Overview of the Challenges and open problems in APP theory

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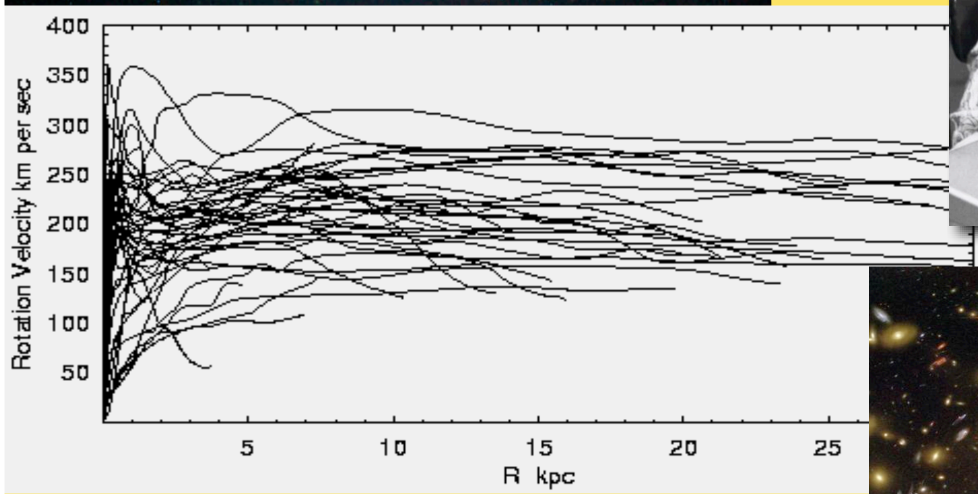
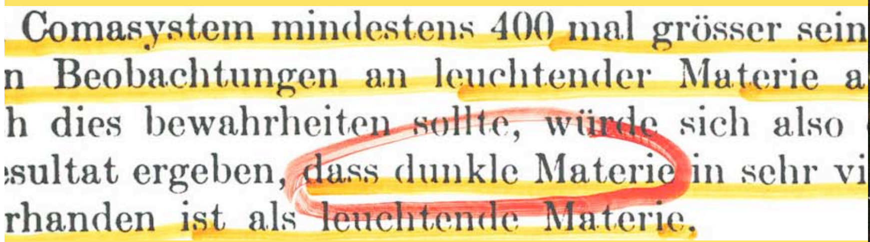
March 17, 2008

Multi-messenger science complements radio/optical/ir/xr astronomy

APP explores regimes where LHC or ILC cannot go

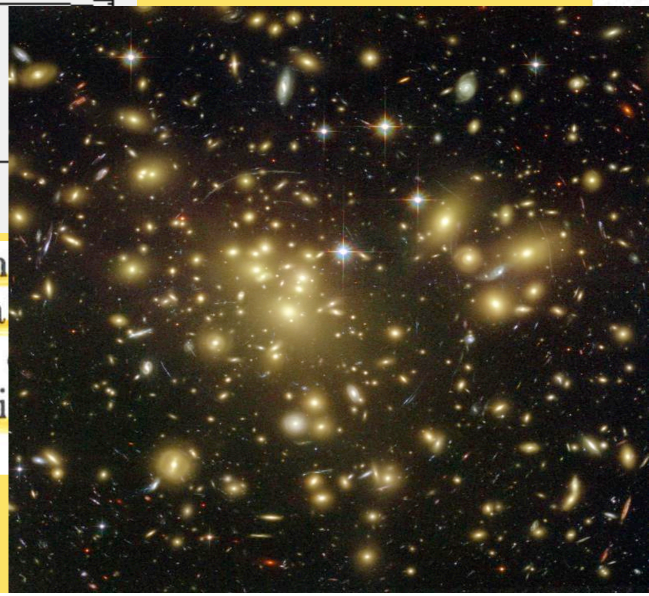
A Brief History of Dark Matter





Comasystem mindestens 400 mal grösser sein
n Beobachtungen an leuchtender Materie a
h dies bewahrheiten sollte, würde sich also
esultat ergeben, dass dunkle Materie in sehr vi
rhanden ist als leuchtende Materie.

Vera Rubin

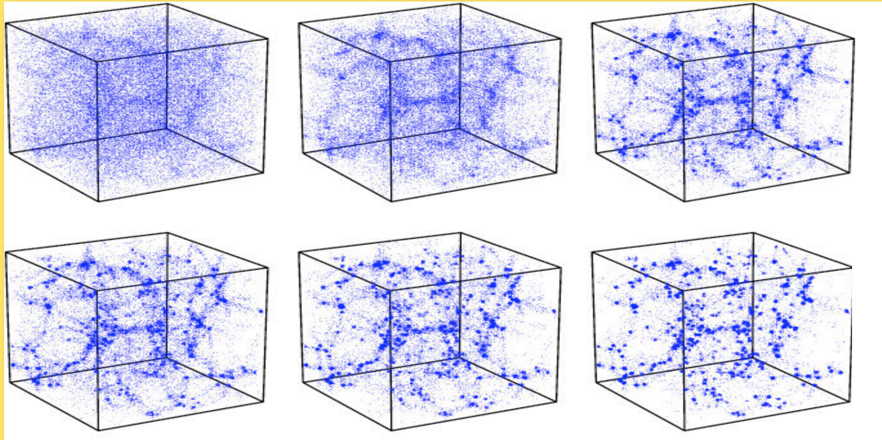


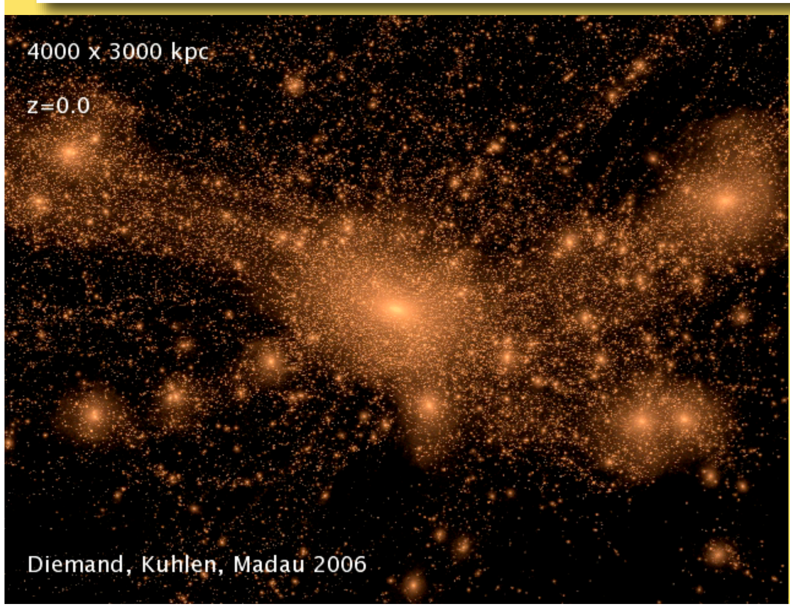
Fritz Zwicky

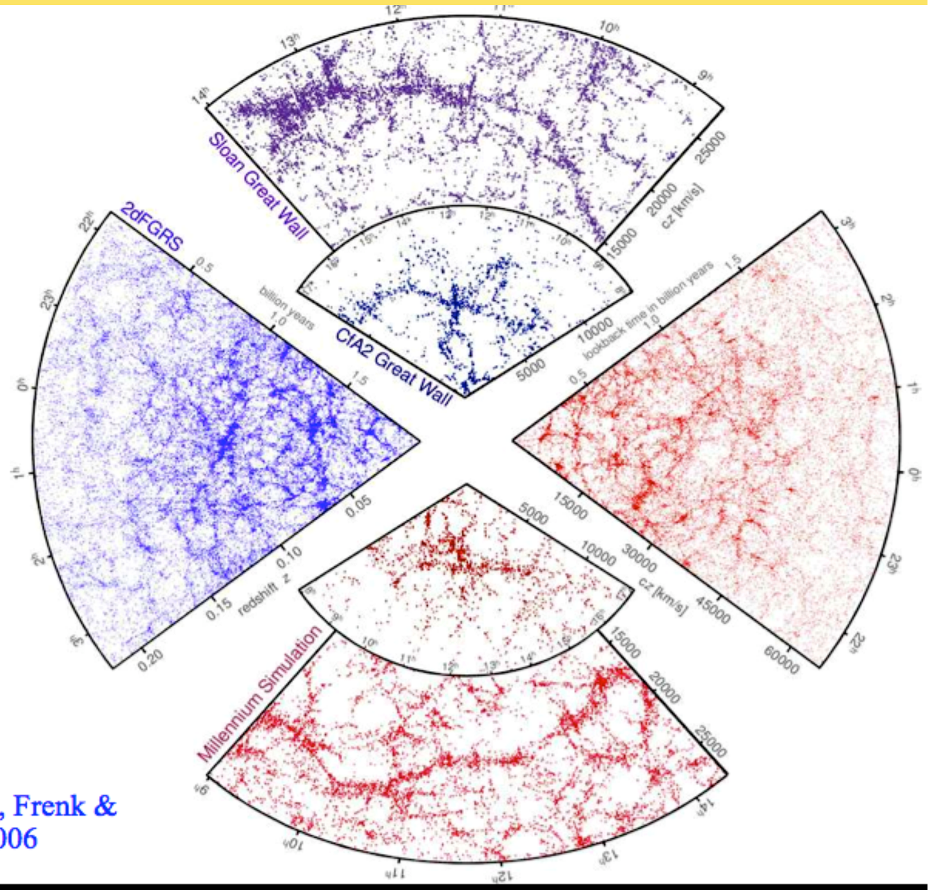
•***WIMPs*** - Weakly Interacting, Massive Particles - are the leading class of dark matter candidates

•The large scale structure of our universe matches that predicted for ***cold***, ***collisionless*** dark matter

•WIMPs seed structure growth and predict a clumpy dark halo



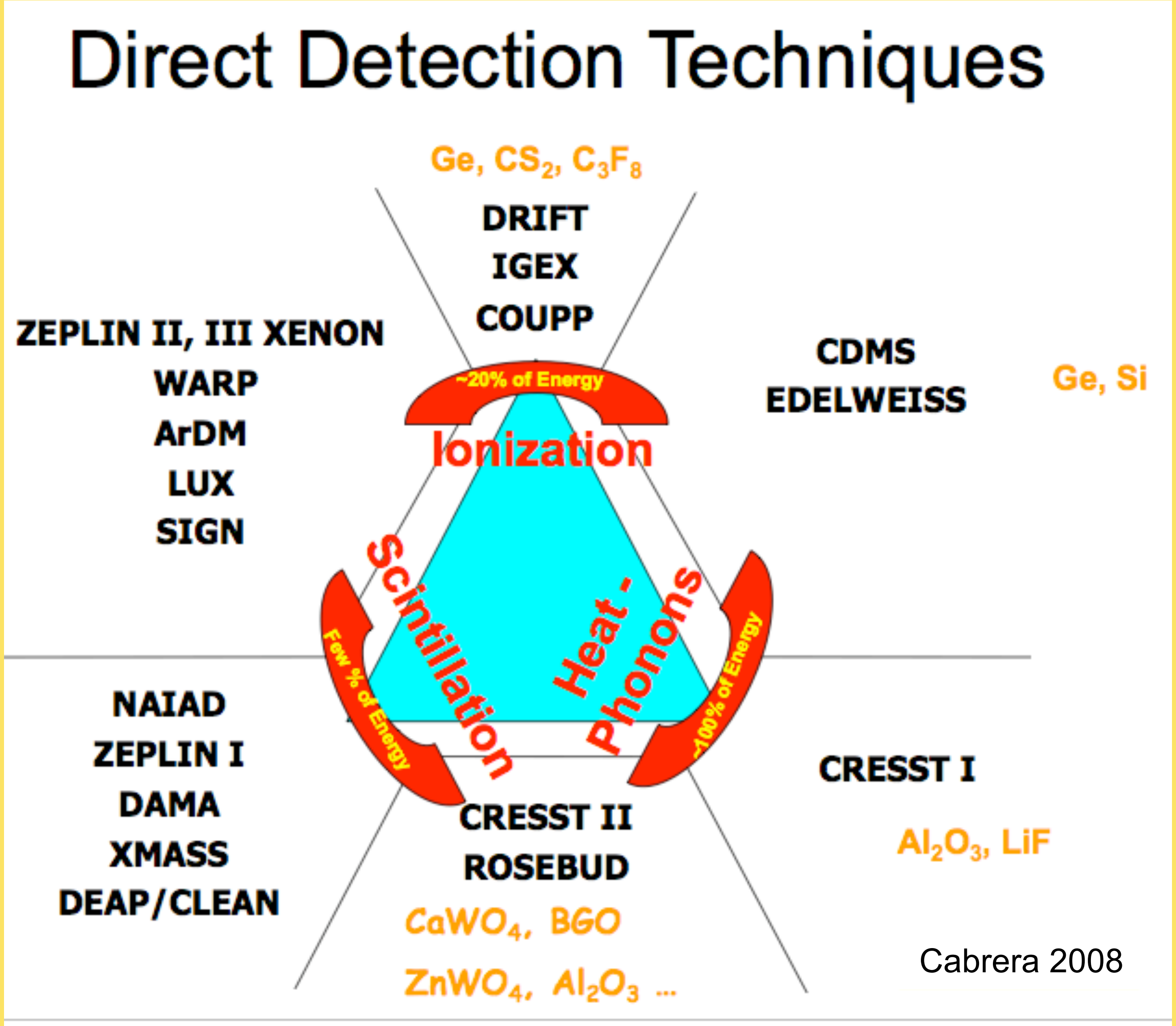


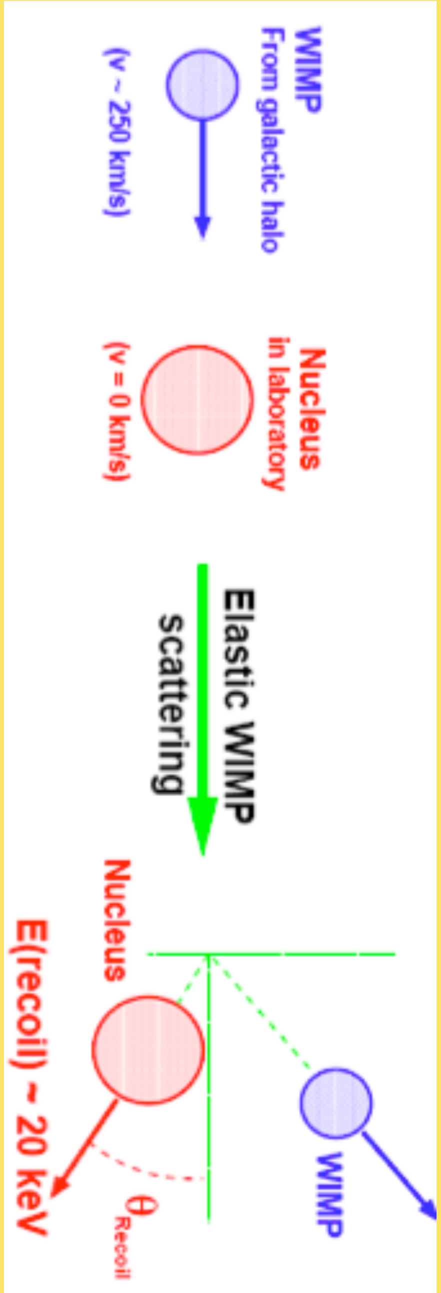


Springel, Frenk &
White 2006

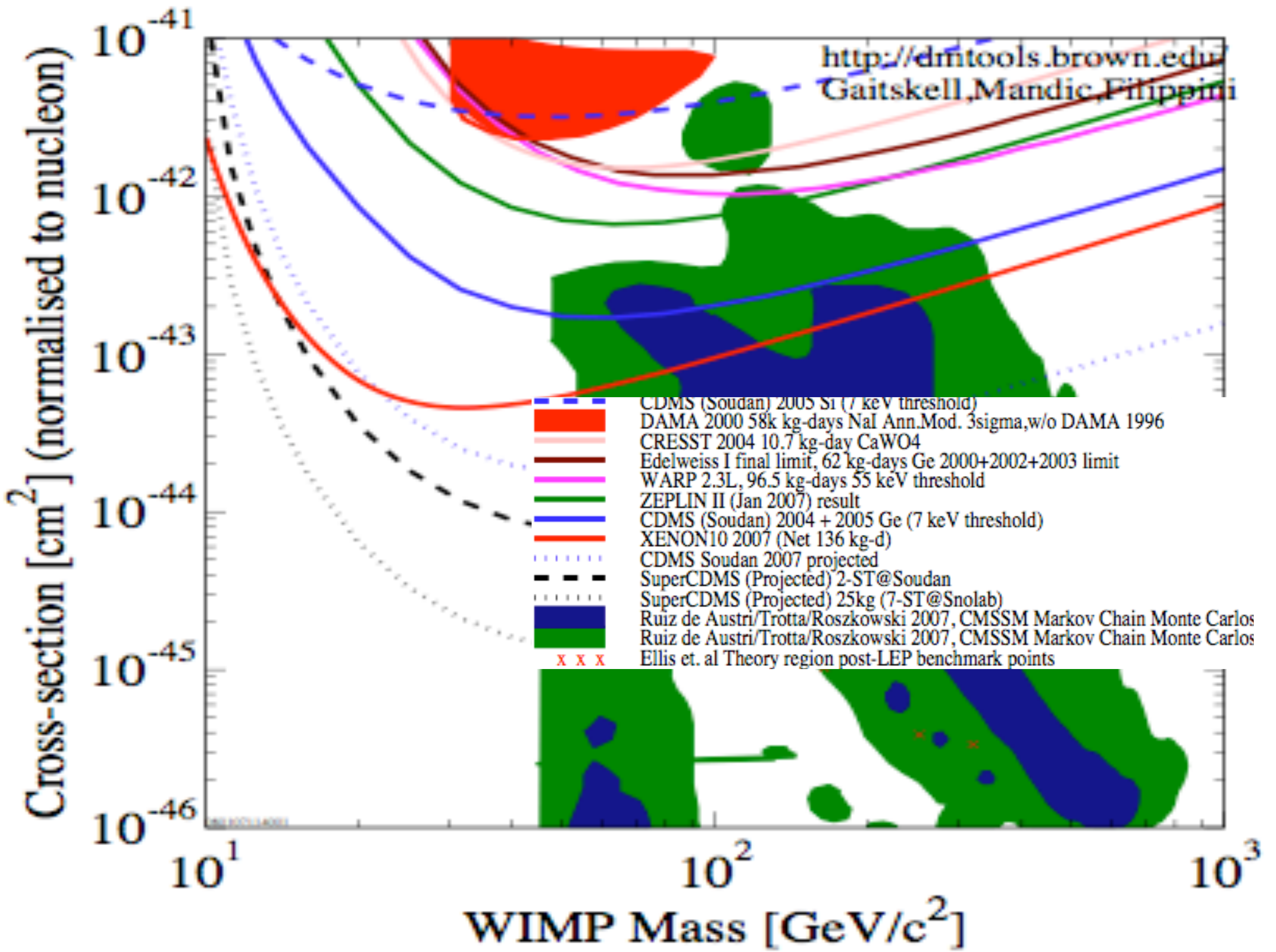
DETECTING THE MILKY WAY DARK HALO:

about ten million WIMPS per sq meter per sec pass through the earth

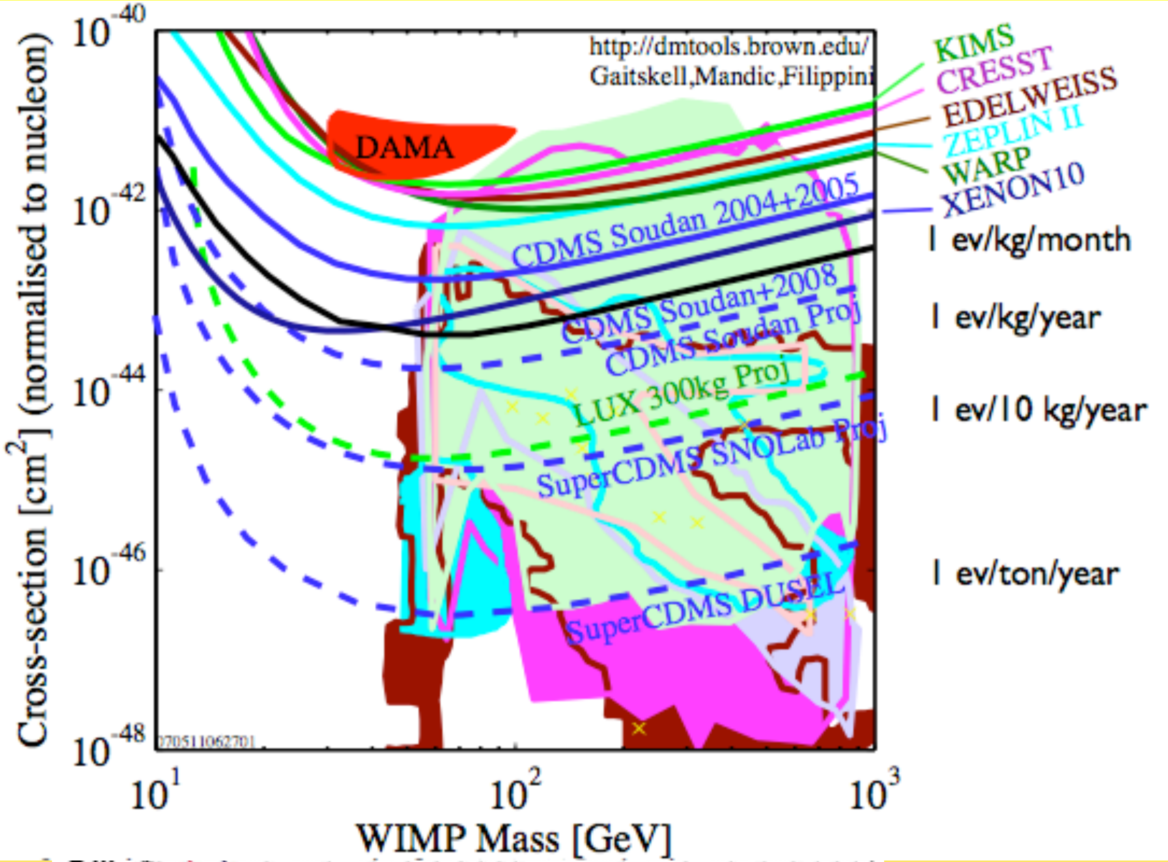


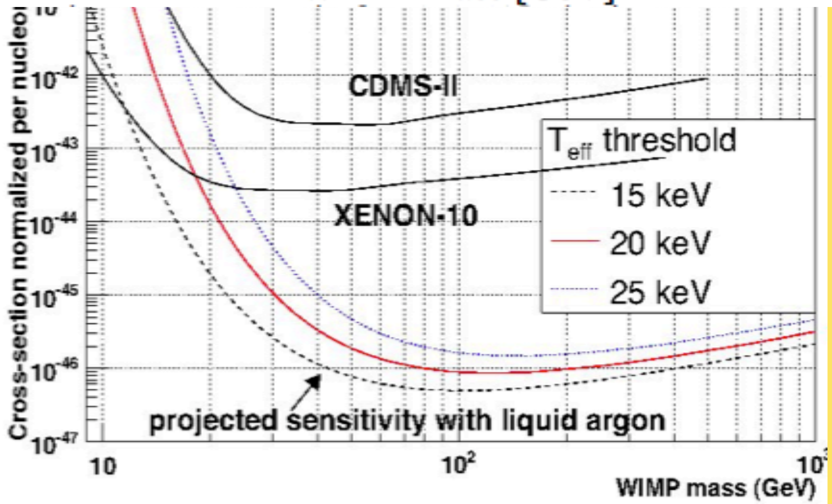


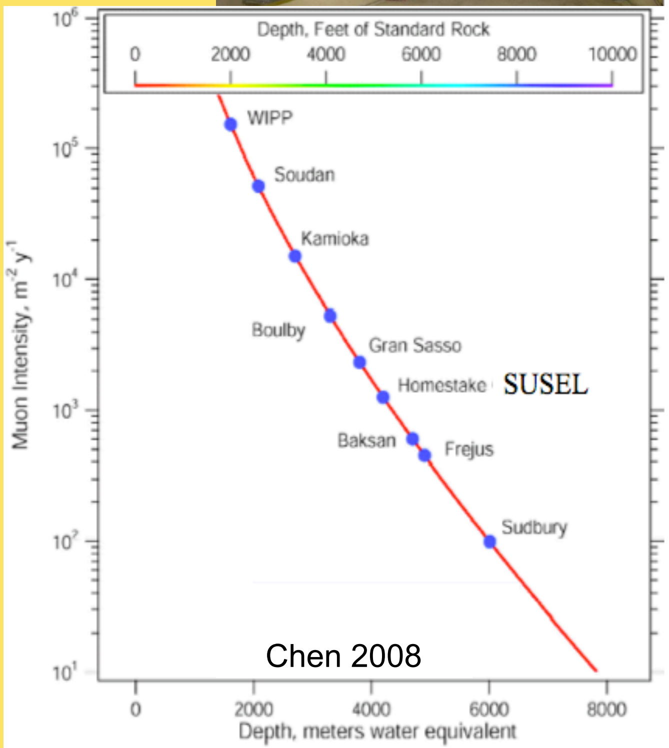
DIRECT DETECTION OF DARK MATTER: 2007 LIMITS



DIRECT DETECTION OF DARK MATTER: FUTURE PROSPECTS



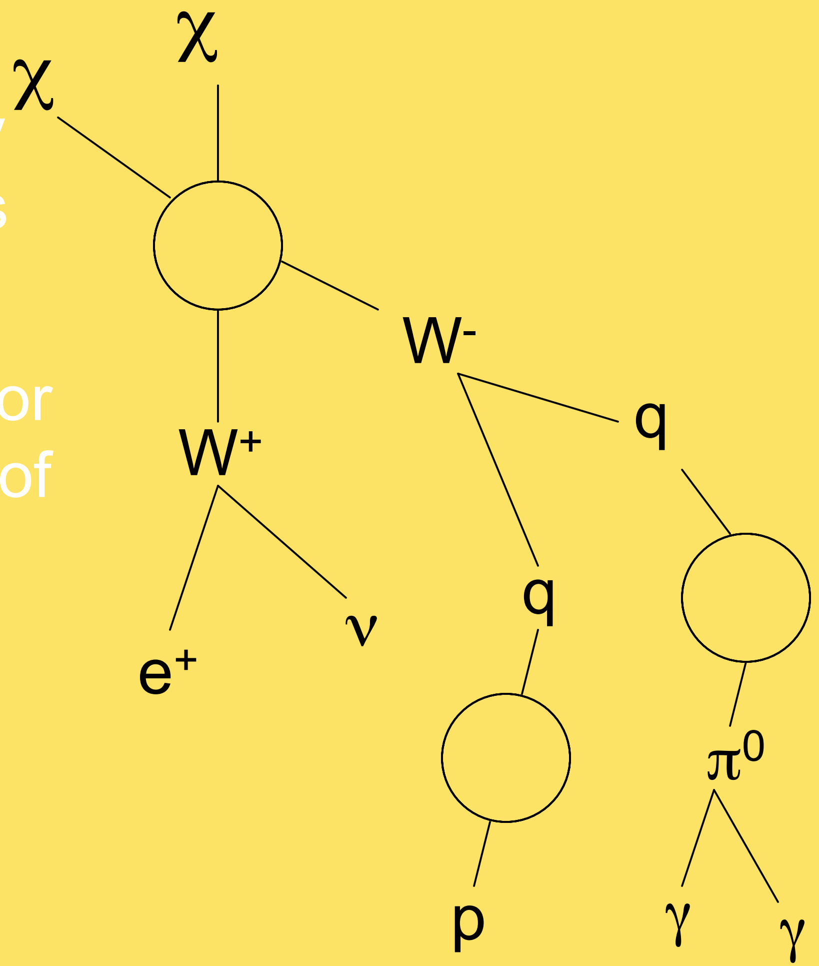




Indirect Detection of Dark Matter

1) **WIMP Annihilation**
   Typical final states include heavy fermions, gauge or Higgs bosons

2) **Fragmentation/Decay**
   Annihilation products decay and/or fragment into some combination of high energy electrons, positrons, protons, antiprotons, deuterium, neutrinos and gamma rays



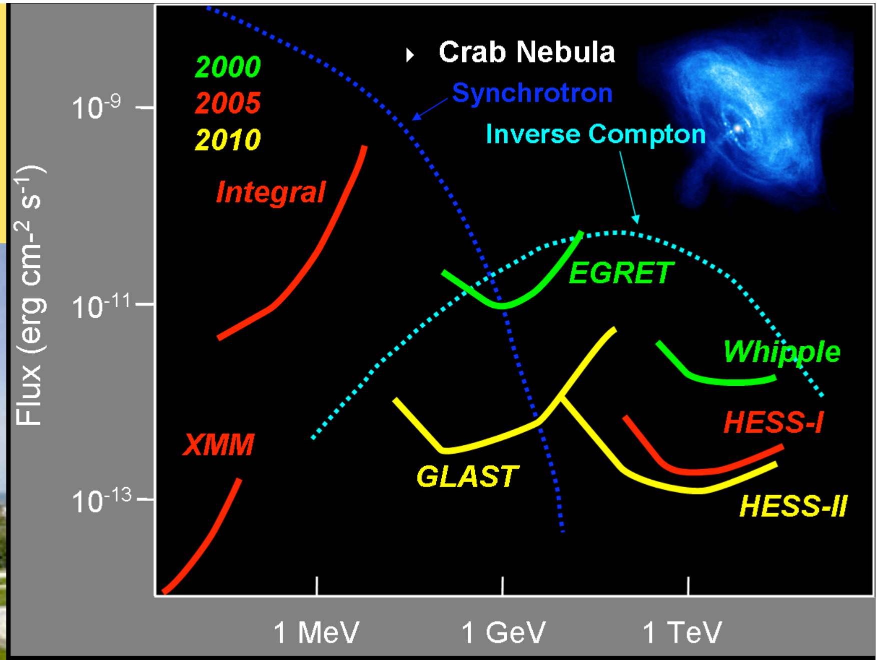
GLAST

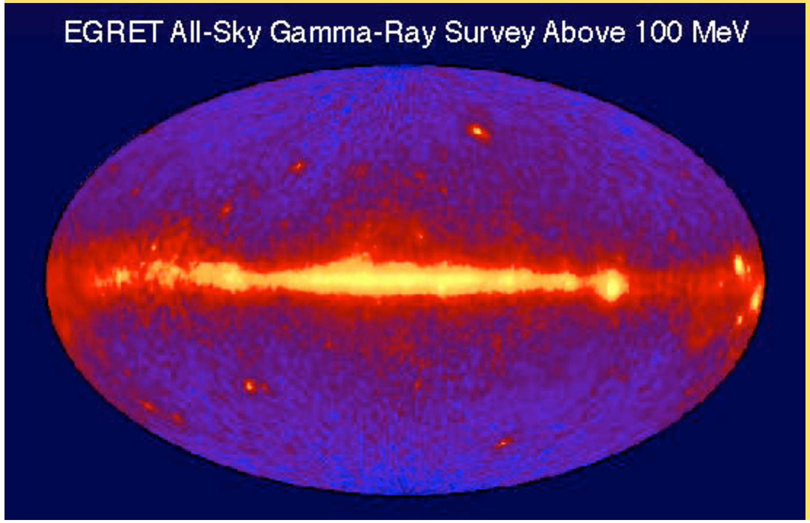
NASA-DOE-Italy- France-Japan-Sweden, Germany

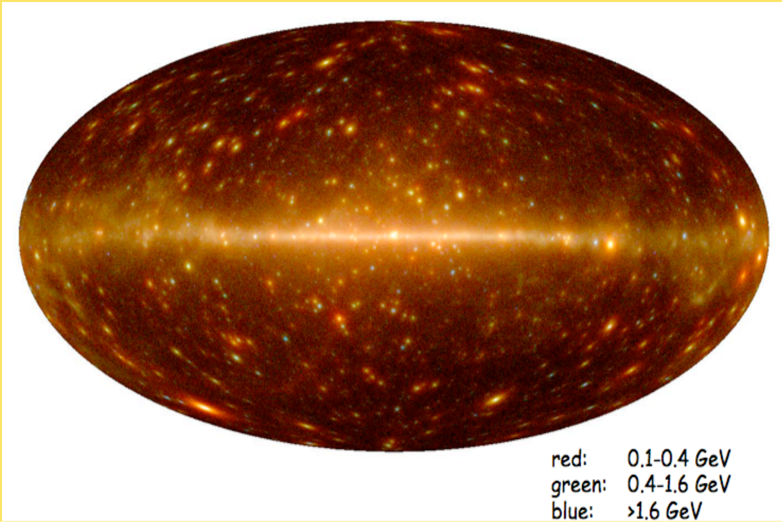
Launch May 16 2008

50-100 x EGRET; high energy extension

- 0.02 - 300 GeV
- 2.5 sr, 0.3 - 0.9m^2
- 5^o - 5' resolution
- Δln E ~ 0.1
- 3 x 10^{-9} cm^{-2} s^{-1} (>0.1 GeV, point source))
- All sky every 3hr

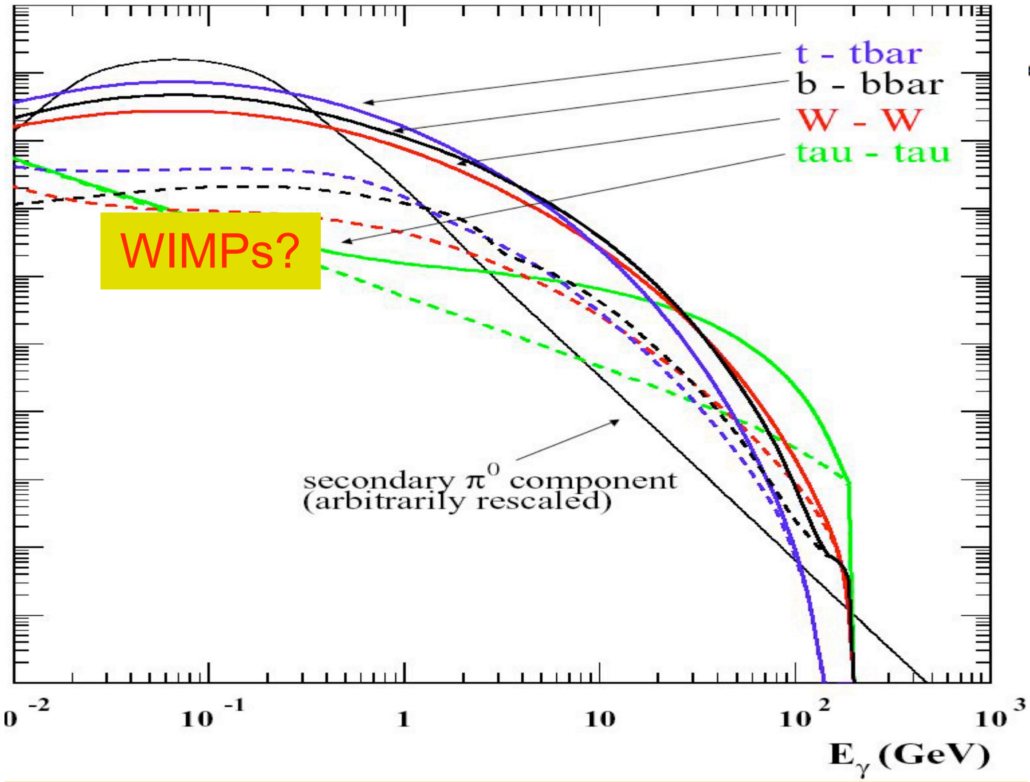


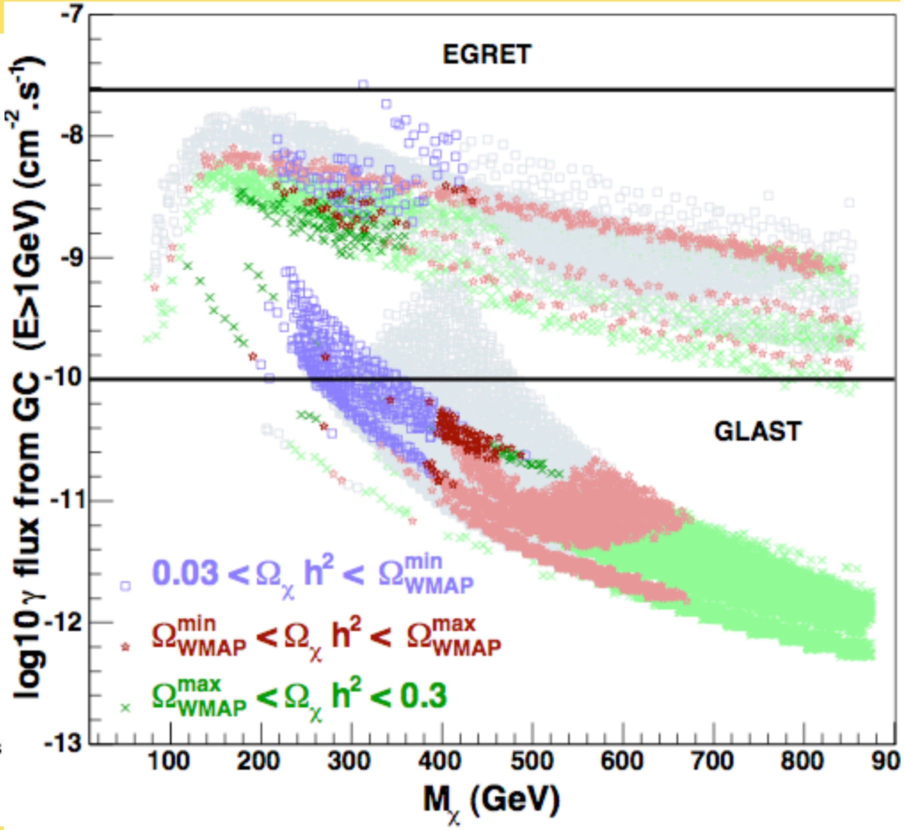




Gamma-rays and dark matter annihilations

Relic WIMP annihilation cross-section of 3×10^{-26} cm^3/s predicts $\sim 10^{39}$ GeV/sec annihilation power for ~100-1000 GeV WIMPs $\longrightarrow \pi^0$ gamma rays





WIMPS: Gamma-Rays from the inner Galaxy

annihilation of 100-1000 GeV WIMPs:

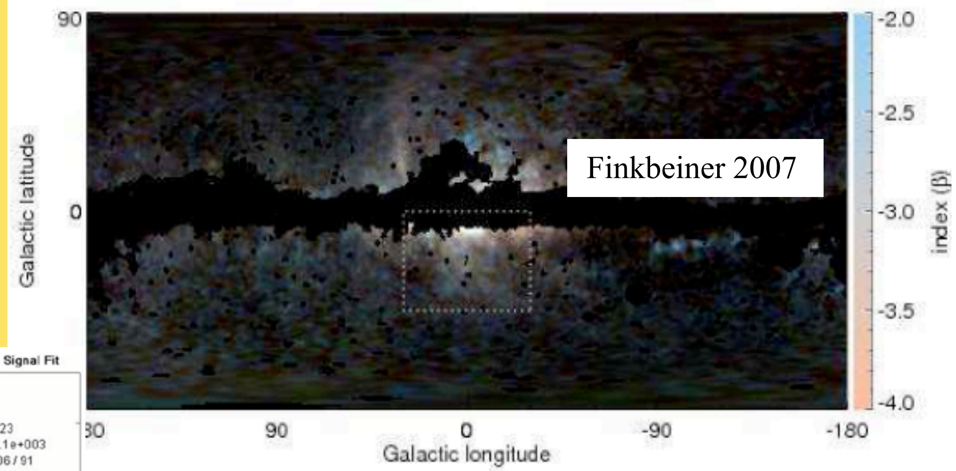
→ synchrotron from e pairs

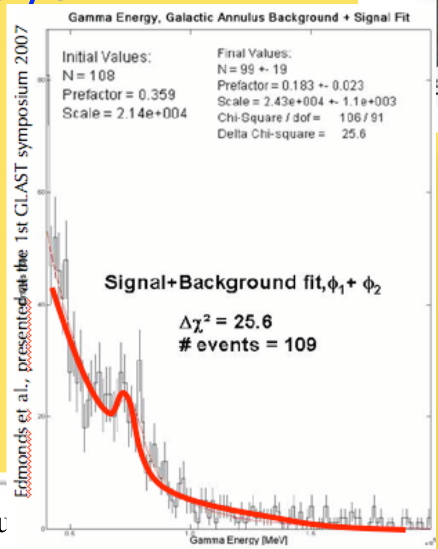
observed (?) with WMAP

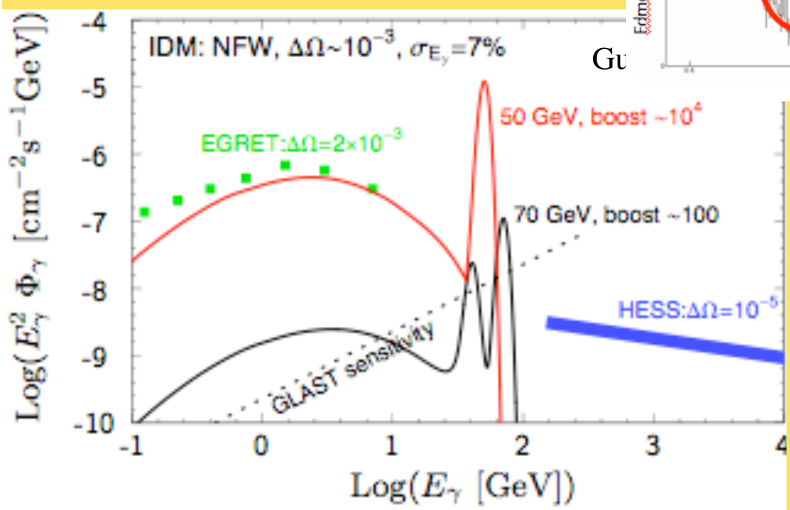
→ π^0 decay gamma rays

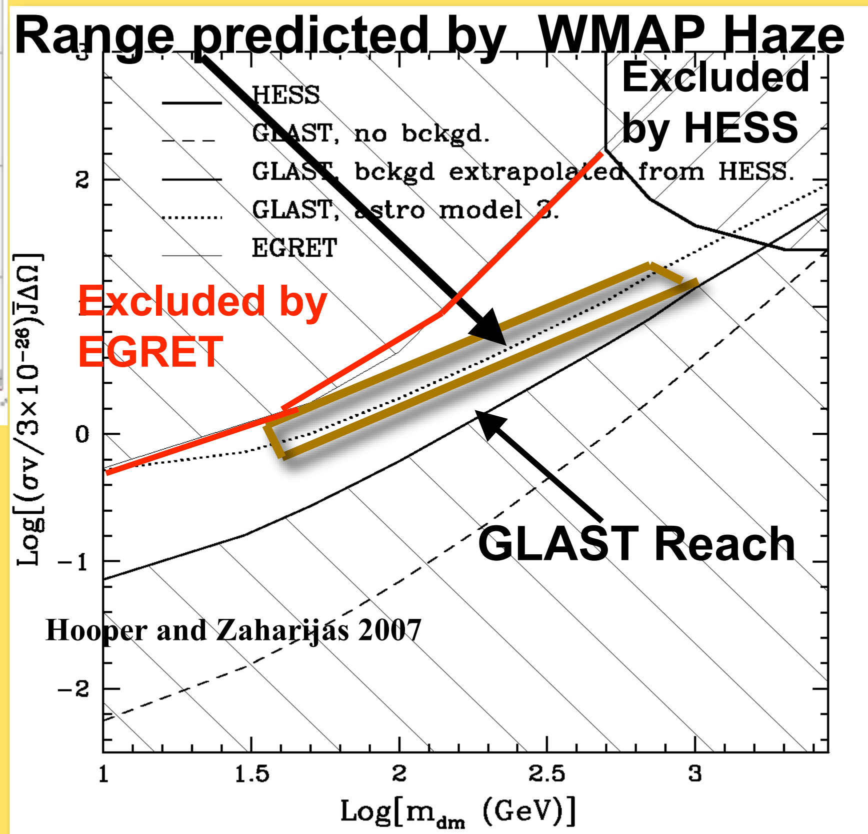
observable by GLAST!

Annihilation line is another “smoking gun”!



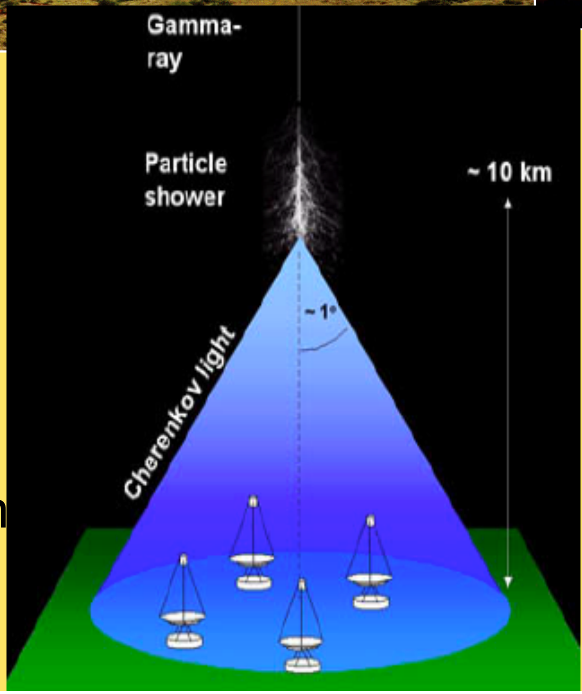


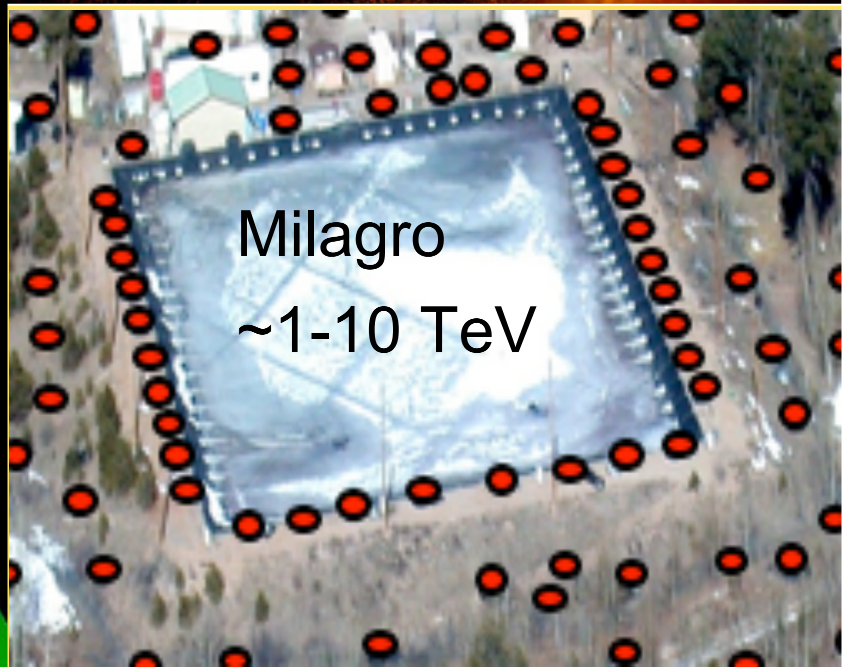




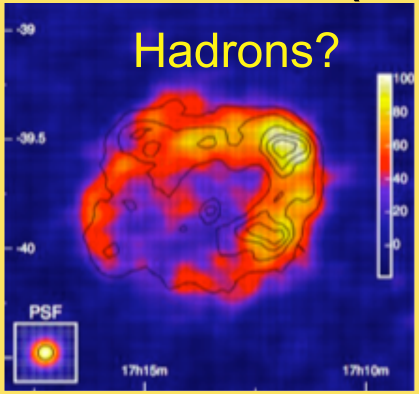
Exploring the Terascale

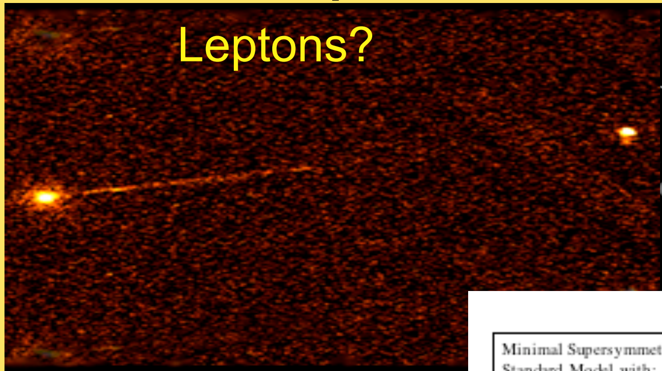
- ~10 ns flash
- ~1^o @ 10 km->10^4 m^2
- Stereo imaging
- ~ 0.1-100TeV
- ~5^o field of view
- ~5’ PSF per photon
- ~100 sources

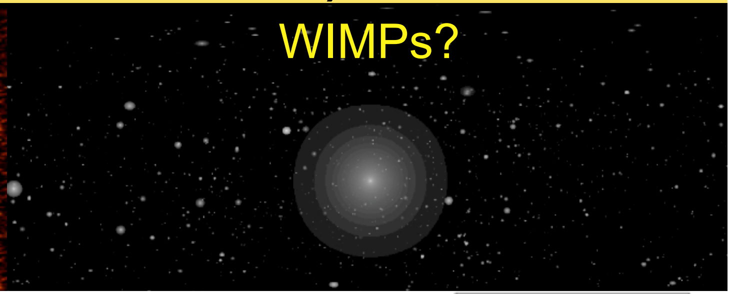


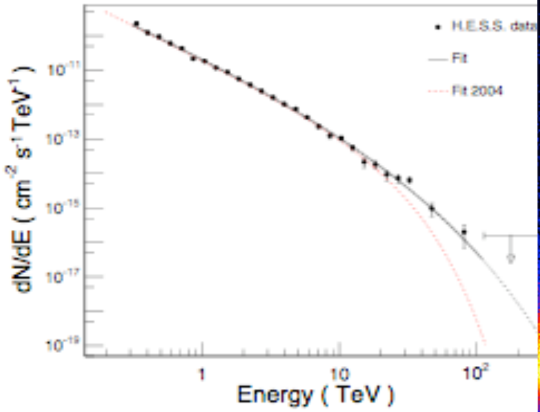


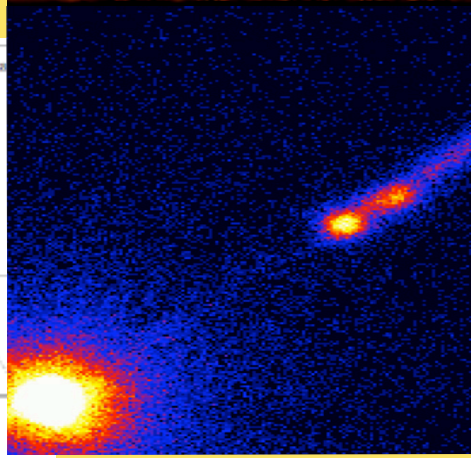
Hadrons vs Leptons vs WIMPS
(Pions vs Compton vs Annihilation)

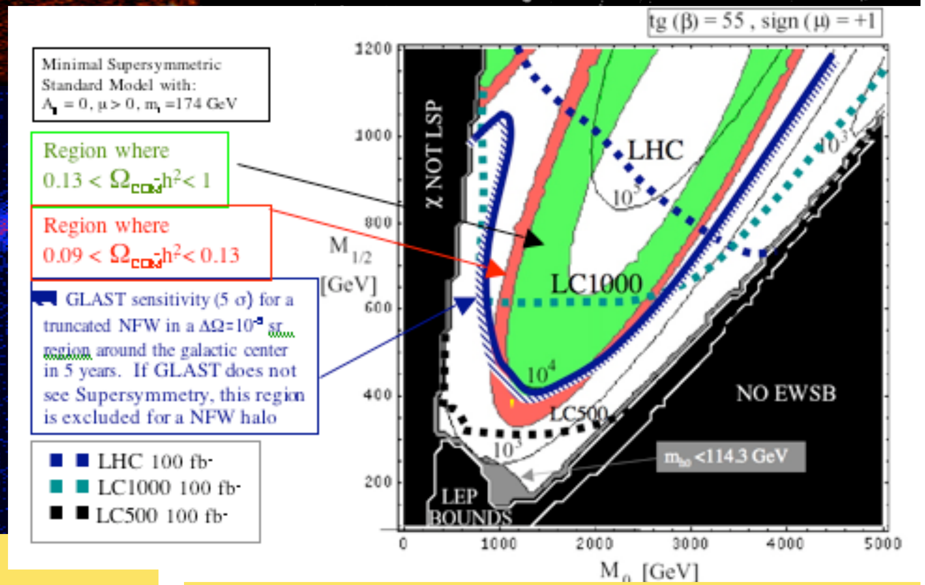












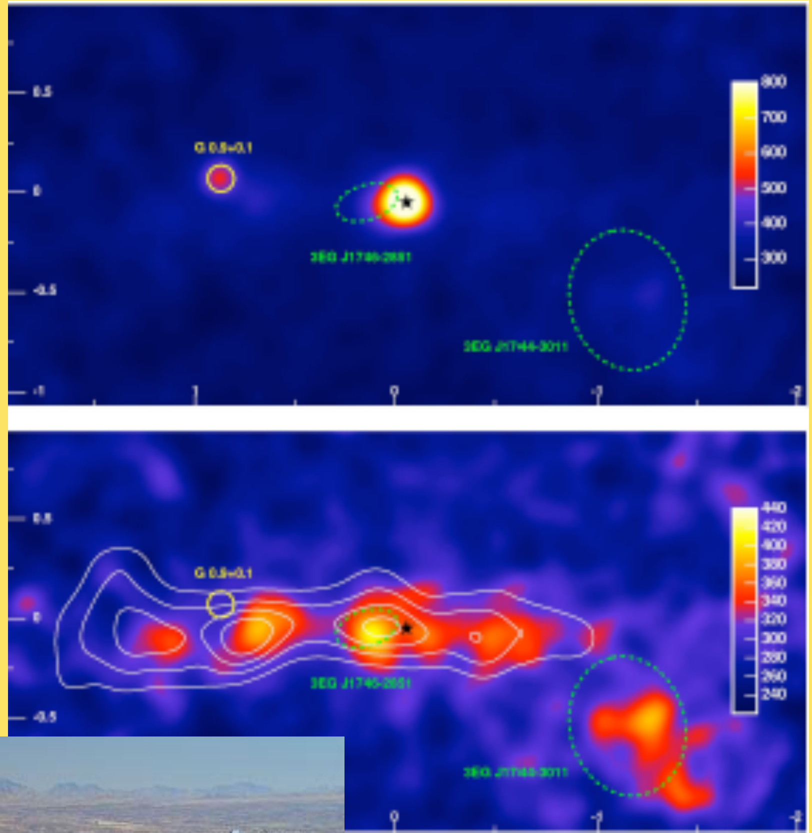
X-ray vs TeV
Fermi acceleration at shocks
Magnetic field amplification
Origin of cosmic rays?

Relativistic jets created by massive black hole in galactic nuclei
Gamma ray emission at small radii
Inverse Compton radiation
2 min variability?

If DM is cosmologically-generated, weakly interacting massive particle, there may be detectable annihilation from Galactic center and dwarf galaxies. Constraints will be combined with LHC and underground direct searches. Need to understand diffuse background.

Gamma-Rays from the Galactic Center

- Simulations predict that the GC contains very high densities of dark matter (and high annihilation rates)
- HESS, MAGIC, WHIPPLE and CANGAROO each claim positive detection of ~TeV gamma-rays
- Dark matter, or other astrophysics?



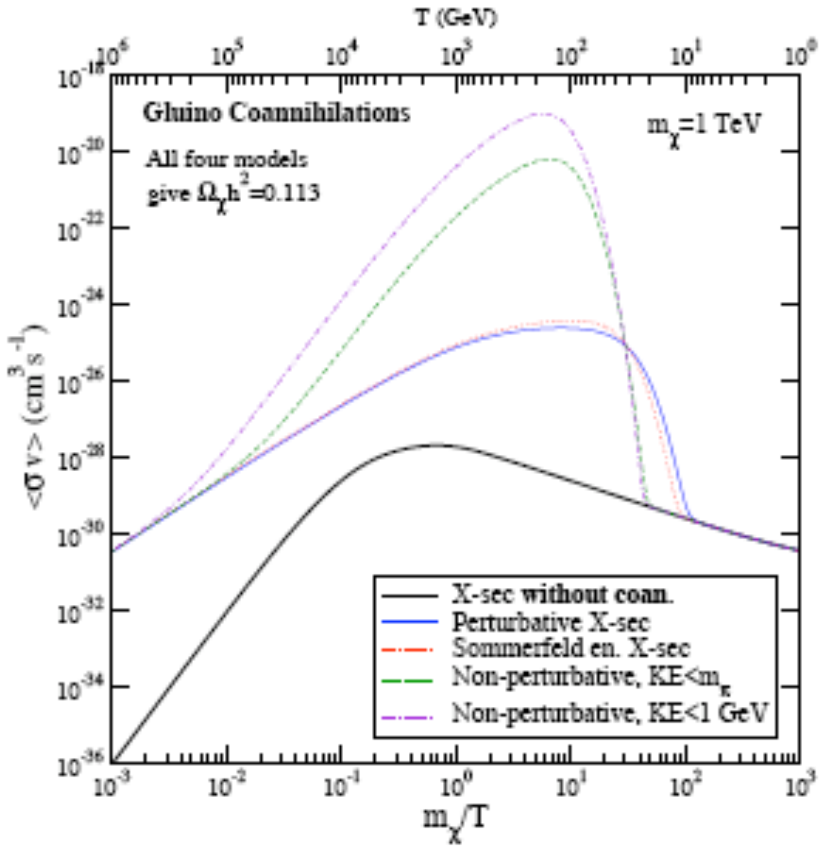
How high can you go in neutralino mass?

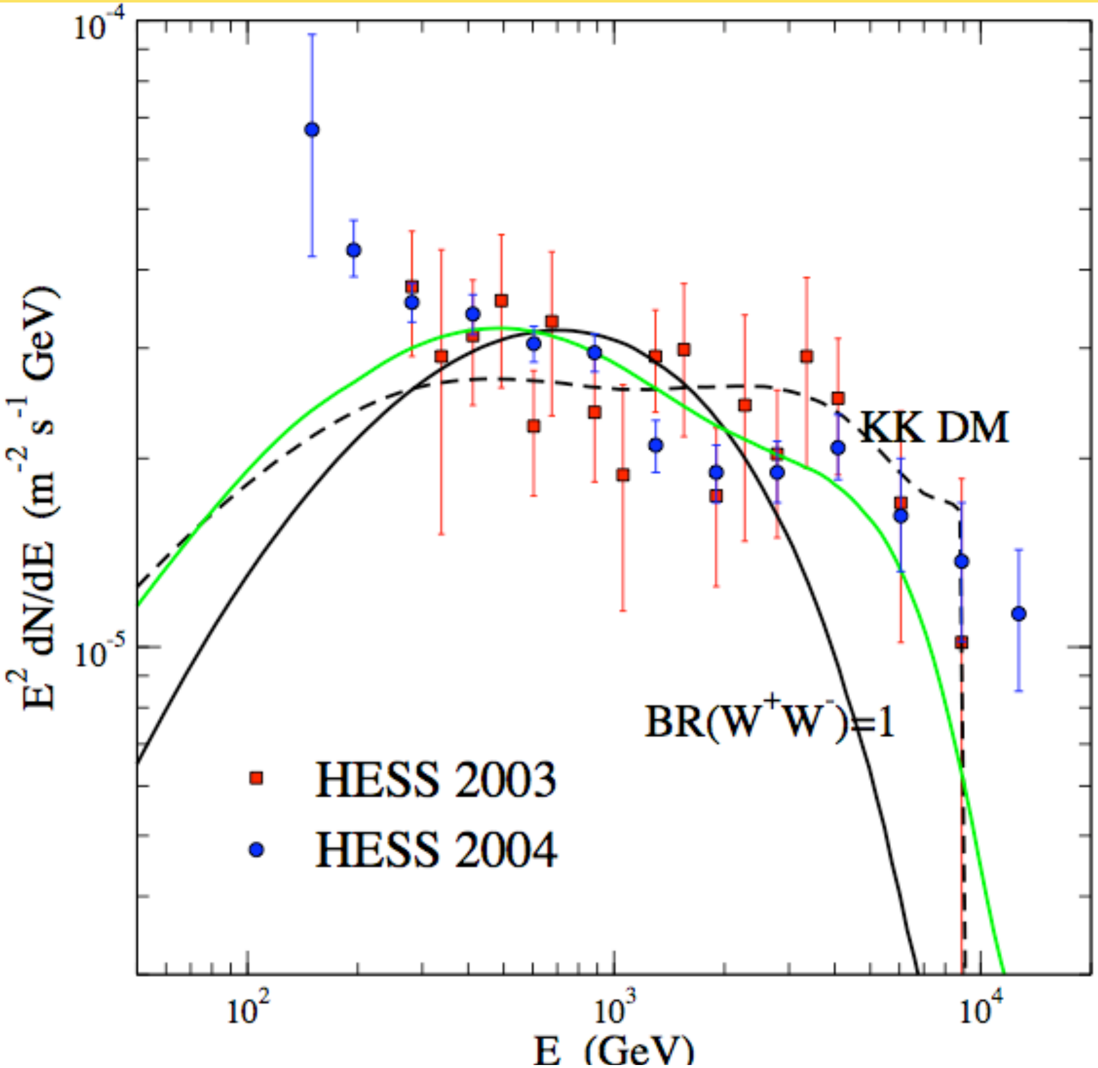
Coannihilations boost cross-section by 10-100 (Profumo 2005)

Stable SUSY LSP can go up to 20+ TeV

Or just lower neutralino component of dark matter

Or lets seek alternative to SUSY LSP……



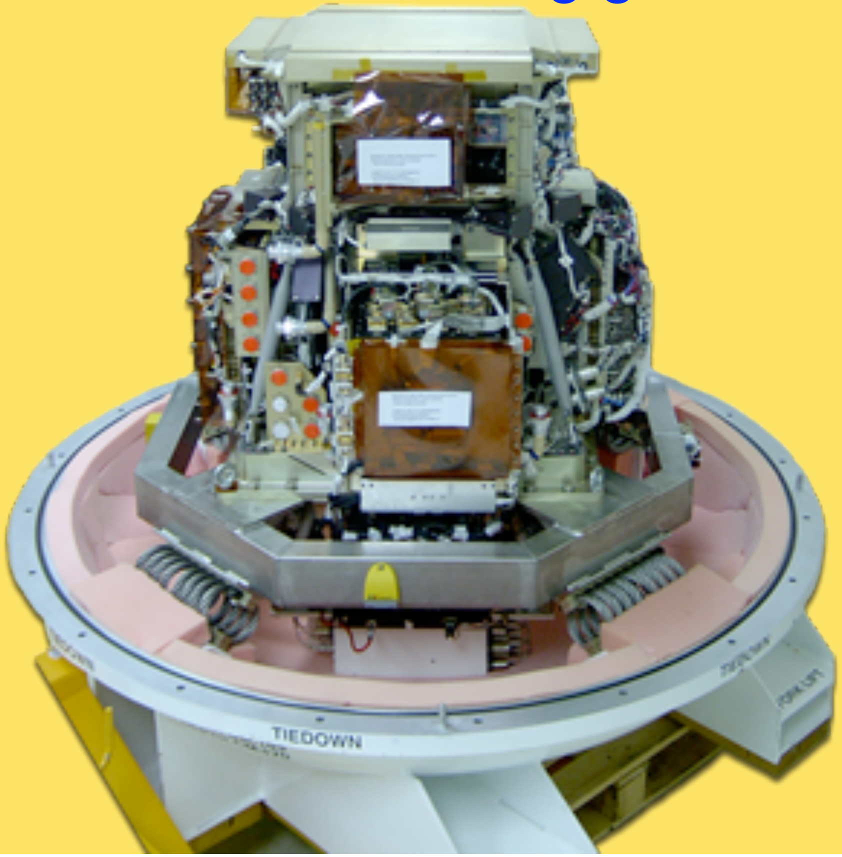


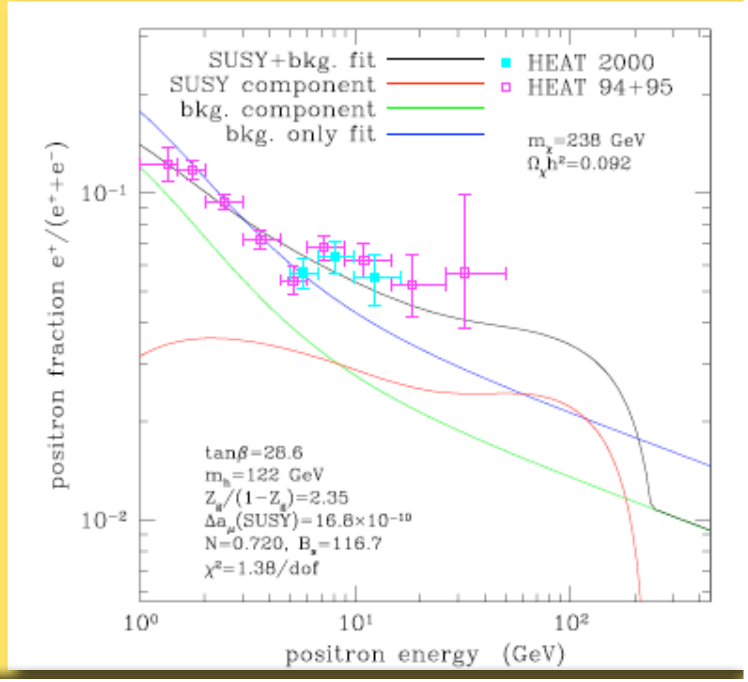
The HEAT Positron Excess

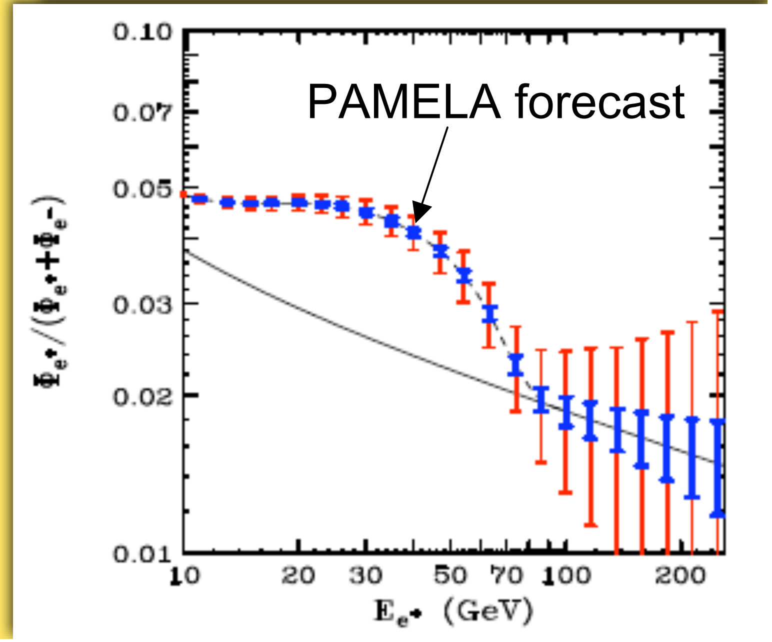
Fit to data can be easily improved if dark matter component is included

Requires annihilation boost of 10-100

PAMELA data (soon) could find bump + cut-off: a ”smoking gun”!



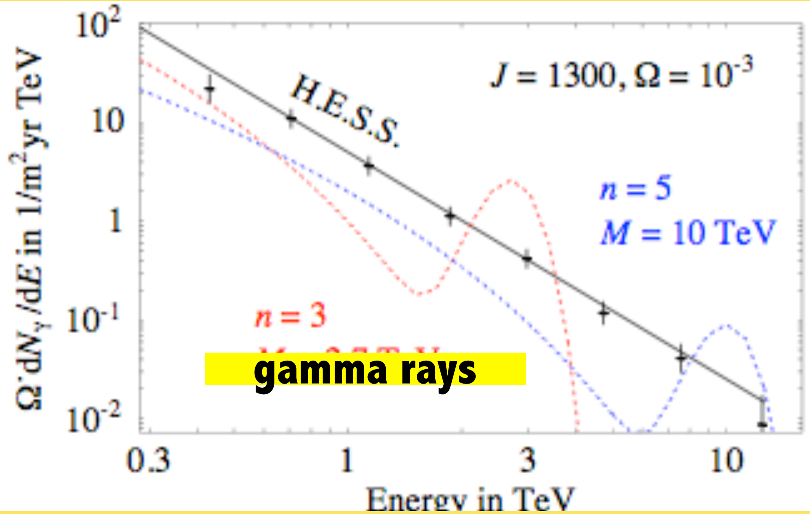


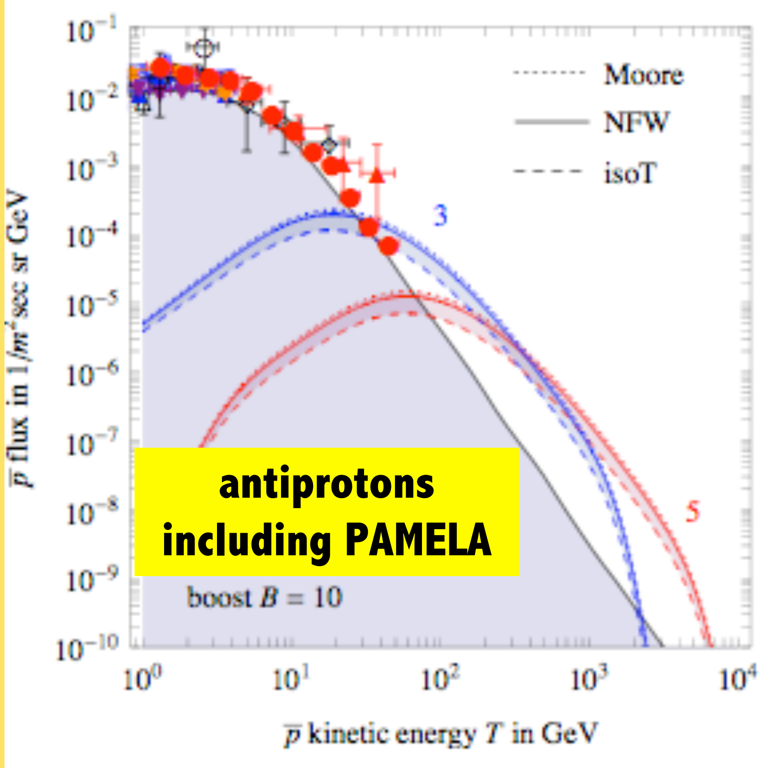


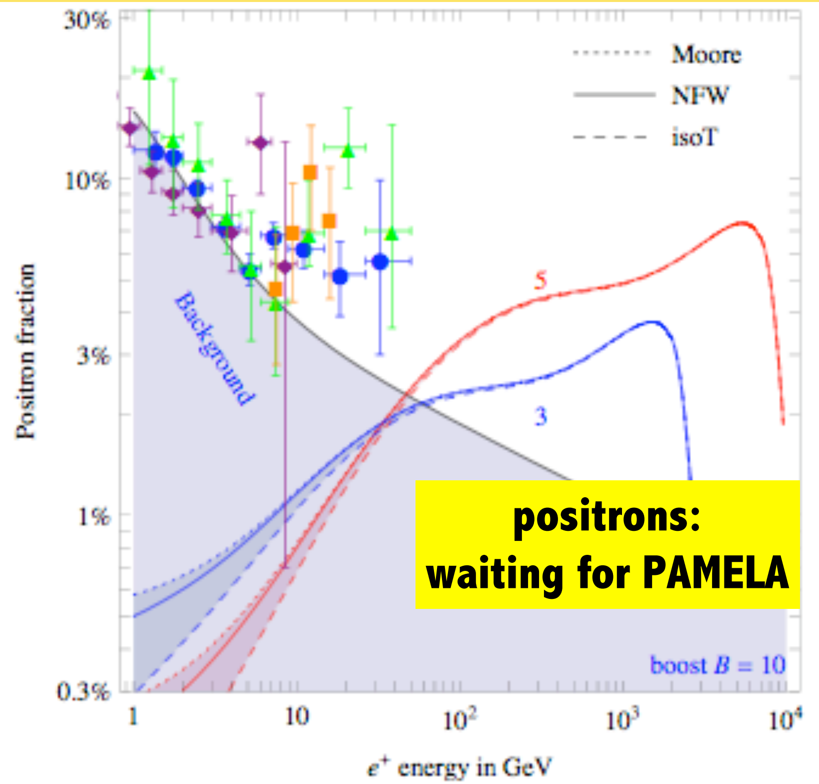
(Cirelli et al. 2007) weak scale and couplings: $M/g \sim (T_0 M_{pl})^{1/2} \sim$ TeV

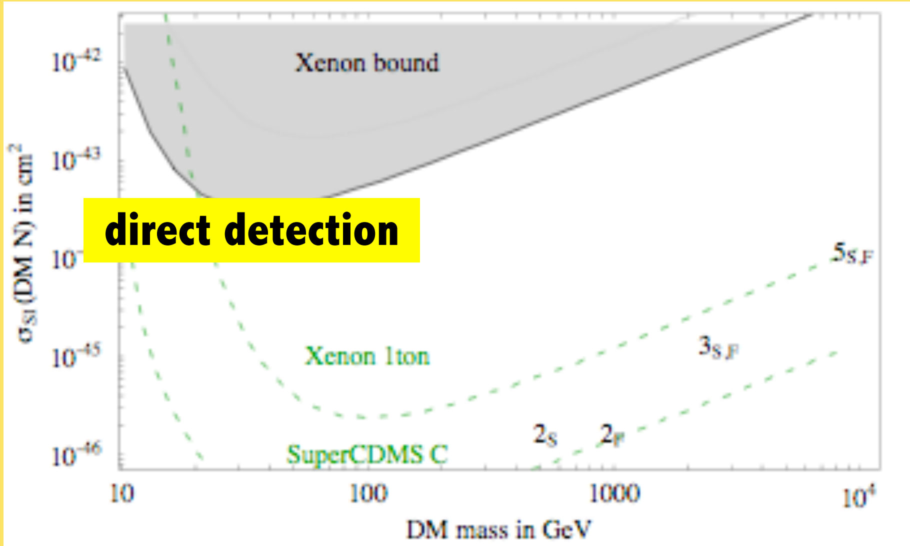
standard model + 1 new multiplet, weakly coupled (< 0.001) to Z

minimal dark matter

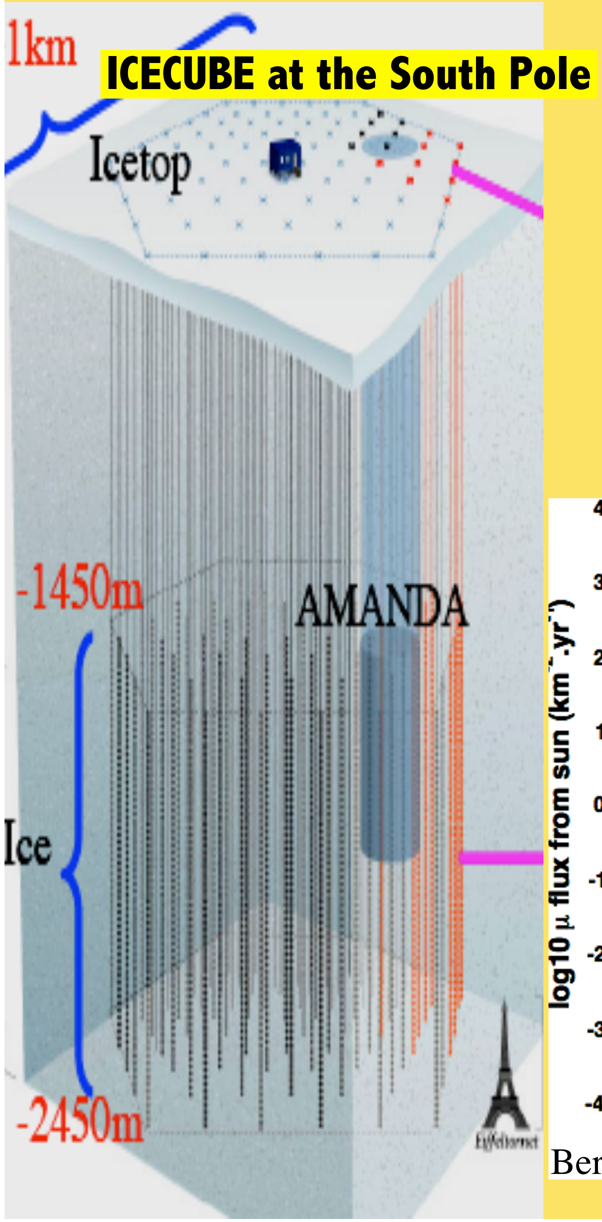


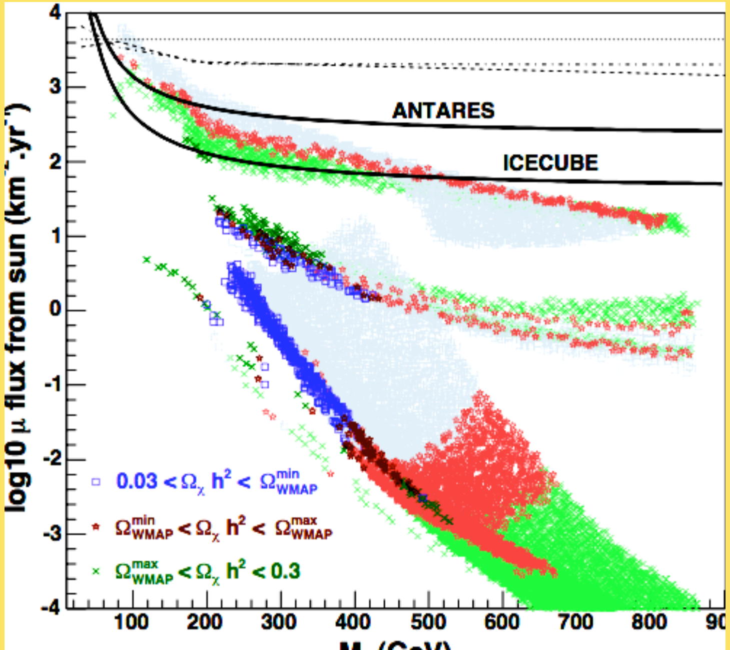




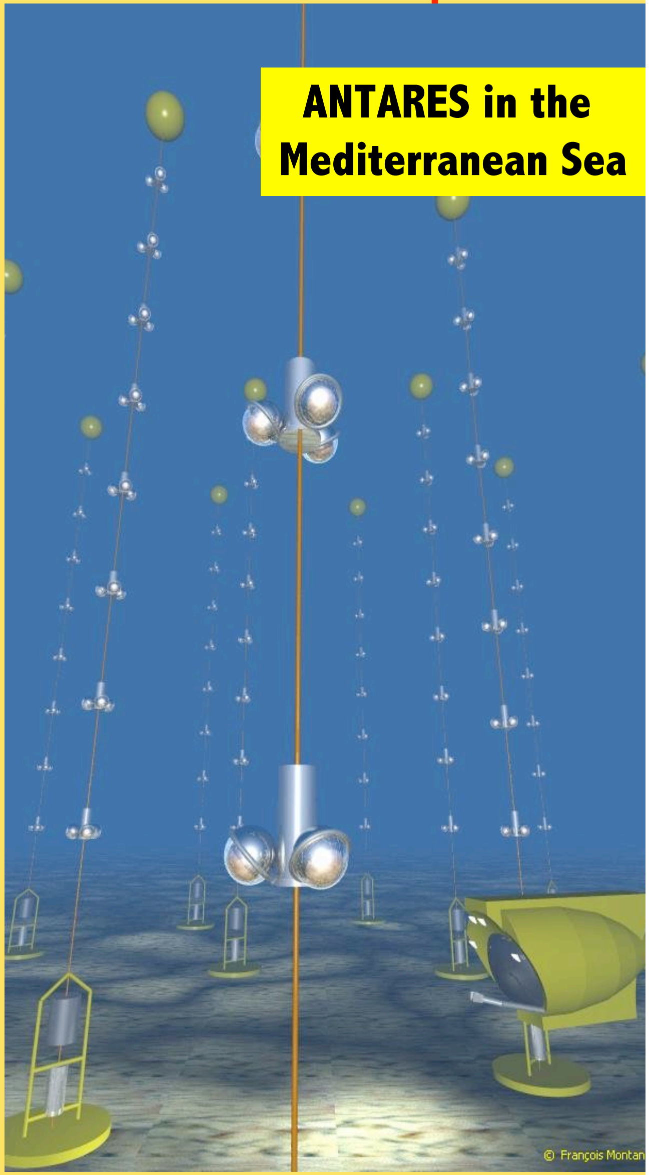


high energy neutrinos from WIMPs annihilating in the sun observable with downward-looking neutrino telescopes

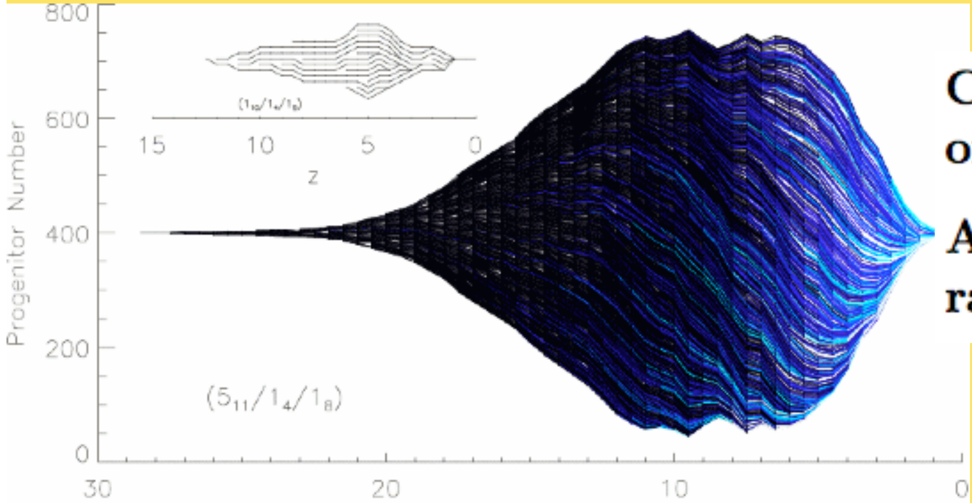




Bertone et al. 2004



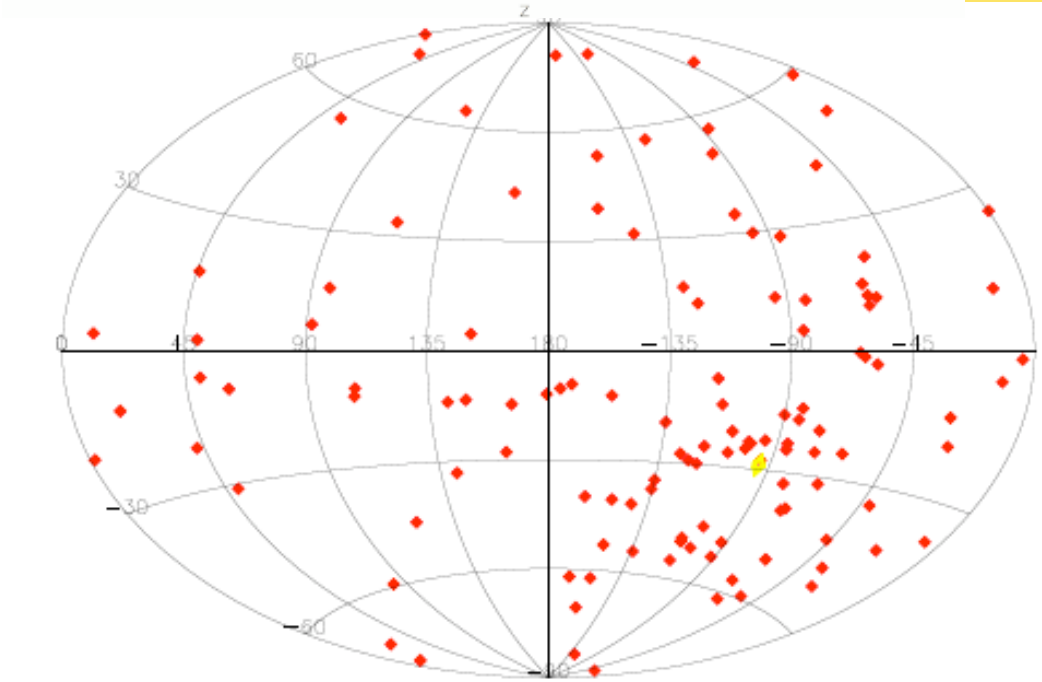
Cold dark matter spikes surround intermediate mass black holes



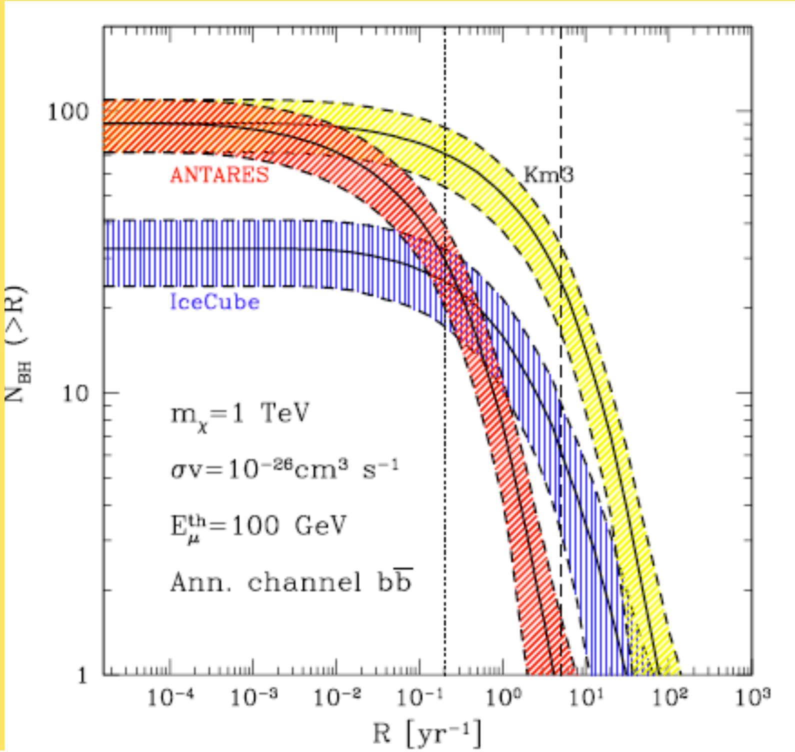
CDM cusp steepens by adiabatic growth of IMBH: $\rho \propto r^{-\gamma} \Rightarrow \rho \propto r^{-\gamma'}$, with $\gamma' = \frac{9-2\gamma}{4-\gamma}$

Annihilation rate is amplified within a radius $GM_{bh}/\sigma^2 \sim 0.003(M_{BH}/10^5 M_\odot)$pc

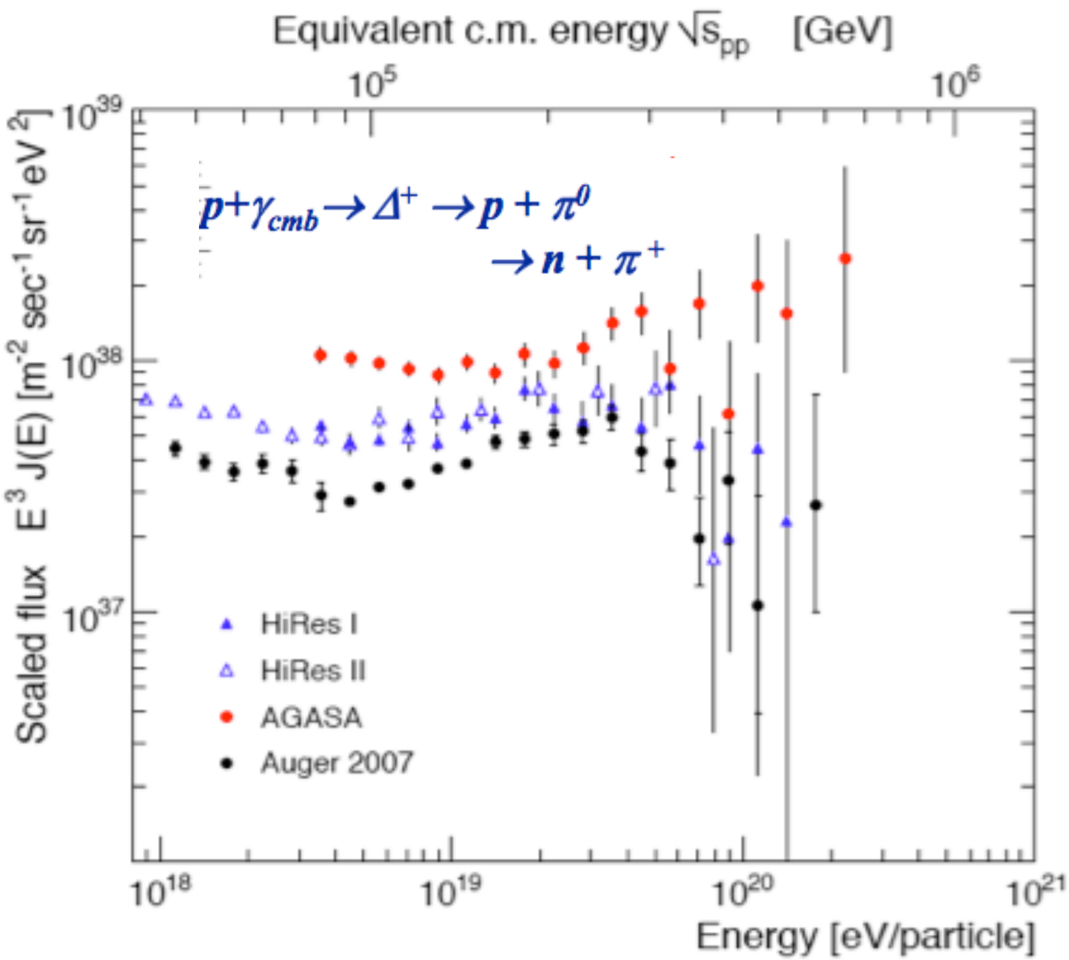
How to detect the nearest IMBHs: neutrinos from dark matter annihilations

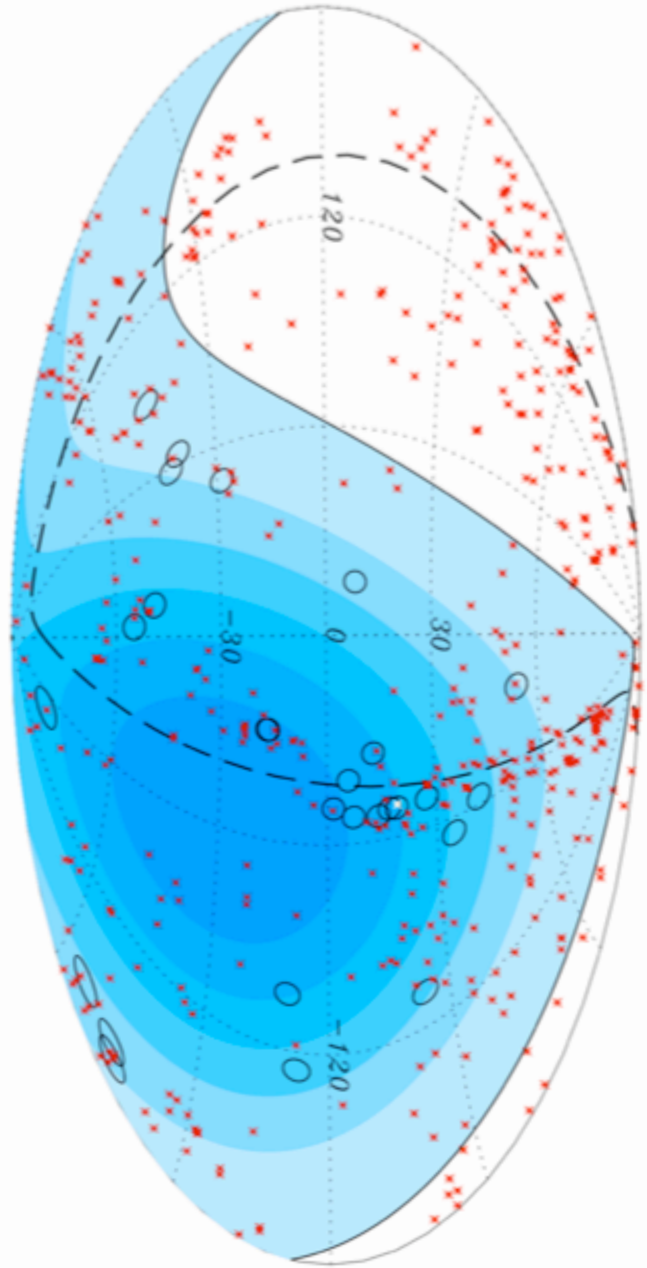


Bertone 2006



AUGER (S)





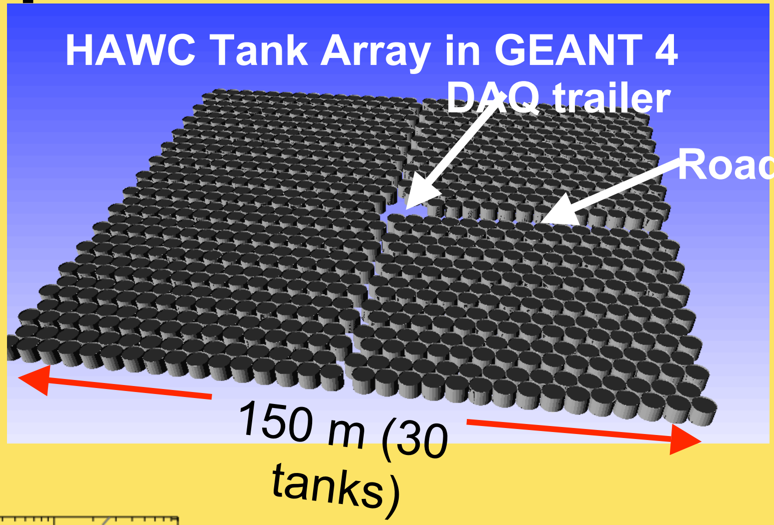
3000 km^2 area observatory in Argentina.

1600 water Cherenkov detectors.

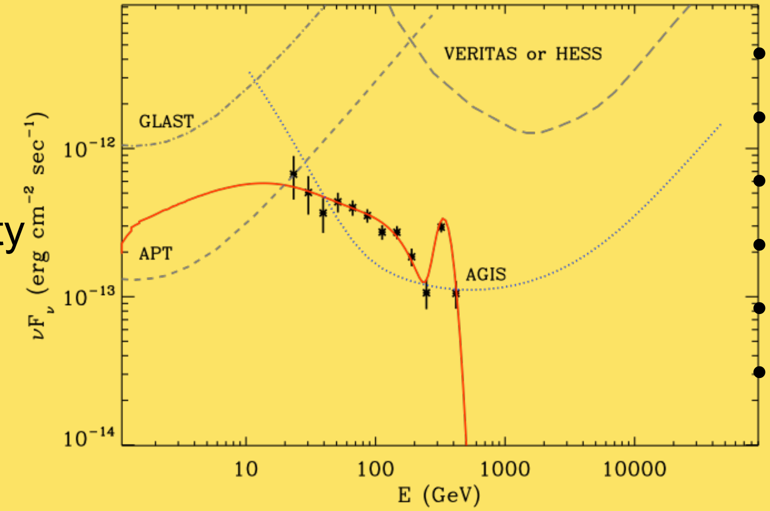
4 fluorescence sites overlooking the array.

Built to understand origin of UHECR's.

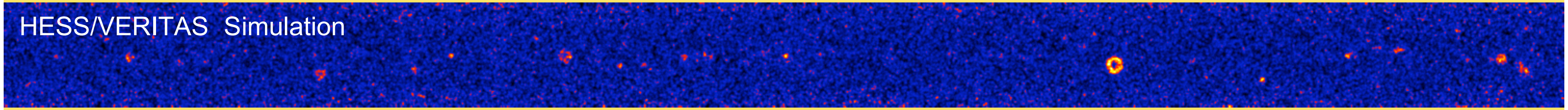
Future TeV Options

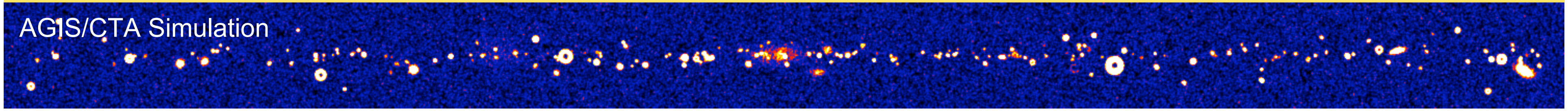


- ~0.04 - 200 TeV
- ~ 50 telescopes
- Large FOV
- ~1’ PSF per photon
- ~10 x VERITAS sensitivity
- ~ $100M class

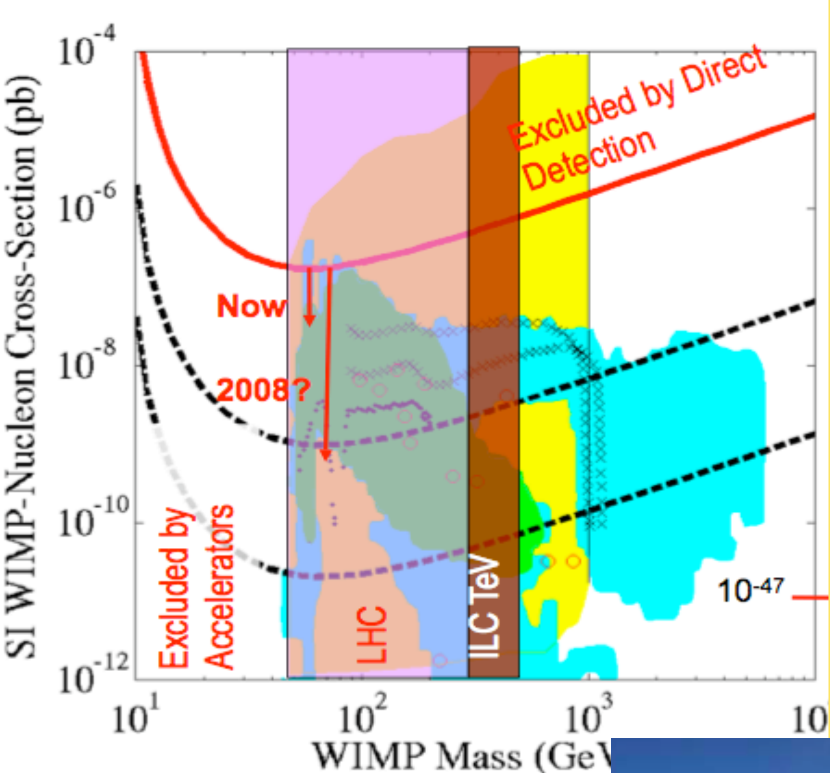


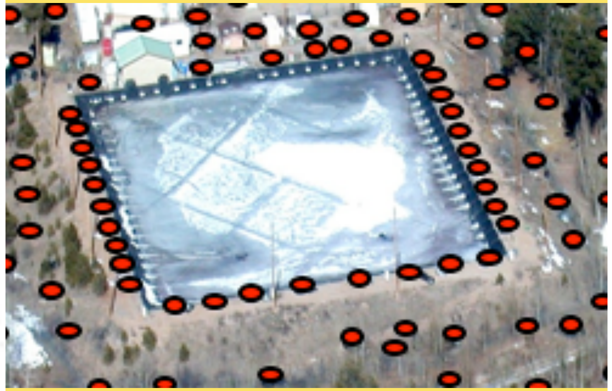
- ~1-100 TeV
- ~15 x Milagro
- Improved rejection
- Wide field
- Large duty cycle
- $10M class

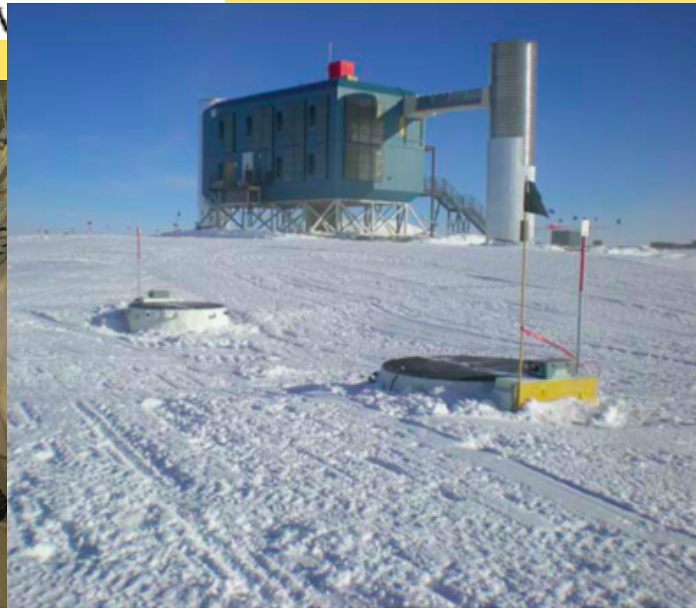




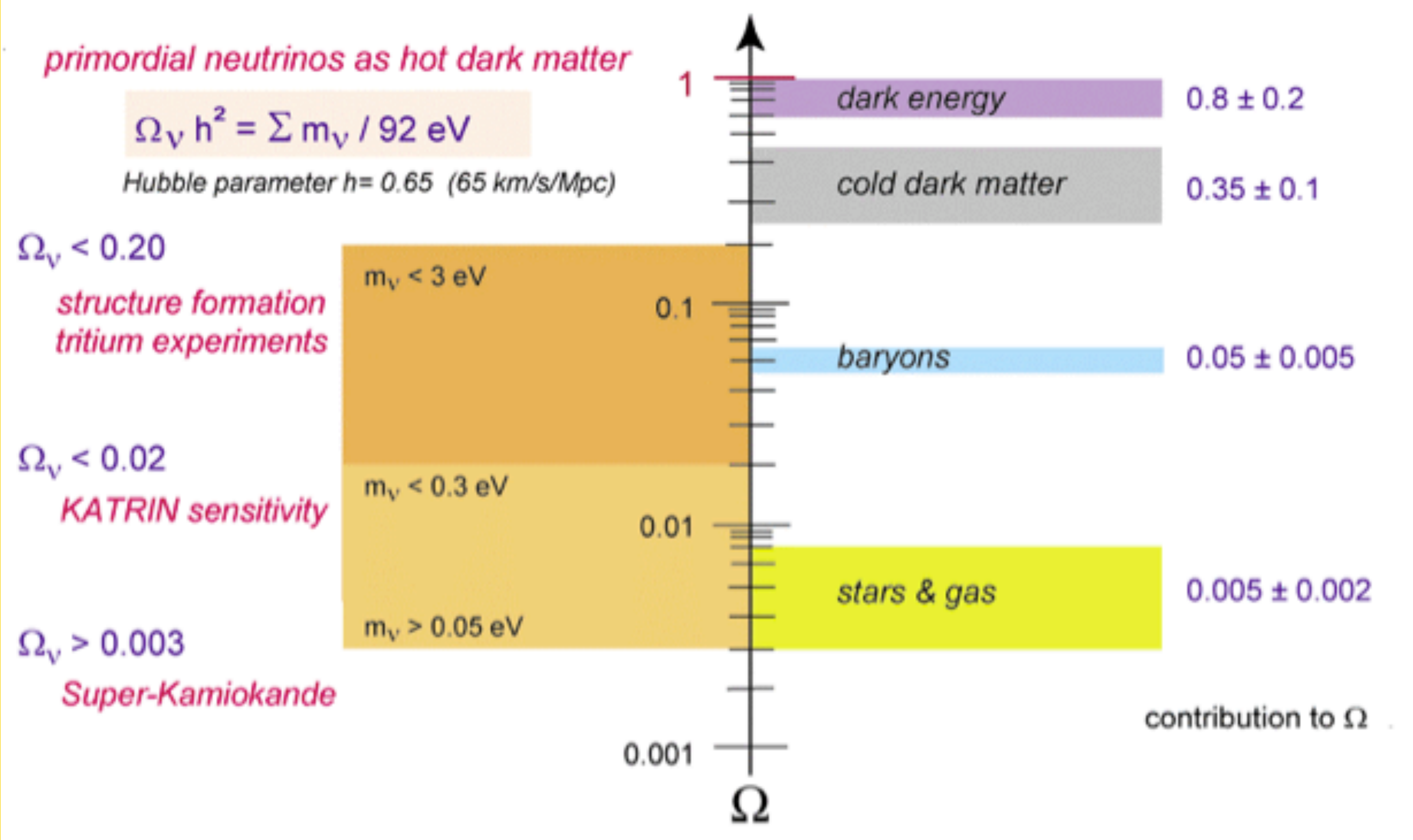
APP explores regimes where LHC or ILC cannot go





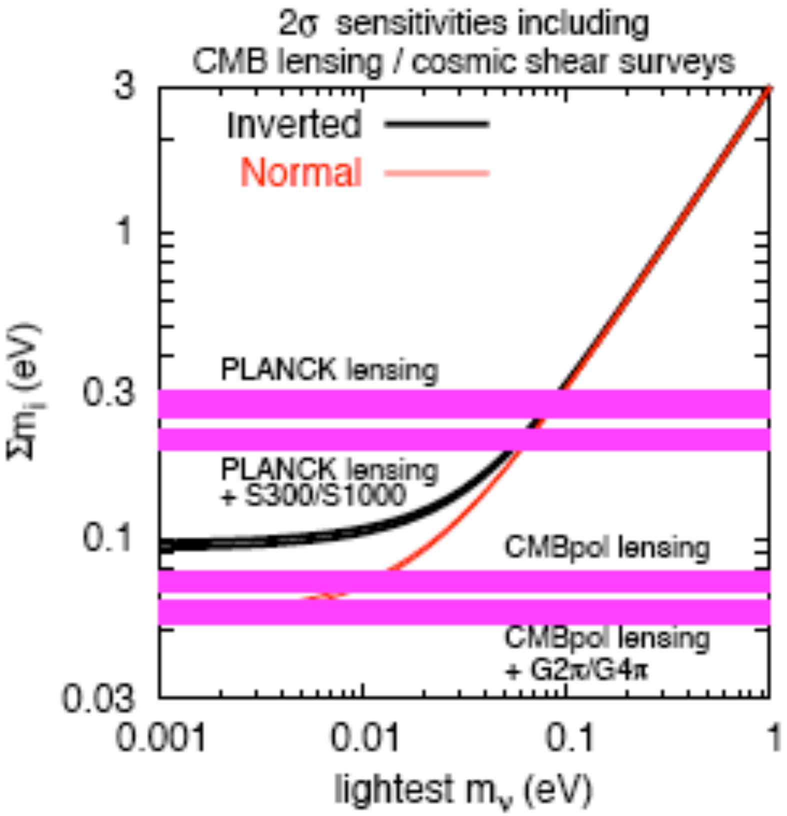


NEUTRINO DARK MATTER?



CURRENT AND FUTURE NEUTRINO MASS LIMITS FROM COSMOLOGY

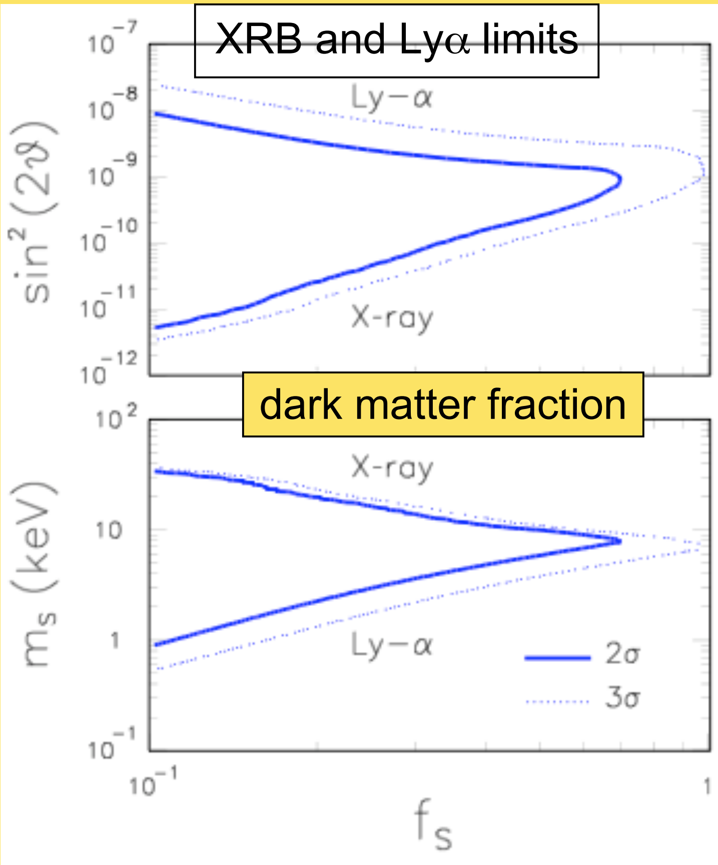
Bound on Σm_ν (eV) [95% CL]	Data used
1.7 – 2.3	**CMB only**
0.68 – 0.91	**WMAP3, other CMB, 2dF/SDSS-gal, SNIa**
0.17-0.48	**WMAP3, other CMB, 2dF/SDSS-gal, SDSS-BAO and/or Ly-α**



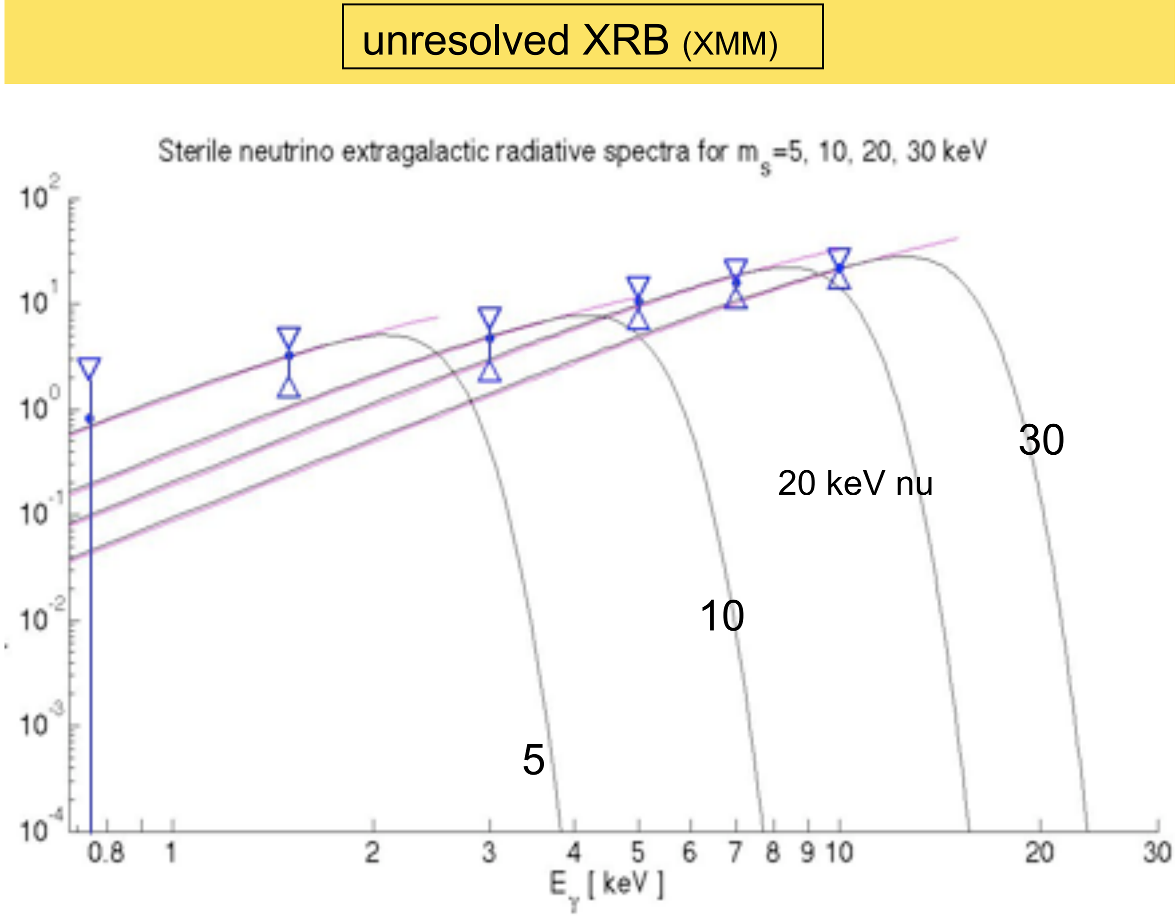
STERILE NEUTRINOS AS DARK MATTER ?

$$\nu_s \longrightarrow \gamma \nu_a$$

$$\Gamma_\gamma = \frac{9\alpha G_F^2}{1024\pi^4} m_s^5 \sin^2 2\theta \simeq 1.38 \times 10^{-22} \sin^2 2\theta \left(\frac{m_s}{\mathrm{keV}}\right)^5 \mathrm{s}^{-1}$$

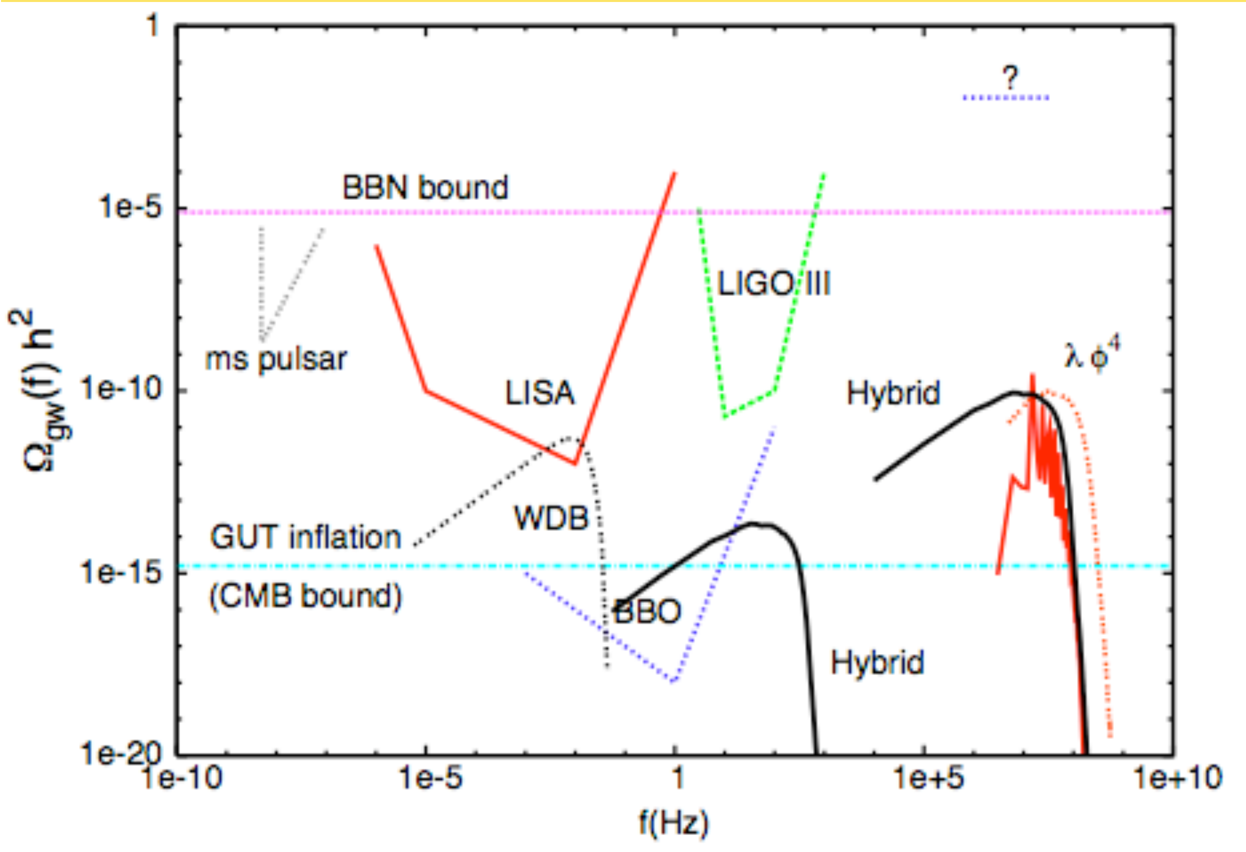


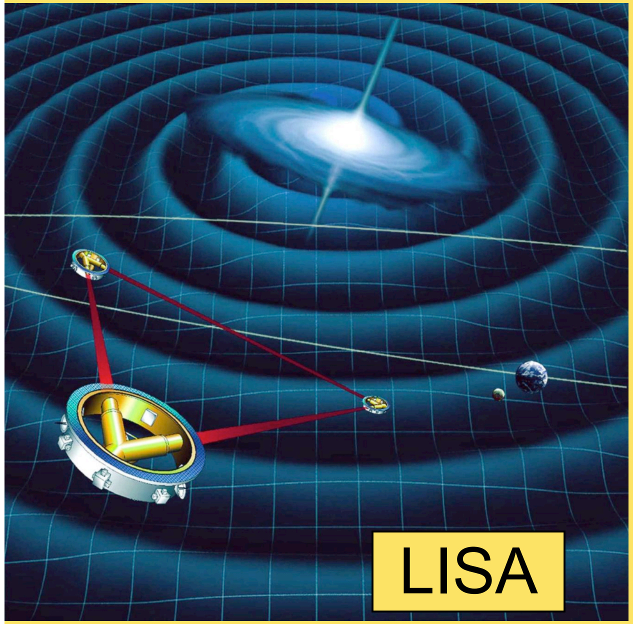
Palazzo et al 2007



Cumberbatch and Silk 2007

PROBING INFLATION WITH GRAVITY WAVES





SOME GOALS OF ASTROPARTICLE PHYSICS

- probing the elementary constituents of matter and energy
- understanding how our universe works at a fundamental level
- exploring the basic nature of space and time
- developing key technologies and trained manpower

- discover the properties of cosmic accelerators and probe galaxy evolution
- seek annihilation/elastic scattering signatures of stable supersymmetric particles: beyond the standard model of particle physics over cosmic distances
- probe the beginning of the universe via gravity waves