

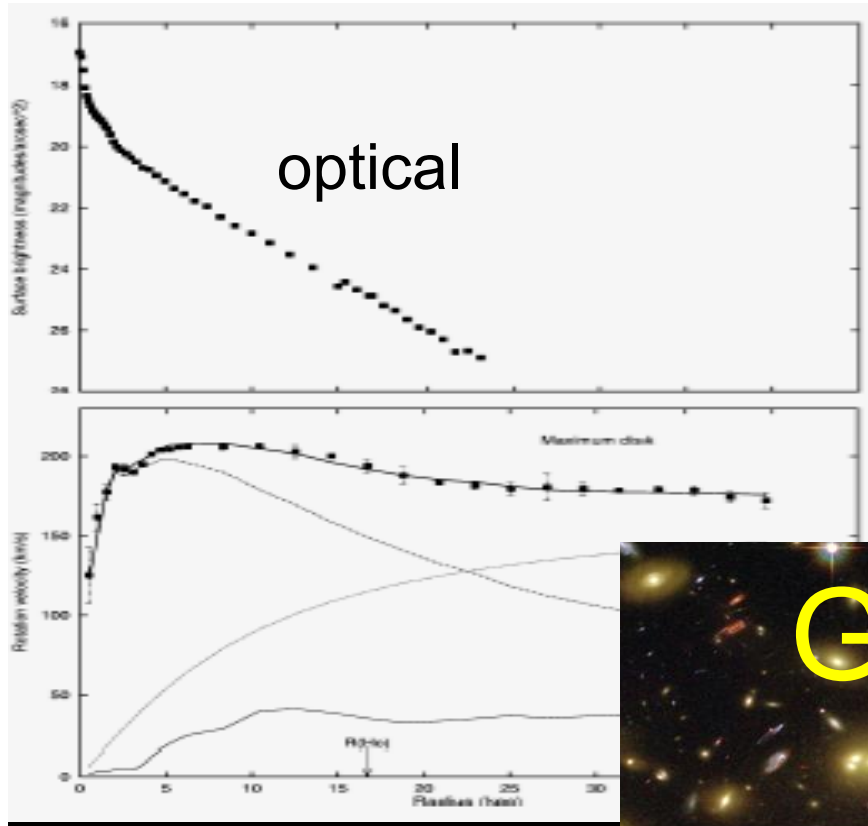
# **DARK MATTERS IN COSMOLOGY**

**Joe Silk**

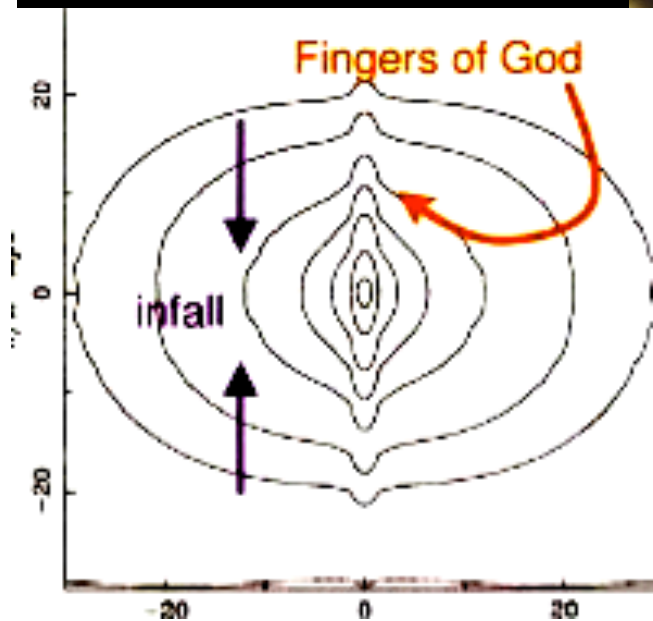
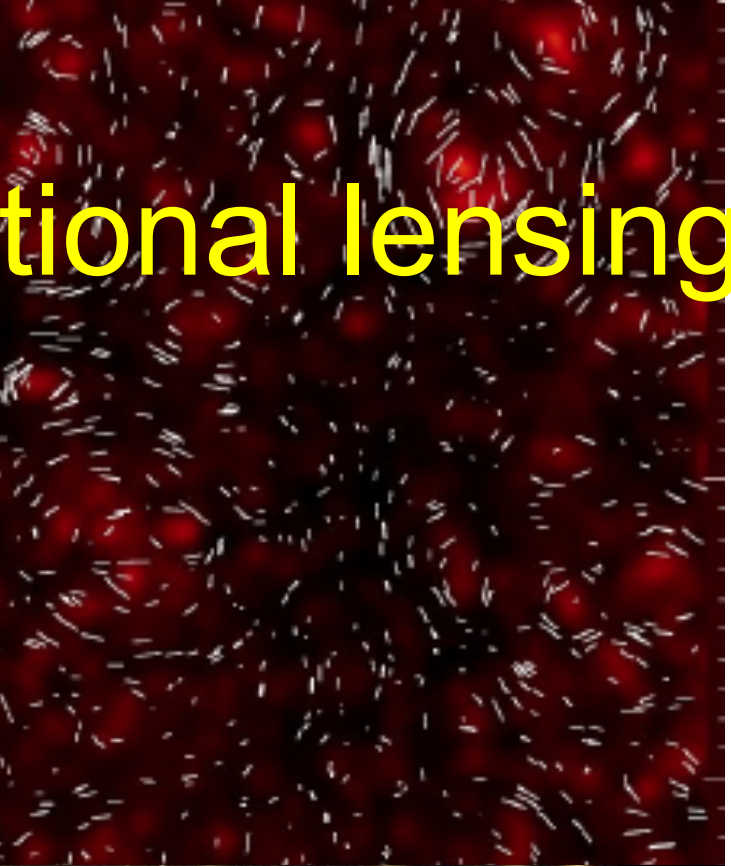
**Oxford/IAP**

**May 2011**

# Rotation curves

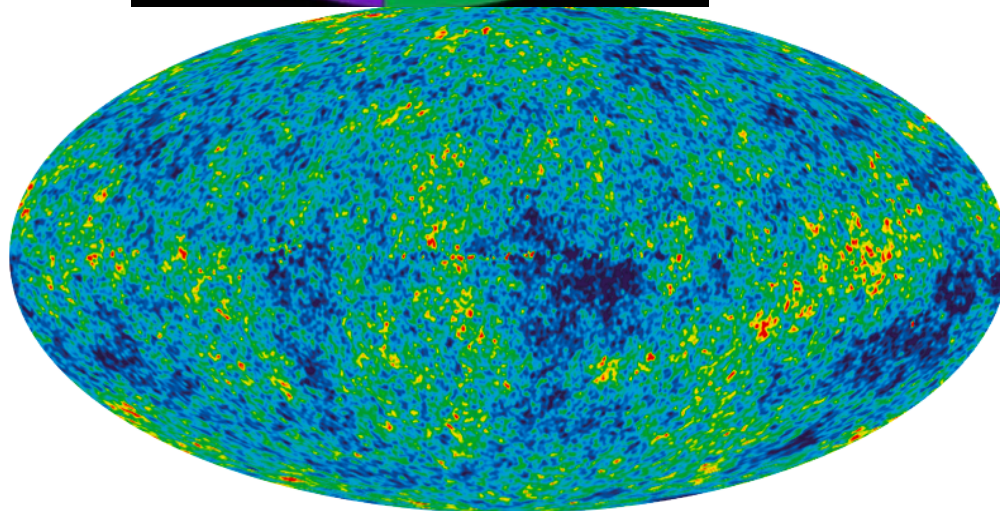
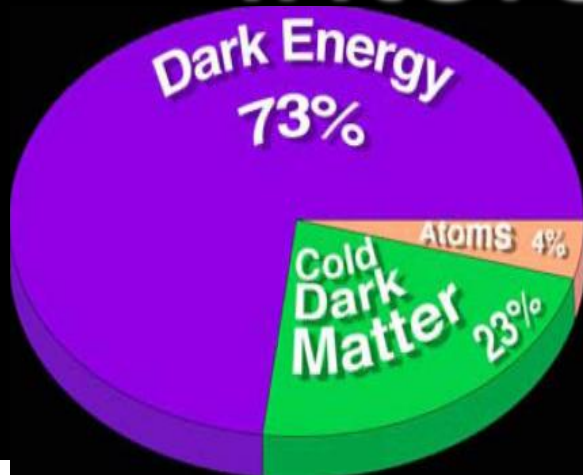


# Gravitational lensing

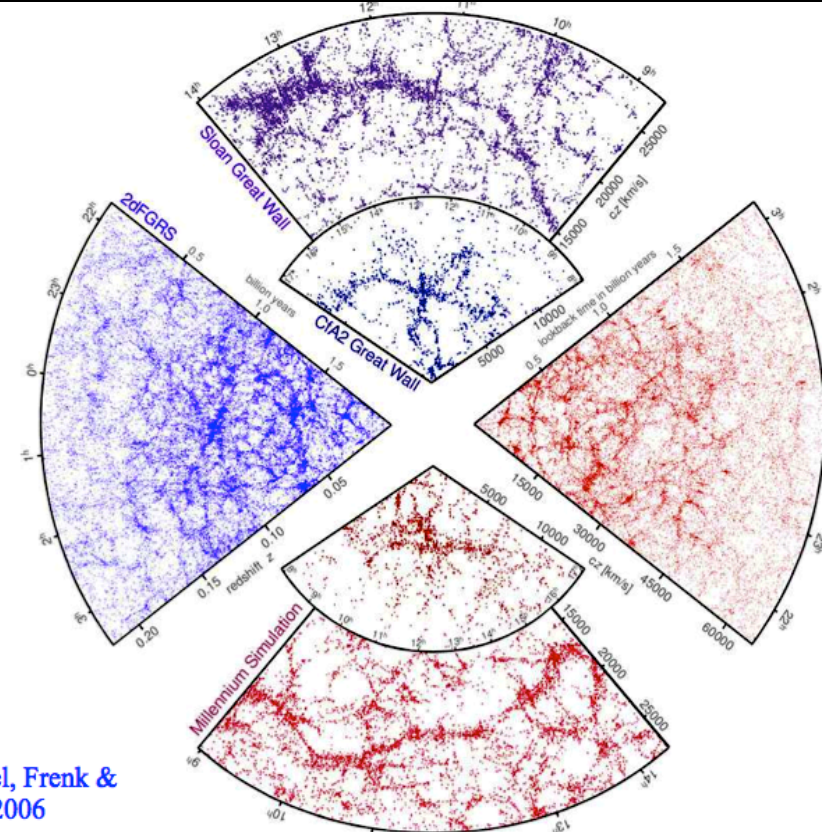


# Redshift space distortions

# Dark Matter is weakly interacting & cold



-200 T( $\mu$ K) +200 WMAP 5-year



Springel, Frenk & White 2006

*primordial neutrinos as hot dark matter*

$$\Omega_\nu h^2 = \sum m_\nu / 92 \text{ eV}$$

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

$$\Omega_\nu < 0.20$$

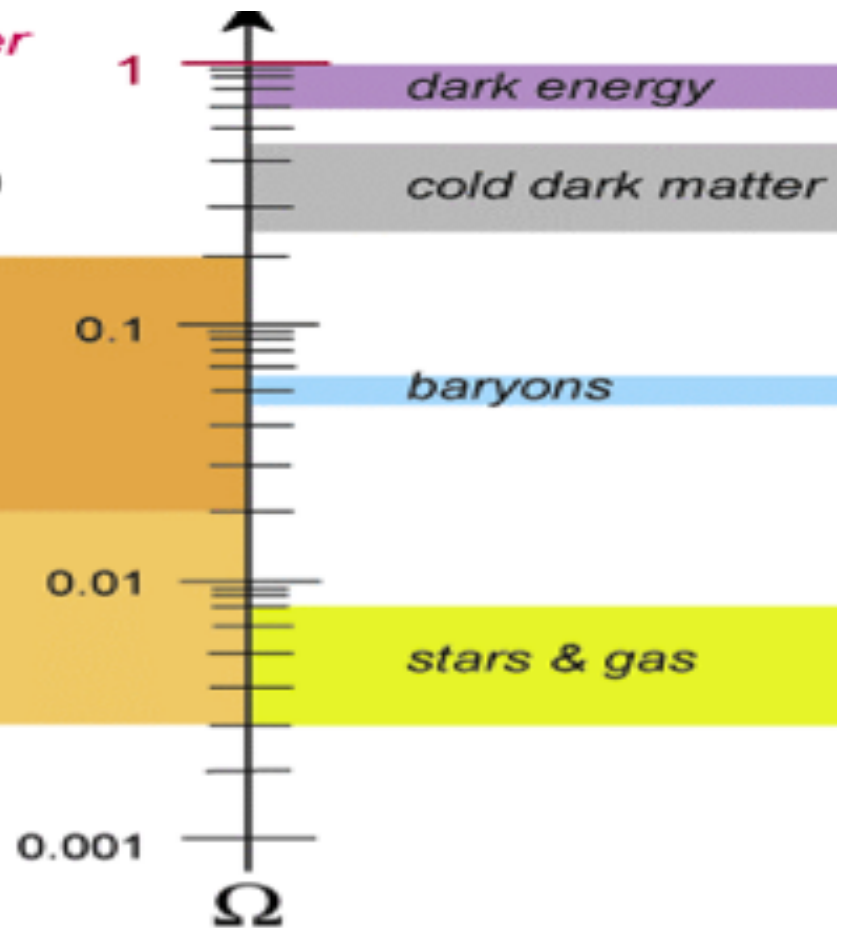
*structure formation  
tritium experiments*

$$\Omega_\nu < 0.02$$

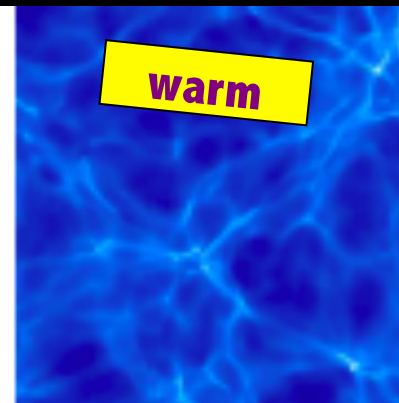
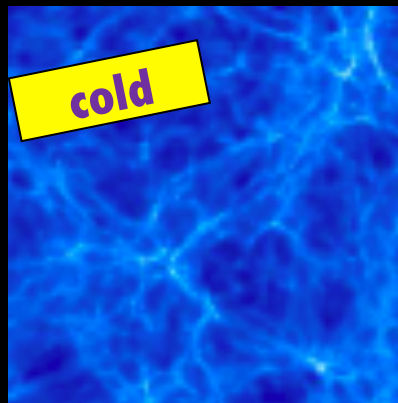
*KATRIN sensitivity*

$$\Omega_\nu > 0.003$$

*Super-Kamiokande*



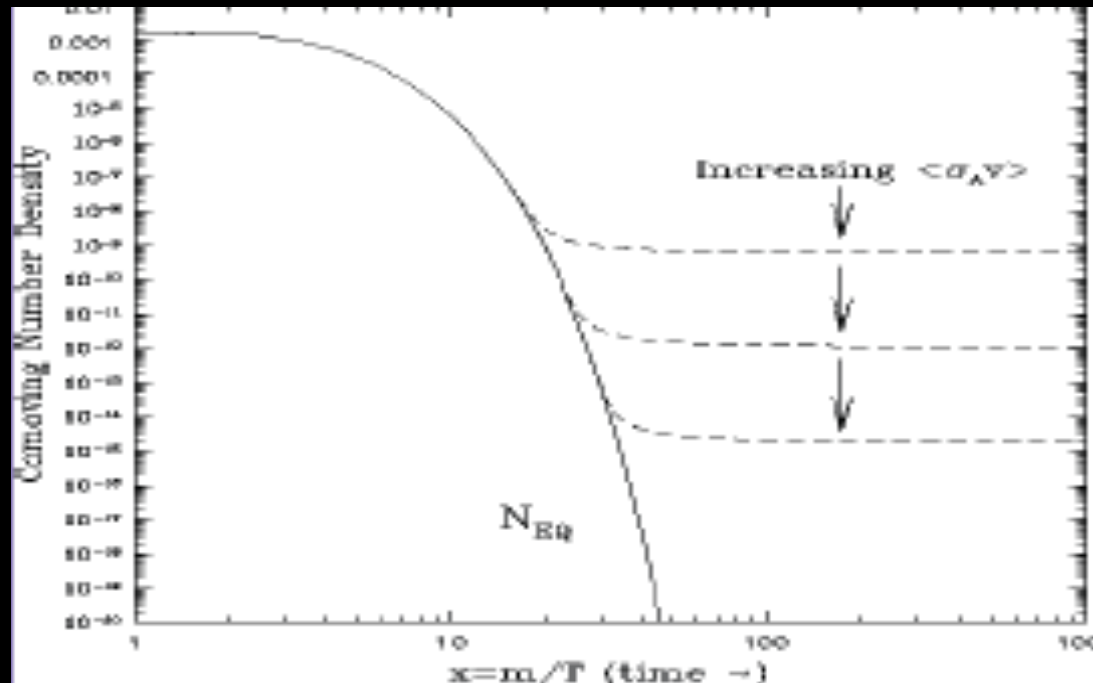
# Dark matter is not neutrinos



Dark matter “most likely” is  
a weakly interacting (massive?) particle  
Eg WIMP (or LSP) motivated by theory of supersymmetry

Favoured SUSY candidate is a WIMP in mass range 0.01-10 TeV

The WIMP miracle: relic abundance if  $\langle\sigma v\rangle\sim 3\times 10^{-26}\text{ cm}^3/\text{s}\sim 1/\Omega_x$

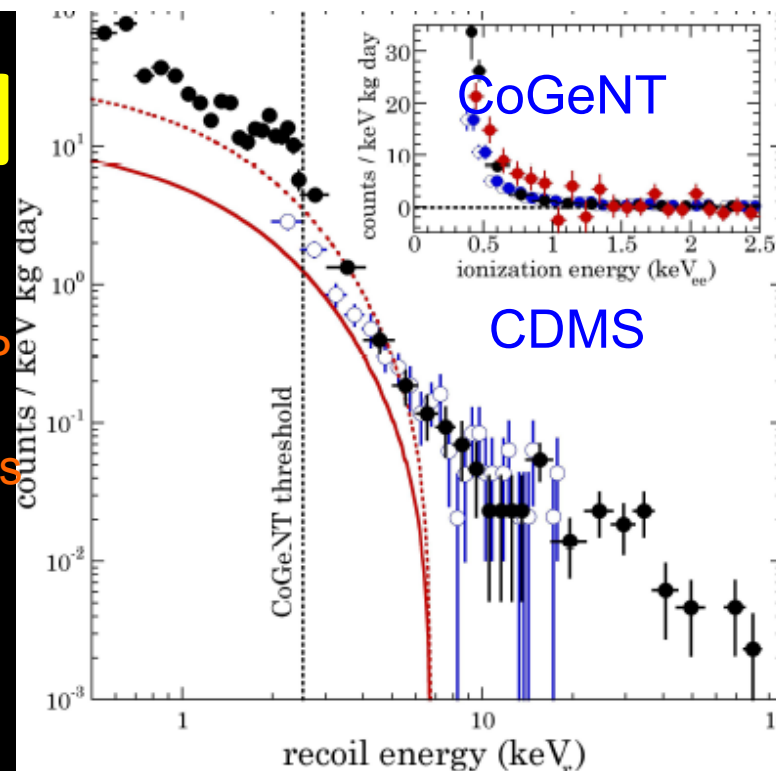
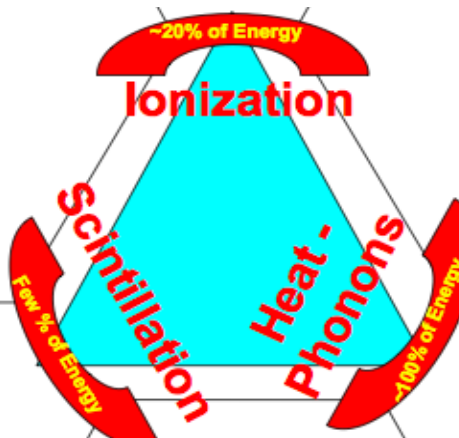
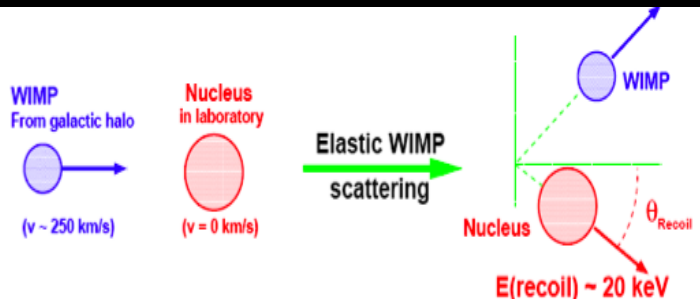


**Astrophysical probes complement collider experiments**

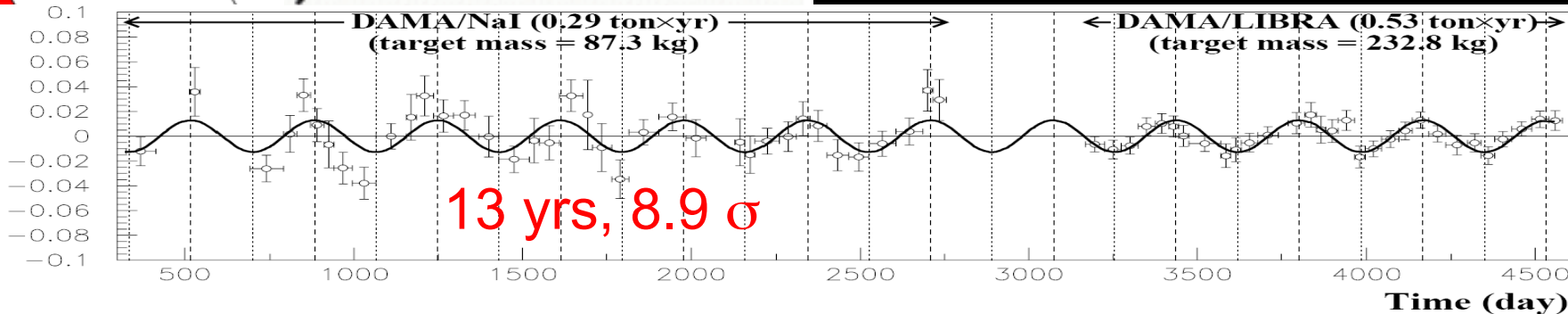
# DIRECT DETECTION

many WIMPs pass through us every second

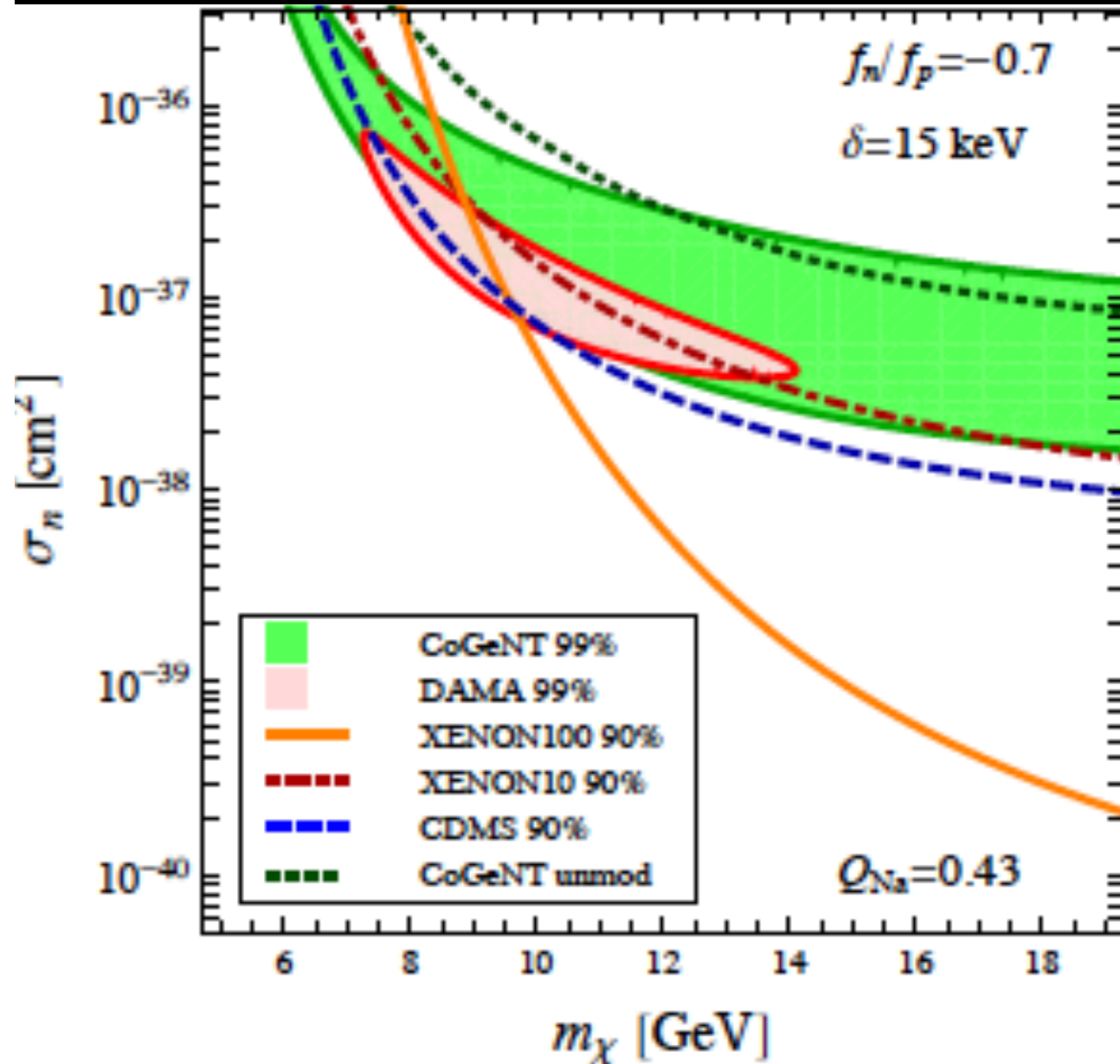
fit to 7GeV WIMP ...but it could be many other things



Residuals (cpd/kg/keV)



# The latest: CoGeNT reports a $2.8\sigma$ annual modulation



and models can be found...

# INDIRECT DETECTION

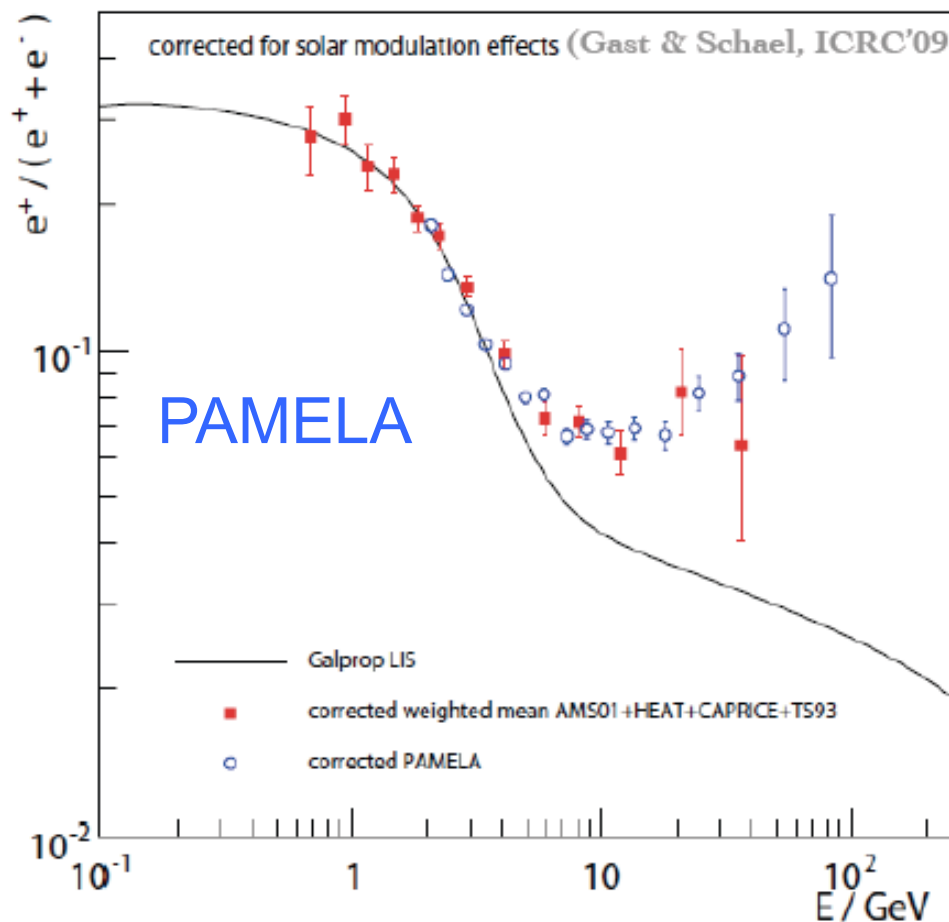
halo WIMPS occasionally  
annihilate today

into energetic particles:  $\nu, \gamma, p, e^+$

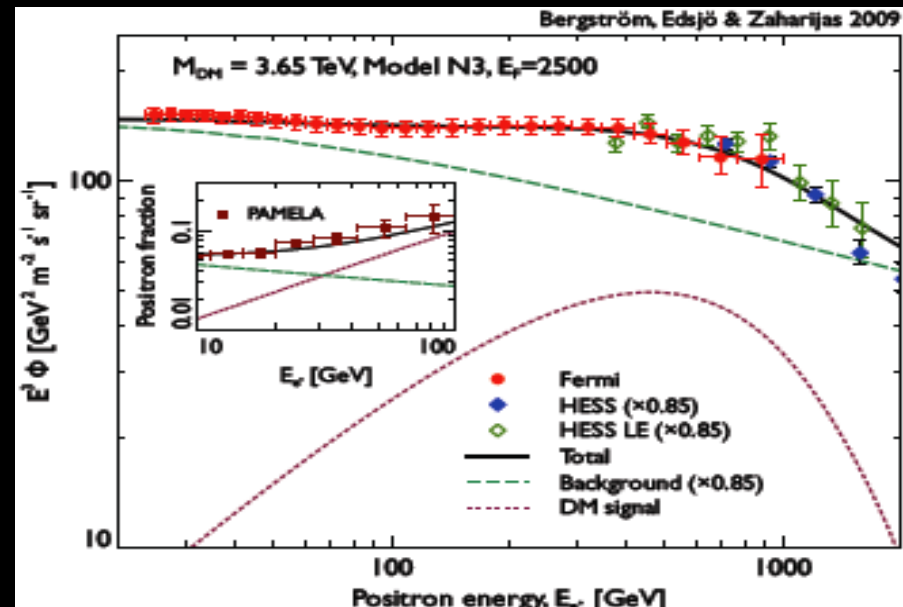


# high energy positrons

Could be a dark matter signature, but the rise plausibly has an astrophysical origin

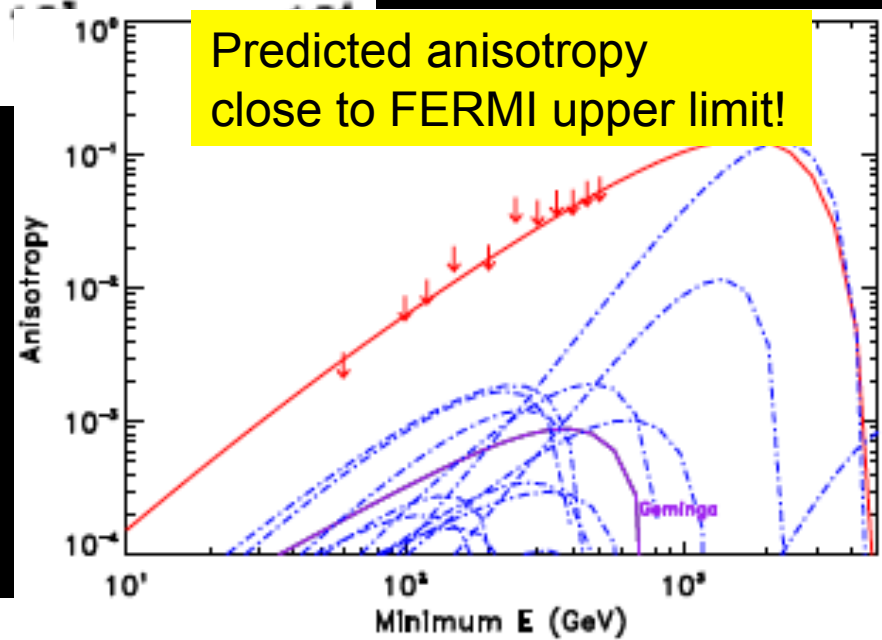
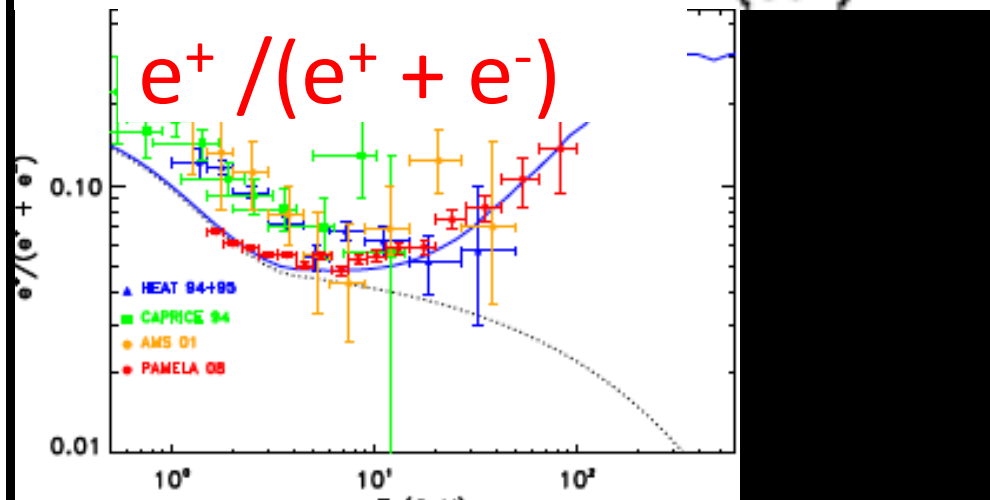
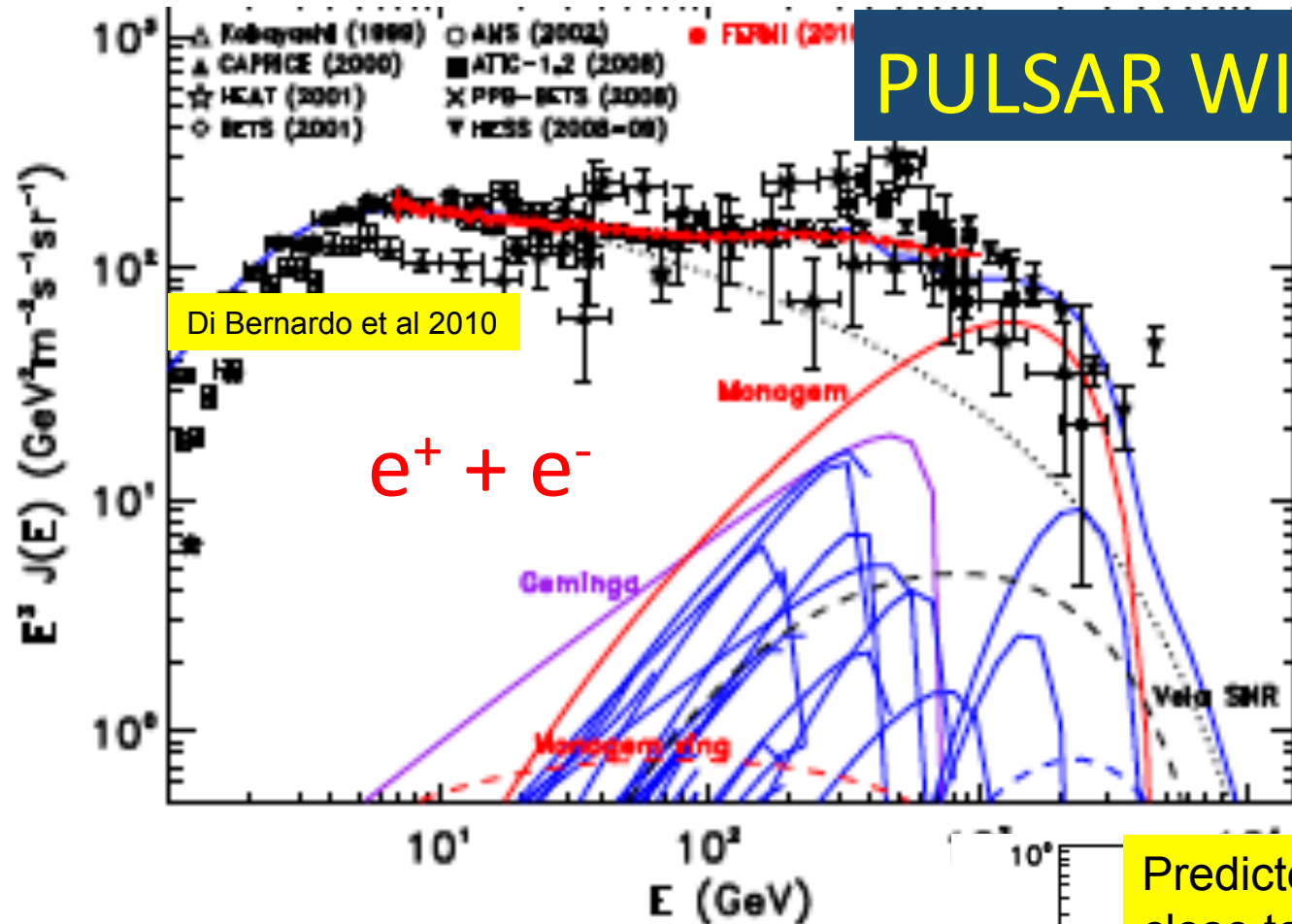


Adriani *et al*, Nature 458:607,2009



Requires boost  $\sim 100$   
since flux  $\sim \rho^2 / m_x^2$

# PULSAR WIND?

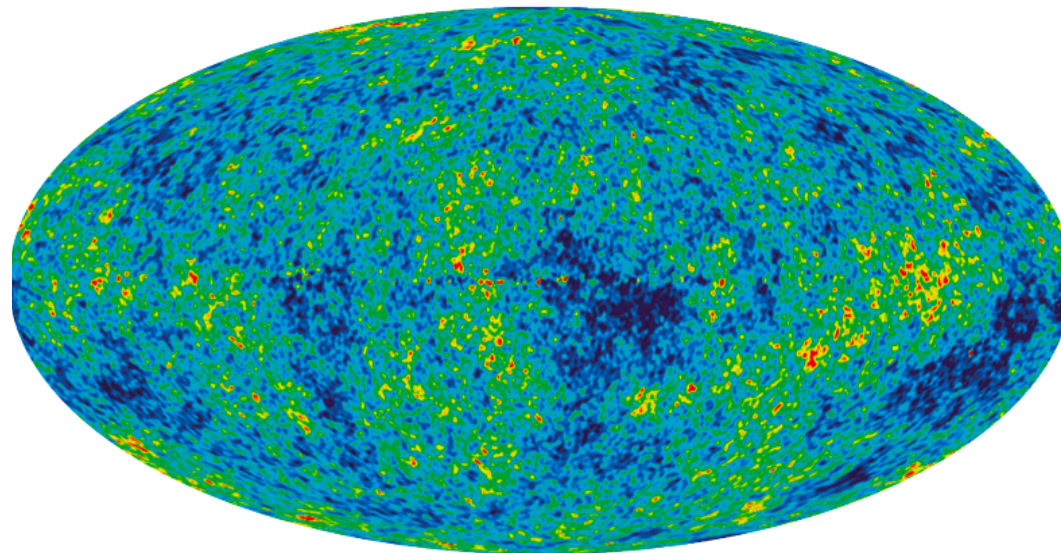


# The WMAP microwave haze

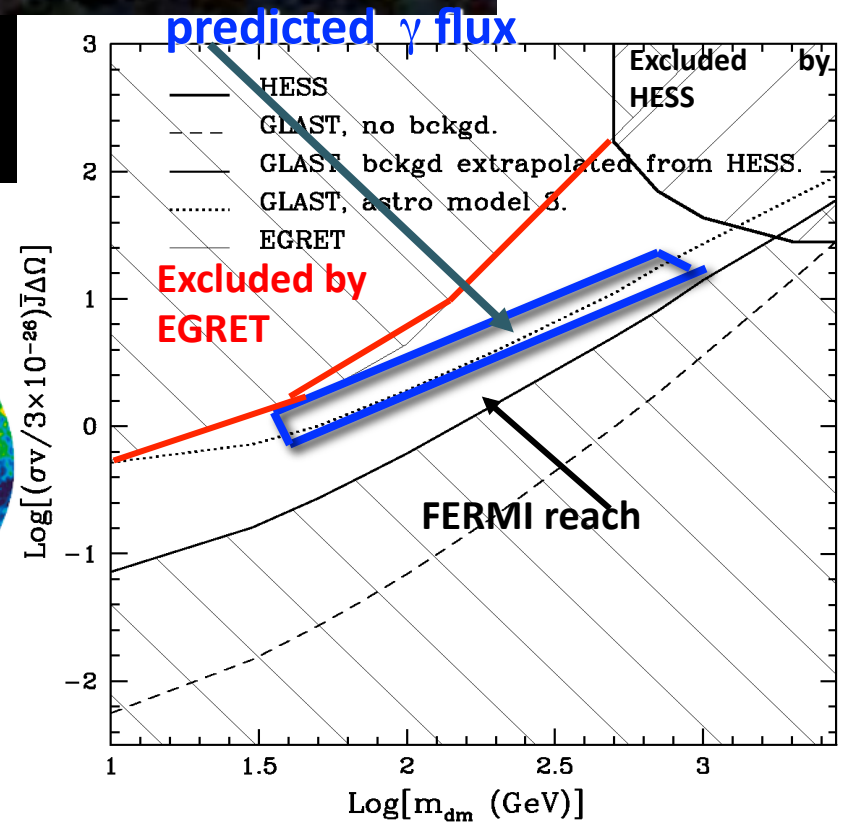
Finkbeiner 2007



Hooper and Zaharias 2007



-200  $T(\mu\text{K})$  +200 WMAP 5-year

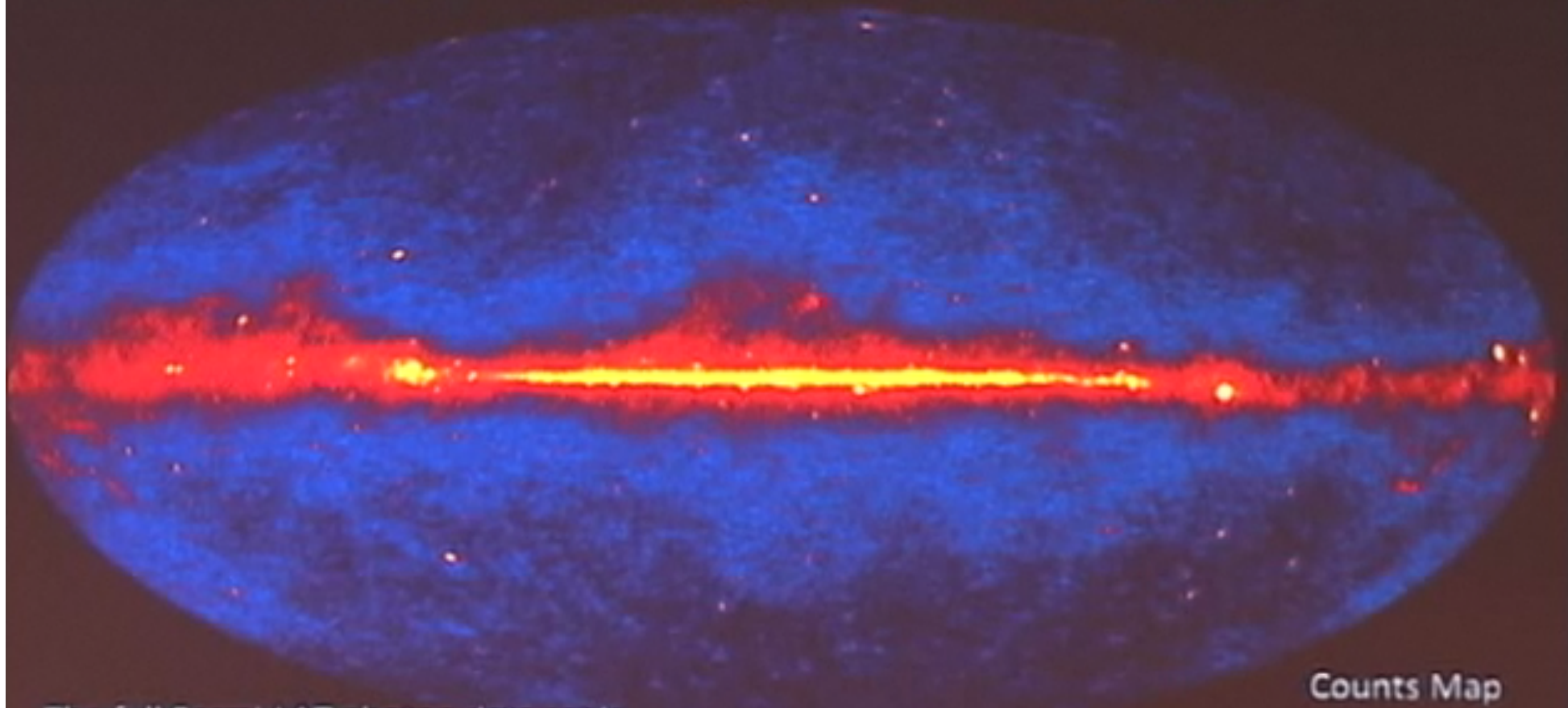


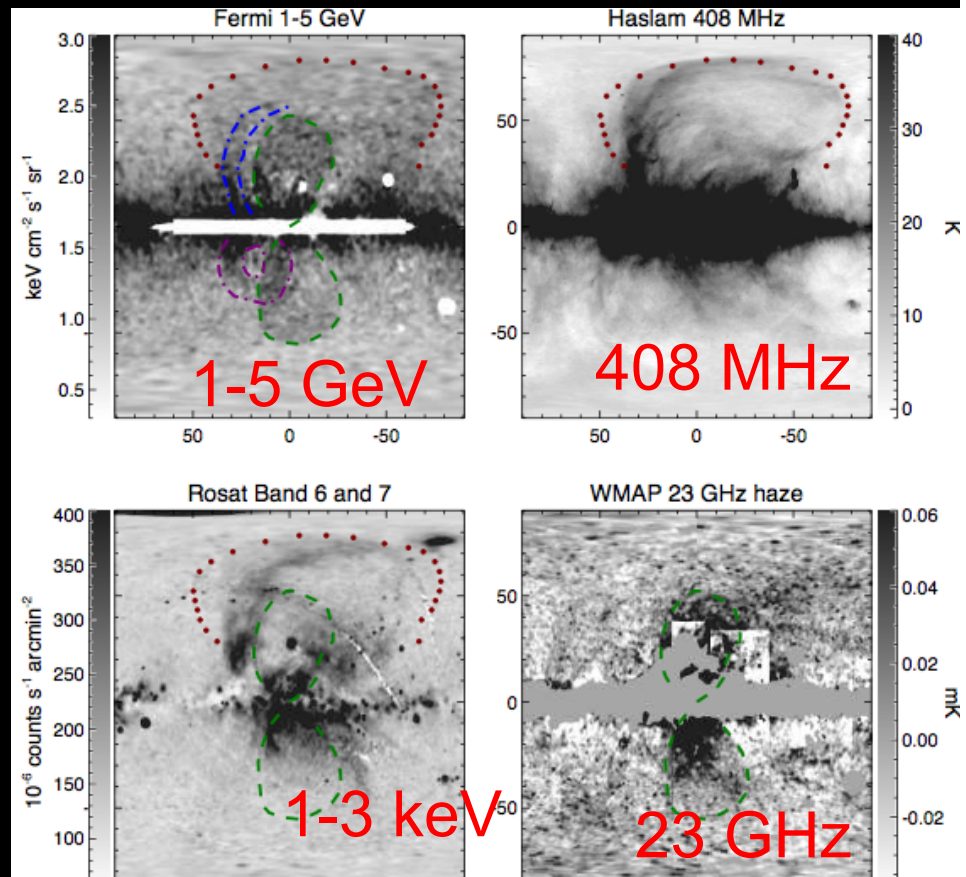
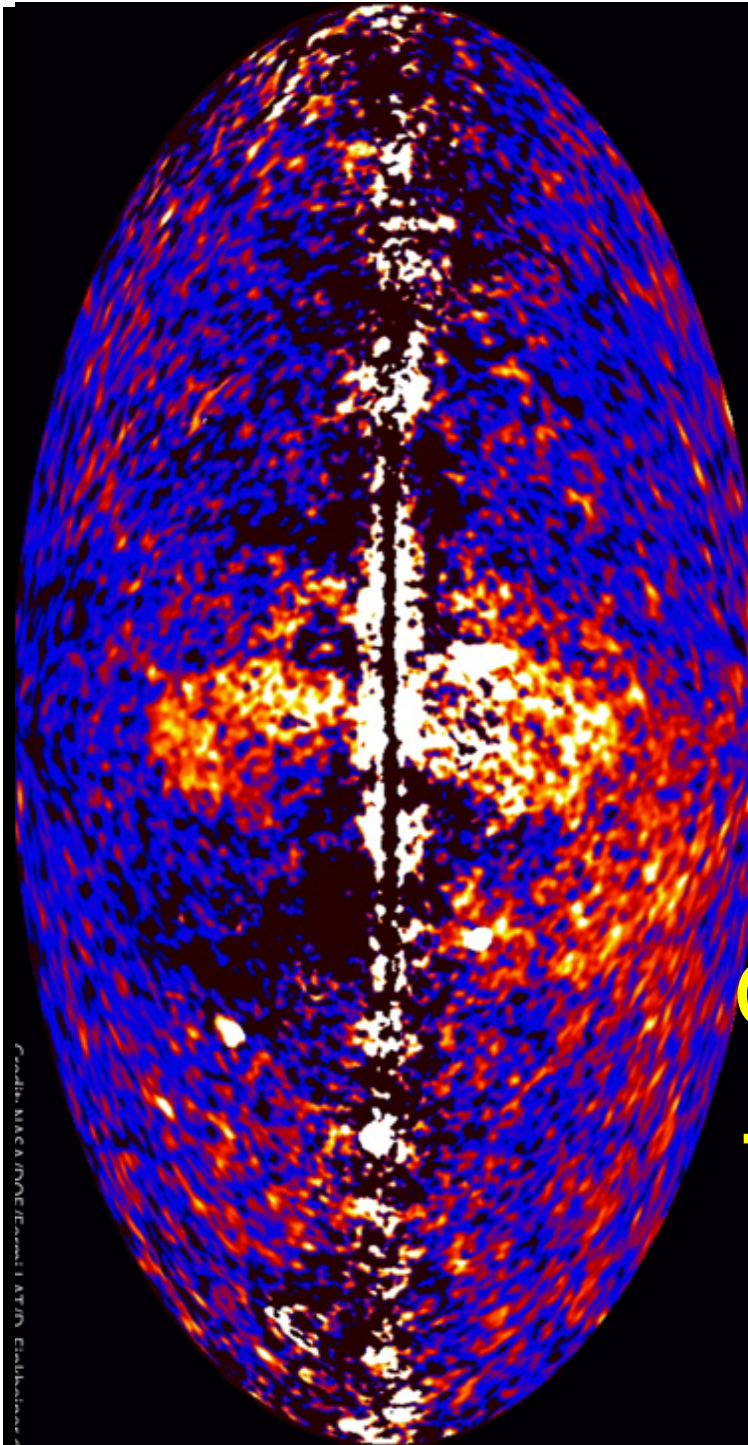
# annihilation $\gamma$ -rays from the centre of the Galaxy ??

predict  $\gamma$  ray “smoking guns”: e.g. morphology of haze..... hard spectrum ..... annihilation line  
.....

FERMI (2009 launch): 0.02 - 300 GeV,  $5^\circ - 5'$ ,  $\Delta E/E \sim 0.1$

## 2-Year All-Sky Map, $E > 1$ GeV





# Giant gamma ray bubbles ...not dark matter

Fermi haze is inverse  
Compton of  $e^+e^-$  on  
interstellar radiation

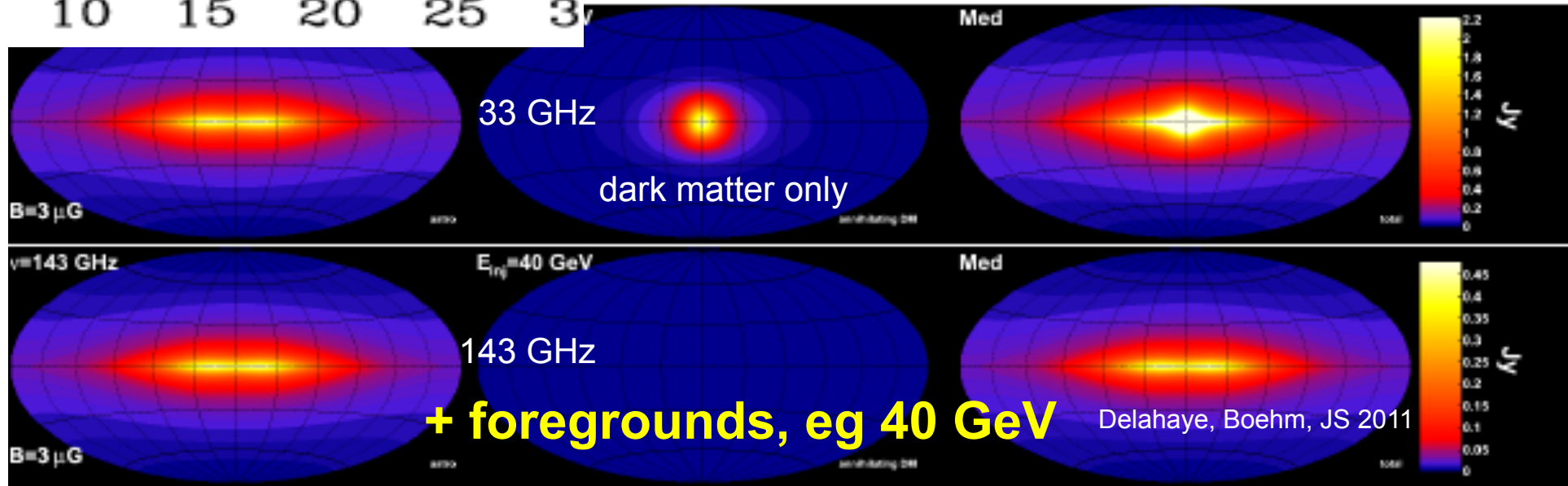
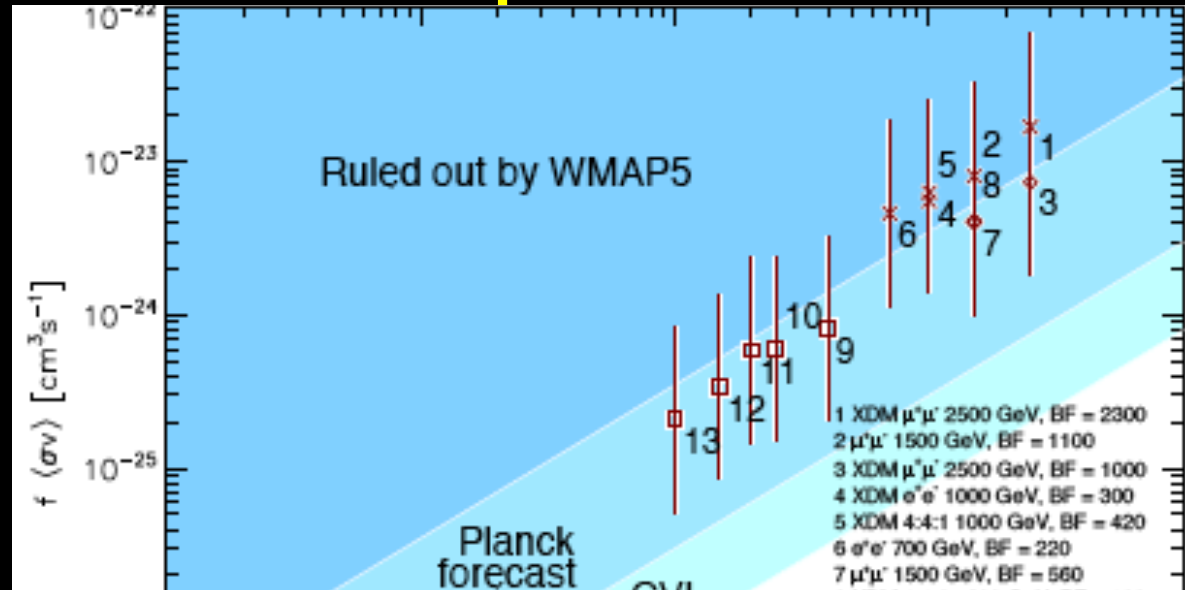
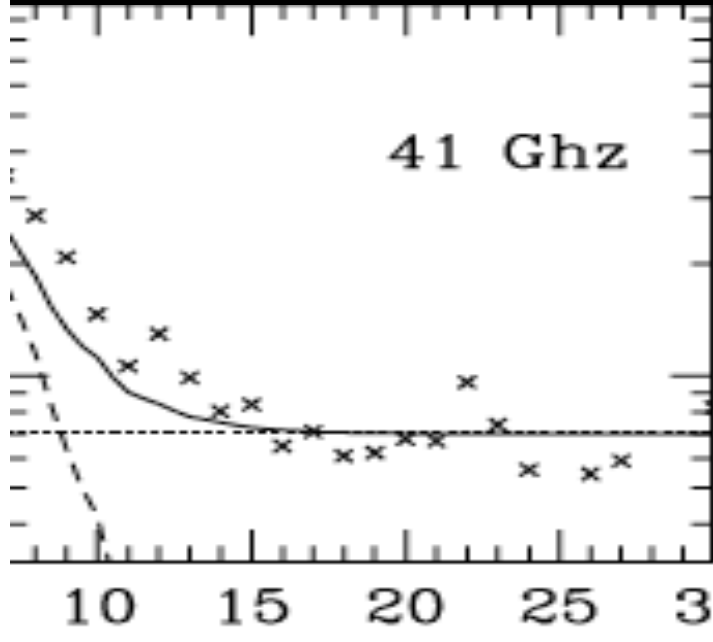
Su et al. 2010

# WMAP haze revived for 8 GeV WIMP annihilations

Hooper & Linden 2010

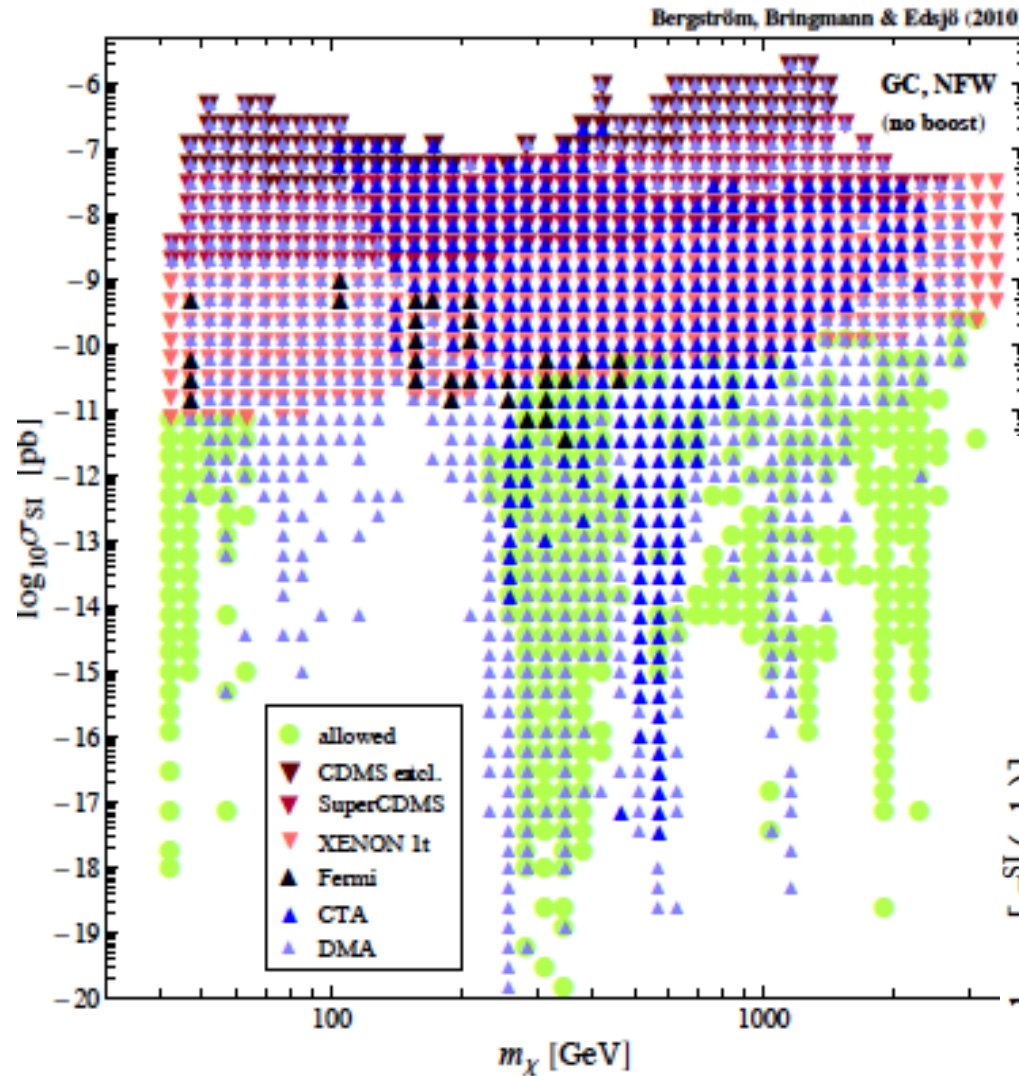
Galli + 2009

## Predictions for PLANCK: CMB temperature fluctuations

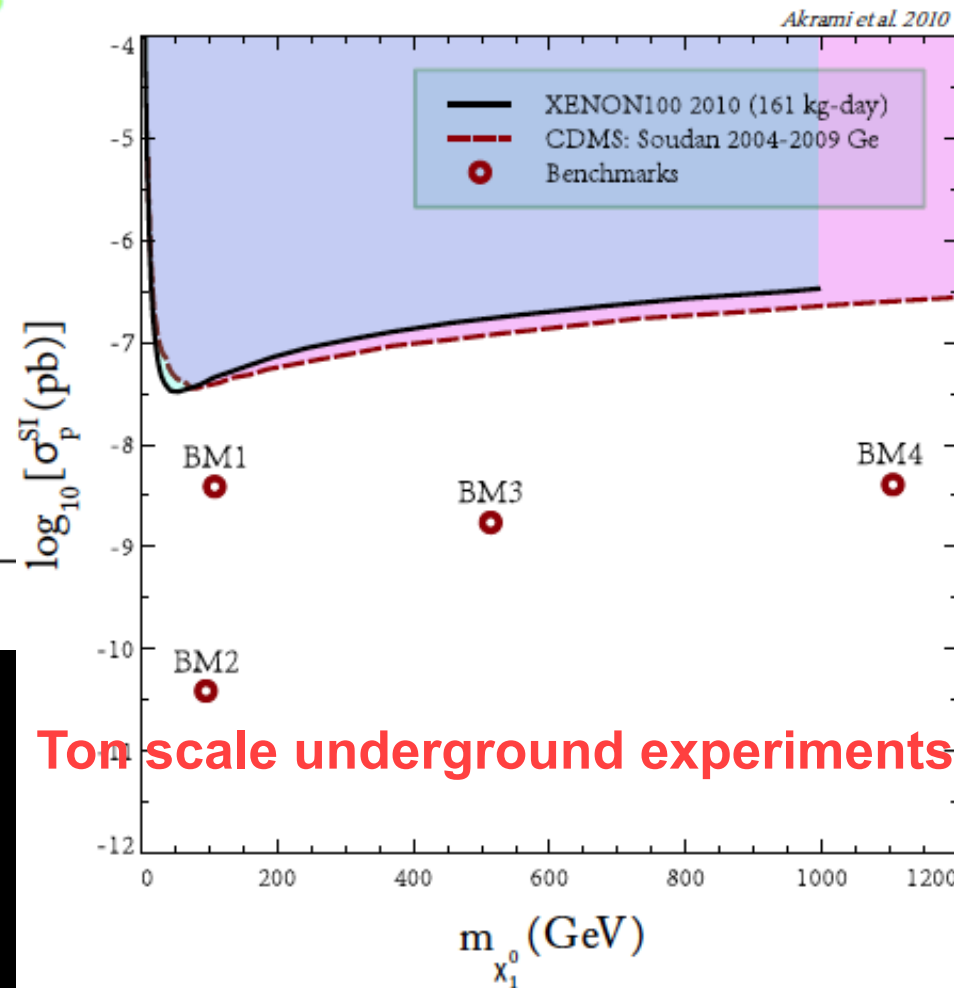


# HOW LOW CAN YOU GO?

Gamma rays and direct detection

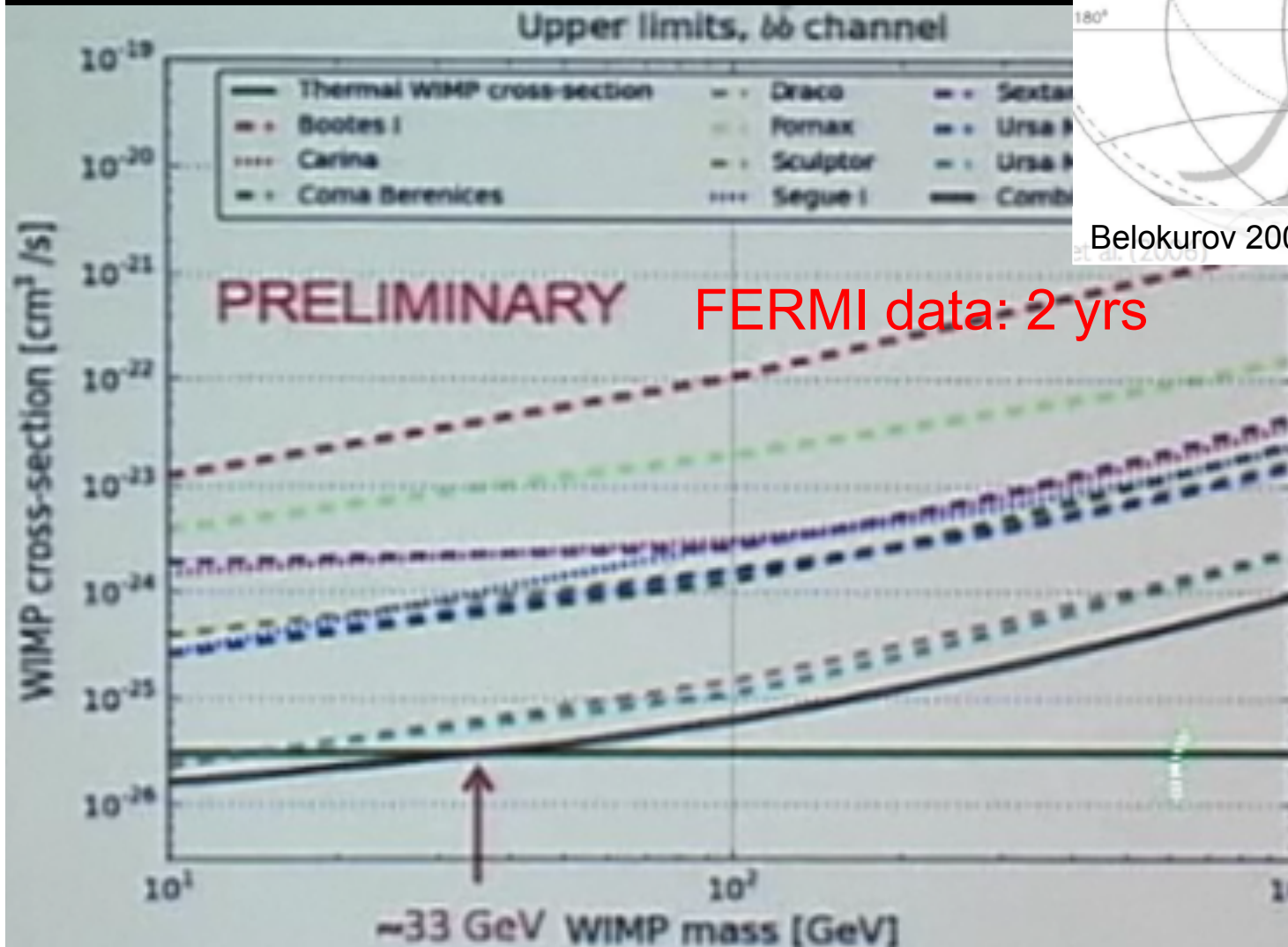
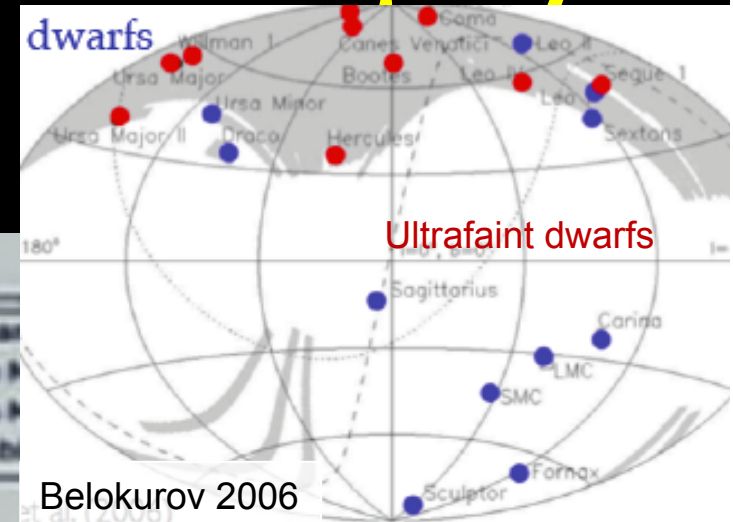


Air Cerenkov telescopes



Ton scale underground experiments

# DWARF GALAXIES AS A PROBE: $\gamma$ rays





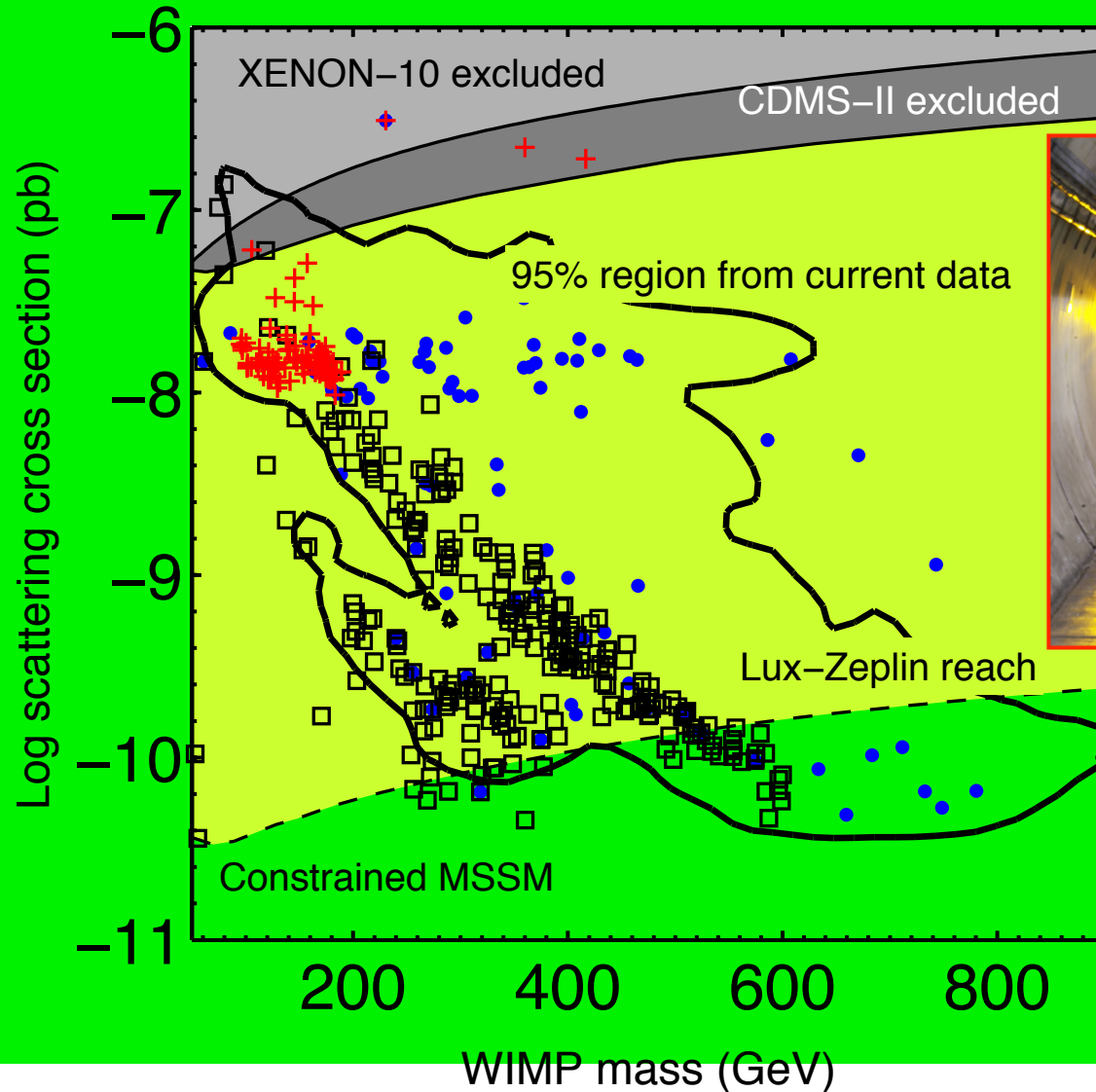
# LHC reach

- Models within LHC reach (18.3 %)
- Models favoured by Planck (5.7 %)
- + Models within IceCube reach (6.5 %)

1 1/fb at 14 TeV energy

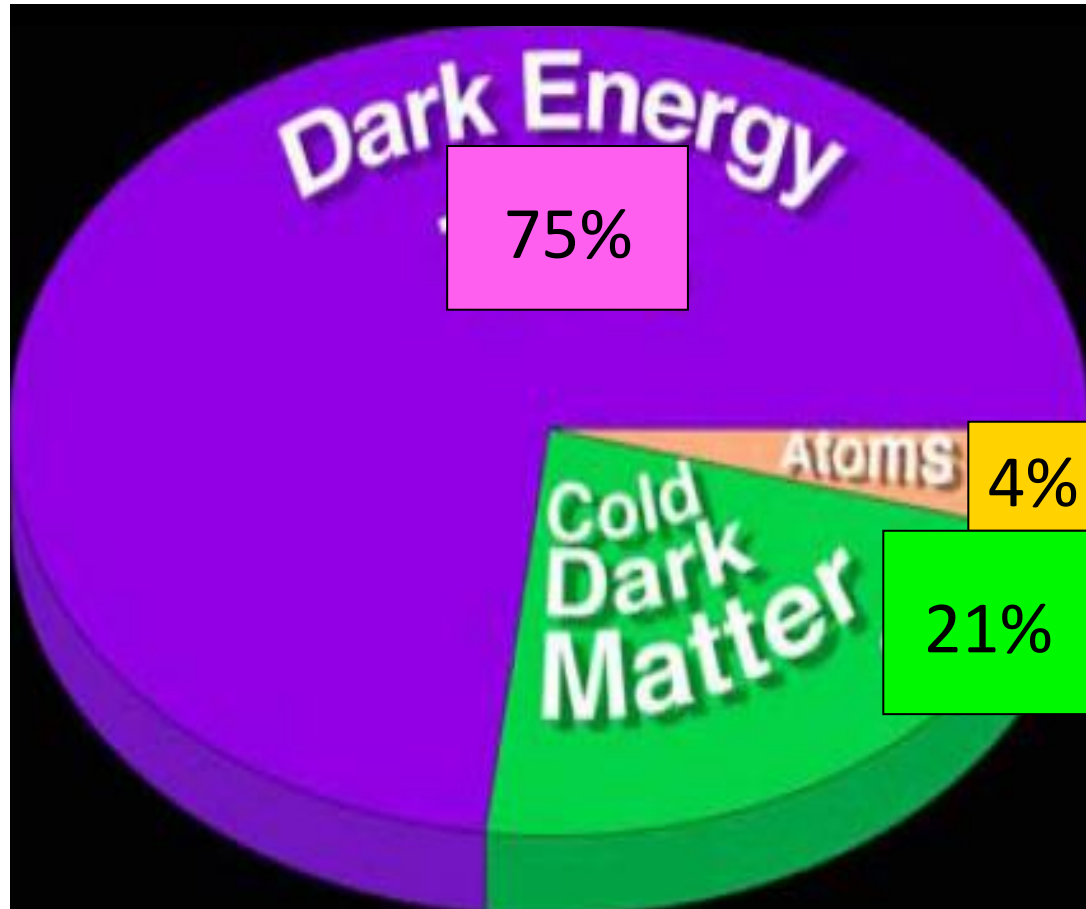
WMAP mean with 5- $\sigma$  Planck uncertainty

5- $\sigma$  for 1 yr of 80 strings data



observe

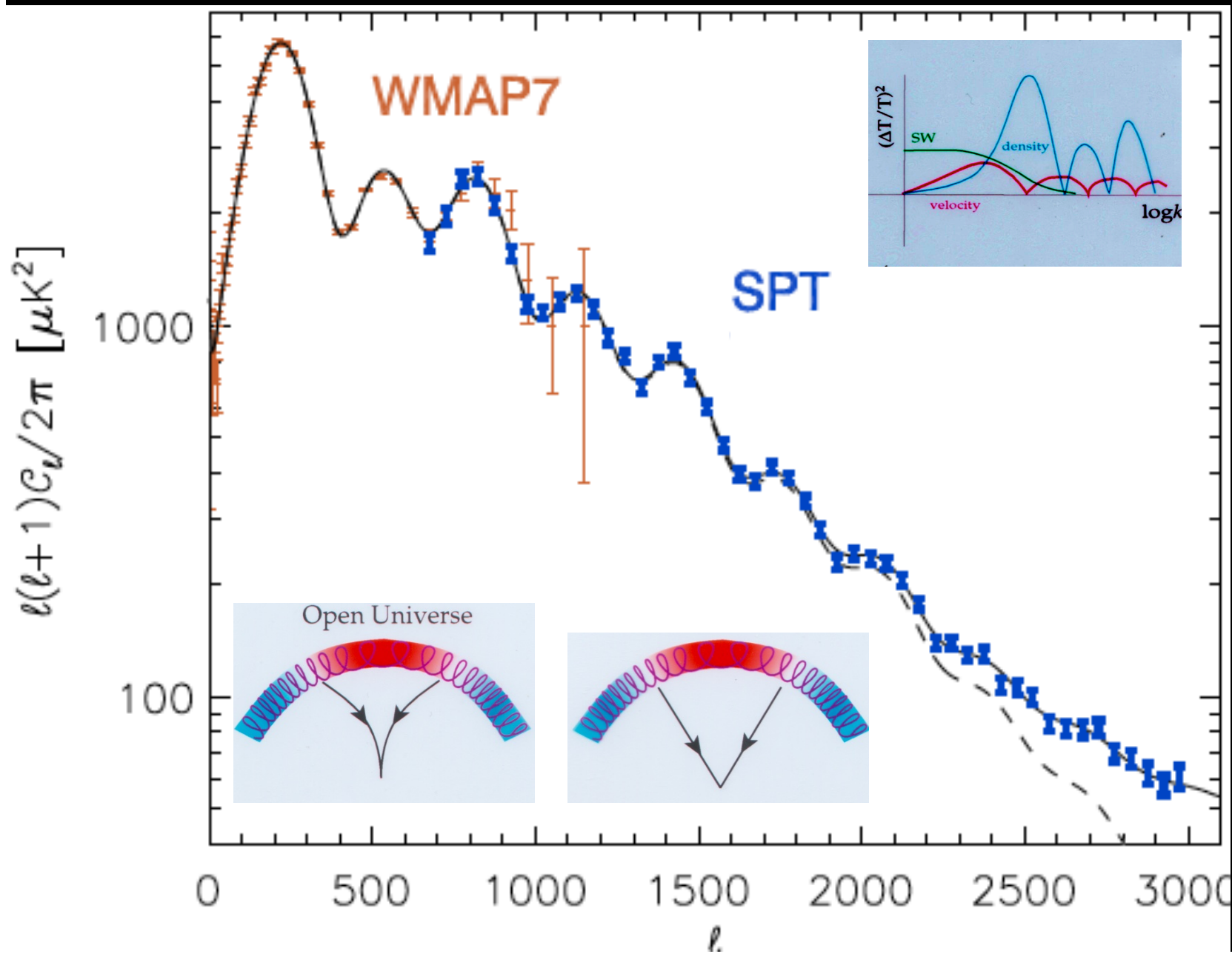
$$\rho_{\text{vac}} \approx 10^{-10} \text{eV}^4$$

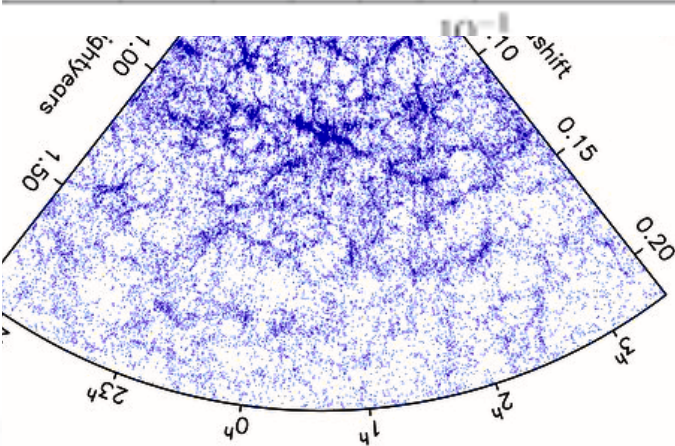
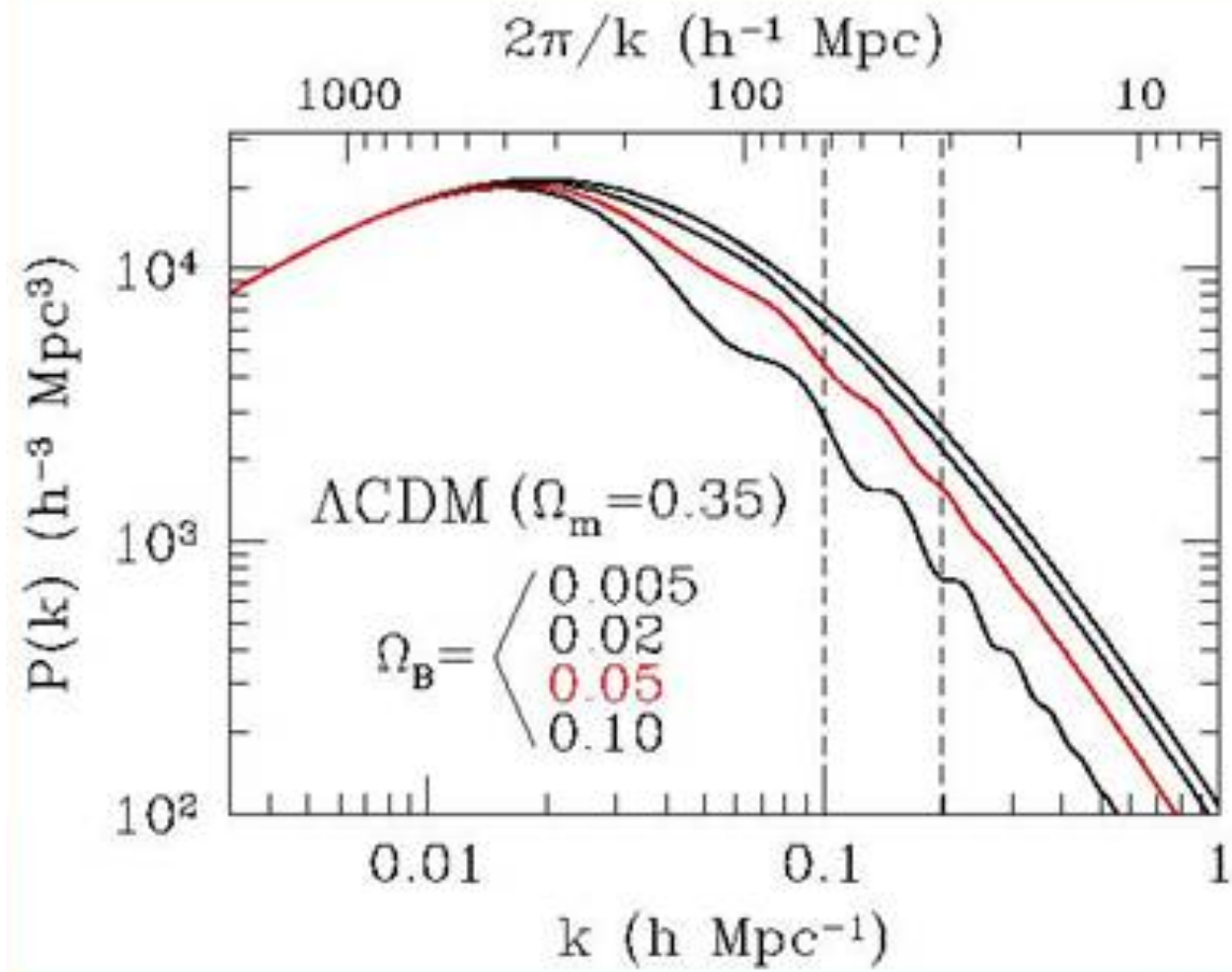
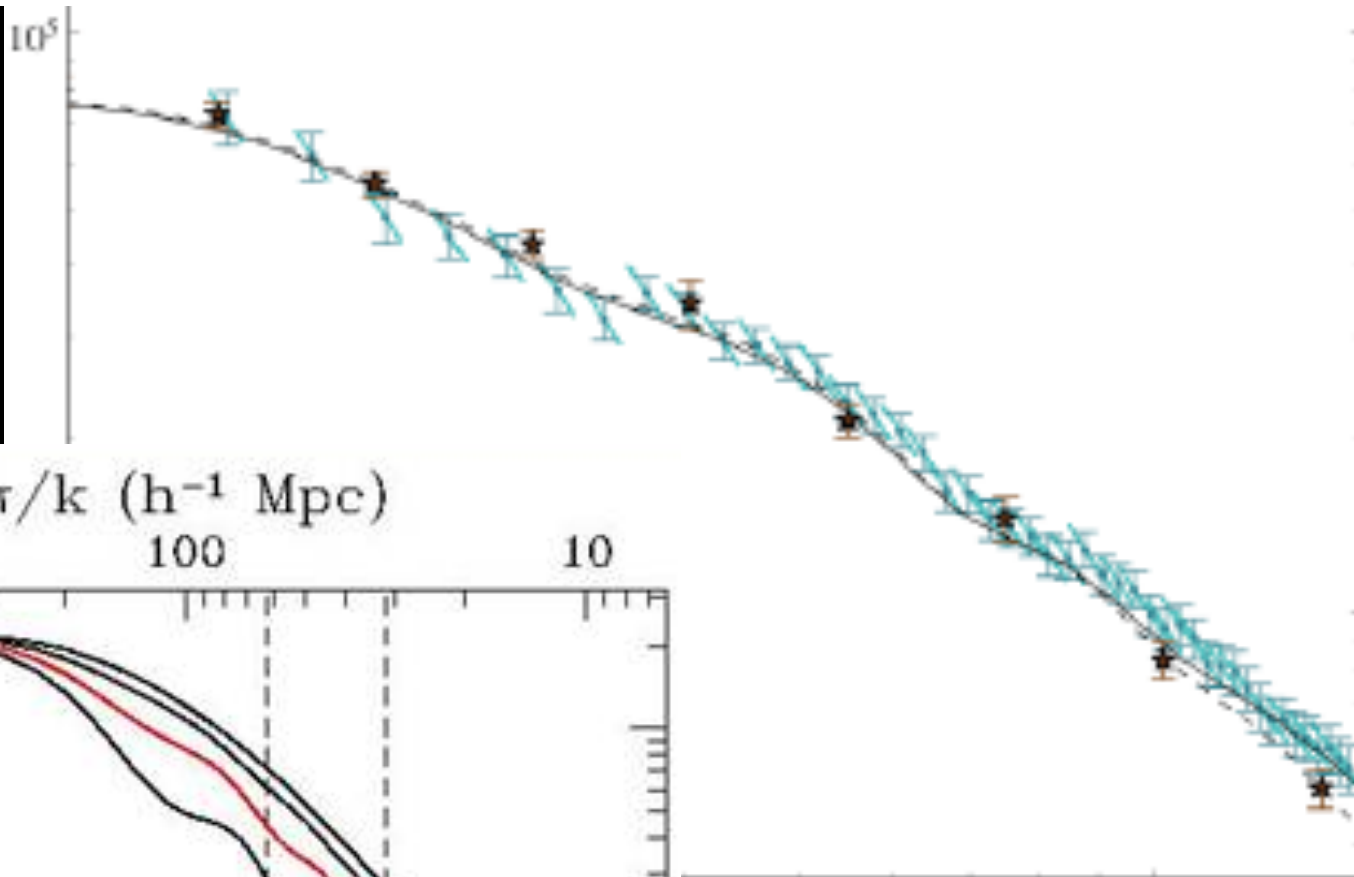
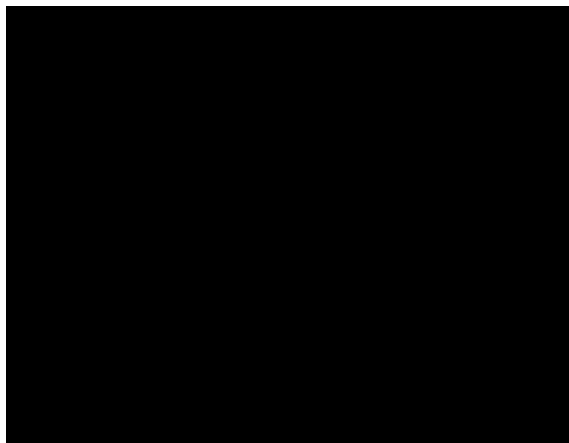


predict

$$M \sim M_{\text{Planck}} = G^{-1/2} = 10^{28} \text{eV} \Rightarrow \rho_{\text{vac}} \sim 10^{112} \text{eV}^4$$

One of the greatest problems in physics!





2DF

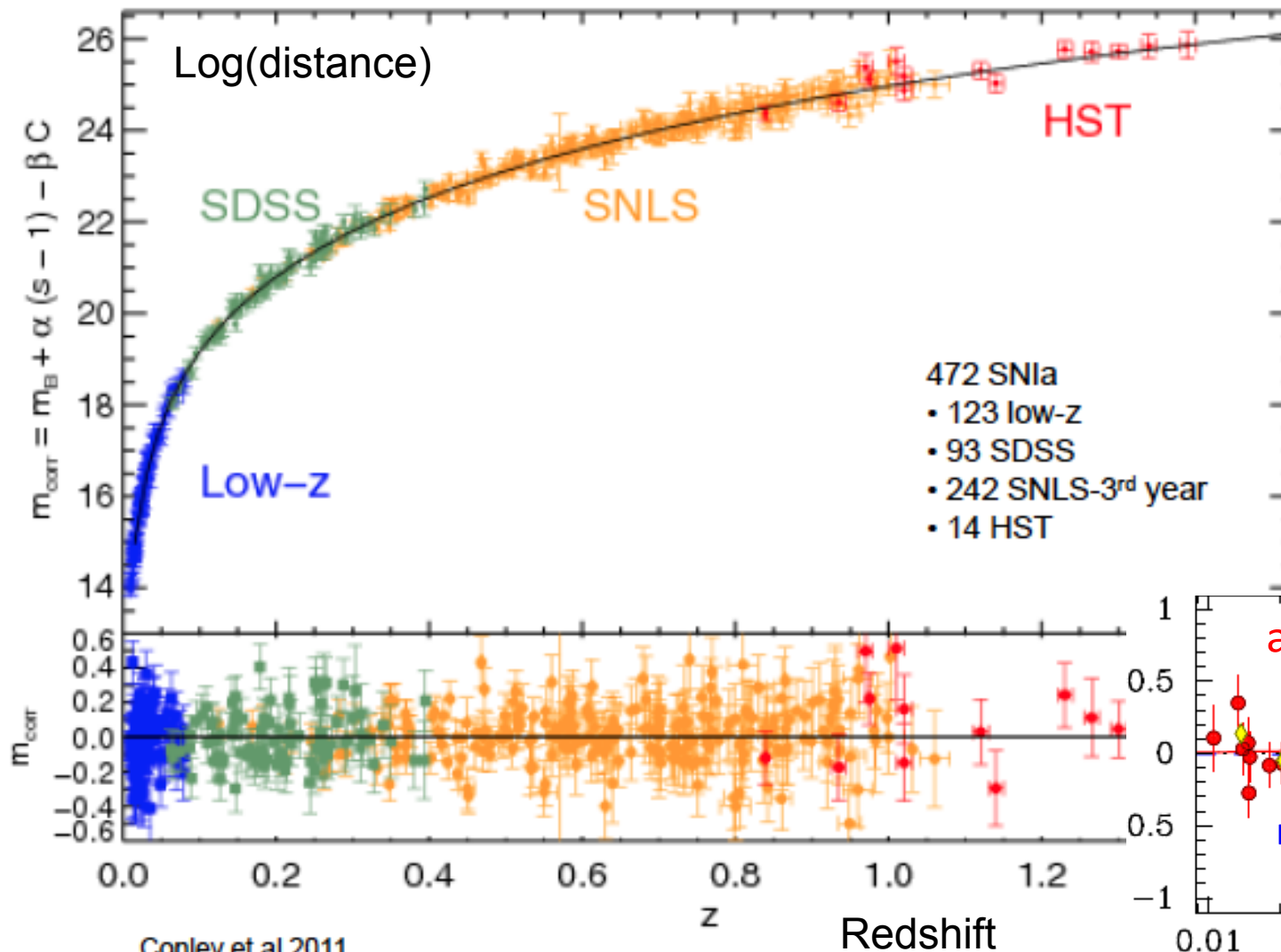
# Discovery of Cosmic Acceleration

Type Ia supernovae that  
exploded when the Universe  
was  $2/3$  its present size are  
 $\sim 25\%$  fainter than expected

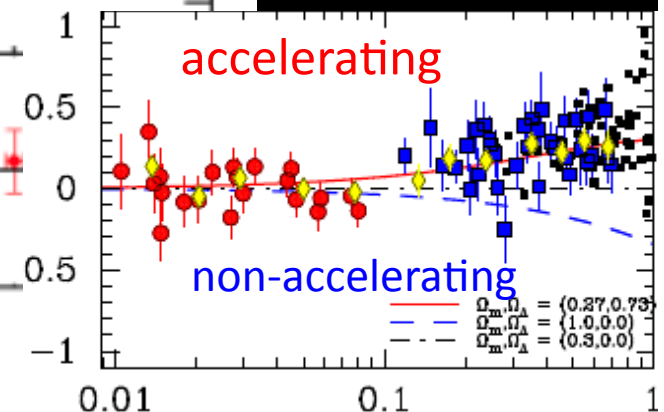


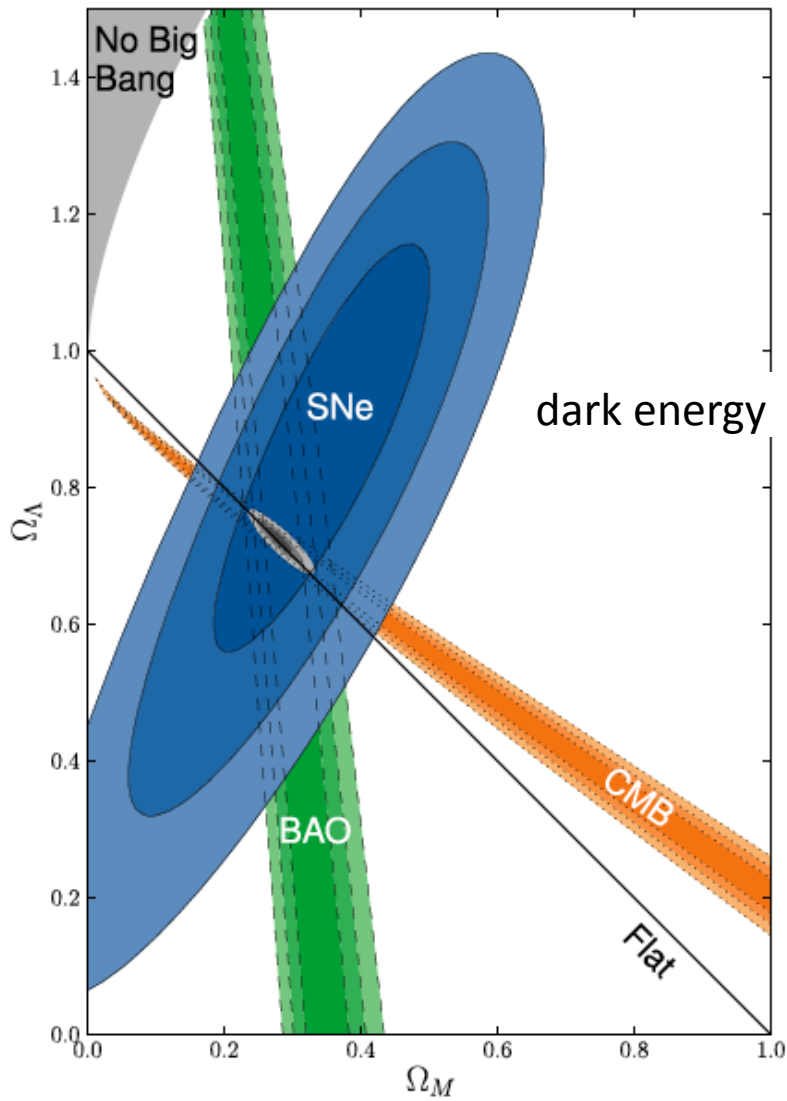
Nearby SN 1994D (Ia)

# Hubble diagram SNIa

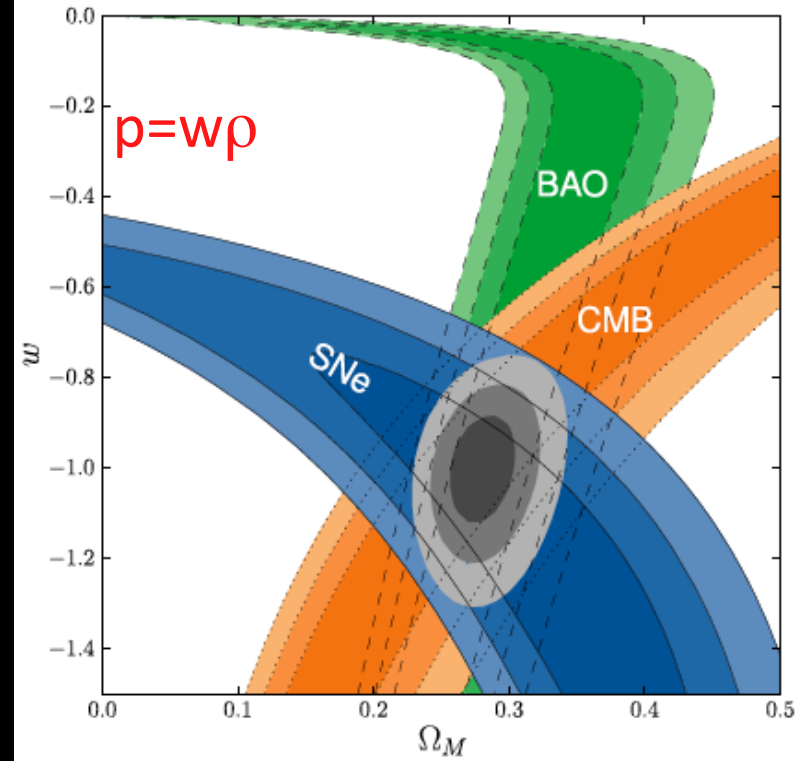


Freedman et al. 2009





dark matter



dark matter

Amanullah et al 2010

Large-scale structure (BAO): DM

CMB fluctuations: DM +DE

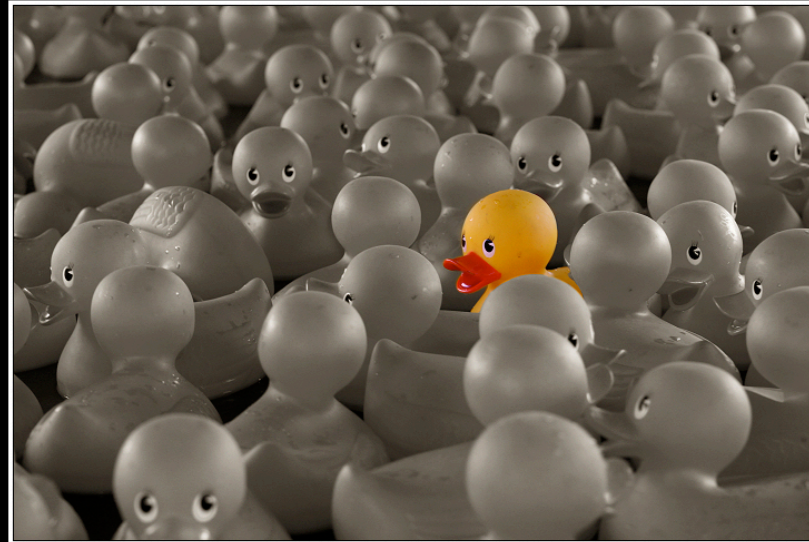
Supernovae: DM - DE







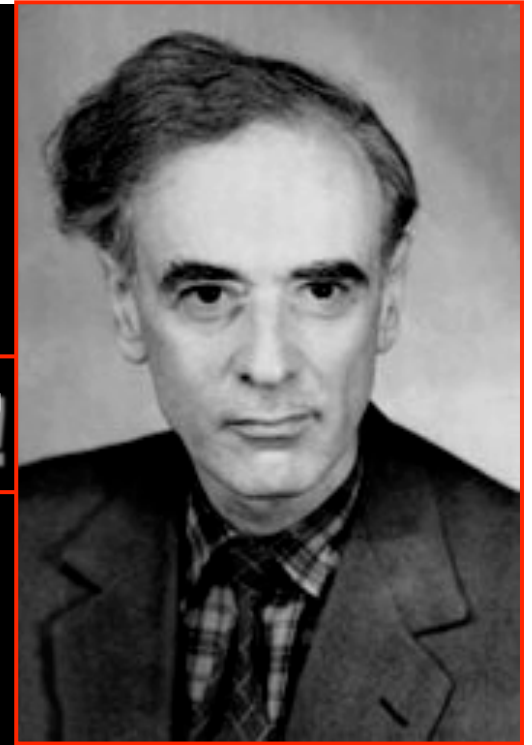
Questions such as "why is a certain constant of nature one number rather than another?" may well be answered by "somewhere in the megaverse the constant equals this number: somewhere else it is that number. We live in one tiny pocket where the value of the constant is consistent with our kind of life



**Successful scientific theories make *predictions*. The multiverse theory is not provable either by observation, or as an implication of well established physics. It can't make any predictions because it can explain anything at all.**

**Landau on Cosmologists:**

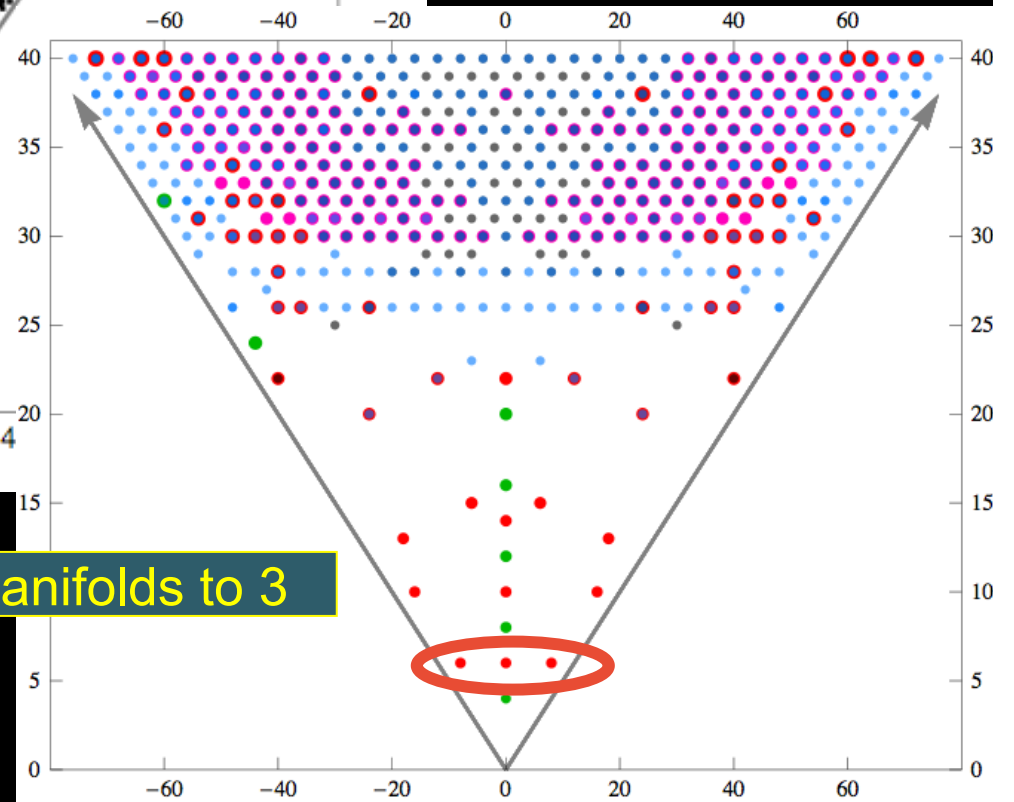
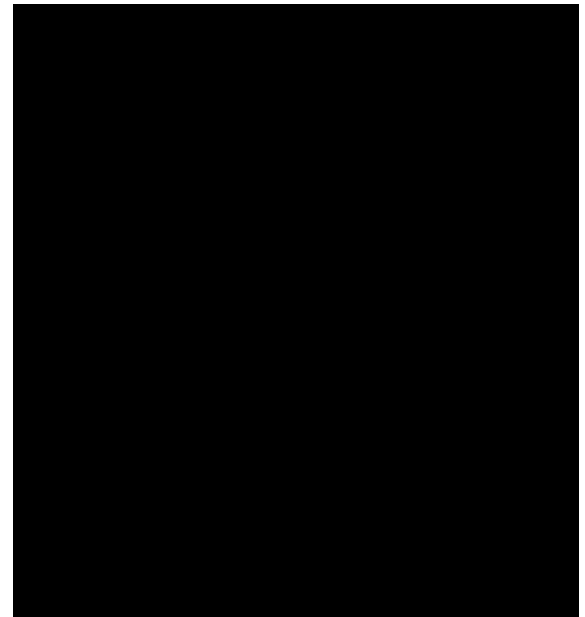
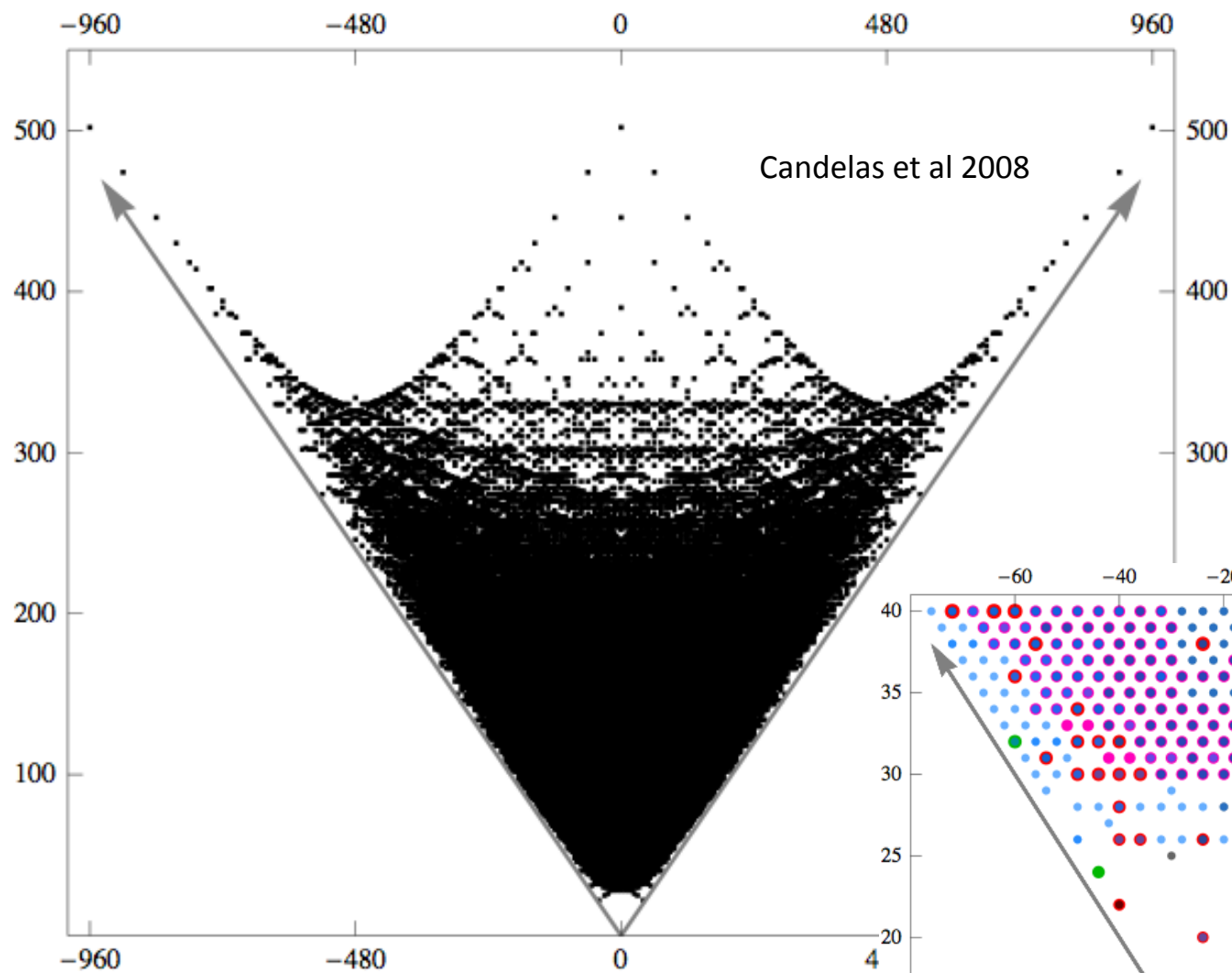
**Often in Error, Never in Doubt!**



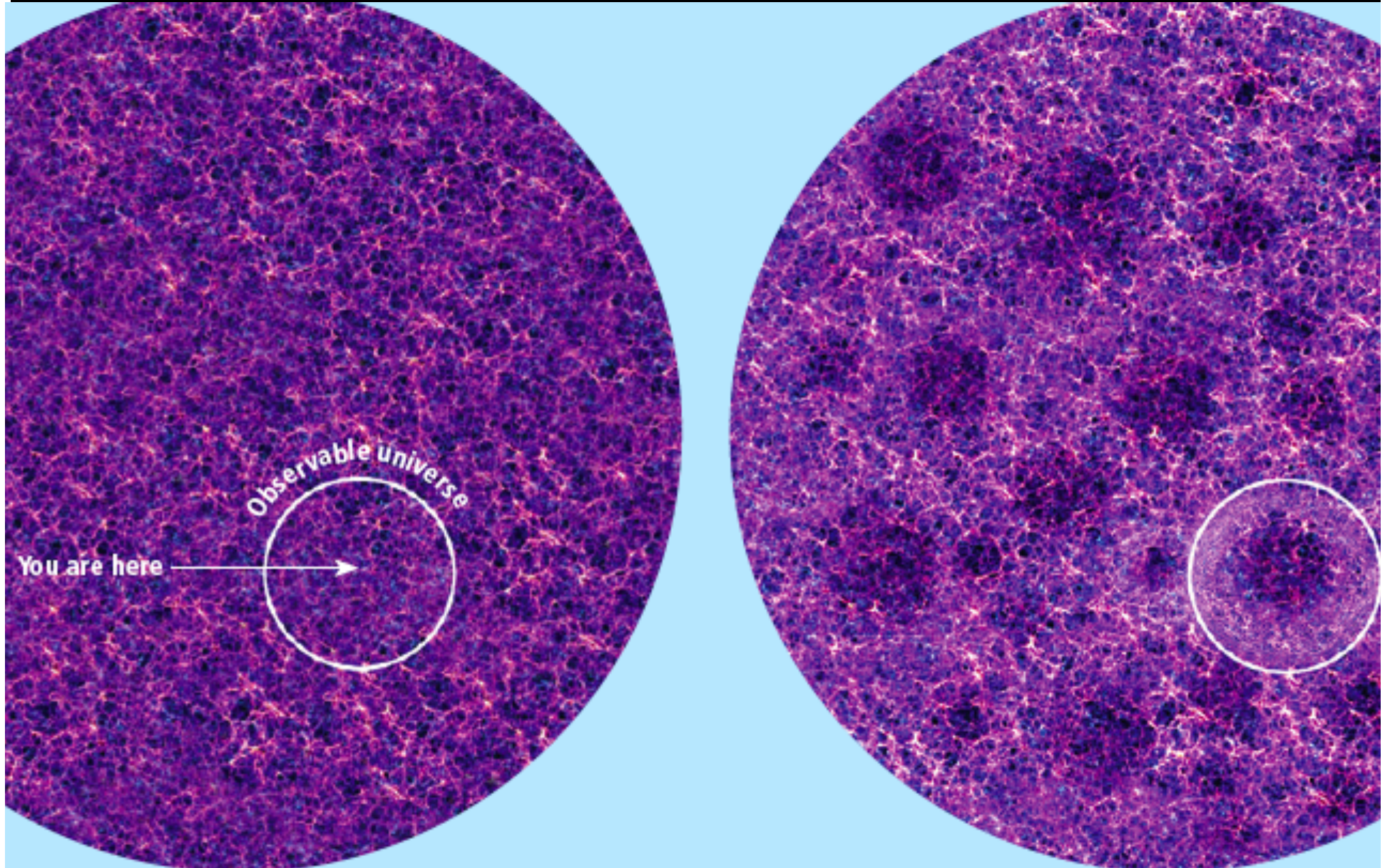
**Alternatives:**

**we may hope for a fundamental  
physics theory of dark energy.....**

**....or seek an astrophysical theory**



an example: from  $10^{500}$  Calabi-Yau manifolds to 3



## DARK MATTER IS AN URGENT PROBLEM

### DETECTION IN MULTIPLE WINDOWS IS ESSENTIAL

- Hints from direct detection
- strong upper limits in  $\gamma$  rays
- may need to go to NMSSM or asymmetric DM

IF WE DETECT DM, RESURRECTION VIA ASTROPHYSICS

IF WE FAIL, RESURRECTION VIA NEW FUNDAMENTAL PHYSICS

MODIFYING NATURE OF DARK MATTER OR GRAVITY

AS FOR DARK ENERGY: NO SOLUTION IN SIGHT.....

HIGHEST PRIORITY IN EXPERIMENTAL COSMOLOGY,  
SO DATA WILL IMPROVE