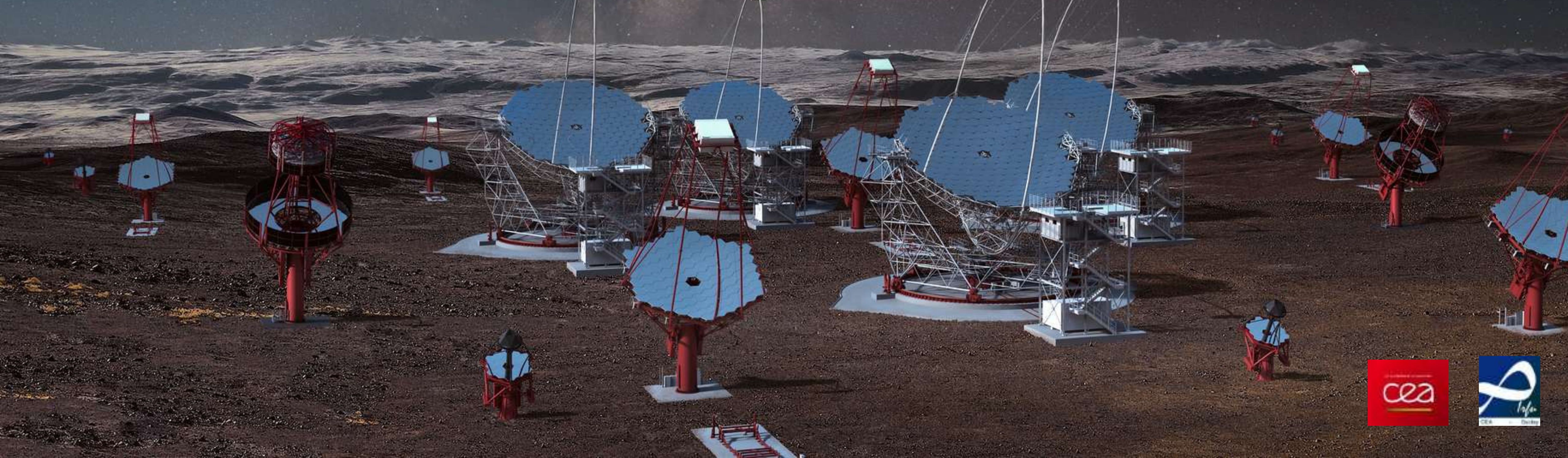
CTAO | CONSORTIUM

The Cherenkov Telescope Array Observatory

Th. Stolarczyk

CEA Paris-Saclay, Irfu, Astrophysics Dept. (AIM)



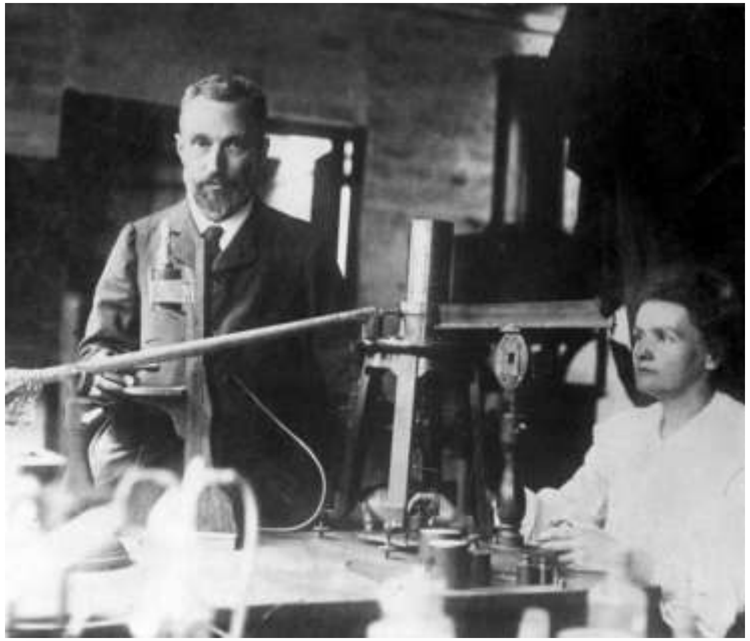
Contents

Some materials taken from ISAPP 2022 W. Hofmann talk & K. Kosack

Why? And how?

Cosmic rays

P. and M. Curie, discovery of radium and polonium (1898)



- Discovered accidentally 1912 (V. Hess, 1912)
  - α, β, γ → *cosmic* rays
- Known as charged particles since (A. Compton, ~1930)
- Atmospheric showers ~10^{15} eV (P. Auger, 1937)

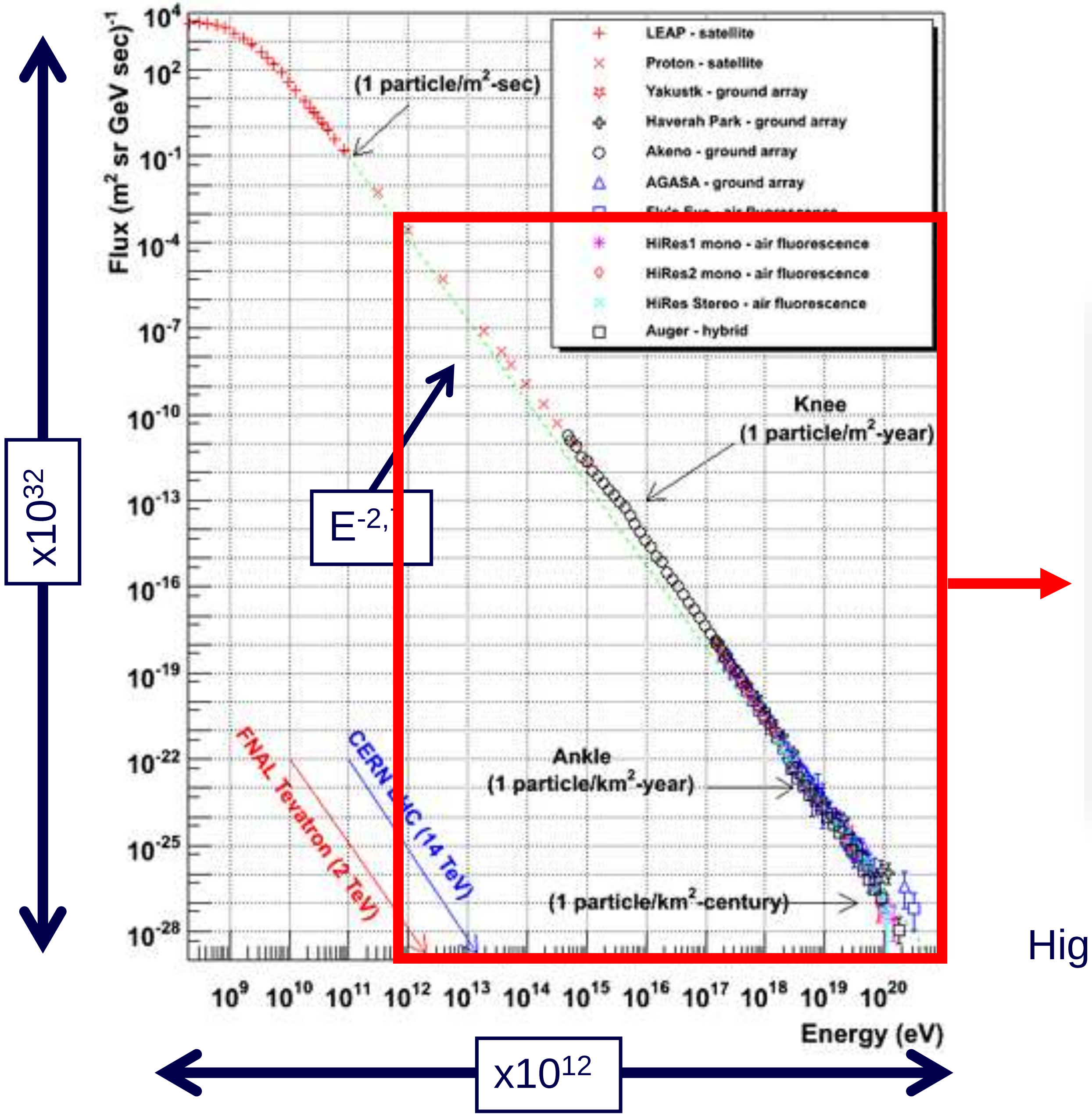
Still a mystery today

- Where do they come from?
- What is their composition?
- What are the objects producing the highest energies?

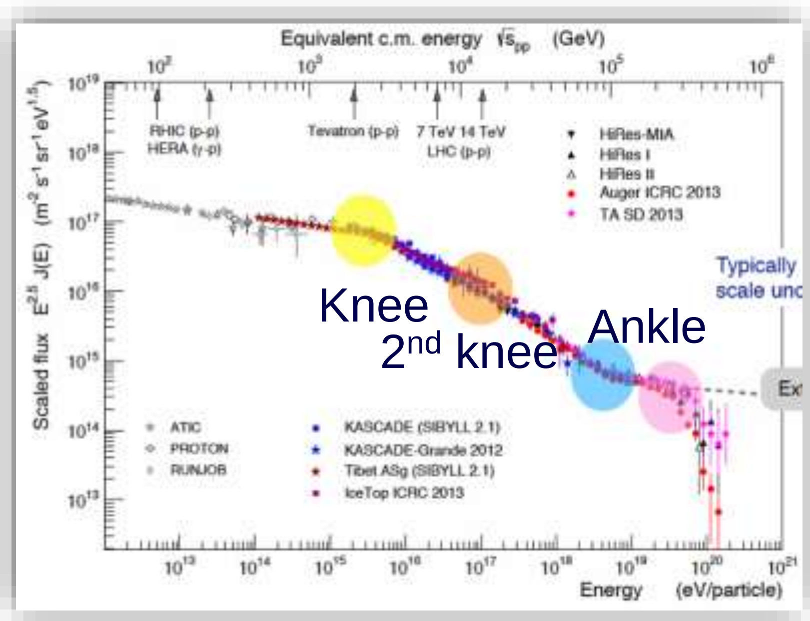
Hess on gondola in 1912 probably in test flight. The date and place is not clear at present.

V. Hess, August 7th 1912, Historical flight

Cosmic rays



→ *Piera Ghia's lecture*



Higher energies: closer to the acceleration process

The Cosmic ray origin(s)

- CR are deviated by magnetic fields (except at Pierre Auger Observatory energies)
- They interact easily with matter

$$\boldsymbol{p + A \rightarrow \pi^{+} + \pi^{-} + \pi^{0}}$$

$$\pi^{0} \rightarrow \boldsymbol{\gamma} + \boldsymbol{\gamma}$$

Gamma-rays

$$\pi^{-} \rightarrow \mu^{-} + \boldsymbol{\bar{\nu}_{\mu}}$$

Neutrinos

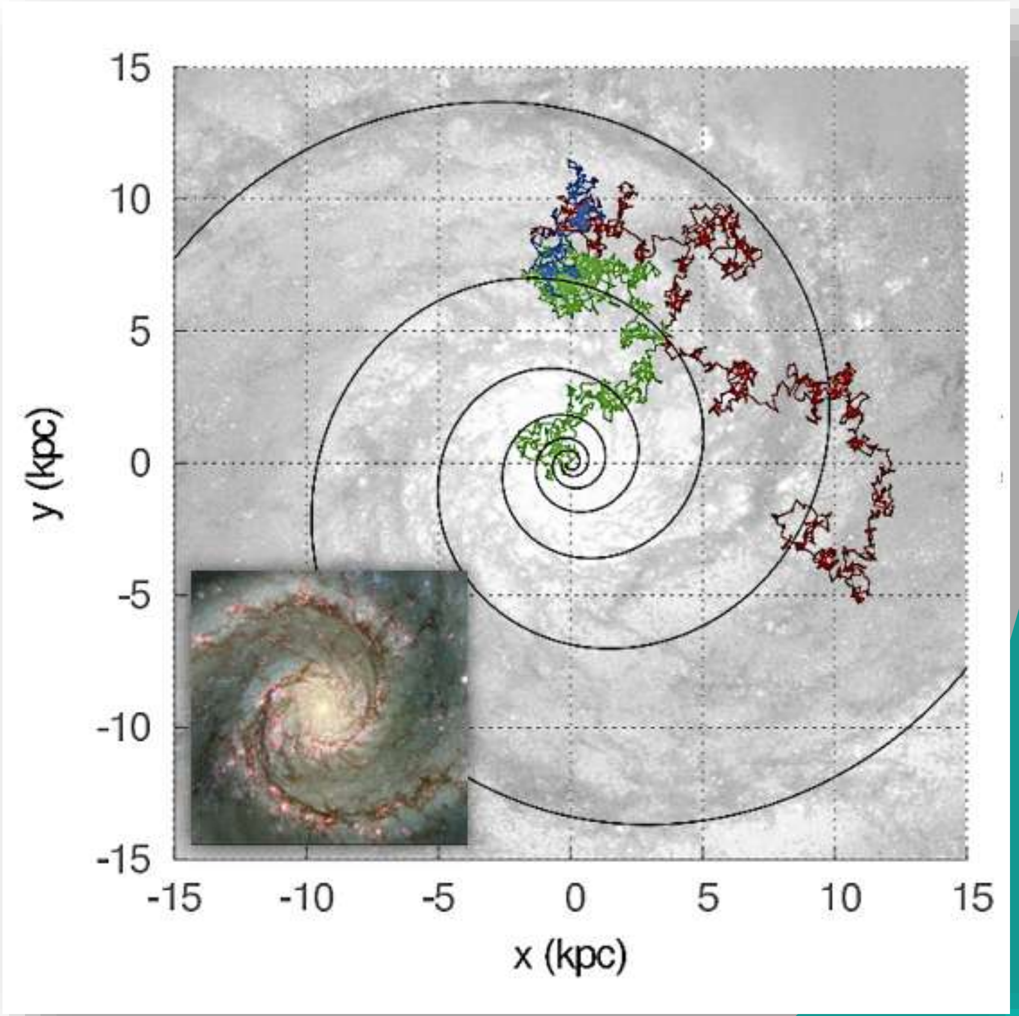
$$\mu^{-} \rightarrow e^{-} + \boldsymbol{\bar{\nu}_{e}} + \boldsymbol{\nu_{\mu}}$$

→ Use γ-rays at high energies (> GeV)

- Atmosphere is opaque → satellites

- Note: neutrinos make the job but ~10^{10} weaker cross sections at 1 TeV

→ Damien Dornic's lecture



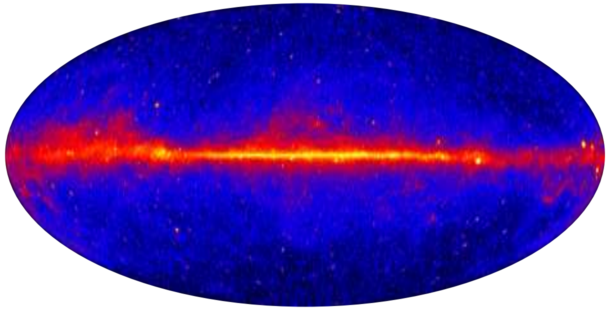
Trajectories for three 1 GeV proton in the galactic magnetic field.
© Galaxie M51, NASA and The Hubble Heritage Team (STScI/AURA) et F. Effenberger et al . A&A 547, A120 (2012)

Detecting γ rays with satellites

Fermi Gamma-ray Space Telescope (LAT) - 50 MeV-1 TeV

DOI: 10.3847/1538-4365/ab6bcb

8 yrs of data



→

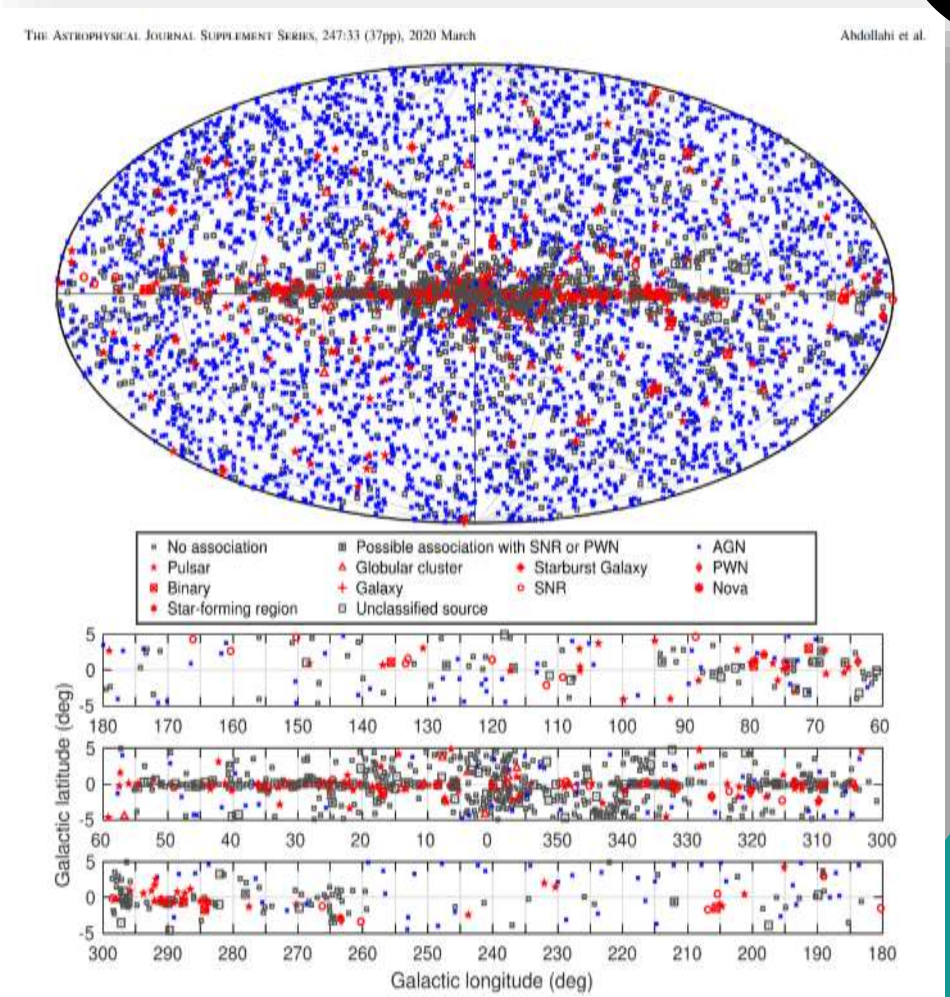


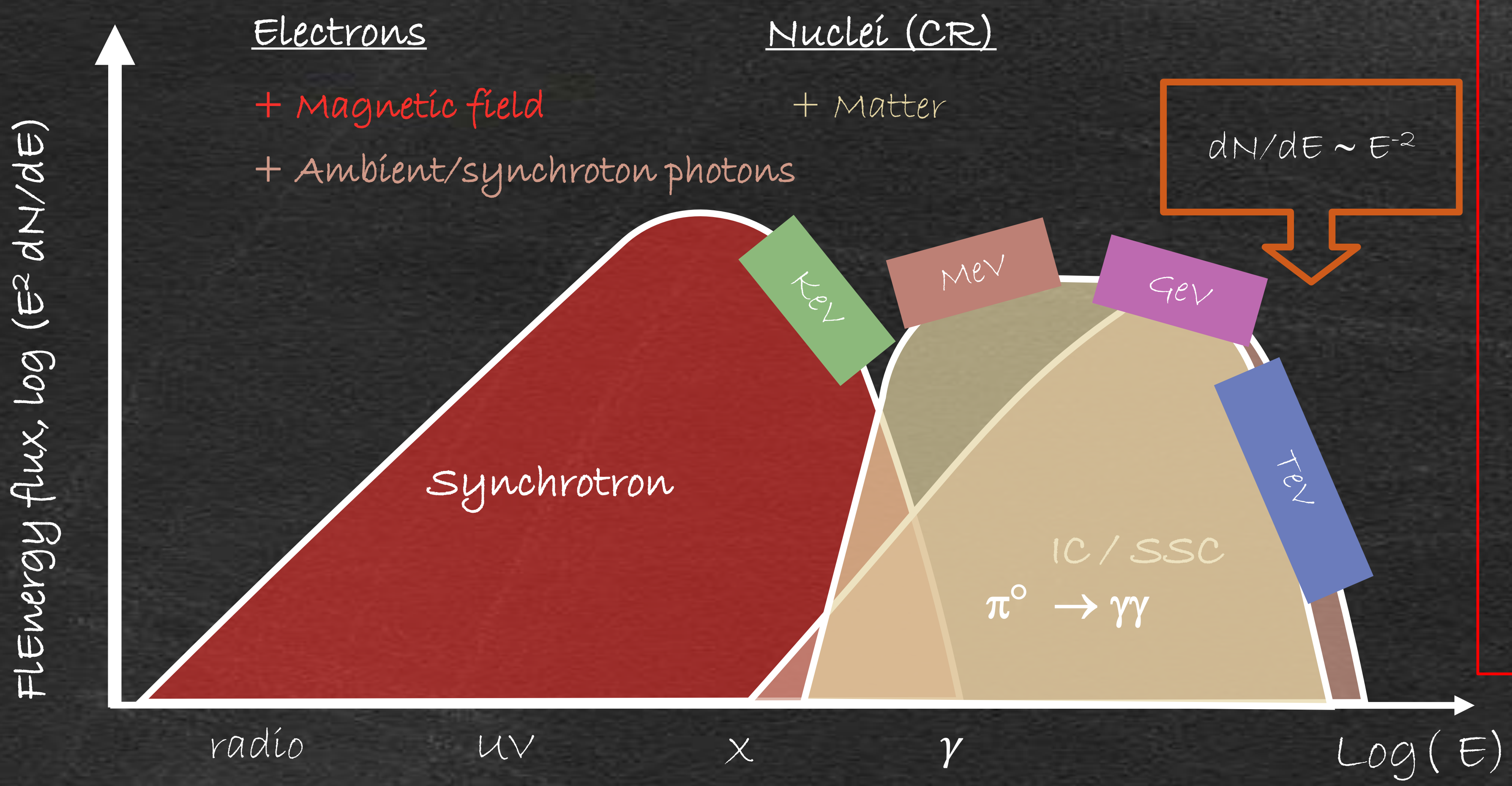
Figure 14. Full sky map (top panel) and blow-up of the Galactic plane split into three longitude bands (bottom panel) showing sources by source class (see Section 6, no distinction is made between associations and identifications). All AGN classes are plotted with the same blue symbol for simplicity. Other associations to a well-defined class are plotted in red. Unassociated sources and sources associated to counterparts of unknown nature are plotted in black.

4FGL Catalogue : 5064 sources

- 1336 unidentified (26%)
- 3624 AGN (87% blazars)
- 239 pulsars
- 17 PWN
- 40 SNR

→ Jean Ballet's lecture

Where the Gammas come from?



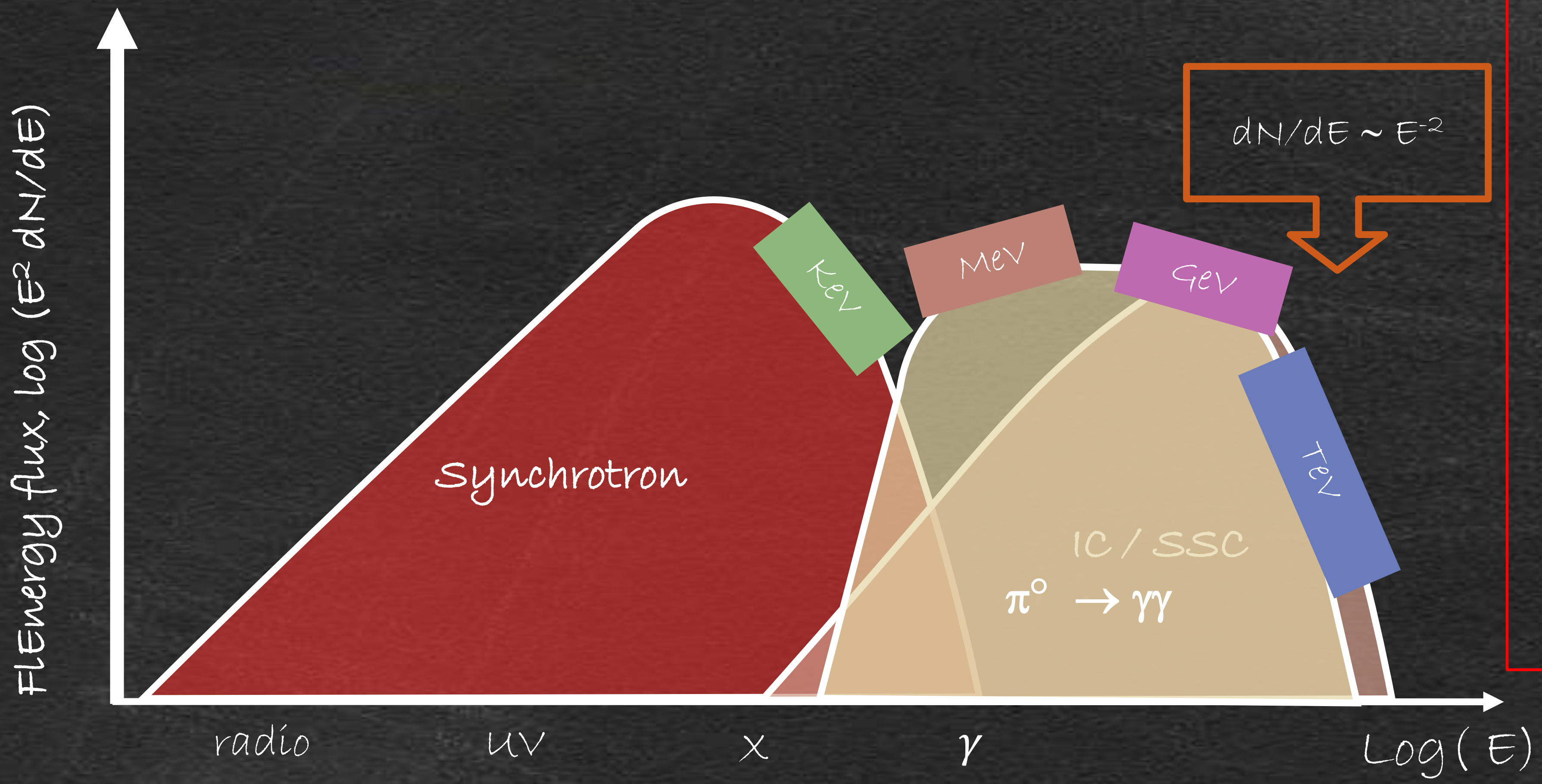
Higher energies can be reached depending on the accelerator

Disentangling the lepton/hadron scenario —> high precision —> high statistics

The reality is usually a mixture of the two —> models

IC = Inverse Compton
SSC = Self synchrotron Compton

Where the Gammas come from?



Fermi / LAT :

$E_{max} \sim 100$ GeV (10^{11} eV)

$S = 1\ m^2$

$dN/dE \sim E^{-2}$

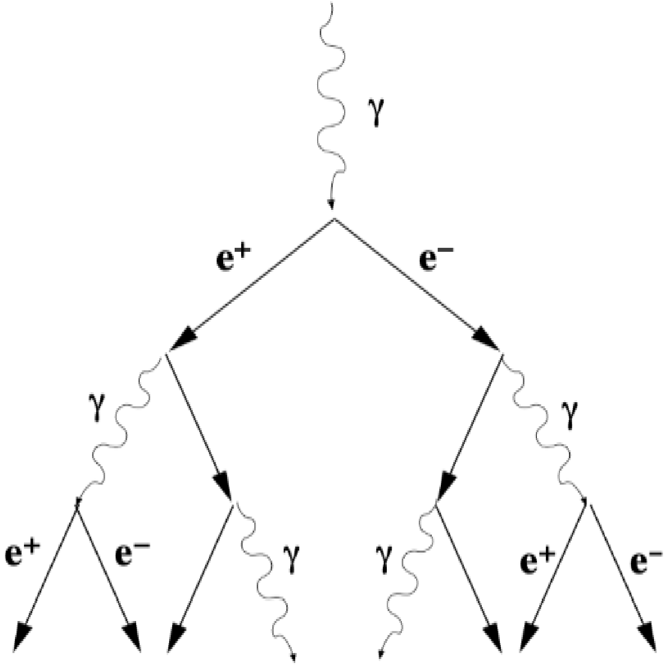
Reaching the knee

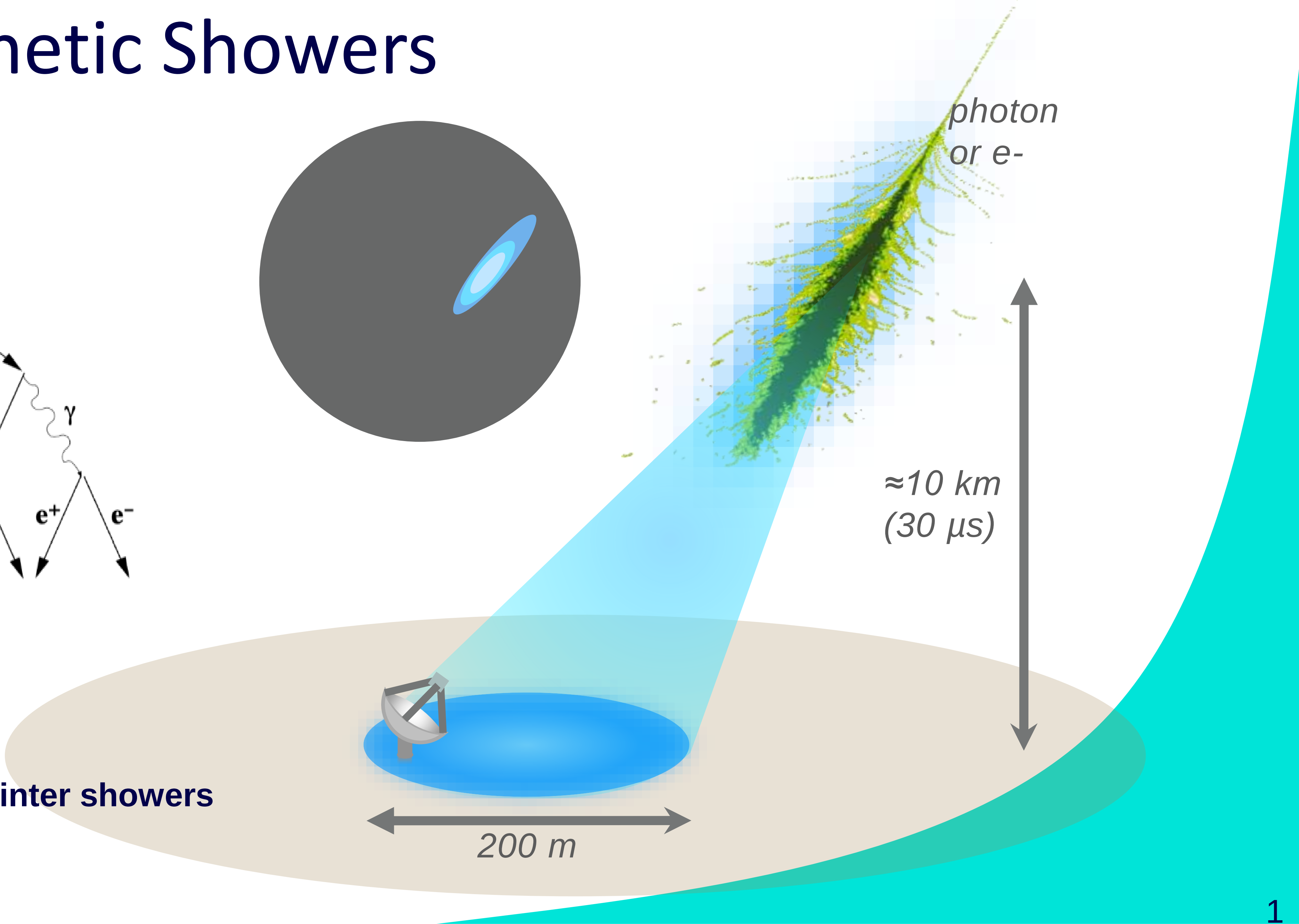
$E' = 100$ TeV (10% in γ)

With the same sensitivity

$S' = 10^6\ m^2$ (1 km^2)

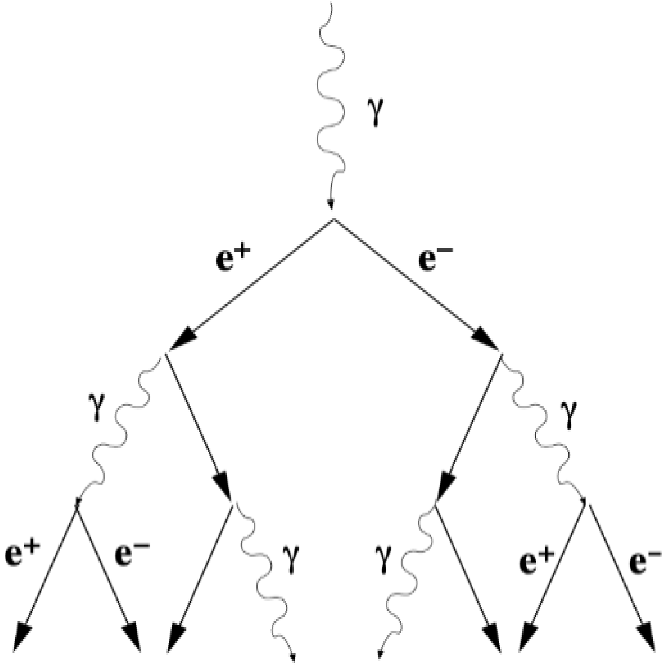
Electromagnetic Showers

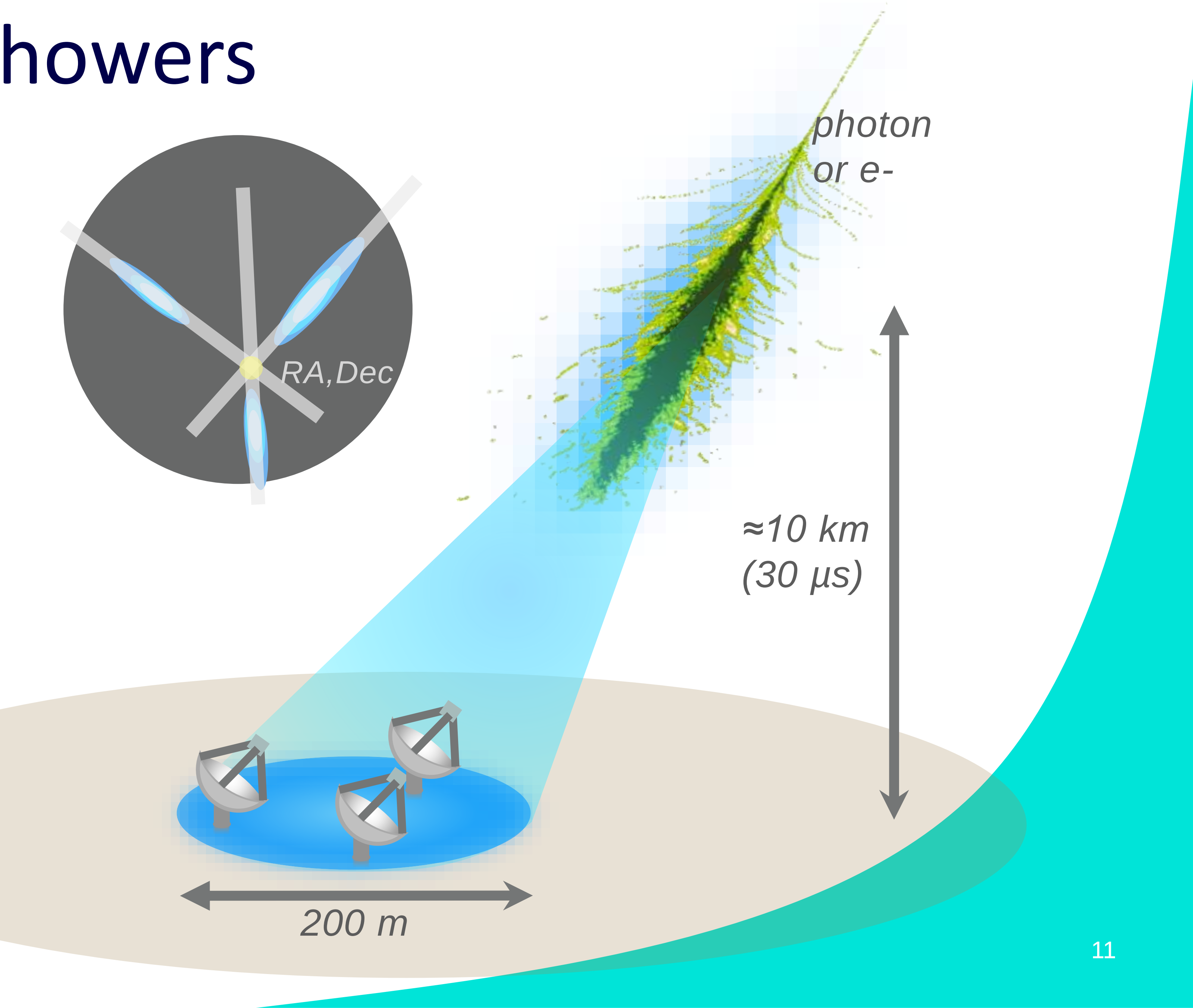




Larger mirror dish = Fainter showers

Electromagnetic Showers



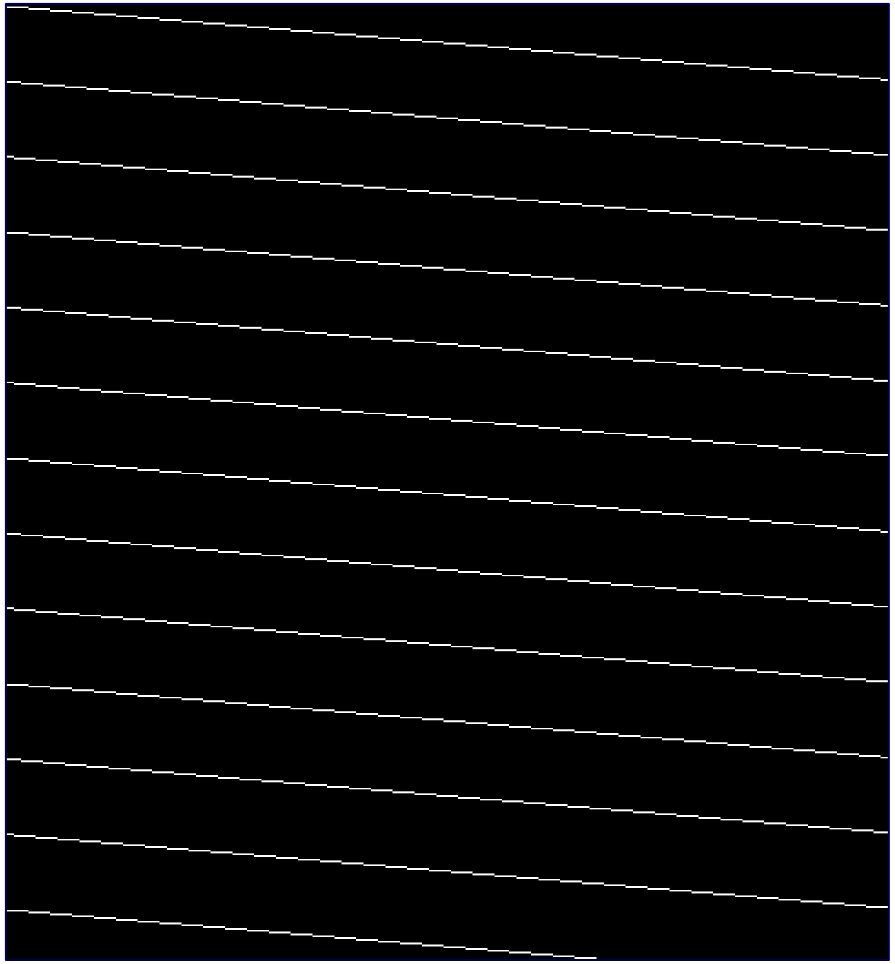


Night Sky background critical
Best response at high zenith angles

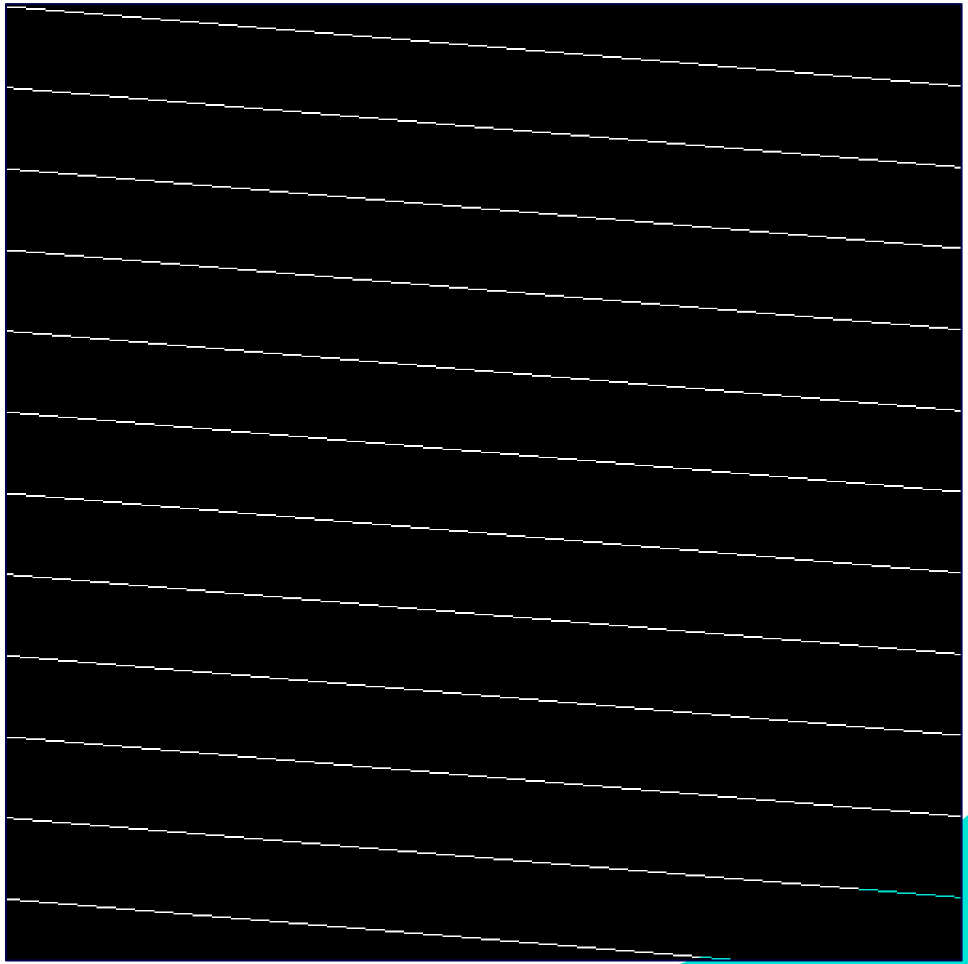
Gamma rays

Total duration ~ 30 µs
Total duration ~ 30 µs

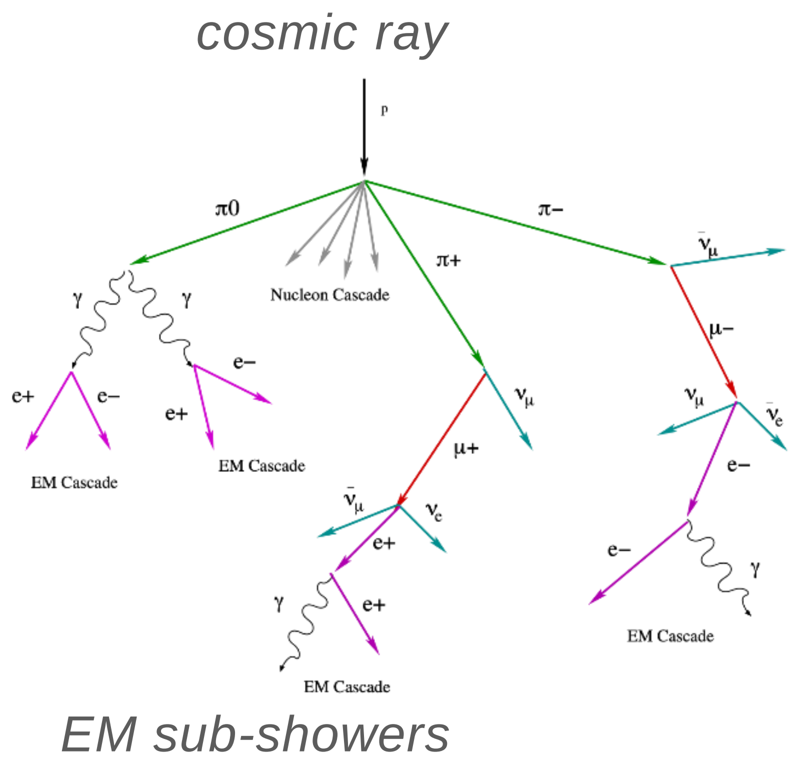
Lateral view

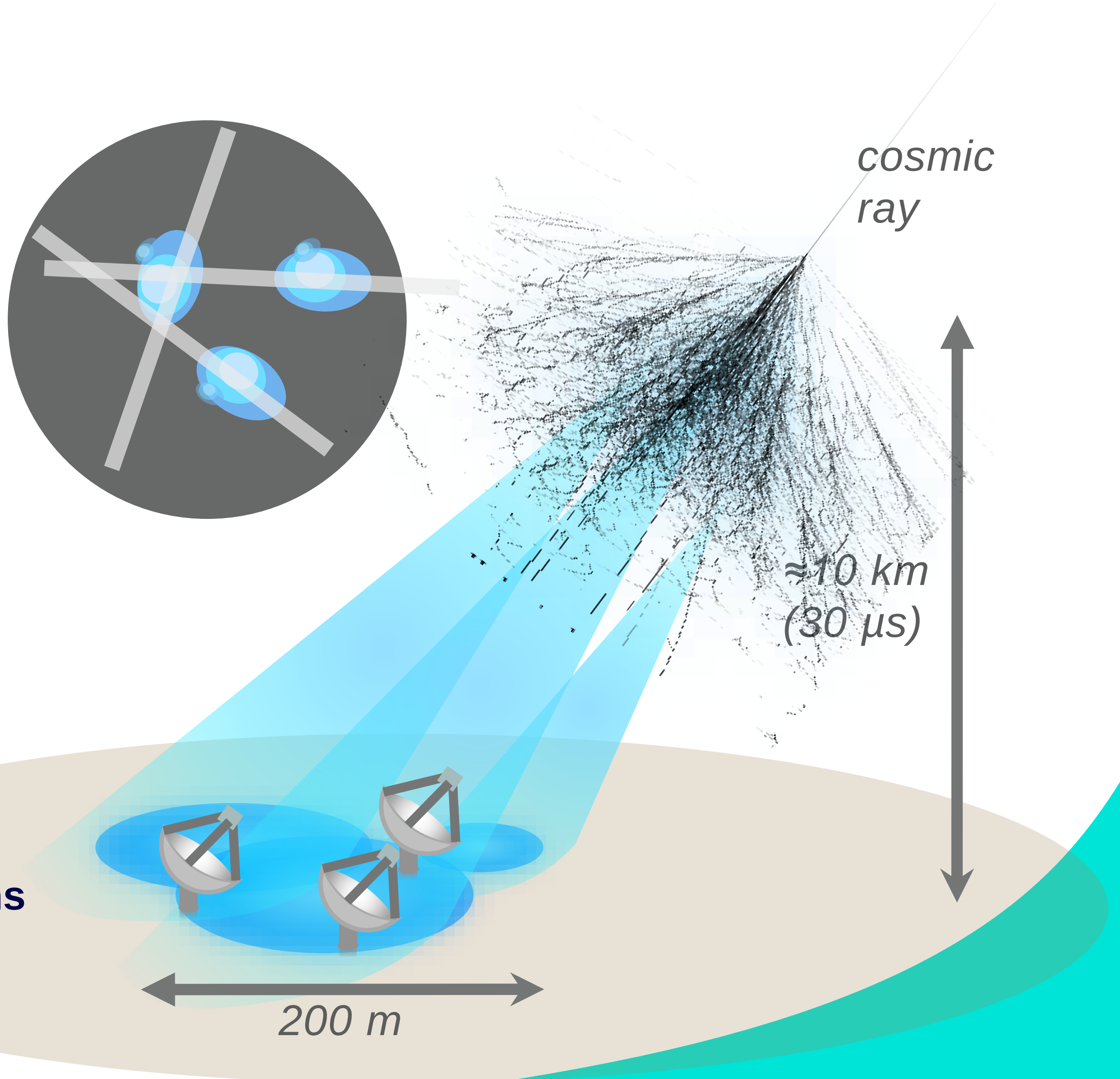


On the ground



Hadronic Showers

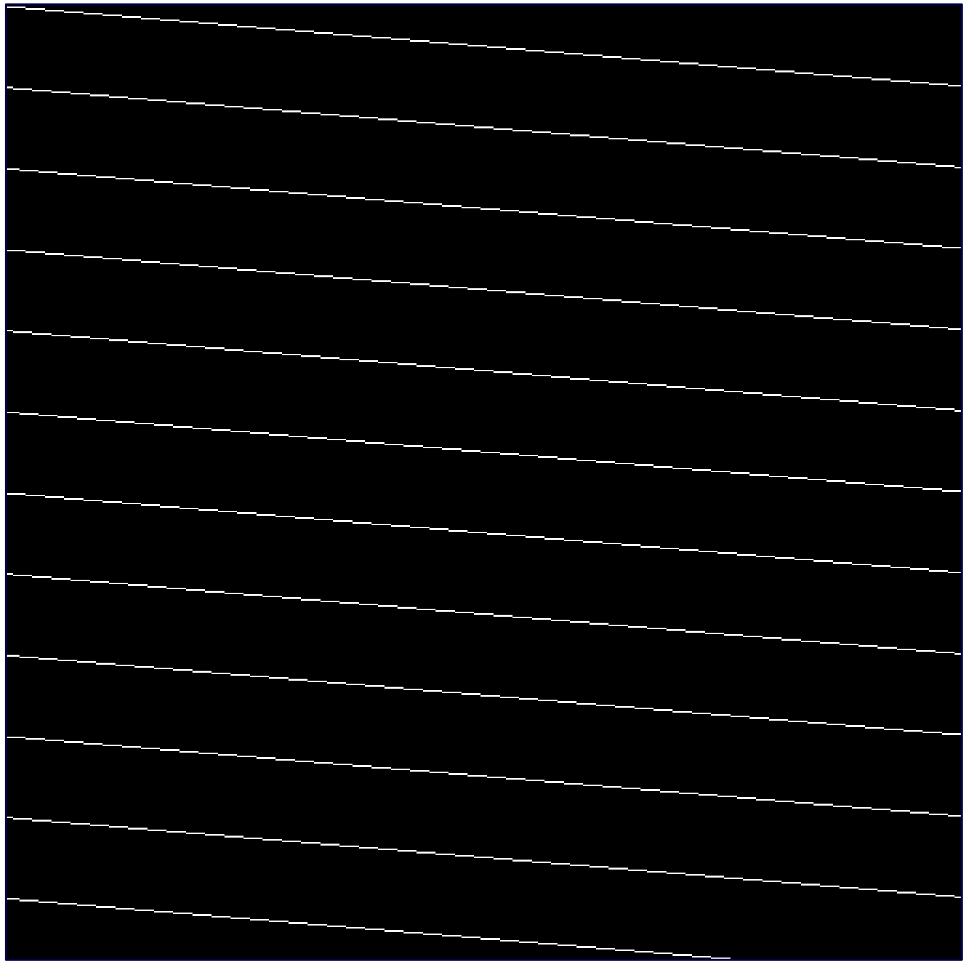




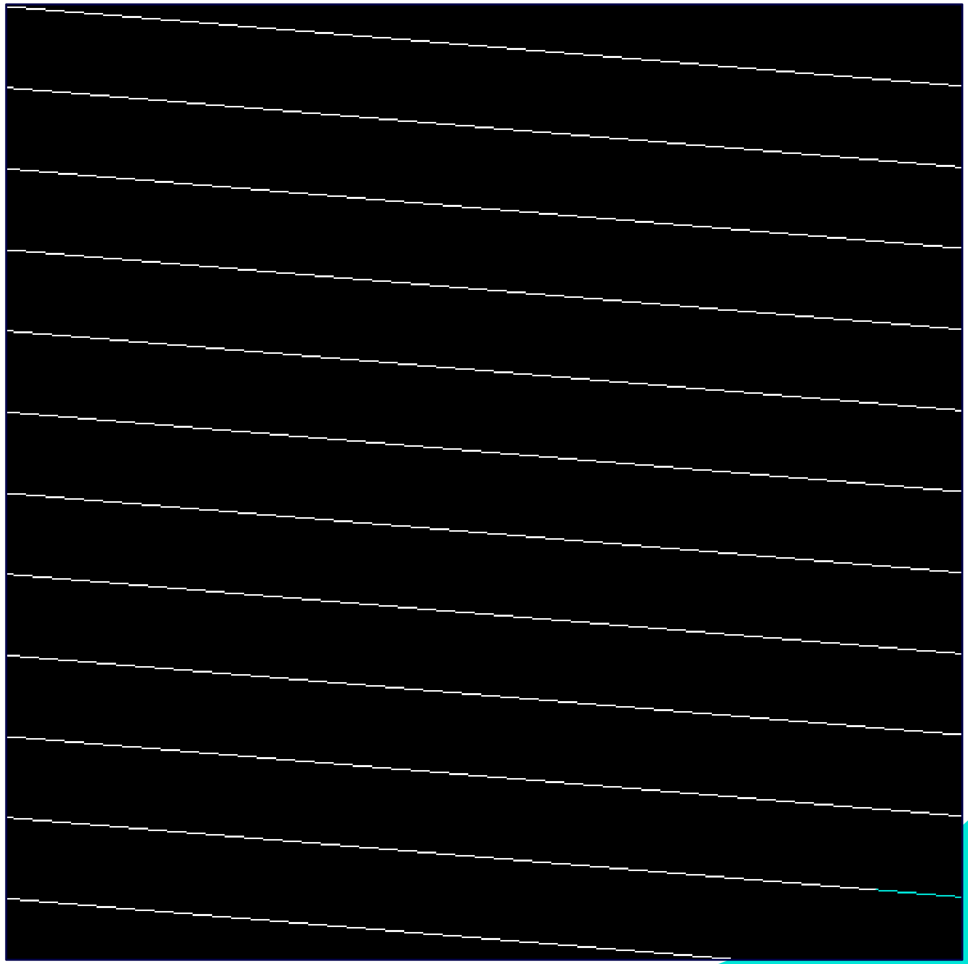
Typically 1 γ (Crab, 1 TeV) for 10^5 protons

Cherenkov light

Proton



Gamma ~ 30 µs



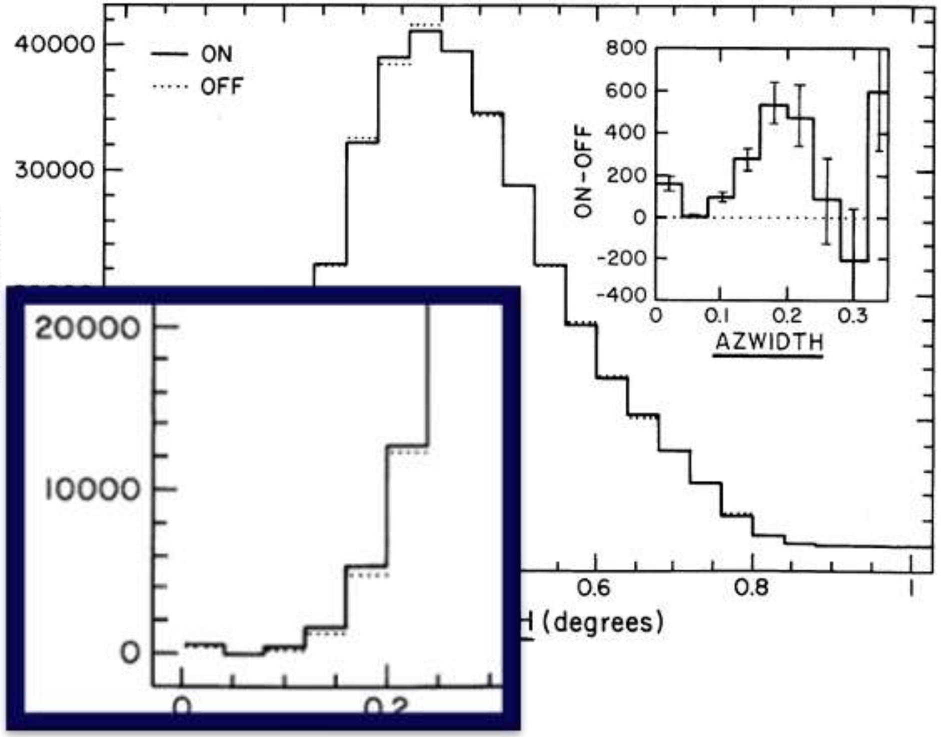
Toward CTAO

Detecting γ rays on ground

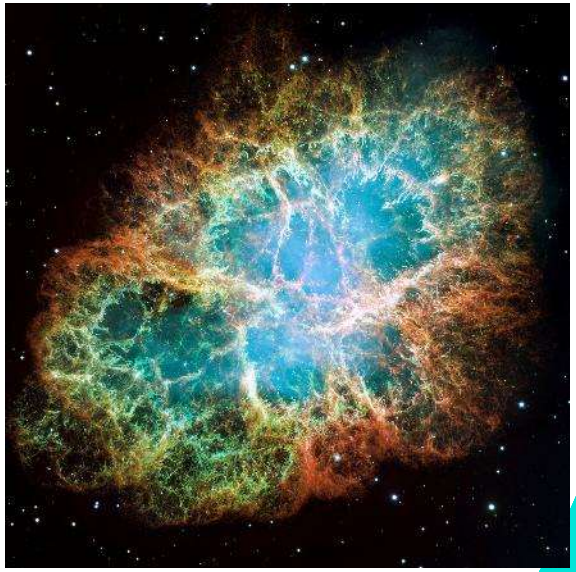
1989, The Crab nebula (E > 100 GeV)

10m-dish single telescope

90h of data



Supernova Remnant (SNR)



(HST)

T. Weekes et al., ApJ 342 (1989) 379

"Observation of TeV Gamma Rays from the Crab Nebula using the Atmospheric Cherenkov Imaging Technique"

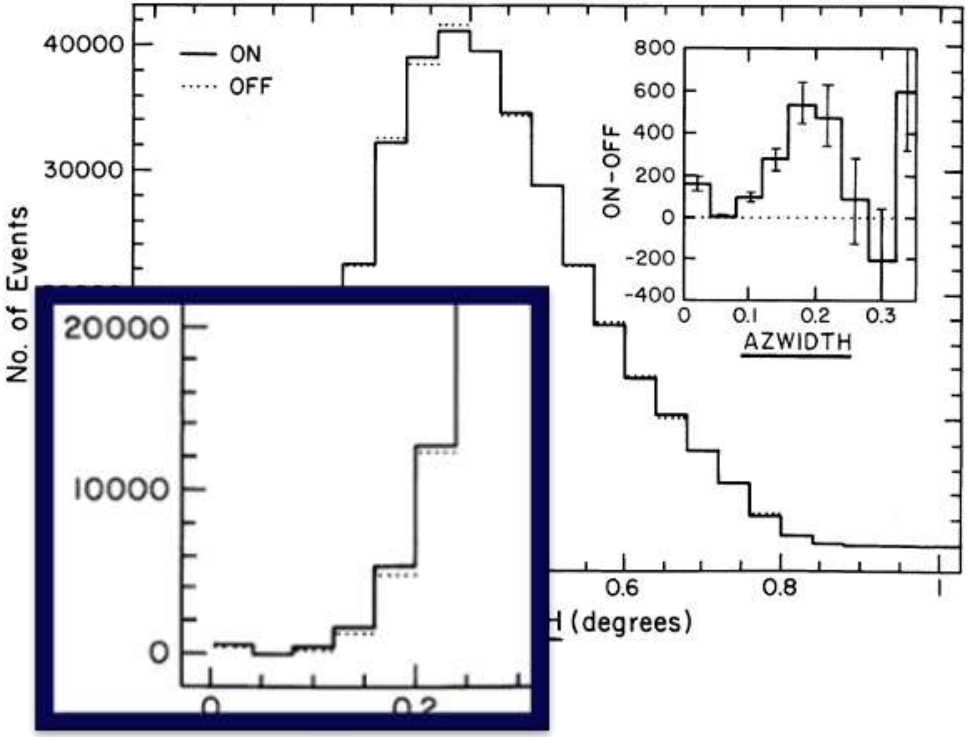
NASA, ESA, J. Hester and A. Loll (Arizona State University)

Detecting γ rays on ground

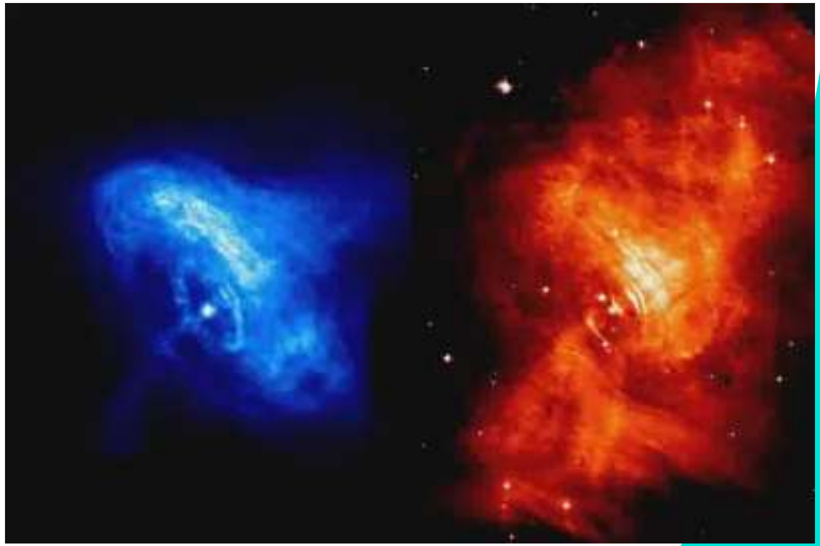
1989, The Crab nebula (E > 100 GeV)

10m-dish single telescope

90h of data



Pulsar Wind Nebula



X-rays (CHANDRA)

Visible (Hubble Telescope)

7 images – Nov 2000 to April 2001

T. Weekes et al., ApJ 342 (1989) 379

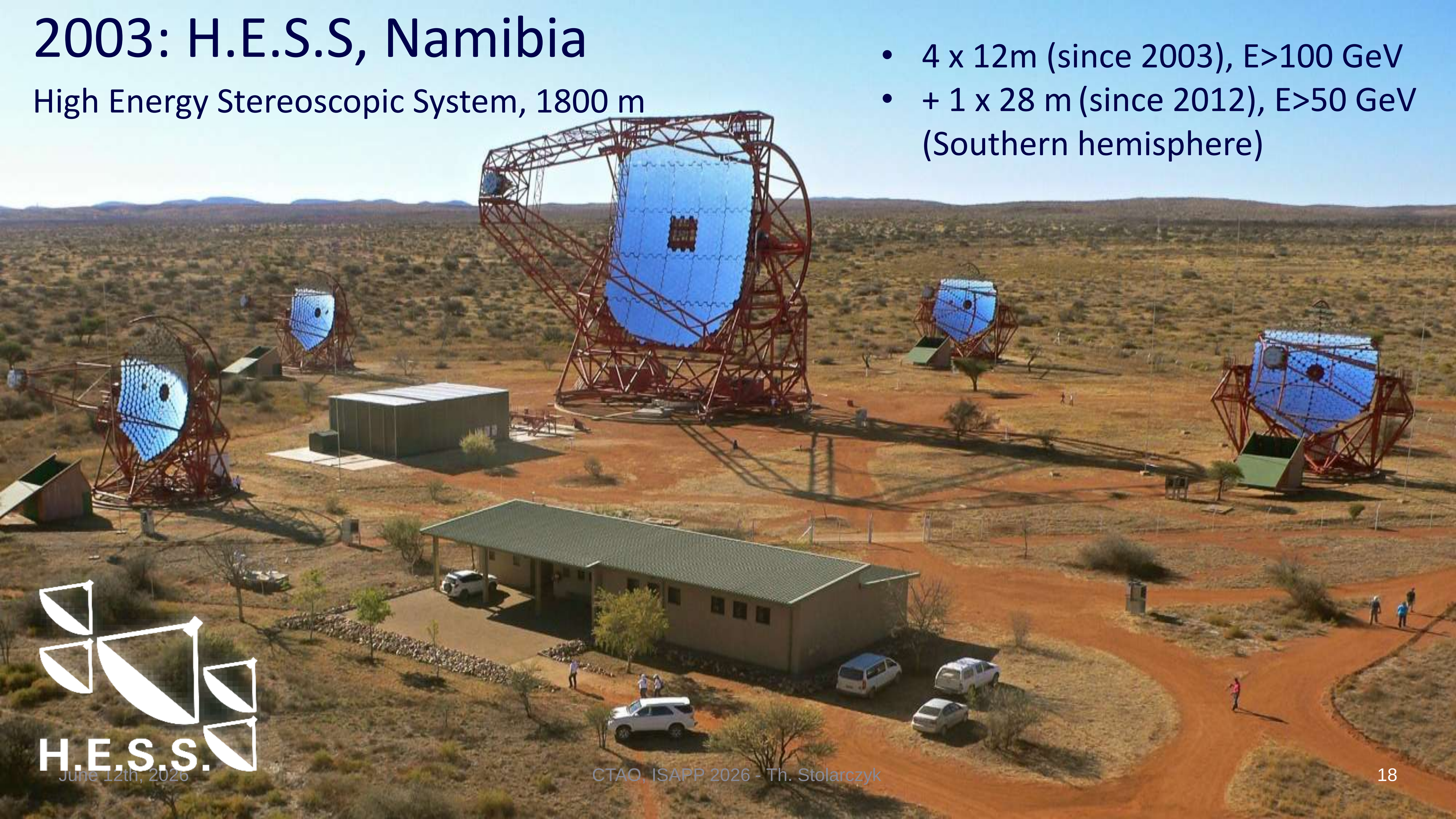
"Observation of TeV Gamma Rays from the Crab Nebula using the Atmospheric Cherenkov Imaging Technique"

NASA, ESA, J. Hester and A. Loll (Arizona State University)

2003: H.E.S.S, Namibia

High Energy Stereoscopic System, 1800 m

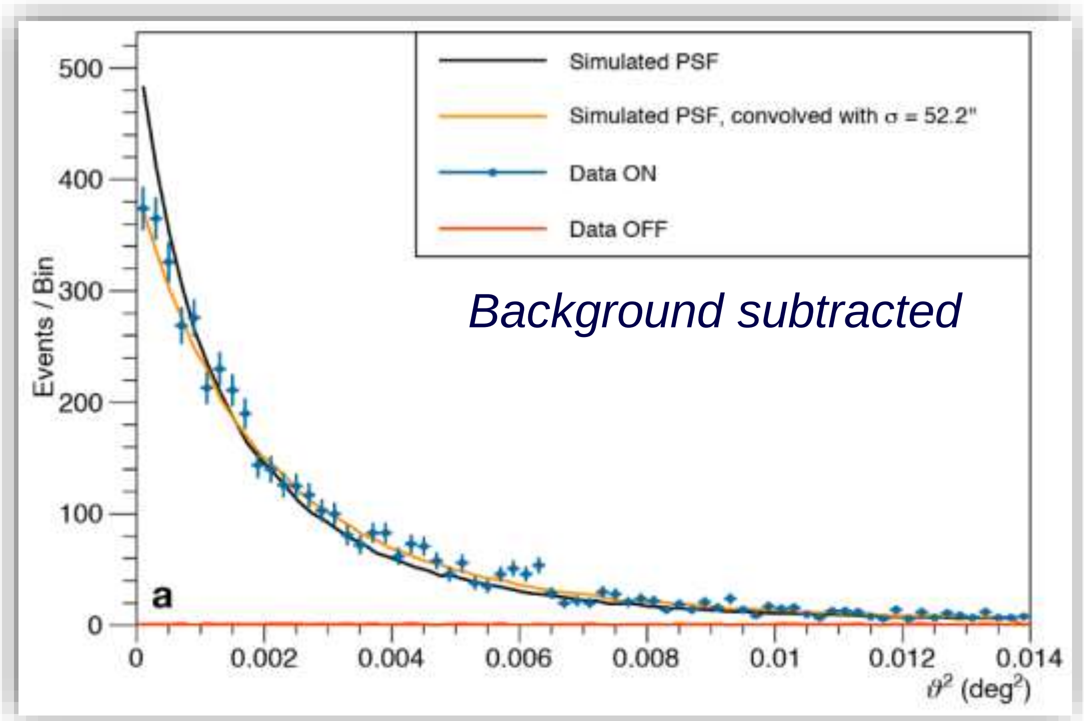
- 4 x 12m (since 2003), E>100 GeV
- + 1 x 28 m (since 2012), E>50 GeV (Southern hemisphere)



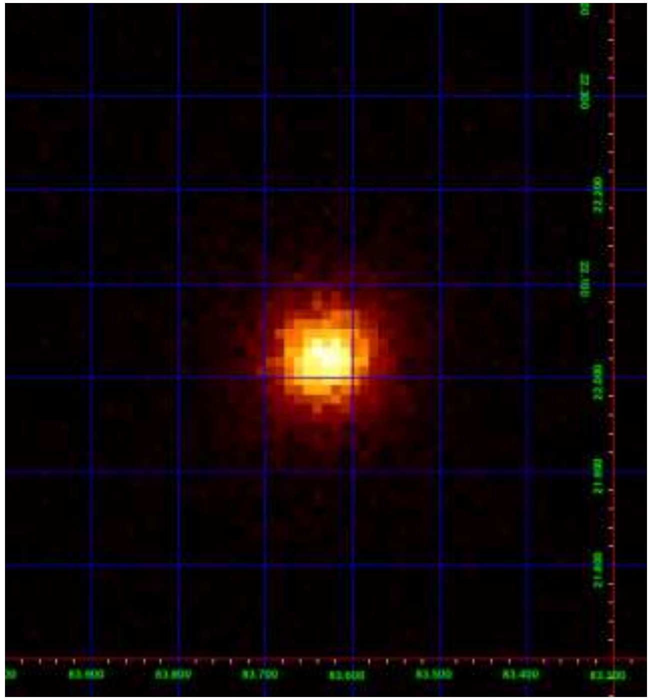
The Crab Nebula with H.E.S.S. (2020)

Resolving the Crab pulsar wind nebula at teraelectronvolt energies

[H.E.S.S. Collaboration](), [*Nature Astronomy*]() volume 4 (2020)



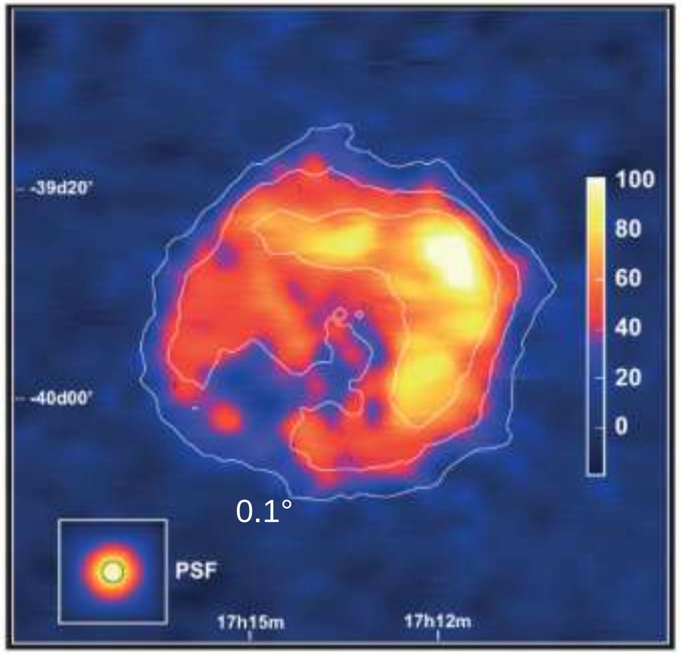
Angle² to the source direction



52”

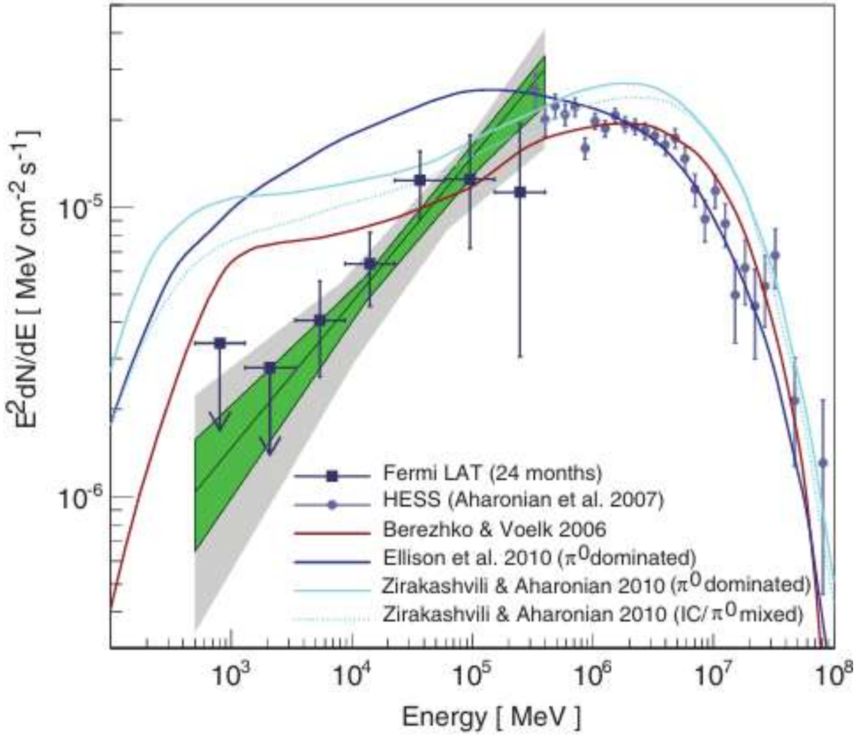
SNR RX J1713.7-3946 (H.E.S.S. 2003)

- Discovered in X-rays by ROSAT (1996)
- One of the first VHE extended source

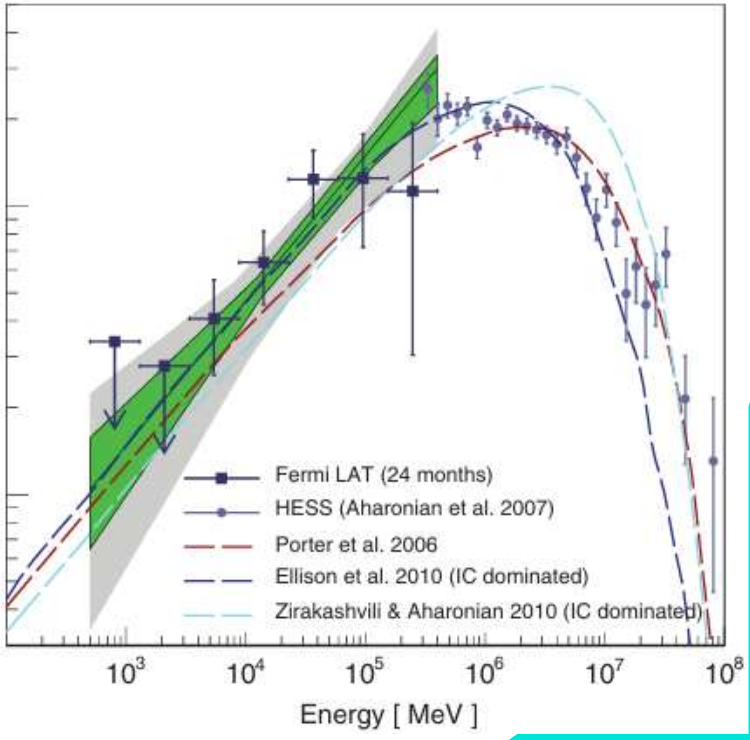


H.E.S.S., A&A, 449, 223, 2006
White contours : 5, 10, 15σ
Updated in 2018 : A&A 612, A6 (2018)

Hadronic model
protons + interstellar gas



Leptonic model
e^- + local photons



A. A. Abdo *et al* 2011 *ApJ* **734** 28

2003, 2009: MAGIC, Canary Islands

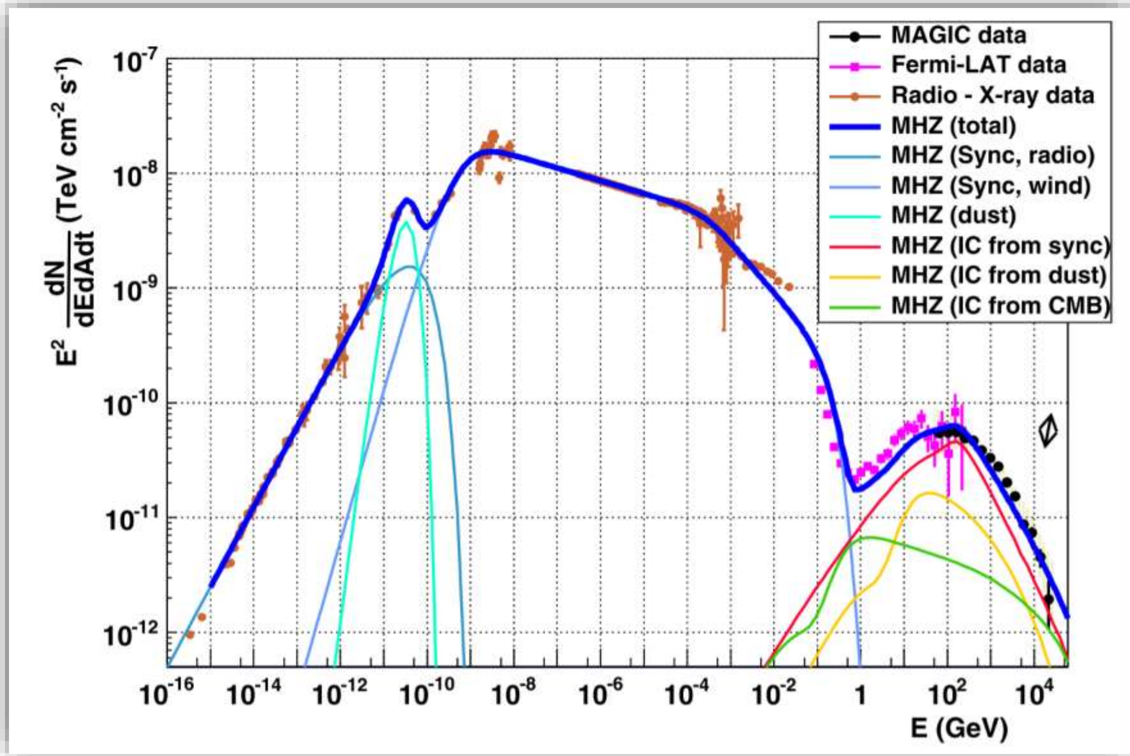
Major Atmospheric Gamma-ray Imaging Cherenkov Telescope, 2200 m, E>20 GeV

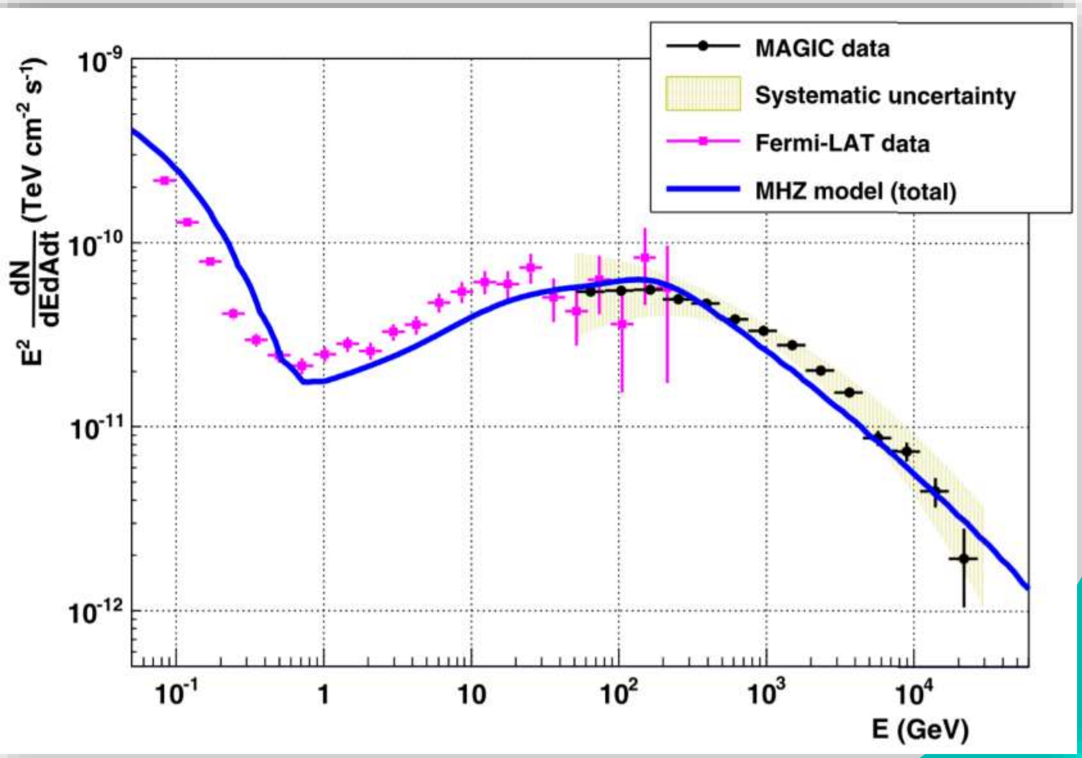
2 x 17 m (Northern Hemisphere)

The Crab Nebula

Measurement of the Crab Nebula spectrum over three decades in energy with the MAGIC telescopes

J. Aleksić et al, JHEA, Volumes 5–6, (2015) 30-38,DOI: [10.1016/j.jheap.2015.01.002](https://doi.org/10.1016/j.jheap.2015.01.002)





Synchrotron *IC*

3 decades

2007: VERITAS

Fred Lawrence Whipple Observatory, 1268 m, Arizona

4 x 12m, (Northern hemisphere)

2005: HAWC, Mexico

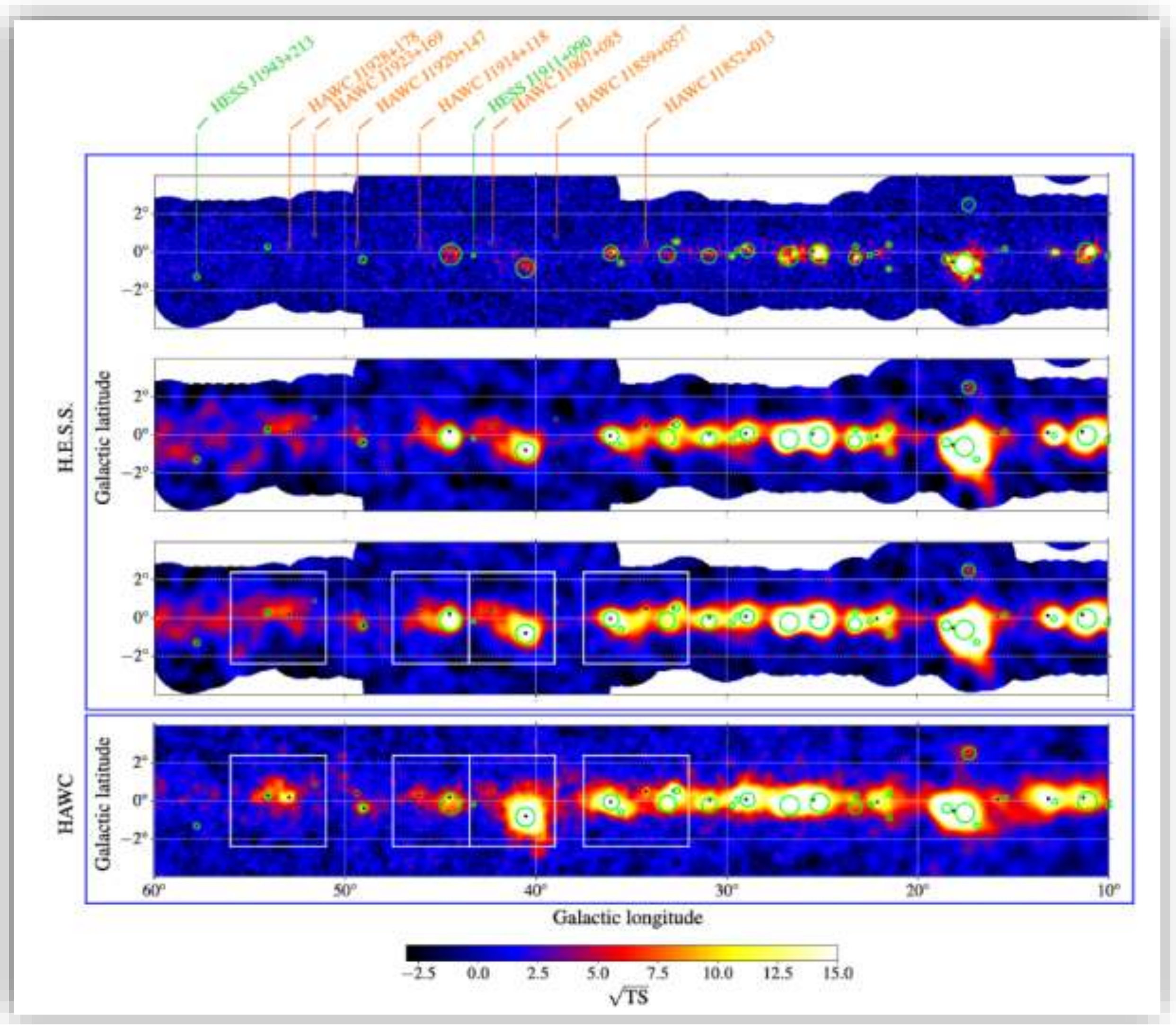
High Altitude Water Cherenkov Experiment, 4100 m, E>>100 GeV
Successor of MILAGRO

(Northern hemisphere)

HAWC Galactic plane

TeV Emission of Galactic Plane Sources with HAWC and H.E.S.S.

ApJl,917:6(2021), DOI: [10.3847/1538-4357/abf64b](https://doi.org/10.3847/1538-4357/abf64b)



H.E.S.S. original (E> 1 TeV, 0.1°)

H.E.S.S. at 0.4° resolution

HAWC Original (1523 days)

2005: LHAASO, Sichuan, China

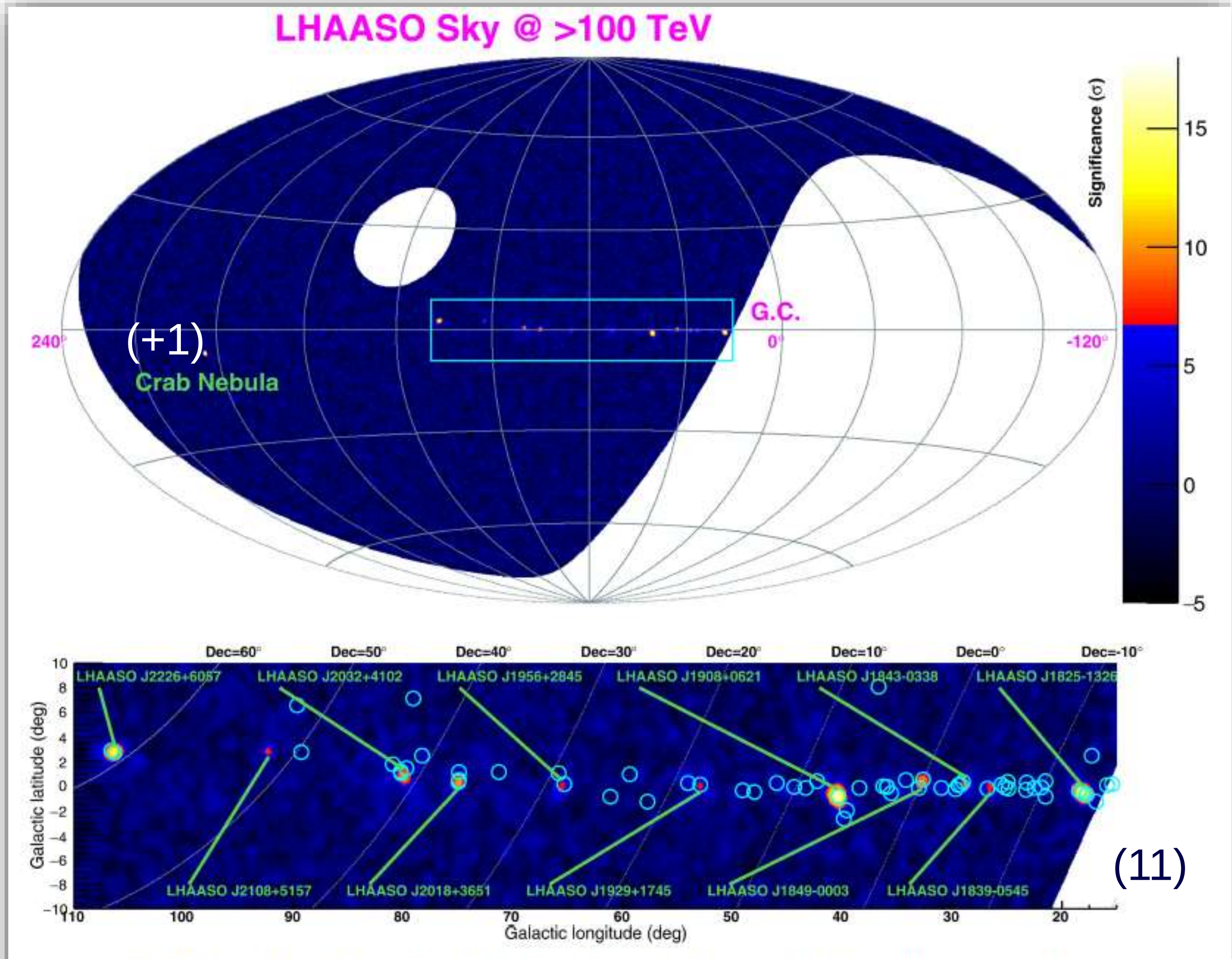
Large High Altitude Air Shower Observatory, 4400 m, E >> 100 GeV
Successor of ARGO-YBJ

(Northern hemisphere)

LHAASO Pevatrons

Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources

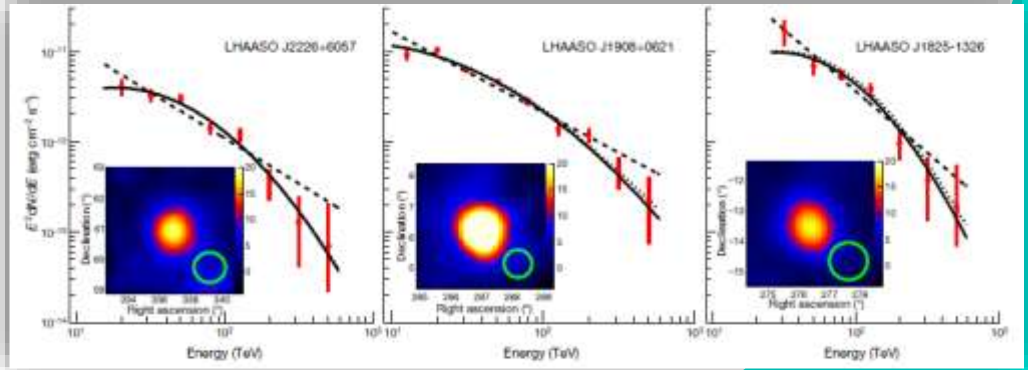
Nature, 594, (2021) 33
DOI: 10.1038/s41586-021-03498-z



Extended Data Fig. 4 | LHAASO sky map at energies above 100 TeV. The circles indicate the positions of known very-high-energy γ-ray sources.

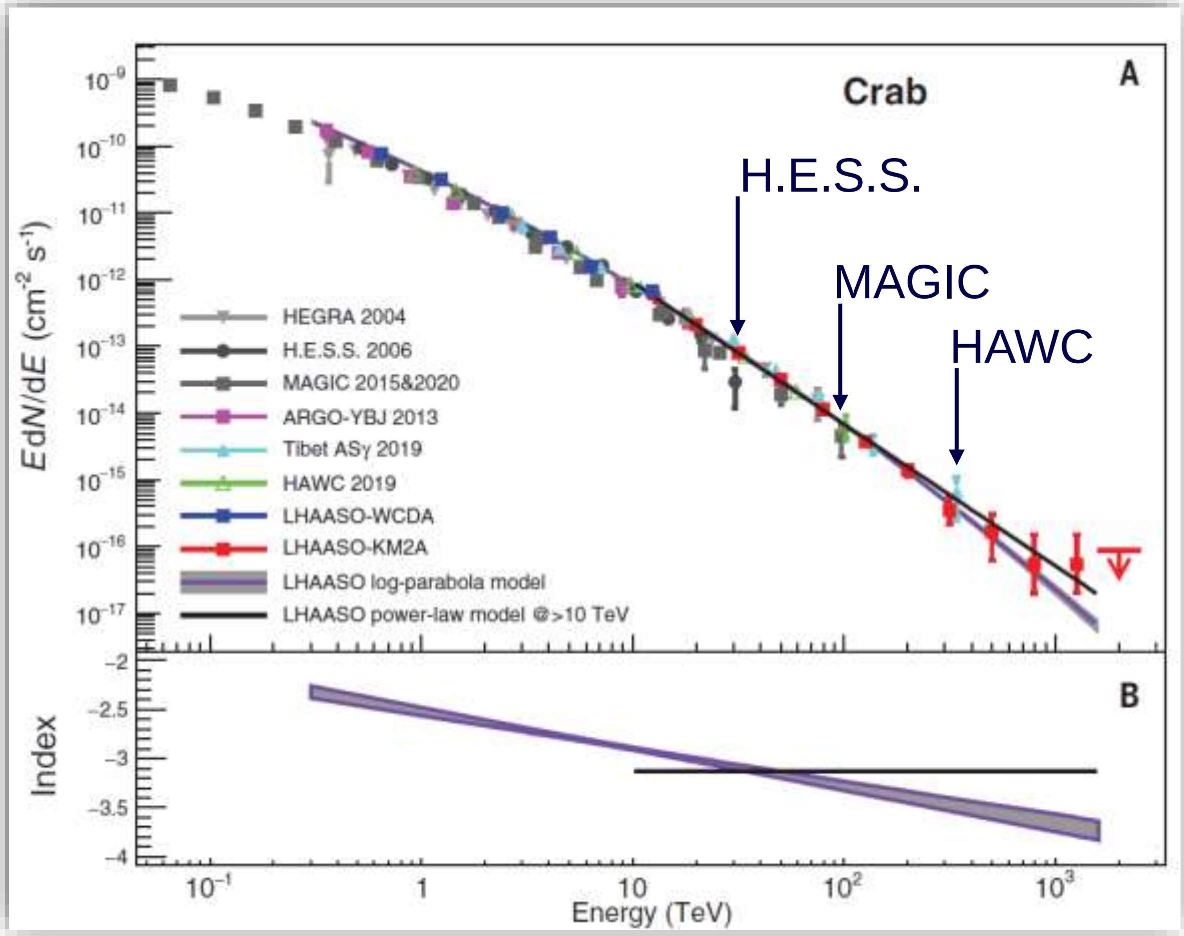
12 sources above 100 TeV

Spectral analysis/fit for 3 /12 sources



LHAASO Pevatrons

Peta–electron volt gamma-ray emission from the Crab Nebula
Cao et al., Science 373, 425–430 (2021) 23 July 2021

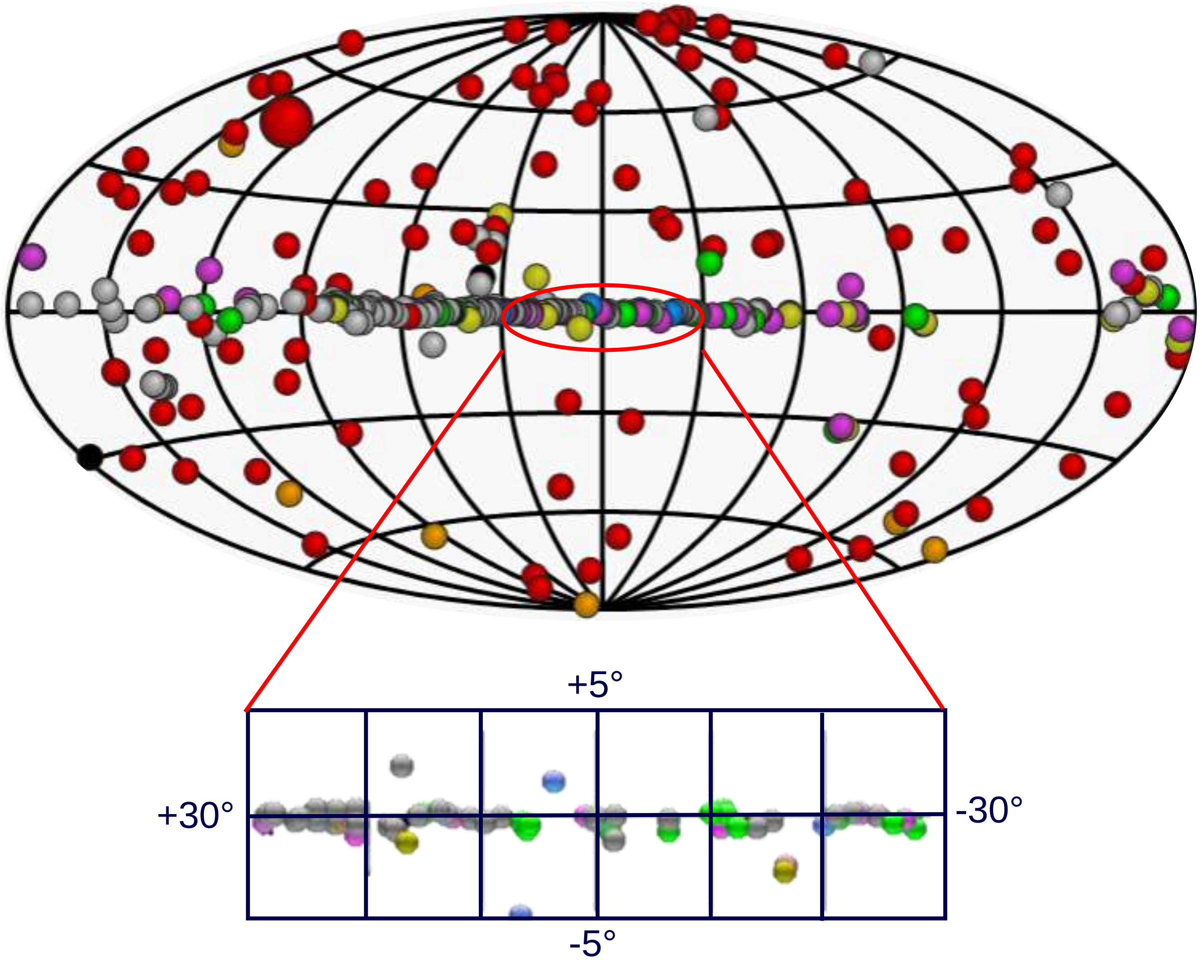


Note: The Crab Nebula is mostly visible in the North

TeVCat: 332 γ ray sources

https://www.tevcat.org/
https://tevcat2.tevcat.org/

3 order of magnitude in flux, 4 decades in energy: 50 GeV – 1 PeV



20% PWNe
26% 42% unid.
72% 30% AGN
22% “SNR”
Fermi-LAT

- GRB, Starburst, Superbubble
- PWN, PWN/TeV Halo, TeV halo, Composite SNR, BIN
- DARK, UNID, TeV halo
- HBL, IBL, FSRQ, AGN (unknown type), FRI, Blazar, EHBL, LLAGN, LBL
- Shell, SNR/Molec. Cloud, Composite SNR, Superbubble
- Binary, PSR, Gamma BIN, Nova, Microquasar
- TeV halo
- Massive Star Cluster, Globular Cluster

Comparison

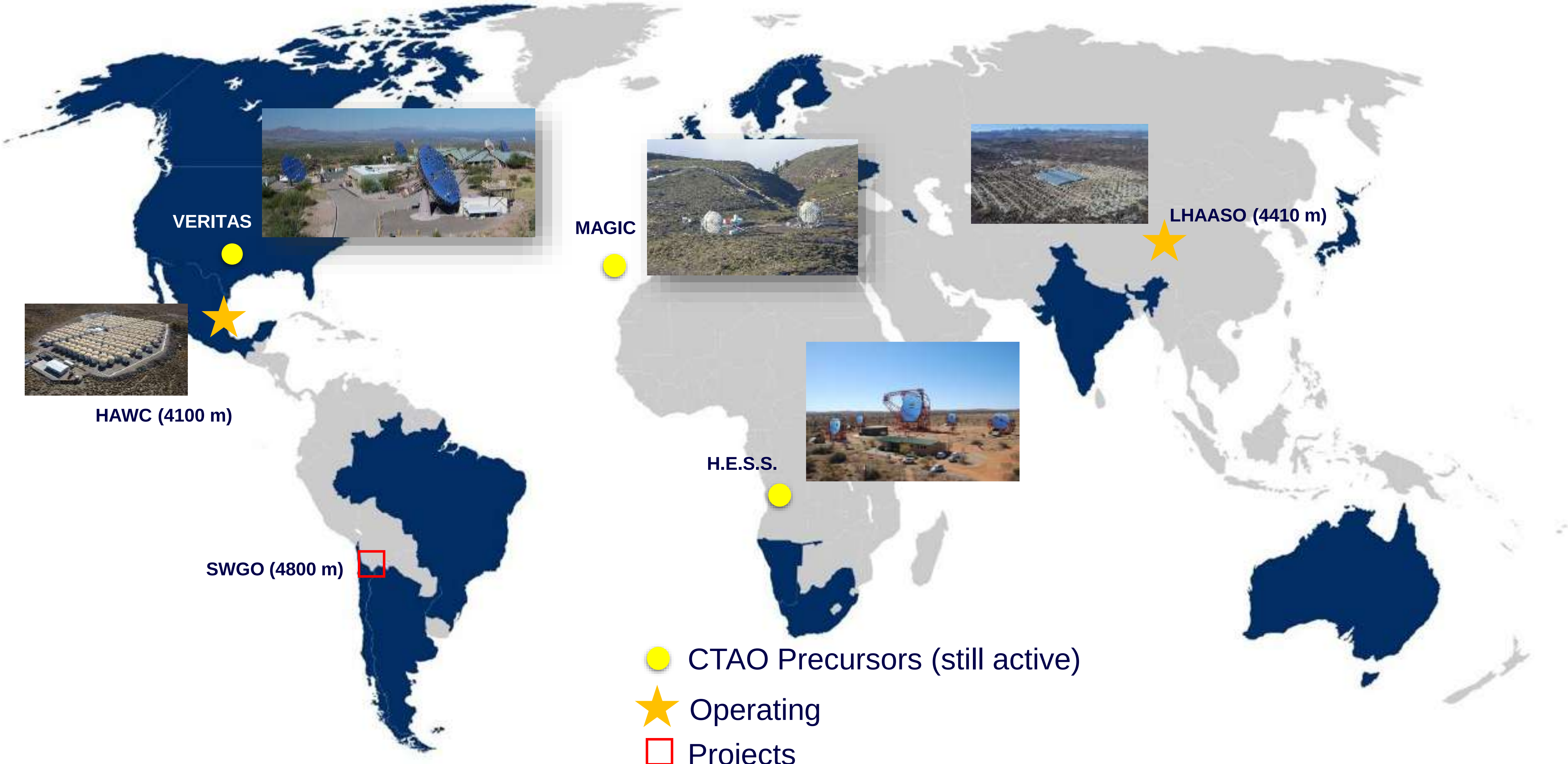
	Fermi-LAT	IACTs (e.g. HESS)	WCTs (HAWC)
Energy Range	30 MeV → 300 GeV	**30 GeV → 100 TeV**	1 TeV → 1 PeV
Field of View	**Effectively All-Sky**	Small (2→ 8°)	**Large (90°)**
PSF (E-dependant)	**good 0.1→ 1.0°**	**Very good 0.01→ 0.1°**	fair 0.1 → 0.3°
Energy Resolution	**good ≈10%**	**good ≈10%**	poor 20%-60%
Duty Cycle	**very good**	Poor (10% → 15%)	**very good**
Sky Coverage	**full**	Half - Targetted	half
Short-Term Sensitivity	good (GeV) poor (>100GeV)	**Excellent (>100GeV)**	poor
Cost	Very high	High	Cheaper
Scalable / Maintanable	No	**Yes**	Yes

The Cherenkov Telescope Array Observatory

Goals

- Benefit from the former generation (H.E.S.S., VERITAS, MAGIC)
  - Create a unique World Wide community
- **Sensitivity** x10 $\Rightarrow$ More telescopes
- Full-sky **coverage** $\Rightarrow$ 2 sites
- Extend the **energy range** (20 GeV to 300 TeV)
  - $\Rightarrow$ Catch fainter showers: large dishes
  - $\Rightarrow$ Increase statistics at HE: increase effective area
- Extend the field of view (x2): **Surveys**
- Few arc-min **angular resolution** : Physics!
- Rapid slewing for **transient follow-up**

In the following: Intermediary configuration α

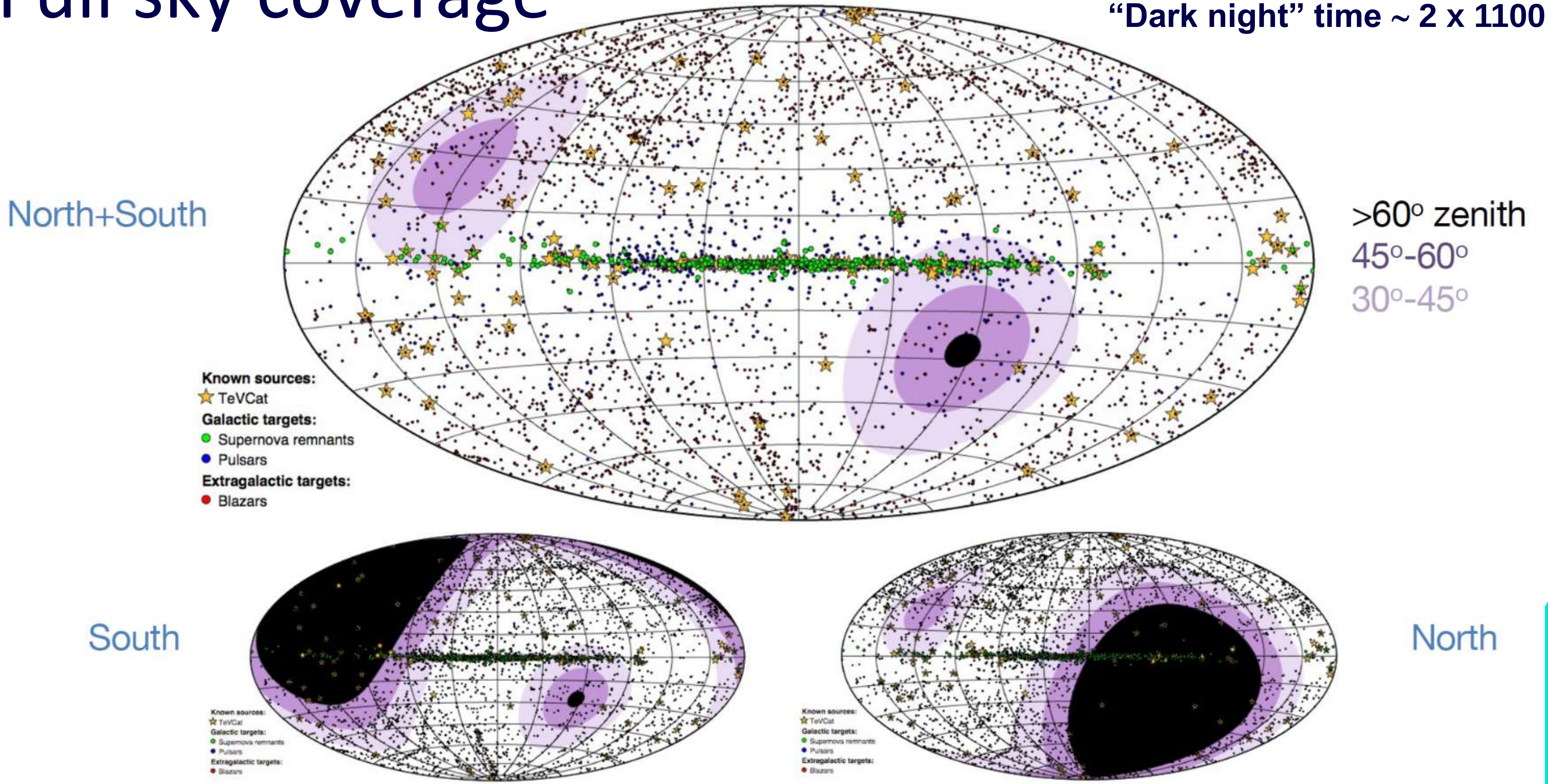

VERITAS
MAGIC
LHAASO (4410 m)
HAWC (4100 m)
H.E.S.S.
SWGO (4800 m)
CTAO Precursors (still active)
Operating
Projects

CTAO

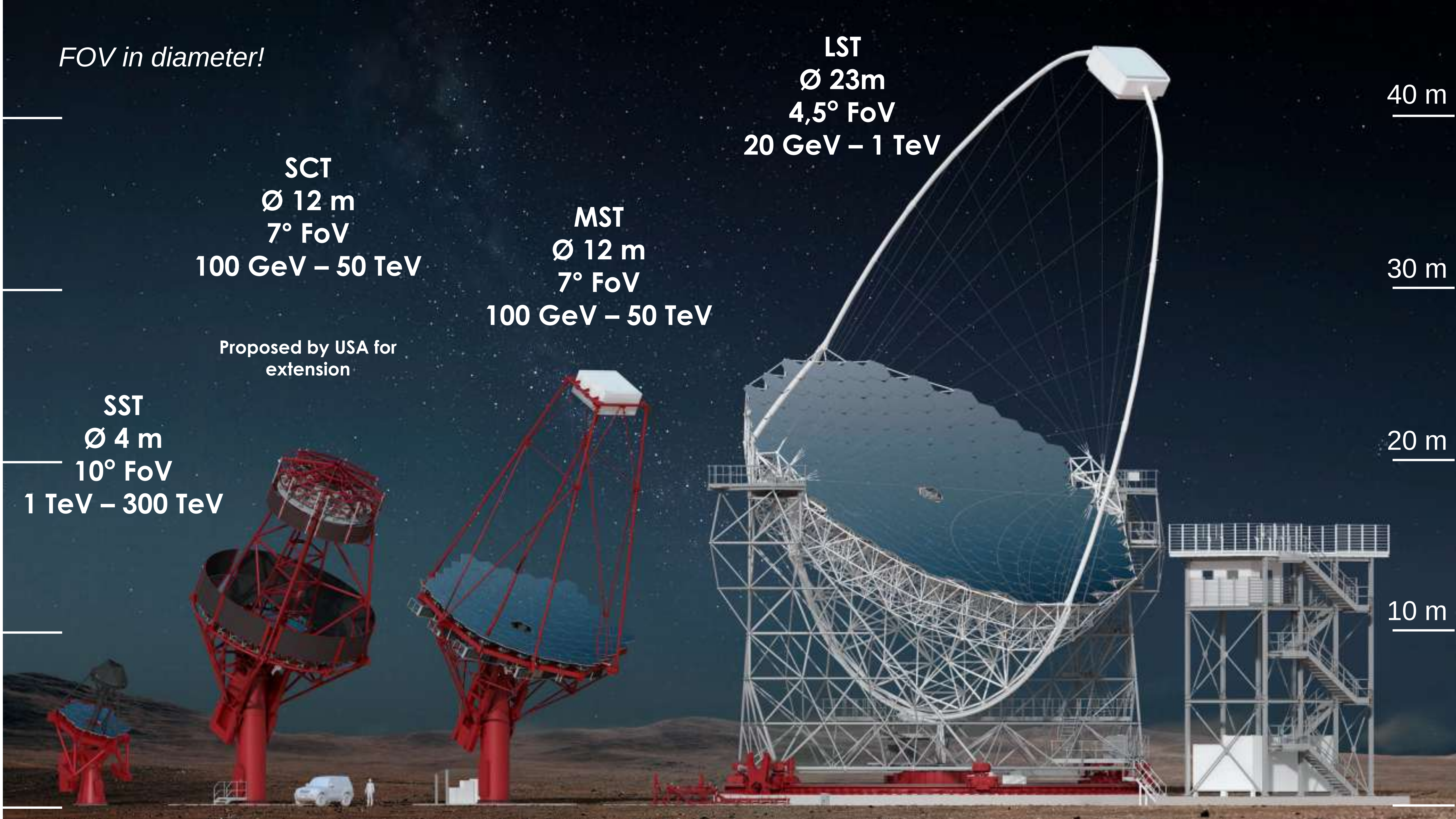
CTAO consortium
30 Countries
> 150 Institutes
~ 1500 Members
Effort started in 2006

Full sky coverage

60% Sky overlap
"Dark night" time ~ 2 x 1100 h

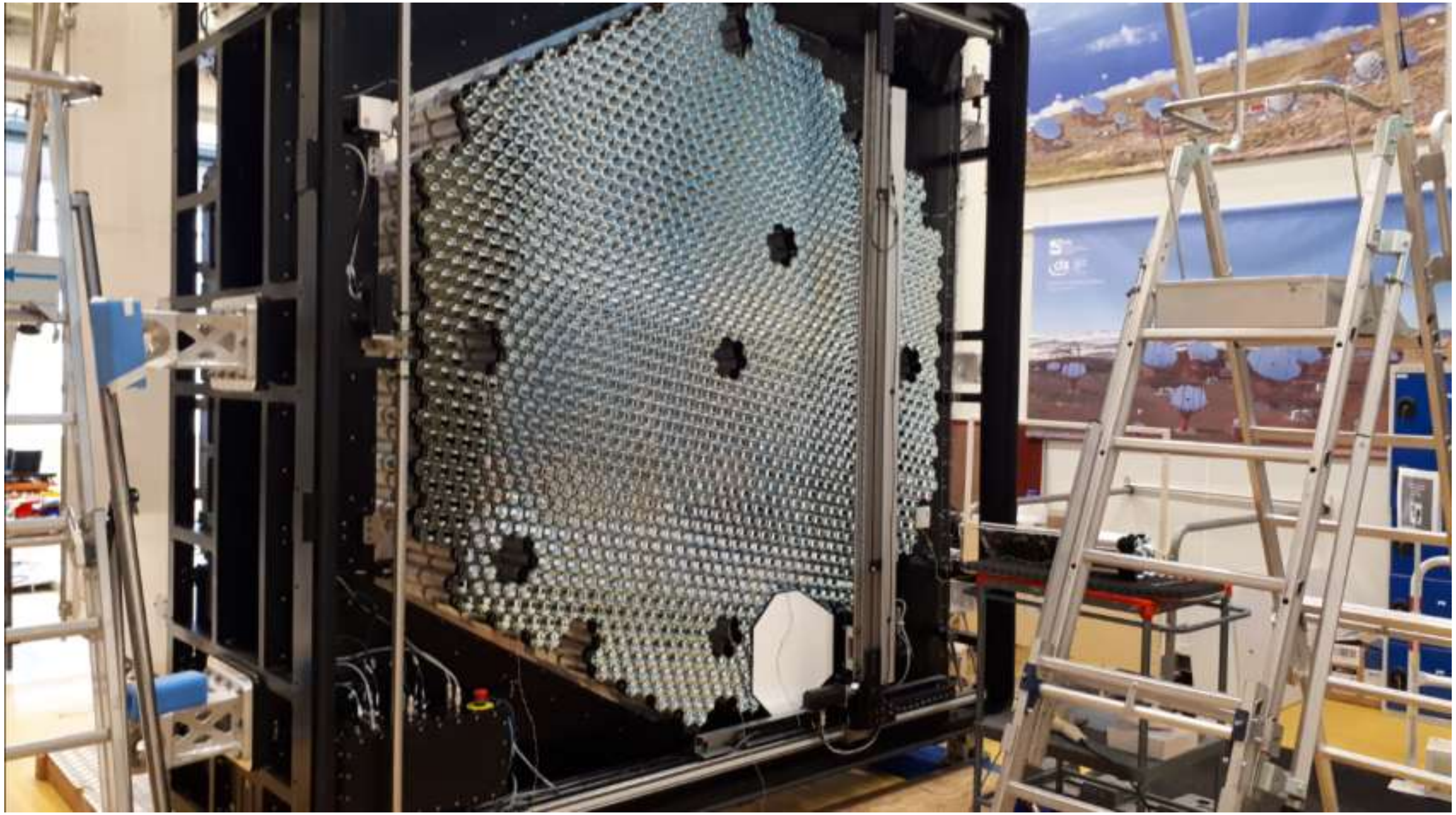


Taken from W. Hofmann, ISAPP 2022

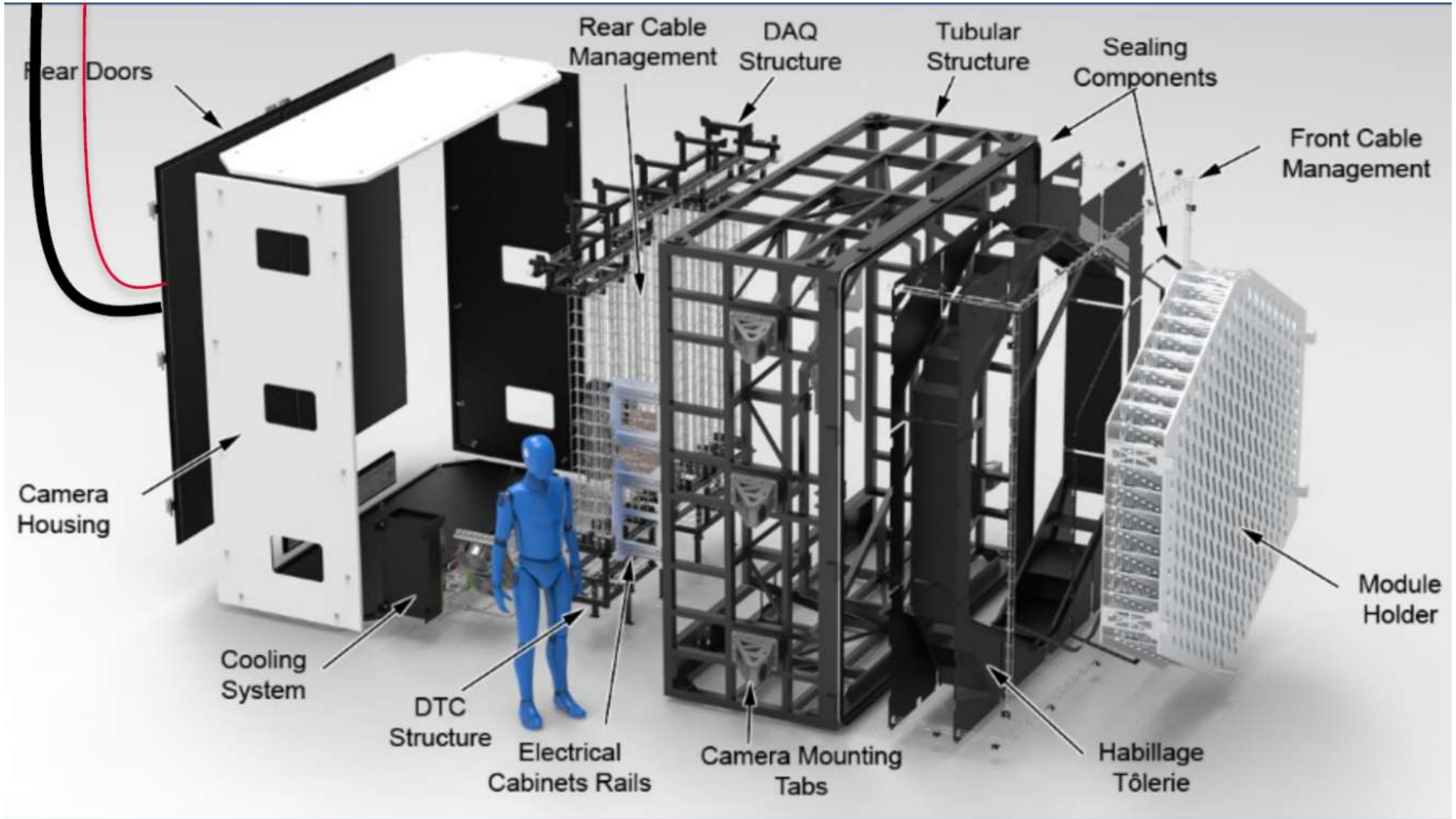

FOV in diameter!
LST
Ø 23m
4,5° FoV
20 GeV – 1 TeV
SCT
Ø 12 m
7° FoV
100 GeV – 50 TeV
Proposed by USA for extension
MST
Ø 12 m
7° FoV
100 GeV – 50 TeV
SST
Ø 4 m
10° FoV
1 TeV – 300 TeV
40 m
30 m
20 m
10 m

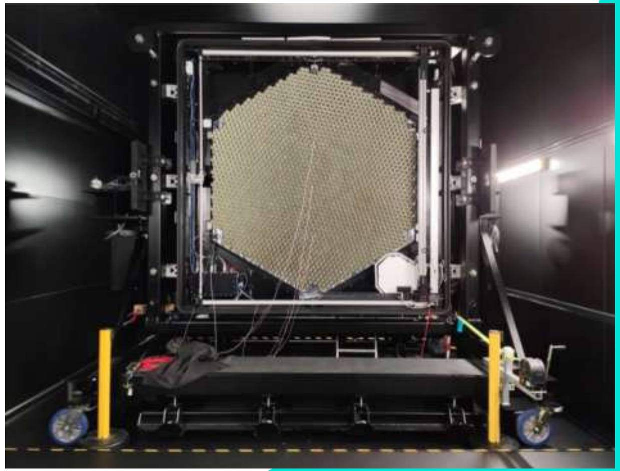
MST with NectarCAM

Visit of the assembly hall next week

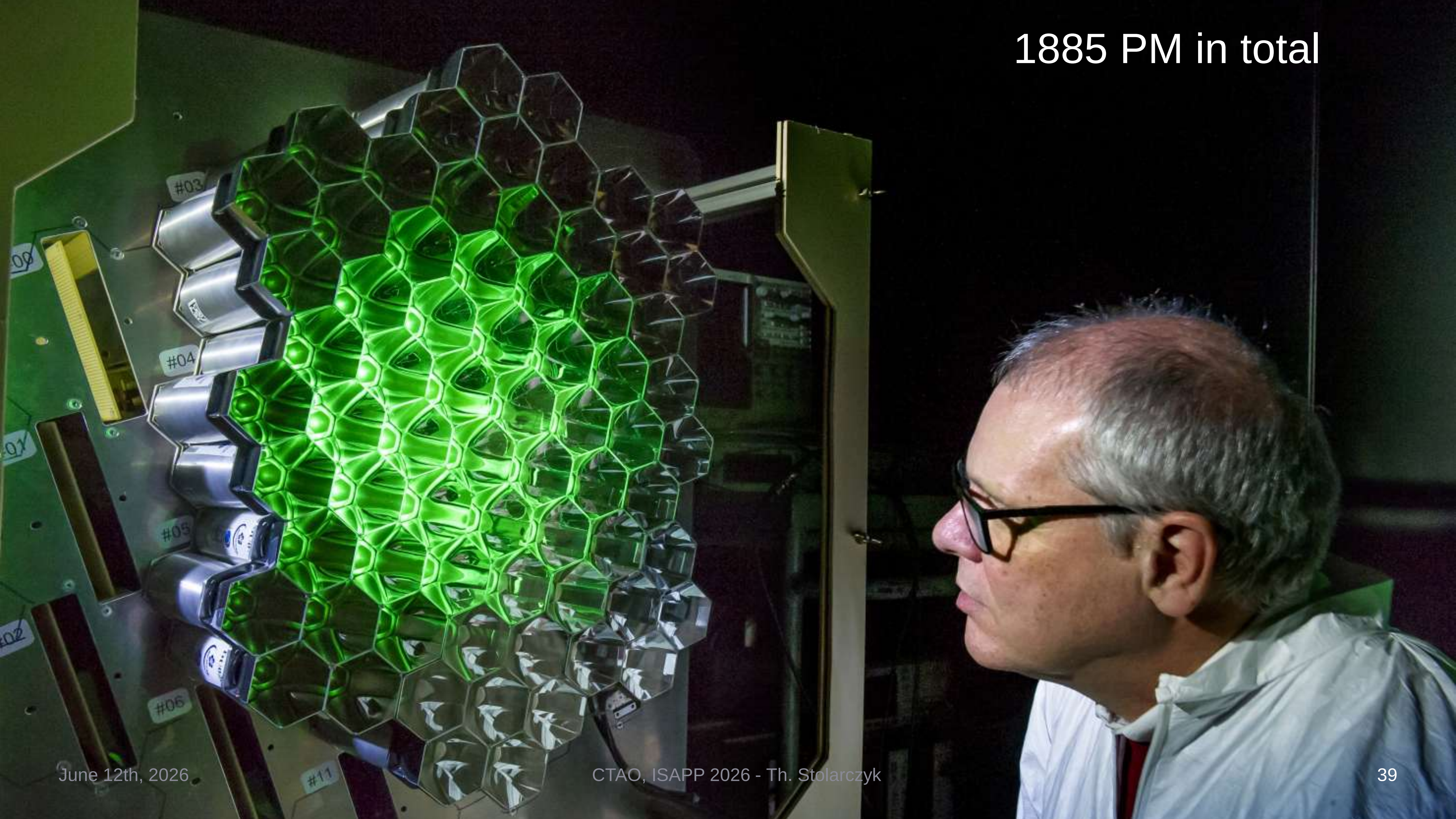


NectarCAM


Rear Doors
Rear Cable
Management
DAQ
Structure
Tubular
Structure
Sealing
Components
Front Cable
Management
Camera
Housing
Module
Holder
Cooling
System
DTC
Structure
Electrical
Cabinets Rails
Camera Mounting
Tabs
Habillage
Tôlerie



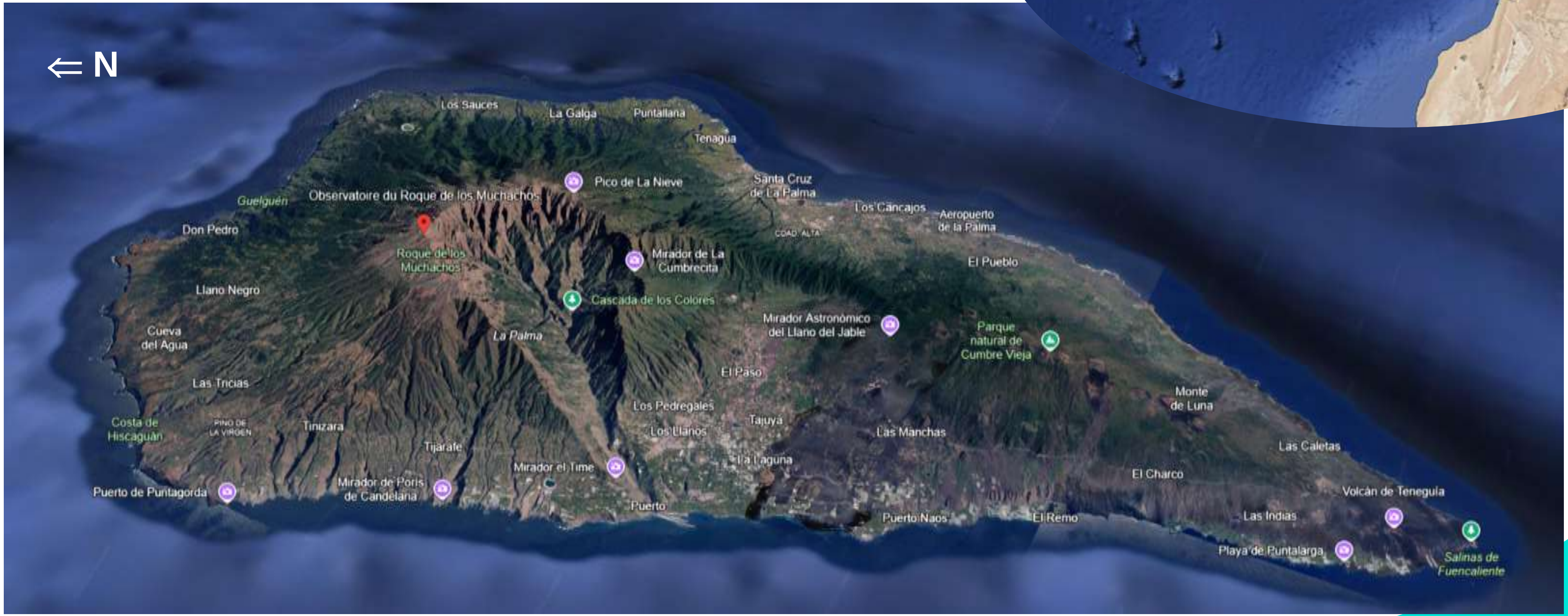
1885 PM in total



Northern array

Observatorio del Roque de los Muchachos, IAC
28° 45′ N, 17° 53′ W

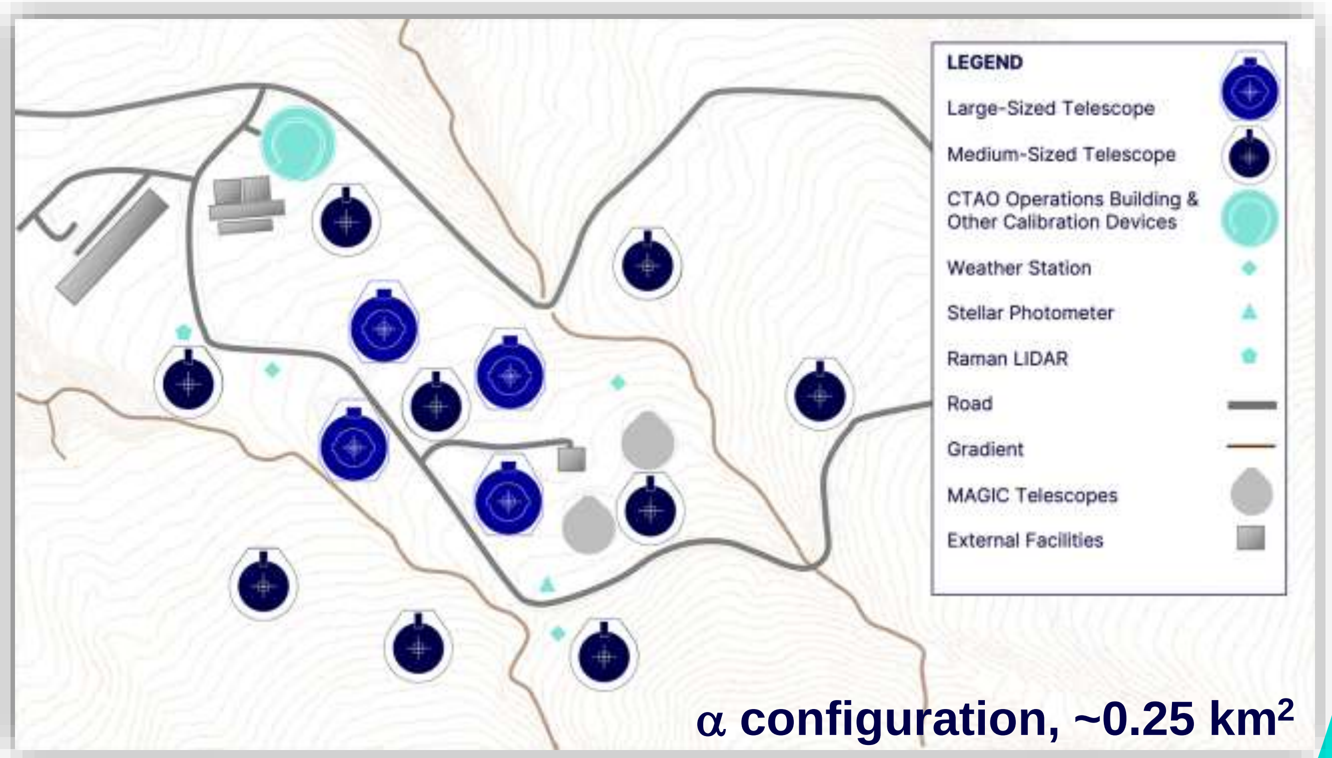
Island of La Palma, Canary Islands, Spain (alt. 2200 m)



Northern array

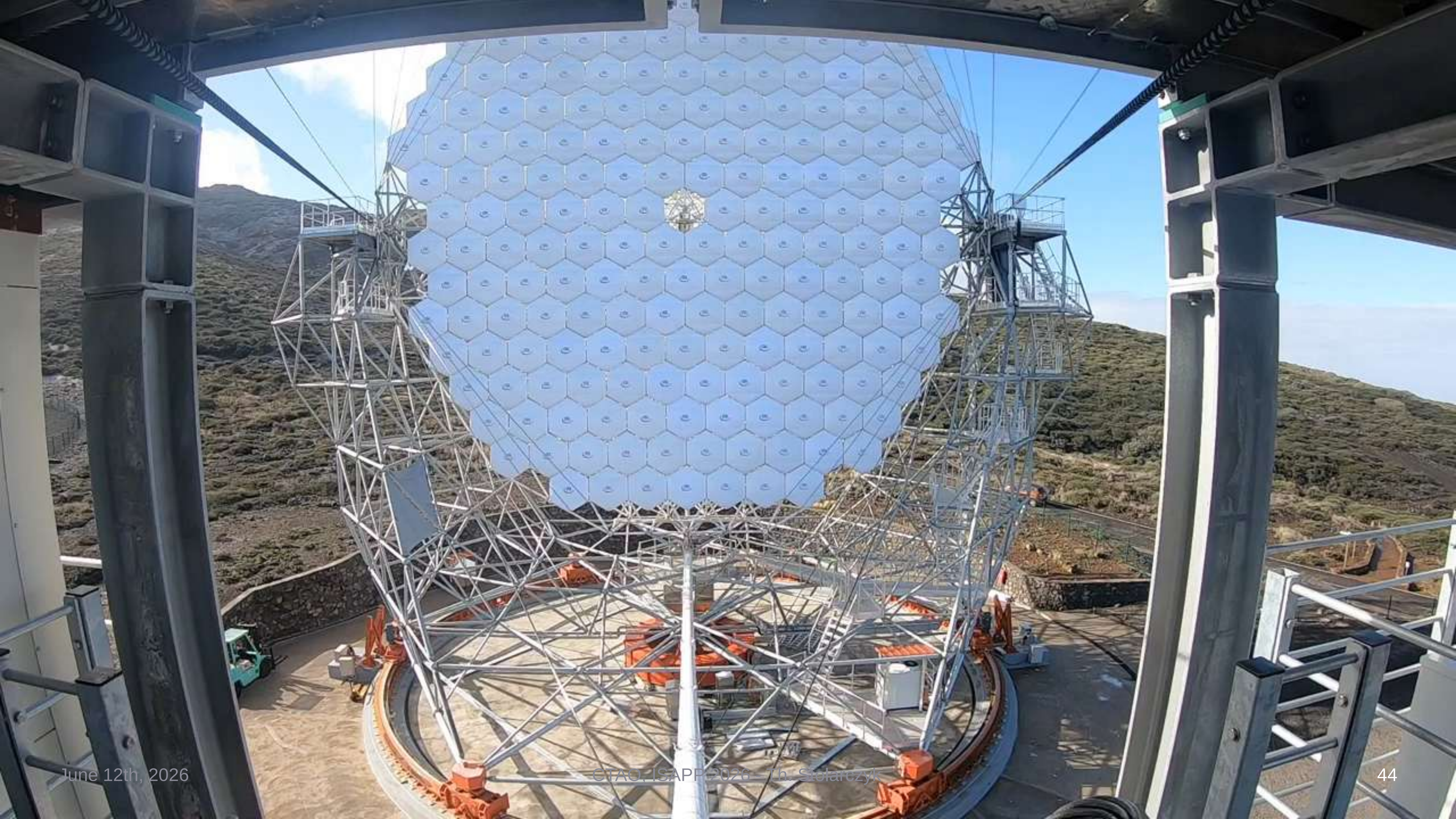
- 4 LSTs, 9 MSTs (NectarCam)
  - 4 LST almost complete
  - 1 MST foundation ready
- **Final goal**: 4 LSTs, 9 + 6 MSTs

configuration ω



α **configuration, ~0.25 km^2**

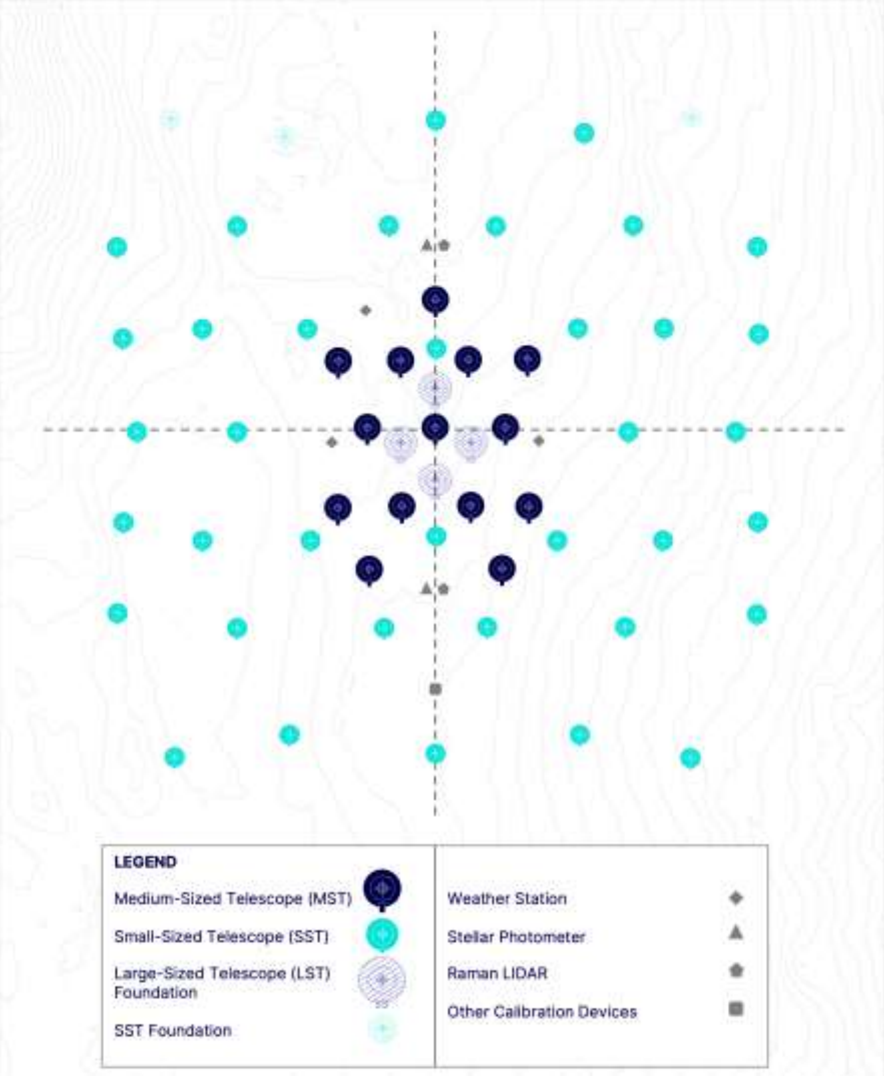

Mid 25
MAGIC



Southern array

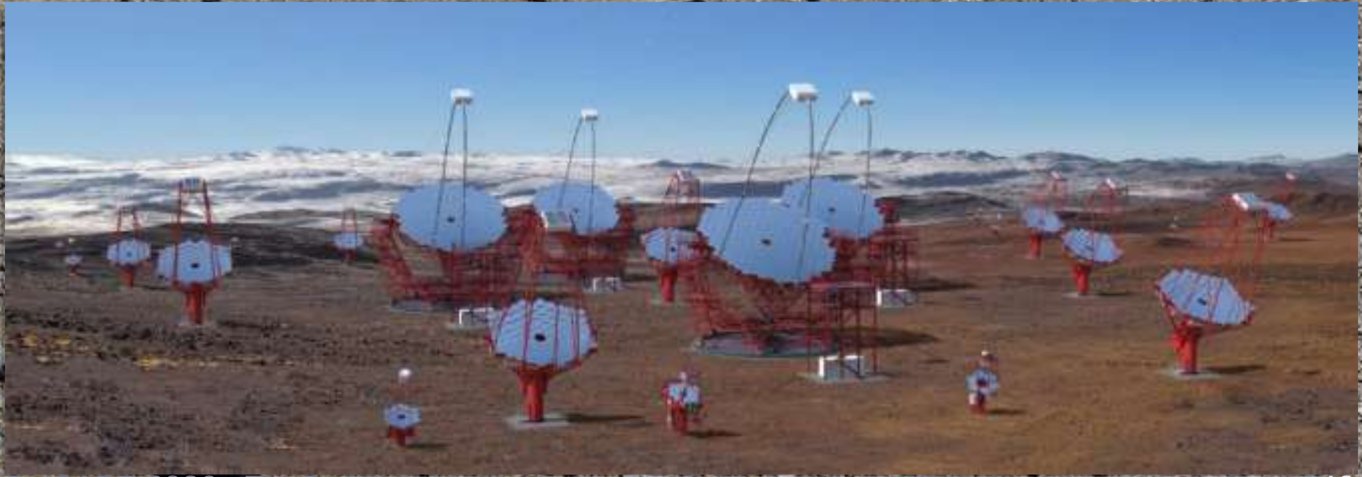
Atacama desert, 2200 m
24° 41′ S, 70° 19′ W

Southern array

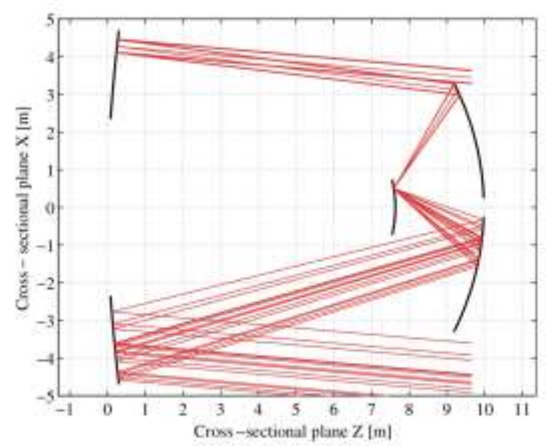


α **configuration, ~3 km^2**

- 3 km^2
- 14 MST (FlashCAM), 37 SST
- Funds for +2 LSTs approved
- **Goal**: 2+2 LST, 14+11 MST, 37+ 33
- 2 MST pathfinders end of 2026



SSTs



- First units this year
- Quest for pevatrons

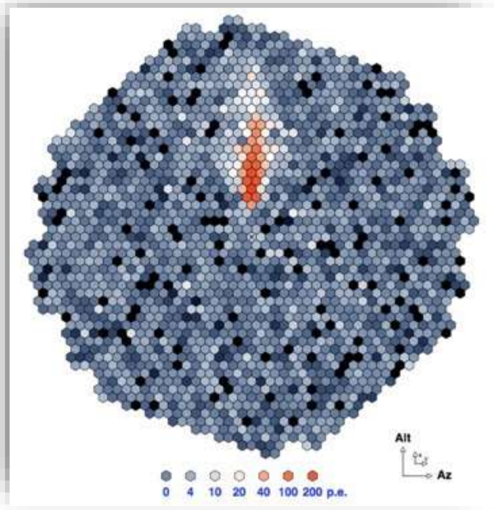
SCT prototype

pSCT Inauguration

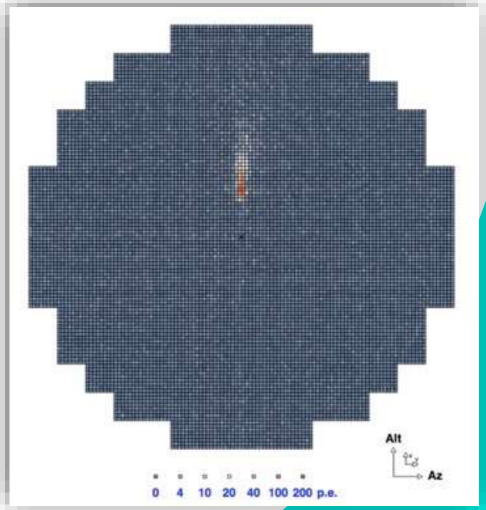
January 17, 2019

Whipple Observatory

- Dual-mirror design
- SiPMT camera



MST



pSCT

Southern array

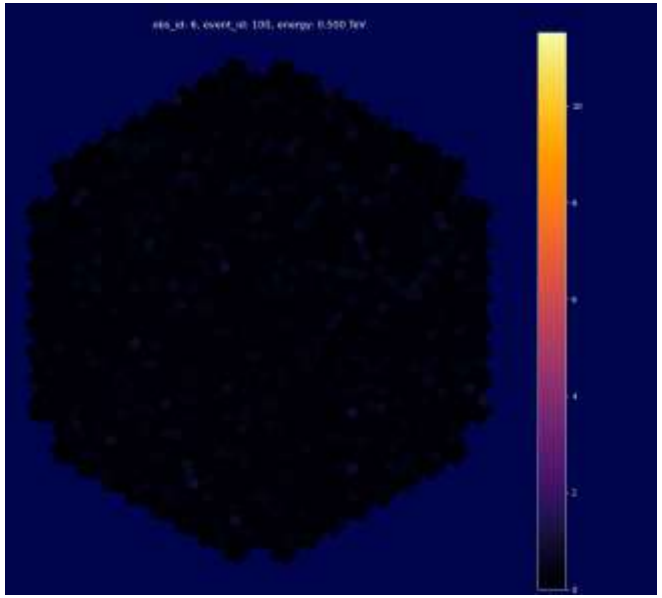
Southern array

16 km interconnection roads

Performance

Data processing

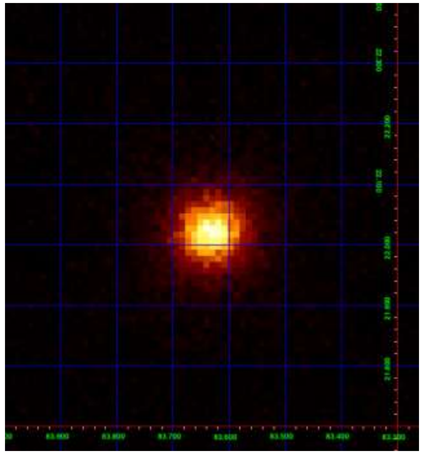
→ *See Federica Bradascio's talk*

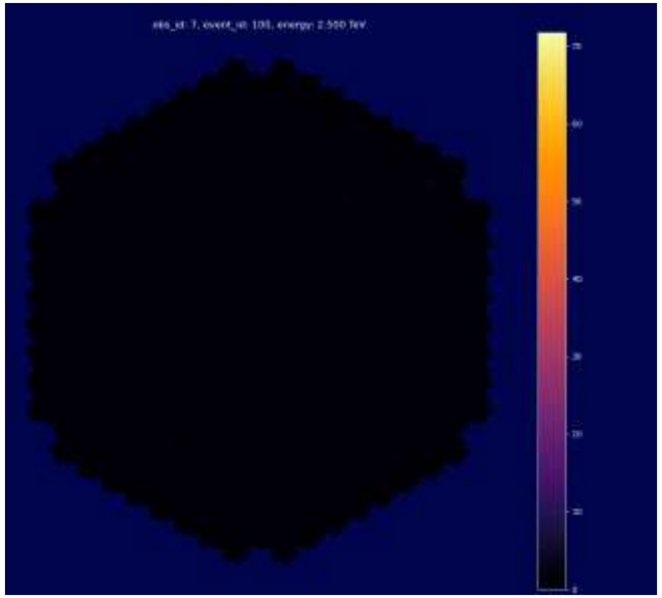


Gammas

1 γ (Crab, 1 TeV) for 10^5 protons

1 γ (Crab, 1 TeV) for 1 proton





Protons

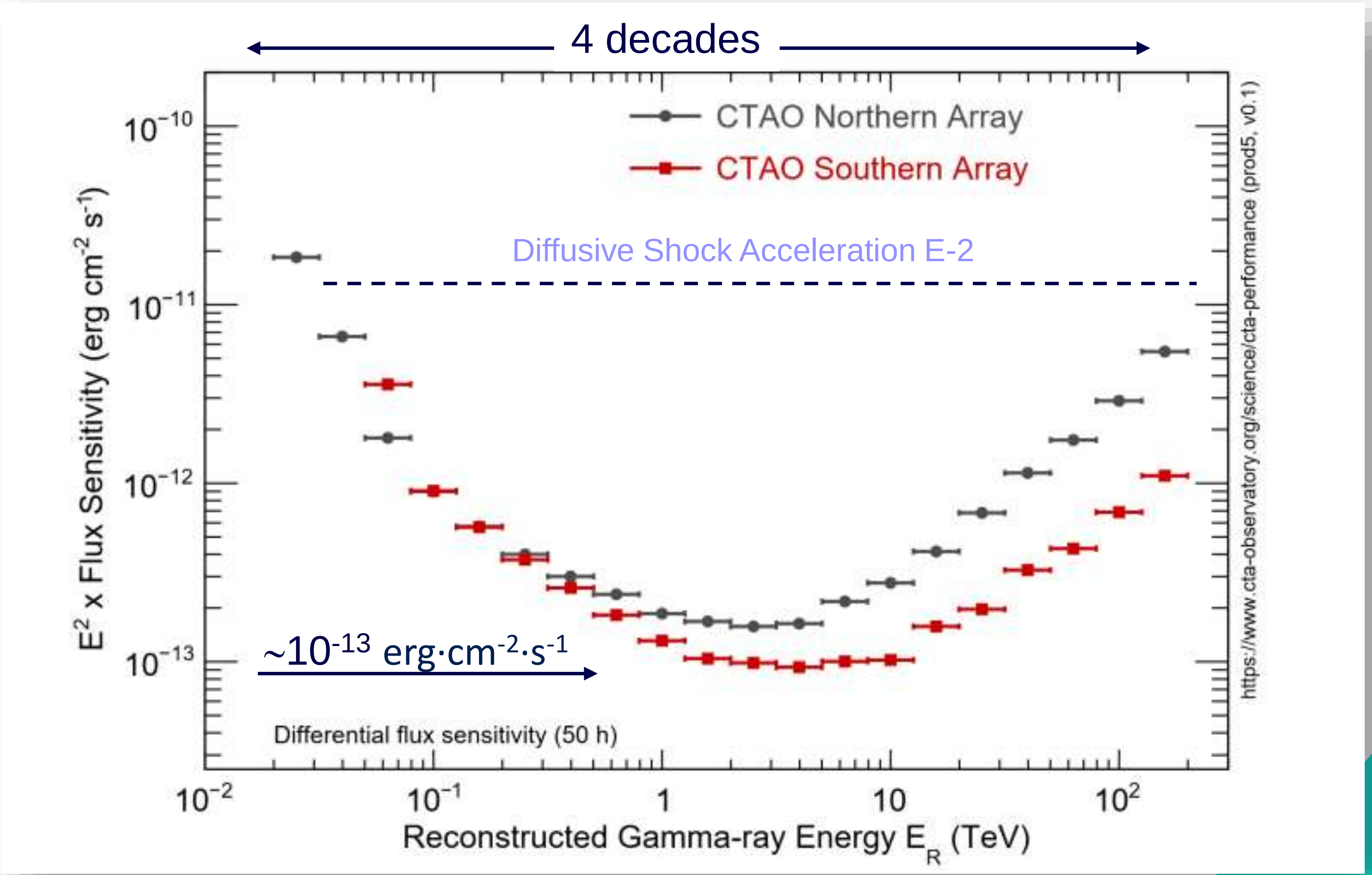
CTAO point-like source sensitivity

α Configuration,
50 h of observation
5 E-bins per decade

$E^2\phi(E) = E^2 \cdot dN/dE$
$(erg^{-1} \cdot cm^{-2} \cdot s^{-1})$
$d\log(E) = dE/E$

$\Rightarrow E^2\phi(E) = E\, dN/d\log(E)$
Energy flux per $\log_{10}(E)$

$dN/dE \sim E^{-2}$
$\Rightarrow E^2\phi(E) = \text{const}$

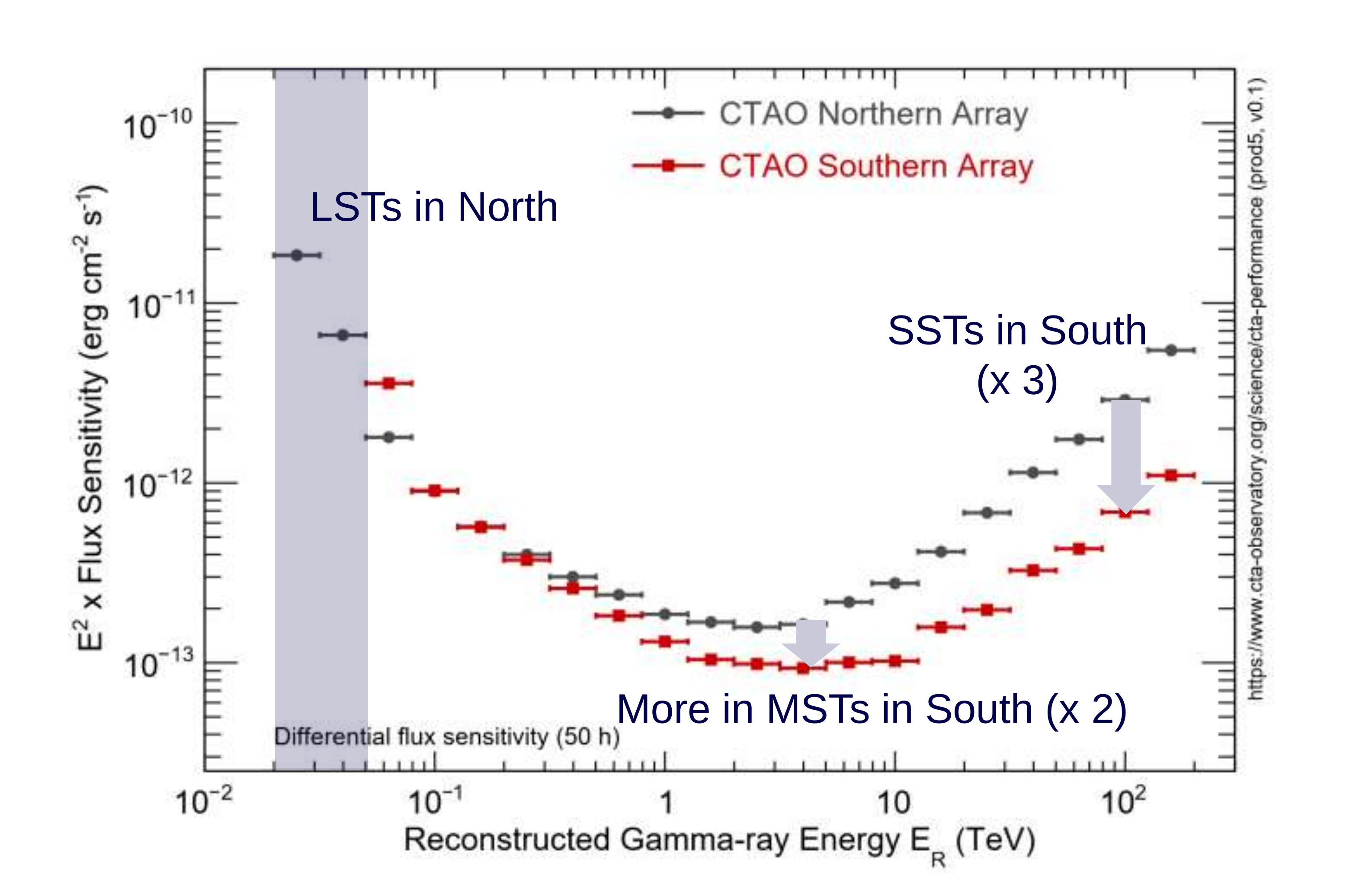


CTAO point-like source sensitivity

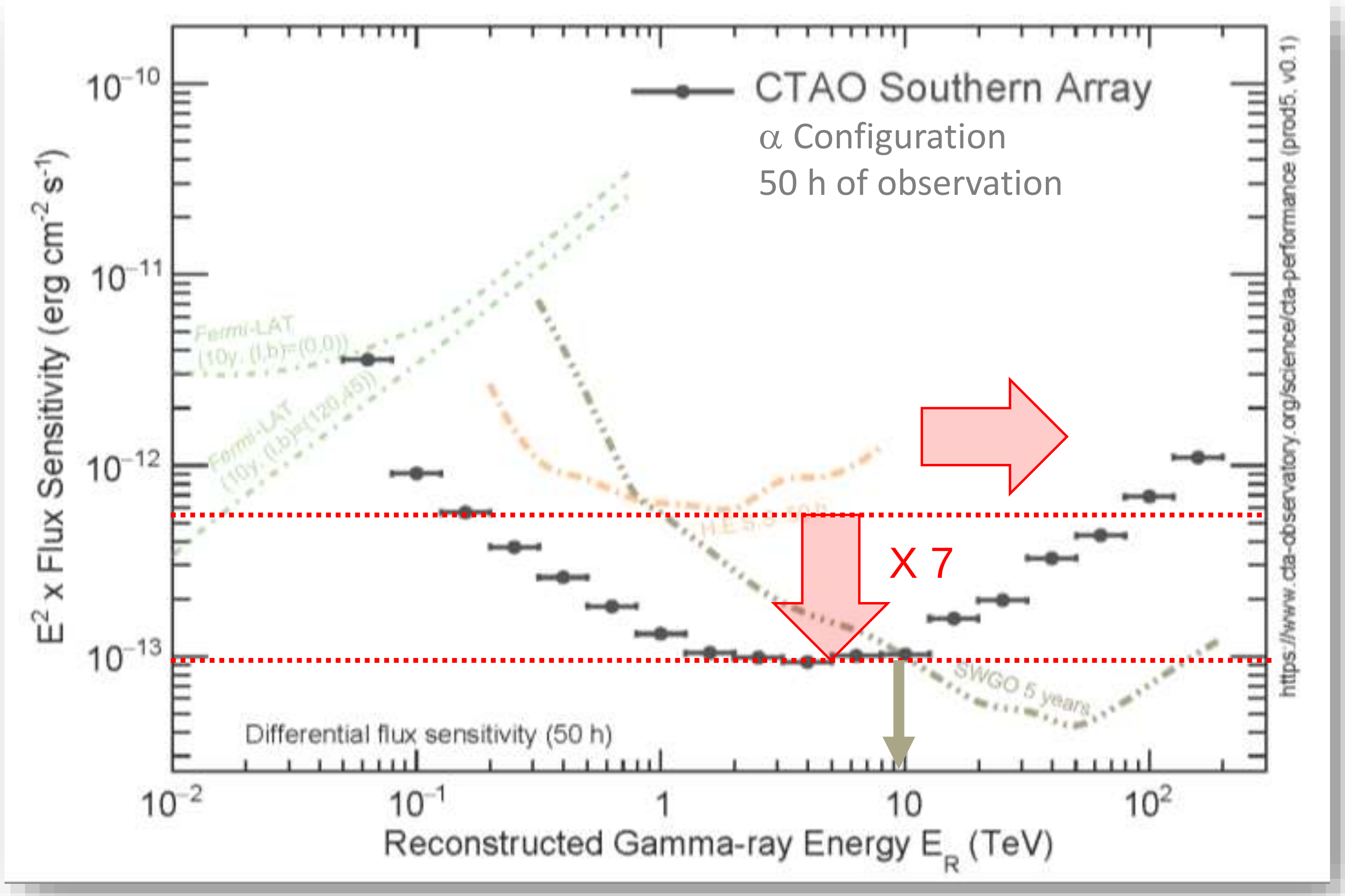
α Configuration,
50 h of observation
5 E-bins per decade

Sensitivity for a 5σ detection with a minimum of 10 signal counts.

South Array has no LST

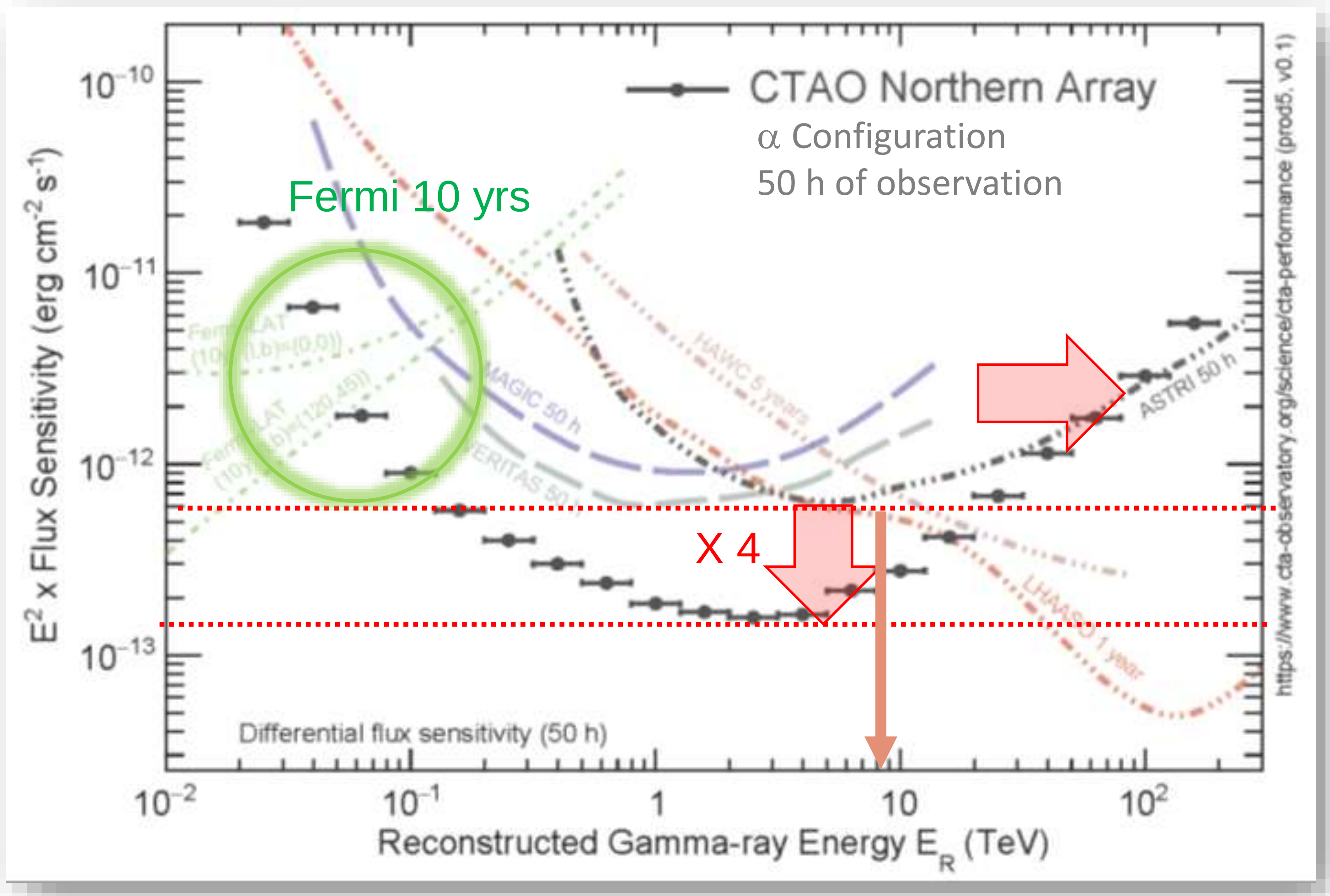


CTAO point-like source sensitivity - South



~10 TeV, SWGO 5 years

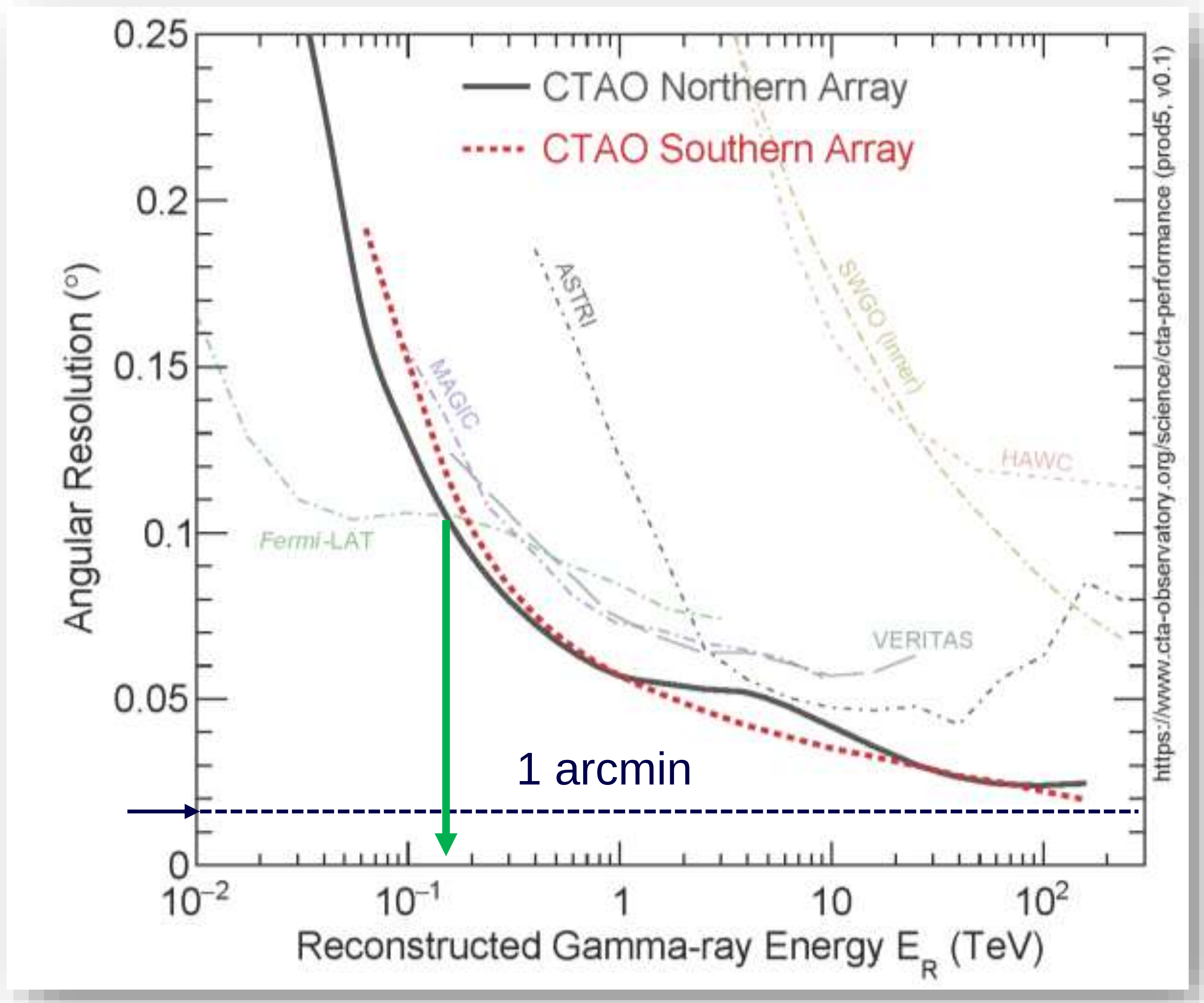
CTAO point-like source sensitivity - North

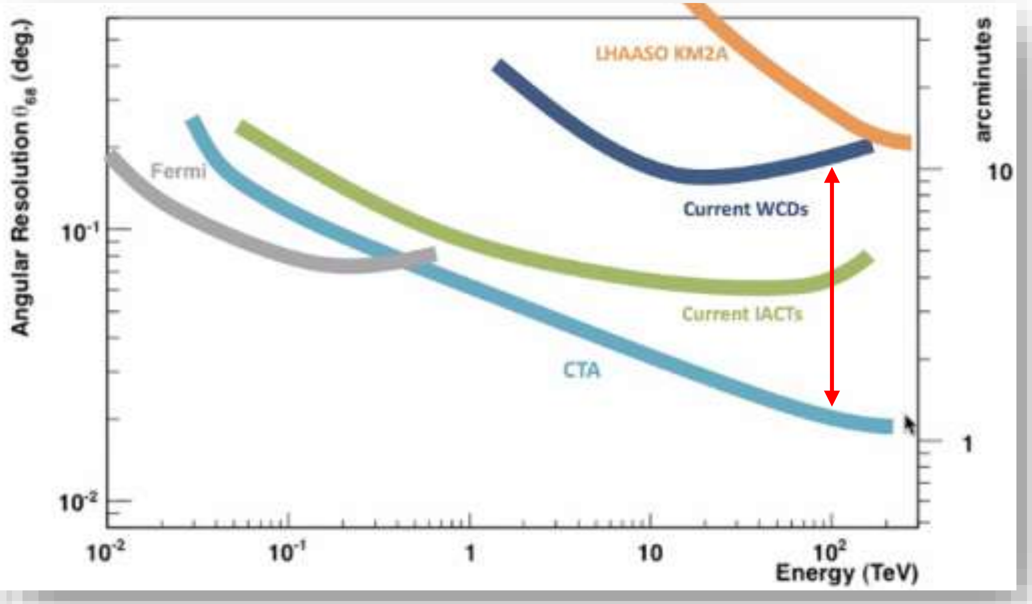


~10 TeV, LHAASO 1 year

Performance – PSF

Point-source location accuracy < 3"

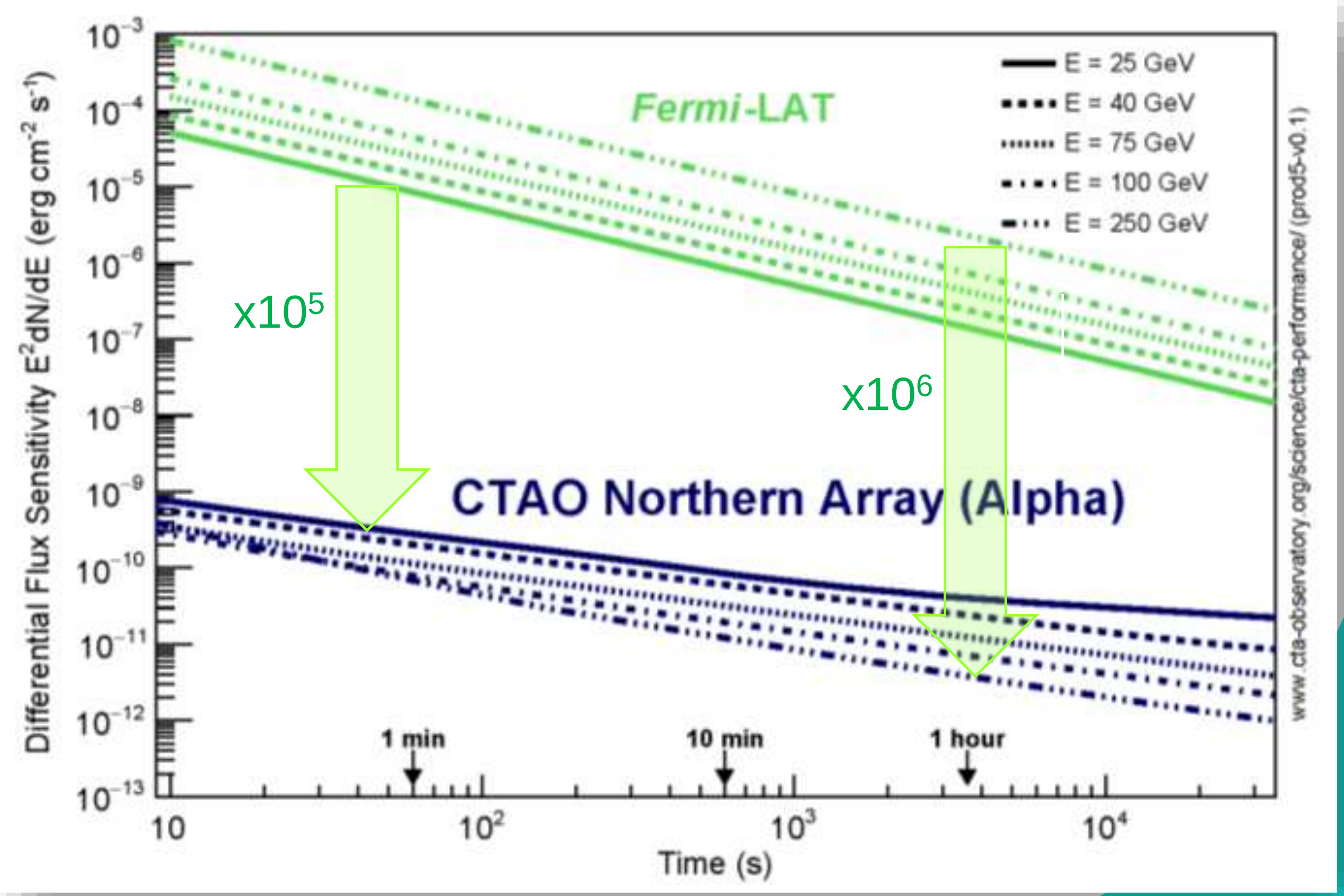




Timing and transients

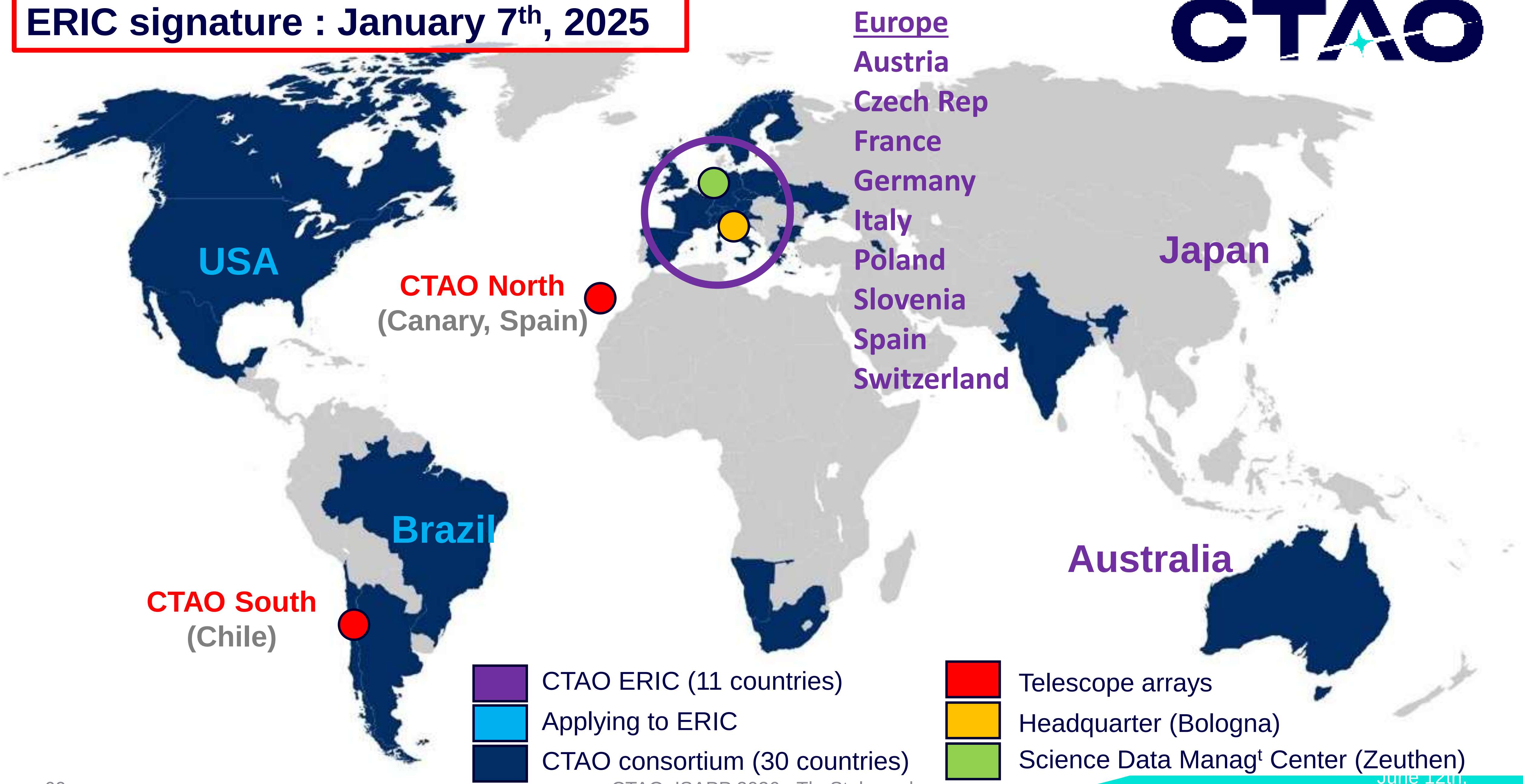
On time scales < 1 h:
10^3 times (at 25 GeV) to 10^6 times (at 250 GeV) more sensitive than Fermi

- Max. Slewing time
  - LST < 30 s
  - SST < 60 s
  - MST < 90 s
- Large field of view
  - 4-10° → Serendipitous events
- Real Time Analysis
  - Alerts sent < 1 minute



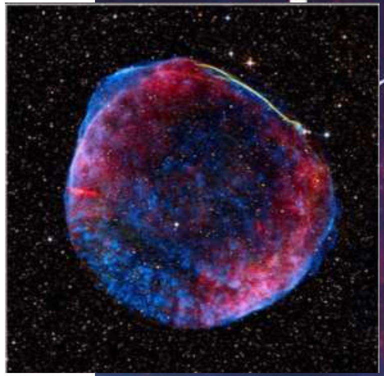
Science with CTAO

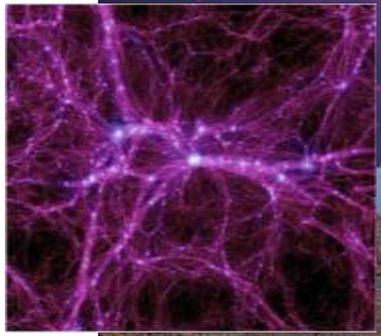
ERIC signature : January 7th, 2025

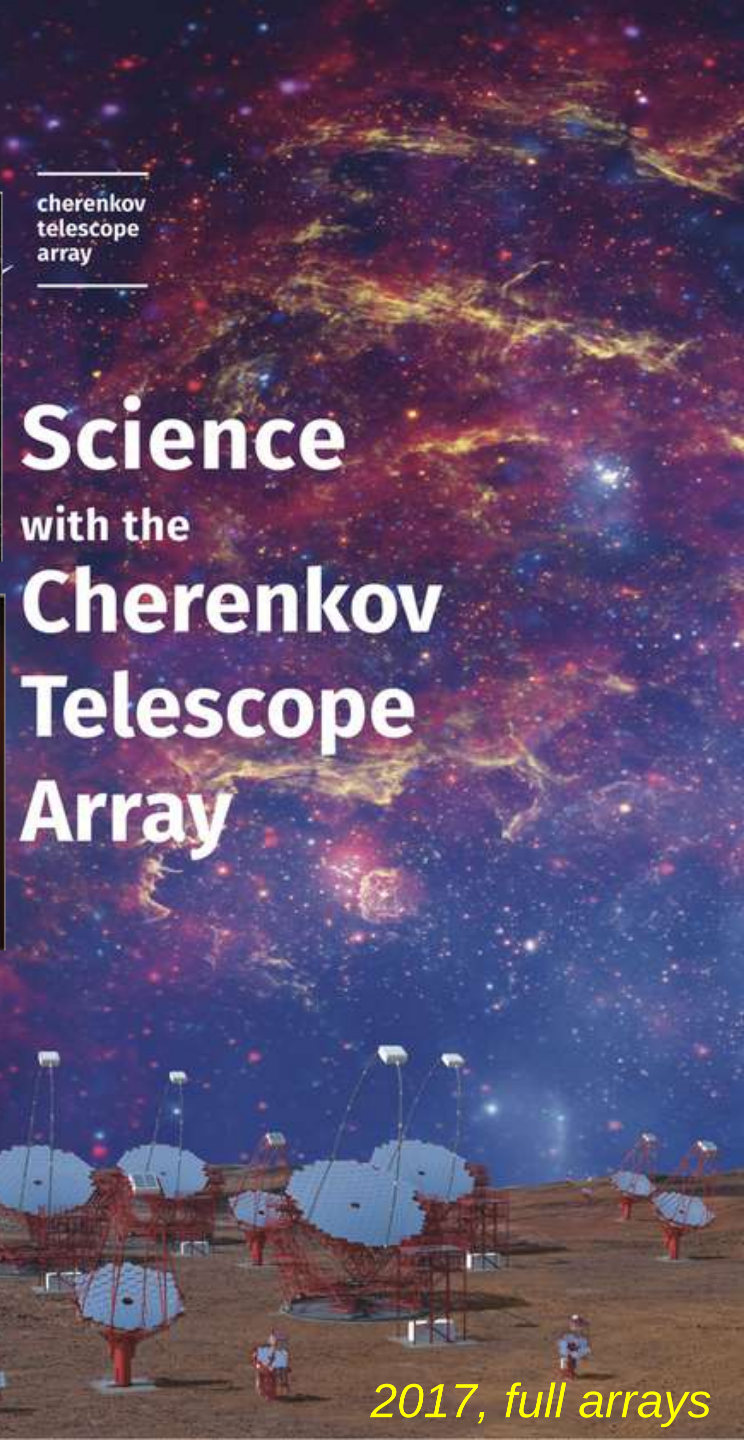


CTAO Science program

1. **Cosmic Particle Acceleration**
   - How and where are particles accelerated?
   - How do they propagate?
   - What is their impact on the environment?
2. **Probing Extreme Environments**
   - Processes close to neutron stars and black holes?
   - Characteristics of relativistic jets, winds and explosions?
   - Cosmic voids: their radiation fields and magnetic fields
3. **Physics Frontiers**
   - What is the nature of Dark Matter?
   - Is the speed of light a constant?
   - Do axion-like particles exist?





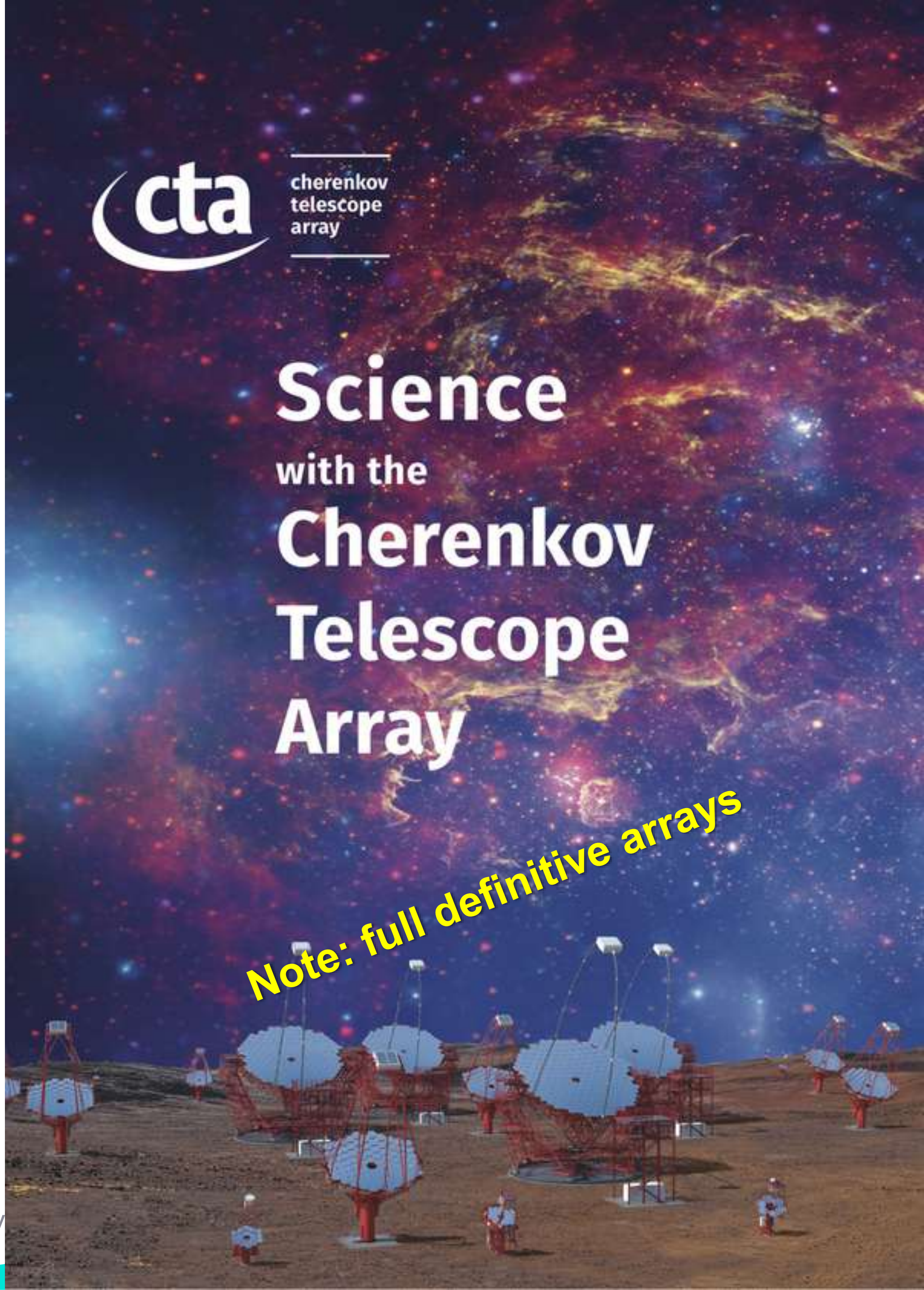


2017, full arrays

Key Science projects

- 40% of guaranteed time to the ERIC members over 10 years
  - Almost entire obs. Time the first 3 years.

- Excellent scientific case
- Production of legacy datasets to a wider community
  - Released after a proprietary period
- Clear added value of doing this as a KSP
  - Too many hours for a Guest Observer;
  - Coherent approach across multiple targets or pointings;
  - Technical difficulty (collaboration expertise).
- Scenario to be optimised with time along with discoveries
- Starting point for more Science from Open-time observations
- Will be defined after a call from CTAO-CO to the Science Collaboration in 2027.



Key Science projects

1. Dark matter program → *Emmanuel Moulin's talk*
2. Galactic plane*
3. Galactic centre survey*
4. LMC survey*
5. Extragalactic survey*

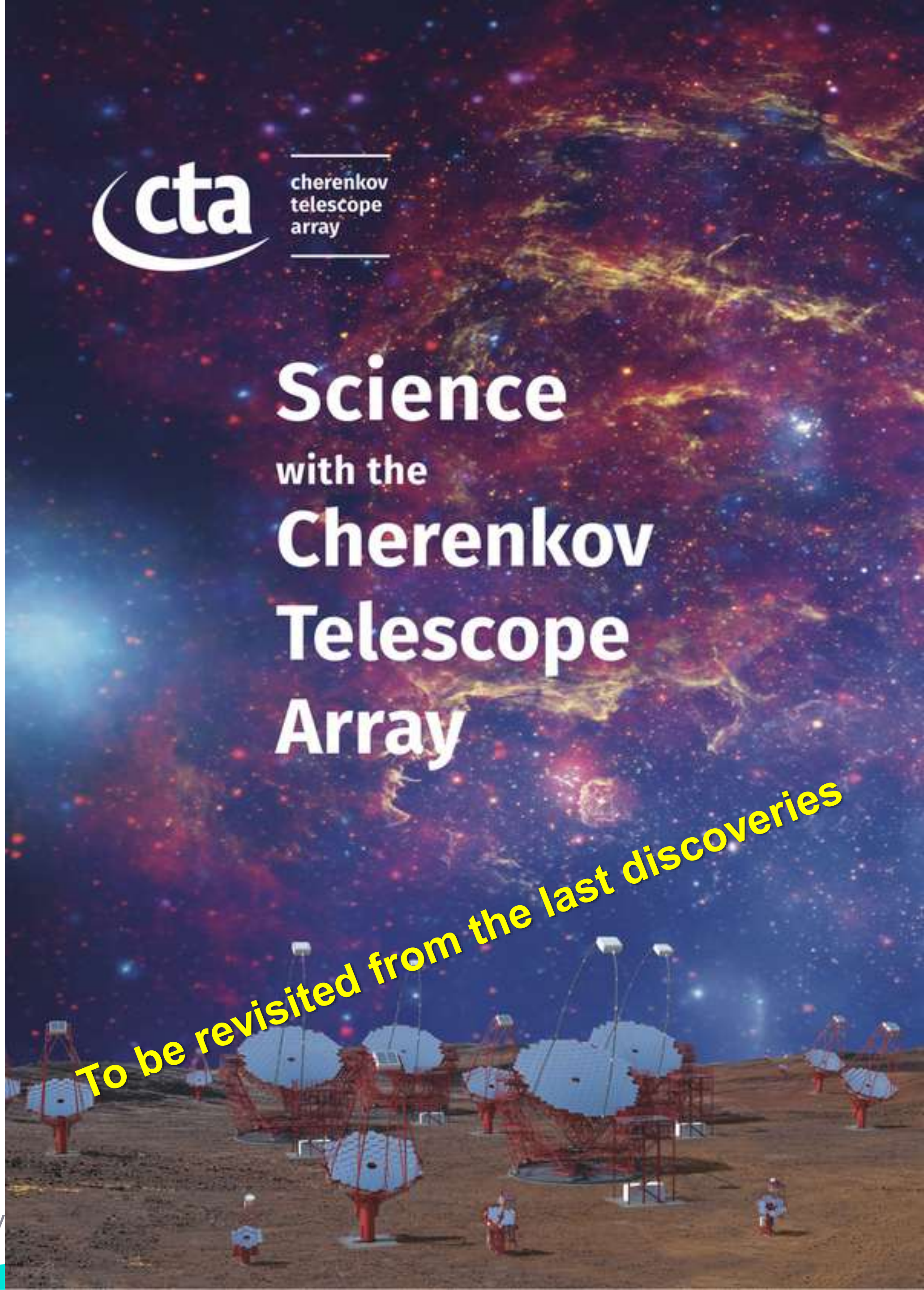
Surveys

6. Transients
7. Cosmic-ray Pevatrons*
8. Star-forming systems
9. Active galactic nuclei
10. Galaxy clusters

Specific objects

Brand new: Stellar Intensity Interferometry

→ *Not presented here*



CTAO publications since 2017

- Prospects for γ-ray observations of the **Perseus galaxy cluster** with the Cherenkov Telescope Array
  - K. Abe et al, JCAP10(2024)004, DOI 10.1088/1475-7516/2024/10/004, ArXiv
- Sensitivity of the Cherenkov Telescope Array to spectral signatures of **hadronic PeVatrons** with application to Galactic Supernova Remnants
  - F. Acero, et al., Astroparticle Physics, Vol. 150, 2023, DOI : 10.1016/j.astropartphys.2023.102850, ArXiv
- Sensitivity of the Cherenkov Telescope Array to TeV photon emission from the **Large Magellanic Cloud**
  - A Acharyya et al., MNRAS, Vol. 523, Issue 4, Aug. 2023, DOI : 10.1093/mnras/stad1576, ArXiv
- Prospects for a **survey of the Galactic plane** with the Cherenkov Telescope Array
  - S. Abe et al JCAP10(2024)081 DOI 10.1088/1475-7516/2024/10/081, ArXiv
- **Dark Matter Line Searches** with the Cherenkov Telescope Array
  - S. Abe et al., JCAP07(2024)047, DOI 10.1088/1475-7516/2024/07/047, arXiv
- Prospects for **dark matter observations in dwarf spheroidal galaxies** with the Cherenkov Telescope Array Observatory
  - K Abe , et al., MNRAS, Vol. 544, Issue 3, December 2025, DOI 10.1093/mnras/staf1798, arXiv
- **Galactic transient sources** with the Cherenkov Telescope Array
  - MNRAS, Vol. 540, Issue 1, June 2025, DOI: 10.1093/mnras/staf655, ArXiv
- Chasing **Gamma-Ray Signals from Binary Neutron Star Coalescences** with the Cherenkov Telescope Array: Prospects and Observing Strategies
  - S. Abe et al 2026 ApJ 1004 46, DOI 10.3847/1538-4357/ae658c, ArXiv

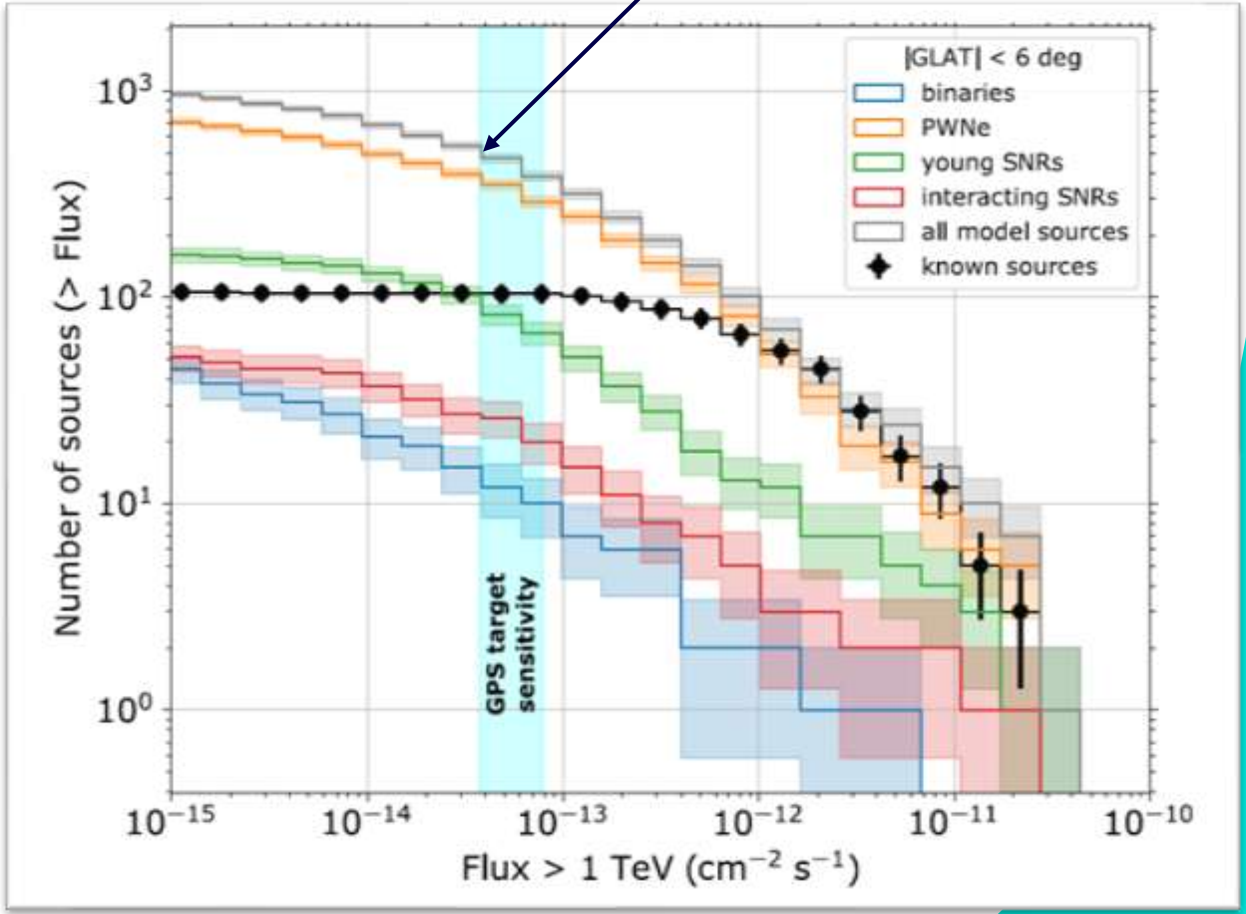
Galactic plane survey

- Goals: contribute answering / clarifying
  - Mechanisms/efficiency of particle acceleration
  - Maximum achievable energies,
  - Nature of the accelerated particles
  - Influence of source's environment
  - Evolution with the age
  - Contributions to the Galactic CRs

- Sky model from known gamma-ray emitters + physically-driven models
  - PWNe (pulsar wind nebulae)
  - SNRs (young and interacting)
  - Compact binary systems
  - Milky Way diffuse emission.

- Total observation time: 1620 hours, over ten years
  - (Omega configuration)

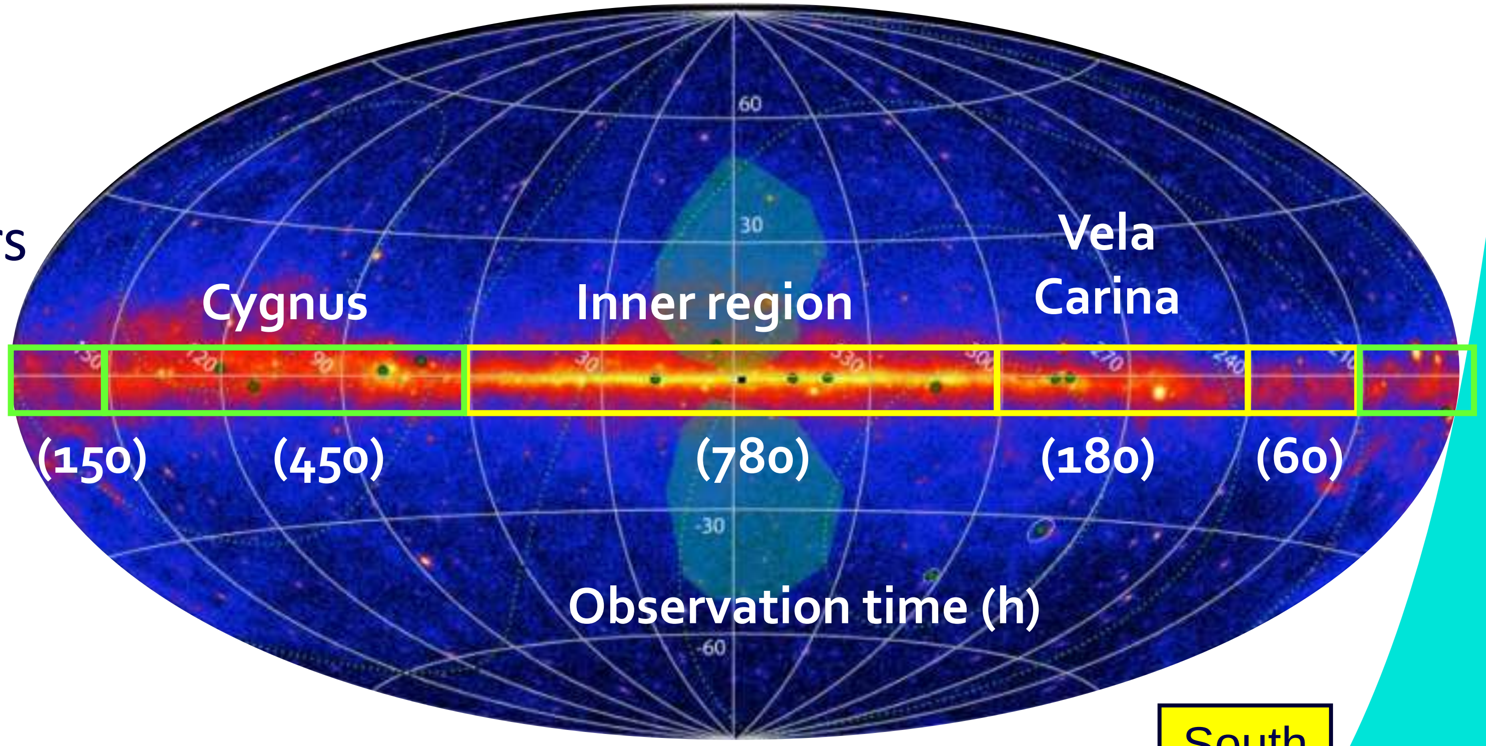
~500 sources



→ Galactic Sources in Pierre Cristofari's lecture

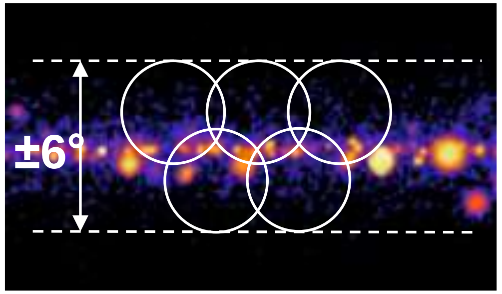
Galactic plane survey (10 years)

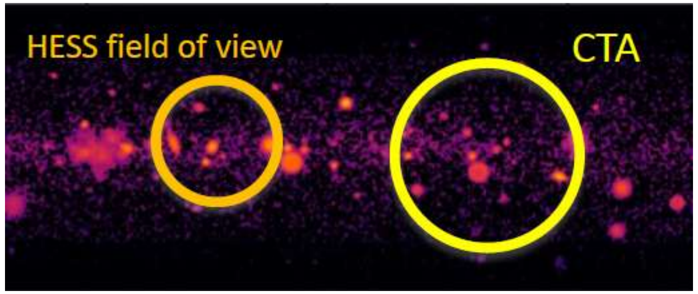
- The full plane
- Depth x 10 compared to precursors
  - 5 10^{-14} cm^{-2} s^{-1} @ 1 TeV
- X 300 the speed of current instrument (large FOV, sensitivity)
- Optimised observation pattern



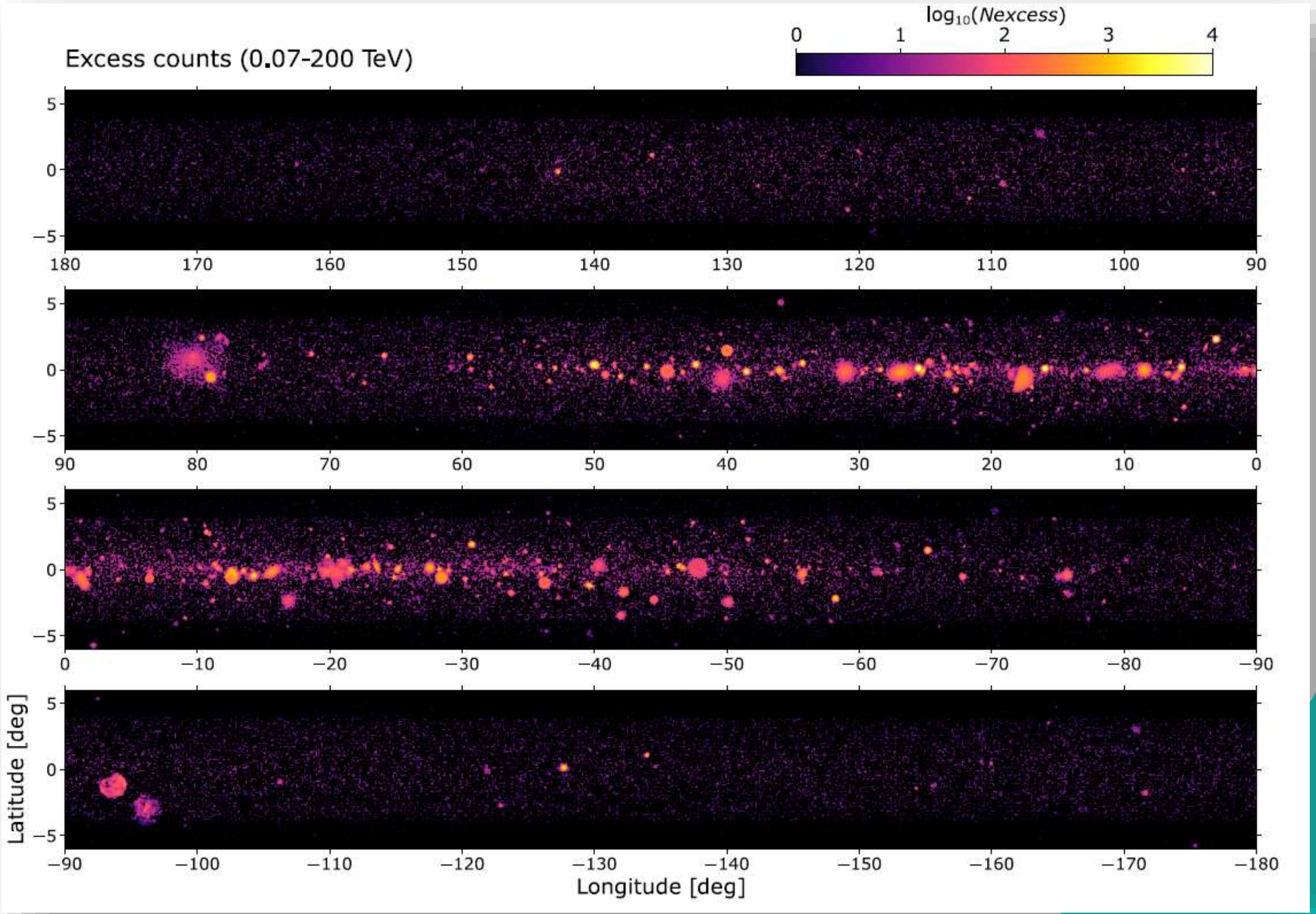
South

North





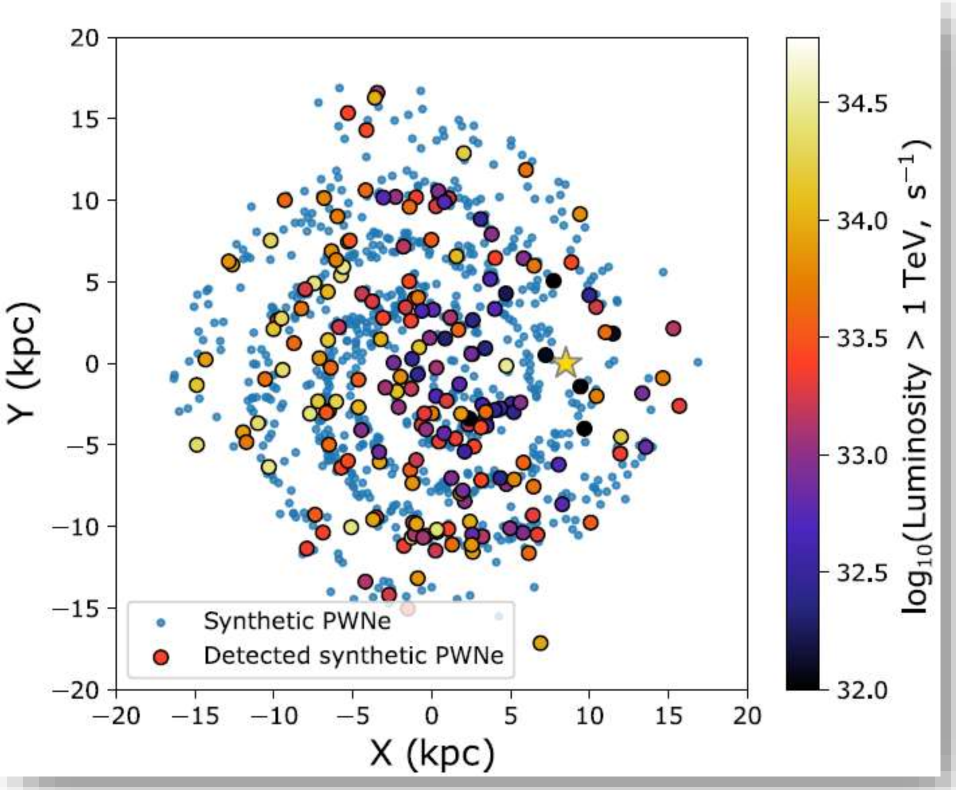
Galactic plane survey (10 years)

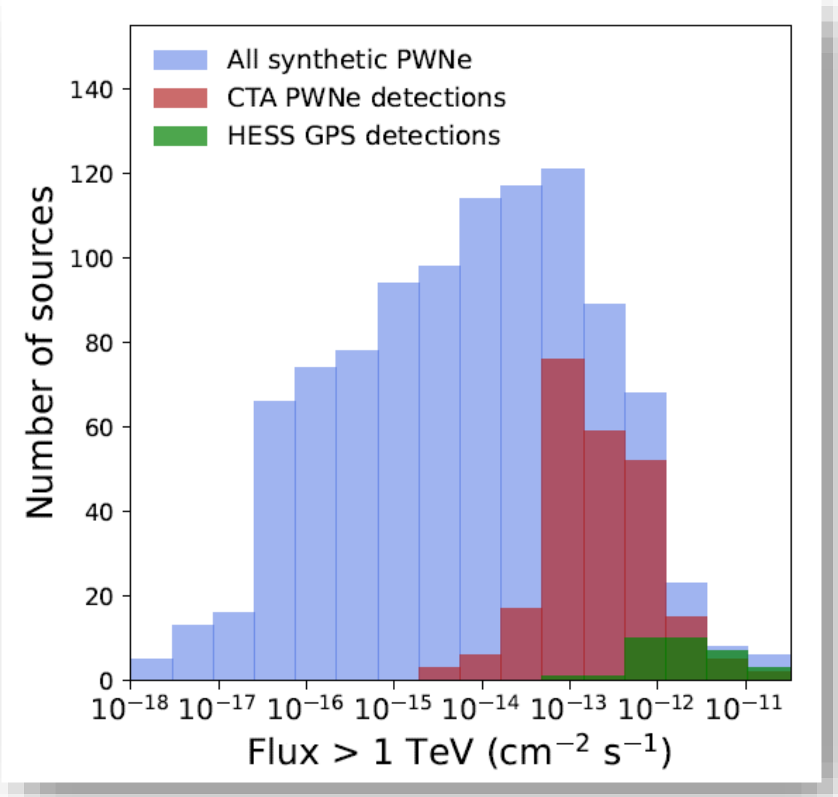


Excess counts above the CR background

- 70 GeV - 200 TeV
- 10 yrs
- |b| < 6°
- Spatial bin width: 0.06°
- smoothed Gaussian at 0.03°

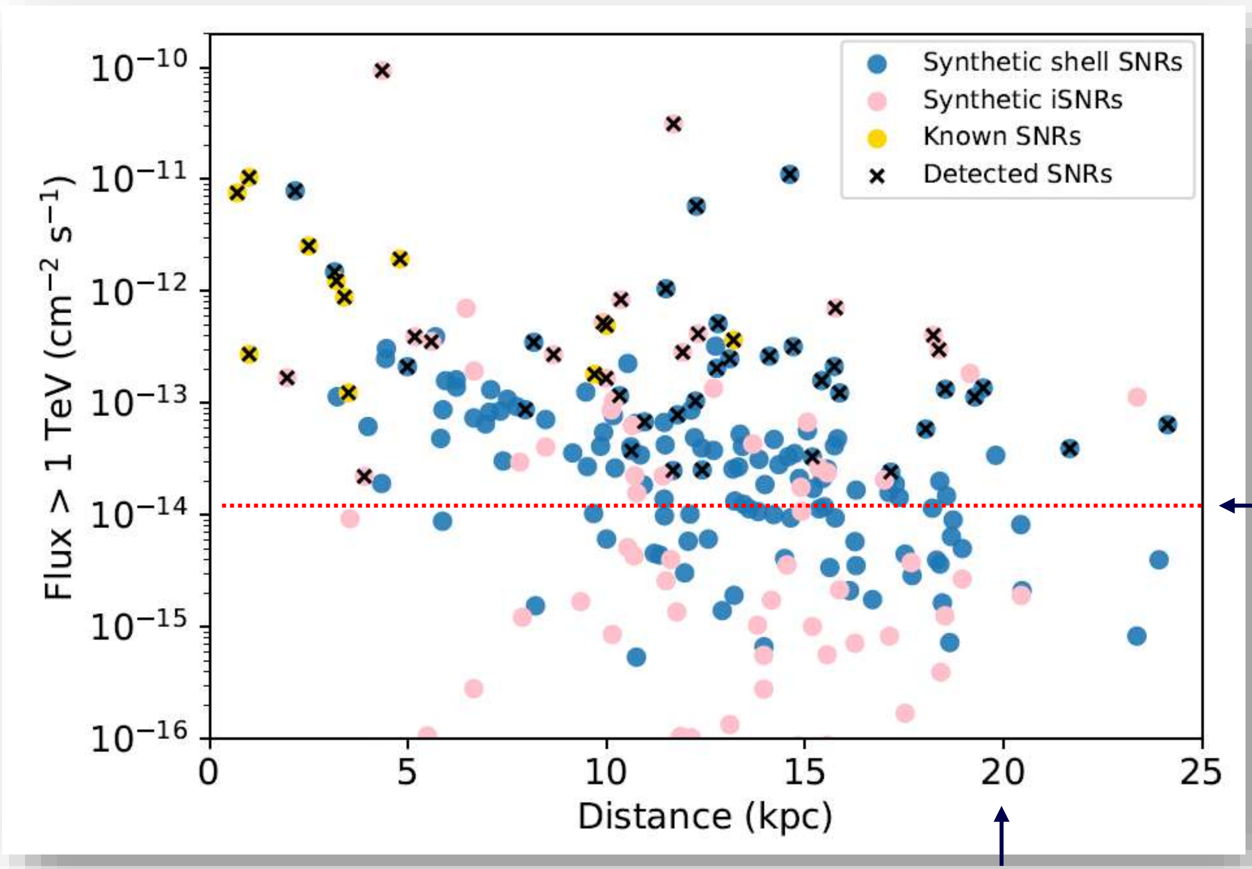
Galactic plane: PWNe





- Dominant source class
- CTAO covers the whole Galaxy > 2.2 10^{34} erg s^{-1}
- Increase in population : x 7, 7 detected as Pevatrons

SNRs



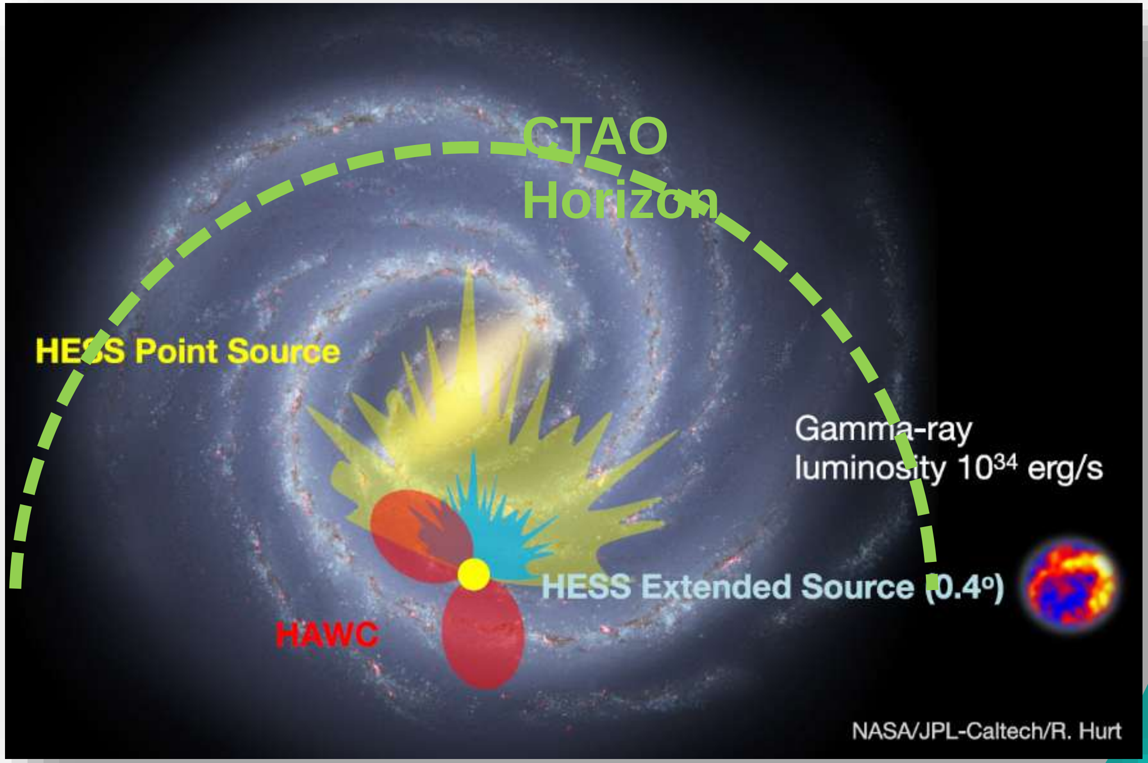
5-10 times better than the current TeV SNR sample

The other side of the Galaxy

- Second most detected population
- Increase x 2
- Most are seen as extended objects

Galactic plane survey: summary

- Distance reach of 20 kpc
- Up to 500 sources (0.07-200 TeV)
  - > x 6 HESS or HAWC catalogues.
  - > 200 PWne
  - ~30 SNR, mostly seen extended
  - Up to 30 Pevatrons candidates
- Plane diffuse emission at TeV
- Input to longer observations (KSP)
- Legacy data set
  - First full Catalogue released < 3 yr
  - → Seeds for guest observers



Prospects for a survey of the Galactic plane with the Cherenkov Telescope Array

- S. Abe et al JCAP10(2024)081 DOI [10.1088/1475-7516/2024/10/081](10.1088/1475-7516/2024/10/081), [ArXiv]()

The Galactic Center

X-ray + radio

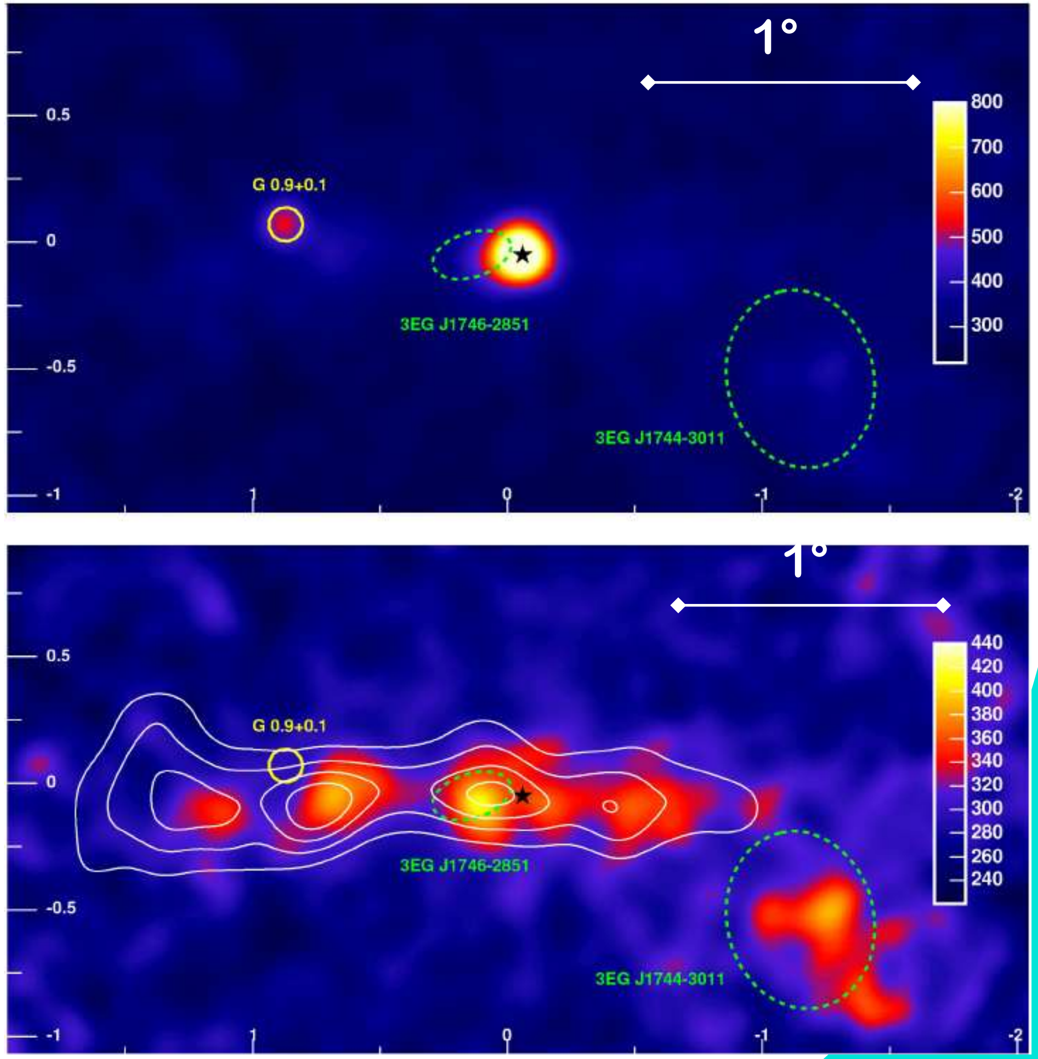
The Galactic Center

A Long list of questions ! (Well suited for a KSP)

- What is the central VHE source?
  - Winds from Sgr A*?
    → Variability (1’ – 1h time scales) ?
  - A pulsar wind nebula ?
- Diffuse emission along the ridge
  - From a VHE accelerator ?

- Fermi Bubbles
  - CR from SN explosion?
    (10% of the SF rate in the Galaxy)
  - Sgr A* past activity ?

→ Disentangle diffuse emission and new sources
  - Many PWNe, SNR expected



Aharonian F., Akhperjanian A.G., Bazer-Bachi A.R. et al. (2006), Nature, **439**, 695

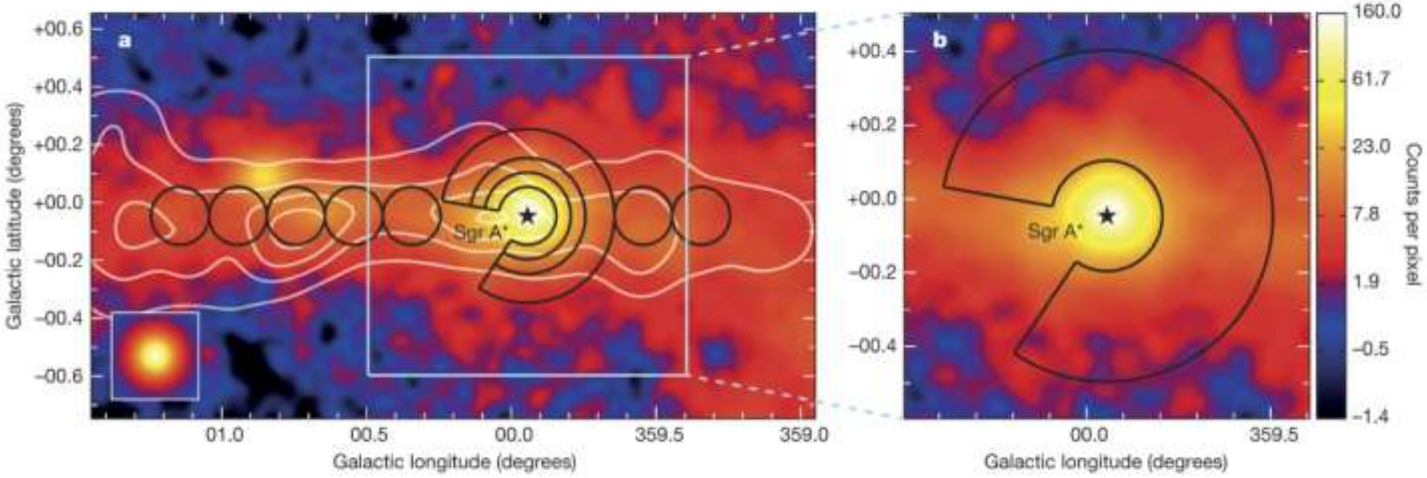
The Galactic Center

Acceleration of petaelectronvolt protons in the Galactic Centre

Nature volume 531, pages476–479 (2016)

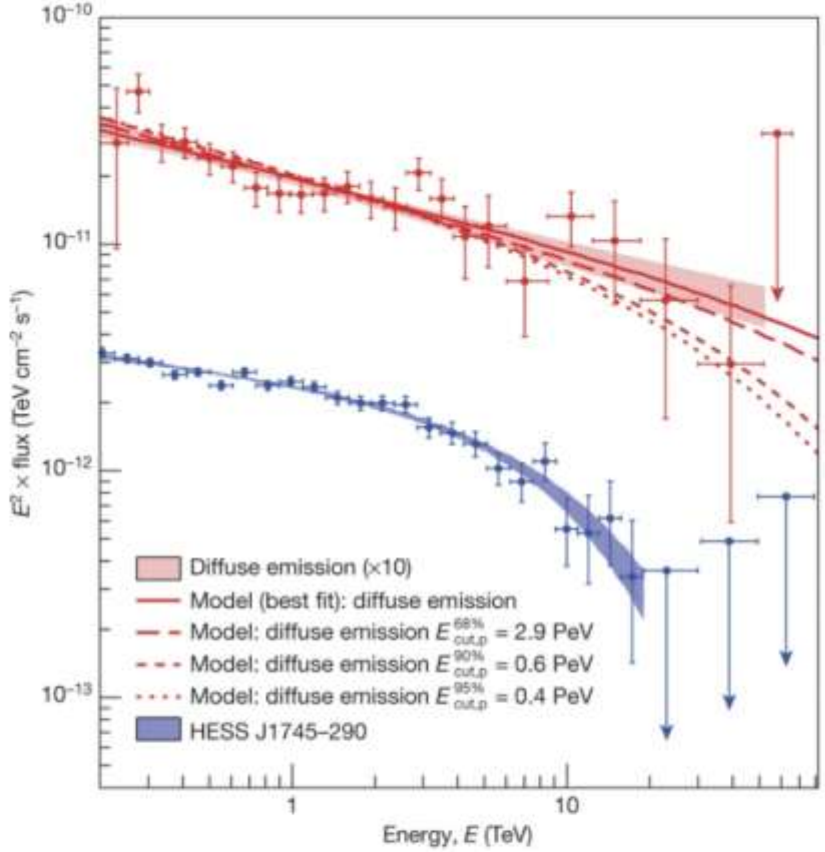
Figure 1: VHE γ-ray image of the Galactic Centre region.

From: Acceleration of petaelectronvolt protons in the Galactic Centre

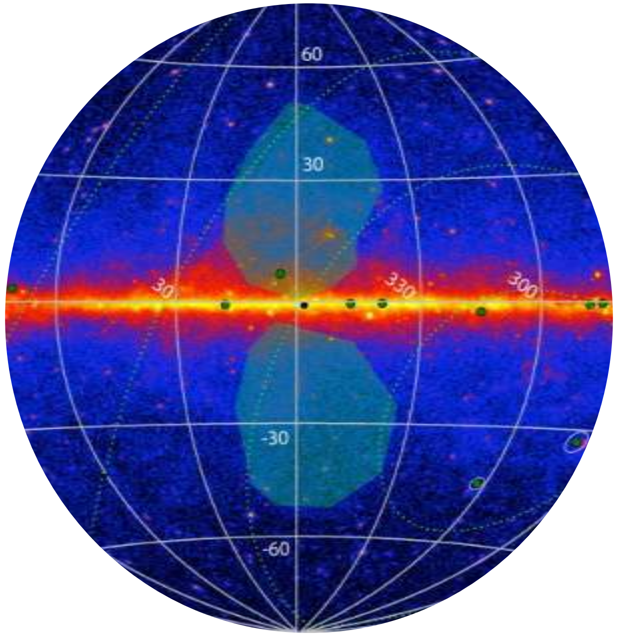


The colour scale indicates counts per 0.02° × 0.02° pixel. **a**, The black lines outline the regions used to calculate the cosmic-ray energy density throughout the central molecular zone. A section of 66° is excluded from the annuli (see Methods). White contour lines indicate the density distribution of molecular gas, as traced by its CS line emission[30]. Black star, location of Sgr A*. Inset (bottom left), simulation of a point-like source. The part of the image shown boxed is magnified in **b**. **b**, Zoomed view of the inner ~70 pc and the contour of the region used to extract the spectrum of the diffuse emission.

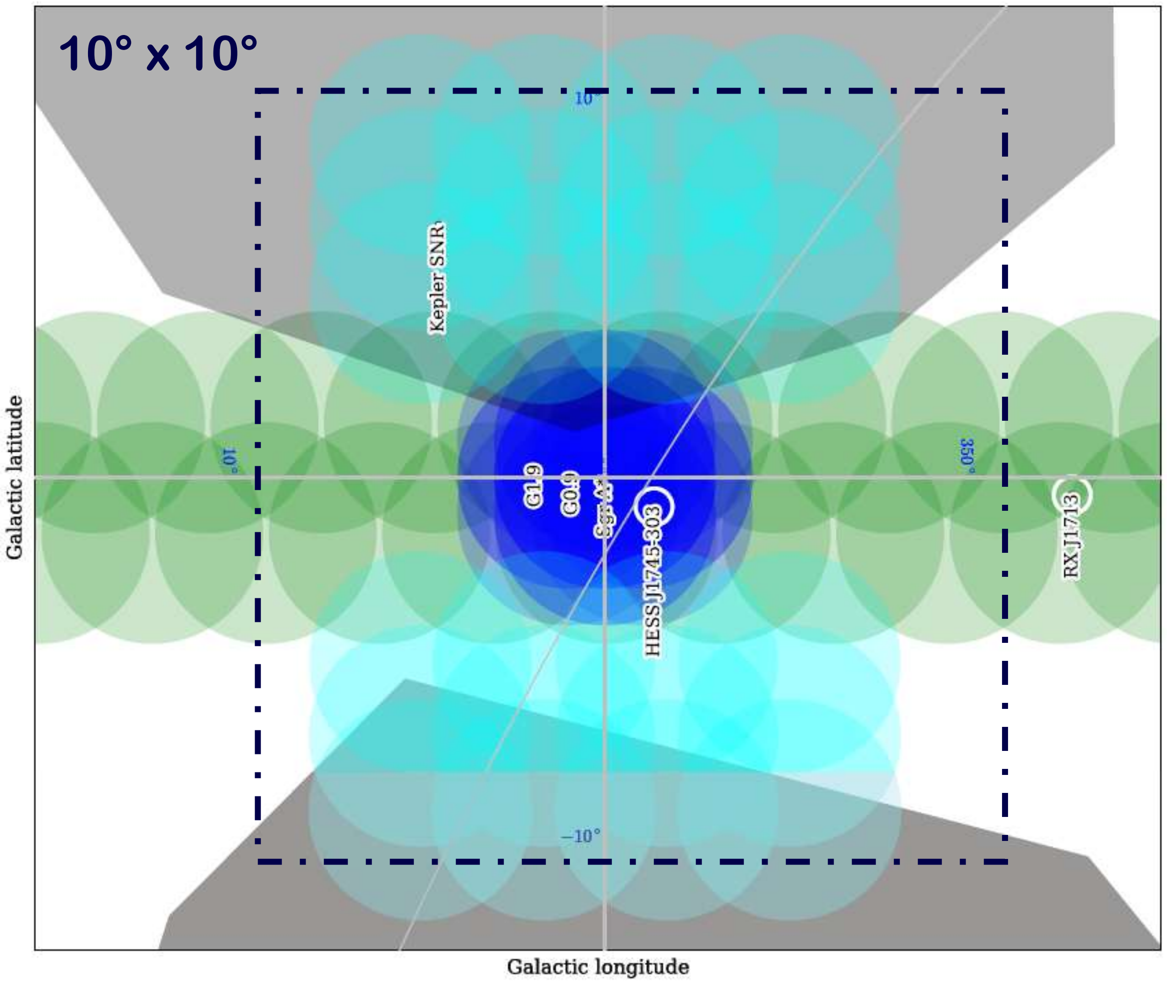
Figure 3: VHE γ-ray spectra of the diffuse emission and HESS J1745−290.



Galactic centre (a possible scenario)



Fermi Bubbles



Centre
~ 500 h

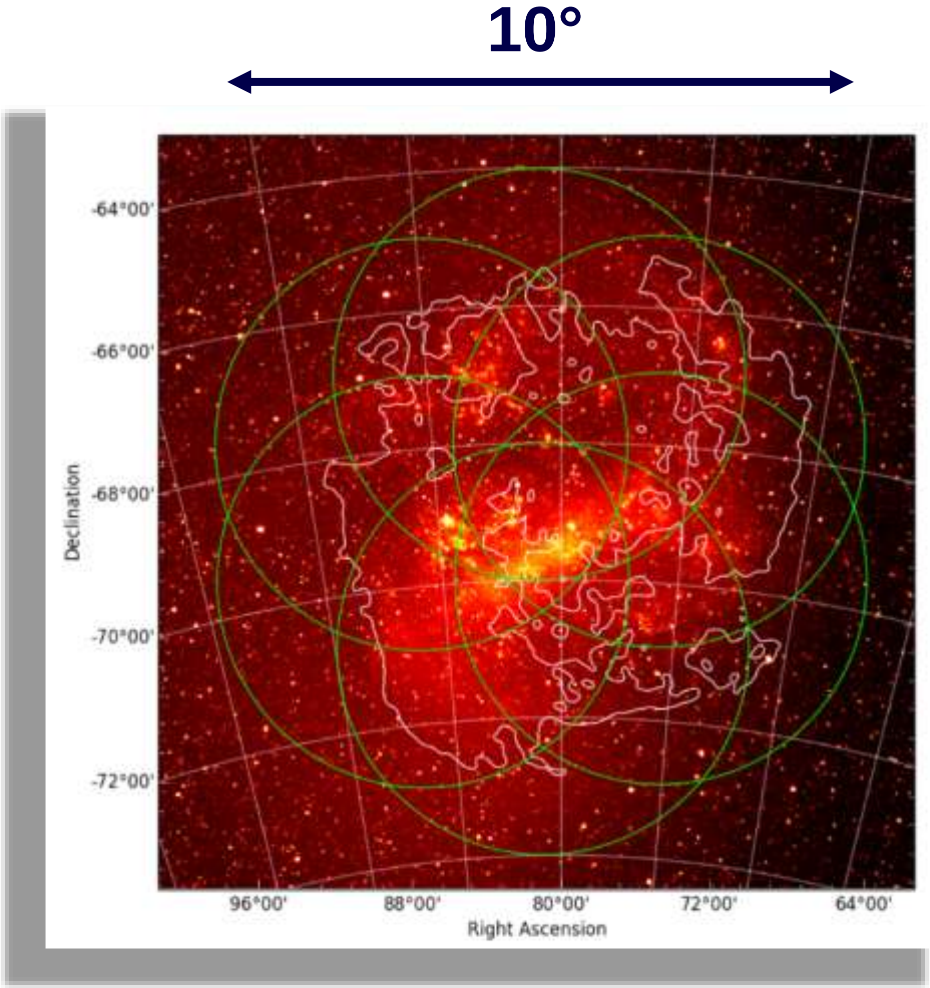
Bulge extension
~ 300 h

GP survey

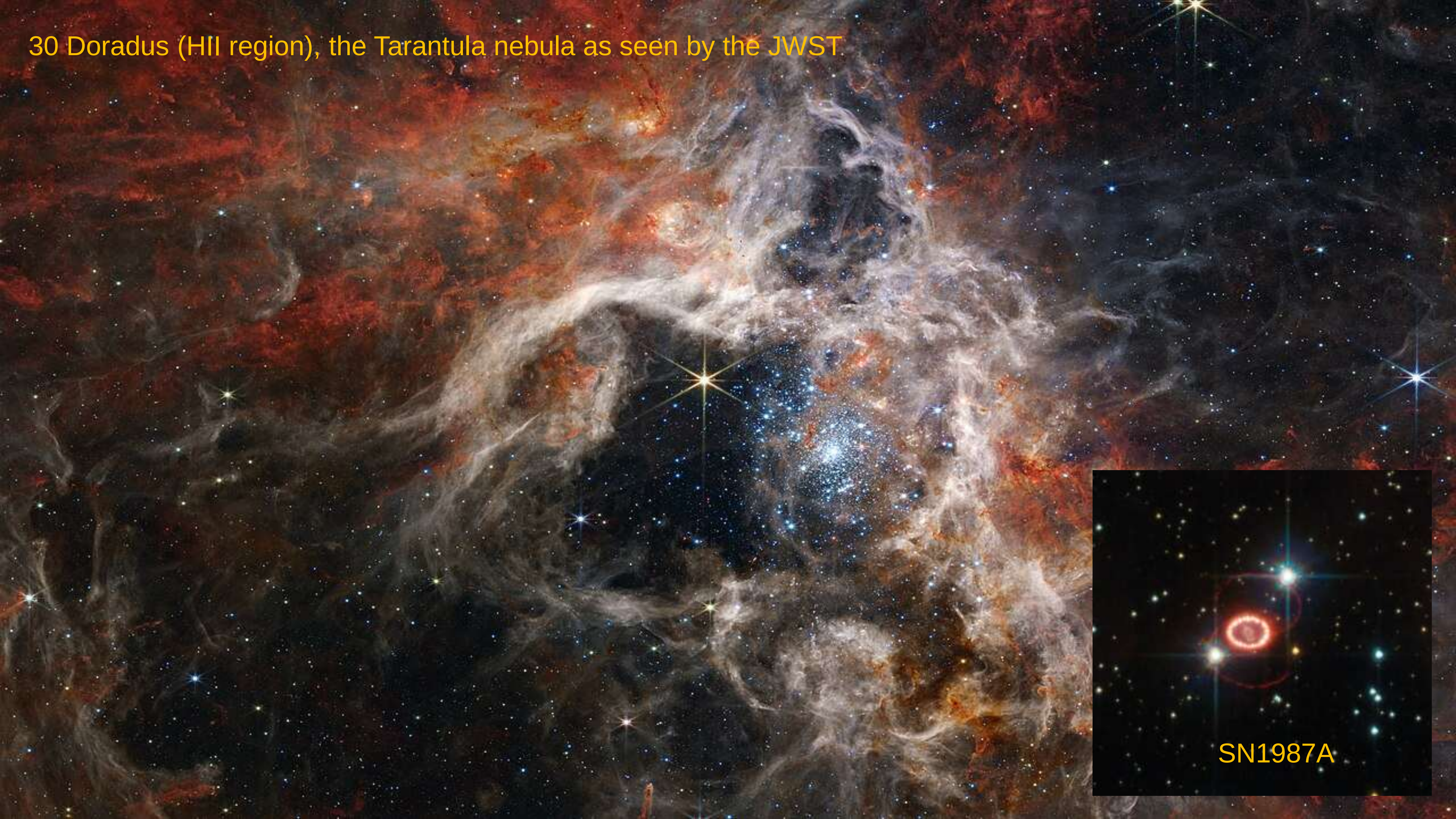
Fermi bubbles

LMC survey

- A laboratory for CR production and transportation study
  - 10% of MW star formation (2% vol.)
  - Spatially resolved sources
- Some genuine VHE sources
  - 30 Doradus, the most luminous HII region of the local group SN1987A remnant (in 30 Doradus)
  - SNR N132B)
  - The most powerful pulsar, PSR J0537-6910
  - LMC P3, γ-binary
  - PSR J0540-6919 (GeV only)
  - Superbubble, 30 Doradus C
- A target for Dark matter search?
  - 50% of 10^9 Solar masses in a Dark halo

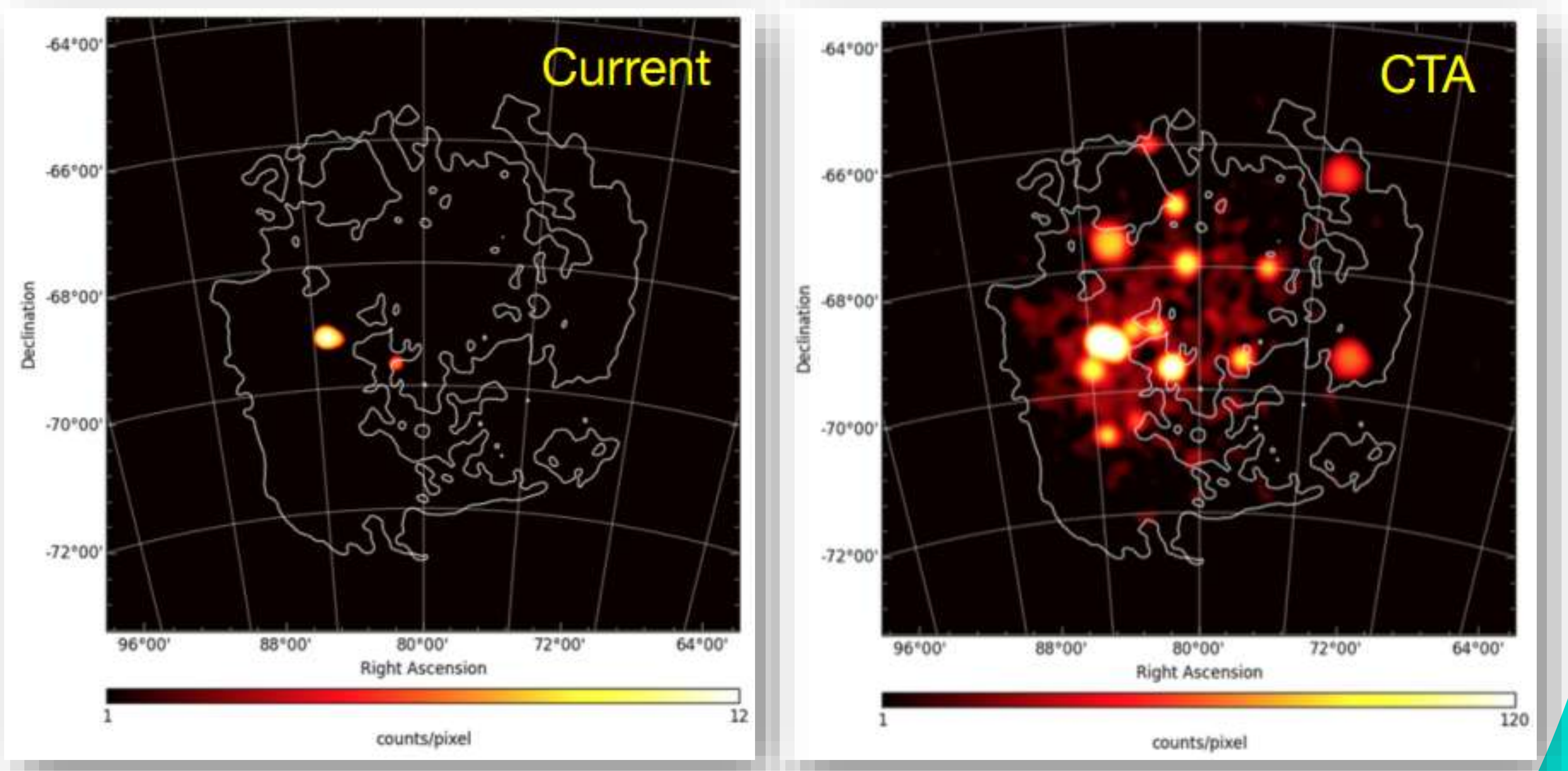


Approximately face-on
No absorption, nor source confusion
Distance ~49 kpc, known at % level


30 Doradus (HII region), the Tarantula nebula as seen by the JWST
SN1987A

LMC survey

(Image from the Science with CTA, 2017)



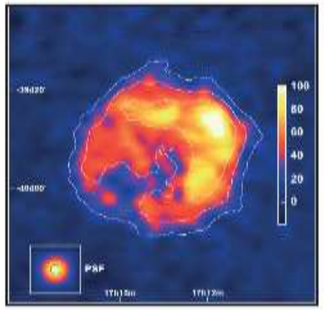
Resolving regions down to 20 pc in size

E>200 GeV

- Deep survey over 4 years (~300 h)
- Continued with 150h over 6 years for SN1987A, if detected

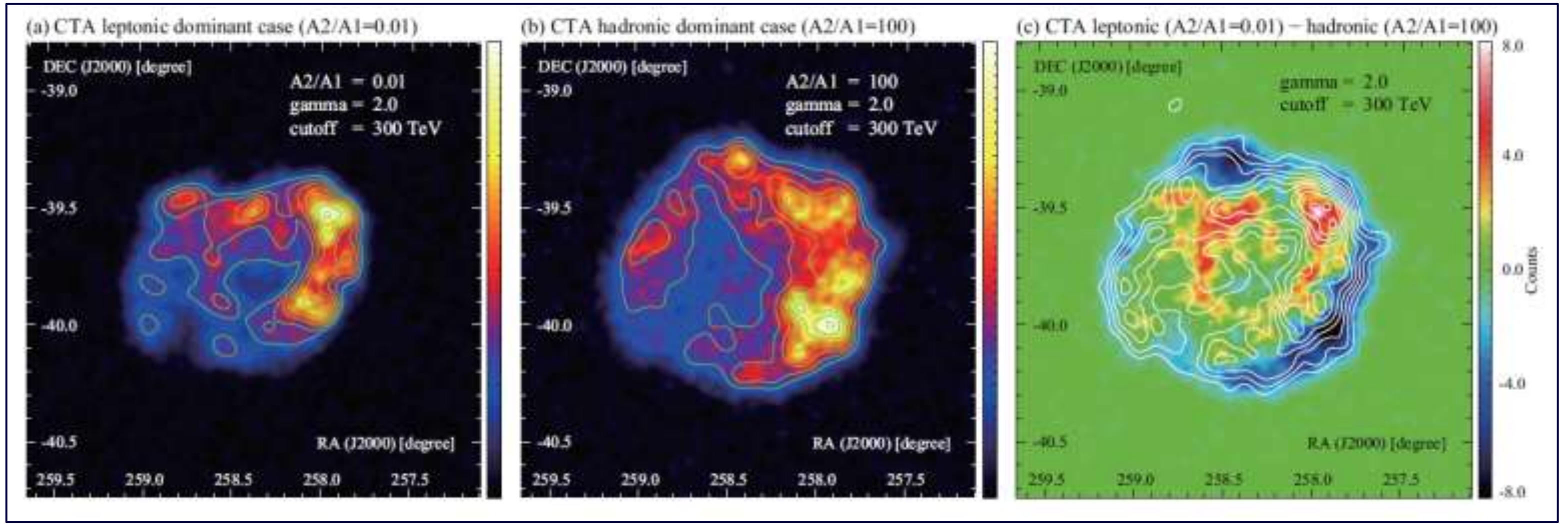
Sensitivity of the Cherenkov Telescope Array to TeV photon emission from the Large Magellanic Cloud
A Acharyya et al., MNRAS, Vol. 523, Issue 4, Aug. 2023, DOI : 10.1093/mnras/stad1576, ArXiv

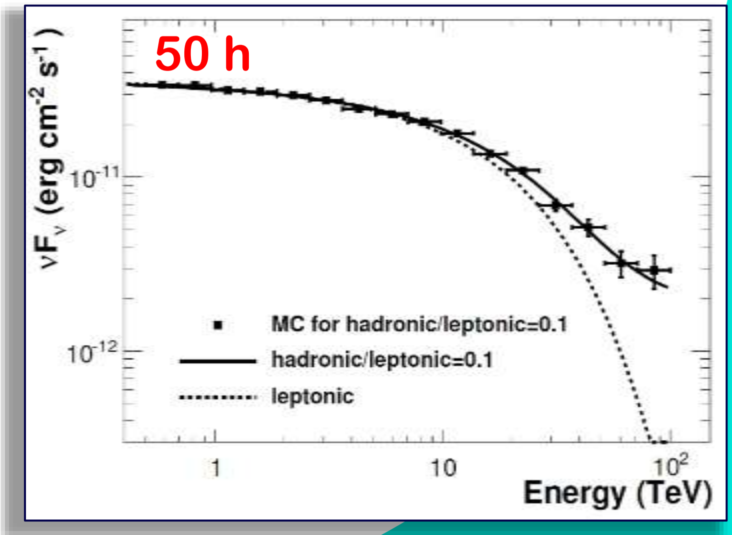
Cosmic ray pevatrons (SNRs)



H.E.S.S., A&A, 449, 223, 2006

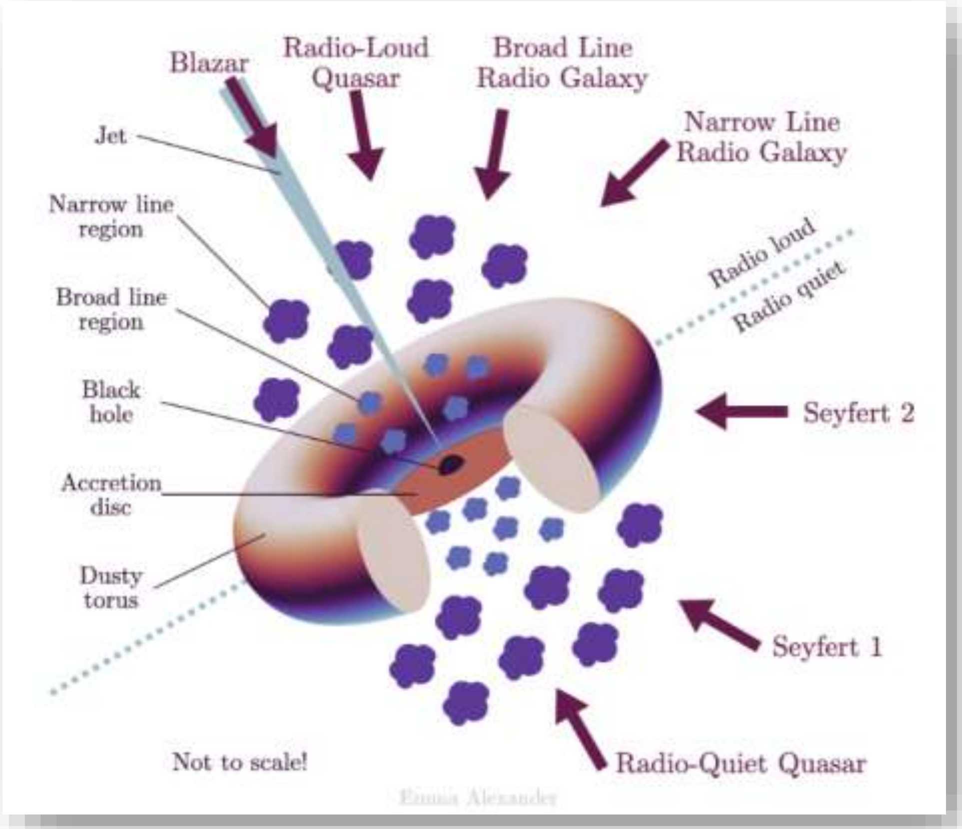
- Galactic Sources emitting > PeV CR → > 100 TeV γ-rays
  - SNRs preferred since a long time, through diffusive shock acceleration
- First indications from H.E.S.S., LHAASO, HAWC but none are SNRs!

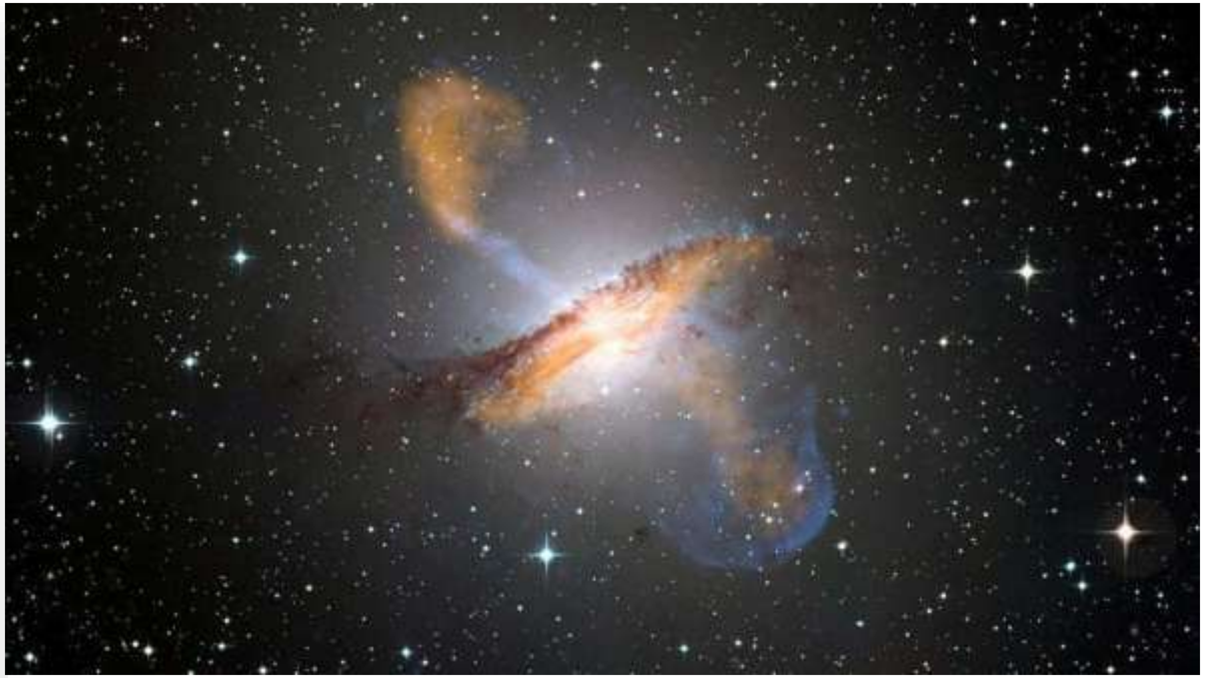




Illustrative

Extragalactic survey





Centaurus A
X, radio, visible, z = 0.00183 (106 Lyr)

→ *Extragalactic Sources in Elina Lindfors' lecture*

Extragalactic survey

- A blind (Uniform sensitivity) survey
  - 25% of the Sky
  - First time!

  Former observations motivated by Known counterparts or flaring states for 50% of the known sources

- A first VHE catalog, Unbiased determination of blazar luminosity function
- Exploring
  - Serendipitous (flaring) sources
  - Dark sources (no signal at lower E)
- Connects to Galactic plane survey
- Covers Coma, Virgo, Cen A, & Fermi bubbles (N)

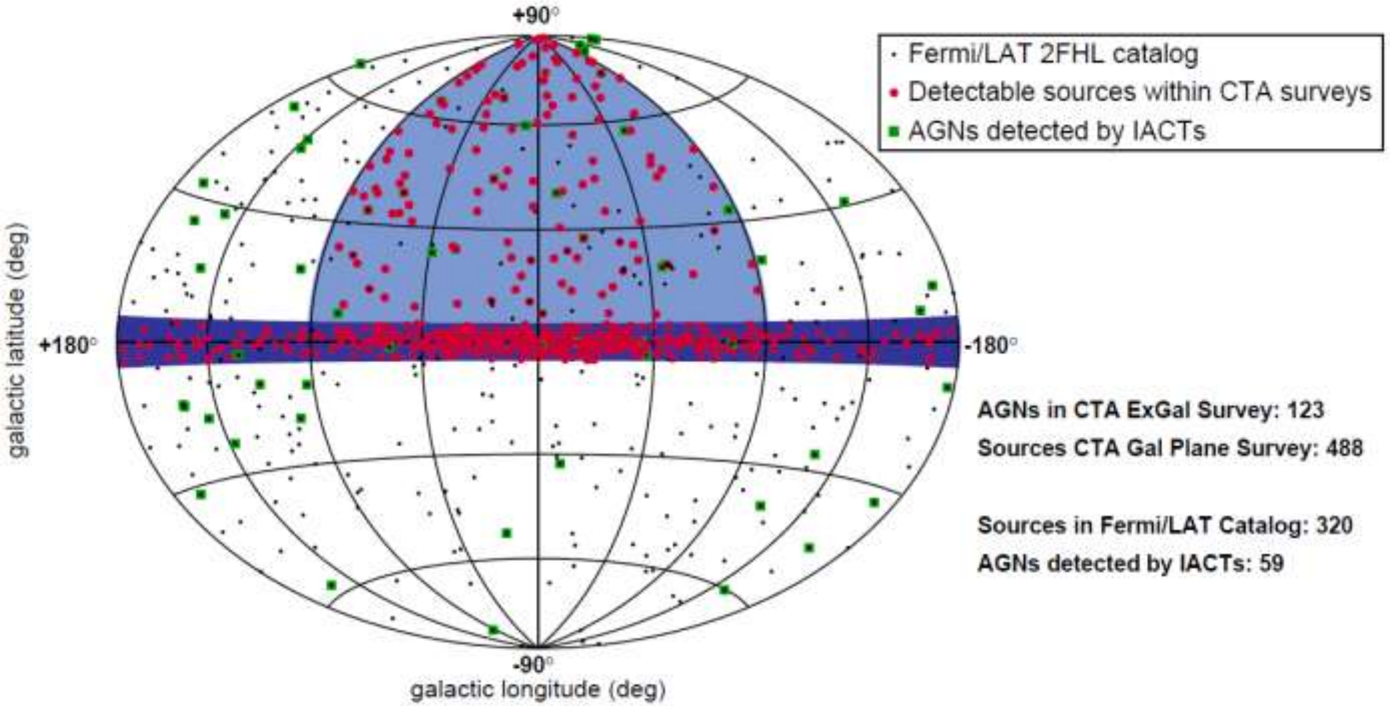
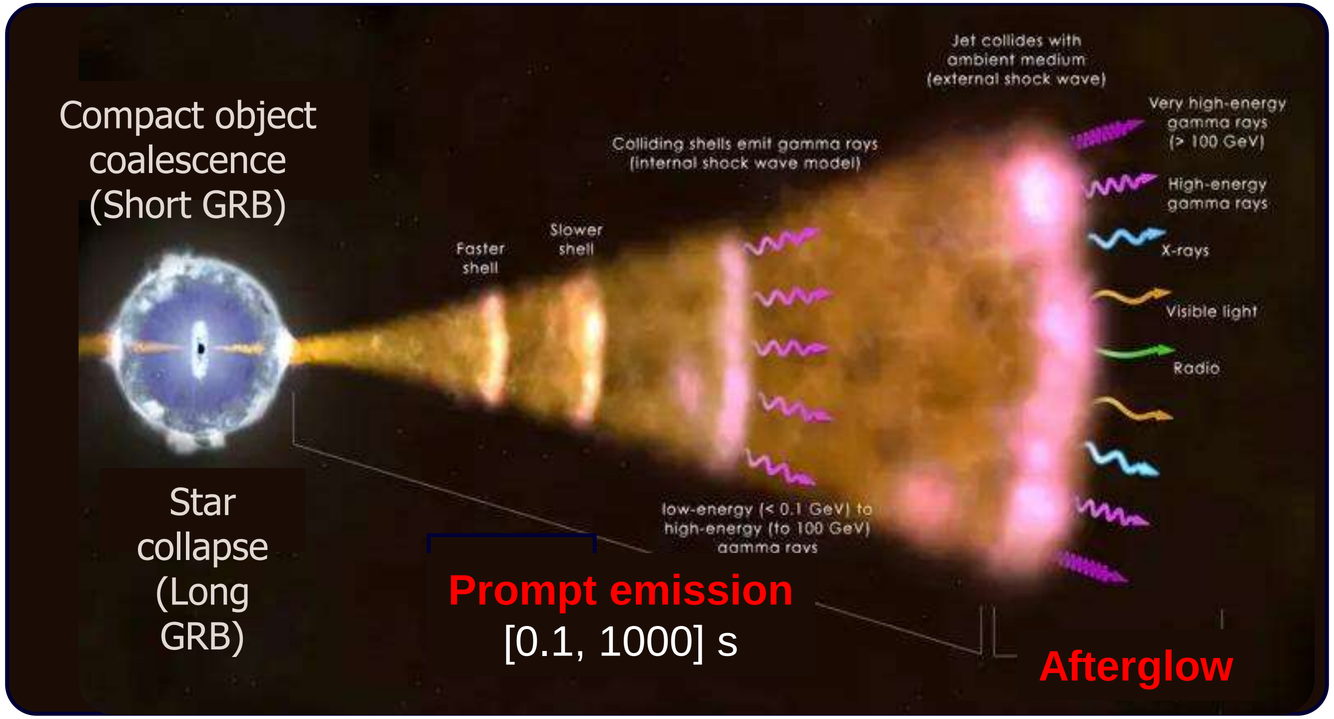


Figure 8.3 – Proposed region of the extragalactic survey in Galactic coordinates: $b > 5°; -90° < l < 90°$, 25% of the sky, marked in a light blue. The Galactic Plane Survey is indicated by a darker blue. Red points show a hypothetical example of the sources to be detected in the extragalactic and Galactic CTA surveys. Extragalactic and unidentified Fermi-LAT hard-spectrum sources (2FHL catalogue [191]) are displayed as black dots whereas green points show the AGN that have been detected so far by IACTs [204].

Transients (GRBs)



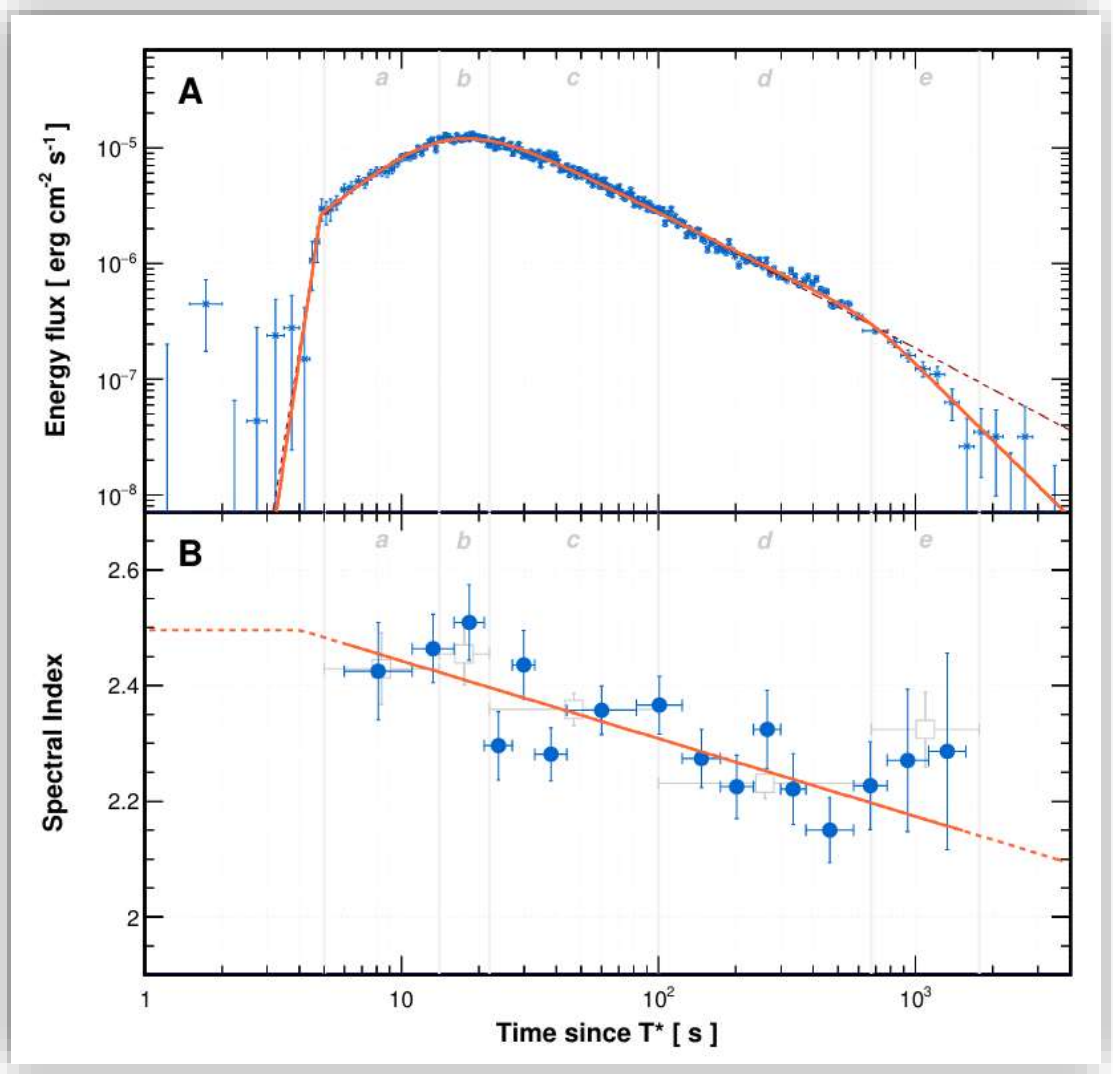
→ *See Diego Götz's talk*

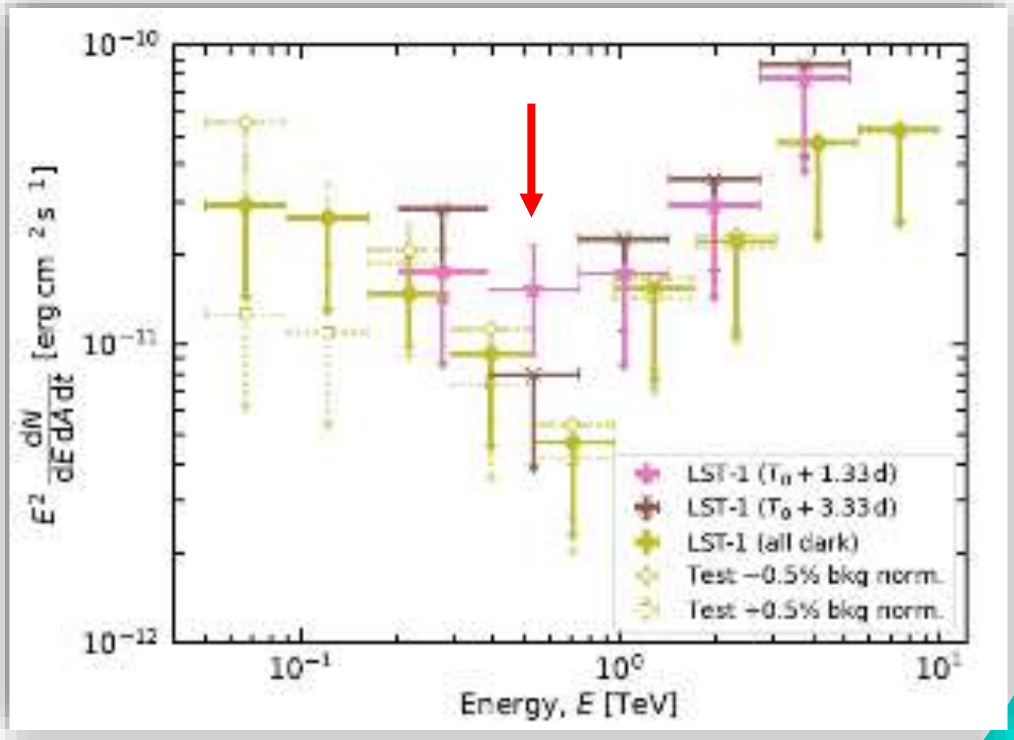
Name	Obs.	σ_{max}	Delay	E range	T90 (s)	Eiso (erg)	z
180720B	**H.E.S.S.**	5.3	10 hr	100 - 400 GeV	49	6×10^{53}	0.65
190114C	**MAGIC**	50	1'	0.2 - 1 TeV	25	2.5×10^{53}	0.42
190829A	**H.E.S.S.**	22	4h20'	0.2 - 3 TeV	63	2×10^{50}	0.0785
201216C	**MAGIC**	>5	57"	100 GeV	30	5×10^{53}	1.1
221009A	**LHAASO/CTAO**	>250	143"	200 GeV – 7 TeV	1000	10^{55}	0.15

GRB 221009A

A tera–electron volt afterglow from a narrow jet in an extremely bright gamma-ray burst

Science, 28 Jun 2023 Vol 380, Issue 6652 pp. 1390-1396, [DOI: 10.1126/science.adg9328](https://doi.org/10.1126/science.adg9328)

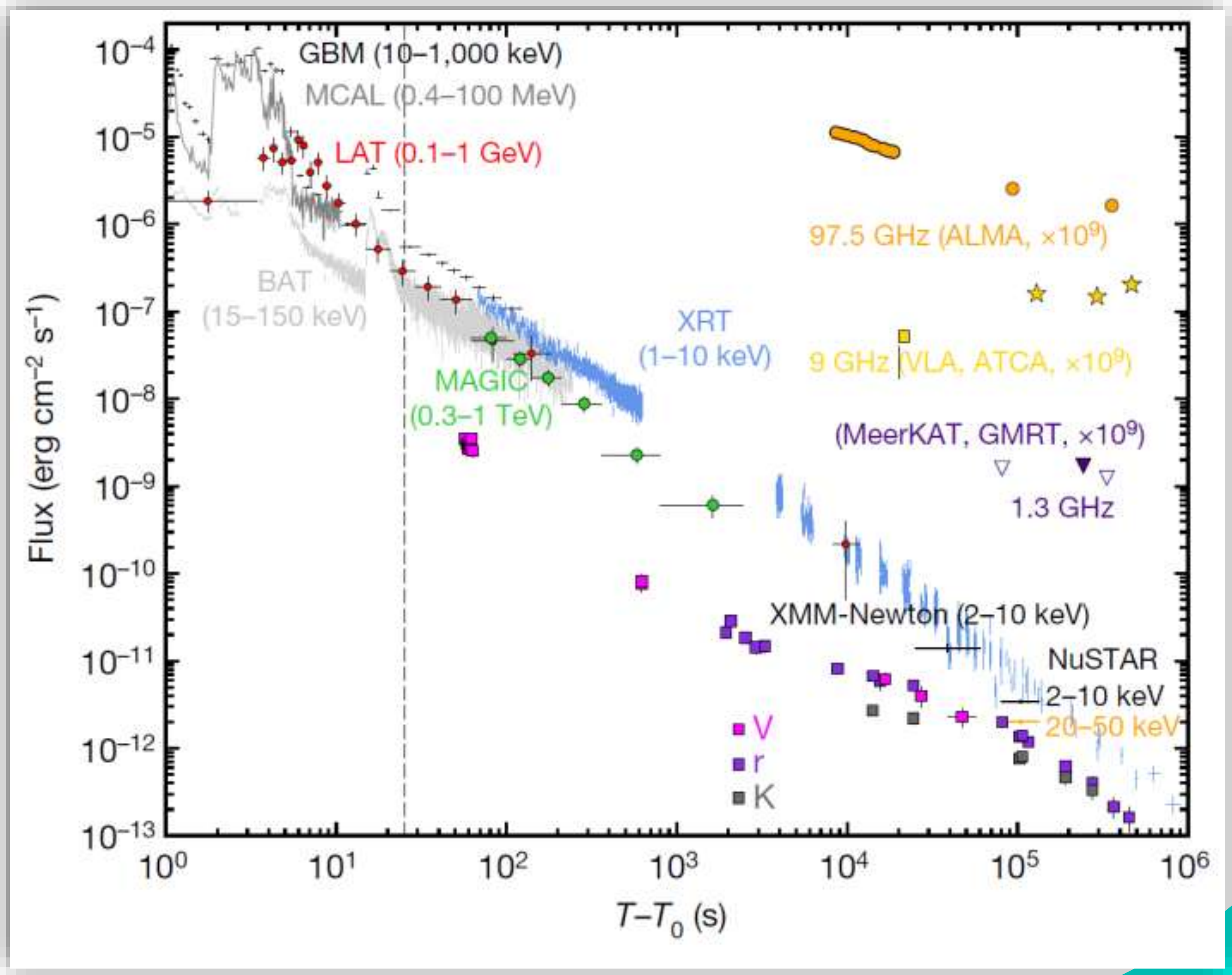




CTAO LST1, 1.6 days delay (Moonlight)

K. Abe et al 2025 ApJL 988 L42, DOI 10.3847/2041-8213/ade4cf

GRB190114C

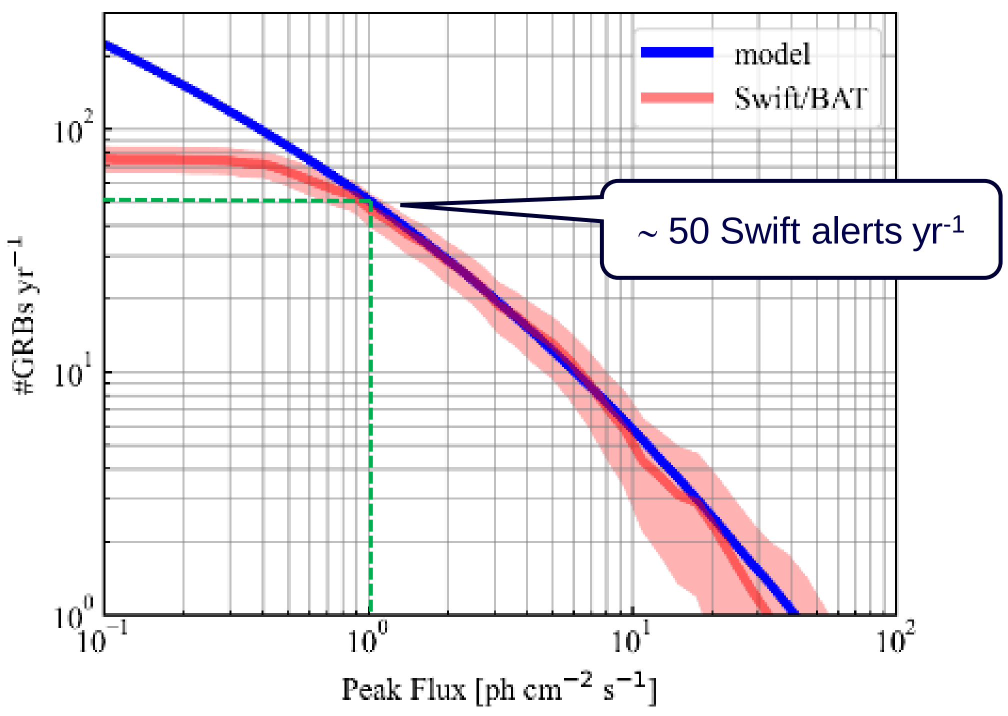


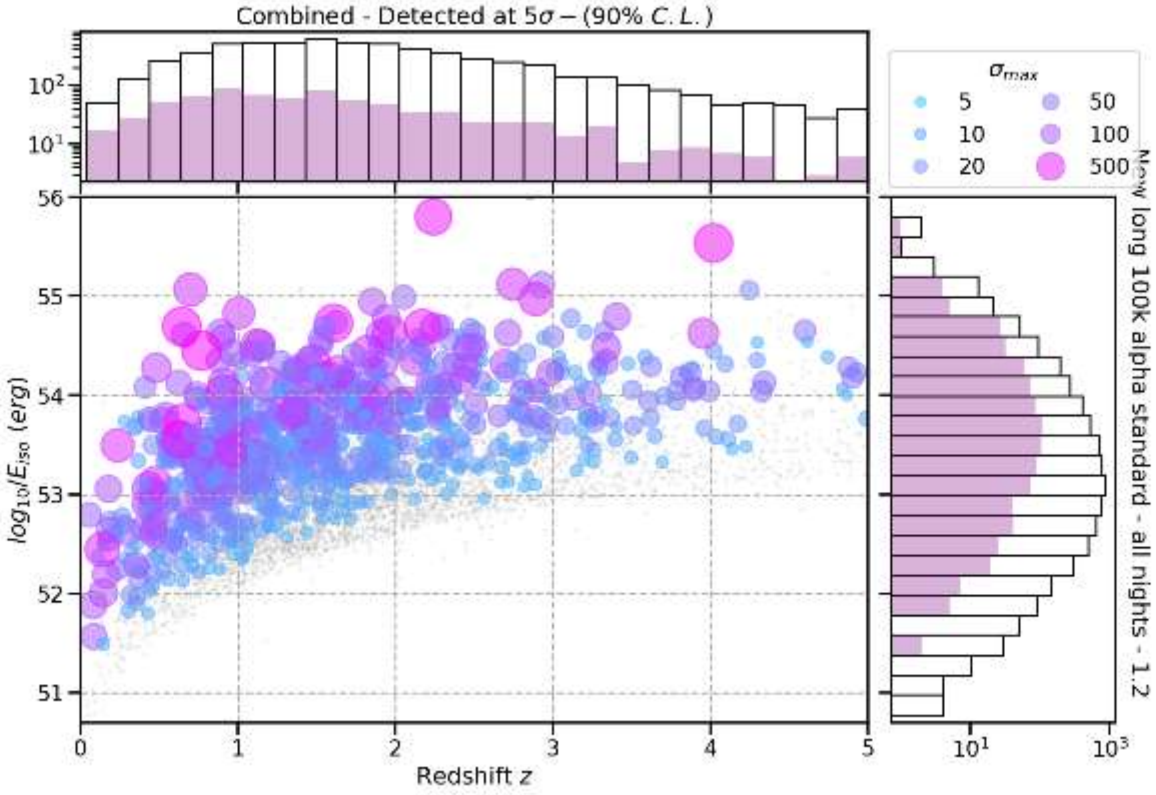
GBM (10–1,000 keV)
MCAL (0.4–100 MeV)
LAT (0.1–1 GeV)
BAT
(15–150 keV)
MAGIC
(0.3–1 TeV)
XRT
(1–10 keV)
97.5 GHz (ALMA, ×10⁹)
9 GHz (VLA, ATCA, ×10⁹)
(MeerKAT, GMRT, ×10⁹)
1.3 GHz
XMM-Newton (2–10 keV)
NuSTAR
2–10 keV
20–50 keV
V
r
K
Flux (erg cm⁻² s⁻¹)
T–T₀ (s)

GRB detections

(Consortium Paper - Preliminary)

Work in progress
Z. Bosnjak, G. Ghirlanda, F. Longo, L. Nava, Th. Stolarczyk





- 6-10 GRB long afterglows per year > 5 sigma
- Potentially 50% with prompt detection (> 30s)

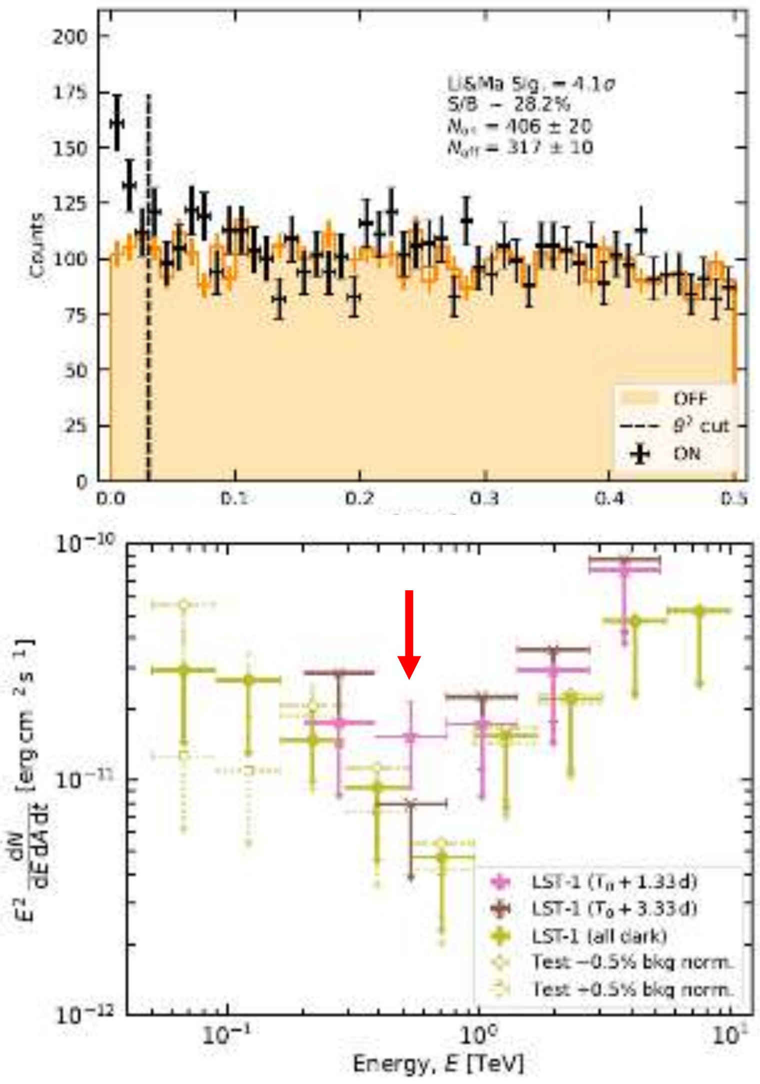
(210 years of Swift alerts, $\Phi_{50\text{-}150keV}$> 1 ph/cm²/s)

Conclusion

LST-1 Science papers

- A detailed study of the **Very-High-Energy Crab Pulsar** emission with the LST-1 telescope
- Detection of the **Geminga pulsar** at energies down to 20 GeV with the LST-1 of CTAO
- **GRB 221009A**: Observations with LST-1 of CTAO and implications for structured jets in long gamma-ray bursts
- LST1 Detection of **OP313** (Quasar)
- **RS Ophiuchi**: the first galactic transient detected with the LST-1
- **SGR 1935** Observations by LST1 (SNR)
- **SN 2024bch** with LST-1
- …

GRB 221009A (during Moonlight time)



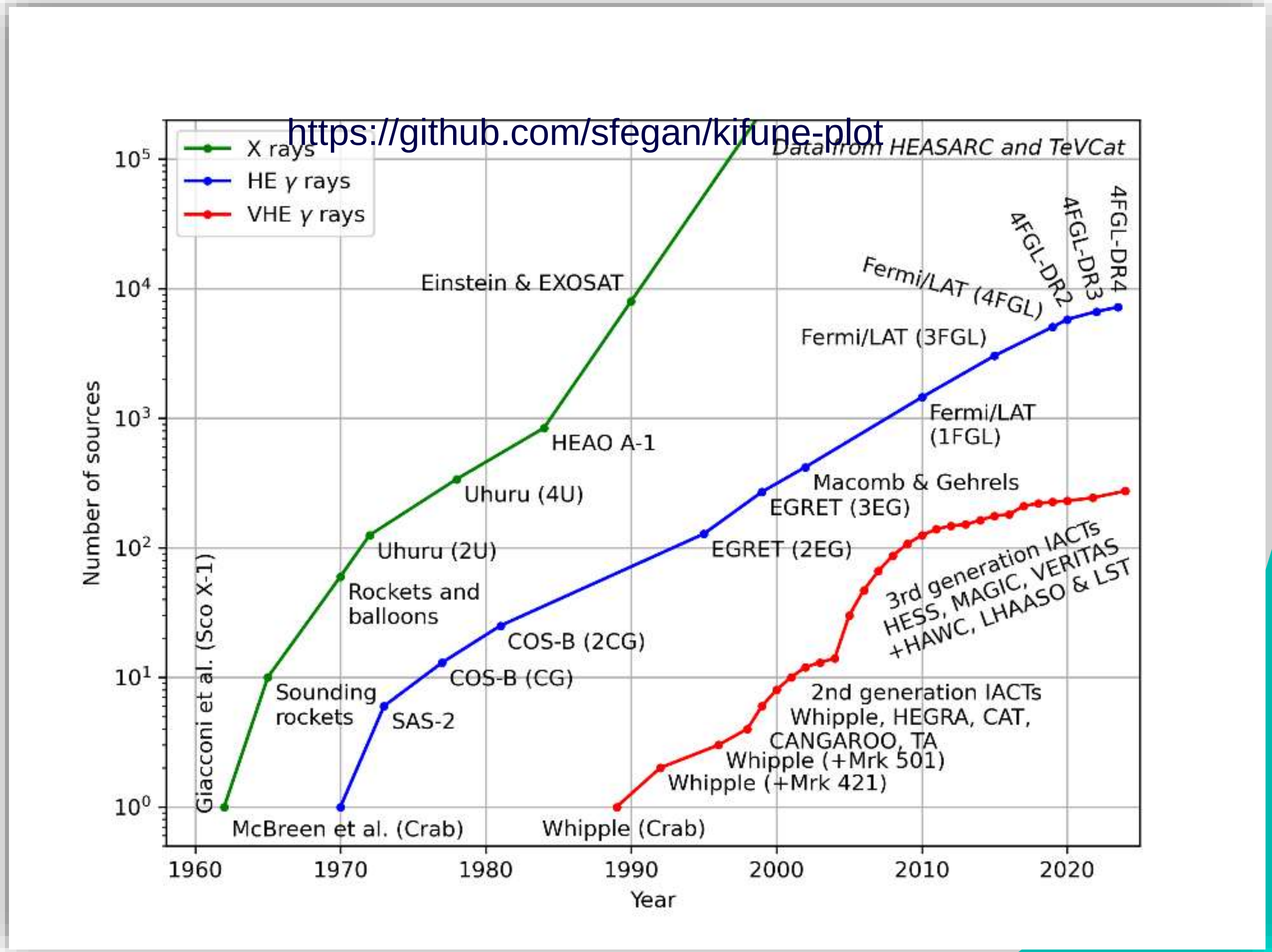
Conclusion

- CTAO, a revolution for science at VHE
  - Unprecedented sensitivity (x10) and angular resolution between 30 GeV and 300 TeV
  - Overlap with existing Fermi legacy (E>30 GeV)
  - The end spectrum of the MWL astrophysics

- Answers to fundamental questions
  - Origin of PeV Cosmic Rays
  - CR influence on ISM and star formation
  - Extreme environment physics
  - Fundamental Science (Dark matter, Lorentz inv. , IGMF)

- Tuned for transients and multimessenger astronomy
  - Low E threshold, short slewing time

→ *Markus Alhers' lecture*



Timeline

- LST-1 already taking data
  - 4 LST inauguration mid-October 26
- MST pathfinders on South Site in 2027
- Early Science starting in 2027
- Construction completion in 2032
  $\Rightarrow$ Start of Observatory operation

- Meanwhile,
  Experience CTAO in realistic conditions!

Science Data Challenge

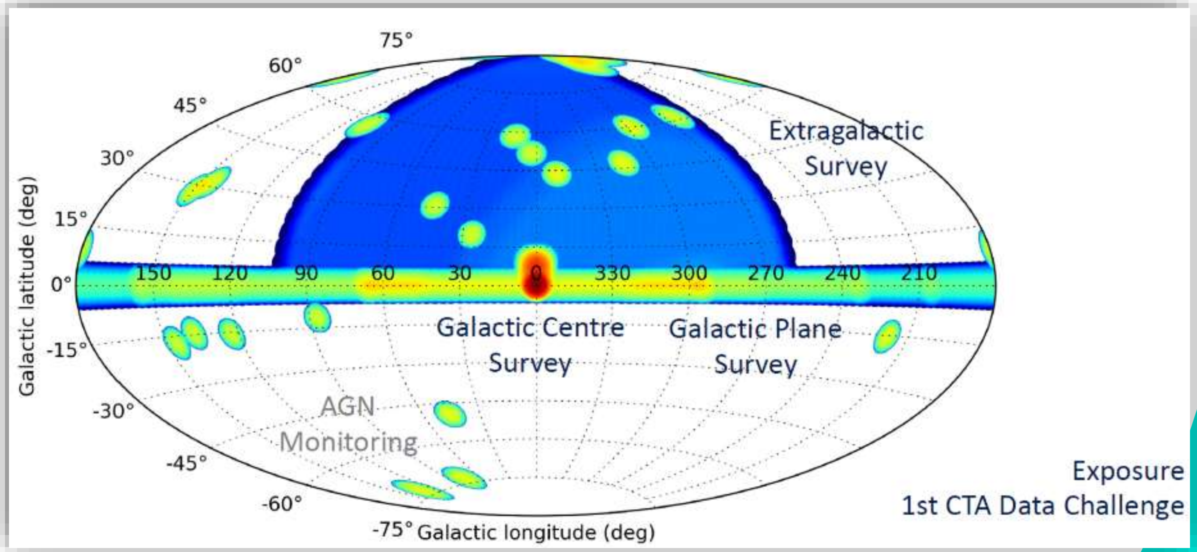
7 years of data – all Science CTAO can offer, as far as we know today

Under preparation, release expected by end 2026

Use prototype Science portal, includes user support

High level data exploitable with Gammapy

Science Data Challenge



This is a discovery machine