cherenkov telescope array

FZU - Day with Particle and Astroparticle RIs

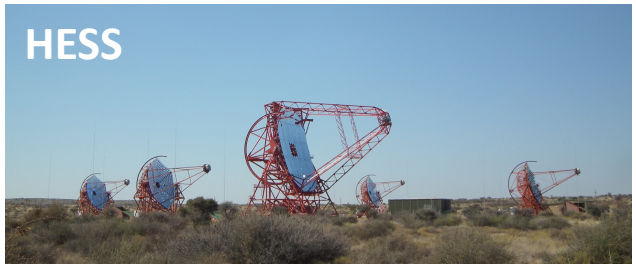
October 17, 2022

The Cherenkov Telescope Array Observatory, building the World's largest ground-based gamma-ray observatory.

FEDERICO FERRINI

What is CTAO ?

- CTAO, the Cherenkov Telescope Array Observatory, is the next generation ground-based facility for gamma-ray astronomy at very high energies, from 20 Gev to 300 Tev
- The concept: 118 telescopes on two sites in the North and South emispheres
  - Full-scope configuration: 19 in the North, 99 in the South
  - Initial configuration under construction: 13 in the North, 51 in the South
- It will be the first open gamma-ray observatory



The CTA Consortium (CTAC)

31 countries
206 institutes
1501 members

CTAO Organisation

In 2014, the CTA Observatory GmbH was founded as interim legal entity, under German law (HQ in Heidelberg) to prepare the CTAO implementation (select and prepare two array sites + Science Data Management Centre)

The final legal entity in charge of construction and operation is going to be a *European Research Infrastructure Consortium: CTAO ERIC*

Headquarters: Bologna

Science Data Management Centre: Zeuthen

Application for CTAO ERIC to EC

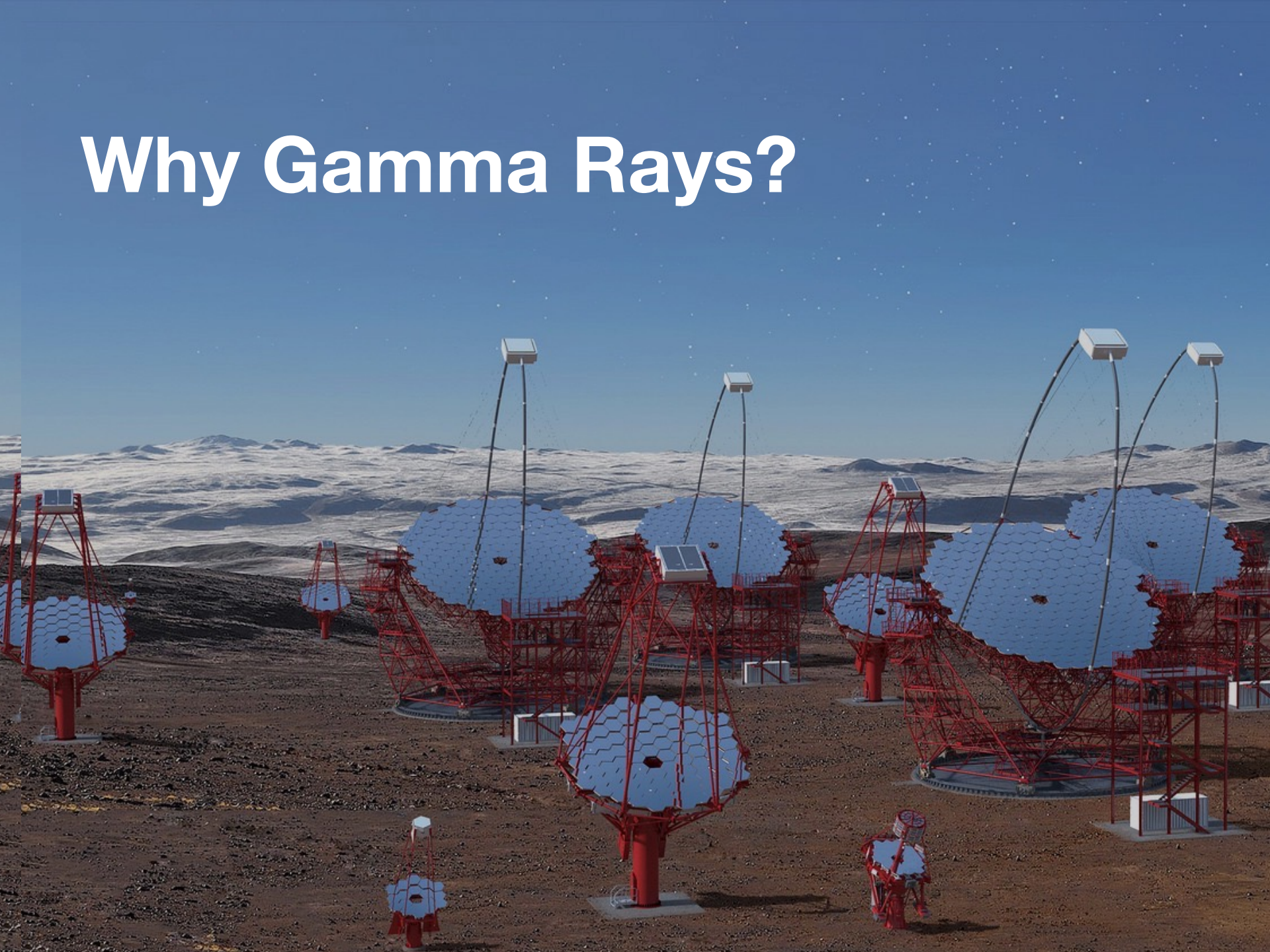
Members, Strategic Partners, Third Party, Observers:

- *Australia*
- *Austria*
- *Brazil*
- *Czech Republic*
- *European Southern Observatory*
- *France*
- *Germany*
- *Italy*
- *Japan*
- *Poland*
- *Slovenia*
- *Spain*
- *Switzerland*

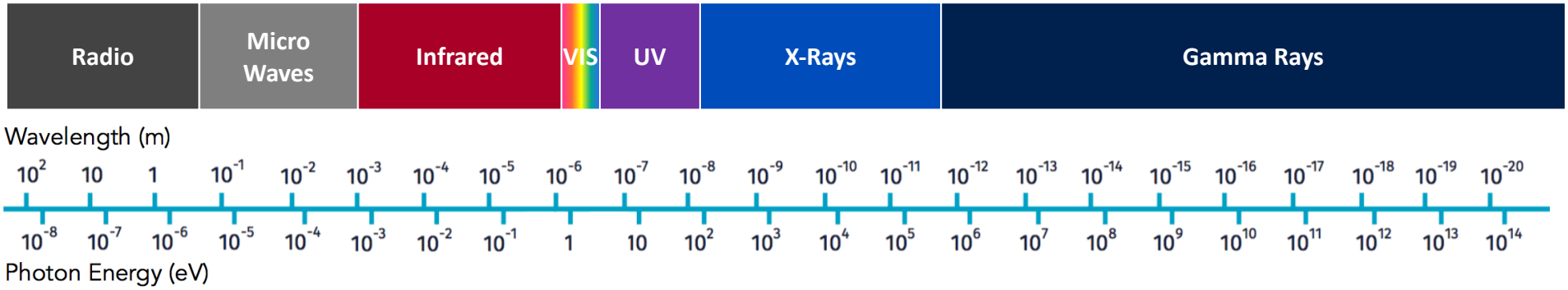
UK
Croatia
Netherlands
South Africa
USA

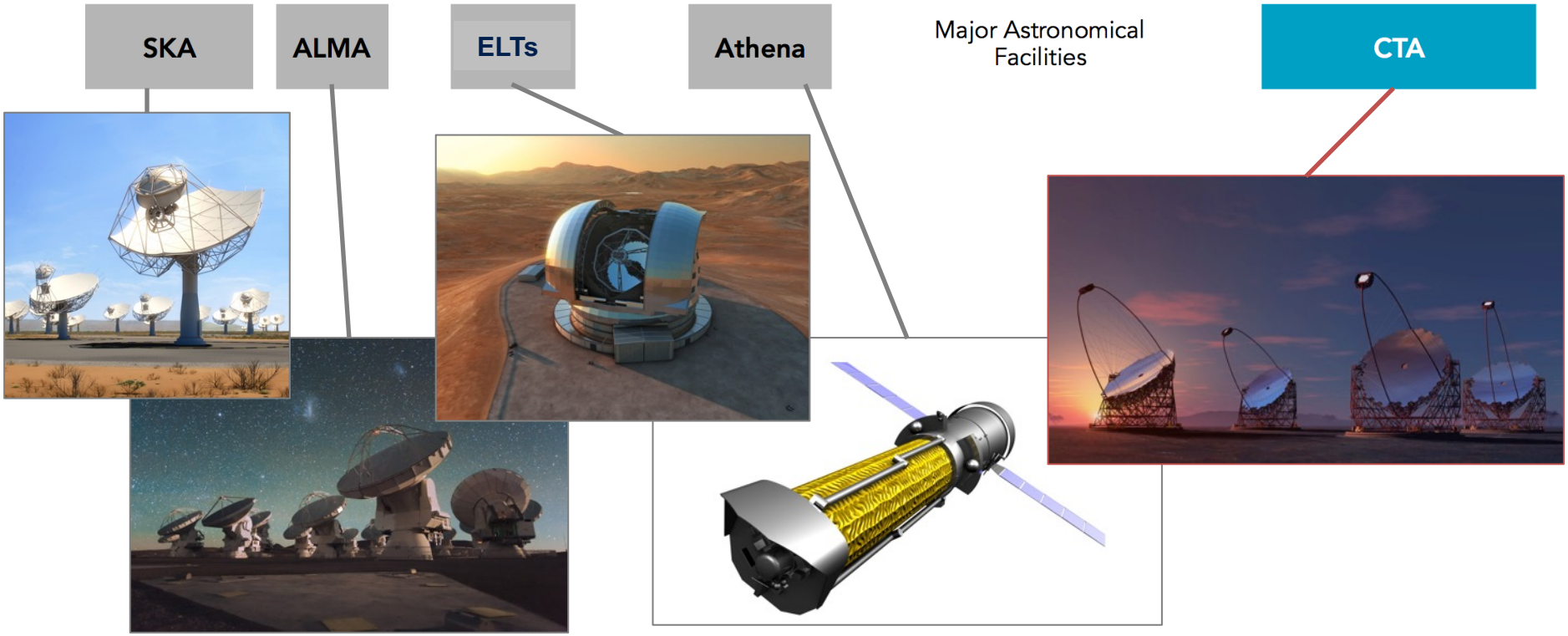
CTAO sites: arrays, headquarter(s), data center

Why Gamma Rays?



Waveband coverage

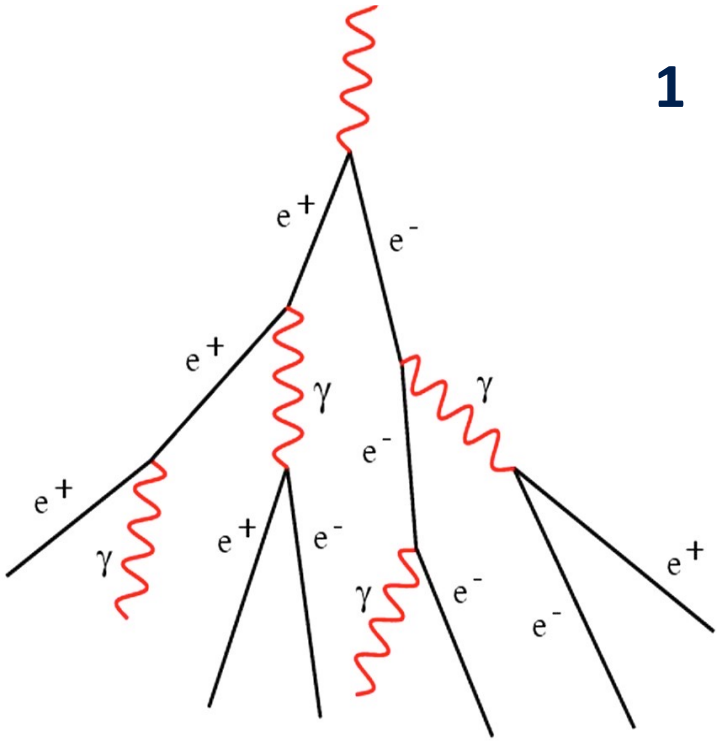




Extended Air Showers

Electromagnetic (EM)

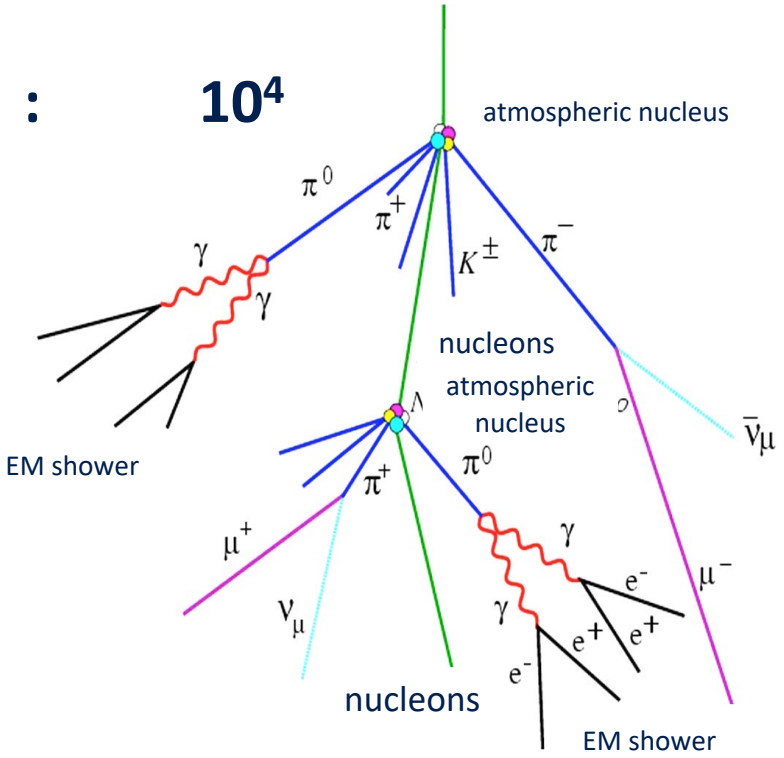
primary γ



1 : 10^4

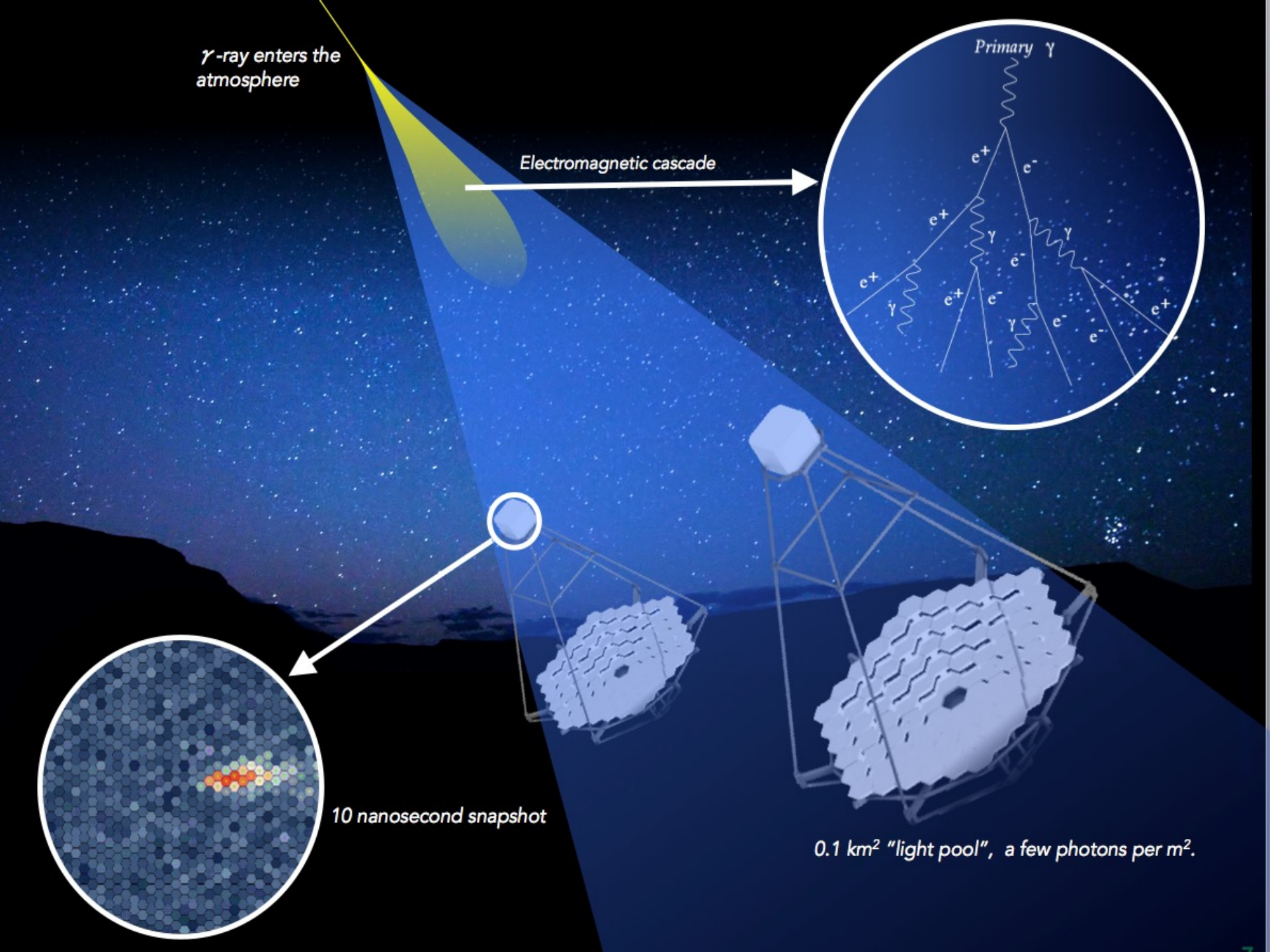
Hadronic

primary cosmic ray (p, alpha, …)



- $\gamma \longrightarrow e^+ e^-$ (pair production)
- $e^{\pm} \longrightarrow \gamma$ (*bremsstrahlung*)

- CR + atm. nucleus $\longrightarrow \pi^{\circ}, \pi^{\pm} + N^*$
- $\pi^{\pm} \longrightarrow \mu^{\pm} + \nu$
- $\pi^{\circ} \longrightarrow \gamma\,\gamma \longrightarrow$ e.m. showers


γ-ray enters the atmosphere
Electromagnetic cascade
Primary γ
10 nanosecond snapshot
0.1 km² "light pool", a few photons per m².

CTAO main scientific themes

COSMIC PARTICLE ACCELERATION

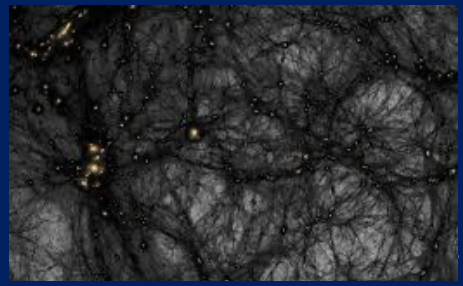
- How & where particles are accelerated?
- How do they propagate?
- What is their impact on the environment?

PROBING EXTREME ENVIROMENTS

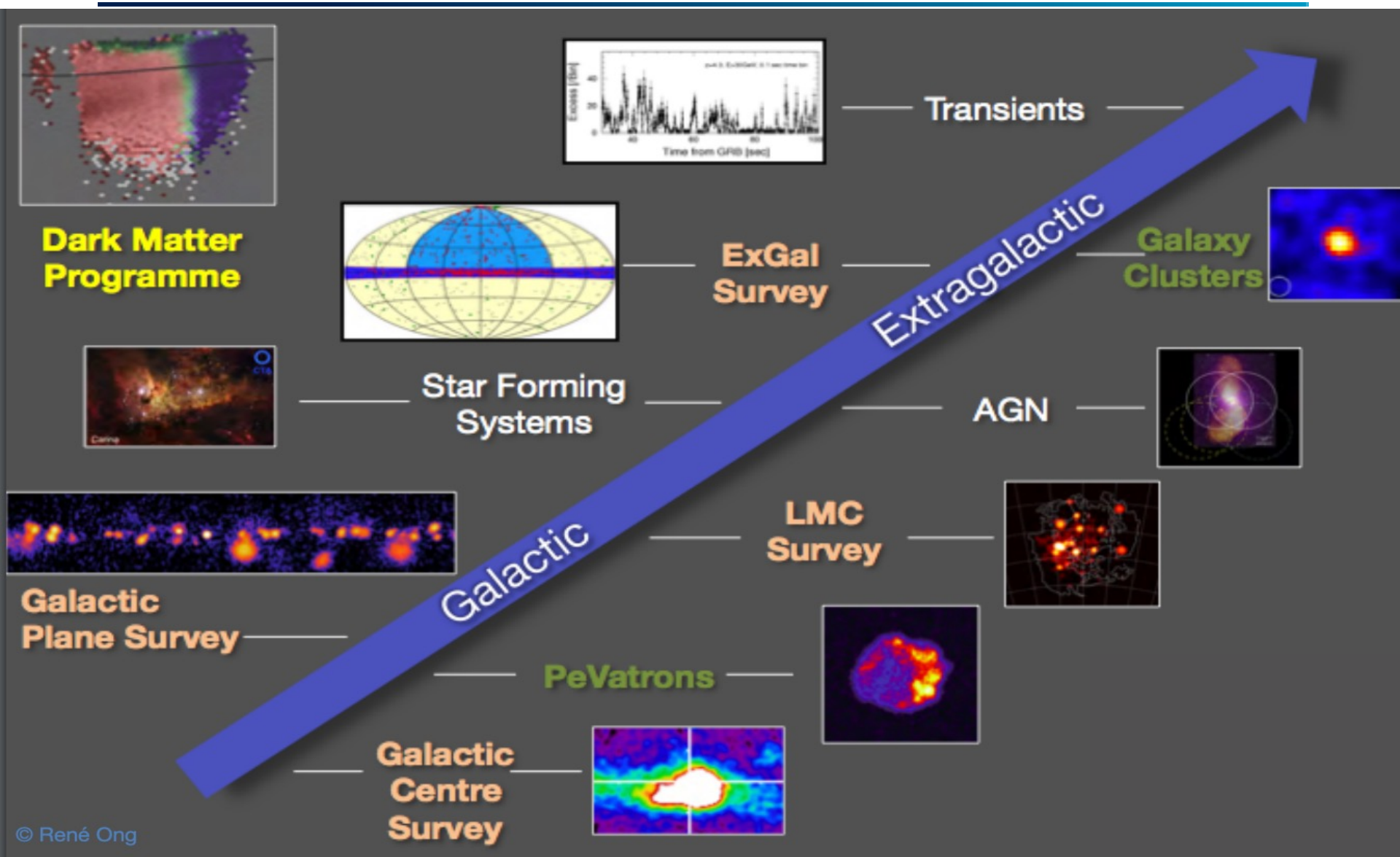
- Which are the processes close to neutron stars and black holes?
- Which are the processes in relativistic jets, winds and explosions
- What are the cosmic voids?

PHYSICS FRONTIERS - BEYOND THE STANDARD MODEL

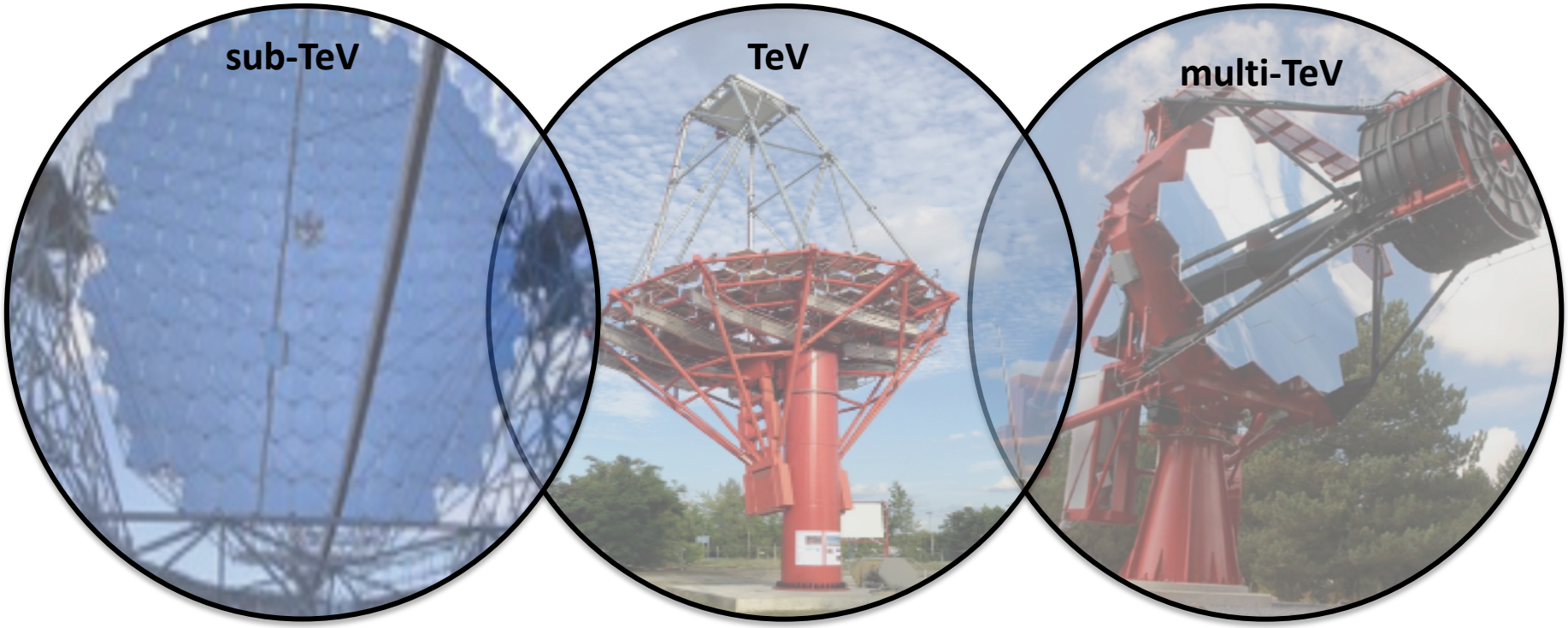
- What's the nature of the dark matter?
- How is it distributed?
- Do axion-like particles exist?
- Is the speed of light a constant for HE photons?



CTAO Key Targets



Science cases determine design



LST

- GRB, AGN, Transients
- Cosmology
- Pulsars, GW

MST

- Surveys, Morphology
- Dark Matter
- UHE neutrinos, Blazars

SST

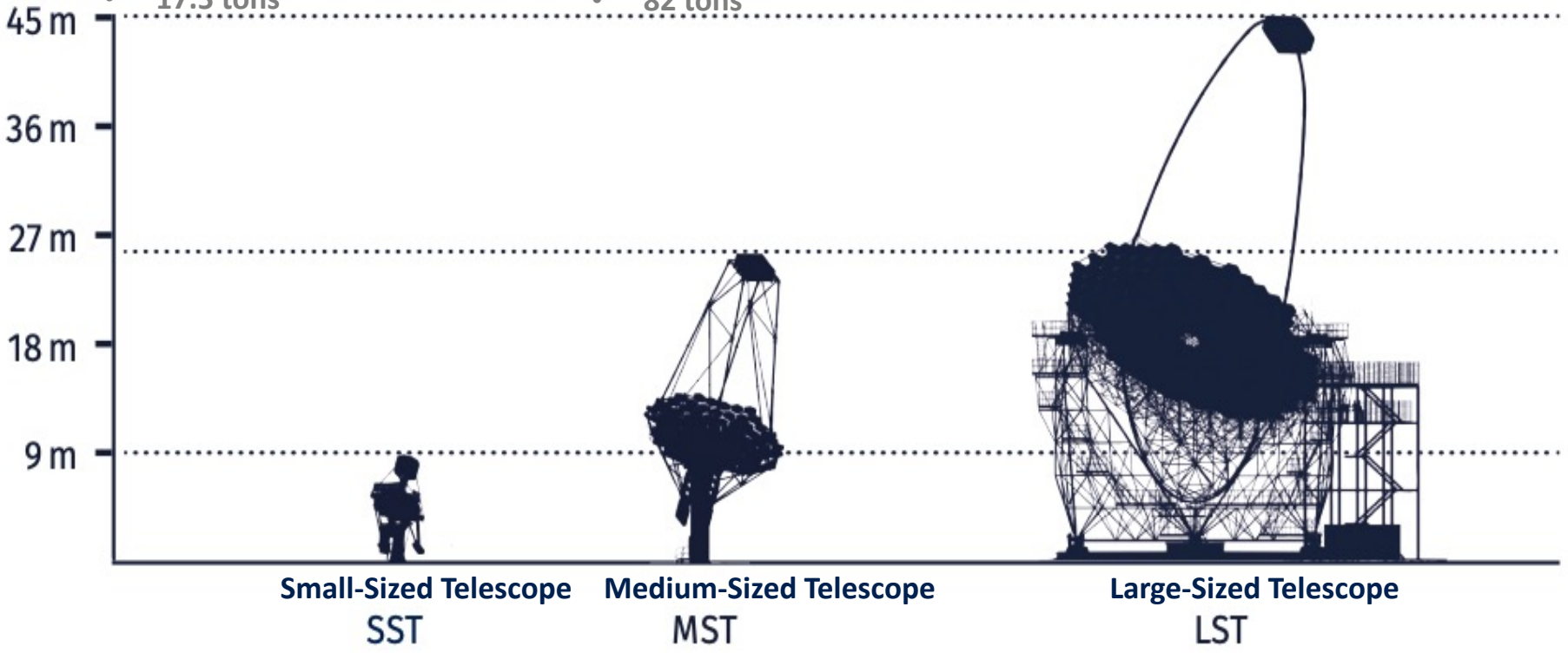
- Pevatrons
- Star-forming regions

3 telescope designs

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

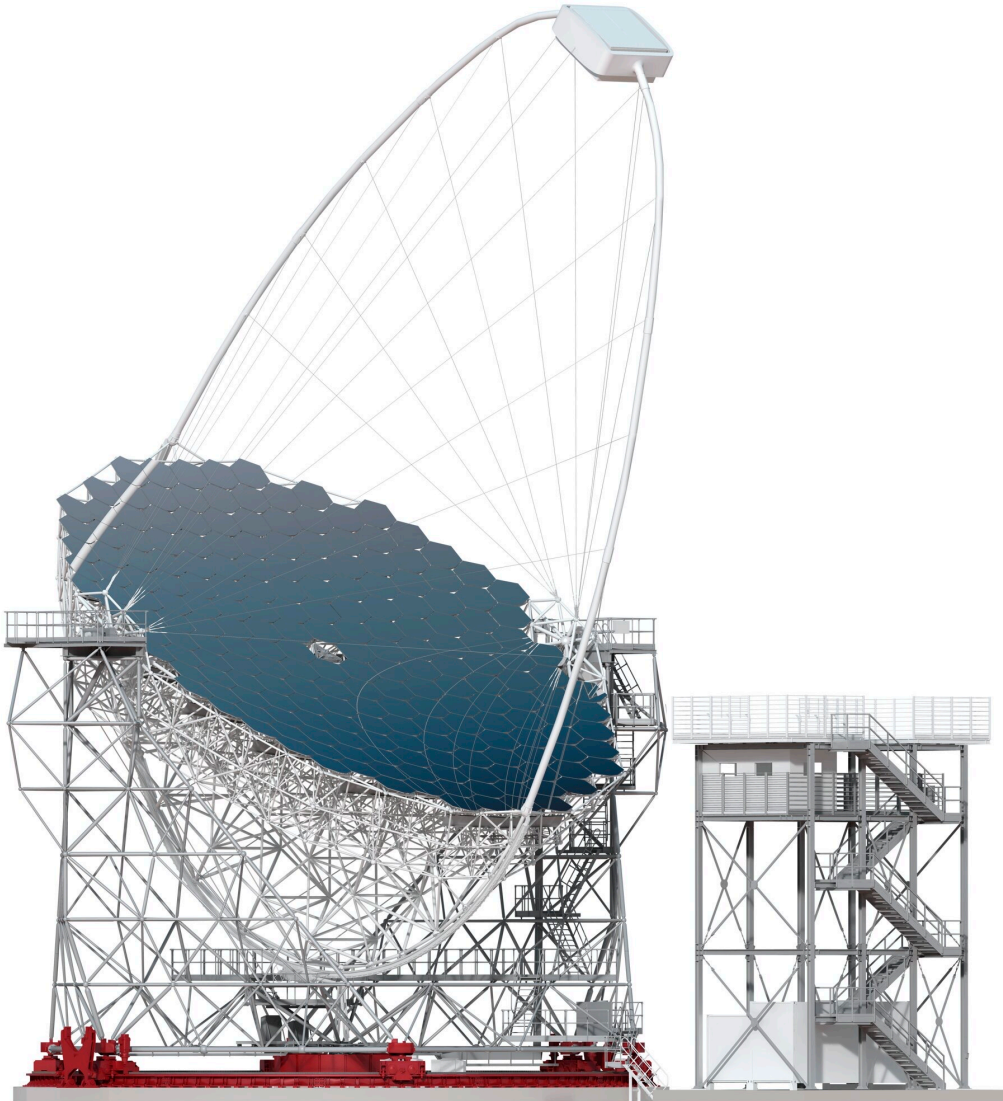
- Davies-Cotton optical design
- 12 m ⌀ reflective surface
- PMT camera – 2 designs:
  - NectarCam: 1855 pixels
  - FlashCam: 1764 pixels
- ~7° FoV
- 82 tons

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



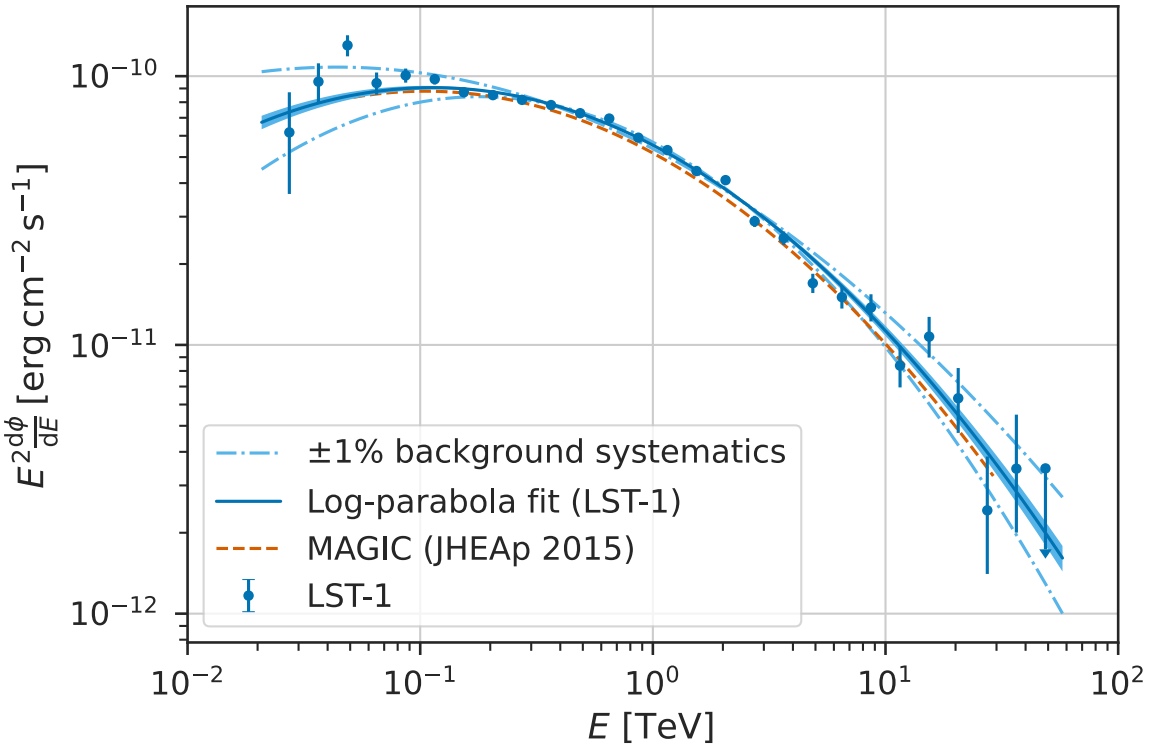
Large-Sized Telescope (LST)

- 4 LSTs will be at the centre of CTAO-North (+4 South)
- Main Parameters:
  - Energy Range (full sensitivity): 20-150 GeV
  - Dish Diameter: 23 m
  - Weight: 100 tons
  - Mirror area: 370 m^2
  - Focal Length: 28 m
  - Field of View: 4.3^o
- Despite its size, will be able to reposition to a new target in 20 seconds to capture brief, low-energy gamma-ray signals



CTAO-N LST1

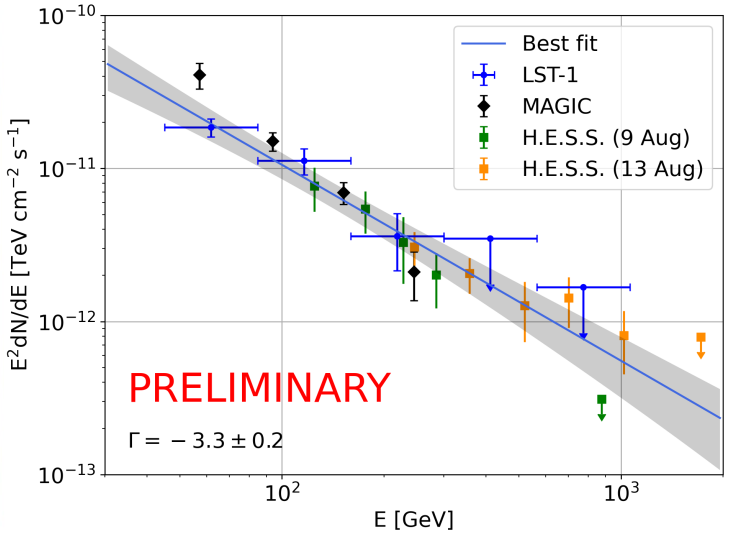
Performance: Crab Nebula spectrum



- 34 h effective time, γ-ray efficiency: 70% from gammaness cut and 70% from θ^2 cut
- Error bars are only statistical.
- Systematics: blue lines correspond to effect of ±1% background.
- Consistent with MAGIC and Fermi-LAT.
- Lowest data point at 25 GeV!

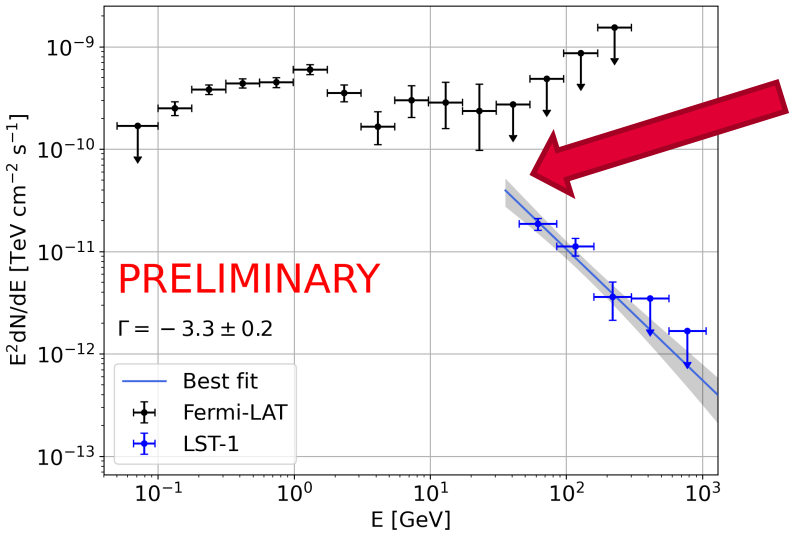
First VHE-detected nova: RS Ophiuci

Credit: David A.Hardy/ www.astroart.org & PPARC.



- LST-1, 4-day average
- MAGIC, 4-day joint data (Acciari 2022)
- H.E.S.S. August 9+13 SEDs (H.E.S.S. coll 2022)

Consistent spectra



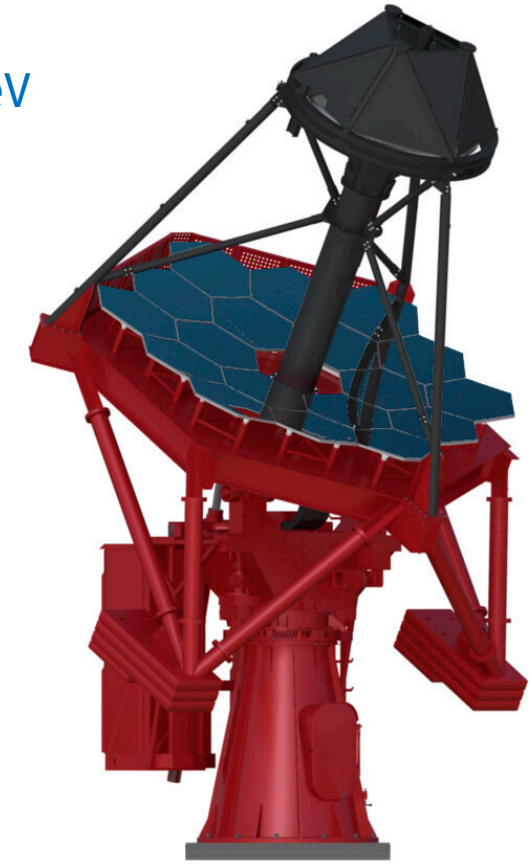
- **No gap between Fermi and LST.**
- **Compare error bars for a few hours with LST1 and 4 days of Fermi.**

Medium-Sized Telescope (MST)

- The MSTs will be tasked to cover the middle of CTAO's energy range.
- Main Paramaters:
  - Energy Range (full sensitivity): 150 GeV – 5 TeV
  - Dish Diameter: 12 m
  - Weight: 82 tons
  - Mirror Area: 88 m^2
  - Focal Length: 16 m
  - Field of View: 7^o
- Two camera designs are being prototyped for the MST.
- The wide field of view will enable the MSTs to take rapid surveys of the gamma-ray sky.

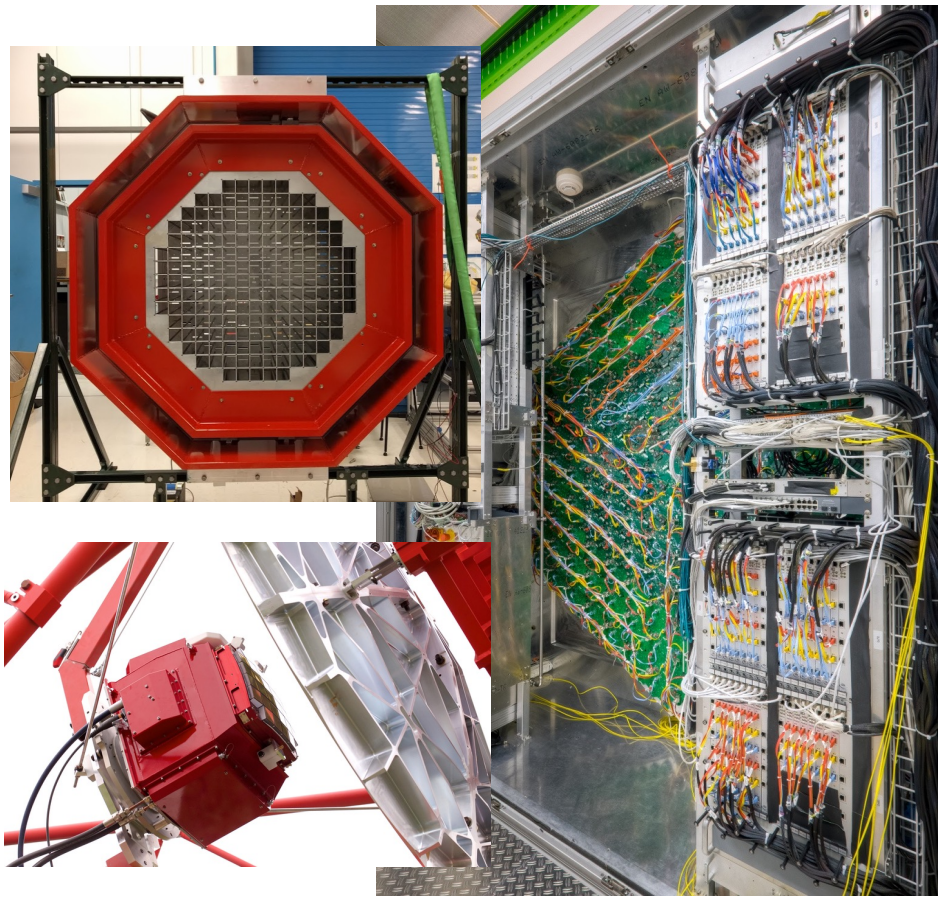
Small-Sized Telescope (SST)

- The SSTs will outnumber all other telescopes in the southern array to capture the highest-energy gamma rays.
- Main Parameters:
  - Energy Range (full sensitivity): 5-300 TeV
  - Dish Diameter: 4.3 m
  - Weight: 17.5 tons
  - Mirror area: 8 m^2
  - Focal Length: 2.2 m
  - Field of View: 8.8^o

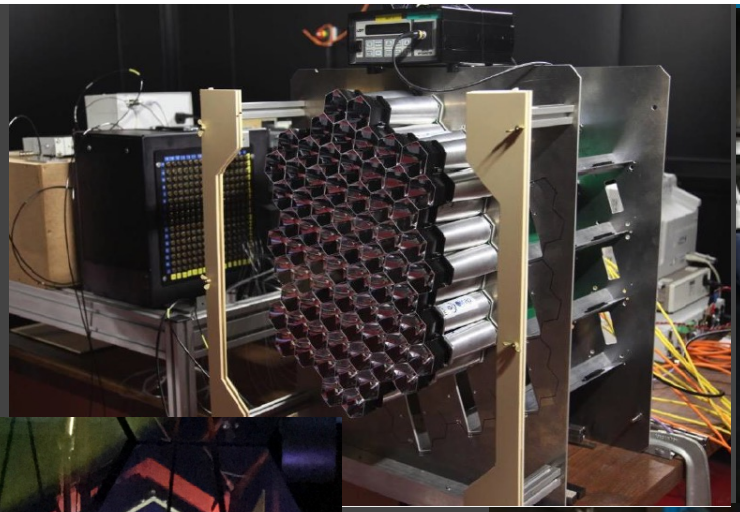


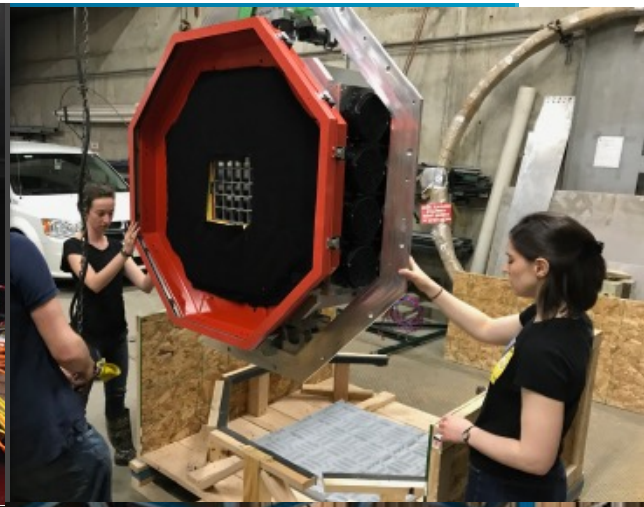
Cameras

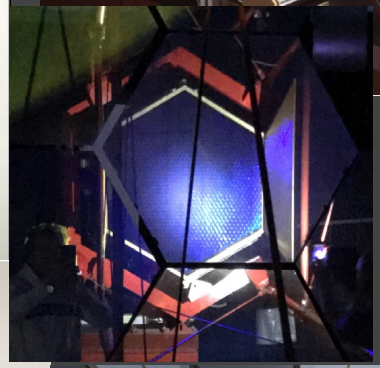
- CTAO's cameras will use high-speed digitisation and triggering technology capable of recording shower images at a rate of one billion frames per second.
- Both photomultiplier tubes (PMTs) and silicon photomultipliers (SiPMs) will convert the light into an electrical signal for a total of 200,000 ultra-fast light-sensitive pixels.

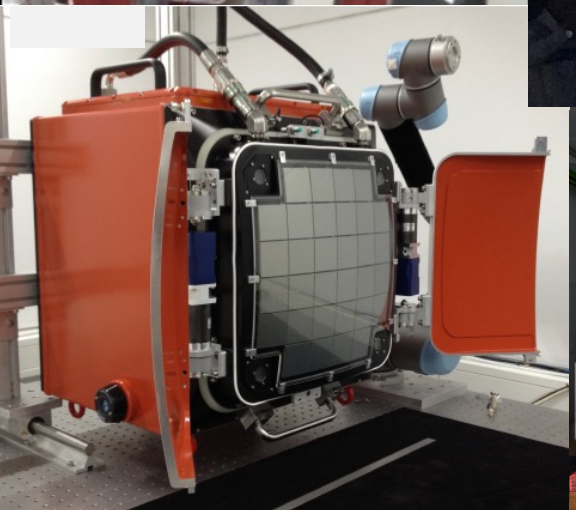


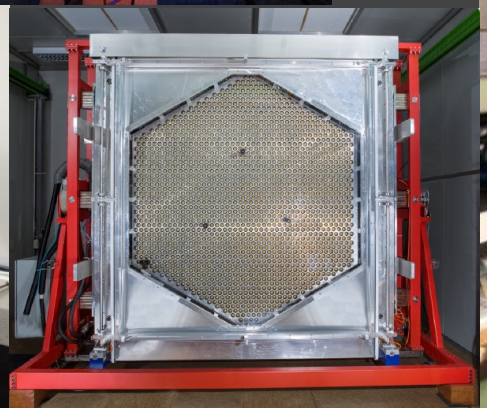
Cherenkov Cameras

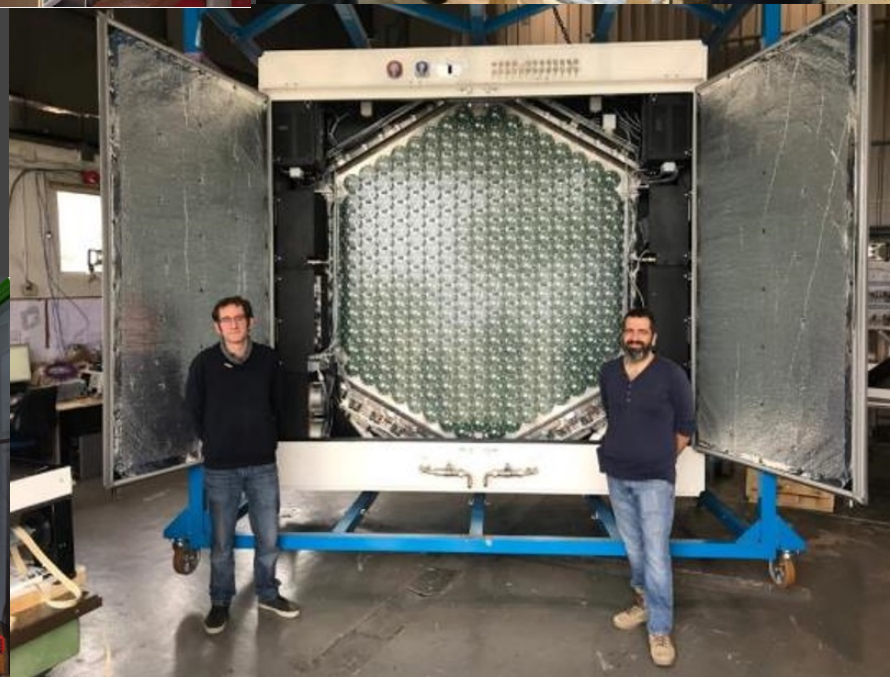




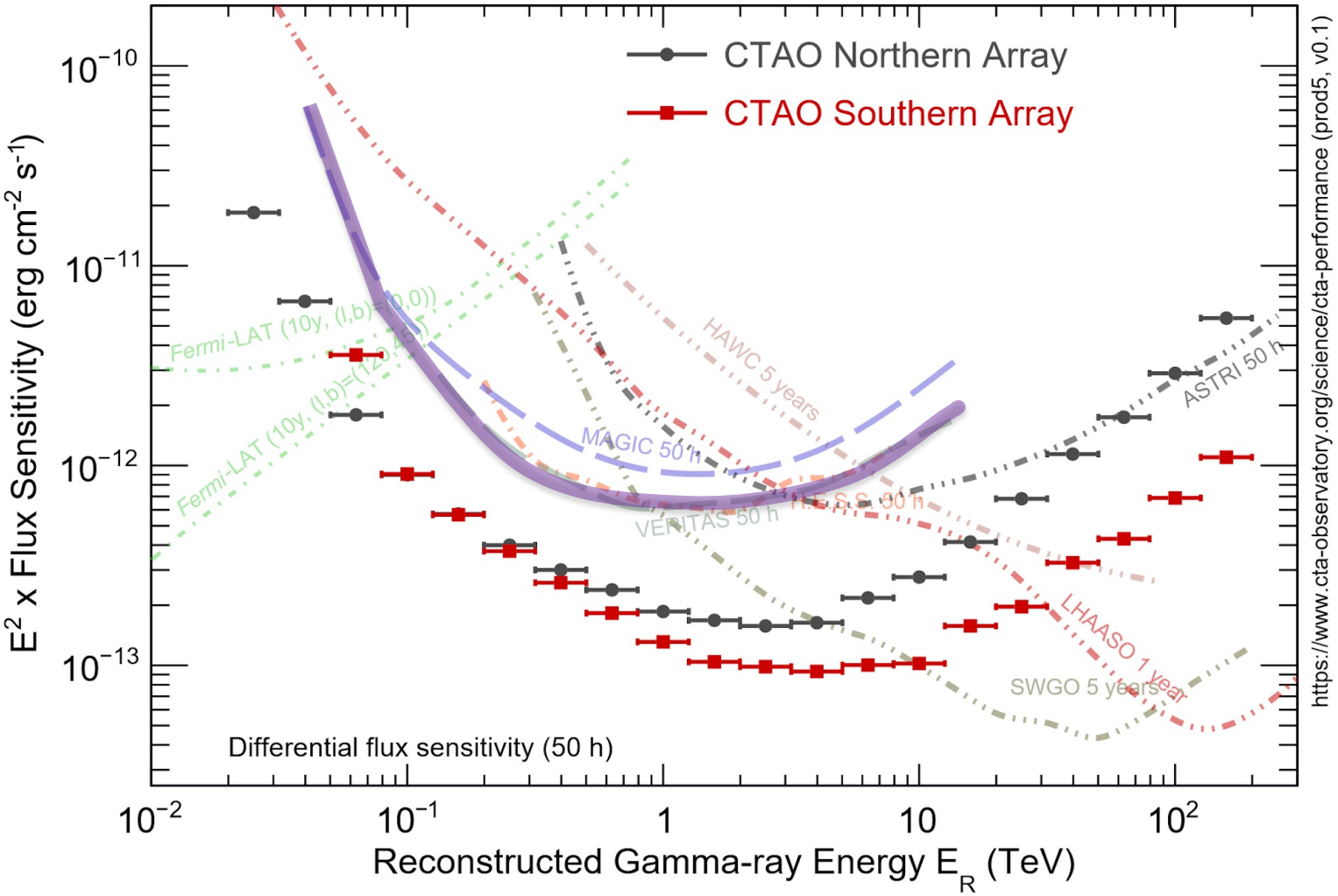








CTAO performance (Alpha Configuration)



Current Construction scope in term of Telescopes:

- Telescope numbers and infrastructure:
  - LST North: 4
  - LST South: 0 - excavation and backfill for four foundations on the South site are included in the CB
  - MST North: 9
  - MST South: 14
  - SST North: 0
  - SST South: 37; 40 foundations to install SST telescopes are included in the CB
- This is the CTAO Alpha configuration - based on the commitments of the ERIC Members and Strategic Partners as detailed in the Money Matrix
- More is coming: Extra funding granted in Italy
  - Enabling in the South 2 LSTs and 5 more SSTs

Two Arrays: Two Eyes on the Sky

Array Coordinates
Latitude: 24° 41' 0.34" South
Longitude: 70° 18' 58.84" West

CTAO-South
Paranal, Chile

~3 km²

area covered by the array of telescopes

image credit: Marc-André Besel, CTAO

image credit: Akira Okumura

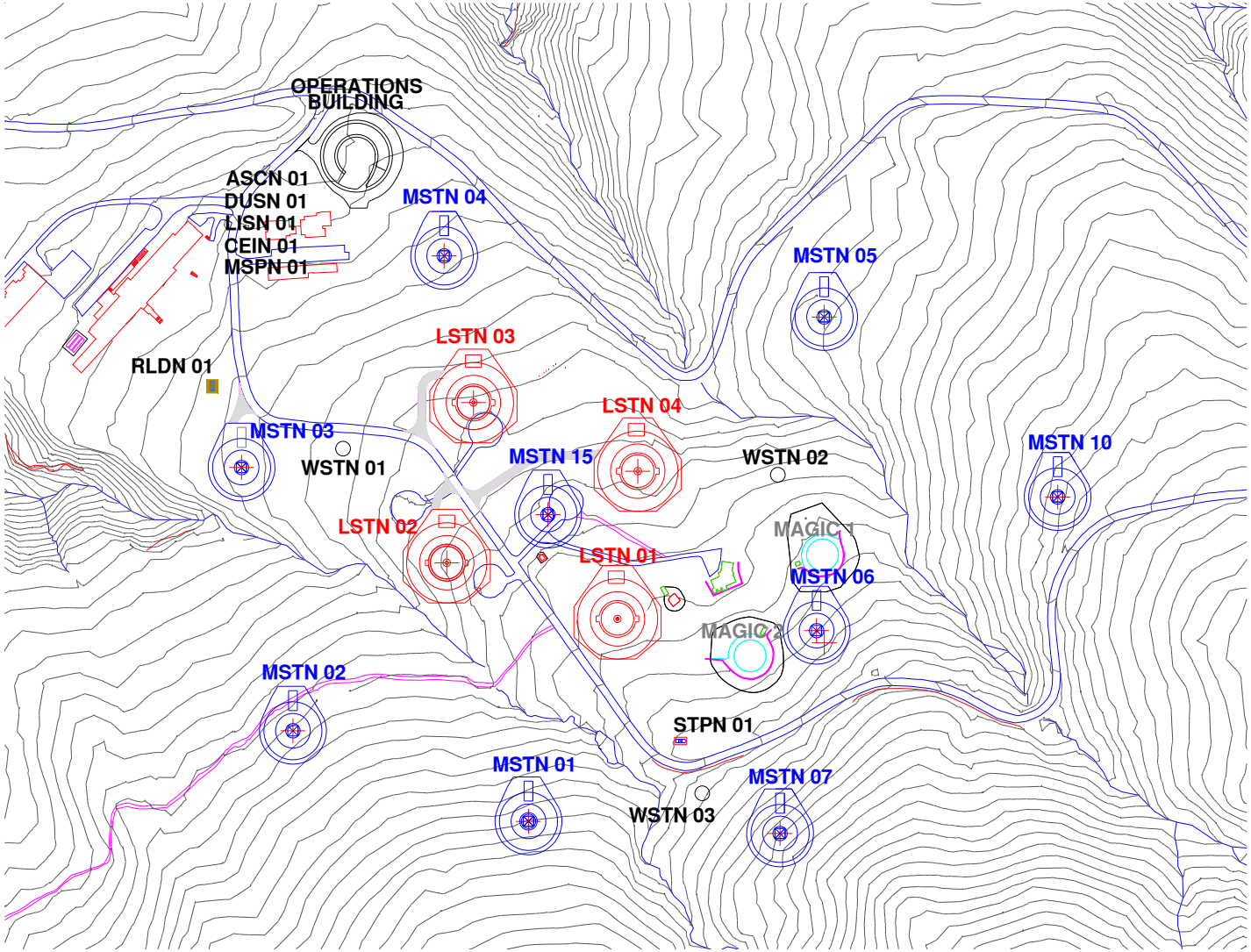
CTAO-North
La Palma, Spain

~0.25 km²

area covered by the array of telescopes

Array Coordinates
Latitude: 28° 45' 43.7904" North
Longitude: 17° 53' 31.218" West

α configuration – CTAO-N layout



CTAO Northern Array – α *configuration*

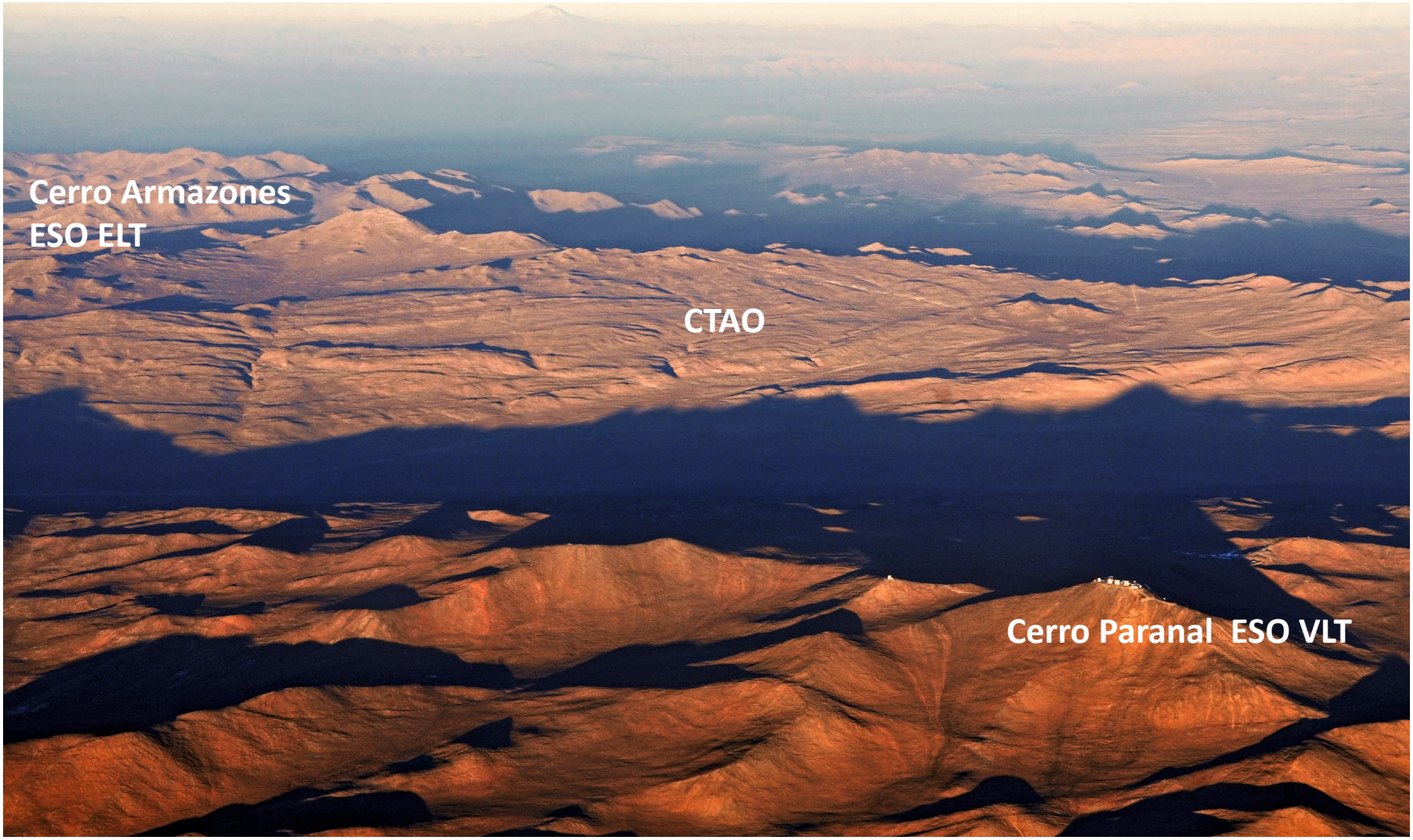
- **9 MSTs** equipped with NectarCam
- **4 LSTs**

→ **13 telescopes**

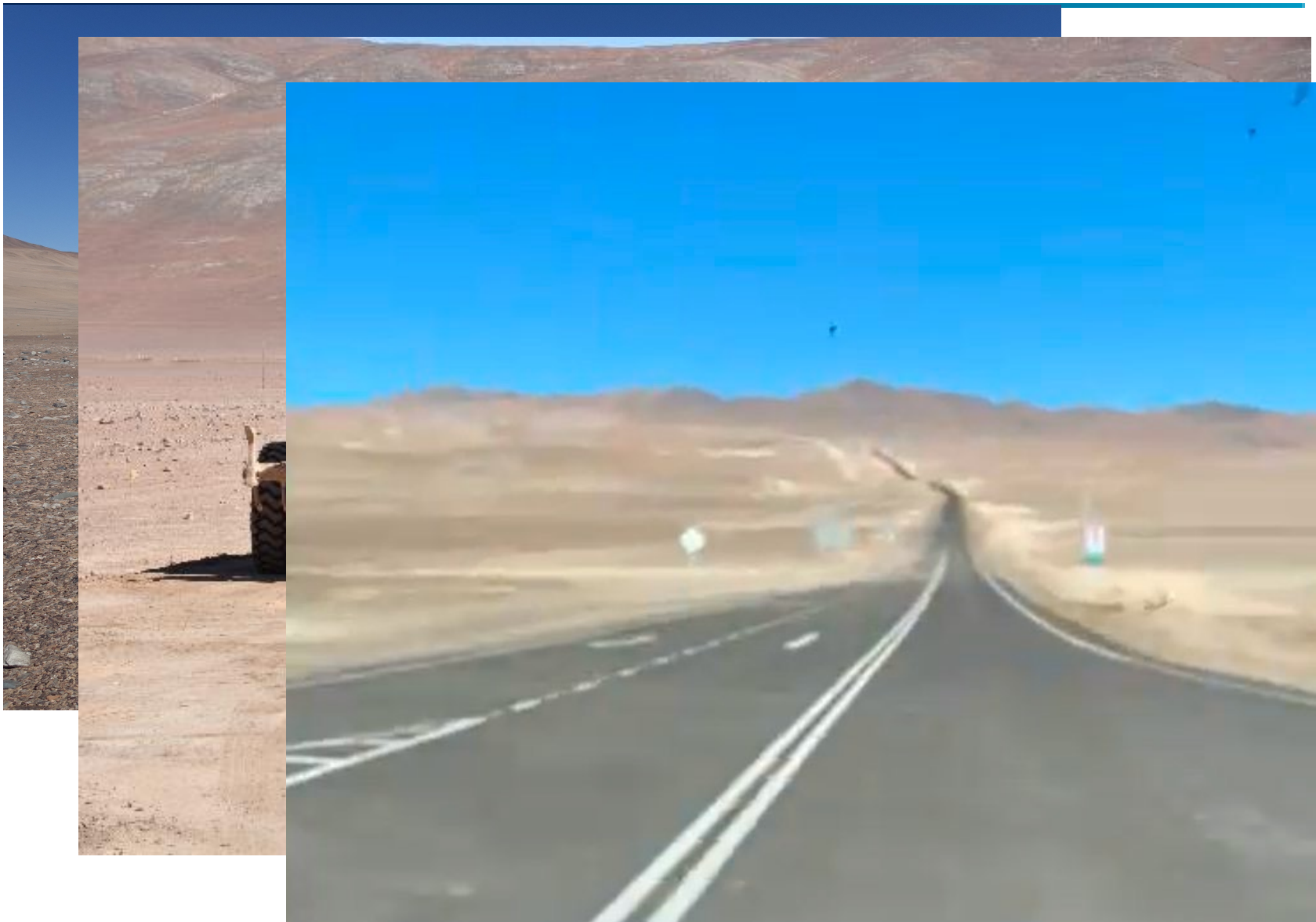
In addition to telescopes, there are other array elements:

- 1 Raman Lidar
- 1 wide-FoV stellar photometer
- 1 moon/sun photometer
- 1 ceilometer
- 1 all-sky camera
- 3 weather station towers
- 2 illuminators

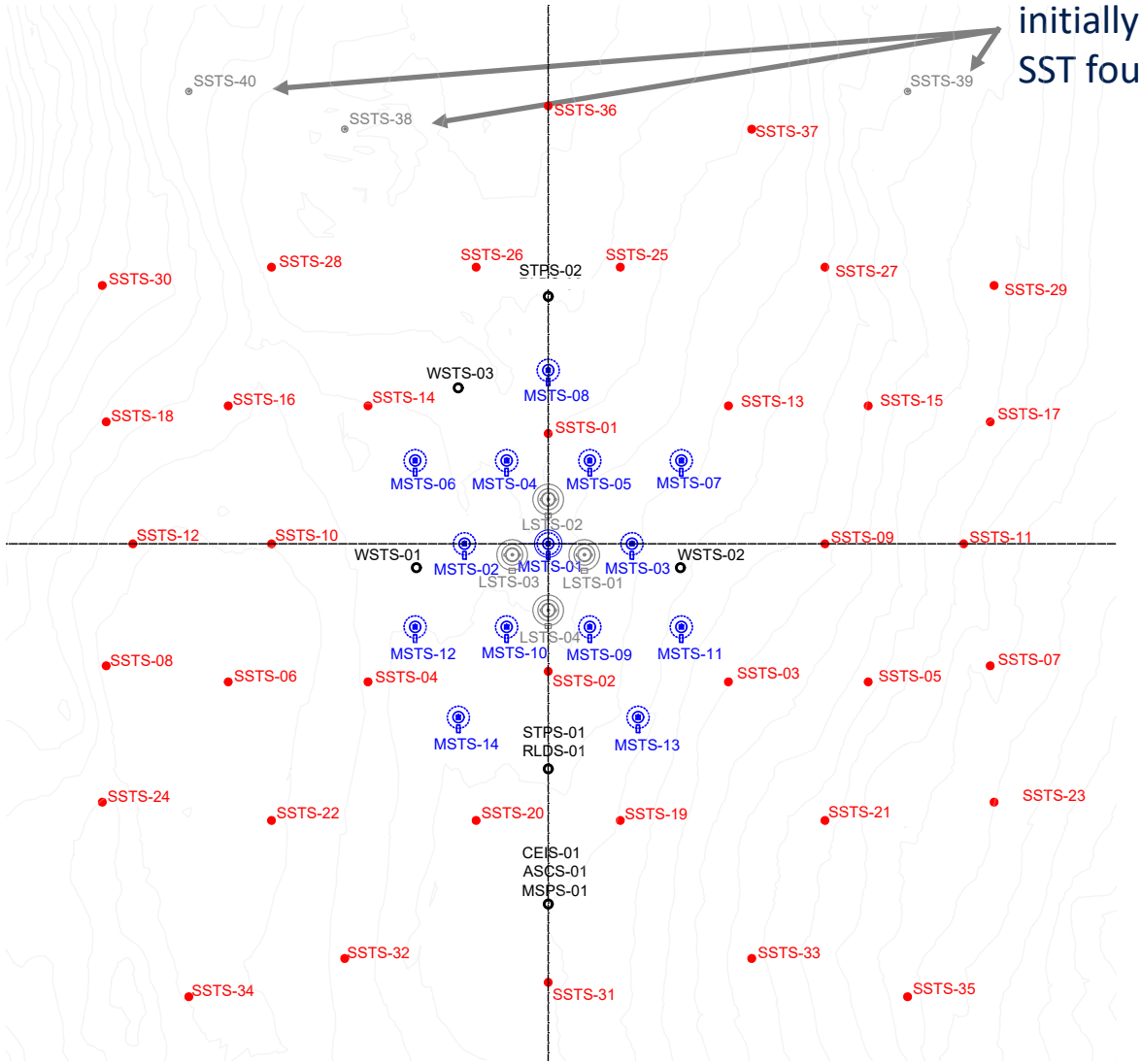
CTAO-South site



CTAO South Access Road



α configuration – CTAO-S layout



CTAO Southern Array - α *configuration*

- **14 MSTs** equipped with FlashCam
- **37 SSTs** out which 2 are located within the MST sub-array, i.e. internal SSTs
- **3 extra SST foundations** that will remain unpopulated
- **4 excavations for LST foundations** (preparatory work)

→ **51 telescopes**, but 58 telescope positions

+ 2/3 LST + 5 SST thanks to Italian extra contribution

In addition to telescopes, there are other array elements:

- 1 Raman Lidar
- 2 wide-FoV stellar photometers
- 1 moon/sun photometer
- 1 ceilometer
- 1 all-sky camera
- 3 weather station towers
- 2 illuminators

Czech Contributions to CTAO – 1

Atmospheric calibration of the observed field-of-view

- The Czech Academy of Science (FZU), Prague, contributes 3 FRAMs, also called "wide-field stellar photometer" (1 for CTAO-N; 2 for CTAO-S) and 2 Sun/Moon photometers.
- It must be highlighted here that these 5 instruments (!) already exist on the respective sites and are taking data in a very stable manner, helping CTAO to better characterize the sites.

Monitoring of atmospheric extinction and clouds across the whole sky

- The Czech Academy of Science, **Olomouc** contributes 2 All-Sky-Cameras, one for each site, which are already taking data on the respective sites, also in an extremely stable manner.
- The Czech Academy of Science, **Prague** contributes 2 Ceilometers, one for each site, which are not yet on site.

Czech Contributions to CTAO - 2

Calibration Algorithms

- The University of Prague contributes the algorithm for the Cherenkov Transparency Coefficient (CTC), which has already been published in Astroparticle Physics, but requires still implementation in the onsite analysis.

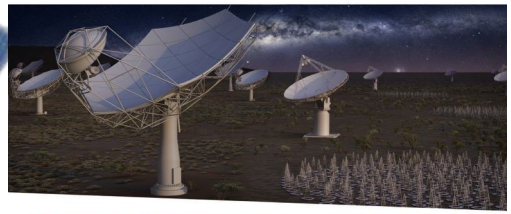
Site characterization

- The Czech groups have been very active in the CTAO site selection and characterization through the analysis of images from the All-Sky-Camera and the FRAMs. This work has not been recognized as an IKC. However, Jan Ebr from FZU Prague has been seconded to CTAO in order to archive these data properly in the framework of DPPS.

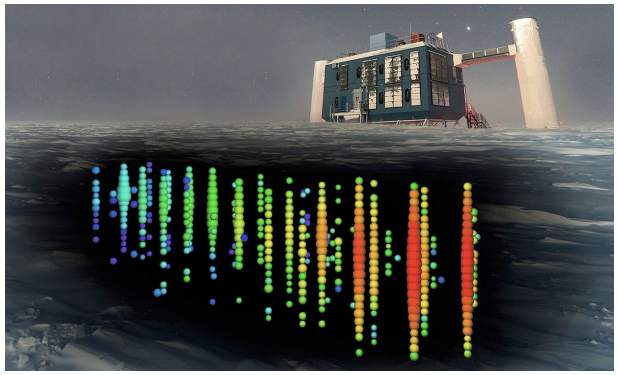
Synergies …

- gamma-ray satellites (Fermi) and ground-based wide-FoV detectors (HAWC, LHAASO)
- radio (SKA and its precursors)
- X-rays (eROSITA and later Athena)
- High-energy neutrino and GW detectors (LIGO/Virgo/KAGRA)
- Cosmic Rays (Auger)
- Dark Matter (CERN)

SKA

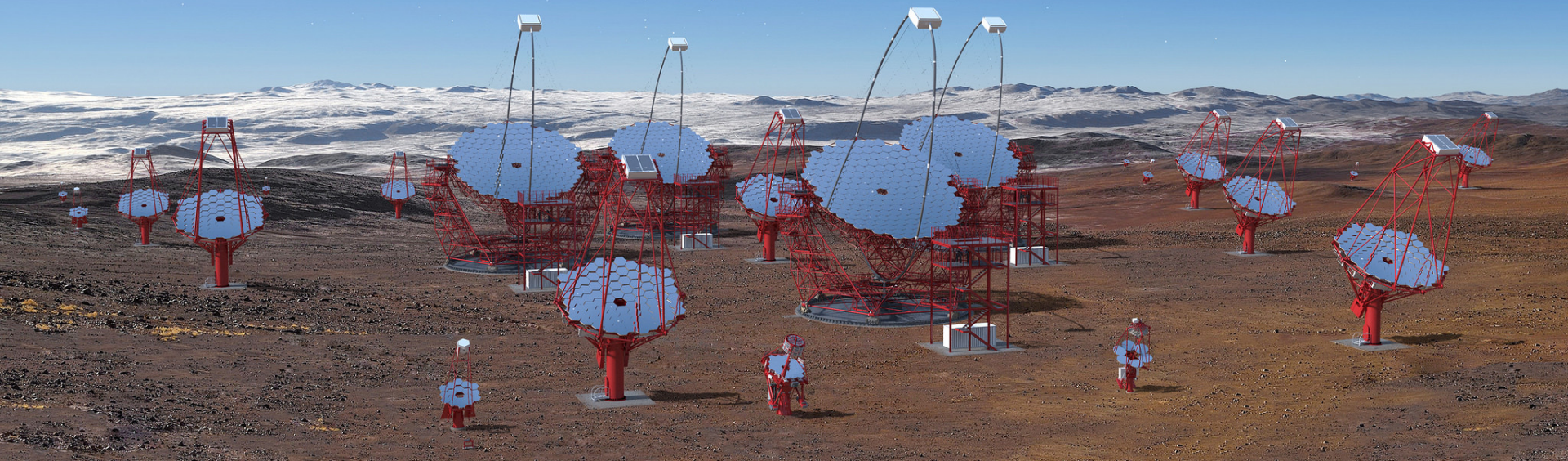


SQUARE KILOMETRE ARRAY
Exploring the Universe with the world's largest radio telescope



Conclusions

- CTAO planned as a major new international user facility
- Two array sites selected, North site being equipped, CTAO HQ in Bologna, Science Data Management Centre in Berlin
- Currently in pre-construction phase, ramping up for construction
- Great science ahead!



cherenkov
telescope
array

Thank you for your attention