Glass cold shaping: a new technology for a new astronomy

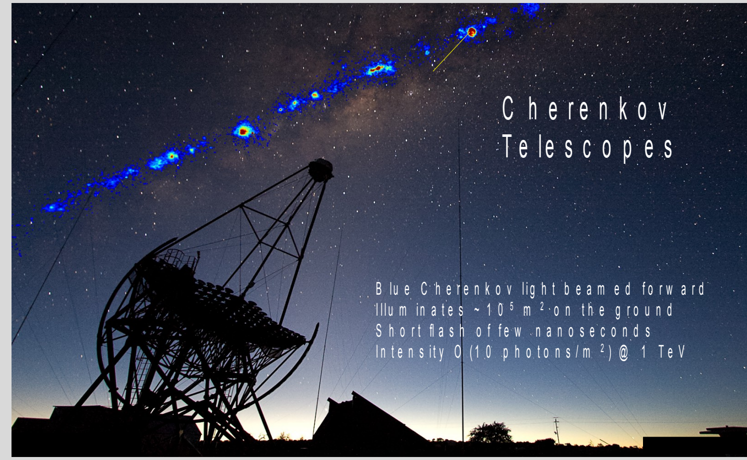
Rodolfo Canestrari

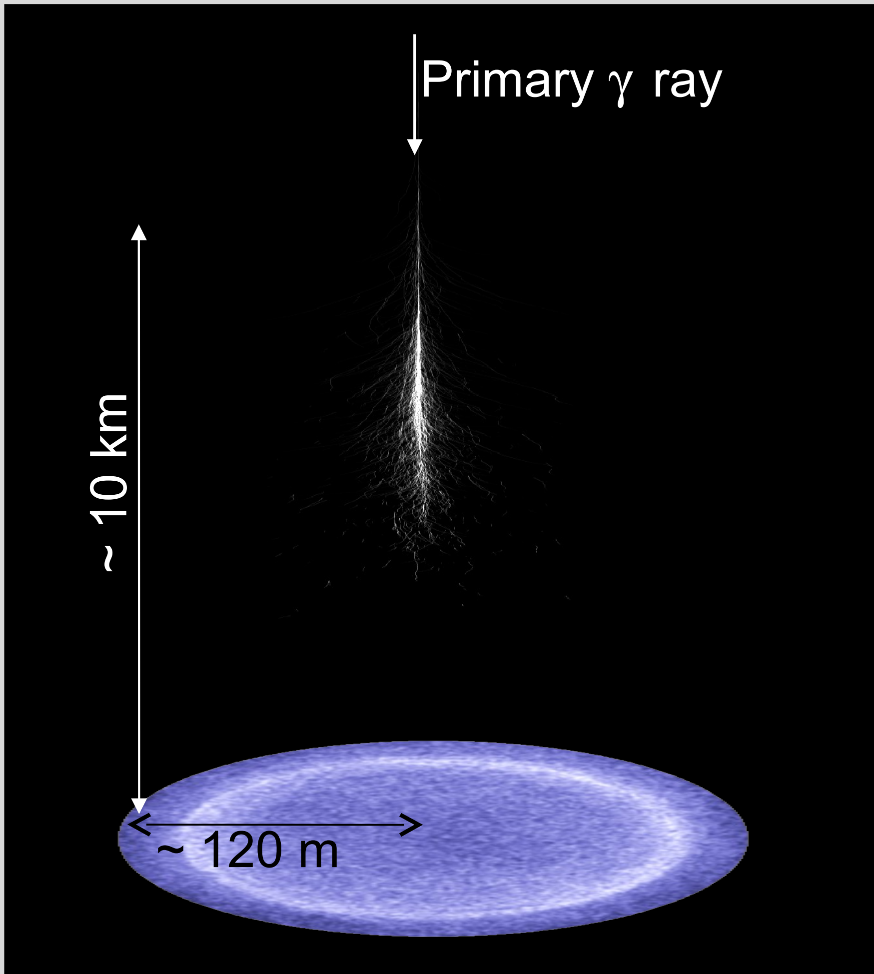
1INAF-Astronomical Observatory of Brera

Outline

- The (Air) Cherenkov telescopes:
  - Detection technique
  - The Cherenkov Telescope Array (CTA) Observatory
  - Highlights on the ASTRI project
- The challenge for a new technology
- The glass cold shaping technology
  - Process and engineering basis
  - MAGIC II
  - CTA-MST
  - ASTRI

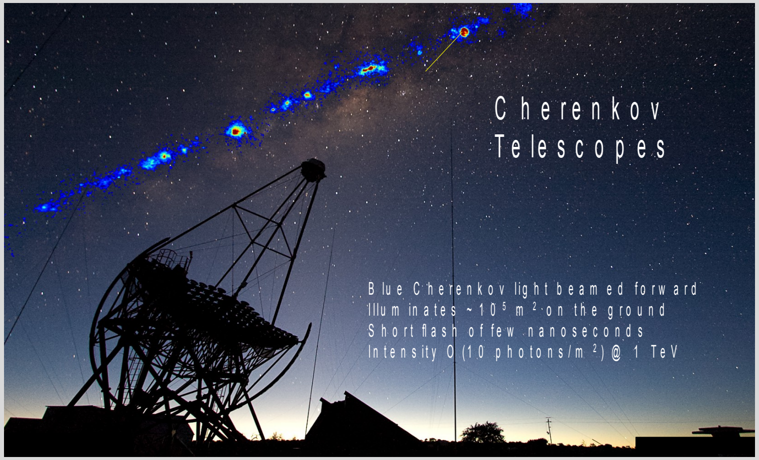
Cherenkov Telescopes: detection technique

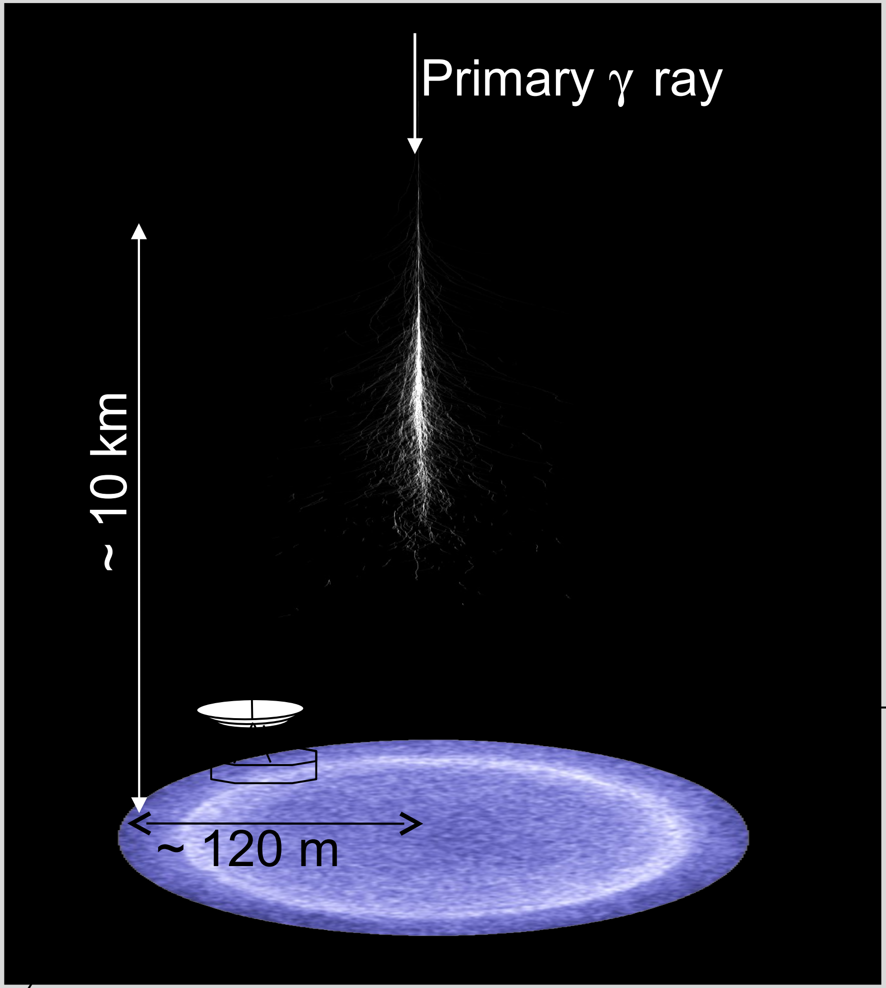


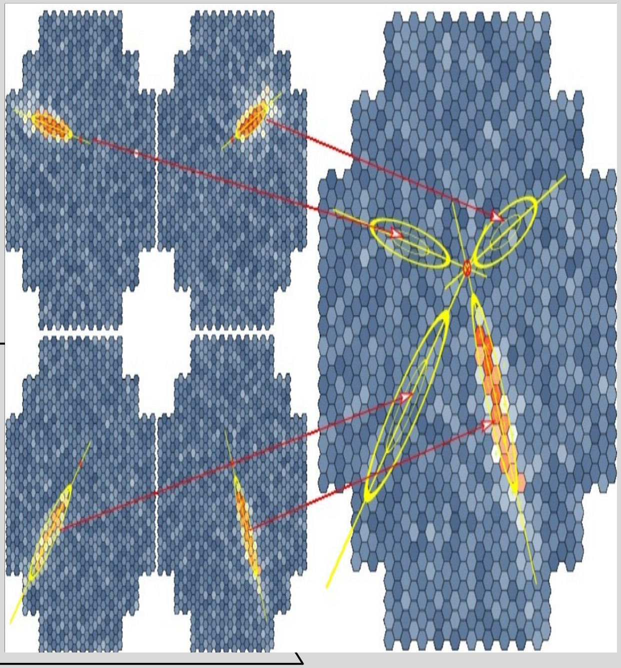


- Very High Energy γ rays are generated by distant sources.
- γ in the atmosphere originates an Electromagnetic Air Shower at about 10 km asl.
- e+e- produce a Cherenkov light flash.
- Cone angle about 1°; it illuminates a radius of about 120 m; it last few nsec.

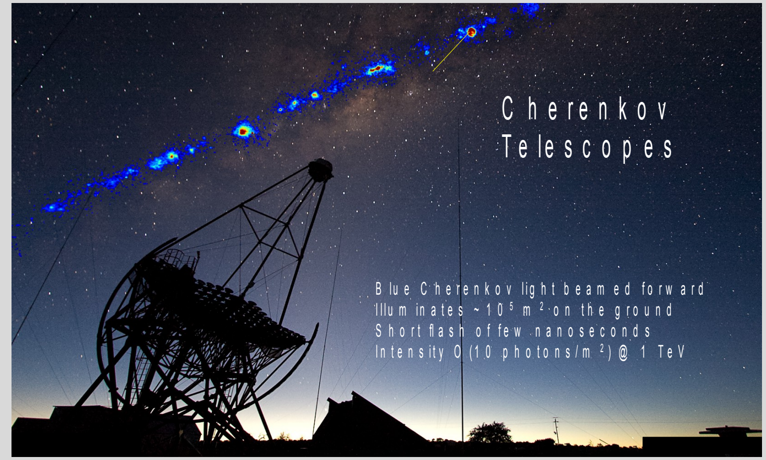
Cherenkov Telescopes: detection technique

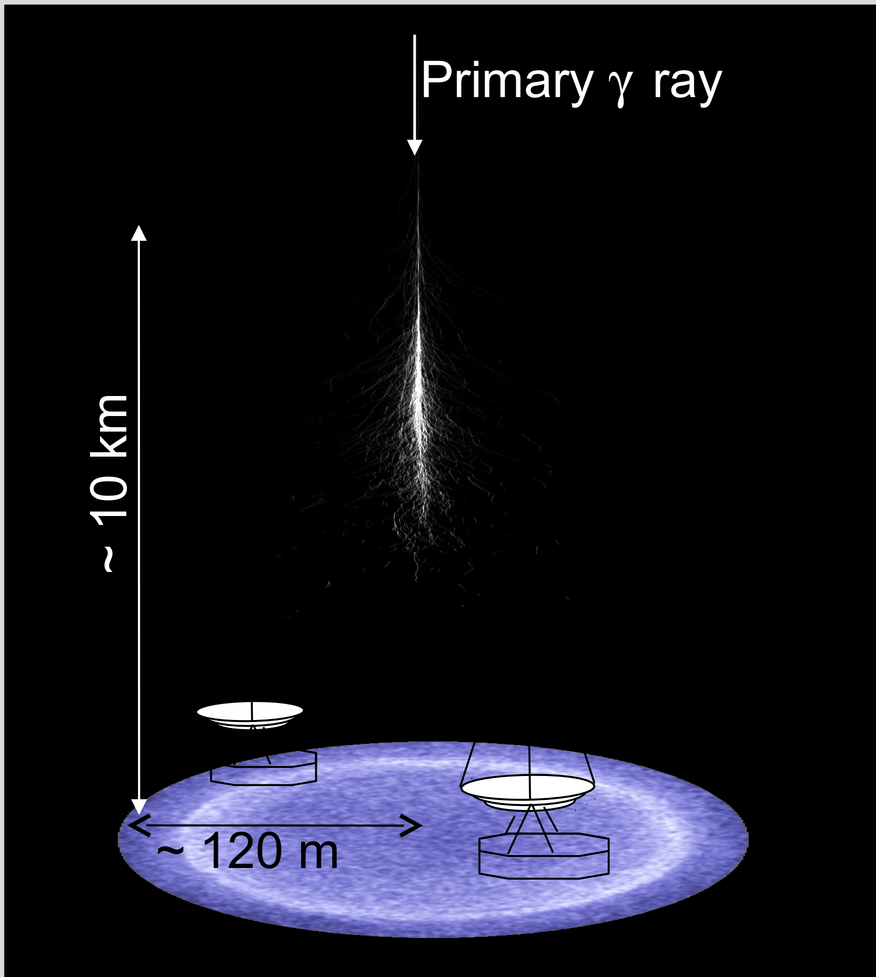


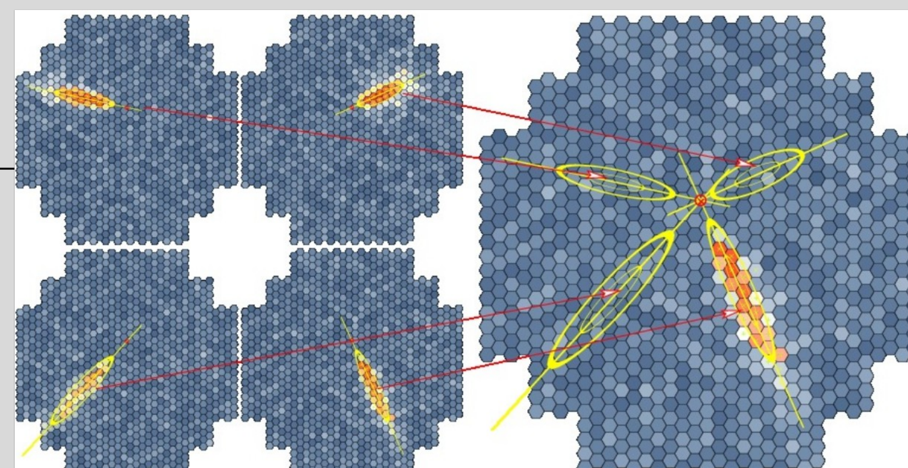




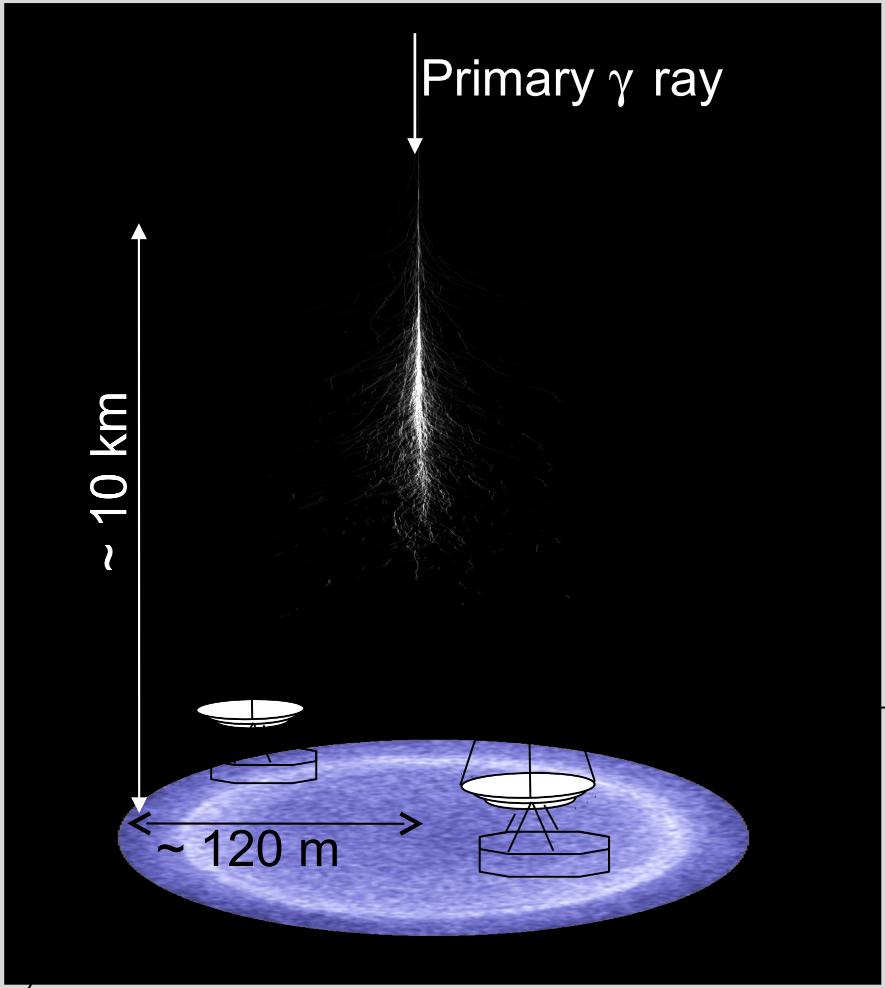
Cherenkov Telescopes: detection technique

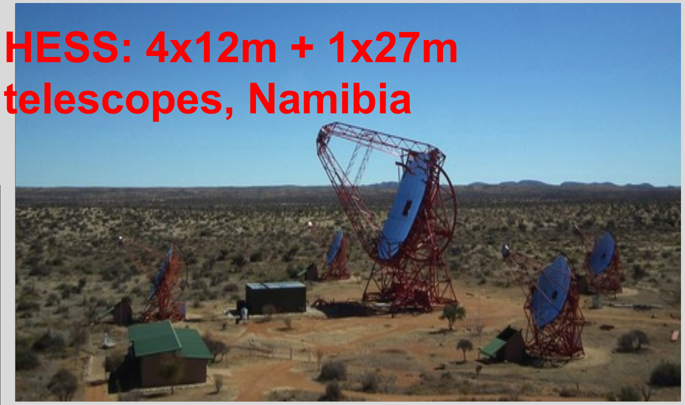






Cherenkov Telescopes: detection technique





The future in VHE gamma ray astronomy:

cta
cherenkov telescope array

10 fold sensitivity of current instruments

10 fold energy range

improved angular resolution

O(100) telescopes in mixed arrays

distributed in two sites (North / South)

operated as observatory

Estimated cost ~200 M€

World-wide cooperation

27 countries

80 parties

348 FTEs

1127 scientists

The CTA Observatory

Low-energy section: 20GeV – 1 TeV

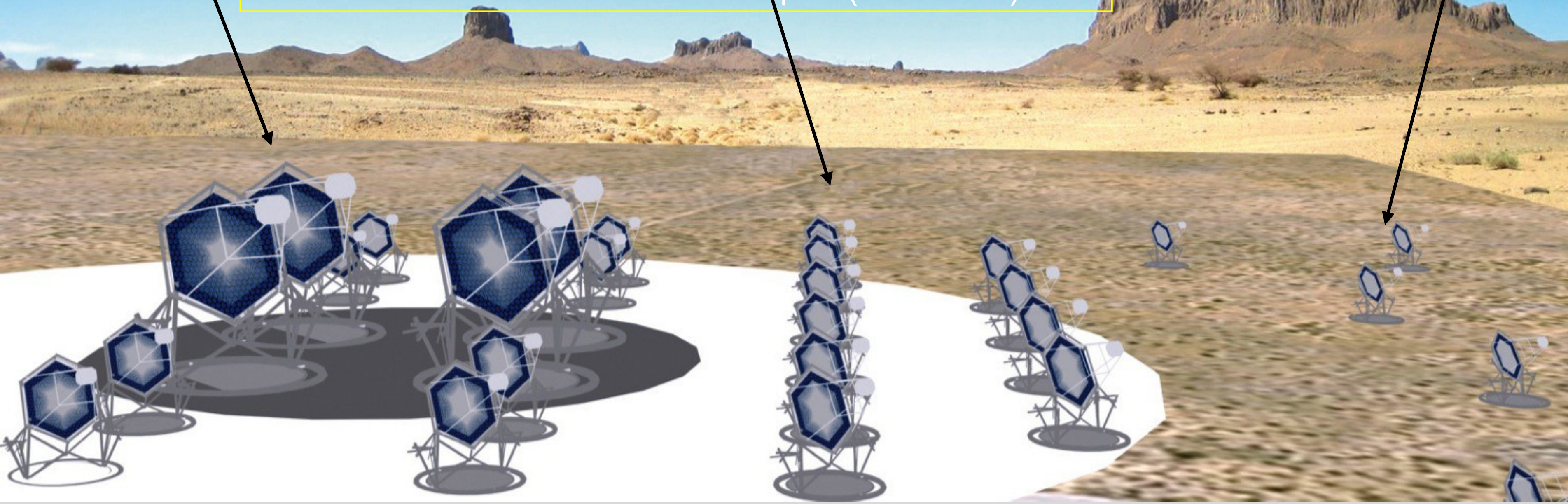
- Large Size Telescopes (24-m class) LST

High-energy section: 1TeV – 100TeV

- 1-Mirror Small Size Telescopes (4-m class) 1M-SST
- 2-Mirror Small Size Telescopes (4-m class) 2M-SST

Core-energy array: 100GeV – 10TeV

- Medium Size Telescopes (12-m class) MST
- Schwarzschild-Couder Telescopes (9-m class) SCT



Highlights on the ASTRI project

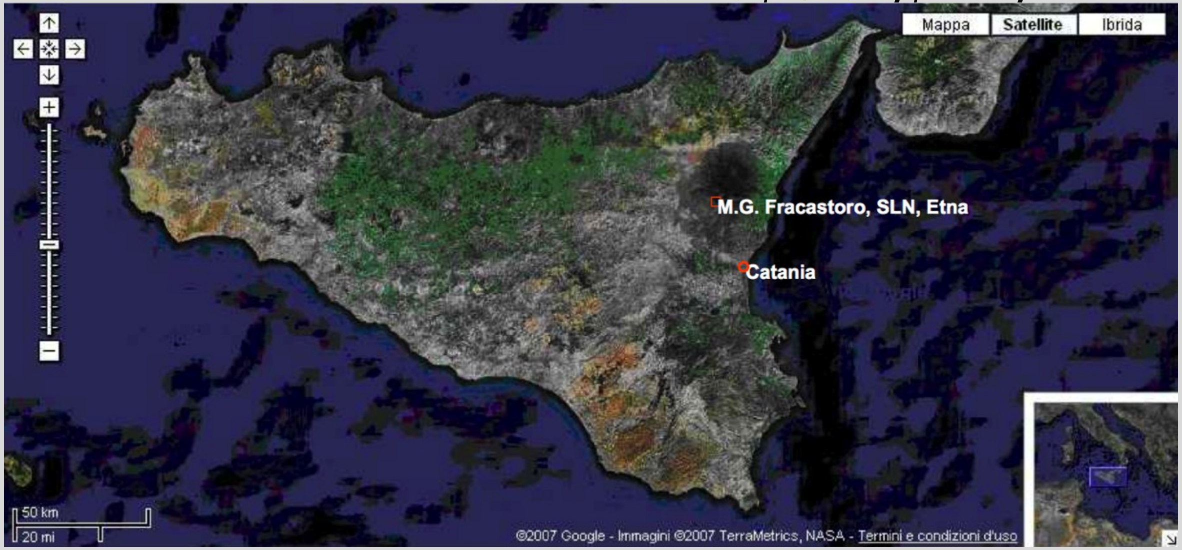
ASTRI is an Italian “Flagship Project” funded by the Ministry of Education, University and Research and led by INAF (Italian National Institute of Astrophysics). Main goals of the project are the design, development and deployment, within the Cherenkov Telescope Array (CTA) framework of:

- An end-to-end prototype of the Small Size Telescopes, named ASTRI SST-2M, to be tested under field conditions in 2014;
- A mini-array composed of SST-2M telescopes to be placed at the chosen Southern site of CTA, to be deployed in 2016;
- The mirrors for the prototype of the Medium Size Telescopes.

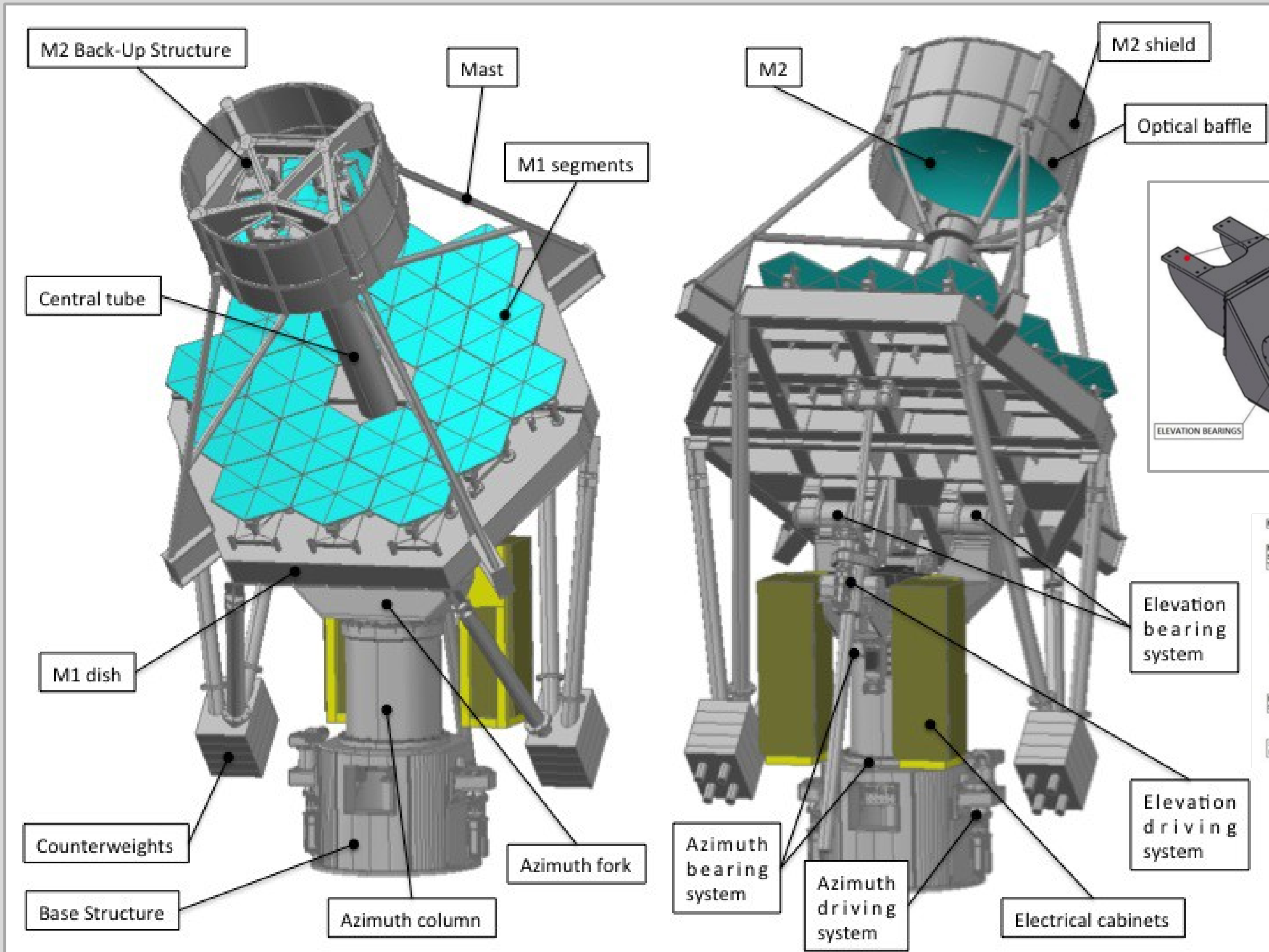
The ASTRI SST-2M prototype is characterized by innovative technological solutions. For the first time, a Cherenkov telescope will have:

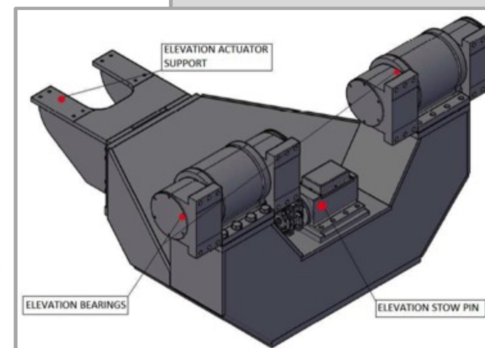
- the optical system arranged in a dual-mirror configuration with a Schwarzschild-Couder optical layout;
- The camera detector at the focal surface is composed by a matrix of Silicon PhotoMultipliers (SiPM).

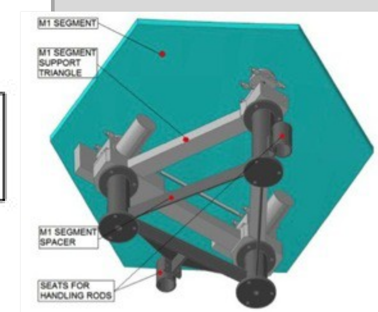
The telescope will be installed at the “M.G. Fracastoro” INAF observing station in Serra La Nave on the Etna Mountain near Catania, Sicily, Italy.



Highlights on the ASTRI project

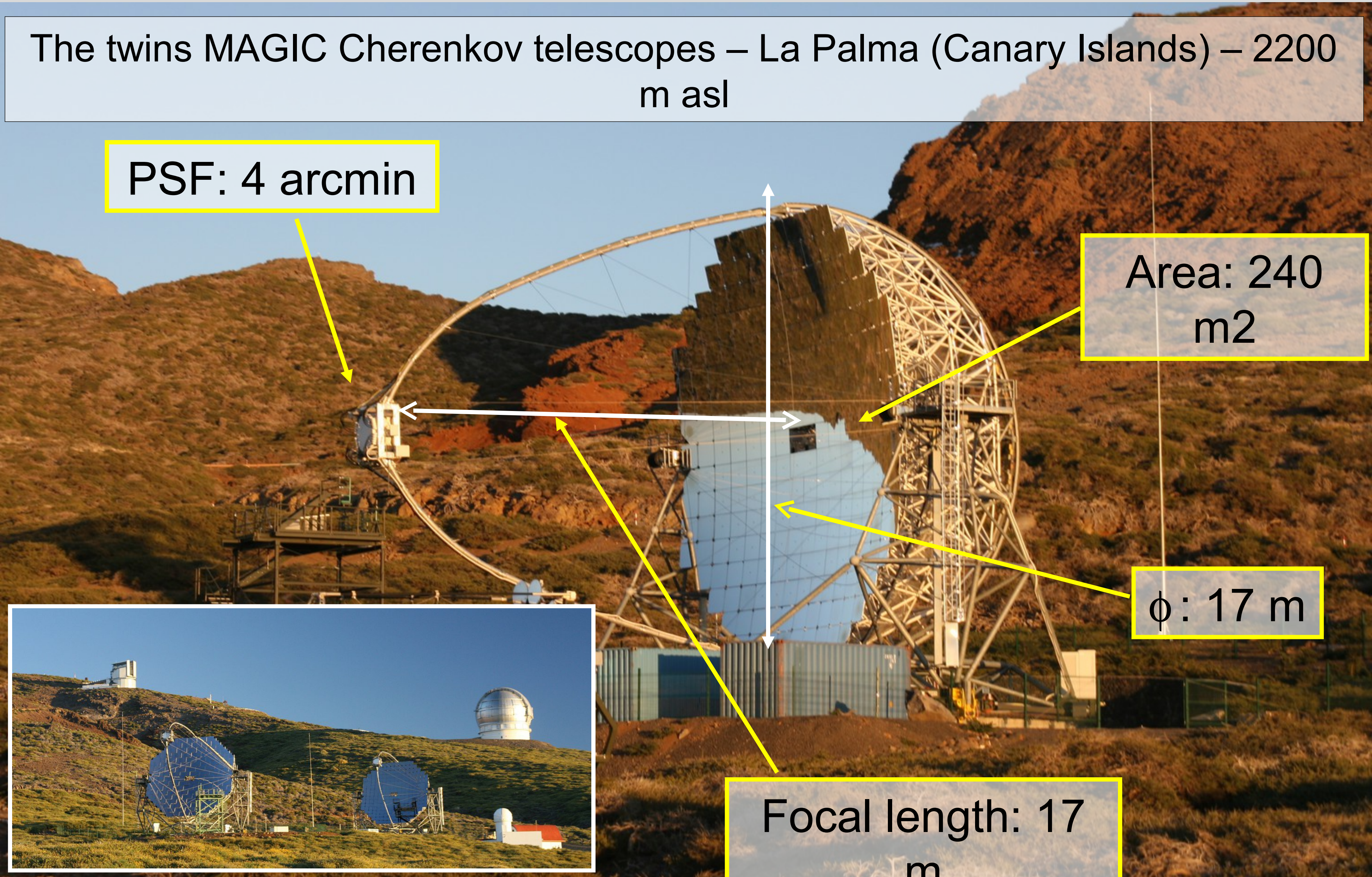






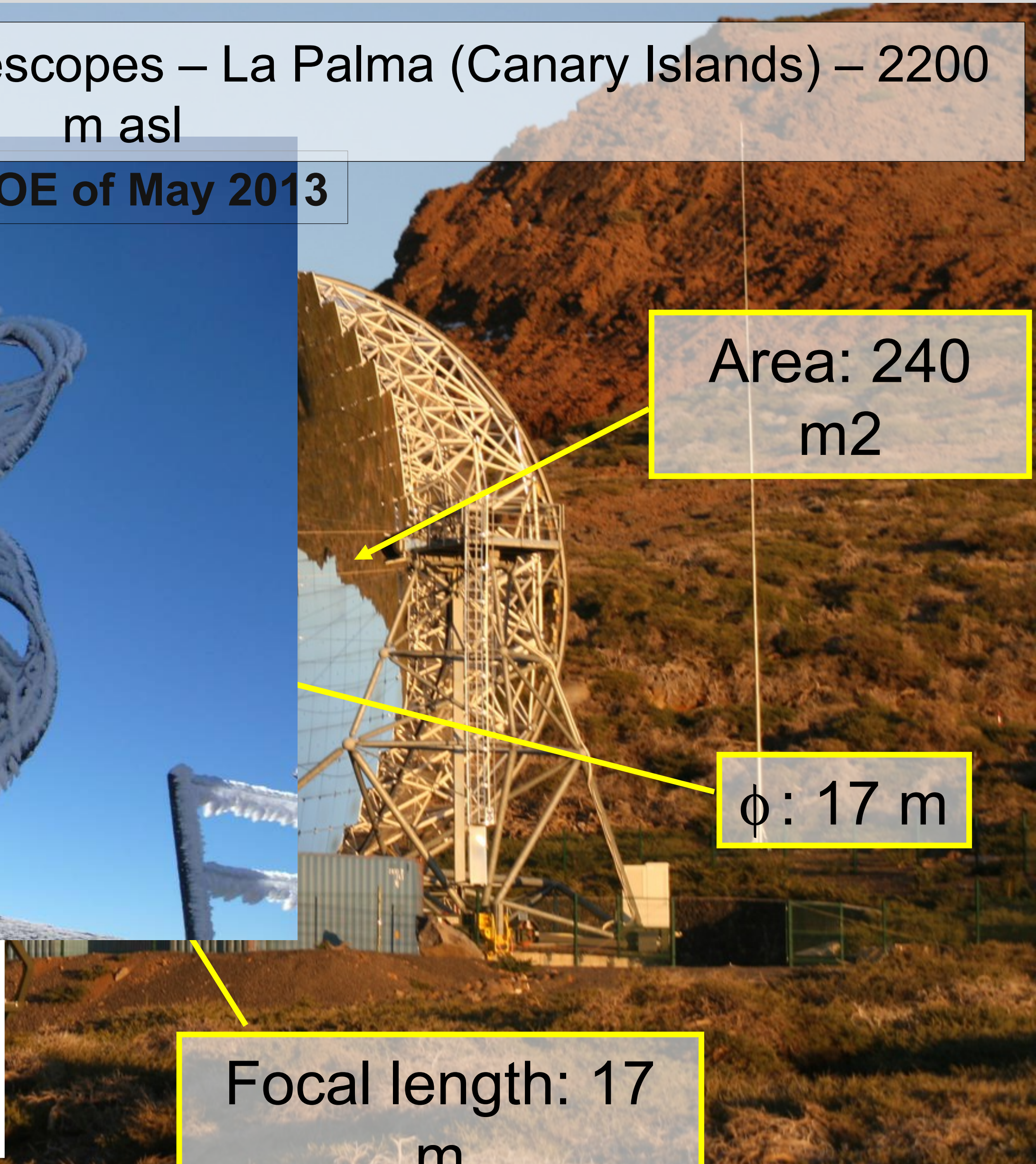
The challenge for a new technology

The twins MAGIC Cherenkov telescopes – La Palma (Canary Islands) – 2200 m asl



The challenge for a new technology

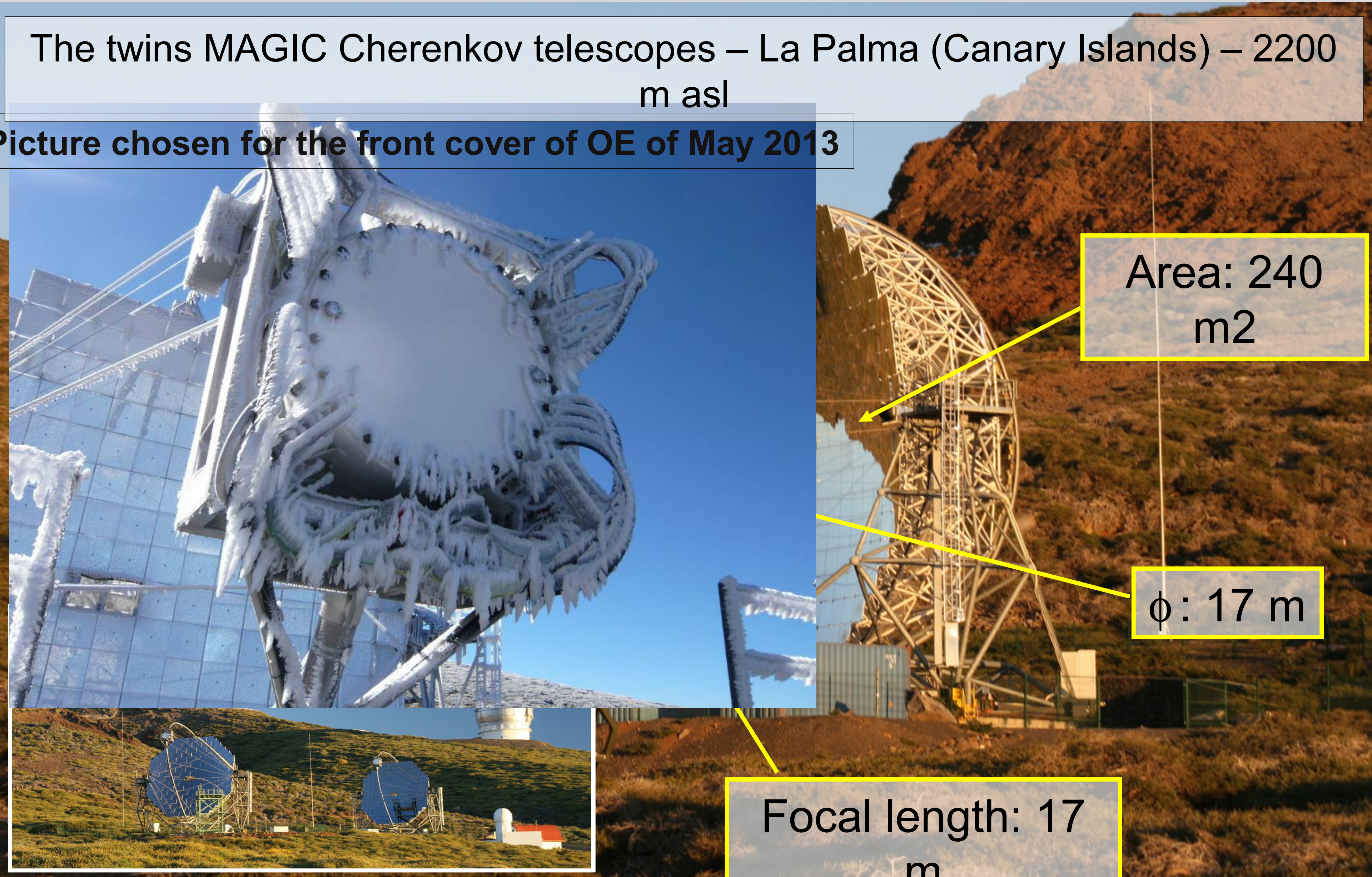
The twins MAGIC Cherenkov telescopes – La Palma (Canary Islands) – 2200 m asl



Picture chosen for the front cover of OE of May 2013

The challenge for a new technology

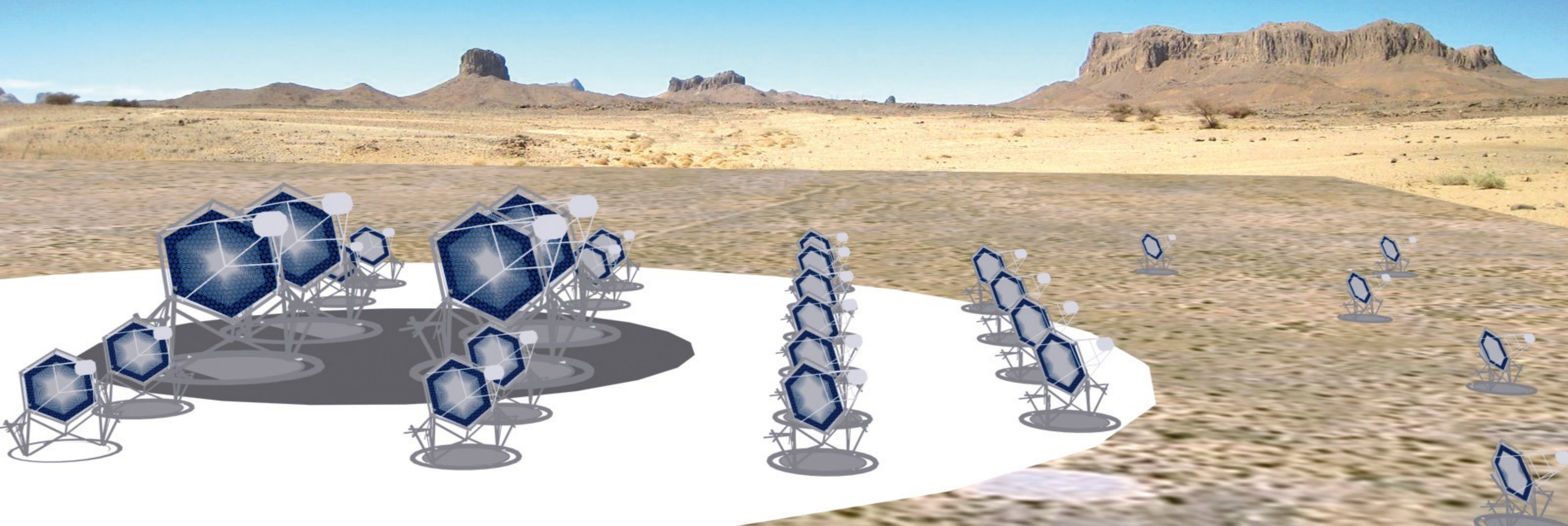
The twins MAGIC Cherenkov telescopes – La Palma (Canary Islands) – 2200 m asl

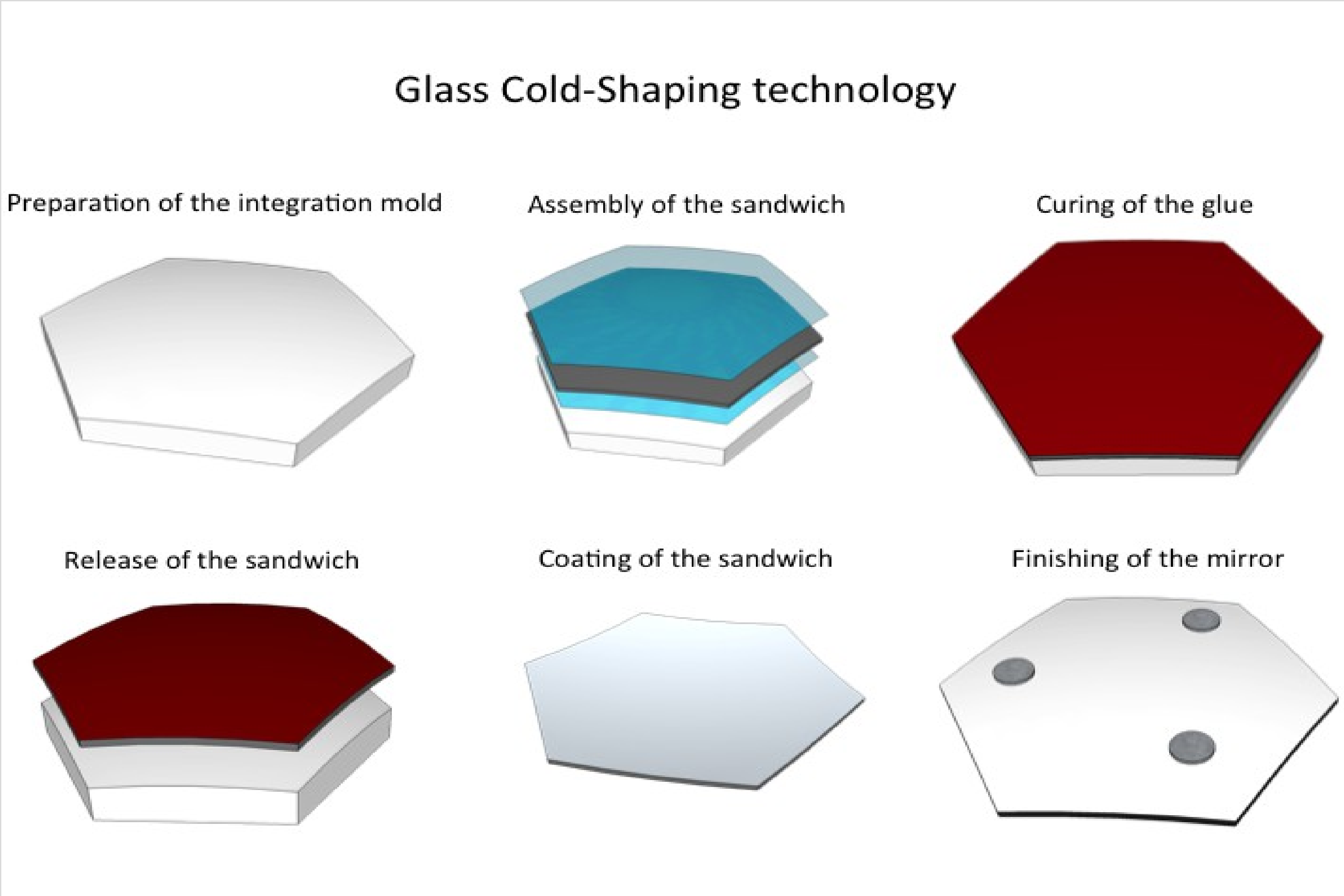


Picture chosen for the front cover of OE of May 2013

The challenge for a new technology

	CTA	Optical tels
Collecting area:	thousands m2	tens m2
Mirror-segment/Area:	≈ 1 m2	< 1 m2 (if not monolithic)
Cost/m2:	≈ k€	several tens/hundreds k€
Weight/m2:	≈ 10 kg/m2	≈ 100 kg/m2
Lifetime:	≈ 10 years	≈ 10 years





Vernani et al. – 7018-32 SPIE Proc. 2008   Pareschi et al. – 7018-33 SPIE Proc. 2008

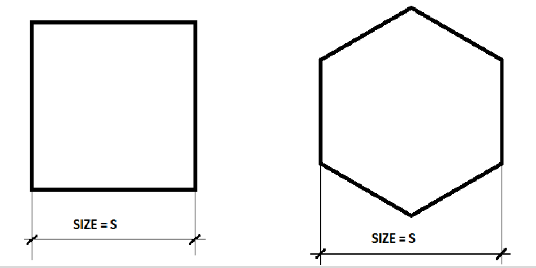
Canestrari R. – SPIE Newsroom http://www.spie.org/48508.xml (May, 2011)

Some questions came up:

- How short in radius of curvature can we go?
- Any influence from the “geometry” of the glass? i.e. dimensions, thickness, shape…
- Which optical shapes can we copy?

Using step-by-step FEA to follow the glass sheet during the whole manufacturing process.

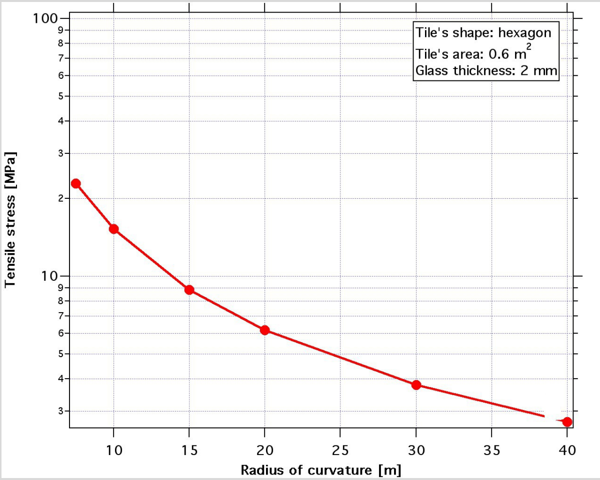
Most critical is the bending step because we want elastic deformation only. Glass is brittle and its strength is not an intrinsic property of the material.

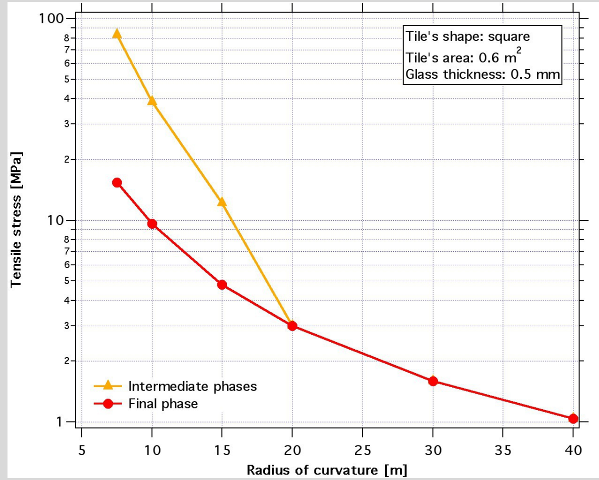


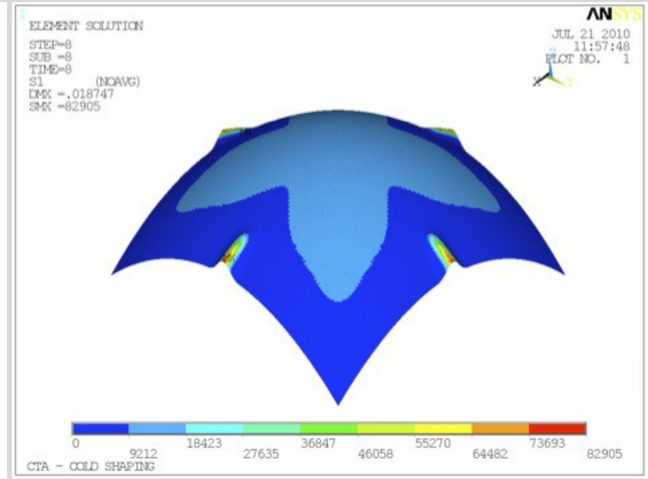
Square shape	Hexagonal shape	Panel area	Glass thickness
S = 0.75 m	S = 0.8 m	0.56 m2	1.0; 1.5; 2.0 mm
S = 1.117 m	S = 1.2 m	1.247 m2	0.5; 1.0; 1.5; 2.0 mm

Canestrari et al. – Optical Engineering vol.52 issue 5 (May, 2013)

Glass foils cold-shaping technology





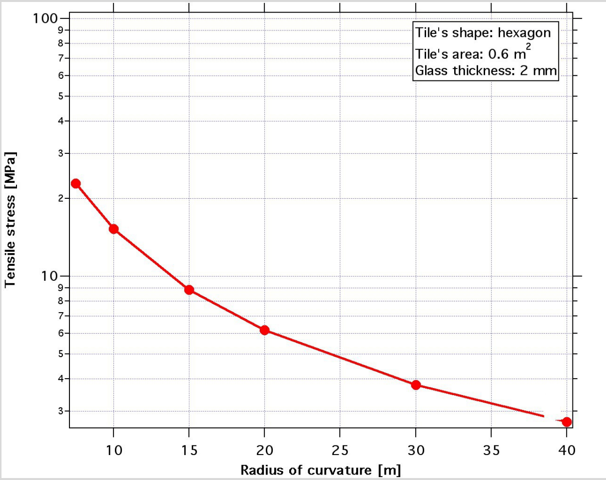


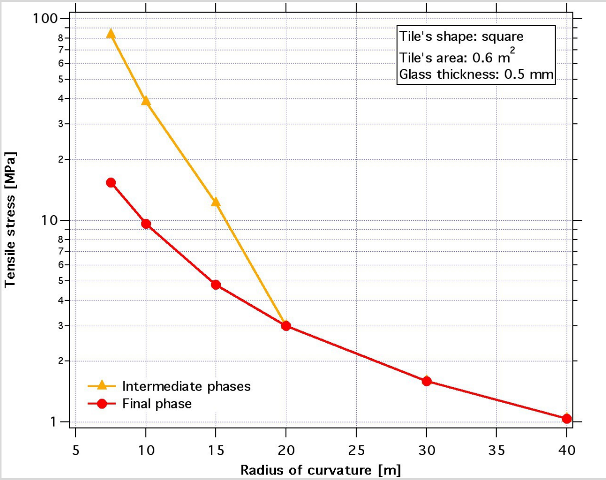
<u>Regular configuration</u>: contact between glass and mold proceed smoothly as the pressure is applied.

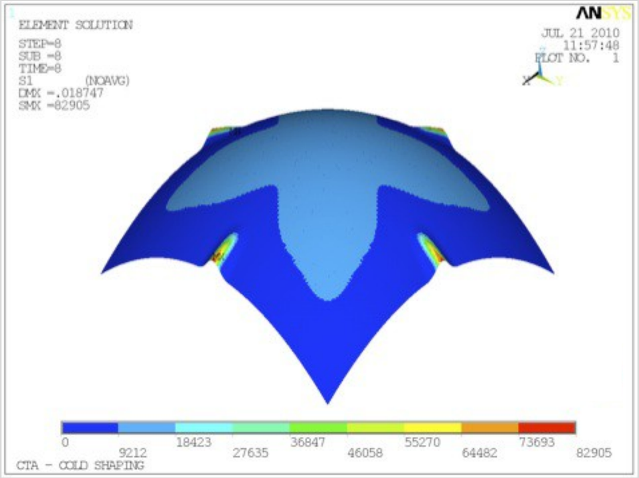
<u>Corrugated configuration:</u> folds not in contact with the mold. At folds location very high stress.

It is made easier by: reducing the curvature; reducing the thickness; increasing the size; changing the geometry from hex to square

Glass foils cold-shaping technology



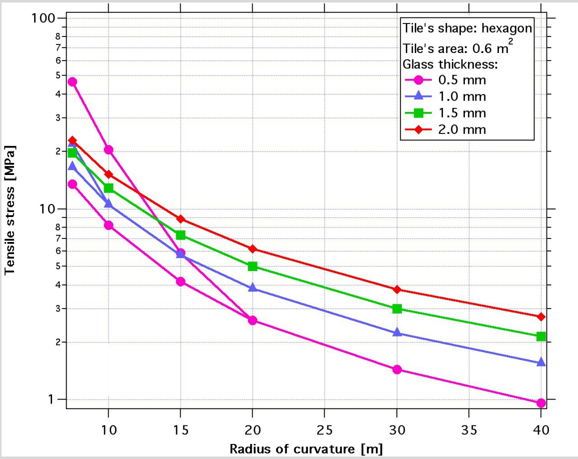


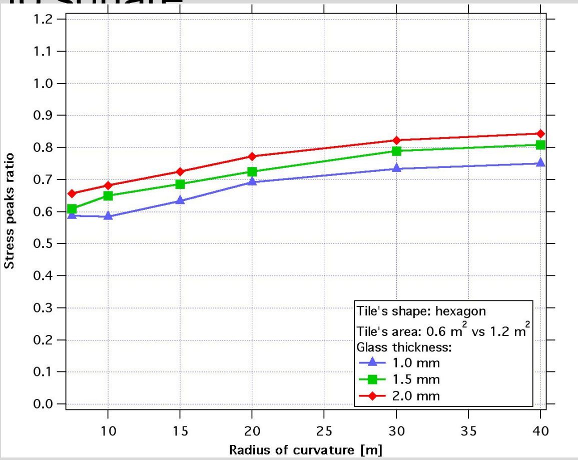


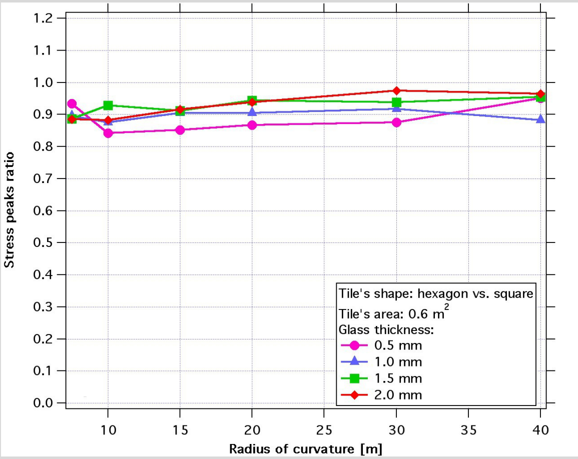
Regular configuration: contact between glass and mold proceed smoothly as the pressure is applied.

Corrugated configuration: folds not in contact with the mold. At folds location very high stress.

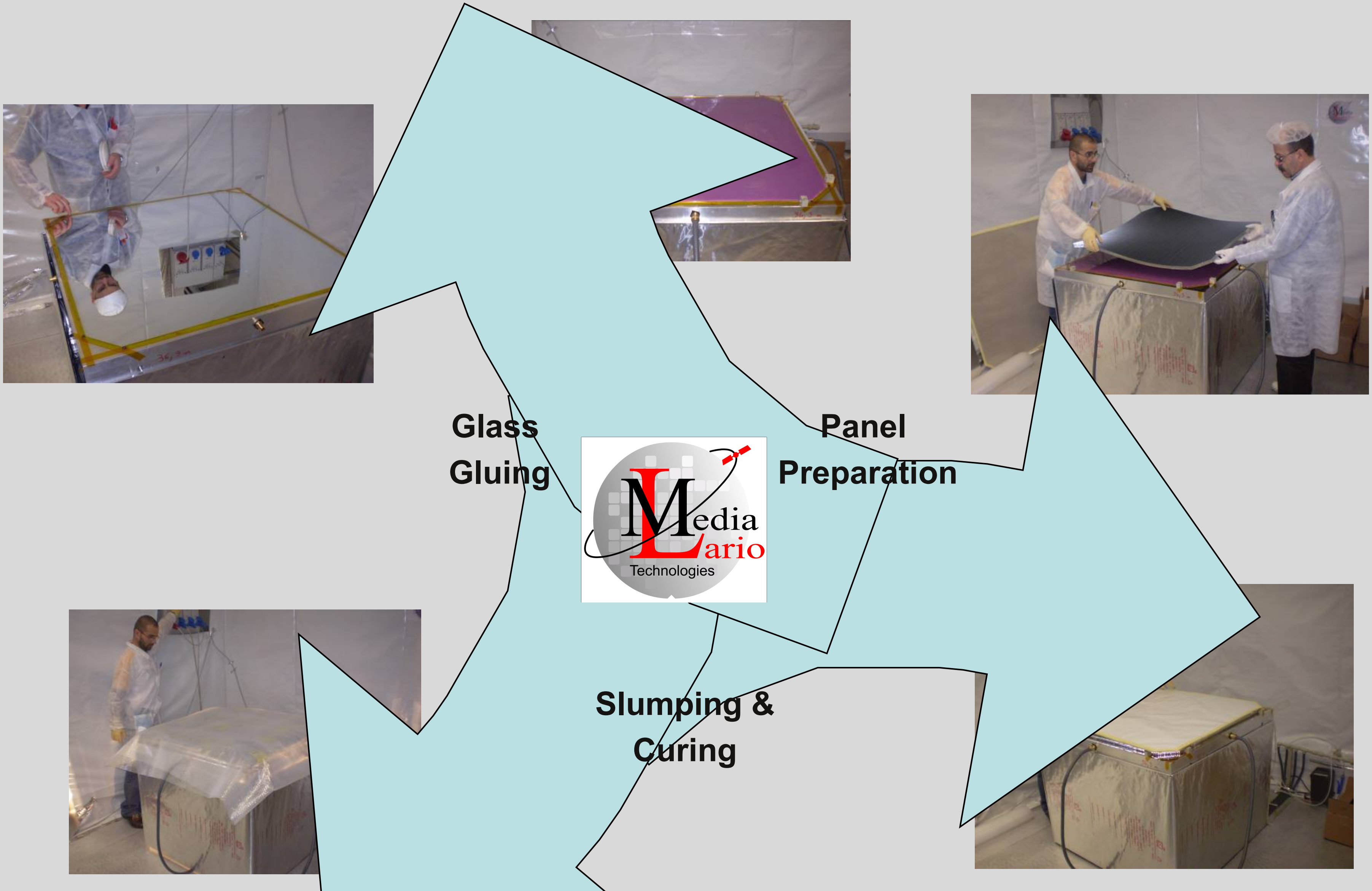
It is made easier by: reducing the curvature; reducing the thickness; increasing the size; changing the geometry from hex to square







A practical example: MAGIC II



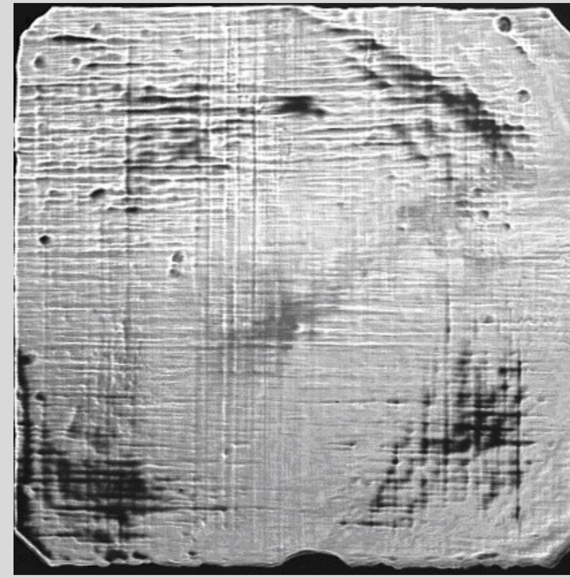
A practical example: MAGIC II

MAGIC mirrors facts:

- Size: 985 x 985 mm
- Weight: 9.5 kg
- Shape: sphere
- Radius: 35-36 m

112 mirrors produced by Media Lario Technology (Italy) in about 3 months (March to June 2008)

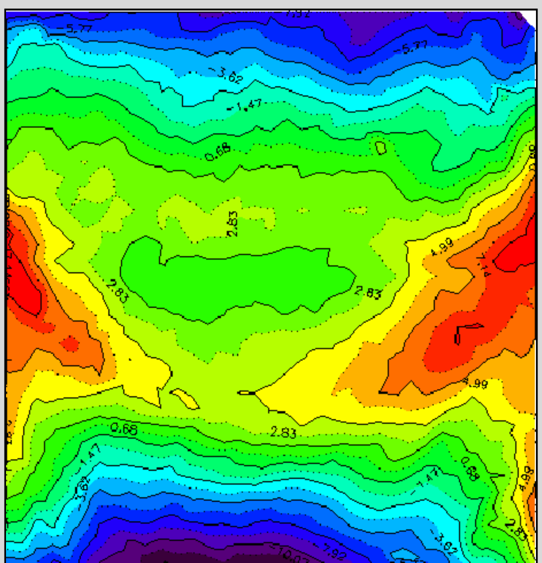
A practical example: MAGIC II



Legenda

- Horizontal lines: intrinsic of the float glass sheet
- Vertical lines: deriving from the honeycomb structure
- Dots: from dust grains trapped
- Shadows: deriving from the defects of the mold shape

Aluminum master

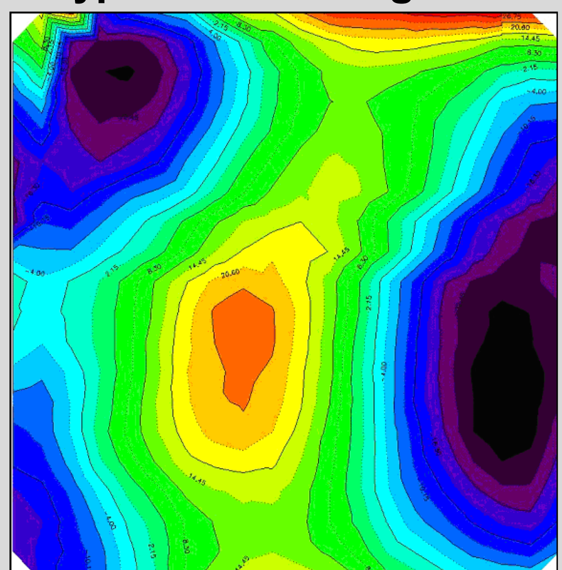


Points: 392

P-V: 21.5 μm

RMS: 4.6 μm

Typical mirror segment

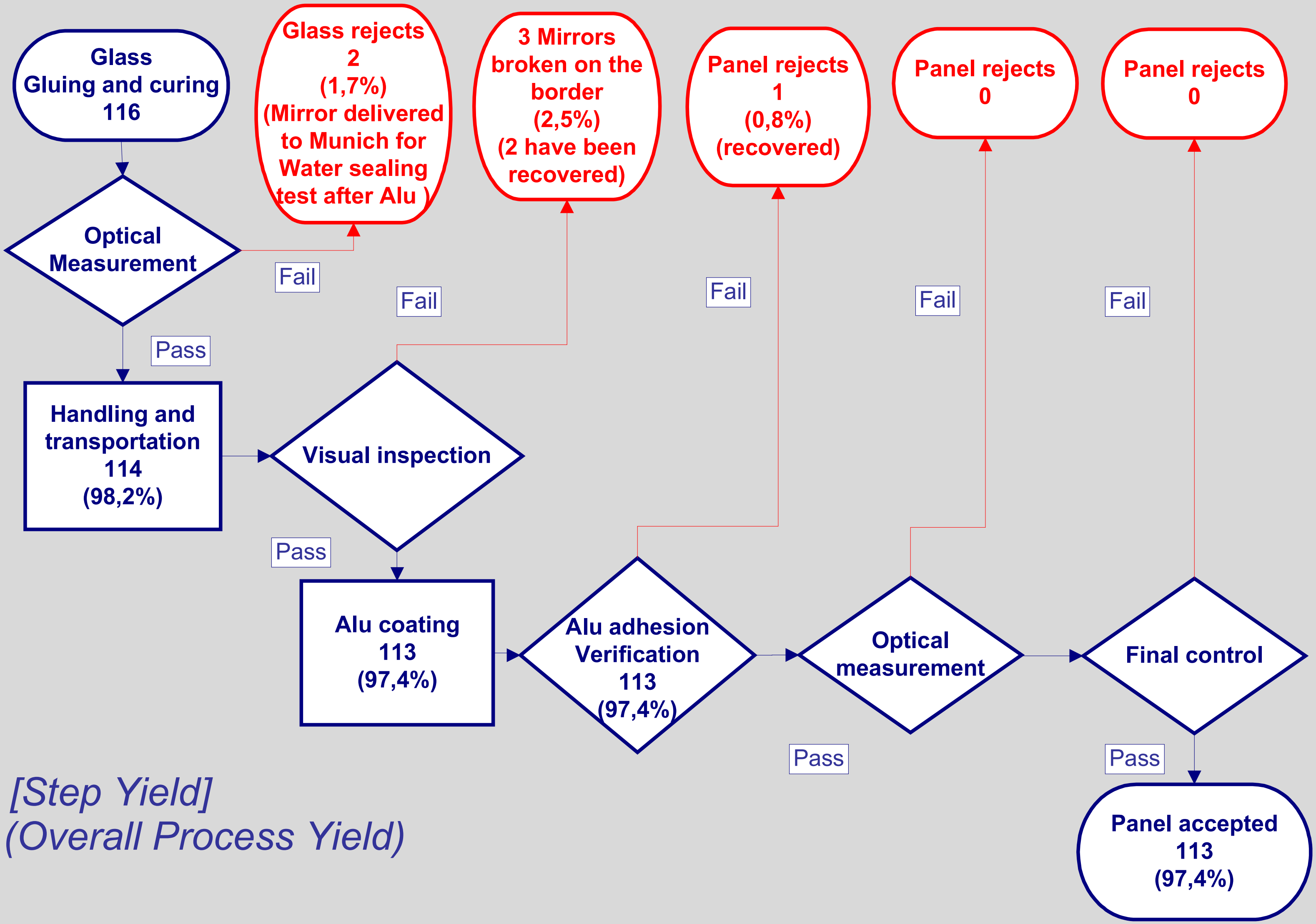


Points: 392

P-V: 62.3 μm

RMS: 15.3 μm

A practical example: MAGIC II

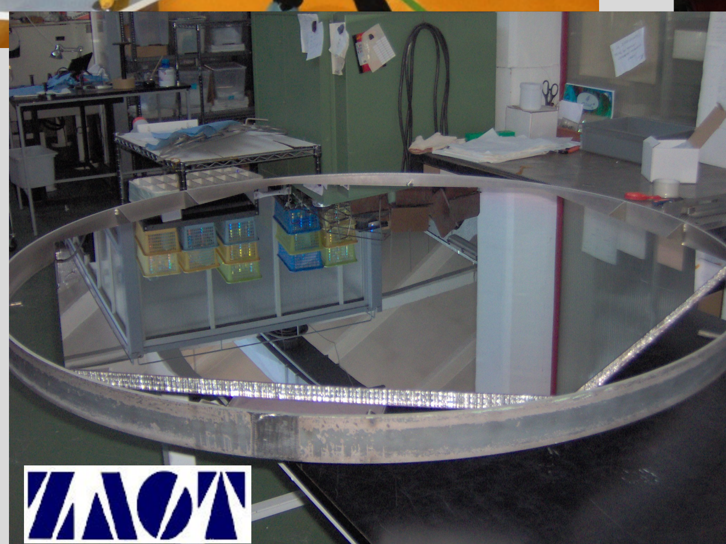


[Step Yield]
(Overall Process Yield)

Another example: CTA-MST

Achievements from the CTA-MST development

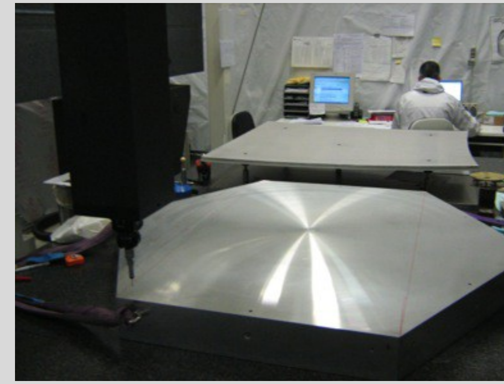
On April 17th 2012, two large boxes with 20 full-size full-specs mirrors have arrived to DESY-Zeuthen



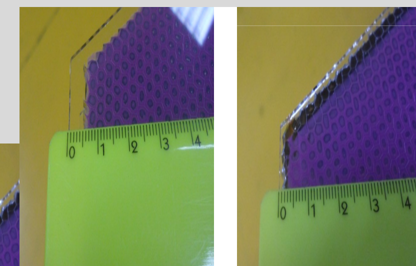
Media Lario Technologies

Another example: CTA-MST

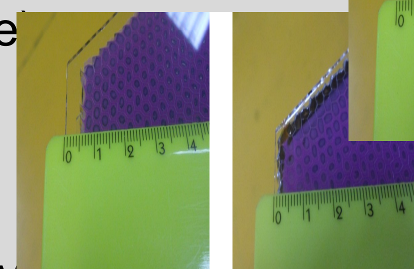
Achievements from the CTA-MST development



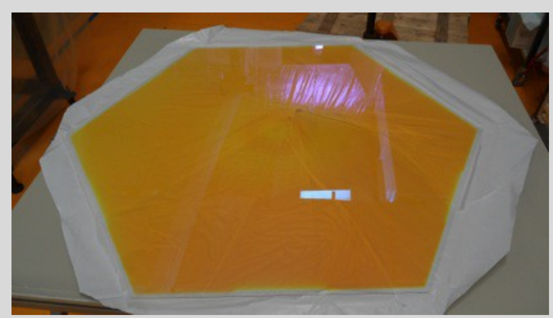
- New mold technology: cheaper (7 k€/each) and good (error = 8 μm rms)
- Very fine control of the radius of curvature of the mirrors: possibility to replicate the mold or to change its radius upon request (under limited values range)

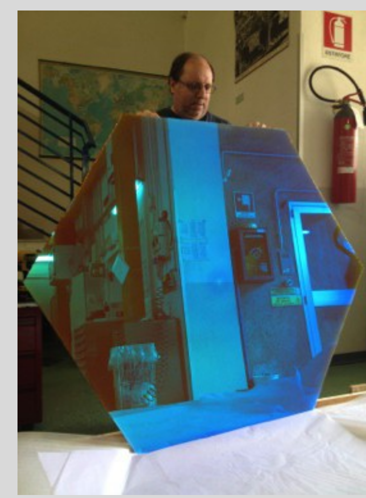


- Less glue per mirror (cheaper) and less honeycomb-free edges (better PSF shape)



- Dielectric coating possible (even if not advisable)

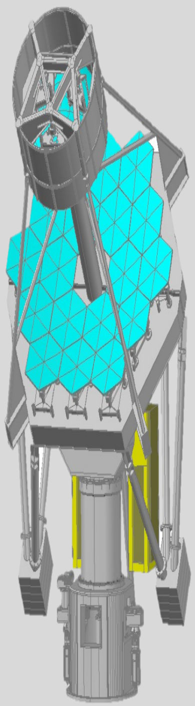


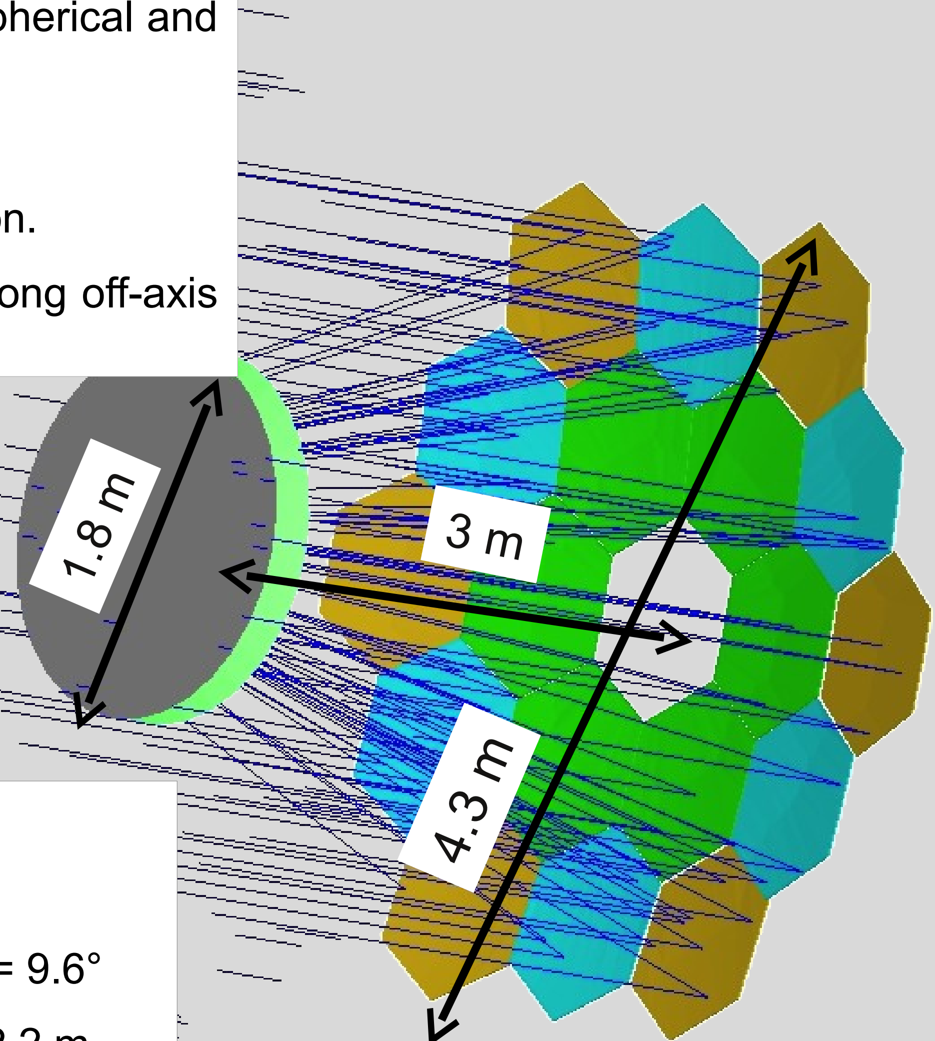


Last example: the ASTRI project

Schwarzschild-Couder is:

- Aplanatic, wide-field, de-magnifying (spherical and coma aberrations free)
- Aspherical optical surfaces.
- Possibility to push the angular resolution.
- Very good optical performances for strong off-axis rays





"Optical" numbers:

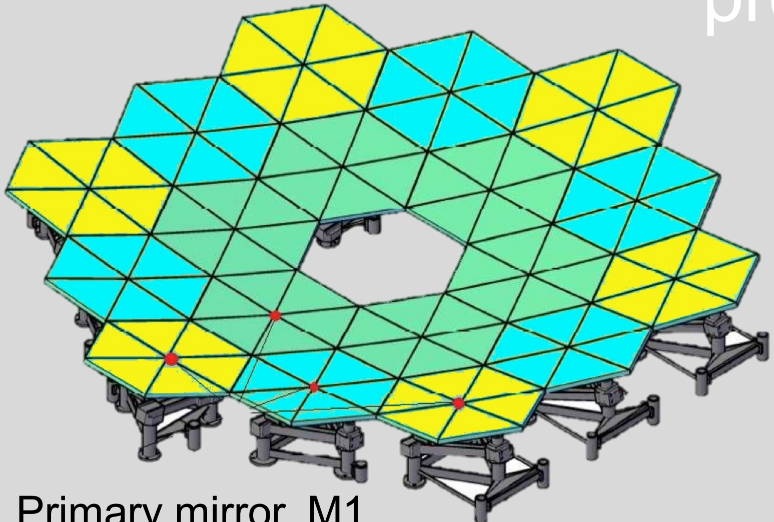
f: 2.15 m F#: 0.5

Pixel size = 0.17° FoV = 9.6°

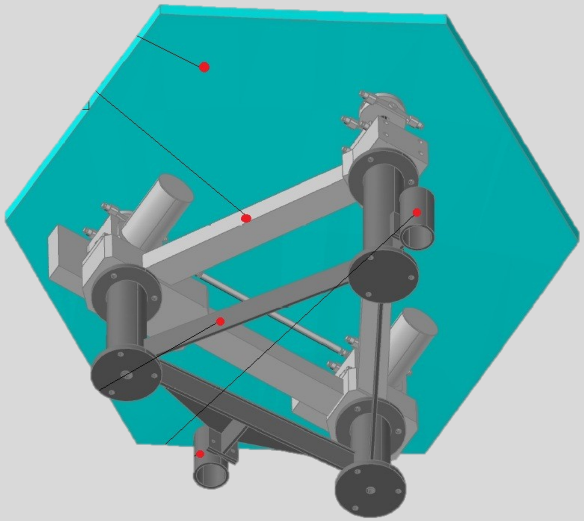
M1 RoC: 8.2 m M2 RoC: 2.2 m

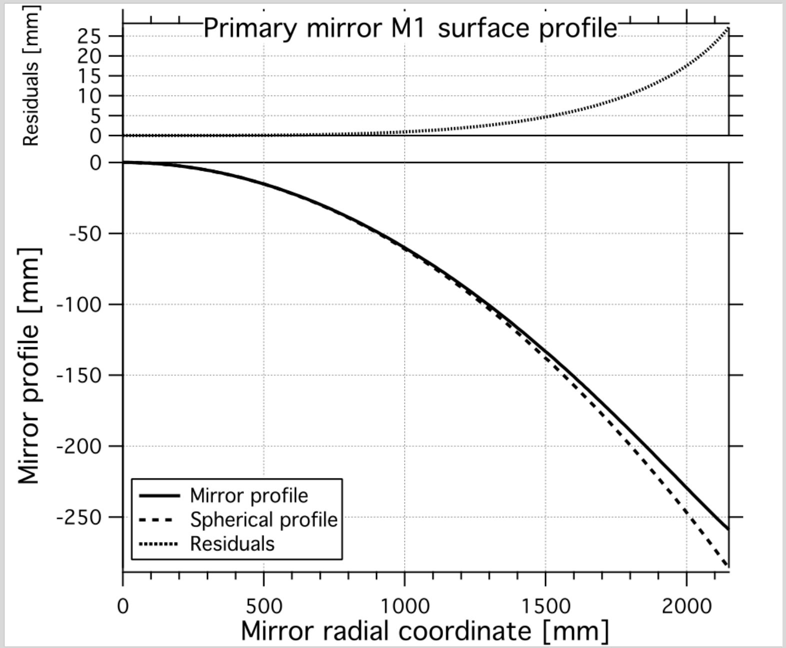
Canestrari et al. – 8861-01 SPIE Proc. 2013

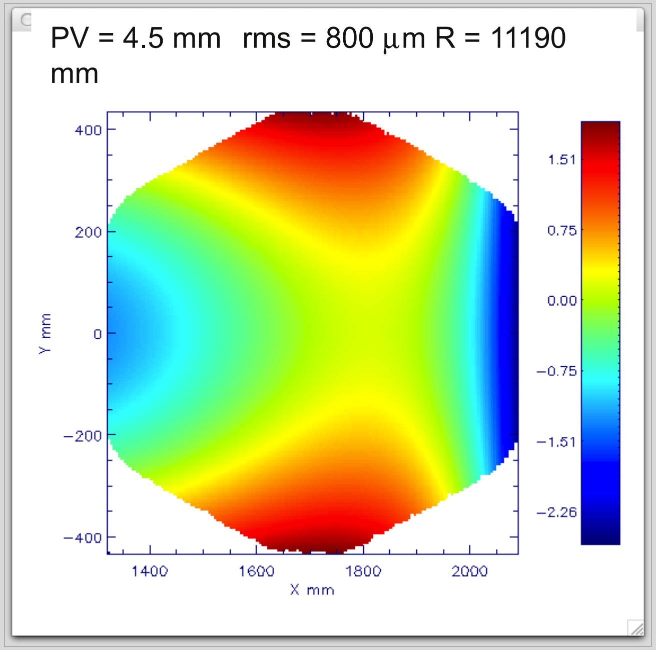
Last example: the ASTRI project



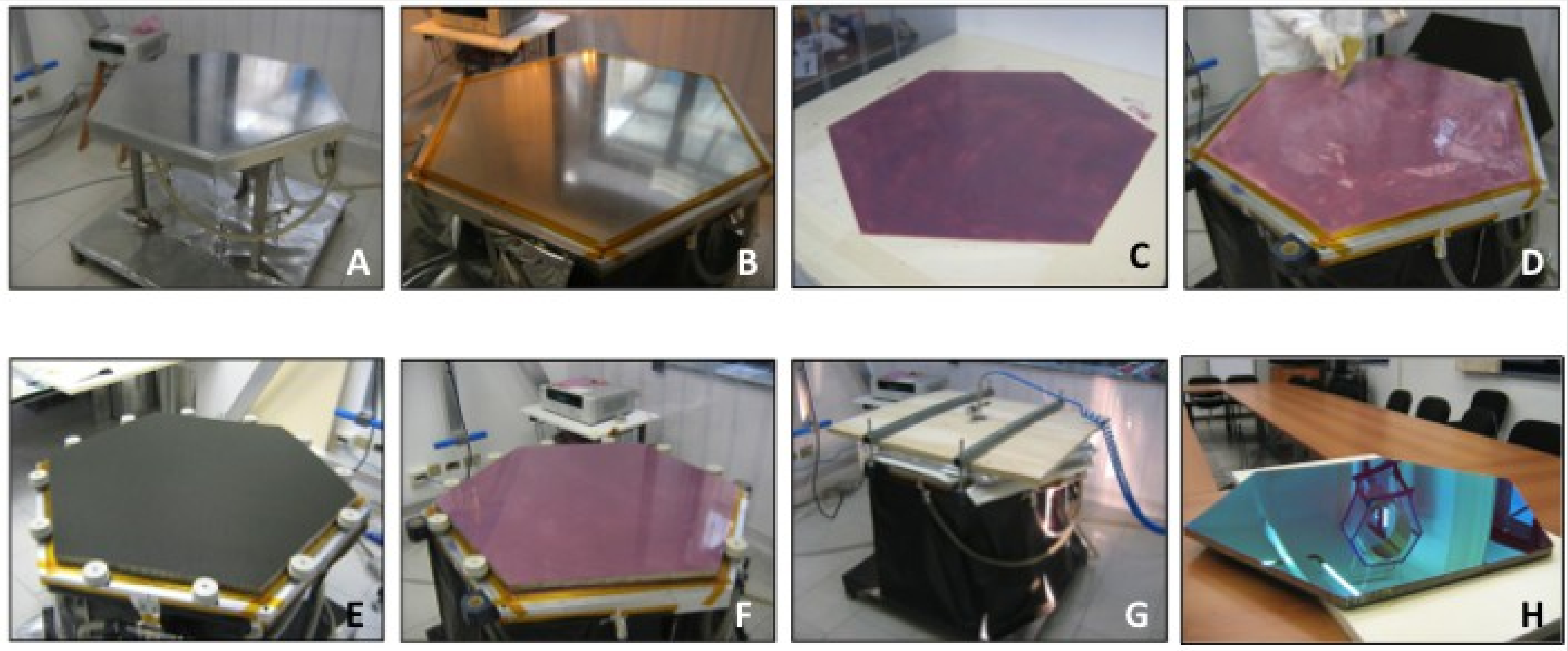
Primary mirror, M1







Last example: the ASTRI project



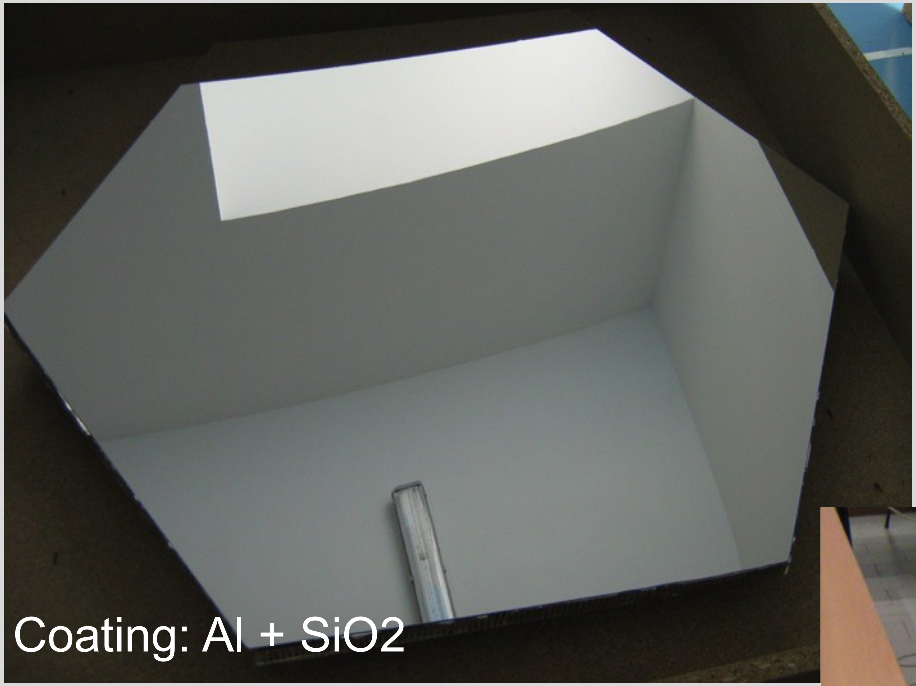
Last example: the ASTRI project

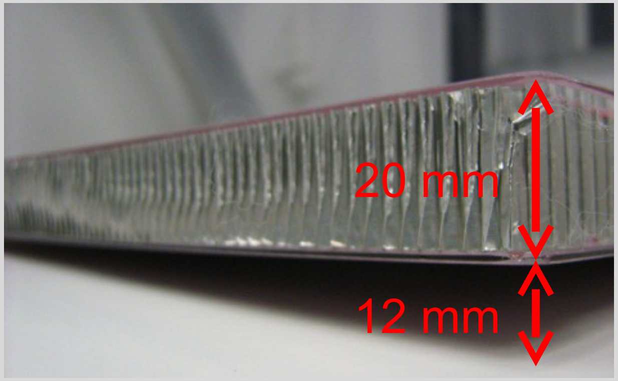
First M1 segments (COR3, most aspheric one) successfully realized in August/September 2012!!

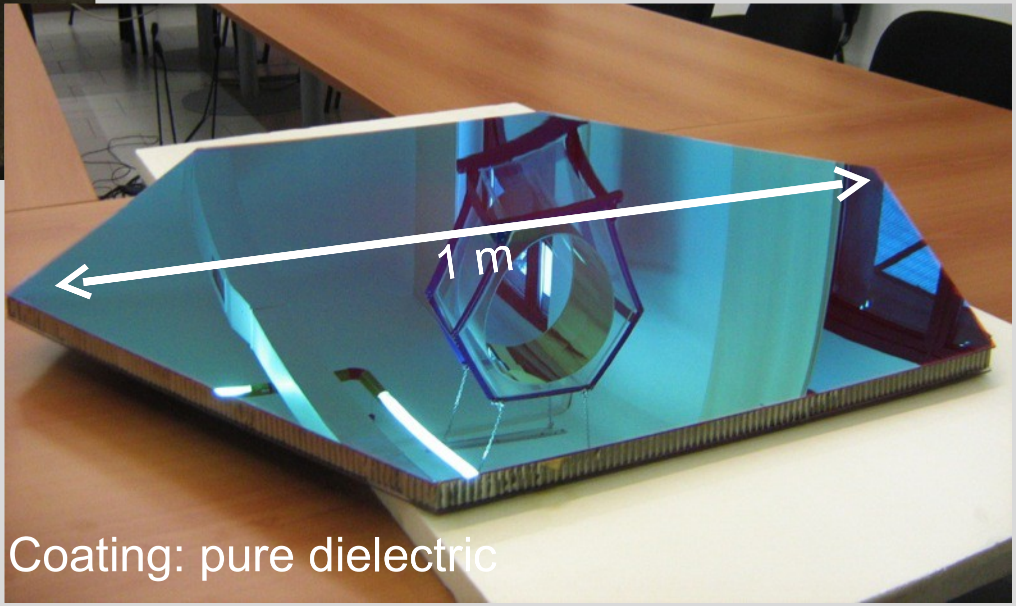
Optical and surface measurements performed with success.

Data analysis and ray tracing tools developed.

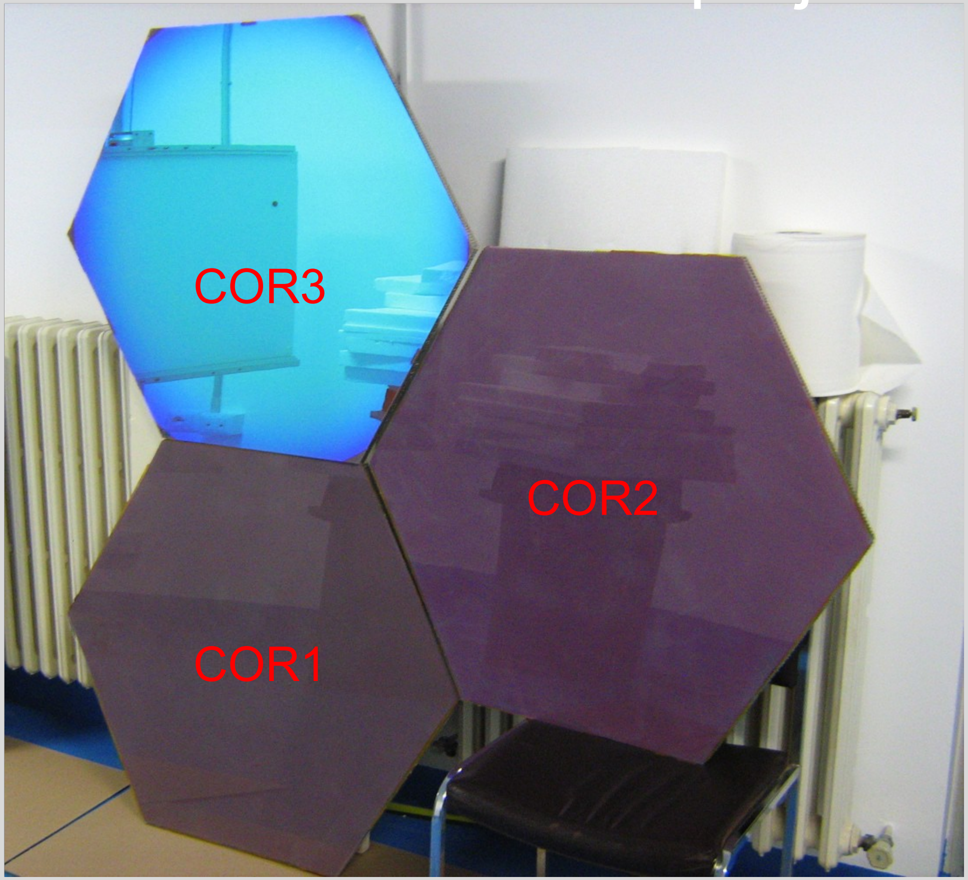
Optical shape almost in spec with the requirements!!!





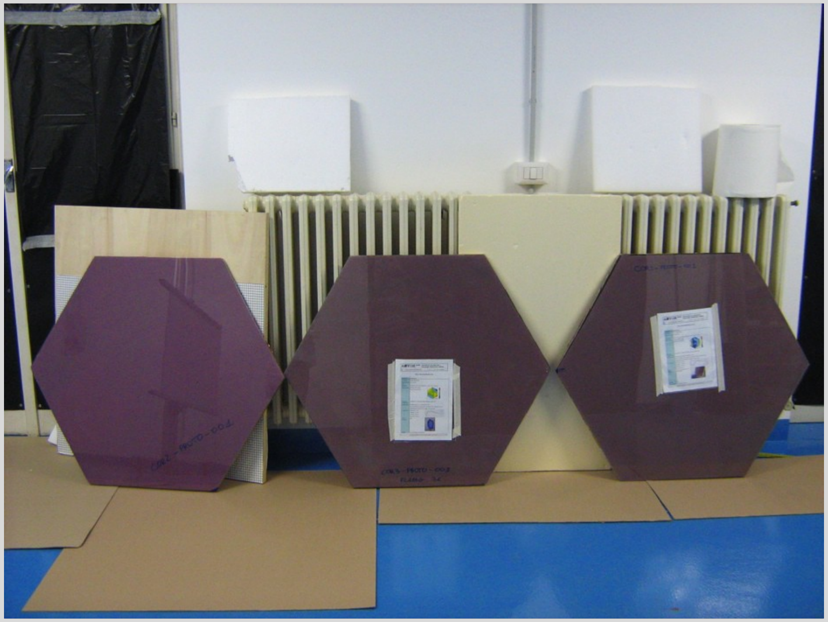


Last example: the ASTRI project



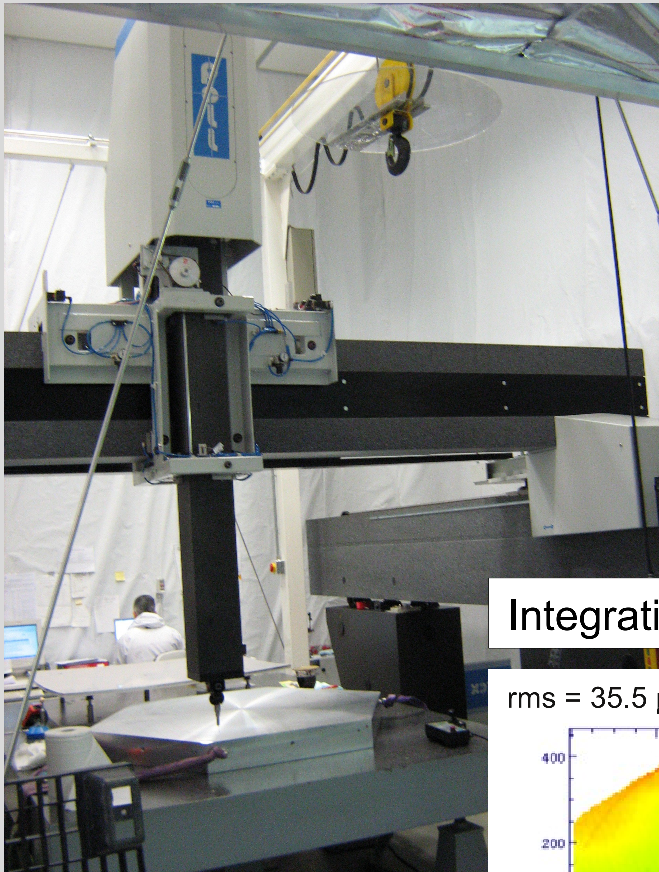
First representative set of mirror segments successfully produced in December 2013.

Quality procedures established. Each mirror segment is coded and comes with ID card.



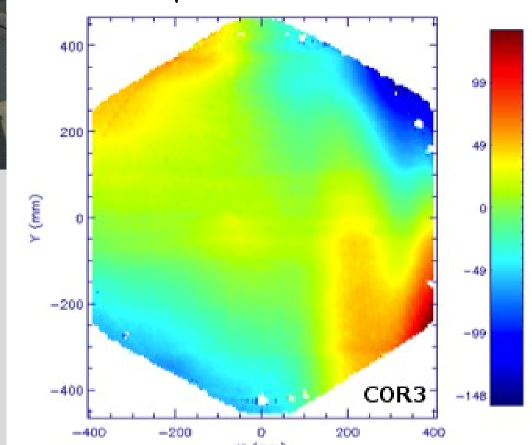
Last example: the ASTRI project

The mold and the mirror have been measured by means of CMM (Zeiss UPMC).



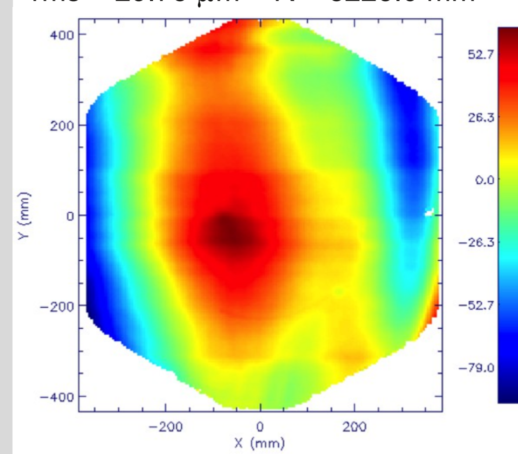
Integration mold, residuals

rms = 35.5 μm   R = 8223.0 mm



Mirror sandwich, residuals

rms = 29.75 μm   R = 8223.0 mm



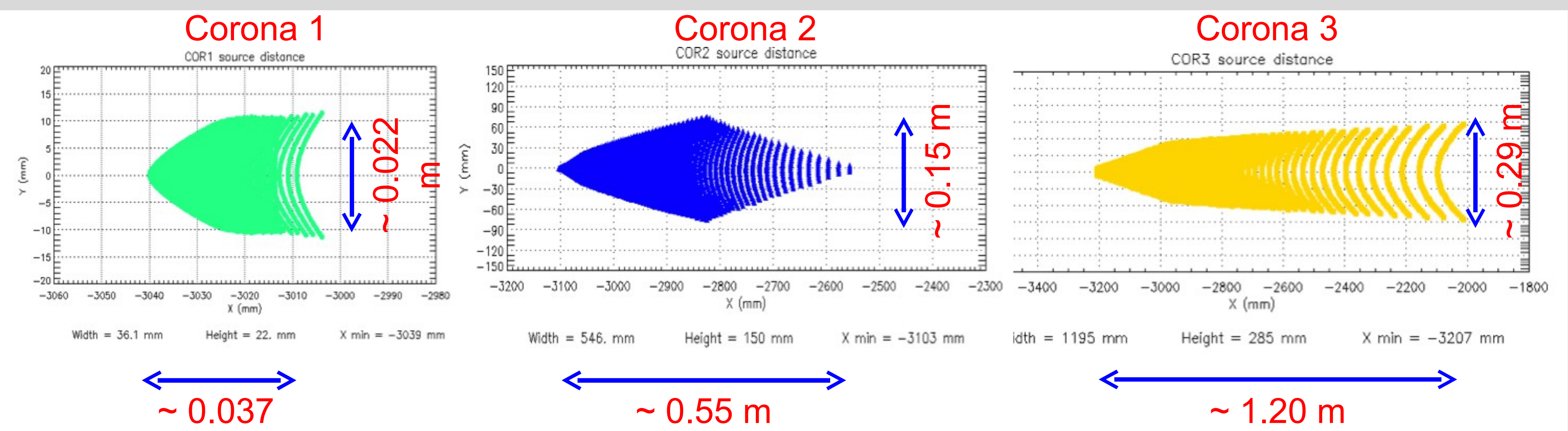
Primary mirror, M1 - metrology

Metrology to measure/characterize our mirrors. Up to now:

- CMM: precise but time consuming; not feasible when in production
- PMD: precise and fast, optimum when in production; but hardly usable for M2

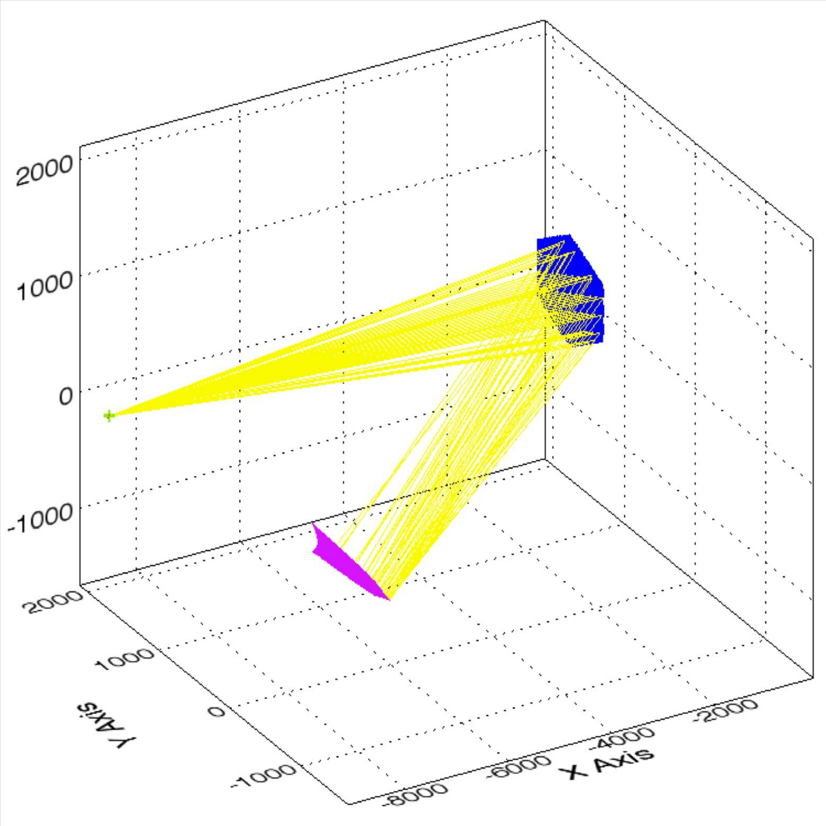
Both are NOT available in house.

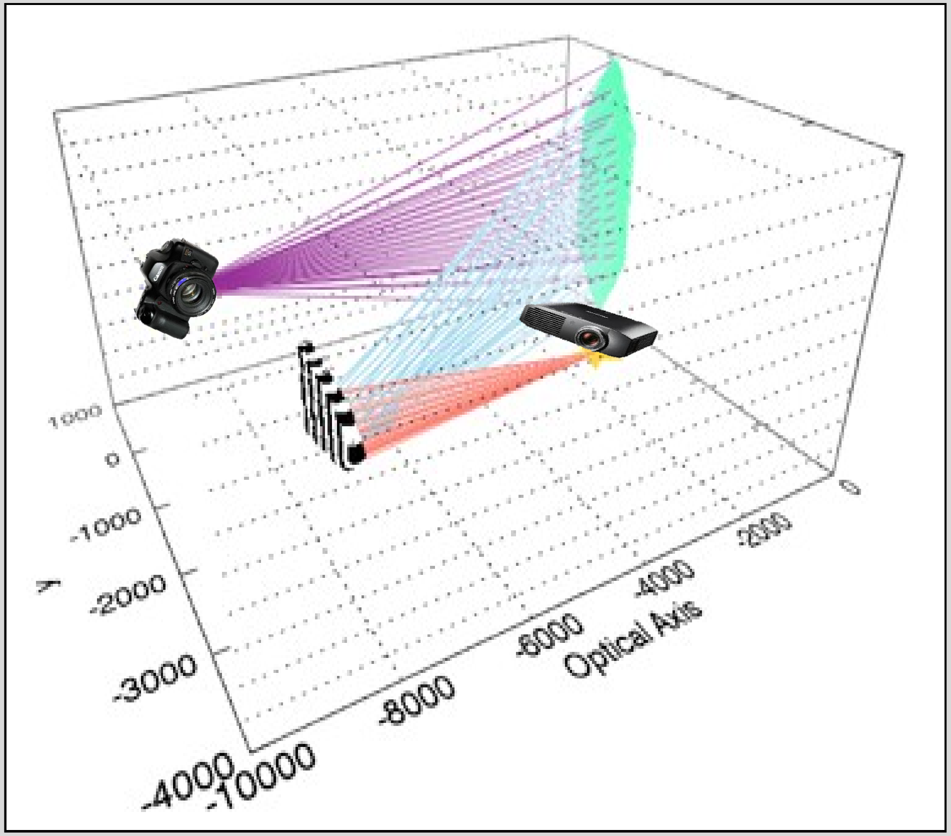
Need of something different AND in house AND cheap AND for (strong) a-sphere AND for off-axis mirrors AND... Looking at classical optical tests used by optician for qualitative evaluations (e.g. Ronchi, Foucault knife-edge, Hartmann…) combined with some new technologies (photographic digital cameras).



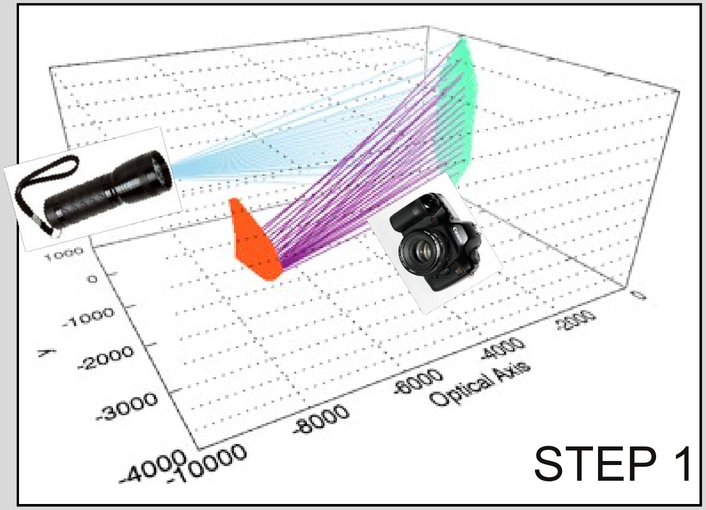
Last example: the ASTRI project

The mirrors have been also measured by means of optical setups: PSF imaging and deflectometry technique.

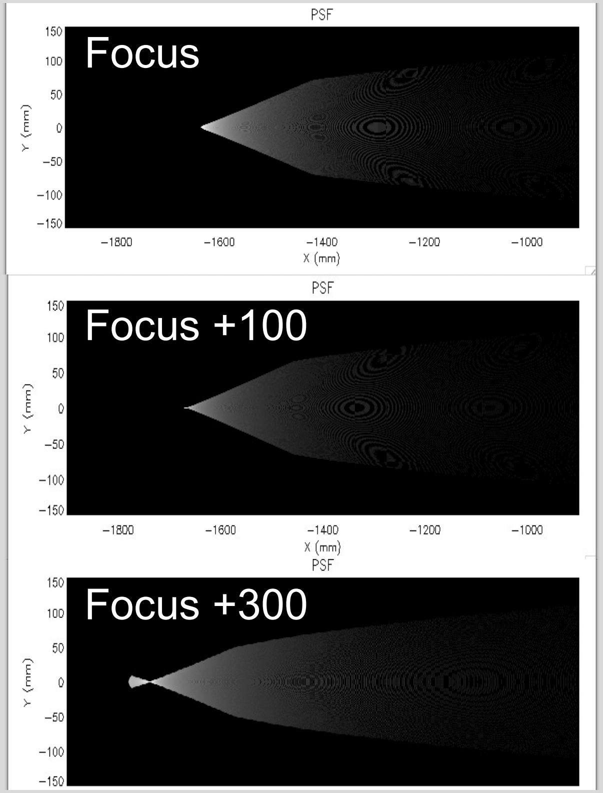




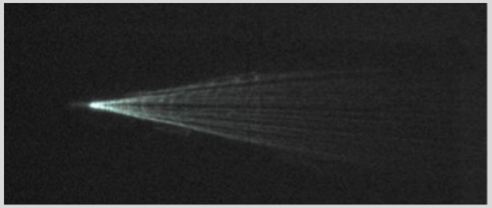
Primary mirror, M1 - metrology

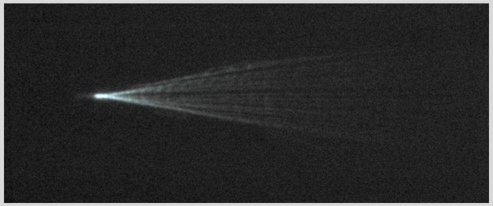


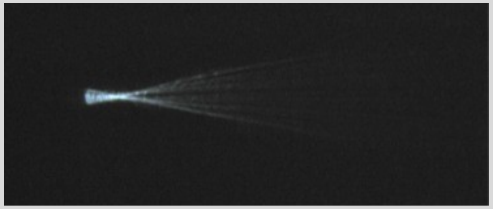
Theoretical



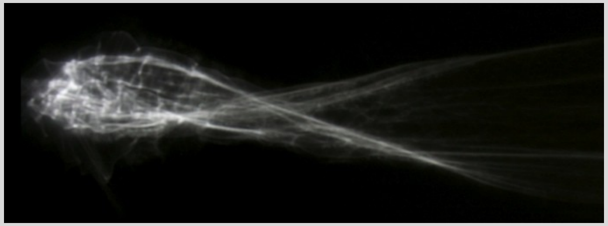
Pictures

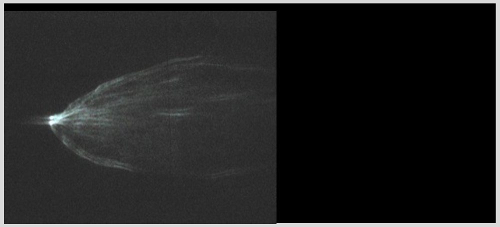


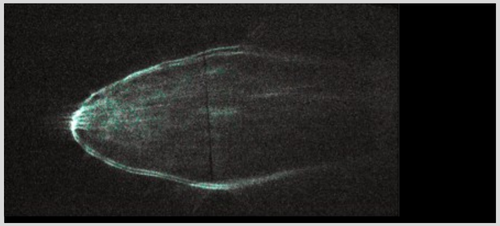




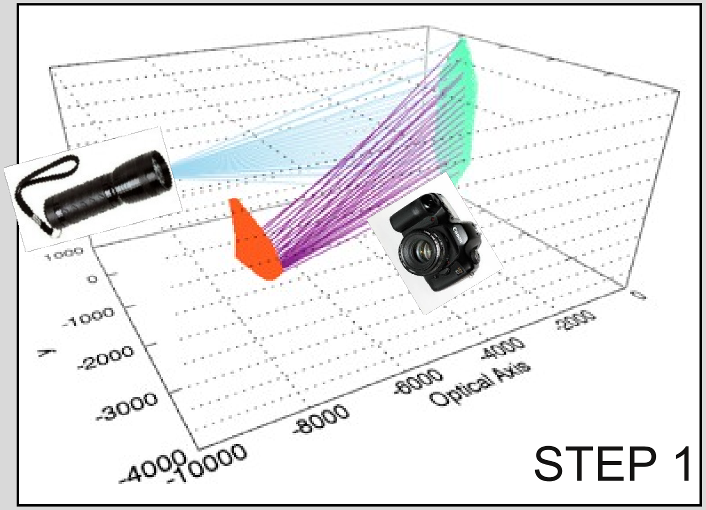
10 mm thick



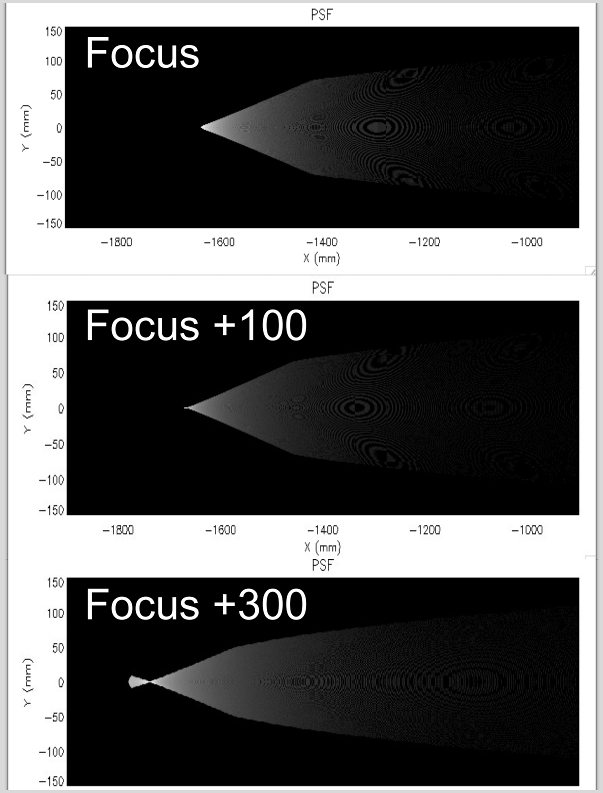




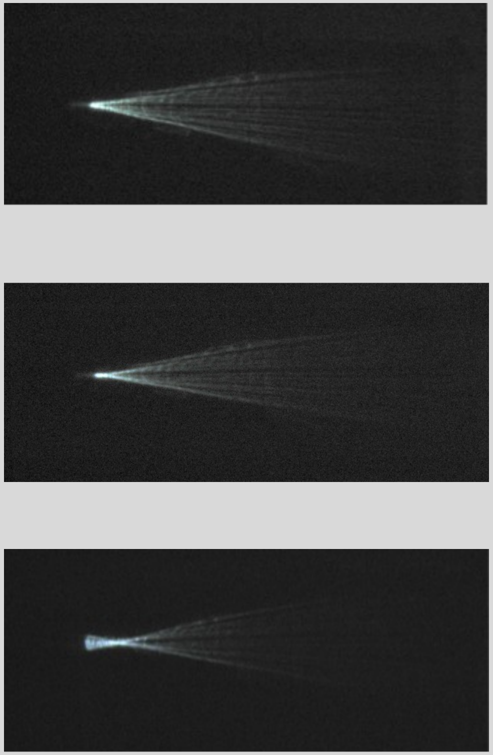
Primary mirror, M1 - metrology



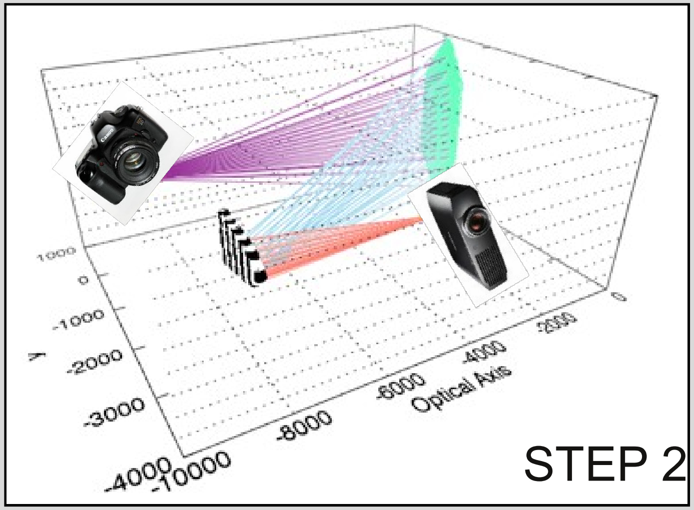
Theoretical

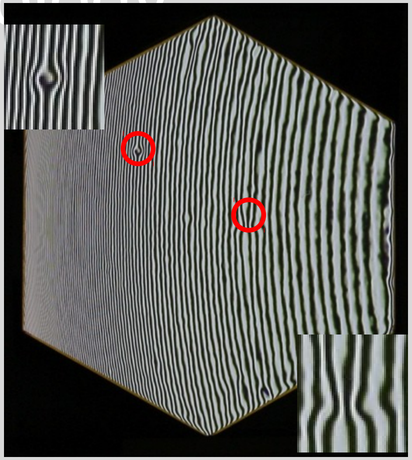


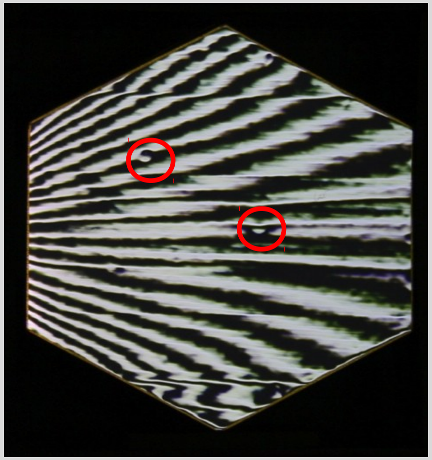
Pictures

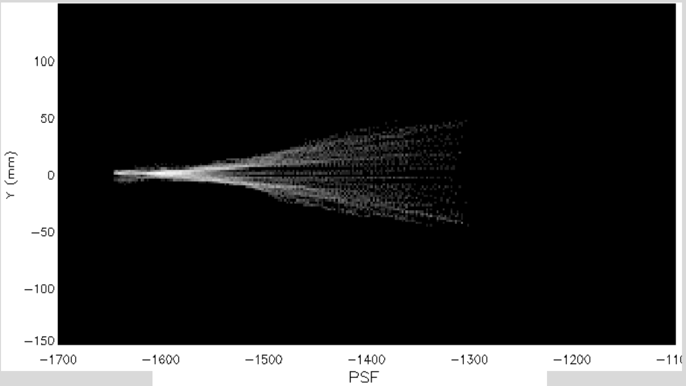


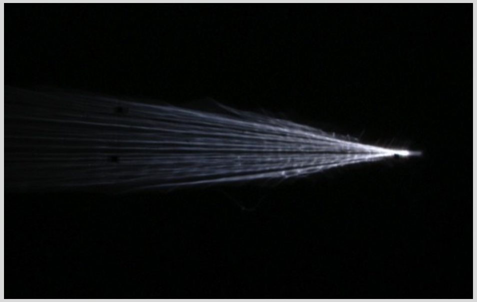
Primary mirror, M1 - metrology

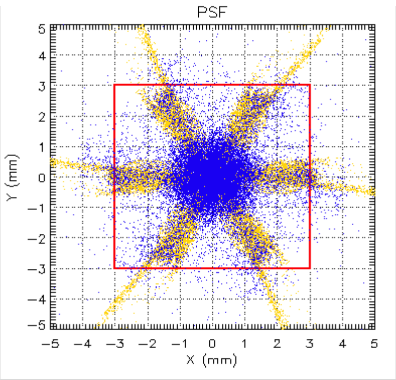


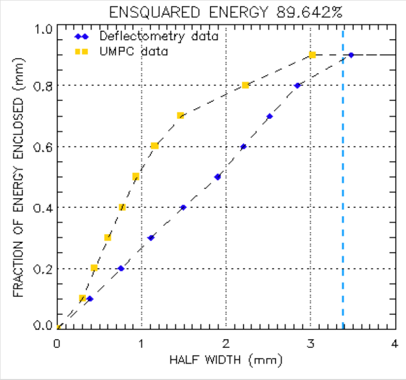


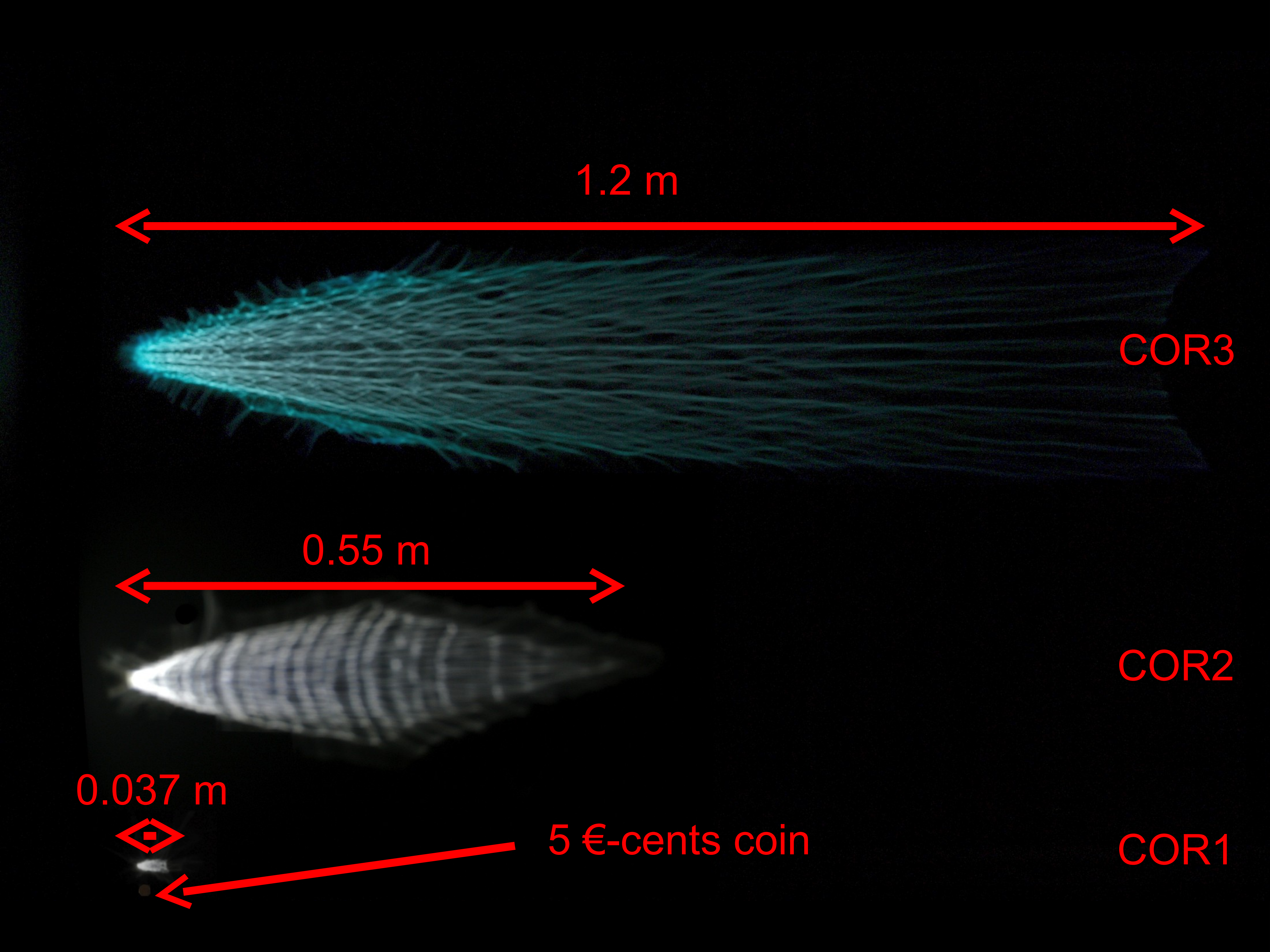











1.2 m
COR3
0.55 m
COR2
0.037 m
5 €-cents coin
COR1