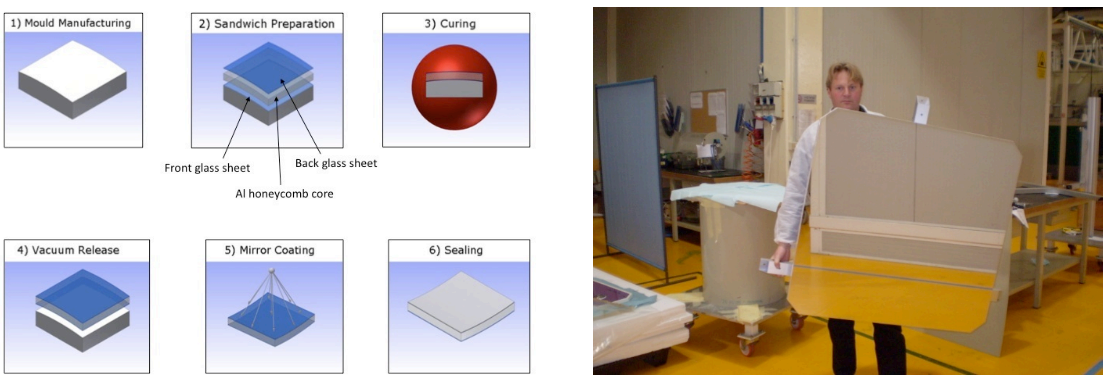


Fig. 3: The main manufacturing phases of the cold-glass slumping technology developed for the production of the mirror segments of the MAGIC II telescope (left). A picture of one of the mirrors produced (right).

The elasticity of glass, although modest, is the working principle of this technology. Since the entire process occurs at room temperature, the glass sheets permanently retain the tensile stresses resulting from bending. Limitations in the surface profiles achievable, particularly the short radii of curvature needed for the SC layout presented in [RD1], are emerging (see [RD6] and [RD7]).

To overcome them, we are implementing a thermal shaping (hot slumping) of the glass sheets before the cold-glass slumping process. Heating the glass to its transformation temperature makes it soft enough to easily accept modeling. This makes it possible to impose the required surface profile, even a very curved one. The change in the profile is permanent, and it leaves the glass free of stress. In this scenario, the cold-glass slumping procedure will act as “integration phase” to pass from a curved glass shell to a stiff mirror segment. Some preliminary mirrors have been realized as we look mainly for a reduction in the radius of curvature (see Fig. 4). A segment having a spherical concave profile of 10 m of radius of curvature has been produced and tested in our labs, achieving promising results and demonstrating the feasibility of this approach (see [RD8], [RD9] and [RD10]).

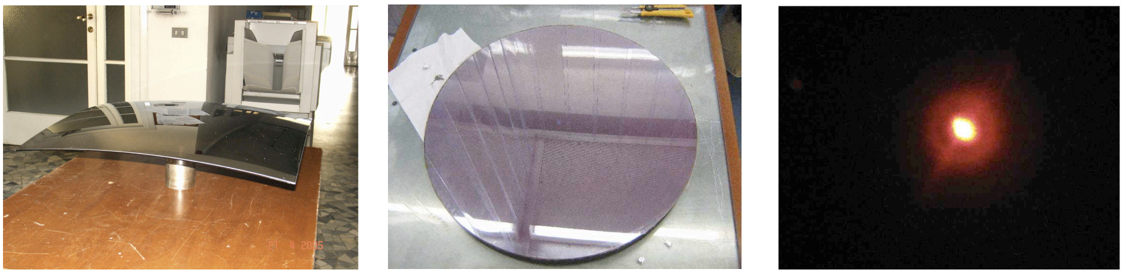


Fig. 4: The images show, respectively: (left) a sample of a glass shell of a mirror with a 3 meter radius of curvature obtained by FLABEG GmbH with the technique of the hot slumping; (center) mirror segment prototype (ϕ = 0.5 m) realized by assembly of hot slumped glass shells into a sandwich structure, the radius of curvature is of about 10 meters (a curvature similar to that of the M1 primary mirror); (right) focused light obtained by the mirror prototype, the size of the bright spot is only few millimeters.

The next step will be to add the aspherical contribution to the main spherical profile. If this test is successful, it could prove that this modification of the cold-glass slumping technology can be adopted for SC Cherenkov telescopes. To this end, an R&D is ongoing with a world’s leading firm (FLABEG GmbH) for mirrors in the solar concentrators market. A set of about 10 glass shells conform to the surface profile of the yellow panel in Fig. 2 (top panel) is in production with the hot slumping technique. Those bent glasses will be used to manufacture and test the engineering model of the M1 mirror segment prototype, the deliverable P1 of [AD1].

4. INDUSTRIAL CONTRACTS, SCHEDULE AND COSTS

The development of the M1 mirror subsystem is conducted through R&D efforts with both industrial partners and in-house activities. Detailed mechanical structural analyses are conducted through FEA and used to support the hardware development. The current status can be summarized as follow:

1. evaluation of the cold-glass slumping technology limits (activities completed, see [RD6] and [RD7]);
2. mechanical design of the M1 mirror segments and related interfaces with the telescope structure (activities under definition). The mirrors will be designed and structural checks will be performed in accordance with [AD2] and [RD11];
3. an engineering model of the supporting structure and control system will be developed and tested in the framework of the activities reported in [RD12];
4. manufacturing and optical testing of one M1 mirror segment is done through a cooperation of industrial partners and in-house integration and testing. Industrial R&D is for:
    a. glass shells thermal bending (activities ongoing: bending tool realization and measurement; glass shells bending, cost estimation for mass production)
    b. coating (activities under definition: metallic and dielectric coatings, recipes, materials, tests)

A summary of the expenses and schedule is:

1. covered through external funds (14.4 k€), CTA IRD proposal #8 "*Engineering analyses for short radius mirrors by cold slumping";*
2. will be covered through external funds (35 k€), CTA IRD proposal #16 *"Design and engineering analyses for short radius mirrors for the SST dual mirror telescopes: a follow-up study"*. We foresee about 3 months from the order;
3. is covered by [RD12] with a time frame of 9 months from the KOM reported in [RD13];
4. M1 mirror segment:
    a. is covered through ASTRI funds (37 k€). Expected glass shells delivery was late Dec 2011, but the industrial partner has recently reported the breakage of the bending tool. The new delivery is expected for late Jan 2012.
    b. will be covered through external funds (40 k€), the CTA IRD proposal #12 *"Pre-industrial development of technologies and facilities for CTA mirror coatings"*. We foresee about 6 months from the order.