The Cherenkov Telescope Array
& complementarity of detection techniques

LHAASO Symposium, 2023

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Max Planck Institute for Nuclear Physics
Heidelberg

for the CTA Consortium

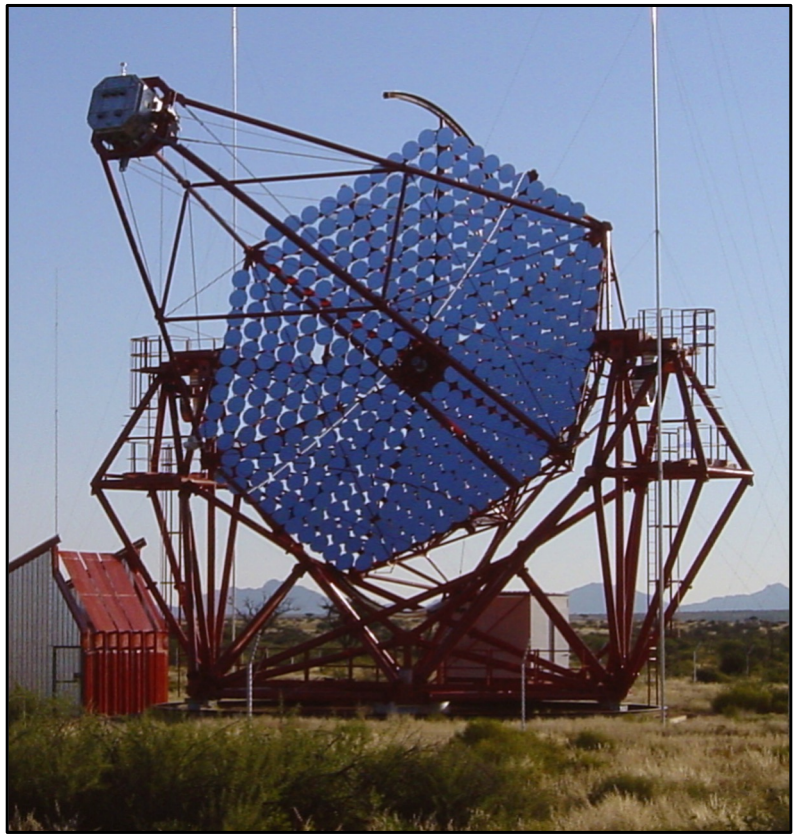
CHERENKOV TELESCOPES

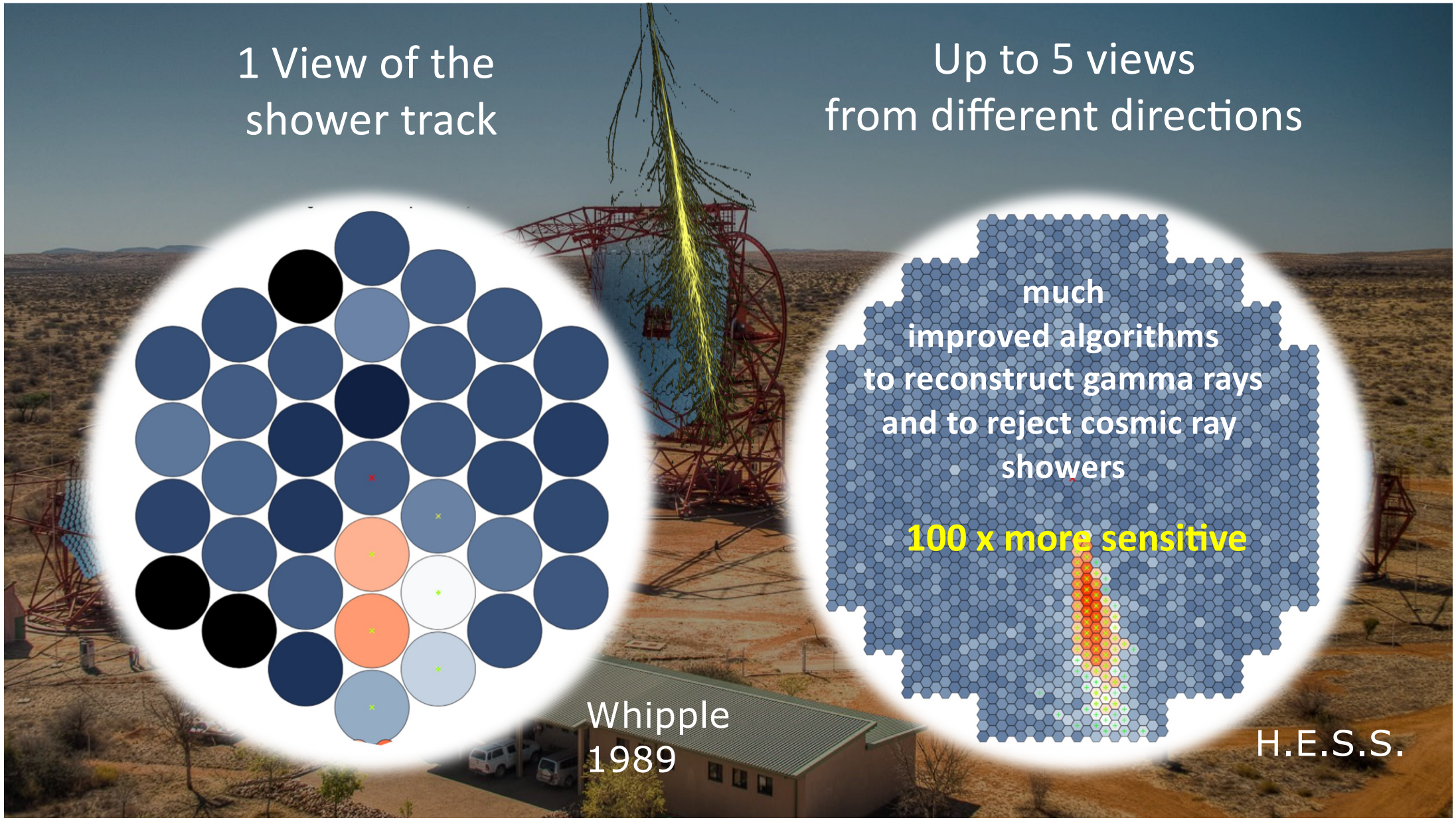
Multiple telescopes provide stereoscopic views of the cascade

A bit like a meteor track, but
very faint (few photons per m^2)
very short-lived (some 10^{-9} seconds)

300 m Ø “light pool”, 10^5 m^2

1989 VS TODAY



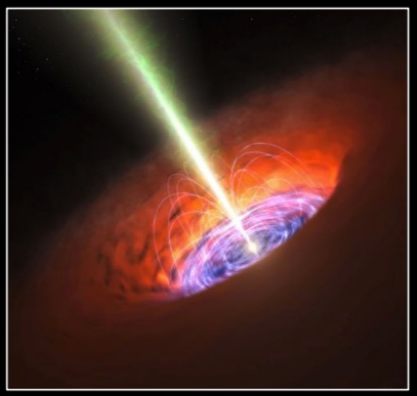

1 View of the
shower track
Up to 5 views
from different directions
much
improved algorithms
to reconstruct gamma rays
and to reject cosmic ray
showers
100 x more sensitive
Whipple
1989
H.E.S.S.

Theme 1: Cosmic Particle Acceleration

- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

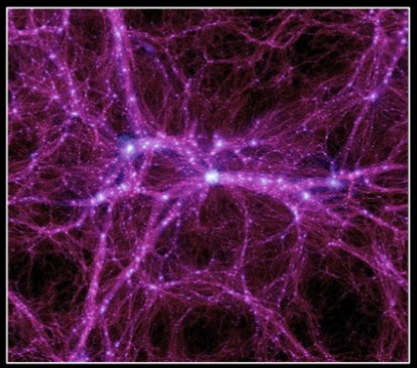
Theme 2: Probing Extreme Environments

- Processes close to neutron stars and black holes?
- Characteristics of relativistic jets, winds and explosions?
- Cosmic voids: their radiation fields and magnetic fields

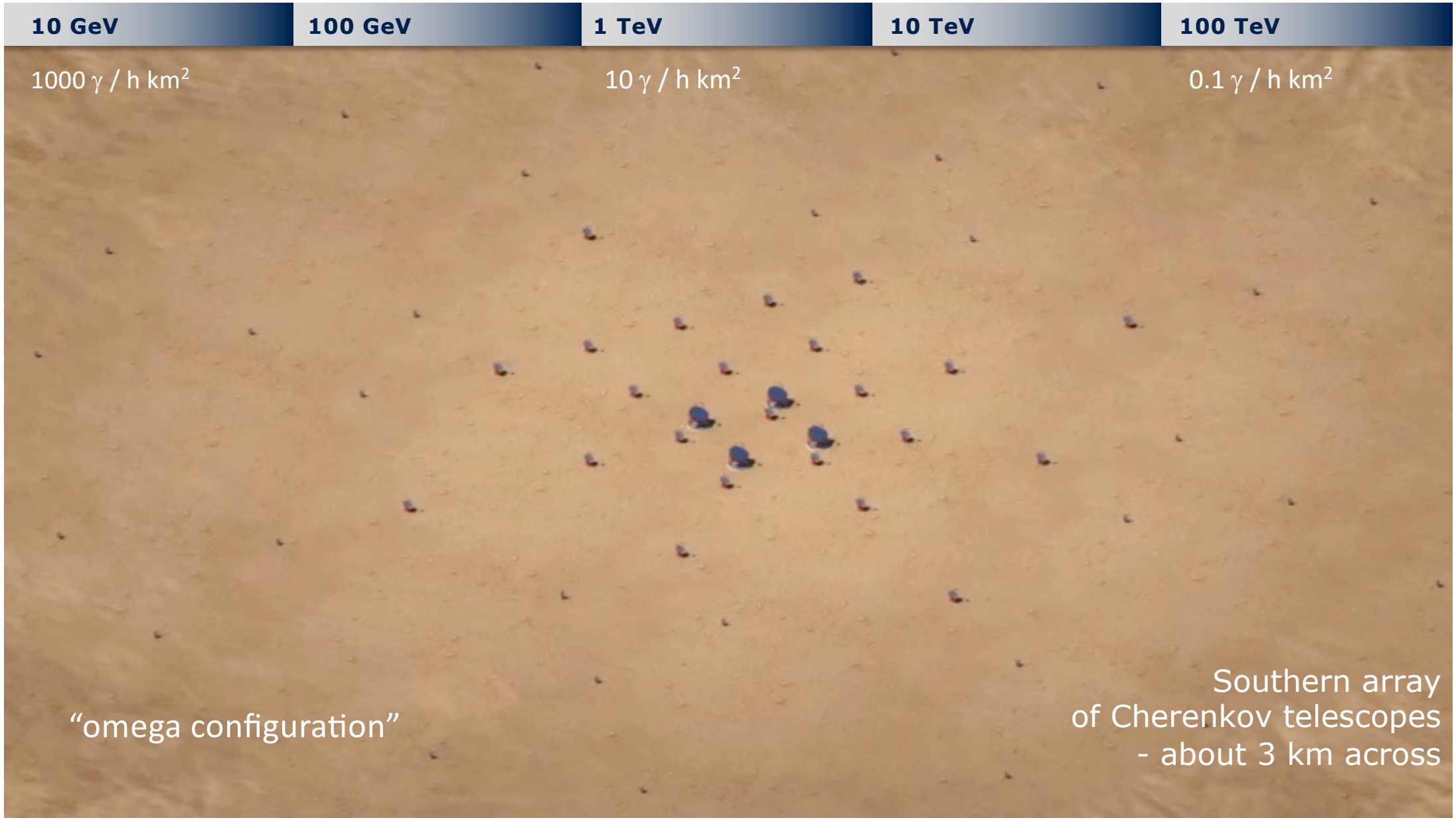


Theme 3: Physics Frontiers

- What is the nature of Dark Matter?
- Is the speed of light a constant?
- Do axion-like particles exist?

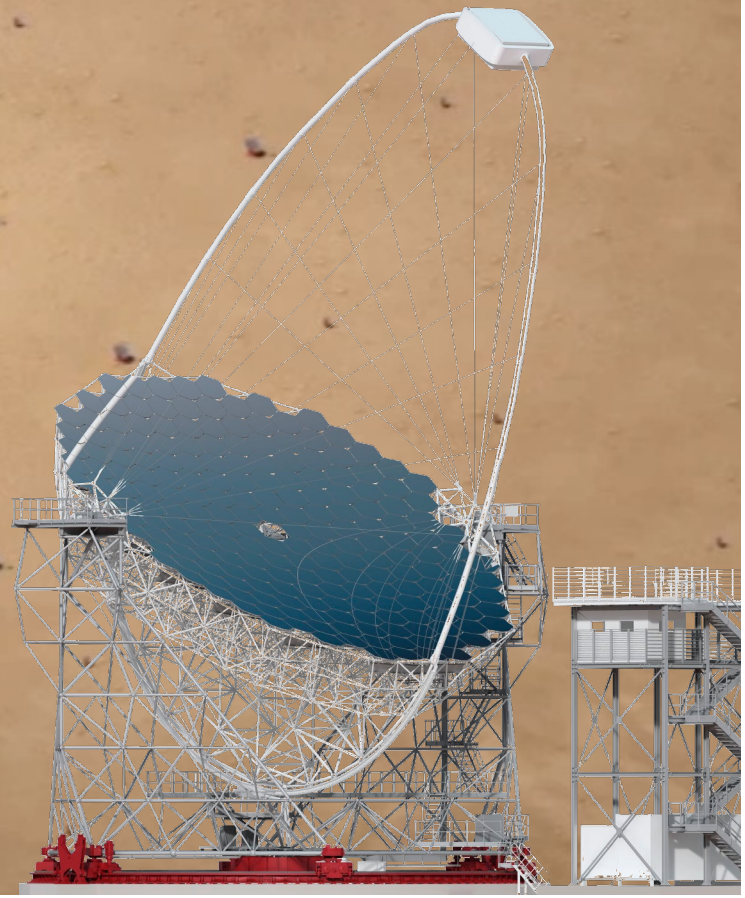


CTA Concept & Array Layout


10 GeV
100 GeV
1 TeV
10 TeV
100 TeV
1000 γ / h km²
10 γ / h km²
0.1 γ / h km²
“omega configuration”
Southern array
of Cherenkov telescopes
- about 3 km across

10 GeV | 100 GeV | 1 TeV | 10 TeV | 100 TeV

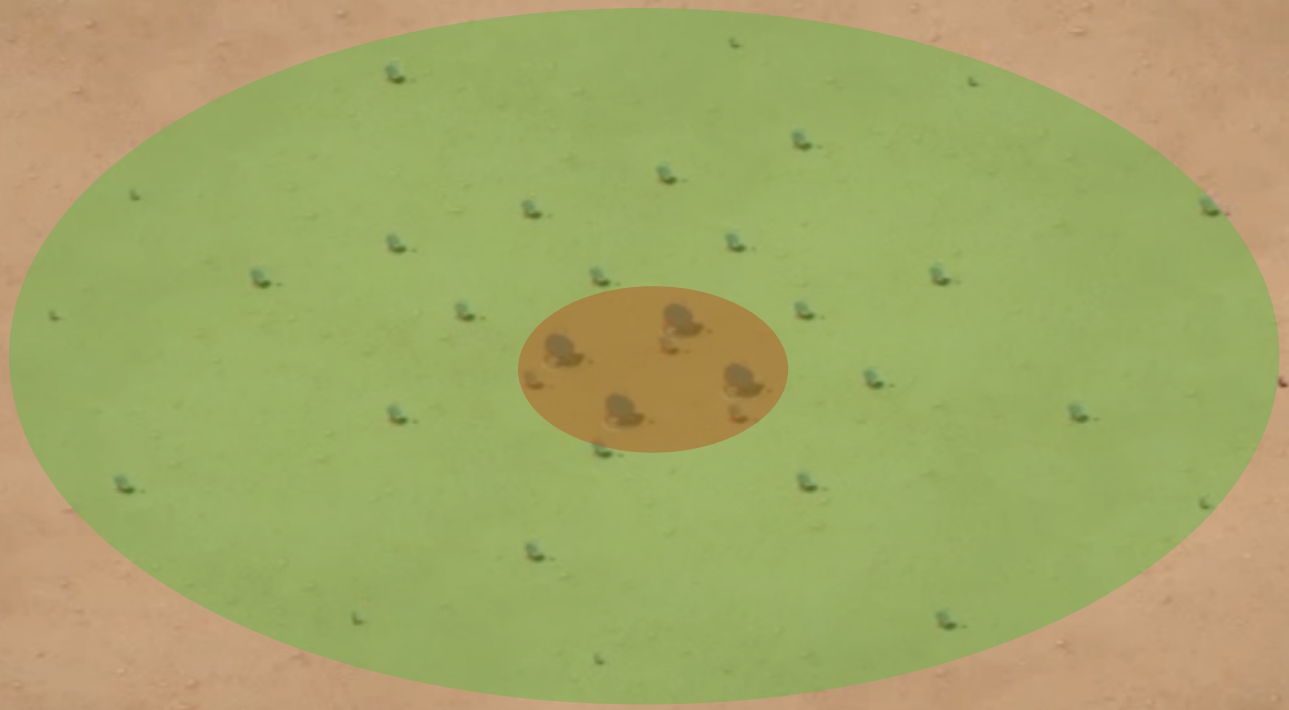
4 x 23 m Ø Large Size Telescopes (LST)

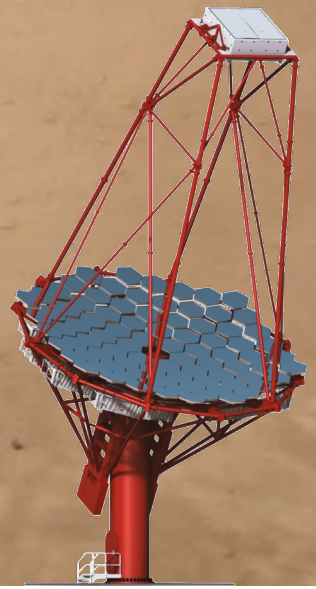


“omega configuration”

10 GeV | 100 GeV | 1 TeV | 10 TeV | 100 TeV

25 x 12 m Ø Medium Size Telescopes (MST) (North: 15)

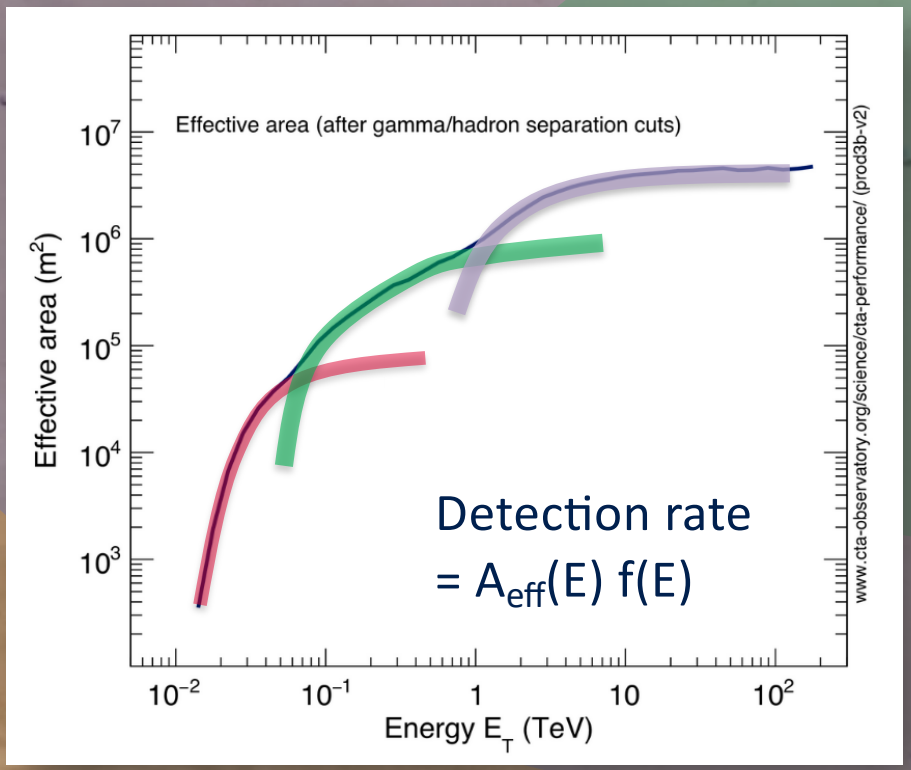




“omega configuration”

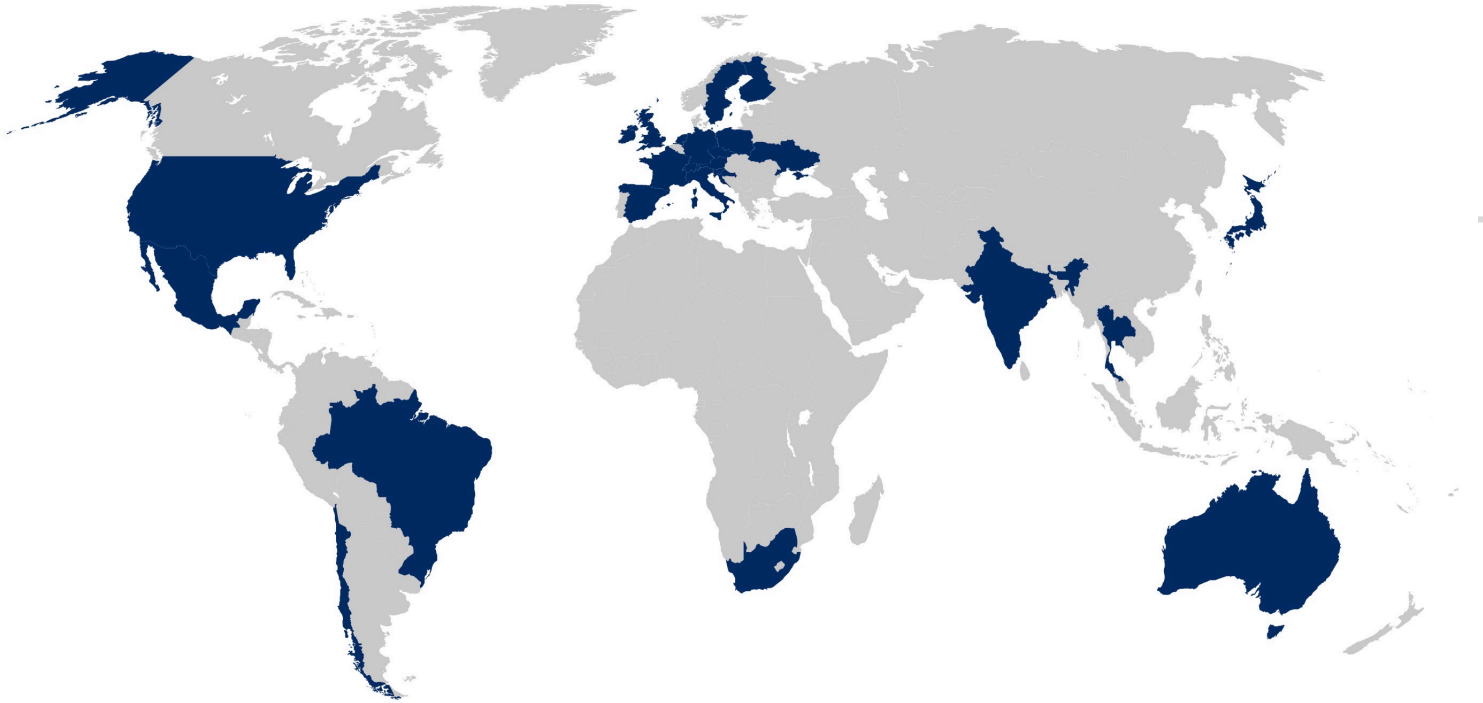
10 GeV | 100 GeV | 1 TeV | 10 TeV | 100 TeV

70 x 4 m ∅ Small Size Telescopes (SST) (South)



Compared to current instruments
up to 400 x increased survey speed

THE CTA CONSORTIUM



25 Countries
over 150 Institutes
about 1500 Members

Effort started in 2006

2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023

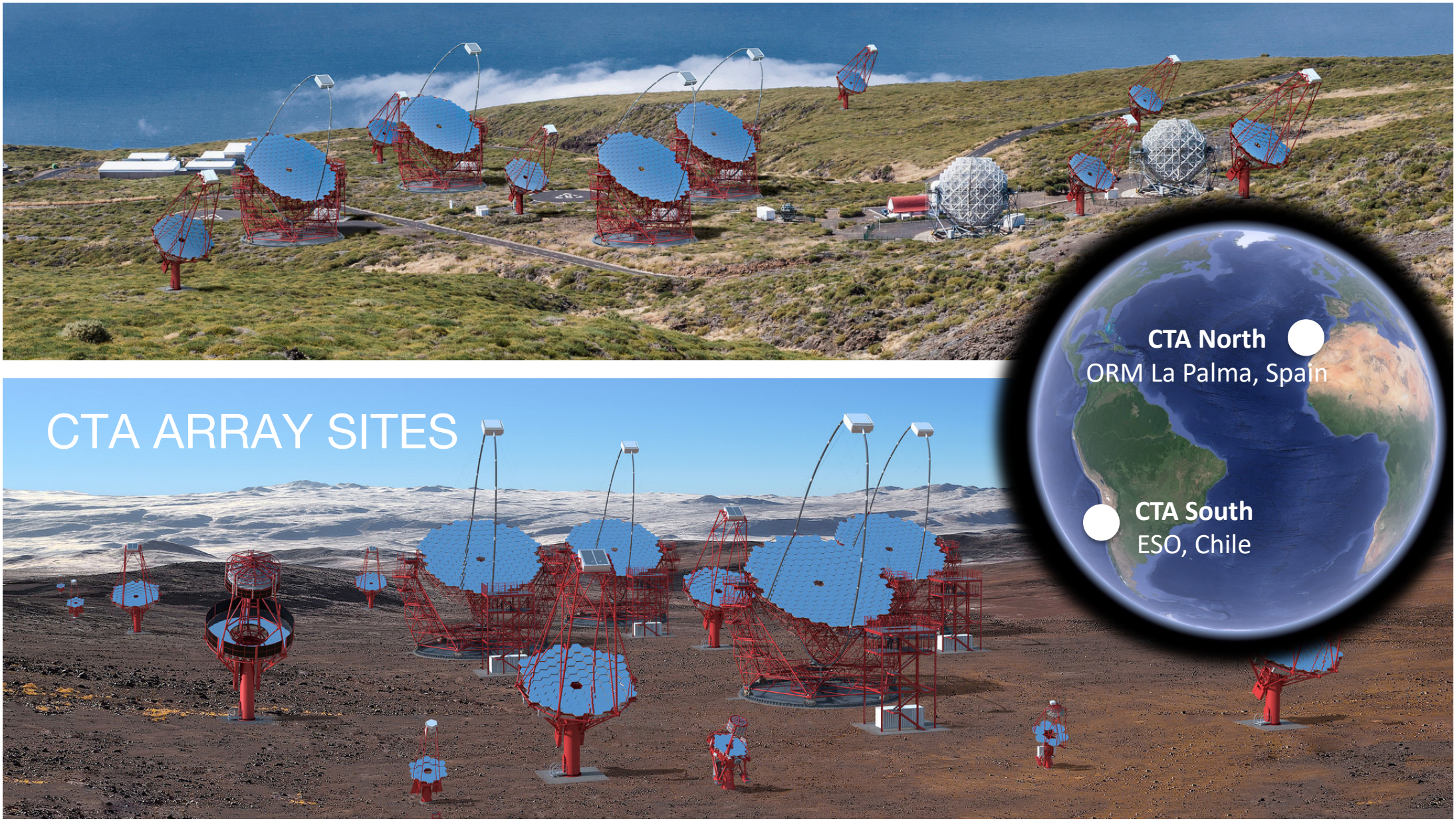
- 2005: CTA project submitted to ESFRI
- 2006: CTA as “emerging proposal” on ESFRI Roadmap
- 2008: CTA Consortium formed
- 2008: CTA on ESFRI Roadmap
- 2010: Project Office established
- 2011: Agency Resource Board founded
- 2012: Declaration of Intent by agencies

- 2014: CTAO gGmbH founded

- 2015: Design Report
- 2015: Site decisions
- 2016: Bologna as future HQ
- 2018: Board of gvt reps to found ERIC

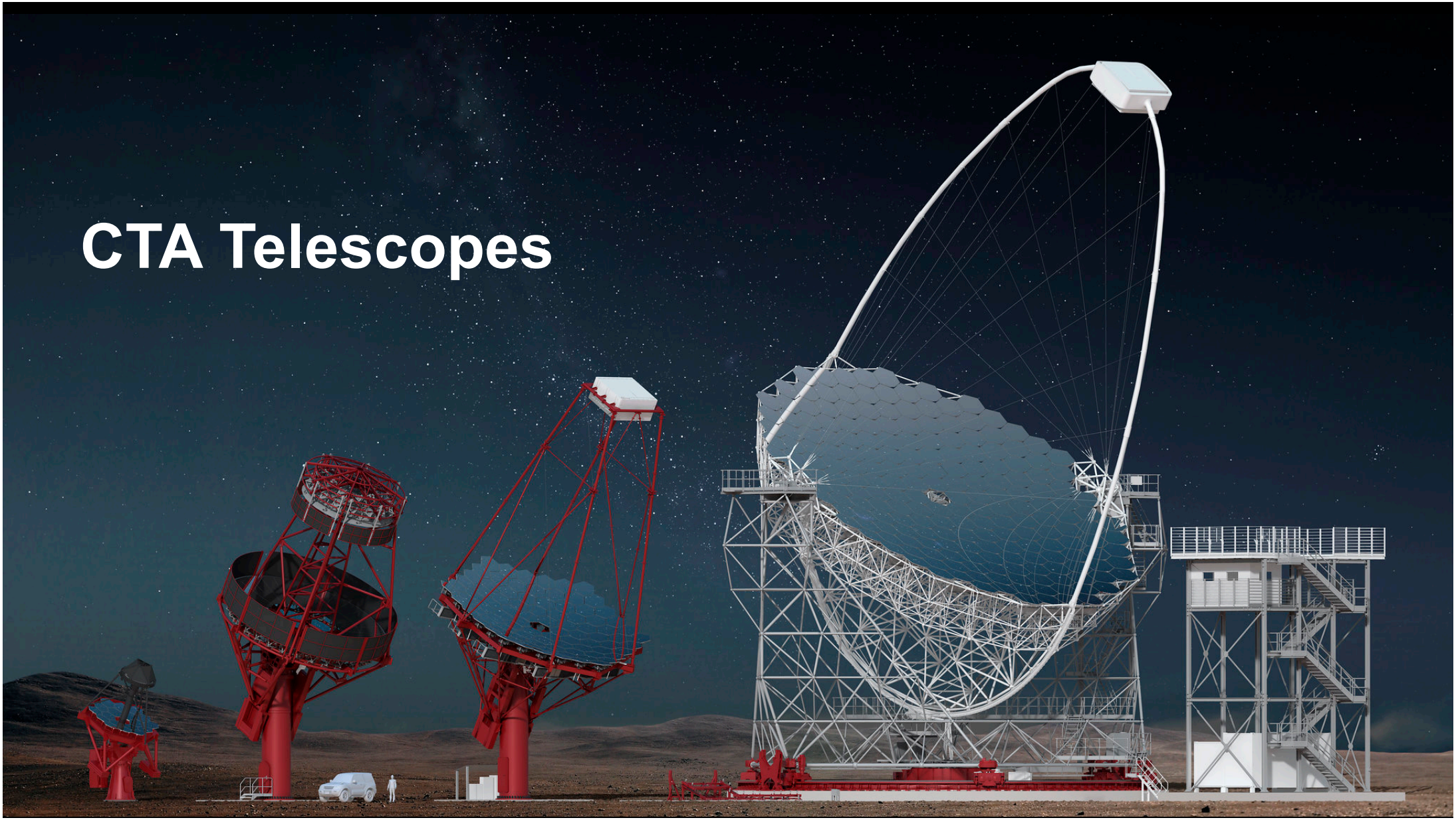
- 2021: Alpha config. funded
- 2023: CTAO ERIC founded (expected)

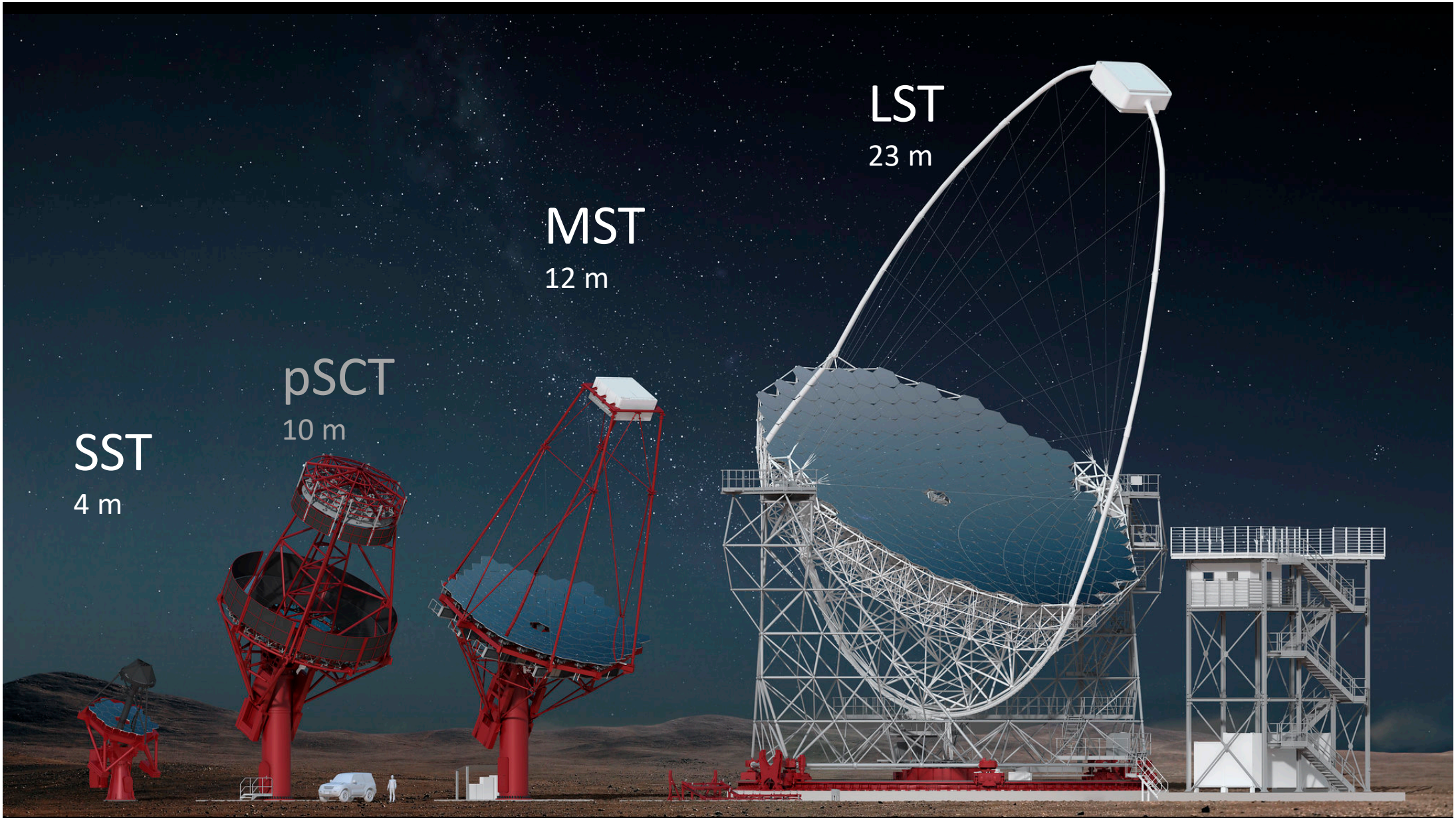
CTA/CTAO TIMELINE


CTA ARRAY SITES
CTA North
ORM La Palma, Spain
CTA South
ESO, Chile

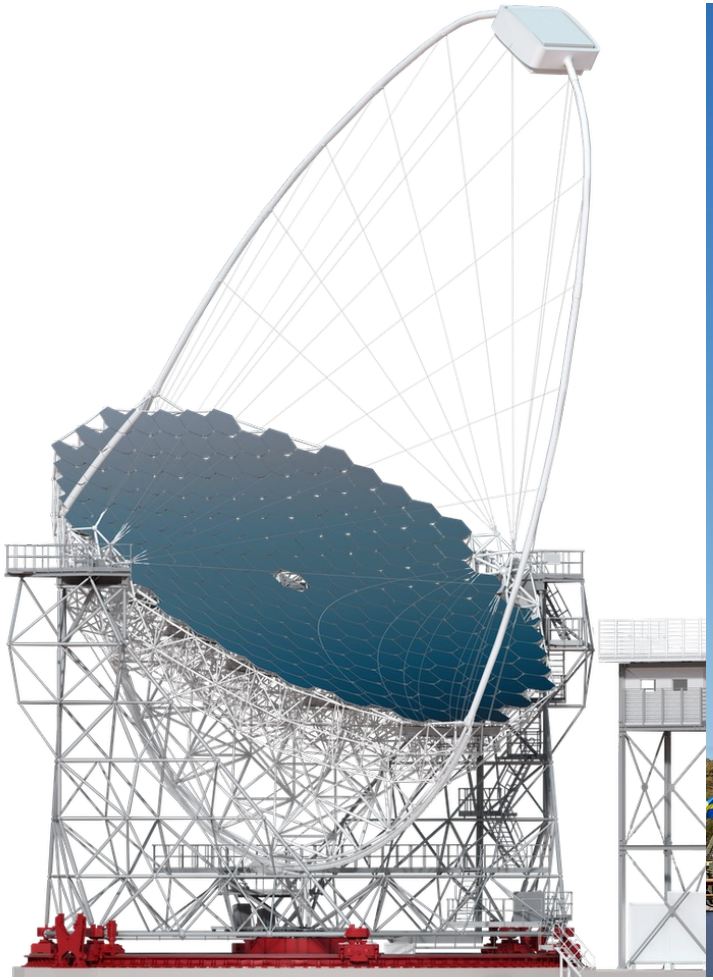

CTA-South Site
ESO Paranal
Vulcano Llullaillaco
6739 m, 190 km east
Cerro Armazones
E-ELT
Cherenkov Telescope Array Site
Cerro Paranal
Very Large Telescope

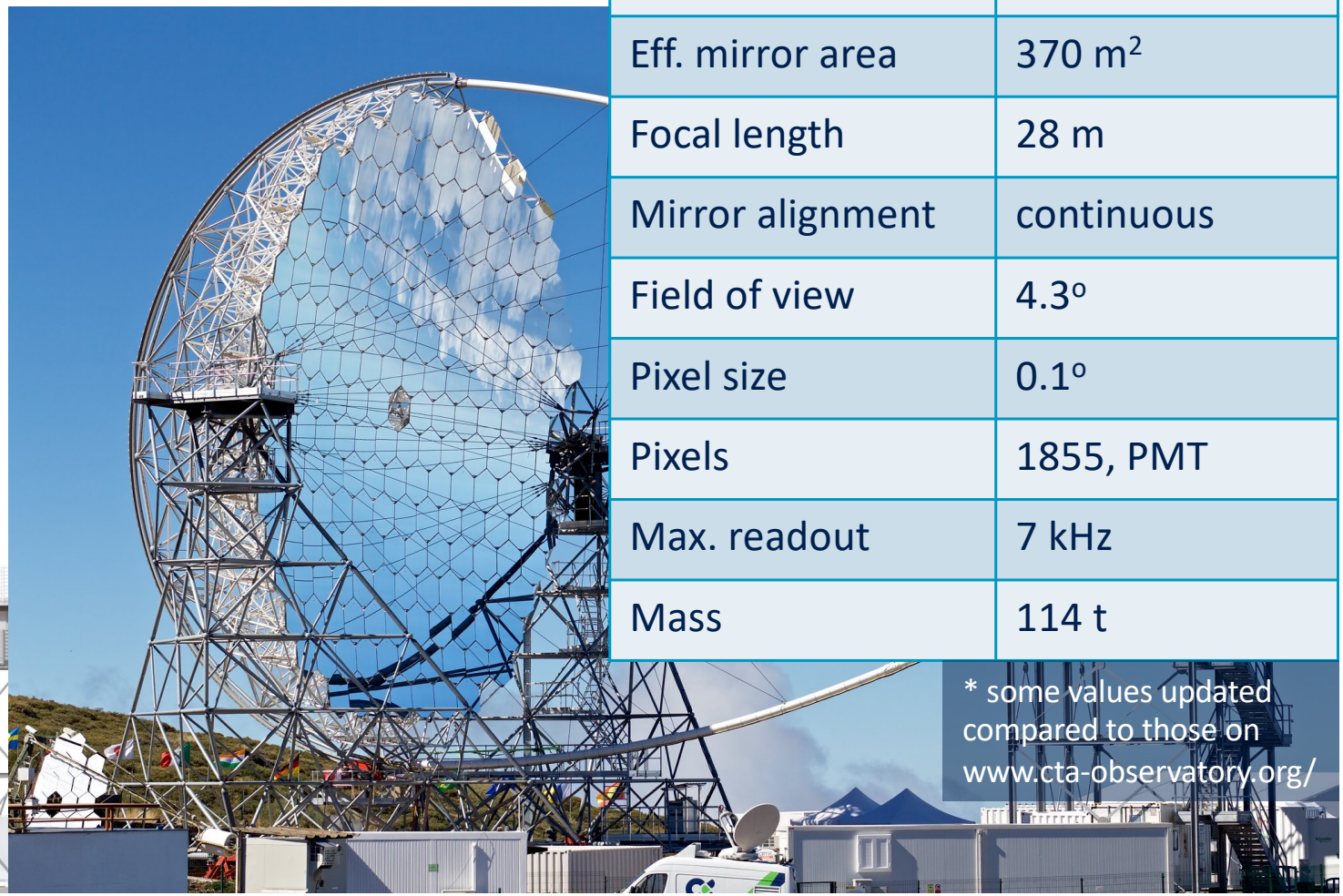
CTA Telescopes




LST
23 m
MST
12 m
pSCT
10 m
SST
4 m

LARGED-SIZED TELESCOPE





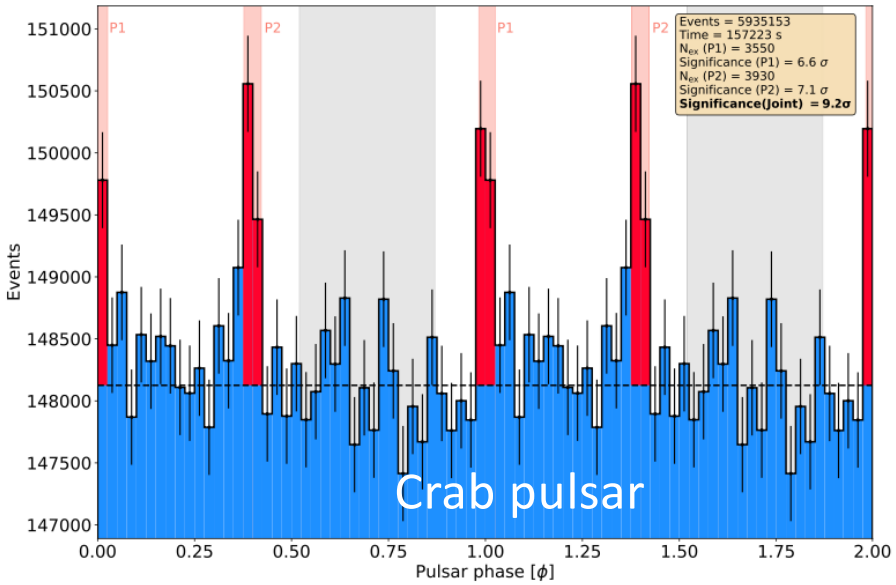
Core energy range	20 – 150 GeV
Optics	Parabolic
Dish diameter	23 m
Eff. mirror area	370 m^2
Focal length	28 m
Mirror alignment	continuous
Field of view	4.3°
Pixel size	0.1°
Pixels	1855, PMT
Max. readout	7 kHz
Mass	114 t

* some values updated compared to those on www.cta-observatory.org/

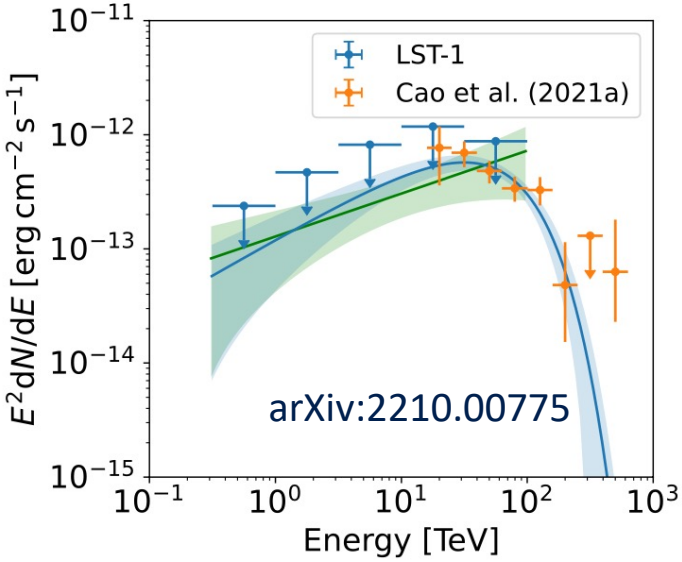
LST-1

PoS(ICRC2021)806

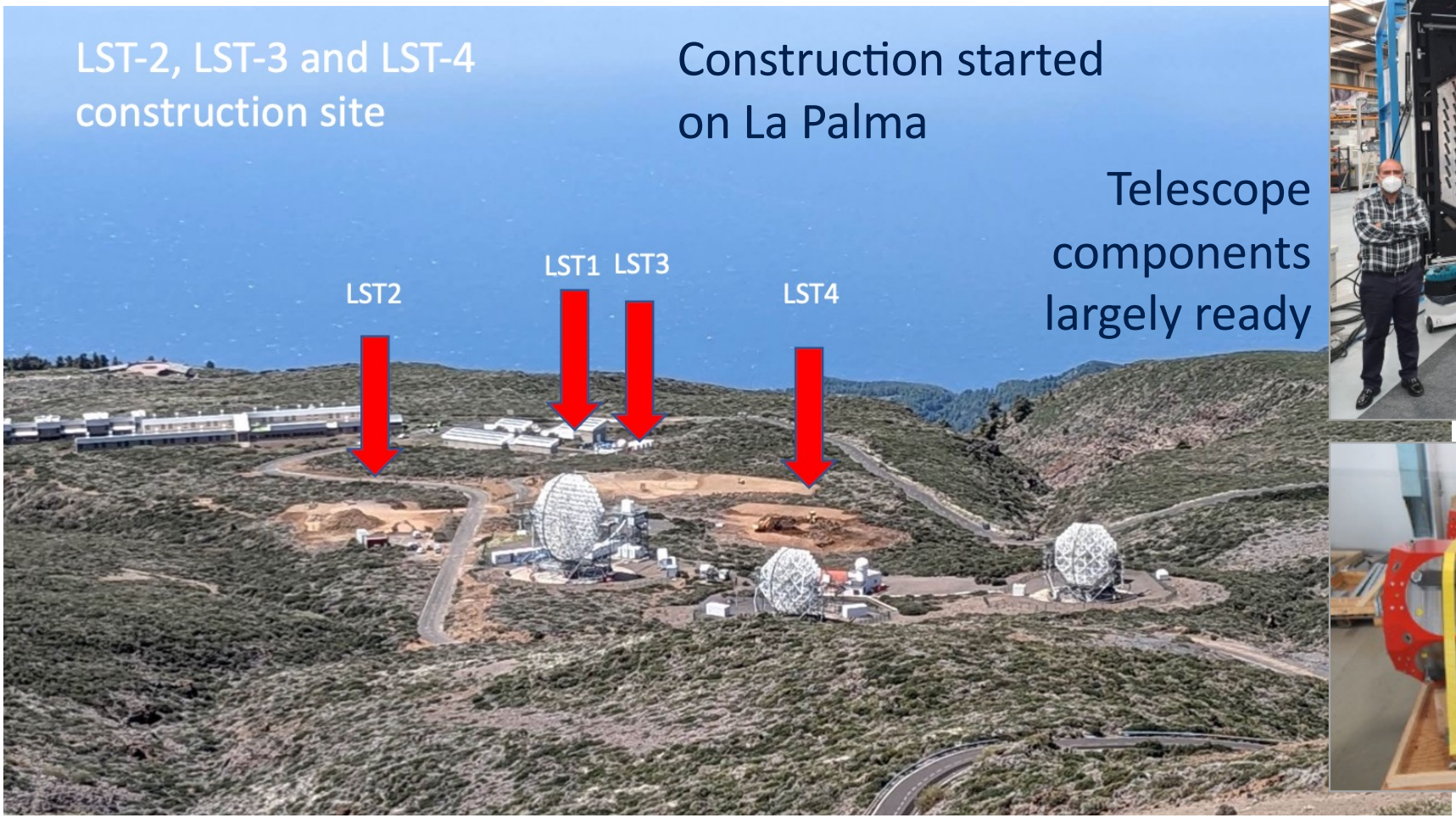
LST-1 inauguration in Oct. 2018
Commissioning & science verification
Well over 1000 h of data accumulated

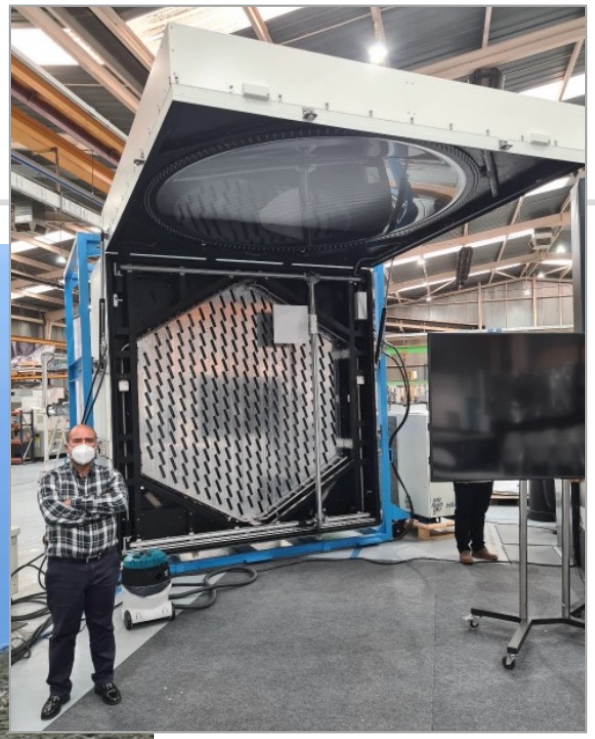


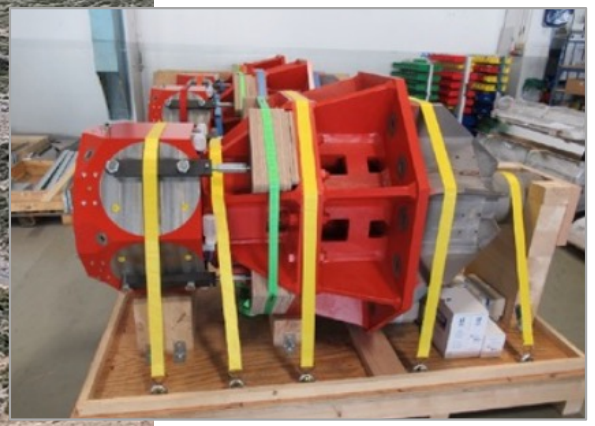
Detection of Crab Nebula and Pulsar; of Rho Ophiuchi; Sag A*, …
AGN Detections: Mrk 501, Mrk 421, 1ES 1959+650, 1ES 0647+250 and PG 1553+113, …
Paper on LHAASO J2108+5157



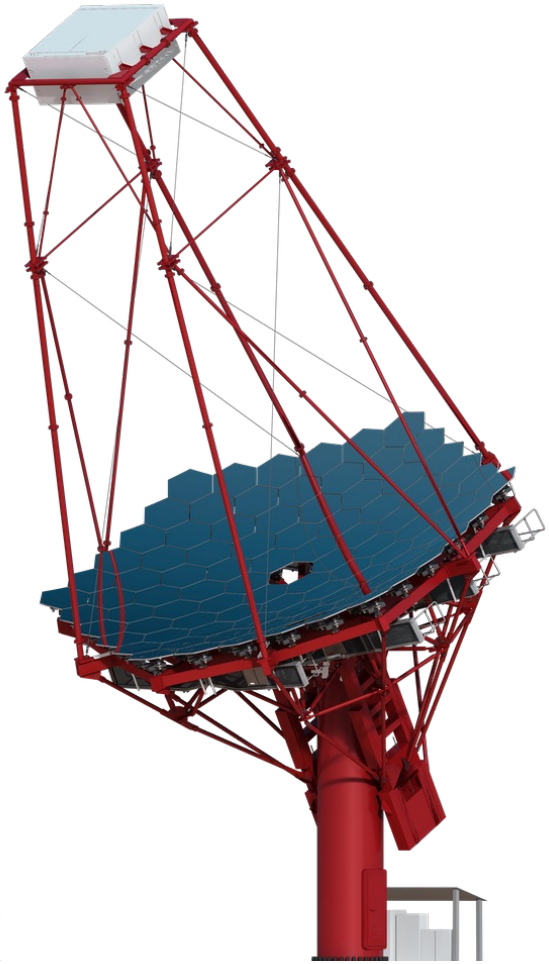
LST-2, LST-3, LST-4







MEDIUM-SIZED TELESCOPE

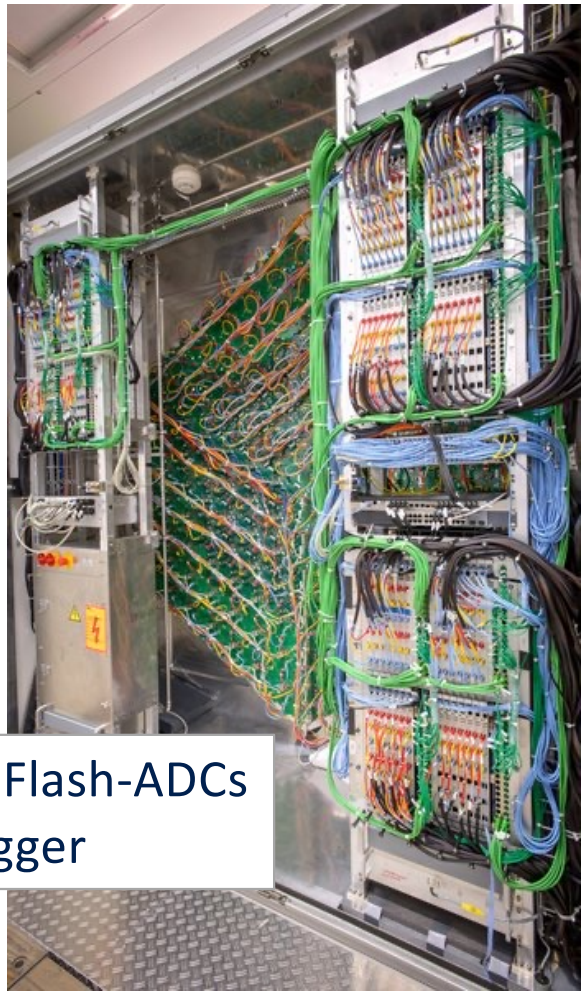


Core energy range	150 GeV – 5 TeV
Optics	Mod. Dav. Cott.
Dish diameter	11.5 m
Eff. mirror area	88 m^2
Focal length	16 m
Mirror alignment	continuous
Field of view	7.7°/7.9°
Pixel size	0.18°
Pixels	1758/1855, PMT
Max. readout	7 kHz
Mass	82 t

* some values updated compared to those on www.cta-observatory.org/

FLASHCAM FOR MST SOUTH

FlashCam
on
HESS CT5

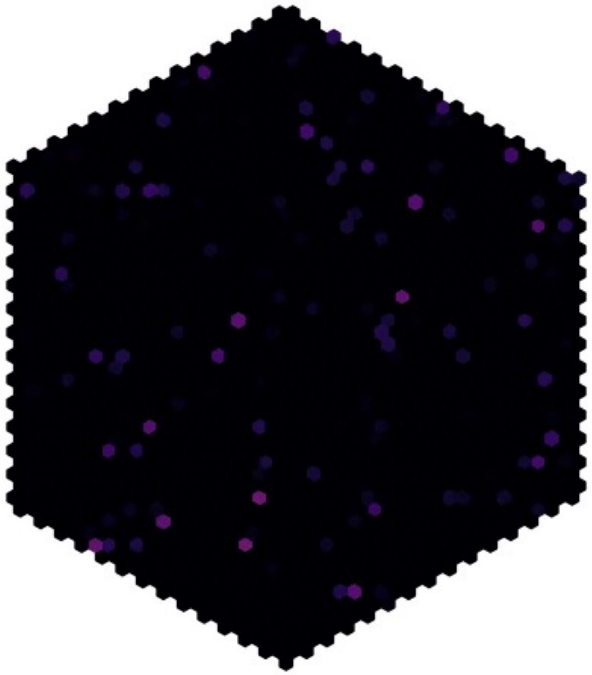


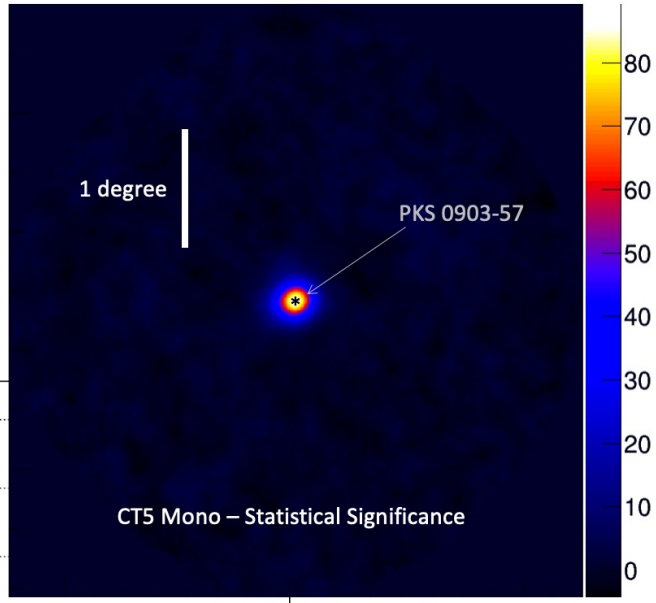
commercial 250 MHz Flash-ADCs
fully digital trigger

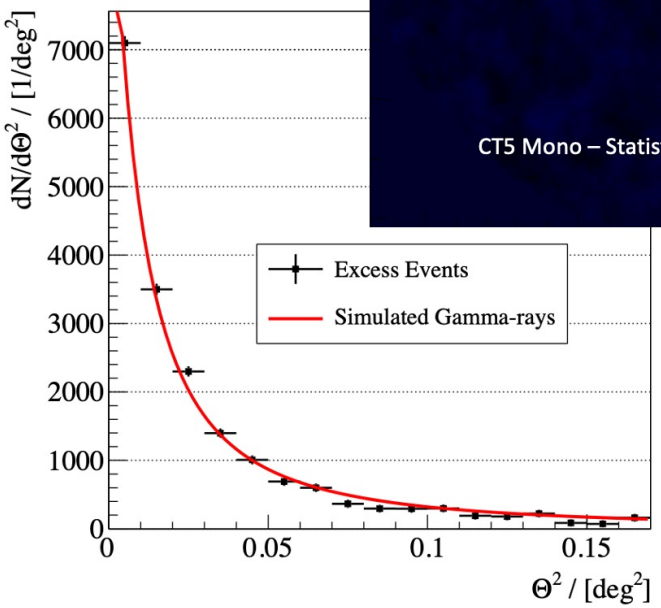
FLASHCAM SCIENCE VALIDATION

In routine science operation since October 2019
Uptime >98%
Very well understood

G. Pühlhofer et al.
arXiv:2108.02596

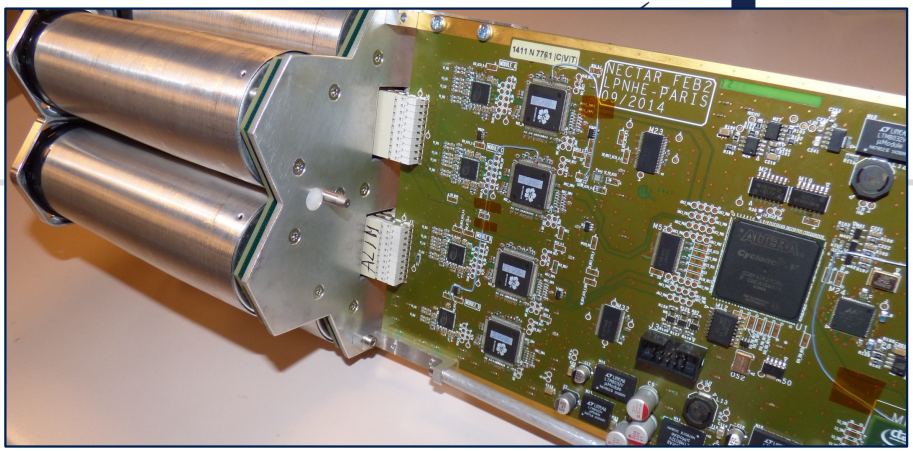


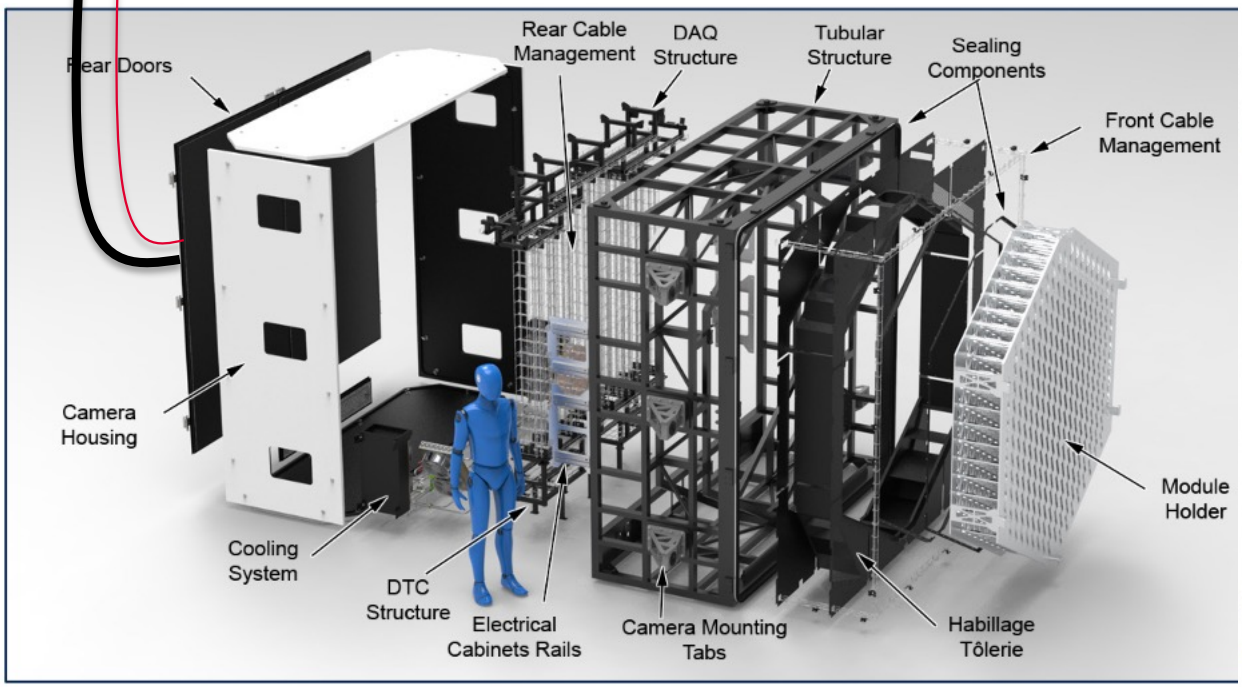


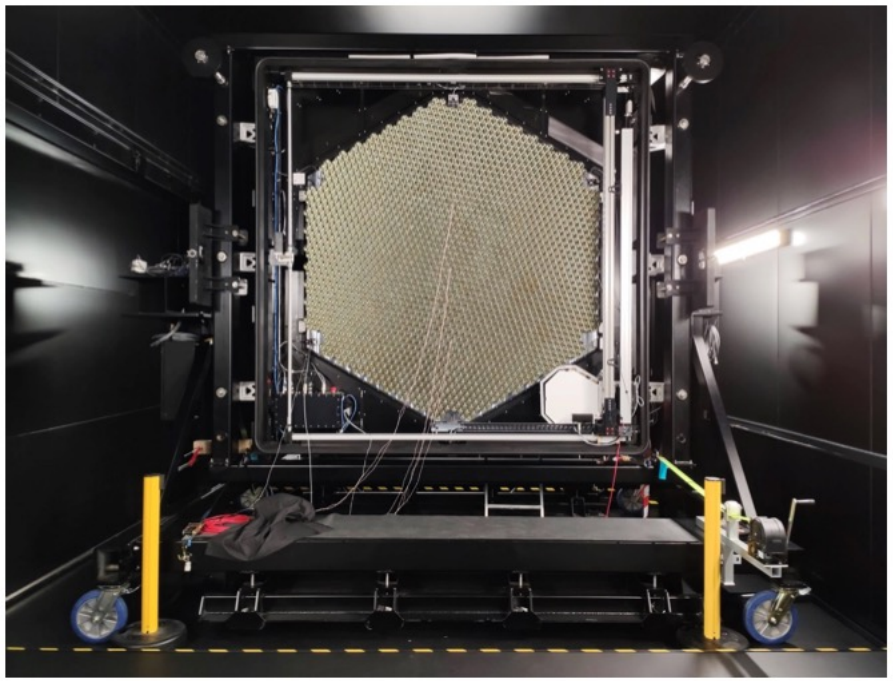


NectarCAM FOR MST NORTH

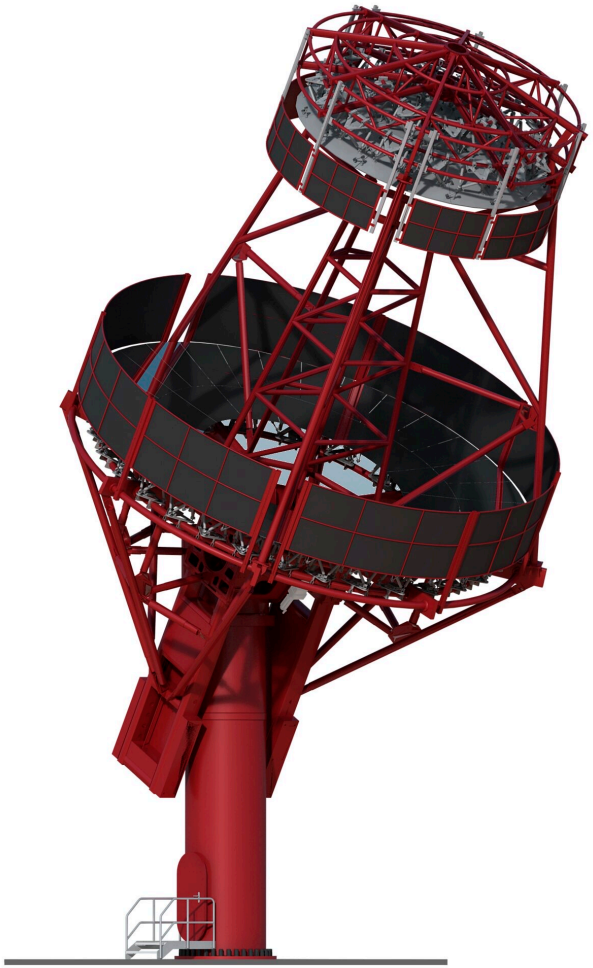
NECTAr GHz analog memory ring sampler ASIC







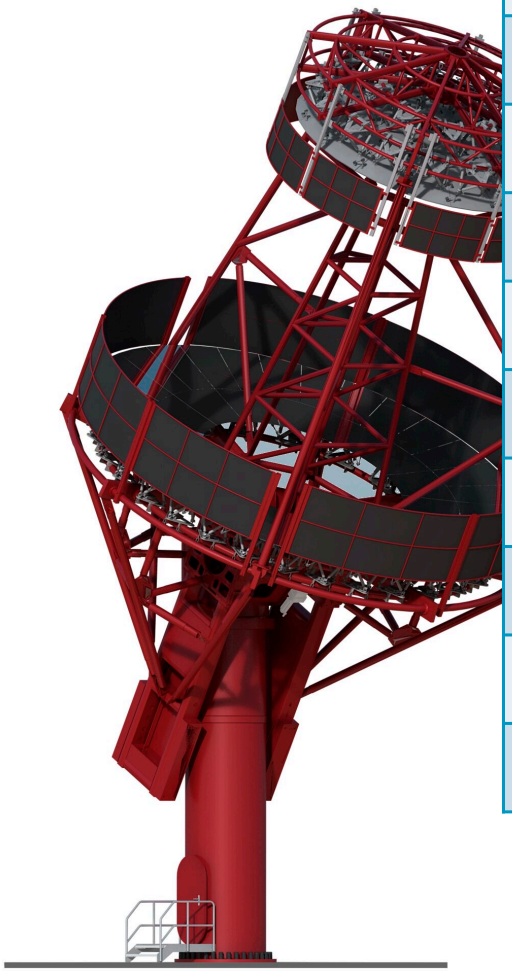
SCT TELESCOPE PROTOTYPE



Dual-mirror design
with SiPMT camera

Proposed for future
expansion of CTA

SCT TELESCOPE PROTOTYPE

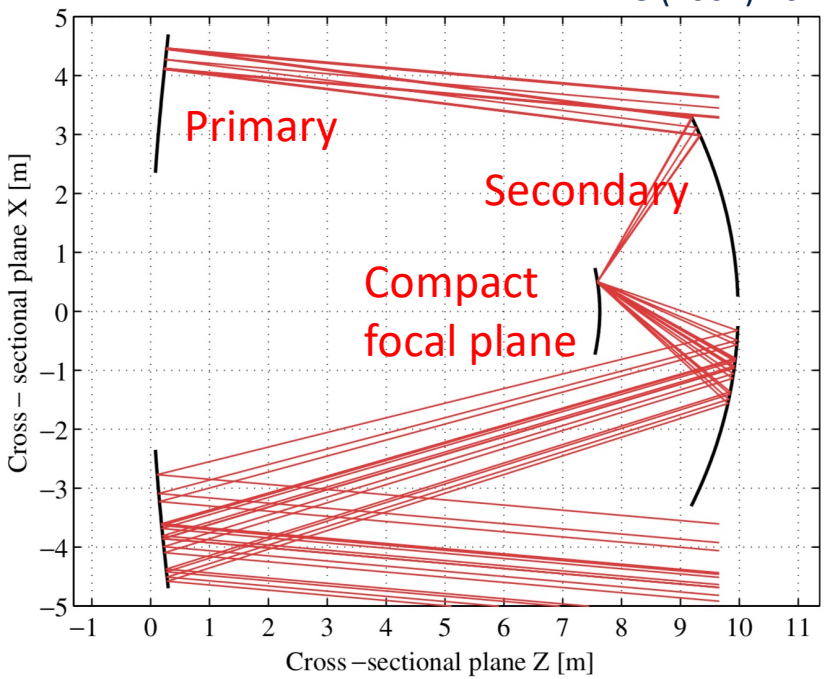


Core energy range	150 GeV – 5 TeV
Optics	Dual-mirror SC
Primary	9.7 m
Secondary	5.4 m
Eff. mirror area	41 m^2
Focal length	5.6 m
Mirror alignment	continuous
Field of view	7.6°
Pixel size	0.07°
Pixels	11328, SiPM
Max. readout	3.5 kHz
Mass	80 t

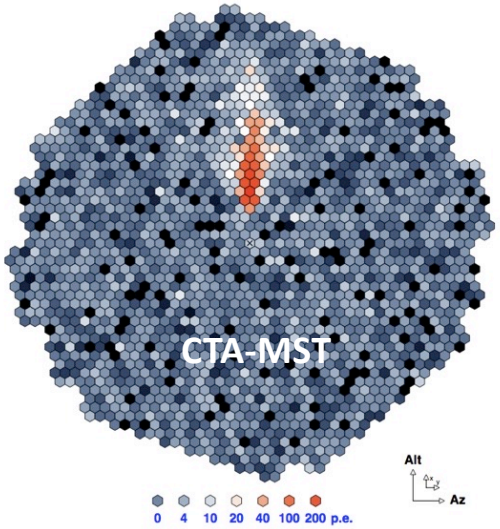
Proposed for future expansion of CTA

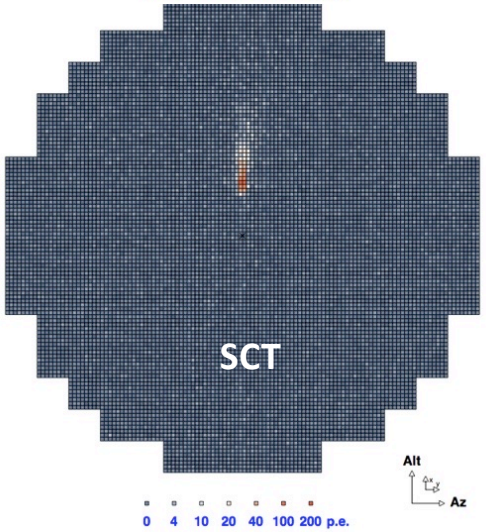
SCT TELESCOPE PROTOTYPE

V. Vassiliev et al.
Astroparticle Physics
28 (2007) 10



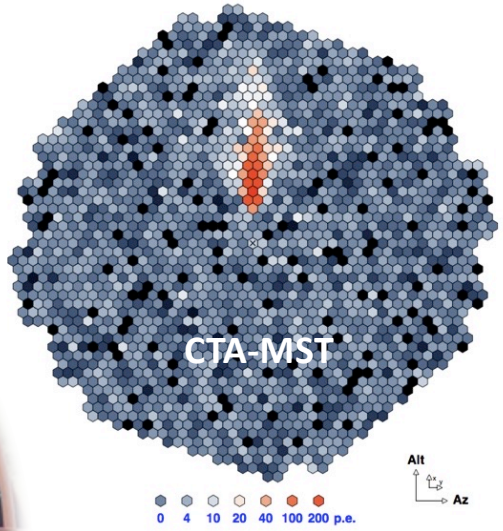
SCT TELESCOPE PROTOTYPE

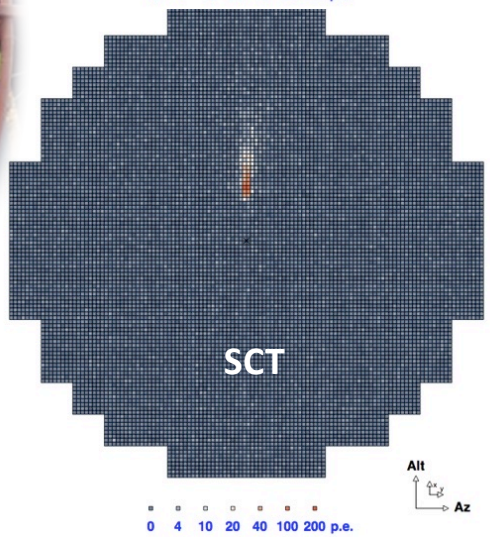




SCT TELESCOPE PROTOTYPE

Back side
of secondary





Complex scheme for mirror alignment validated, PSF meets expectations

Deivid Ribeiro
arXiv:2110.07463v

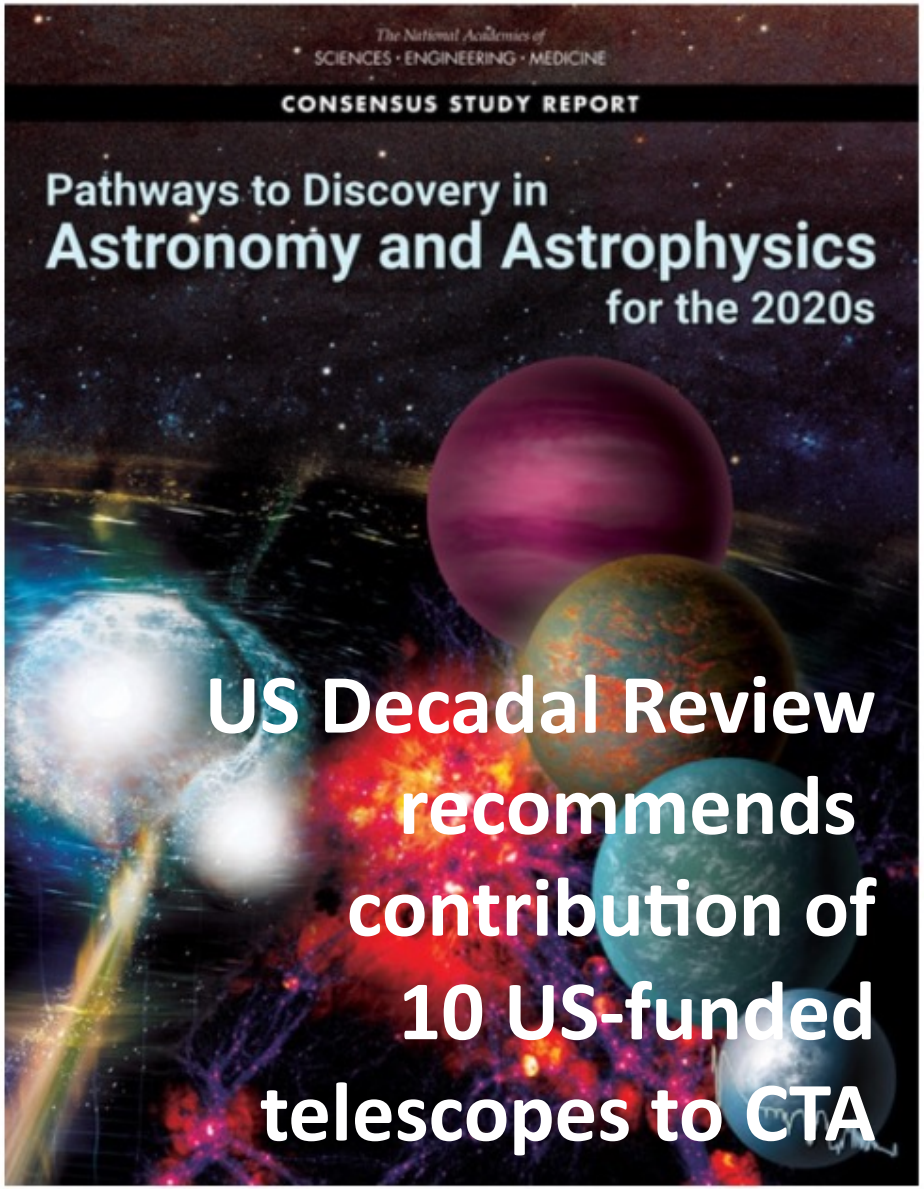
Crab detection with partially equipped camera

C.B. Adams et al.
arXiv:2109.06225

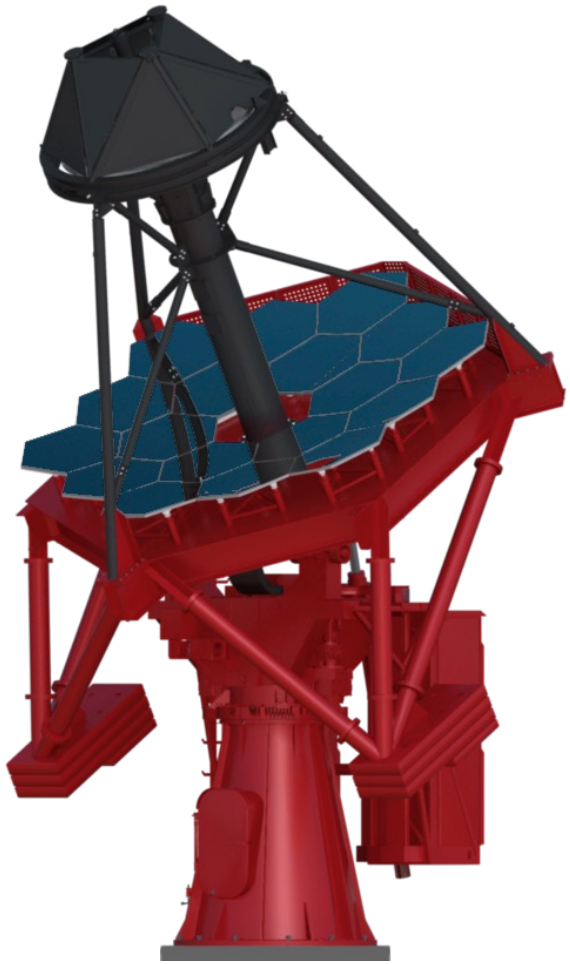
Camera upgrade in progress, to cover full field of view

B.C. Adams et al.
arXiv:2203.08169

SCT TELESCOPE



SMALL-SIZED TELESCOPE

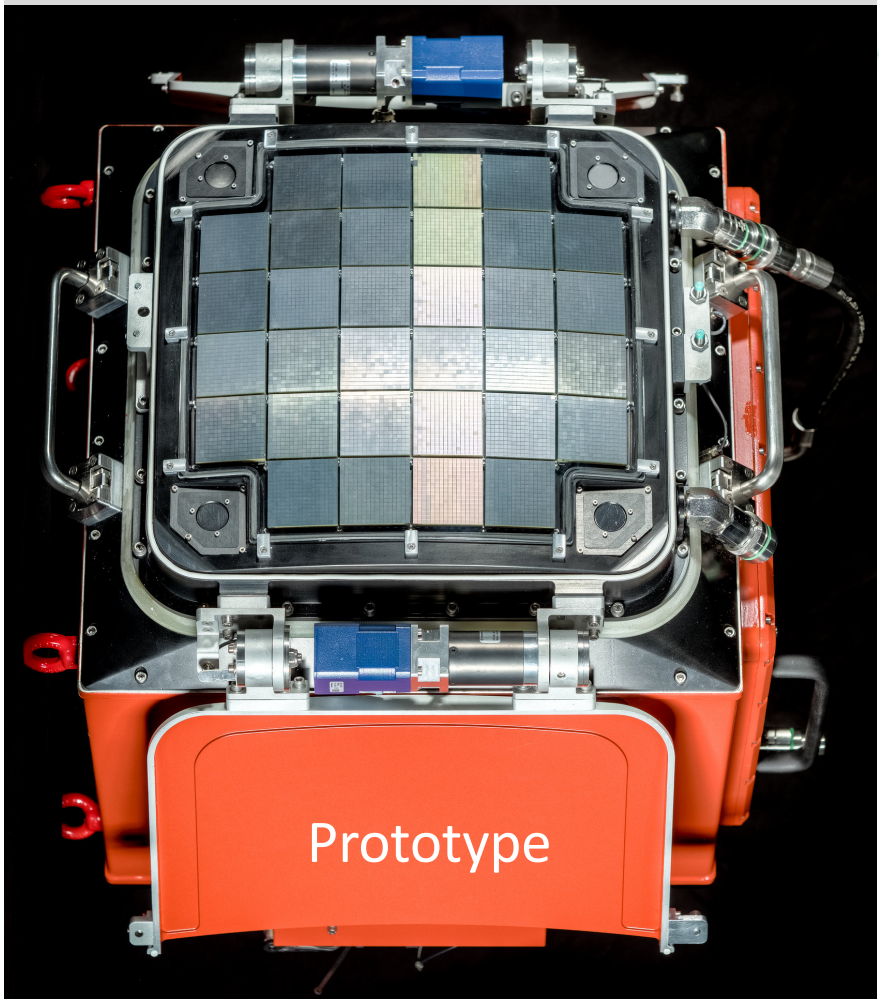


ASTRI telescope on Teneriffe

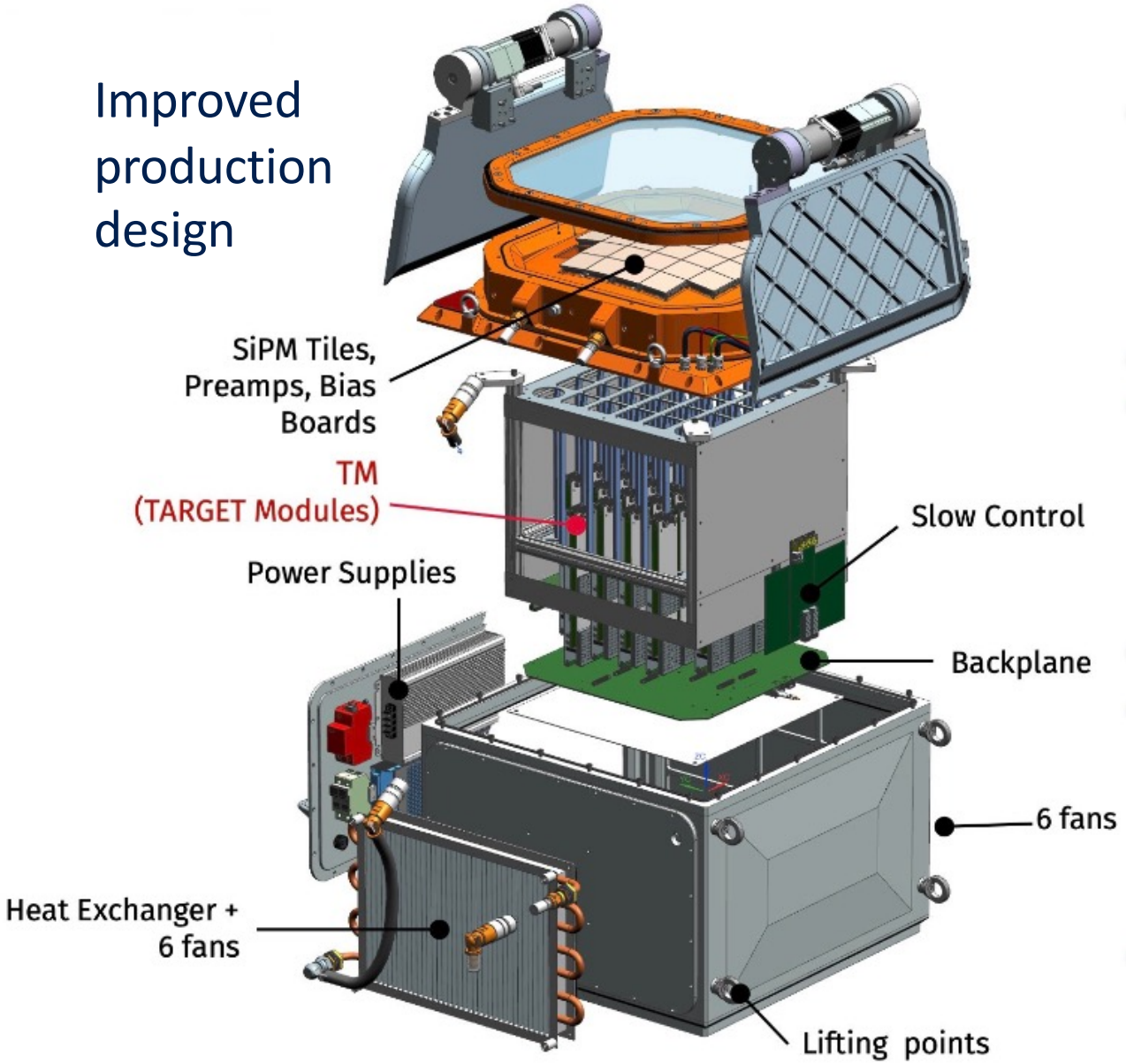
Core energy range	5 – 300 TeV
Optics	Dual-mirror SC
Primary	4.3 m
Secondary	1.8 m
Eff. mirror area	>5 m^2
Focal length	2.15 m
Mirror alignment	fixed
Field of view	8.8°
Pixel size	0.16°
Pixels	2048, SiPM
Max. readout	0.6 kHz
Mass	17.5 t

* some values updated compared to those on www.cta-observatory.org/

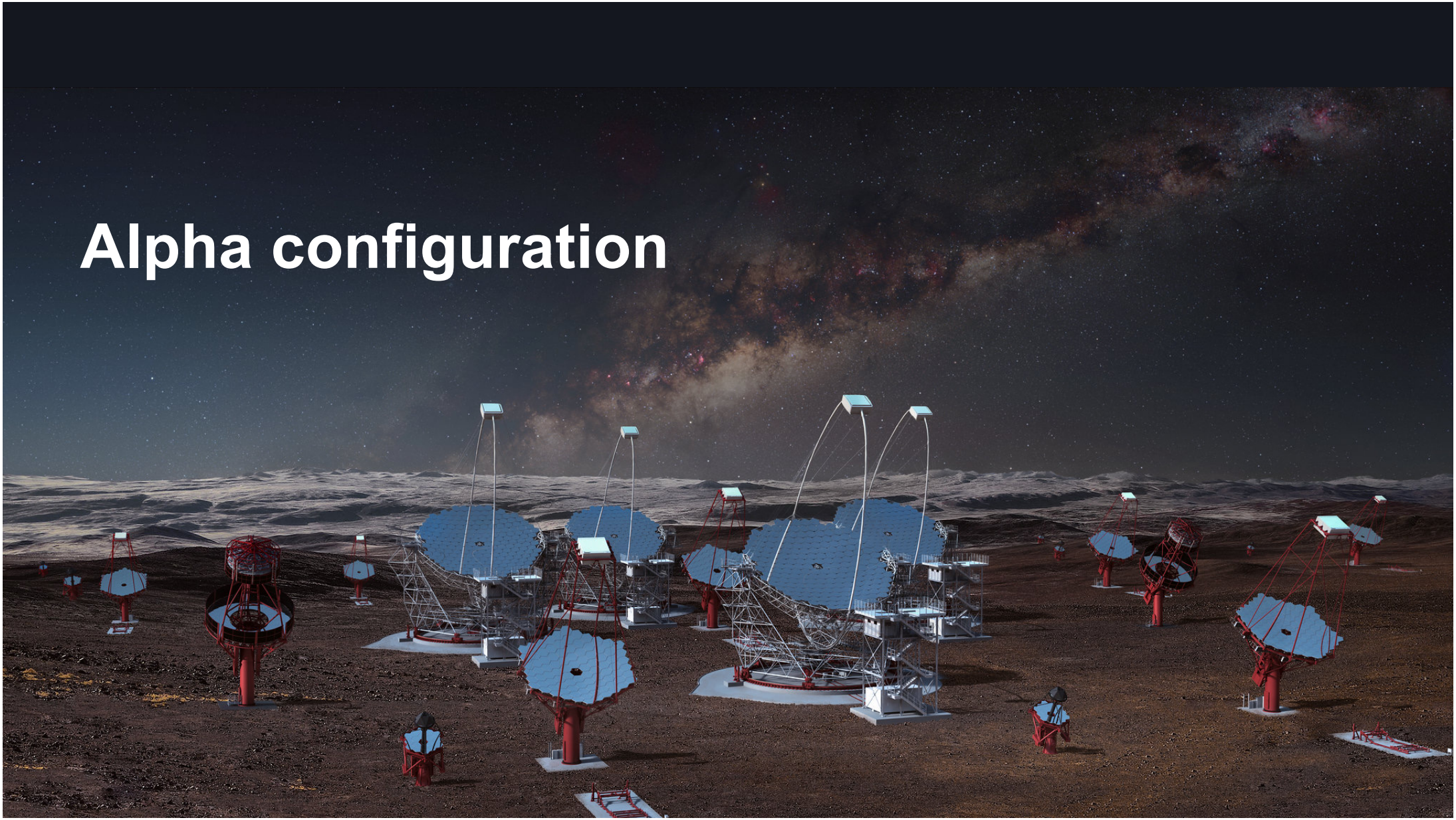
SST CAMERA



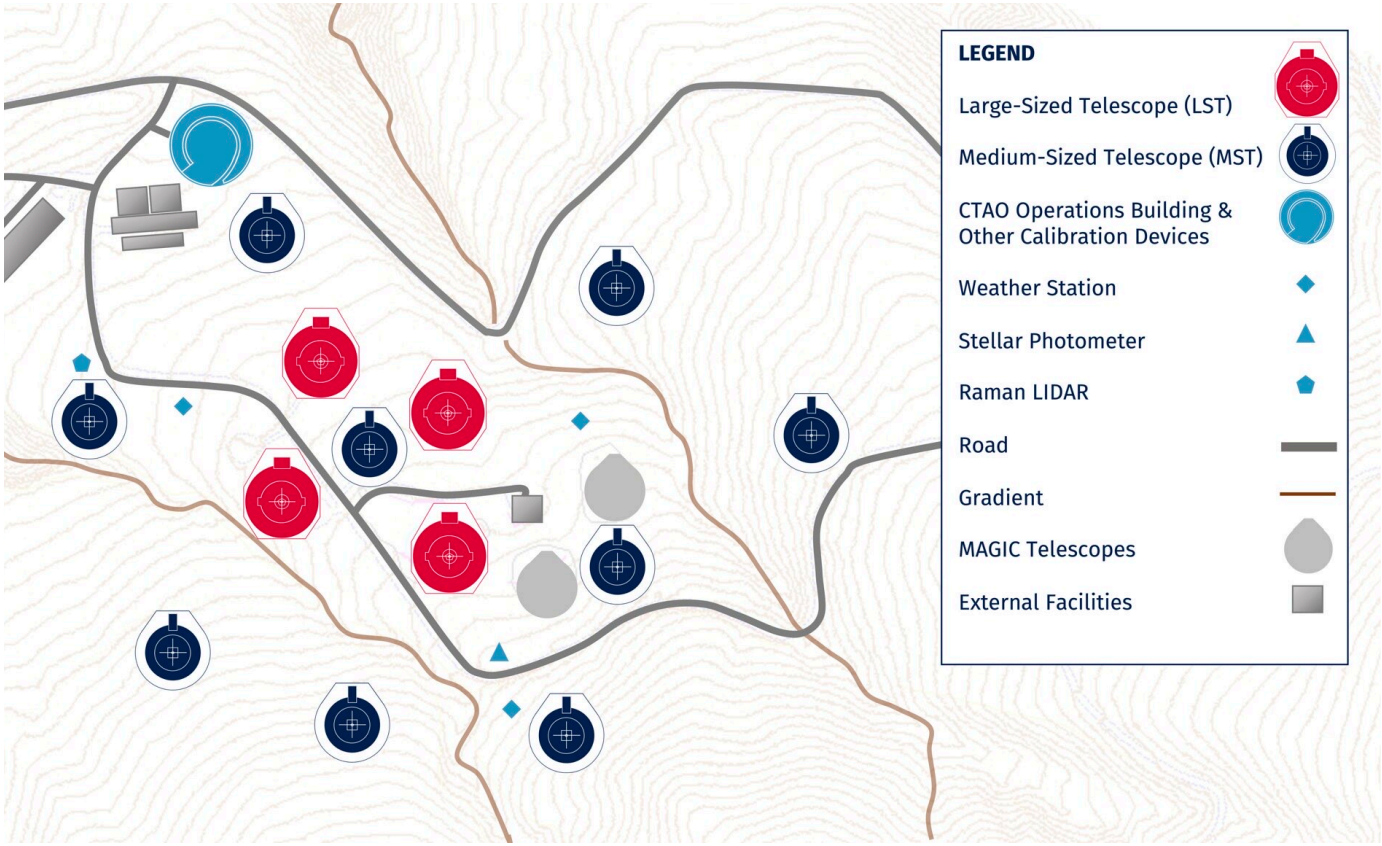
Improved production design



Alpha configuration

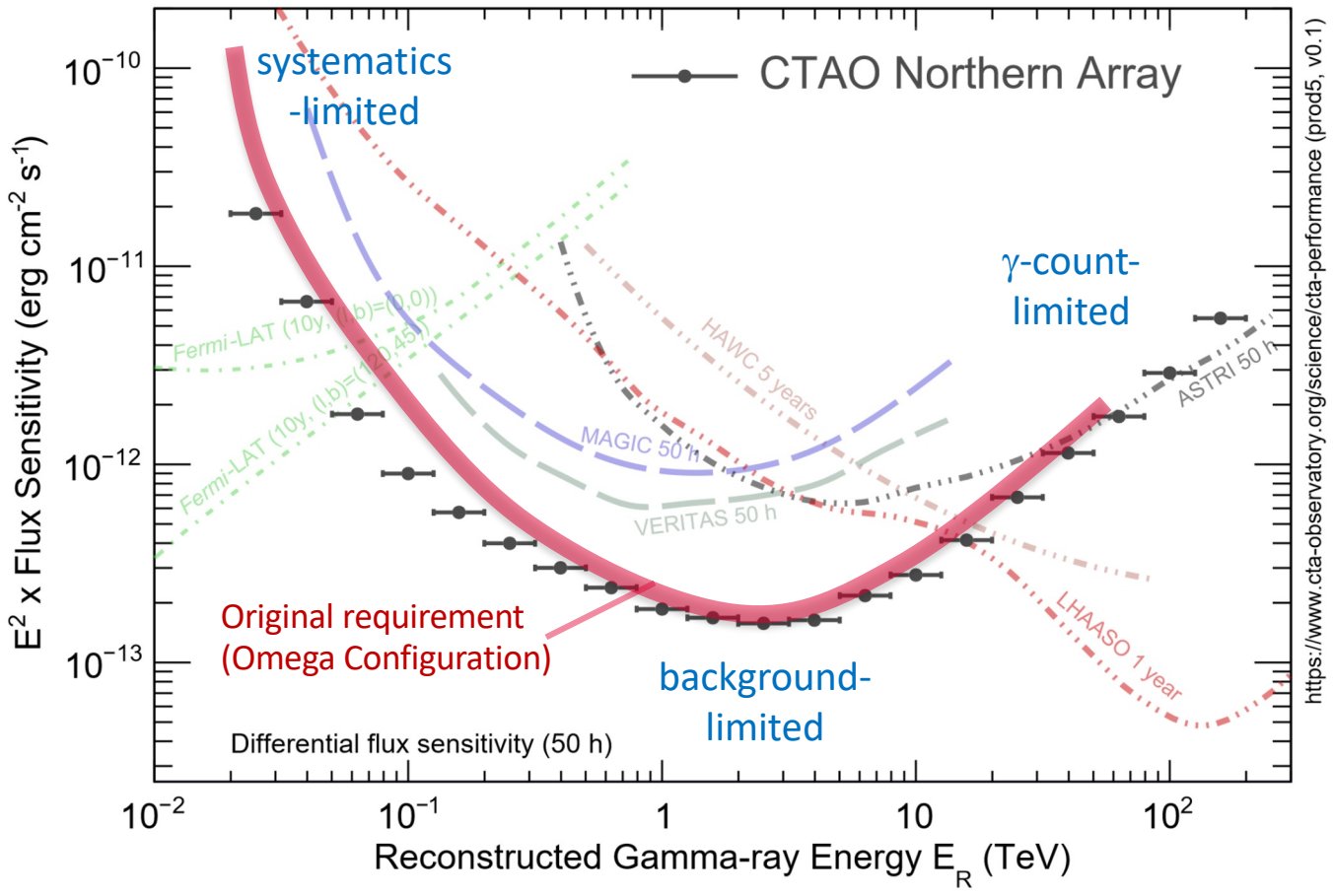


CTAO NORTH ARRAY only large and medium-sized telescopes



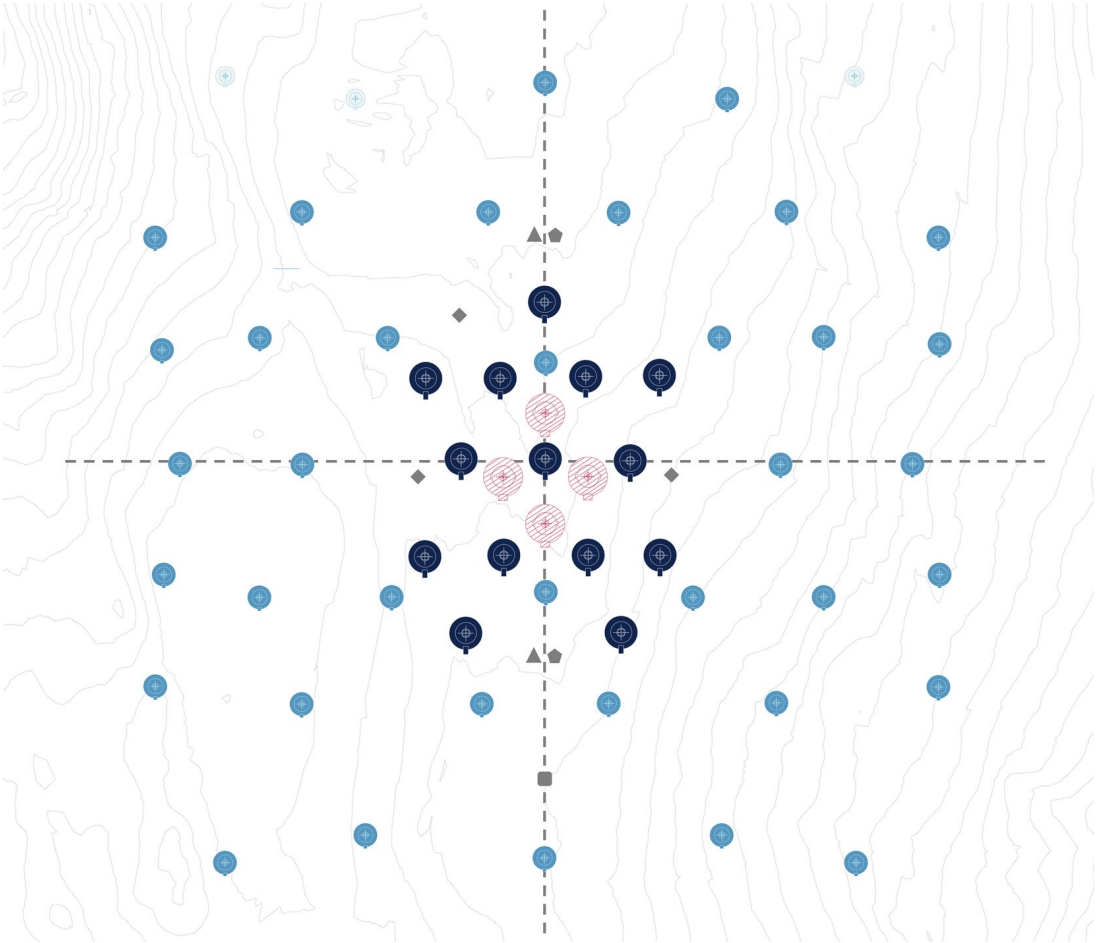
Tel.	Alpha	Omega
LST	4	4
MST	9	15
SST	0	0

SENSITIVITY: NORTHERN ARRAY



Alpha Configuration, 50 h

CTAO SOUTH ARRAY initially only small and medium sized telescopes

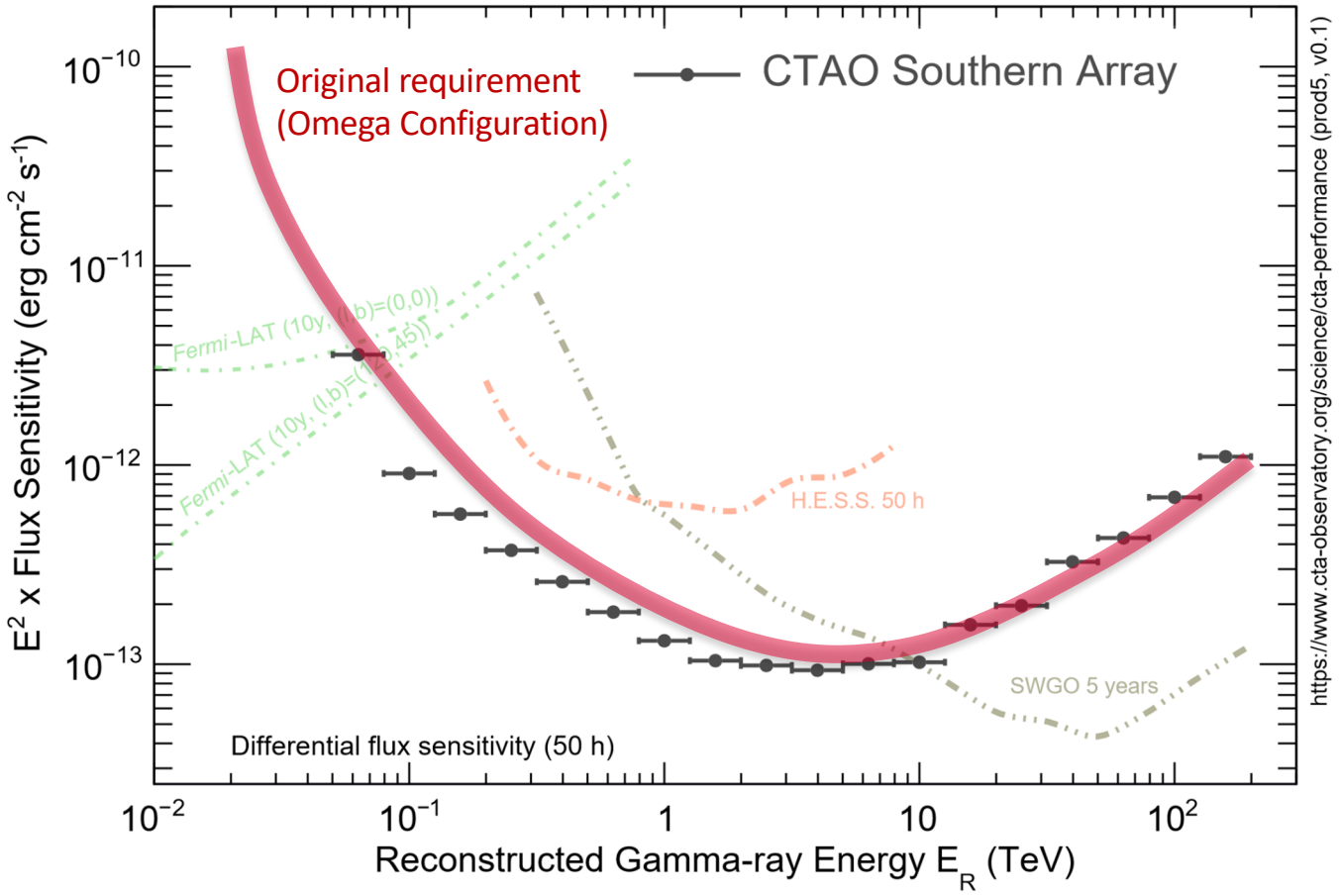


LEGEND

- Medium-Sized Telescope (MST)
- Small-Sized Telescope (SST)
- Large-Sized Telescope (LST) Foundation
- SST Foundation
- Weather Station
- Stellar Photometer
- Raman LIDAR
- Other Calibration Devices

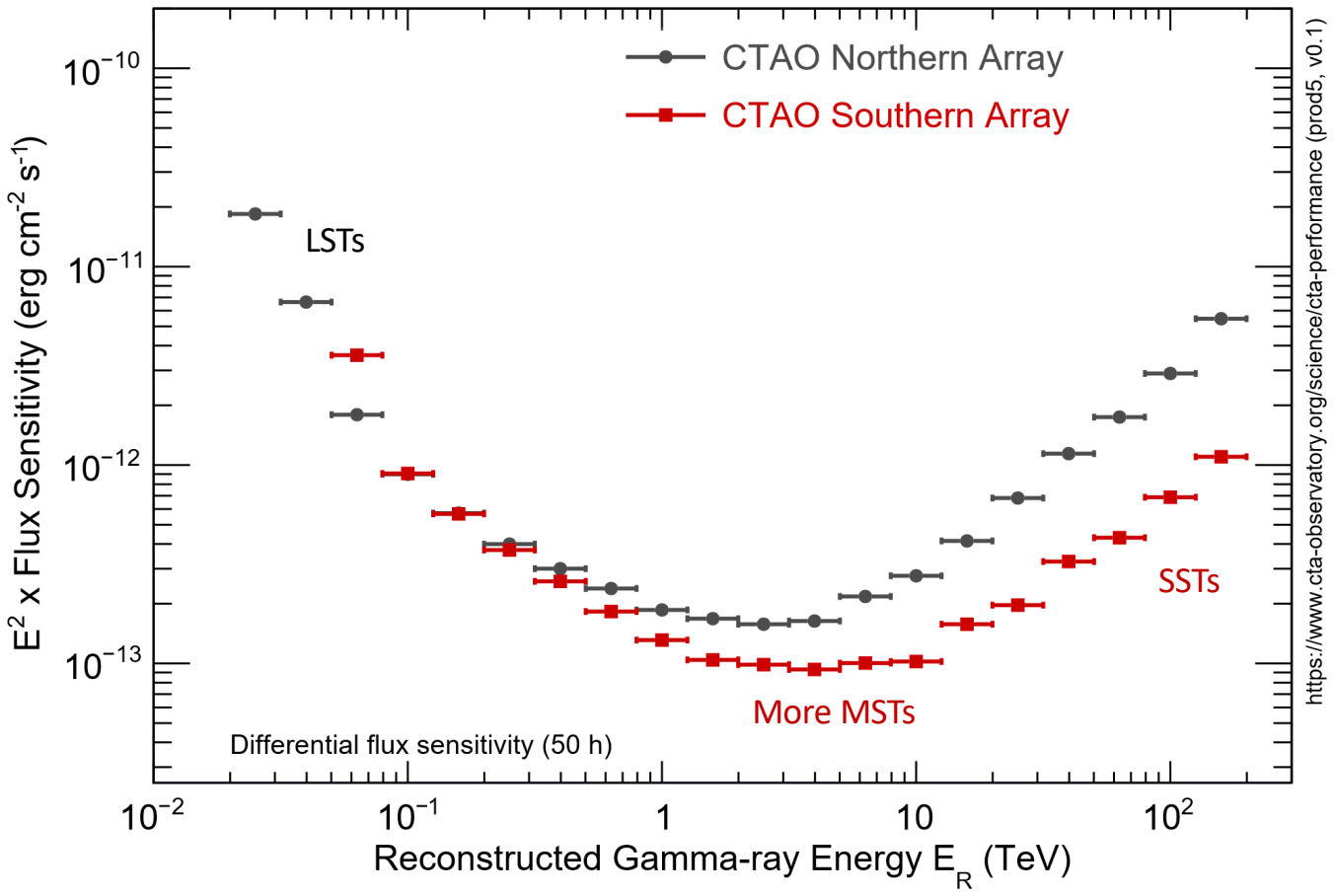
Tel.	Alpha	Omega
LST	4 foundations	4
MST	14	25
SST	37	70

SENSITIVITY: SOUTHERN ARRAY



Alpha Configuration, 50 h

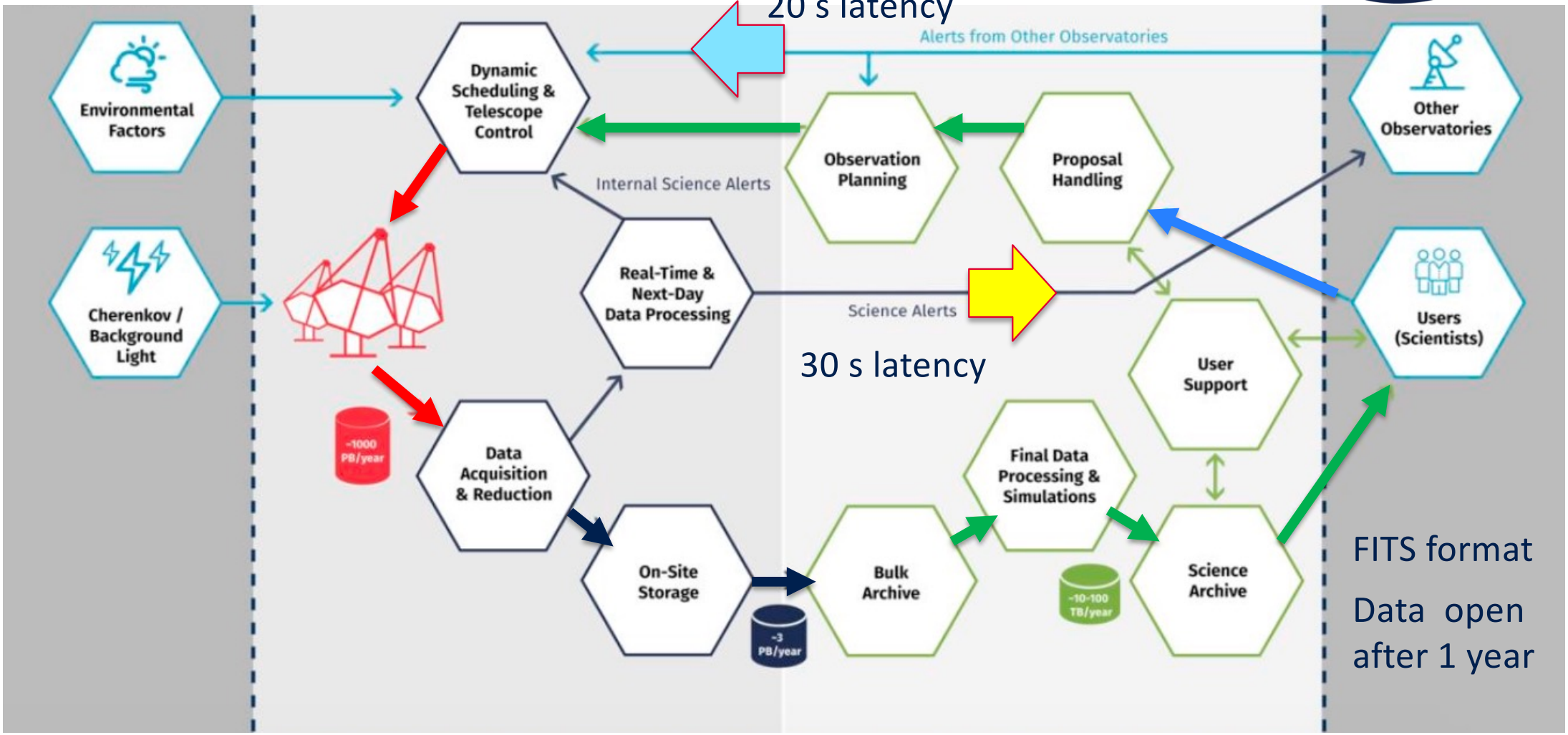
NORTH VS SOUTH



Alpha Configuration, 50 h

CTA Observatory

CTA OBSERVATORY



TIME ALLOCATION

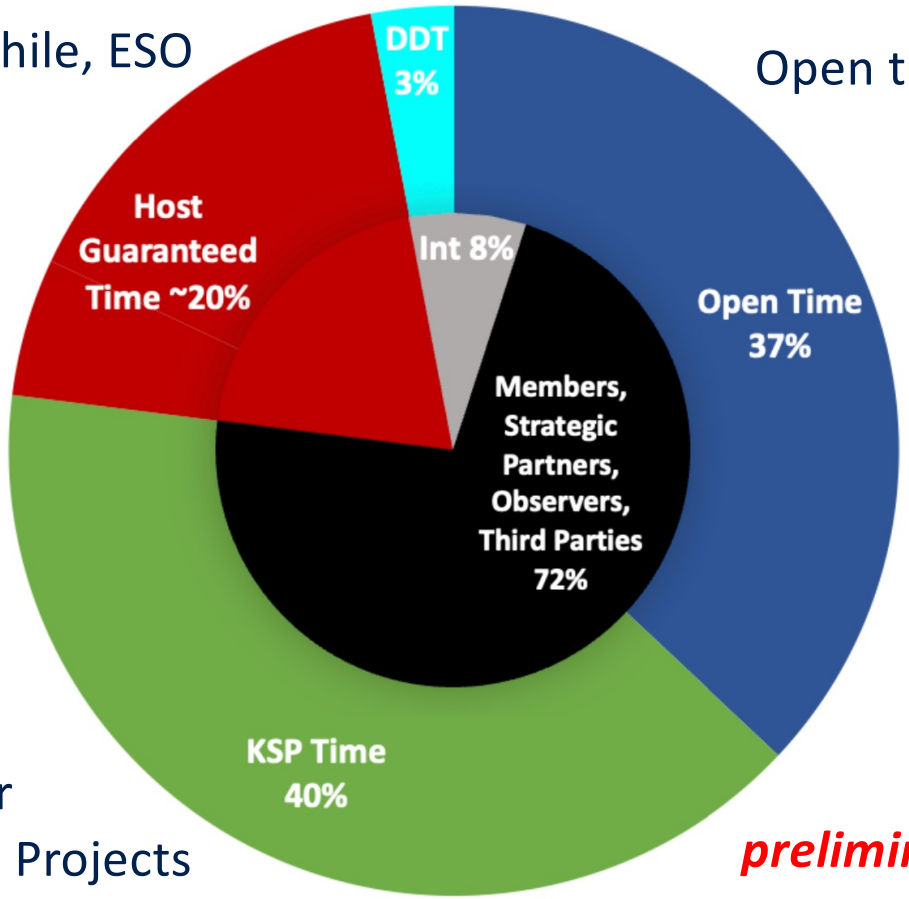
- Proposal-driven
- Evaluation by Time Allocation Committee
- Allocation by CTAO DG

Bulk of time reserved for parties contributing to CTAO ERIC

DDT

Spain, Chile, ESO

Open time



Time reserved for large Key Science Projects

preliminary

POTENTIAL KEY SCIENCE PROJECTS

1. Dark Matter Programme
2. Galactic Centre
3. Galactic Plane Survey
4. Large Magellanic Cloud Survey
5. Extragalactic Survey
6. Transients
7. Cosmic-ray PeVatrons
8. Star-forming Systems
9. Active Galactic Nuclei
10. Cluster of Galaxies
11. Beyond Gamma Rays

Surveys

Key objects

www.worldscientific.com/worldscibooks/10.1142/10986

CTA CONSORTIUM PAPERS

Science with CTA, arXiv:1709.07997; https://www.worldscientific.com/worldscibooks/10.1142/10986

Sensitivity of the Cherenkov Telescope Array to a dark matter signal from the Galactic centre, arXiv:2007.16129; JCAP01(2021)057

Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray propagation, arXiv:2010.01349; JCAP02(2021)048

Sensitivity of the Cherenkov Telescope Array to spectral signatures of hadronic PeVatrons with application to Galactic Supernova Remnants, arXiv:2303.15007, Astroparticle Physics, in press

Sensitivity of the Cherenkov Telescope Array to TeV photon emission from the Large Magellanic Cloud, MNRAS, submitted