FROM ASTRI to CTA-SST: the ASTRI heritage in CTAO

Giorgia Sironi on behalf of the CTAO SST Consortium

The 2° LHAASO Simposium, 21 -25 March 2025,
Henry Cheng International Conference Center, Hong Kong

Summary

- ASTRI in the CTA framework
- ASTRI heritage 1: telescopes
- ASTRI heritage 2: mirrors
- ASTRI heritage 3: know-how
- Conclusions

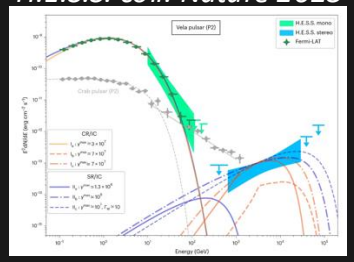
The CTA framework

CTA – Cherenkov Telescope Array:

- more than 100 Imaging Air Cherenkov Telescopes
- 20 GeV-300 Tev (LST + MST +SST)
- implemented at two sites.

Science cases of the VHE astronomy

H.E.S.S. coll. Nature 2023



sub-TeV

- Transients
- Cosmological sources
- Pulsars

TeV

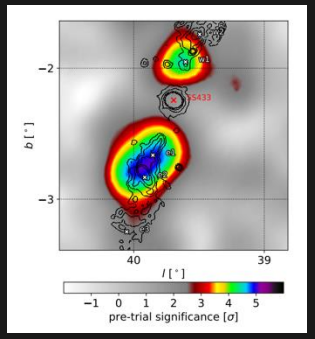
- EBL
- Dark Matter
- diffuse emission
- morphological studies
- surveys

multi-TeV

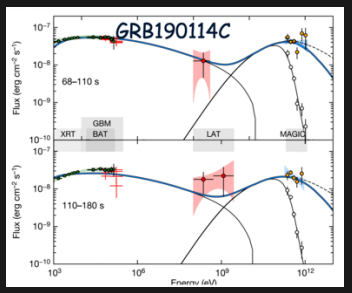
- PeVatrons
- SFRs

20 GeV 500 GeV 1 TeV 10 TeV 300 TeV

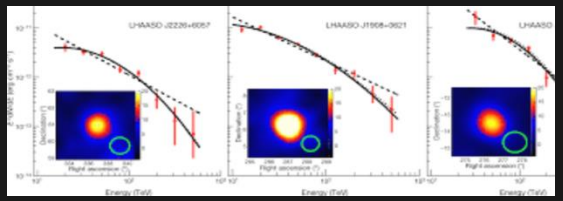
HAWC coll. Nature 2018



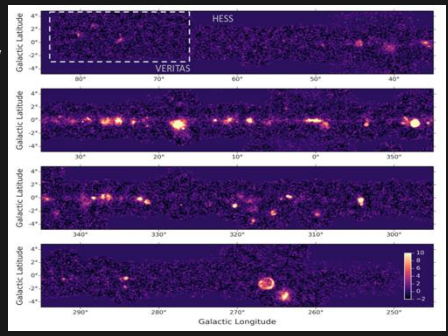
MAGIC coll. Nature 2020



LHAASO coll. Nature 2021



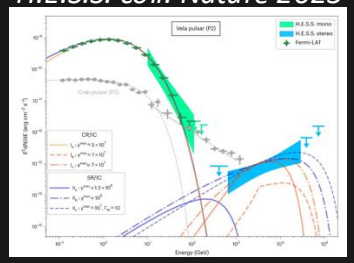
GPS VERITAS + H.E.S.S.



Science cases of the VHE astronomy

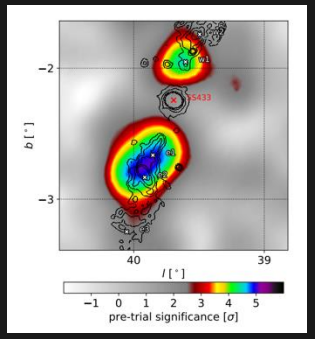
CTAO

H.E.S.S. coll. Nature 2023



LST MST SST

HAWC coll. Nature 2018



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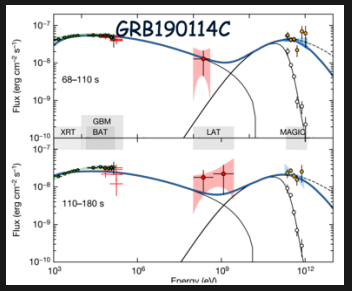

20 GeV 500 GeV 1 TeV 10 TeV 300 TeV

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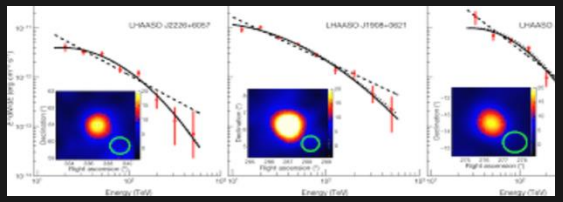

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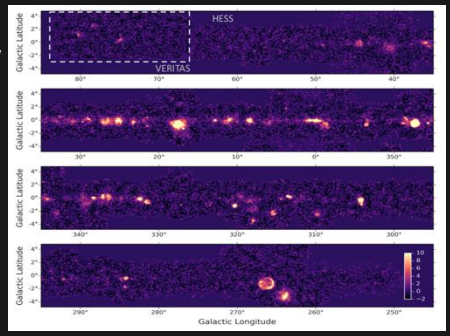
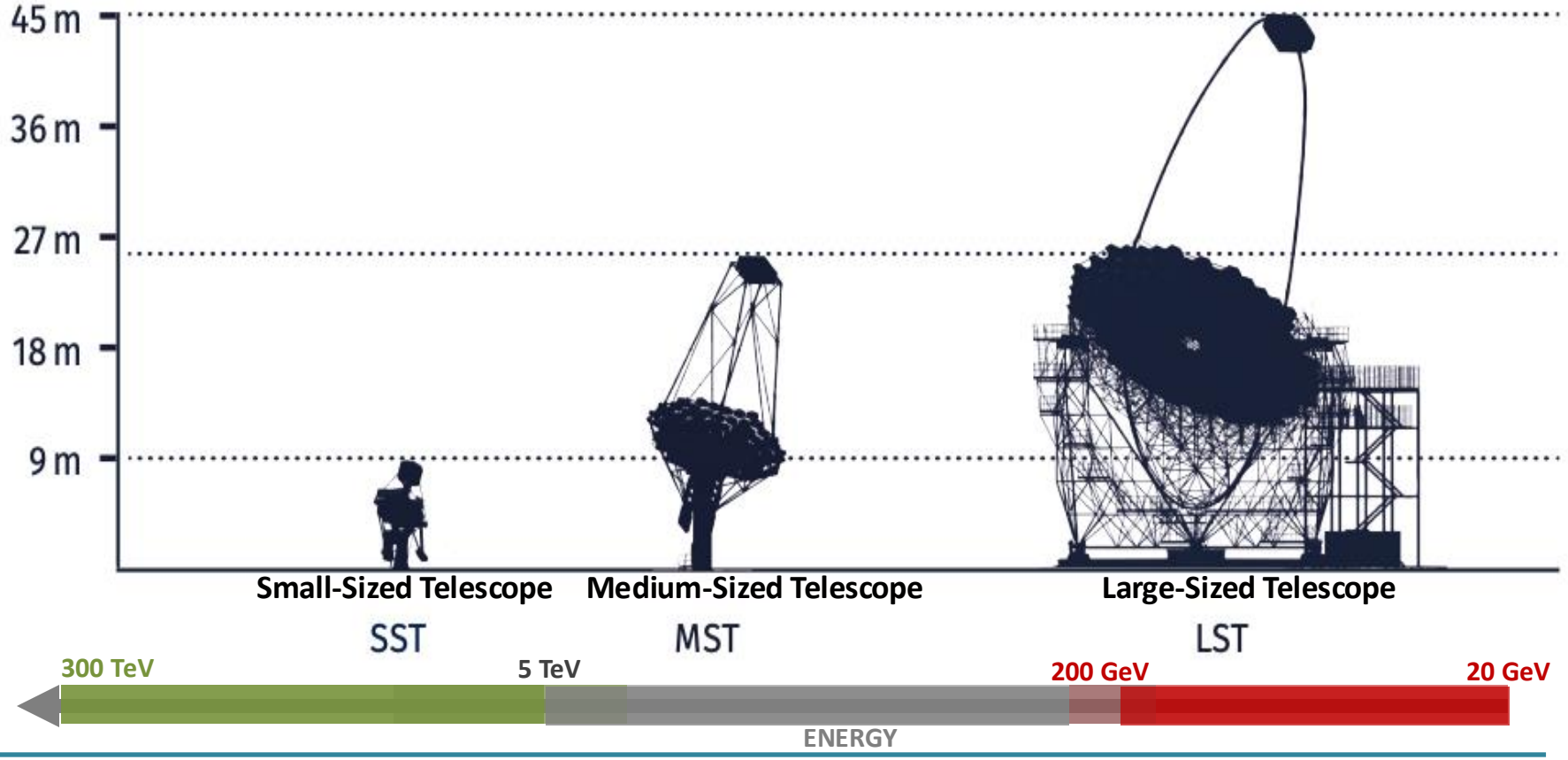


CTA-Telescopes

- 2-mirror Schwarzschild-Couder optical design
- 4.3 m ⌀ primary reflective surface
- SiPM camera: 2048 pixels (0.16°)
- 8.8° FoV
- 17.5 tonne

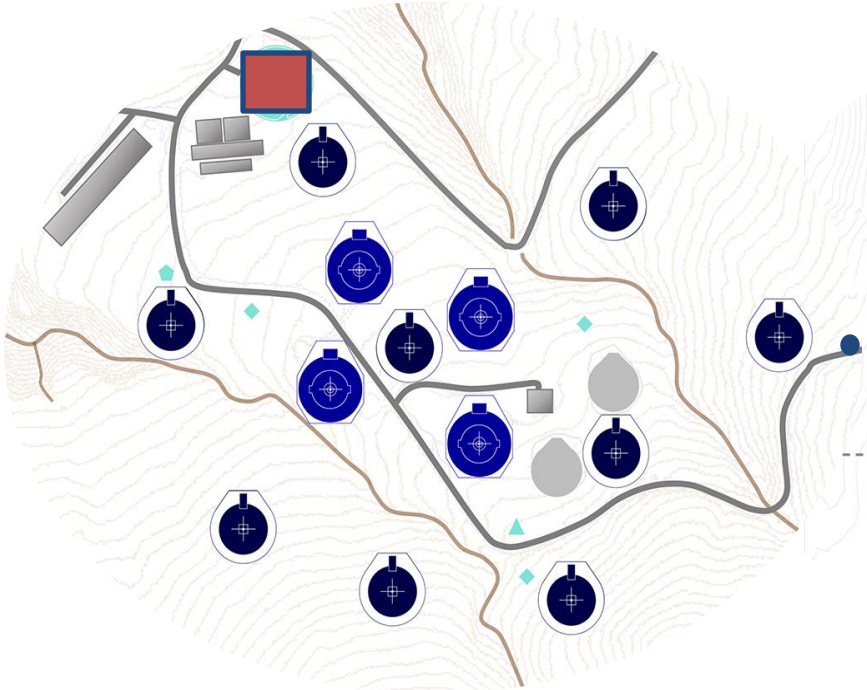
- Davies-Cotton optical design
- 12 m ⌀ reflective surface
- PMT camera – 2 designs:
  - NectarCam: 1855 pixels
  - FlashCam: 1764 pixels
- ~7° FoV
- 82 tonne

- Parabolic optical design
- 23 m ⌀ reflective surface
- PMT camera: 1855 pixels (0.1°)
- 4.3° FoV
- 100 tonne

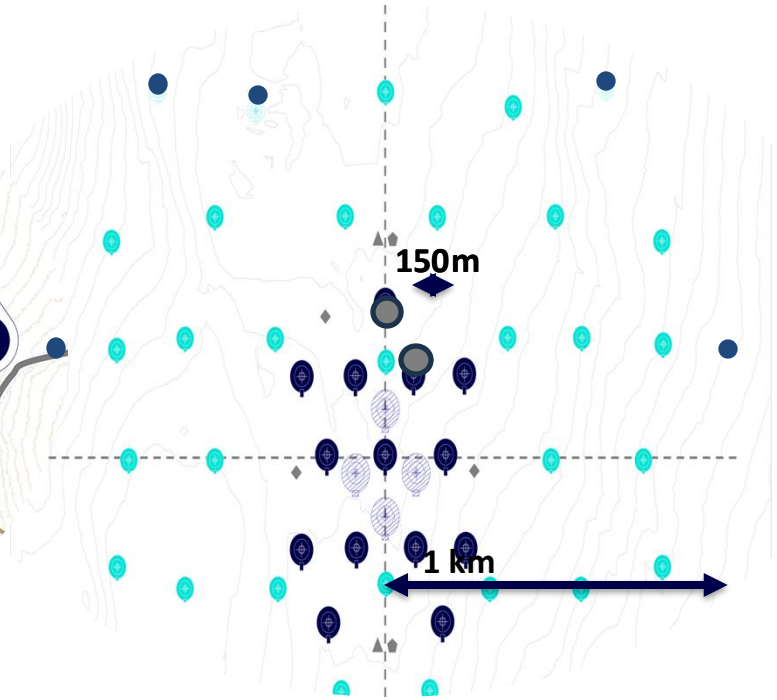


Improved - Alpha configuration

CTAO Northern array



CTAO Southern array

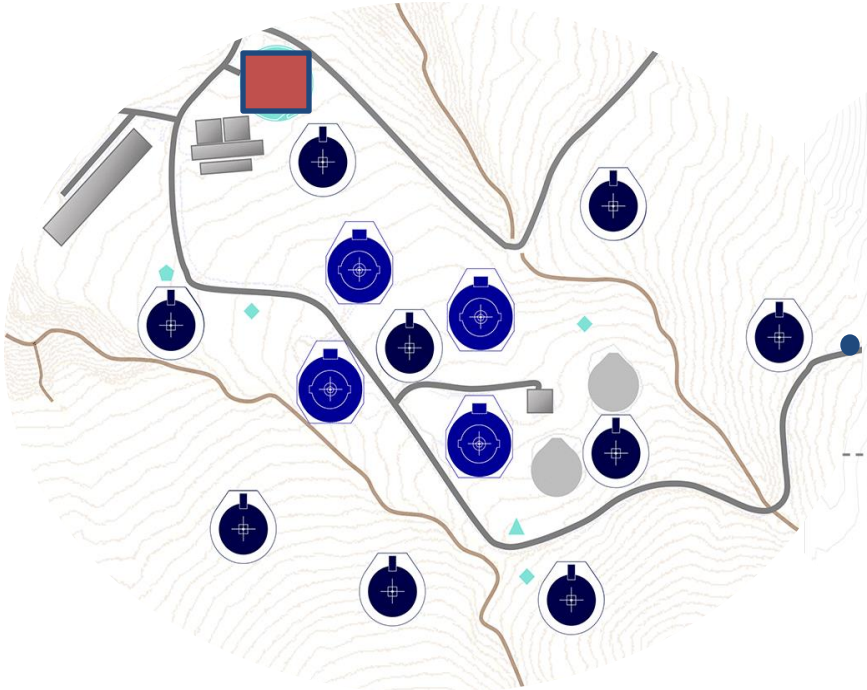


PNRR

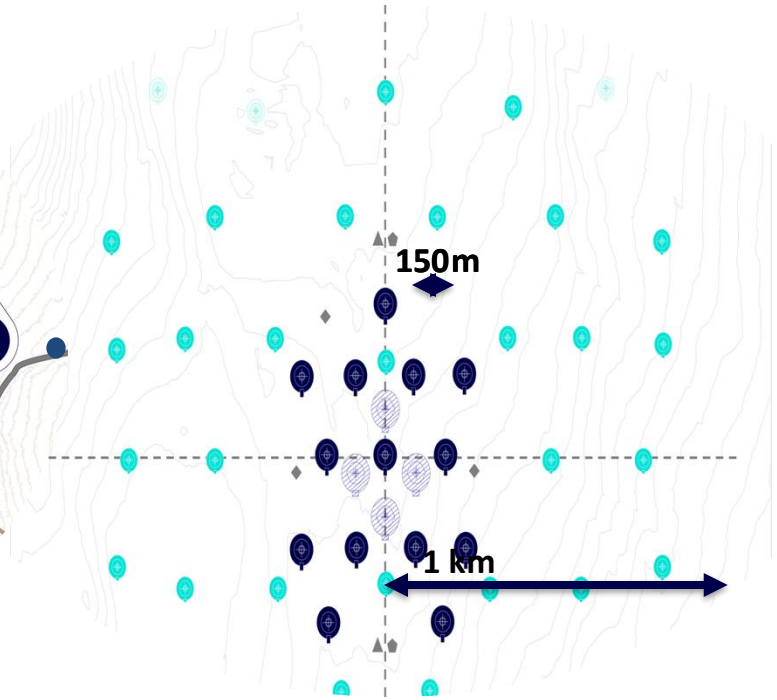
+ 5 CTA - SST
+ 2 CTA - LST

Alpha configuration

CTAO Northern array



CTAO Southern array

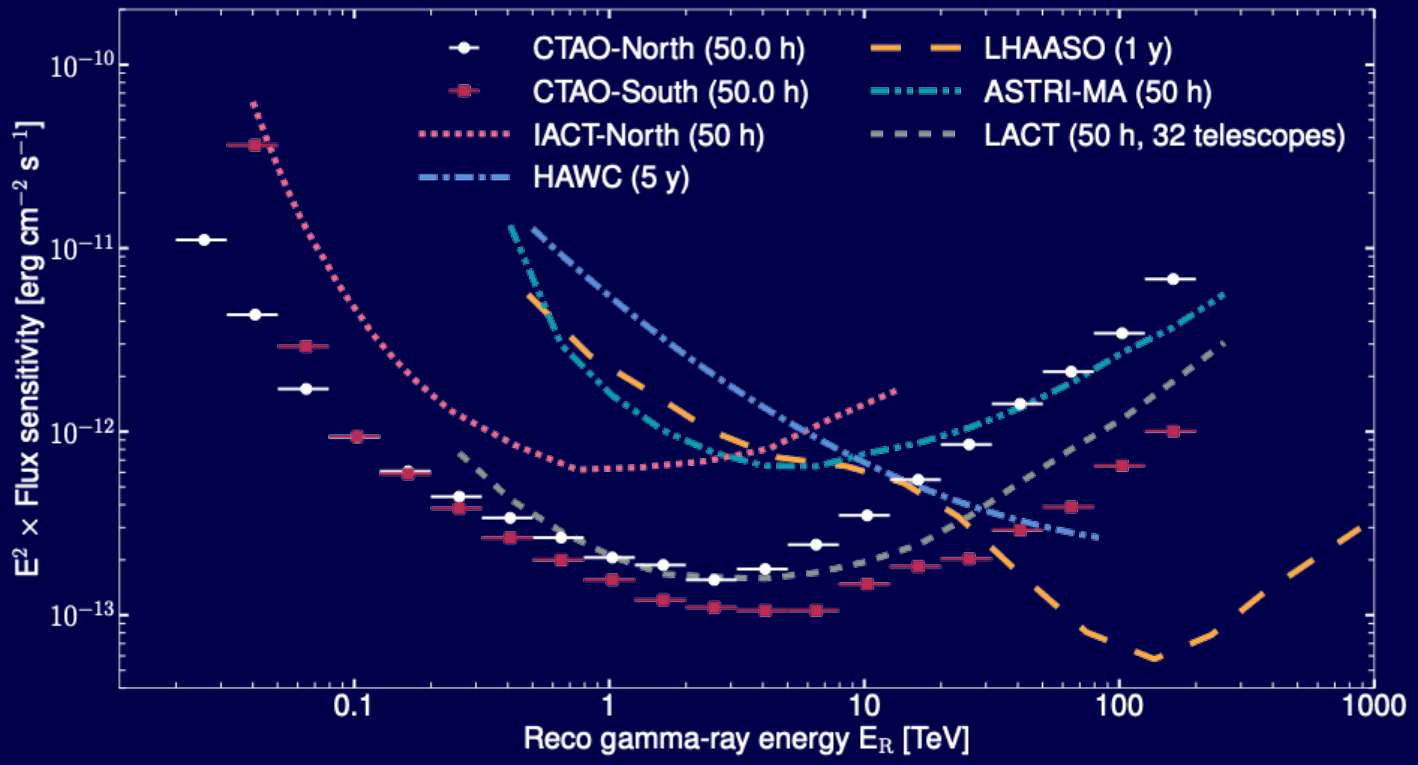


PNRR

+ 5 CTA - SST
+ 2 CTA - LST

Steady-source performance

We are opening the multi-TeV science to the Southern sky



Credits R .Zanin – CTAO Project Scientist

Steady-source performance

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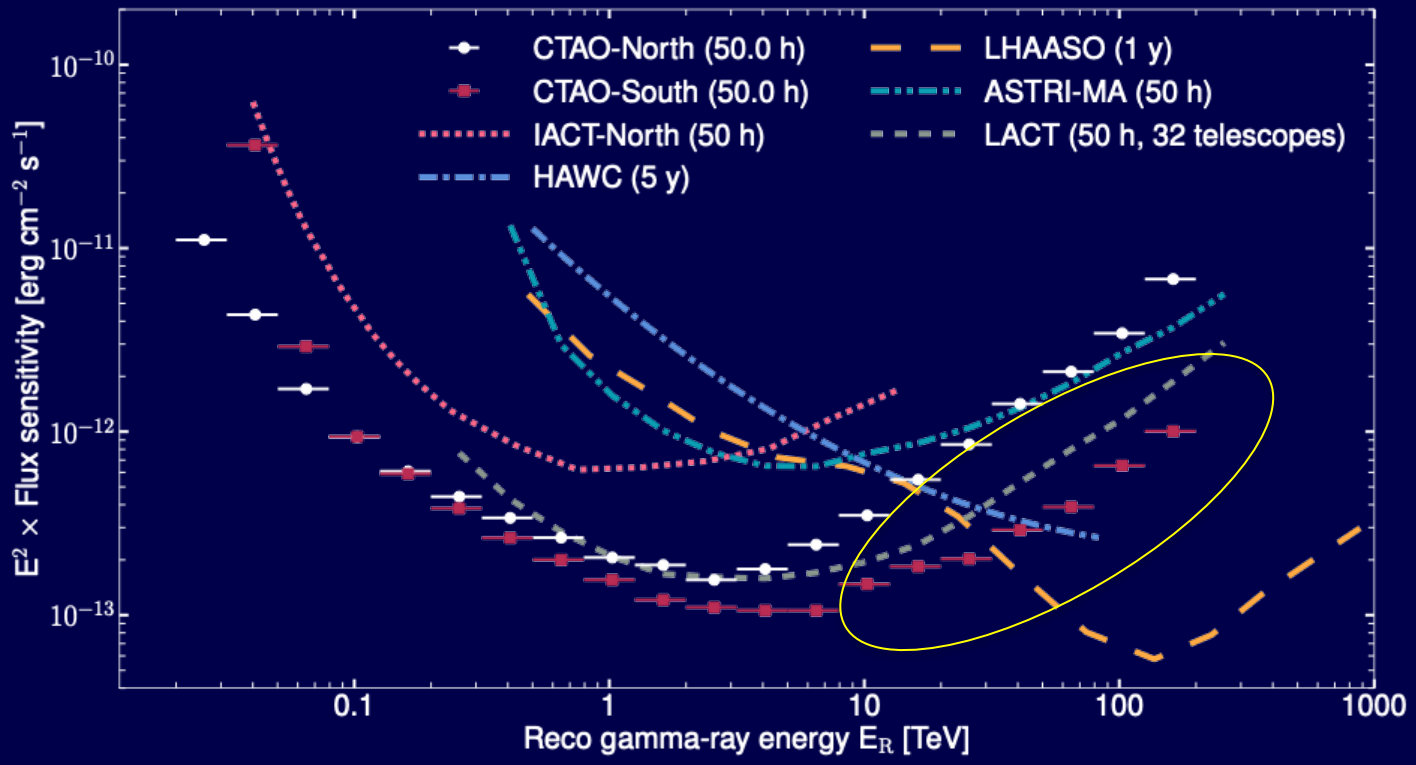
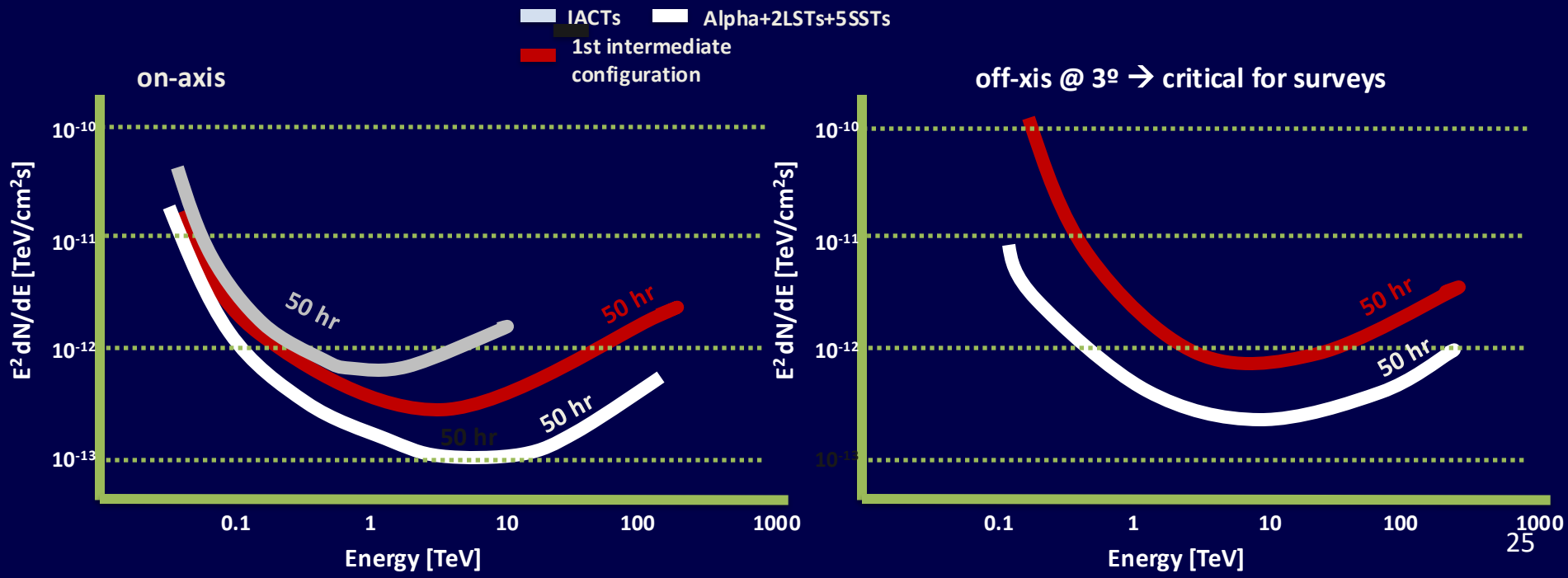


Credits R .Zanin – CTAO Project Scientist

In 3 years from now



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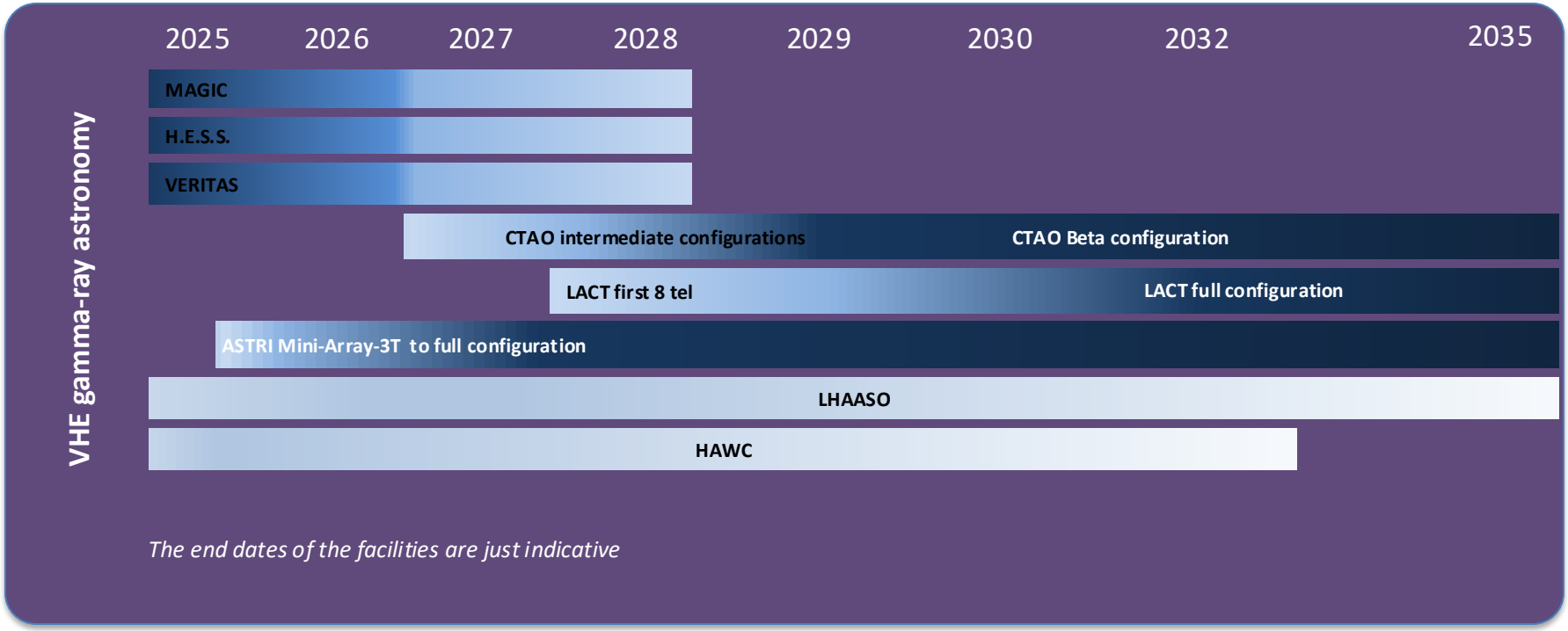
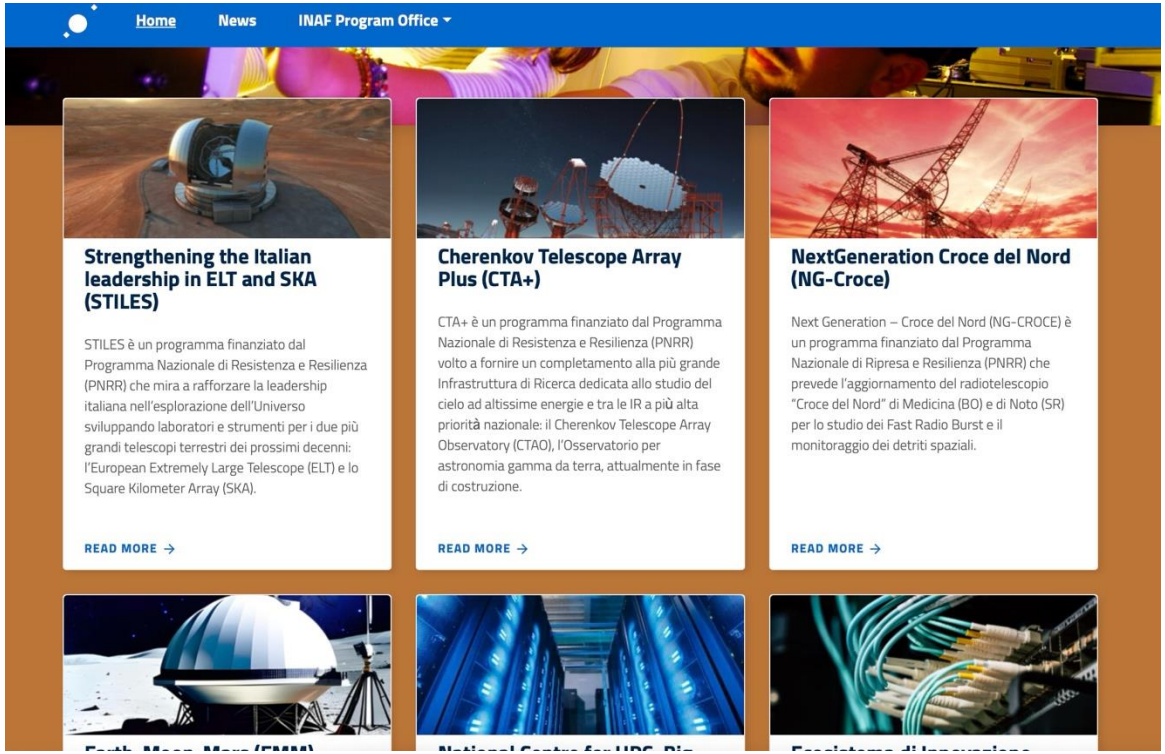
Timeline


VHE gamma-ray astronomy
2025
2026
2027
2028
2029
2030
2032
2035
MAGIC
H.E.S.S.
VERITAS
CTAO intermediate configurations
CTAO Beta configuration
LACT first 8 tel
LACT full configuration
ASTRI Mini-Array-3T to full configuration
LHAASO
HAWC
The end dates of the facilities are just indicative

PNRR to be completed within 2025

- 10 SST telescopes structures
- M1 mirrors for 10 SST
- M2 mirrors
- +2 LST full telescopes for the S-site



PNRR to be completed within 2025
+
CTAO ERIC

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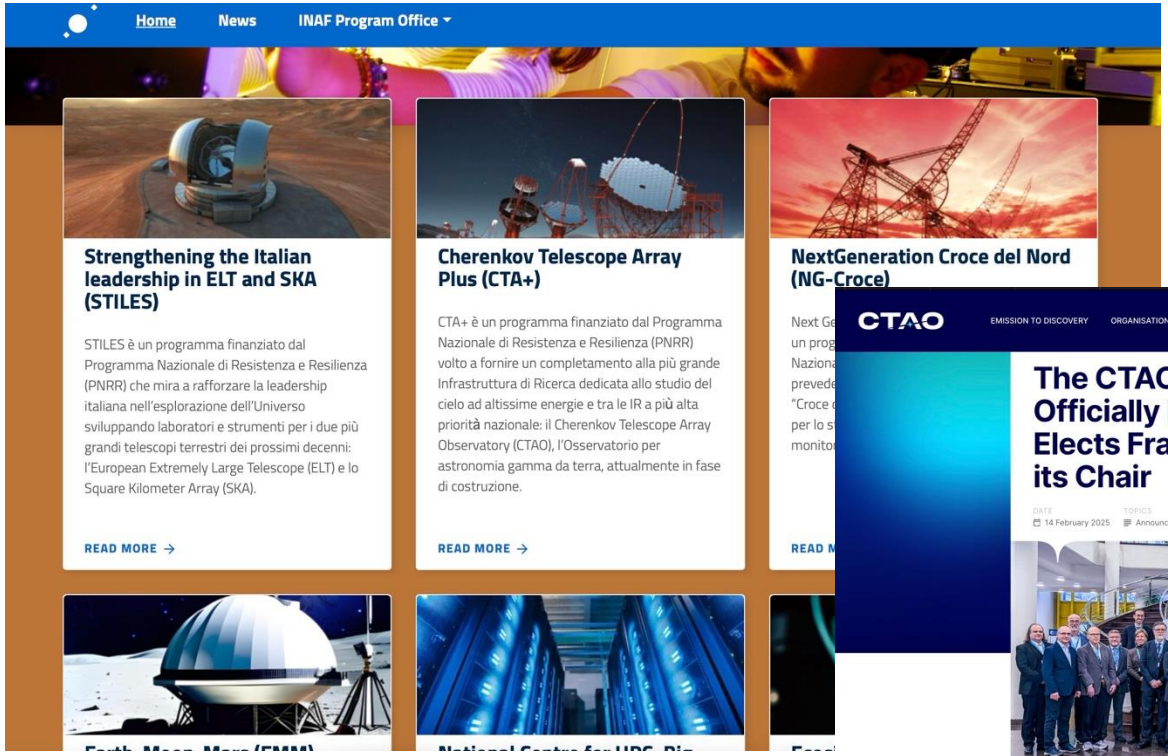

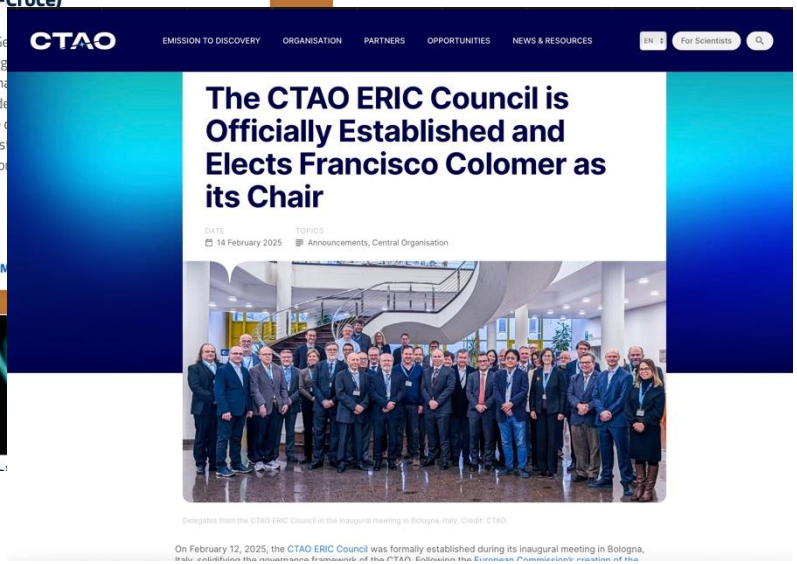

Summary

- ASTRI in the CTA framework
- ASTRI heritage 1: telescopes
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- ASTRI heritage 3: know-how
- Conclusions

ASTRI heritage in CTA #1: Telescope

CTA-SST selected in 2020

- ASTRI Optical Design
- Upgraded telescope structure
- Upgraded CHEC-S Camera

SST TELESCOPE COORDINATION (ON BEHALF OF SST Consortium)

- Responsible of SST PRO Organization and Management
- Coordination with SST ESC
- Liaison with CTAO PM
- Interfaces coordination (STR/CAM, TEL HW/CTA Infra TEL SW/ACADA)
- Management and technical coordination
- Product, Quality and Safety Assurance
- RAM and Risk Management
- AIT/V approach and coordination
- On-Site AIV
- Support exploitation

The **IAG-USP** Institute from Brazil will contribute to the AIT/AIV activities in Chile

SST Structure

- Product, Quality and Safety Assurance
- Design & Analysis
- CAD, FEM & Optical Analysis
- Interfaces with CTA INFRA and ACADA
- Subsystems procurement
- SW development coordination & HW/SW integration
- SST CAM Accommodation
- RAM and Risk Management
- Development and AIT/V
- On-Site TEL AIT

SST CAMERA Consortium

SST Camera

- Management Support
- Product, Quality and Safety Assurance,
- Design & Analysis
- CAD and FEM
- Interfaces with CTA INFRA and ACADA
- Subsystems procurement
- Software development and HW/SW integration
- Input to CAM Accommodation on STR
- RAM and Risk Management
- Development and AIT/V
- On-Site TEL AIT support

SST Camera Consortium

- **DE:** MPIK, DESY, ECAP
- **UK:** Universities of: Durham, Leicester, Liverpool, Oxford
- **NL:** UvA, Groningen
- **JP**: Nagoya
- **AU**: Universities of: Adelaide, Western Sydney, Sydney, Australian National, New South Wales, Monash, Curtin

Contribution in SST-MECH serial production

- Management Support
- Product, Quality and Safety Assurance
- Design & Analysis
- CAD and FEM
- Interfaces with SST MEC
- Input to SST STR for design
- RAM and Risk Management
- Development and AIT/V
- On-site AIT/V support

ASTRI heritage in CTA #1: Telescope

CTA-SST selected in 2020

- ASTRI Optical Design
- Upgraded telescope structure
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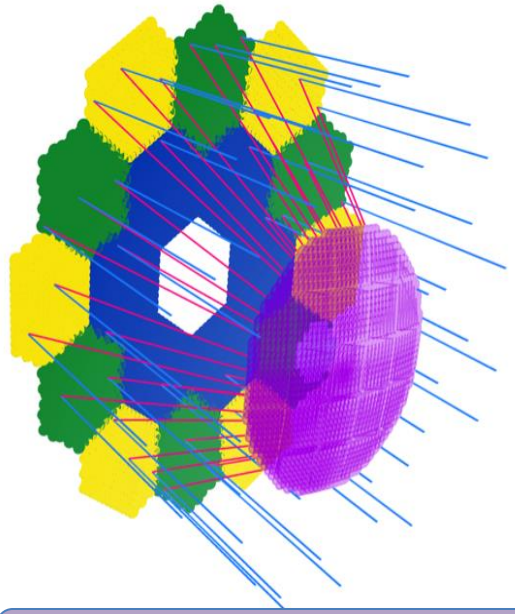
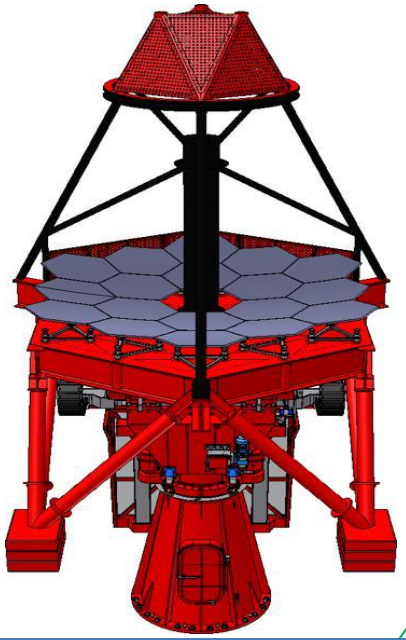
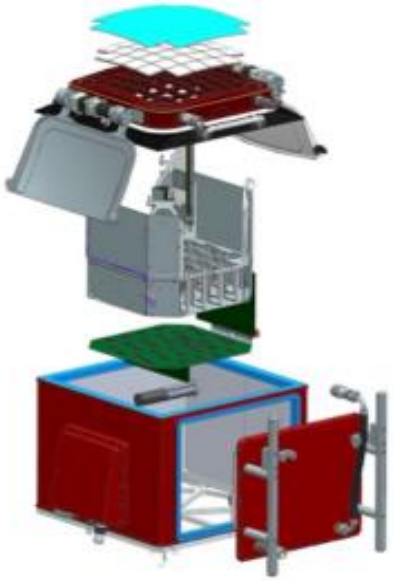
The ASTRI-Horn prototype
Polynomial SC design



Updated ASTRI Mini-Array
structure



Updated
CHEC-S camera

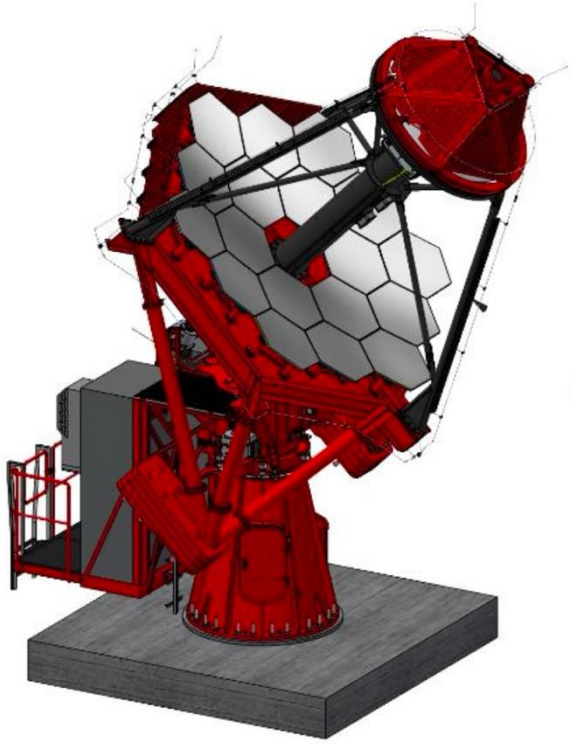


To be verified at the South site environmental conditions

ASTRI heritage in CTA #1: Telescope

CTA-SST

- ASTRI Optical Design
- Upgraded telescope structure
- Upgraded CHEC-S Camera



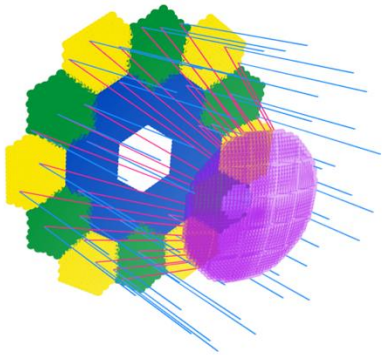
	Small-sized telescope (SST) main properties:
Optical Design	modified Schwarzschild-Couder
Primary reflector diameter	4.3 m
Secondary reflector diameter	1.8m
Effective mirror area (including shadowing)	>5 m^2
Focal length	2.15 m
Total weight	<17.5 t
Field of view	>8.8 deg
Number of pixels in SST Camera	2048
Pixel size (imaging)	0.16 deg
Photodetector type	SiPM
Telescope data rates (before array trigger)	>600 Hz
Telescope data rates (readout of all pixels; before array trigger)	2.6 Gb/s
Positioning time to any point in the sky (>30° elevation)	70s
Telescope Post Processing Pointing Precision	< 7 arcsecs

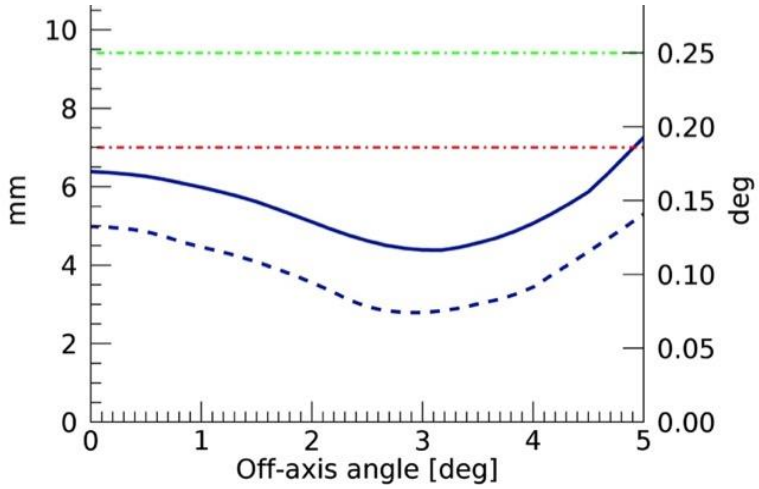
ASTRI heritage in CTA #1: Telescope

CTA-SST →
- ASTRI Optical Design
- Upgraded telescope structure
- Upgraded CHEC-S Camera

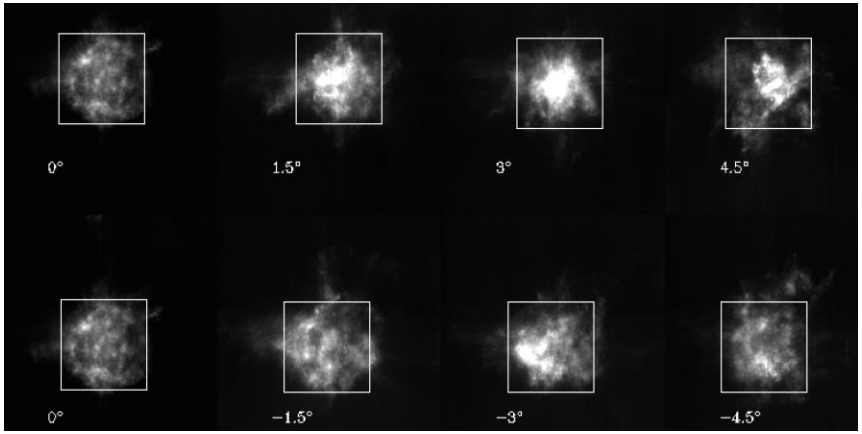
Advantage of the **ASTRI optical design**:

- Aplanatic
- Flat off-axis angular resolution (D80<0.2 deg)
- FOV extension to > 10 degrees





Final alignment check and D80 across the FOV for ATRI-Horn telescope



https://doi.org/10.1051/0004-6361/201731602)

ASTRI heritage in CTA #1: Telescope

CTA-SST selected in 2020

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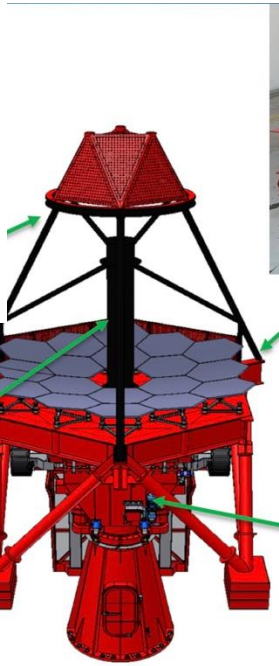
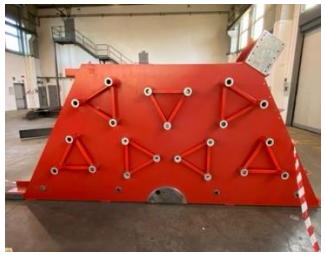
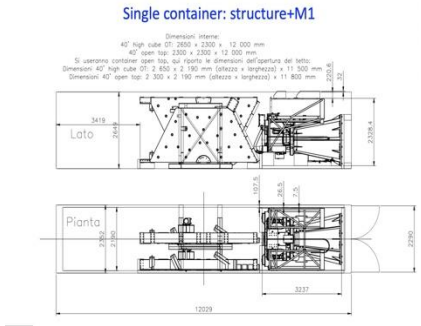


(Integration of ASTRI MA Telescope)



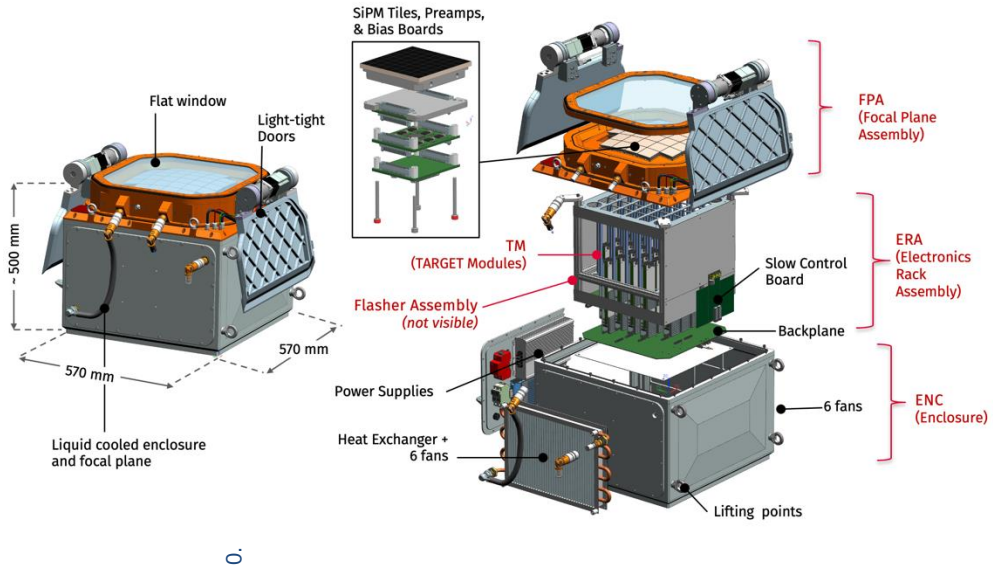


ASTRI heritage in CTA #1: Telescope

CTA-SST selected in 2020

- ASTRI Optical Design
- Upgraded telescope structure
- Upgraded CHEC-S Camera

- SST-CAM Development based on 2 prototypes
  - CHEC-M (MAPMs)
  - CHEC-S (SiPMs)
- Low Cost, High Performance
  - Fine pixelation, large FoV
    - 32 modules of 64 pixels each
    - Tile on a radius of curvature of 1 m
    - 6 mm x 6 mm (~0.15°) pixels
    - 2048 SiPM pixels
    - 9° FoV
  - Efficient trigger & full waveform readout
    - @1GSa/s for all pixels in every event
    - Max readout rate: 1200 Hz
  - Continuous measurement of DC light



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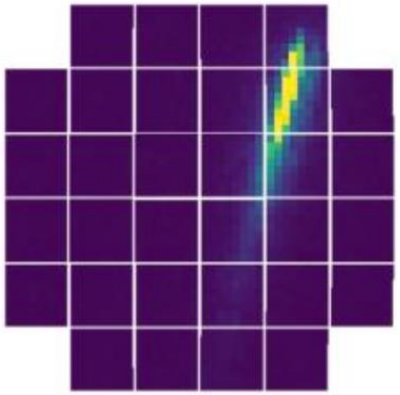
Mechanical CAM mounted on ASTRI-1 in Tenerife (November 2023)

CHEC-S on ASTRI Data



Summary

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- ASTRI heritage 2: mirrors
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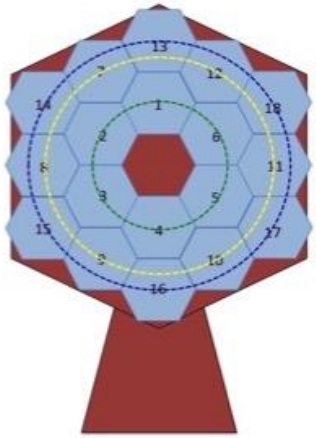
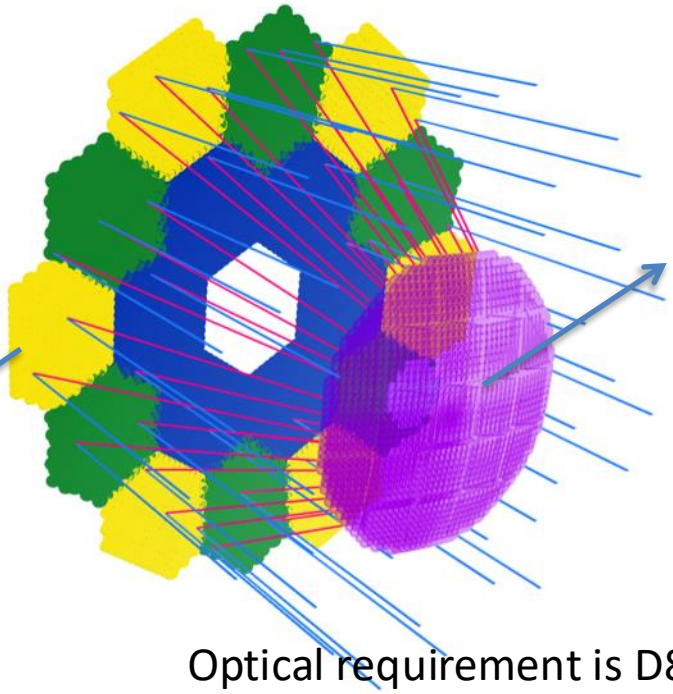
- Conclusions

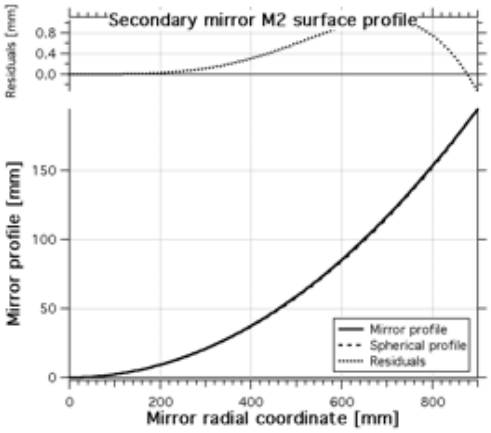
ASTRI heritage in CTA #2: Mirrors

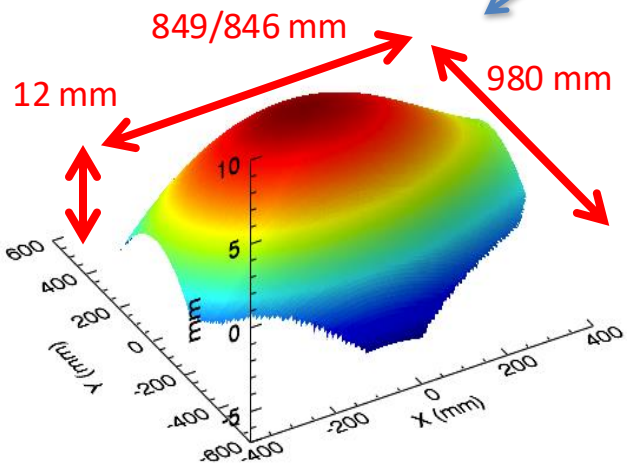
IACTs are uncovered, fast moving large collectors

- Segmented optics
- High multiplicity
- Light weight









Optical requirement is D80 < 0.25 deg across the FOV of 5 degrees

- Aspheric shape
- Very low surface roughness
- P-V shape error about 200 micron

ASTRI heritage in CTA #2: Mirrors

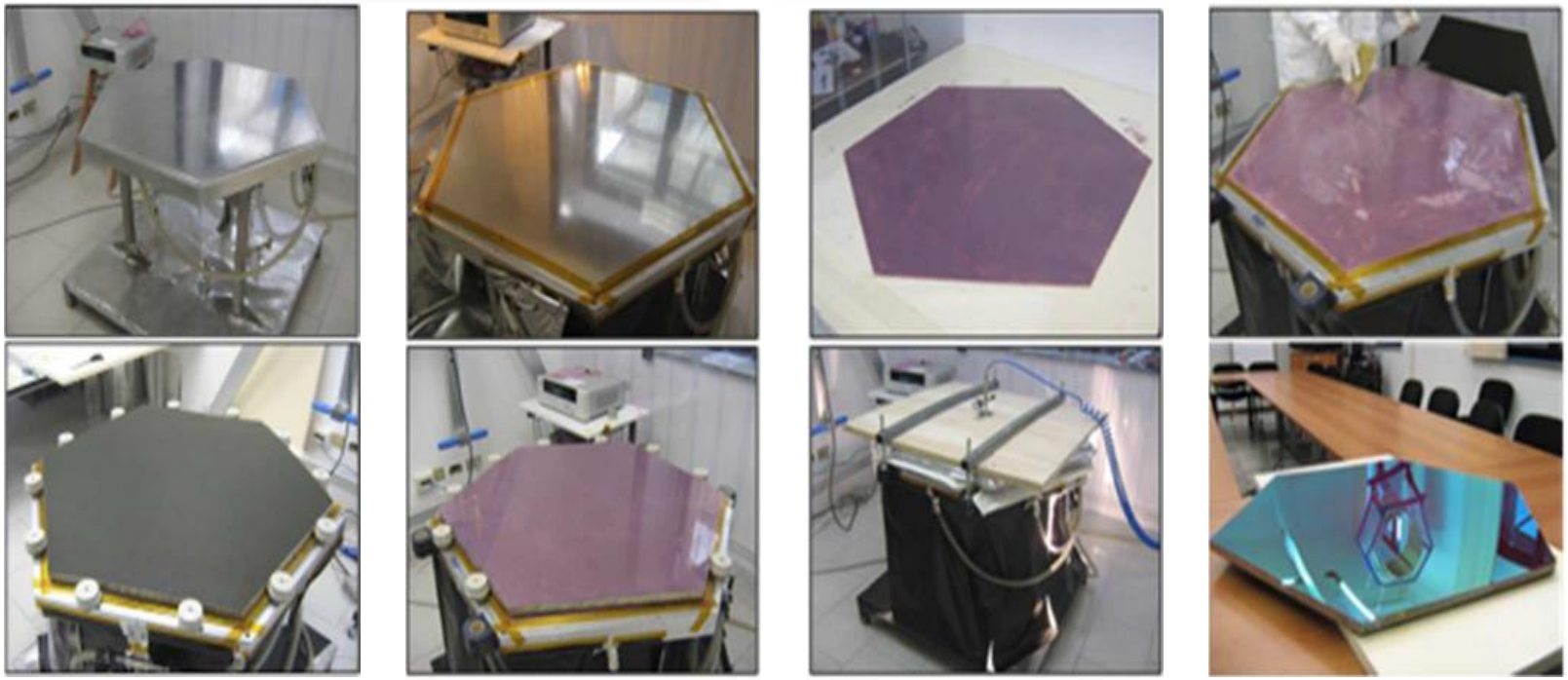
IACTs are large, uncovered, fast moving collectors →
- Segmented optics
- High multiplicity
- Light weight

M1 mirrors produced by **glass cold-slumping** developed by INAF-OAB and Media Lario

ASTRI Astrofisica con Specchi a Tecnologia Replicante Italiana

MIUR

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE



CTA-SST M2 Mirrors manufacturing

M2 mirror substrates produced by glass hot-slumping:

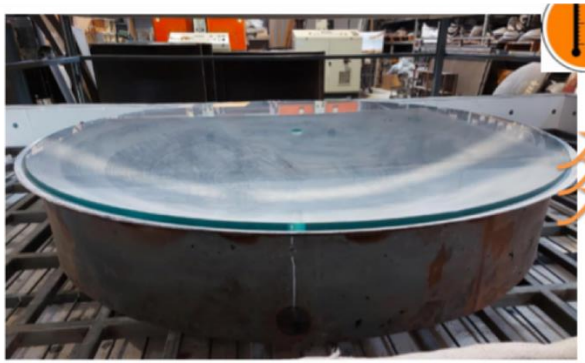


Fig. 2 ASTRI M2 mould + flat glass sheet

Fig. 3 ASTRI M2 mould + slumped glass sheet

Fig. 4: ASTRI M2 with I/Fs to the telescope

M2 DIMENSIONS: Diam. 1800 mm, Concavity/Sag. ~200 mm

RADIAL PROFILE: Aspherical shape, difference from sphere ~1 mm

GLASS: Monolithic foil, Circular shape, Thickness 19 mm, good starting microroughness

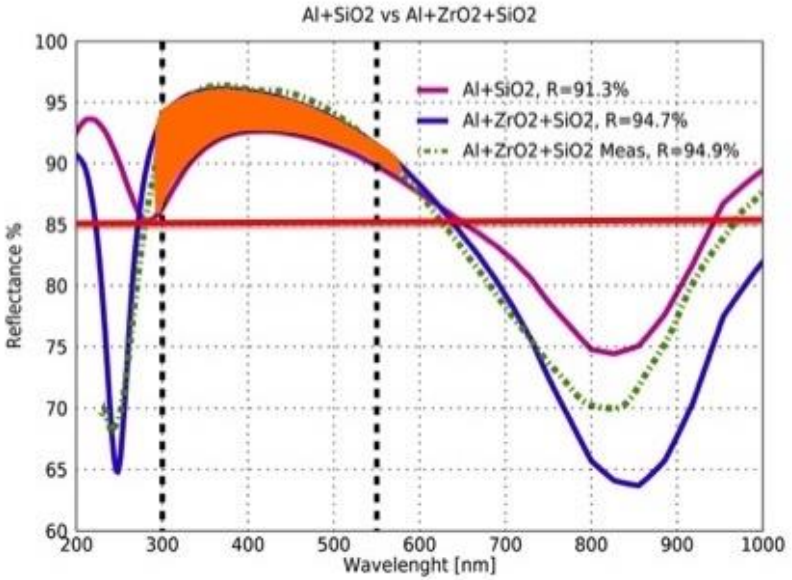
I/Fs: 12 stainless steel PADs glued on back

MOULD: Fe mould, negative shape of M2 for indirect slumping (~600°C, 17h cycle)

ASTRI heritage in CTA #2: Mirrors

IACTs are large, uncovered, fast moving collectors

- Segmented optics
- High multiplicity
- Light weight



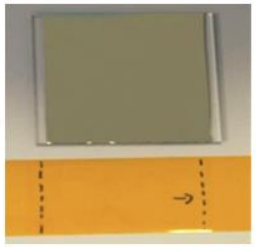
Test name	Description
Visual Inspection	ISO 9211-4: 2006(E)
R%	Average reflectivity in 300-550 nm measured with Spectrophotometer Filmetrics F20-UVX
R% Uniformity	Range of R% measured on 13 points uniformly distributed along three diagonals
Adhesion Test	ISO 9211-4: 2006(E), Method 02, Severity 01 (rate 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-COR3 mirror during Damp Heat test

MST mirror in the climatic chamber during the thermal tests

Coating sample

ASTRI-COR3 mirror during Damp Heat test



Sample and Kapton tape show no anomalies after removal

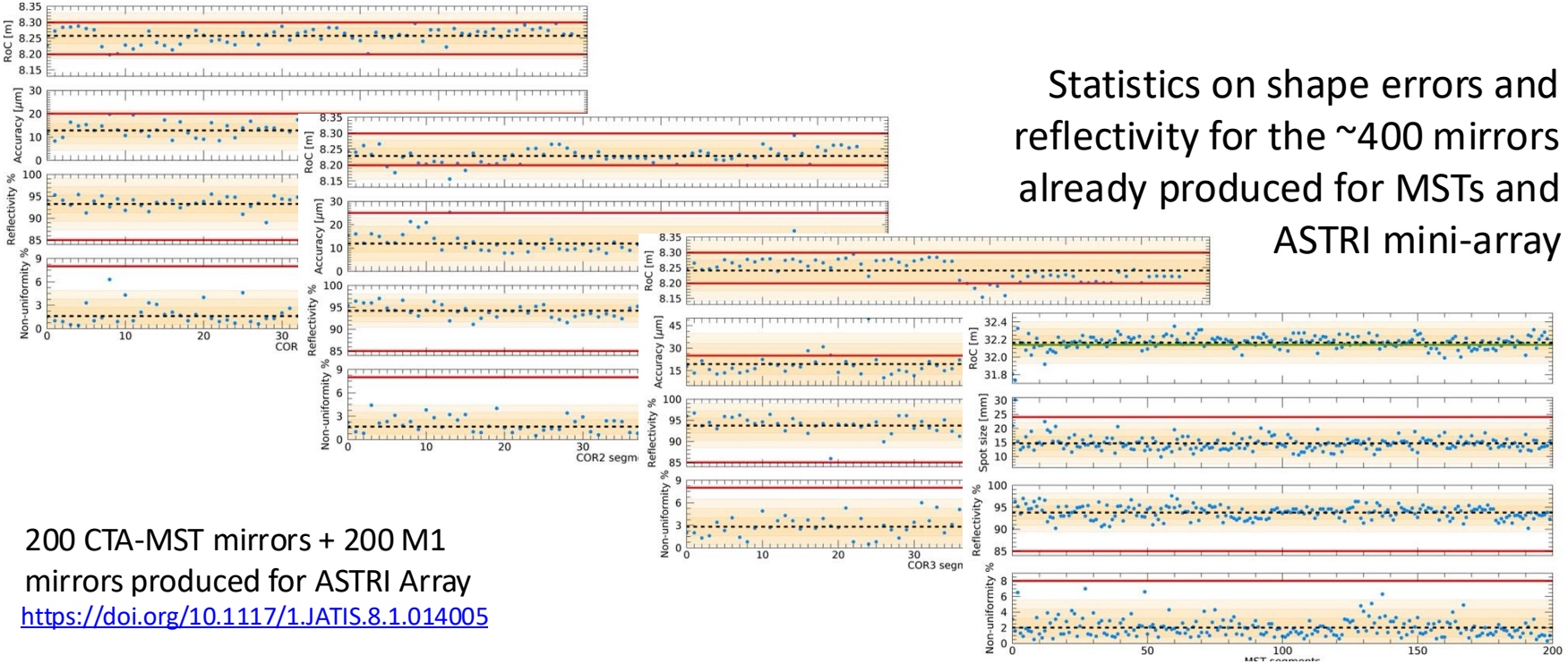
ASTRI heritage in CTA #2: Mirrors

IACTs are uncovered, fast moving large collectors

- Segmented optics
- High multiplicity
- Light weight

INAF mirrors in CTA everywhere

- 200 MST mirrors (already produced)
- 450 LST mirrors (in 2025 on PNRR)
- 37+5 x 18 SST M1 mirrors



Statistics on shape errors and reflectivity for the ~400 mirrors already produced for MSTs and ASTRI mini-array

200 CTA-MST mirrors + 200 M1 mirrors produced for ASTRI Array

https://doi.org/10.1117/1.JATIS.8.1.014005

Summary

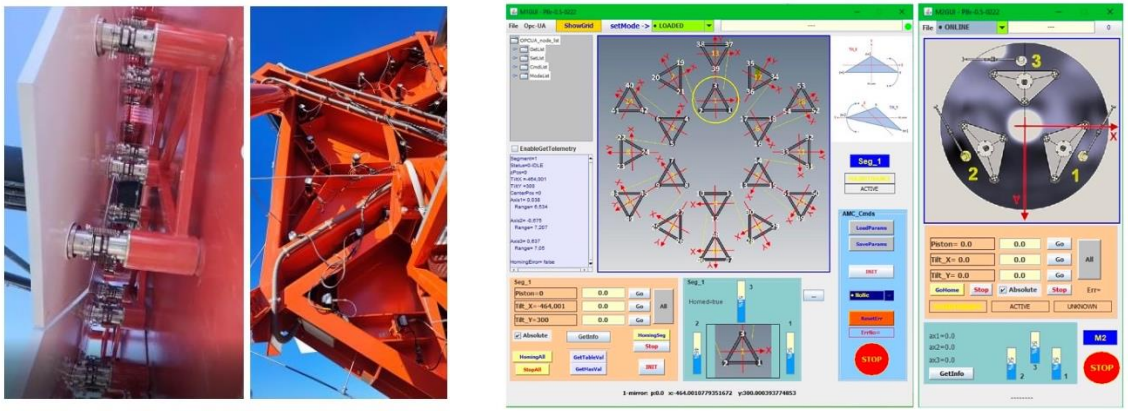
- ASTRI in the CTA framework
- ASTRI heritage 1: telescopes
- ASTRI heritage 2: mirrors
- ASTRI heritage 3: know-how
- Conclusions

Alignment

ASTRI heritage in CTA #3: know-how

Structure is very stiff → Optical alignment performed by removable actuators + optical camera

Figure 6. The optical camera. Left: a 3D view showing the main active components of the optical camera. Center: the real object mounted inside the optical camera body. Right: the optical camera mounted on ASTRI-1.



M1 actuators

Figure 7. Left: the engineering GUI for the management of the actuators of M1. Right: the same but for M2 actuators

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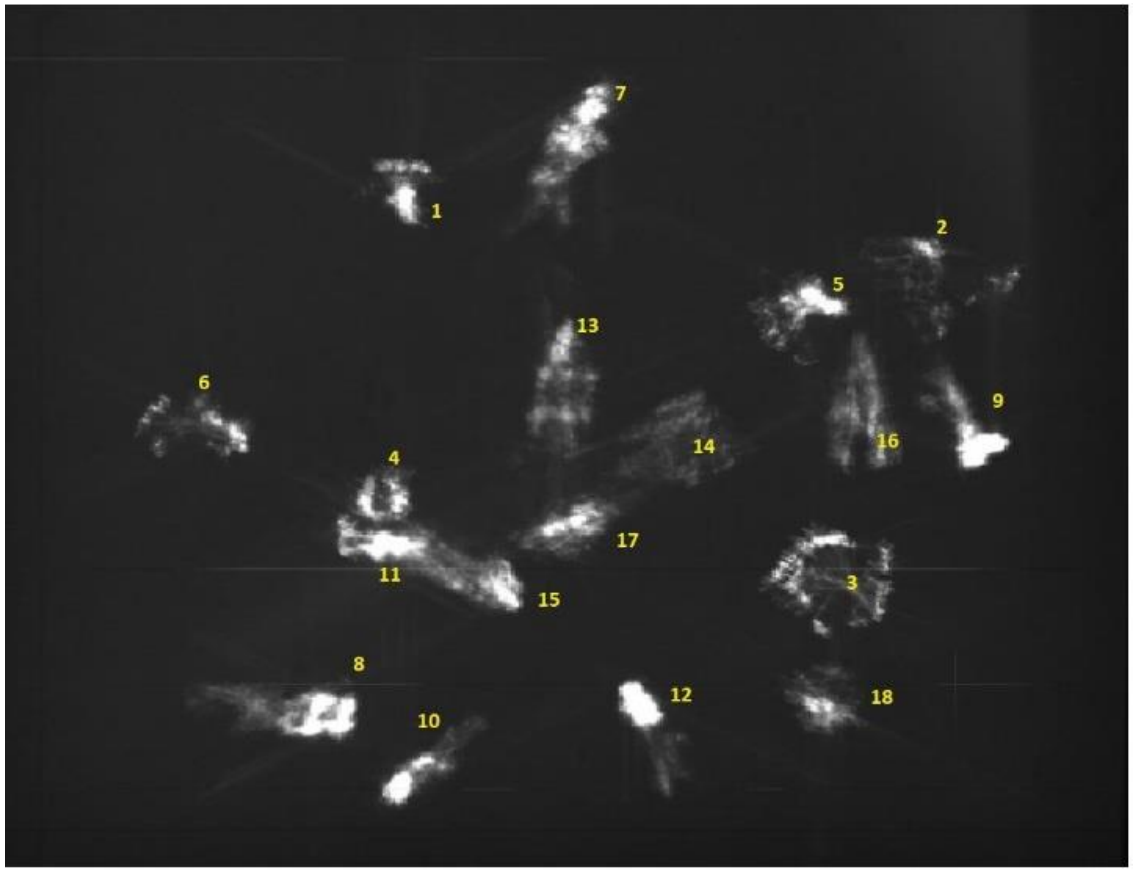
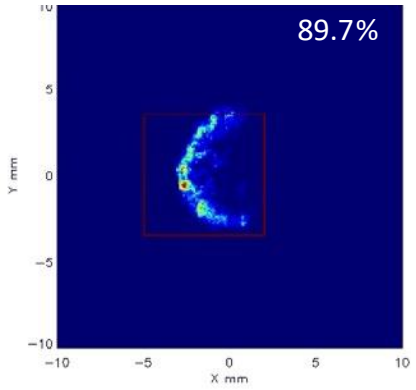


Alignment

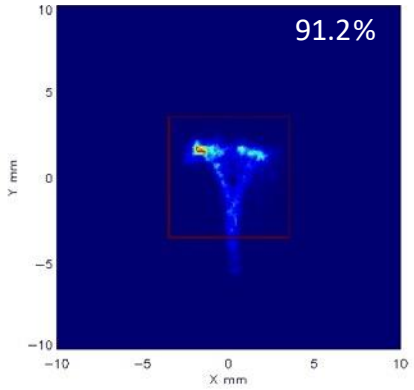
ASTRI heritage in CTA #3: know-how

Structure is very stiff → Optical alignment performed by removable actuators + optical camera

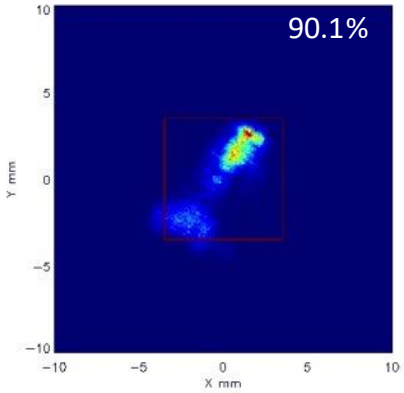
Corona1 – 1 mirror

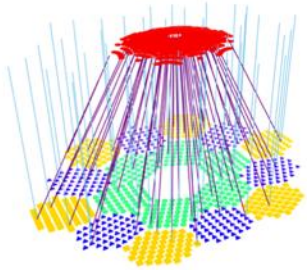


Corona2 – 1 mirror

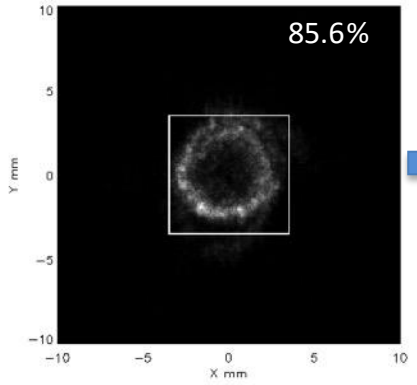


Corona3 – 1 mirror

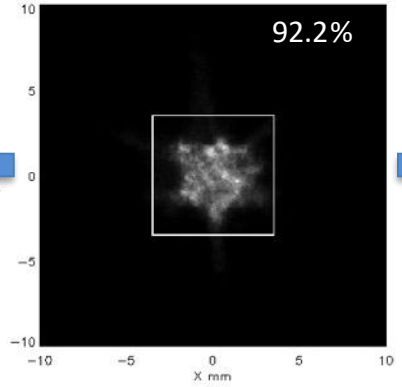




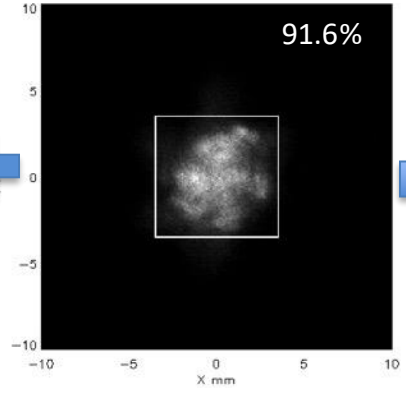
Corona1 – 6 mirror



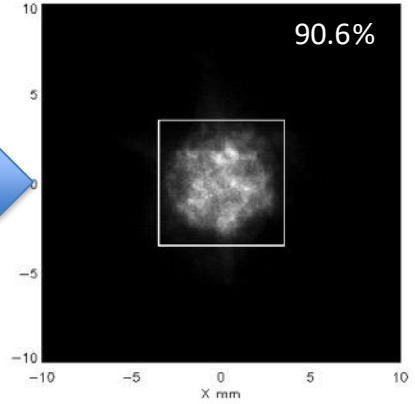
Corona2 – 6 mirrors



Corona3 - mirrors



Total



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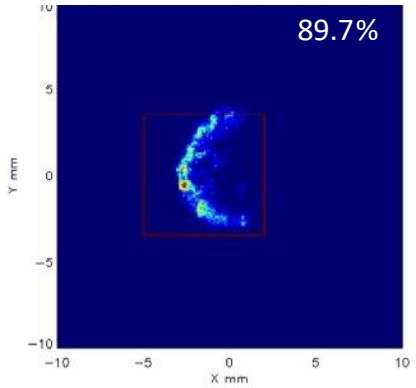
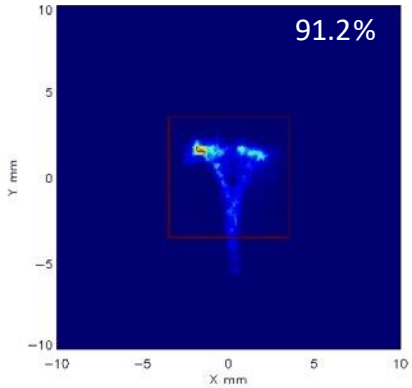
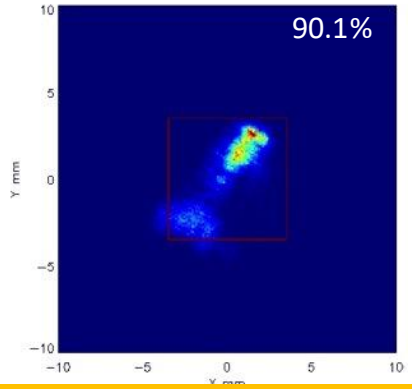
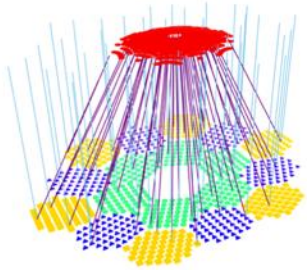


Corona2 – 1 mirror



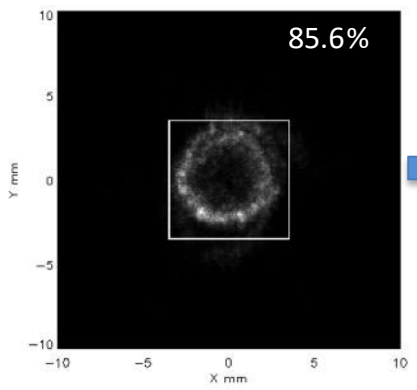
Corona3 – 1 mirror

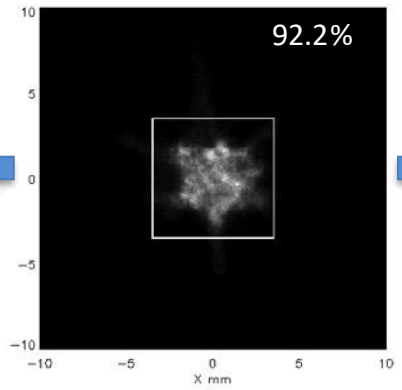


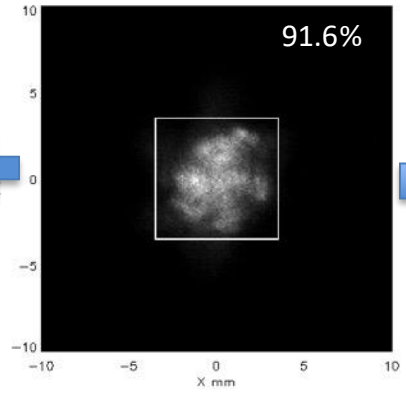


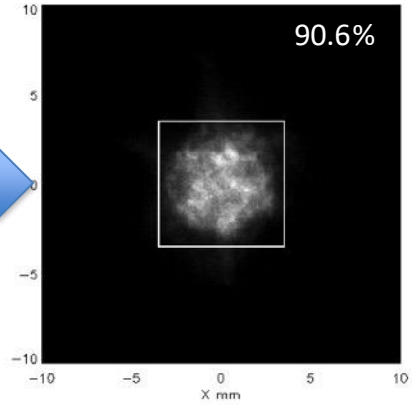
ASTRI - Horn on site
ASTRI Mini Array - remote

Total







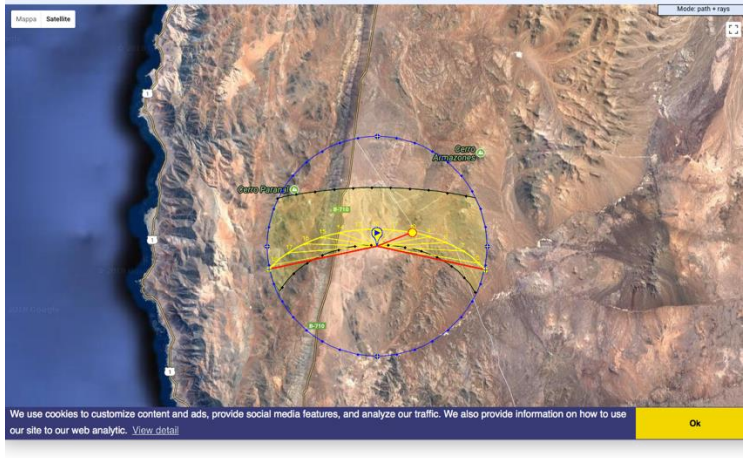


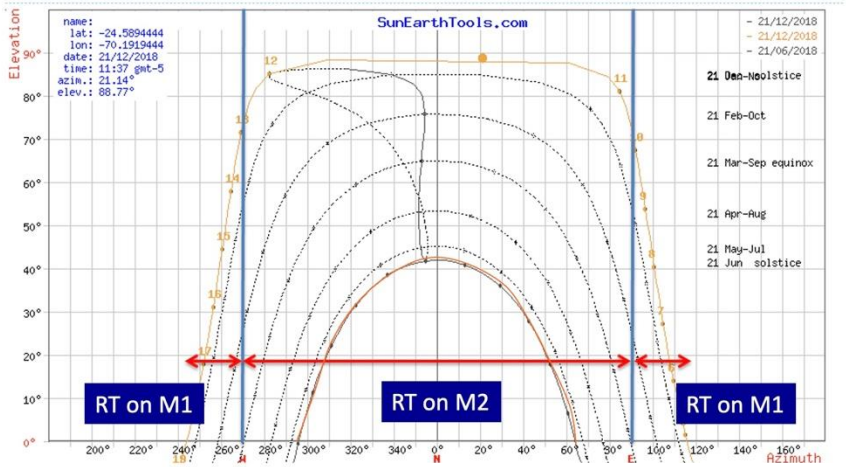
ASTRI heritage in CTA #3: know-how

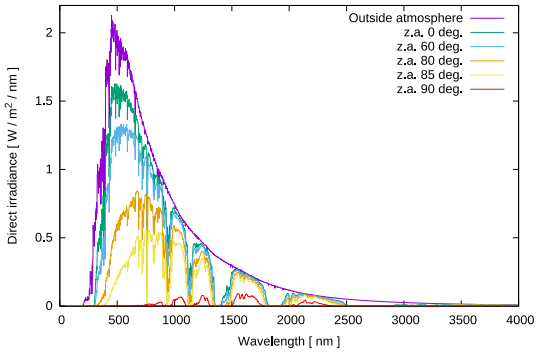
Safety of the parking

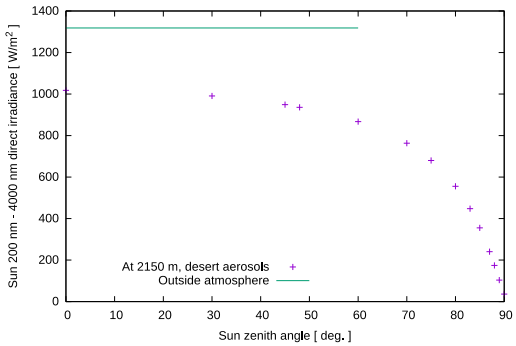
IACTs are light concentrators with no domes → fire accident is a real issue

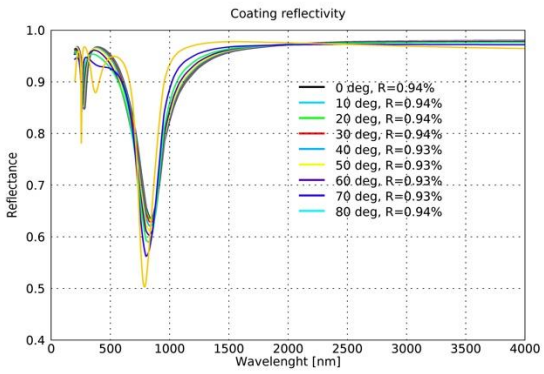
- Sunlight concentration simulation
- Study of the areas above energy density safety limit (> 0.5-0.2 W/cm^2)
- Parking position











Safety of the parking

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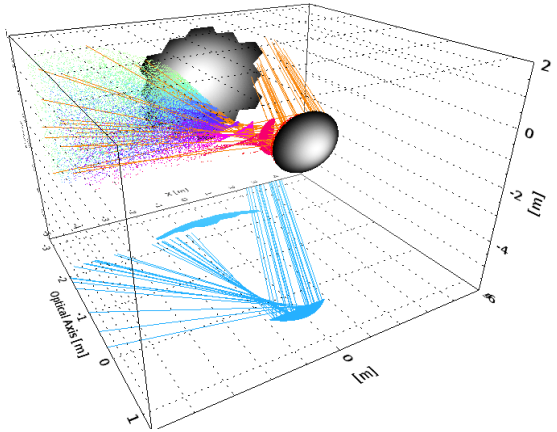
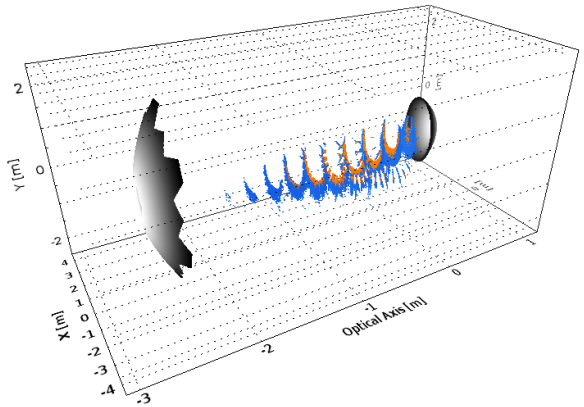
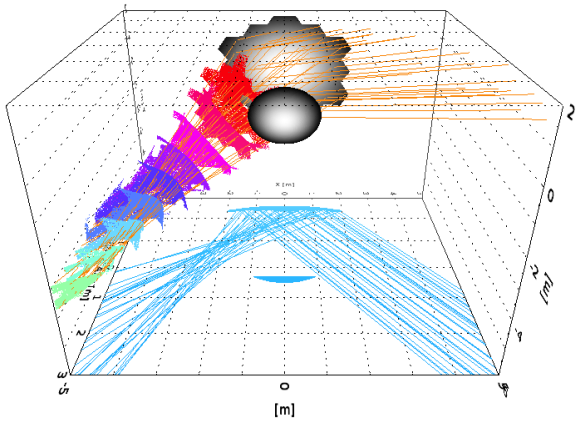
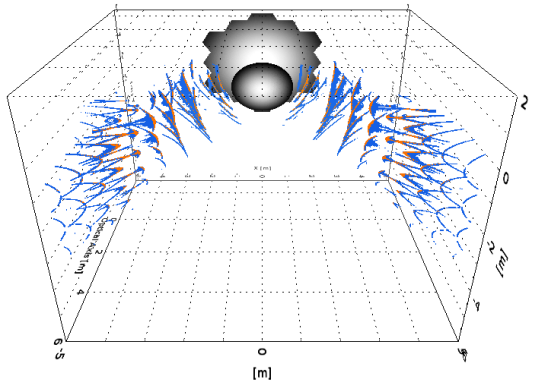
21 June





21 December





Safety of the parking

ASTRI heritage in CTA #3: know-how

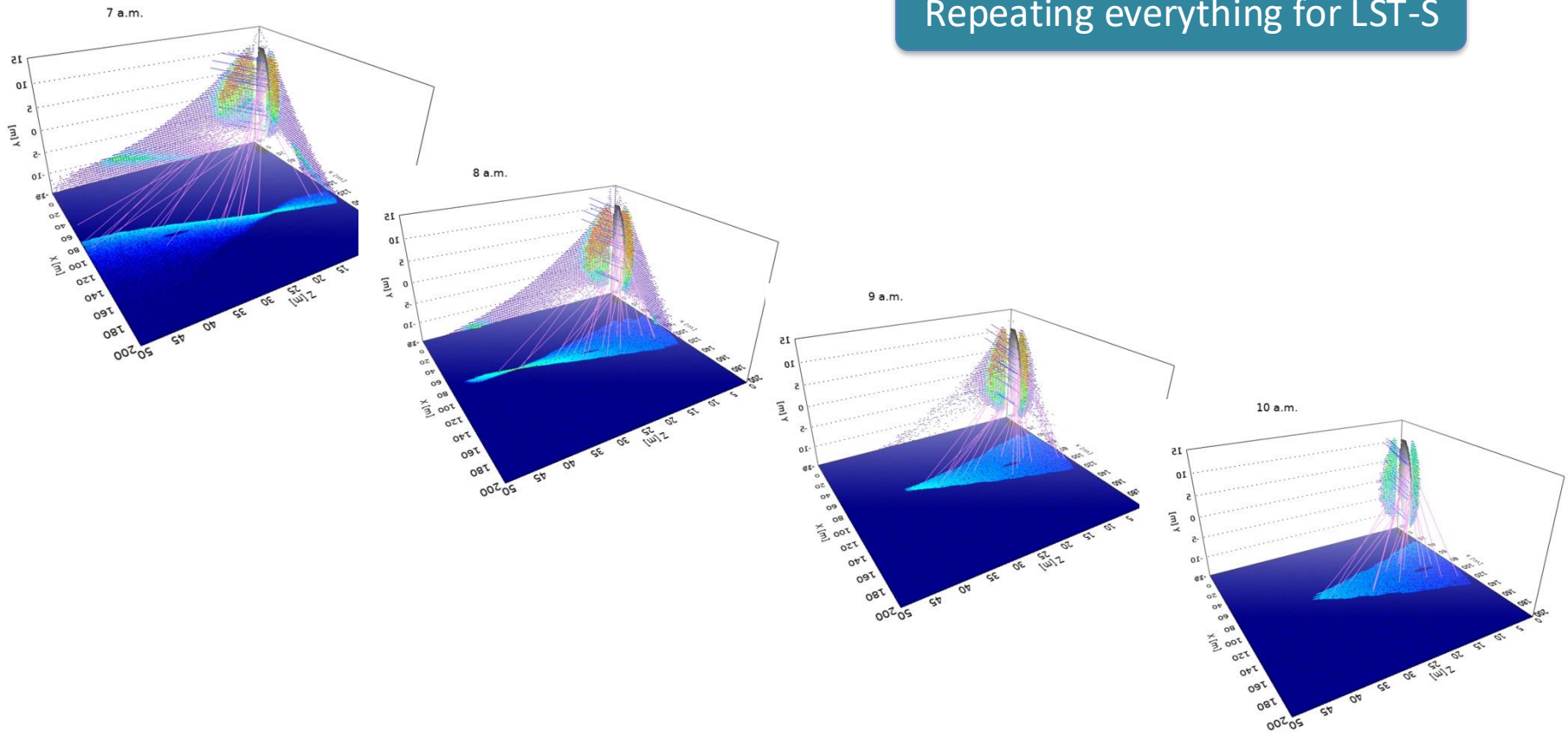
IACTs are light concentrators with no domes → fire accident is a real issue

Sunlight concentration simulation

Study or the areas above energy density safety limit (> 0.5-0.2 W/cm^2)

21 December

Repeating everything for LST-S



Conclusion

- CTA-SST baseline based on ASTRI-HORN+CHEC-S camera
- CTAO ERIC establishment and PRNN boosted the activities
- ASTRI structure upgrades already tested for ASTRI Array
- Strong ASTRI know-how heritage

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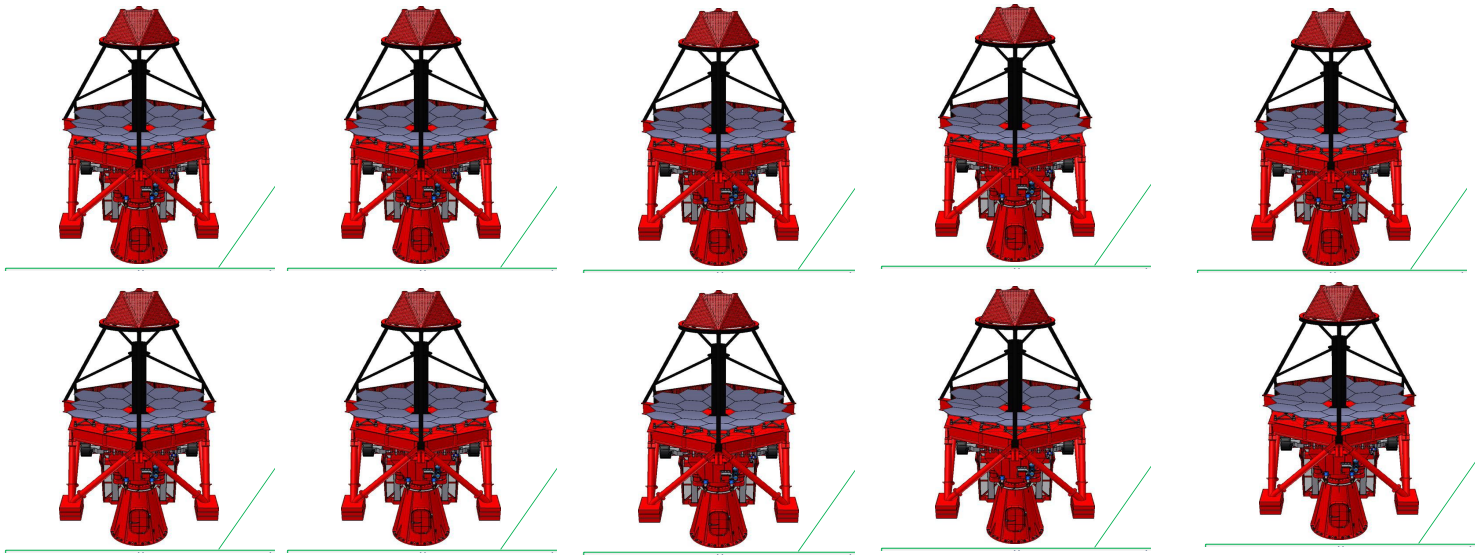

10 Opto-mechanical structure will be completed within 2025

Thanks for your attention!