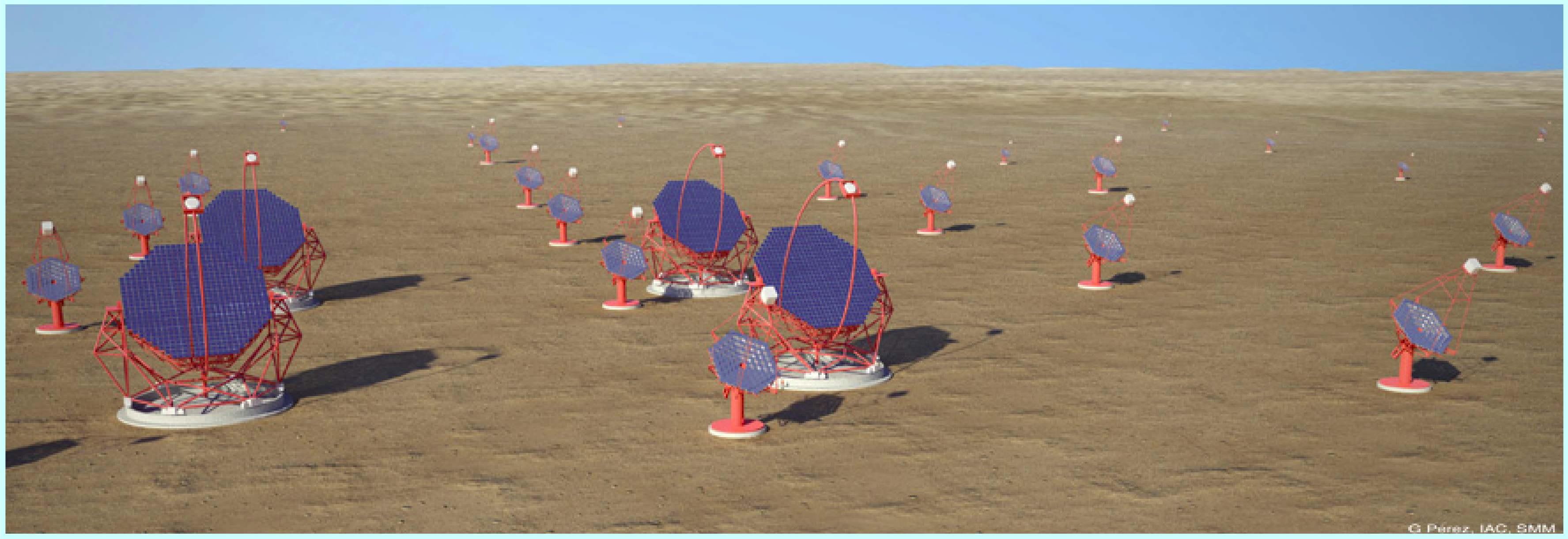
Georgia Tech Physics College of Sciences

cta cherenkov telescope array

The Cherenkov Telescope Array

On behalf of the CTA Consortium

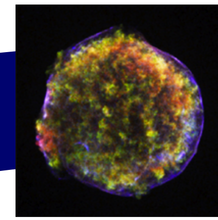


Nepomuk Otte

School of Physics &
Center for Relativistic Astrophysics
Georgia Institute of Technology

Astrophysics and more in the VHE Band

Shocks
Diffusion



SNRs

Jets
Winds

Binaries

Cosmic
rays

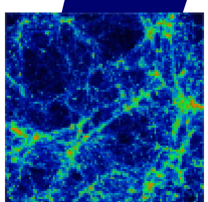
Starbursts

Shocks
Diffusion

Pulsars/
PWN

Jets
Accretion

AGN



Dark
matter

Jets
Shocks

GRBs

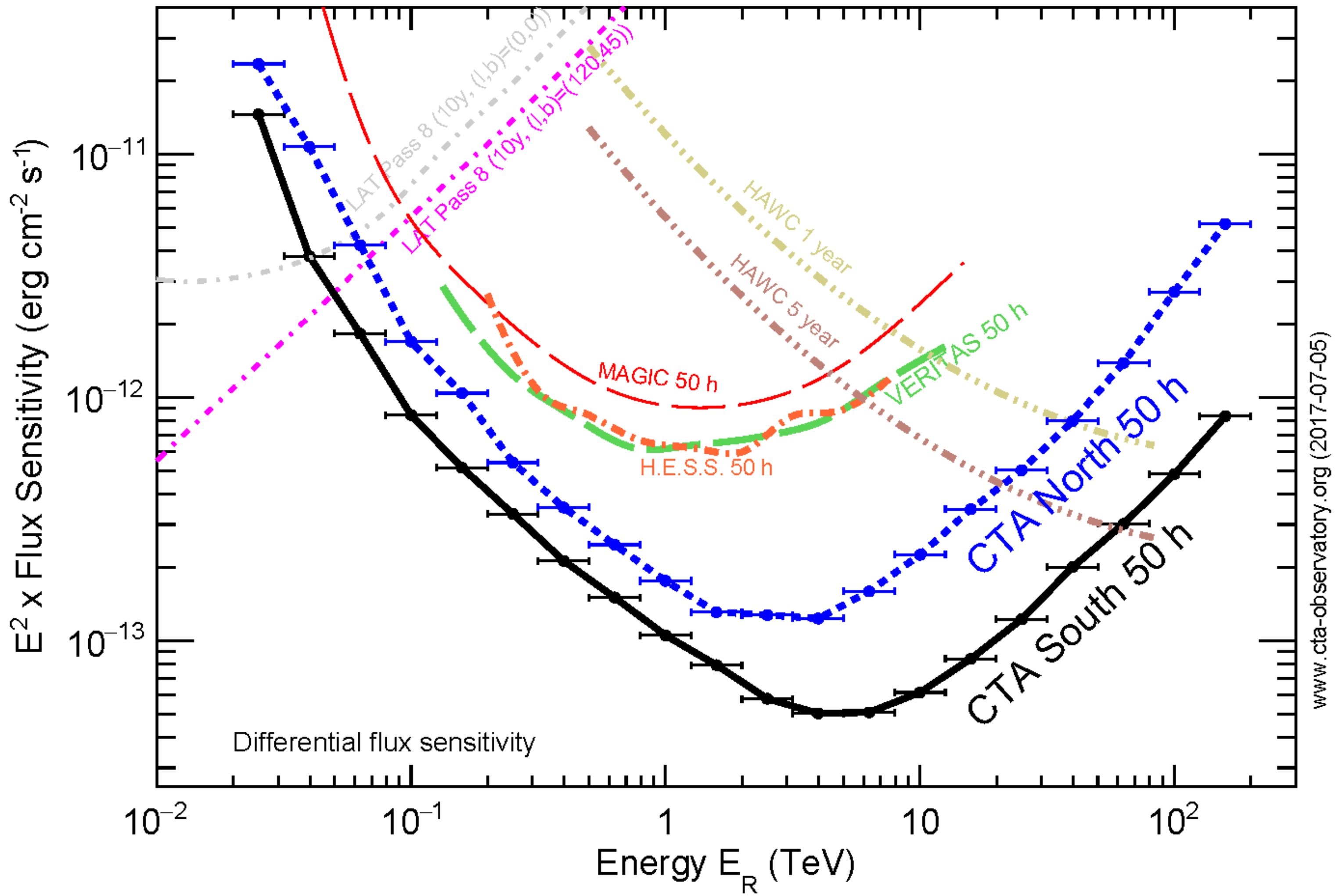
Intergalactic
medium

EBL
IGM

VHE gamma rays probe

Particle acceleration and propagation
Cosmic rays
Highest energy processes in a large variety of objects
Intergalactic medium
Dark matter and fundamental physics

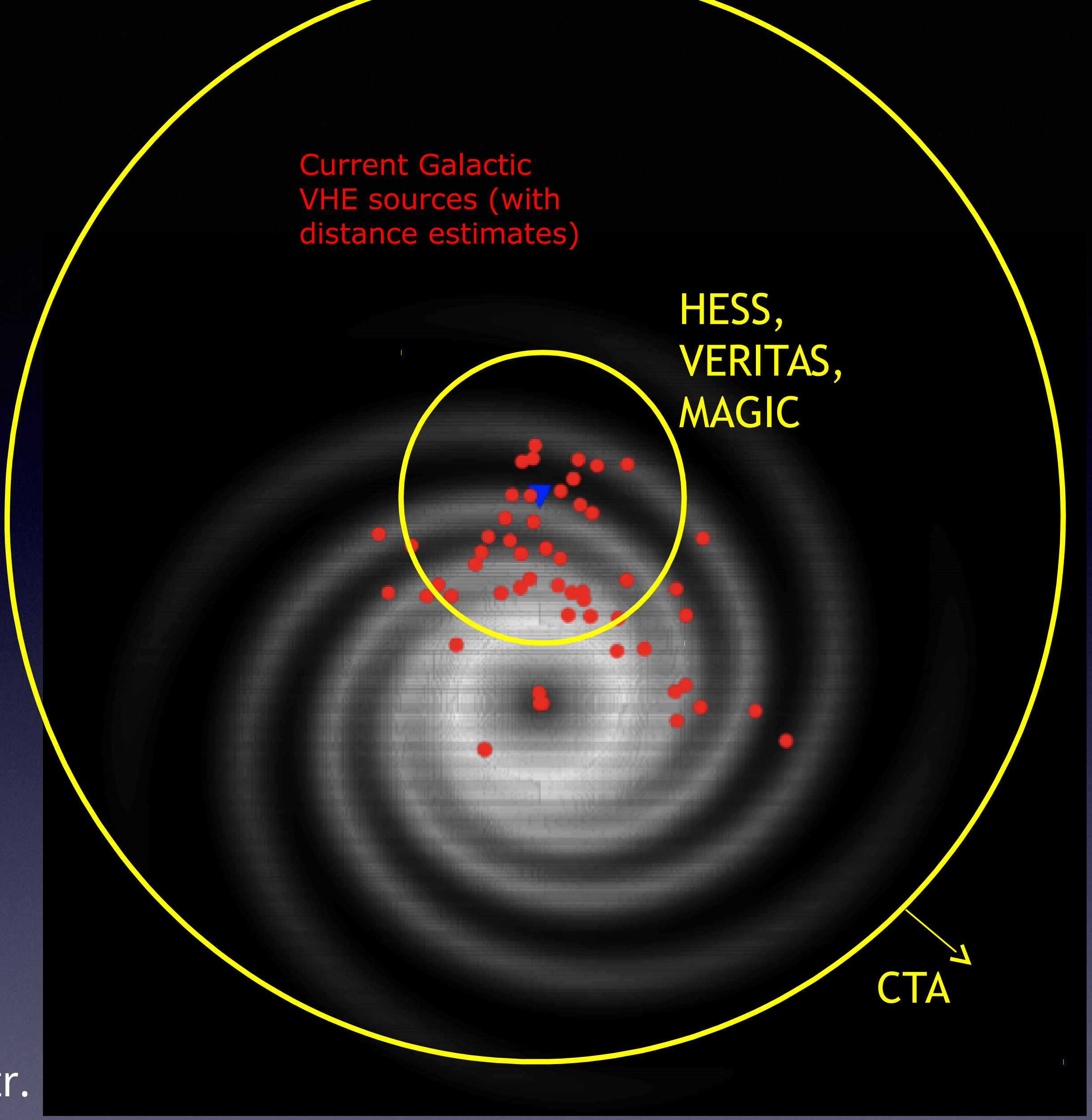
Differential Flux Sensitivity



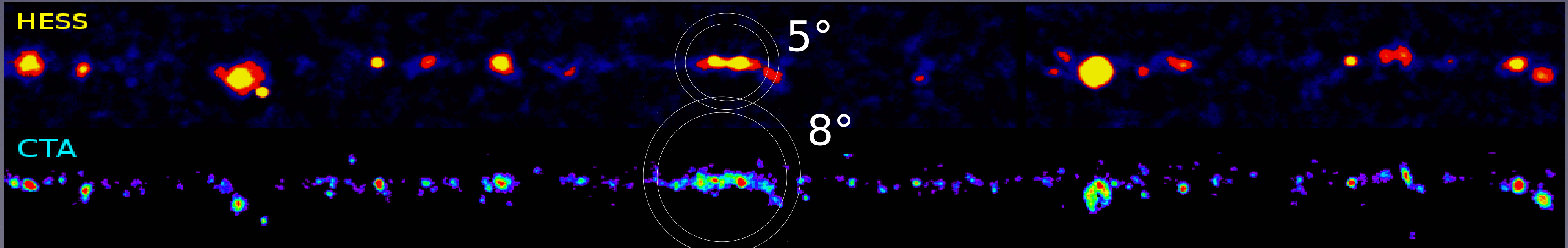
Major sensitivity improvement & wider energy range

-> Factor of ~x10 increase in source population

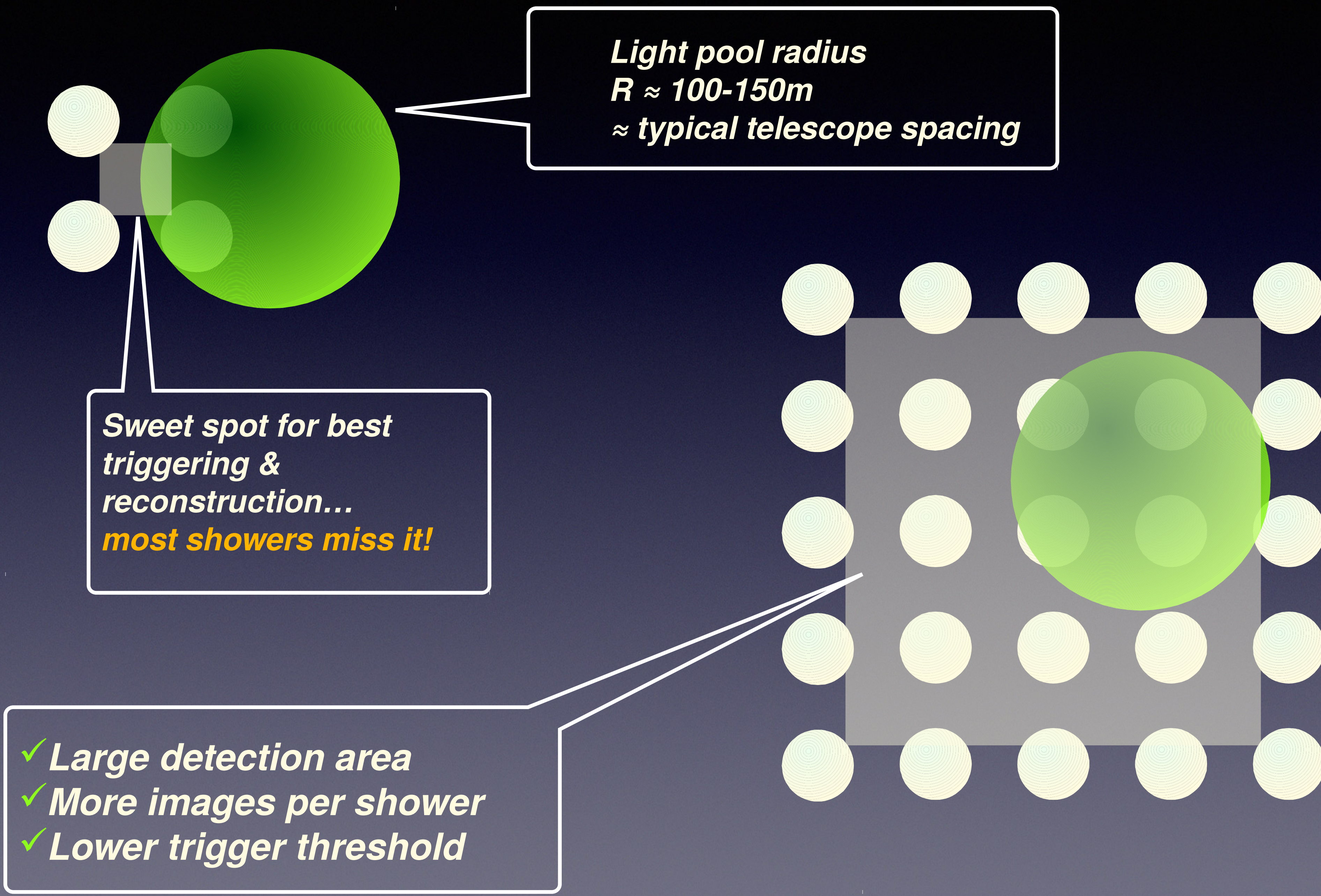
Galactic Discovery Reach

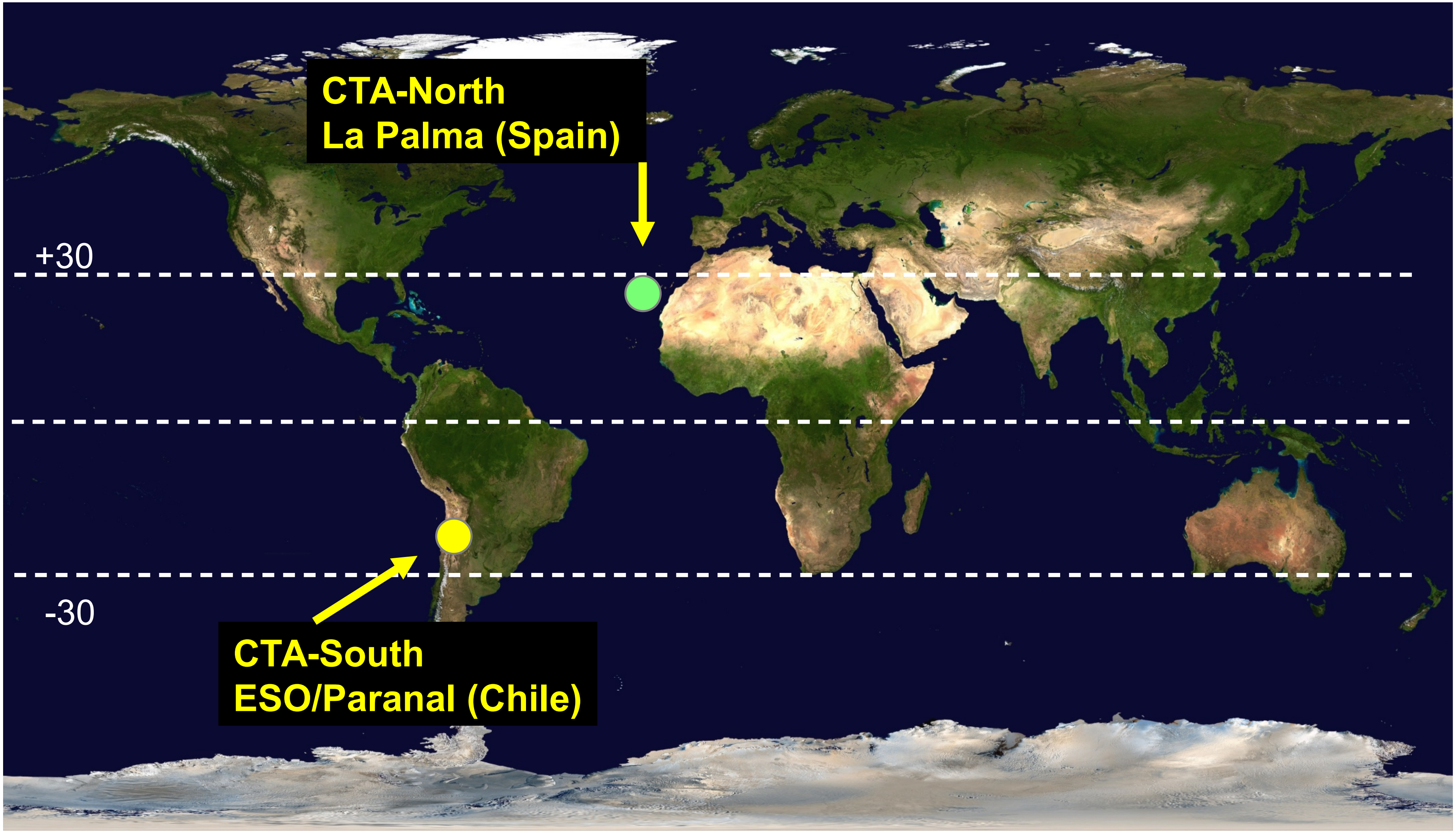


Survey speed:
x300 faster than current instr.



From current arrays to CTA




CTA-North
La Palma (Spain)
+30
-30
CTA-South
ESO/Paranal (Chile)

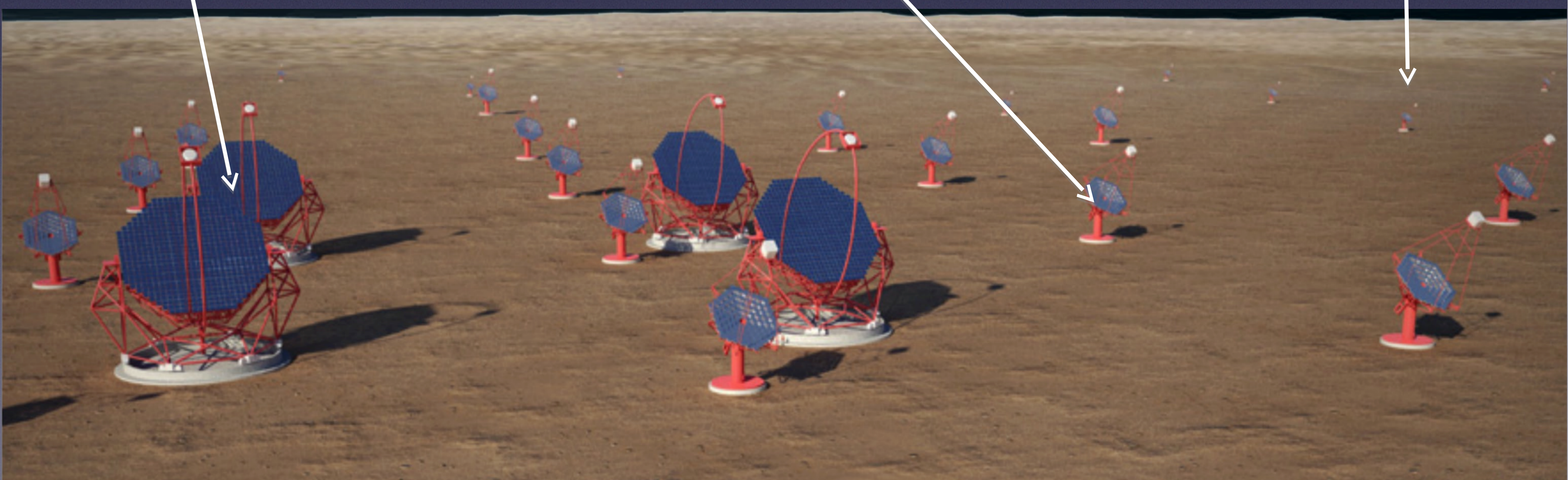
CTA Design (S array)

science optimization under budget constraints

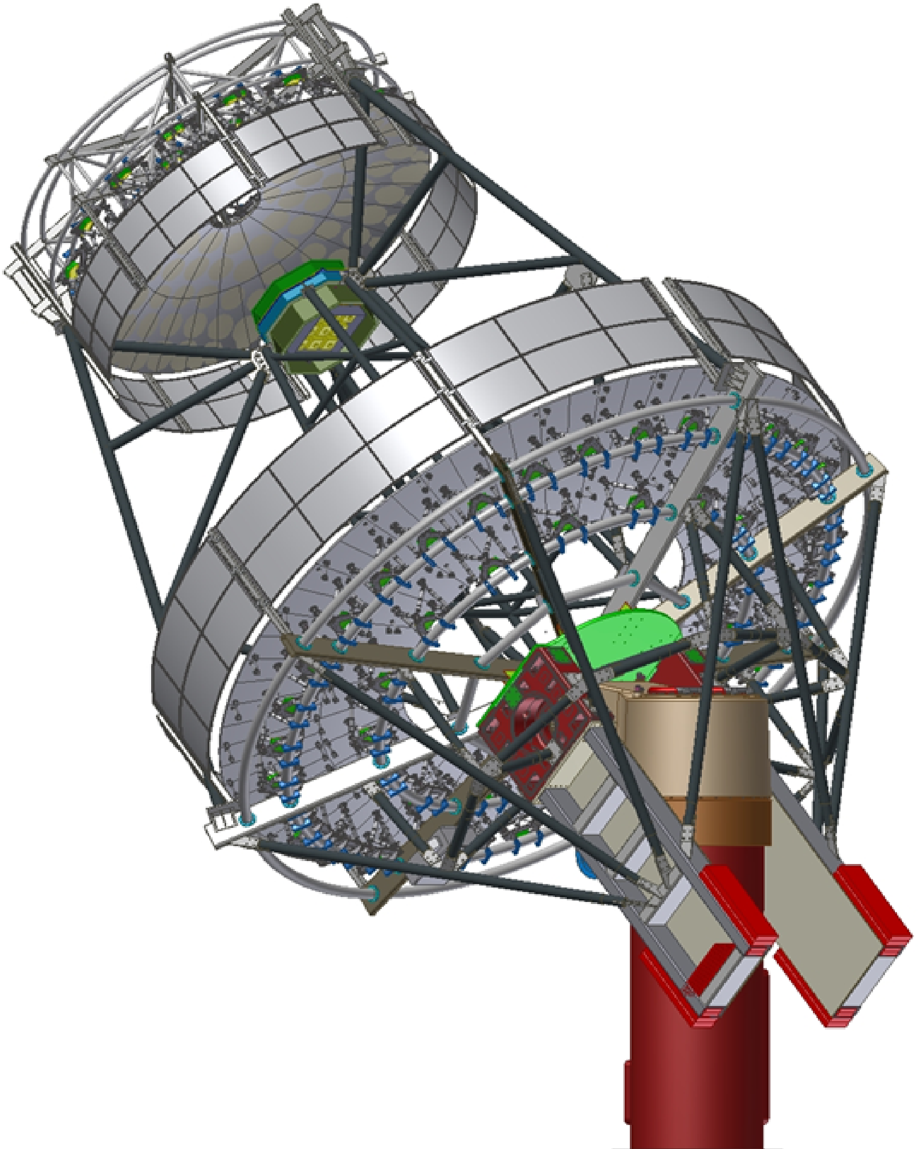
Low energies
Energy threshold 20-30 GeV
23 m diameter
4 telescopes
(LST's)

Medium energies
100 GeV – 10 TeV
9.7 to 12 m diameter
25 telescopes
(MST's/SCT's)

High energies
Up to 300 TeV
10 km^2 area at few TeV
4m diameter
70 telescopes
(SST's)



Medium-Sized 2-Mirror Telescope (SCT)



9.7 m primary
5.4 m secondary
5.6 m focal length, f/0.58
50 m^2 mirror dish area
PSF better than 4.5'
across 8° FOV

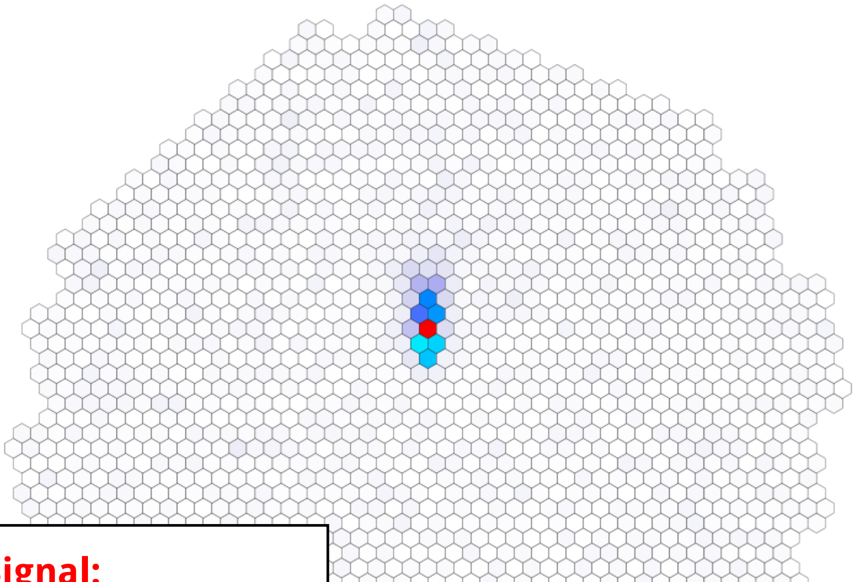
8° field of view
11328 x 0.06° SiPM pixels
TARGET readout ASIC

SCTs can augment / replace MSTs in either S or N
proposed US contribution

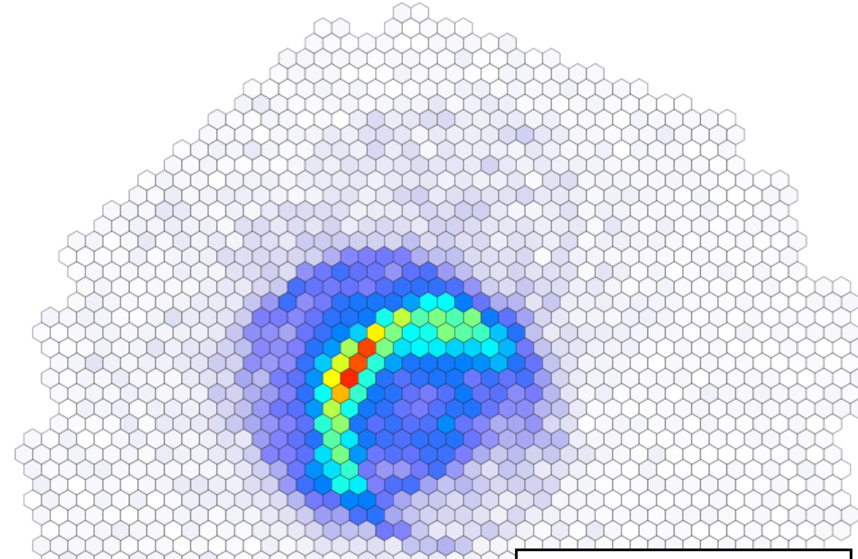
→ Increased γ-ray collection area
→ Improved γ-ray ang. resolution
→ Improved DM sensitivity

SCT: Superior Imaging

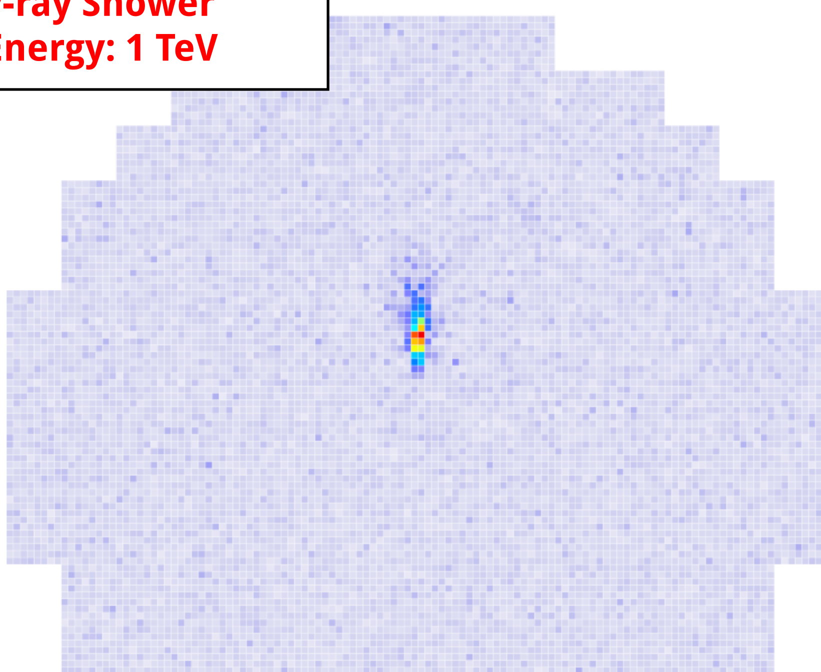
Better optical performance across field of view → use higher resolution camera



“Baseline”
Single-Mirror
Telescope Images
8° field of view
0.18° pixels
1,800 channels

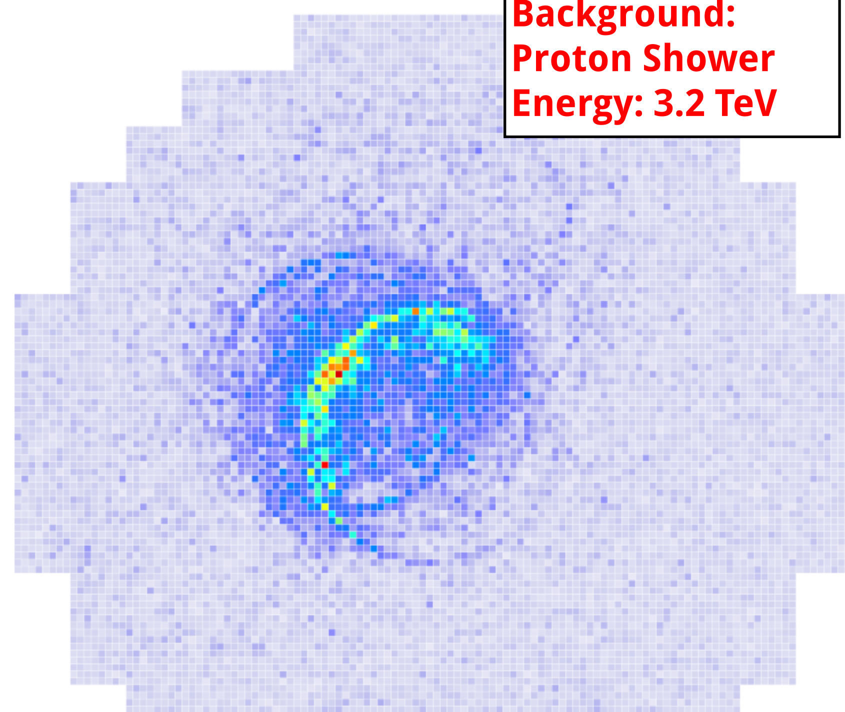


Signal:
γ-ray Shower
Energy: 1 TeV



SCT
Two-Mirror
Telescope Images
8° field of view
0.067° pixels
11,328 channels

Background:
Proton Shower
Energy: 3.2 TeV

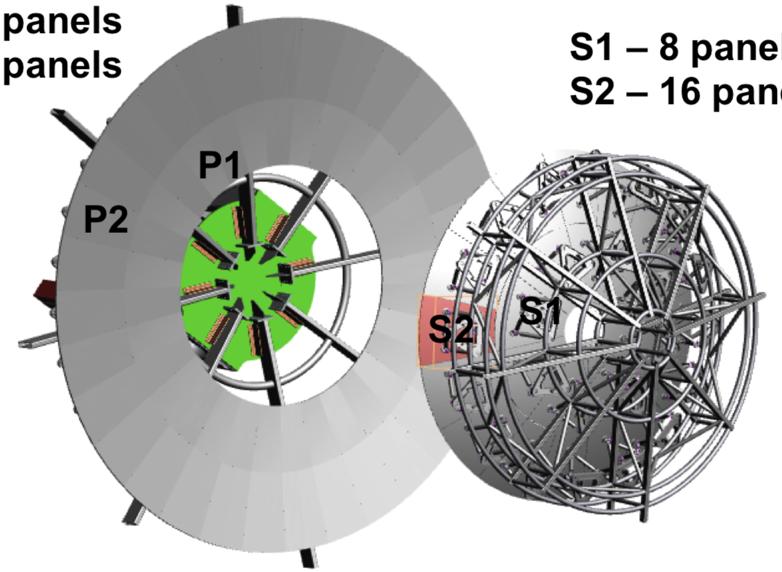


Prototype construction in Arizona

http://cta-psct.physics.ucla.edu

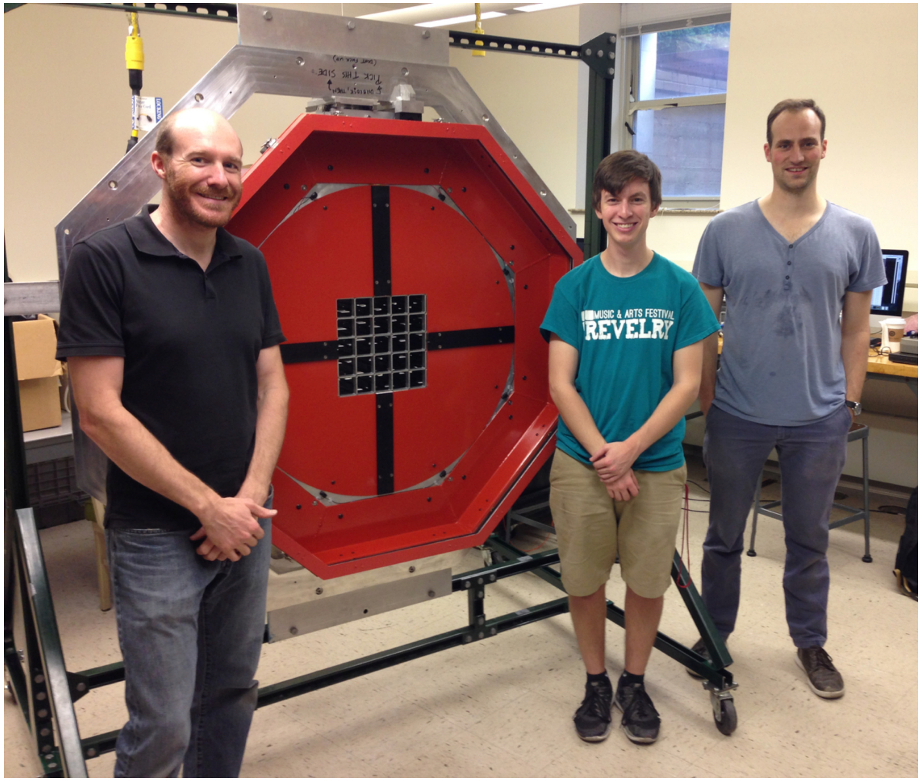
live web cam

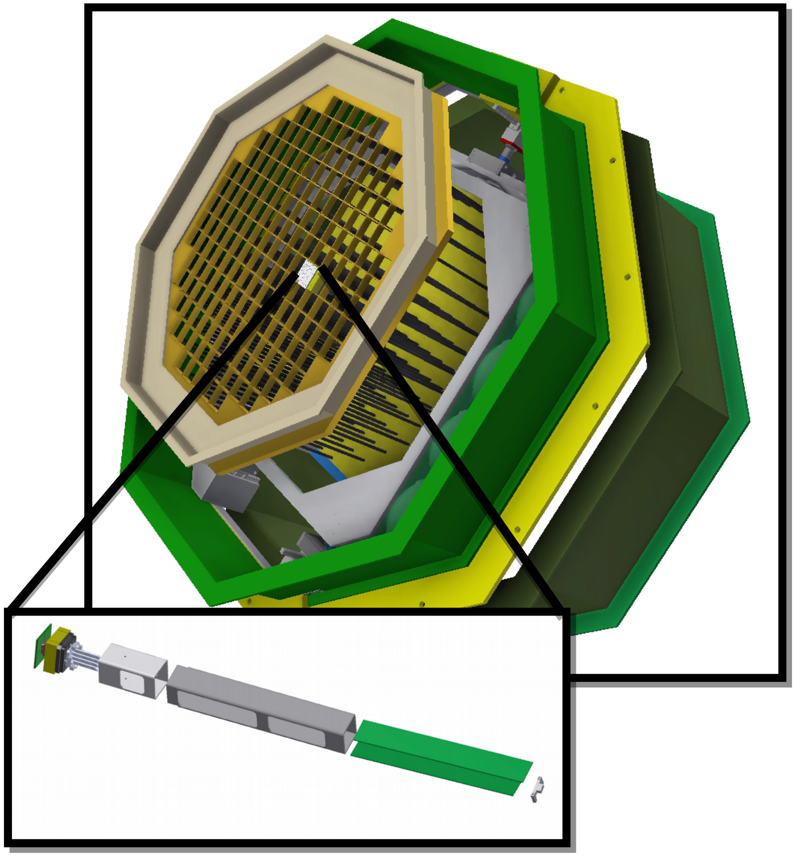
Mirrors



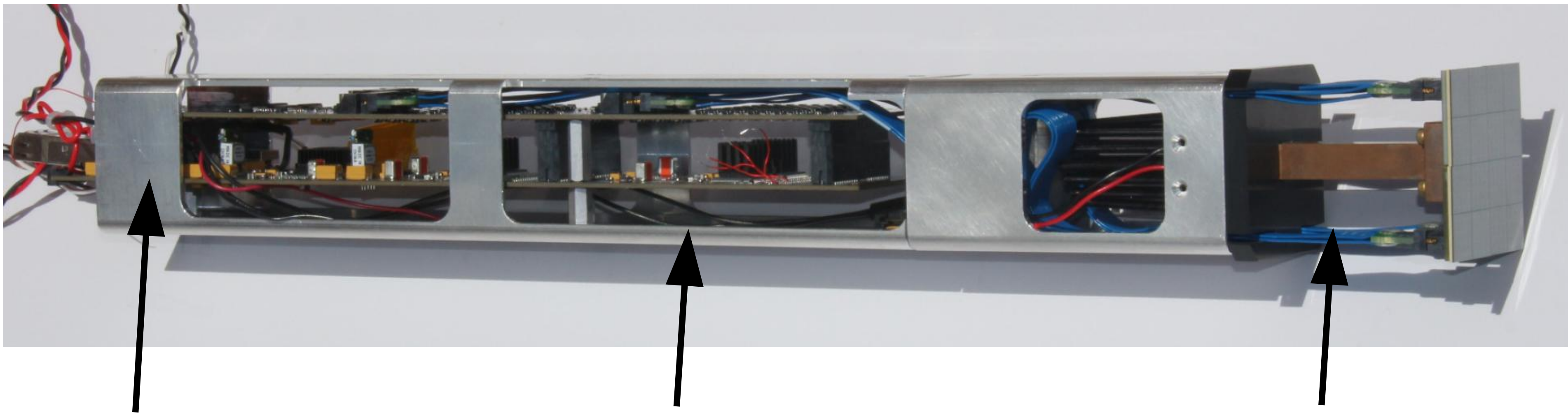
- All primary panels completed and delivered
- S1: 4 of 20 pre-shaped glass foils sent from Flabeg to Media Lario for assembly into panels
- S2: 39 of 40 glass foils sent from Flabeg to Media Lario for panel assembly
- Metrology of S2 panels underway before coating
- Coating of all S1 and S2 panels to be completed this summer
- Mounting on telescope expected in fall 2017

Camera





Camera Modules



module cage

- Spring-loaded slip joint design allows thermal breathing without distorting the focal plane.

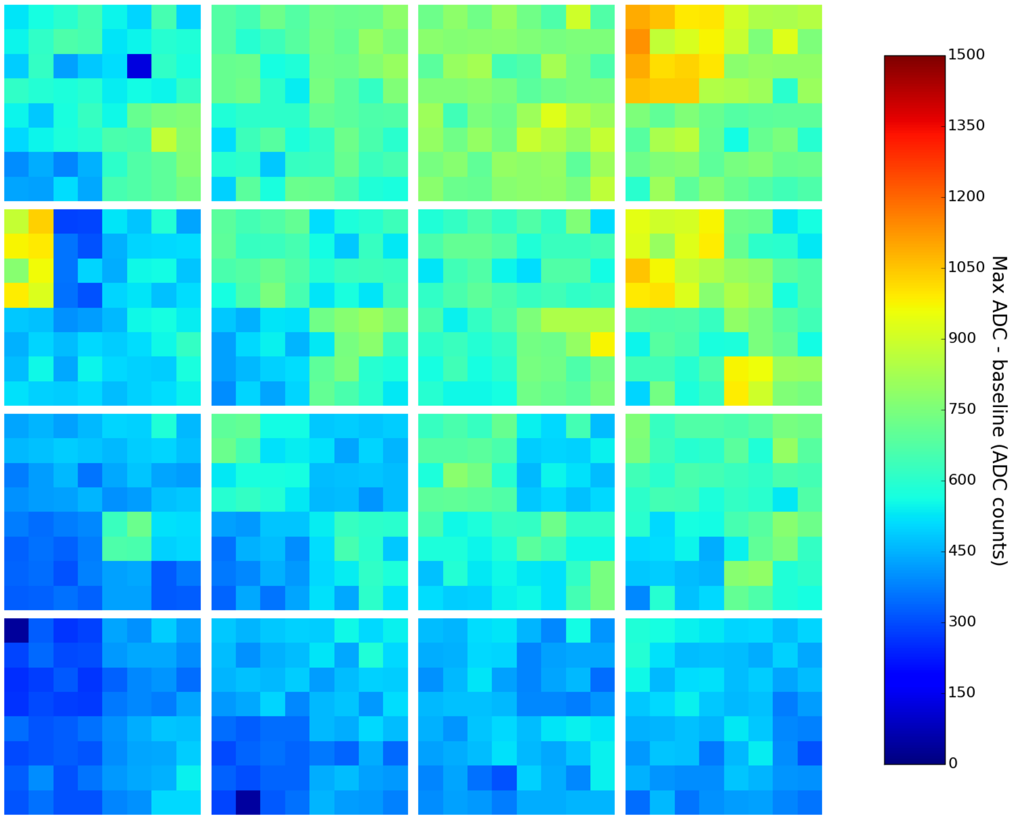
front-end electronic boards

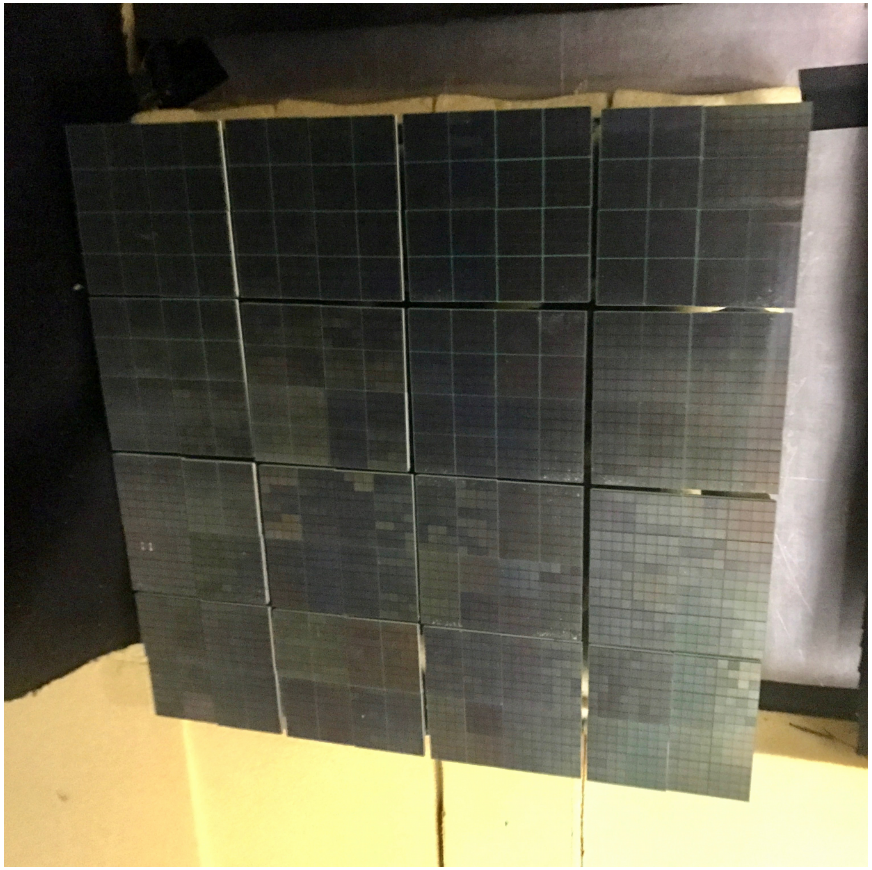
- Preamplifiers
- TARGET7 digitizer and trigger
- SiPM power distribution and trim
- SiPM temperature controller

focal plane module

- Silicon photomultipliers
- Height registry
- Temperature controlled

First Light: LED Flasher

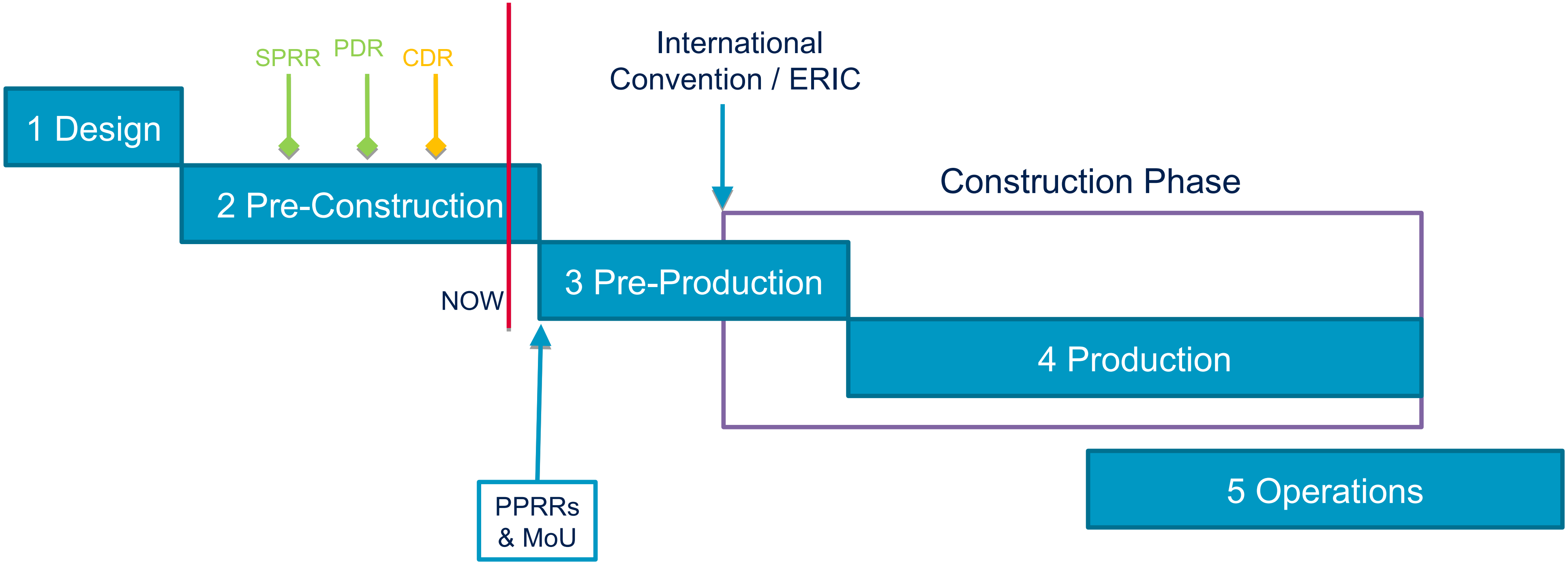




16 modules (1024 channels) installed

Flasher design based on STFC funded GCT calibration system, provided by Durham University.

CTA Phases & Timeline



- 2016-7: Hosting agreements, site preparations start
- 2018: Start of construction
- Funding level at ~65% required for *baseline implementation*
  - start with *threshold implementation*
  - additional funding & telescopes needed to complete baseline CTA
- Construction period of ~6 years
- Initial science with partial arrays possible before construction end

Summary

- CTA is the next generation imaging atmospheric Cherenkov array
  - Ten times improvement in sensitivity will truly open the VHE sky (milliCrab sensitivity)
  - Resolve transients < 1 minute
  - 2 arcminute angular resolution @ 1 TeV
  - Open observatory
    - Data released to public after proprietary period
    - Only member countries can propose observations and work with proprietary data
- Prototyping of all telescopes is well under way
  - PSCT completed by the end of the year

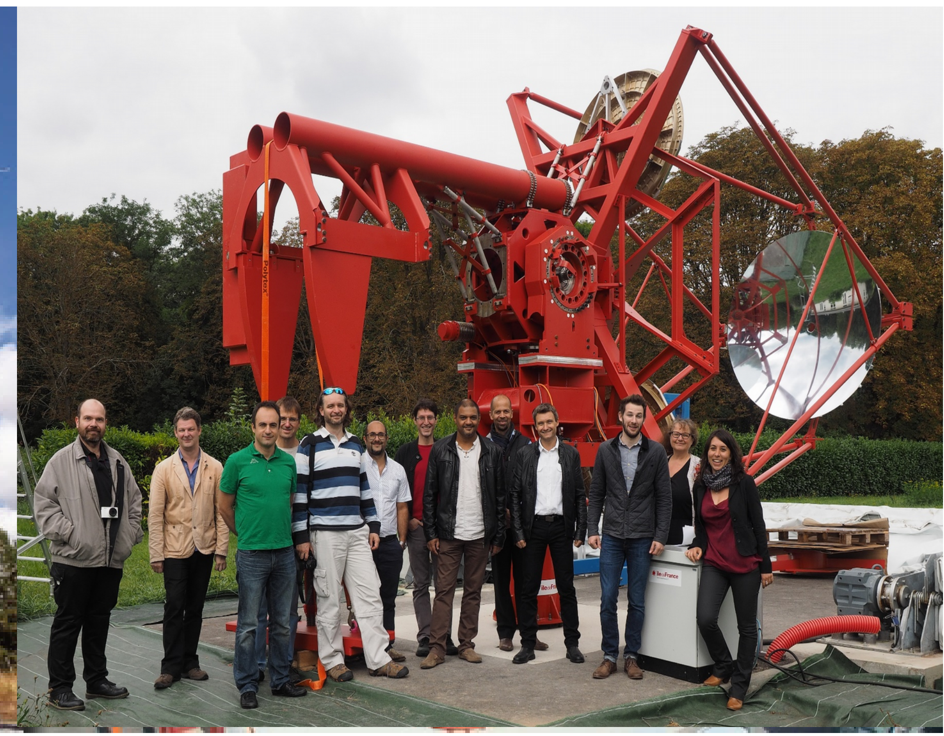
Backup

Small Telescopes (SSTs)

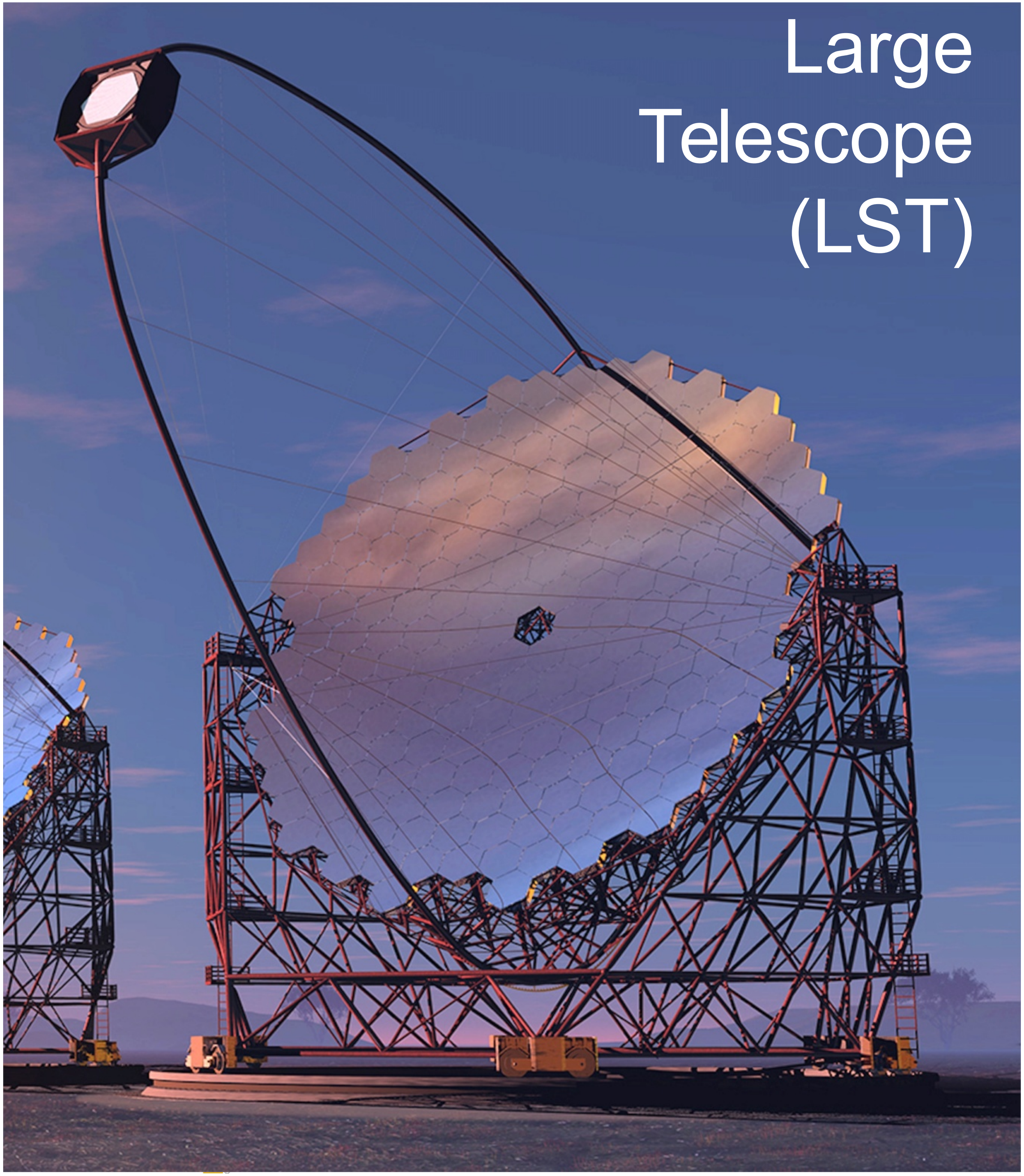
- 3 different prototype designs
- 2 designs use two-mirror approaches (Schwarzschild-Couder design)
- All use SiPM as photosensors
- 7-9 m^2 mirror area, FOV of 9°

SST-1M
Krakow, Poland

SST-2M ASTRI
Mt. Etna, Italy



SST-2M GCT
Meudon, France



23 m diameter
390 m^2 dish area
28 m focal length
1.5 m mirror facets

4.5° field of view
0.1° pixels
Camera ∅ over 2 m

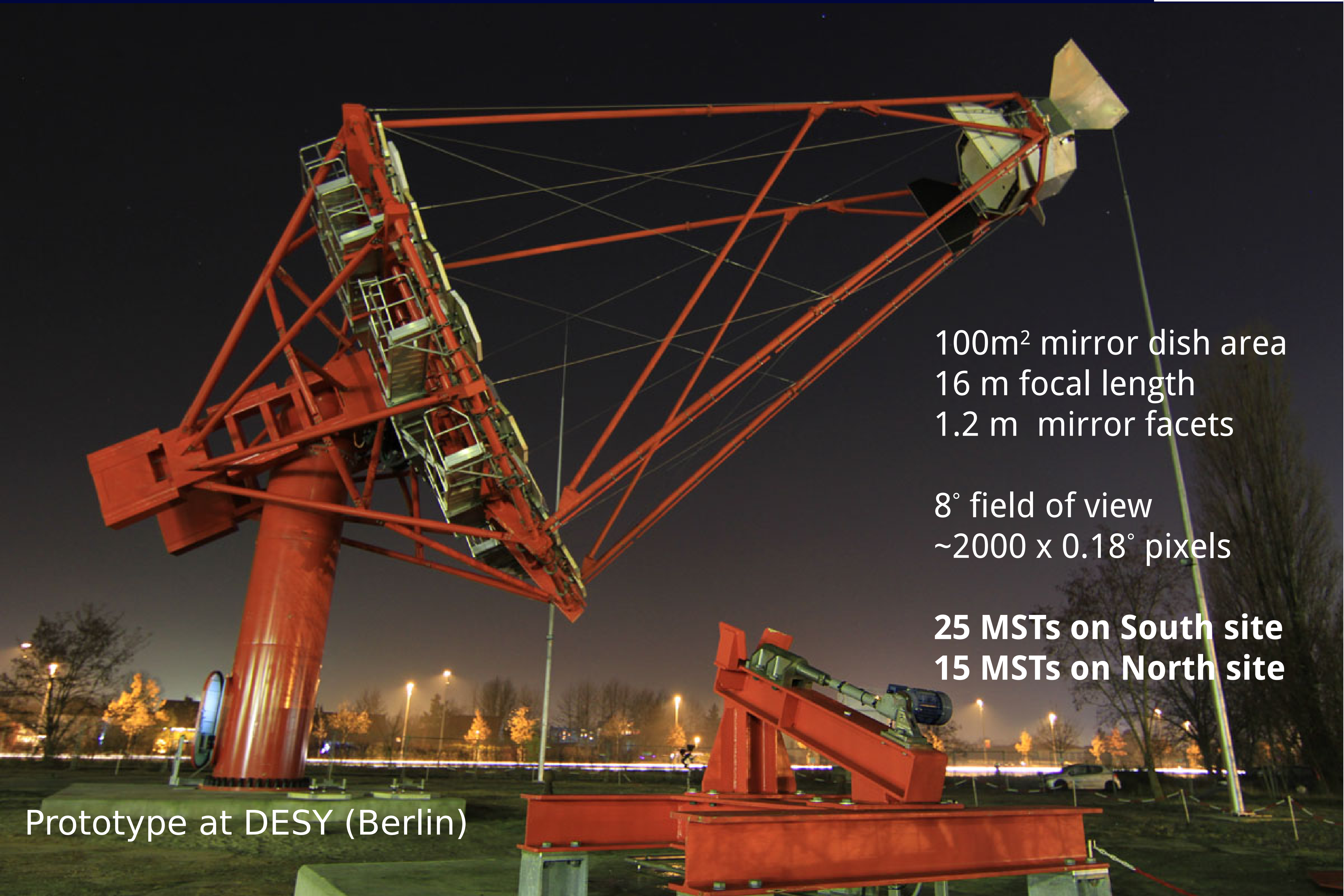
Carbon-fiber structure
for 20 s positioning

Active mirror control

4 LSTs on South site
4 LSTs on North site

Prototype construction
Underway (La Palma)

Medium Telescope (MST)

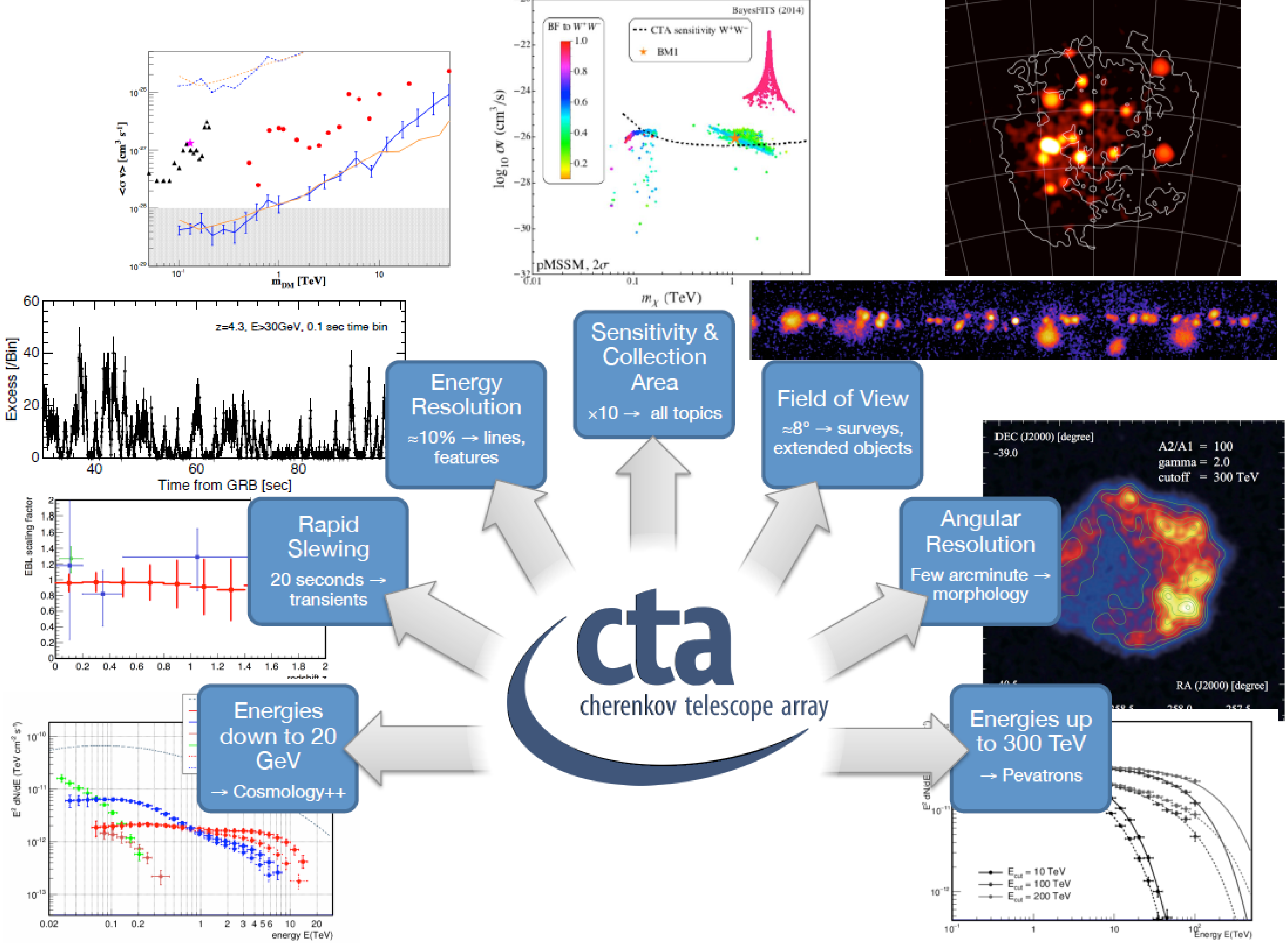


100m² mirror dish area
16 m focal length
1.2 m mirror facets

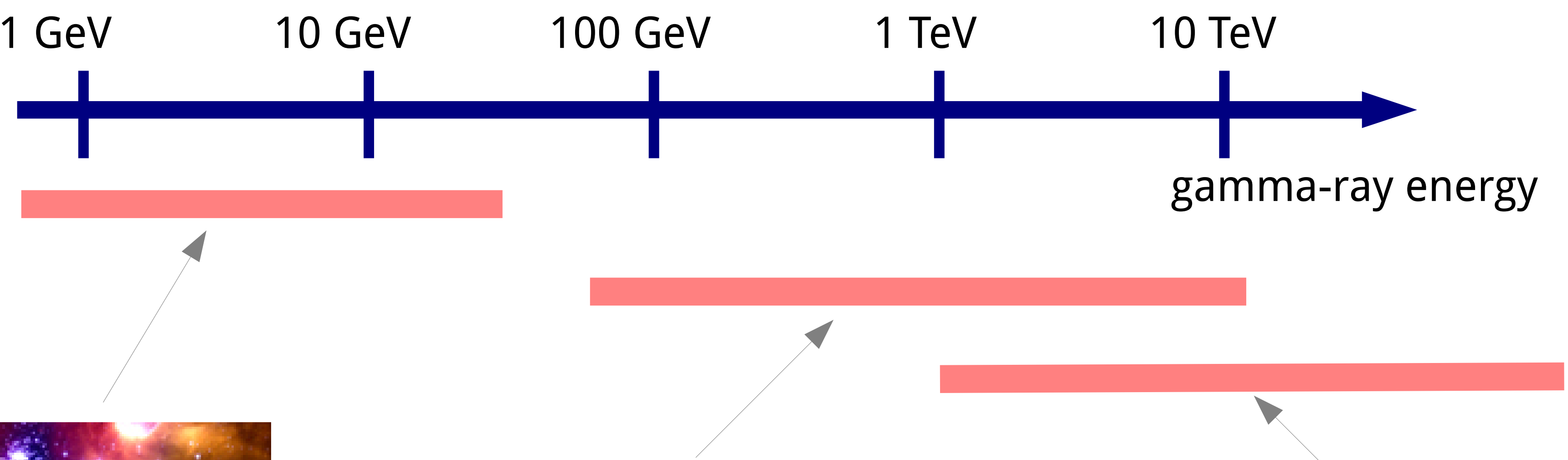
8° field of view
~2000 x 0.18° pixels

25 MSTs on South site
15 MSTs on North site

Prototype at DESY (Berlin)


Energy Resolution
≈10% → lines, features
Sensitivity & Collection Area
×10 → all topics
Field of View
≈8° → surveys, extended objects
Rapid Slewing
20 seconds → transients
Angular Resolution
Few arcminute → morphology
Energies down to 20 GeV
→ Cosmology++
Energies up to 300 TeV
→ Pevatrons
cta
cherenkov telescope array
z=4.3, E>30GeV, 0.1 sec time bin
Excess [/Bin]
Time from GRB [sec]
EBL scaling factor
pMSSM, 2σ
BayesFITS (2014)
CTA sensitivity W⁺W⁻
BM1
DEC (J2000) [degree]
RA (J2000) [degree]
A2/A1 = 100
gamma = 2.0
cutoff = 300 TeV
energy E(TeV)
Energy E(TeV)

Gamma-Ray Instruments

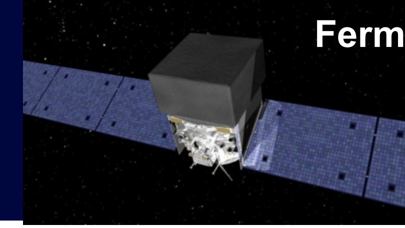


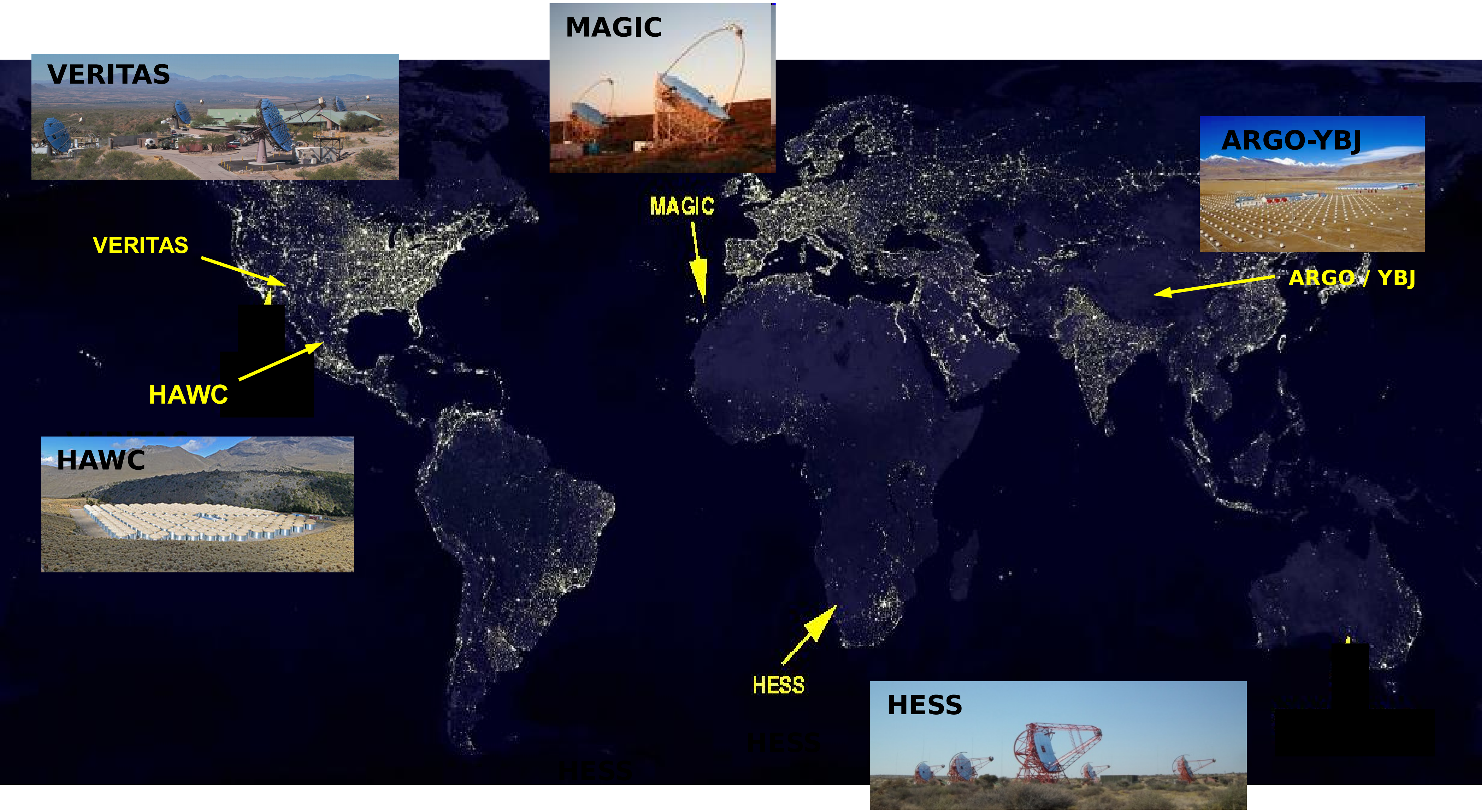
Satellites
Fermi-LAT

Cherenkov telescopes
Like VERITAS and CTA

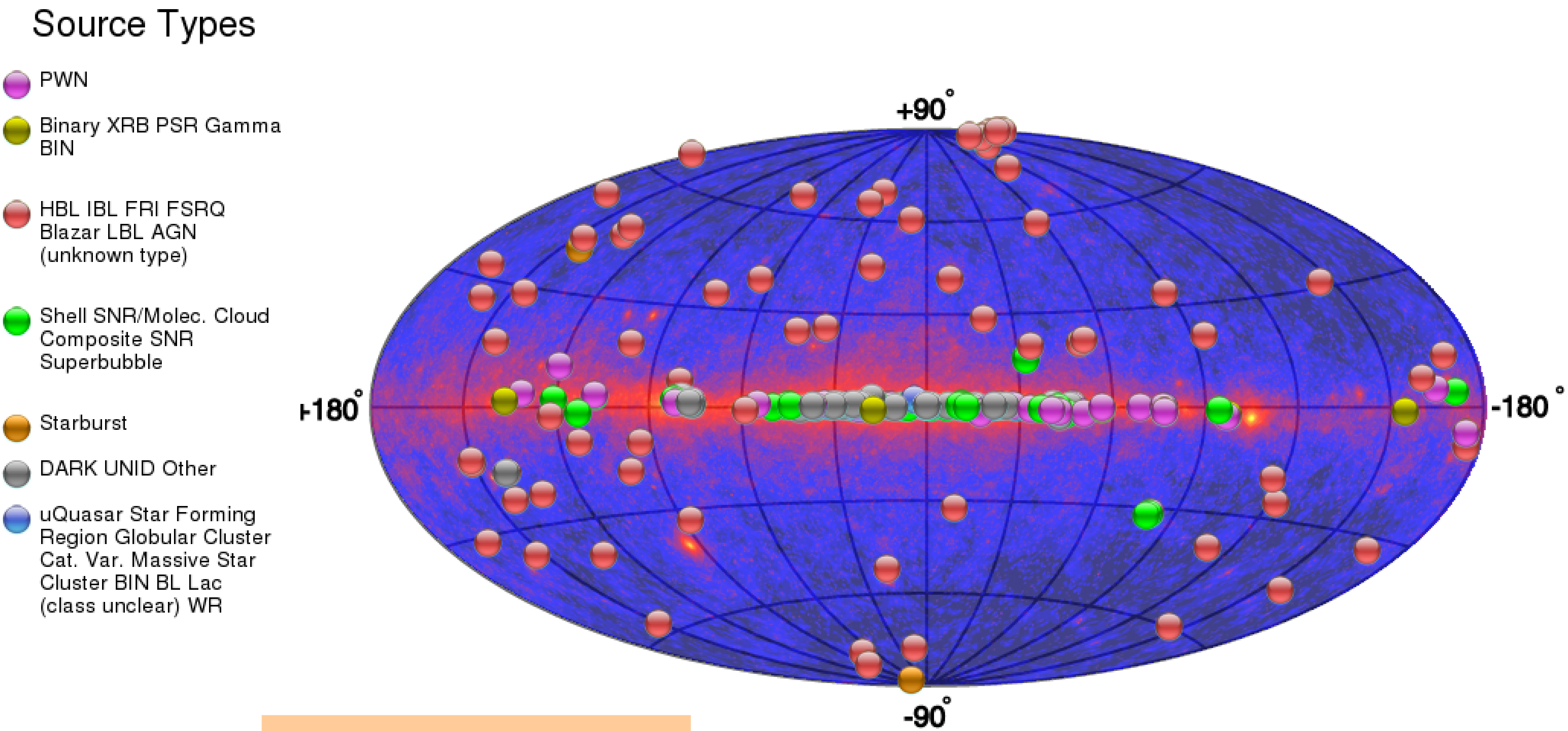
Water Cherenkov detectors
Like HAWC

Gamma Ray Telescopes (2015)





The VHE Sky is bright



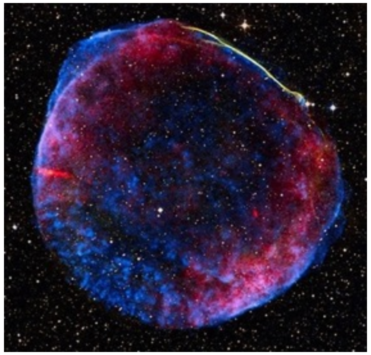
175 sources

Over the past 25 years

http://tevcat.uchicago.edu/

CTA Key Science

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



Probing Extreme Environments
Processes close to neutron stars and black holes?
Processes in relativistic jets, winds and explosions?
Exploring cosmic voids

Physics frontiers – beyond the Standard Model
What is the nature of Dark Matter? How is it distributed?
Is the speed of light a constant for high-energy photons?
Do axion-like particles exist?

Planning for the Future

What do we know, based on current instruments?

Great scientific potential exists in the VHE domain

- *Many more sources & deeper probes for new physics*

IACT technique is very powerful

- *Have not yet reached its full potential -> large Cherenkov array*

Exciting science in both Hemispheres

- *Argues for an array in both S and N*

Open observatory -> Substantial reward

- *Open data/access, MWL connections to get the best science*

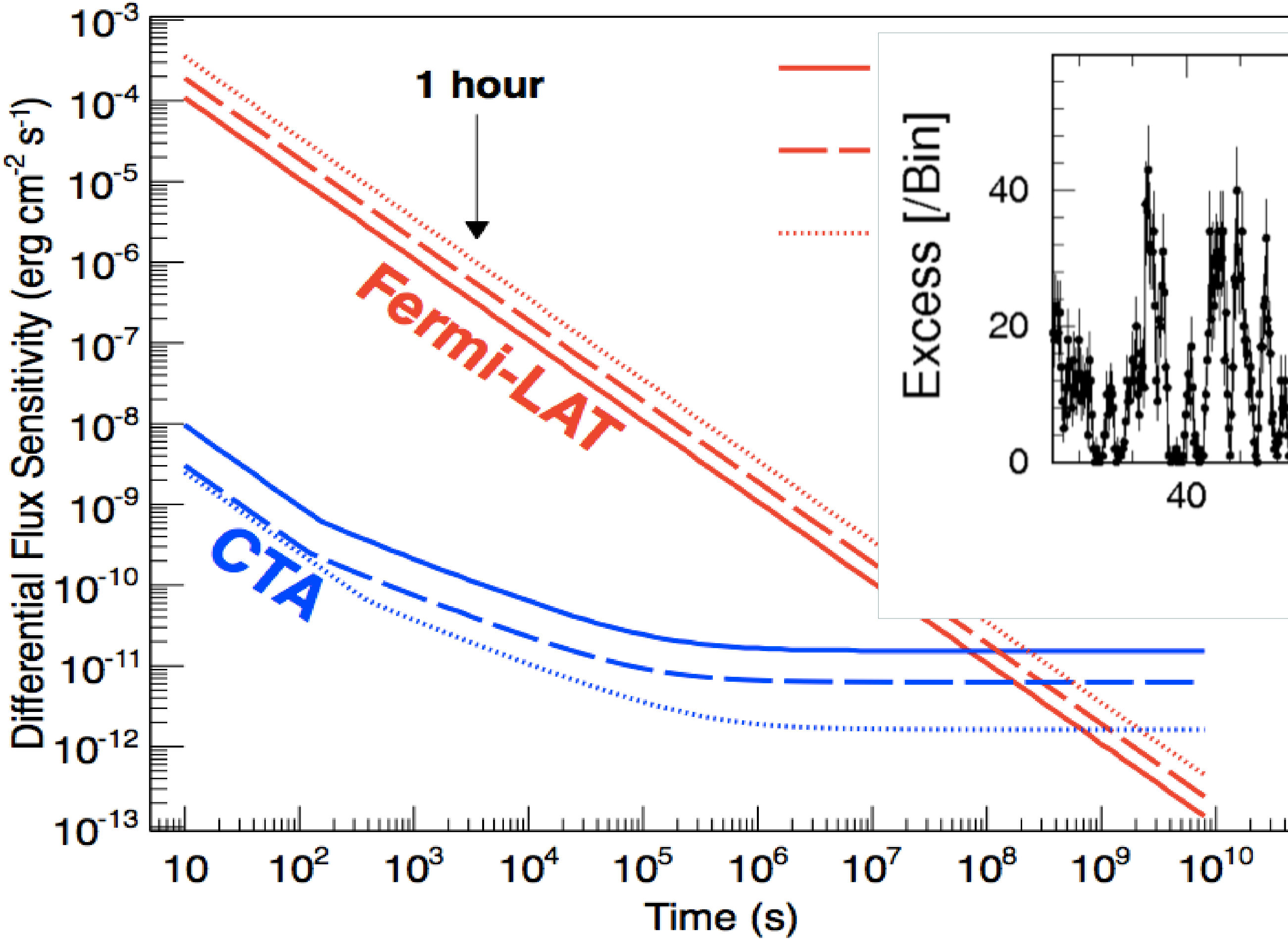
International partnerships required by scale/scope

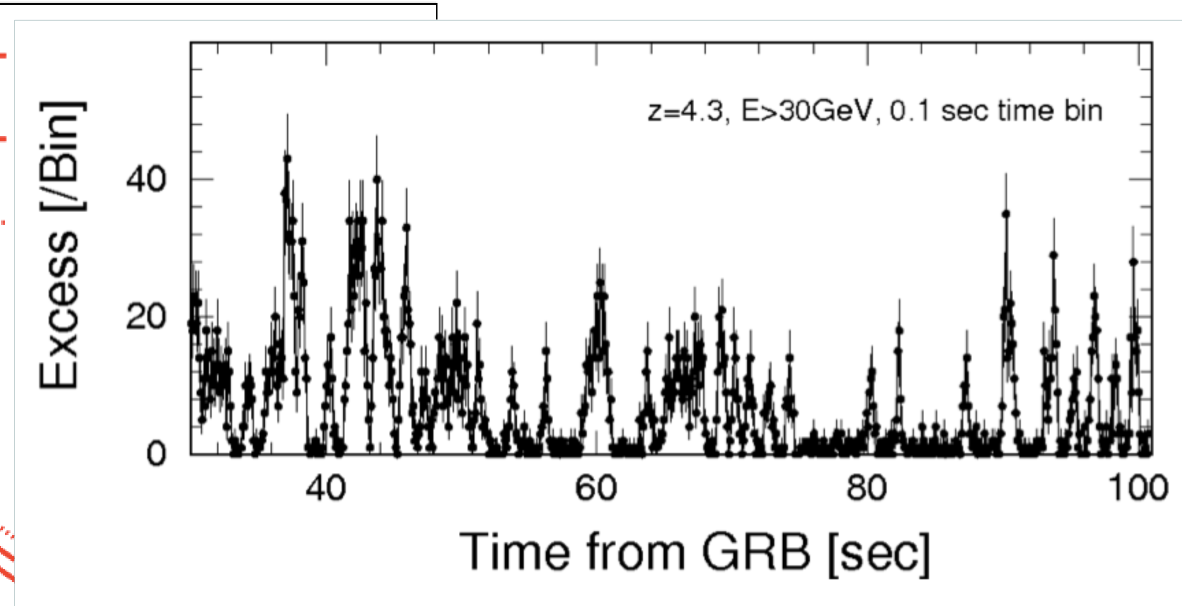
- *CTA must develop the instrument and the observatory*

Transient Capabilities (<100 GeV)

Hinton & Funk
arXiv:1205.0832

S. Inoue et al.,
arXiv:1301.3014





GRB (z=4.3) Light curve

Huge potential for short-timescale phenomena
(GRB's, AGN, Micro-quasars, etc.)

Benefits of Large IACT Arrays

Detection of more photons

→ Larger collection area

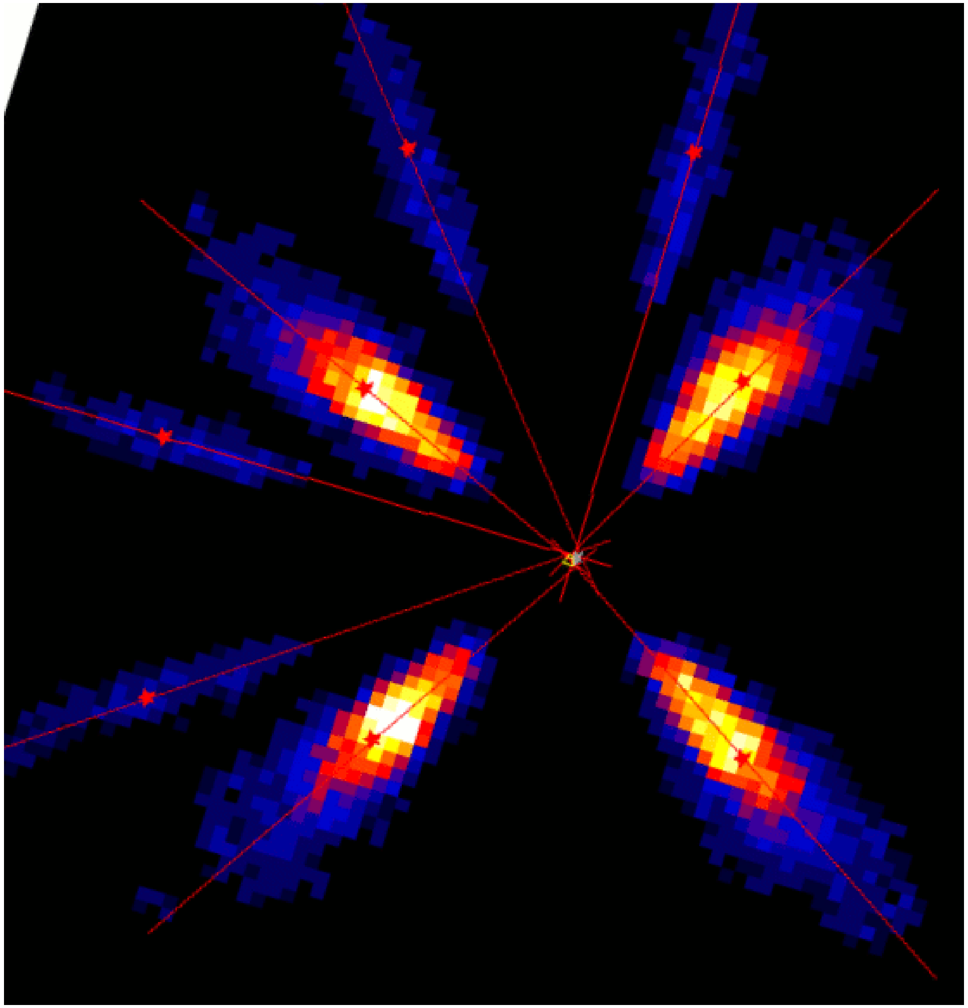
Better spectra, fainter sources, faster transients

Better measurement of air showers and hence primary gammas

→ Improved angular resolution

→ Improved background rejection

Better spectra, fainter sources, faster transients, better morphology studies



Simulation:
Superimposed images from 8 cameras

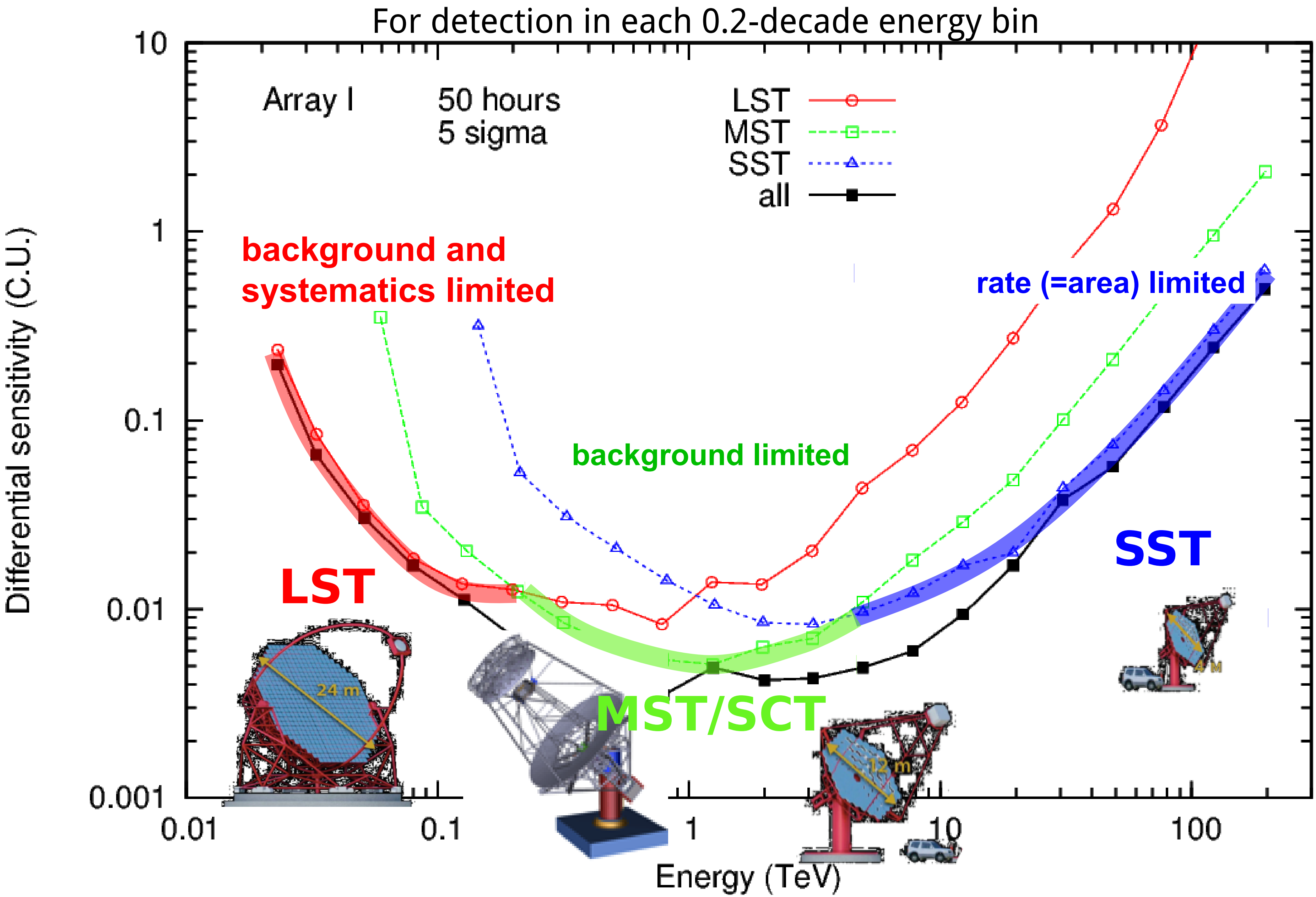
Telescope Specifications

SiPM Cameras ←→

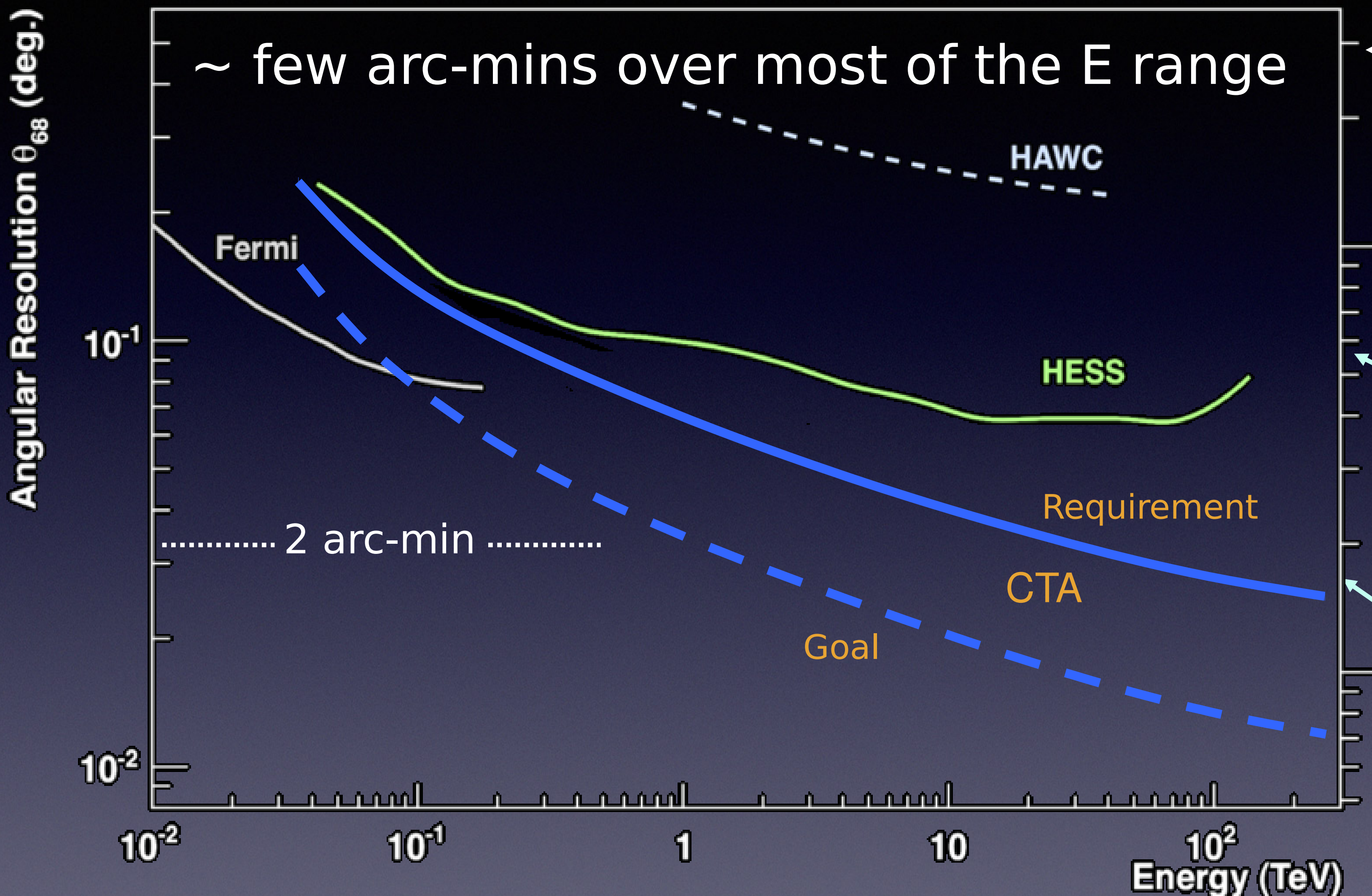
3 SST types

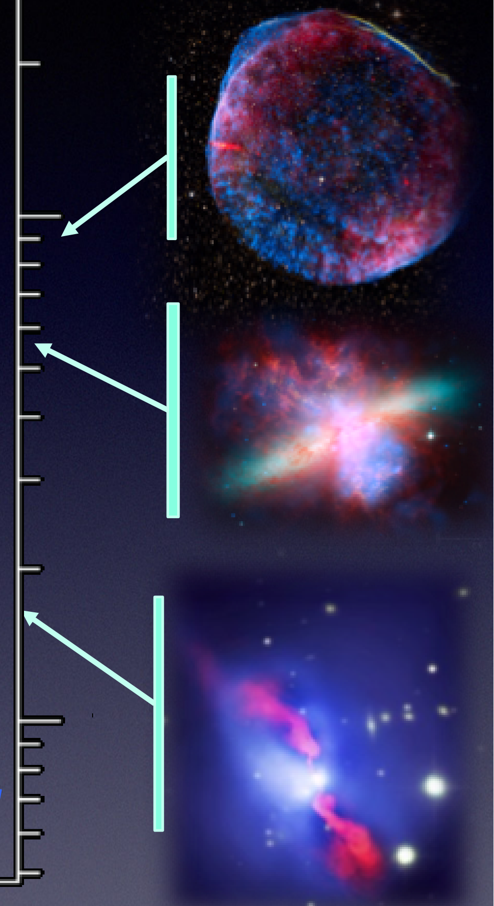
	LST **"large"**	**MST** **"medium"**	**SCT** **"medium 2-M"**	**SST** **"small"**
Number	**4 (S)** **4 (N)**	**25 (S)** **15 (N)**	**≤ 24** **(S and N)**	**70 (S)**
Energy range	20 GeV to 1 TeV	200 GeV to 10 TeV	200 GeV to 10 TeV	> few TeV
Effective mirror area	> 330 m^2	> 90 m^2	> 50 m^2	> 5 m^2
Field of view	> 4.4°	> 7°	> 7°	> 8°
Pixel size ~PSF θ_{80}	< 0.12°	< 0.18°	< 0.07°	< 0.25°
Positioning time	50 s, 20 s goal	90 s, 60 s goal	90 s, 60 s goal	90 s, 60 s goal
Target capital cost	7.4 M€	1.6 M€	< 2.0 M€	500 k€

Flux Sensitivity (Crab Units)

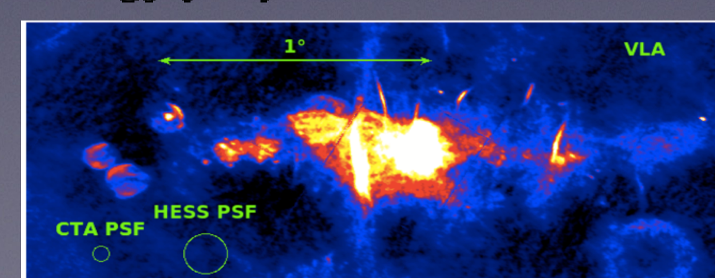


Angular Resolution





Angular resolution critical for
Source morphology and identification



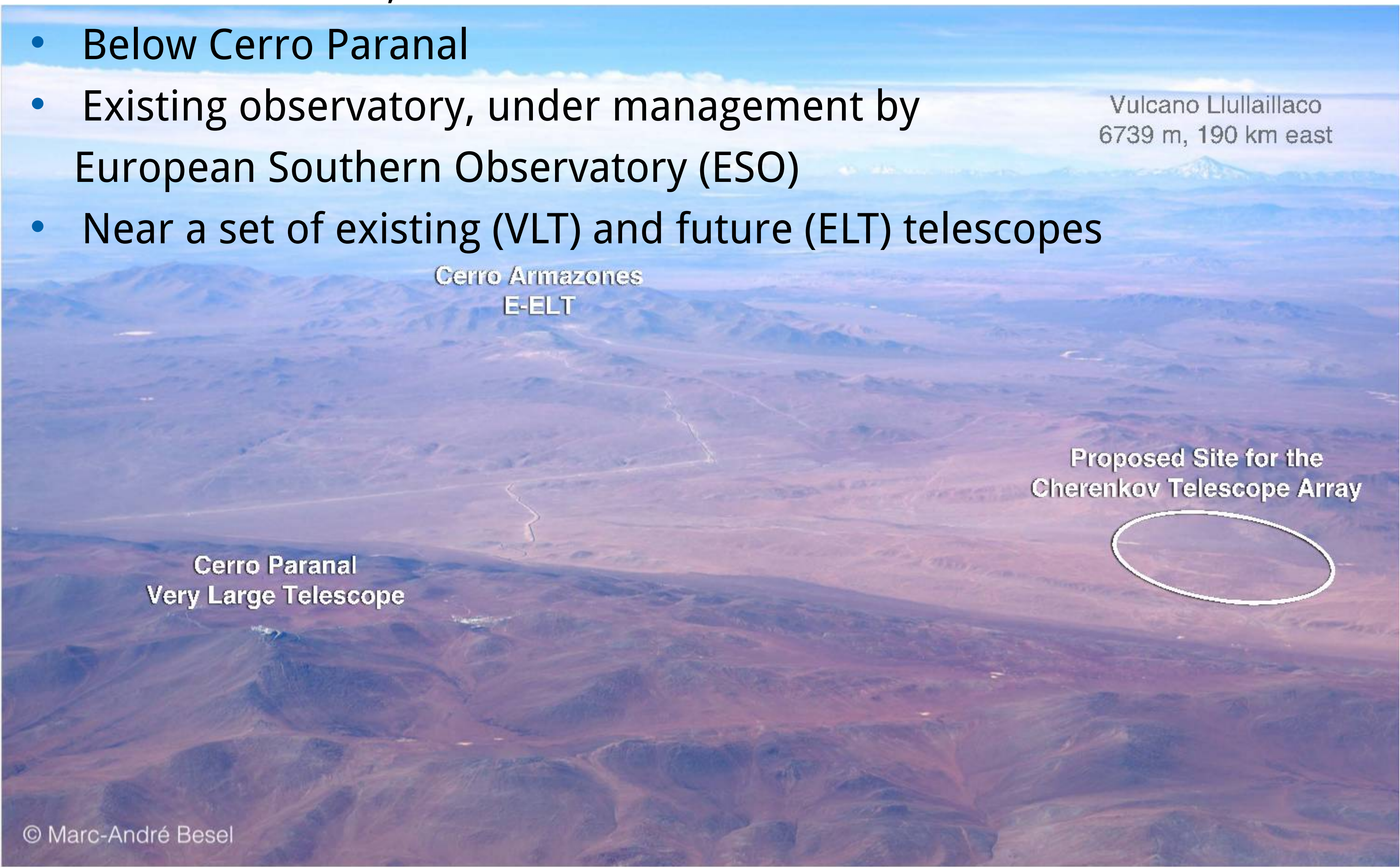
Galactic-Center
region

LA PALMA

- Canary Islands, Spain
- Observatorio del Roque de los Muchachos
- Existing observatory, under management by Instituto de Astrofisica de Canarias (IAC)
- Site of LST prototype & existing MAGIC telescopes

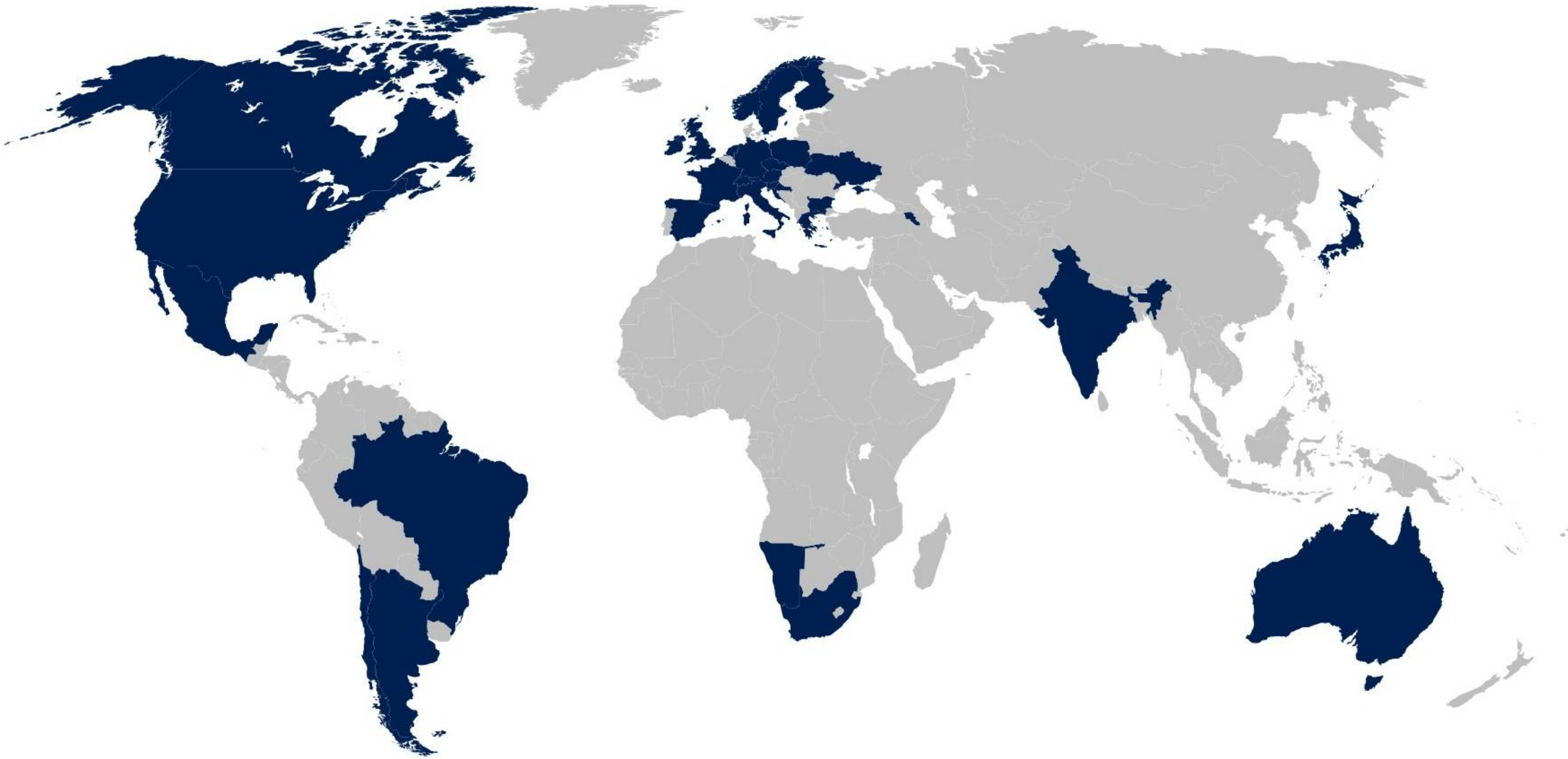
ESO/PARANAL

- Atacama Desert, Chile
- Below Cerro Paranal
- Existing observatory, under management by European Southern Observatory (ESO)
- Near a set of existing (VLT) and future (ELT) telescopes



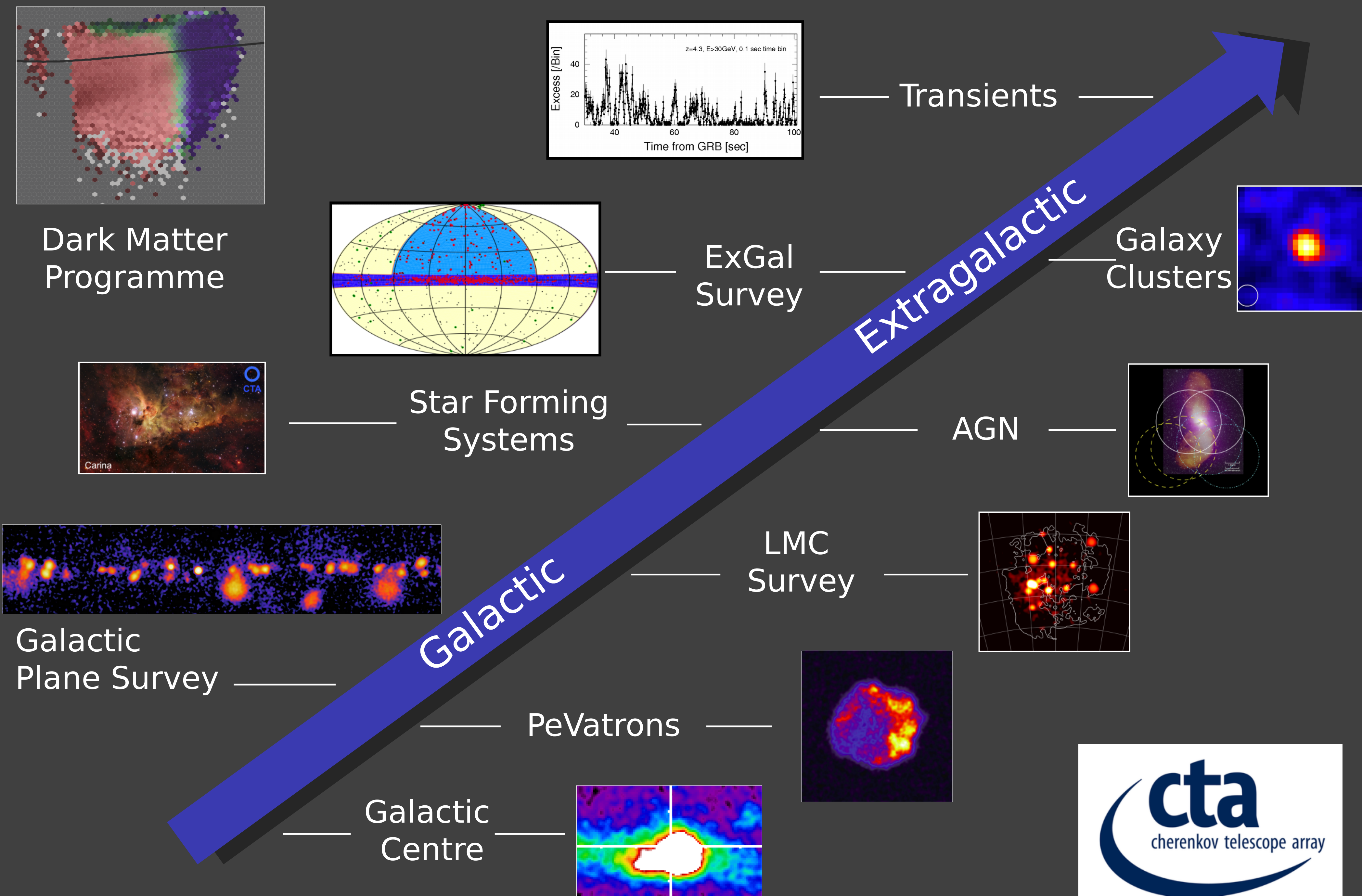
CTA Consortium

CTA is being developed by the CTA Consortium:

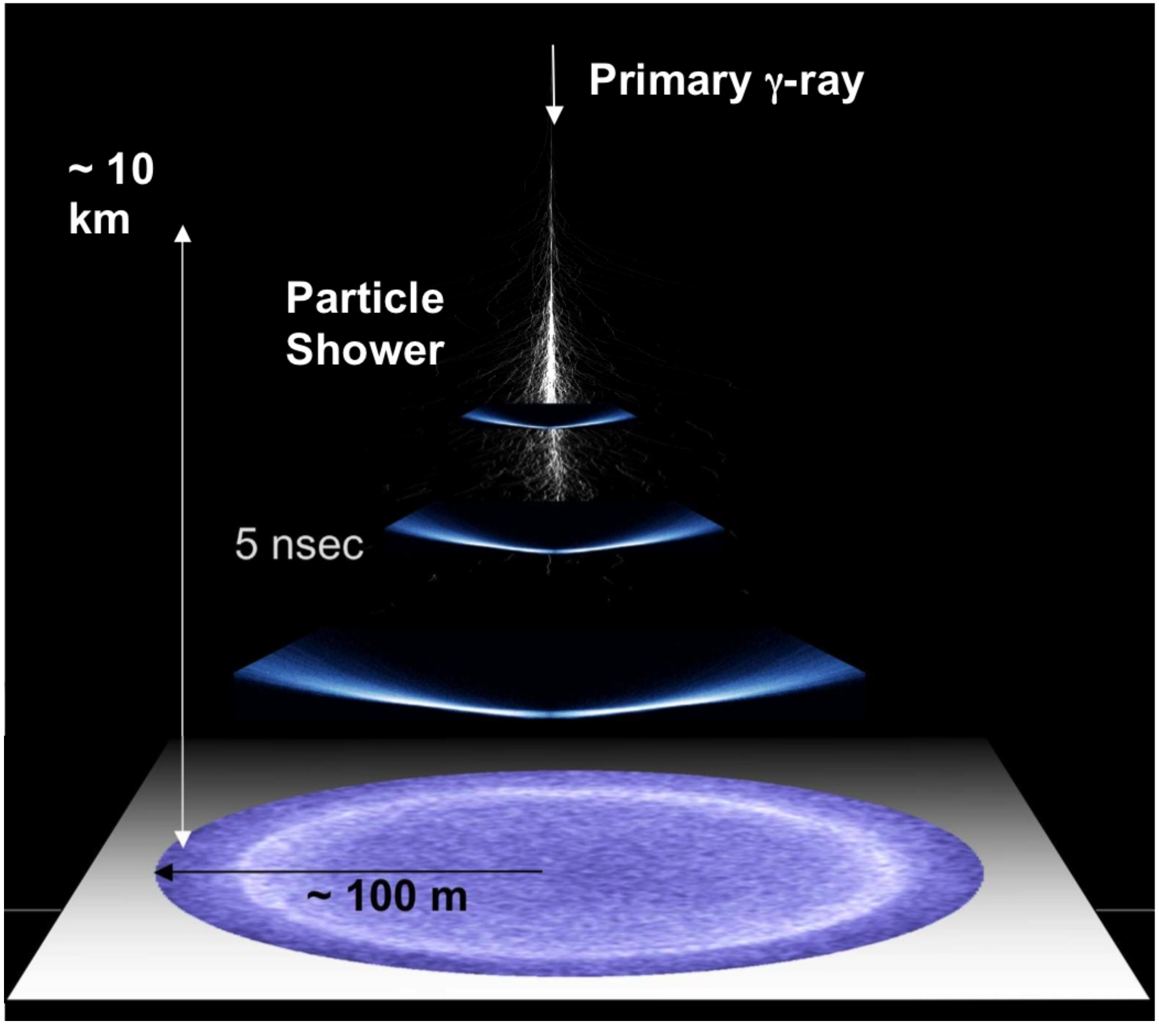


31 countries, ~1270 scientists, ~180 institutes, ~420 FTE

Key Science Projects (KSPs)



Imaging Atmospheric Cherenkov Technique



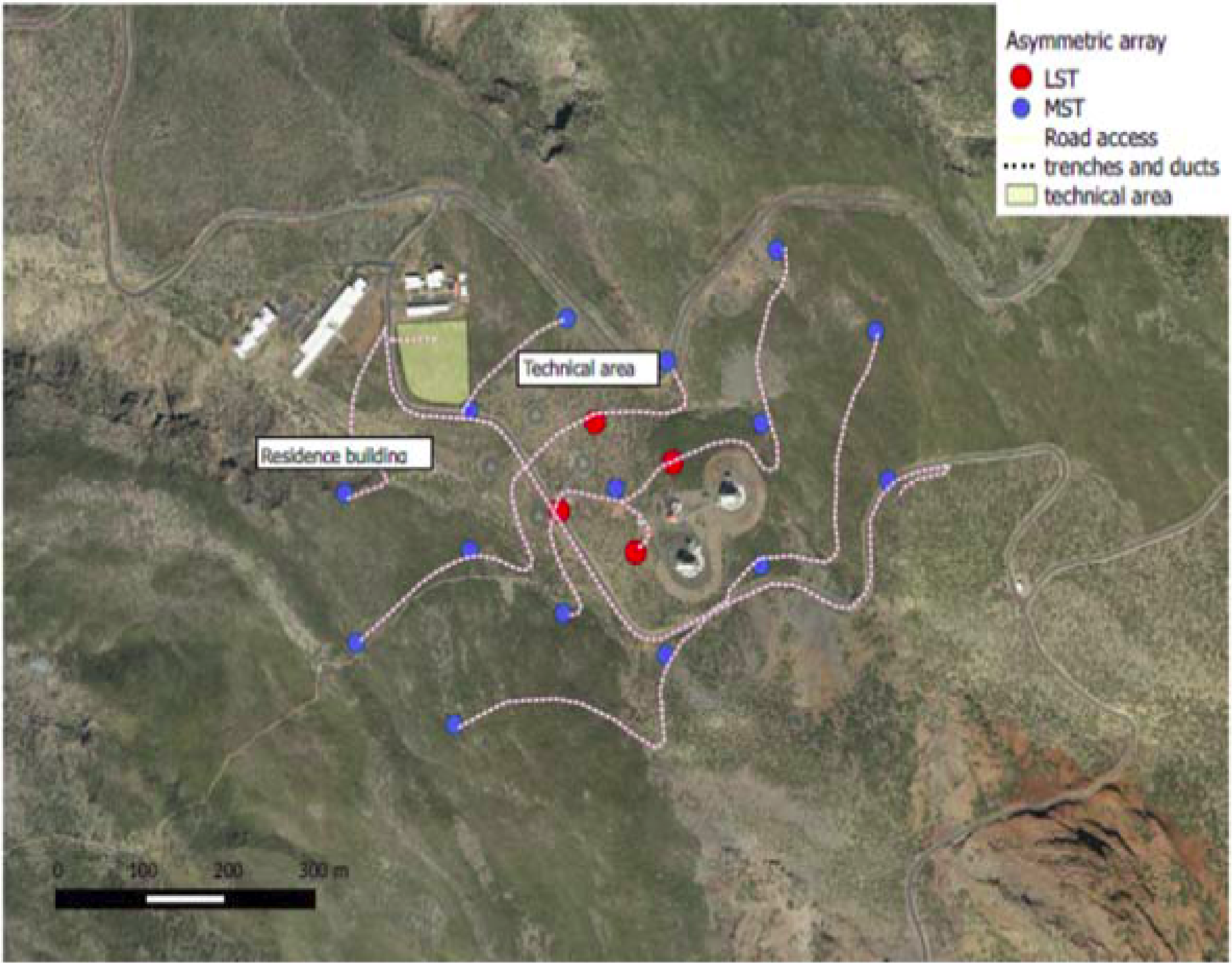
Huge light pool of 100,000 m^2

A very faint flash of blue light that last a couple of nanoseconds

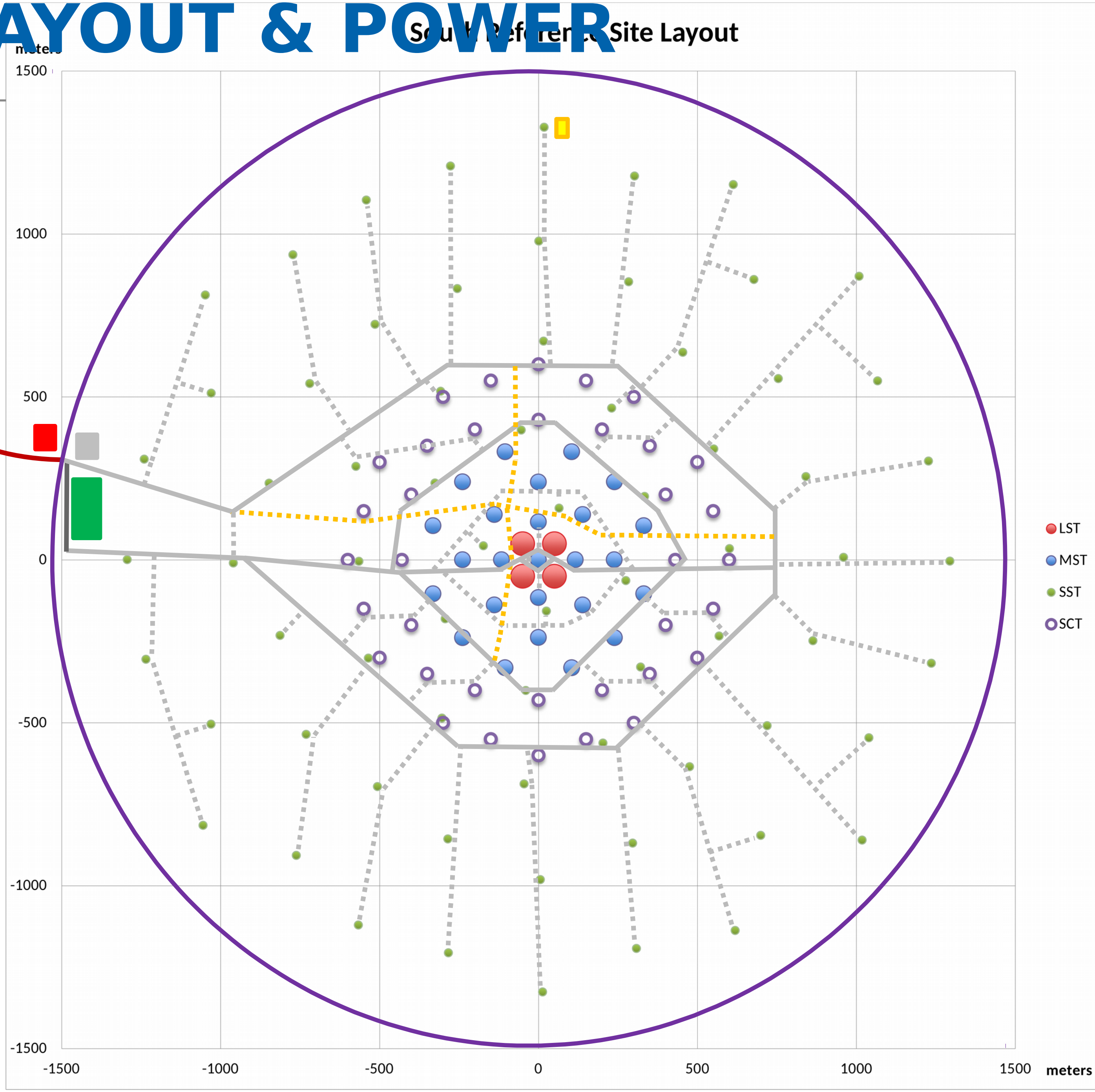
150 Cherenkov photons / m^2 for 1 TeV gamma ray

VHE gamma rays come in small numbers:
Less than one gamma-ray per square meter per year

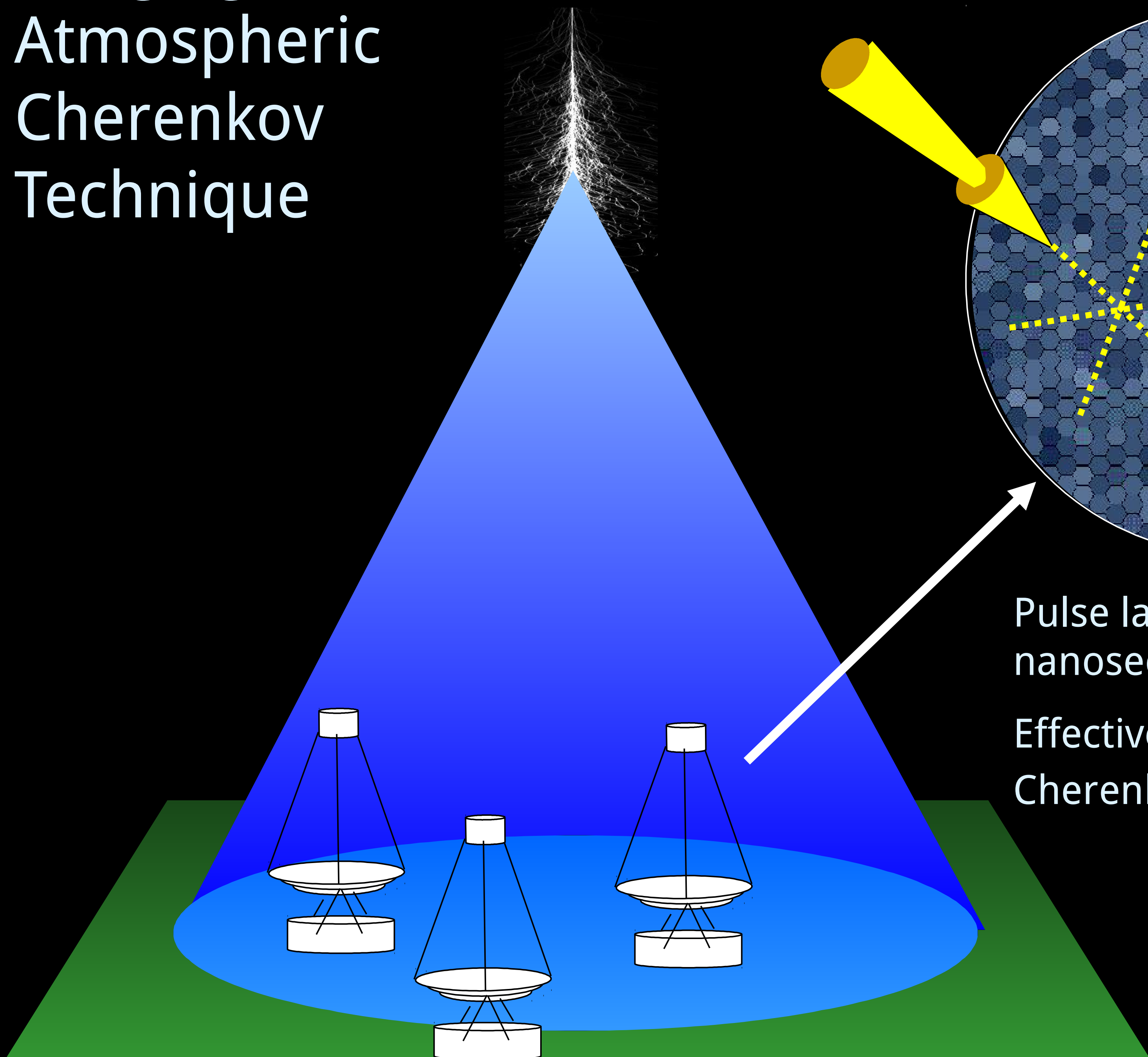
LA PALMA – Possible Layout

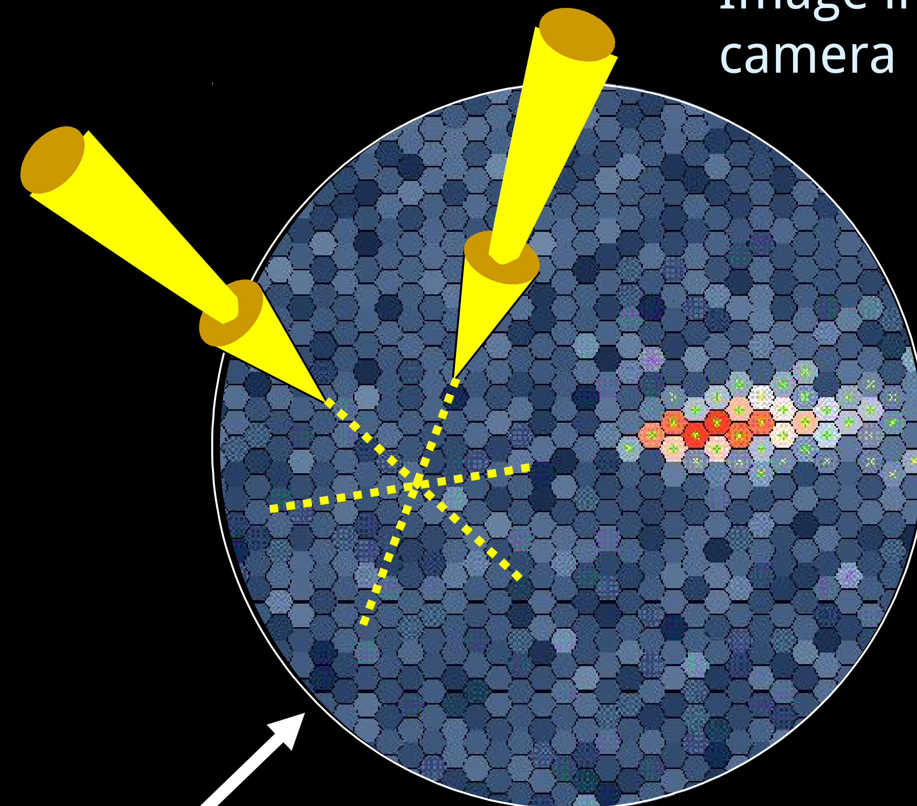


ESO/PARANAL – POSSIBLE LAYOUT & POWER



Imaging Atmospheric Cherenkov Technique





Pulse lasts a few nanoseconds

Effective area = Cherenkov light pool~10^5 m^2!

Auxiliary systems as of May 2017