The Southern Wide-field Gamma-ray Observatory

SWGO Science WG Activities & opportunities

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SWGO
The Southern Wide-field Gamma-ray Observatory

The Science case for SWGO

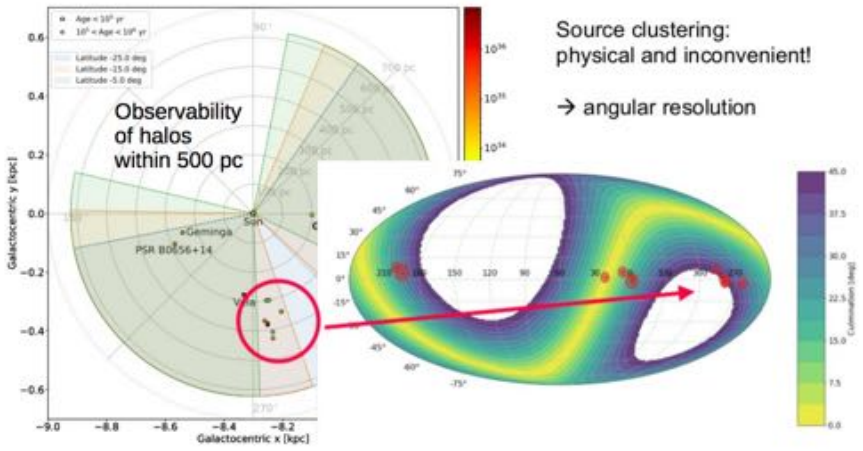
- Detection of short-timescale phenomena
  - Low-energy threshold for detection of short-timescale (< 1hr) transient events down to 100 GeV
- Search for PeVatrons
  - Improved sensitivity up to a few 100s TeV to search for PeV Galactic particle accelerators.
- PWNe and Gamma-ray Halos
  - Unique potential for accessing the high-energy end of the Galactic Population.
- Dark Matter and Diffuse Emission
  - Unique access to the Galactic Center and Halo at the high-energy end of the spectrum.
- Cosmic-rays
  - Unique complement to LHAASO for anisotropy studies, with capability to reach low-angular scale.
  - Good muon tagging implies good mass resolution for composition studies up to the knee.

Science WG organisation

- Galactic Task Force
  - → TF leaders: Alison Mitchell, Ekrem Oguzhan Angüner
- Extragalactic and Transients Task Force
  - → TF leaders: Giovanni La Mura, Francesco Longo*
- Fundamental Physics Task Force
  - → TF leaders: Humberto Martínez-Huerta, Andrea Albert
- Cosmic Rays Task Force
  - → TF leaders: Andrew Taylor, Gwenael Giacinti*
- IRFS Task Force (jointly with ASWG)
  - → TF leaders: Tulun Ergin, Laura Oliveira - Nieto

Science WG organisation

- Galactic Task Force topics
  - → Pulsar Halos
  - → Galactic PeVatrons
  - → Galactic Diffuse Emission & Fermi Bubbles
  - → Galactic Center Region
  - → Galactic Center
  - → SNRs
  - → Microquasars
  - → Novae



Science WG organisation

Galactic Science Topics

https://www.swgo.org/SWGOWiki/doku.php?id=galactic_accelerators_task_force

- Pulsar Wind Nebulae and Pulsar Halos → R. Lopez-Coto, AM
- Galactic PeVatrons → EOA (Ozi), T. Ergin
- Galactic Diffuse Emission and Fermi Bubbles → G. Giacinti
- Galactic Centre Region → J. Djuvsland, H. Ren, B. Reville
- Binaries, including Microquasars → X. Wang, D. Huang

Galactic Science WG report in Prague

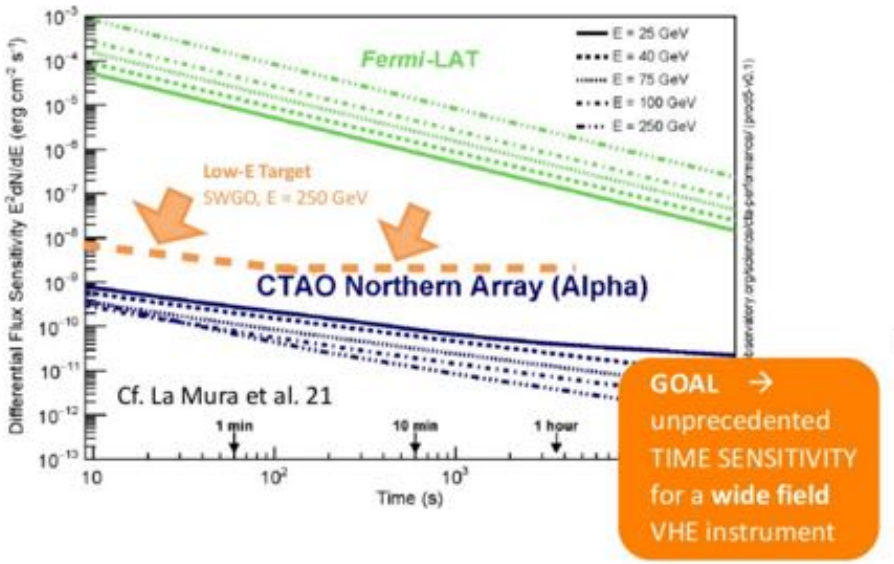
- Other source classes e.g. SNRs in general
- Galactic transient phenomena e.g. Novae

Interested in participating? Feel free to add your name and contact those listed for any topic. New ideas welcome.

Many results will be revised when IRFs are available.

Science WG organisation

- Extragalactic and Transients Task Force topics
  - Gamma Ray Bursts
  - Active Galactic Nuclei



Science WG organisation

IRFs for transients

The goal of this effort is two-fold:

- Produce a set of IRFs complying with GADF definitions
- Set up a sensitivity estimate ahead of the transit calculation

For this stage, tables are preferred with respect to maps because:

- Tables are direct inputs to *gammapy*'s sensitivity estimator
- Tables can be easily inspected and compared with expectations
- It is easy to convert Table → Map

gammapy provides suitable data structures to represent GADF tables. Drifting instruments can use *EffectiveAreaTable2D*, *EnergyDispersion2D*, *PSF3D* and background.

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Science WG organisation

Transient/EG Task Force → M6

- Preparing the IRF benchmark testing framework:
  - → development of *gammapy* transient models (accounting for spectral and temporal properties)
  - → derivation of IRF tables
- Task force organization:
  - → The TF meets regularly on a bi-weekly schedule on Monday at 15 CEST (next meeting October 16). Zoom link:

https://videoconf-colibri.zoom.us/j/96685774976?pwd=K256ekZjSkdtdTBOWTNrQ0JESmlMQT09

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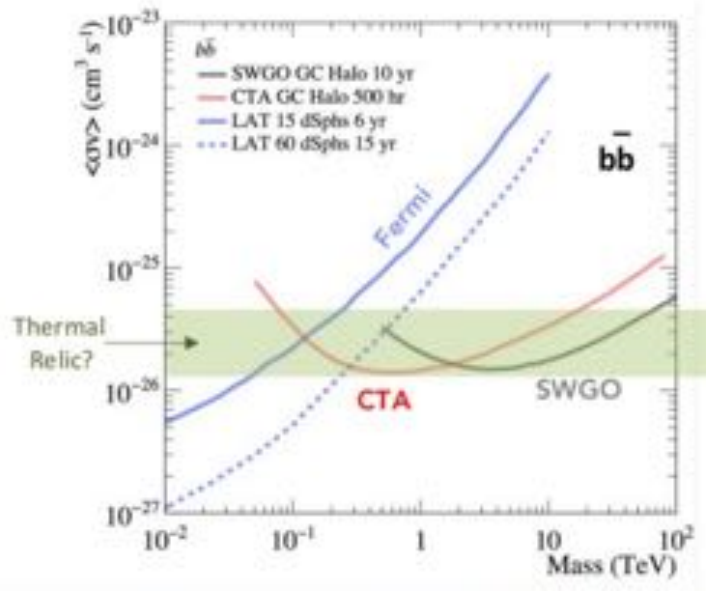
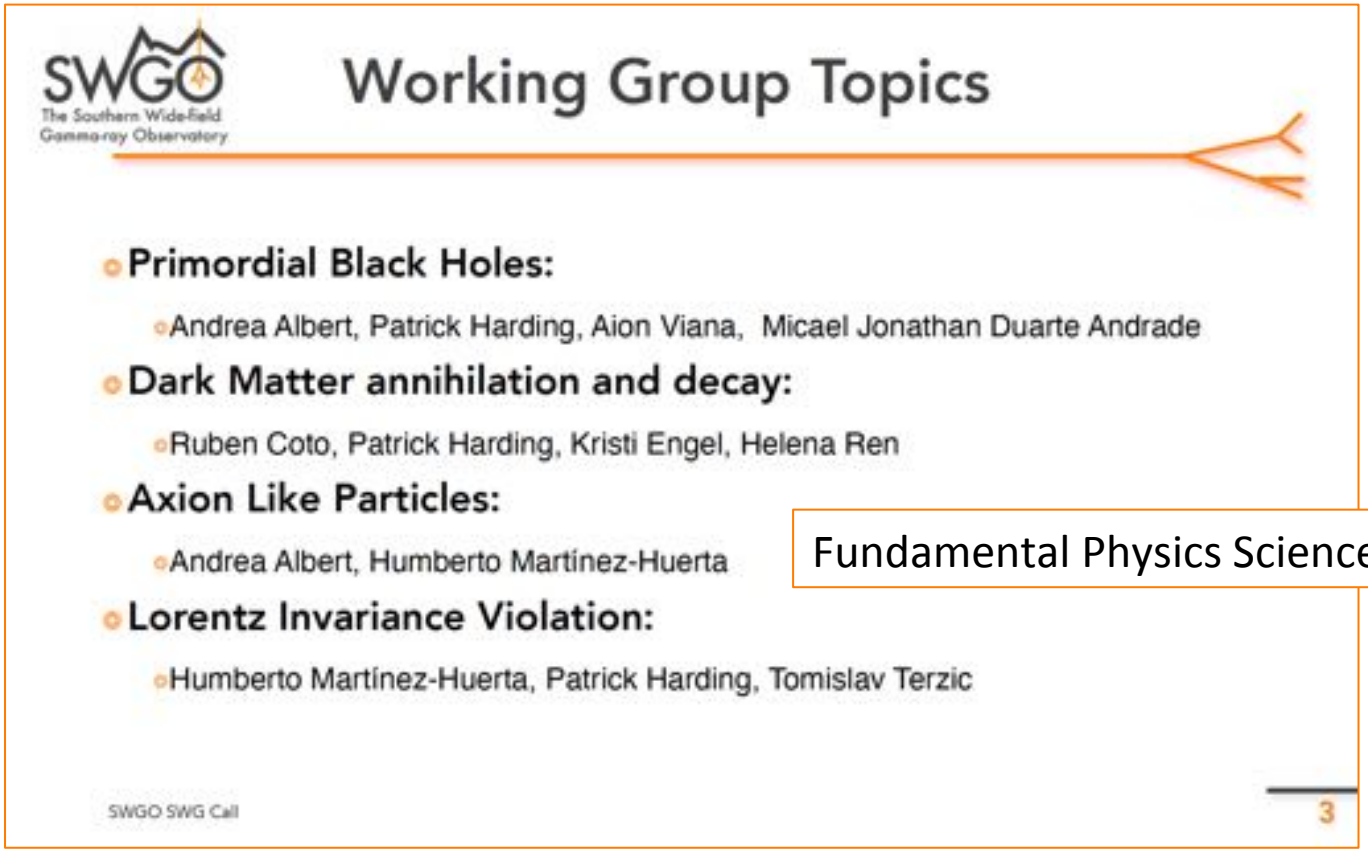
Science WG organisation

- Fundamental Physics Task Force topics
  - WIMPs
  - PBHs
  - ALPs
  - LIV



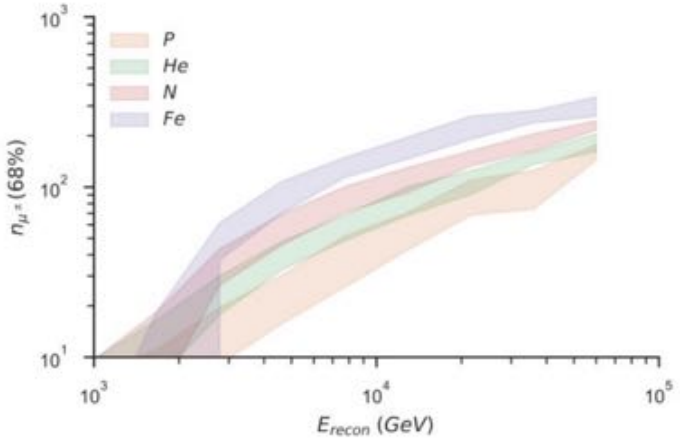
Science WG organisation



Fundamental Physics Science WG report in Prague

Science WG organisation

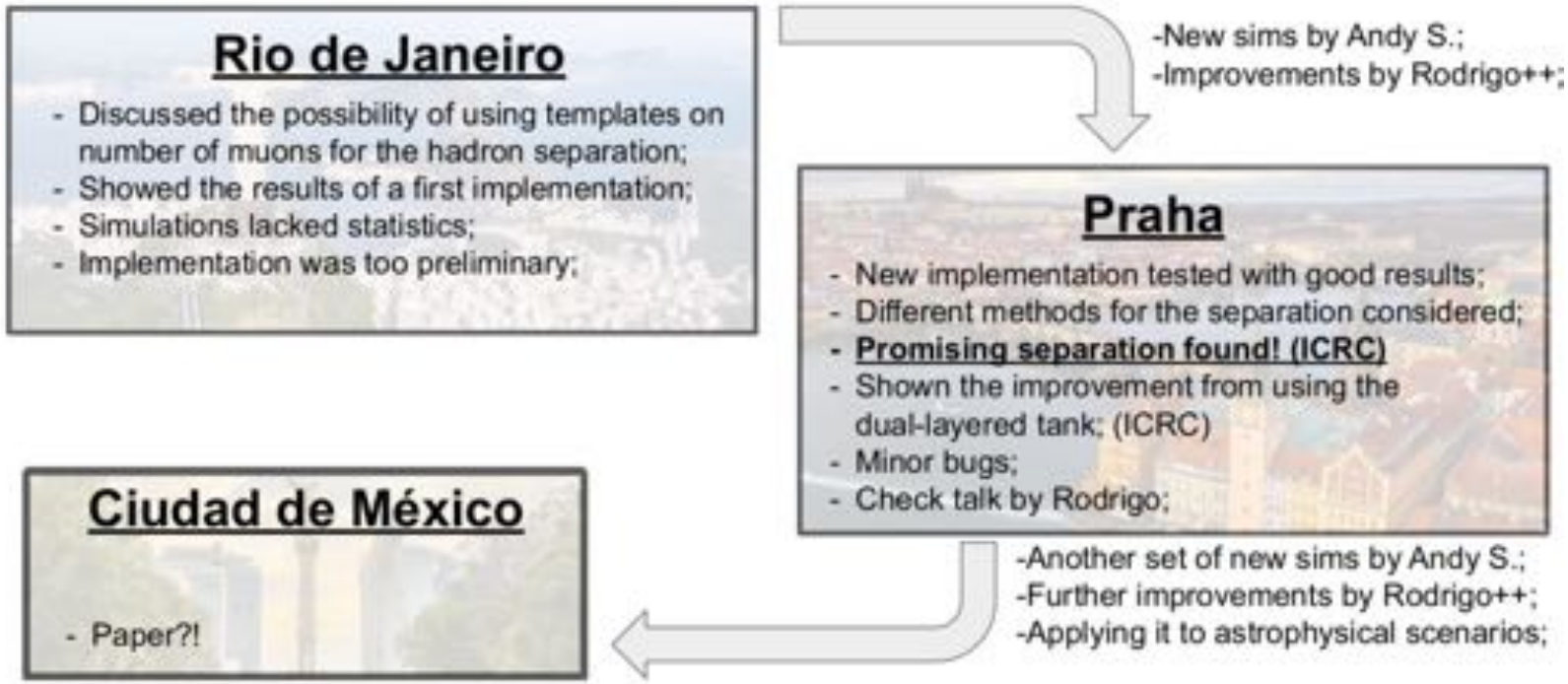
- Cosmic rays Task Force topics
  - Hadronic Cosmic Ray Anisotropy
  - Hadronic Cosmic Ray Spectrum and Composition
  - Cosmic Ray Electron Anisotropy
  - Cosmic Ray Electron Spectrum
  - Heliospheric Physics
  - Air-Shower Studies
  - UHECR Accelerators



Science WG organisation

Currently mostly focused on the CR mass-dependent anisotropy.

Cosmic Rays Science WG report in Prague



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Current status

- The science benchmarks & Preliminary calculations are ready.
- IRFs will be ready soon. The science WG will redo these calculations & **Evaluate the science benchmarks wrt the candidate configurations**
  - **Science input for the evaluation of the different array** choices.

SWGO R&D Phase Milestones	
M1	R&D Phase Plan Established
M2	Science Benchmarks Defined
M3	Reference Configuration & Options Defined
M4	Site Shortlist Complete
M5	Candidate Configurations Defined
M6	Performance of Candidate Configurations Evaluated
M7	Preferred Site Identified
M8	Design Finalised
M9	Construction & Operation Proposal Complete

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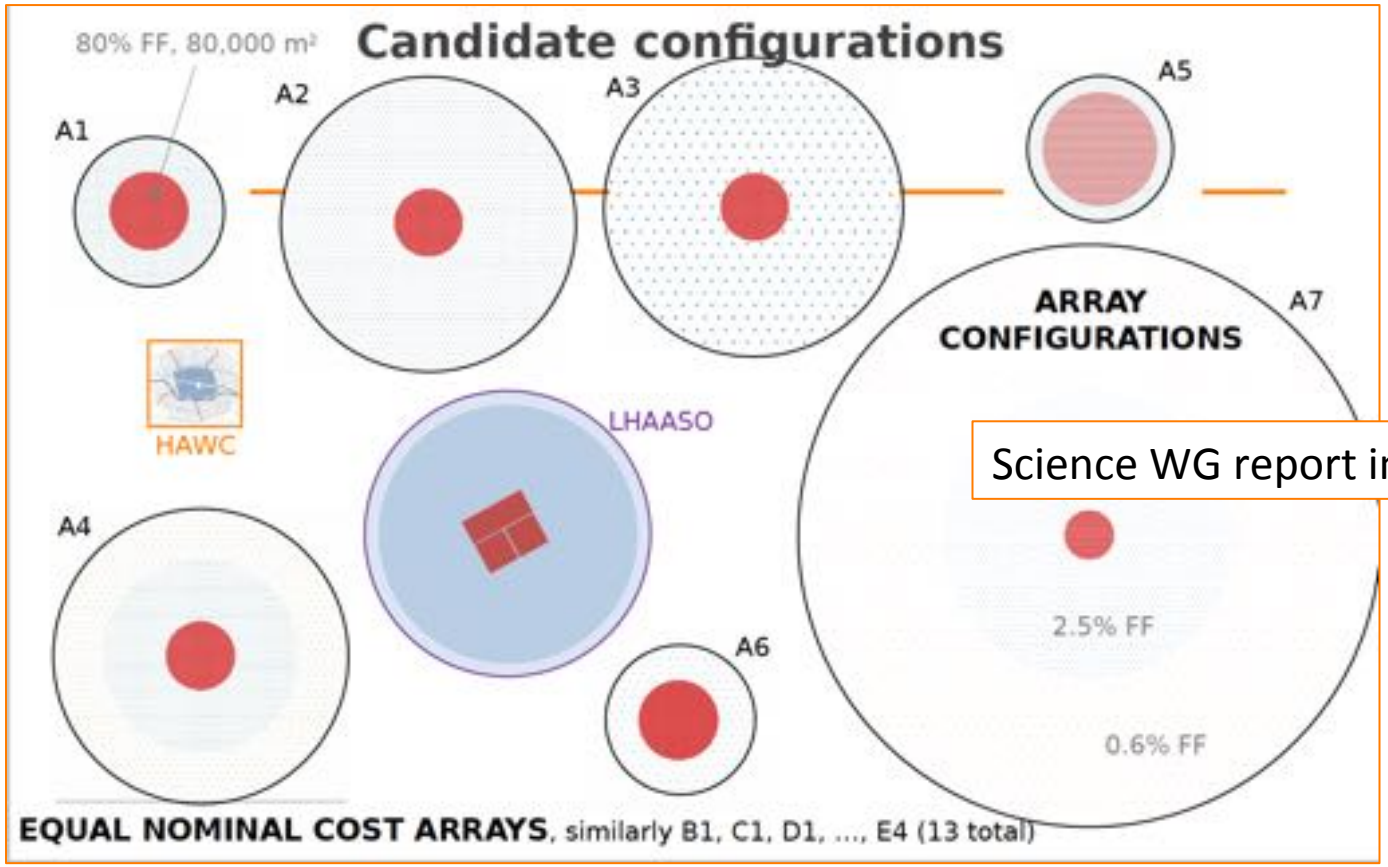
Toward M6



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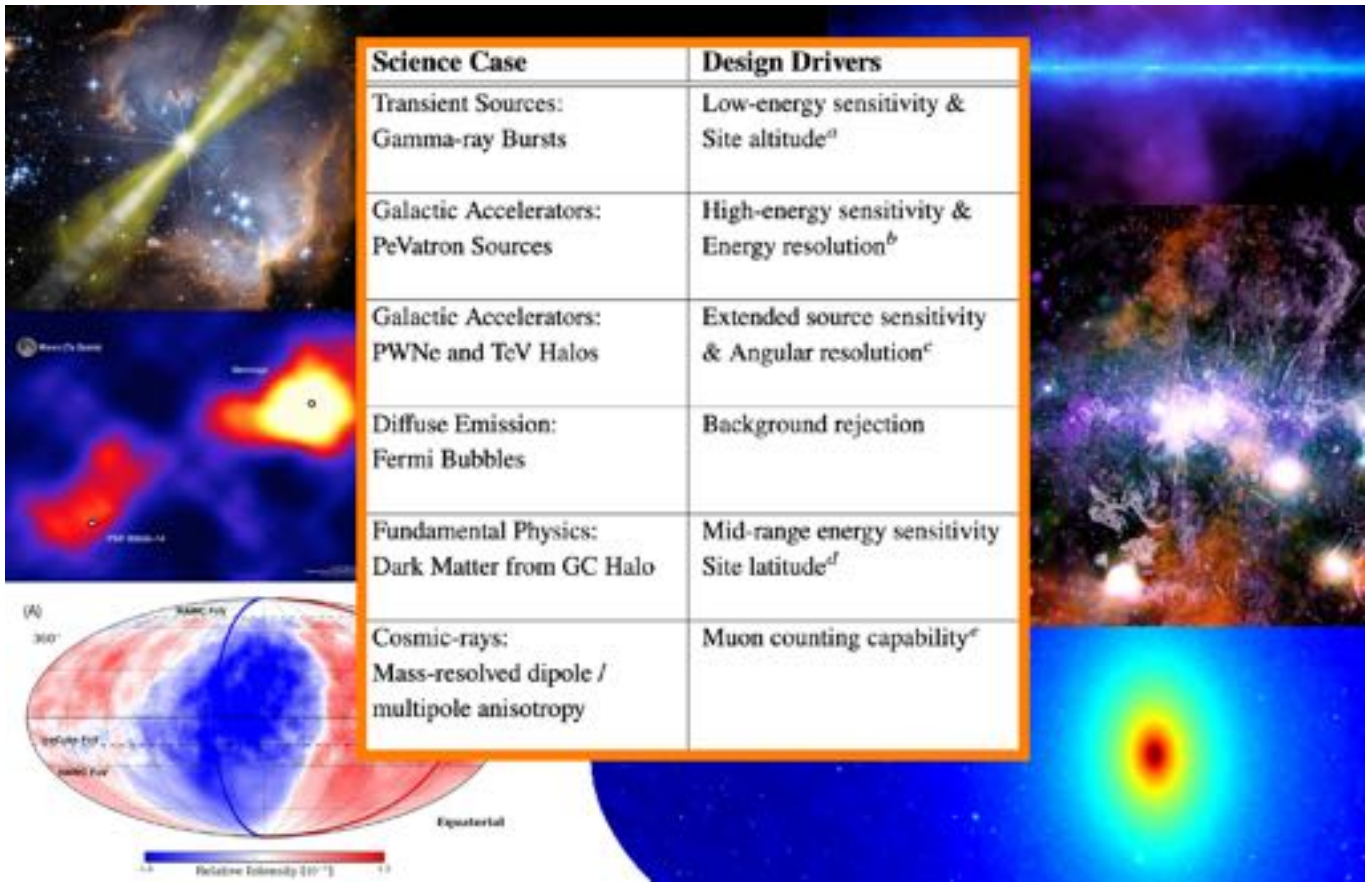

Science Case	Design Drivers
Transient Sources: Gamma-ray Bursts	Low-energy sensitivity & Site altitude[a]
Galactic Accelerators: PeVatron Sources	High-energy sensitivity & Energy resolution[b]
Galactic Accelerators: PWNe and TeV Halos	Extended source sensitivity & Angular resolution[c]
Diffuse Emission: Fermi Bubbles	Background rejection
Fundamental Physics: Dark Matter from GC Halo	Mid-range energy sensitivity Site latitude[d]
Cosmic-rays: Mass-resolved dipole / multipole anisotropy	Muon counting capability[e]

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Science Case	Design Drivers	Benchmark Description
Transient Sources: Gamma-ray Bursts	Low-energy sensitivity & Site altitude[a]	Min. time for 5σ detection: F(100 GeV) = 10^{-8} erg/cm^2.s, PWL index = -2., F(t) $\propto t^{-1.2}$
Galactic Accelerators: PeVatron Sources	High-energy sensitivity & Energy resolution[b]	Maximum exp-cutoff energy detectable 95% CL in 5 years for: F(1TeV) = 5 mCrab, index = -2.3
Galactic Accelerators: PWNe and TeV Halos	Extended source sensitivity & Angular resolution[c]	Max. angular extension detected at 5σ in 5-yr integration for: F(>1TeV) = 5×10^{-13} TeV/cm^{-2}.s
Diffuse Emission: Fermi Bubbles	Background rejection	Minimum diffuse cosmic-ray residual background level. Threshold: < 10^{-4} level at 1 TeV.
Fundamental Physics: Dark Matter from GC Halo	Mid-range energy sensitivity Site latitude[d]	Max. energy for $b\bar{b}$ thermal relic cross-section limit at 95% CL in 5-years, for Einasto profile.
Cosmic-rays: Mass-resolved dipole / multipole anisotropy	Muon counting capability[e]	Max. dipole energy at 10^{-3} level; Log-mass resolution at 1 PeV – goal is A=[1, 4, 14, 56]; Maximum multipole scale > 0.1 PeV

Table 1: SWGO Science Benchmarks. [a]Site altitude to be greater than 4.4 km above sea level. [b]Energy resolution < $O(30\%)$ throughout core energy range 1-100 TeV. [c]Angular resolution ~ 0.15° throughout core energy range 1-100 TeV. [d]Site latitude not constraining among candidates under consideration. [e]WCD units with muon identification capability for γ/hadron discrimination.

The set of core science cases has been defined to guide the R&D studies and to benchmark the final observatory design among different options and trade-offs.

The benchmarks reflect a minimum set of science goals that encompass the full set of performance requirements for the Observatory.

The quantitative benchmarks will be used to compare and select a set of candidate configurations for the array, currently under study.

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Benchmark 1 (Transients - GRBs)

Benchmark Definition. The science benchmark is described as the minimum integration timescale to achieve 5σ detection for a reference source with flux at 100 GeV of 10^{-8} erg/cm^2.s, a power law spectral index of -2. and a flux evolution with time $\propto t^{-1.2}$. The reference source is representative of the GeV emission for the *~ 10 - 20% brightest LAT GRBs.*

Science Case	Design Drivers	Benchmark Description
Transient Sources: Gamma-ray Bursts	Low-energy sensitivity & Site altitude[a]	Minimum integration for 5σ detection: F(100 GeV) = 10^{-8} erg/cm^2.s, PWL index = -2., F(t) $\propto t^{-1.2}$
Galactic Accelerators: PeVatron Sources	High-energy sensitivity & Energy resolution[b]	Maximum exp-cutoff energy detectable at 95% CL in 5 years for: F(1TeV) = 5 mCrab, PWL index = -2.3
Galactic Accelerators: PWNe and TeV Halos	Extended source sensitivity & Angular resolution[c]	Maximum source angular extension detectable at 5σ in 5-yr integration for: F(>1TeV) = 5×10^{-13} TeV/cm^{-2}.s
Diffuse Emission: Fermi Bubbles	Background rejection	Minimum diffuse cosmic-ray residual background level. Threshold: < 10^{-5} level at 1 TeV.
Fundamental Physics: Dark Matter from Galactic Halo	Mid-range energy sensitivity Site latitude[d]	Maximum energy for $b\bar{b}$ thermal-relic cross-section limit at 95% CL in 5-years, for Einasto profile.
Cosmic-rays: Mass-resolved dipole/multipole anisotropy	Muon counting capability[e]	Maximum dipole energy at 10^{-3} level; Log-mass dipole resolution at 1 PeV – goal is to achive A={1, 4, 14, 56}; Maximum multipole scale > 0.1 PeV

Tab. 1 SWGO Science Benchmarks. [a]Site altitude parameter to enter design discrimination as altitude dependent IRFs. [b]Energy resolution not constraining as long as $O(30\%)$ throughout energy range. [c]Angular resolution not constraining as long as ~ 0.2° – 0.3° throughout energy range. [d]Site latitude not severely constraining, but sites closer to 30° South are slightly favoured. [e]Capability for individual muon identification to play important role in mass discrimination.

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Benchmark 2 (Galactic accelerators - PeVatrons)

Benchmark Definition. The science benchmark is described as the maximum energy of an exponential cutoff detectable at 95% CL after 5-year integration for a reference source with flux normalization at 1 TeV of 5 mCrab and a hard power law spectral index of -2.3. The reference source is *representative of the potential PeVatron source population in the HESS Galactic Plane Survey.*

Science Case	Design Drivers	Benchmark Description
Transient Sources: Gamma-ray Bursts	Low-energy sensitivity & Site altitude[a]	Minimum integration for 5σ detection: F(100 GeV) = 10^{-8} erg/cm^2.s, PWL index = -2., F(t) $\propto t^{-1.2}$
Galactic Accelerators: PeVatron Sources	High-energy sensitivity & Energy resolution[b]	Maximum exp-cutoff energy detectable at 95% CL in 5 years for: F(1TeV) = 5 mCrab, PWL index = -2.3
alactic Accelerators: WNe and TeV Halos	Extended source sensitivity & Angular resolution[c]	Maximum source angular extension detectable at 5σ in 5-yr integration for: F(>1TeV) = 5×10^{-13} TeV/cm^{-2}.s
ffuse Emission: rmi Bubbles	Background rejection	Minimum diffuse cosmic-ray residual background level. Threshold: < 10^{-5} level at 1 TeV.
undamental Physics: ark Matter from Galactic Halo	Mid-range energy sensitivity Site latitude[a]	Maximum energy for $b\bar{b}$ thermal-relic cross-section limit at 95% CL in 5-years, for Einasto profile.
osmic-rays: lass-resolved dipole/multipole nisotropy	Muon counting capability[e]	Maximum dipole energy at 10^{-3} level; Log-mass dipole resolution at 1 PeV – goal is to achive A=(1, 4, 14, 56); Maximum multipole scale > 0.1 PeV

Tab 1. SWGO Science Benchmarks. [a]Site altitude parameter to enter design-discrimination as altitude-dependent IRFs. [b]Energy resolution not constraining as long as O(30%) throughout energy range. [c]Angular resolution not constraining as long as ~ 0.2° – 0.3° throughout energy range. [d]Site latitude not severely constraining, but sites closer to 30° South are slightly favoured. [e]Capability for individual muon identification to play important role in mass-discrimination.

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Benchmark 3 (Extended sources – PWNe & TeV Halos)

Science Case	Design Drivers	Benchmark Description
Transient Sources: Gamma-ray Bursts	Low-energy sensitivity & Site altitude[a]	Minimum integration for 5σ detection: F(100 GeV) = 10^{-6} erg/cm^2.s, PWL index = -2., F(t) $\propto t^{-1.2}$
Galactic Accelerators: PeVatron Sources	High-energy sensitivity & Energy resolution[b]	Maximum exp-cutoff energy detectable at 95% CL in 5 years for: F(1TeV) = 5 mCrab, PWL index = -2.3
Galactic Accelerators: PWNe and TeV Halos	Extended source sensitivity & Angular resolution[c]	Maximum source angular extension detectable at 5σ in 5-yr integration for: F(>1TeV) = 5×10^{-13} TeV/cm^{-2}.s
…use Emission: …ni Bubbles	Background rejection	Minimum diffuse cosmic-ray residual background level. Threshold: < 10^{-5} level at 1 TeV.
…damental Physics: …k Matter from Galactic Halo	Mid-range energy sensitivity Site latitude[d]	Maximum energy for $b\bar{b}$ thermal-relic cross-section limit at 95% CL in 5-years, for Einasto profile.
…mic-rays: …s-resolved dipole/multipole …otropy	Muon counting capability[e]	Maximum dipole energy at 10^{-3} level; Log-mass dipole resolution at 1 PeV – goal is to achive A=[1, 4, 14, 56]; Maximum multipole scale > 0.1 PeV

Benchmark Definition. The science benchmark is described as the maximum source angular extension detectable at 5σ after 5-year integration for an integral flux above 1 TeV of 5×10^{-13} TeV/cm^{-2}.s. The reference source is *representative of the PWNe population in the HESS Galactic Plane Survey, assuming a Geminga-like spectrum and diffusion coefficient.*

Tab. 1 SWGO Science Benchmarks. [a]Site altitude parameter to enter design discrimination as altitude-dependent IRFs. [b]Energy resolution not constraining as long as $O(30\%)$ throughout energy range. [c]Angular resolution not constraining as long as ~ 0.2° – 0.3° throughout energy range. [d]Site latitude not severely constraining, but sites closer to 30° South are slightly favoured. [e]Capability for individual muon identification to play important role in mass-discrimination.

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Benchmark 4 (Diffuse Galactic emission)

Benchmark Definition. The science benchmark is described as the minimum diffuse cosmic-ray residual background level attainable above 1 TeV, as this is the biggest limiting factor in the detectability of large-scale diffuse emission.

Science Case	Design Drivers	Benchmark Description
Transient Sources: mma-ray Bursts	Low-energy sensitivity & Site altitude[a]	Minimum integration for 5σ detection: F(100 GeV) = 10^{-8} erg/cm^2.s, PWL index = -2., F(t) $\propto t^{-1.2}$
actic Accelerators: atron Sources	High-energy sensitivity & Energy resolution[b]	Maximum exp-cutoff energy detectable at 95% CL in 5 years for: F(1TeV) = 5 mCrab, PWL index = -2.3
actic Accelerators: Ne and TeV Halos	Extended source sensitivity & Angular resolution[c]	Maximum source angular extension detectable at 5σ in 5-yr integration for: F(>1TeV) = 5×10^{-13} TeV/cm^{-2}.s
Diffuse Emission: Fermi Bubbles	Background rejection	Minimum diffuse cosmic-ray residual background level. Threshold: < 10^{-5} level at 1 TeV.
Fundamental Physics: Dark Matter from Galactic Halo	Mid-range energy sensitivity Site latitude[d]	Maximum energy for $b\bar{b}$ thermal-relic cross-section limit at 95% CL in 5-years, for Einasto profile.
Cosmic-rays: Mass-resolved dipole/multipole anisotropy	Muon counting capability[e]	Maximum dipole energy at 10^{-3} level; Log-mass dipole resolution at 1 PeV – goal is to achive A=(1, 4, 14, 56); Maximum multipole scale > 0.1 PeV

Tab. 1 SWGO Science Benchmarks. [a]Site altitude parameter to enter design discrimination as altitude-dependent IRFs. [b]Energy resolution not constraining as long as $O(30\%)$ throughout energy range. [c]Angular resolution not constraining as long as ~ 0.2° – 0.3° throughout energy range. [d]Site latitude not severely constraining, but sites closer to 30° South are slightly favoured. [e]Capability for individual muon identification to play important role in mass-discrimination.

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Benchmark 5 (Dark Matter from GC & Halo)

Benchmark Definition. The science benchmark is described as the maximum energy for achieving the WIMP thermal-relic cross-section limit for the $b\bar{b}$ channel at 95% CL in 5-years, for Einasto profile. The choice of channel is to have the channel with weakest current limits as a clear reference for discriminating between designs.

Science Case	Design Drivers	Benchmark Description
Transient Sources: …mma-ray Bursts	Low-energy sensitivity & Site altitude[a]	Minimum integration for 5σ detection: F(100 GeV) = 10^{-8} erg/cm^2.s, PWL index = -2., $F(t) \propto t^{-1.2}$
…actic Accelerators: …Patron Sources	High-energy sensitivity & Energy resolution[b]	Maximum exp-cutoff energy detectable at 95% CL in 5 years for: F(1TeV) = 5 mCrab, PWL index = -2.3
…actic Accelerators: …Ne and TeV Halos	Extended source sensitivity & Angular resolution[c]	Maximum source angular extension detectable at 5σ in 5-yr integration for: F(>1TeV) = 5×10^{-13} TeV/cm^{-2}.s
…use Emission: …mi Bubbles	Background rejection	Minimum diffuse cosmic-ray residual background level. Threshold: < 10^{-5} level at 1 TeV.
Fundamental Physics: Dark Matter from Galactic Halo	Mid-range energy sensitivity Site latitude[d]	Maximum energy for $b\bar{b}$ thermal-relic cross-section limit at 95% CL in 5-years, for Einasto profile.
Cosmic-rays: Mass-resolved dipole/multipole anisotropy	Muon counting capability[e]	Maximum dipole energy at 10^{-3} level; Log-mass dipole resolution at 1 PeV – goal is to achive A={1, 4, 14, 56}; Maximum multipole scale > 0.1 PeV

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Benchmark 6 (Cosmic-rays)

Benchmark Definition. A ref. exposure of 5 years is considered. The science goal is ultimately to understand the nature of the evolution of the dipole and multipoles between 0.1-multi PeV. To do this our required benchmarks are:

- (i) the energy scale up to which the dipole anisotropy can be detected at 10^{-3} level
- (ii) the log-mass resolution required to achieve the decomposition of the cosmic ray spectrum into four mass group A={1, 4, 14, 56}, in the 0.1-1 PeV energy range
- (iii) the multipole l – scale up to which the cosmic ray anisotropy can be probed, for events with energies above 0.1 PeV.

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Science Case	Design Drivers	Benchmark Description
nsient Sources: mma-ray Bursts	Low-energy sensitivity & Site altitude[a]	Minimum integration for 5σ detection: F(100 GeV) = 10^{-8} erg/cm^2.s, PWL index = -2., F(t) $\propto t^{-1.2}$
lactic Accelerators: Vatron Sources	High-energy sensitivity & Energy resolution[b]	Maximum exp-cutoff energy detectable at 95% CL in 5 years for: F(1TeV) = 5 mCrab, PWL index = -2.3
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Benchmark driven by the capability of SWGO to detect the mass-resolved CR anisotropy.

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The Science WG activity

- Toward M6
  - Be able to evaluate the benchmarks wrt to the candidates configurations
  - Science Inputs for the evaluation of Different Array choices
  - Update of Science Benchmarks definition
  - Create a "Figure of Merit" for each Science Benchmark (with numbers)
- IRF task force development
  - Joint work with ASWG
- Specific Data analysis Use cases
  - What about a DataChallenge?
  - Might help for Development of SWGO papers

Opportunities in Science WG

- Toward M6
  - Be able to evaluate the benchmarks wrt to the candidates configurations
  - Science Inputs for the evaluation of Different Array choices
  - Update of Science Benchmarks definition
  - Create a "Figure of Merit" for each Science Benchmark (with numbers)
- IRF task force development
  - Joint work with ASWG
- Specific Data analysis Use cases
  - What about a DataChallenge?
  - Working group for DataChallenge?
  - Might help for Development of SWGO papers