# CMB constraints on WIMP Dark Matter

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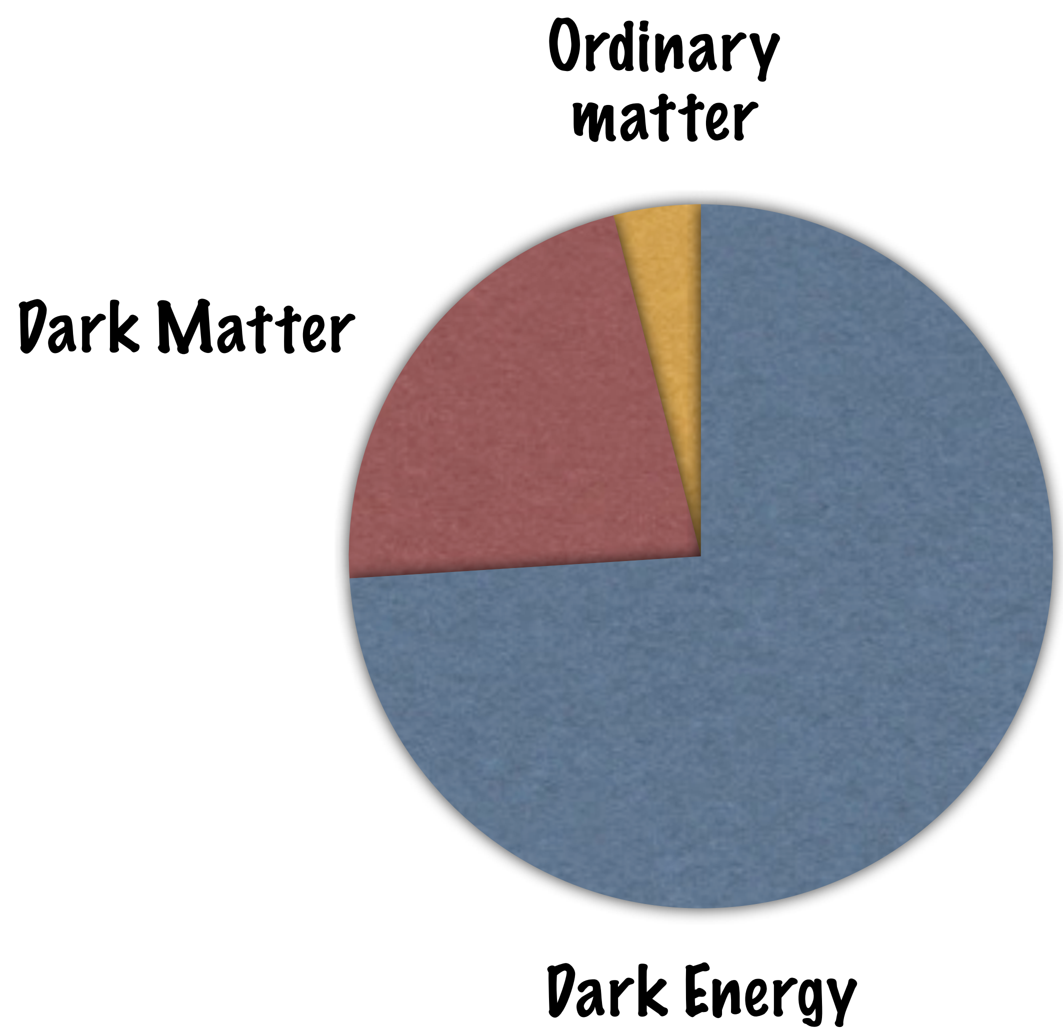
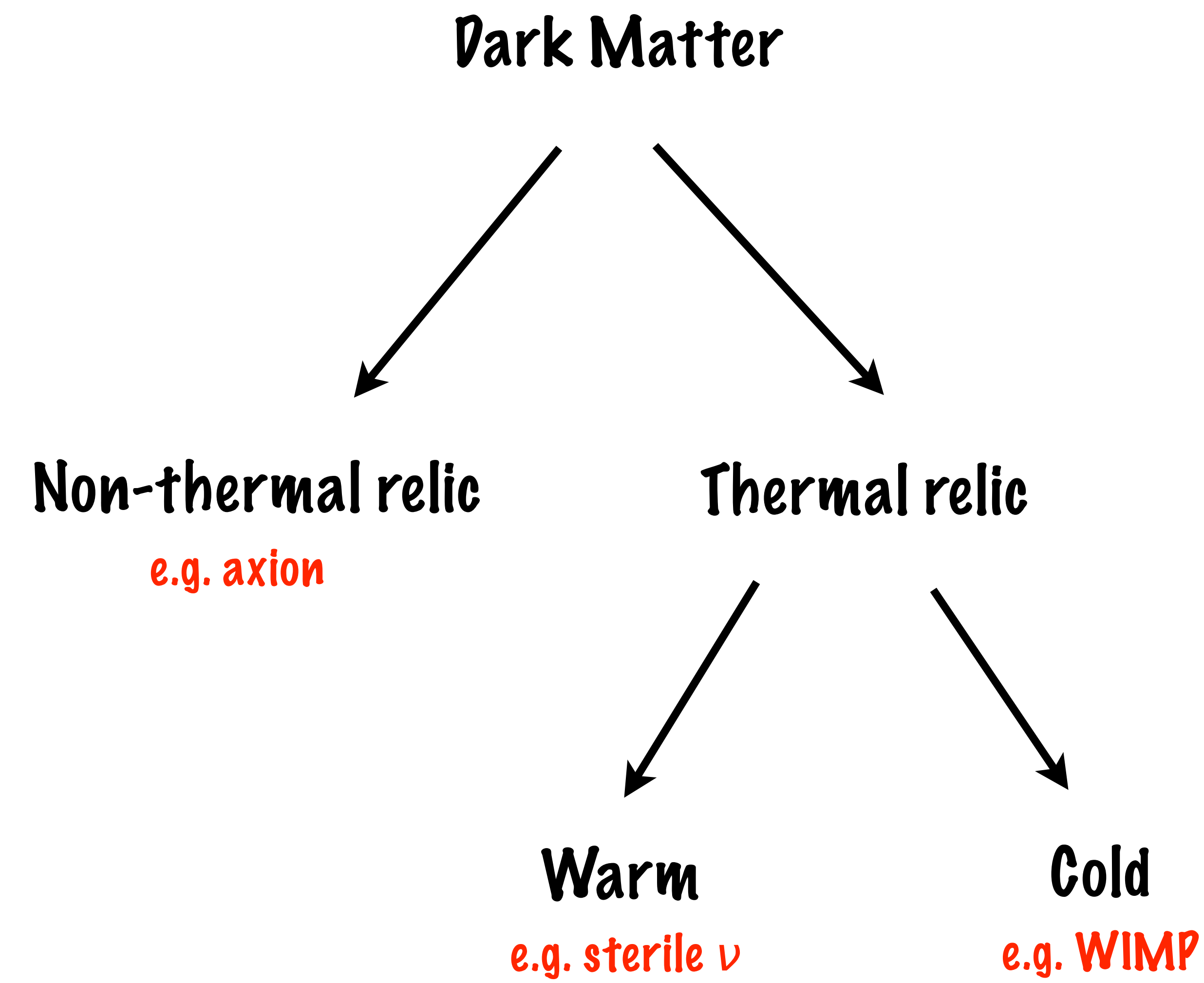
Aravind Natarajan
Carnegie Mellon University



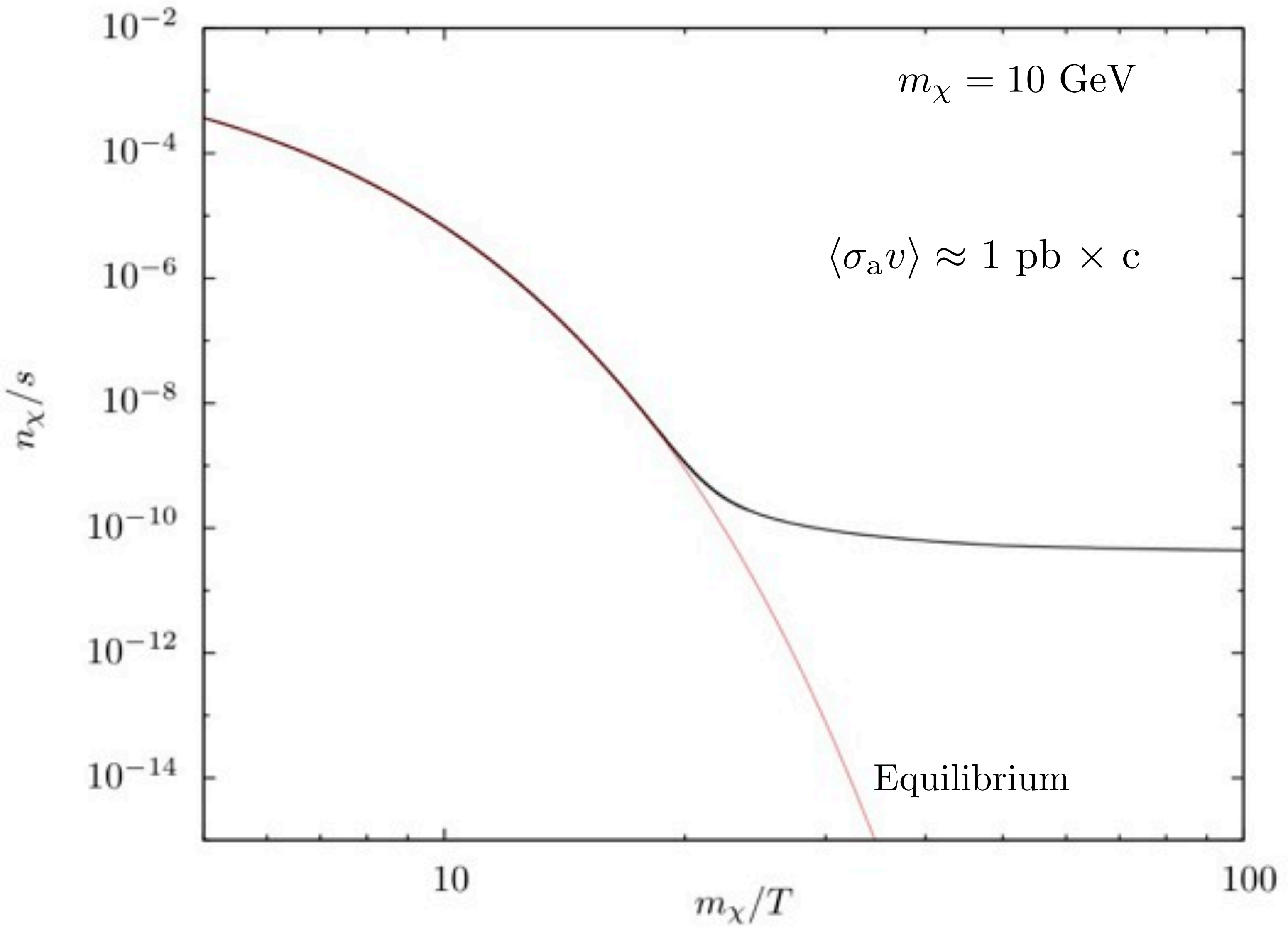

Axions

Lightest SuSy Particle

Lightest KK Particle

Sterile neutrino

# *Thermal relics -*




Freeze out: $n_\chi\langle\sigma_a v\rangle \lesssim H$

$n_\chi/s \longrightarrow 3.85\times10^{-11}$

$s(\text{today}) \approx 2890\ \text{cm}^{-3}$

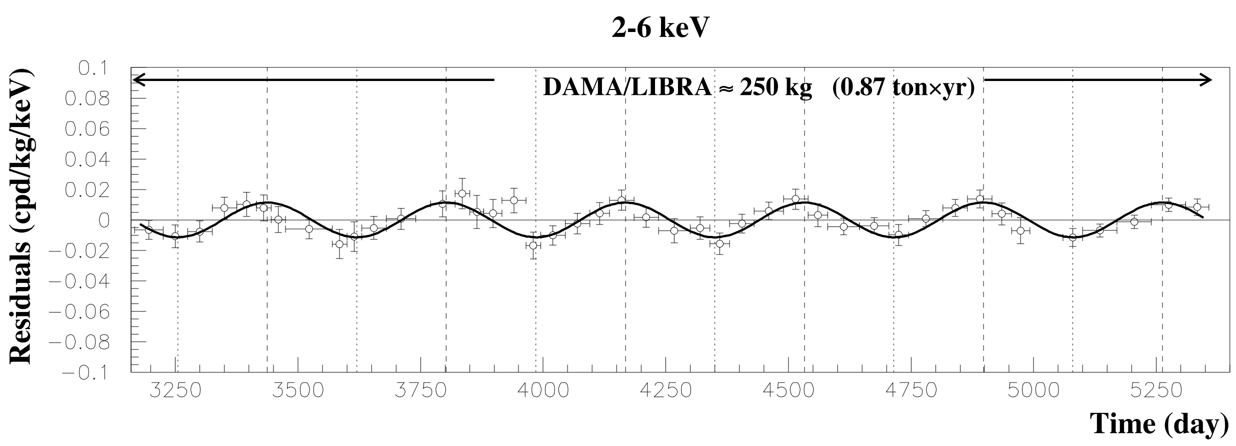
$\Omega_\chi = (n_\chi/s)_0\ s_0\, m_\chi\, /\, \rho_{\text{crit}}$

$\Omega_\chi h^2 = 0.106$

# Has WIMP dark matter been detected ?

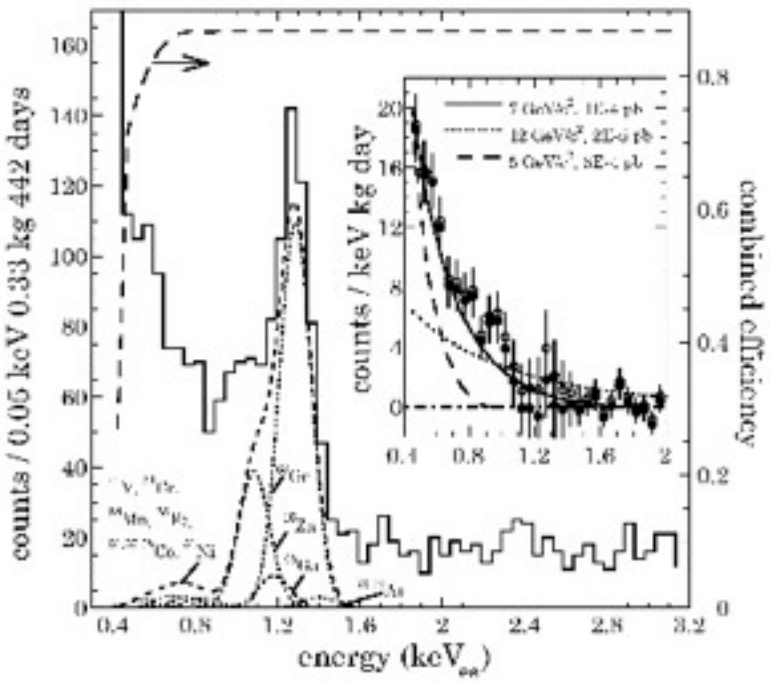
## DAMA

Bernabei et al 2010



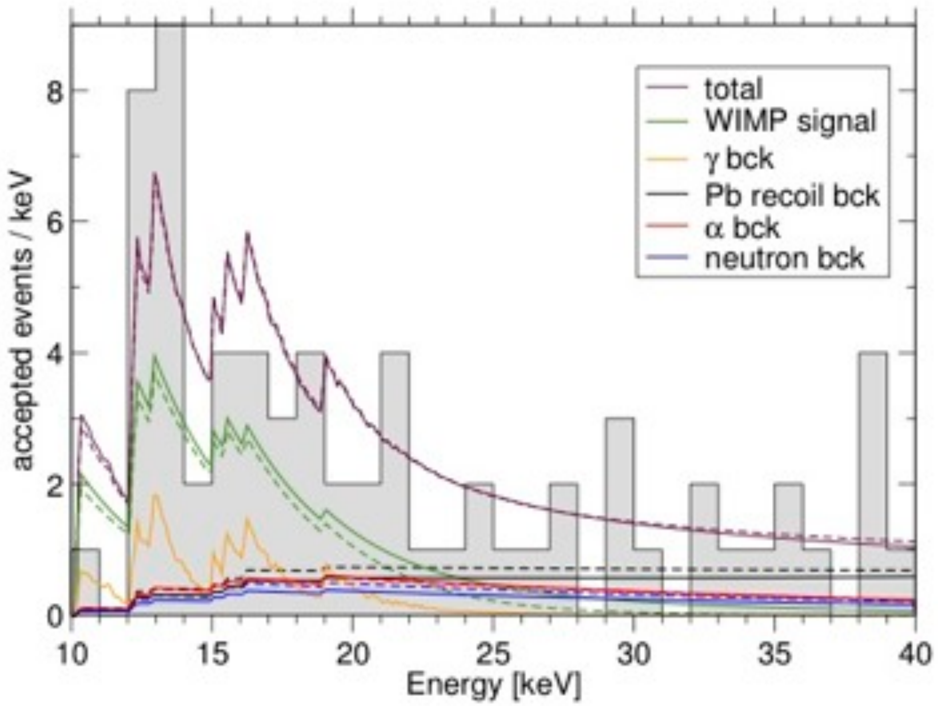

## CoGeNT

Aalseth et al 2011




## CRESST

Angloher et al 2011



# Outline -

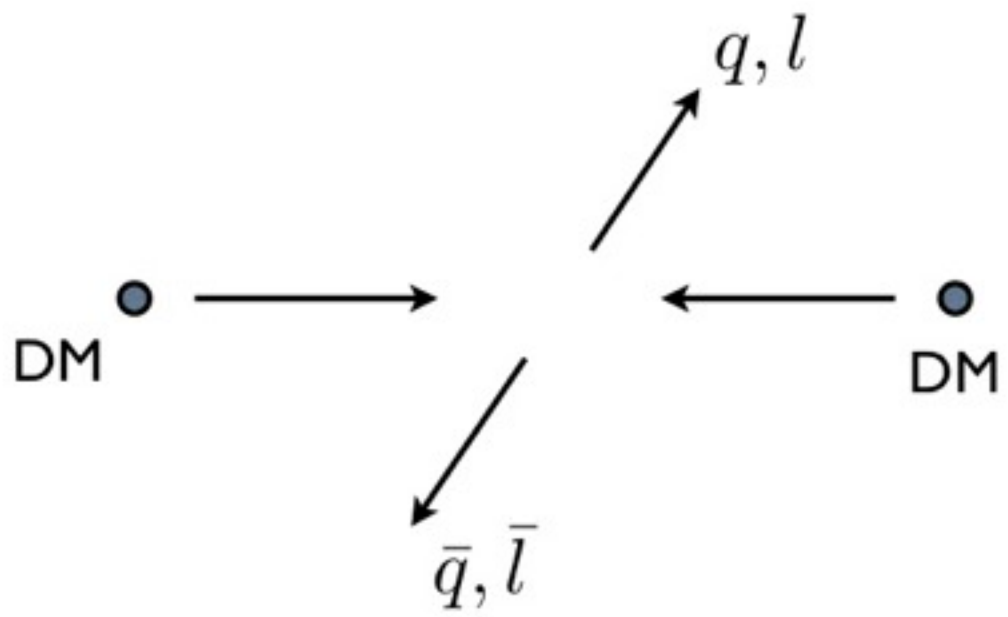
- Direct detection experiments favor a light WIMP $m_\chi \approx 10$ GeV

- Indirect detection experiments can check this !

- The CMB anisotropies have been measured to high accuracy.
  CMB theory is linear and well understood.

- We will use combined data from WMAP, SPT, BICEP, and QUaD.
  Watch out for Planck!

# *WIMPs annihilate to standard model particles.*

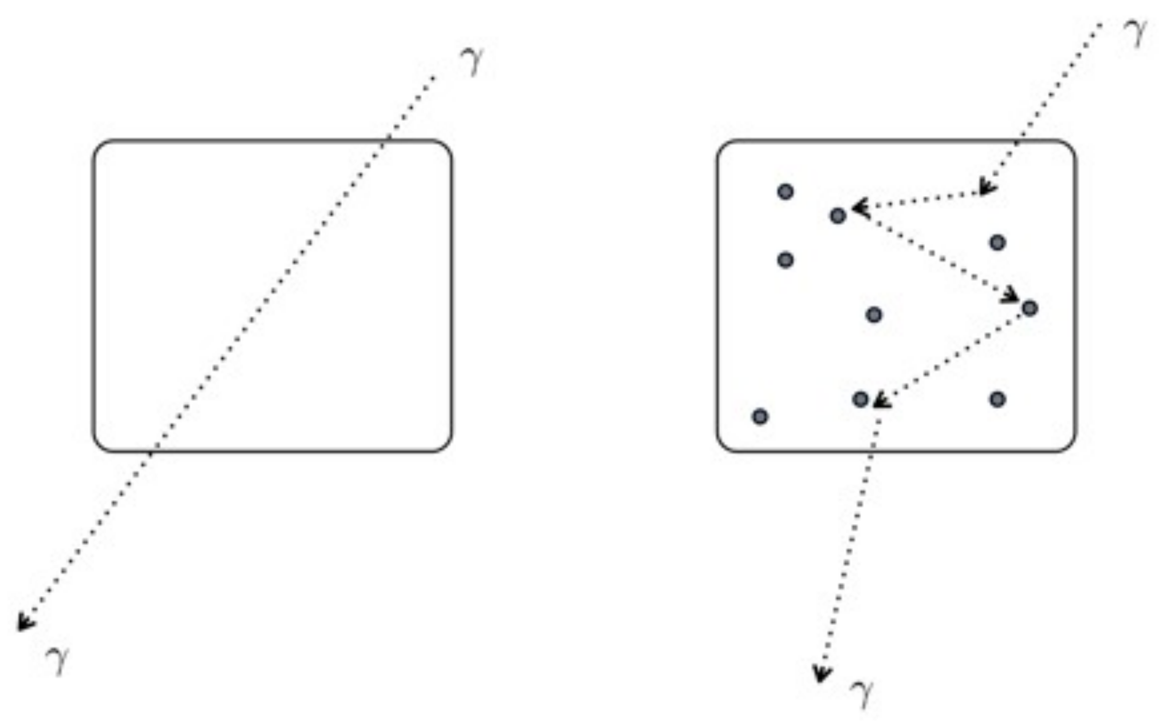



- Energy is released by particle annihilation.

- Some of this energy is absorbed by gas.
  The gas is heated and ionized.

Pierpaoli, PRL 2004
Chen, Kamionkowski, PRD 2004
Mapelli, Ferrara, Pierpaoli, MNRAS 2006
Chuzhoy, ApJ 2008
Natarajan, Schwarz, PRD 2008

# *WIMPs annihilate to standard model particles.*



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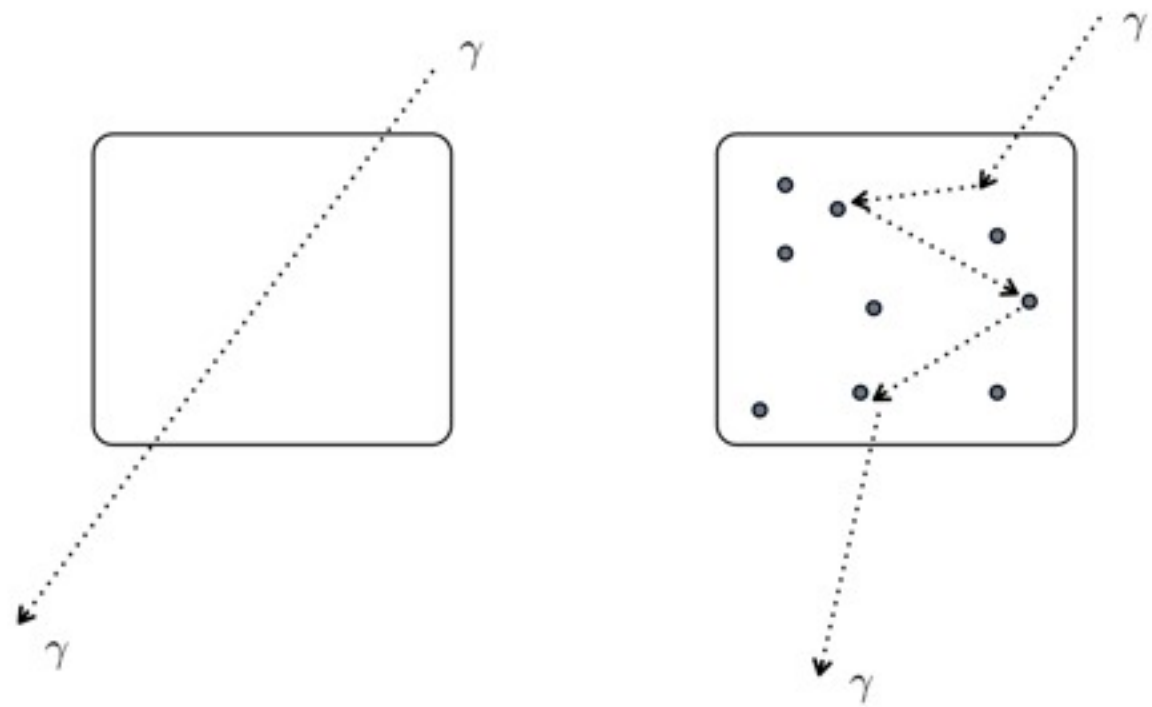
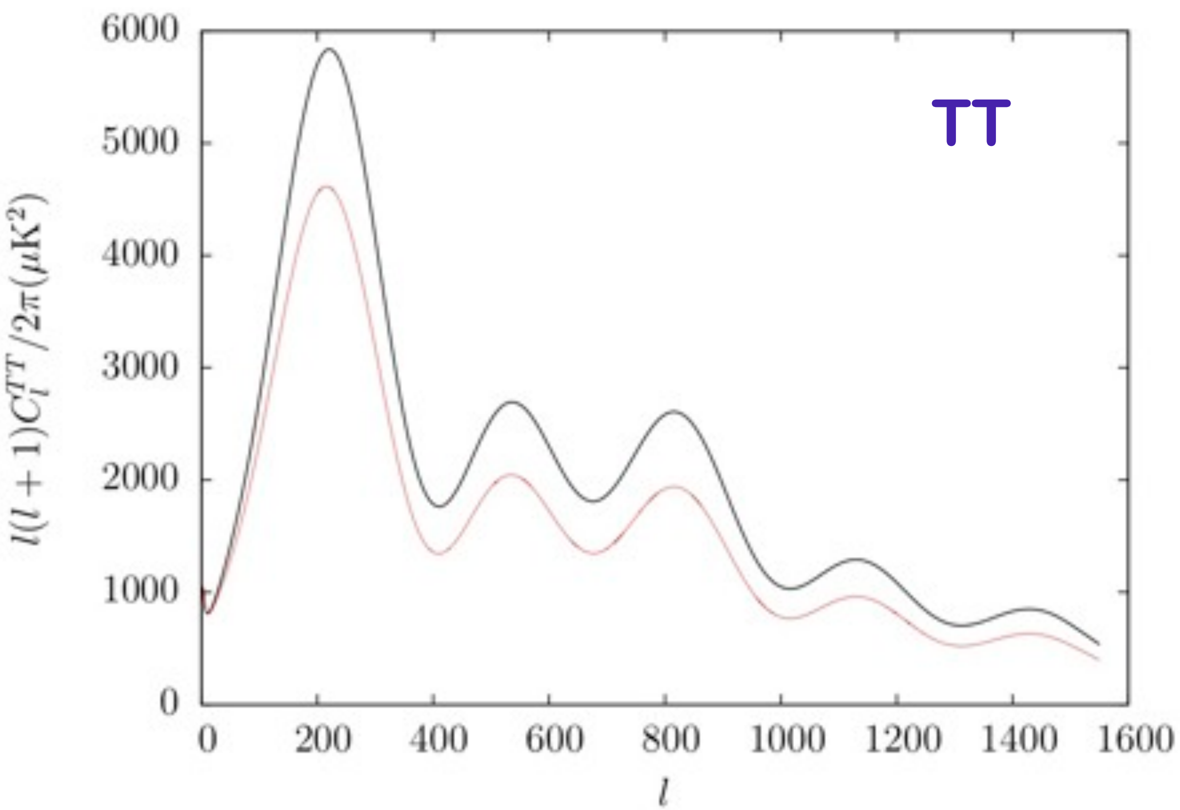
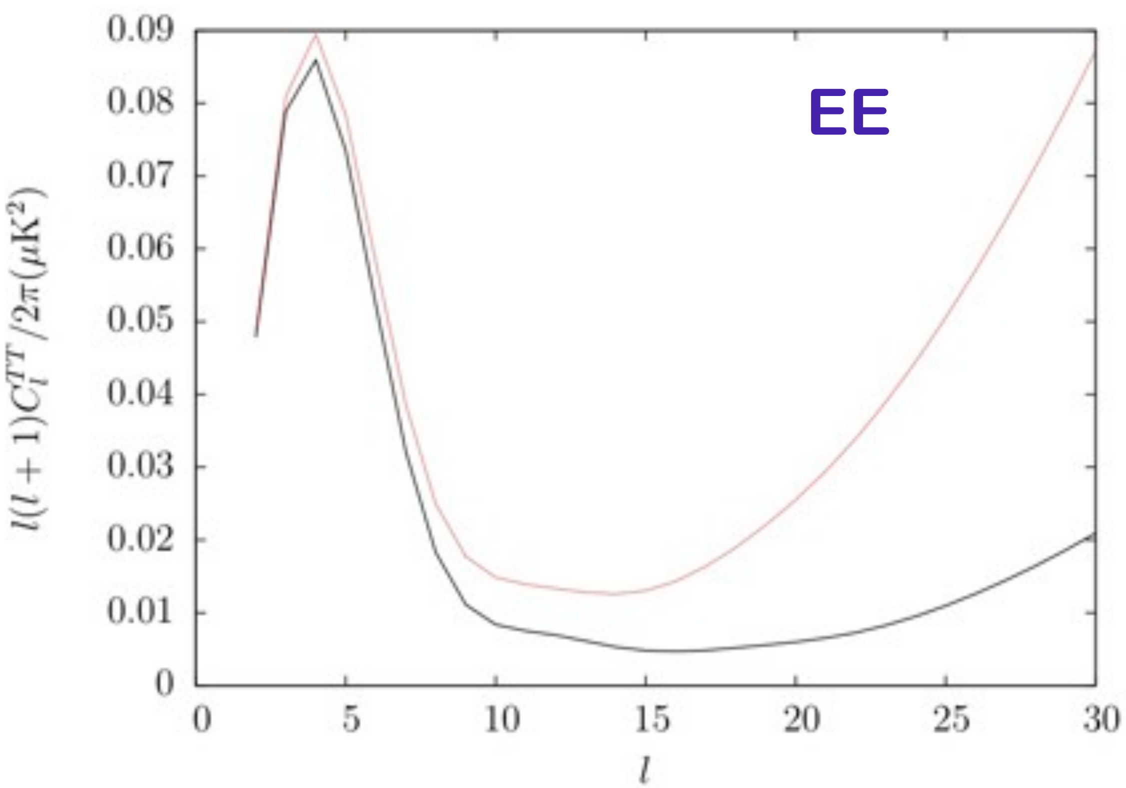
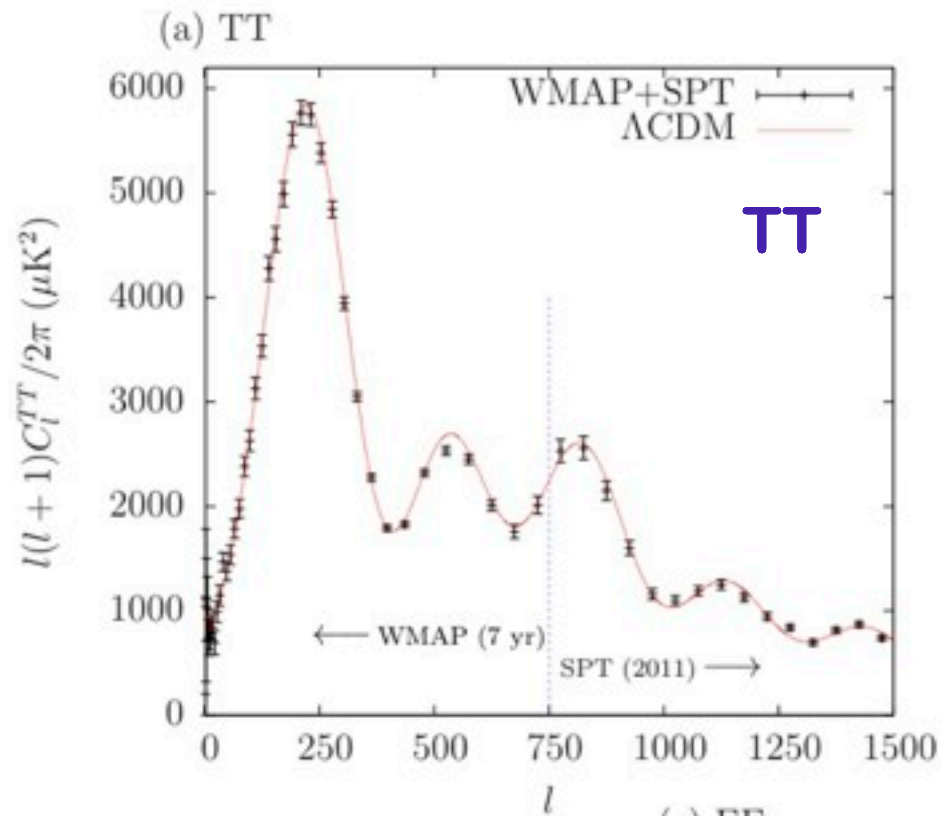


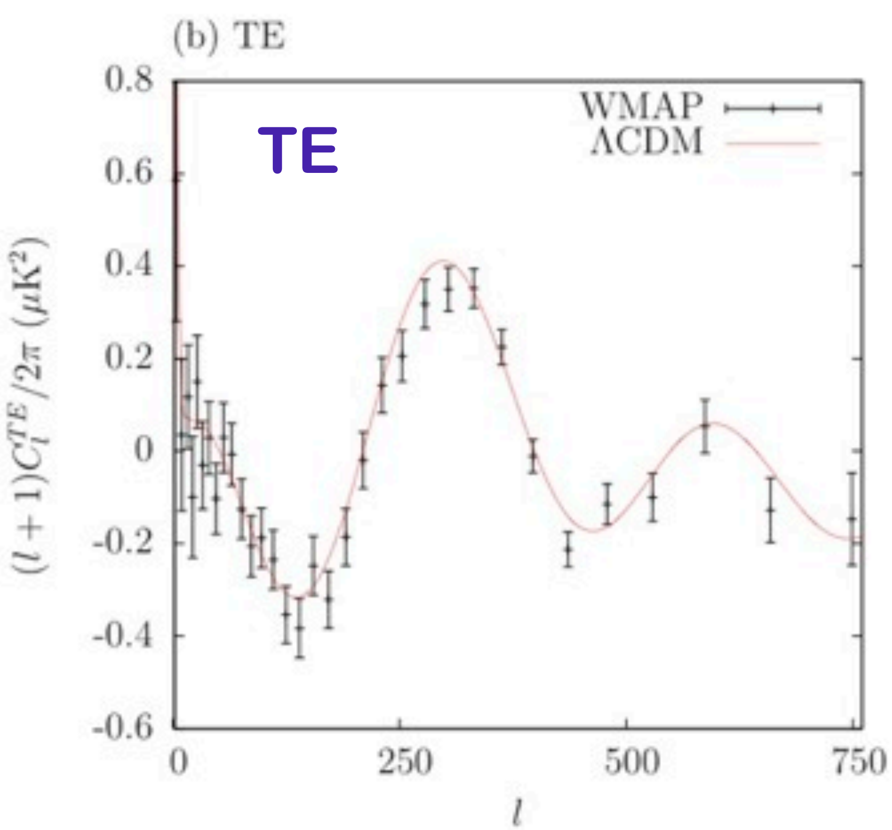

Padmanabhan, Finkbeiner, PRD 2005
Slatyer, Padmanabhan, Finkbeiner, PRD 2009
Natarajan, Schwarz PRD 2009, PRD 2010
Galli, Iocco, Bertone, Melchiorri PRD 2009, PRD 2011
Hütsi, Chluba, Hektor, Raidal, A&A 2011
Natarajan, arXiv 2012

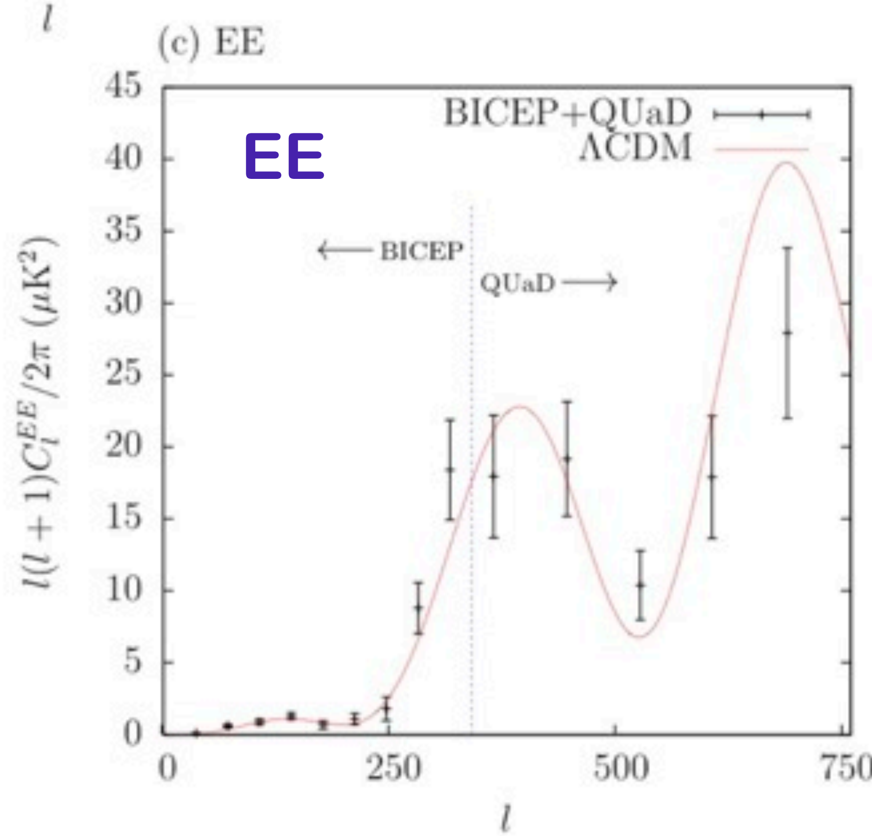


# *The data set -*




TT: l < 750 WMAP 7yr
750 < l < 1500 SPT (2011)

TE: l < 750 WMAP 7yr

EE: l < 350 BICEP
350 < l < 750 QUaD


Larson et al. (WMAP) ApJS 2011
Keisler et al. (SPT) ApJ 2011
Chiang et al. (BICEP) ApJ 2010
Pryke et al. (QUaD) 2009

# CMB parameter estimation -

$$\{m_\chi, A_\mathrm{s}, n_\mathrm{s}, h, \Omega_\mathrm{b}h^2, \Omega_\chi h^2\}$$

$$A_\mathrm{s} \propto \sigma_8^2$$

$$\langle\sigma_\mathrm{a} v\rangle = 3\times10^{-26}\ \mathrm{cm}^3/\mathrm{s}$$

$$dE/dt \propto \langle\sigma_\mathrm{a} v\rangle/m_\chi$$

CMB Boltzmann code CLASS J. Lesgourgues 2011

Assumptions:

- Single step reionization at z = 10.5
- No running of the spectral index.
- Dark energy density constant with time.

# CMB parameter estimation -

$$\{m_\chi, A_\mathrm{s}, n_\mathrm{s}, h, \Omega_\mathrm{b}h^2, \Omega_\chi h^2\}$$

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$$dE/dt \propto \langle \sigma_\mathrm{a} v \rangle / m_\chi$$

$m_\chi = \infty$ ΛCDM with no DM ann.

$\chi^2 = 92.5 / 96$ d.o.f.

$10^9 A_s = 2.24$ $n_s = 0.97$ $h = 0.69$

$\Omega_m h^2 = 0.1395$ $\Omega_b h^2 = 0.0225$

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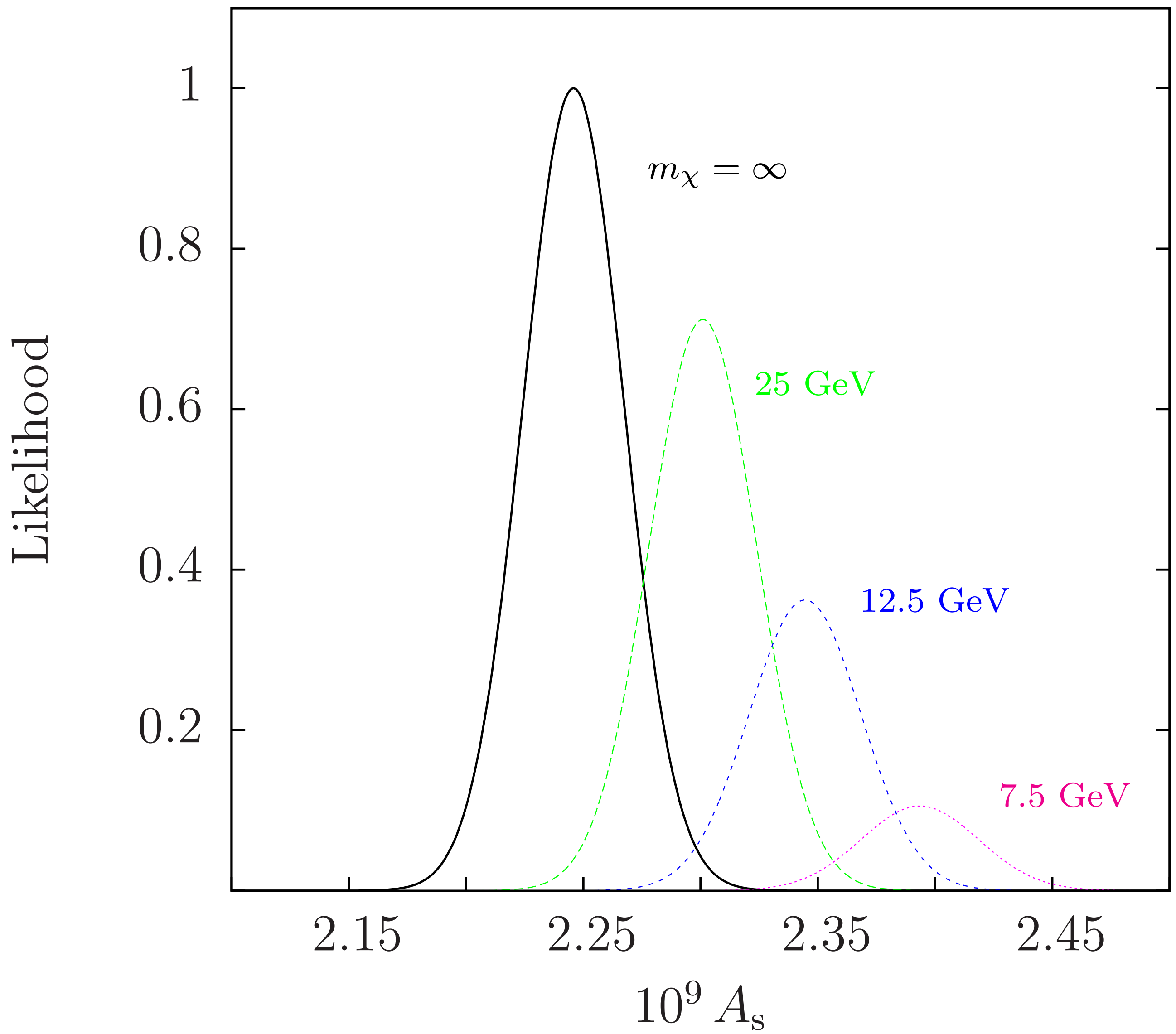
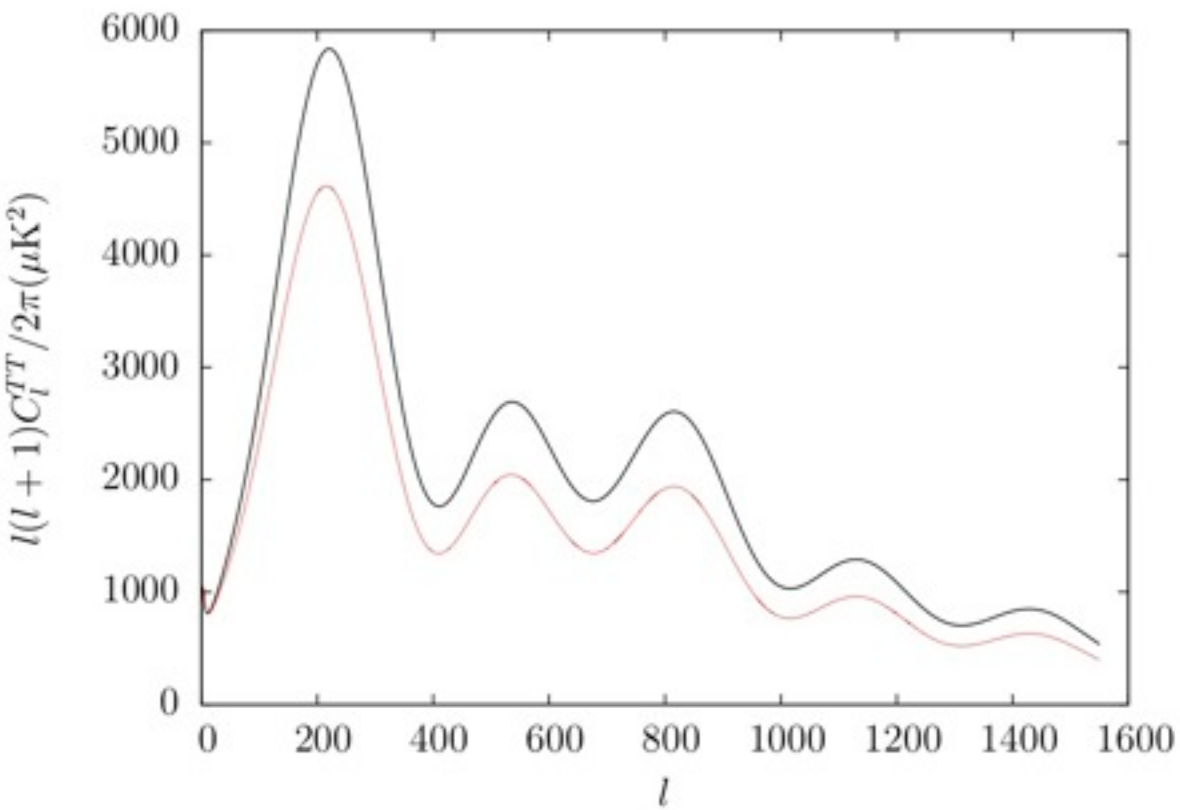



$$C_l \sim A_\mathrm{s} e^{-2\tau}$$



# CMB parameter estimation -

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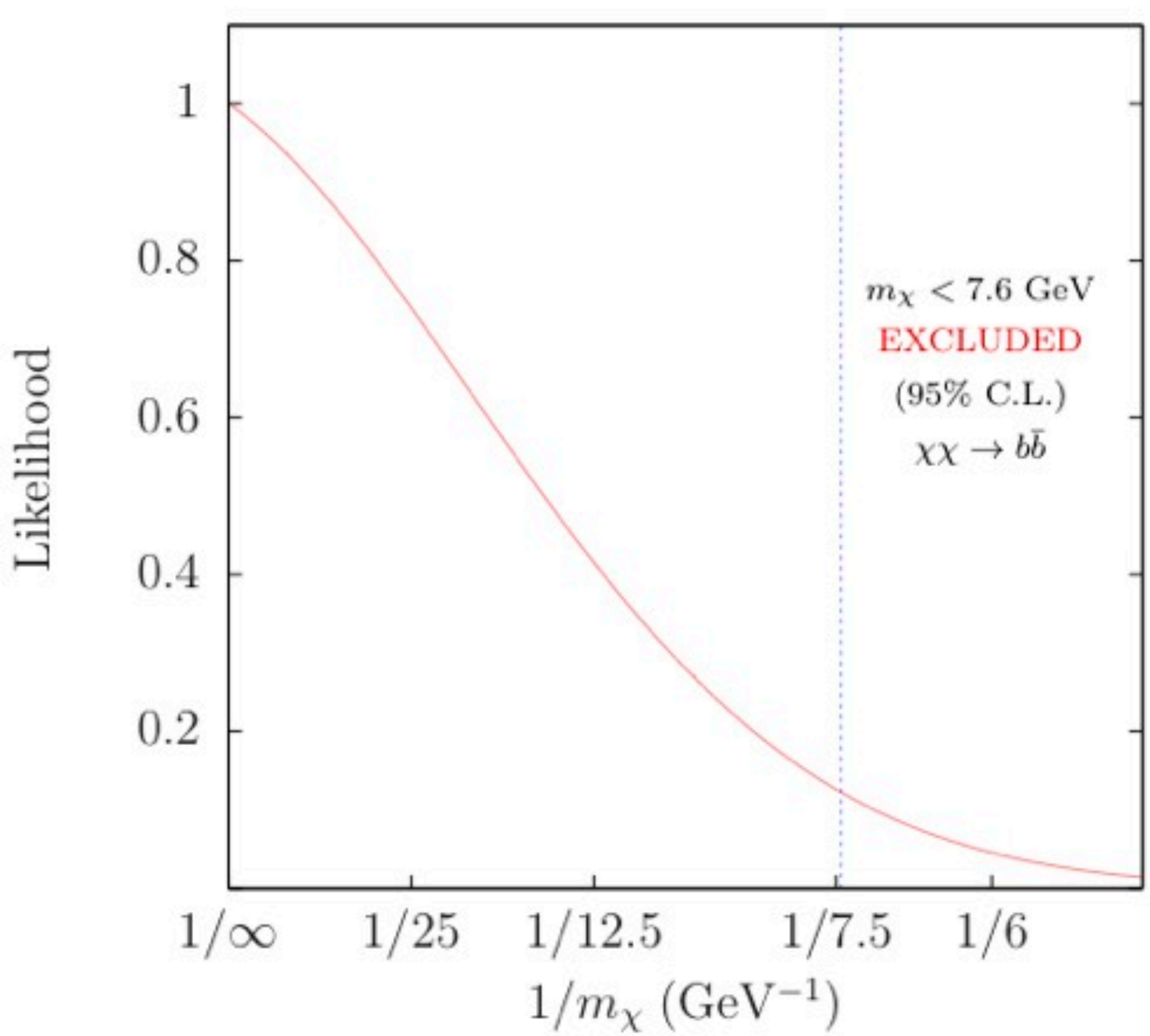



WIMP mass > 7.6 GeV (95%)
if $N_{eff}$ = 3.04

$$\langle \sigma_a v \rangle = 3 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$$

$$\chi\chi \to b\bar{b}$$

WIMP mass > 8.6 GeV (95%)
if $N_{eff}$ = 3.85

Number of neutrinos

- Standard model: 3.04
- SPT + WMAP: 3.85 ± 0.62
- ACT + WMAP: 5.3 ± 1.3

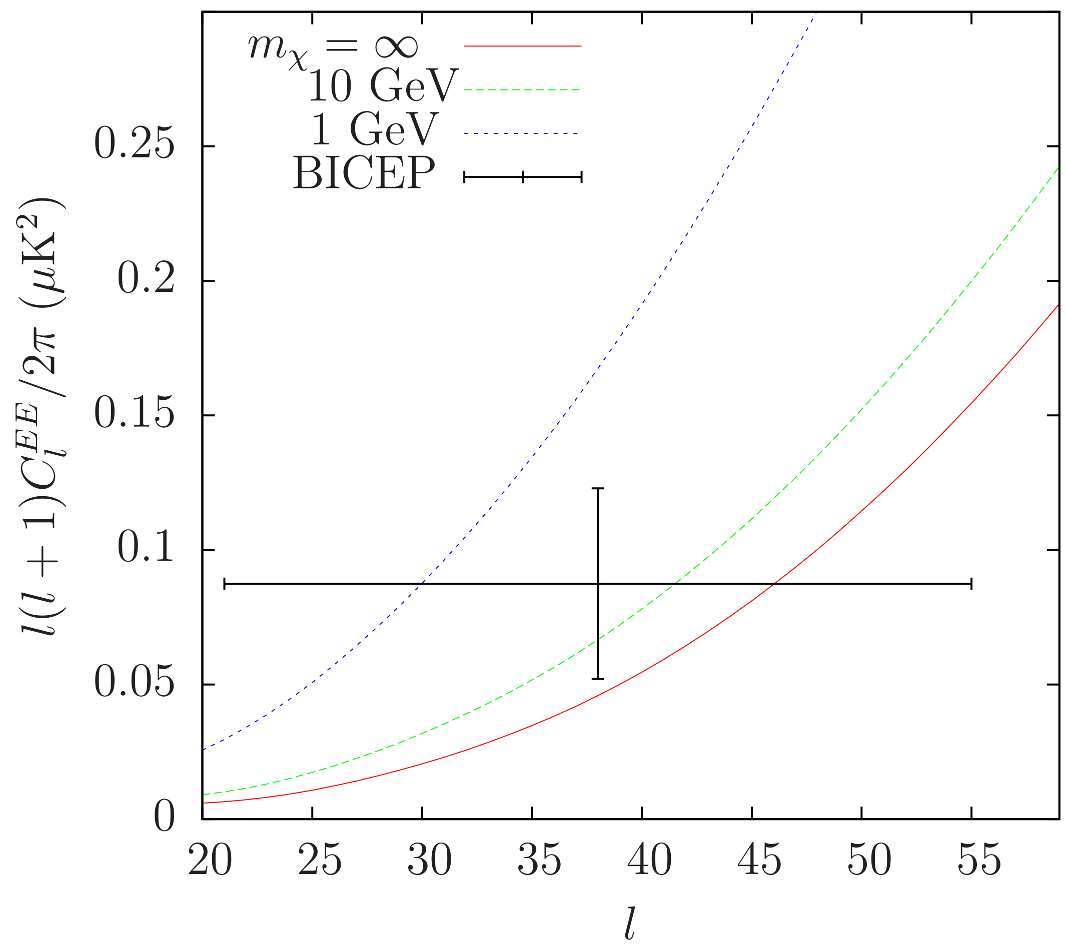
# Why Planck will do better:

# Measuring the EE power spectrum -

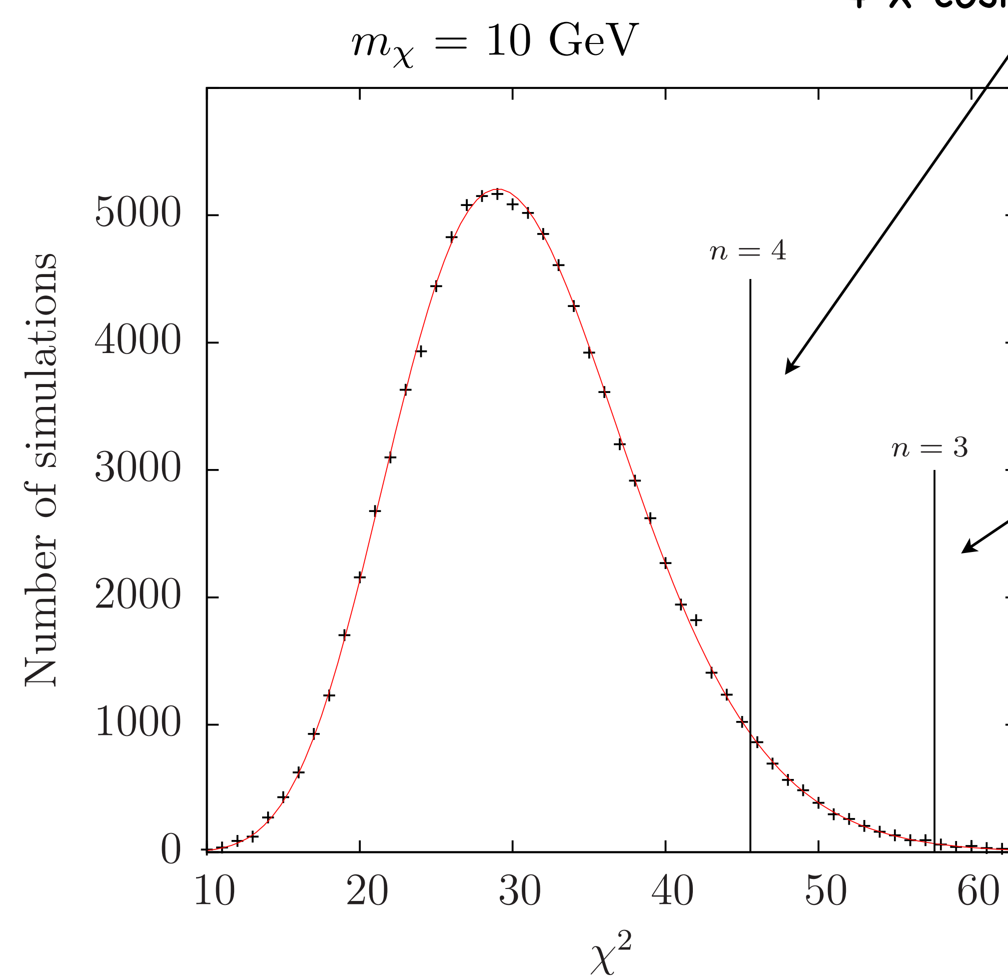
The overall amplitude $A_s$ is nearly degenerate with $m_\chi$ (and with $\tau$ )
The degeneracy can be overcome with CMB polarization.

# Why Planck will do better:

# Measuring the EE power spectrum -




4 x cosmic variance




3 x cosmic variance

$A_s$ ($\sigma_8$) is fixed by the TT power spectrum.

Thus, the $m_\chi$ $A_s$ degeneracy is broken by EE + TT.

WMAP: EE error ≈ 50 x cosmic variance at l = 40.

Planck: Instrument noise ≈ cosmic variance at l = 20.

# Why Planck will do better:
# Measuring the EE power spectrum -

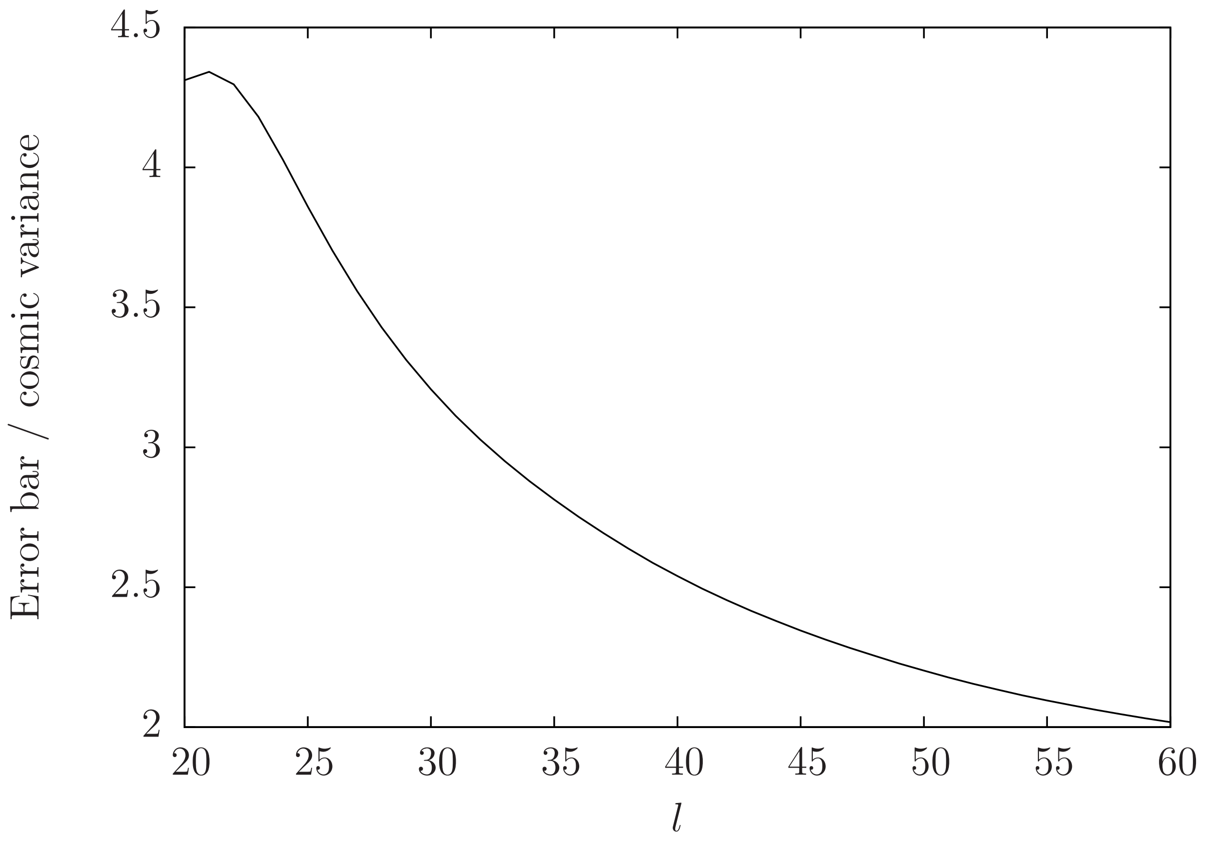
143P Polarization sensitive channel:

$$\Delta T = 82\ \mu\mathrm{K}\ \sqrt{\mathrm{s}}$$

$$n_{\mathrm{bol}} = 8$$

$$f_{\mathrm{sky}} \approx 70\ \%$$

$$\frac{\delta C_l^{EE}}{C_l^{EE}} = \sqrt{\frac{2}{2l+1}}\,\frac{1}{f_{\mathrm{sky}}^{1/2}}\left[1 + \frac{(f_{\mathrm{sky}} w)^{-1}}{C_l^{EE}} e^{l(l+1)\sigma_{\mathrm{b}}^2}\right]$$




WIMP mass > 10 GeV at > 3σ with 2 year obs. with Planck

# Conclusions-

- The CMB is a good probe of low mass WIMPs.
  We analyzed data from the WMAP, SPT, BICEP, and QUaD expts.

- Data from CMB observations requires $m_\chi >$ 7.6 GeV (95% C.L.)
  for the simplest WIMP models.

- The degeneracy between $A_s$ and $e^{-2\tau}$ is broken by polarization.
  Accurate measurements of the EE polarization for $l > 20$ will place strong constraints on DM properties.