Neutrino masses and the 2dFGRS

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Outline

- Massive neutrinos and the matter power spectrum
- The 2dF Galaxy Redshift Survey
- Cosmological parameters from the 2dFGRS
- Constraint on the total neutrino mass from the 2dFGRS
- Adding CMB data
- Summary

The matter power spectrum

- Defined from the density perturbation field

$$\delta(\mathbf{x}) = (\rho(\mathbf{x}) - \langle\rho\rangle) / \langle\rho\rangle$$

- $P(k,z) = \langle|\delta_{\mathbf{k}}|^2\rangle = P_{in}(k)[T(k,z)]^2$
- Spectrum of primordial perturbations:

$$P_{in}(k) = Ak^n$$

Parameters (flat cosmologies)

- Matter density: Ω_m (in units of $\rho_0 = 10.54 h^2$ keV cm^{-3})
- Baryon density: Ω_b
- Neutrino density: Ω_ν
- Hubble parameter: $H_0 = 100h$ km $s^{-1} Mpc^{-1}$
- Amplitude: A
- Spectral index: n

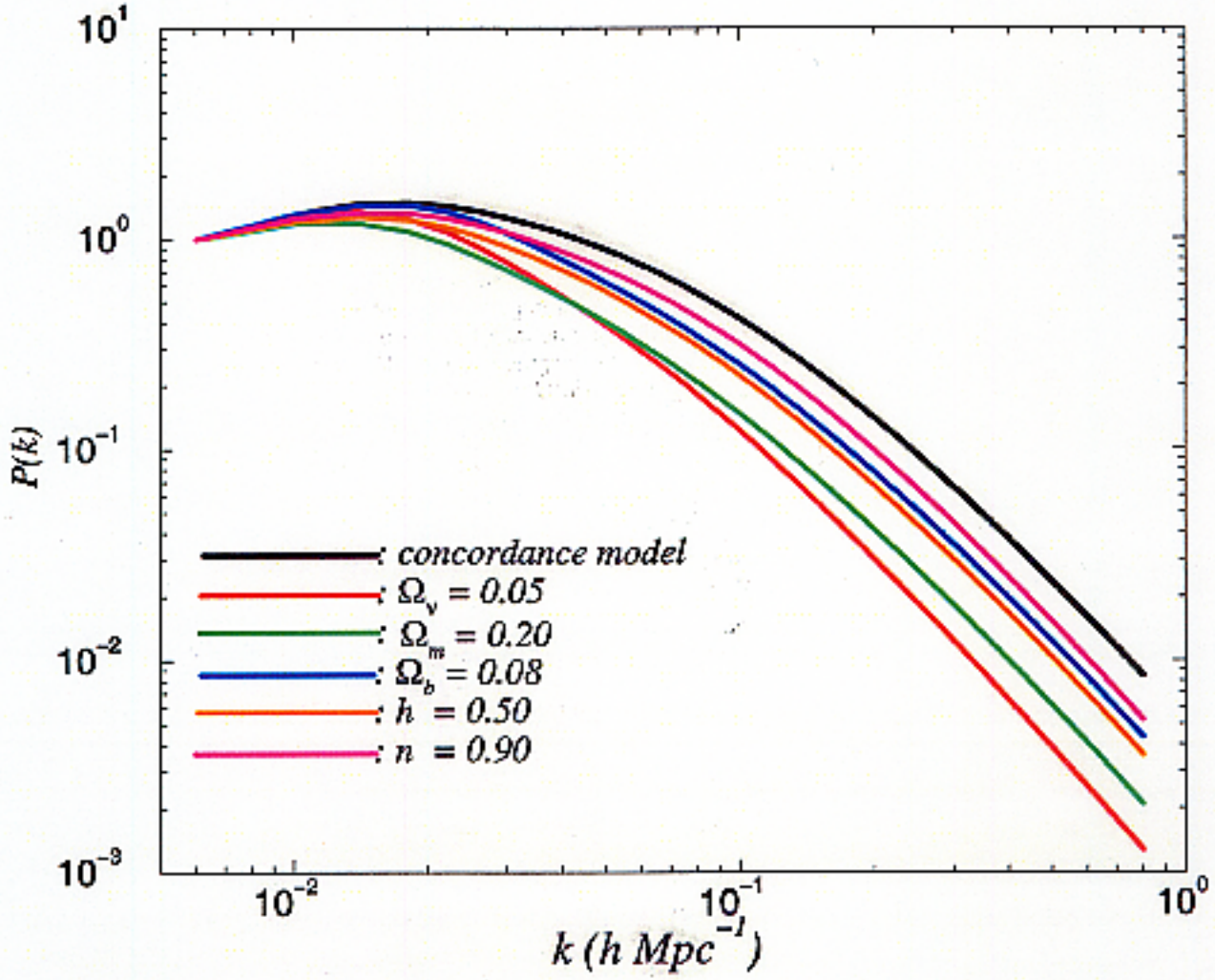
The basic idea

- Structures form by gravitational growth of small overdensities
- Light, massive neutrinos, contributing

$$\Omega_\nu h^2 = m_\nu^{tot} / 94\ \mathrm{eV}$$

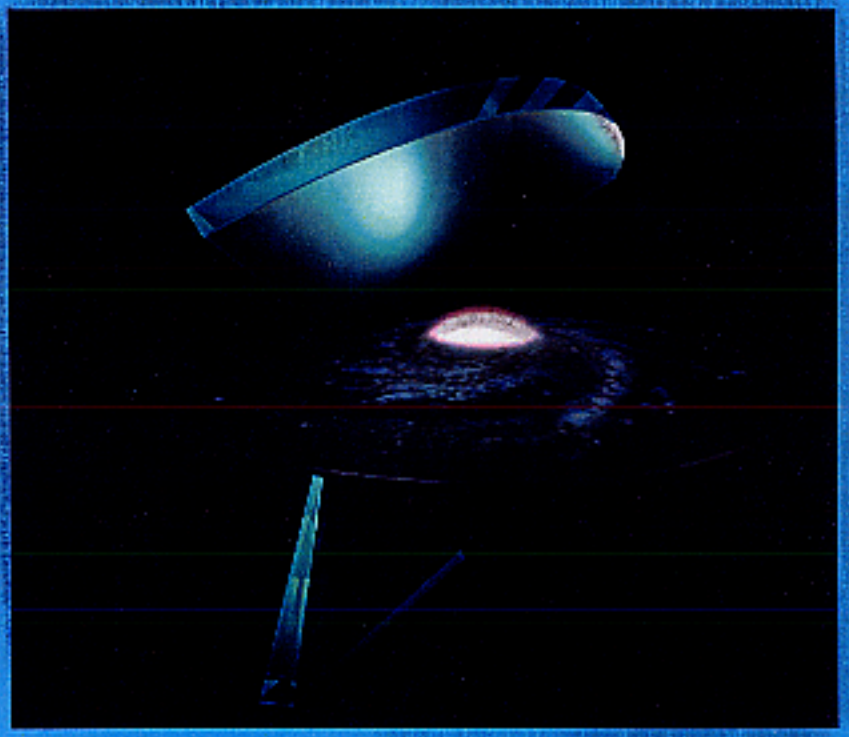
to the total density, can free–stream over large distances, suppressing growth of fluctuations on scales smaller than

$$k_{nr} = 0.026 (m_\nu / 1\ \mathrm{eV})^{1/2} \Omega_m^{1/2}\ h\ \mathrm{Mpc}^{-1}$$


10^1
10^0
10^{-1}
10^{-2}
10^{-3}
$P(k)$
10^{-2}
10^{-1}
10^0
$k\ (h\ Mpc^{-1})$
: concordance model
: $\Omega_\nu = 0.05$
: $\Omega_m = 0.20$
: $\Omega_b = 0.08$
: $h = 0.50$
: $n = 0.90$

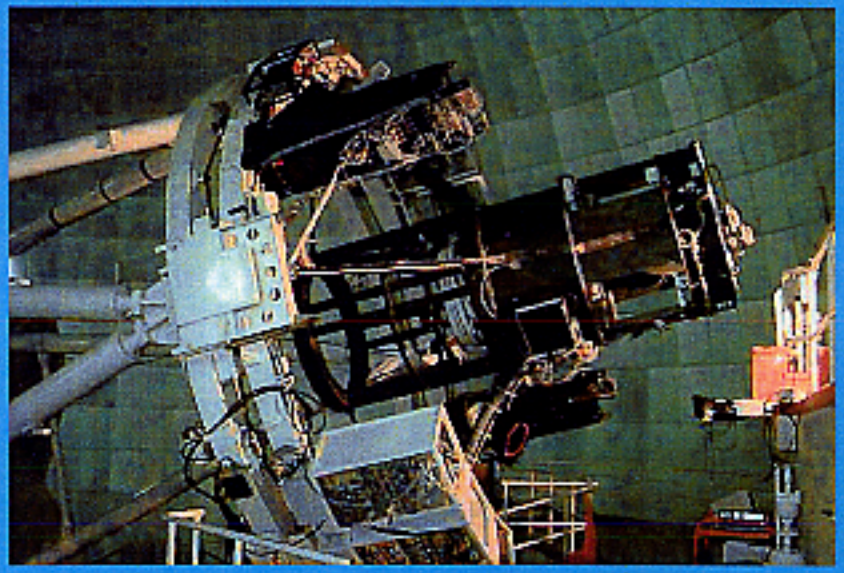
The 2dFGRS: aims

- Measure P(k) on scales up to a few hundred Mpc
- Measure redshift–space distortions
- Measure higher–order clustering statistics (biasing, Gaussianity)



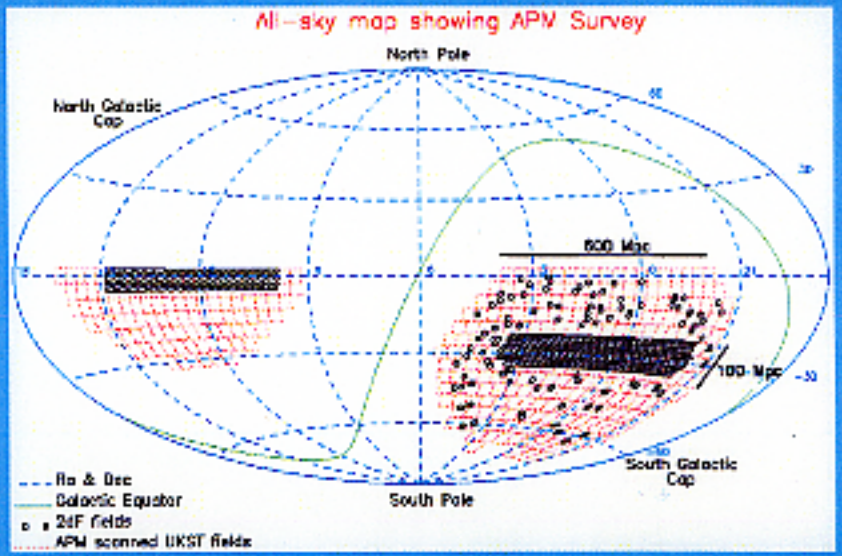
The 2dFGRS

- Named after the Two–degree Field multifibre spectrograph, can observe spectra for 400 objects simultaneously



The 2dF Galaxy Redshift Survey

- Source catalogue (APM)
- Geometry: two declination strips + 100 random 2–degree fields
- Complete survey has ~ 240 000 redshifts



What redshift surveys measure

- Galaxy redshift surveys measure the distribution of luminous matter.
- Good theoretical reasons to expect light to trace mass at large scales.

Galaxy – galaxy correlation function:

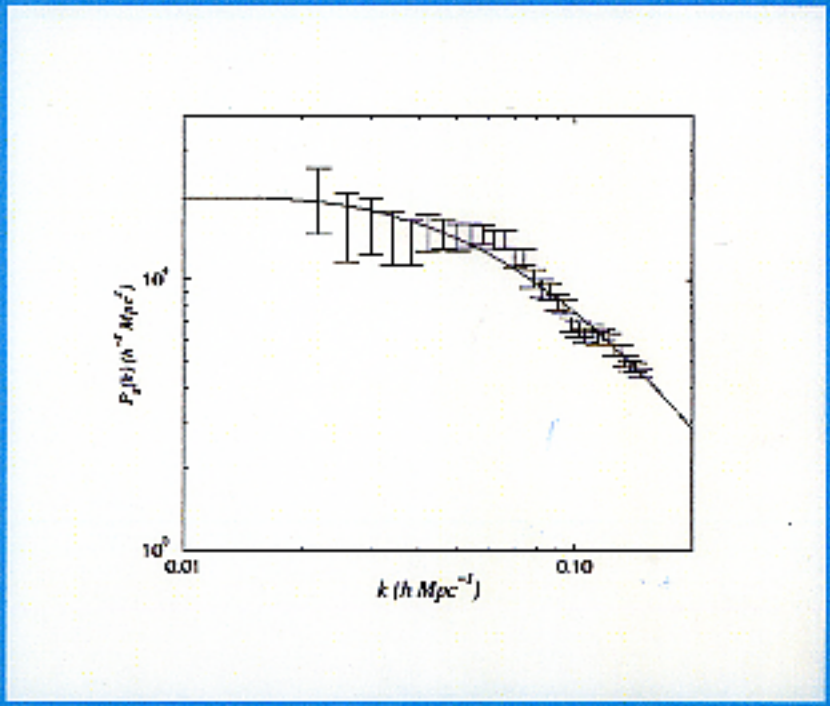
$$\delta^2 P_2 = n_V^2 [1 + \xi(r)] \delta V_1 \delta V_2$$

Galaxy power spectrum:

$$P_g(k) = \int d^3 r e^{i\vec{k}\cdot\vec{r}} \xi(r)$$

Cosmological parameters from 2dFGRS

- The power spectrum of the 2dFGRS constrains the matter density and the baryon fraction (Percival et al. MNRAS 327 (2001) 1297)
- Combine with CMB...



Cosmological parameters

- From the 2dFGRS P(k) alone:

$$\Omega_m h = 0.20 \pm 0.03$$

$$\Omega_b / \Omega_m = 0.15 \pm 0.07$$

- From 2dFGRS + CMB: (examples)

$$\Omega_k = 0.001$$

$$\Omega_\Lambda = 0.71 \pm 0.05$$

$$h = 0.69 \pm 0.05$$

(Efstathiou et al. MNRAS 330 (2001) L29)

Adding massive neutrinos

- Repeat analysis with massive neutrinos included
- Parameters:

$$0.1 < \Omega_m h < 0.5$$

$$0 \leq f_\nu = \Omega_\nu / \Omega_m < 0.3$$

$$0 < f_b = \Omega_b / \Omega < 0.3$$

$$0.4 < h < 0.9$$

$$0.7 < n < 1.3$$

- Assume bias is linear on large scales, leave the amplitude A as an additional free parameter

Biasing

- Measure the galaxy power spectrum, need to relate it to the matter power spectrum

$$b^2(k) = P_g(k) / P_m(k)$$

- The 2dFGRS power spectrum is consistent with linear biasing on large scales: $b = \text{const} \simeq 1$

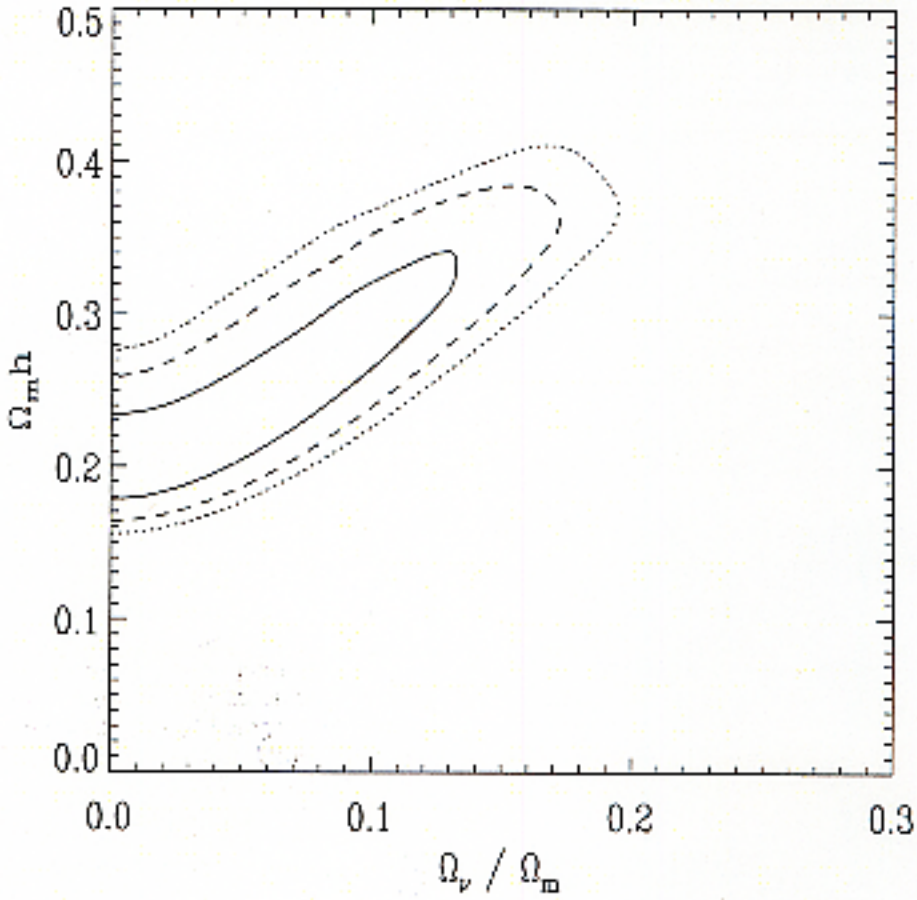
  (Verde et al. MNRAS 335 (2002) 432,
  Lahav et al. MNRAS 333(2002) 961)

- Assume linear biasing, leave b as a parameter

Priors

- Hubble parameter: $h = 0.70 \pm 0.07$
- BBN: $\Omega_b h^2 = 0.020 \pm 0.002$
- Matter density: $0.1 < \Omega_m < 0.5$

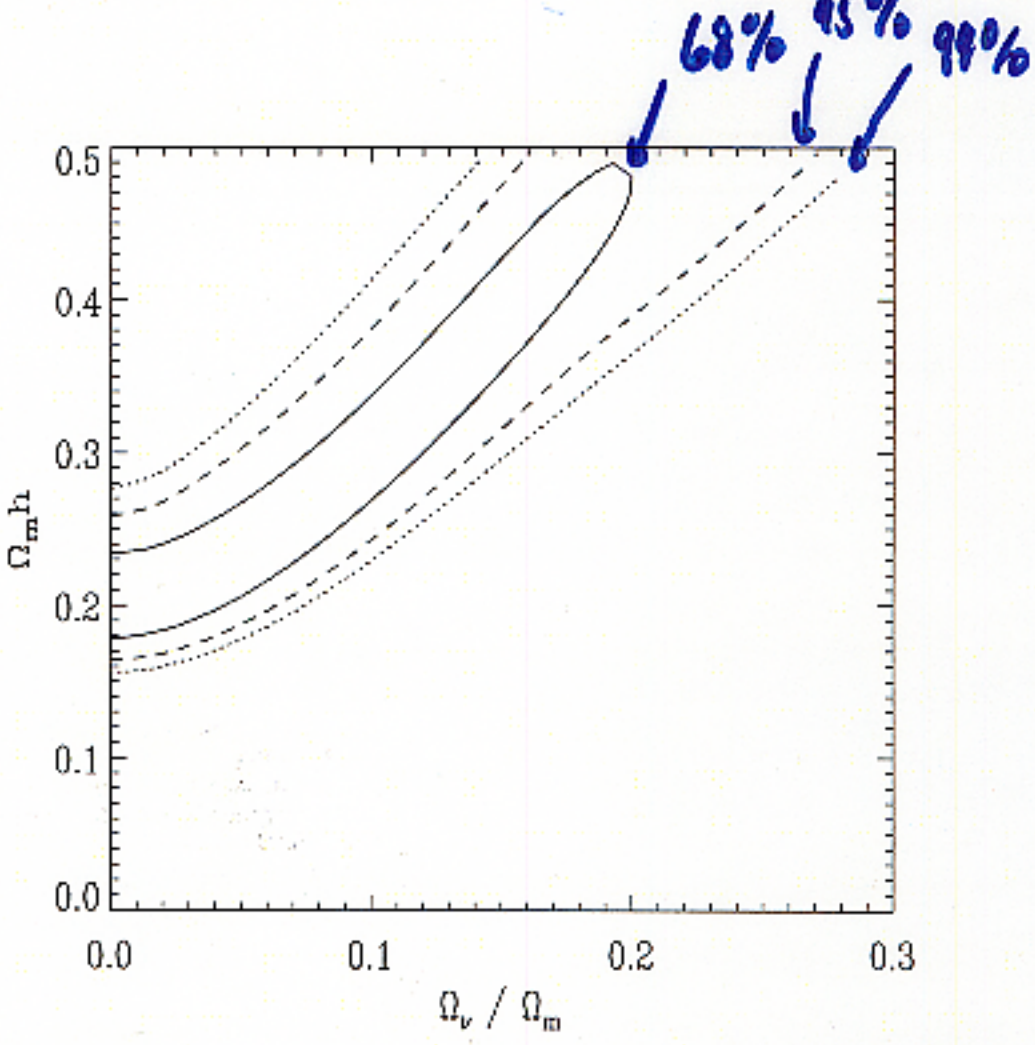
  $\Omega_m = 0.28 \pm 0.14$ (SNIa)
- Spectral index: $n = 1.0 \pm 0.1$ (CMB)



PRIOR $0.1 < \Omega_m < 0.5$

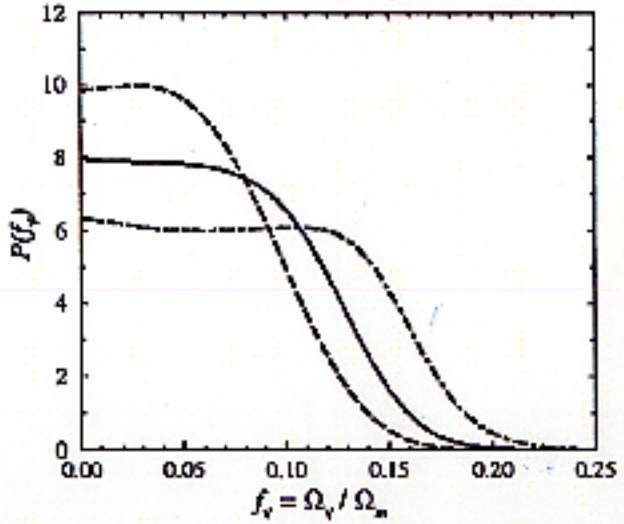
CONTOURS OF

$$P_r(f_\nu, \Omega_m h \mid \text{DATA}) = \int df_\nu \int dh \int dA\, e^{-\frac{1}{2}\chi^2(\vec{p})}$$



Results

- For fixed n=1:
- $m_{\nu,tot} < 1.8(\Omega_m/0.3)$ x $(h/0.7)^2$ eV
- 1.8 –> 2.2 after marginalizing over n



Effect of priors

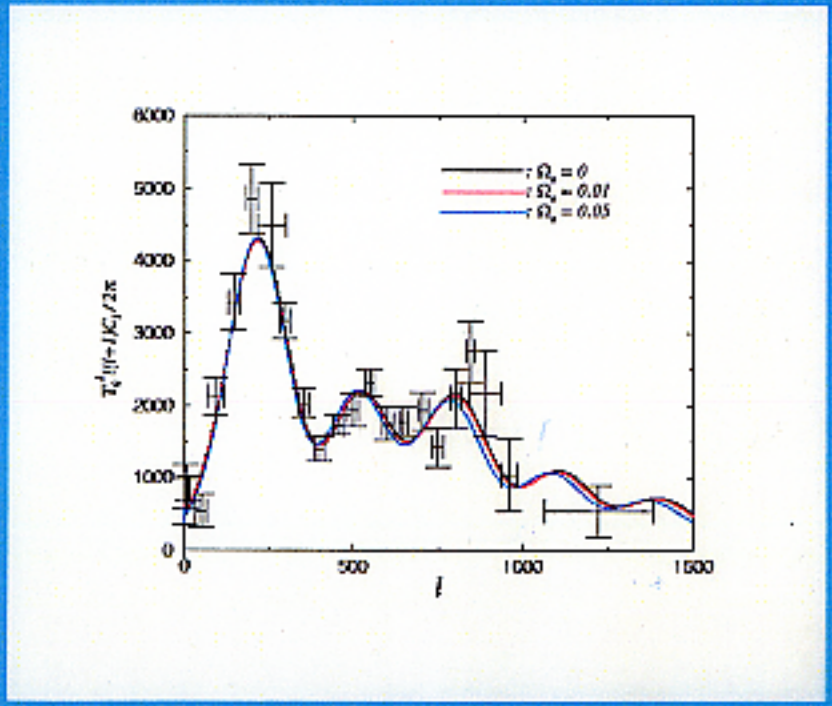
- No priors: $f_\nu < 0.24$
- Prior on h or baryon density only: $f_\nu < 0.20$
- Prior on Ω_m only: $f_\nu < 0.15$
- Full set of priors, P(k) for $k < 0.10$ h Mpc^{-1}: $f_\nu < 0.20$

Massive neutrinos and the CMB

- Anistropies in the CMB are caused by effects at the last scattering surface, z ~ 1100
- The temperature was then around 0.2 eV
- If neutrinos are a significant part of the dark matter, their masses must be in that range, or higher.
- Hence, they were essentially non–relativistic at the LSS, and similar to CDM.

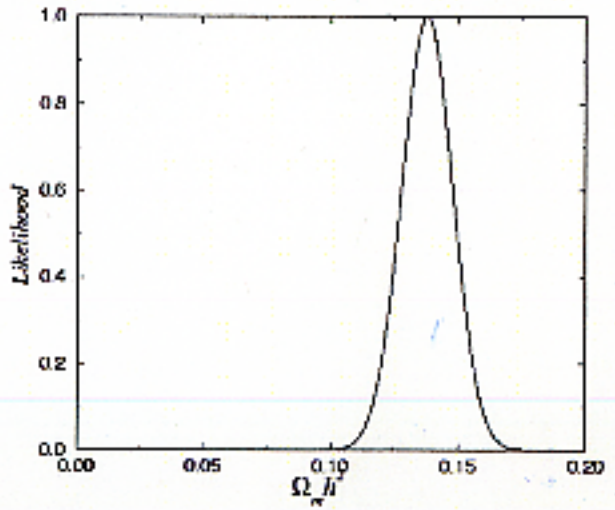
Adding the CMB

- CMB depends weakly on the neutrino mass
- However, adding CMB data breaks degeneracies, in particular it provides a tight constraint on the matter density



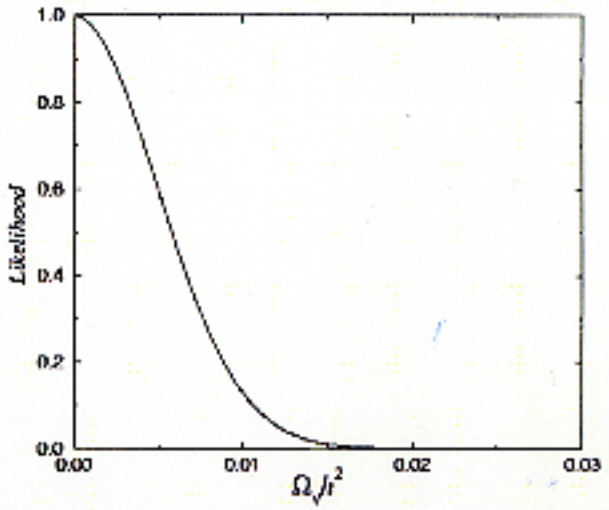
Adding the CMB

- Use **physical densities** $\Omega_m h^2$,...
- Combined with HST prior on h and BBN constraint on the baryon density



Constraint on $m_{\nu,tot}$

- Marginalising over h, A, $\Omega_b h^2$, $\Omega_m h^2$, we get a 95 % confidence limit on the sum of the neutrino masses:
- $m_{\nu,tot} < 0.93$ eV



Caveats

- The limits assume "standard" cosmologies
- Furthermore, they assume standard neutrino physics: no sterile neutrinos etc.
- Have assumed all neutrinos drop out of equilibrium at the same time
- Have assumed the simplest biasing scheme.

Summary

- Analysis of the 2dFGRS P(k) puts a limit on the total neutrino mass ~ 2 eV
- Need good priors on other parameters, combining 2dFGRS with CMB data helps ($m_\nu^{tot} < 0.9$ eV, see Lewis & Bridle, astro−ph/0205436)
- Better limits will come from SDSS + MAP...