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The search for high altitude sites in South America for the SWGO detector

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The Southern Wide-field Gamma-ray Observatory (SWGO) is a project for a new generation of extensive air shower front detectors, based primarily on the water Cherenkov technique, to be located in the Southern Hemisphere, where no other instrument of that kind is currently operating in the TeV gamma-ray energy range. The reference configuration of SWGO foresees an array of about 6,000 water Cherenkov tanks deployed over a circle of 320 m diameter, about 80,000 m^2 area. In order to reach a sensitivity at energies around and below 1 TeV competitive with current and future detectors, SWGO will be placed at altitude above 4,400 m a.s.l. Preliminary site searches have found several candidate sites in Argentina, Bolivia, Chile and Peru. The major challenge will be the water provision, considering that at least 10^5 m^3 of water will be required. This poster will present the challenges and status of the SWGO site search in South America.

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1. Introduction

The field of gamma-ray astrophysics has shown a fervent activity in the past three decades, and has recently reached the fully-fledged status of a precise astronomy field. The contribution of MeV and GeV satellite-based detectors such as INTEGRAL, AGILE and Fermi-LAT [5] is astonishing in data volume and scientific results. In the GeV-TeV range, ground-based imaging Atmospheric Cherenkov telescope (IACTs) such as H.E.S.S., MAGIC and VERITAS [7] have again demonstrated that, although the Earth atmosphere is impenetrable to gamma rays, the observation of by-products of the extended atmospheric showers generated (EAS) by the cosmic particles can be precisely scrutinized providing energy resolution of the order of 10%, angular resolution below 0.1° and sensitivities capable of detecting transient events as short as few seconds. IACTs detect the Cherenkov photons emitted *around* the EAS. However, it is also possible to detect the EAS particles directly. This poses the challenge to locate the instrument at the height of the EAS. The altitude at which the EAS has its maximum depends on an energy [1]. For an altitude of 4.5 km a.s.l. a shower of 100 GeV (100 TeV) generate respectively 200 (10^5) electromagnetic particles. Therefore, in order to reach sensitivities in the TeV range or below, one needs to place a particle detector at high altitudes. Currently operating major experiments in this field are: HAWC, a 150 m diameter instrument located in the Sierra Negra volcano near Puebla (Mexico) at an altitude of 4,100 m a.s.l made up of more than 600 water Cherenkov units [8] and LHAASO, located at an altitude of 4,410 m in the Yangbajing region in Sichuan (China) [9] and made up of about 10k detectors spread over 1 km^2. These instruments build on the experience of the previous generation of such detectors: Milagro and ARGO-YBJ among others [4]. In order to detect the charged particles constituting the EAS, different techniques can be used, therefore such detectors can be different in realization. Electrons, positrons, muons and MeV photons, consituting electromagnetic and hadronic showers, can be detected when crossing small depth of water (1-2m) through the Cherenkov emission within. These *water tanks* are equipped with a fast photon detector, such as a photomultiplier. The EAS is reconstructed by either segmenting a large pool of water into individual detector units or by arranging several thousands of independent water tanks into a detector array. The signal pattern in the array allows to reconstruct energy and direction with precision down to less than $< 10\%$ and 0.1° respectively according to the instrument layout (see H. Schoorlemmer, this conference, for SWGO expected performance). Other methods of detecting the shower particles are based on Resistive Plate Counters (RPCs) or scintillators.

HAWC and LHAASO are both located in the Northern Hemisphere, though at different longitudes. They have an optimal visibility of the extragalactic sky, however, their acceptance toward the Galactic center and the Galactic plane is limited to a fraction of the yearly duty cycle and to low altitude above the horizon, in which the instrument response is significantly worse than at zenith. For this reason, a number of institutes have formed an R&D consortium named SWGO (Southern Wide-Field Gamma-ray Observatory) [3] (see J. Hinton, this conference), for the ideation of a shower front instrument to be located in the Southern Hemisphere. The R&D consortium was formed in Padova in 2019 and will last until 2023 in order to provide a full-fetched design of detector with the following requirements:

- To be located in South America at a latitude between 10° and 30° South.

- To be placed at an altitude of 4.4 km or higher.
- To cover an energy range from hundreds of GeV to hundreds of TeV.
- To operate close to 100% duty cycle and order steradian field of view.
- With the possibility of extensions and/or enhancements. Modular and scalable.

A set of science goals were also defined to guide the observatory design (see U. Barres; R. Lopez Coto; La Mura; A. Viana; A. Taylor; A. Albert, this conference). The figure of merit can be achieved with different detector design options, and at the moment there is no final choice about both the definition of the elemental cell of the experiment and of the experiment layout. In this contribution, we are interested in the detector characteristics that affect the choice of the site for the installation of SWGO.

1.1 SWGO main detector designs and construction challenges.

The SWGO consortium is currently exploring three main detector designs:

- detector units placed in an array of individual tanks [TANK]
- detector units assembled in an artificial pond [POND]
- detectors units immersed (or deployed) in a natural or artificial lake [LAKE]

Presentation about these detectors design can be found elsewhere in this conference (F. Werner; F. Bisconti; R. Conceicao; S. Kunwar; H. Goksu). Generally speaking, the instrument must be composed of a high-fill factor (> 80%) dense core array spread over an area of at least 200 m diameter, dedicated to the shower-core accurate location, and a sparse array of detector, with less constraints on the fill factor, dedicated to the shower containment and the shower particle identification. Generally speaking, the larger the array, the higher the energy reach of the instrument. In all cases above, the area of the single unit/cell is of about 10 m^2, and the number of units is several thousands. For the reference configuration, this translates into a minimum required instrumented area of about 80,000 m^2 and not less than 2.8×10^5 m^3 of purified water (see J. Hinton, this conference). The purification and transport of water is not only a matter of costs. The exact nature of the detector (water tanks, scintillators, RPCs) or the use of different photon detector, has little or no relevance for the choice of the site and it is not discussed here. Of the proposed solutions, the natural lake options clearly require a natural lake. Manmade lake or ponds can be aggressive solution in natural zones, specially if digged in the ground, while over-the-ground pools are less aggressive. Tanks can instead be placed and removed after their endlife.

Building an array of several thousand detectors at altitude larger than 4,400 m a.s.l. is a challenging endeavour. Labour at those altitudes is exhausting and special attention shall be paid to logistics: carrying material and water to remote places can require thousands of long trips. For this reason, the SWGO consortium aims at having a design that is as simple as possible and maintenance-free, which also will reflect on the site choice. The main challenge is related to the water provision: water may be scarce in some sites or precious to the environment or the local communities. Therefore, it is important to consider all socio-political and budget costs connected to water retrieval. The requirement in terms of power and ethernet bandwidth are instead not extremely challenging. It is estimated that SWGO would not need more than 50 kW power and 10MB/s bandwidth.

The idea is to operate SWGO for at least a decade. However, as shown by similar endeavours such as the Pierre Auger Observatory (PAO) [12], multi-decade observation runs are more than justified in terms of scientific returns for these wide ground-based installations, and larger operation times are under debate in SWGO.

2. Candidate sites

The SWGO consortium has issued a call for candidate sites in 2019 that will end with a short list of selected sites toward the end of 2021. Four south-American countries have proposed one or several candidate sites: Argentina, Bolivia, Chile and Peru. A short table describing the main site characteristics is reported in Tab. 1. A geographical map is shown in Fig. 1. A more in-depth discussion country by country is given afterwards. Some pictures of the different sites are also shown in Fig. 2. The site characterization is also discussed by L. Chytka (this conference).

Figure 1: Geographical map of SWGO candidate sites (obtained with Google Earth).

2.1 Argentina

Argentina hosts two candidate sites in the Salta region: the Cerro Vecar site at 4,800 m a.s.l, that is currently hosting also the LLAMA [13] and QUBIC experiments [14] and the Alto Tocomar site, a plateau right below the Cerro Vecar mountain, at 4,430 m a.s.l. The sites are owned by the Salta province and are located at about 33 km (30 min) from the village San Antonio de los Cobres

Country	Site Name	Latitude	Altitude [m a.s.l]	Other installations
Argentina	Alto Tocomar	24.19 S	4,430	
	Cerro Vecar	24.19 S	4,800	LLAMA, QUBIC
Bolivia	Chacaltaya	16.23 S	4,740	ALPACA
Chile	Pajonales	22.57 S	4,600	ALMA and others
	Pampa La Bola	22.56 S	4,770	ALMA and others
Peru	Imata	15,50 S	4,450	
	Yanque	15.44 S	4,800	
	Sibinacocha	13.51 S	4,900	

Table 1: Locations of SWGO candidates sites in South America

Figure 2: Pictures of some of the candidate sites. From top to bottom and left to right: Pajonales and Pampa La Bola (Chile), Cerro Vecar and Alto Tocomar (Argentina), Sibinacocha (Peru)

(3750 m a.s.l). The access road to the site is at about 178 km (3:00 hr by car) from the International Airport "General Martín Miguel de Güemes" (code SLA) and 7 km from Salta (1150 m a.s.l.). The sites are located in the Los Andes Reserve, in a sub-zone classified as "sustainable use zone" (Área de uso sustentable) where several activities are allowed. The Province is pursuing the creation of an Astronomy Park in the area ("Salta, Ventana al Universo"). The sites are easily reachable all year round. The climate at the site is characterized by two distinct periods, 8 months of dry season, with clear sky during winter, and 4 months where all precipitation occurs during summer, with possible storms. The precipitation regime is 120 mm/yr with no snow accumulation for both sites. Average temperature along the year is 1-2°C for Cerro Vecar and 3-5°C for Alto Tocomar. A feasible water source has been identified in the nearby river San Antonio de los Cobres, whose water is not potable. Power and ethernet is being implemented in the framework of the Astronomy Park. The Cerro Vecar and the Alto Tocomar sites can be instrumented over a flat area of 600 m diameter, with limitations in case of a 1000 m extension in case of the Alto Tocomar site.

2.2 Bolivia

The Bolivian city of La Paz is the highest administrative capital in the world, located at 3640 m a.s.l. At about 1 h from La Paz, the historical Chacaltaya observatory is situated, where in 1947 the Brazilian physicist Cesar Lattes and colleagues discovered the pion. Chacaltaya was also a ski resort some decades ago. Very close to the Chacaltaya mountain lies a wide plateau, which is the current construction site of the ALPACA EAS detector [15]. The area is located at 4700 m a.s.l. and it is a rectangle of roughly 500×1350 m^2. The current owner is the local community “Achachicala Originario” in the area, but agreements can be made for purchase or rent of the land. The place is windy (about 15 m/s wind) and cold, with snow precipitations instead of rain, which sometimes block the access to the site, specially in the summer (December to March). The main airport is in the El Alto town at 4150 m a.s.l., about 15 km (1 h) from the site. The city “El Alto” is only 4 km to La Paz. There is ample water content around the site, which can either be channeled to the site (1 km away) or found underground (100 m well). Ethernet and power can be obtained easily at the site due to its closeness to La Paz. The main power line up to Chacaltaya Laboratory is passing through the proposed experimental site.

2.3 Chile

The two proposed Chilean sites, Pajonales and Pampa La Bola, lie within the Atacama Astronomical Park (AAP) , which is about 45 km from San Pedro de Atacama, an important tourist spot in the Antofagasta Region. These proposed sites are next to the international highway that links Chile and Argentina through the Jama pass. The AAP is a 50-year concession (starting in 2013) for Astronomy projects over a 360 km area, much of it rather flat. It was granted by the Ministry of National Assets to the National Agency of Science and Technology (ANID) of the Ministry of Science, Technology, Knowledge, and Innovation. The main international airport in the country is the Santiago airport, connected to the Calama airport (100 km from San Pedro de Atacama) with several daily flights. The AAP surrounds the large area in which the ALMA Observatory is located [17] and the AAP already hosts several scientific instruments, such as TAO, CCAT-prime, CLASS, ACT, Simons Observatory, Simons Array, and USACH Solar. The site is managed by the AAP Foundation and it is a government-granted scientific reserved area. Water is not available directly at the site. So far, the closest identified location to acquire large amounts of (drinking-quality) water is the town of Calama, 150 km from the site. Pampa La Bola has less than 2% inclination over the central 320 m and is still quite flat (about 2% on average) over at least 2×2 km^2, whereas Pajonales is on a slope of roughly 8%.

2.4 Peru

Peru is the northernmost location for SWGO. It is currently providing several proposed sites: Imata, in the Arequipa region, candidate site for a tank-based or pond-based detector; Yanque, a similar solution but at higher altitudes, and the small lakes Cochachaca and Cocha Uma near the lake Sibinacocha in the Cuzco region, the sole candidate for a lake-option detector. The owners of the lands in Peru are the districts. Districts can sign land use agreements. All sites have accessibility granted around the year, as well as power and bandwidth. Peru is the only country proponent with a high altitude natural water reservoir to host the "lake solution" fulfilling the volume, depth and other criteria. The Imata region is a high altitude plateau. Close to one of the Imata lakes there is a flat area of approximately 3 km radius. During the year the temperature is always above zero during the day, on average 12°C. At night time the temperature is around -2°C or -10°C in summer and winter respectively. From April to November there is not much rain. The rainy season is from December to March, where the accumulated rain is on average about 2 mm per day. There are no problems with roads blocked by snow. Snow is rare and usually not heavy. The Aeropuerto Internacional Rodríguez Ballón de Arequipa (AQP) is located at 115 km (1h.20m drive). Arequipa, 90 minutes driving, is at 2,300 m a.s.l.

3. Summary, discussion and conclusions

SWGO is an endeavour for a particle shower front detector for gamma-rays in the 100 GeV to above tens of 100 TeV (possibly above the PeV, if the instrument can be extended). It builds on the experience of HAWC and LHAASO and aims at complementing these instruments in the southern hemisphere, as well as collaborating with the Cherenkov Telescope Array [6]. Several candidate sites are investigated in the Andes, at altitudes above 4,400 m a.s.l and over four countries: Argentina, Bolivia, Chile and Peru. The site must be a flat plateau of at least 300 m diameter, possibly up to 1000 m diameter, and it will host thousands of detector units/cells, to be operated with minimum maintenance over the year. The reference configuration for SWGO is that of individual water tanks, equipped with photomultipliers tube. The amount of water is the main challenge for this instrument, along with the construction in remote areas, where labour work is fatiguing. Once completed, it will be the only instrument of this kind in the southern hemisphere, providing valuable scientific results.

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