Snowmass2021 - Letter of Interest

Advancing Particle Astrophysics with the Southern Wide-field Gamma-ray Observatory (SWGO)[*]

Thematic Areas: (check all that apply □/■)

□ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
□ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
■ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
□ (Other) *[Please specify frontier/topical group]*

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Abstract: We outline the science motivation for the Southern Wide-field Gamma-ray Observatory (SWGO), a next-generation wide field-of-view gamma-ray survey instrument sensitive to gamma rays from 100 GeV to hundreds of TeV. Its science topics include unveiling Galactic and extragalactic particle accelerators, monitoring the transient sky at very high energies, probing particle physics beyond the Standard Model, and the characterization of the cosmic-ray flux.

[*]This Letter contains excerpts and material from White Papers submitted for the Astro2020 Decadal Survey [1;2]

The Southern Wide-field Gamma-ray Observatory (SWGO; www.swgo.org) is a next-generation, ground-based survey instrument that will provide a unique view on gamma-ray and cosmic-ray emission from ∼100 GeV to hundreds of TeV. The facility will improve upon the success of the High-Altitude Water Cherenkov (HAWC) Observatory[3] in Mexico that is surveying the Northern gamma-ray sky with nearly 100% duty cycle and an instantaneous field-of-view of ∼2 sr. Since 2015, HAWC has discovered new TeV sources and source classes, set new world-leading limits on dark matter decay and annihilation, and played a crucial role in multi-messenger observations[4–22]. The success of the water Cherenkov technology implemented by HAWC has inspired an ambitious Chinese-lead effort, LHAASO, in the Northern Hemisphere, which uses a similar design[23].

Recent years have seen a wealth of paradigm-shifting discoveries including a kilonova associated with merging neutron stars[12], a gamma-ray burst (GRB) with photons detected up to 1 TeV[24], and a detection of a sub-PeV neutrino from a flaring Active Galactic Nucleus (AGN)[17]. The global multi-messenger astrophysics community recognizes the importance of facilities in both hemispheres that continuously survey the gamma-ray sky in the space and time domains. Wide-field-of-view observatories can not only provide prompt alerts of transient events to the astrophysics community, they also maintain a comprehensive archive of continuing observations about gamma-ray emission covering large regions in the sky.

The anticipated sensitivity of SWGO is shown in the left panel of Figure 1, in comparison with the existing High Energy Stereoscopic System (H.E.S.S.) instrument, the HAWC Observatory, and the Cherenkov Telescope Array Southern Hemisphere Observatory (CTA-South), which is currently under construction. SWGO will have a total sky coverage of ∼8 sr (2/3 of the sky), as shown in the right panel of Figure 1, as well as a duty cycle near 100%. In contrast to the imaging atmospheric Cherenkov Telescope (IACT) sensitivities, which apply to targeted observations of a small region of the sky, the SWGO sensitivity applies to a large number of sources throughout its sky coverage simultaneously. Figure 1 also applies strictly to point sources, i.e., with true extents smaller than the instrument point-spread-function. Sources with moderate angular extents will reduce the sensitivity for IACTs more severely than for SWGO.

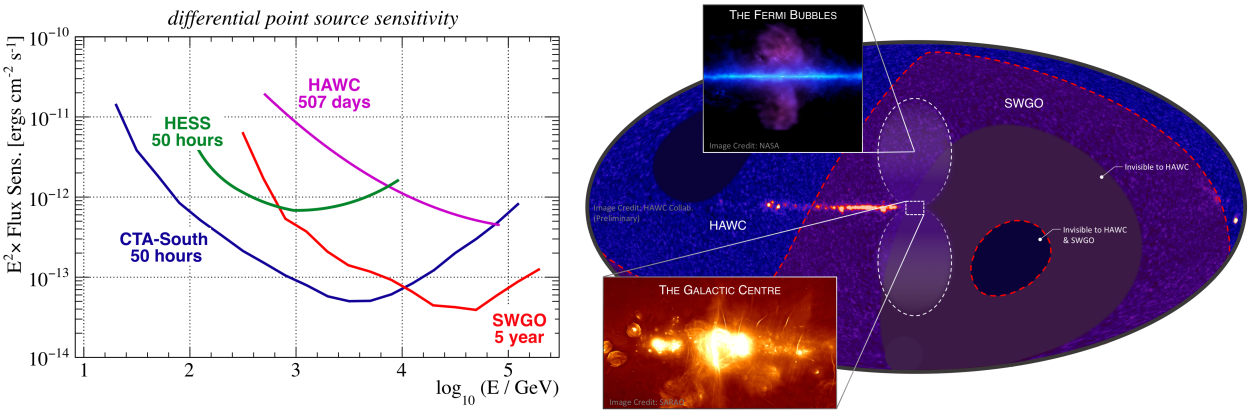

Figure 1: *Left:* Differential point-source sensitivity as a function of energy for the proposed SWGO detector compared to other existing or proposed instruments. *Right:* Sky coverage of SWGO in Galactic coordinates overlaid on HAWC significance map containing over 50 sources.

The core science cases of SWGO are as follows:[1]

- Detection of short-timescale phenomena[25]— low-energy threshold for detection of short-timescale (<1 hr) transient events down to 100 GeV
- Search for PeVatrons[26]— Improved sensitivity up to a few 100s of TeV to search for PeV Galactic particle accelerators

Objective	Major Requirements
Measure TeV halos around nearby PWNe	wide field-of-view
Identify sources of PeV Galactic cosmic rays	sensitivity to highest energies
Measure the Galactic Center morphology	wide field-of-view, sensitivity to highest energies
Study the nature of the Fermi bubbles	wide field-of-view
Measure the Galactic diffuse emission	wide field-of-view
Measure the local cosmic-ray anisotropy	wide field-of-view
Measure solar cosmic-ray interactions	large unbiased duty cycle
Search for new Galactic VHE emitters	wide field-of-view, large unbiased duty cycle
Detect AGN flares and issue alerts	large unbiased duty cycle, sensitivity $\lesssim$1 TeV
Search for periodicity in AGNs	large unbiased duty cycle
Measure long-term emission from AGNs	large unbiased duty cycle
Search for neutrino VHE counterparts	large unbiased duty cycle
Search for counterparts to GW events	wide field-of-view, large unbiased duty cycle
Measure nearby bright GRBs	wide field-of-view, sensitivity $\lesssim$1 TeV
Search for dark matter annihilation/decay	wide field-of-view, sensitivity to highest energies
Probe Lorentz invariance Violation	sensitivity to highest energies
Search for PBHs and ALPs	wide field-of-view

Table 1: Key objectives for SWGO and the most important requirements for achieving them, that is, the properties that make SWGO ideal for such studies (from Ref. 2; reproduced with permission).

- Pulsar Wind Nebulae (PWNe) and Gamma-ray halos[27]— Unique potential for accessing the high-energy end of the Galactic population
- Dark matter and diffuse emission[28;29]— Unique access to the Galactic Center and Halo at the high-energy end of the spectrum
- Cosmic rays[30]— Unique complement to LHAASO for anisotropy studies, with the capability to reach low angular scale. Additionally, good muon tagging implies good mass resolution for composition studies up to the *knee*

The key science objectives of SWGO appear in Table 1, along with the design requirements necessary to achieve them. Sensitivity to astrophysical particle accelerators in the local Galactic neighborhood is one of the greatest strengths of SWGO. Measurements of TeV gamma-ray emission around Geminga and PSR B0656+14 by HAWC suggest that nearby pulsars strongly influence their surroundings[13], leading to a new understanding of particle propagation in the vicinity of PWNe[31]. The large angular extents of these TeV halos allow us to study the propagation of particles within them in unprecedented detail[32]. Locating SWGO in the Southern Hemisphere will place within reach $\sim$12 Geminga-like middle-aged pulsars within 1 kpc of Earth for study, along with many older and/or more distant pulsars likely to have similar TeV halos. A thorough understanding of these local accelerators is necessary for interpreting the unexpected excess of positrons observed at Earth[33], either as being due to a local source or some more exotic mechanism[34;35]. Additionally, with its sensitivity to the highest energies, SWGO is uniquely suited to detect sources of cosmic rays with energies in excess of 1 PeV—expected to produce VHE gamma rays above 100 TeV[20;36–38]—and measure any cutoffs in their spectra that indicate the maximum energy to which they are able to accelerate particles.

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