Prospects for Dark Matter searches with the MAGIC telescope

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(**MAGIC** Collaboration)

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The MAGIC Collaboration

> 100 physicists
16 institutions
11 countries

Canary Island La Palma

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MPI Munich, Germany
IFAE Barcelona, Spain
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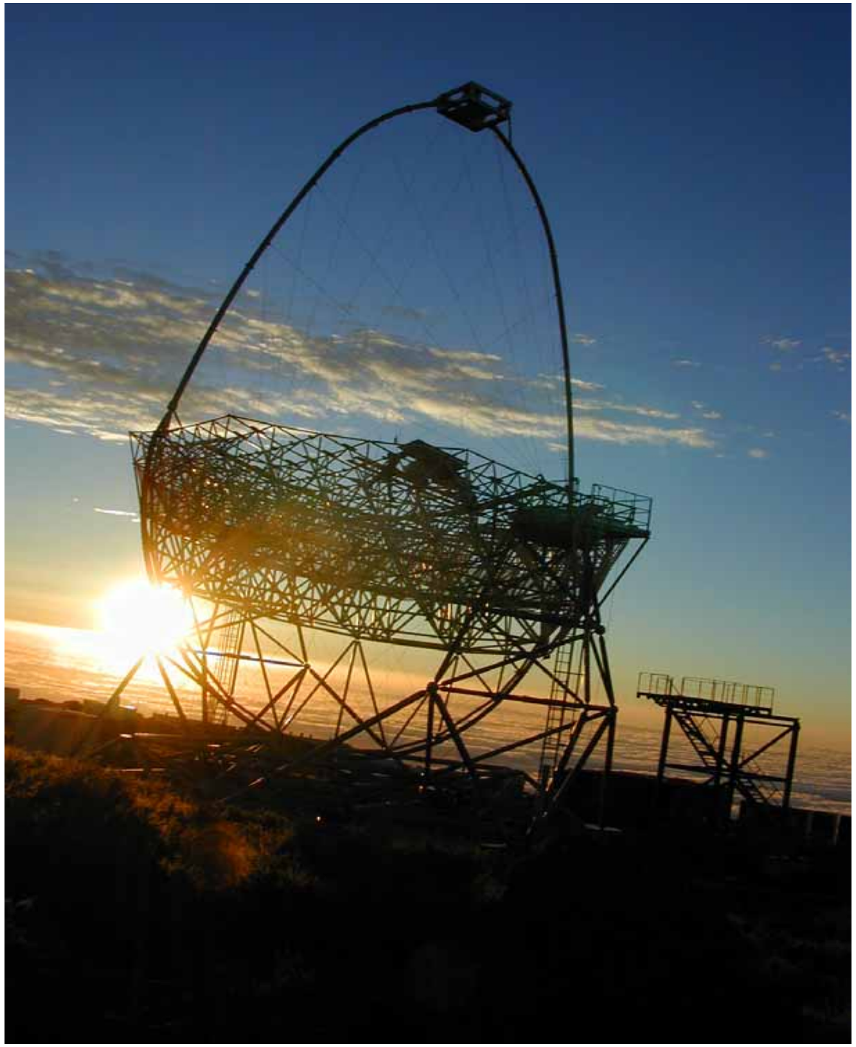
U. Würzburg, Germany
UCM Madrid, Spain
U. Von Humboldt, Berlín, Germany
ETH, Zrich, Switzerland
UAB Barcelona, Spain
Crimean Observatory, Ukraine
U.C. Davis, U.S.A.
U. Lodz, Poland
U. Siena, Italy
U.Udine/ INFN Trieste, Italy
U. Potshefstroom, South Africa
Tuorla Observatory, Finland
Yerevan Phys. Institute, Armenia

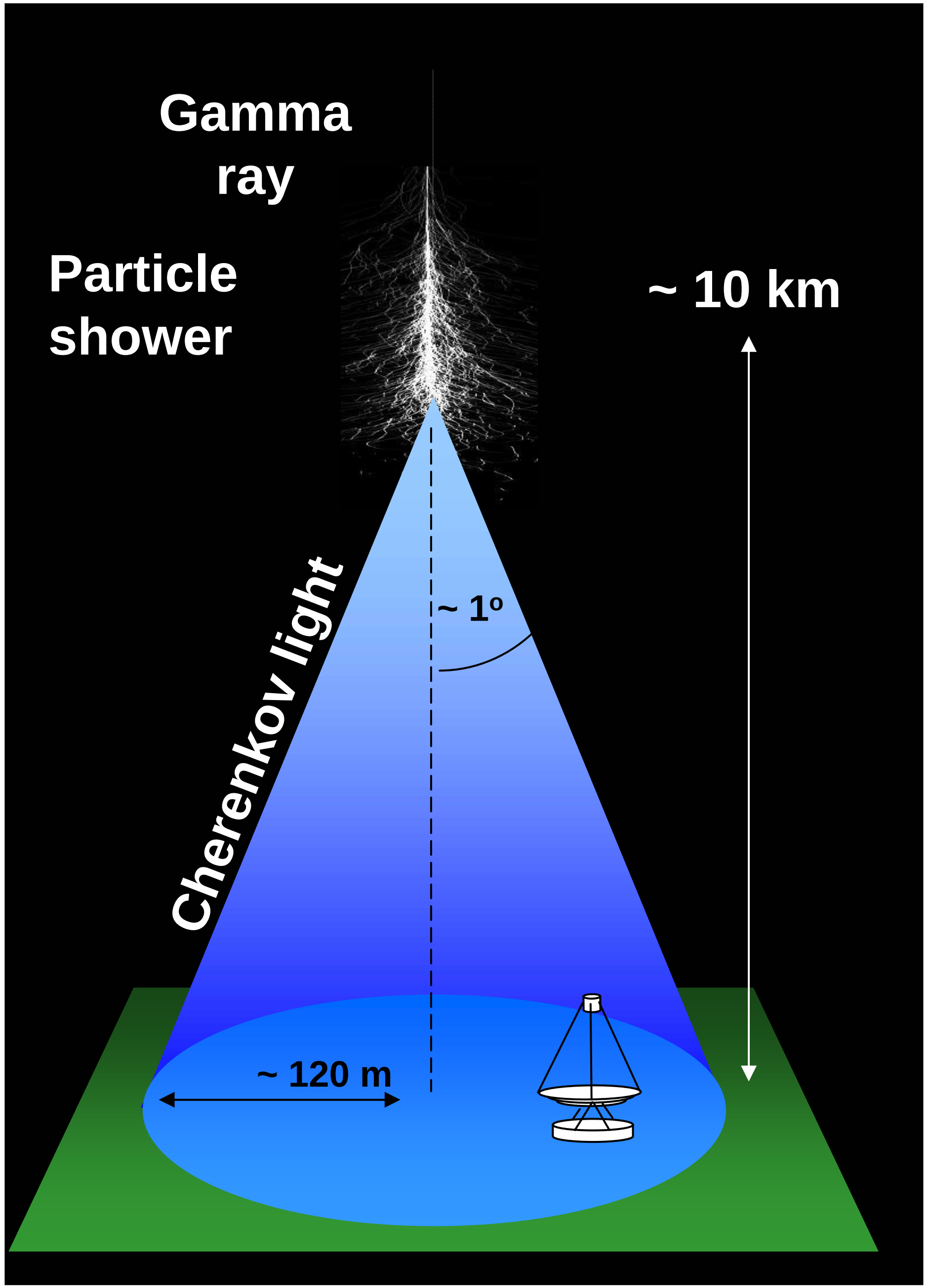
MAGIC

Major Atmospheric Gamma Imaging Cherenkov Telescope

- Design optimised for
  - low threshold : $E_\gamma < 30$ GeV
  - high sensitivity :
    $10^{-10}\ [\mathrm{cm}^2 \cdot \mathrm{s}]^{-1}$ at 30 GeV
  - fast repositioning : $t_R < 30$ s
- Many new technological elements
- Large Imaging Cherenkov Telescope (17 m diameter)



Imaging Air Cherenkov Telescopes (IACTs)



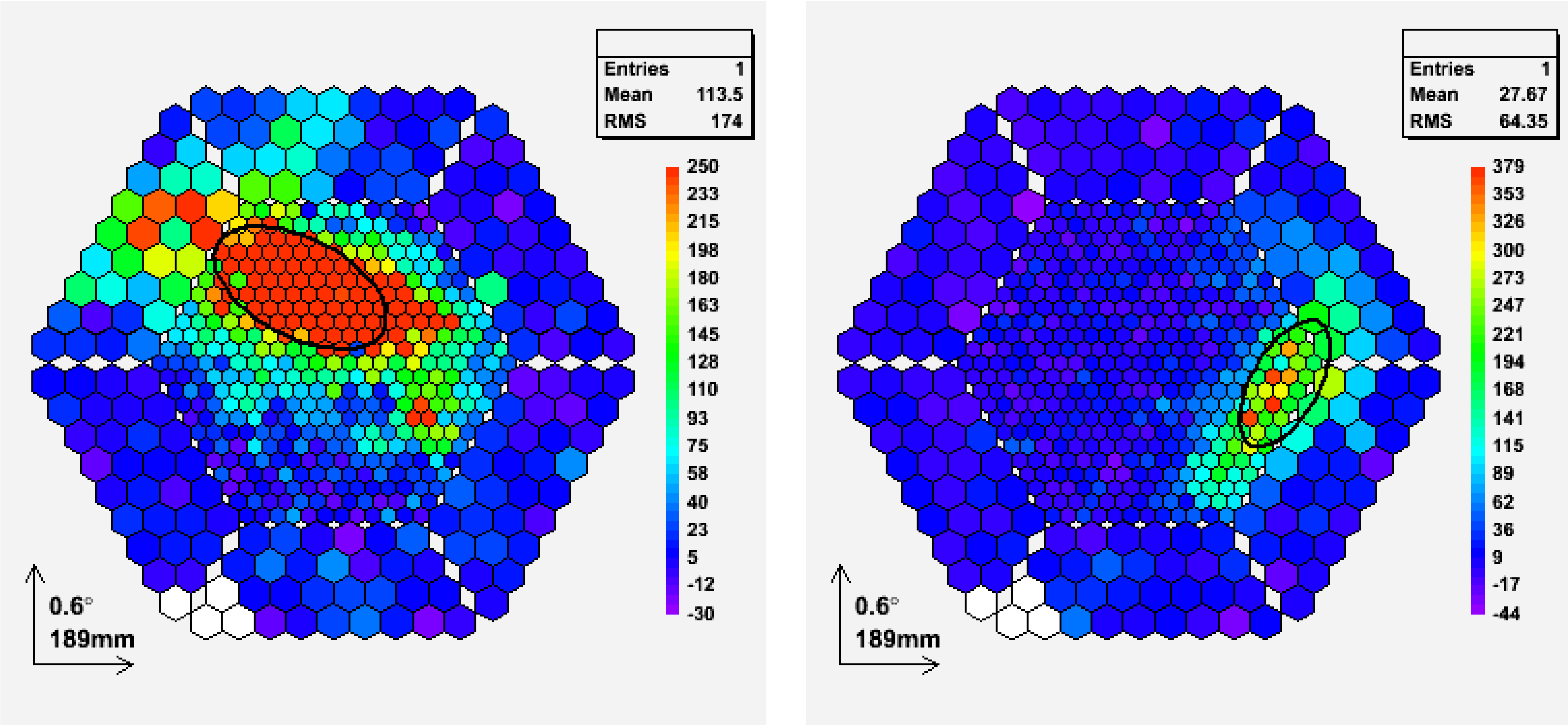
The principle

The primary Cosmic Ray particle induces an air shower in the atmosphere. The Cherenkov light produced in the shower is collected by the IACT. A picture of the shower is obtained in the camera, which measures the amount of Cherenkov light emitted from the different regions of the shower.

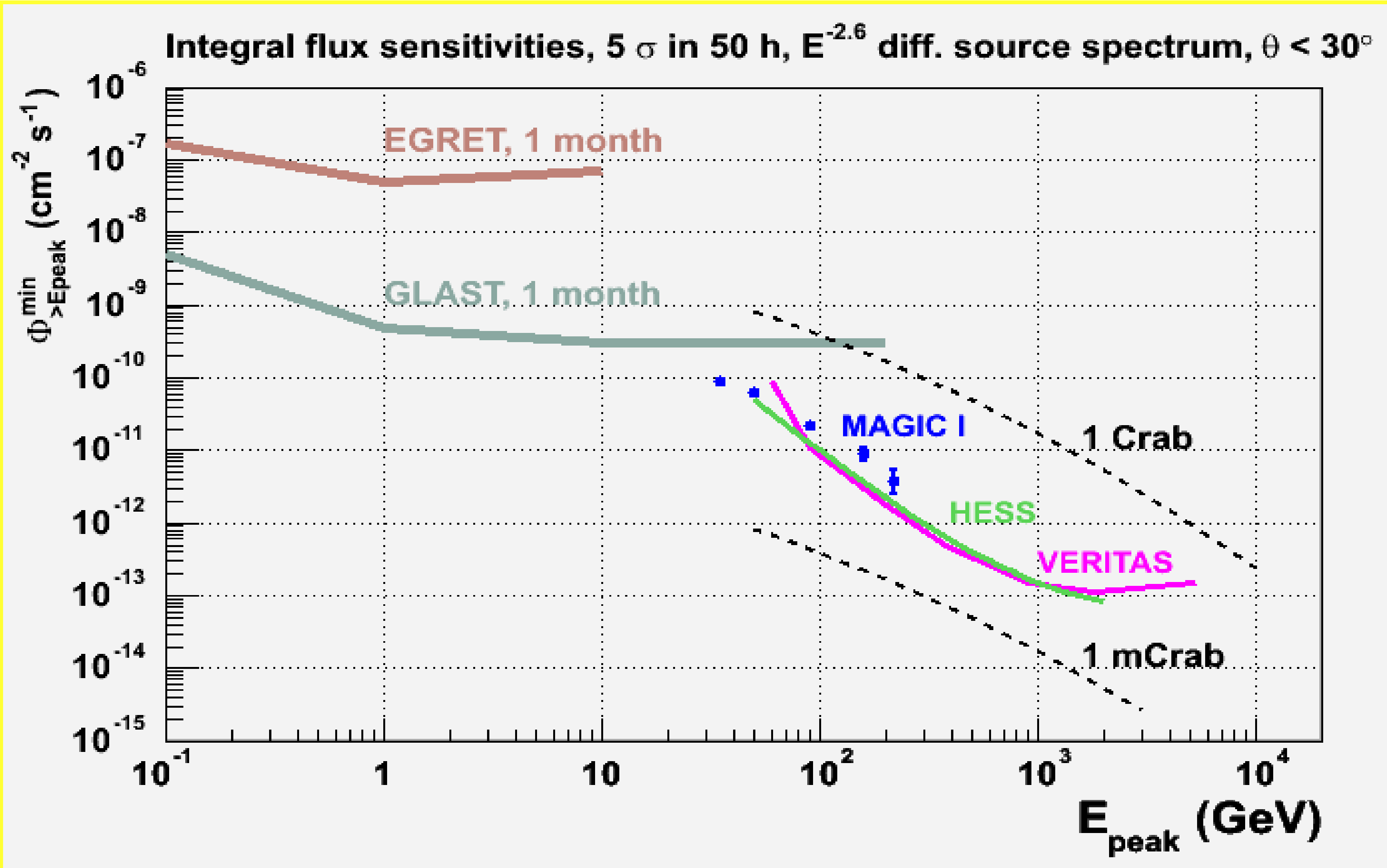
Size of **the Cherenkov light pool :** **$\sim 10^4$-10^5 m^2**

Camera : 3.5^0 FOV, 576 pixels (Ø = 0.1^0, 0.2^0)

Shower images in the MAGIC camera



Integral flux sensitivity for point sources



Dark Matter search

Supersymmetric extensions of the Standard Model of particle physics lead to various DM candidates. The most plausible candidate is the lightest SUSY particle, the neutralino χ :

χ : stable, neutral, Majorana fermion (30 GeV < M_χ < 1500 GeV)

Indirect search for Dark Matter :

look for gammas from $\chi\,\chi$-annihilations in DM halos

$$\chi\,\chi \rightarrow \;....\; \pi^0 \;.............\; \pi^\pm$$

$$□ \quad \gamma\,\gamma \qquad\qquad □ \quad e^\pm \rightarrow e^\pm\,\gamma_{synch}$$

Backgrounds to the DM γ-ray flux

- CR electrons
- CR hadrons

} (**main backgrounds** for IACTs)

- Galactic diffuse γ emission (main background for satellites)

  from the interaction of CR particles with the galactic matter and radiation fields

- Extragalactic photon background

  unresolved AGNs, cosmological neutralino background

Photon flux from $\chi\,\chi$-annihilation

$$\chi\,\chi \rightarrow \;\ldots\; \pi^0$$

$$\square \quad \gamma\,\gamma$$

$$\frac{d\,N_\gamma^{annihil}(\Omega,E,M_\chi)}{dt\;dA\;d\Omega\;dE} = \frac{dN_\gamma(E,M_\chi)}{dE}\,\frac{\langle\sigma\cdot v\rangle}{4\pi\,M_\chi^{\;2}} \quad \square \quad \int_{los} \rho^2(r(s,\Omega))\;ds$$

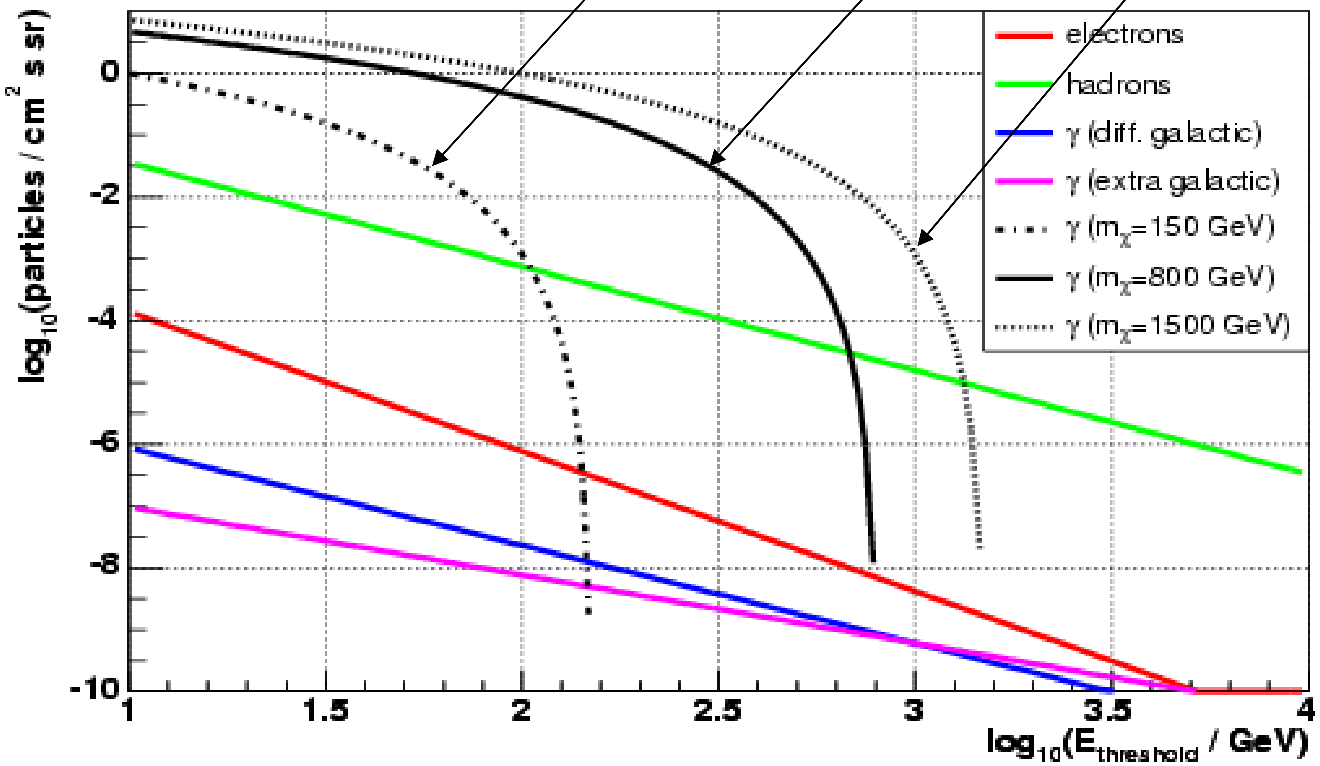
PARTICLE PHYSICS
dependence on energy and Mχ
SUSY predictions

ASRTROPHYSICS
radial (angular) dependence
predictions from simulations

parameters in the predictions chosen to satisfy the experimental constraints

Energy dependence of backgrounds (integrated over E > E_{th})

annihilation gamma flux (arb.units) for M_χ=150 GeV, 800 GeV, 1.5 TeV



experiments are sensitive to $M_\chi > E_{th}$

Density profiles of DM halos

$$\text{Moore}: \quad \rho(r) = \frac{\rho_0}{(r/r_s)^{1.5}[1+(r/r_s)^{1.5}]}$$

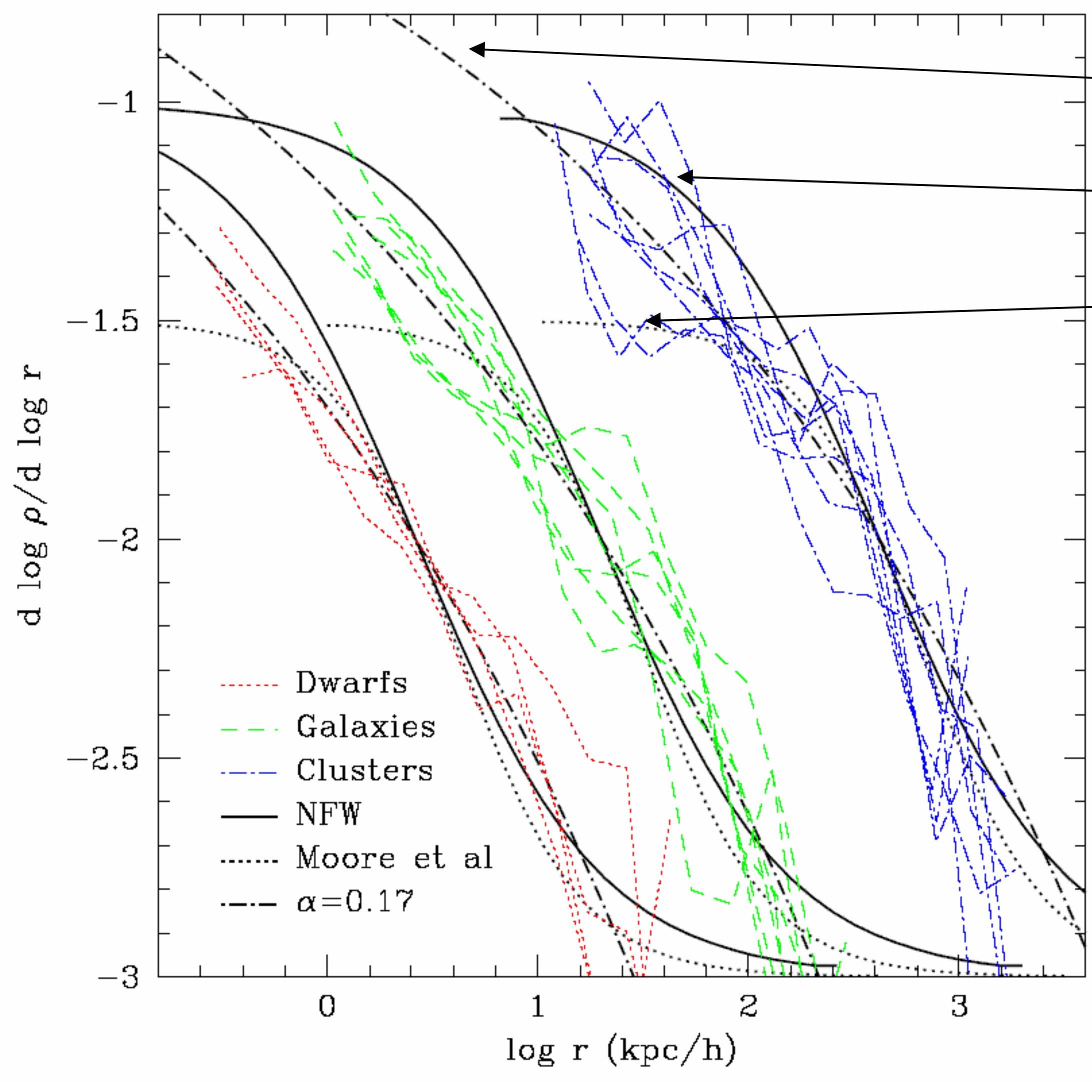
$$\text{NFW}: \quad \rho(r) = \frac{\rho_0}{(r/r_s)^{1.0}[1+(r/r_s)]^2}$$

$$\text{SWTS}: \log(v_c / v_{max}) = -a\,[\log(r / r_{max})]^2 \qquad v_c = \sqrt{\frac{G \cdot M(r)}{r}}$$

$$\alpha\ \text{profile}: \rho(r) = \rho_* \cdot \exp\left(\frac{-2}{\alpha}\left[\left(\frac{r}{r_*}\right)^{\alpha} - 1\right]\right)$$

predictions for $\int_{los} \rho^2 ds$ differ by 4 orders of magnitude !

Logarithmic slope $\beta = \frac{d(\log \rho(r))}{d(\log r)}$ of density profiles from simulations



α profile

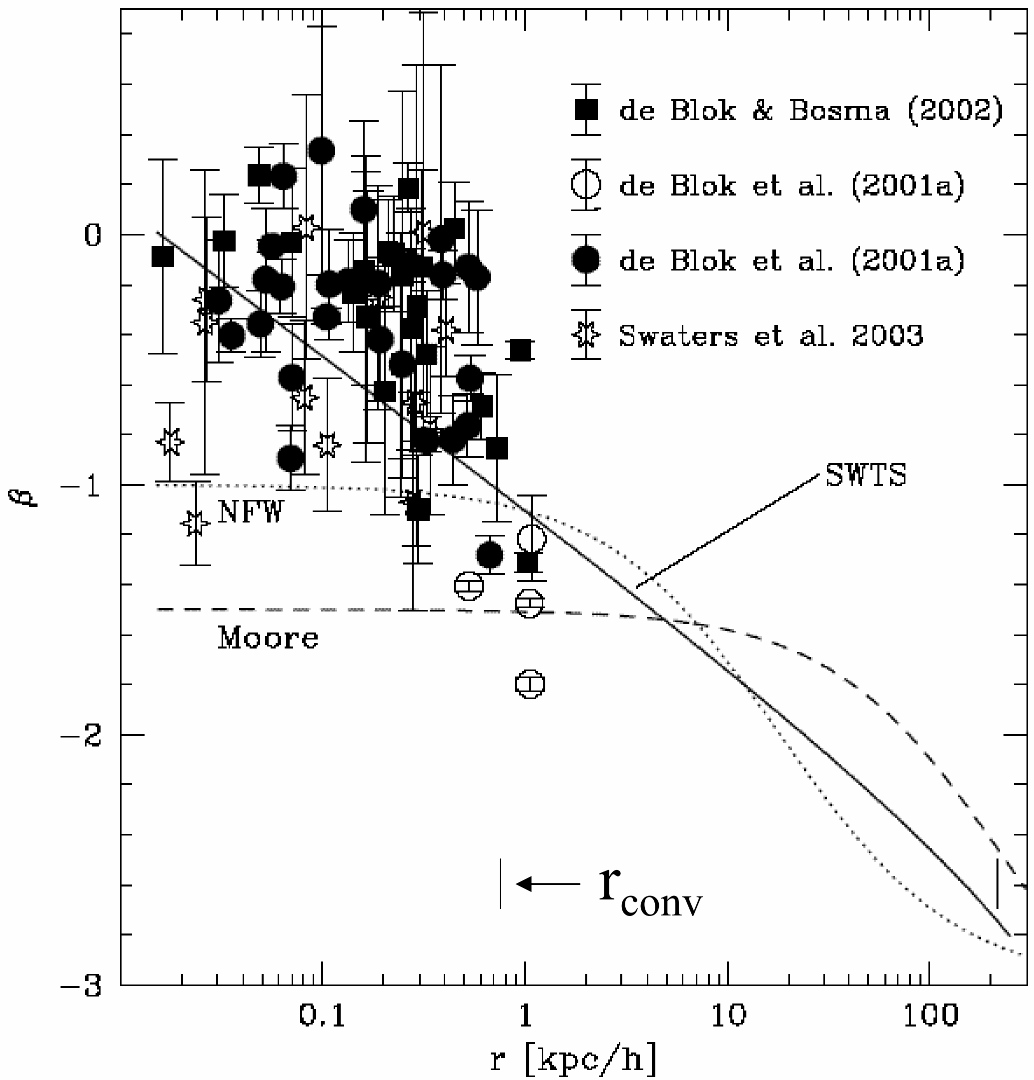
NFW (r^{-1})

Moore $(r^{-1.5})$

no evidence for an asymptotic slope !

J.F.Navarro et al.: astro-ph/0311231

Logarithmic slope $\beta = \frac{d(\log \rho(r))}{d(\log r)}$ of density profiles of LSB galaxies



experimental density profiles are shallower than NFW

SWTS, NFW, Moore } from fits to circular velocity profiles (from simulations)

W.J.G.Blok, astro-ph/0311117

F.Stoehr : astro-ph/0403077

Effects which may enhance the DM density

- in simulations baryons are usually not taken into account

- adiabatic compression of DM due to baryonic infall leads to a spiky DM density profile (A.Klypin et al.: ApJ 573 (2002) 597); effect may be reduced
  - by transfer of angular momentum from baryons to the DM
  - by scattering of DM particles by stars

- effects due to the presence of a black hole

(O.Y.Gnedin et al.: astro-ph/0308385)

  - if BH grew adiabatically ⟶ $\rho \sim r^{-2.3 \text{ to } -2.4}$
  - if BH grew instantaneously ⟶ $\rho \sim r^{-4/3}$
  - if BH was formed by mergers of BHs ⟶ $\rho \sim r^{-1/2}$
  - if BH grew away from the DM center ⟶ $\rho \sim r^{-1/2}$

Is the DM density profile near the GC cuspy ($\rho \sim r^{-\alpha}$, $\alpha \sim$ 1-1.5) ?

astrophysical evidences against :

- fast rotating Galactic bar
- microlensing data
- radio emission from GC
- EGRET data at high Galactic latitudes

V.P.Debattista et al.: ApJ 493 (1998) L5, astro-ph/9710039

A Galactic bar rotating rapidly within a massive halo loses angular momentum to the halo, and thus is slowed down, through dynamical friction.

There is evidence that the Galactic bar has a high pattern speed, implying that the DM density is negligible in the bar region.

J.J.Binney et al.: astro-ph/0108505

Contributions to the circular speed curve in the inner galaxy ($r < 8$ kpc)

- for a cuspy halo, normalized to the local DM density, the contribution from DM is calculated
- a lower limit on the contribution from baryons is estimated from microlensing data

The sum of the two contributions exceeds the observed Galactic rotation curve even for the least concentrated density profile (NFW)

R.Aloisio et al.: astro-ph/0402588

At the GC, the accretion flow onto the central BH sustains strong magnetic fields that can induce synchrotron (radio) emission by $e^{\pm}$, generated in $\chi\chi$-annihilations during advection on the BH.

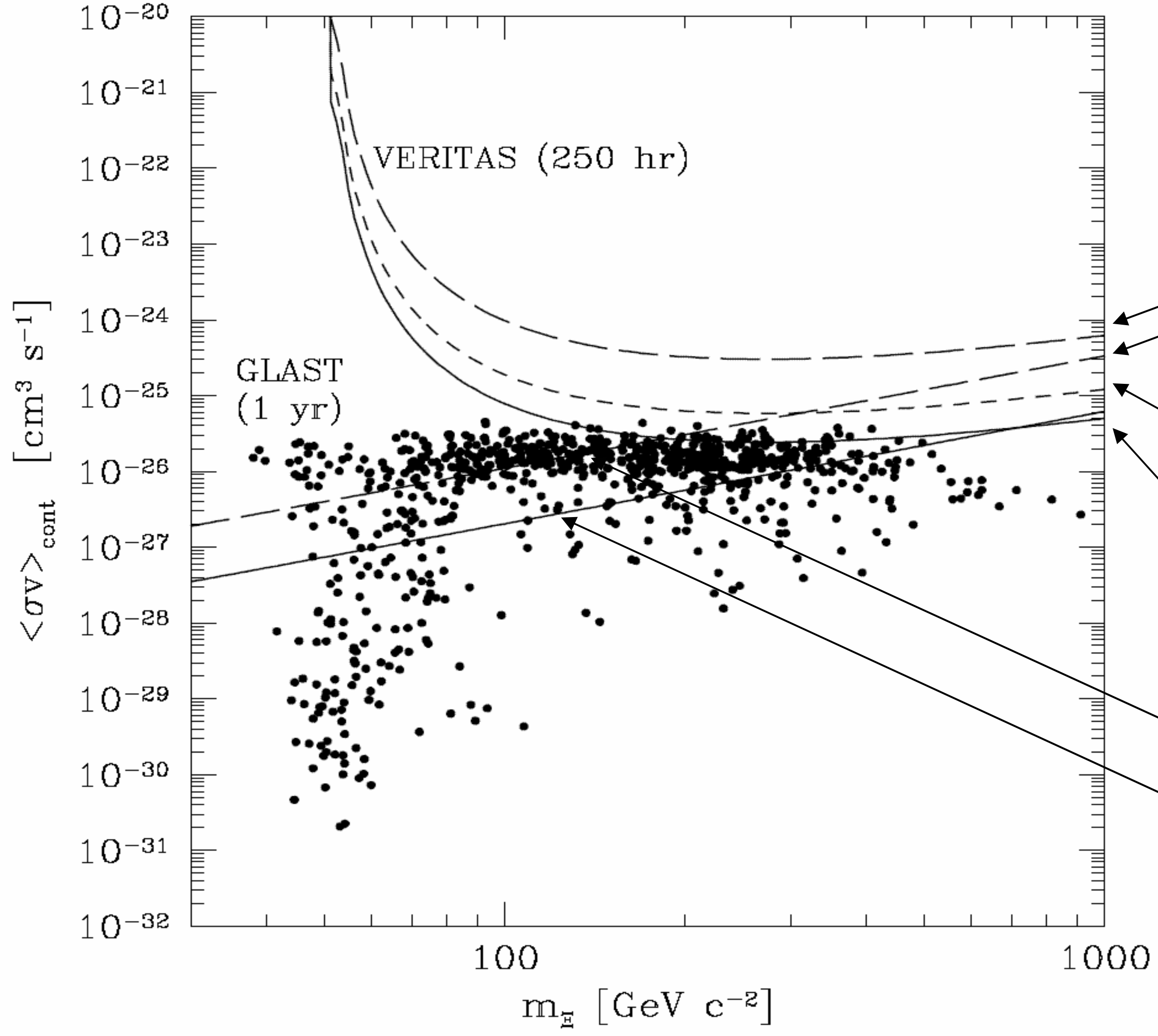
- for an NFW profile the predicted flux is below the observed emission
- an NFW profile with a DM spike due to adiabatic compression would generate a signal well above the observed data

S.Peirani et al.: astro-ph/0401378

- if DM halo of Milky Way has a density profile with a central core :
  expected γ – ray intensity above 1 GeV at $b = 90^0$ is
  comparable to the EGRET bound (if $M_\chi < 50$ GeV)
- if profile has a central cusp :
  expected γ – ray intensity is at least one order of magnitude
  below the EGRET bound

Galactic Center

Limits for a 3σ detection, with E_{th} = 50 GeV, $A_{eff} = 10^4$ m^2, $\sigma = 0.1^0$



SWTS (r = 1.75^0), brightest substructure

SWTS (r = 1.75^0), GC

NFW (r = 0.1^0), GC

outside gallactic plane :

r = 5^0

annulus : 25^0 < r <35^0

F.Stoehr et al.: astro-ph/0307026

Galactic Center

Limits for a 3σ detection, with
$T_{obs} = 250$ h, $\sigma = 0.1^0$,
$E_{th} = 50$ GeV, $A_{eff} = 10^4$ m^2

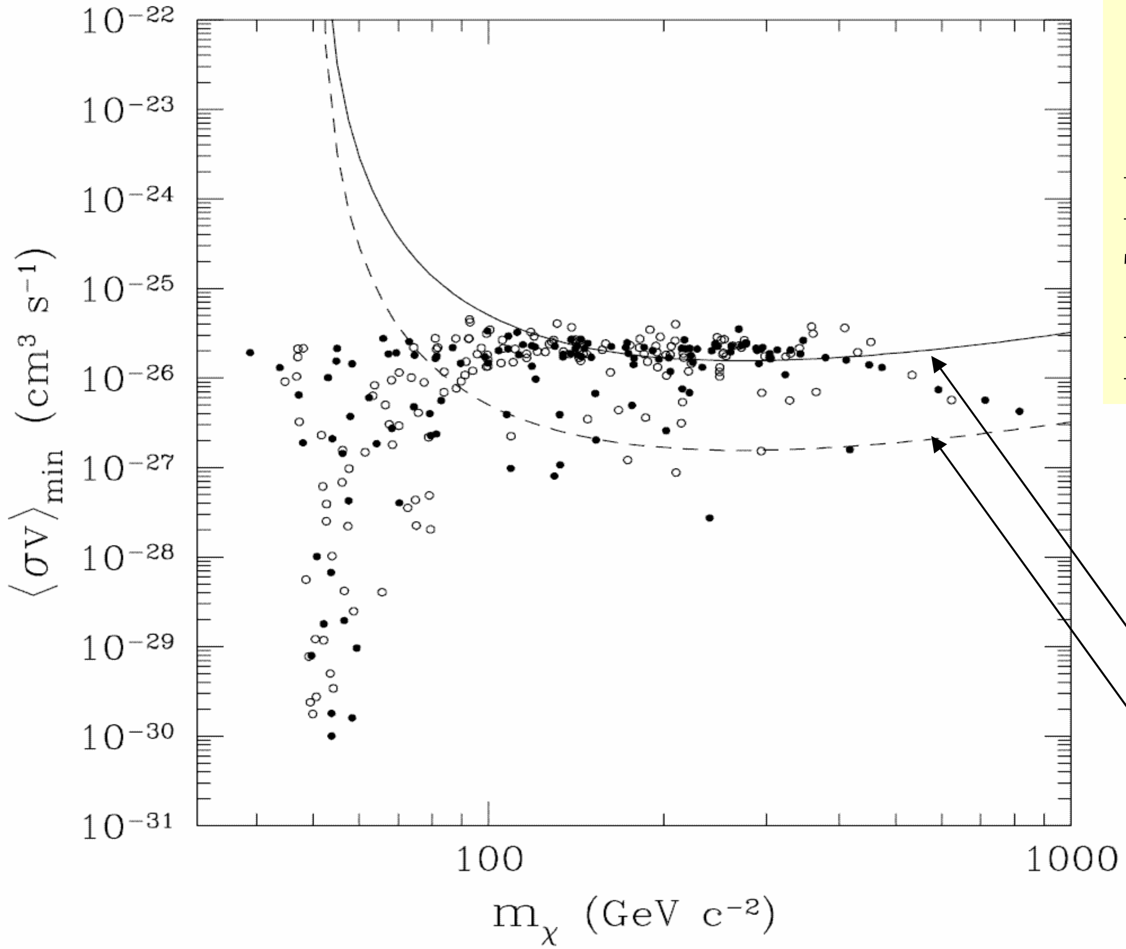
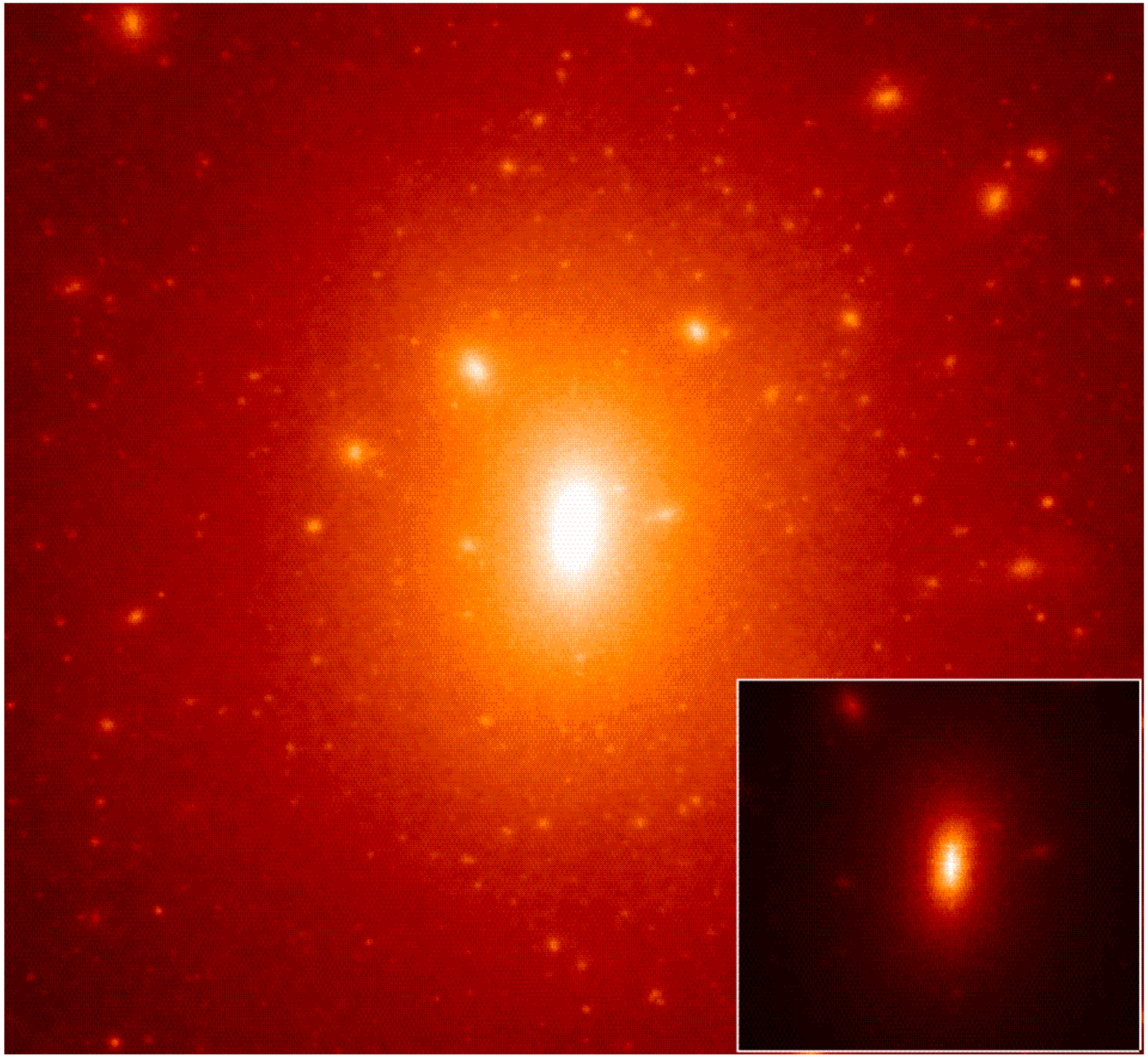


FIG. 1: Minimum detectable annihilation cross section times velocity as a function of WIMP mass. The filled circles correspond to SUSY model WIMPs with $\Omega_\chi h^2 = 0.11 \pm 0.01$ [31] and the open circles correspond to SUSY models with $\Omega_\chi h^2$ between 1σ and 2σ away from the central value.

Moore ($\rho \sim r^{-1.5}$)
without baryonic compression
with baryonic compression

no hadronic, only electron background considered

F.Gnedin et al.:
astro-ph/0308385



Annihilation radiation from simulation

log scale

linear scale (central region)

F.Stoehr et al. : astro-ph/0307026

270 kpc = r_{200}

Substructures (subhalos)

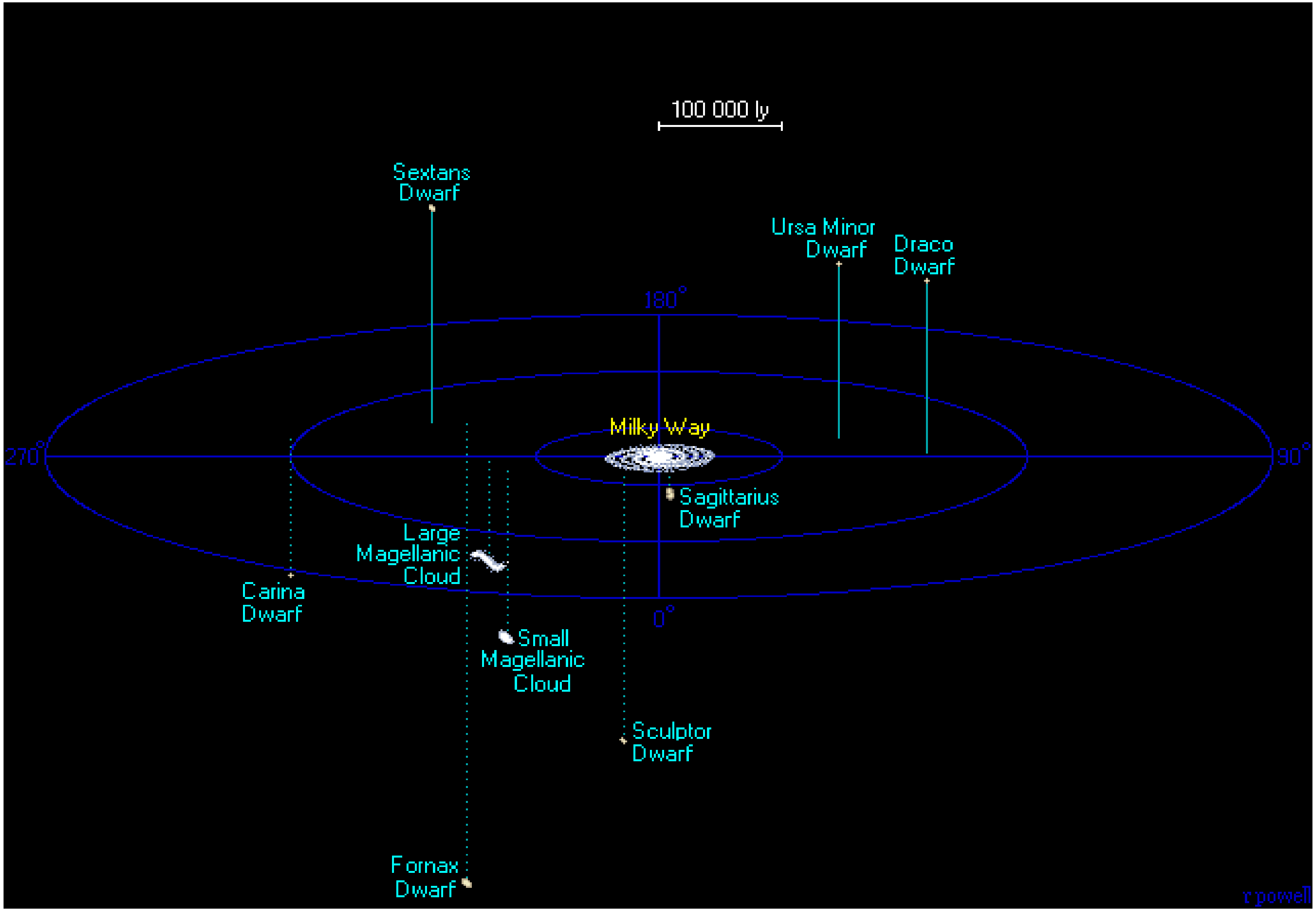
From simulations (F.Stoehr et al.: MNRAS 345 (2003) 1313) :

- 5-10% of halo mass is contained in subhalos
- the annihilation luminosity per unit mass (J/M) is by a factor 4 higher for subhalos than for the main halo
- there is a close correspondence between the most massive subhalos and the known Milky Way satellites :

F.Stoehr et al.: MNRAS 335 (2002) L84

E.Hayashi et al.: ApJ 584 (2003) 541

The Milky Way and its satellites



100 kpc

Milky Way satellites Draco and Sagittarius

they are favoured for observations due to their

- proximity (< 100 kpc)
- low baryonic content, no central BH (which may change the DM cusp)
- large M/L ratio (implying dominance of DM)

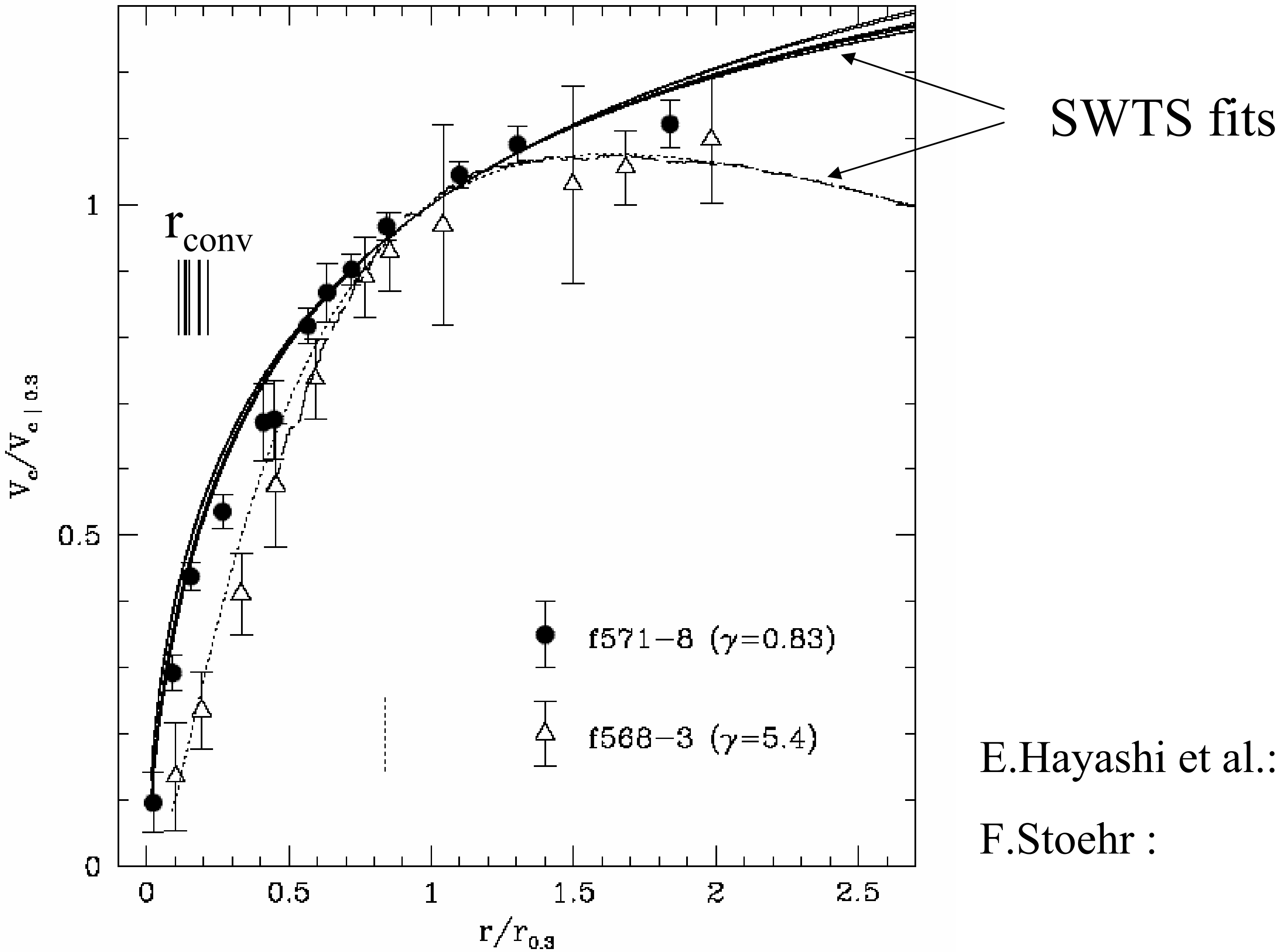
	Draco	Sagittarius
heliocentric distance	79 kpc	24 kpc
M/L	245 M_o/L_o	100 M_o/L_o
mass	$8.6\cdot10^7$ M_o	$5\text{-}20\cdot10^8$ M_o
Θ_{cul}	29.1^0	59.3^0
optimal $\Delta\Omega$	$\Delta\Omega_{res}$	0.4^0 (or $\Delta\Omega_{res}$)

DM halo profile in LSB and dwarf Spheroidals

- LSB rotation curves : the discrepancy between the extrapolated circular velocity profiles (from simulations) and the observed profiles is becoming smaller (F.Stoehr, astro-ph/0403077)
- H I rotation curves of many dSphs are broadly compatible with both core and cusp density profiles
- H II rotation curves for some dSphs are not compatible with cusped density profiles (S.Blais-Quellette et al.: AJ 118 (1999) 2123)
- survival of a kinematically cold substructure (in Ursa Minor) is incompatible with a cusped halo (which would destroy it); (J.T.Kleyna et al.: AJ 588 (2003) L21)

For the 2 nearest dSphs (Sagittarius, Draco) there is no direct evidence either for or against central cusps

Rotation curves of two LSB galaxies

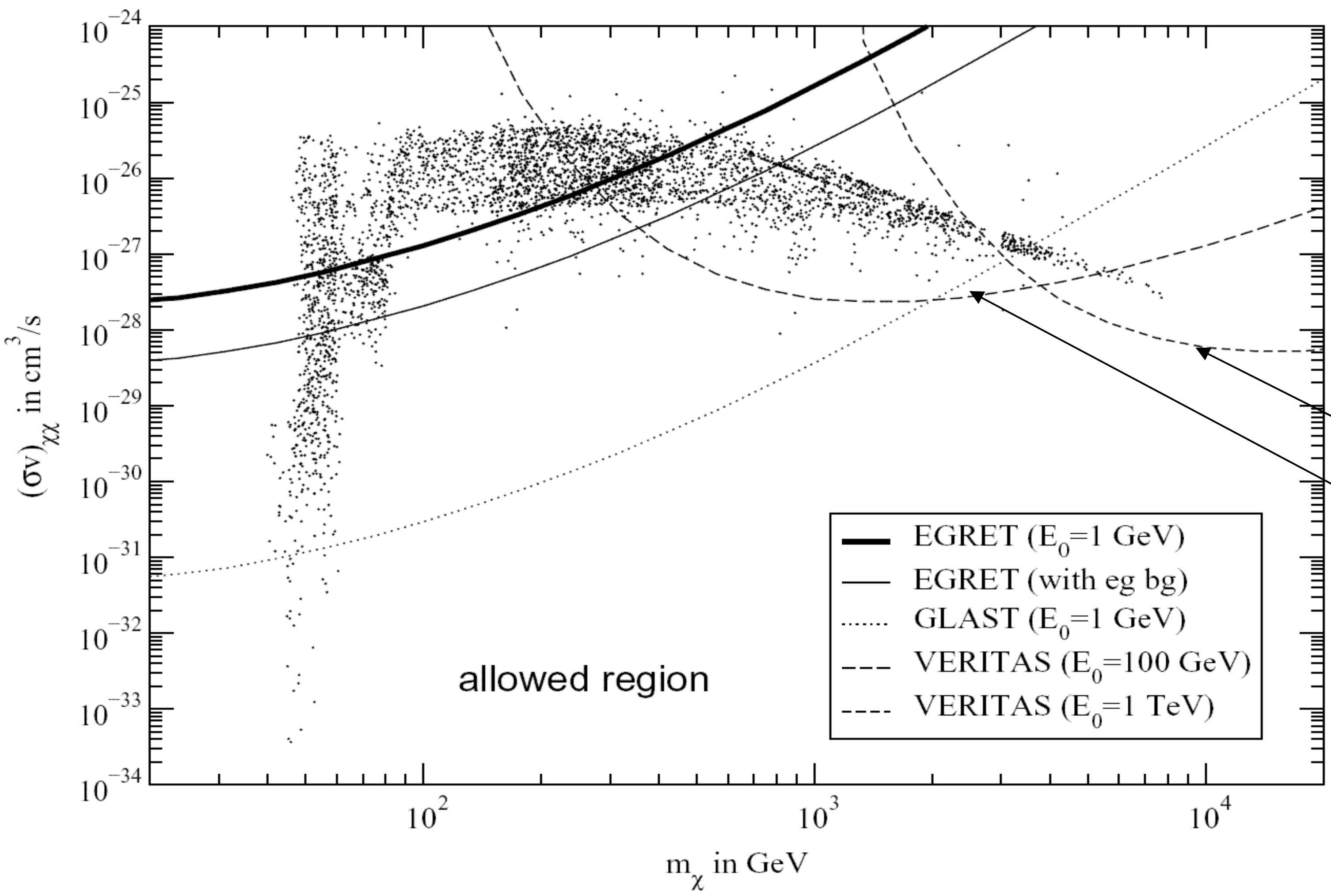


E.Hayashi et al.: astro-ph/0310576

F.Stoehr : astro-ph/0403077

Dwarf spheroidal Draco

Limits for a ?σ detection, with T_{obs} = 50 h, E_{th} = 100 GeV or 1 TeV



no angular average made

SIS profile (r^{-2})

E_{th} = 1 TeV

E_{th} = 100 GeV

C.Tyler :
astro-ph/0203242

Conclusions

With its high sensitivity and low energy threshold, MAGIC is prepared to search for DM signals

The detection limits depend strongly on the DM profile in the innermost region of the (sub)halo

Galactic Center :

- there is increasing evidence that the halo of the Milky Way is not cusped; the detection of a DM signal is therefore unlikely

Milky Way satellites Draco and Sagittarius :

- a cusped density profile is not yet excluded
- SWTS (between r^{-1} and r^{0}) : detection is out of range
- cuspy profile ($r^{-1.5}$) : strong constraints on SUSY parameters