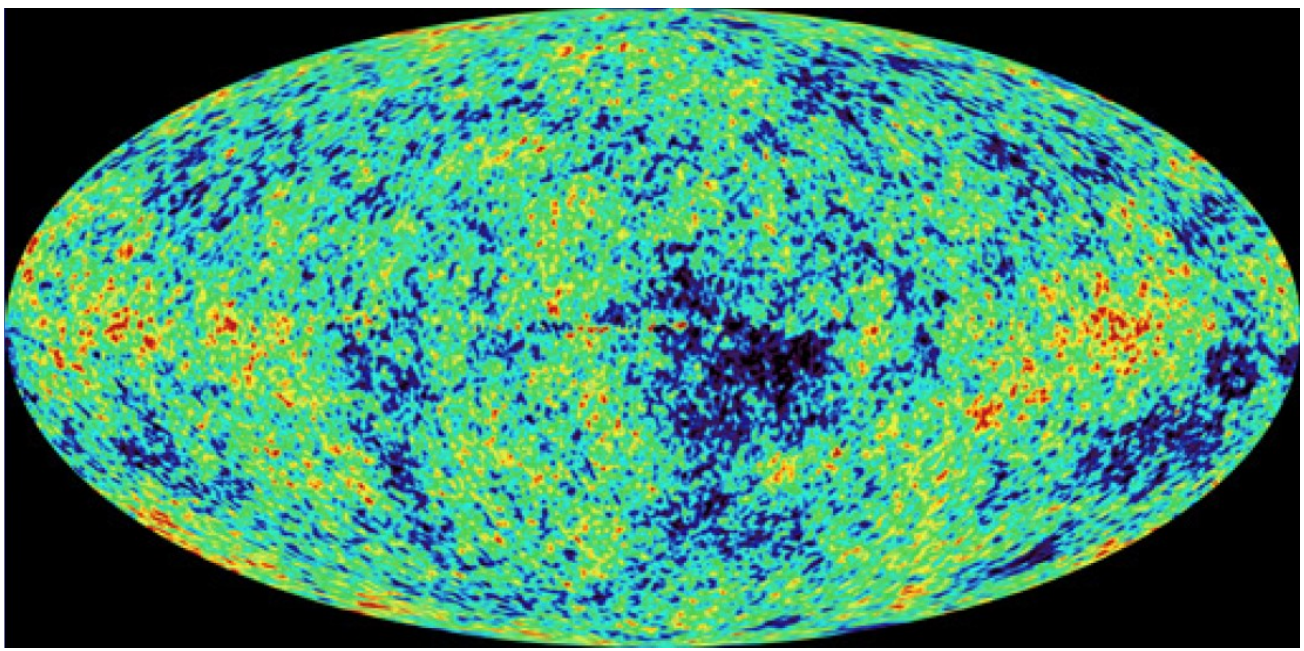
Indirect Dark Matter Search: overview

outline

- observatianal evidence for DM
- candidates for DM: SUSY neutralinos
- methods of WIMPs detection: indirect search
- space-based and ground-based indirect detection experiments

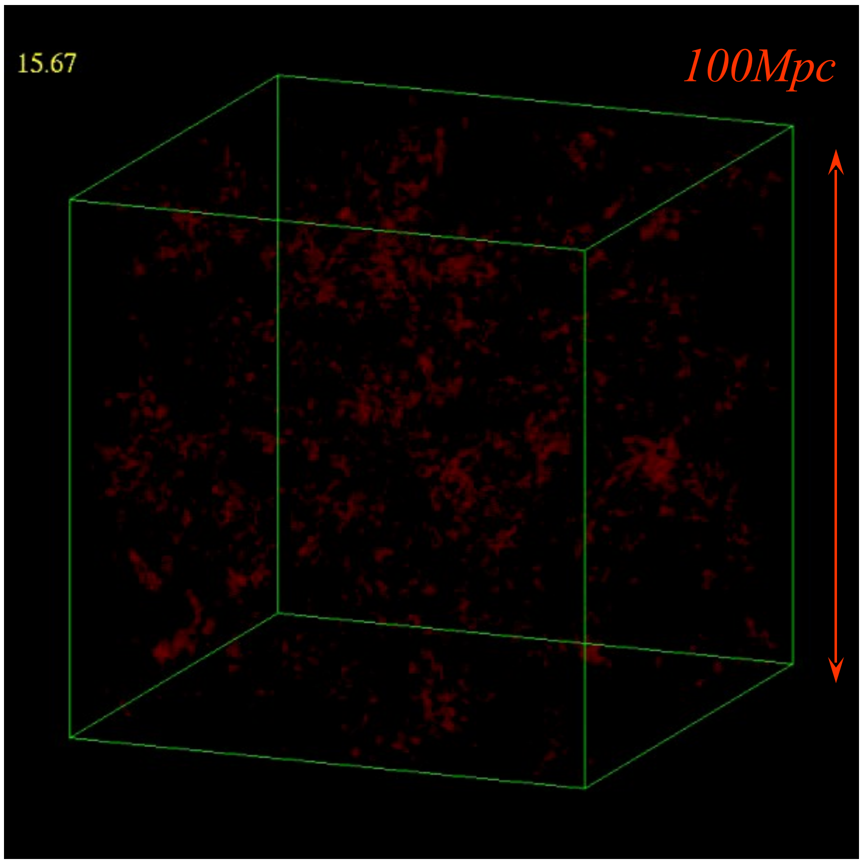
Observational evidence for Dark Matter

- rotation curves of spiral galaxies
- binding of galaxies in clusters
- dynamics of galaxy clusters
- gravitational lensing
- measurements of anisotropies in the CMB

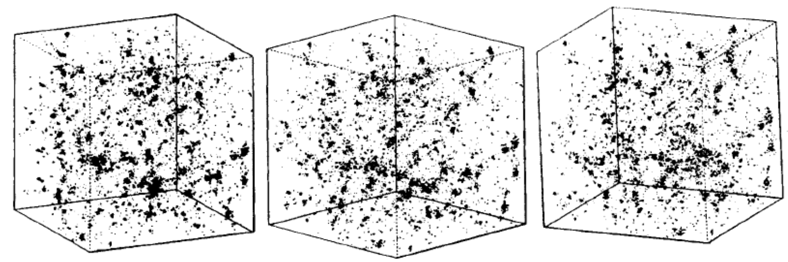


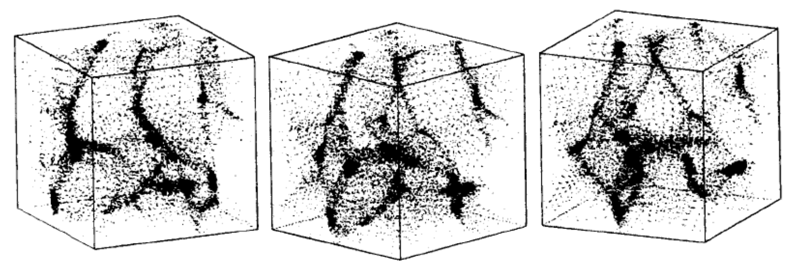
Non-baryonic Hot vs. Cold Dark Matter

Simulation of DM density



cold dark matter:
bottom-up scenario





hot dark matter:
top-down scenario

Good particle physics candidates for CDM

acronym CCDM

- Cold
- Collisionless
- Lifetime comparable to age of Universe

WIMPs

Weakly Intracting Massive Particles
(3 GeV < m_χ < 50 TeV)

thermal relics from Big Bang

- SUSY neutralino
- axino
- gravitino
- "Little Higgs"
- Mirror particles
- Kaluza-Klein states
- Heavy neutrino-like particles
- plus hundreds more in literature…

non-thermal relics from Big Bang
(maybe superheavy)

- Wimpzillas
- Cryptons

axions

(1μeV < m_χ < 2 meV)
introduced to solve strong CP problem

MPI: CAST axions produced in the sun through scattering of γ off el. charges

SUSY -WIMPs

SUSY = symmetry Fermion <-> Boson
requires superpartners of different spin for all standard model partners

R – parity: $R = (-1)^{3(B-L)+2S}$

quarks <-> squarks
leptons <-> sleptons
gauge bosons <-> gauginos
Higgs bosons <-> higgsinos

$$\chi_i^o = N_{i1}\widetilde{B} + N_{i2}\widetilde{W}^3 + N_{i3}\widetilde{H}_1^0 + N_{i4}\widetilde{H}_2^0$$

LSP (lightest supersymmetric particles) χ_i^0 are spin $1/2$ majorana particles

SUSY WIMPs calculations

- DarkSUSY is a fortran package for supersymmetric dark matter calculations
- high-precision relic density calculations are needed to match WMAP precision on $\Omega_{CDM}h^2$

"Neutralino dark matter made easy"

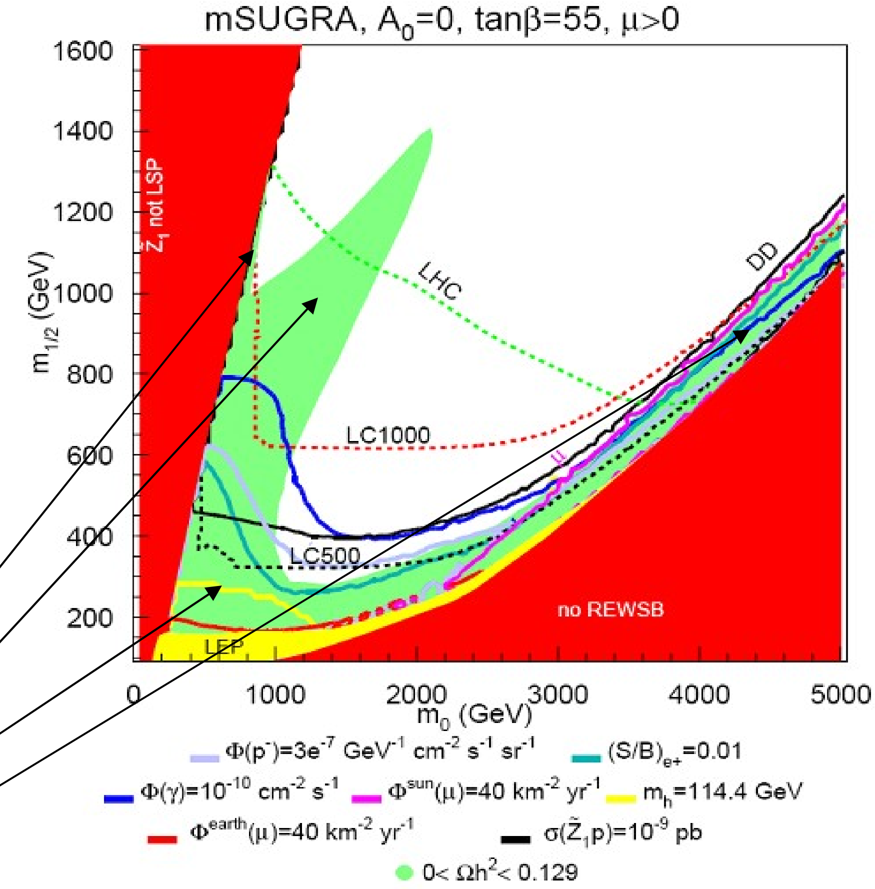
Can be freely dowloaded from http://www.physto.se/~edsjo/ds

mSUGRA for SUSY WIMPs

mSUGRA is the simplest model for SUSY DM
- R-parity conservation
- radiative electroweak symmetry breaking

H. Baer, A. Belyaev, T. Krupovnickas, J. O'Farrill, JCAP 0408:005,2004

5 free mSUGRA parameters (set at GUT scale):
- $m_{1/2}$ soft SUSY breaking fermionic mass
- m_0 soft SUSY breaking bosonic mass
- A_0 soft SUSY breaking trilinear scalar coupling
- $\tan\beta$ ratio of Higgs fields
- $sign(\mu)$ sign of the Higgs superfield parameter



- stau coannihilation region ($m_\chi \approx m_{stau}$)
- funnel region ($m_{A,H} \approx 2m_\chi$)
- bulk region (low m_0 and $m_{1/2}$)
- hyperbolik branch/focus point ($m_o >> m_{1/2}$)

Methods of WIMPs detection

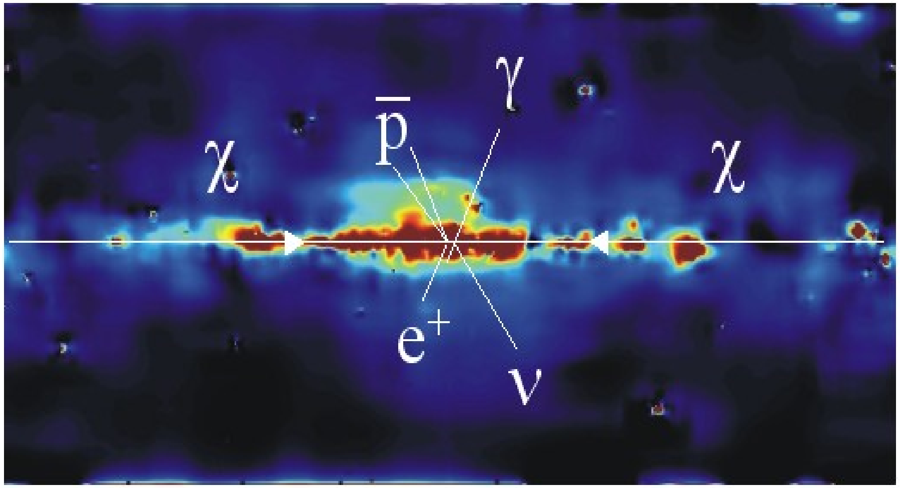
- possible *discovery at accelerators* (Fermilab, LHC …)
- *direct detection* of halo particles in terrestial detectors
- *indirect detection* in ground- or space-based experiments

The basic process for indirect detection is annihilation of neutralinos

annihilation products

- neutrinos
- antiprotons
- positrons
- gamma rays

(antiprotons and positrons: antimatter)



Indirect detection: neutralino example

$$\tilde{\chi}\tilde{\chi} \rightarrow f\bar{f}, q\bar{q}, HH, W^{+}W^{-}, ZZ, Z\gamma, \gamma\gamma \rightarrow e^{+}, \bar{p}, \gamma, \nu$$

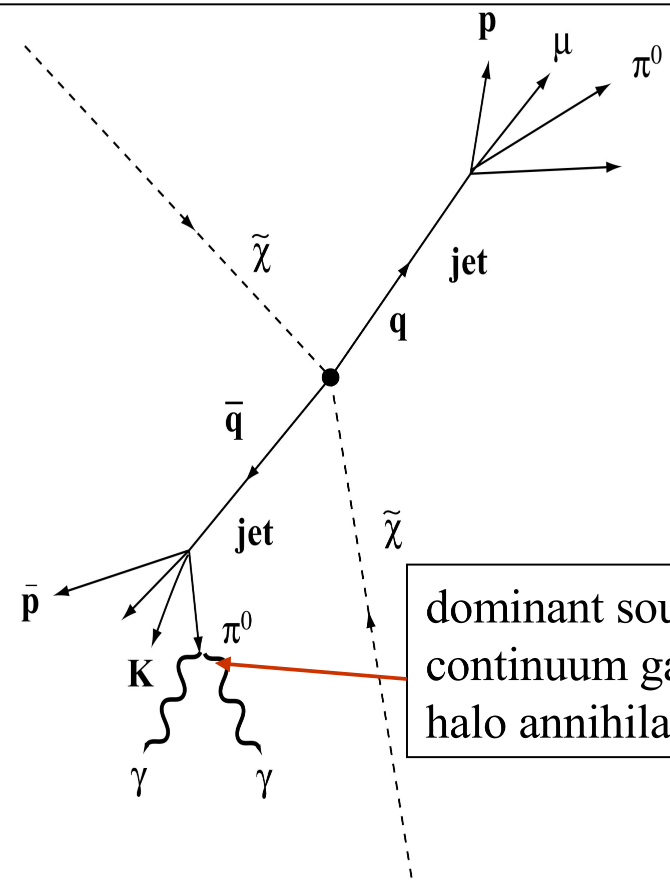
usually the heaviest kinematically allowed final states dominates (b or t quarks, W&Z bosons)

annihilation rate per unit volume:

$$\Gamma_{ann} = \frac{1}{2}\langle\sigma v\rangle\frac{\rho^{2}}{m^{2}}$$

σ: annihilation cross section
υ: relative velocity (Bolzmann distributed)
m: neutralino mass
ρ: neutralino density

enhanced for clumpy halo, near galactic centre and in Sun & Earth



dominant source of continuum gammas in halo annihilations

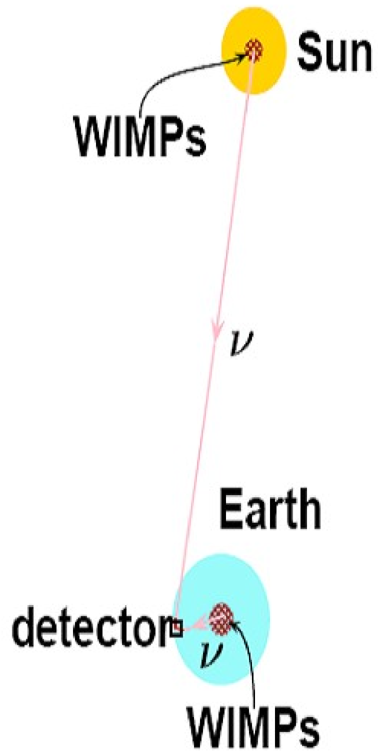
High Energy Neutrinos

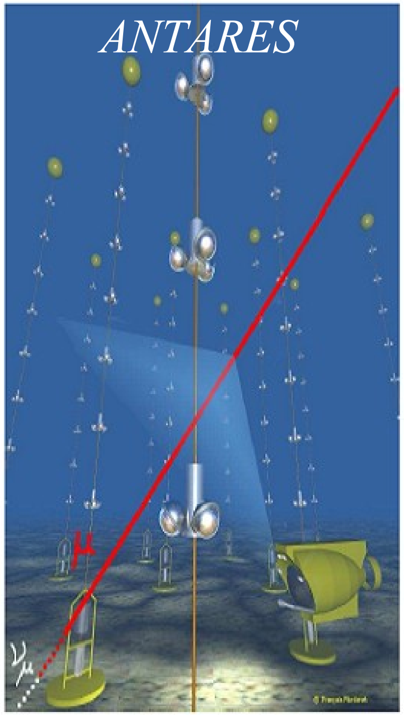
observation of high energy neutrinos originating from the neutralino annihilation in the core of sun or earth

$$b\bar{b}, c\bar{c}, W^{+}W^{-}, ZZ \Rightarrow b \rightarrow c l \nu_{l},$$

$$c \rightarrow s l \nu_{l}, W \rightarrow l \nu, Z \rightarrow \nu_{l} \nu_{\bar{l}}$$

$$\nu_{\mu} \rightarrow \mu$$





Cherencov light emitted by muons along the track can be detected

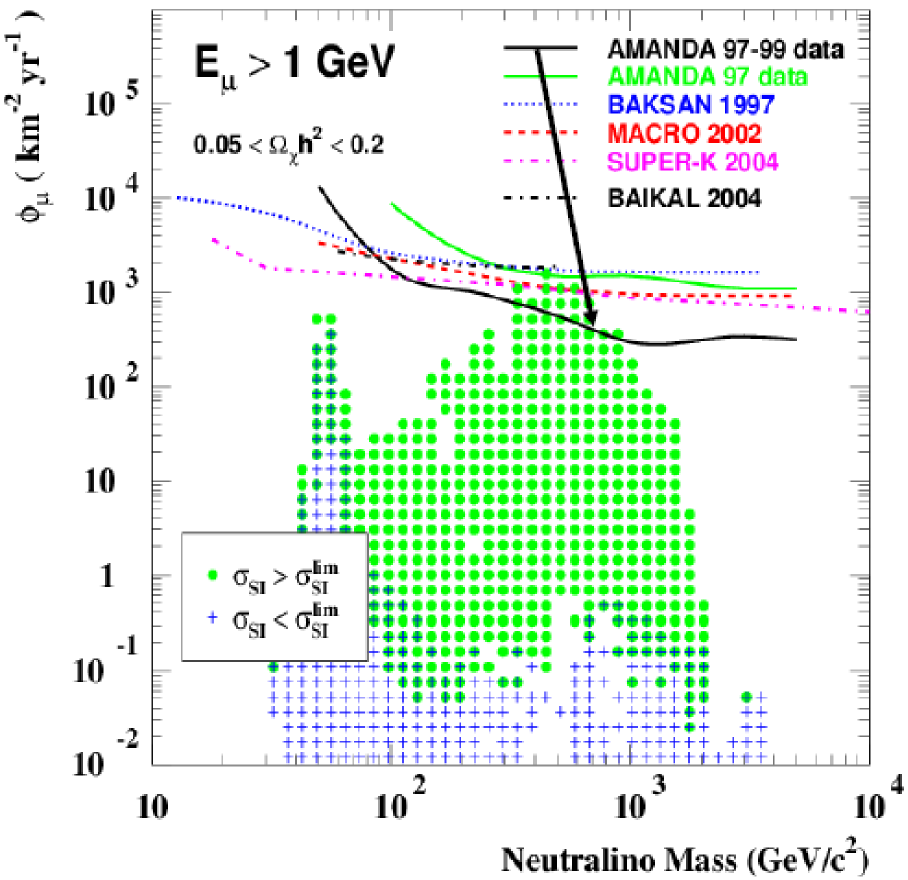
first limits by existing neutrino detectors (SuperK, AMANDA)

under construction:
ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch project in the Mediterranean Sea), *IceCube*

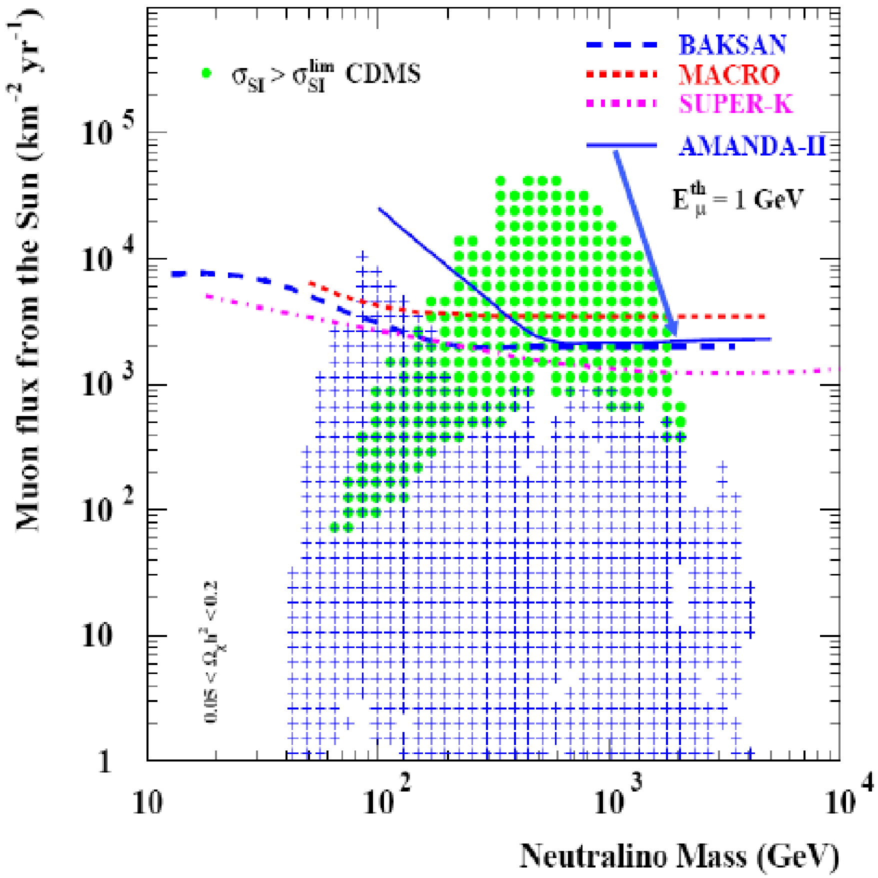
AMANDA muon flux limit: Earth & Sun

- no significant excess above expectation from atmospheric muons was found
- upper limits were derived on muon flux, which are compatative with other indirec searches

(accep. Astropart. Phys.)

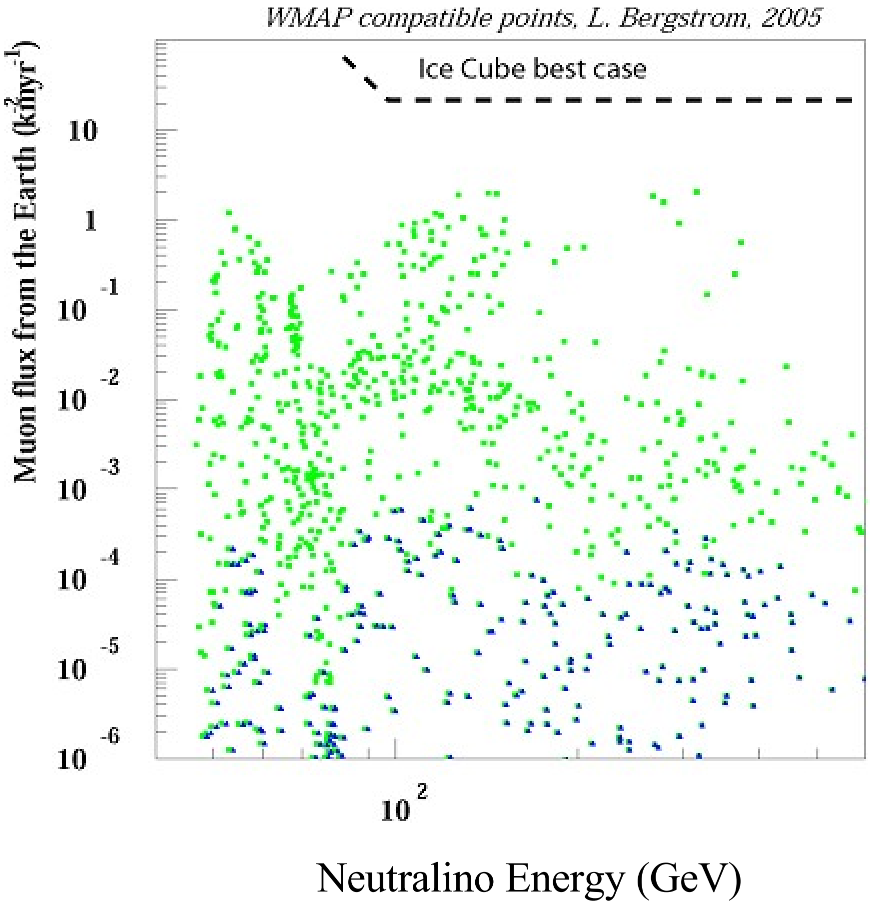


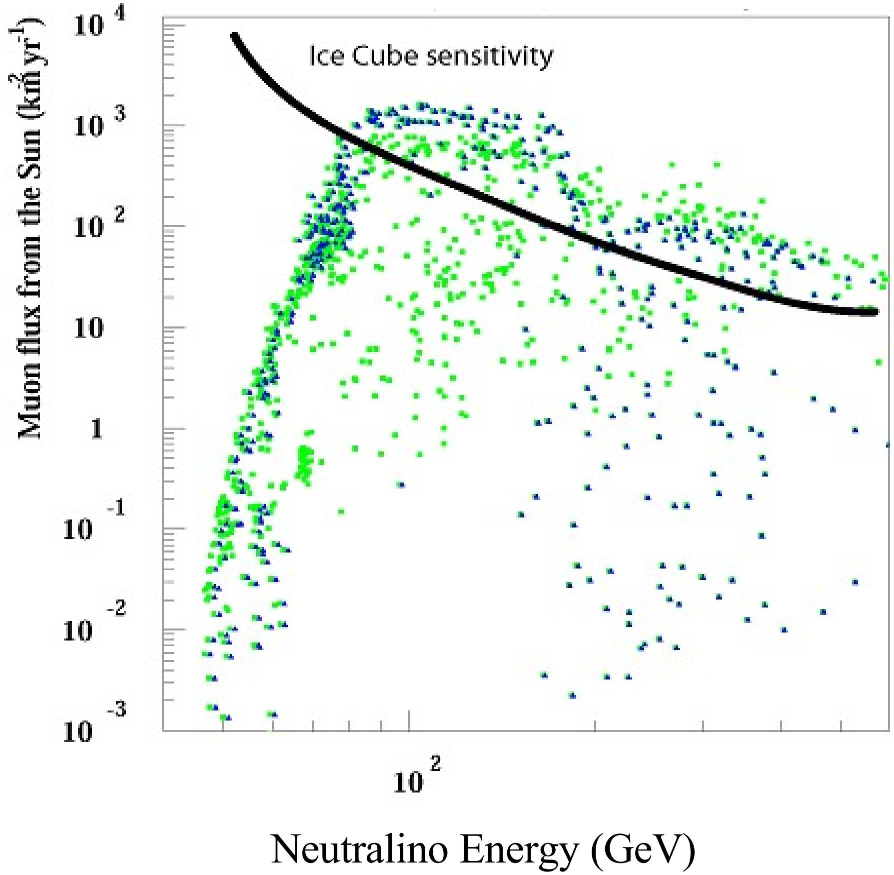
(Astropart. Phys. 24(2006)459-466)



Prospects for IceCube
(neutrinos from the Earth & Sun, MSSM)

- Present case: 25 GeV threshold, WMAP relic density
- Future: 25 GeV threshold, WMAP relic density, $s_{SI} < 10^{-8}$ pb

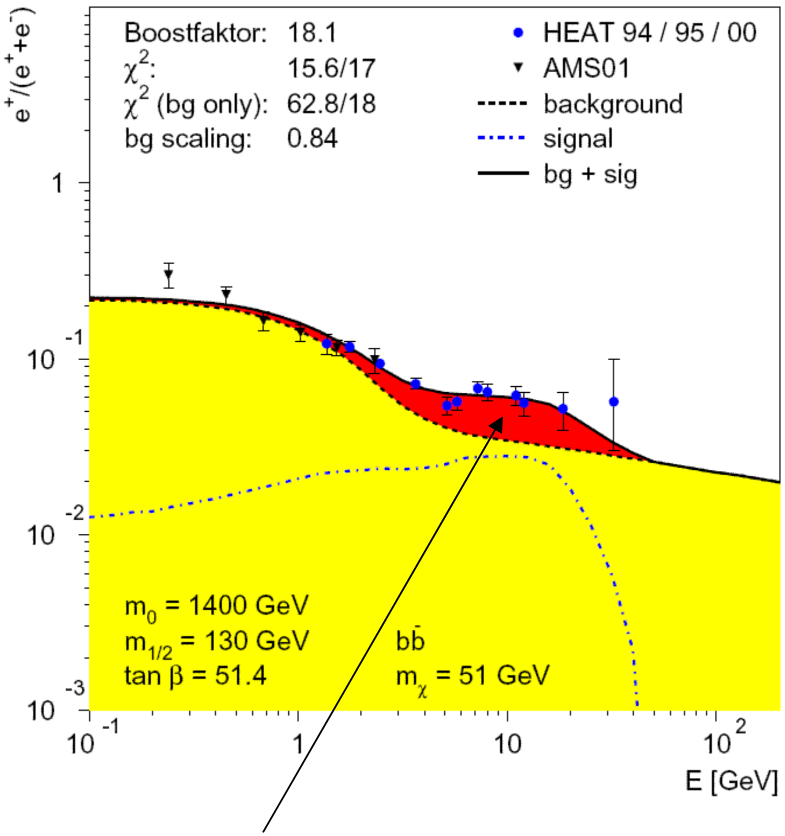




Cosmic Ray Anti-Matter

positrons or anti–protons originating from neutralino annihilation in the galactic halo

HEAT (High-Energy Antimatter Telescope) baloon experiment, future: PAMELA



presence of local DM substructure ?

(Silk et al. 2006)

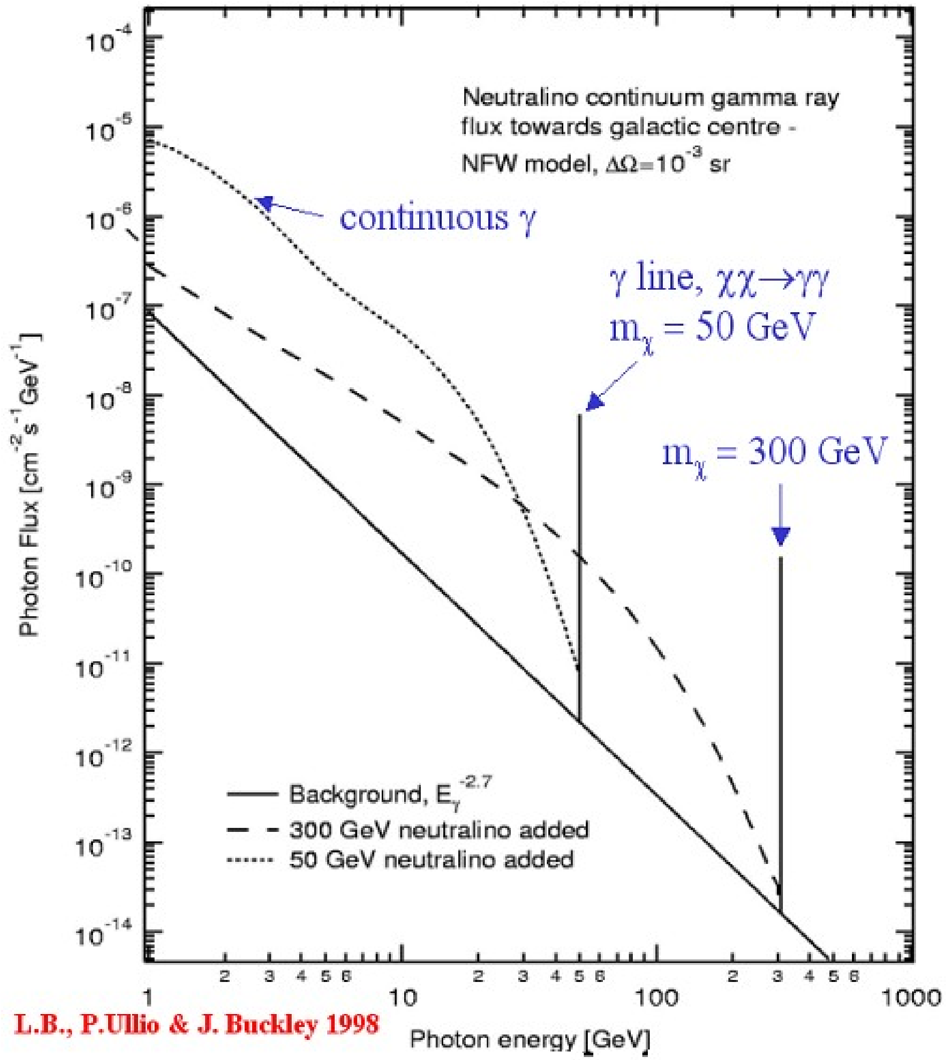
small anti-matter enhancement in positron signal at ~8 GeV (Couto et al. 1999)

Indirect Detection through γ - rays

Observation of gamma – rays originating from neutralino annihilation in the galactic core or halo

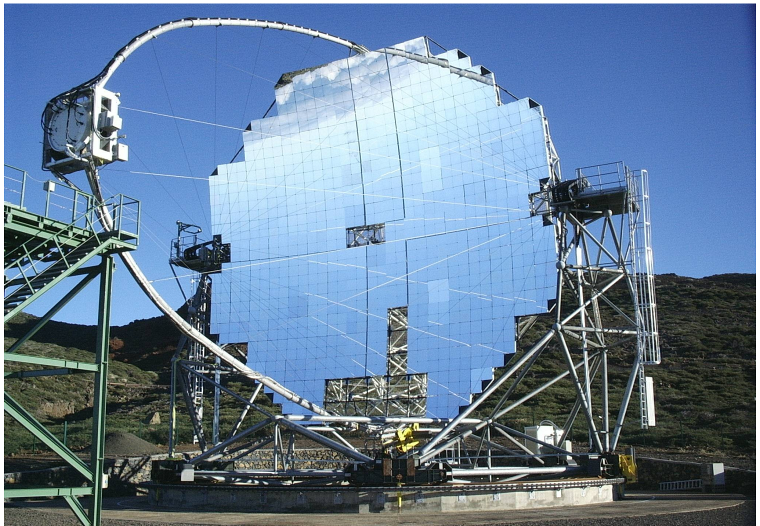
Advantage of gamma-ray:

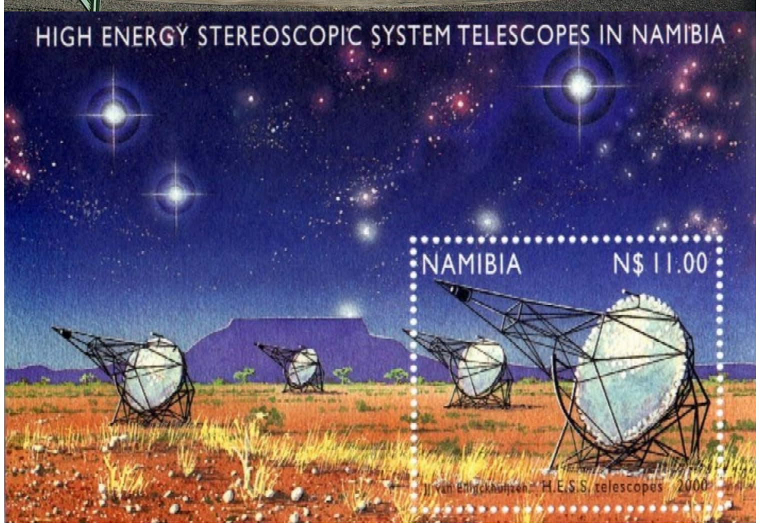
- point back to the sourse
- energy scecrum has a very characteristic cut-off at the mass of the DM particle
- flux of DM particles sould be stable in time
- enhanced flux possible thanks to halo density profile and substructure (as predicted by CDM)



Gamma Rays Observation

ground based Air Cherenkov Detectors (MAGIC, H.E.S.S., CANGAROO, furure: VERITAS …)





satellite experiments (EGRET, INTEGRAL, future: GLAST)

Gamma Flux from WIMPs annihilation

$$\frac{dN_\gamma^{annihil}(\Omega,E,M_\chi)}{dt\, dA\, d\Omega\, dE} = \frac{dN_\gamma(E,M_\chi)}{dE}\,\frac{\langle\sigma\cdot v\rangle}{4\pi\, M_\chi^{2}}\,\frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_{los} \rho^{2}(r(s,\Omega))\, ds$$

$\frac{dN_\gamma(E,M_\chi)}{dE}$ fragmentation functions, simulations (Pythia, …), depends on M_χ + SUSY parameters

$\langle\sigma\cdot v\rangle$ function of M_χ + SUSY parameters, if only neutralinos are DM: given by $\Omega_{wimp} \approx 6\cdot 10^{-27}\,cm^{3}s^{-1}\langle\sigma v\rangle^{-1} \approx 0.23$

$\frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_{los} \rho^{2}(r(s,\Omega))\, ds$ depends on angular resolution $\Delta\Omega$ + dark matter density $\rho^{2}(r(s,\Omega))$

Dependence on DM density profile

$$\rho(r) = \rho_0 \frac{(r/r_0)^{-\gamma}}{\left(1+(r/a)^{\alpha}\right)^{\frac{\beta-\gamma}{\alpha}}} \left(1+(r_0/a)^{\alpha}\right)^{\frac{\beta-\gamma}{\alpha}}$$

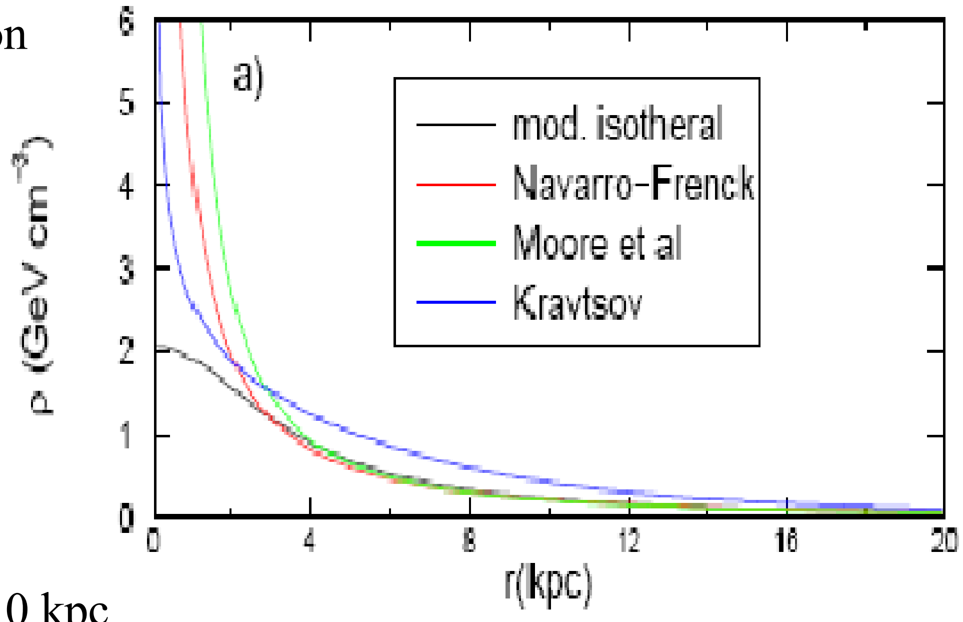
r_0= 8.5 kpc: distance of earth to the galactic center
ρ_0=0.3 GeV/cm3: local dark matter density
a: distance scale

• spherically symmetric isothermal distribution
(α, β, γ) = (2, 2, 0), a=3.5 kpc

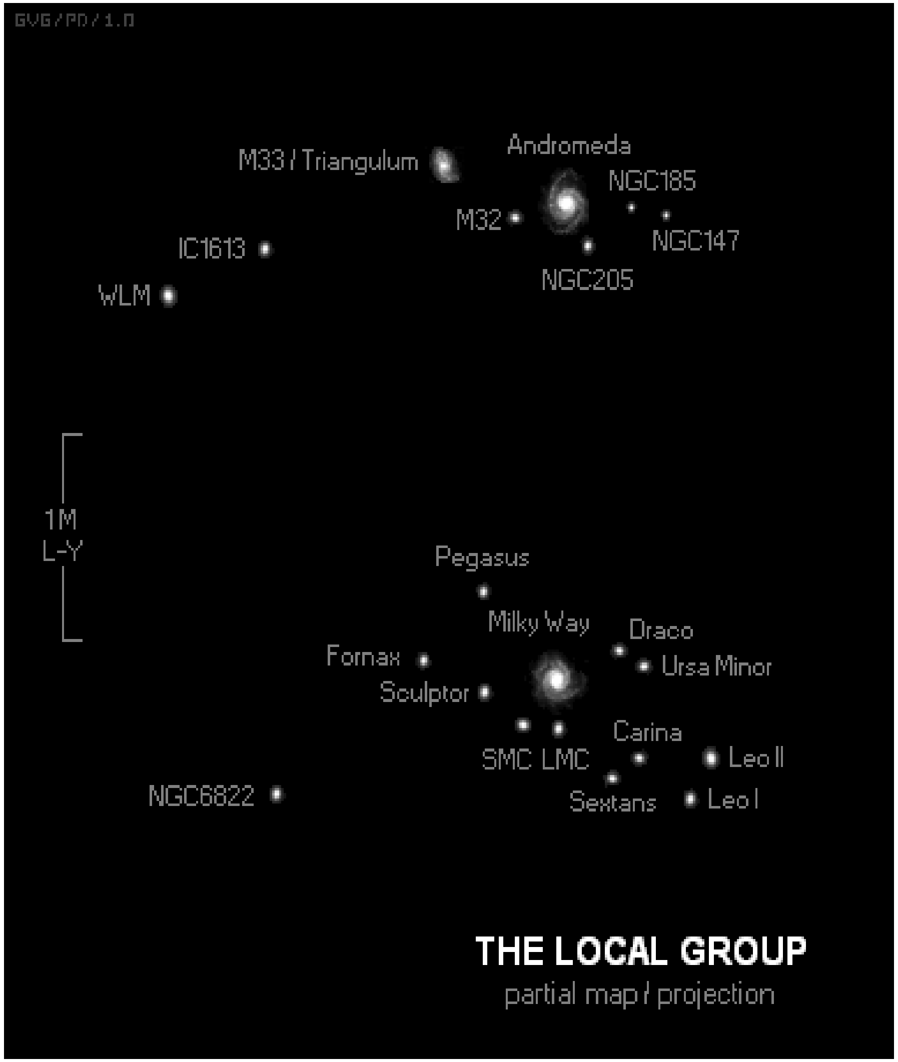
•Navarro, Frenk, White profile
(α, β, γ) = (1, 3, 1), a=20 kpc

• Moore et al. profile
(α, β, γ) = (1.5, 3, 1.5), a=28 kpc

• Kravtsov et al. Profile
ρ_0=0.6 GeV/cm3, (α, β, γ) = (2, 3, 0.4), a=10 kpc



Candidates for the Indirect Search



- galactic center (center of Milky Way)
- satellites of Milky Way (Draco)
- nearby galaxies (M31, M87)

Draco is dwarf spheroidal galaxy in the Local Group

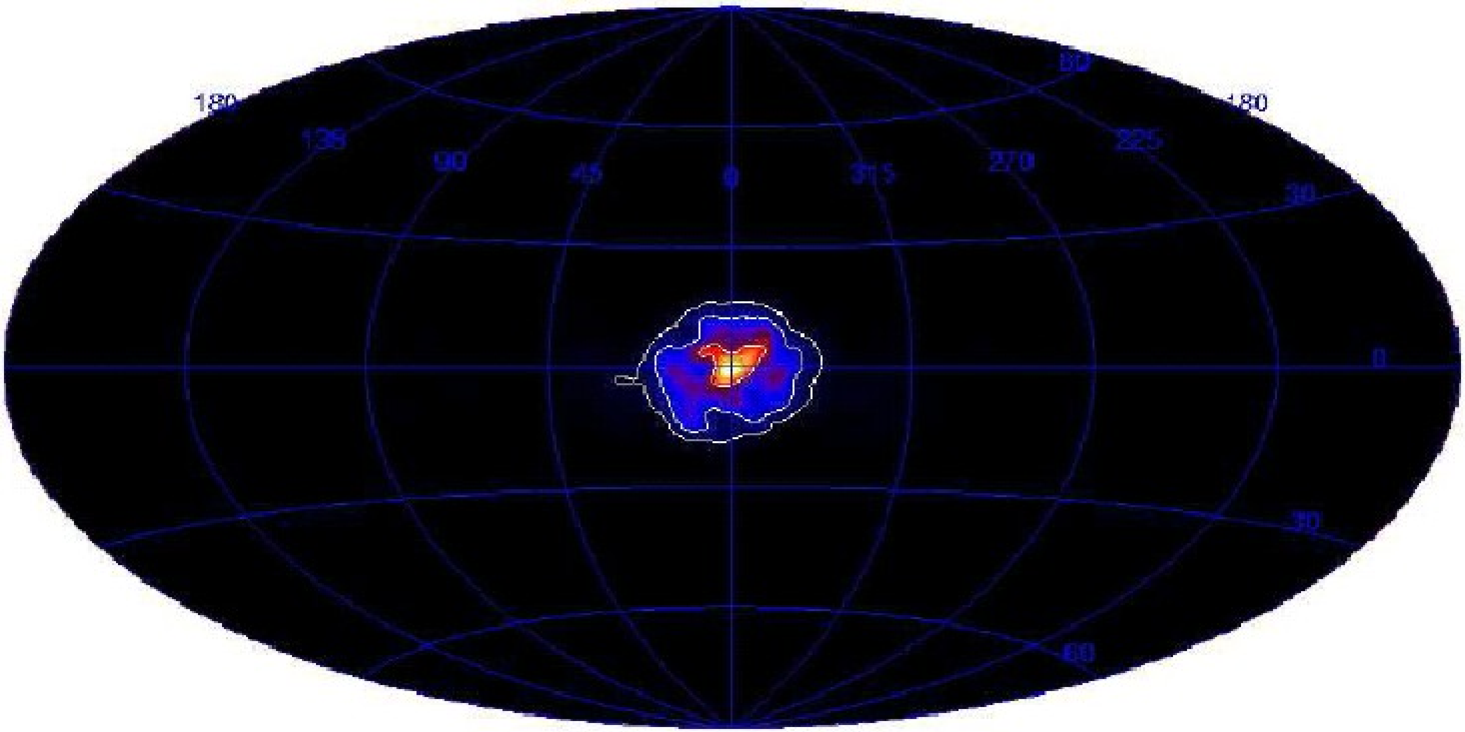
- most DM dominated dwarf satellite
- Mass-to-Light ratios up to 300
- starpoor, therefore cleaner observation conditions then in galactic center

MAGIC, GLAST, CACTUS

INTEGRAL

(INTErnational Gamma-Ray Astrophysics Laboratory)

The *MeV - scale DM* particle giving the 511 keV annihilation line at the galactic center???

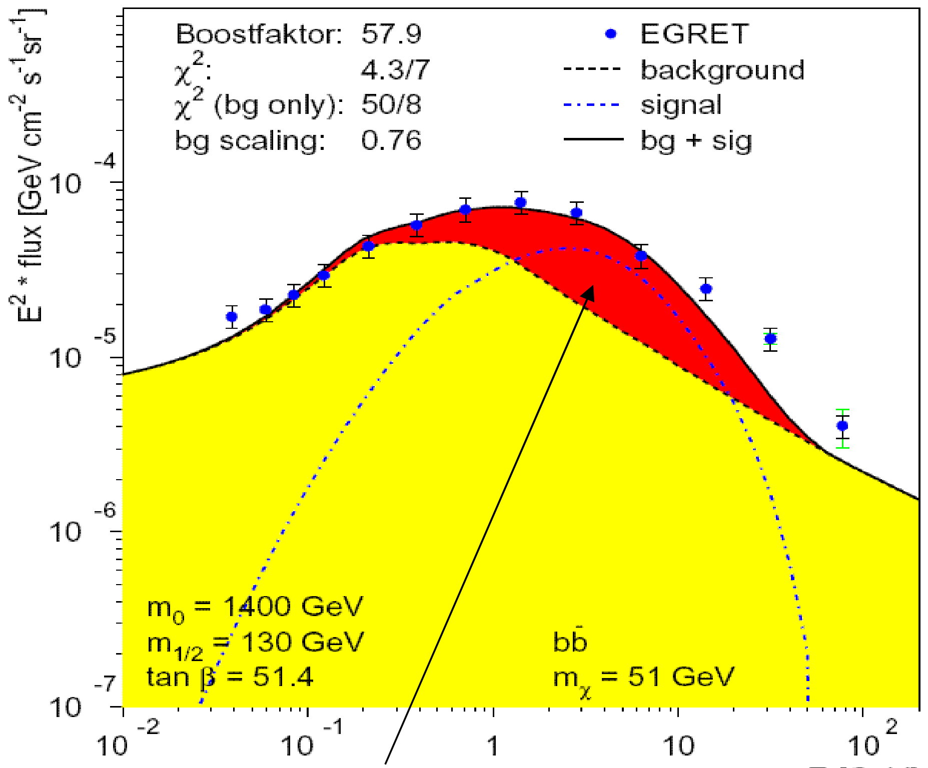


INTEGRAL all-sky picture of positronium gamma line (511 keV) emission – unknown origin (J. Knödlseder et al., astro-ph/0506026)

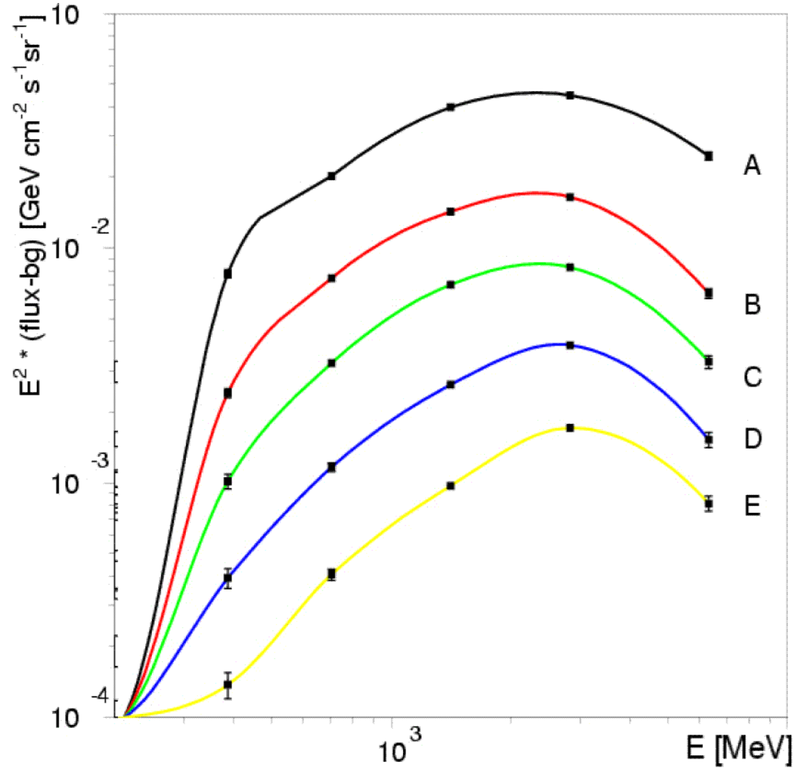
EGRET satellite

(The Energetic Gamma Ray Experimet Telescope)

- The *50 – 70 GeV neutralino DM* particle which explains the EGRET galactic gamma ray spectrum??? (Boer et al., 2004)
- Investigation on the internal consistency of the DM halo model are needed



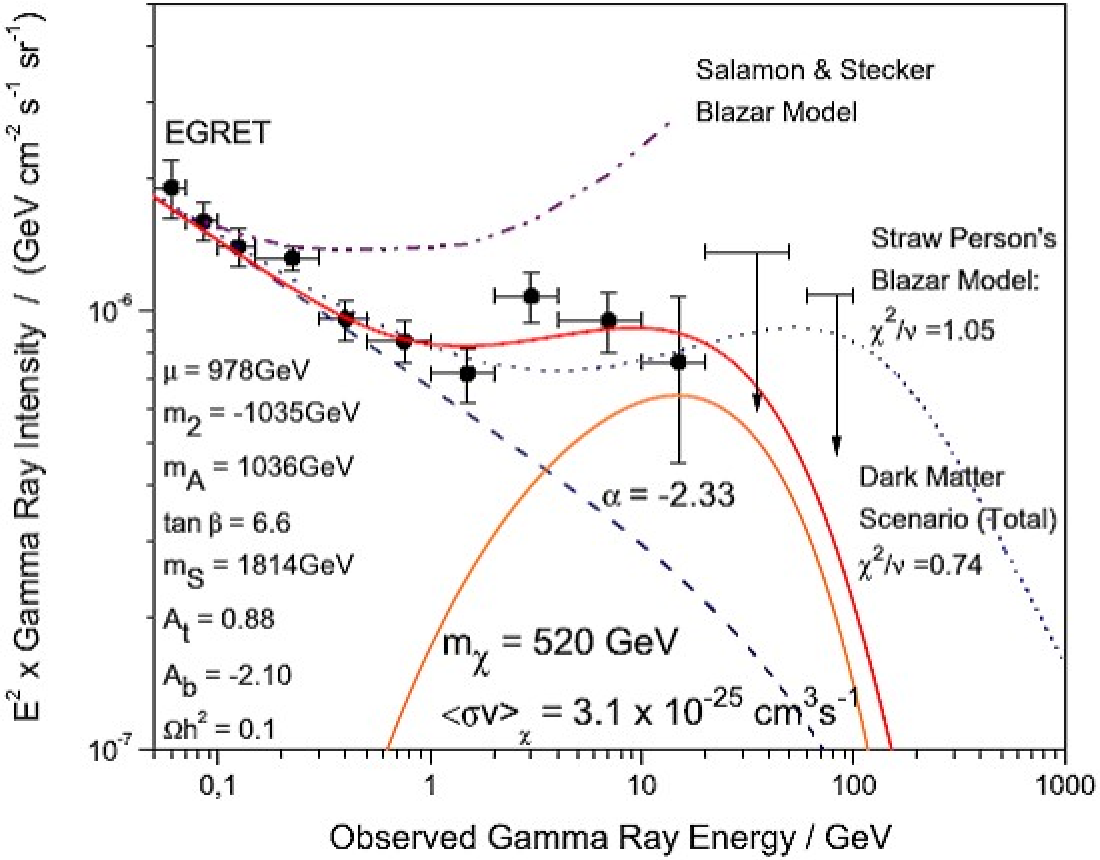
excess of diffuse galactic gamma-rays flux over expected background



same spectrum for different directions of our galaxy

EGRET satellite

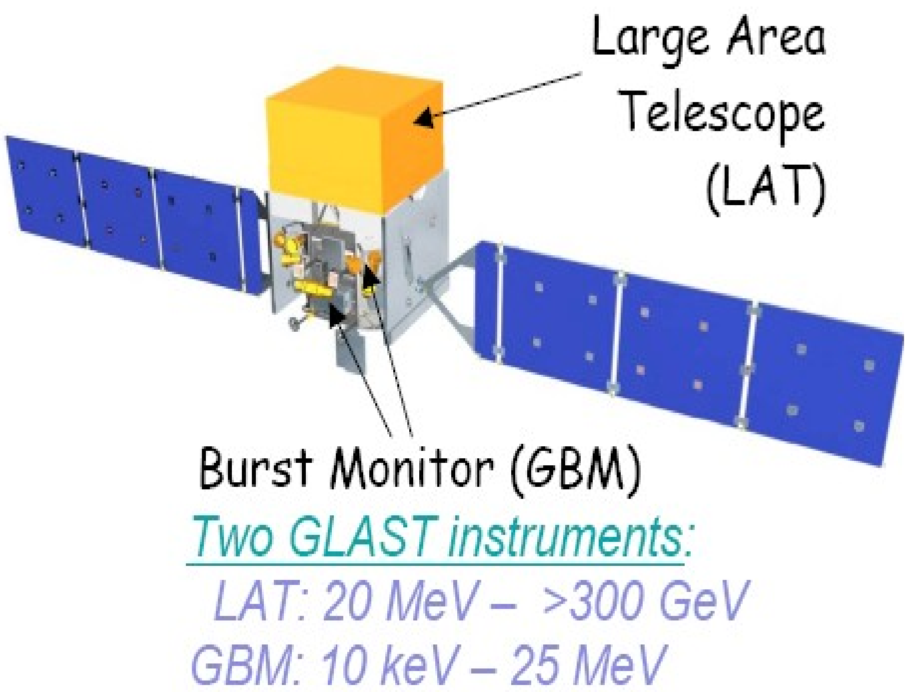
The *500 GeV neutralino DM* particle which explains the EGRET extragalactic gamma ray spectrum??? (Elsässer & Mannheim, Phys. Rev. Lett. 94:171302, 2005)

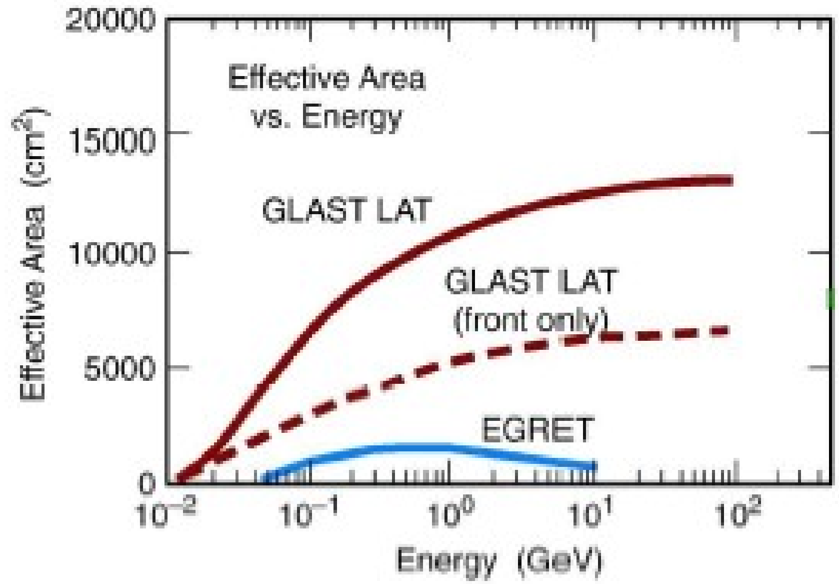


GLAST

(Gamma-ray Large Area Space Telescope): launch 2007

- GLAST *can search* for DM signals *up to 300 GeV*
- It is also likely to detect a few thousand new GeV blazars

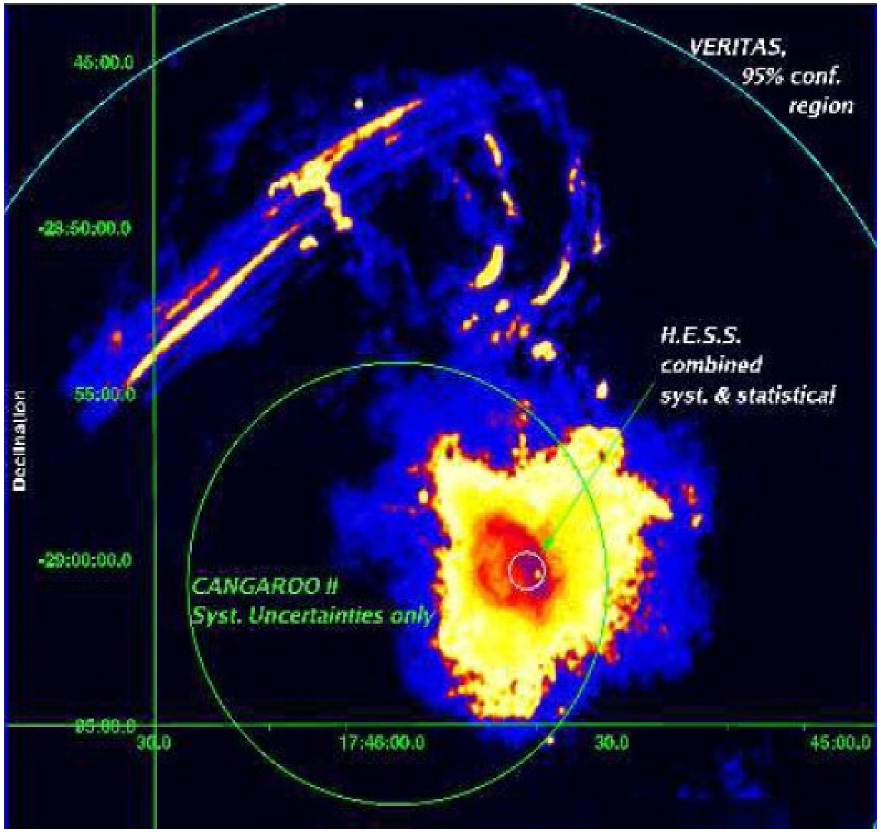


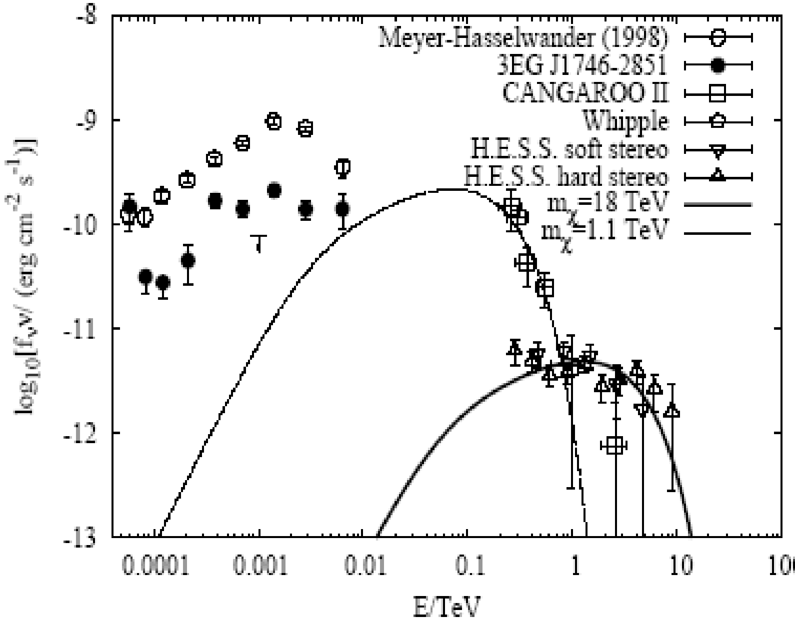


H.E.S.S.

(High Energy Stereoscopic System)

The *20 TeV DM* particle giving the HESS signal from the galactic center???
(D. Horns, astro-ph/0408192)

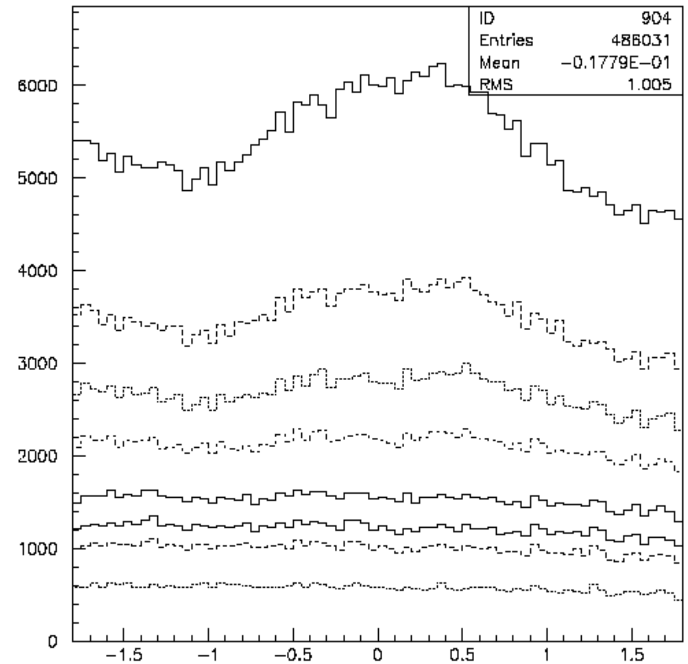




CACTUS sollar array

A *few hundred GeV DM* particle in Draco giving the signal in CACTUS???

- preliminary and unpublished data
- however, signal looks too strong
- should be detectable by GLAST

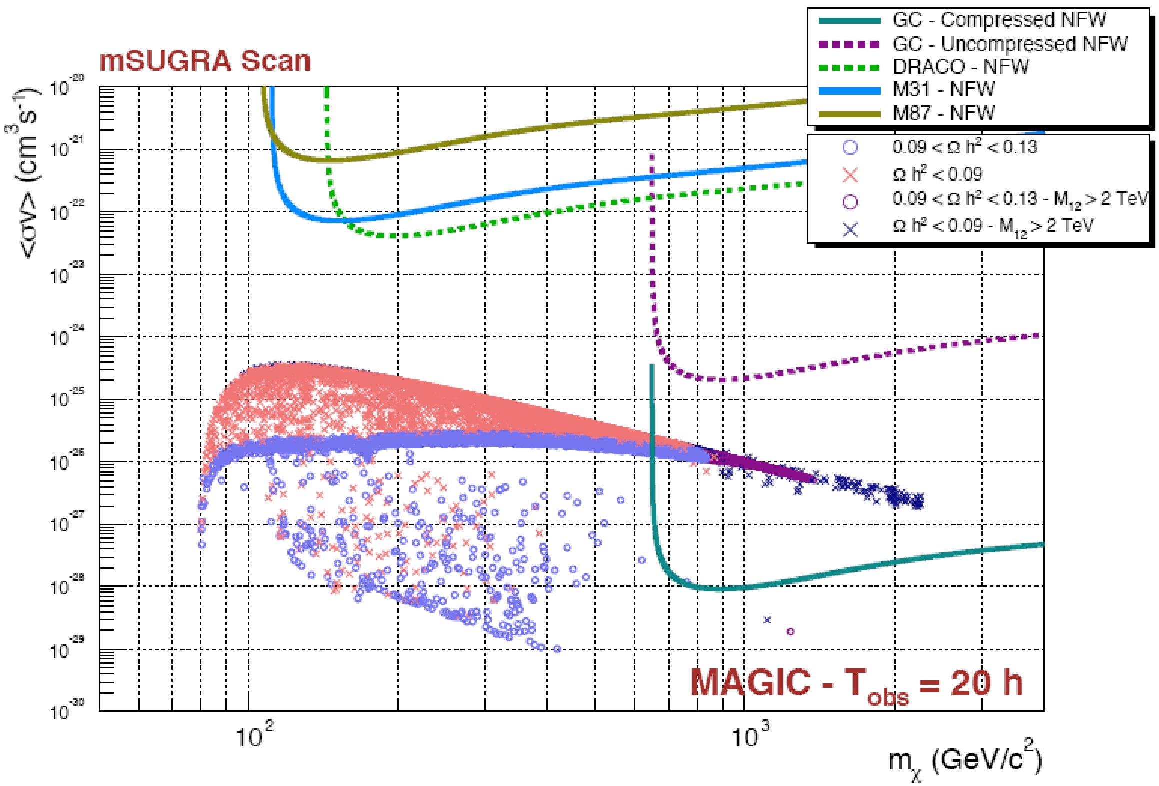


Increasing energy

100

150 GeV

Prospects for MAGIC
(Major Atmospheric Gamma-ray Imaging Cherencov Telescope)



Conclusions

- the existence of *non-baryonic Dark Datter* has been definitely established
- *CDM* is favoured
- supersymmetric particles (*neutralinos*) are still among the best-motivated candidates
- indications of *gamma-ray excess* from galactic center, the galactic halo, the extragalactic flux and perhaps from the Draco dwarf galaxy (at MeV, GeV, and TeV energies!), however, more definitive spectral signature is needed (the gamma line would be a *"smoking gun"*)
- many new experiments (GLAST, VERITAS, AMS) are coming on soon
- Where does the GeV excess in galactic and extragalactic gamma-rays come from? *GLAST data will be crucial.*
- ACTs will soon have interesting data on dwarf galaxies
- the various indirect and direct detection methods are *complementary* to each other and to LHC
- *The dark matter problem may be near its solution…*