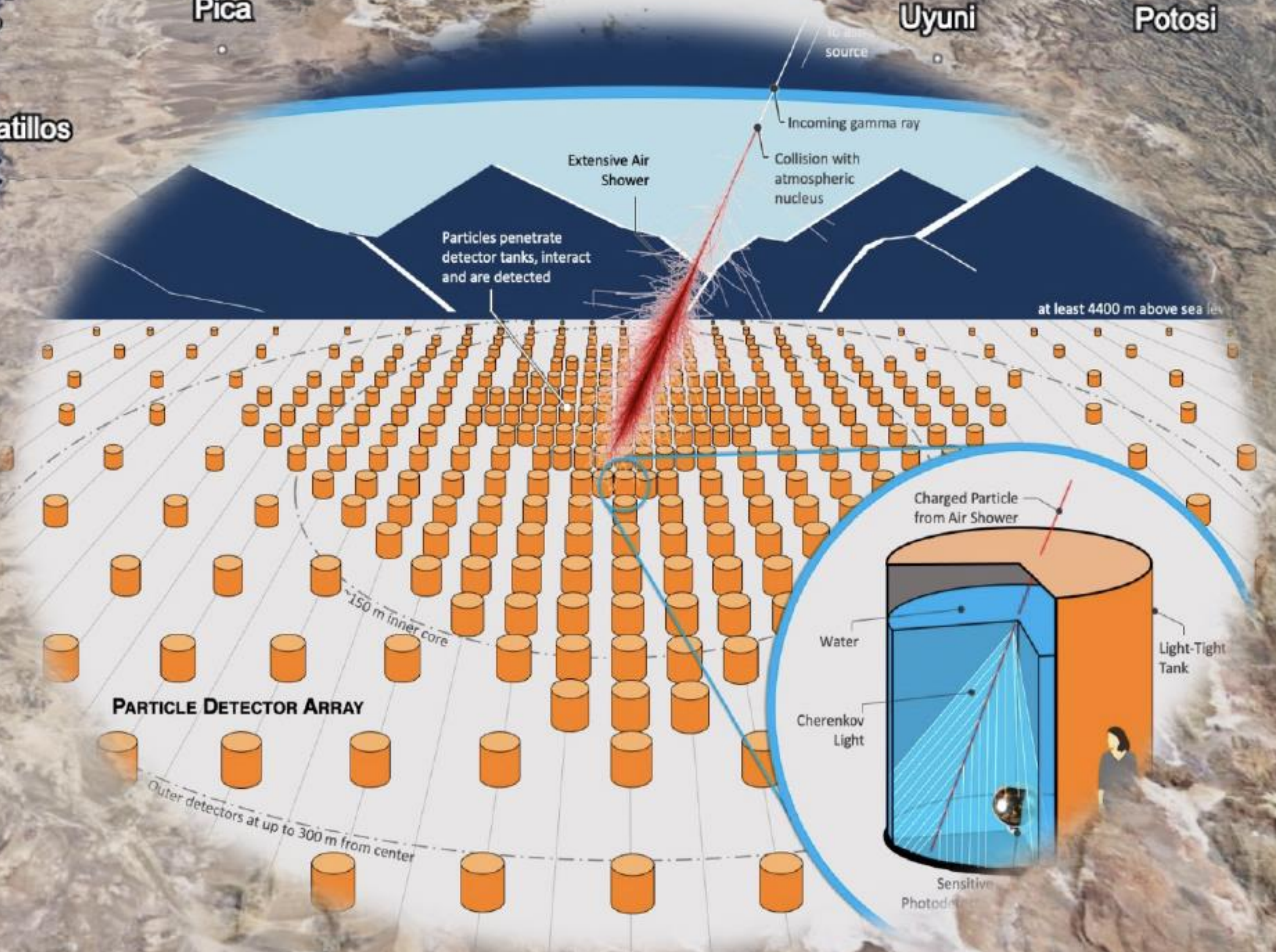
Astroparticle Symposium
Tribute to Berrie Giebels
19 Nov 2025

The Southern Wide-field Gamma-ray Observatory

Alt 4,770 m – Lat 22.946 S – Long 67.6775 W

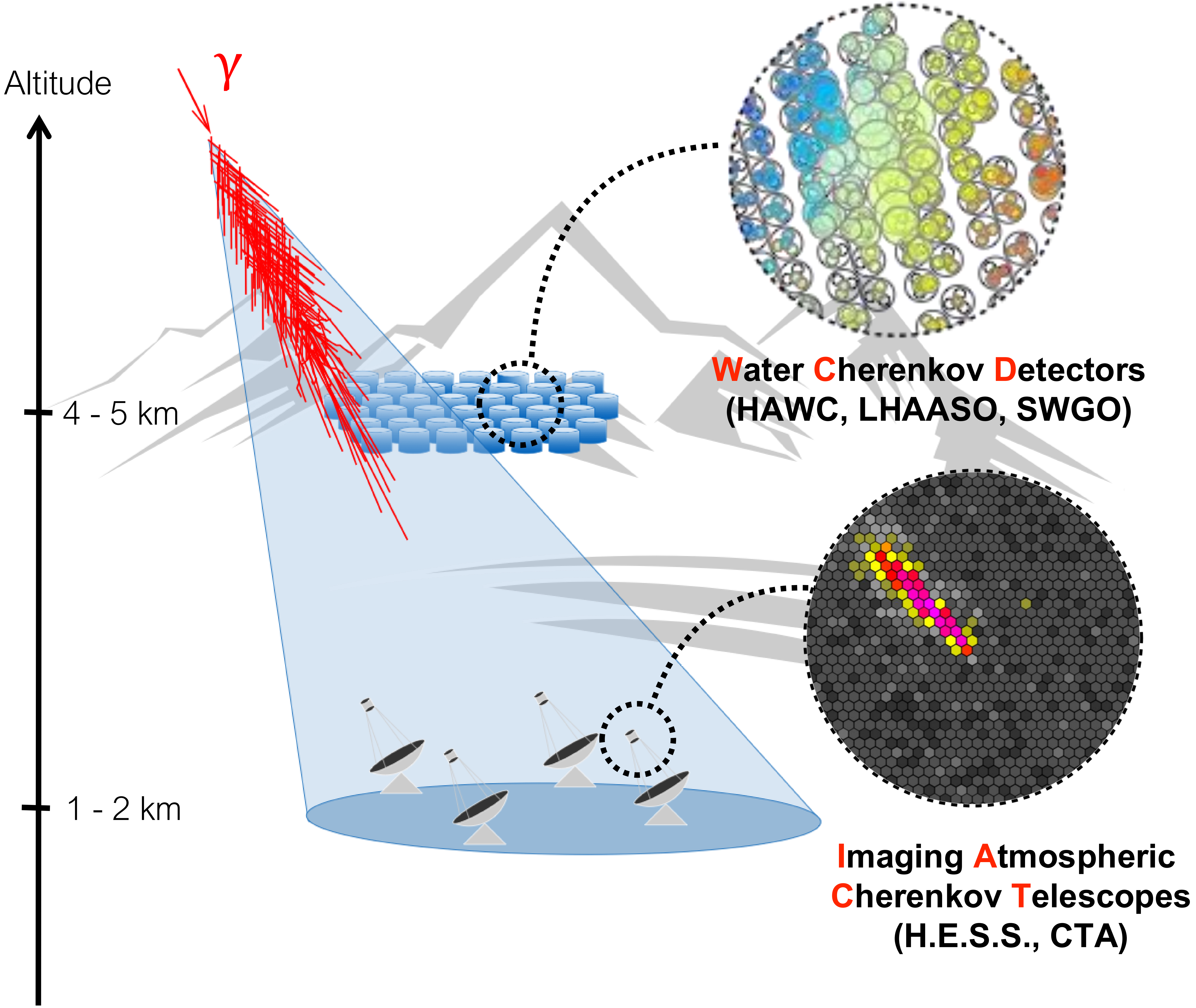
Marianne Lemoine-Goumard

LP2i Bordeaux

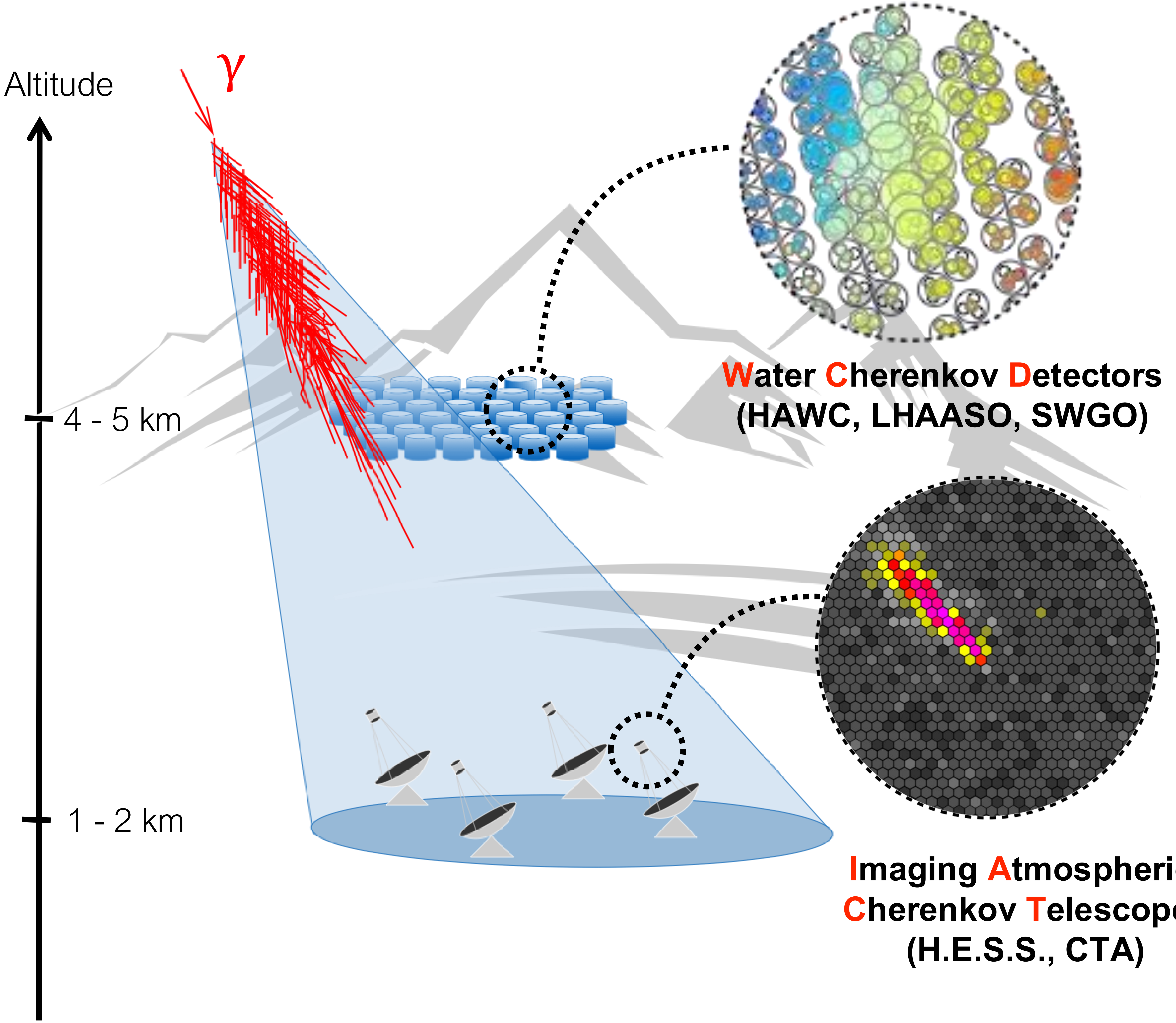


- ▶ Ground based instruments
- Science cases : results from HAWC and LHAASO
- SWGO: design, prototypes and construction
- Science with SWGO

Ground based instruments

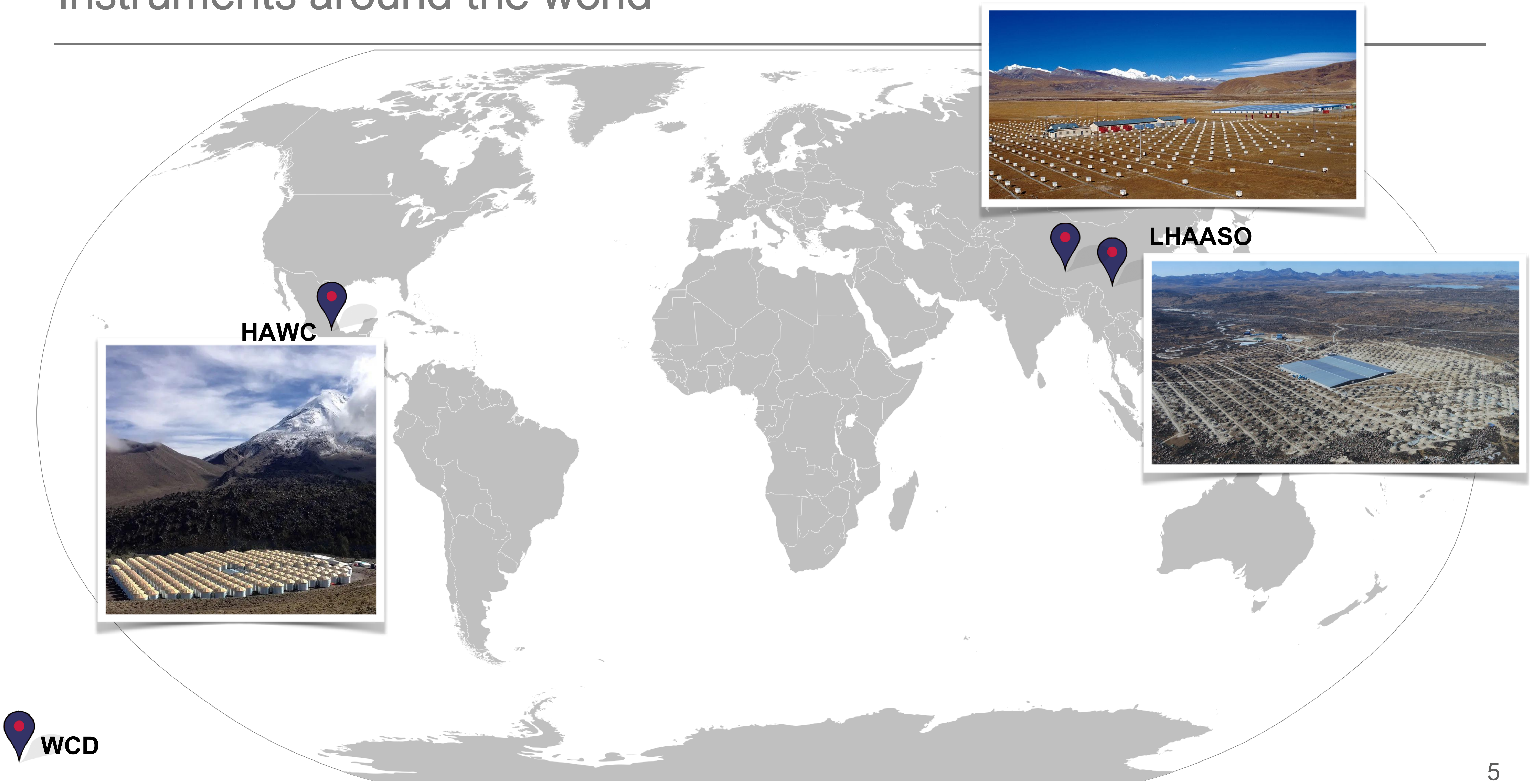


Ground based instruments



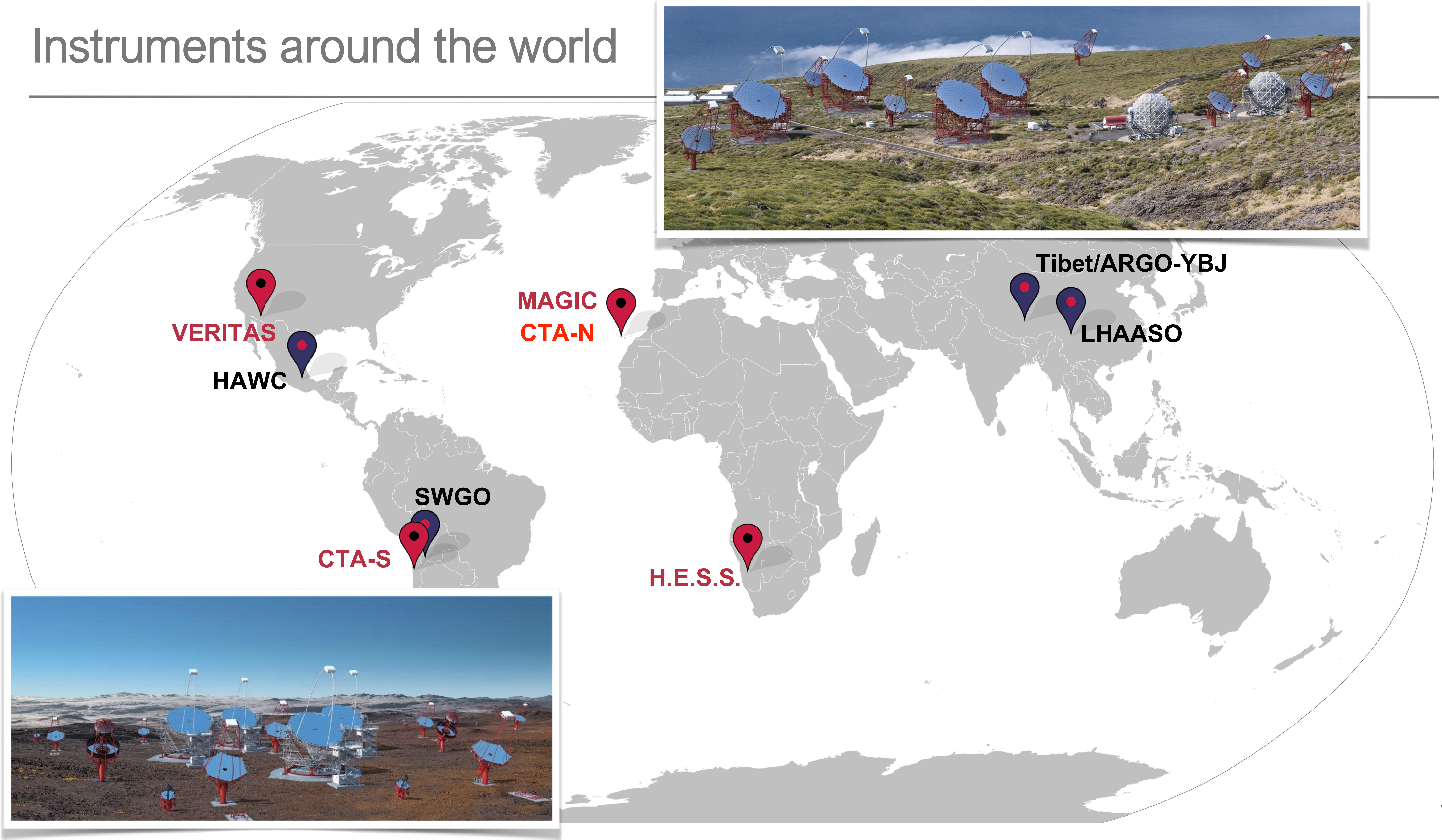
	Duty cycle	Field of view	Energy range	Energy resolution	Angular resolution
Water Cherenkov Detectors (HAWC, LHAASO, SWGO)	✓ ~95%	✓ 90^{o}	✓ 0.5 - 100 TeV	✗ 20% at 1 TeV 10% at 100 TeV (on-array events)	✗ $0.8 - 0.1^{o}$
Imaging Atmospheric Cherenkov Telescopes (H.E.S.S., CTA)	✗ ~10% ~1000 h/y	✗ 5^{o}	✓ 0.03 - 100 TeV	✓ < 10% for E > 1 TeV	✓ $0.1 - 0.05^{o}$

Instruments around the world

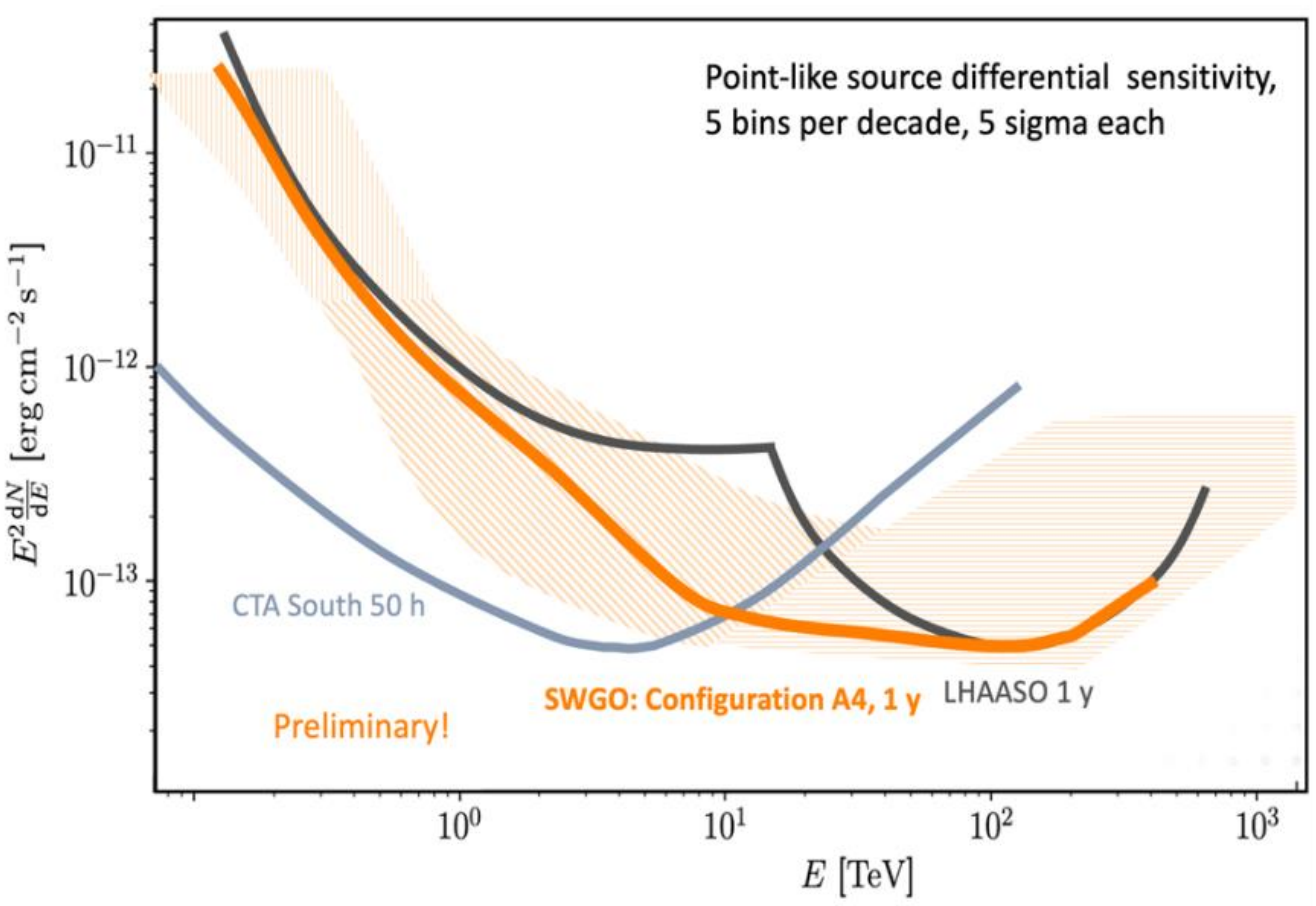


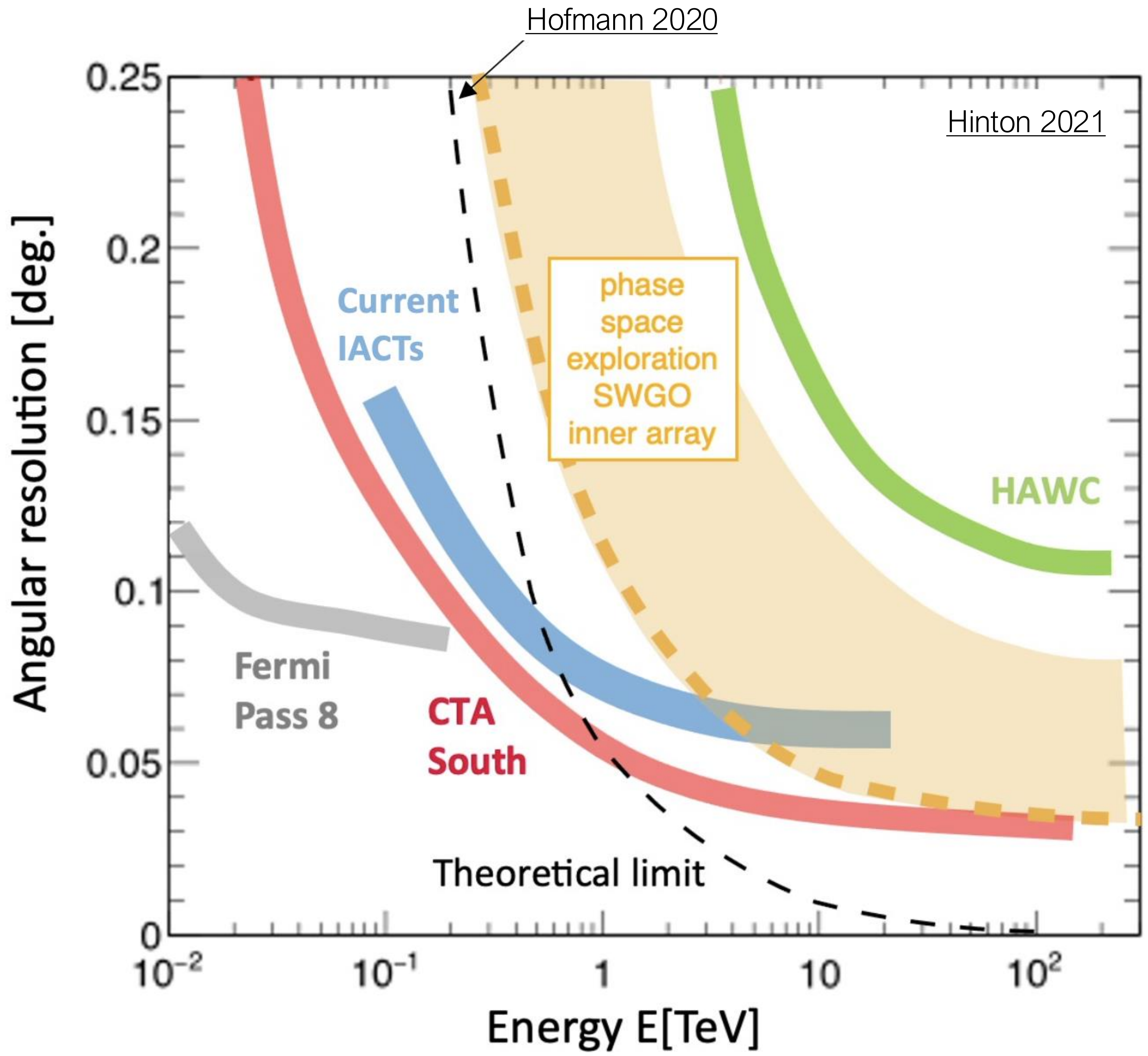
Instruments around the world

Instruments around the world



Stronger together !





- Ground based instruments
- ▶ Science cases : results from HAWC and LHAASO
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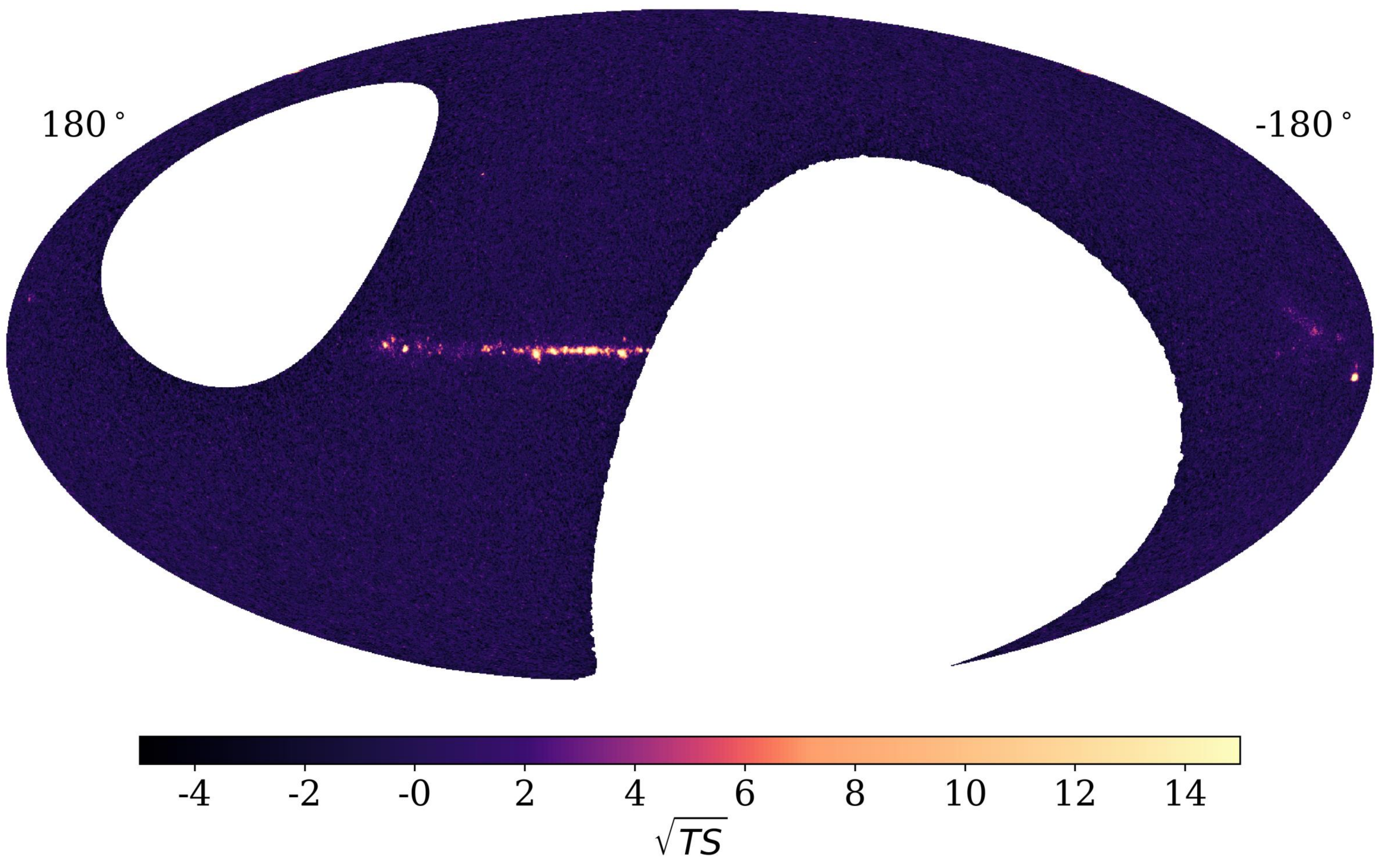
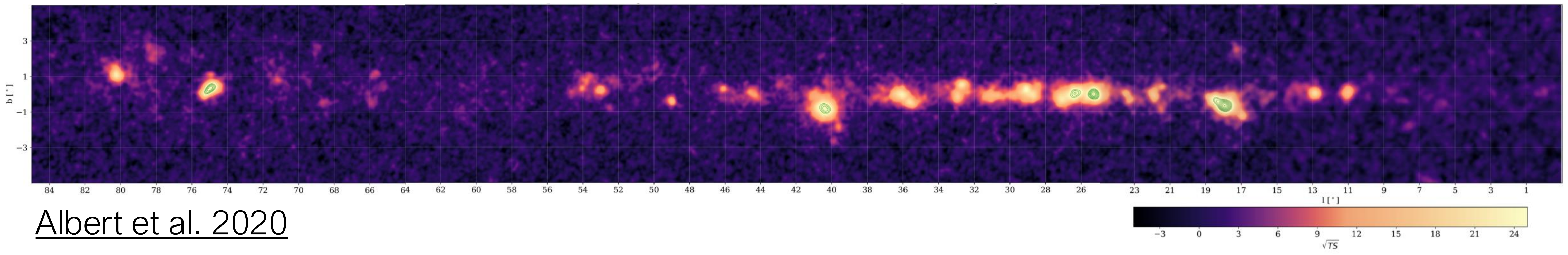
Catalogue of VHE and UHE ɣ-ray sources - search for PeVatrons

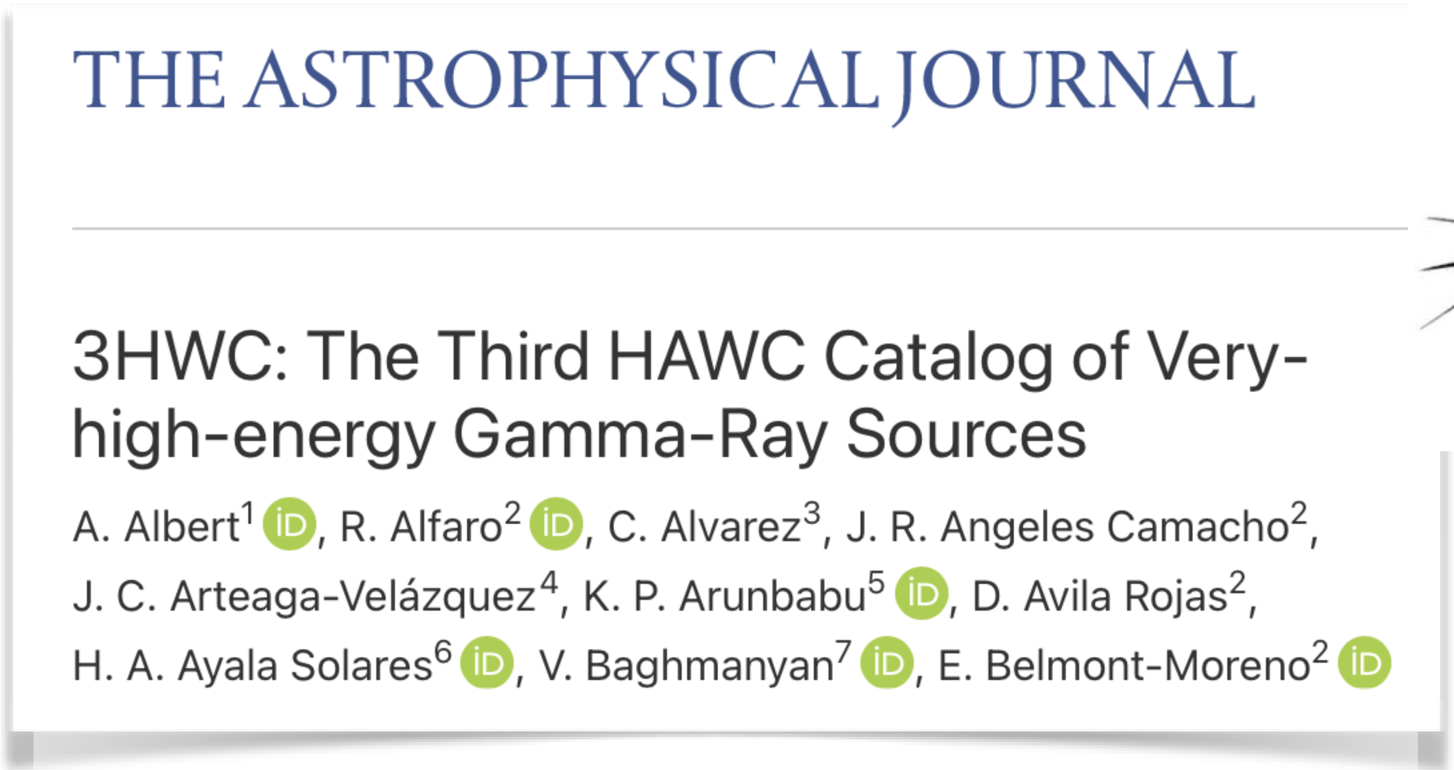
65 sources reported by HAWC, including
9 sources with E > 56 TeV, 3 sources > 100 TeV



1910 days

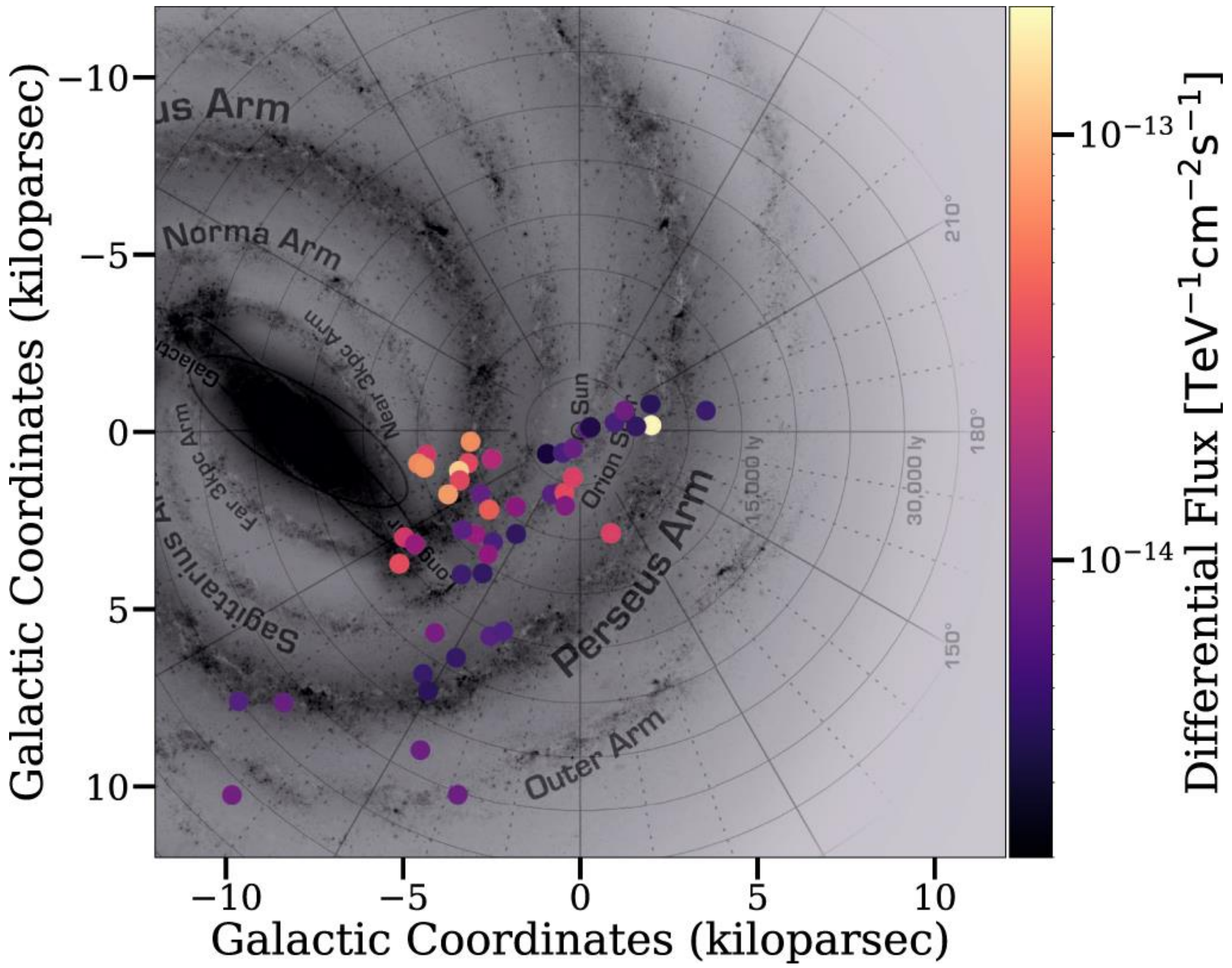


Albert et al. 2020


THE ASTROPHYSICAL JOURNAL

3HWC: The Third HAWC Catalog of Very-high-energy Gamma-Ray Sources

A. Albert[1], R. Alfaro[2], C. Alvarez[3], J. R. Angeles Camacho[2], J. C. Arteaga-Velázquez[4], K. P. Arunbabu[5], D. Avila Rojas[2], H. A. Ayala Solares[6], V. Baghmanyan[7], E. Belmont-Moreno[2]



49 HAWC sources are spatially associated with a pulsar (with available distance)

Catalogue of VHE and UHE ɣ-ray sources - search for PeVatrons

The First LHAASO Catalog of Gamma-Ray Sources

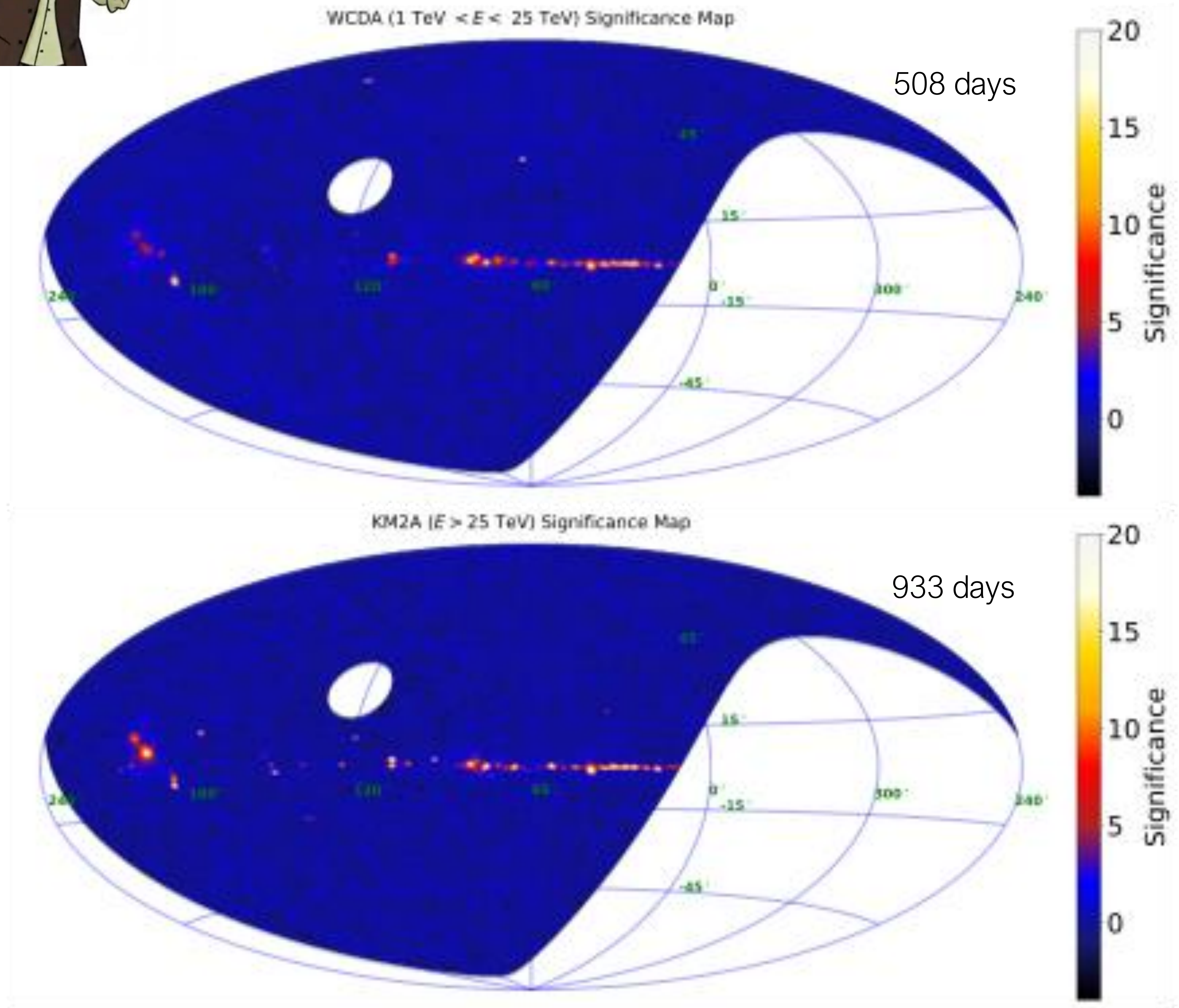
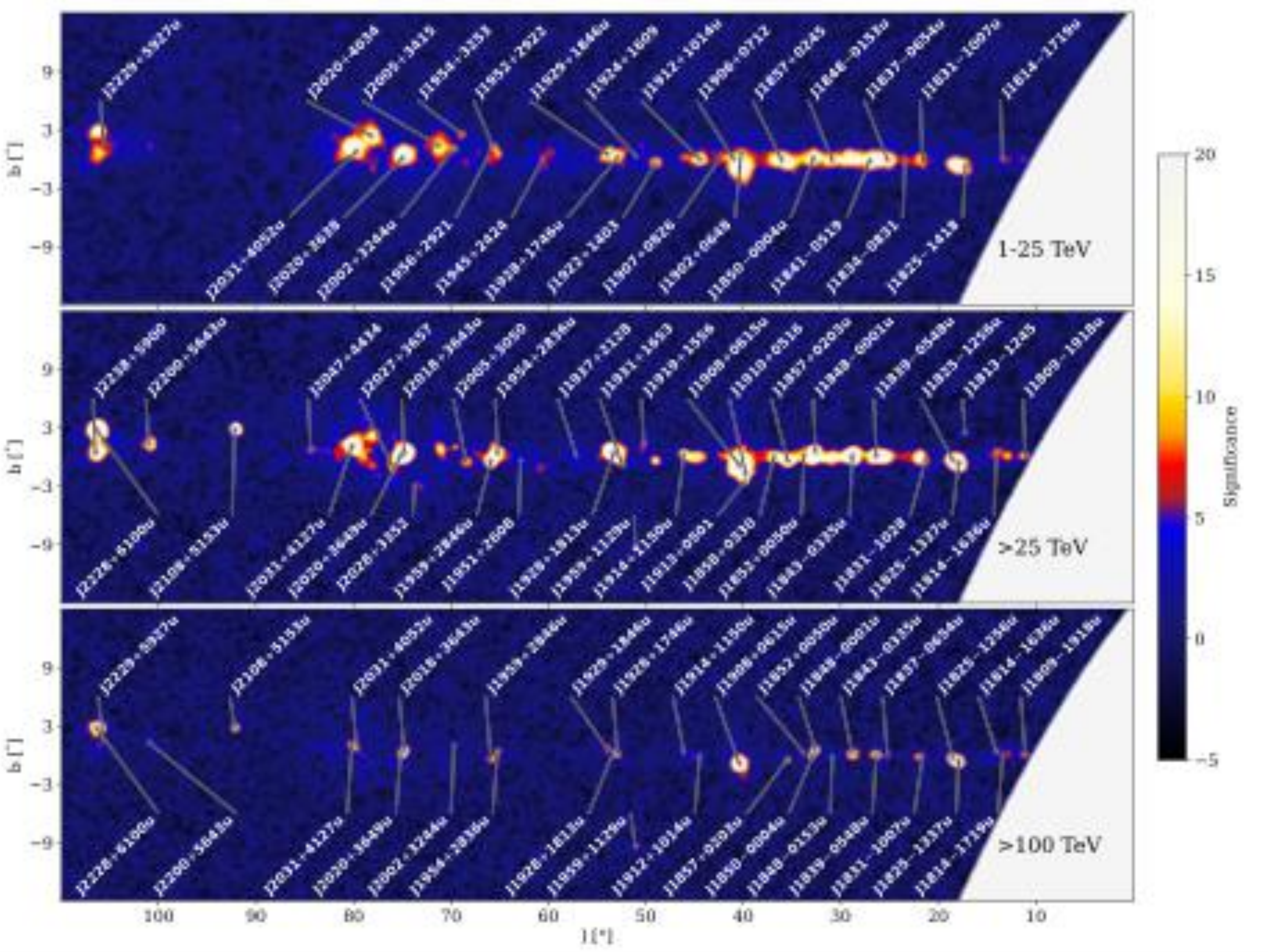


Figure 1. Significance maps of the region monitored by LHAASO. A point test source with a spectral in of 2.6 for WCDA data and 3.0 for KM2A data is used.

90 sources reported by LHAASO,
43 of them detected at UHE (> 100 TeV)



Cao et al. 2024

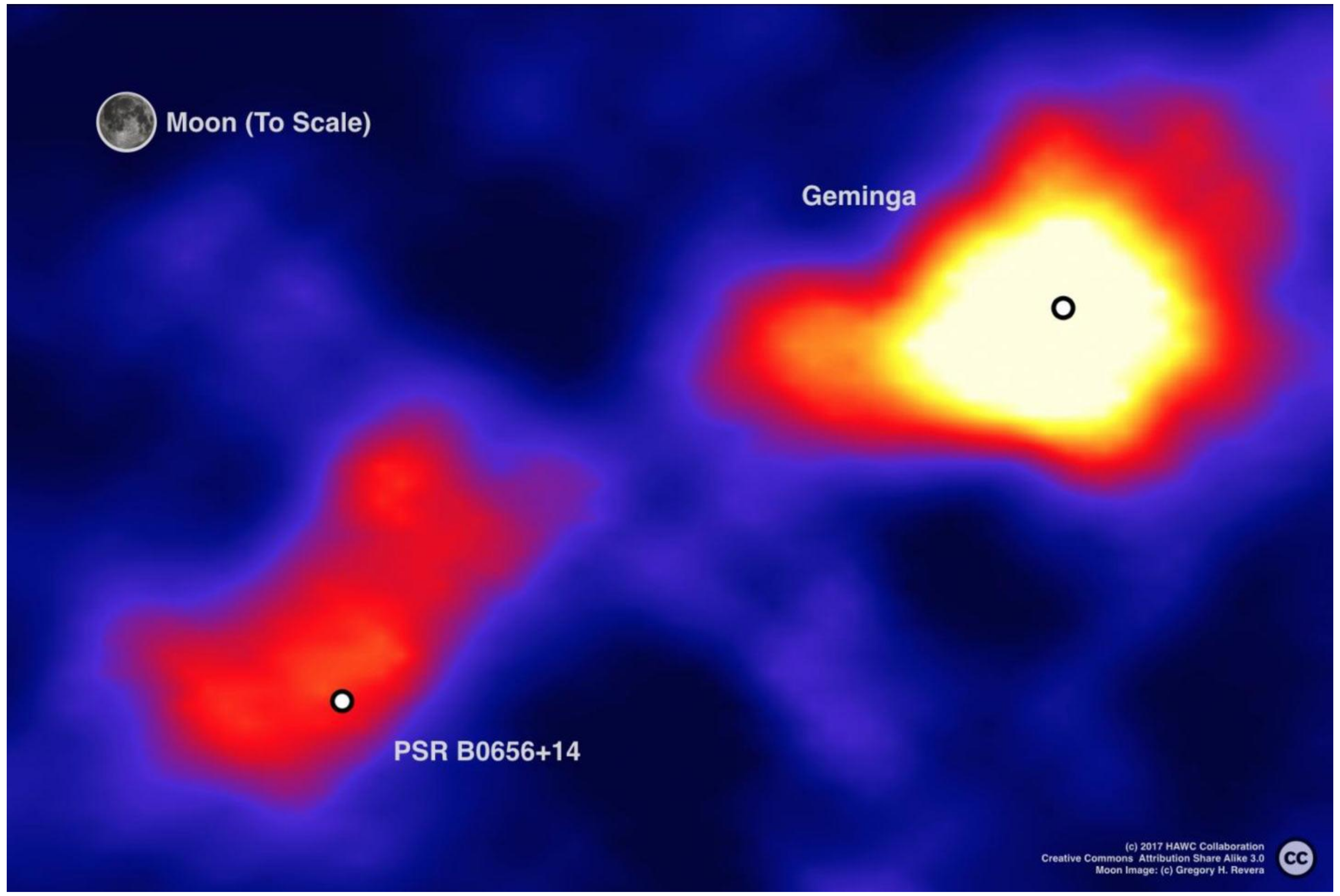
(Very) extended sources

New class of VHE ɣ-ray sources : pulsar halos

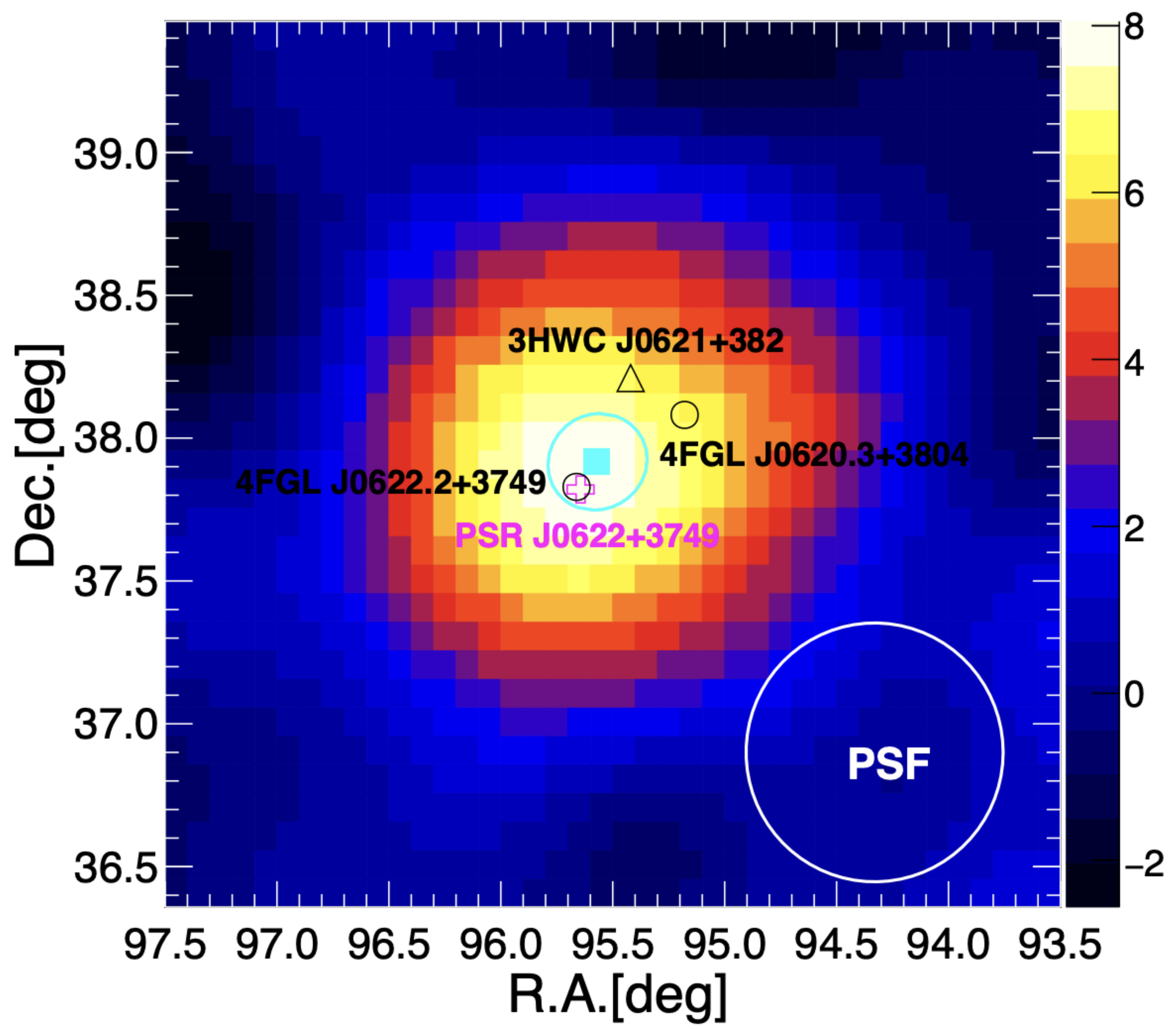
- Constrain positron excess
- Probe ISM characteristics (diffusion coefficient)
- Understand galactic pulsar population
- Find mis-aligned pulsars

Challenging for Cherenkov telescopes (but not impossible)

-> Detection of Geminga by H.E.S.S. (HESS collaboration, 2023)

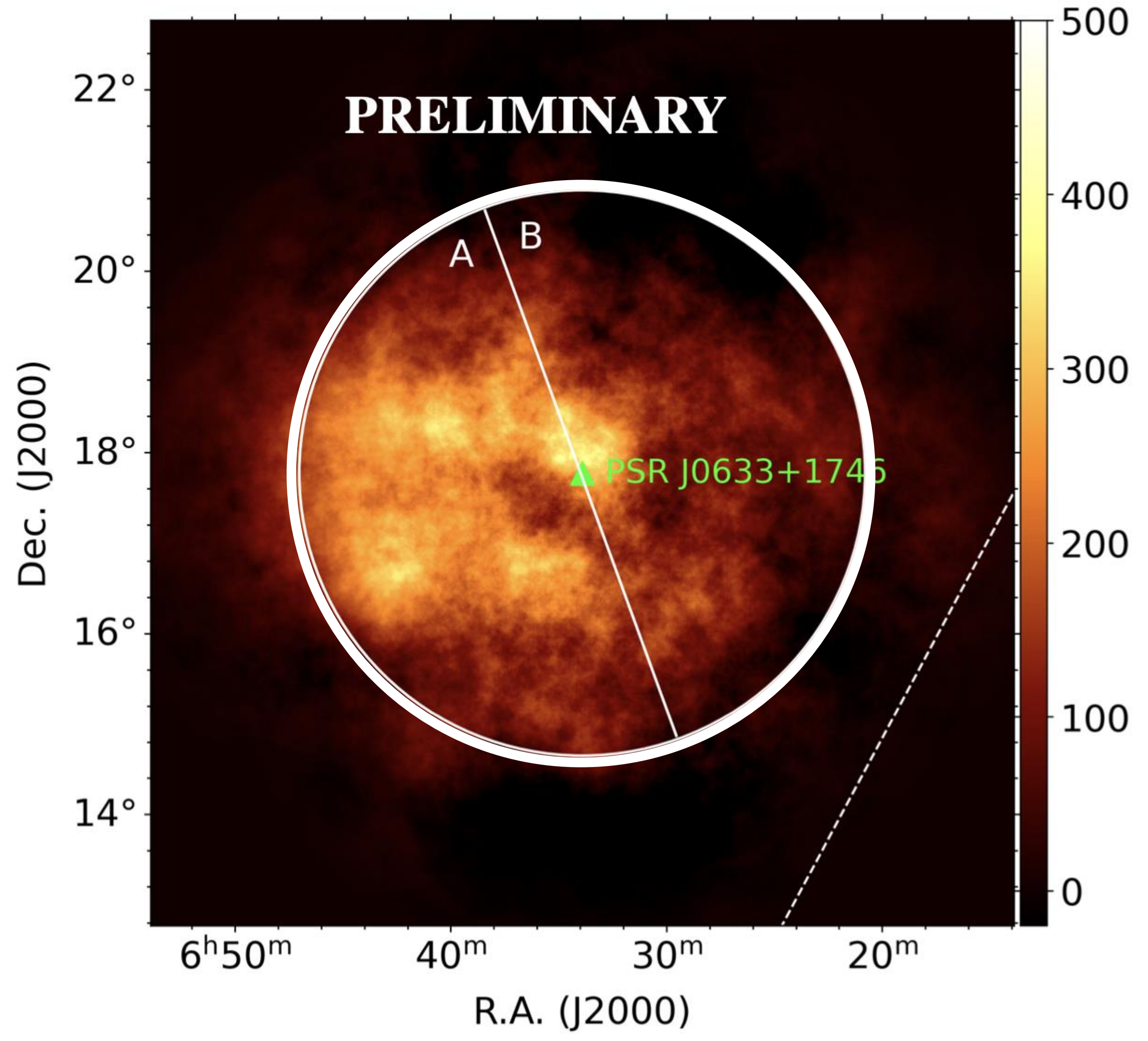


The HAWC collaboration, Science 358, 911 (2017)
First announced by MILAGRO (2009)

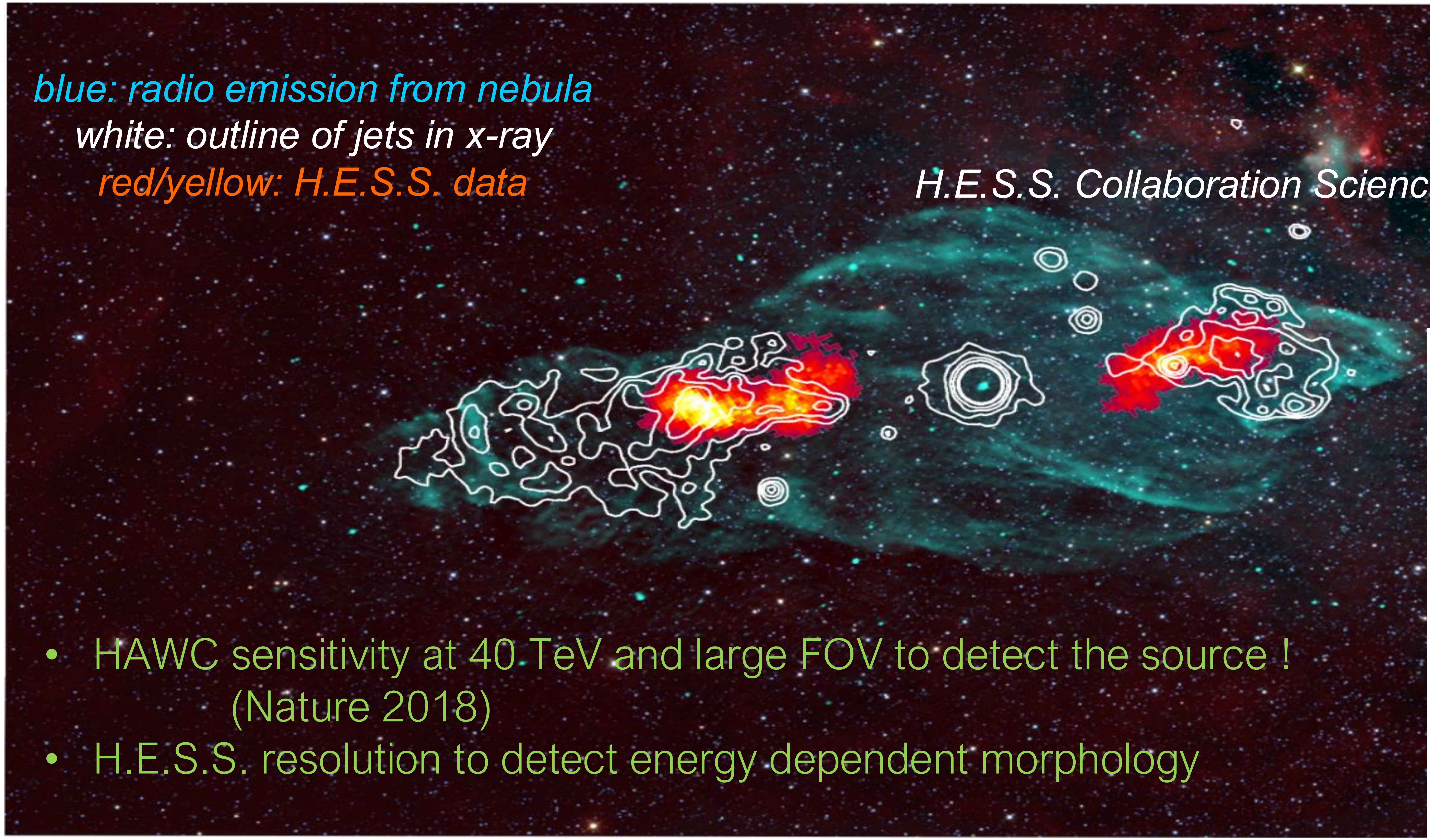


Aharonian et al. 2021

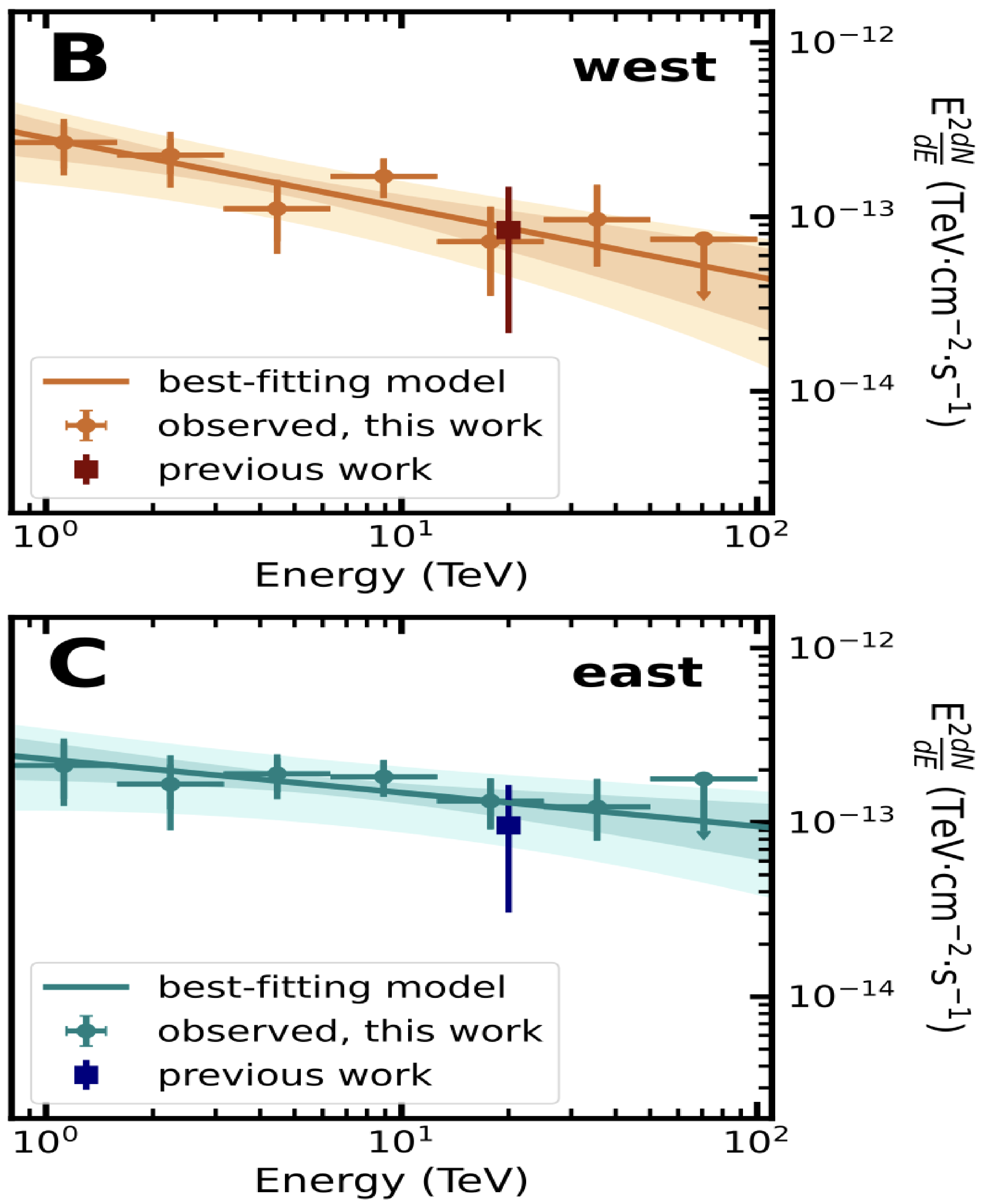
Mitchell et al. 2021



A big surprise from particle detectors: microquasars !



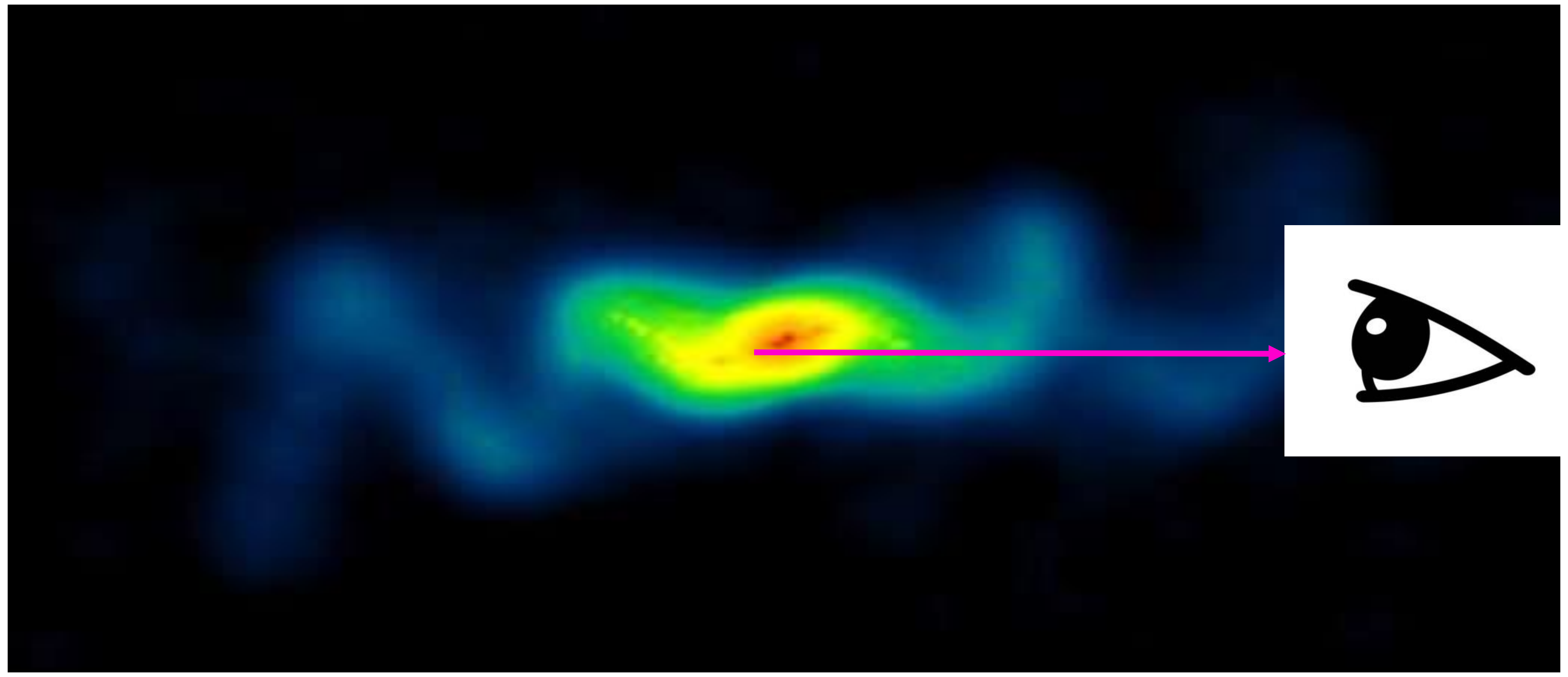
- HAWC sensitivity at 40 TeV and large FOV to detect the source ! (Nature 2018)
- H.E.S.S. resolution to detect energy dependent morphology

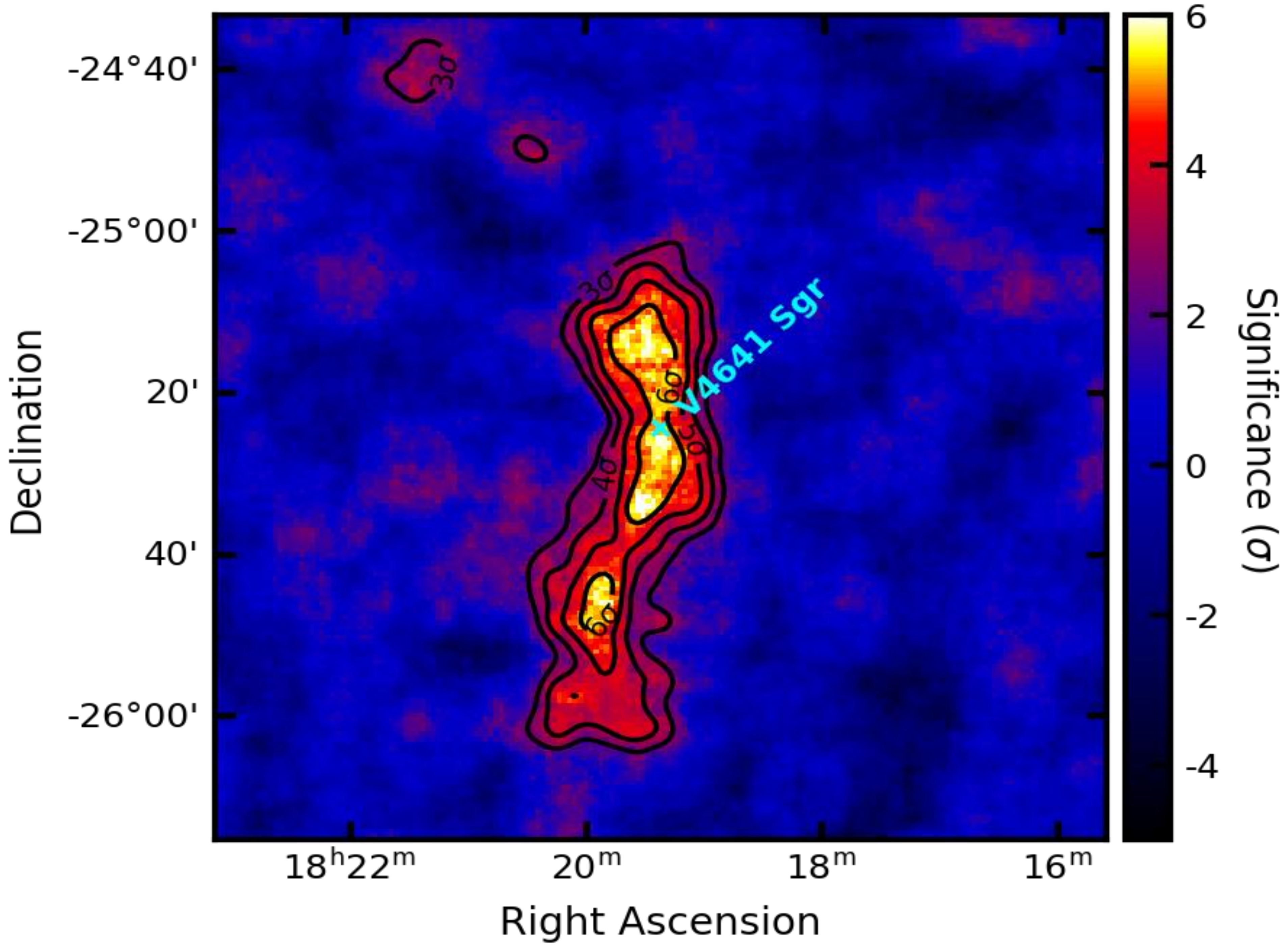


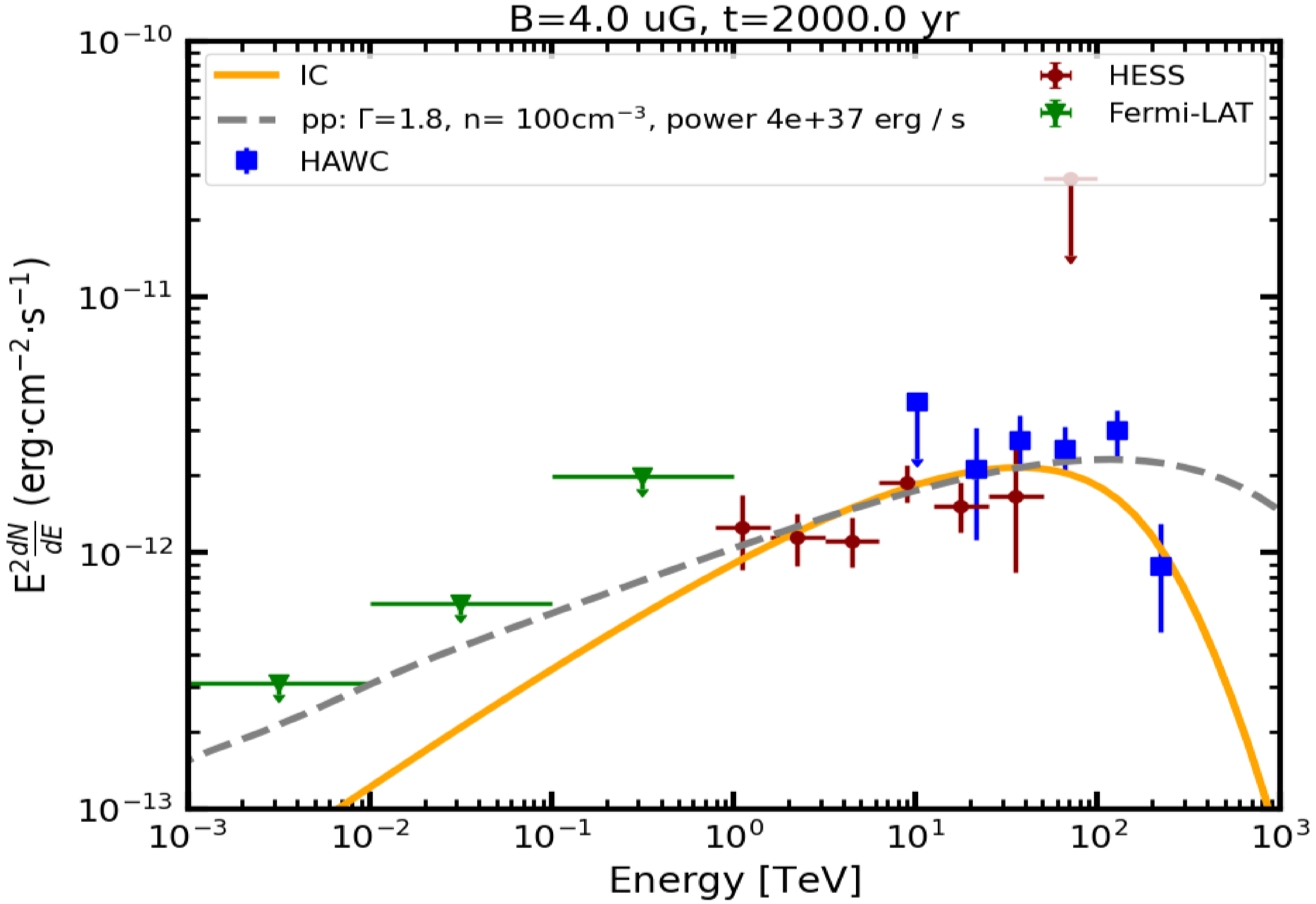
Energy dependent morphology =>
Electrons accelerated at E > 200 TeV
Emission requires shocks at distances of 25 pc to 30 pc

Another HAWC surprise : V4641 Sgr

Detected by HAWC (Nature 2024)
5° off plane => barely observed with H.E.S.S.
LMXB with a B9III companion star (2.8 days period)
Presence of a fast jet pointing towards us
But V4641 not at the centre of TeV emission
Very extended structure : 100 pc long (if D=6.2 kpc)
protons require very high density
Electrons require low magnetic field (< 5 muG ; SS 433 : 20 muG)







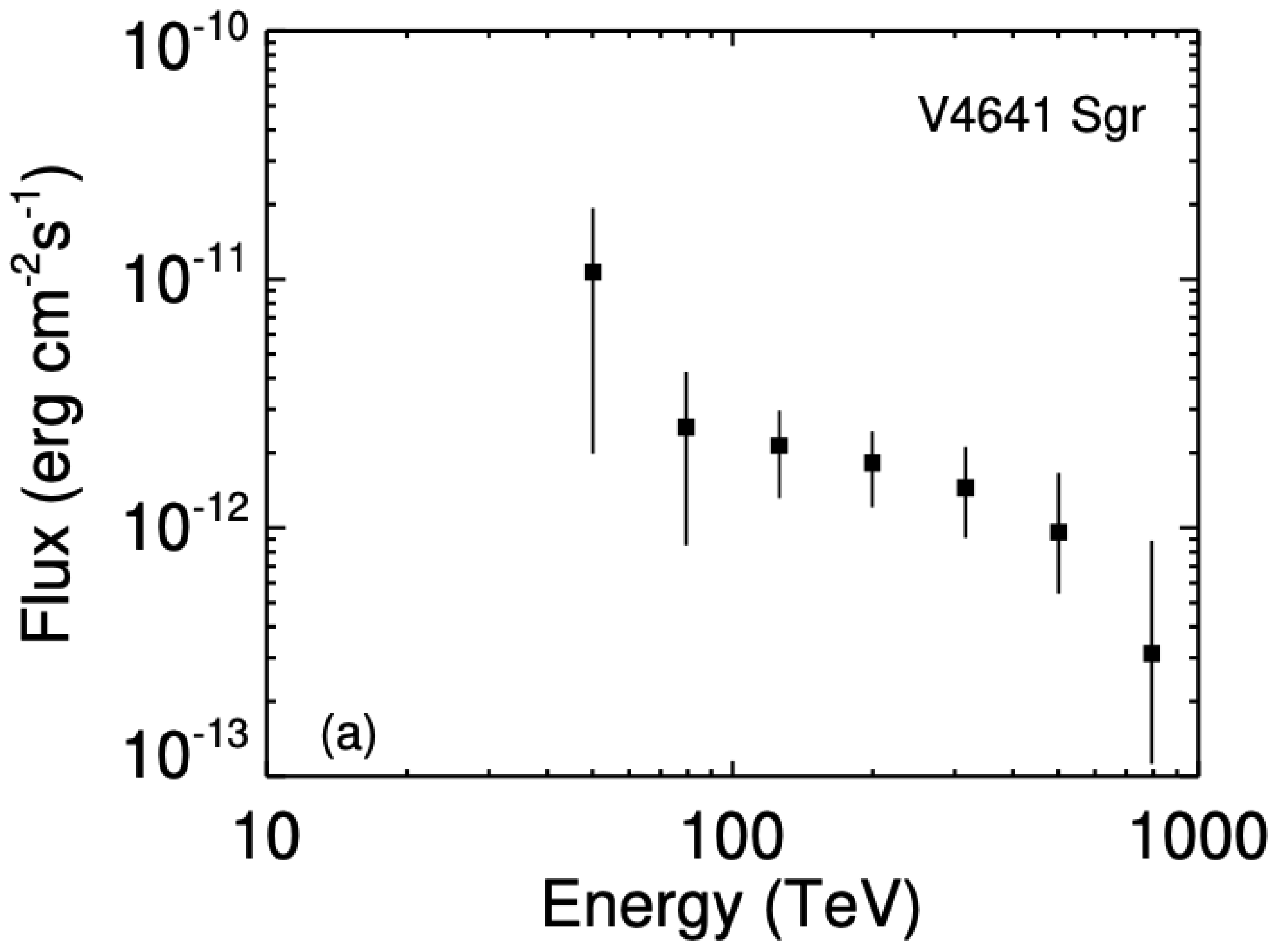
PeV acceleration from microquasars !

LHAASO now detects 5 BH-jet systems above 25 TeV : SS 433, V4641 Sgr, GRS 1915+105, MAXI J1820+070 and Cygnus X-1

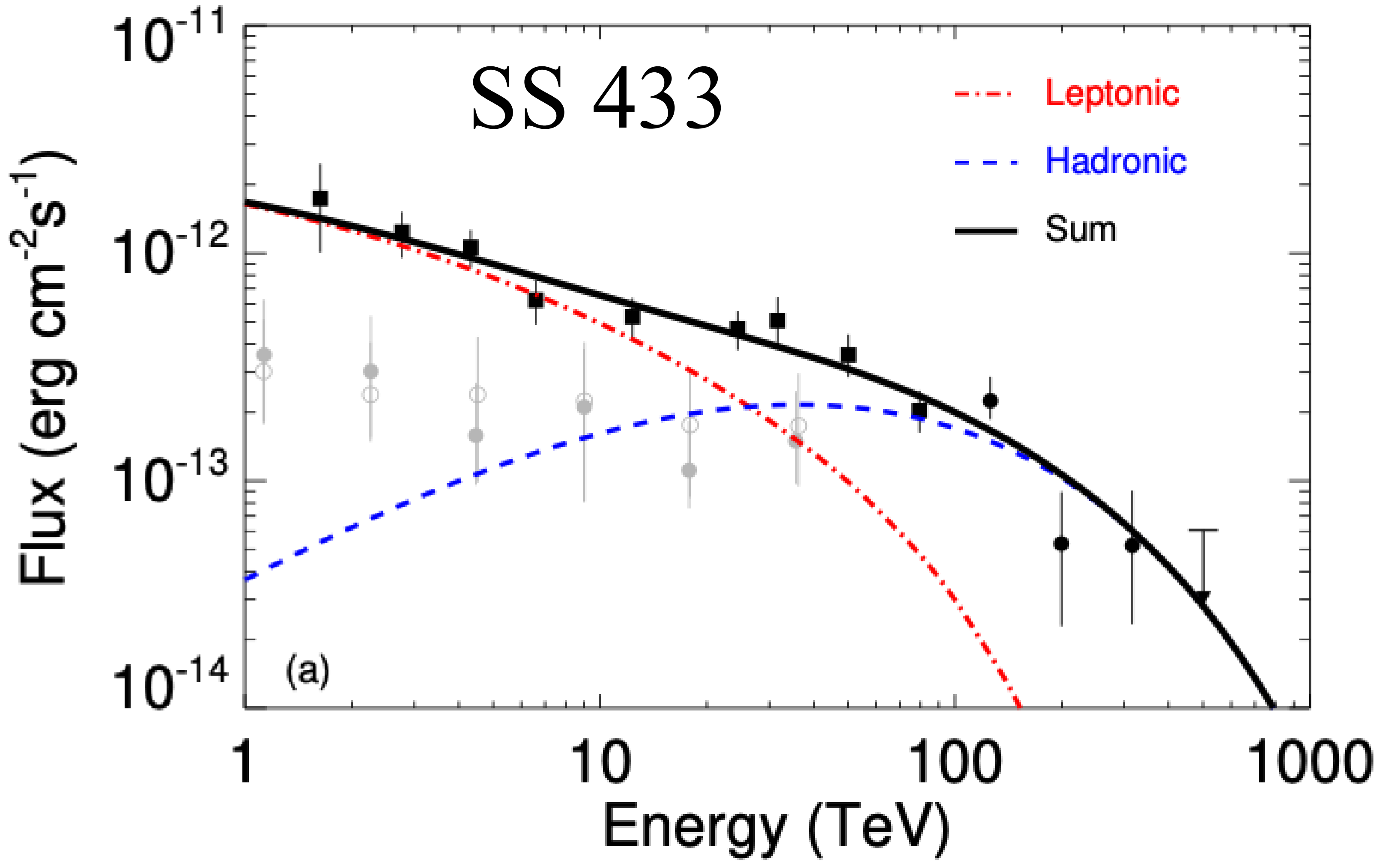
Data up to 30 TeV can be explained well via the IC radiation of electrons

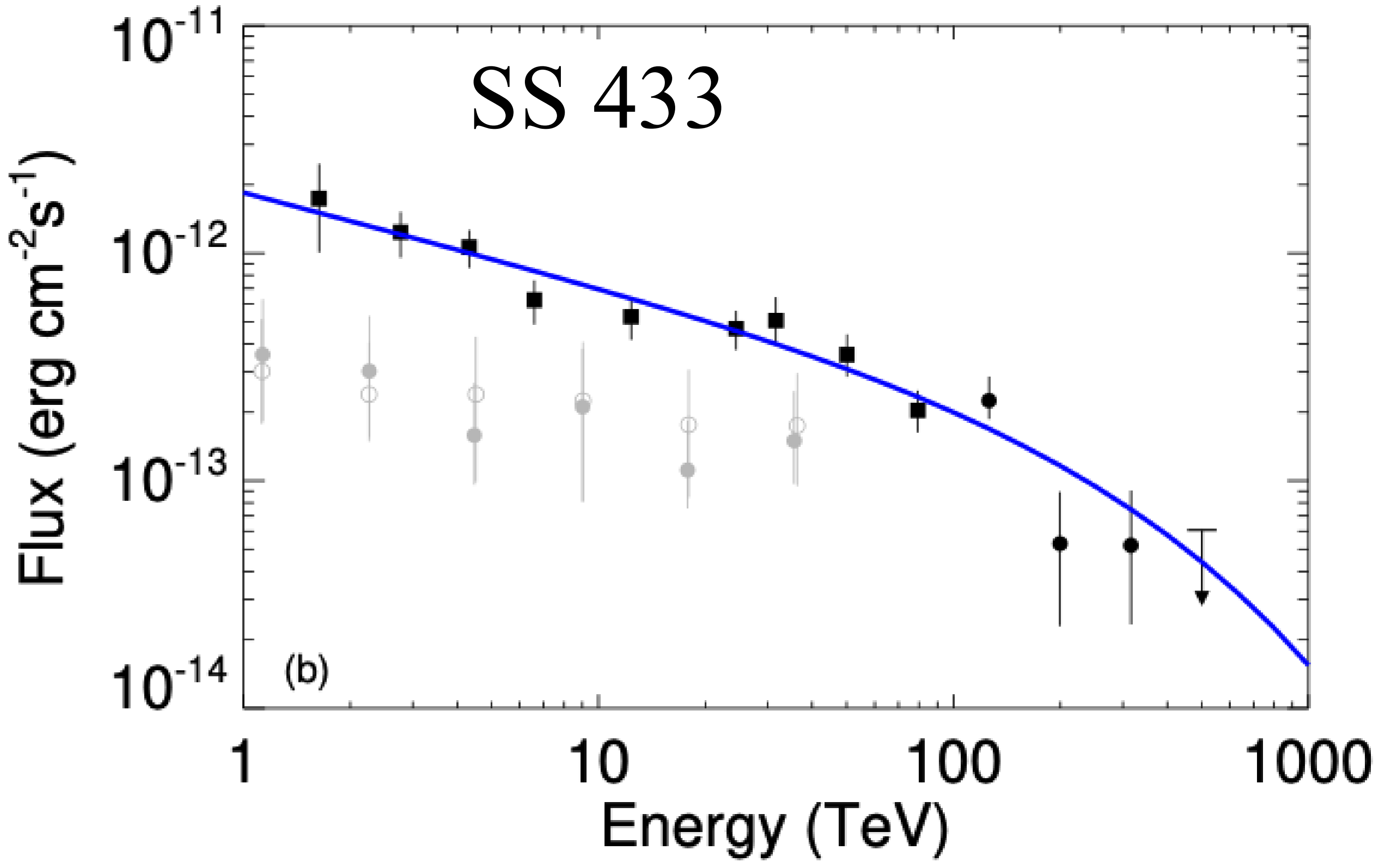
Above 100 TeV, suppression by the Klein-Nishina effect => additional hadronic component needed => SS 433 injecting PeV protons at a power of ~10^{38} erg/s ?

V4641 Sgr : electrons face difficulties to reproduce spectrum up to PeV => in hadronic scenario, V4641 energizes protons up to energies of ~10 PeV

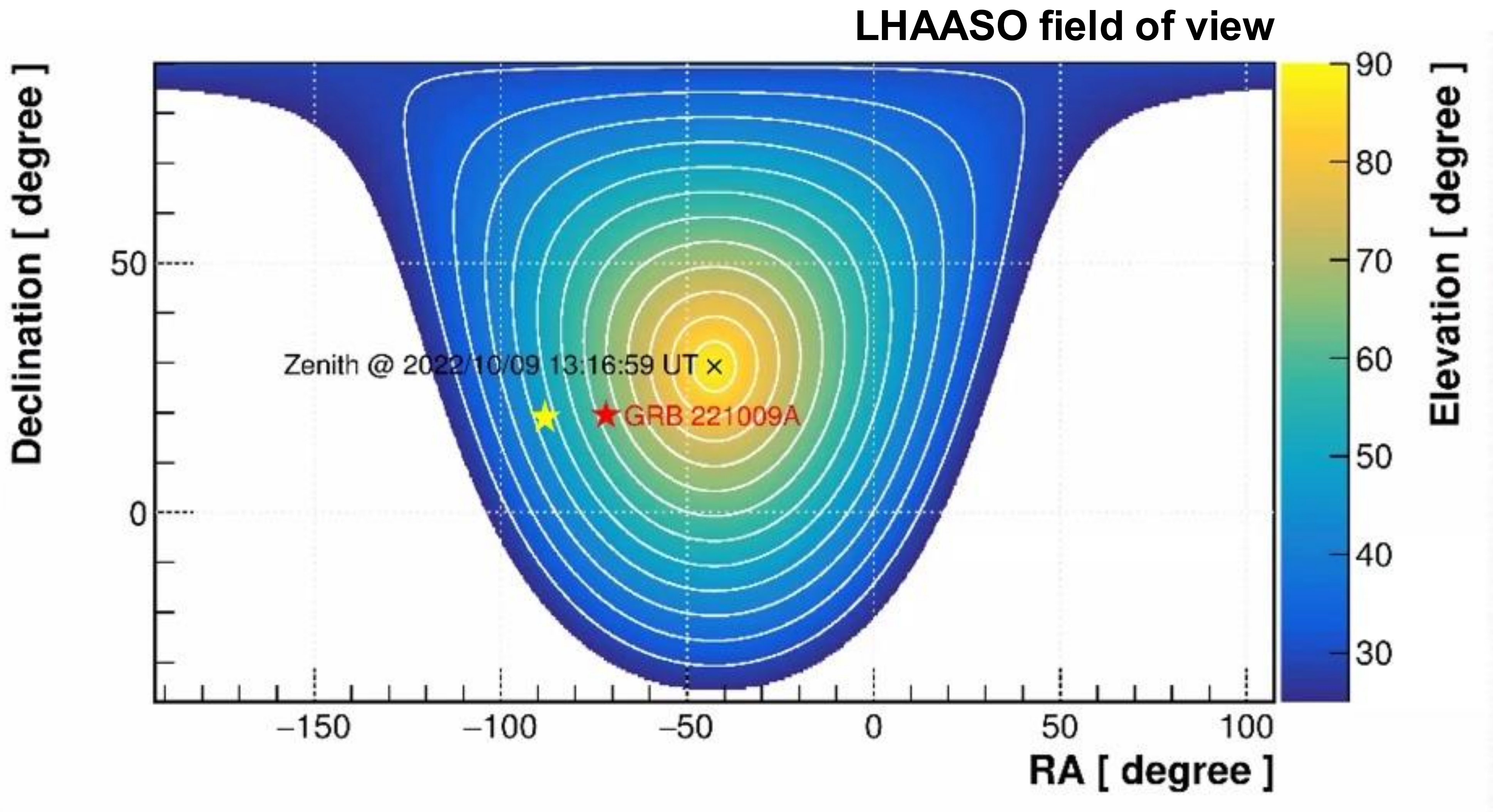


LHAASO collab., arXiv:2410.08988





Transient events



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TITLE:   GCN CIRCULAR
NUMBER:  32677
SUBJECT: LHAASO observed GRB 221009A with more than 5000 VHE photons up to around 18 TeV
DATE:    22/10/11 09:21:54 GMT
FROM:    Judith Racusin at GSFC  <judith.racusin@nasa.gov>

Yong Huang, Shicong Hu, Songzhan Chen,  Min Zha, Cheng Liu, Zhiguo Yao and
Zhen Cao report on behalf of the LHAASO experiment

We report the observation of GRB 221009A, which was detected by Swift (Kennea
et al. GCN #32635), Fermi-GBM (Veres et al. GCN #32636, Lesage et al. GCN #32642),
Fermi-LAT (Bissaldi et al. GCN #32637), IPN (Svinkin et al. GCN #32641) and so on.
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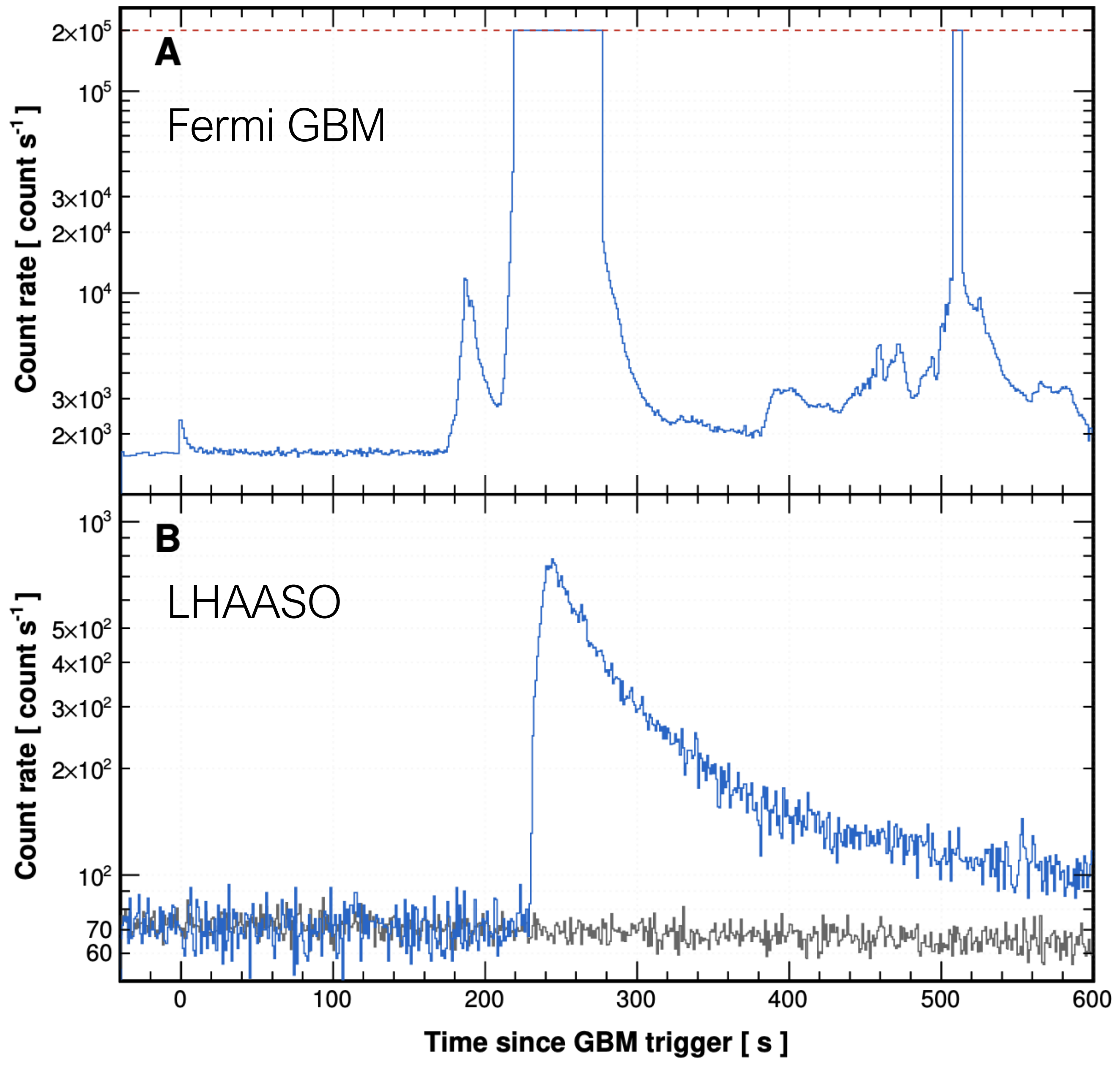
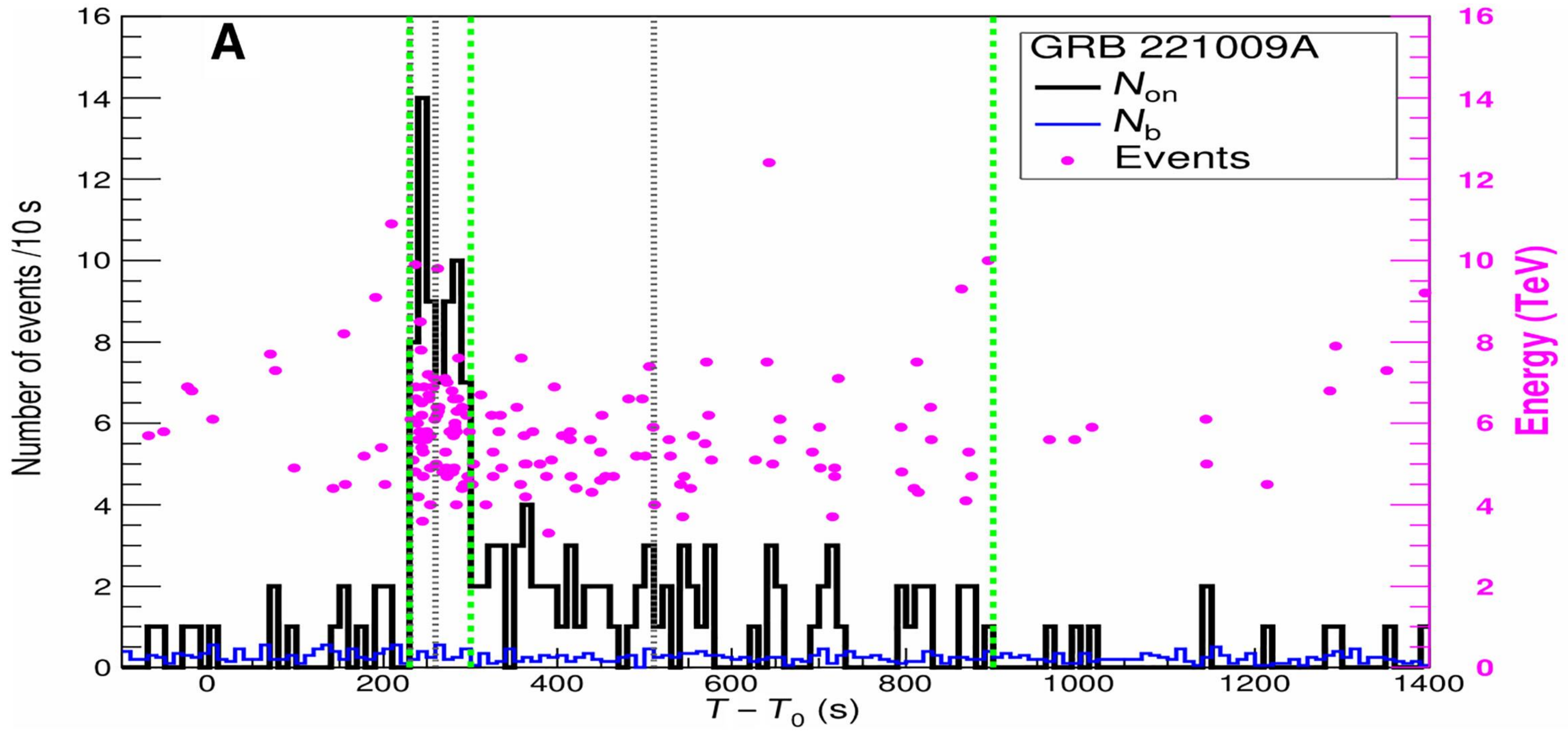
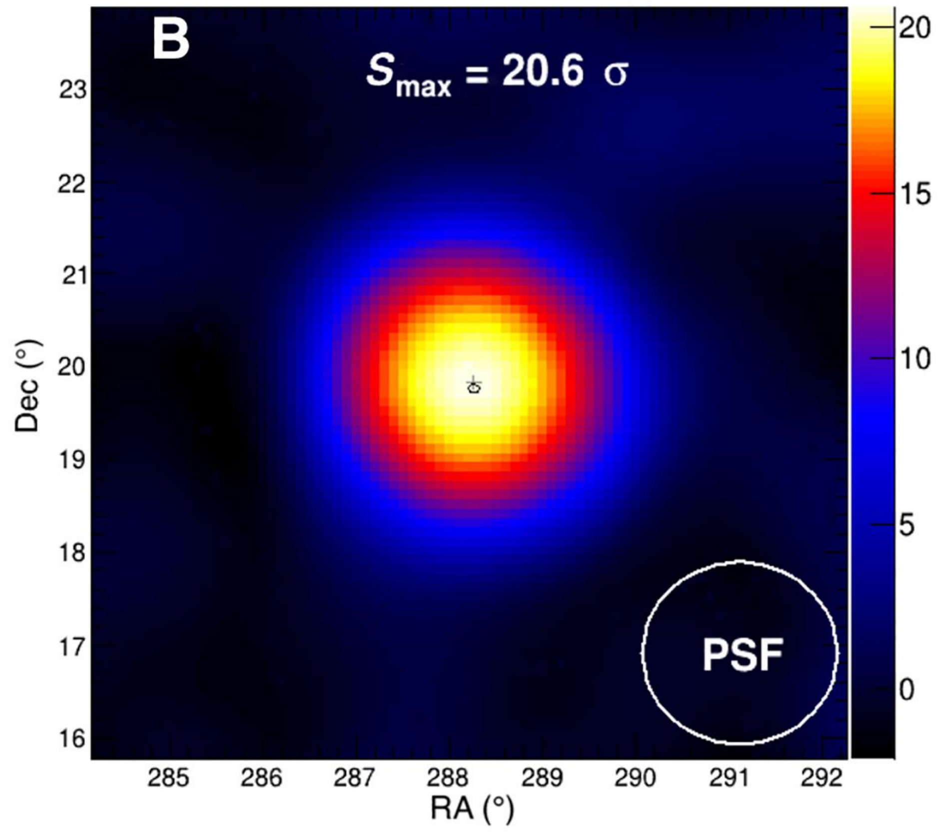
More than 64,000 photons (> 0.2 TeV) detected within the first 50 minutes







Ground based instruments

Science cases : results from HAWC and LHAASO

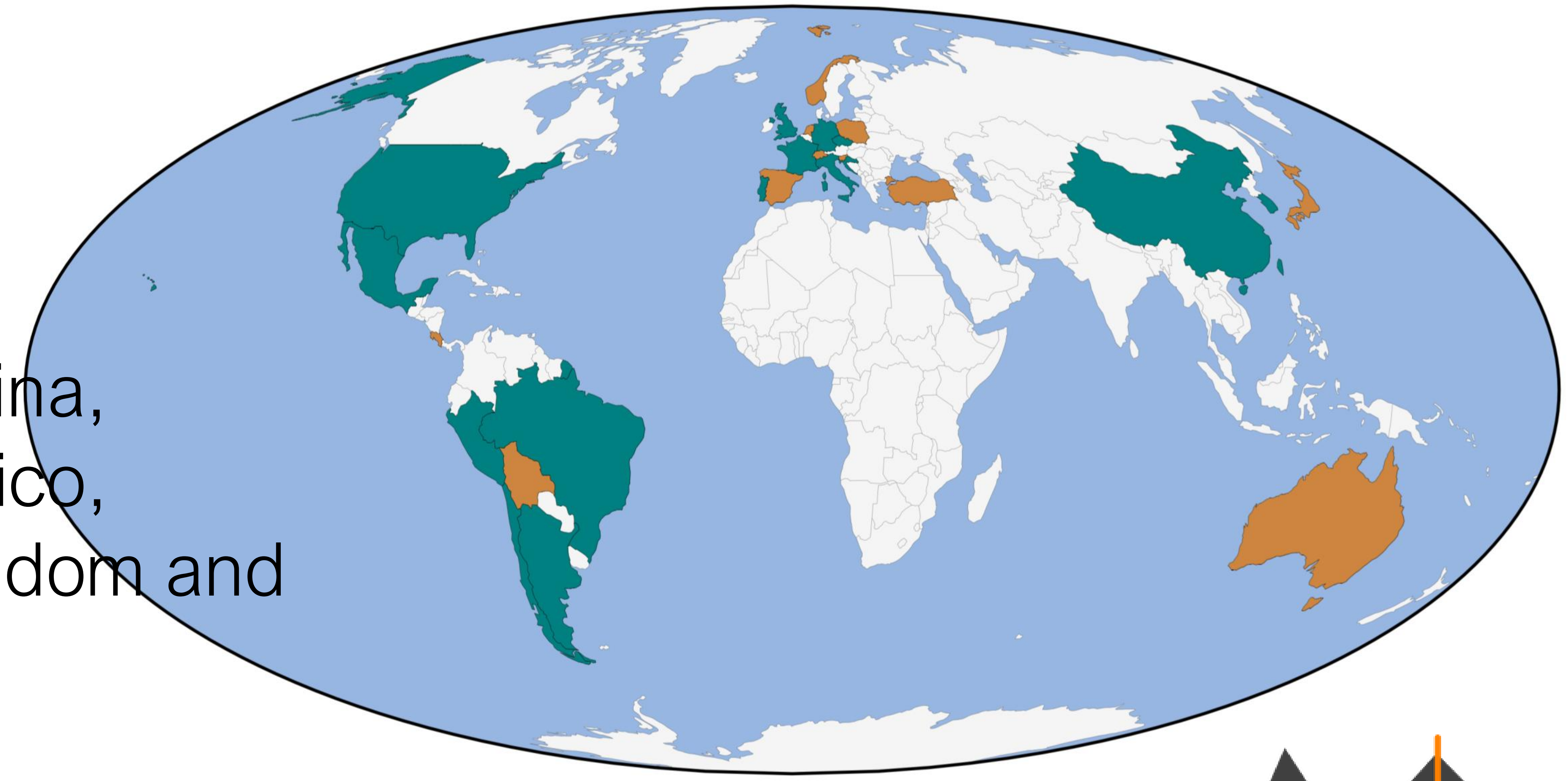
▶ SWGO: design, prototypes and construction

Science with SWGO

SWGO : The Southern Wide-field Gamma-ray Observatory

The SWGO collaboration

- Founded in 2019
- 90 research institutions from 16 countries
- **Full partner institutes** in Argentina, Brazil, Chile, China, Croatia, Czech Republic, France, Germany, Italy, Mexico, Netherlands, Peru, Portugal, South Korea, United Kingdom and United States
- **Supporting scientists** in 10 additional countries



Spokesperson : Jim Hinton, MPIK Heidelberg, Germany

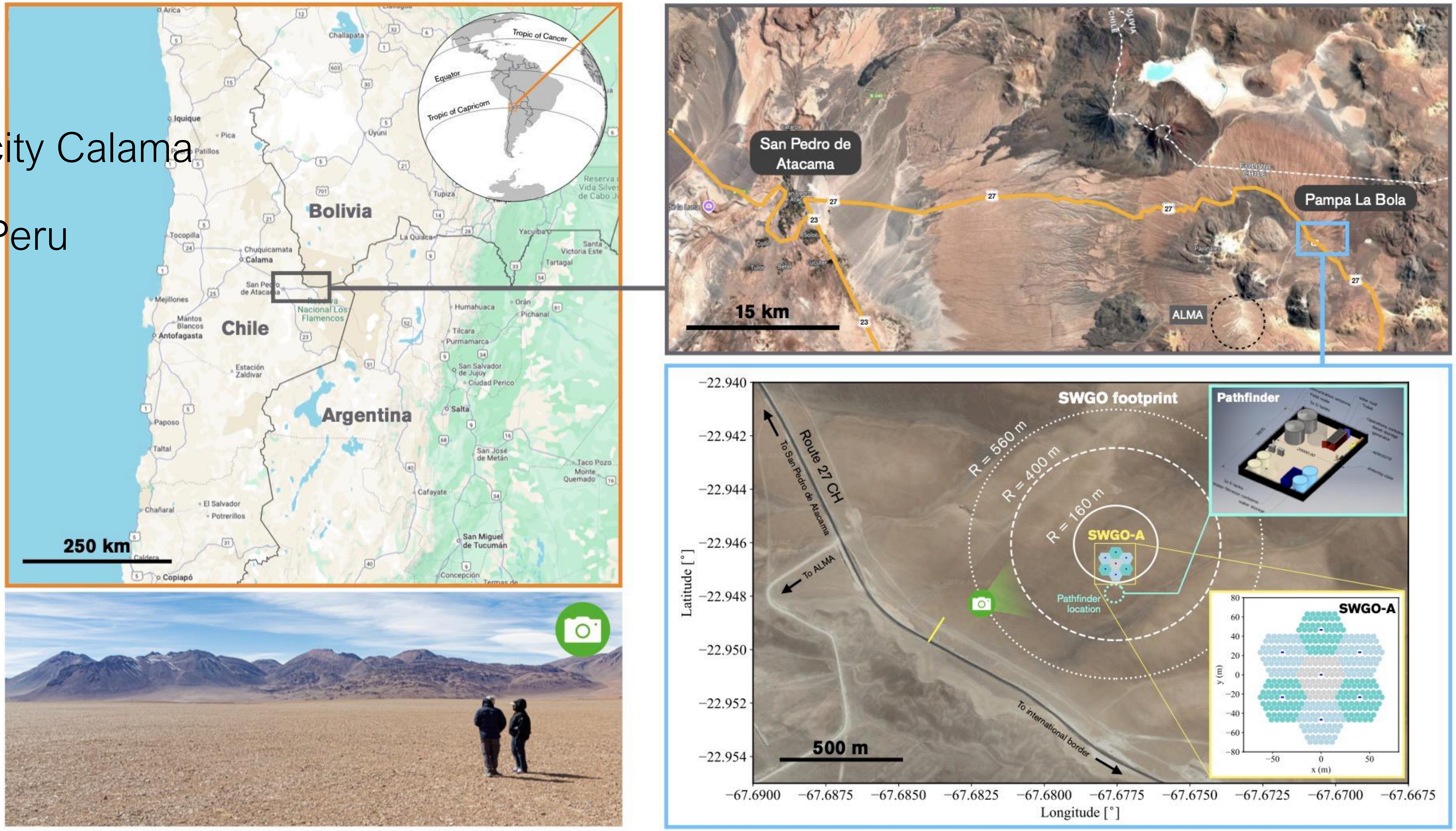
Vice-spokespersons :

Petra Hüntemeyer, MTU, Michigan, US
Ulisses Barres de Almeida, CBPF, Brazil

SWGO members and guests at the site of the project, Pampa La Bola (12th Collaboration Meeting, San Pedro de Atacama, 5-9 May, 2025)

SWGO - Site selection !

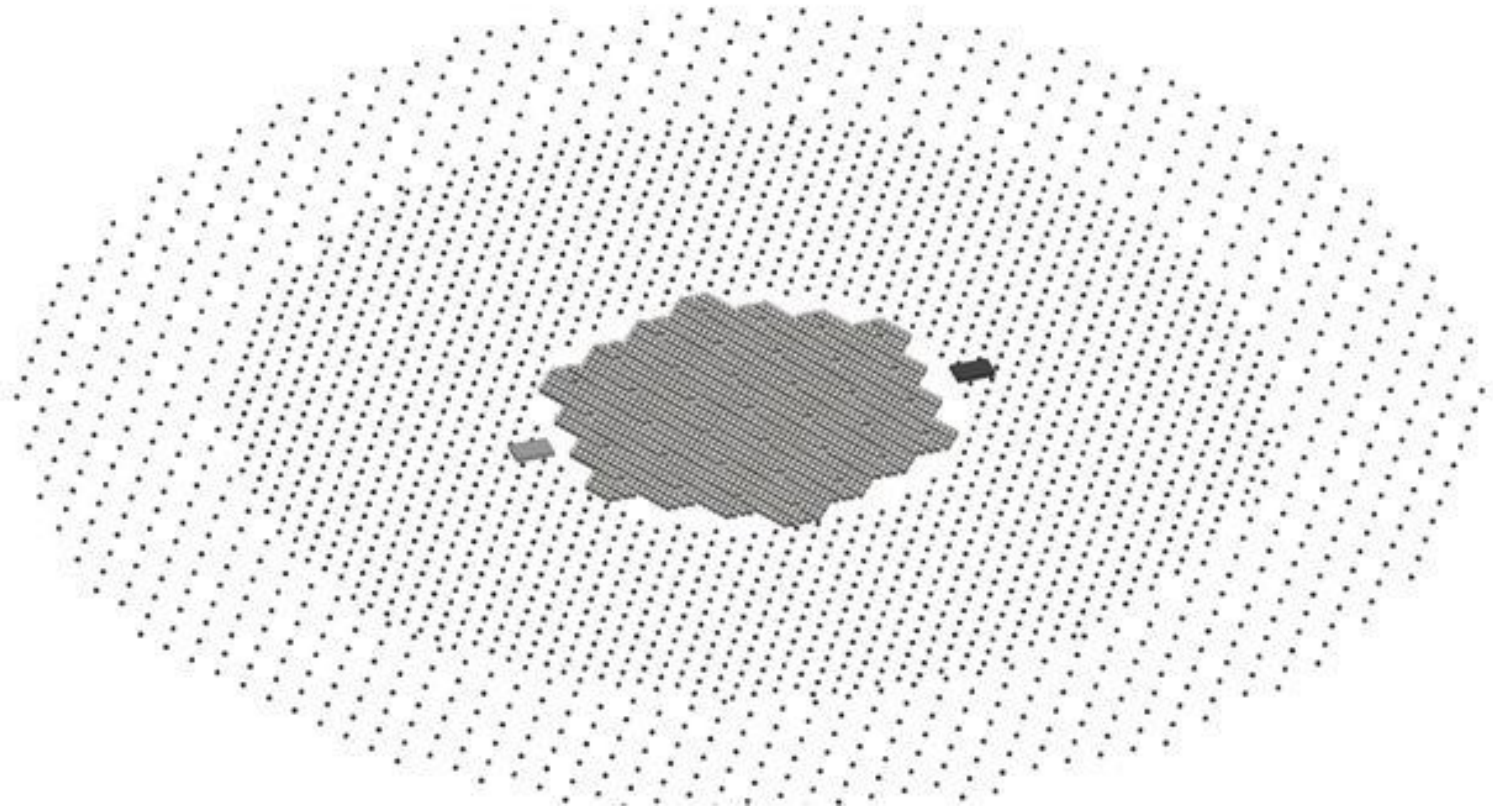
- July 2024: preferred site identified: Pampa La Bola, Atacama Astronomical Park, Chile (neighbour of ALMA)
- altitude : 4700 m
- water from the nearby city Calama
- back-up site : Imata in Peru



Baseline array layout

Three zones:

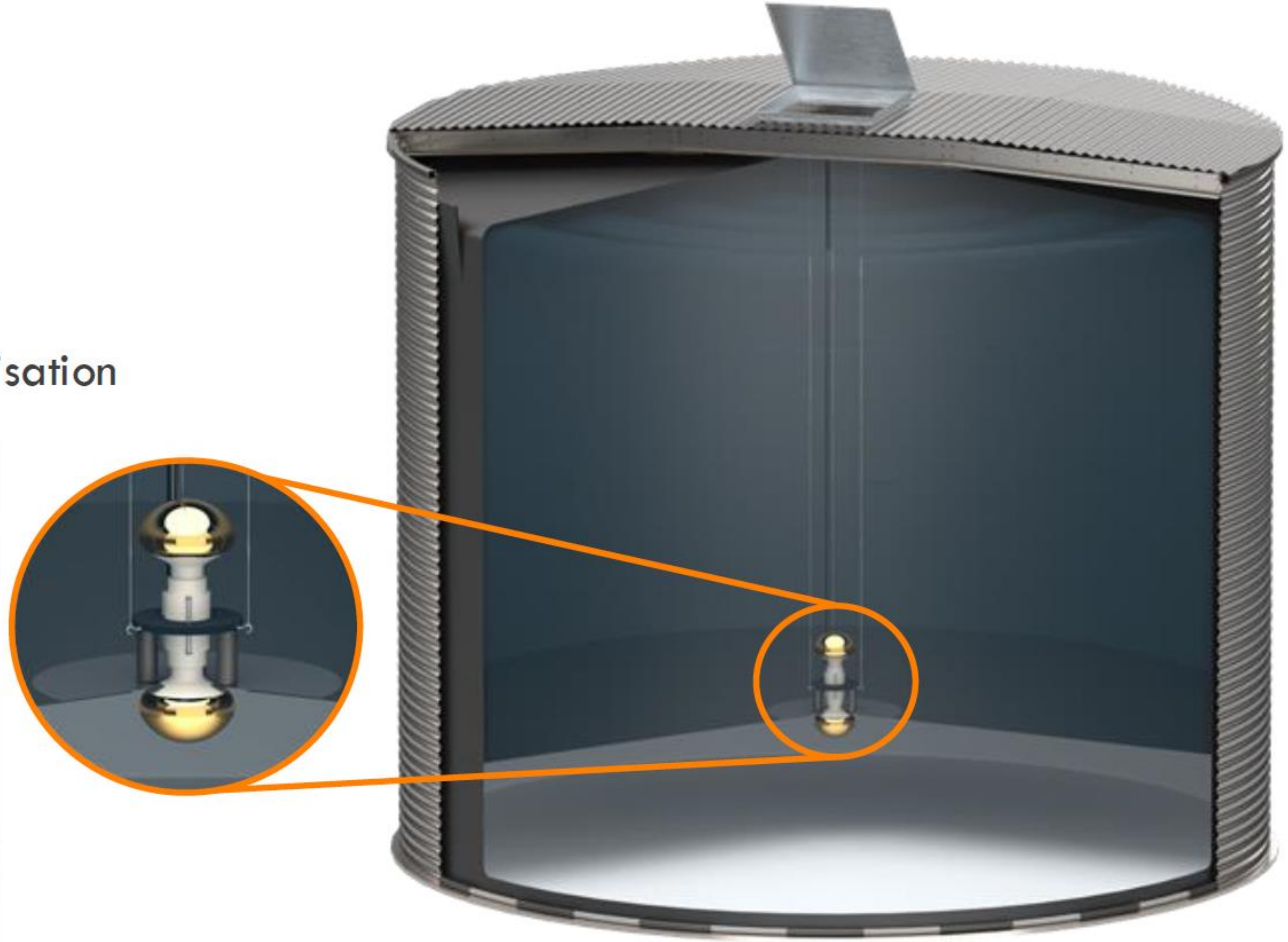
- ► Inner array: FF=65%, R=156m, 2587 tanks
- ► Outer array:
- • FF=4%, R=400m, 792 tanks
- • FF=1.6%, R=560m, 384 tanks



Inner array baseline design (1)

- Steel tanks assembled on site
  - 5.2 m Ø, 4.1m height
- Double-PMT unit in each detector
  - 10-inch PMTs
- Signals collected at Field Nodes
  - Serve 55 WCDs each, 250 MS/s digitisation

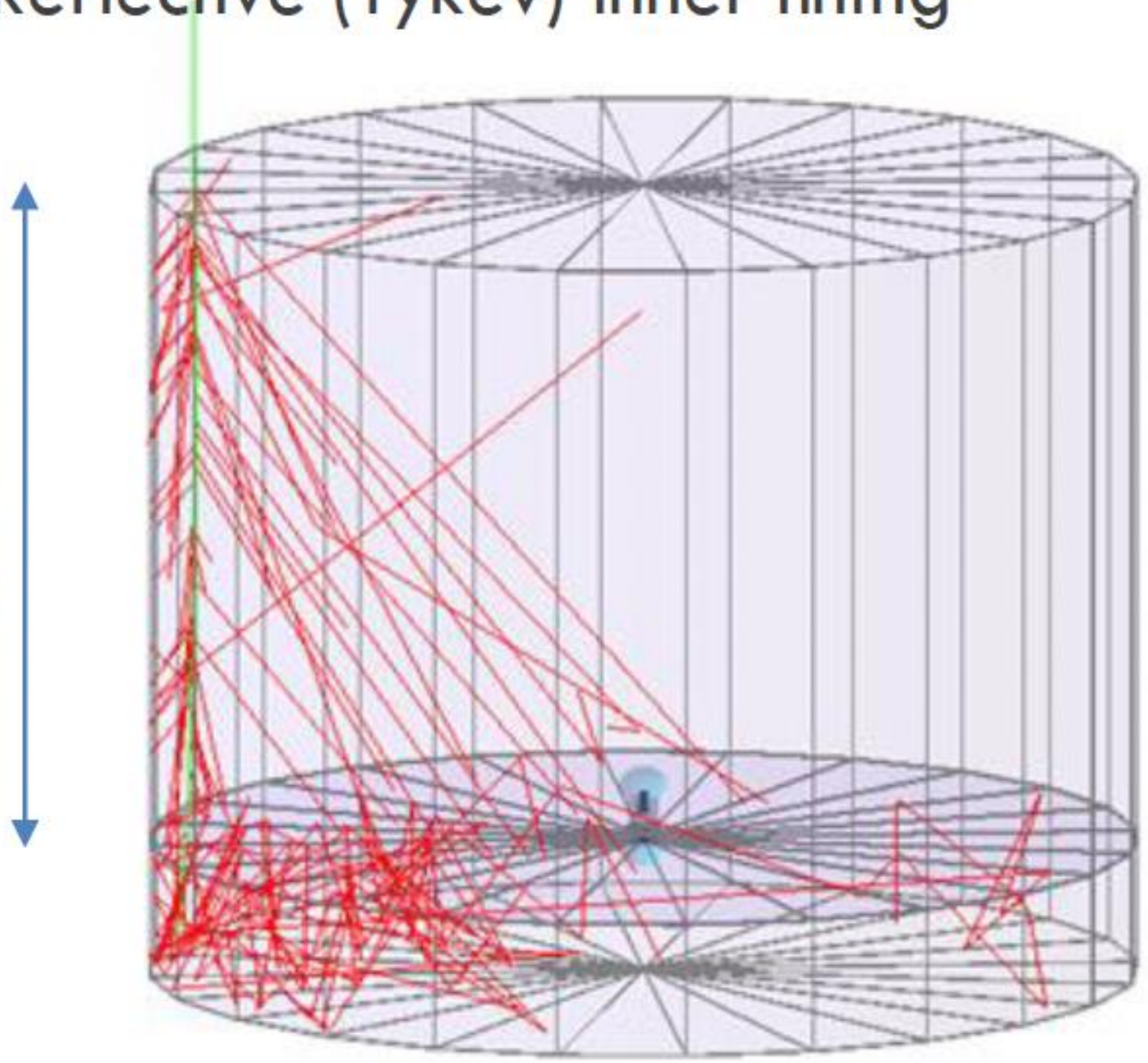




Inner array baseline design (2)

- Custom LDPE Bladders inside each steel tank
- Double-layered detectors
  - Separated by membrane
- Lower chamber is for background rejection → muon tagging
  - Reflective (Tykev) inner lining

8 radiation lengths

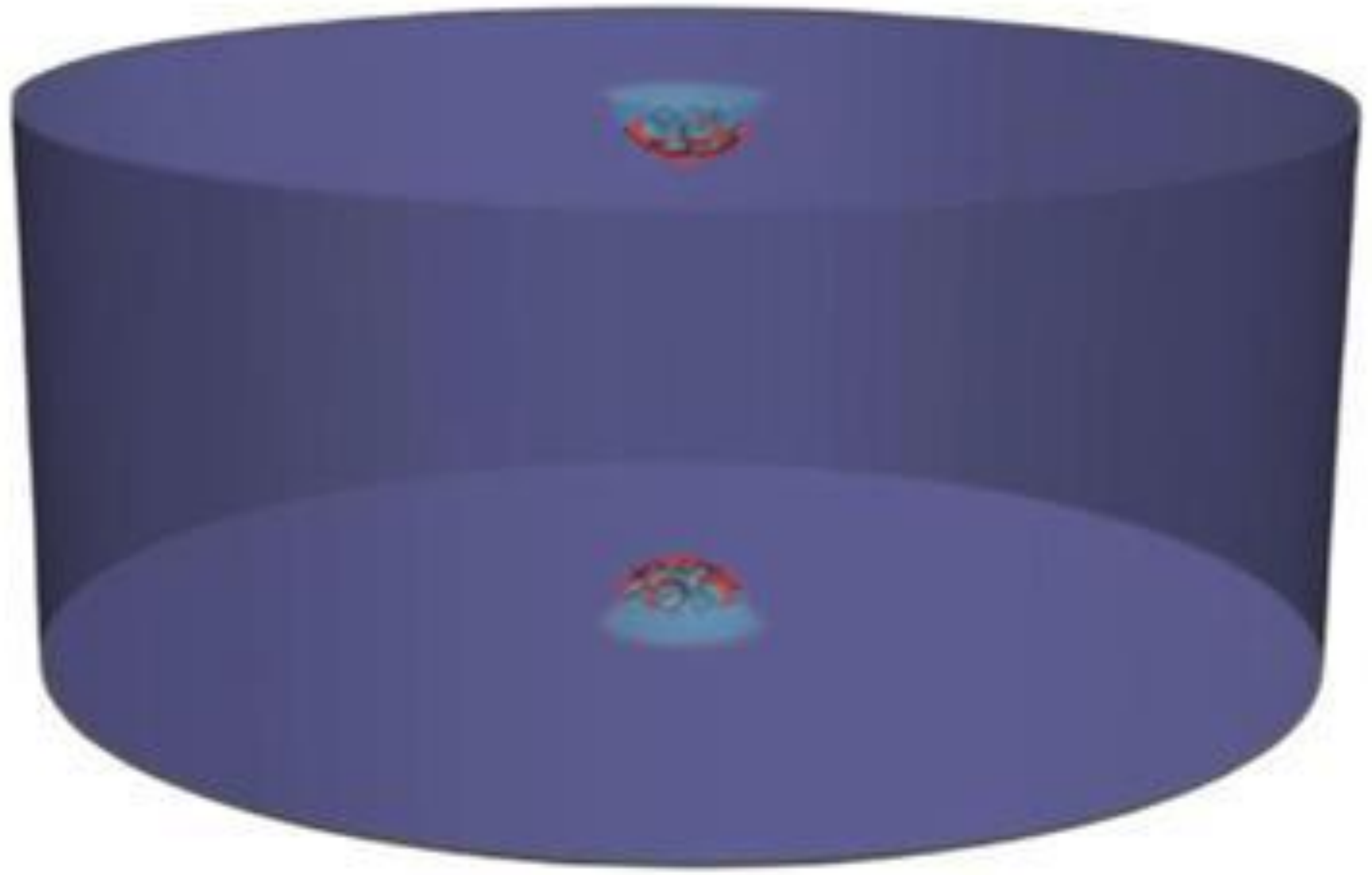


Inflated with air to check for light leaks

Outter array studies

Large dual layer tanks as for the inner array is one option but also considering

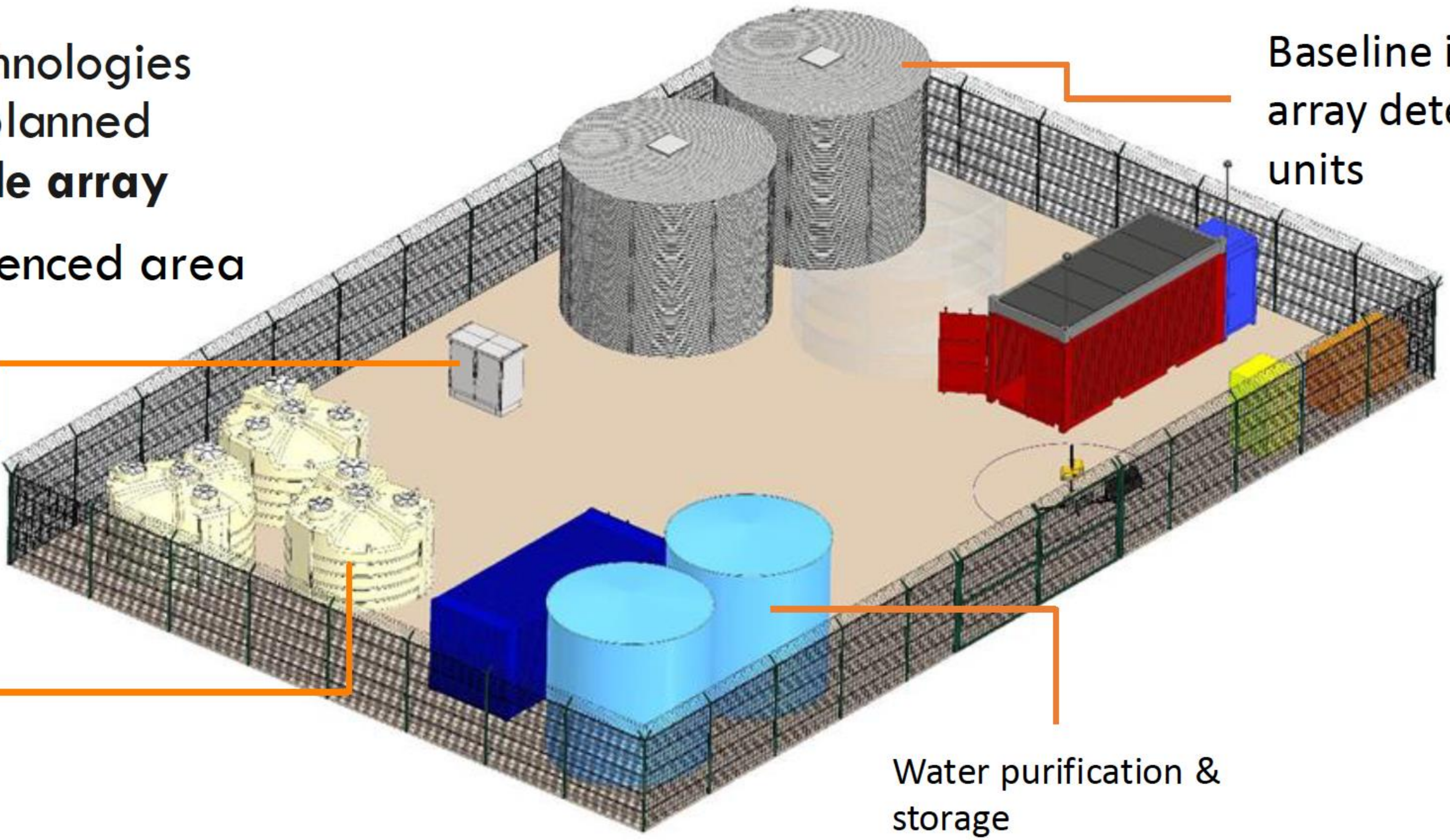
- ► Smaller tanks as potentially more cost-effective for low fill factor (1-4 %); potentially rotomolded (plastic) rather than steel
- ► Single layer with multi-PMT 3'' PMT module
- • Heritage from KM3Net, Hyper-K



First step on site: The Pathfinder

To validate technologies & procedures planned for the **full-scale array**

- 20x30m fenced area



Baseline inner array detector units

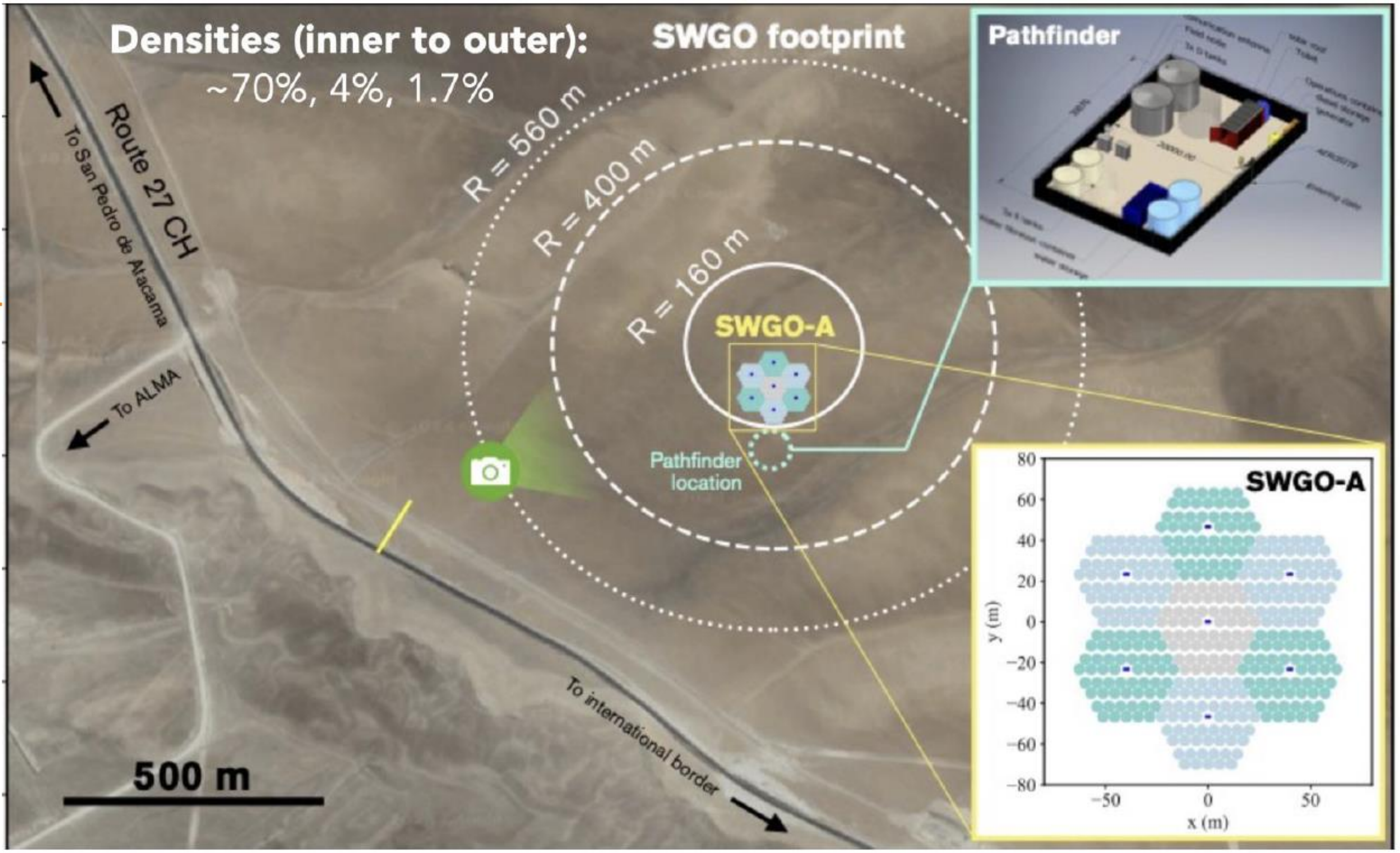
Field node

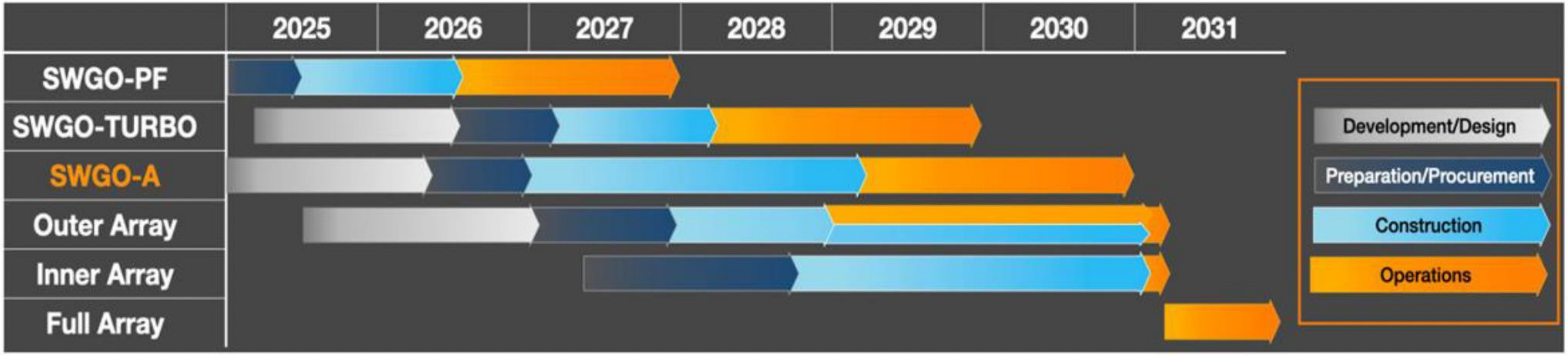
Outer array prototype detector units

Water purification & storage

SWGO Stages

- Beyond the pathfinder:
  - SWGO-A – 385 WCDs in inner array
  - Outer WCD engineering array ~50 tanks
  - 800 radio antennae array (SWGO-TURBO)
  - Construction to full scale as funding allows





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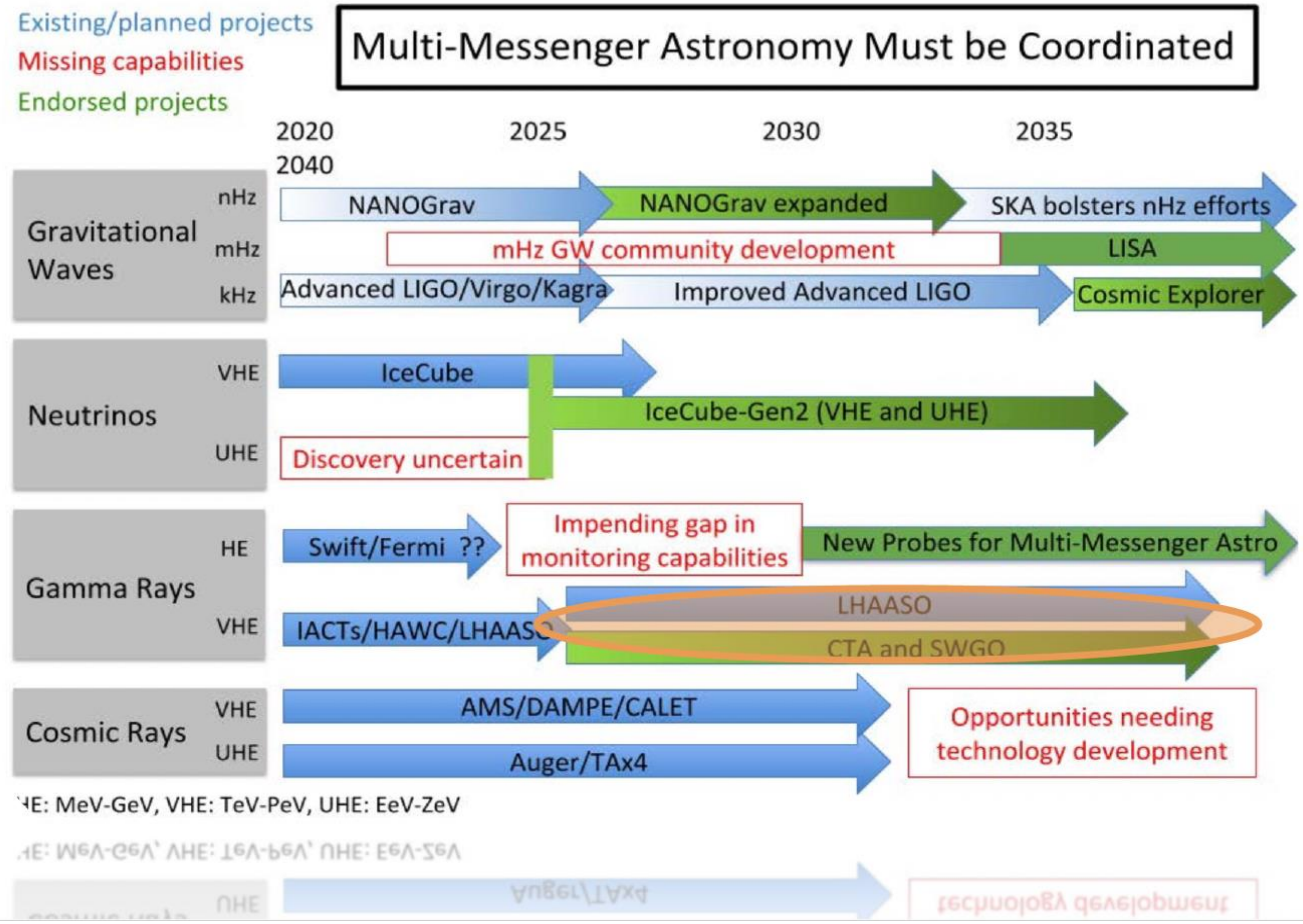
The Southern Wide-field Gamma-ray Observatory

Gamma-Ray Messenger

"[...] the Cherenkov Telescope Array (CTA) and the **Southern Wide-Field Gamma-Ray Observatory (SWGO)** [...] will be valuable themselves - gamma rays reveal processes that longer-wavelength photons cannot - and will greatly enhance the returns of neutrino and gravitational-wave observatories."
– Astro2020 Report

"The **combination of CTA and LHAASO/SWGO provides an integrated observational capability that maximizes the scientific opportunities** for all-sky multi-messenger astronomy."
– Astro2020 Report

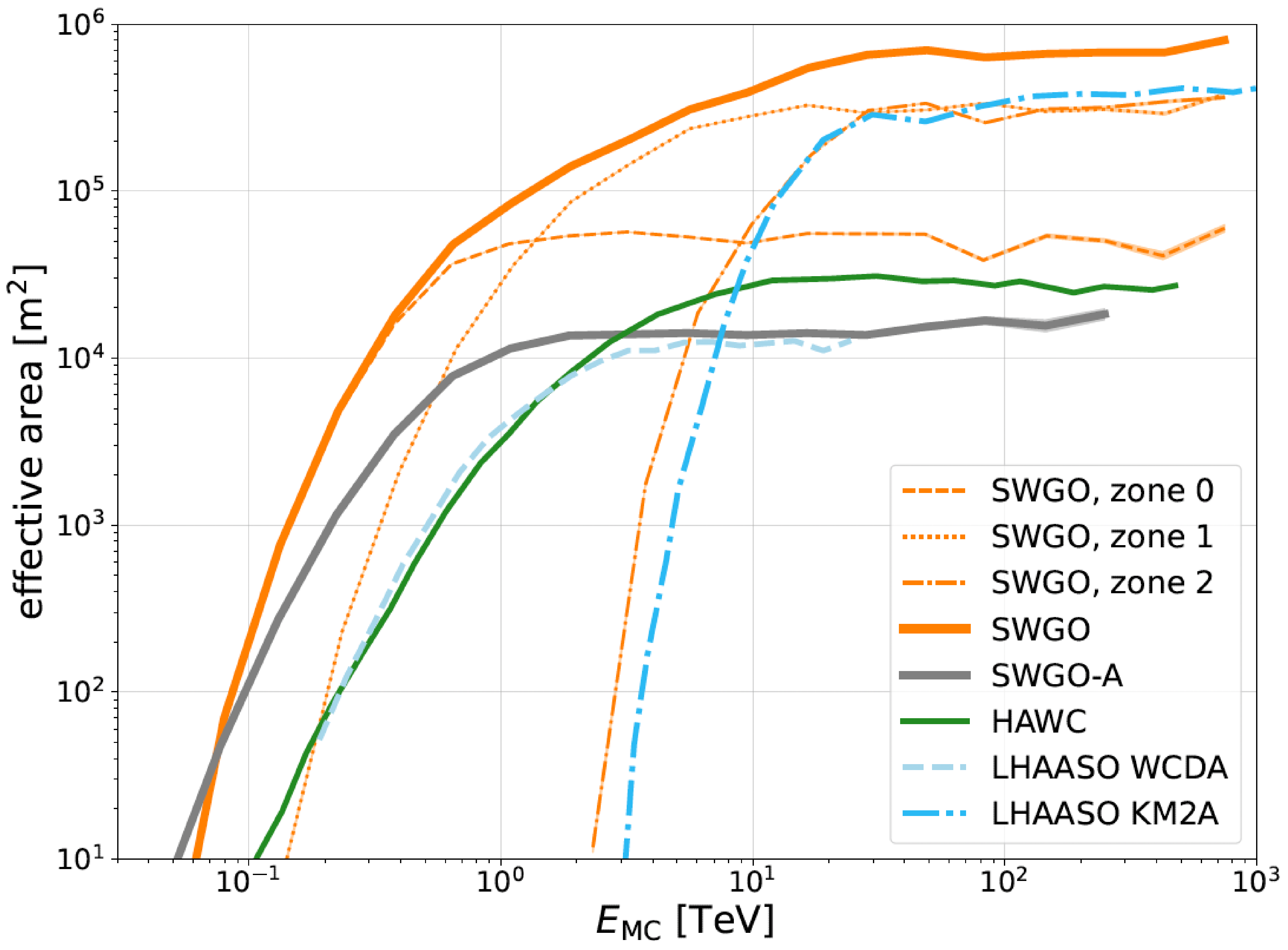
"... the Southern Wide-field Gamma-ray Observatory (SWGO) ... **will have unprecedented sensitivity to the highest energies and [is] critical to carrying on the legacy of science at the forefront of particle and astroparticle physics."**
– Report of the Topical Group on Cosmic Probes of Fundamental Physics for Snowmass 2021

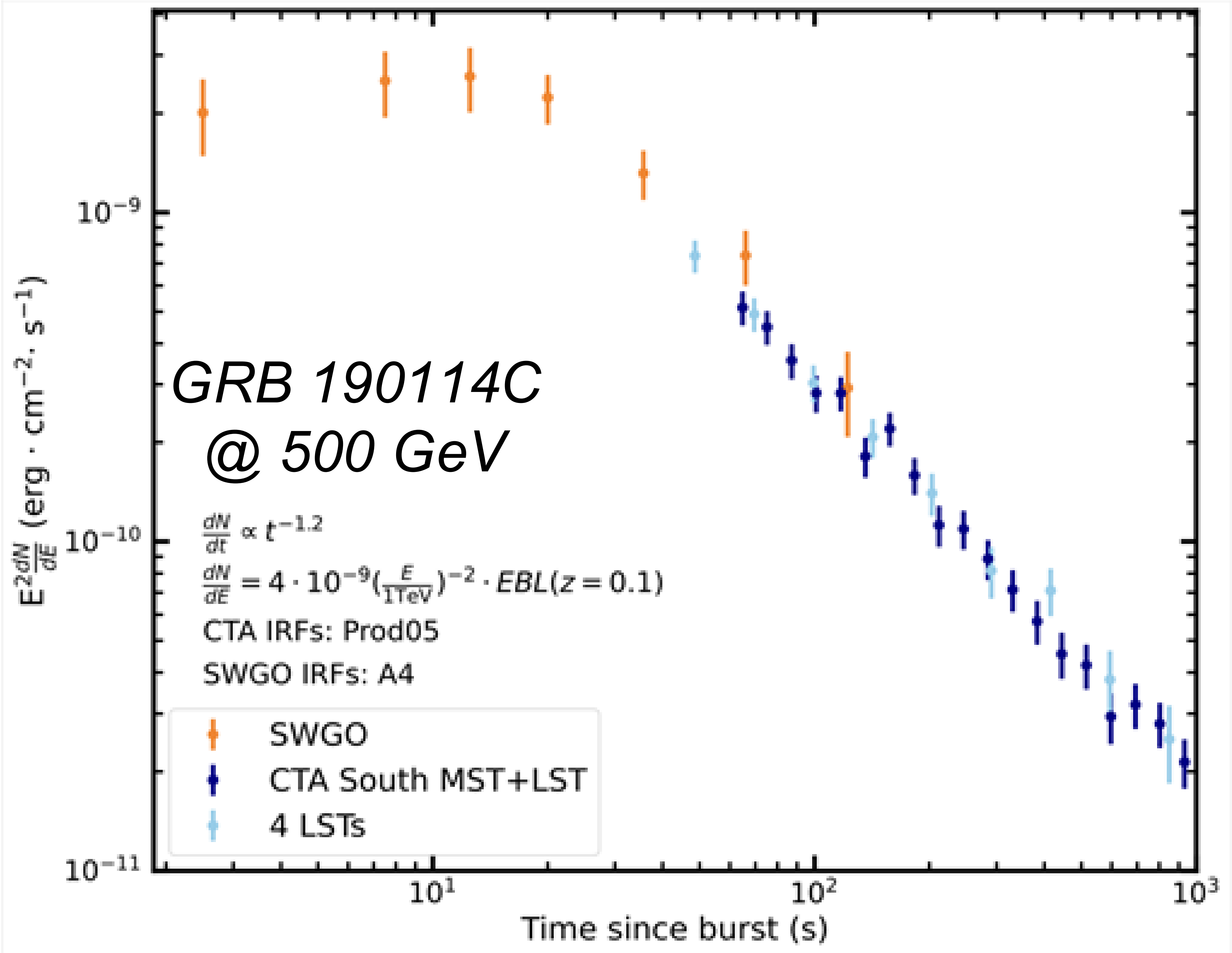


Catching transient events

Strong complementarity with CTAO-South

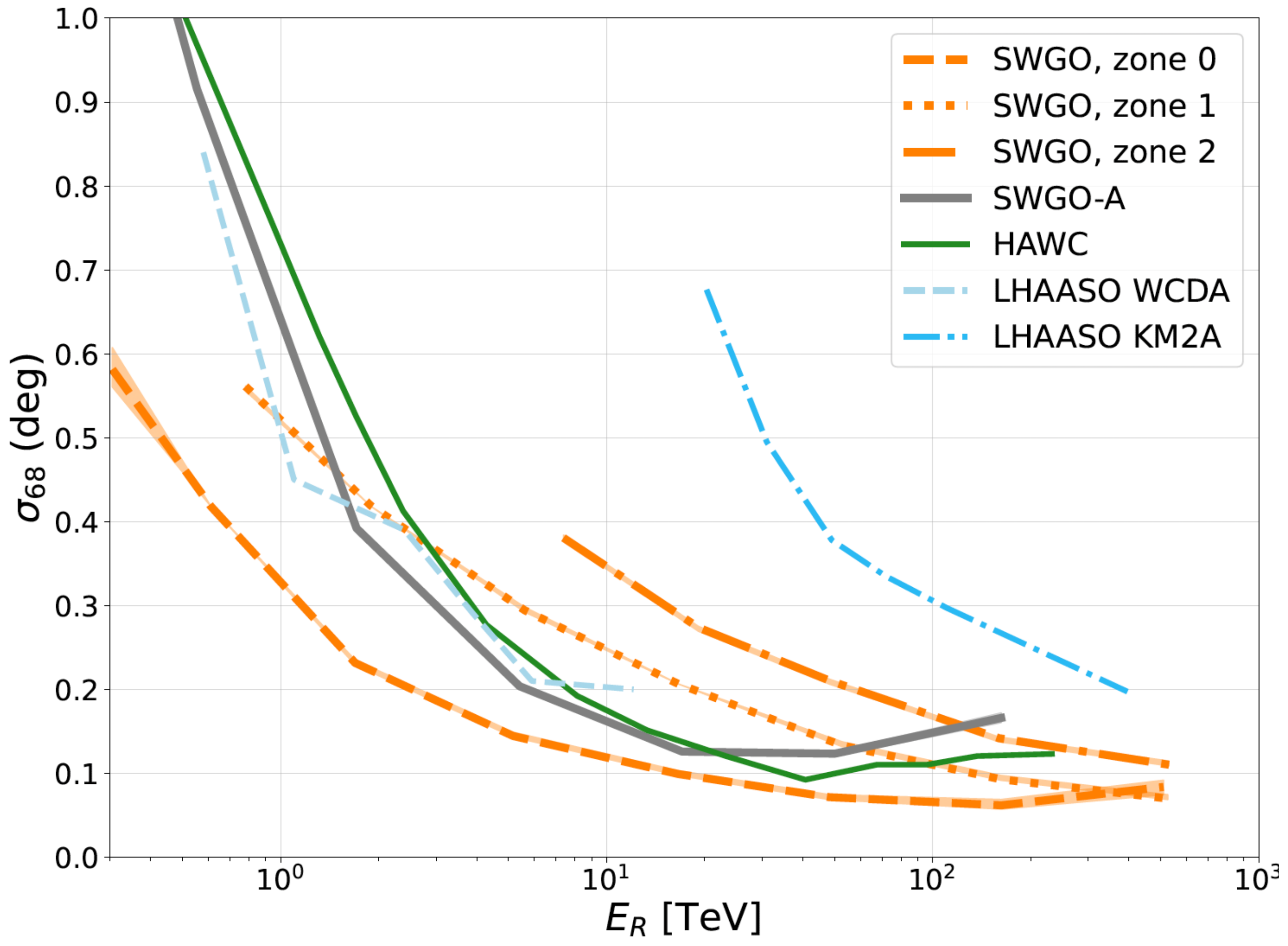
- SWGO: high duty cycle & field of view, UHE sensitivity
- CTAO: low E and resolution



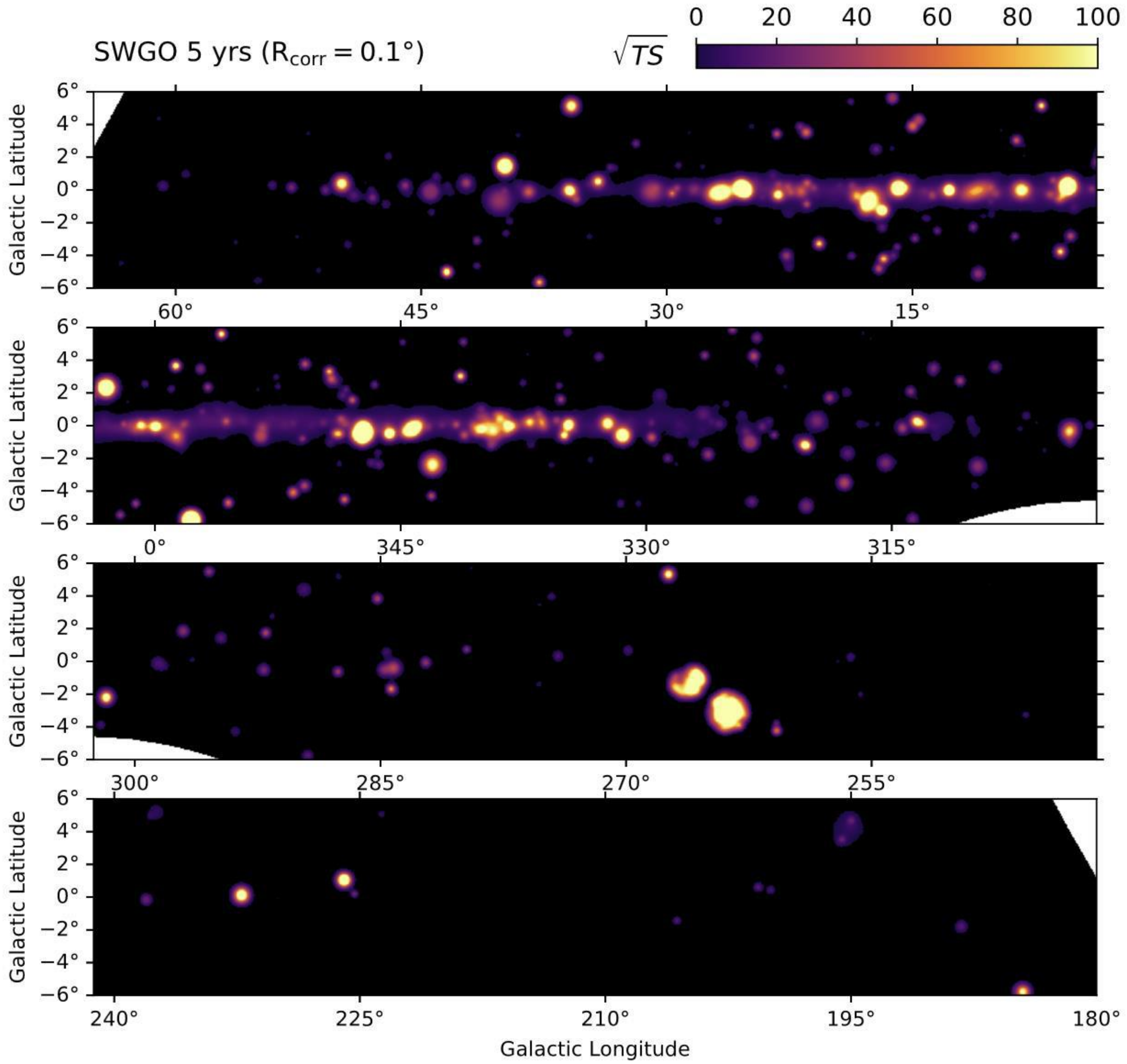


Galactic Plane Survey

- Simulations using the CTA-GPS model
- Number of detections of CTA-GPS matched by SWGO in 5 years !
- 70% sources in common => increase total number of detections by joint analysis



Catalogue	Detected sources
HGPS[a]	96
3HWC[b]	48
1LHAASO[c]	54
Future surveys	**Expected detections**
CTA-GPS[d]	461
SWGO-A 1 yr	70
SWGO-A 5 yrs	135
SWGO 1 yr	359
SWGO 5 yrs	487
SWGO 10 yrs	536
SWGO 10 yrs + CTA-GPS[e]	603



Detection of PeVatrons

Inputs

- A common open data format: GADF (the VHE standard)
- IRFs of CTA and SWGO
- An open library: Gammapy

Goals

- Ability to detect a 0.1° source with a spectrum made with a PowerLaw and an ExponentialCutoff

Parameters

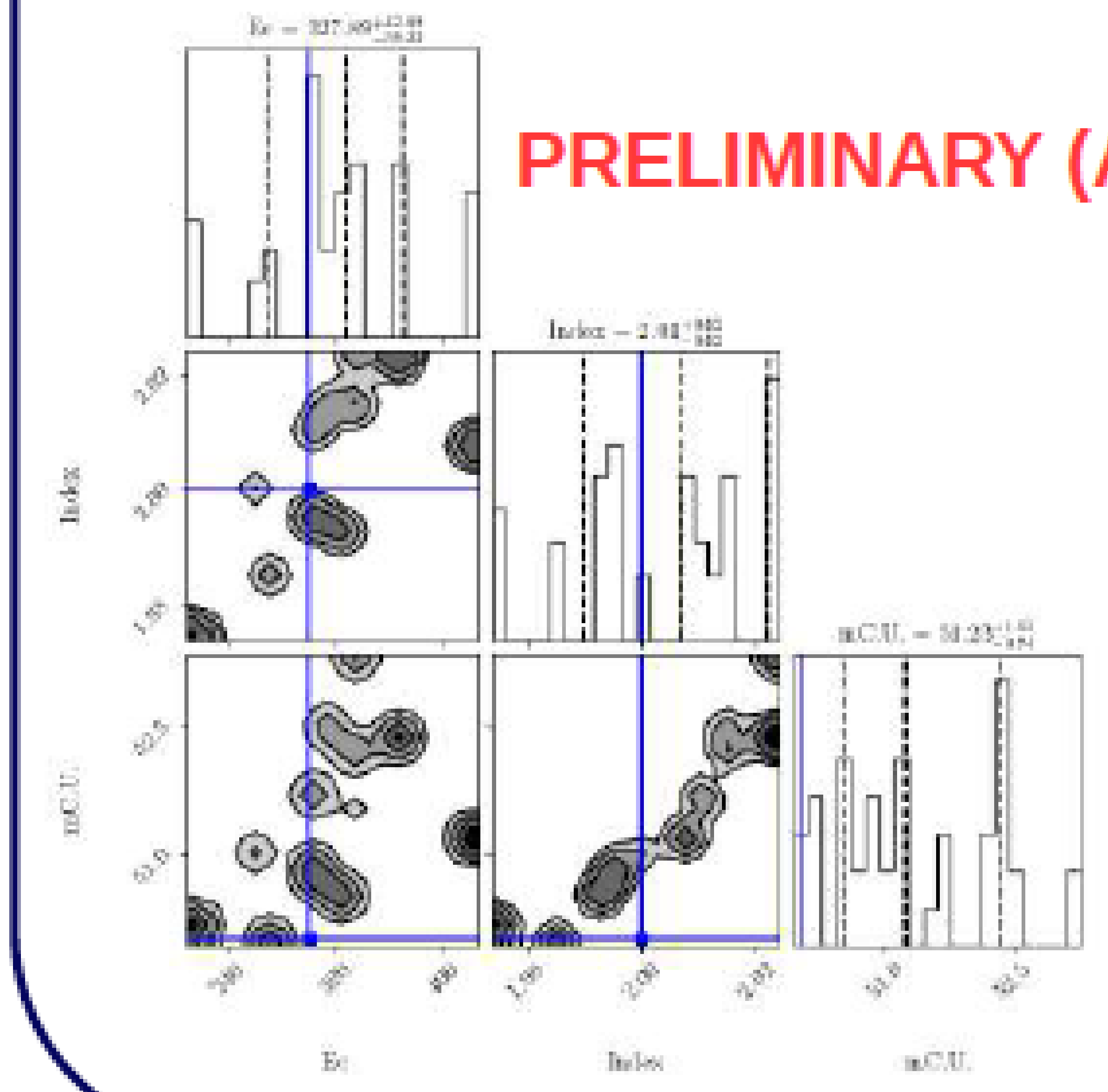
- Flux: 5% Crab Unit above 1TeV
- Index: -2
- Ec: 300 TeV (from the knee)
- 10h of CTA, 1yr of SWGO

SWGO

N_{sim}=231 - N_{fitted}=231 (100%)

N_{PL}=188 (81.4%)

N_{ExpPL}=43 (18.6%)



PRELIMINARY (A4)

CTA

N_{sim}=231 - N_{fitted}=231 (100%)

N_{PL}=231 (100%)

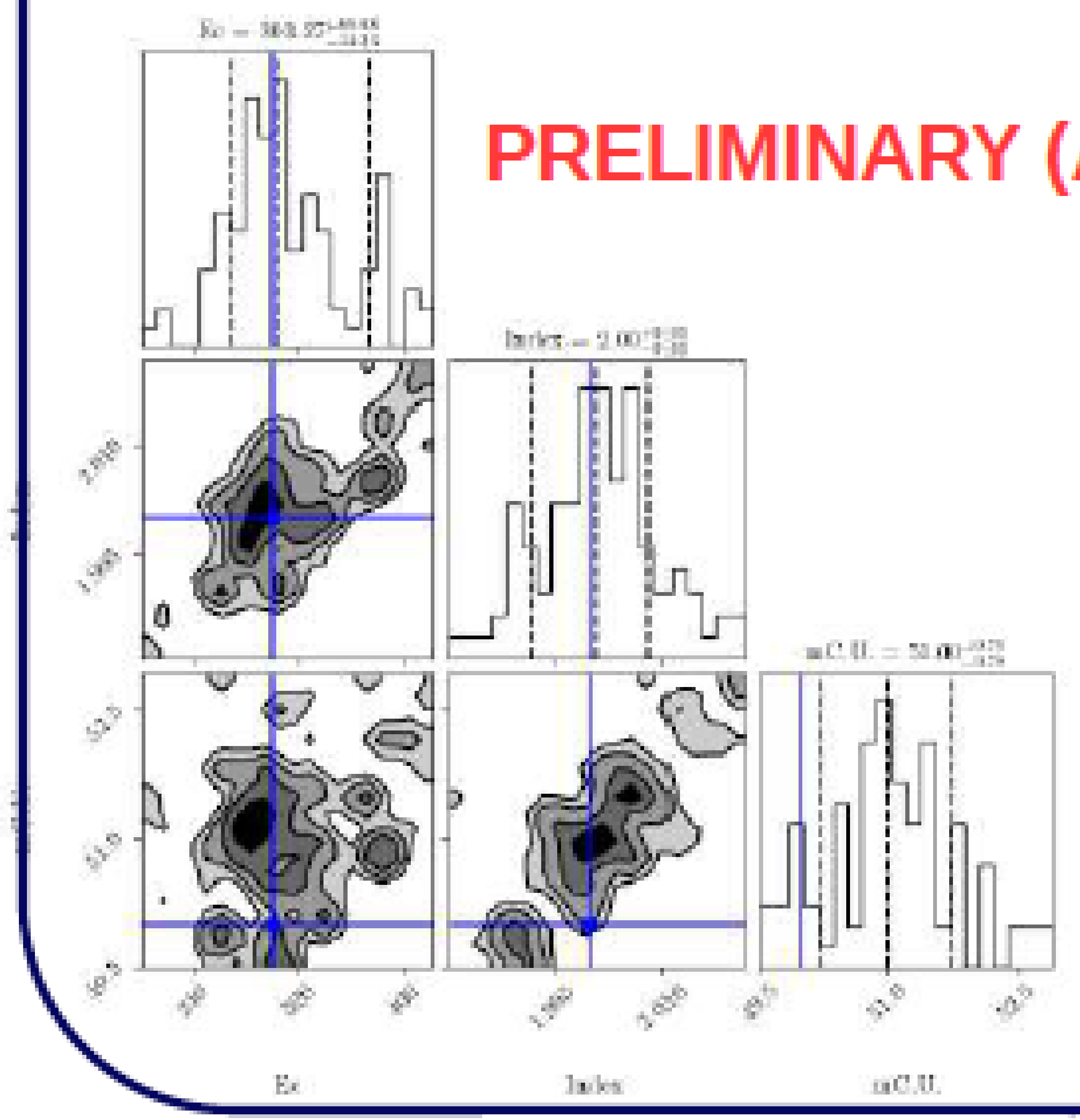
N_{ExpPL}=0 (0%)

CTA + SWGO

N_{sim}=116 - N_{fitted}=116 (100%)

N_{PL}=18 (15.5%)

N_{ExpPL}=98 (84.5%)



PRELIMINARY (A4)

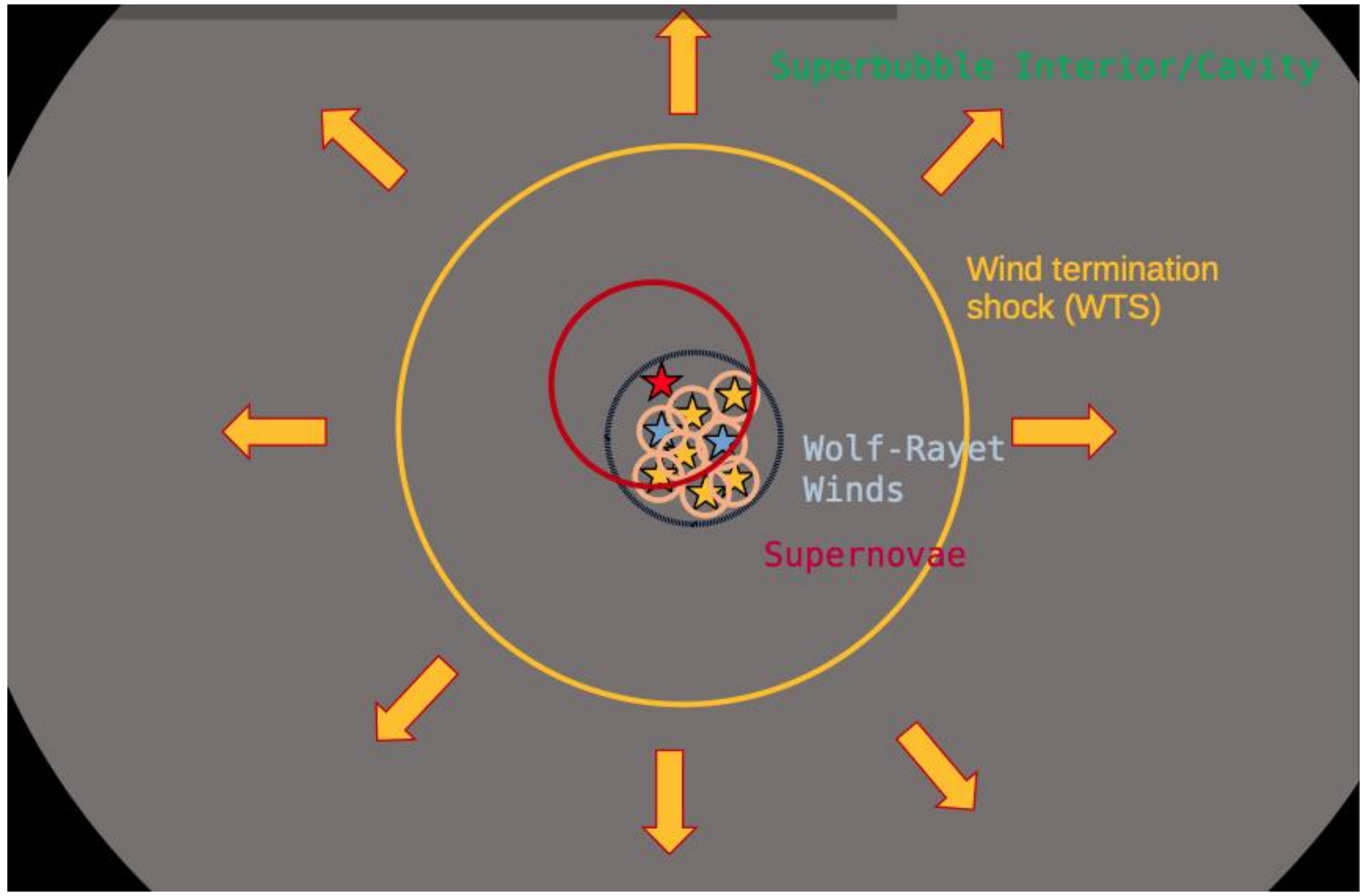
Massive stellar clusters

Massive stars produced at the collapse of GMCs form compact groups consisting of tens of massive (O, WR type) stars and remain linked during their life (1-10 Myr)

SWs and SN explosions => *superbubbles* filled with turbulent plasma shocks

Conditions can be more favourable than in individual SNRs

Massive star cluster : Bounded group of stars which contains SN progenitors (ZAMS > 8 Msol)



Acceleration mechanism	U [km/s]	B [μG]	R [pc]	E_{max}, canonical [PeV]	E_{max}, optimistic [PeV]
SB forward shock	30	1 – 10	50 – 100	0.01	0.1
SNR inside SB	3000	10 – 50	10 – 30	1	5
WTS around a compact cluster	2000	10 – 50	5 – 30	1	5
SNR embedded in a WTS	5000	10 – 50	5 – 30	5	10
HD turbulence	100	1 – 10	50 – 100	0.5	1
Collection of individual winds (loose cluster)	10 – 100	10 – 50	1 – 10	0.05	0.5

Table 1. Benchmark estimates of the maximum proton energy achievable via various acceleration mechanisms expected to take place inside superbubbles. The canonical values correspond to the values commonly inferred from observations of typical examples, e.g. Westerlund 1 as a young compact cluster, Cygnus OB2 as a loose cluster, etc. Optimistic values choose favourable, yet plausible combinations of the physical conditions.

Morlino, Blasi, Peretti, Cristofari 2021
Vieu, Reville, Aharonian 2022

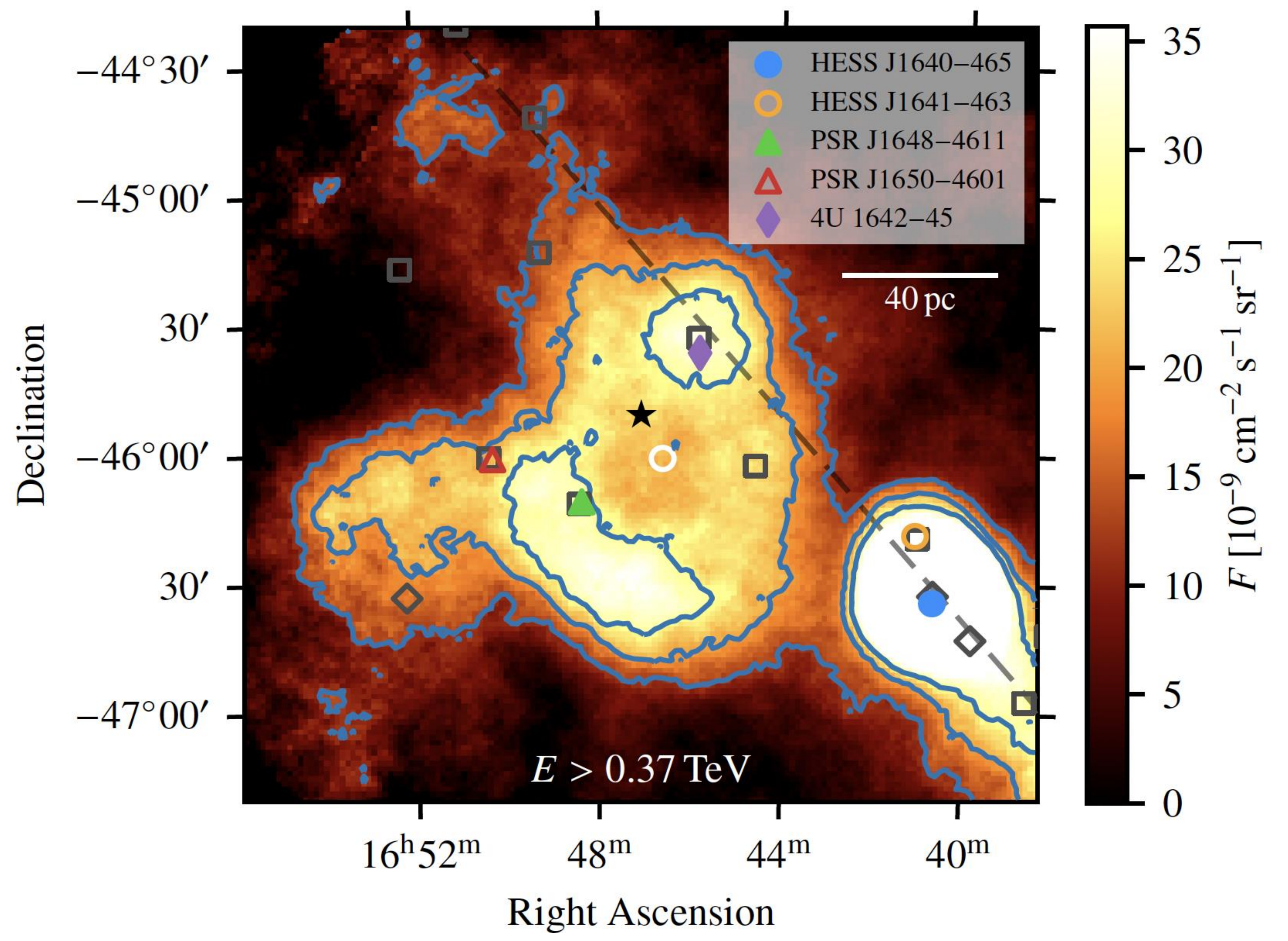
The interesting case of Westerlund 1

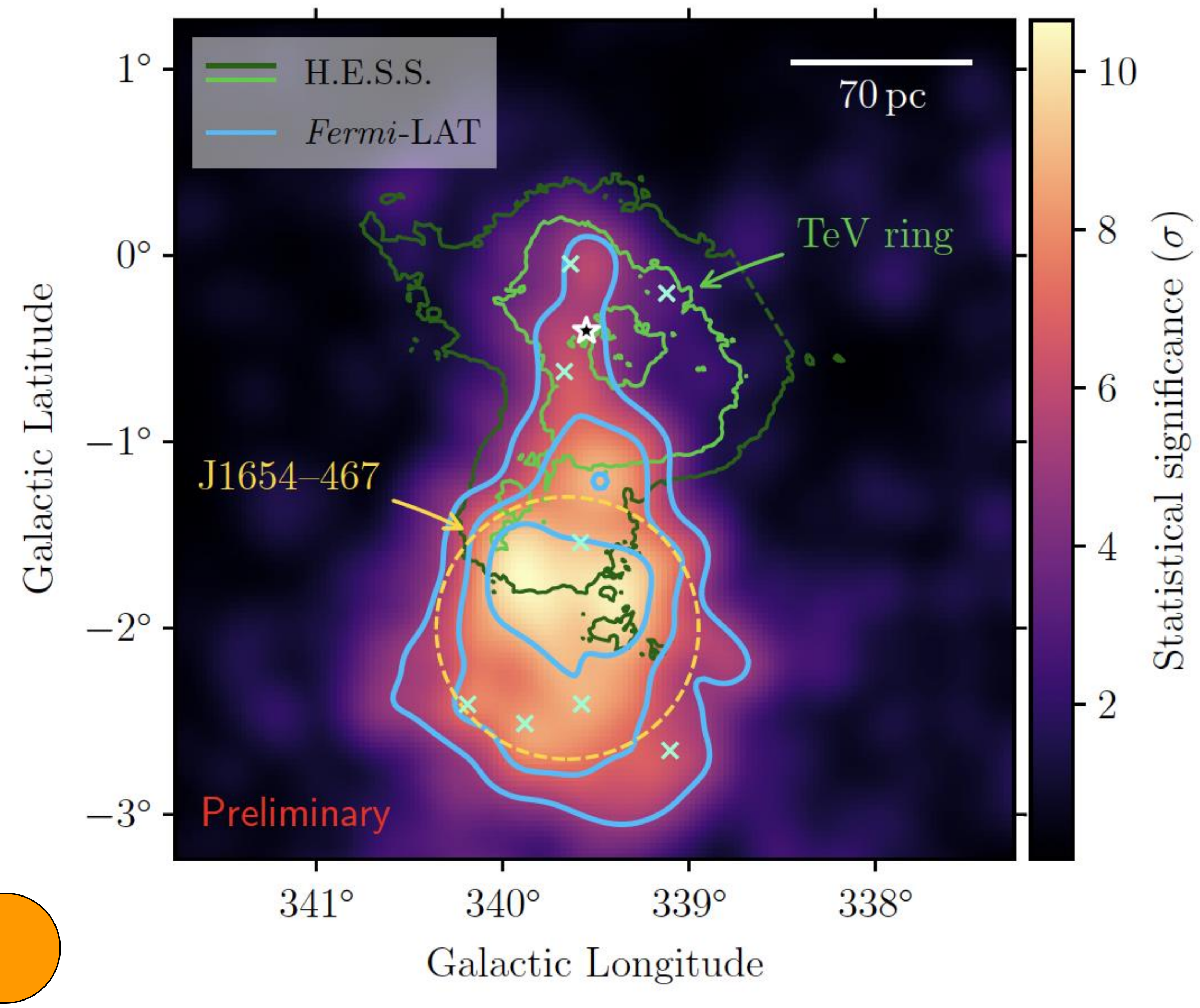
Most massive known young stellar cluster in Milky Way

- Half-mass radius: ~ 1 pc
- Total mass: ~10^5 solar masses
- Age: 3.5 – 5 Myr
- Distance: ~4 kpc

HESS dataset : 164h from 2004-2017 on HESS J1646-458
=> Shell like structure detected at TeV
Only Wd 1 can explain bulk of emission
Acceleration at cluster wind termination shock

Fermi observations:
extended emission region (> 100 pc)
Electron energy density in outflow: $Ue \sim (1 - 10)$ eV cm^{-3}
diffusive shock acceleration theory predicts $\eta p > \eta e \Rightarrow Up > Ue$
‣ *the outflow is loaded with – and potentially driven by – cosmic rays*



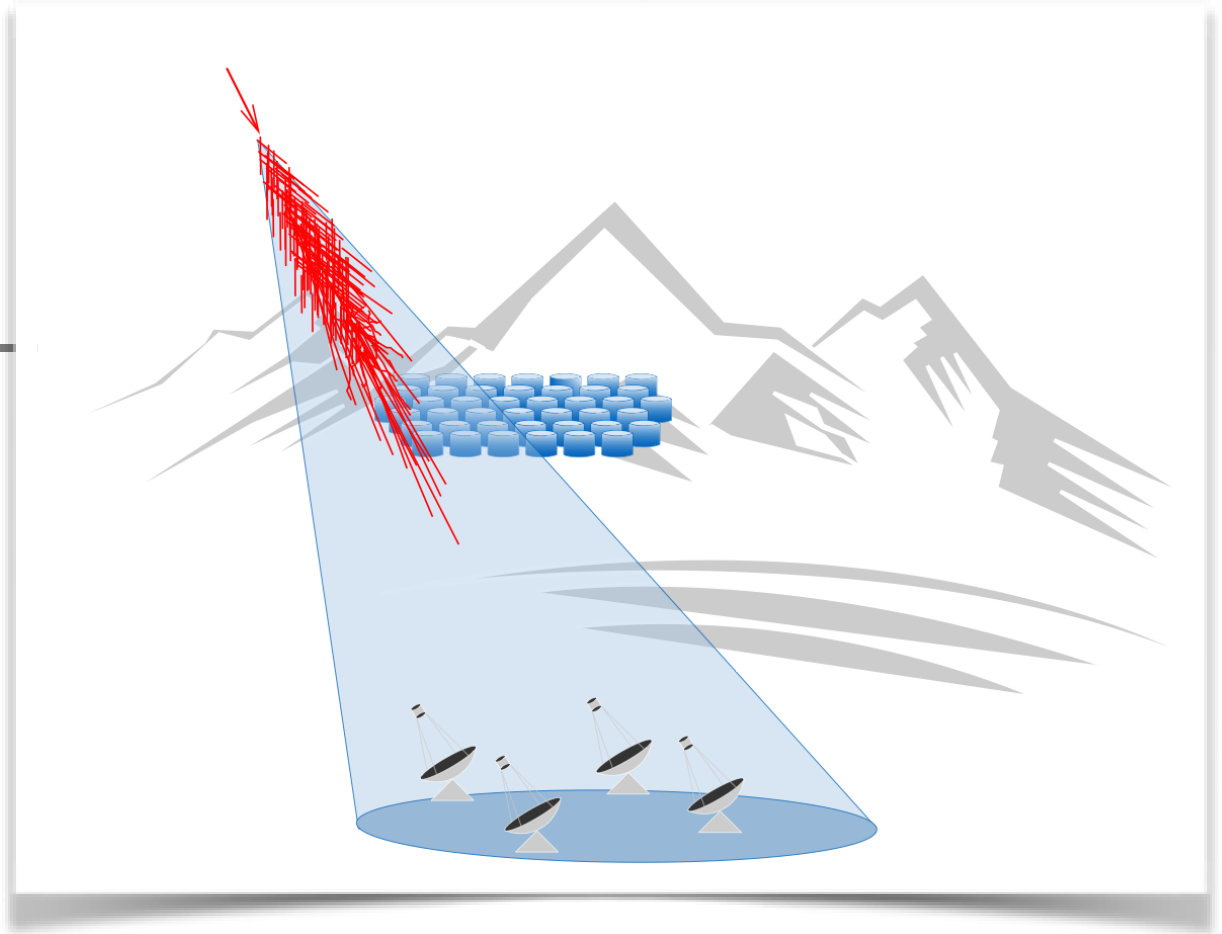


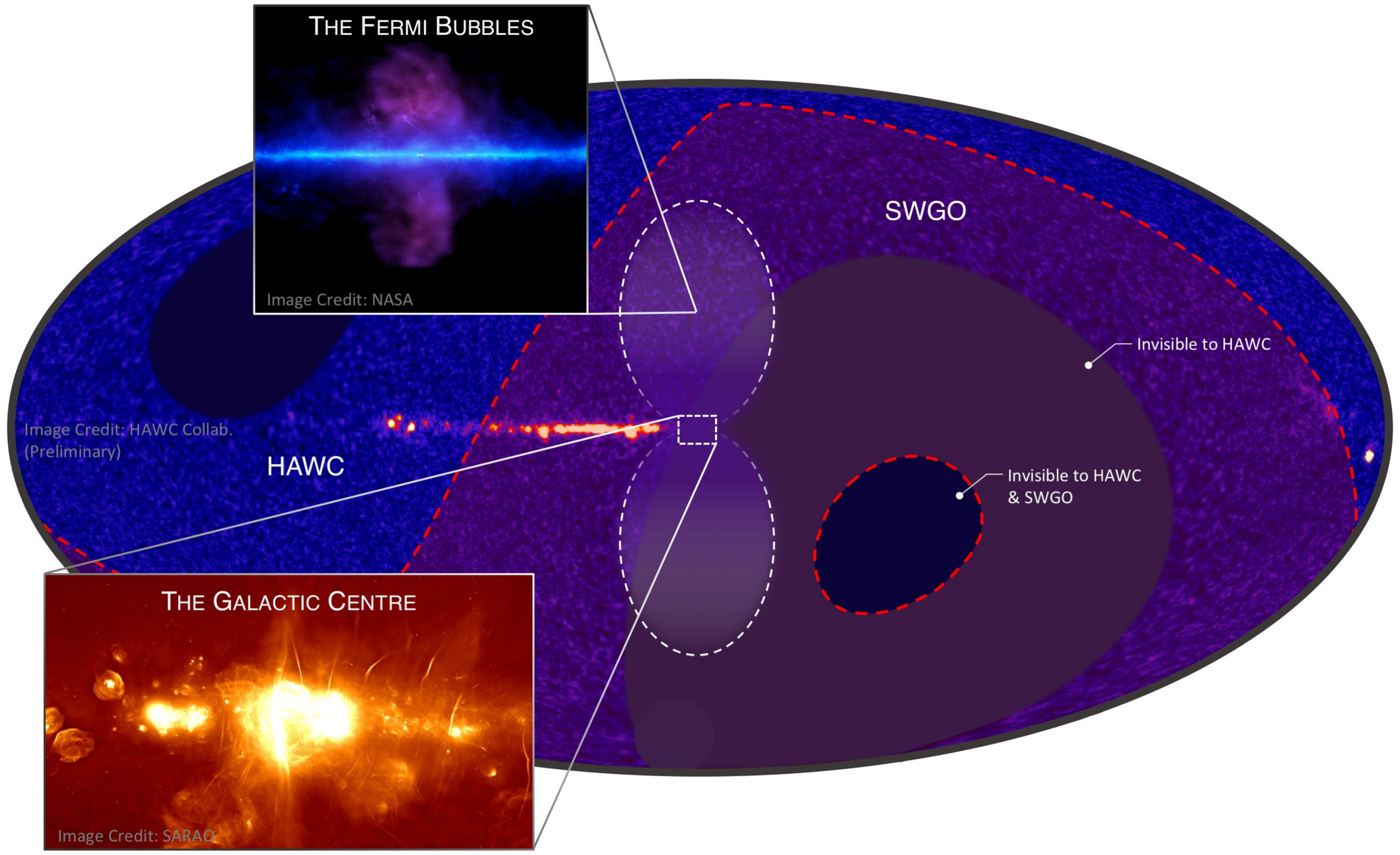
MLG et al. Nature Com., accepted

Summary

- ► **Two complementary detection techniques to detect γ rays from the ground**
- ► HAWC and LHAASO covering the Northern hemisphere.
  SWGO brings the successful wide-field gamma-ray approach to a new hemisphere ! First major instrument of this type in the South
- ► Complementarity with CTAO for transient, very extended

  sources and PeVatrons) ; synergy with neutrino and GW alerts
- ► NOW approaching construction:
- • Pathfinder in Pampa la Bola in 2026
- • SWGO-A construction from 2027 (with NSF support)





See science case white paper for details:
https://arxiv.org/abs/2506.01786

Thank you for your attention