Constraints on Dark Matter annihilation signals with the H.E.S.S. Inner Galaxy Survey

Ref. A. Montanari et al. on behalf of the H.E.S.S. Collaboration; POS(ICRC2021)511

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H.E.S.S.

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7th Heidelberg International Symposium on High Energy Gamma-Ray Astronomy

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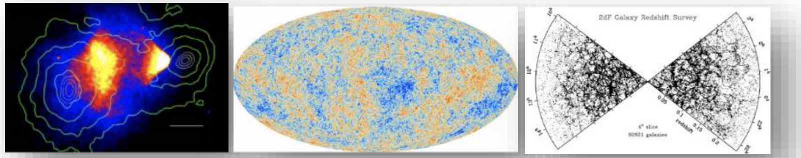
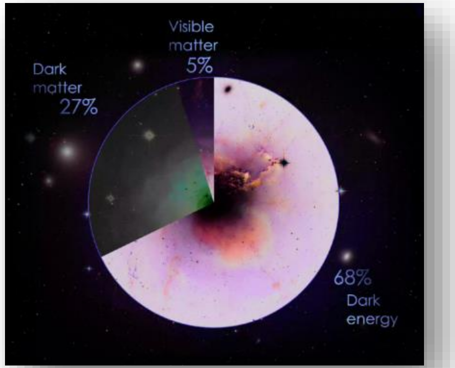
Introduction: WIMPs & Indirect Dark Matter search in gamma rays

Evidence

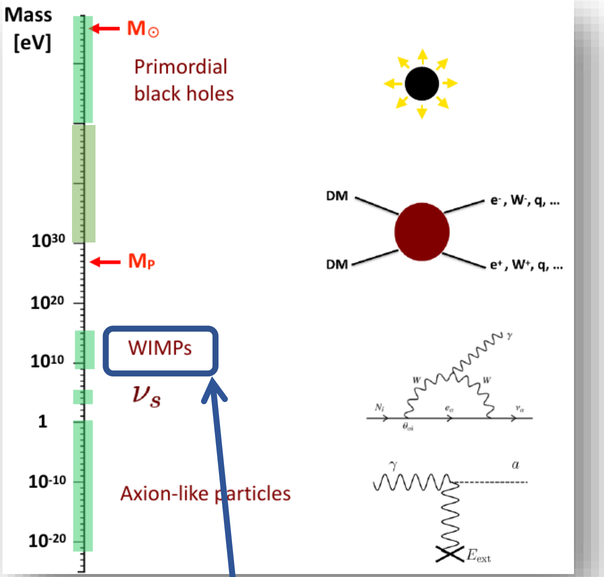


Bullet cluster CMB LSS ….



- Dark Matter doesn't (DM) scatter/emit/absorb light.
- Does have mass (and hence gravity).
- About 84% of the matter in the universe.
- Forms the primordial "scaffolding" for the visible universe.
- Forms "halos" around galaxies.
- Interacts with other particles weakly or not at all (except by gravity).

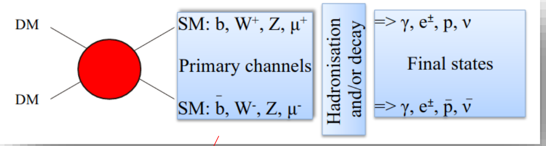
Candidates…



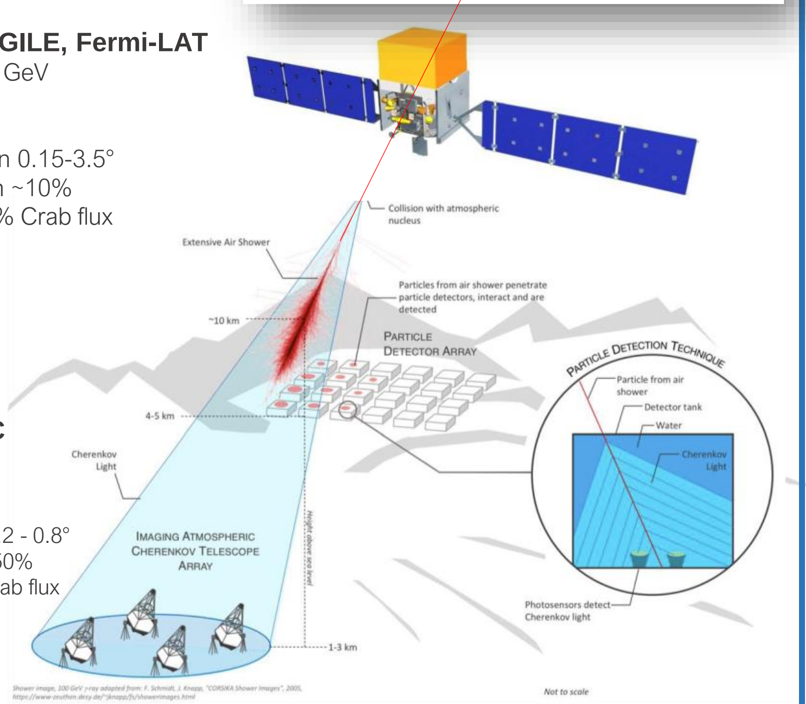
- Focusing on **Weakly Interacting Massive Particles (WIMPs)**
- WIMPs created thermally in the Early Universe
  - $\langle\sigma v\rangle_{th} = 3x10^{-26}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$

Detection…

WIMPs can self-annihilate → detectable gamma-rays



Satellites – AGILE, Fermi-LAT
~20 MeV → 300 GeV
>2 sr FoV
100% duty cycle
angular resolution 0.15-3.5°
energy resolution ~10%
sensitivity a few % Crab flux



WCDs – HAWC
~100 GeV → 1 PeV
90% duty cycle
~sr FoV
angular resolution 0.2 - 0.8°
energy resolution ~50%
sensitivity 5-10% Crab flux

IACTs – H.E.S.S., MAGIC, VERITAS
~30 GeV → ~100 TeV
small FoV : ~ 5°
duty-cycle: 10-15%
angular resolution <0.1°
Energy resolution ~10%
sensitivity 1% Crab flux

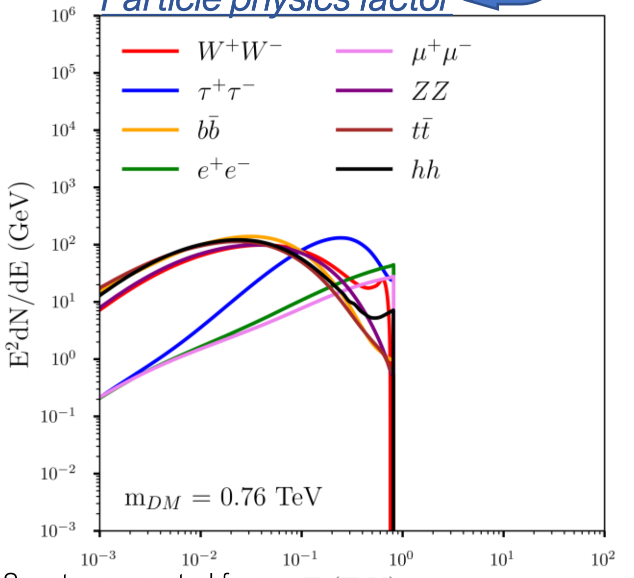
Introduction: WIMPs & Indirect Dark Matter search in gamma rays

Gamma-ray flux and Dark Matter distribution

- Assuming annihilation process almost at rest
  → A smoking-gun signature for DM is a very distinct energy cut-off, close to the DM particle mass.
- Gamma-ray flux expected from DM annihilations:

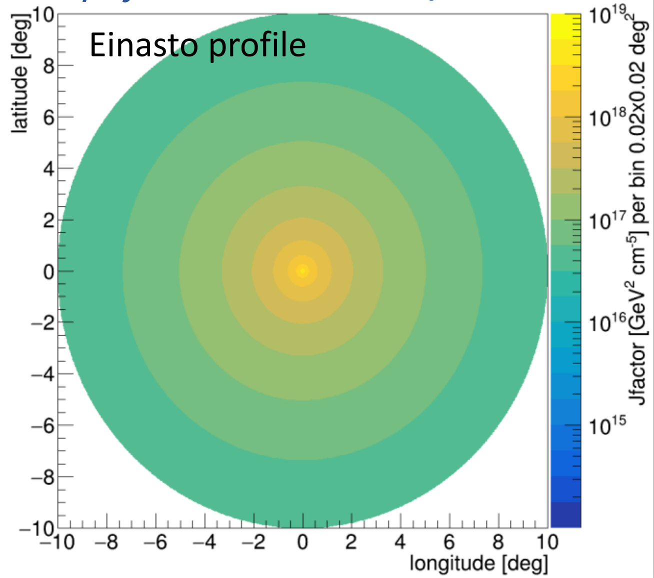
$$\frac{d\phi_\gamma}{dE}(E_\gamma, \Delta\Omega) = \frac{\langle\sigma v\rangle}{8\pi m_{DM}^2} \sum_f Br_f \frac{dN_f}{dE_\gamma} J(\Delta\Omega)$$

Particle physics factor

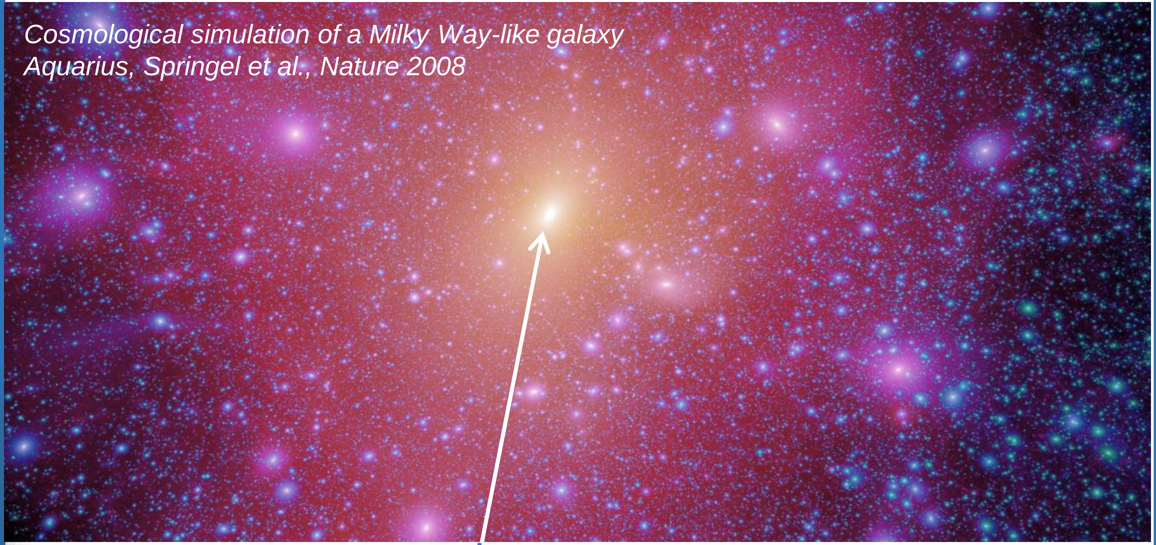


Spectra computed from
Ref. Cirelli et al., JCAP 1103, page 051

Astrophysical factor $J(\Delta\Omega) = \int \rho^2 (r(s,\theta)) ds d\Omega$



Targets for Indirect search



Most promising target:

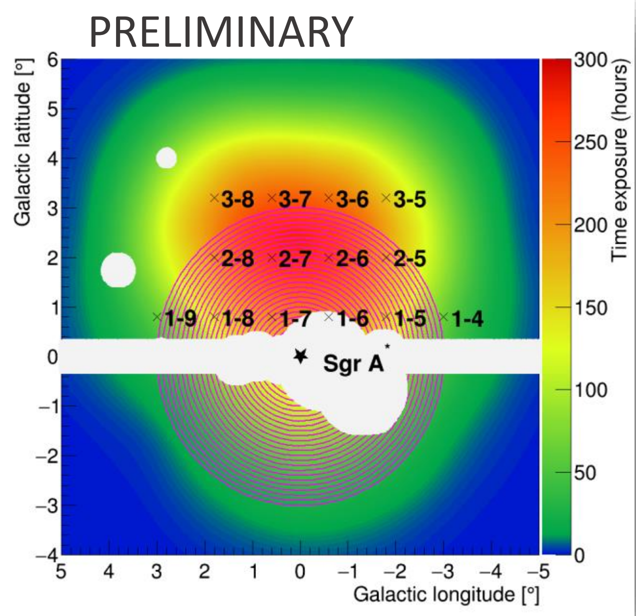
- Galactic Centre (GC)
  - Proximity (~8kpc)
  - Possibly brightest source of DM annihilation signals
  - DM profile: core? cusp?
  - High astrophysical background/source confusion
- Inner Galactic halo
  - Large statistics
  - Galactic diffuse background

Inner Galaxy Survey dataset

- The first ever conducted VHE gamma-ray survey of the Galactic Center (GC) region.
- ➢ Aim: to provide unprecedented sensitivity to DM signals in the GC region.

Dataset: 2014-2020 observations

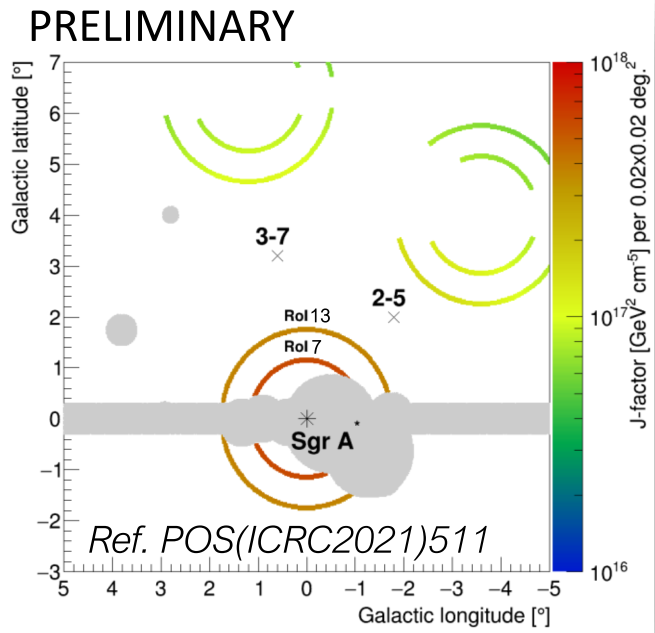
- 2014-2020 exposure map with IGS pointing positions
- Total 546 hours of high-quality data
- 25 regions of interest (ROI) defined to search for DM;
- Set of exclusion regions to avoid gamma-ray contamination in the ROIs.



Data analysis

Reflected background method for the OFF region:

- Symmetric OFF to the ON wrt the pointing positions
- Excluded regions are cut symmetrically
- Cut overlapping areas and areas where OFF is closer to the GC than the ON
- The DM signal is always larger in the ON
- Repeated for all the 25 ROI and over the ~1300 runs.



2D binned Poisson likelihood function → energy (i) and space (j) bins

Total Likelihood: $\mathcal{L} = \prod \mathcal{L}_{i,j}$

- Systematic uncertainties included via a nuisance parameter *;
  - A value of 1% is used for the determination of the limits;
- No significant excess in the FoV:
  → 95% C.L. upper limits on the free parameter <σv> from a log-Likelihood ratio test statistics (TS).
- Computation of expected upper limits and containment bands from independent realizations for ON and OFF measurements

* Refs: Silverwood, et al, JCAP03, 055 (2015); Lefranc, et al. Phys. Rev. D91, 122003 (2015); CTA Dark Matter Programme (2019)

Upper limits on <σv>

H.E.S.S. upper limits

- No significant excess in the FoV:
- 95% C.L. upper limits on <σv> from the TS;

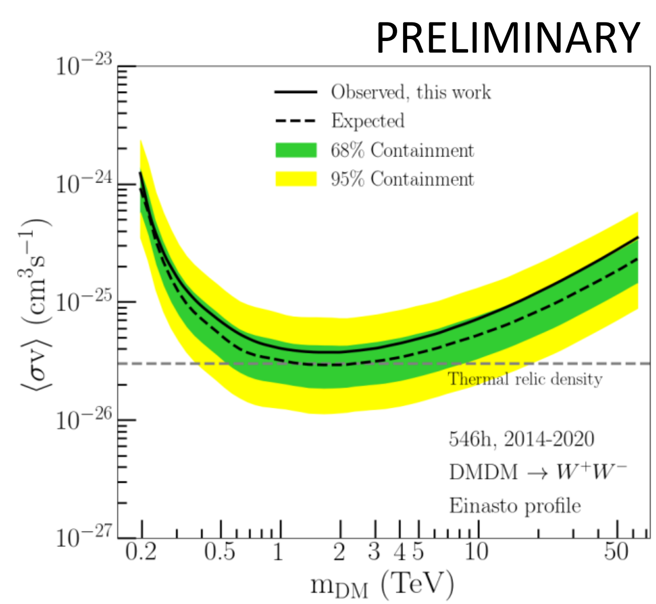
→ H.E.S.S. observed upper limits.

- Computation of expected upper limits and containment bands from independent realizations for ON and OFF measurements

→ H.E.S.S. mean expected upper limits;

→ Containment bands plotted at 1σ and 2σ level.

- Systematic uncertainty included in the limits via a nuisance parameter in the likelihood function.

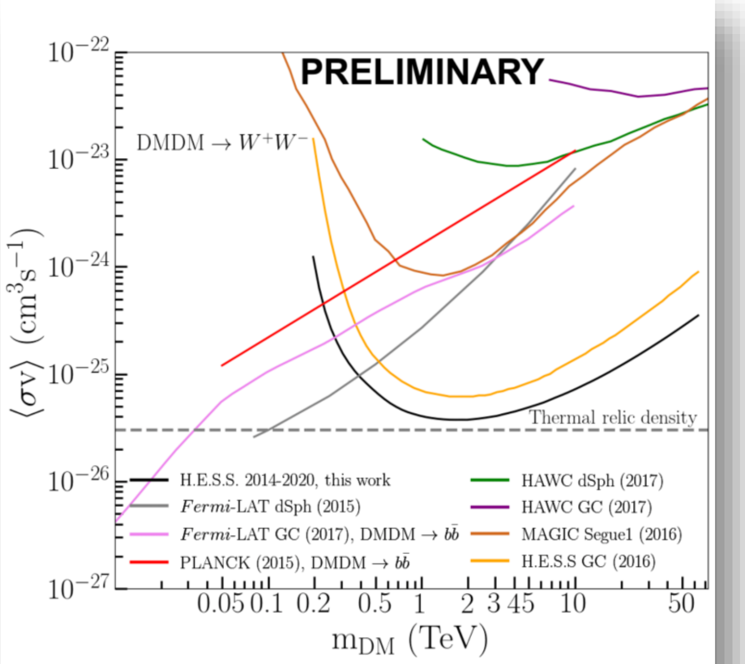


Ref. POS(ICRC2021)511

Summary

Fermi-LAT dSph and GC, HAWC dSph and GC, MAGIC Segue 1, PLANCK CMB, H.E.S.S. GC (2016) and this work.

→ Most constraining limits in the TeV-energy range.



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- IGS campaign with pointing positions up to 3.2° is very fruitful.
- VHE observations of the GC region are unique to study WIMPs.
- With the unprecedented IGS dataset:
  → strongest constraints obtained in the TeV mass range.
- Limits computed in other channels
  → can probe the thermal relic scale.
- The IGS is one of the H.E.S.S. legacies and it paves the way for CTA.
- More observations of the GC have already started as part of the H.E.S.S. Legacy program.