Science with the Southern Wide-Field Gamma-ray Observatory (SWGO)

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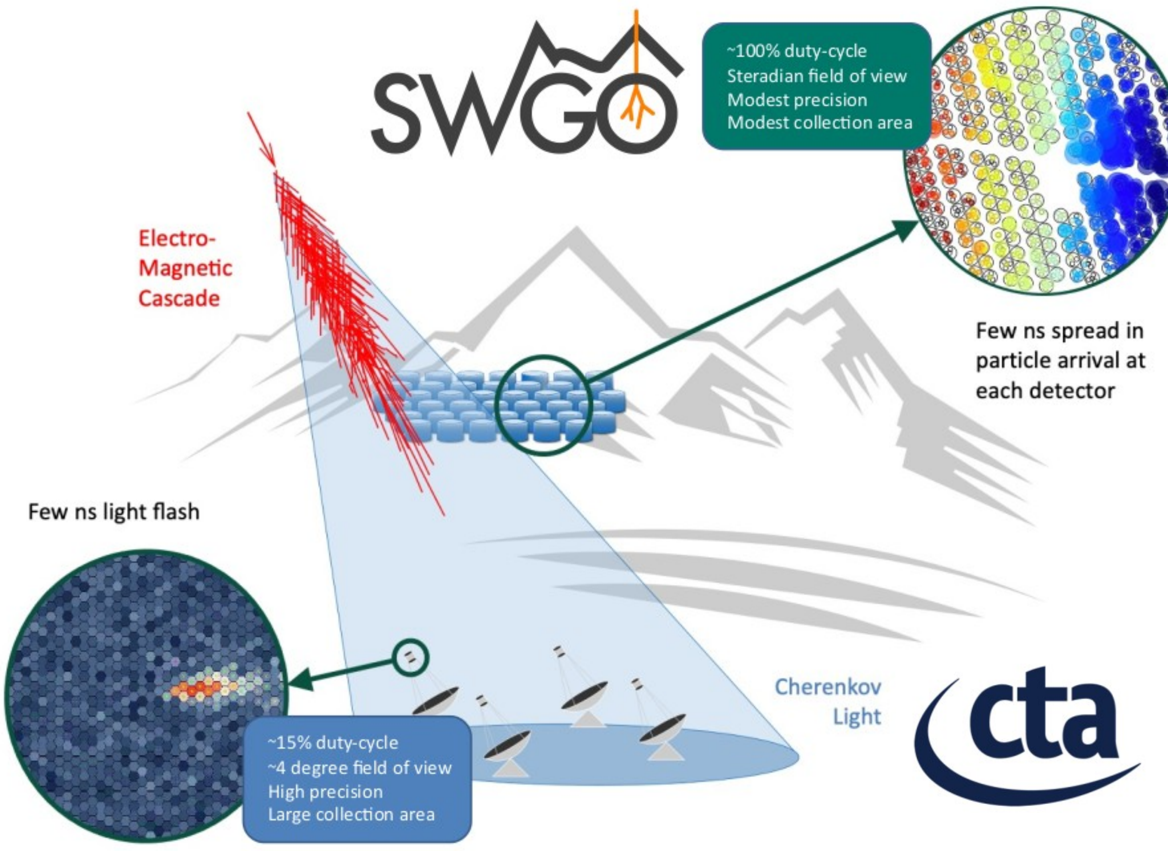
For the SWGO Collaboration (www.swgo.org)

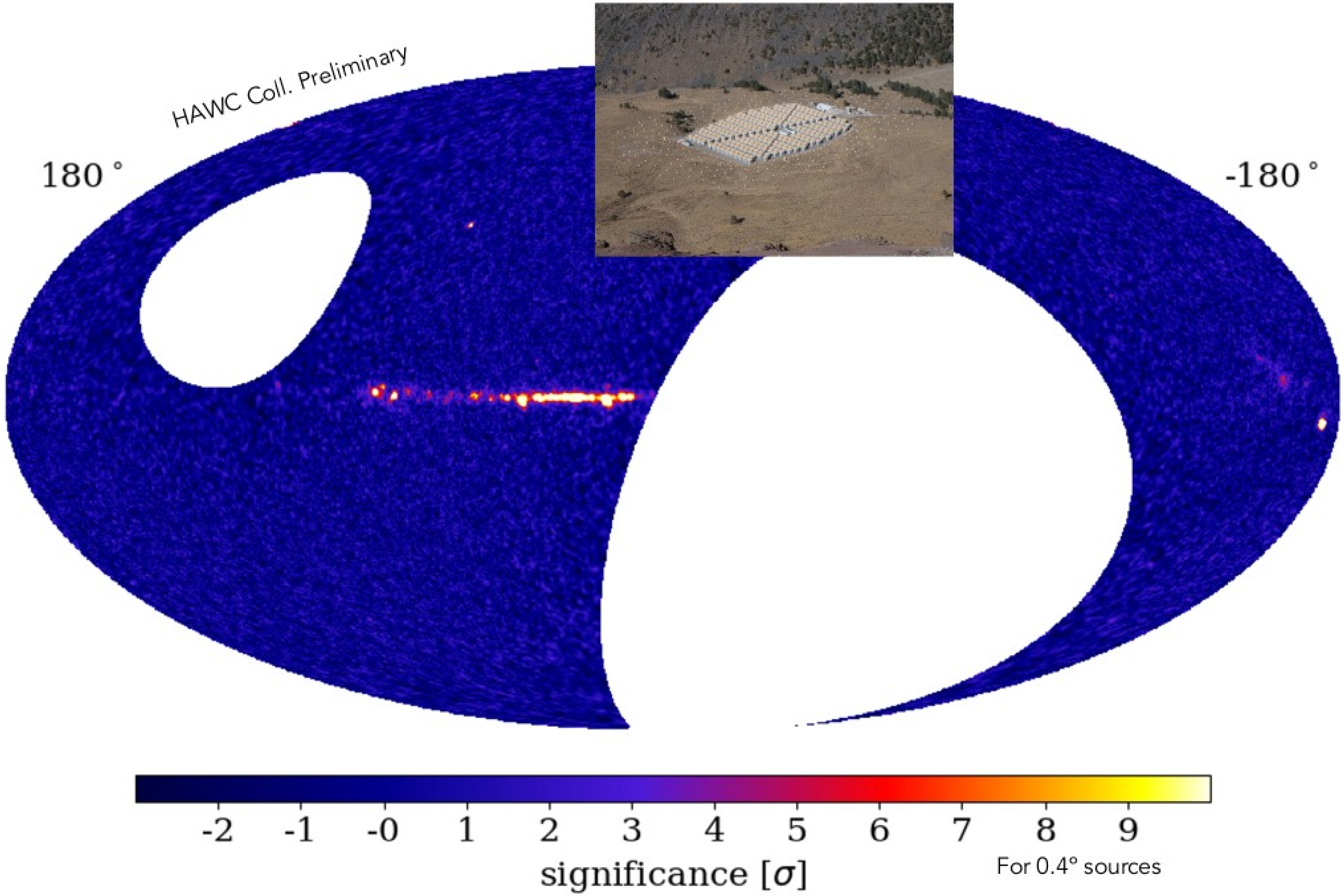
TeVPA 2021 Conference, Wednesday 27 October 2021

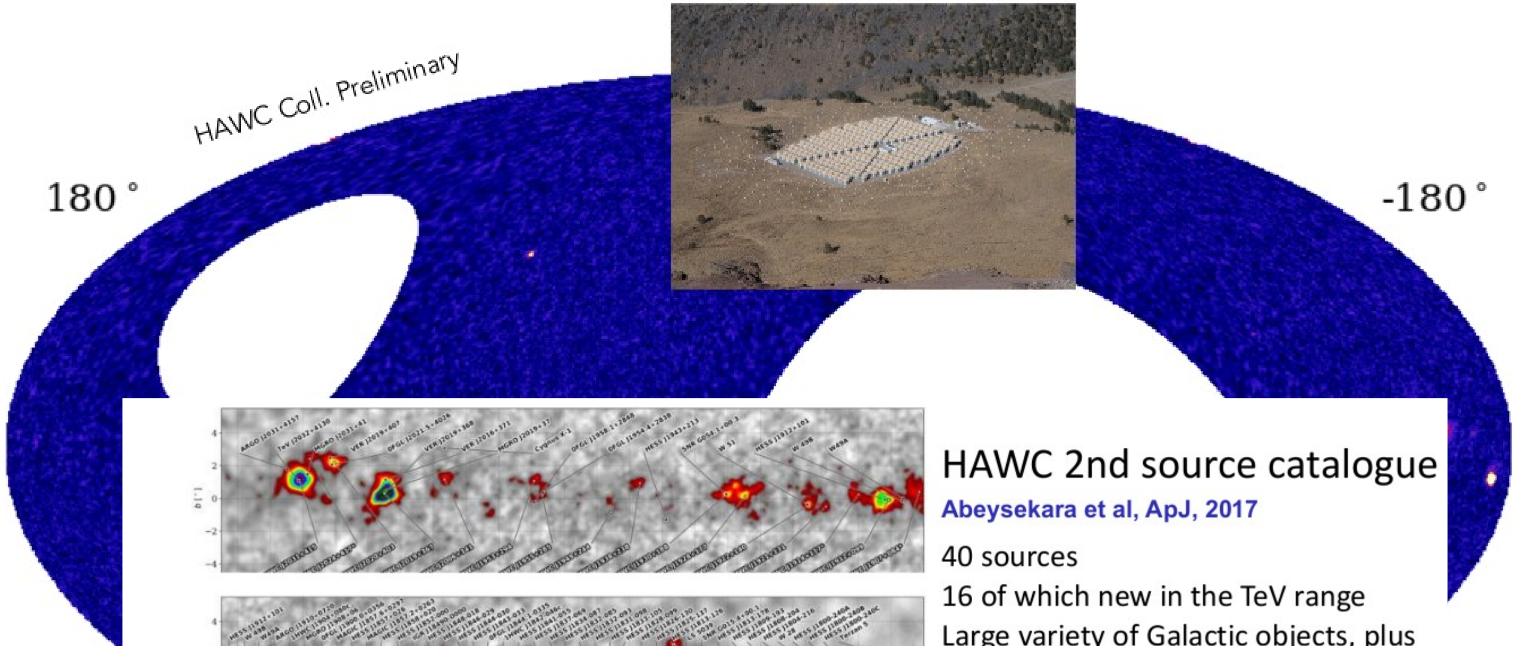
Ground-based γ-ray astronomy

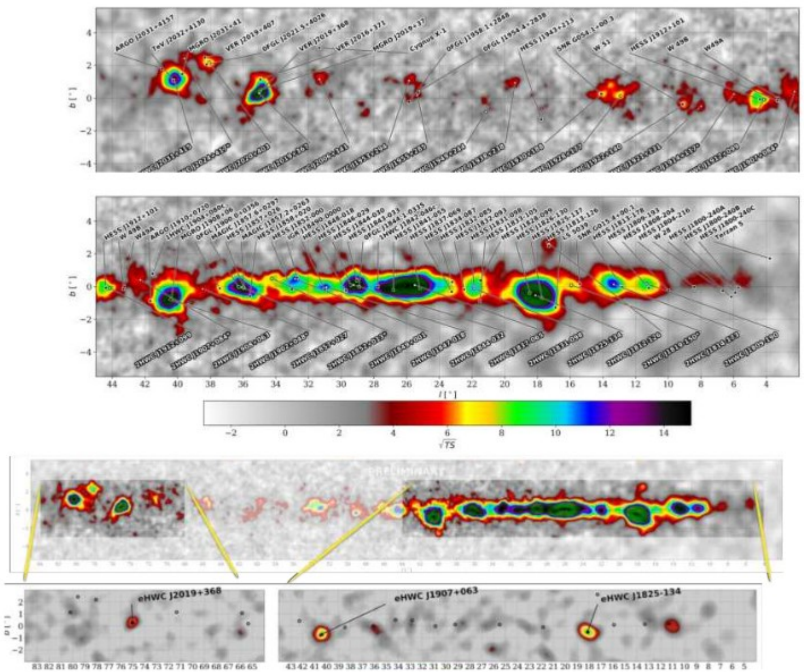
Complementary techniques



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





HAWC 2nd source catalogue

Abeysekara et al, ApJ, 2017

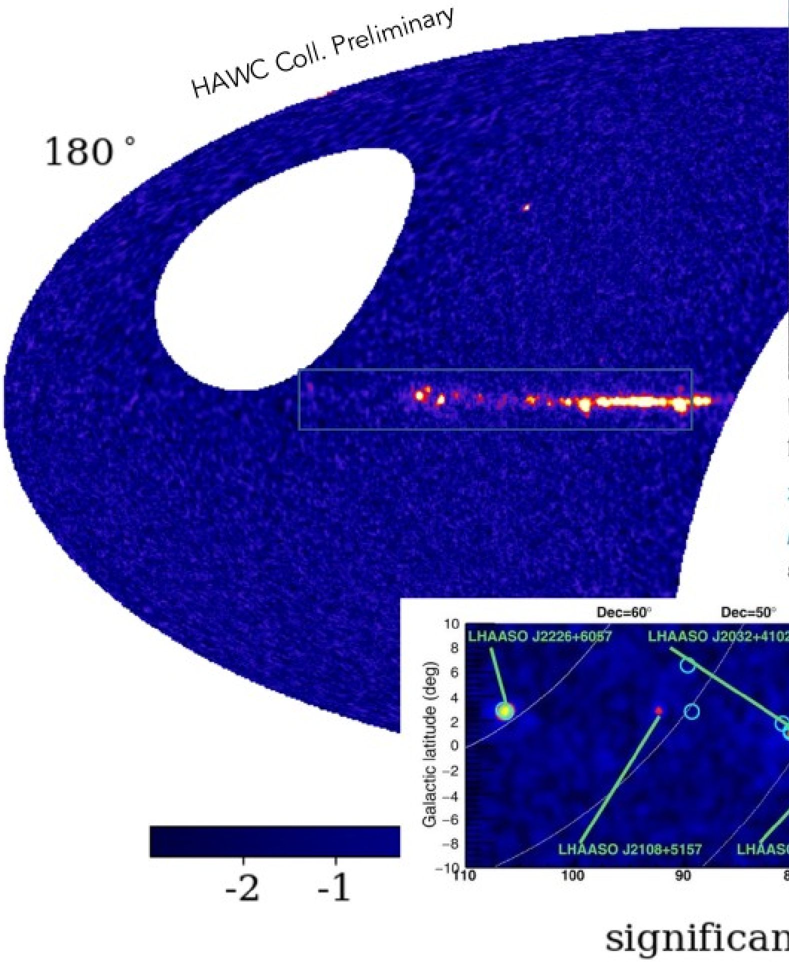
40 sources
16 of which new in the TeV range
Large variety of Galactic objects, plus few AGN.

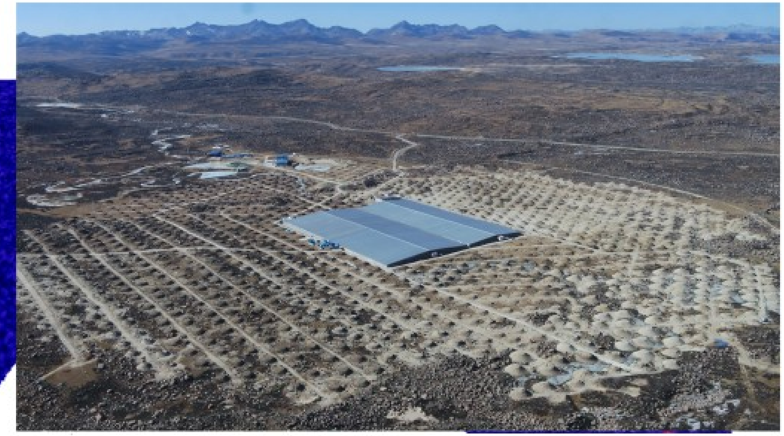
HAWC Collaboration+19

4 sources detected at 100+ TeV,

MGRO 2019+371
MGRO 1908+06
HESS J1825+137
Crab Nebula

LHAASO PeVatrons:



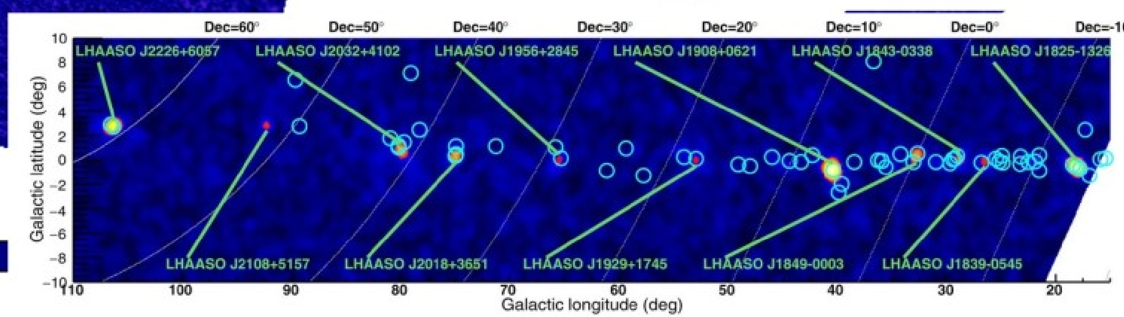


Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources

Zhen Cao, F. A. Aharonian, [...]X. Zuo

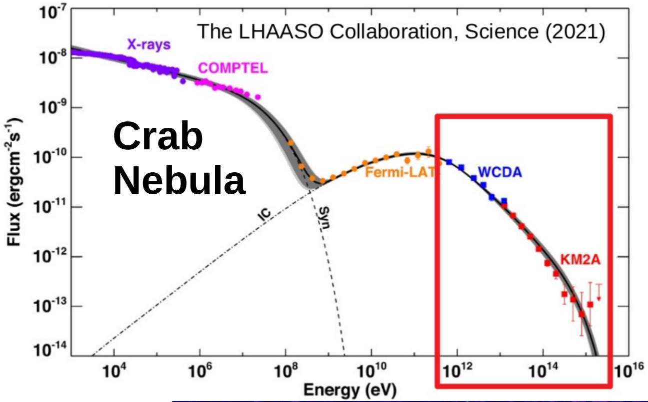
Nature **594**, 33–36 (2021) | Cite this article

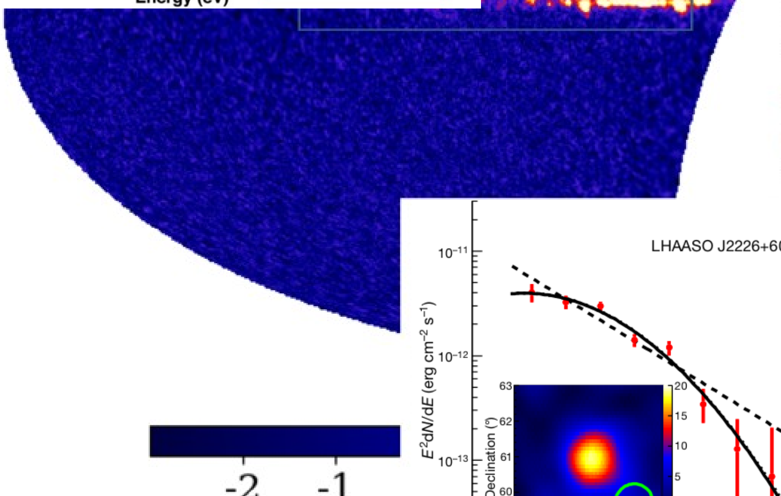
8285 Accesses | **637** Altmetric | Metrics

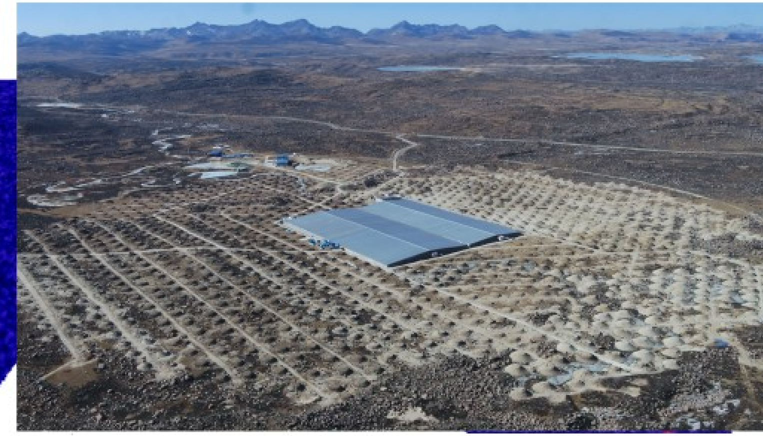


For 0.4° sources

LHAASO PeVatrons:







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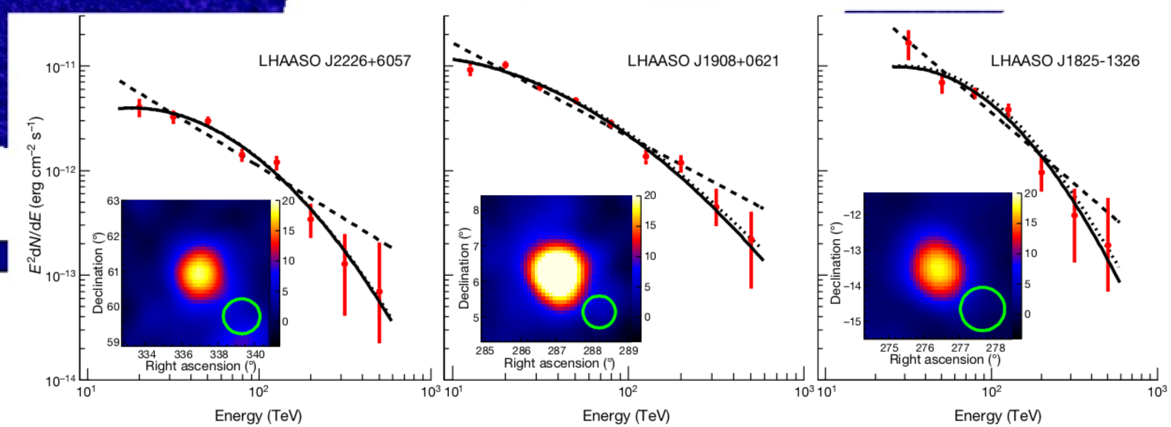
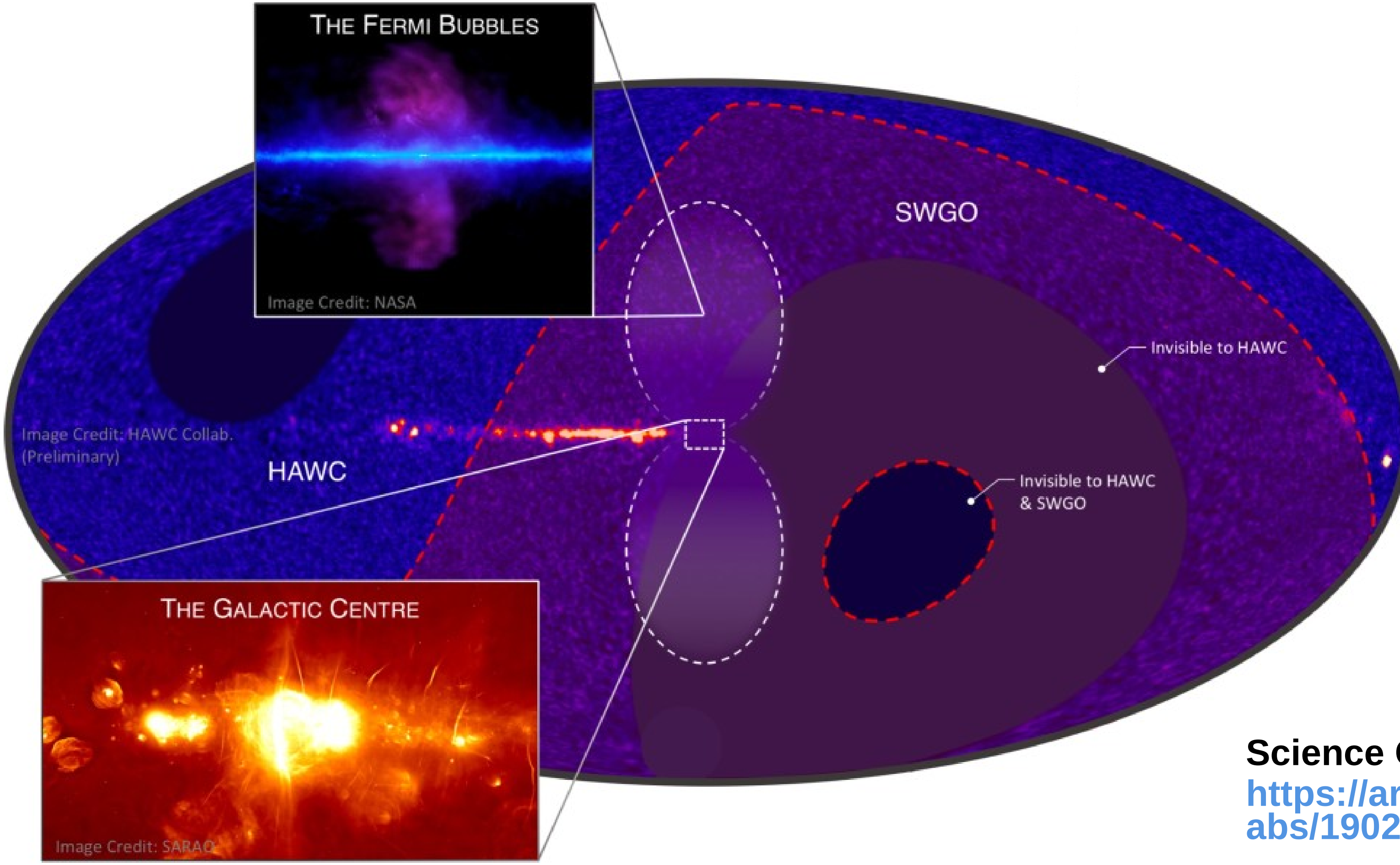
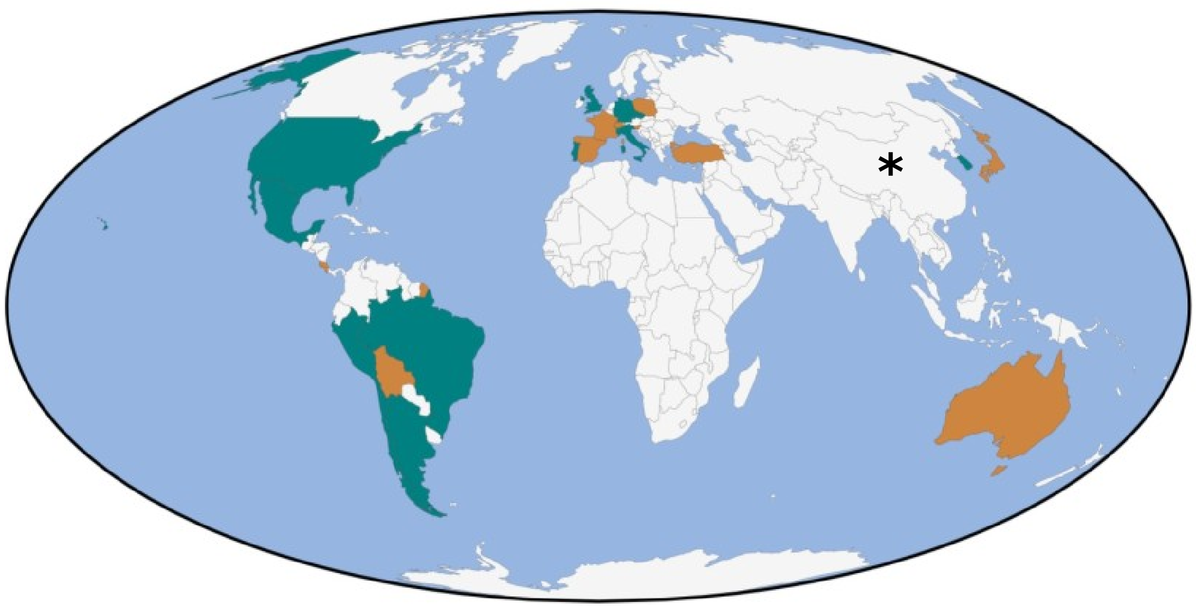




Science Case:
https://arxiv.org/abs/1902.08429

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

The SWGO Collaboration



Countries in SWGO

Institutes

Argentina*, Brazil, Chile, Czech Republic, Germany*, Italy, Mexico, Peru, Portugal, South Korea, United Kingdom, United States*

Supporting scientists + China

Australia, Bolivia, Costa Rica, France, Japan, Poland, Slovenia, Spain, Switzerland, Turkey

**also supporting scientists*

- Formed in 2019; 3 yr R&D phase (design & site choice)
- 47 institutes in 12 countries + Supporting scientists
- * In China: TDLI, SJTU Shanghai – Hao Zhou (周浩) & GG

Working Groups & Milestones

	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

- Spokespersons
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  → Jim Hinton (Germany), Petra Huentemeyer (USA), Ulisses Barres (Brazil)


Science
Gwenael Giacinti & Francesco Longo


Analysis & Simulations
Ruben Conceição, Harm Schoorlemmer & Andy Smith


Detector
Felix Werner & Lukas Nellen


Site
Marcos Santander & Arthur Moraes


Outreach & Comms
Elisa Prandini & Ana Pichel

Working Group Coordinators

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.

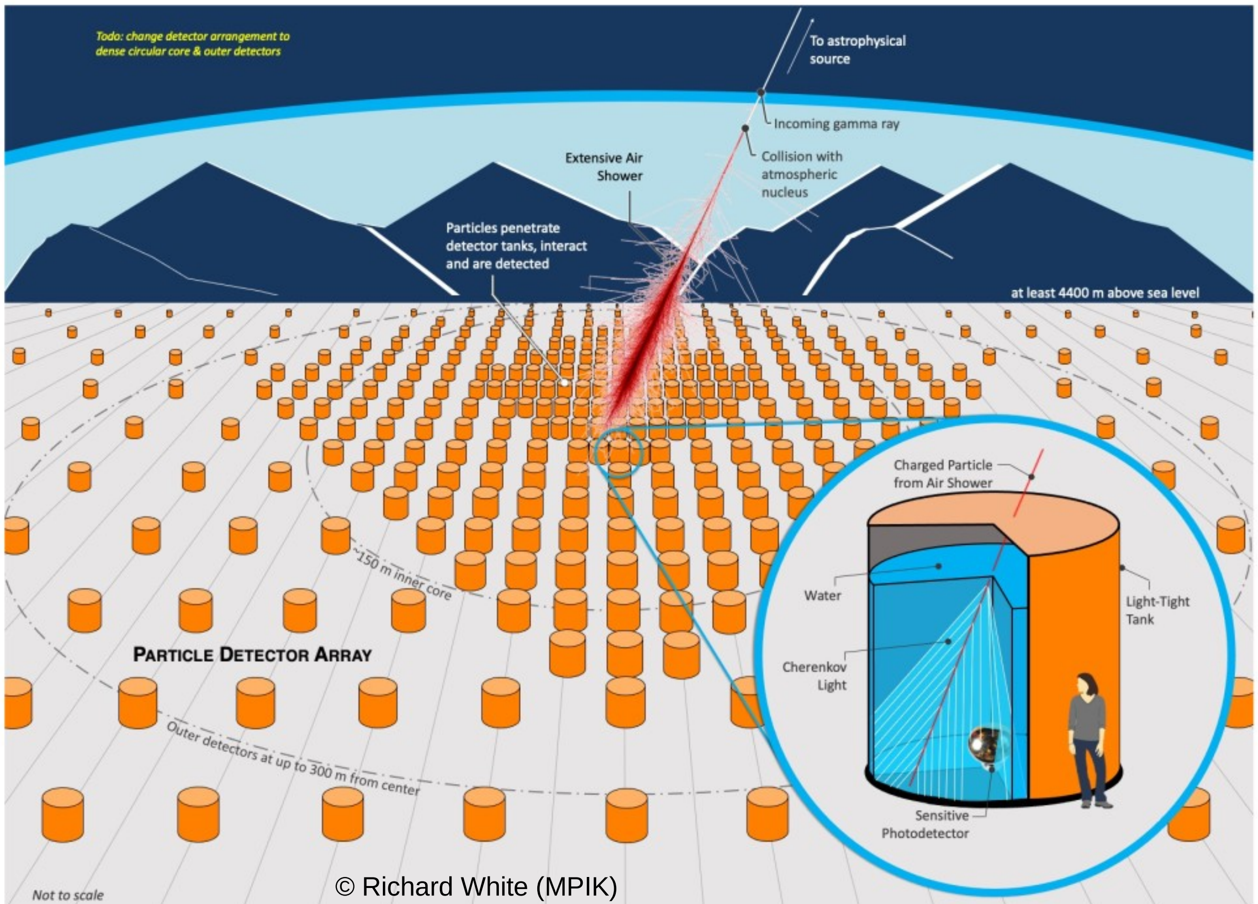
The Science Case for SWGO

- 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 $\sim 10^{-11}$ 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.

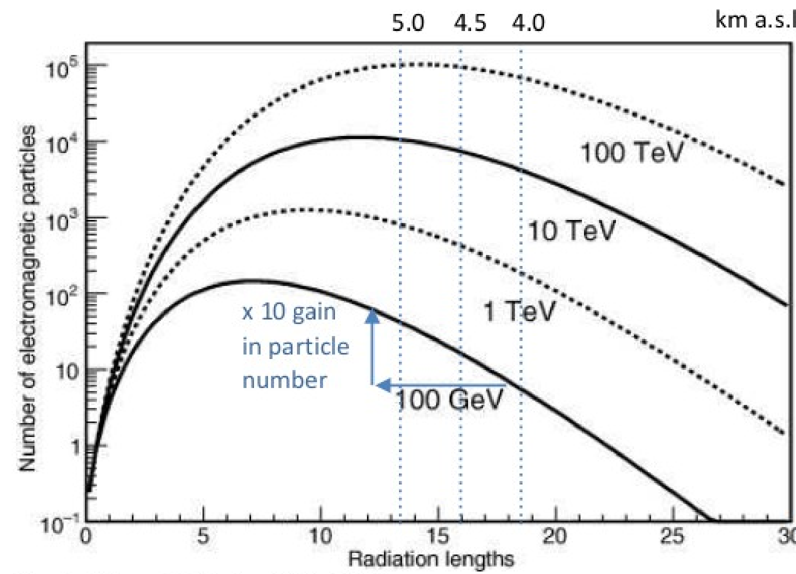
The Concept



- 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.

Site candidates for SWGO

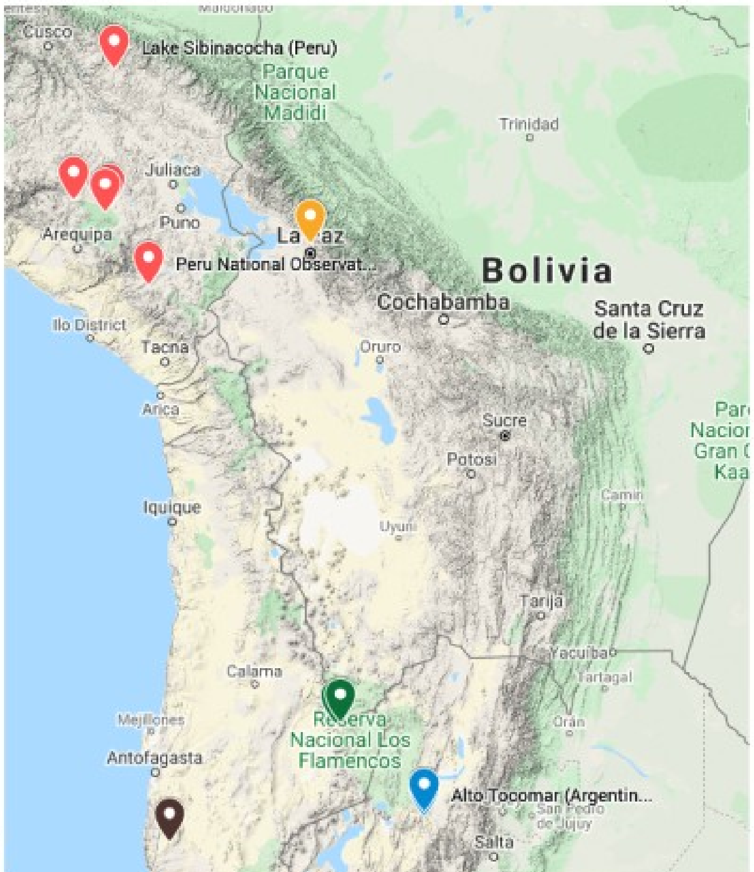
The Andes provides a number of high-altitude plateaus and high-altitude lakes that constitute suitable sites for a particle array aiming to extend the low-energy frontier for Wide-Field Observatories.



Adapted from G. Sinnis, NJPh, 2009

Site candidates for SWGO

lat. 15 S



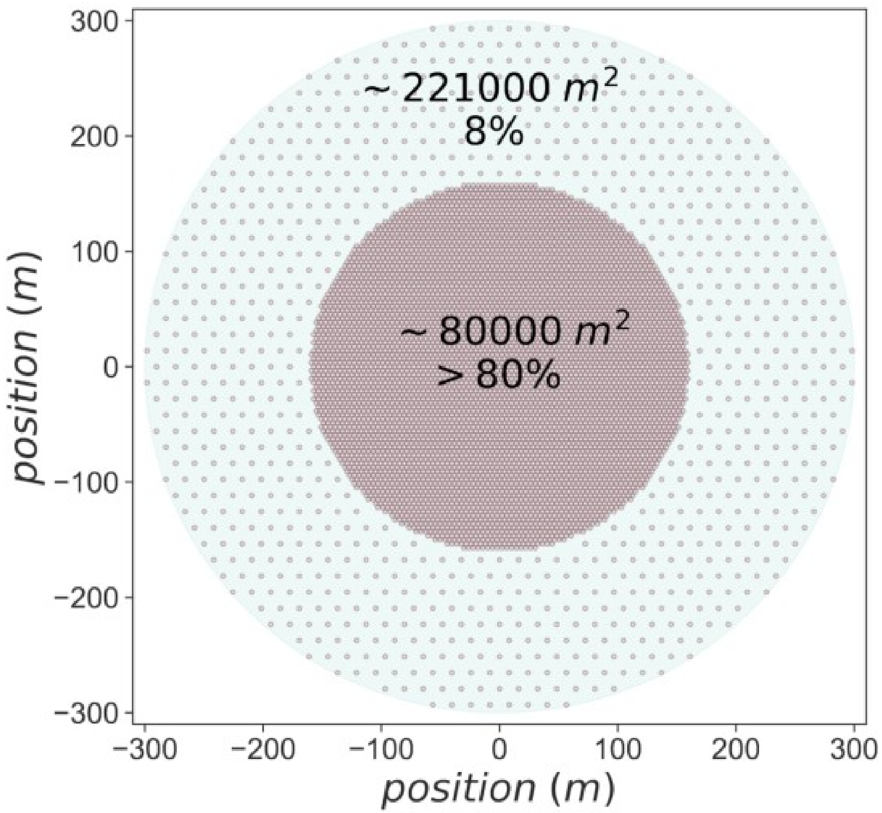
lat. 23 S

- 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)


Bolivia 4.7k
Chile 4.8 k
Peru
STATE OF ACRE
Bolivia
Cochabamba
Santa Cruz de la Sierra
Chile
Argentina 4.8 k
Peru 4.9 k

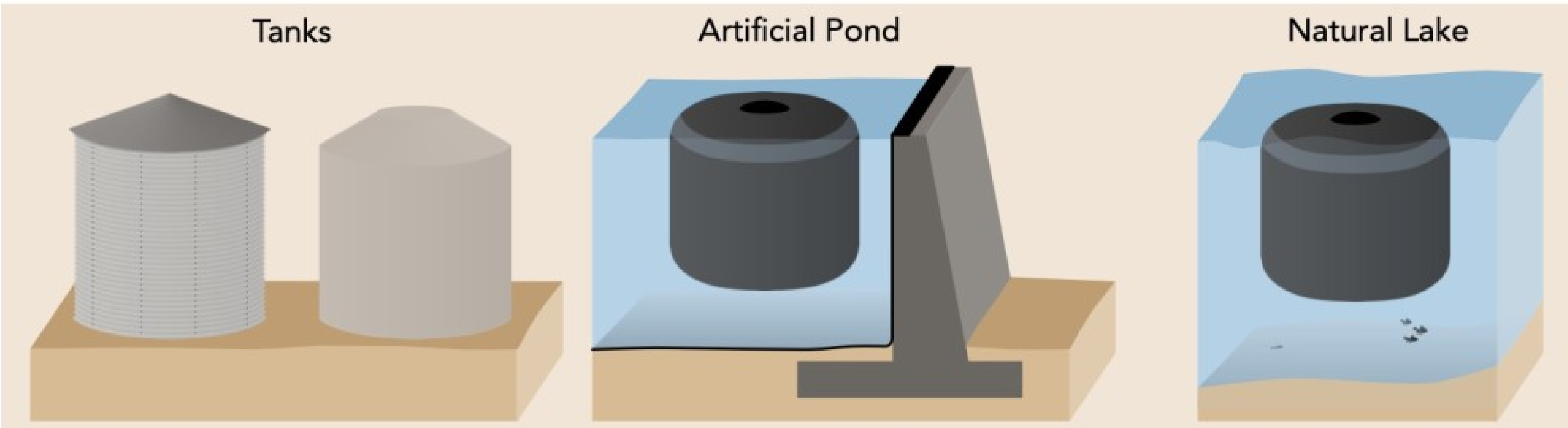
Detector layout (Reference config.)

Design based primarily on **Water Cherenkov Detector (WCD) units.**



- The SWGO reference configuration
  - → A **dense core array** with excellent gamma/hadron separation for low energy detection < 300 GeV, with circa 5x the effective area of HAWC.
  - → An **extended sparse array** with peak sensitivity between 50 and 100 TeV to approach LHAASO's performance at the PeV range
  - → **Muon tagging capability** at individual WCD units for cosmic-ray studies and improve background rejection
  - → **Improved** angular (~0.15°) and energy (~30%) resolution in the core 1-100 TeV range

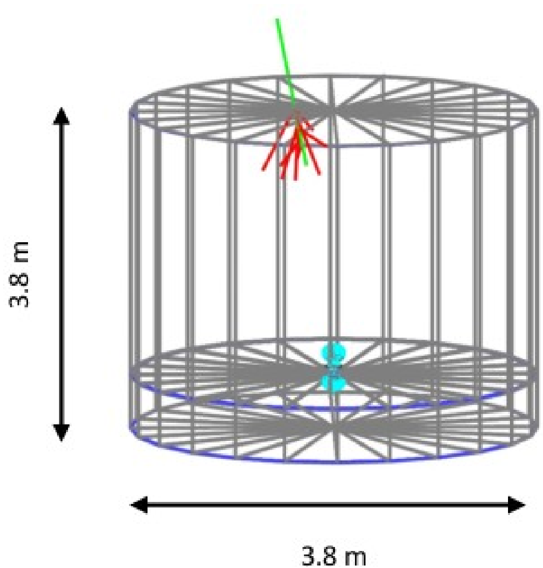
Design options



- Exploring 3 concepts for the detector units: **Tanks** (like HAWC), **pond** (like LHAASO), and a **natural lake**.
- Exploring unit dimensions, photosensors, … (Performance/Cost optimization)

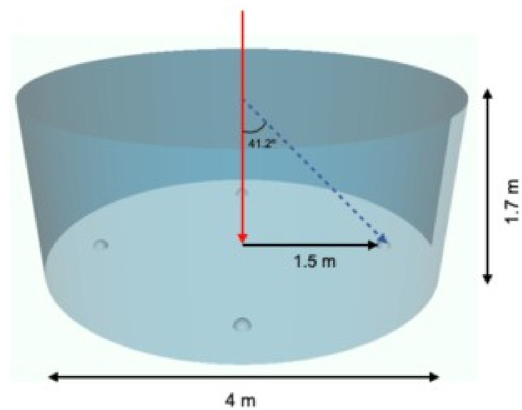
Units: Testing different concepts

Double-layered Water Cherenkov Detector:



Kunwar et al, Proc. ICRC 2021

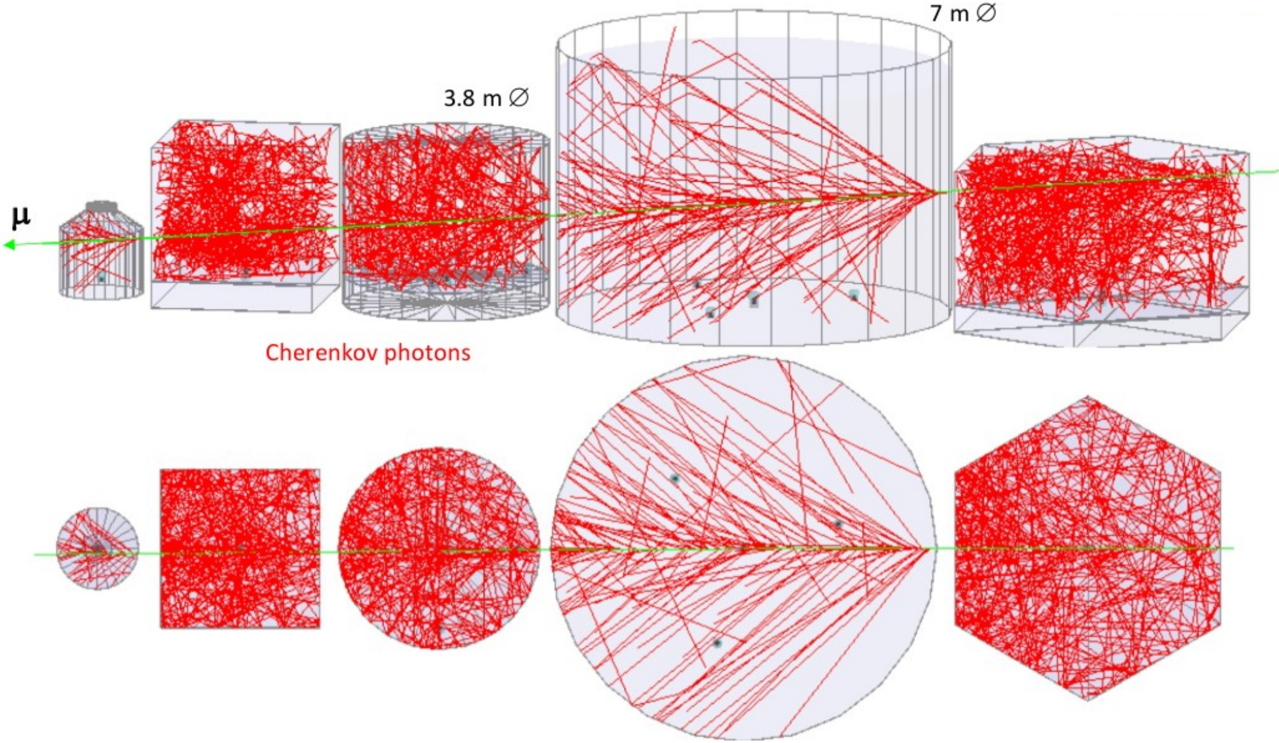
Smaller Water Cherenkov Detector with 4 PMTs:



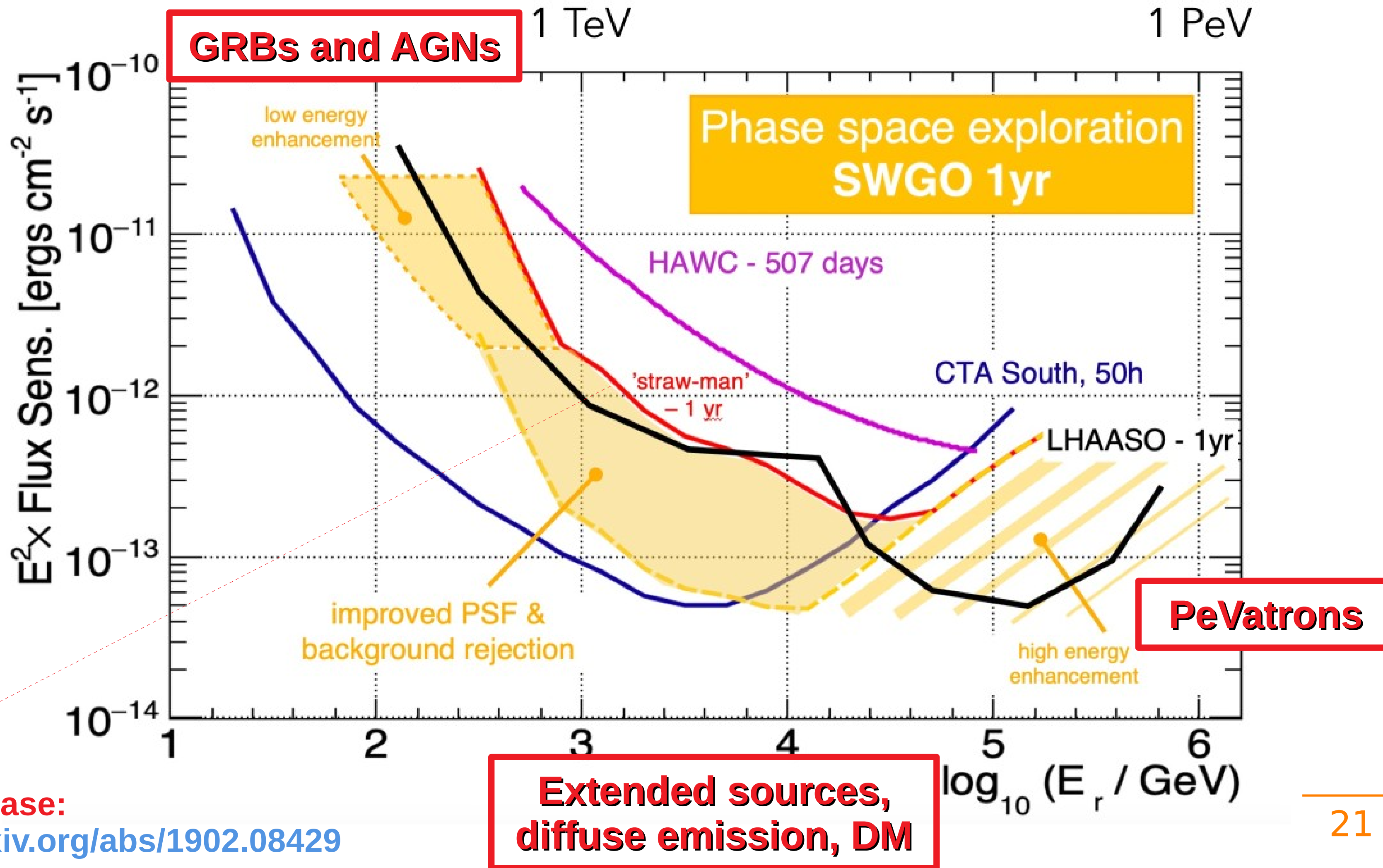
Conceição et al, Eur.Phys.J.C 81 (2021) 6, 542

Analysis & Simulations

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



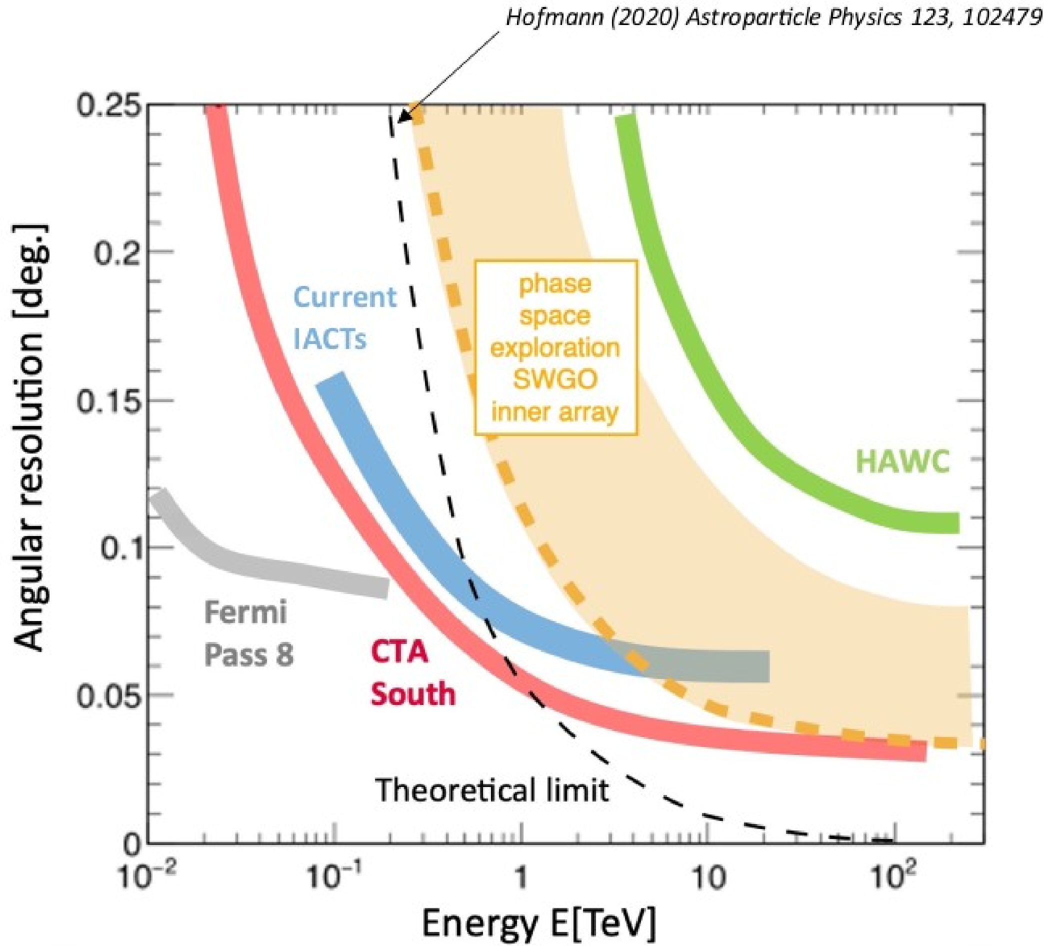
Sensitivity range (exploration)



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

The set of **core science cases** has been defined to guide the R&D studies and to benchmark the final observatory design among different options and trade-offs.

The **benchmarks** reflect a minimum set of science goals that encompass the full set of performance requirements for the Observatory.

The **quantitative benchmarks** will be used to compare and select a set of candidate configurations for the array, currently under study.

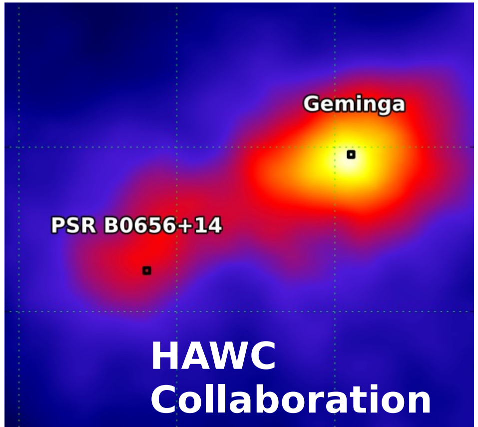
Science Case	Design Drivers	Benchmark Description
Transient Sources: Gamma-ray Bursts	Low-energy sensitivity & Site altitude[a]	Minimum integration for 5σ detection: F(100 GeV) = 10^{-8} erg/cm^2.s, PWL index = -2., F(t) $\propto t^{-1.2}$
Galactic Accelerators: PeVatron Sources	High-energy sensitivity & 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

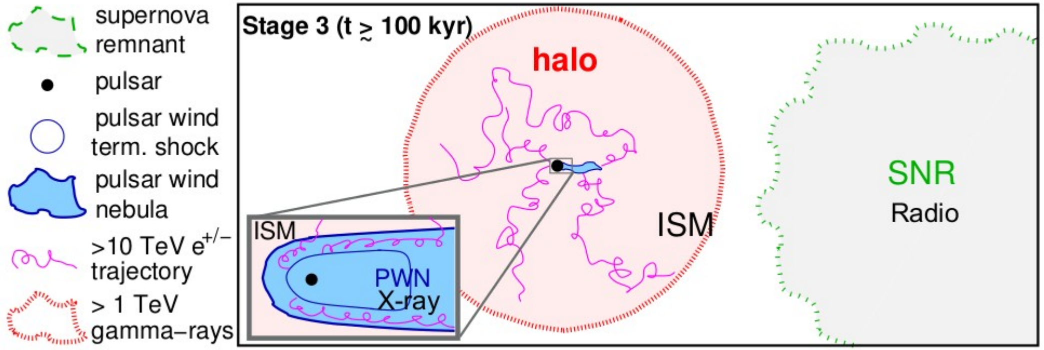
Tab. 1 SWGO Science Benchmarks. [a]Site altitude parameter to enter design discrimination as altitude-dependent IRFs. [b]Energy resolution not constraining as long as O(30%) throughout energy range. [c]Angular resolution not constraining as long as $\sim 0.2^\circ - 0.3^\circ$ throughout energy range. [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.

Galactic sources and large-scale emission

- Search for **PeVatrons**: Good view of the Galactic plane and of its sources (Southern hemisphere), Sensitivity at ~100 TeV.

- CTA will provide a detailed view of the Galactic plane.
SWGO will be a complementary observatory:
  - Improved sensitivity to sources with **large angular sizes** (>0.5º), such as PWNe and TeV γ-ray halos.
  - SWGO should expand the energy reach of known sources and probe deeper into more extended ones, with excellent ang. separation capabilities <0.5º.



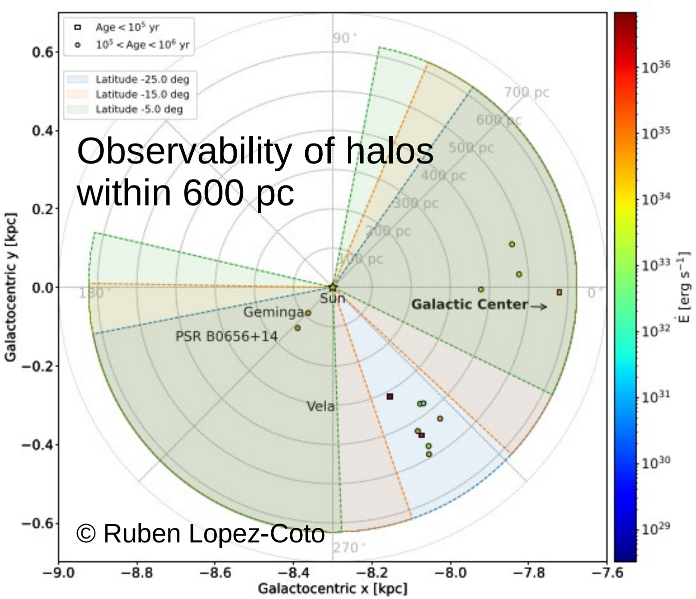


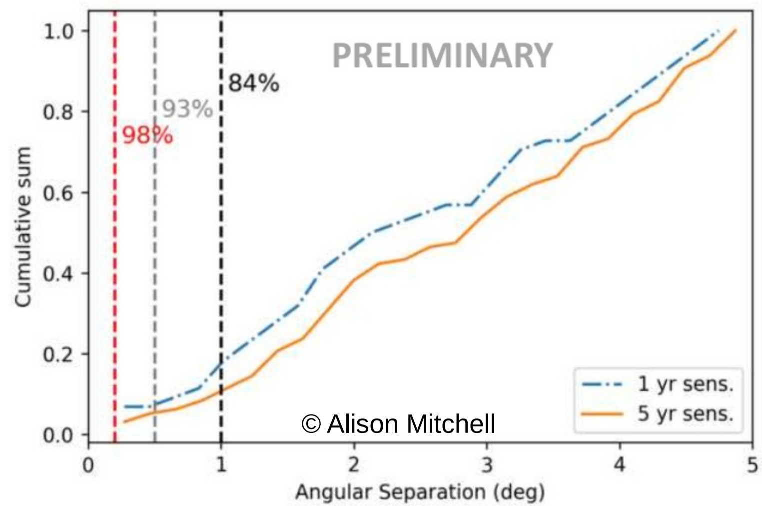
Giacinti et al, A&A 636 (2020) A113

TeV γ-ray halos

See R. Lopez-Coto's talk for details

- Mainly studied by **wide-field instruments** due to their extension.
- **SWGO** will be able to:
  → Characterize nearby ones through morphological measurements,
  → Observe and detect further away ones (need for a good angular resolution to avoid source confusion).





Required angular resolution:
→ 0.5° to resolve 93% of halos within 500pc;
→ 0.2° to resolve 98% of them.

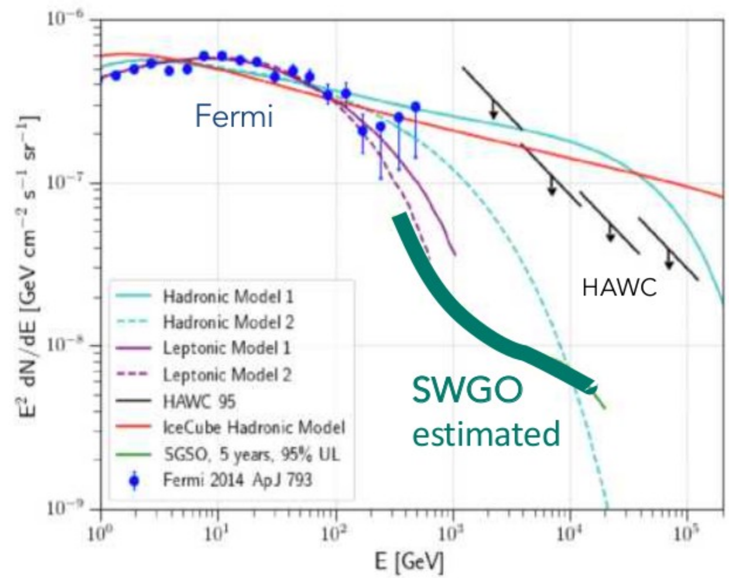
Diffuse emission and Fermi Bubbles

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

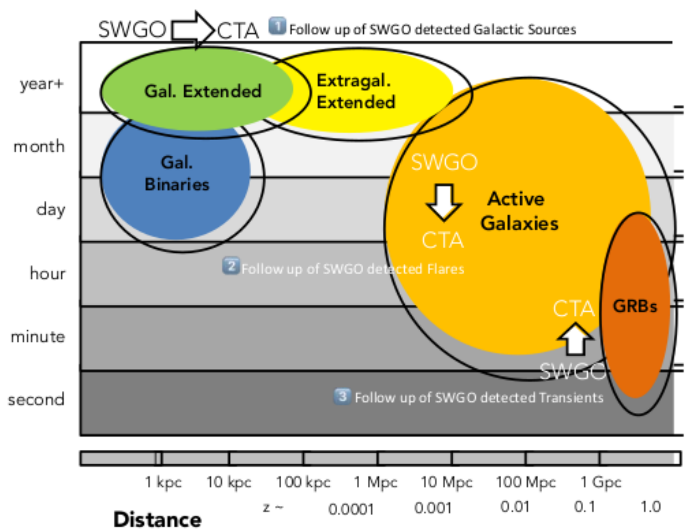
  → A wide-field instrument with an excellent background rejection will be optimal for the detection of such very extended, dim emission.

- **Fermi Bubbles**:

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

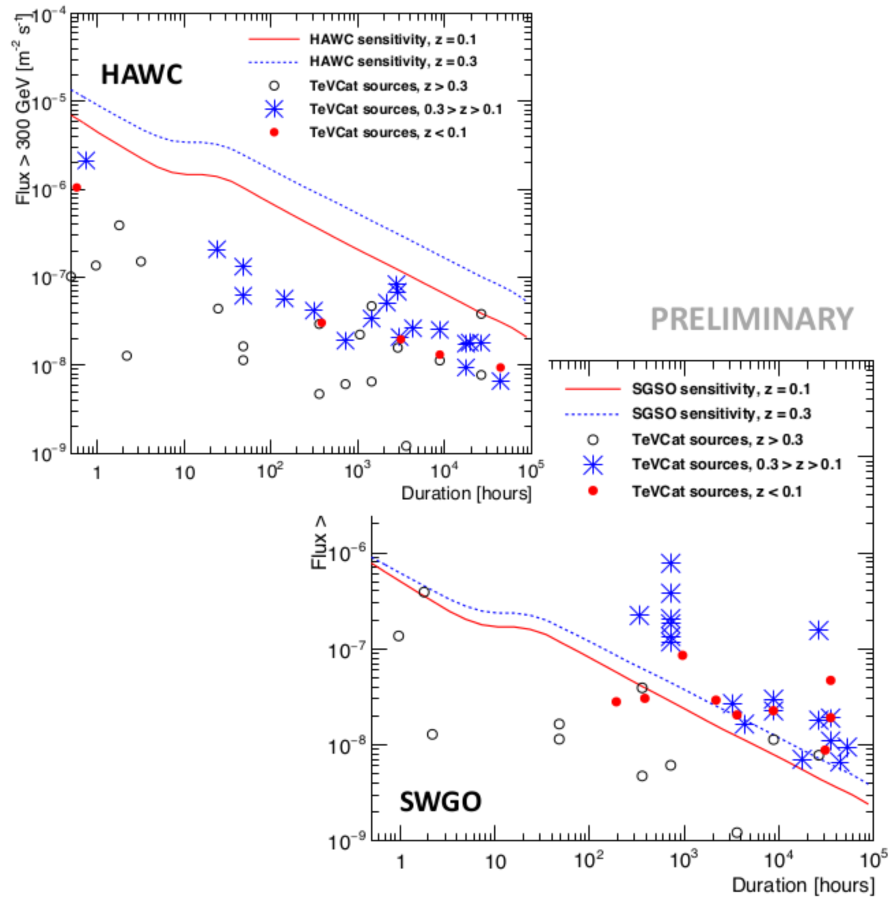


Gamma-ray transients

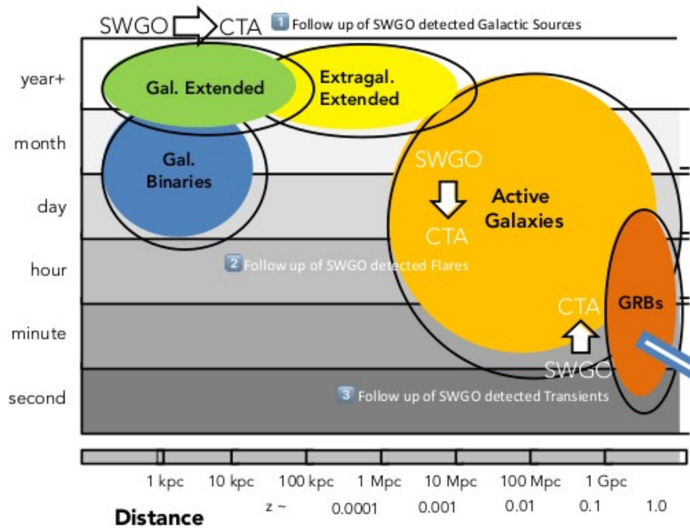


SWGO will represent significant improvement with respect to HAWC in the detection of short-time variability.

It will be a pivot instrument for triggering follow-up observations of HE AGN flares and in the multi-messenger domain.



Gamma-ray transients



- GRBs were recently detected by ground-based telescopes.
- An important multi-messenger link.
- Since 2019: afterglow emission of 4 GRBs of detected by IACTs > 100 GeV
- SWGO will provide triggers with the early afterglow and observe the prompt emission

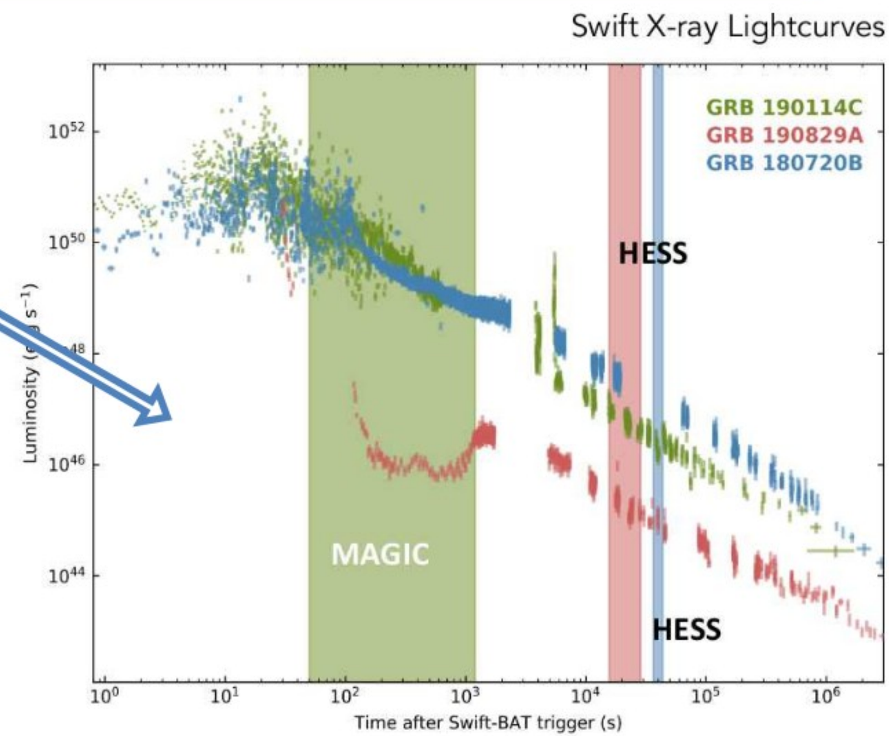
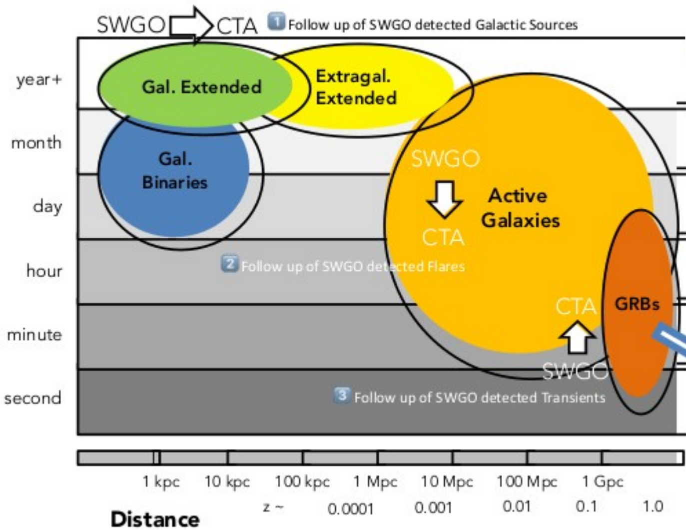
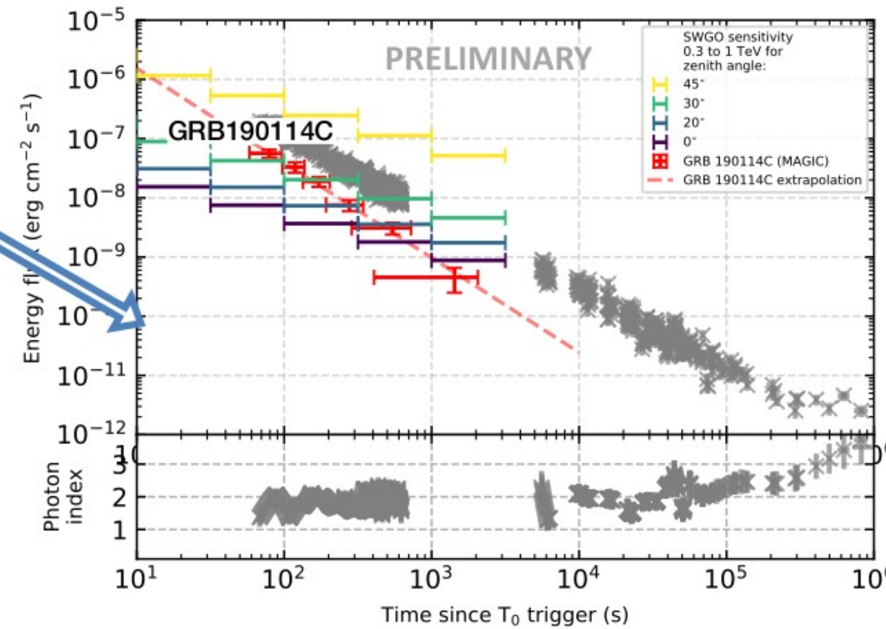


Figure © Jim Hinton, MPIK, adapted.

Gamma-ray transients

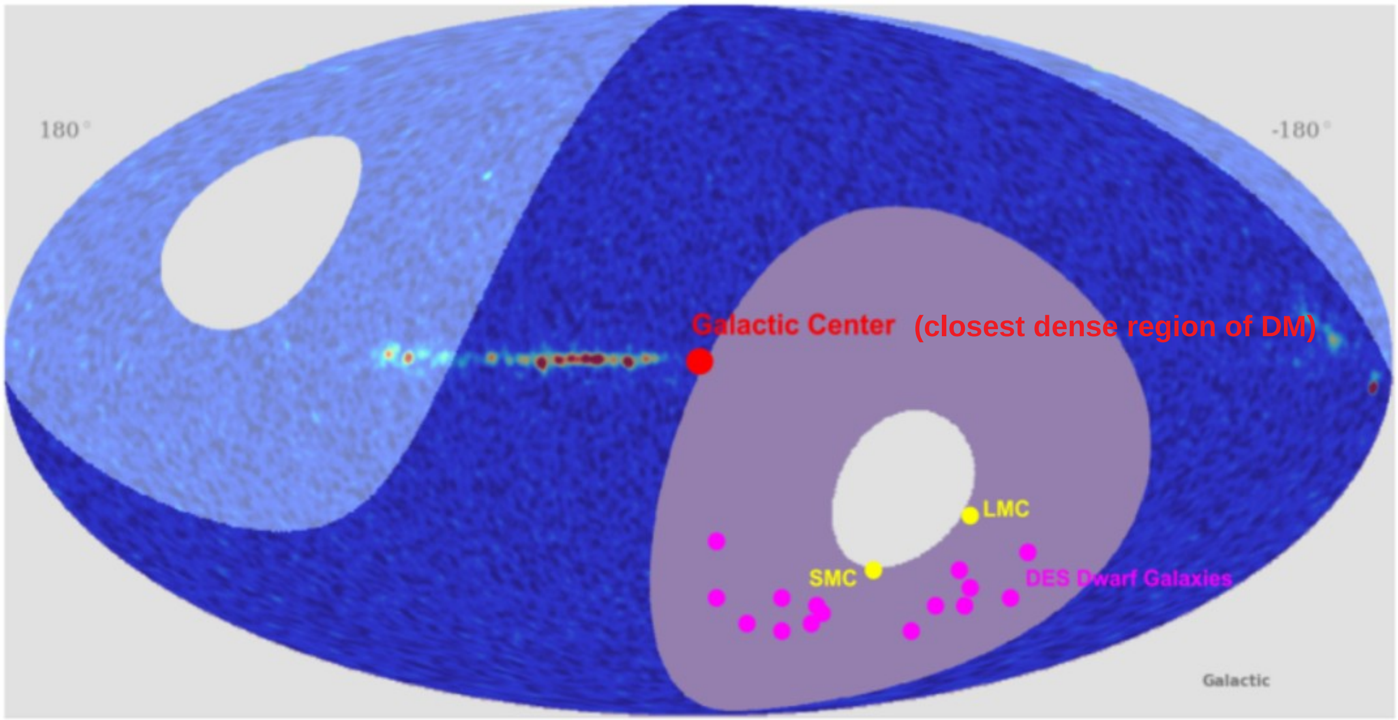




SWGO will complement observations of the Southern transient sky, filling-up a missing niche in the global network of multi-messenger astronomy.

It will be a powerful trigger for GRB transients, down to < 1 ks timescales.

Dark Matter targets in SWGO's FoV

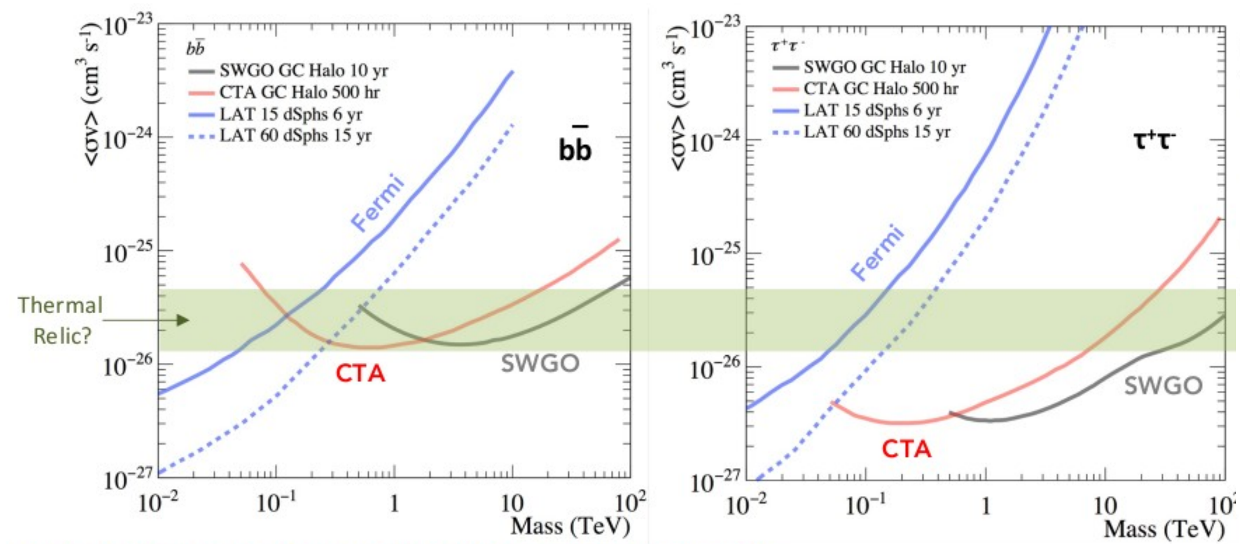


HAWC skymap with SWGO view (shaded) overlaid

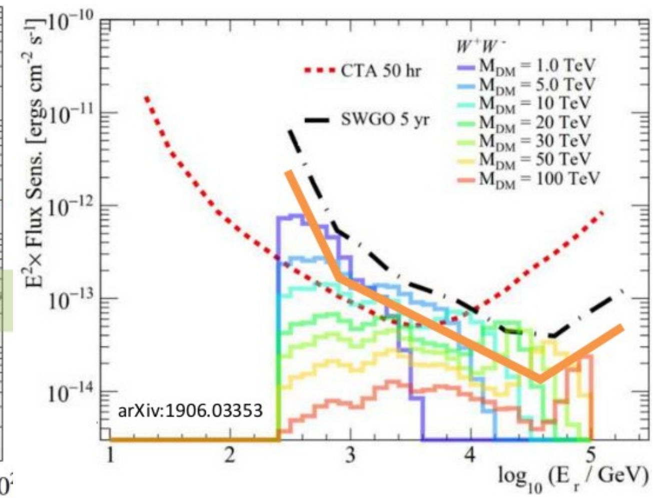
Slide from A. Albert (LANL), APS (April 2021)

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



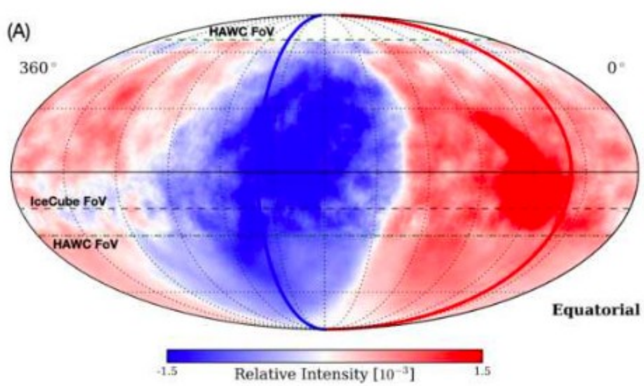
- SWGO + CTA + Fermi will explore thermal WIMPs from 5 GeV to 100TeV.

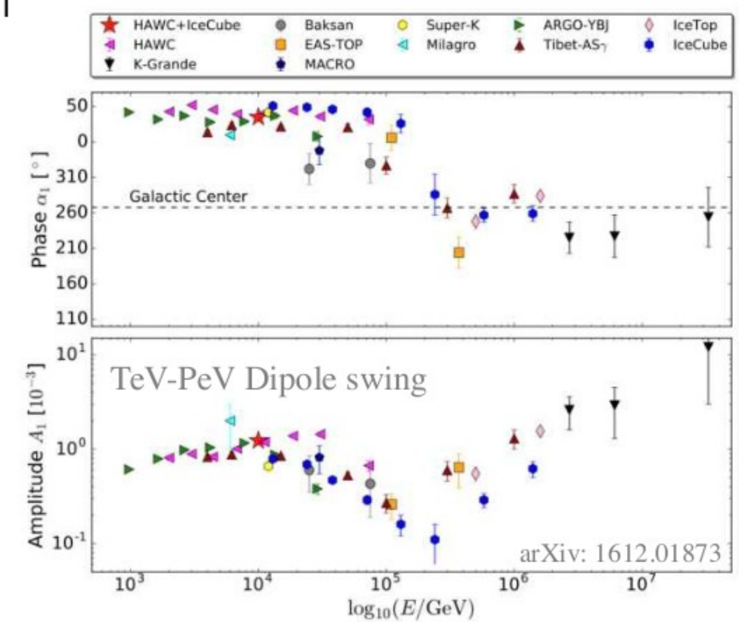
Cosmic rays

- 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

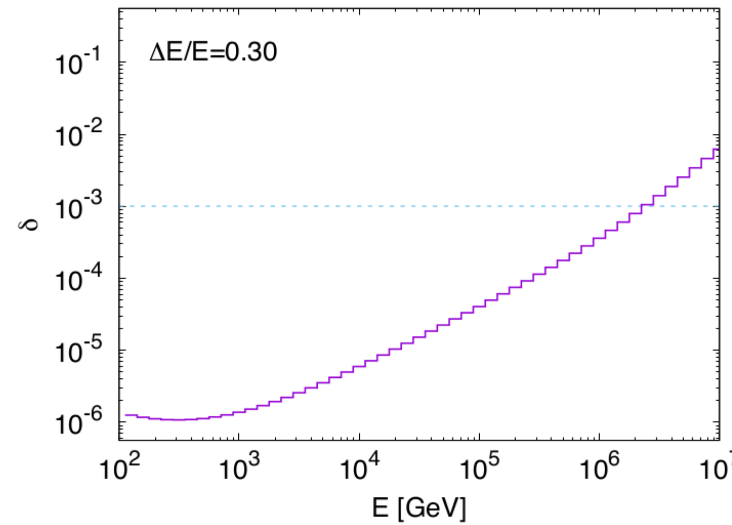


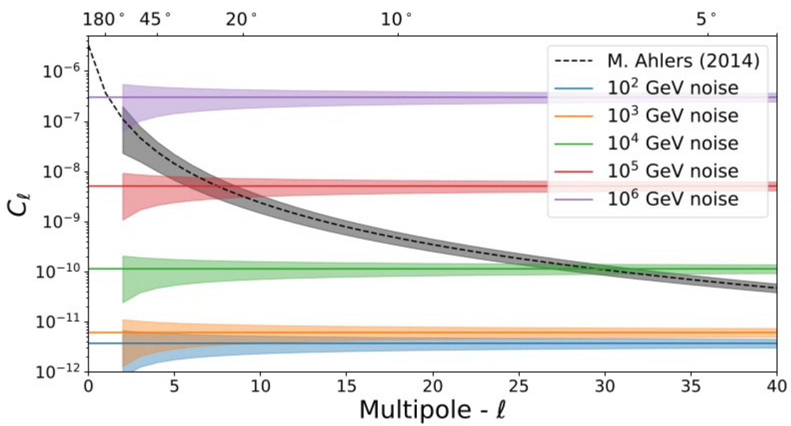


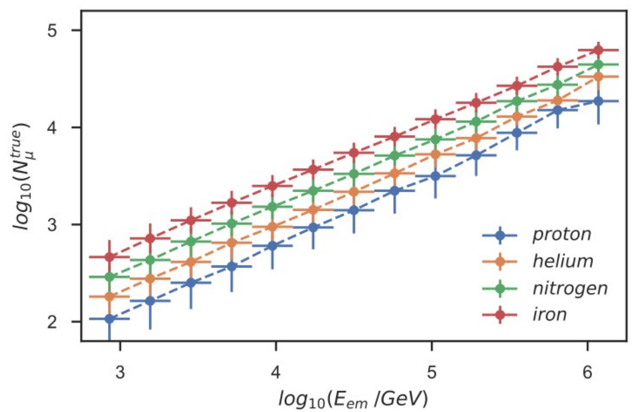
arXiv: 1612.01873

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).
- Currently studying how many mass groups between proton and iron may be resolved.







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. SWGO advancing towards design and site choices. Choice of site and detector in 2023.
- Very open for new partners.
  Looking forward to strong partnerships with LHAASO and CTA!
  - → Strong synergies with LHAASO expected: A complete view of the sky (diffuse emission, CR anisotropy, etc...)
  - → Strong complementarity with CTA and neutrino observatories: e.g. Detection of hard spectrum sources for CTA followup, Triggering CTA/MM Observatories on flares or transients, etc...

Thank you! 谢谢！

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