cherenkov telescope array

The Cherenkov Telescope Array

CTA & its Key Science Projects

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*: see http://www.cta-observatory.org/consortium_authors/authors_2017_10.html for full author list

Content

Why?

Lessons learned and open questions

How?

Making the most of ground-based gamma-ray observations

Core Science

The Key Science Projects of CTA

The CTA Community

Observatory – Consortium – Guest Observers & co.-I's

Status of CTA

Timeline – CTA is now!

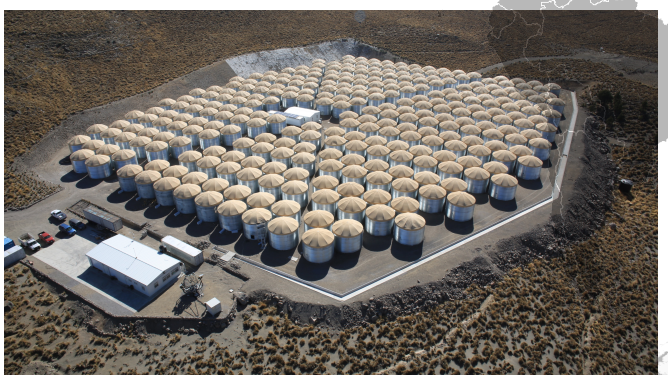
cherenkov telescope array

CTA – Why?

Major TeV facilities

VERITAS
4 Medium-Size Tel. ('MSTs')
2007: Full operation
2009: Relocation of T1
2012: PMT upgrade

MAGIC
2 Large-Size Tel. ('LSTs')
2003: MAGIC-I
2009: MAGIC-II
2012: PMT upgrade



HAWC
Particle-detector water tanks

H.E.S.S.
4 MSTs (2003) + 1 LST (2012)

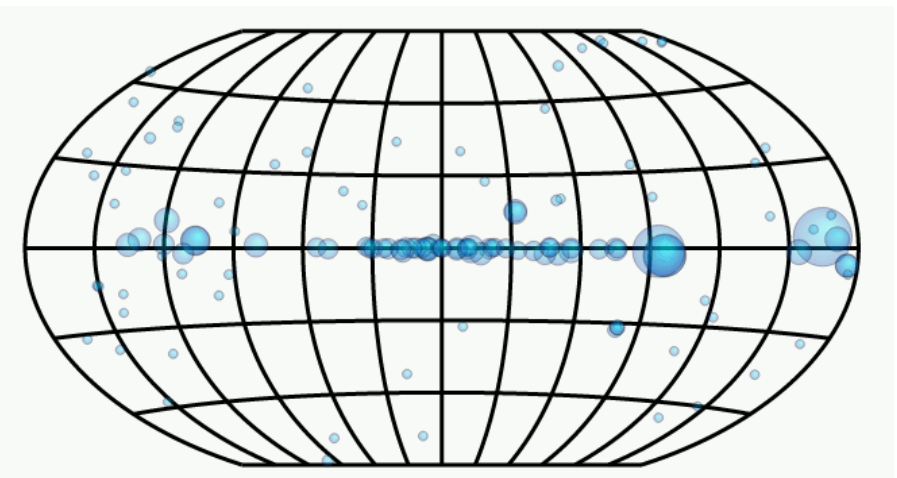
Evolution the TeV sky

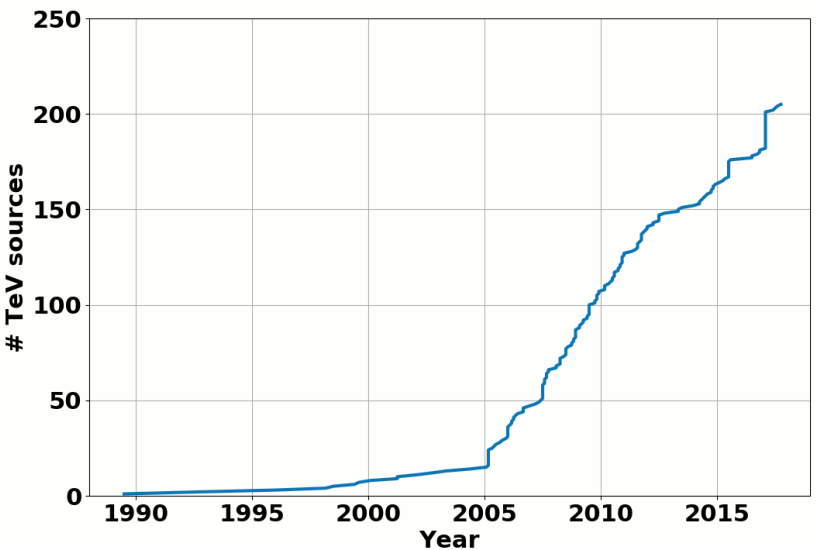
1989 – early 2000s

Childhood of gamma-ray astronomy, triggered by Whipple → Crab Nebula + ~5 AGNs

2003-Now

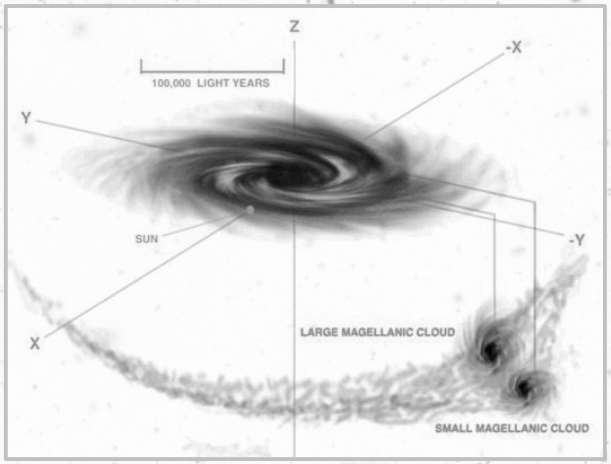
Growth triggered by H.E.S.S./MAGIC (2003), VERITAS (2007), and more recently HAWC (2015)
→ >200 sources! A much-larger-than-expected variety of objects!

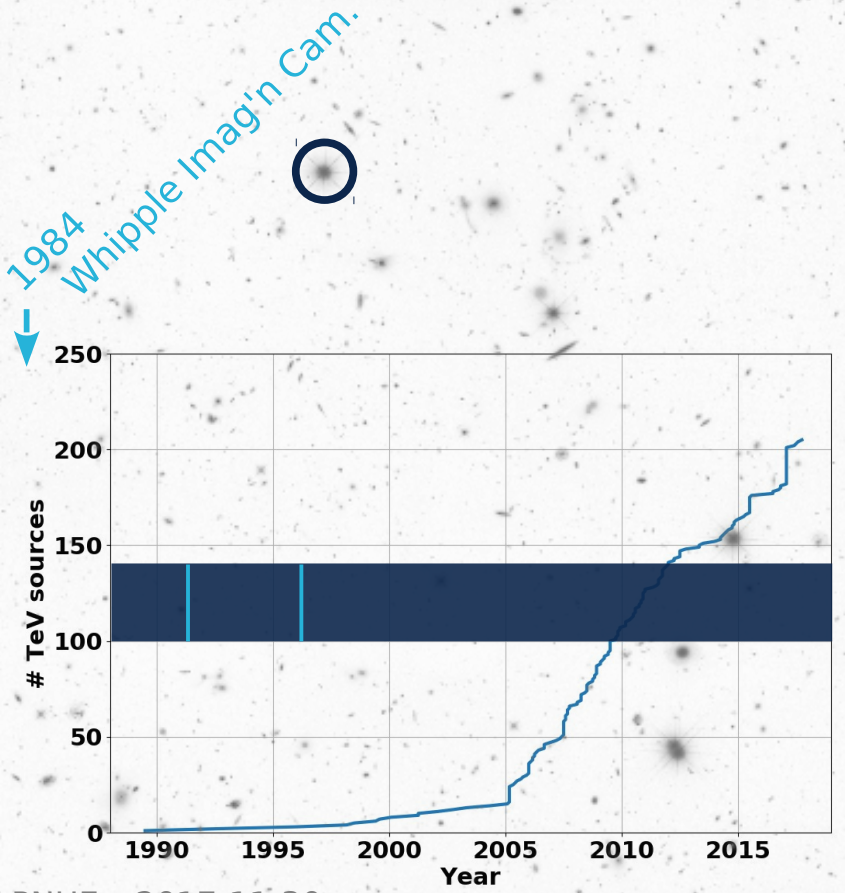




Selected results

TeV Astronomy: Nature & Science





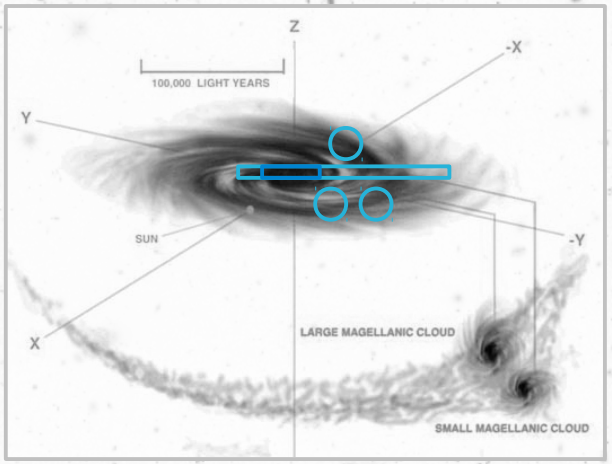
Blazar Mkn 421

. Detection of TeV photons from the active galaxy Markarian 421, Nature 358, 477 (1992)

. Extremely rapid bursts of TeV photons from the active galaxy Markarian 421, Nature 383, 319 (1996)

Selected results

TeV Astronomy: Nature & Science



Galactic Plane Survey Science 307, 1938 (2005)
A New population of very high energy γ-ray sources in the Milky Way

Galactic Center Ridge Nature 439, 695 (2006)
Discovery of very-high-energy γ-rays from the Galactic Centre ridge

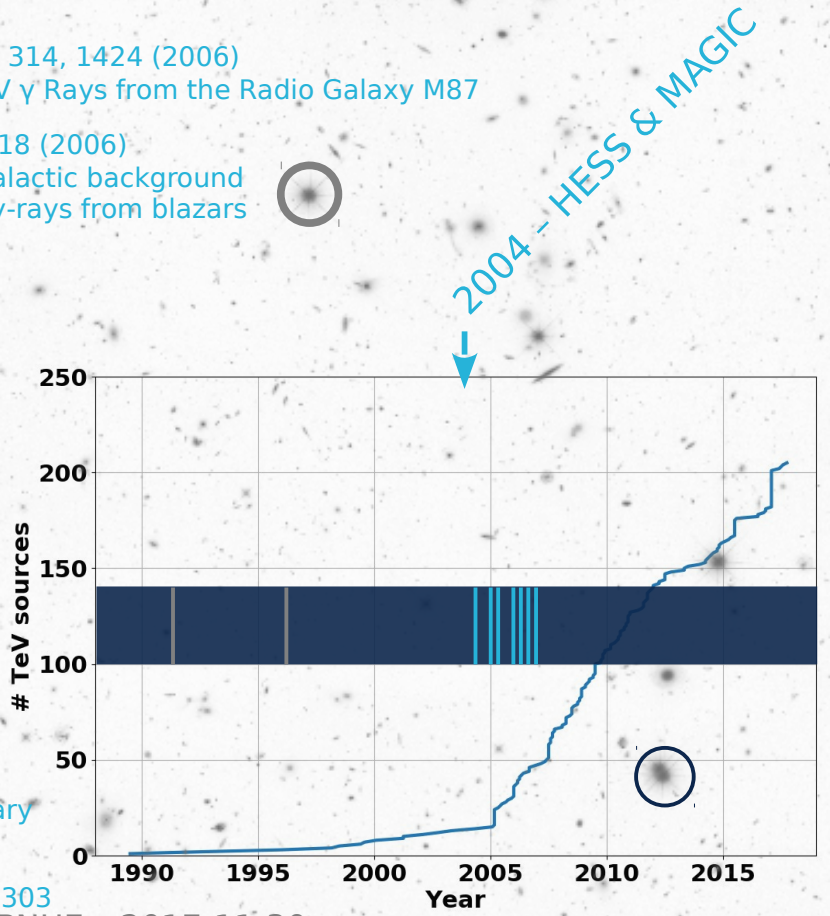
SNR RX J1713.7-3946 Nature 432, 75 (2004)
High-energy particle acceleration in the shell of a supernova remnant

X-ray binary LS 5039 Science 309, 746 (2005)
Discovery of Very High Energy Gamma Rays Associated with an X-ray Binary

Microquasar LS I +61 303 Science 312, 1771 (2006)
Variable Very-High-Energy γ-Ray Emission from the Microquasar LS I +61 303

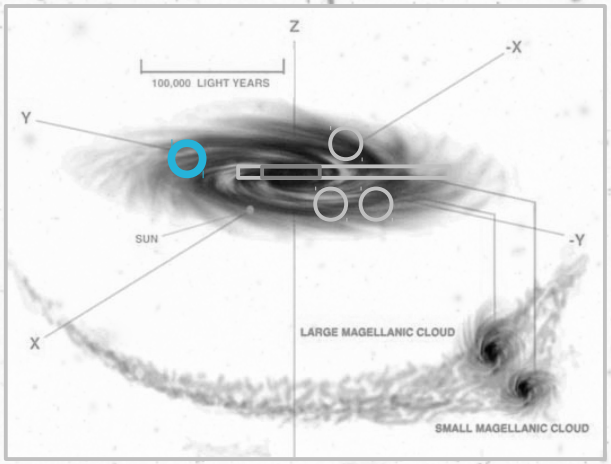
AGN M87 Science 314, 1424 (2006)
Fast Variability of TeV γ Rays from the Radio Galaxy M87

EBL Nature 440, 1018 (2006)
A low level of extragalactic background light as revealed by γ-rays from blazars



Selected results

TeV Astronomy: Nature & Science



Crab Pulsar

. Observation of Pulsed γ-Rays Above 25 GeV from the Crab Pulsar with MAGIC, Science 322, 1221 (2008)

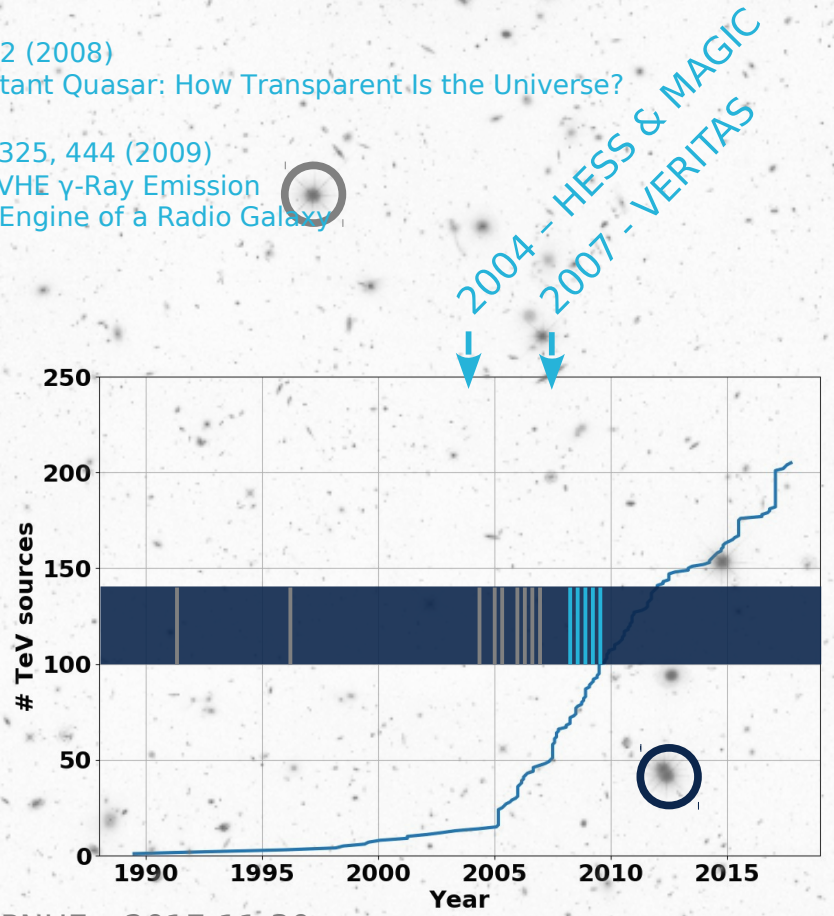
. Detection of Pulsed Gamma Rays Above 100 GeV from the Crab Pulsar, Science 334, 69 (2011)

Starburst M82 Nature 462, 770 (2009)
A connection between star formation activity and cosmic rays in the starburst galaxy M82

Starburst NGC 253 Science 326,1080 (2009)
Detection of Gamma Rays from a Starburst Galaxy

EBL Science 320, 752 (2008)
VHE γ-rays from a Distant Quasar: How Transparent Is the Universe?

AGN M87 Science 325, 444 (2009)
Radio Imaging of the VHE γ-Ray Emission Region in the Central Engine of a Radio Galaxy



Selected results

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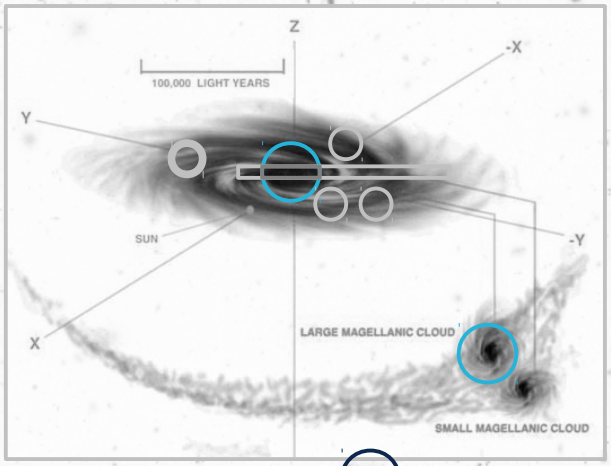
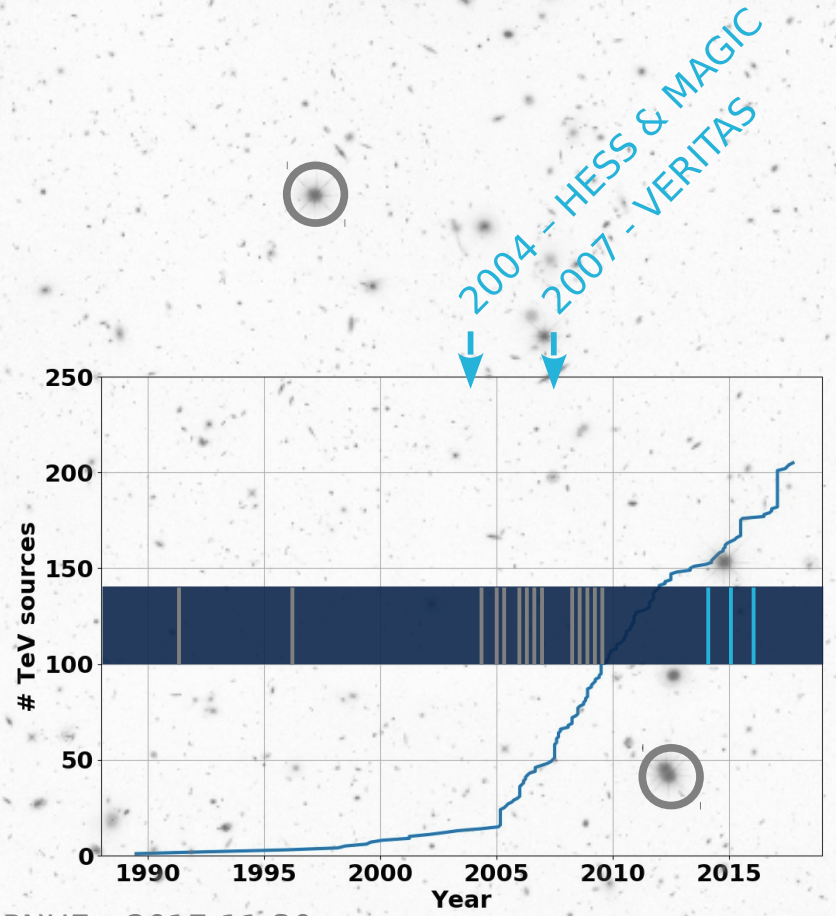




Pevatron Galactic Centre Nature 531, 476 (2016)
Acceleration of petaelectronvolt protons in the Galactic Centre

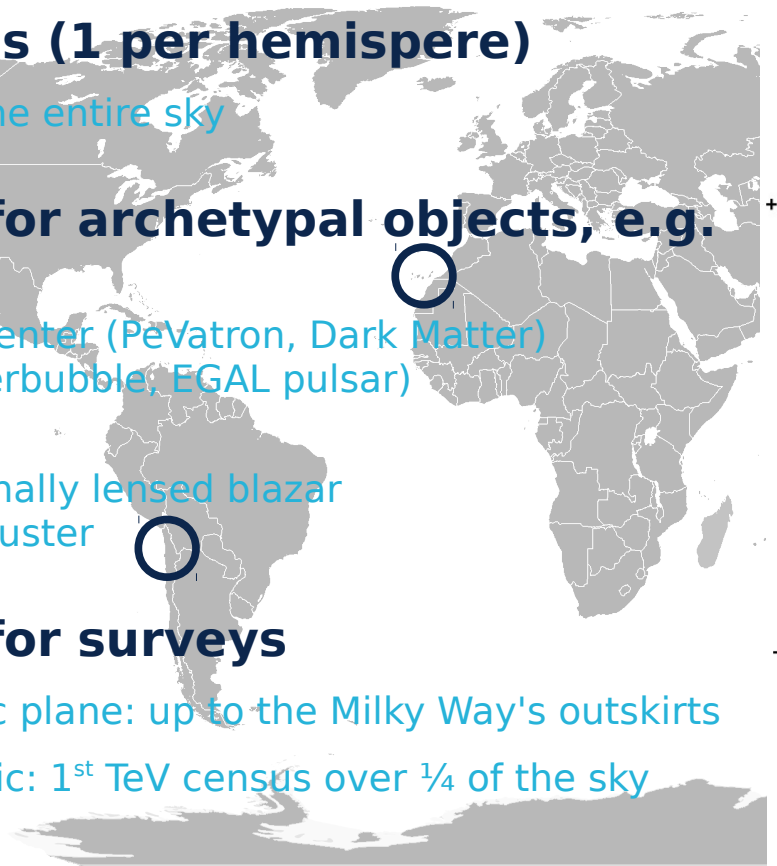
LMC Science 347, 406 (2015)
The exceptionally powerful TeV γ-ray emitters in the LMC

AGN IC310 Science 346, 1080 (2014)
Black hole lightning due to particle acceleration at subhorizon scales

cherenkov telescope array

CTA – How?

Access to the full sky



Two sites (1 per hemispere)

Access to the entire sky

Crucial for archetypal objects, e.g.

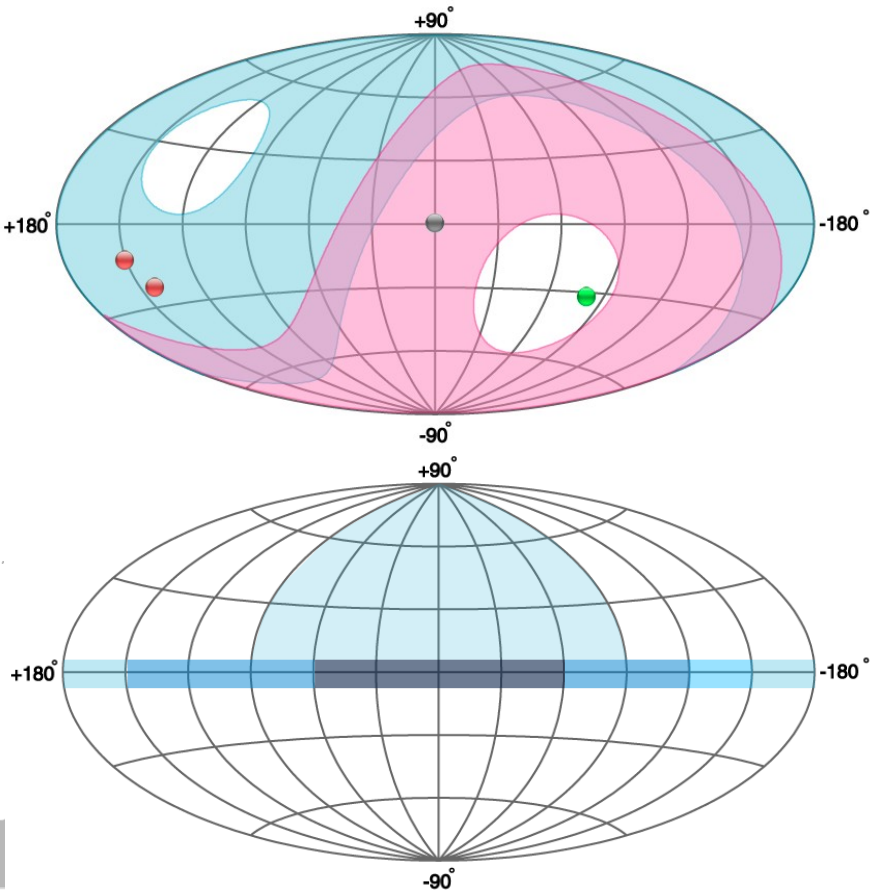
South:
. Galactic Center (PeVatron, Dark Matter)
. LMC (Superbubble, EGAL pulsar)

North:
. Gravitationally lensed blazar
. Perseus Cluster

Crucial for surveys

Full Galactic plane: up to the Milky Way's outskirts

Extragalactic: 1st TeV census over ¼ of the sky



Precision Č measurements

Imaging Atmospheric Č Technique

a. Shape of the shower → bckgd rejection
b. Size of the shower → energy estimator
c. (Time gradient → direction estimator)

Multiplicity is key

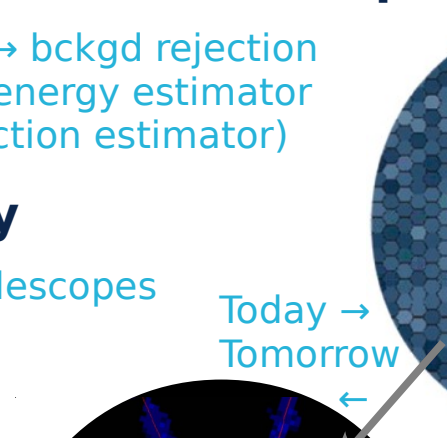
Coincidence from ++ telescopes
→ precision on a, b, **c**

Telescope Size

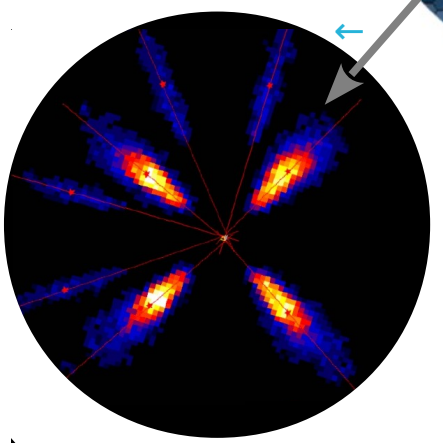
Low-energy γ rays:
fainter Č signal
→ Large mirrors

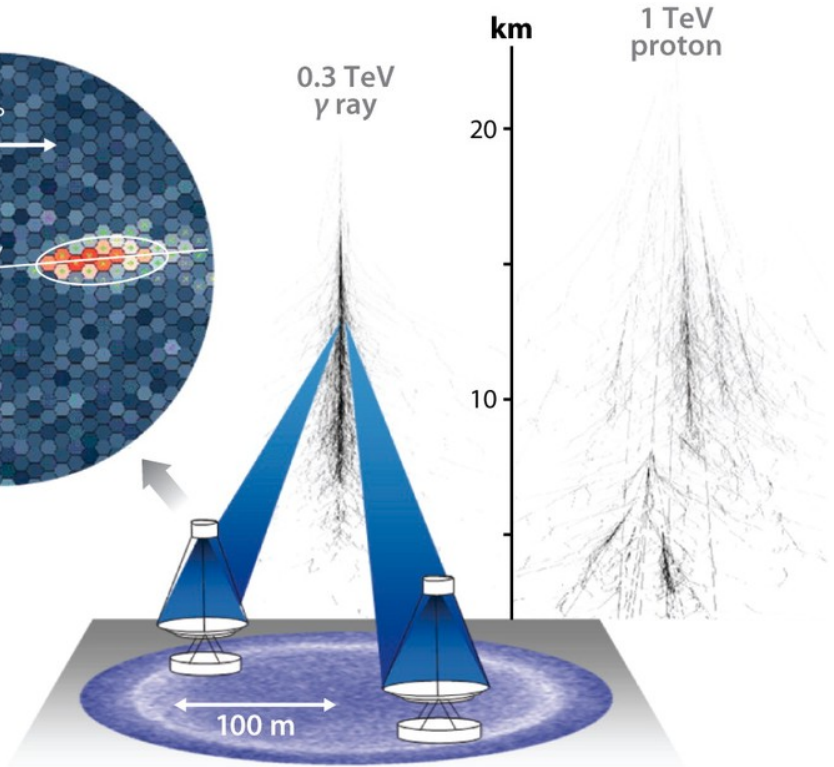
Array

High-energy γ rays:
Scarcer (PWL spectra)
→ Large array layout



Today →
Tomorrow
←

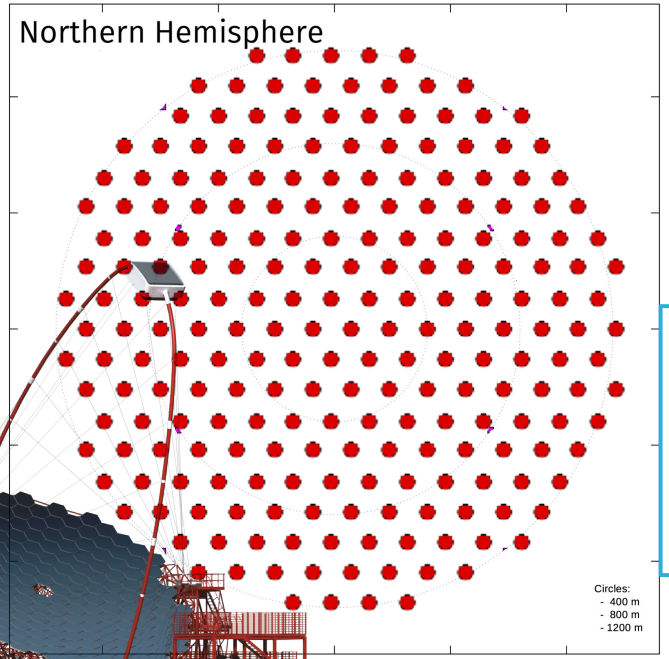


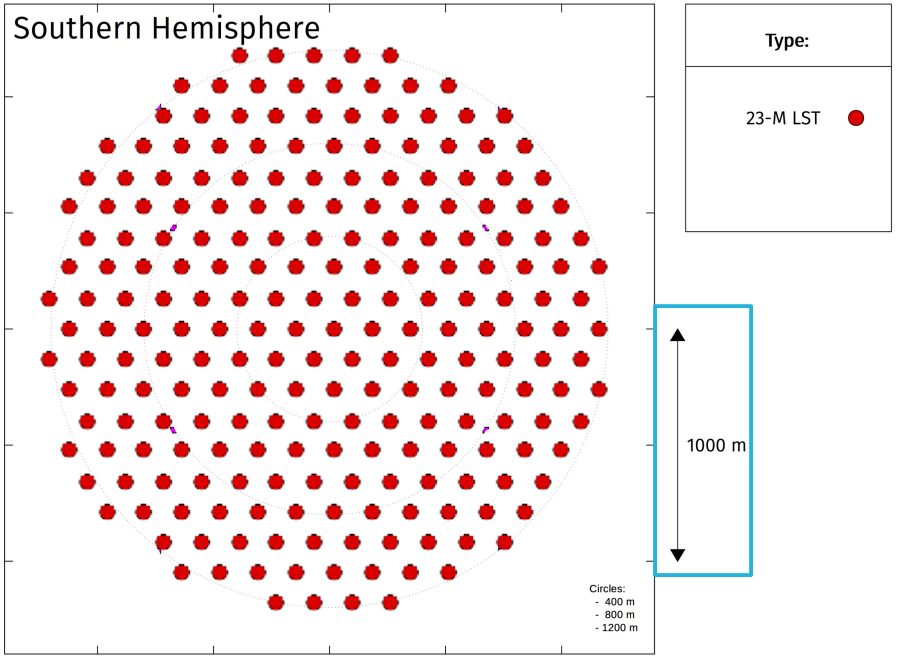


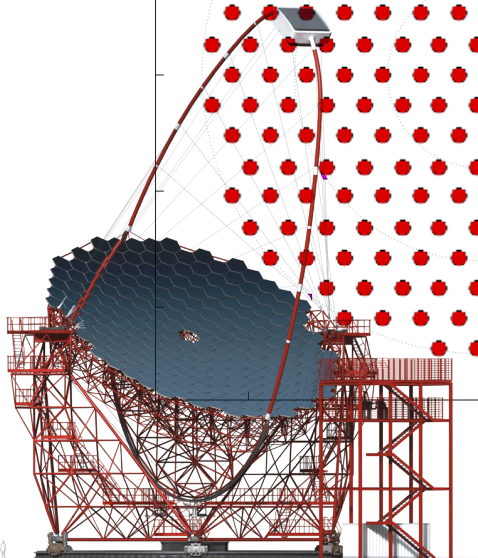
Brute-force solution

In an ideal world, with an infinite budget:

Pave kilometer-square areas with large telescopes, every ~100m (Č ground imprint)



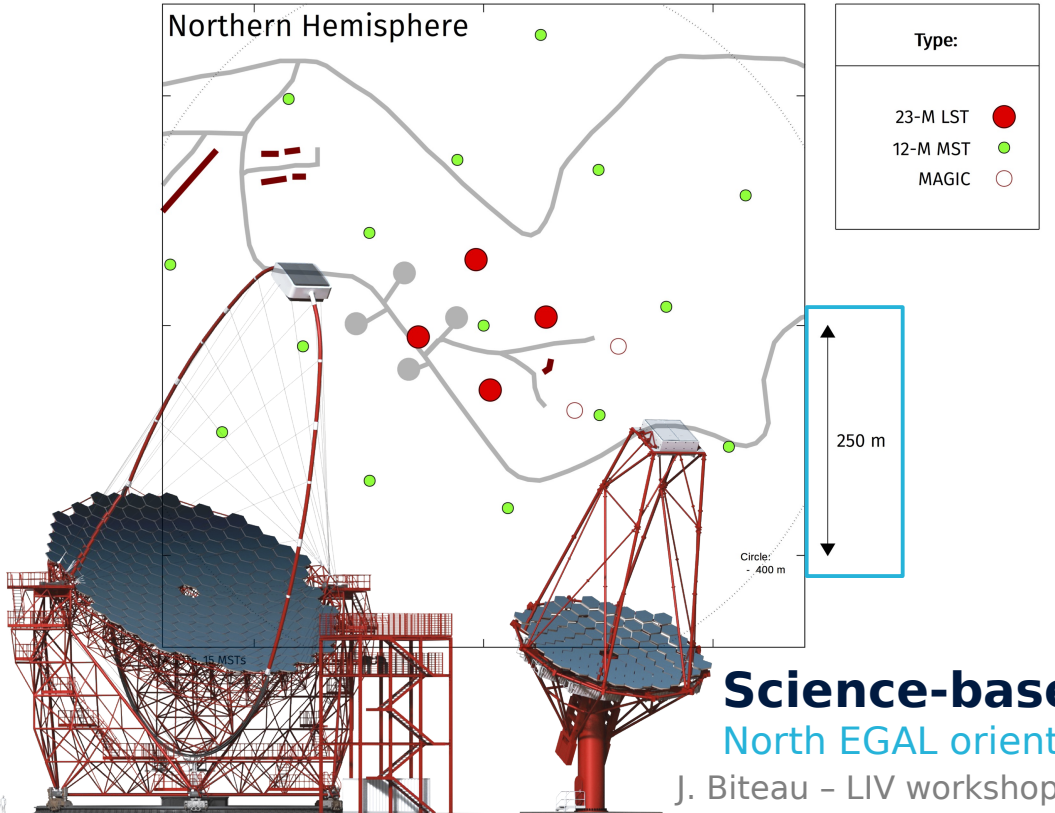


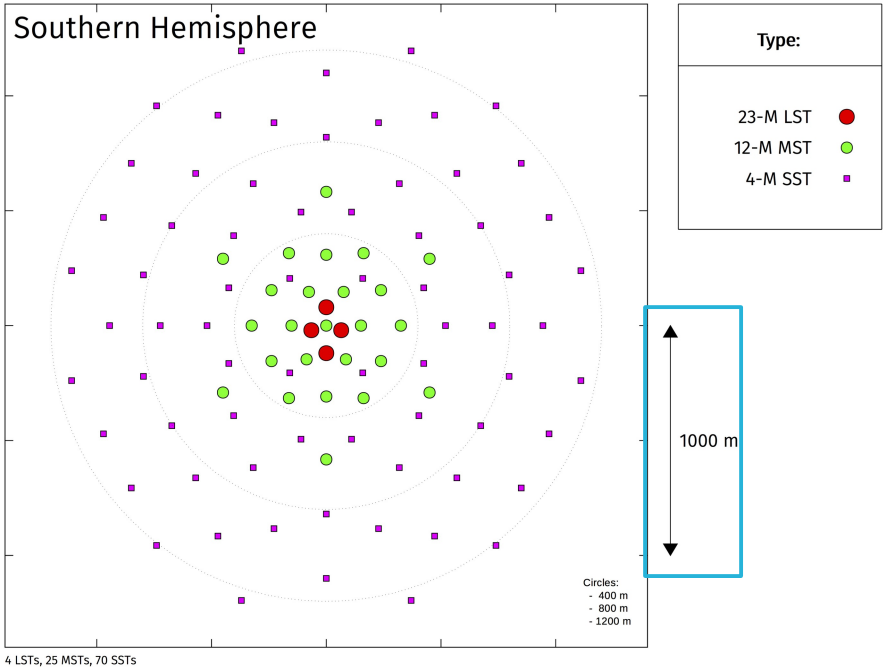


Optimized layout

Shower-based optimization

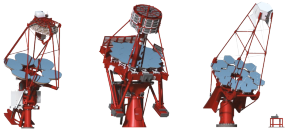
LST (~23m): low E *~20-200 GeV* – MSTs: mid E *~0.2-2 TeV* – SSTs: high E *>2 TeV*





Science-based optimization

North EGAL oriented: EBL absorption at high-E



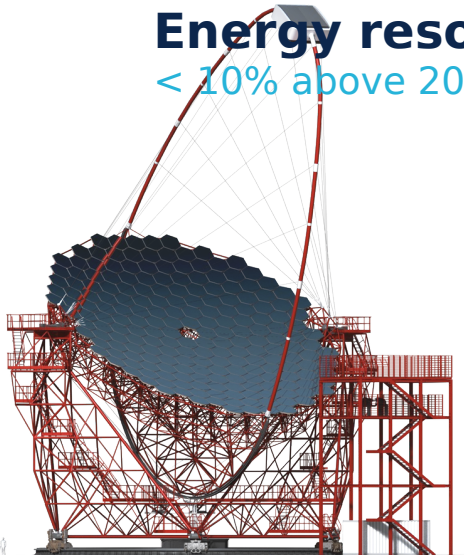
Key performance

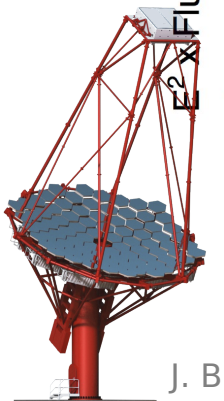
Sensitivity++
10s of GeV to 100s of TeV

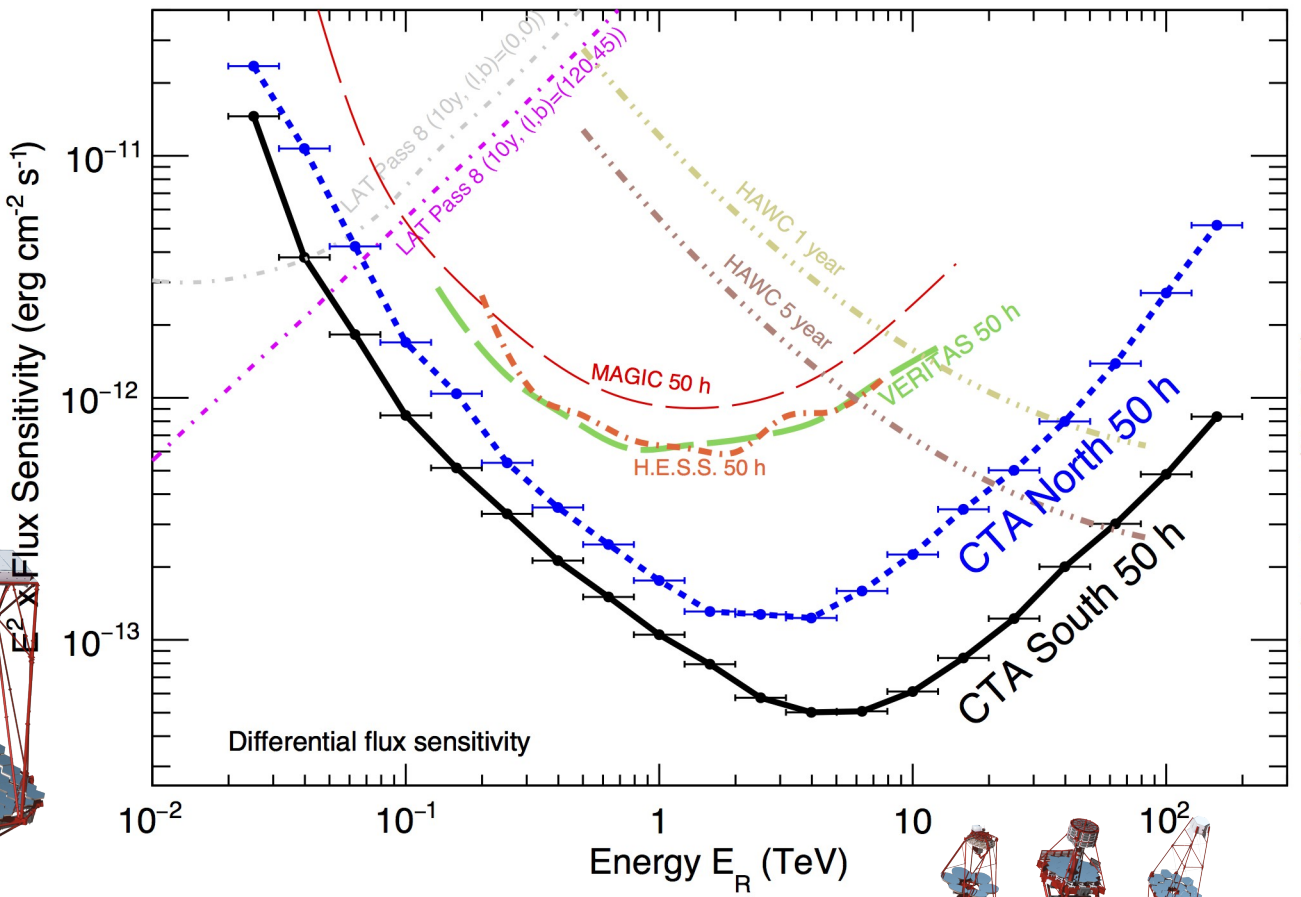
Field of view
MSTs:: ~5°x 5° → ~8°x 8°

Angular resolution
Better than 3' > 1 TeV

Energy resolution
< 10% above 200 GeV







Observation modes

Deep field

Optimal performance → particularly important for faint objects / highest-quality observation

Observation modes

Survey

Divergent pointing option → trade-off between sensitivity for a fixed livetime vs energy & angular resolution

Observation modes

Snapshot

Monitor ++ objects at the same time → repoint towards the 'bursting' one in < 50s for LSTs, < 90s for MSTs, SSTs

CTA – Core Science

Key Questions

Understanding the Origin and Role of Relativistic Cosmic Particles

. What are the sites of high-energy particle acceleration in the universe?
. What are the mechanisms for cosmic particle acceleration?
. What role do accelerated particles play in feedback on star formation and galaxy evolution?

Probing Extreme Environments

. What physical processes are at work close to neutron stars and black holes?
. What are the characteristics of relativistic jets, winds and explosions?
. How intense are radiation fields and magnetic fields in cosmic voids? What is their evolution?

Exploring Frontiers in Physics

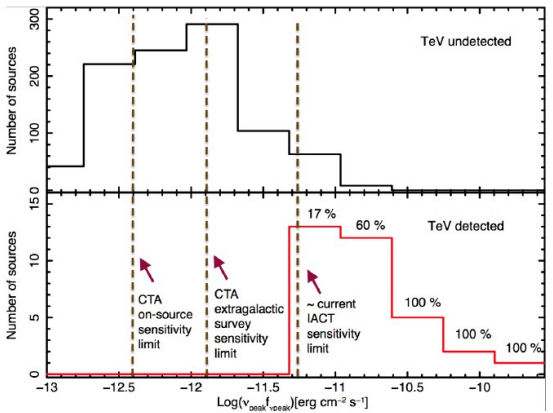
. What is the nature of dark matter? How is it distributed?
. Are there quantum gravitational effects on photon propagation?
. Do axion-like particles exist?

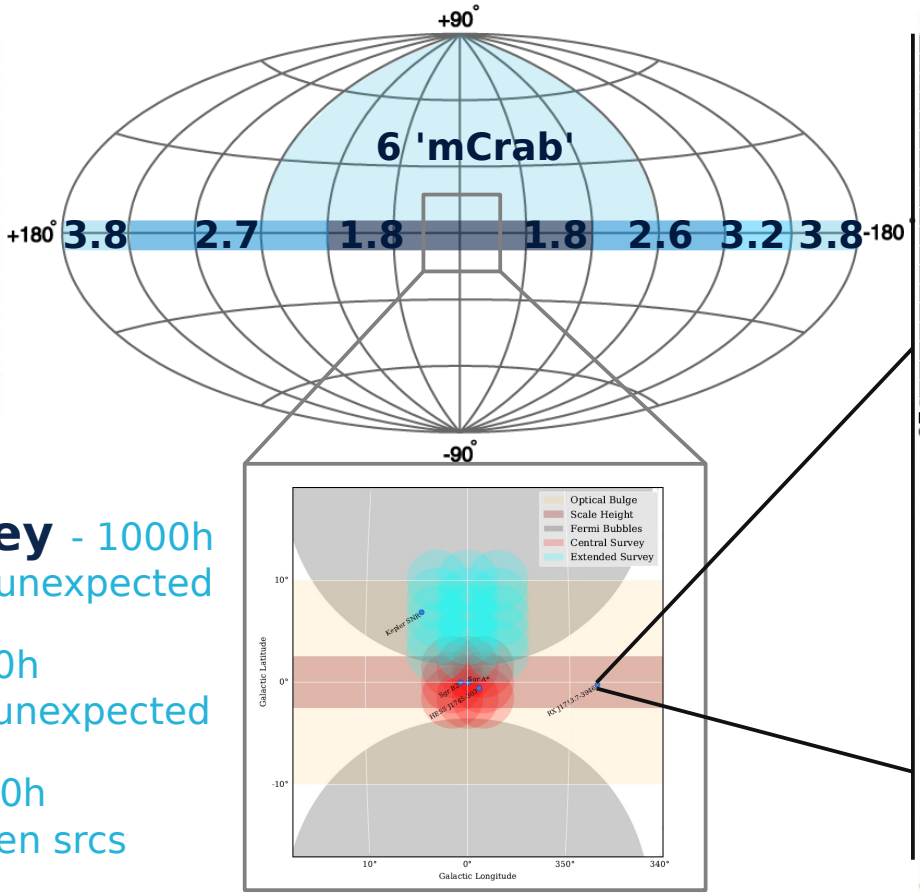
Key Science Projects

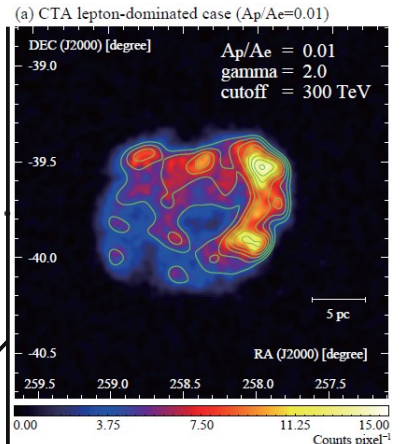
Theme		Question	Dark Matter Programme	Galactic Centre Survey	Galactic Plane Survey	LMC Survey	Extra-galactic Survey	Transients	Cosmic Ray PeVatrons	Star-forming Systems	Active Galactic Nuclei	Galaxy Clusters
Understanding the Origin and Role of Relativistic Cosmic Particles	1.1	What are the sites of high-energy particle acceleration in the universe?		✔	✔✔	✔✔	✔✔	✔✔	✔	✔	✔	✔✔
	1.2	What are the mechanisms for cosmic particle acceleration?		✔	✔	✔		✔✔	✔✔	✔	✔✔	✔
	1.3	What role do accelerated particles play in feedback on star formation and galaxy evolution?		✔		✔				✔✔	✔	✔
Probing Extreme Environments	2.1	What physical processes are at work close to neutron stars and black holes?		✔	✔	✔			✔✔		✔✔	
	2.2	What are the characteristics of relativistic jets, winds and explosions?		✔	✔	✔	✔	✔✔	✔✔		✔✔	
	2.3	How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?					✔	✔			✔✔	
Exploring Frontiers in Physics	3.1	What is the nature of Dark Matter? How is it distributed?	✔✔	✔✔		✔						✔
	3.2	Are there quantum gravitational effects on photon propagation?						✔✔	✔		✔✔	
	3.3	Do Axion-like particles exist?					✔	✔			✔✔	

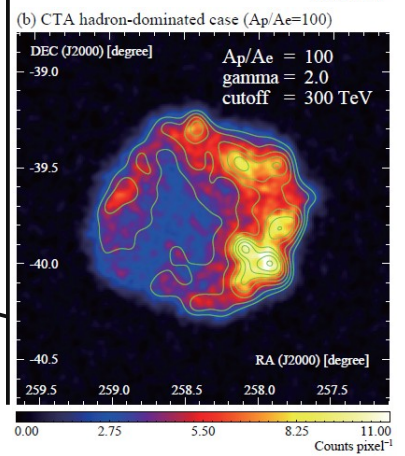
Large / deep surveys

Field of view & Two hemispheres









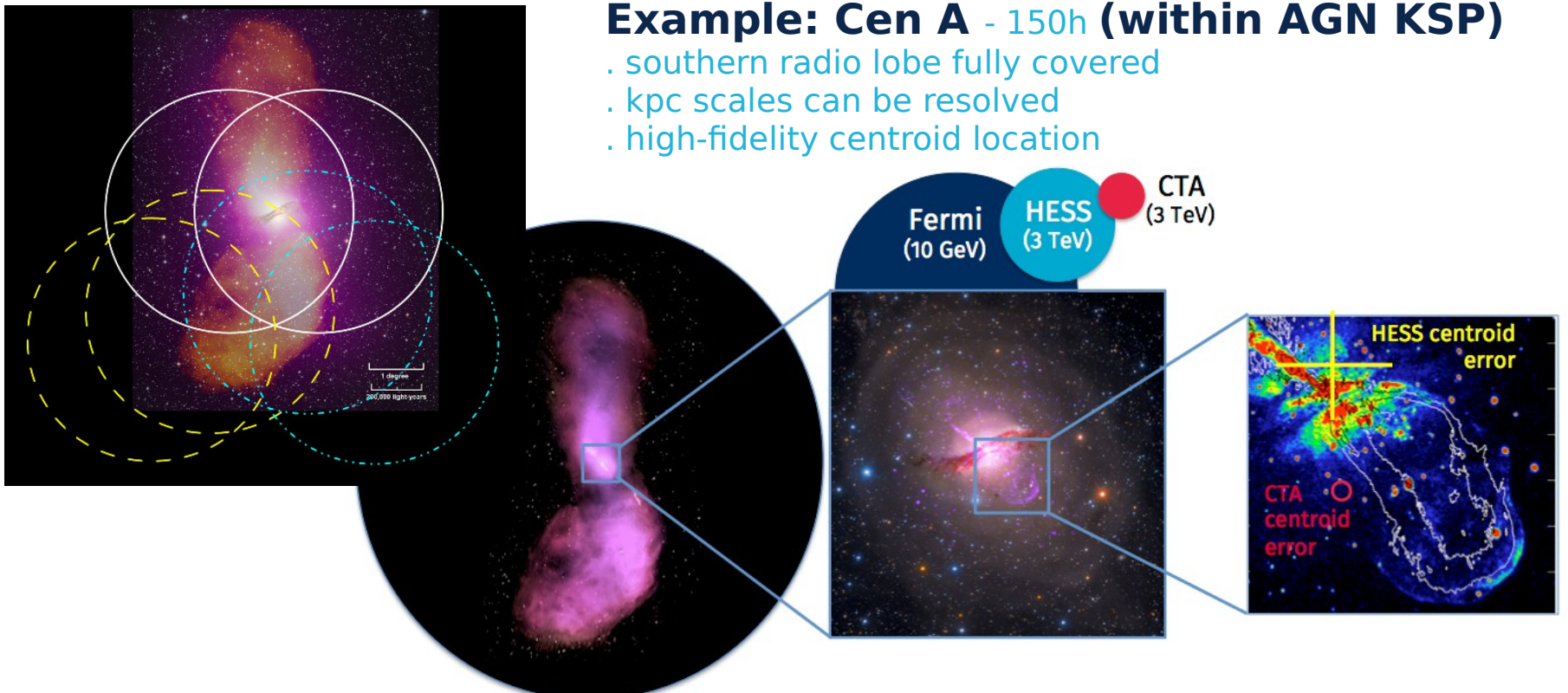
Extragalactic Survey - 1000h
30-150 srcs + unbiased + unexpected

Galactic Plane - 1600h
300-600 srcs + full Gal. + unexpected

Galactic Center - 800h
DM + SgrA*+ Ridge + Dozen srcs

High-quality imaging

Field of view & Angular resolution



Example: Cen A - 150h **(within AGN KSP)**

. southern radio lobe fully covered

. kpc scales can be resolved

. high-fidelity centroid location

+ M87 - 100h **(AGN KSP)** - radio lobe

High-quality imaging

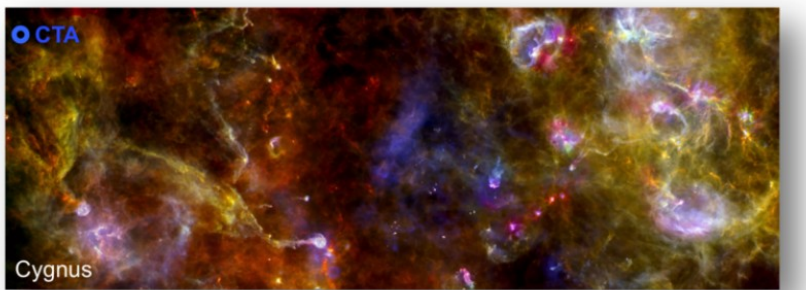
Field of view & Angular resolution

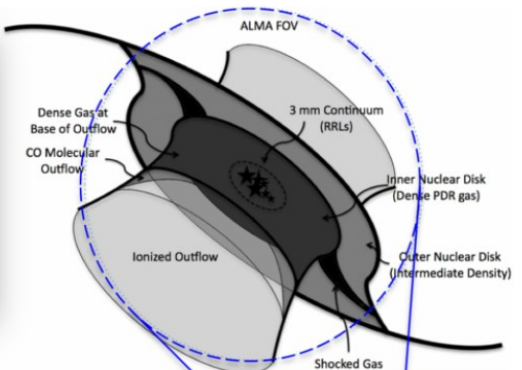
Large Magellanic Cloud Survey - 250h

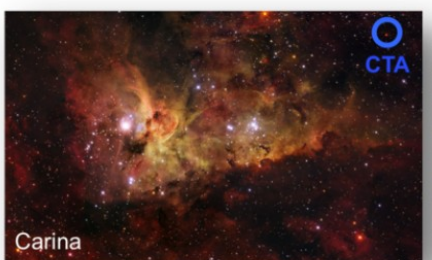
Face-on, dozen srcs incl. SN 1987A, superbubble, 2 powerful pulsars

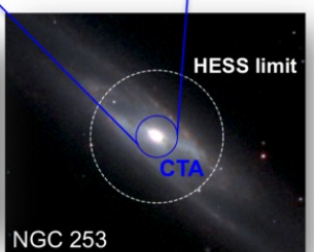
Star-forming systems - GPS + 450h: M31, NGC253, M82, Arp220

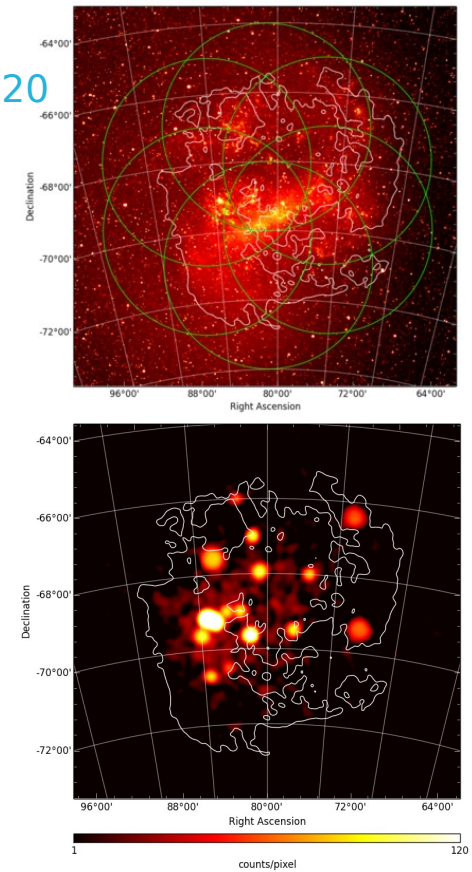
From stellar clusters to starburst glaxies











High-quality spectra

Energy dispersion

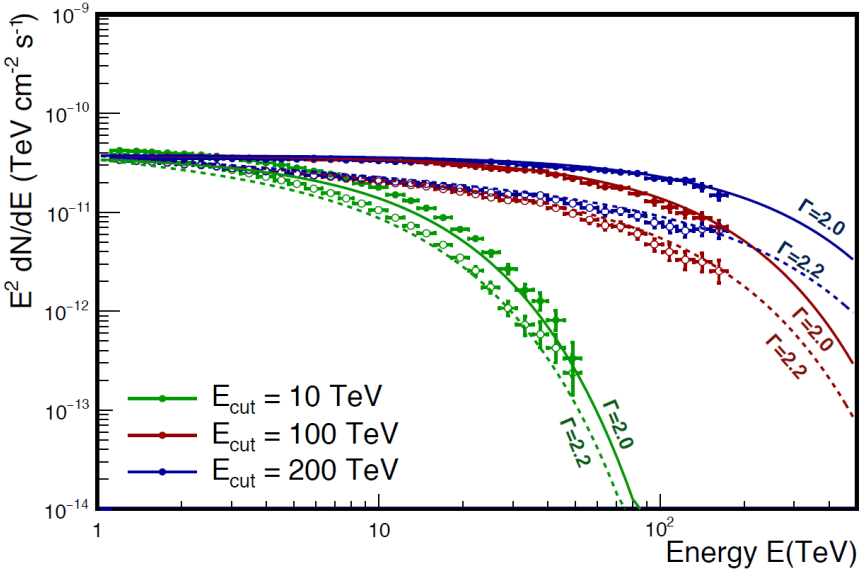
Cosmic-ray Pevatrons - 300h

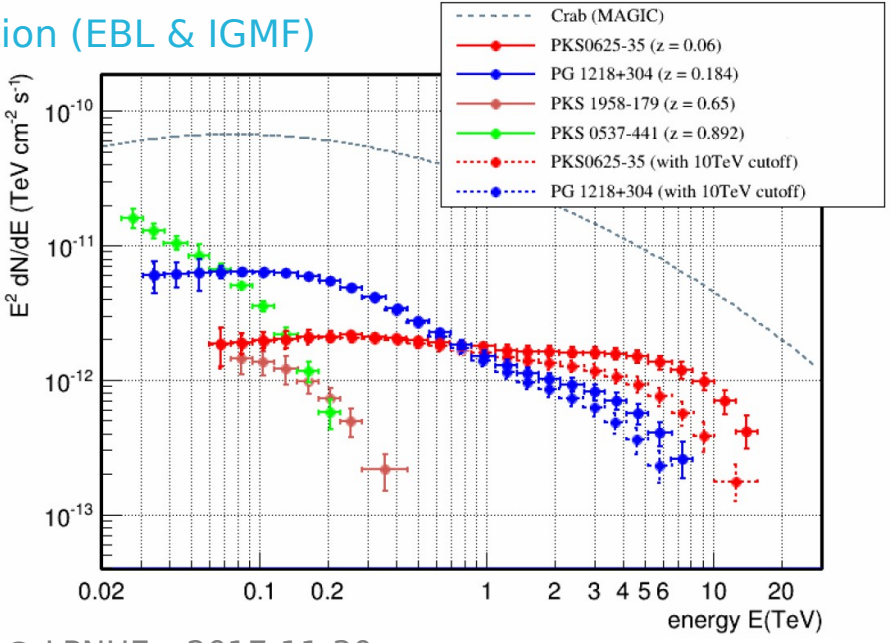
RX J1713.7-3946 + 5 candidate PeVatrons detected in the Galactic Plane Survey

Active Galactic Nuclei - 300h on high-quality spectra + M87/CenA

~40 objects targeted: ¾ already detected at TeV energies + ¼ based on *Fermi*-LAT extrapolations

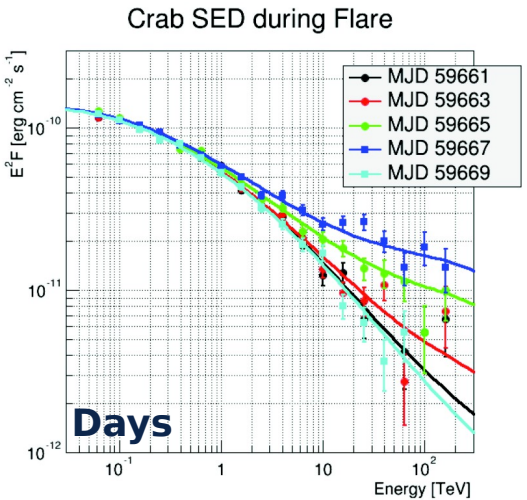
→ acceleration & radiative processes + propagation (EBL & IGMF)





Transients & Outbursts

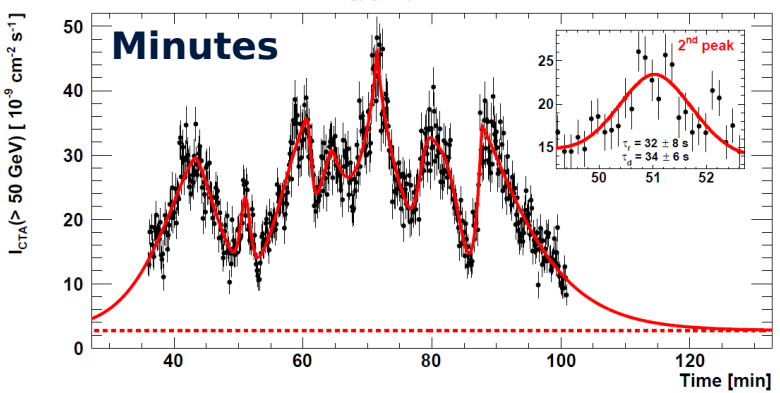
Effective area and Slewing

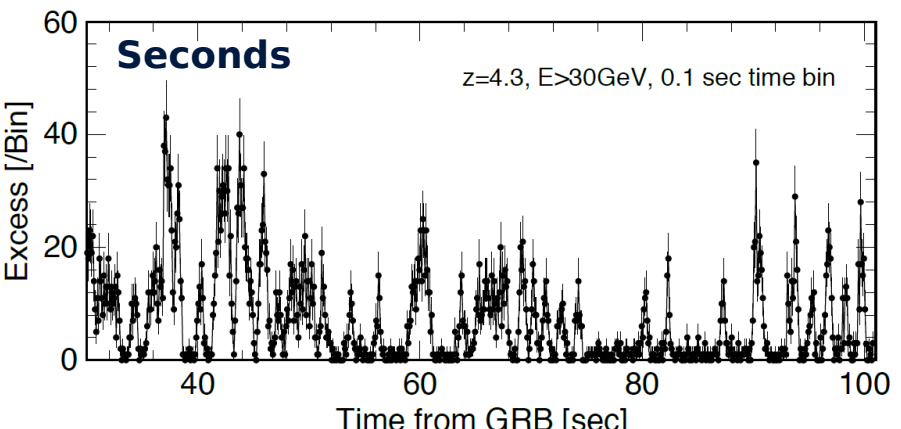


Transients - 2000h (full-array follow-up)
Galactic transients, GRBs, MWL, ν & GW, self-triggered transients

Active Galactic Nuclei - 1500h (long-term monitoring)
+ sub-array snapshot / follow-up + 1200 h (full-array follow-up)
. Variability of AGNs (FSRQs, BL Lacs, radio galaxies) on all time scales
. New classes of TeV AGN → NLSy1?

Triggers to the outside world: < 1 min





Astrophysics & beyond

Possible discoveries in fundamental physics!

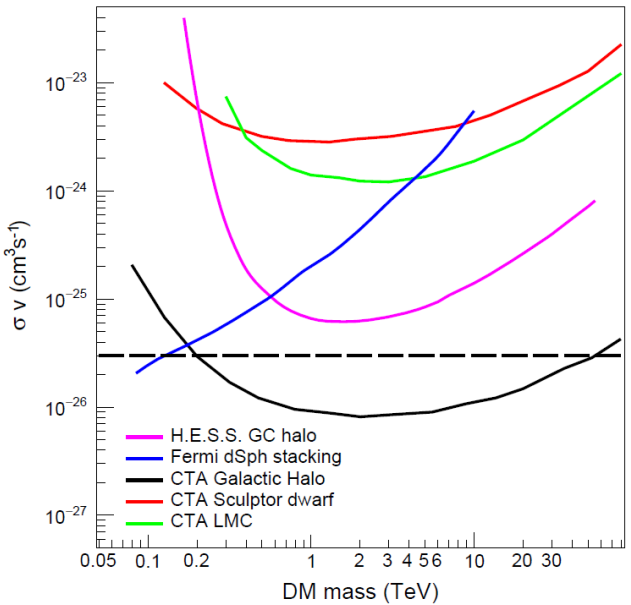
Galaxy clusters - 300h on Perseus

Perseus: structure formation shocks + cosmic-ray content of the intra-cluster medium + NGC 1275 & IC 310

+ decaying DM and γ-WISPs (axion-like) coupling

Dark Matter Program - GC + dSphs(300h) + 700h

Down to the thermal cross section for WIMPs



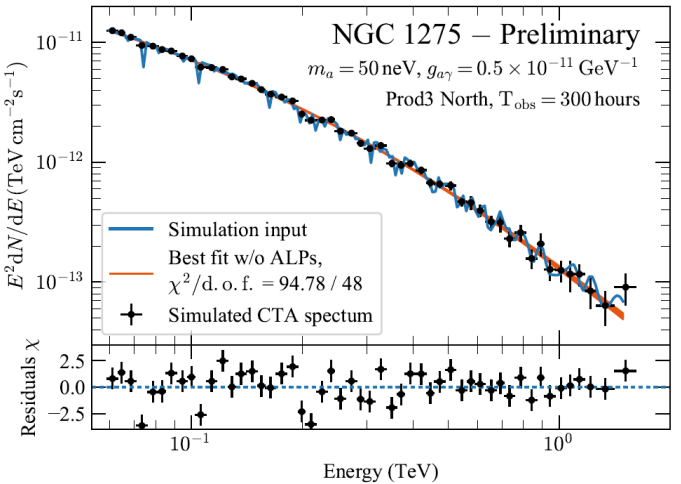
Lorentz Invariance Violation

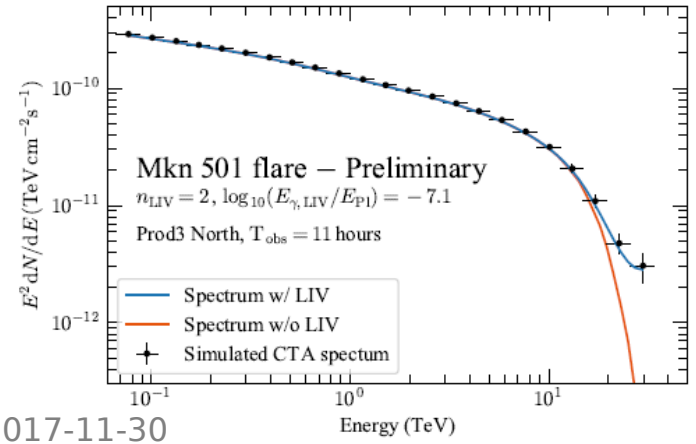
E-dependent delays

Probed by the combination of AGN flares (AGN KSP), GRBs (Transients KSP) and pulsars (GPS & LMC?)

Threshold effects

Probed by the high-quality spectra of AGN (AGN KSP)





cherenkov telescope array

The CTA Community

CTA Users

The CTA Observatory

First true open observatory for
very-high-energy gamma-ray astronomy

Time distribution

40% Key Science Project (CTA Consortium)

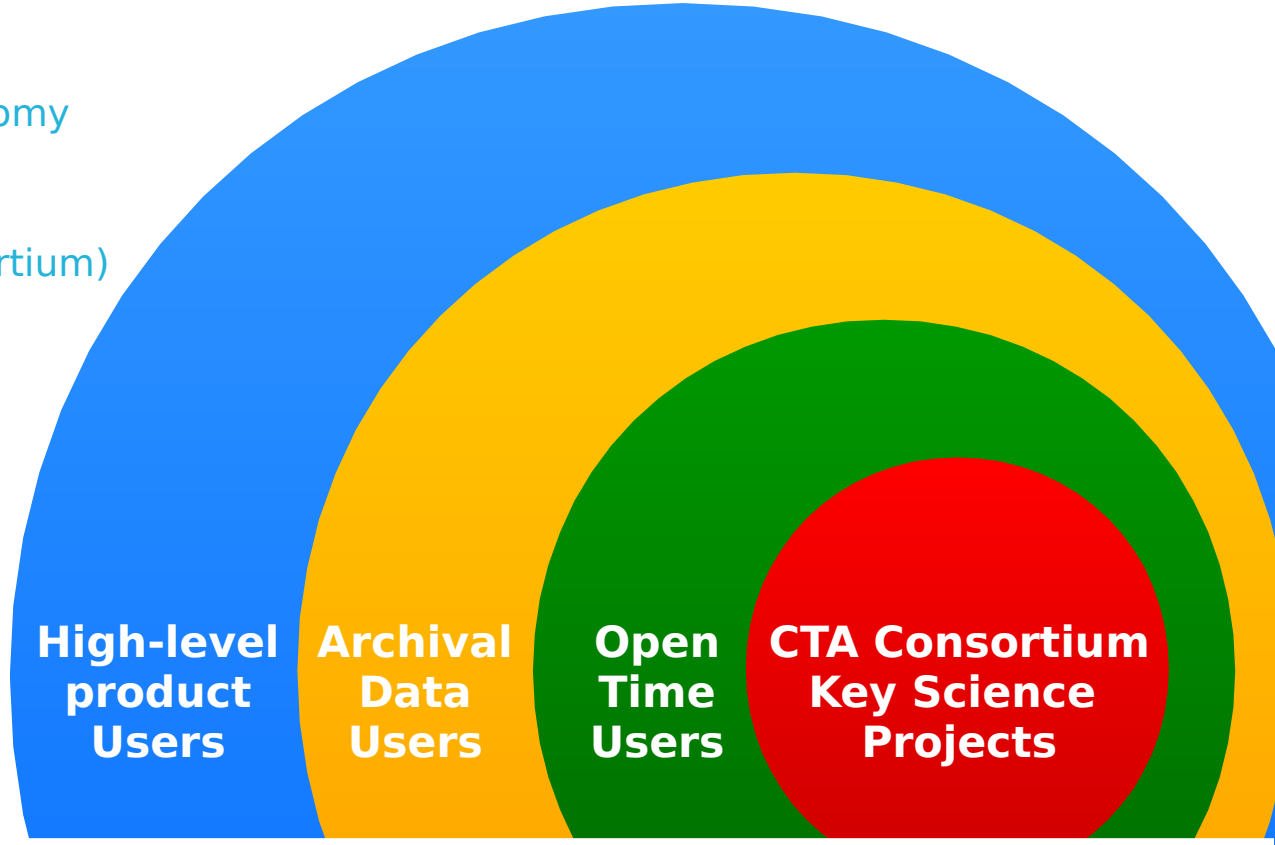
10% Host-country time

50% User time

Annual Guest Observer proposals, with P.I. from participating countries

Open data

High-level data accessible after
a one-year proprietary period



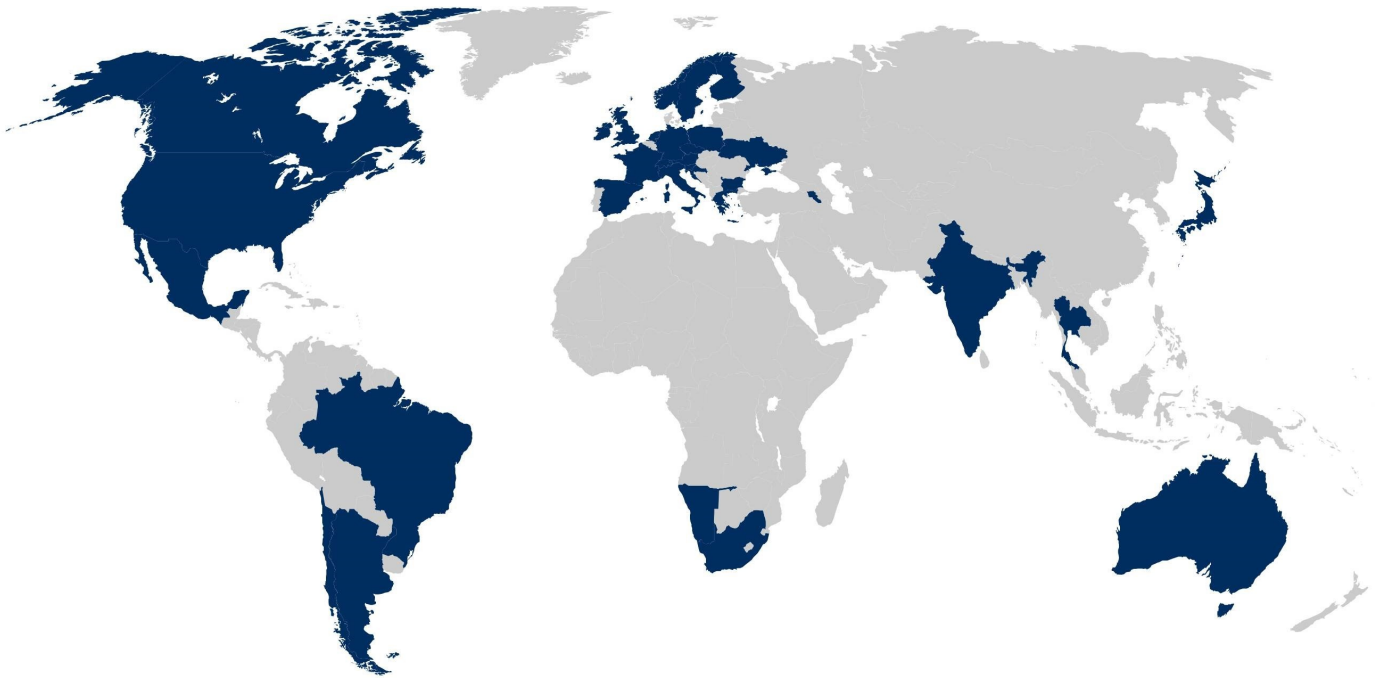
CTA Users

The CTA Consortium

32 countries, 92 parties, 208 parties: 1402 members (480 FTE) *as of May 2017*

Definition of the project and of its component - definition of the Key Science Projects

Release of catalogs, maps, likelihood/posterior profiles...

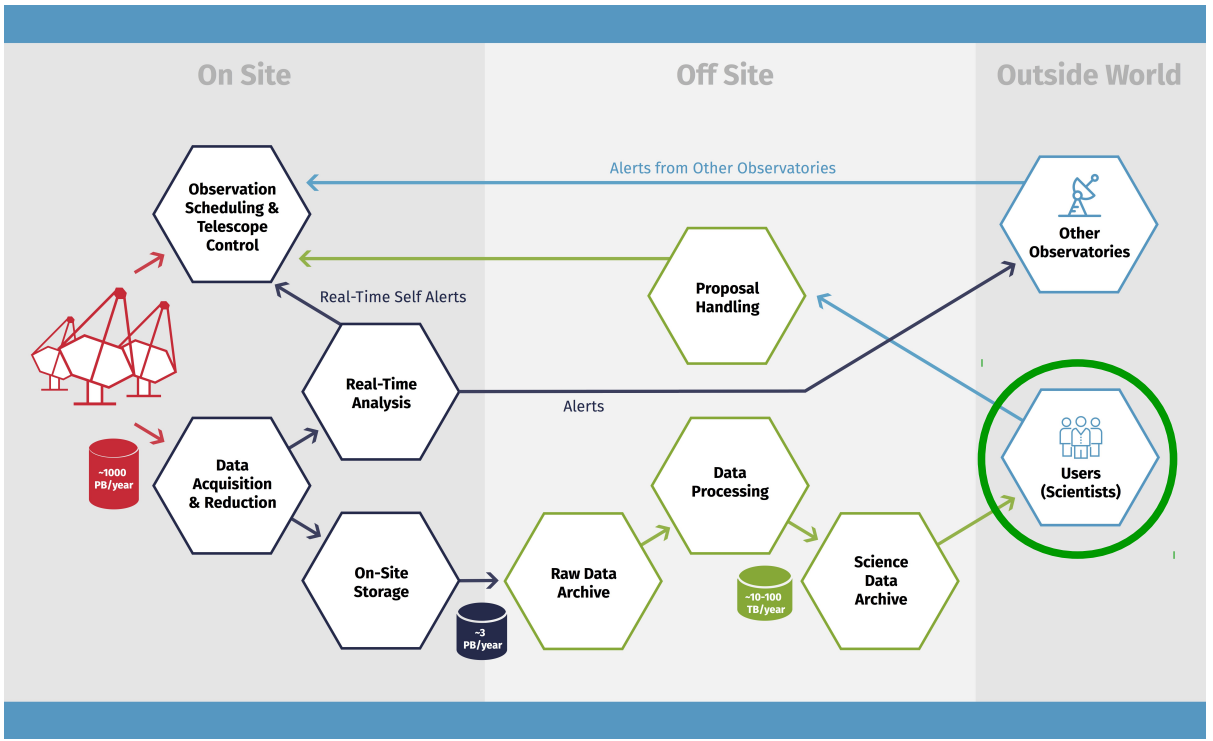


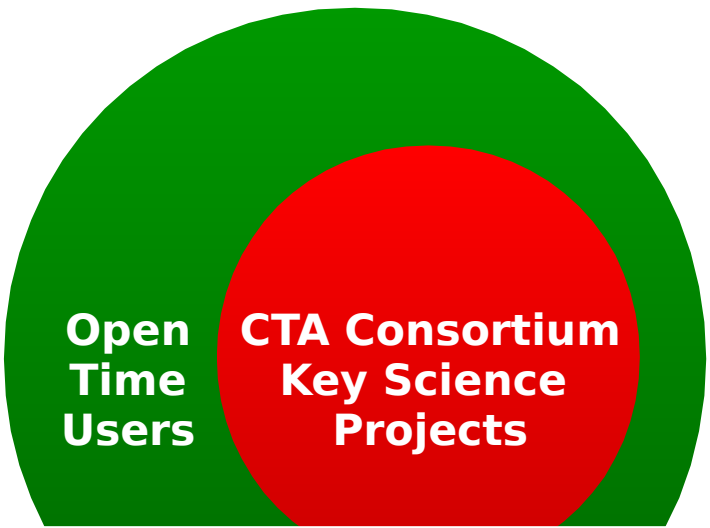
CTA Consortium Key Science Projects

CTA Users

Guest observers

Estimated Co-Is of guest-observer proposals O(5000). CTA → data products and support.



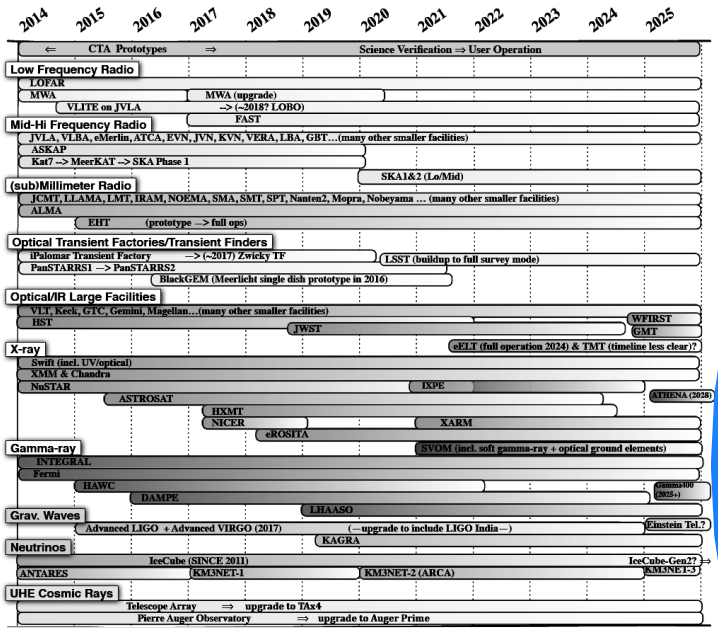


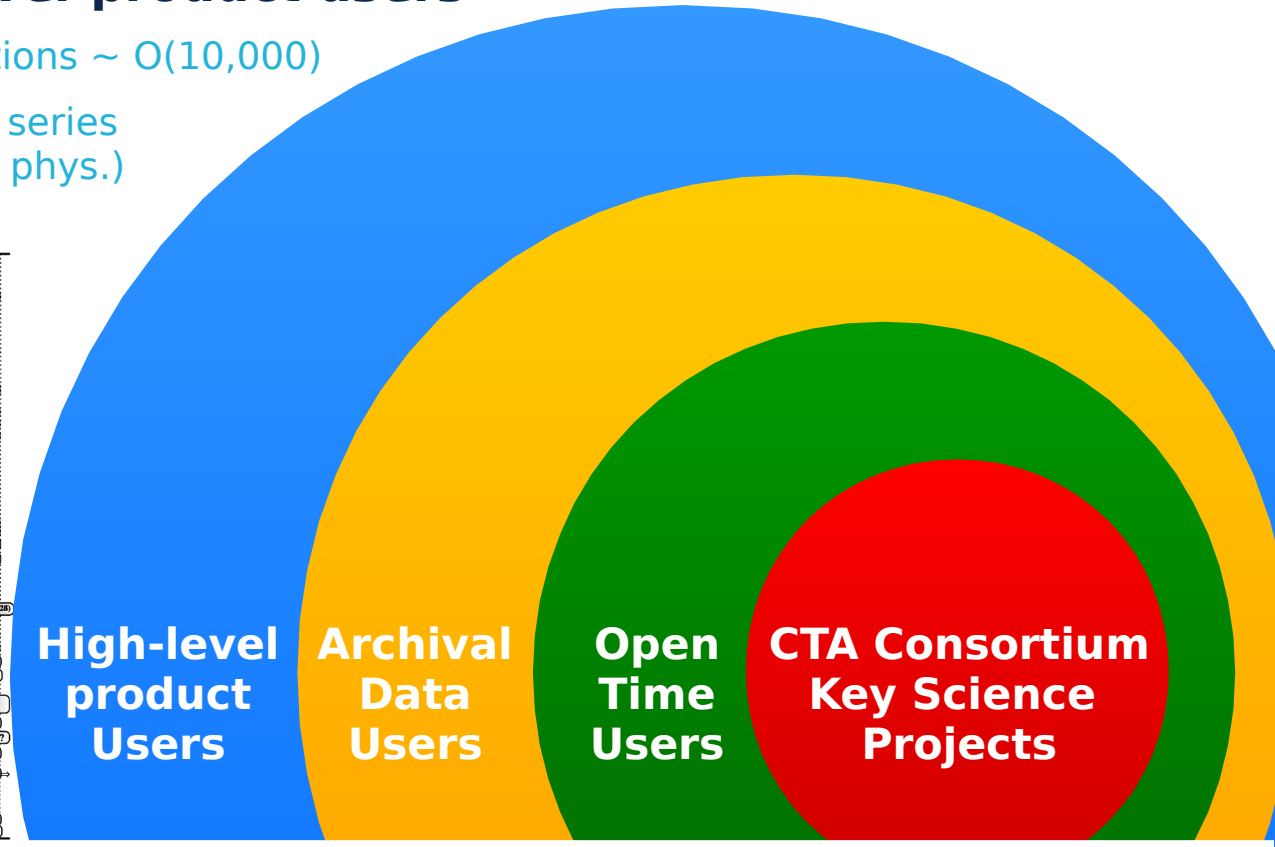
CTA Users

Archival data and high-level-product users

Co-authors of archive-based publications ~ O(10,000)

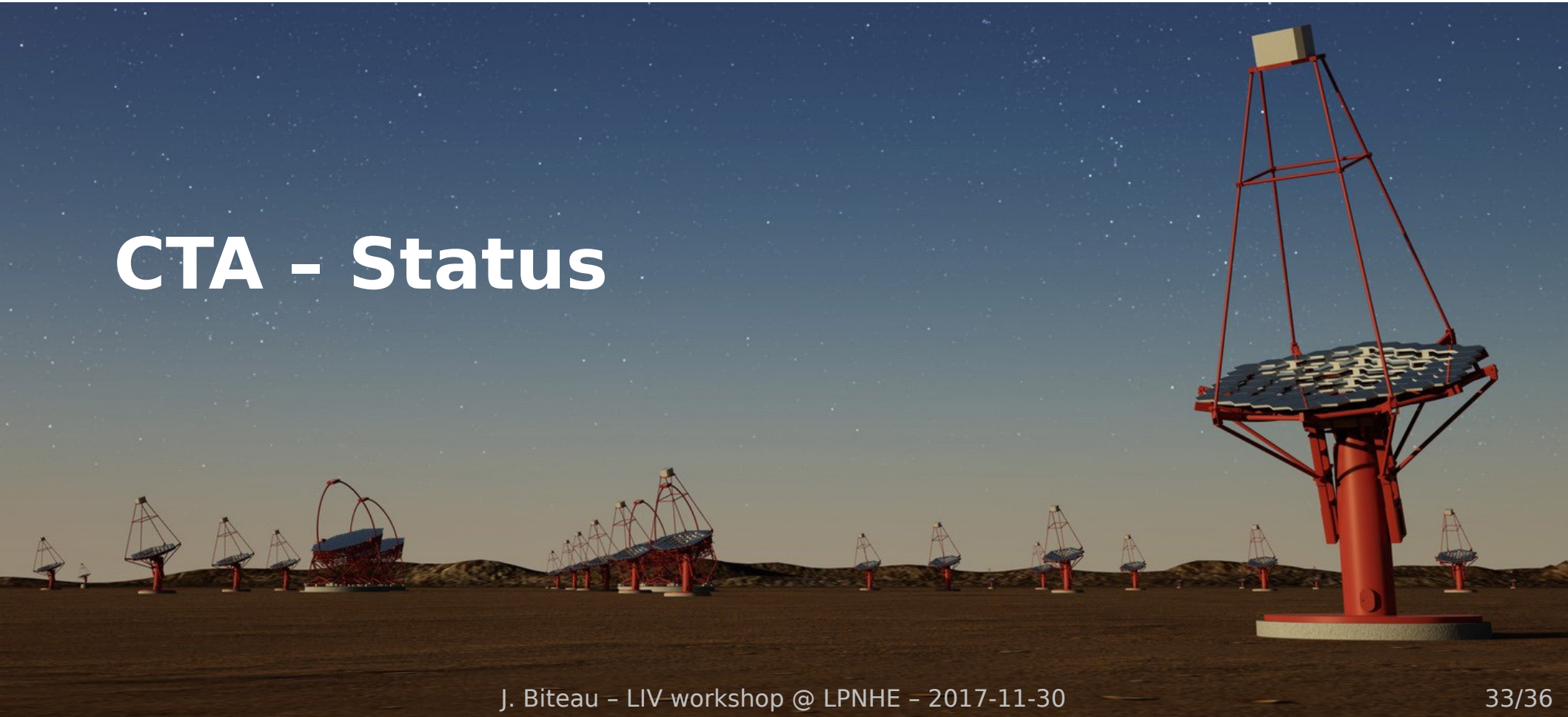
Wide community engaged through a series of workshops (astropart., astro, part. phys.)





cherenkov telescope array

CTA – Status



CTA Timeline

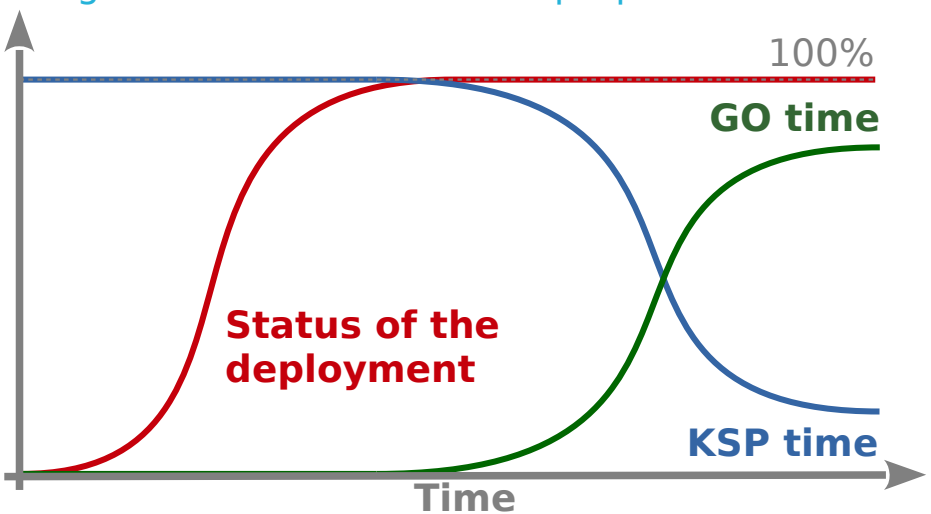
A brief history of CTA

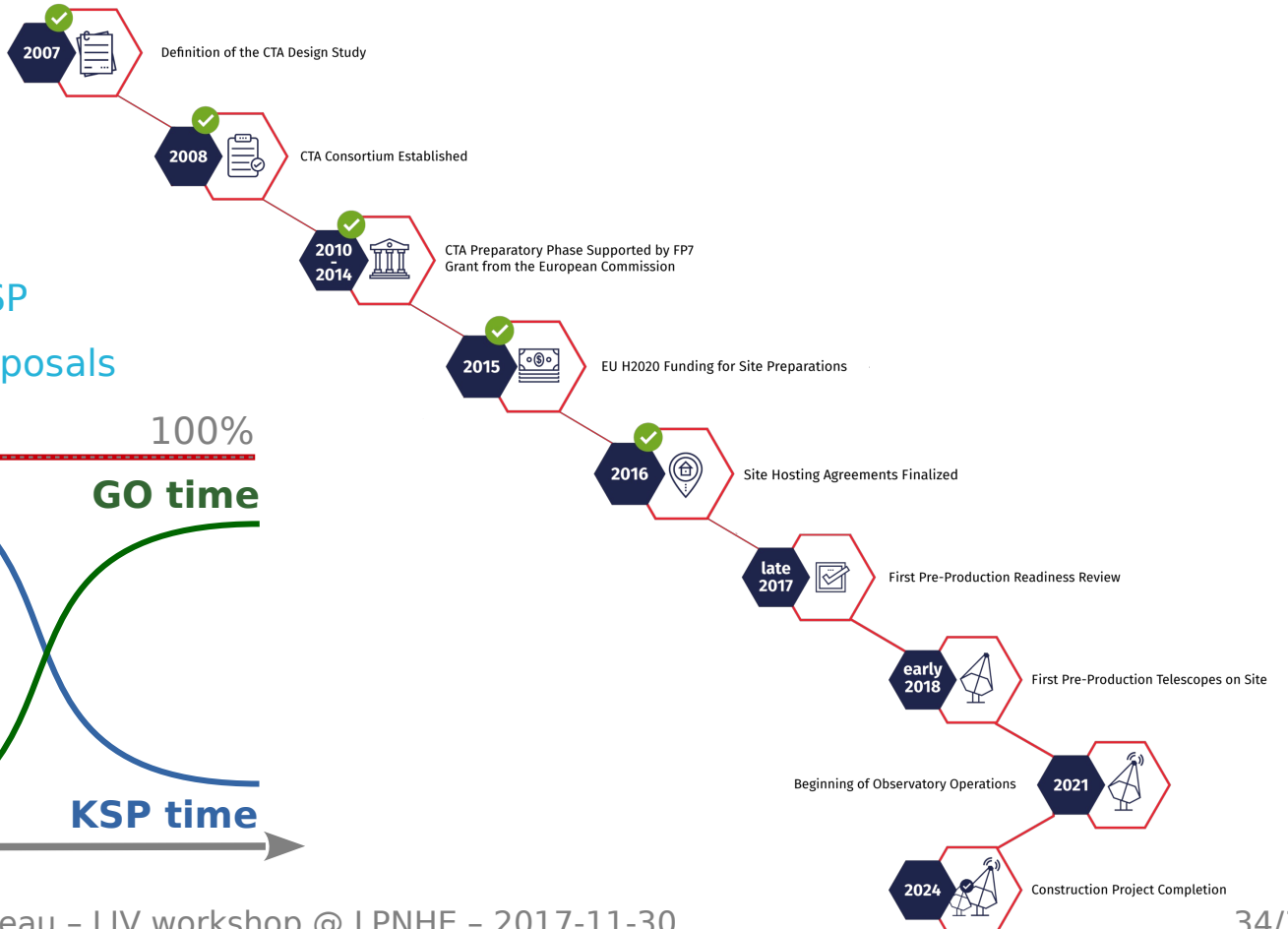
10 years of design for a first telescope on site in 2018

Deployment up to 2024

1st years largely dedicated to KSP

Progressive transition to GO proposals





Status of the sites

The CTA Observatory

Active work ongoing on both sites for the deployment of the array

Southern site

Northern site

CTA – Live!


LST 1 in real time:
http://webcam.lst1.iac.es/stream2view.htm
MERO TSK