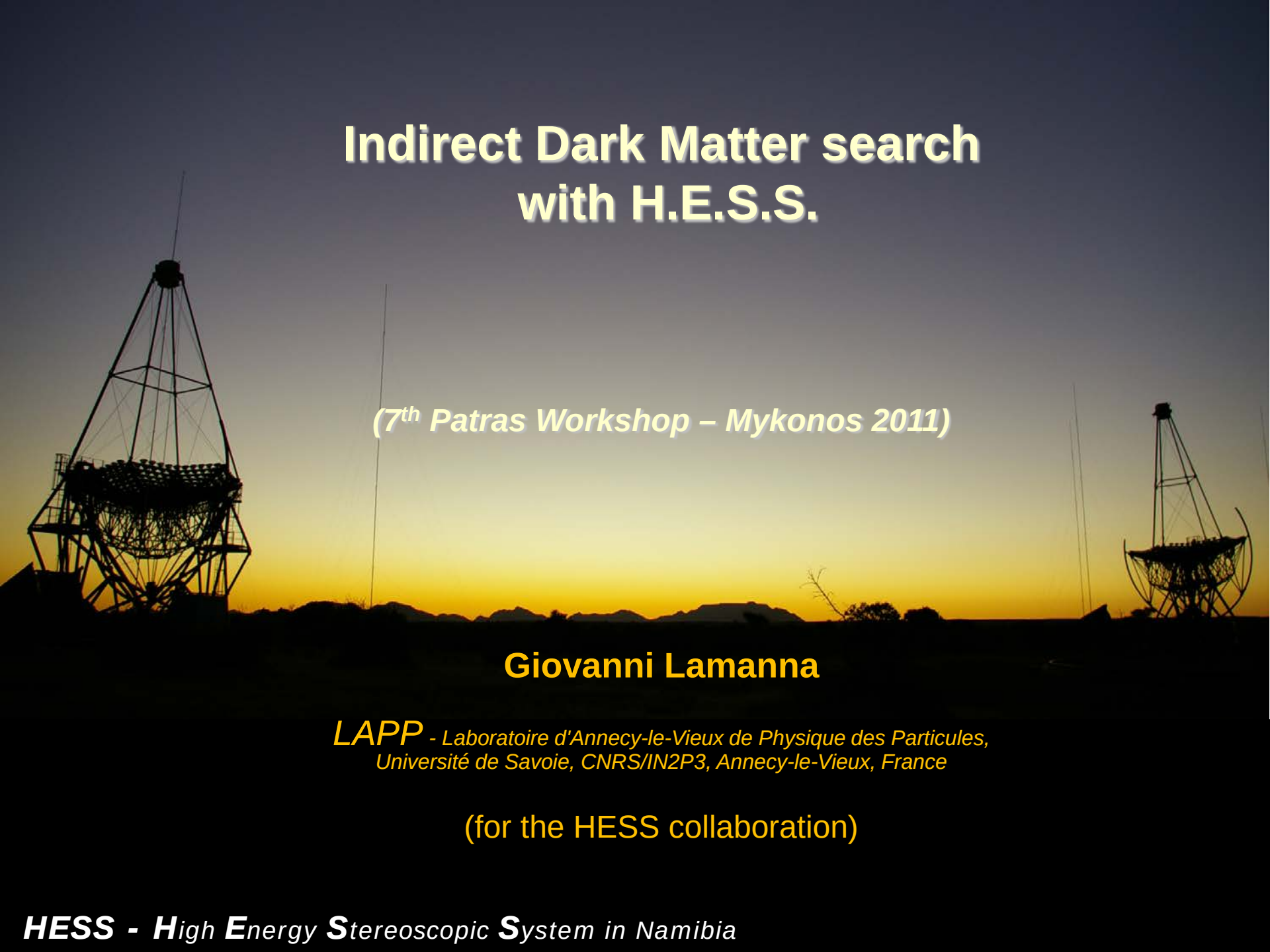


Indirect Dark Matter search with H.E.S.S.

(7th Patras Workshop – Mykonos 2011)

Giovanni Lamanna

LAPP - Laboratoire d'Annecy-le-Vieux de Physique des Particules, Université de Savoie, CNRS/IN2P3, Annecy-le-Vieux, France

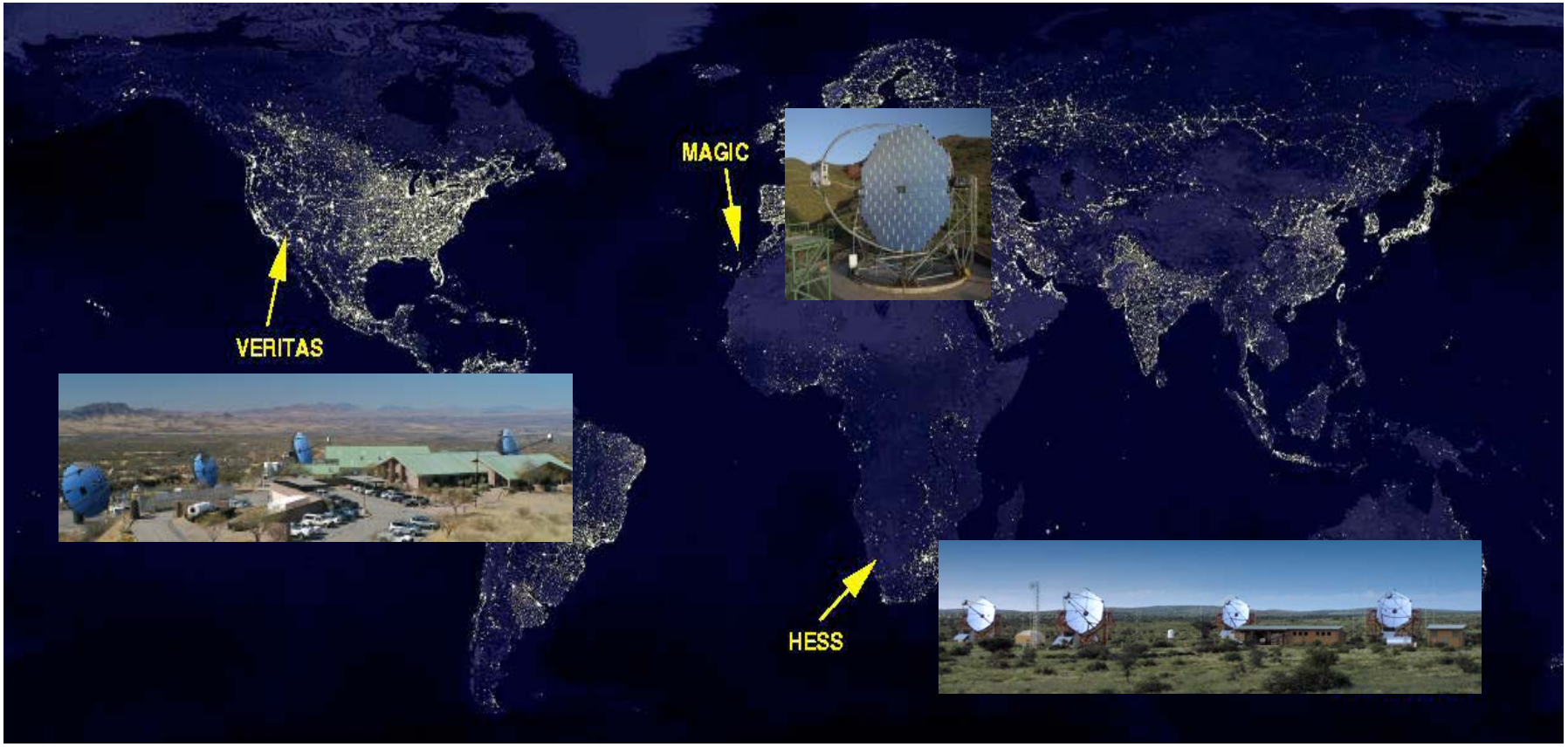
(for the HESS collaboration)

HESS - High Energy Stereoscopic System in Namibia

- Introduction:
  - Imaging Air Cherenkov Telescope system (e.g. H.E.S.S.)
  - Dark Matter
- Indirect search for Dark Matter and the γ messengers
- Reviewing the H.E.S.S. results
- Conclusions

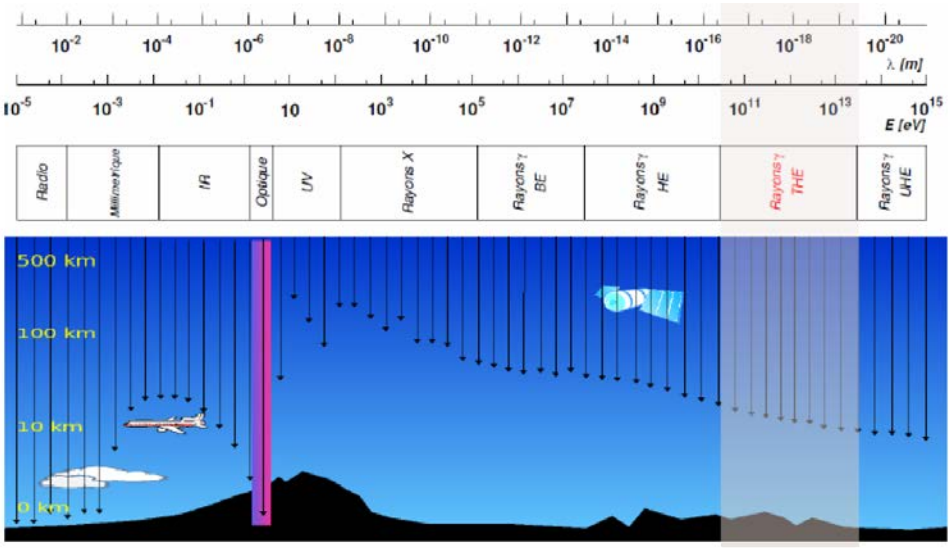
Major VHE IACT systems

- Proven and highly performing detection technology



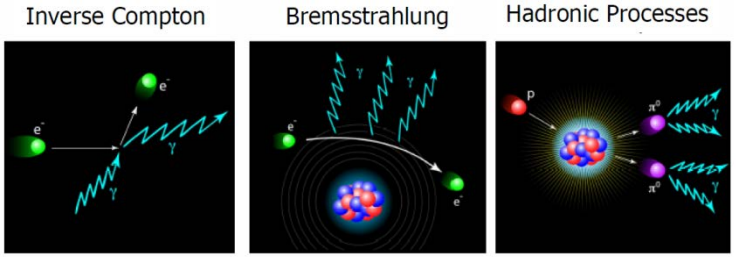
- A large spectrum of results and more than 100 gamma-ray astrophysics sources: toward “VHE γ-astronomy”

GeV-TeV γ-ray astronomy

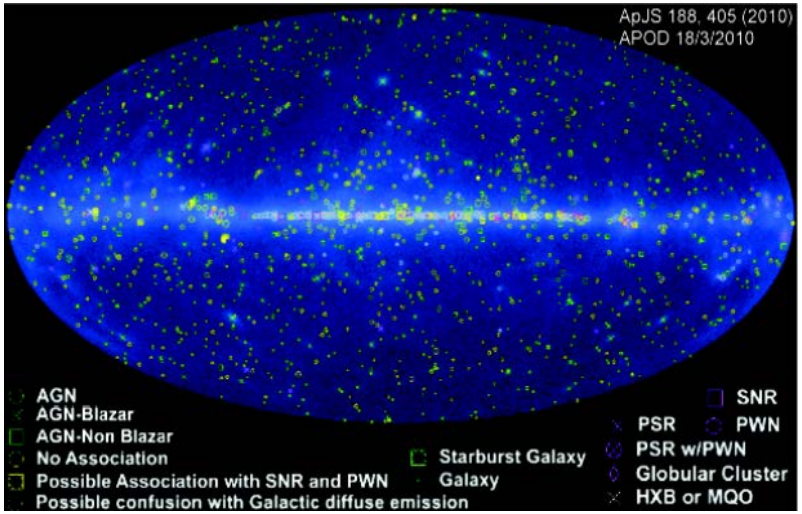


Straight line propagation:

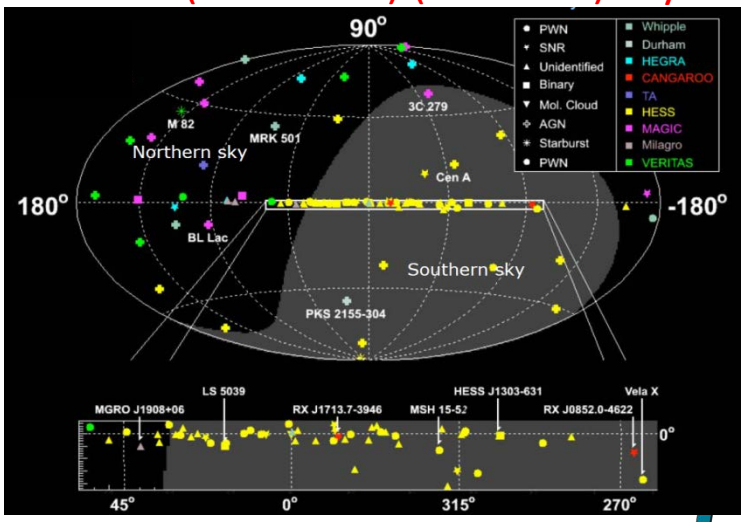
→ exploration of the non-thermal Universe
→ origin and propagation of Cosmic Rays



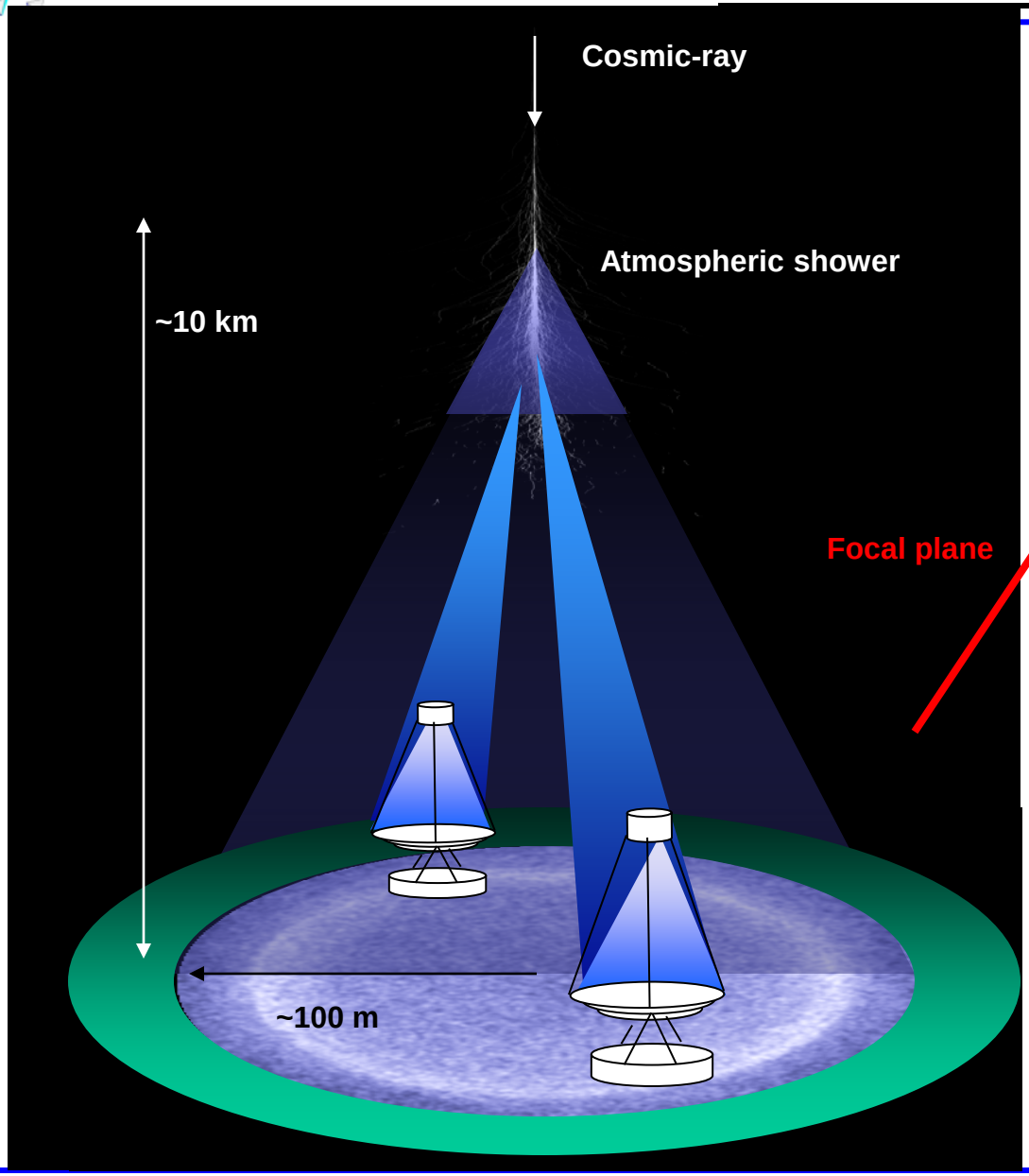
Fermi (MeV-GeV) sky

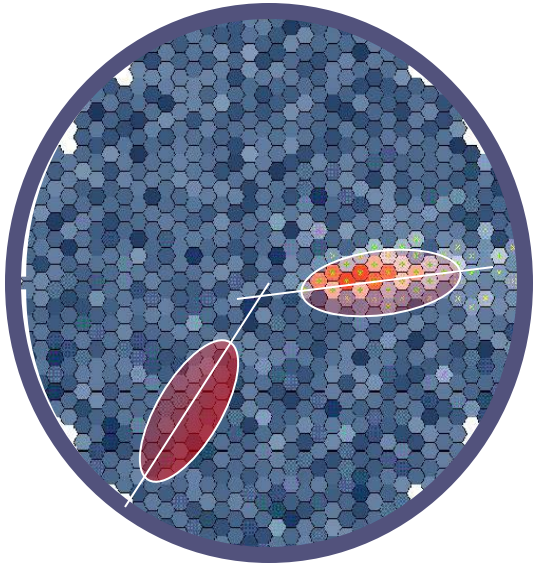


HESS (and IACTs) (GeV-TeV) sky



The atmospheric Cherenkov technique





Shower development:
- Cherenkov light cone
  $\alpha=\arccos(1/n\beta)$, $\beta=v/c\sim1$; $\alpha=1^{o}$ at 10 km
- Flash of 5 ns blue light
- 100 m radius lighted surface
- Light ~ path ~ CR primary energy

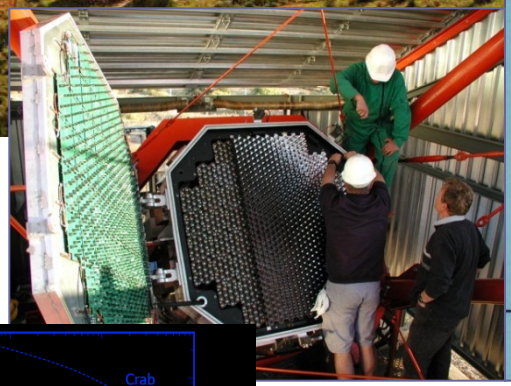
Cameras' images analysis:
- Shower energy and direction
- CR-p background rejection

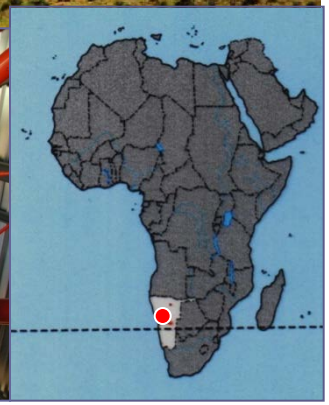
Stereoscopy:
- Improving the angular resolution and the bg. rejection

H.E.S.S.: High Energy Stereoscopic System

A system of 4 telescopes in Namibia (1800 m) (since 2004):

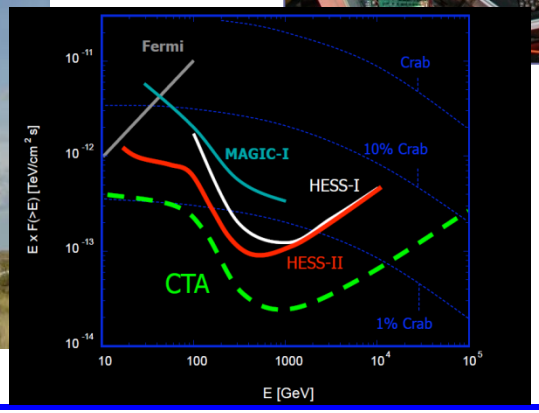
- 13 m diameter *dish* (107 m^2)
- 15 m focal distance
- 960 pixels (0.16º) camera
- Sensitivity 100 GeV – 100 TeV (detecting Crab in 30 s)
- 15% energy resolution
- 4' to 6‘ angular resolution





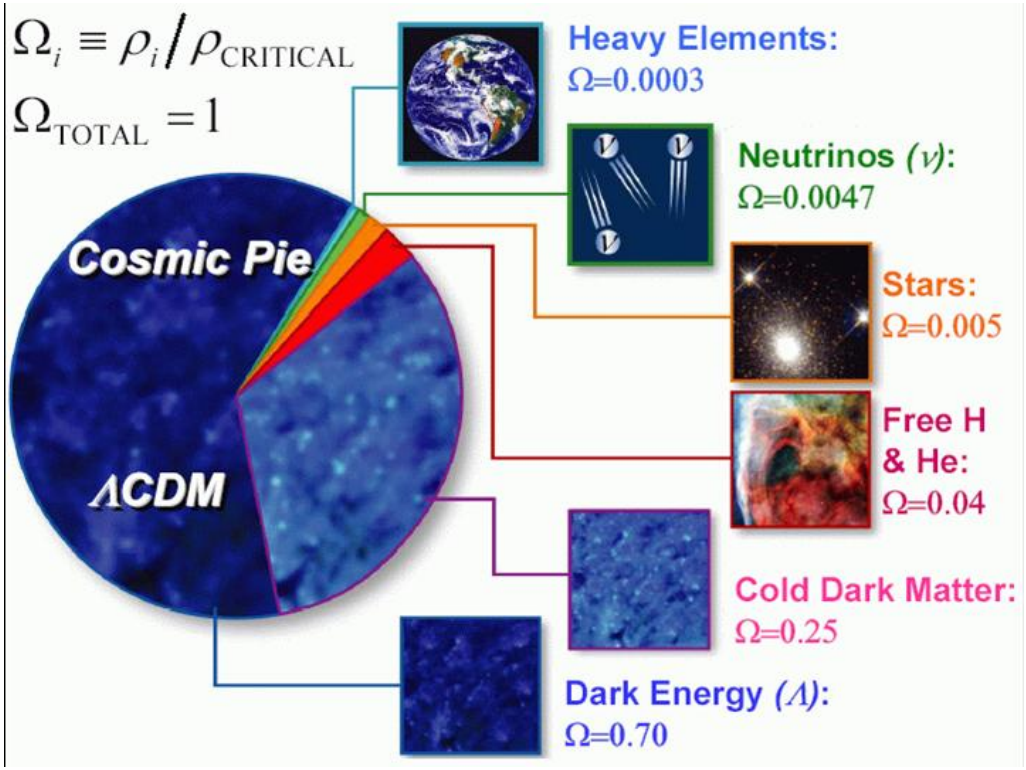
HESS 2 (5th telescope) in construction:

- 2048 pixels (0.07º)
- 30 m diameter *dish*
- Lower energy threshold and higher sensitivity

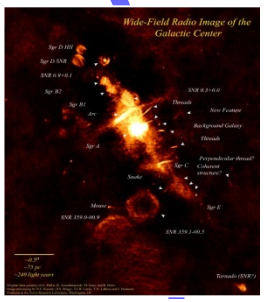


… and CTA :
“First TeV γ-ray Observatory”

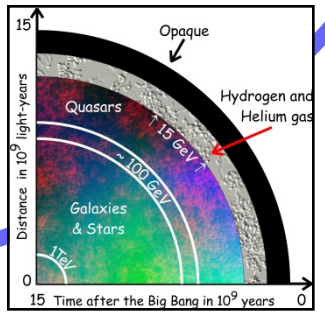
Concordance Cosmological Standard Model fitting all measurements.



VHE γ-ray telescopes may contribute in subjects such as:

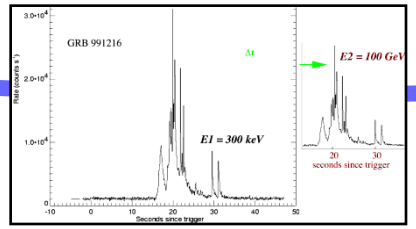


Origin of Dark Matter



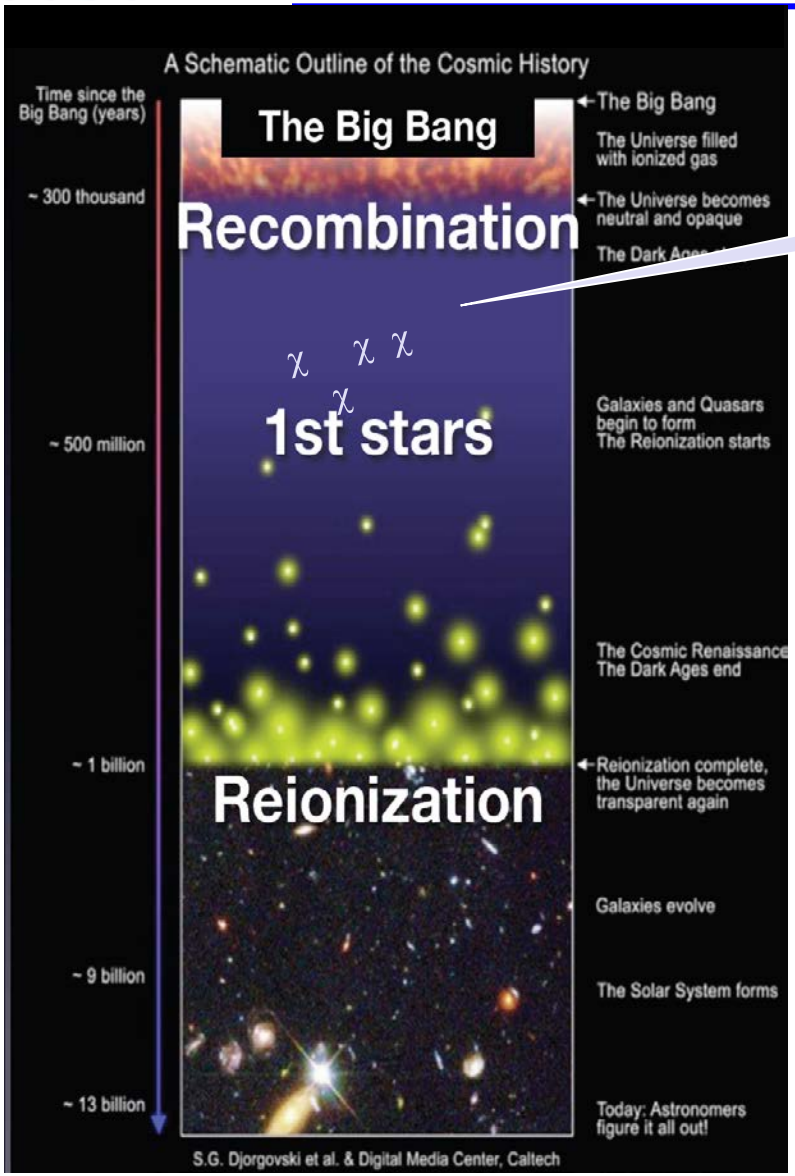
Cosmological γ-Ray Horizon

…



Test of the speed of light invariance

Cosmology and γ-ray Astronomy



Cold Dark Matter χ introduced to explain structures formation

- inflation period followed by « reheating »

- Dark matter WIMPs ($m_\chi > 50$GeV) particles annihilation until their decoupling from the thermic bath

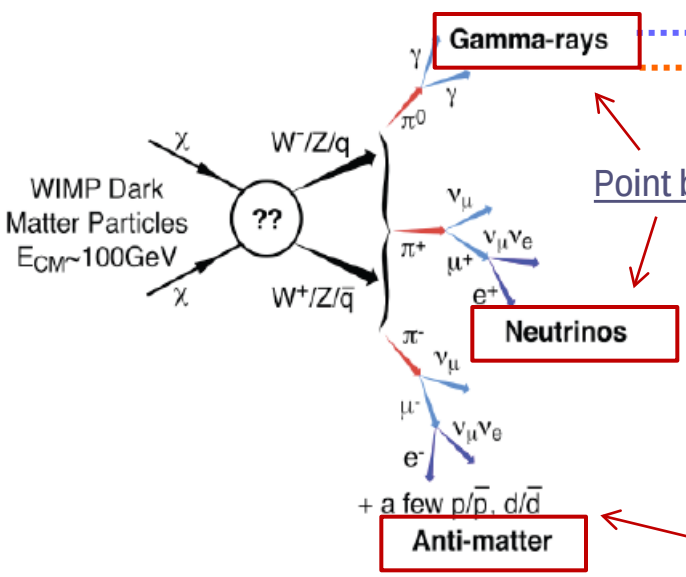
- structures formation into the DM potential wells, annihilation processes resumed at the center of dense structures.

The annihilation processes $\chi\chi \rightarrow \gamma$ … as source of HE gamma radiation.. but also particles e+e-, ν, …

The understanding of the observable Universe (its objects and their evolution) requires the existence of non-baryonic dark matter:

The γ-ray astronomy for indirect search of the presence and the nature of WIMPs

DM candidates and indirect search



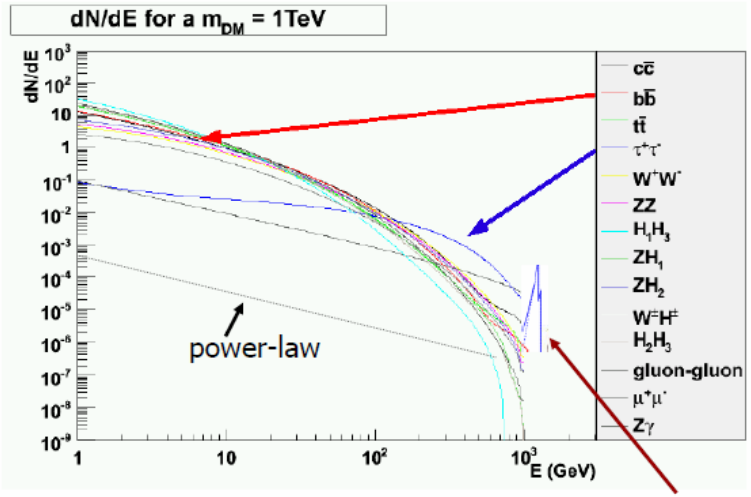
Point back to source

Search for excess components in cosmic rays (DIFFUSION)

Continuum γ-ray spectra
From π^0s decays.
Spectra extends up to m_c

$\chi\chi \rightarrow \gamma\gamma$
$\chi\chi \rightarrow \gamma Z$

Mono-energetic γ-lines
Loop suppressed annihilations.



b-bbar & $\tau^+\tau^-$: major components with differents spectrum shapes

2nd order process: lines !
$XX \rightarrow \gamma\gamma$, $Z\gamma$

LSP (**neutralino**, axino, …),
LKP, Axions, axion clusters, Solitons
Supermassive wimpzillas.

N-body simulations of structure formation strongly favor CDM Paradigm of **WIMP**

$$\Phi_\gamma(E) \cong \frac{dN_\gamma}{dE\, dS\, dt\, d\Omega} = \boxed{\frac{1}{4\pi}\frac{<\sigma v>}{m_\chi^2}}\ \boxed{\frac{dN_\gamma}{dE}(E)}\ \boxed{< J >}$$

New Physics

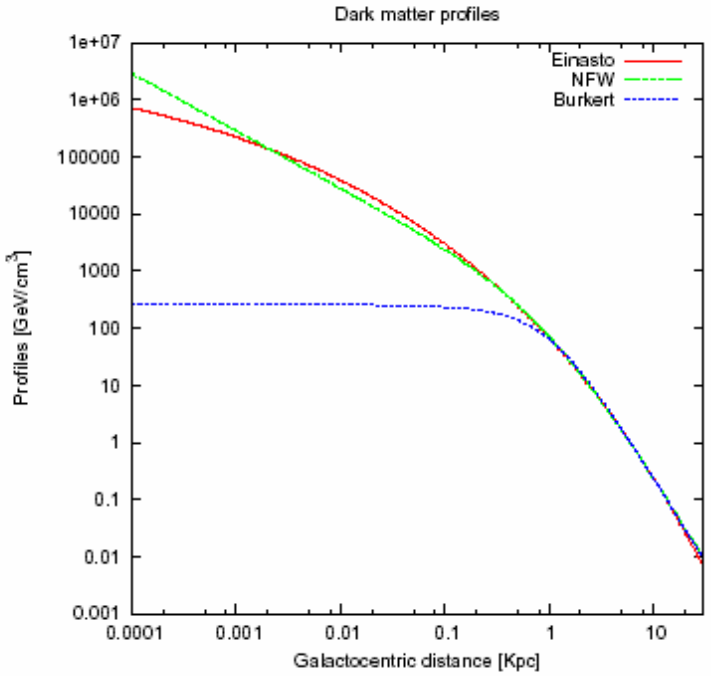
WIMP nature ?

Particle Physics

BR uncertainties

Astrophysics

- DM distribution uncertainties
- High density regions
- Integration angle



$$< J > = \int \frac{1}{2\delta_{stst}} \rho^2(\vec{r})\, ds\, d\Omega$$

$$\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1+(r_\odot/a)^\alpha}{1+(r/a)^\alpha}\right]^{\frac{\beta-\gamma}{\alpha}}$$

$$N_\gamma = T_{\rm obs} \int_0^{m_{DM}} A_{\rm eff}(E_\gamma) \frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} dE_\gamma$$

$$\langle \sigma v \rangle_{min}^{95\%\, C.L.} = \frac{4\pi}{T_{\rm obs}} \frac{m_{DM}^2}{\bar{J}(\Delta\Omega)\Delta\Omega} \frac{N_\gamma^{95\%\, C.L.}}{\int_0^{m_{DM}} A_{\rm eff}(E_\gamma) \frac{dN_\gamma}{dE_\gamma} dE_\gamma}$$

Indirect search for DM: where to look for…

Galaxy clusters:

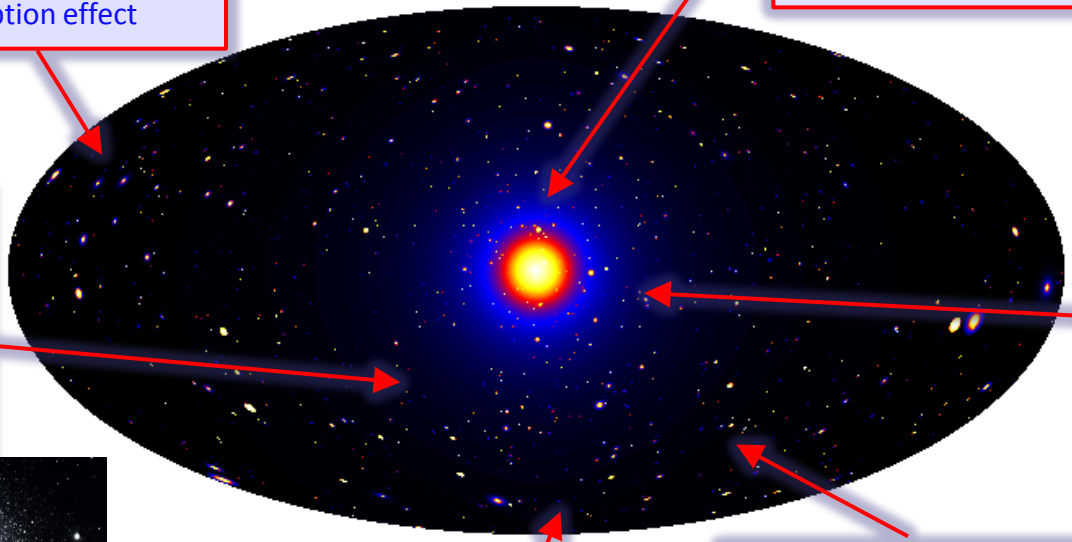
+ low background, astronomical data

- distance, low statistics, EBL absorption effect

Galactic center:

+ close and good statistics

- astrophysics source confusion and diffuse γ-background



Dwarf Spheroidal Galaxies:

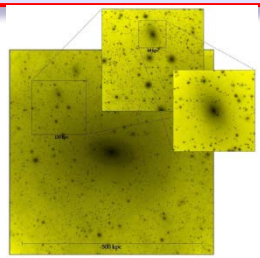
+ off galactic plane (low background), astro. data

- low statistics, tidal disruption

Galactic halo, sub-halos, clumps:

+ (may be) close and good statistics

- number and position unknown, diffuse γ-bg., large uncertainties



Extragalactic:

+ large statistics

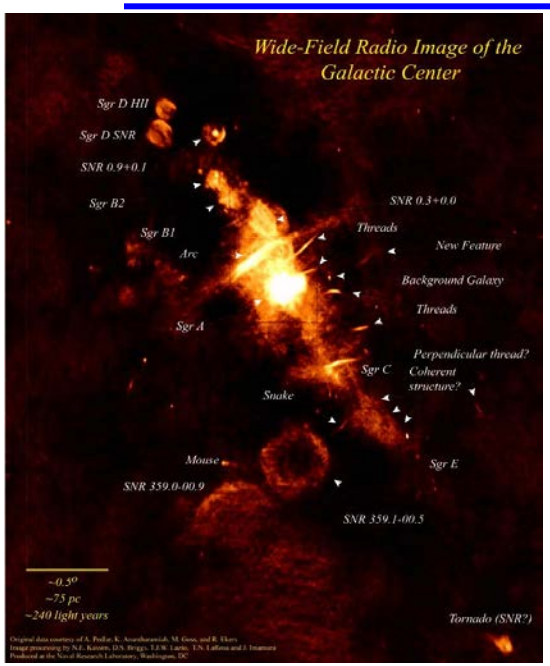
- Astrophysics and diffuse background

IMBH:

+ Survey-mode obs. time

- Astrophysics, distribution and location uncertainties

The Galactic Center region



+ Proximity (~8 kpc) and possibly high DM concentration

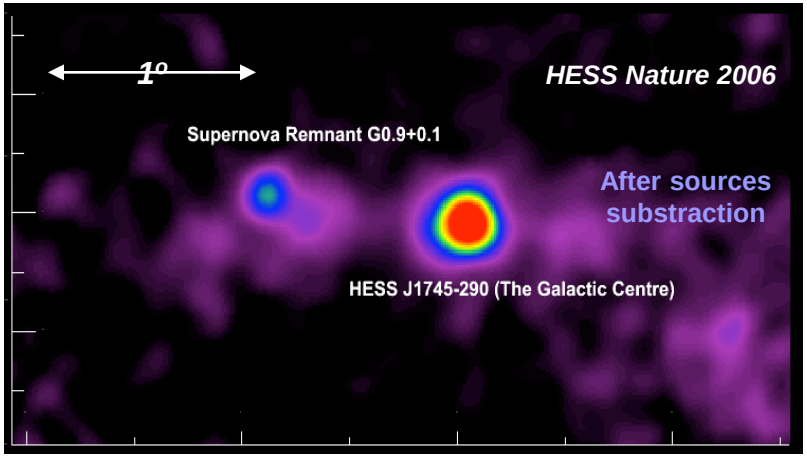
- Extreme environment:

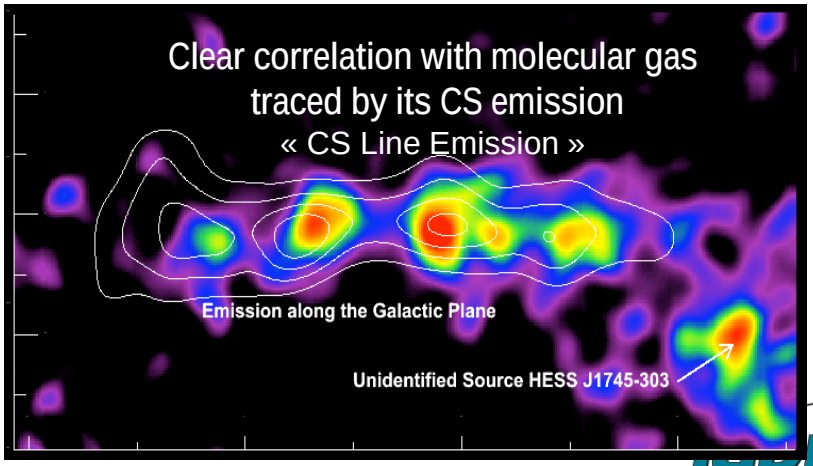
Totally obscured in the Optical; Visible from Radio to IR and high energies

Galactic Center:

10 % of galactic interstellar medium
[giant molecular clouds]
Host the nearest [hypothetical] super-massive BH
Variety of VHE emitters: SNRs, Molecular Clouds, non-thermal arcs...

Galactic Center Ridge seen by HESS





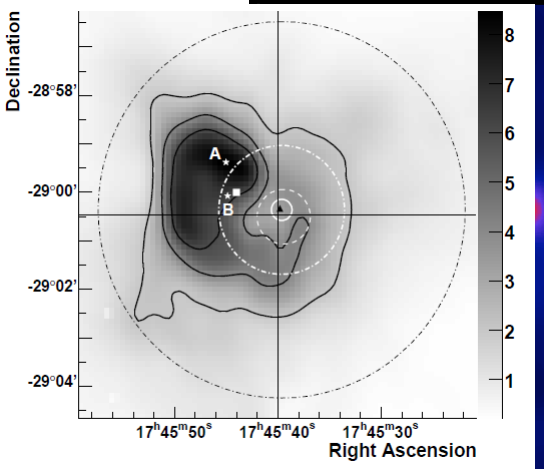
The Galactic Center gamma-ray spectrum

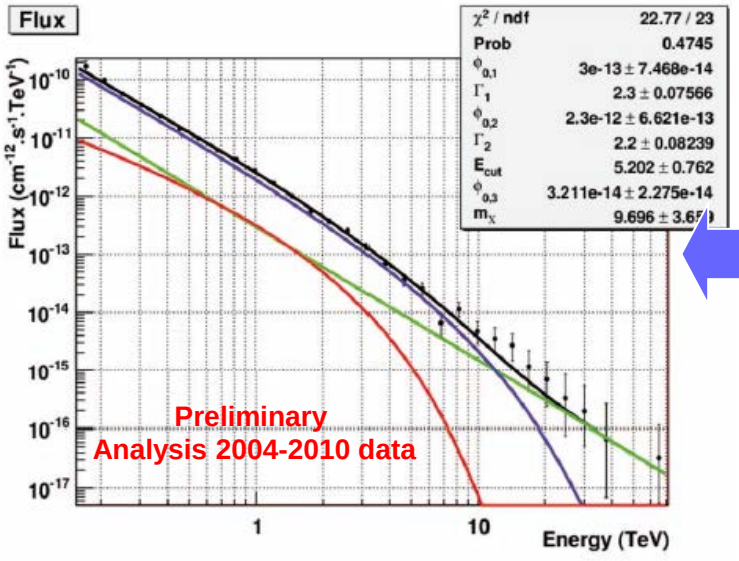
- Point like source HESS J1745-290 with little extension (similar to NFW halo profile).

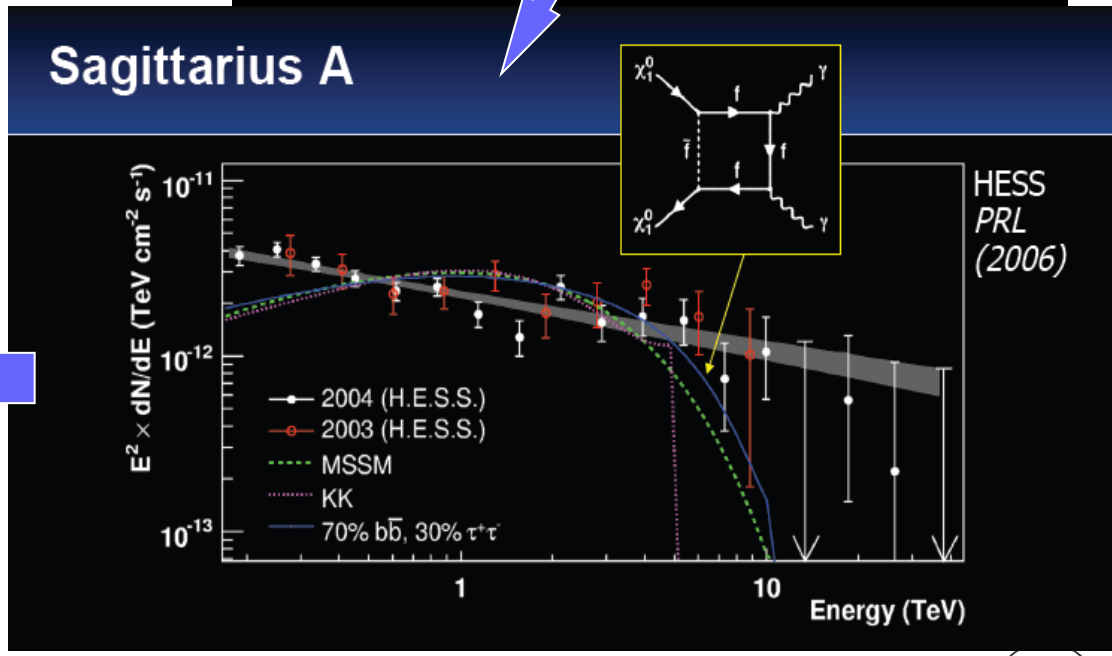
- A massive WIMP hypothesis (non-natural !?)

- A power law spectrum (Γ=2.3) et *cut-off* @ 7-9 TeV : astrophysics accelerator

- Under the hypothesis of DM spectrum + power-law spectrum : upper limit



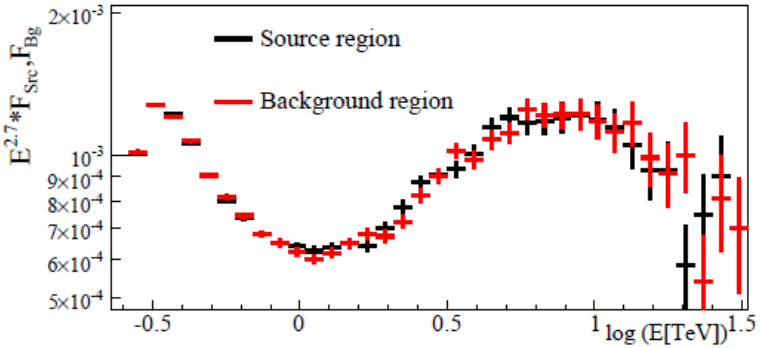


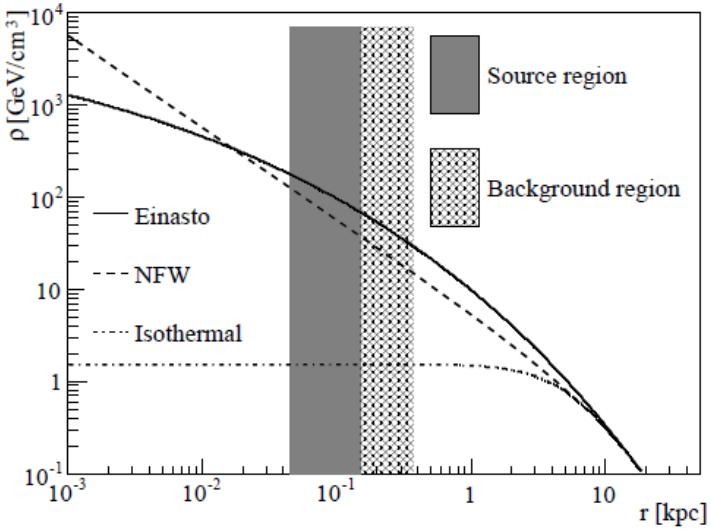


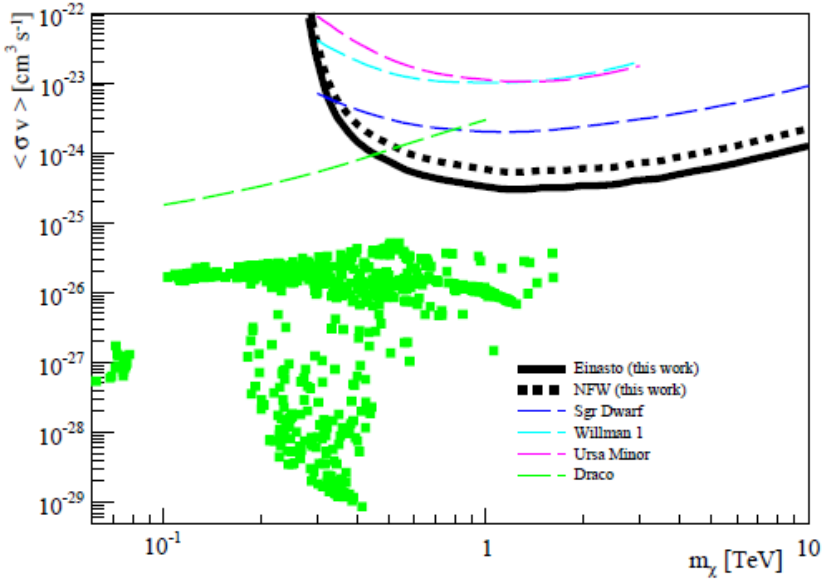
The Galactic Center Halo

- IDM search towards a region of projected distance 45-150 pc (0.3 -1.0 deg radial dist.) from the GC (limited differences between NFW and Einasto), excluding the galactic ridge.

- Isotropic TeV emission from uniform residual cosmic-rays flux background .



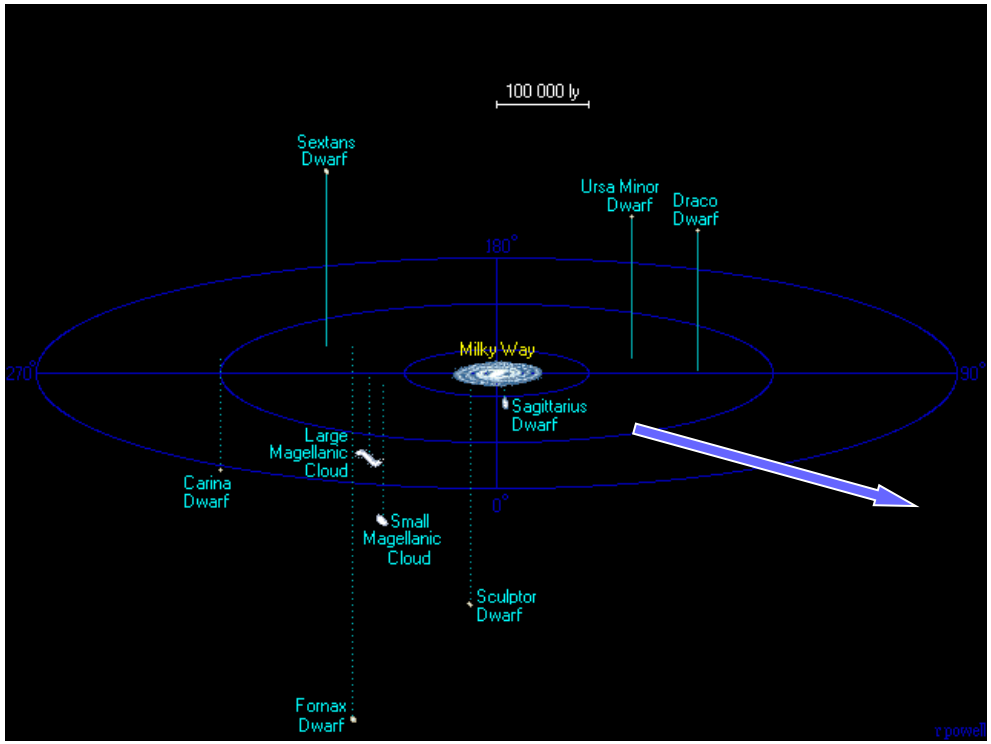




- No DM signature from galactic center halo.

- Stringent upper limits on the velocity-weighted annihilation cross-section : **$\langle\sigma v\rangle \sim 10^{-25}$ -10^{-24} cm^3 s^{-1}**

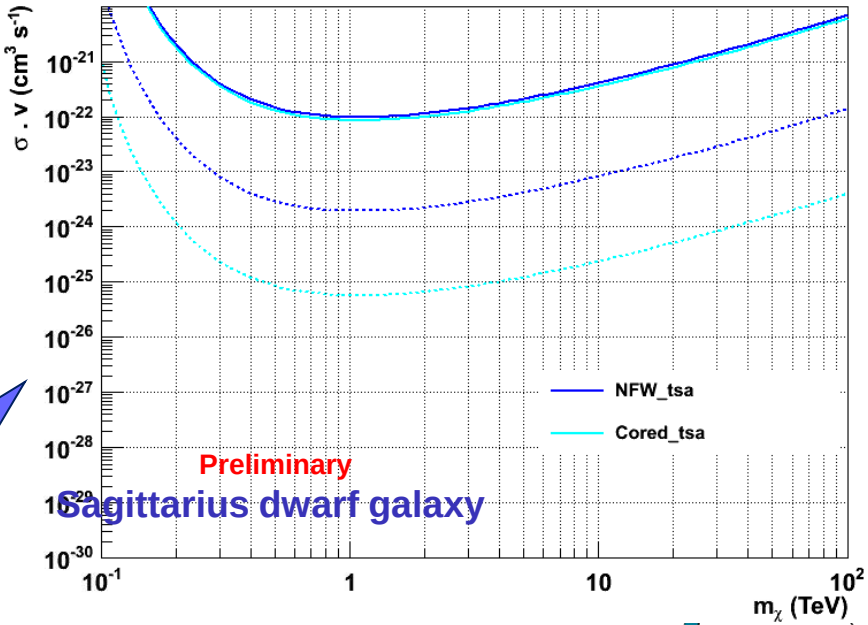
DM search in our neighborhood: Sagittarius Dwarf



- Dwarf spheroidal galaxies: High value of the M/L ratio implying large density of DM

- Low presence of gas disfavors a gamma-ray signal of classical origin

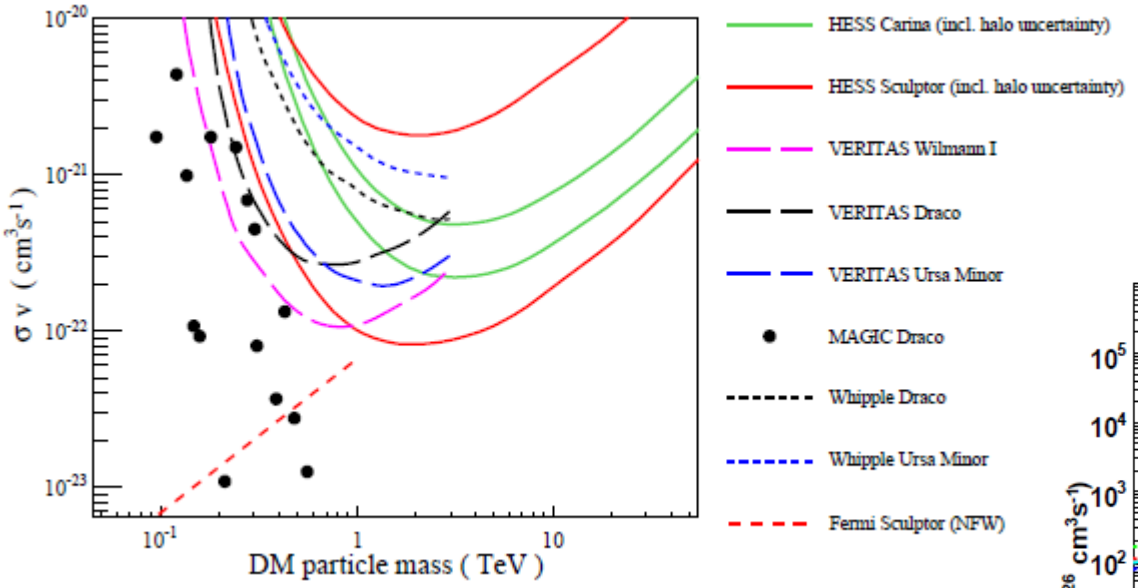
- ~ 10^{-12} cm^{-2} s^{-1} flux upper limits
- Constraints in the plot {<σv>, mχ} depending on the DM density profile



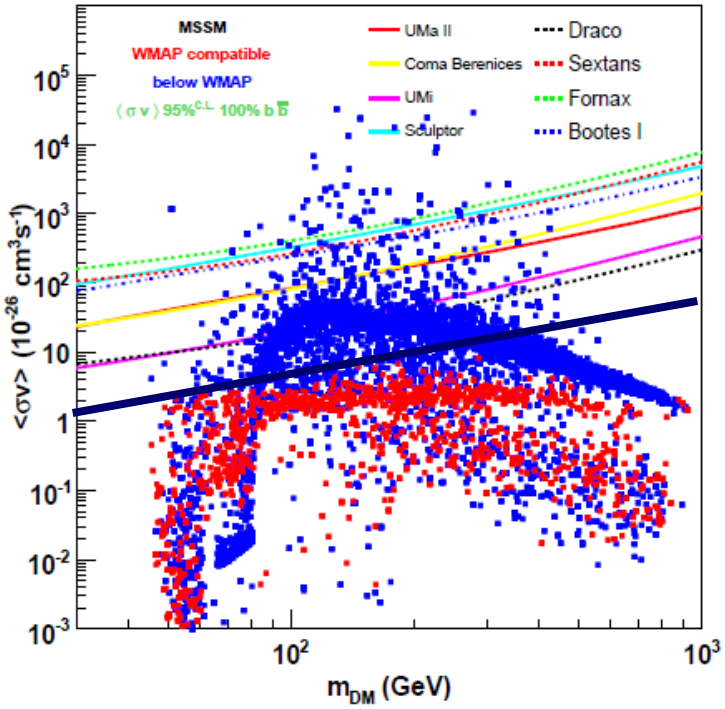
Final halo models <J> ~ 10^{23} GeV^2 cm^{-5} (taking into account tidal disruption)

DM search in our neighborhood: dwarf galaxies

Limits for a list of targets
from different observatories
(**HESS, MAGIC, VERITAS, Whipple, Fermi**)



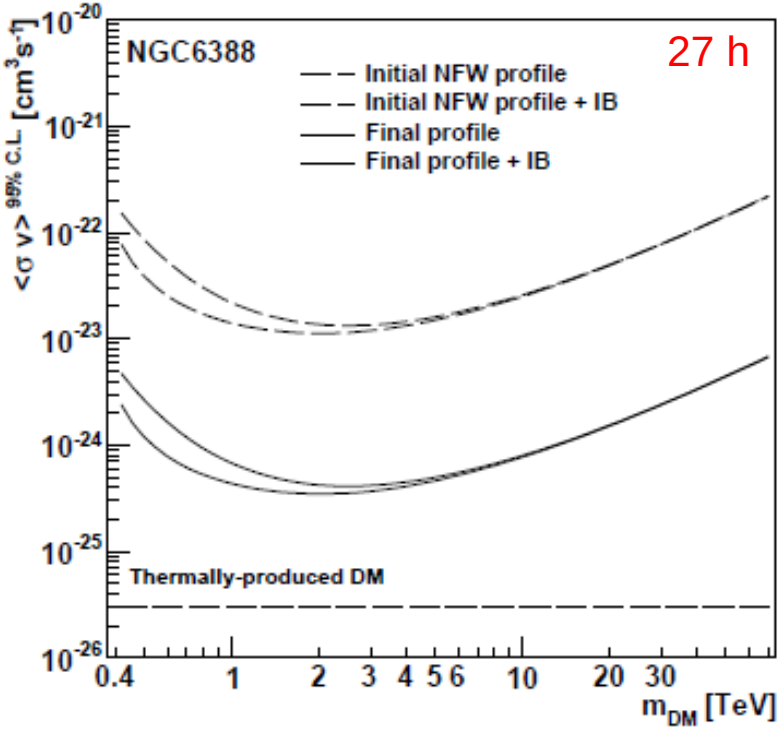
95 % limits obtained from **Fermi** observations on a list of selected dwarfs and preliminary **stacked analysis** (best limit !).

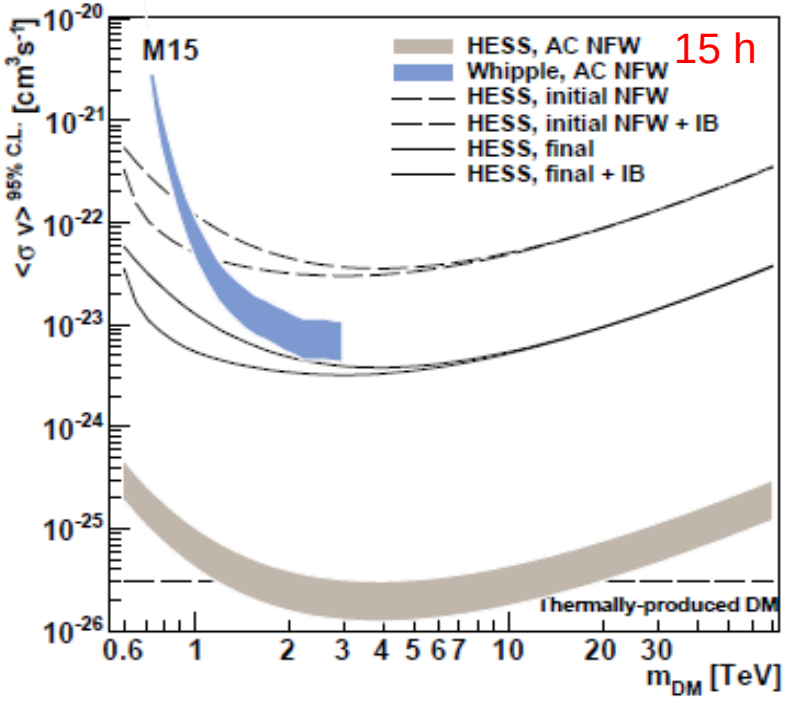


<J> of dSph derived from velocity dispersion measurements of their stellar population and luminosity profile.
In case of lack of available observational data -> NFW (and tidal radius when applicable)

DM search in globular clusters

- Hypothesis: Globular clusters formed in a dark matter minihalos in the primordial formation.
- DM content modeled considering: adiabatic contraction of DM by baryons; adiabatic growth of black hole in the halo; DM kinetic heating by stars.
- M15 is metal poor -> cosmological origin;
- NGC 6388 not metal poor but hosts > 10^3 solar masse black hole -> primordial origin.
- DM pulled in the center by baryons during evolution.

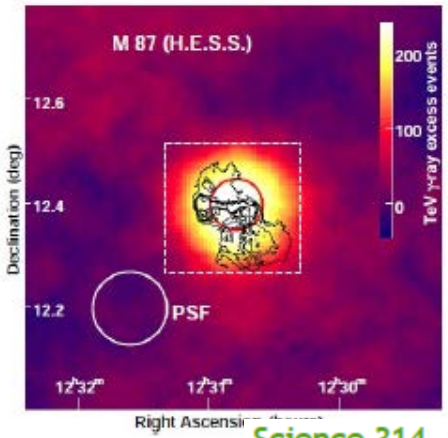




DM search in cluster of galaxies

The radio galaxy M87: central galaxy of Virgo cluster hosting a central black hole of 3-10^9 M_{Sol}

- Point like source (89h)
- Variability of γ-ray flux: from year to year, on a time scale of ~ 2 days
- The core of the Virgo cluster as emitting zone is excluded
- Compact emission: Dark Matter γ-ray production is excluded

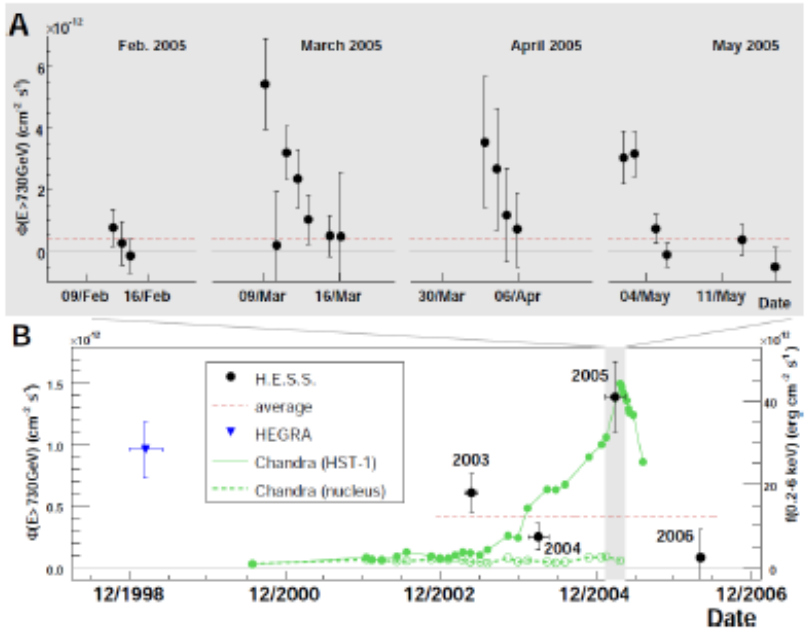


Science 314, 1424, 2006

Observation of 3 more galaxy clusters:

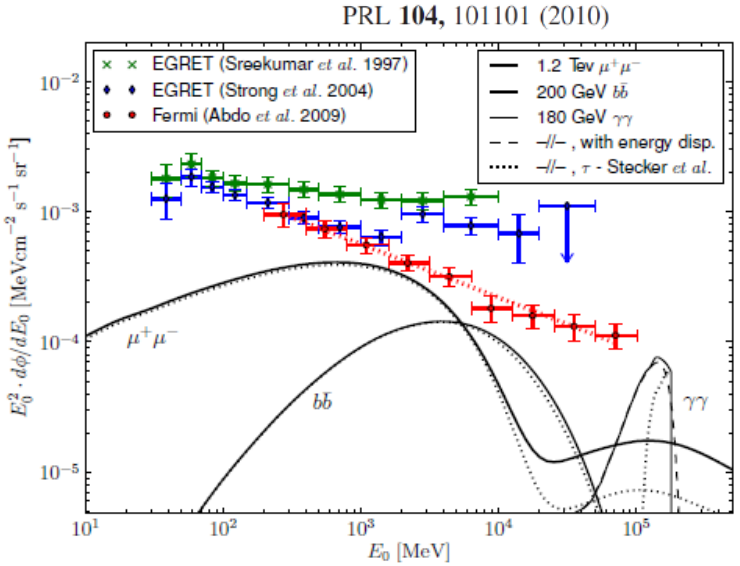
- **Coma (ACO 1656)** (8.2h),
- **Abell 496** (14.6 h)
- **Abell 85** (32.5h)

→ No signal
→ Constraints on non-DM models derived.



	VERITAS	MAGIC	Whipple	Fermi
Cluster of Galaxies	Coma (19 h)	Perseus (24 h)	Perseus (14 h) Abel 2029 (7h)	AWM 7 Fornax M49 NGC 4636 Centaurus Coma

Extragalactic diffuse emission by FERMI (10 MeV -100 GeV)

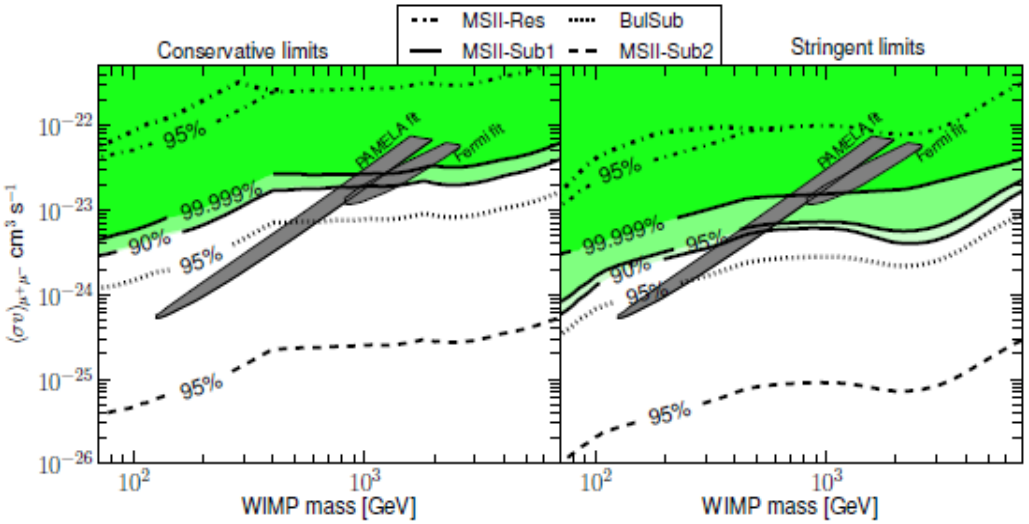


Power-law Γ = 2.41 far from gammas-DM continuum and lines emission

Leptophilic scenario

- Exclusion regions for different structure scenarios (N-body simulations + analytical approximation when going from cosmological to smaller scales)

-Best fit regions (grey contours) to Fermi-LAT and Pamela electron and positron spectra



CR- electrons and positrons (HESS, Fermi and PAMELA)

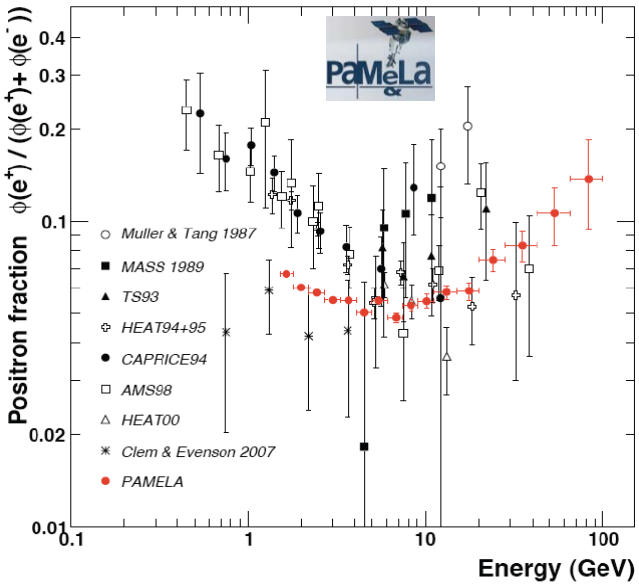
(NB: electrons = electrons + positrons)

- Spectrum of electrons: (power law) $\propto E^{-\Gamma}$

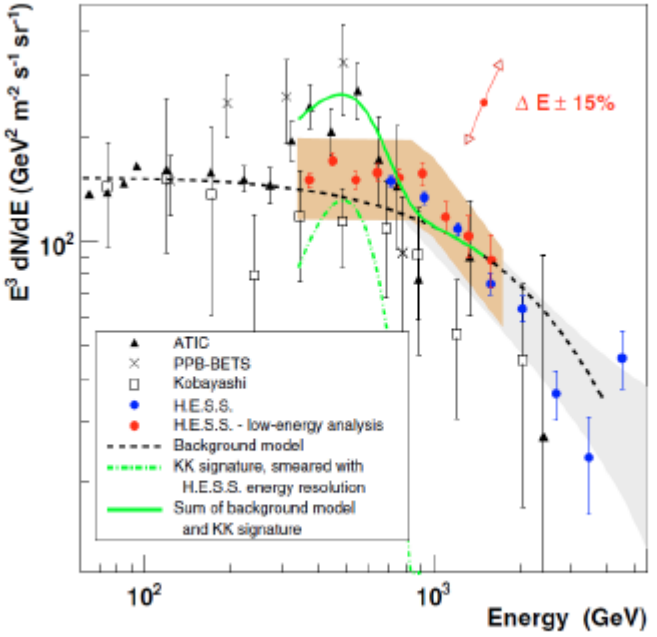
  E< 900 GeV: $\Gamma = 3.0$

  E> 900 GeV: $\Gamma = 4.1$

A&A 508, 561, 2009



Spectrum of electrons by
H.E.S.S., Fermi-LAT, and ATIC



- **Possible interpretations: revised diffusion model and/or extra component (astrophysical or DM)**
- **DM contribution is not required, however cannot be ruled out**

Conclusions

Astroparticle Physics and high energy gamma-ray astronomy are quickly developing domains.
- learning about our Galaxy.
- valuable contributions to Fundamental issues in Cosmology: Dark and Relic components of the Universe.

Till now, no solid discovery with HESS but constraining theory:
Uncertainties on the DM distribution and DM models

HESS2 and CTA for future perspectives with γ–rays: higher sensitivities and larger exposures.
Although solving Dark Matter enigma needs:
- astrophysical detection,
- direct and indirect searches;
- study of its properties in laboratory (LHC)
- making connection among these complementary approaches.

DM density profiles

The « core » profile:

$$\rho_{\mathrm{CORE}}(r) = \frac{\rho_s}{1 + \left(\frac{r}{r_s}\right)^2}$$

ApJ 361, 408, 1990

$$\rho_{\mathrm{CORE}}(r) = \frac{v_a^2}{4\pi G} \frac{3r_s^2 + r^2}{(r_s^2 + r^2)^2}$$

(for Sagittarius)

PRD 69, 123501, 2004

The NFW profile:

$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_s}{\left(\frac{r}{r_s}\right)\left(1 + \frac{r}{r_s}\right)^2}$$

ApJ 490, 493, 1997