Snowmass2021 - Letter of Interest

*Searching for Dark Matter Signals in the Galactic Center 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: Despite mounting evidence that astrophysical dark matter exists in the Universe, its fundamental nature remains unknown. In this Letter, we present the prospects to detect and identify dark-matter particles through the observation of very-high-energy ($\gtrsim$ TeV) gamma rays coming from the annihilation or decay of these particles in the Galactic halo. The observation of the the Galactic Center and a large fraction of the halo by the future Southern Wide-field Gamma-ray Observatory (SWGO) would reach unprecedented sensitivity to dark-matter particles in the mass range of $\sim$500 GeV to 100 TeV. Combined with other gamma-ray observatories (present and future), a thermal relic cross-section could be probed for all particle masses from nearly 100 TeV down to the GeV range in most annihilation channels.

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

Although the evidence for astrophysical dark matter (DM) is plentiful, the nature of the DM is undetermined. One primary direction for DM searches is for Weakly Interacting Massive Particles (WIMPs). These are particles with masses in the GeV–100 TeV range and weak-scale interaction strength, although related models have expanded the mass range to include PeV masses and stronger interactions, or even decaying DM (e.g., dark glueballs[3–9], and hidden sector DM[10;11]).

If the DM has a mass well above the TeV scale, the only discovery space may be astrophysical— these particles would be well above achievable collider searches for DM and would have number densities too low for direct-detection searches. However, with the high-dark-matter-density regions observed astrophysically and the high-energy reach of astrophysical experiments, DM masses much greater than 1 TeV can be probed through their annihilation or decay. In particular, the Galactic Center (GC) region is the most interesting location to look for gamma rays from DM interactions. This region is expected to be the brightest source of DM annihilations in the gamma-ray sky by several orders of magnitude due to its large DM density and relative proximity to Earth. Even considering possible signal contamination from other astrophysical sources, it is one of the most promising targets to detect the presence of new massive particles. An experiment constructed in the Southern Hemisphere, designed for the observation of extended sources of gamma rays at the TeV scale and above, would be highly sensitive to these DM gamma-ray signals due to the GC transiting close to directly overhead in relation to the experiment.

We propose a next generation gamma-ray observatory that will have the best sensitivity at high energies ($>$10 TeV). The Southern Wide-field Gamma-ray Observatory (SWGO)[12;13] is planned to be located in the Southern Hemisphere and have a sensitivity $\sim 10\times$ better than the High-Altitude Water Cherenkov (HAWC) Observatory[14]. Both measure relativistic particles in extensive air showers caused by cosmic-ray and gamma-ray interactions in the atmosphere. These arrays have a wide field-of-view and observe $\sim 2/3$ of the sky every day with a near-100% duty cycle. They complement Imaging Atmospheric Cherenkov Telescopes (IACTs), which have smaller fields-of-view. For example, SWGO will be able to observe extended objects, like the regions relatively far from the GC, allowing for backgrounds that minimize contamination from gamma-ray sources, thus increasing its sensitivity to emission from the wider DM halo. This ability to observe a more extended region makes the sensitivity less dependent on the assumed behavior of the DM density profile than pointed IACTs.

Figure 1 shows the 95% C.L. sensitivity upper limits on $\langle\sigma v\rangle$ (the thermal relic cross-section) versus $M_{\rm DM}$ for three annihilation channels from 10 years of observation with SWGO, here modeled as a 200,000 m^2 water Cherenkov detector (10 times the HAWC area). A sensitivity smaller than the nominal thermal relic cross-section $\langle\sigma v\rangle \lesssim 3 \times 10^{-26}$ cm^3 s^{-1} is reachable in the mass range of ∼500 GeV to 100 TeV in some channels.

By combining deep observations of the GC region by a ground-based gamma-ray survey observatory with other gamma-ray observatories, such as the *Fermi*-LAT[18] and the Cherenkov Telescope Array (CTA)[19], a thermal relic cross-section could be probed for WIMP masses $\lesssim$ 100 TeV in most annihilation channels (see Figure 1 and Refs. 17;20). For masses close to the overlap region with CTA, greatly increased confidence in a detection could be achieved by measurements in both detectors.

The DM flux spectra are characterized by a hard cutoff at the DM mass; observing such a cutoff would be one of the strongest indications that an observed gamma-ray source originates from DM interactions. SWGO achieves peak sensitivity at the energy scale where these cutoffs would be apparent for multi-TeV-mass DM. In the case of a DM particle in the mass range 10–80 TeV annihilating into $\tau^+\tau^-$, such an instrument would provide the WIMP mass measurement by probing the spectral cutoff, with CTA helping to constrain the morphology. We note that this mass range also has considerable foreground advantages over the GeV range in terms of astrophysical foreground, with a much shorter list of objects capable of accelerating particles to these energies and, in particular, avoiding the magnetospheric emission of pulsars

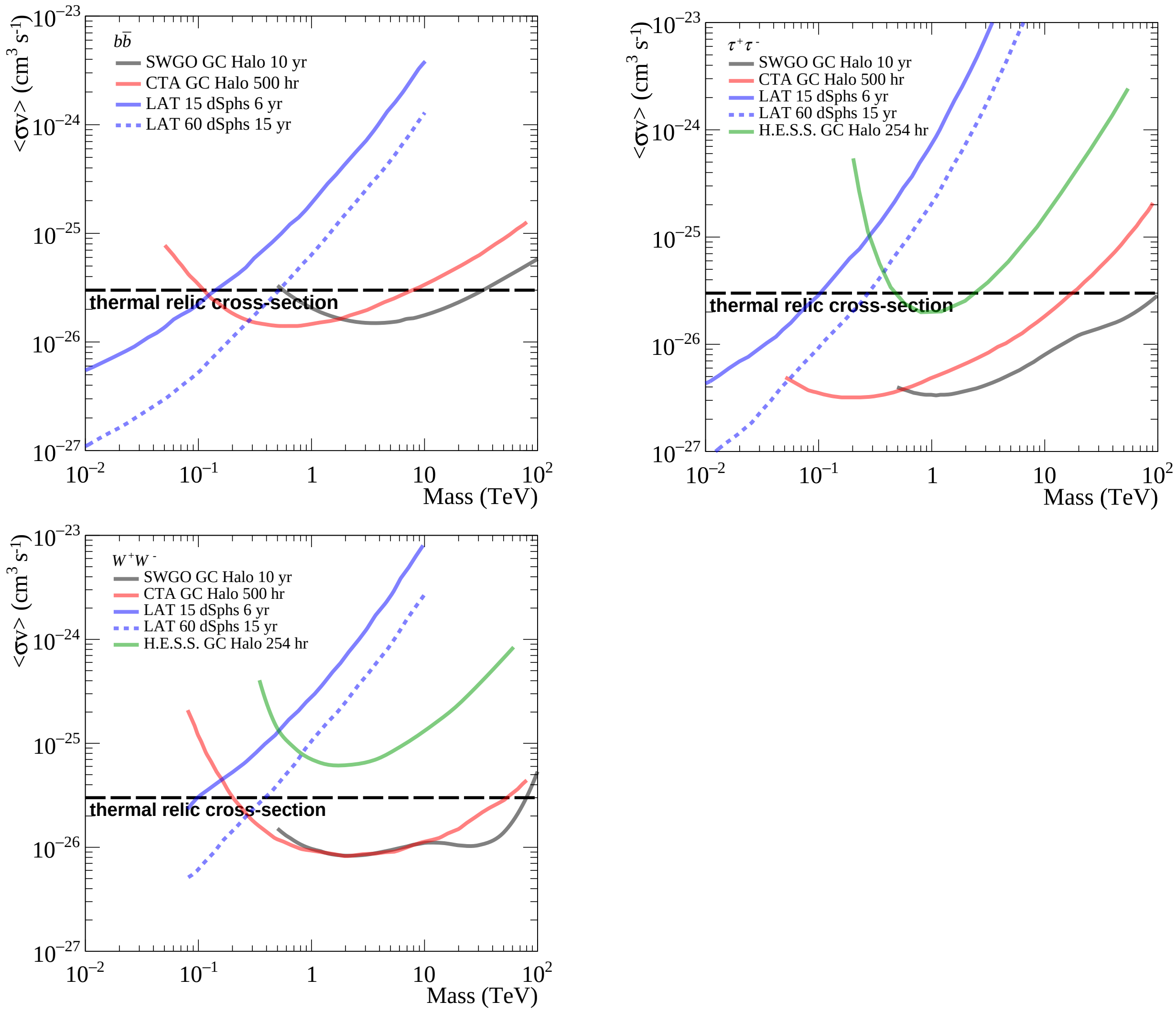

Figure 1: Expected 95% C.L. upper limit on the velocity-weighted cross section for DM self-annihilation into $\tau^+\tau^-$ (top-left), $b\bar{b}$ (top-right) and W^+W^- (bottom) as a function of $M_{\rm DM}$, for SWGO and CTA [15] observations of the GC halo. Current Galactic Center H.E.S.S. limits [16] towards the GC halo, and Fermi-LAT limits towards dwarf galaxies (solid blue line) as well as projected sensitivities (dashed blue line) are also plotted [17]. The nominal value of the thermal-relic cross-section is plotted as well (long-dashed black line).

whose spectra can mimic a DM annihilation spectrum in the GeV [21;22].

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