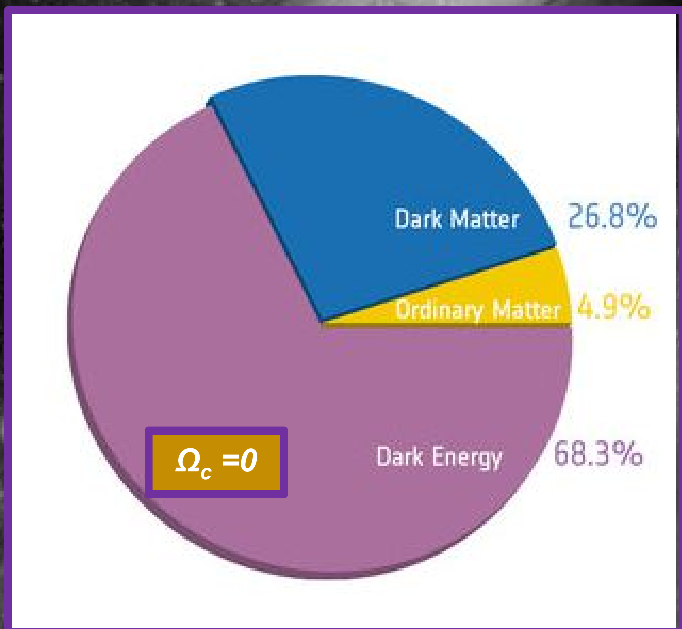
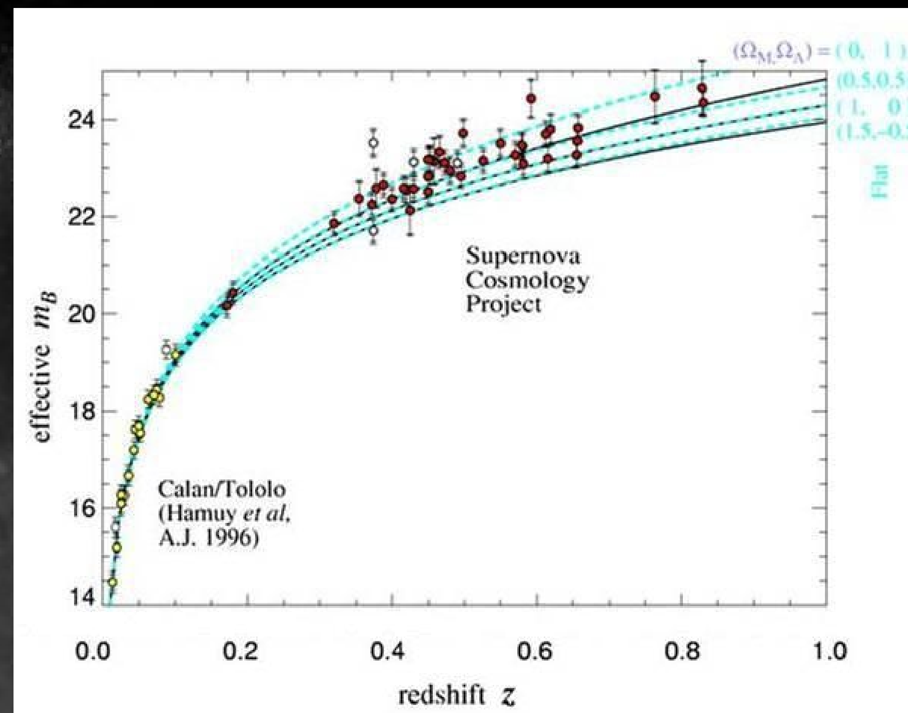
Neutrino is (not) an issue ?!

Z. Sakr with A. Blanchard and S. Ilic

The Universe is accelerating its expansion





$$H^2(z) = H_0^2\left(\Omega_M(1+z)^3 + \Omega_c(1+z)^2 + \Omega_\Lambda\right)$$

$$R_{\mu\nu} - \frac{1}{2}R\,g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

$$H^2 = \overbrace{\frac{8\pi G}{3}\rho}^{\text{matter density}} - \overbrace{\frac{kc^2}{R^2}}^{\text{curvature}} + \overbrace{\frac{\Lambda}{3}}^{\text{dark energy}}$$

Change the Left side or the Right side ?

$$p_v = \omega \rho_v c^2 \rightarrow \Lambda = 8\pi G \rho_v$$

ω= -1

Calculations failed by a factor of 120 !!!

OR

ω cte ≠ -1

OR

$$w(z) = w_0 + w_1 \frac{z}{1+z}\,.$$

$$-k^2\Phi = 4\pi G Q(a,k) a^2 \rho_M \Delta_M\,, \qquad \Phi = \eta(a,k)\Psi\,.$$

OR

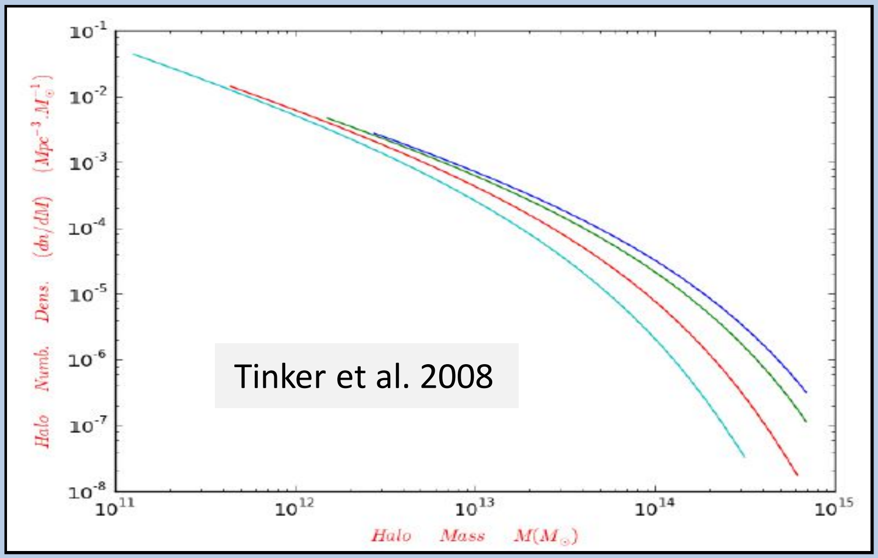
$$S = \frac{1}{2\kappa^2}\int \mathrm{d}^4x \sqrt{-g}\, f(R) + S_m(g_{\mu\nu}, \Psi_m)\,,$$

From Dark Matter Haloes to Cluster of Galaxies

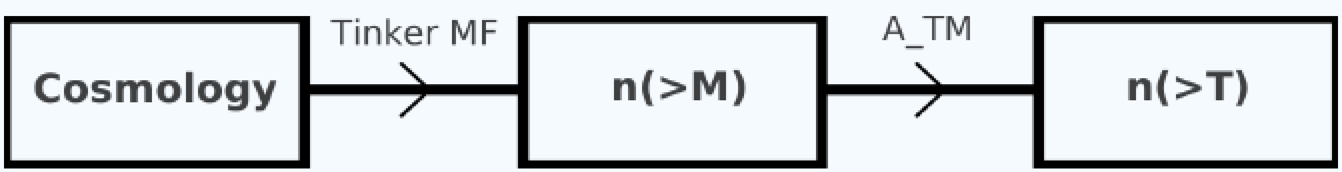
$$\begin{cases} \dfrac{dn}{dm} = f(\sigma)\dfrac{\bar{\rho}_m}{m^2}\left(-\dfrac{d\ln\sigma}{d\ln m}\right) \\ f(\sigma) = A\left[\left(\dfrac{\sigma}{b}\right)^{-a} + 1\right]\exp\left(-\dfrac{c}{\sigma^2}\right) \end{cases}$$

- rms density flucuations

$$\sigma^2(R) = \int \frac{dk}{k}\frac{k^3 P(k)}{2\pi^2} W^2(kR)$$



$P(k,z) = P(k,0) \times T(k,z)^2 \times G(k,z)^2$



Relate the **Linear** Growth factor to DE models through the **Growth Index** γ

$$\ddot{\delta}_m + 2H\nu\dot{\delta}_m - 4\pi G\mu\rho_m\delta_m = 0$$

$$f' + f^2 + \left(1 + \nu + \frac{H'}{H}\right)f - \frac{3}{2}\mu\Omega_m = 0$$

$$f_g \equiv \frac{d\log G}{d\log a} \approx \Omega_M(a)^\gamma$$

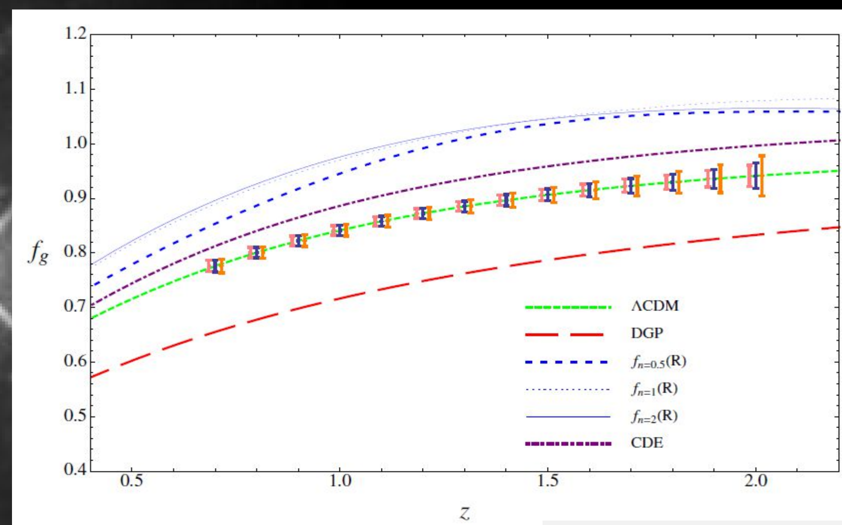
$$G(a) \approx \exp\left\{\int_1^a \frac{da'}{a'}\left[\Omega_M(a')^\gamma\right]\right\}$$

γ_{LCDM} =0.545

$$\gamma_0 = \frac{3(1-w)}{5-6w}$$

$$\gamma = 0.55 + 0.05\,[1 + w(z=1)]$$

The value of γ is 0.545 for *w =-1* but differs in MG scenarios, which means that a large deviation from $\gamma_{\Lambda CDM}$ signifies a quintessence nature or the breakdown of GR on large distance or a substantial DE clustering.



Amendola et al. 2013

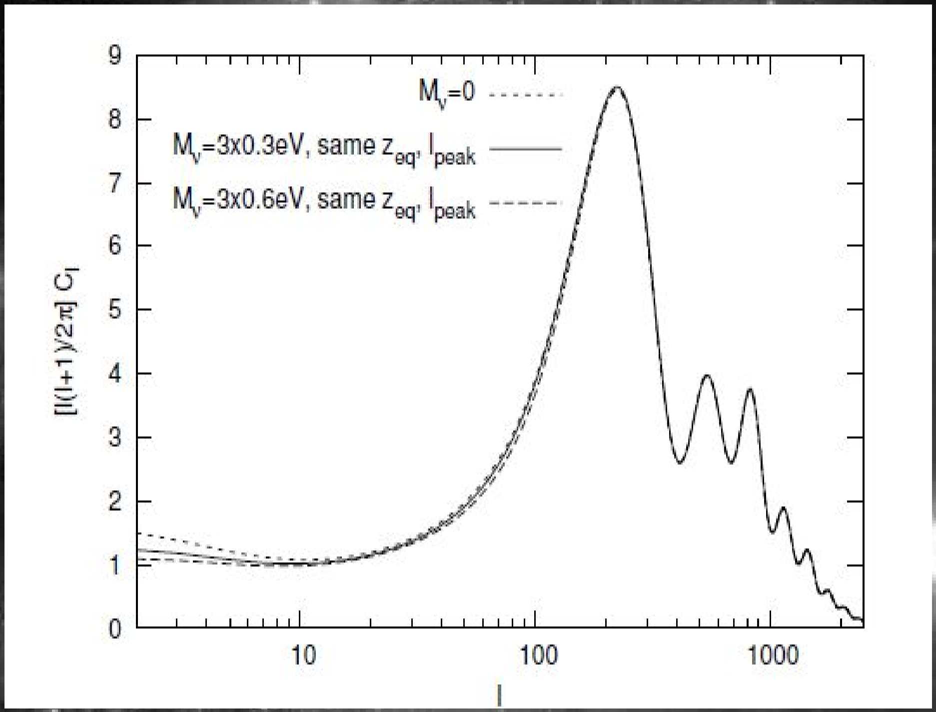
From Dark Matter Haloes to Cluster of Galaxies

-Self-similar + heating by collapse + virial theorem)

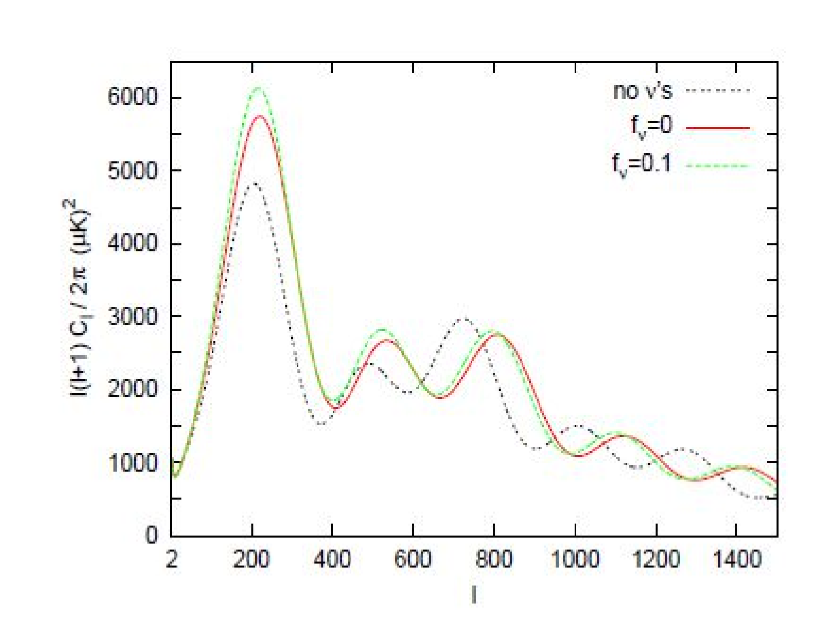
- $T \,\alpha\, GM/R$
- T_X-M scaling law : $T \,\alpha\, ATM * M^{2/3} * (1 + z)$
- *ATM* : free normalisation parameter

$$\text{Cosmology} \xrightarrow{\text{Tinker MF}} n(>M) \xrightarrow{\text{A\_TM}} n(>T)$$

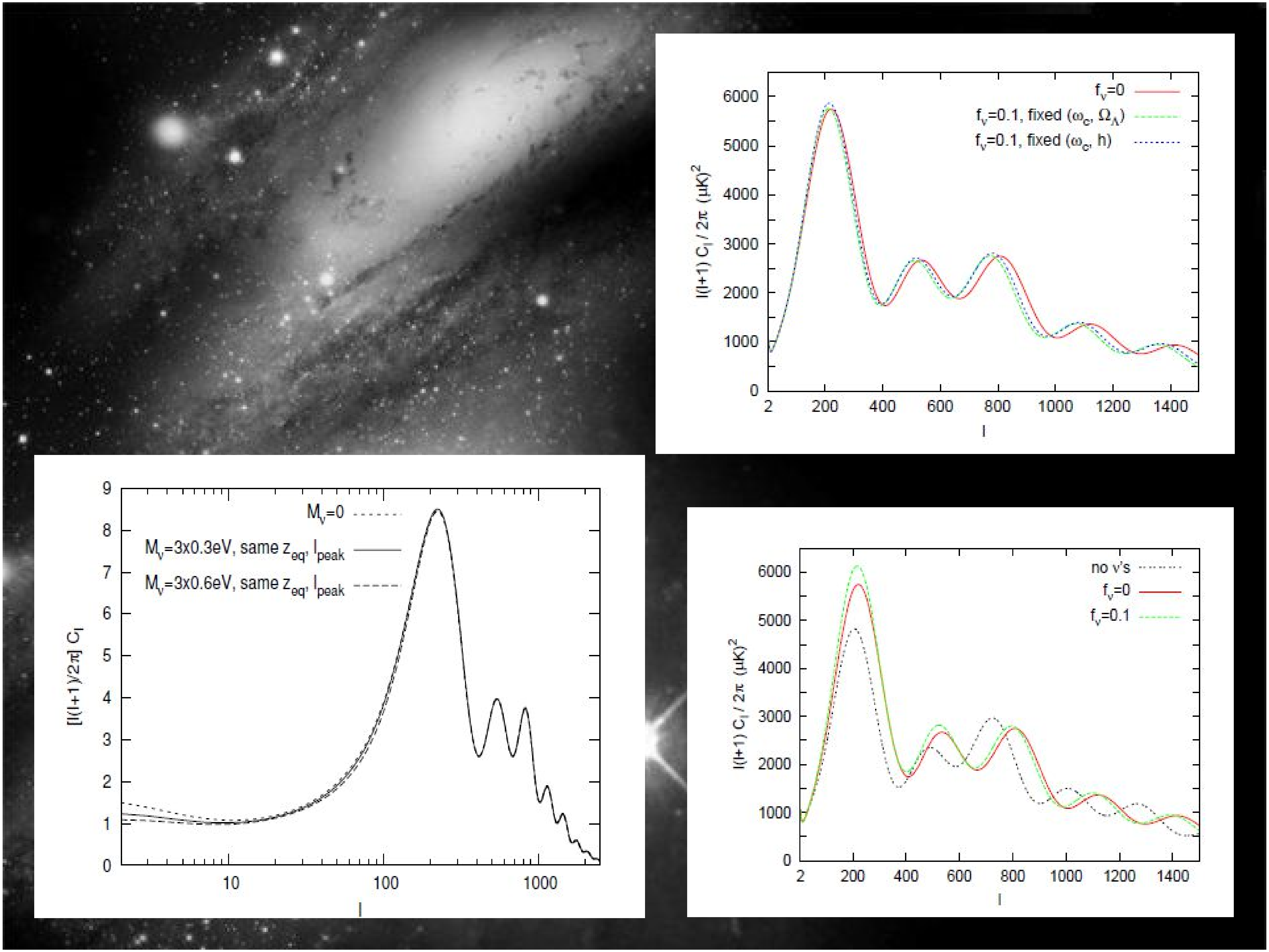
Neutrinos are also among the things that could influence also the background and the growth of structures



Lesgourges & Pastore 2013

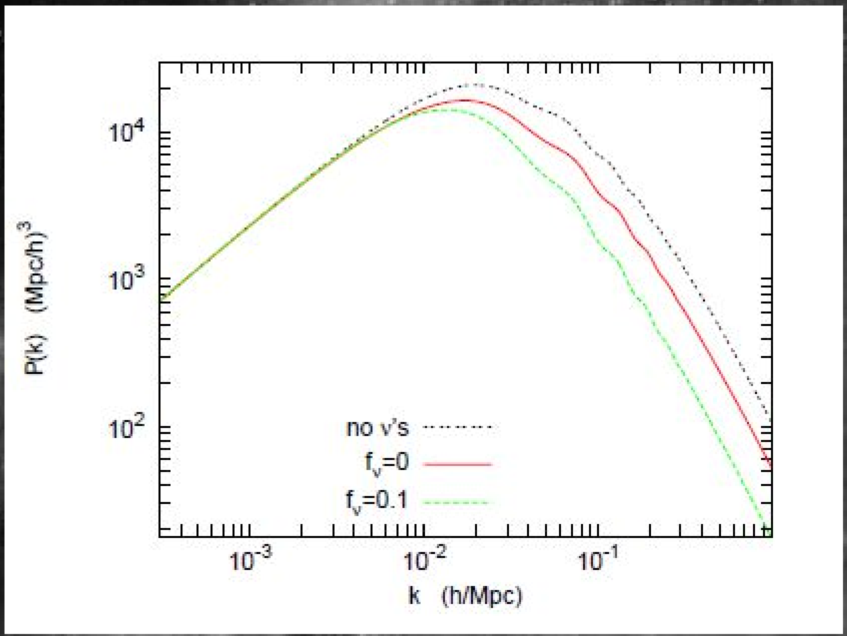


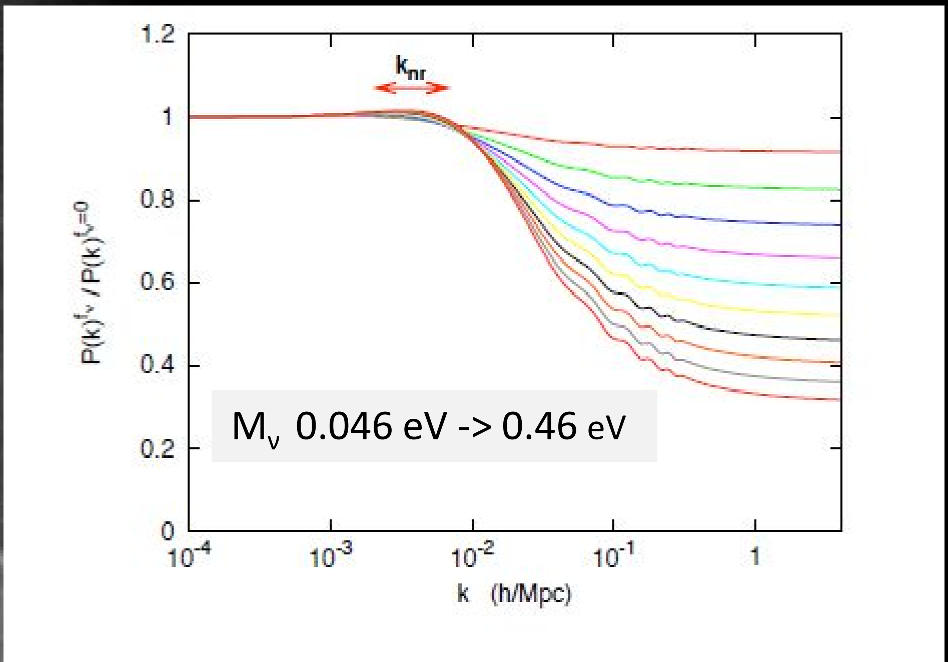
Lesgourges & Pastore 2006



f_ν=0
f_ν=0.1, fixed (ω_c, Ω_Λ)
f_ν=0.1, fixed (ω_c, h)
l(l+1) C_l / 2π (μK)^2
l
M_ν=0
M_ν=3x0.3eV, same z_eq, l_peak
M_ν=3x0.6eV, same z_eq, l_peak
[l(l+1)/2π] C_l
l
no ν's
f_ν=0
f_ν=0.1
l(l+1) C_l / 2π (μK)^2
l

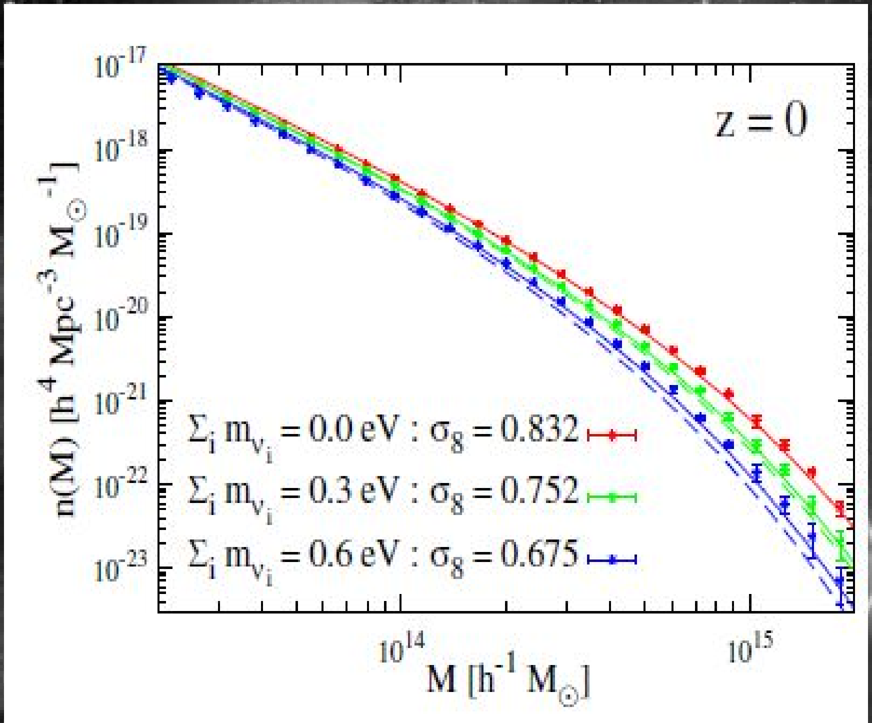
Neutrinos are also among the things that could influence also the background and the growth of structures

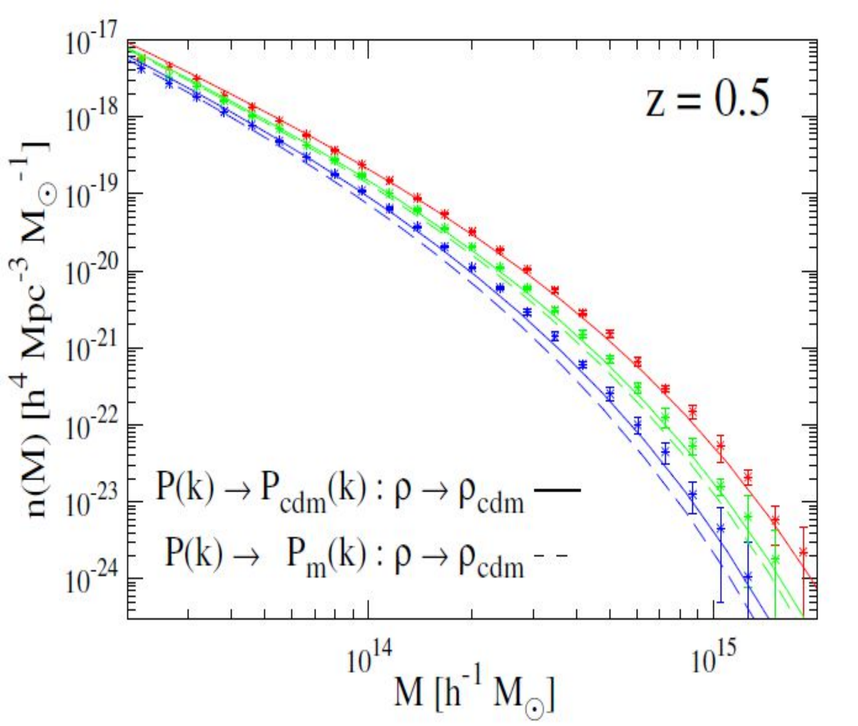




Lesgourges & Pastore 2013

Neutrinos are also among the things that could influence also the background and the growth of structures





Costanzi et al. 2013

$$
\begin{cases}
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f(\sigma) = A\left[\left(\dfrac{\sigma}{b}\right)^{-a}+1\right]\exp\left(-\dfrac{c}{\sigma^2}\right)
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$$

- rms density flucuations

$$\sigma^2(R) = \int \frac{dk}{k}\frac{k^3 P(k)}{2\pi^2}W^2(kR)$$

$P(k,z) = P\ (k,0)\ \ x\ T(k,z)^2\ x\ G(k,z)^2$

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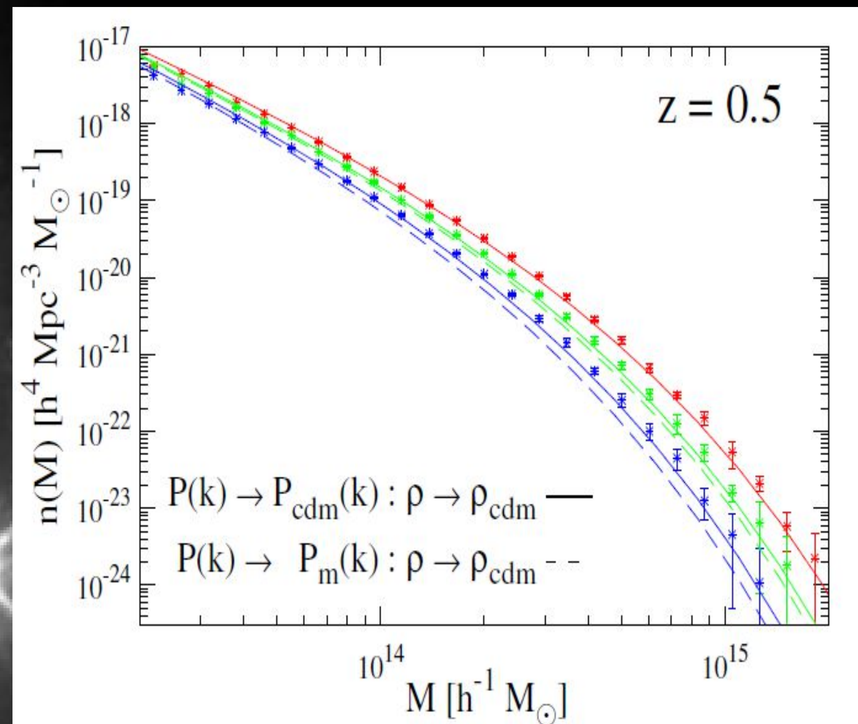
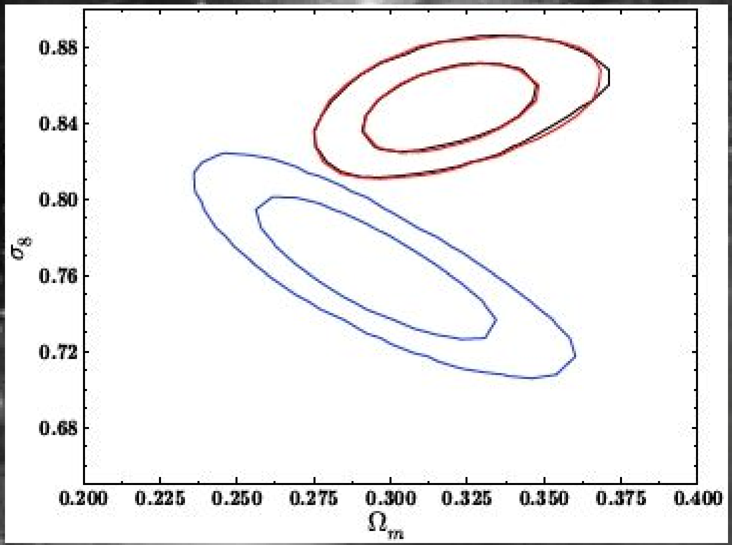
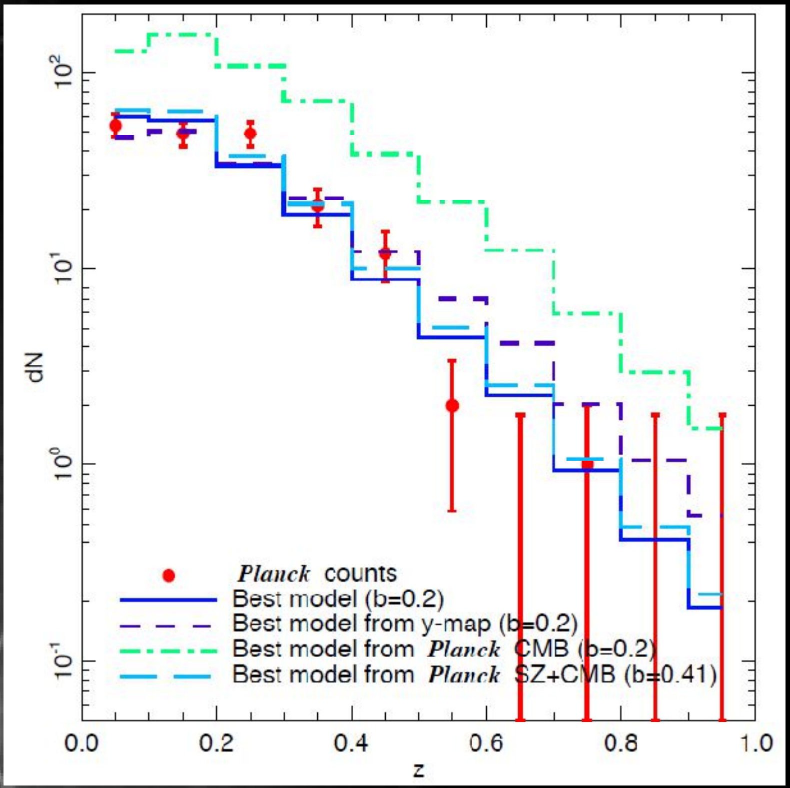


Costanzi et al. 2013

Could either one be changed to solve a discrepancy that appeared between $\sigma_{8,CMB}$ from Planck Mission probe of the CMB and $\sigma_{8,LSS}$ from Cluster of Galaxies





"we believe that for the purposes of this paper it is premature to use cluster counts together with CMB measurements to search for new physics. We will explore a number of possibilities for reducing the tension between Planck CMB measurements and SZ cluster counts, including non-zero neutrino masses"

Planck Col. XX 2013

Tools of investigation

Experiences:

CMB : [2015 Planck_highl_TTTEEE, Planck_lowl, Planck_lensing]

X-ray Clusters Local Universe : [BAX 2014]

BAO : [Boss 2014]

Markov Chain:

Planck Likelihood

Weinbull Likelihood

χ^2 Likelihood

Codes:

CLASS : Boltzman Code CMB and P_K generator

Mn_Weinbull: Mass Function Module implemented with the Collaboration of S. Ilic : use Tinker 2008 and includes Neutrino and Growth index Effects

BAO Module : D_a vs R_s comparison for different z

MCMC experiments conducted

Classical case LCDM

CMB : [2015 Plk_highl_TTTEEE, Plk_lowl, Plk_lensing]

['omega_b'] = [2.2253, None, None, 0.028]
['omega_cdm'] = [0.11919, None, None, 0.0027]
['100*theta_s'] = [1.0418, None, None, 3e-4]
['ln10^{10}A_s'] = [3.0753, None, None, 0.0029]
['n_s'] = [0.96229, None, None, 0.0074,]
['tau_reio'] = [0.09463, None, None, 0.013]

['N_eff'] = 0.00641
['m_ncdm'] = [0.2, 0,1, 0.05]

MCMC experiments conducted

CMB : [2015 Plk_highl_TTTEEE, Plk_lowl, Plk_lensing]
X-ray Clusters Local Universe : [BAX 2014]

['ATM'] = [6.29, 0,10, 0.5]
['GAMMA'] = [0.55, 0,1, 0.05]
['N_eff'] = 0.00641
['m_ncdm'] = [0.2, 0,1, 0.05]

…. Varying neutrinos, Gamma and ATM …

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['ATM'] = [6.29, 0,10, 0.5]
['GAMMA'] = [0.55, 0,1, 0.05]
['N_eff'] = 0.00641
['m_ncdm'] = [0.2, 0,1, 0.05]
['w'] = [-1.0, -1.2,-0.33, 0.01]

.... in *W*CDM

$$\boxed{\gamma = 0.55 + 0.05\,[1 + w(z=1)]}$$

Conclusions still to be consolidated …

*The presence of massive neutrinos **do not** solve the discrepancy and leave the **door open** for new physics*

The same can be said to wCDM ($w \neq -1$ but cte) or a parametrisation of w (CPL $w(a) = w_0 + (1-a)w_1$)

More to come ….

1

….testing other modified gravity models through more complex parameterization of γ

$$\gamma(z) = \gamma_0 + \gamma_1 \frac{z}{1+z}.$$

$$f_g \equiv \Omega_m(z)^\gamma (1+\eta),$$

$$\gamma(\omega) = \sum_{n=0}^{N} \gamma_n \frac{\omega^n}{n!} + \mathcal{O}(\omega^{N+1})$$

$\gamma_0+\gamma_1 z$ (Polarski 2008)
$\gamma_0+\gamma_1(1-\Omega_m)$ (Gong 2008)
$\gamma_0+\gamma_1(1-a)$ (Fu, Wu, Yu 2009)

2

….adding Supernovas as another standard geometrical probe & SZ + Weak Lensing as another structure growth probe.

Even more advanced stage : tackling the Non Linear growth of structures theoretically

By

Modeling δ_c and Δ_{vir} through modified gravity

OR

Change of the mass function itself