Constraints on Neutrino Masses from WMAP5 and CFHTLS

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OUTLINE

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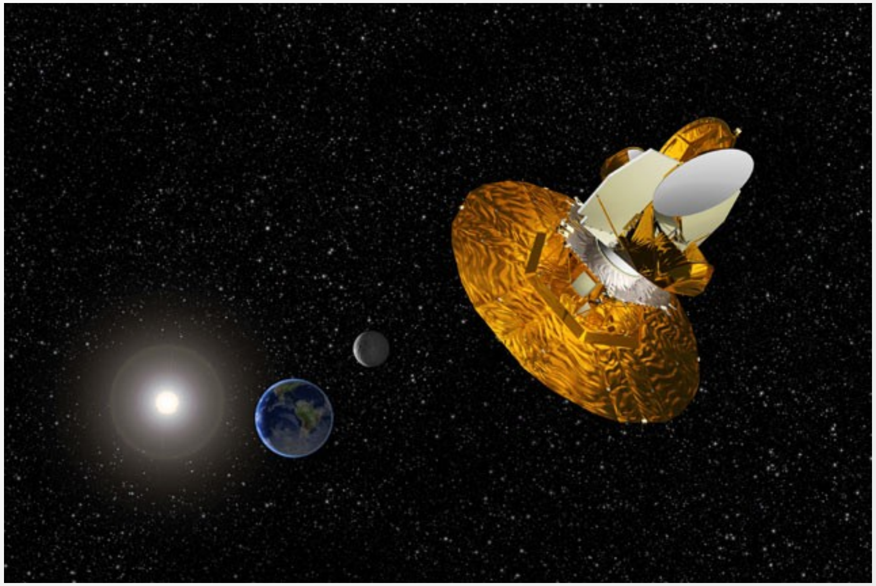
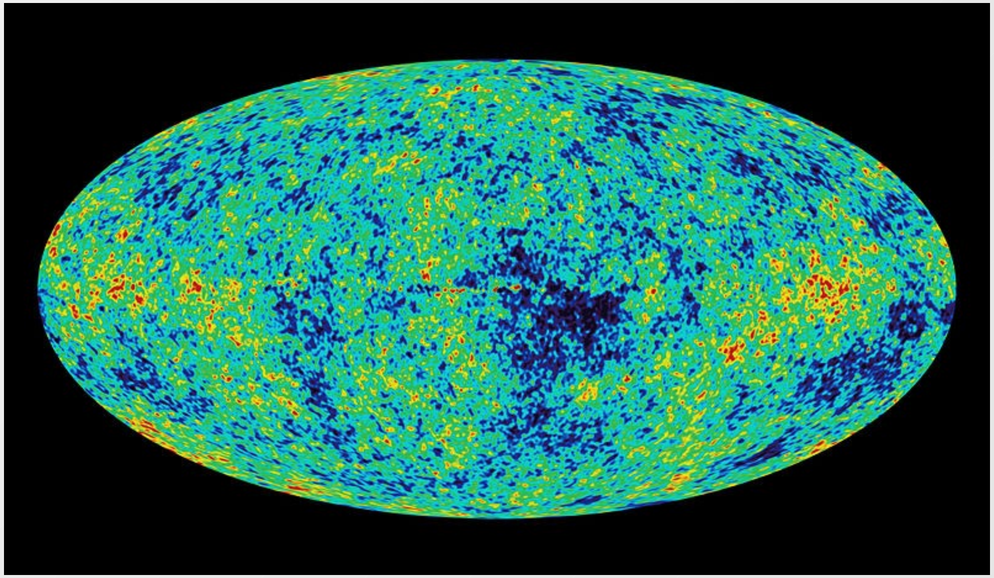
  - cosmological perturbations in the presence of massive neutrinos
  - weak lensing (cosmic shear)
- Constraints on Neutrino Masses from CMB Anisotropies and Cosmic Shear
- Summary

WMAP5 (CMB Anisotropies)

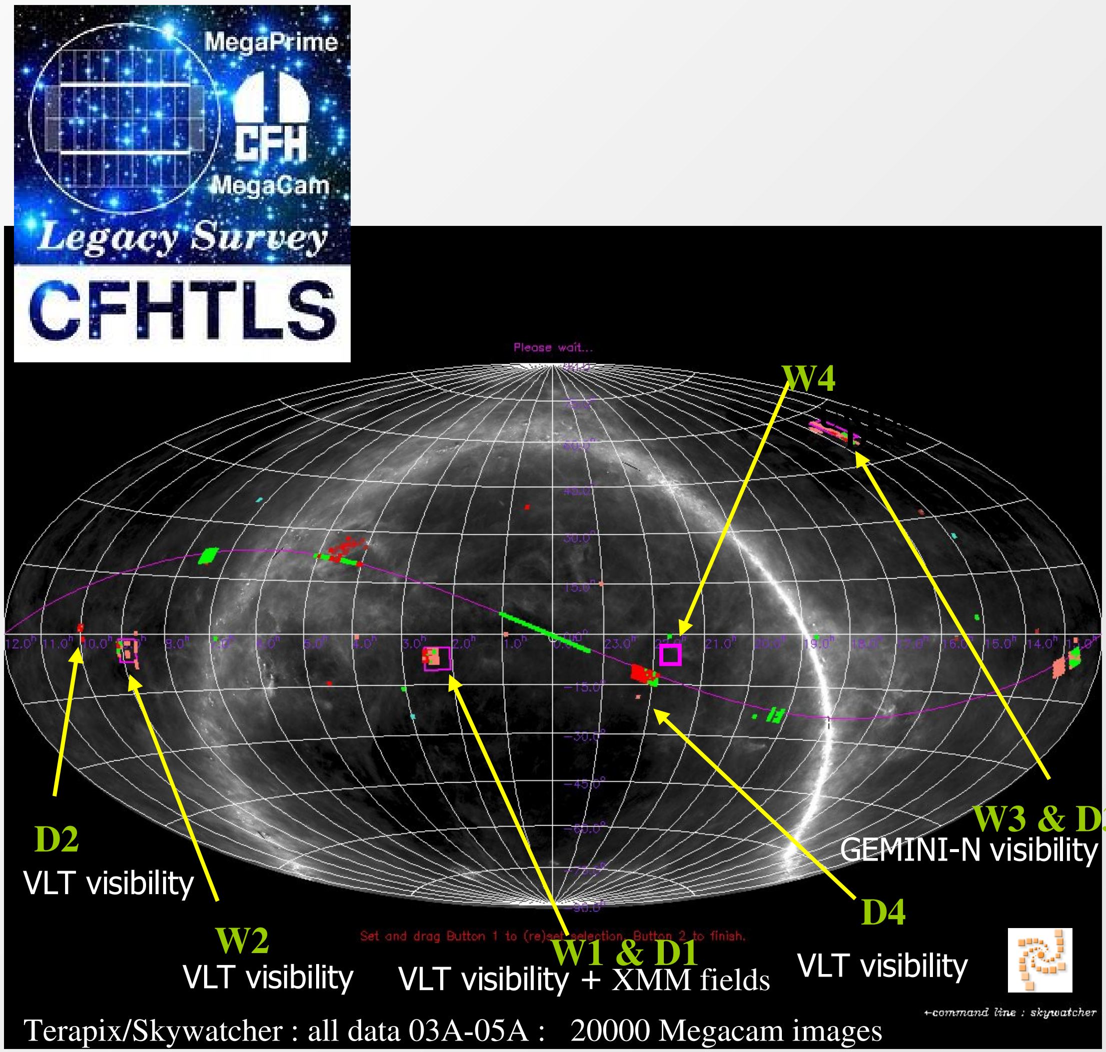


WMAP Team (NASA)



- observing microwave background anisotropies (I, Q, U)
- snap shot of photon's distribution at z=1100 (380,000 yr)
- plenty of information about matter contents of the universe

CFHTLS (Cosmic Shear)



- Canada-France-Hawaii Telescope Legacy Survey
- imaging observation of galaxies of $\mathcal{O}(10^6)$
  - 450 nights over 5 yr
- 2 pt correlation
- photometric redshift in the future

Roles of Massive Neutrinos (MNs) in Cosmology

- MNs contribute to the matter density in the universe
  - change the Matter-Radiation Equality Time
  - change the distance to the CMB surface

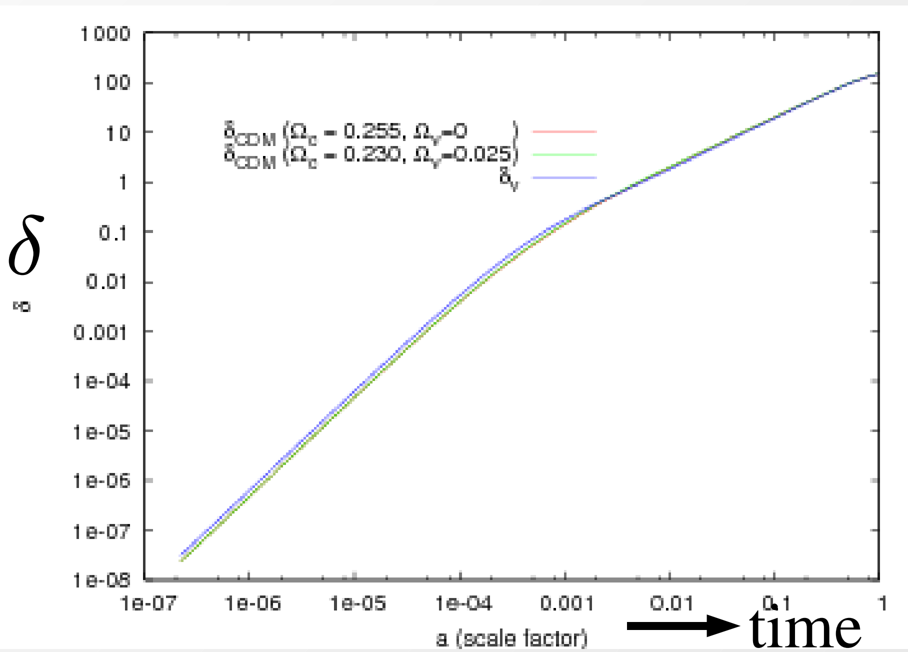
  ---> look at the CMB spectrum (WMAP5)

- Free streaming of MNs slows the evolution of structures in the universe
  - change the amplitude of the matter-power spectrum
  - change the shape of the matter power spectrum

  --->look at the matter power spectrum (CFHTLS)

Evolution of density perturbations in the presence of massive neutrinos

$k = 3.0 \times 10^{-3}\mathrm{Mpc}^{-1}$



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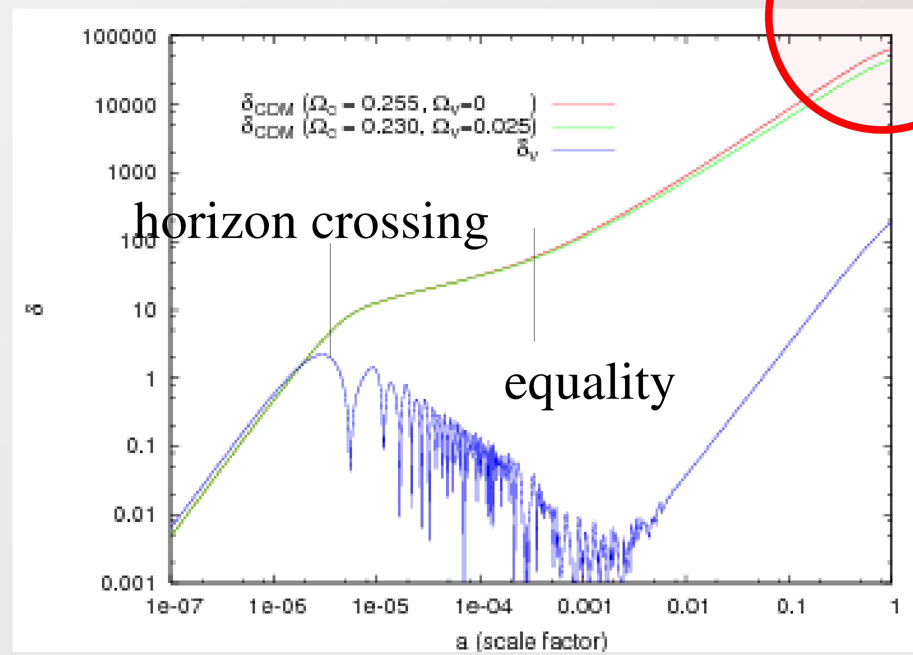


$$\delta(x) = \frac{\delta\rho(x)}{\rho} = \int d^3k\,\delta(k)e^{ik\cdot x}$$ Fourier mode of density fluctuation

$$\ddot{\delta} + 2H\dot{\delta} = 4\pi G\left(\rho_{\rm cdm}\delta_{\rm cdm} + \rho_\nu\delta_\nu\right)$$ at large scales

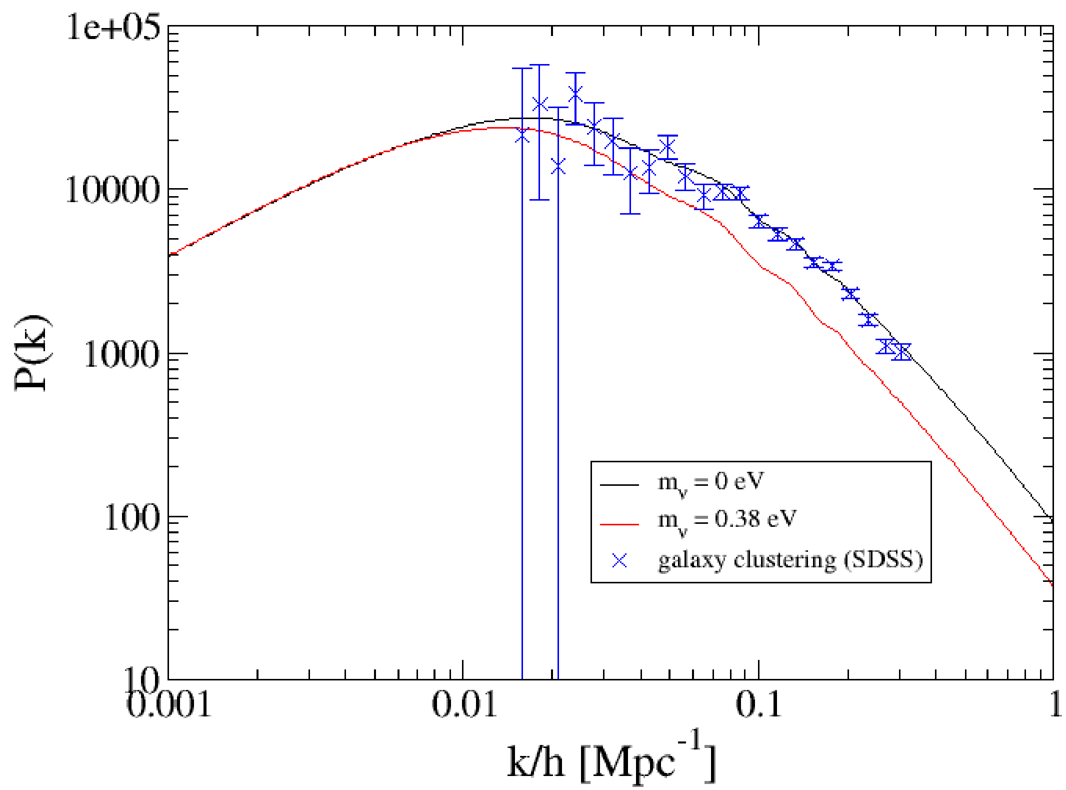
$$\ddot{\delta} + 2H\dot{\delta} = 4\pi G\left(\rho_{\rm cdm}\delta_{\rm cdm} + \rho_\nu\delta_\nu\right)$$ at small scales

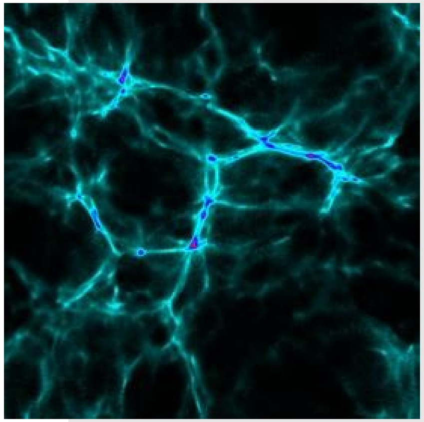
friction due to expansion (marks $2H$)

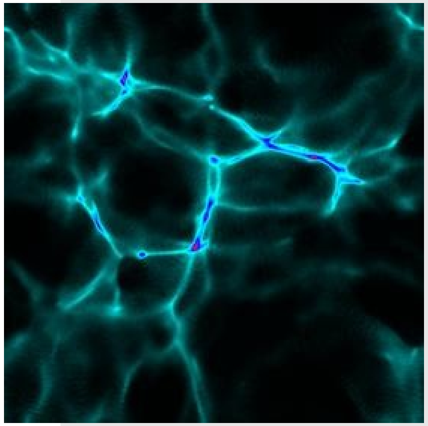
gravitational force (marks $\rho_{\rm cdm}\delta_{\rm cdm}$)

Matter Power Spectrum P(k)

- Power of density fluctuation $P(k) = <\delta\delta>$

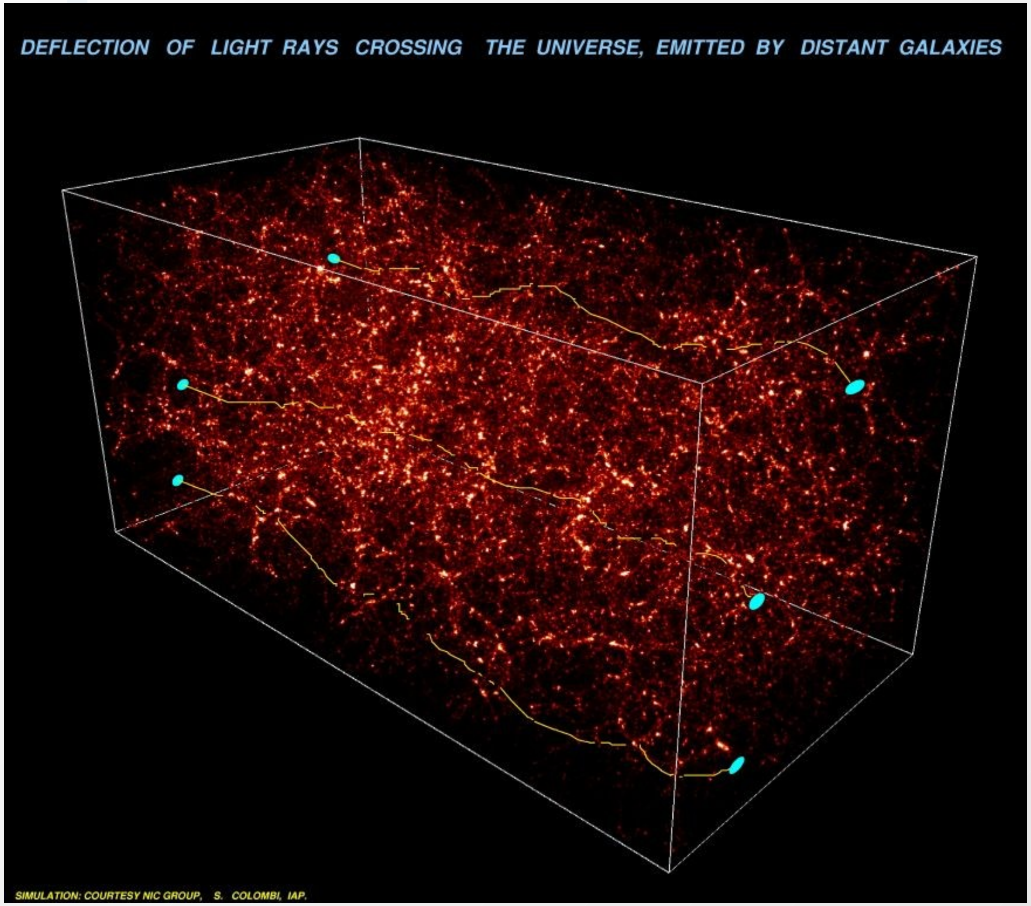


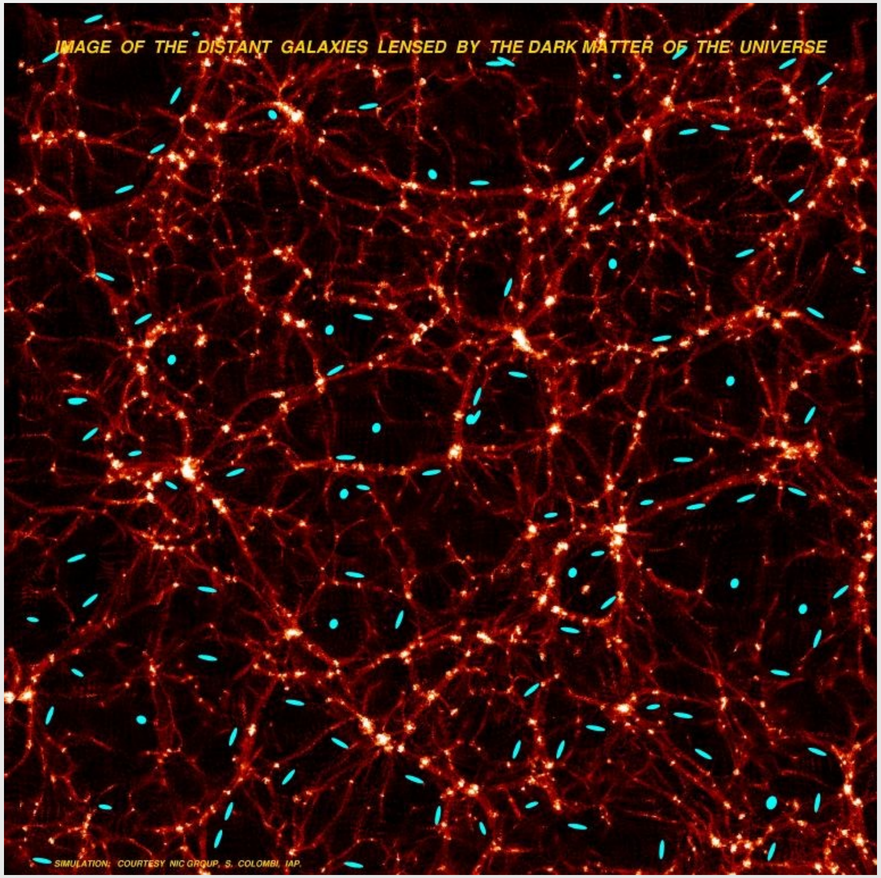




- Neutrinos can not clump below free streaming scale
- --> smaller power at small scales
- power remains the same at large scales

Cosmological Weak Lensing (Cosmic Shear)





- bundles of light from distant galaxies are distorted by intervenning mass structure

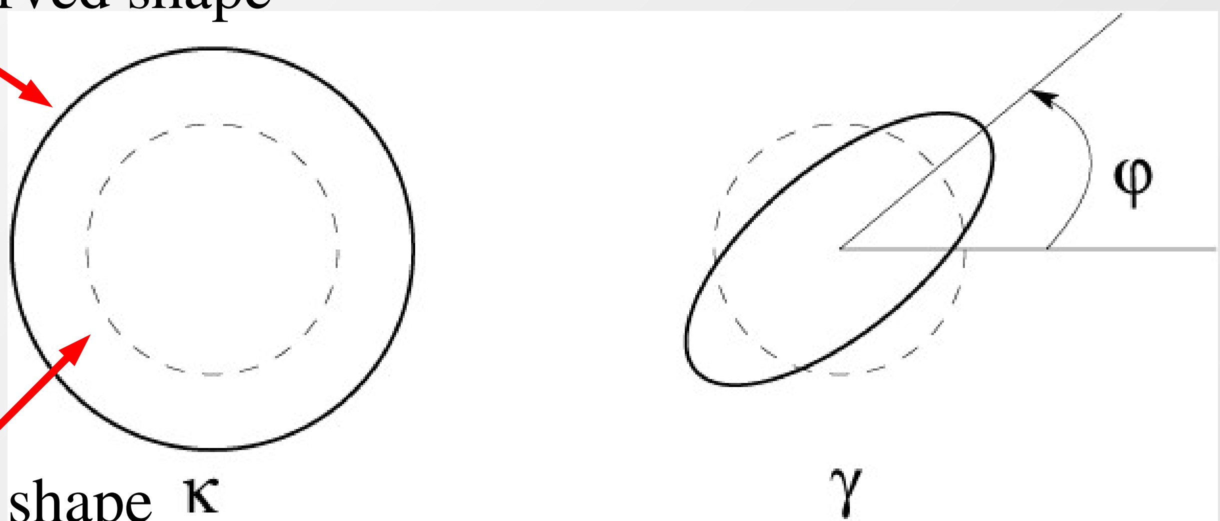
http://www.astro.uni-bonn.de/~webiaef/research/lensing/lenses-3e.shtml

Observable: ellipticity (Shear)

- The distortions can be describd as mapping betwen the source plane(S) and image plane(I)

$$\delta x_i^S = A_{ij} \delta x_j^I \qquad A_{ij} = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

observed shape



intrinsic shape

$$\gamma_1 = |\vec{\gamma}| \cos 2\varphi$$
$$\gamma_2 = |\vec{\gamma}| \sin 2\varphi$$
$$\gamma = \frac{a-b}{a+b}$$

- Convergence κ is difficult to be measured.
  Shear γ is easier.

Link between Theory and Observation

Observation: Two-point correlation function

$$\xi(\theta) = \left\langle \gamma(\vec{r})\gamma^*(\vec{r}+\vec{\theta}) \right\rangle$$

Theory: the lensig power spectrum

distribution of galaxy

$$P_\kappa(\ell) = \frac{9}{4}\Omega_m^2 \left(\frac{H_0}{c}\right)^4 \int \frac{d\chi}{a^2(\chi)} P_\delta\left(\frac{\ell}{\chi};\chi\right) \times \left[\int_\chi^{\chi_{lim}} d\chi' n(\chi') \frac{\chi'-\chi}{\chi'}\right]^2$$

power of density fluctuation

These two are related through the relation

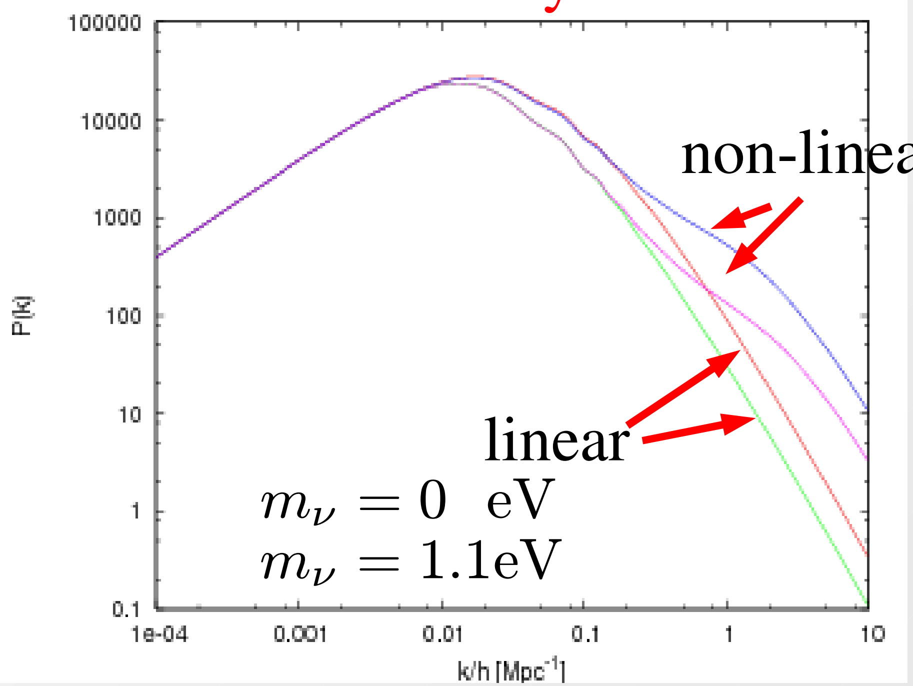
$$\xi(\theta) = \int \frac{\ell d\ell}{2\pi} P_\kappa(\ell) J_0(\ell\theta)$$

Non-linear effect (1)

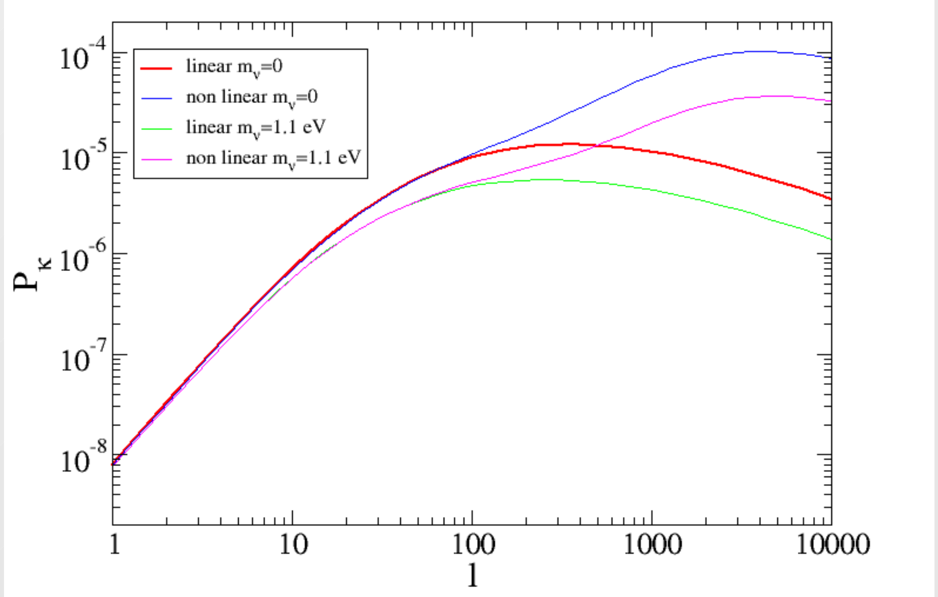
- perturbation theory breaks down when $< \delta^2 > \sim k^3 P(k) \sim 1$
- fitting fomulae calibrated with LCDM N-body simulation:

$$^{NL}P(k,z) = f(^{L}P(k,z)) \quad \text{e.g., Smith et al., (2003)}$$

Power of density fluctuation



Lensing power spectrum

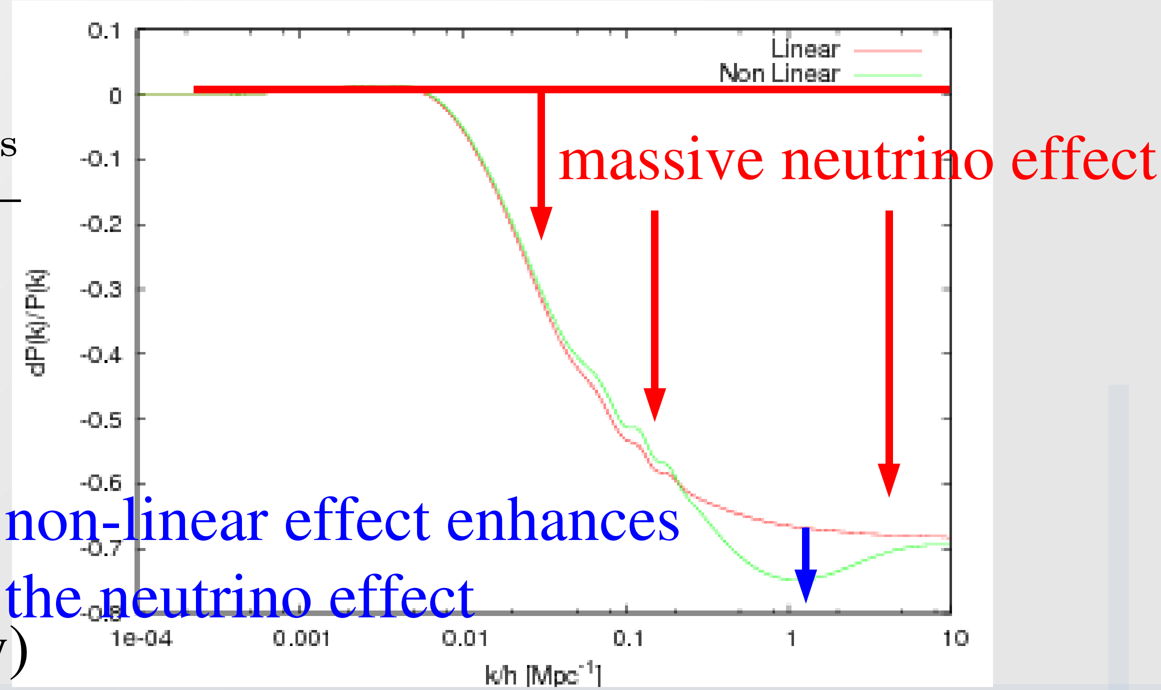


Non-Linear effect (2)

- Baryon and Dark Matter go into nonlinear regime while Neutrino stays almost linear
- So we model the P(k) as (Hannestad, 2006)

$$P(k) = \left[f_\nu \sqrt{P_\nu^L(k)} + (f_b + f_c) \sqrt{P_{b+c}^{NL}(k)} \right]^2$$

$$\frac{P^{\rm massive} - P^{\rm massless}}{P^{\rm massless}}$$



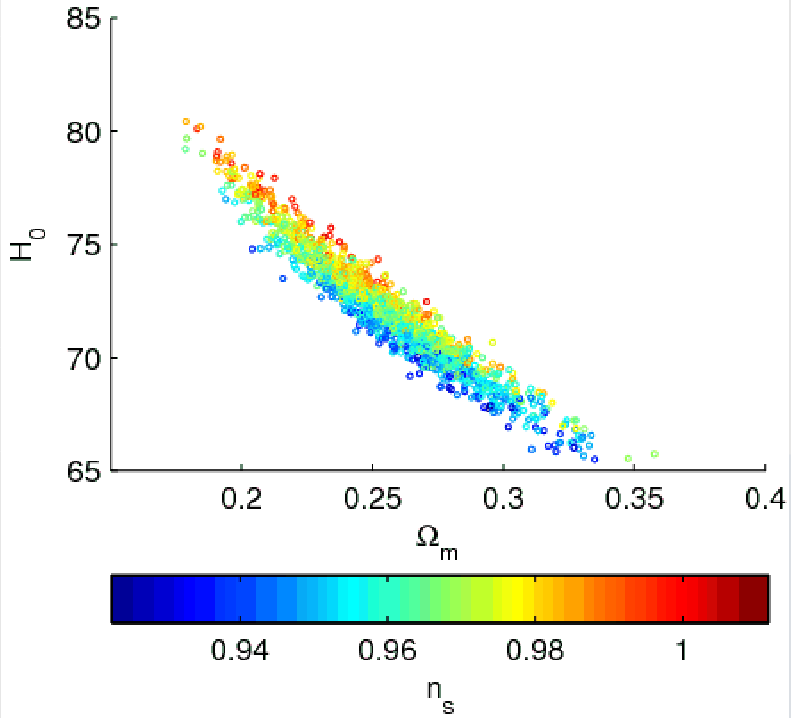
This should be checked by N-body simulations including massive neutrinos. (Saito's Talk today) ⟸

MCMC likelihood analysis

- cosmological parameters (7 params)

$$\vec{P} = (\Omega_b h^2, \Omega_c h^2, \theta, \tau, m_\nu, n_s, A_s)$$

- explore the likelihoods of WMAP5 and CFHTLS data using Markov Chain Monte Calro sampling

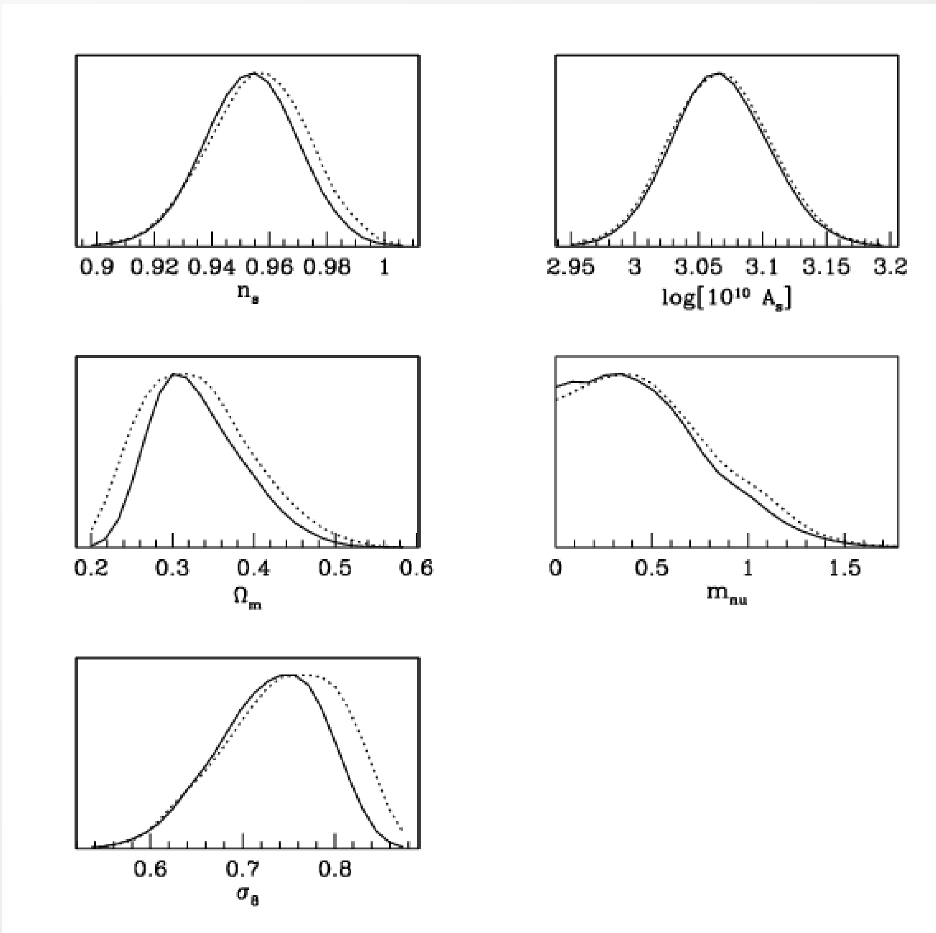


- CosmoMC:
  Cosmological MCMC engine

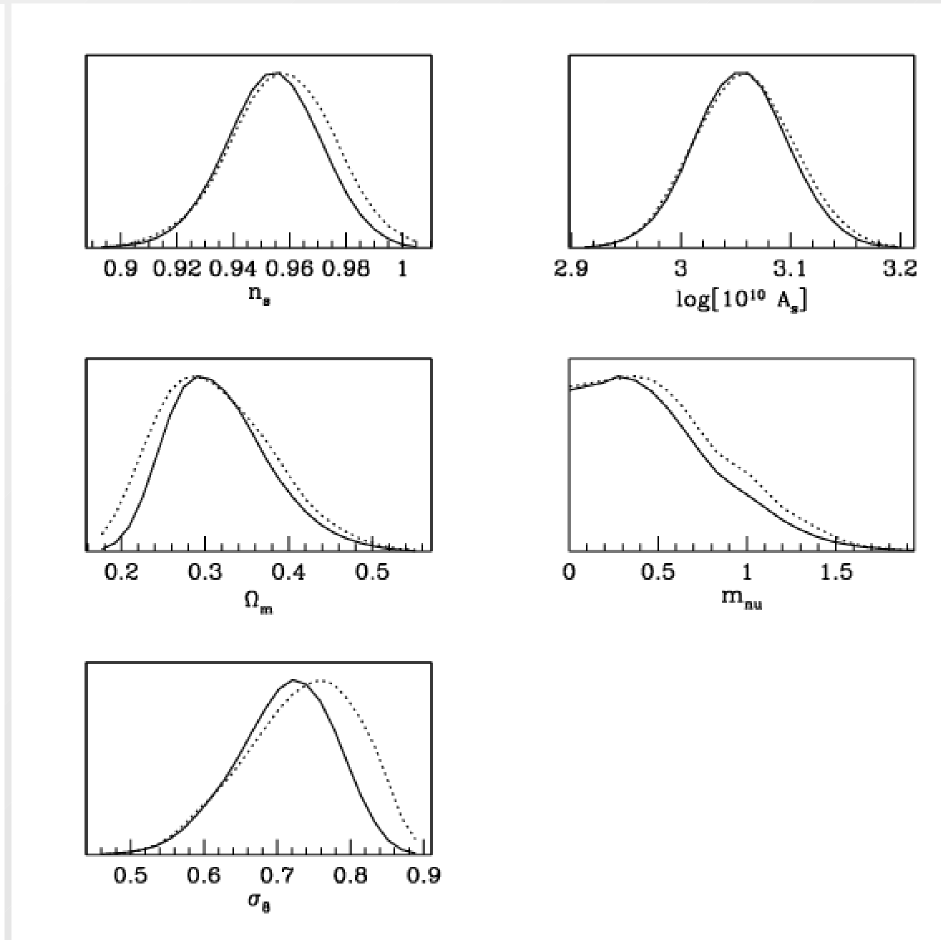
(http://cosmologist.info/cosmomc)

1D probability distributions

- WMAP5+CFHTLS

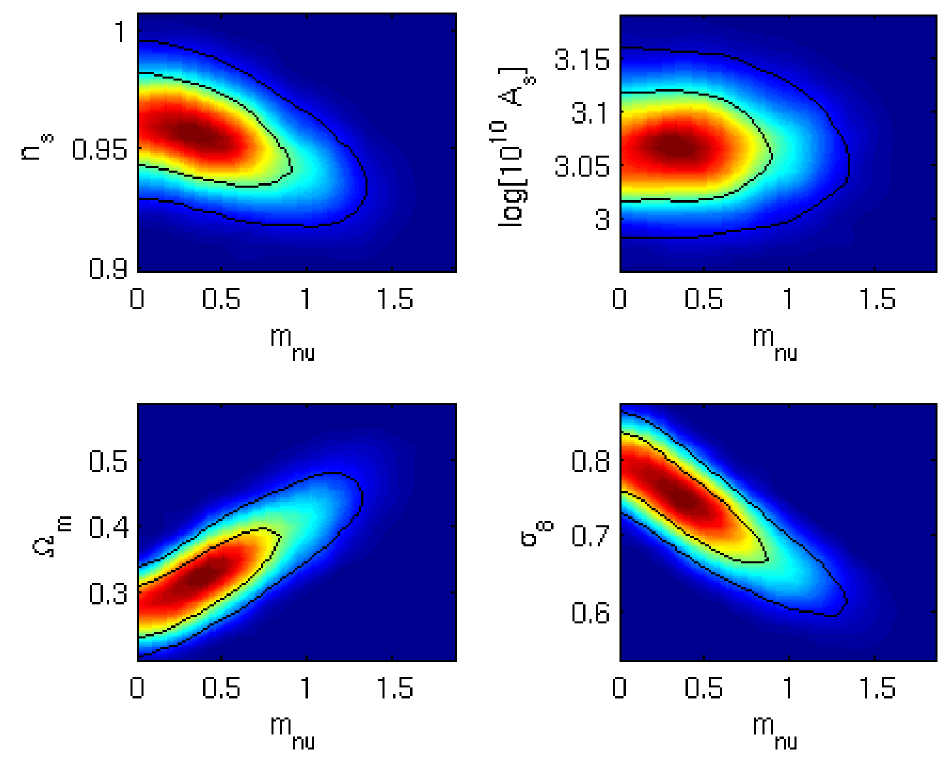


- WMAP5 only

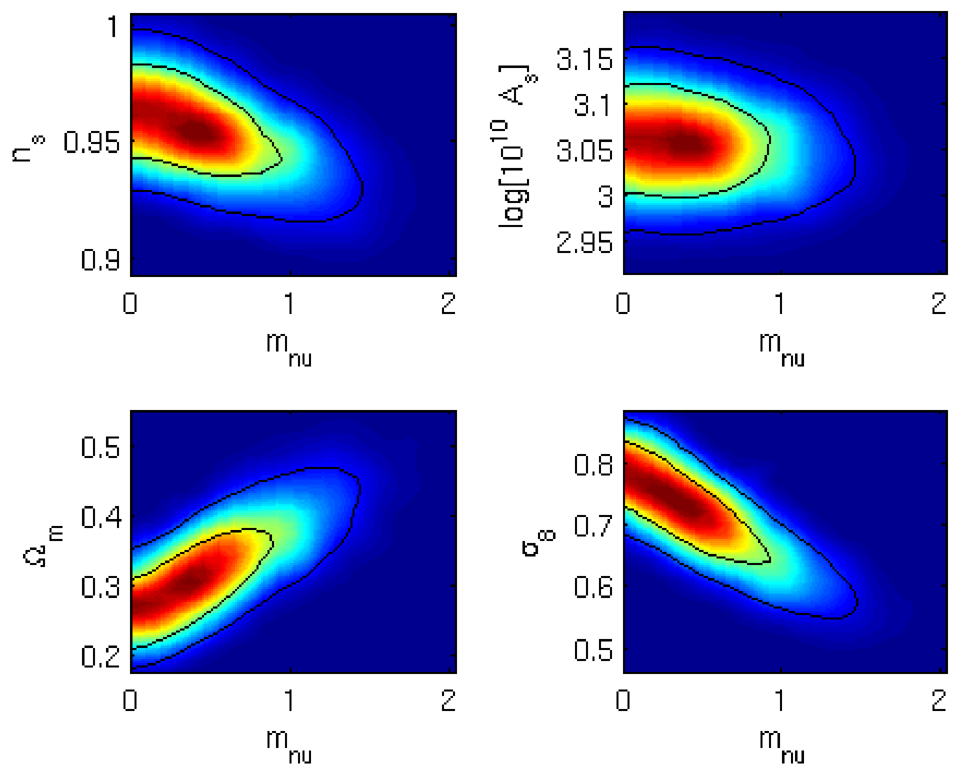


2D probablity distributions

- WMAP5+CFHTLS

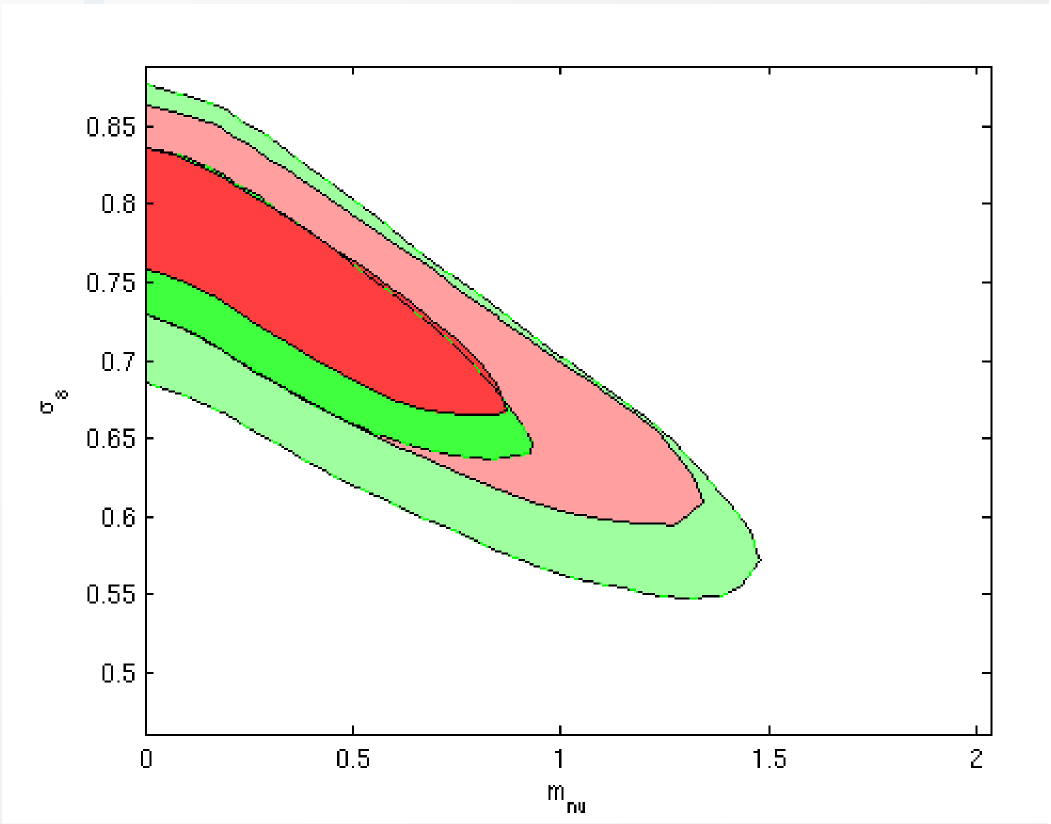


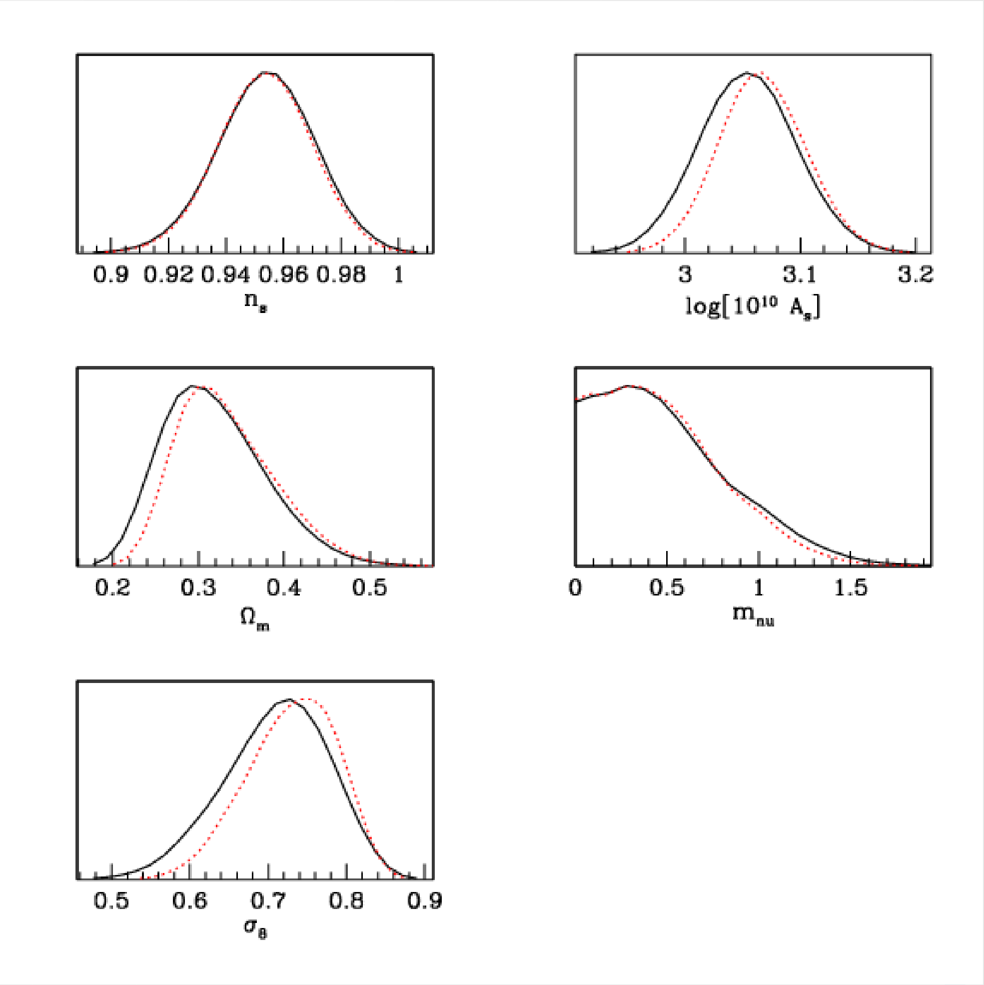
- WMAP5



Comparison of the results

- Green (WMAP5), Red(+CFHTLS)

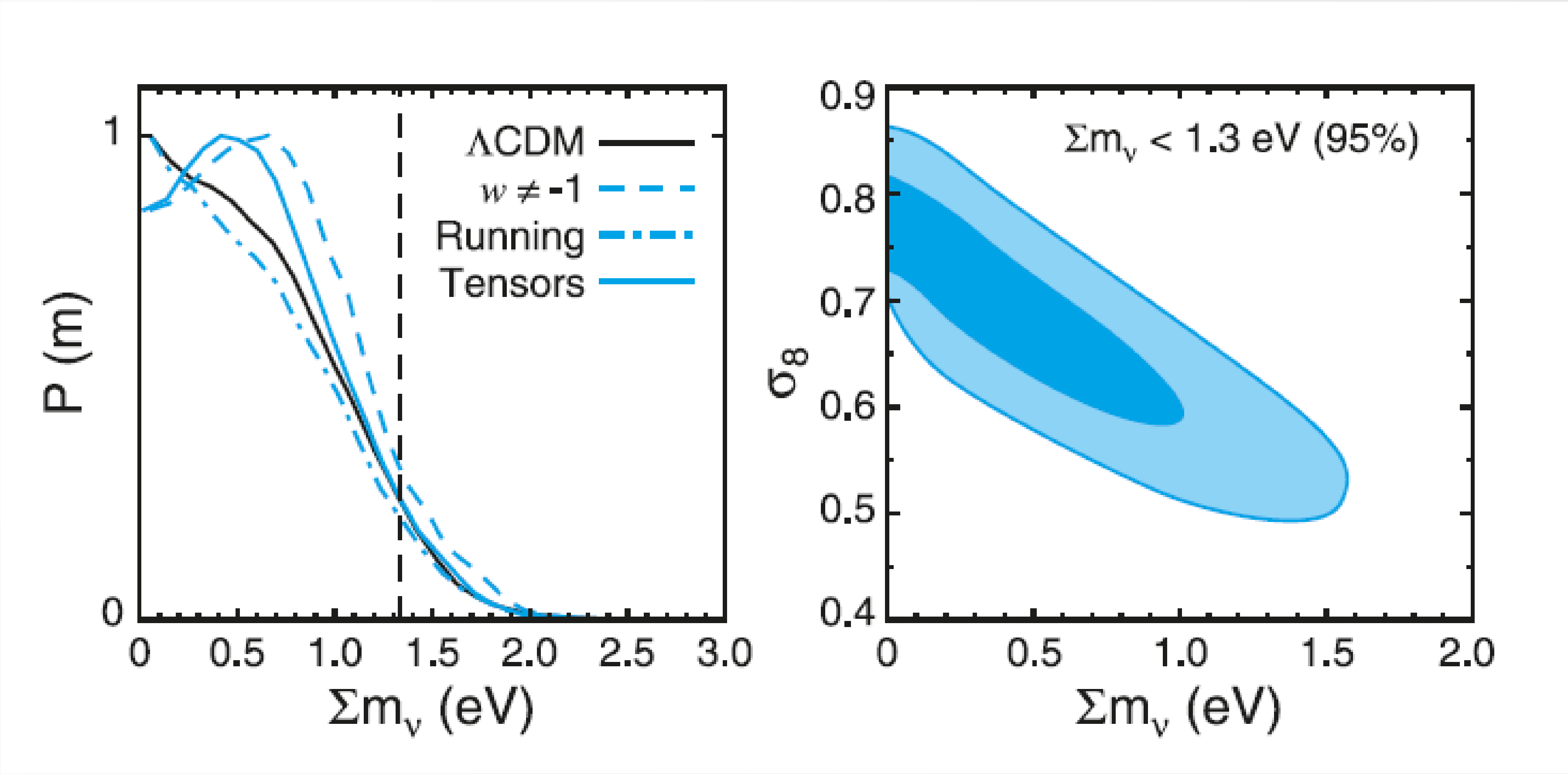




WMAP5 -- $m_\nu < 1.2$ eV

WMAP5+CFHTLS -- $m_\nu < 1.1$ eV

WMAP5 official release



Dunkley et al., 2008

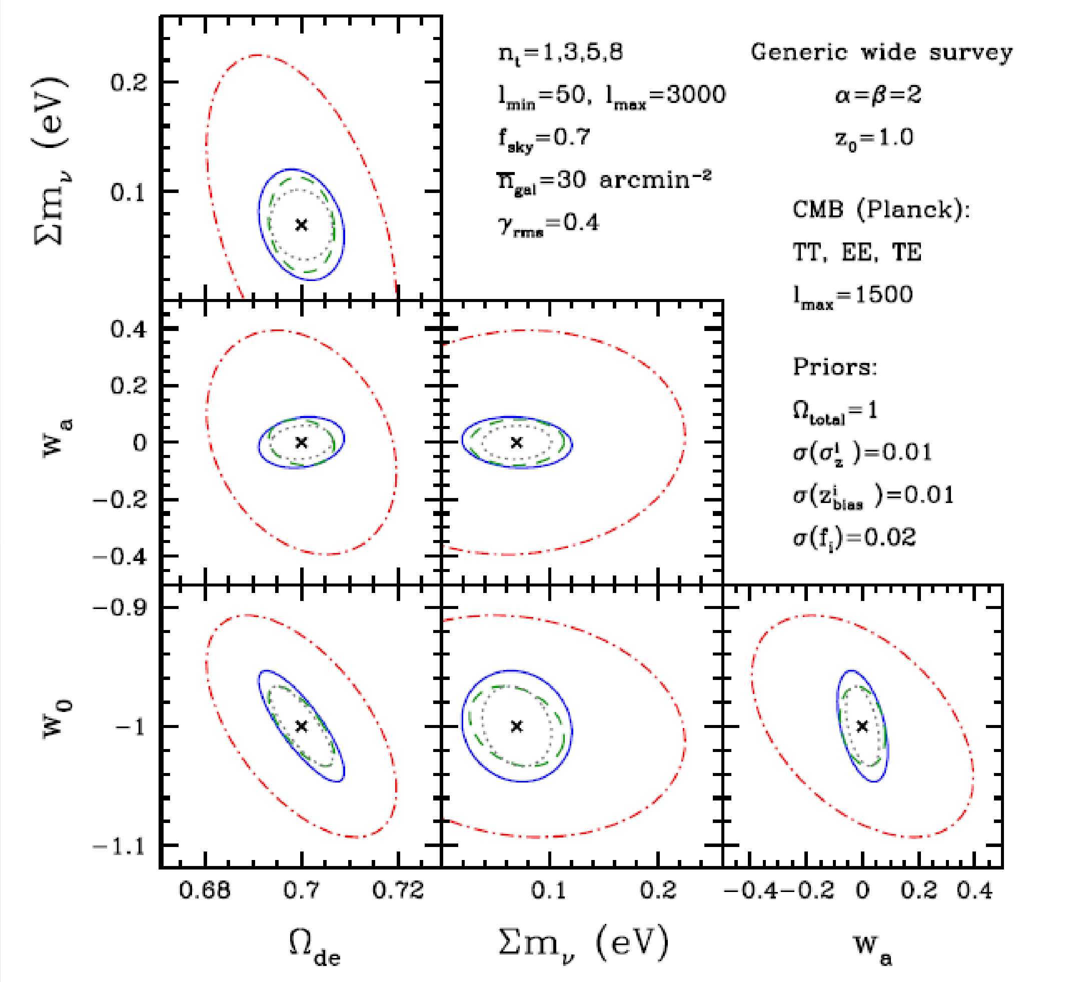
- our results are almost consisntent with WMAP5
- I think the small diff is due to SZ marginalization

Future: weak lensing tomography

- photometric redshift about source galaxies will give us additional information on the growth of structure

$$\sigma\left(\sum m_\nu\right) \lesssim 0.05\text{eV}$$

(Hannestad, JCAP 0606, 2006)



Summary

- massive neutrinos alter the shape and amplitude of the matter power spectrum
- Current weak lensig data is still weak:
  - $\sum m_\nu < 1.2\ \mathrm{eV}$ (WMAP5)
  - $\sum m_\nu < 1.1\ \mathrm{eV}$ (+CFHTLS)
- future weak lensing survey will put the constraint down to 0.05 eV.