ISSUES AND CHALLENGES IN ASTROPARTICLE PHYSICS

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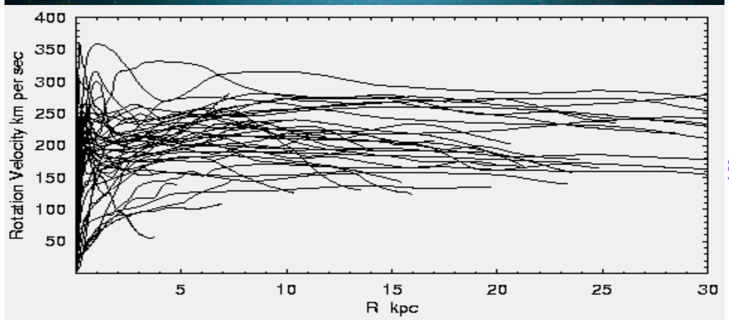
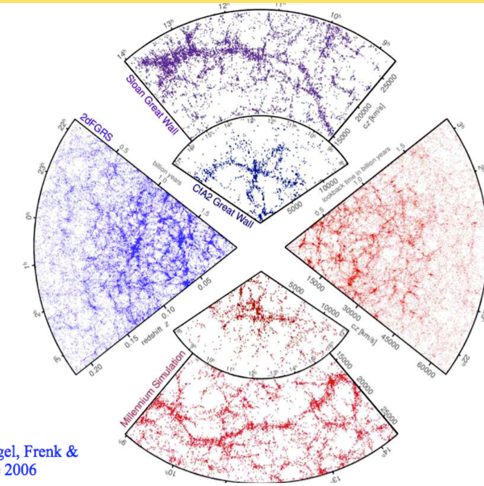
University of Oxford
September 24, 2008

APP provides synergy of radio/optical/ir/xr/γr/cr astronomy

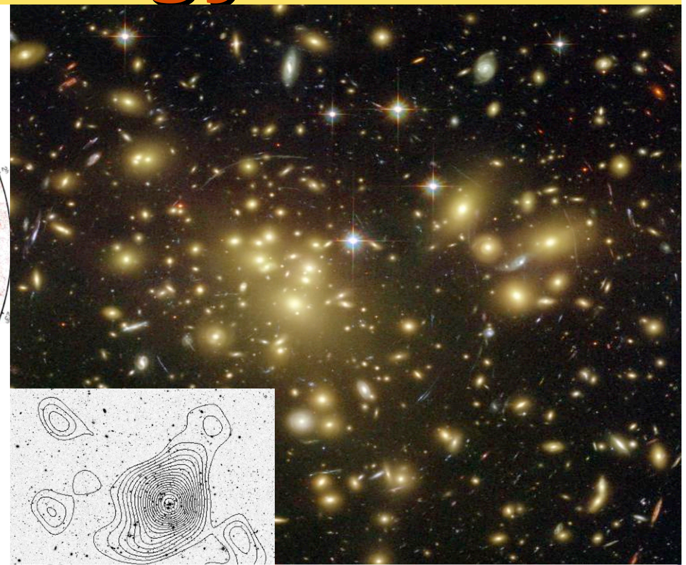
APP can explore regimes where LHC (or ILC) cannot go

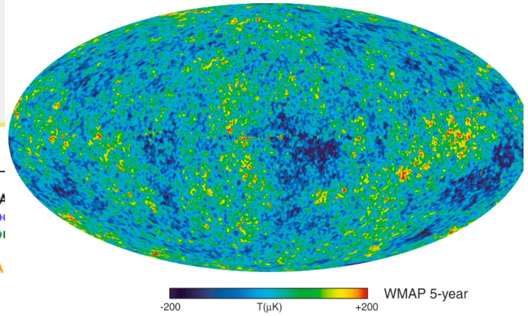
Dark Matter and Energy

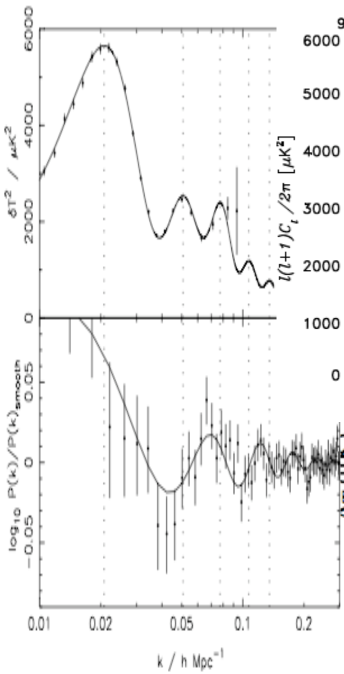


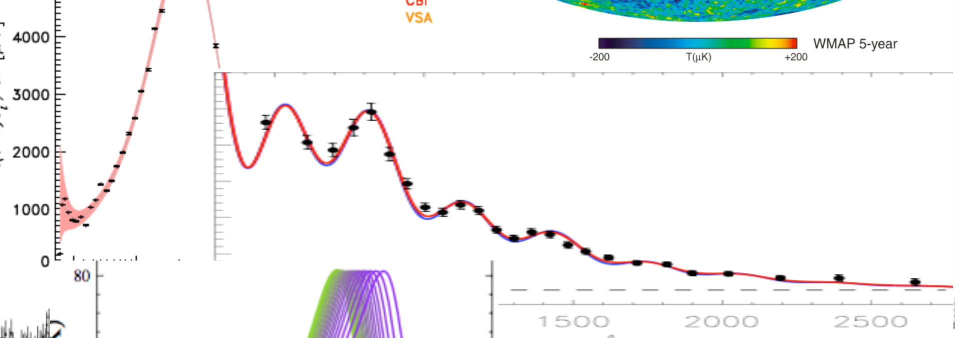


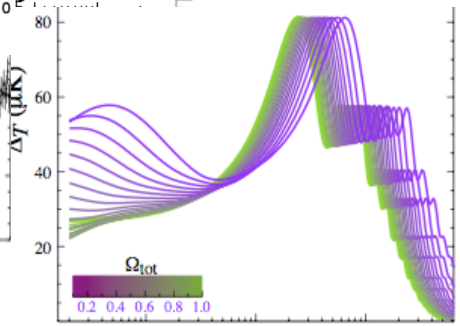
Springel, Frenk & White 2006

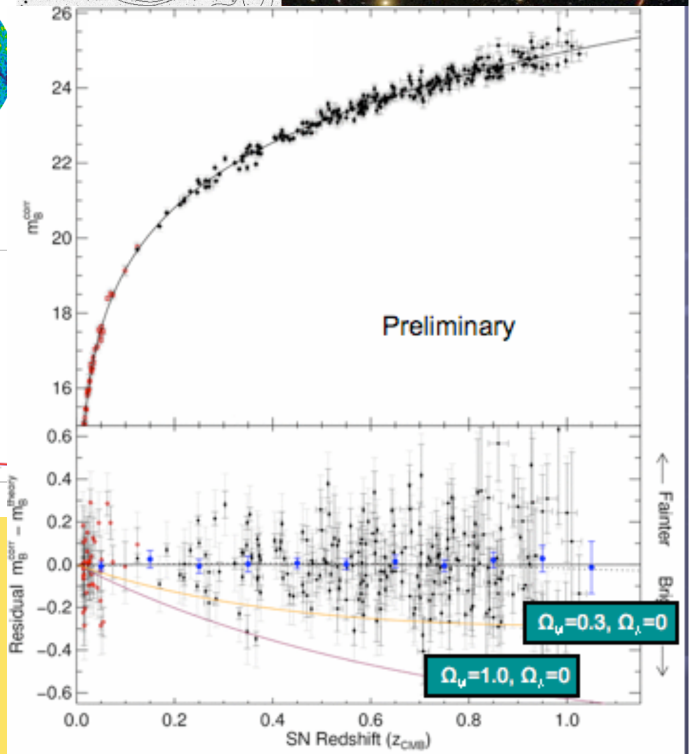












EXPLANATION OF LARGE-SCALE STRUCTURE IS A SUCCESS

BUT AT A PRICE: DARK MATTER AND DARK ENERGY

Clustering/BAO/lensing: DM

CMB fluctuations: DM +DE

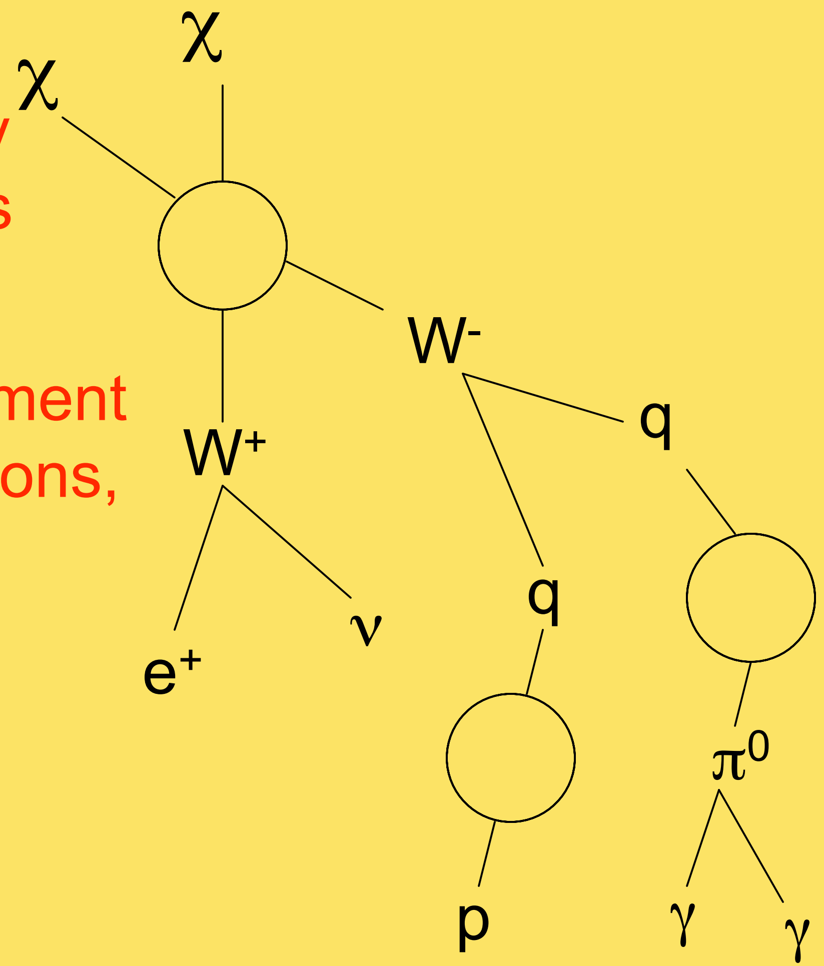
Supernovae: DM - DE

CHALLENGES OF ASTROPARTICLE PHYSICS ARE TO DETECT DARK MATTER AND UNDERSTAND DARK ENERGY

Indirect Detection of Dark Matter

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

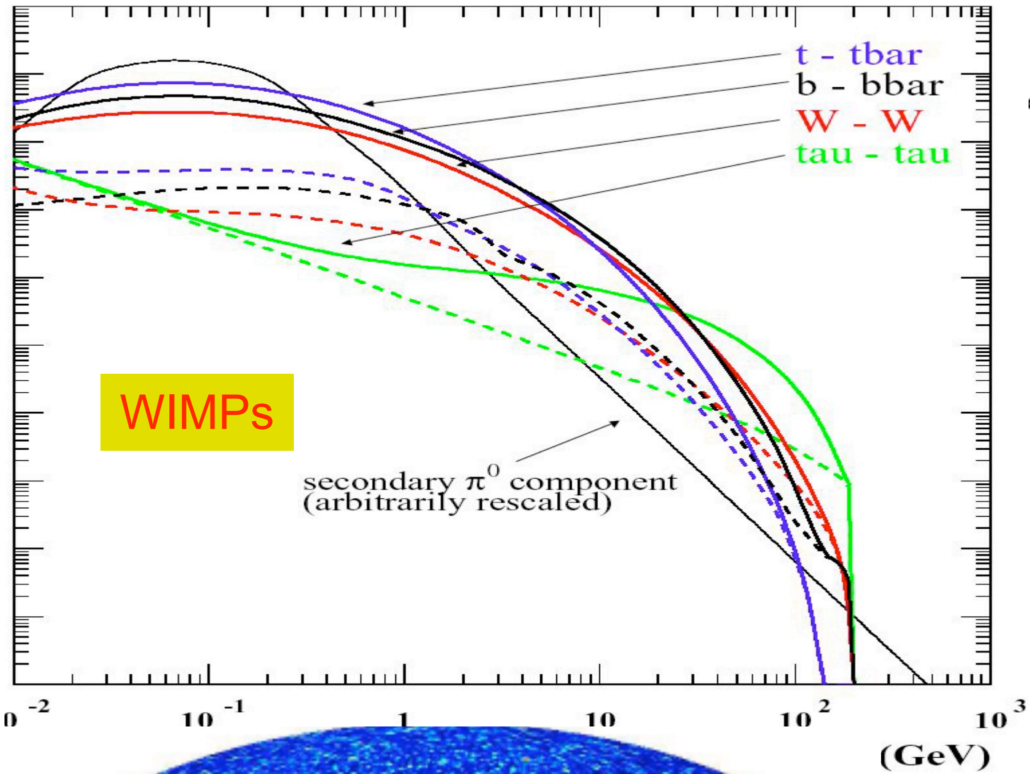
2) **Fragmentation/Decay**
   Annihilation products decay/fragment into high energy electrons, positrons, protons, antiprotons, deuterium, neutrinos and gamma rays

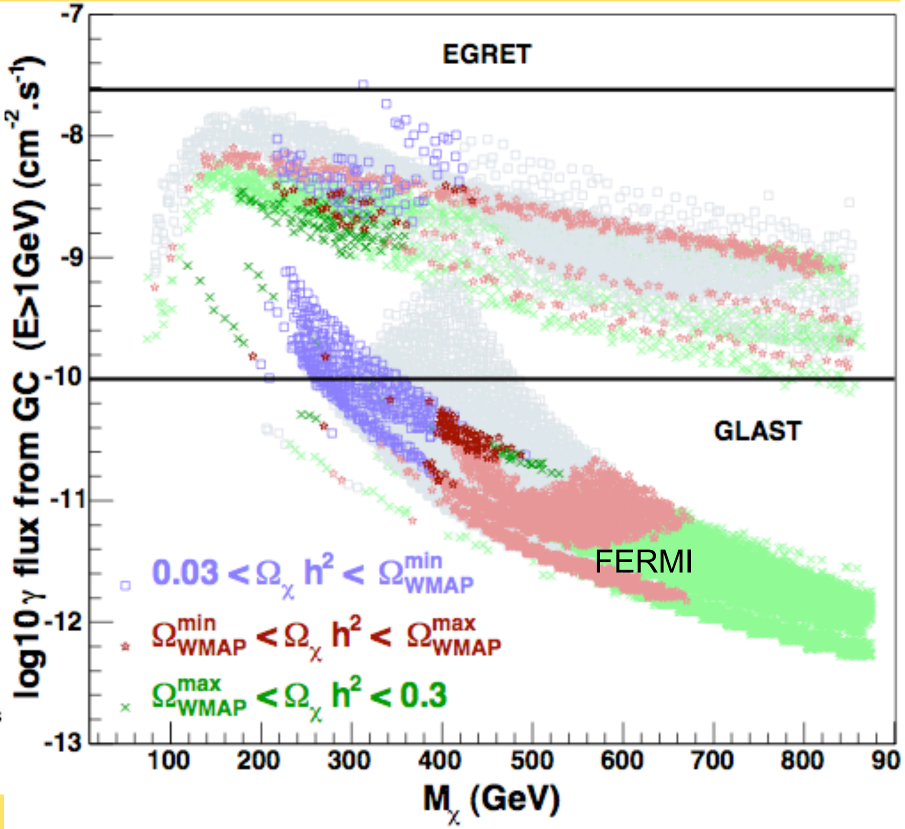


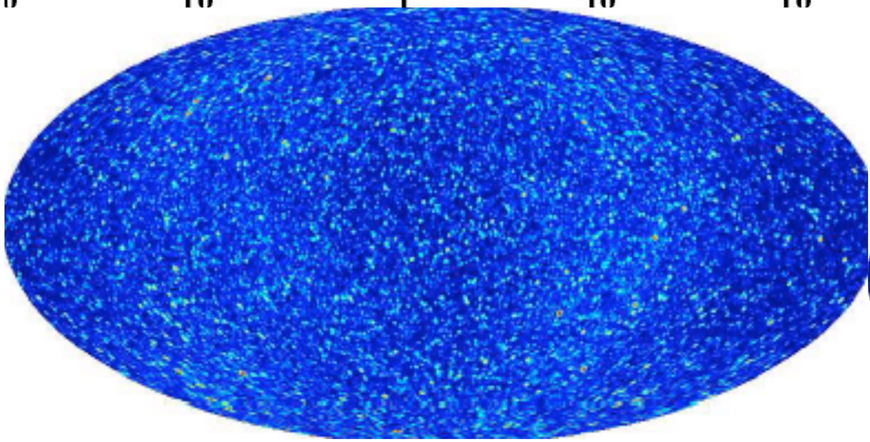
Gamma-rays and dark matter annihilations

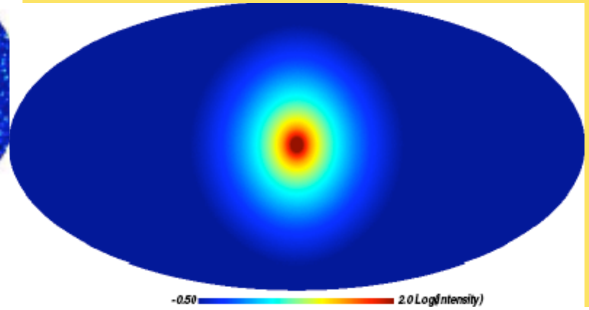
Relic annihilation cross-section predicts ~10^{39} GeV/s in total annihilation power

~100-1000 GeV WIMPs ⟶ π^0 gamma rays









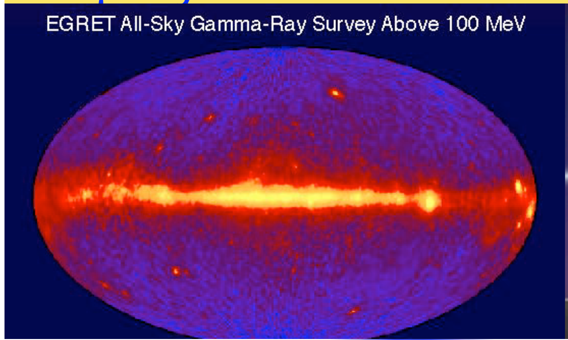
CDM simulations with 1000 M_{sun} resolution weighted by density^2

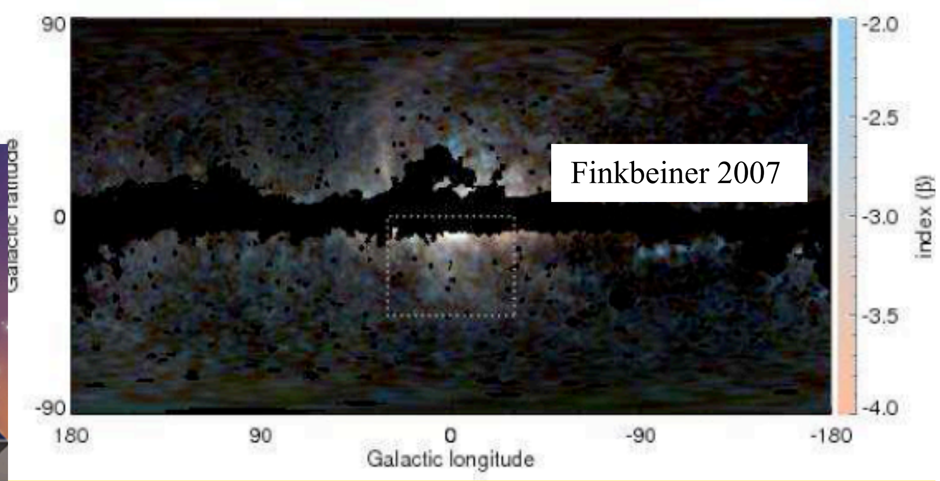
Springel+ 2008

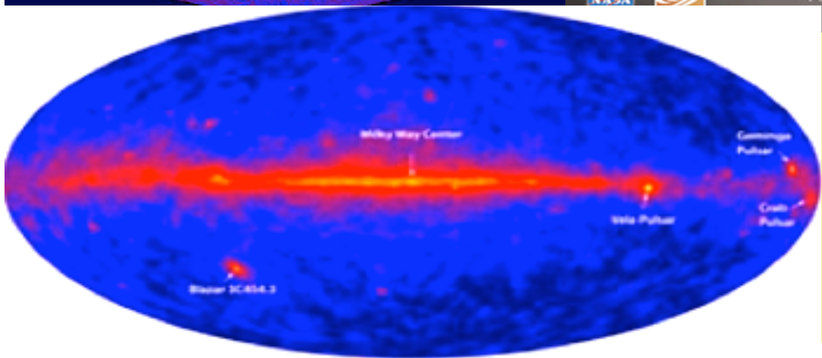
WIMPS: Gamma-Rays from the inner Galaxy

annihilations → WMAP synchrotron

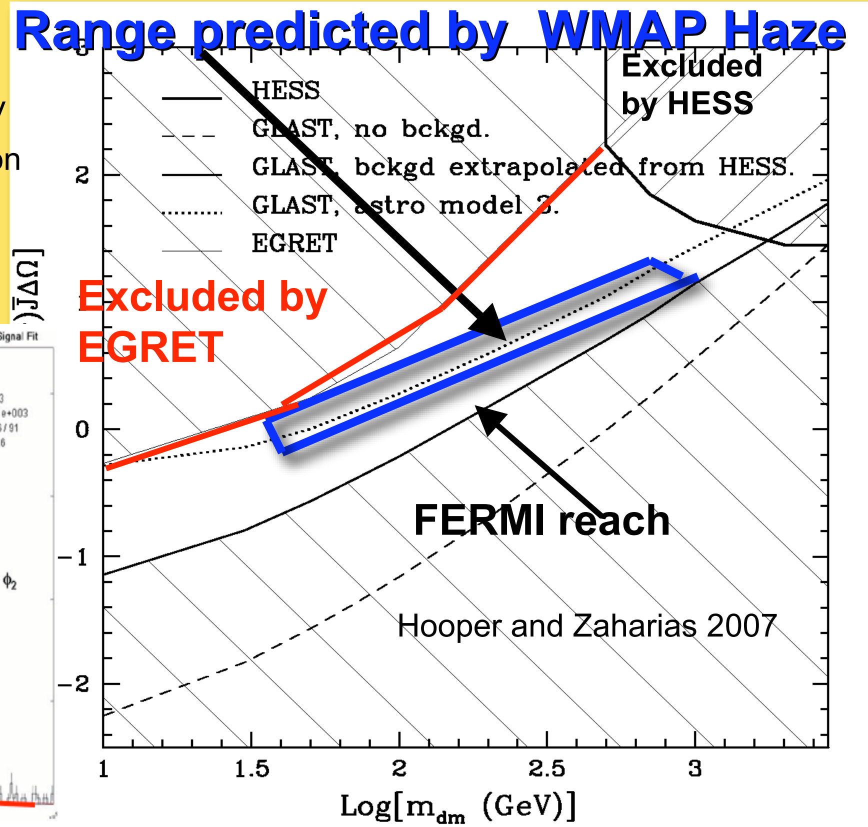
→ γ rays observable by FERMI!

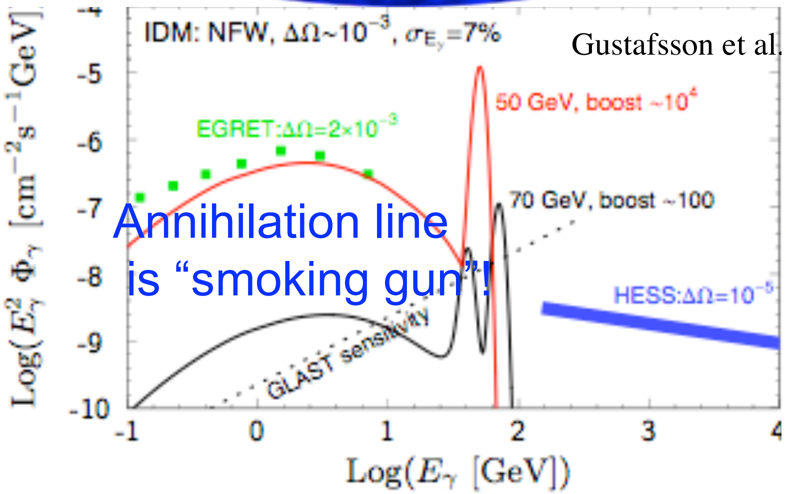


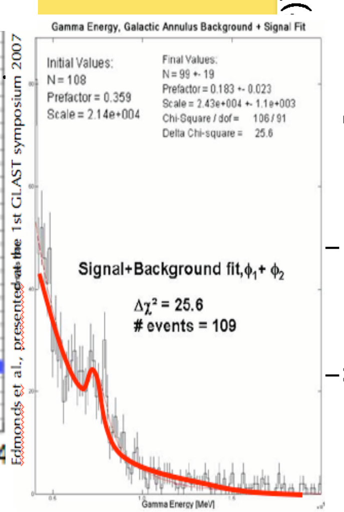




0.02 - 300 GeV
5° - 5' resolution
$\Delta \ln E \sim 0.1$





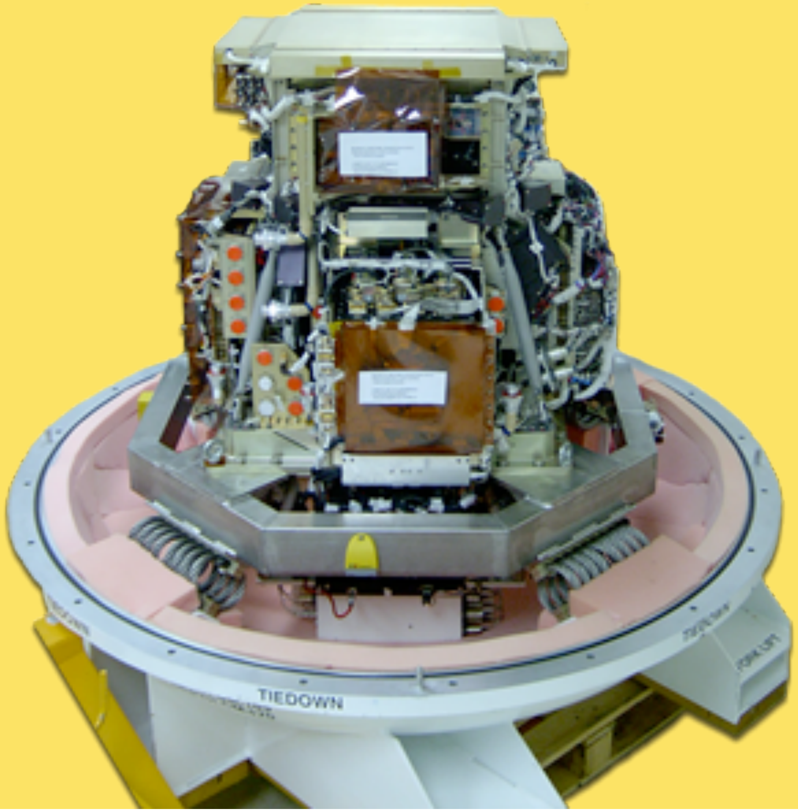


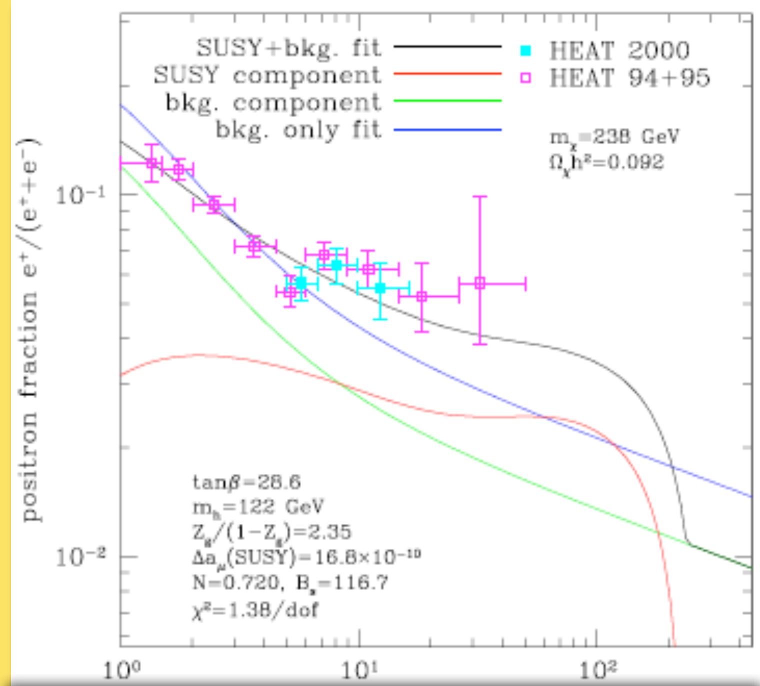
The HEAT Positron Excess

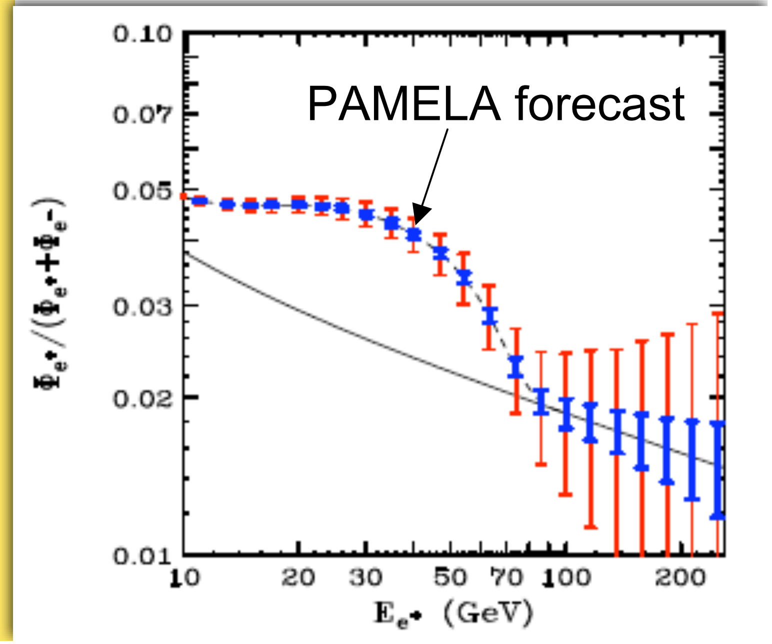
Fit to data can be improved if dark matter component is included

Requires annihilation boost of ~10: difficult to understand

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



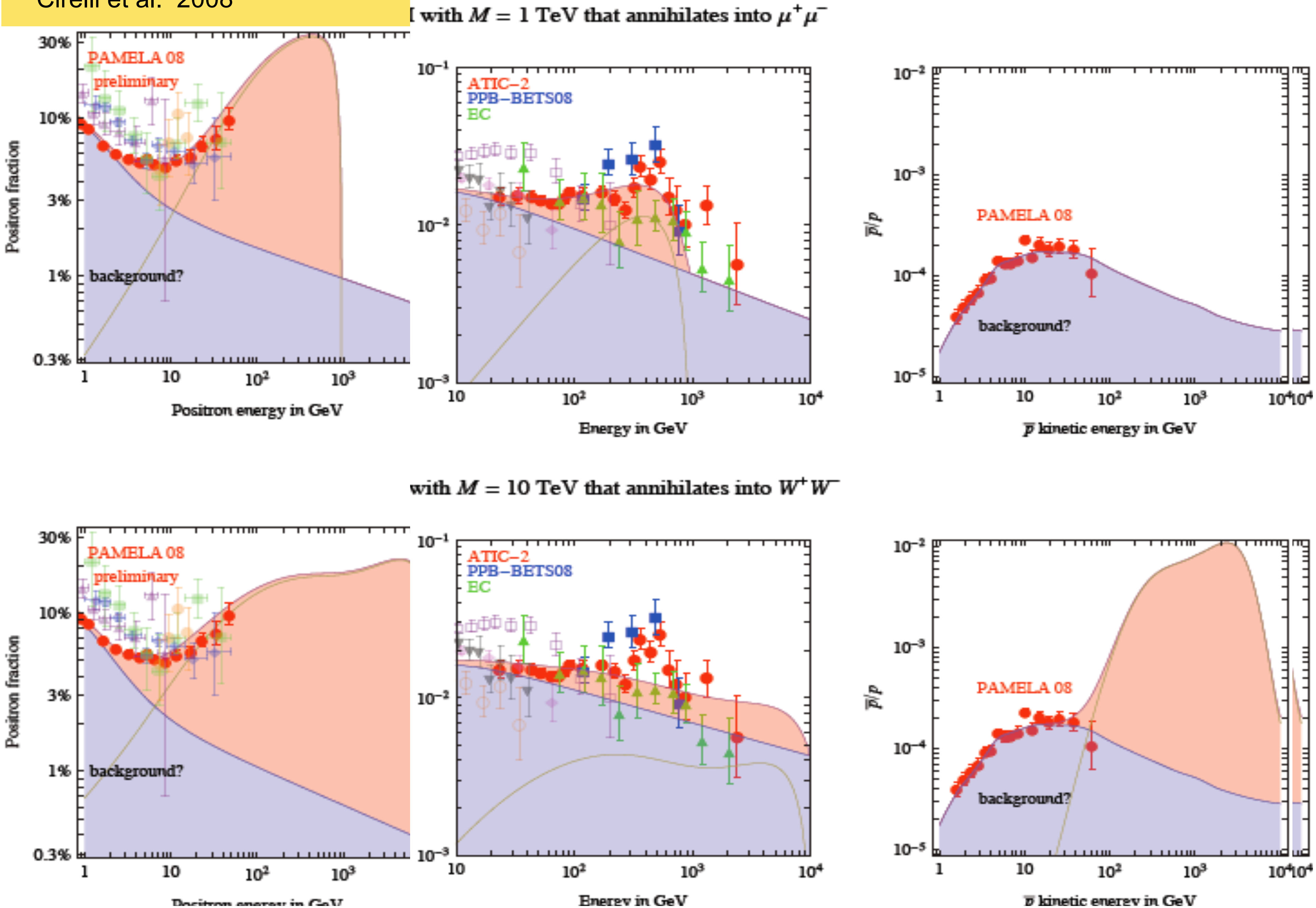




“The data points shown in our figure have been graphically extracted from a photo of a slide shown by M. Boezio at IDM08, Stockholm, 20/08/2008”

Cirelli et al. 2008

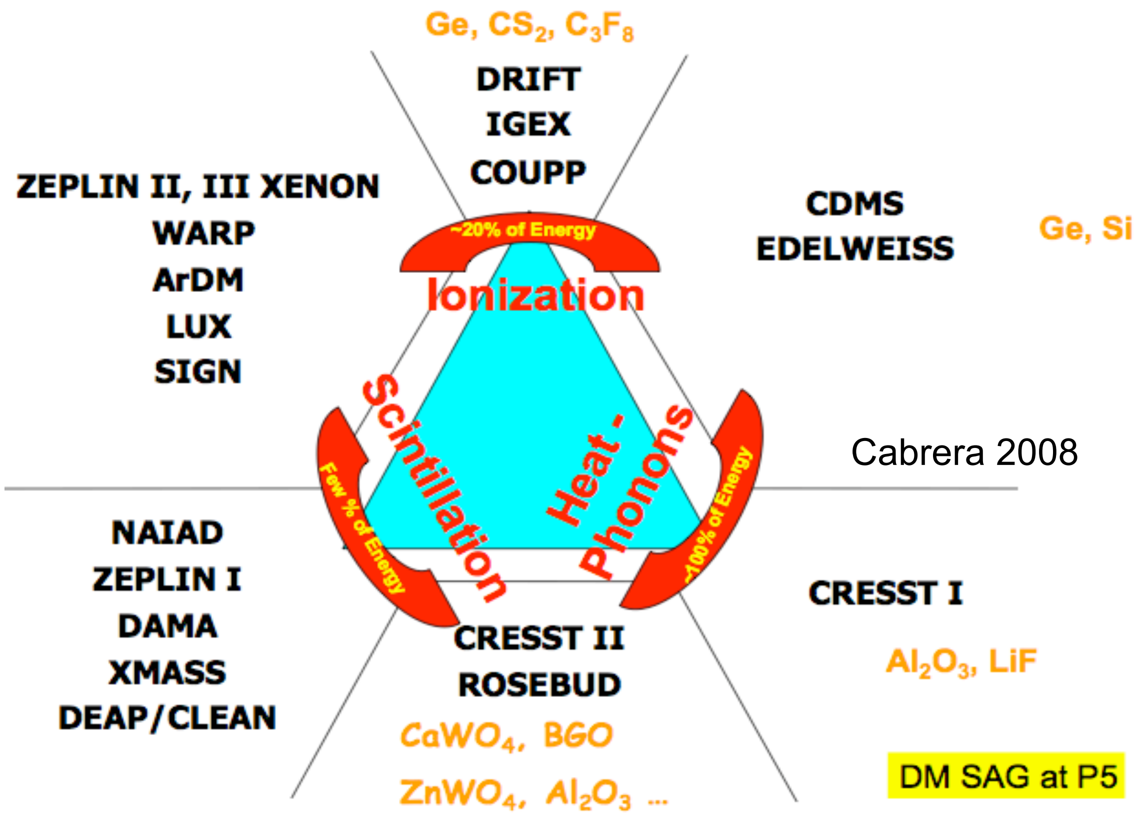
weak scale and couplings: $M/g \sim (T_0 M_{pl})^{1/2}$ ~ TeV
standard model + 1 new multiplet, weakly coupled (< 0.001) to Z
But a large boost factor is needed



DETECTING THE MILKY WAY DARK HALO:

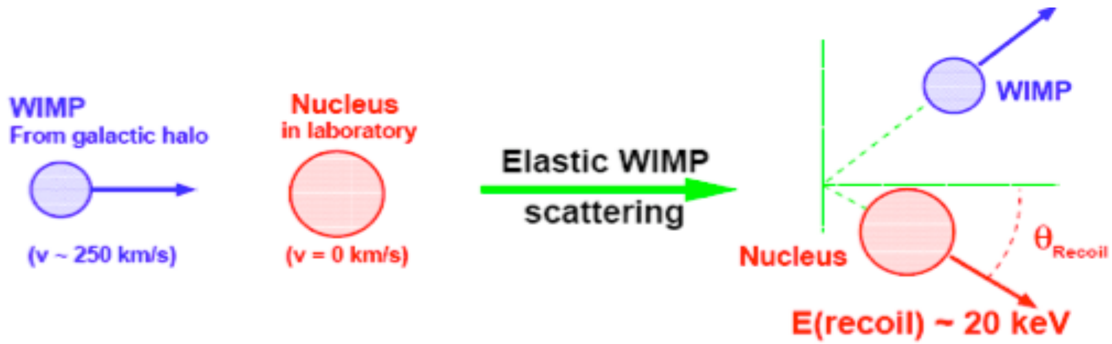
about ten million WIMPS per sq meter per sec pass through the earth

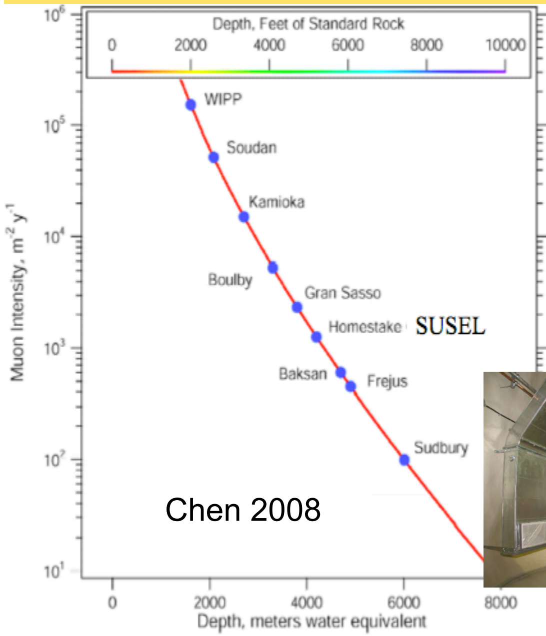
Direct Detection Techniques



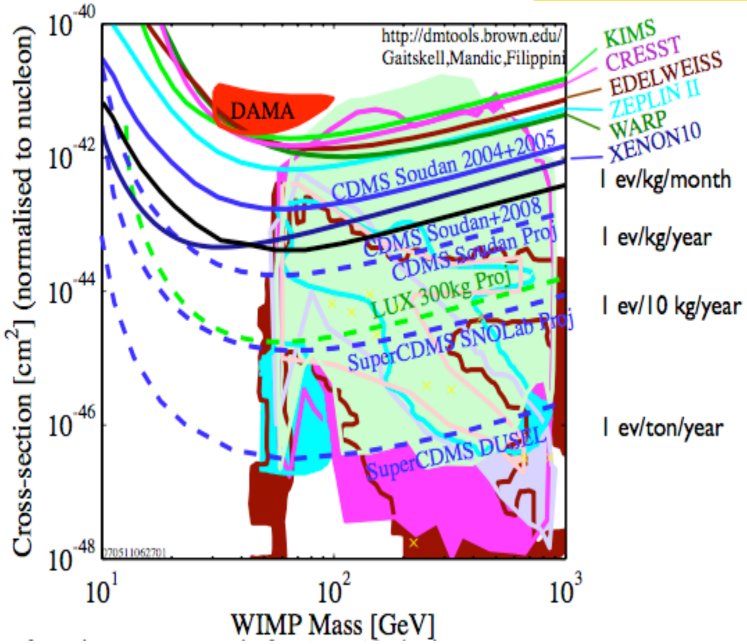
Cabrera 2008

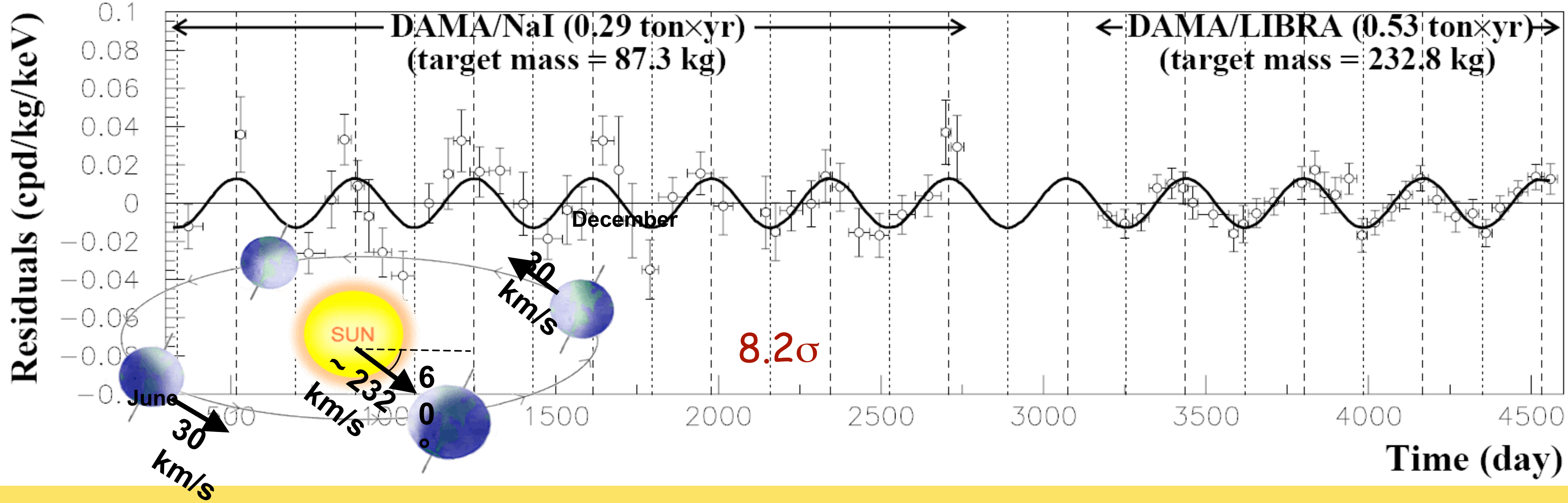
DM SAG at P5

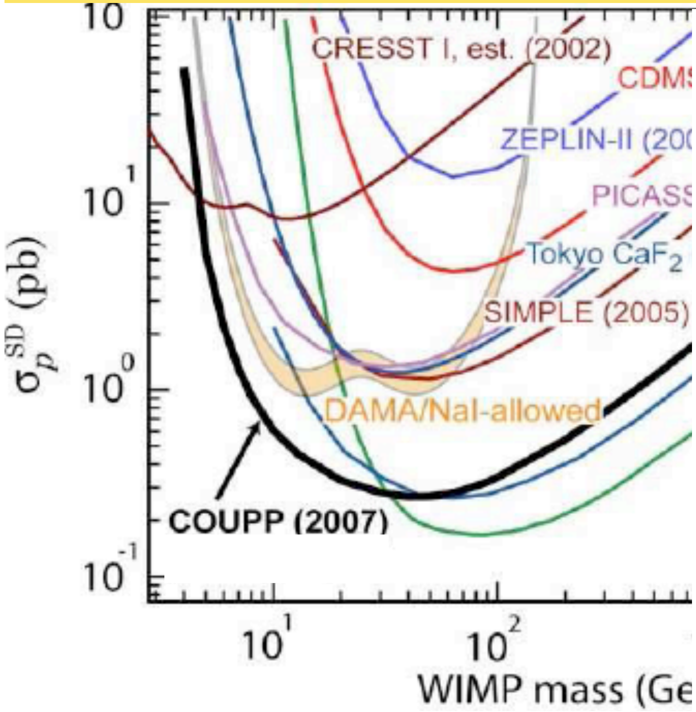


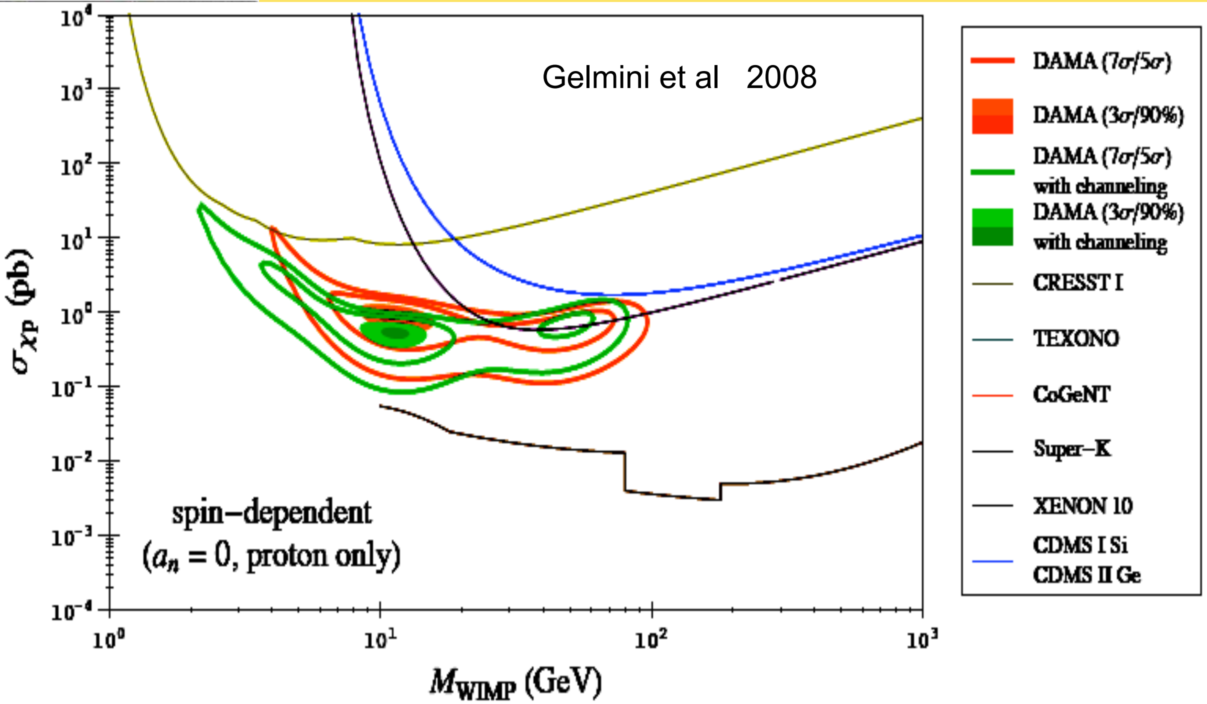


Chen 2008



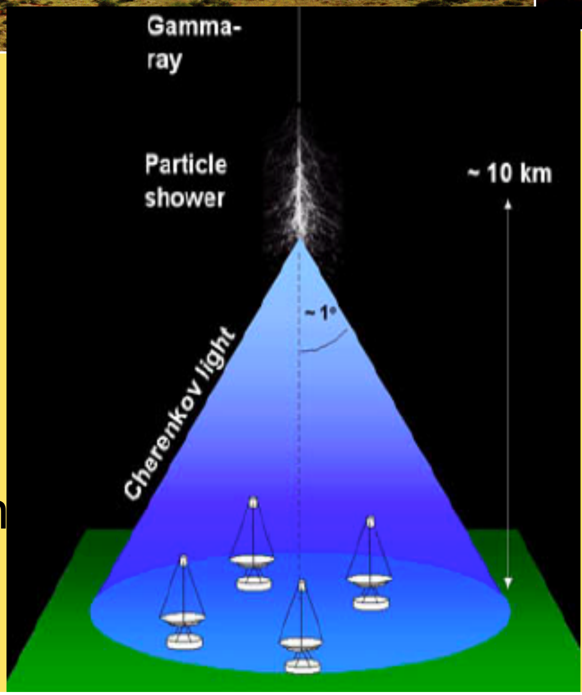

DAMA/NaI (0.29 ton×yr)
(target mass = 87.3 kg)
DAMA/LIBRA (0.53 ton×yr)
(target mass = 232.8 kg)
Residuals (cpd/kg/keV)
Time (day)
December
June
SUN
30 km/s
~232 km/s
60°
8.2σ

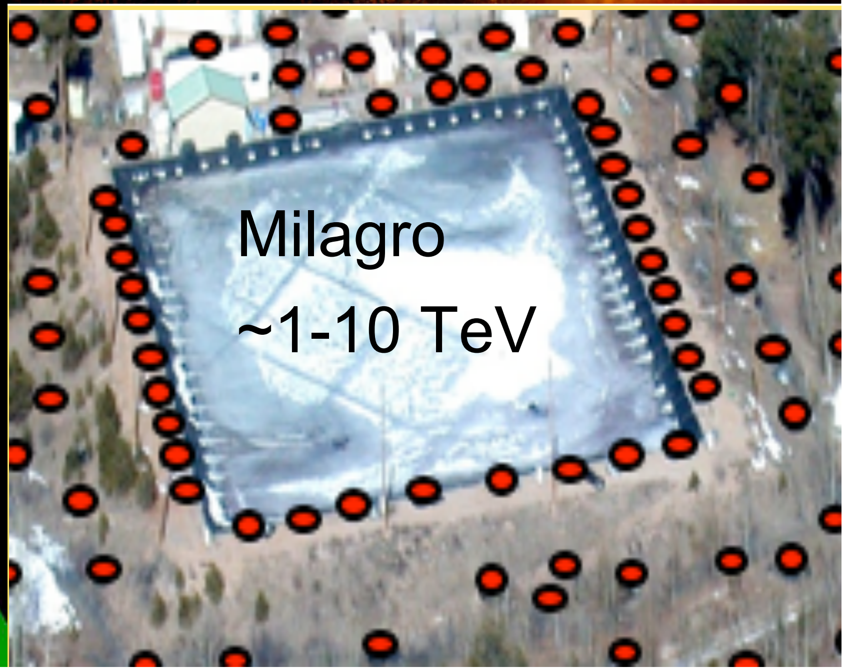

CRESST I, est. (2002)
ZEPLIN-II
PICASS
Tokyo CaF2
SIMPLE (2005)
DAMA/NaI-allowed
COUPP (2007)
σpSD (pb)
WIMP mass (Ge


Gelmini et al 2008
spin−dependent
(an = 0, proton only)
σχp (pb)
MWIMP (GeV)
DAMA (7σ/5σ)
DAMA (3σ/90%)
DAMA (7σ/5σ) with channeling
DAMA (3σ/90%) with channeling
CRESST I
TEXONO
CoGeNT
Super−K
XENON 10
CDMS I Si
CDMS II Ge

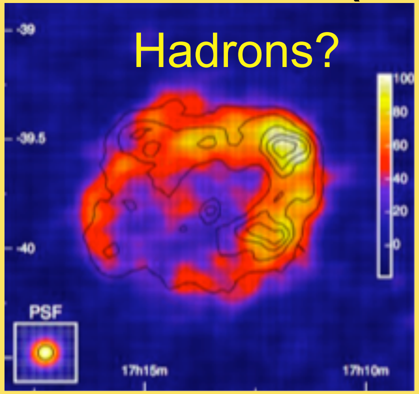
Exploring the Terascale

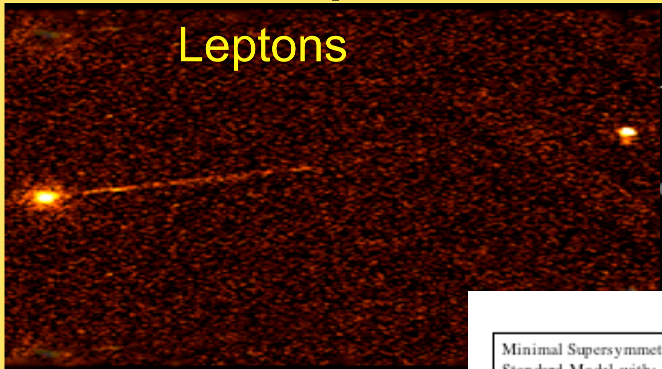
- ~10 ns flash
- ~1° @ 10 km->10^4 m^2
- Stereo imaging
- ~ 0.1-100TeV
- ~5° field of view
- ~5' PSF per photon
- ~100 sources

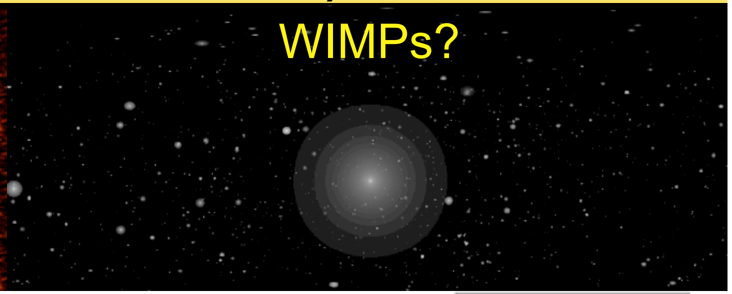


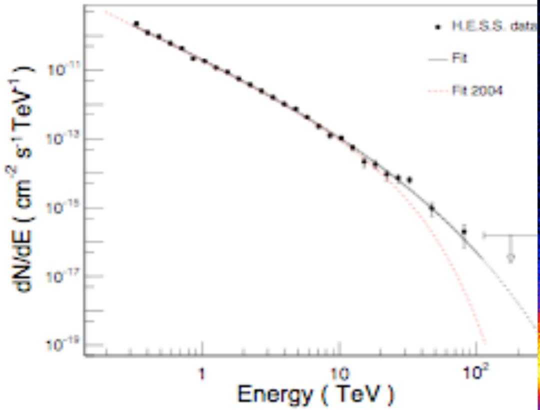


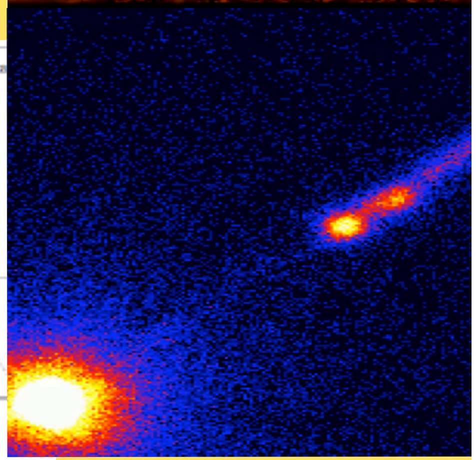
Hadrons vs Leptons vs WIMPS
(Pions vs Compton vs Annihilation)

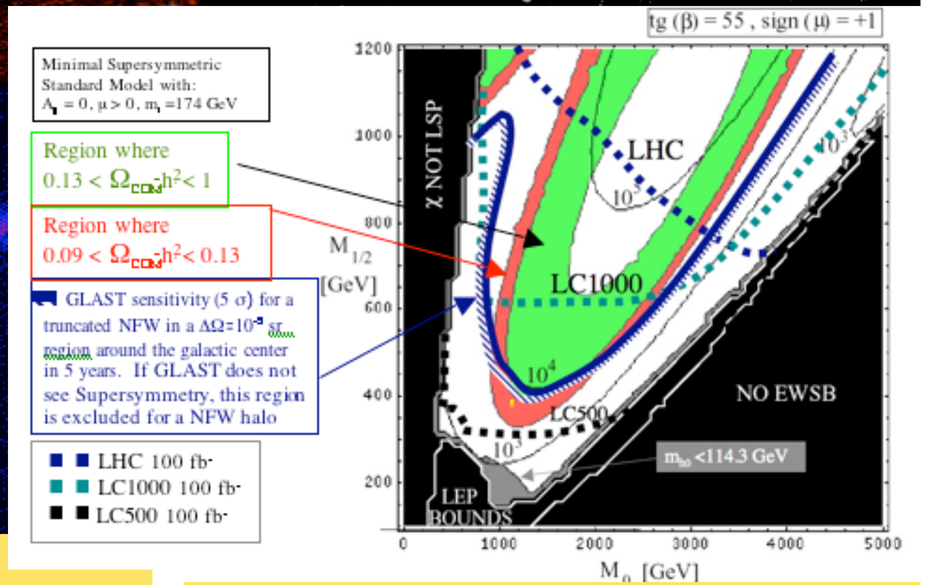












X-ray vs TeV
Fermi acceleration at shocks
Magnetic field amplification
Origin of cosmic rays?

Relativistic jets from massive black holes in galactic nuclei
Gamma ray emission at small radii
Inverse Compton radiation
100 sec variability?

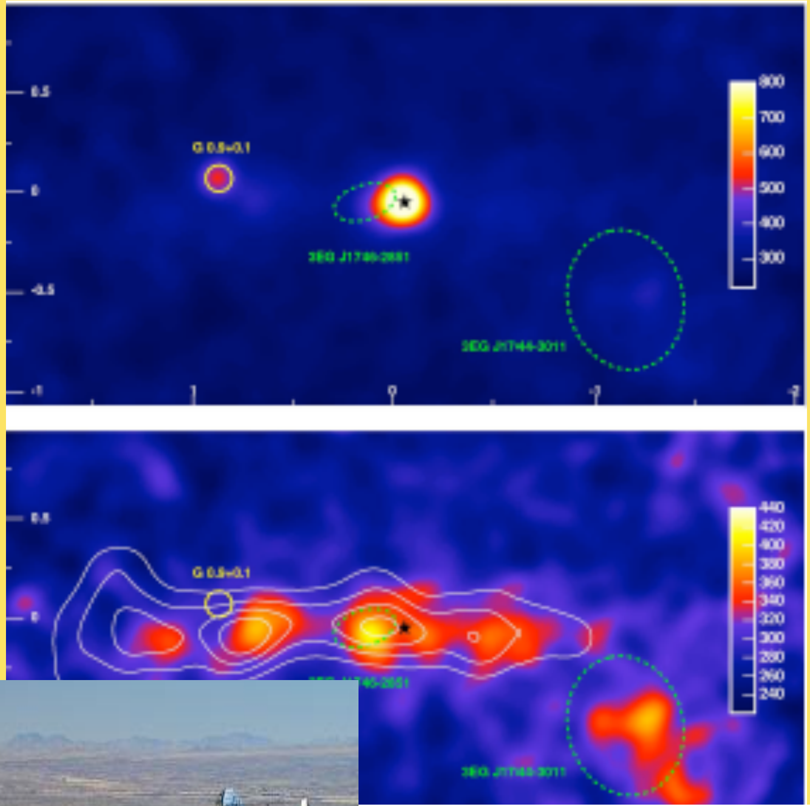
If DM is cosmologically-generated, weakly interacting massive particle, there may be detectable annihilation from Galactic Center and dwarf galaxies. Constraints will be combined with LHC and direct searches.

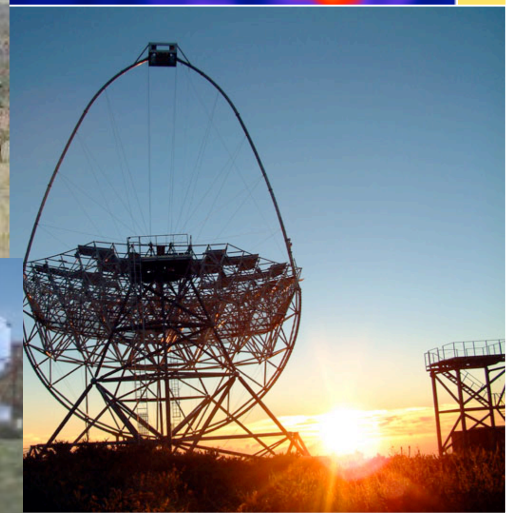
Gamma-Rays from the Galactic Center

•Simulations predict GC contains high densities of dark matter

•HESS, MAGIC, WHIPPLE and CANGAROO each claim positive detection of ~TeV gamma-rays

•Dark matter, or near-BH astrophysics?



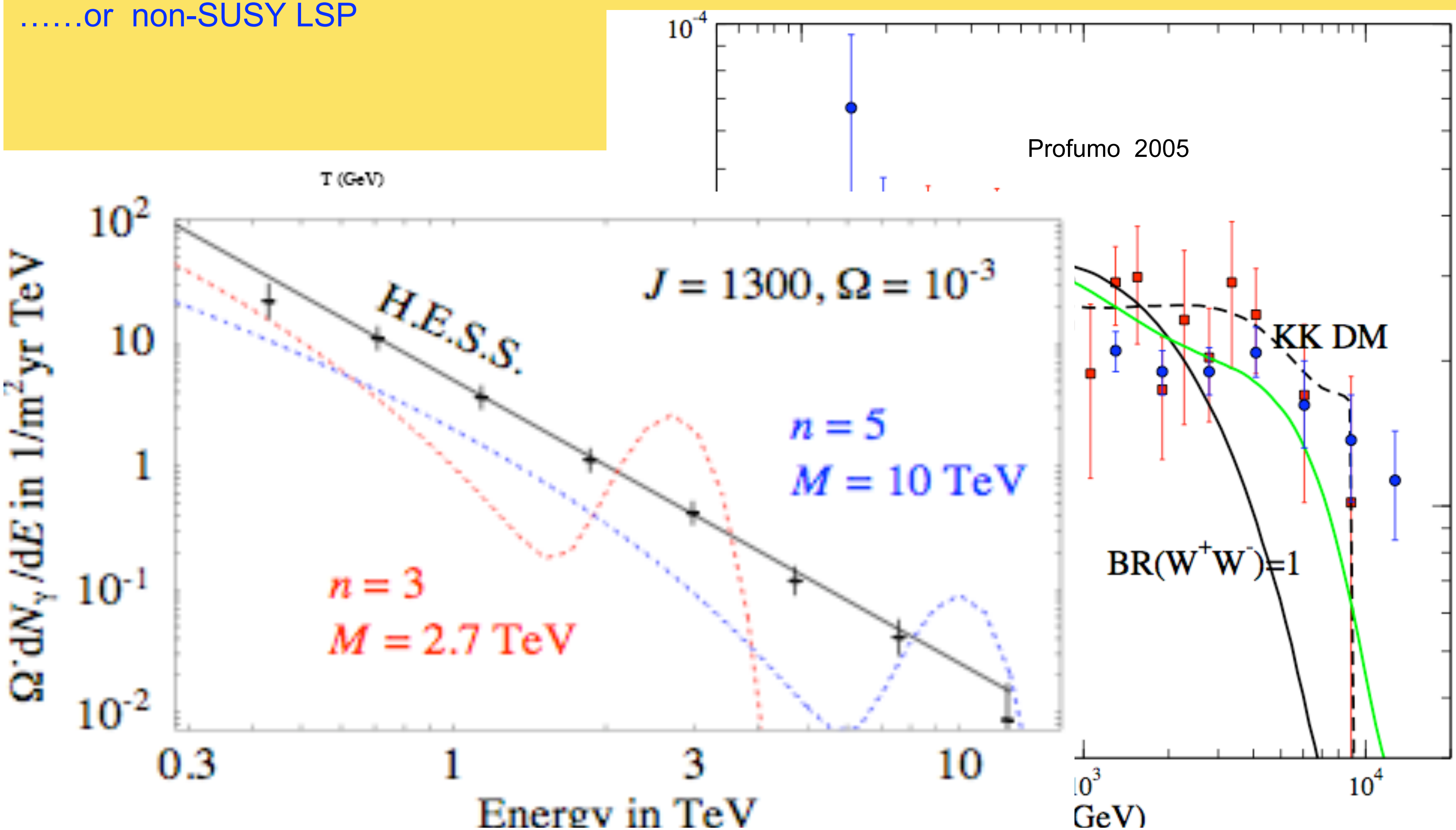


How high can you go in neutralino mass?

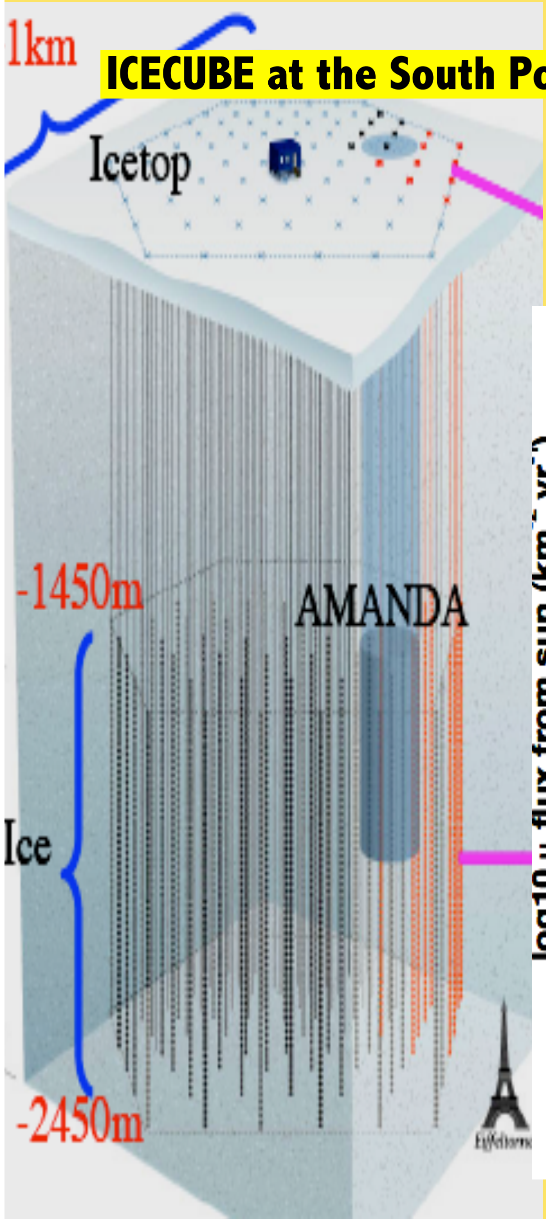
Coannihilations + Sommerfeld boost cross-section by 10-100

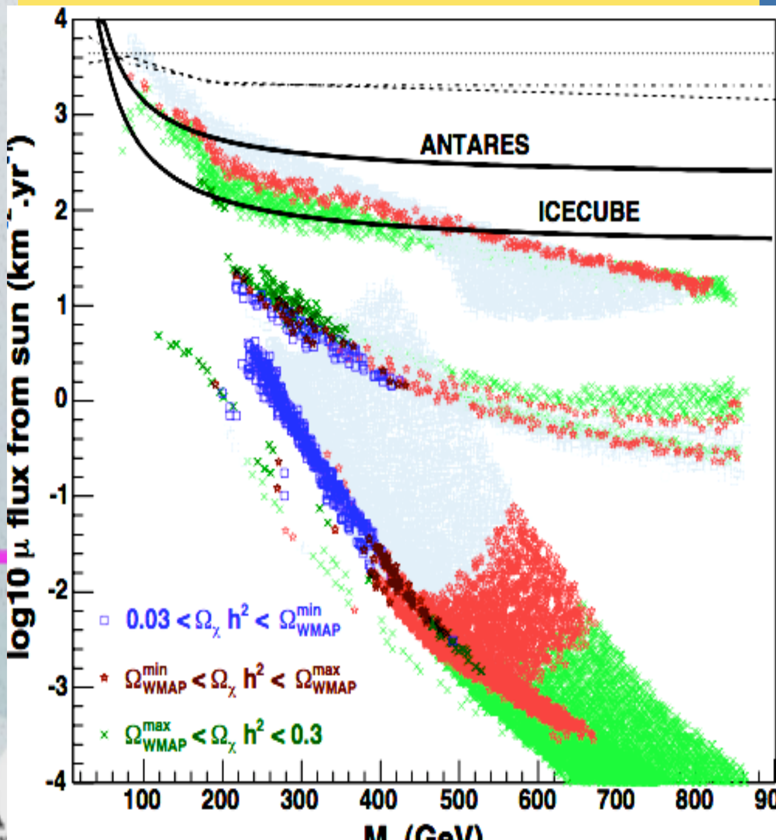
⇨ SUSY LSP up to 20+ TeV

……or non-SUSY LSP

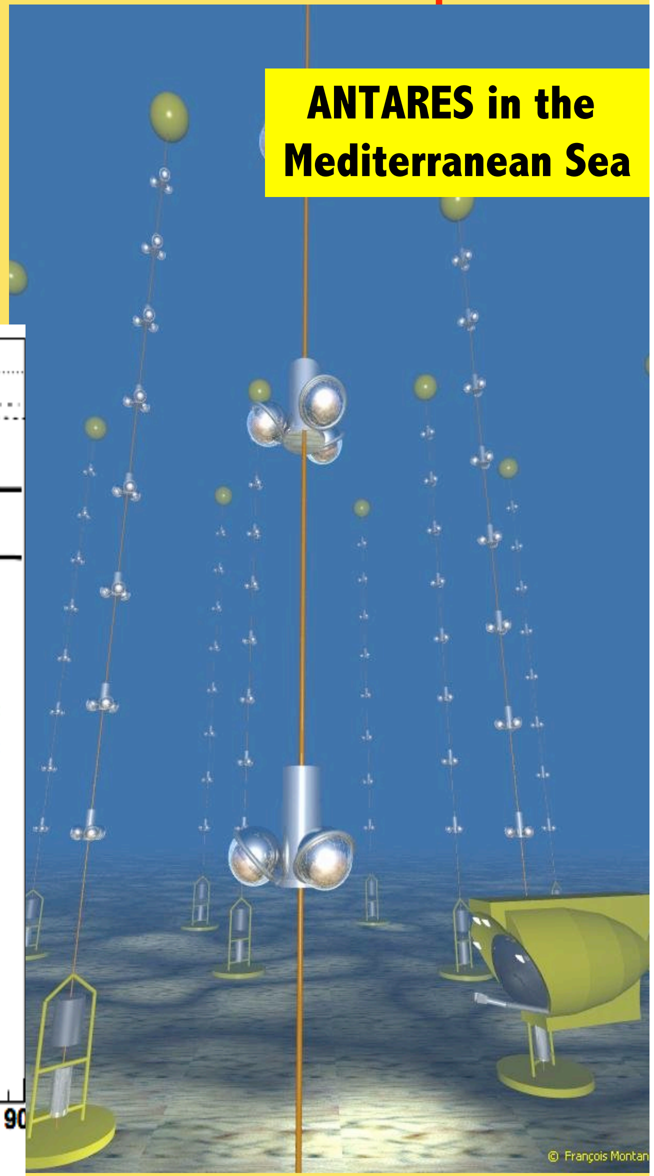


high energy neutrinos from WIMPs annihilating in the sun observable with downward-looking neutrino telescopes





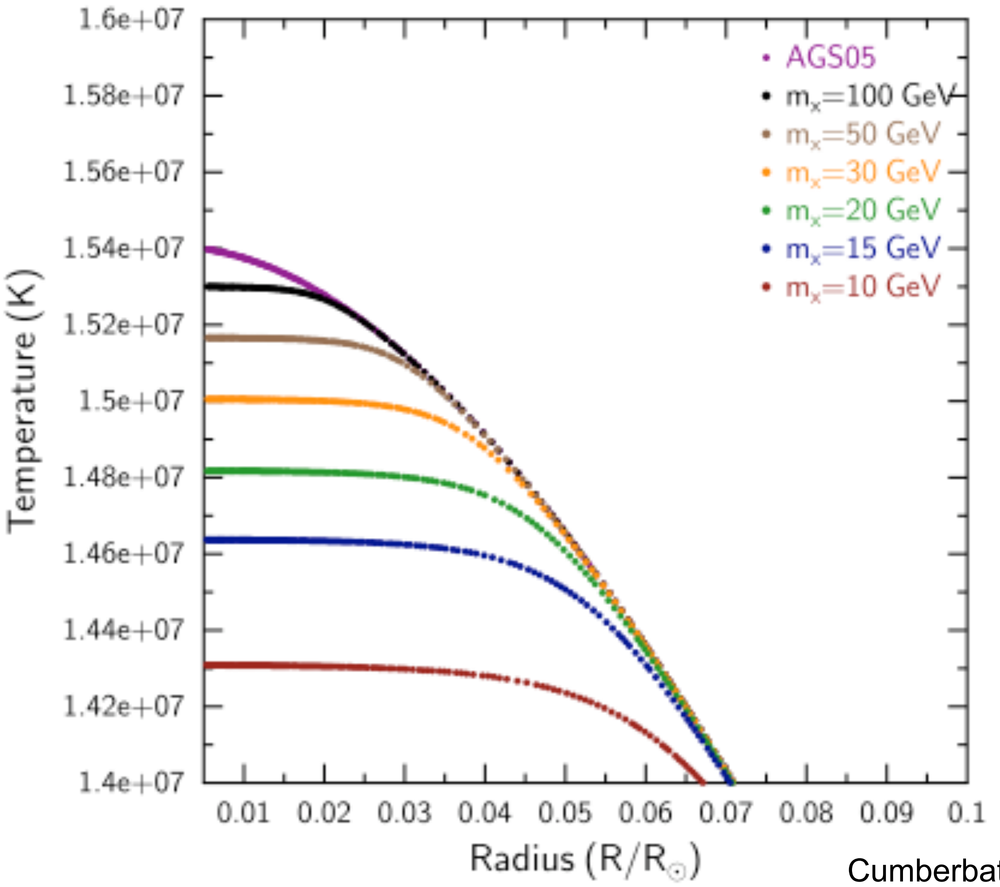
Bertone et al. 2004

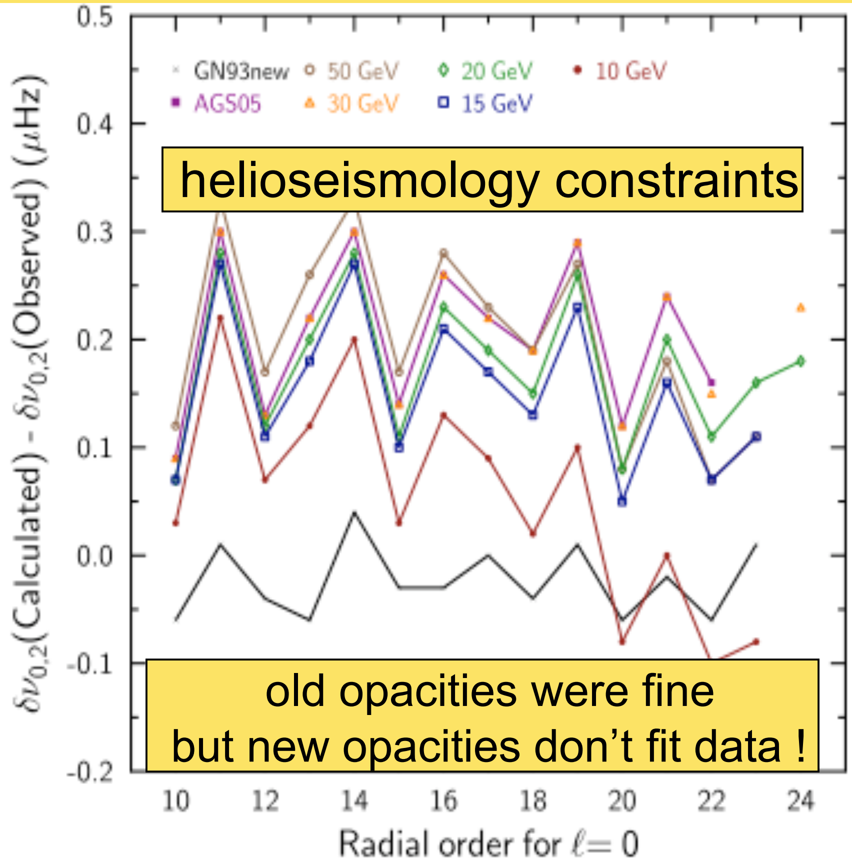


STARS AS NEUTRALINO TRAPS

If annihilation rate is low and m_x ~5-20 GeV, WIMPS can modify the core properties of the sun.

Stars could be very different near the galactic centre where dm density is high: solar mass stars become short-lived!

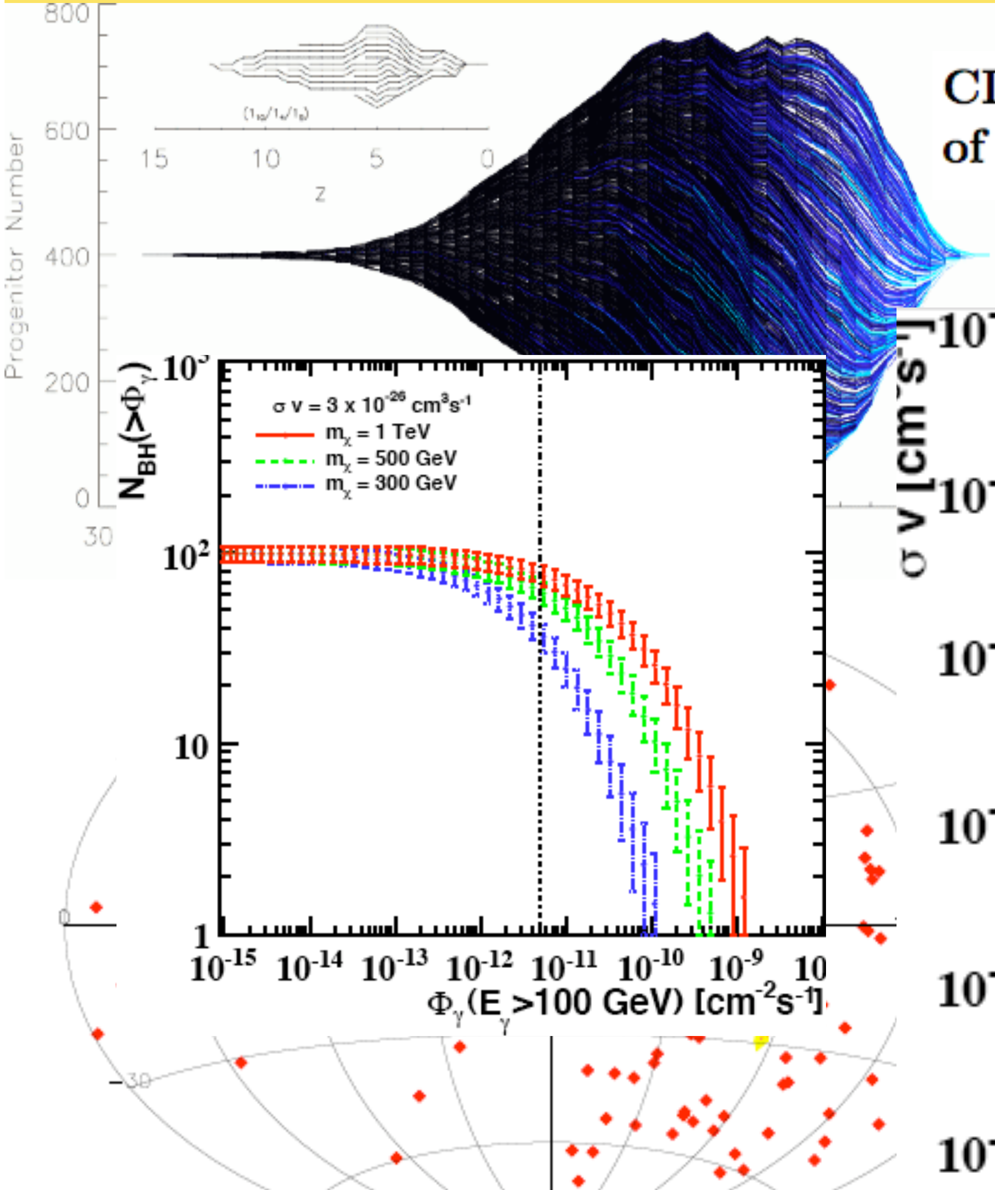




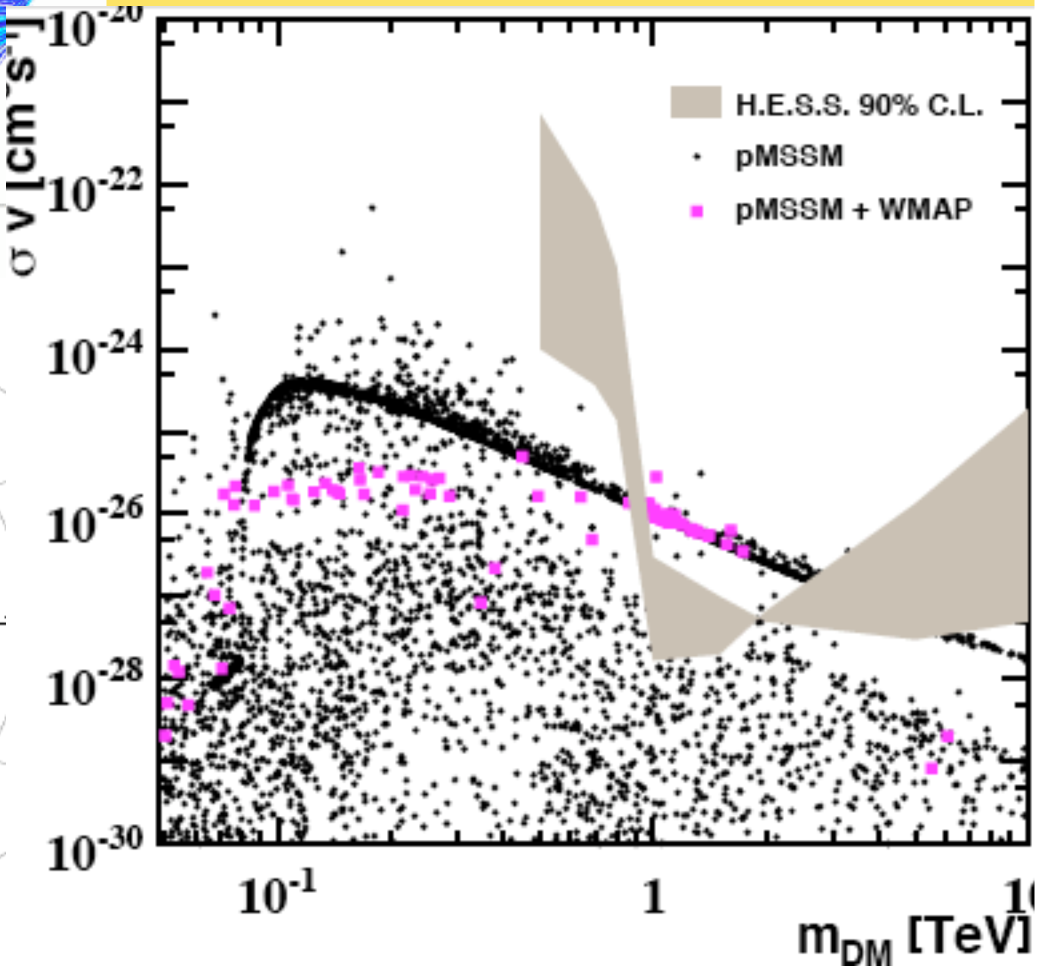
Cumberbatch et al 2008

Cold dark matter spikes surround intermediate mass black holes

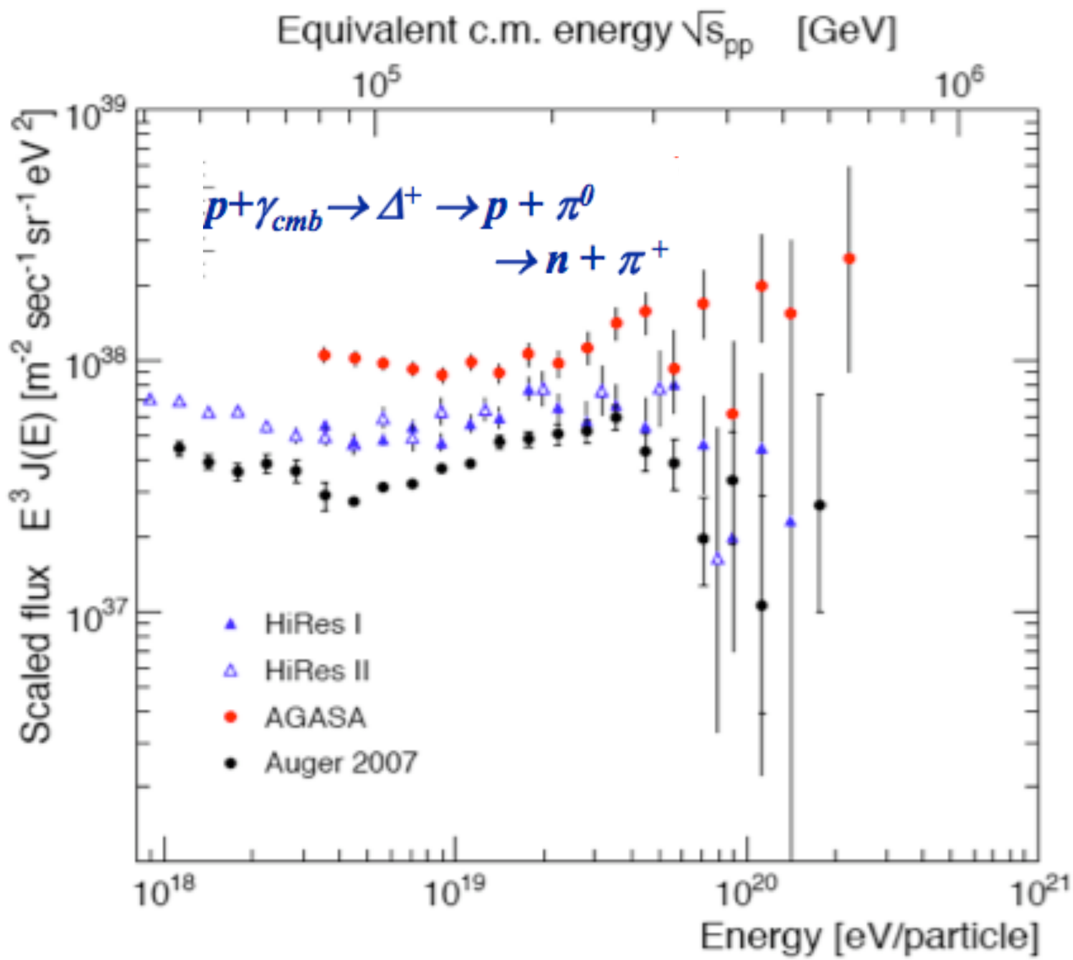
CDM cusp steepens by adiabatic growth of IMBH: $\rho \propto r^{-\gamma} \Rightarrow \rho \propto r^{-\gamma'}$, with $\gamma' = \frac{9-2\gamma}{4-\gamma}$



Bertone et al 2006



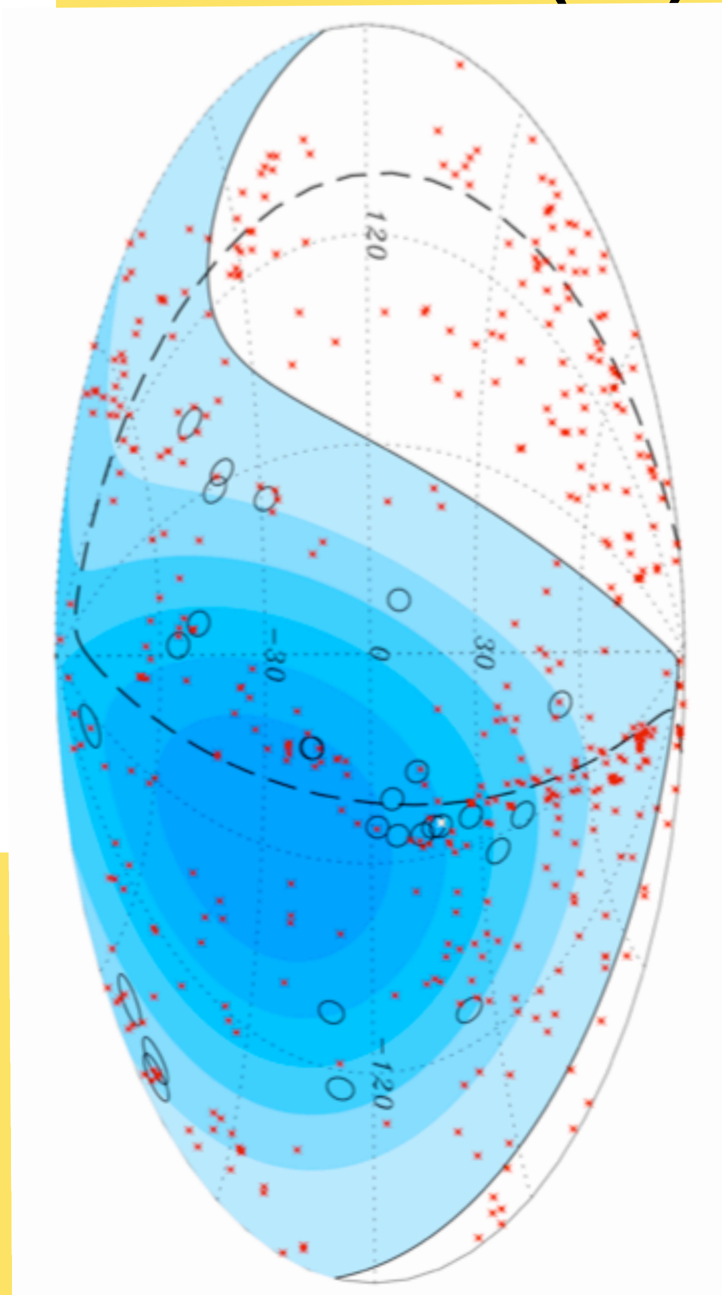
AUGER (S)



3000 km^2 area observatory in Argentina.

1600 water Cherenkov detectors.

4 fluorescence sites overlooking the array.

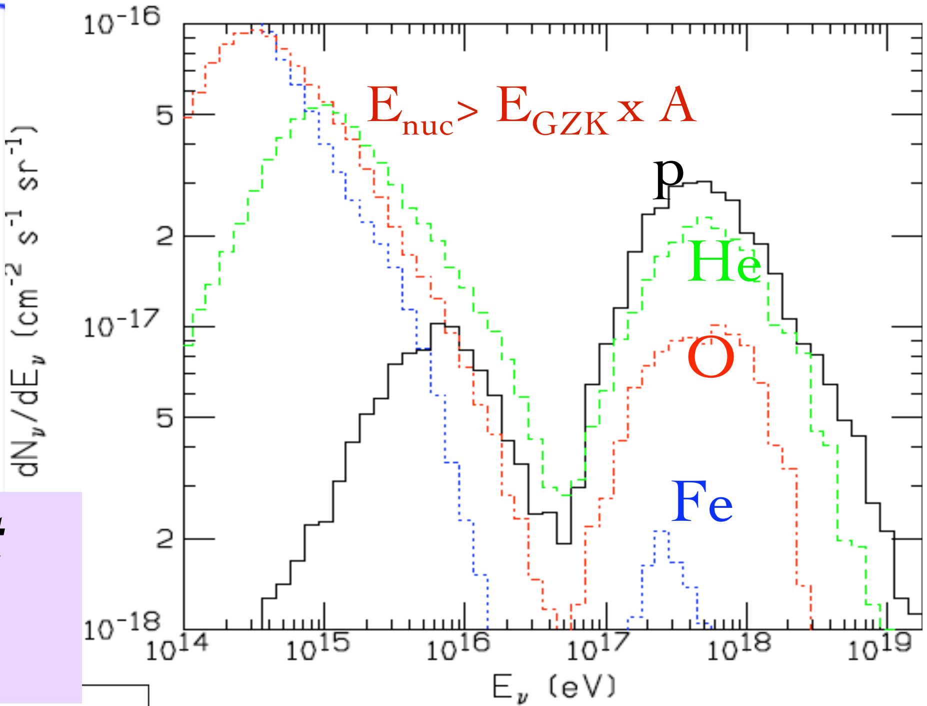


GZK mechanism :

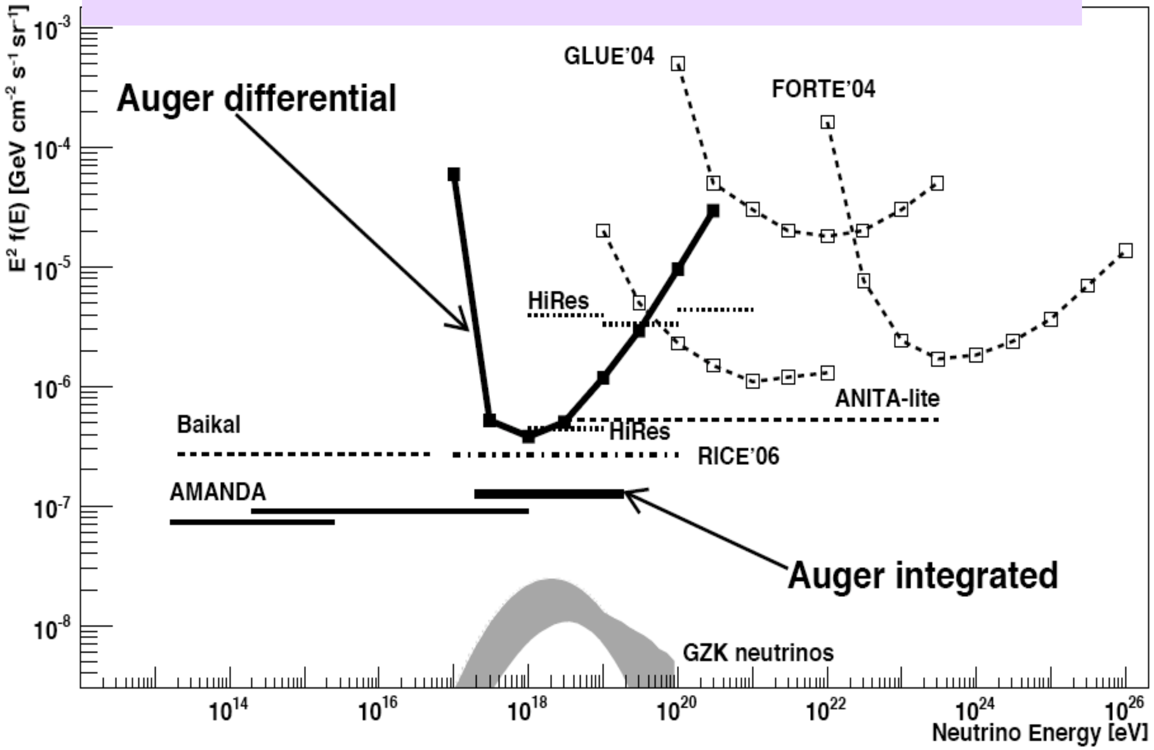
$$p+\gamma_{CMB} \rightarrow \Delta^{+} \rightarrow n+\pi^{+}$$

- $n \rightarrow p+e^{-}+\bar{\nu}_e$
- $\pi^{+} \rightarrow \mu^{+}+\nu_\mu$
- $\mu^{+} \rightarrow e^{+}+\nu_e+\bar{\nu}_\mu$

$E_{THRESH.} \sim 6\times10^{19}$ eV



The cosmic ray sources *must* also be neutrino sources



Auger can see UHE νs as inclined deeply penetrating showers at

rate ∝ cosmic neutrino flux x ν-N cross-sectn

AND

earth-skimming $\nu_\tau \rightarrow \tau$ as *upgoing* hadronic shower, at

rate ∝ cosmic neutrino flux

1 EeV (10^{18} eV) ⇒ 50 TeV cms vs LHC: 14 TeV cms

NEUTRINO DARK MATTER

primordial neutrinos as hot dark matter

$\Omega_\nu h^2 = \Sigma m_\nu / 92\ eV$

Hubble parameter h= 0.65 (65 km/s/Mpc)

$\Omega_\nu < 0.20$

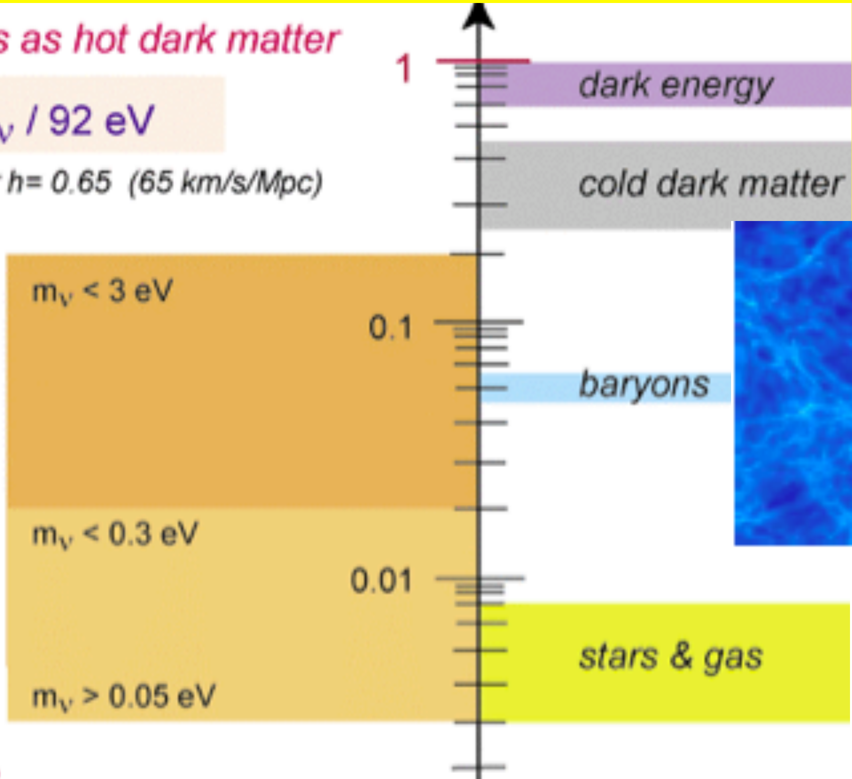
structure formation
tritium experiments

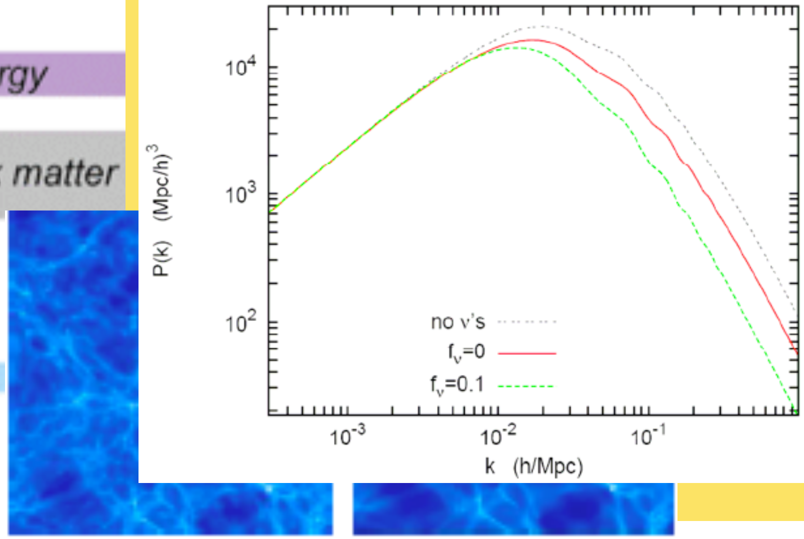
$\Omega_\nu < 0.02$

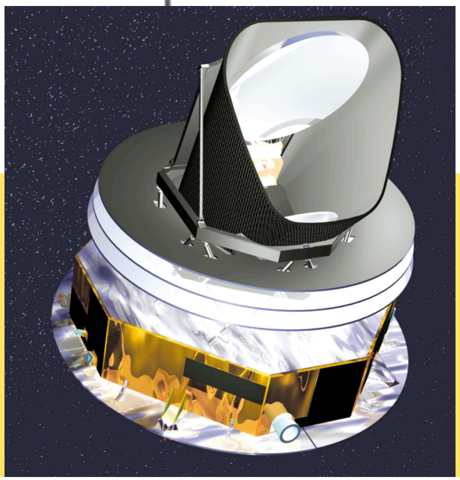
KATRIN sensitivity

$\Omega_\nu > 0.003$

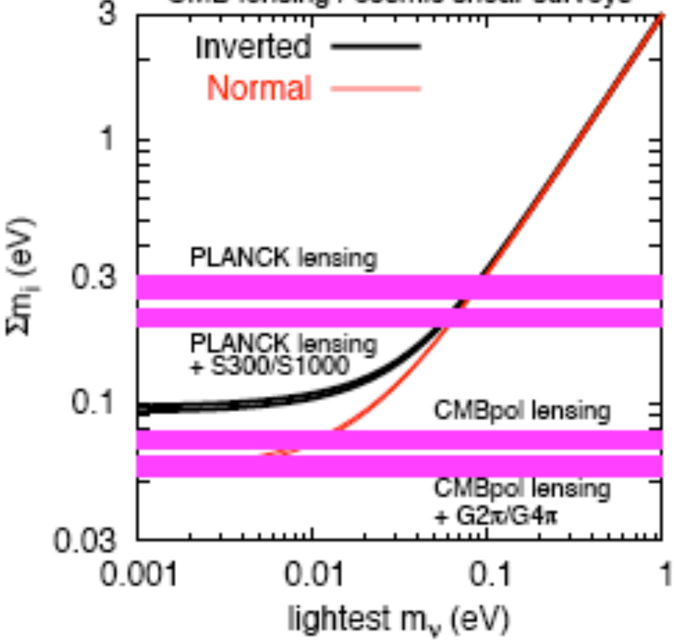
Super-Kamiokande





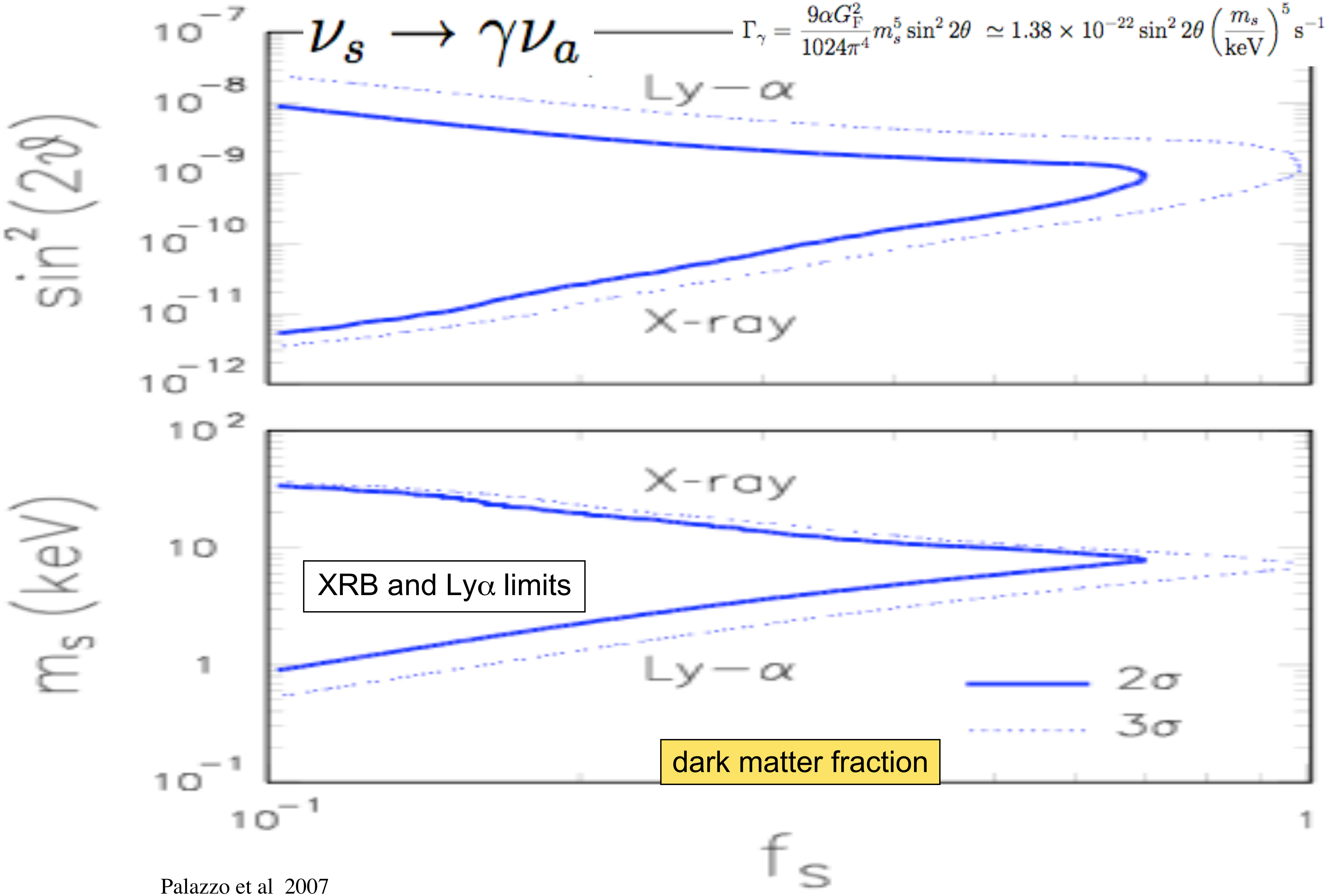


2σ sensitivities including
CMB lensing / cosmic shear surveys



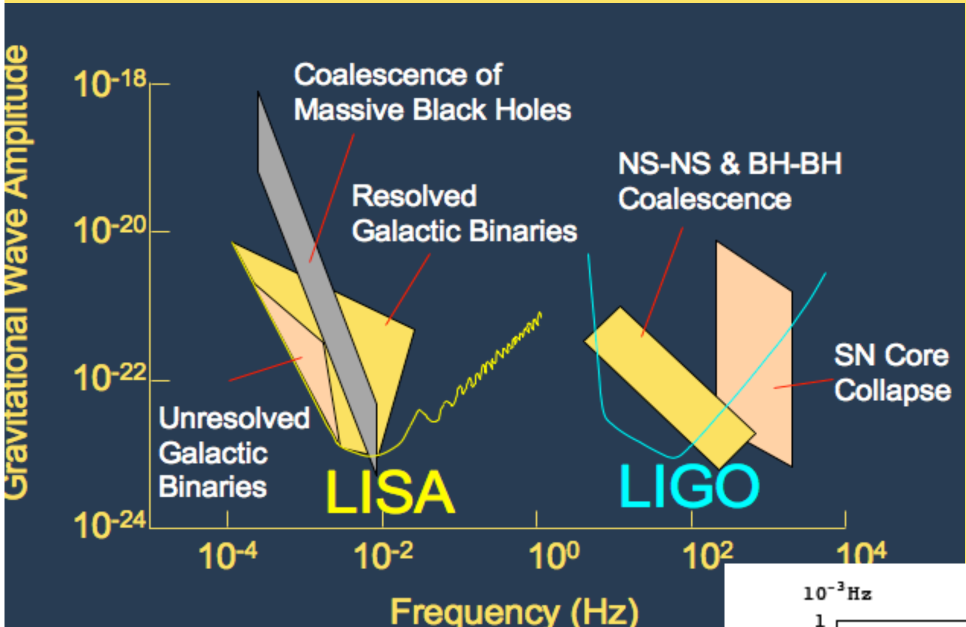
STERILE NEUTRINOS AS DARK MATTER ?

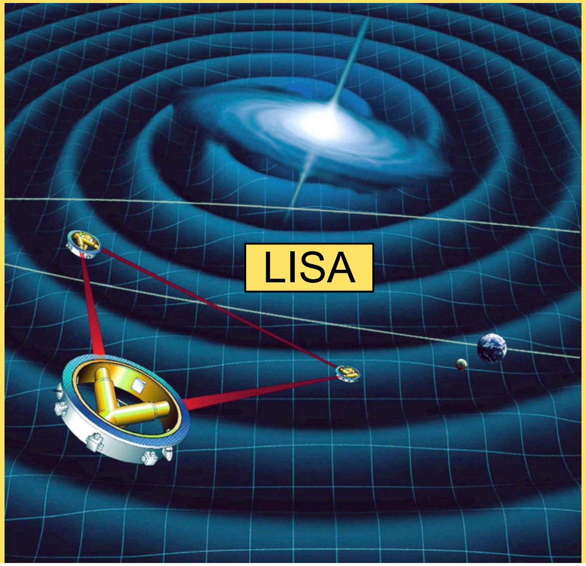
$$\nu_s \to \gamma \nu_a \qquad \Gamma_\gamma = \frac{9\alpha G_F^2}{1024\pi^4} m_s^5 \sin^2 2\theta \simeq 1.38 \times 10^{-22} \sin^2 2\theta \left(\frac{m_s}{\text{keV}}\right)^5 \text{s}^{-1}$$

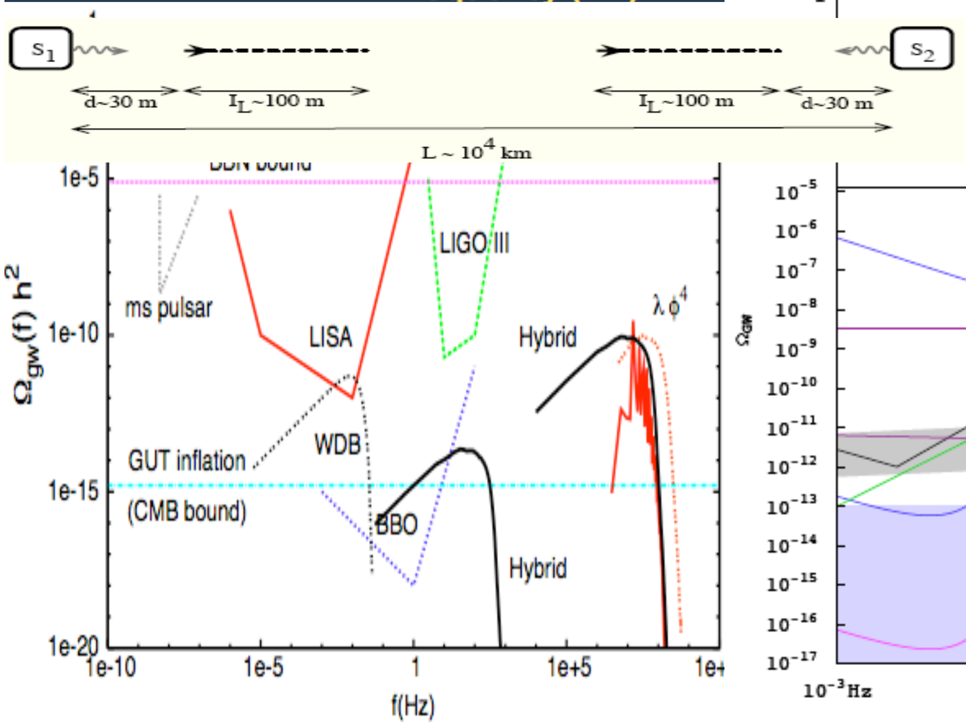


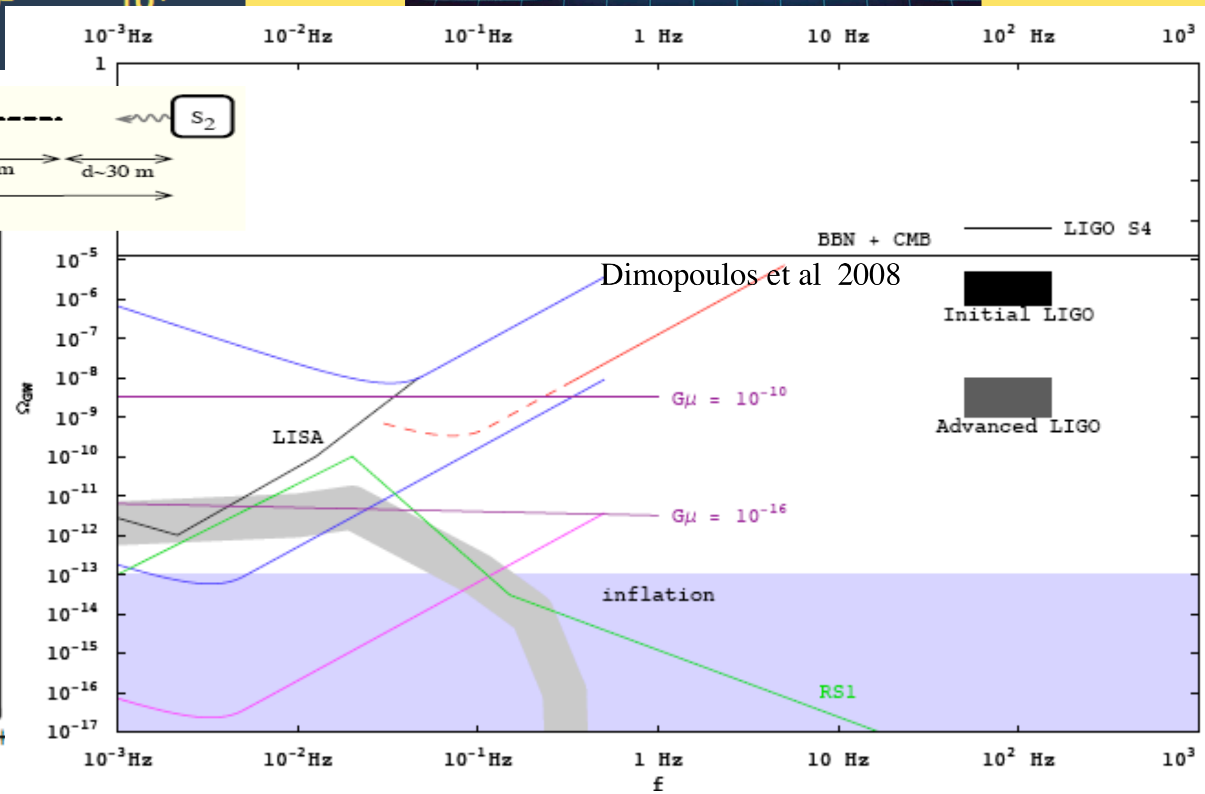
Palazzo et al 2007

PROBING INFLATION WITH GRAVITY WAVES









APP explores regimes where LHC or ILC cannot go