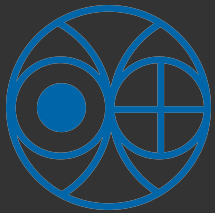


Talk delivered at WHEPP joint session

Measuring Neutrino Mass from Cosmological Observations



Arindam Mazumdar
Physical Research Laboratory
Ahmedabad-380009

Λ CDM cosmology

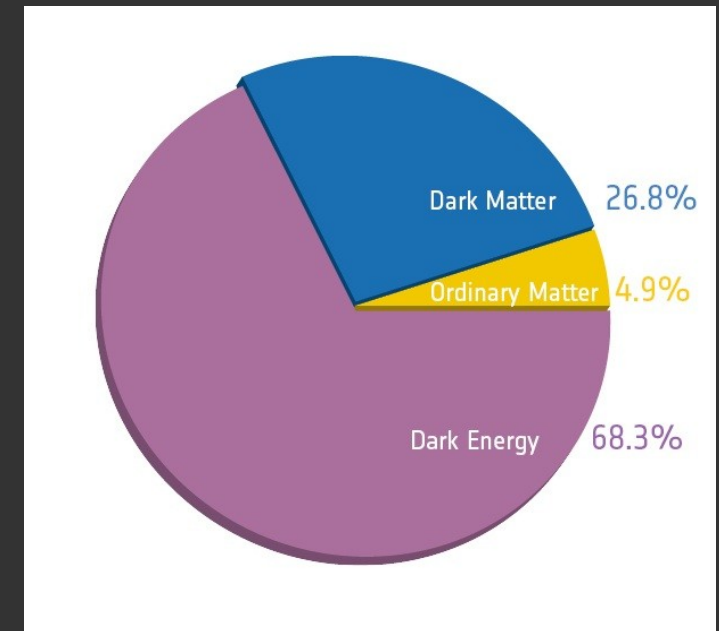
6 parameters

Late time

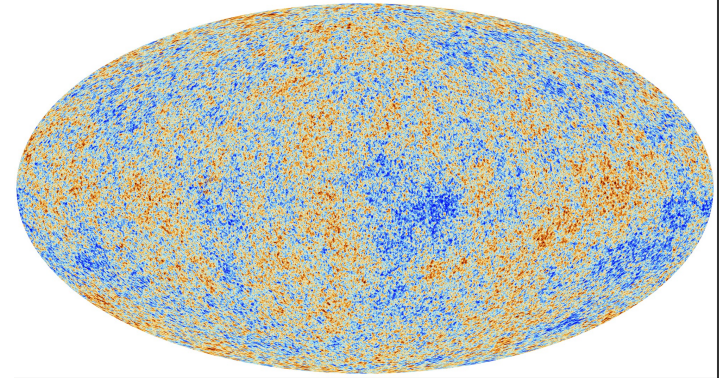
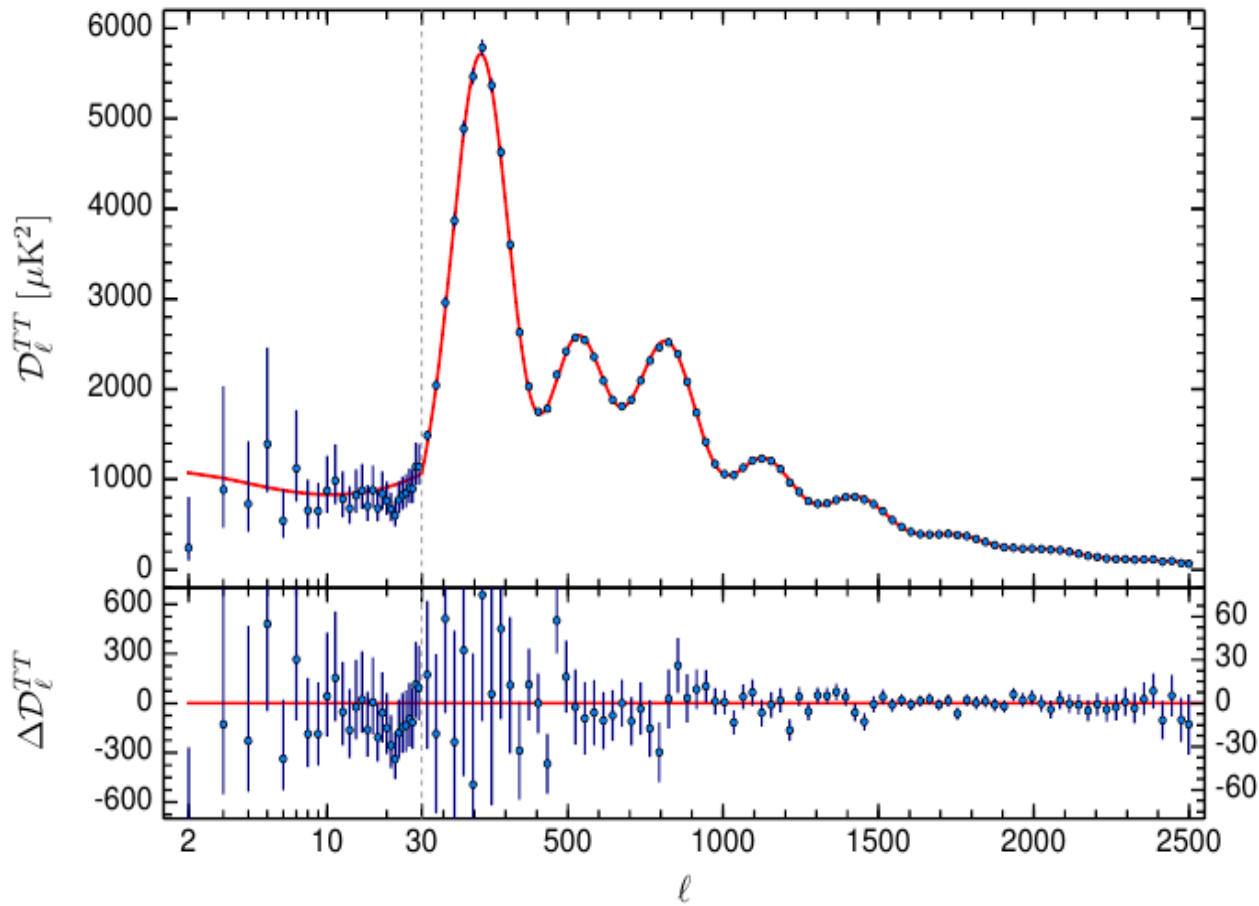
1. Θ , BAO scale (or Hubble value today H)
2. Dark matter density today, Ω_{cdm}
3. Baryon density, Ω_b
4. Re-ionization depth τ_{reion}

Early Universe

5. Amplitude of primordial fluctuations A_s
6. Spectral index primordial fluctuations n_s



CMB

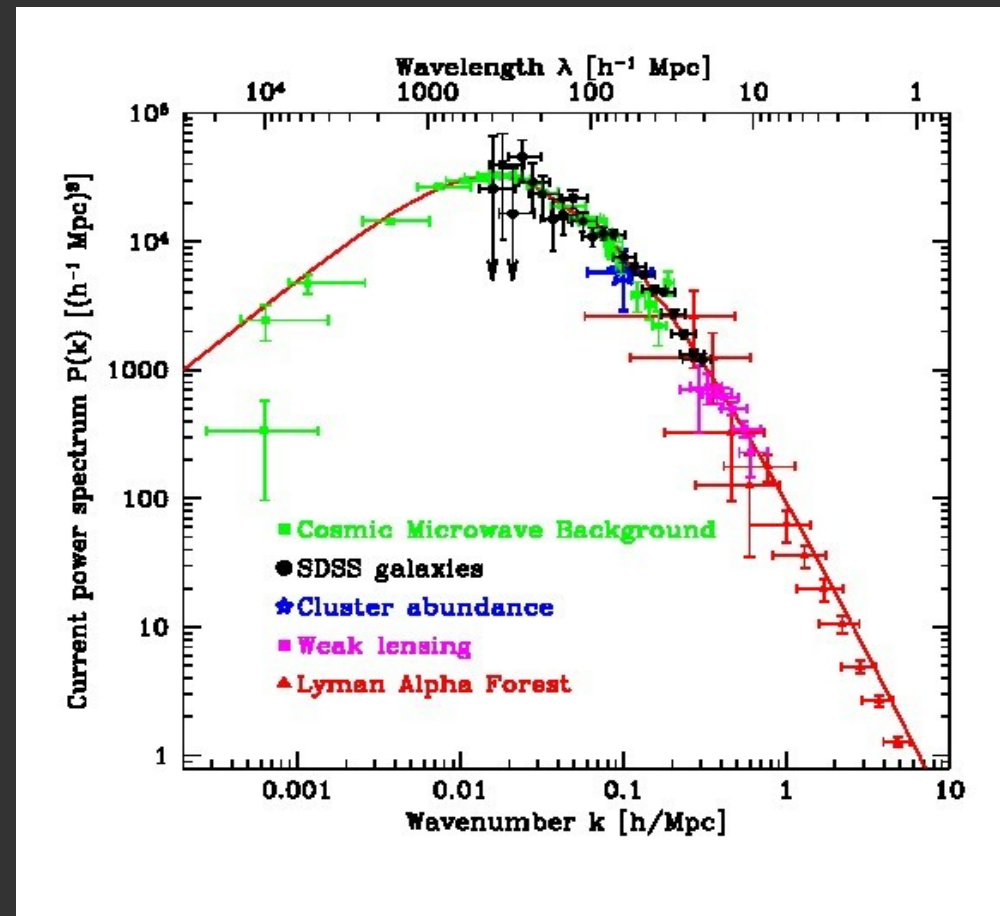


Planck (2015)

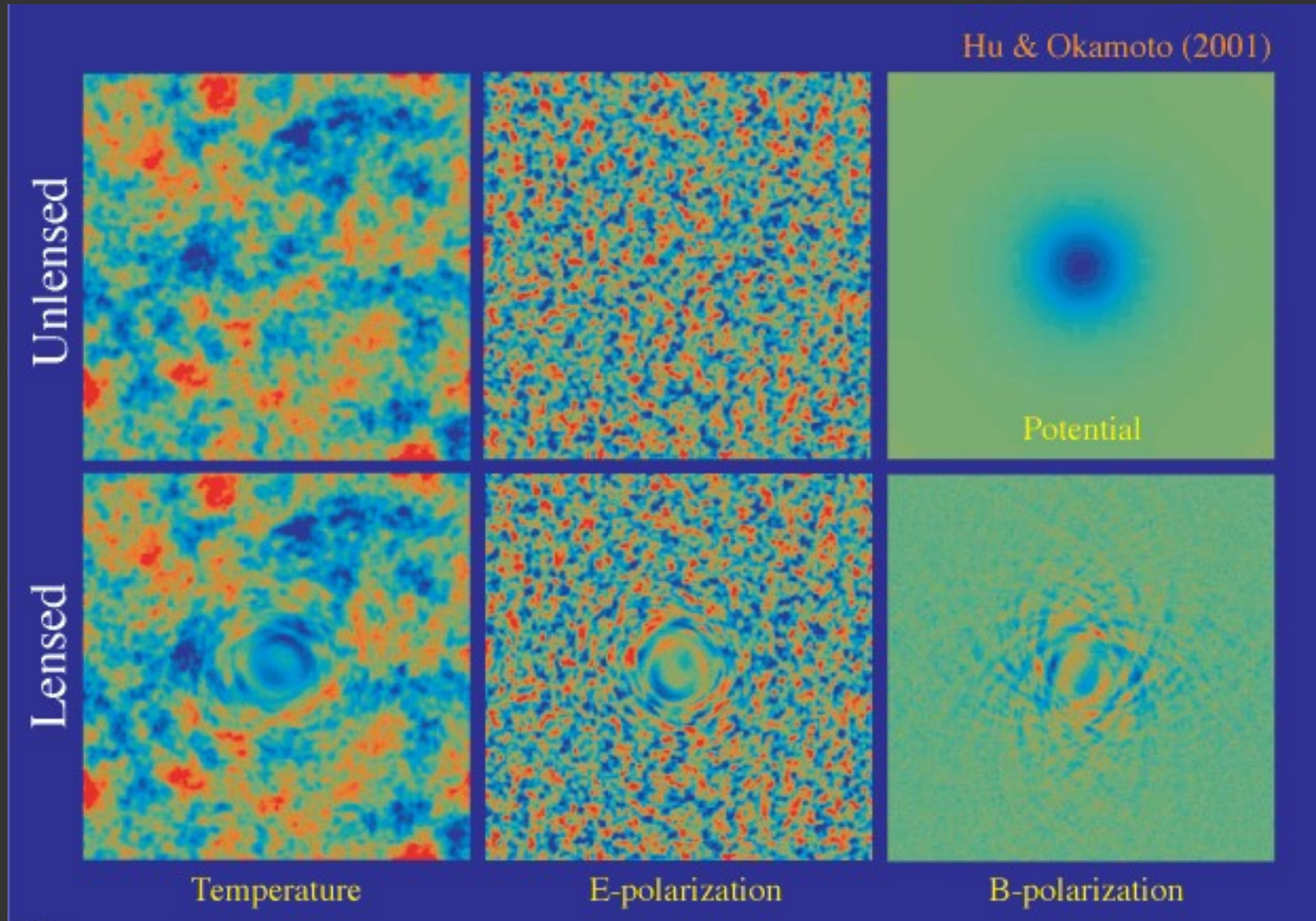
Large Scale Structure (LSS)

Experiments

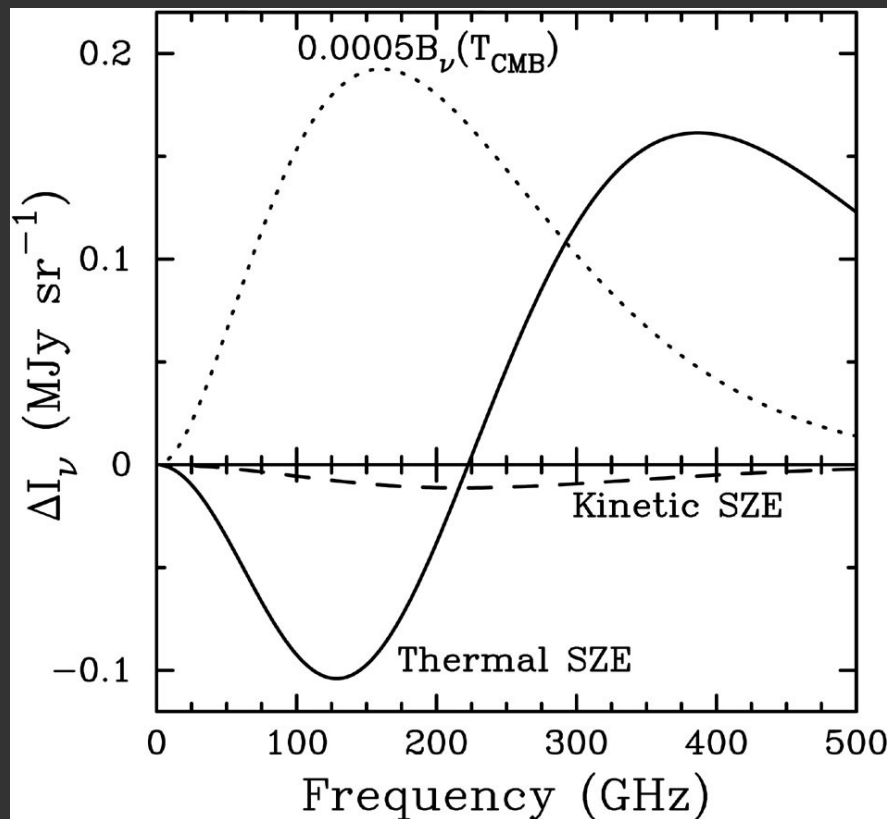
1. CFHTLenS : Gravitational Lensing
2. Planck Lensing : Gravitational Lensing
3. Planck SZ : Sunyaev-Zeldovic effect
4. SPT : Sunyaev-Zeldovic effect
5. SDSS, BOSS
6. Dark Energy Survey (DES)



Lensing



Sunyaev-Zeldovich Effect



1. μ - Distortion

Injects some extra photon in distribution

2. y - Distortion

Inverse Compton scattering increases the energy of CMB photons

What does LSS measure

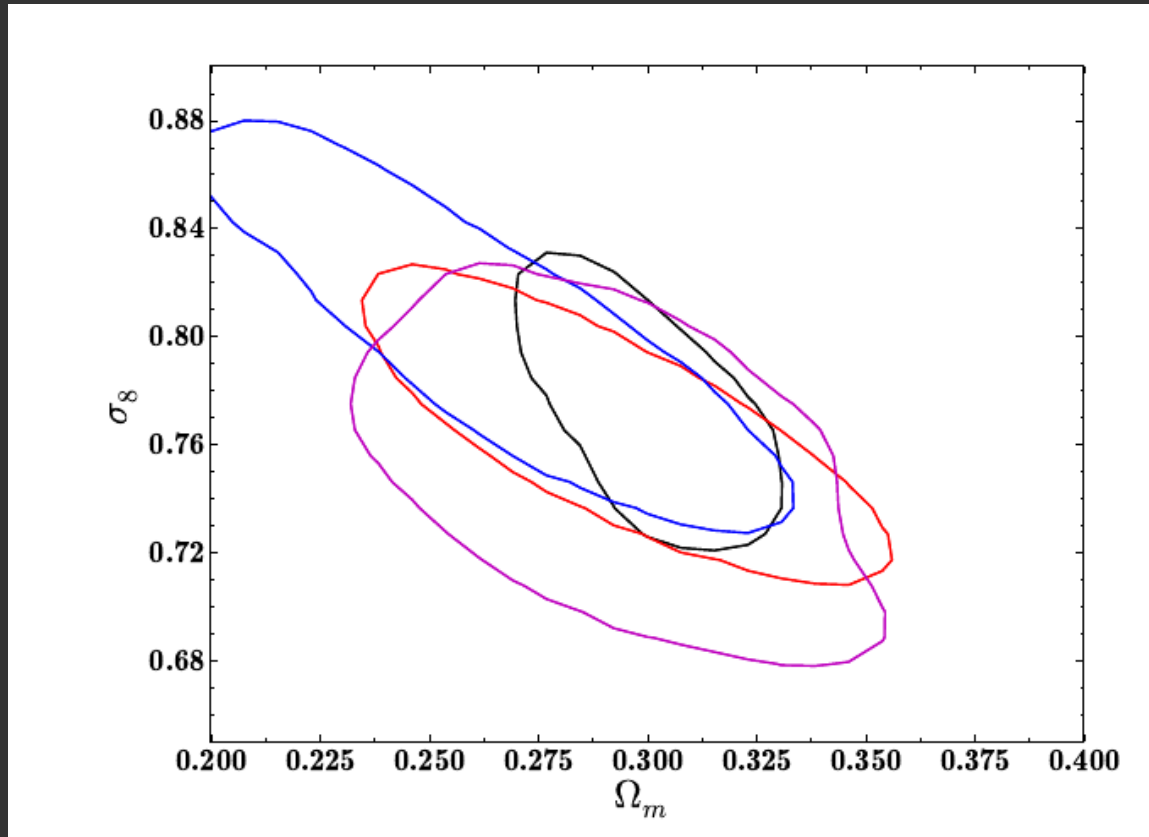
- Number of clusters in a given volume
- This is proportional to σ_8

$$\sigma^2 = \frac{1}{2\pi^2} \int dk k^2 P(k, z) |W(kR)|^2$$

- $W(k, R)$ is called window function
- Number of clusters is proportional to a combination

$$\sigma_8 (\Omega_m^0)^\alpha$$

LSS observations (SZ)



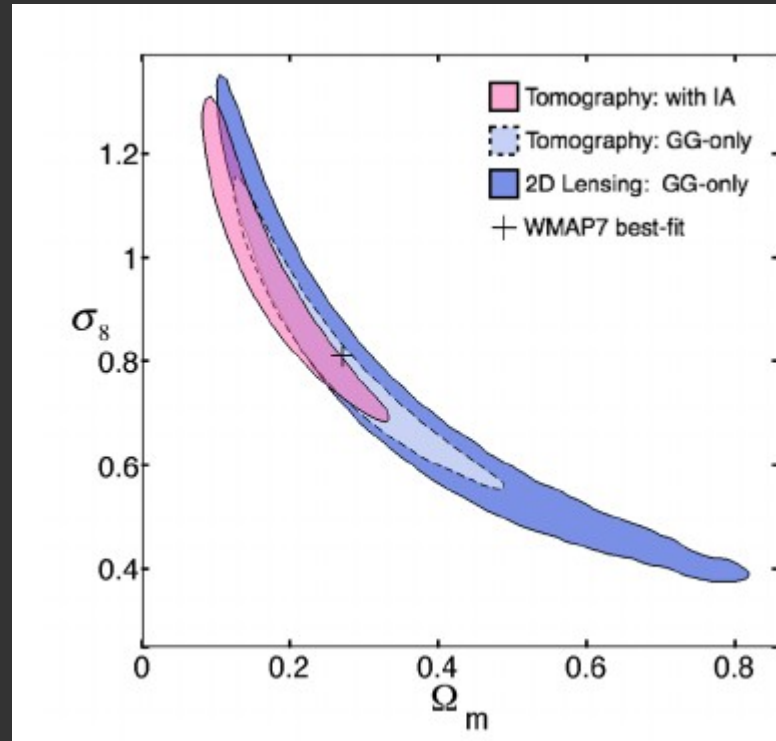
Likelihood $\sigma_8 \left(\frac{\Omega_m^0}{0.27} \right)^{0.3} = 0.78 \pm 0.01$

Planck SZ (2013)

15th Dec , 2017

WHEPP-XV(2017)

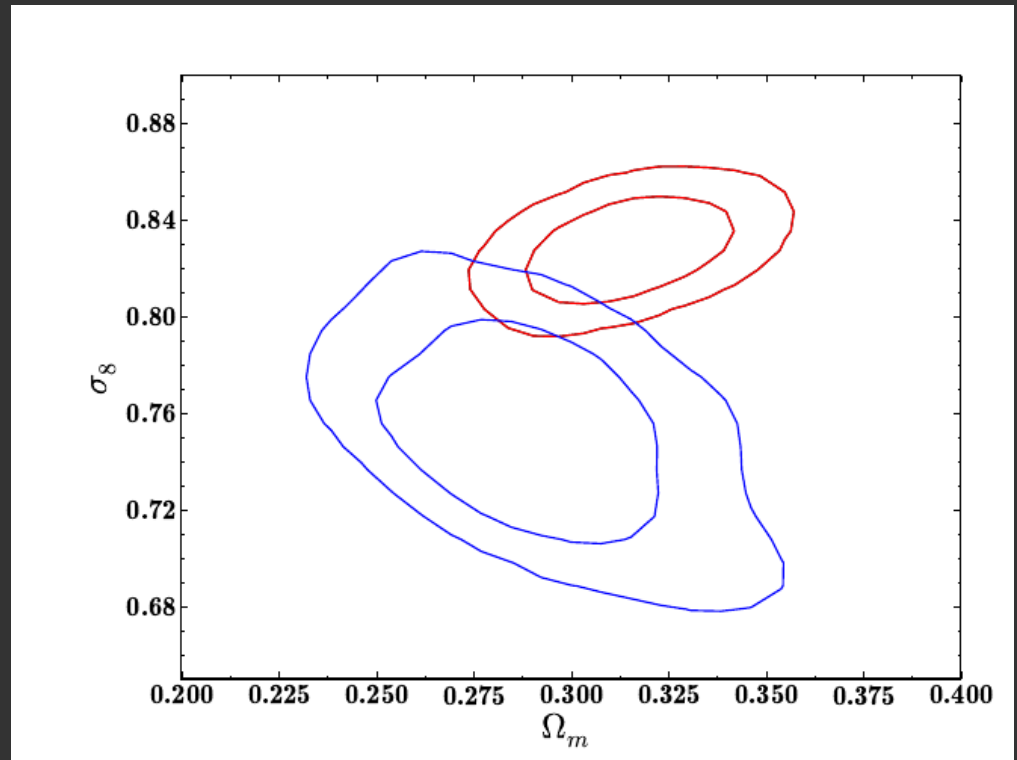
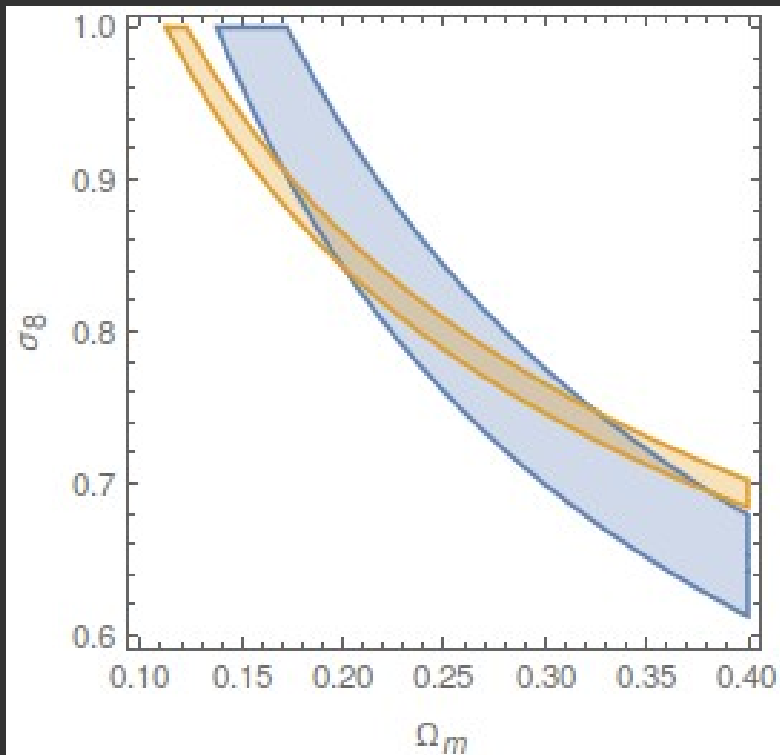
LSS observations (Lensing)



CFHTLens (2012)

$$\text{Likelihood} \quad \sigma_8 \left(\frac{\Omega_m^0}{0.27} \right)^{0.46} = 0.774 \pm 0.04$$

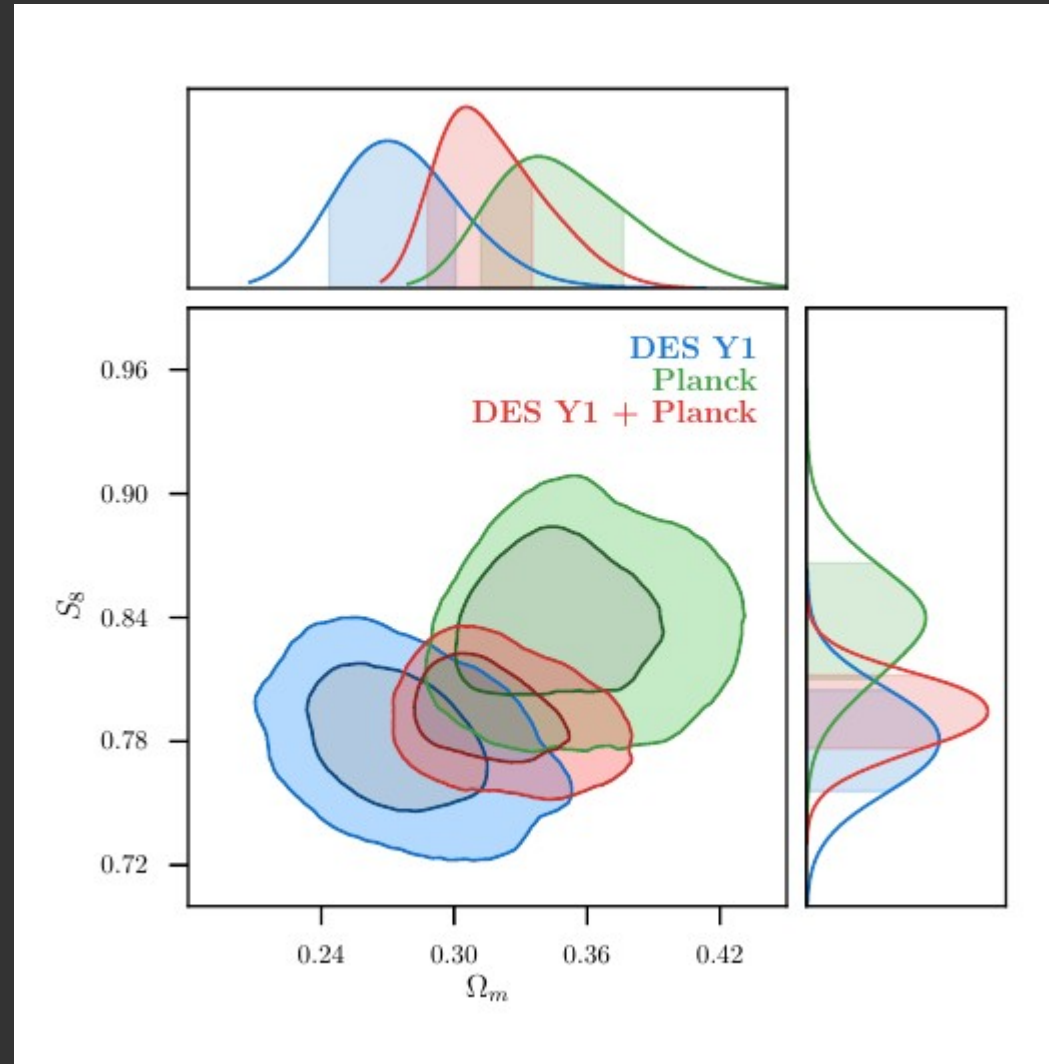
LSS observations



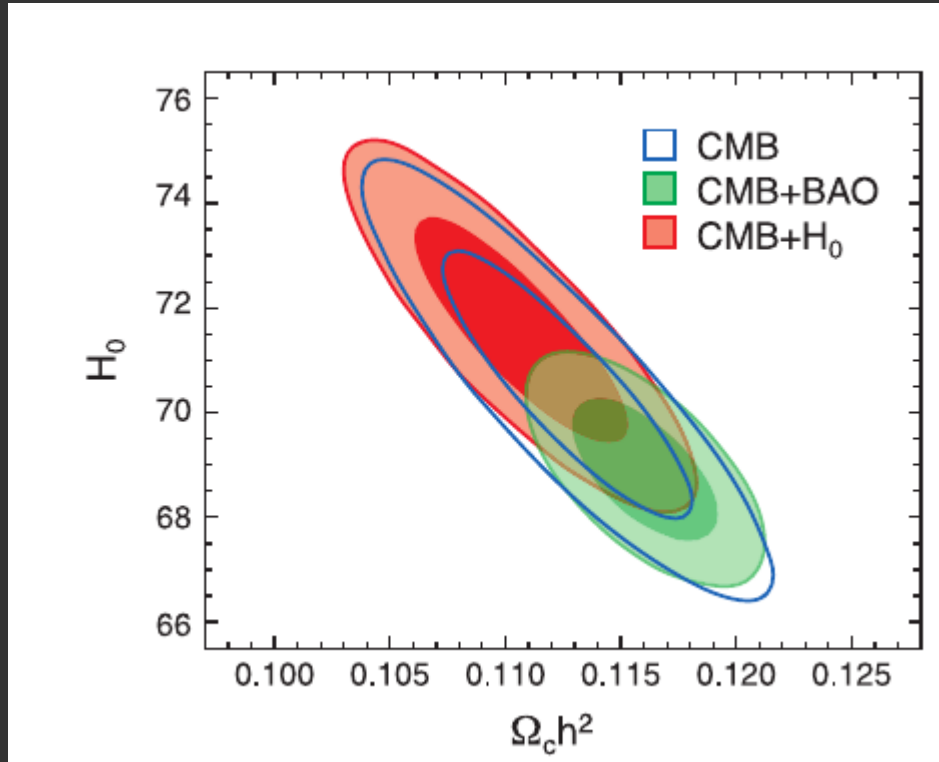
Planck SZ (2013)

Latest DES result

arXiv:1708.01530



Tension in H_0



WMAP-9 years

Planck -2015

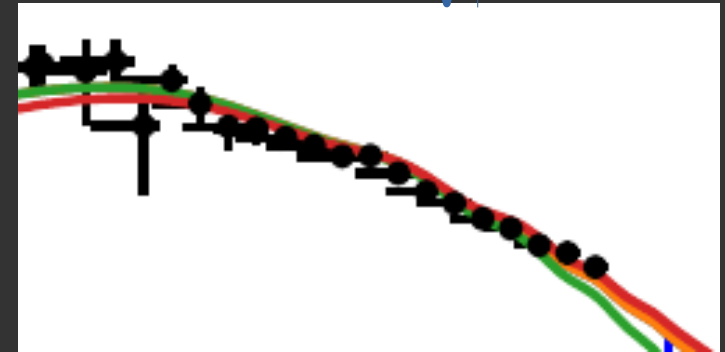
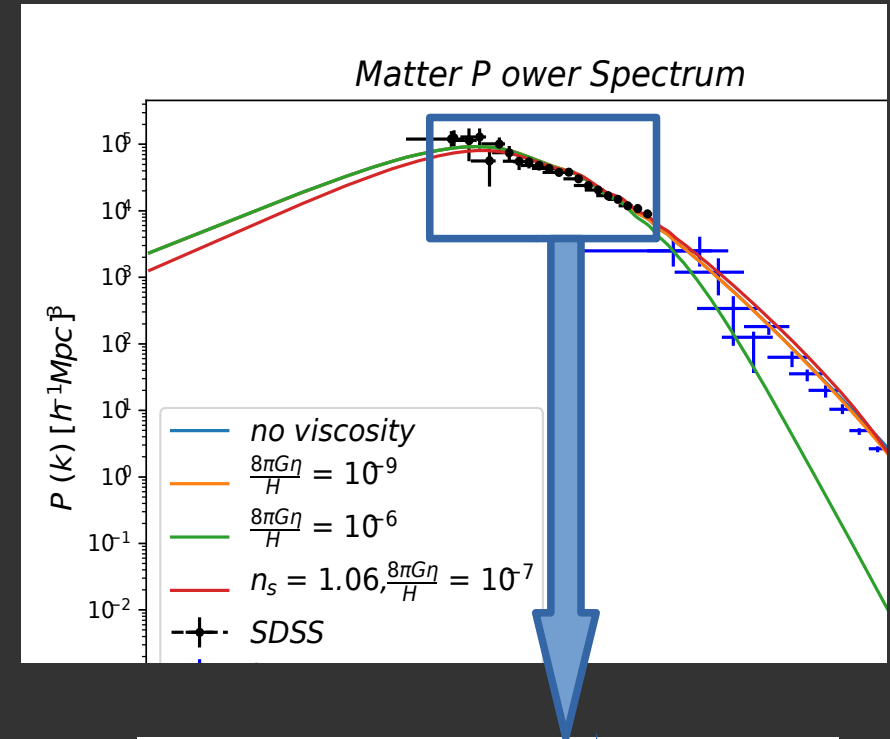
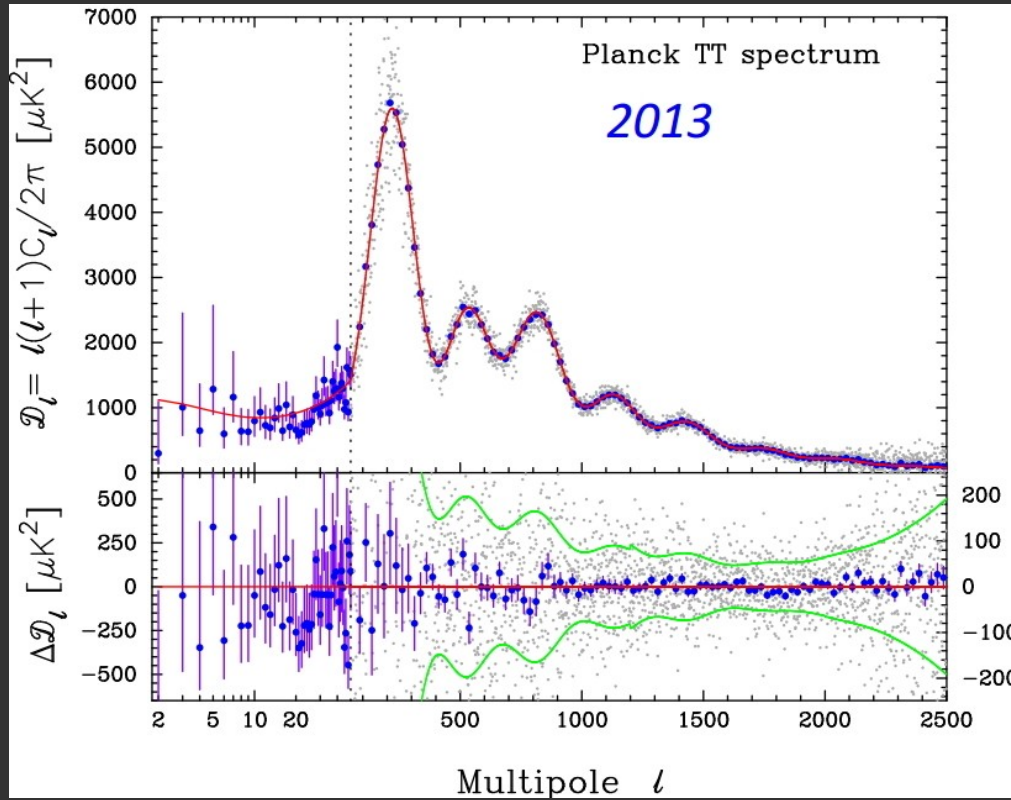
67.8 ± 0.9 km/s/Mpc

BOSS-BAO

70.5 ± 1.6 km/s/Mpc

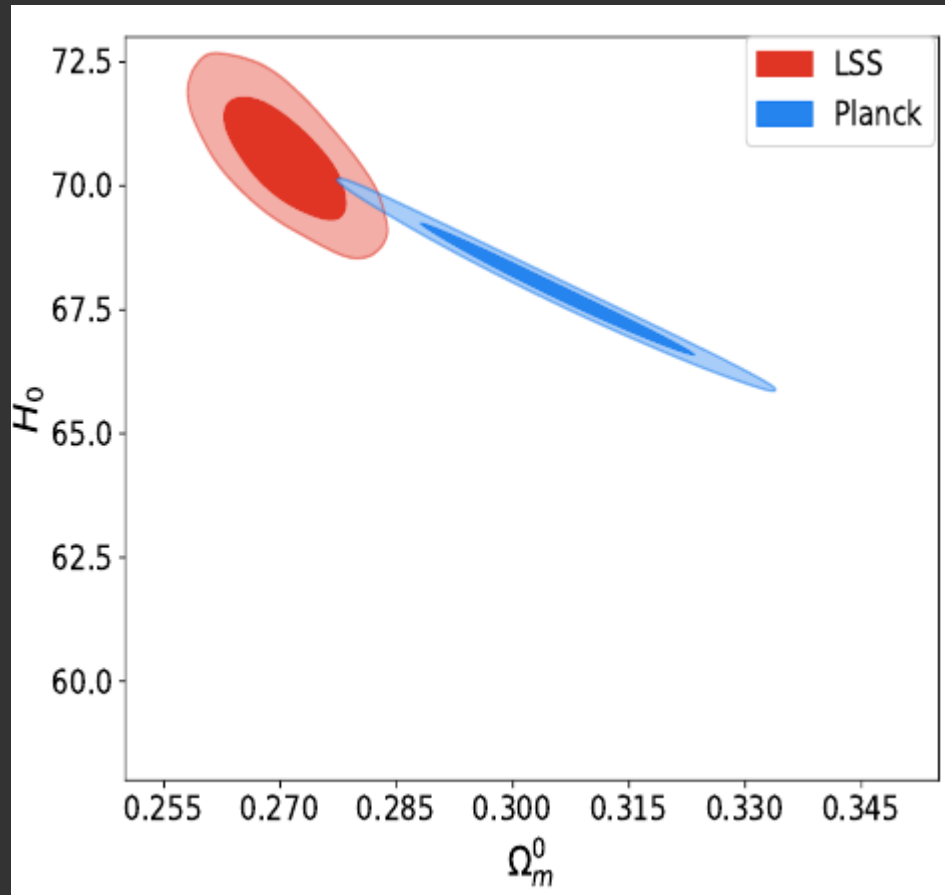
Measurement of H_0

Baryon Acoustic Oscillation Scale (Θ)



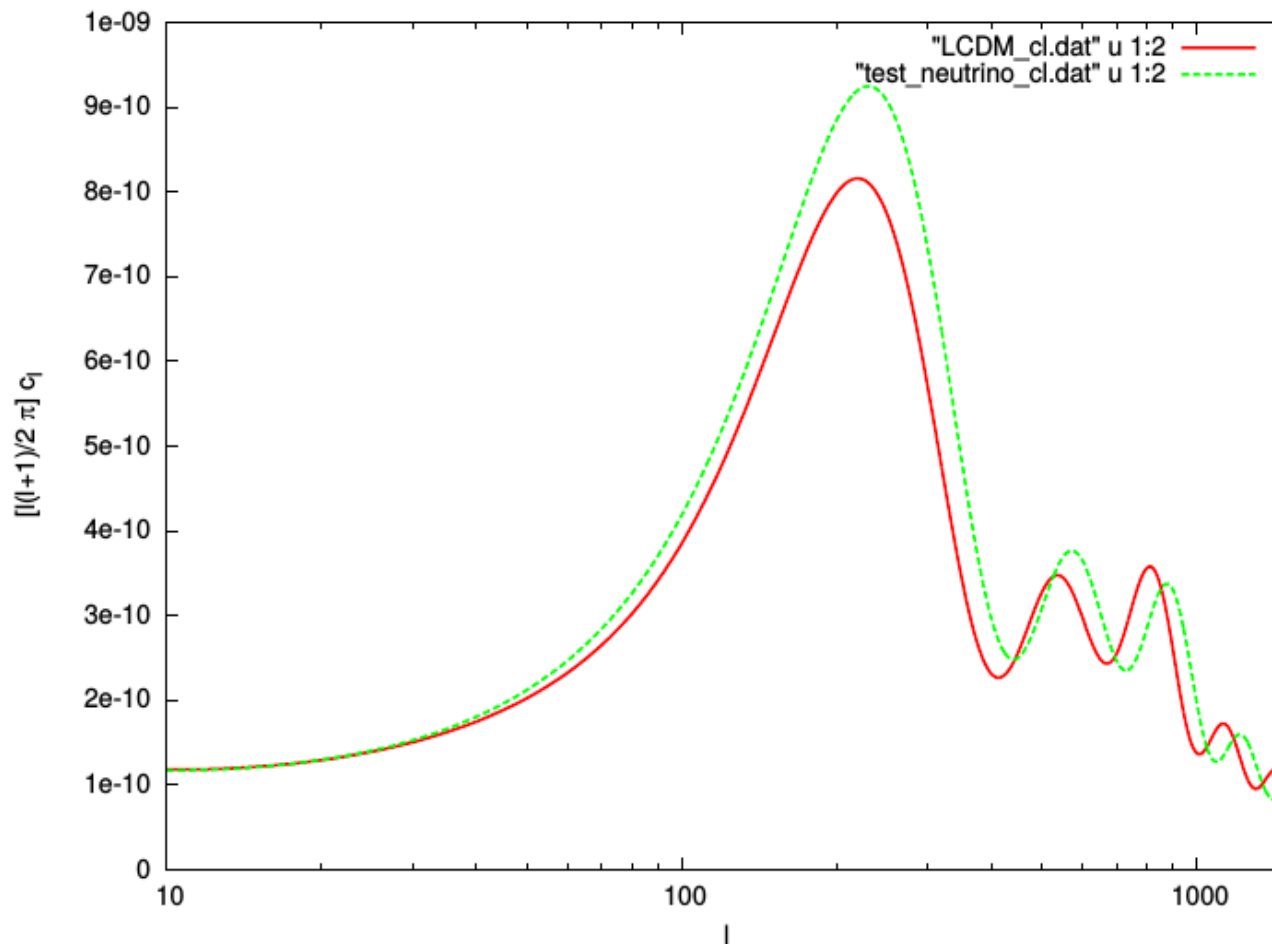
$$\frac{H(z)}{H_0} = \sqrt{\Omega_m(1+z)^3 + \Omega_{DE}f(z) + \Omega_k(1+z)^2 + \Omega_{rad}(1+z)^4}$$

H_0 tension



arXiv:1712.01254

Massive neutrinos

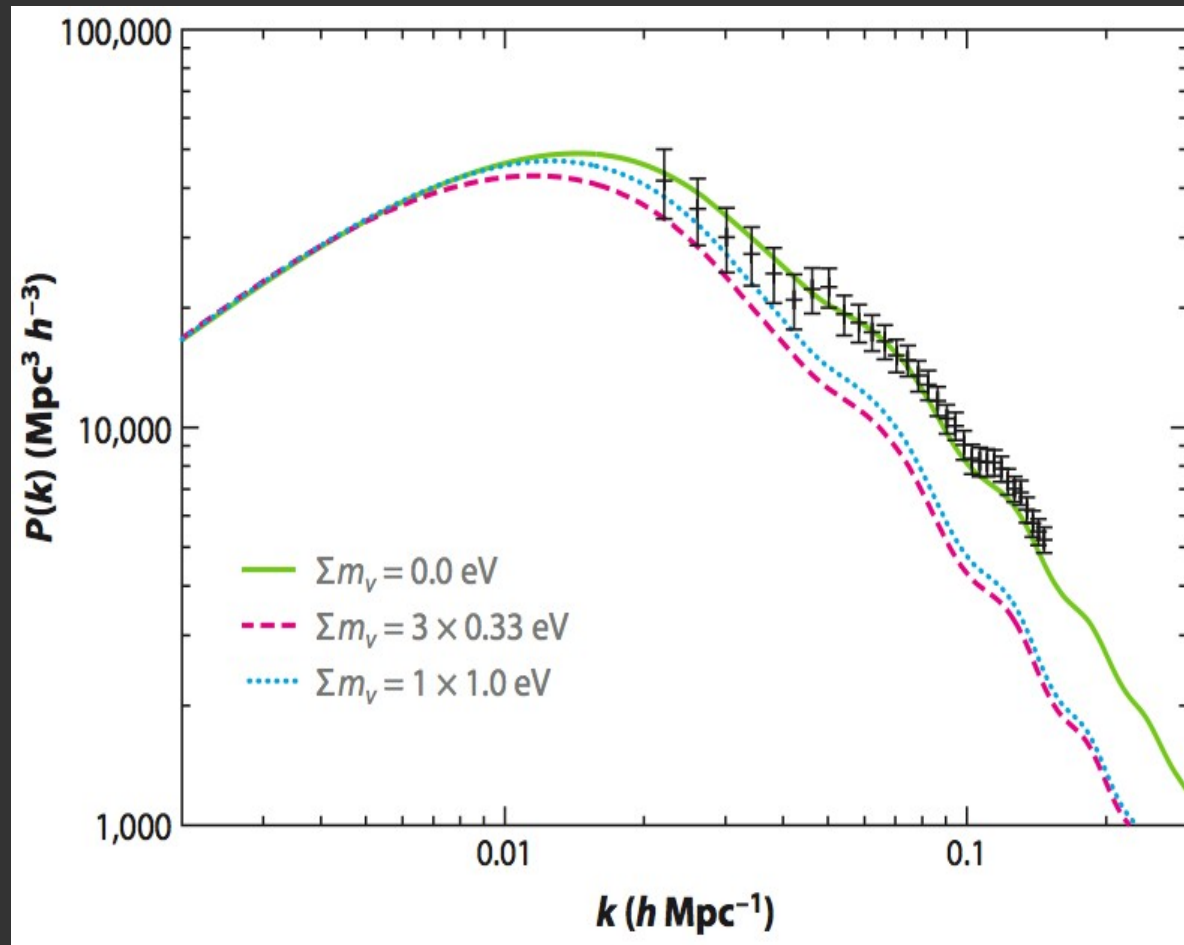


CMB : TT spectrum

Red curve: zero neutrino mass

Green curve:
3 massive neutrinos
With 0.24 eV mass
for each, all other
cosmological parameters
are kept same.

Massive neutrinos

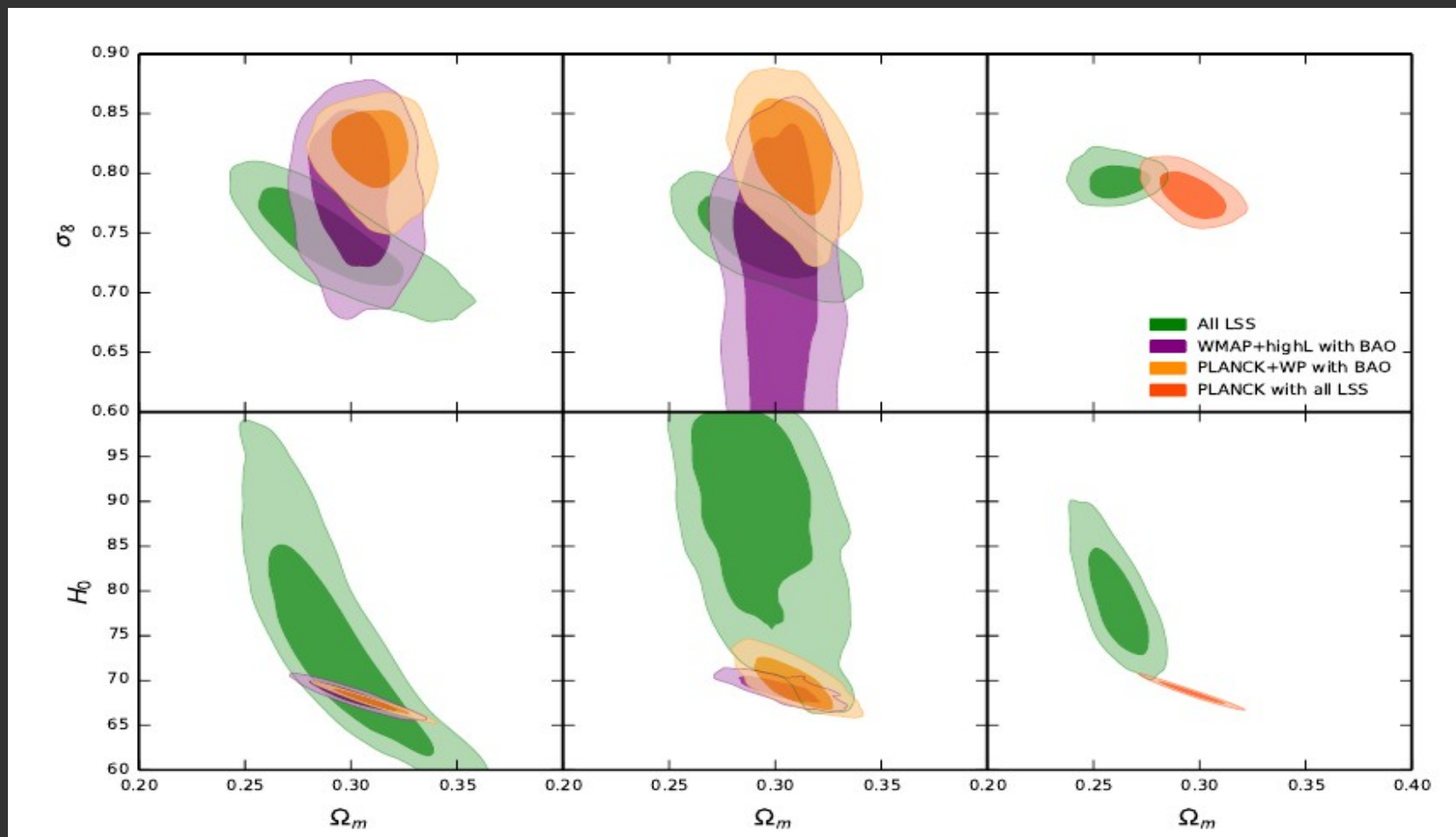


arXiv:1111.1436

Attempts to resolve these tensions

Massive Neutrino

Sterile Neutrino



Richard A. Battye, Tom Charnock, Adam Moss : arXiv:1409.2769

Attempts to resolve these tensions

PRL 112, 051303 (2014)

PHYSICAL REVIEW LETTERS

week ending
7 FEBRUARY 2014



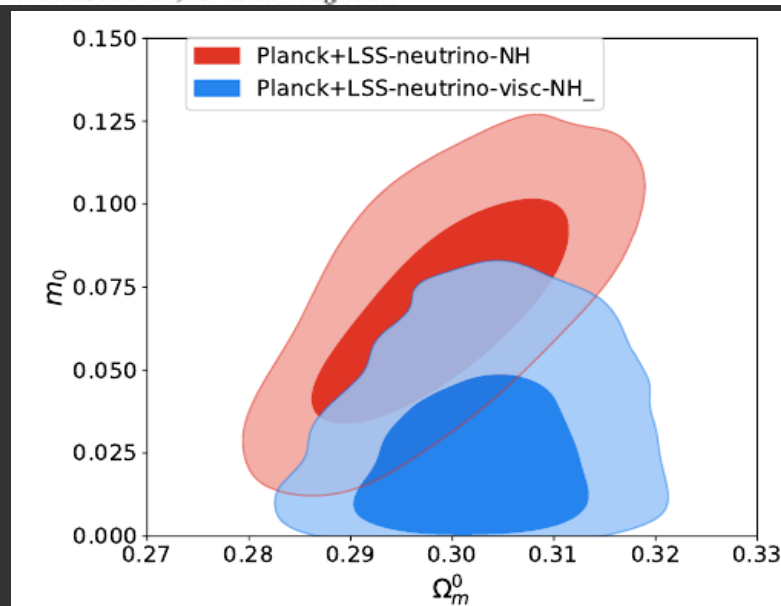
Evidence for Massive Neutrinos from Cosmic Microwave Background and Lensing Observations

Richard A. Battye*

Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom

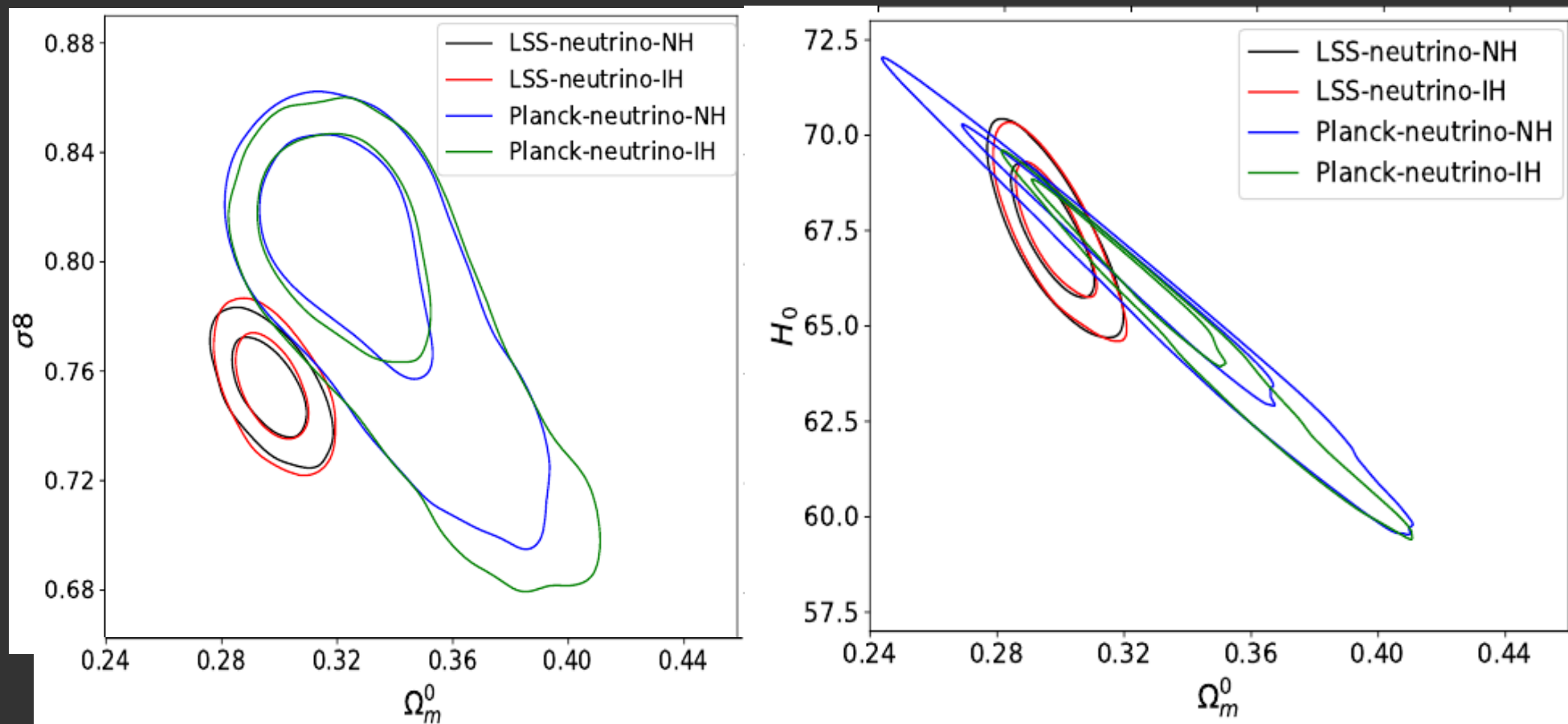
Adam Moss†

Centre for Astronomy & Particle Theory, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom



1712.01254

Attempts to resolve these tensions



arXiv:1712.01254

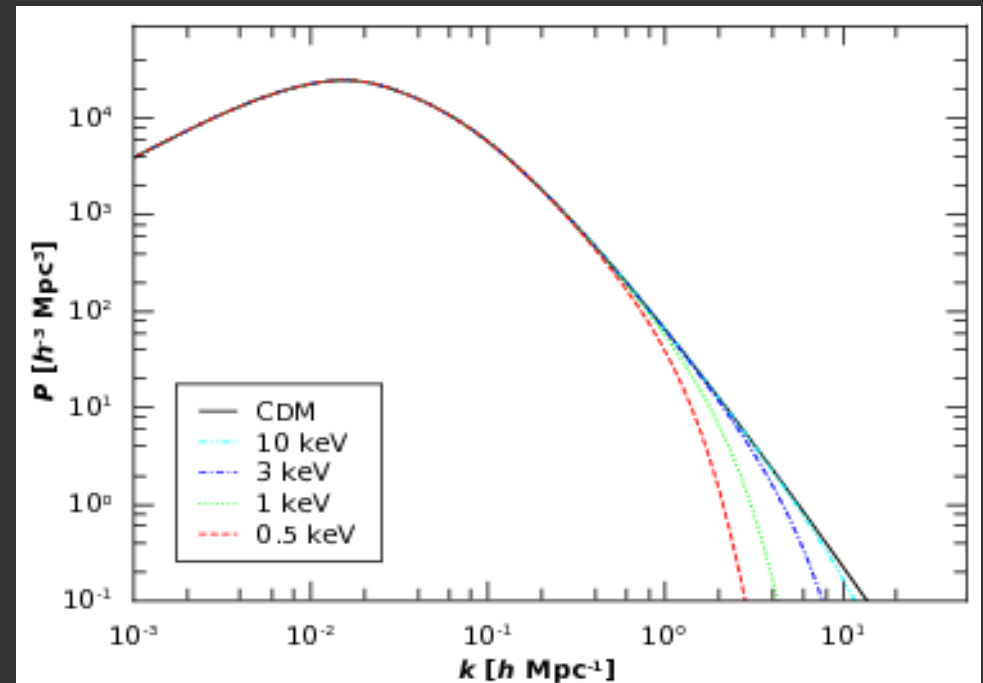
KeV sterile neutrino

- Does not have any effect on CMB
- Only modifies Matter $P(k)$ similarly like **warm dark matter**

Latest Bound

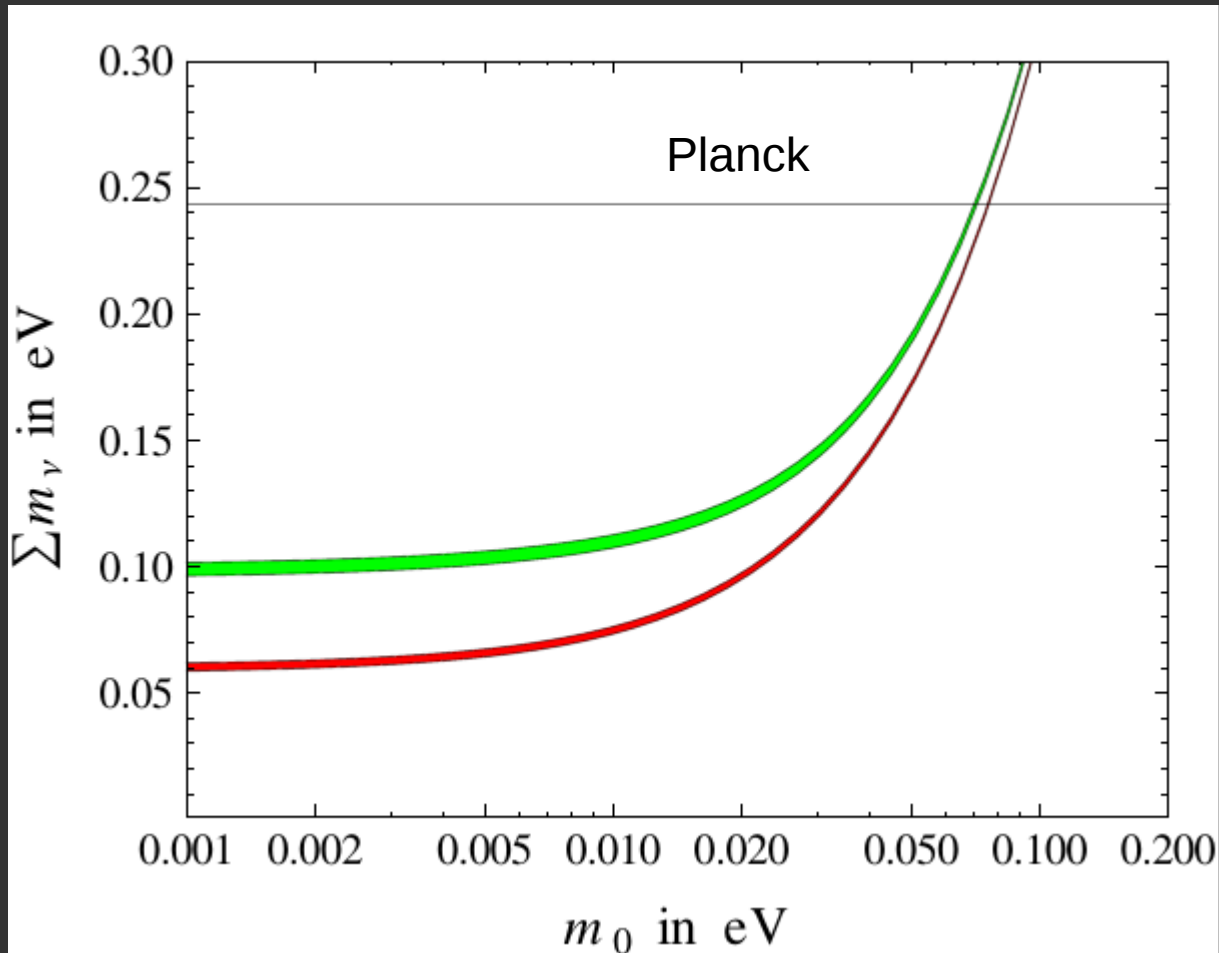
$m > 5.5 \text{ KeV}$

ArXiv:1703.02302



arXiv:1109.6291

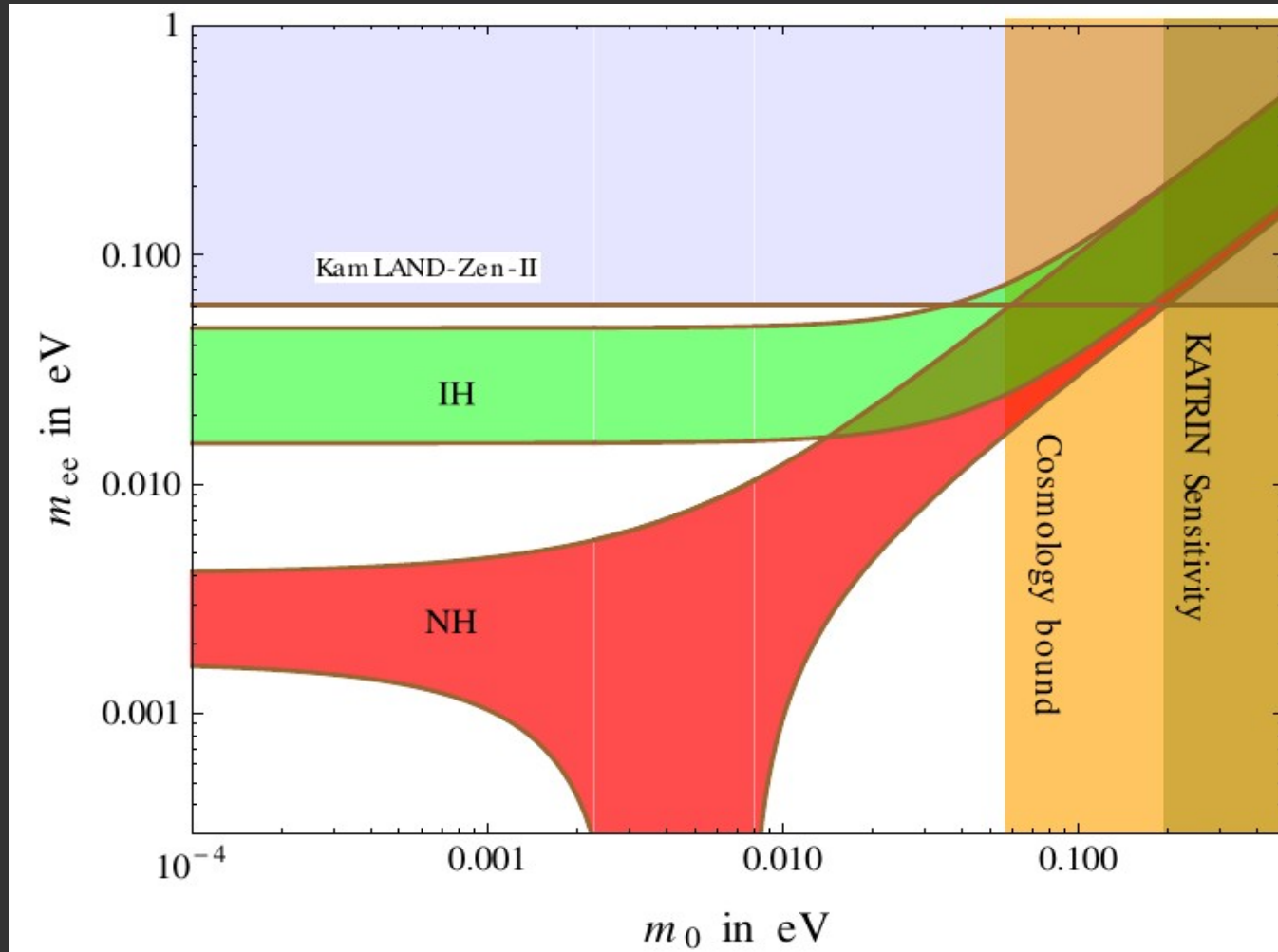
Distinguishing Hierarchy



TT constraint

$$\sum m_\nu < 0.715$$

Neutrinoless double beta decay



Future

- DES result might improve the constraints.
- Nonlinear description of dark matter perturbations, if improved, can also constrain the neutrino mass in a better way.
- Inclusion of exotic physics, like
 - 1) dark-matter neutrino interaction,
 - 2) self-interacting dark matter
 - 3) dark radiation
 - 4) $f(R)$ gravity at late time
 - 5) etc.

All those physics which can affect CMB and LSS can modify neutrino mass bound.

Example

PRL **110**, 121302 (2013)

PHYSICAL REVIEW LETTERS

week ending
22 MARCH 2013



Cosmology Based on $f(R)$ Gravity Admits 1 eV Sterile Neutrinos

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Thank You