Overview of the Cherenkov Telescope Array

Manel Martinez

Gamma-Ray Astrophysics with CTA

July 2017-Sexten

OUTLINE:

1) The make of the CTA project

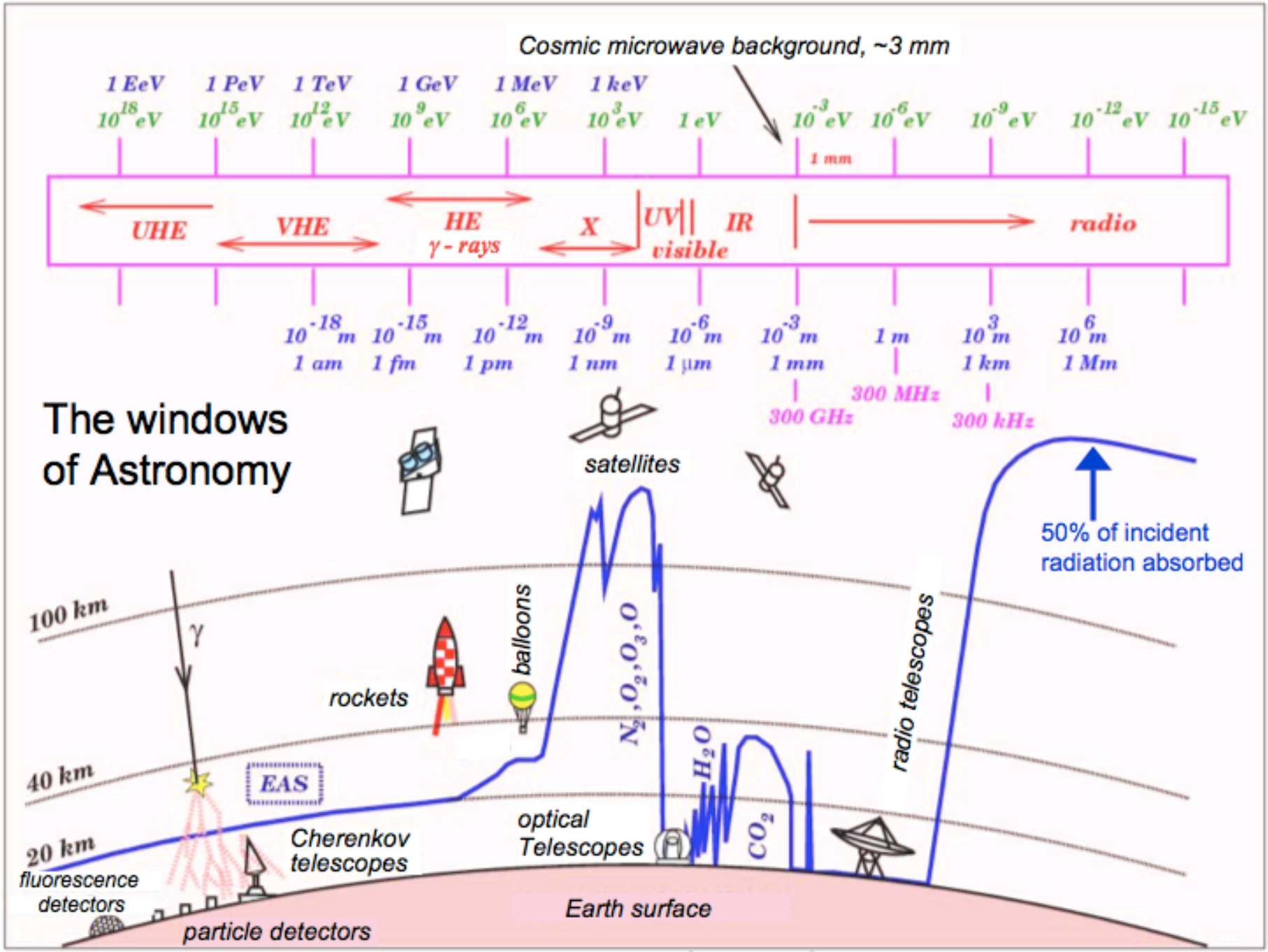
2) CTA will be an observatory

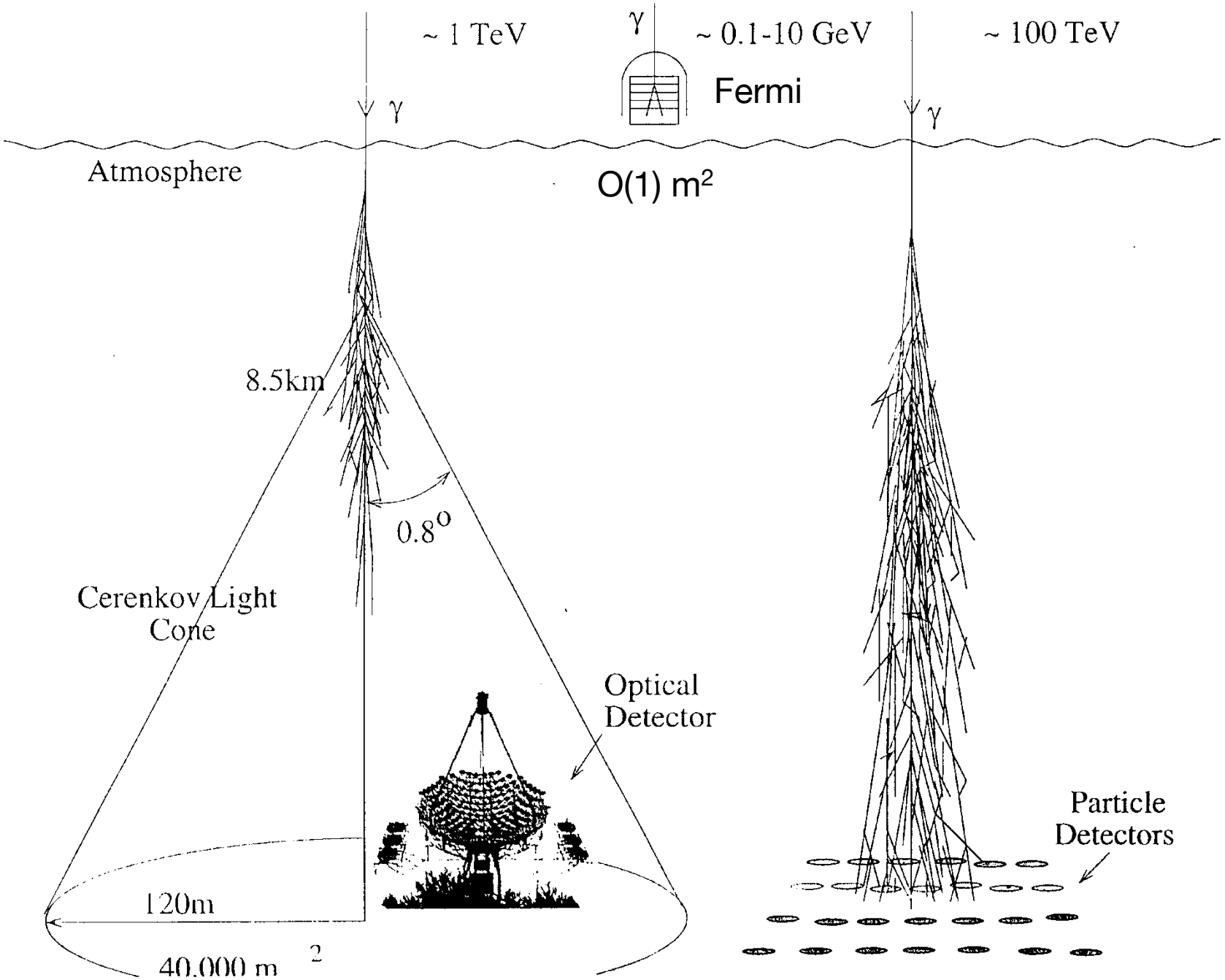
3) Summary and Outlook

Summary and outlook

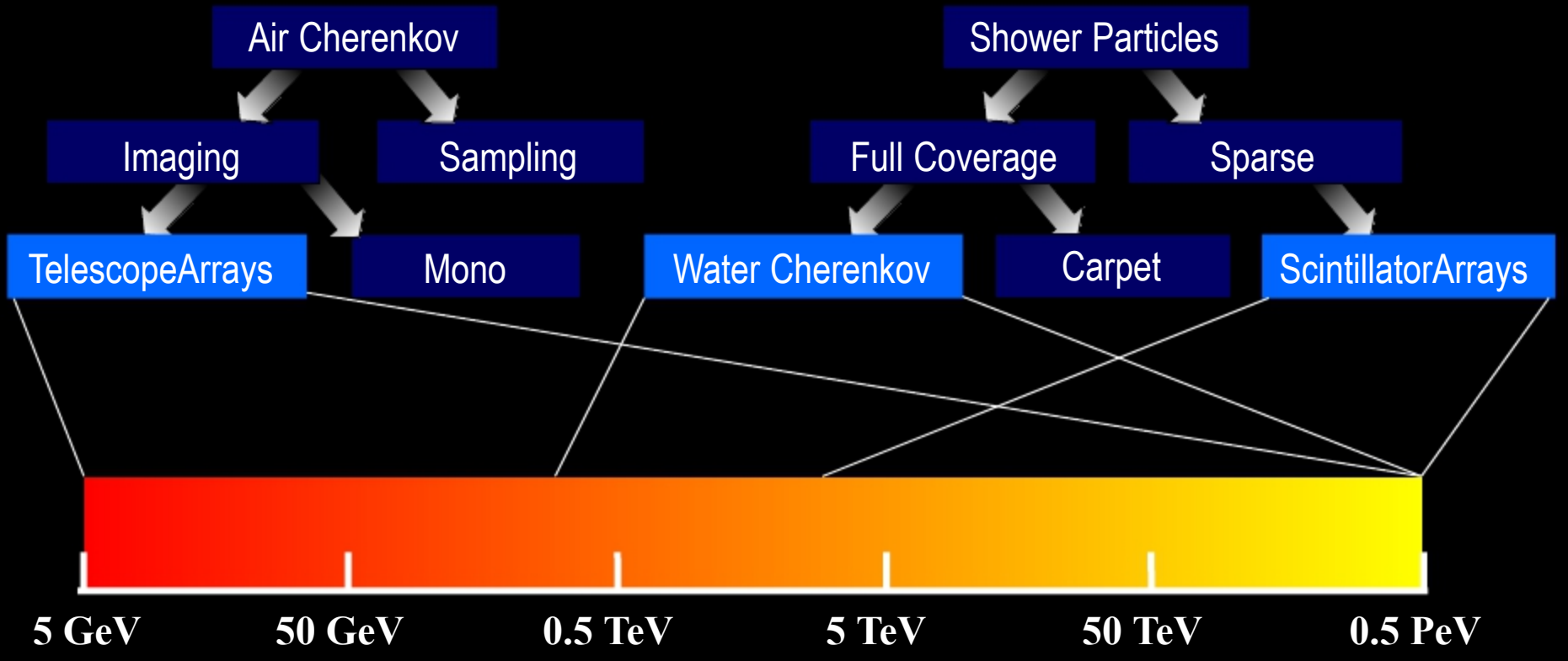
- The initial idea of CTA came in 2006, and since then it has evolved in such a way that it has managed to rank high in the roadmaps of all relevant European forums (ESFRI, ASPERA, ASTRONET) and American reviews (PASAG, Decadal Review).
- After over 10 years of work, CTA is just completing the Preproduction Phase by having passed a CDR, downselecting North and South Observatory sites, Headquarters and Science Data Management Centre, having working prototypes of most of its elements, and heading towards the Preconstruction Phase with its de-facto first telescope in construction already in CTA-North.
- CTA shall be soon the first ground-based open Observatory in the field of Astroparticle Physics, providing a new leap in our exploration of the High Energy Universe.
- **CTA is (finally…) coming on stage !.**

1) THE MAKE OF THE CTA PROJECT


Cosmic microwave background, ~3 mm
1 EeV
10^18 eV
1 PeV
10^15 eV
1 TeV
10^12 eV
1 GeV
10^9 eV
1 MeV
10^6 eV
1 keV
10^3 eV
1 eV
10^-3 eV
1 mm
10^-6 eV
10^-9 eV
10^-12 eV
10^-15 eV
UHE
VHE
HE
γ - rays
X
UV
visible
IR
radio
10^-18 m
1 am
10^-15 m
1 fm
10^-12 m
1 pm
10^-9 m
1 nm
10^-6 m
1 μm
10^-3 m
1 mm
1 m
10^3 m
1 km
10^6 m
1 Mm
300 GHz
300 MHz
300 kHz
The windows of Astronomy
satellites
50% of incident radiation absorbed
100 km
γ
rockets
balloons
N2,O2,O3,O
H2O
CO2
radio telescopes
40 km
EAS
optical Telescopes
20 km
Cherenkov telescopes
fluorescence detectors
Earth surface
particle detectors

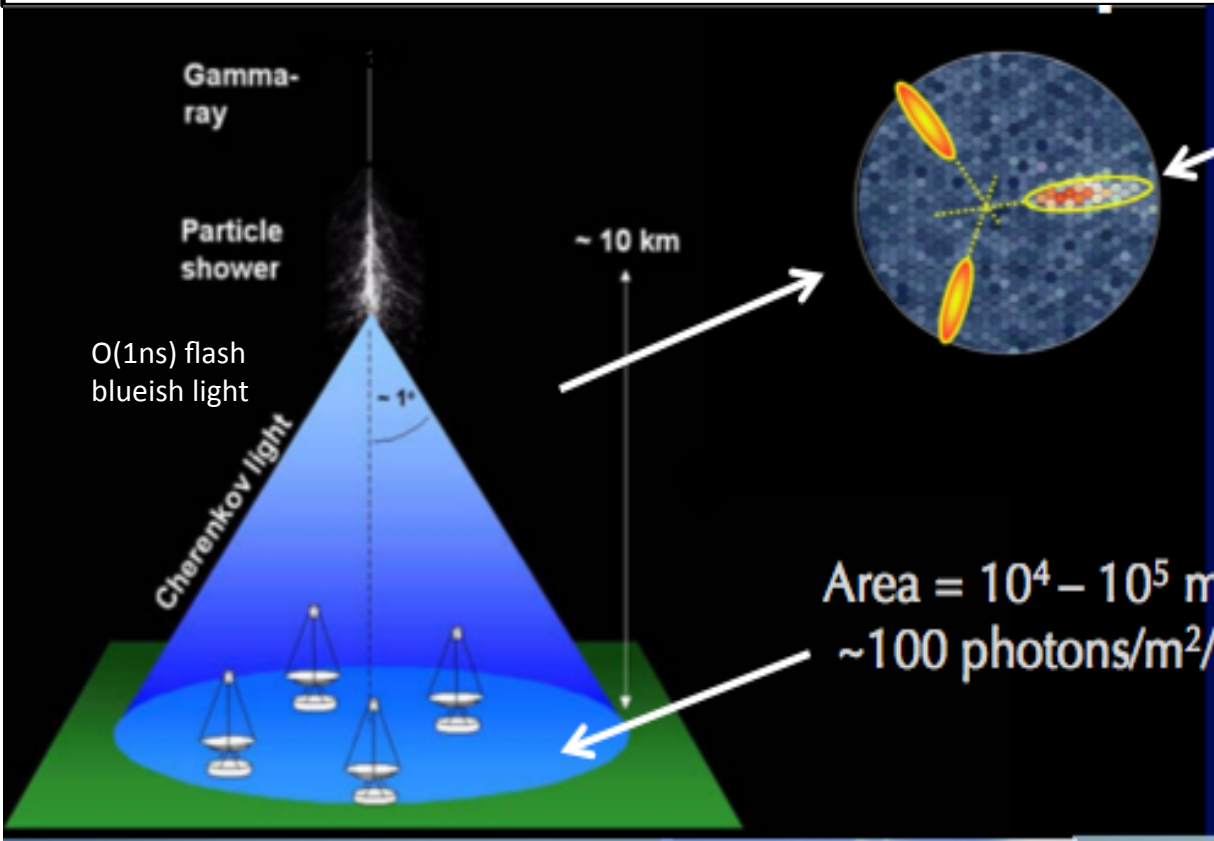

~ 1 TeV
γ
~ 0.1-10 GeV
~ 100 TeV
Fermi
γ
γ
Atmosphere
O(1) m²
8.5km
0.8°
Cerenkov Light
Cone
Optical
Detector
Particle
Detectors
120m
40,000 m²

VHE Gamma-Ray Detection Techniques



- Many different approaches have been tried
  - Not all have stood the test of time
  - Major projects planned using three of them

Imaging Cherenkov principle

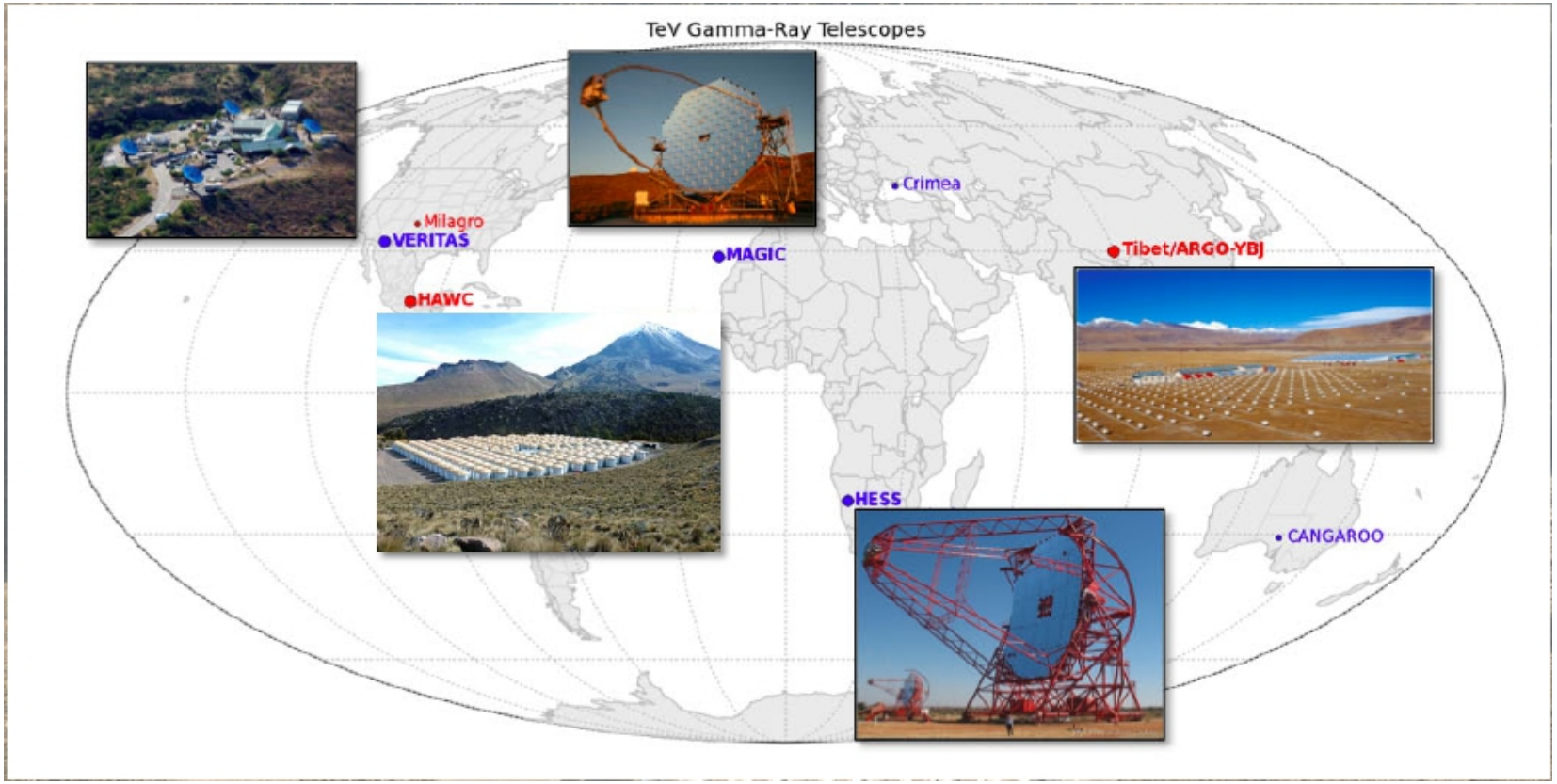


γ-ray origin location on the camera focal plane (sky)

Area = $10^4 - 10^5$ m^2
~100 photons/m^2/TeV

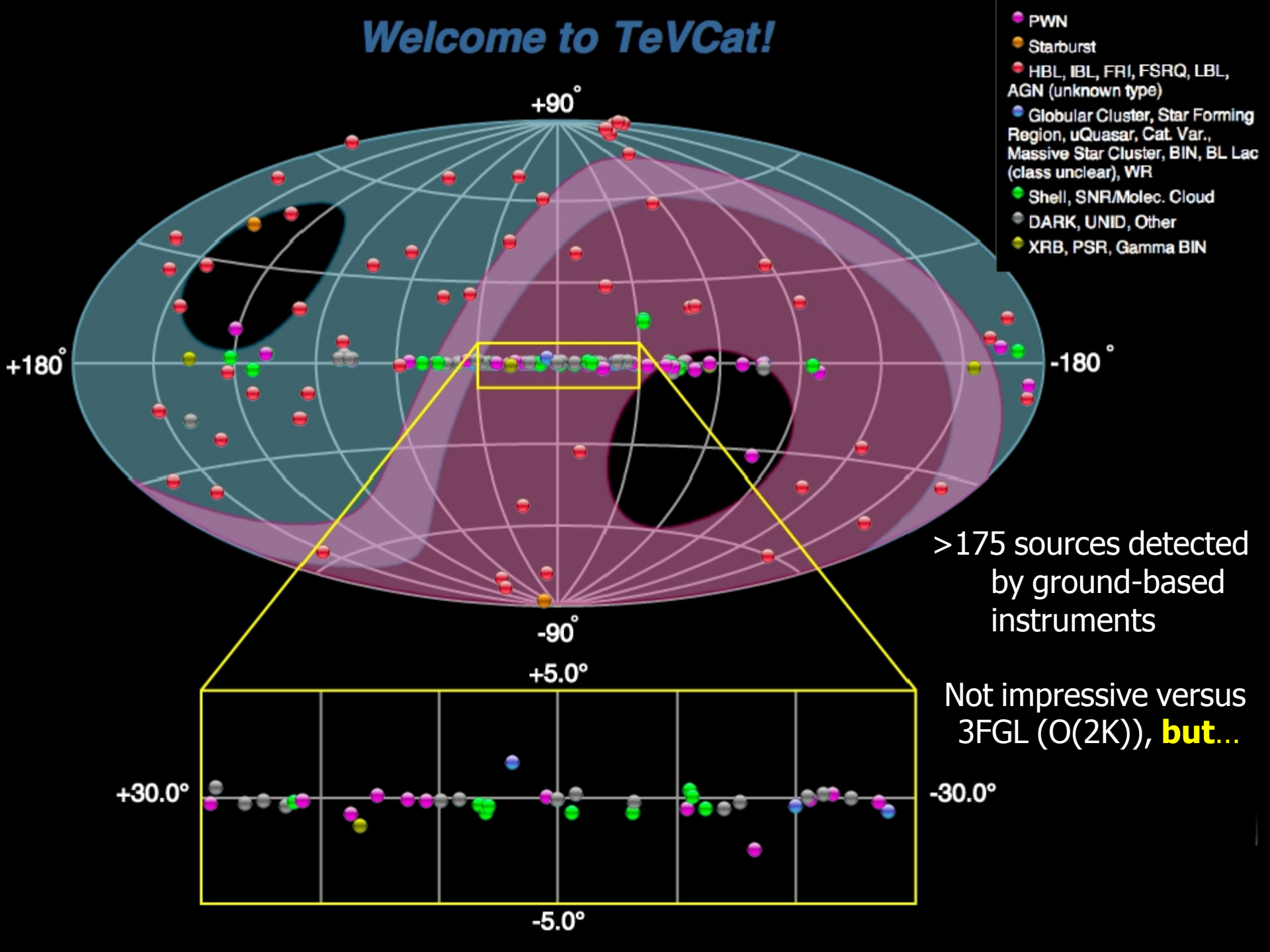
➔ Much larger effective area than space-based Fermi-LAT

TeV Observatories



• **Cherenkov Telescopes:** low uptime, small FOV, excellent bkg rejection and angular resolution
-> deep surveys, point sources, high-resolution energy spectra

• **Particle detector arrays:** high uptime, large FOV, reasonable background rejection and angular resolution
-> unbiased surveys, transients, extended/diffuse emission, cosmic rays and solar physics


Welcome to TeVCat!
PWN
Starburst
HBL, IBL, FRI, FSRQ, LBL, AGN (unknown type)
Globular Cluster, Star Forming Region, uQuasar, Cat. Var., Massive Star Cluster, BIN, BL Lac (class unclear), WR
Shell, SNR/Molec. Cloud
DARK, UNID, Other
XRB, PSR, Gamma BIN
+90°
+180°
-180°
-90°
+5.0°
+30.0°
-30.0°
-5.0°
>175 sources detected by ground-based instruments
Not impressive versus 3FGL (O(2K)), but…

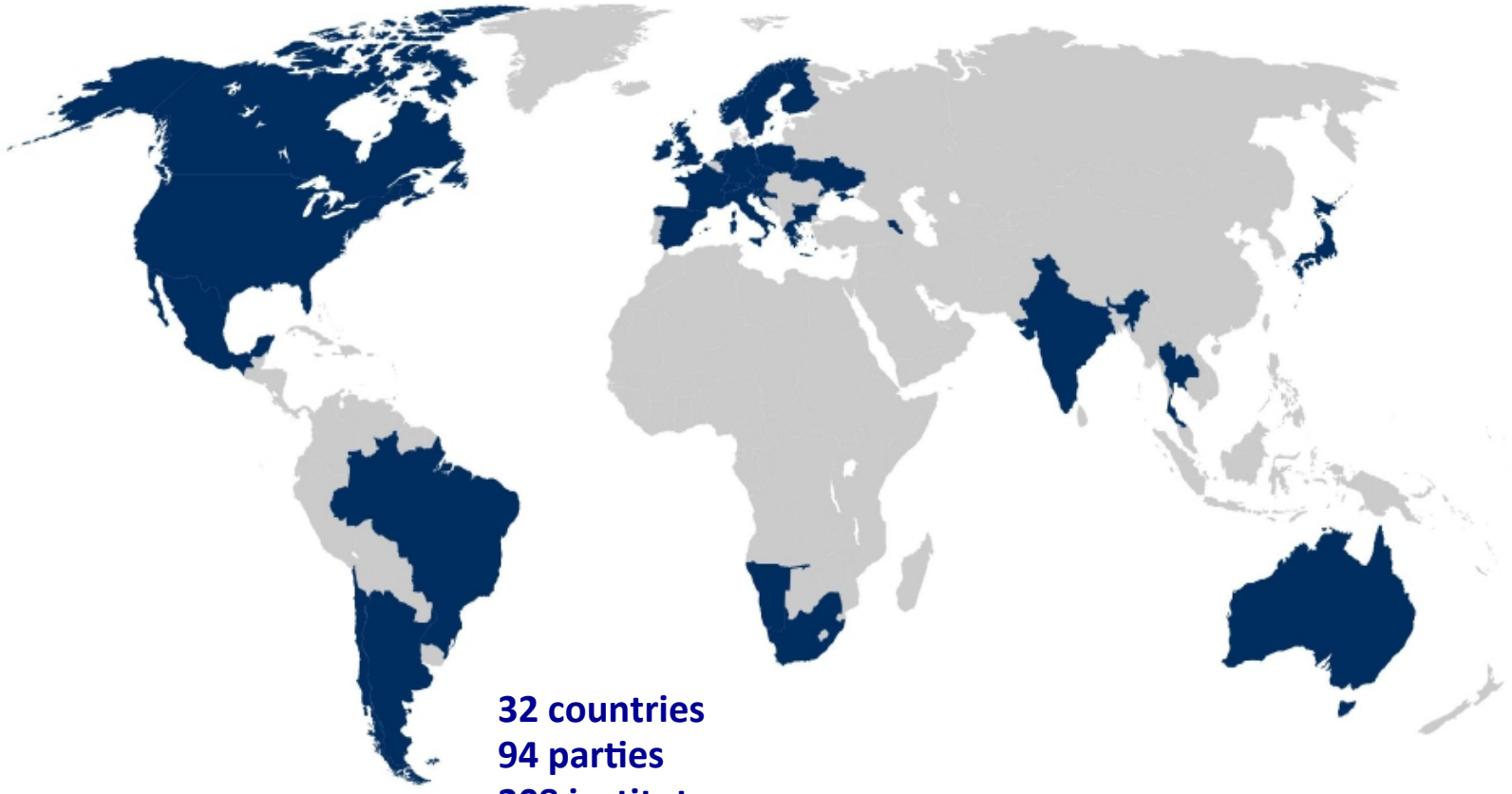
TeV Impact

Highlights from **H.E.S.S., MAGIC,VERITAS**

- *Microquasars:* Science 309, 746 (2005), Science 312, 1771 (2006)
- *Pulsars:* Science 322, 1221 (2008), Science 334, 69 (2011)
- *Supernova Remnants:* Nature 432, 75 (2004)
- *The Galactic Centre:* Nature 439, 695 (2006)
- *The Magellanic Cloud:* Science 347, 406 (2015)
- *Surveys:* Science 307, 1839 (2005), PRL 95, 251103 (2005)
- *Starbursts:* Nature 462, 770 (2009), Science 326,1080 (2009)
- *AGN:* Science 314,1424 (2006), Science 325, 444 (2009), Science 346, 1080 (2014)
- *EBL:* Nature 440, 1018 (2006), Science 320, 752 (2008)
- *Dark Matter:* PRL 96, 221102 (2006), PRL 106, 161301 (2011)
- *Lorentz Invariance:* PRL 101, 170402 (2008)
- *Cosmic Ray Electrons:* PRL 101, 261104 (2009)

WHAT IS CTA ?

CTA consortium: a world-wide effort



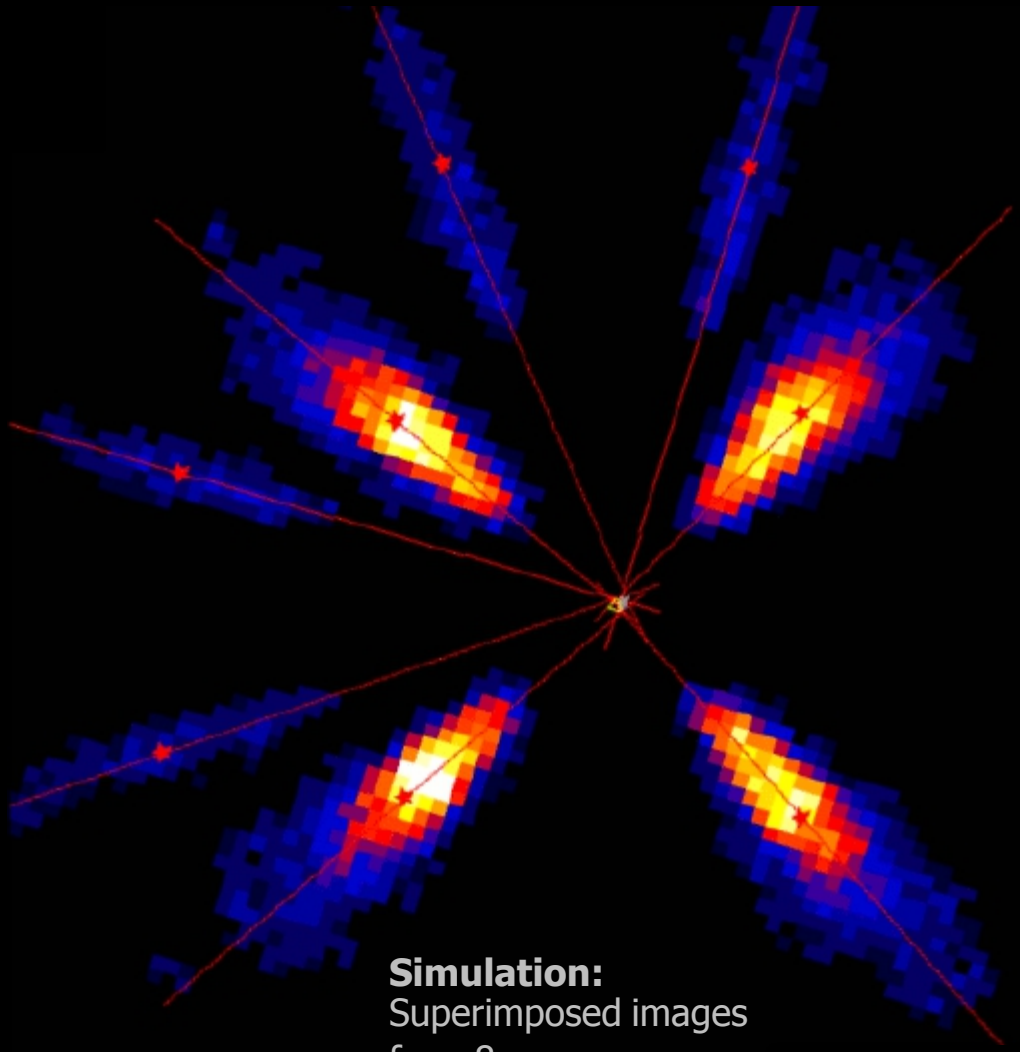
32 countries
94 parties
208 institutes
1402 members (480 FTE)

(May 2017)

How to do better with IACT arrays?

- More events
  - More photons = better spectra, images, fainter sources
    - Larger collection area for gamma-rays
- Better events
  - More precise measurements of atmospheric cascades and hence primary gammas
    - Improved angular resolution
    - Improved background rejection power

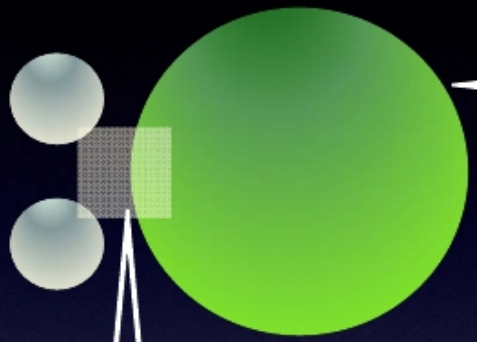
☞ More telescopes !



Simulation:
Superimposed images from 8 cameras

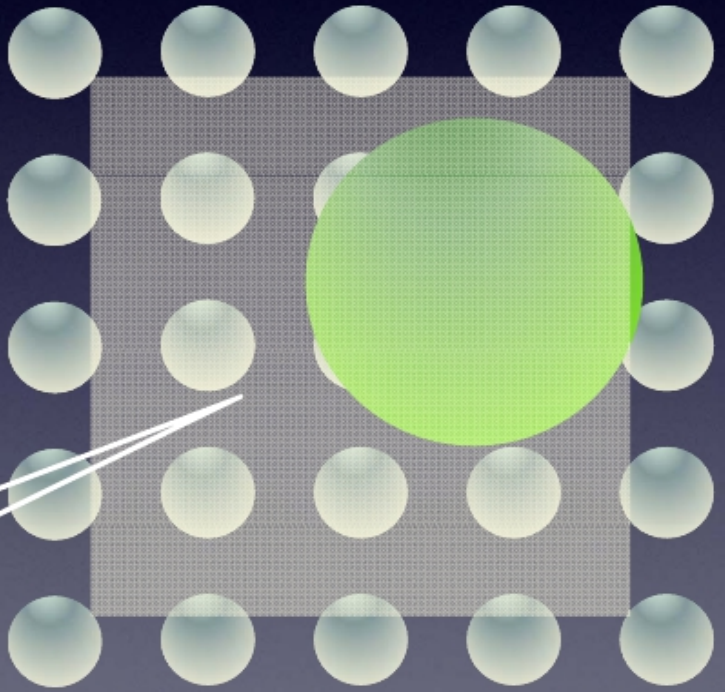
Larger Area

More Contained Events



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

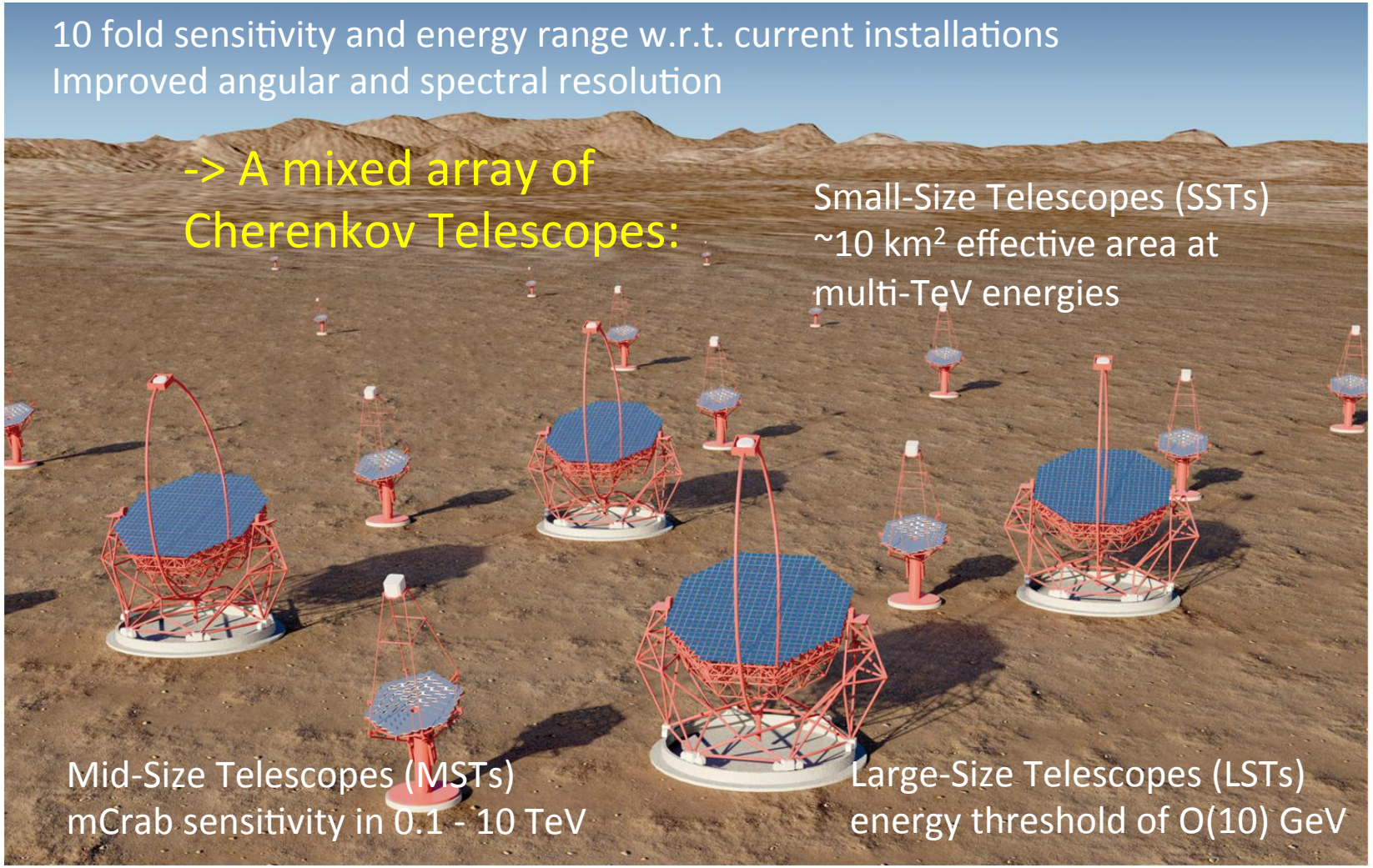
Sweet spot for best triggering & reconstruction…
most showers miss it!



✓ *Larger detection Area*
✓ *More Images per shower*
✓ *Better γ-ray reconstruction*
✓ *Lower energy threshold*

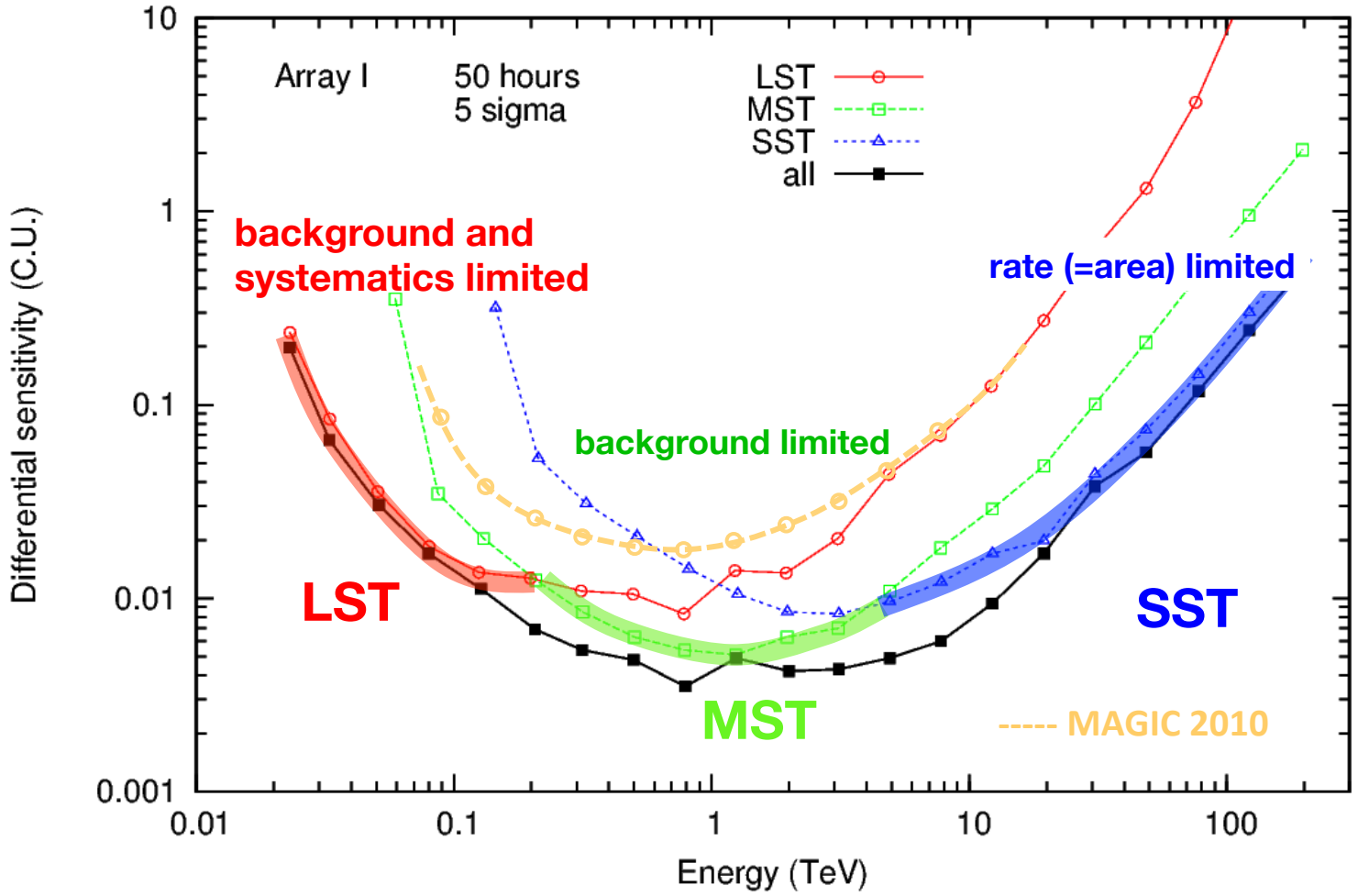
What is CTA?

An advanced facility for very-high energy gamma-ray astronomy

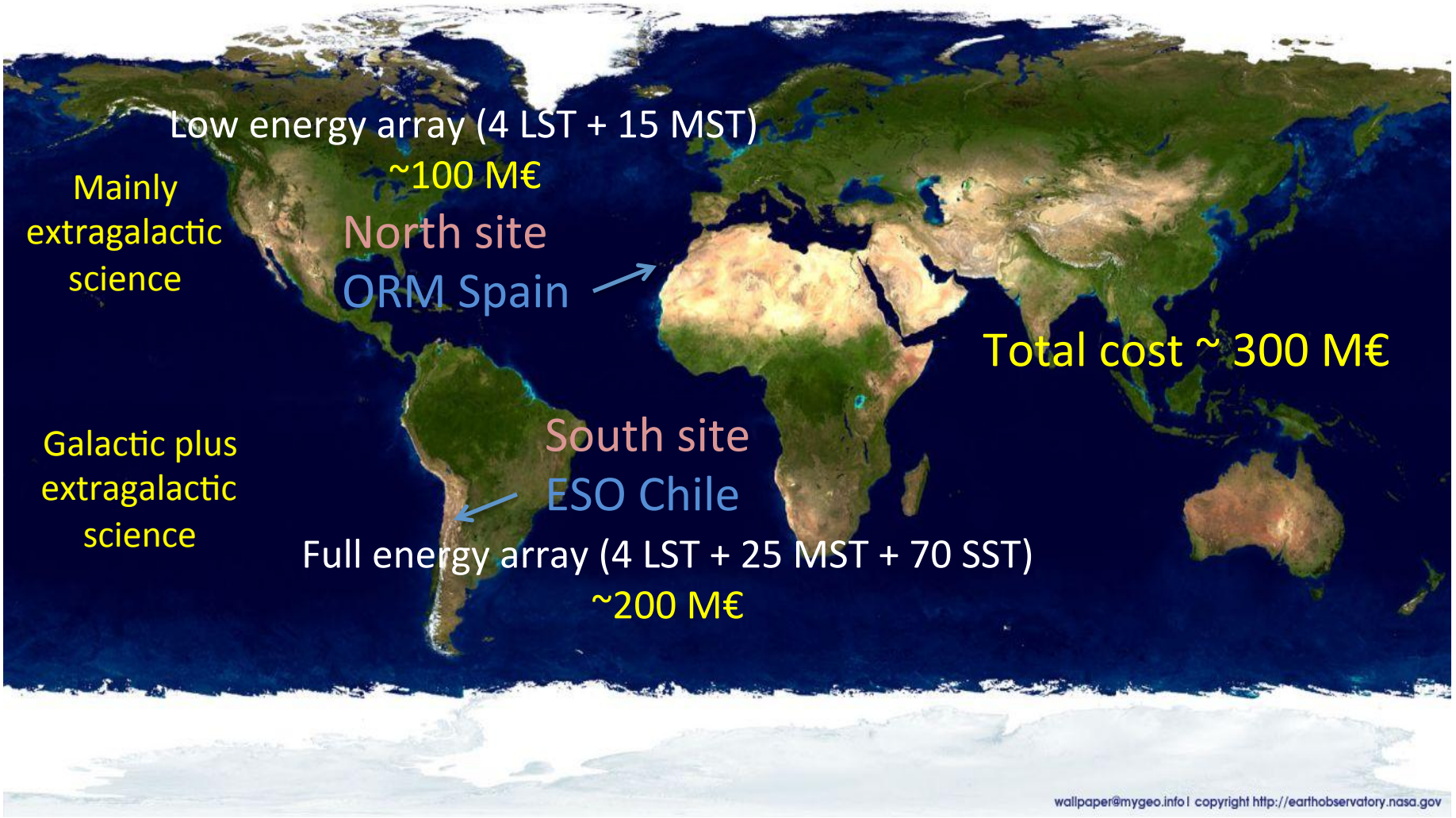


CTA sensitivity in units of Crab flux

for 5 σ detection & $N_\gamma > 10$ in each 0.2-dex bin in E, in 50 h

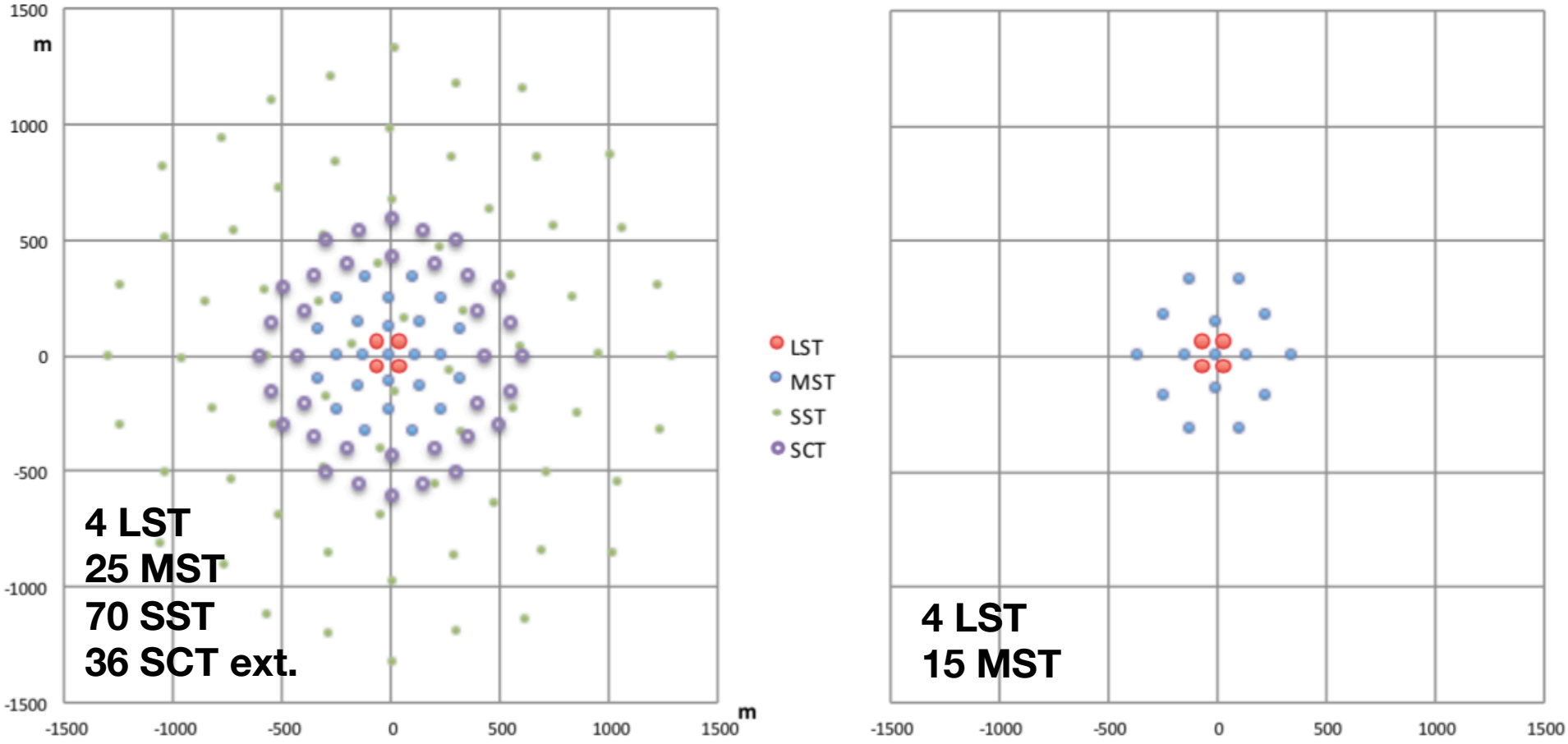


All-sky coverage: two observatories



ARRAY LAYOUTS

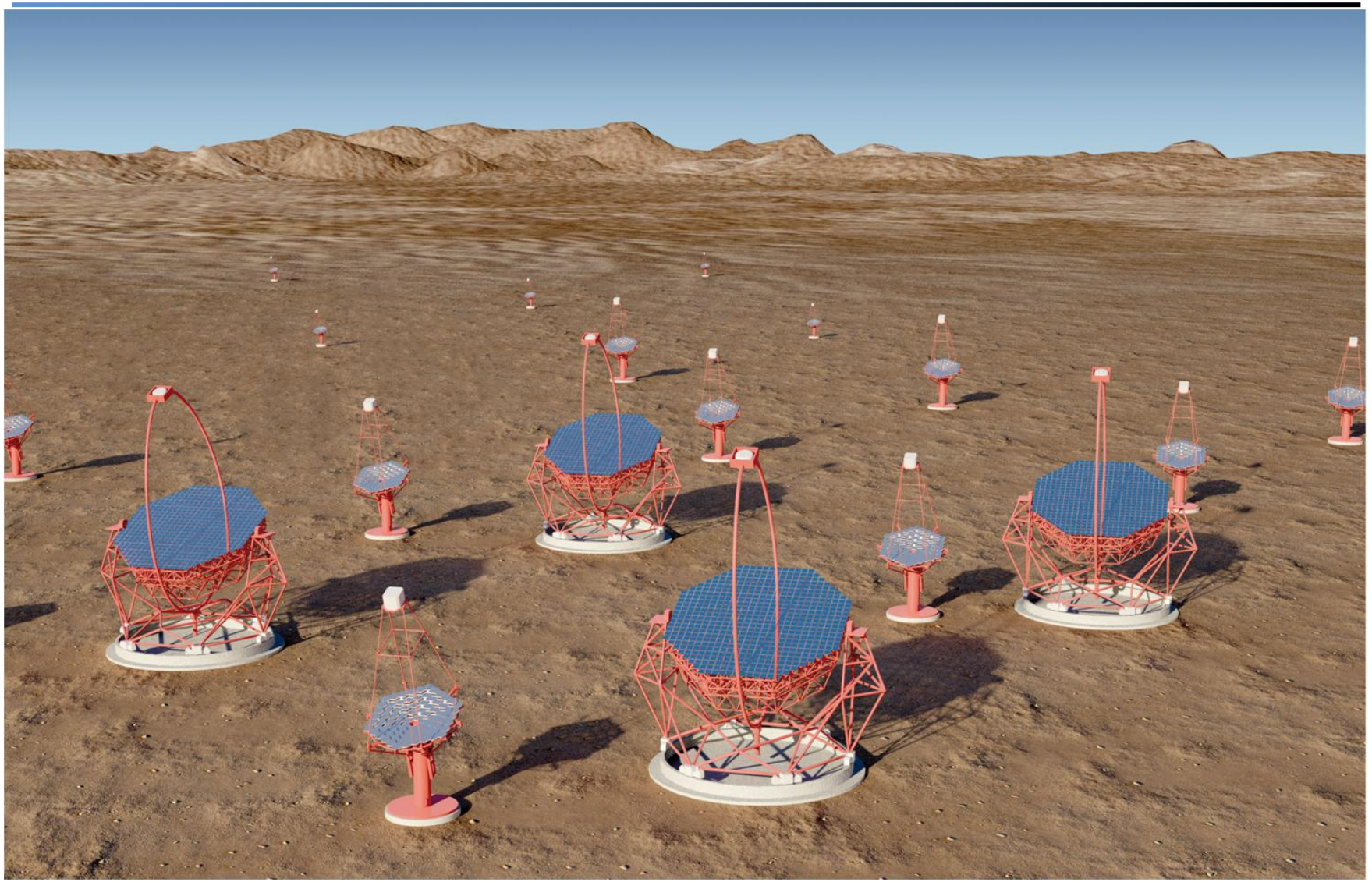
Reference (baseline) layouts



CTA-South

CTA-North

cta
cherenkov telescope array



… just brute force ?

No !

actually, smart force…

CTA observation modes

- Very deep field

CTA observation modes

Monitoring
4 telescopes

Monitoring
4 telescope

Deep field
~1/2 of telescopes

Monitoring
4 Telescopes

Deep field
~1/3 of telescopes

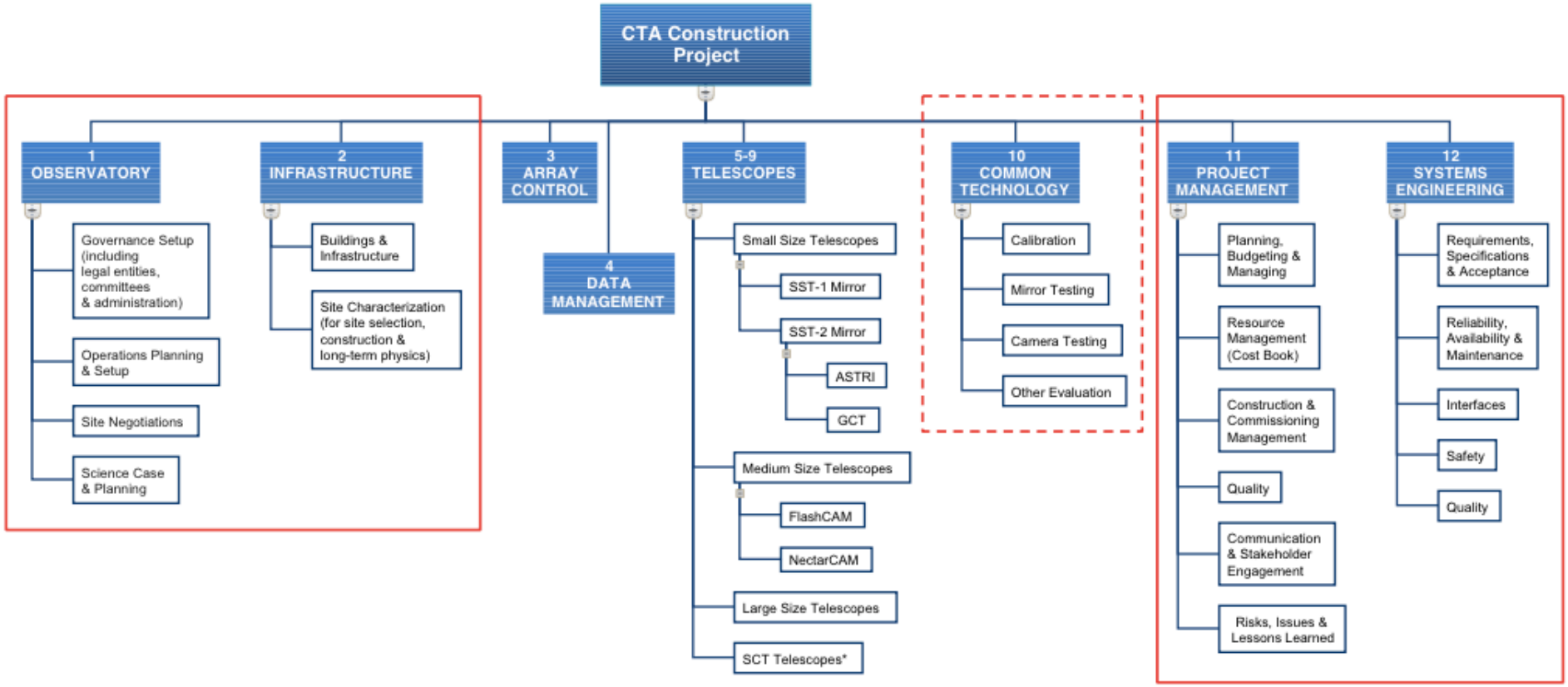
Monitoring
1 telescope

CTA observation modes

Survey mode:
Full sky at current sensitivity in ~1 year

CTA status and plans

OVERALL WBS -> **TDR** VOLUMES



WBS is for all phases (not all activities apply to all phases)

Over 5000 pages !

=> CDR passed in June 2015

Small size telescopes

SST 1M

Science drivers
Highest energies (> 5 TeV)
Galactic science, PeVatrons

Array layout
South site: 70 SST
North site: -

ASTRI

First Cherenkov light
May 2017

GCT

First Cherenkov light
May 2016

Medium size telescopes

Science drivers
Mid energies (100 GeV – 10 TeV)
DM, AGN, SNR, PWN, binaries, starbursts, EBL, IGM

Characteristics
Modified Davies-Cotton design
12 m diameter
90 m2 effective mirror area
1.2 m mirror facets
16 m focal length
8° field of view
0.18° PMT pixels

Array layout
South site: 25 MST
North site: 15 MST

Status
Telescope prototyped (Berlin-Adlershof)
Prototype cameras under construction (2 types: NectarCAM & FlashCam)

Schwarzchild-Couder Mid Size Telescope (SCT) prototype mechanics ready in Arizona

Large size telescopes

Science drivers
Lowest energies (< 200 GeV)
Transient phenomena
DM, AGN, GRB, pulsars

Characteristics
Parabolic design
23 m diameter
370 m2 effective mirror area
28 m focal length
2 m2 mirror facets
4.5° field of view
0.11° PMT pixels
active mirror control
Carbon-fibre structure (fast repointing)

Array layout
South site: 4 LST
North site: 4 LST

Status
All elements prototyped
Prototype telescope under construction in La Palma

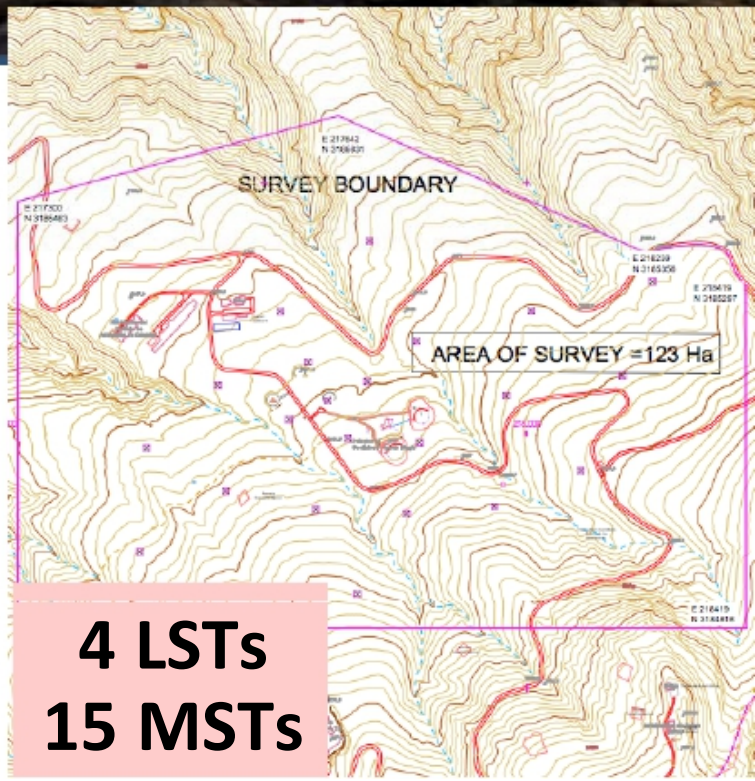
LST1: Foundations ready at ORM

Rail and central pin being commissioned

First CTA Telescope on-site taking shape !

LA PALMA – CTA North

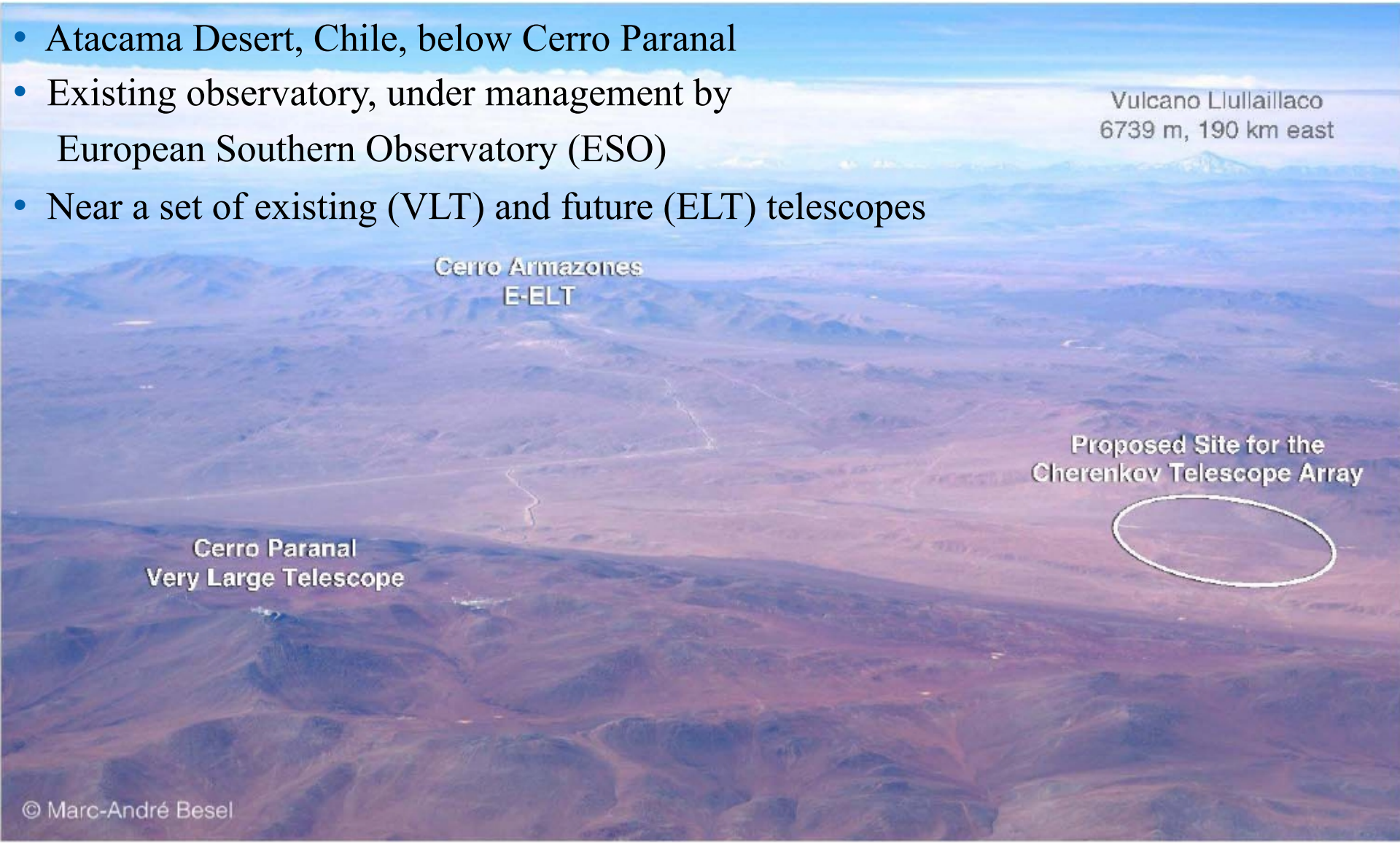
- Canary Islands, Spain
- Observatorio del Roque de los Muchachos
- Existing observatory, under management by Instituto de Astrofisica de Canarias (IAC)
- Site of LST 1 & existing MAGIC telescopes
- Current work: topographical study, building concepts, tender for geotechnical study soon



4 LSTs
15 MSTs

ESO/PARANAL – CTA South

- 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 News

For the latest CTA news and project updates, follow us on Facebook, Twitter and YouTube.

Announcements

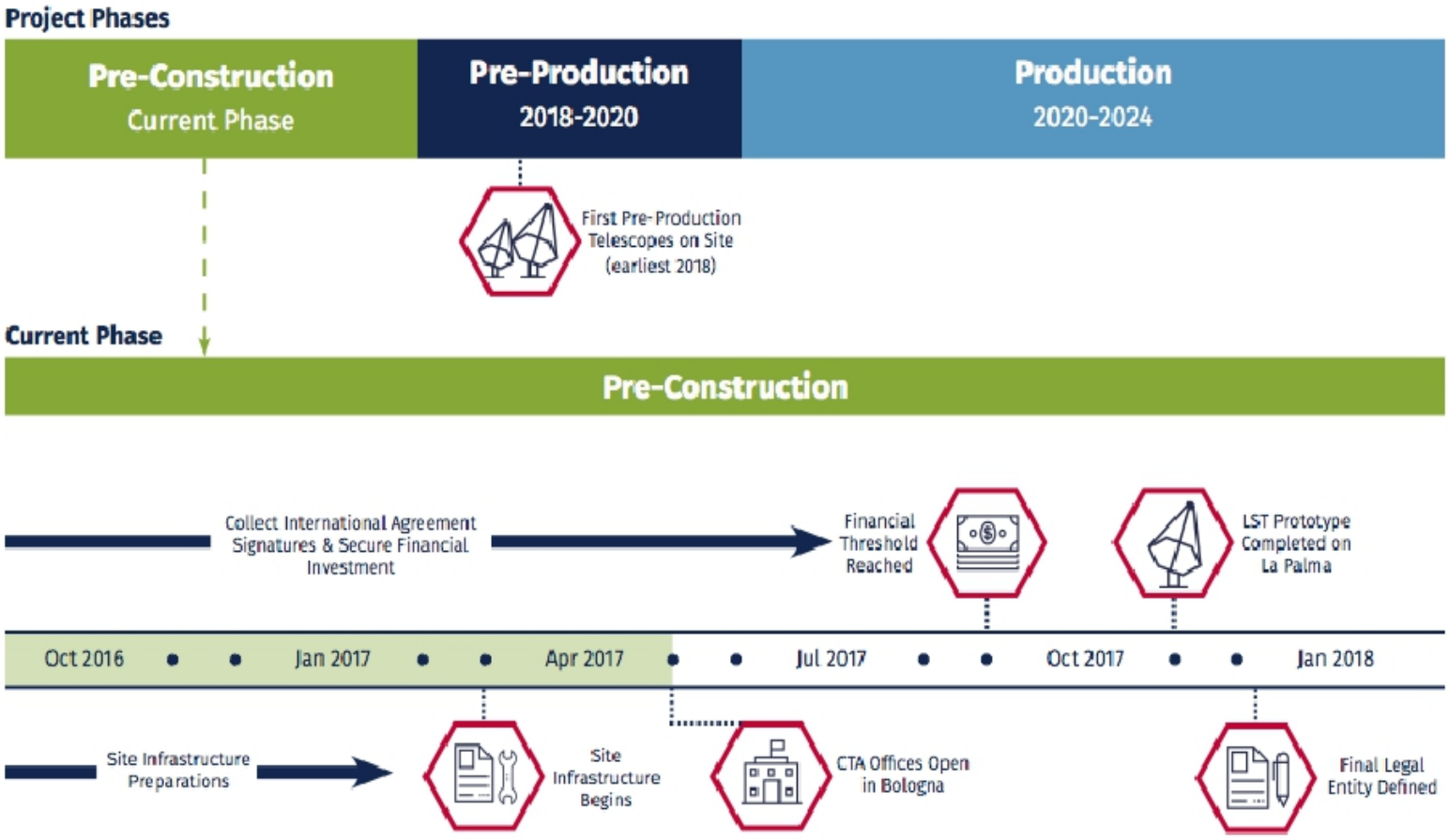
Headquarters and Science Data Management Centre Sites Selected

14 June 2016 (download full news release)

Figure 1: Computer rendering of CTA Headquarters Building, Bologna (Credit: Bologna University Project Office)

Figure 2: Architectural rendering of CTA Science Data Management Centre Building, Zeuthen (Credit: Dahm Architekten & Ingenieure, Berlin)

Deployment


Project Phases
Pre-Construction
Current Phase
Pre-Production
2018-2020
Production
2020-2024
First Pre-Production Telescopes on Site (earliest 2018)
Current Phase
Pre-Construction
Collect International Agreement Signatures & Secure Financial Investment
Financial Threshold Reached
LST Prototype Completed on La Palma
Oct 2016
Jan 2017
Apr 2017
Jul 2017
Oct 2017
Jan 2018
Site Infrastructure Preparations
Site Infrastructure Begins
CTA Offices Open in Bologna
Final Legal Entity Defined

2) CTA
WILL BE AN OBSERVATORY

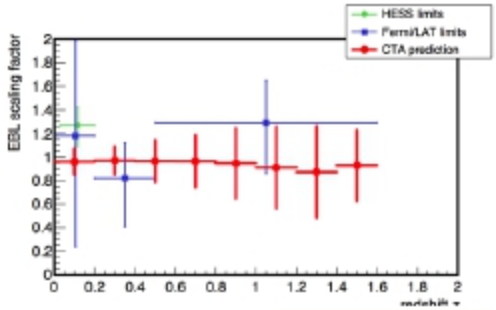
WHAT FOR, CTA ?

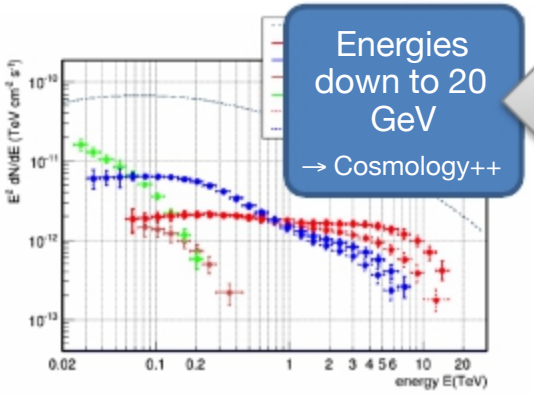
CTA RESEARCH TOPICS

- Cosmic Rays
  - sites of acceleration in our galaxy and beyond
  - search for pevatrons
  - CR interactions within galaxies & clusters
- Probing extreme environments
  - relativistic jets & winds in the vicinity of neutron stars & black holes
- Probing the intergalactic medium
  - B-fields, background radiation fields
- Physics frontiers
  - indirect DM searches (WIMPS, axions)
  - testing the invariance of the speed of light

An overview of the CTA Science Case…

(credit Jim Hinton, Project Scientist)

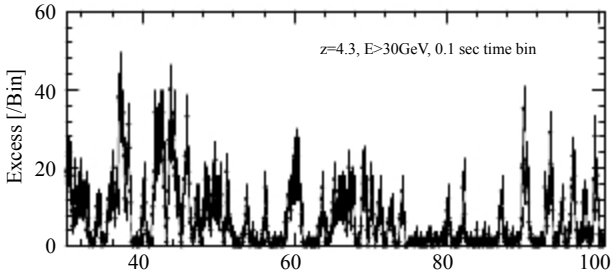


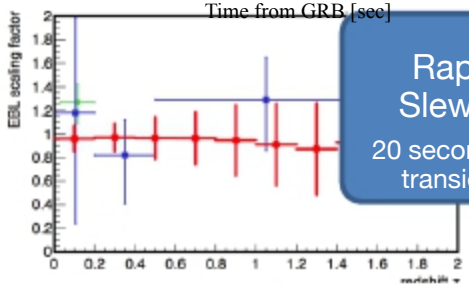


Energies down to 20 GeV

→ Cosmology++

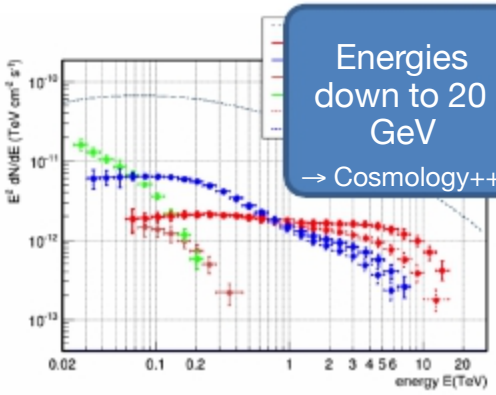
cta
cherenkov telescope array





Rapid Slewing

20 seconds → transients



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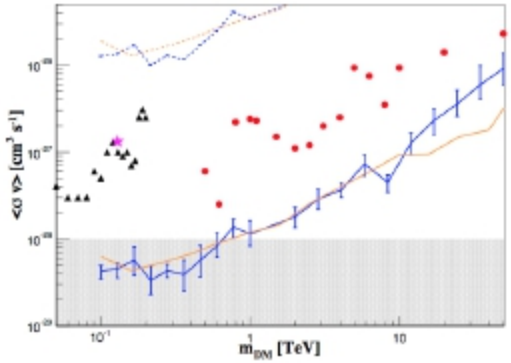
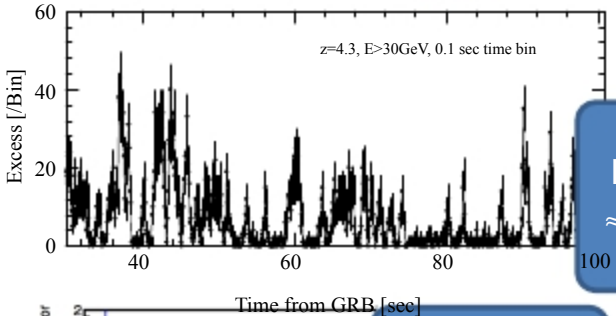
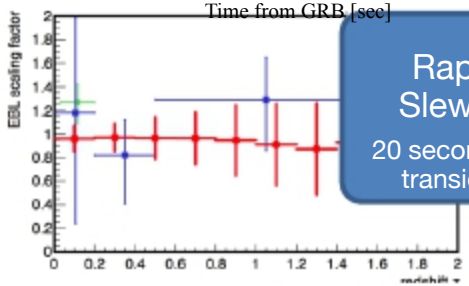




Energy Resolution

≈10% → lines, features



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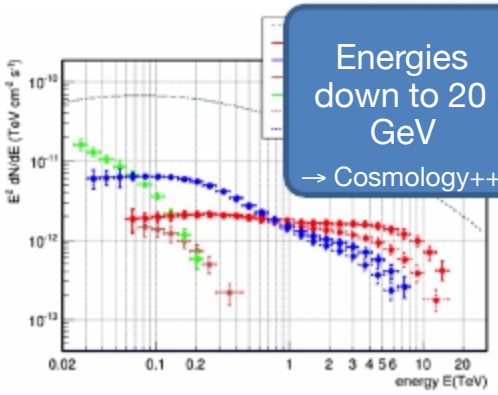
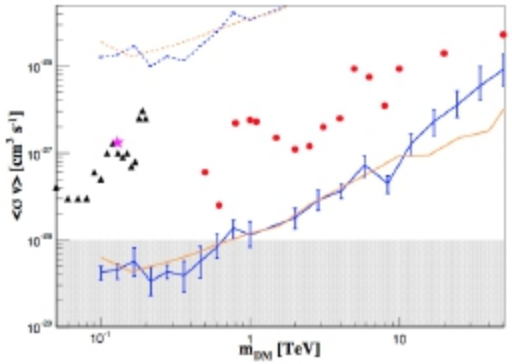
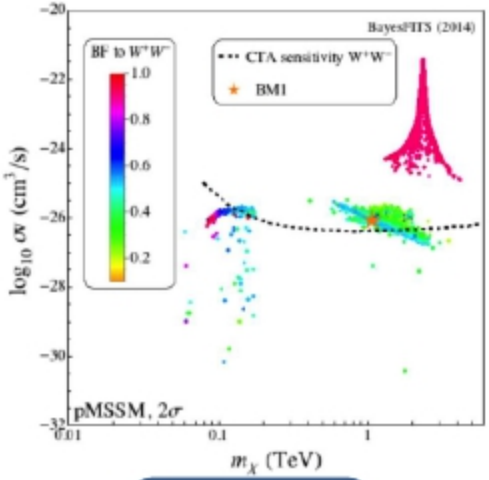
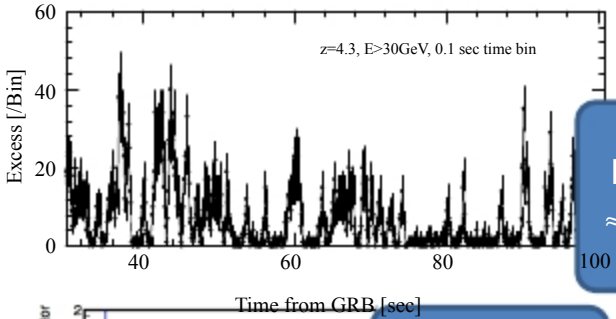








Energy Resolution

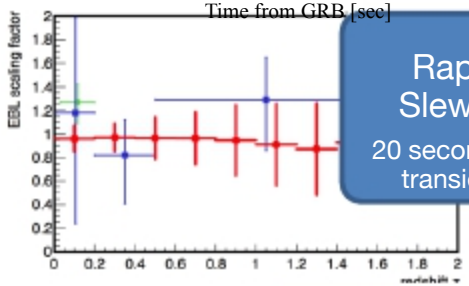
≈10% → lines, features

Sensitivity & Collection Area

×10 → all topics

Rapid Slewing

20 seconds → transients

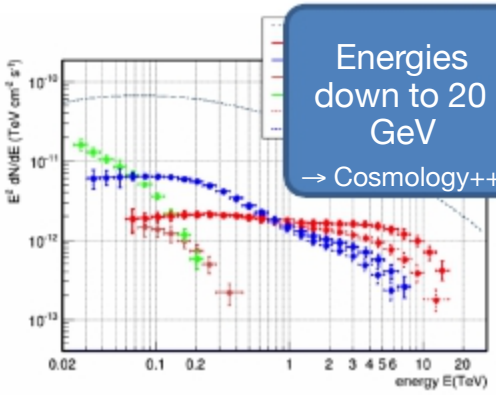


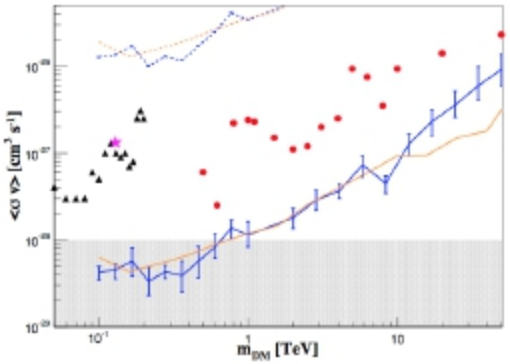
cta

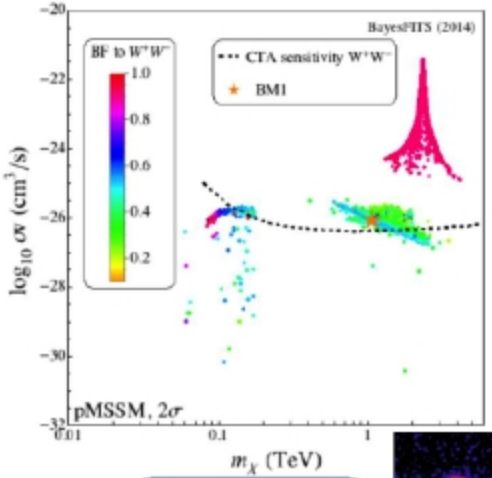
cherenkov telescope array

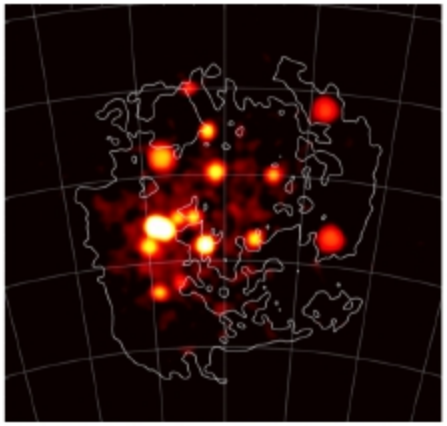
Energies down to 20 GeV

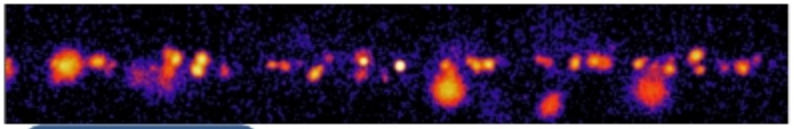
→ Cosmology++

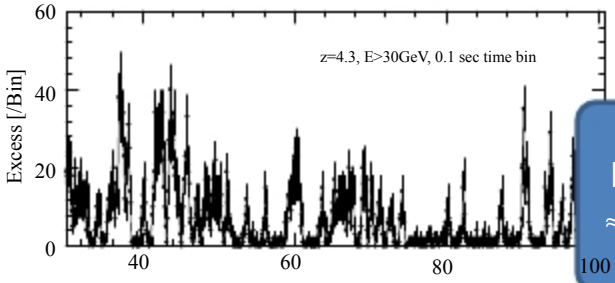








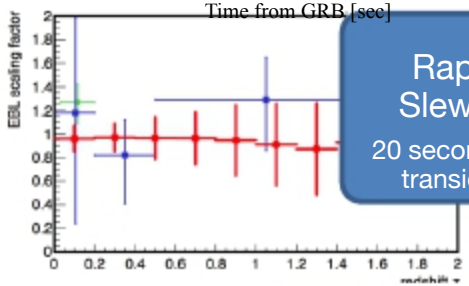




Energy Resolution
≈10% → lines, features

Sensitivity & Collection Area
×10 → all topics

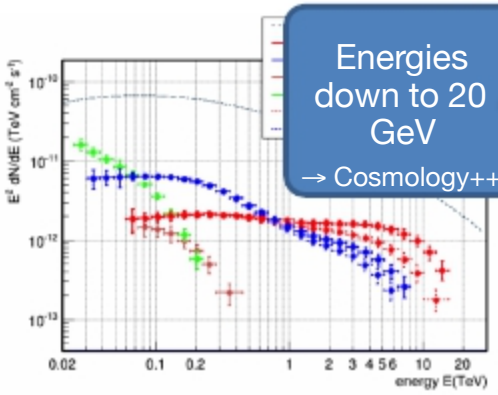
Field of View
≈8° → surveys, extended objects

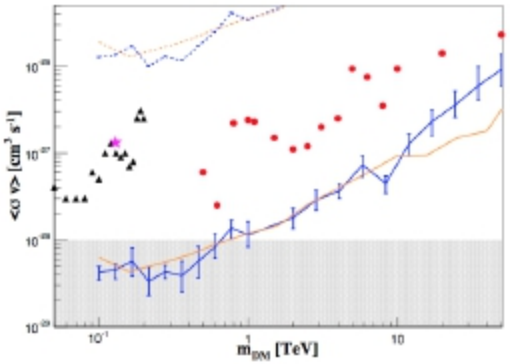


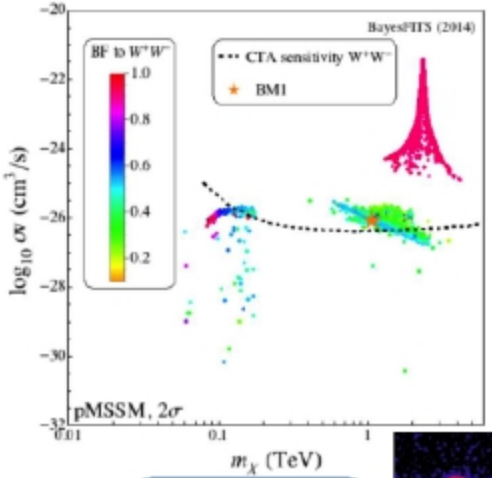
Rapid Slewing
20 seconds → transients

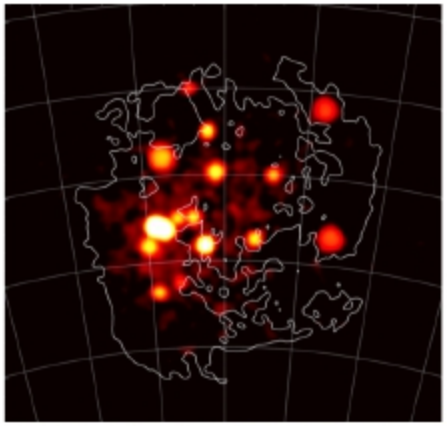
cta
cherenkov telescope array

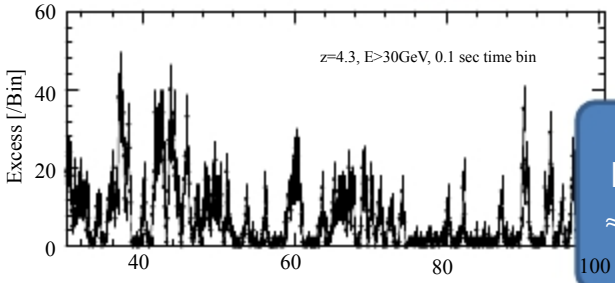
Energies down to 20 GeV
→ Cosmology++

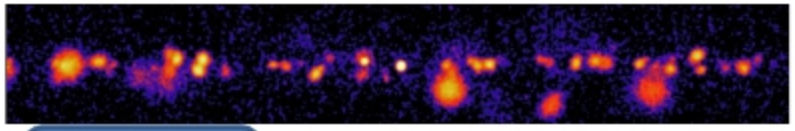


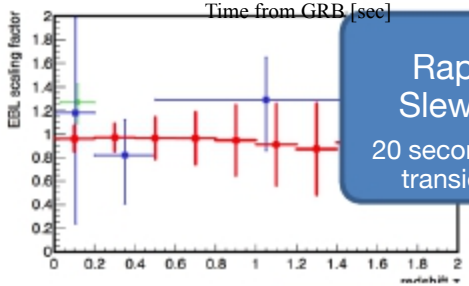


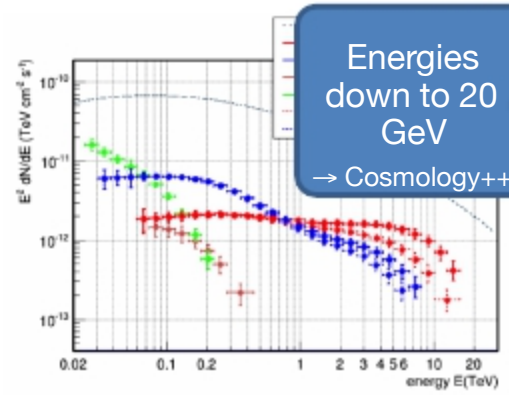


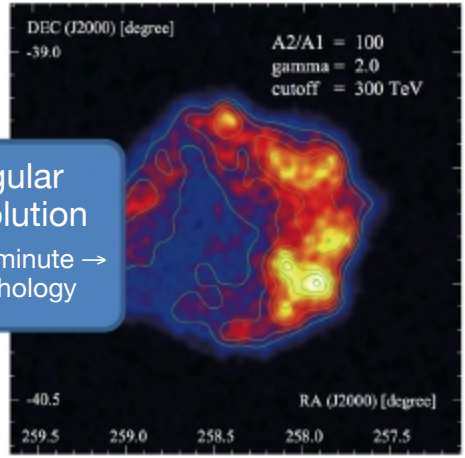












Energy Resolution
≈10% → lines, features

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++

cta
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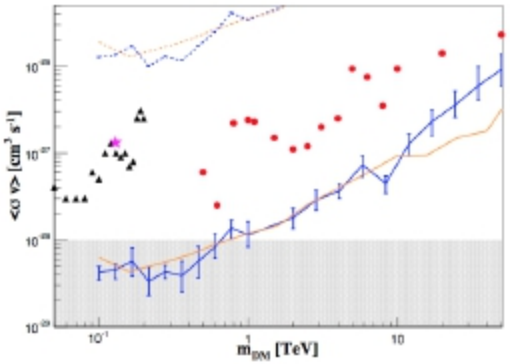

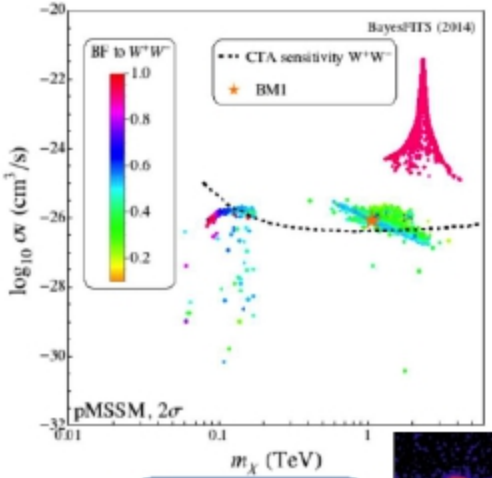

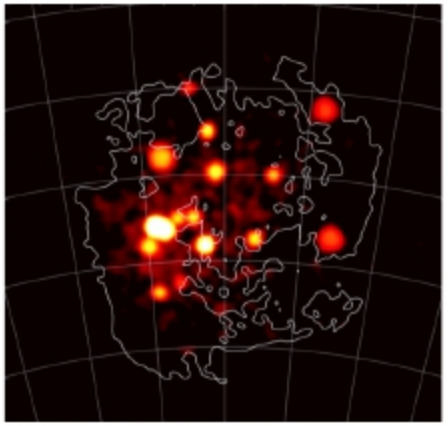

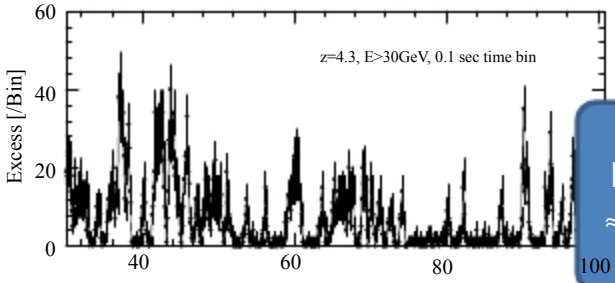

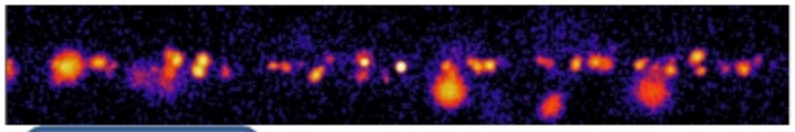

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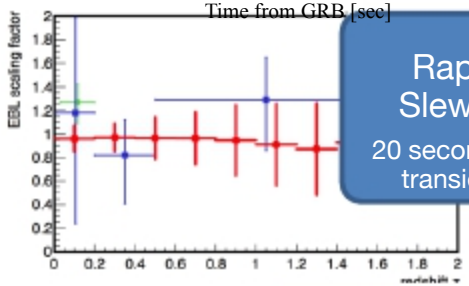

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Angular Resolution
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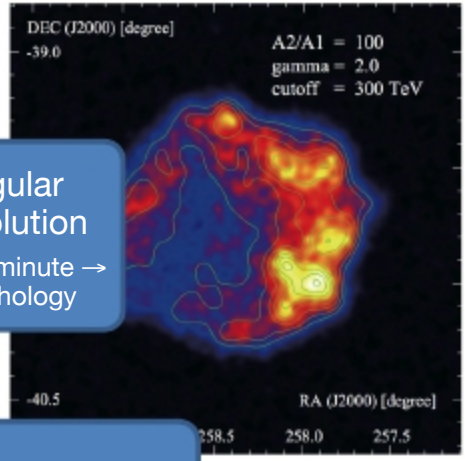

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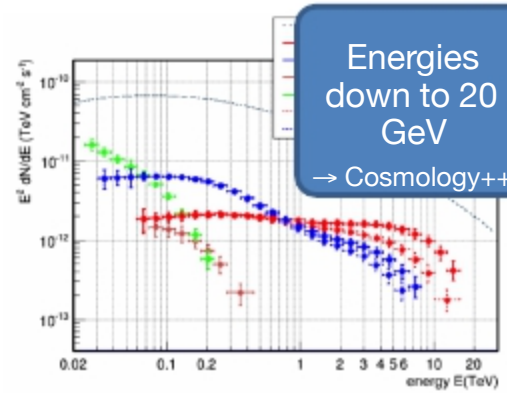
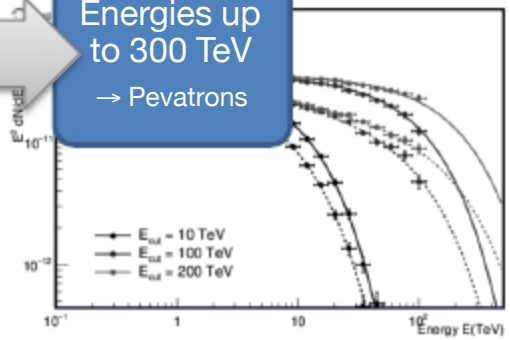
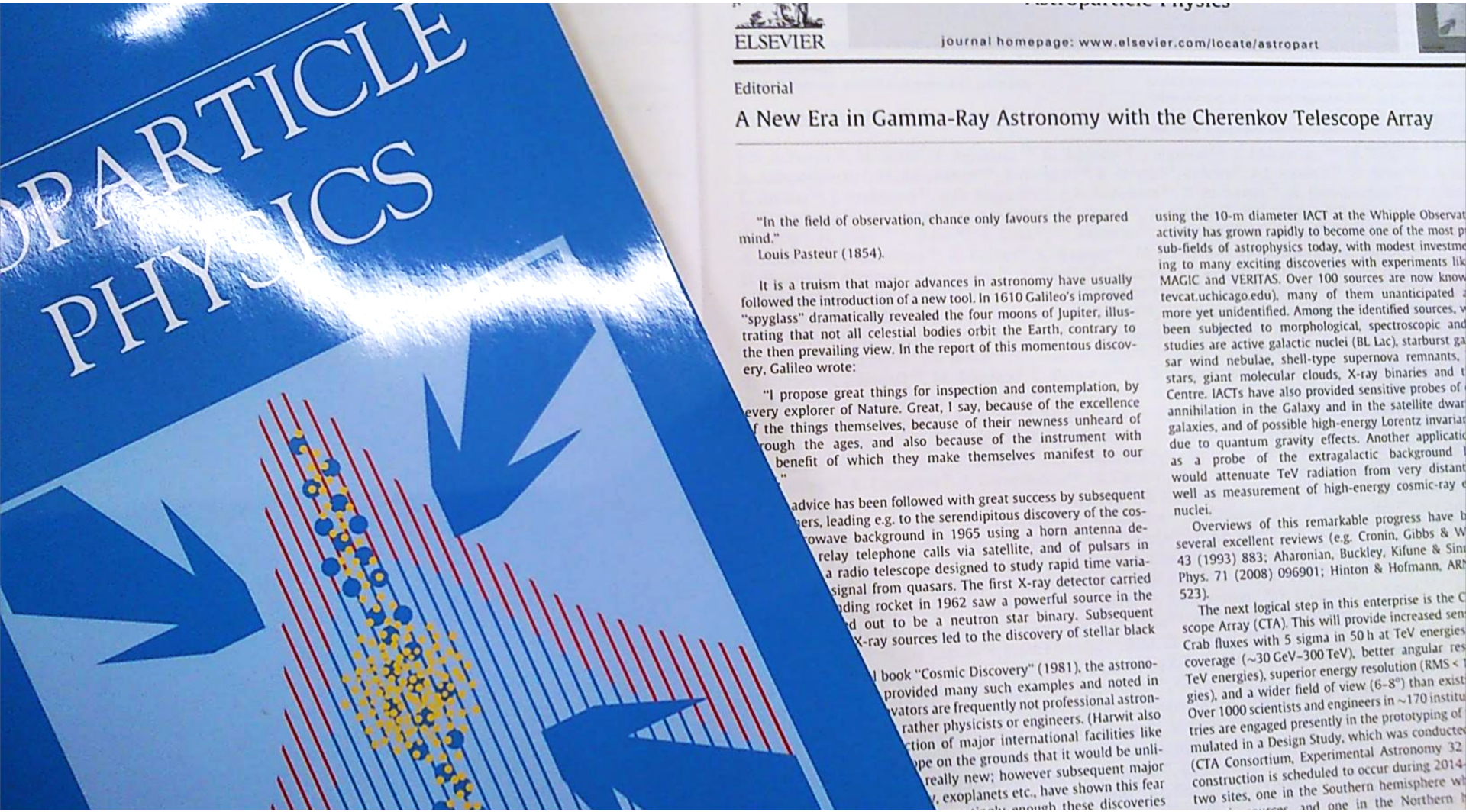


Energies up to 300 TeV
→ Pevatrons



ASTROPARTICLE PHYSICS: CTA SPECIAL ISSUE MARCH 2013



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Editorial

A New Era in Gamma-Ray Astronomy with the Cherenkov Telescope Array

"In the field of observation, chance only favours the prepared mind."
Louis Pasteur (1854).

It is a truism that major advances in astronomy have usually followed the introduction of a new tool. In 1610 Galileo's improved "spyglass" dramatically revealed the four moons of Jupiter, illustrating that not all celestial bodies orbit the Earth, contrary to the then prevailing view. In the report of this momentous discovery, Galileo wrote:

"I propose great things for inspection and contemplation, by every explorer of Nature. Great, I say, because of the excellence f the things themselves, because of their newness unheard of rough the ages, and also because of the instrument with benefit of which they make themselves manifest to our ."

advice has been followed with great success by subsequent ers, leading e.g. to the serendipitous discovery of the cos- owave background in 1965 using a horn antenna de- relay telephone calls via satellite, and of pulsars in a radio telescope designed to study rapid time varia- signal from quasars. The first X-ray detector carried nding rocket in 1962 saw a powerful source in the d out to be a neutron star binary. Subsequent X-ray sources led to the discovery of stellar black

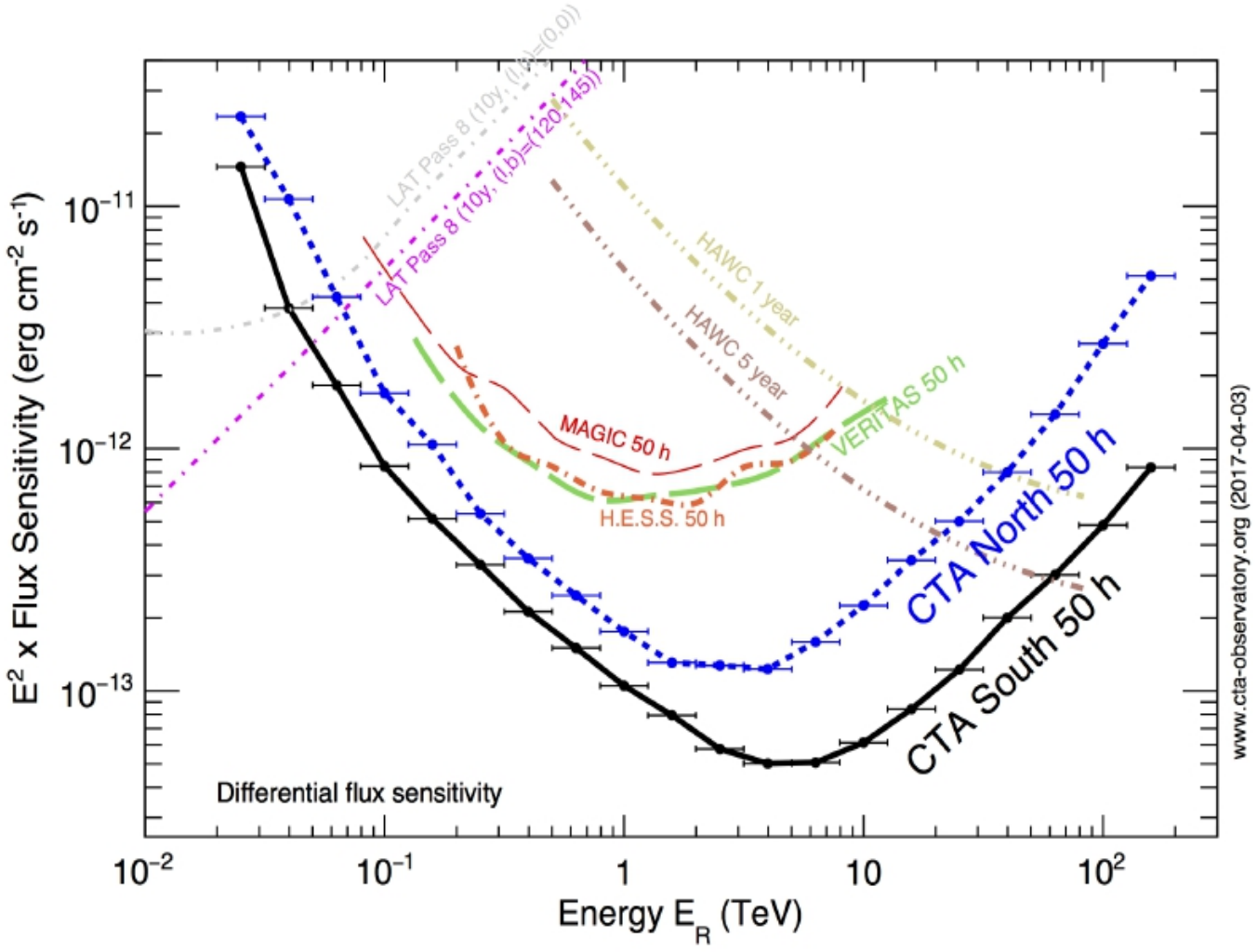
l book "Cosmic Discovery" (1981), the astrono- provided many such examples and noted in vators are frequently not professional astron- rather physicists or engineers. (Harwit also ction of major international facilities like pe on the grounds that it would be unli- really new; however subsequent major , exoplanets etc., have shown this fear

using the 10-m diameter IACT at the Whipple Observat activity has grown rapidly to become one of the most p sub-fields of astrophysics today, with modest investme ing to many exciting discoveries with experiments lik MAGIC and VERITAS. Over 100 sources are now know tevcat.uchicago.edu), many of them unanticipated more yet unidentified. Among the identified sources, w been subjected to morphological, spectroscopic and studies are active galactic nuclei (BL Lac), starburst ga sar wind nebulae, shell-type supernova remnants, stars, giant molecular clouds, X-ray binaries and t Centre. IACTs have also provided sensitive probes of annihilation in the Galaxy and in the satellite dwar galaxies, and of possible high-energy Lorentz invariar due to quantum gravity effects. Another applicatio as a probe of the extragalactic background would attenuate TeV radiation from very distant well as measurement of high-energy cosmic-ray nuclei.

Overviews of this remarkable progress have b several excellent reviews (e.g. Cronin, Gibbs & W 43 (1993) 883; Aharonian, Buckley, Kifune & Sin Phys. 71 (2008) 096901; Hinton & Hofmann, AR 523).

The next logical step in this enterprise is the C scope Array (CTA). This will provide increased sen Crab fluxes with 5 sigma in 50 h at TeV energies coverage (~30 GeV–300 TeV), better angular res TeV energies), superior energy resolution (RMS < gies), and a wider field of view (6–8°) than exist Over 1000 scientists and engineers in ~170 institu tries are engaged presently in the prototyping of mulated in a Design Study, which was conducte (CTA Consortium, Experimental Astronomy 32 construction is scheduled to occur during 2014 two sites, one in the Southern hemisphere wh and one in the Northern

CTA sensitivity

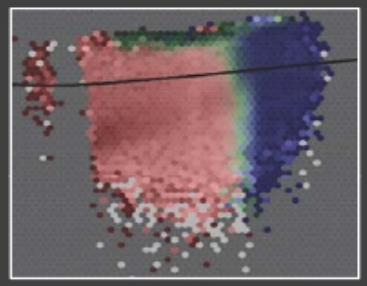


World Scientific open-access Book (>200 pages)

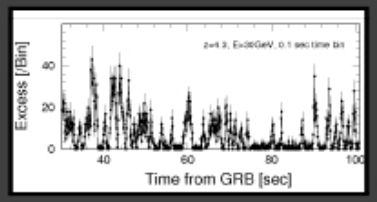
CTA Key Science Programs

Ready for publication

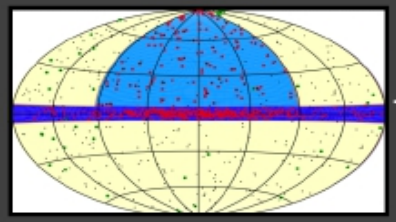
Key Science Projects (KSPs)



Dark Matter Programme

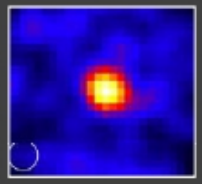


Transients



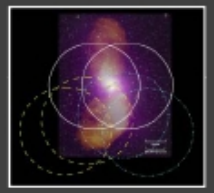
ExGal Survey

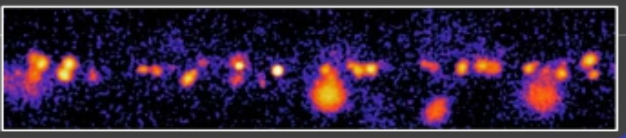
Galaxy Clusters



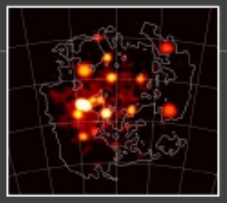
Star Forming Systems

AGN

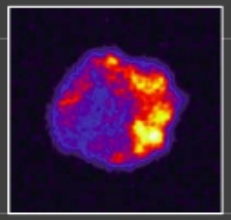




LMC Survey

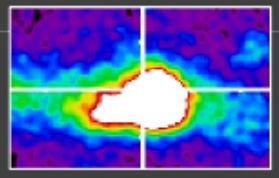


Galactic Plane Survey



PeVatrons

Galactic Centre

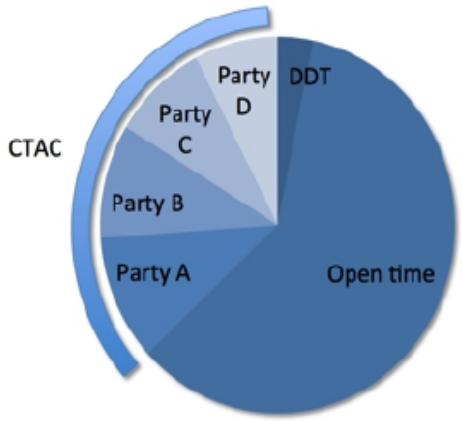


Extragalactic

Galactic

CTA AS AN OBSERVATORY

Observing Time

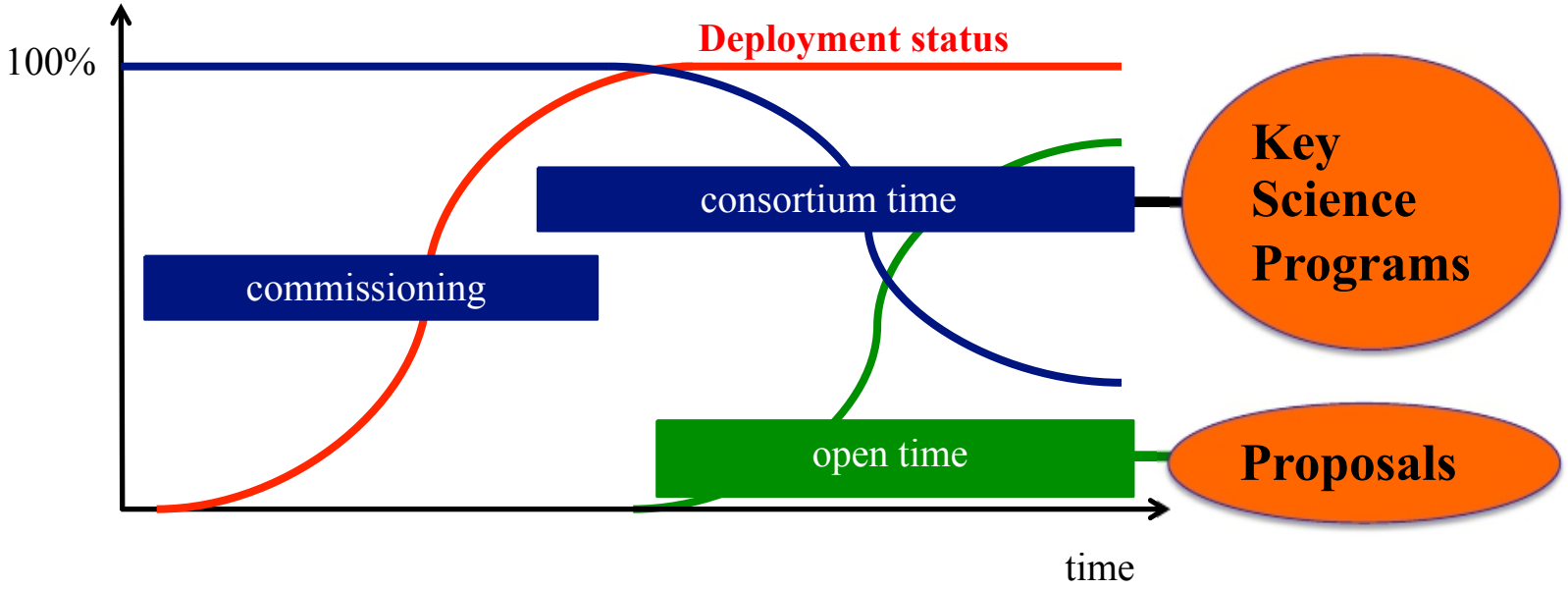


Current assumptions

CTA parties pool the observing time in:

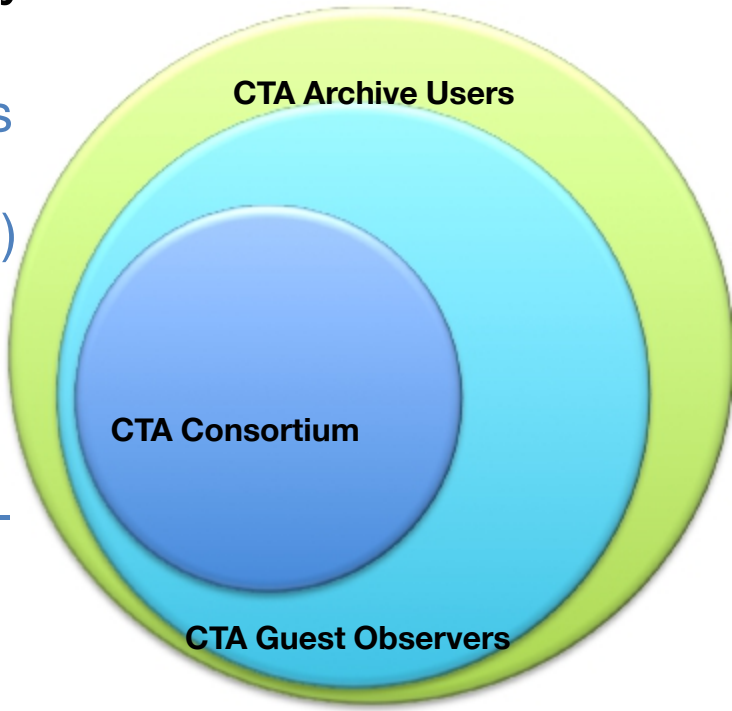
- Open time (for scientists of party countries)
- Consortium time (Key Science Projects)

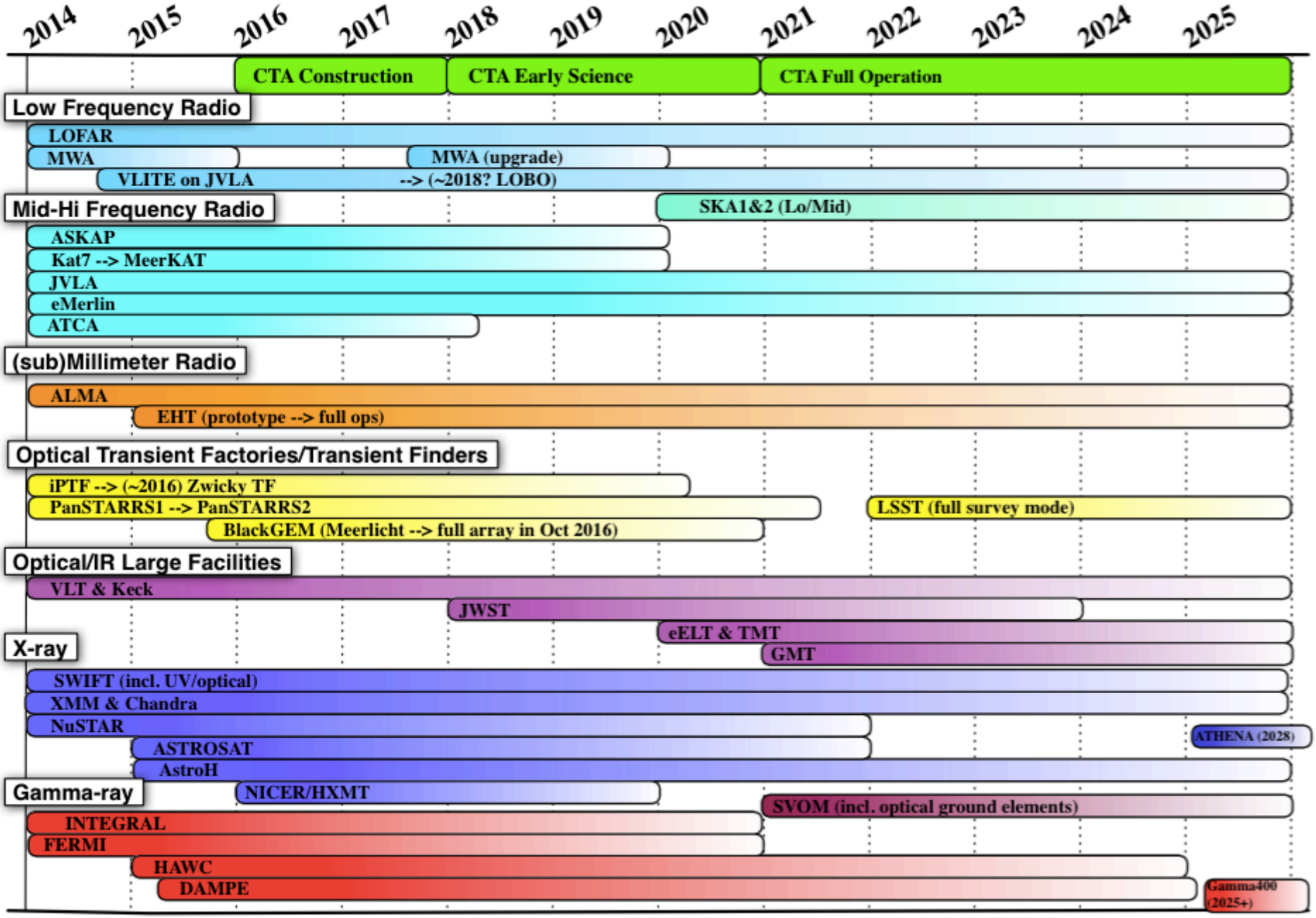
All data will become fully public after a proprietary period (typically one year)



USER COMMUNITY

- CTA is the first true open observatory for VHE gamma-ray astronomy
  - Annual AOs for Guest Observer proposals
    - With PI from participating country
  - Anticipate public archive for all (high-level) data after one year proprietary period
- Community Size?
  - Consortium 1000, Estimated Co-Is of GO proposals O(5000), Co-authors of archive-based publications O(10000)
- Series of workshops held to engage with a wider community
  - Particle Physics, X-ray, Cosmic ray (+several more general)





Complementarity with other Observatories (Jim Hinton 2015)

3) SUMMARY AND OUTLOOK

Summary and outlook

- The initial idea of CTA came in 2006, and since then it has evolved in such a way that it has managed to rank high in the roadmaps of all relevant European forums (ESFRI, ASPERA, ASTRONET) and American reviews (PASAG, Decadal Review).
- After over 10 years of work, CTA is just completing the Preproduction Phase by having passed a CDR, downselecting North and South Observatory sites, Headquarters and Science Data Management Centre, having working prototypes of most of its elements, and heading towards the Preconstruction Phase with its de-facto first telescope in construction already in CTA-North.
- CTA shall be soon the first ground-based open Observatory in the field of Astroparticle Physics, providing a new leap in our exploration of the High Energy Universe.
- **CTA is (finally…) coming on stage !.**

AND

Since CTA shall be an Open Observatory,

….all of you are invited to make out of it

a great scientific discovery machine

in a few years from now !