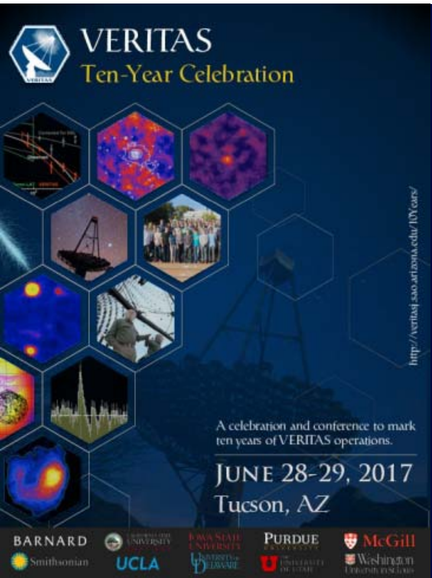
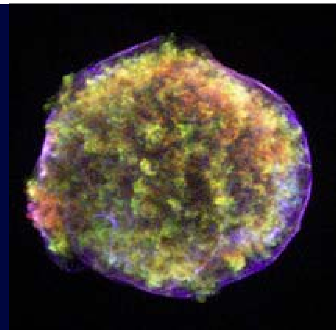
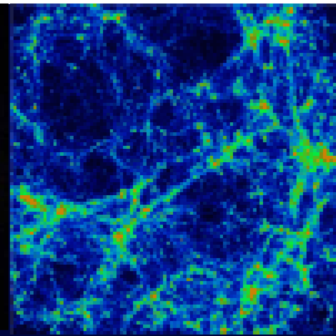
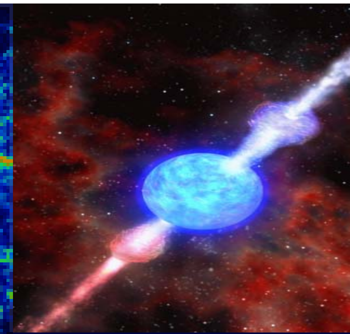
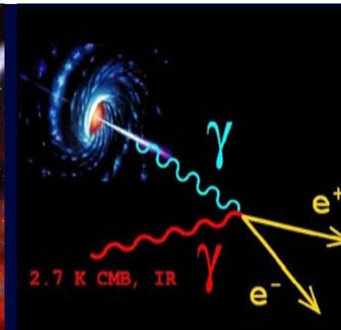
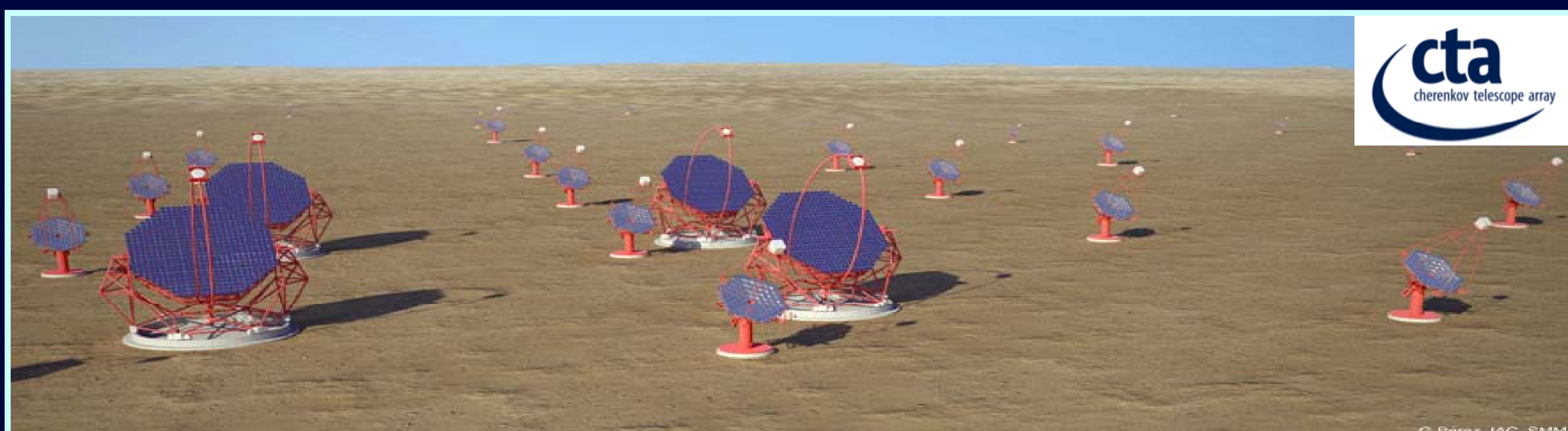


VERITAS 10yr Celebration

The Cherenkov Telescope Array

Rene A. Ong (UCLA),
for the CTA Consortium



Outline

- **Motivation & History**

  This Marvelous (Cherenkov) Technique
  Early Cherenkov telescope arrays – The promise of the 90’s
  → Motivation for CTA

- **Cherenkov Telescope Array**

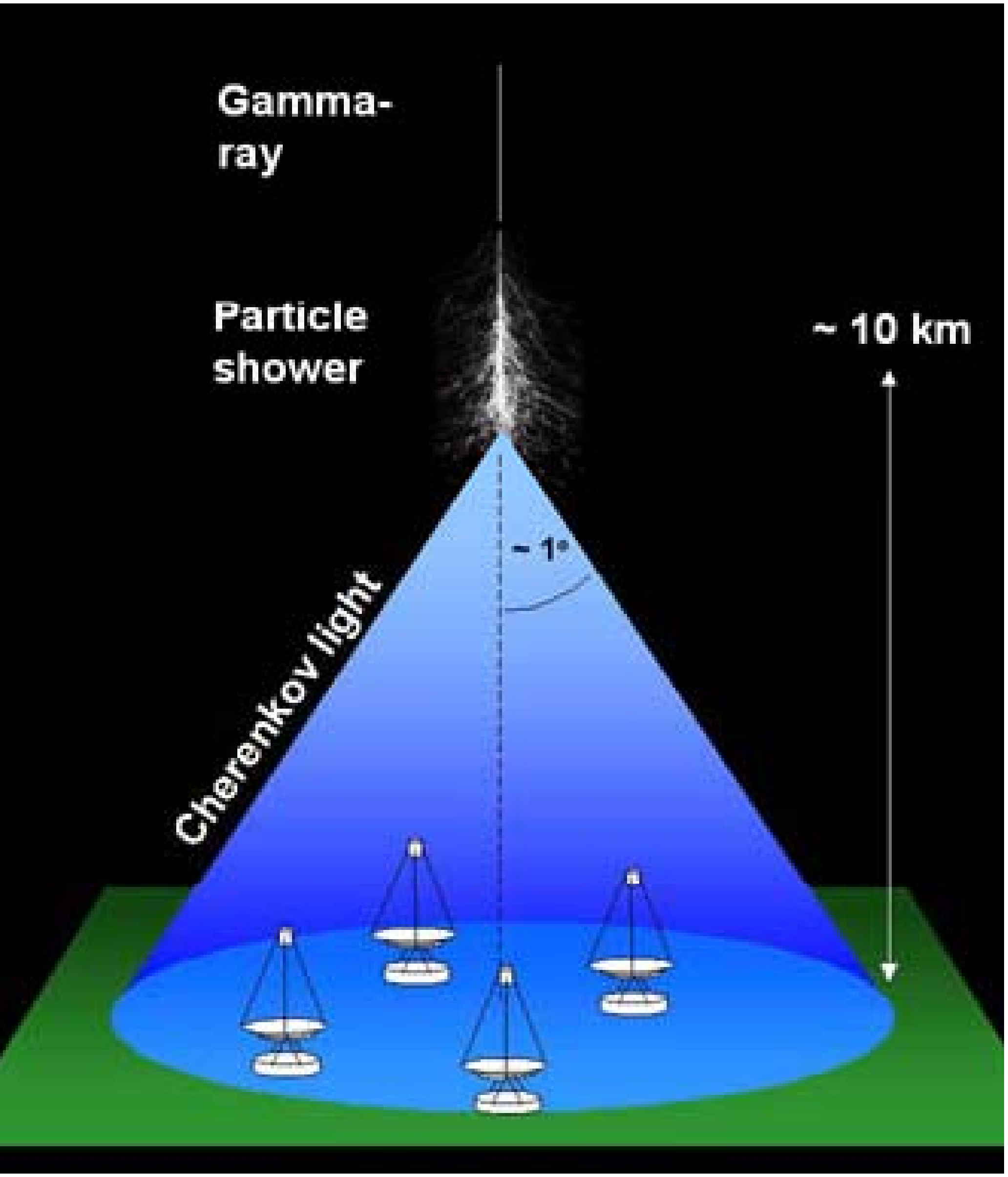
  Science Drivers → requirements
  CTA Design & Performance → Scientific Capabilities
  Key Science Projects

- **CTA Implementation & Status**

  Prototype telescopes, sites
  Present status (2017)

- **Summary – how we got to CTA**

This Marvelous Technique



Atm. Cherenkov showers:

- V. large light pool ~250m diameter
- Rapid time structure ~ 5 ns
- Very calorimetric

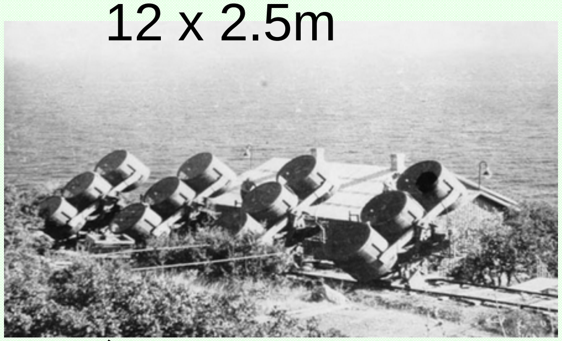
Imaging technique:

- Excellent shower reconstruction
- Large background rejection
- Improved by:
  - More views of shower
  - Higher resolution images

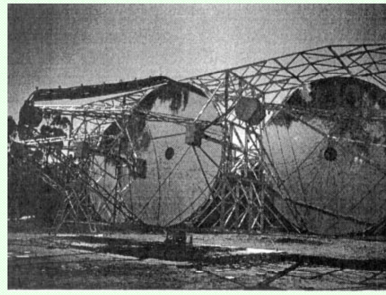
Granularity of Cherenkov emission is remarkably small (< 1 arc-min) !

Early Cherenkov telescope arrays

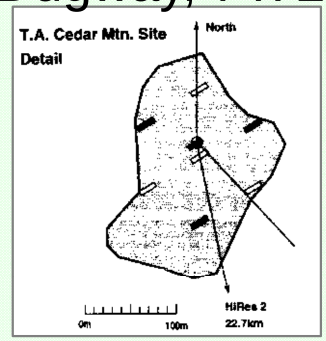
Crimean Obs
12 x 2.5m



Durham V, VI.
Narrabri, 3 x 7m



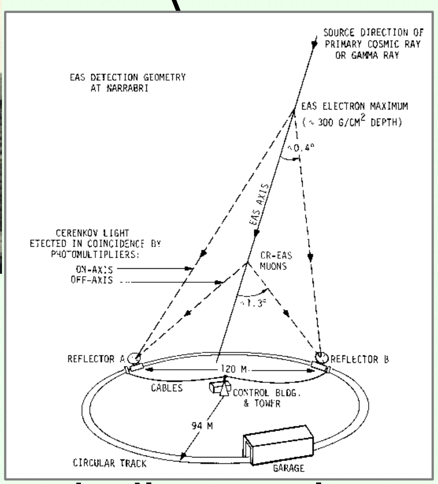
Tel Array,
Dugway, 7 x 2m



Imaging

1970 1980 1990 2000

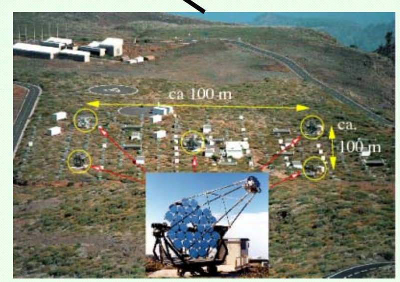
Harwell
1962



Grindlay et al.
Narrabri
2 x 7m

GRANITE
Whipple
10m + 11m

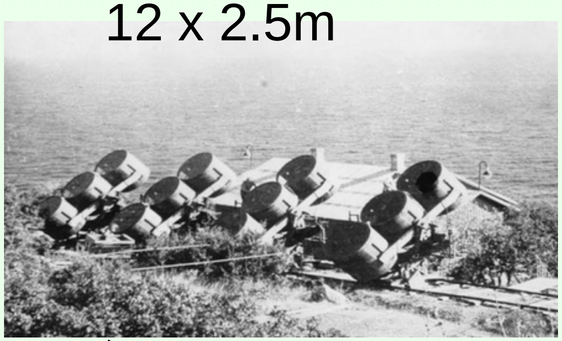
CANGAROO
- BIGRAT
Woomera
2 x 4m



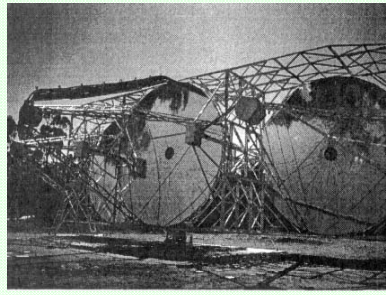
HEGRA IACT
La Palma
6 x 3.4m

Early Cherenkov telescope arrays

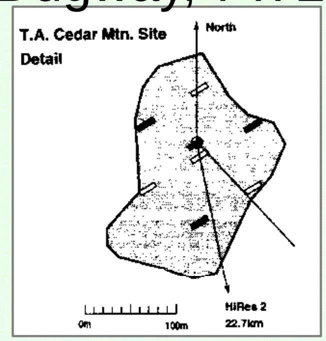
Crimean Obs
12 x 2.5m



Durham V, VI.
Narrabri, 3 x 7m



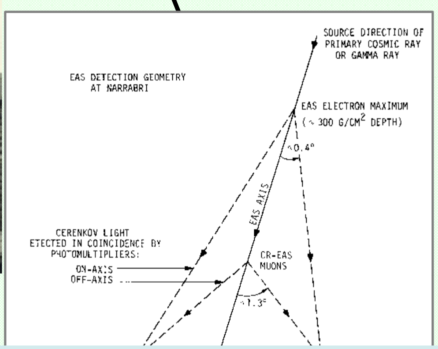
Tel Array,
Dugway, 7 x 2m



Imaging

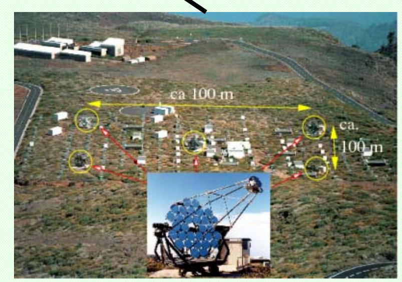
1970 — 1980 — 1990 — 2000

Harwell
1962



2 x 7m

2 x 4m

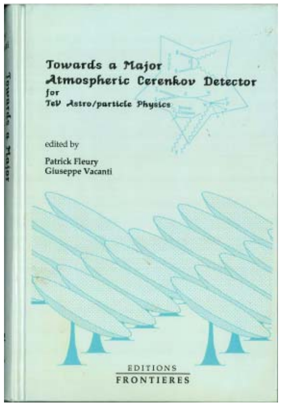


HEGRA IACT

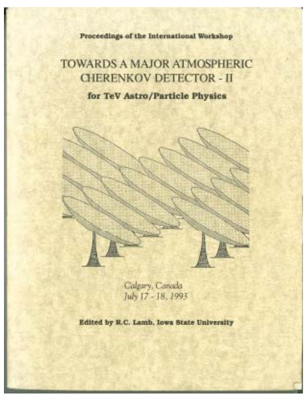
The promise of arrays of Cherenkov telescopes has been well appreciated for many years

The Promise of the 1990's

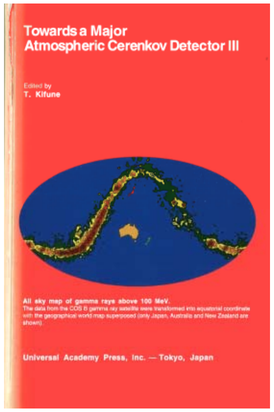
Towards a Major Atmospheric Cherenkov Detector



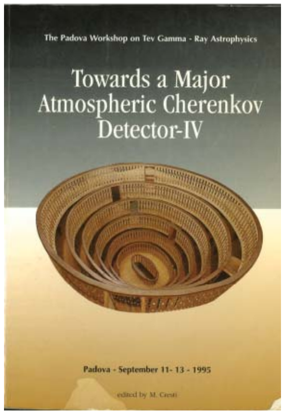
I. 1992 PALAISEAU



II. 1993 CALGARY

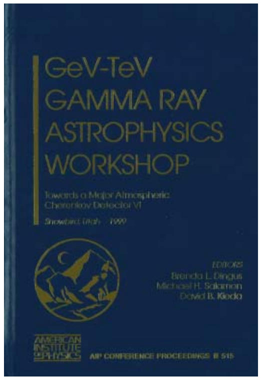


III. 1994 TOKYO



IV. 1995 PADOVA

V. 1997 KRUGER PARK

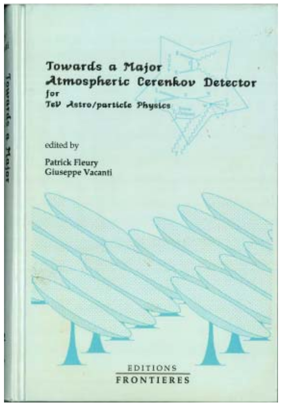


VI.. 1999 SNOWBIRD

(and then the meeting got hijacked!)

The Promise of the 1990's

I. 1992 PALAISEAU



T. Weekes
Summary Talk
"Quo Vadis"

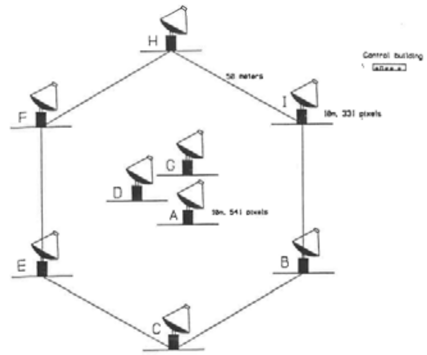
The scale of the Large Array Project is far beyond that normally considered for atmospheric Cherenkov telescopes. Given the climate for funding these days it will probably be only accomplished if it is undertaken as an international collaboration. It should not be undertaken prematurely; there must be a clear scientific justification for it, the design must be carefully optimized and its individual components must be thoroughly tested. The design should carefully consider all the science (other than gamma-ray astronomy) that might be done with this unique instrument; funding may well be dependent on the inclusion of some of these aspects in the design. It was the almost general consensus the time was not yet ripe for this ambitious project but we should be laying the groundwork for this undertaking over the next 1-2 years.

The Promise of the 1990’s → Solar Cherenkov Arrays, Stereo Imaging

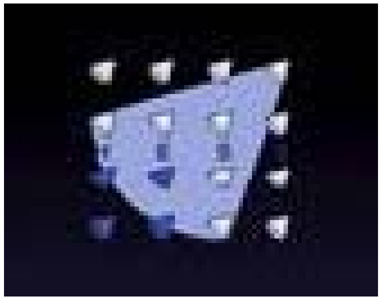
V. 1997 Kruger Park

The Promise of the 1990's → "Big 4"

V. 1997 Kruger Park



VERITAS-9



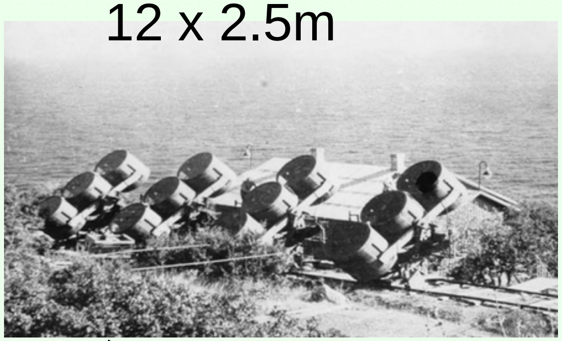
H.E.S.S.-16

Large Telescopes under Development 392

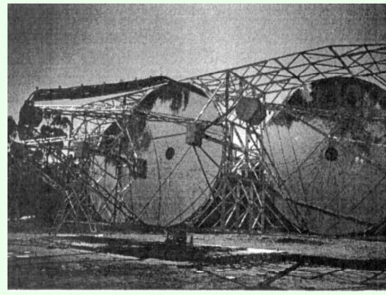
"The Big 4"

Early Cherenkov telescope arrays

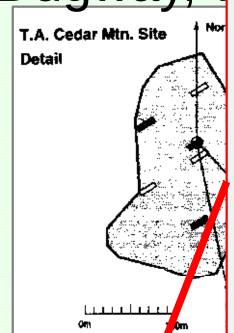
Crimean Obs
12 x 2.5m



Durham V, VI.
Narrabri, 3 x 7m



Tel Array,
Dugway, 7

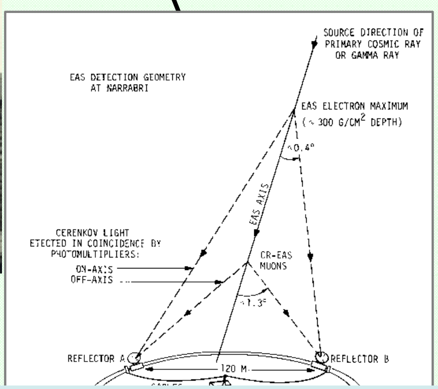


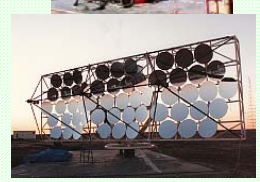
3^{rd} Generation
Imaging Arrays
CANGAROO
HESS
MAGIC
VERITAS

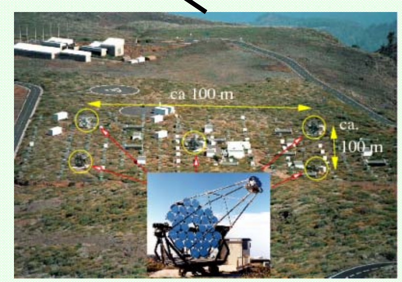
Imaging

1970 1980 1990 2000

Harwell
1962







HEGRA IACT

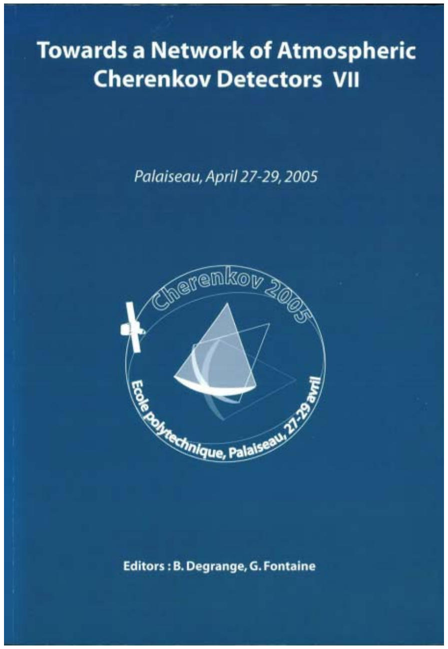
The promise of arrays of Cherenkov telescopes
In the 1990's → Big Four

2 x 7m

2 x 4m

The Return to Palaiseau 2005

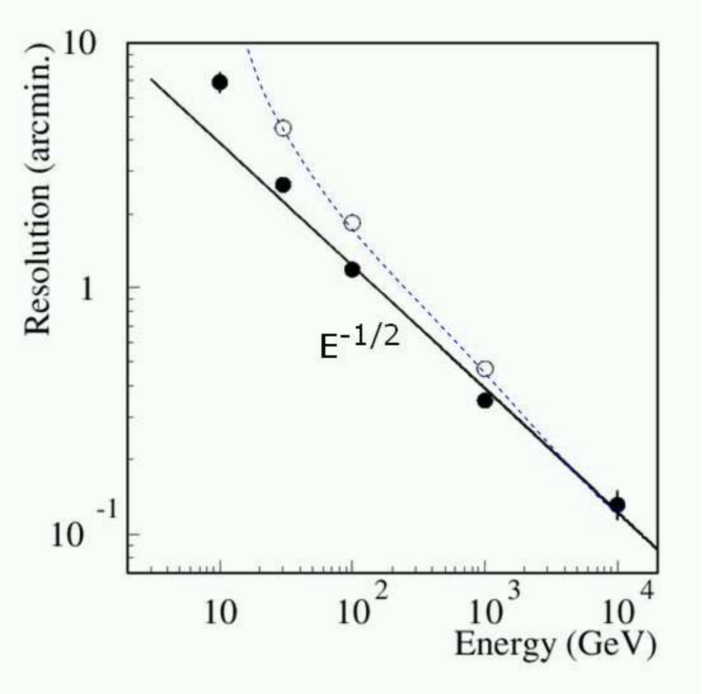
VII. 2005 Palaiseau

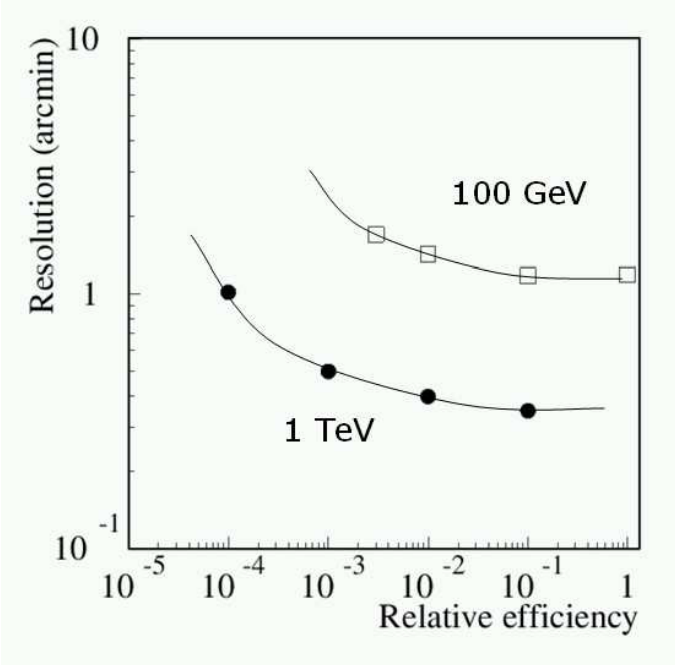


Session 4: The future of ground-based VHE astronomy

The Return to Palaiseau 2005

W. Hofmann, *Performance Limits for Cherenkov Telescopes*





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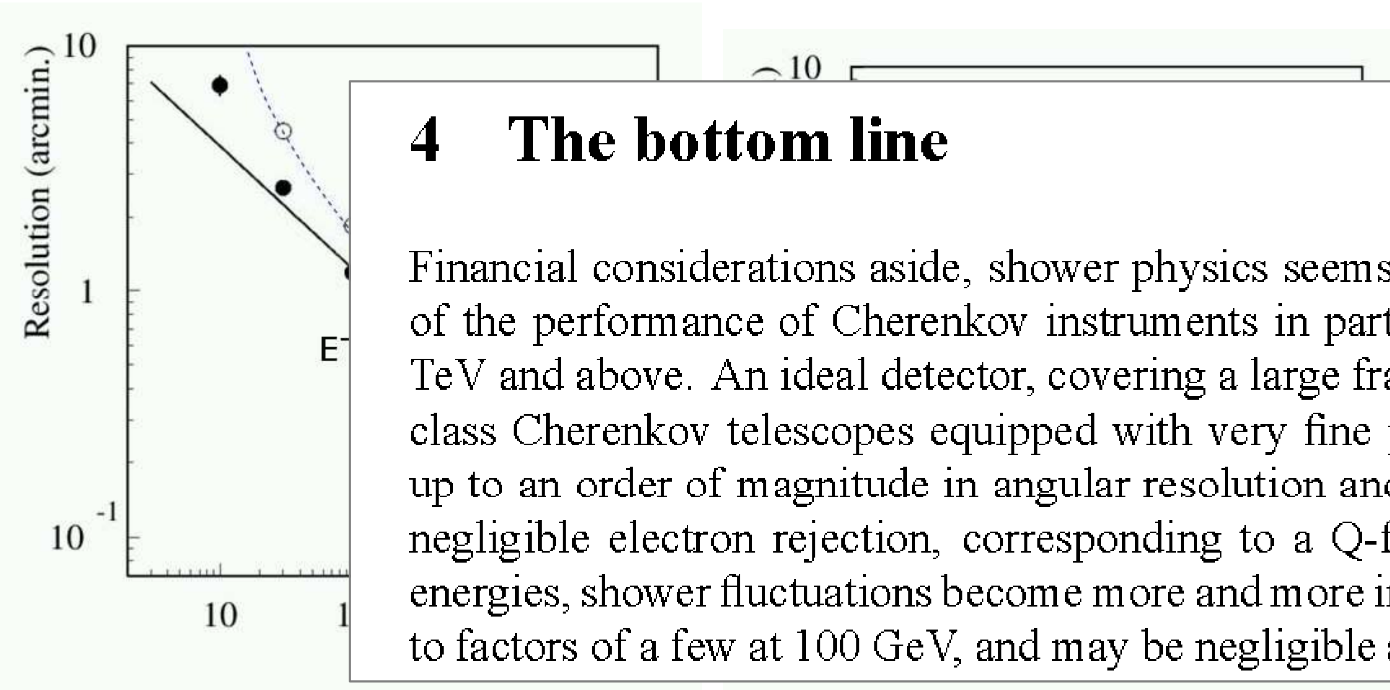
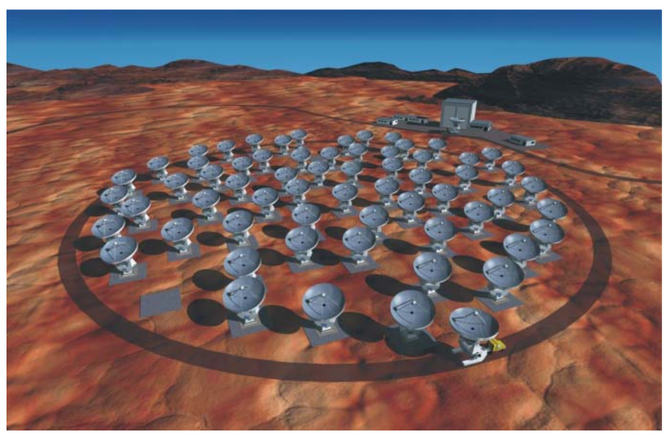
W. Hofmann, *Performance Limits for Cherenkov Telescopes*



4 The bottom line

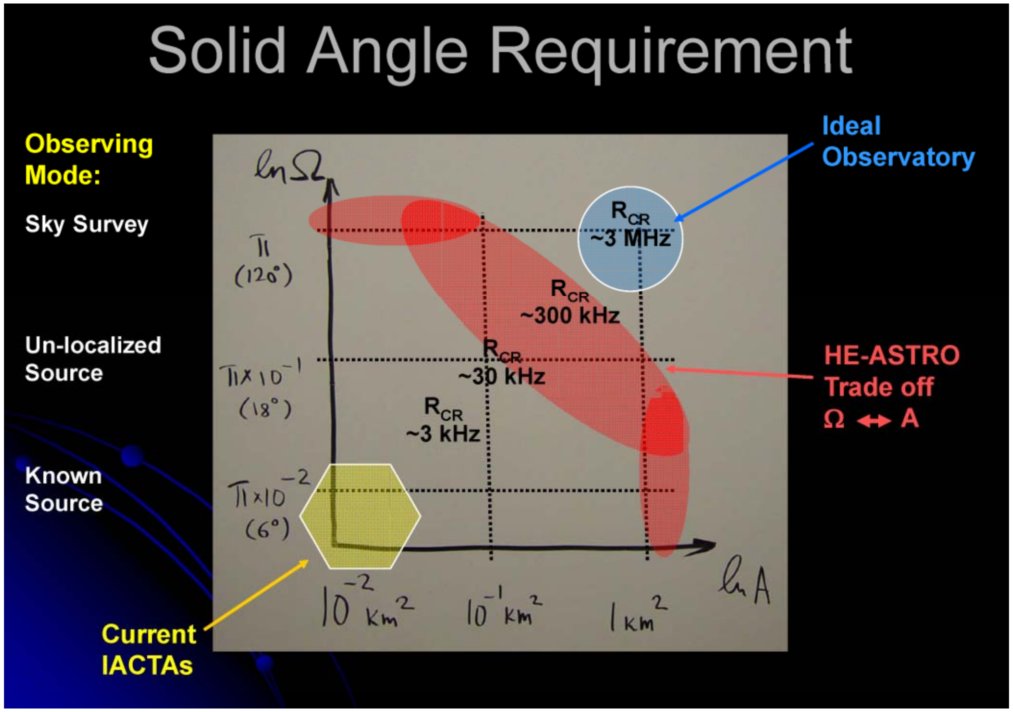
Financial considerations aside, shower physics seems to allow further improvement of the performance of Cherenkov instruments in particular in the domain around a TeV and above. An ideal detector, covering a large fraction of the ground with 10 m class Cherenkov telescopes equipped with very fine pixels could provide a gain of up to an order of magnitude in angular resolution and in proton rejection, and non-negligible electron rejection, corresponding to a Q-factor of about 3-5. At lower energies, shower fluctuations become more and more important and gains are reduced to factors of a few at 100 GeV, and may be negligible at even lower energies.

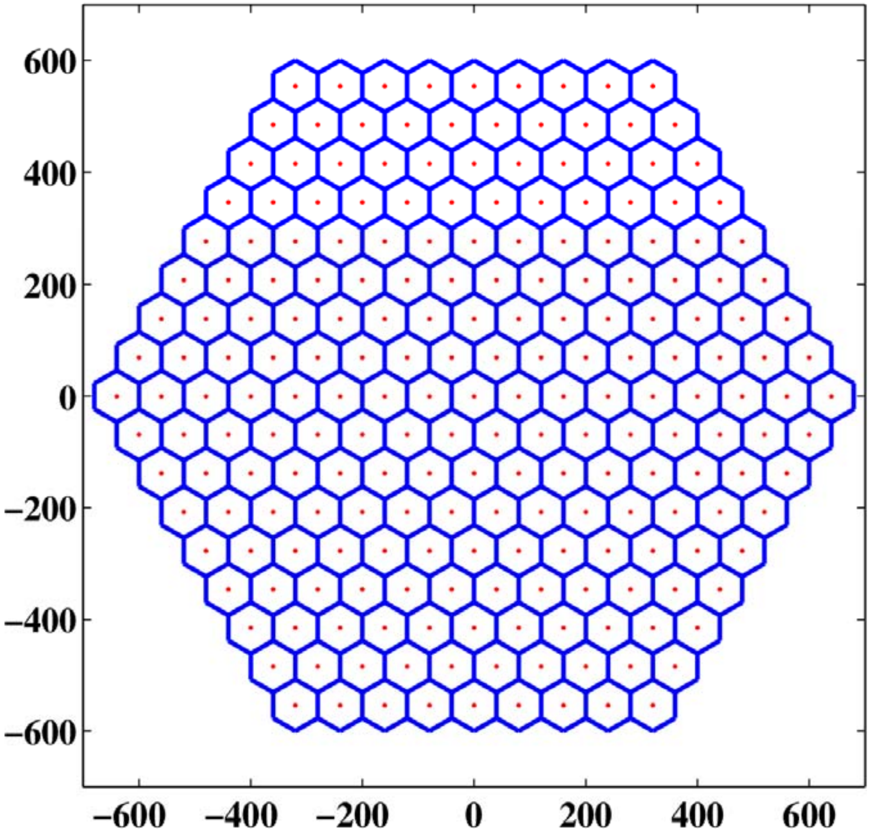


"… a dense array of (high resolution) medium-size telescopes "

The Return to Palaiseau 2005

S. Fegan & V. Vassiliev, *High Energy All Sky Transient Radiation Obs.*

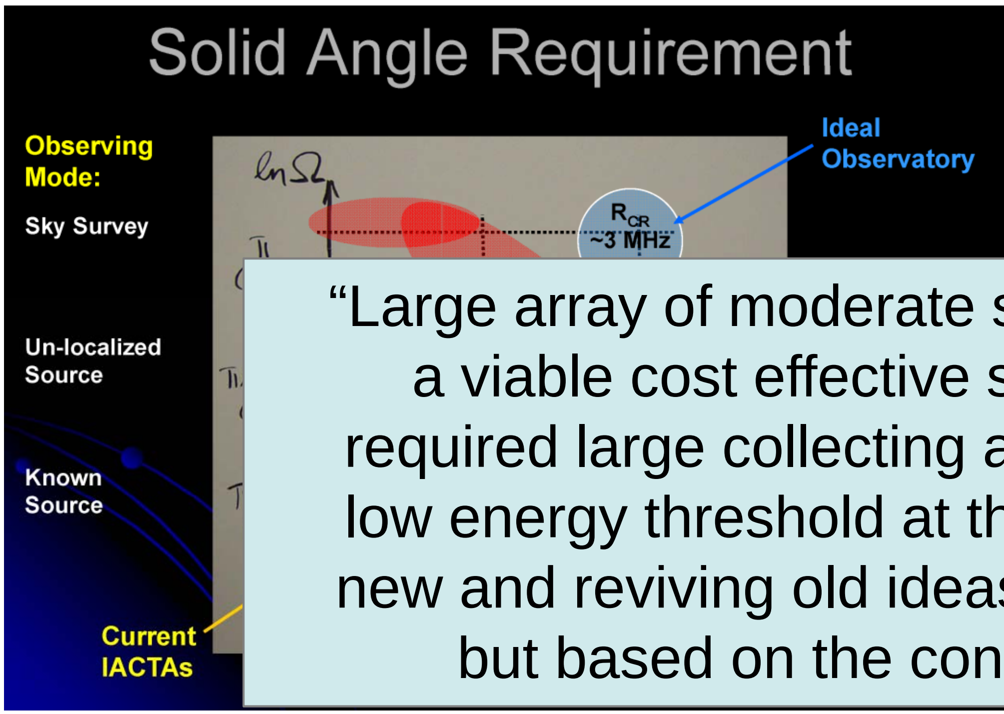


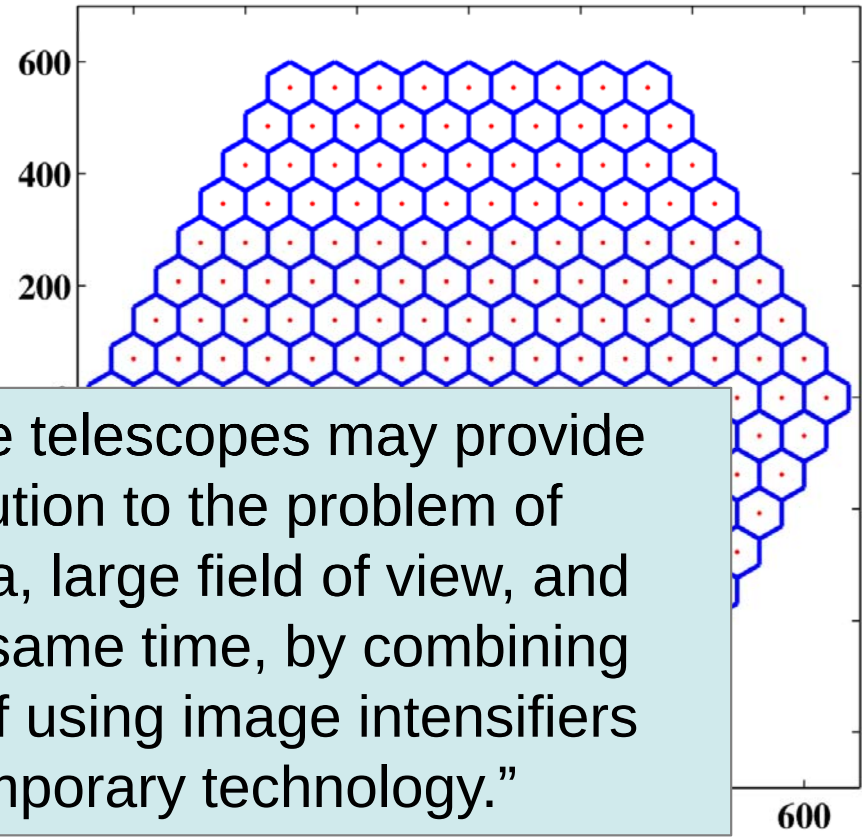


HE-ASTRO:
217 Telescopes (ø10m), 80m separation.
1.1 km^2 collection area & 12^o FOV.
Challenging !

The Return to Palaiseau 2005

S. Fegan & V. Vassiliev, *High Energy All Sky Transient Radiation Obs.*

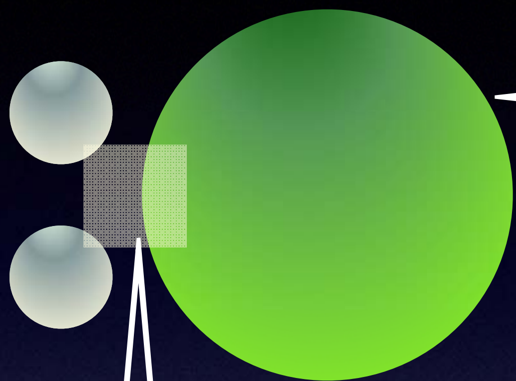




"Large array of moderate size telescopes may provide a viable cost effective solution to the problem of required large collecting area, large field of view, and low energy threshold at the same time, by combining new and reviving old ideas of using image intensifiers but based on the contemporary technology."

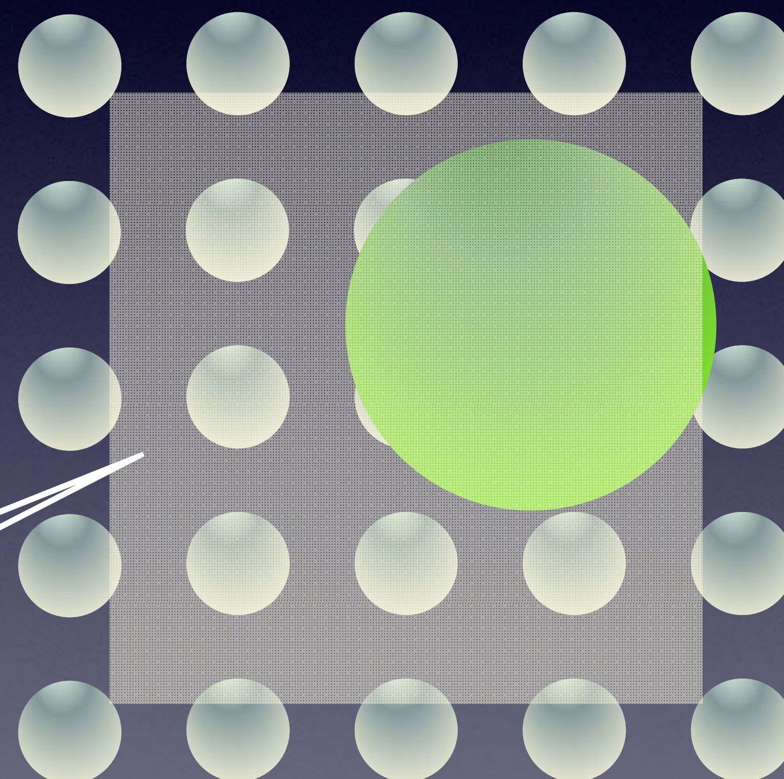
HE-ASTRO:
217 Telescopes (ø10m), 80m separation.
1.1 km^2 collection area & 12^o FOV.
Challenging !

The Power of Contained Events



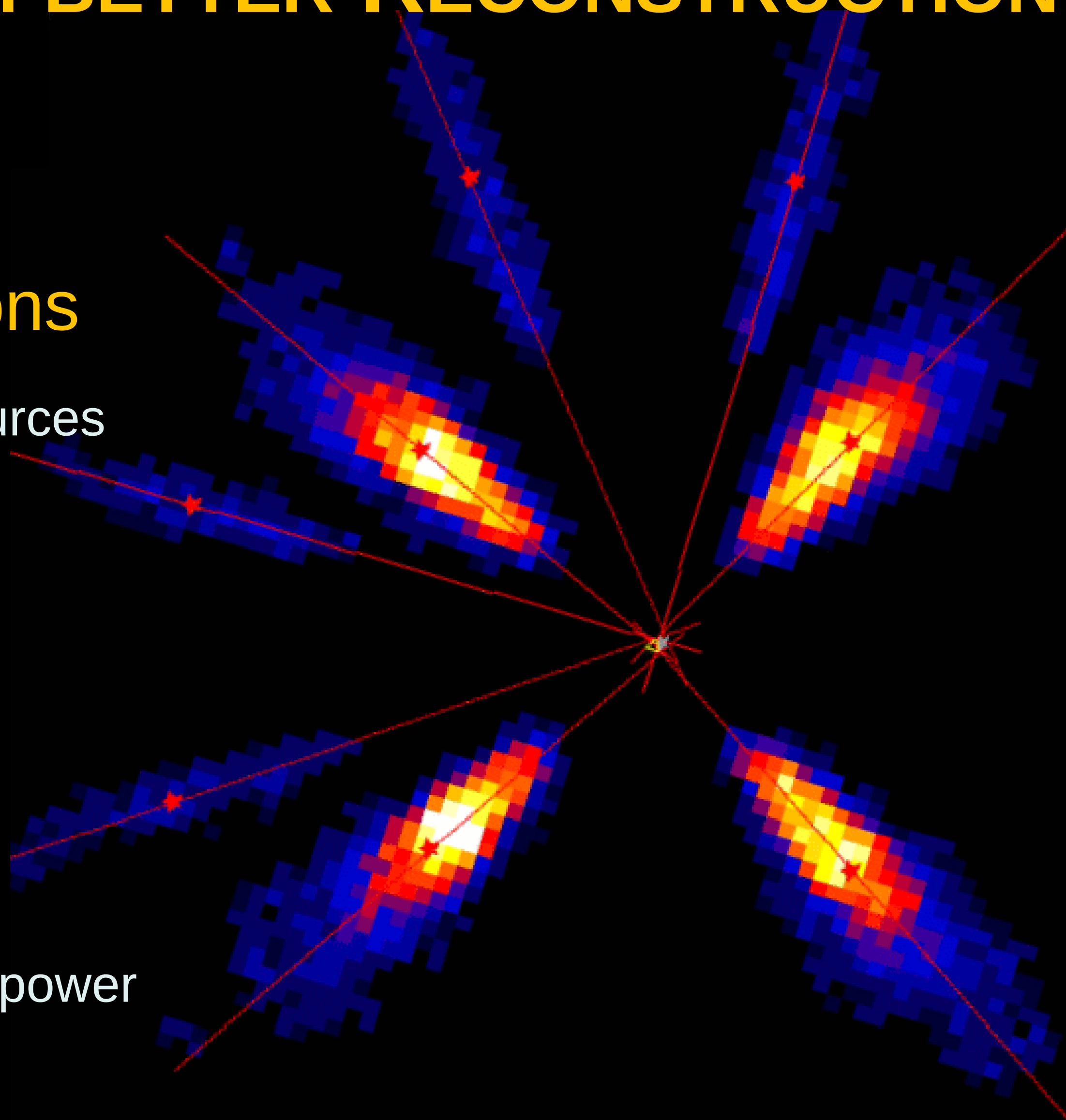
Light pool radius
R ≈ 100-150m
≈ typical telescope Spacing

Sweet spot for best triggering & reconstruction…
most showers miss it!



- ✓ *Large detection Area*
- ✓ *More Images per shower*
- ✓ *Lower trigger threshold*

Many Views → Much better Reconstruction



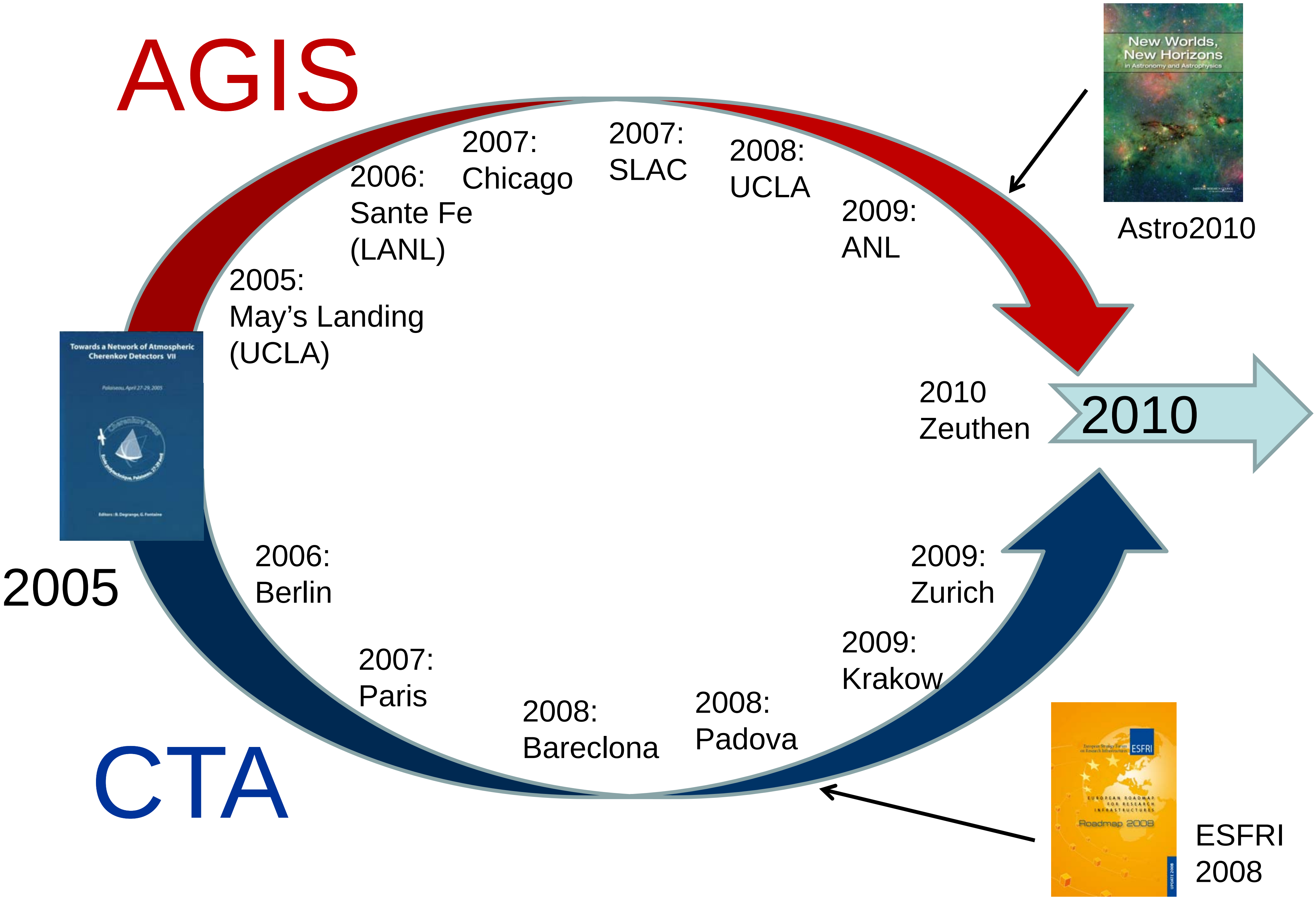
➡ More events, more photons

- Better spectra, images, fainter sources
  - ✓Larger light collecting area
  - ✓Better reconstructed events
- Better measurement of air shower and hence primary gammas
  - ✓Improved angular resolution
  - ✓Improved background rejection power

➡ More telescopes!

Simulation:
Superimposed images from 8 cameras

Parallel Paths



Planning for the Future

What do we know, based on current instruments?

Great scientific potential exists in the VHE domain

- *Frontier astrophysics & important connections to particle 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

- *Numerous funding streams → a challenge to coordinate*


cta
cherenkov telescope array

Science Themes

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?
- Processes in relativistic jets, winds and explosions?
- Exploring cosmic voids

Theme 3: Physics Frontiers – beyond the SM

- 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?

Summary of Key Science Questions

Bottom line: GeV and TeV gamma-ray sources are ubiquitous in the universe and probe extreme particle acceleration, and the subsequent particle interactions and propagation.

1. Where and how are the bulk of CR particles accelerated in our Galaxy and beyond? (one of the oldest surviving questions of astrophysics)
2. Can we understand the physics of jets, shocks & winds in the variety of sources we see, including pulsars, binaries, AGN, starbursts, and GRBs?
3. How do black holes of all sizes efficiently particles? How are the structures (e.g. jets) formed and how is the accretion energy harnessed?
4. What do high-energy gamma rays tell us about the star formation history of the Universe, intergalactic radiation fields, and the fundamental laws of physics?
5. What is the nature of dark matter and can we map its distribution through its particle interactions?
6. What new, and unexpected, phenomena will be revealed by exploring the non-thermal Universe?

Bonus science: optical interferometry, cosmic-ray physics, OSETI, etc.

Requirements & Drivers

Energy coverage down to 20 GeV
(Discovery domain: GRBs, Dark Matter)

Energy coverage up to 300 TeV
(Pevatrons, hadron acceleration)

Good energy resolution, ~10-15%:
(Lines, cutoffs)

Large Field of view 8-10°
(Surveys, extended *sources, flares)*

Rapid Slew (20 s) to catch flares:
(Transients)

10x Sensitivity & Collection Area
(Nearly every topic)

Angular resolution < 0.1° above most of E range
(Source morphology)

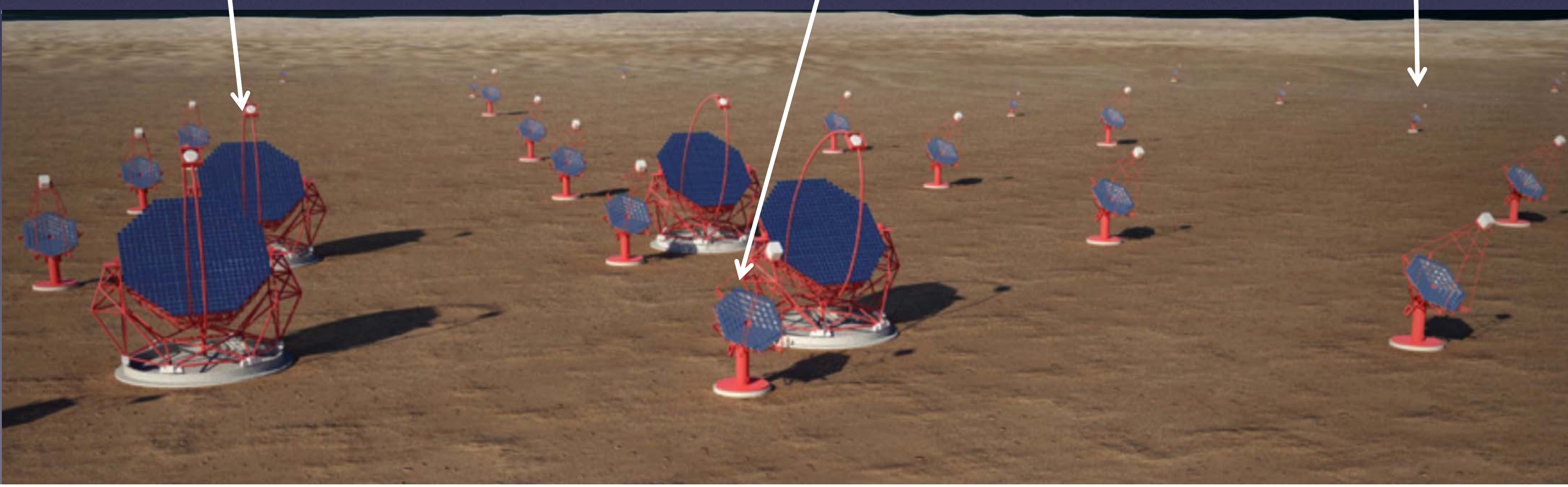
CTA Design (S array)

Science Optimization under budget constraints

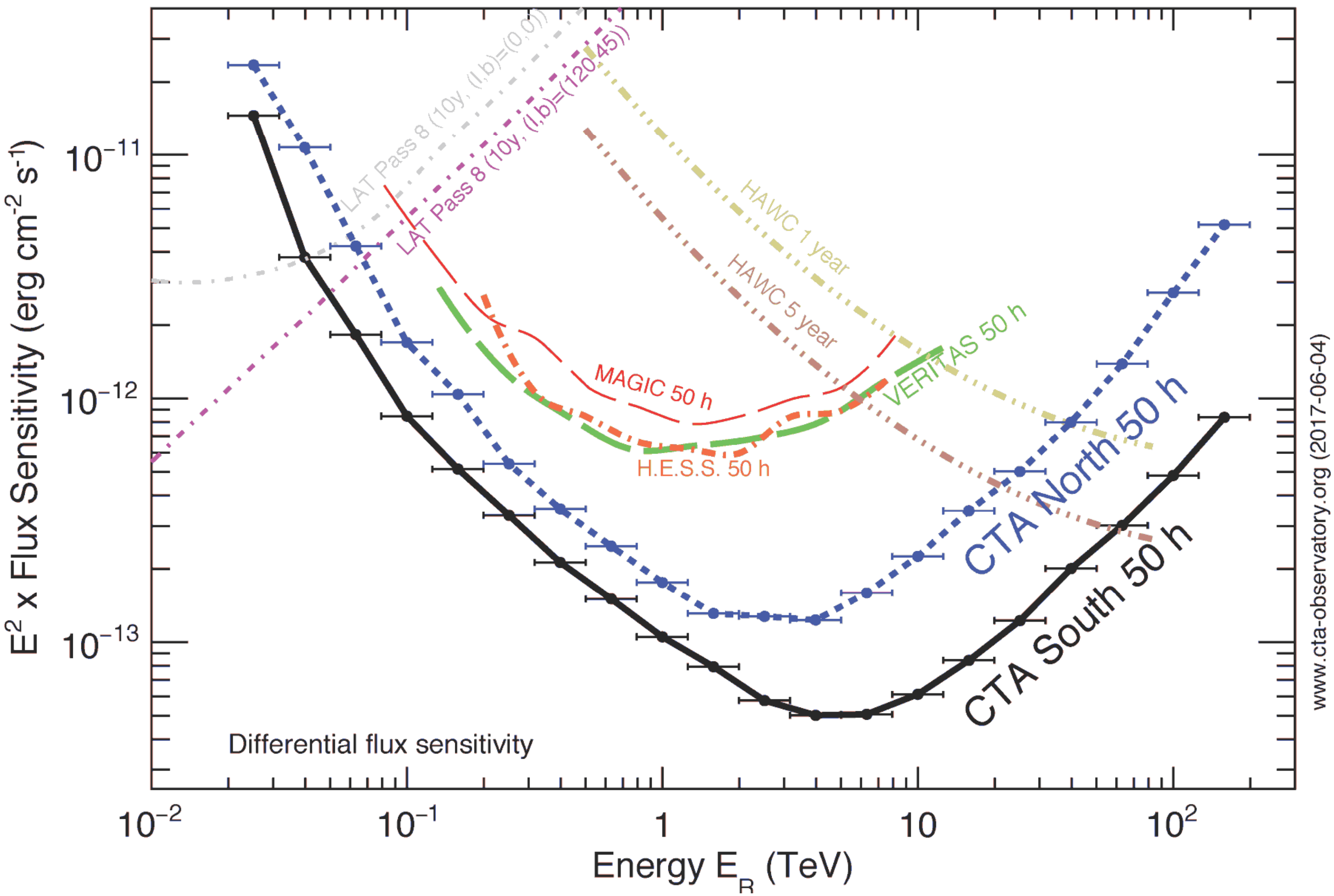
Low energies
Energy threshold 20-30 GeV
23 m diameter
4 telescopes
(LST's)

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

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



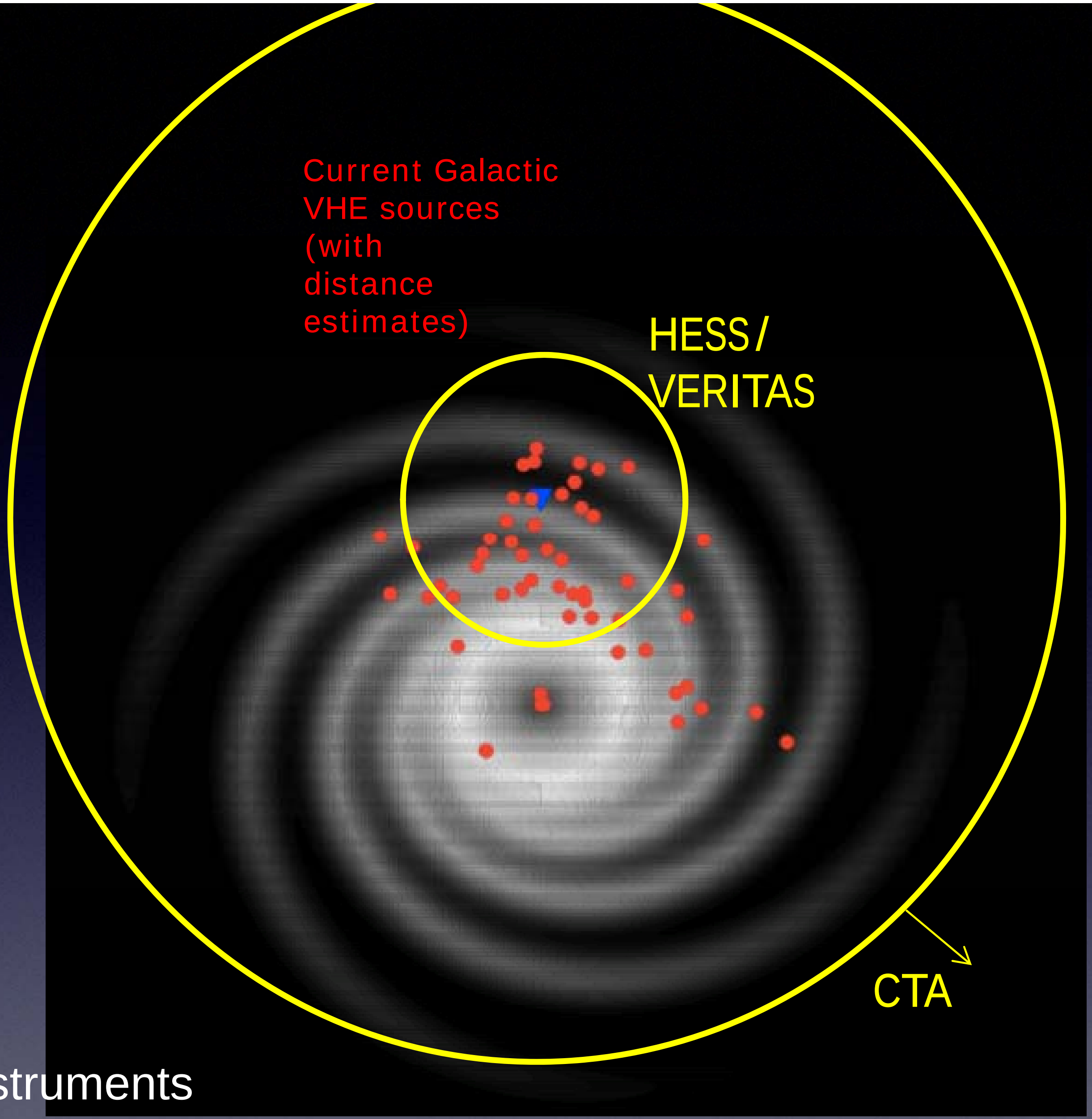
Flux Sensitivity



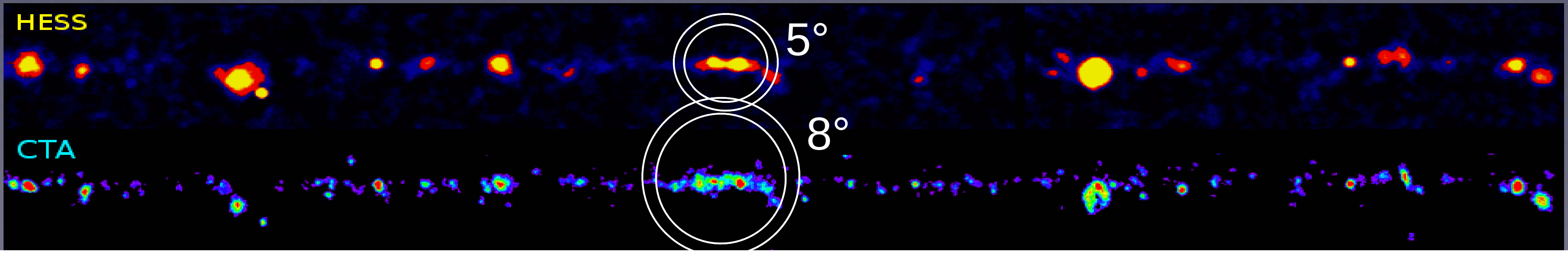
Major sensitivity improvement & wider energy range

→ Factor of >10 increase in source population

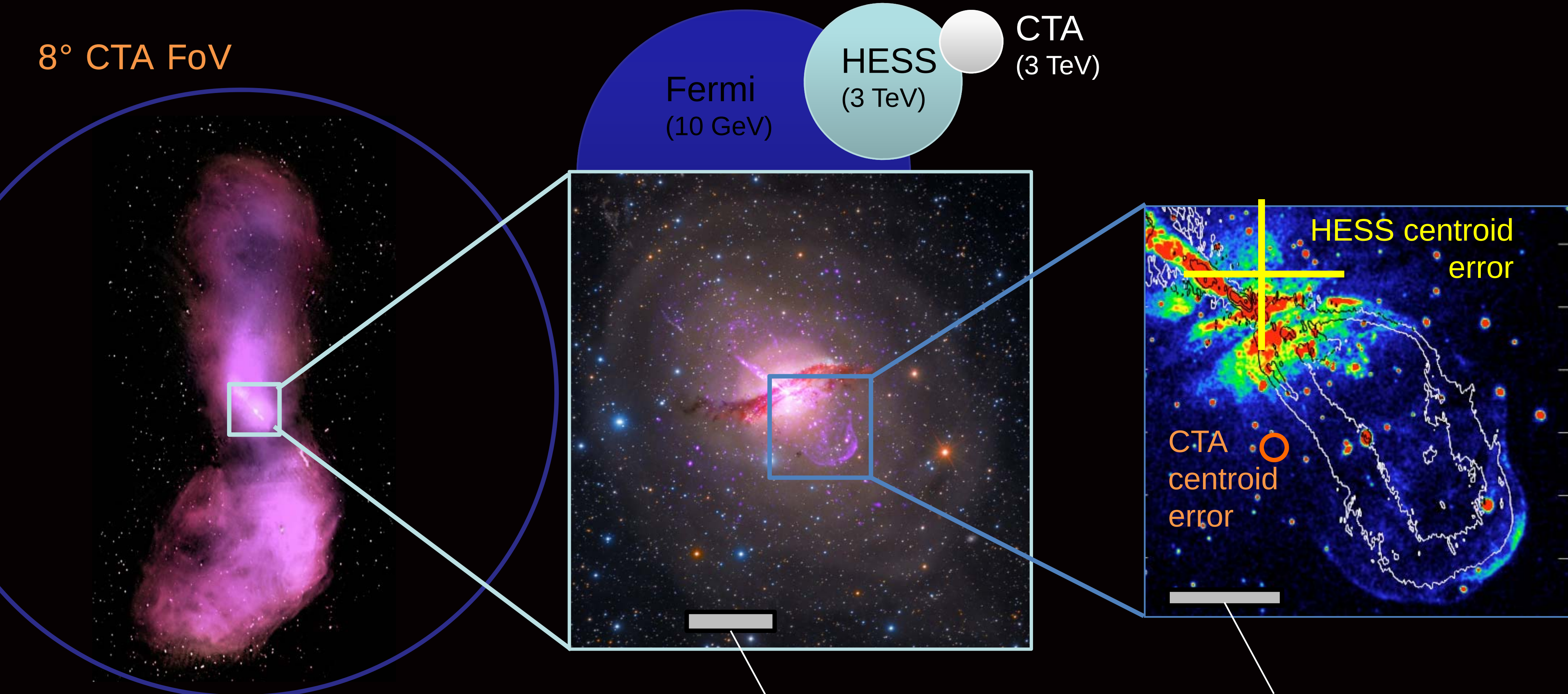
Galactic Discovery Reach



Survey speed:
x300 faster than current instruments



Angular Resolution

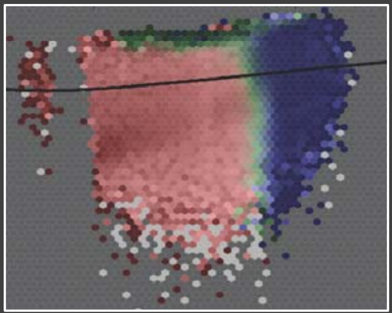


0.1°
Typical
HESS/MAGIC/VERITAS
Resolution

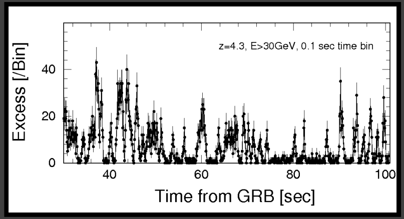
2 ʻ
CTA > 1 TeV

Example: Cen A

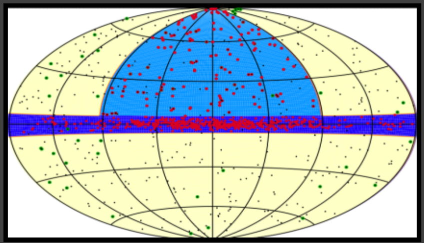
Key Science Projects (KSPs)



Dark Matter Programme

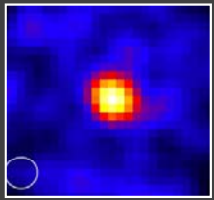


Transients



ExGal Survey

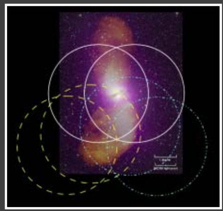
Galaxy Clusters

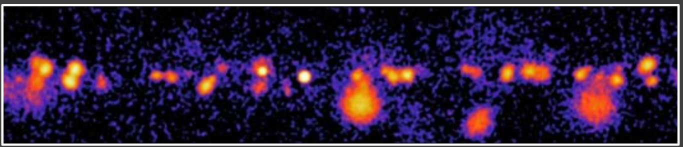


Extragalactic

Star Forming Systems

AGN

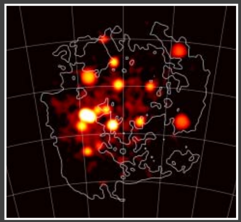


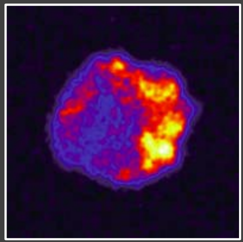


Galactic Plane Survey

Galactic

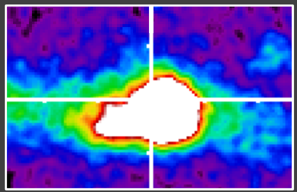
LMC Survey





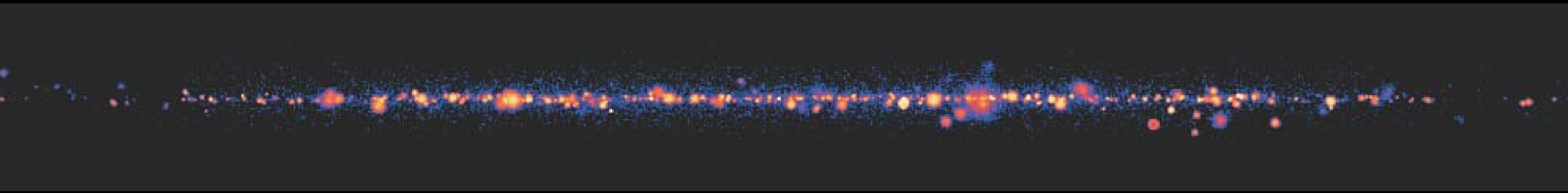
PeVatrons

Galactic Centre

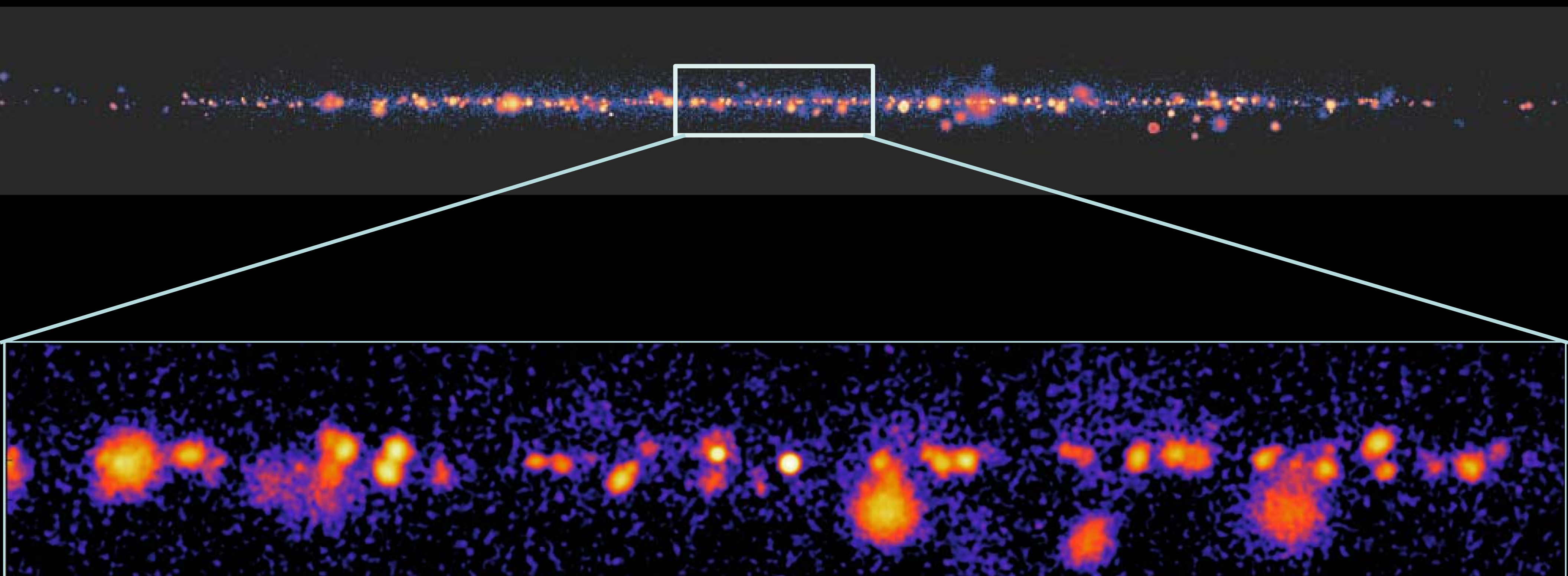


cta cherenkov telescope array

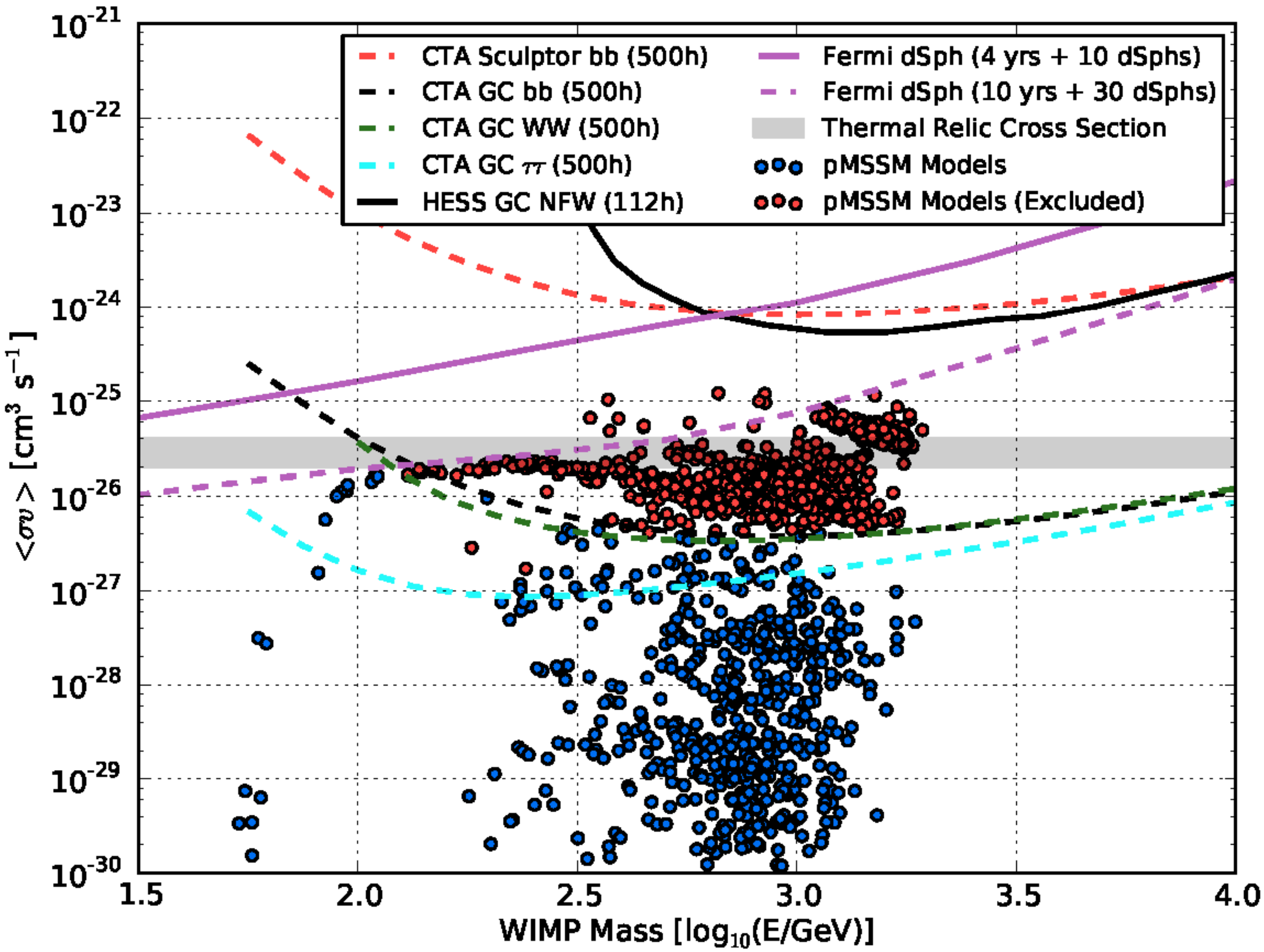
Galactic Plane Survey (GPS)



Galactic Plane Survey (GPS)



Dark Matter Reach

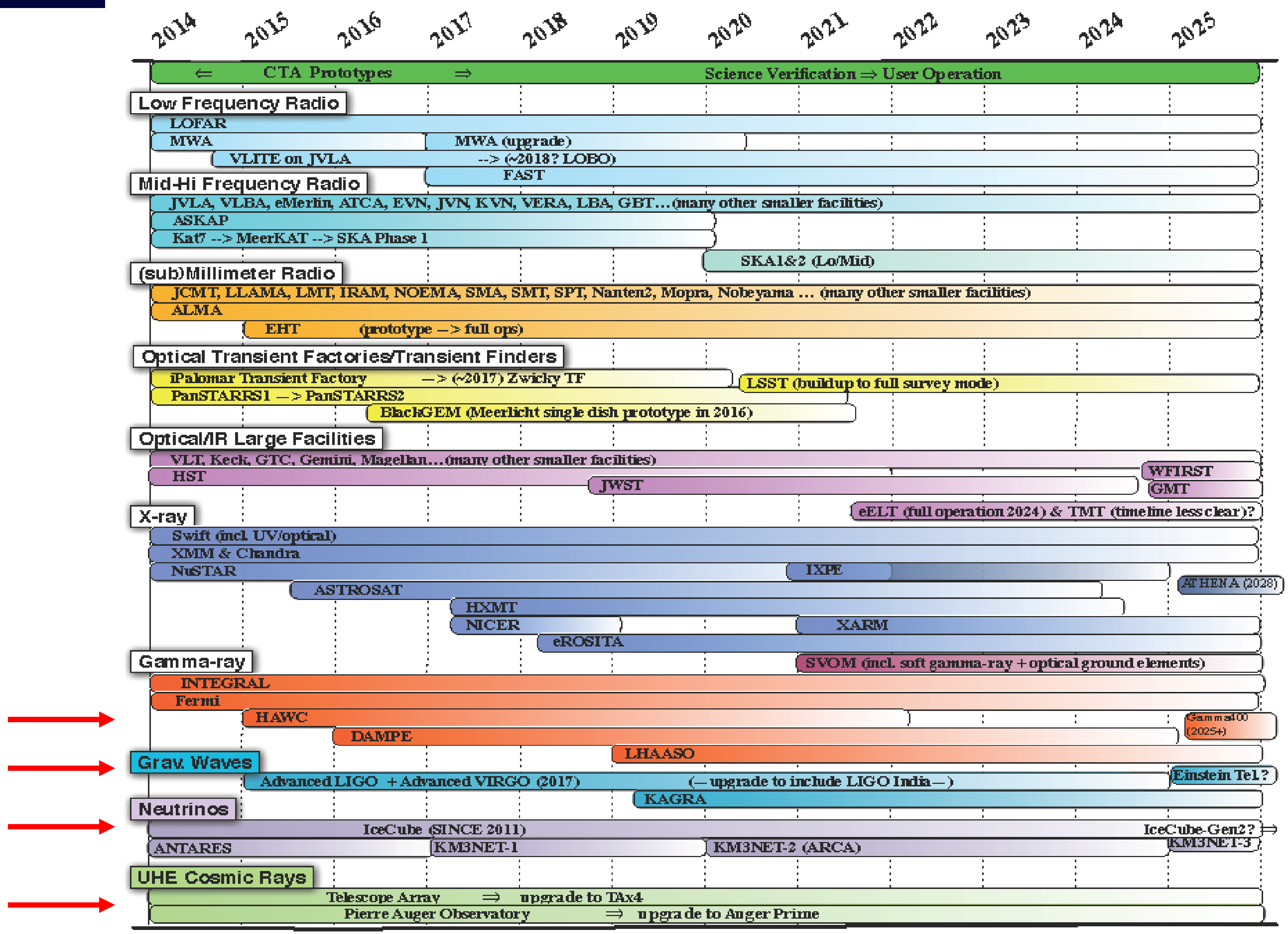


M. Wood et al.
arXiv:1305.0302

Sensitivity below thermal relic in TeV mass range

- *critical reach, not achieved by direct detectors or LHC*

Important MWL/MM Synergies



Caveat: Observatory timelines are very uncertain; this represents a notional picture based on available information

Science with CTA

200 page document describing core CTA science

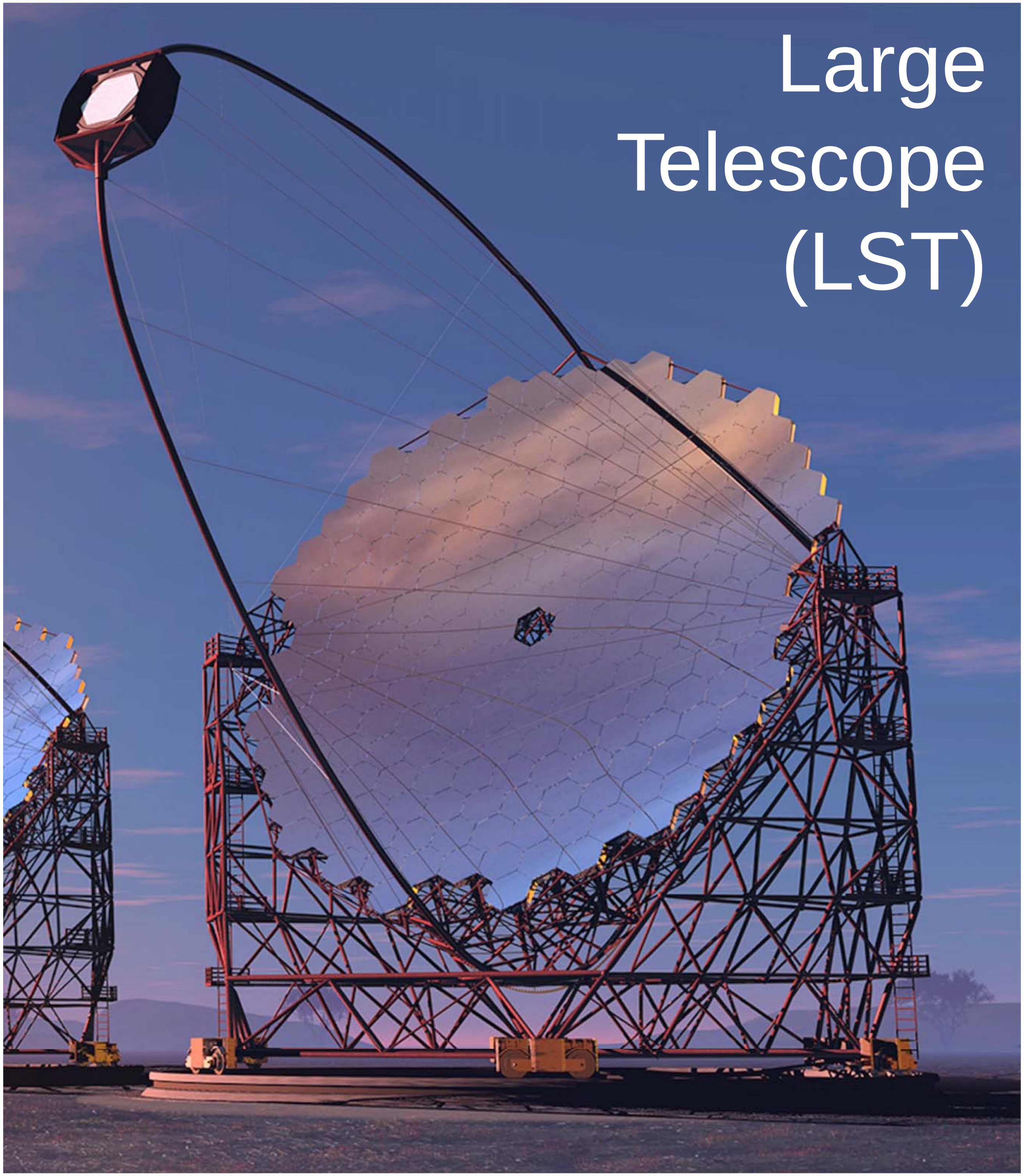
Will soon be put on axViv and become a regular book

CTA Implementation & Status

CTA Consortium

CTA is being developed by the CTA Consortium:

32 countries, ~1402 scientists, ~208 institutes, ~480 FTE



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

4.5^o field of view
0.1^o 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

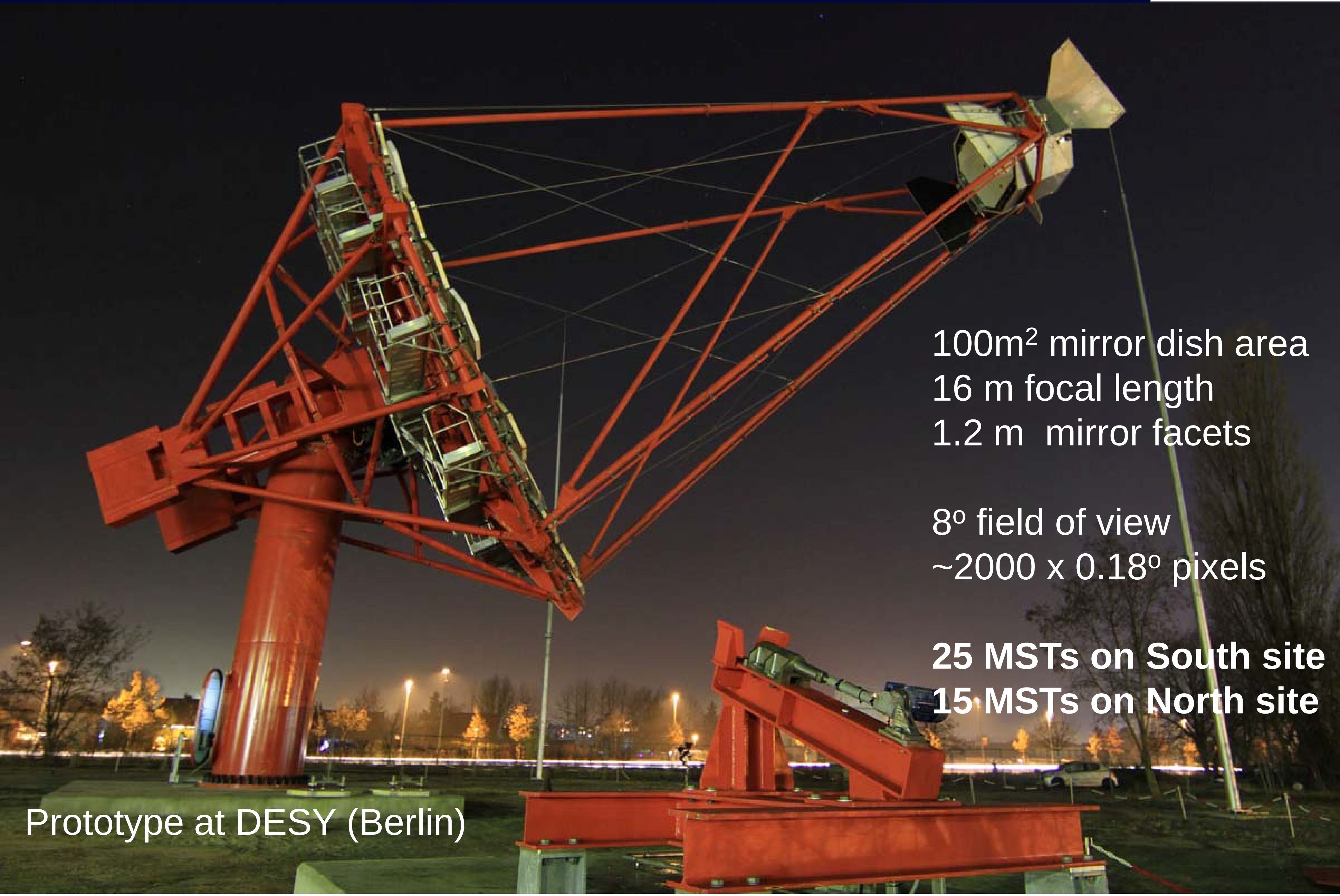
Prototype construction
Underway (La Palma)

LST 1 Foundation

LST 1 Foundation Completed

LST: Structure & Mirrors

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

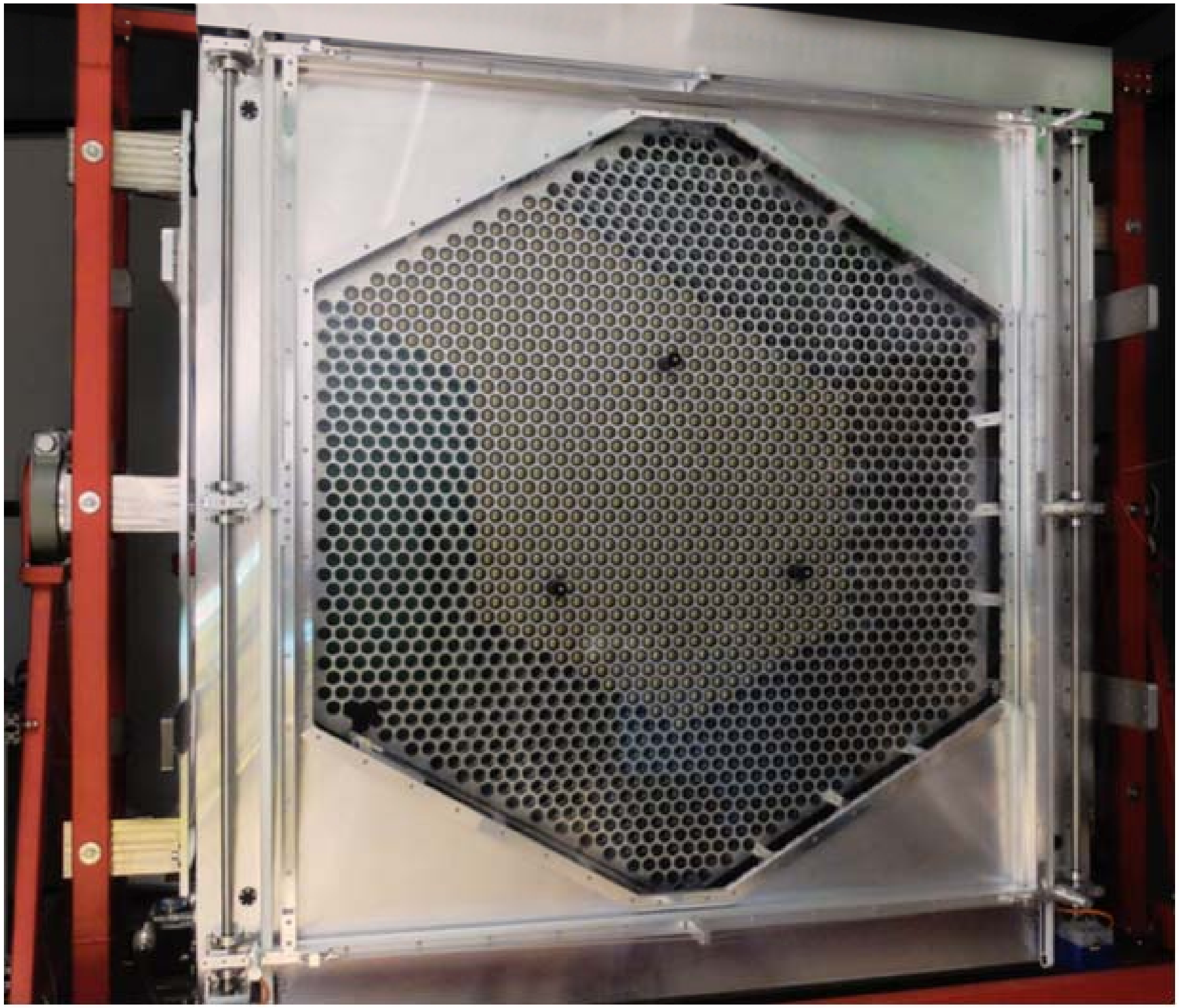
25 MSTs on South site
15 MSTs on North site

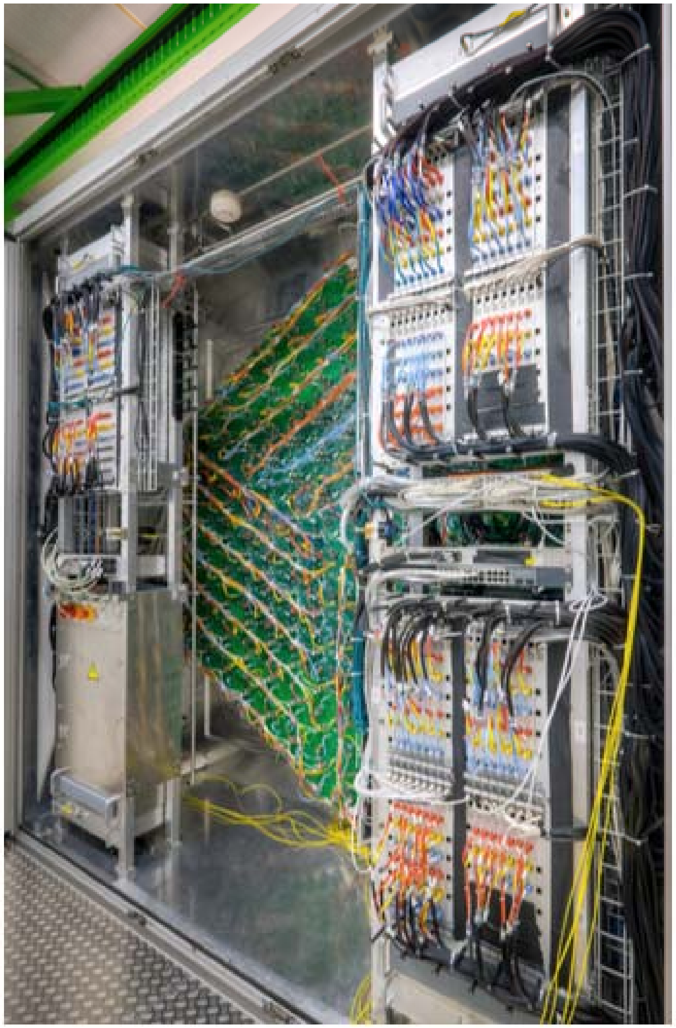
Prototype at DESY (Berlin)

MST: Structure

Updated structure to improve rigidity

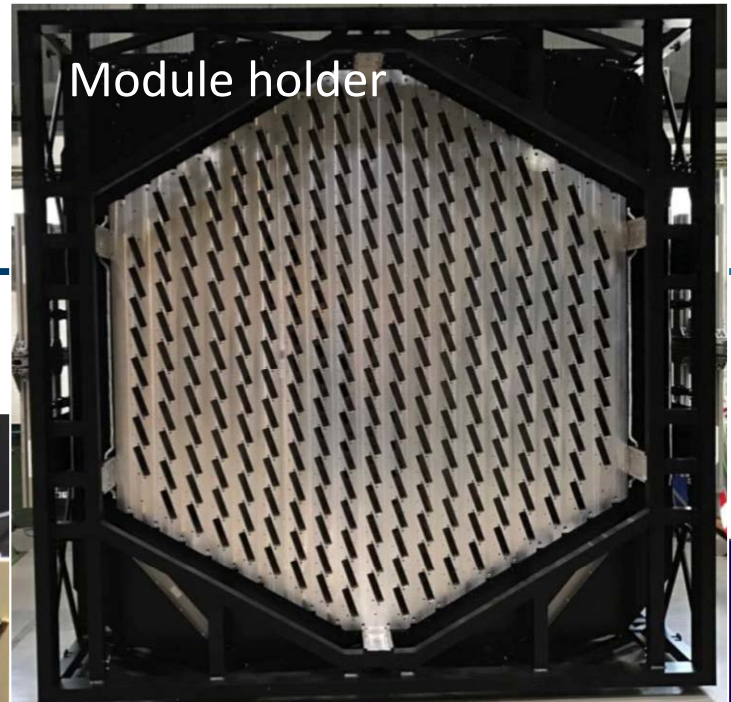
MST: FlashCam

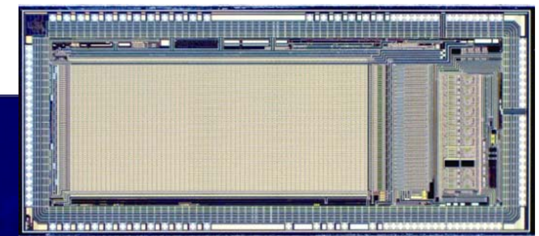


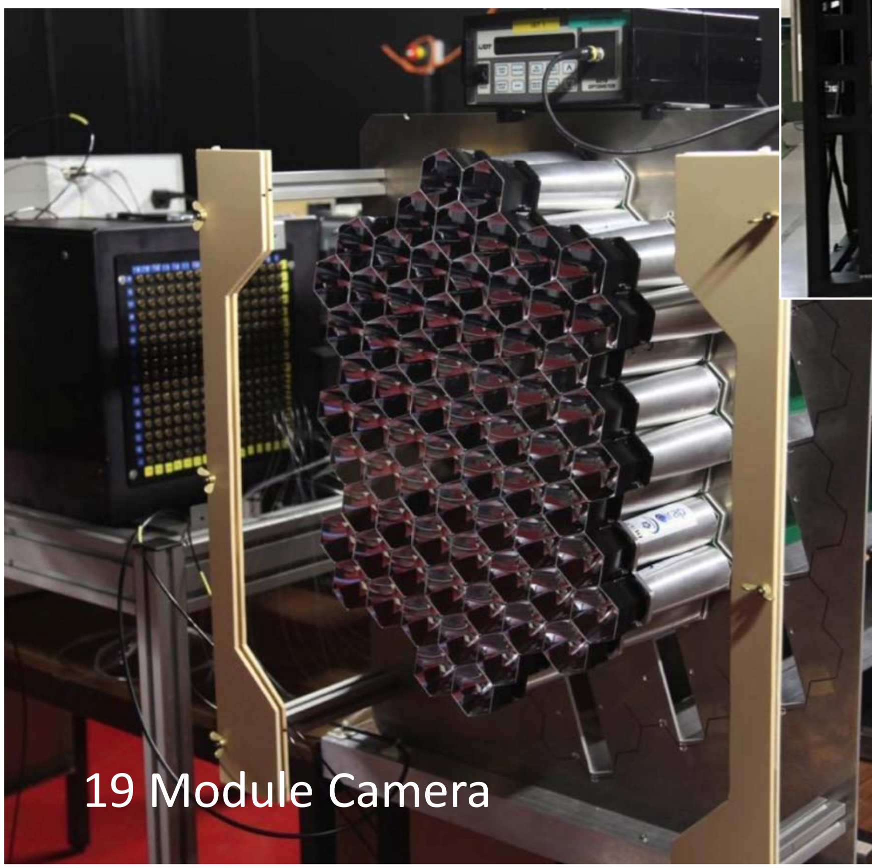


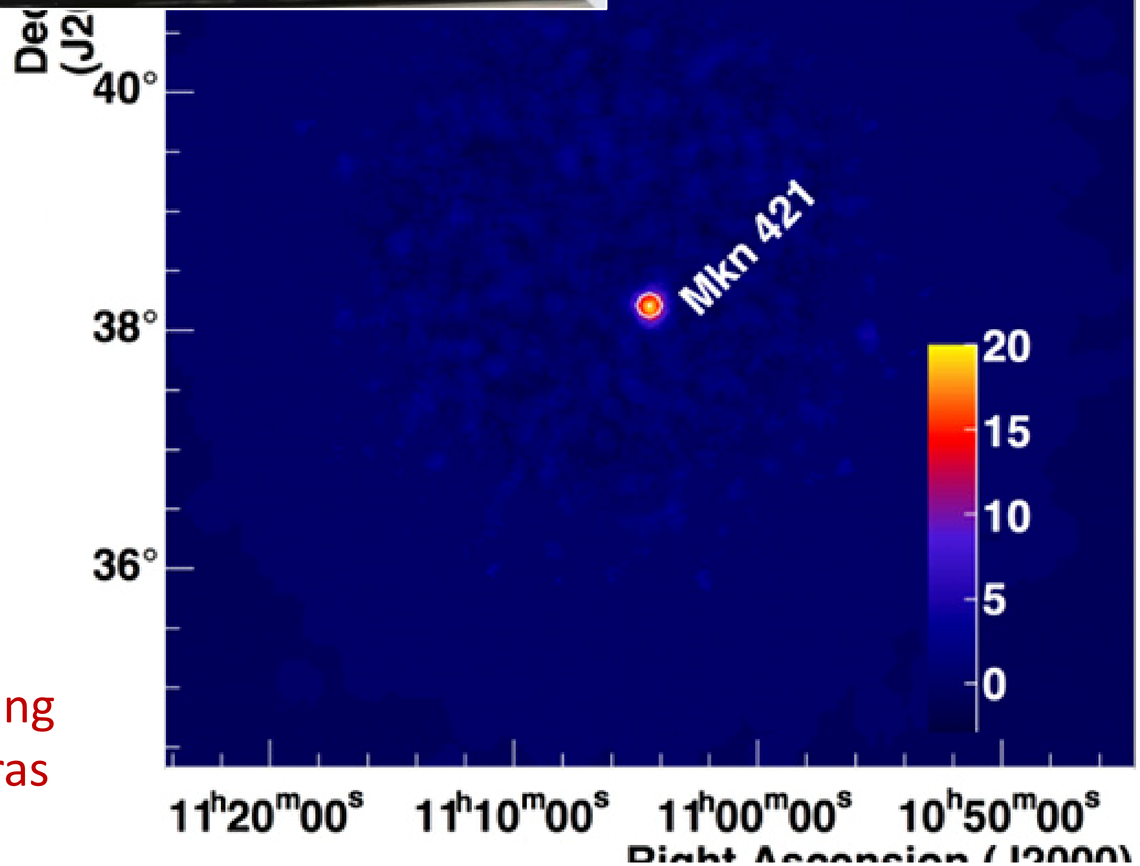
250 MHz sampler, digital pipeline

MST: NectarCam



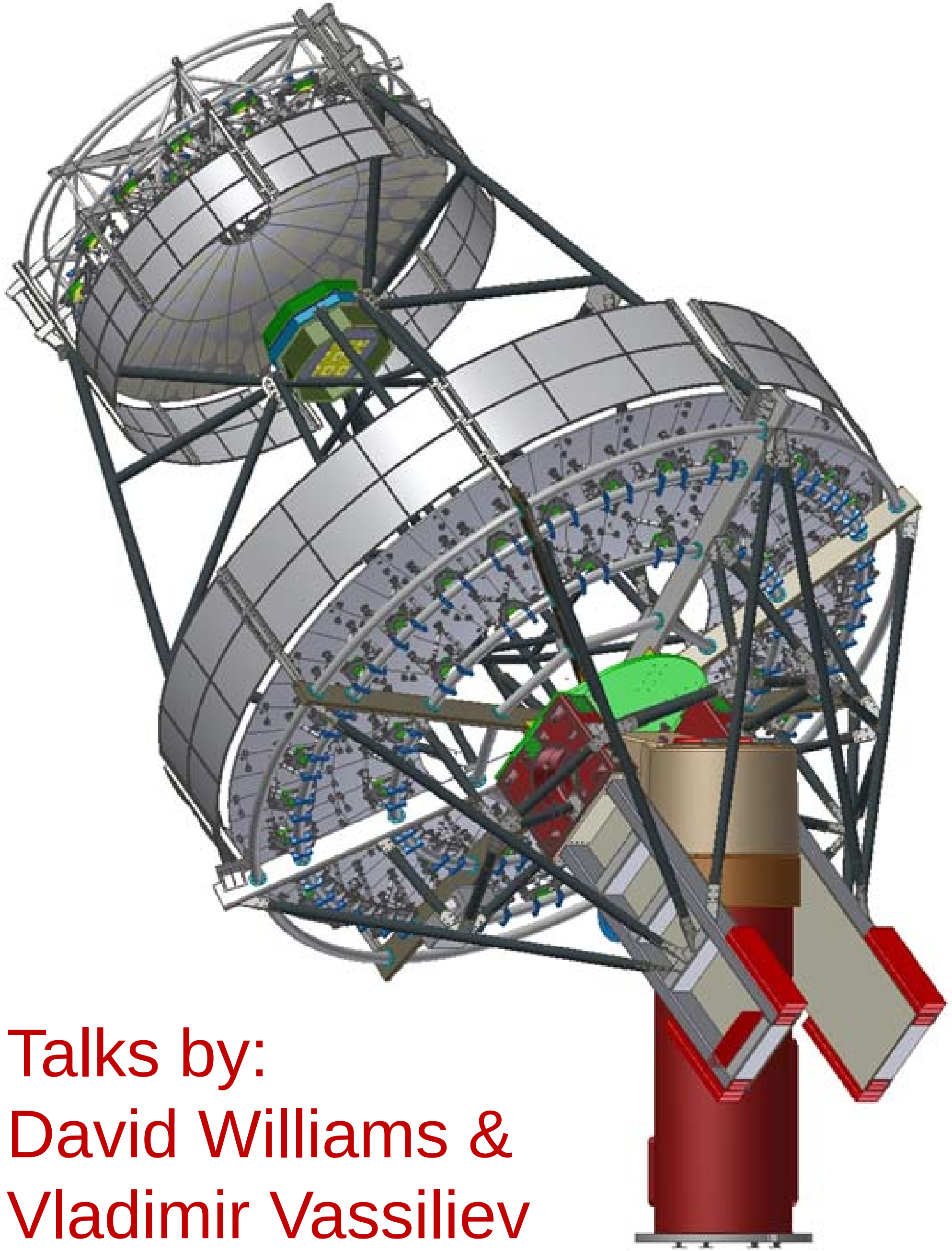






H.E.S.S. Mrk 421 using new (Nectar) cameras

Medium Telescope 2-mirror (SCT)



Talks by:
David Williams &
Vladimir Vassiliev

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^o FOV

8^o field of view
11328 x 0.07^o SiPMT pixels
TARGET readout ASIC

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

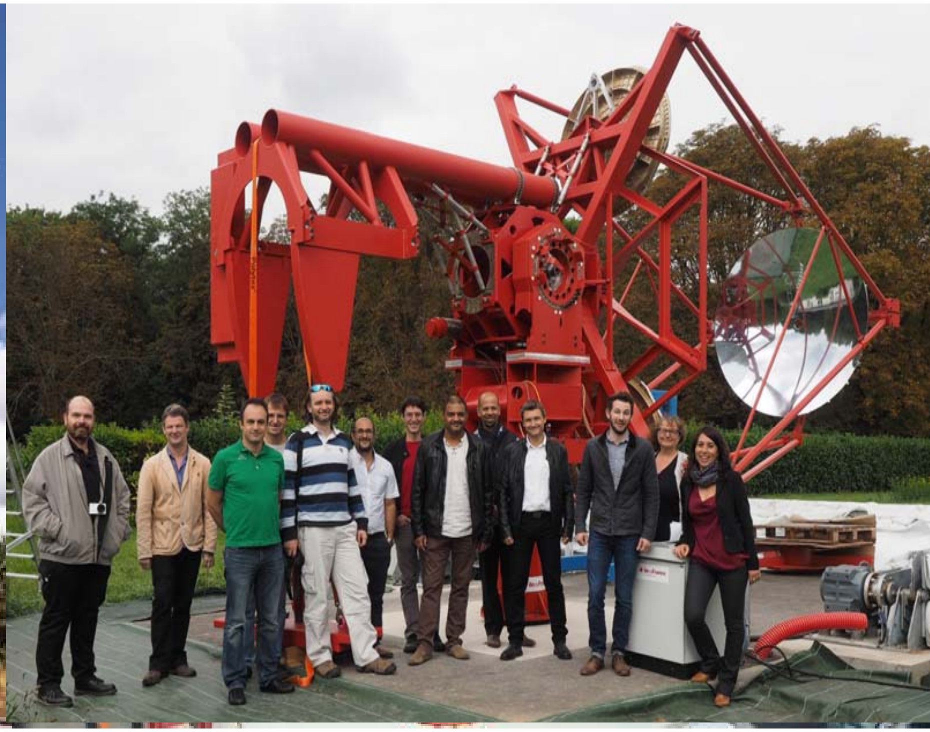
➜ Increased γ-ray collection area
➜ Improved γ-ray ang. resolution
➜ Improved DM sensitivity

Small Sized Telescopes (SSTs)

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

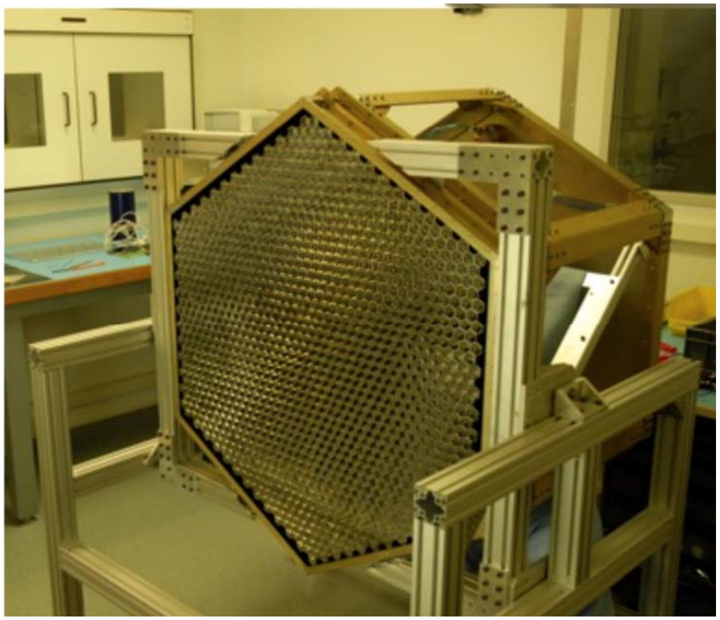
SST-1M
Krakow, Poland

SST-2M ASTRI
Mt. Etna, Italy

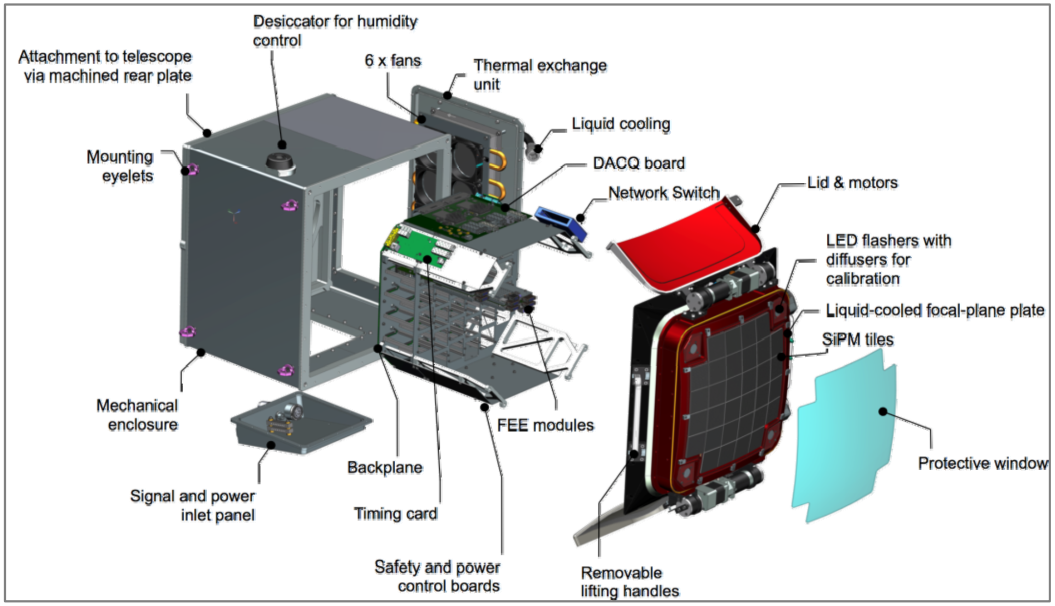


SST-2M GCT
Meudon, France

Small Sized Telescopes (SSTs)



SST-1M
Digicam – close to being installed on telescope

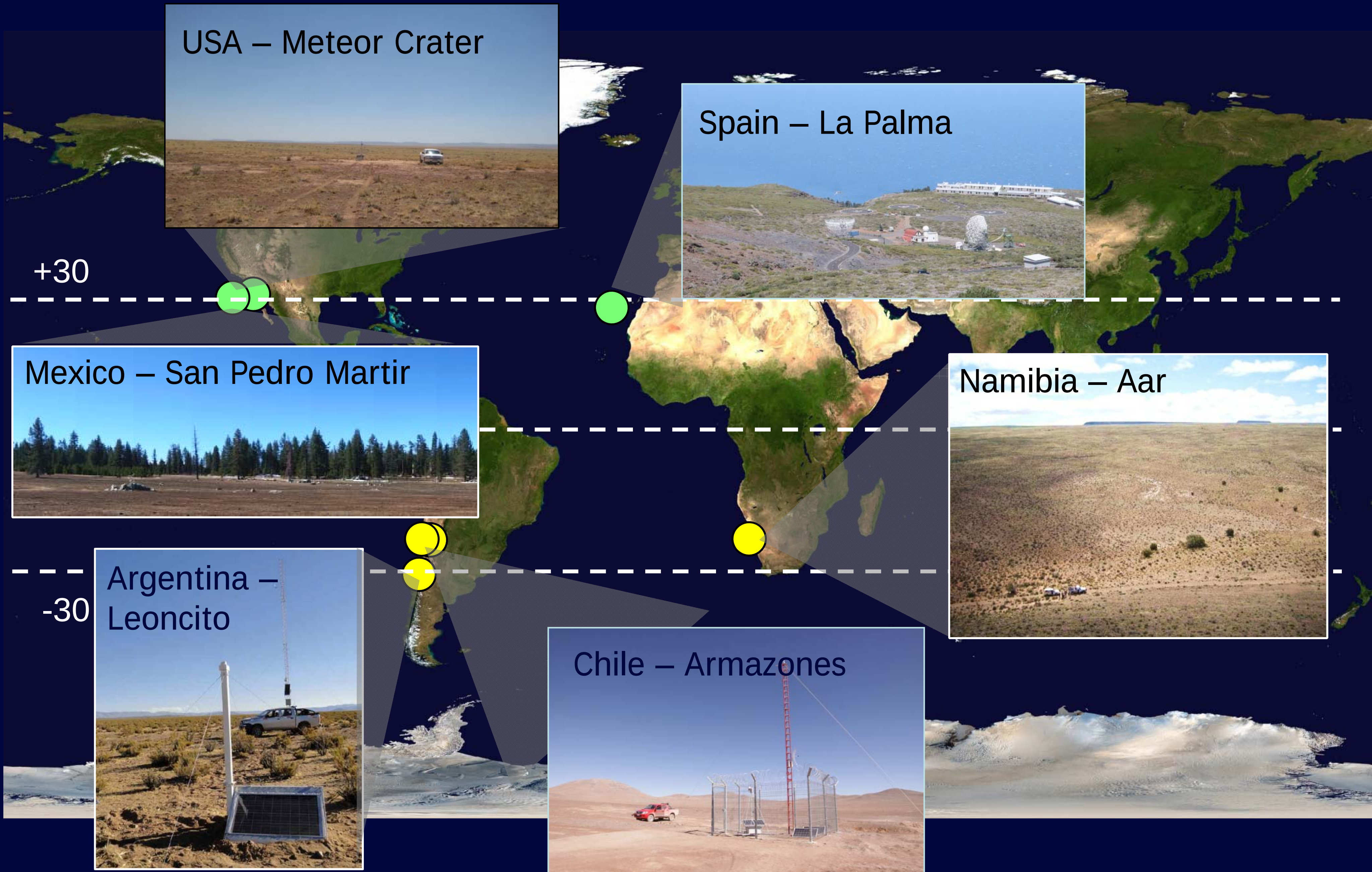


SST-2M-GCT
Si-PM camera 75% complete
(similar readout to SCT)

SST-2M-ASTRO
Camera now installed
Undergoing tests/initial data

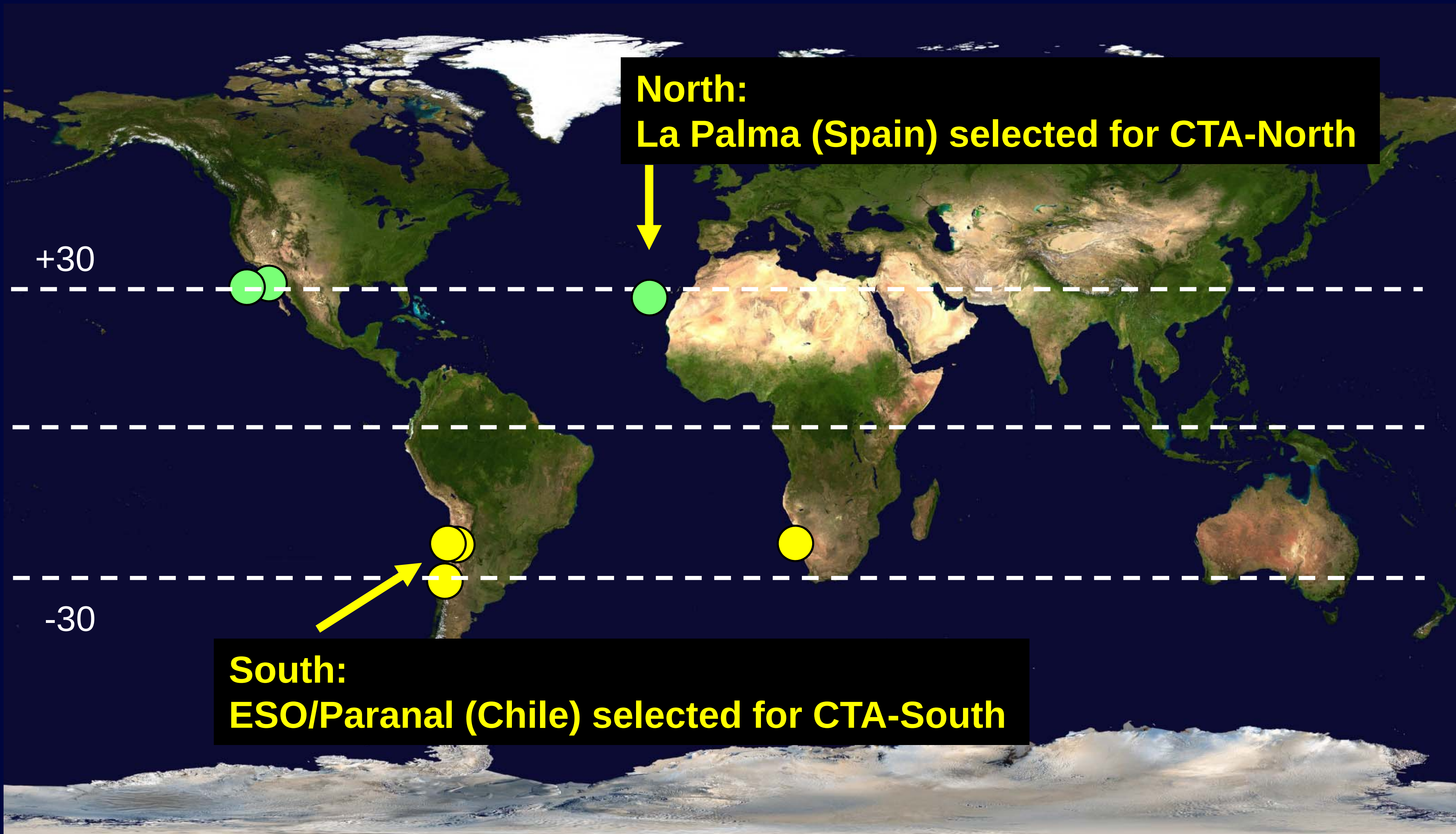
Site Selection

Two sites to cover full sky, latitude 20º-35º in N, S



Site Selection

Two sites to cover full sky at 20°-35° N, S

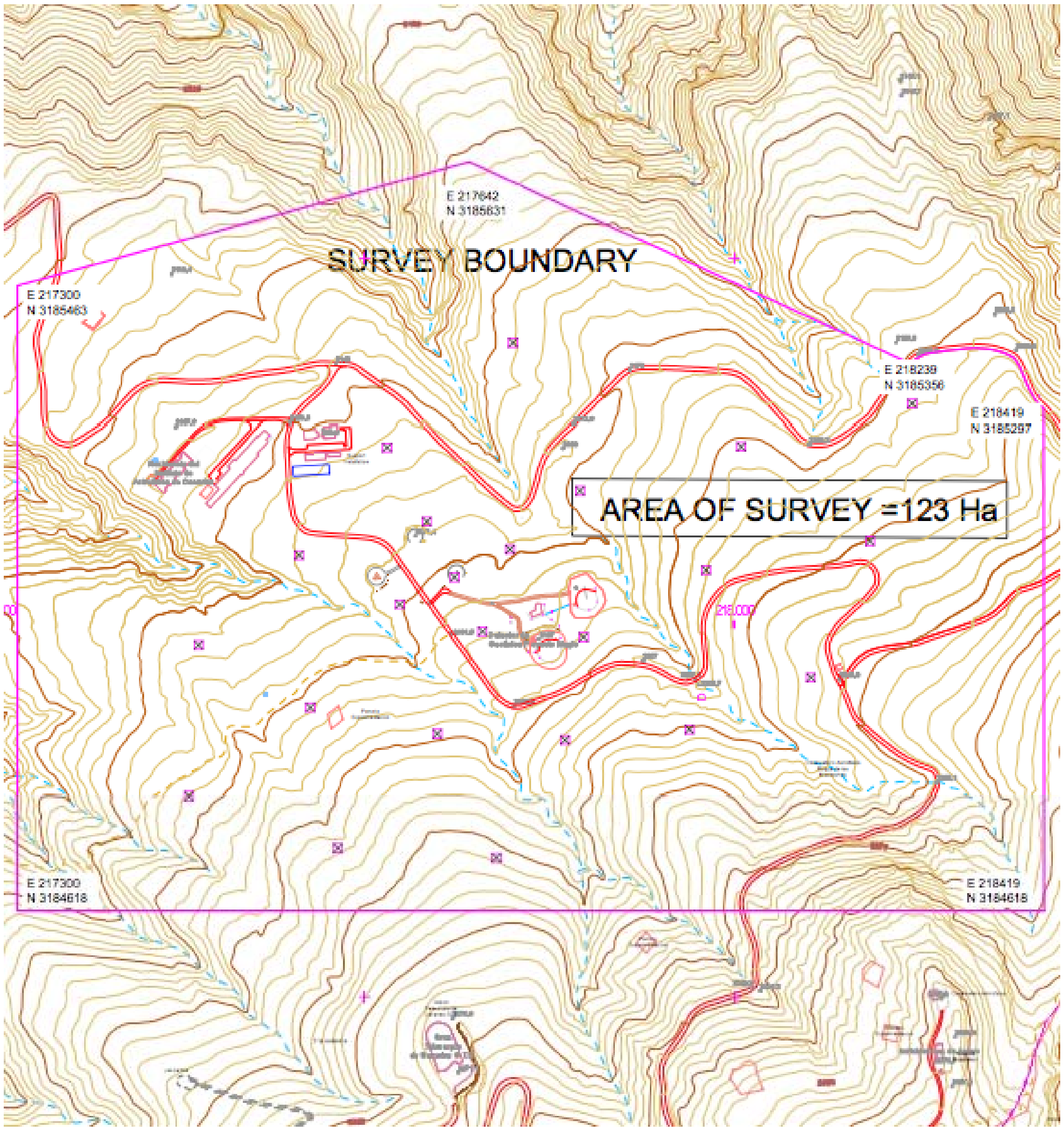


LA PALMA

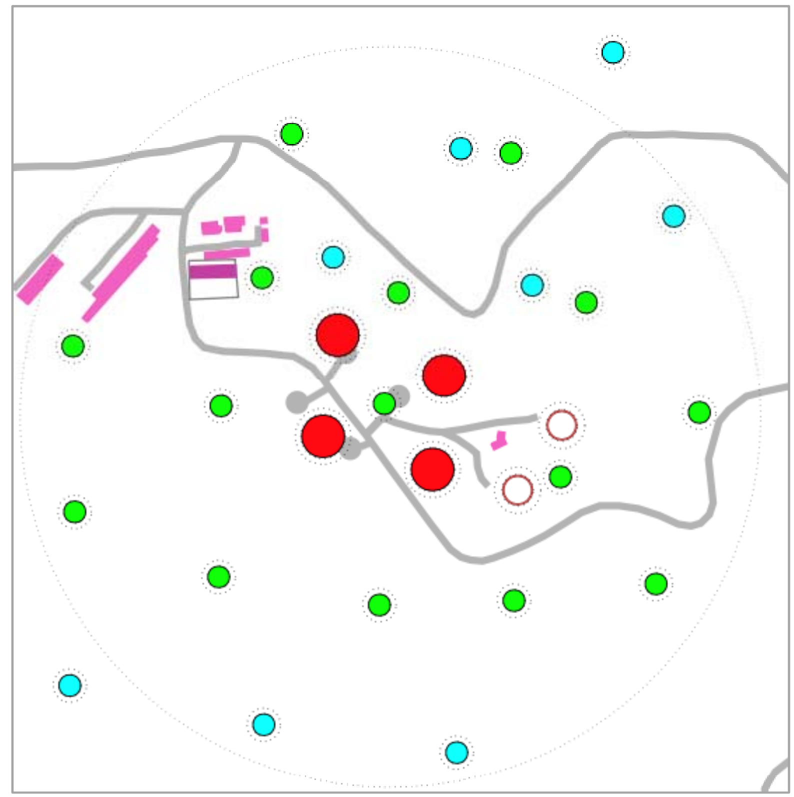
- Canary Islands, Spain
- Observatorio del Roque de los Muchachos
- Existing observatory, under management by Instituto de Astrofisica de Canarias (IAC)
- Site of LST 1 & existing MAGIC telescopes

North Layout

4 LSTs
15 MSTs



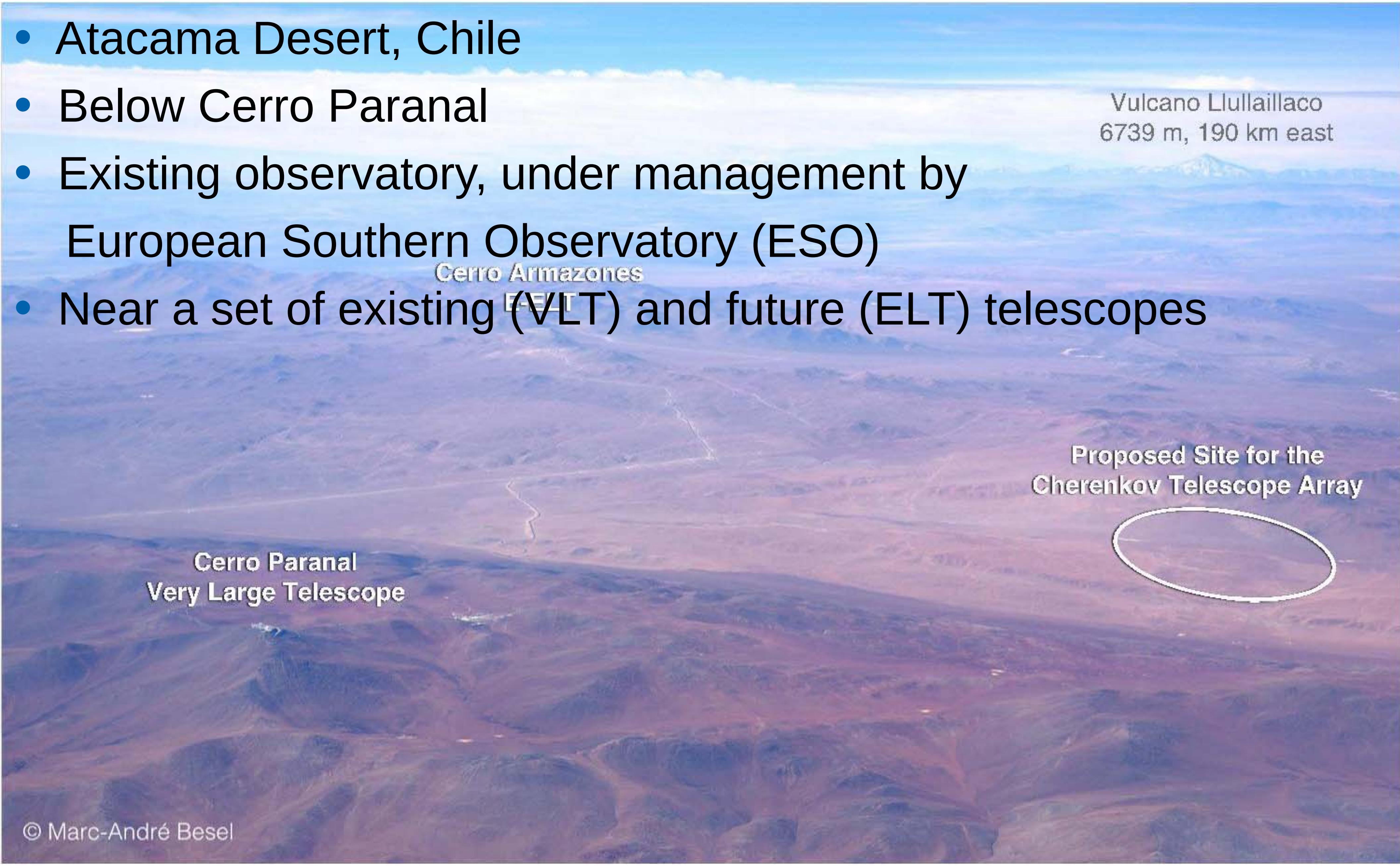
Possible layout – still in progress



Current work:
topographical study
building concepts
tender for geotechnical, RIBA
design contracts soon

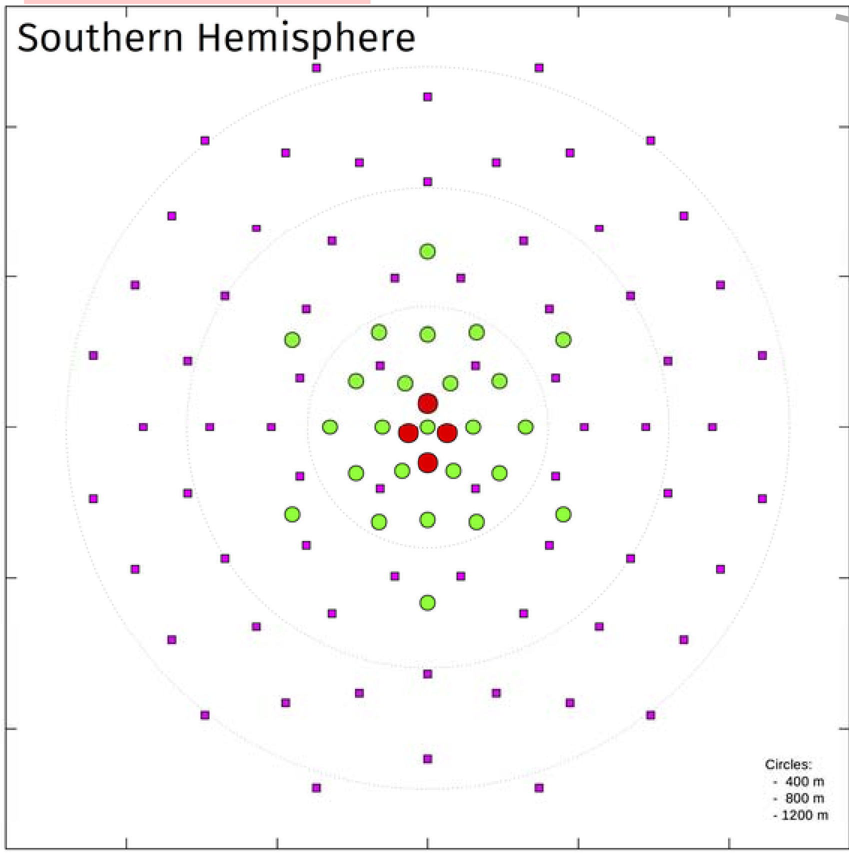
ESO/PARANAL

- 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

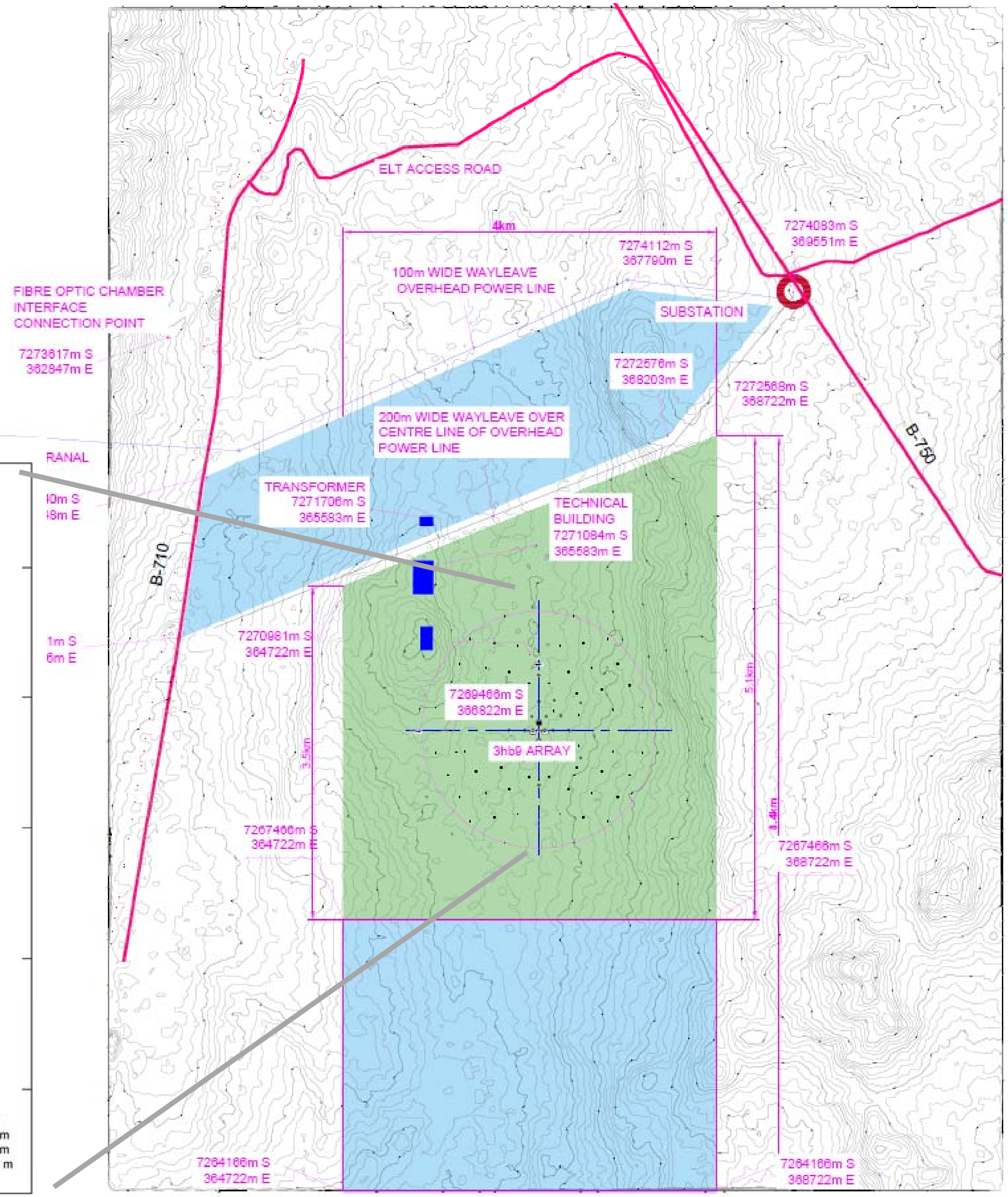


CTA South

4 LSTs
25 MSTs
70 SSTs

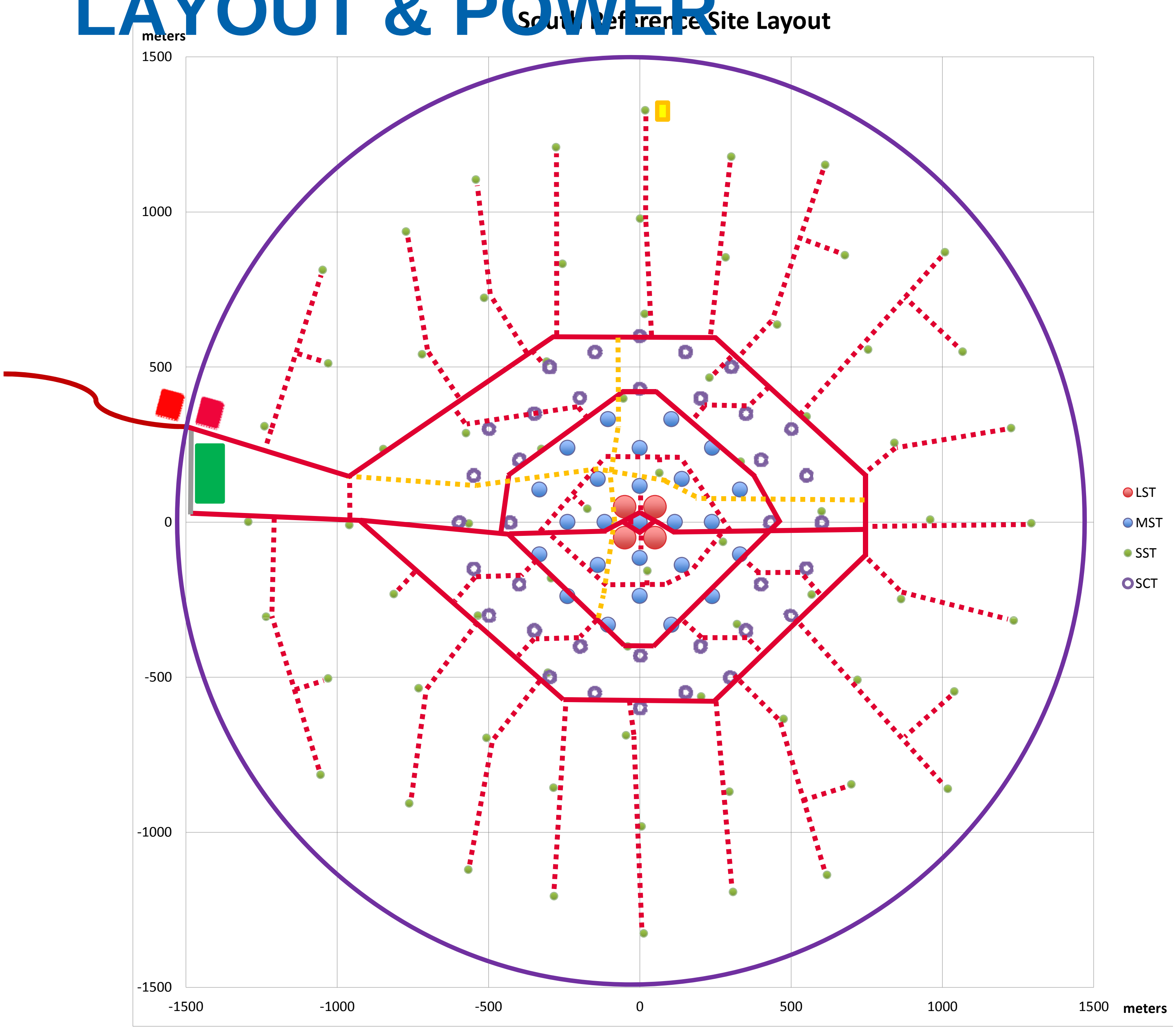


4 LSTs, 25 MSTs, 70 SSTs

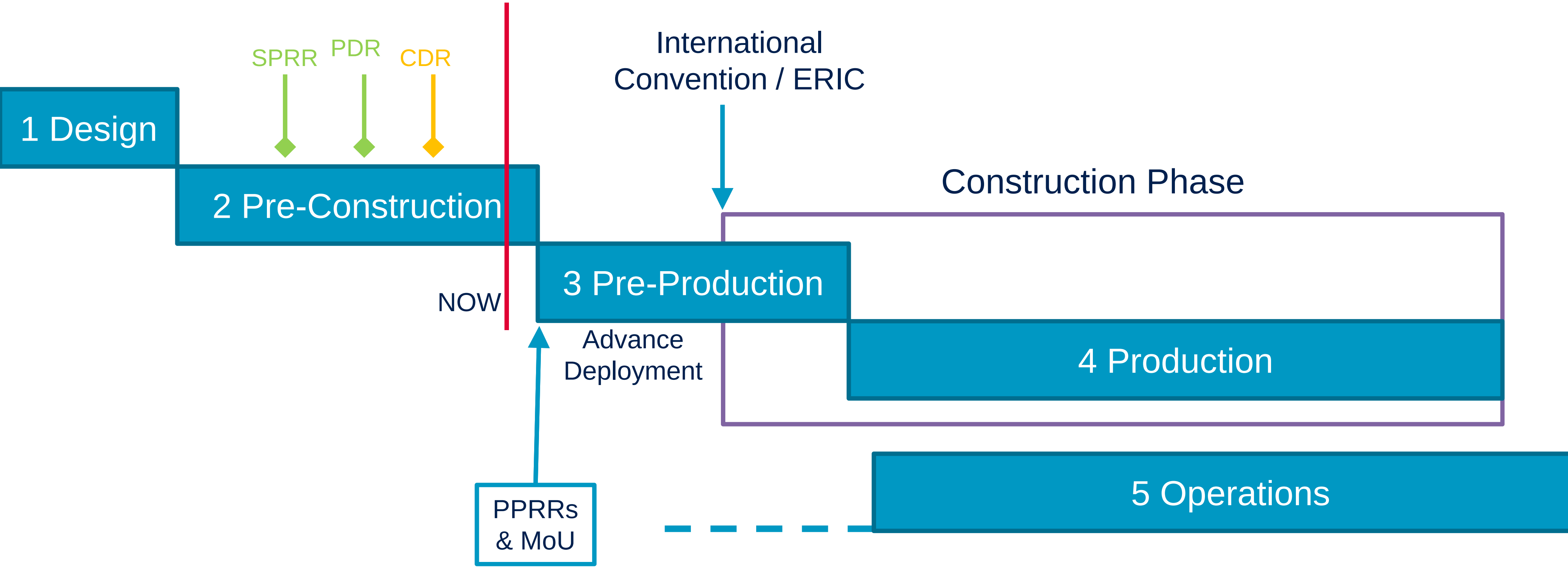


Current work: geotechnical studies (boreholes, etc.), topographical survey, RIBA-3,4 (roads, power, ducting, buildings)

ESO/PARANAL – POSSIBLE LAYOUT & POWER



CTA Phases & Timeline



- 2016: Hosting agreement, site preparations start (N)
- 2017: Hosting agreement, site preparations start (S)
- Funding level at ~65% of required for *baseline implementation*
  → start with *threshold implementation*
  → additional funding, telescopes needed to complete CTA
- Construction period of 5-6 years
- Initial science with partial arrays possible before construction end

Summary

- **3rd Generation instruments (e.g. VERITAS) Critical**

  With many discoveries, VHE γ-rays are now well-recognized and exciting area of research

  Outstanding science potential & the power of the atmospheric Cherenkov technique → CTA

- **Cherenkov Telescope Array (CTA)**

  Excellent sensitivity & resolution over wide energy range

  Far-reaching science program

  Open observatory with all data released to public

  CTA requires a broad partnership of countries and communities

- In next decade, CTA will start to provide high-quality data, of a quality not yet seen with any gamma-ray technique
- However, all of this rests squarely on the foundation of earlier work that developed the technique and the science over period of 30 years – a great deal of that foundation came in the US or people working in US.

Acknowledgements

Thanks to all my VERITAS and CTA colleagues!

Special thanks to:

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David Williams