Indirect dark matter searches with imaging atmospheric Cherenkov telescopes

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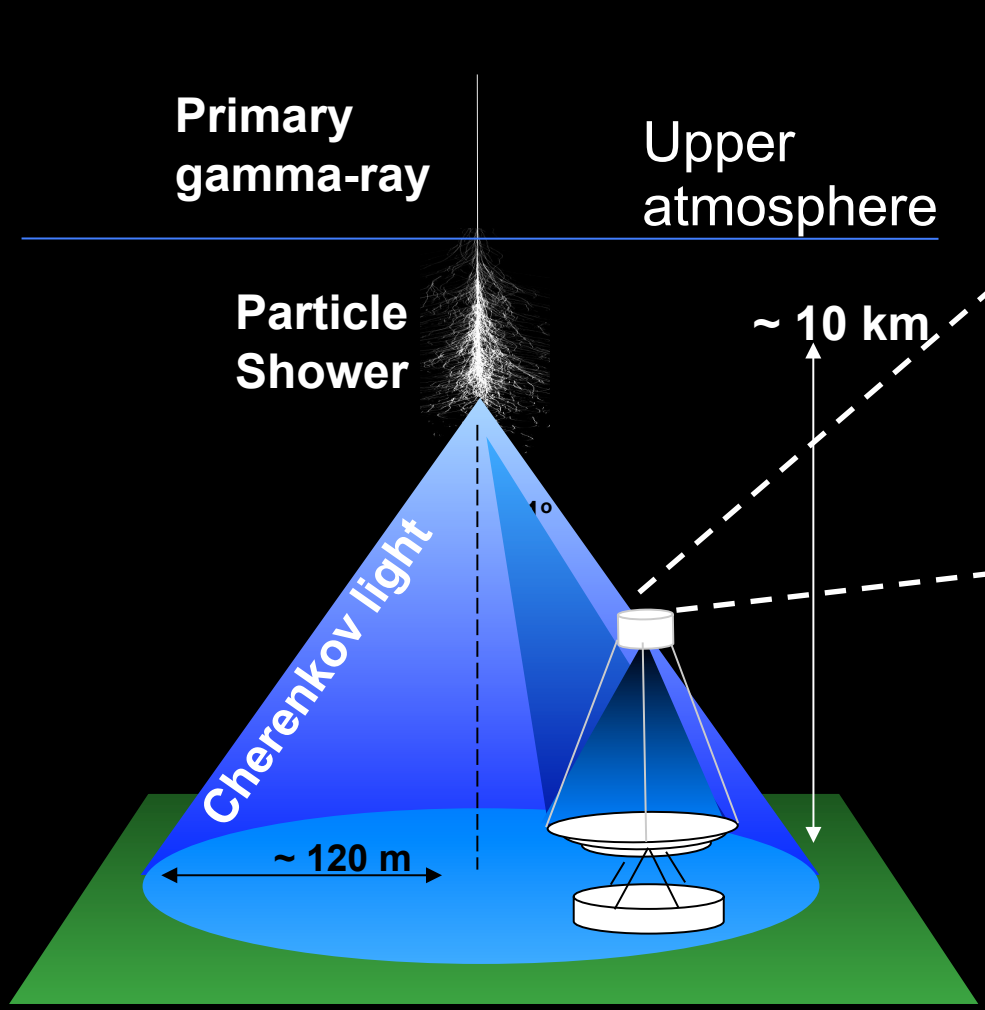
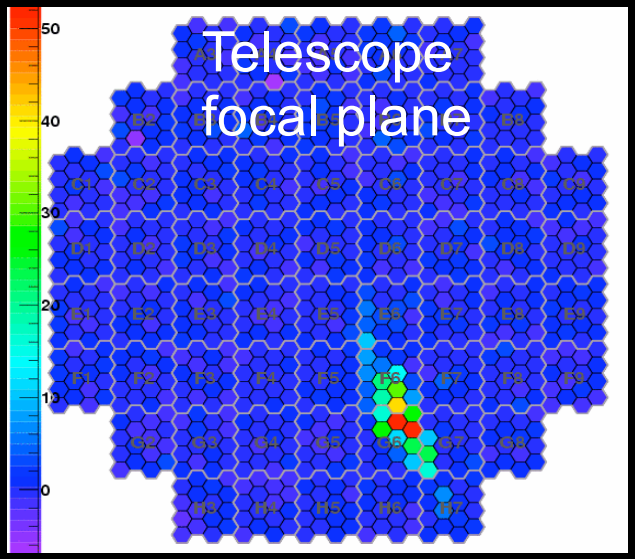
Outline:

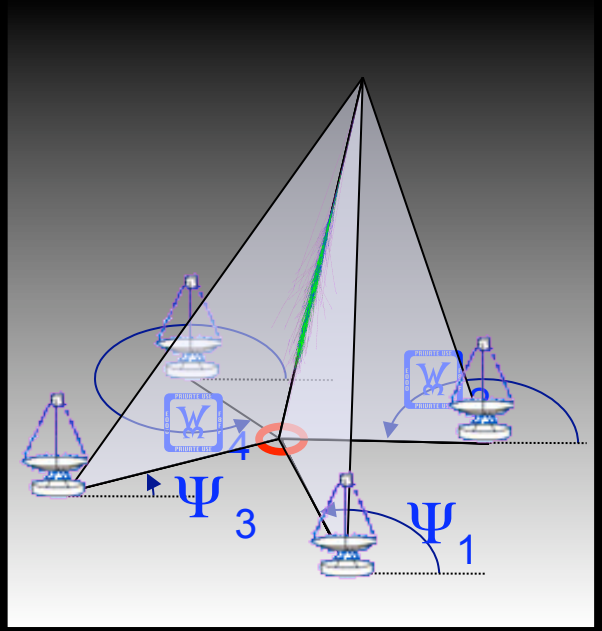
- The Galactic Center
- Galaxy clusters
- Galactic globular clusters
- Dwarf spheroidal galaxies
- Substructures in the Galactic halo

The IACT world : 3rd generation

The atmospheric Cherenkov technique







Stereoscopy:

- Improve the hadron rejection and the reconstruction of the gamma
- Rejection of the isolated muons

Gamma-ray flux from WIMP annihilations

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

$$\Phi_{PP} = \frac{1}{4\pi} \frac{<\sigma v>}{2m_\chi^2} \int_{Eth}^{m_\chi} \sum_f BR_f \frac{dN^f{}_\gamma}{dE_\gamma} dE_\gamma$$

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

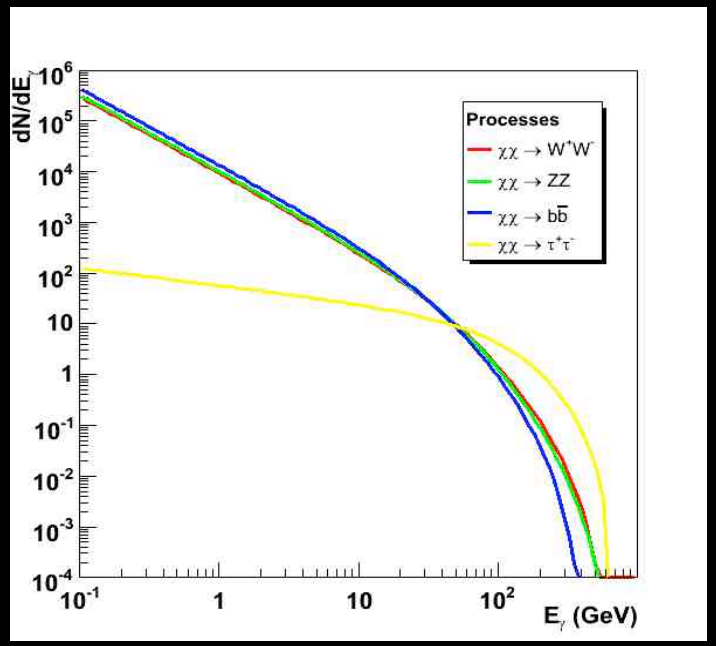
Particle Physics :

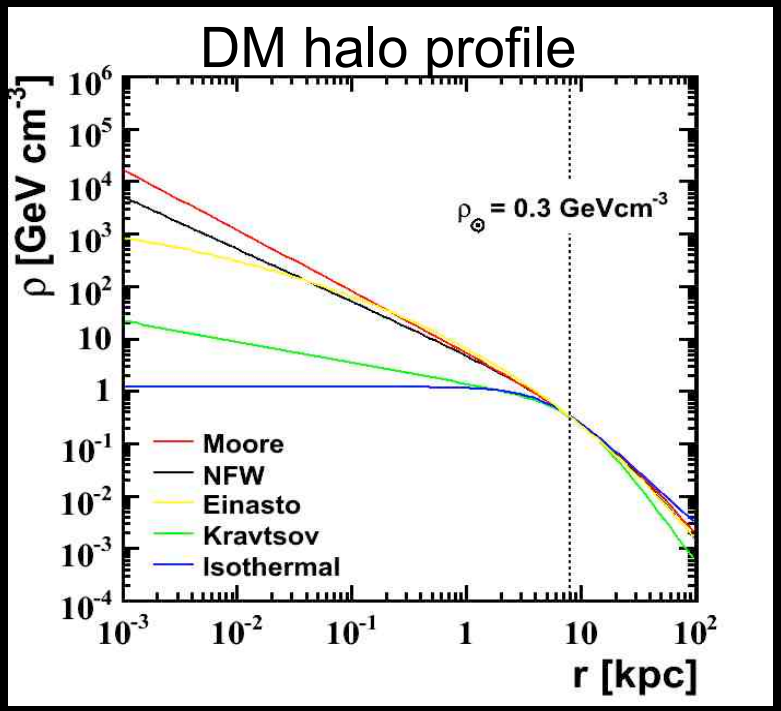
- Cross sections
- Branching ratios
- Differential photon yield
- DM particle mass

Astrophysics : Dark matter halo

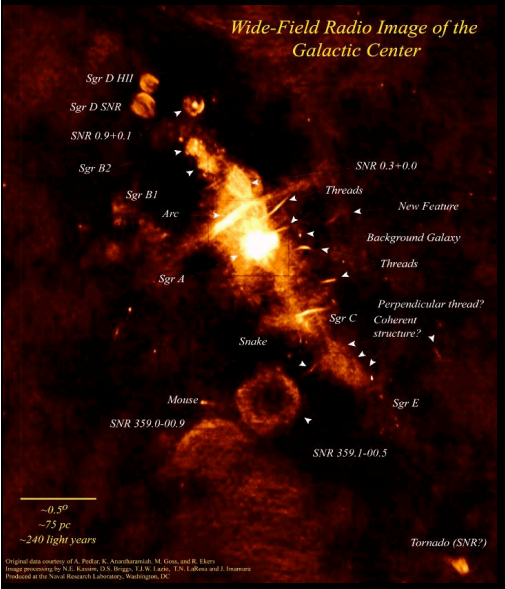
→ model required for the profile

Gamma spectrum: typically a continuum with an exponential cut-off at the DM particle mass





Dark matter « hot spots »

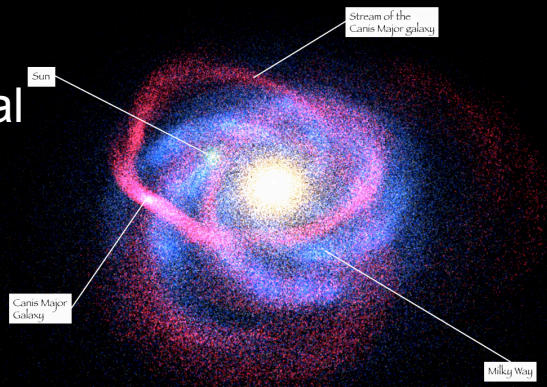


Galactic Centre

- 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

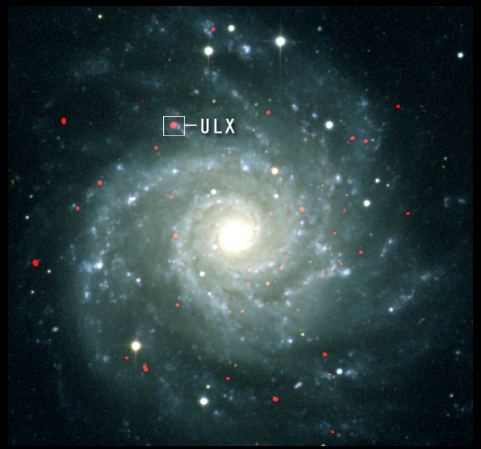


Substructures in the Galactic halo

- Lower signal
- Cleaner signal

Intermediate Mass Black Hole

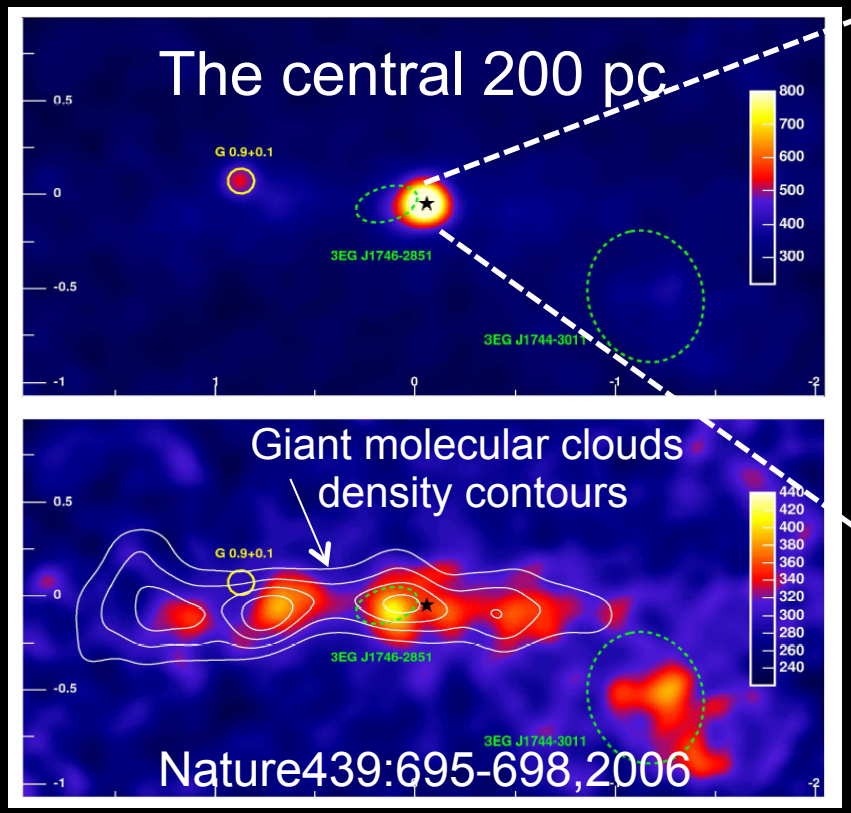
- High signal
- Clean signal
- Unproven existence

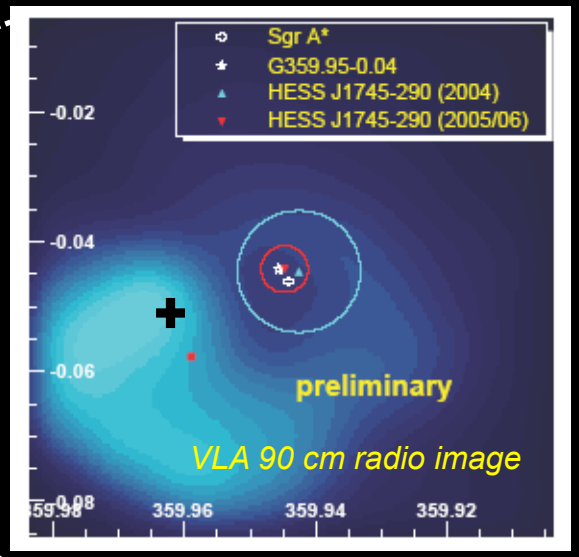


Galaxy clusters

- High signal
- High astrophysical background signal

The Galactic Center seen by H.E.S.S.





- Best fit position:
  l=359d56'41'' ± 6.4''$_{stat}$ ± 6''$_{syst}$
  b=-0d2'39.2'' ± 5.9''$_{stat}$ ± 6''$_{syst}$
- VHE emission from Sgr A East maximum excluded at 7 sigma level
- VHE emission follows radio flux? excluded at 5.3 sigma level

Diffuse emission along the GC ridge:

correlates fairly well with

giant molecular clouds (white contours)

➔ Cosmic ray interaction

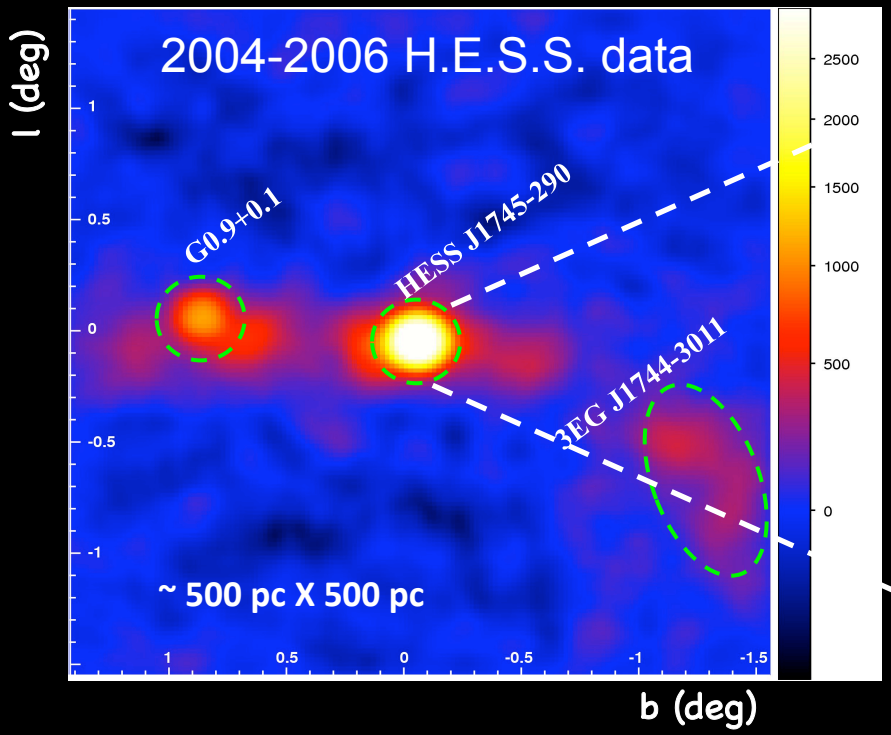
- Position relative to the radio position of Sgr A* : 7.3'' ± 8.7''$_{stat.}$ ± 8.5''$_{syst}$
- Bulk of the VHE emission not from Sgr A East
- Both SMBH and PWN are good candidates

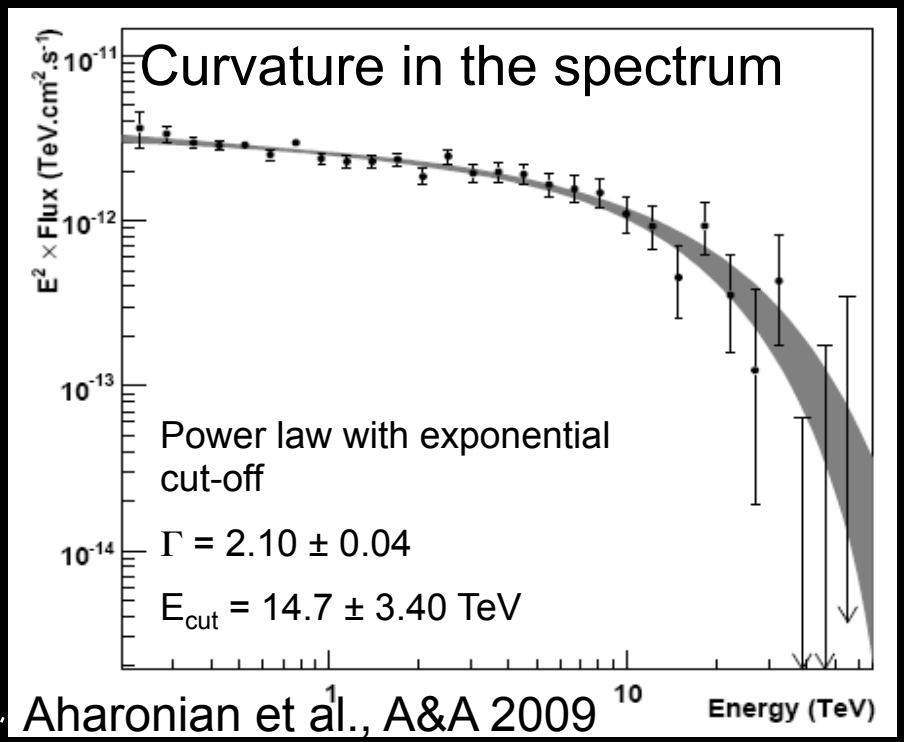
The TeV signal from the Galactic Center

- ❑ strong emission (>10% of Crab above 1 TeV)
- ❑ point like source (PSF=0.1 deg)
- ❑ constant flux: 1 g/minute
- ❑ no significant fluctuation (10min→1 year)
- ❑ flare sensitivity: 2.5 (6h) → 0.75 (1month)
- ❑ no significant periodicity (28 min → 1year)

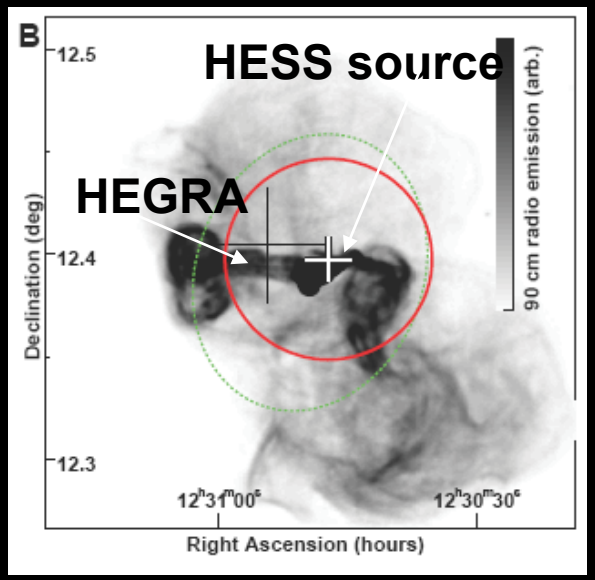
- Most probably, if DM signal exists is overcome by other astrophysical emitters
- A DM contribution is not excluded: estimated to be < 10%

❑ Interpretation of DM signal embedded in astrophysical emission is hard



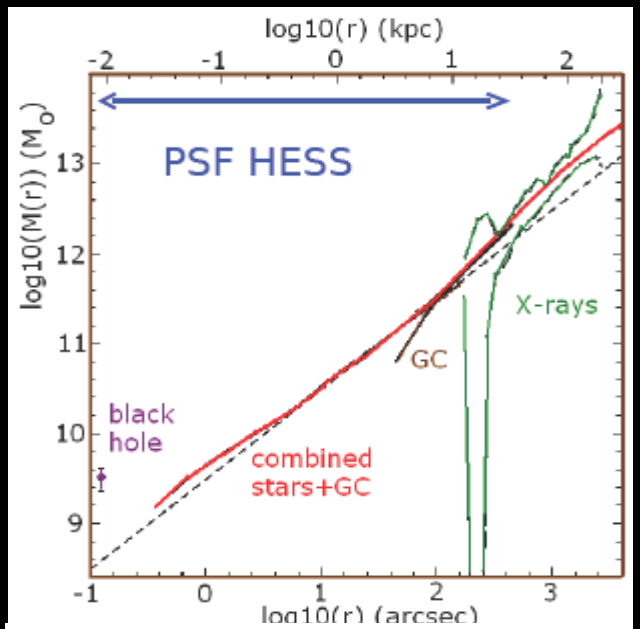


Galaxy clusters : a TeV signal from M87 in the Virgo cluster



❑ **Active galaxy :**
- black hole $(3.2 \pm 0.9) \times 10^9 M_{sun}$,
  $R_s = 3.2 \times 10^4$ s = 9 h
- distance: 16.3 Mpc
- jet axis 20-40 deg. from line of sight

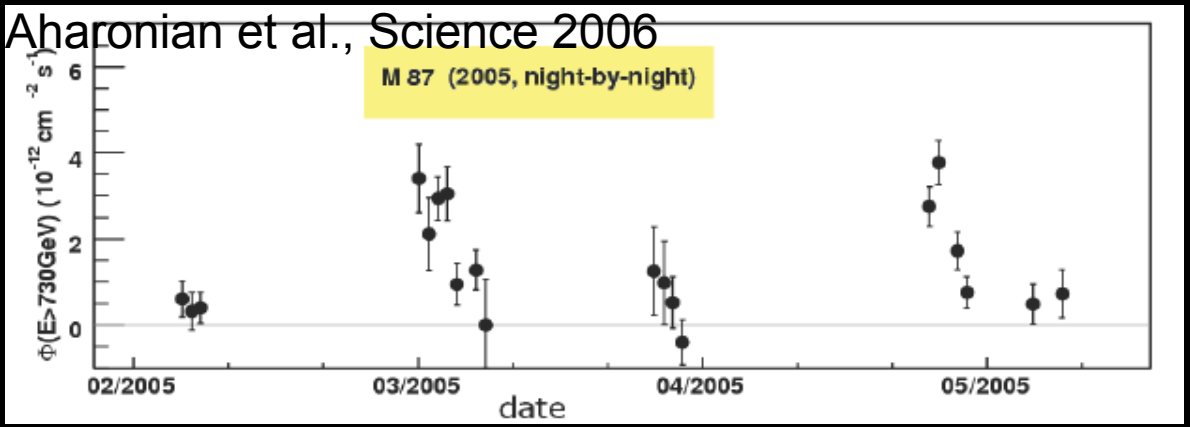
❑ M(r) well constrained
- Predicted flux: ~10^{-3} of HESS flux



(Romanowski, Kochanek '01)

❑ Point-like source: < 3' (99% C.L.)
❑ Power law spectrum: $\Gamma = 2.22 \pm 0.25$ (2005)
$\Gamma = 2.62 \pm 0.35$ (2004)

Aharonian et al., Science 2006

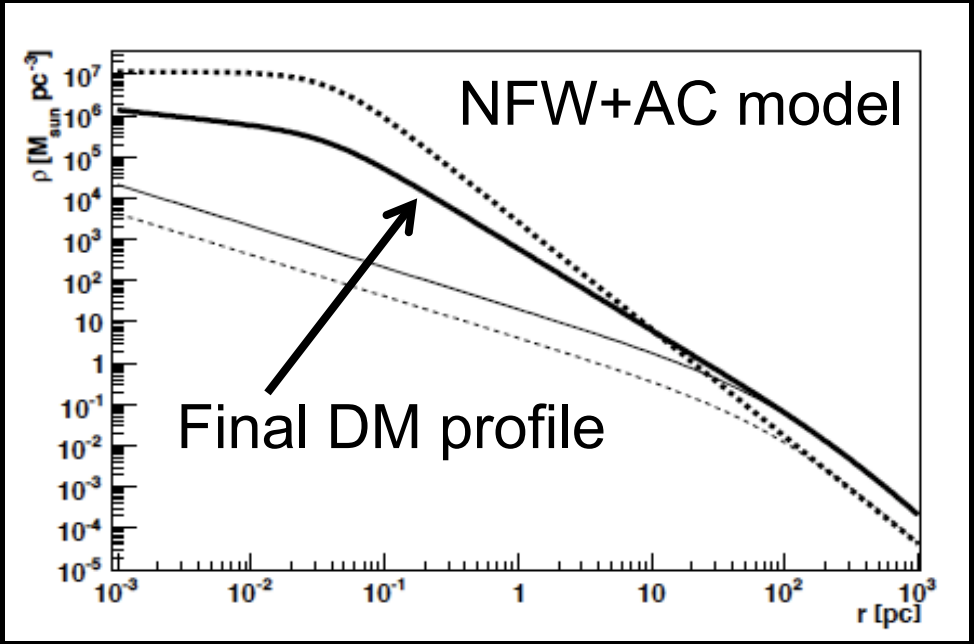


Long term variability ~1 year (3.2σ)
Short term variability ~2 days (4σ)
Emission region size < ~50 R_s
⇒ production site: black hole?

Short term and long term variability exclude the whole signal to be of DM origin

Whipple results on M15

No significant amount of DM in globular clusters

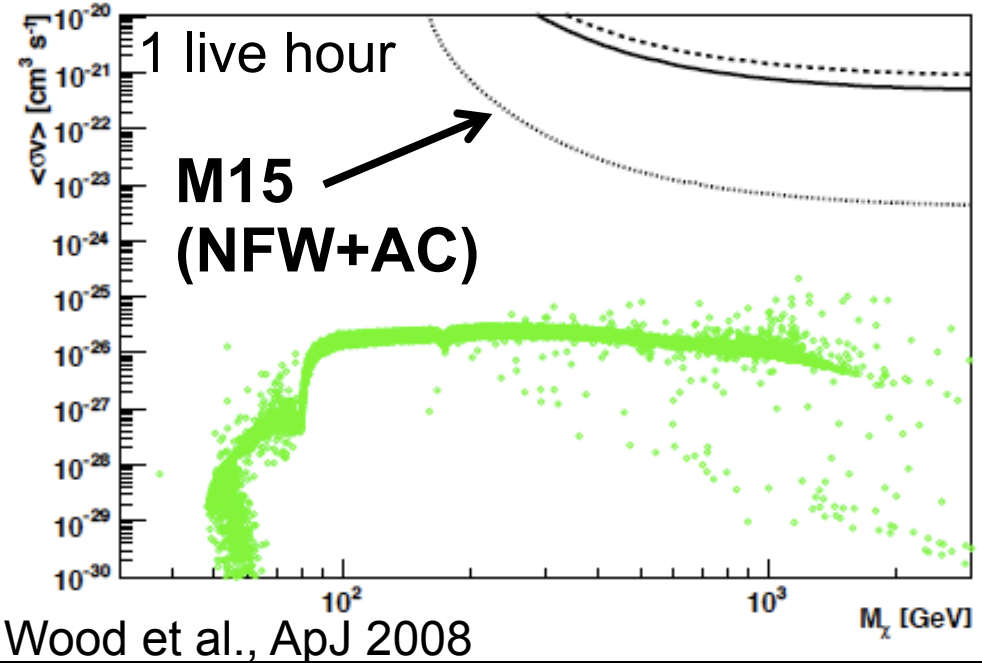


- **No gamma excess found**
- **Exclusion on <σv> (95% C.L.):**

For 1 TeV neutralino $\langle\sigma v\rangle < 10^{-23}$ $cm^3 s^{-1}$

Not possible to exclude any MSSM models

- **Condensation of baryons should have been pulled DM inward thus increasing the DM density in the center**
  - ➔ **Modelling within the adiabatic contraction model (Blumenthal, 1986)**

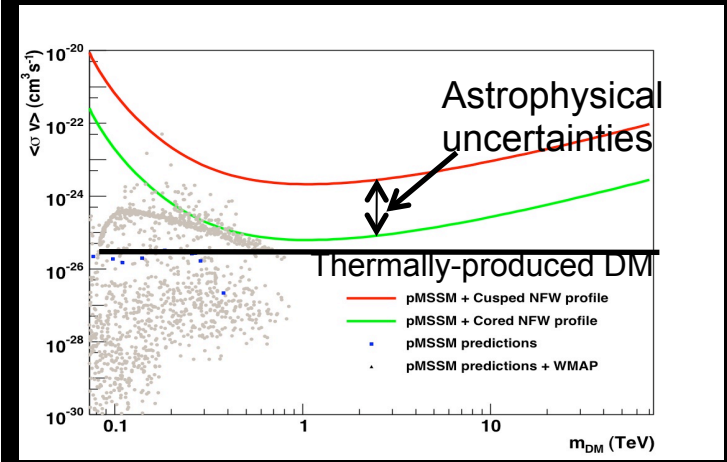


Wood et al., ApJ 2008

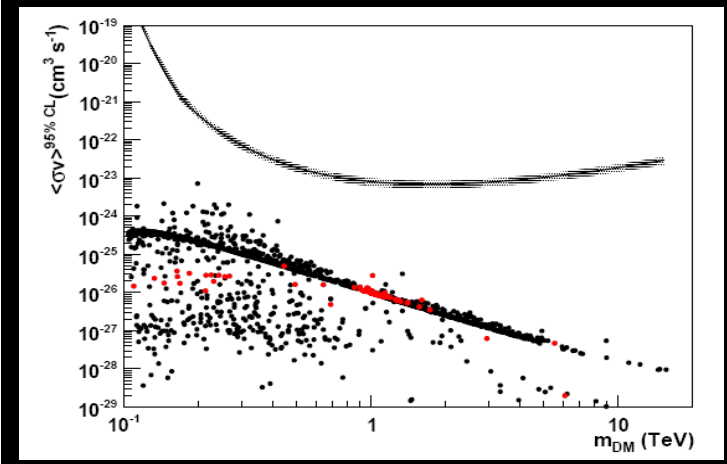
Satellite galaxies of the Milky Way

❑ HESS:

- 2006 Sagittarius: 11 h



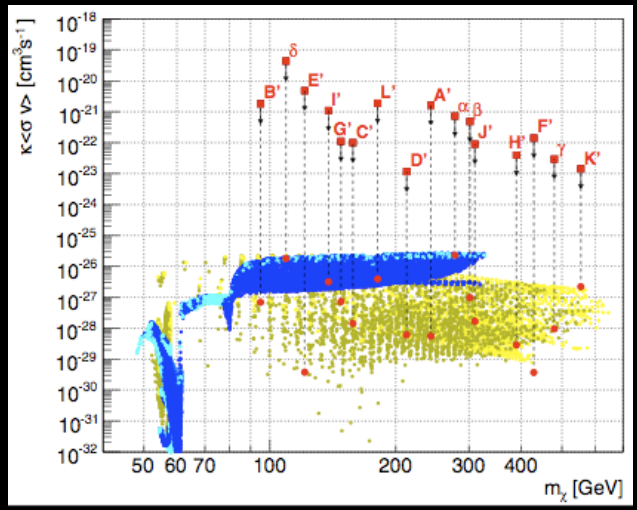
- 2007 Canis Major: 9 h



- 2008/2009 Sculptor, Carina

❑ MAGIC:

- 2008 Draco: 8 h

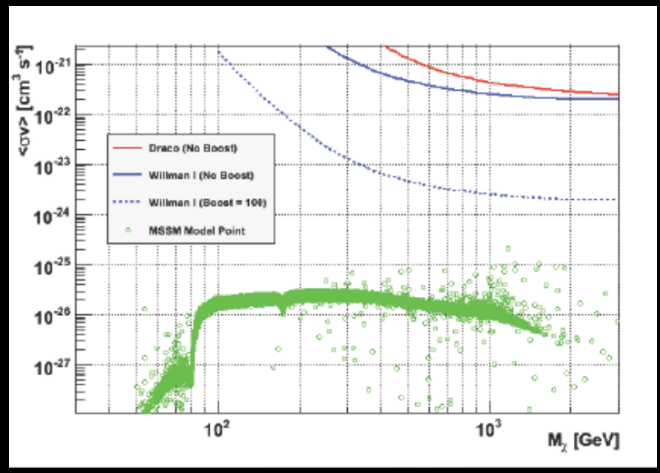


- 2009 Willman 1: 15 h

❑ **Only very high flux enhancement can be excluded**

❑ VERITAS:

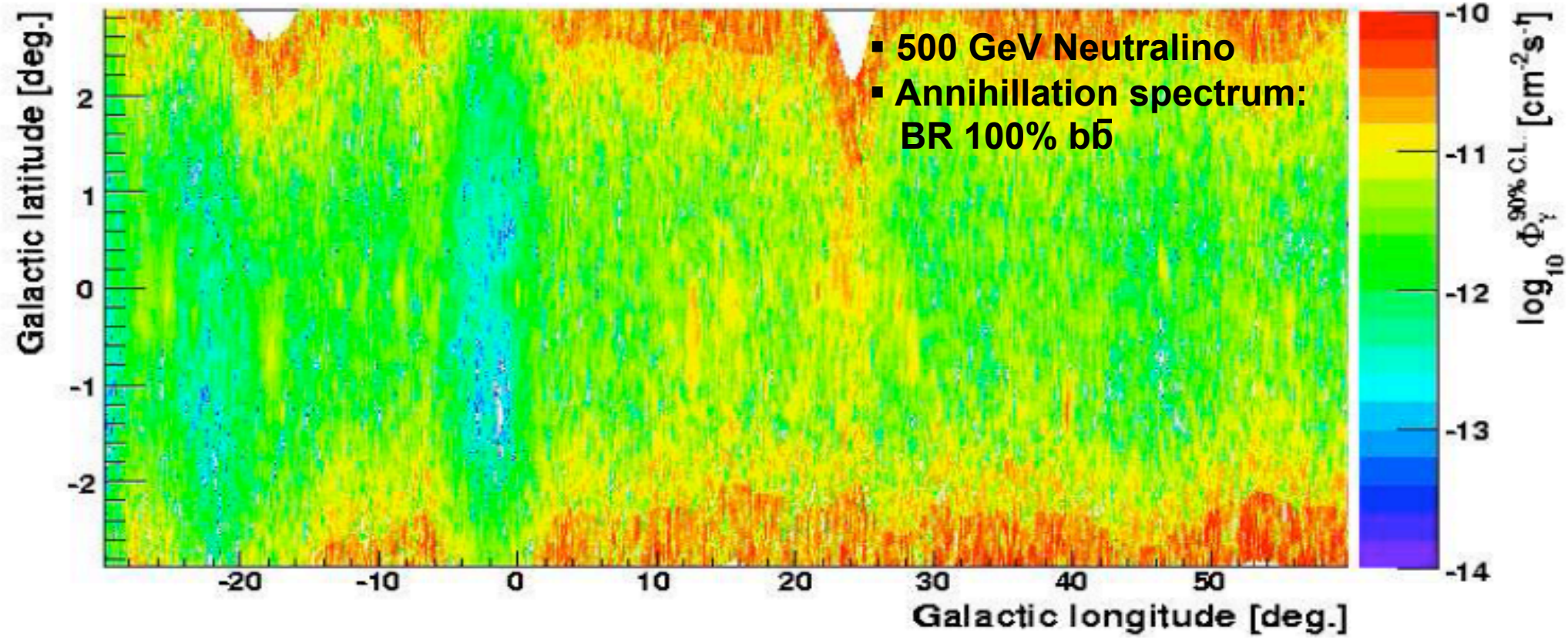
- Draco: 20h
- Ursa Minor: 20 h
- Willman 1: 15h



- About to submit the paper

No dark matter signal so far, only upper limits

H.E.S.S. flux sensitivity map to DM annihilations in a large FoV



Aharonian et al., 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}

- H.E.S.S. able to start clump searches

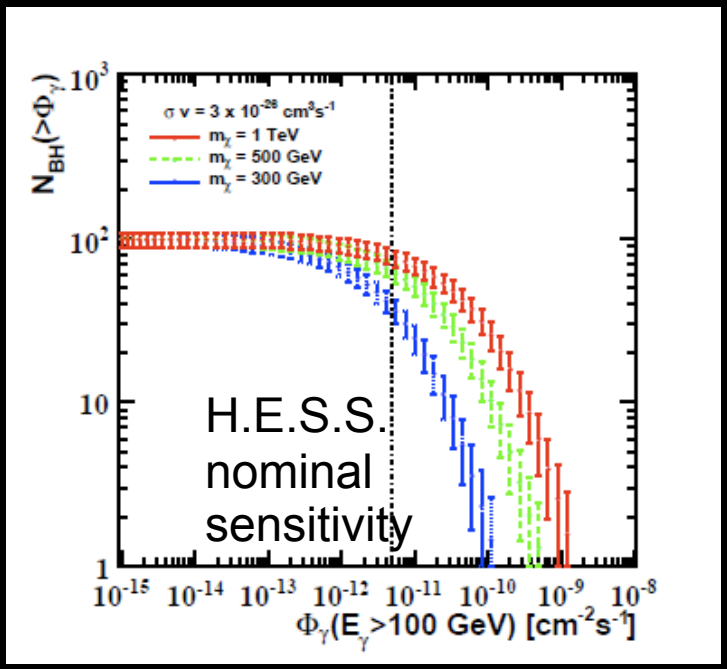
The case for DM mini-spikes around Intermediate Mass Black Holes

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

No plausible candidate within the H.E.S.S. data
e.g. unidentified sources do not show the expected features :
- intrinsic spatial extension
- pure power-law spectrum up to ~10 TeV

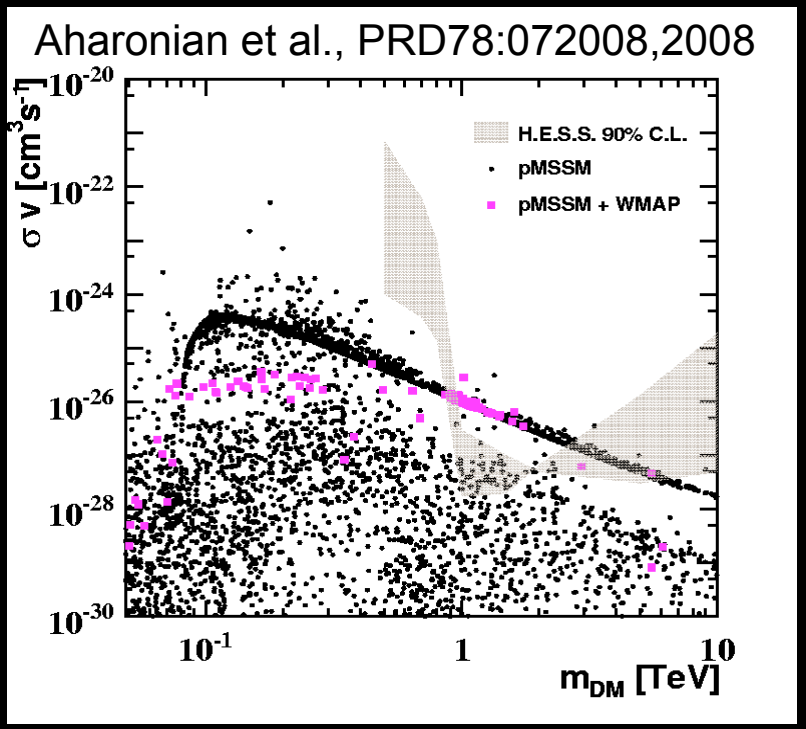
Gamma-ray luminosity from IMBH :

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



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

Aharonian et al., PRD78:072008,2008

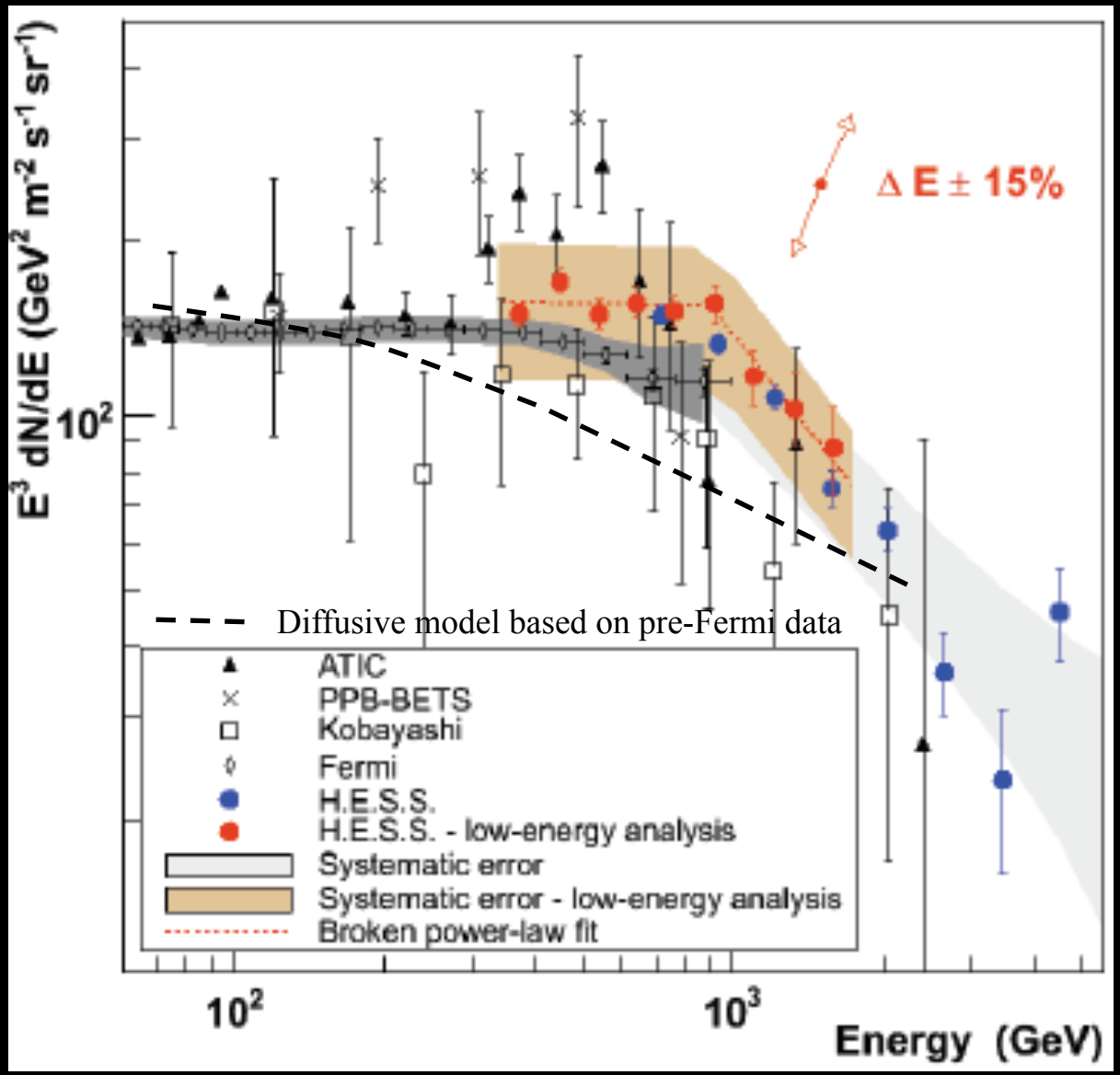


Cosmic-ray electron spectrum

- ATIC excess of $e^+ + e^-$ in the 300 GeV – 800 GeV
- HESS spectrum in 340 GeV – 5 TeV
  No prominent spectral feature,
  ATIC cannot strictly be excluded
  due to energy scale incertainty
- Fermi in the 20 GeV – 1TeV

Significatif excess by Fermi

- dark matter annihilation: plausible…
- local source of e^+e^- : nearby pulsars, SNRs



Perspectives: H.E.S.S. 2 and MAGIC 2

1 large telescope at the center of the existing array

- 28 m in diameter, 647 m²
- focal distance : 35 m
- 2048 PMTs
- field of view : 3.5°

➔ Lower the energy threshold
➔ Access to new category of sources

2 telescopes

- 17 m in diameter
- Sensitivity x 2
- Energy resolution +40%
- Angular resolution +30%

Next generation of IACTs : CTA/AGIS Wish list...

- Improved angular resolution (x2-3)

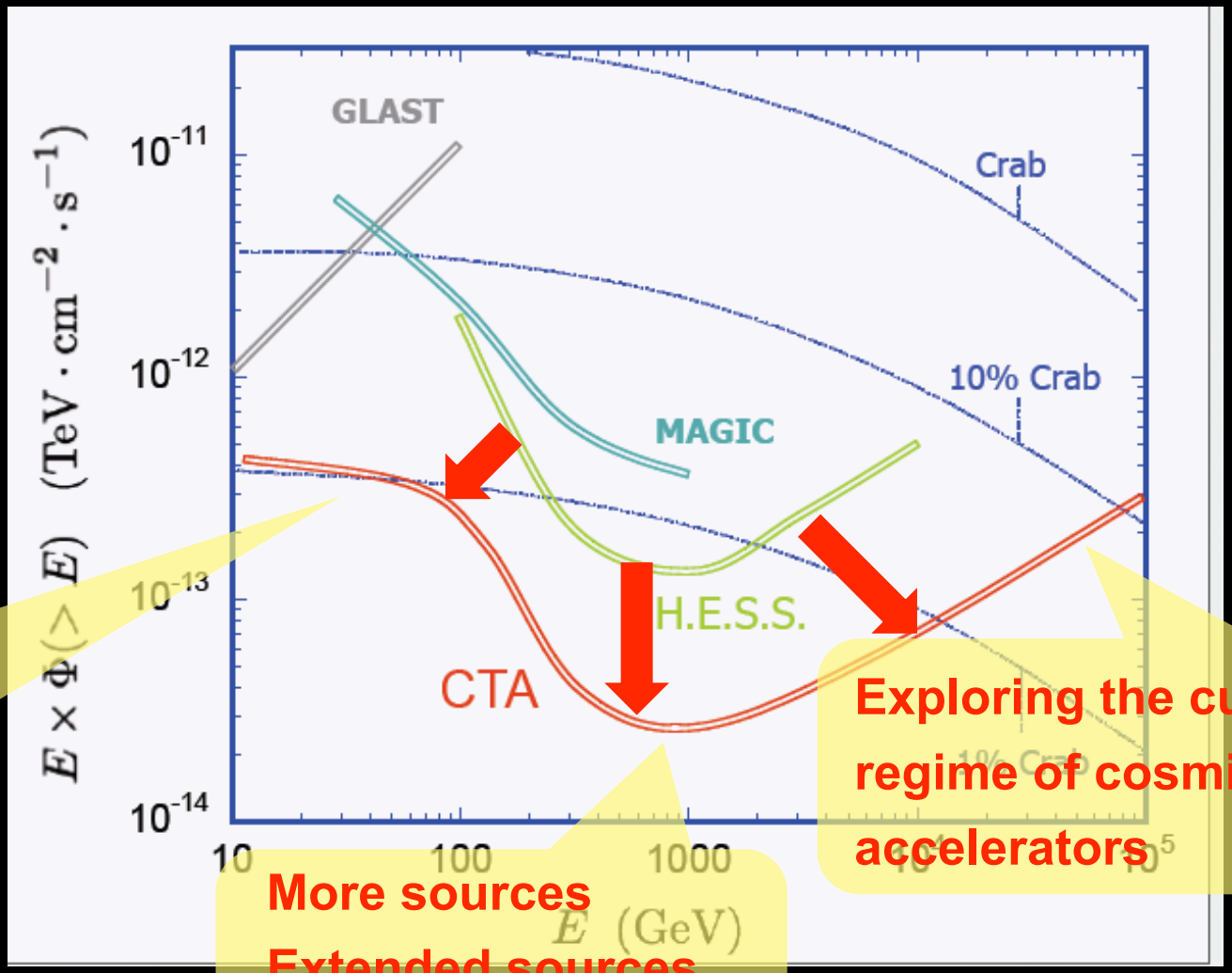
source morphology

- Large FoV (6-8 deg.)

extended sources, survey

- Large detection area (x10)

transient sources



High-gz AGN, pulsar
Indirect DM searches
Cosmology
Propagation physics

More sources
Extended sources
Population studies

Exploring the cutoff regime of cosmic accelerators

CTA general design

- Design
  - Increase the array from 4 to ~100 telescopes
  - Distribute them over ~1 km^2
  - Telescopes of 2 to 3 different sizes
- Development
  - Use well-proven technology of current IACTs
  - High automatization
- Observatory
  - Open to external astronomer

Low energy section

Energy threshold

of some 10 GeV

Core array

mCrab sensitivity

in the 100 GeV -10 TeV domain

High energy section

10 km^2 area

at multi-TeV energy

Summary

- **Galactic Center observed by HESS, MAGIC**
  - ✓ Bulk of the gamma-ray signal unlikely to be of dark matter origin
  - ✓ Standard astrophysical emitters
- **Centers of galaxy clusters**
  - ✓ Ongoing IACTs do not have the required sensitivity
- **Dwarf satellite galaxies of the Milky Way**
  - ✓ Some of them are already observed: Draco, Sagittarius, Wilman 1,…
  - ✓ No TeV gamma-ray signal
  - ✓ Astrophysical uncertainties on the dark matter halo profile
- **Galactic globular clusters:**
  - ✓ No TeV gamma-ray signal from Whipple on M15
  - ✓ Modeling required for the contraction of dark matter
- **Galactic substructures in the Galactic halo:**
  - ✓ One IMBH mini-spike formation scenario well constrained by HESS
- **Anomalous feature in the electron/positron spectrum?**
  - ✓ If so, likely to be local astrophysical sources