Dark Matter Searches with Wide-field TeV Observatories

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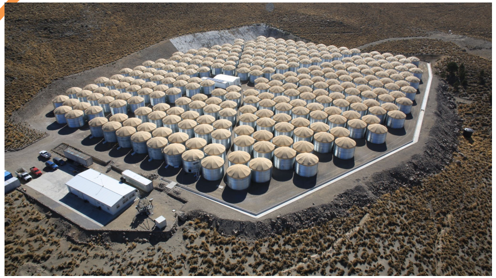
HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

Wide-field Gamma-ray Observatories

SWGO
The Southern Wide-field
Gamma-ray Observatory

GeV Gamma-ray
Wide FoV



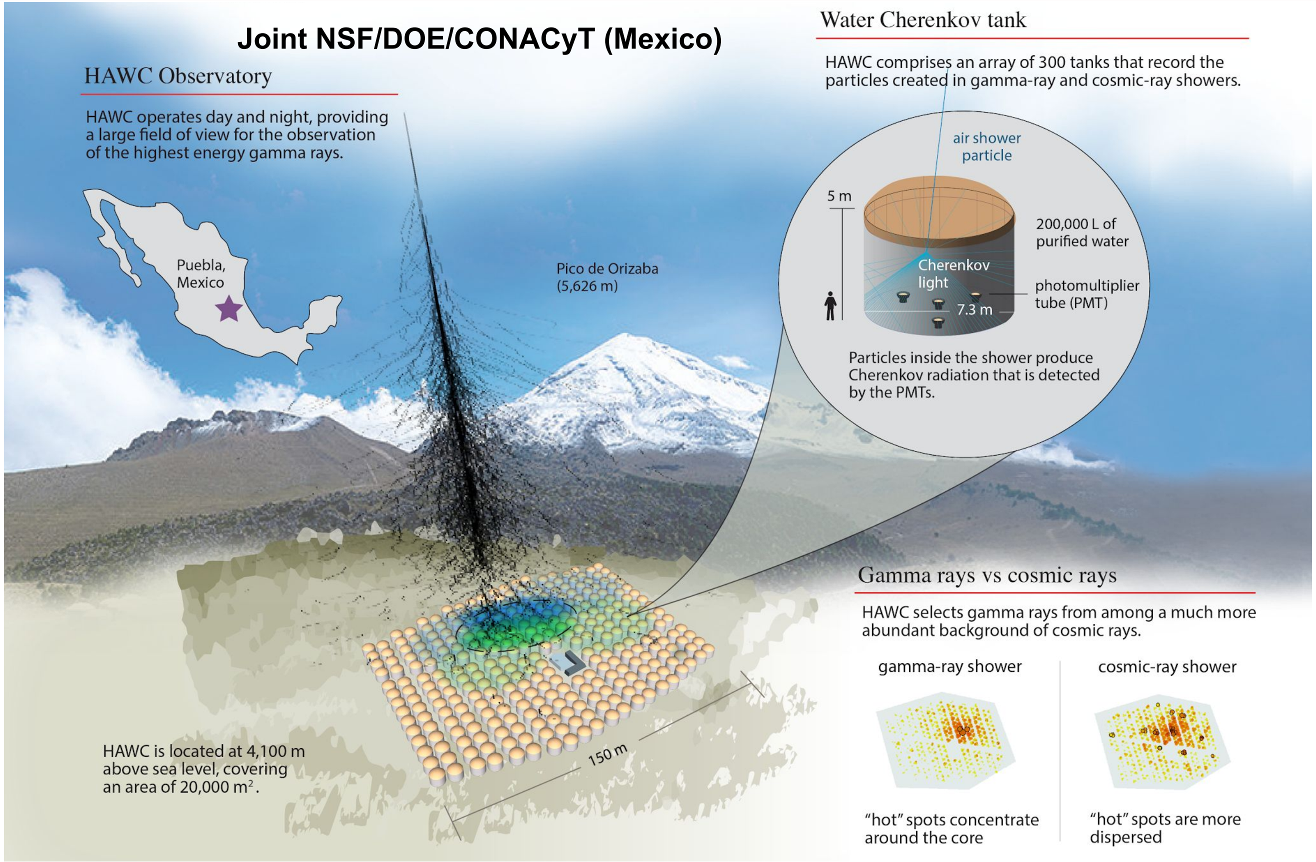
e.g. HAWC, LHAASO, SWGO
TeV Gamma-ray Wide FoV

IACTs (e.g. HESS)
TeV Gamma-ray
Small FoV

Wide-field Gamma-ray Observatories

	Ground-particle Arrays	IACT Arrays
Field of view	90°	3°–10°
Duty cycle	>95%	10%–30%
Energy range	∼500 GeV – >100 TeV	30 GeV – >100 TeV
Angular resolution	0.4°–0.1°	0.05°–0.02°
Energy resolution	60%–20%	∼7%
Background rejection	90%–99.8%	>95%

The High Altitude Water Cherenkov Gamma-ray Observatory (HAWC)

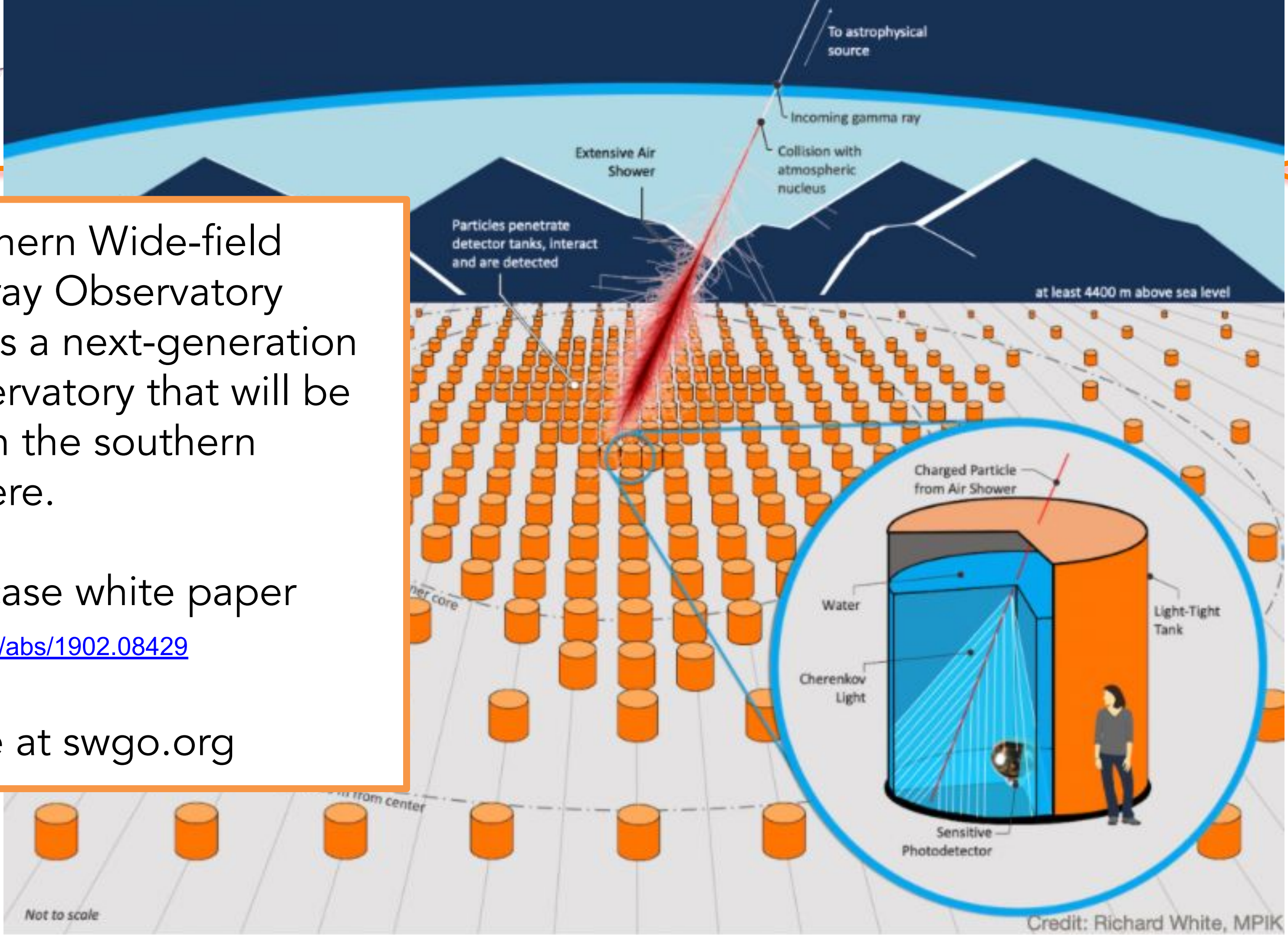


The Southern Wide-field Gamma-ray Observatory (SWGO) is a next-generation TeV Observatory that will be located in the southern hemisphere.

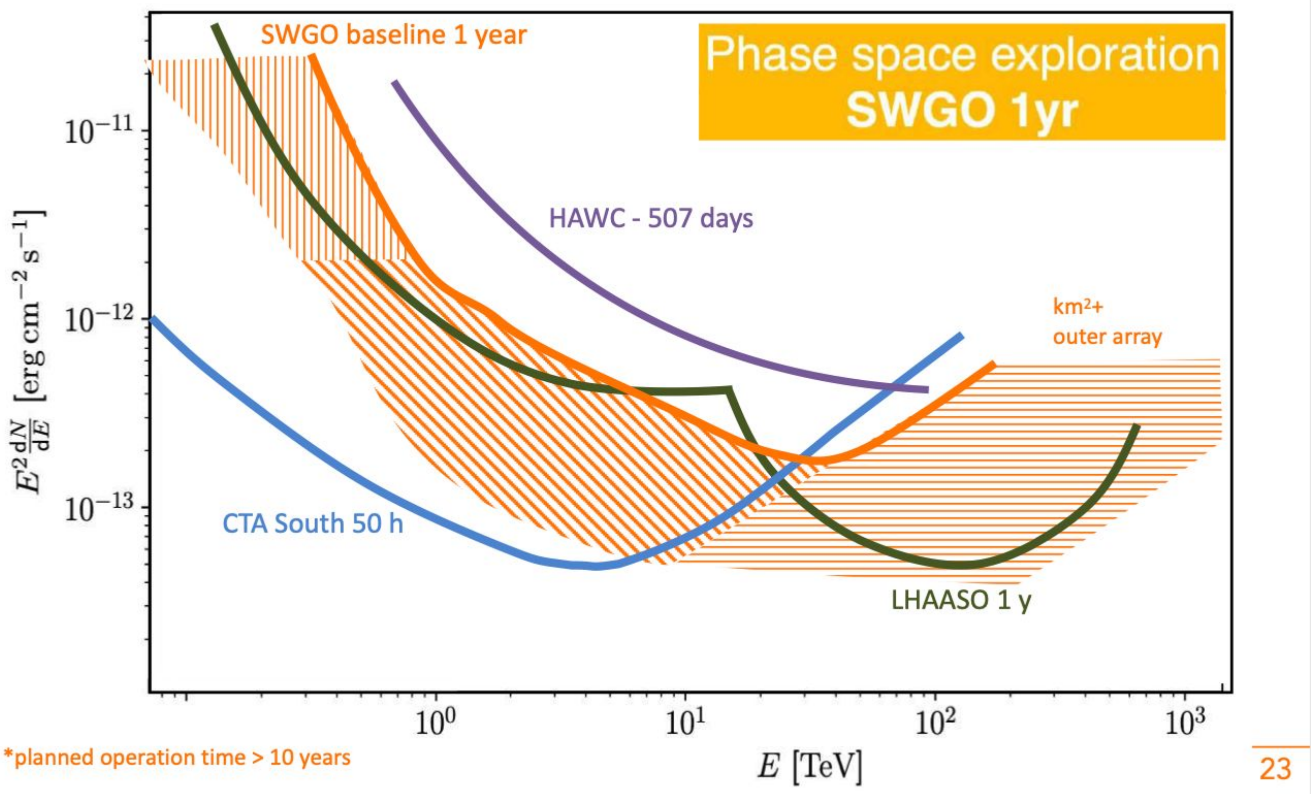
Science case white paper

https://arxiv.org/abs/1902.08429

See more at swgo.org



Gamma-ray Sensitivity



*planned operation time > 10 years

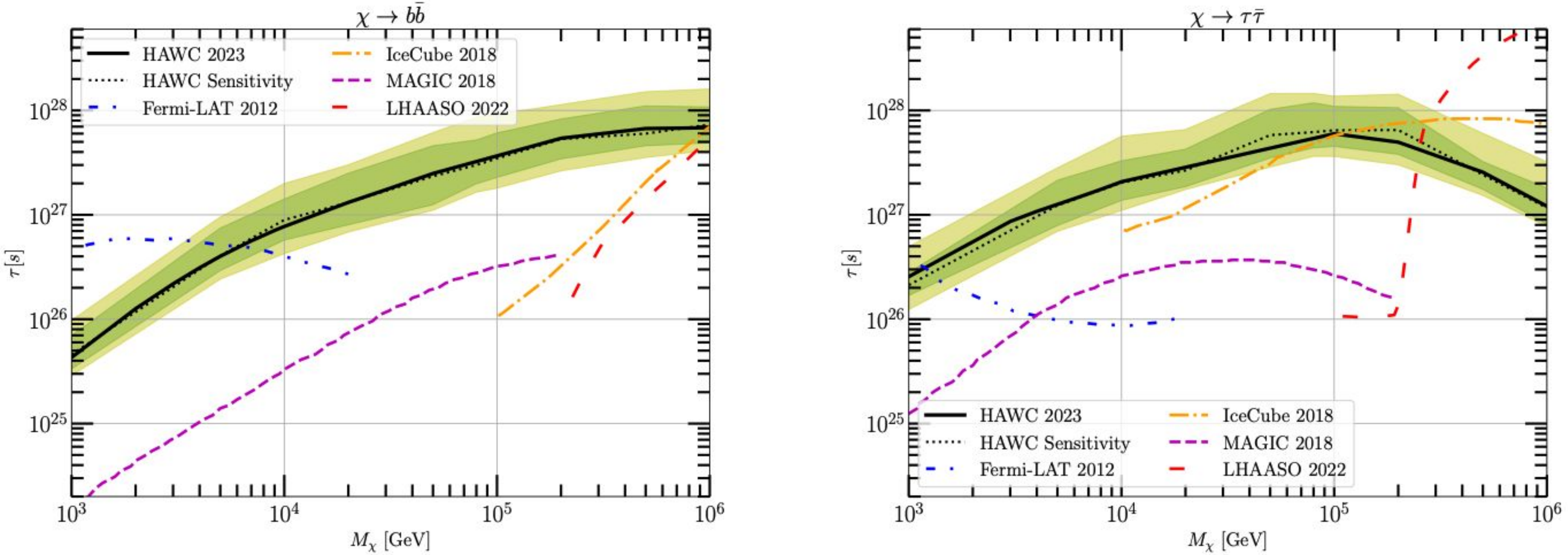
Wide FoV Dark Matter Searches

- Gamma rays maintain directionality so we search for gamma ray sources in dark matter rich regions from dark matter annihilation/decay

- Wide FoV advantage
  - Wide field of view -> daily monitoring of several DM regions
    - Galactic Center, dwarf galaxies, galaxy clusters, undiscovered dwarfs, dark subhalos
    - Which sources you are sensitive to depends on your location! (e.g. northern or southern hemisphere)
  - Wide field of view -> good sensitivity to extended sources
    - e.g. the Galactic Center, Virgo Cluster
  - High energy reach -> most sensitive for DM mass above ~20 TeV
    - Better sensitivity at high energies than CTA
    - More overlap with IceCube DM search parameter space
      - Multimessenger studies!

HAWC Dark Matter Searches
Virgo Cluster

DM Decay Lifetime Lower Limits

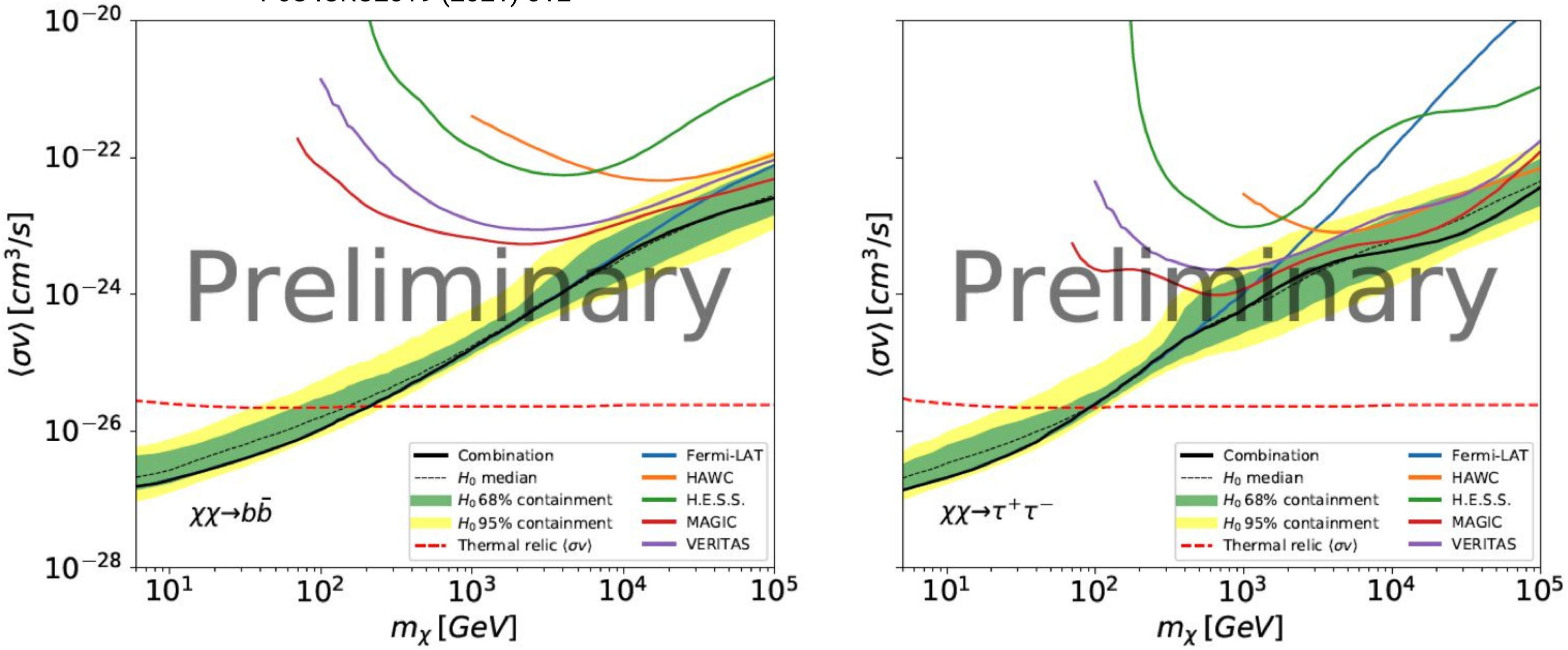


HAWC Collaboration submitted to PRD (2023)

- → Extended source (8°)
- → HAWC has best decay limits above ~10 TeV
- → Highest energy (mass) overlaps with IceCube -> multimessenger searches

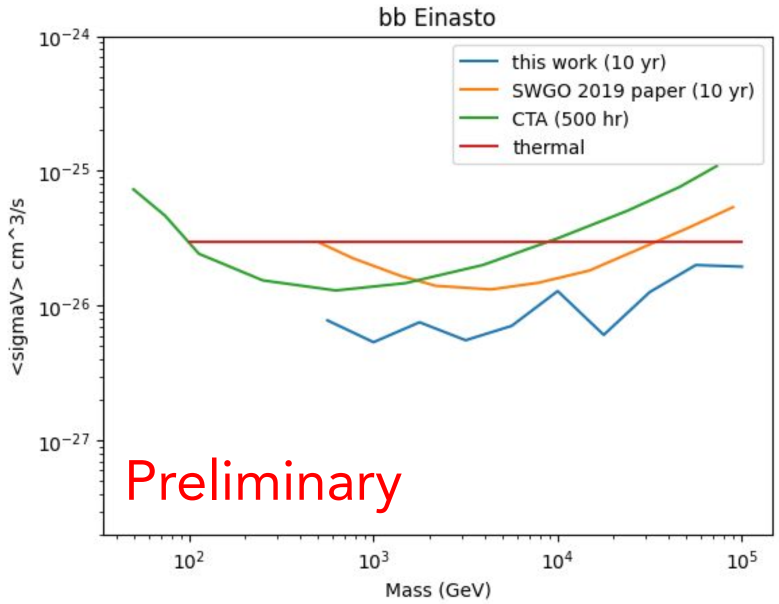
HAWC Dark Matter Searches dSph Galaxies

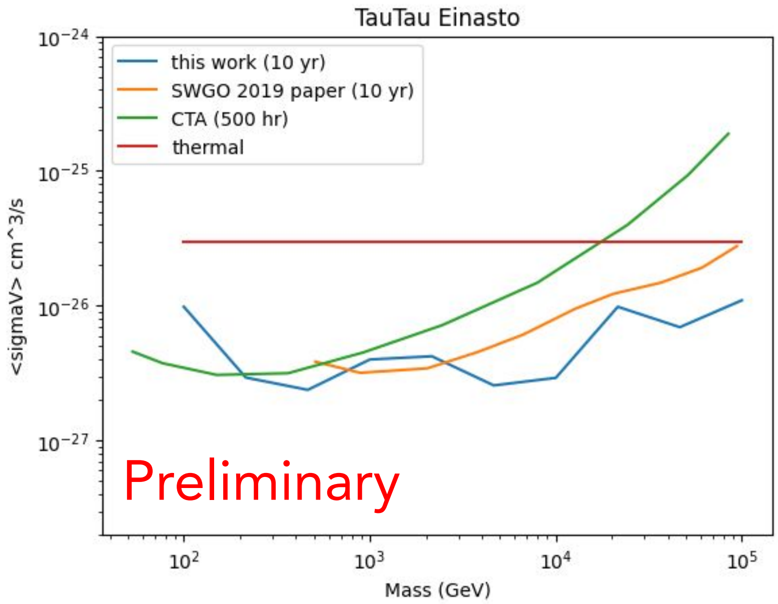
PoS ICRC2019 (2021) 012



- → Joint analysis using 5 gamma-ray observatories
- → Mass 5 GeV – 100 TeV probed

Next Generation Wide FoV Observatory Galactic Center Expected Limits

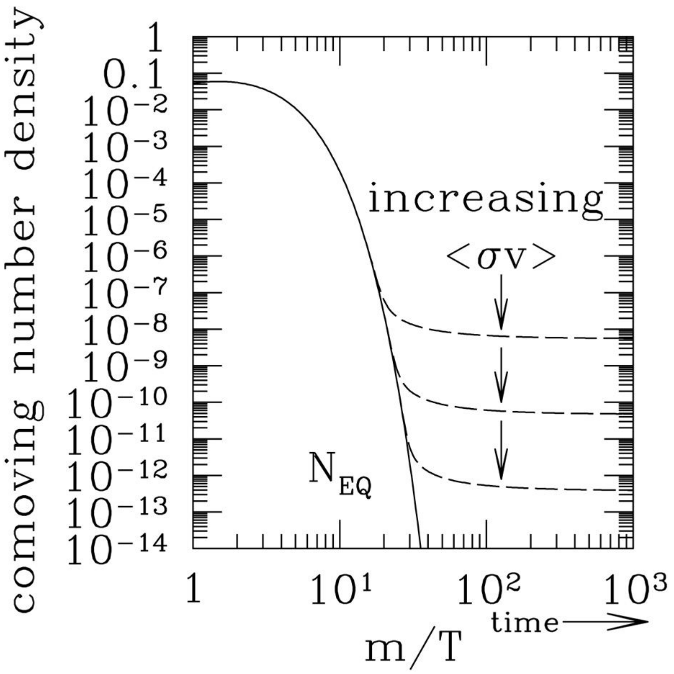




- Results from a preliminary study of DM sensitivity for a future wide FoV observatory
- Template fitting using GammaPy (limits are averaged over 200 simulations/fits); previous 2019 study masked the GP
- Used publicly available “strawman” IRFs https://github.com/harmscho/SGSOSensitivity
  - see SWGO science white paper for details https://arxiv.org/pdf/1902.08429.pdf
- Background Sources were: Sgr A* (HESS J1745-290), SNR 0.9+0.1, IEM, Galactic Ridge
  - See backup slides for detailed background info; used $GAMMAPY_DATA/cta-1dc/index/gps/

Thermal Relic WIMPs are Not Dead

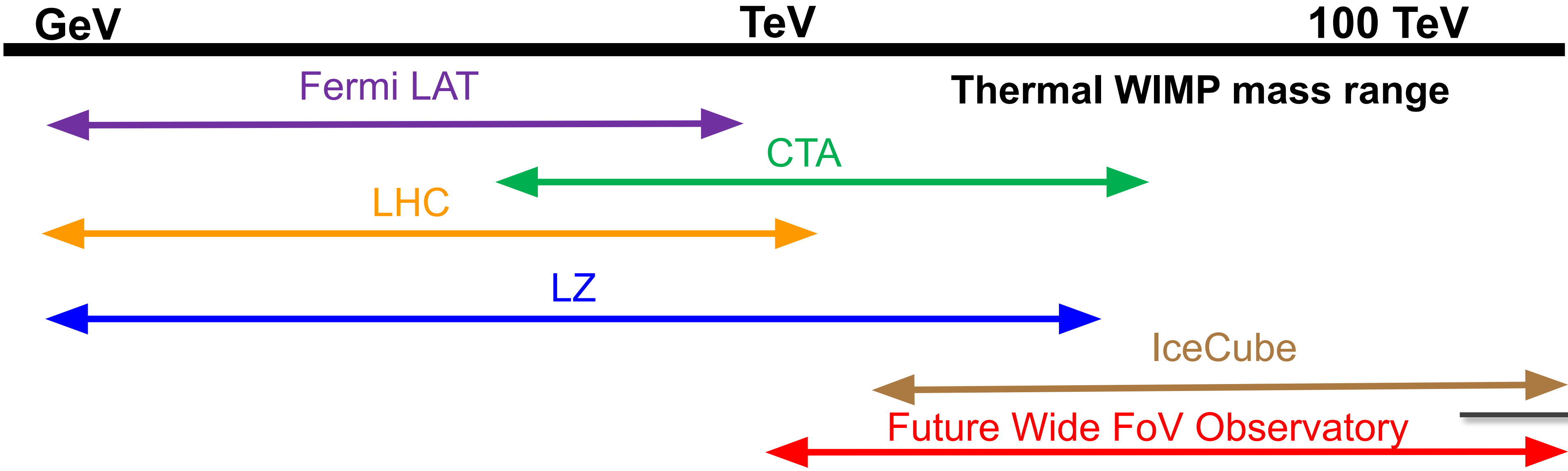
- Weakly Interacting Massive Particle (WIMP)
  5 GeV - 100 TeV mass scale
- A thermally-coupled ~100 GeV particle in the early Universe with weak scale σ_{ann} independently produces the observed dark matter abundance today measured by the CMB
- Several WIMP candidates from independently motivated theories like SUSY
- Thermal WIMPs aren't the only dark matter candidates, but are a well-motivated hypothesis we must test!
  - → We have only just begun to probe WIMP phase space. e.g. Fermi LAT dwarf spheroidal limits exclude mass < ~100 GeV (in bb and tautau chs)
  - → Heavy (> 100 TeV) models also exist
    - ✔ e.g. https://arxiv.org/abs/2208.11740



E. Kolb and M. Turner, *The Early Universe*, Westview Press (1994)

Sensitivities to thermal WIMPs

- Wide FoV is the only future gamma-ray experiment that probe up to 100 TeV in mass
- Wide FoV is the only future gamma-ray experiment with significant overlap with IceCube
  → Multimessenger!
- Indirect (astrophysical) detection is the only way to probe >20 TeV WIMPs



Conclusions

- Wide FoV TeV Observatories offer an exciting and unique view of the gamma-ray sky

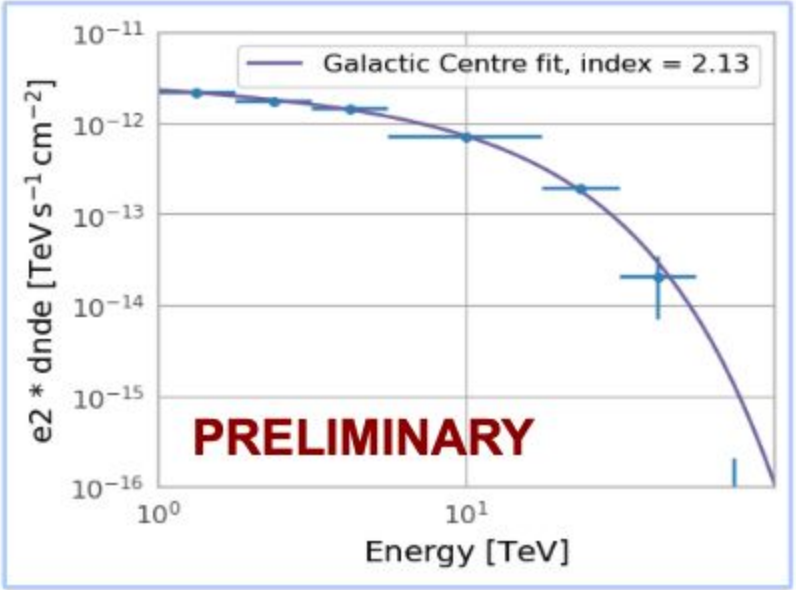
- They are able to probe heavy mass dark matter models other experiments cannot
  - Next generation observatories are expected to reach up to 100 TeV for thermal relic WIMPs

- HAWC has set strong constraints from observations of >20 sources

- Design and sensitivity studies for the next generation Wide FoV TeV Gamma-ray Observatory in the southern hemisphere are underway.
  - Preliminary results show it will open up new regions of DM discovery space

Background Point Sources

- Sgr A* (HESS J1745-290)
  - Power law with exponential cutoff



- SNR 0.9+0.1
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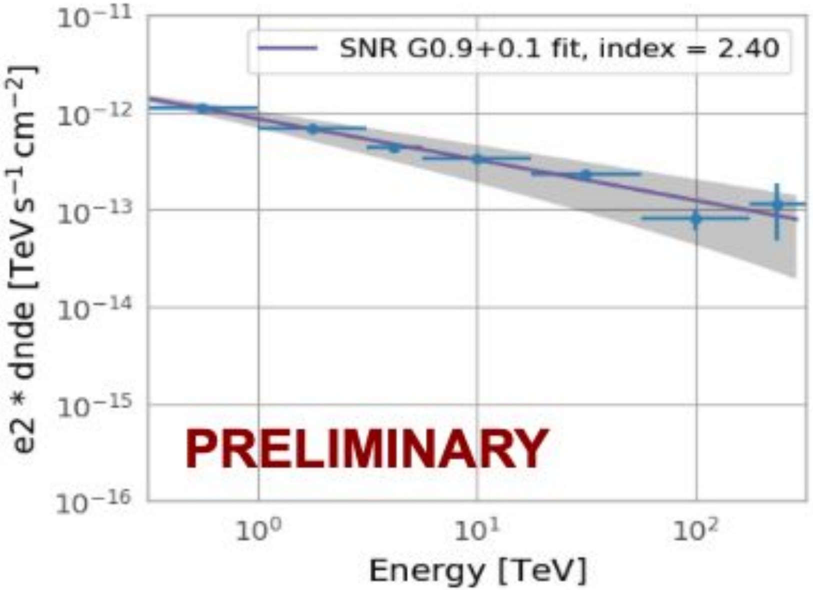
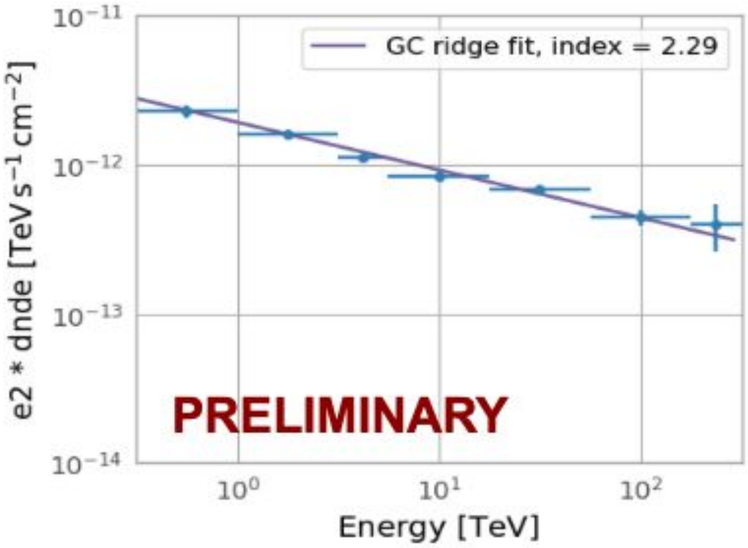


Galactic Center Background Diffuse Sources

- Galactic Ridge IEM default models with GammaPy
  - cta-gps-simulation-paper/skymodel/iem/gcridge_map.fits
  - IEM_base_v2.fits (based on Fermi diffuse gll_iem_v06_cutout)



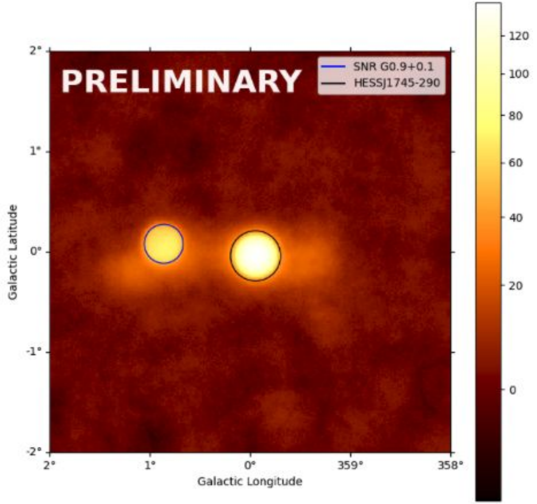
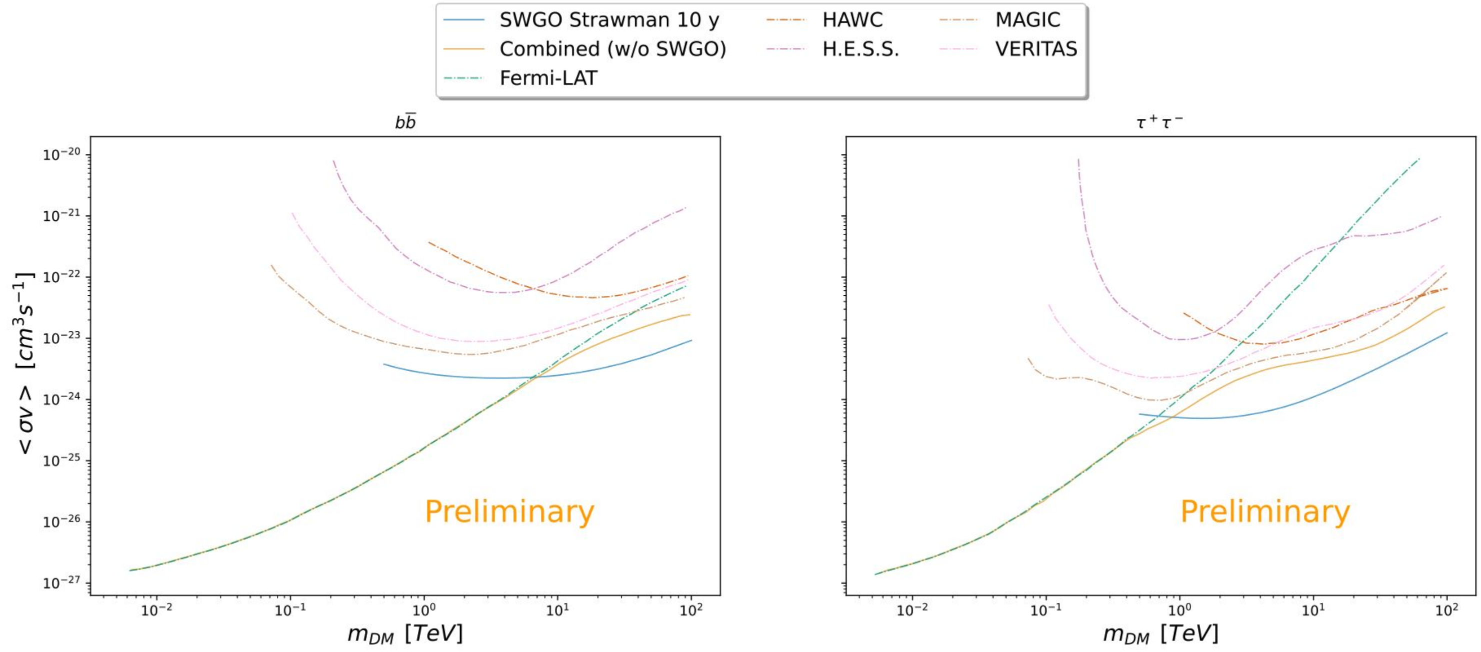


Fig 1: The significance map (correlation radius of 0.1 degrees) of the simulated GC region: the central source, SNR 0.9+0.1, the GC ridge and the diffuse background. Energy ranges from 100 GeV to 200 TeV and observation time is 1 year (365 transits).

Galactic Center Background Sources

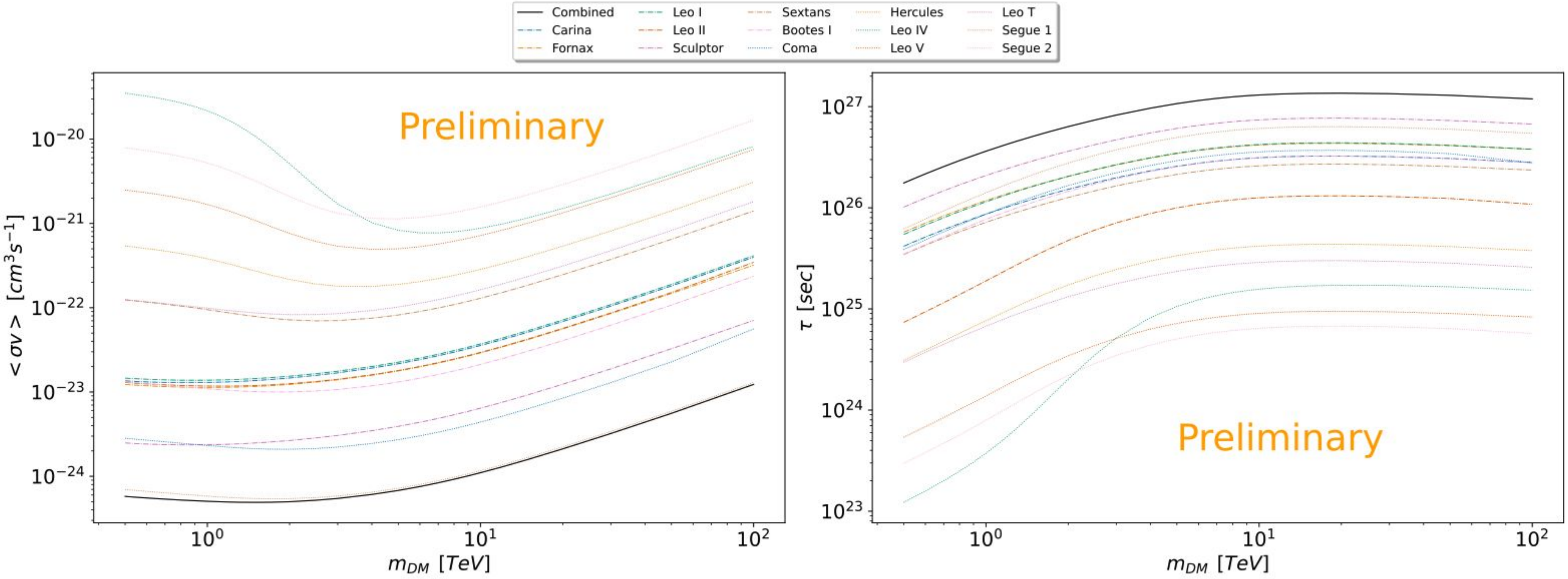
- Sgr A* (HESS J1745-290)
  - Power law with exponential cutoff
  - Index free
  - Amplitude free
  - $\Lambda = 0.1\ \mathrm{TeV}^{-1}$ fixed
- SNR 0.9+0.1
  - Power law with exponential cutoff
  - Index = 2.4, fixed
  - Amplitude free
- IEM default models with GammaPy
  - PowerLawNorm
  - Norm free
  - Tilt = 0, fixed
- Galactic Ridge (from GammaPy)
  - PowerLaw
  - Index = free
  - Amplitude = free

Next Generation Wide FoV Observatory dSph Expected Limits



- Combined limits using 14 dSphs
- Used publicly available "strawman" IRFs https://github.com/harmscho/SGSOSensitivity
- Andrade et al ICRC 2023

Next Generation Wide FoV Observatory dSph Expected Limits



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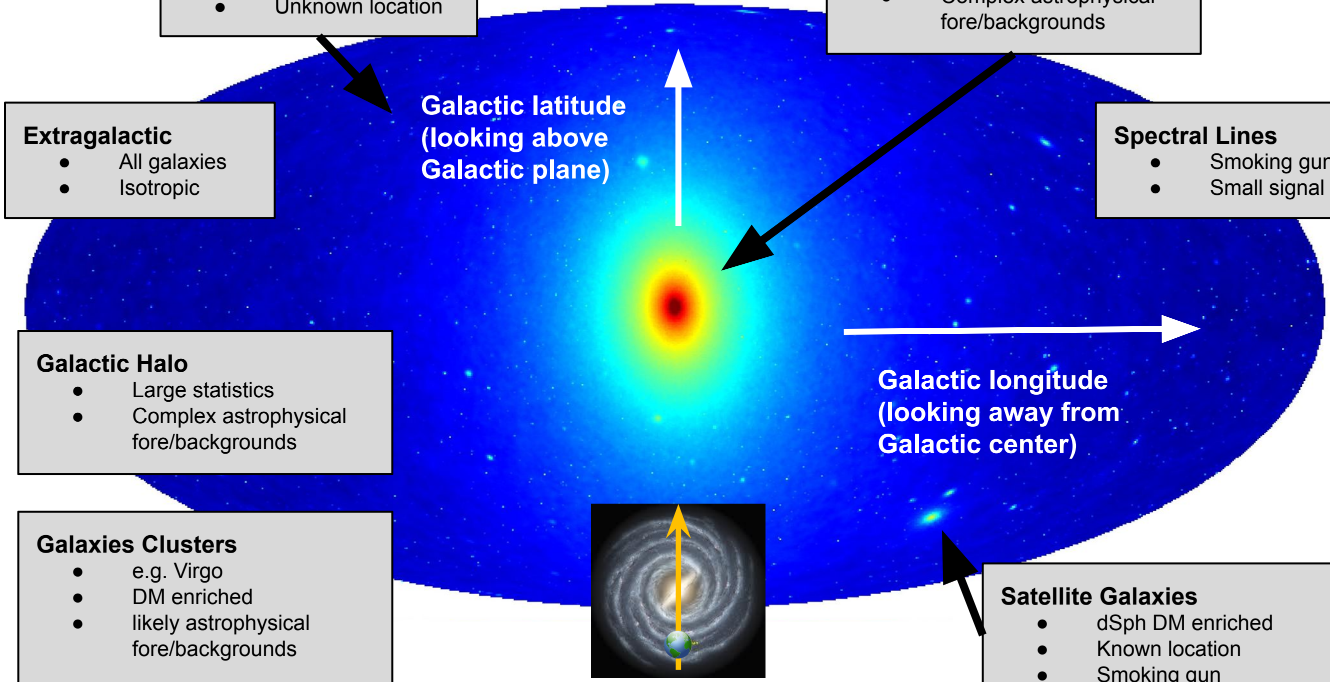
Dark Matter Targets

DM clumps in Halo
- Few backgrounds
- Unknown location

Galactic Center
- Large statistics
- Complex astrophysical fore/backgrounds

Extragalactic
- All galaxies
- Isotropic

Spectral Lines
- Smoking gun
- Small signal



Galactic Halo
- Large statistics
- Complex astrophysical fore/backgrounds

Galaxies Clusters
- e.g. Virgo
- DM enriched
- likely astrophysical fore/backgrounds

Satellite Galaxies
- dSph DM enriched
- Known location
- Smoking gun

Gamma ray signal from dark matter only – Aquarius simulation