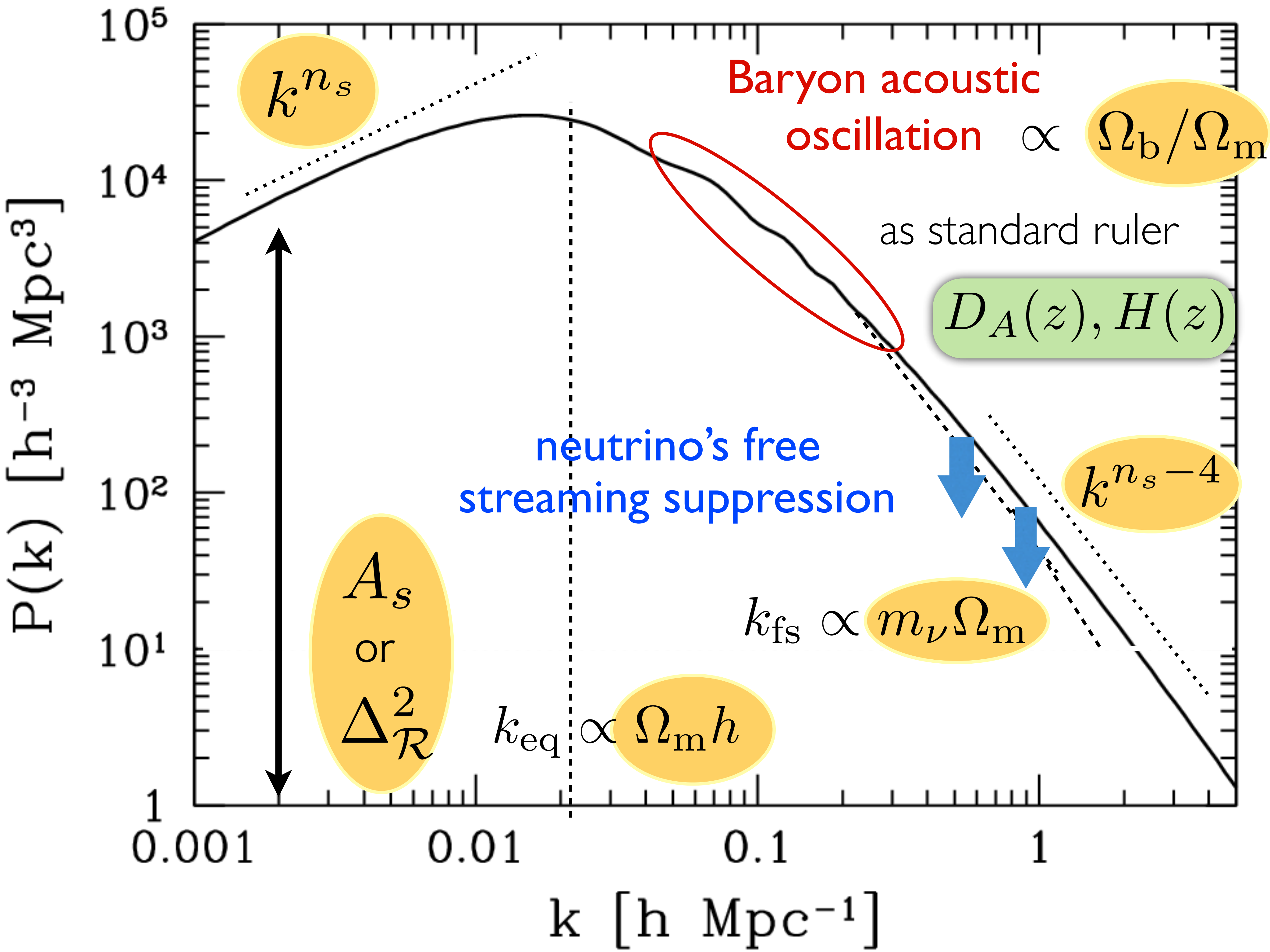
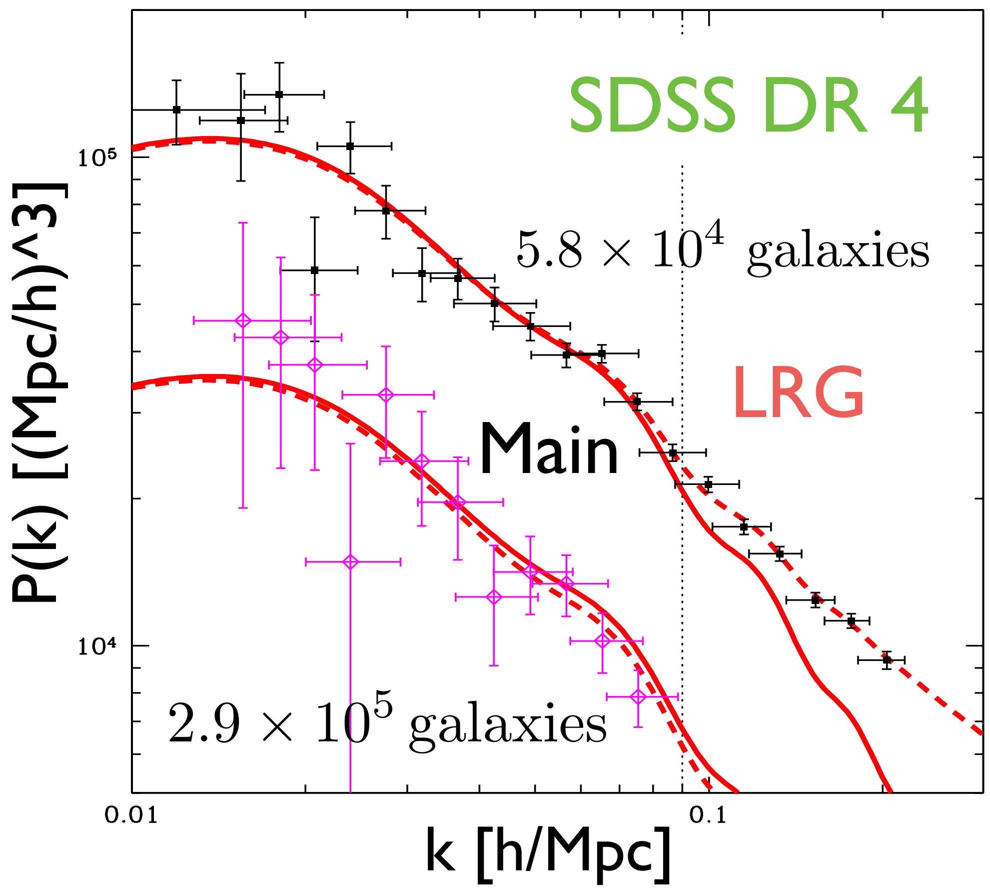
Linear theory of structure formation

(Linear) matter power spectrum

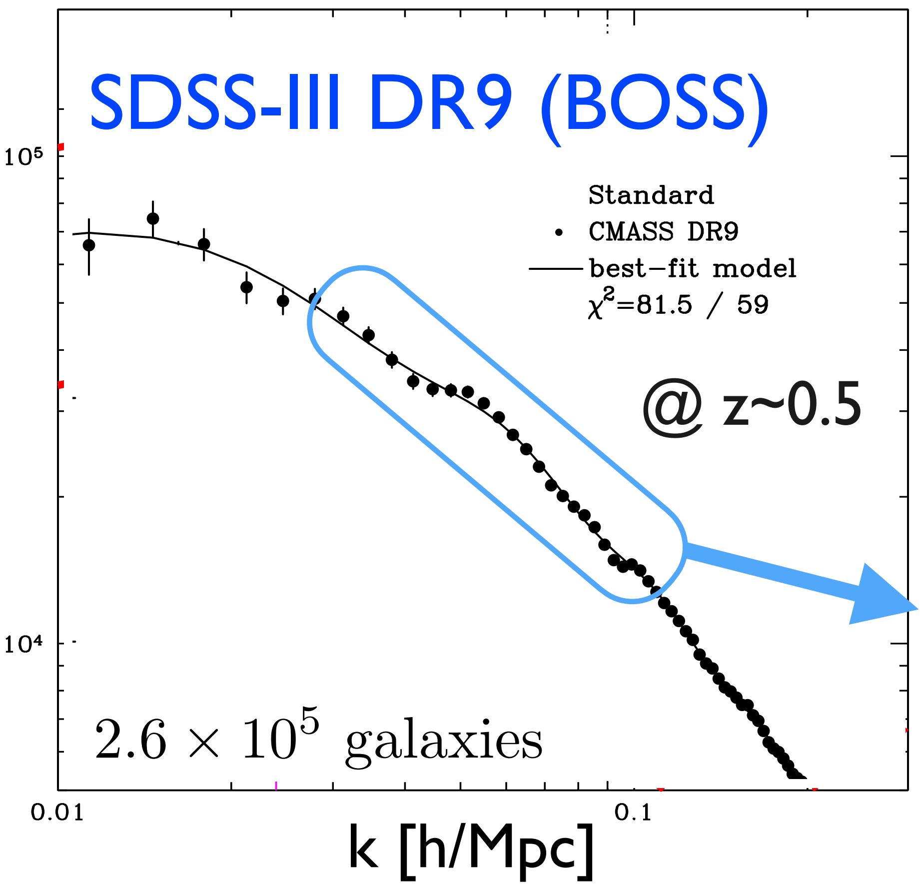


Galaxy power spectrum

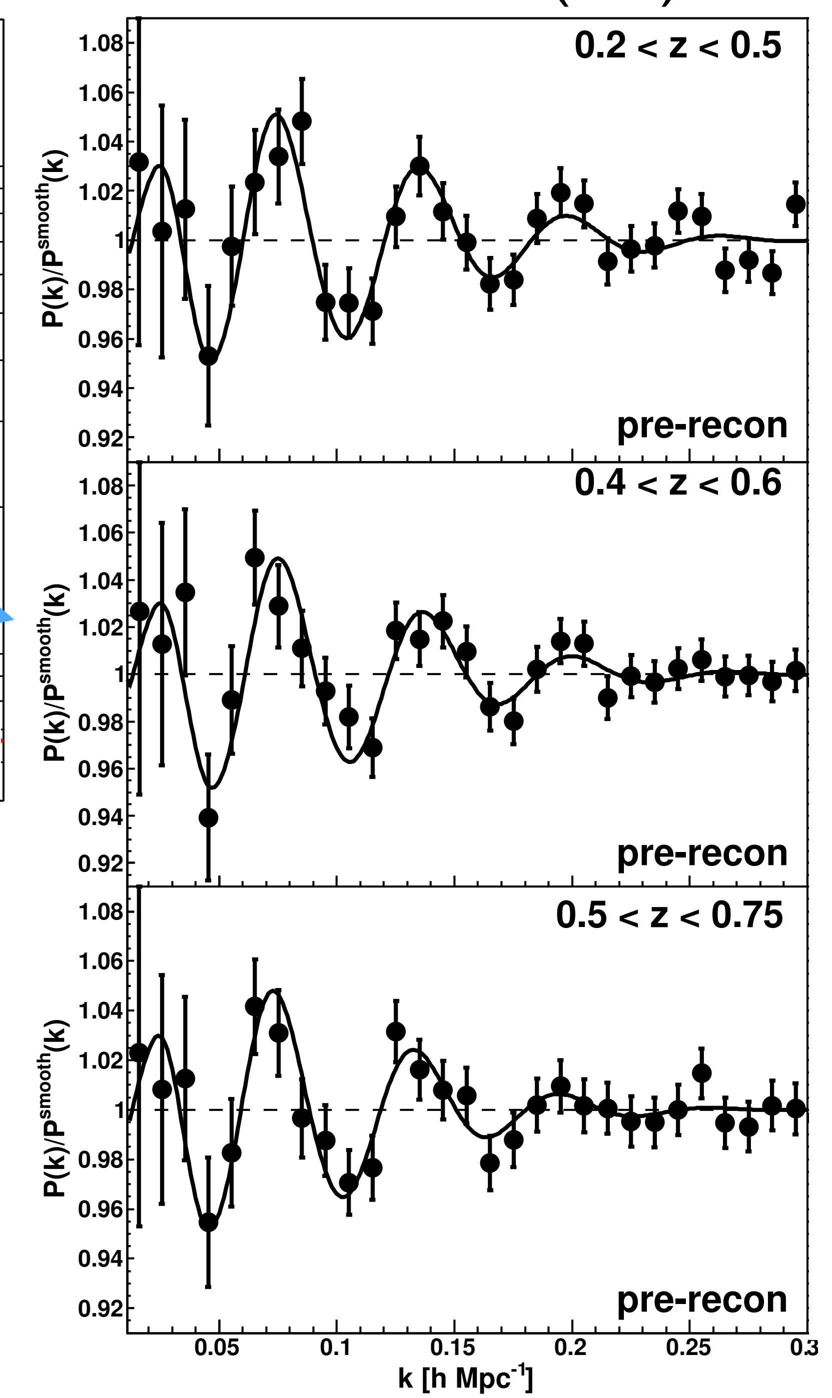
Tegmark et al. ('06)



Anderson et al. ('12)



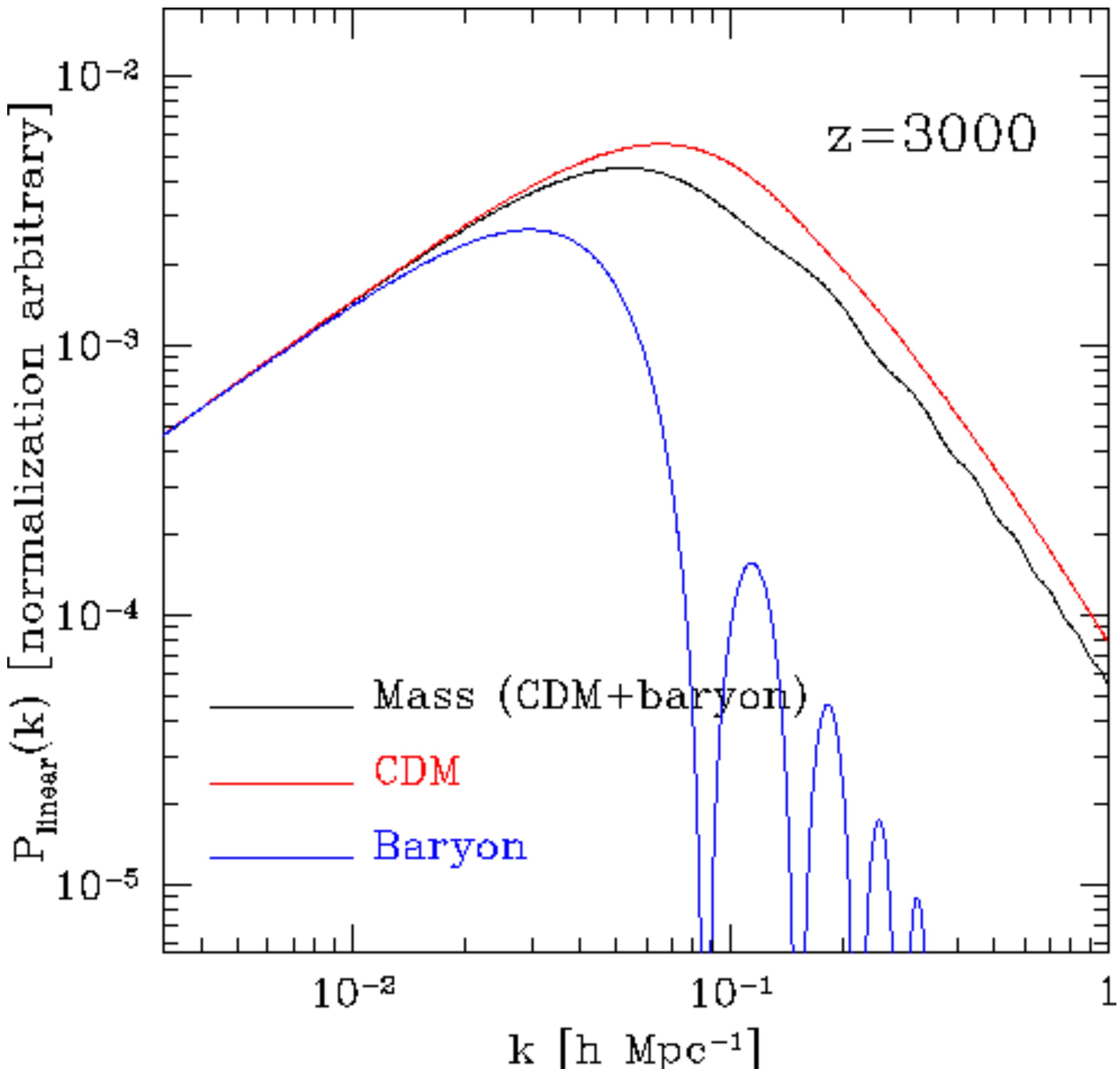
Beutler et al. ('16)



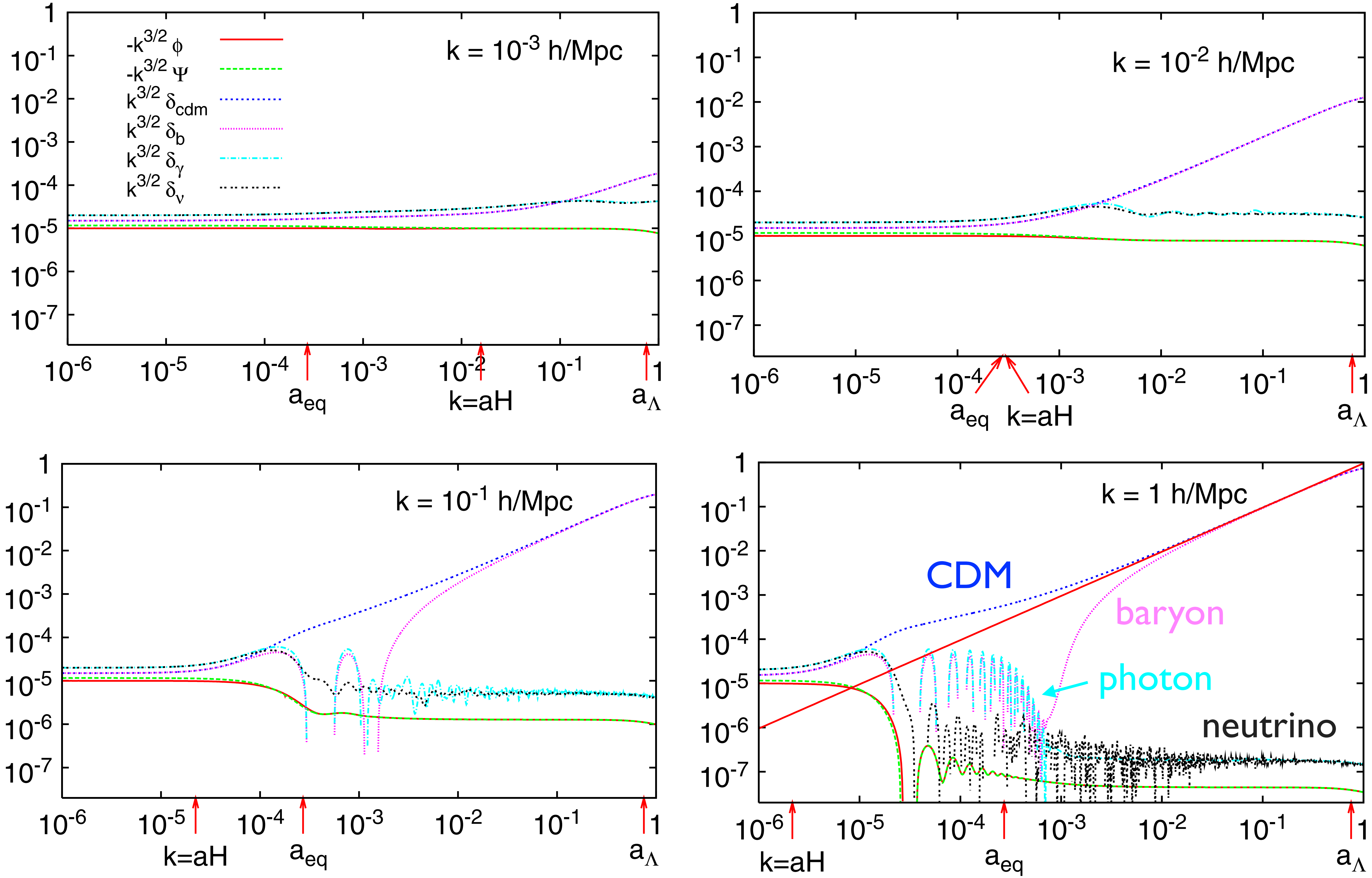
SDSS-III DR12 (BOSS)

1.2×10^6 galaxies

Evolution of power spectrum

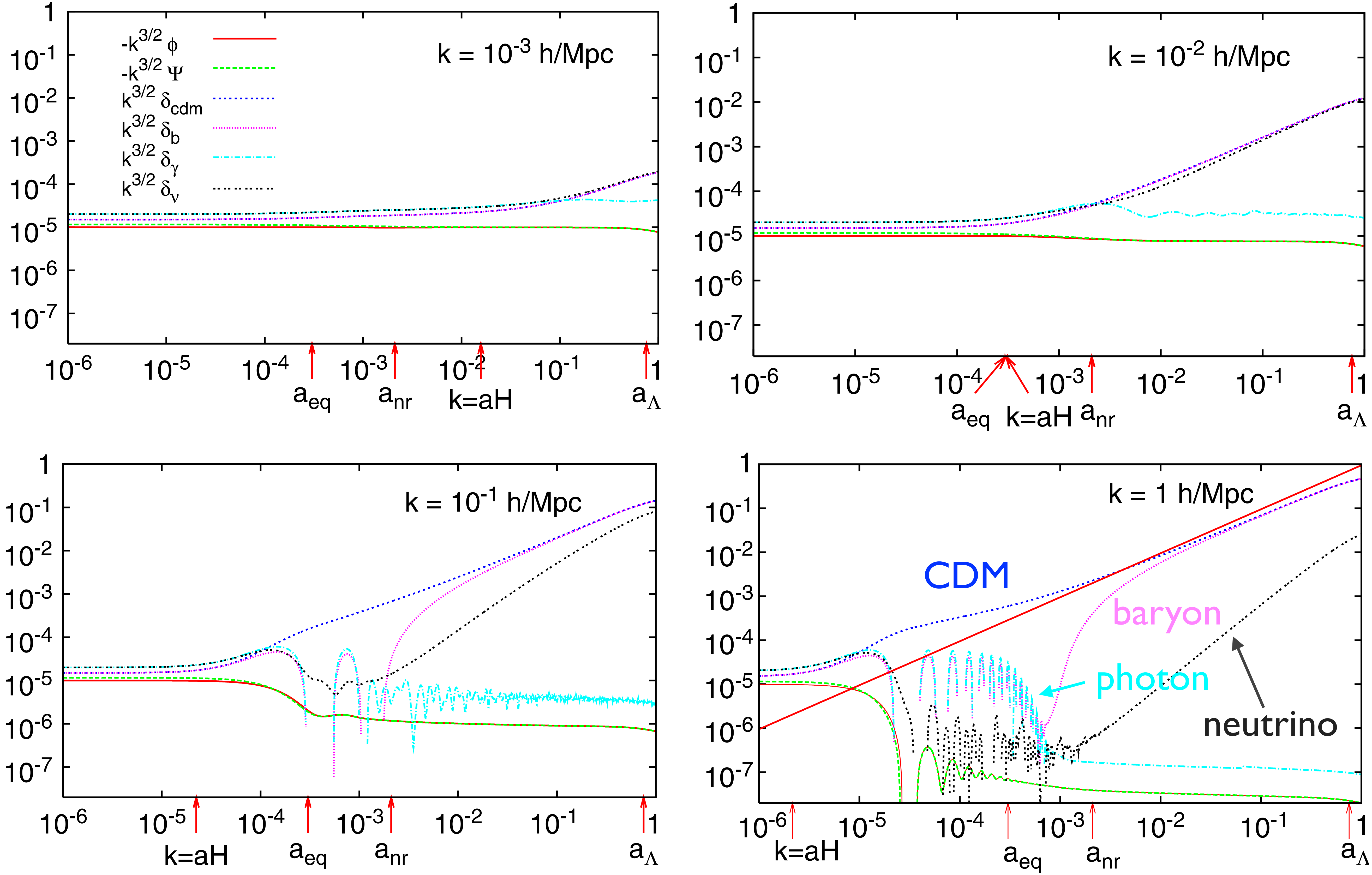


ΛCDM (massless neutrino)



Lesgourgues & Pastor, Phys.Rep. 429 ('06) 307

ΛMCDM (massive neutrino) $(f_\nu = 0.1)$

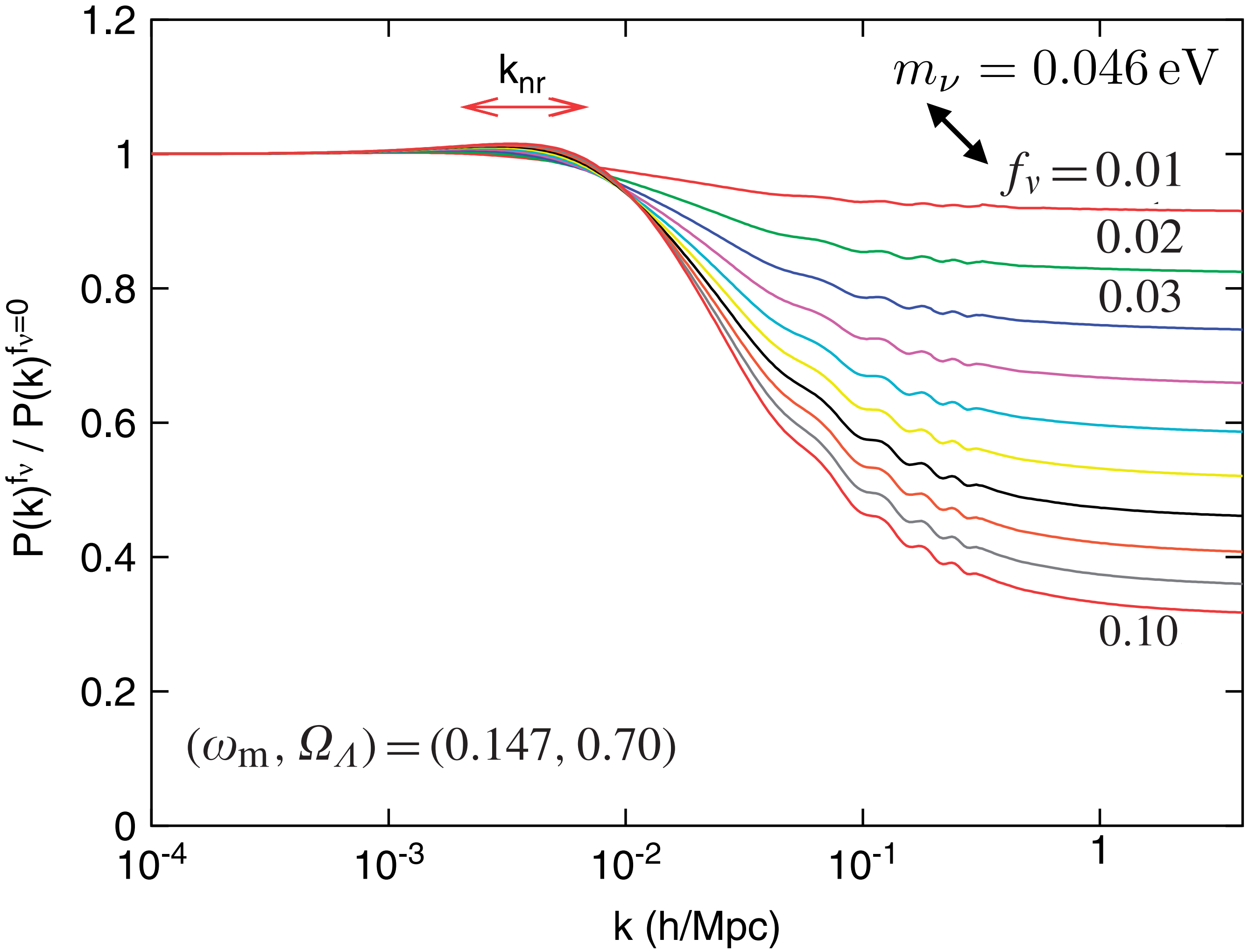


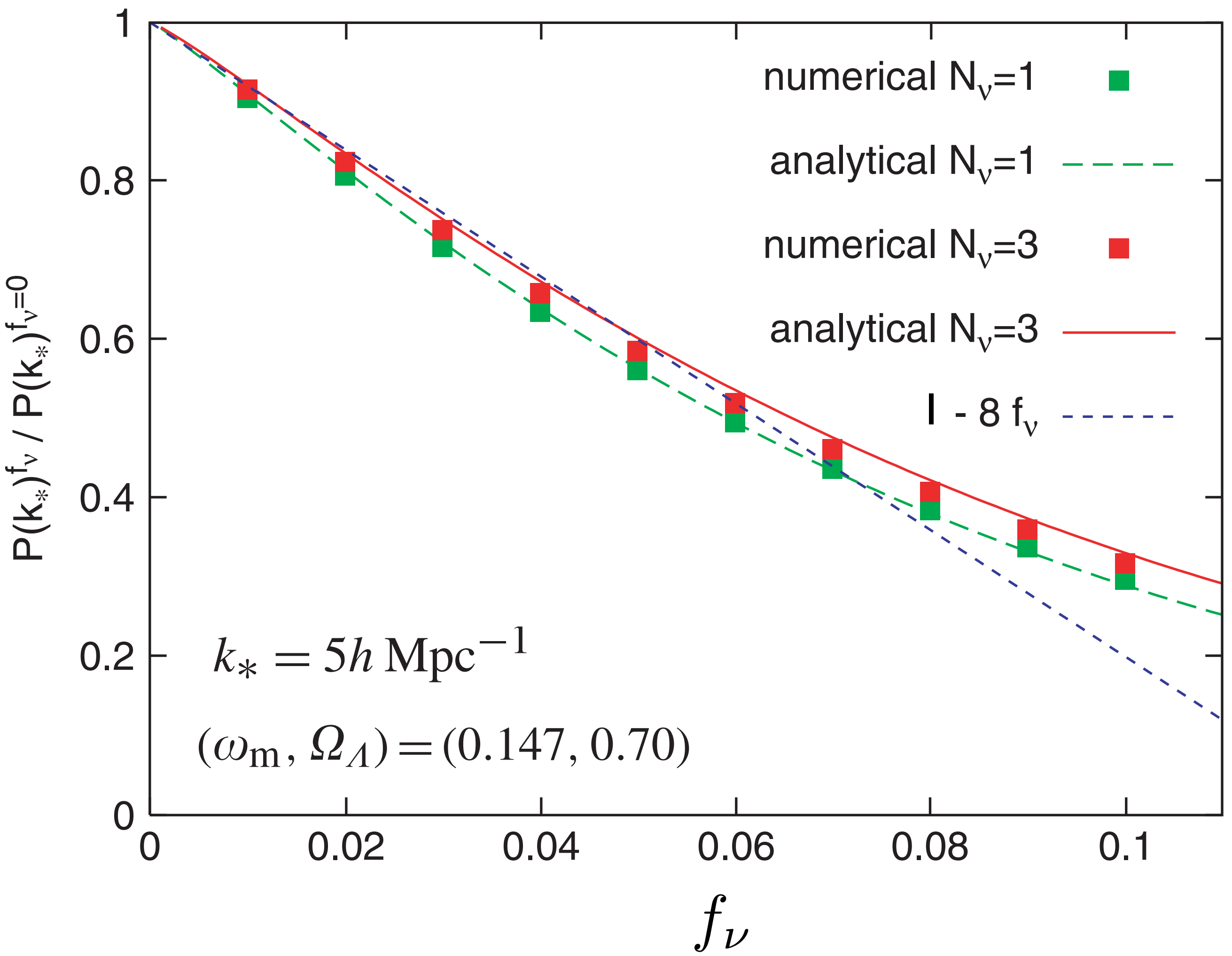
Lesgourgues & Pastor, Phys.Rep. 429 ('06) 307

ν's free-streaming suppression

$$k_{\rm FS} = \frac{0.677}{(1+z)^2}\,\frac{m_\nu}{1\,{\rm eV}}\,\sqrt{\Omega_{\rm m,0}(1+z)^3+\Omega_\Lambda}\;h\,{\rm Mpc}^{-1}$$

$$\frac{P(k)|_{f_\nu\neq 0}}{P(k)|_{f_\nu=0}} = (1-f_\nu)^3\left\{1.9\times 10^5\,\frac{\Omega_{\nu,0}h^2}{N_{\rm eff}}\,\frac{D_1(a)}{a}\right\}^{-(6/5)f_\nu}$$

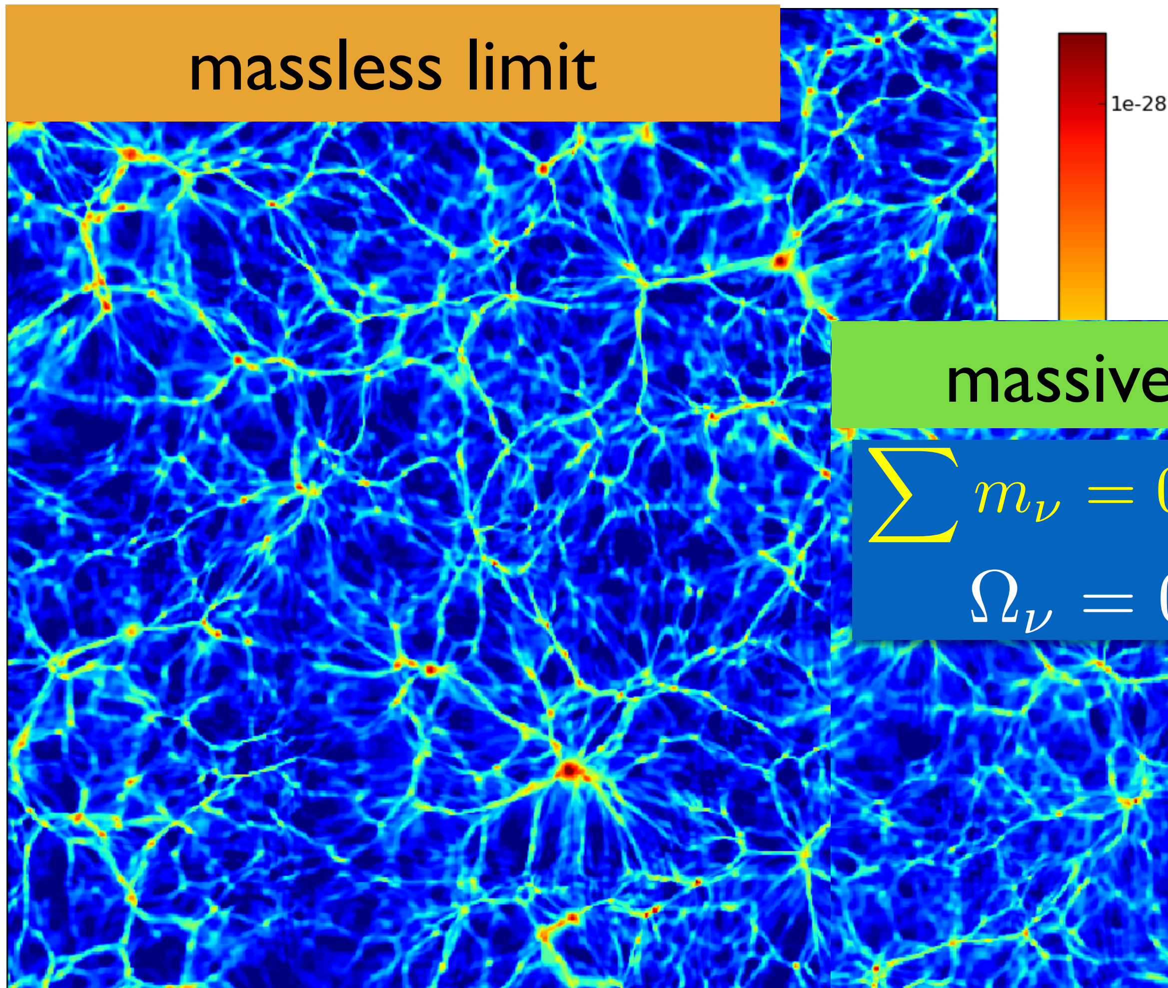


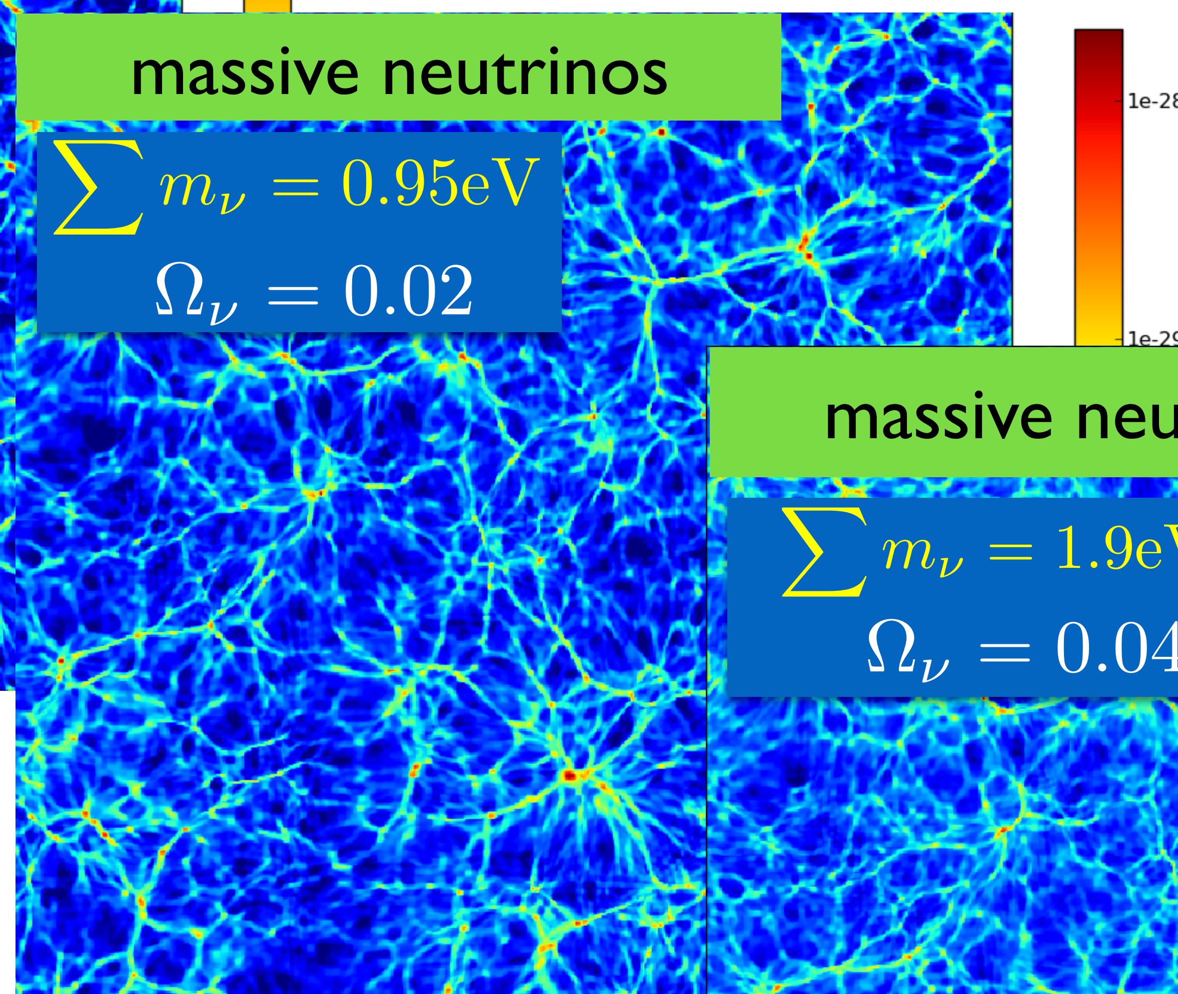


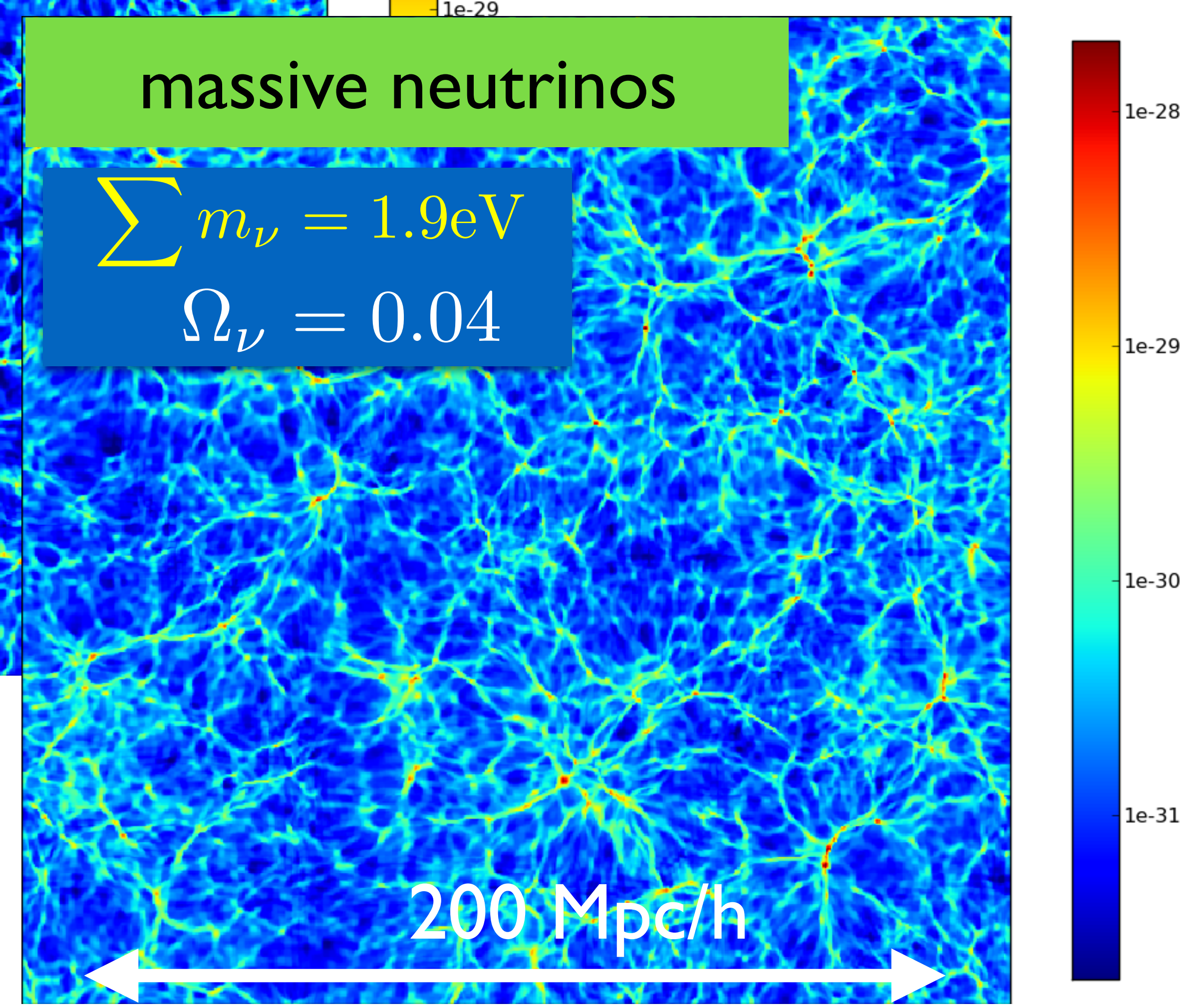
Lesgourgues & Pastor,
Phys.Rep. 429 ('06) 307

Impact on large-scale structure

N-body simulations





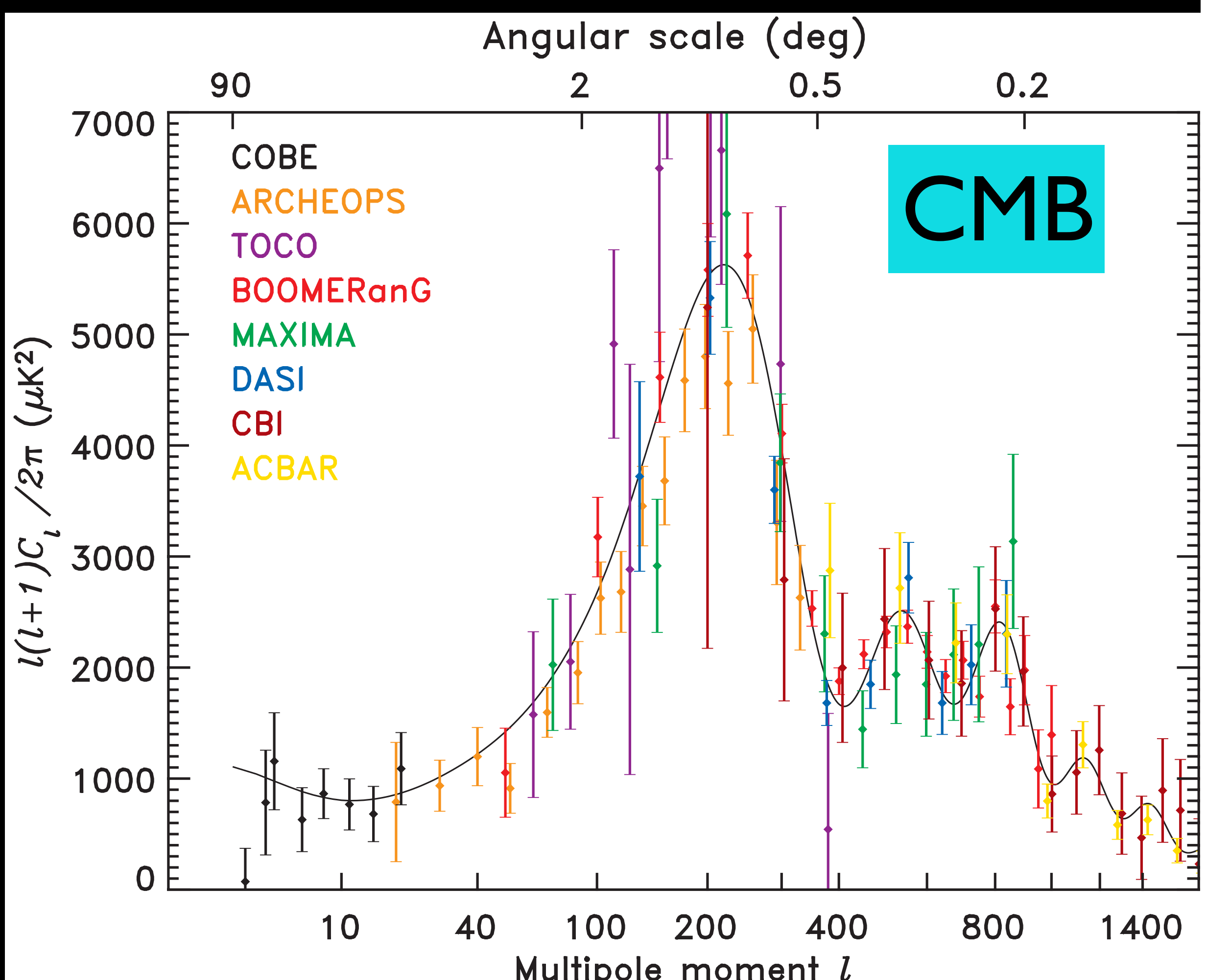


$$\Omega_{\rm m} = \Omega_{\rm cdm} + \Omega_{\rm b} + \Omega_\nu$$
$$= 0.266$$

S. Agarwal & H. Feldman ('11)

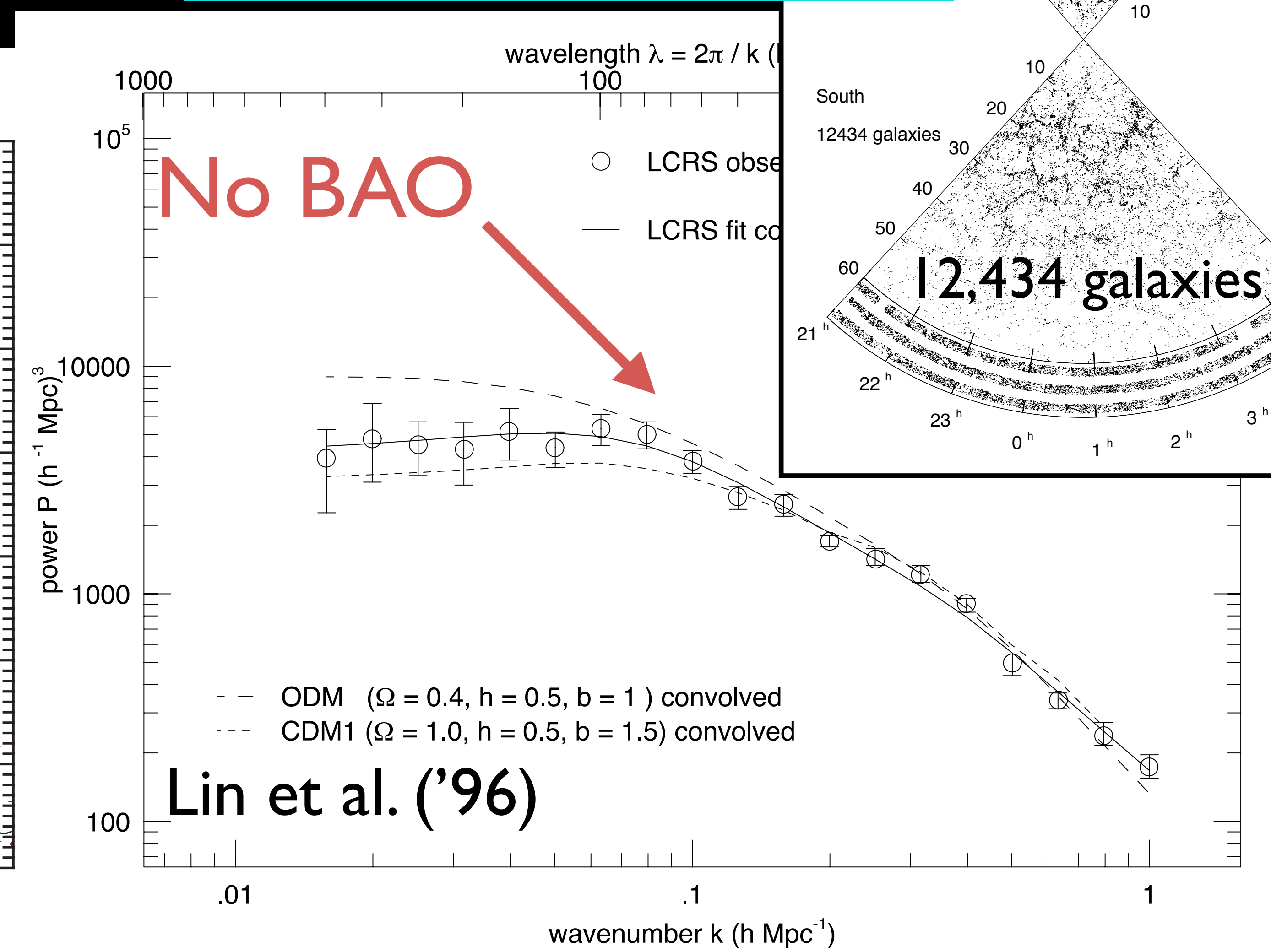
Pre-precision cosmology era

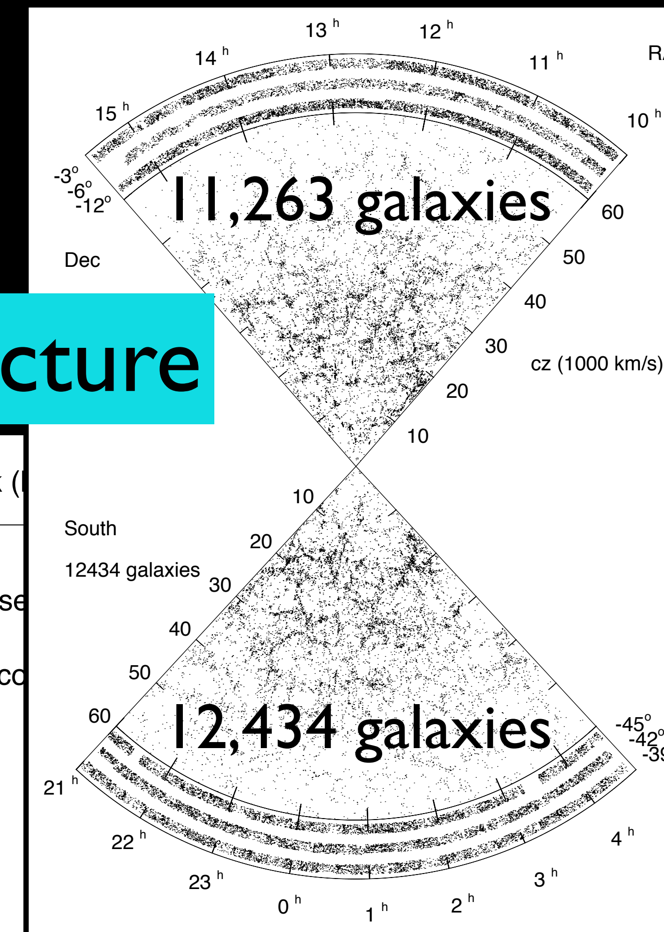
No full-sky & high-resolution CMB measurements



Hinshaw et al. ('01)

Large-scale structure





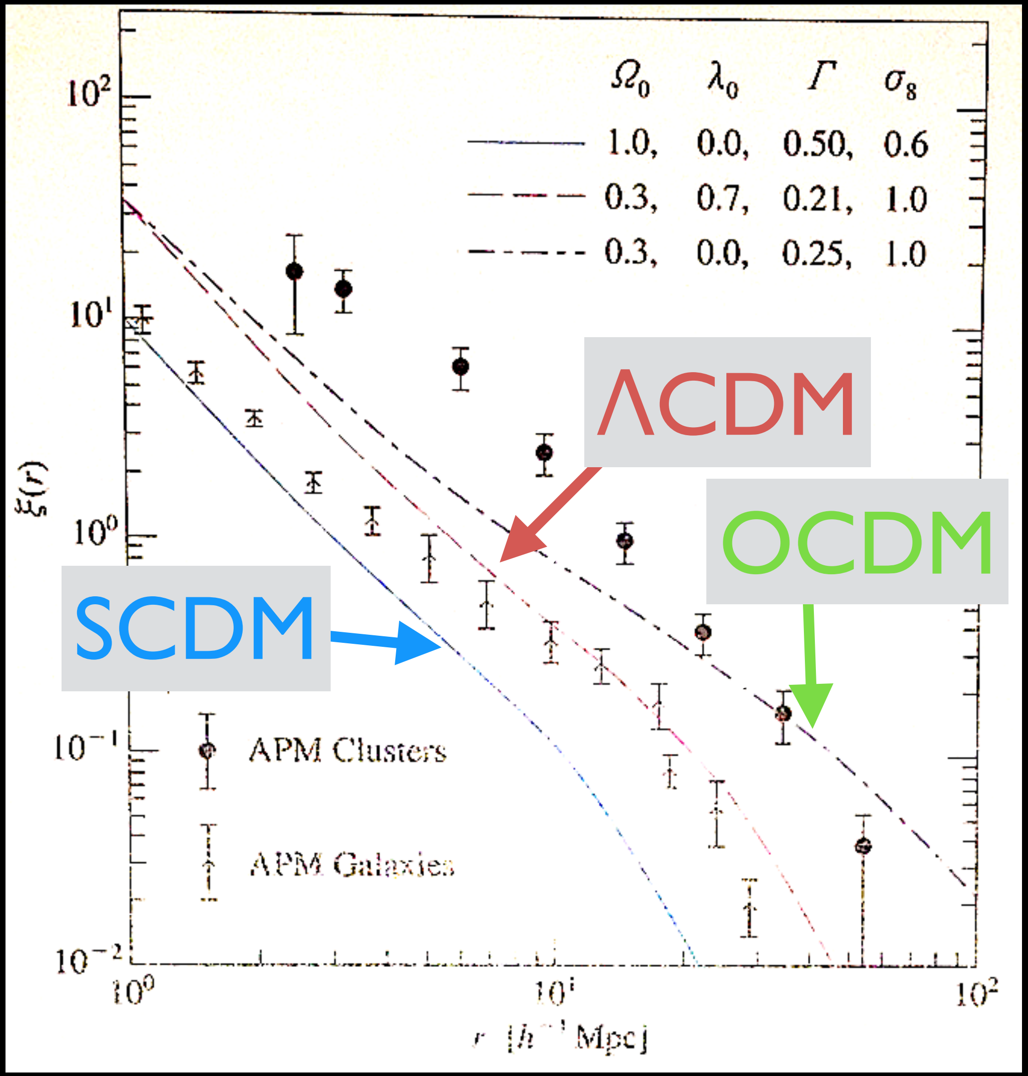
Las Campanas redshift survey (largest survey before SDSS/2dF)

Standard model candidates

SCDM (Standard CDM) $(\Omega_{\rm m} = 1,\ \Omega_{\rm DE} = 0,\ h \simeq 0.5,\ \sigma_8 \simeq 0.6)$

OCDM (Open CDM) $(\Omega_{\rm m} \simeq 0.3,\ \Omega_{\rm DE} = 0,\ h \simeq 0.8,\ \sigma_8 \simeq 1.0)$

ΛCDM (Lambda CDM) $(\Omega_{\rm m} \simeq 0.3,\ \Omega_{\rm DE} \simeq 0.7,\ h \simeq 0.7,\ \sigma_8 \simeq 1.0)$



Hard to distinguish between each other with limited cosmological observations

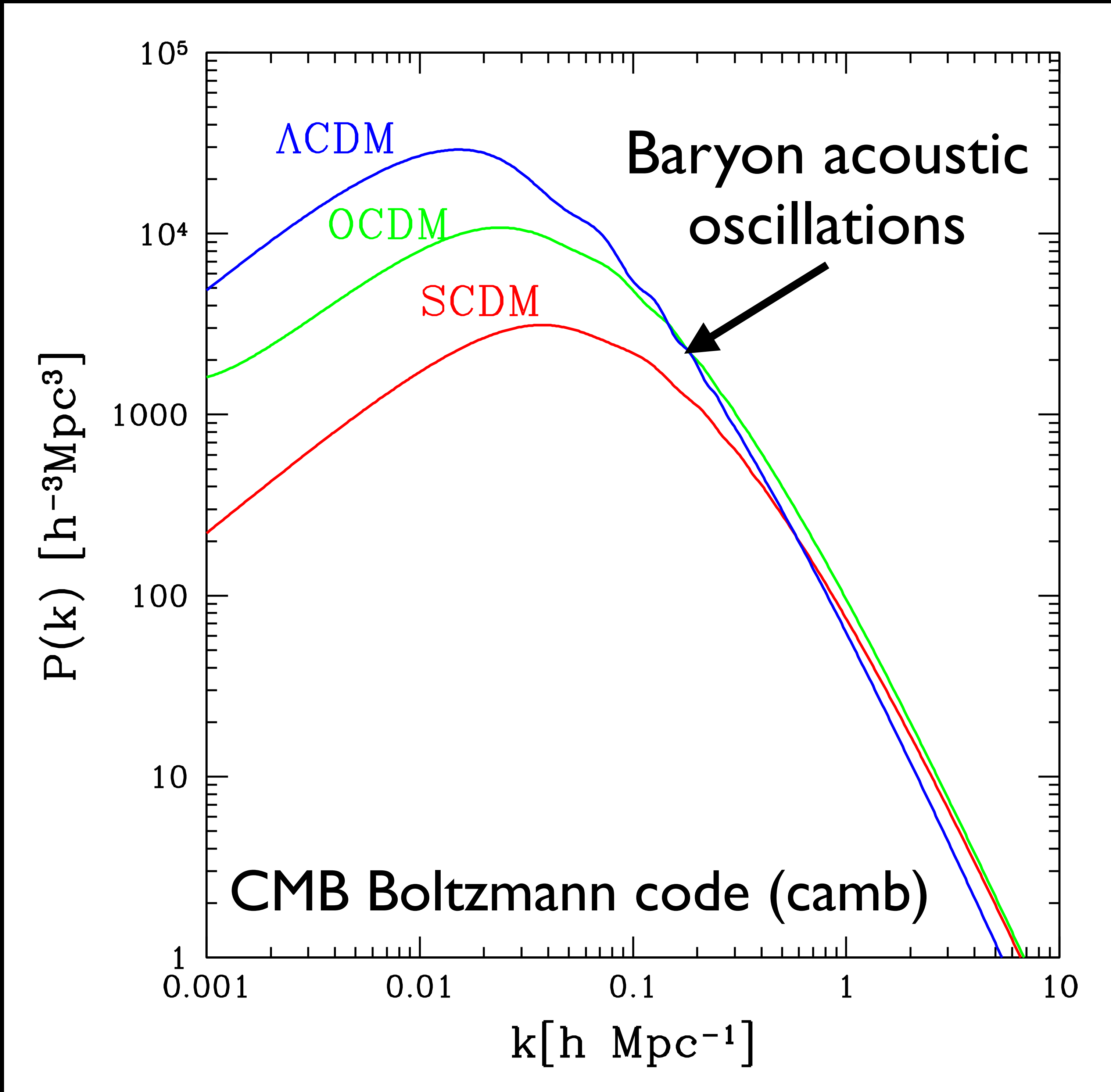
BUTSURI 56, No.3 (2001) p.169

Linear power spectrum

SCDM $(\Omega_m = 1, \Omega_\Lambda = 0, \sigma_8 = 0.59)$

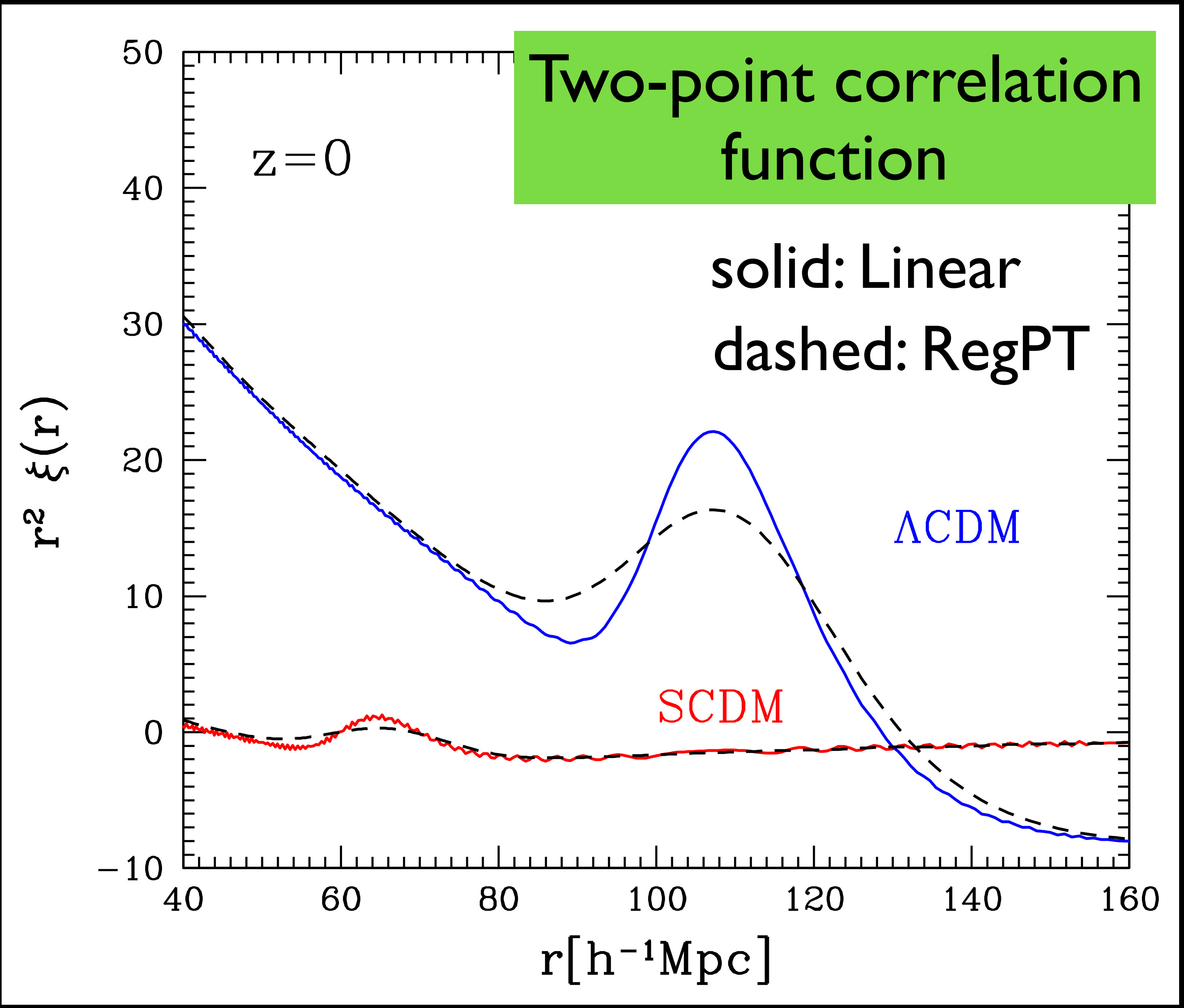
ΛCDM $(\Omega_m = 0.272, \Omega_\Lambda = 0.728, \sigma_8 = 0.81)$

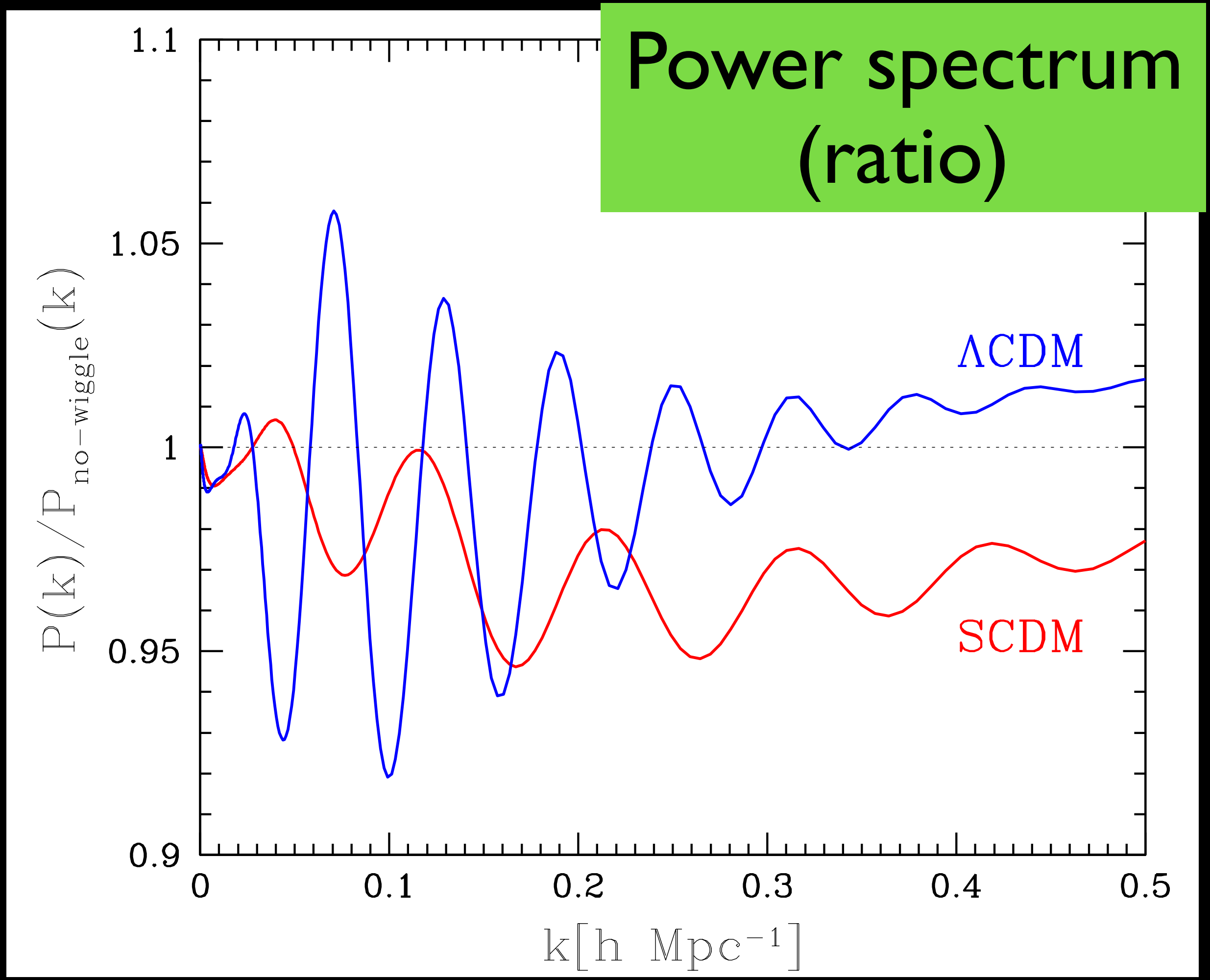
OCDM $(\Omega_m = 0.45, \Omega_\Lambda = 0, \sigma_8 = 0.80)$



Baryon acoustic oscillations
in SCDM model

BAO signal can be too much small to detect !!





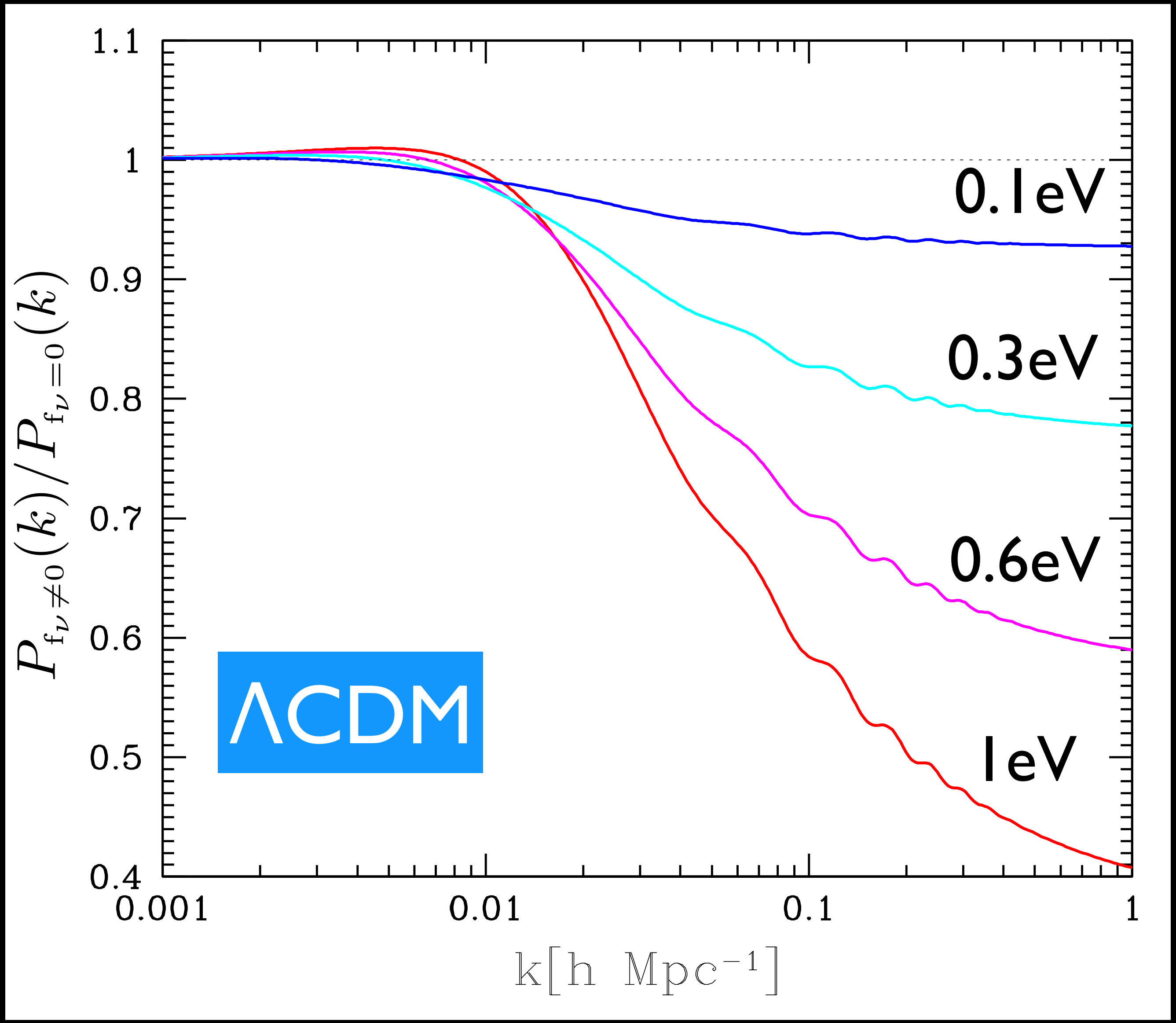
With a small signal of BAO, accurate measurement of cosmic expansion is difficult

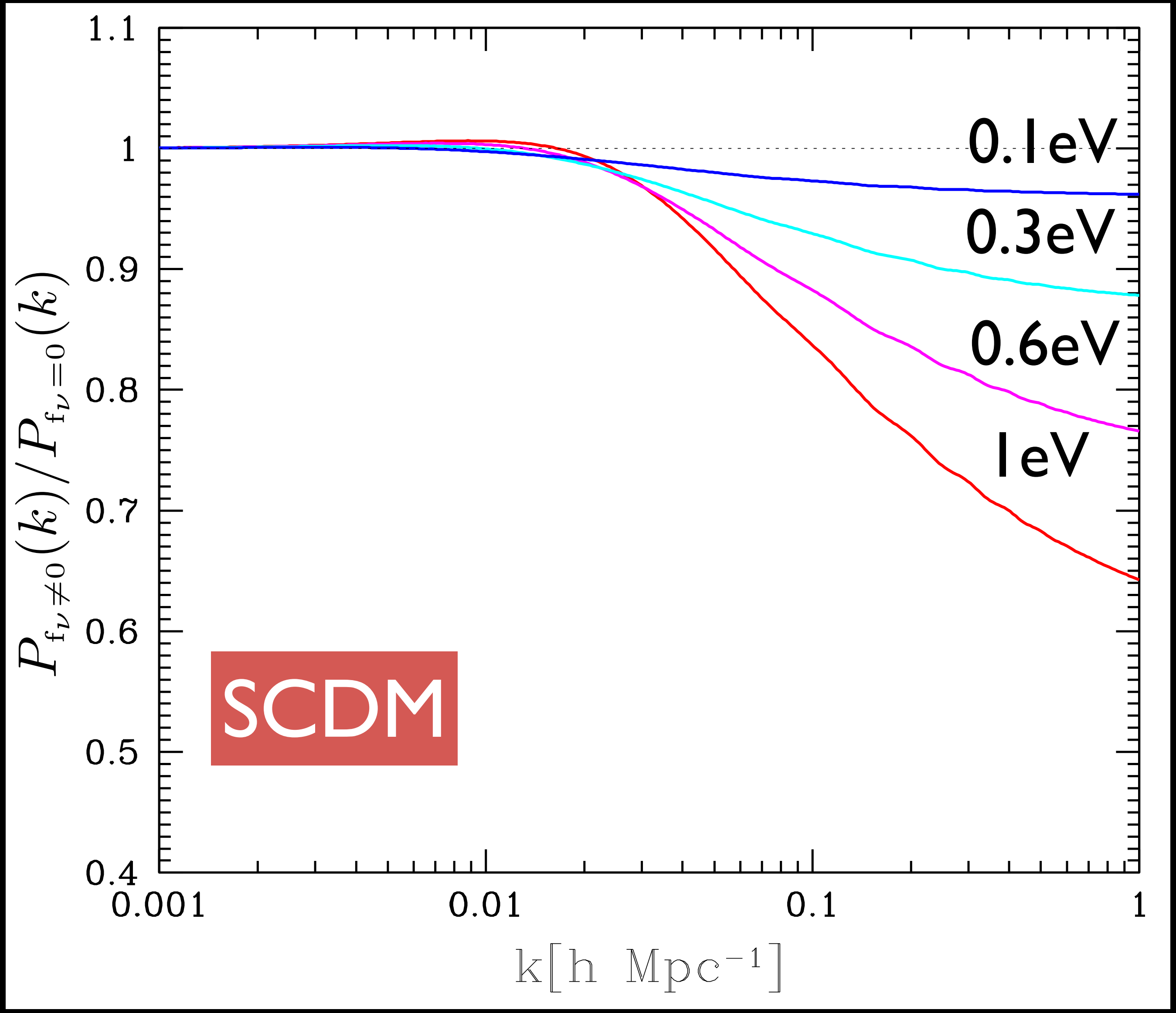
ν's free-streaming suppression

in SCDM model

$$\frac{P_{f_\nu \neq 0}(k)}{P_{f_\nu = 0}(k)} \simeq 1 - 8\, f_\nu \quad ; \quad f_\nu = \frac{\Omega_\nu}{\Omega_m}$$

(e.g., Hu et al. '98)





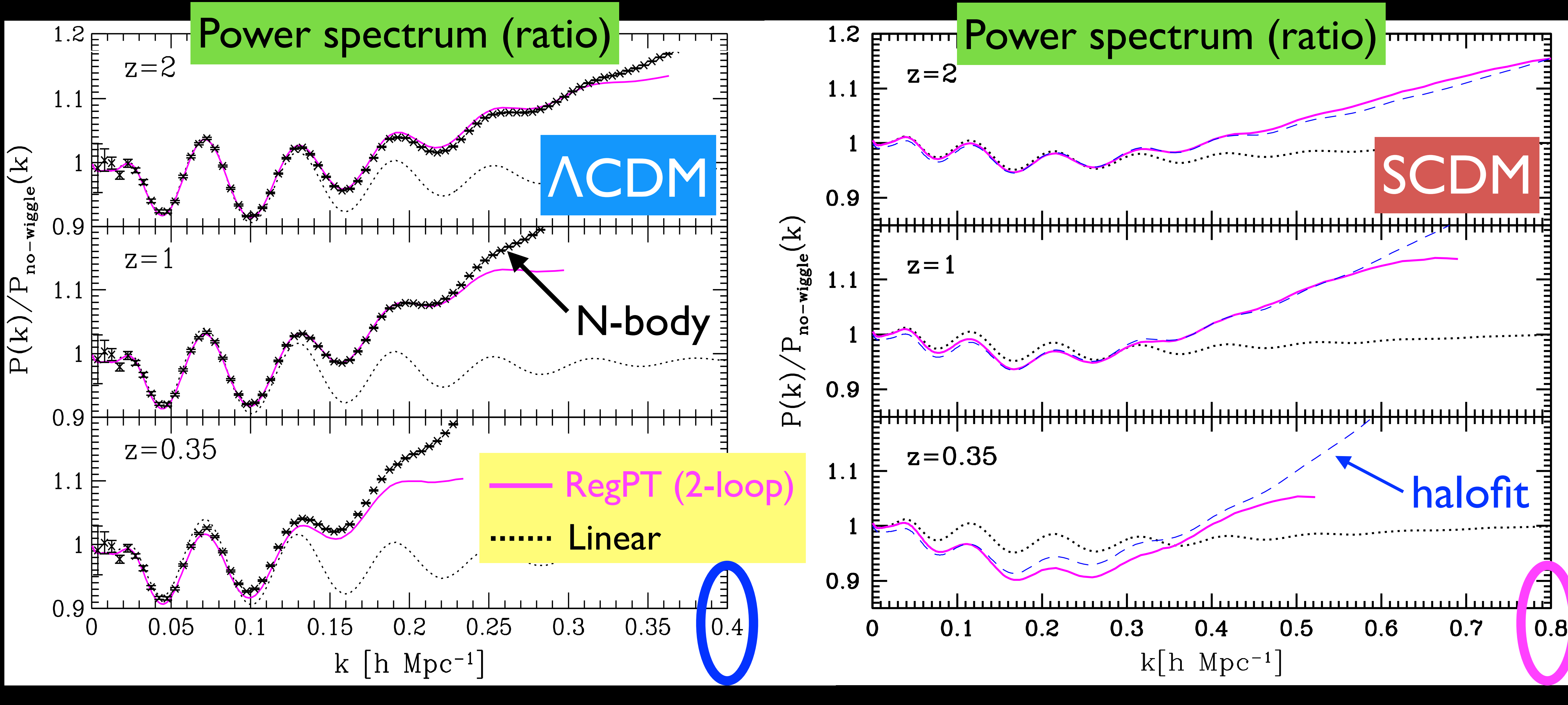
Suppression effect diminishes in SCDM

Nonlinear gravitational evolution

Perturbation theory (PT) calculation can do a great job at high-z

(but soon becomes worse at low-z)

Even the standard PT would be much more powerful and accurate



Large-scale structure in SCDM

～summary～

- BAO : signal is tiny, and even the detection is challenging
- ν's free-streaming suppression : more difficult to measure ν-mass
- Nonlinear evolution : standard PT does work well. No chance to develop resummation/renormalization technique ?
- Redshift-space distortions : Test of gravity may get in trouble

size of RSD $\propto \; f(z) \equiv \dfrac{d\ln D_+(z)}{d\ln a} \simeq \{\Omega_{\rm m}(z)\}^{\gamma} \xrightarrow{\text{in SCDM}} 1$

Development of precision cosmology will never happen in SCDM…
ΛCDM (also OCDM) may be the best suited for precision cosmology !!