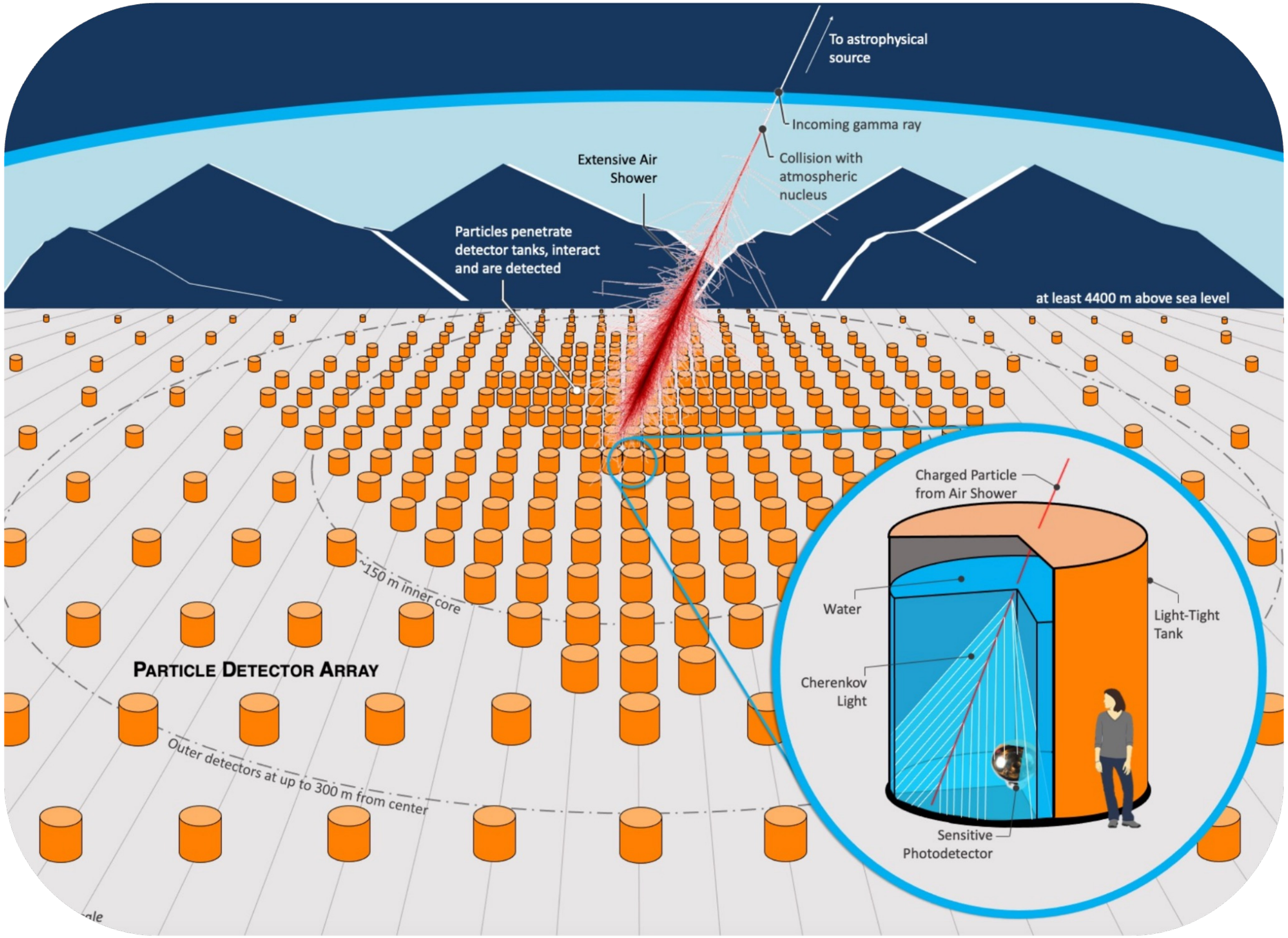
The Southern Wide-Field Gamma-Ray Observatory



Petra Huentemeyer
(petra@mtu.edu)
for the
SWGO Collaboration

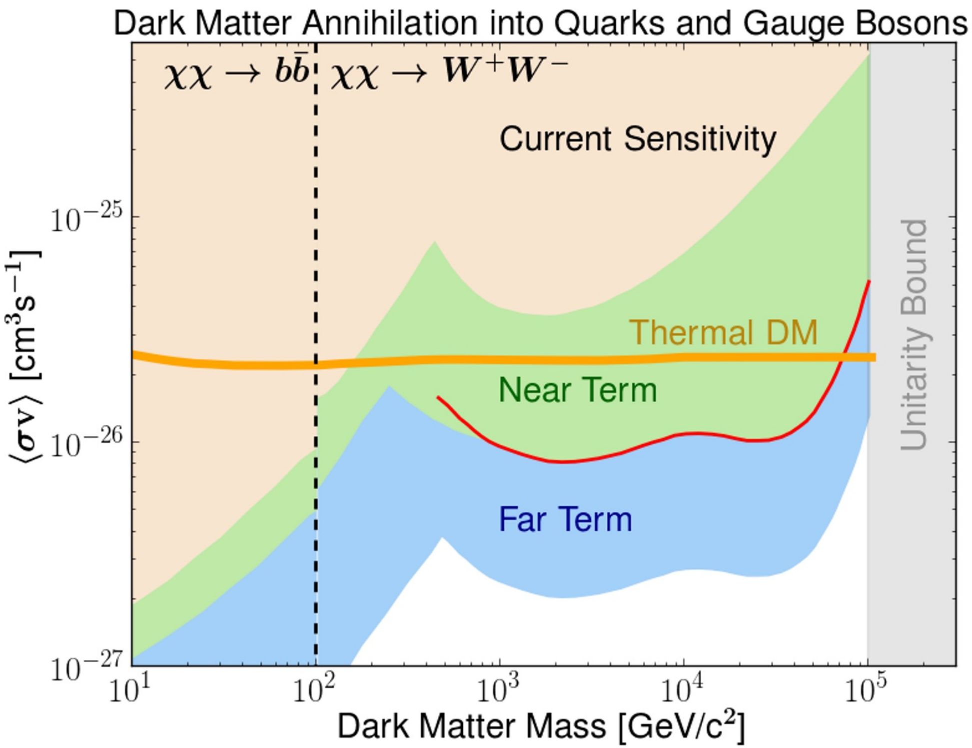
P5 Town Hall
March 23rd , 2023

Argonne National Lab

Physics with SWGO

- SWGO will observe gamma rays from non-thermal particle interactions in the Universe
- Search for WIMP dark matter at the highest masses
  - ✓ Look for BSM physics including Axion-like particles, violations of Lorentz Invariance, and Primordial Black Holes
  - ✓ Study particle acceleration and propagation to higher energies than accelerators on earth
- SWGO will be the first survey TeV gamma-ray observatory to probe the southern hemisphere sky
  - ✓ Daily coverage of ⅔ of the sky will complement pointed observatories like CTA

Pushing WIMP Dark Matter Search Up to Theoretical Bounds

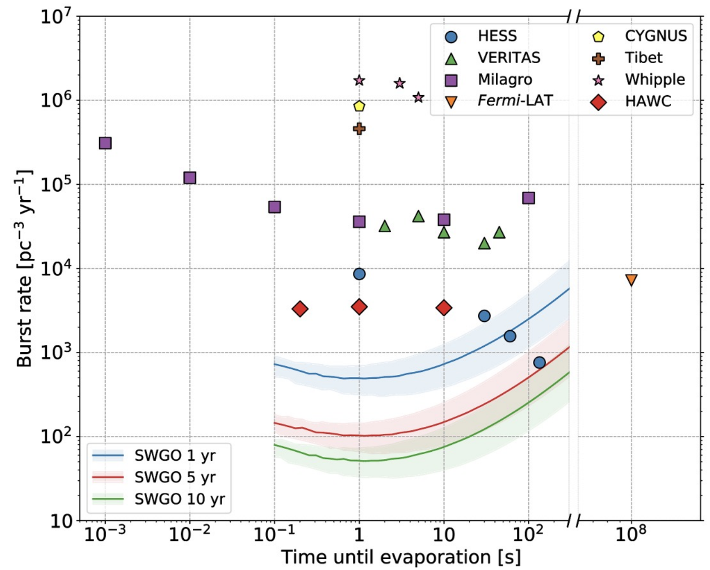


"In the near future, the SWGO ... [has] the potential to **probe the thermal freeze-out scenario** ... approaching the 100 TeV scale where we can begin to set unitarity-based limits"
– Snowmass 2021 Report

- Thermal Relic WIMPs are well-motivated theory that has not been fully probed
  - ✓ mass range is 5 GeV to 100 TeV, only probe up to 200 GeV with Fermi LAT
- Search for thermal WIMPs up to the theoretical Unitarity Bound
  - ✓ SWGO limits are strongest driver for next-generation exclusion of Thermal Relic WIMPs to all masses
  - ✓ significant overlap with CTA gives opportunity to see signals with multiple independent instruments

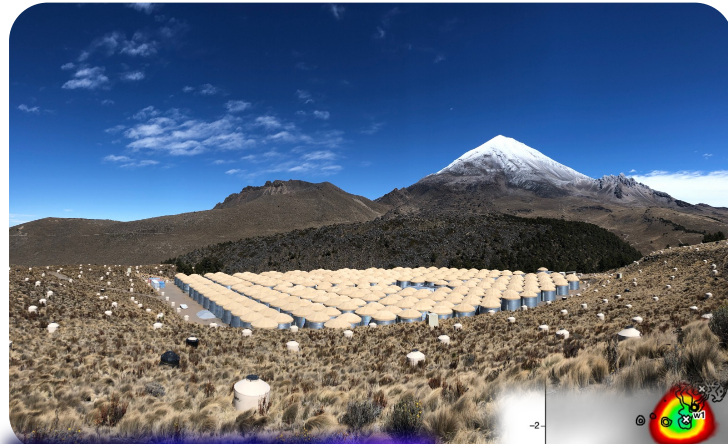
Non-WIMP BSM Searches

- Axion-like Particles (ALPs) would give high energy (>50 TeV) signals from extragalactic sources
  - ✓ SWGO's high energy range will produce unprecedented sensitivity to ALPs
- Primordial Black Holes would be nearby gamma ray bursts
  - ✓ SWGO's wide field of view and daily survey of the sky increases our chance to see transients like PBHs
- Observation of high energy gamma rays constrain Lorentz Invariance
  - ✓ SWGO's sensitivity at the highest energies increases chances of seeing highest energy gamma ray ever detected



"High energy gamma rays … offer probes of **new physics including** the **decays of super-heavy relics left behind from the Big Bang, cosmic strings, and axion-photon conversion** in largescale magnetic fields."
– Snowmass 2021 Report

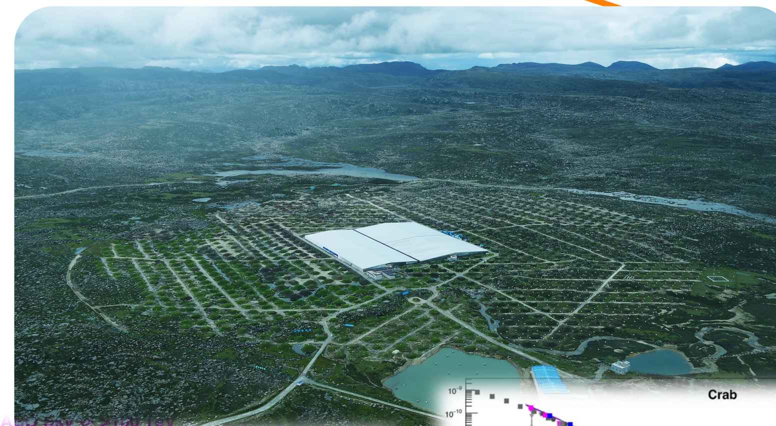
Cosmic Accelerators & Their Surroundings: HAWC & LHAASO Results

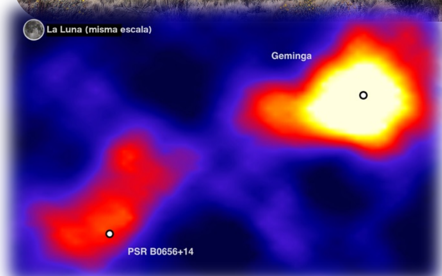


# of Sources

2007: 8 (Milagro survey)

2022: >100, >~ 20 emitting with E_γ > 100 TeV

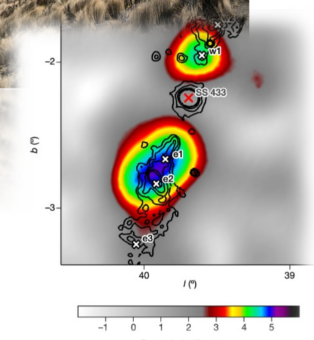




PARTICLE ASTROPHYSICS

Extended gamma-ray sources around pulsars constrain the origin of the positron flux at Earth

Abeysekara *et al.*, *Science* **358**, 911–914 (2017) 17 November 2017



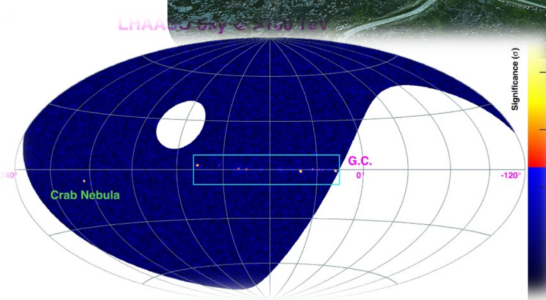
LETTER

Corrected: Publisher Correction

https://doi.org/10.1038/s41586-018-0565-5

Very-high-energy particle acceleration powered by the jets of the microquasar SS 433

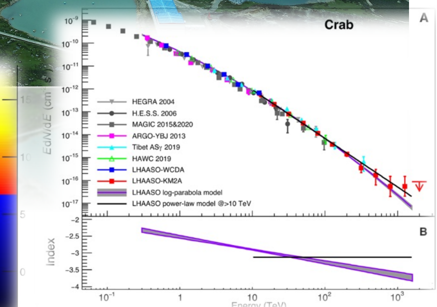
82 | NATURE | VOL 562 | 4 OCTOBER 2018



Article

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

34 | Nature | Vol 594 | 3 June 2021



RESEARCH

ASTROPARTICLE PHYSICS

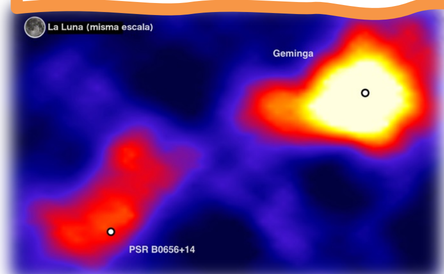
Peta–electron volt gamma-ray emission from the Crab Nebula

Cao *et al.*, *Science* **373**, 425–430 (2021) 23 July 2021

Cosmic Accelerators & Their Surroundings: HAWC & LHAASO Results

SWGO The Southern Wide-field Gamma-ray Observatory

```
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.

GRB 221009A is detected by LHAASO-WCDA at energy above 500 GeV, centered at
RA = 288.3, Dec = 19.7 within 2000 seconds after T0, with the significance above
100 s.d., and is observed as well by LHAASO-KM2A with the significance about 10 s.d.,
where the energy of the highest photon reaches 18 TeV.

This represents the first detection of photons above 10 TeV from GRBs.

The LHAASO is a multi-purpose experiment for gamma-ray astronomy (in the energy
band between 10^11 and 10^15 eV) and cosmic ray measurements.
```



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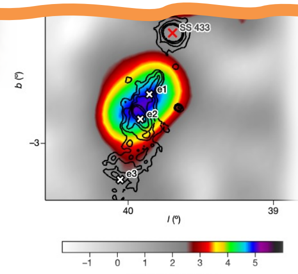
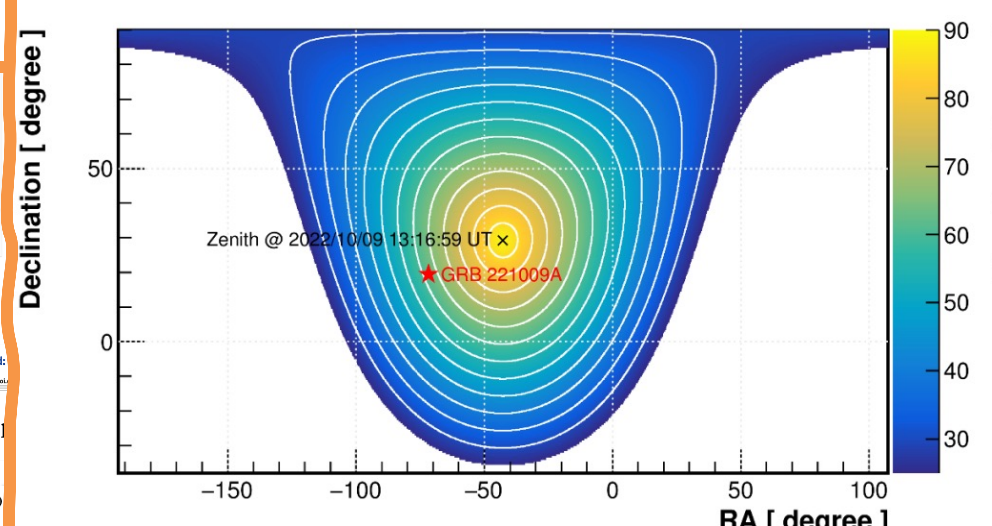


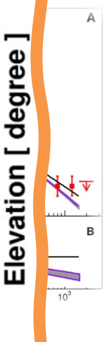
LETTER

Corrected:

Very-high-energy particle acceleration powered by the jets of the microquasar SS 433

82 | NATURE | VOL 562 | 4 OCTO





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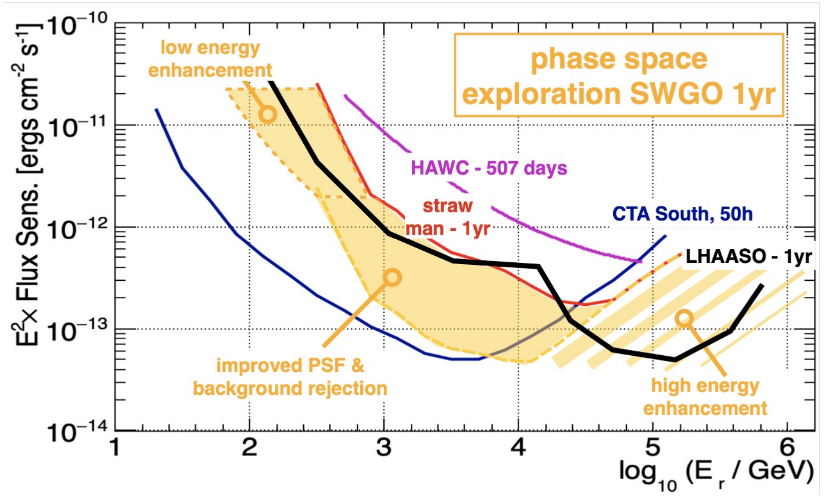
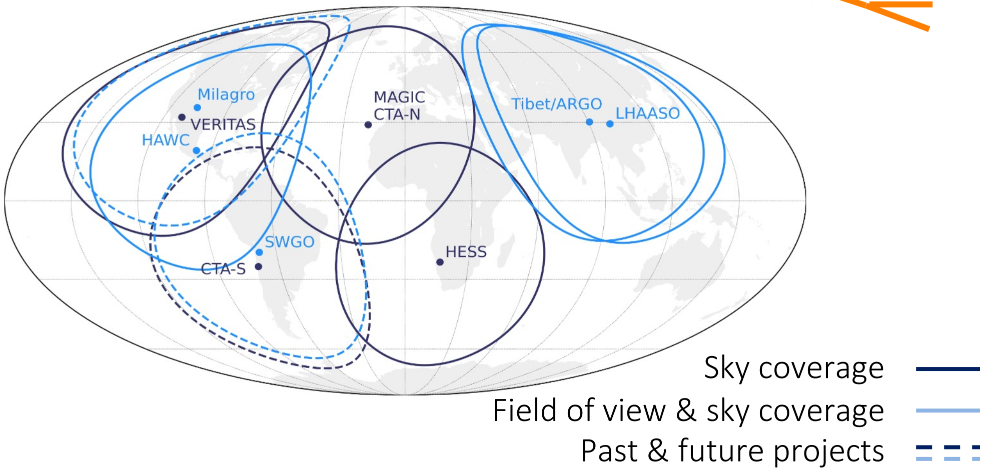
y 2021

Unique Wide-field Observations up to ~PeV





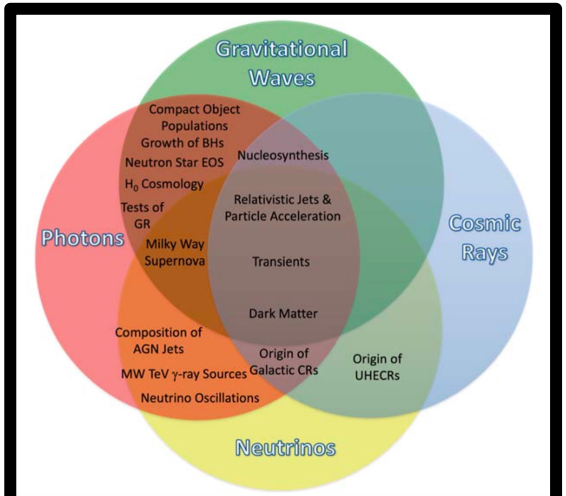
"Next-generation gamma-ray telescopes such as the **Southern Wide-field Gamma-ray Observatory (SWGO)** [and] the **Cherenkov Telescope Array (CTA)** … will open up the **access to new sky regions and energy ranges**, and **advance fundamental physics studies** with significantly improved sensitivities."
– Snowmass 2021 Report

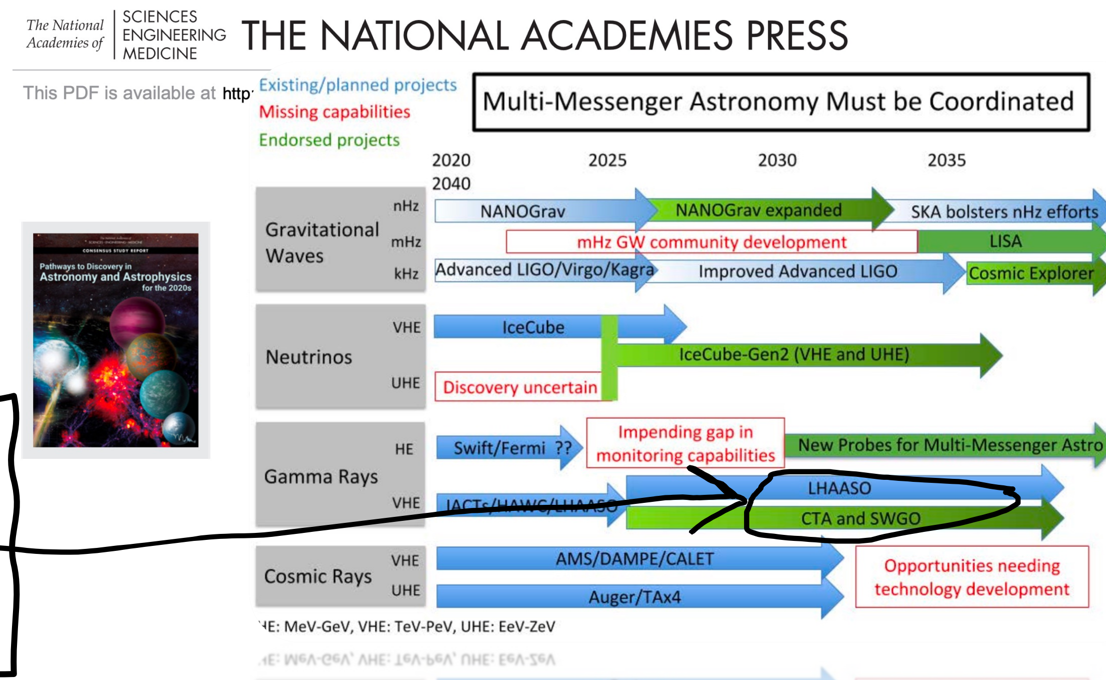
"**The panel endorses U.S. participation in the Cherenkov Telescope Array (CTA) and the Southern Wide-Field Gamma-Ray Observatory (SWGO)** as VHE observatories that extend source sensitivities to fainter sources, higher redshifts, and faster emission time scales, providing complementary catalogs of sources that span distance scales from the Milky Way to the cosmos."
– Astro2020 Report

The Southern Wide-field Gamma-ray Observatory

Photon Messenger

"U.S. participation in TeV-range groundbased experiments for precision studies - for example, 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

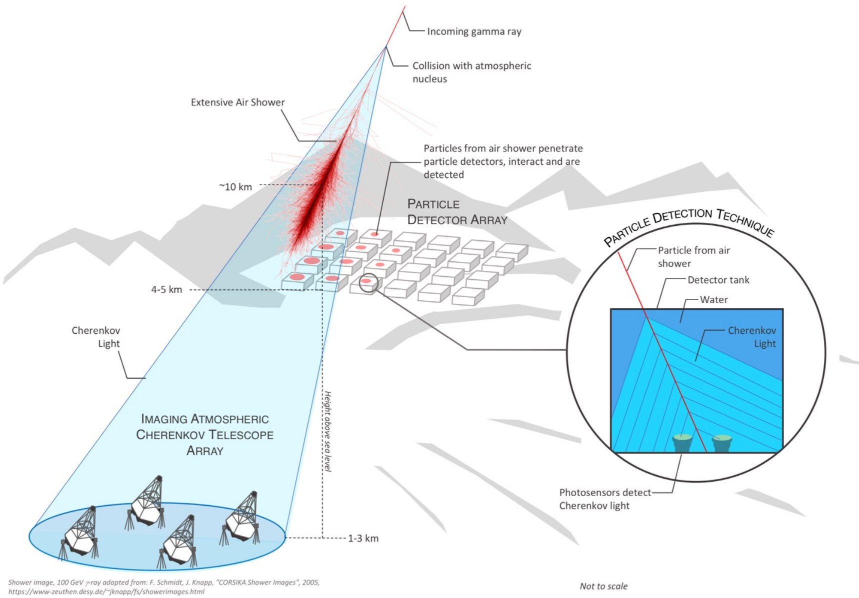




Panel on Particle Astrophysics and Gravitation recommends contributions by the U.S. to SWGO at the level of ~$20M

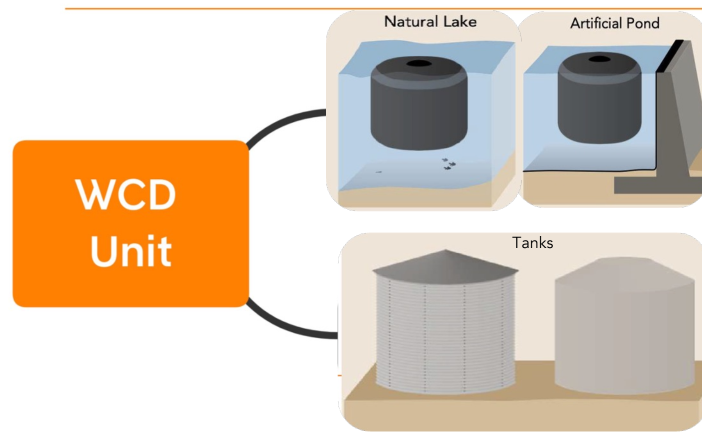
SWGO
The Southern Wide-field Gamma-ray Observatory

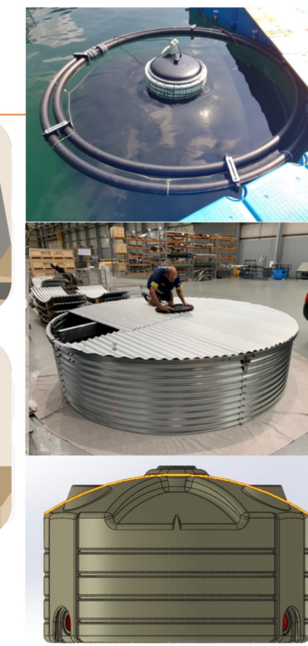
A Water Cherenkov Detector Array



Building on the success & experience of HAWC & LHAASO

Two concepts:
Land-based and lake-based





Location: Eight Site Candidates

The Southern Wide-field Gamma-ray Observatory

Scope, Phases & Milestones

- Small scale project
  - ✓ US contribution: ~$20-$30M
- R&D Phase
  - ✓ Nov 2019: First SWGO Collaboration Meeting
  - ✓ 2024: Expected Completion - Site and design choices made

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

Scope, Phases & Milestones

- Small scale project
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SWGO
The Southern Wide-field Gamma-ray Observatory

M2: Science Benchmarks

SWGO R&D Phase Milestones	
M1	R&D Phase Plan Established
M2	Science Benchmarks Defined ✓
M3	Reference Configuration & Options Defined
M4	Site Shortlist Complete
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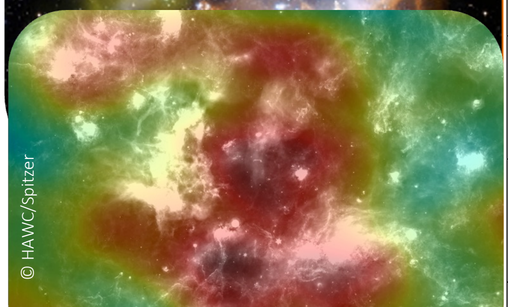
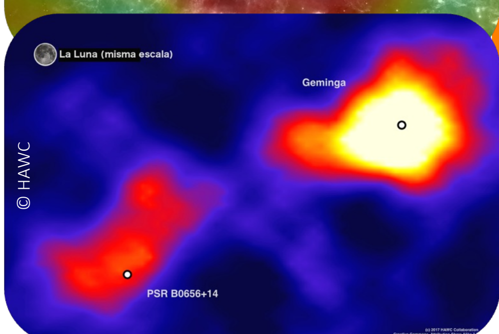
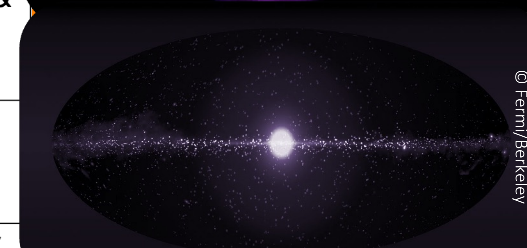
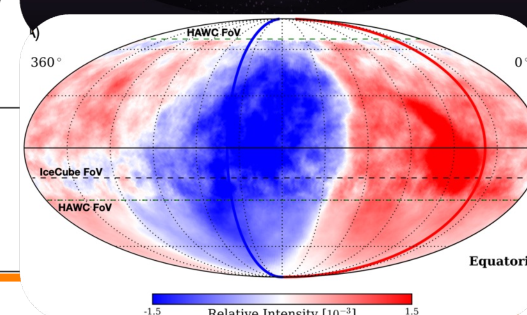




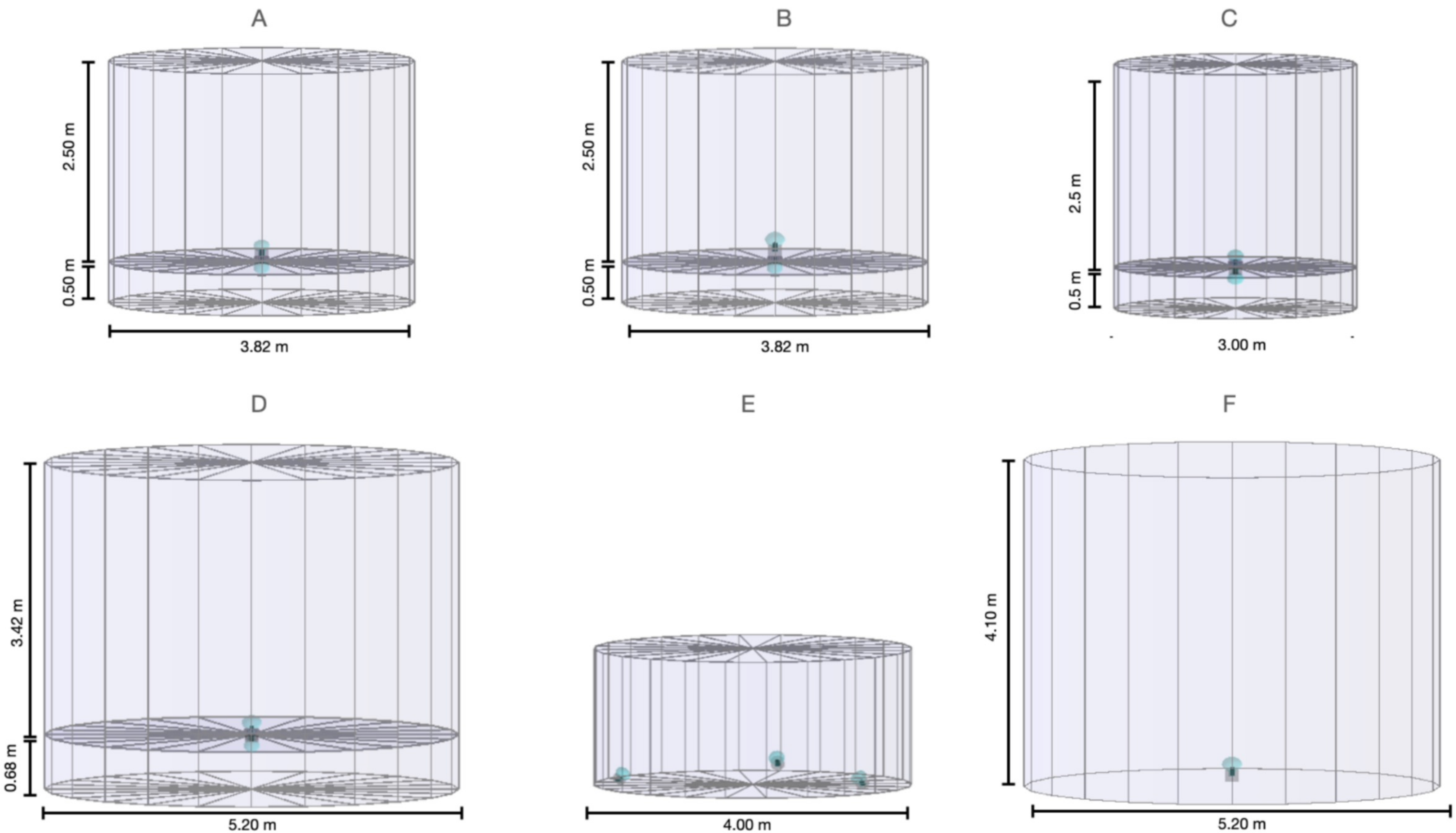
Science Case	Design Drivers
Transient Sources: Gamma-ray Bursts	Low-energy sensitivity & Site altitude[a]
Galactic Accelerators: PeVatron Sources	High-energy sensitivity & Energy resolution[b]
Galactic Accelerators: PWNe and TeV Halos	Extended source sensitivity & Angular resolution[c]
Diffuse Emission: Fermi Bubbles	Background rejection
Fundamental Physics: Dark Matter from Galactic Halo	Mid-range energy sensitivity Site latitude[d]
Cosmic-rays: Mass-resolved dipole/multipole anisotropy	Muon counting capability[e]





M2/M3/M5: Reference & Candidate Configurations

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



M2/M3/M5: Reference & Candidate Configurations

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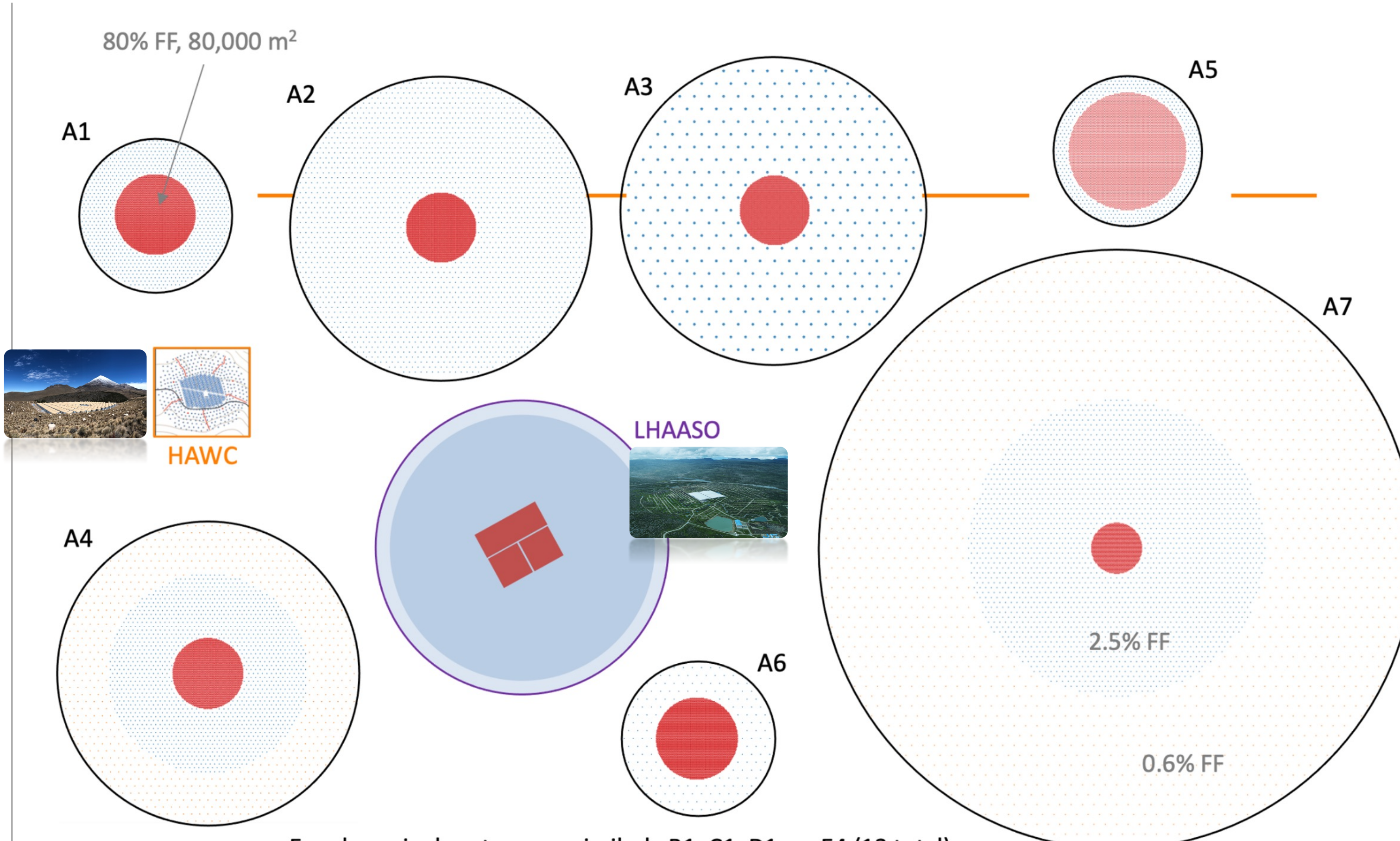
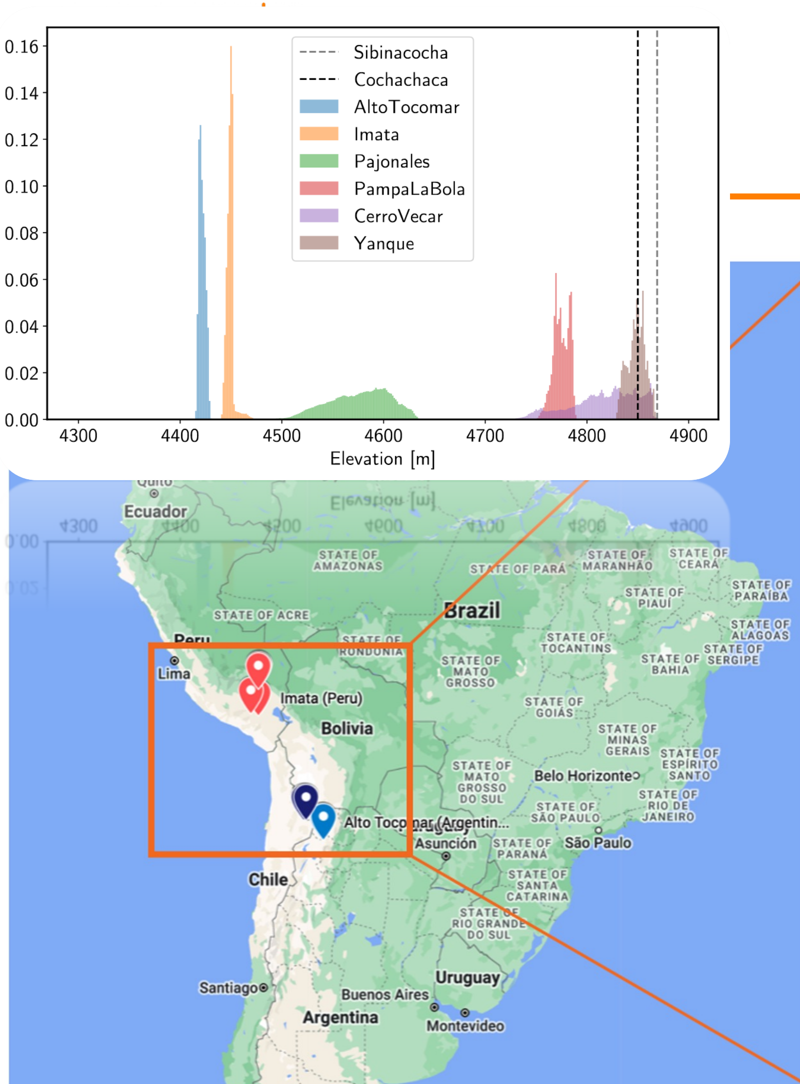


Equal nominal cost arrays, similarly B1, C1, D1, ..., E4 (13 total)

M4:
Site Shortlisting

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



Peru:
- Yanque (primary)
- Sibinacocha (primary)
- Imata (backup)

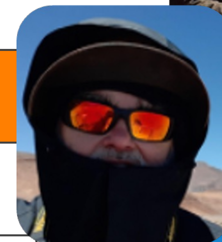
Chile
- Pampa La Bola (primary)
- Pajonales (backup)

Argentina
- Cerro Vecar (primary)
- Alto Tocomar (backup)

Toward M7: Preferred Site Identification

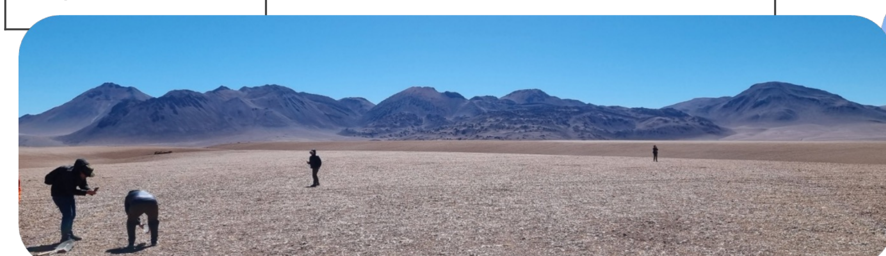
Site Visit Itinerary Fall ‘22

Country	Site	Date
Peru	Yanque	19. 10.
Peru	Imata	20. 10.
Peru	Lakes	22. 10.
Chile	Pampa La Bola	26. 10.
Chile	Pajonales	27. 10
Argentina	Cerro Vecar, Alto Tocomar	30. 10



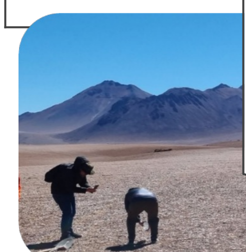


Toward M7: Preferred Site Identification

The Southern Wide-field Gamma-ray Observatory

Country
Peru
Peru
Peru
Chile
Chile
Argentina



SWGO site visit report

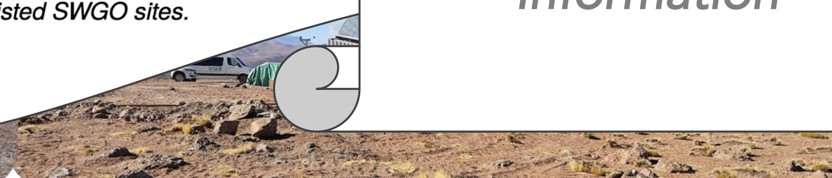
U. Barres[1], T. Bulik[2], B. Dingus[3], F. Guarino[4], P. Huentemeyer[5], D. Mandat[6], L. Mendes[7], L. Nellen[8], A. Sandoval[9], M. Santander[10], H. Zhou[11]

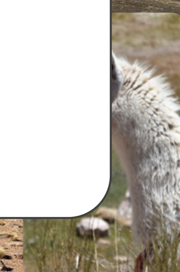
[1] *CBPF, Brazil.*
[2] *Astronomical Observatory, University of Warsaw, Poland.*
[3] *University of Maryland, USA.*
[4] *Dipartimento di Fisica "E. Pancini" dell'Univerità degli Studi di Napoli and INFN Napoli*
[5] *Michigan Technological University, USA.*
[6] *FZU, Czech Republic.*
[7] *LIP, Portugal.*
[8] *Instituto de Ciencias Nucleares, UNAM, Mexico.*
[9] *Instituto de Fisica, UNAM, Mexico.*
[10] *University of Alabama, USA,*
[11] *Tsung-Dao Lee Institute, Shanghai Jiao Tong University, China.*

The Southern Wide-field Gamma-ray Observatory

17th March 2023

Report of the site visiting team to the shortlisted SWGO sites.





Strengths & Weaknesses

Recommendations

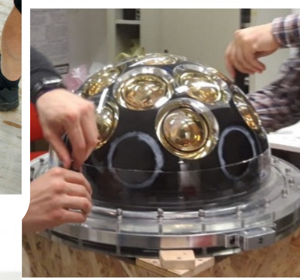
Requests for Information

Toward M8: Detector Design

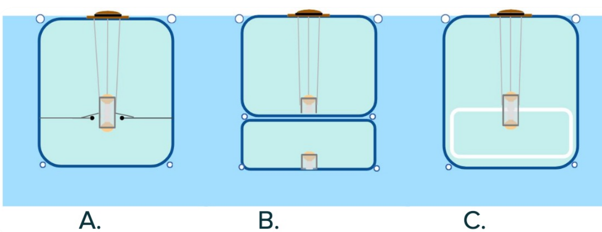
Prototyping:

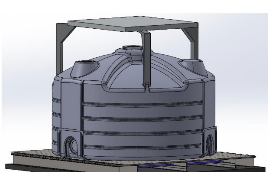
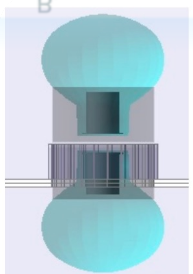
- Lots of progress being made!
- U.S. contribution: so far mostly analysis & simulation and expertise

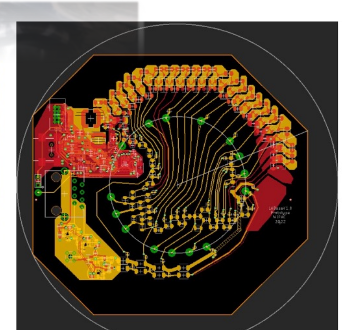
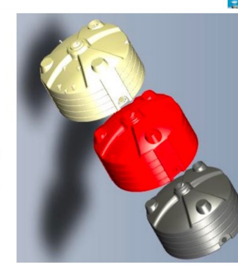




Option A

Phases, Milestones & Achievements

M9	Construction & Operation Proposal Complete	D9.1	Science Performance Requirements	Doc	**SP**
		D9.2	Conceptual Design Report	Doc	**SP**
		D9.3	Operating small-scale on-site prototype of baseline design	Phys	**Det**
		D9.4	Prototypes of key elements of final software	SW	**A&S**

- Preparatory Phase: 2025
  - → Detailed construction planning
  - → Engineering Array
- Full Construction Phase: 2027+
- Data taking:
  - → Start during the preparatory phase
  - → Continuous data taking is part of the verification process
  - → Expand on experiences with HAWC & LHAASO

A Global Collaboration

The Southern Wide-field Gamma-ray Observatory

- Spokespersons:

  Jim Hinton (SP, Germany)

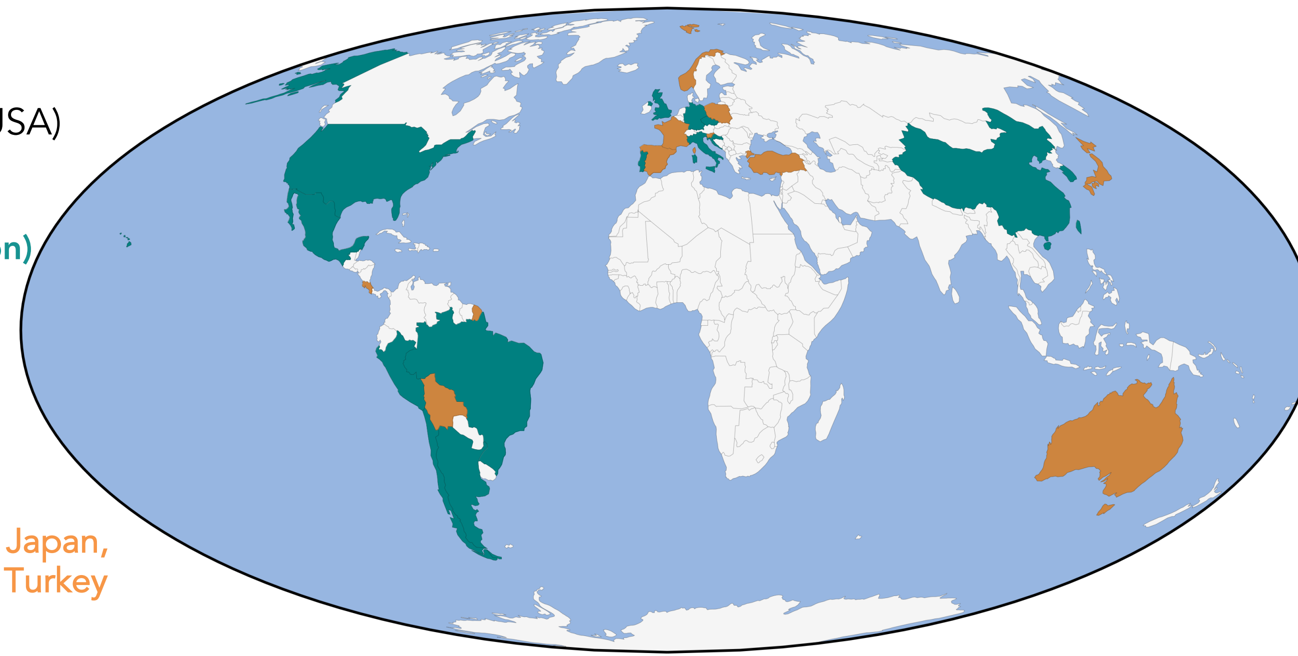
  Ulisses Barres (VSP, Brazil)

  Petra Huentemeyer (VSP, USA)

swgo.org

Member Countries (Steering Committee Representation)
Argentina, Brazil, Chile, China*, Croatia*, Czech Republic, Germany, Italy, Mexico, Peru, Portugal, South Korea*, United Kingdom, United States

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



- A growing project: 41 institutions in July 2019 → Now: 80 institutions (14 countries)

U.S. Participation & Leadership

SWGO
The Southern Wide-field Gamma-ray Observatory

Approved by collaboration Aug 5, 2022

6. **The governing body of the SWGO Collaboration** during the R&D and Preparatory Phases is the Steering Committee, chosen from the list of members of the signatory parties (institutes or consortia thereof) to the SoI. The Spokespersons team for the R&D and Preparatory Phases consist of a Spokesperson and two Vice-Spokespersons. An Executive Committee will join the management team during the Preparatory Phase. The structure of the collaboration is detailed in Article 4.

- Adrian Rovero (Argentina)
- Arthur Moraes (Brazil)
- Claudio Dib (Chile)
- Hao Zhou (China)
- Marina Manganaro (Croatia)
- Jakub Vicha (Czech Republic)
- Christopher Van Eldik (Germany)
- Alessandro de Angelis (Italy, INFN)
- Marco Tavani (Italy, INAF)
- Andres Sandoval (Mexico)
- Jose Bellido Caceres (Peru)
- Mário Pimenta (Portugal)
- Jason Lee (South Korea)
- Jon Lapington (UK)
- Pat Harding (USA)

SWGO

Collaboration Charter

V1.0 (17-07-2022)

Version submitted for final approval by the Collaboration, pending collaboration structures pertaining exclusively to Preparatory Phase and transition beyond the R&D Phase.

Ulisses Barres de Almeida

Table of Contents

U.S. Participation & Leadership

The Southern Wide-field Gamma-ray Observatory

Working Group Coordinators

The current coordinators are:

- **Science**: Gwenael Giacinti email & Francesco Longo email
- **Detector**: Fausto Guarino email, Lukas Nellen email & Wayne Springer email
- **Analysis & Simulations**: Ruben Conceição email, Harm Schoorlemmer email & Andrew Smith email
- **Outreach & Communications**: Ana Pichel email & Humberto Martinez-Huerta email
- **Site**: Dusan Mandat email & Marcos Santander email

Advisory Group

- Ingo Allekotte (Argentina)
- Pedro Brogueira (Portugal)
- Paula Chadwick (UK)
- Brenda Dingus (USA, chair)
- Carola Dobrigkeit (Brazil)
- Stefan Funk (Germany)
- Jordan Goodman (USA)
- Werner Hofmann (Germany)
- Giorgio Matthiae (Italy)
- Peter Mazur (USA)
- Michael Schneider (USA)
- Danilo Zavrtanik (Slovenia)

Speakers & Publication Committee

- Humberto Martinez-Huerta (Mexcio)
- Carlo Vigorito (Italy)
- Anthony Brown (UK)
- Jing Zhao (China)
- Kirsten Tollefson (USA)

Summary of International Participation & Arrangements

- ***SWGO is a young collaboration***: International and national participation has been growing fast since its foundation in July 2019
- ***U.S. institutions play leading role*** as they are recognized within SWGO for their leading expertise in WCD design and construction
- At the same time, there is a ***strong commitment and existing R&D support internationally*** (spec. Germany, Italy at the level of ~$2M)
- Further resources and experience are becoming accessible via ***newly added member countries*** including but not limited to China
- In an effort to lay the foundation for a research funding environment in which all current Latin American SWGO partners are able to stay involved in SWGO even after the site decision has been made, our South American colleagues are working with the ***Centro Latino-Americano de Física (CLAF),*** an intergovernmental institution for the promotion of the Physical Sciences in Latin America under the auspices of UNESCO, and have organized a high-level meeting to take place at the CBPF in connections with the first in-person SWGO collaboration meeting since the beginning of the pandemic
- ***SWGO will be a multi-agency project***
  - ✓ Project office not yet defined, current SP team consists of representatives from Europe (SP), South America (VSP), and North America (VSP)
  - ✓ Model for multilateral coordination between funding agencies in multiple countries will need to be worked out between SWGO member countries

Construction & Operation Costs

- Current Estimates are based on the costed reference design (see above)
  - ✓ ***Construction***
    - ➢ $10k/detector unit (tank) x 6000 detector units → $60M
    - ➢ Does not include labor & site preparation (host country dependent)
  - ✓ ***Operations***
    - ➢ < 5% construction cost (high reliability, similar to HAWC, which is remotely operated and has a duty cycle of >98%
  - ✓ ***U.S. contribution to total: 1/3***
    - ➢ with 1/3 from Europe and 1/3 in-kind from South America
  - ✓ ***Relatively straight forward cost profile:***
    - ➢ Upfront: Site preparation, infrastructure & detector optimization costs
    - ➢ Flat array construction costs over ~4 years
  - ✓ ***Contingency: 20%***
    - ➢ Can pin down the costs per detector unit/tank pretty well

SWGO
The Southern Wide-field Gamma-ray Observatory

U.S. Personnel

- Personnel required by project phase
  - Construction – FTE estimates depend
    - On finally chosen detector design & observatory site
    - On available in-kind contribution from host country
  - Operations
    - HAWC/Auger/LHAASO represent lower limit, especially if U.S. will host one of the data centers
  - Data Analysis
    - NSF/DOE funding models in the past:1 PD, 1 PhD per grant on average
    - Growth of number of institutions in the U.S. required to significantly contribute to science output
    - Additional FTE required to prepare and maintain data sets and science tools to be accessible to the science community
    - Again HAWC model represents lower limit

Scope of R&D Required

- Currently personnel at 5 institutes are partially funded through NSF to work on R&D for SWGO
  - ✓ Supports work on detector performance studies through analysis & simulation (M2/M5), participation in site shortlisting and selection (M4), and advisory service on detector design (M6)
- Funding required and requested for 8 institutes prototype work toward M6-M9 and Prep Phase starting this year: ~$3M

Working Group	Deliverables
Site	Site evaluation
	Site selection
Analysis & Simulation	Array design evaluation
	Simulation refinement
Detector	Implementation site
	Mechanical & DAQ tests
Electronics	Prototype & test White Rabbit design
	Initial Production

SWGO
The Southern Wide-field Gamma-ray Observatory

Summary & Outlook

"Southern Hemisphere locations are advantageous for observing both the **Galactic Center and the central dense region of the Milky Way's dark matter halo"** – Snowmass 2021 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

"The combination of CTA and LHAASO/SWGO provides an integrated observational capability that maximizes the scientific opportunities for all-sky multi-messenger astronomy. **The success of the broad U.S. program in multi-messenger astrophysics would be greatly enhanced by access to these world-leading facilities. The development of these facilities depends critically on decades of U.S. investment that cannot be capitalized upon without continued U.S. involvement."**
– Astro2020 Report