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Rencontres IPhT/SPP

24 janvier 2012

Effects of massive neutrinos on the large-scale structure of the universe

in standard cosmology.

Lesgourgues, Pastor, '06 Phys Rep. 429, 307

Abazajian et al. , arXiv: 1103.5083

Y. Wong, talk in PONT, 2011

The neutrino background

Cosmic neutrino background...

- Prediction of the standard hot big bang.
- Process of decoupling fixed by weak interactions.
  - **Temperature** today: $T_{\nu,0} = \left(\frac{4}{11}\right)^{1/3} T_{\mathrm{CMB},0} = 1.95\,\mathrm{K}$
  - **Number density** per flavour: $n_{\nu,0} = \frac{6}{4}\frac{\zeta(3)}{\pi^2} T^3_{\nu,0} = 112\ \mathrm{cm}^{-3}$
  - **Energy density** per flavour: $\Omega_\nu h^2 = \frac{m_\nu}{93\,\mathrm{eV}}$

If m_ν > 1 meV

Neutrinos can be a significant component of the total dark matter content.

Mininum amount of neutrino dark matter

$$\min \sum m_\nu \sim 0.05\ \mathrm{eV} \rightarrow \min \Omega_\nu \sim 0.1\,\%$$

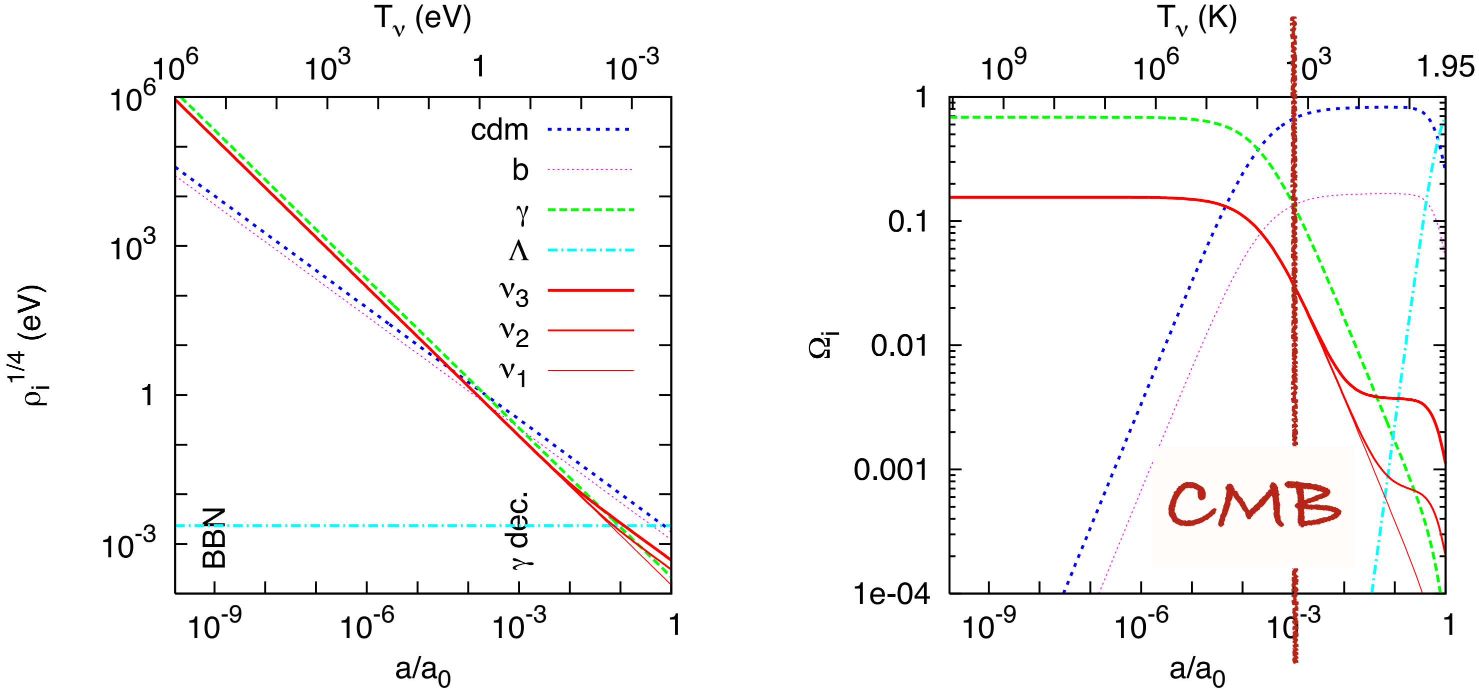


Fig. 5. Evolution of the background densities from the time when $T_\nu = 1$ MeV (soon after neutrino decoupling) until now, for each component of a flat ΛMDM model with $h = 0.7$ and current density fractions $\Omega_\Lambda = 0.70$, $\Omega_{\rm b} = 0.05$, $\Omega_\nu = 0.0013$ and $\Omega_{\rm cdm} = 1 - \Omega_\Lambda - \Omega_{\rm b} - \Omega_\nu$. The three neutrino masses are distributed according to the Normal Hierarchy scheme (see Sec. 2) with $m_1 = 0$, $m_2 = 0.009$ eV and $m_3 = 0.05$ eV. On the left plot we show the densities to the power 1/4 (in eV units) as a function of the scale factor. On the right plot, we display the evolution of the density fractions (i.e., the densities in units of the critical density). We also show on the top axis the neutrino temperature (on the left in eV, and on the right in Kelvin units). The density of the neutrino mass states ν_2 and ν_3 is clearly enhanced once they become non-relativistic. On the left plot, we also display the characteristic times for the end of BBN and for photon decoupling or recombination.

Effects on LSS growth: an overview

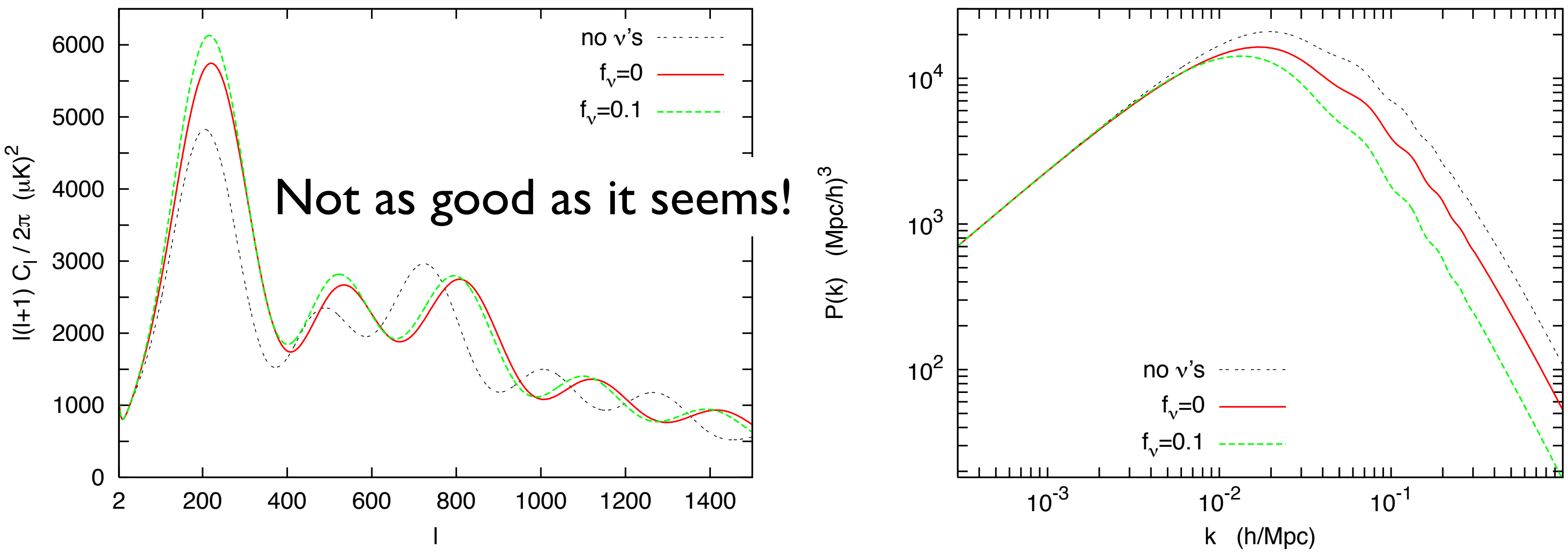


Fig. 14. CMB temperature anisotropy spectrum C_l^T and matter power spectrum $P(k)$ for three models: the neutrinoless ΛCDM model of section 4.4.6, a more realistic ΛCDM model with three massless neutrinos ($f_\nu \simeq 0$), and finally a ΛMDM model with three massive degenerate neutrinos and a total density fraction $f_\nu = 0.1$. In all models, the values of ($\omega_{\rm b}$, $\omega_{\rm m}$, Ω_Λ, A_s, n, τ) have been kept fixed.

The linear growth rate with neutrinos

For dark matter

$$\begin{aligned}\dot{\delta}_c(\mathbf{k},\tau) + \theta_c(\mathbf{k},\tau) &= 0 \\ \dot{\theta}_c(\mathbf{k},\tau) + \mathcal{H}\theta_c(\mathbf{k},\tau) + \frac{3}{2}\mathcal{H}^2\delta_{\rm total}(\mathbf{k},\tau) &= 0\end{aligned}$$

For neutrinos (effective equations)

$$\begin{aligned}\dot{\delta}_\nu(\mathbf{k},\tau) + \theta_\nu(\mathbf{k},\tau) &= 0 \\ \dot{\theta}_\nu(\mathbf{k},\tau) + \mathcal{H}\theta_\nu(\mathbf{k},\tau) + \frac{3}{2}\mathcal{H}^2\delta_{\rm total}(\mathbf{k},\tau) - k^2 c_s^2(\tau)\delta_\nu(\mathbf{k},\tau) &= 0\end{aligned}$$

... a free-streaming scale

Within the freestreaming "horizon"

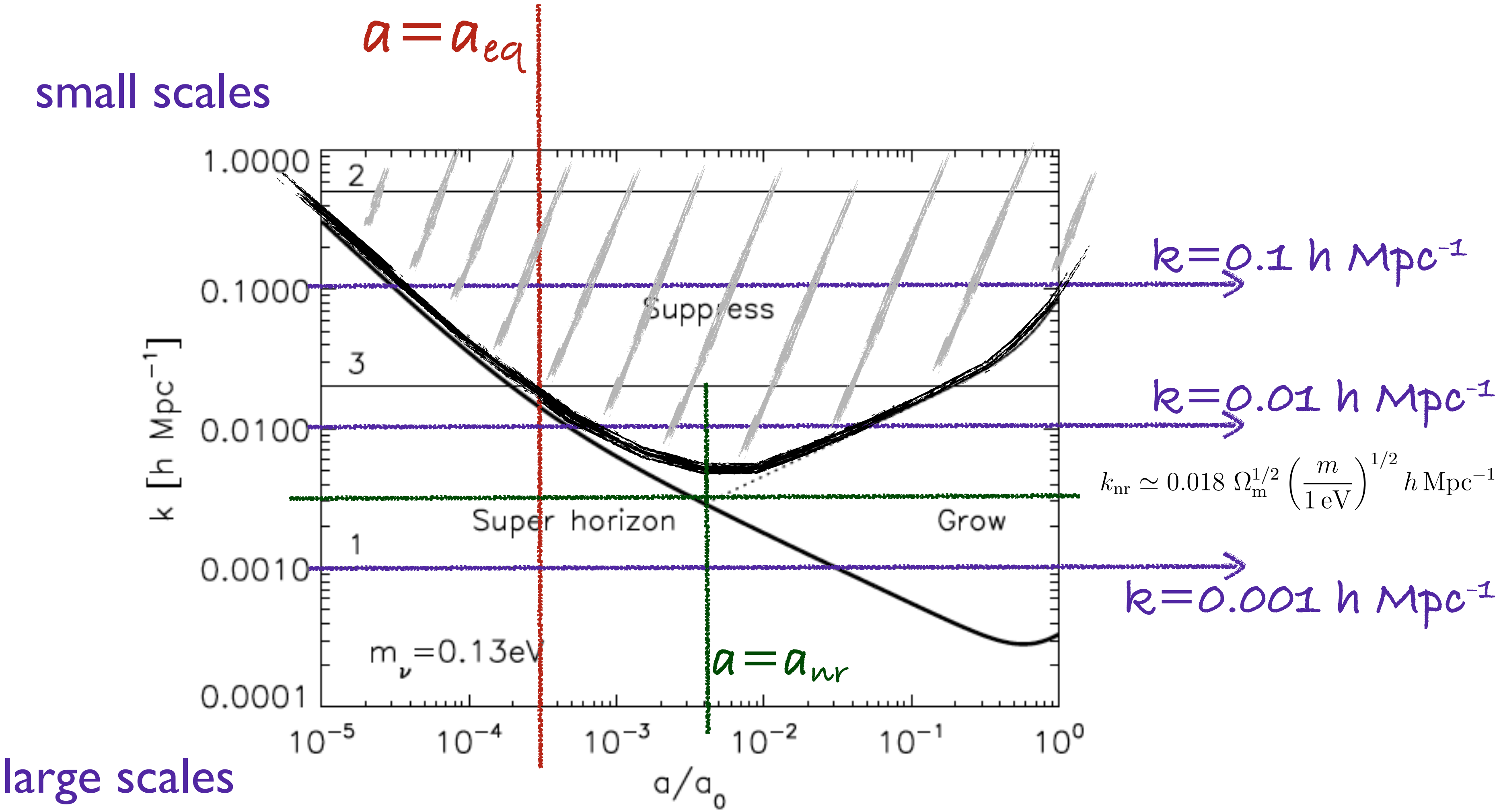
$$\ddot{\delta}_{\rm cdm} + \frac{2}{\tau}\,\dot{\delta}_{\rm cdm} - \frac{6}{\tau^2}(1 - f_\nu)\,\delta_{\rm cdm} = 0$$

$$f_\nu \equiv \frac{\rho_\nu}{(\rho_{\rm cdm} + \rho_{\rm b} + \rho_\nu)} = \frac{\Omega_\nu}{\Omega_{\rm m}} \qquad f_\nu \to 0.0035$$

$$\delta_{\rm cdm} \propto a^{(-1+\sqrt{1+24(1-f_\nu)})/4}$$

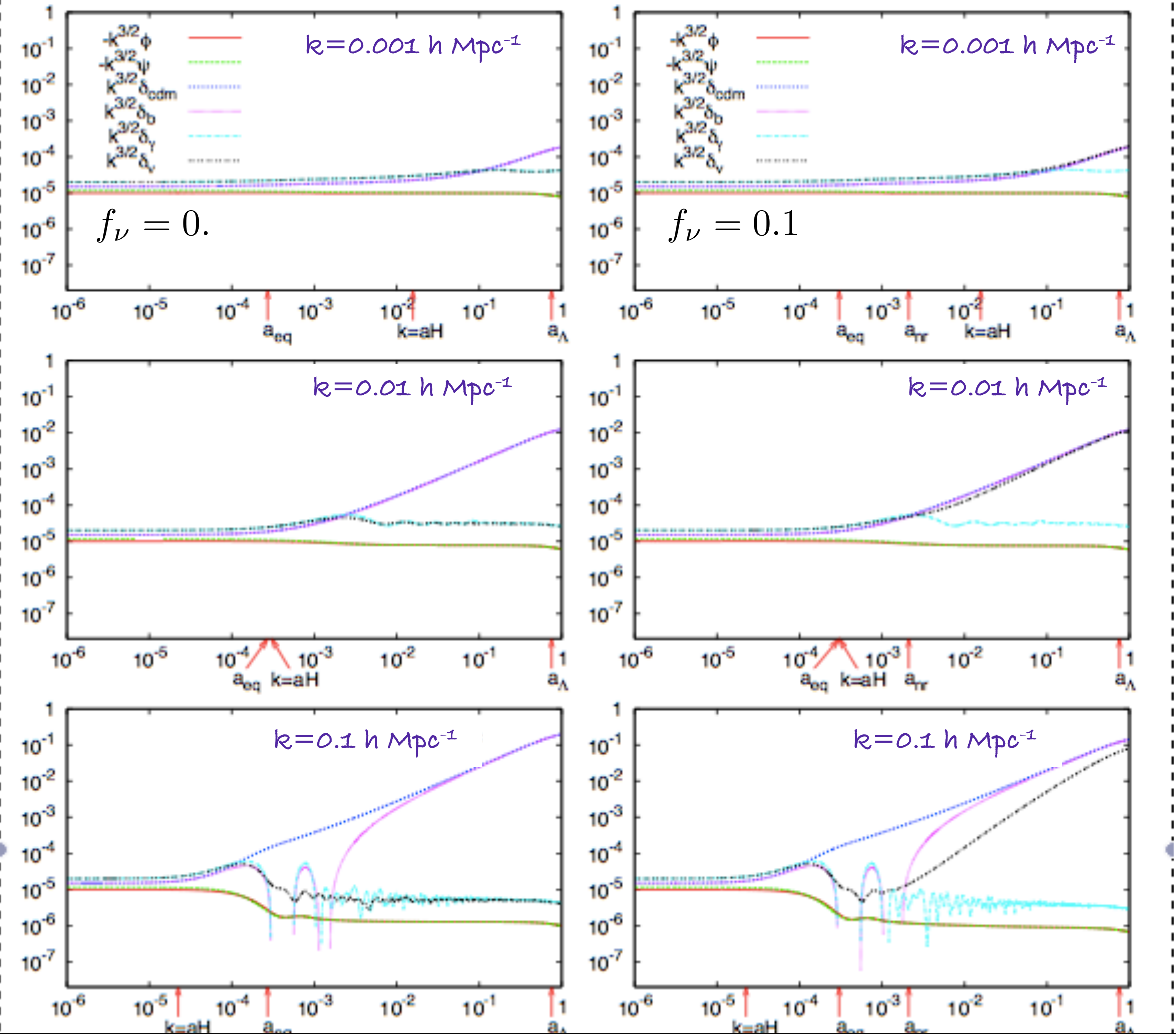
$$\approx 1 - 0.6 f_\nu$$

Free-Streaming horizon



Regions where the growth of neutrino density contrast (for each species) is suppressed $\delta_{\rm cdm} \propto a^{1-.6 f_\nu}$

Shoji, Komatsu arXiv:1003.0942v3



$-k^{3/2}\phi$
$-k^{3/2}\psi$
$k^{3/2}\delta_{cdm}$
$k^{3/2}\delta_b$
$k^{3/2}\delta_\gamma$
$k^{3/2}\delta_\nu$
k=0.001 h Mpc^{-1}
$f_\nu = 0.$
$f_\nu = 0.1$
k=0.01 h Mpc^{-1}
k=0.1 h Mpc^{-1}
a_{eq}
a_{nr}
k=aH
a_Λ

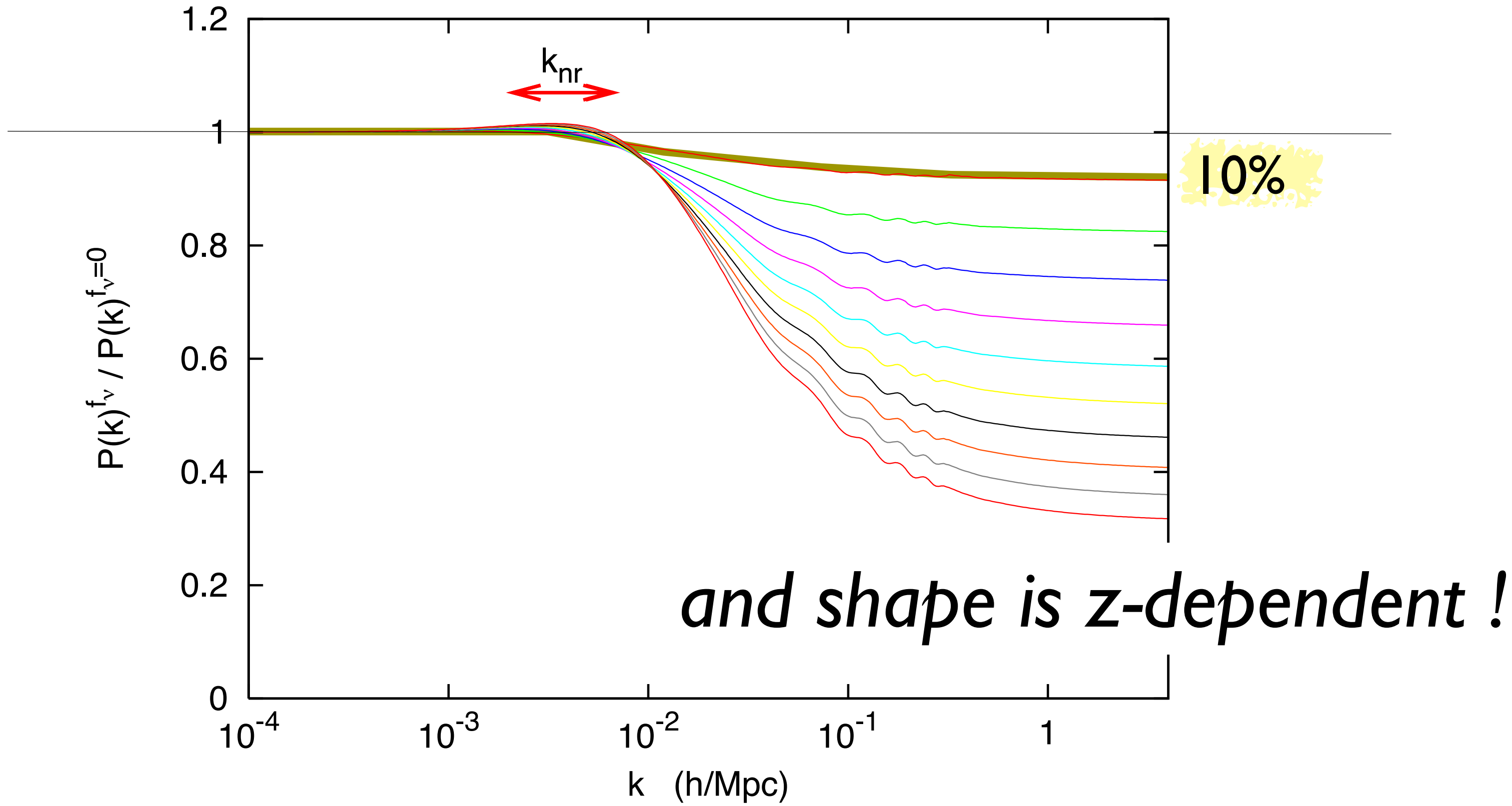
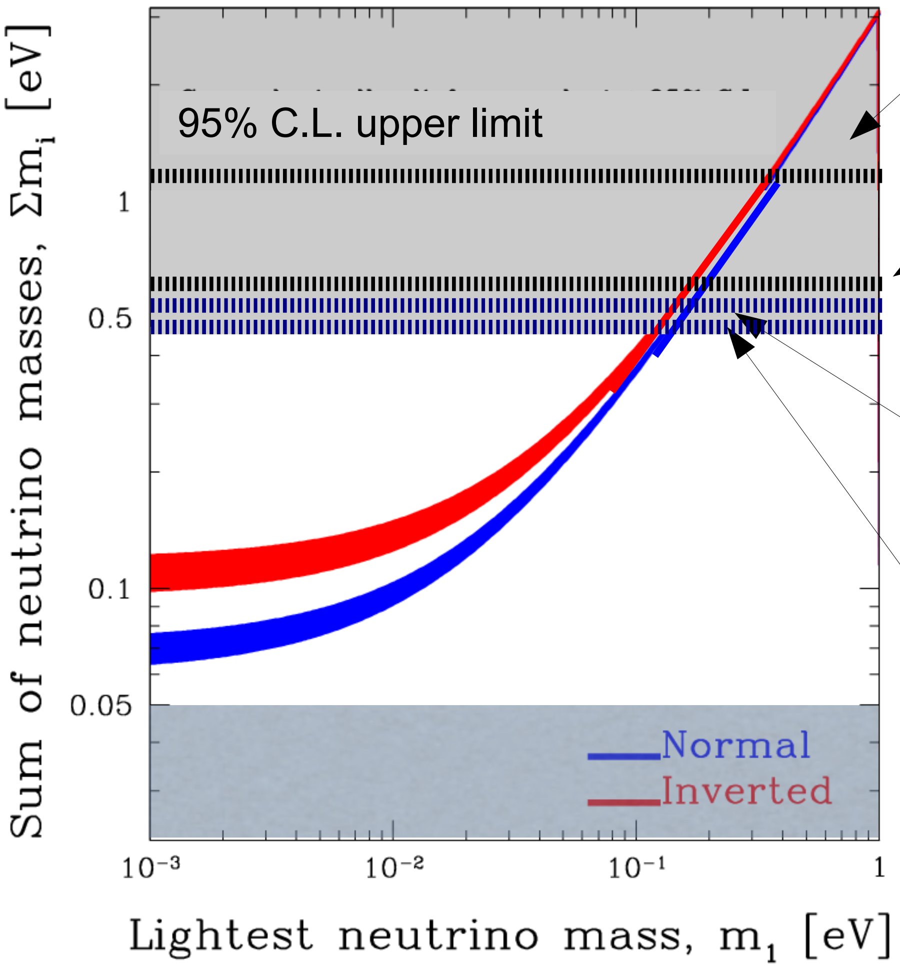
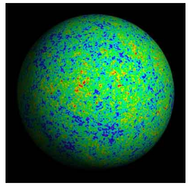


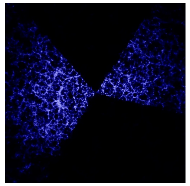
Fig. 13. Ratio of the matter power spectrum including three degenerate massive neutrinos with density fraction f_ν to that with three massless neutrinos. The parameters $(\omega_{\rm m}, \Omega_\Lambda) = (0.147, 0.70)$ are kept fixed, and from top to bottom the curves correspond to $f_\nu = 0.01, 0.02, 0.03, \ldots, 0.10$. The individual masses m_ν range from 0.046 eV to 0.46 eV, and the scale $k_{\rm nr}$ from $2.1 \times 10^{-3} h\,{\rm Mpc}^{-1}$ to $6.7 \times 10^{-3} h\,{\rm Mpc}^{-1}$ as shown on the top of the figure. $k_{\rm eq}$ is approximately equal to $1.5 \times 10^{-2} h\,{\rm Mpc}^{-1}$.

Present status...

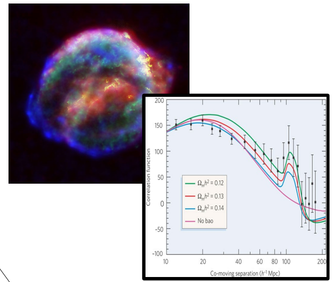




WMAP7 only*
Komatsu et al. 2010



WMAP7+SDSS-HPS *
Hannestad, Mirizzi, Raffelt & Y^3W 2010



WMAP5+SDSS-HPS +SN+HST
Reid et al. 2009
(extended models)

WMAP5+Weak lensing*
Tereno et al. 2008
Ichiki et al. 2008

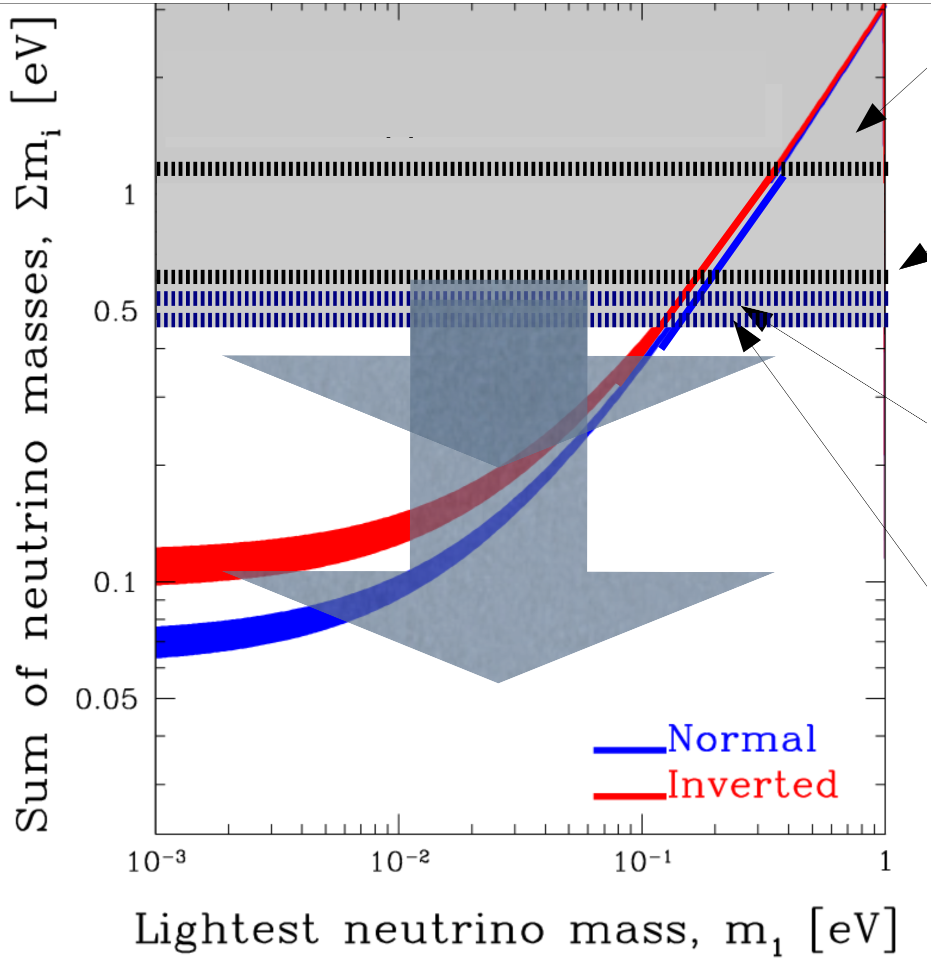
* ΛCDM+m_ν

A bit of forecast

Probe	Current $\sum m_\nu$ (eV)	Forecast $\sum m_\nu$ (eV)	Key Syster		
CMB Primordial	1.3	0.6	Recombina		
CMB Primordial + Distance	0.58	0.35	Distance ments		
Lensing of CMB	∞	0.2 – 0.05	NG of anisotropie		
Galaxy Distribution	0.6	0.1	Nonlinearit		
Lensing of Galaxies	0.6	0.07	Baryons, N metric reds		
Lyman α	0.2	0.1	Bias, Metals, QSO continuum	SDSS, BOSS, Keck	BigBOSS [81], TMT [99], GMT [89]
21 cm	∞	0.1 – 0.006	Foregrounds, Astrophysical modeling	GBT [11], LOFAR [91], PAPER [53], GMRT [86]	MWA [93], SKA [95], FFTT [49]
Galaxy Clusters	0.3	0.1	Mass Function, Mass Calibration	SDSS, SPT, ACT, XMM [101] Chandra [83]	DES, eRosita [87], LSST

Planck -- CMBPol

k=0.001–1Mpc^{-1} for weak lensing !

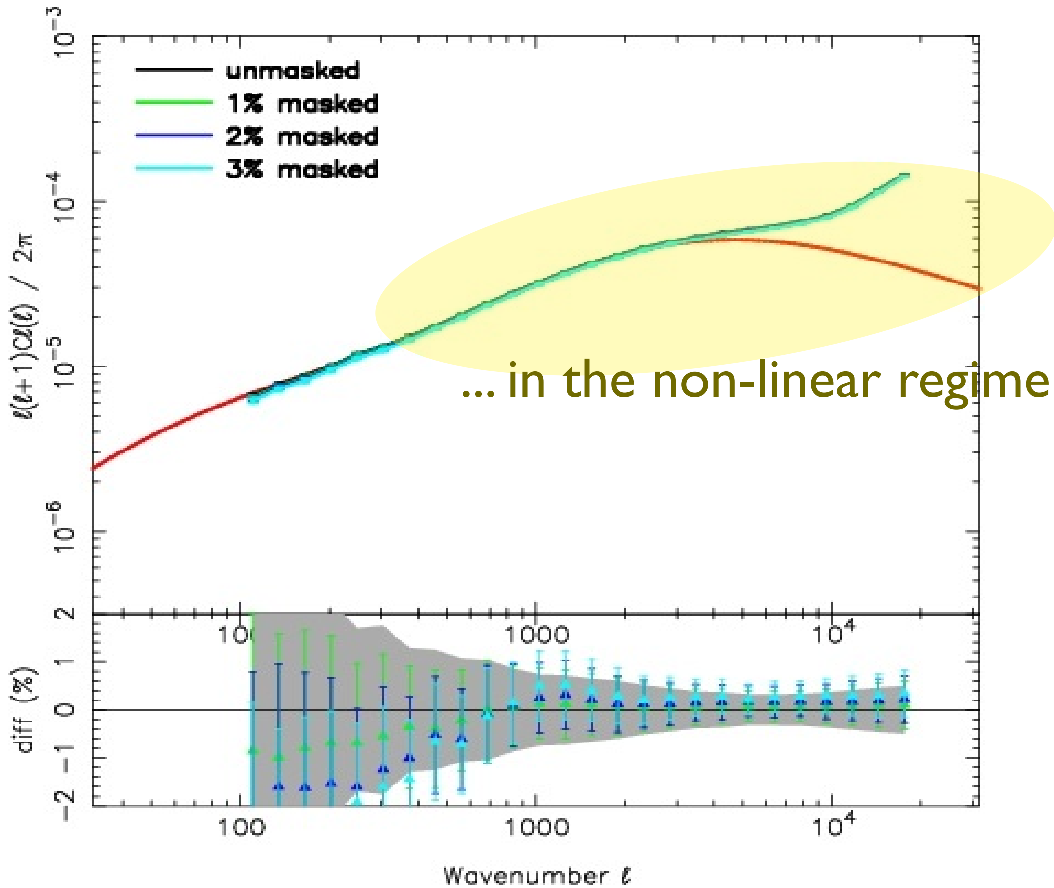


in combination with WMAP; 95% upper limits

Abazajian et al. 1103.5083

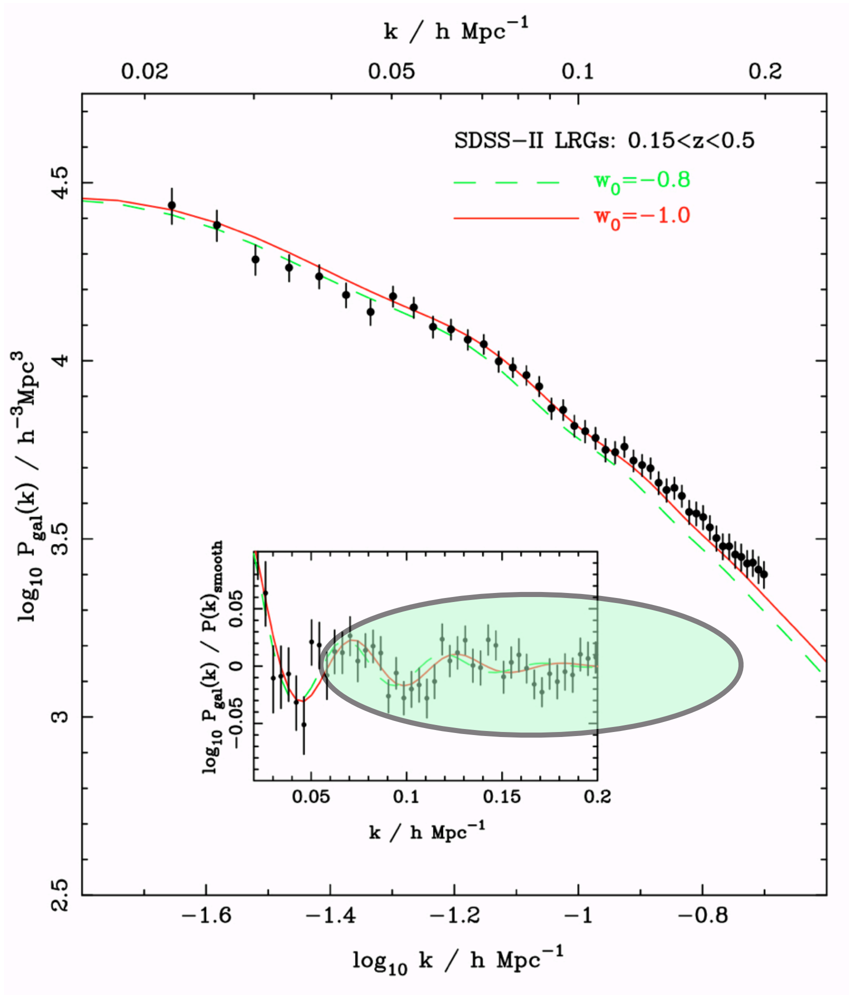
a critical reading: beyond the linear theory...

Cosmic shear



From the Euclid red book

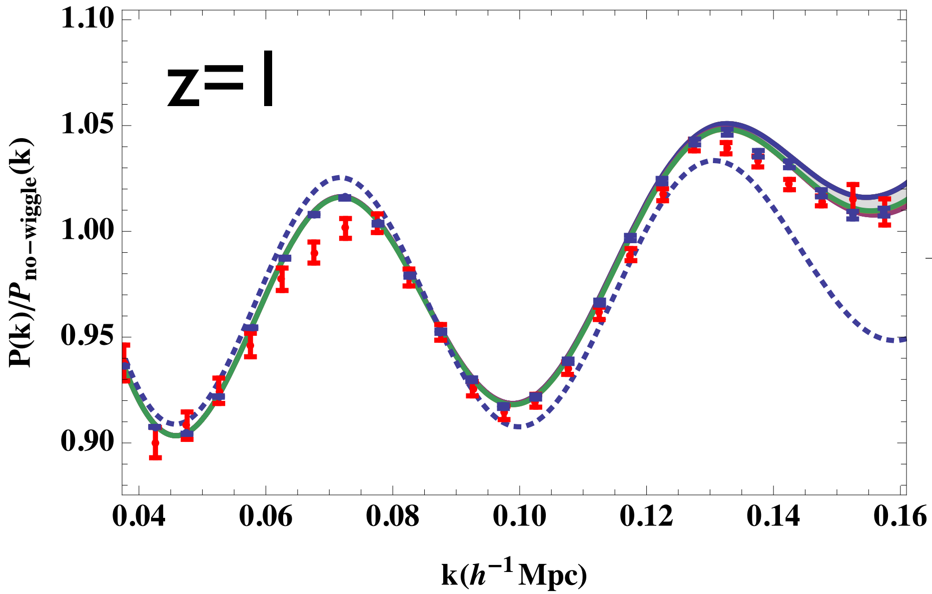
BAO



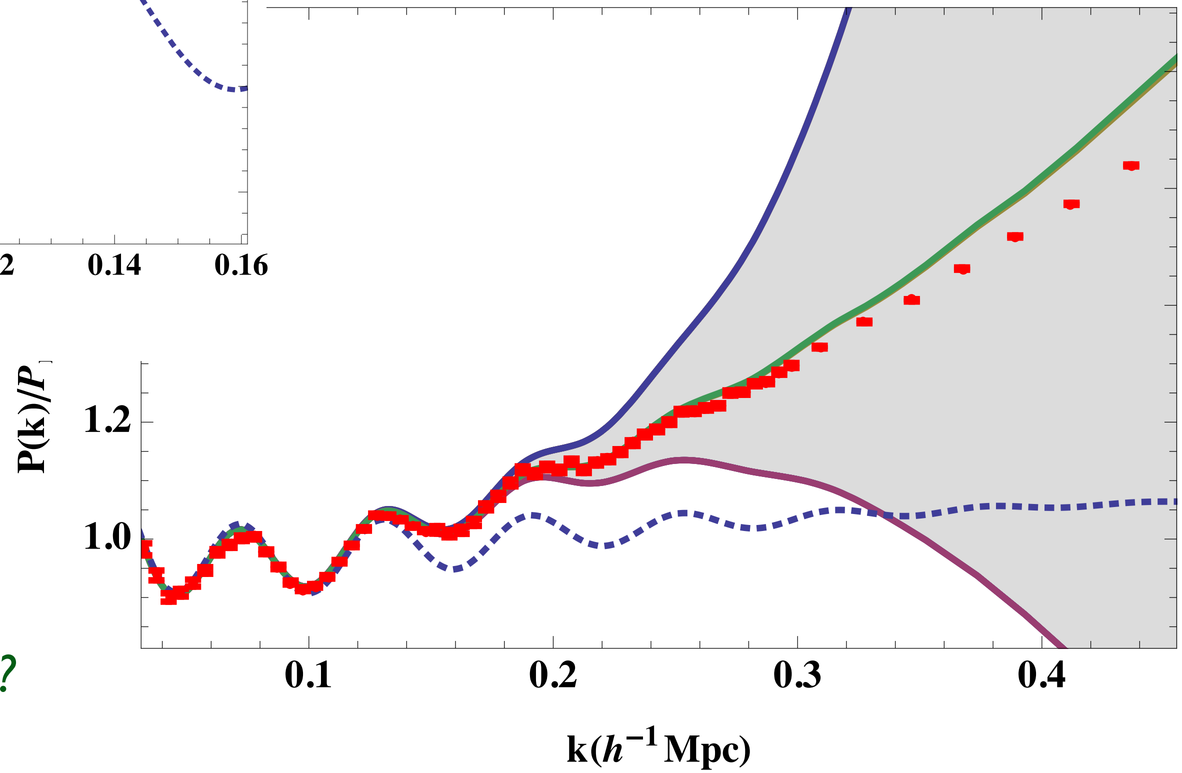
State of the art for Perturbation Theory calculations

$$\dot{\delta}_c(\mathbf{k},\tau) + \theta_c(\mathbf{k},\tau) = \alpha(\mathbf{k}_1,\mathbf{k}_2)\theta(\mathbf{k}_1)\delta(\mathbf{k}_2)$$

$$\dot{\theta}_c(\mathbf{k},\tau) + \mathcal{H}\theta_c(\mathbf{k},\tau) + \frac{3}{2}\mathcal{H}^2\delta_{\rm total}(\mathbf{k},\tau) = \beta(\mathbf{k}_1,\mathbf{k}_2)\theta(\mathbf{k}_1)\theta(\mathbf{k}_2)$$



2-loop results(!) for Λ-CDM



FB, A.Taruya, T. Nishimichi, '??

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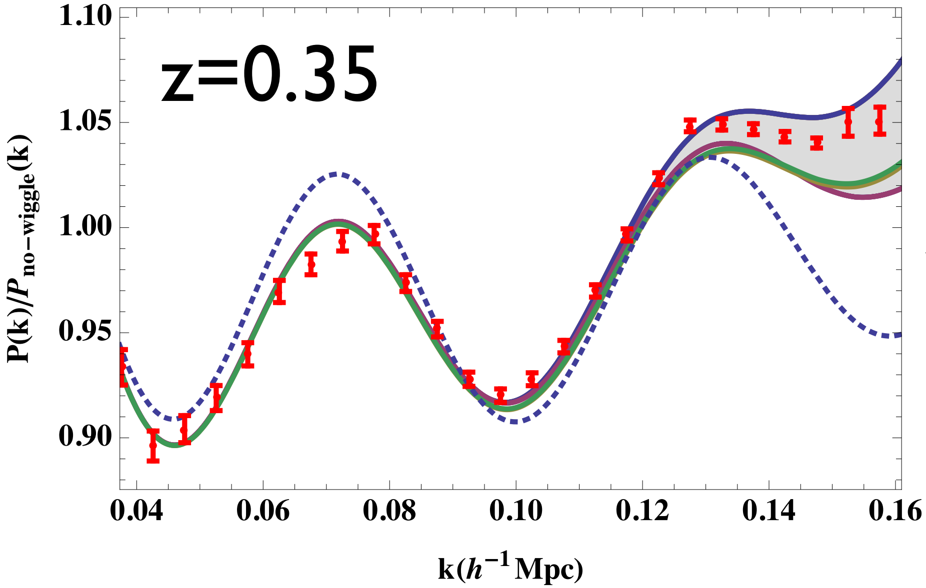

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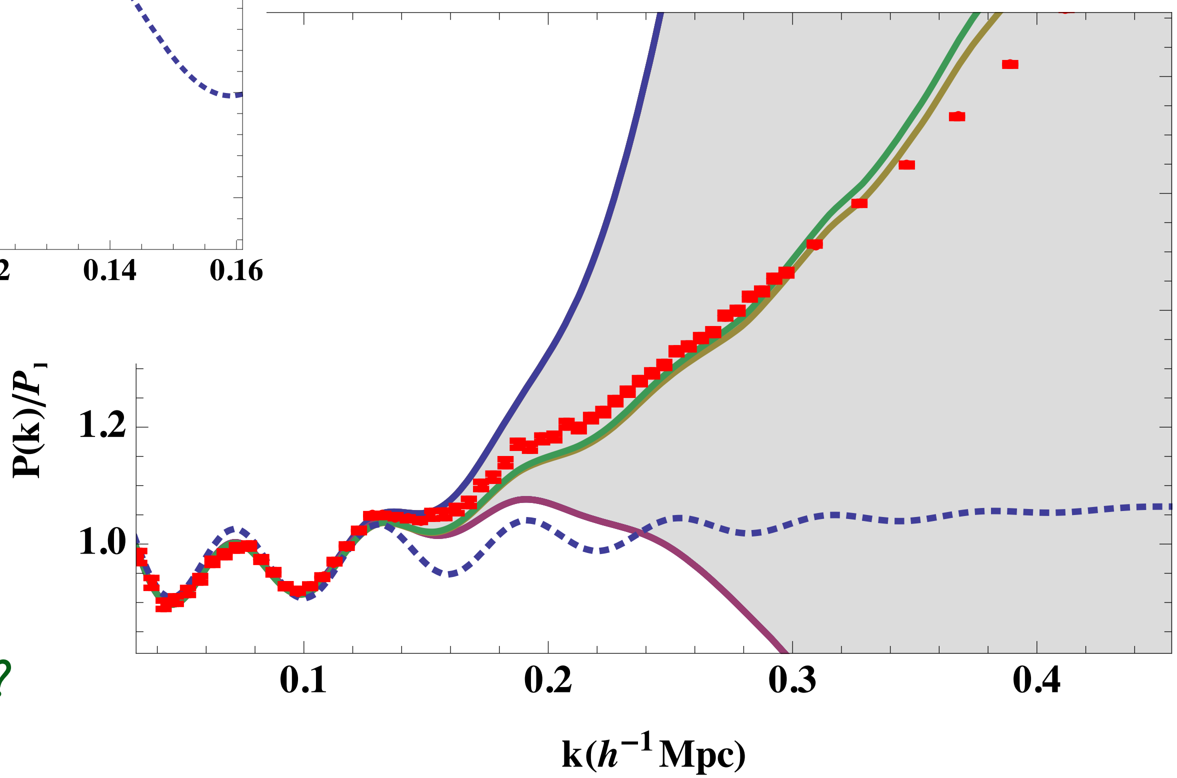

FB, A.Taruya, T. Nishimichi, '??

Conclusions

- Constraints from linear regime calculations (CMB) are solid;
- local LSS observations offer a potential for important discoveries - provided theoretical constraints are well controlled (NL evolution);
- z-evolution is key to separate from other parameters;