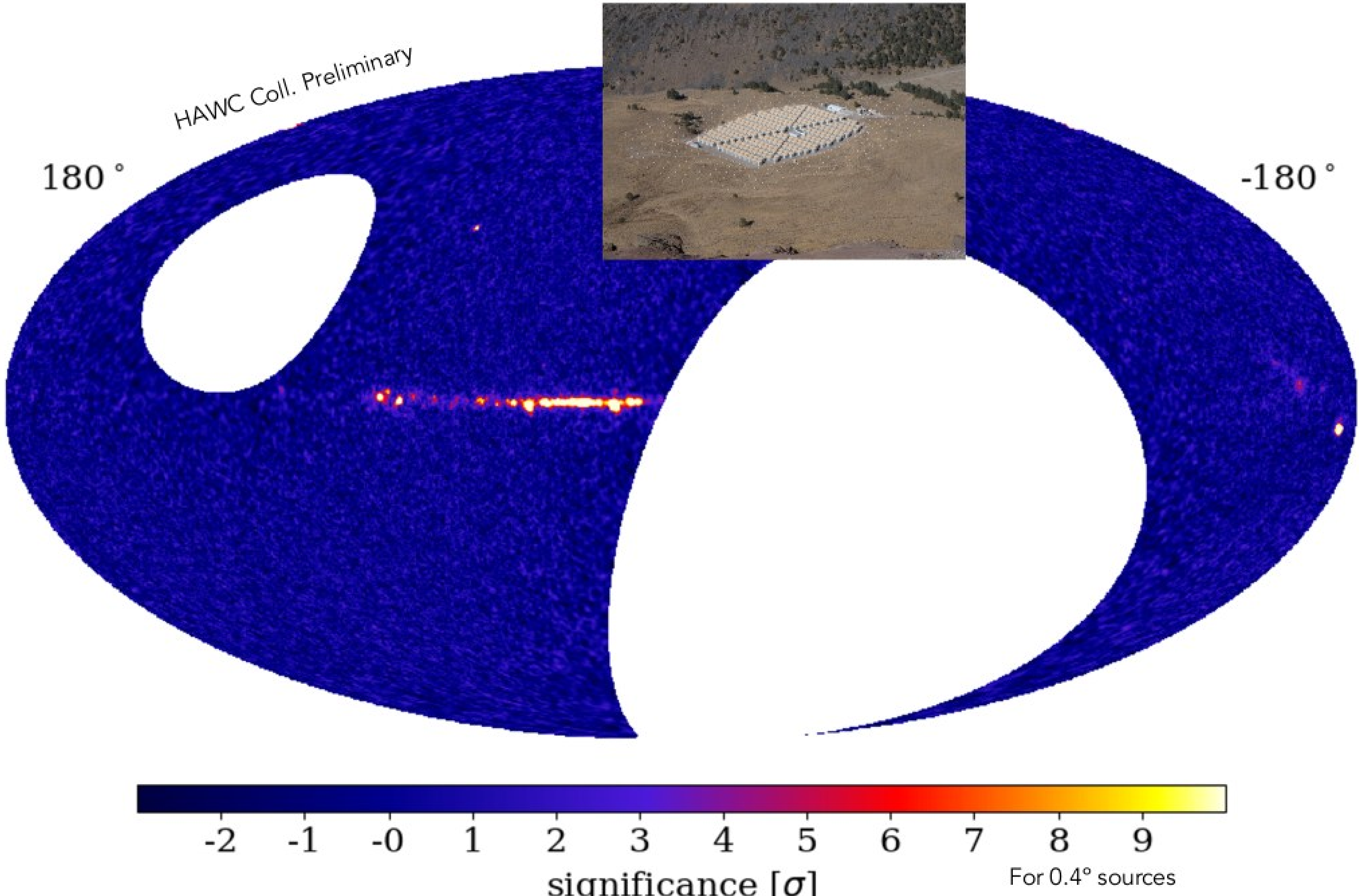
The Southern Wide-Field Gamma-ray Observatory (SWGO), and its science

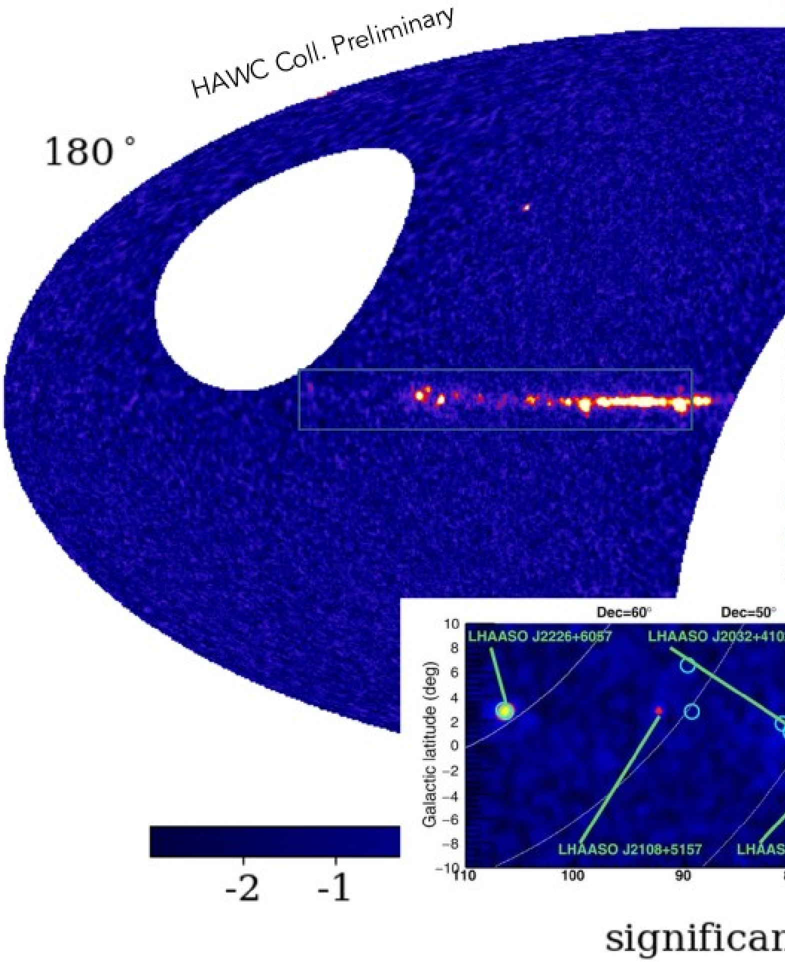
Gwenael Giacinti - 贾鸿宇 (TDLI, SJTU)

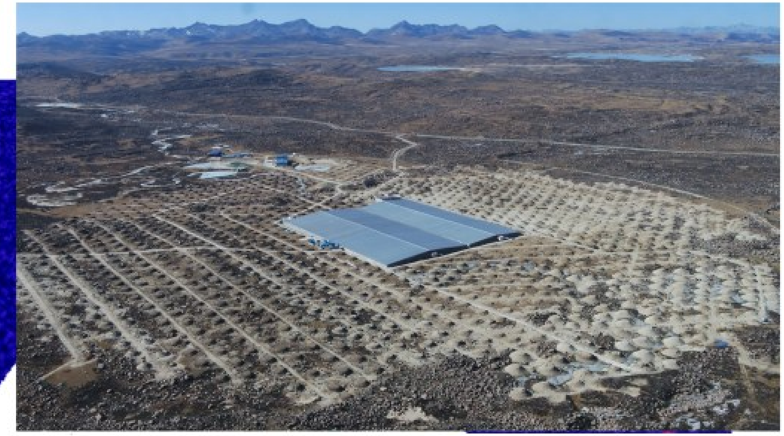
For the SWGO Collaboration (www.swgo.org)

Current & near-future observatories


HAWC Coll. Preliminary
180 °
-180 °
-2 -1 -0 1 2 3 4 5 6 7 8 9
significance [σ]
For 0.4° sources

LHAASO PeVatrons:

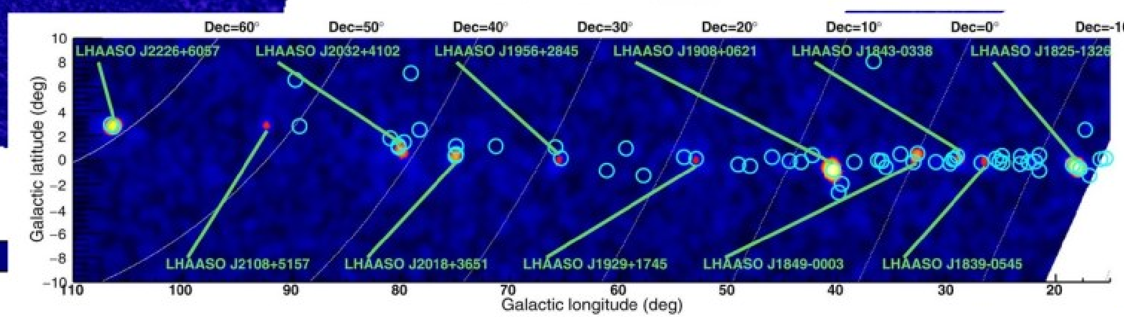




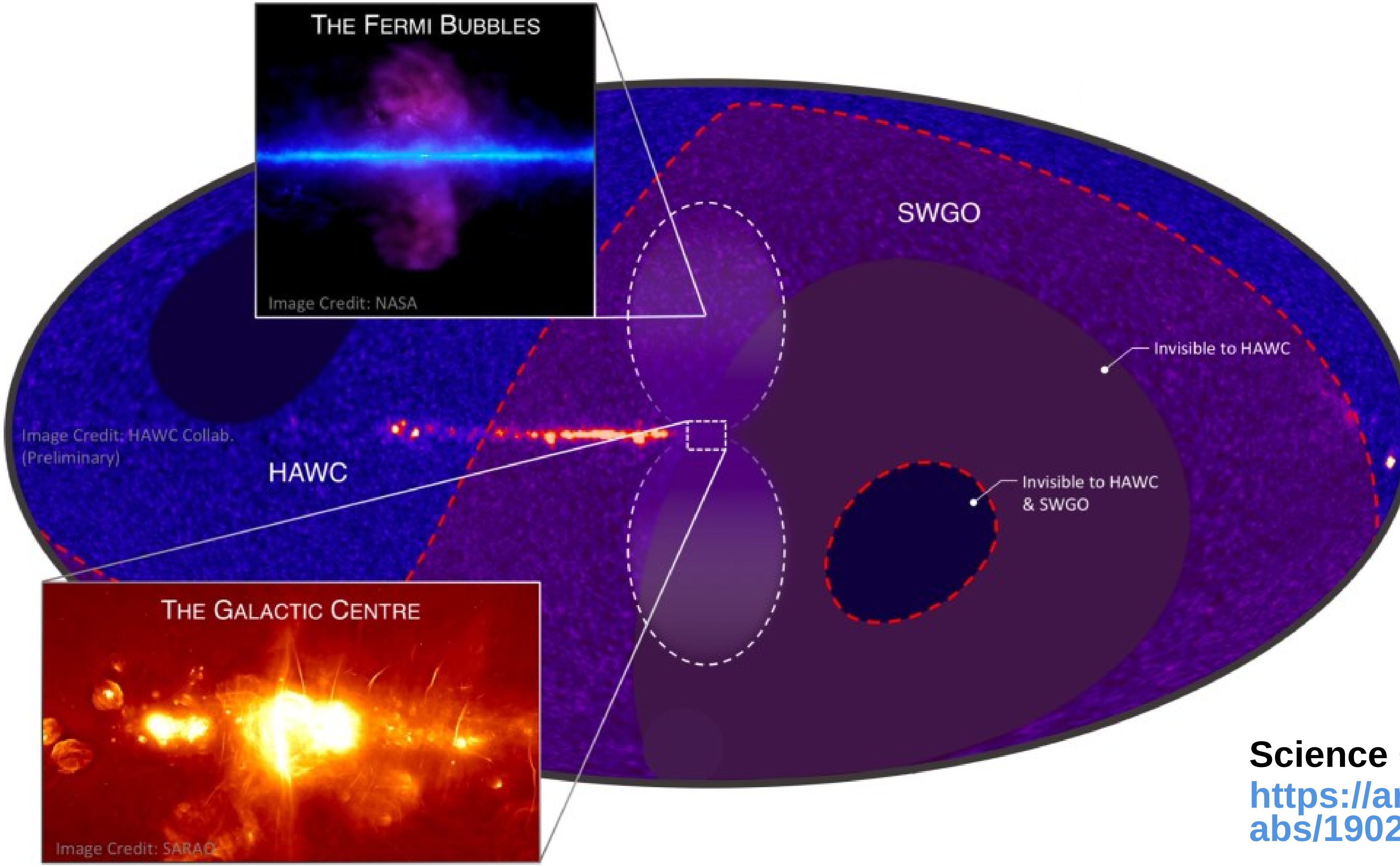
Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources

Zhen Cao, F. A. Aharonian, […]X. Zuo

Nature **594**, 33–36 (2021) | Cite this article



For 0.4° sources

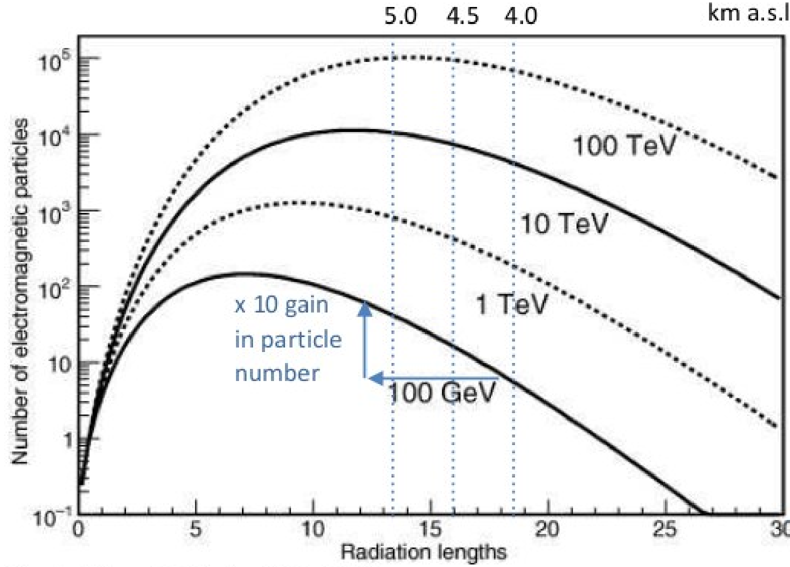


Science Case: https://arxiv.org/abs/1902.08429

- Access to the Galactic plane and Galactic center,
- Complementary with LHAASO and HAWC → Niche for SWGO.

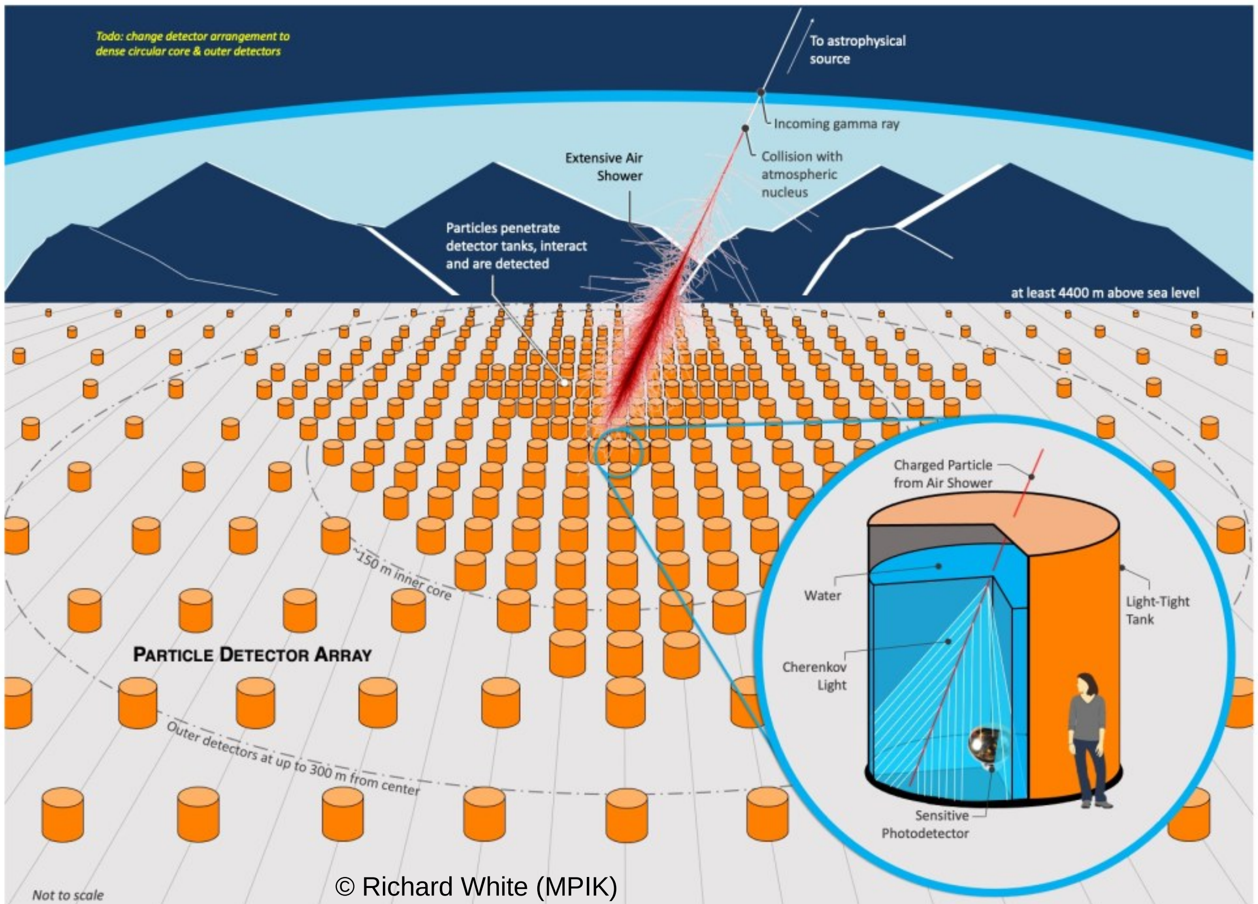
Site candidates for SWGO

The Andes provides a number of high-altitude plateaus and high-altitude lakes that constitute suitable sites for a particle array aiming to extend the low-energy frontier for Wide-Field Observatories.



Adapted from G. Sinnis, NJPh, 2009

The Concept



- Extended energy range
  - From c. 100 GeV to the PeV scale
- Design Elements
  - water Cherenkov detector (WCD) units
  - Large (80,000 m^2) high-fill factor core
  - Low-fill factor outrigger covering at least an area of 200,000 m^2
- Site
  - Deployed at high-altitude in the Andes
  - Above 4,4 km a.s.l.

The Science Case for SWGO

- Detection of short-timescale phenomena
  - Low-energy threshold for detection of short-timescale (< 1hr) transient events down to 100 GeV
- Search for PeVatrons
  - Improved sensitivity up to a few 100s TeV to search for PeV Galactic particle accelerators.
- PWNe and Gamma-ray Halos
  - Unique potential for accessing the high-energy end of the Galactic Population.
- Dark Matter and Diffuse Emission
  - Unique access to the Galactic Center and Halo at the high-energy end of the spectrum.
- Cosmic-rays
  - Unique complement to LHAASO for anisotropy studies, with capability to reach low-angular scale.
  - Good muon tagging implies good mass resolution for composition studies up to the knee.

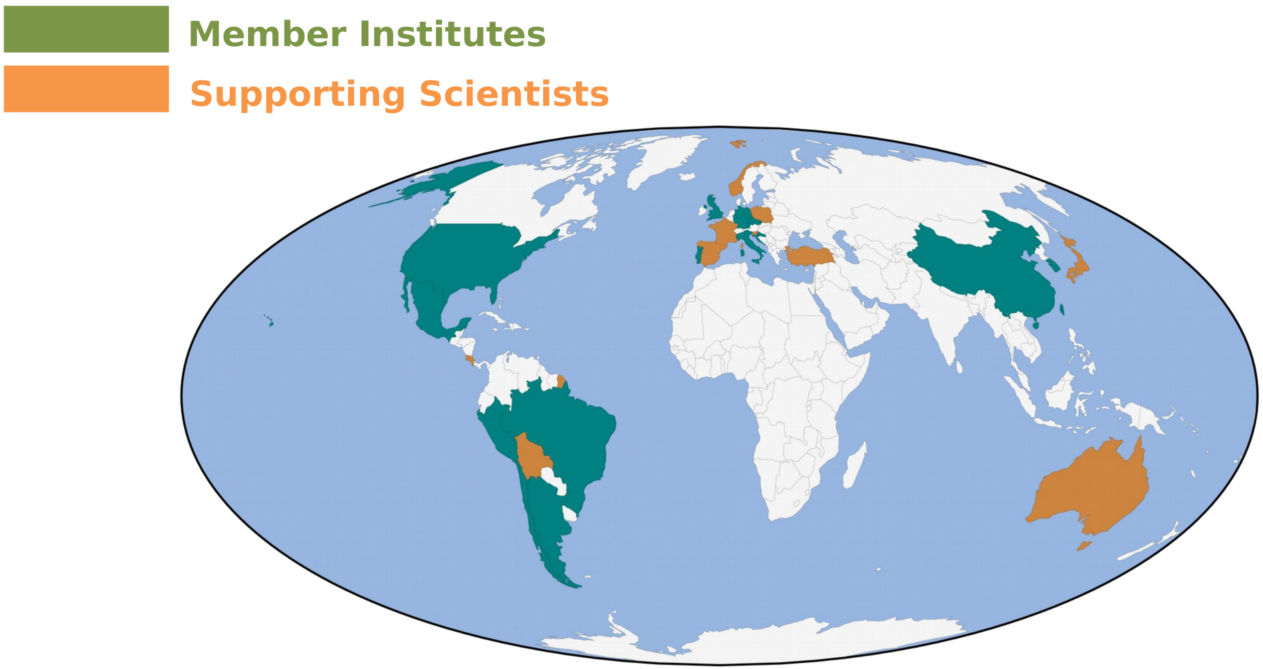
The Science Case for SWGO

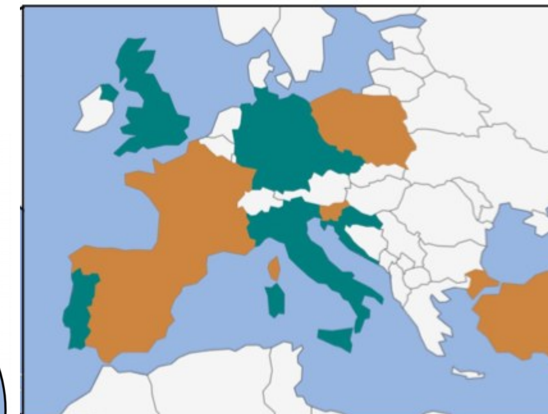
- Detection of sl
  - Low-energy thr … nts down to 100 GeV
- Search for PeV
  - Improved sensi … e accelerators.
- PWNe and Ga
  - Unique potenti … tion.
- Dark Matter ar
  - Unique access t … he spectrum.
- Cosmic-rays
  - Unique comple … each low-angular scale.
  - Good muon tag … up to the knee.

Design Implications

- Decreasing of the low-energy threshold to c. 100 GeV, at ~10^{-11} erg/cm^2.s (5-year)
  - Combination of Improved design and background rejection, plus high-altitude site > 4.5 km a.s.l.
- Large array (> 200.000 m^2) to achieve good sensitivity > 100 TeV
  - Aim is to push sensitivity <10^{-13} erg/cm^2.s in the range 100-300 TeV.
- Muon counting capability
  - For cosmic-ray studies and background subtraction.
- Improved angular (0.2 deg) and energy resolutions (<30%) above 10 TeV.

The SWGO Collaboration



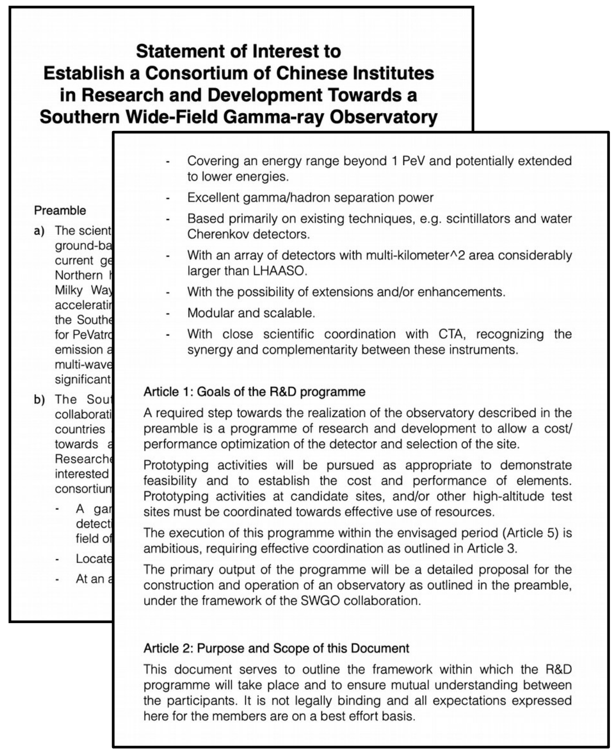


Argentina	Italy
Brazil	Mexico
Chile	Peru
China	Portugal
Croatia	South Korea
Czech Rep.	United Kingdom
Germany	United States

- SWGO partners
  - → 14 countries, 66 institutes
  - → + supporting scientists

The Chinese Consortium

- Signed by 65 faculty members, postdocs, and grad students from 12 institutes



Statement of Interest to Establish a Consortium of Chinese Institutes in Research and Development Towards a Southern Wide-Field Gamma-ray Observatory

Preamble

- Covering an energy range beyond 1 PeV and potentially extended to lower energies.
- Excellent gamma/hadron separation power
- Based primarily on existing techniques, e.g. scintillators and water Cherenkov detectors.
- With an array of detectors with multi-kilometer^2 area considerably larger than LHAASO.
- With the possibility of extensions and/or enhancements.
- Modular and scalable.
- With close scientific coordination with CTA, recognizing the synergy and complementarity between these instruments.

Article 1: Goals of the R&D programme

A required step towards the realization of the observatory described in the preamble is a programme of research and development to allow a cost/performance optimization of the detector and selection of the site.

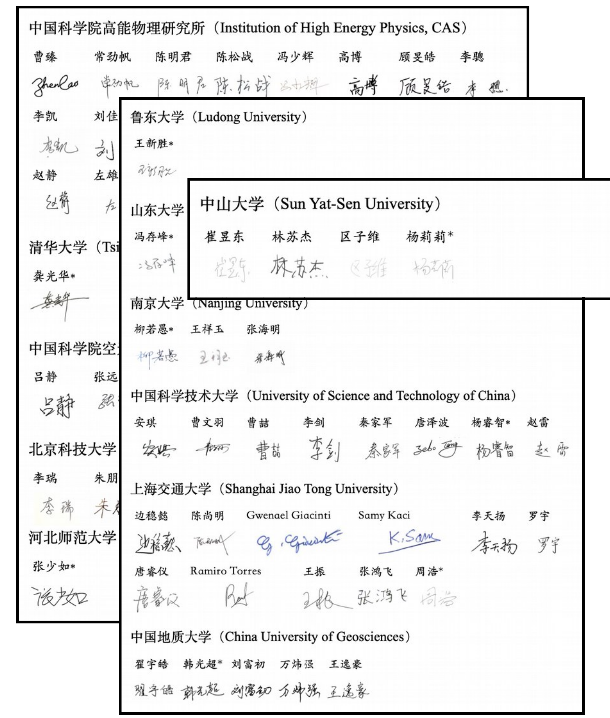
Prototyping activities will be pursued as appropriate to demonstrate feasibility and to establish the cost and performance of elements. Prototyping activities at candidate sites, and/or other high-altitude test sites must be coordinated towards effective use of resources.

The execution of this programme within the envisaged period (Article 5) is ambitious, requiring effective coordination as outlined in Article 3.

The primary output of the programme will be a detailed proposal for the construction and operation of an observatory as outlined in the preamble, under the framework of the SWGO collaboration.

Article 2: Purpose and Scope of this Document

This document serves to outline the framework within which the R&D programme will take place and to ensure mutual understanding between the participants. It is not legally binding and all expectations expressed here for the members are on a best effort basis.



中国科学院高能物理研究所（Institution of High Energy Physics, CAS）

曹臻 常劲帆 陈明君 陈松战 冯少辉 高博 顾旻皓 李骢

李凯 刘佳

赵静 左雄

清华大学（Tsi

龚光华*

中国科学院空

吕静 张远

北京科技大学

李瑞 朱朋

河北师范大学

张少如*

鲁东大学（Ludong University）

王新胜*

山东大学

冯存峰*

中山大学（Sun Yat-Sen University）

崔显东 林苏杰 区子维 杨莉莉*

南京大学（Nanjing University）

柳若愚* 王祥玉 张海明

中国科学技术大学（University of Science and Technology of China）

安琪 曹文羽 曹喆 李剑 秦家军 唐泽波 杨睿智* 赵雷

上海交通大学（Shanghai Jiao Tong University）

边稳懿 陈尚明 Gwenael Giacinti Samy Kaci 李天扬 罗宇

唐睿仪 Ramiro Torres 王振 张鸿飞 周浩*

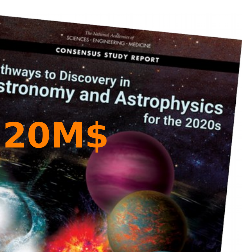
中国地质大学（China University of Geosciences）

翟宇皓 韩光超* 刘富初 万炜强 王逸豪

Status & Plan

	SWGO R&D Phase Milestones	
✓	M1	R&D Phase Plan Established
✓	M2	Science Benchmarks Defined
✓	M3	Reference Configuration & Options Defined
✓	M4	Site Shortlist Complete
✓	M5	Candidate Configurations Defined
✓	M6	Performance of Candidate Configurations Evaluated
→	M7	Preferred Site Identified
	M8	Design Finalised
	M9	Construction & Operation Proposal Complete

- R&D Phase
  - Kick off meeting Oct 2019
  - Expected completion 2025
    - ✓ Site and Design Choices made
  - Then:
- Preparatory Phase
  - Detailed construction planning
  - Engineering Array
- (Full) Construction Phase
  - 2027+



- Roadmaps
  - → US Decadal Review
  - → SNOWMASS, APPEC, Astronet

INITIAL site candidates

lat. 15 S

lat. 23 S

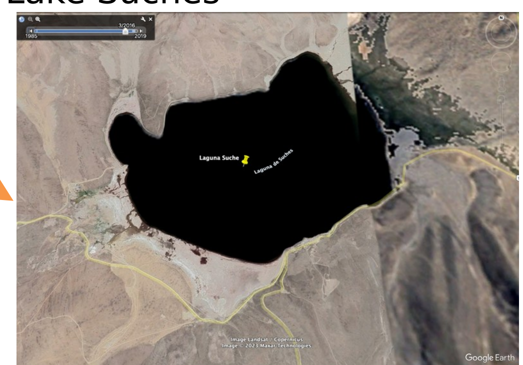
- Alto Tocomar (Argentina)
- Cerro Vecar (Argentina)
- Chacaltaya (Bolivia)
- AAP Pajonal (Chile)
- AAP Pampa La Bola (Chile)
- Lake Sibinacocha (Peru)
- Imata (Peru)
- Sumbay (Peru)
- Peru National Observatory
- Yanque (Peru)

Site now CHOSEN!

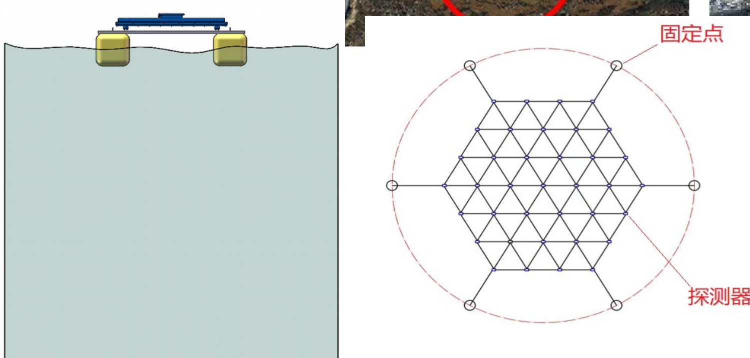
Potential Lakes

Lake Sibinacocha

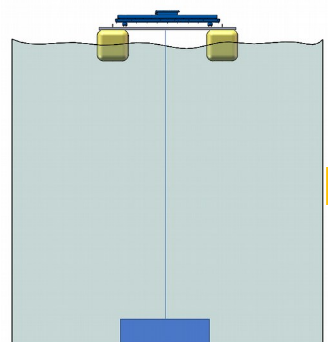
Lake Suches



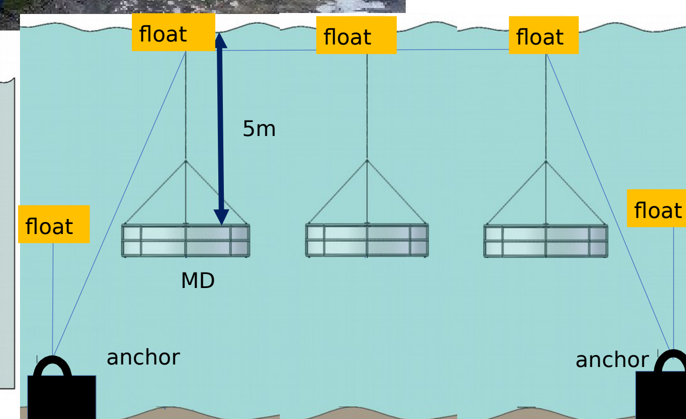
Deployment in Lake



Fixed by cable net

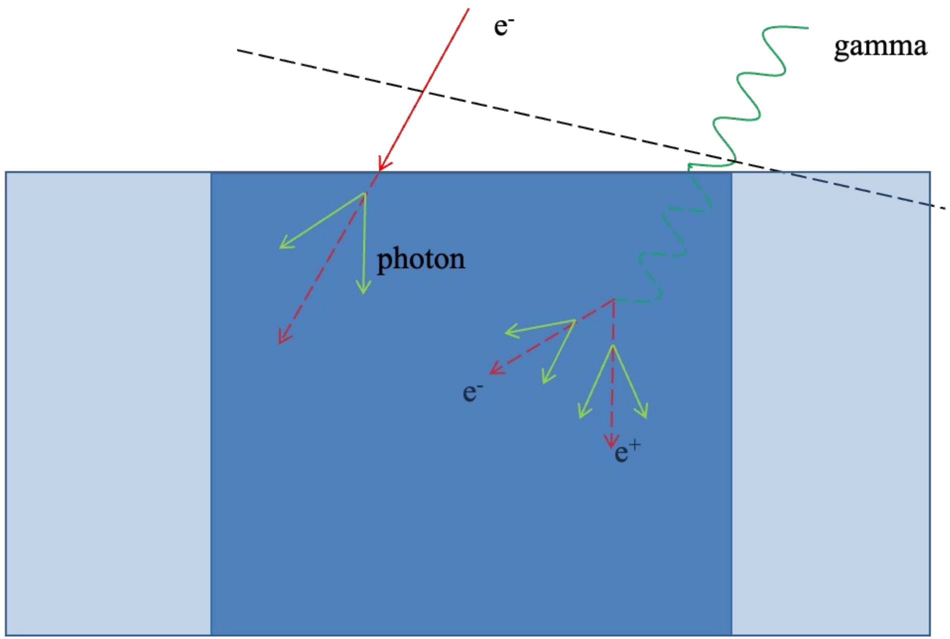


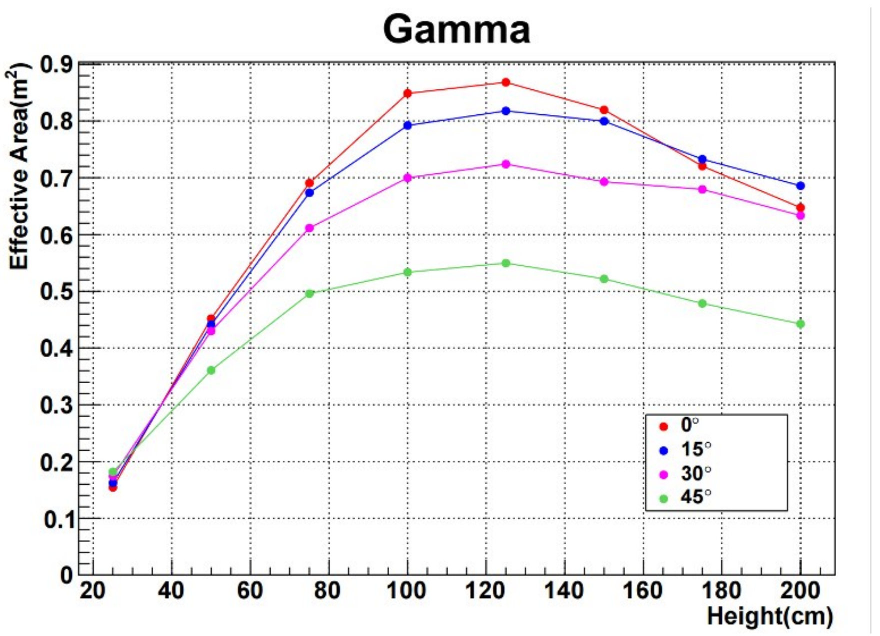
Fixed by anchor



Simulation for a Lake Array

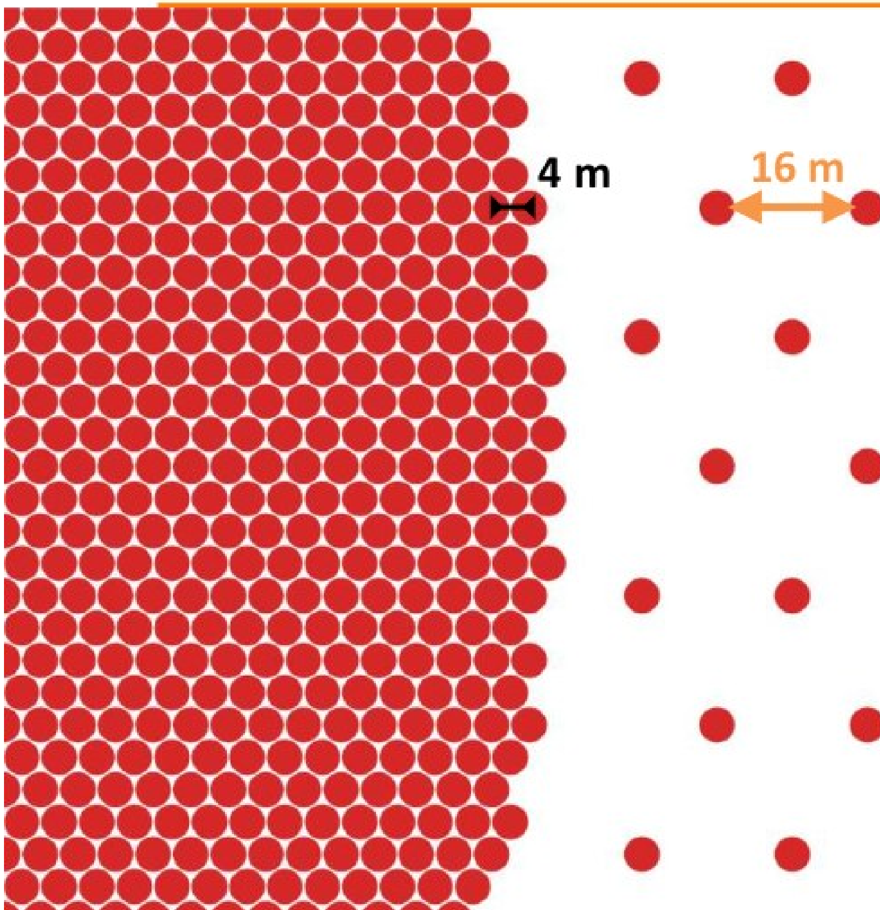
Unit detector simulation





SWGO
The Southern Wide-field Gamma-ray Observatory

The baseline detector concept

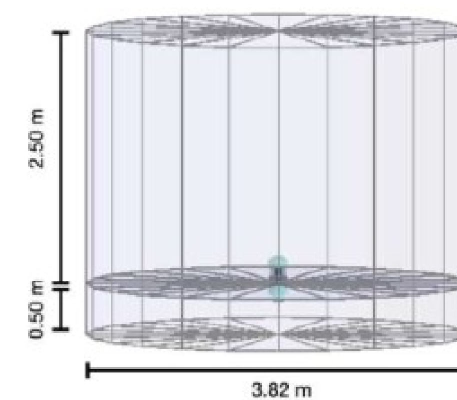


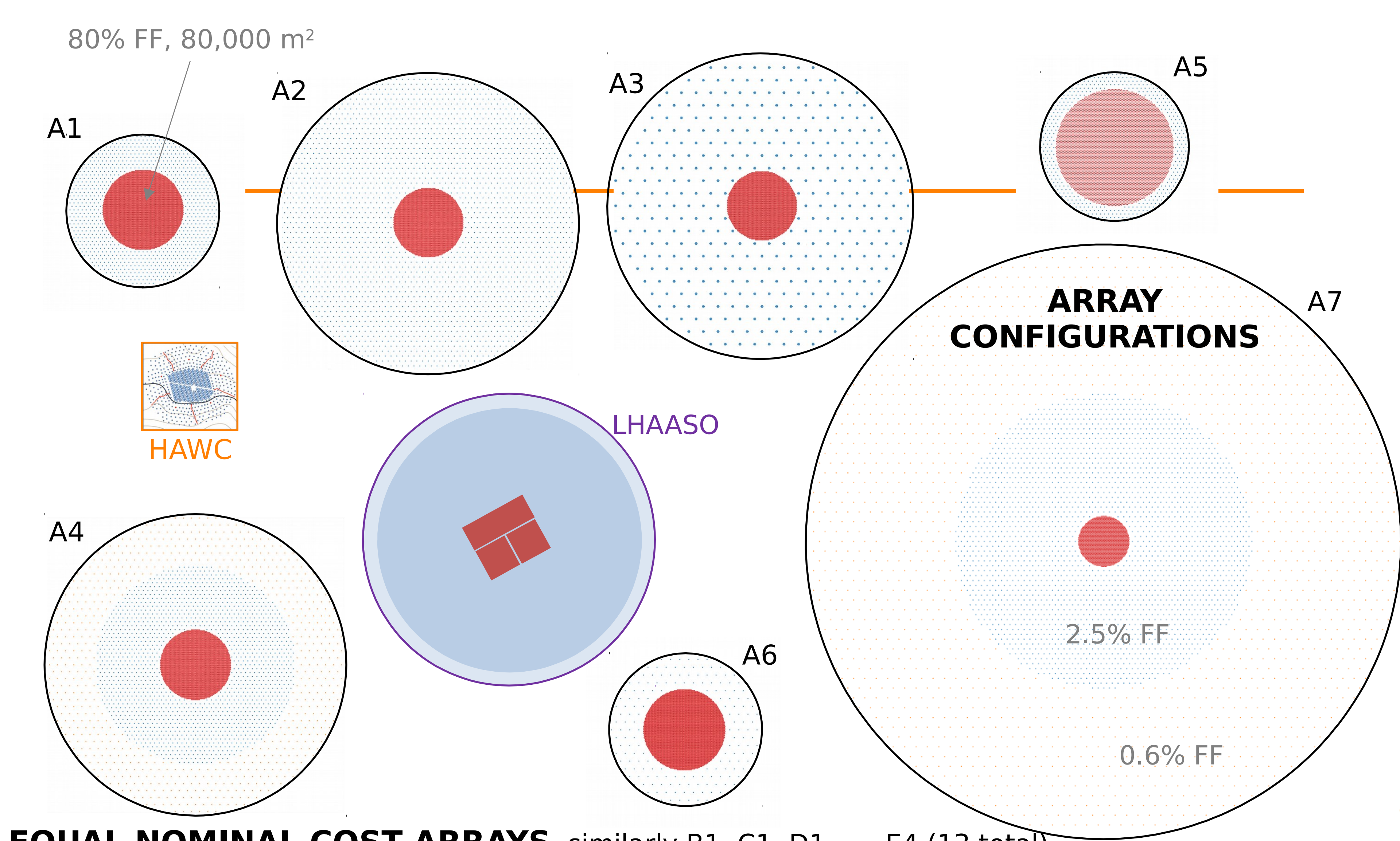
Core: Ø 320 m, FF = 80%
5,700 WCD units

Outer: Ø 600 m, FF = 5%
880 WCD units

Altitude: 4,700 m a.s.l.

✧ muon counting

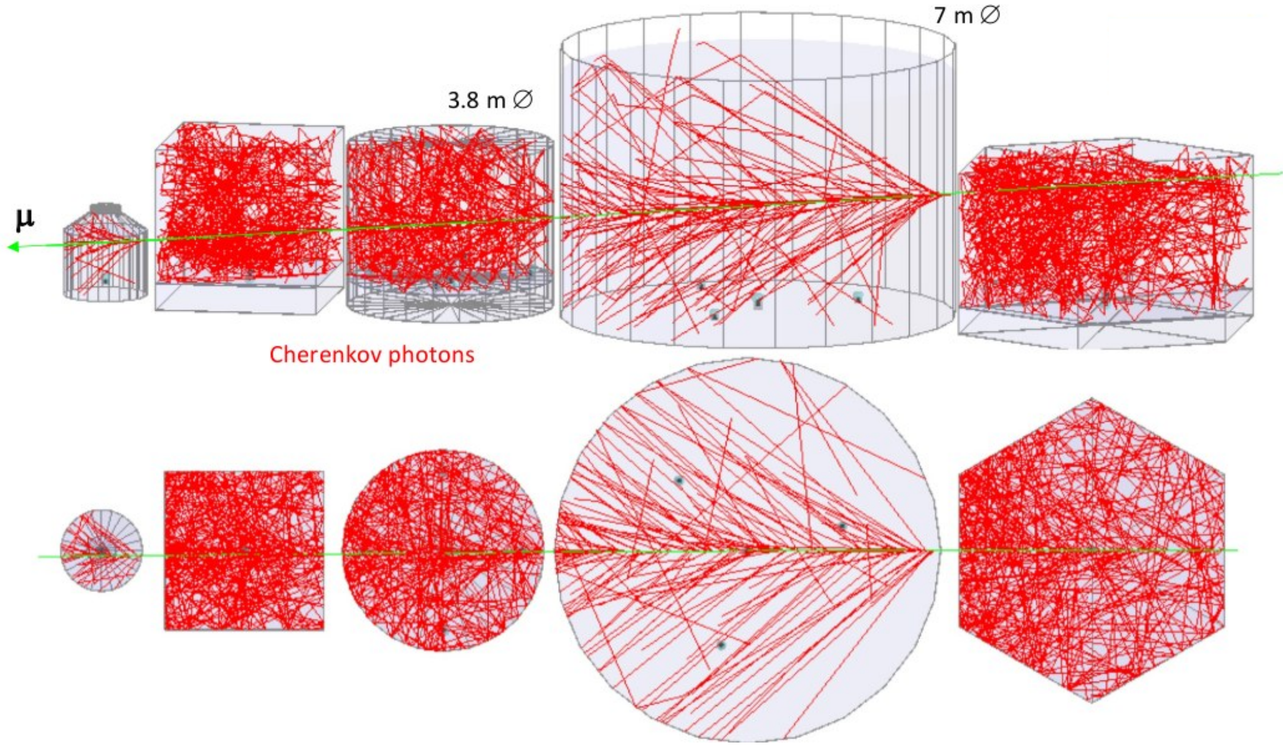




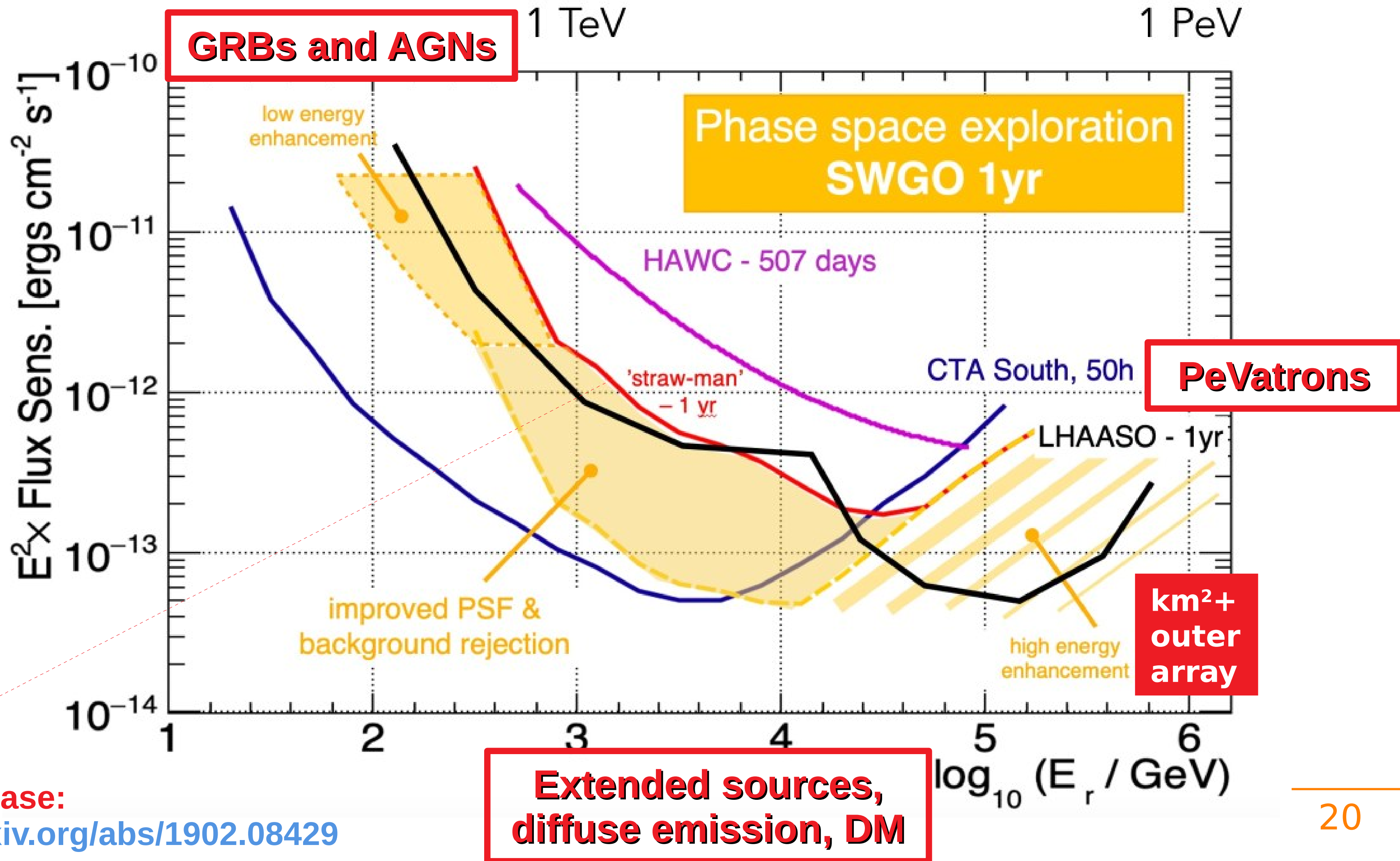
EQUAL NOMINAL COST ARRAYS, similarly B1, C1, D1, ..., E4 (13 total)

Analysis & Simulations

- Simulations to compare different detector concepts,
- Build on the analysis & simulations framework from HAWC.



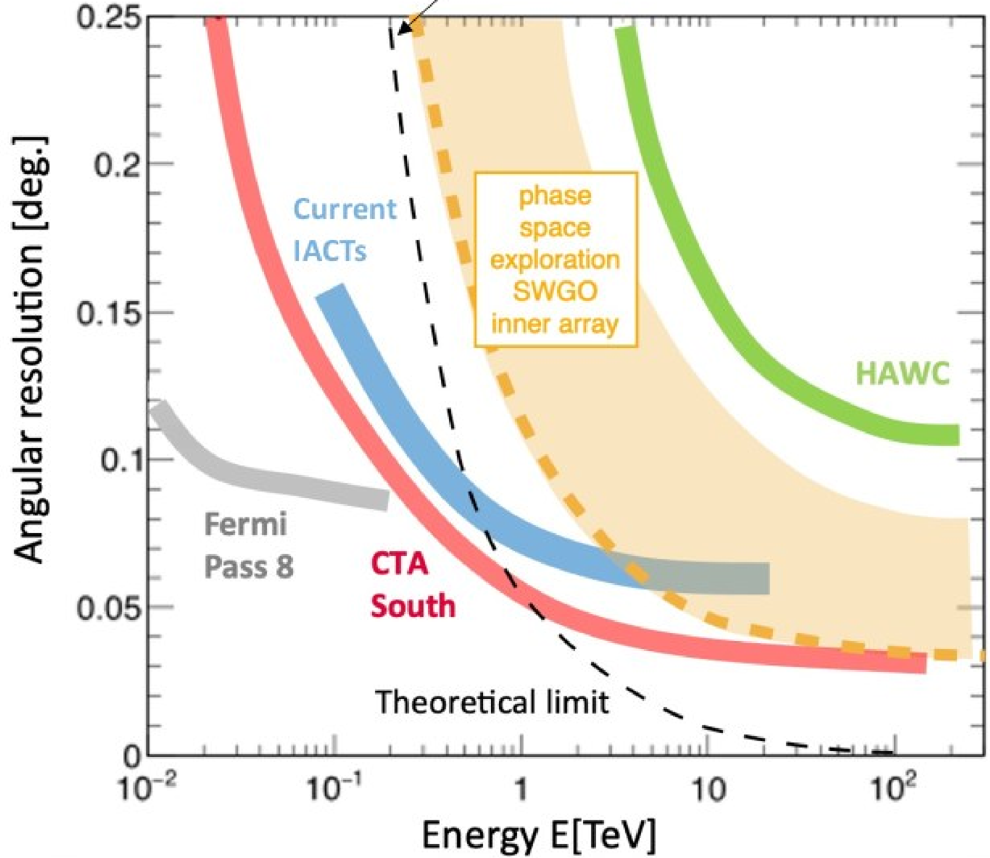
Sensitivity range (exploration)



Science Case:
https://arxiv.org/abs/1902.08429

Angular resolution

◎ Goal:
To have an unprecedented resolution for such a wide field VHE-UHE observatory.



Core Science Cases & Benchmarks for SWGO

Science Case	Design Drivers	Benchmark Description
Transient Sources: Gamma-ray Bursts	Low-energy sensitivity & Site altitude[a]	Minimum integration for 5σ detection: F(100 GeV) = 10^{-8} erg/cm^2.s, PWL index = -2., F(t) $\propto t^{-1.2}$
Galactic Accelerators: PeVatron Sources	High-energy sensitivity & Energy resolution[b]	Maximum exp-cutoff energy detectable at 95% CL in 5 years for: F(1TeV) = 5 mCrab, PWL index = -2.3
Galactic Accelerators: PWNe and TeV Halos	Extended source sensitivity & Angular resolution[c]	Maximum source angular extension detectable at 5σ in 5-yr integration for: F(>1TeV) = 5×10^{-13} TeV/cm^{-2}.s
Diffuse Emission: Fermi Bubbles	Background rejection	Minimum diffuse cosmic-ray residual background level. Threshold: < 10^{-5} level at 1 TeV.
Fundamental Physics: Dark Matter from Galactic Halo	Mid-range energy sensitivity Site latitude[d]	Maximum energy for $b\bar{b}$ thermal-relic cross-section limit at 95% CL in 5-years, for Einasto profile.
Cosmic-rays: Mass-resolved dipole/multipole anisotropy	Muon counting capability[e]	Maximum dipole energy at 10^{-3} level; Log-mass dipole resolution at 1 PeV – goal is to achive A={1, 4, 14, 56}; Maximum multipole scale > 0.1 PeV

Tab. 1 SWGO Science Benchmarks. [a]Site altitude parameter to enter design discrimination as altitude-dependent IRFs. [b]Energy resolution not constraining as long as $O(30\%)$ throughout energy range. [c]Angular resolution not constraining as long as $\sim 0.2° - 0.3°$ throughout energy range. [d]Site latitude not severely constraining, but sites closer to 30° South are slightly favoured. [e]Capability for individual muon identification to play important role in mass-discrimination.

Transients with SWGO (GRBs)

- Short-timescale sensitivity of ground-particle detectors is much worse than IACTs at low E! But room for improvement < 1 TeV

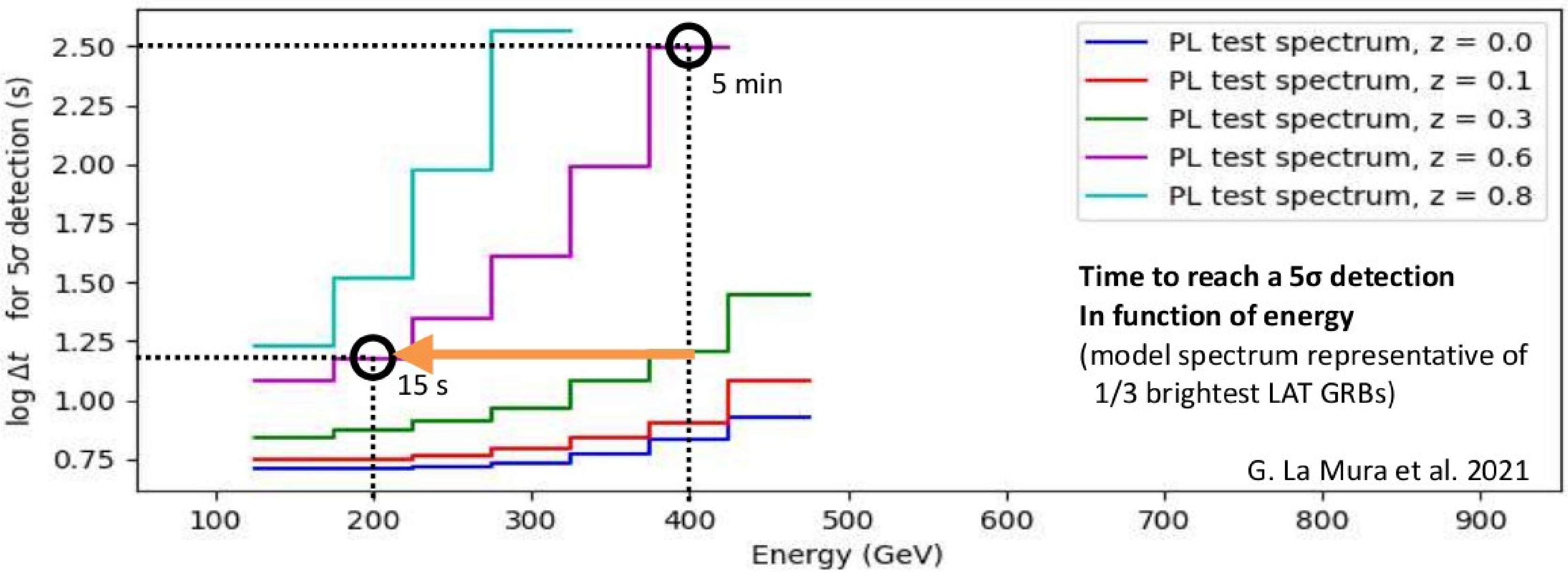
1 min sensitivity:
- Fermi-LAT: 10^{-7} erg/cm^2/s @ 1 GeV
- SWGO: 10^{-9} erg/cm^2/s @ < 500 GeV
- CTA: 10^{-11} erg/cm^2/s @ 100 GeV

- And a number of other advantages…
  - **100% duty cycle** → higher rate and monitoring capability of transients → bridging the gap with satellite facilities
  - **Serendipitous view** - observation of onset / prompt emission of GRBs
  - **A trigger instrument**!
    - Blind searches and offline checks for afterglow triggers
      - Critical synergy with IACTs and other MWL + MM instruments

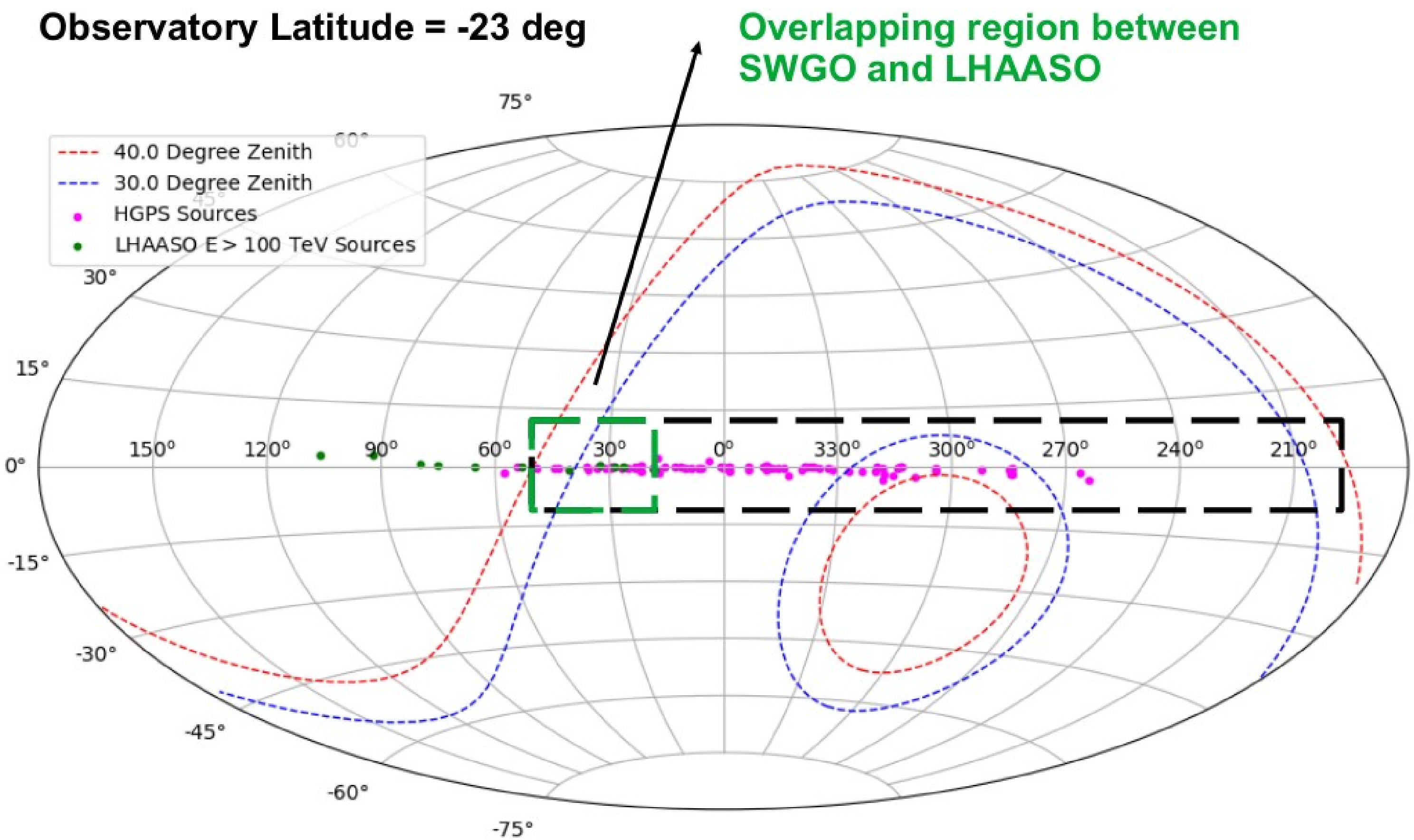
✧ **SWGO can bring the 10s deg^2 error boxes (GBM, GW) down to ~ deg^2**

Transients with SWGO

- Energy threshold is crucial for variability studies, in particular short-transient events such as GRBs

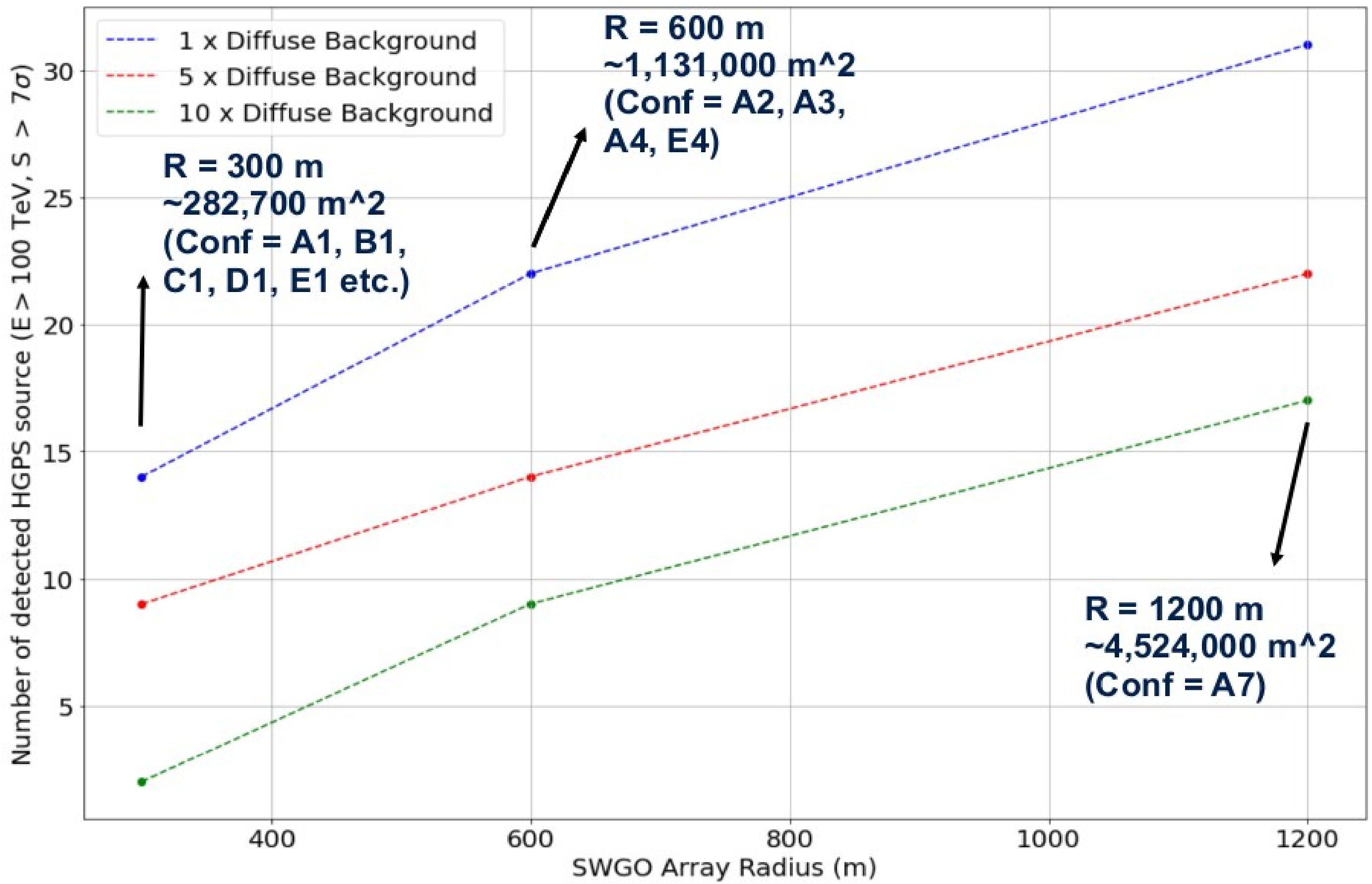


Number of detectable PeVatrons



Results for E > 100 TeV
SWGO Detections

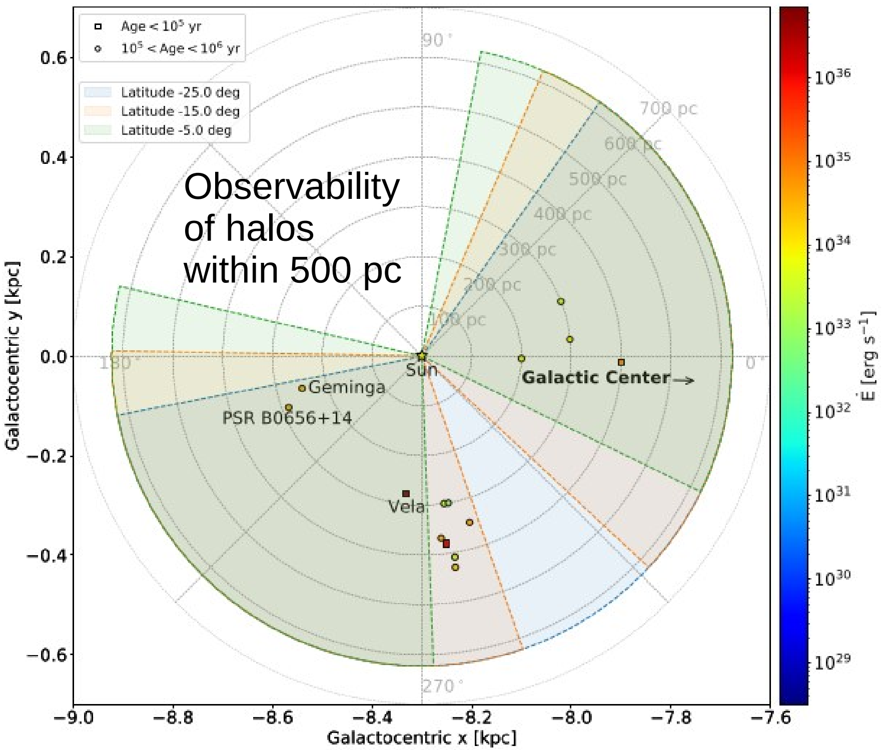
The Southern Wide-field Gamma-ray Observatory



Results are given for 1-year observation time

Coverage of nearby TeV halos

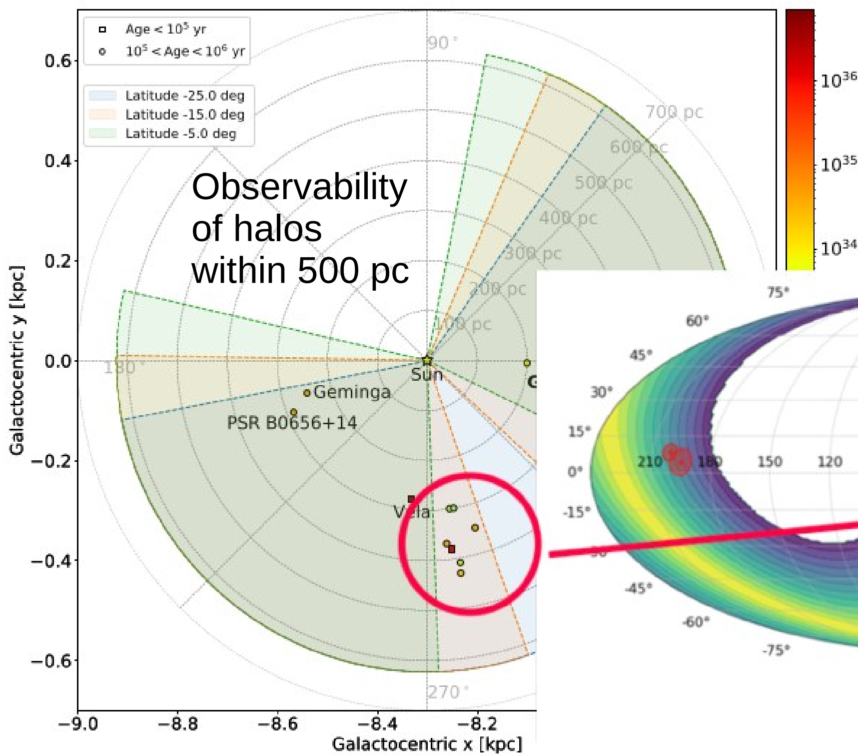
Nearby → more likely to be extended
Latitudes > 15º South preferred for optimum coverage



←Includes all nearby pulsars that could produce a halo.

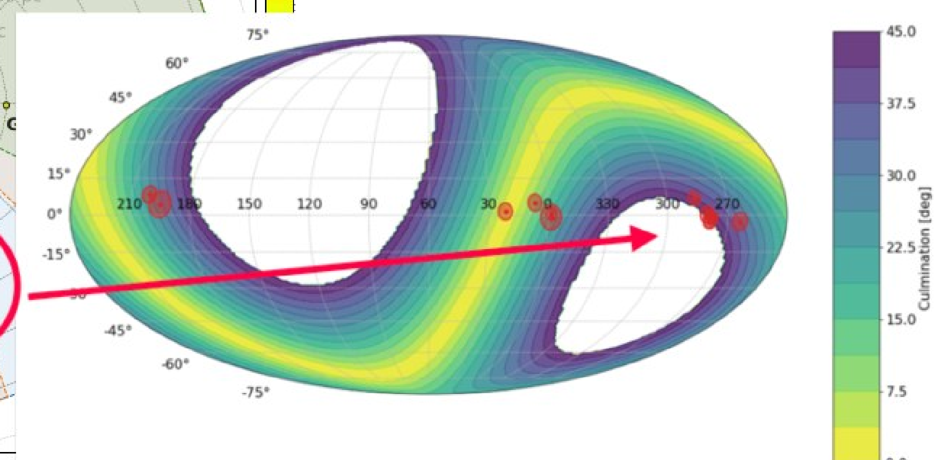
Coverage of nearby TeV halos

Nearby → more likely to be extended
Latitudes > 15º South preferred for optimum coverage

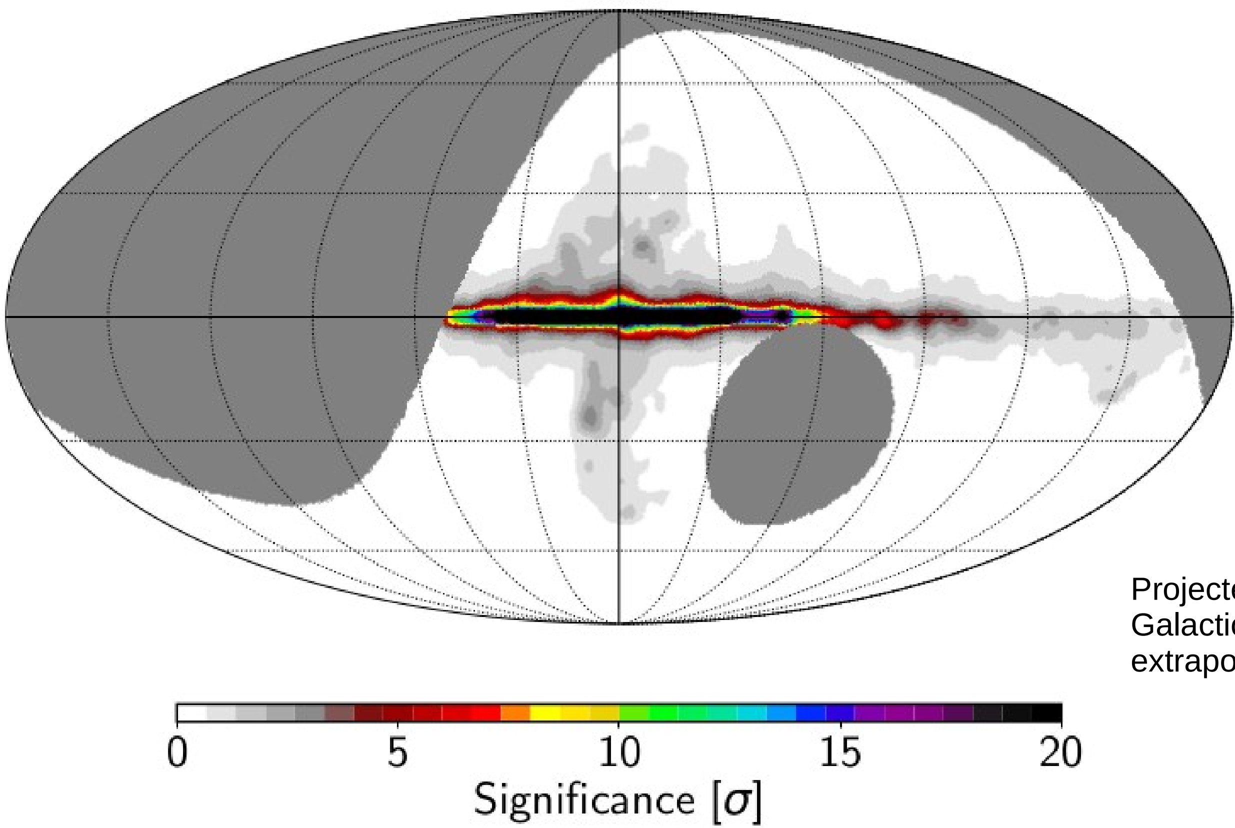


Source clustering:
physical and inconvenient!

→ angular resolution



Diffuse emission and Fermi Bubbles



Projected significance for the observation of the Galactic diffuse emission with 1 yr based on an extrapolation of the Fermi diffuse model.

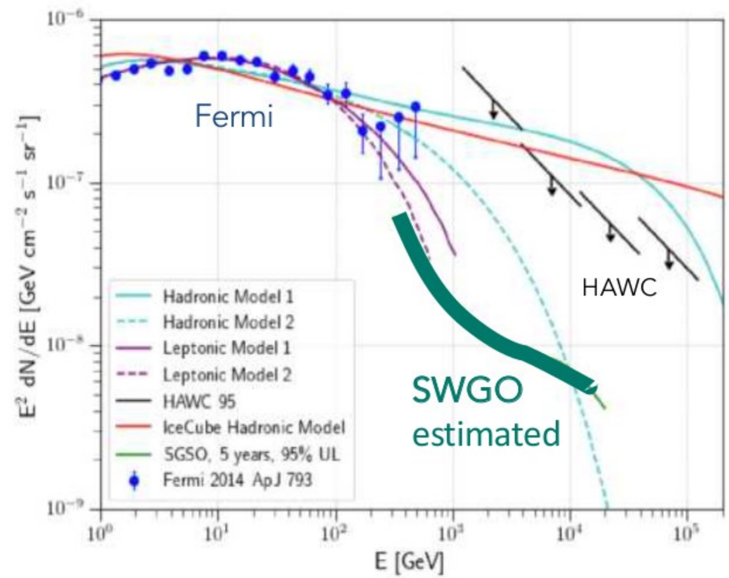
Diffuse emission and Fermi Bubbles

- **Diffuse emission from the Galactic Plane** up to PeV energies:

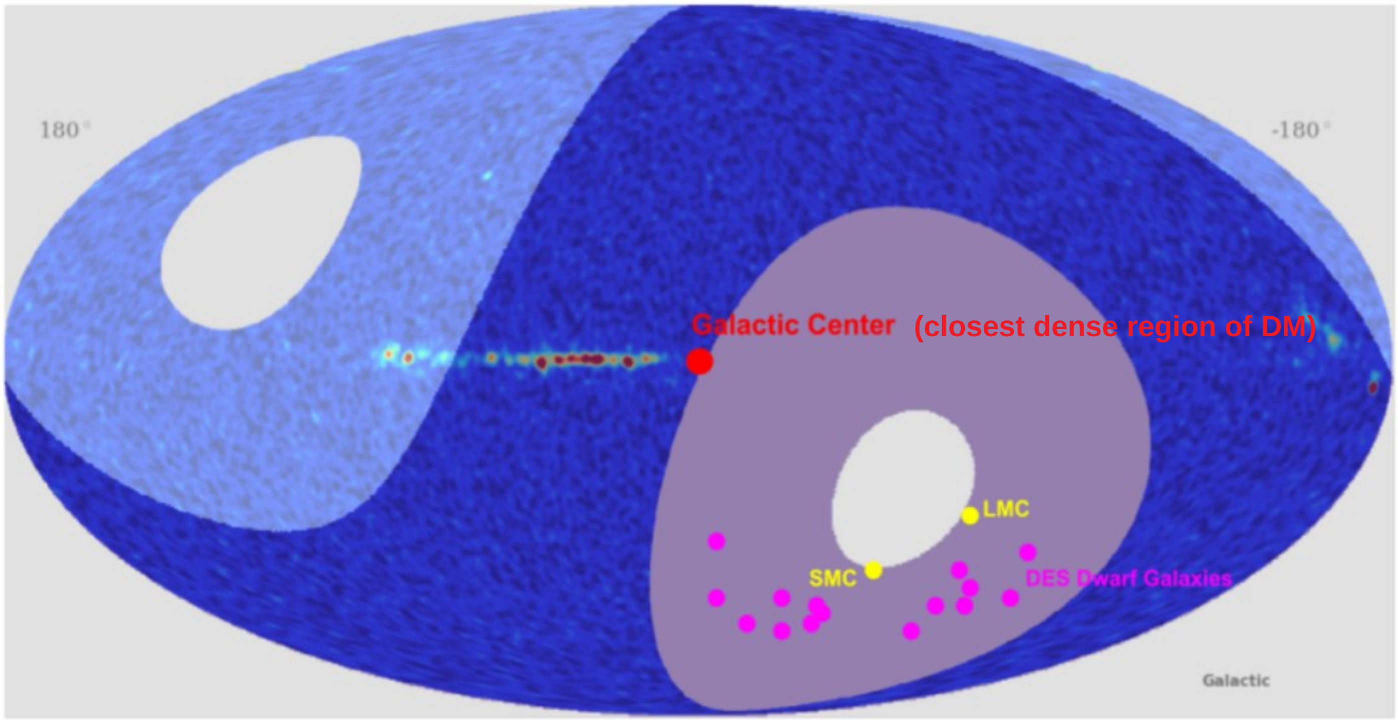
  → A wide-field instrument with an excellent background rejection will be optimal for the detection of such very extended, dim emission.

- **Fermi Bubbles**:

  → Their (non-)detection at TeV energies will allow to disentangle between a number of theoretical scenarios.



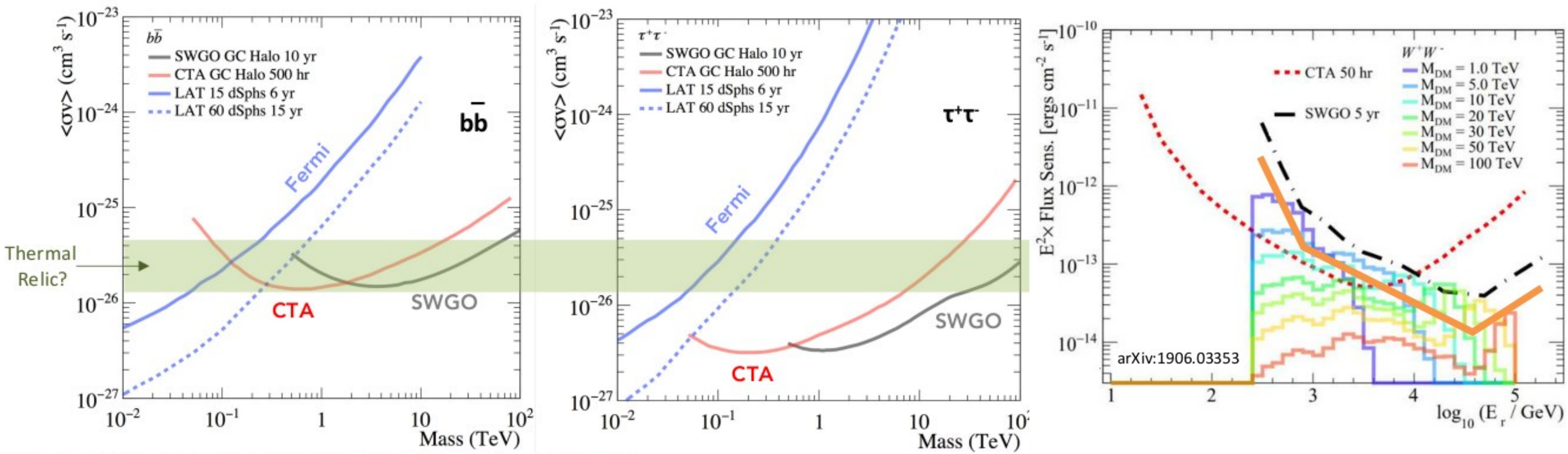
Dark Matter targets in SWGO's FoV



HAWC skymap with SWGO view (shaded) overlaid

WIMP Annihilation

- Reaching critical sensitivity: Thermal relic WIMP annihilation signature accessible over a very wide mass range (Galactic Center/Halo observations at VHE).



NB Sensitivity improving for both CTA + SWGO – analysis improvements

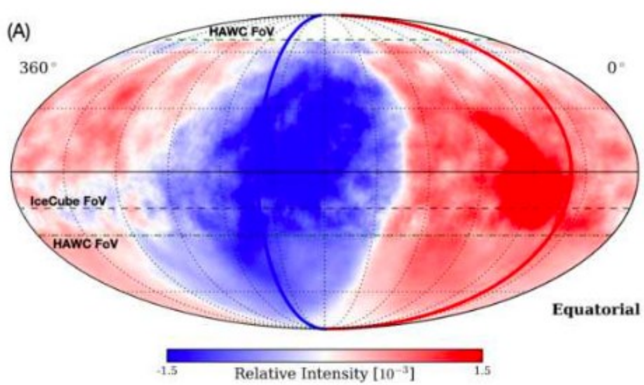
- SWGO + CTA + Fermi will explore thermal WIMPs from 5 GeV to 100TeV.

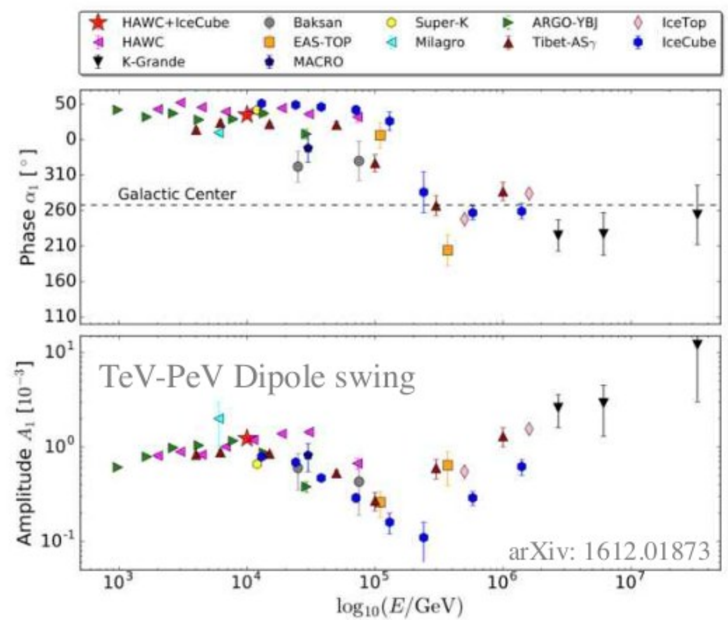
Cosmic rays

- Anisotropy Studies
  - Complementary to LHAASO, HAWC, IceCube for dipole studies at the highest energies
  - Low-scale anisotropy, and understanding of ISM turbulence and local CRs
- Unprecedented mass-separation potential
  - For composition studies
  - Joint mass-dependent anisotropy studies

Cosmic-ray TeV dipole skymap

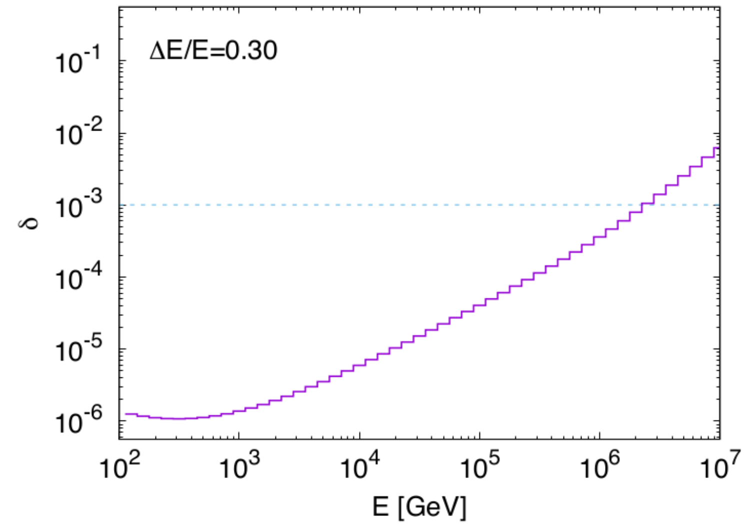
arXiv: 1812.05682

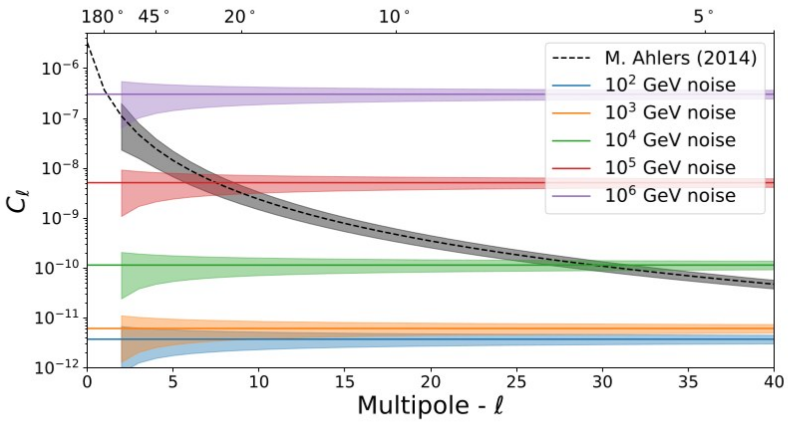


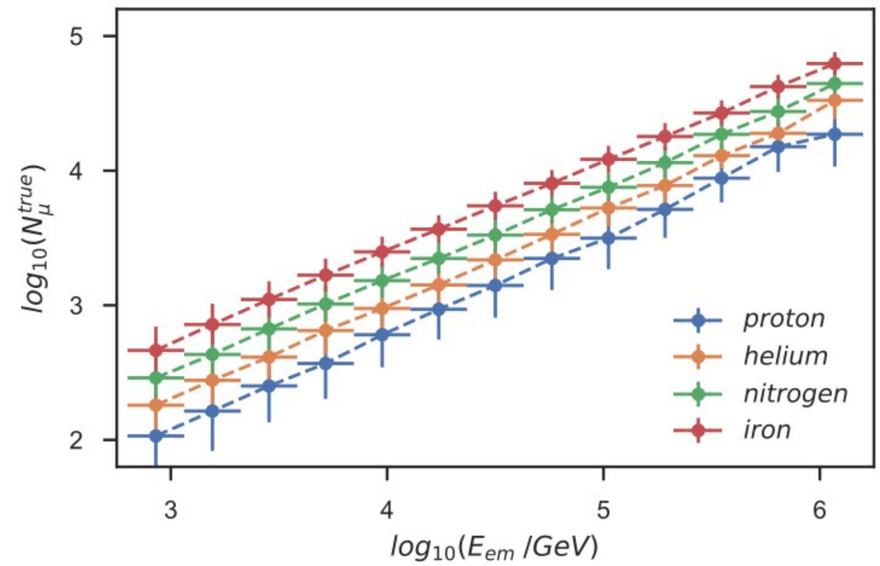


Cosmic rays

- A probe of the dipole (10^{-3} amplitude) will be achievable up to energies of at least 3 PeV.
- At 10 TeV (100 TeV), a probe of multipoles up to l~20 (l~6) will be possible (strawman).
- **Muon tagging** will allow for 4 mass groups between proton and iron to be resolved. (Equal logarithmically-spaced (**σ_{lnA}≃1**) possible at **> 3 TeV.**)







Conclusions

- The southern sky needs a wide-field VHE-UHE gamma-ray observatory:
  - → Unique view of the Galaxy and its center
- A strong Science Case from 100 GeV to PeV:
  - → PeVatrons, Galactic sources (incl. extended, e.g. halos), VHE diffuse emission, (extragalactic) transients, physics beyond the SM, CR physics,...
- R&D phase under way. Choice of site completed.
- SWGO China involved in a possible lake site extension, especially useful for PeVatron science