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Galactic Centre with the Southern Wide Field-of-view Gamma-ray Observatory

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The Galactic Centre (GC) region is a highly interesting region for very high energy gamma-ray studies due to its proximity and diverse sources. It is also a unique place for Dark Matter (DM) searches, since we expect a large amount of DM in this region and it is nearby. Currently a new detector is under development to observe the GC region, called the Southern Wide field-of-view Gamma-ray Observatory (SWGO). This instrument will be the first water Cherenkov detector located in the Southern Hemisphere sensitive to >100 GeV gamma rays. In our work, we are going to present a simulation of the GC gamma-ray emission as seen by a SWGO-like observatory. To do so we are using the models published by the Cherenkov Telescope Array (CTA) Collaboration together with simulated Instrument Response Functions (IRFs) for testing purposes. This also allows us to predict the expected sensitivity of SWGO to WIMP DM annihilations using a template based method. A sensitivity study during the design phase of the observatory is important in order to choose the best detector design to get outstanding physics results.

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1. Introduction

The central few hundred parsecs of our galaxy are one of the most complex regions to be studied in gamma-ray emission, due to its rich diversity of sources. The central source detected by the H.E.S.S.Collaboration [1] and the Supernova Remnant (SNR) G0.9+0.1 [2] are surrounded by very energetic diffuse emission. This diffuse emission has been modelled by the H.E.S.S.collaboration and follows roughly the distribution of the gas in the Central Molecular Zone (CMZ). However the cosmic ray density within few tens of parsecs was found to increase towards the Galactic Centre (GC) [3, 4]. This suggests that relevant particle acceleration is taking place in the GC region. However the origin of the particle acceleration is still unclear and under debate.

The GC has also been observed at very-high-energies by *Fermi*-LAT, which discovered the amazing Fermi Bubbles [5, 6]. This feature is very similar to outflows observed in other galaxies, and supports once again the presence of particle acceleration in the region.

So far *Fermi*-LAT and H.E.S.S. inspected the emission and spectrum of the accessible components in the gamma-ray regime, but none of the existing water tank Cherenkov Detectors (HAWC and LHAASO) has the GC in their field of view. The Southern Wide field-of-view Gamma-ray Observatory (SWGO) aims to fill this gap. SWGO [7, 8] will be a ground-based particle detector located in the Southern Hemisphere. SWGO will have a very high duty cycle and wide-field of view observatory. This instrument is now in its design phase. In addition to being the only wide-field of view TeV observatory in the Southern Hemisphere, it will be complementary to the Cherenkov Telescope Array (CTA), which will have a much smaller field of view. Observations with this kind of instrument will expand our knowledge about the emission of the sources in the GC region up to higher energies. Therefore, we will be able to better constrain the particle acceleration models and improve our understanding of the astrophysical scenario in the GC.

In this proceeding, we present a very preliminary simulation of the GC region as seen by an observatory like SWGO. This has been done using the simulated SWGO "straw man" configuration [9] instrument response functions (IRFs), together with models of the gamma-ray sources provided by the CTA Collaboration. For simplicity, we limit the components of our simulation to the three mentioned sources, plus the diffuse galactic background.

The Dark Matter (DM) sensitivity prediction in the GC region has also been studied. The interest in DM detection in this region is justified by the expected increase of DM density towards the center of the galaxy. This is reflected in DM distributions following cuspy profiles, like the Navarro–Frenk–White (NFW) profile [10] and the Einasto profile [11]. On the other hand, the Weakly Interacting Massive Particles (WIMPs) have been proposed as one of the candidate particles for DM [12–14]. Here the NFW and the Einasto profiles are used to predict SWGO sensitivity to WIMP DM annihilation, using a template based model to study the energy-dependent behaviour. The region of interest in the previous study with SWGO IRFs [15] was imited to the inner 10° of the galaxy and the central ±0.3° band in Galactic latitude was masked to avoid standard astrophysical background. In our analysis, we focuse on the central 2° of the GC region. And masking is not applied, instead we include the astrophysical sources into our model fitting.

2. SWGO Observatory

SWGO is an under research and design phase observatory, currently reaching its Milestone M6. It is expected to be a huge array of particle detector units, filling a km square area, at a height of above 4000 km. There are three primary technology options for the water Cherenkov detector units for SWGO: individual tanks (as in HAWC), artificial water volumes in ponds (as in the WCD of LHAASO) and individual bladders in to a natural lake.

Several candidate sites have been considered, all of them in South America. The reference configuration [16] of the detector units, as a starting point to perform scientific evaluations is based on 3.8 m diameter and 3 m deep tanks divided in to a top layer and a muon rejection layer. The reference configuration of the array of detectors consists of a dense central array with a fill factor ≈80% extending out to 160 m, and a much lower density (fill factor ≈5%) outer detector array out to 300 m.

The "straw man" configuration used to produce the IRFs adopted in this work[1] is, however, an older toy model of the SWGO observatory as explained in [9]. The authors want to emphasize that this is an example set of IRFs for testing purposes and that the preliminary results in this proceeding does not imply the expected or final performance of SWGO itself.

3. The Galactic Centre at Very-High-Energies

The non-DM three gamma-ray sources considered here to simulate the GC in gamma-rays are:

- the point-like central source or HESS J1745-290, in spatial coincidence with the central super massive black hole SgrA*,
- the point-like composite pulsar wind nebula and SNR 0.9+0.1,
- and the diffuse emission from the GC ridge or central molecular zone (CMZ)

The spatial and spectral models of the sources follow those provided by the CTA repository [17]. These models are based on past and currently existing IACTs observations, with addition of sources detected by *Fermi*-LAT based on the 3FHL catalogue and by HAWC based on the 2HWC catalogue. A diffuse background emission for the full sky has been also included [].

The tool used to make the simulation is Gammapy version 1.1, which is a open-source Python package for gamma-ray astronomy data analysis [18, 19].

In figure 1 we show the central ≈200 pc of the simulated GC. The spectrum of each of the components are in figure 2. The result corresponds to a observation time of 365 transits (days).

We plot the spectrum of the two point-like sources on the explored differential point source sensitivity phase-space for SWGO in the design phase in figure 3. It can be seen that the gamma-ray emission from the non-DM sources will be detected within one year of observation according to the expected sensitivity.

[1] `https://github.com/harmscho/SGSOSensitivity`

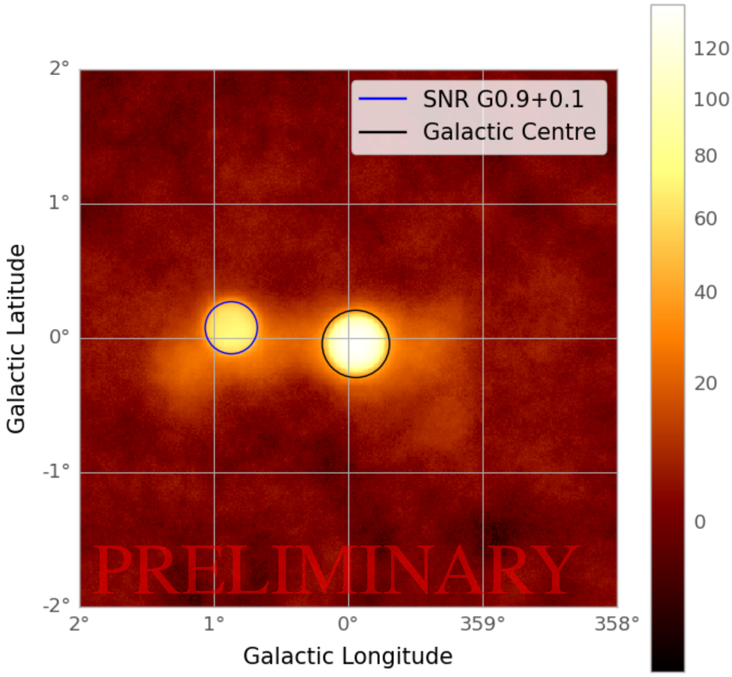


Figure 1: The significance map computed using a correlation radius of 0.1 degrees of the simulated GC region. The colors are the square root of TS. The list of components includes: the central source, SNR 0.9+0.1, the diffuse GC ridge and the diffuse background emission. The integration in energy ranges from 100 GeV to 200 TeV and the observation time is 1 year (365 transits).

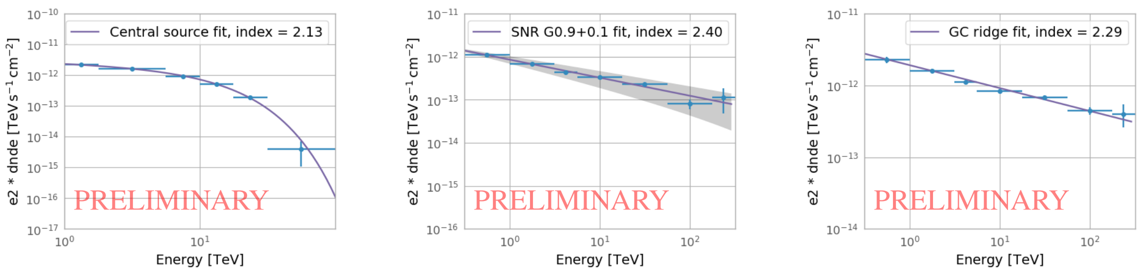


Figure 2: Spectrum of the three simulated sources. Fit of the spectrum with a exponential cut-off power law model for the central source (left), and a simple power law model for SNR 0.9+0.1 (middle) and the GC ridge (right).

4. Dark Matter sensitivity

Two different DM density profiles: NFW and Einasto has been examined for the DM analysis. The DM mass ranges from 500 GeV to 100 TeV, and the observation time for this analysis is ten years. Moreover, only the WIMPs self-annihilation process is considered, for DM particles annihilating into 2 different channels: $b\bar{b}$ and $\tau^+\tau^-$. The velocity-weighted cross section at a corresponding expected upper limit at 95% confidence level (CL) is computed. This is done by comparing the null hypothesis likelihood (model without DM) against the hypothesis with DM likelihood, evaluated at

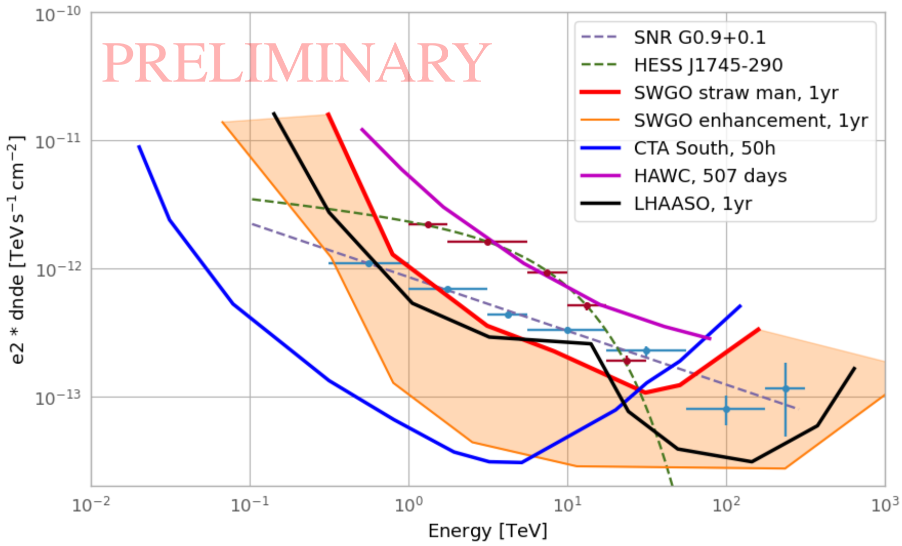


Figure 3: Spectrum of the two point sources: the central source and SNR 0.9+0.1, on top of the expected point source SWGO sensitivity phase-space, for a observation time of one year. Also plotted are the sensitivity curve of other observatories, with a certain observation time.

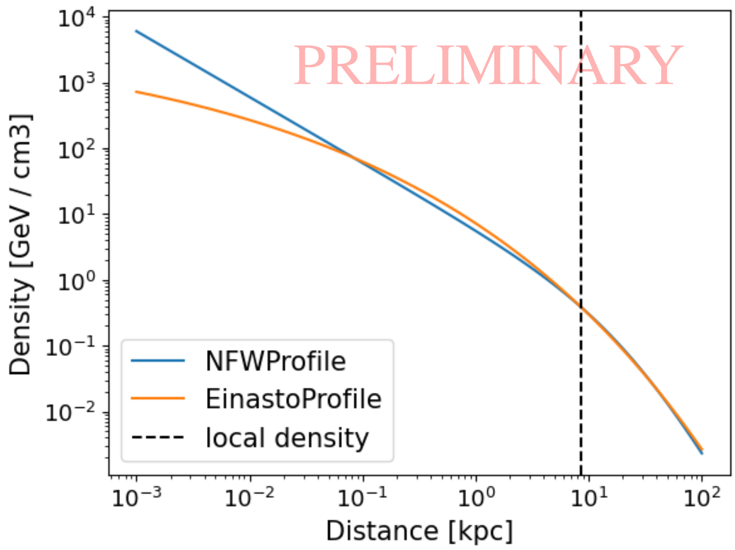
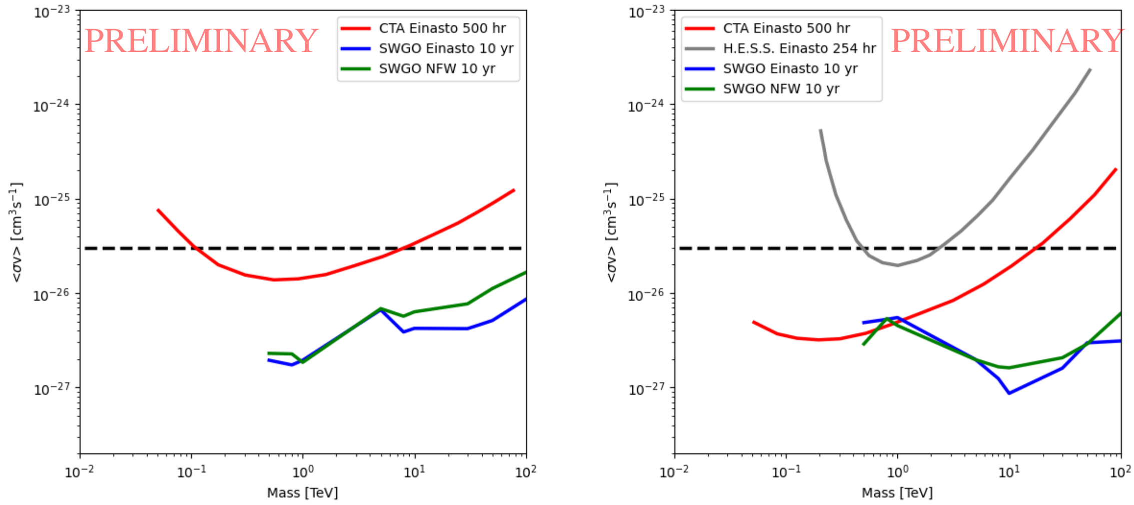


Figure 4: The NFW profile and the Einasto profile as function of the distance to the GC.

the value of the cross section which maximizes the likelihood, as following the method described in [15].

The two different DM profiles are shown in figure 4, where the vertical line indicates the local DM density, i.e. at a distance of 8.5 kpc from the GC. The velocity-weighted cross section at 95% CL for each channel, DM mass and DM density profile is shown in figure 5.



(a) $b\bar{b}$ **(b)** $\tau^+\tau^-$

Figure 5: The velocity-weighted cross section for DM self-annihilation at a expected 95% C.L. upper limit. The horizontal line is the thermal relic annihilation cross-section ($\sim 3 \times 10^{-26} cm^3 s^{-1}$ [20]). Left: Self-annihilation of the DM particles into $b\bar{b}$. Right: Self-annihilation of the DM particles into $\tau^+\tau^-$. The observation time is 10 years (3650 transits). CTA and H.E.S.S. curves are extracted from [15]. We emphasize that this is a result for an example set of IRFs for testing purposes, therefore this does not imply the expected or final performance of SWGO itself.

5. Conclusions

We develop a method to simulate the gamma-ray emission from the GC region detected by a SWGO-like observatory, with a wide field of view in the southern hemisphere. The spectrum of each of the simulated sources (central source, SNR G0.9+0.1 and GC ridge) are shown. And we compared the spectrum of the two point-like sources to the explored SWGO sensitivity phase-space. It is shown that observations with SWGO will extend the known spectrum to higher energies, and thus will further constrain the spectral models for these sources.

From the DM point of view, we computed the expected upper limits for WIMPs self-annihilation using two different DM density profiles and two annihilation channels.

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