The Cherenkov optics qualification facilities at INAF-OAB laboratories
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for the CTA ASTRI Project

INAF-IASF Milano

This work was conducted in the context of the CTA ASTRI Project
The role of @INAF-OAB in the CTA project

The metrology facilities @INAF-OAB
  - The 2f facility
  - The deflectometry laboratory
  - Possible facilities upgrades

Conclusion
The CTA project

Two sites (North and South) for a whole-sky coverage
Operated as on open Observatory
A factor of 10 more sensitive w.r.t. the current IACTs

A few large telescopes to cover the range
20 - 200 GeV

~km² array of medium-sized telescopes for the 100 GeV to 10 TeV domain

4 LSTs (N & S)

15 MSTs (N)
25 MSTs + 24 SCTs (S)

~10km² array of small-size telescopes, sensitive above a few TeV up to 300 TeV

70 SSTs (S)
RAF-OAB contribution to CTA

- Small Size Class Telescope (SST):
  - INAF realized the end-to-end ASTRI telescope prototype
  - INAF-OAB is responsible for ASTRI mirrors manufacturing and characterization
- Medium Size Class Telescope (MST): INAF-OAB is providing mirrors as in kind contribution.
ASTRI and MST mirrors are manufactured by glass cold slumping technology. This technology was developed in synergy by INAF-OAB and Media Lario and successfully used for MAGIC mirrors.

- Based on replica process ⇒ suitable for the multiplicity of CTA mirrors
- Lightweight and cost-saving
- Shape error within few microns

The 2f facility was adopted to measure MST mirrors

**MST – Medium Size Telescope**

Desy, Berlin

Optical configuration:
Davies-Cotton
Dish Diameter = 12 m
Focal length = 16 m
Mirror = segmented in 84 spherical panels
1 panel = hexagon of 1.2 m side-to-side
Layout of the 2f facility

\[ \frac{1}{f} = \frac{1}{p} + \frac{1}{q}, \quad p = q = \text{RoC} \Rightarrow f = \frac{\text{RoC}}{2} \]

Indoor section:
- light source
- CCD camera, mounted on a translation stage

Outdoor section:
- stage for mirror support and alignment

http://arxiv.org/abs/1504.02962
Outdoor mirror bench:

- Motorized (stepper motor + encoder): tip/tilt for alignment + focus over a wide range (30-36 meters ⇒ suitable for both MST and MAGIC mirrors)
- Adaptable for mirrors of different sizes (up to 1.5 m) and weights (up to 45 kg)
- Operated with a Command&Control SW interface on an indoor desktop computer
- External cabinet + thermocouple for ambient temperature monitoring
Indoor optical bench:

- Motorized x-y stage for focal plane scanning (300x300 mm)
- Finger Lakes CCD camera PL4301 with filter wheel (neutral and band-pass): 2084x2084 px @ 24 μm (49.5x49.5 mm)
- High intensity LED sources (with neutral filters on a filter wheel): white, red (626 nm), green (525 nm) and blue (470 nm)
- Laser meter (accuracy +/- 5 mm over 200 m)
- Image acquisition at different distances
- Measure of the PSF dimension (r80)
- Identification of RoC as distance where the PSF is smaller

Focal length study

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- At nominal focal length
- Mosaic of 3x3 images (15 x 15 cm)
- Calculate the r80

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Mirror production industrialized by Media Lario Technologies
INAF-OAB is leading the contract and performing independent tests

- Mean RoC: 32.15 m (72 studied mirrors)
- Mean r80 at the nominal RoC: 8.03 mm (32 studied mirrors)
ASTRI SST telescope prototype

- ASTRI telescope is an end-to-end system realized by INAF (Italian National Institute for astrophysics) as prototype for the CTA SST
- The ASTRI telescope is installed at Serra la Nave (Mt. Etna, Sicily)

Dish Diameter = 4 m
Focal length = 2.15 m
Optical configuration: polynomial Schwarzschild-Couder
Primary Mirror = segmented in 18 panels
1 panel = hexagon 85 cm side-to-side
ASTRI is a polynomial Schwarzschild-Couder telescope

The main advantages of the SC design are:
- Double mirror reflection ⇒ shorter focal length
- Better plate scale ⇒ large FOV with a small camera

The main disadvantage is that SC design requires aspheric optics:
- Segmented aspheric optics ⇒ free-form not focusing panels
Strongly aspheric surfaces:

- Segment residuals wrt best fit sphere
- Very large best focus images \(\Rightarrow 2f\) test not possible

Corona 1

PV 4.5 mm - Rms 800 \(\mu\)m
RoC = 8.6 m

~ 80 mm

Corona 2

PV 2.8 mm – Rms 670 \(\mu\)m
RoC = 9.8 m

~ 650 mm

Corona 3

PV 5.7 mm – Rms 972 \(\mu\)m
RoC = 11.7 m

~ 1200 mm
Deflectometry test:
- Illuminate the mirror with a defined pattern and observe the distortions after its reflection
- Calculate normal vectors to the reflecting surface
- Make the ray-tracing simulation in the acquisition configuration
- Compare really reflected images with the simulated ones
Laser meters

Mirror under test

18 Mpx CCD camera

Mirrors stack

Ultra HD 65” TV screen movable over 6 m length

10 meters

10 meters

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Validation by comparison of:

- Images simulated by ray-tracing of the measured surface
- Pictures acquired in direct illumination

Ray-tracing Simulations @different distances

Real image @different distance:

Ray-tracing Simulations @telescope focal plane
All ASTRI M1 segments were characterized only by means of INAF-OAB deflectometry facility.

- To evaluate the mirrors quality we compared the simulated PSF with the expected theoretical PSFs.

Panel PSF simulation

- Inner ring
- Middle ring
- Outer ring

Theoretic

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All ASTRI M1 segments were characterized only by means of INAF-OAB deflectometry facility.

- To evaluate the test reliability we compared the simulated PSF with the PSF directly measured at the telescope focal plane.
All ASTRI M1 segments were characterized only by means of INAF-OAB deflectometry facility.

The final obtained PSF of the ASTRI telescope, measured observing Polaris, results to be fully compliant with the requirement to concentrate the 80 % of the source light in the pixel of the focal-plane camera.
Direct measure of mirror surface: 

http://arxiv.org/abs/1504.02962
Facilities possible upgrade

It is promising, we will go on working on it!
Conclusions

- The 2f and the deflectometry facilities @ INAF-OAB are reliable tools to measure spherical and aspheric mirrors.

- They can be used to characterize in an independent way the SST and MST mirrors.

- They can be used to monitor the mirror replica process applied by industries during the production phase of CTA.
Ray-tracing PSF simulation of the measured optic slope errors allowed us to

- Determine the best reciprocal position of the single M1 panels’ PSFs
- Foresee the optical quality of the telescope

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