neutrino and cosmology

- Phenomenology
- Observational constraints
- Perspectives

- Lesgourgues & Pastor 2006, Phys. Rep. 429, 307
- Shoji & Komatsu 2010, arXiv:1003.0942
- Komatsu 2011, ApJS, 192:18 (WMAP7 analysis)
- De Putter at al. 2012, arXiv:1201.1909 (SDSS-III)
- Xia et al. 2012, arXiv:1203.5105 (CFHTLS)
- Benson et al. 2011, arXiv:1112.5435 (SPT clusters)
- Viel et al., JCAP06 (2010) 015 (Lyman-α)
- Seljak et al., JCAP10 (2006) 014 (Lyman-α)

Jean-Marc Le Goff

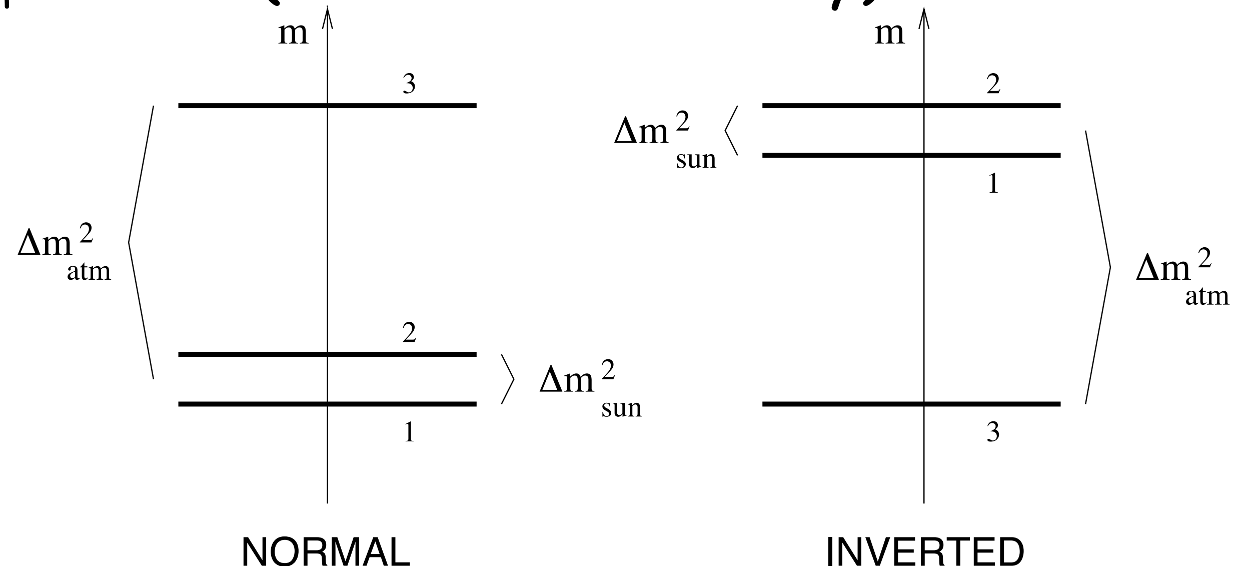
cosmo-club, may 2012

direct constrains on neutrino masses

- ν oscillations :

  Δm_{12}^2=7.58 10^{-5} eV^2 (solar)

  Δm_{23}^2=2.43 10^{-3} eV^2 (atmospheric)
- tritium β decay $m(\nu_e) < 2$ eV (95% CL)
- 0.056 eV $< \Sigma\, m_i <$ 6 eV (normal hierarchy)
- 0.095 eV $< \Sigma\, m_i <$ 6 eV (inverted hierarchy)



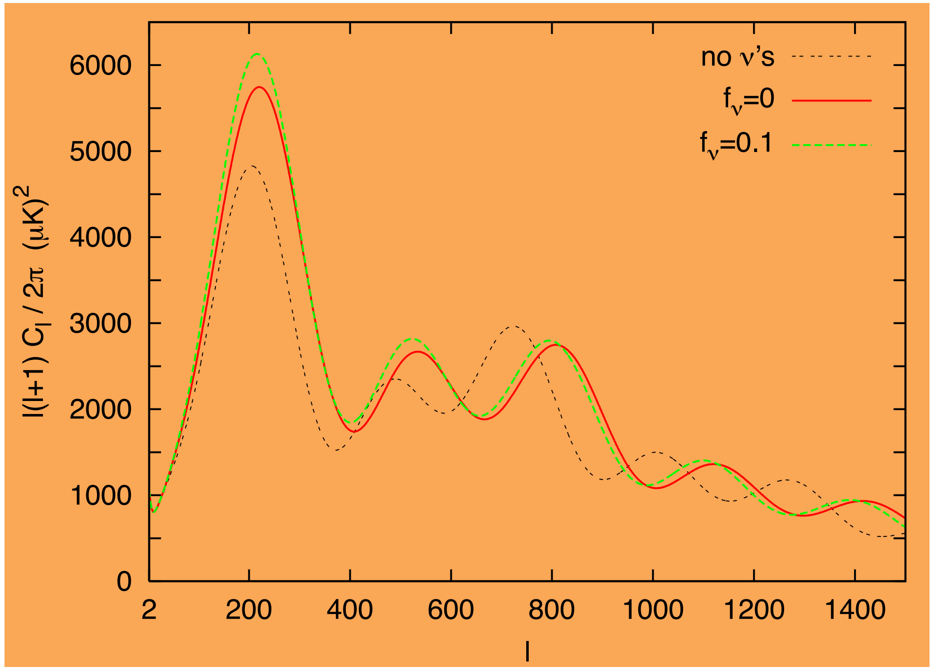
ν phenomenology in cosmology

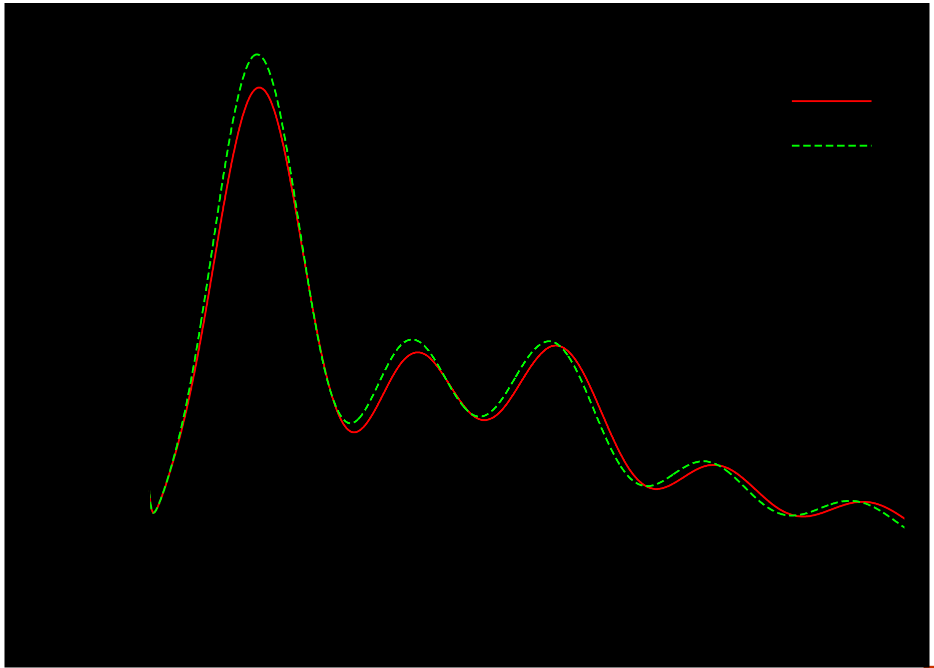
cosmic neutrino background

- high T : ν in equilibrium
- T < 1 MeV : ν decouple -> $\rho_\nu^{comobile}$ = cst
- T < m_e e^+e^- annihilation heat up the γ
- $T_\gamma / T_\nu = (11/4)^{1/3} = 1.40$ $\quad$ $n_\nu = (3/11)\, n_\gamma = 113\ /cm^3$
- $$\rho_R = \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{eff}\right]\rho_\gamma$$
- some e^+e^- -> $\nu\,\bar{\nu}$ so $N_{eff} = 3.046$
- $$f_\nu = \frac{\Omega_\nu}{\Omega_m} = \frac{\sum m_i}{\Omega_m h^2 \times 94.1 eV} \approx \frac{\sum m_i}{13.3 eV}$$

Effect on CMB

- existence of CνB significantly changes CMB
- if $f_\nu < 0.1$ (Σm_i<1.3 eV) : ν NR after decoupling
  only indirect effect: changes $t_{eq} \sim 1/(1-f_\nu)$





m_ν and density fluctuations

- high z : δ_b δ_γ oscillate, δ_{cdm} grows logarithmically, relativistic ν "free stream" over all scales: $\delta_\nu \approx 0$
- z< z_{eq} : δ_{cdm} grows linearly
- z=1090 : δ_b starts to grow
- when z < z_{nr} = 1890 (m_ν /1eV) : ν non relativistic

  free streaming length

  large scales $\delta_{CDM} \propto a$

  small scales $\delta_{CDM} \propto a^{1-0.6 f_\nu}$ $f_\nu = \frac{\Omega_\nu}{\Omega_m}$

Effect on different scales

small scale modes

$\delta_\nu \approx 0$

$\delta_{CDM} \propto a^{1-0.6 f_\nu}$

z=1090 to z=0

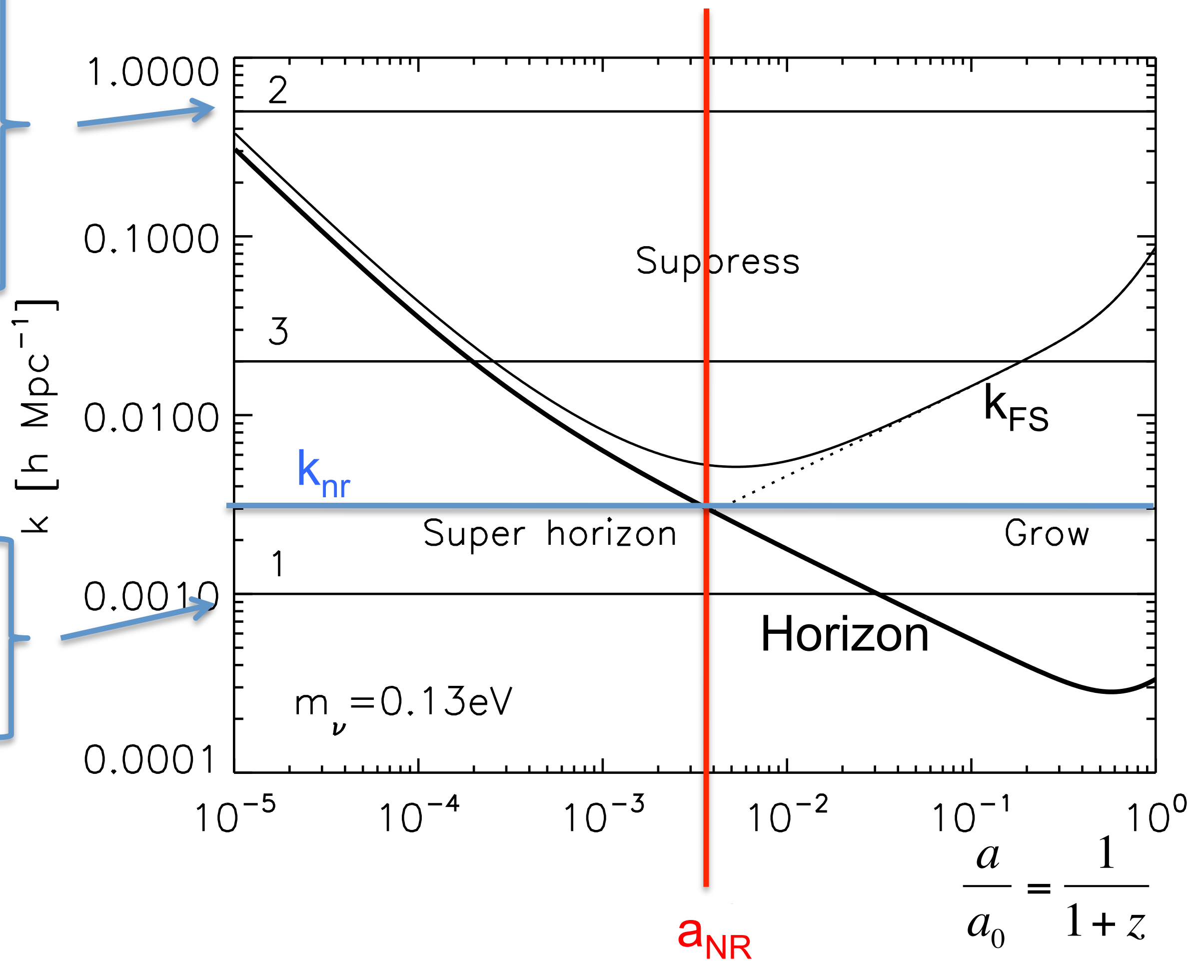
-> $\Delta P(k) = -8 f_\nu P(k, m_\nu = 0)$

large scale modes ($k < k_{nr}$)

$\delta_\nu \approx \delta_{cdm}$

P(k) not reduced by m_ν

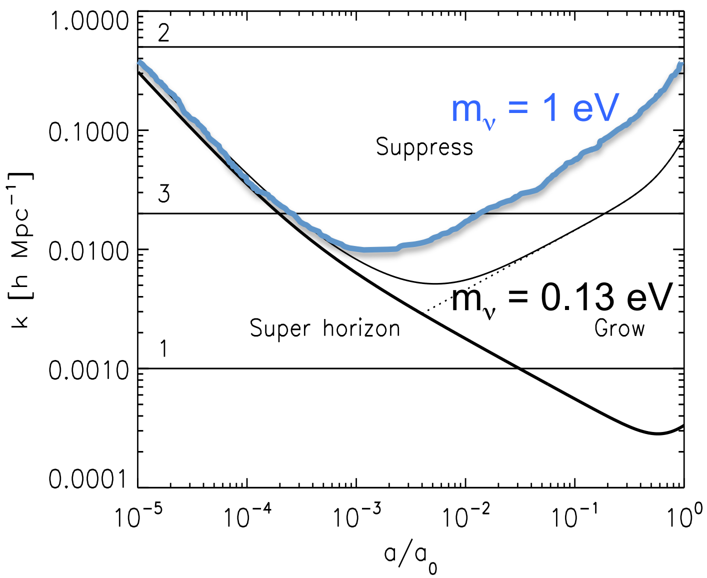
(Shoji & Komatsu 2011)

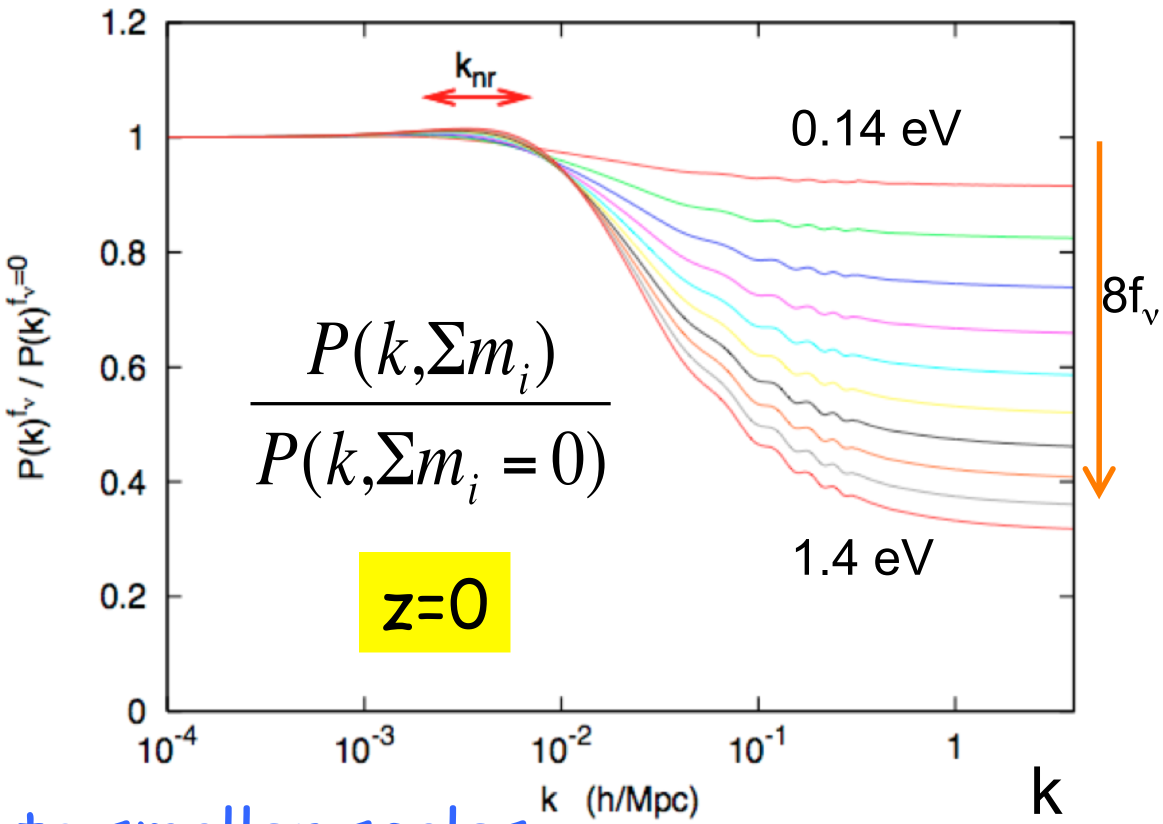


$\frac{a}{a_0} = \frac{1}{1+z}$

Resulting P(k,z=0)

When m_ν increases :





k_{nr} increases

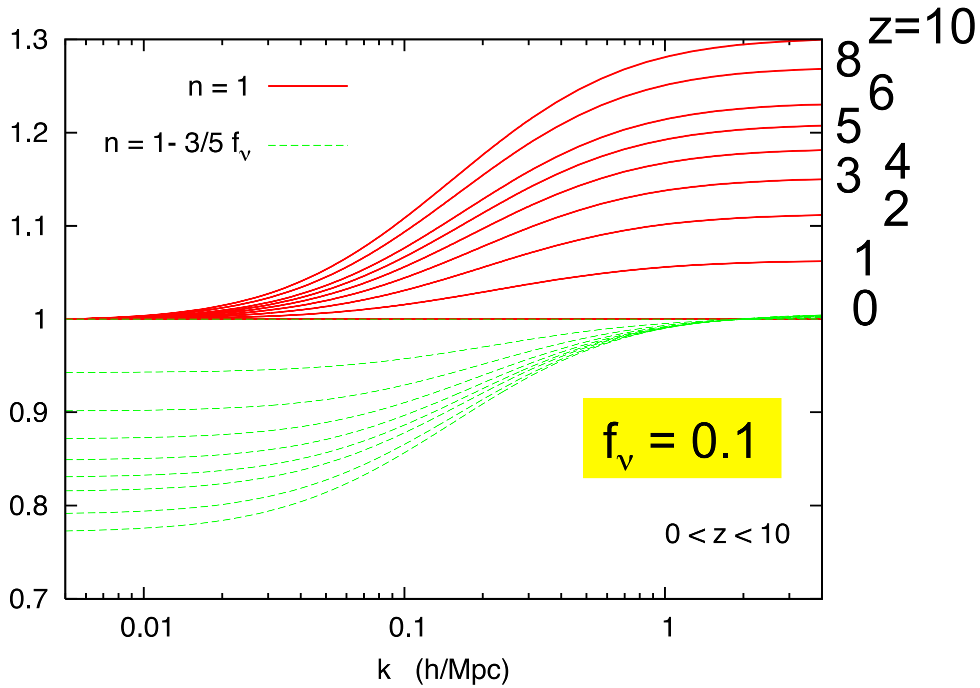
$|\Delta P/P| = 8\ f_\nu$ increases

more effect but limited to smaller scales

z dependence

- due to ν shape of P(k) is z dependent

$$\frac{P(k,z)}{D^{2n}(z) \times P(k,0)}$$



degeneracies

CMB

- ok with minimal 7 parameter cosmological model
- Ω_k or N_{eff} create degeneracy -> requires LSS

LSS

- depends on k and z range

if only access to transition region, degenerate with n_s

Note: difference between 3 identical masses, normal and inverted hierarchies is only 0.1% on P(k)

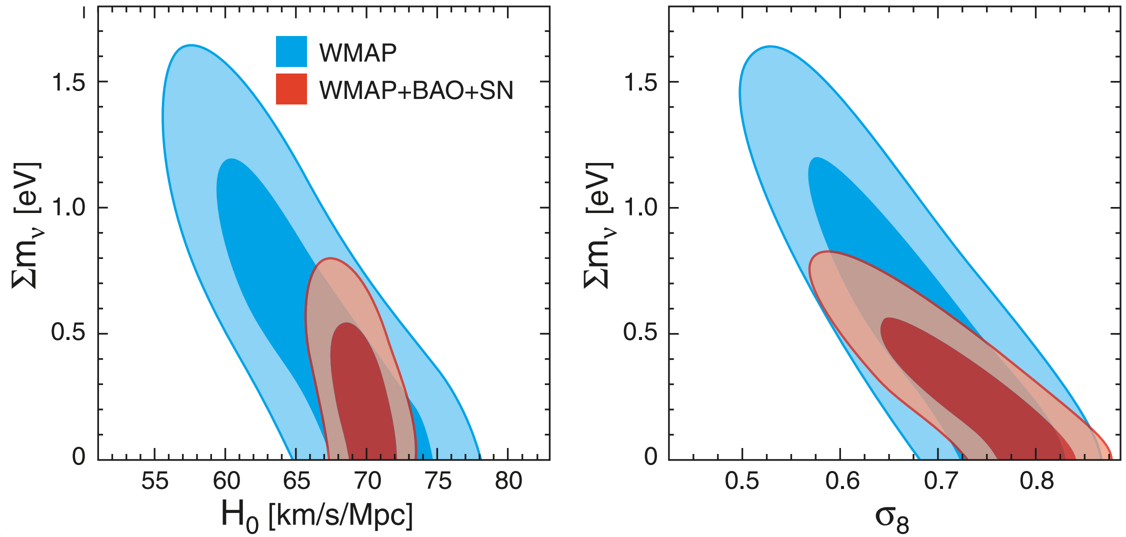
Observational constraints

CMB + distances

- WMAP7 alone: Σ m_i < 1.3 eV for w=-1 (< 1.4 for w≠-1)
- WMAP7 + BAO + SN : Σ m_i < 0.71 eV (0.91)
- WMAP7 + BAO + H_0 : Σ m_i < 0.58 eV (1.3)

BAO+SN needed to remove anticorrelation Σ m_i and w

(Komatsu et al. 2011)



- independent measurement of σ_8 would help a lot

CMB + LSS

cluster data N(z) -> σ_8 and Ω_m

- WMAP7 + H_0 + SPTclusters : $\Sigma\, m_i < 0.28$ eV for $w \neq -1$

but spread in σ_8 measurement

$P_{LSS}(k)$: marginalize over bias parameter

- WMAP7 + SDSSII+ H_0 : $\Sigma\, m_i < 0.44$ eV (0.71)
- WMAP7 + H_0 + SN + (SDSSII+ CFHTLS) :

  $\Sigma\, m_i < 0.33$ eV for $w = -1$ (Xia et al. 2012)
- WMAP7 + SDSS DR8 + H_0 : $\Sigma\, m_i < 0.26$ eV

  $\Sigma\, m_i < 0.36$ eV (scale dependent bias) (de Putter 2012)

issues: bias, ν and NL growth

Lyman α

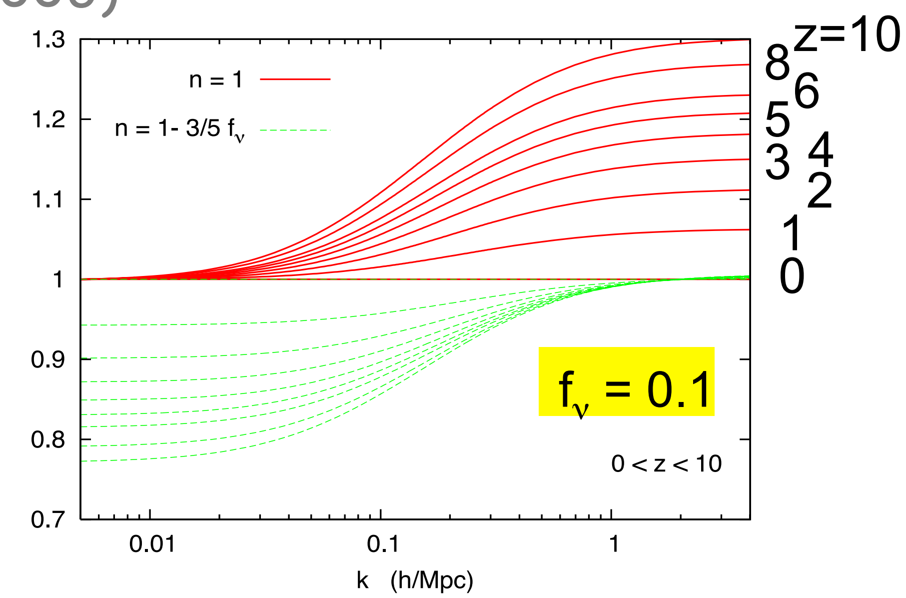
- $0.1 < k < 2$ h/Mpc, $2 < z < 4$
- Lyman α + WMAP3 + SN + BAO + LSS :

  $\Sigma\, m_i < 0.17$ eV (Seljak et al., 2006)

  but tension on σ_8

- Lyman α alone: $\Sigma\, m_i < 0.9$ eV

  (Viel et al. 2010)



- issues : <F>, T- ρ relation, hydro simulations

number of species N_{eff}

- BBN : $N_{eff} = 2.5^{+1.1}_{-0.9}$ (95% CL)
- WMAP7: $z_{eq} = 3145 \pm 140$

$$1 + z_{eq} = \frac{\Omega_m}{\Omega_r} = \frac{\Omega_m}{\Omega_\gamma \left(1 + 0.2271 N_{eff}\right)}$$

WMAP7+BAO+H_0 : $N_{eff} = 4.34^{+0.86}_{-0.88}$ (1σ)

- WMAP7+BAO+H_0+SPT : $N_{eff} = 3.91 \pm 0.42$!!!

  and then $\Sigma\, m_i = 0.34 \pm 0.17 < 0.63$ eV (95%) !!!

  instead of $\Sigma\, m_i < 0.28$

Perspectives

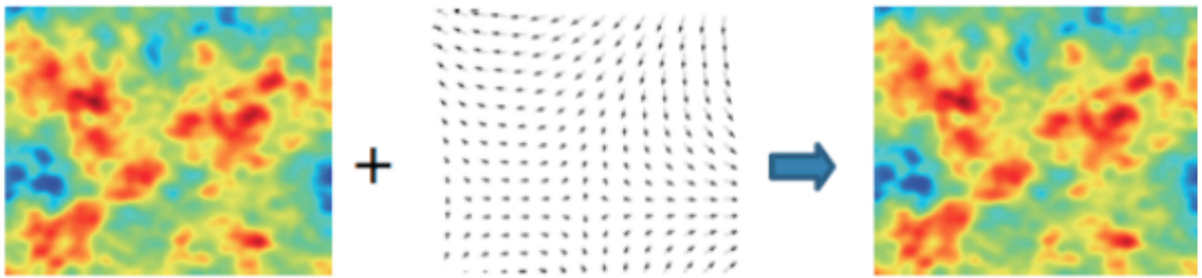
CMB

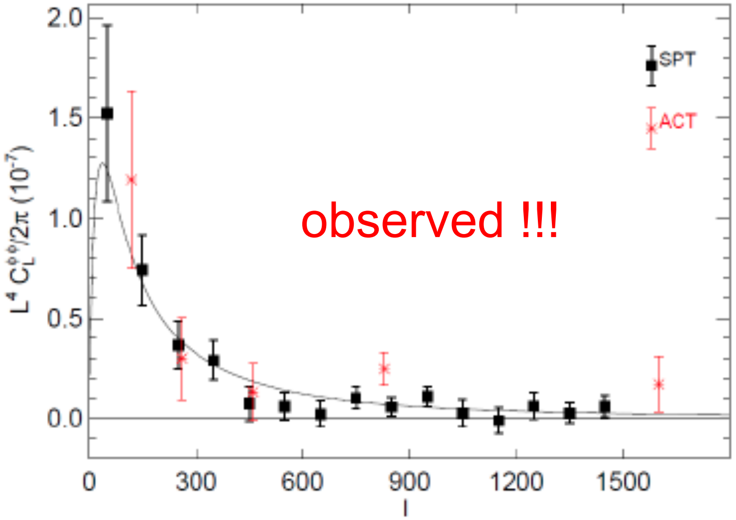
Planck

$\sigma(M_\nu)$	Parameters	Fiducial M_ν	PLANCK sensitivity
0.3	$7 + \{\alpha, T/S, \Omega_k, Y_{He}\}$	0	Slightly optimistic
0.07	$7 + \{\Omega_k\}$	0.07	Very optimistic
0.3	$7 + \{Y_{He}\}$	0.3	Up-to-date
0.45–0.49	$7 + \{Y_{He}\}$	0.1	Up-to-date
0.51–0.56	$7 + \{\alpha, w, N_{eff}, Y_{He}\}$	0.1	Up-to-date

Experiment	$6 + m_\nu + Y_{He}$ 8 parameters	idem + α, w, N_{eff} 11 parameters
BICEP + QUaD	1.3–1.6	1.5–1.9
BRAIN + ClOVER	1.5–1.8	1.7–2.0
PLANCK	0.45–0.49	0.51–0.56
SAMPAN	0.34–0.40	0.37–0.44
PLANCK + SAMPAN	0.32–0.36	0.34–0.40
INFLATION PROBE	0.14–0.16	0.25–0.26

CMB lensing P(k)





- Large scale structure potentials gravitationally deflect CMB photons by a lensing deflection angle $\mathbf{d}(\mathbf{n})$
- Measurement of the deflection field is a measurement of matter fluctuations AND the geometry of the universe

  -> very useful for cosmological constraints

- Can find lensing because it breaks Gaussianity: non-Gaussian part of lensed T 4-point function ~ deflection power spectrum

CMB and galaxy lensing

- CMB lensing: access to LSS at $z \lesssim 3$
  without issues of bias and NL effects

Experiment	8 parameters	11 parameters
BICEP + QUaD	0.31–0.36	0.36–0.40
BRAIN + ClOVER	0.34–0.43	0.42–0.51
PLANCK	0.13–0.14	0.15–0.15
SAMPAN	0.10–0.17	0.12–0.18
PLANCK + SAMPAN	0.08–0.10	0.10–0.12
INFLATION PROBE	0.032–0.036	0.035–0.039

- galaxy weak lensing

	+ Planck	+ CMBpol
SNAP	0.10	0.05
LSST	0.052	0.031
PanStarr	0.045	0.027

other probes

- Lyman α : 0.1 eV
- Planck + BAO (BigBoss) : 0.1 eV
- galaxy survey, Euclid : 0.10 eV
- radio survey, SKA : 0.05 eV

CONCLUSIONS

current constrains

- CMB + distances (conservative) : Σ m_i < 0.58

  but adding parameters: w, N_{eff}, Ω_k ?
- CMB + LSS : Σ m_i < 0.26 – 0.36

  scale dependent bias, NL

Perspectives

- CMB lensing Planck 0.13-0.15
- Galaxy weak lensing (LSST + Planck) 0.05