Dark matter searches with Imaging Atmospheric Cherenkov telescopes

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Planck 2010
From the Planck Scale to the ElectroWeak Scale
31 May - 4 June 2010

The current IACT world

VERITAS Arizona, USA
1275m a.s.l.
4 telescopes, Ø12m
Stereoscopy
>2007

MAGIC Canari Island, Spain
La Palma, 2225m a.s.l.
1 telescope, Ø17m
>2004
MAGIC 2 : 2nd telescope, Ø17m
>2009

H.E.S.S. Namibia
1800m a.s.l.
4 telescopes, Ø13m
stereoscopy
>2003
HESS 2 : 5th telescope, Ø28m
>2010

Gamma-ray flux from WIMP annihilations

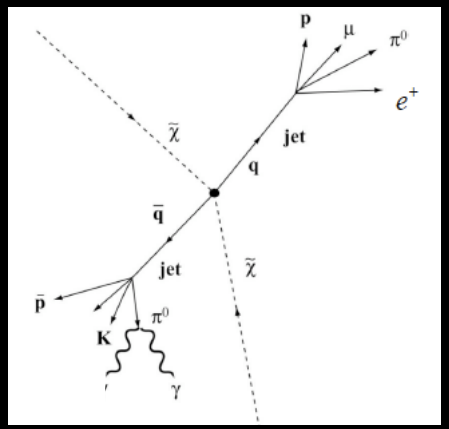
$$\Phi_\gamma = \Phi_{PP} \times \Phi_{ASTRO}$$

$$\Phi_{PP} = \frac{1}{4\pi} \frac{<\sigma v>}{2m_{DM}^2} \int_{E_{th}}^{m_{DM}} \sum_f BR_f \frac{dN_\gamma^f}{dE_\gamma} dE_\gamma$$

$$\Phi_{ASTRO} = \frac{1}{\Delta\Omega} \int_{\Delta\Omega} d\Omega \int_{l.o.s} \rho^2(r[s]) ds$$

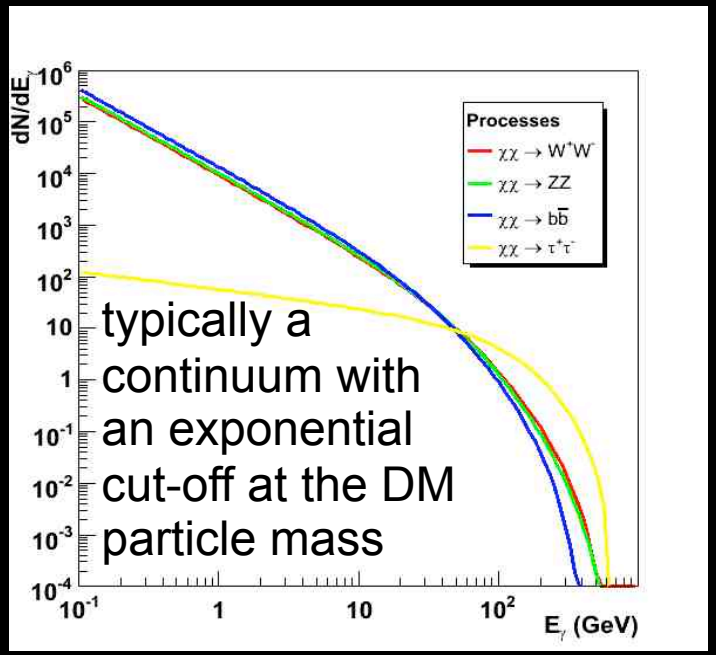
Particle Physics :

- Cross sections
- Branching ratios
- Differential photon yield
- DM particle mass



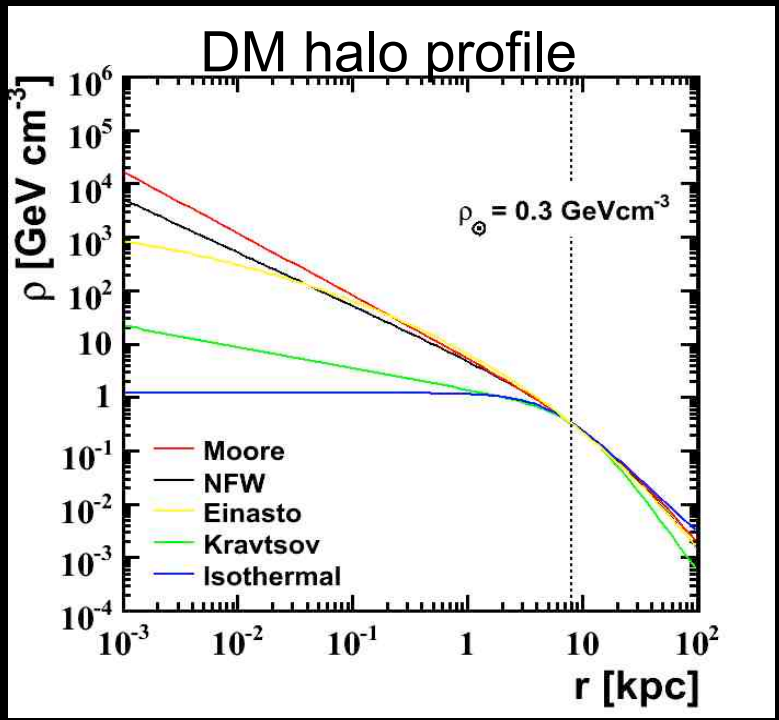
Also:

- ❑ Gamma lines but BR ~10^{-3}
- ❑ Internal bremmstrahlung: GeV to TeV gamma for $E_\gamma > 0.6 m_{DM}$



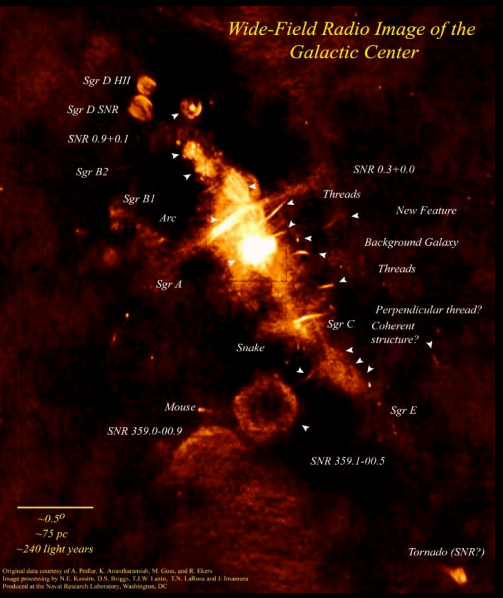
Astrophysics : Dark matter halo

→ model required for the profile



Dark matter « hot spots »

Searches performed on amplification sites

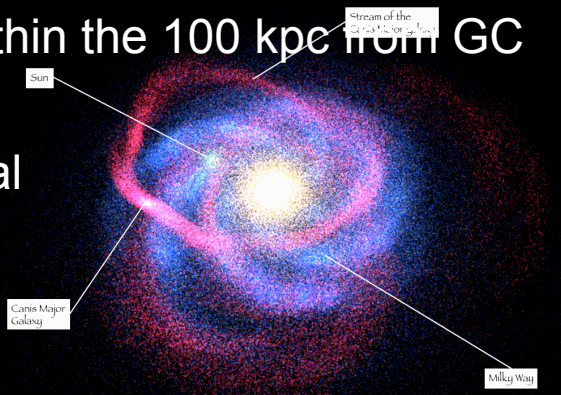


Galactic Centre

- Proximity (~8kpc)
- Possibly high DM concentration :
  DM profile : core? cusp?
- High astrophysical background

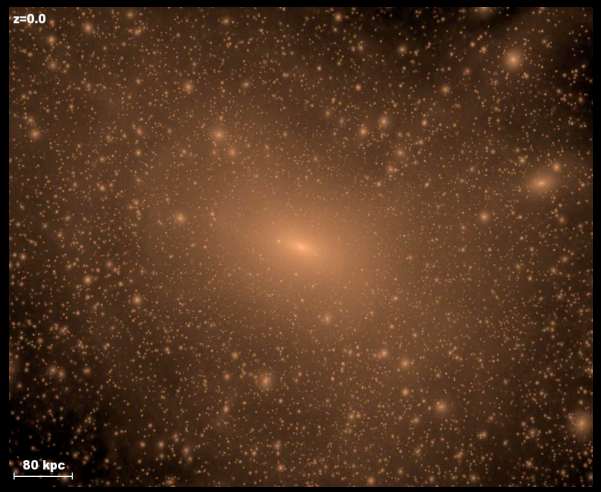
Galaxy satellites of the Milky Way

- Many of them within the 100 kpc from GC
- High M/L
- Low astrophysical background



Substructures in the Galactic halo

- Lower signal
- Cleaner signal

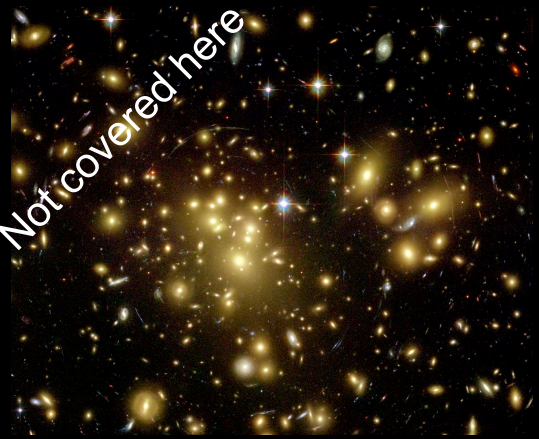


The case for Intermediate Mass Black Hole

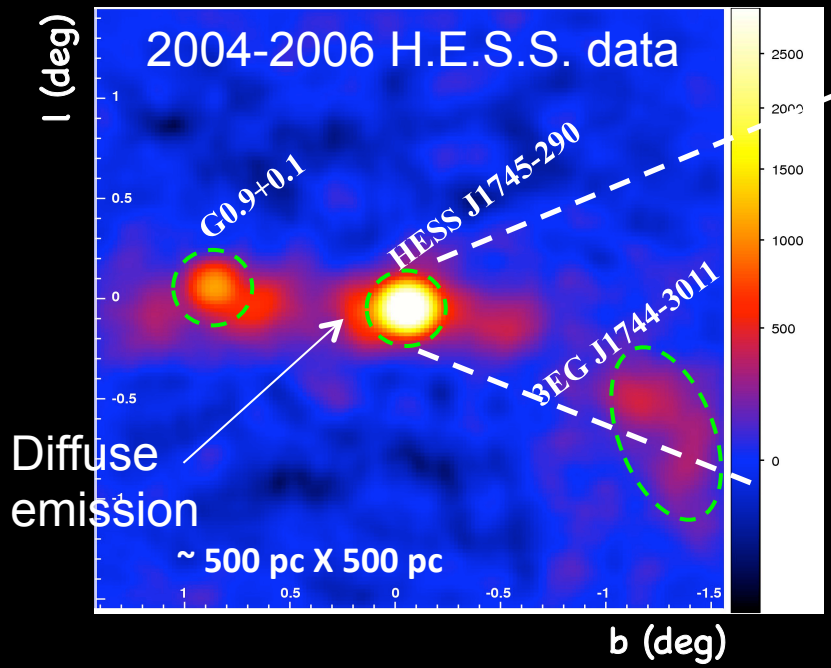
- High signal
- Clean signal
- Unproven existence

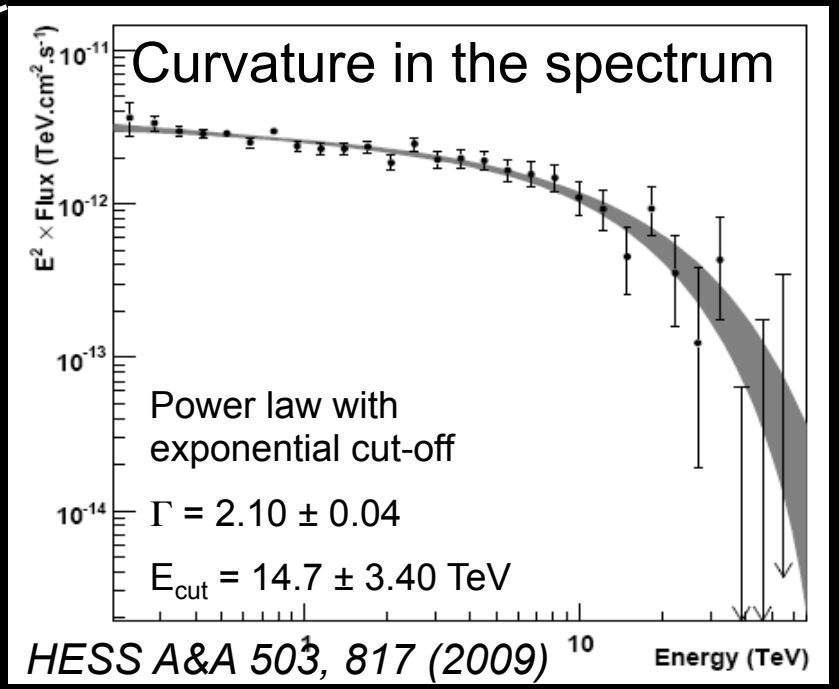
Galaxy clusters

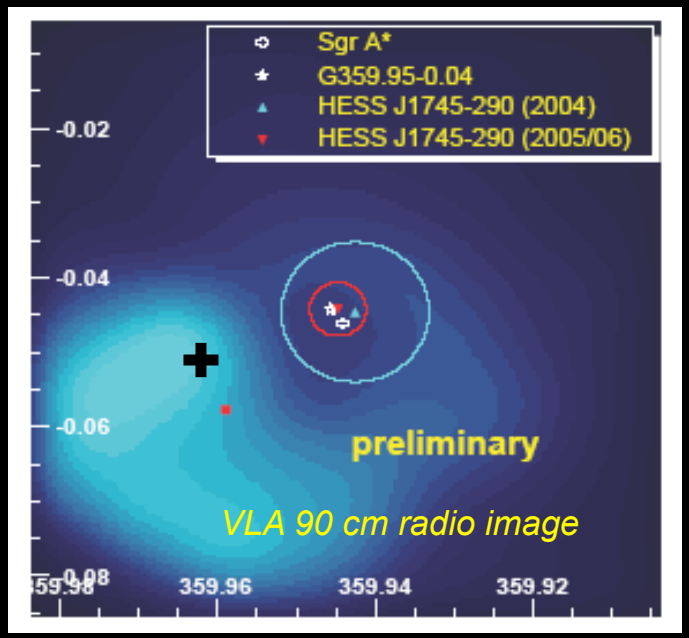
- High signal
- High astrophysical background signal



The TeV signal from the Galactic Center







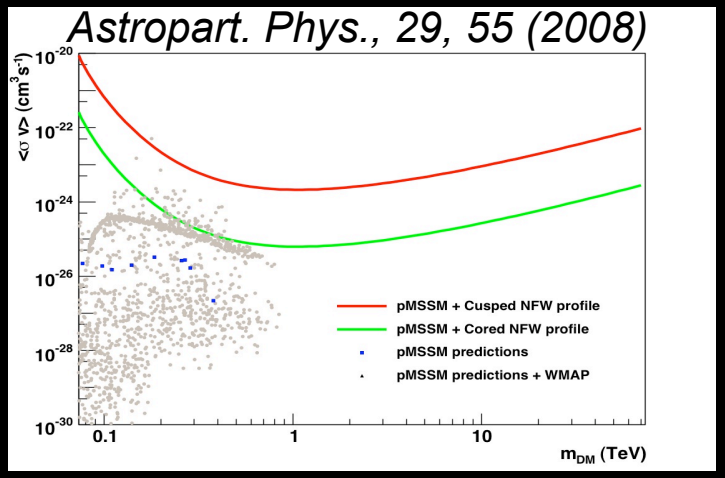
- Bulk of VHE emission from Sgr A East excluded
- SMBH and PWN are good candidates
- Most probably, if DM signal exists is overcome by standard astrophysical emitters
- A DM contribution is not excluded: estimated to be < 10%

Interpretation of DM signal embedded in astrophysical emission is hard

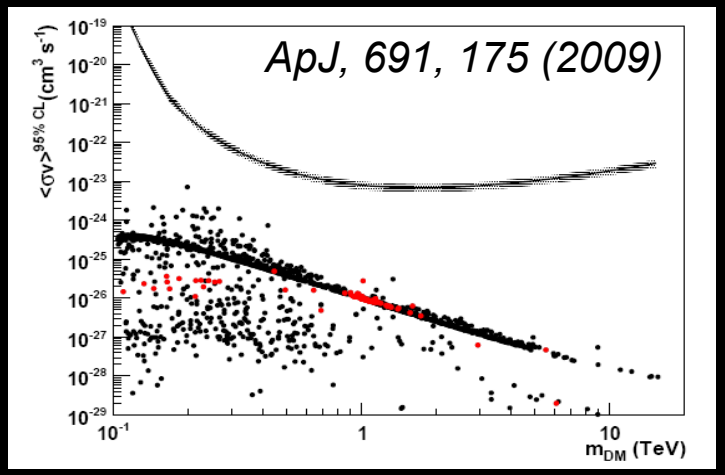
Satellite galaxies of the Milky Way

❑ HESS:

- 2006 Sagittarius: 11 h



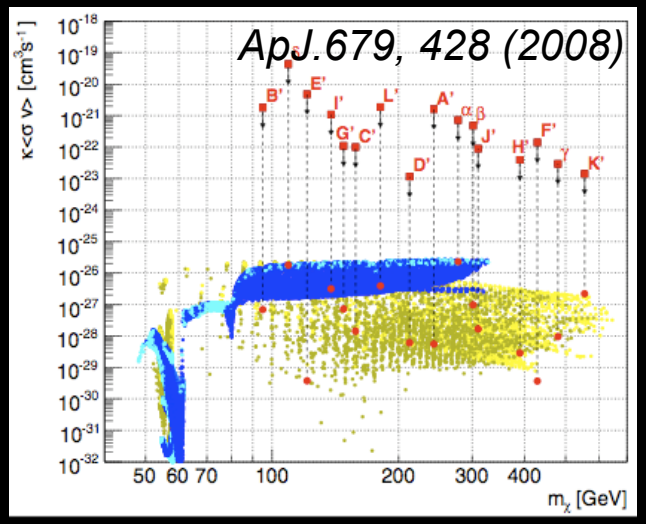
- 2007 Canis Major: 9 h



- 2008/2009 Sculptor, Carina

❑ MAGIC:

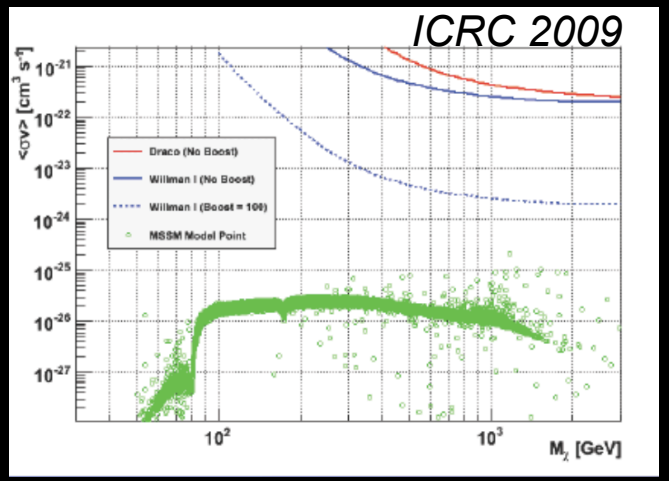
- 2008 Draco: 8 h



- 2009 Willman 1: 15 h

❑ VERITAS:

- Draco: 20h
- Ursa Minor: 20 h
- Willman 1: 15h



Only very high flux enhancement can be excluded

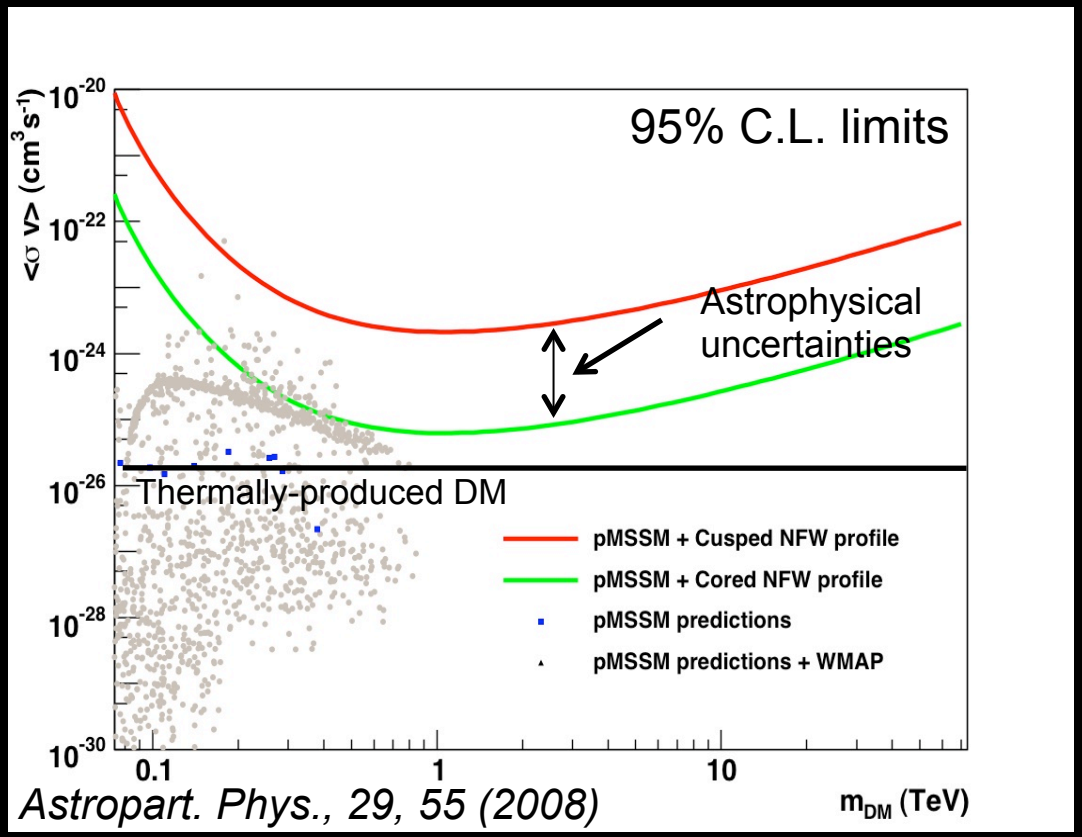
No dark matter signal so far, nor hints only upper limits

HESS constraints on DM annihilations from Sagittarius

- Distance from Sun : 24 kpc
- Mass ~3×10^8 M_{sun}
- Tidally disrupted

BUT the DM halo modelling is hard due to tidal disruption
Core/Cusp profile?

Exclusion on the velocity-weighted annihilation cross-section :



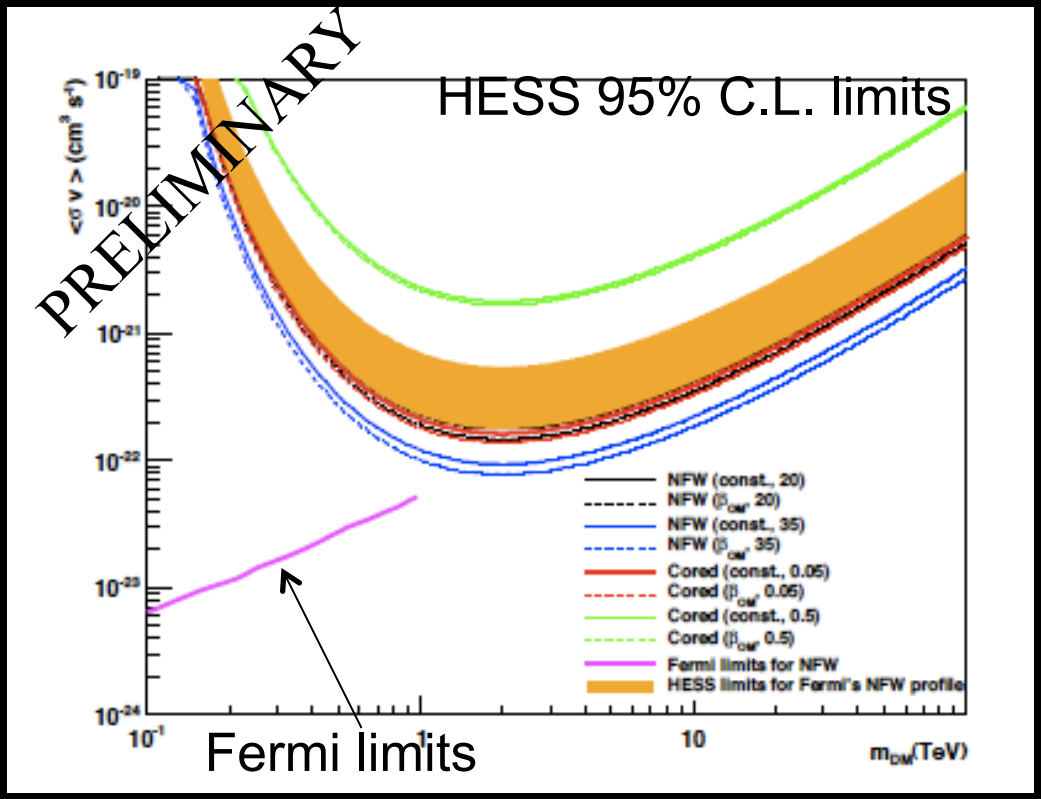
- pMSSM models obtained with DarkSUSY4.1
  ⇒ large scan of the parameter space

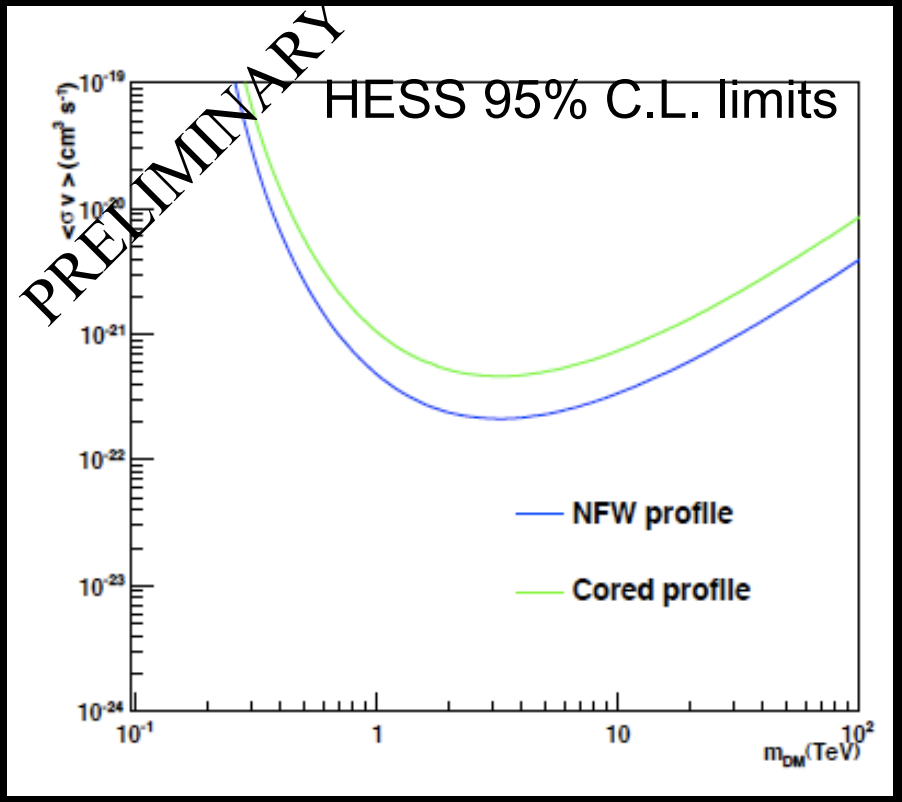
Strong contraints with the core model:
- neutralinos: $\langle\sigma v\rangle \sim 2 \times 10^{-25}$ cm³s⁻¹
For LKP : $\langle\sigma v\rangle \sim 4 \times 10^{-26}$ cm³s⁻¹

Sculptor/Carina dwarf galaxies (1)

- Distance from Sun : 79 kpc
- Mass ~1x10^9 M_{sun}
- No significant disruption

- Distance from Sun : 101 kpc
- Mass ~2x10^8 M_{sun}
- Some disruption





- ❑ Various DM halo profiles ➔ helps to estimate the astrophysical uncertainties
- ❑ Astrophysical factor enhancement from substructures:
  - ➔ negligible for pointlike searches towards the galaxy center (a few percent)

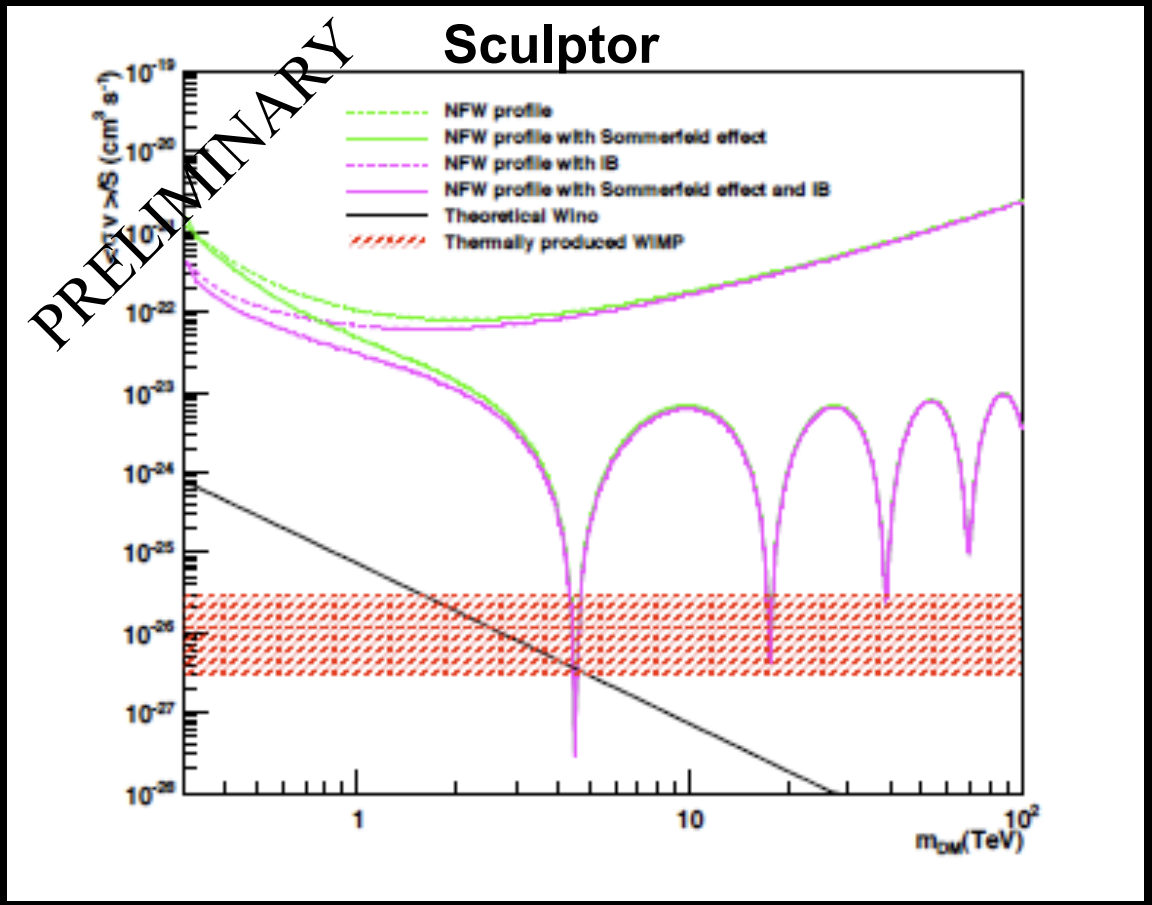
Sculptor/Carina dwarf galaxies (2)

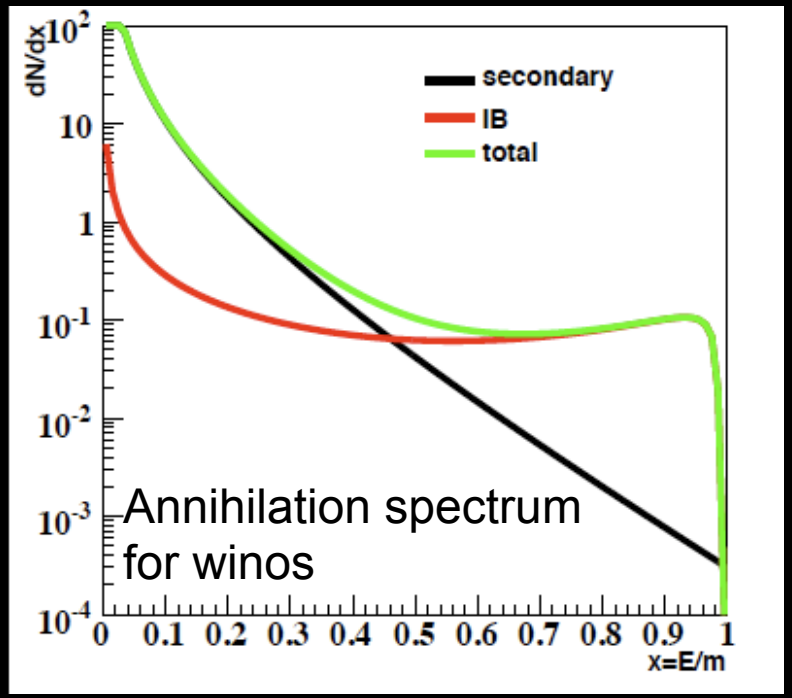
- Particle physics enhancement: Sommerfeld effect

➔ particularly effective in the low-velocity regime

- Internal bremsstrahlung:

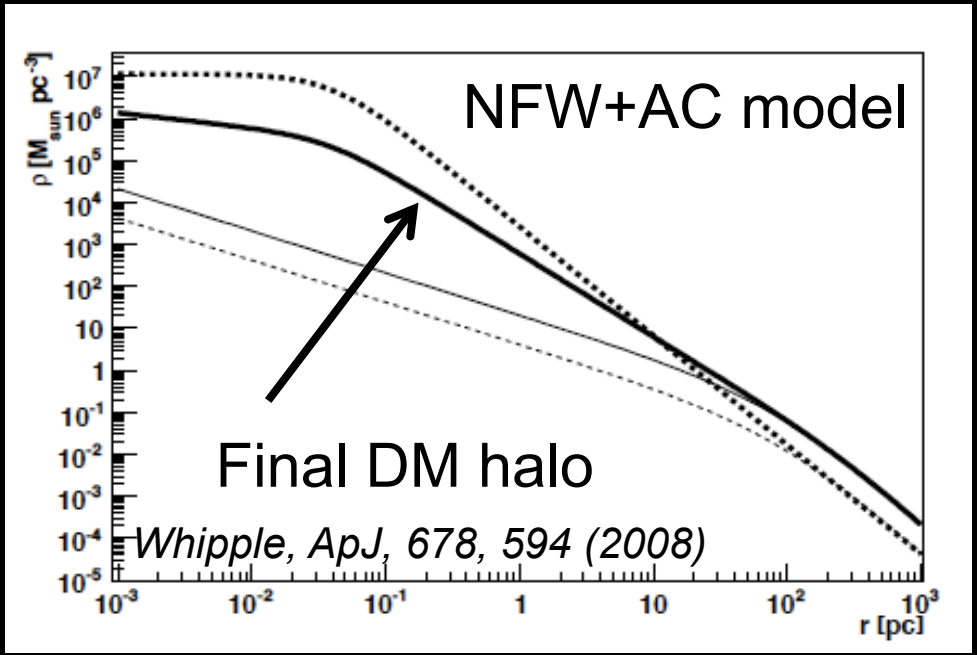
➔ may enhance the gamma-ray flux in some specific region of the MSSM parameter space





- In stau coannihilation region of mSUGRA: considerable contribution for wino annihilation from the IB *(Bringmann et al., 2008)*
- Significant effect on the limit in the low mass regime

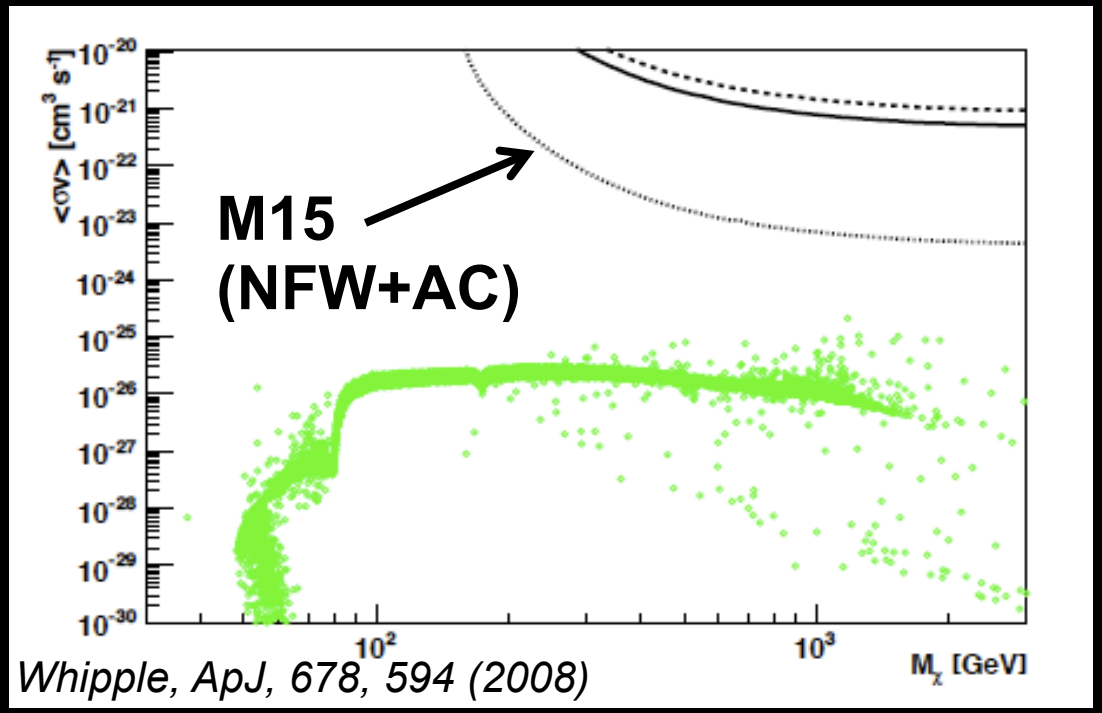
Dark matter in Galactic globular clusters? The example of M15



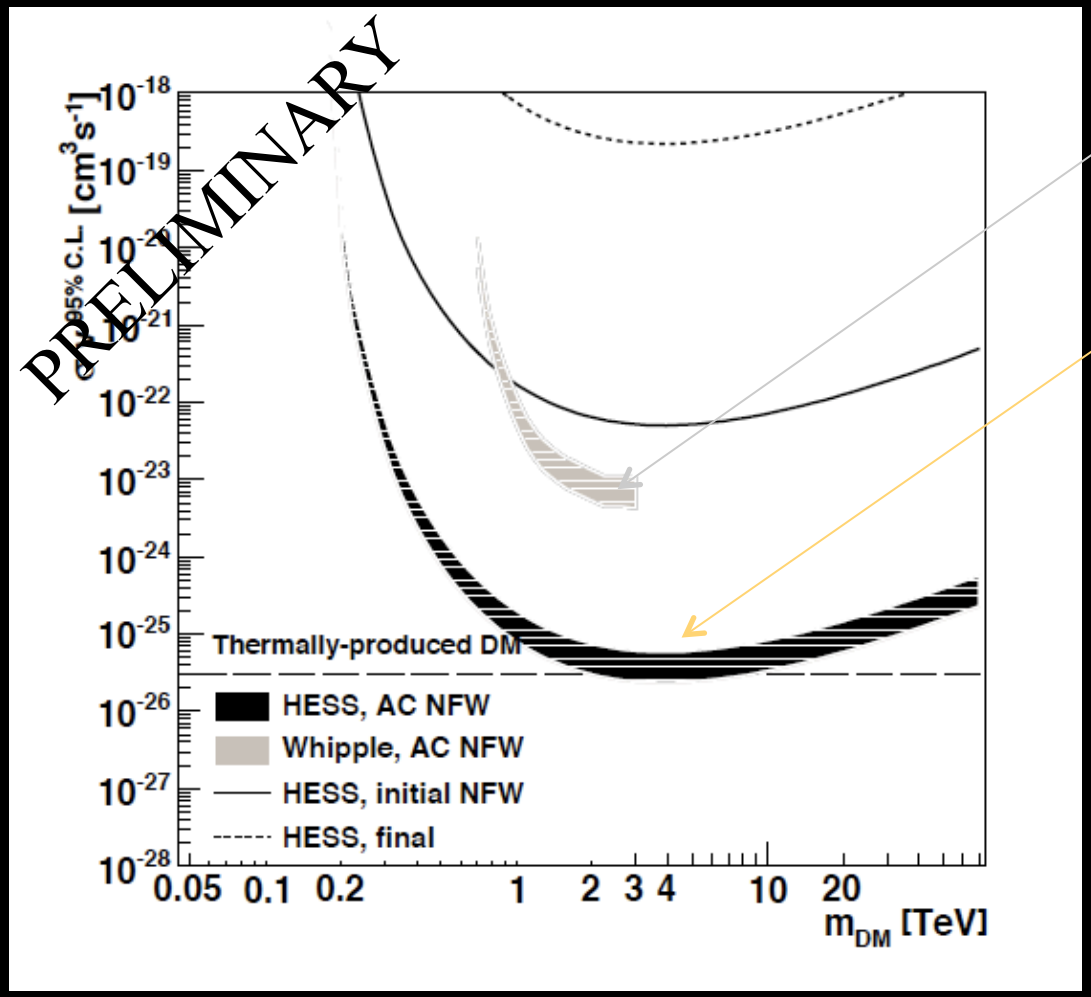
- No clear observational evidence of a significant amount of DM
- Mass profile well described by a pure baryonic component
- However, in the cosmological formation paradigm, globular clusters may have been formed in a DM halo

- Optimistic DM halo profile
- Exclusion on $\langle\sigma v\rangle$ (95% C.L.):
  ~ 10^{-23} $cm^3 s^{-1}$

Not possible to exclude any MSSM models



HESS constraints on M15



Whipple limit with **AC** halo

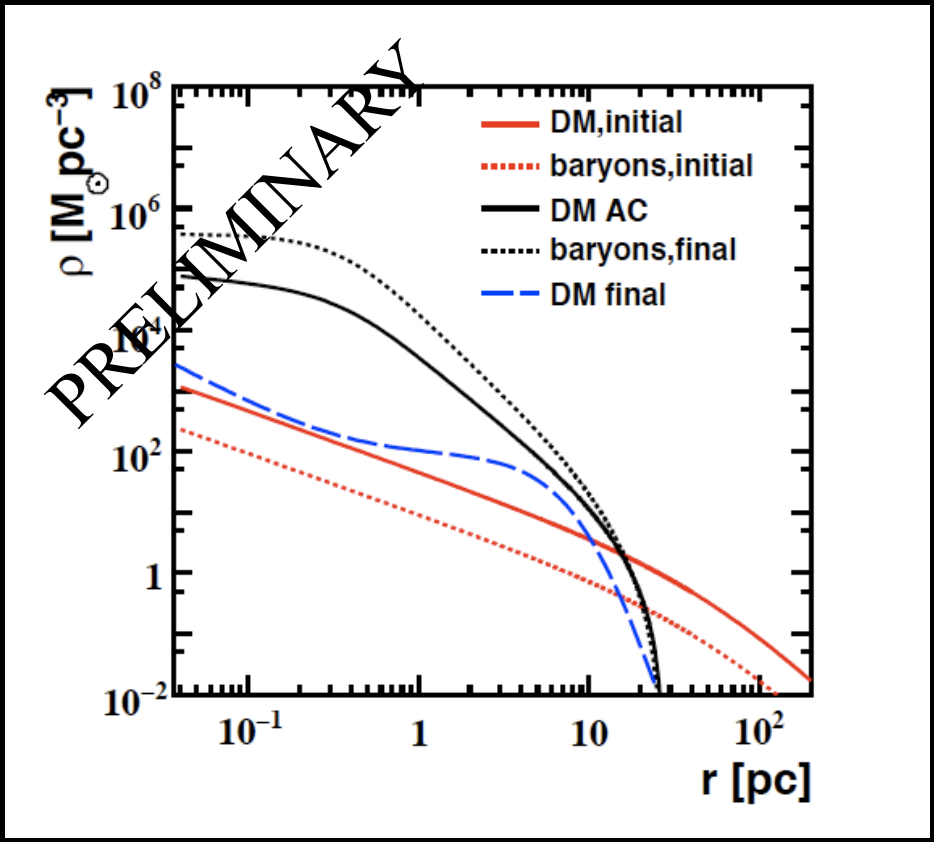
H.E.S.S. limit using Whipple DM halo modelling

- ✓ Very dense stellar environment
- ✓ Hypothetical DM halo affected by scattering off of stars

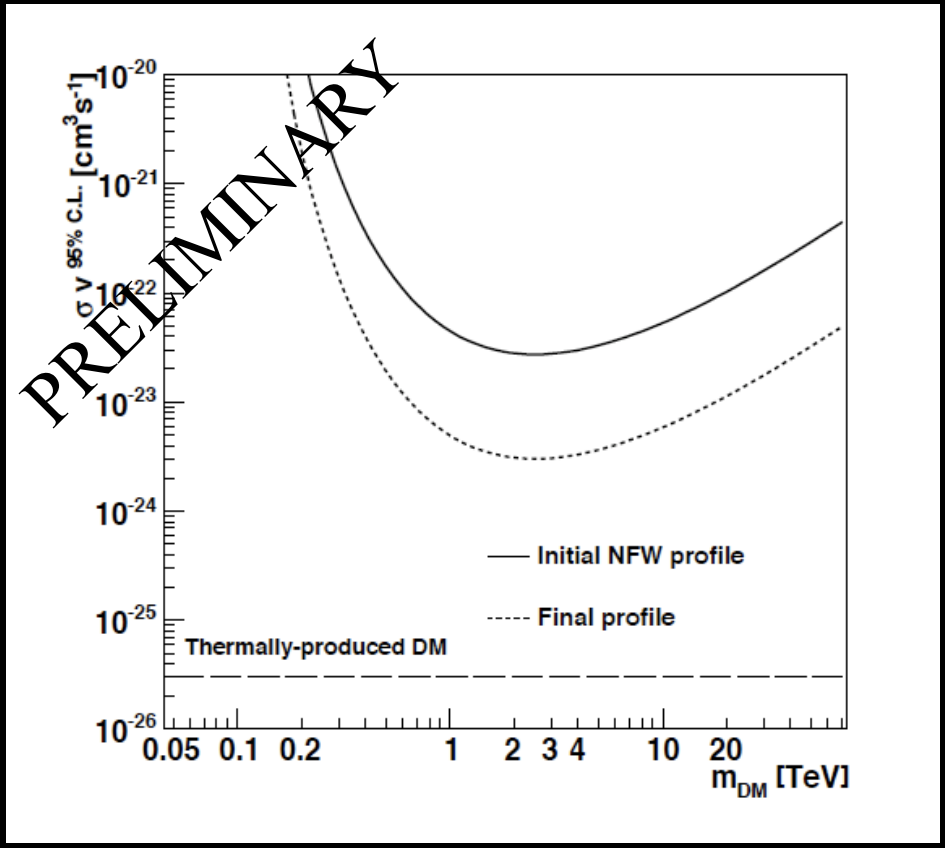
➔ DM in the core likely to have been wiped out

- ❑ Interaction between stars and DM cannot be neglected
- ❑ Dark matter halo modelling is hard

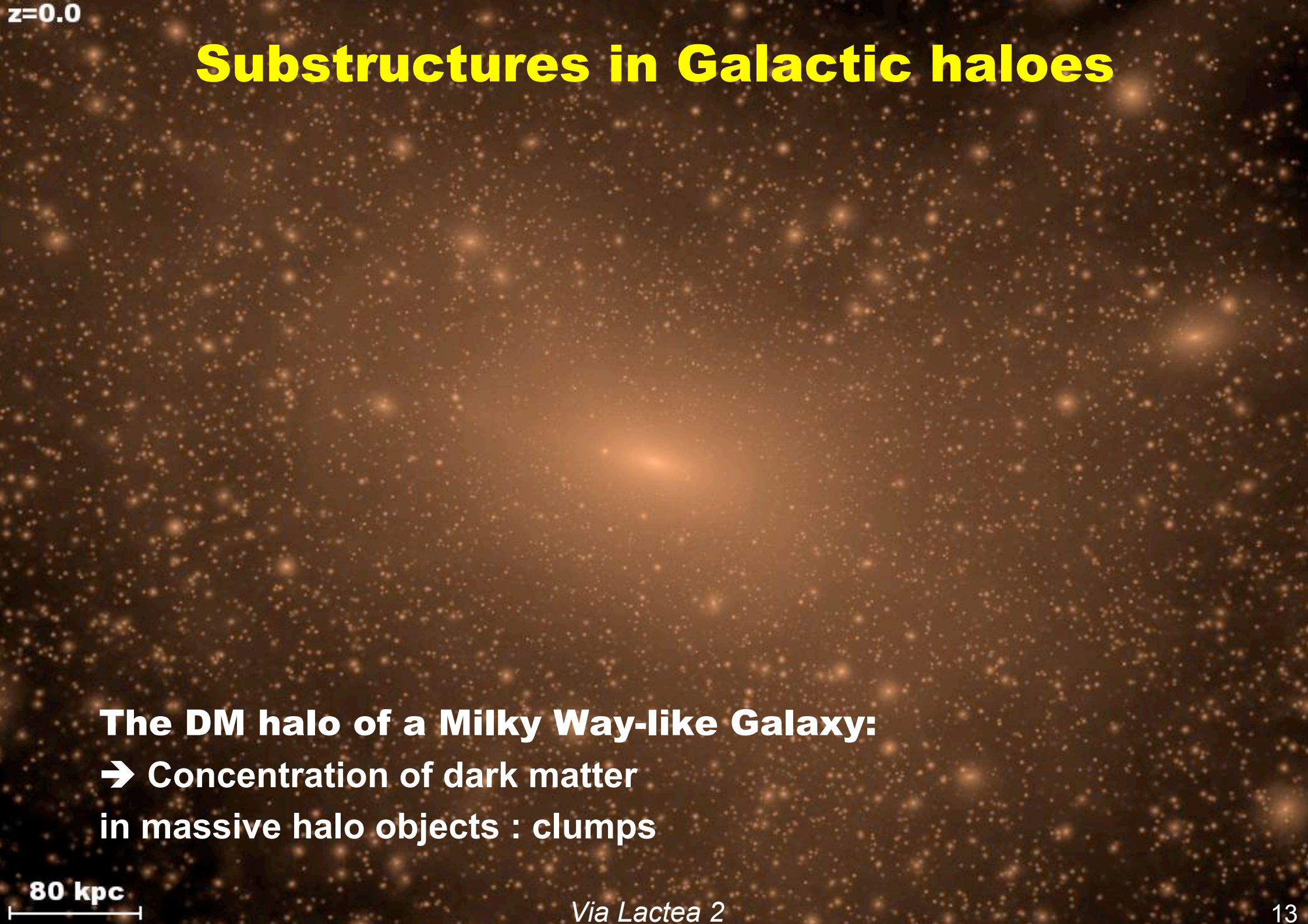
HESS constraints on NGC 6388



- Initial DM profile : NFW
- Adiabatic contraction of DM by baryons infall
- Adiabatic black hole growth may have steepened the DM profile
- Scattering off of stars on DM
  - ➔ DM in the core likely to have been wiped out



Constraints using a realistic DM halo profile of ~10^{-23} cm^3s^{-1}



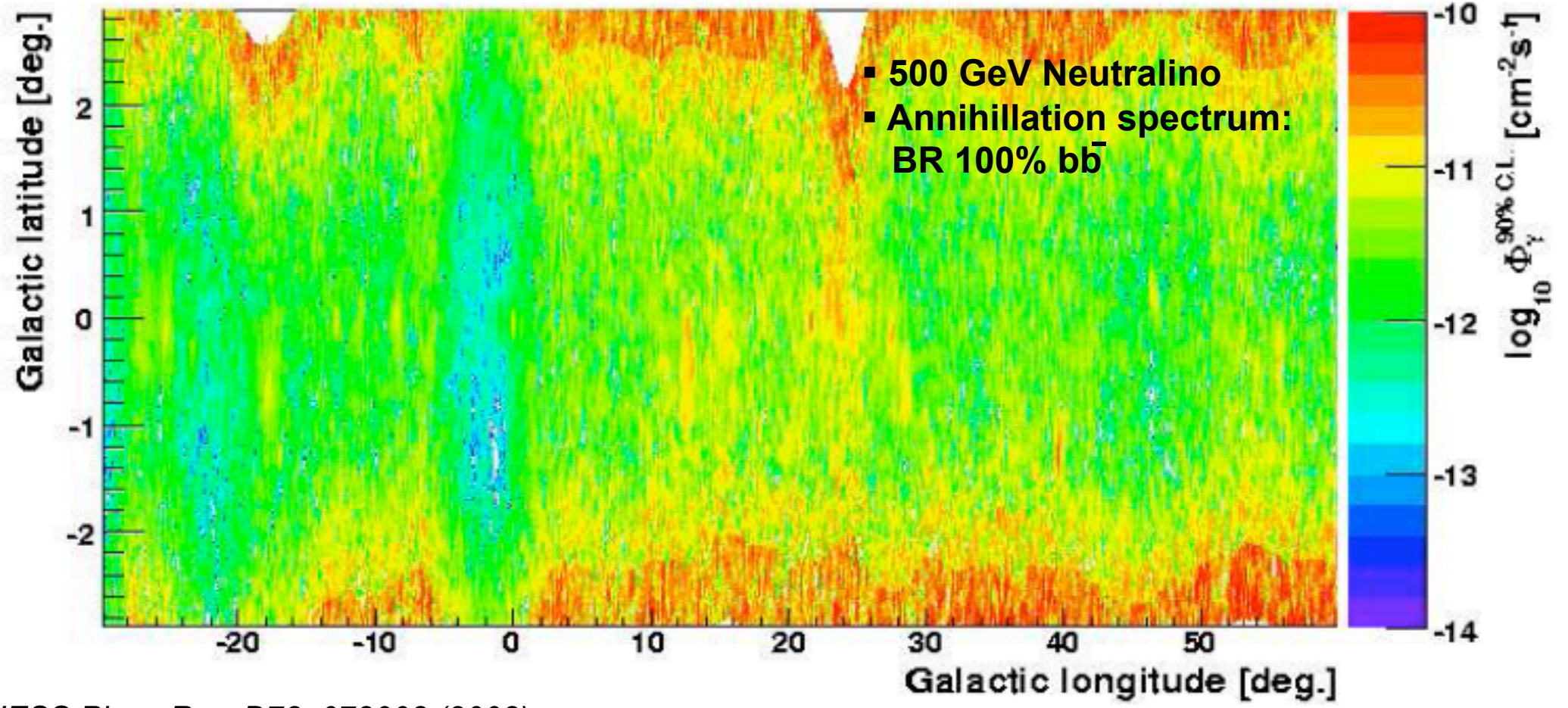
Substructures in Galactic haloes

The DM halo of a Milky Way-like Galaxy:

➔ Concentration of dark matter

in massive halo objects : clumps

HESS flux sensitivity map to Dark Matter annihilations

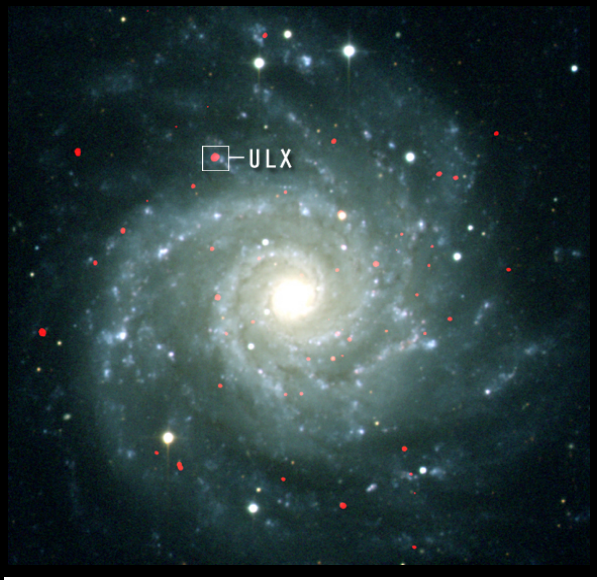


HESS Phys. Rev. D78, 072008 (2008)

- H.E.S.S. flux sensitivity map in a large field of view: [-30,60] x[-3,3] deg.^{2}

$\Rightarrow$ at the level of 10^{-12} $cm^{-2}s^{-1}$

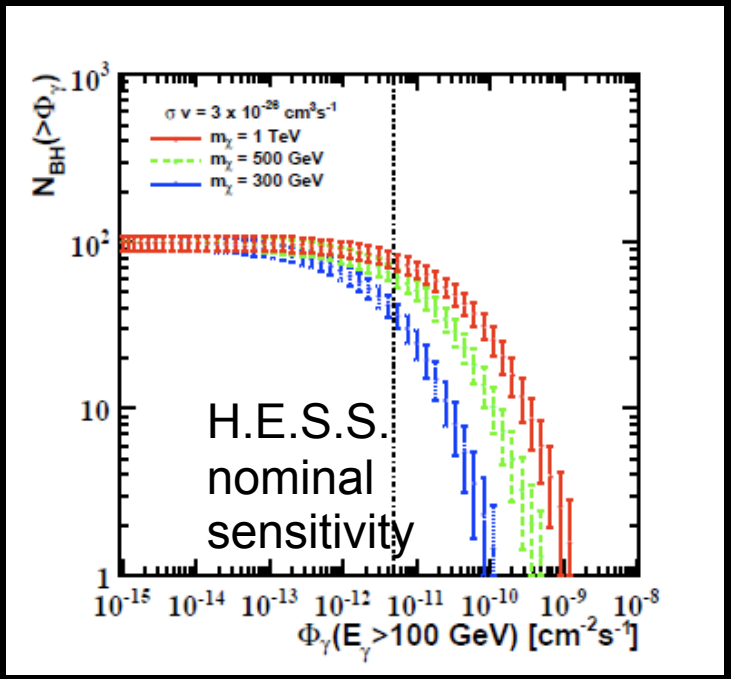
The case for DM mini-spikes around Intermediate Mass Black Holes



- ~100 IMBHs de ~10^5 $M_\odot$ in the Galactic halo (Koushiappas, 2004)
- Accumulation of DM around these objetcs (Bertone, 2005)

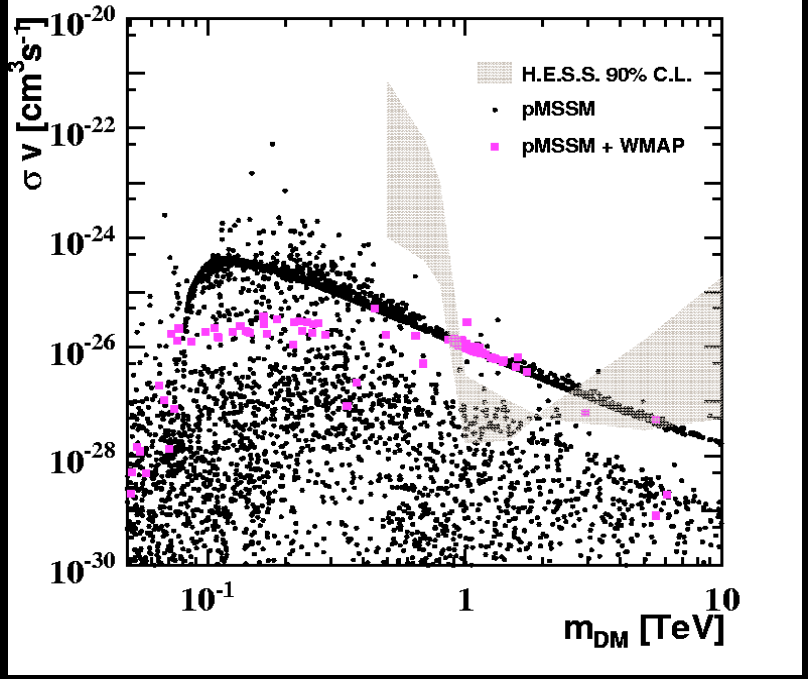
Gamma-ray luminosity from IMBH :

H.E.S.S. sensitivity can put strong constraints on particle physics models in this scenario



- Strong contraints on the annihilation cross section inMSSM
- Contraints on the entire gamma-ray production scenario around IMBHs

Aharonian et al., PRD78:072008,2008



Summary

- **Galactic Center**
  - ✓ Bulk of the gamma-ray signal unlikely to be of dark matter origin
  - ✓ Standard astrophysical emitters
- **Dwarf satellite galaxies of the Milky Way**
  - ✓ Some of them are already observed: Draco, Sagittarius, Wilman 1, Sculptor, Carina
  - ✓ No TeV gamma-ray signal
  - ✓ Astrophysical uncertainties on the dark matter halo profile
- **Galactic globular clusters:**
  - ✓ No TeV gamma-ray signal towards M15, NGC6388
  - ✓ DM halo modelling required to handle correctly the influence of stars
- **Galactic substructures in the Galactic halo:**
  - ✓ One IMBH minispike formation, albeit optilmistic, scenario well constrained by HESS
  - ✓ Robust constraints obtained from a widely accepted N-body simulation Via Lactea