WMAP Constraint on Neutrino Masses

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1. Introduction

Tritium beta decay experiments:

$$m_{\nu_e} < 3 \text{ eV}$$

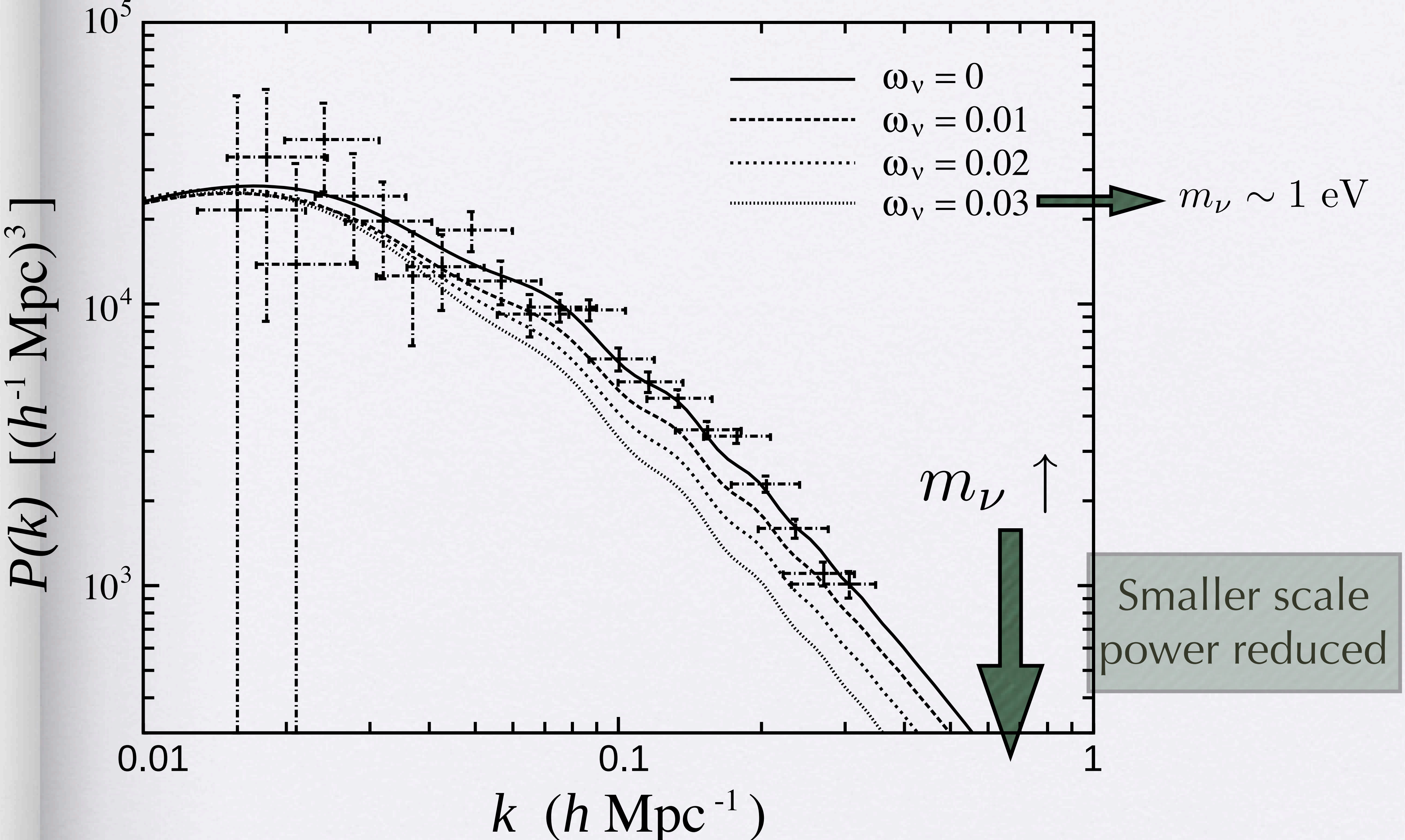
Cosmological bounds:
(WMAP+SDSS)

$$m_\nu < 0.6 \text{ eV}$$

Tegmark et al.
[SDSS collaboration]

Matter power spectrum

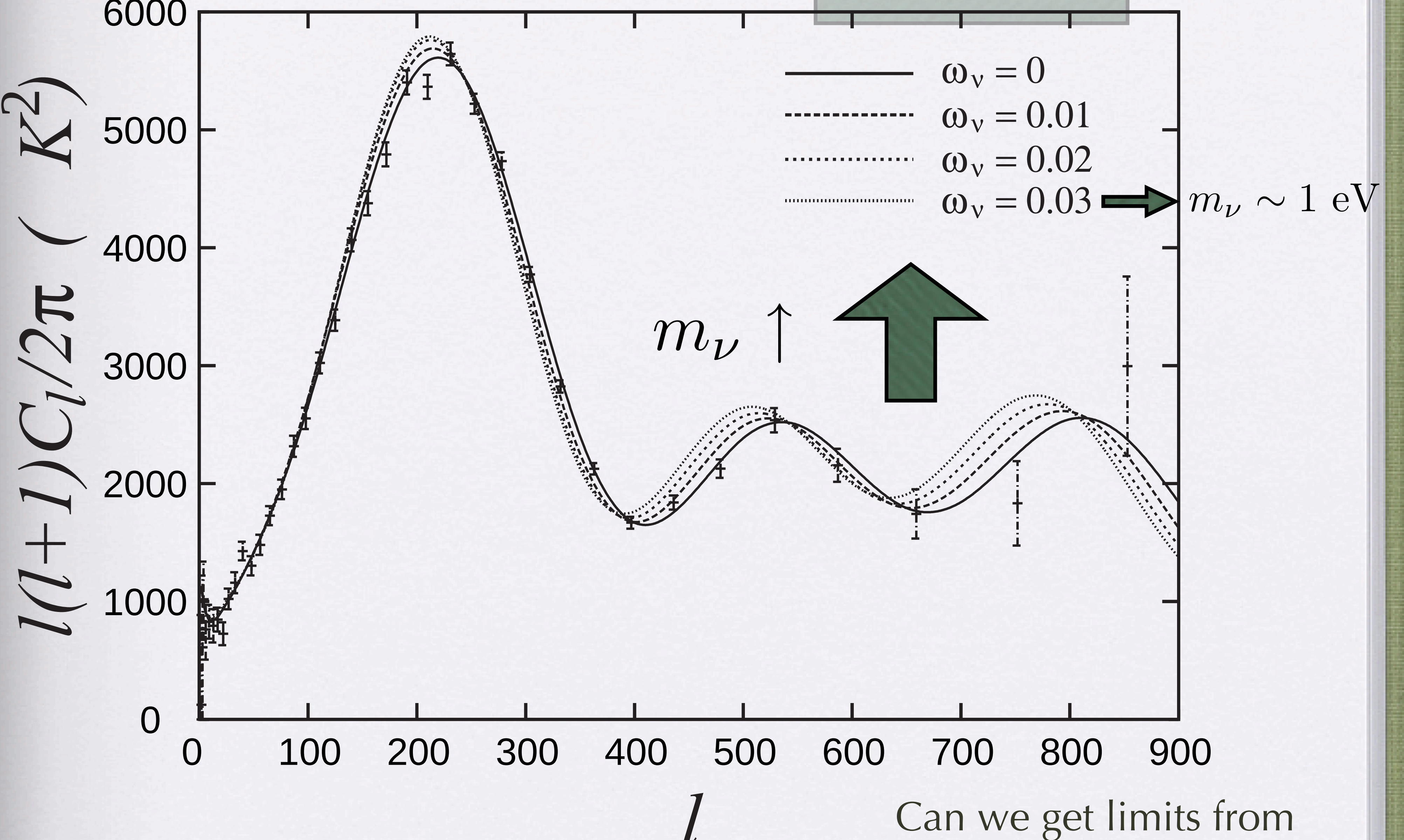
power spectrum of galaxies from the SDSS



CMB

WMAP TT angular power spectrum

Smaller scale power enhanced



Can we get limits from CMB alone ?

Motivations for CMB alone limit

- Tegmark et al.'s analysis shows WMAP alone does not constrain neutrino masses. They claim that 100% HDM is allowed.
- Galaxy clustering data suffer from unknown biasing and not well-controlled nonlinear effects.

Result

Only slightly weaker limit is obtained using CMB (WMAP) data alone (95% CL):

$$m_\nu < 0.7 \text{ eV}$$

cf.) WMAP+SDSS

$$m_\nu < 0.6 \text{ eV}$$

2. Limit on the neutrino mass from WMAP alone

Cosmological parameters

$$\omega_i \equiv \Omega_i h^2$$

- ω_b : baryon density
- ω_m : matter density (baryon+CDM)
- h : Hubble parameter
- τ : reionisation optical depth
- n_s : scalar spectral index
- A : overall normalisation

- ω_ν: neutrino mass density

$$\omega_\nu = \frac{\sum m_\nu}{94.1 \text{ eV}}$$

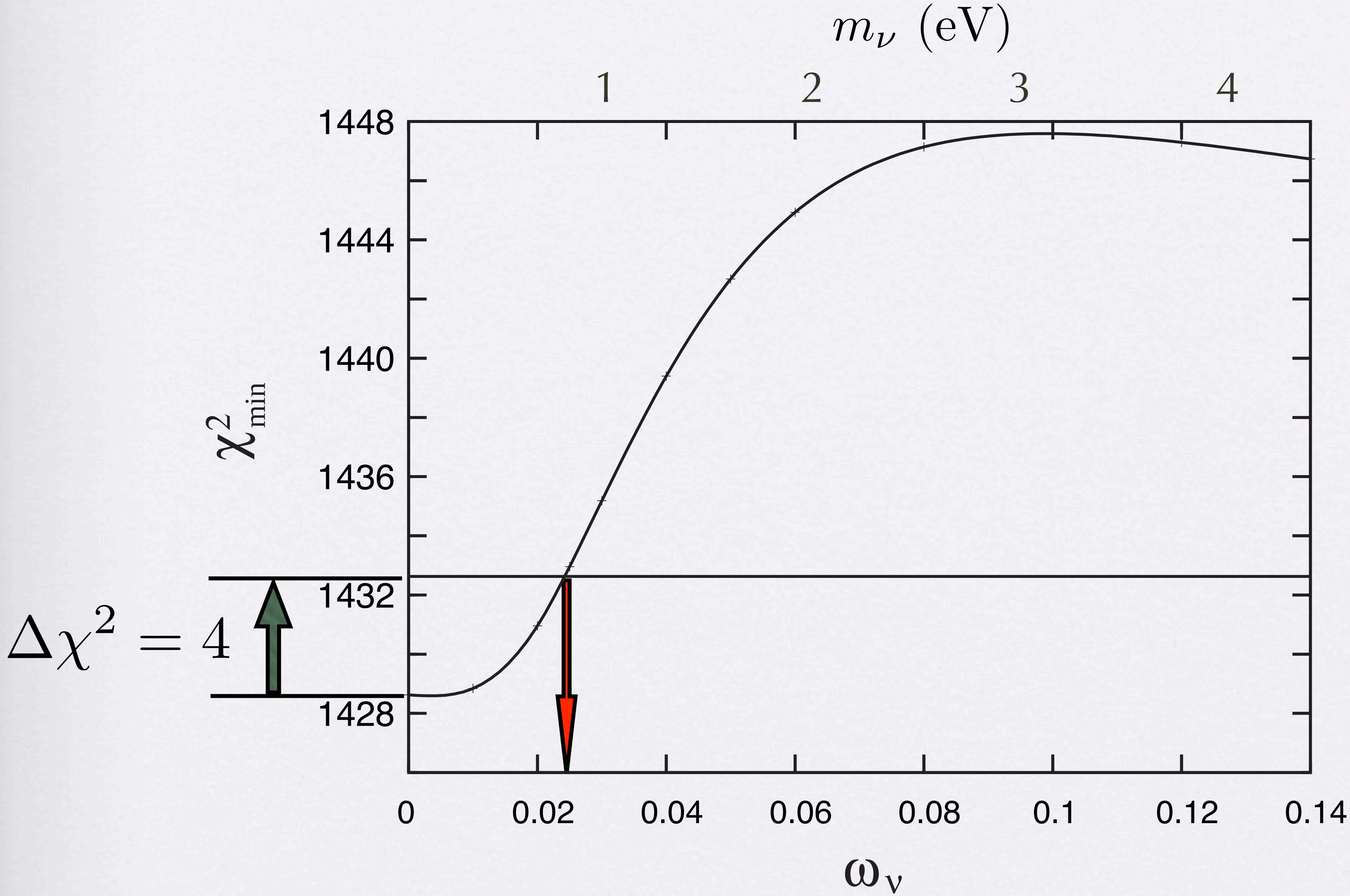
$$m_\nu = 31.4\ \omega_\nu \text{ eV}$$ (equal mass for three generations assumed)

Vacuum energy is taken to satisfy the flat universe assumption

$$\Omega_{\text{tot}} \equiv \Omega_\Lambda + \Omega_m + \Omega_\nu = 1$$

Run CMBFAST to calculate CMB multipoles and WMAP χ^2 for $O(10^6)$ sets of parameters.

χ^2-minimisation (fix ω_ν and vary other 6 parameters)

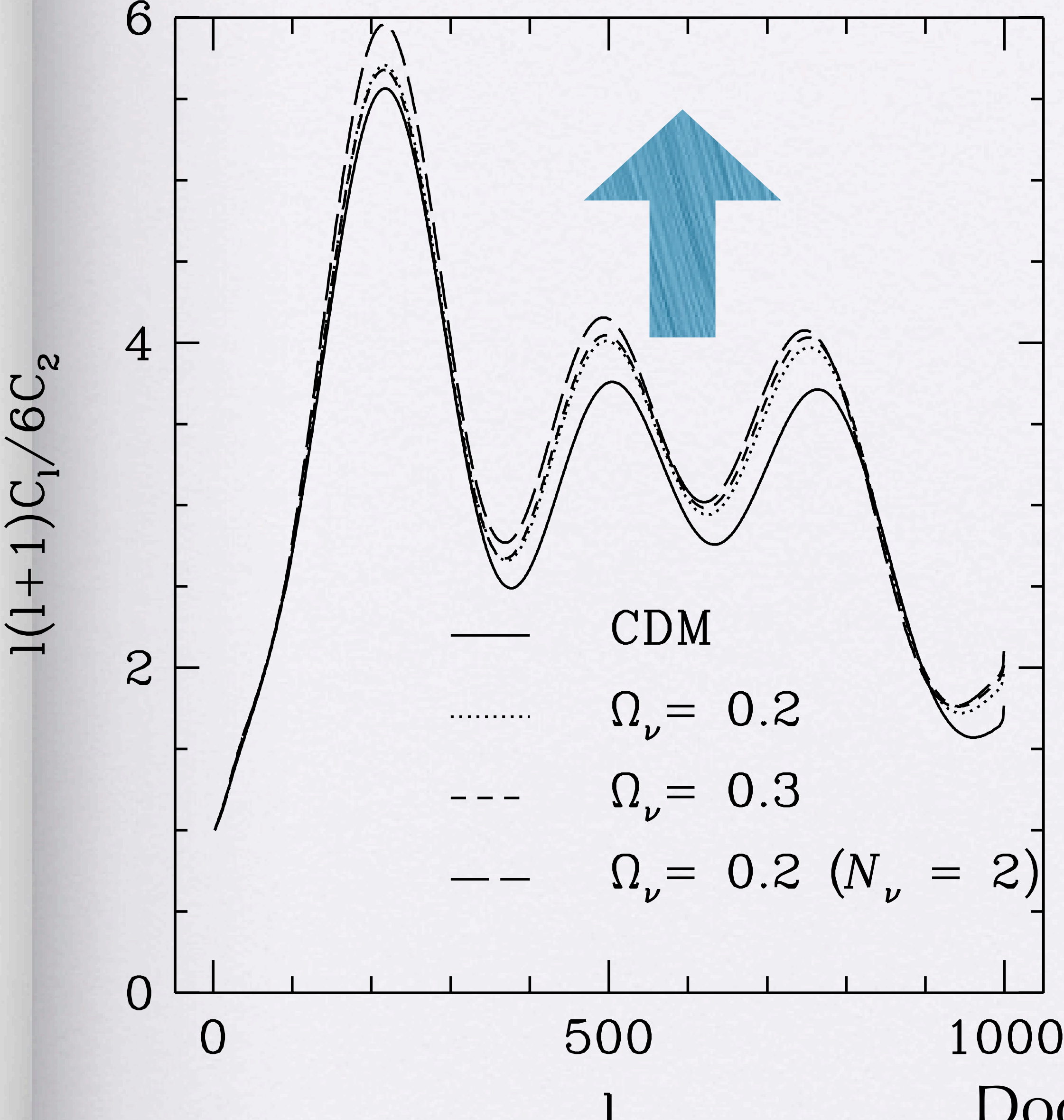


$\omega_\nu < 0.024$ (95%) or $m_\nu < 0.7$ eV

3. The reduced CMB observables and the neutrino mass

- Interpretation of the limit.
- The role of massive neutrinos in CMB.

Effect of massive neutrinos on CMB



Smaller scale power is enhanced as $m_\nu \uparrow$

ν becomes non-rel. and erases density perturbations

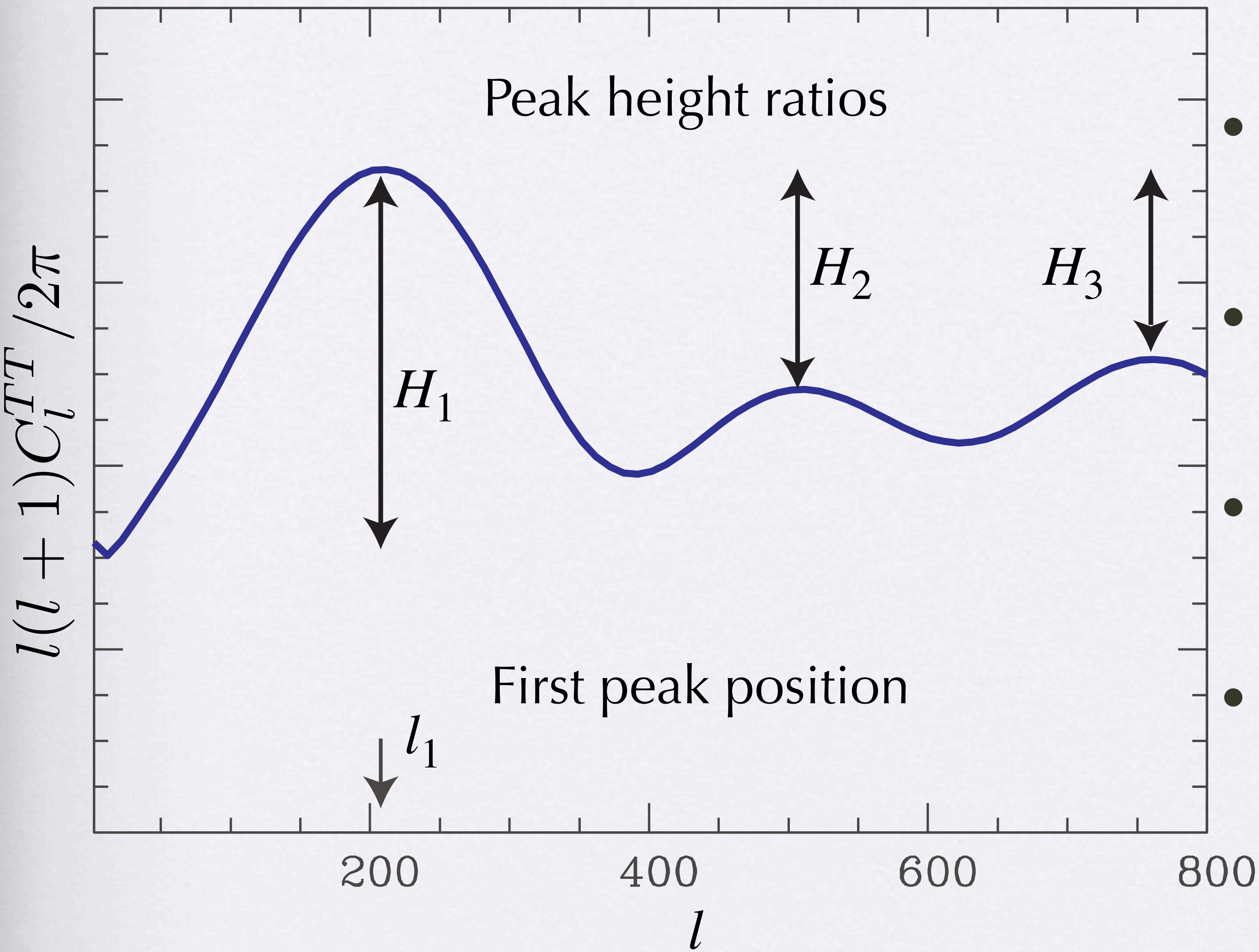
Faster decay of gravitational potentials

More forcing of the acoustic oscillations

Dodelson, Gates, Stebbins (1995)

Reduced CMB observables

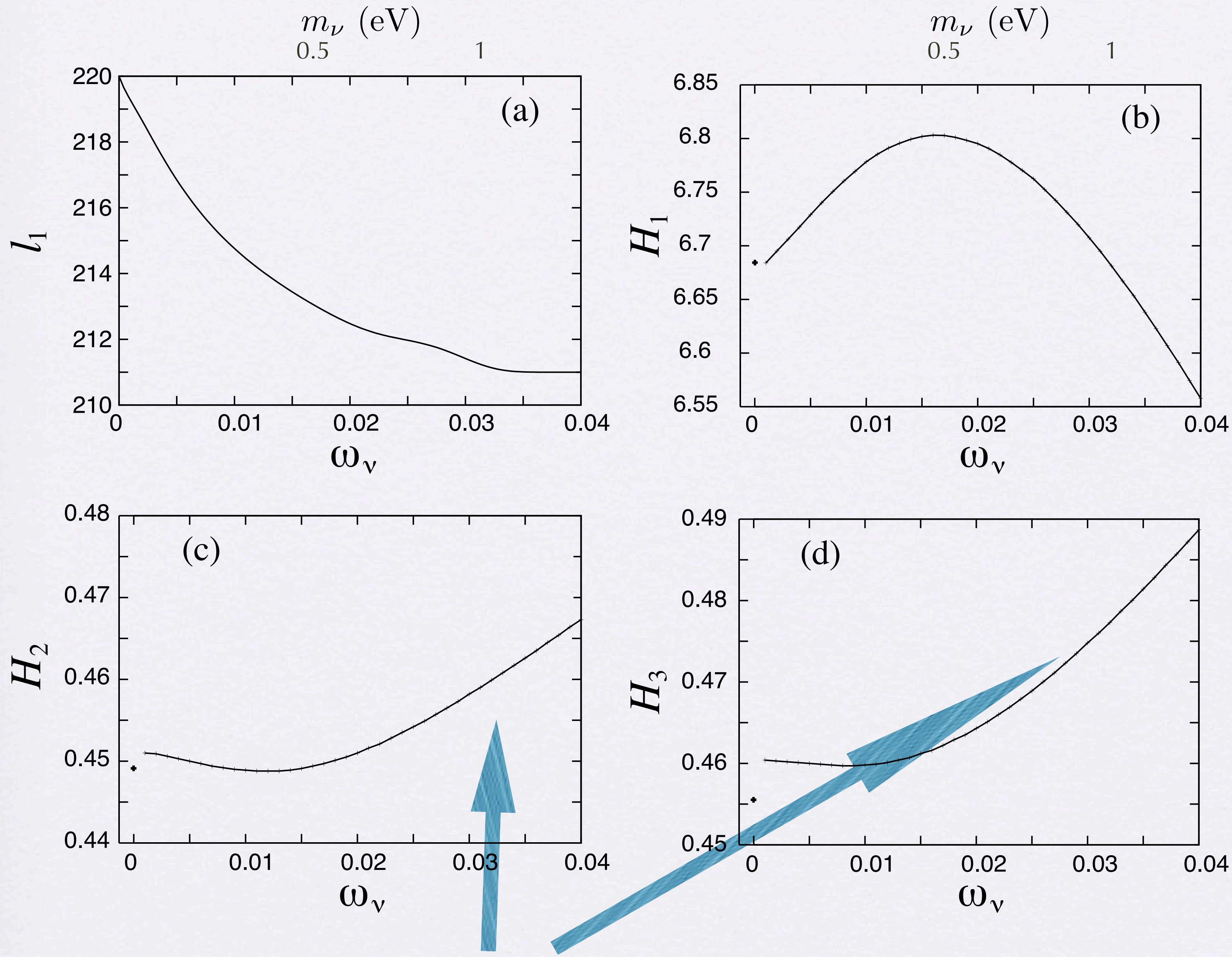
$$(\Delta T_l)^2 \equiv l(l+1)C_l^{TT}/2\pi$$



- ℓ_1
- $H_1 \equiv \left(\frac{\Delta T_{l_1}}{\Delta T_{10}}\right)^2$
- $H_2 \equiv \left(\frac{\Delta T_{l_2}}{\Delta T_{l_1}}\right)^2$
- $H_3 \equiv \left(\frac{\Delta T_{l_3}}{\Delta T_{l_1}}\right)^2$

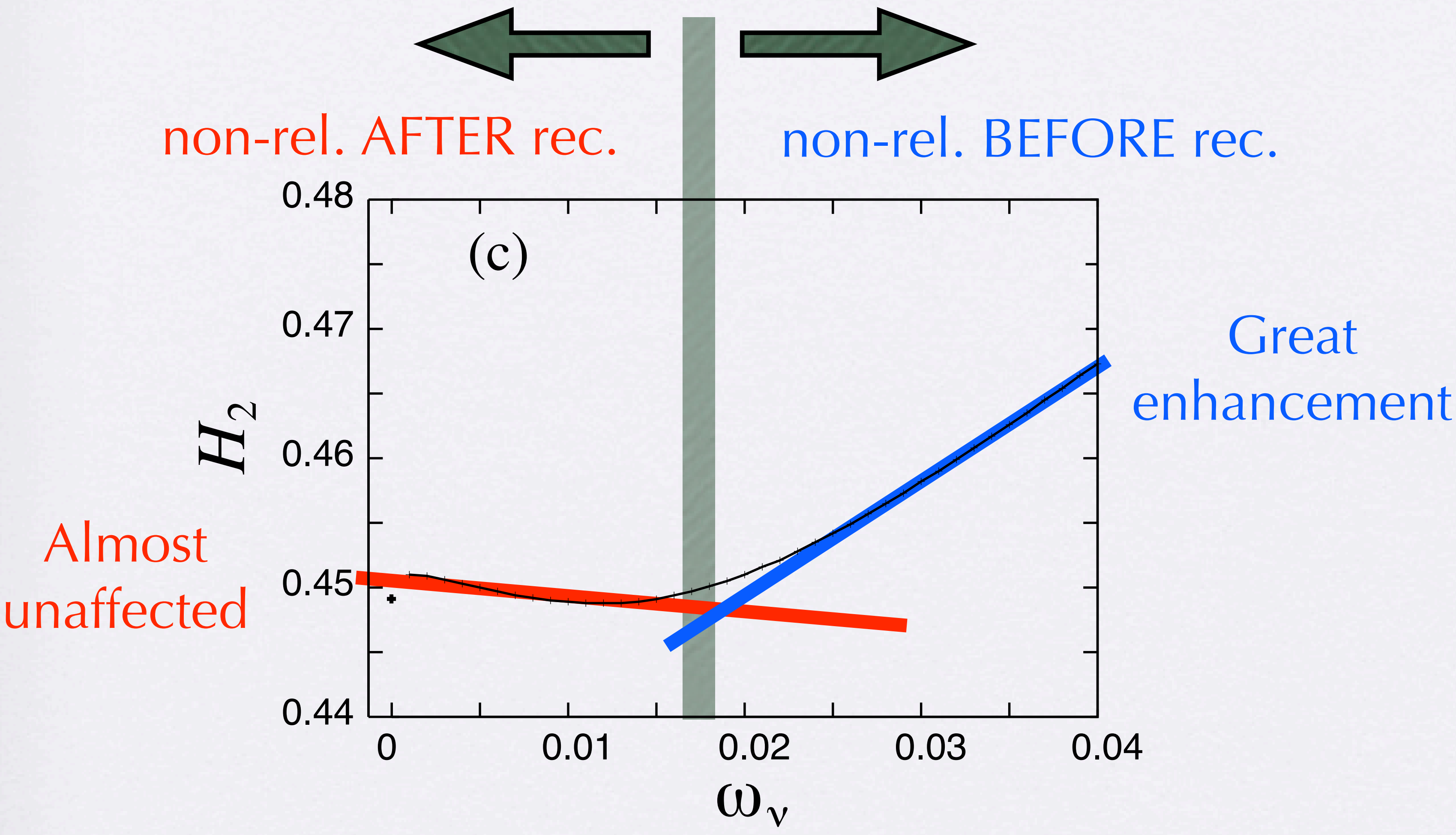
Hu, Fukugita, Zaldarriaga, Tegmark (2001)

Response to the variation of neutrino masses



Conspicuous enhancement for $\omega_\nu > 0.017$ $(m_\nu > 0.5\ \text{eV})$

For $\omega_\nu > 0.017$ $(m_\nu > 0.5 \text{ eV})$, massive neutrinos become non-relativistic BEFORE the epoch of recombination, $z_{\text{rec}} \approx 1088$ $(T_\gamma \sim 0.3 \text{ eV})$



4. Conclusion

- A subelectronvolt upper limit on the neutrino mass can be derived from the WMAP data alone.

$$m_\nu < 0.7 \text{ eV} \qquad [95\% \text{ CL}]$$

- We can obtain the limit because massive neutrinos with $m_\nu > 0.5$ eV become non-relativistic before recombination epoch. WMAP excluded the signal which would be produced by $m_\nu > 0.5$ eV .