INSTITUTO DE ASTROFÍSICA DE ANDALUCÍA

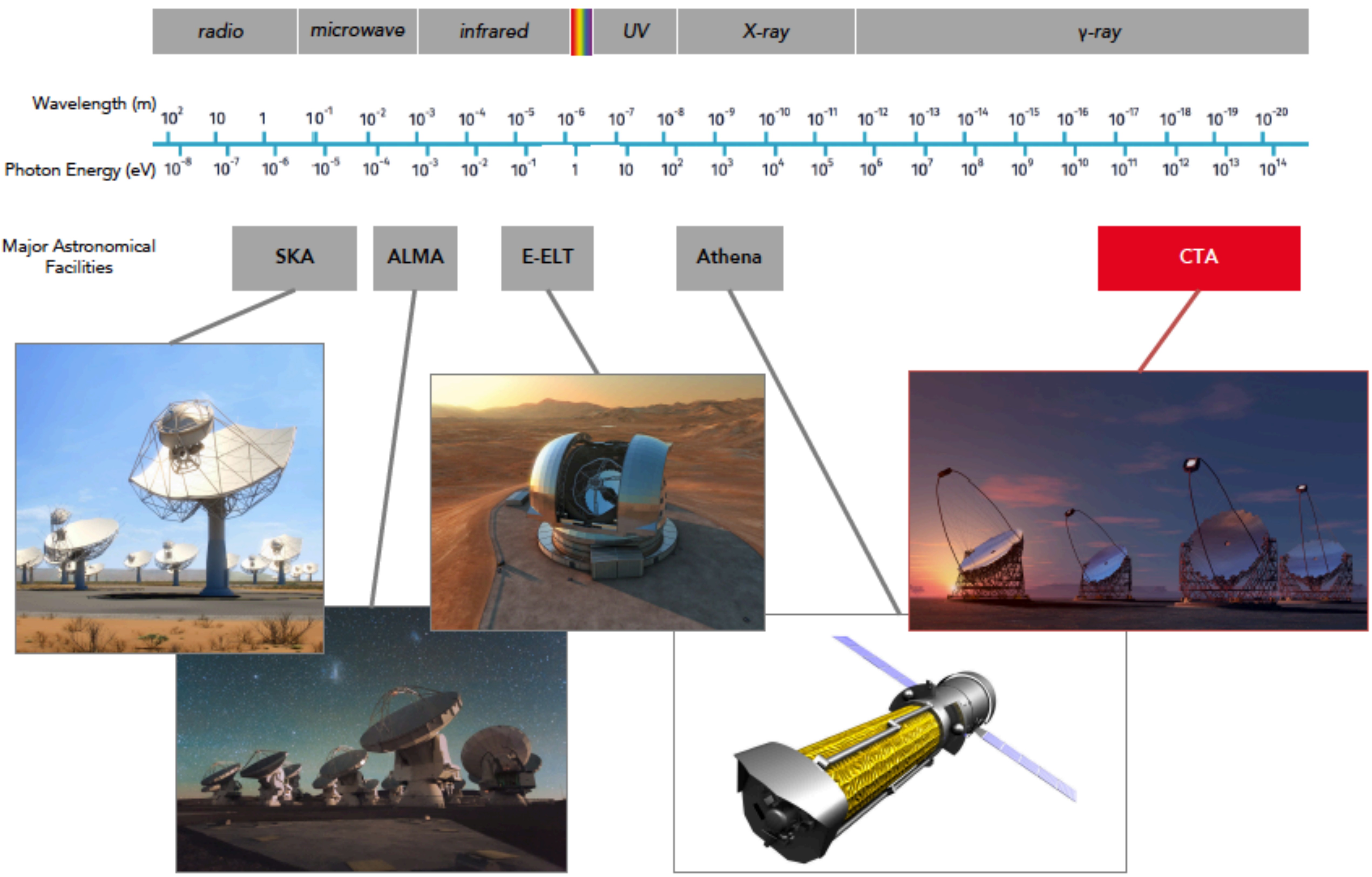
EXCELENCIA SEVERO OCHOA

CSIC

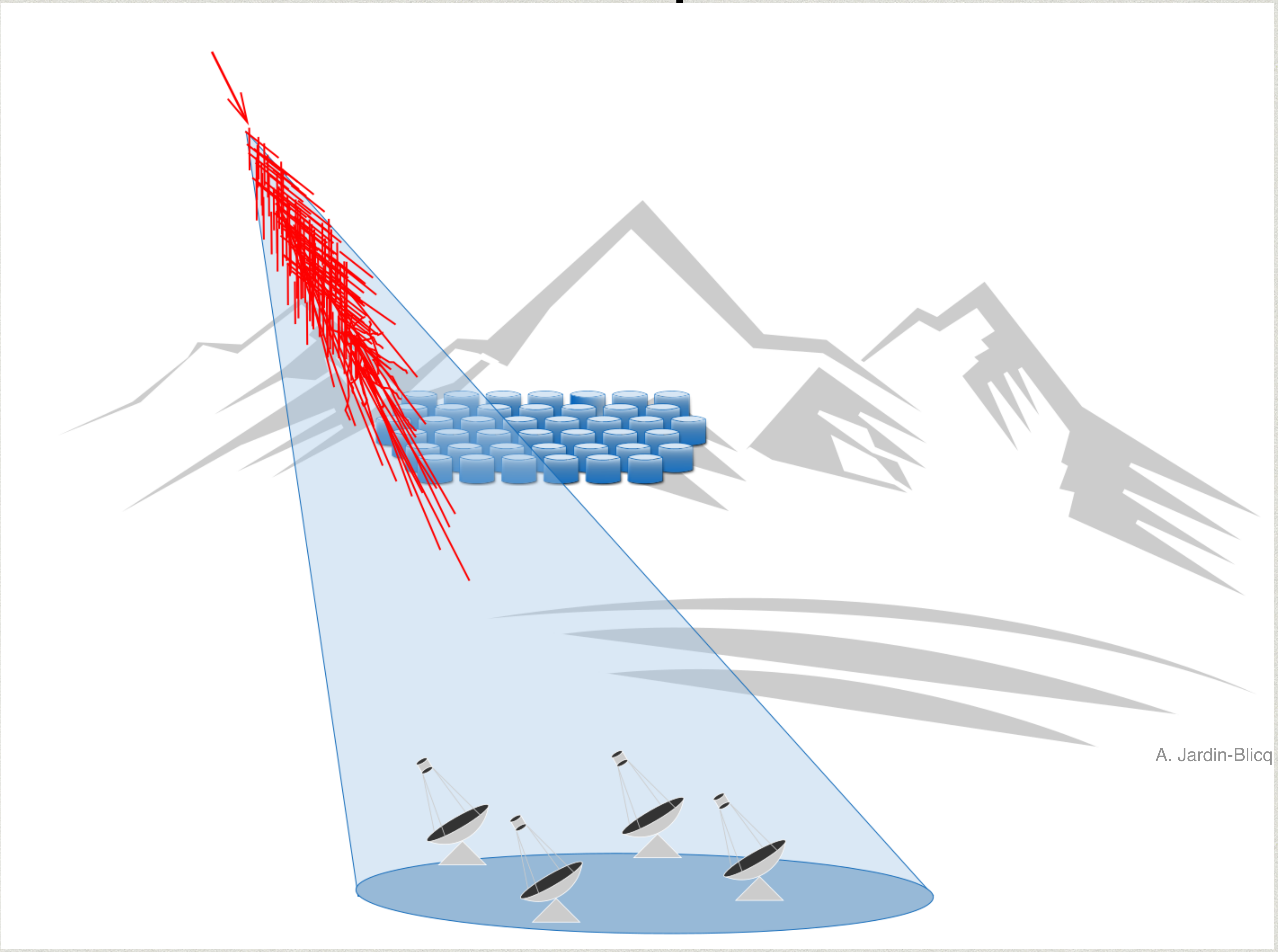
Very High Energy Gamma-ray Astronomy with SWGO: The **S**outhern **W**ide-Field **G**amma-ray **O**bservatory

Rubén López-Coto - IAA-CSIC - 28/03/23

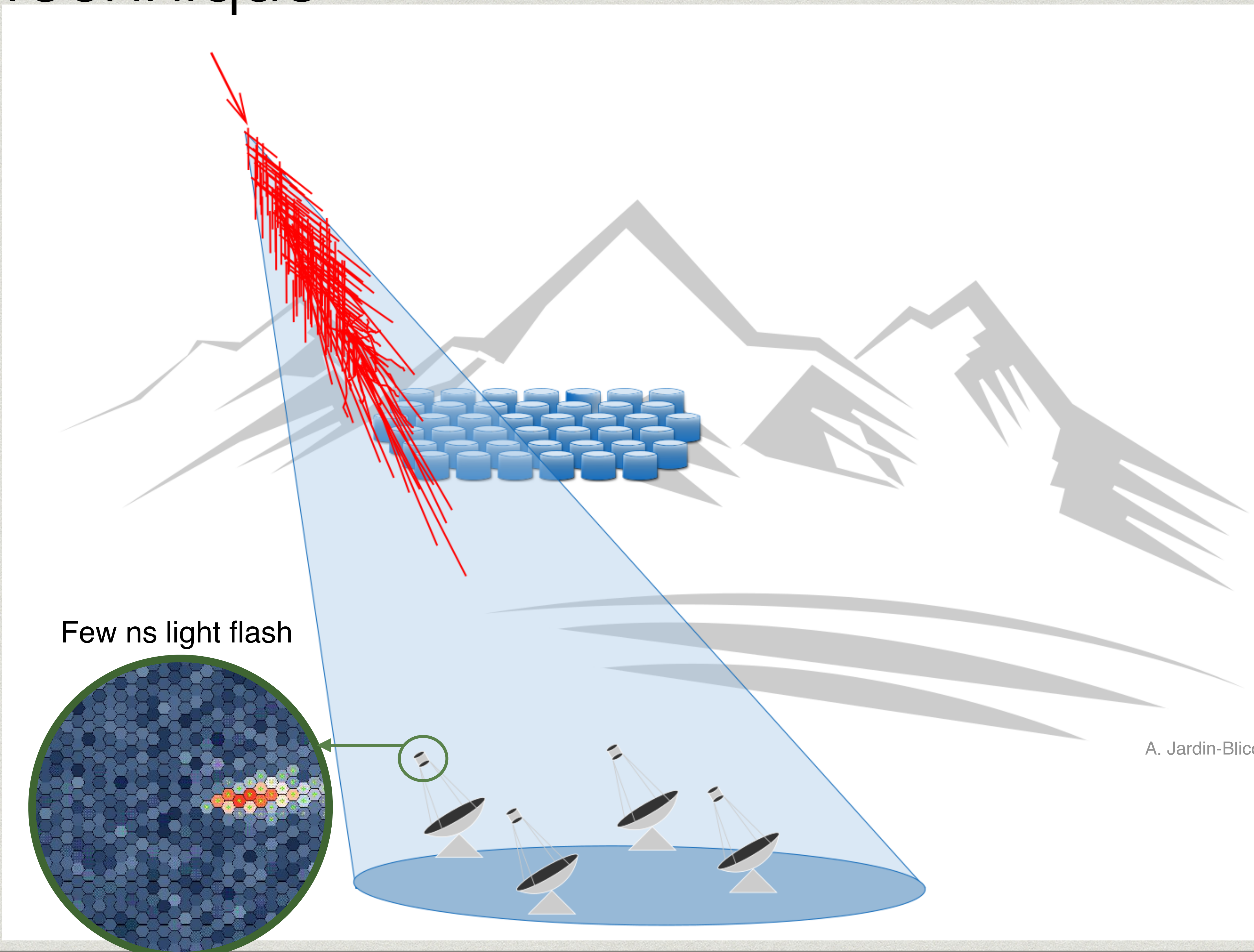
The EM spectrum



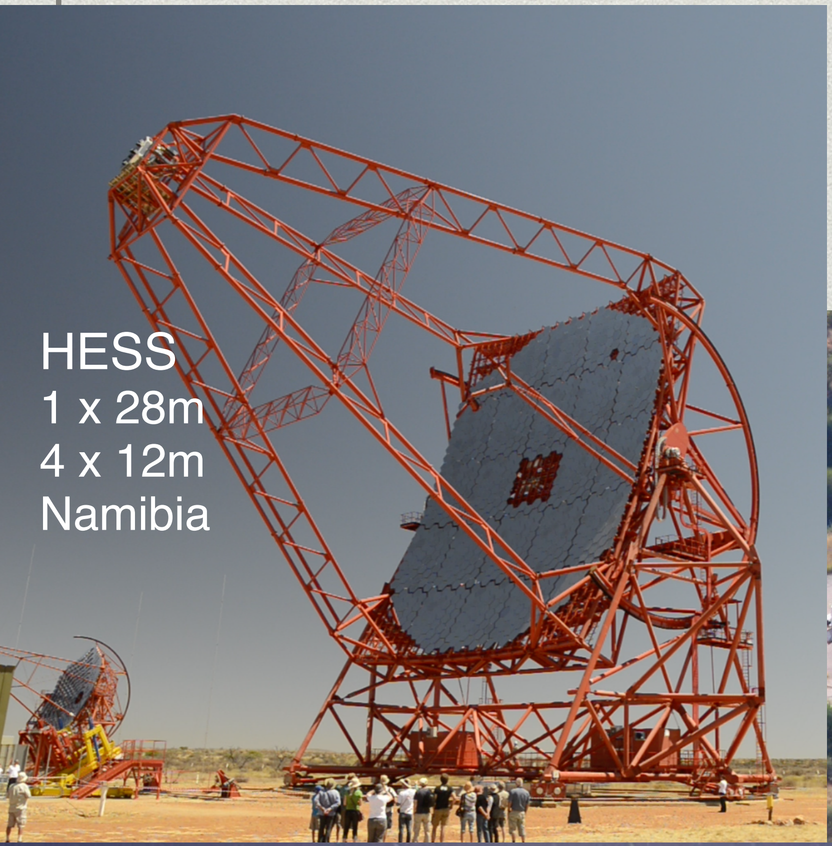
Shower development



The Imaging Atmospheric Cherenkov Technique



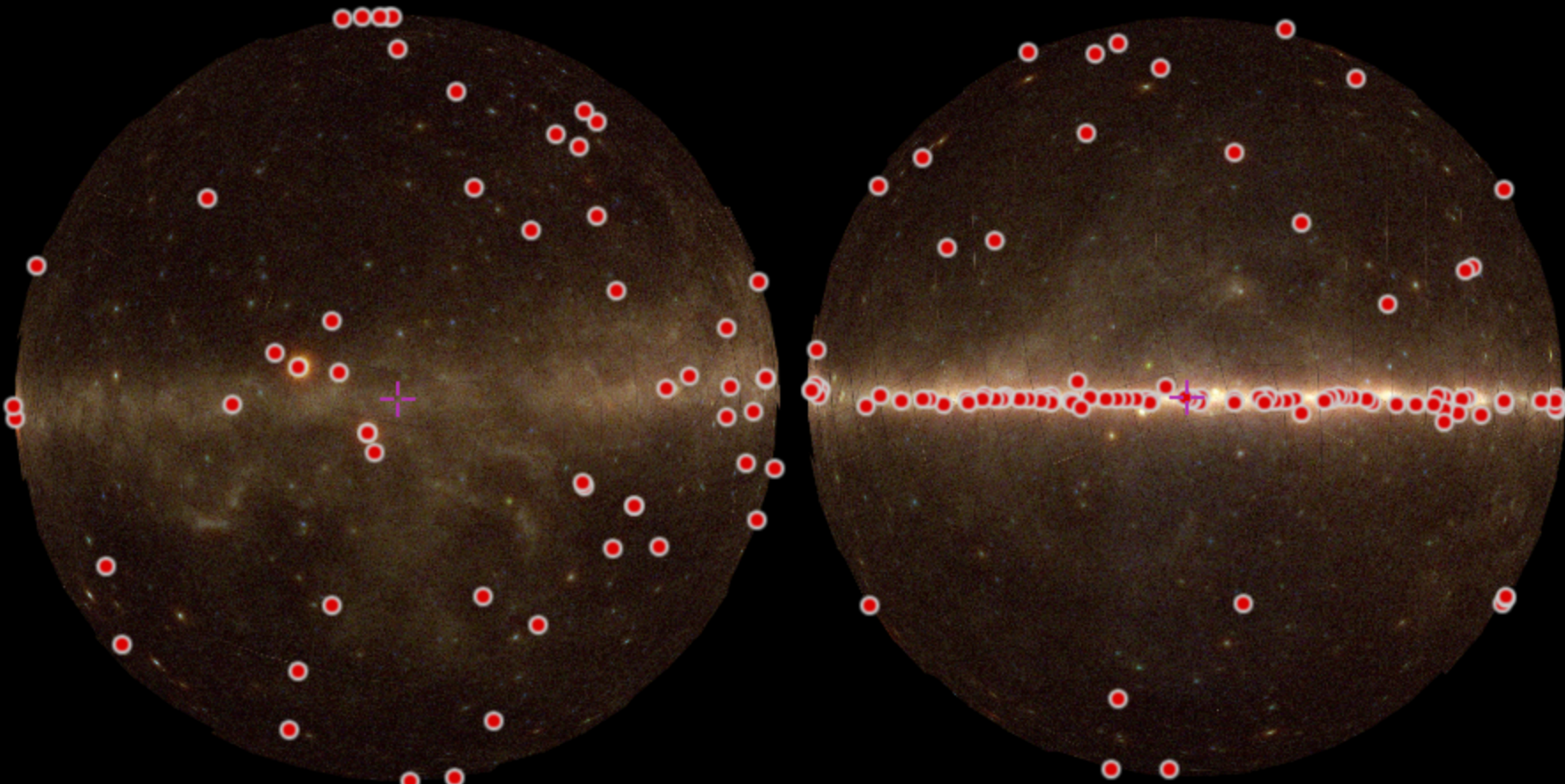
Imaging Atmospheric Cherenkov Telescopes



The current ‘IACTs’

- 1.5-2.5 km altitudes
- 2-5 Telescopes
- few degree FoV

The TeV Sky

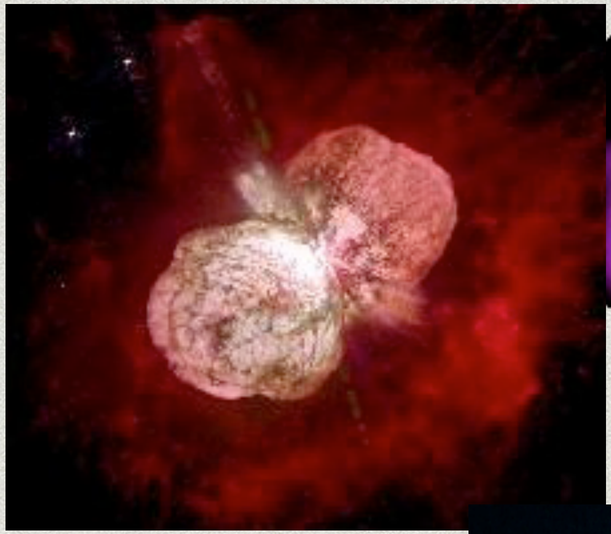


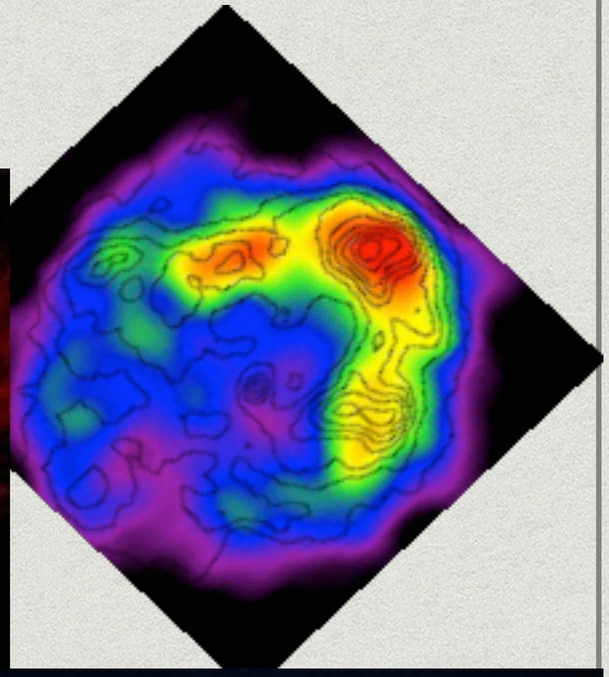
~200 TeV sources

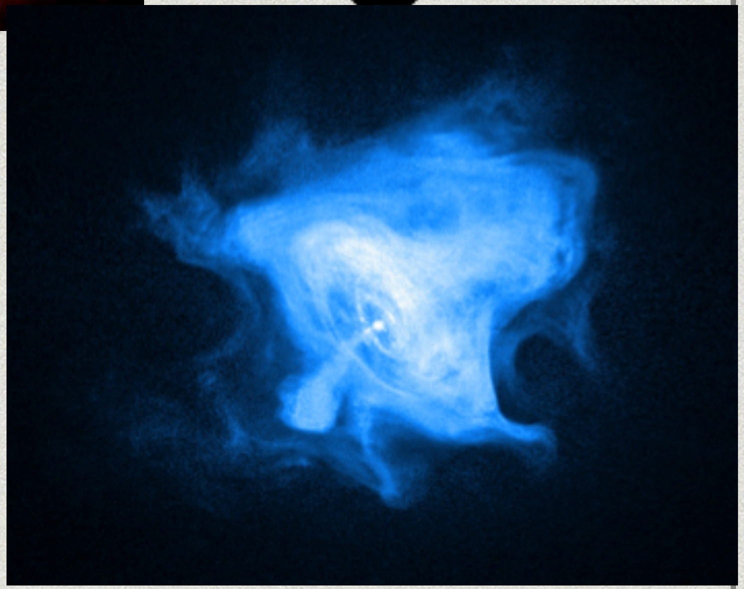
TeV gamma-ray sources

Great variety of TeV emitters!

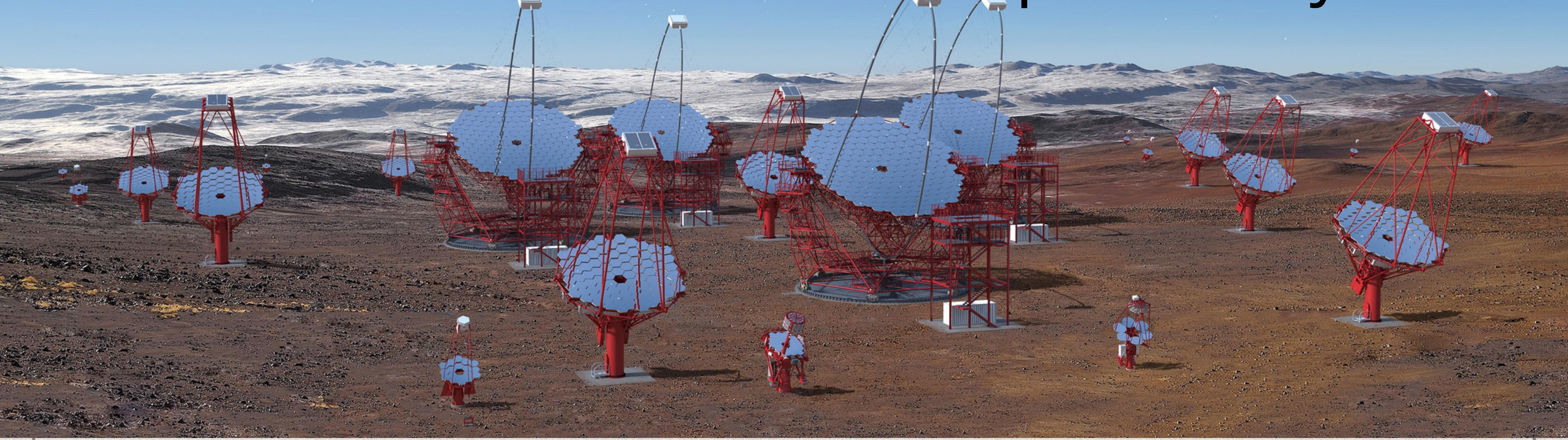
- Galactic
  - Supernova remnants
  - Bombarded molecular clouds
  - Stellar binaries - colliding wind & X-ray
  - Massive stellar clusters
  - Pulsars and pulsar wind nebulae
  - Supermassive black hole Sgr A*
- Extragalactic
  - Starburst galaxies.
  - Milky Way satellites.
  - Radio galaxies.
  - Flat-spectrum radio quasars.
  - ‘BL Lac’ objects.
  - Gamma-ray bursts.







The Cherenkov Telescope Array



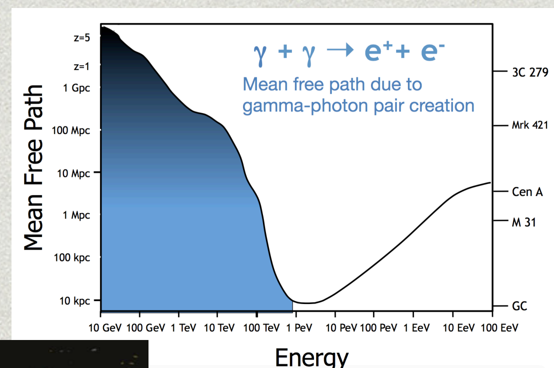
A global effort to build the first true VHE observatory

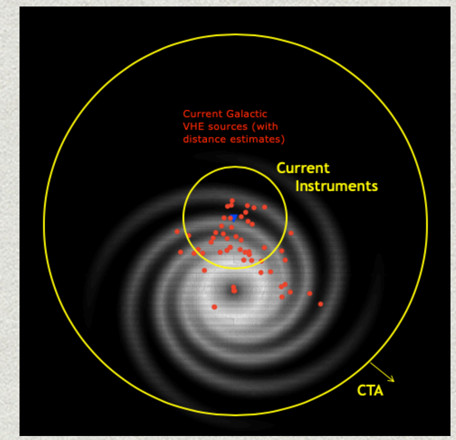
- A user facility serving a wide community
- Data access to all scientists of participating countries
- A huge improvement in all aspects of performance
- ~100 telescopes on two sites

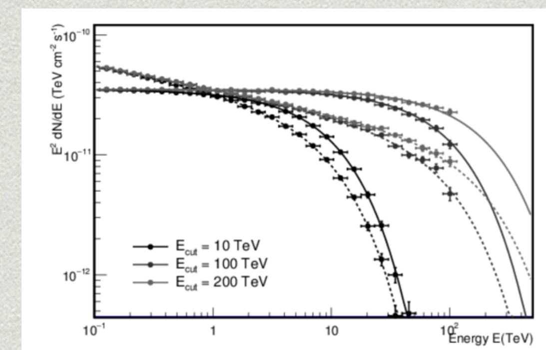
31 nations and >1400 scientists involved - Including full teams from HESS, MAGIC + VERITAS

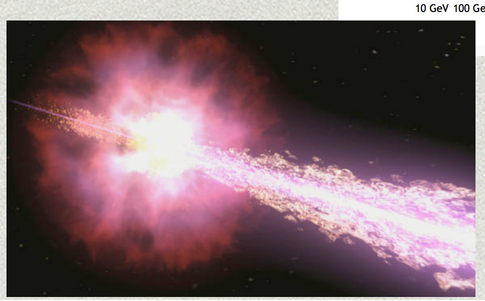
CTA Design drivers

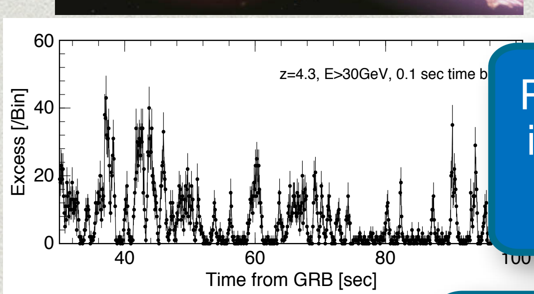
DESIGN DRIVERS

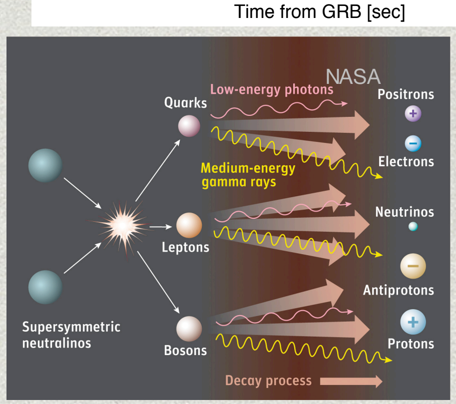


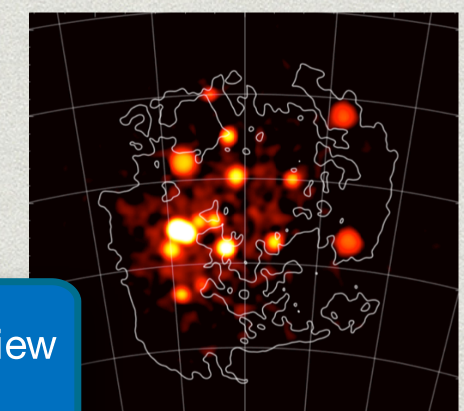


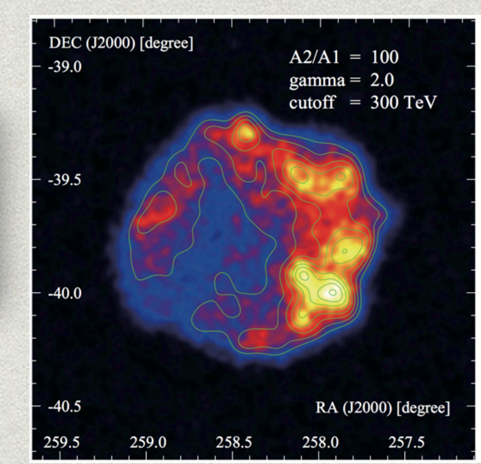












10 x Sensitivity, Large Collection Area
→ all topics

Energies down to 20 GeV
→ Cosmology++

Energies up to 300 TeV
→ Pevatrons

Rapid Slewing in 20 seconds
→ transients

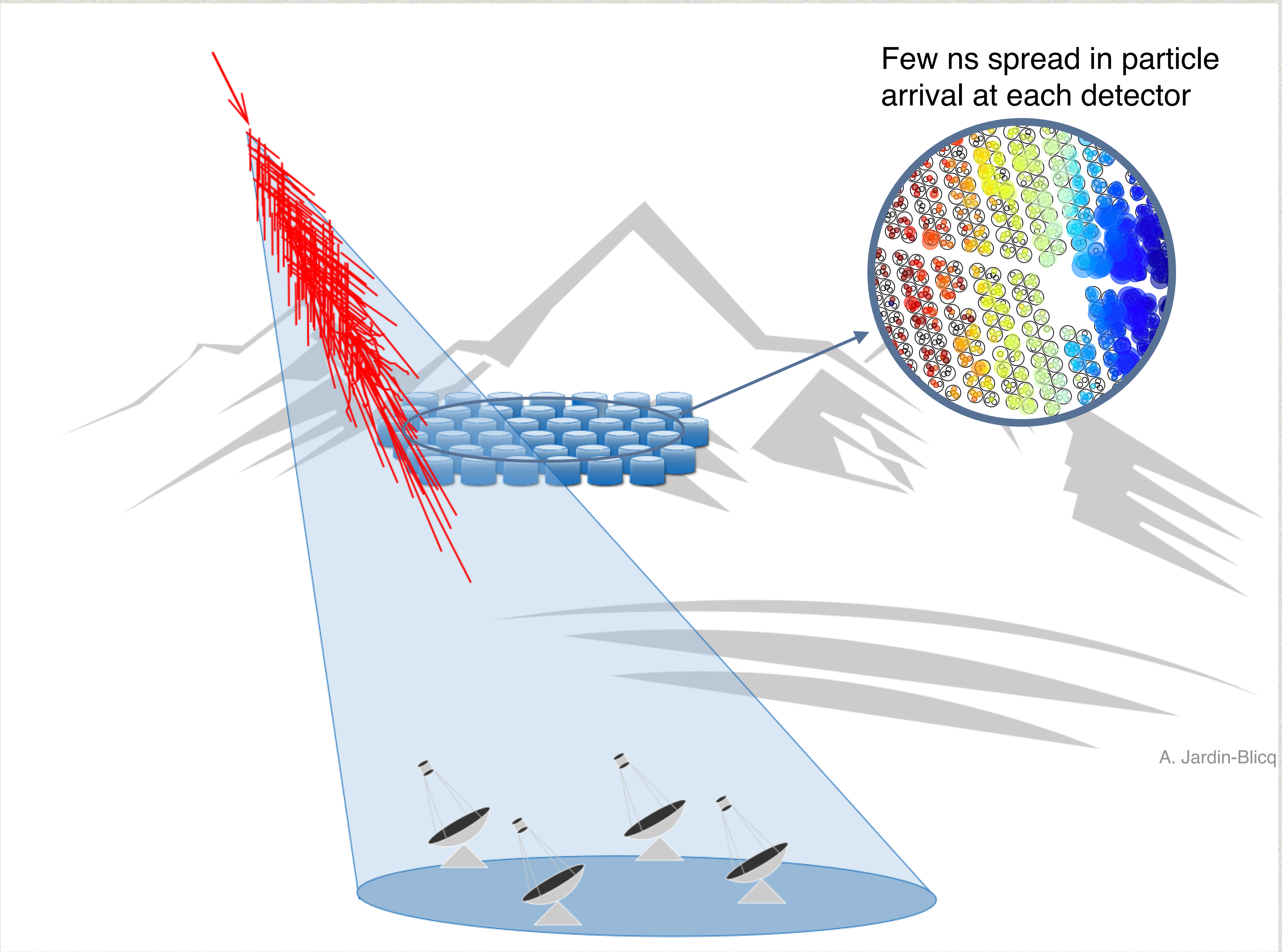
8° Field of View
→ surveys, extended objects

10% Energy Resolution
→ lines, features

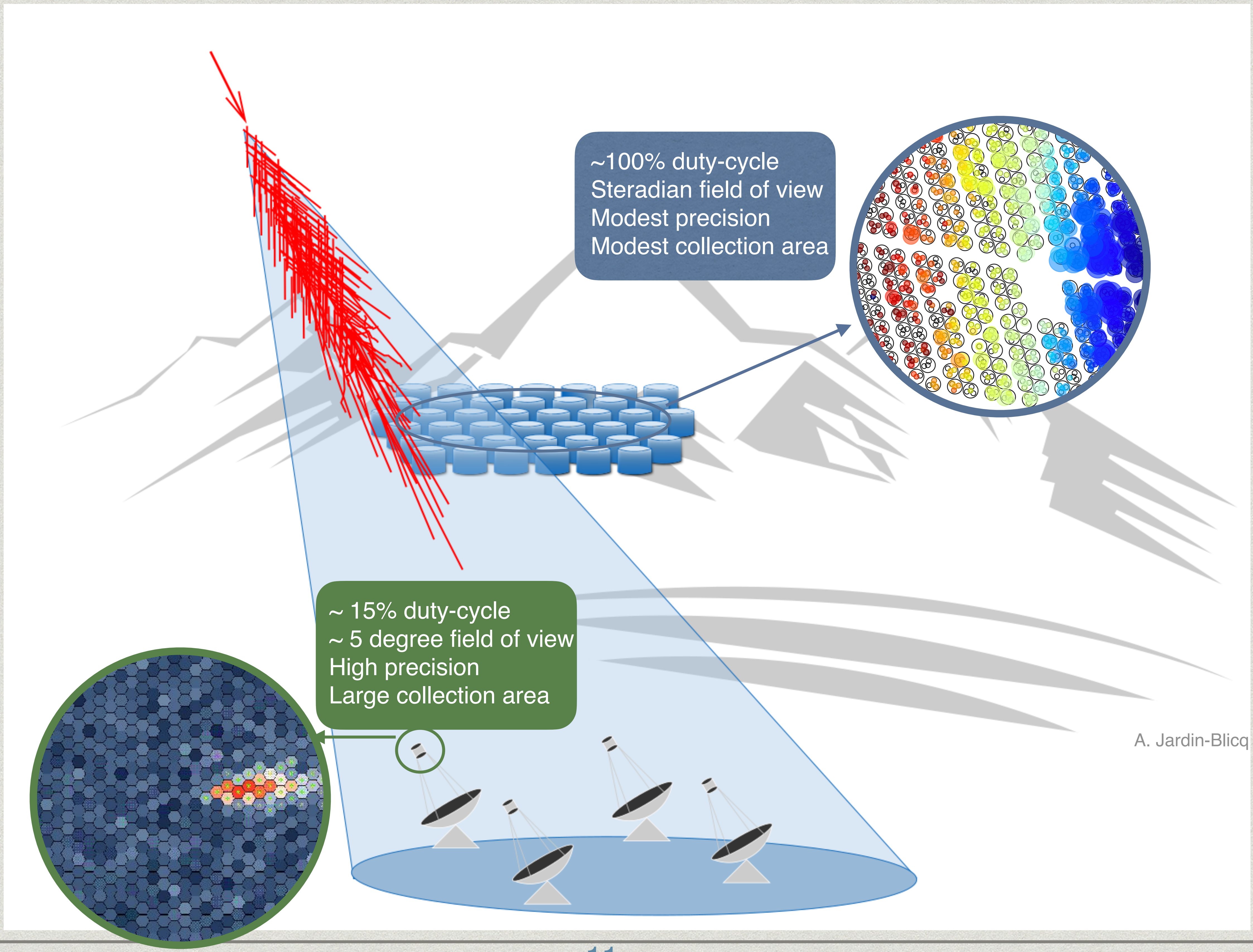
Few ‘ Angular Resolution
→ morphology

cta

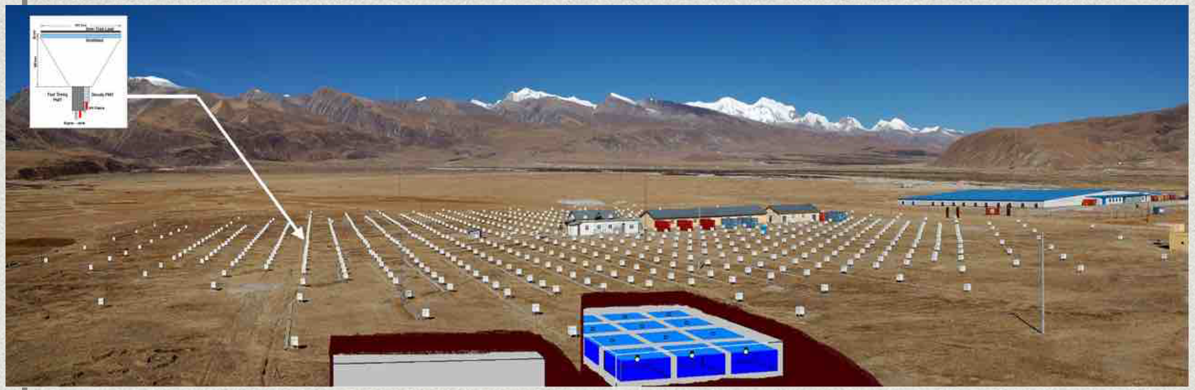
Particle Detector Technique

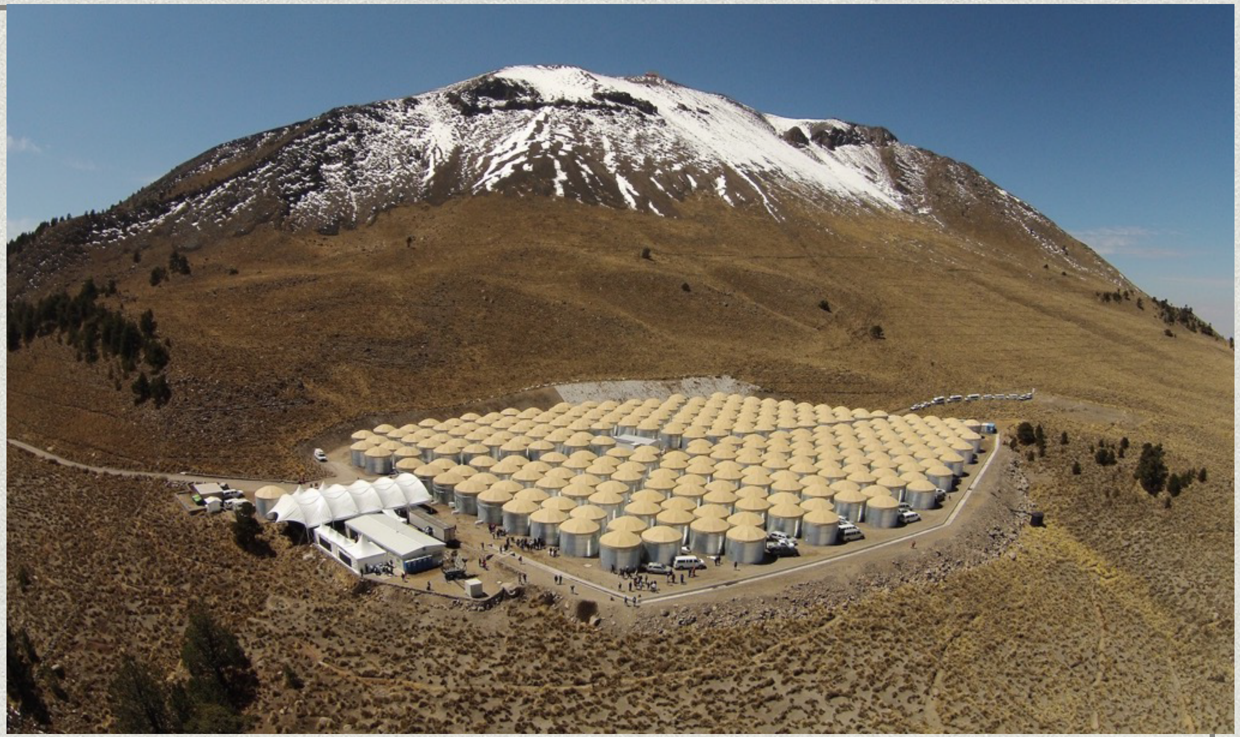


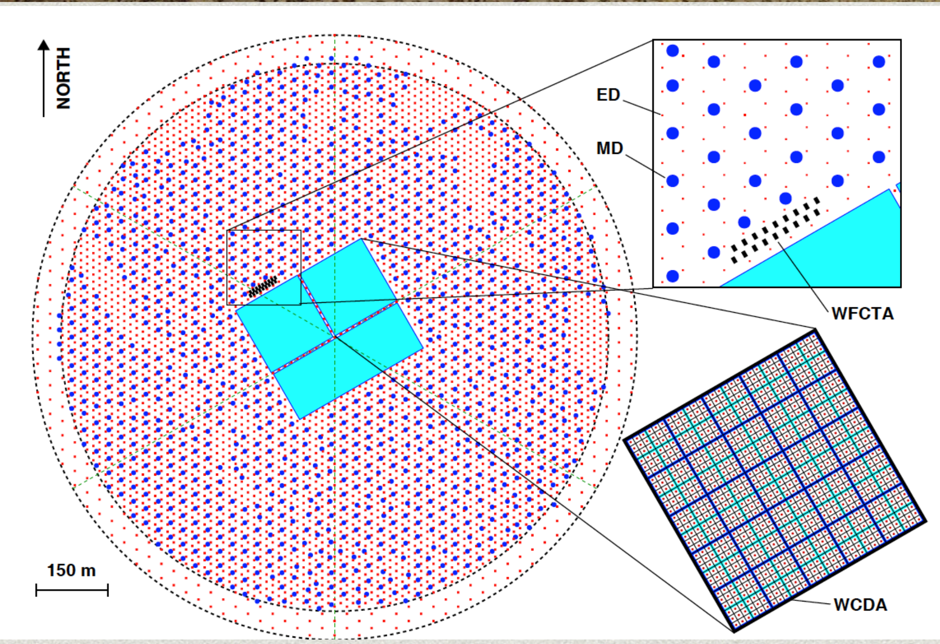
IACTs vs Particle Detectors



Gamma-ray Particle Detector facilities

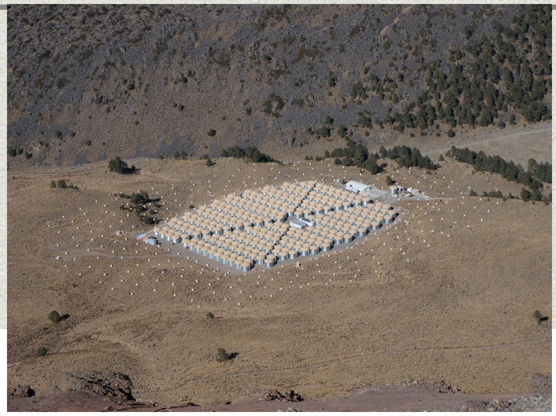


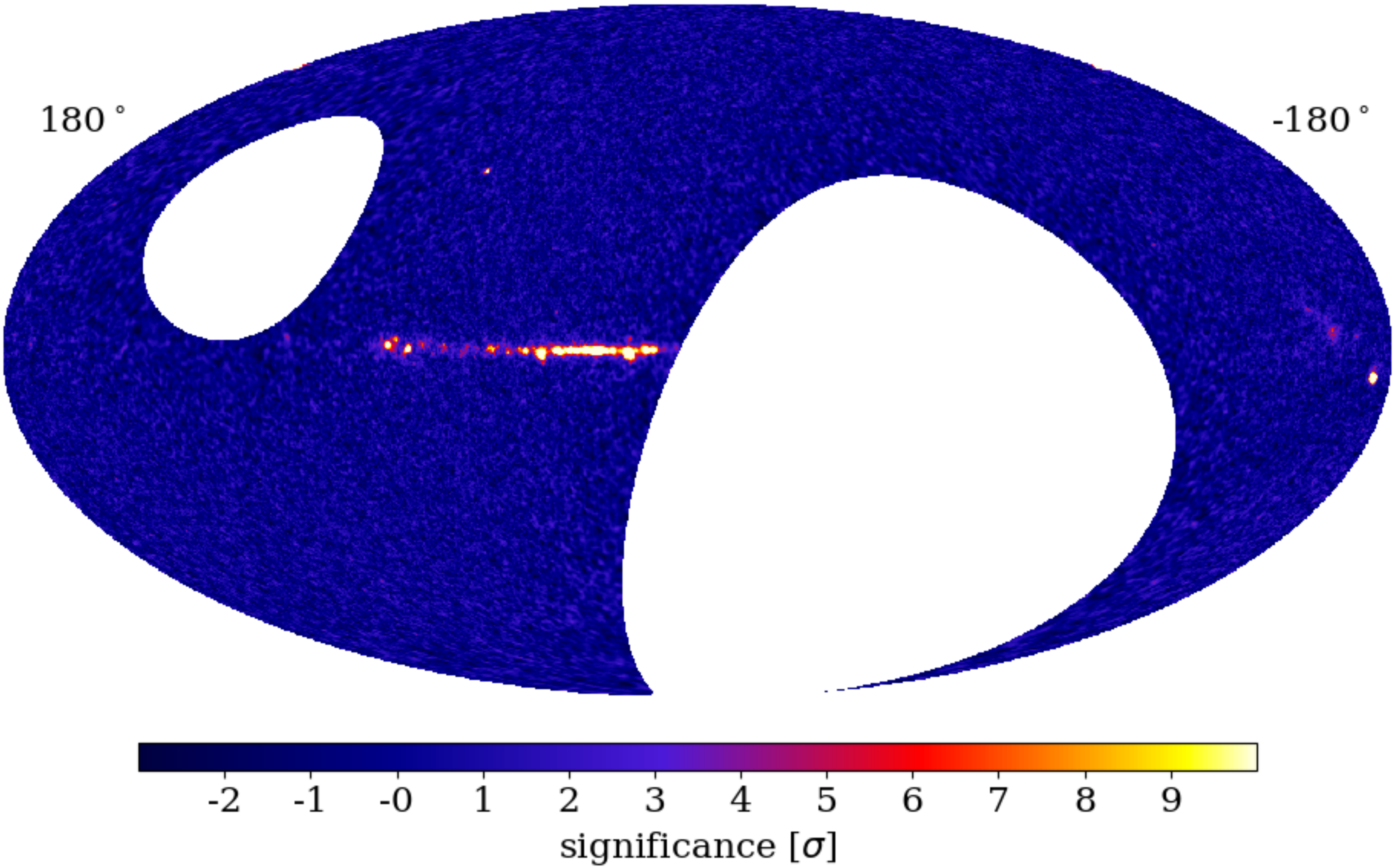




- Proposed solutions:
  - **Tibet AS-γ** (Scintillators, Area = 36,900 m^2).
  - **ARGO** (Resistive Plate Chambers (RPCs), Area = 6,700 m^2).
  - **Milagro** (Water Cherenkov Detector (WCD), Area = 5,000 m^2).
  - **HAWC** (WCD, Area = 22,000 m^2).
  - **LHAASO** (Hybrid, Area (for gammas) = 80,000 m^2).

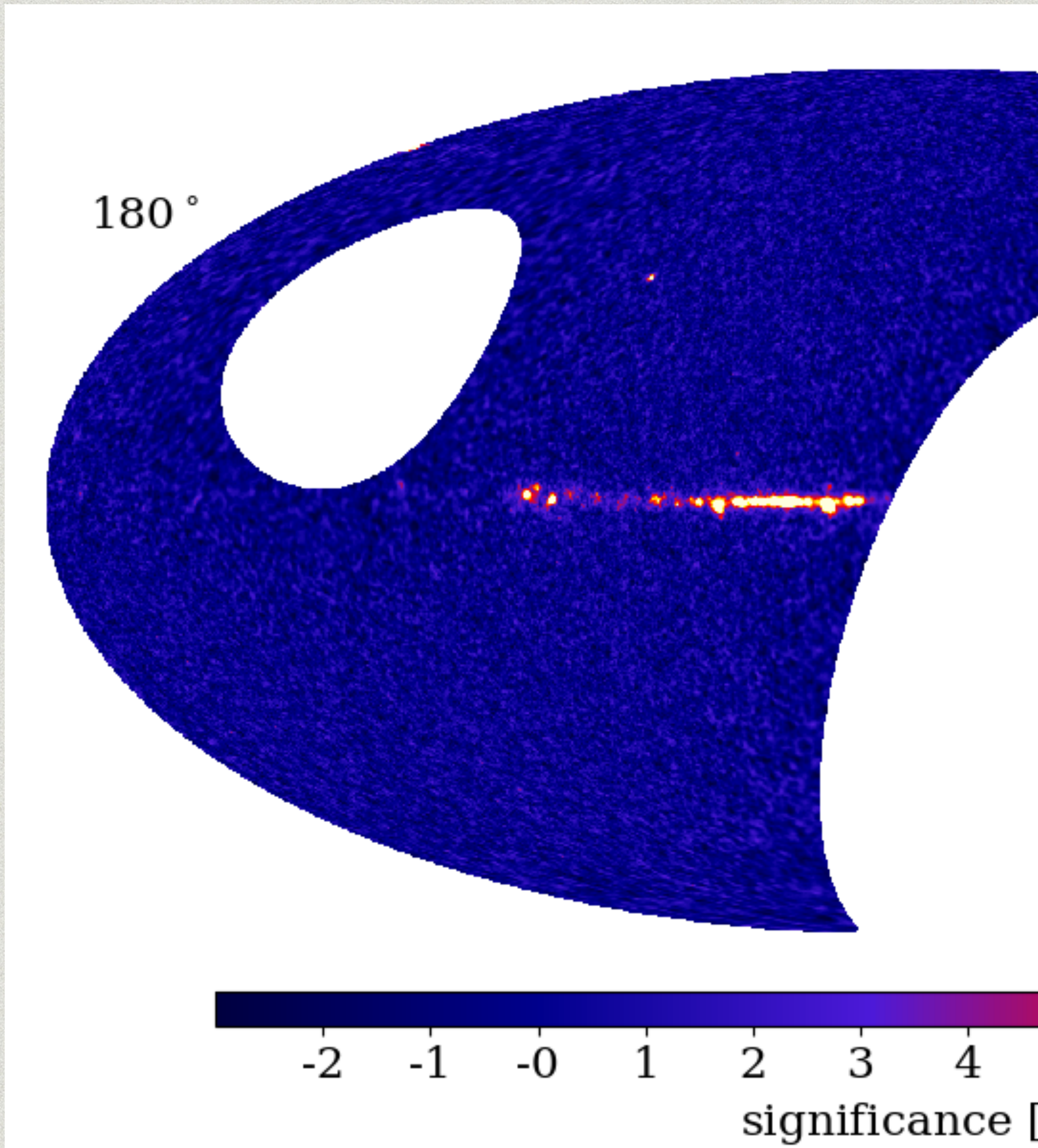
HAWC Sky

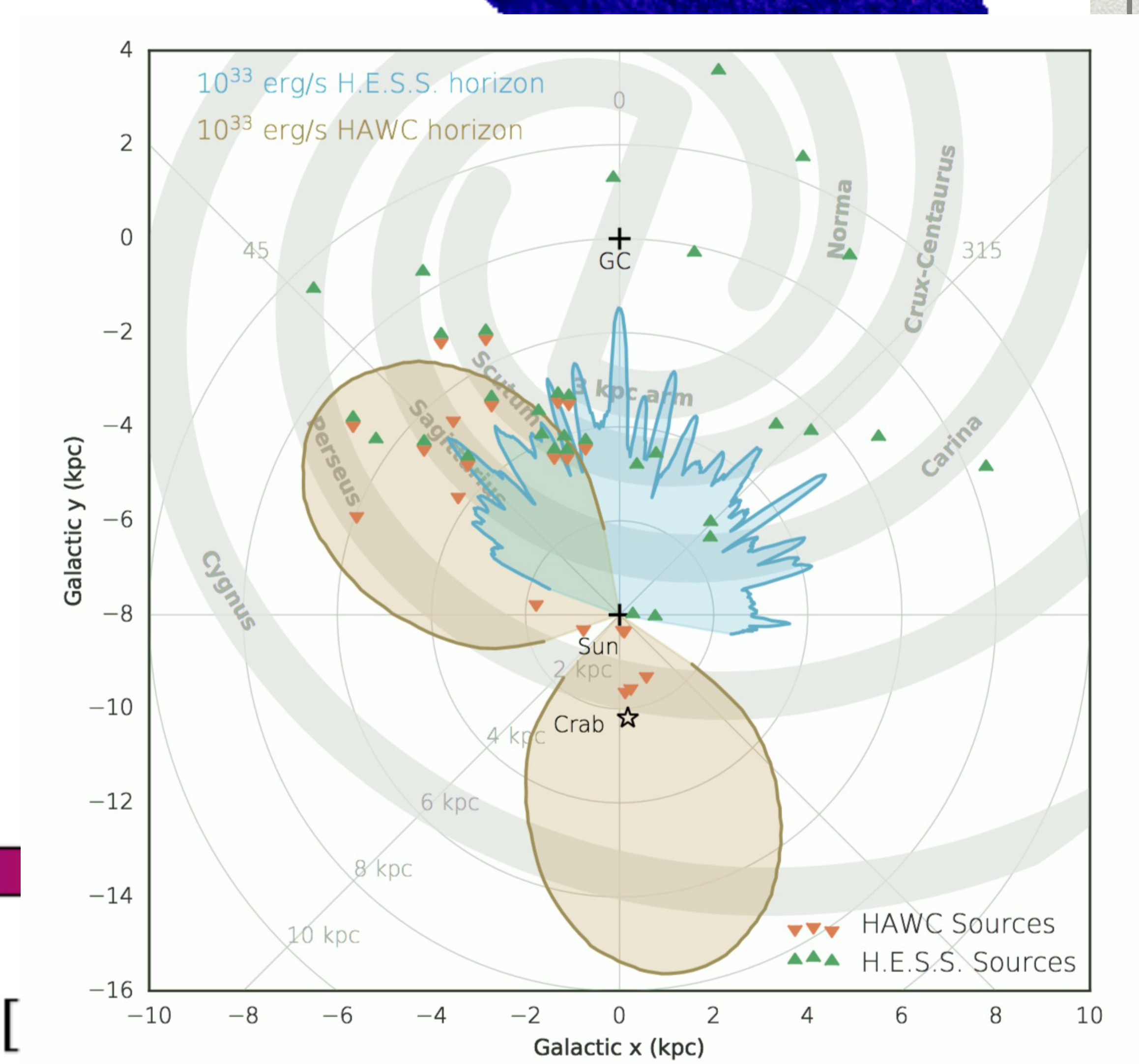




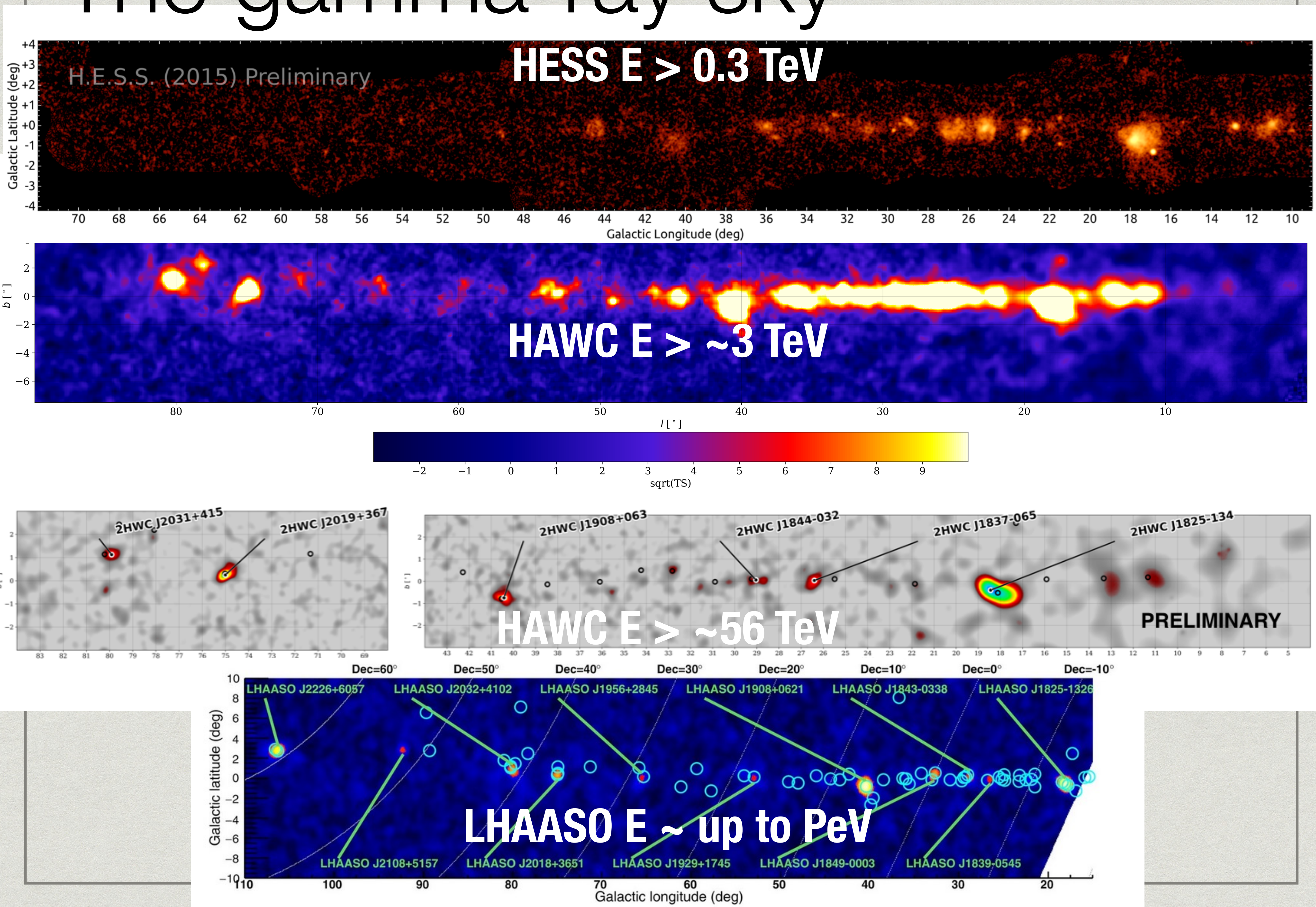
HAWC Sky

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory





The gamma-ray sky



Motivation

- We would like to build a wide FoV VHE gamma-ray observatory in the Southern Hemisphere, but why?
  - -> Need to evaluate the **physical motivations**.

- The physics that will be on the reach of this detector will also influence its design and location.

- We need to be able to answer the questions:
  - Is this type of detector *necessary*?
  - Are there any sources that can only be observed by this instrument?
  - Can it perform better than any other instrument for given types of sources?

The main ¿competitor?: CTA

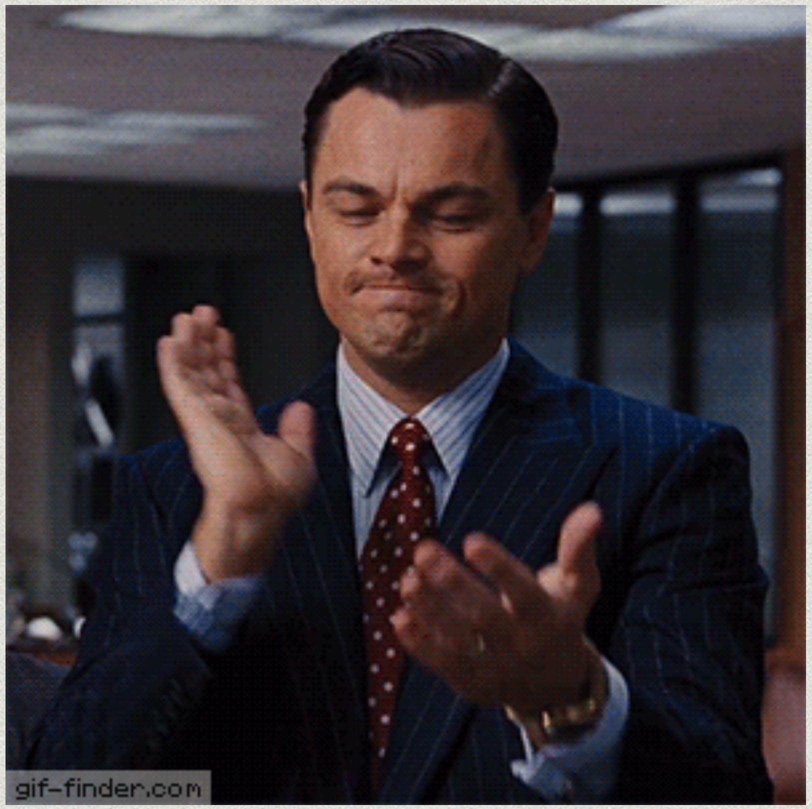
- CTA in the Southern Hemisphere.
  - ~100 IACTs
  - ~10x better sensitivity than current IACTs.
  - < 10% energy resolution.
  - < 0.05 deg angular resolution.
  - ~ 8 deg FoV (telescope-dependent).

- Summary:
  - Outstanding point-like sensitivity.
  - Much better sensitivity to extended sources contained in the FoV than particle arrays.
  - Galactic plane survey will lead to a 2 mCrab sensitivity in the galactic plane.

Conclusion

We should not (and effectively cannot) try to beat CTA

Thanks

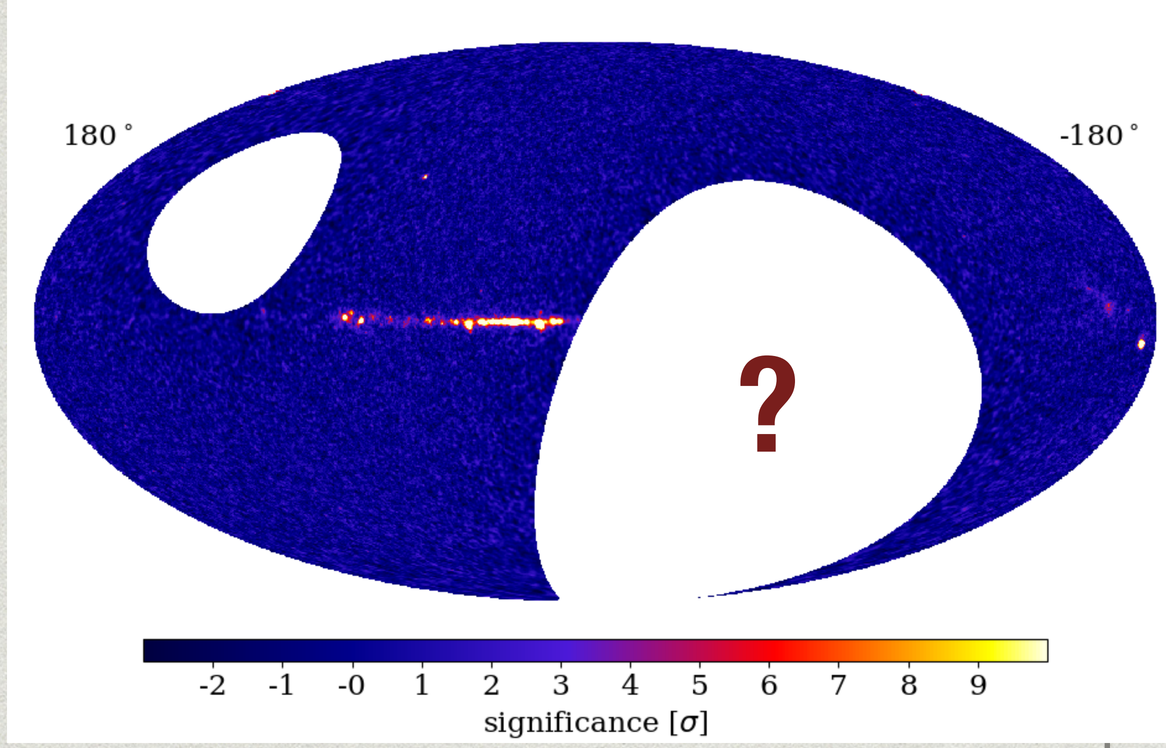


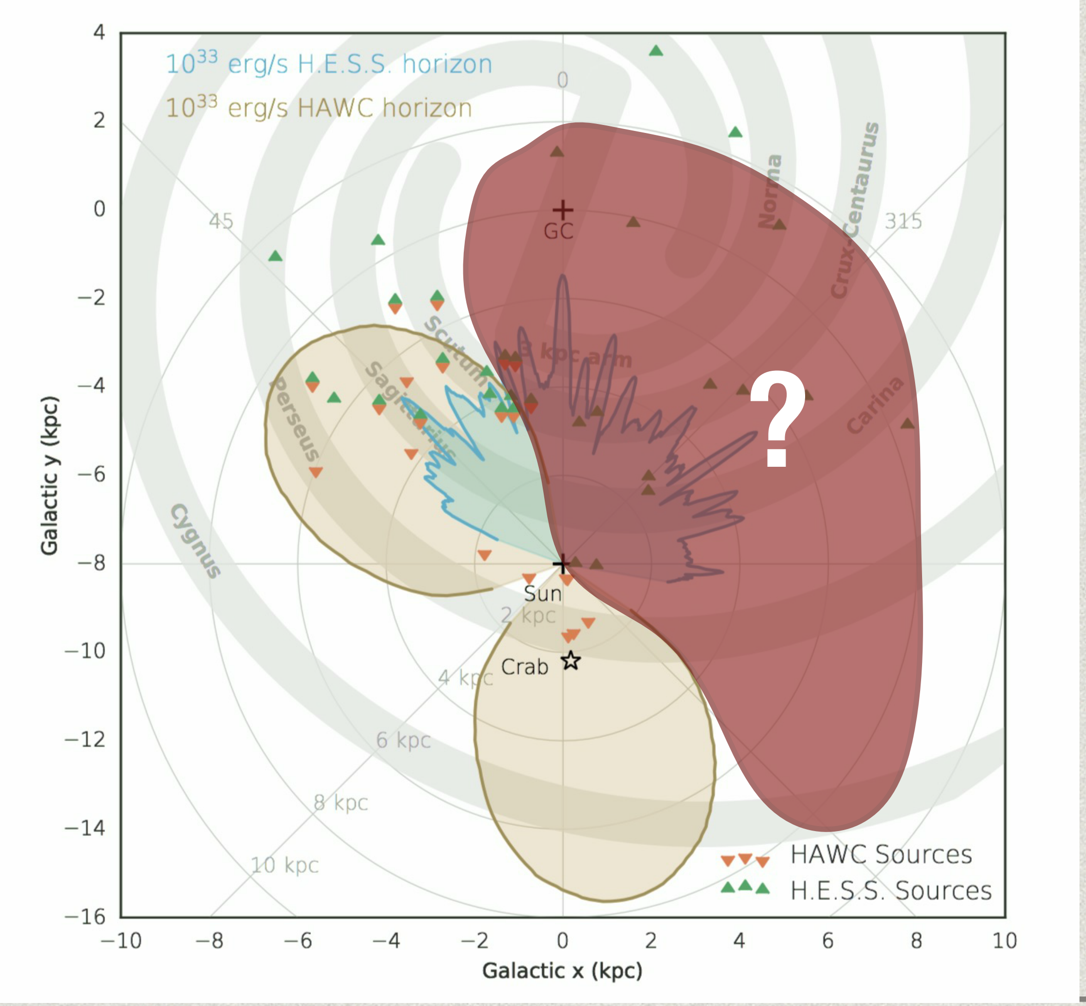
Complement

Sensitivity of HAWC/LHAASO falls to almost nothing at the Galactic Centre

- Most of the volume of the Galaxy not probed with a wide FoV detector, half of the extragalactic sky, the Galactic Center!!!

Strong motivation to **complement** the established northern instruments with a Southern hemisphere counterpart

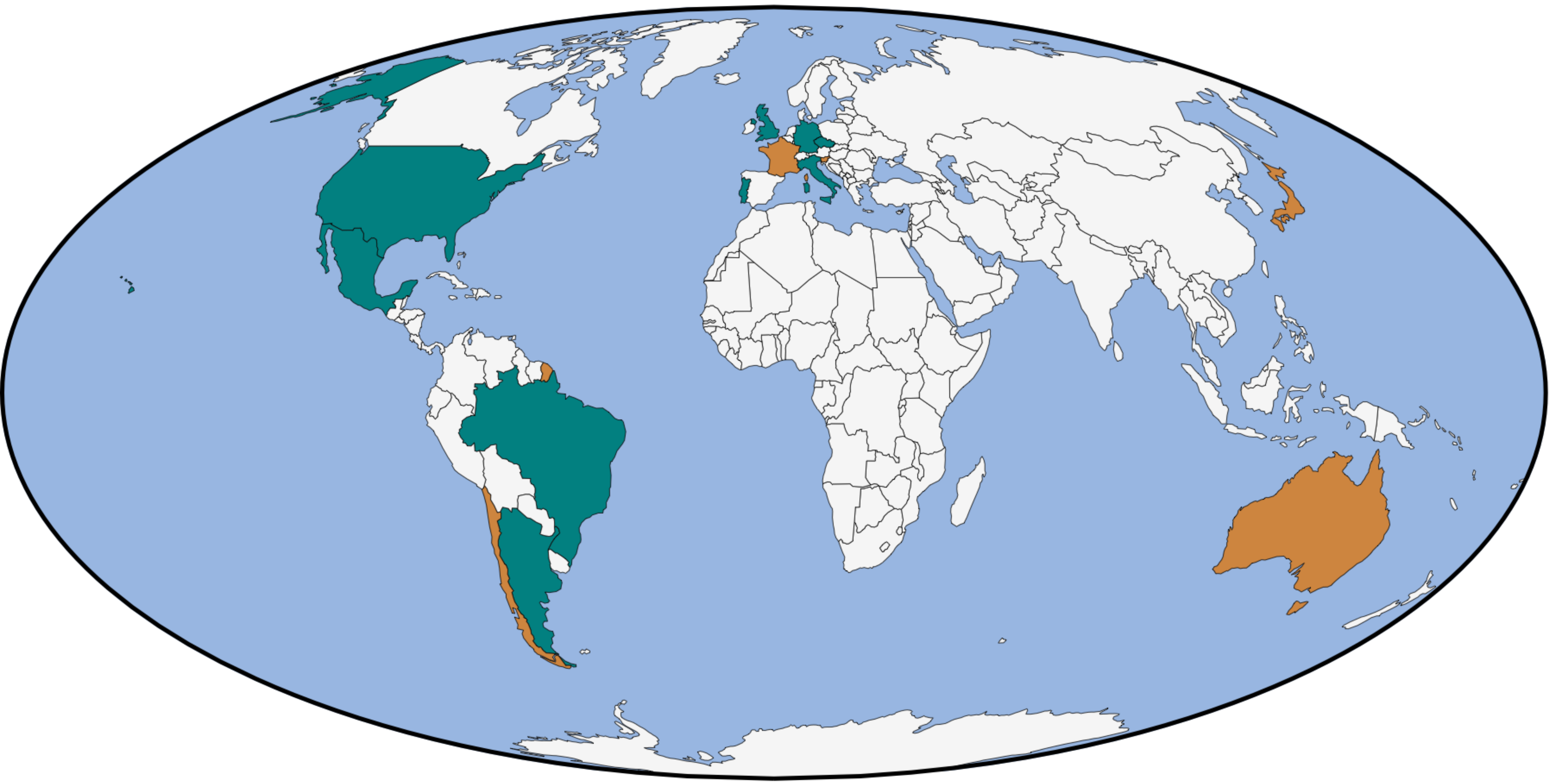




SWGO

Southern Wide-field Gamma-ray Observatory

- In comparison to HAWC -> Higher **altitude**, larger **area**, higher **efficiency detection units**, larger **fill factor**.
    - => lower threshold and better sensitivity.
- Collaboration established in July 2019 to develop the design/plan.
- First collaboration meeting October 2019.
- 3 year programme, 9 countries signed up + supporting scientists.



Countries in SWGO

Institutes

Argentina*, Brazil, Czech Republic, Germany*, Italy, Mexico, Portugal, United Kingdom, United States*

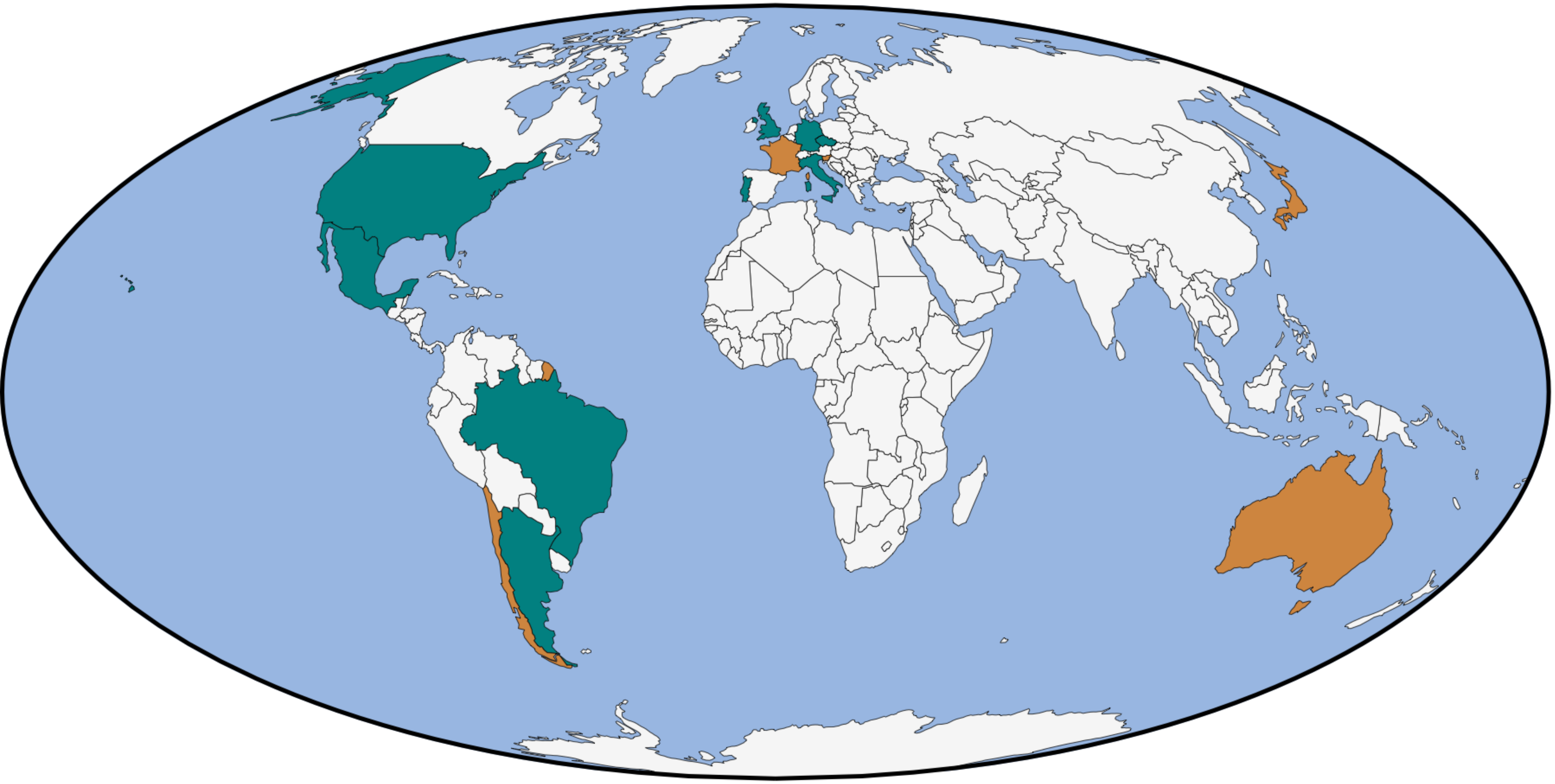
Supporting scientists

Australia, Chile, France, Japan, Slovenia

**also supporting scientists*

Organization

- Spokesperson: Jim Hinton (Germany)
- Deputy spokespeople: Petra Huentemeyer (US), Ulisses Barres (Brasil)
- Five working groups:
  - Science
  - Site
  - Detector
  - Analysis & Simulations
  - Outreach & Communications



Countries in SWGO

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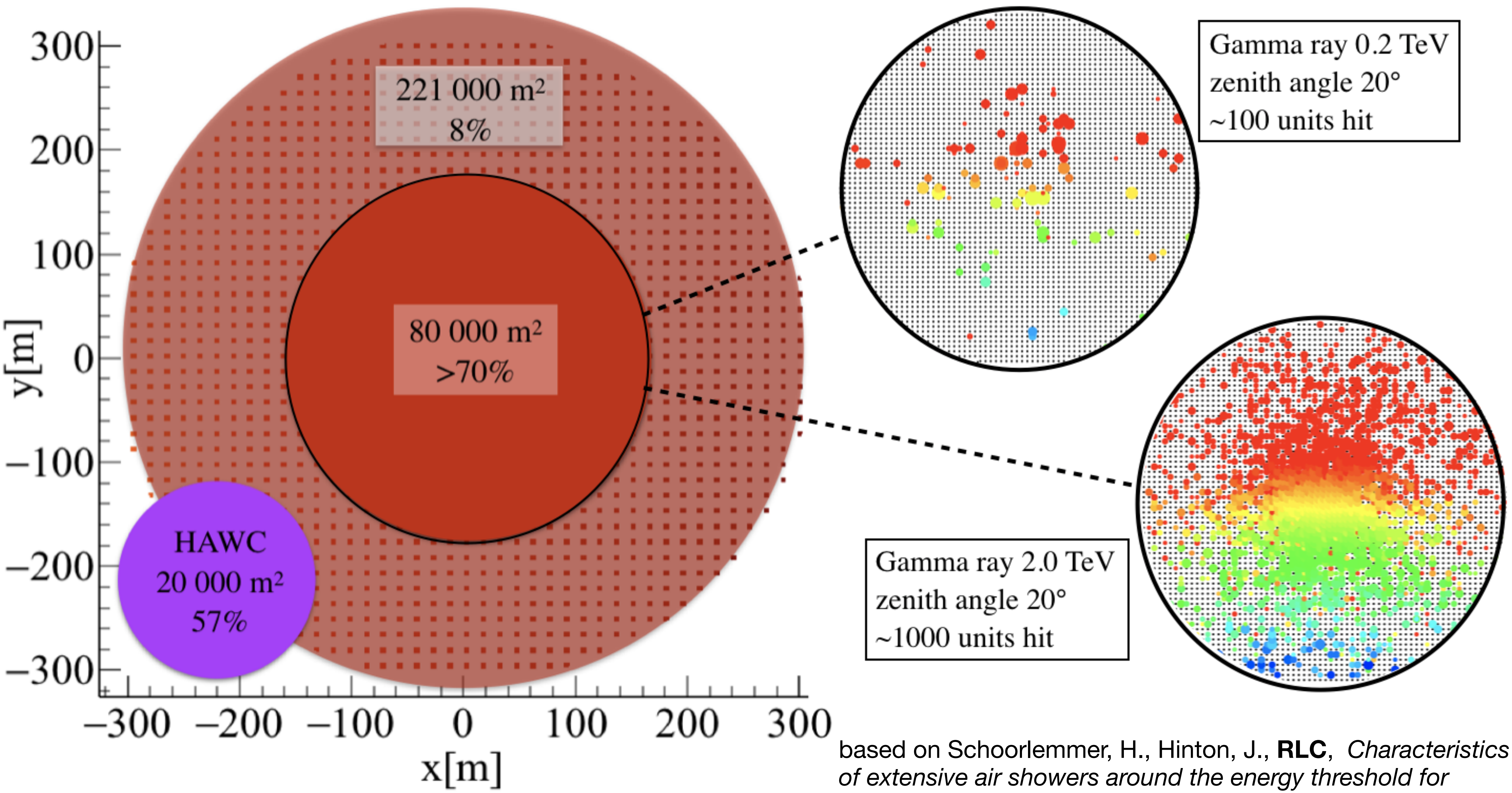
Argentina*, Brazil, Czech Republic, Germany*, Italy, Mexico, Portugal, United Kingdom, United States*

Supporting scientists

Australia, Chile, France, Japan, Slovenia

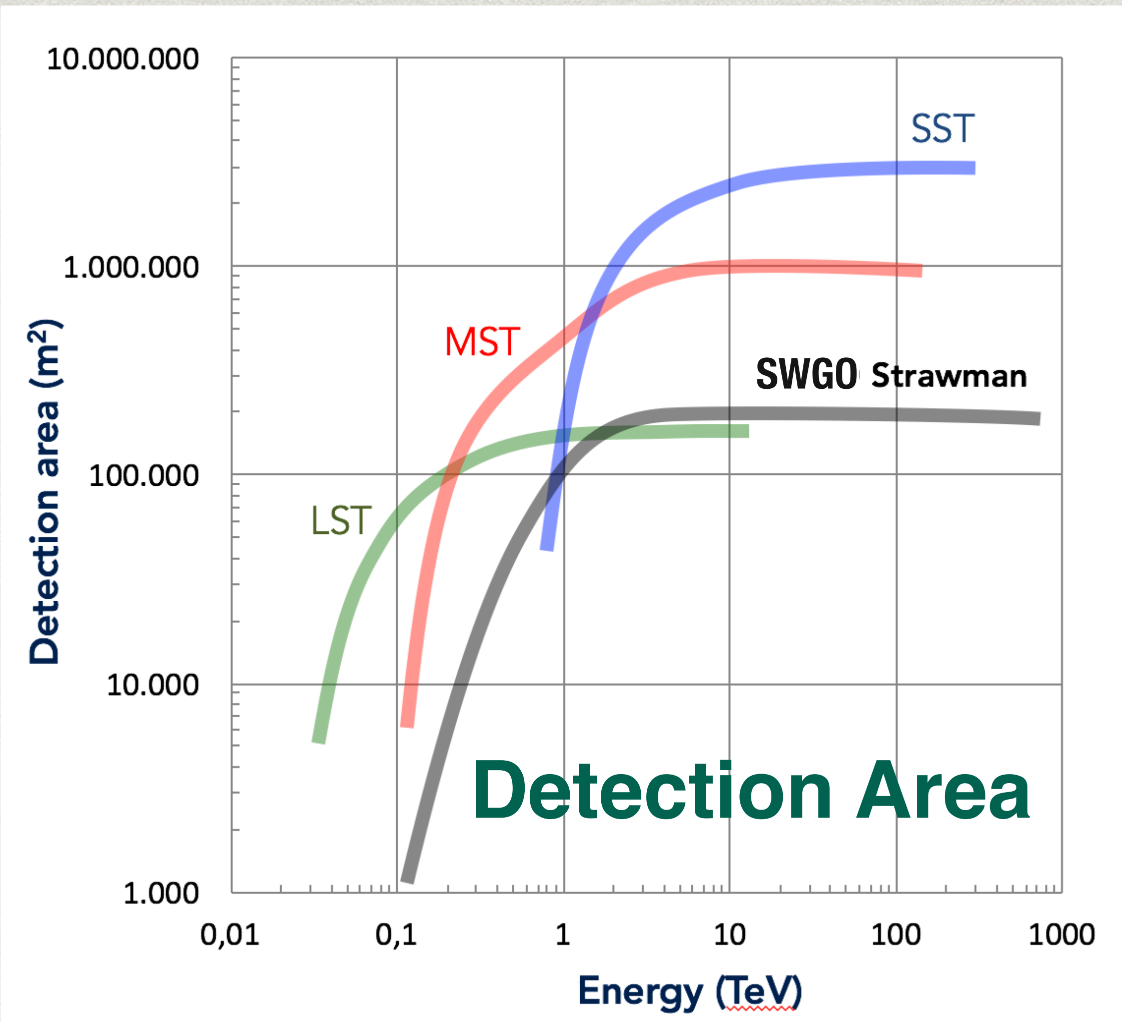
**also supporting scientists*

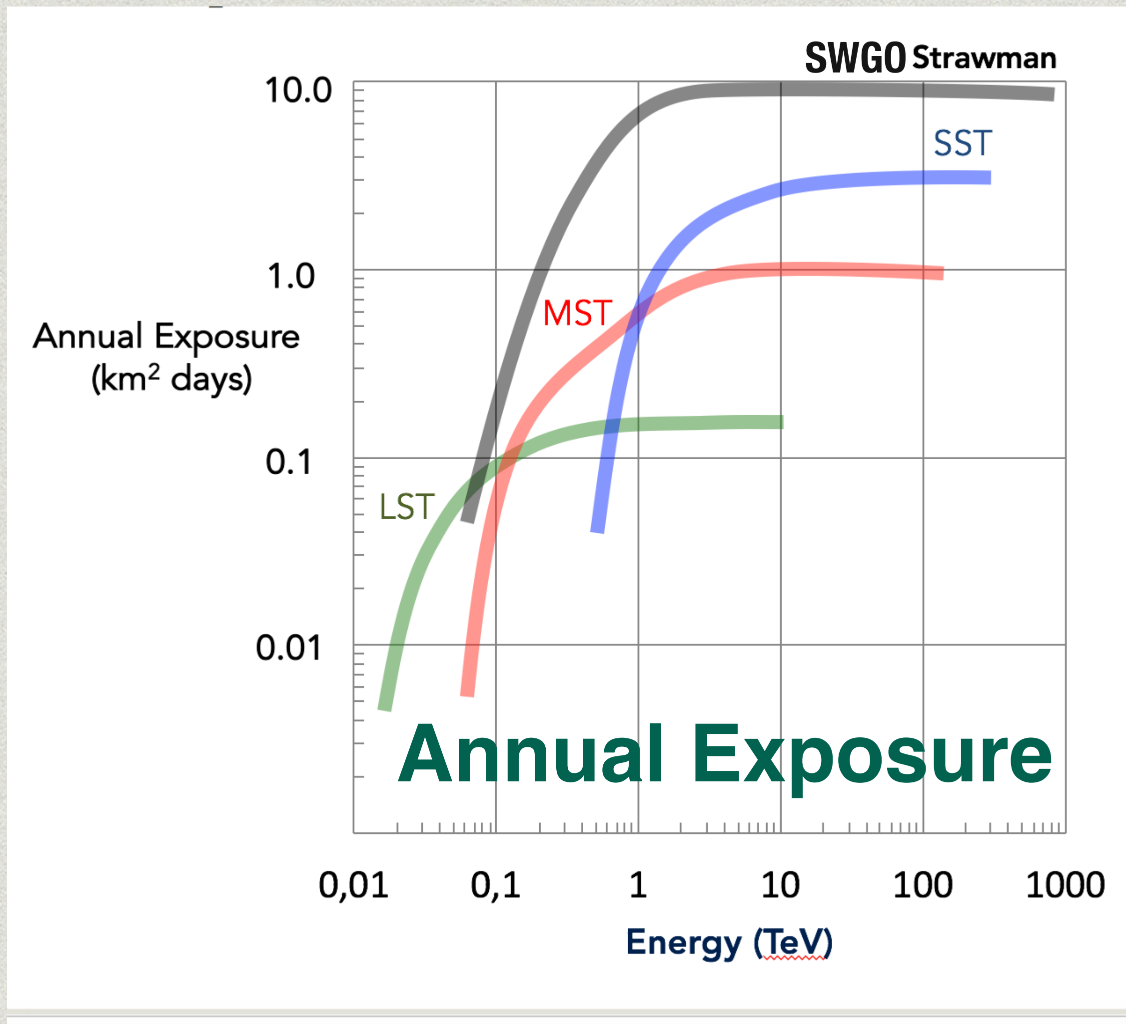
Strawman detector array



based on Schoorlemmer, H., Hinton, J., **RLC**, *Characteristics of extensive air showers around the energy threshold for ground-particle-based γ-ray observatories*, EPJC, 79 (2019).

Detection area

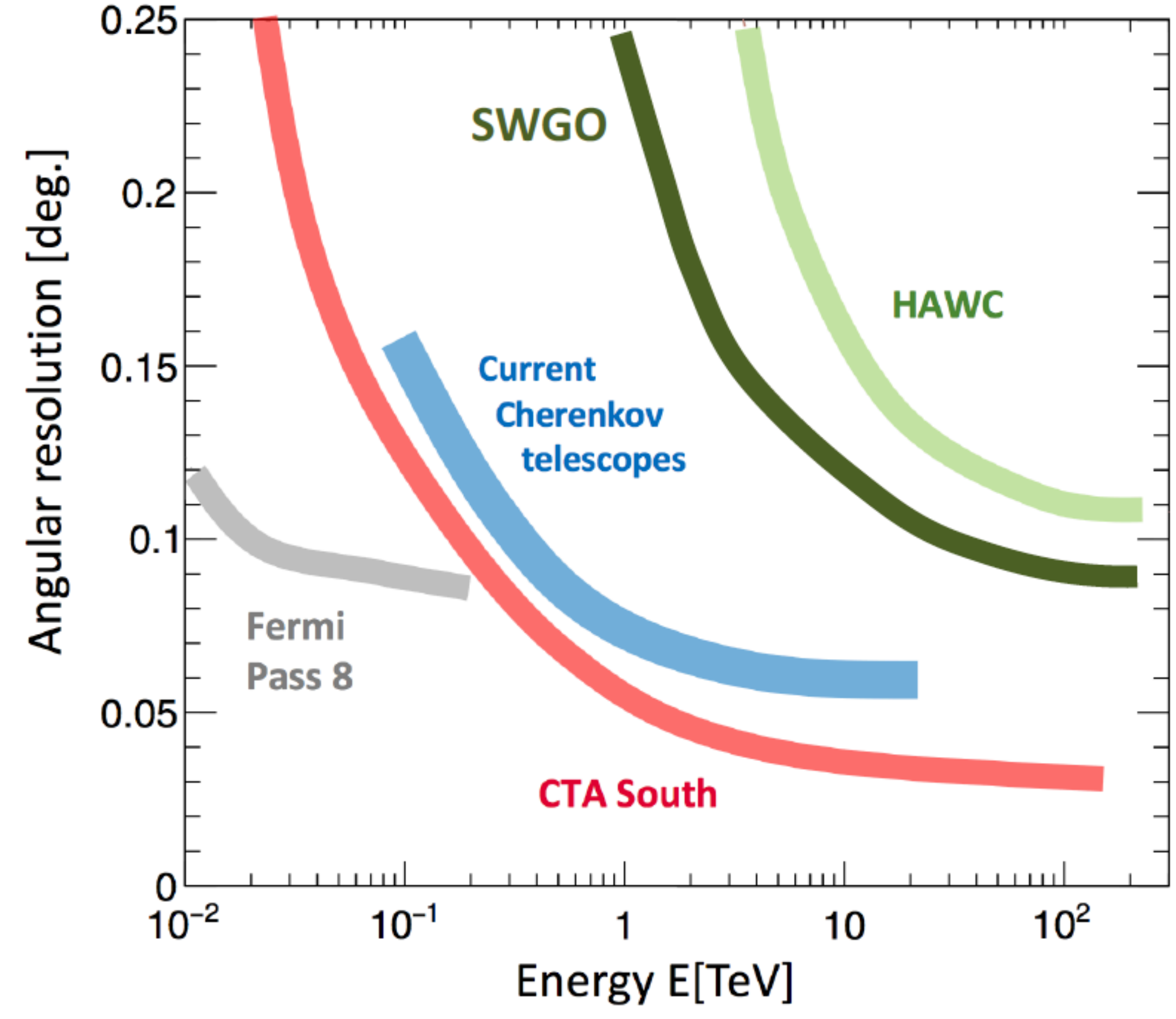




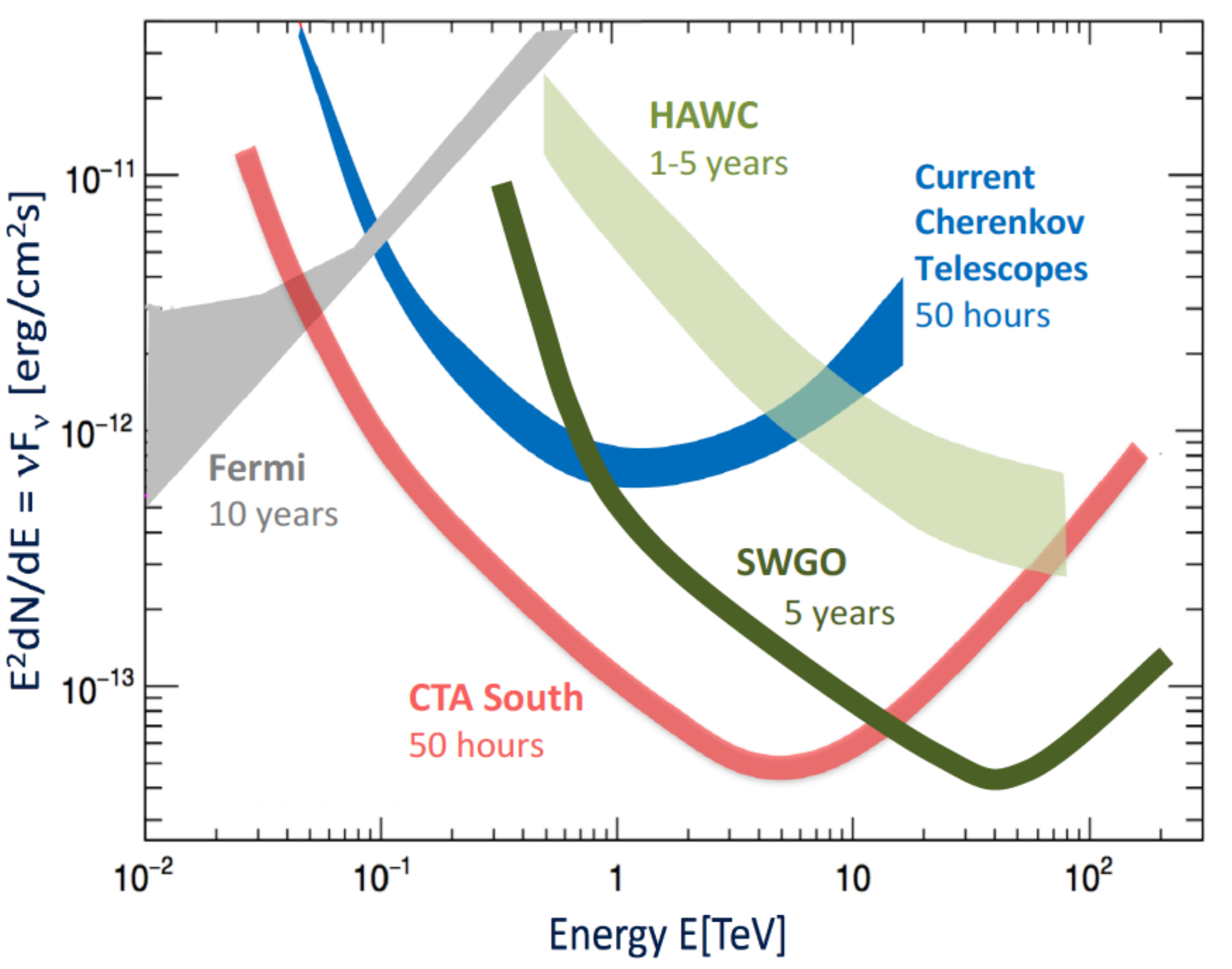
- **Short timescales:** If CTA can get there -> more sensitivity
- **Steady sources:** If background can be suppressed -> more sensitivity than CTA over several years

Performance comparison

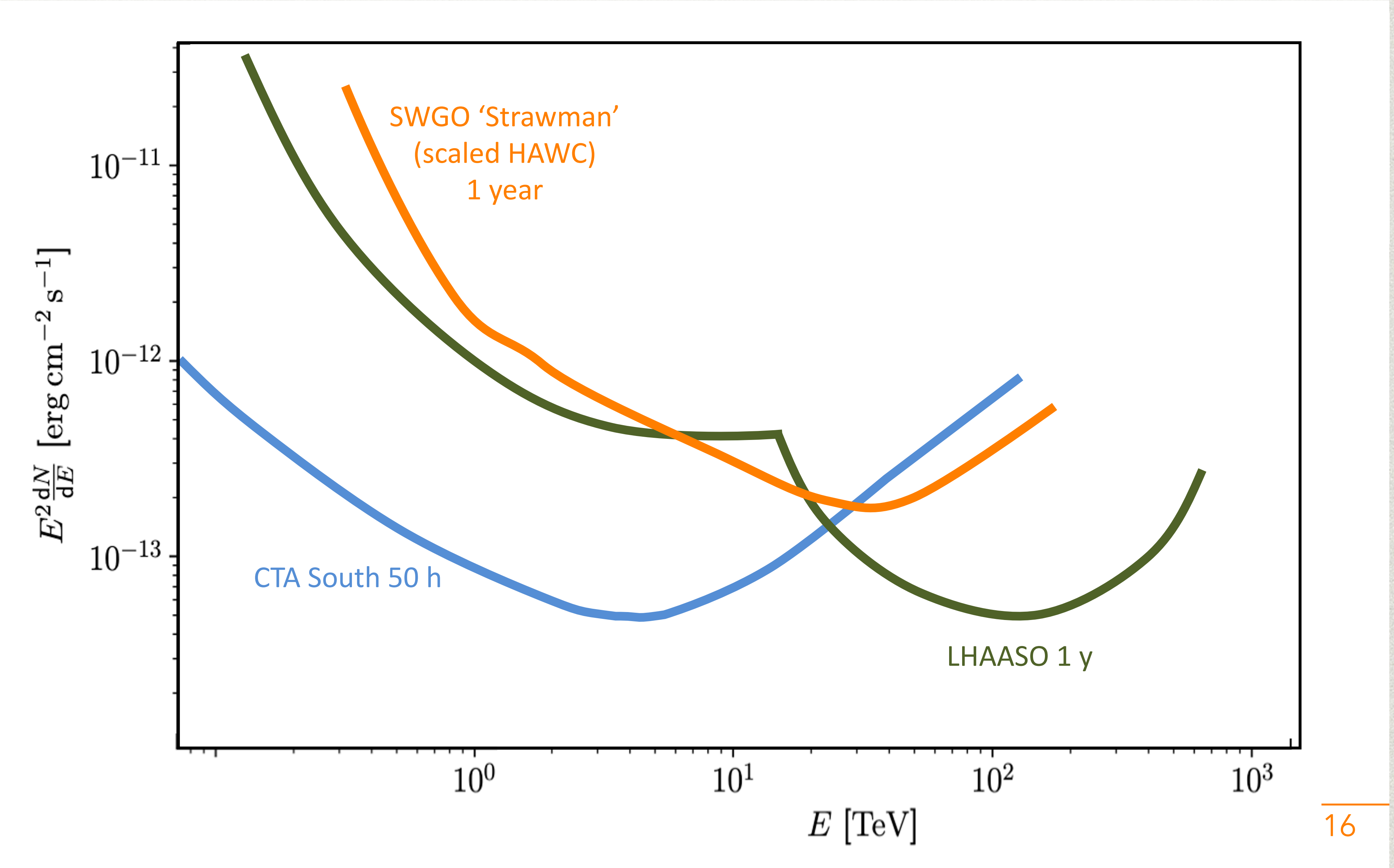
Angular resolution



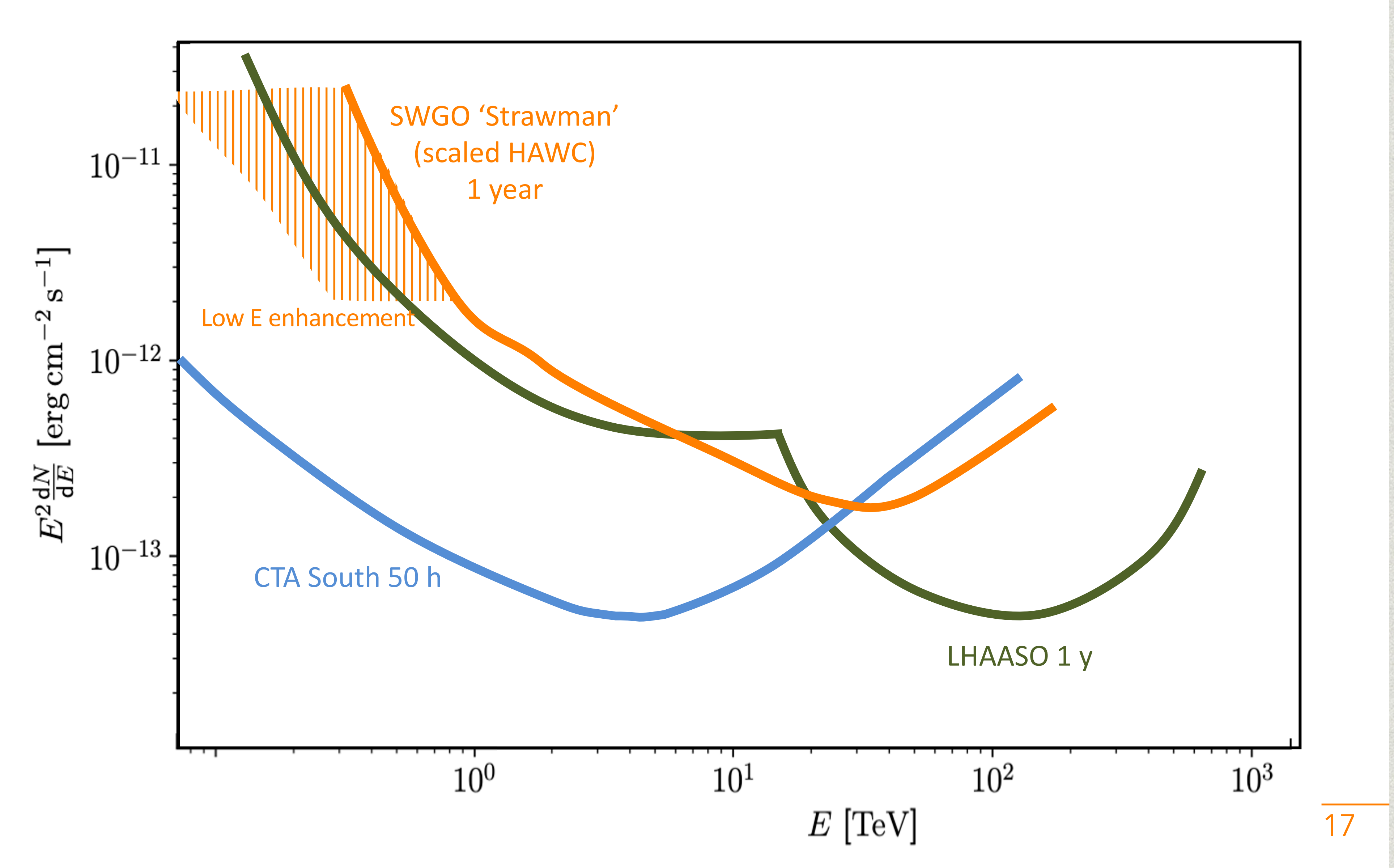
Sensitivity



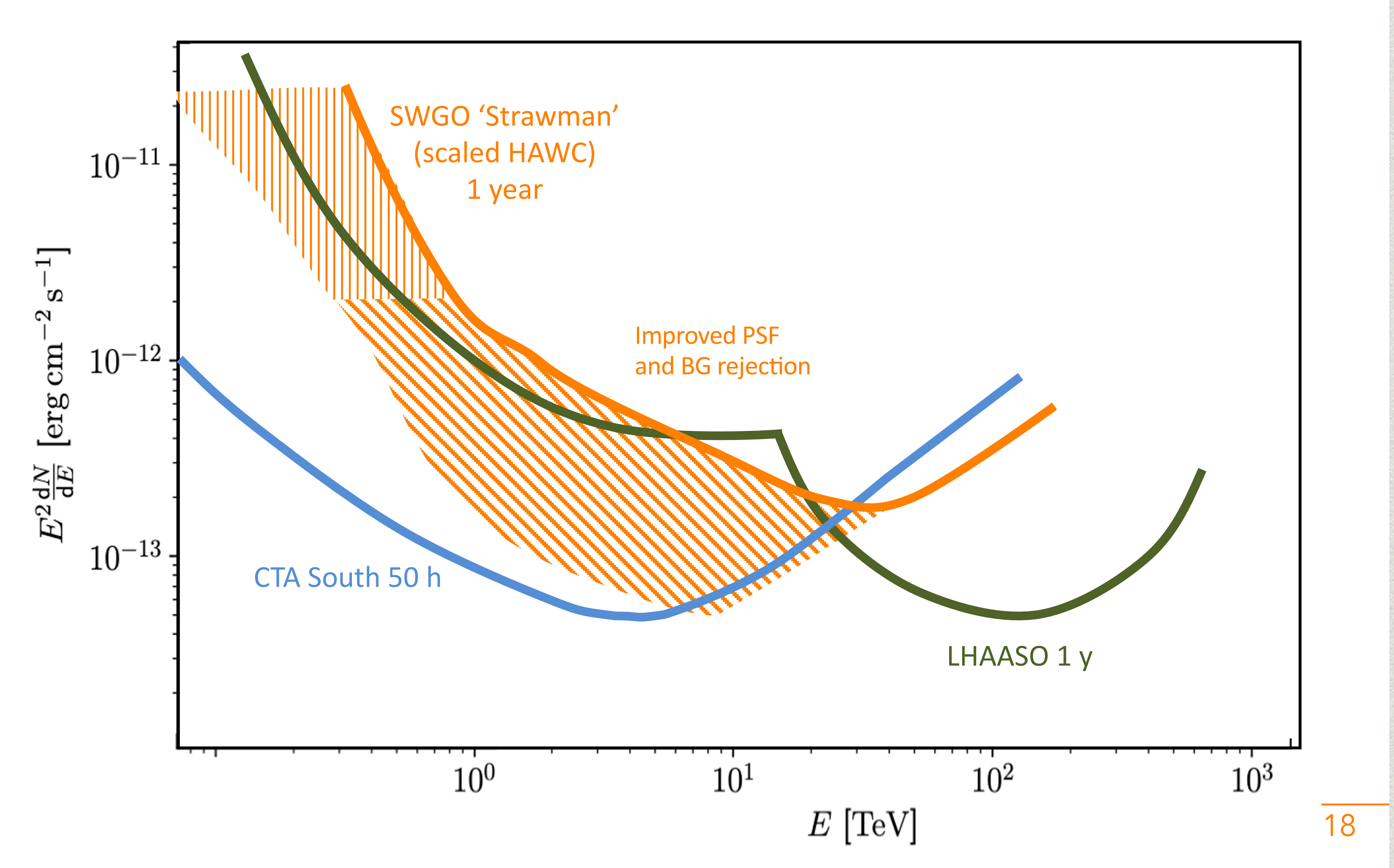
Performance comparison



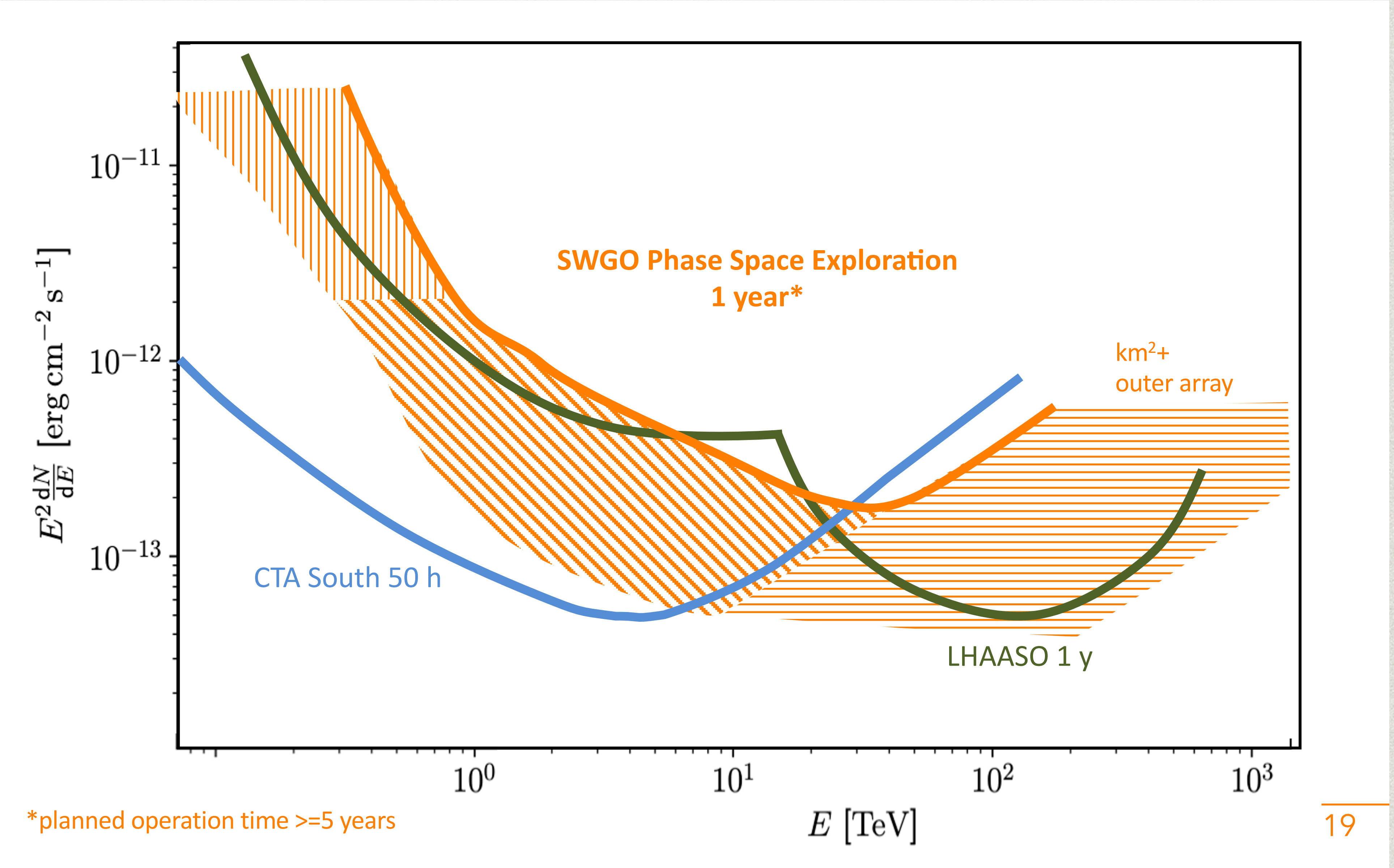
Performance comparison



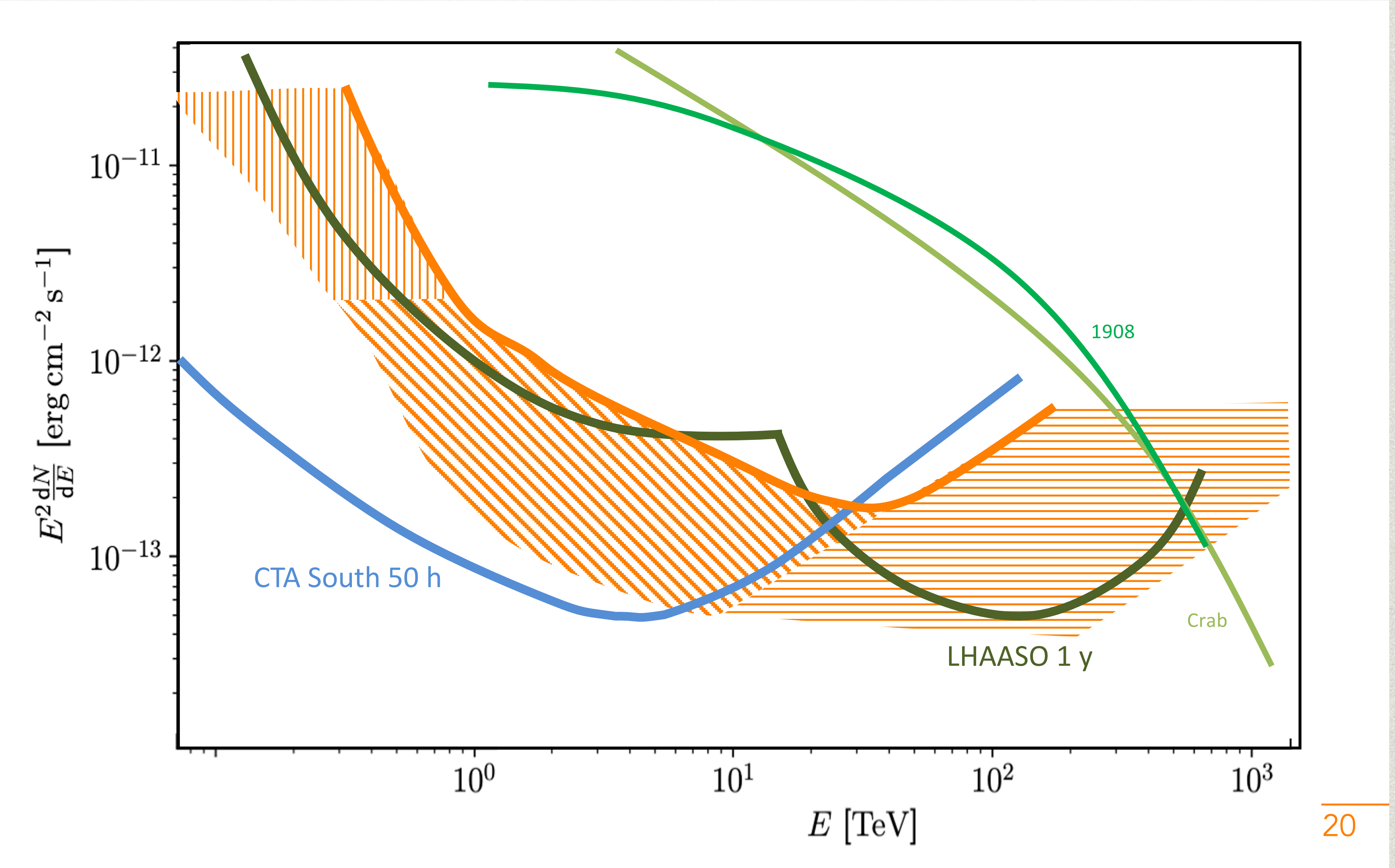
Performance comparison



Performance comparison



Performance comparison



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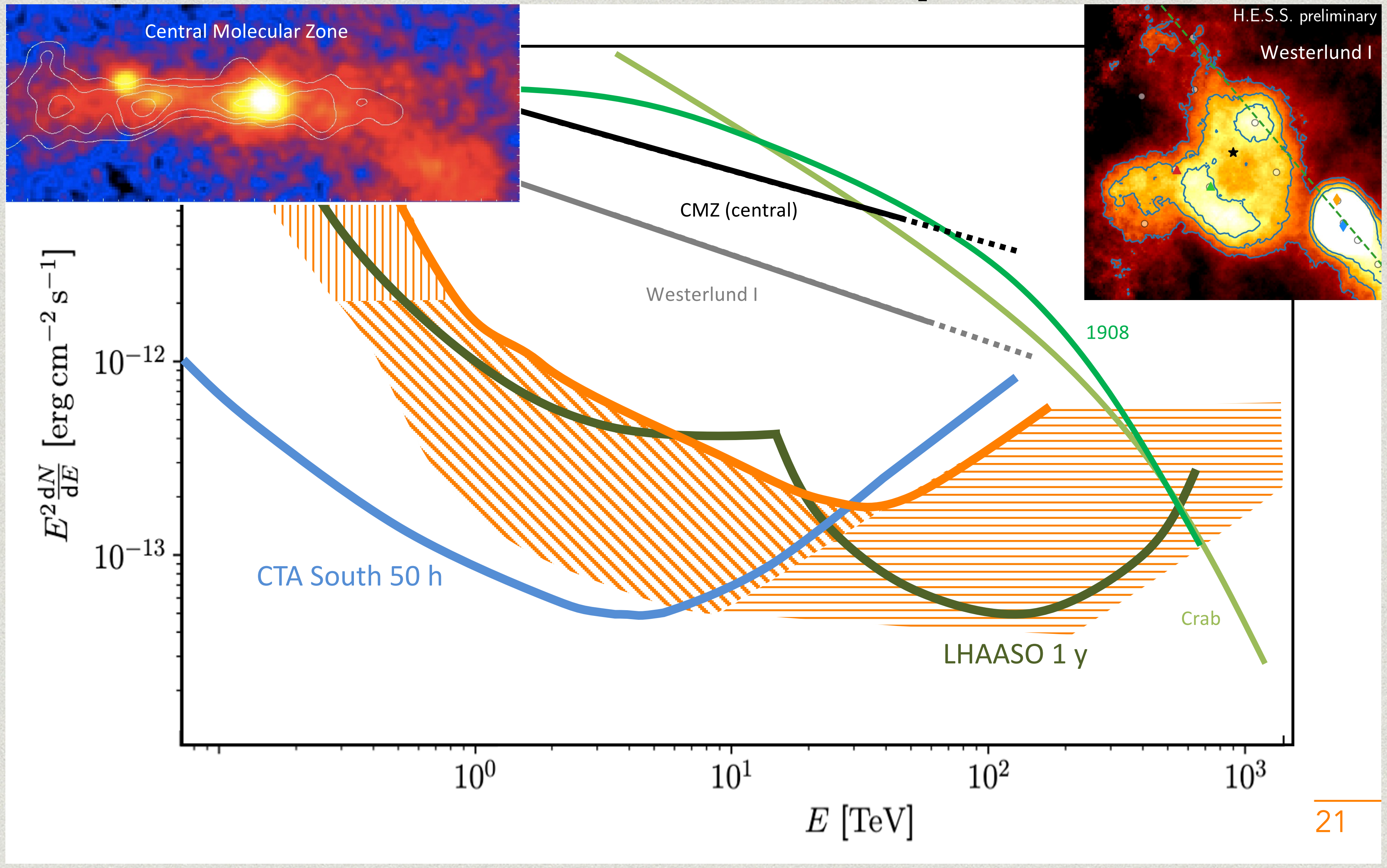
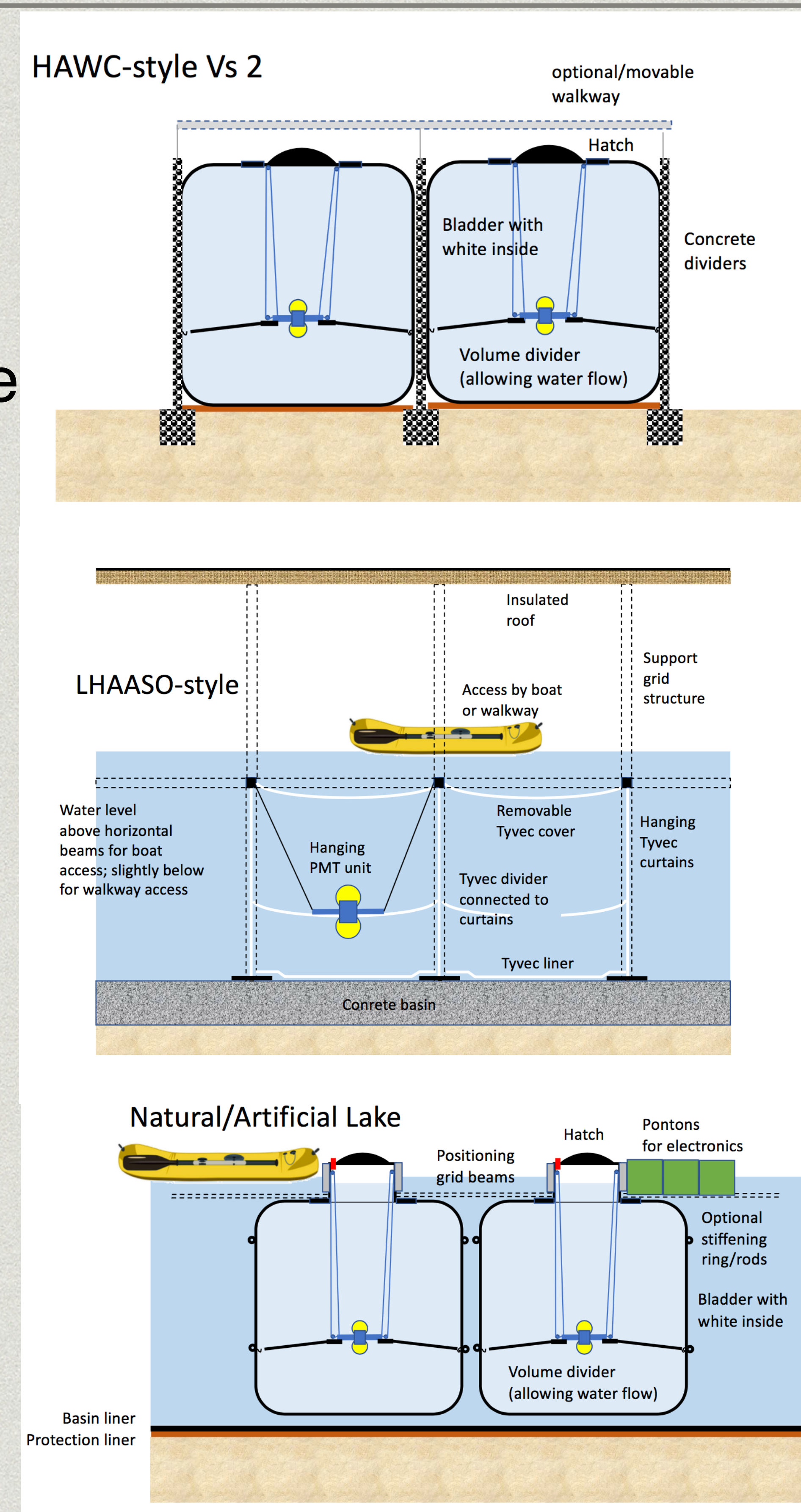


Technology

- Water Cherenkov as main detection technique
  - Unit dimensions?
  - Construction approach?
  - Photosensor?
  - Electronics?

- Perfomance/Cost optimization process

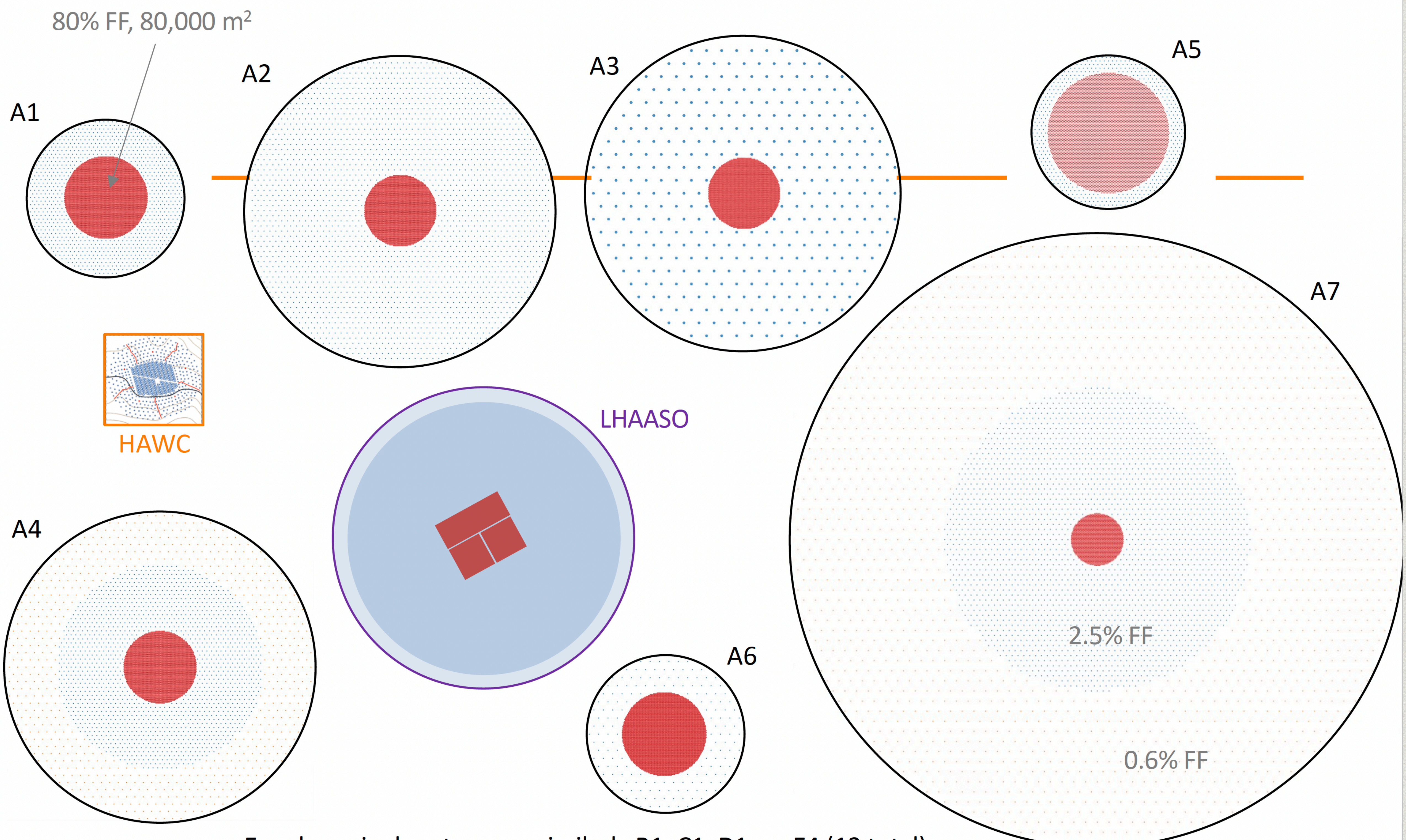
- Additionally:
  - Scintillators (bottom)
  - Resistive Plate Chambers (top)



The Site

- Proposal: Build it in the **Andes**
- Above 4.7 km to reach sub-TeV sensitivities

Layouts



Equal nominal cost arrays, similarly B1, C1, D1, …, E4 (13 total)

Astrophysical motivations: White Paper

Science Case for a Wide Field-of-View Very-High-Energy Gamma-Ray Observatory in the Southern Hemisphere

arXiv:1902.08429

A. Albert[1], R. Alfaro[2] H. Ashkar[3], C. Alvarez[4],4 J.Álvarez[5], J.C. Arteaga-Velázquez[5], H. A. Ayala Solares[6], R. Arceo[4], J.A. Bellido[7], S. BenZvi[8], T. Bretz[9], C.A. Brisbois[10], A.M. Brown[11], F. Brun[3], K.S. Caballero-Mora[4], A. Carosi[12], A. Carramiñana[13], S. Casanova[14,15], P.M. Chadwick[11], G. Cotter[16], S. Coutiño De León[13], P. Cristofari[17,18], S. Dasso[19,20], E. de la Fuente[21], B.L. Dingus[1],23 P. Desiati[22], F. de O. Salles[23], V. de Souza[24], D. Dorner[25], J. C. Díaz-Vélez[21,22], J.A. García-González[2], M. A. DuVernois[22], G. Di Sciascio[26], K. Engel[27], H. Fleischhack[10], N. Fraija[28], S. Funk[29], J-F. Glicenstein[3], J. Gonzalez,[30] M. M. González[28], J. A. Goodman[27], J. P. Harding[1], A. Haungs[31], J. Hinton[15], B. Hona[10], D. Hoyos[32,33], P. Huentemeyer[10], A. Iriarte[34], A. Jardin-Blicq[15], V. Joshi[15], S. Kaufmann[11], K. Kawata[35], S. Kunwar[15], J. Lefaucheur[3], J.-P. Lenain[36], K. Link[31], R. López-Coto[37], V. Marandon[15], M. Mariotti[38], J. Martínez-Castro[39], H. Martínez-Huerta[24], M. Mostafá[6], A. Nayerhoda[14], L. Nellen[32], E. de Oña Wilhelmi[40,41], R.D. Parsons[15], B. Patricelli[42,43], A. Pichel[19], Q. Piel[12], E. Prandini[38], E. Pueschel[41], S. Procureur[3], A. Reisenegger[44,45], C. Rivière[27], J. Rodriguez[2,46], A. C. Rovero[19], G. Rowell[7], E. L. Ruiz-Velasco[15], A. Sandoval[2], M. Santander[47], T. Sako[35], T. K. Sako[35], K. Satalecka[41], H. Schoorlemmer[15,⋆], F. Schüssler[3,⋆], M. Seglar-Arroyo[3], A. J. Smith[27], S. Spencer[16], P. Surajbali[15], E. Tabachnick[27], A. M. Taylor[41], O. Tibolla[11,48], I. Torres[13], B. Vallage[3], A. Viana[24], J.J. Watson[16], T. Weisgarber[22], F. Werner[15], R. White[15], R. Wischnewski[41], R. Yang[15], A. Zepeda[49], H. Zhou[1]

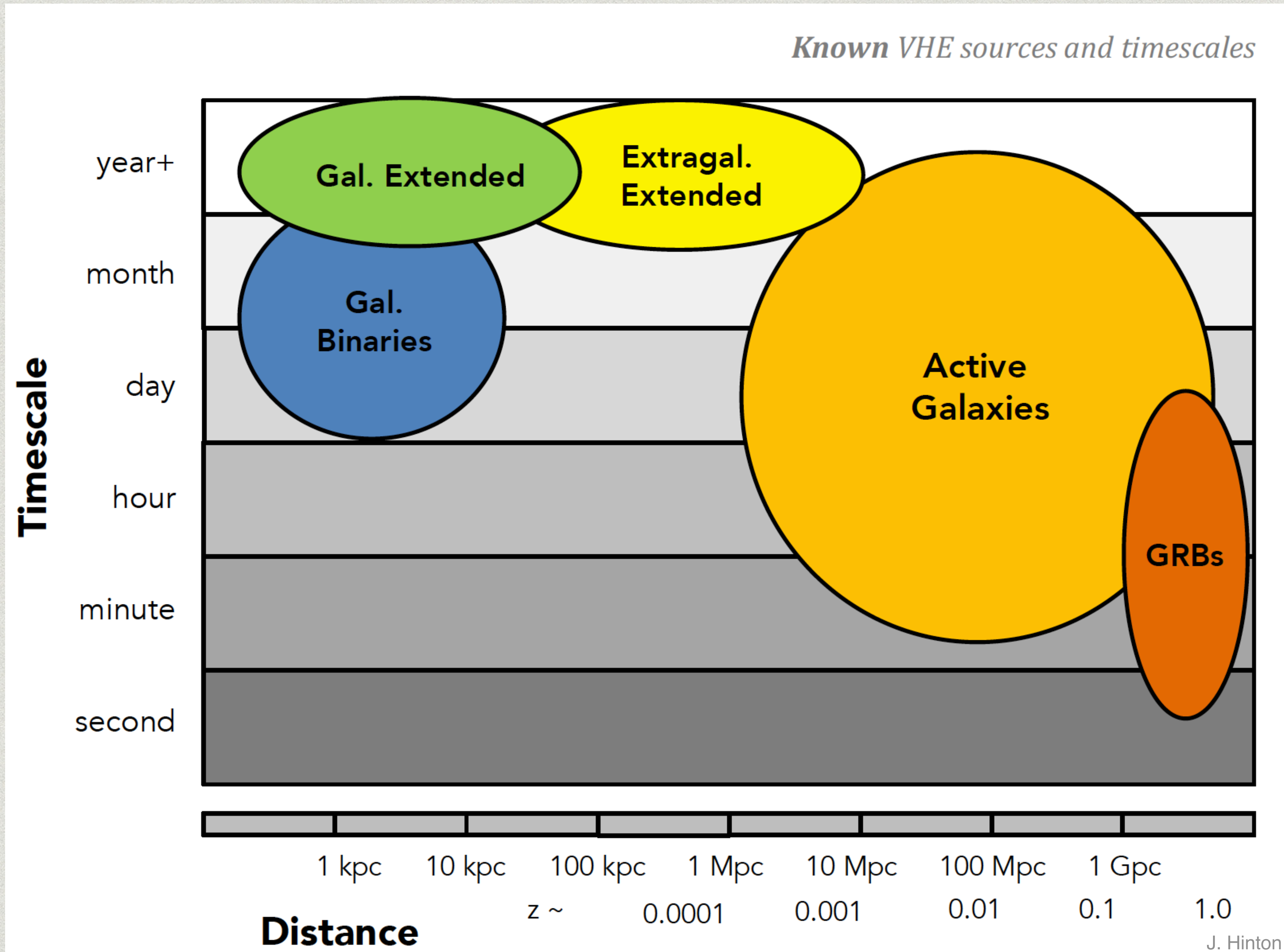
Physic cases evaluation

- Due to the forthcoming CTA, we will not be able to compete on point-like steady sources.

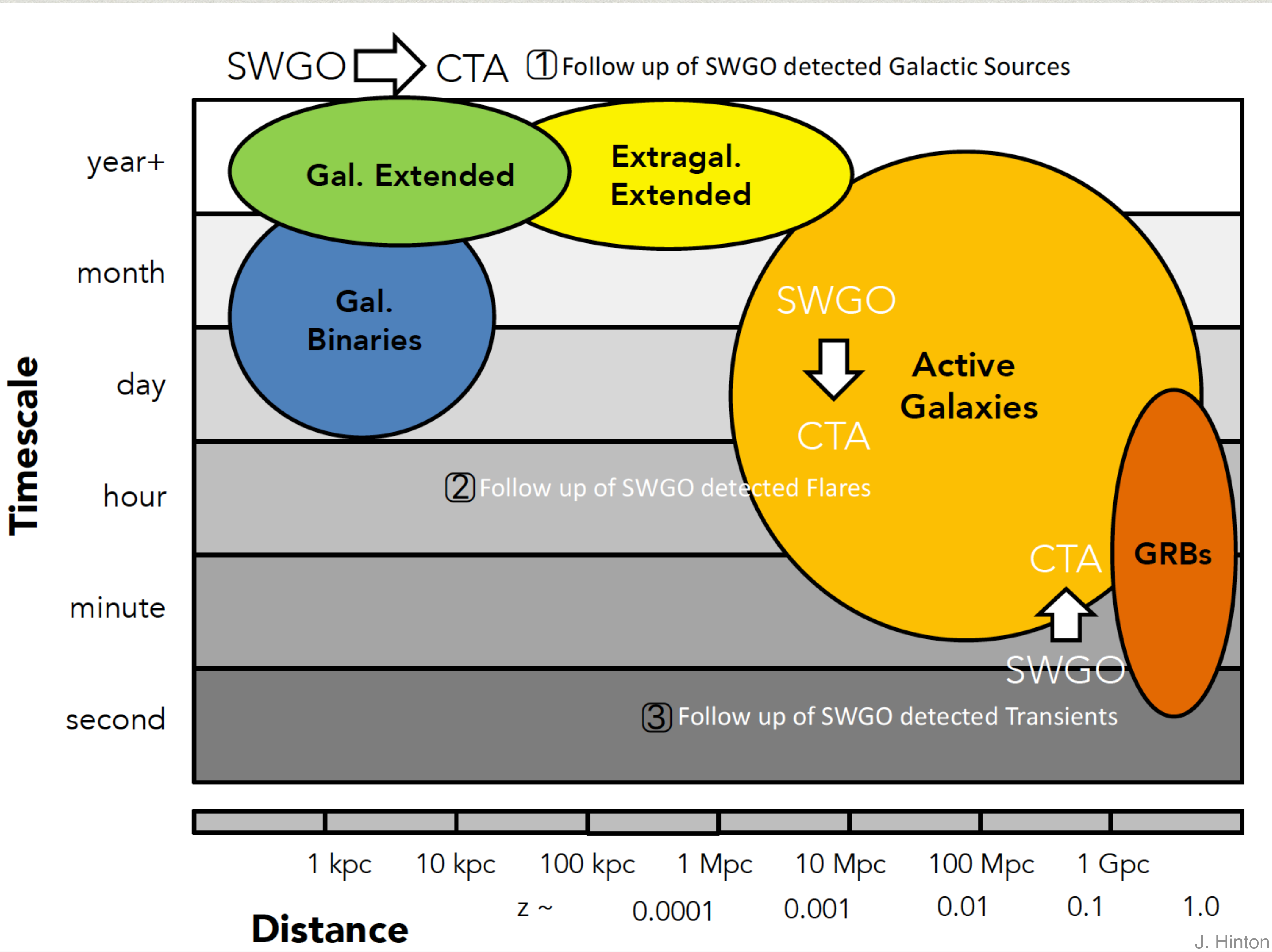
- There are some things difficult for CTA as:
  - Very **extended** sources
  - **Strong flaring** sources lasting ~minutes
  - Flaring sources at sub-TeV energies to provide **triggers for CTA**
  - Continuous and unbiased monitoring of **transient events**

- We need to construct an instrument with:
  - ~ sr continuous sky coverage
  - Sensitive in the sub-TeV range for flaring events
  - Still with a good sensitivity at TeV energies for very extended sources.

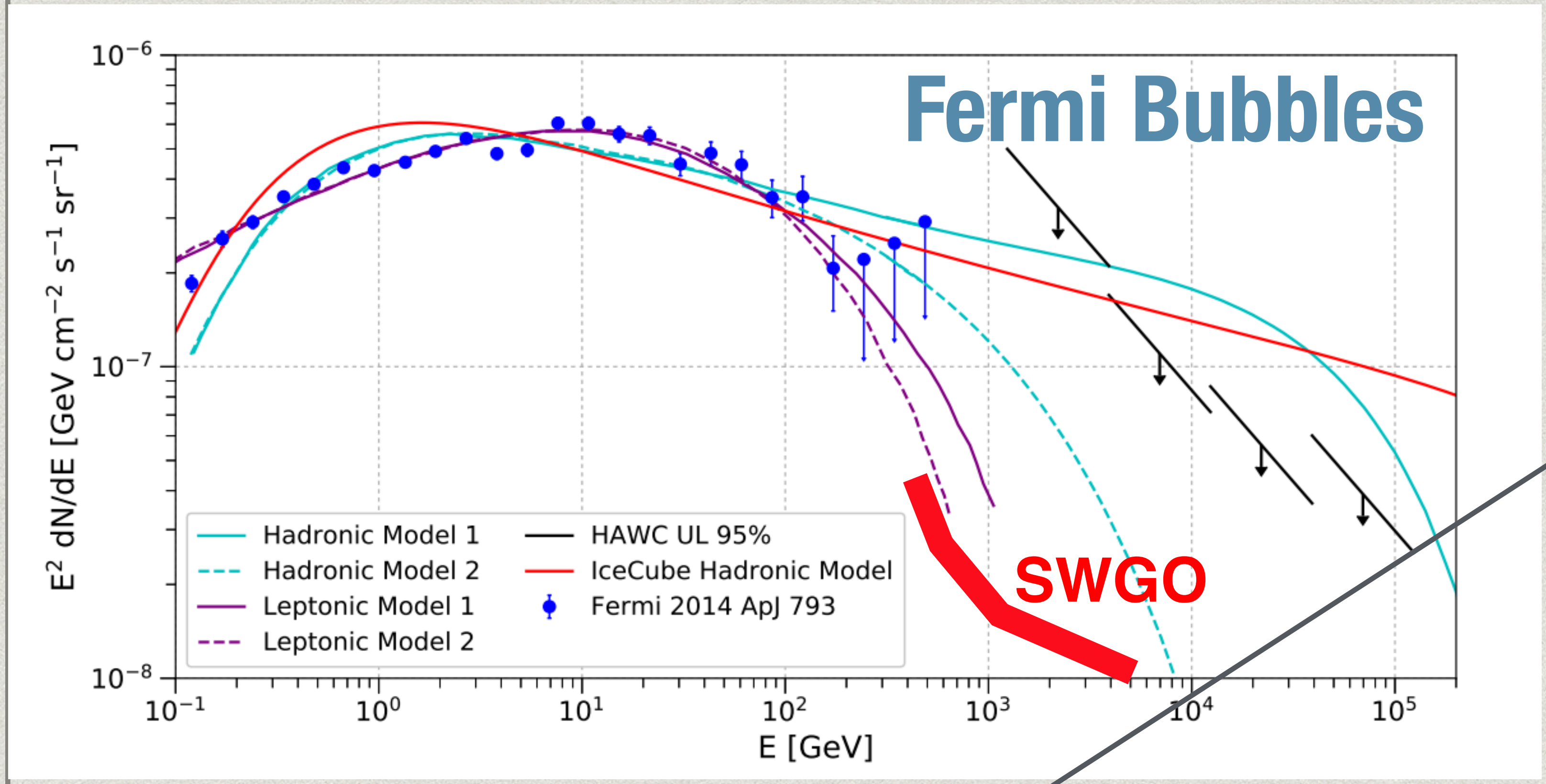
Timescale for sources



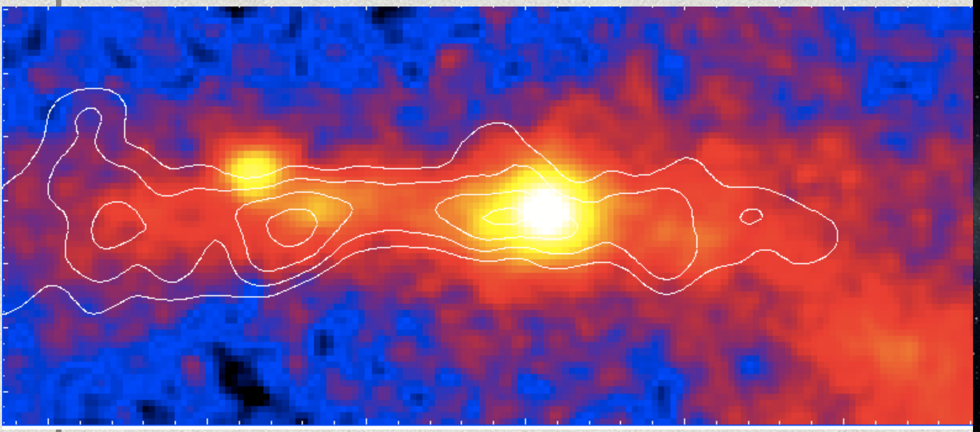
Timescale for sources

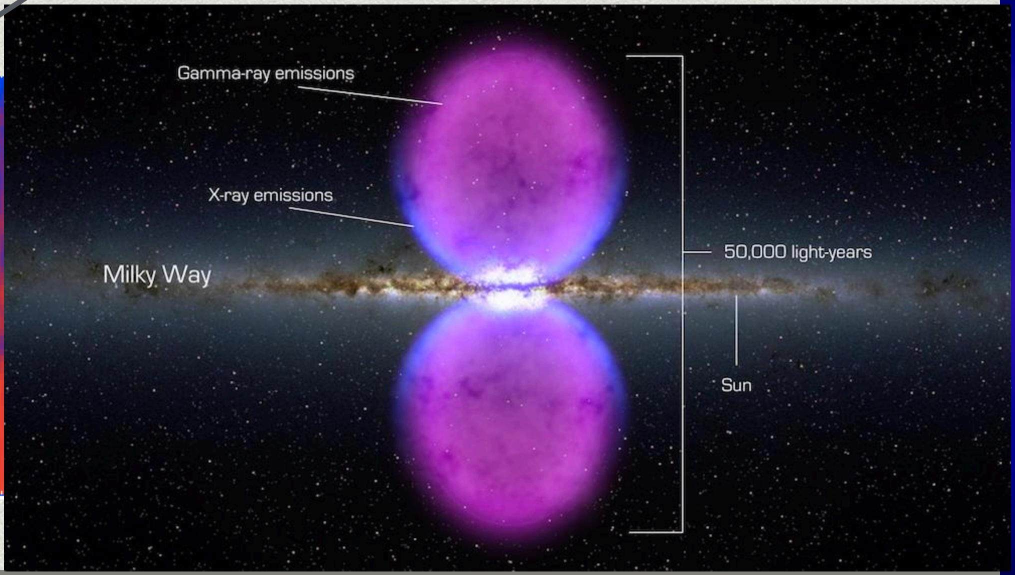


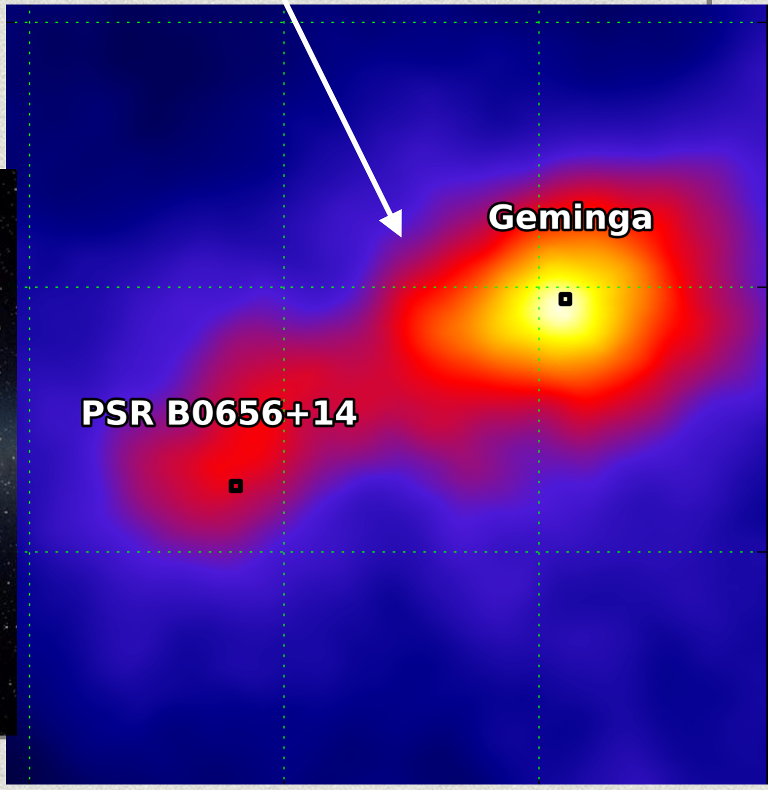
Very extended sources



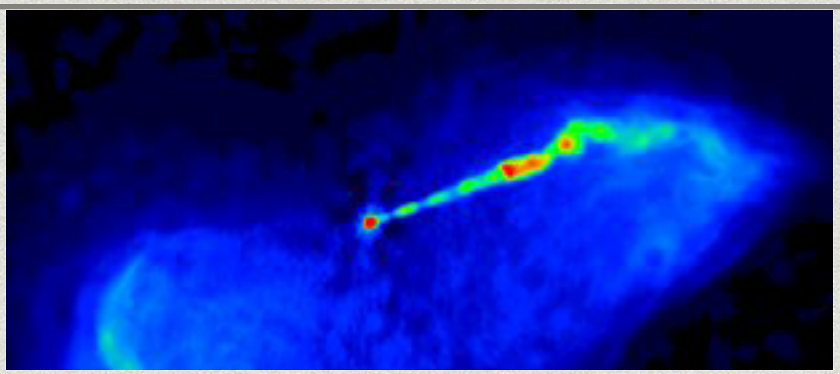
- CTA will give the detailed view of the Galactic Plane
- What about SWGO?
  - Local (off-plane, large angular size) sources
  - Diffuse Galactic Emission (e.g. atomic gas and IC emission up to large scale heights)
  - Central Molecular Zone Chimneys -> Fermi Bubbles
  - ‘Halos’ around CR accelerators



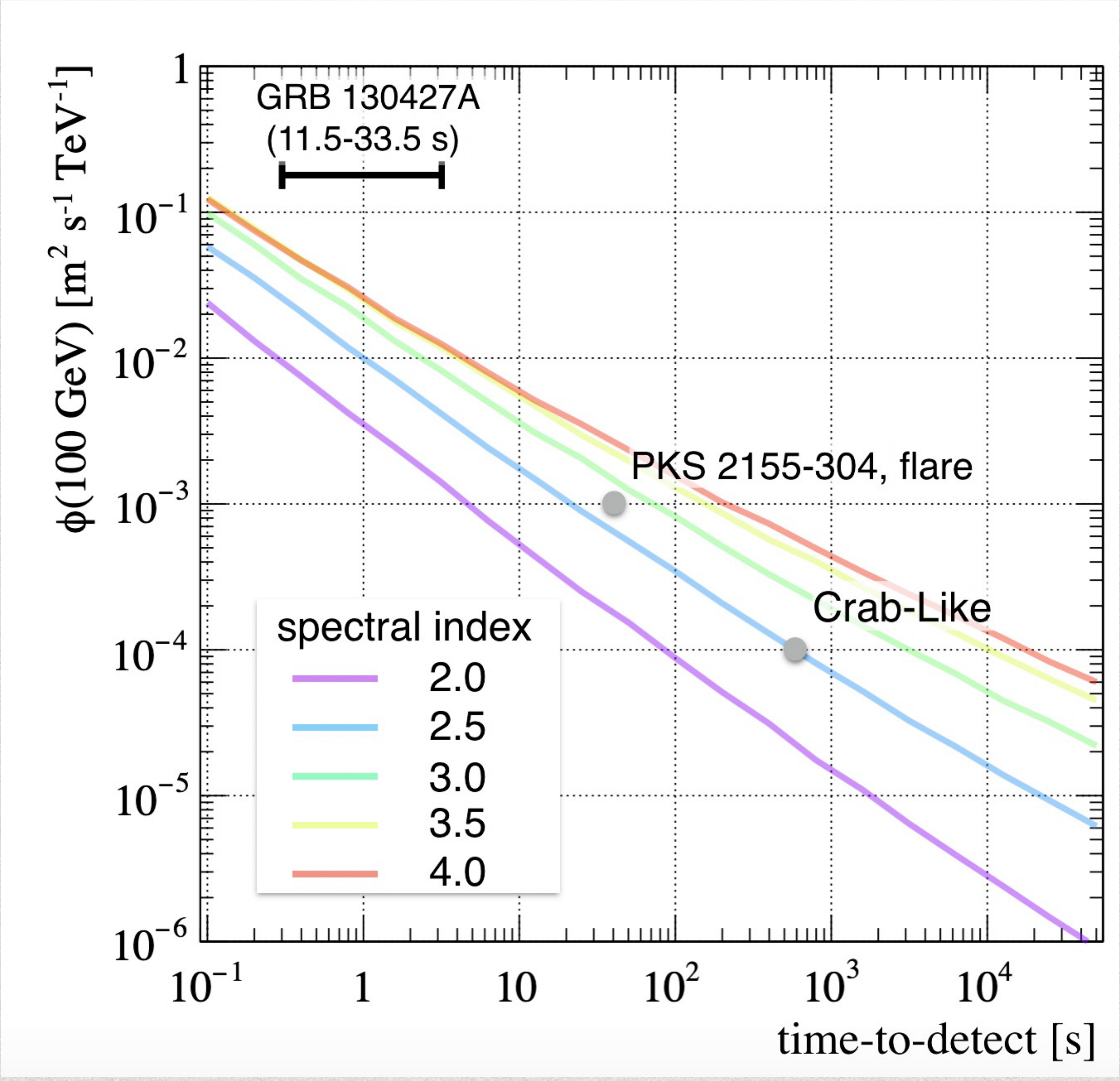




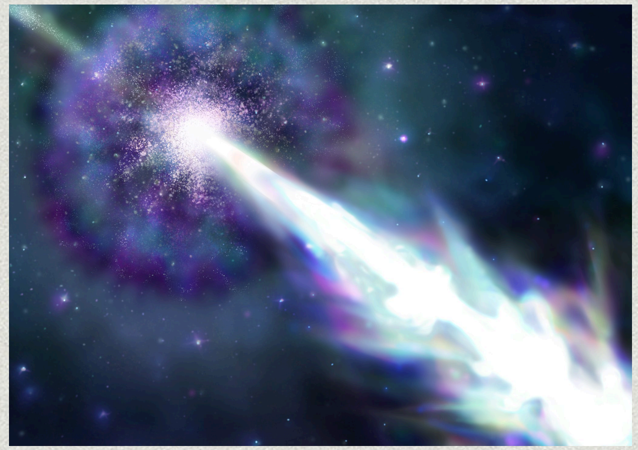
Flares

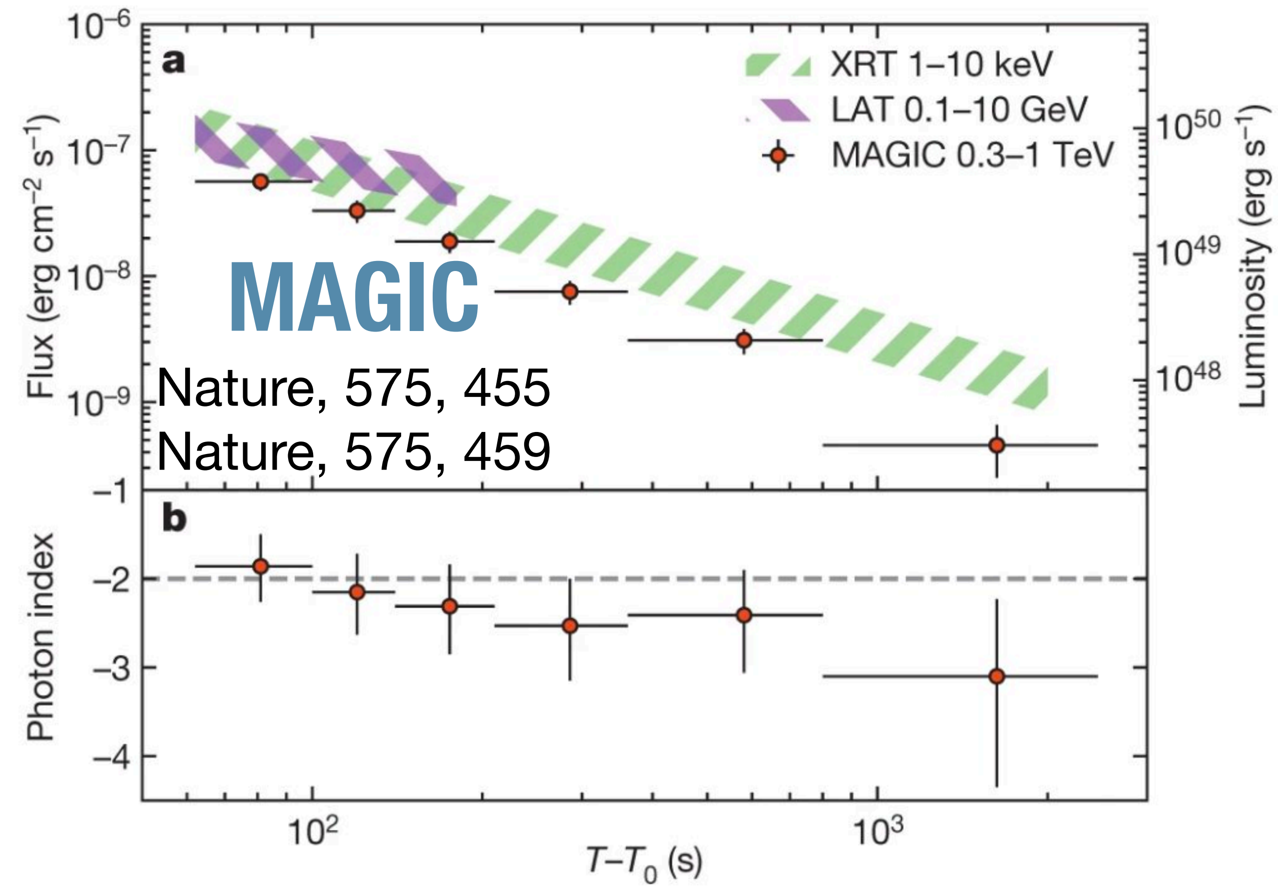


- Bright AGN flares detectable on short timescales with SWGO
- Triggers to CTA
  - Better short-timescale sensitivity than the Fermi satellite.
  - Selection of highest energy events which are most promising for many CTA science cases (LIV, Axions, Hadron acceleration, …)
- Long-term monitoring with SWGO

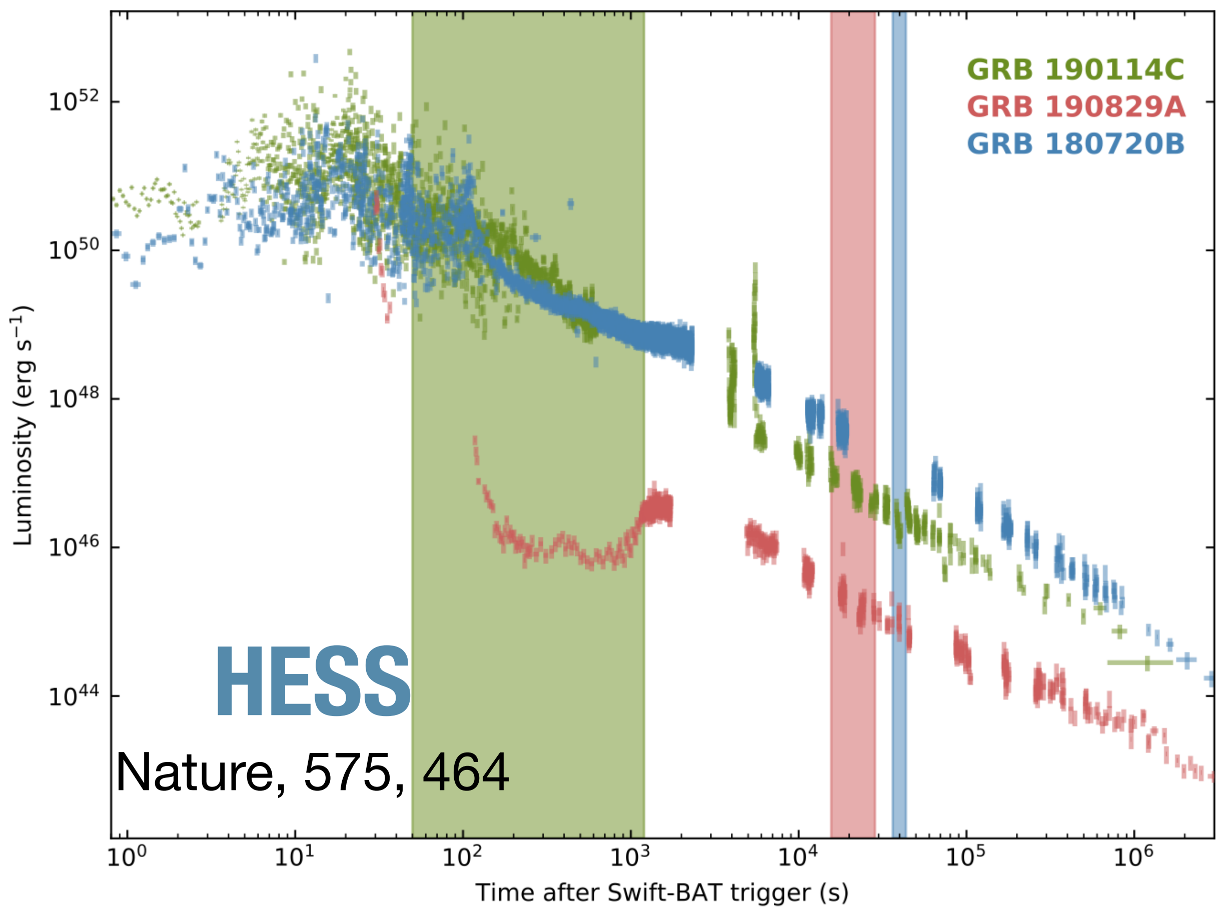


GRBs





- The big news of 2019
  - 3 GRB detections - HESS+MAGIC
  - Emission up to ~TeV established
  - Emission deep in to afterglow
  - All Swift-BAT triggers
- Most GRBs are not well localized
  - BAT FoV is 1.4 sr
  - SWGO as finder for VHE bursts triggers to CTA
- Also GW error boxes…

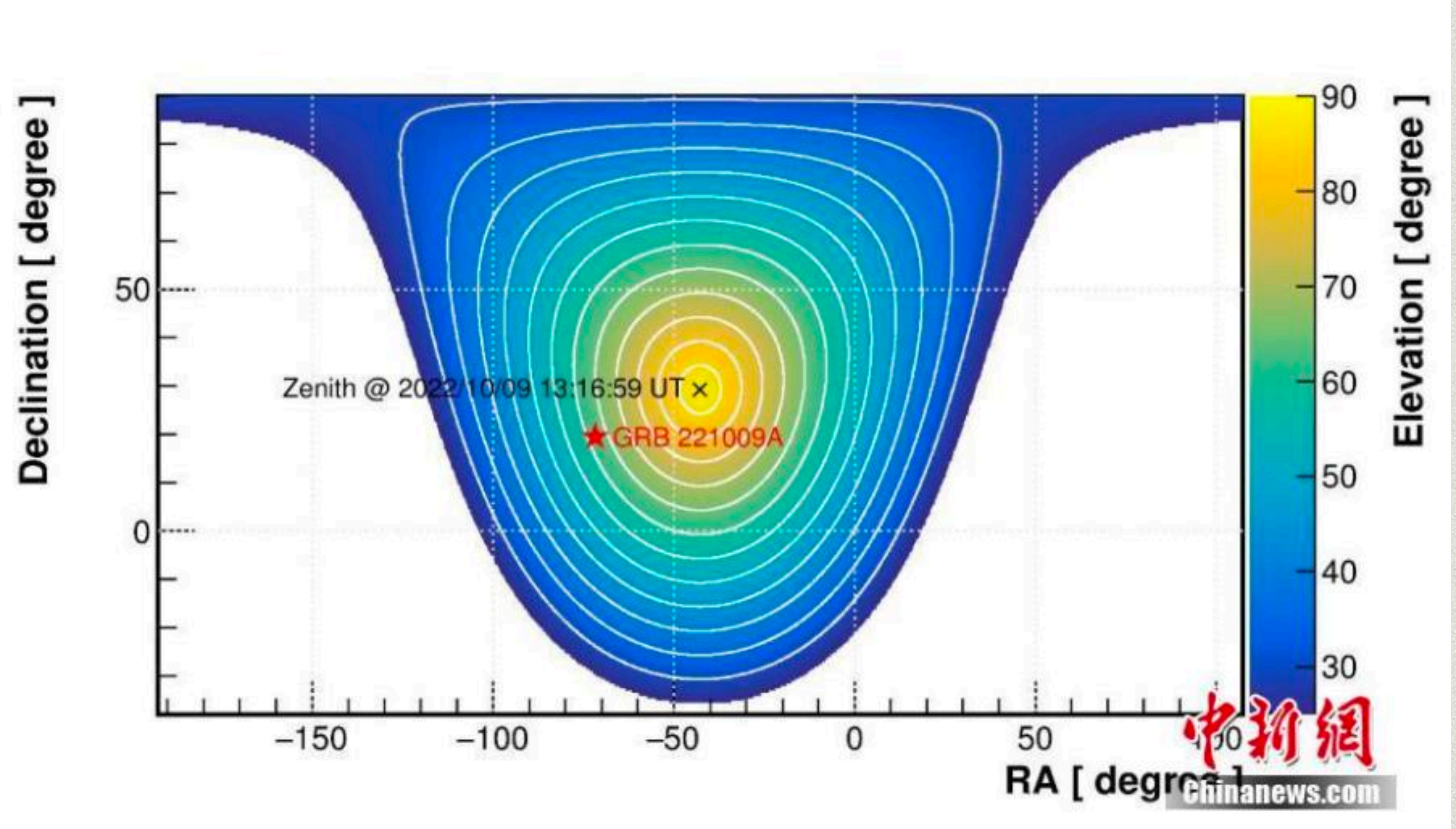


GRBs

GRB 221009A

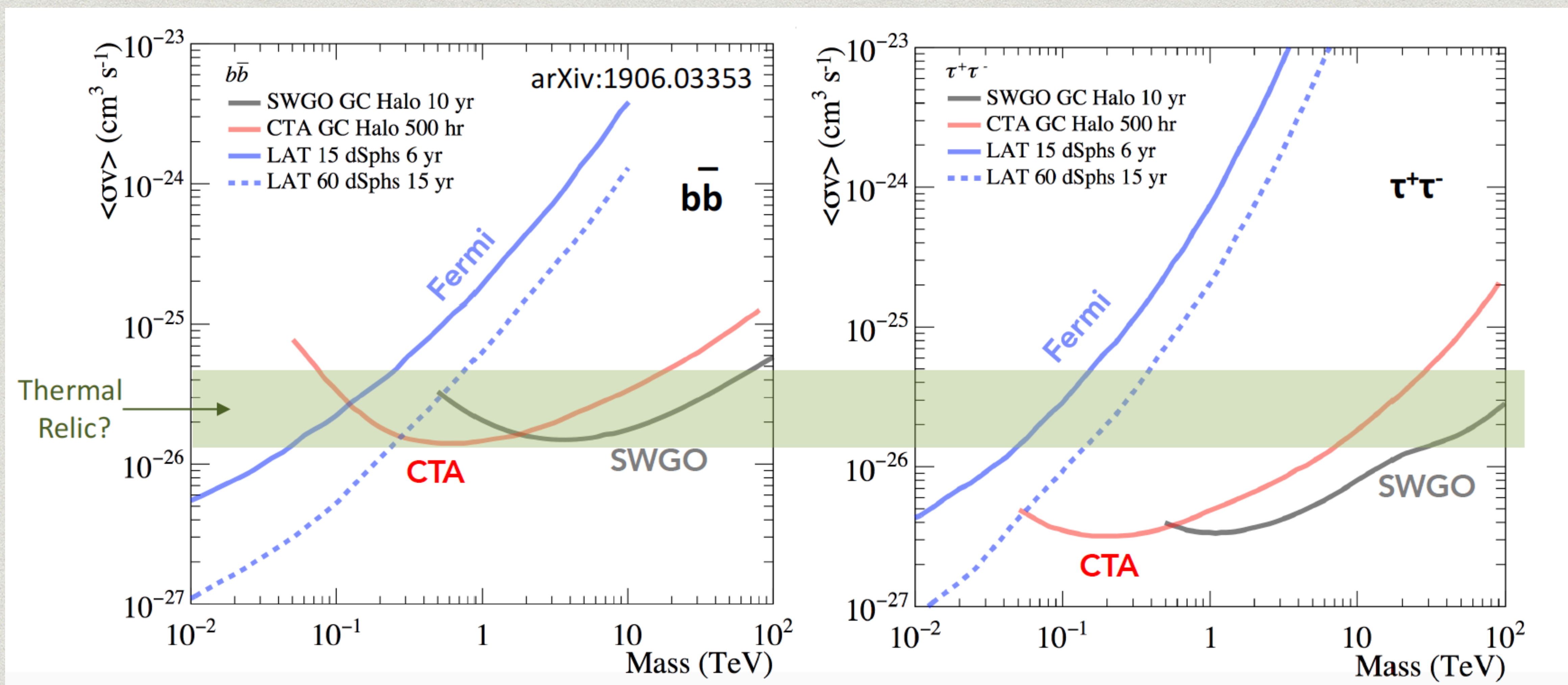
A historic one

- Photons up to 18 TeV!!
  - Detection by LHAASO right overhead.
- 5000 photons in ~30 minutes



WIMP Annihilation

- New generation of instruments reaches the critical sensitivity
- Thermal relic WIMP accessible over a very wide mass range (Galactic Centre/Halo observations @ VHE)



Conclusion

- Strong motivation for a southern hemisphere wide field of view high duty cycle detector!
  - SWGO – 3 year design/preparation period -> project launch!

- Strong complementarity between SWGO & CTA
  - Detecting hard spectrum sources -> CTA follow-up.
  - Triggering CTA: flares and transients.
  - Large scale emission complementing CTAs detailed view.
  - Covering together very wide range of WIMP masses.

Proposed Site,
Salta Province, Argentina