PROCEEDINGS OF SCIENCE

The Southern Wide-field Gamma-ray Observatory (SWGO)

Jakub Vícha[a] **on behalf of the SWGO Collaboration**[b]

[a] *Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
[b] *www.swgo.org*

E-mail: vicha@fzu.cz, swgo_spokespersons@swgo.org

The surface detection of gamma-ray showers has the advantage of a very high duty cycle and wide field-of-view observations across the sky in comparison to Cherenkov telescopes. The scientific potential of a wide-field gamma-ray observatory has already been demonstrated by the experiments HAWC, ARGO and LHAASO in the Northern hemisphere. The Southern Wide-field Gamma-ray Observatory (SWGO) will be located at a site in South America at an altitude above 4400 m a.s.l., and cover an energy range from 100s of GeV to 100s of TeV. The current status of the ongoing R&D phase of the future SWGO experiment including the scientific perspectives, candidate sites and possible detector concepts is briefly presented.

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1. Gamma-ray Observations

The high-energy (gamma) photons (above 100 MeV) arriving to the top of the atmosphere can be efficiently detected up to energies of ~100 GeV. This direct detection of gamma rays is currently well covered by the Fermi experiment[1]. At energies above ~100 GeV, the experiments observe primary gamma rays indirectly using two detection techniques of cascades of electromagnetic particles. These cascades initiated by a primary gamma ray need to be distinguished from the more frequent hadron-induced showers (cosmic rays).

Firstly, the Cherenkov light that is produced during the propagation of secondary electrons and positrons in the atmosphere is collected by a single or multiple telescopes installed usually around 2 km above the sea level. These optical telescopes are pointed to a given direction in the sky with a narrow field of view (FoV) within ~5 degrees collecting the Cherenkov light during dark nights of very small or no moonlight (duty cycle ~15%). The Cherenkov Telescope Array (CTA) experiment[2] is going to be unprecedently good in the resolution of energy and arrival direction, and collected exposure above ~10 GeV. Large discovery potential is foreseen for this experiment. There are two CTA sites currently being built to cover the whole sky: one located on Canary Islands in the Northern hemisphere and the second one in Chile, Cerro Amazones, in the Southern hemisphere.

Secondly, the particle densities of gamma-ray showers are sampled on ground at an altitude above 4 km using arrays of particle detectors (e.g. water-Cherenkov detectors) with almost full duty cycle. In the Northern hemisphere, the ongoing HAWC[3] experiment and the currently being built LHAASO [1] experiment observe the gamma rays in a wide FoV (~steradian) at the cost of a lower angular and energy resolution, and higher energy threshold than the Cherenkov telescopes.

1.1 Motivation for wide-field Observatory in the South

There is currently no wide FoV observatory in the Southern hemisphere that could complement the very precise observations by CTA and wide-field observations of LHAASO in the Northern hemisphere in the near future. A significant part of the southern sky is therefore not yet surveyed with a long exposure. Especially, the Galactic center and most of the so-called Fermi bubbles [2] lack long-term gamma observations above 100 GeV, see Fig. 1. Additionally, many transient events (e.g. Gamma-ray bursts (GRBs) or AGN flares) located in the southern sky are currently escaping detection (Swift-BAT[4] FoV ~1.4 sr). The first three cases of GRB detection above 100 GeV were announced in 2019 [4].

Therefore, a wide FoV observatory located in the South would have a great scientific potential complementing the very precise measurements of CTA to a predefined targets or follow-up searches, and covering the whole sky together with LHAASO. The Southern wide-field Gamma-ray Observatory (SWGO)[5] is being developed with following initial characteristics:

- as low energy threshold as possible (~100 GeV),
- located in South America between 10 and 30 degrees south above 4.4 km a.s.l.,

[1] https://fermi.gsfc.nasa.gov
[2] https://www.cta-observatory.org
[3] https://www.hawc-observatory.org
[4] https://swift.gsfc.nasa.gov
[5] https://www.swgo.org

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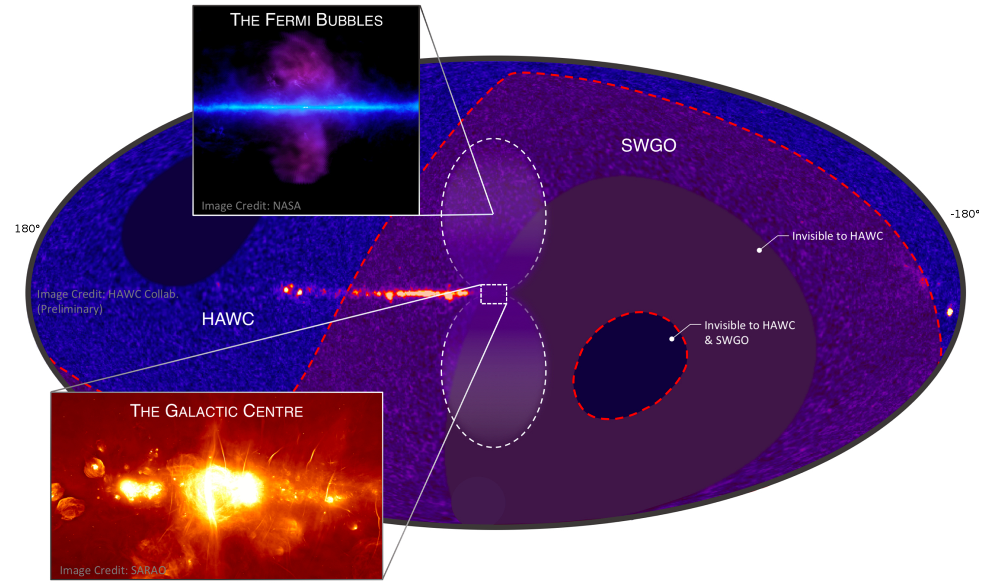

Figure 1: Illustration of the sky coverage of SWGO overlaid on the HAWC sky survey in galactic coordinates. Picture taken from [3].

- based on water-Cherenkov detectors,
- high detection efficiency and fill factor of detectors,
- size at least about 4-times the HAWC size (~LHAASO size) to reach 100 TeV,
- outer low-density array to suppress background from high-energy showers,
- good angular (<1 degree) and energy resolution (<50%),
- efficient identification of primaries (gamma-hadron separation and mass composition of cosmic rays).

2. SWGO in R&D phase

The SWGO Collaboration was established in June 2019 aiming to develop during the ~**3-year** R&D phase a full proposal for a future wide-field gamma-ray observatory in South America. About 200 scientists from more than 50 institutions from 12 countries share experiences from experiments like HAWC, ARGO, MAGIC, HESS, Auger, CTA, Fermi-LAT and others to explore the possibilities of the future observatory together with more than 30 supporting scientists from 10 countries. At the end of the R&D phase of SWGO, we expect to have

- the science goals defined,
- the most suitable site selected,

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- the detector concept defined and fully optimized,
- precisely estimated performance using detailed Monte Carlo simulations,
- a proposal with final detailed costing.

SWGO R&D Phase Milestones	
M1	R&D Phase Plan Established
M2	Science Benchmark Cases Chosen
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

Figure 2: Milestones for the SWGO R&D phase.

The nine defined milestones for the SWGO R&D phase are listed in Fig. 2. The core science cases were already defined this year (M2). The reference design (M3) was chosen recently during the 3rd Collaboration meeting held online on November 2020. The collection of detailed information on candidate sites is ongoing with the shortlisting (M4) foreseen in 2021. We plan to deliver the final proposal by the end of 2022.

3. Science Goals

There are four main topics included in the core science cases[6] defined for the SWGO.

- **Transients**, the short-time scale phenomena like GRBs or AGN flares, see e.g. [5], multi-messenger astronomy.
- **Galactic accelerators**, especially those capable to accelerate particles to PeV energies, studies of gamma-ray halos, and pulsar-wind nebulae, see [6].
- **Dark matter**, annihilations probed in a wide WIMP mass-range up to 100 TeV observing the center and halo of our Galaxy [7].
- **Cosmic rays**, studied through the mass composition (muon identifications) and large-scale anisotropy studies potentially covering the whole sky together with the LHAASO experiment, see e.g. [8].

These science goals raise demands on the SWGO detector: decreasing the energy threshold as low as possible (~100 GeV, see e.g. [9]), good identification of primary mass/gamma-hadron separation, dense area (diameter ~300m) of high fill factor (~80%) surrounded by a sparser array of stations (diameter ~600m) and very good angular (~0.2°) and energy resolutions (~30-40%, see e.g. [10]).

[6]Detailed description of science cases: https://arxiv.org/pdf/1902.08429.pdf

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4. Detector Concepts

There are 4 concepts of water-Cherenkov detector units that are studied during the R&D phase to find the most optimal solution[7] maximizing the scientific potential at the selected site for a given budget. The target cost of SWGO is currently about 50M USD.

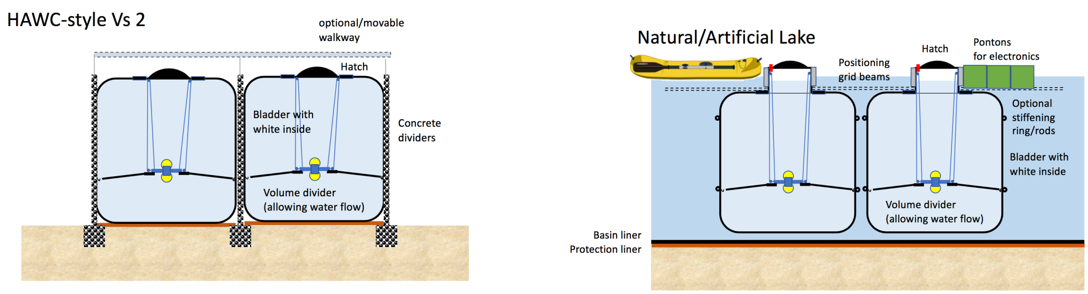

Figure 3: Left: Scheme of the reference concept of **double-layered** stations with 2 photosensors and Tyvec walls. Right: Scheme of the detectors in a **natural lake**. Credits: SWGO Collaboration.

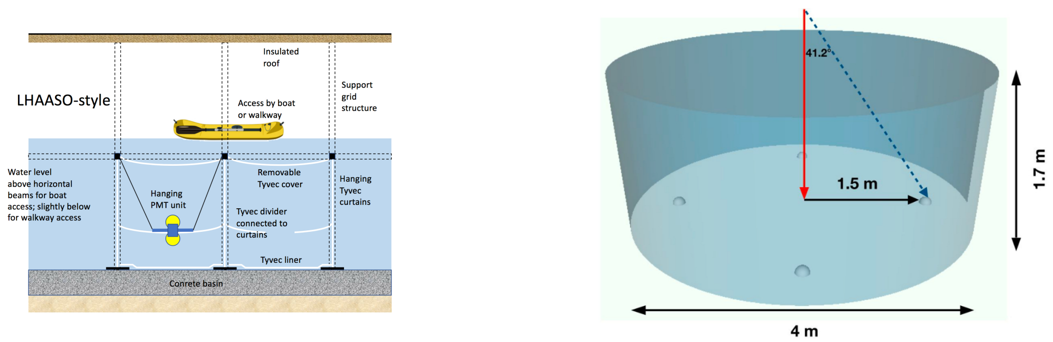

Figure 4: Left: Scheme of a **water pound** separated by Tyvec partitions. Right: Visualization of the concept of a **small station** with 4 photosensors and Tyvec walls. Credits: SWGO Collaboration.

The **double-layer** concept (left panel of Fig. 3) is the reference concept to which the other concepts will be compared during the R&D phase. In this case, the upper part (2.5m height) is designed to collect the light from all particles passing through into a single photosensor aiming upwards. The signal in the lower part (0.5m height) is collected by a single photosensor aiming downwards being sensitive mainly to muons, which helps to identify the primary particle.

The second option is to place the double-layered bladders into the **natural lake** (right panel of Fig. 3) and save on the water transport cost that can be a substantial part of the SWGO budget.

The third option is to build a large **pond of water** (left panel of Fig. 4) that contains the double-layered bladders inside.

The last option is to place 4 photosensors at the bottom of **smaller stations** (right panel of Fig. 4) to save on the overall amount of water and tag the muons through the non-uniformity of individual signals.

[7]More details about the SWGO layout: https://arxiv.org/pdf/1907.07737.pdf

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5. Candidate Sites

The candidate sites are located in **Peru**, **Bolivia**, **Argentina** and **Chile** (see Fig. 5). Argentina: Alto Tocomar (~4400m a.s.l.) and Cerro Vecar (~4800m a.s.l.). Bolivia: Chacaltaya Plateau (~4700m a.s.l.). Chile: Pajonales (~4400m a.s.l.) and Pampa la Bola (~4600m a.s.l.). Peru: Imata (~4400m a.s.l.) a, Yanque (~4800m a.s.l.) Laguna Sibinacocha (~4900m a.s.l.).

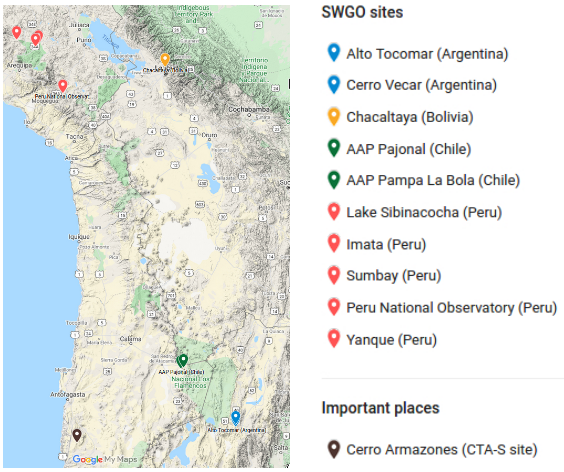

Figure 5: The geographical map with locations of candidate SWGO sites. The location of CTA South is marked as well. Credits: SWGO Collaboration.

Acknowledgements

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