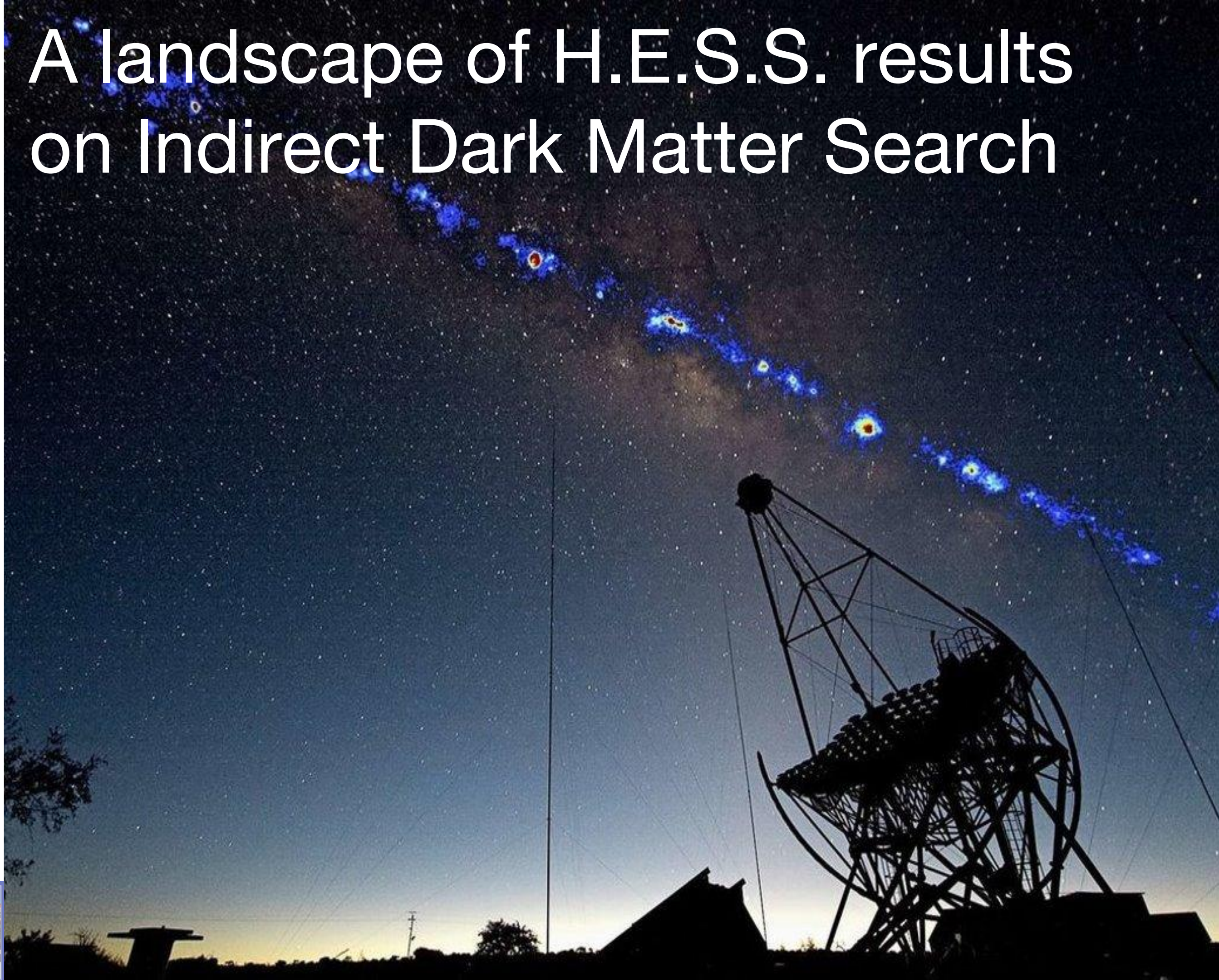
A landscape of H.E.S.S. results on Indirect Dark Matter Search

Alessandro Montanari,
on behalf of
the H.E.S.S. Collaboration

Landessternwarte, ZAH,
Heidelberg University

34th Rencontres de Blois
16 May 2023



H.E.S.S.

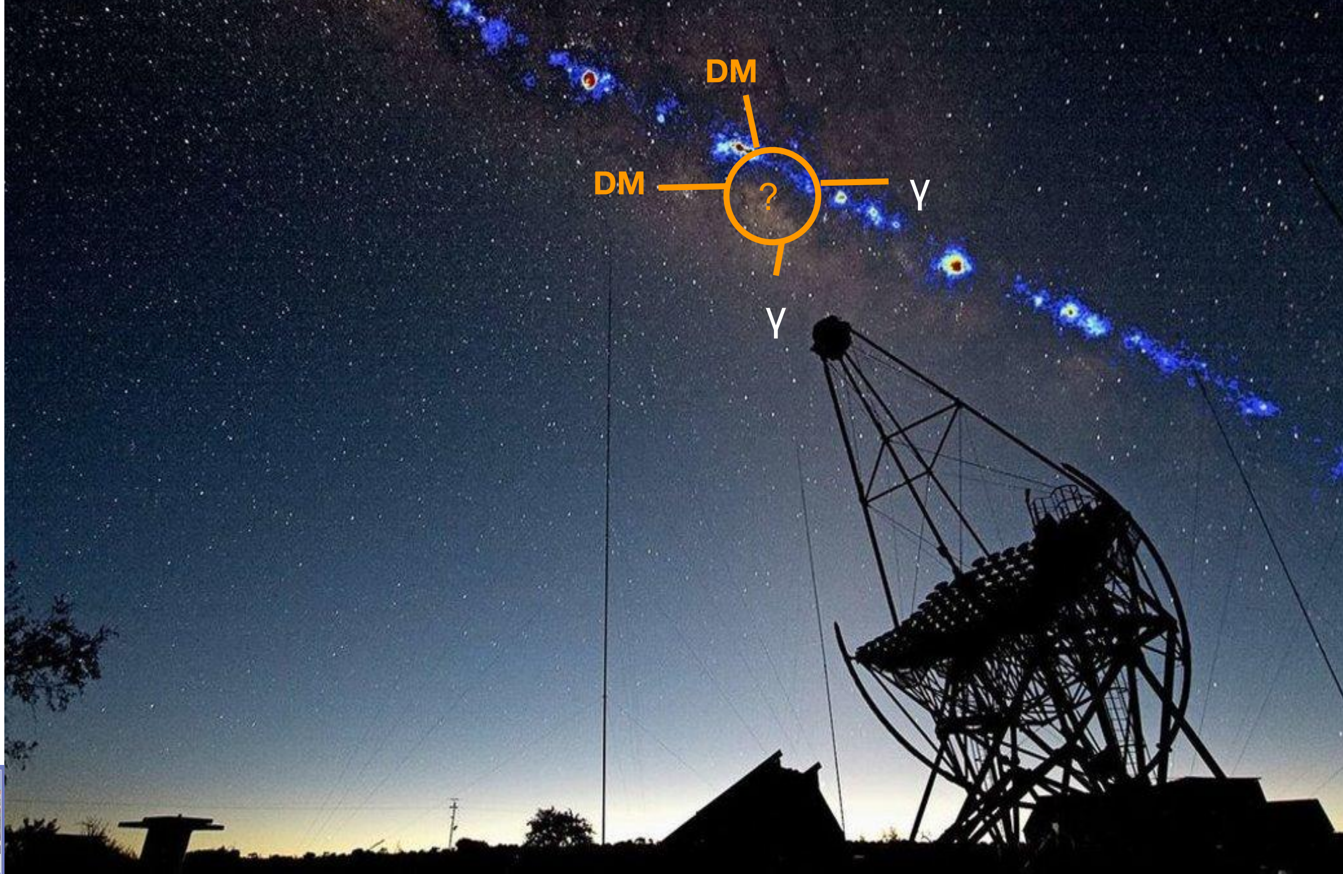
34th Rencontres de Blois May 14–19
BLOIS
PARTICLE PHYSICS AND COSMOLOGY 2023

A landscape of H.E.S.S. results on Indirect Dark Matter Search

Alessandro Montanari,
on behalf of
the H.E.S.S. Collaboration

Landessternwarte, ZAH,
Heidelberg University

34th Rencontres de Blois
16 May 2023



H.E.S.S.

Search for dark matter with gamma rays

Flux for annihilation…

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\frac{dN_\gamma}{dE_\gamma}\times\int_{\Delta\Omega} d\Omega \int_{l.o.s.} \rho^2(r[s])ds$$

Search for dark matter with gamma rays

Flux for annihilation…

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\frac{dN_\gamma}{dE_\gamma} \times \int_{\Delta\Omega} d\Omega \int_{l.o.s.} \rho^2(r[s])ds$$

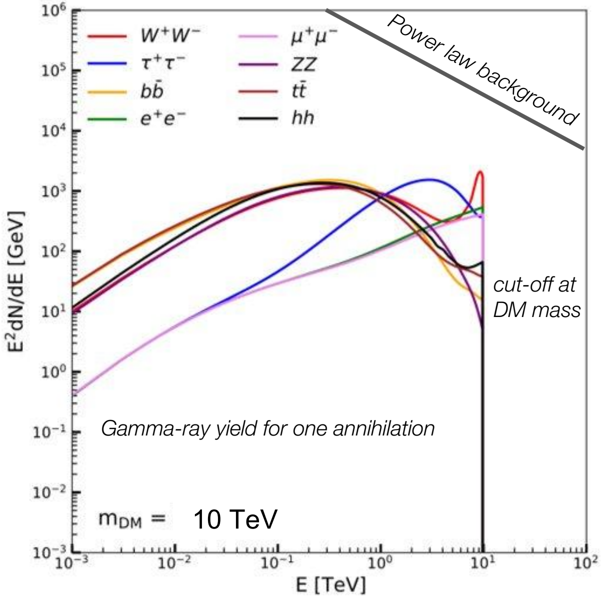
Particle physics factor:

- Differential photon yield
- DM particle mass
- Cross section

→ No target dependence

→ Uncertainties on the particle physics model

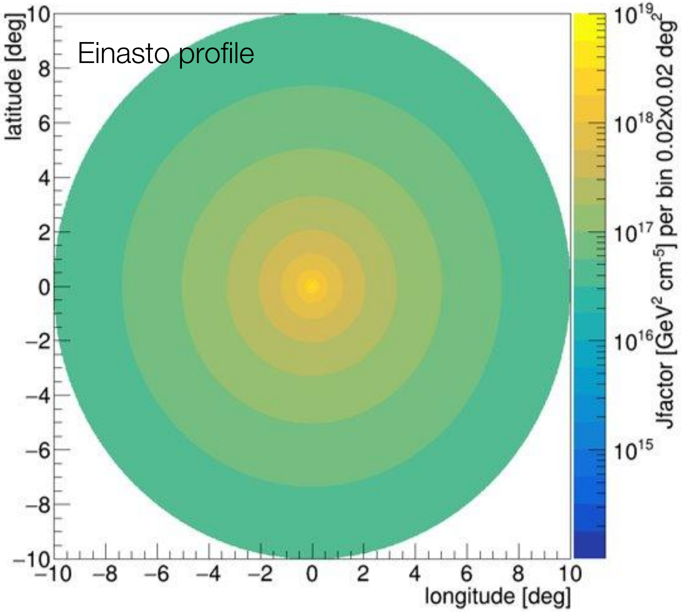
Spectra computed from Cirelli et al. JCAP 1103, page 51



Search for dark matter with gamma rays

Flux for annihilation…

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\frac{dN_\gamma}{dE_\gamma}\times\int_{\Delta\Omega}d\Omega\int_{l.o.s.}\rho^2(r[s])ds$$



Astrophysics factor: J-factor

- DM distribution in the target
- Large uncertainties…
  - Baryon feedback
  - Tidal Stripping
  - Clustering

→ Looking for the target with the largest J-factor

Search for dark matter with gamma rays

Flux for annihilation…

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\frac{dN_\gamma}{dE_\gamma}\times\int_{\Delta\Omega} d\Omega \int_{l.o.s.} \rho^2(r[s])ds$$

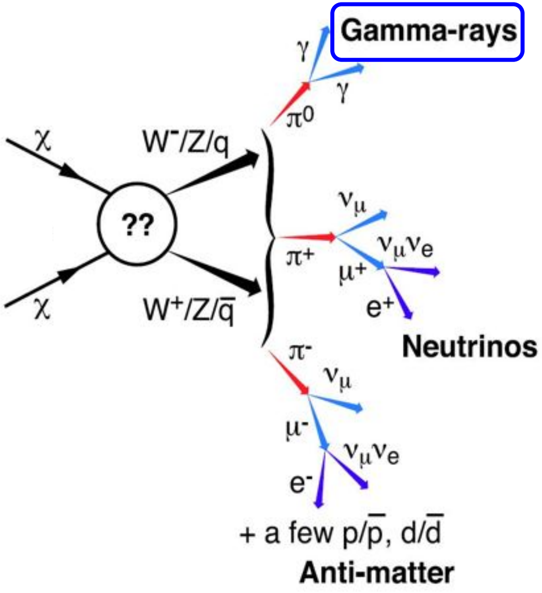
Weakly Interacting Massive Particles (WIMPs)

- Weak interaction mass scale and ordinary gauge couplings → right relic DM density with no fine-tuning

$$\Omega_{\rm DM}h^2 = \frac{3\times 10^{-27}{\rm cm}^3{\rm s}^{-1}}{\langle\sigma v\rangle} \qquad \langle\sigma v\rangle_{\rm W} \sim \frac{\alpha^2}{m_{\rm WIMP}^2} \sim 3\times 10^{-26}{\rm cm}^3{\rm s}^{-1}$$

- Mass scale at GeV-TeV
- Benchmark for indirect detection: thermally produced WIMPs

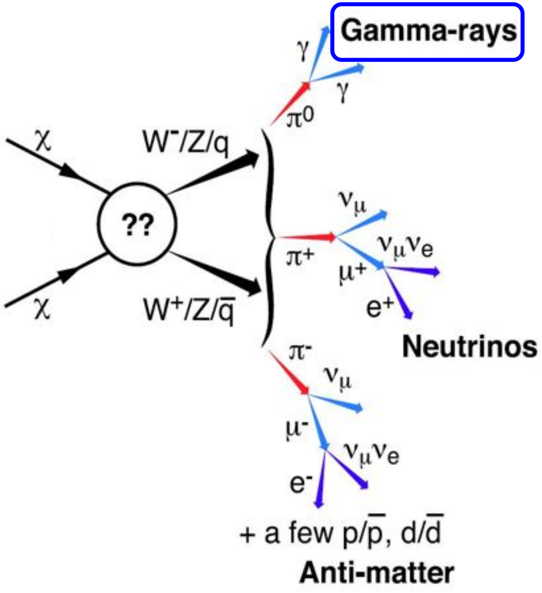
Dark matter can be identified



- WIMPs might annihilate to SM model particles
  → **Very High Energy (VHE, E > 100 GeV) γ-rays**

- Pointing back to the source
  → **Reveal abundance and distribution of DM**
- Spectral features characteristic of DM
  → **Discrimination from background**

Dark matter can be identified

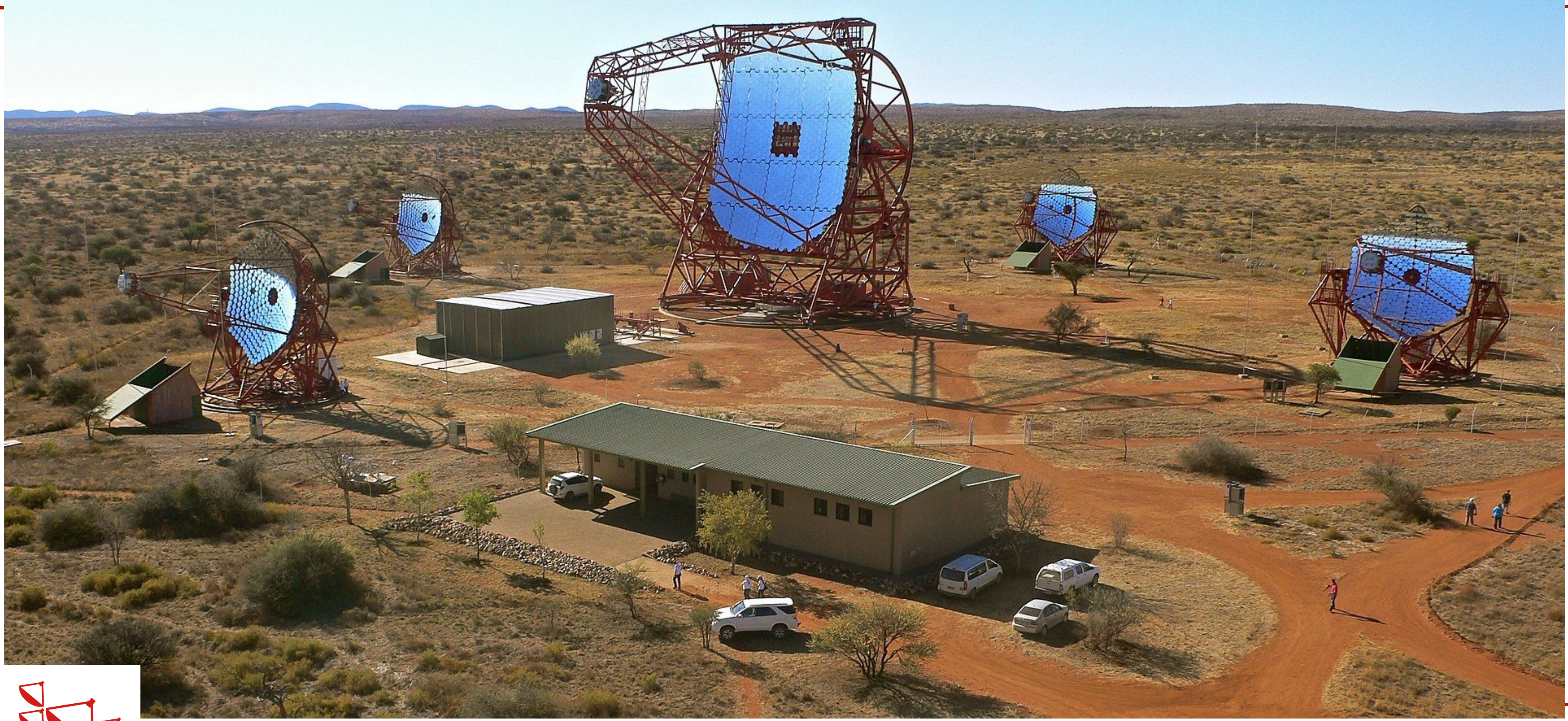


- WIMPs might annihilate to SM model particles
  → **Very High Energy (VHE, E > 100 GeV) γ-rays**

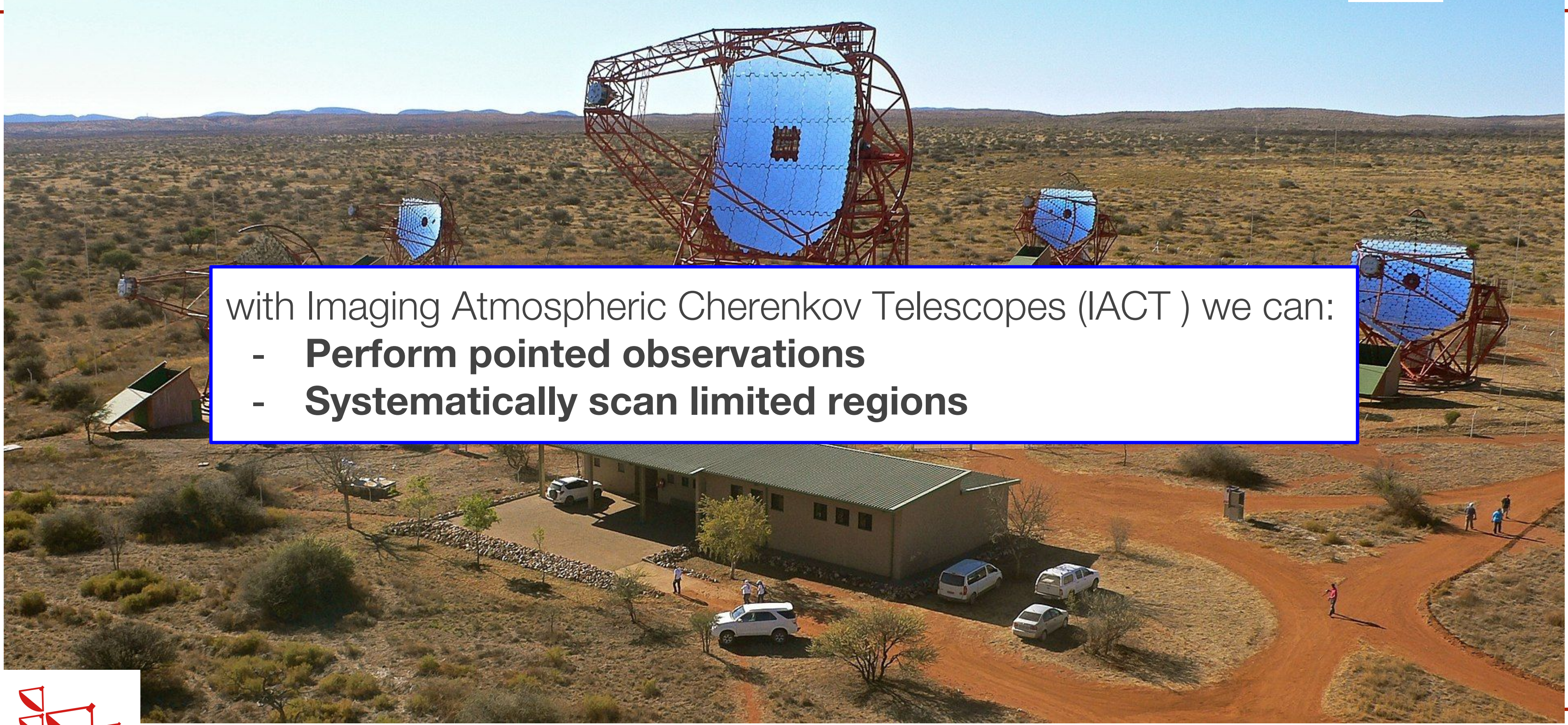
- Pointing back to the source
  → **Reveal abundance and distribution of DM**
- Spectral features characteristic of DM
  → **Discrimination from background**

Identification of DM is possible

The H.E.S.S. observatory



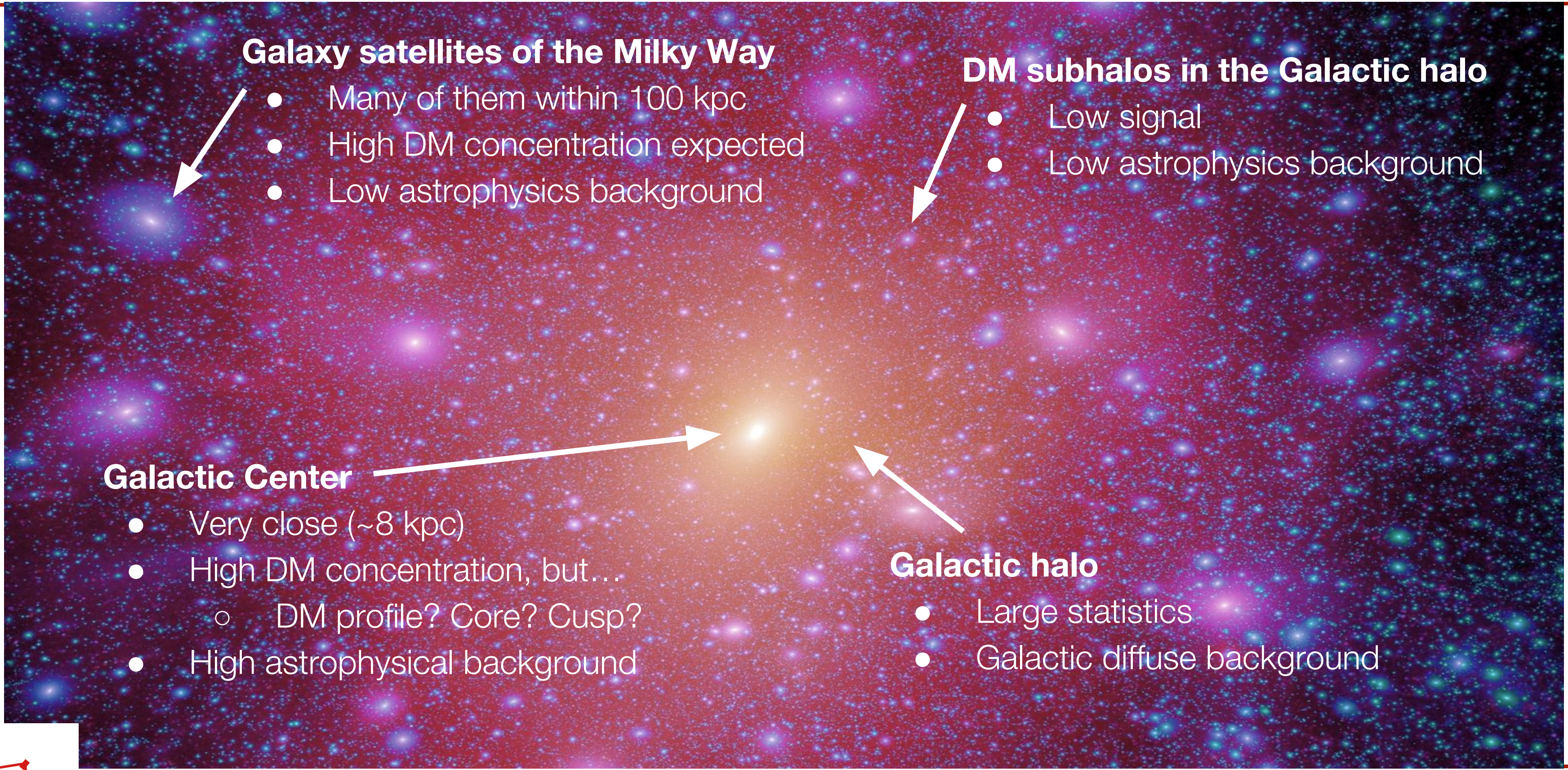
The H.E.S.S. observatory



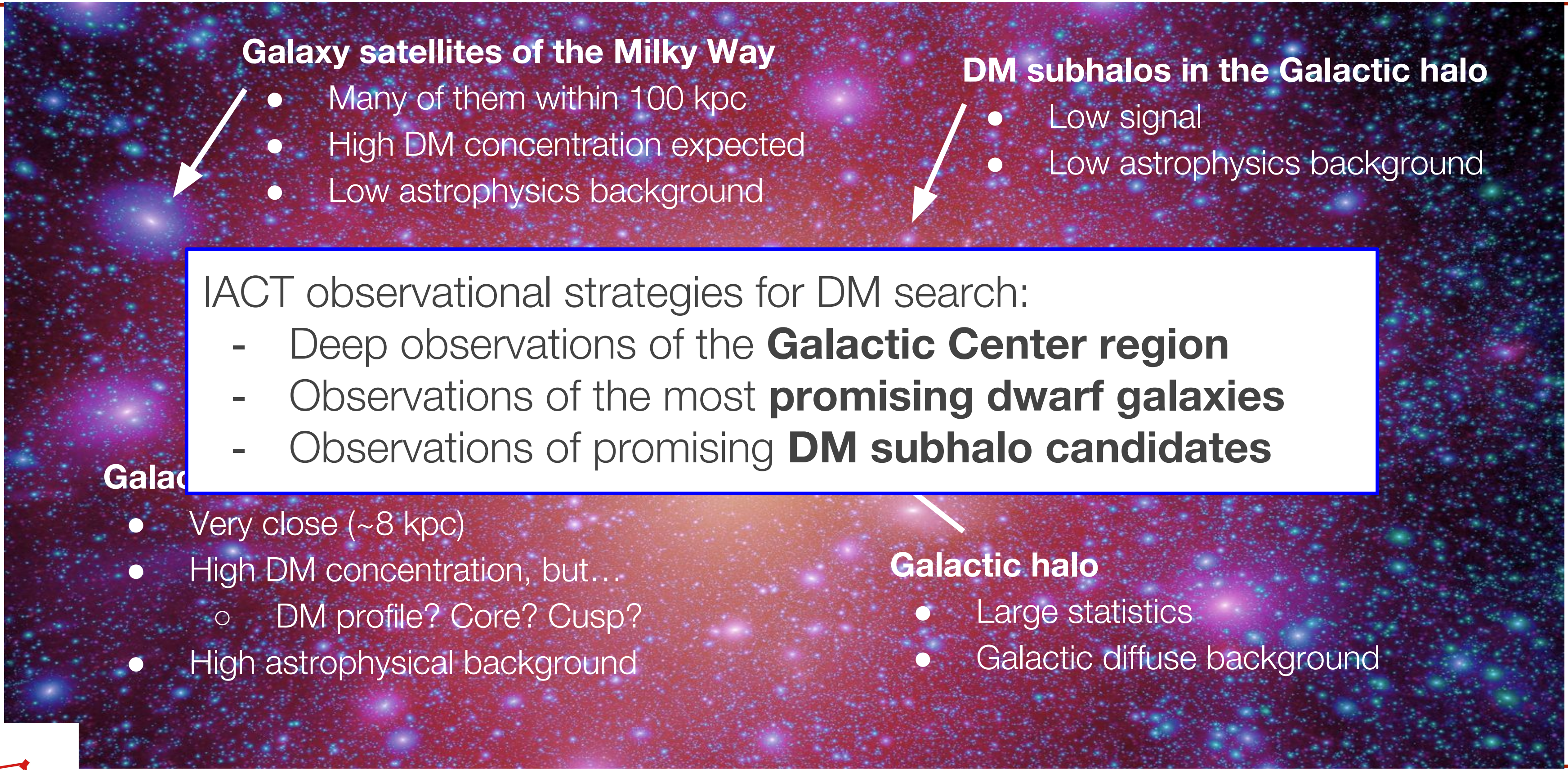
with Imaging Atmospheric Cherenkov Telescopes (IACT) we can:

- **Perform pointed observations**
- **Systematically scan limited regions**

Targets to search for dark matter



Targets to search for dark matter



Galaxy satellites of the Milky Way
- Many of them within 100 kpc
- High DM concentration expected
- Low astrophysics background

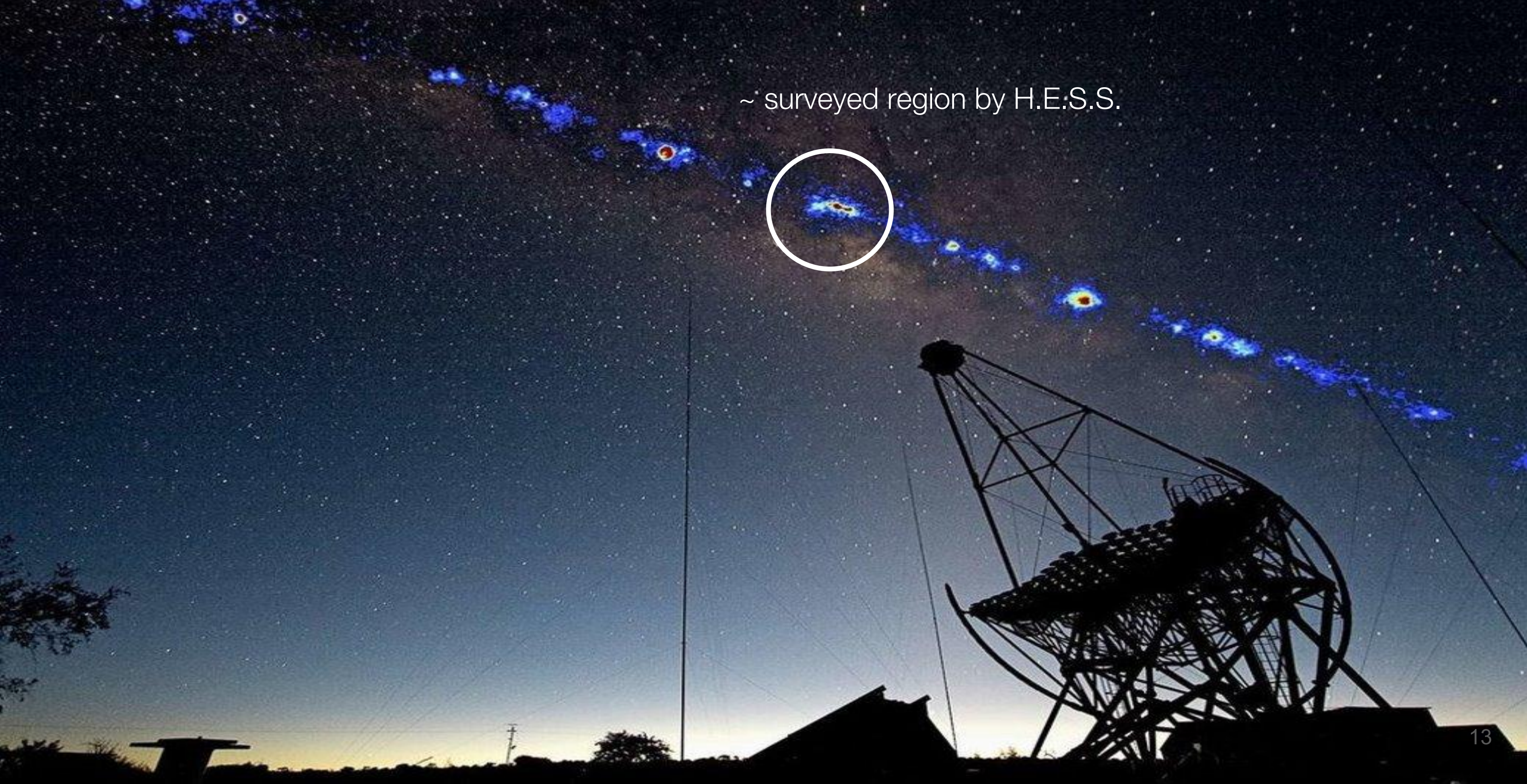
DM subhalos in the Galactic halo
- Low signal
- Low astrophysics background

IACT observational strategies for DM search:
- Deep observations of the **Galactic Center region**
- Observations of the most **promising dwarf galaxies**
- Observations of promising **DM subhalo candidates**

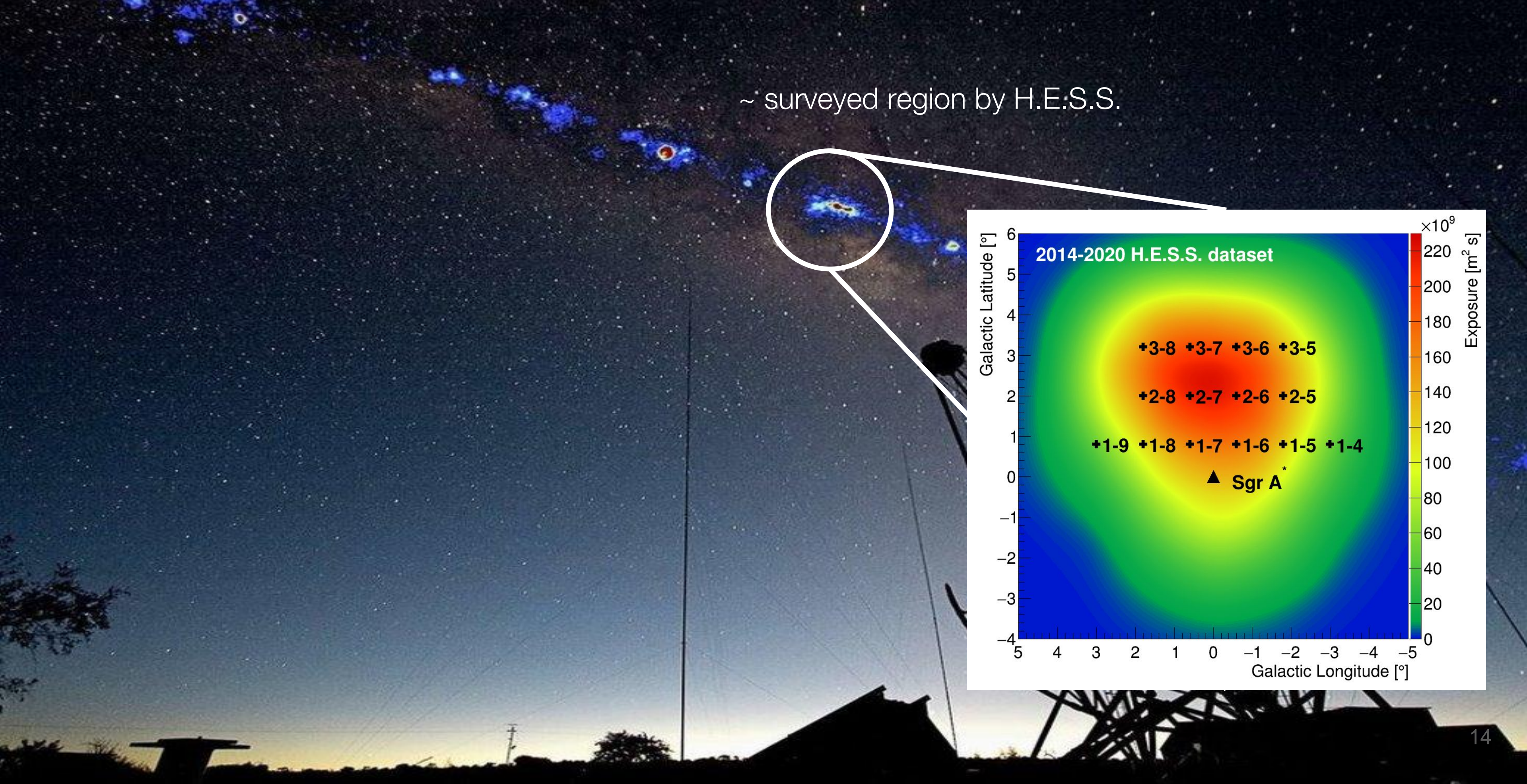
Galac
- Very close (~8 kpc)
- High DM concentration, but…
  - DM profile? Core? Cusp?
- High astrophysical background

Galactic halo
- Large statistics
- Galactic diffuse background

Galactic Center searches



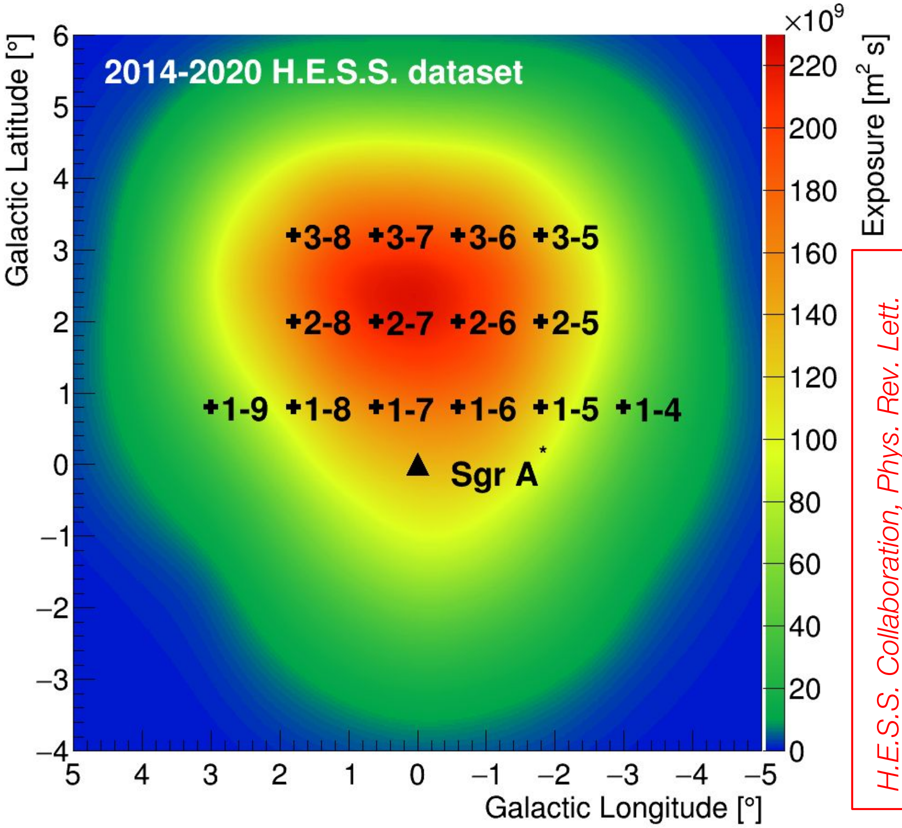
Galactic Center searches



The Inner Galaxy Survey

- The Inner Galaxy Survey (IGS, 2014-2020)
  → 546 hours of high quality data
- H.E.S.S. multi-year observational program of the inner few degrees around the Galactic Center, conducted with the full five-telescopes array

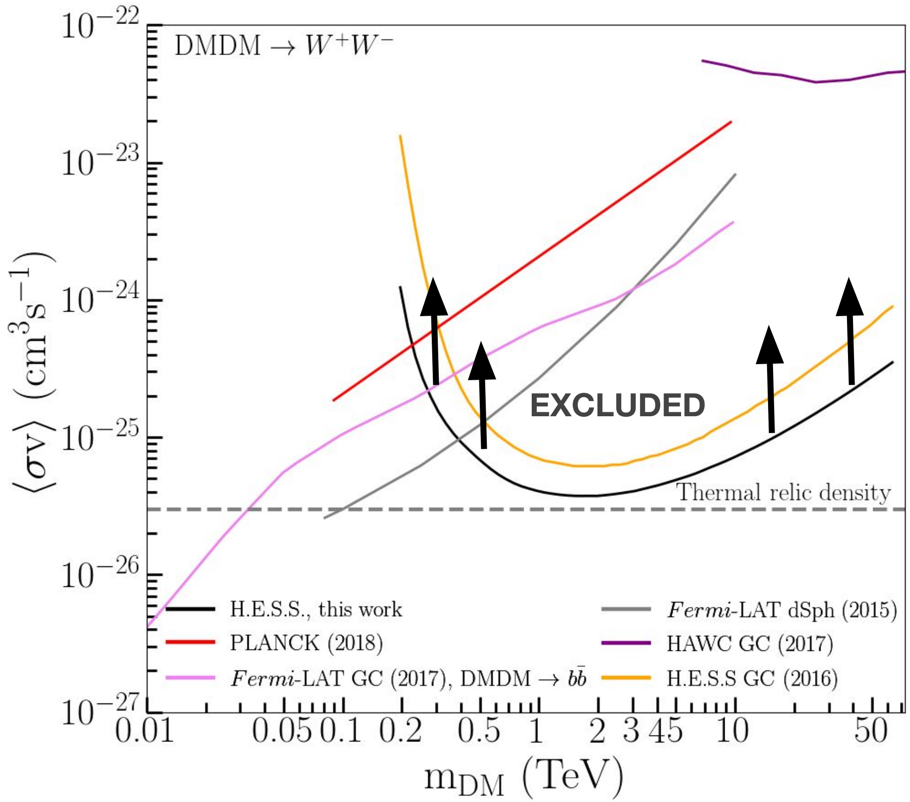
- **One of the motivations: to reach the best sensitivity possible to DM annihilation signals**



H.E.S.S. Collaboration, Phys. Rev. Lett. 129, 111101 (2022)

Constraints on the continuum

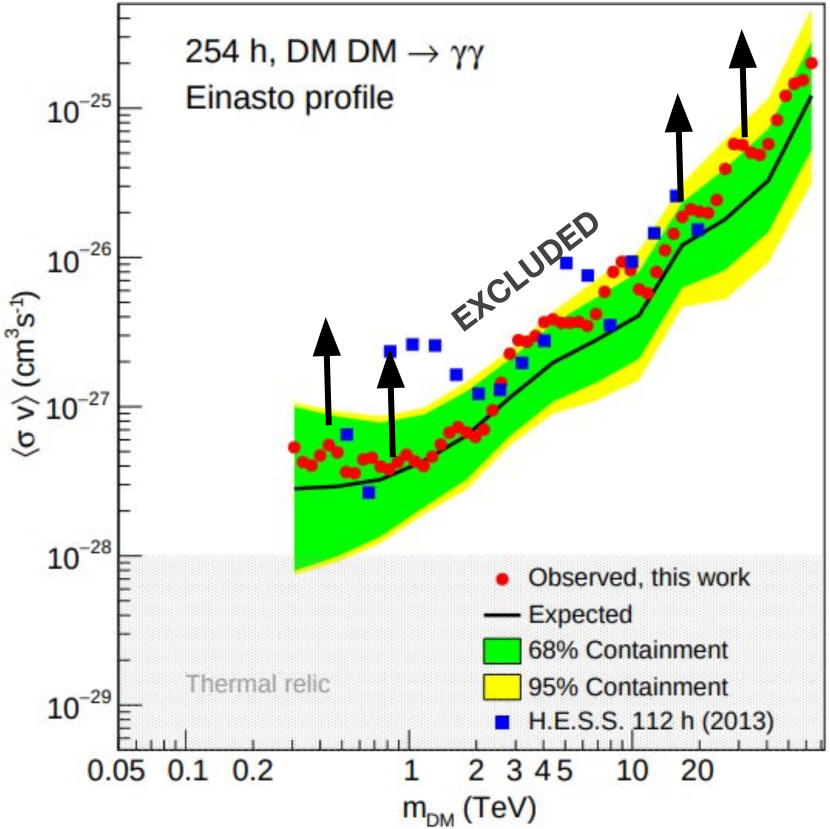
- No excess compatible with DM signal
  → Computation of upper limits on the annihilation cross section
- **Most constraining limits for TeV mass range for the channels tested:**
  - annihilation into the W^+W^- channel $\langle\sigma v\rangle = 3.7\times10^{-26}$ cm³/s at 1.5 TeV
- **Comparing w/ other experiments**



H.E.S.S. Collaboration, Phys. Rev. Lett. 129, 111101 (2022)

Constraints on the line

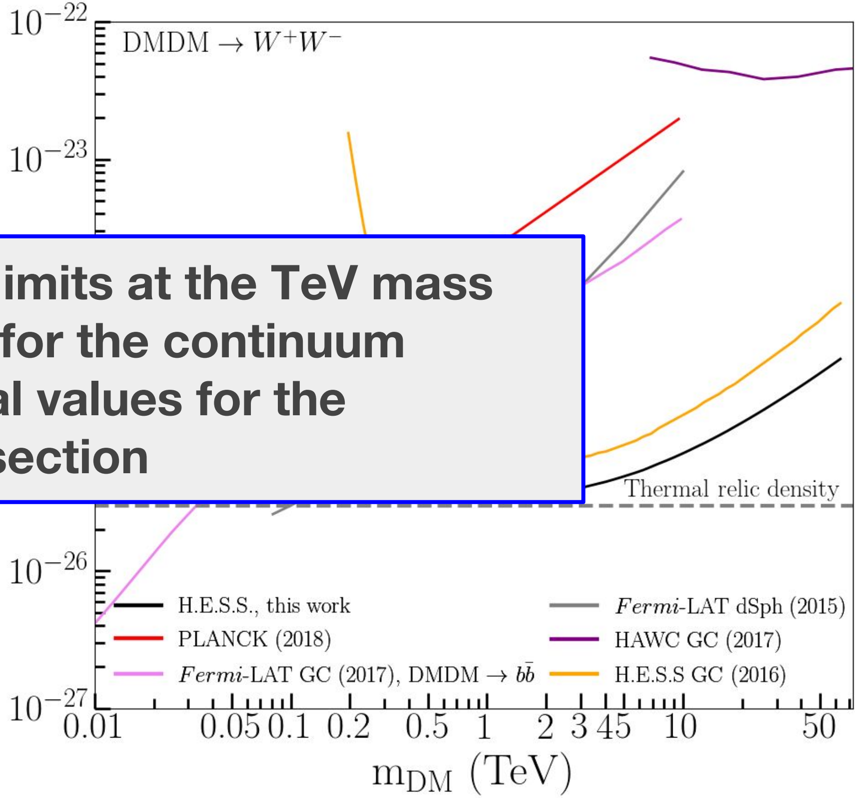
- Using H.E.S.S. I data, collected between 2004 and 2014, for a total of 254 hours
- No excess compatible with DM signal
  → Computation of upper limits on
  the annihilation cross section
- **Limits for above 300 GeV:**
  - annihilation into the $\gamma\gamma$ channel**$\langle\sigma v\rangle$= 4x10^{-28} cm^3/s at 1 TeV**



H.E.S.S. Collaboration, Phys. Rev. Lett. 120, 201101 (2018)

Constraints on the continuum

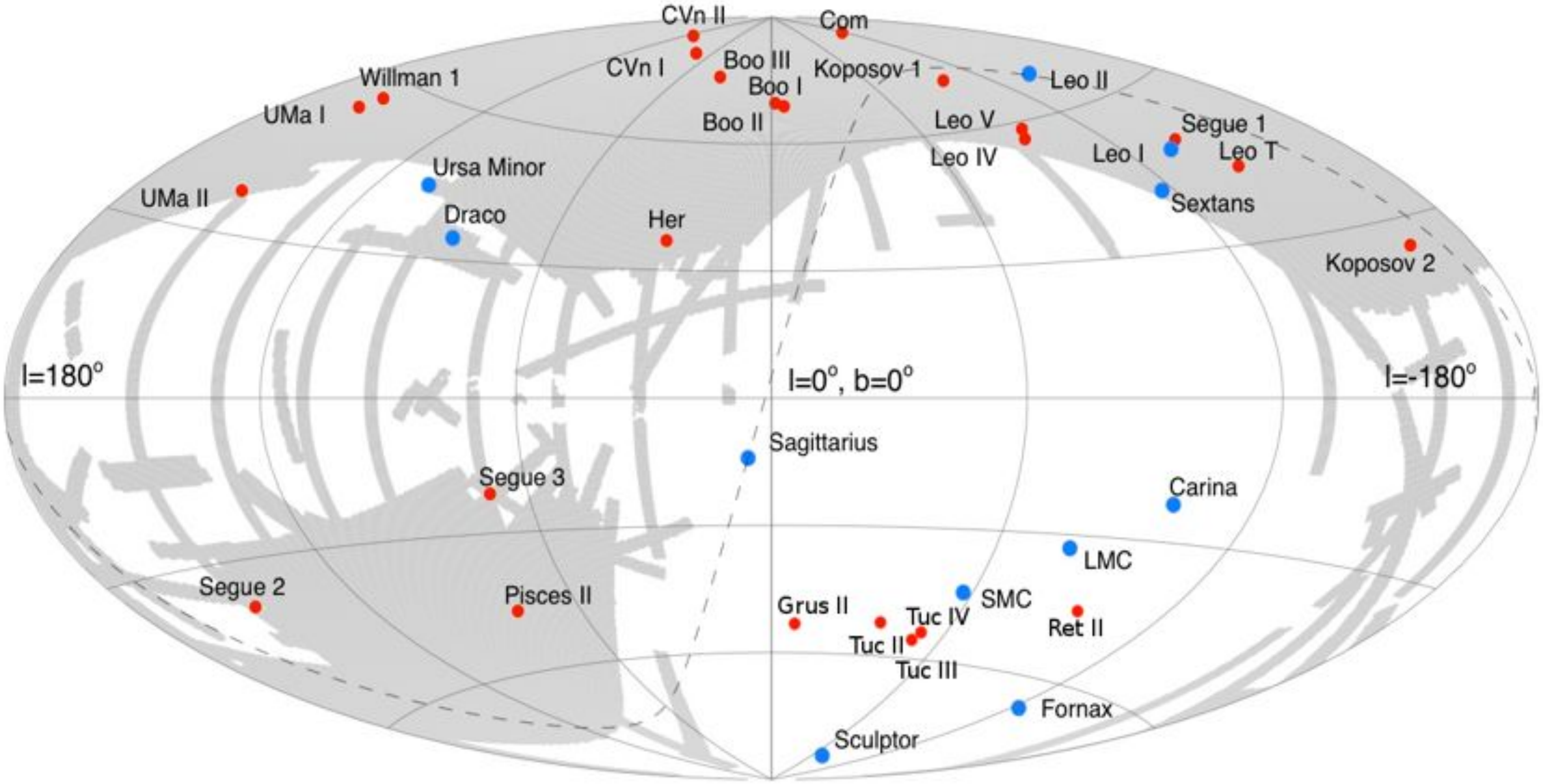
- No excess compatible with DM signal
  → Computation of upper limits on
  the annihilation cross section
- **Most constra**
  mass range
  tested:
  - annihilati
    channel⟨σv⟩= 3.7x10^{-26} cm^3/s at
    1.5 TeV
- **Comparing w/ other experiments**



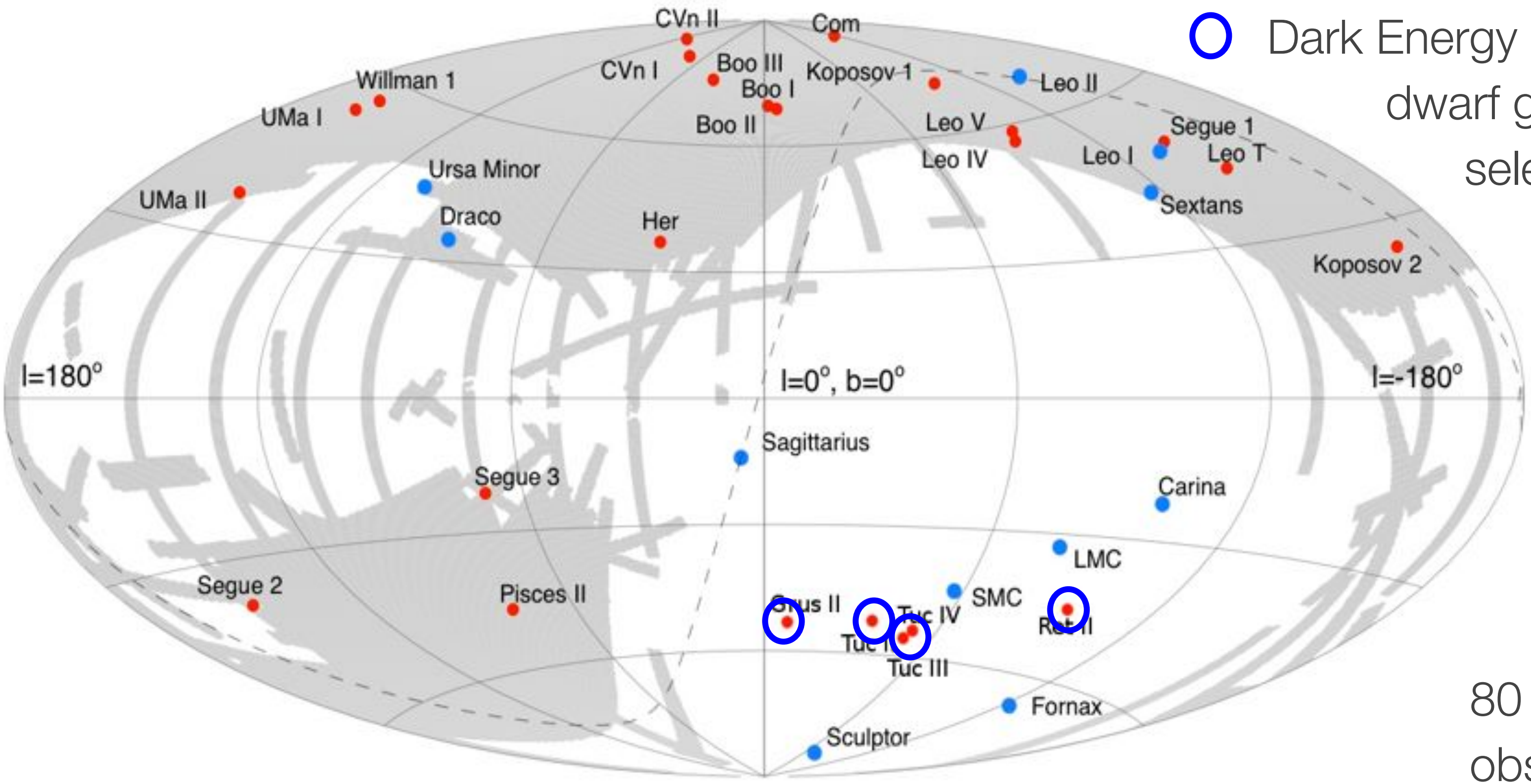
- **Most constraining limits at the TeV mass range with the IGS for the continuum**
- **Challenging thermal values for the annihilation cross section**

H.E.S.S. Collaboration, Phys. Rev. Lett. 129, 111101 (2022)

Searches towards dwarf galaxies



Observations of DES dwarf galaxies



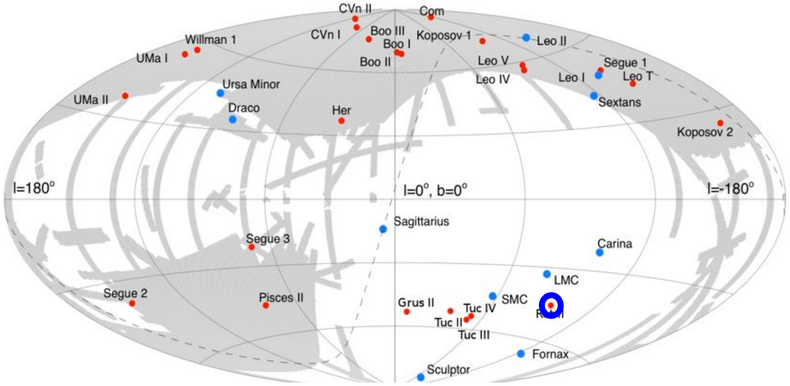
Dark Energy Survey (DES) dwarf galaxy satellites selected and observed by H.E.S.S.

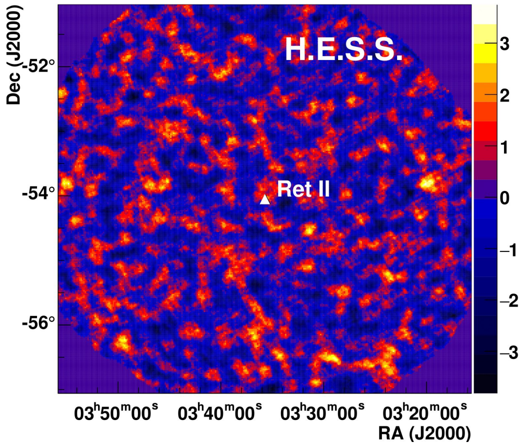
H.E.S.S. Collaboration, Phys. Rev. D 102, 062001 (2020)

80 hours of observations

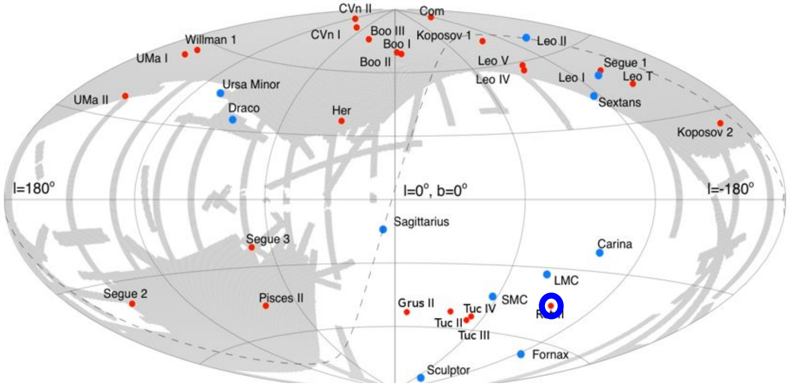
No observed positive excess

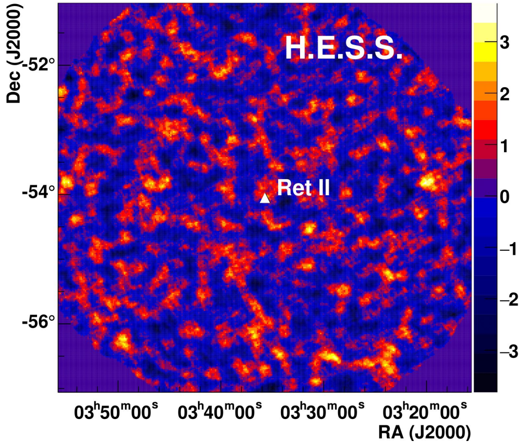
H.E.S.S. Collaboration, Phys. Rev. D 102, 062001 (2020)





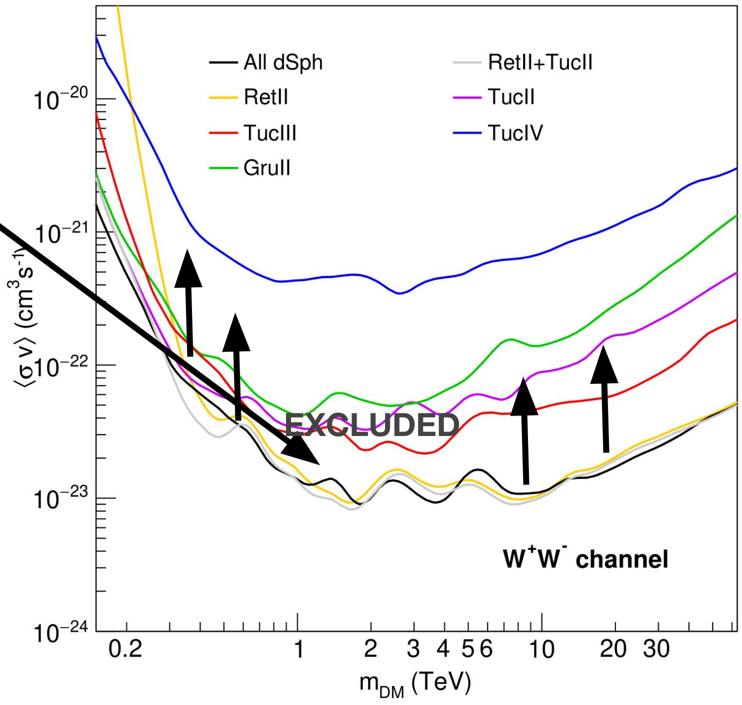
Constraints on the continuum





H.E.S.S. Collaboration, Phys. Rev. D 102, 062001 (2020)

Combined limits of H.E.S.S. observations of Ret II, Tuc II, Tuc III, Tuc IV, and Grus II

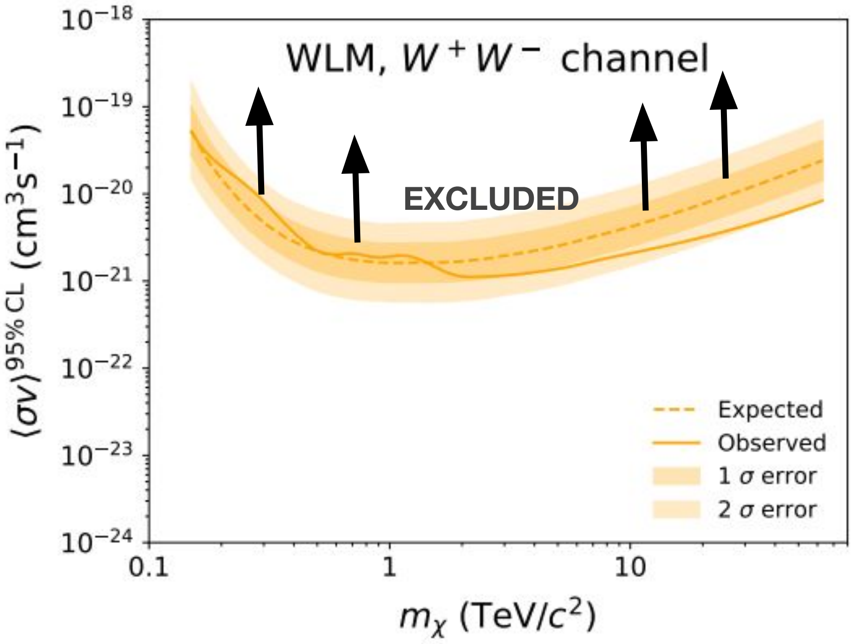


Constraints on the continuum

H.E.S.S. Collaboration, Phys. Rev. D 103, 102002 (2021)

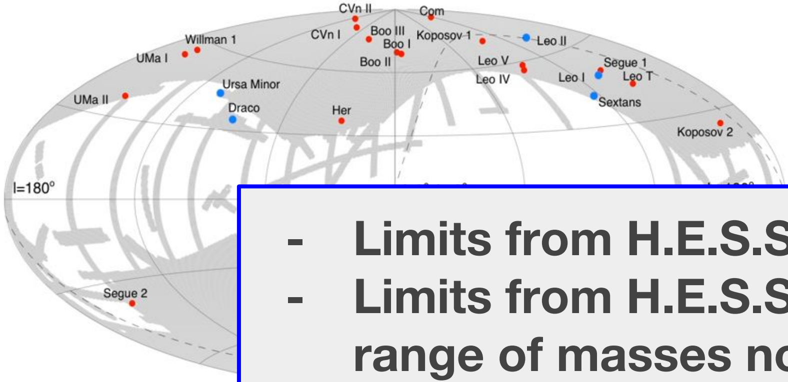
- Complementary targets are dwarf irregular galaxies
- 18 hours of observations with H.E.S.S. of the Wolf-Lundmark-Melotte galaxy
- DM distribution well parametrized by a *coreNFW*

→ **Improvement of a factor at least 10 w.r.t. previous limits from other experiments**

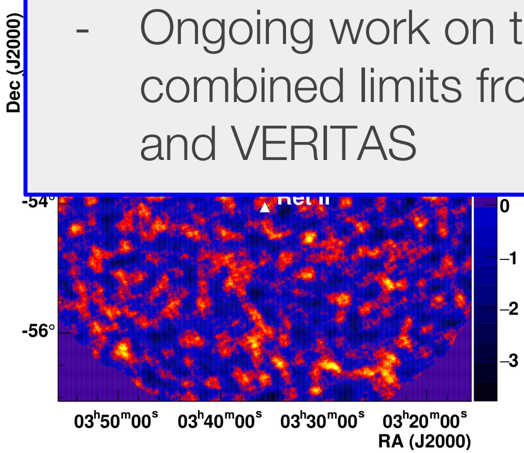


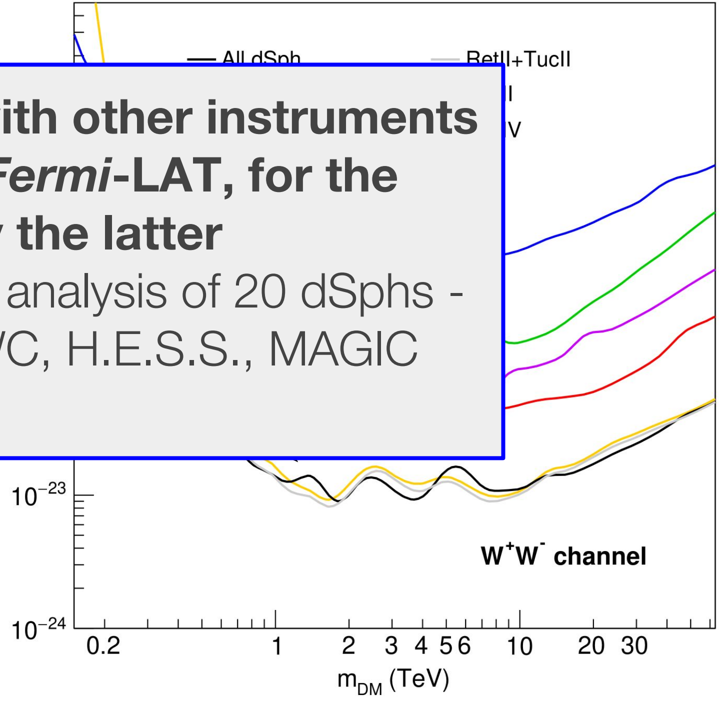
Constraints on the continuum

H.E.S.S. Collaboration, Phys. Rev. D 102, 062001 (2020)



Stacked



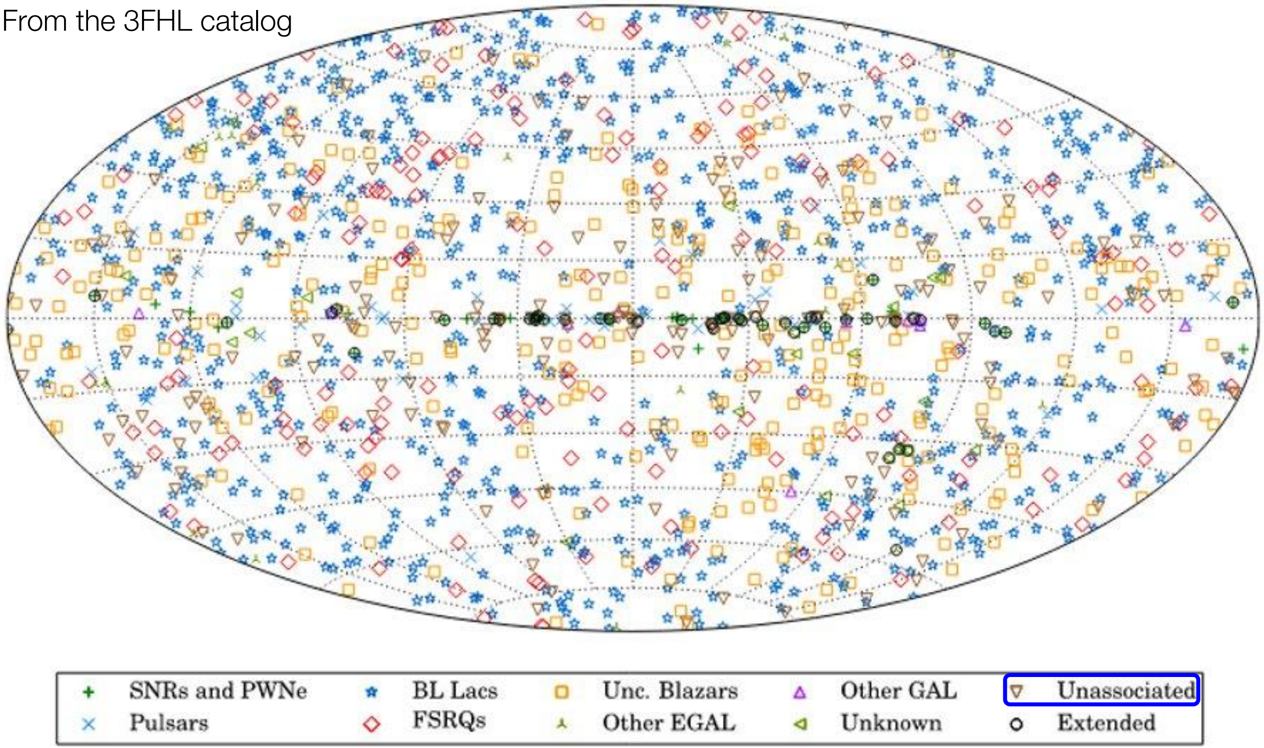


- **Limits from H.E.S.S. competitive with other instruments**
- **Limits from H.E.S.S. complement *Fermi*-LAT, for the range of masses not accessible by the latter**
- Ongoing work on the multi-instrument analysis of 20 dSphs - combined limits from *Fermi*-LAT, HAWC, H.E.S.S., MAGIC and VERITAS

Selection of the most promising DM subhalos

Ref. *Ajello et al., Astrophys. J. Suppl. 2017, 232, 18*

From the 3FHL catalog

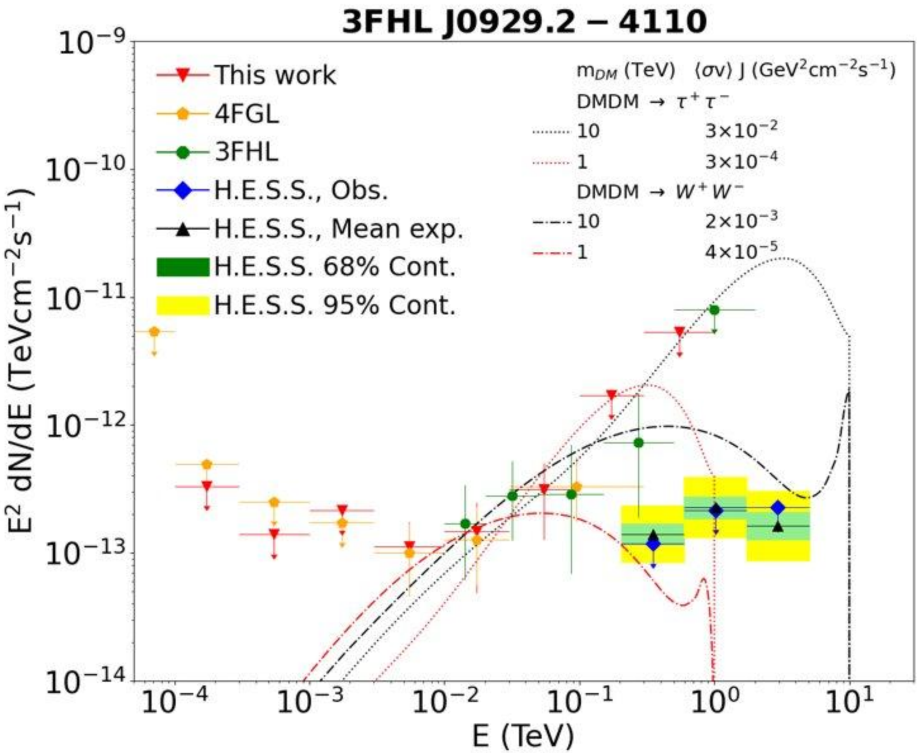


Thorough selection of **the most promising unassociated sources** in the *Fermi*-LAT catalog as DM subhalos - the unidentified Fermi objects (UFOs)

4 observed by H.E.S.S.

UFO spectral energy distribution

- *Fermi*-LAT flux points and upper limits
- DM-induced emission models are viable according to *Fermi*-LAT measurements
- Need massive DM because no energy cut-off is seen from the *Fermi*-LAT data analysis

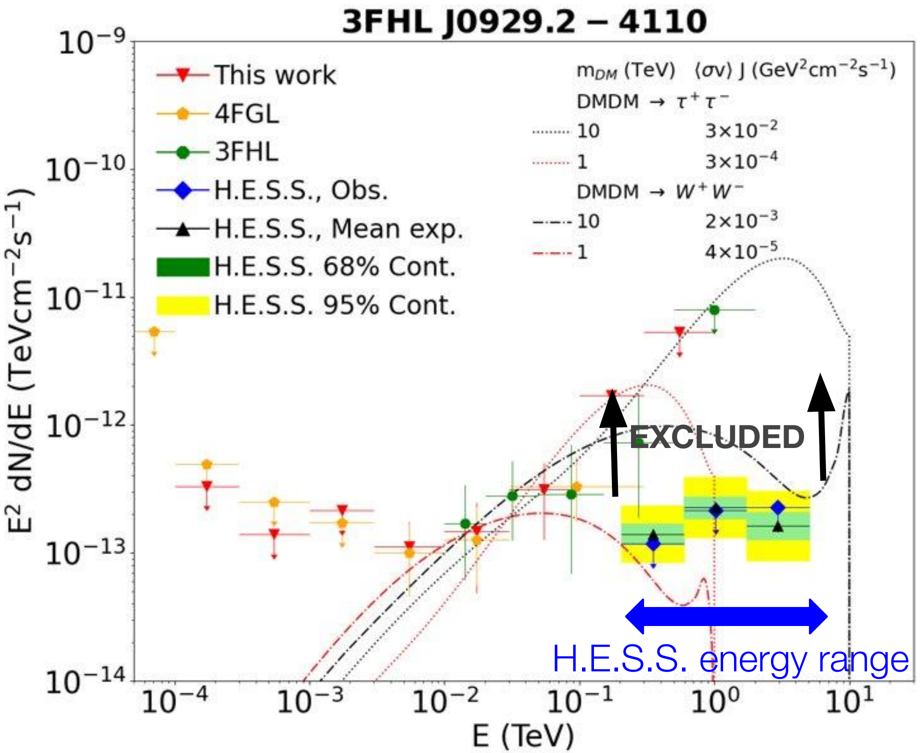


H.E.S.S. Collaboration, Astrophys. J. 918, 17 (2021)

H.E.S.S. upper limits

- *Fermi*-LAT flux points and upper limits
- DM-induced emission models are viable according to *Fermi*-LAT measurements
- Need massive DM because no energy cut-off is seen from the *Fermi*-LAT data analysis

→ **H.E.S.S. upper limits (no excess found) constrain some viable DM-induced emission models for *Fermi*-LAT**



H.E.S.S. Collaboration, Astrophys. J. 918, 17 (2021)

DM-induced models excluded

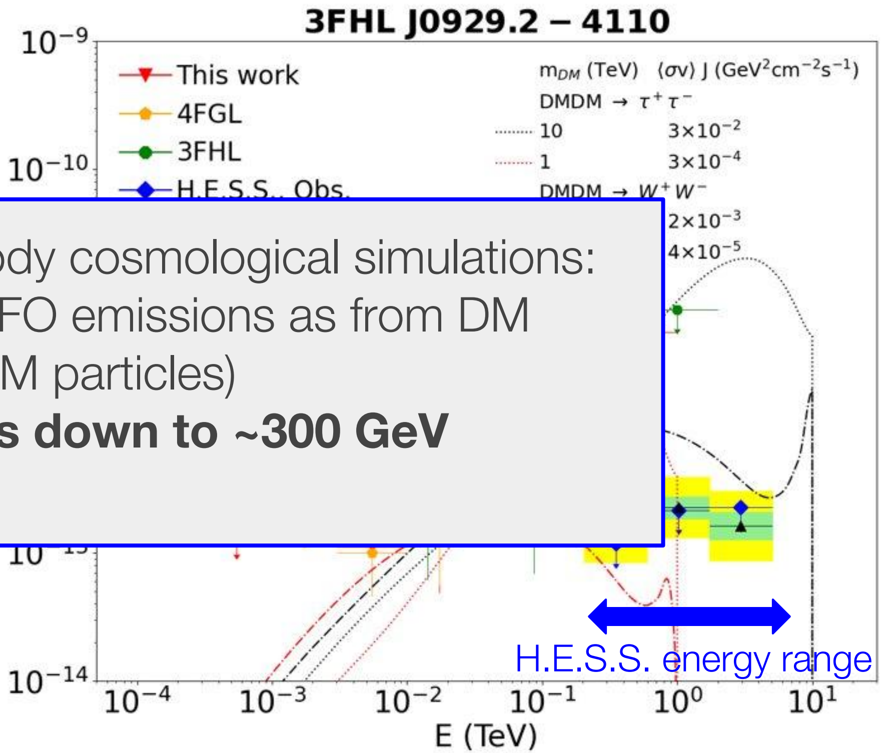
- *Fermi*-LAT flux points and upper limits
- DM-induced emission models are viable according to *Fermi*-LAT measurements
- Need ... cut-o... analys...

→ **H.E.S.S. upper limits (no excess found) constrain some viable DM-induced emission models for *Fermi*-LAT**

From the statistical analysis and N-body cosmological simulations:

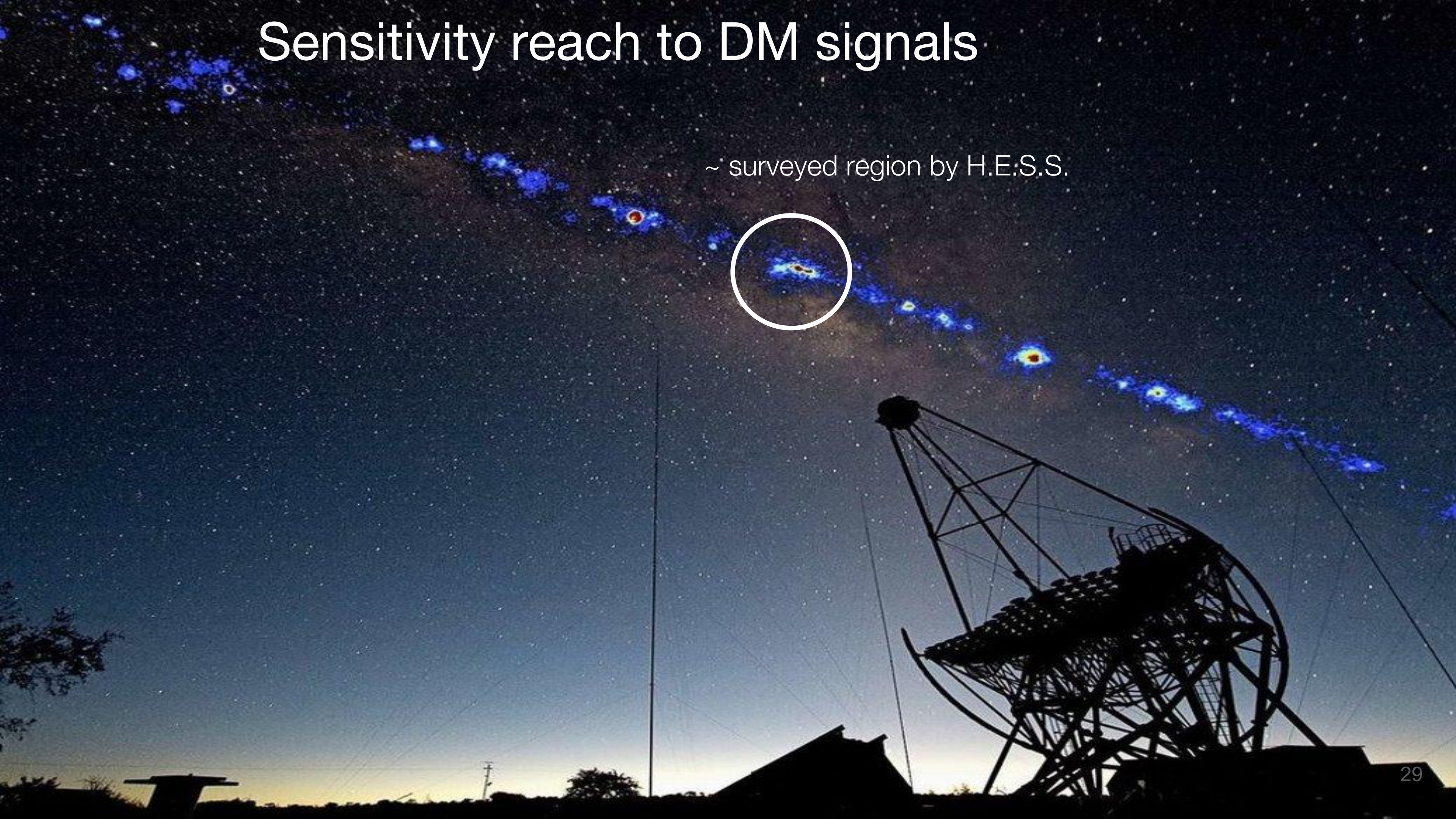
- High J-factor values to explain UFO emissions as from DM (assuming thermally-produced DM particles)

→ **UFOs excluded as DM subhalos down to ~300 GeV with H.E.S.S. limits**



H.E.S.S. Collaboration, Astrophys. J. 918, 17 (2021)

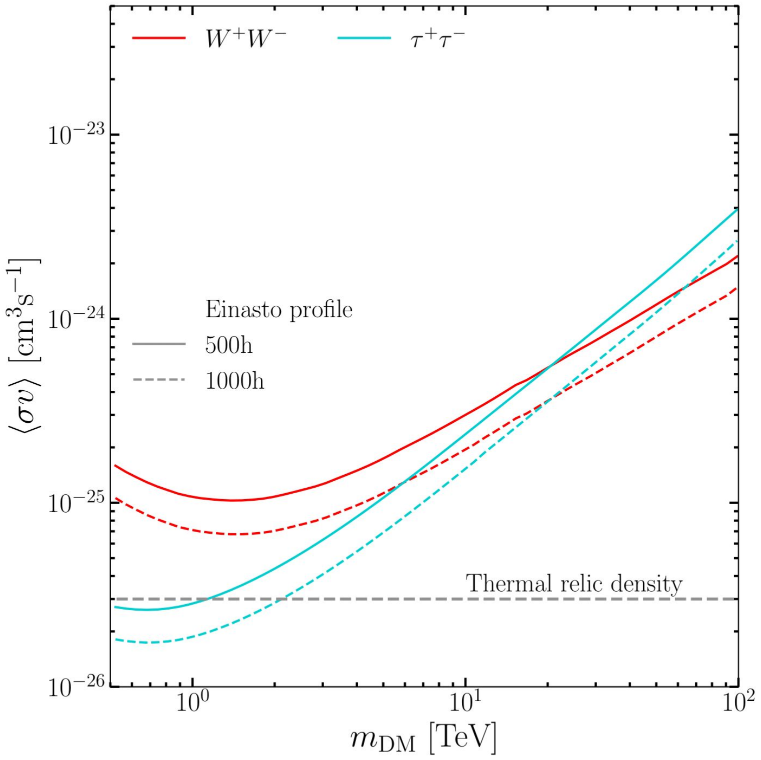
Sensitivity reach to DM signals



Assessing the sensitivity to dark matter signal

- **Mock dataset of H.E.S.S. IGS observations**
  → 500h and 1000h of flat exposure
- Most up-to-date setup:
  - Andvanced calculations for theoretical gamma-ray DM annihilation yields
  - Recent DM profiles determination from measurements of the MW rotation curve

    Cautun et al., MNRAS, 494.3, (2020)
  - Background modeling considering residual and conventional TeV astrophysical background



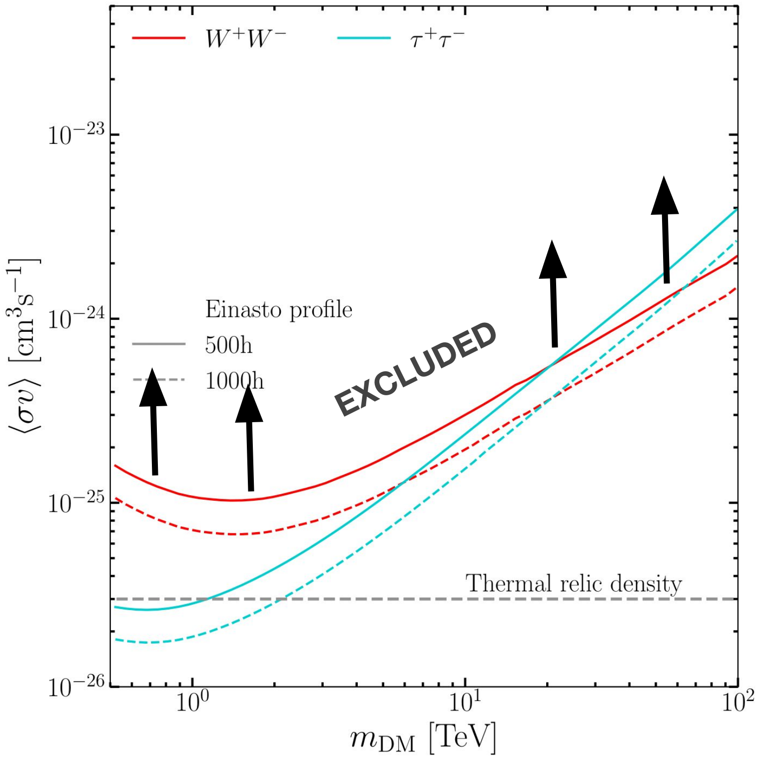
AM, Emmanuel Moulin and Nicholas L. Rodd, Phys. Rev. D 107, 043028 (2023)

Assessing the sensitivity to dark matter signal

- Mock dataset of H.E.S.S. IGS observations
  → 500h and 1000h of flat exposure
- Most up-to-date setup:
  - Andvanced calculations for theoretical gamma-ray DM annihilation yields
  - Recent DM profiles determination from measurements of the MW rotation curve

    Cautun et al., MNRAS, 494.3, (2020)
  - Background modeling considering residual and conventional TeV astrophysical background

→ **Assessing the ~ final sensitivity reach of the current generation of IACTs**

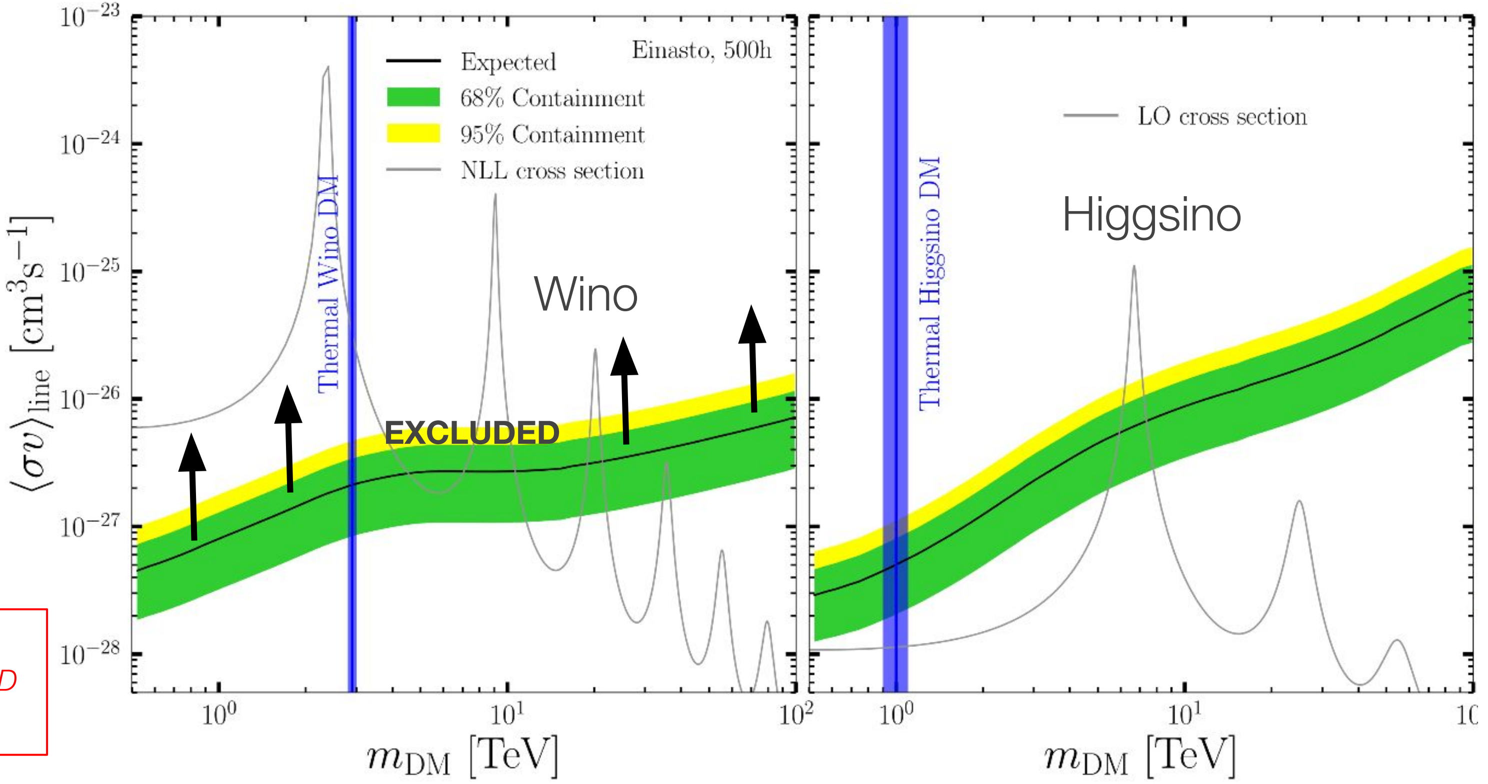


AM, Emmanuel Moulin and Nicholas L. Rodd, Phys. Rev. D 107, 043028 (2023)

Prospects for canonical DM models

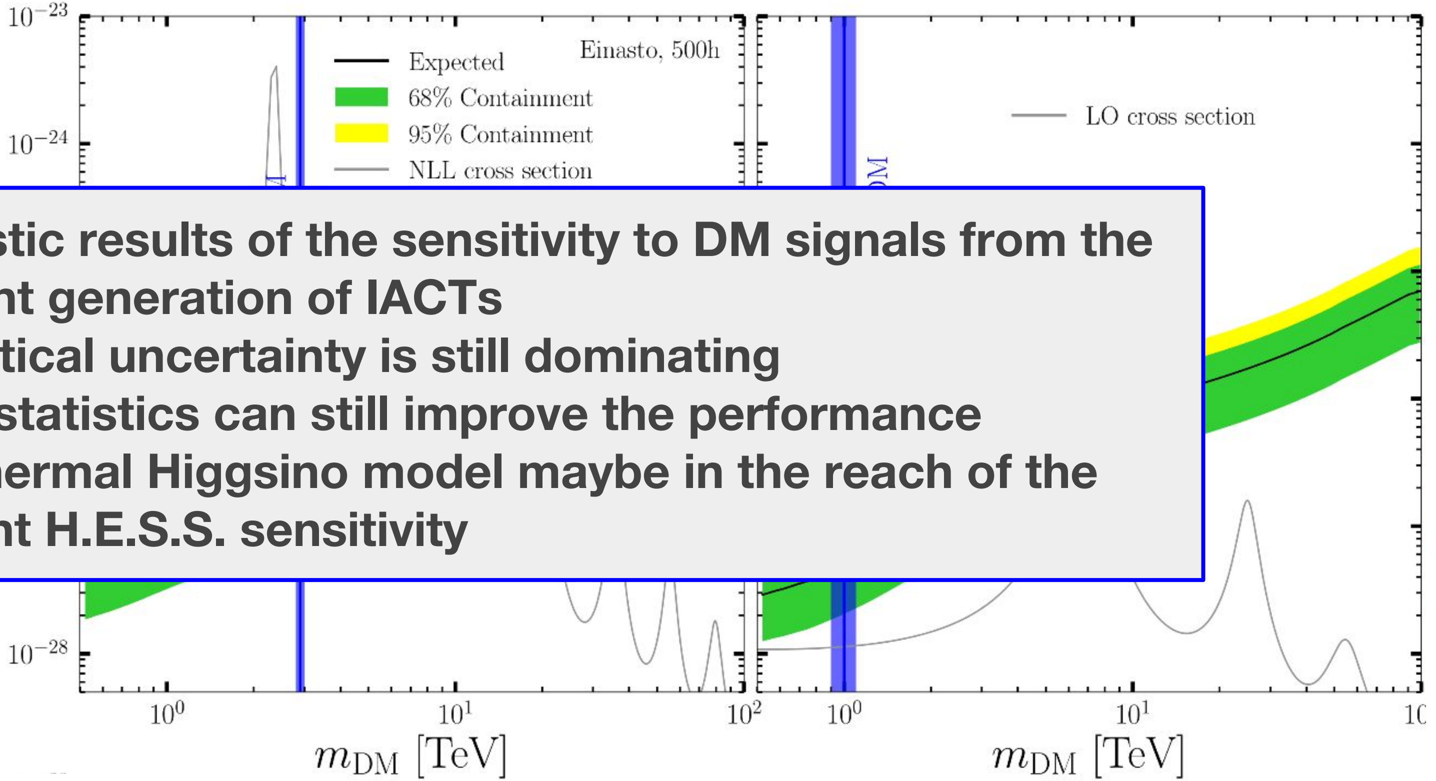
- Thermal Winos excluded
- Higgsino DM masses excluded at around 6.5 TeV

AM, Emmanuel Moulin and Nicholas L. Rodd, Phys. Rev. D 107, 043028 (2023)



Prospects for canonical DM models

- Thermal Winos excluded
- Higgs[...] mass[...] exclu[...] aroun[...] TeV



- Realistic results of the sensitivity to DM signals from the current generation of IACTs
- Statistical uncertainty is still dominating

→ More statistics can still improve the performance

→ The thermal Higgsino model maybe in the reach of the current H.E.S.S. sensitivity

AM, Emmanuel Moulin and Nicholas L. Rodd, Phys. Rev. D 107, 043028 (2023)

Summary and outlook

After more than 20 years of observations with H.E.S.S.

→ **Most constraining limits at the TeV** mass range with the H.E.S.S. IGS, for the continuum

→ Competitive limits from **H.E.S.S. observations of dwarf galaxies**

➔ Ongoing work on the multi-instrument analysis of 20 dSphs

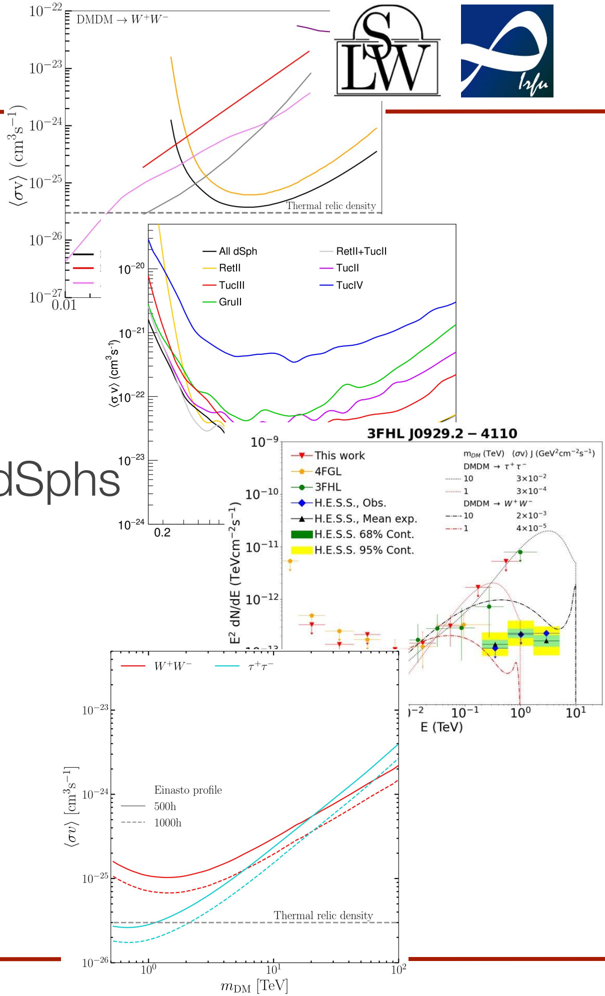
→ **Excluded DM subhalo interpretation for the brightest candidates** down to ~300 GeV with H.E.S.S. limits

→ **Statistical uncertainty is still dominating**

➔ The H.E.S.S. IGS observations are ongoing

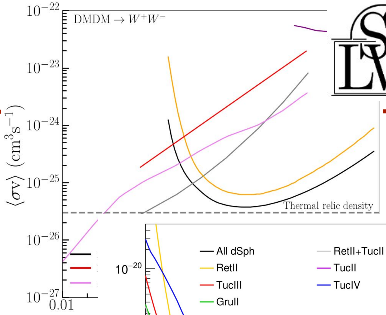
→ **The thermal Wino DM model is already excluded**

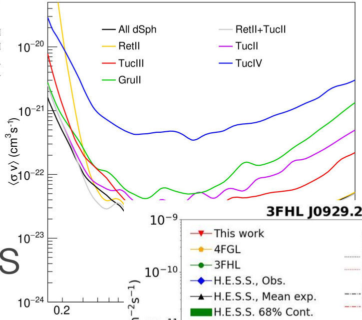
→ The thermal Higgsino model maybe in the reach of the current H.E.S.S. sensitivity

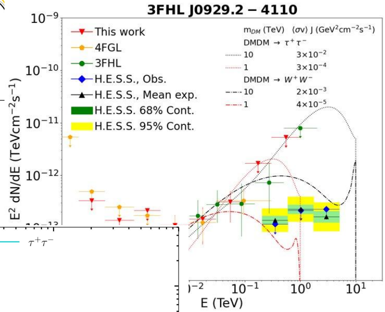


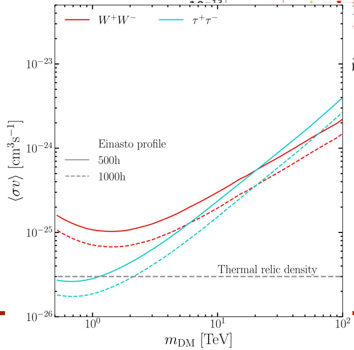
Thank you for your attention!

Summary and outlook









After more than 20 years of observations with H.E.S.S.

→ **Most constraining limits at the TeV** mass range with the H.E.S.S. IGS, for the continuum

→ Competitive limits from **H.E.S.S. observations of dwarf galaxies**

- ➔ Ongoing work on the multi-instrument analysis of 20 dSphs

→ **Excluded DM subhalo interpretation for the brightest candidates** down to ~300 GeV with H.E.S.S. limits

→ **Statistical uncertainty is still dominating**

- ➔ The H.E.S.S. IGS observations are ongoing

→ **The thermal Wino DM model is already excluded**

- → The thermal Higgsino model maybe in the reach of the current H.E.S.S. sensitivity

Backup slides

Search for dark matter with gamma rays

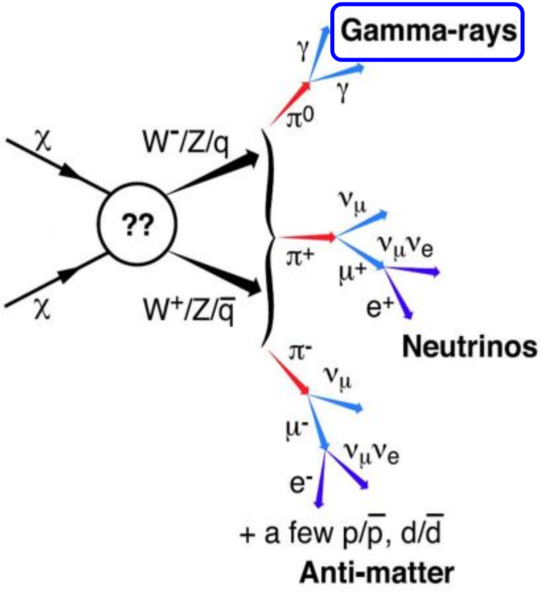
Flux for decay…

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{4\pi}\frac{1}{m_{\rm DM}\tau}\frac{dN_\gamma}{dE_\gamma} \times \int_{\Delta\Omega} d\Omega \int_{l.o.s.} \rho(r[s])ds$$

If the source is distant:

- every point in the source is distant → *r* ~ *R*
- the flux depends approximately ~ M/R^2 (M total mass of the source)
- strongest signal from targets with the largest DM mass and also quite close → **strongest constraints from galaxy clusters observations**

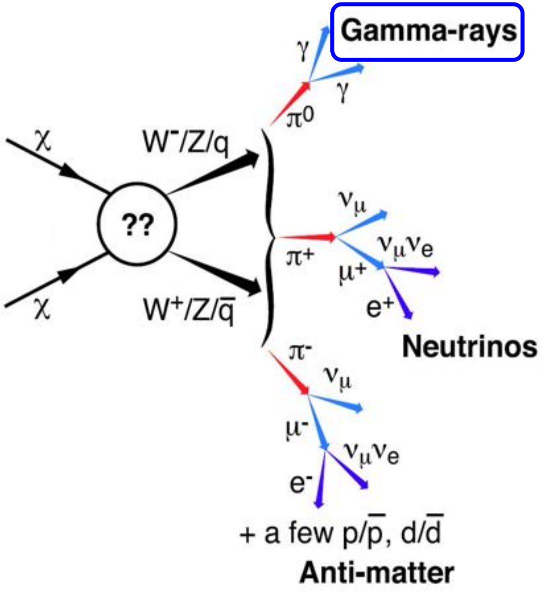
Gamma-rays from dark matter annihilation



- WIMPs might annihilate to SM model particles
- Particles in the final state

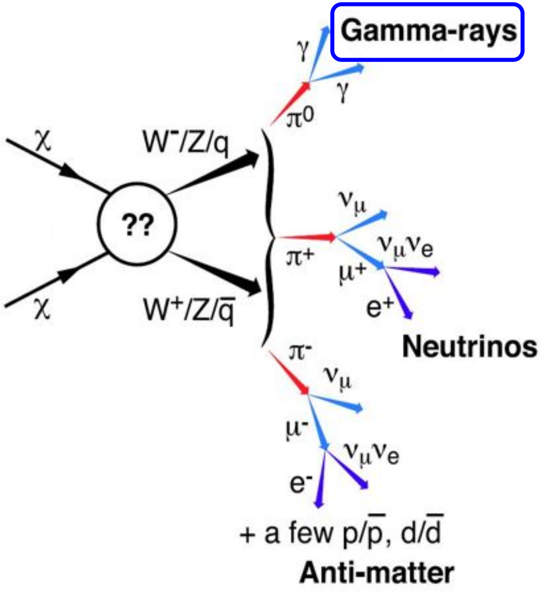
  → **Very High Energy (VHE, E > 100 GeV) γ-rays**

Gamma-rays from dark matter annihilation



- WIMPs might annihilate to SM model particles
- Particles in the final state
  → VHE (E > 100 GeV) γ-rays
- VHE γ-rays point back to the source
  → **Reveal abundance and distribution of DM**
- Spectral features characteristic of DM
  → **Discrimination from background**

Dark matter can be identified

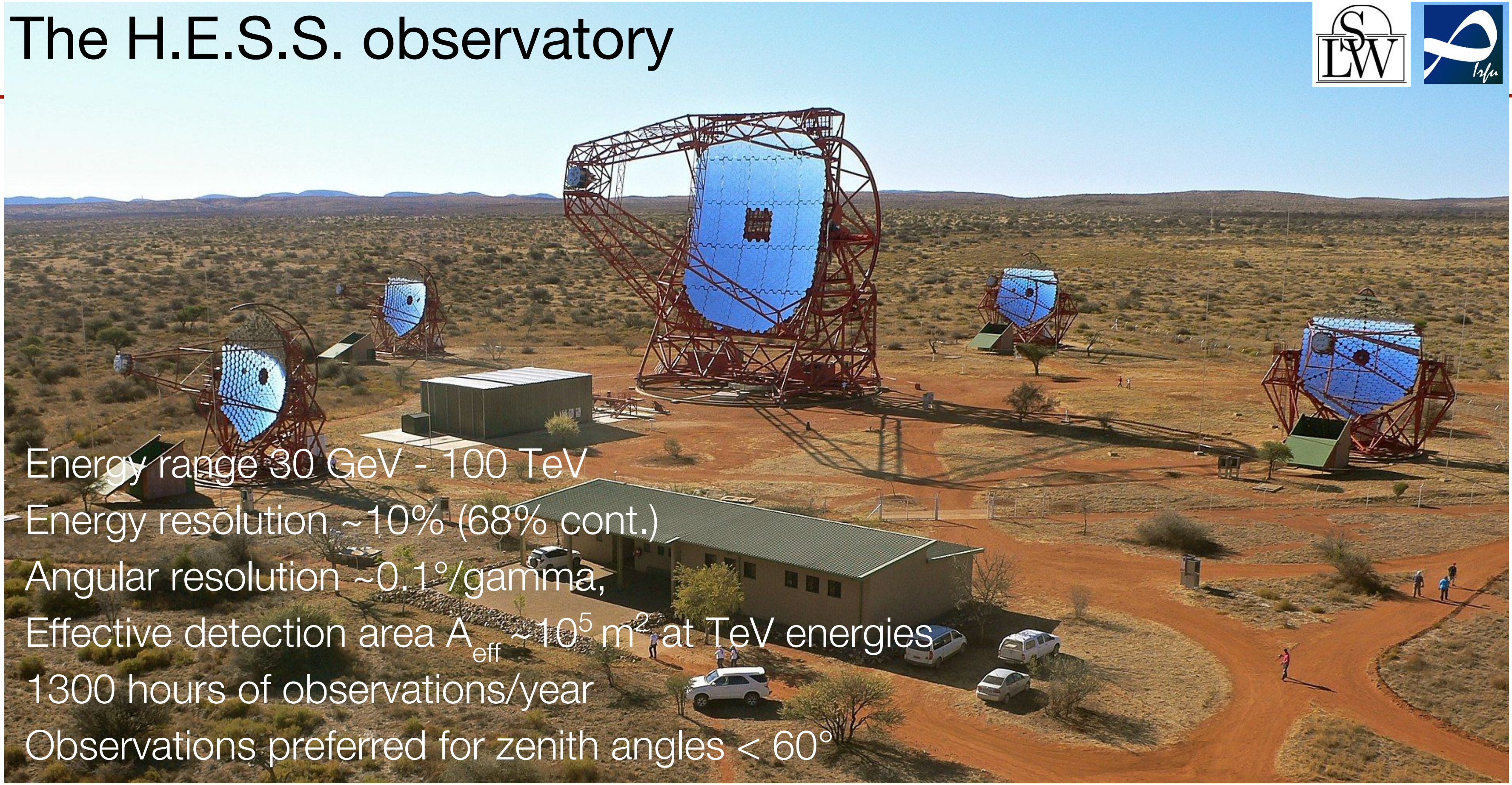


- WIMPs might annihilate to SM model particles
- Particles in the final state
  → VHE (E > 100 GeV) γ-rays
- VHE γ-rays point back to the source
  → Reveal abundance and distribution of DM
- Spectral features characteristic of DM
  → Discrimination from background

Identification of DM possible:

- γ-rays distribution → DM density distribution
- γ-rays spectrum → reaction processes and DM mass

The H.E.S.S. observatory



Energy range 30 GeV - 100 TeV

Energy resolution ~10% (68% cont.)

Angular resolution ~0.1°/gamma,

Effective detection area A_{eff} ~10^5 m^2 at TeV energies

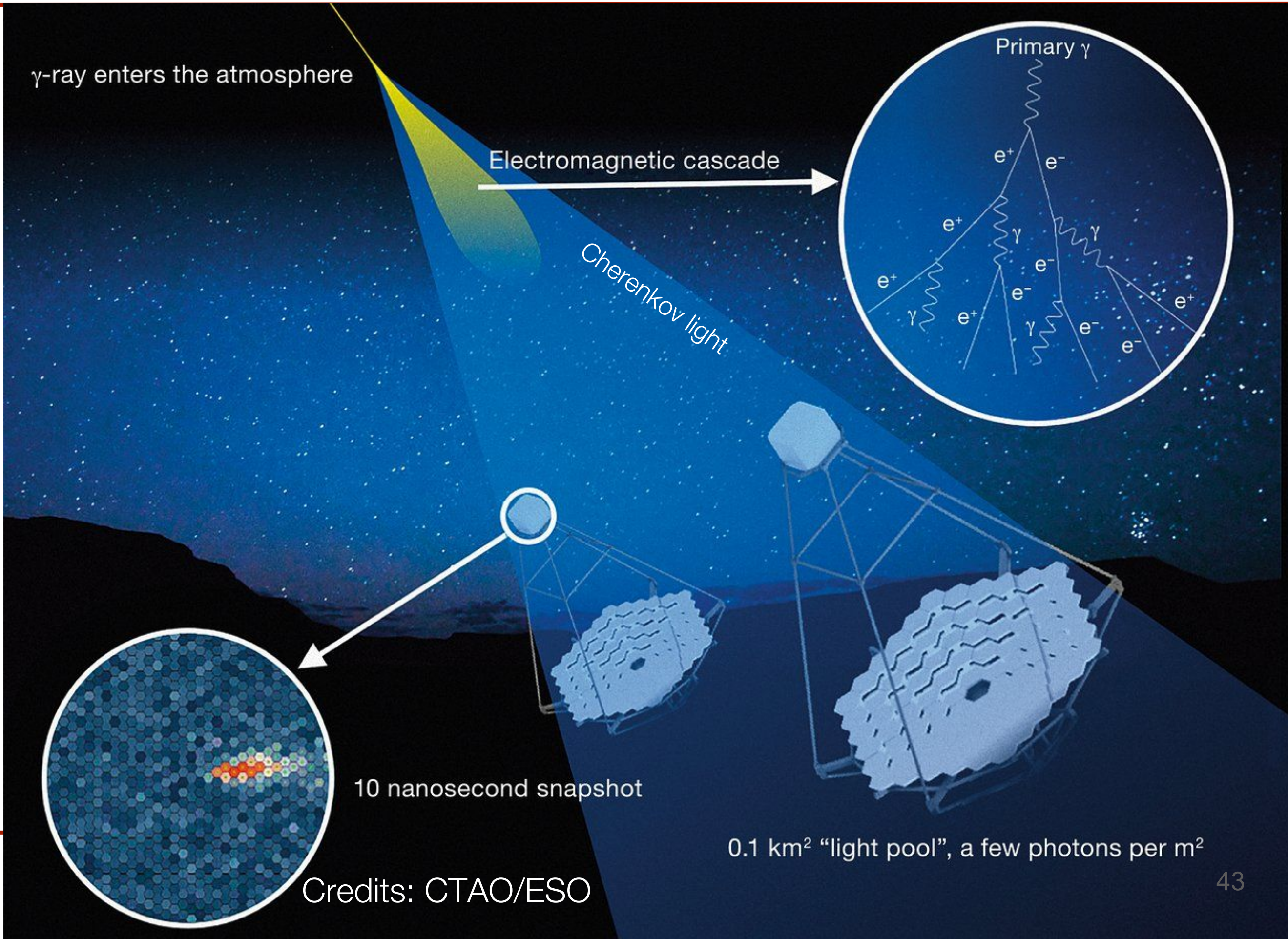
1300 hours of observations/year

Observations preferred for zenith angles < 60°

Imaging Atmospheric Cherenkov Technique

IACT observational strategy:

- **Pointed observations or systematic scans of limited regions**



Search for dark matter with gamma rays

Flux for annihilation…

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\frac{dN_\gamma}{dE_\gamma} \times \int_{\Delta\Omega} d\Omega \int_{l.o.s.} \rho^2(r[s])ds$$

Particle physics factor:

- Differential photon yield
- DM particle mass
- Cross section

Astrophysics factor: J-factor

- DM distribution in the target
- Large uncertainties…
  - Baryon feedback
  - Tidal Stripping
  - Clustering

Data analysis with Test Statistics

$$L(N_{\rm S}, N_{\rm B}|N_{\rm ON}, N_{\rm OFF}, \alpha) = \frac{(N_{\rm S}+N_{\rm B})^{N_{\rm ON}}}{N_{\rm ON}!} e^{-(N_{\rm S}+N_{\rm B})} \frac{(N'_{\rm S}+\alpha N_{\rm B})^{N_{\rm OFF}}}{N_{\rm OFF}!} e^{-(N'_{\rm S}+\alpha N_{\rm B})}$$

- Counting experiment, measured events
- Expected events in the ON and OFF regions
- Ratio between the angular size of the ON and OFF regions
- **Comparison of hypotheses through Log-Likelihood Ratio Test Statistics (TS)**
  - Signal against background-only

$$LLRTS = -2\,ln\left(\frac{L_1}{L_0}\right)$$

- No significant excess in the dataset

  → **Upper limits (U.L.) on the free parameter that we want to test**

Upper limit determination with the TS

- Comparison of hypotheses through Log-Likelihood Ratio Test Statistics (TS)

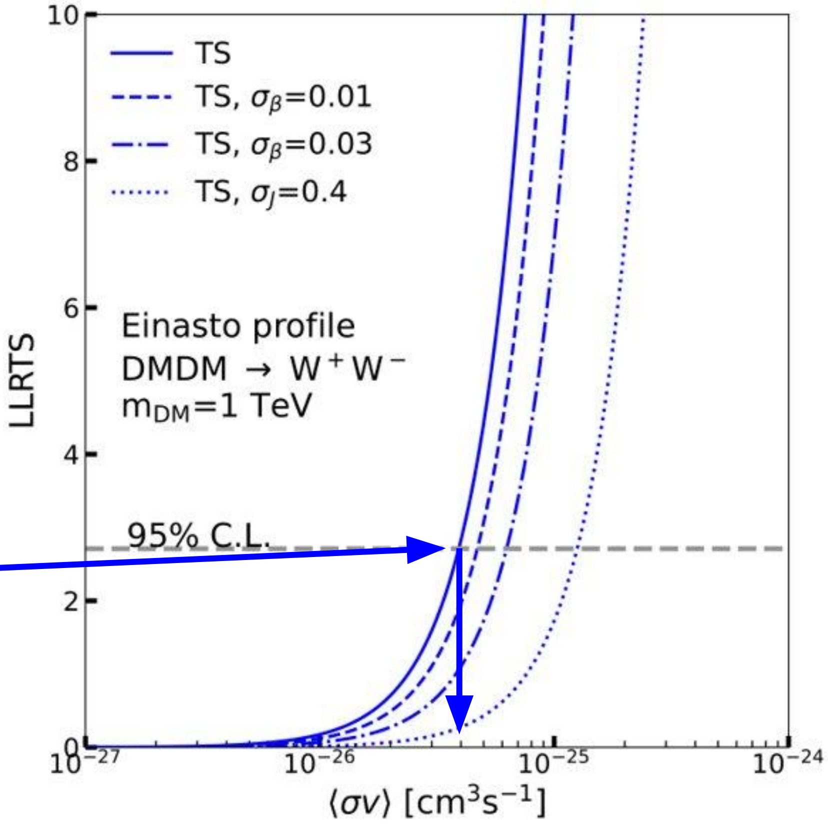
$$LLRTS = -2\ ln\left(\frac{L_1}{L_0}\right)$$

- No significant excess in the dataset
  → **Upper limits (U.L.) on the free parameter that we want to test**

LLRTS (1dof) = 2.71 for 95% C.L. UL

Ref. Cowan, G., Cranmer, K., Gross, E. et al. Eur. Phys. J. C 71, 1554 (2011)

Example for Dark Matter search



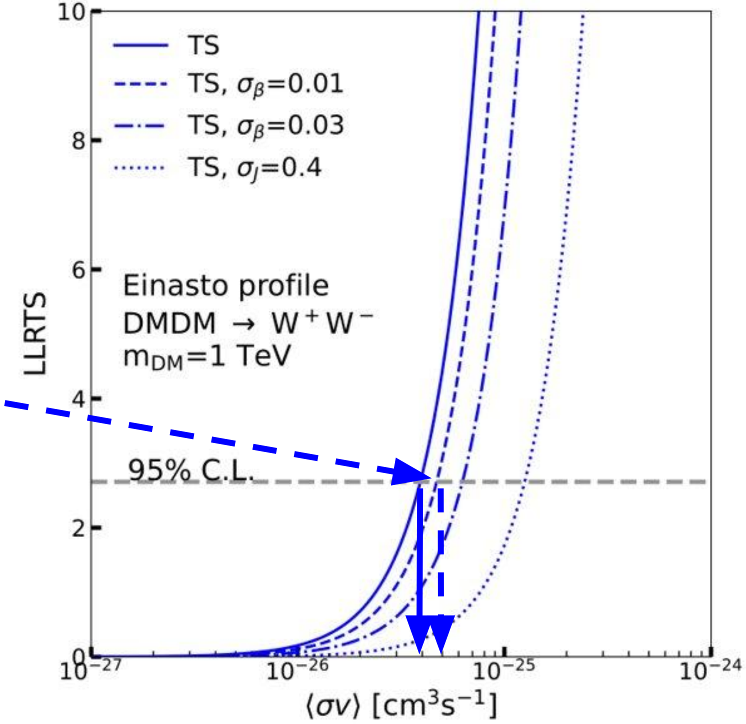
Systematic uncertainty

$$L(N_S, N_B | N_{ON}, N_{OFF}, \alpha, \beta) = \frac{[\beta(N_S + N_B)]^{N_{ON}}}{N_{ON}!} e^{-\beta(N_S+N_B)} \frac{[\beta(N'_S + \alpha N_B)]^{N_{OFF}}}{N_{OFF}!} e^{-\beta(N'_S+\alpha N_B)} e^{(1-\beta)^2/2\sigma_B}$$

- No significant excess in the dataset
  → Upper limits (U.L.) on the free parameter that we want to test

Upper limits for 1% systematic uncertainty: 20% less constraining

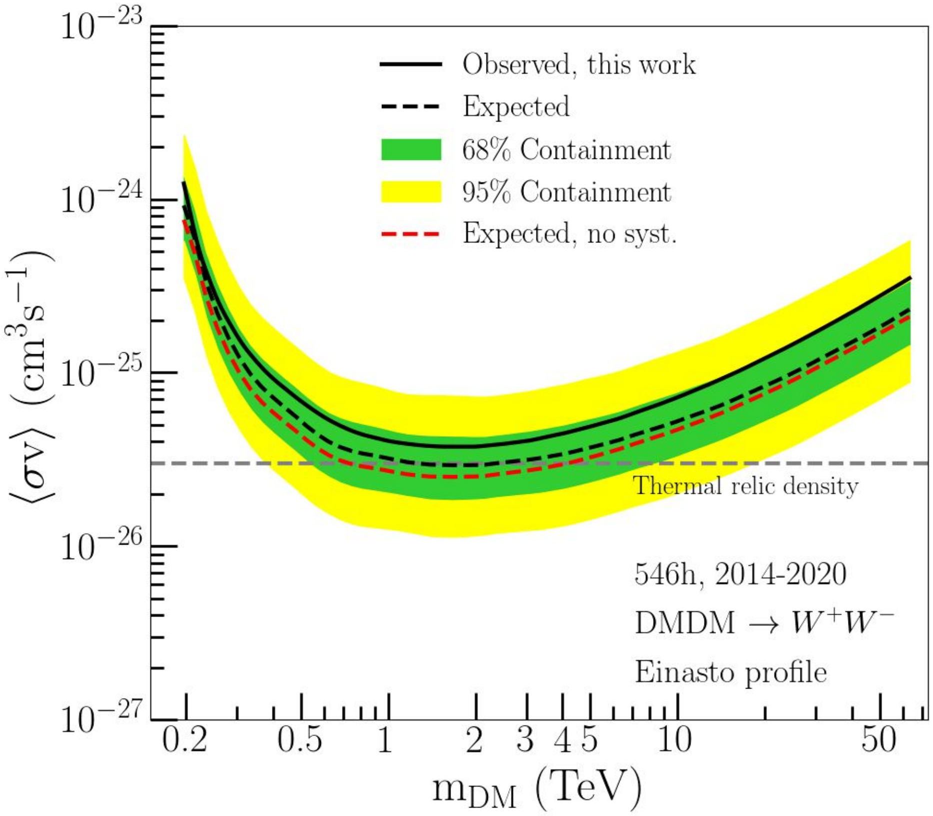
Using a nuisance parameter in the Likelihood



Refs. H., Silverwood, et al., JCAP 03, 055 (2015)
E. Moulin, et al., CTA Dark Matter Programme (2019)
V. Lefranc, et al., Phys. Rev. D 91, 12203 (2015)

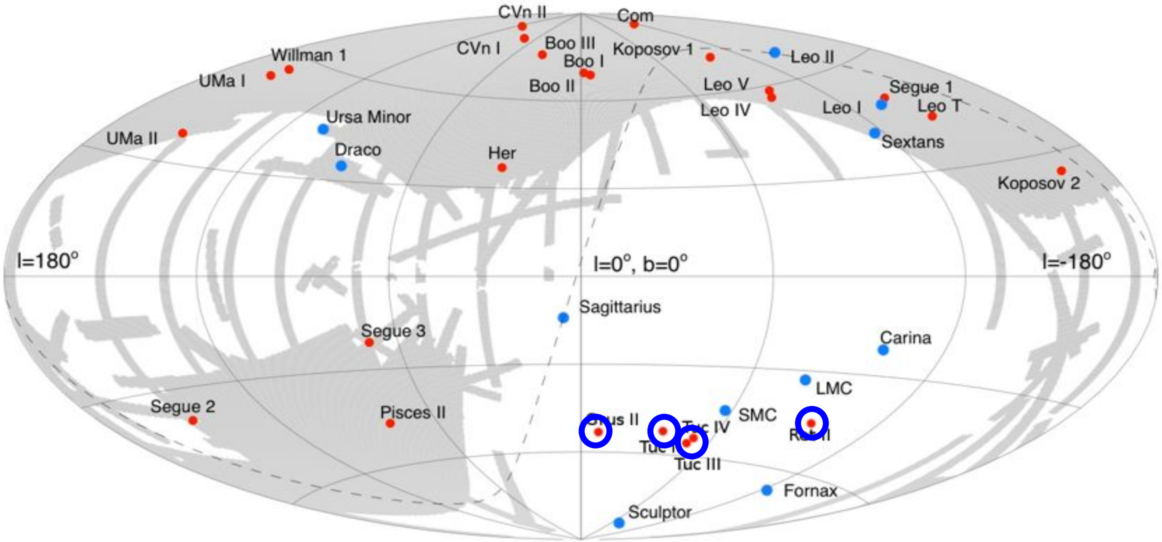
Constraints on the continuum

- No excess compatible with DM signal → Computation of upper limits on the annihilation cross section
- **Most constraining limits for TeV mass range** for the channels tested:
  - annihilation into the W^+W^- channel **$\langle\sigma v\rangle$= 3.7x10^{-26} cm^3/s at 1.5 TeV**



H.E.S.S. Collaboration, Phys. Rev. Lett. 129, 111101 (2022)

Searches towards dwarf galaxies



Modeling the DM distribution:

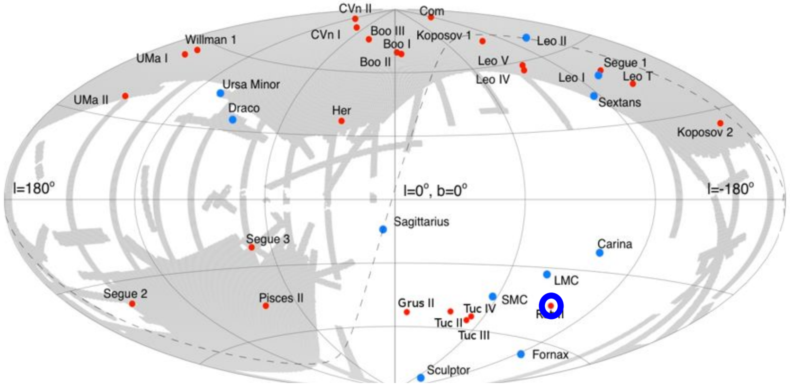
- Pressure-supported systems
- Use kinematic tracers of the gravitational potential
- Works very well in DM-dominated environments, e.g. dwarf galaxies, via the Jeans equation modeling

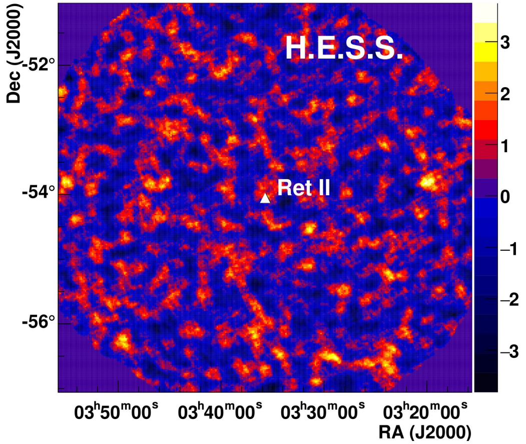
Determination for Reticulum II

- Stellar velocity dispersion → J-factor

H.E.S.S. Collaboration, Phys. Rev. D 102, 062001 (2020)

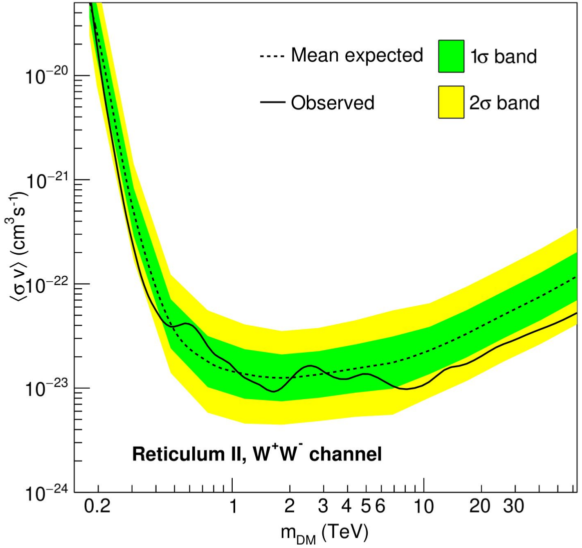
Limits and uncertainty on the J-factor

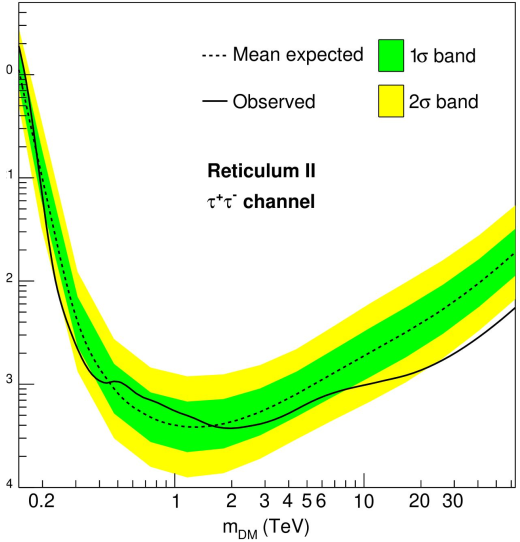




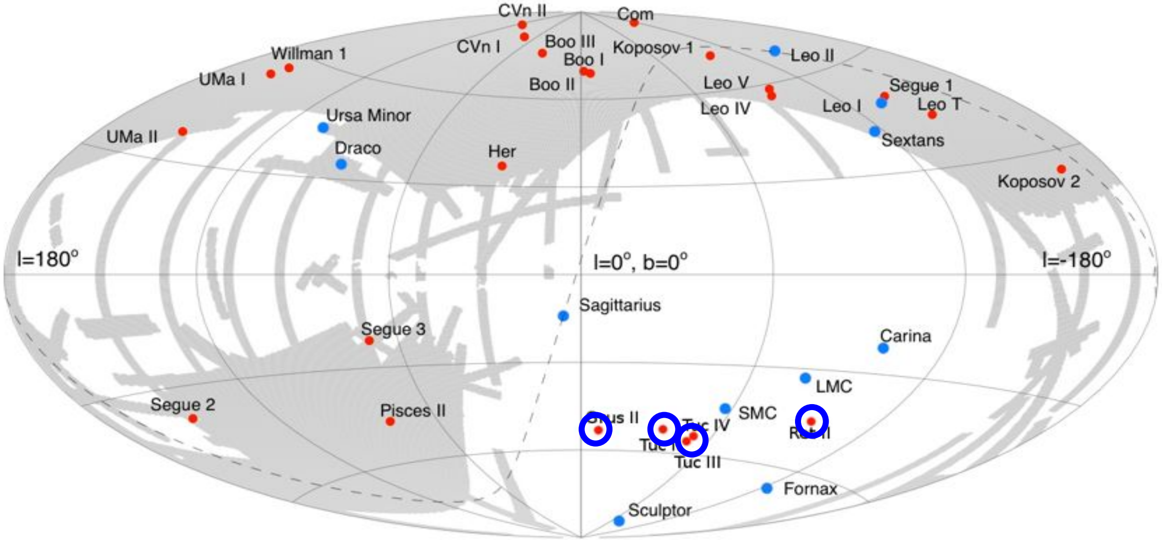
H.E.S.S. Collaboration, Phys. Rev. D 102, 062001 (2020)

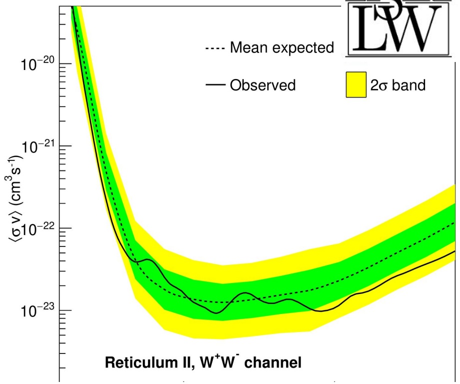
Results for various annihilation channels and including the uncertainty on the J-factor

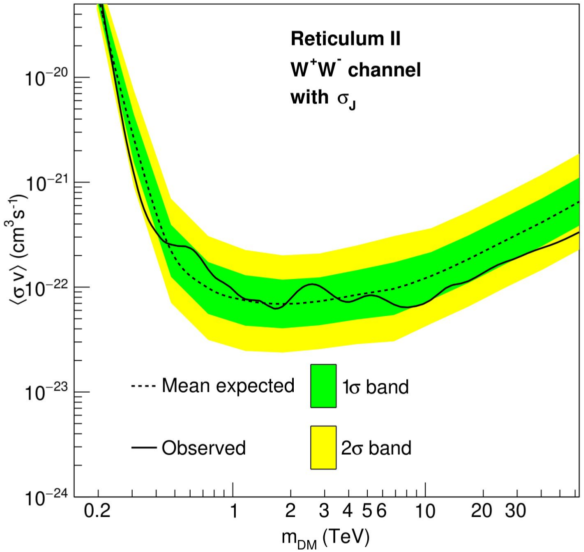




Limits and uncertainty on the J-factor







Determination for Reticulum II

- Stellar velocity dispersion → J-factor

→ **Uncertainty on the J-factor included in the limits**

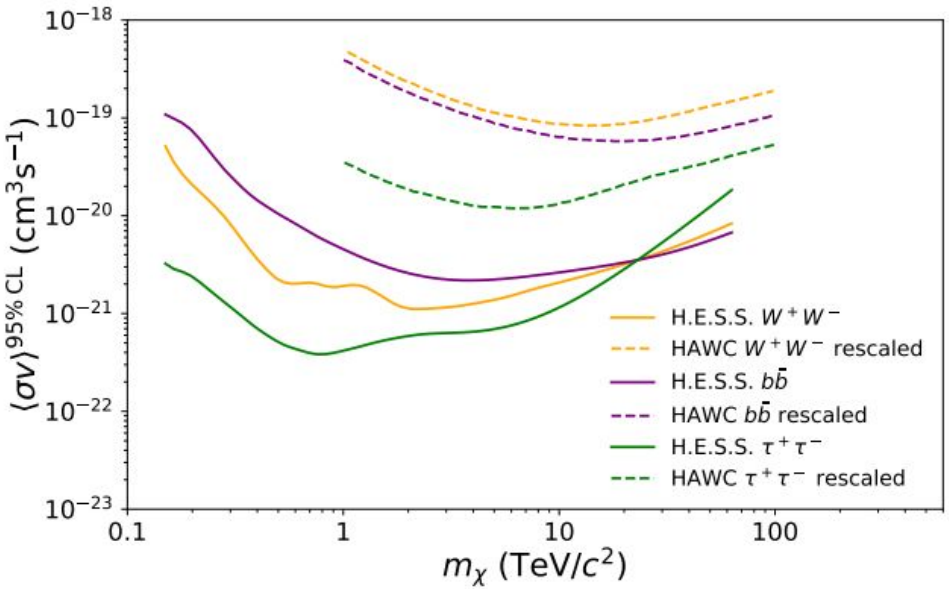
H.E.S.S. Collaboration, Phys. Rev. D 102, 062001 (2020)

Constraints on the continuum

H.E.S.S. Collaboration, Phys. Rev. D 103, 102002 (2021)

- Complementary targets are dwarf irregular galaxies
- 18 hours of observations with H.E.S.S. of the Wolf-Lundmark-Melotte galaxy
- DM distribution well parametrized by a *coreNFW*

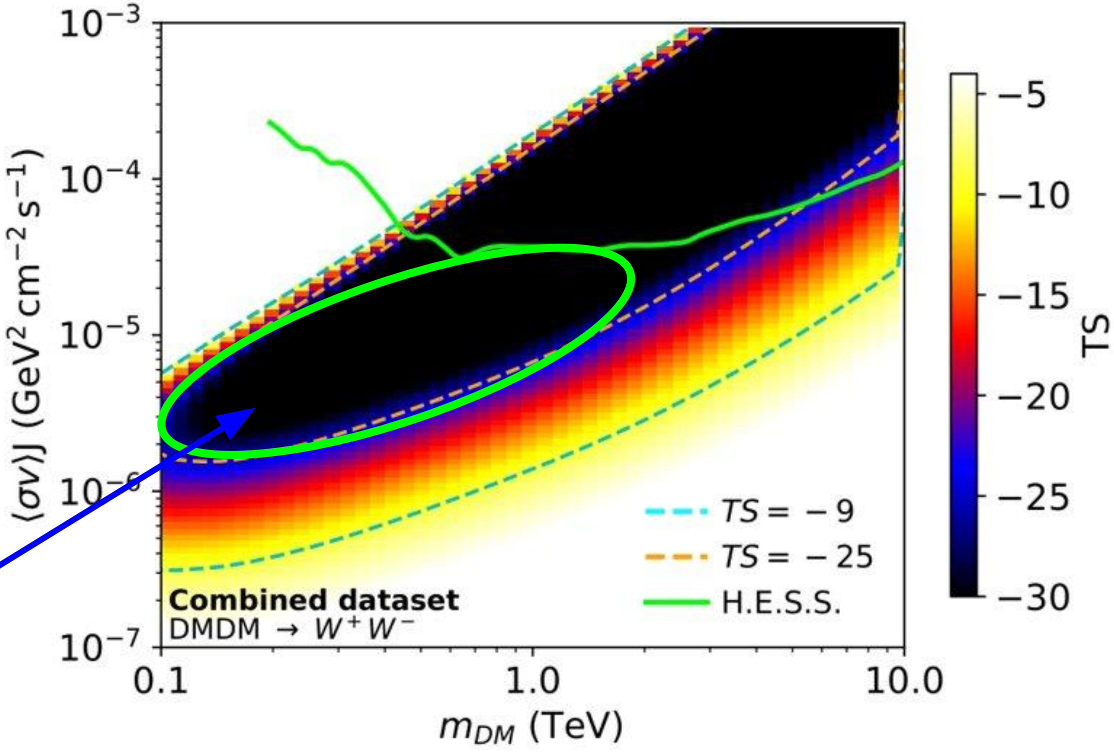
→ **Improvement of a factor at least 10 w.r.t. previous limits from other experiments**



DM-induced models for UFO emissions

- Combination of Fermi-LAT and H.E.S.S. datasets
- 95% C.L. combined U.L. on the product between the annihilation cross section and the J-factor

- Some viable models to explain the stacked Fermi-LAT datasets and considering the H.E.S.S. U.L.

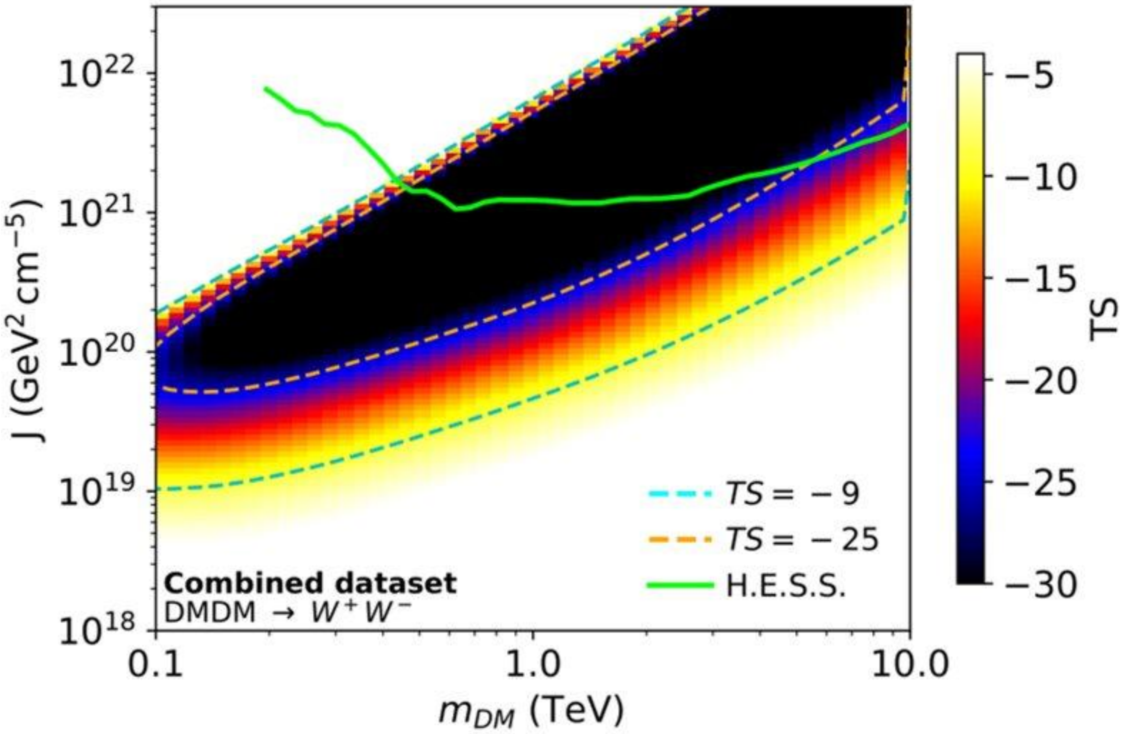


H.E.S.S. Collaboration, Astrophys. J. 918, 17 (2021)

Allowed J-factors for the UFOs

- Assuming thermally produced WIMPs, we fix the annihilation cross section
- J-factors allowed given combined H.E.S.S.
- But, high J-factors for the UFOs from cosmological simulations

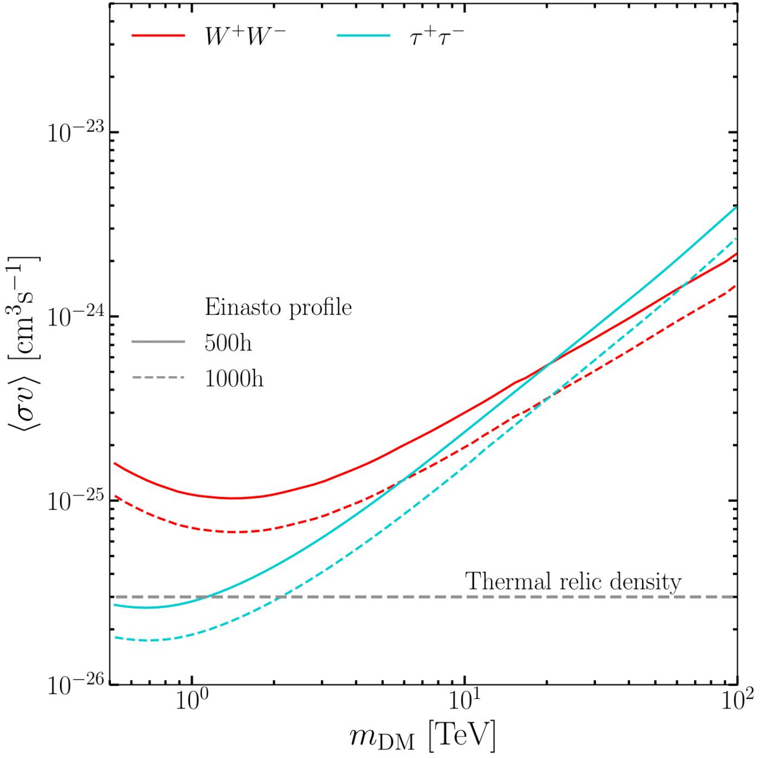
→ **DM induced emission for the UFOs very unlikely, according to the H.E.S.S. constraints**



H.E.S.S. Collaboration, Astrophys. J. 918, 17 (2021)

Assessing the sensitivity to dark matter signal

- Mock dataset of H.E.S.S. IGS observations
  → **simulating 500h and 1000h of flat exposure**
- Most up-to-date and andanced calculations for theoretical gamma-ray DM annihilation yields
- Recent DM profiles determination from measurements of the MW rotation curve
  Cautun et al., MNRAS, 494.3, (2020)
- Background modeling considering residual and conventional TeV astrophysical background



AM, Emmanuel Moulin and Nicholas L. Rodd, Phys. Rev. D 107, 043028 (2023)

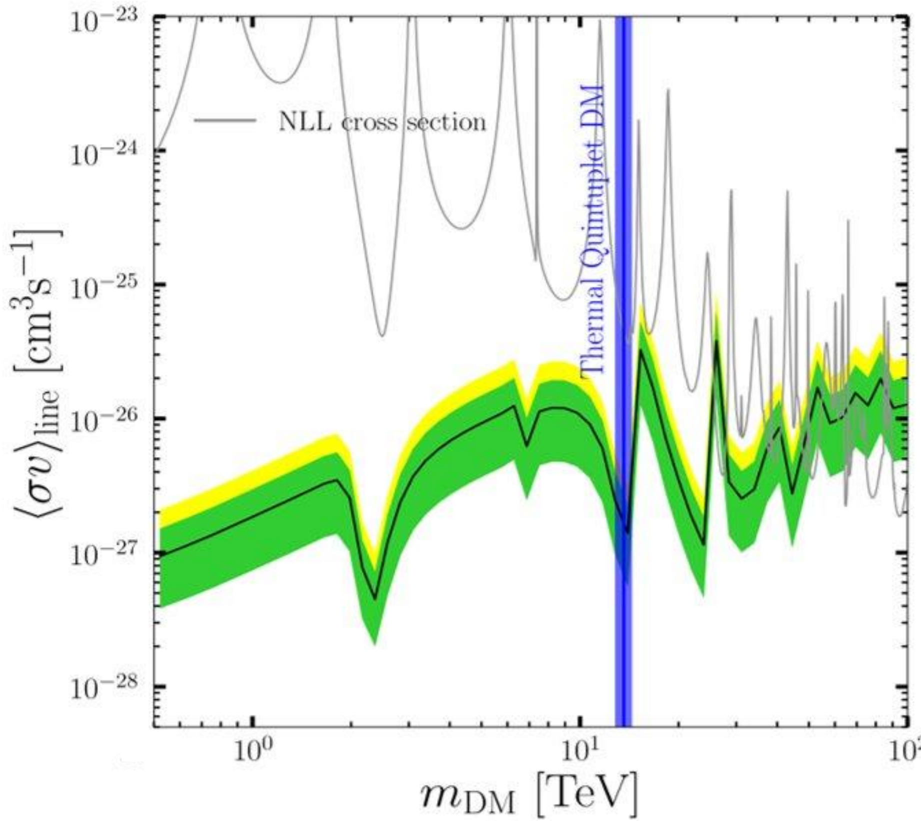
Prospects for canonical DM models

- The Quintuplet, TeV scale state charged under representation 5 of SU(2)

Ref. for the spectra Bauer, C. W., Rodd N. L., and Webber B. R., JHEP 06, 121 (2021)

- **Thermal Quintuplet excluded within the present sensitivity**
- **A few non-thermally produced Quintuplet models are still available above several ten TeV masses**

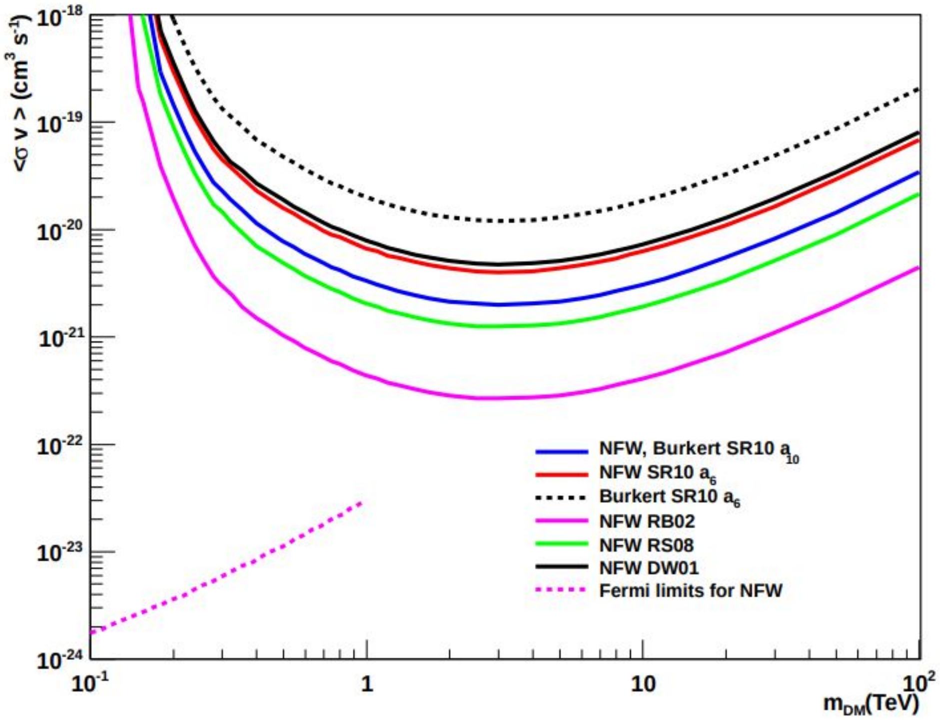
AM, Emmanuel Moulin and Nicholas L. Rodd, Phys. Rev. D 107, 043028 (2023)



Limits from galaxy clusters

- Observations of the Fornax galaxy cluster
- 14.5 hours of total live time
- Possible enhancements to the gamma-ray flux are considered:
  - DM substructures
  - Sommerfeld effect
- Limits for different particle models and annihilation channels

→ **reaching⟨σv⟩~ $10^{-22\text{-}23}$ cm^3/s at 1 TeV**



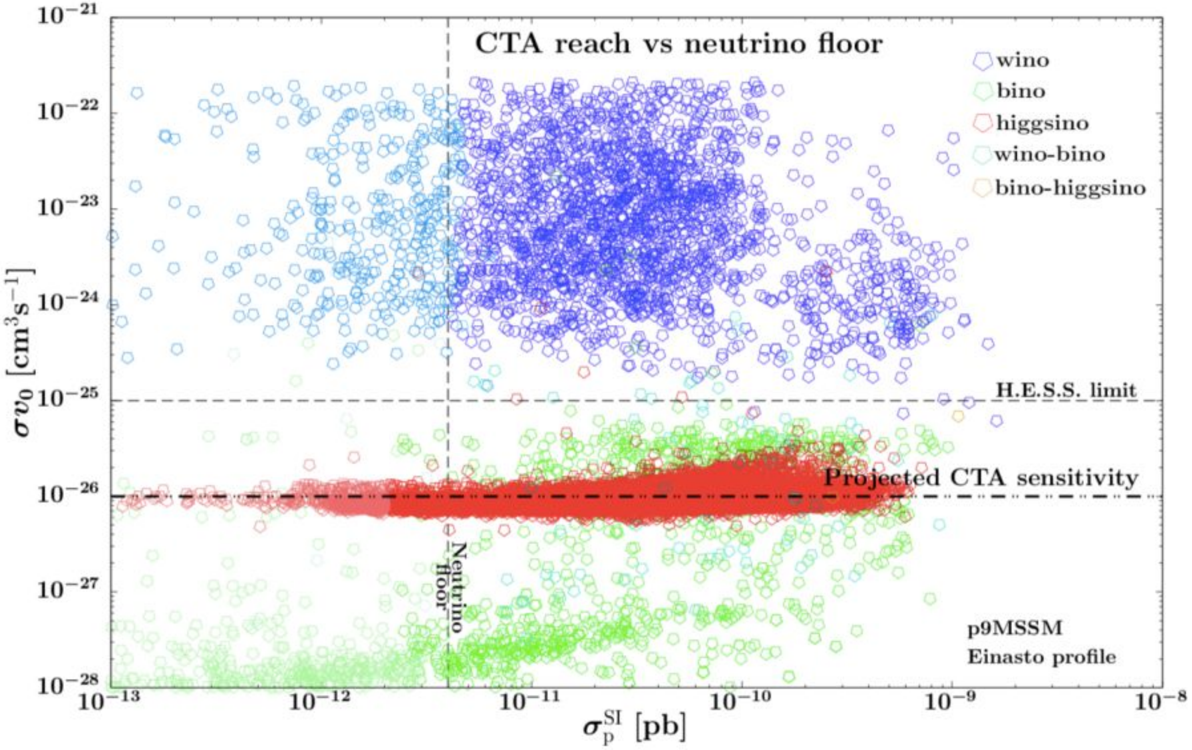
H.E.S.S. Collaboration, Astrophys. J., 750, 123 (2012)

Points of the p9MSSM in the (σ^{SI}, σv_0) space

9-parameter MSSM framework

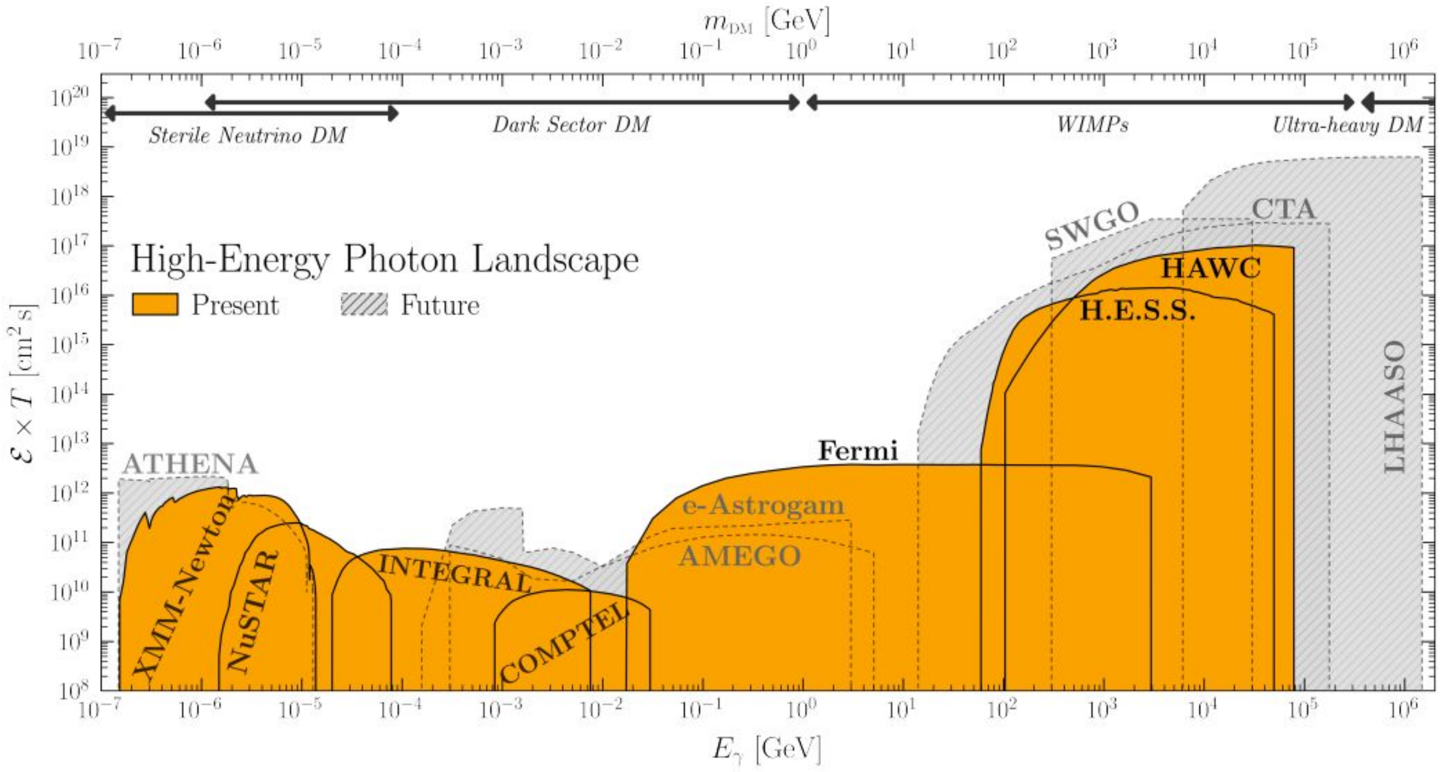
- Reference irreducible neutrino floor (m_χ = 2 TeV)
- H.E.S.S. limits at m_χ = 2.5 TeV
- CTA projected limits at m_χ = 1 TeV

Points are upper limits on σ^{SI} sensitivity from XENON1T



Hryczuk A., Jodlowski K., Moulin E. et al., JHEP, 43, 1910 (2019)

Landscape of photon indirect detection



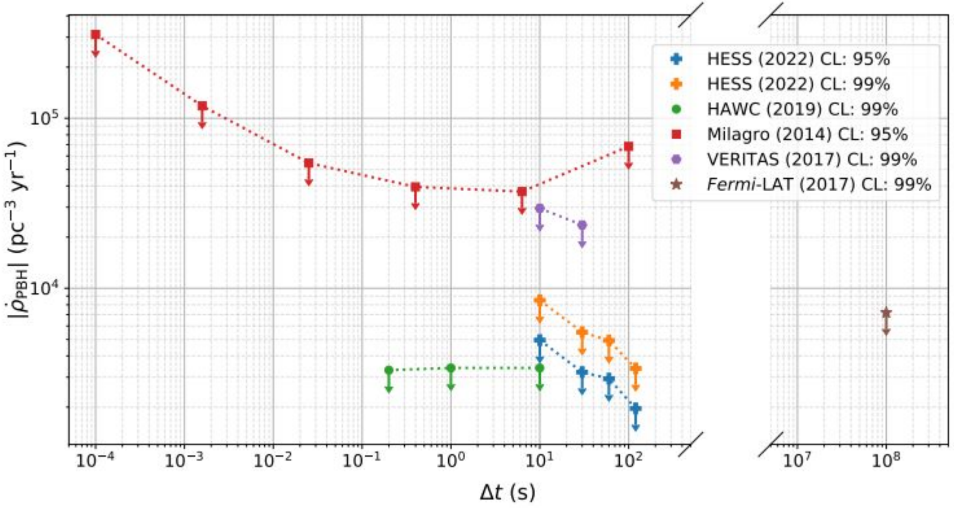
Boddy, Lisanti, McDermott, Rodd, Weniger et al., arXiv: 2203.06380

Constraints on DM from PBHs evaporation

- Limit on Primordial Black Holes (PBHs) evaporation
- Number of gamma-rays from PBH evaporation scales as $\sqrt{\Delta t}$
- Background increases as Δt
- Optimal time window of few tens of seconds

→ **Signature of PBH, burst of few gamma-like events arriving coincidentally**

→ **Upper limits on the burst rate**



H.E.S.S. Collaboration, JCAP 04 (2023)

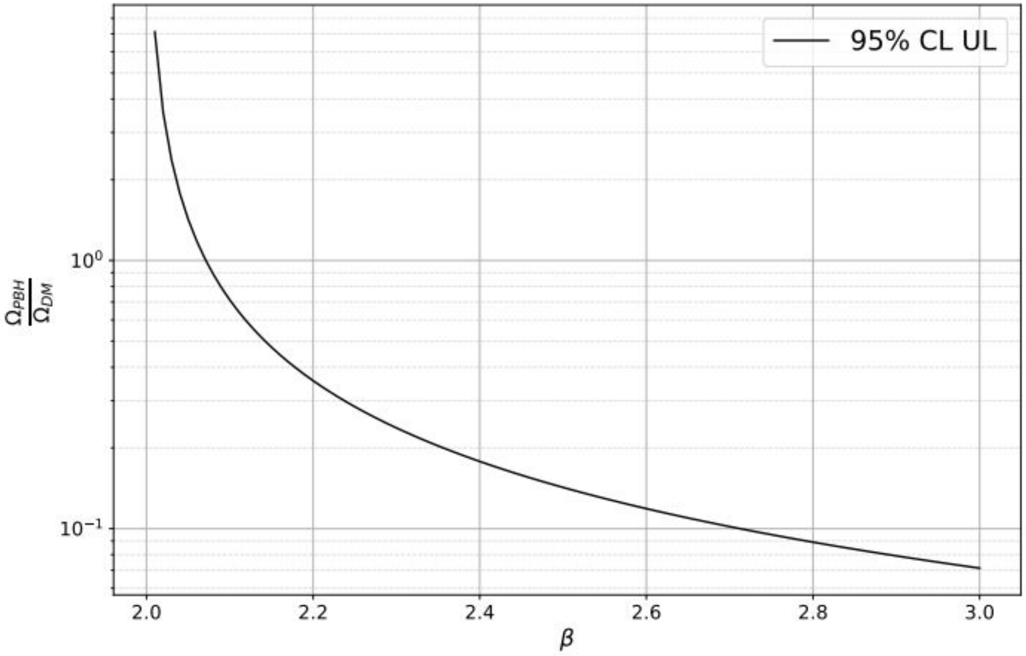
Constraints on DM from PBHs evaporation

- Limit on Primordial Black Holes (PBHs) evaporation

- Constraints on initial fraction of DM in PBHs:

→ **Order of 0.1 Ω_{DM}, assuming PBH initial mass power-law distribution**

→ **Subdominant fraction of DM**



H.E.S.S. Collaboration, JCAP 04 (2023)