The Southern Wide-field Gamma Ray Observatory (SWGO)

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Abstract

The Southern Wide-Field Gamma Ray Observatory (SWGO) is a collaboration to develop and construct an air-shower array for ground-based gamma ray observations in the Southern Hemisphere. The plan is to improve on or at least equal the performance of similar observatories, like LHAASO or HAWC. The detector will be installed at an altitude above 4400 m a.s.l. It will consist of Water-Cherenkov based detector units in an arrangement to allow the detection of gamma rays from a few hundred GeV up to a few PeV. The observatory will have a rich science program, which will allow it to complement IACTs and existing ground-based detectors in the Northern Hemisphere. We will present the status and advances in the design of the Observatory, prototyping, and site selection for the project.

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1 Introduction

SWGO is an international Collaboration involving 15 Countries, around 90 institutions and 48 Supporting Scientists [1]. It was established in 2019 with the goal of creating a ground-based particle gamma-ray observatory, also known as Extensive Air Shower (EAS) arrays, to survey and monitor the Southern Hemisphere sky, complementing the Imaging Atmospheric Cherenkov Telescopes (IACT) and the existing ground-based detectors in the Northern and Southern Hemispheres . The goal energies to explore are few hundred of GeV up to the PeV scale [2]. Nowadays the dominant IACT are VERITAS [3], MAGIC [4] and HESS [5] plus CTA [6] and the existing ground particle based telescopes are HAWC [7] and LHAASO [8]. SWGO also is thought to look for synergies with the instruments in the Southern Hemisphere, not only from science results but also from detection techniques.

2 Science Program

It includes a wide range of possibilities, from astrophysics to fundamental particle physics. As mentioned, IACT and ground-based detectors are complementary, while IACT provide a better energy and angular resolution as well as a more powerful background rejection; the ground-based ones observe the whole overhead sky and work with almost 100 % of duty cycle. Therefore the IACT can better perform studies on known sources, and ground-based detectors are better to search of transients events and of galactic accelerators [9].

2.1 Galactic

The galactic science program considers the study of Pulsar Halos, currently being studied by IACT, HAWC [10, 11] and LHAASO [12]; Galactic Pevatrons like Supernova Remnants (SNR) [8,13–17]; the Galactic Diffuse Emission [18,19] & Fermi Bubbles [20–22], being studied by Fermi-LAT [23, 24], the IACT [21] and with radio emission [25]; the Galactic Center region Dark Matter (DM) [26–29,31]; and Galactic Binaries as Microquasars [32,33]. A study on the capability of SWGO to understand DM has shown that its design would make it sensitive enough to probe thermal DM for a large range of multi-TeV DM masses and interaction channels when observing the Galactic halo. In addition, such an observatory would produce competitive, if not the best, limits for dark matter from Galactic substructure targets with masses from 100 GeV to several hundreds of TeV [29].

2.2 Extragalactic & Transients

The Extragalactic science program includes Gamma Ray Bursts (GRB), Cosmic Ray flux (CR) [36], Particle Physics Beyond Standard Model (BSM) [35] and Gravitational Waves (GW) among others. The ability of EAS arrays to cover large sky areas will help constraining the Very High Energy (VHE) properties of early GRB emission. Since SWGO will be installed at a high altitude, it will be able to detect low energy shower particles ($\sim$ 20 MeV) with high time resolution ($\sim$ 2 ns), which will improve the background suppression and achieve very good monitoring sensitivities, below the TeV energy domain. The systematic investigation of GRBs in the VHE range will cover a fundamental role in the quickly evolving field of Multi-Wavelength and Multi-Messenger Astrophysics [34].

2.3 Fundamental Physics

Due to the planned sensitivity range of SWGO, 500 GeV to >2 PeV, as well as its wide sky coverage, searches for BSM such as signals from DM particles, Primordial Black Holes (PBH), Axion-like Particles and Lorentz invariance violations (LIV) will be possible. Regarding the search for DM, the measurements that SWGO can obtain from the Southern sky will help test models to measure the Weakly Interacting Massive Particle (WIMP) DM, in the theoretical range that considers the maximum mass of 100 TeV. It will also be possible to study DM from a wide variety of astrophysical regions and environments where the density of these particles is high, such as Dwarf Spheroidal Galaxies, Dwarf Irregular Galaxies, Galaxy Clusters, the Galactic halo of the Milky Way and its DM structures, diffuse gamma rays and the Sun. Another way to measure DM densities in the Universe is to consider stable counter parts of evaporating PBHs, which must have been created in the early stages of the Universe and are associated with the measurement of intense gamma-ray transient emission. SWGO will enable such searches, improving the sensitivity by 1-2 orders of magnitude compared to current TeV observatories. Cold DM candidates as Axion like particles (ALP),from gamma rays arriving from extragalactic objects, are also able to be searched in the TeV range. It is expected that SWGO can place stringent limits on Grand Unified theories (GUTs) such as String theories, where LIV is mentioned since they are slightly dependent on energy TeV scales. The existence of cosmic gamma rays which SWGO could detect on these energies, as well as their flux and tiny effects in a large difference in timing could help to detect LIV [35]. As mentioned, SWGO will reach energies up to the PeV range, giving the opportunity to explore extragalactic objects in a nobel sky region for such high energies [35].

2.4 Cosmic Rays

The Anisotropy, one example of the efforts for studying the CR flux with SWGO can be seen in [36], where the potential of SWGO to estimate the muon component to separate different particle species is shown. This separation will be useful to measure the composition-dependent behaviour of the CR anisotropy. The features of the CR spectrum, especially the knee region (3-5 PeV) can be studied to compare the results of ARGO [37] and KASCADE [38], or the HAWC break at $\sim$30 TeV [39]. SWGO will be a complementary detector in the Southern hemisphere to lead the discovery of more PeVatrons [40]. The Collaboration is also producing the corresponding EAS simulations to obtain a realistic particle distribution at ground, the lateral profile, the muon content and the average particle properties at ground to be used in the several studies [41]. Nowadays only few TeV gamma-ray detectors can monitor the Sun, therefore SWGO will have a main role for studying CR interactions with the solar atmosphere, where there is production of such gamma rays. The production mechanisms and the influence of the solar cycle will be constrained giving information not known so far. Considering the available searches for solar atmospheric neutrinos, the constraints will be improved. The study of magnetic fields near the Sun and in the interplanetary environment will benefit from measurements of the "shadow" in the Galactic cosmic rays flux originated in the Sun, obtained by SWGO [42].

3 Site Candidates

Originally 7 places were proposed to host SWGO, after dedicated visits to each one of them, the election was based in the constructing, operation and maintaining costs, the possible risks that could be faced during the different stages of the building and operation and the environmental, cultural and social impact of the experiment in the local community, looking for a feasible integration of SWGO. The table 1 shows the characteristics of the sites in the shortlist.

Country	Site name	Altitud (m a.s.l.)	Latitud
Argentina	Alto Tocomar	4,430	24.19 S
Chile	**Pampa La Bola**	4,770	22.25 S
Perú	Imata	4,450	15.50 S

Table 1: SWGO candidate host sites shortlist.

The latitudes are between 15ºS and 24ºS and all of them could host a 1 km^2 array [9]. On July 2024, during the Collaboration meeting in Rio de Janeiro, Brazil, the SWGO Steering Committee chose the Pampa La Bola as the best site to host the experiment and detailed negotiations started. Pampa La Bola is located near the town of San Pedro de Atacama, where the Atacama Astronomical Park is established. The Park administers a concession to the Chilean National Agency for Research and Development, the land amounts an area of 360 km2. At the neighbouring lands there are several research facilities, such as the Atacama Large Millimeter/submillimeter Array (ALMA). This Antofagasta Region is conformed by an extensive plateau on the Andes at an altitude of 4,770 meters, which makes the place ideal for astrophysics observations and excellent long-term operations for SWGO [43].

4 The Detector

SWGO is a ground based or EAS detector array, several kind of detectors, configurations and sizes are currently being studied, which include cylindrical tanks made of corrugated steel sheet or roto molded; an open pound and a natural lake with floating bladder have been studied as well. The array will have a 100 % duty cycle as required for the science program.

4.1 Concept array

A 1 km^2 array is being condisered, the sizes and configurations look for something similar to LHAASO if possible and several m^2 bigger than HAWC ($\sim 80,000\ m^2$) plus a configuration with inner and outer zones is being explored [9]. The inner array for low energies seems to work fine with a fill factor between 40 % and 80 %, and a radius between 140 m and 220 m. The outer array would have a fill factor of around 2 % of fill factor for higher energies and a radius between 600 m and 800 m, a configuration of two zones for the outer array is being explored [44].

4.2 WCD Concepts

The Water Cherenkov Detector (WCD) concepts aimed to maximize the gamma-hadron separation, using a double layer design with a single PMT per layer, a deep single layer with a single central PMT or a shallow single layer with 3 PMTs [44]. With the double layer option a large background rejection power at energies larger than 1 TeV seems to be obtained, and with 400 units an efficiency of 50% for gamma could be reached [45]. For the inner array double layer large tanks give the most promising performance and improve background rejection. The results of the simulation studies for the inner array suggest a double layer tank with a single centrally deployed photo sensor unit, a diameter between 3.8 m and 5.5 m, an overall depth between 3.0 m and 4.5 m, a white wall lower chamber and either partially or fully back upper one. The current statistics at UHE do not allow us to reach strong conclusions on the outer array WCD [44].

4.3 Photo sensor options

For the photo sensor unit several devices have been explored, namely a large area of Photomultiplier Tubes (PMT), a Silicon Photomultiplier (SiPM) array, and a multi-sensor array [44]. To collect the light a Winston cone is being considered or a wave-length shifting (WLS) plate of fibers. A MultiPMT considered as a large area PMT is also being studied [45].

5 Sensitivity

The so called A4 configuration, being studied with simulations, uses an inner and an outer array, with a density of detector units that decreases with distance from the center, a preliminary expected sensitivity of SWGO for this configuration, for 1 year of working is shown in Figure 1. This shows that the performance of SWGO is comparable to the one of CTA South and LHAASO [44].

6 Status and plan

The Research and Development (R&D) plan for SWGO has 9 phase milestones (M), including R&D phase plan establishment (M1), definition of science benchmarks (M2), definition of reference configuration and options (M3), definition of the site shortlist (M4), definition of candidate configurations (M5), evaluation of the performance of candidate configurations (M6), identification of the preferred site (M7), design completion (M8) and construction & operation proposal complete (M9). As mentioned, the preferred site is already identified, which means that the status is in M7. The expected completion of R&D phase is in early 2025, the preparatory phase will be in 2026, and the expected full construction phase will begin in 2027, the plan is to operate the observatory for at least 20 years. [44, 45].

7 Outreach

It is important for the collaboration to have an impact in the culture and spread of science, and that is why there is already an outreach program on the way. There is material that can

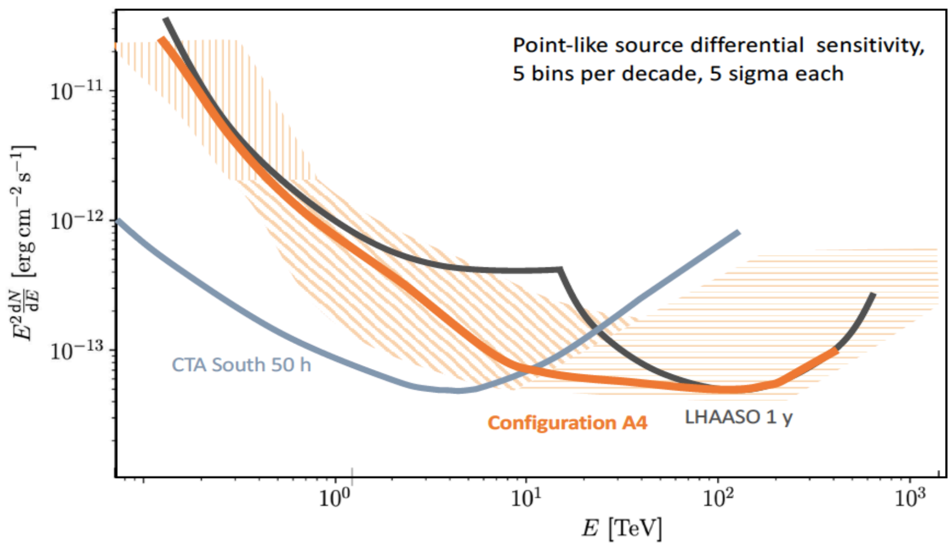

Figure 1: Preliminary comparison of the sensitivity of SWGO (Configuration A4) with CTA and LHAASO [44].

be downloaded from the site [46], which includes videos, an event visualizer, brochures in several languages, and a poster. Information to reproduce a 3D simulation of one of the WCD prototypes is available for demonstration and explanation purposes as well.

8 Conclusion

SWGO is an experiment which will complete the information on gamma rays and cosmic rays obtained by the existing detectors (CTA, HAWC, LHAASO and other IACT, satellite and ground based instruments) from the Southern hemisphere, for energies from few hundred GeV up to the PeV scale. It has a well-established rich science program including synergies with the current and future instruments. The site which will host SWGO is already chosen and the R&D phase is about to be completed.

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SWGO
The Southern Wide-field Gamma-ray Observatory

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