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SUMMER SCHOOL IN COSMOLOGY AND ASTROPARTICLE PHYSICS

10 - 21 July 2006

Strategies for dark matter detection

Part 4

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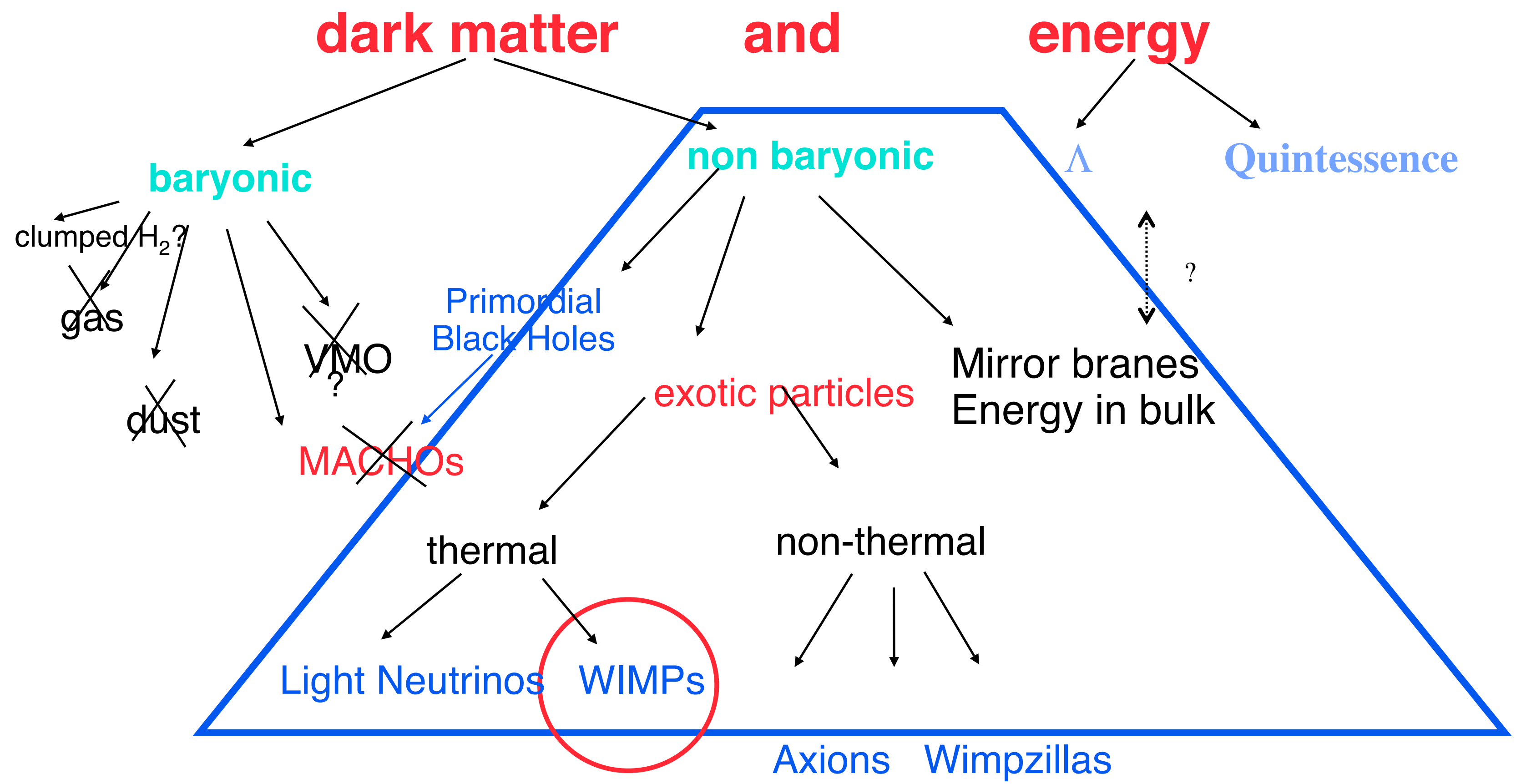
Search for Dark Matter

WIMPs: Indirect Detection

Gamma Rays
Positrons
Antiprotons
Neutrinos

Non Thermal Candidates

Deciphering the Nature of Dark Matter



Weakly Interactive Massive Particles

Particles in thermal equilibrium
+ decoupling when nonrelativistic

Freeze out when annihilation rate $\approx$ expansion rate

$$\Rightarrow \Omega_x h^2 = \frac{3 \cdot 10^{-27} cm^3 / s}{\langle \sigma_A v \rangle} \Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2} \quad \rho_\chi \approx \frac{M_{EW}^2 T^3}{M_{Pl}}$$

Generic Class

Cosmology points to W&Z scale
Inversely standard particle model requires new physics at this scale
(e.g. supersymmetry) => significant amount of dark matter
We have to investigate this convergence!

Directly fixes annihilation rate in halo

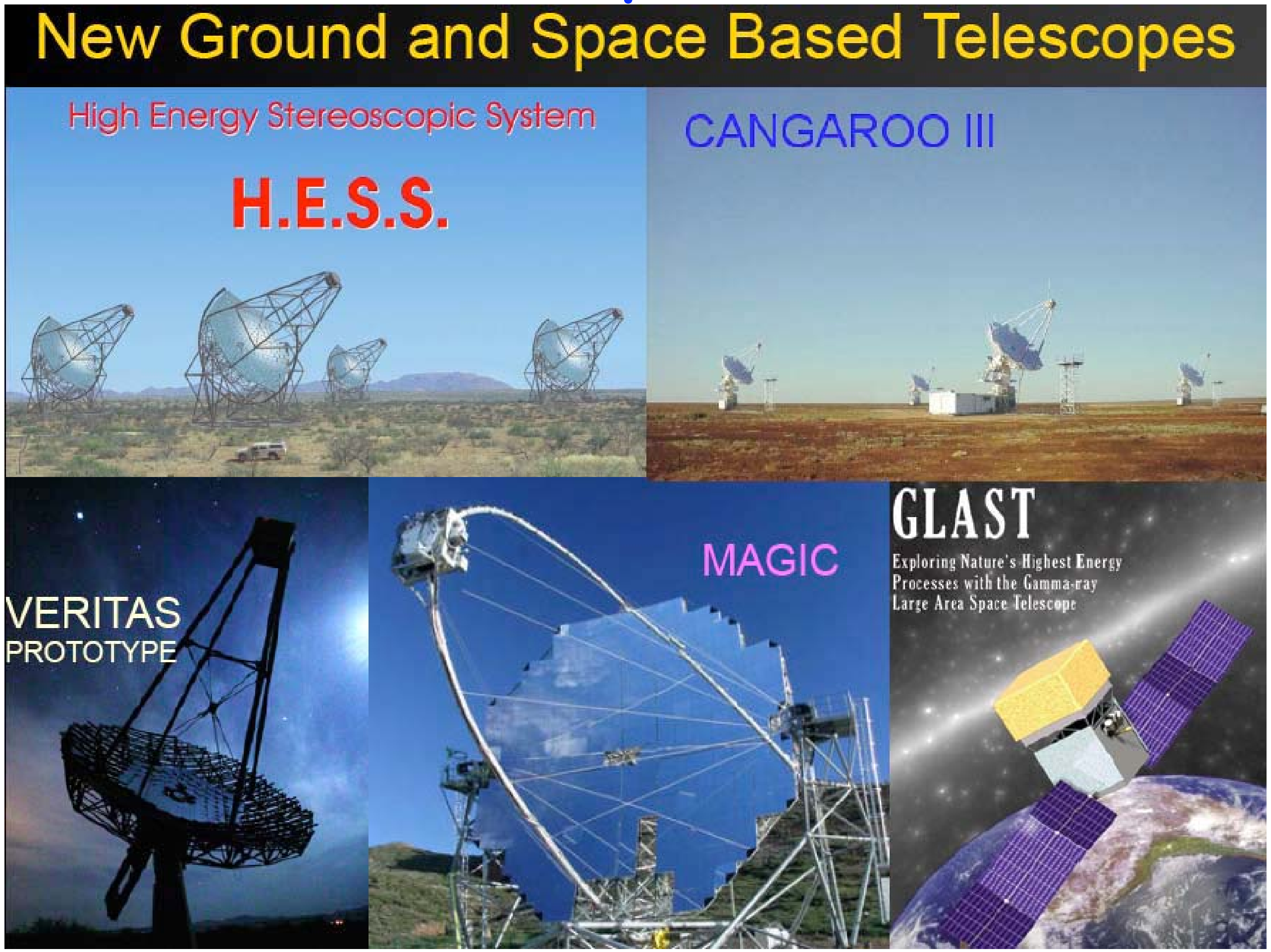
$$\chi\bar{\chi} \rightarrow \begin{array}{c} \gamma + X, \gamma\gamma, \gamma Z \\ e^+ X \\ \bar{p}\ X, \bar{d}\ X \\ \nu\ \bar{\nu}, \nu\ X \end{array}$$

Sensitive to a number of details fixed by Astrophysics

$\approx$ density^2 i.e. cusp discussion is central
Confinement time
Astrophysics backgrounds (e.g. Supernovae remnants, black holes)

Gamma Rays

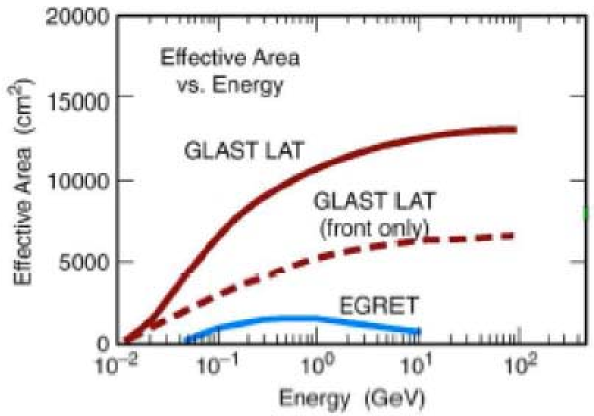
2 techniques
- < 300 GeV GLAST
- > 200 GeV Atmospheric Cerenkov



GLAST

Launched 2007. All sky survey ≠ ACT

USA-France-Italy-Sweden-Japan-Germany collaboration, launch 2007

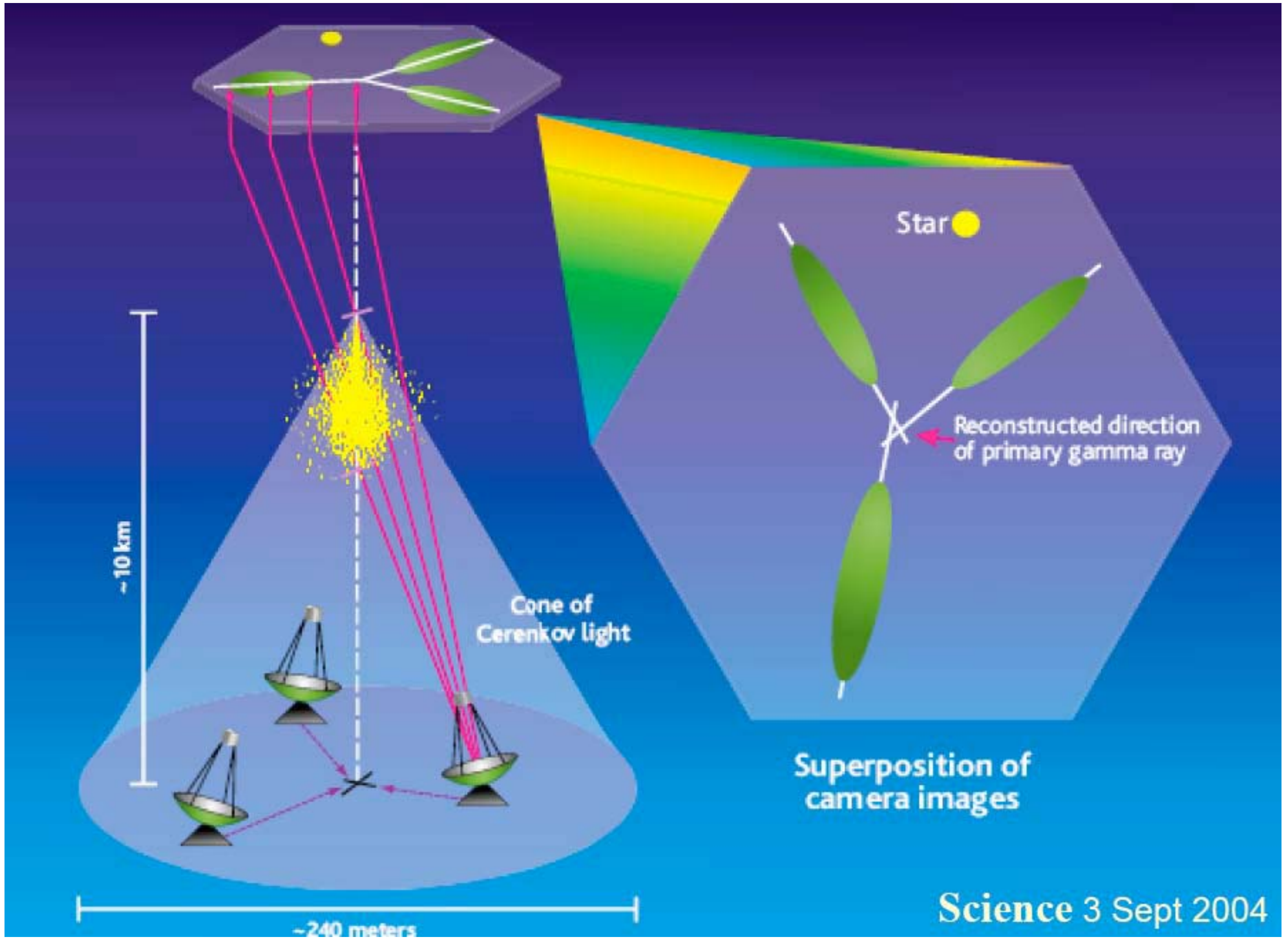


GLAST can search for dark matter signals up to 300 GeV. (It is also likely to detect a few thousand new GeV blazars …)

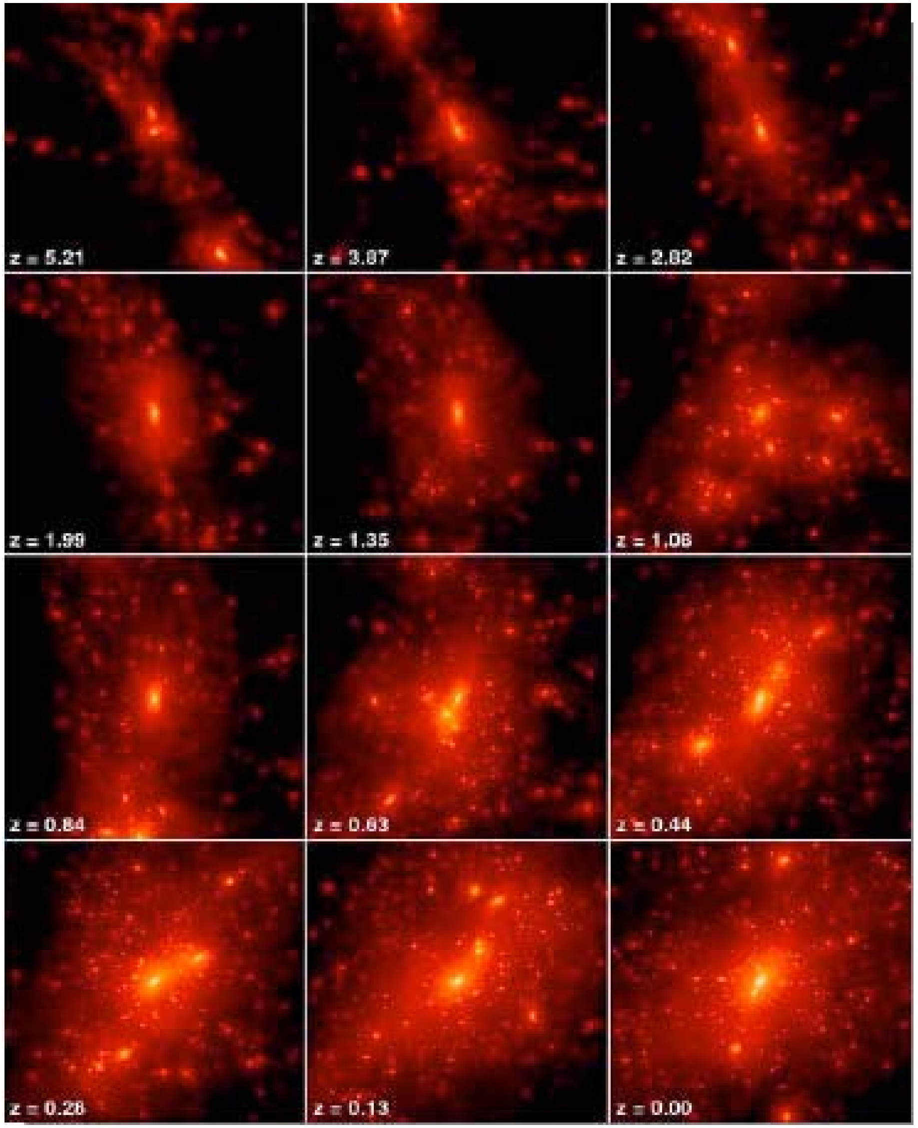
Atmospheric Cerenkov

Look at cosmic shower.

Select gamma rays by shape



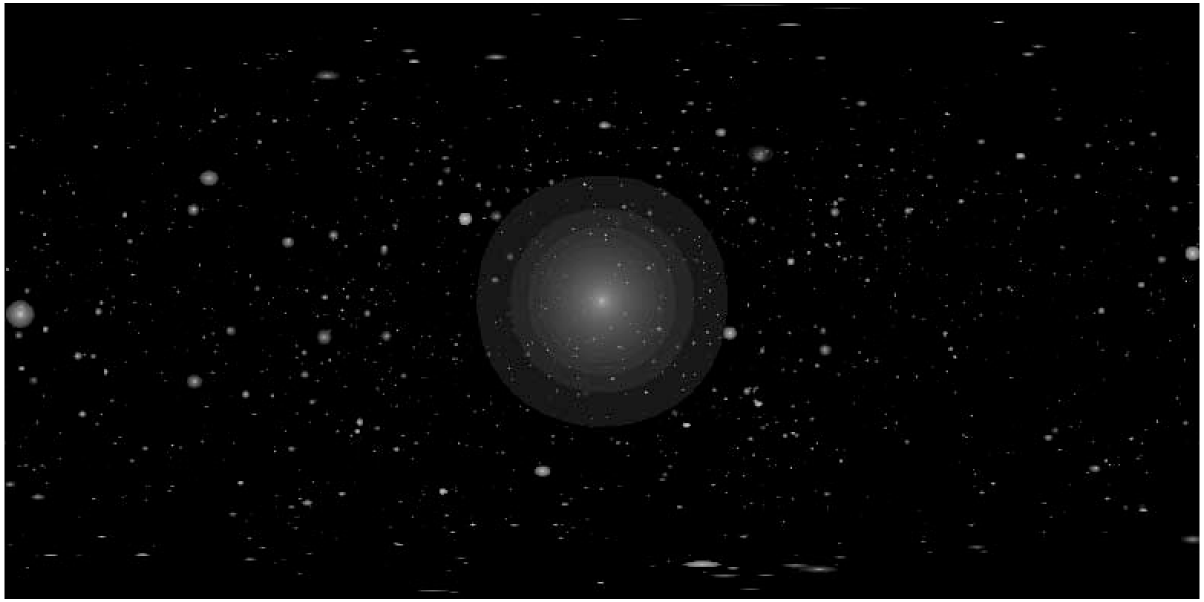
Clumps in halo



"Milky Way" simulation, Helmi, White & Springel, PRD, 2002

Boost factor $B = \frac{n^2_{clumpy}}{n^2_{Smooth}}$

Gamma Rays



The γ ray sky from Dark Matter annihilation Ted Baltz 2006 based on Taylor/Babul 2005

In SUSY

Annihilation cross section is relatively constant (50% cases maximal:Baltz)
≠ elastic cross section

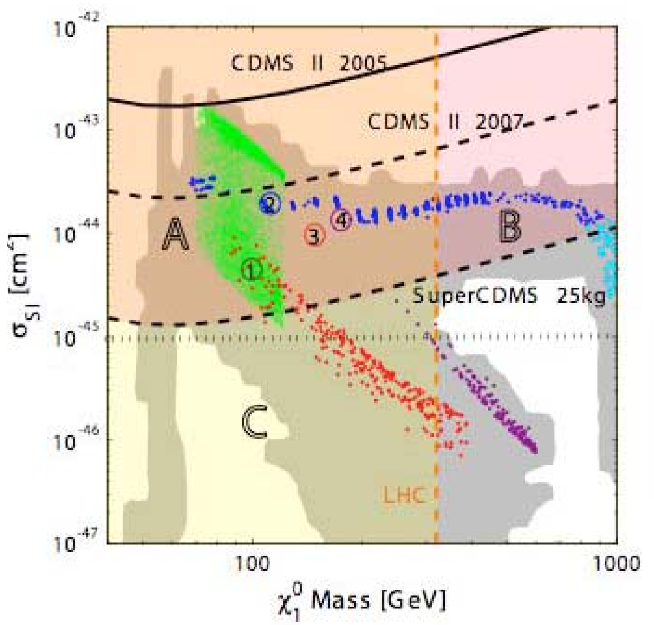
$$N_\gamma \propto J \frac{\langle \sigma v \rangle}{m} \text{ with } J \propto \int_0^r \rho^2 dr$$

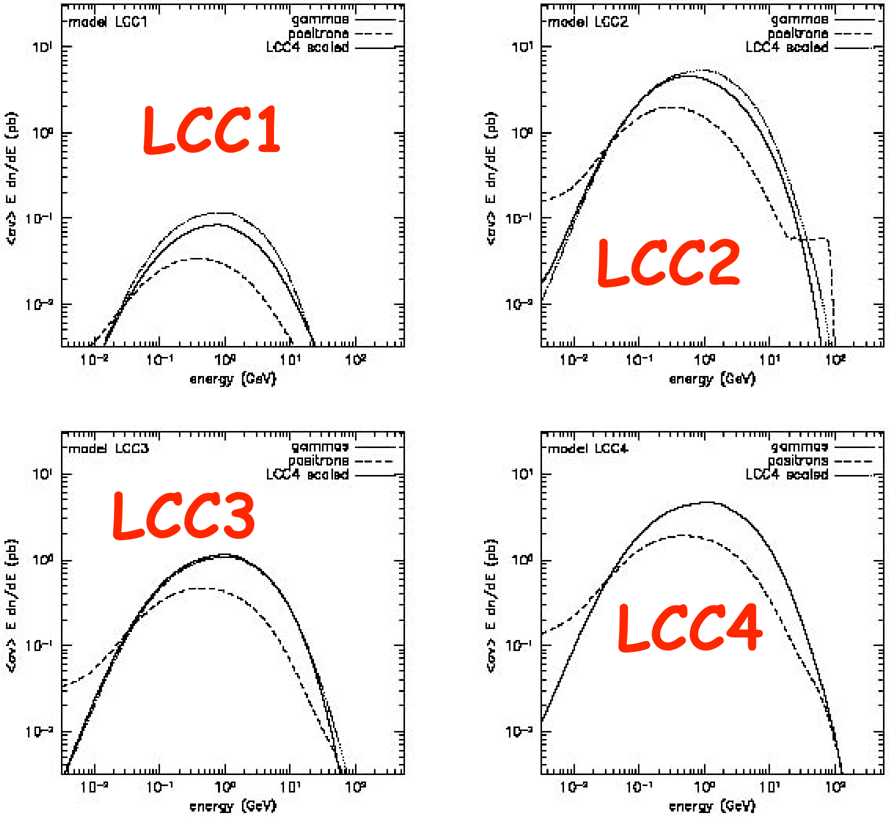
⇒Many unknown sources at high latitude: Smoking gun
⇒Map the inhomogeneities of the galaxy

Gamma and Electron spectra

Baltz et al Astro-ph 0602187

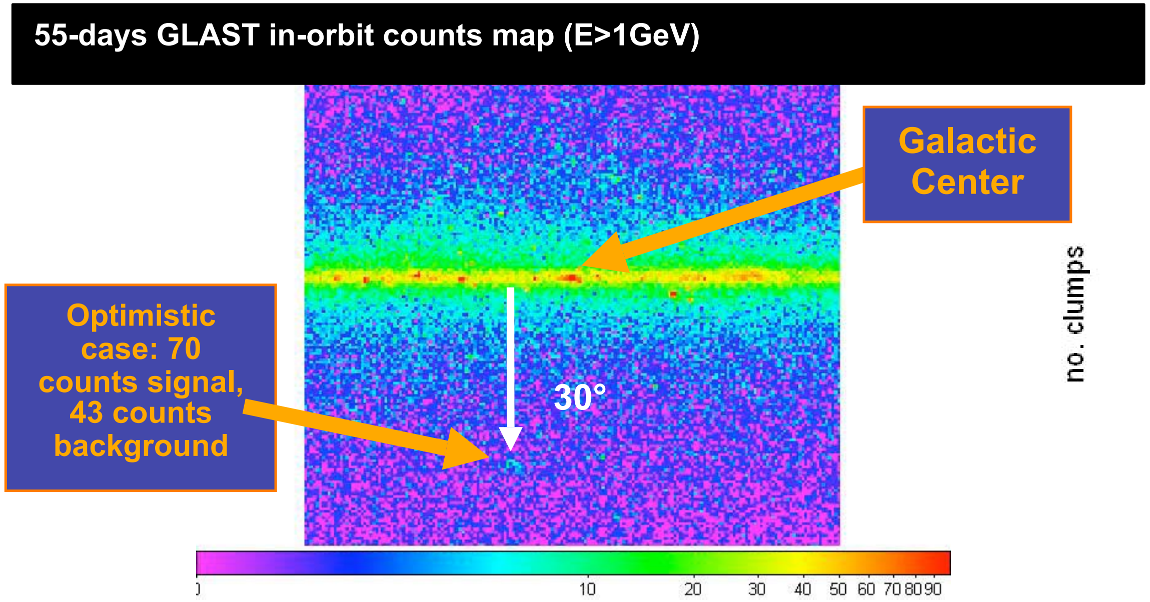
For 2 models out of 4 nearly maximal

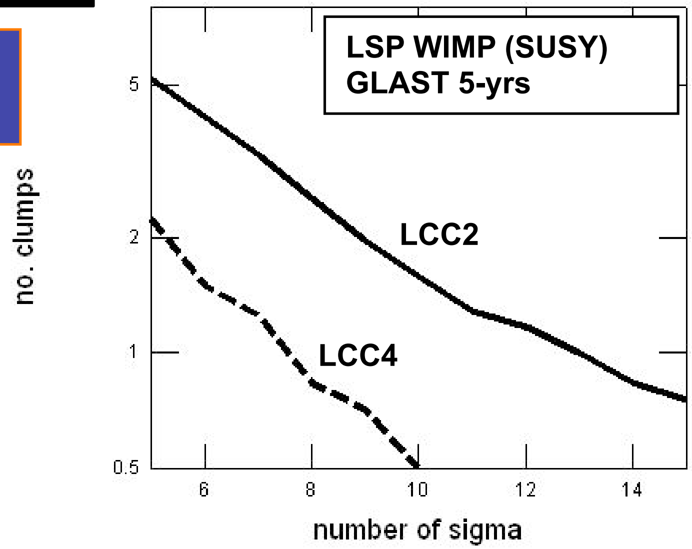




GLAST Discovery Potential

GLAST: All sky survey ≠ ACT





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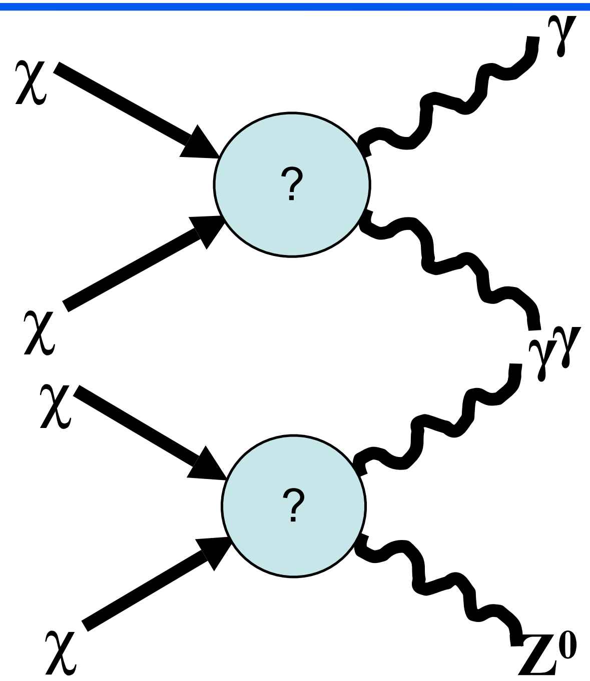
Gamma Lines

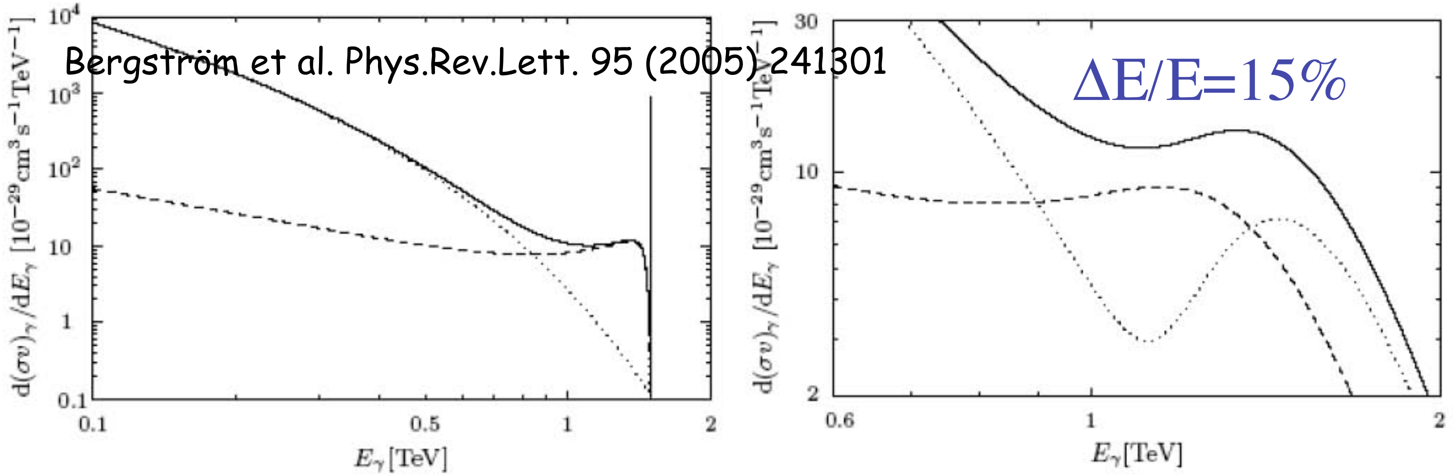
For γγ Line, energy = WIMP mass

For WIMP masses > M_Z /2

can also have γZ^0 line

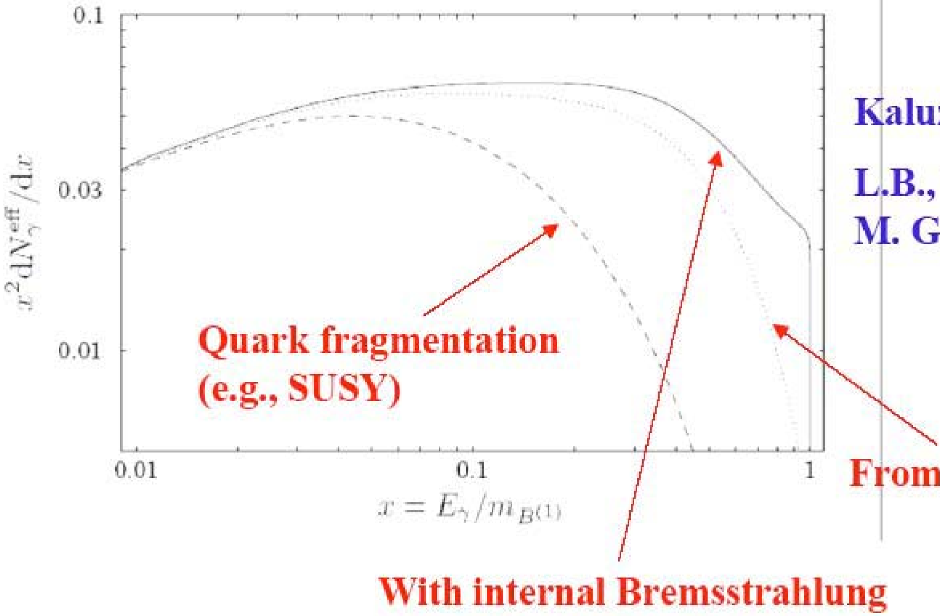


Branching fractions are in the range 10^{-2} - 10^{-4}



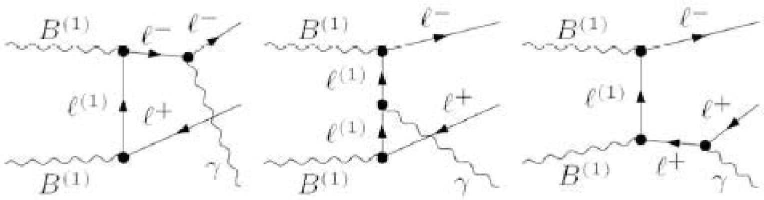
Kaluza Klein

Harder spectra



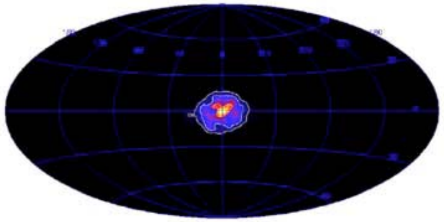
Kaluza-Klein models

L.B., T. Bringmann, M. Eriksson & M. Gustafsson, PRL 2005

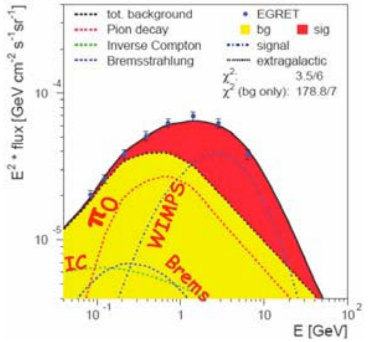


Has Dark Matter been Discovered

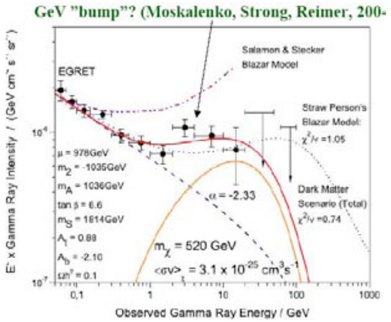
511 keV line from galactic center



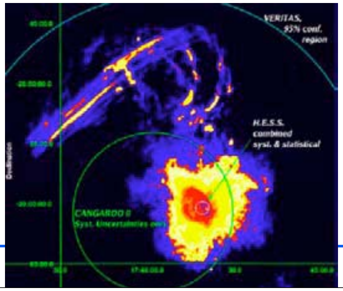
EGRET Galactic gamma rays
(50-70GeV)



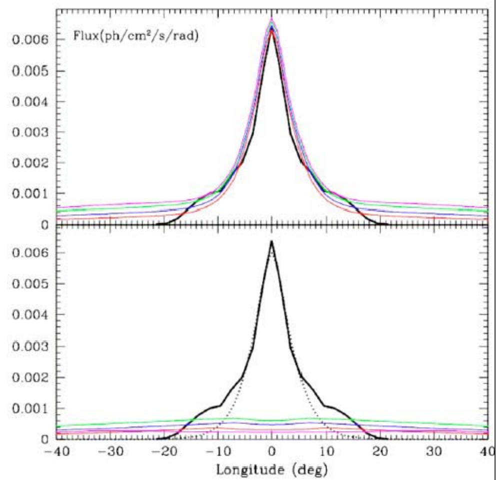
EGRET extragalactic background
(500 GeV)



TeV Signal from Galactic Center



511 keV line from Galactic Center

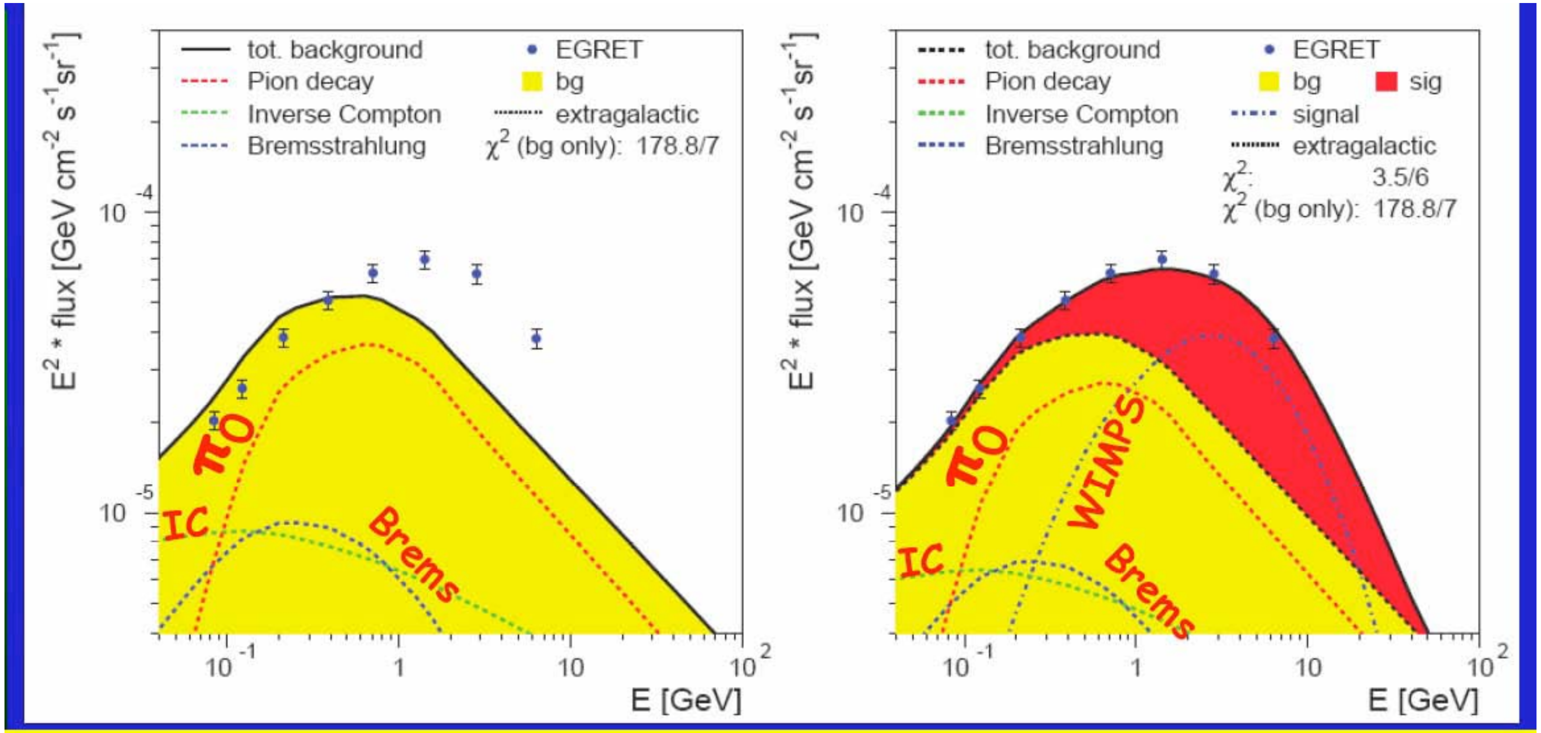


Very difficult to imagine a few MeV particle

Conventional explanation: radioactivity of SN 1a; positrons transported from disk to bulge via magnetic fields N. Prantzos, 2005

Galactic Excess "seen" by EGRET

Wim de Boer ≠ EGRET team

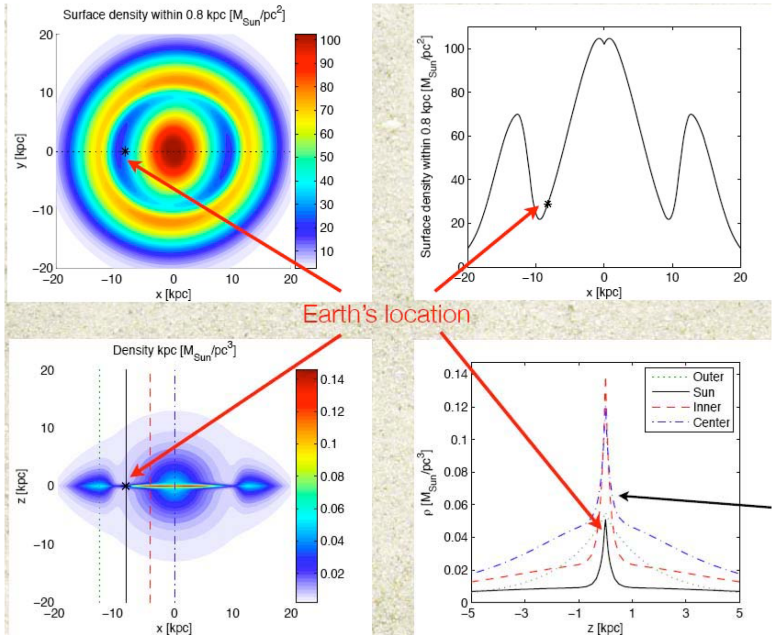


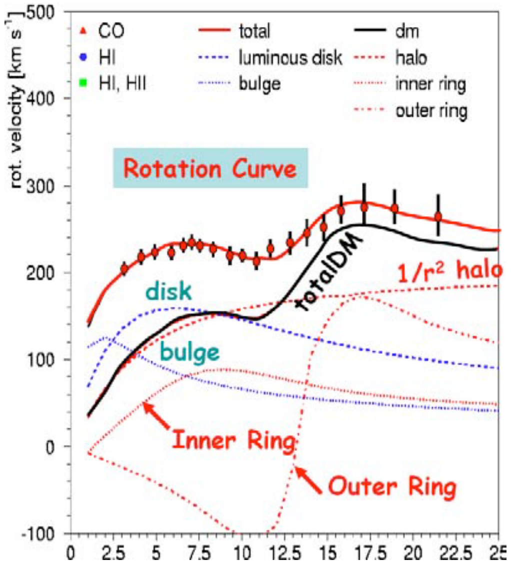
Fit only KNOWN shapes of BG + DMA, i.e. 1 or 2 parameter fit
NO GALACTIC models needed. Propagation of gammas straightforward

If normalization free, only relative point-to-point errors of ≤7% important, not absolute normalization error of 15%. Statistical errors negligible.

Galactic Excess "seen" by EGRET

No what you expect from dark matter





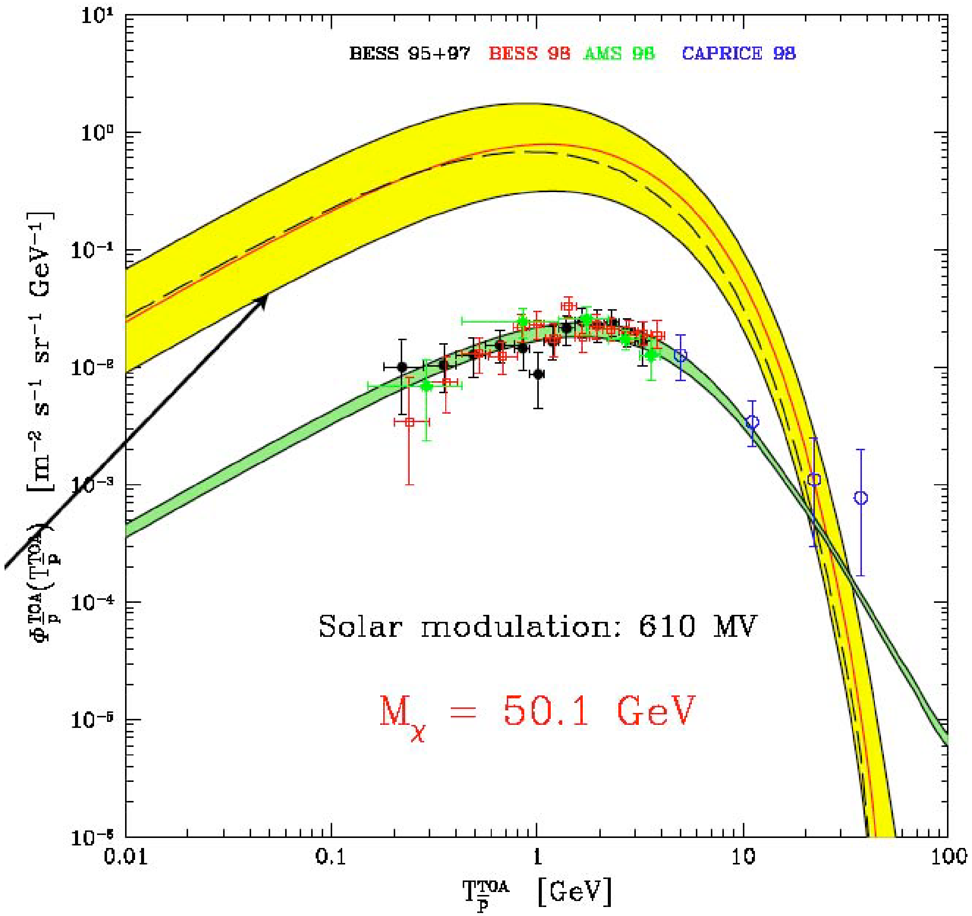
Would point to problem with cosmic ray propagation model

GALPROP: Moskalenko, Strong, Reimer

Galactic Excess "seen" by EGRET

Too large an antiproton flux

Bergström et al Astro-ph 0603632



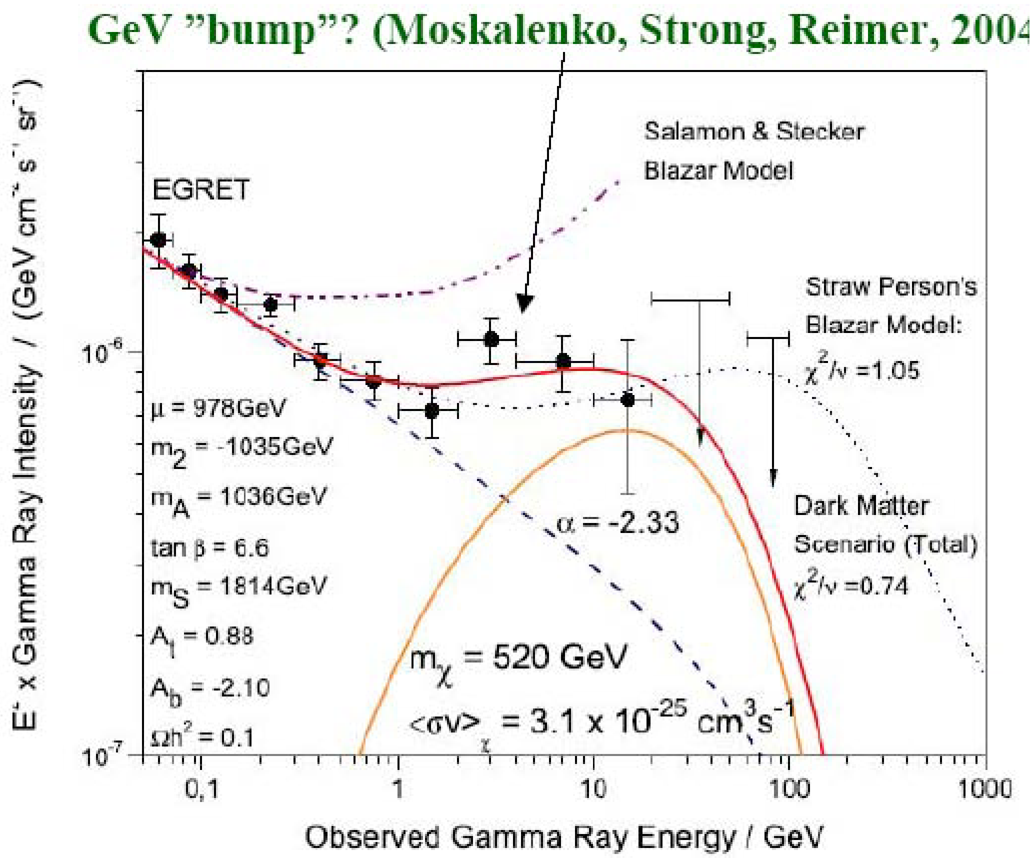
Extragalactic EGRET Excess

Elsässer et Mannheim Phys. Rev. Lett 94(2005)171302

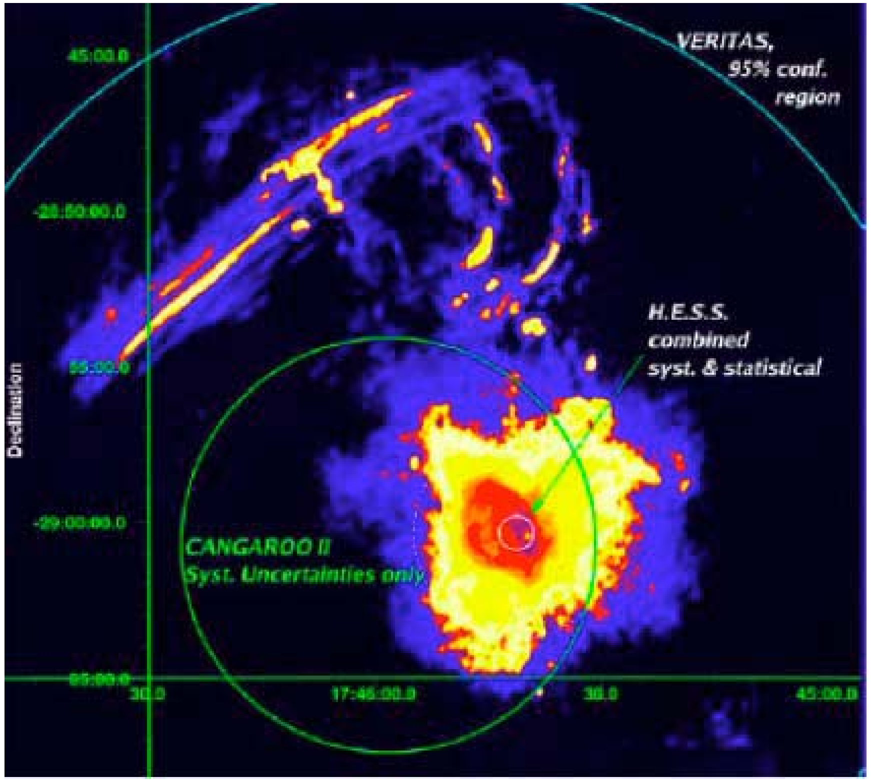
need steep profile of subhalo

+ fine tuning to get annihilation rate

Wait for GLAST!



TeV signal from the Galactic Center



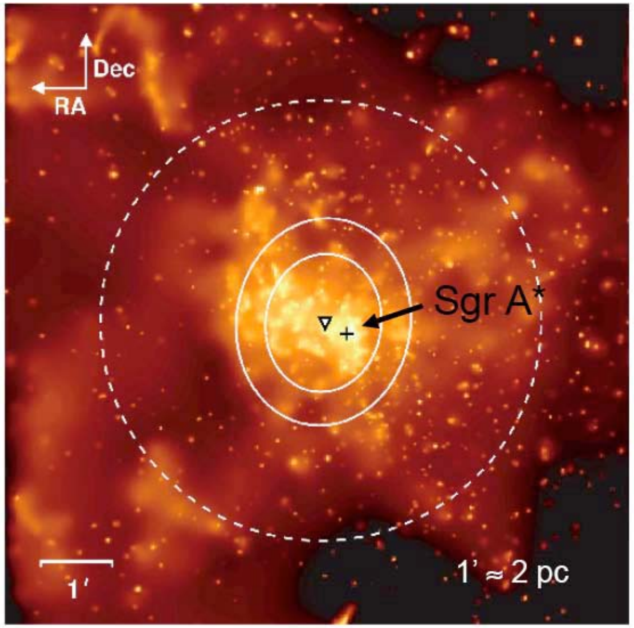
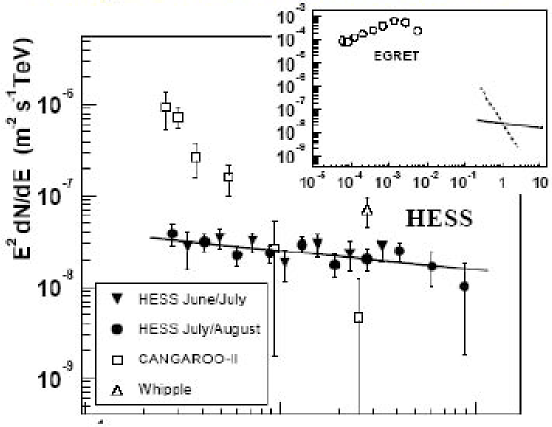


Fig. 2. Centre of gravity of the VHE signal (triangle), superimposed on a 8.5′ by 8.5′ Chandra X-ray map (Munro et al. 2003) of the GC. The

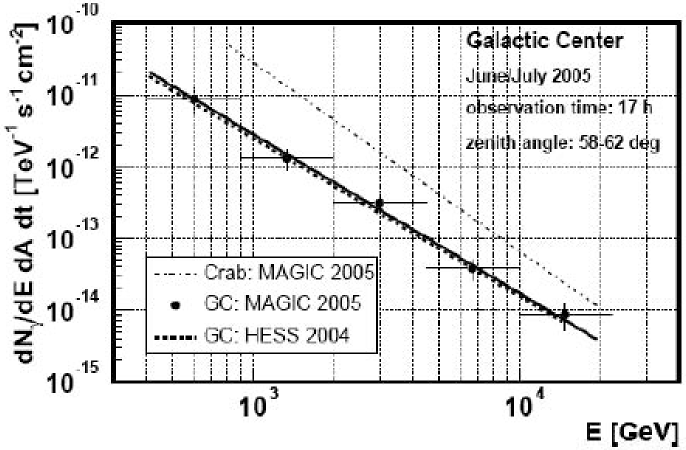
TeV signal from Galactic Center

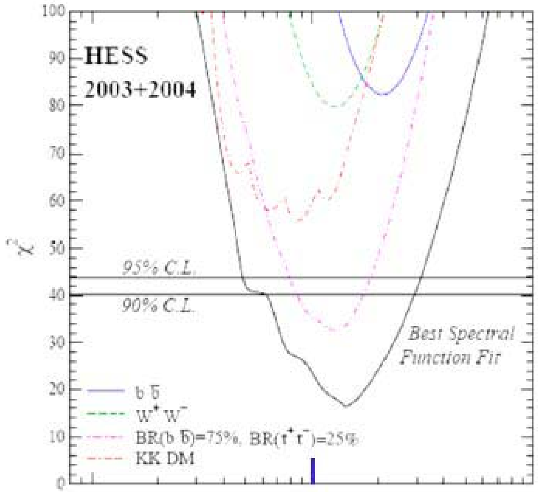
Bergström Marina Del Rey 2006

July 2004: H.E.S.S. data



MAGIC, 2006





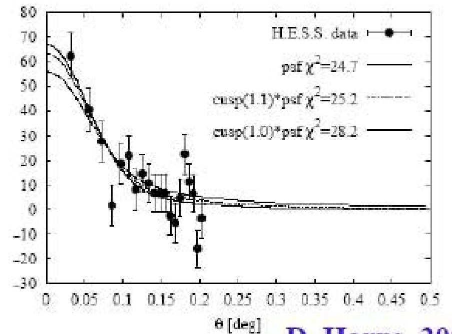
10 TeV

Need 10 – 20 TeV particle:

SUSY would need finetuning

(S. Profumo, 2005; see also J. Hall & P.Gondolo, 2006)

Angular distribution consistent with cusp

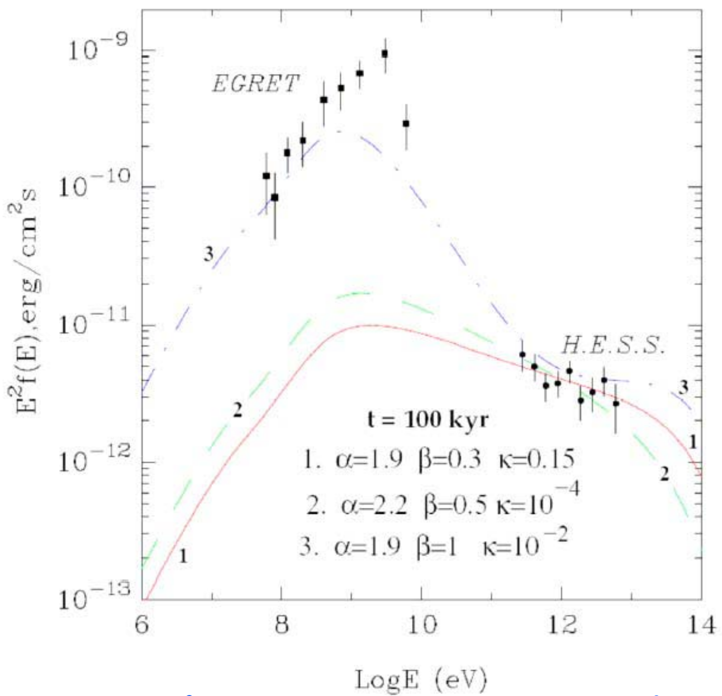


D. Horns, 2004

TeV signal from Galactic Center

Interpretation

Dark matter 10-20TeV
Sagitarius A* (3 10^6 Black Hole)
Sag A* East (SN remnant)
Plerionic source
Interaction cosmic rays with Molecular Clouds
Aharonian and Neronov 2005



Note: another source seen on Galactic Center Ridge

Positrons

Spectral features possible

- annihilations to W pairs
- electron / positron line

  Tiny branching ratio in SUSY

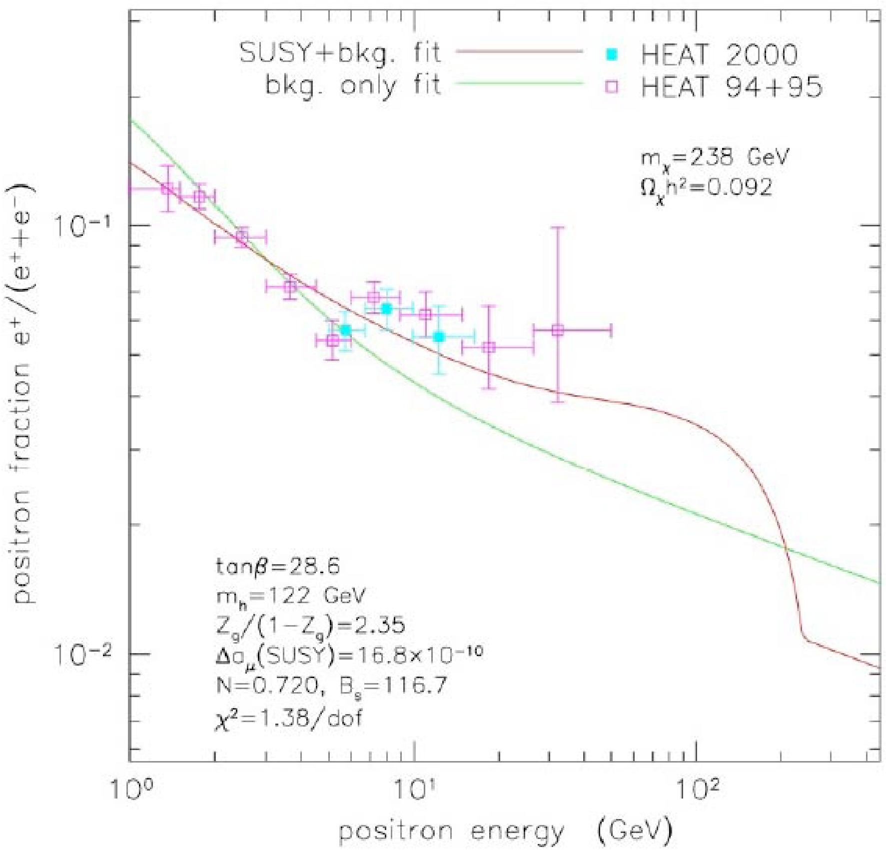
  KK particles - dominant mode!

Features can survive diffusion and energy loss in the galaxy

HEAT excess?

PAMELA will sort this out soon

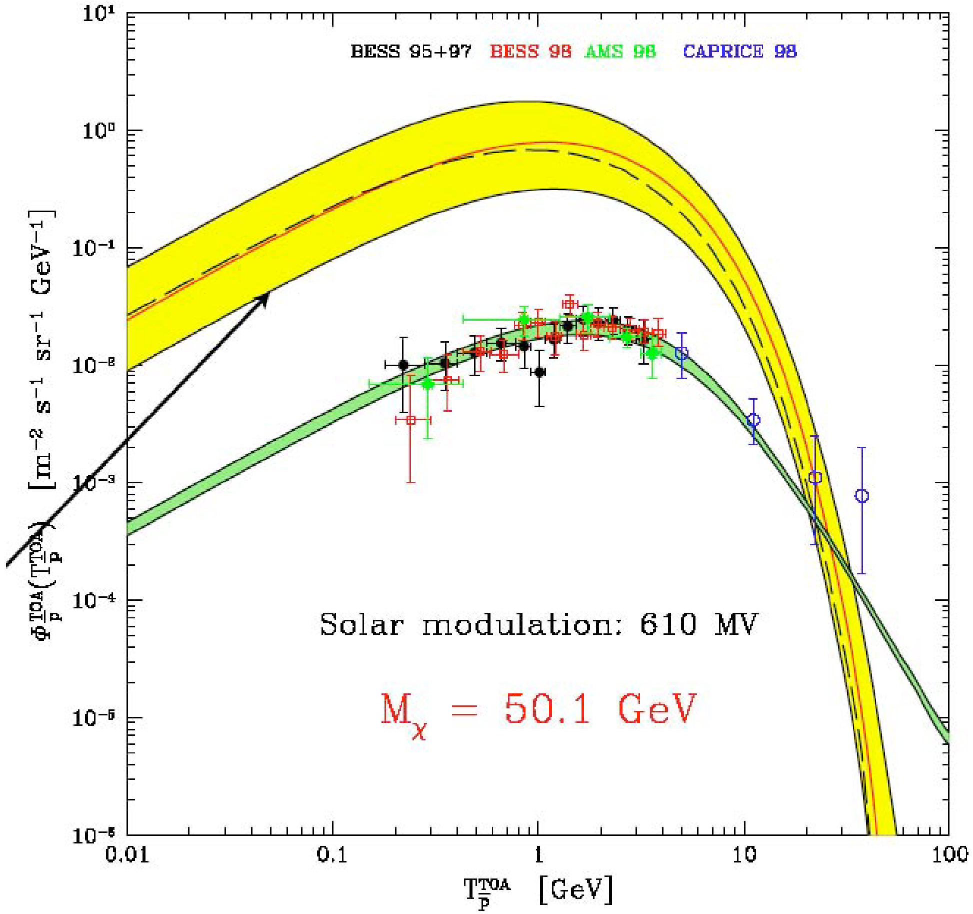
Unfortunately large uncertainty on propagation



Antiprotons and Antideuteron

Currently

Pamela, AMS

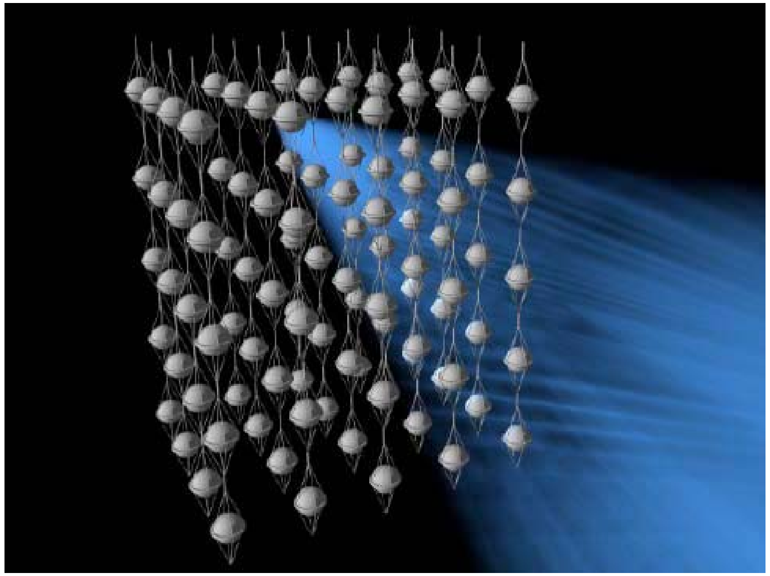


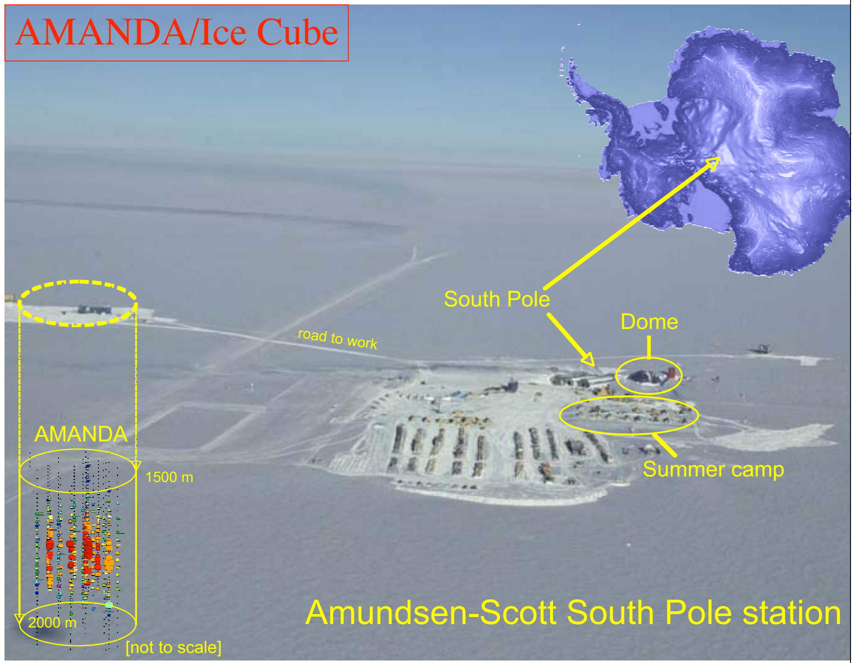
Unfortunately large uncertainty on propagation

High Energy Neutrino Detection

Look for Cerenkov light from muon

in ice: AMANDA-> Ice Cube (1km^3)
in deep sea : Antares, Nemo, Nestor + Baikal

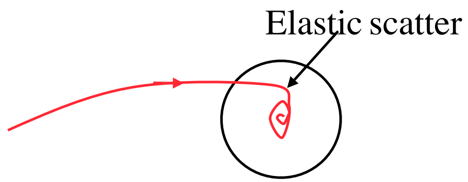




Neutrinos from Sun/Earth

Capture by sun & earth

Trapped
=> annihilation in center



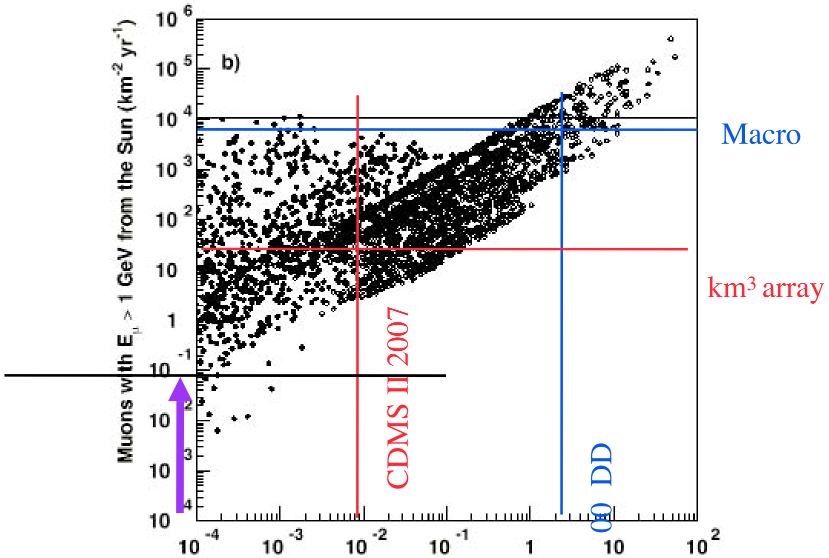
Observable: high energy neutrino

$$\frac{dn}{dt} = \Gamma_{elast} n - \Gamma_{ann} n^2 \;\Rightarrow \text{in equilibrium } \Gamma_{ann} n^2 = \Gamma_{elast} n$$

$\Rightarrow$ measure elastic scattering

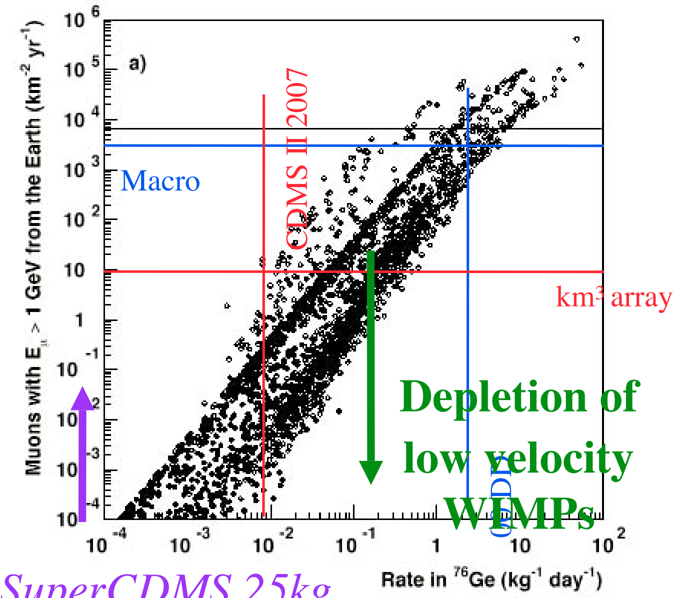
More or less proportional

Sun (also spin dependent)



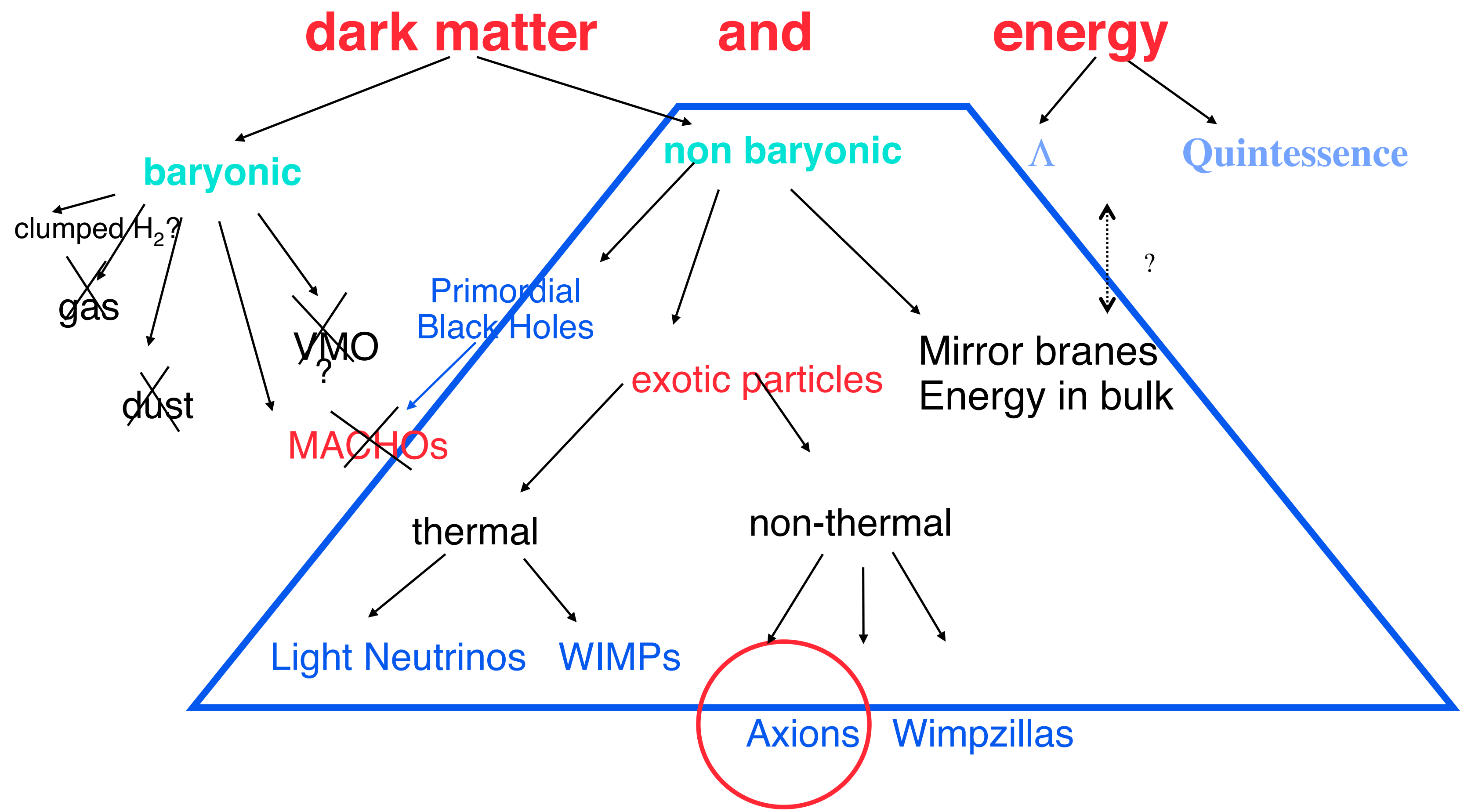
SuperCDMS 25kg

Earth



SuperCDMS 25kg

Deciphering the Nature of Dark Matter



Axions

Invented to save QCD from strong CP violation

Current experimental limits are such that if they exist, they have to be cosmologically significant

Window: 10^{-6}-10^{-3} eV

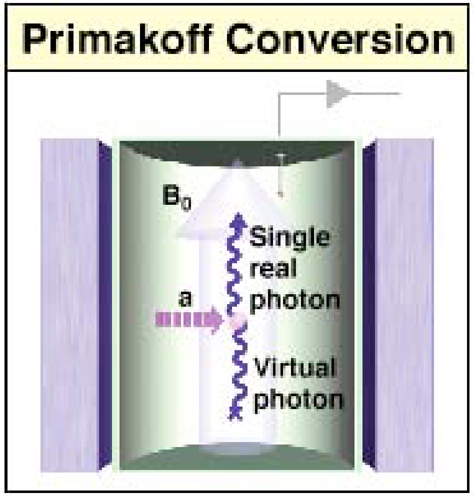
Produced out of equilibrium

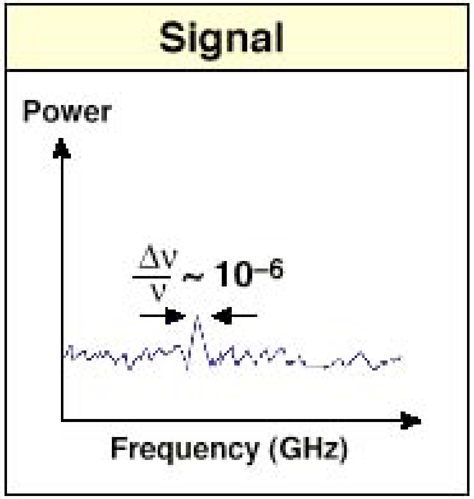
Theoretical discussion if Peccei Quinnn symmetry breaking occurs after inflation
=> global strings which radiate axions. Technically difficult to compute (Shellard≠Sikivie)
Loss mass region may be not favored

Method of detection

$$m_a = 0.62\text{eV}\left(\frac{10^7\text{GeV}}{f_a}\right)$$

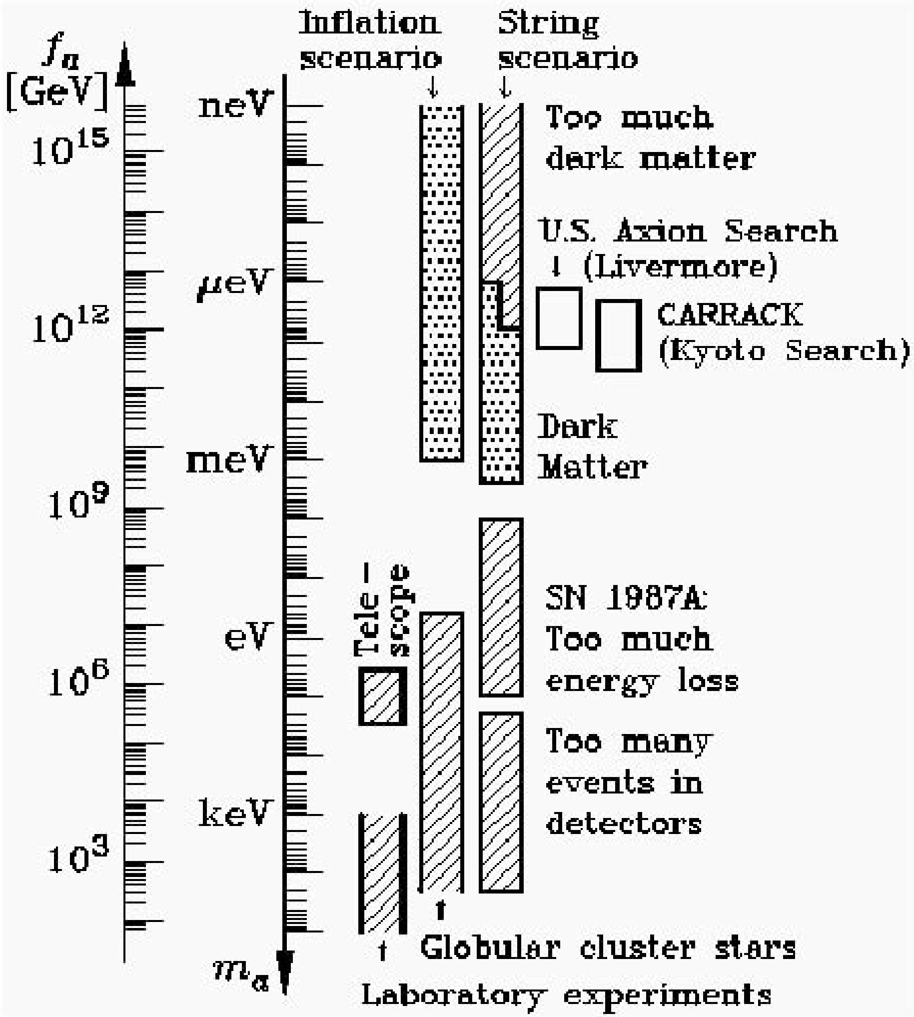
$$L_{a\gamma\gamma} = \left(\frac{\alpha_{em}}{2\pi f_a}\right)\vec{E}.\vec{B}\times O(1)$$





Tunable cavity: Most suitable for low mass region

Axion limits (Raffelt)



Axions

After 2 pilot experiments missing sensitivity

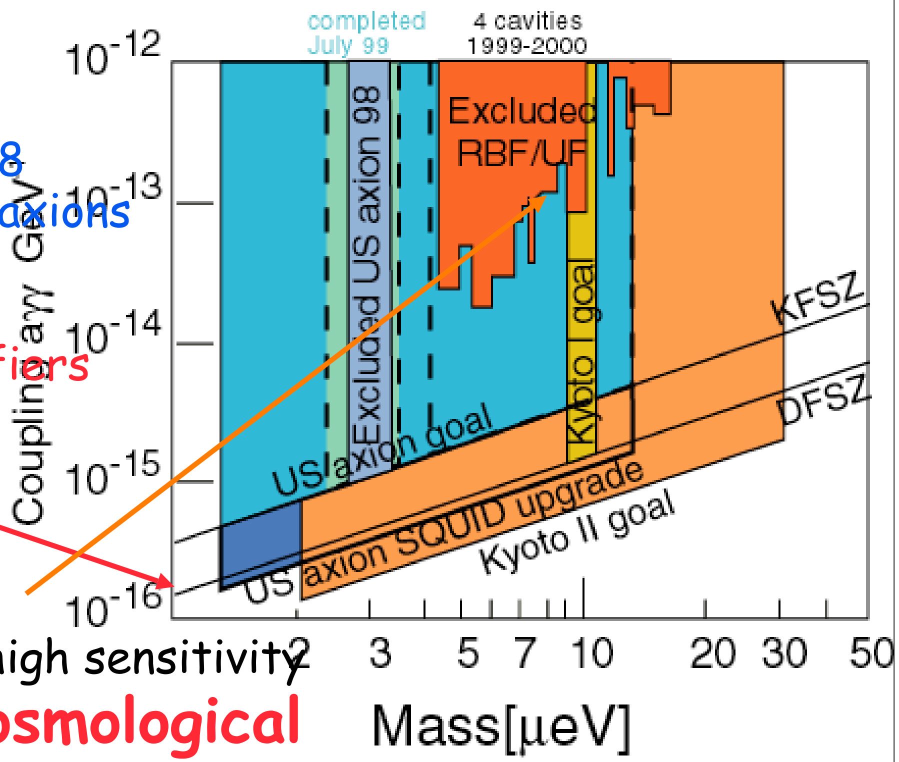
The US axion experiment

Livermore-MIT-UC Berkeley/LBNL
- U. Florida -U. Chicago/FNAL
- -INR Moscow experiment

First data analyzed, published, PRL 98
demonstrated sensitivity to KSVZ axions

Currently scanning wider region

Approved upgrade :DC SQUID amplifiers
Allowing to reach DFZS



Kyoto experiment

Matsuki et al. (Rydberg atoms)
Starting in narrow region but high sensitivity

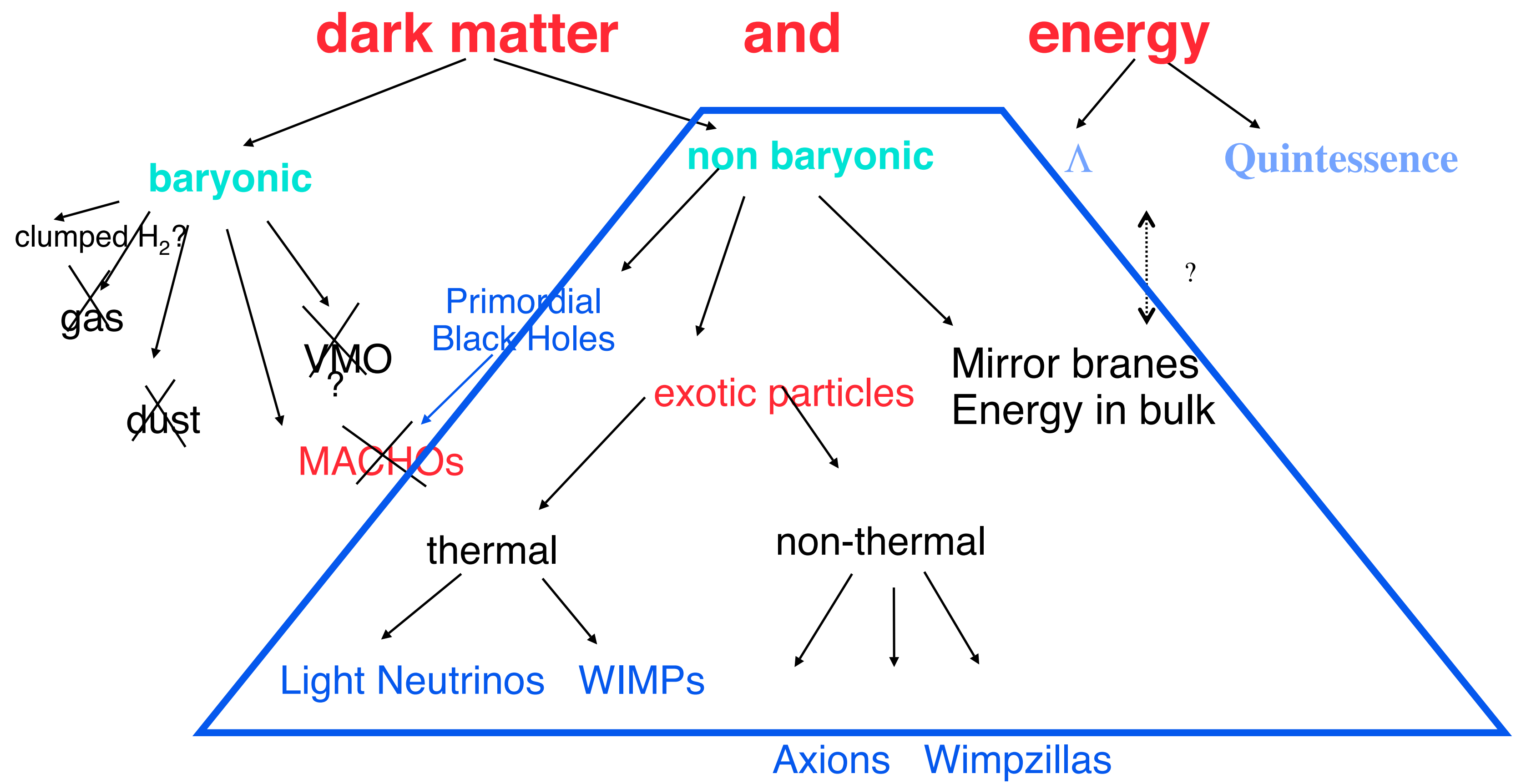
These experiments reach a cosmological sensitivity!

Potential Problem: one decade out three mass decades allowed

New idea (Adelberger et al.)

Torsion balance matter. magnetic field interaction

Deciphering the Nature of Dark Matter



Other Candidates

WIMPZILLAs

10^{12} Gev/c^2

Gravitational production toward the end of inflation

Chung,Kolb,Riotto Phys. Rev. Lett. **81** (1998) 4048, Phys Rev **D 59** (1999)23501 and **D 60**(1999) 63504

Kuzmin and Tkachev Phys Rept **320** (1999) 199 and Phys rev **D 59** (1999) 123006

Disruption of virtual pairs of particles/antiparticles (vacuum fluctuations) by fast expanding space

Resulting particle density independent of the interaction strength!

Can be electrically charged, strongly interacting etc...

Detection

May be responsible for high energy cosmic rays: fine tuning of decay time?

If strongly interacting, could lead to high energy τ neutrino from sun/earth

Many Other Possible Candidates!

Proposed strategy

Investigate whether they are at all allowed by existing limits

Analyze existing data to put constraints

Only embark in major search program if there are at least two independent justifications and the model is generic

Conclusions

Fascinating time in cosmology

Extraordinary progress (CMBR, Large Scale Structure)
But profound mystery
- What is the non baryonic dark matter?
- What is this mysterious dark energy?

+ unnaturalness of the model which recalls the artificiality of epicycles

From this point of view: 2 scientific priorities

Detect Dark Matter: show that it is not an epicycle
- if we succeed this would be a second Copernican revolution!
- very much linked to fundamental particle physics
  - Neutrino mass and see saw mechanism
  - Supersymmetry
  - May be even baryogenesis

Constrain better the nature of Dark Energy and if possible pin down its properties in the laboratory!
- Likely that we are touching some very fundamental underlying property of quantum gravity

Conclusions 2

Searches for WIMPs are essential

Theoretical convergence of Cosmology
Particle Physics
Also convergence of instrumental approaches:

Complementarity of Colliders
Direct Detection
Indirect Detection

Direct Detection Roadmap

Elastic scattering identifying event by event nuclear recoil
Phonon mediated detectors are leading the pack
challenge: extrapolate to 100kg/1 ton
Importance => Development of other large mass technology
liquid Xe or Ar is best candidate but will need some time to master complex phenomenology

Best route to connection to galaxy is low pressure TPC: Particle Physics technology: we should be ready to make ≈10000 m^3 chambers

Indirect detection could provide important smoking gun

Eventually we might be able to have a full self consistent picture between colliders, direct and indirect detection:nature of Dark Matter