The development of ASTRI telescopes from ASTRI-HORN prototype to ASTRI Mini Array and CTA-SST

G. Sironi – INAF OAB
for the ASTRI Project

Hands on the extreme universe with high energy gamma rays, Sexten, 18 July 2022

Summary

- ASTRI beginning

- ASTRI development
  - Optical design
  - Optics
  - Structure
  - Camera
  - Optical throughput

- ASTRI mini-array & CTA-SST

Summary

➢**ASTRI beginning**

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➢ASTRI mini-array & CTA-SST

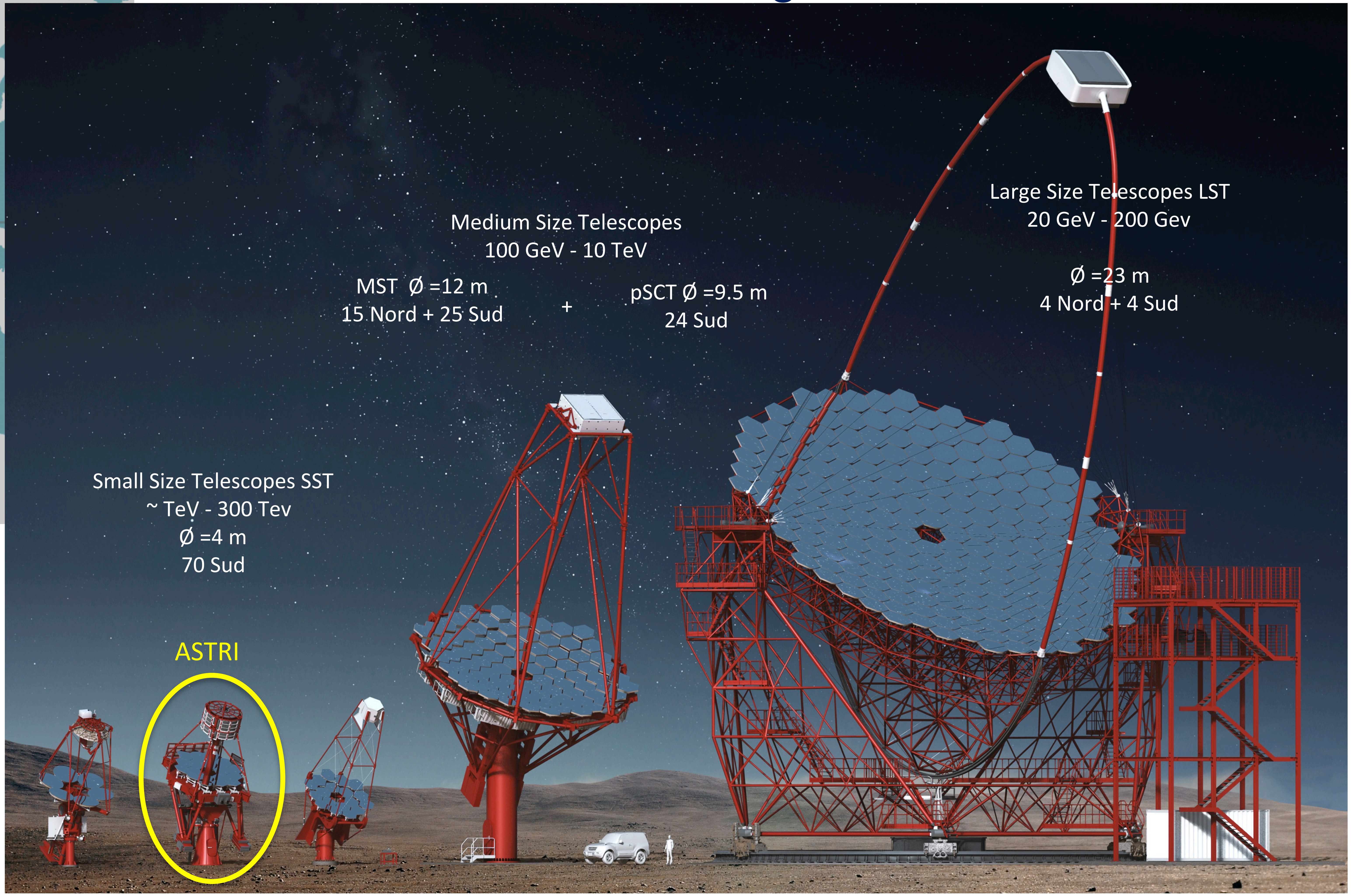
ASTRI beginning

Mini-Array

Astrofisica con Specchi
a Tecnologia Replicante Italiana

ISTITUTO NAZIONA
DI ASTROFISICA
NATIONAL INSTITUT

CTA rendering 2015



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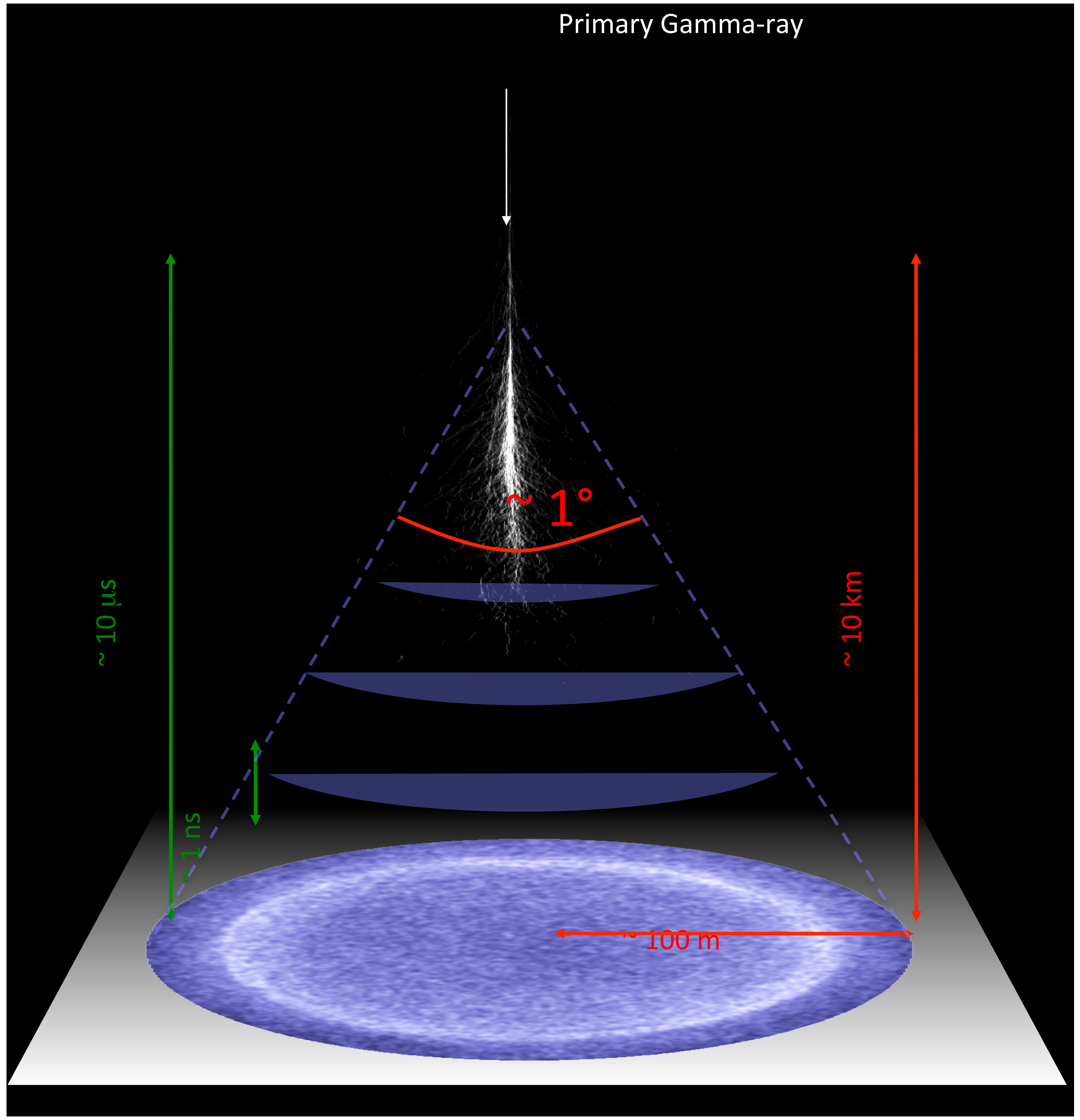
Optical design: requirements



- Very High Energy g-rays (E > 20GeV) are generated by a variety of cosmic sources.

- gamma-rays interact with the atmosphere generating a particle cascade which produces detectable light by means of the Cherenkov effect:

  - Origin at about 10 km asl.
  - Cone angle about 1°;
  - Illuminating radius about 100 m;
  - Shower lifetime about 10 ms;
  - Light wave-front about 1 ns
  - Light density about 10 ph/m2;
  - (NSB about 108 ph/m2/s)

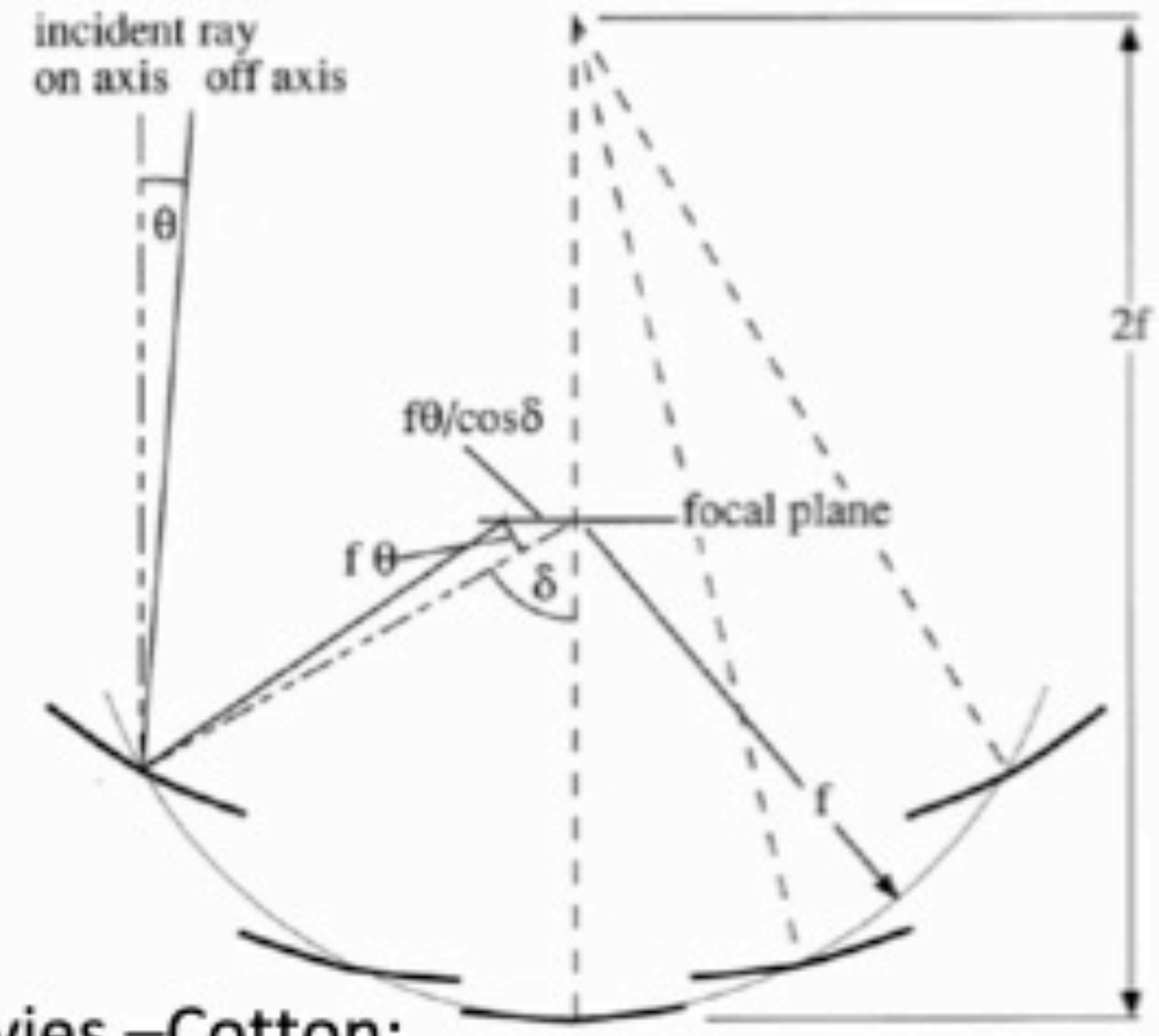
Optical design: IACTs

Mini-Array

1952: Galbraith Jelley try to detect Cherenkov signals from Earth →

Ground Based Gamma Astronomy

Cherenkov light pulse ~6 ns → To separate night sky background it is not possible to integrate → The native area should be sufficient to collect signal



Davies –Cotton:
Spherical facets on a parabolic dish

MAGIC

Optical design

Karl Schwarzschild (1873 – 1916)

- Solved Einstein's field equations of general relativity
- Formalized the Schwarzschild metric, defining the Schwarzschild radius for BH description.
- Formalized optics theory
- Photography, electromagnetism…

Optical design

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- Photography, electromagnetism…

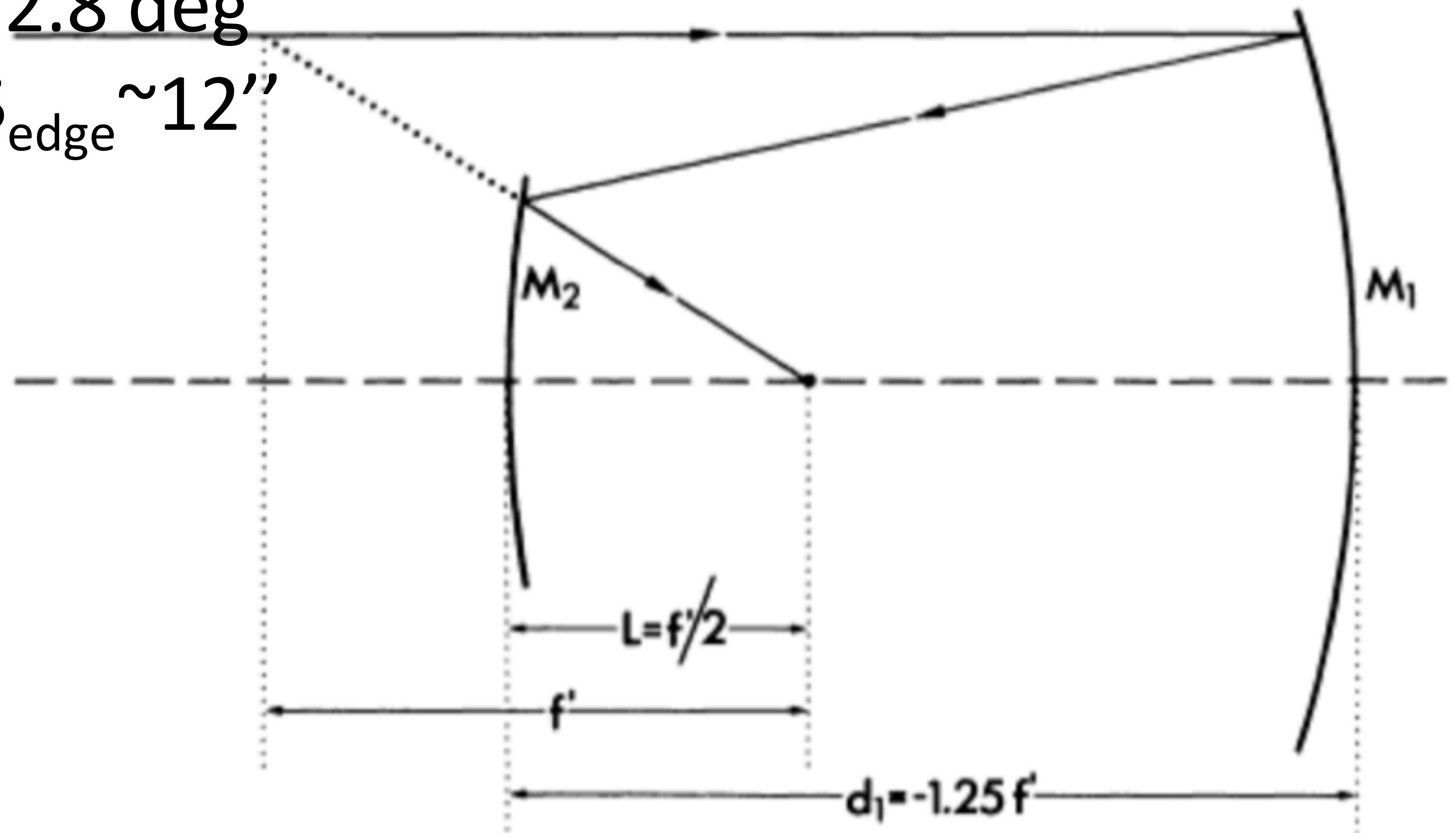
KS: f/3.0

b_{S1}= -13.5 (Hyperbola)

b_{S2}= 1.963 (Spheroid)

FoV:2.8 deg

RMS_{edge}~12''



1905: Karl Schwarzschild solved the equations of Seidel for spherical aberration and coma finding a relation between parameters capable to make a telescope aplanatic.

"For any geometry, 2 aspheric mirrors allow the correction of SI and SII to give an aplanatic telescope"

Optical design

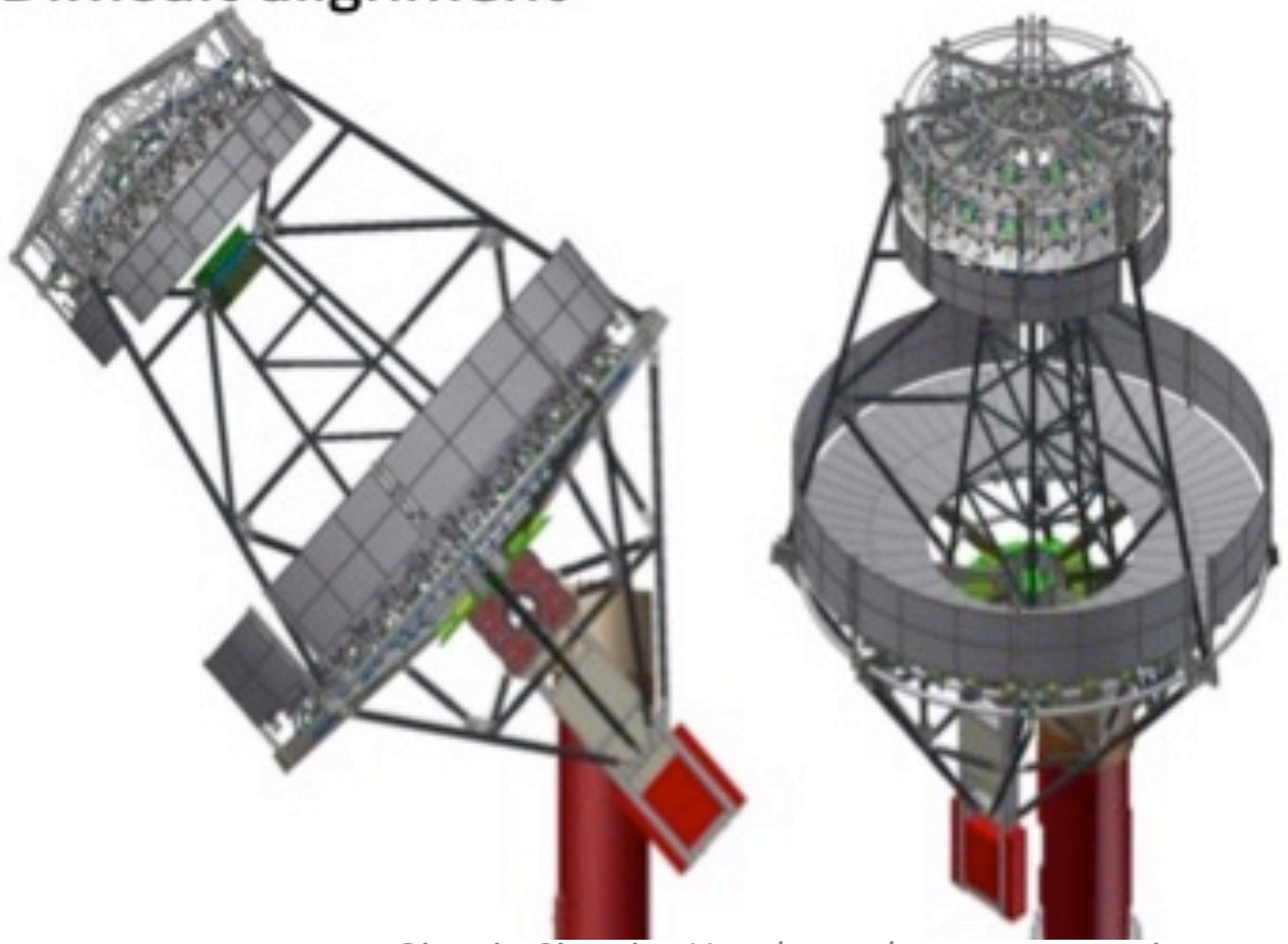
Mini-Array

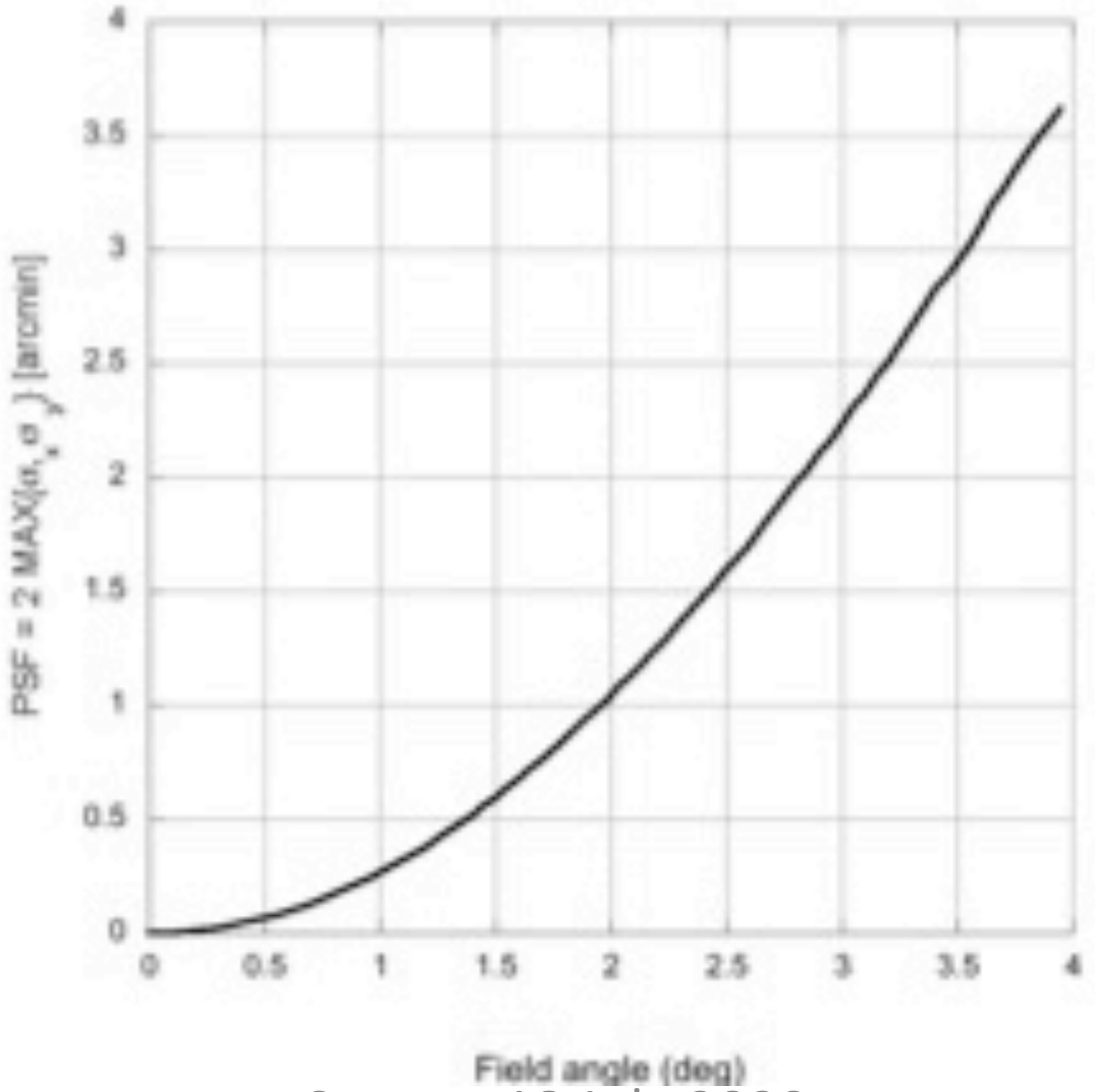
2007: V. **Vassiliev** proposed to apply the **Schwarzschild-Couder solution to Cherenkov** telescopes.

SC design for CTA Medium Size class Telescope

- ➢ Better resolution off-axis
- ➢ Smaller plate scale →smaller camera
- ✧ Difficult aspheric mirrors manufacturing
- ✧ Difficult alignment

Design	pSCT	MST
fl	5.58	16
D	~10 m	19.2
Area	40 m2	88 m2
F/#	~0.6	1.3
Design	SC	DC
FoV	8.3°	~8°
PSF	~0.06′	0.06°
Pixel [ang]	~0.06′	0.14°
Pixel [mm]	6.2	4 cm
Pixel #	11328	



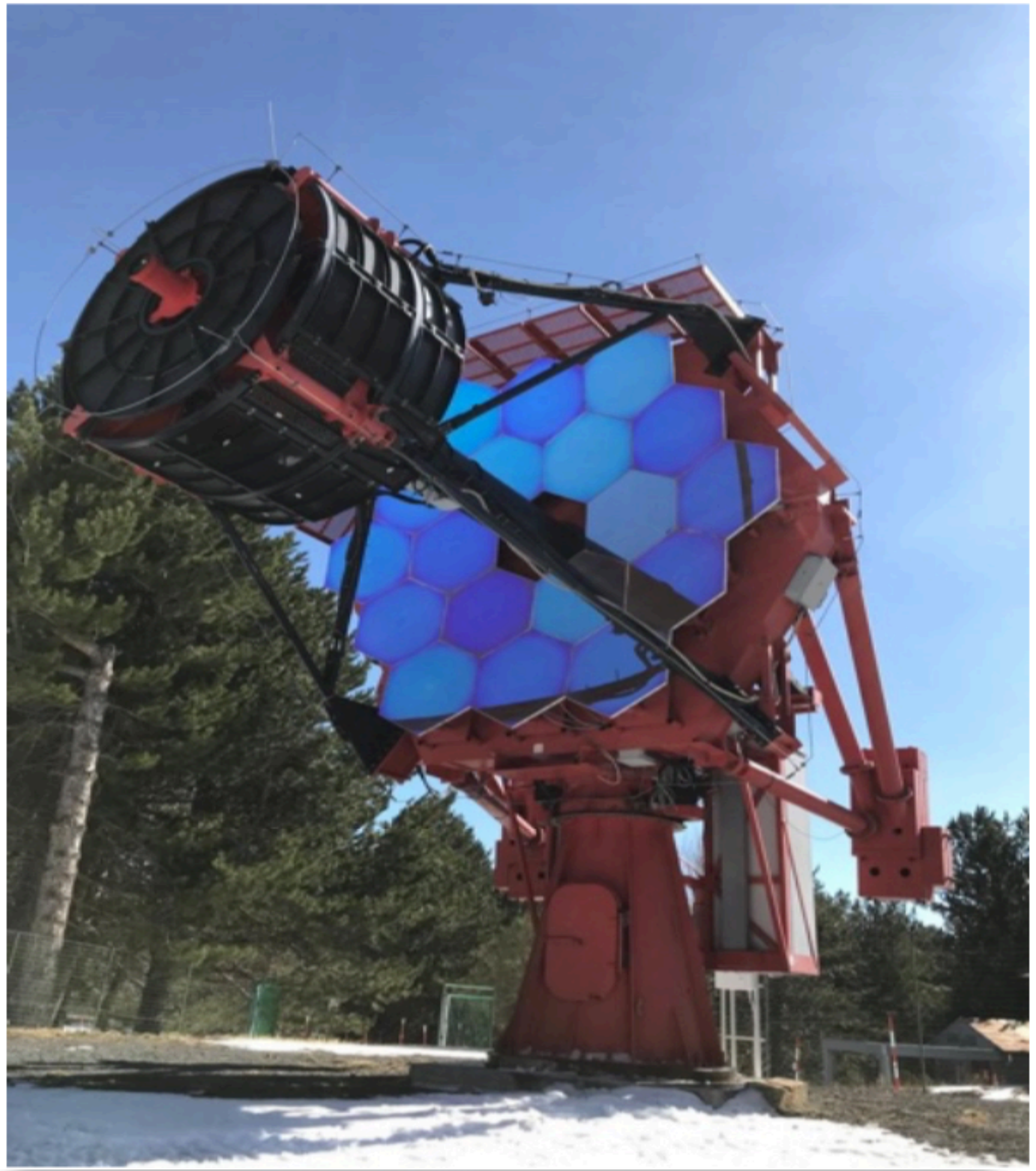


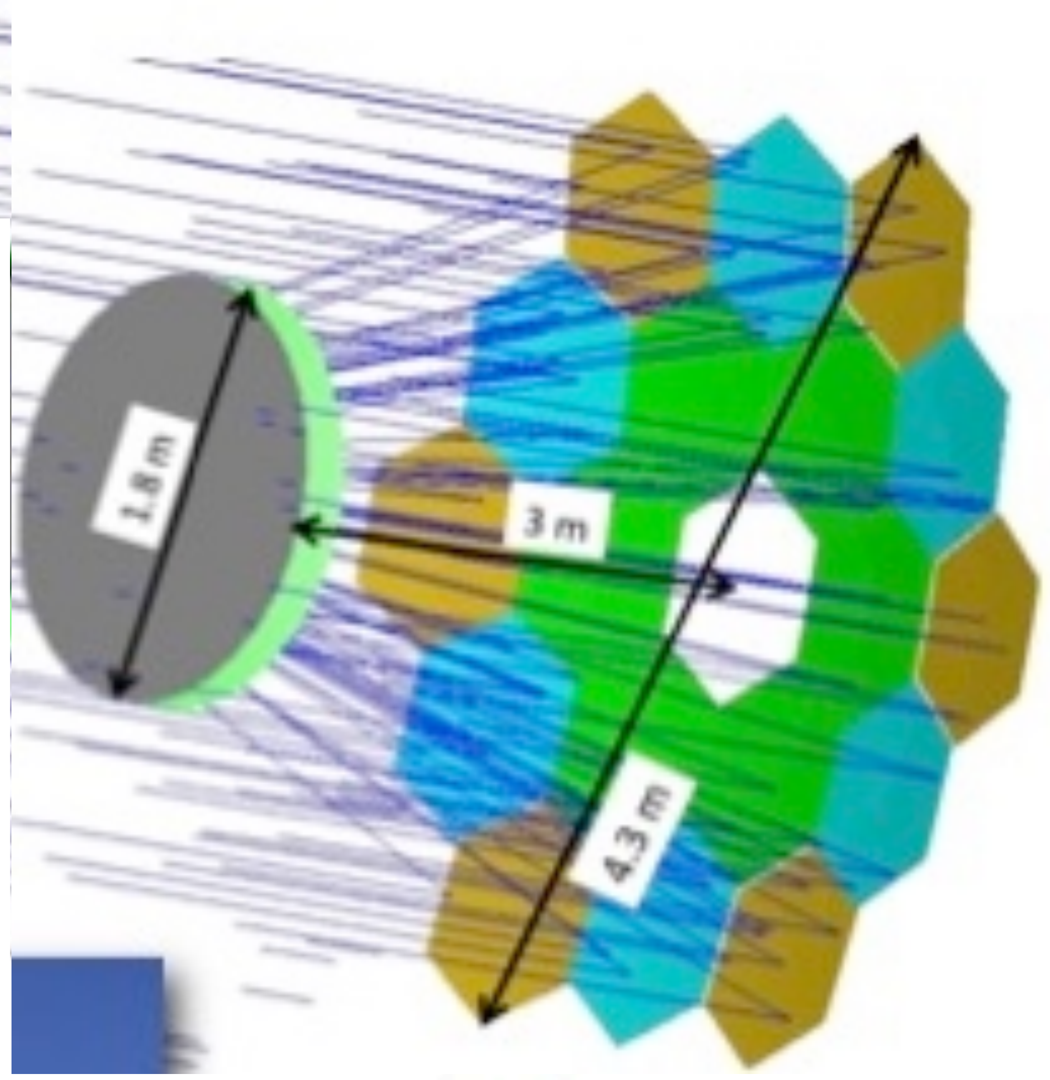
Optical design

INAF & ASTRI collaboration proposed to apply the **Schwazschild-Coude–like polynomial solution** to Cherenkov telescopes.

ASTRI telescope:

- ➢ Very fast optics
- ➢ In spec off-axis
- ✧ Very aspheric optics





ASTRI numbers:
F#: 0.5
f: 2.15 m
M1 RoC: 8.2 m
M2 RoC: 2.2 m
DET RoC: 1 m
Pixel size = 0.19°
PSF (D80) < 0.16°
FoV = 9.6°

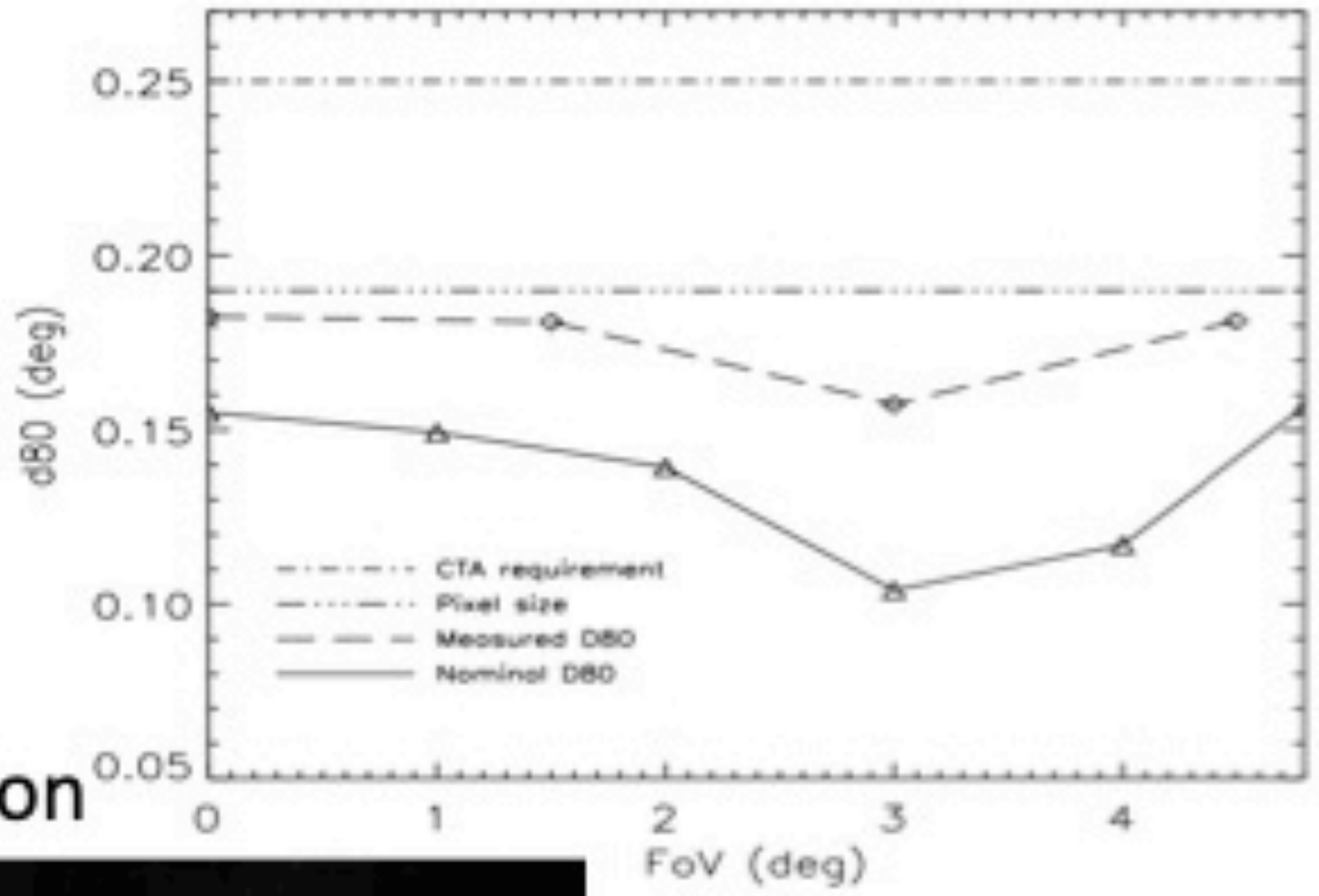
Optical design

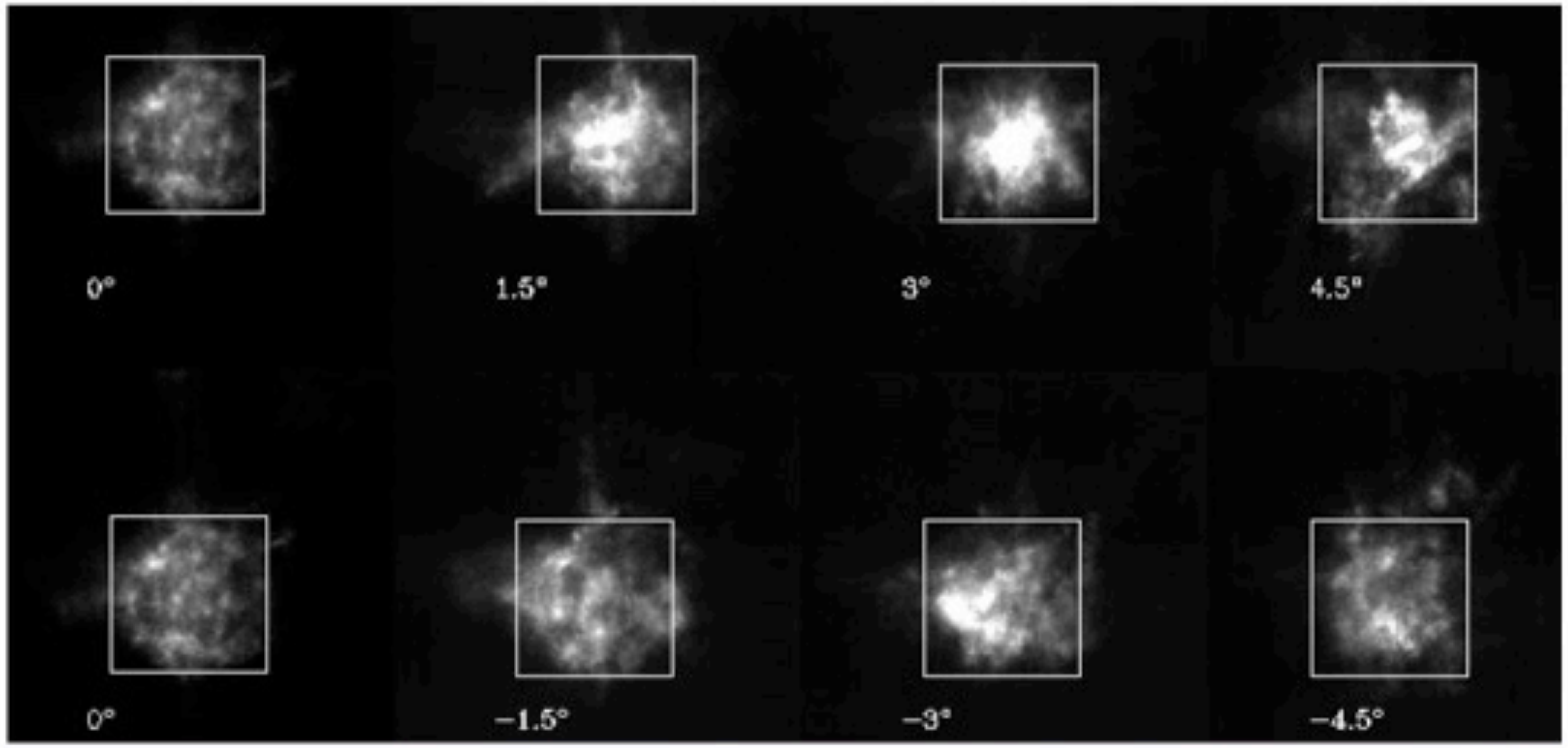
Mini-Array

ASTRI optical design is optimized to maintain PSF within 1 pixel even at 5° off-axis.

- Very fast optics
- Good resolution off-axis

Real angular resolution is never perfect!!
On-axis value shall consider to the typical manufacturing and alignment and pixel dimension





80% energy inside 1 pixel across the FOV

ASTRI Calibration, Giro et al. 2017

Optical design

Specific requirement → First empirical focalization → Analytical solution → RT Polynomial optimization →

IACTs

Few fast pulses ↓ Large Area

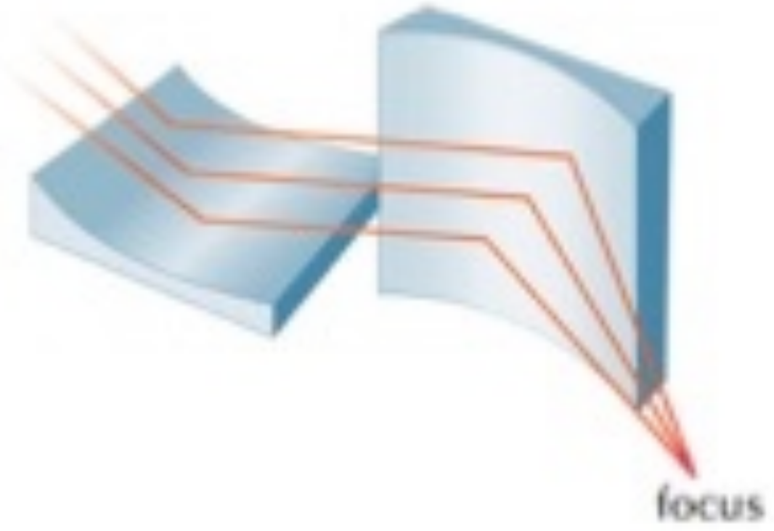

Davies- Cotton


Schwarzschild-Couder

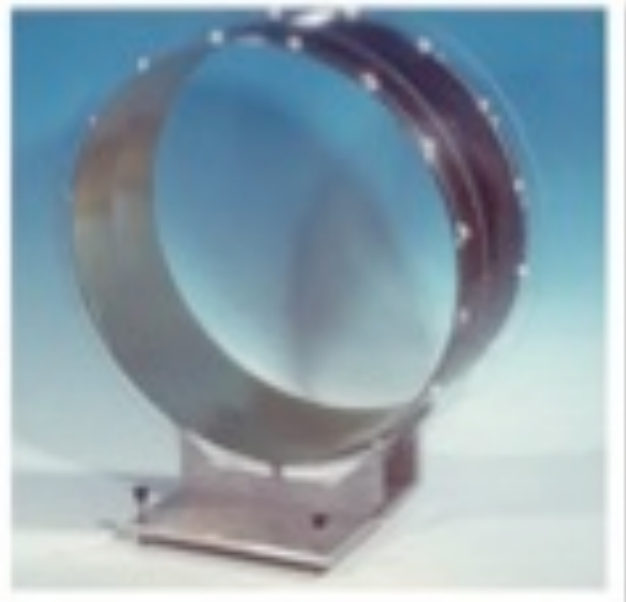

ASTRI

X-ray telescpes

High Energy ↓ Grazing Incidence

Kirkpatrick - Baez


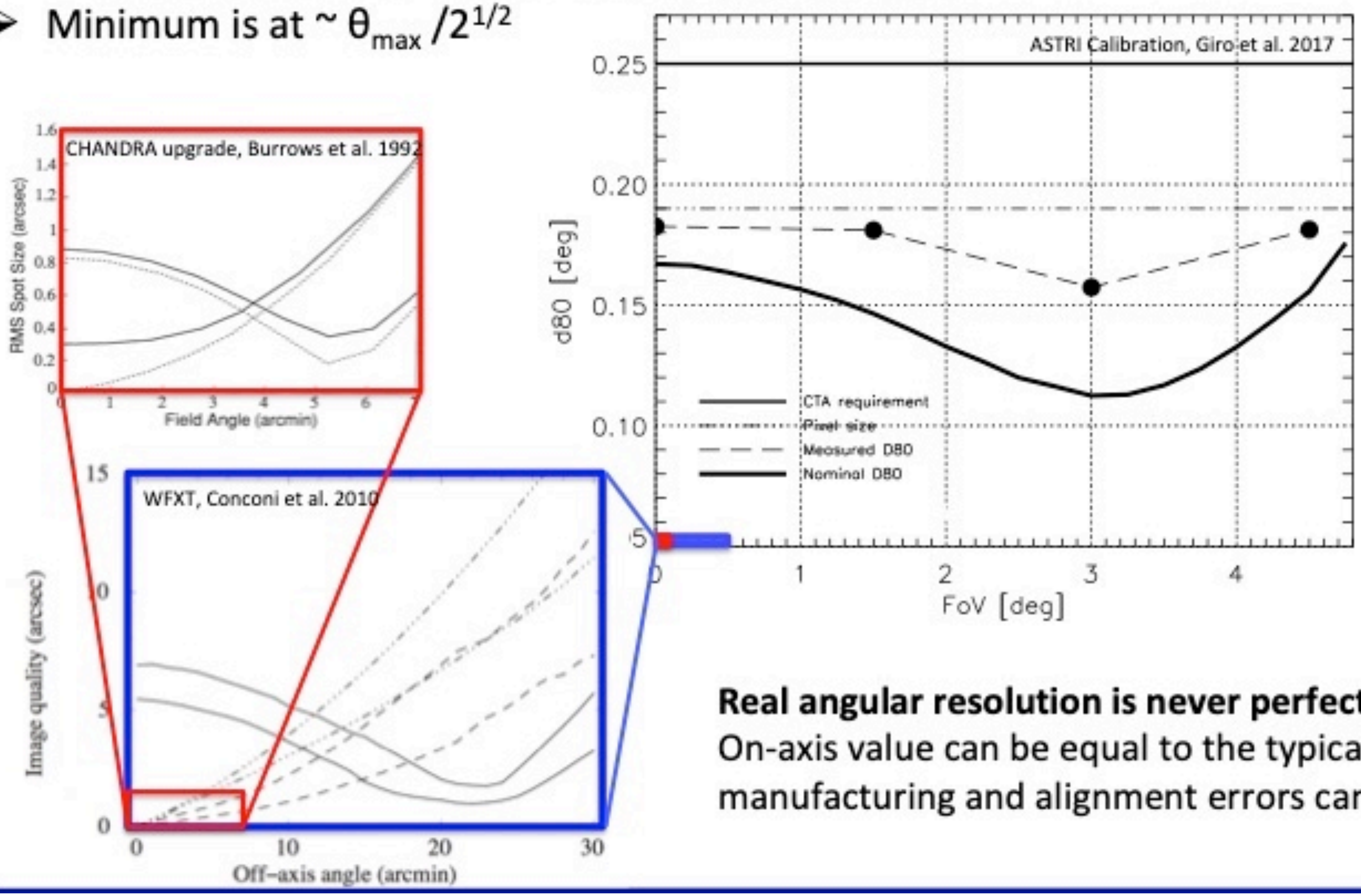
Wolter & Wolter-Schwarzschild

WFXT


Optical design

Polynomial solutions can be generalized for all purposes

- RMS value should be chosen according specification
- Minimum is at ~ $\theta_{max} / 2^{1/2}$



Real angular resolution is never perfect!!
On-axis value can be equal to the typical manufacturing and alignment errors can be

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Mini-Array

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ASTRI Optics: manufacturing

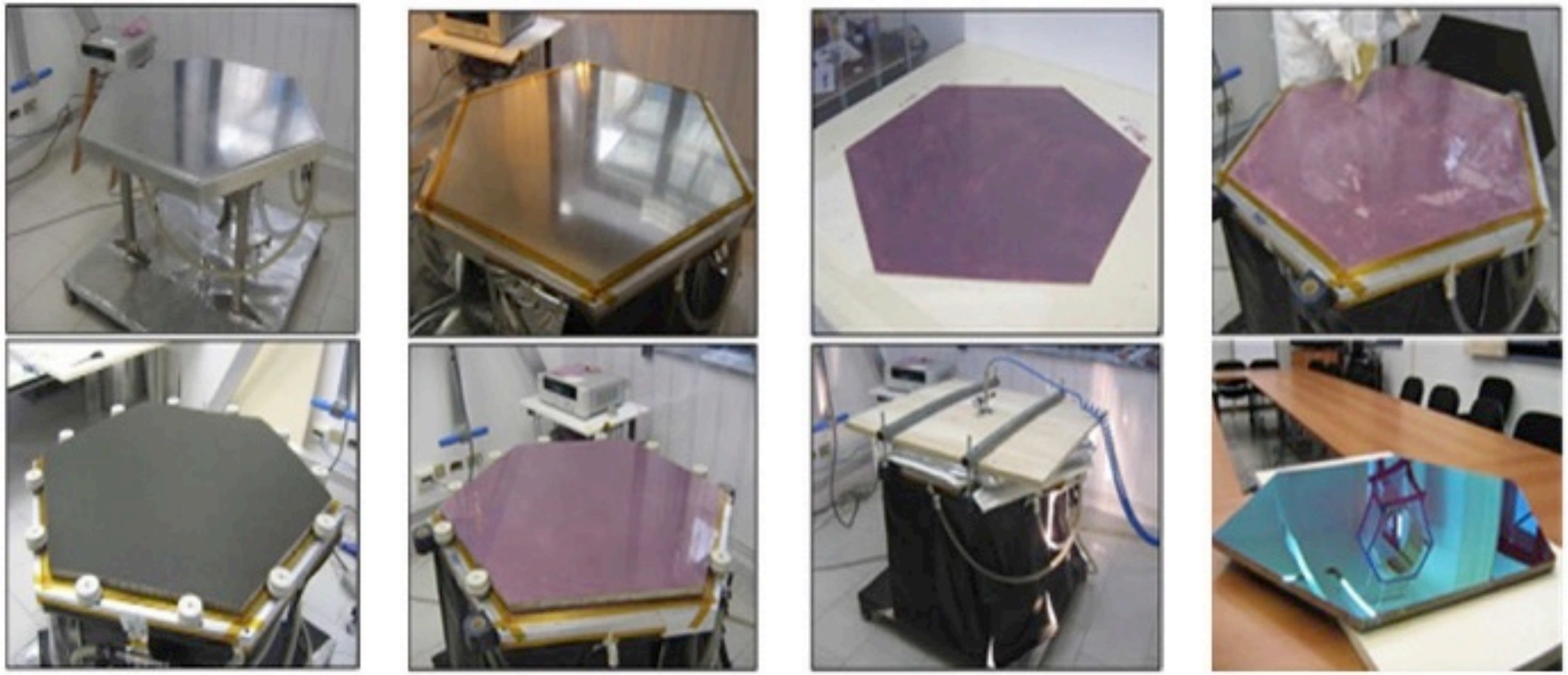
ASTRI Mini-Array

M1 mirrors substrates:

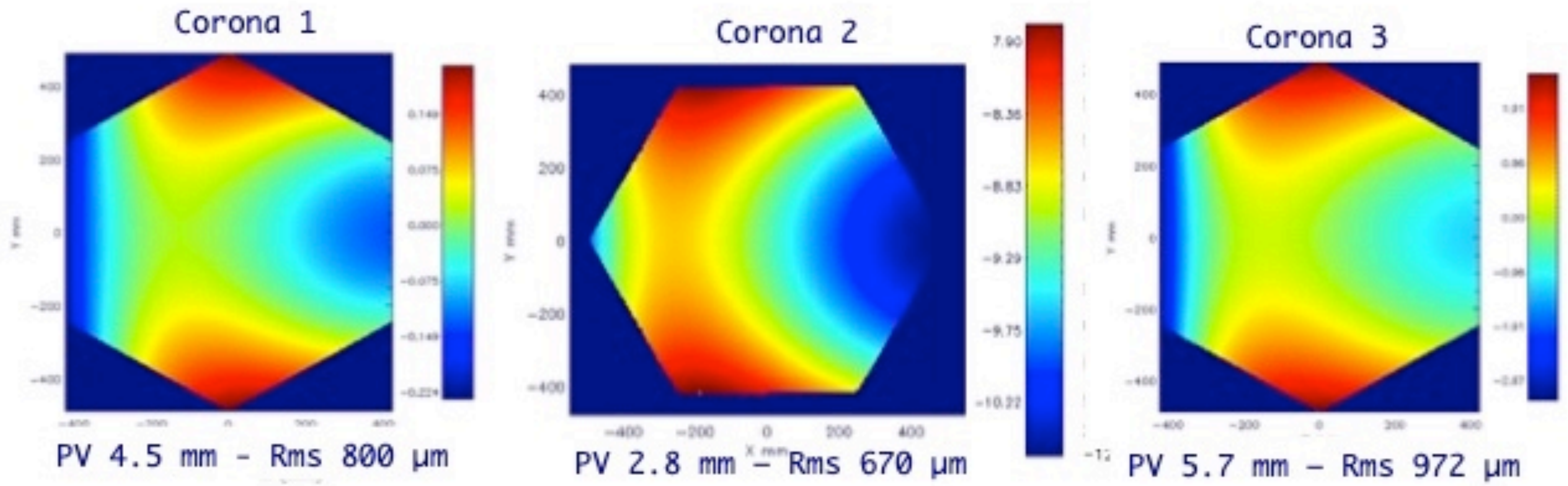
- ASTRI prototype M1 mirrors manufactured at INAF-OAB
- Mini-Array M1 mirrors produced by Media Lario
- No structural changes wrt ASTRI prototype
    - same moulds, same materials, same process

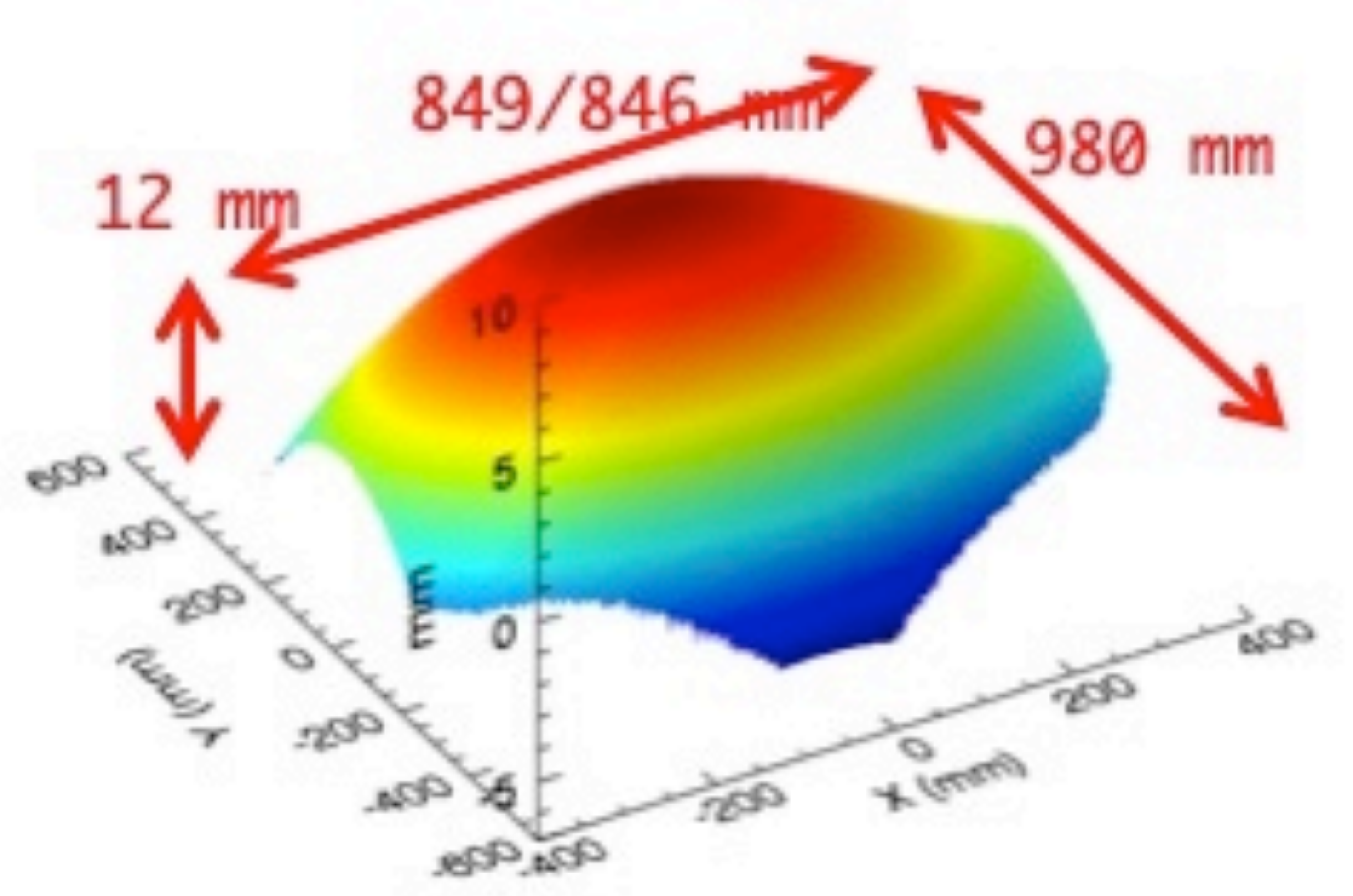
ASTRI Astrofisica con Specchi a Tecnologia Replicante Italiana

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS



ASTRI Optics: metrology

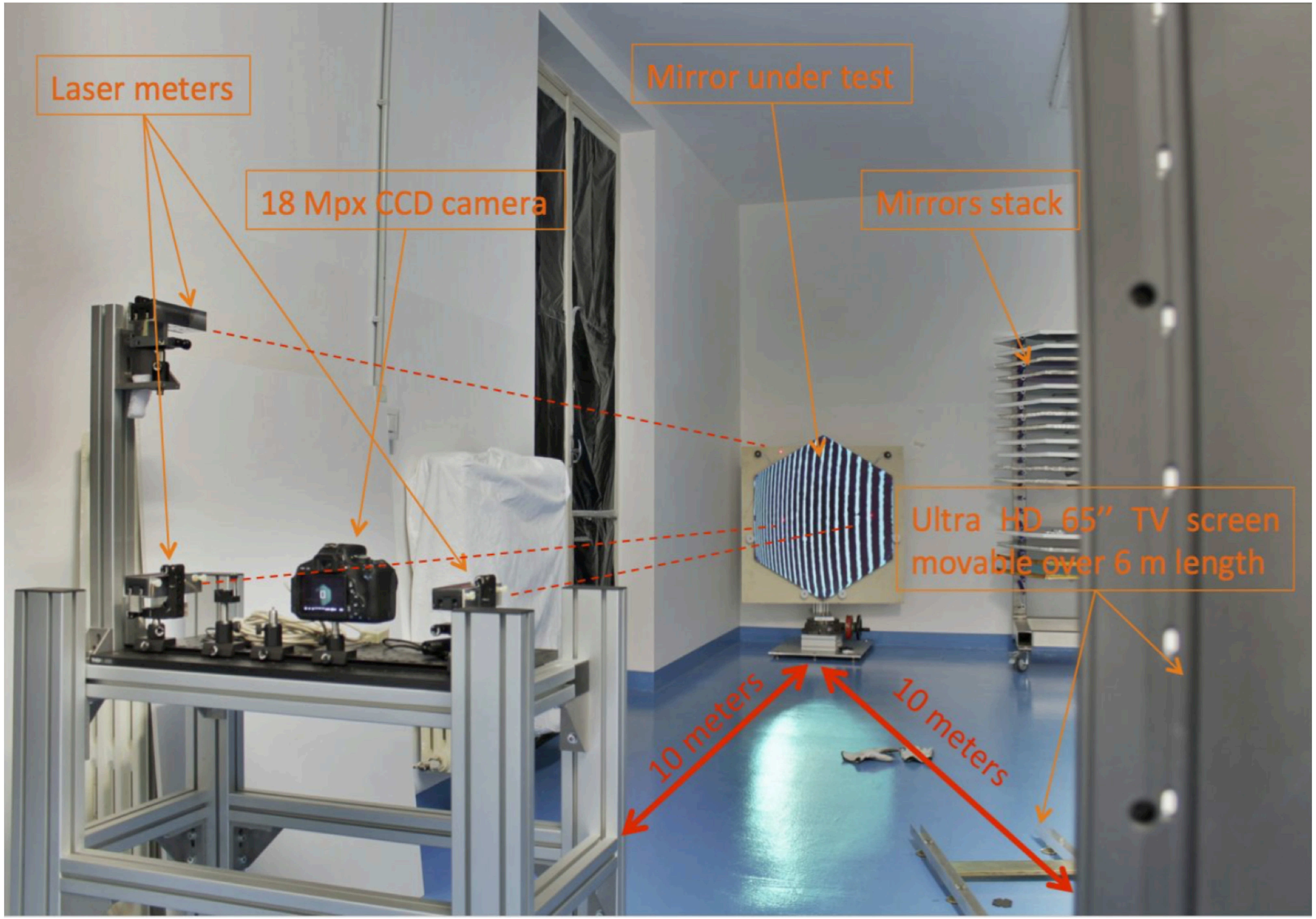




- Not accurate enough to be measured with CGH interferometry (100-200 µm PV)
- Too big to be measured by means of a single point profiler with a spatial resolution in the millimeter scale in a cost-effective time

ASTRI Optics: metrology

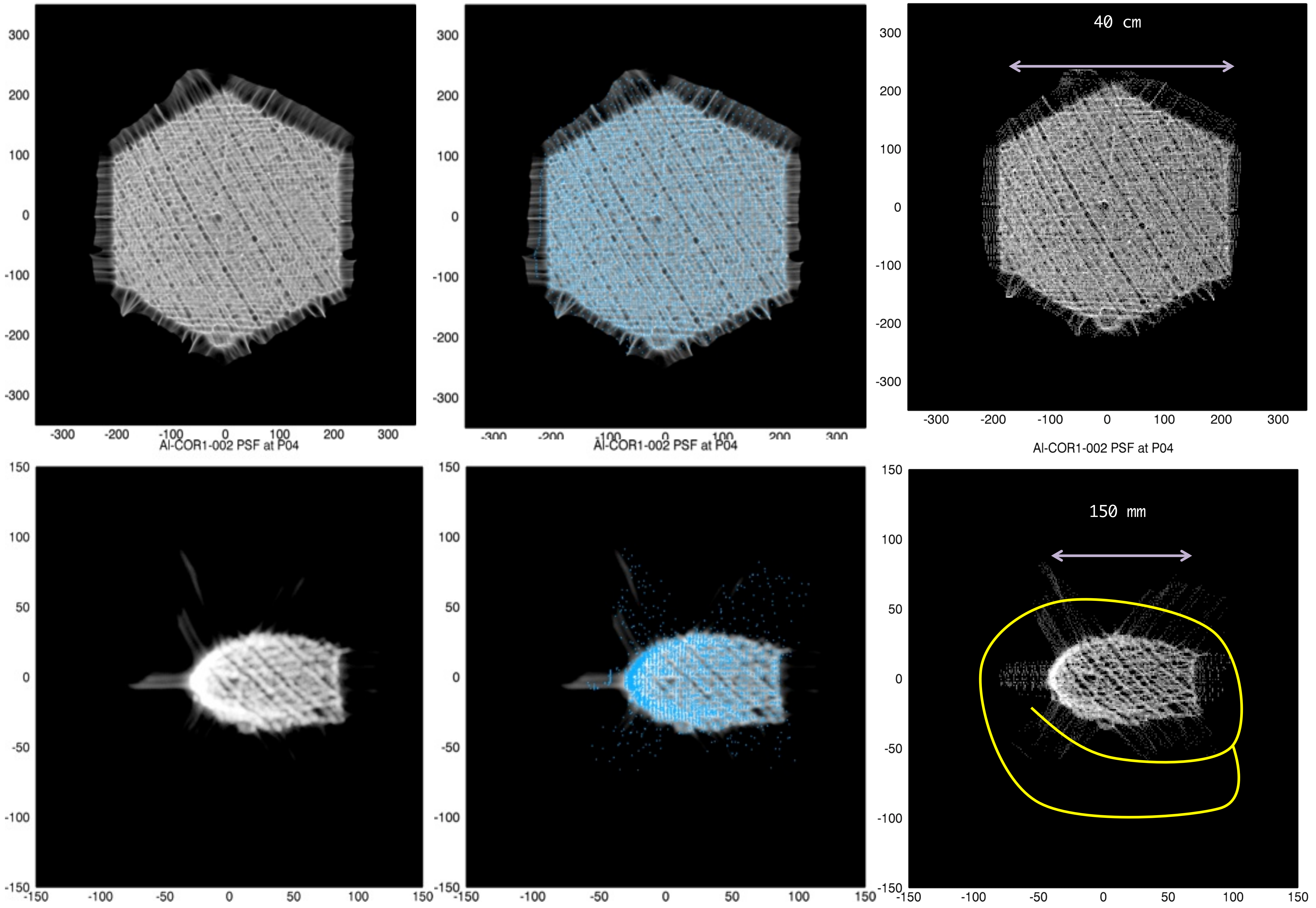
Mini-Array



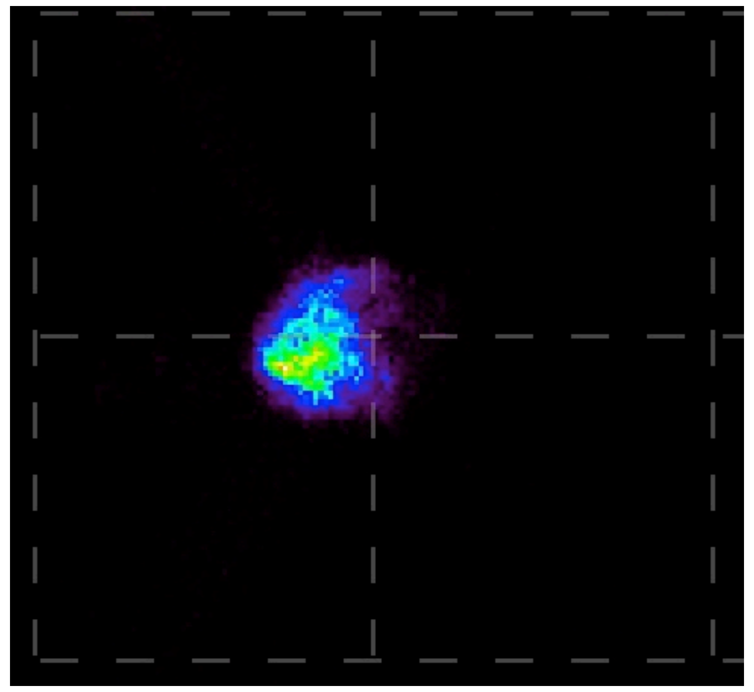
ASTRI Optics: metrology

- ➢Matching of the focal length and extrapolation of the PSF at the focal plane

Pseudo-PSF pictures | Pseudo-PSF pictures + Ray-tracing points | Ray-tracing Simulation Image



15 mm



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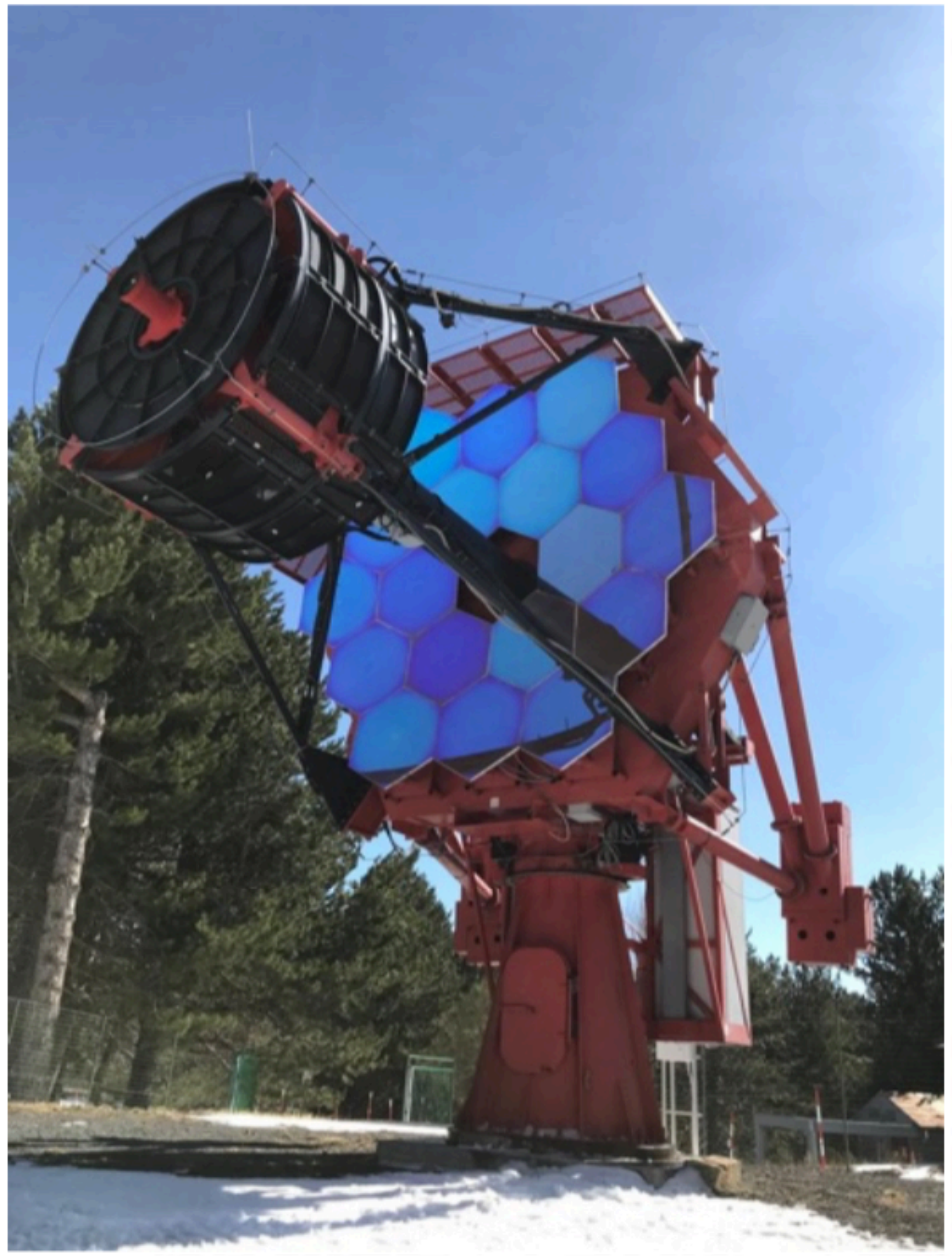
ASTRI Structure: optimization

- Precursors' structures tested on ASTRI-HORN
- Structure optimized on the basis of the ASTRI experience



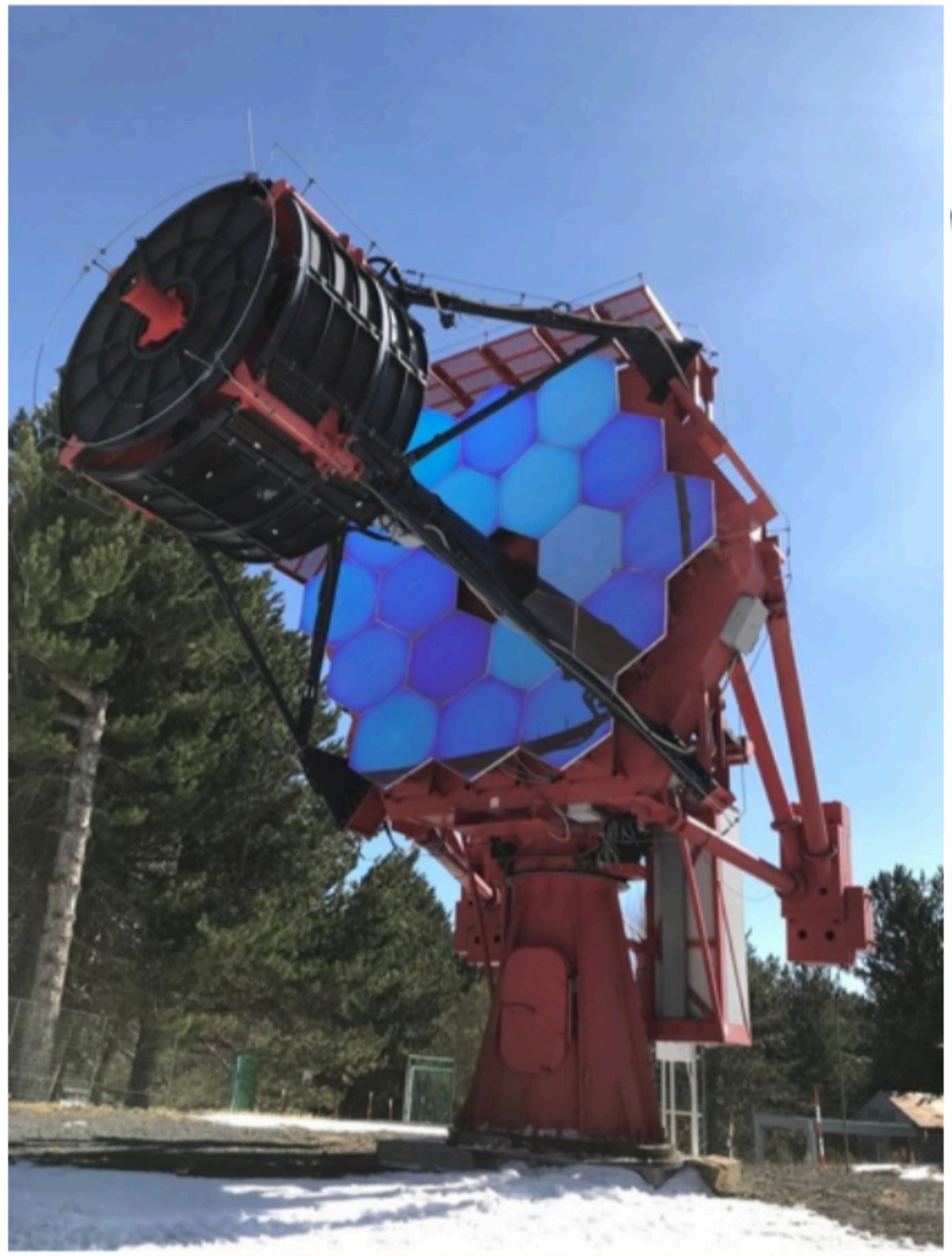
ASTRI-Horn

Courtesy of EIE group

ASTRI-Mini Array / CTA-SST

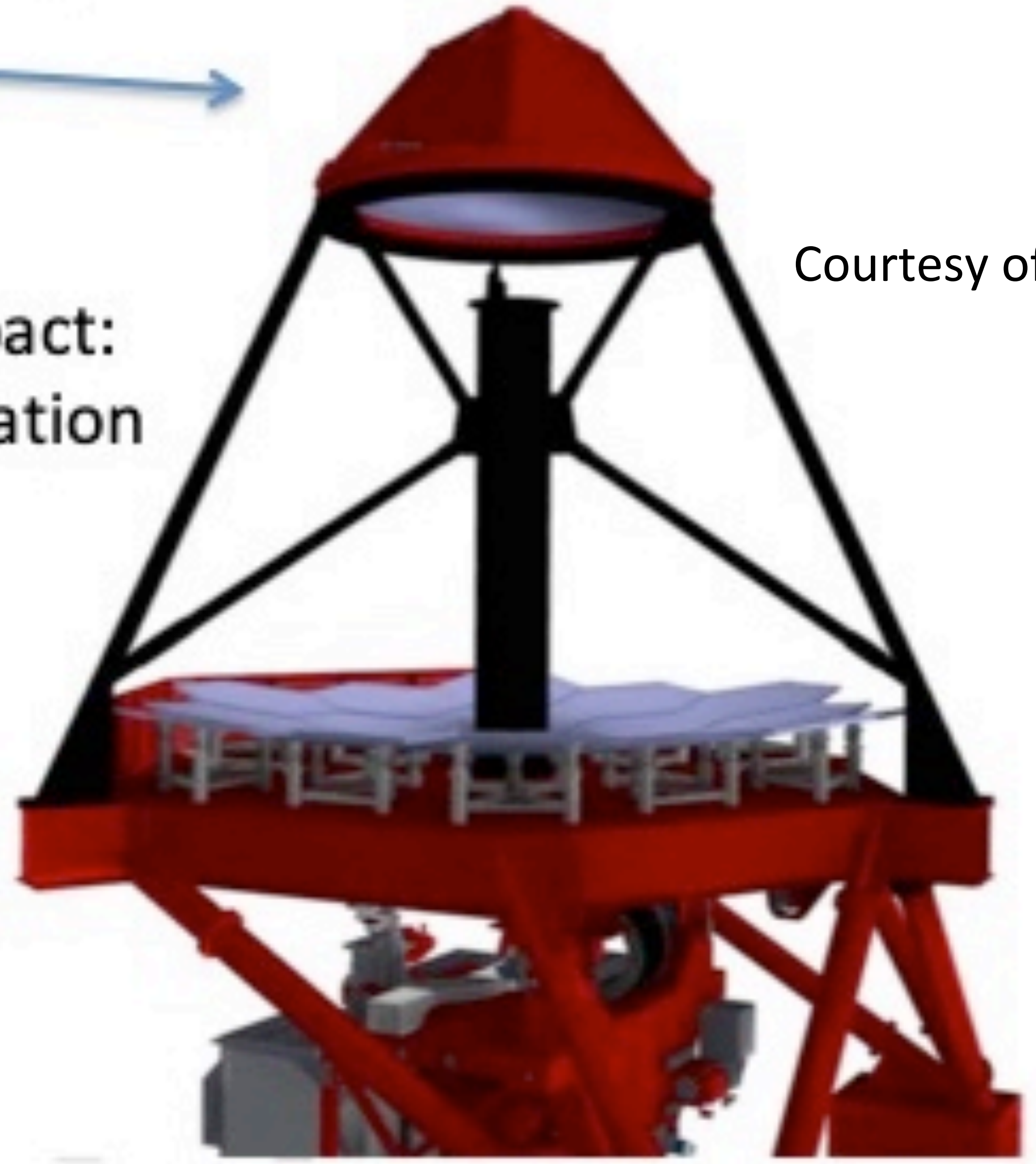
ASTRI Structure: M2 support

- Precursors' structures tested on ASTRI-HORN
- Structure optimized on the basis of the ASTRI experience
  1. **M2 BUS modified**



ASTRI-Horn

- ✓ optimized for maintenance purposes: M2 actuators are easier accessible
- ✓ more compact: less obscuration

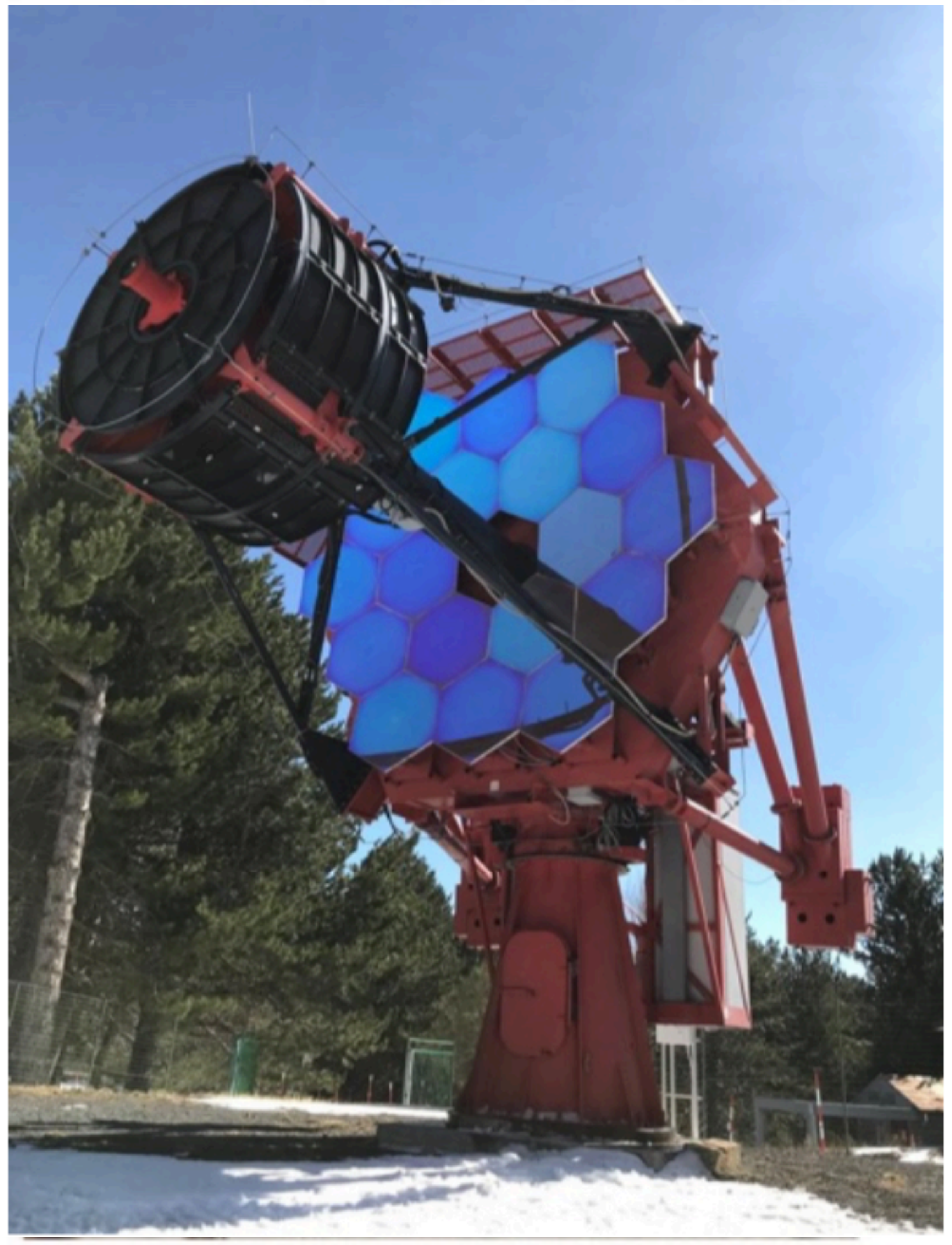


Courtesy of EIE group

ASTRI Precursors

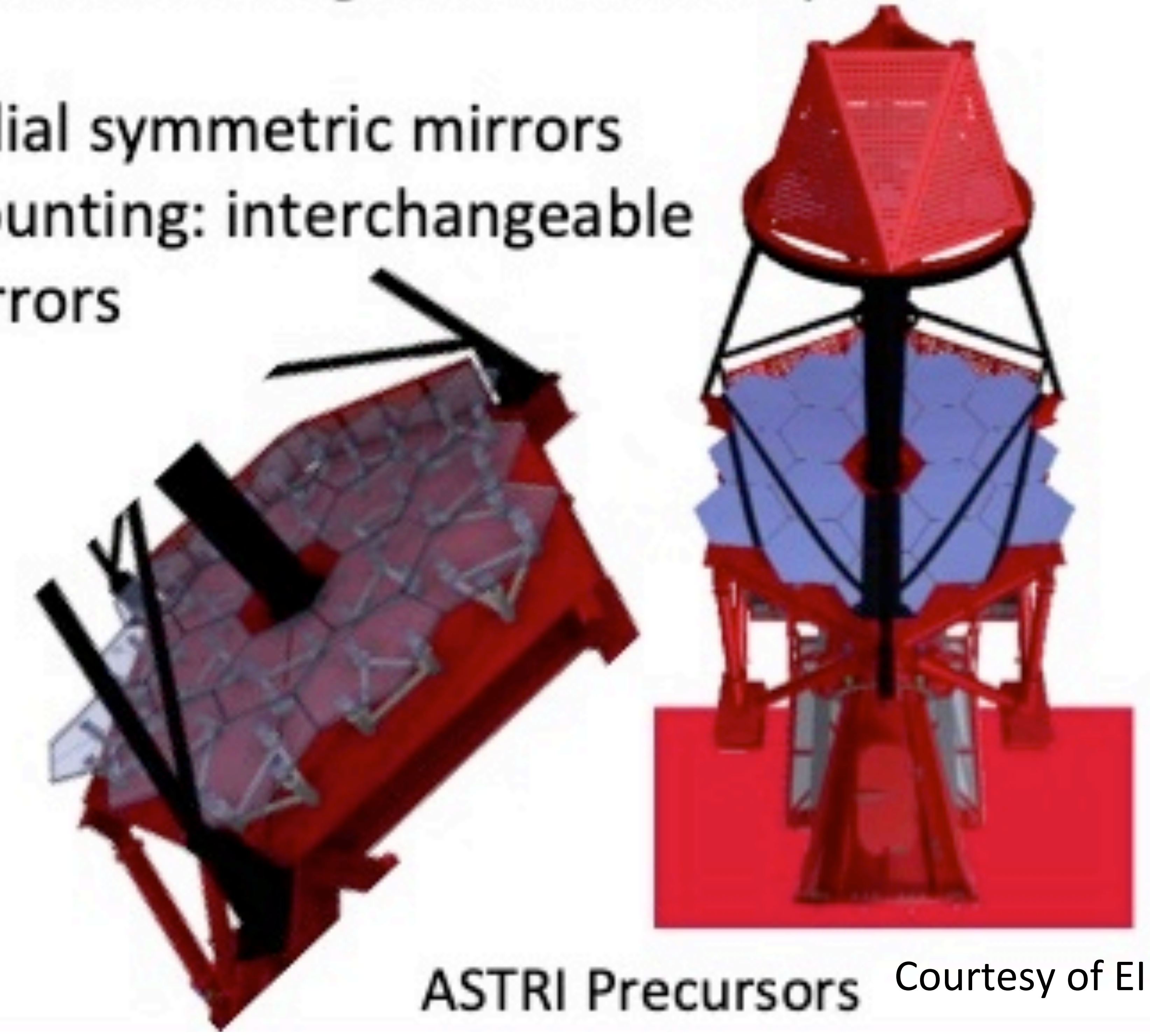
ASTRI Structure: dish

- Precursors' structures with ASTRI-HORN
- Structure optimized on the basis of the ASTRI experience
  1. M2 BUS modified
  2. **M1 dish optimization**



ASTRI-Horn

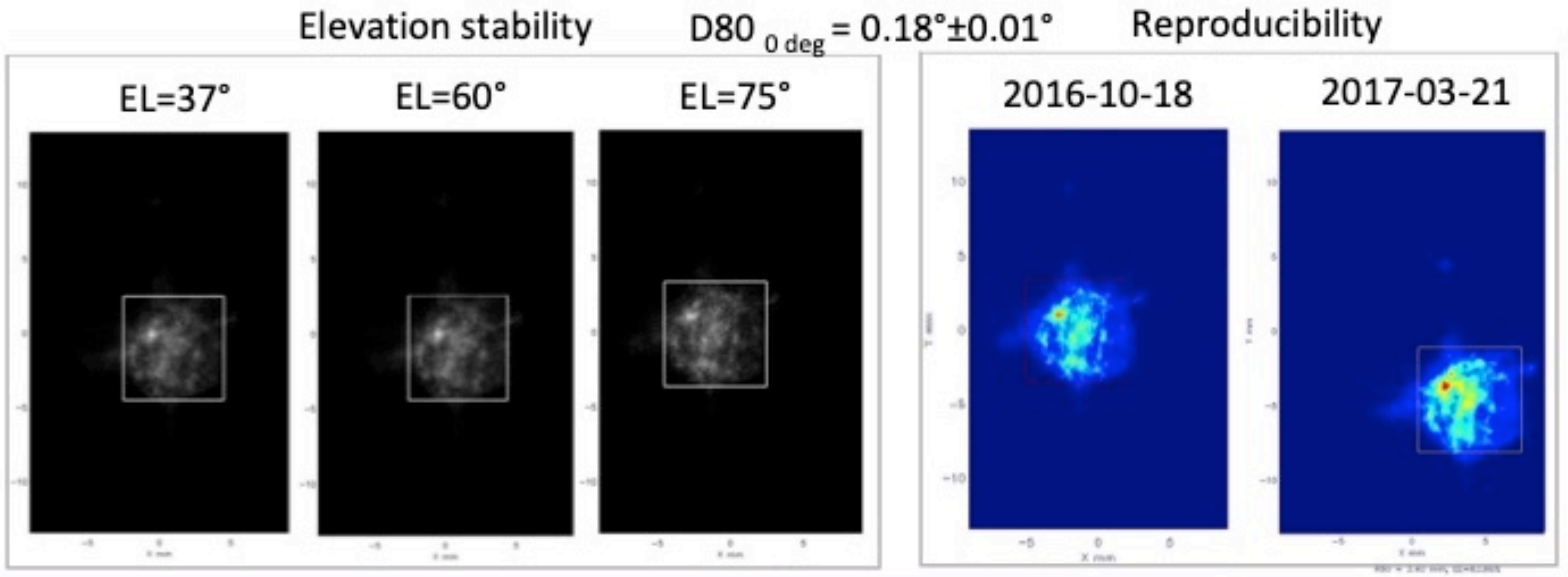
- ✓ Dish rotation : better loads distribution, allows avoiding of customized parts
- ✓ radial symmetric mirrors mounting: interchangeable mirrors



ASTRI Precursors Courtesy of EIE group

ASTRI Structure: actuators

- Precursors' structures provided by GEC group (same of ASTRI prototype)
- Structure optimized on the basis of the ASTRI experience
  1. M2 BUS modified
  2. M1 dish optimization
  3. **Removable Mirrors Actuators**
     - ✓ The optical qualification demonstrated that realignment is not needed in operational mode



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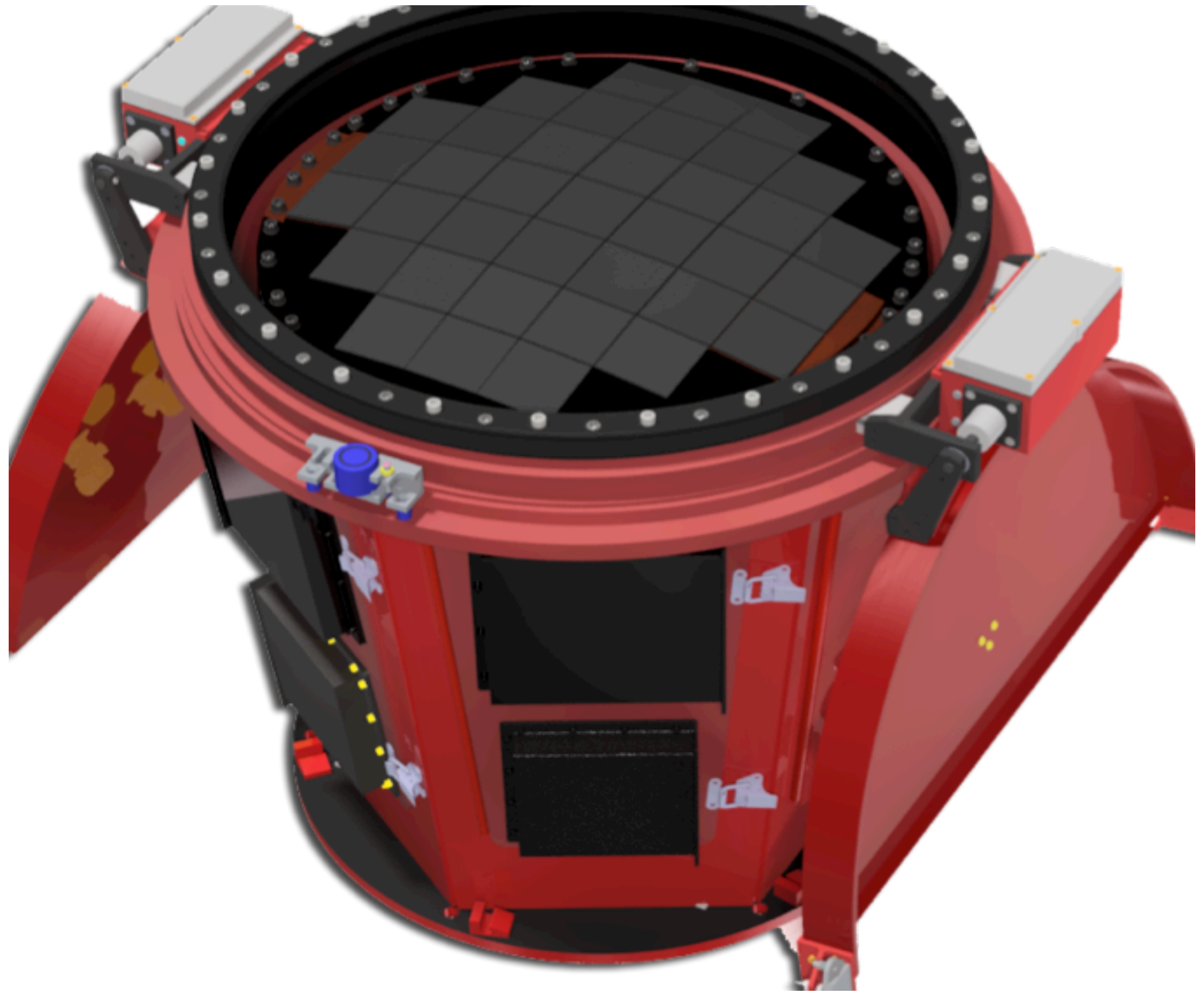
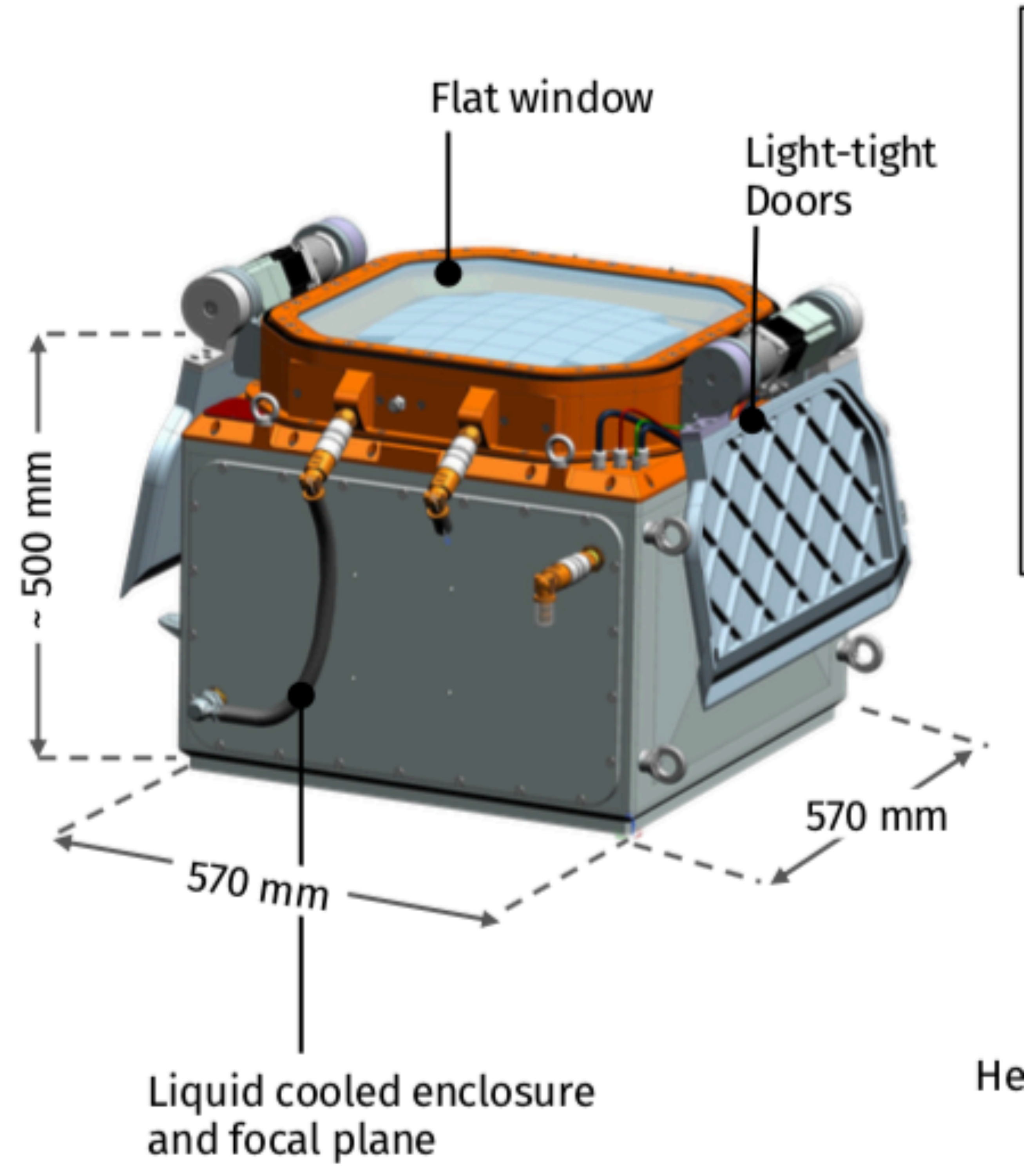
ASTRI: Camera

ASTRI Mini-Array

ASTRI Camera: developed by INAF for ASTRI-Horn and industrialized for ASTRI Mini-Array

CTA-SST CECH camera (collaboration led by Max Plank Institute)





FIELD OF VIEW OF 10.5 deg IN DIAMETER

FIELD OF VIEW OF 9 deg IN DIAMETER

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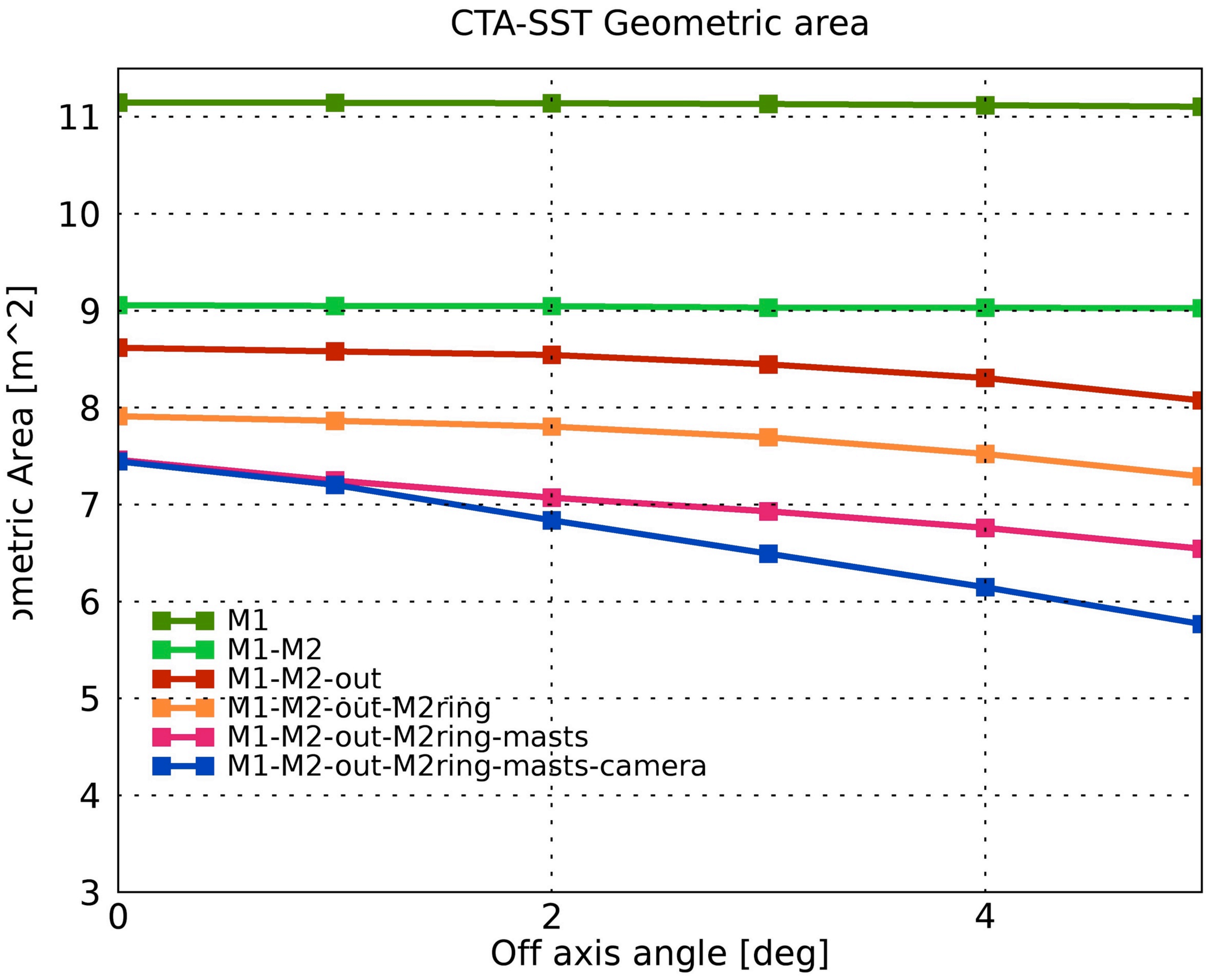
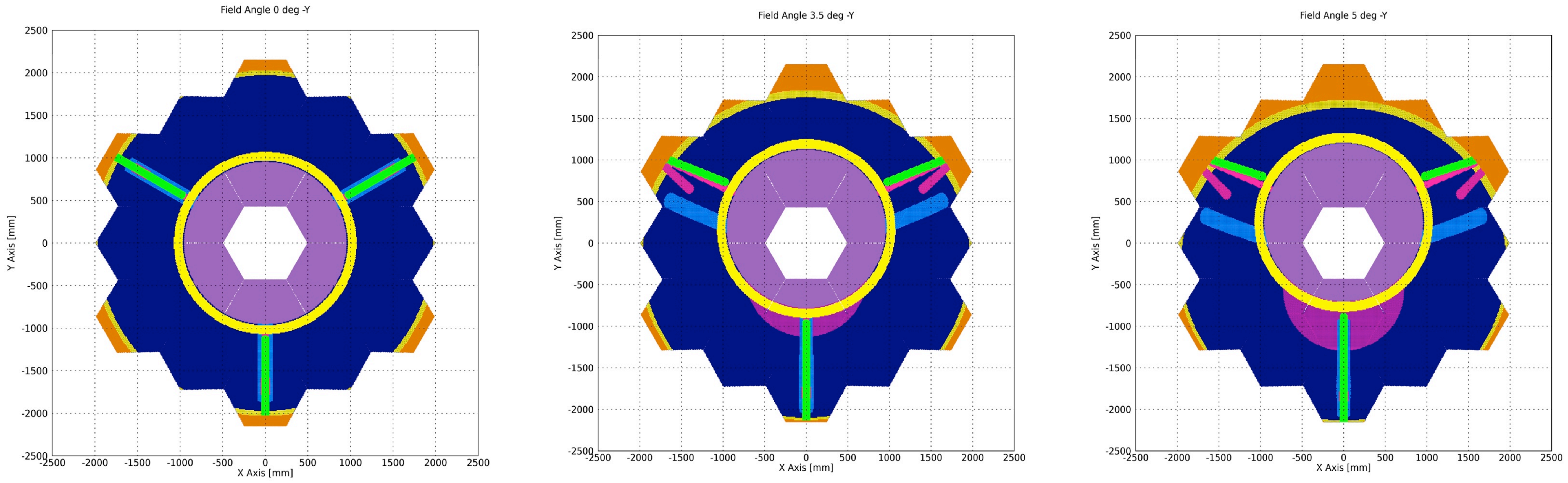
ASTRI: geometric area

- Shadowing depends on off-axis angle
- Geometric area shall be >5.5 m^2 across FOV
- Secondary mirror, structure, camera are sources of vignetting



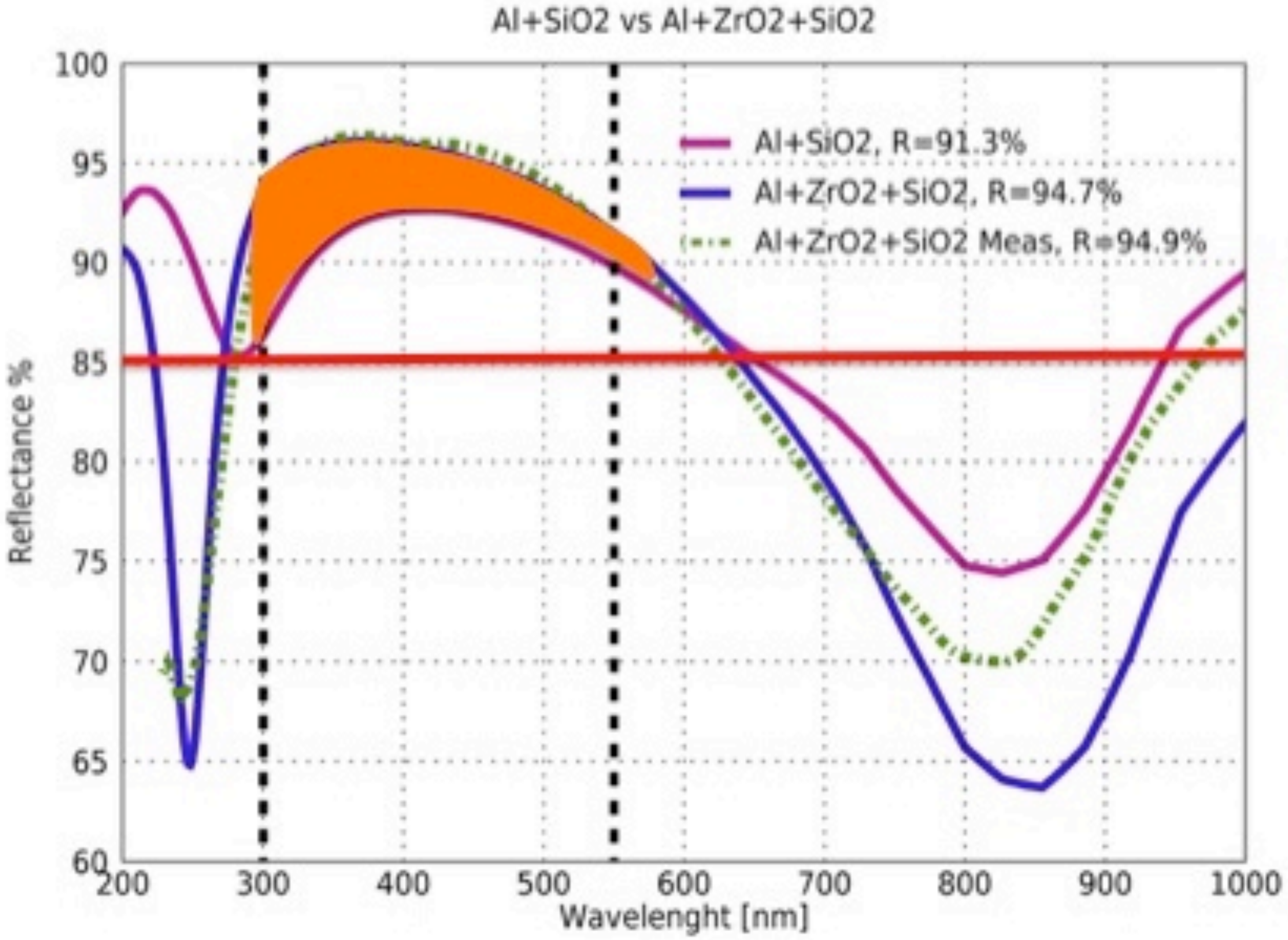


ASTRI: reflectivity

Coating requirements problem #1:

B-TEL-0120

*New: "Mirrors initial **average** reflectivity should be >85% at all wavelengths in the range 300-550 nm"*



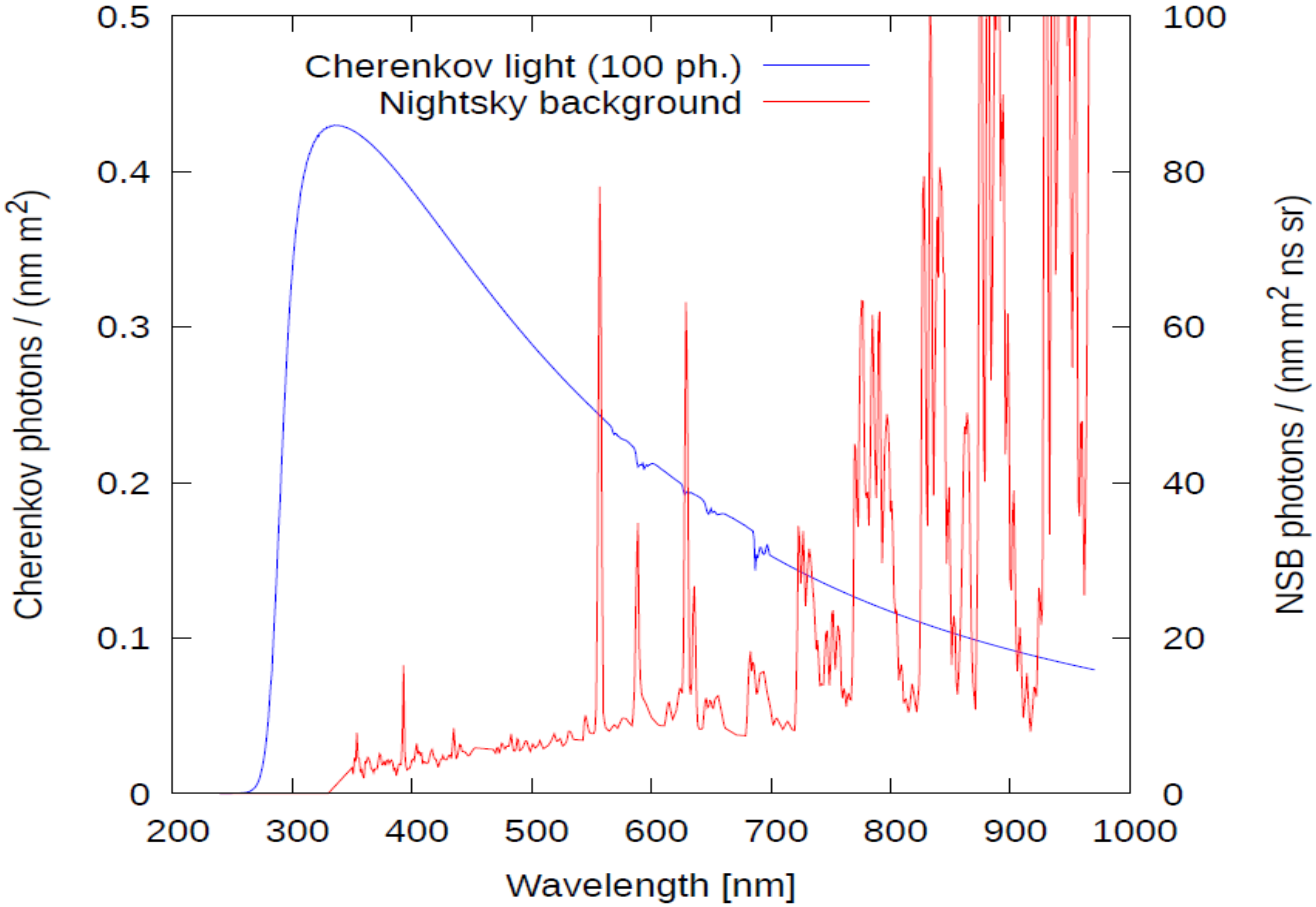
Requirement was clarified after the contract for mirror production.

Average on space, not on wavelengths!!

We switched to ZrO2 protective layer.

ASTRI: reflectivity

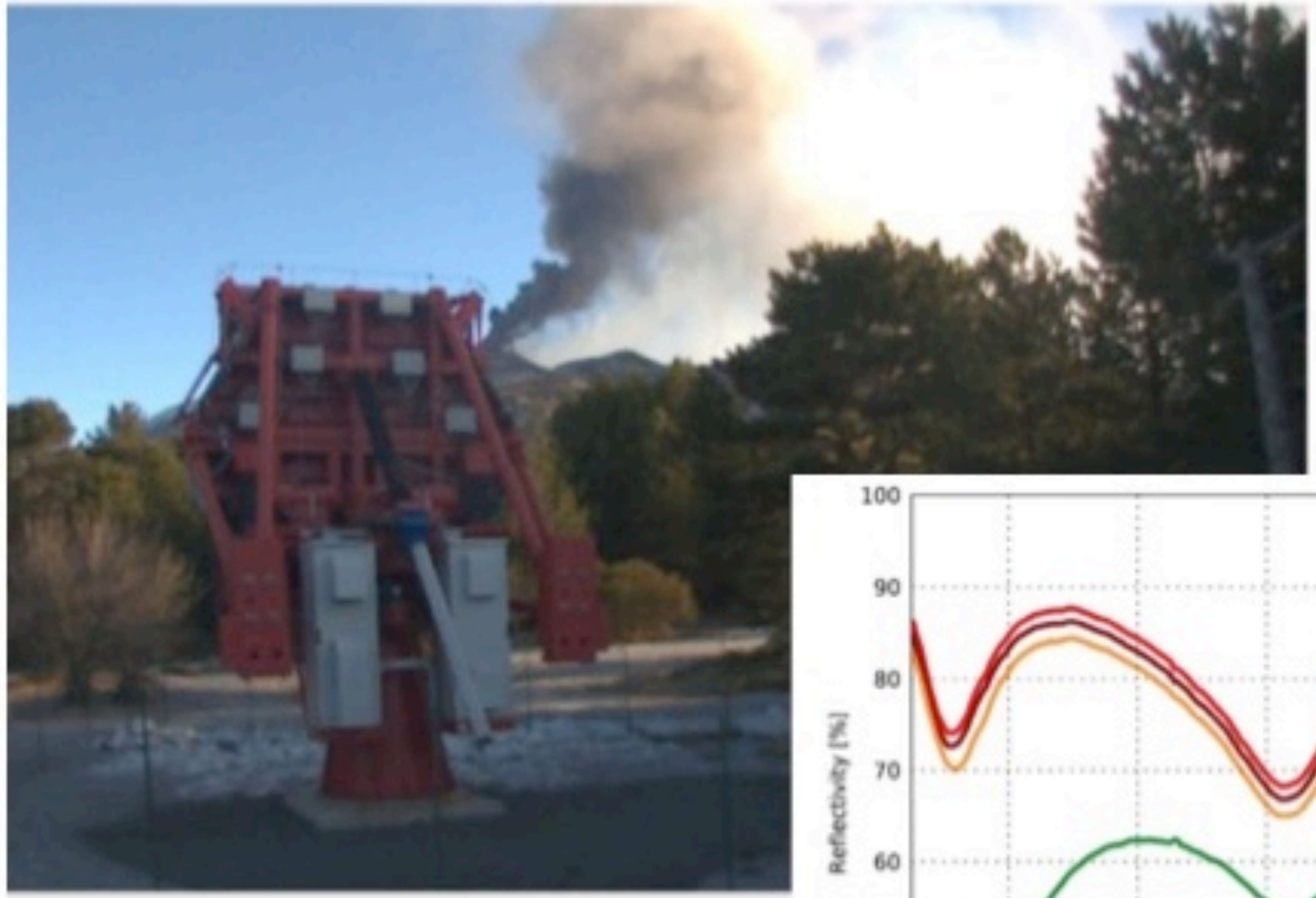
ASTRI Mini-Array

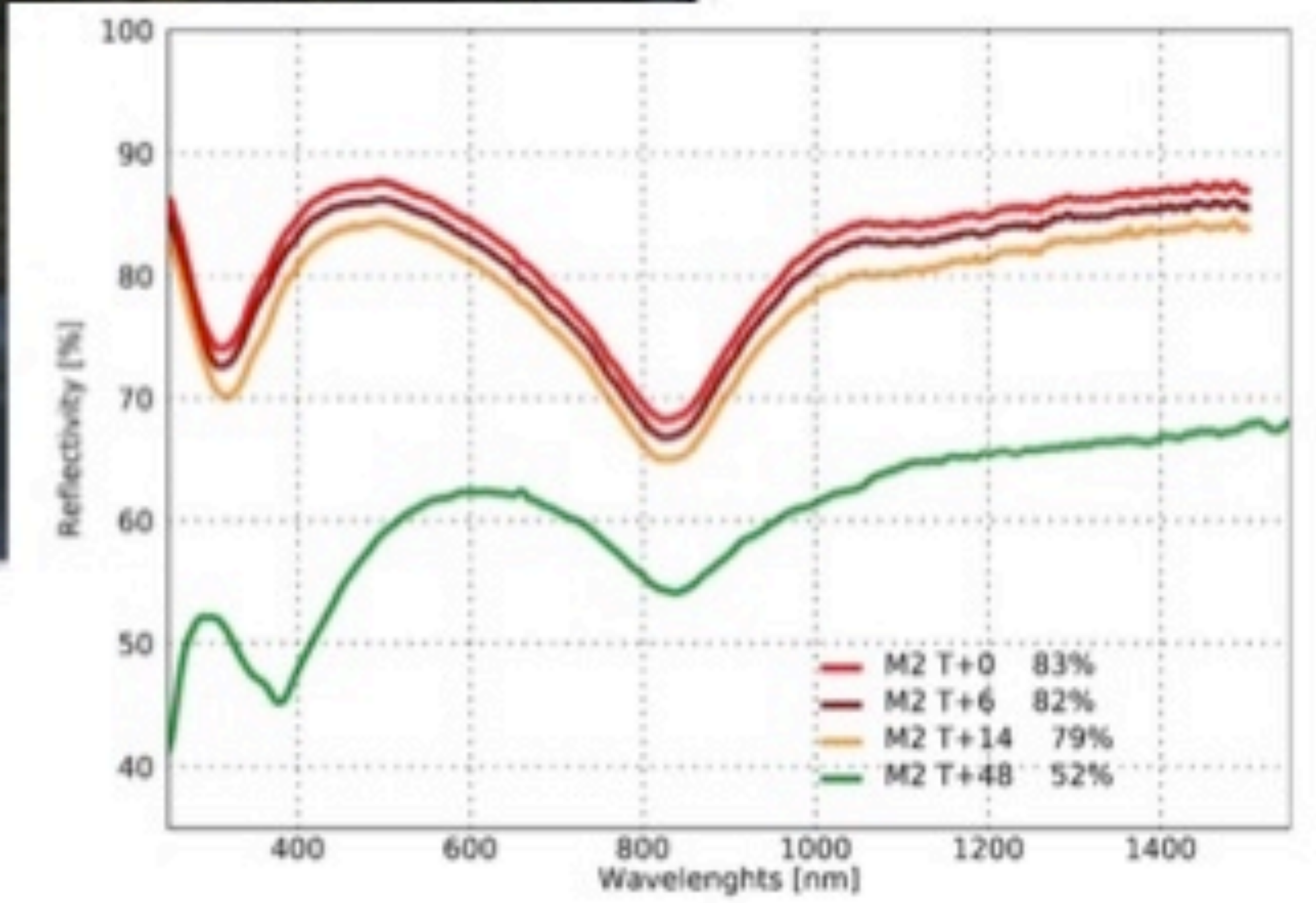


ASTRI: reflectivity

Mt. Etna atmosphere is one of the most aggressive

- Strong coating degradation in correspondence of eruptions





Water repellent layer now under test

ASTRI: reflectivity

ASTRI Mini-Array

MLT proposed an extensive test plan to qualify mirrors durability:

- Tests on new AL+SiO2+ZrO2 coating on-going
- All ISO tests are performed by external certifier (TUV)

Test name	Description	
Visual Inspection	ISO 9211-4: 2006(E)	
R%	Average reflectivity in 300-550 nm measured with Spectrophotometer Filmetrics F20-UVX	●
R% Uniformity	Range of R% measured on 13 points uniformly distributed along three diagonals	●
Adhesion Test	ISO 9211-4: 2006(E), Method 02, Severity 01 (rate of tape removal: slow)	●
Damp Heat	ISO 9022-2:2002(E), Method 12, Severity 03-1	●
Thermal cycling	Specific procedure agreed with INAF • From 20°C to -20°C (0.125°C/min → Plateau of 12 hours) • From -20°C to 70°C (0.125°C/min → Plateau of 4 hours • Cool down to 20°C	
Abrasion	ISO 9211-4: 2006(E), Method 01, Severity 02	
Salt Mist	ISO 9022-4: 2002(E), Method 40, 24h (Severity according to ISO 9211-3:2008)	
Solar Radiation	ISO 9022-9:2016 [RD6], Method 20, Severity 01-1, with the following conditions: • Max temperature 70 ± 2 °C instead of 55 ± 2°C specified by ISO • Total irradiance 1.2 ± 0.1 kW/m² instead of 1 ± 0.1 kW/m² specified by ISO	●
Aggressive env.	Panels exposed to open air (TBD) / Accelerated test method to be identified	?
Sand and Dust	MIL-STD-810F_01Jan2000, Met 510.4, Procedure I (Blowing Dust) – Same as ALMA panels	?

ASTRI: reflectivity

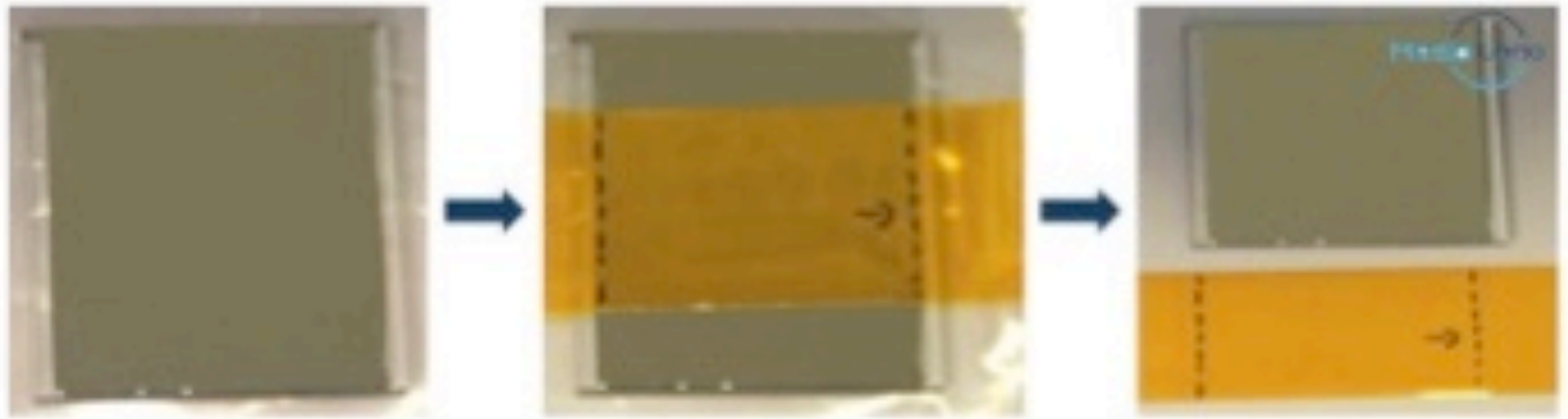
MLT proposed an extensive test plan to qualify mirrors durability:

- Adhesion on samples (ISO 9211-4:2006 method 02 severity 01)
  No anomalies observed

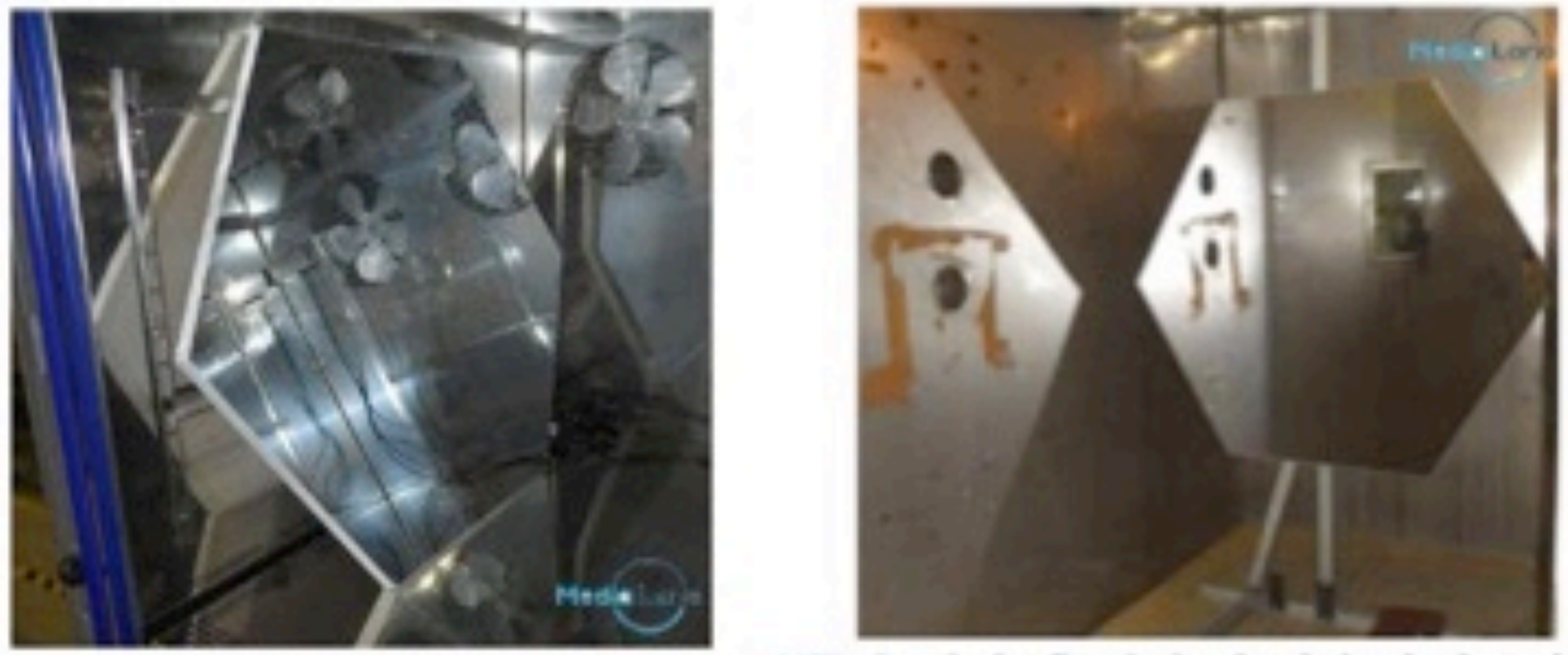
- Damp Heat on full ASTRI mirror (ISO 9022-1:2002, Method 12, severity 03-1)
  No reflectivity loss – passed

- Thermal cycling (5 cycles)
  From 20°C to -20°C (Plateau 12 h)
  From -20°C to 70°C (Plateau 4 h)
  No coating or shape failures

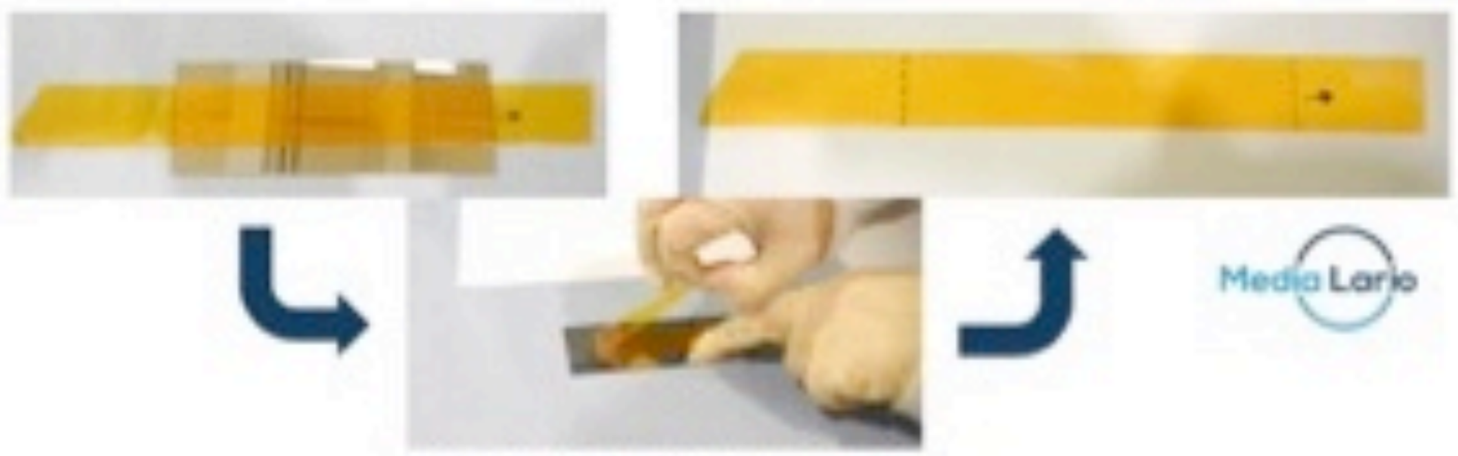
- Solar radiation(ISO 9022-9:2016 method 40 24h)
  No reflectivity degradation



Coating sample — Kapton tape applied on sample — Sample and Kapton tape show no anomalies after removal



ASTRI-COR3 mirror during Damp Heat test — MST mirror in the climatic chamber during the thermal tests



Adhesion Test after Solar Test on samples

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The ASTRI Mini-Array Project

The ASTRI Mini-Array is a project whose purpose is to construct, deploy and operate an array of 9 Cherenkov telescopes of the 4 meters class at the Observatorio del Teide in Tenerife (Spain) in collaboration with IAC.

More than 150 researchers belonging to

- INAF institutes (IASF-MI, IASF-PA, OAS, OACT, OAB, OAPD, OAR)
- Italian Universities (Uni-PG, Uni-PD, Uni-CT, Uni-GE, PoliMi) & INFN
- Fundacion Galileo Galilei
- International institutions (IAC - Spain, University of Sao Paulo – Brazil, North-West University – South Africa, IAC – Spain, Université / Observatoire de Geneve - CH).

Italian and foreign industrial companies are and will be involved in the ASTRI Mini-Array project with important industrial return.

The ASTRI Mini-Array Project

Design and implementation of the telescope's & cameras electro-mechanical structures

Implementation of the site infrastructure @Tenerife

Design and implementation of cameras

Production of the SiPM sensors

ASIC design and production

Production of the primary mirrors reflecting panels

Coating of the secondary mirrors via magnetron sputtering

Polishing of the secondary mirrors surfaces

Production of the secondary mirrors via thermal slumping

Control sw based on the Alma Common Software

The ASTRI Mini-Array Project

Mini-Array

June 2022

Phase 0
- 1 Telescope Structure
- m-ICT

Autumn 2022

Phase 1
- 3 Telescope Structures

Late Spring 2023

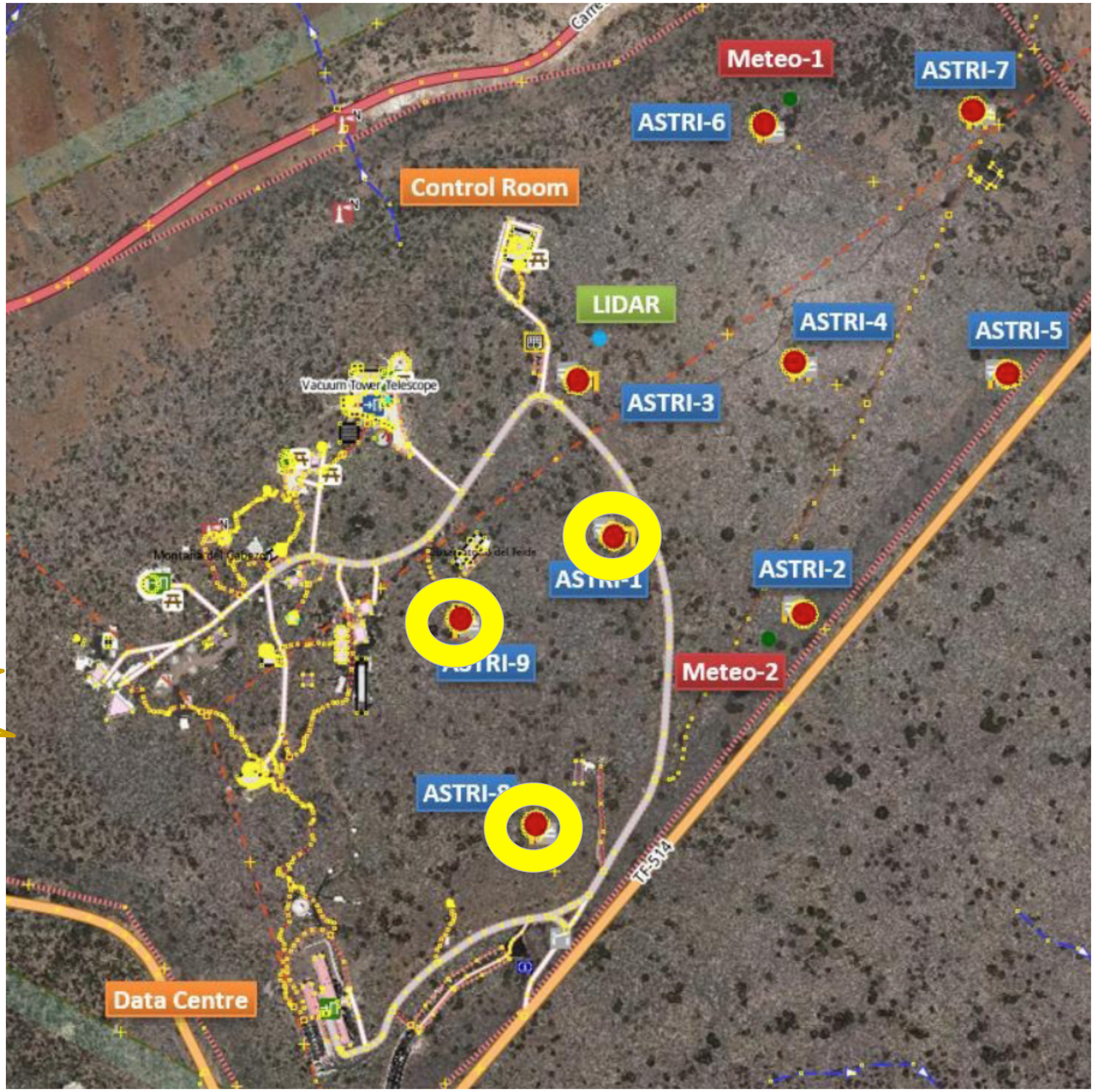
Phase 2
- 3 Telescope Structures + Cameras

Early observations

Autumn 2023

Phase 3
- Full Array

End of 2024

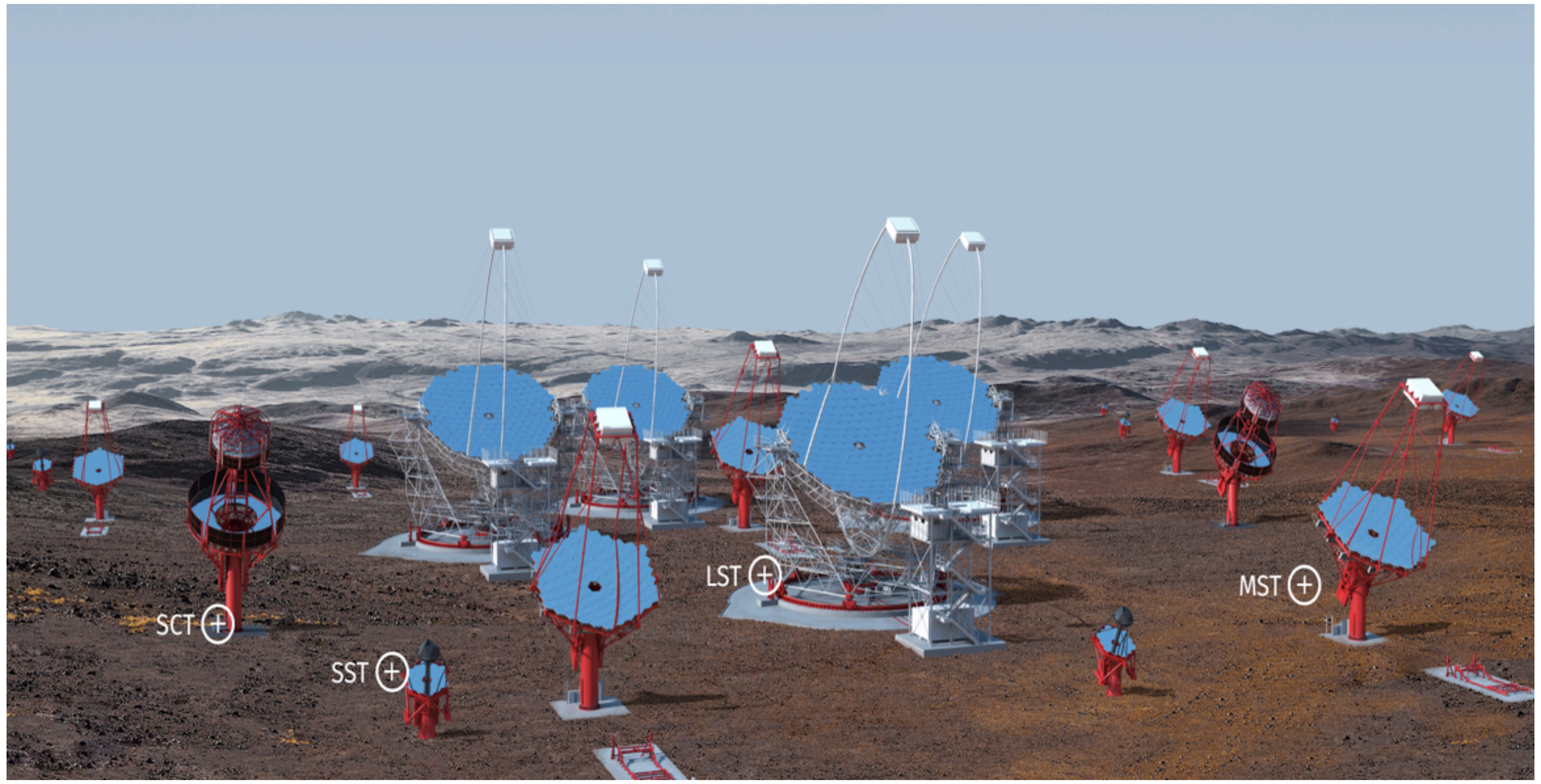


ASTRI: mini-array and CTA-SST

ASTRI-Mini Array 1° telescope June 2022

CTA-SST….in bridging phase

Next step CTA-SST



ASTRI telescopes @ South site:
Alpha configuration 35 (42)
Omega configuration 70

INDUSTRIALIZATION PROCESS!

View of the Mini-Array area