DEMNUni: The Dark Energy and Massive Neutrino Universe project

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CENTRE DE PHYSIQUE THÉORIQUE

Outline

1. Cosmological impact of the neutrino mass
2. Presentation of the DEMNUni
3. Neutrino simulations
4. Conclusions and perspectives

DEMNUni simulations

Research Group:

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Mauro Roncarelli, *DIFA-Università di Bologna*

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Klaus Dolag, *Universitaets-Sternwarte Muenchen*

DEMNUni simulations

- 8×10^6 cpu-hours on BGQ/FERMI at CINECA (PI: C. Carbone)
- 10 mixed dark matter cosmological simulations for CMB and LSS analysis in the presence of evolving dark-energy (w_0, w_a) and massive neutrinos
- Baseline Planck cosmology
- Gadget-3 with ν-particle component (Viel et al. 2010)
- box-side size: 2 Gpc/h
- particle number: 2×2048^3 (CDM+ν)
- CDM mass: 8×10^{10} $M_\odot$/h (neutrino particle mass depends on M_ν)
- softening length: 20 kpc/h
- starting redshift: z_{in}=99

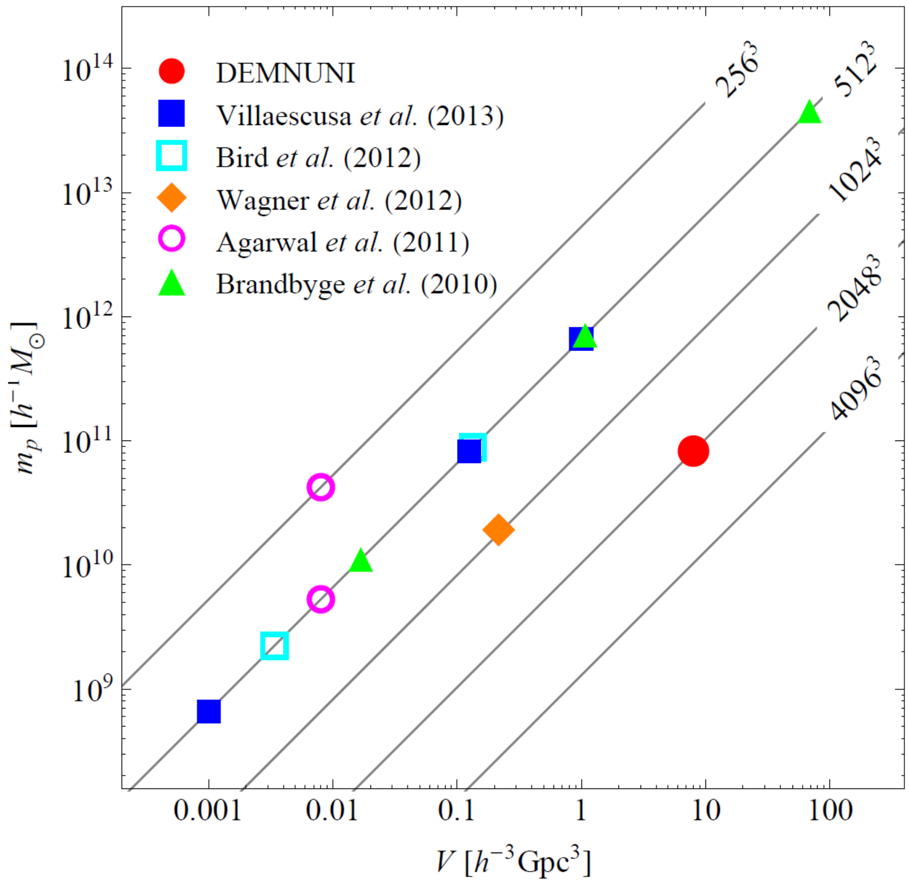
$$k_{\rm nr} = 0.018 (m_\nu/1{\rm eV})^{1/2} \Omega_m^{1/2} h/{\rm Mpc}$$

DEMNUni simulations

Simulations outputs:

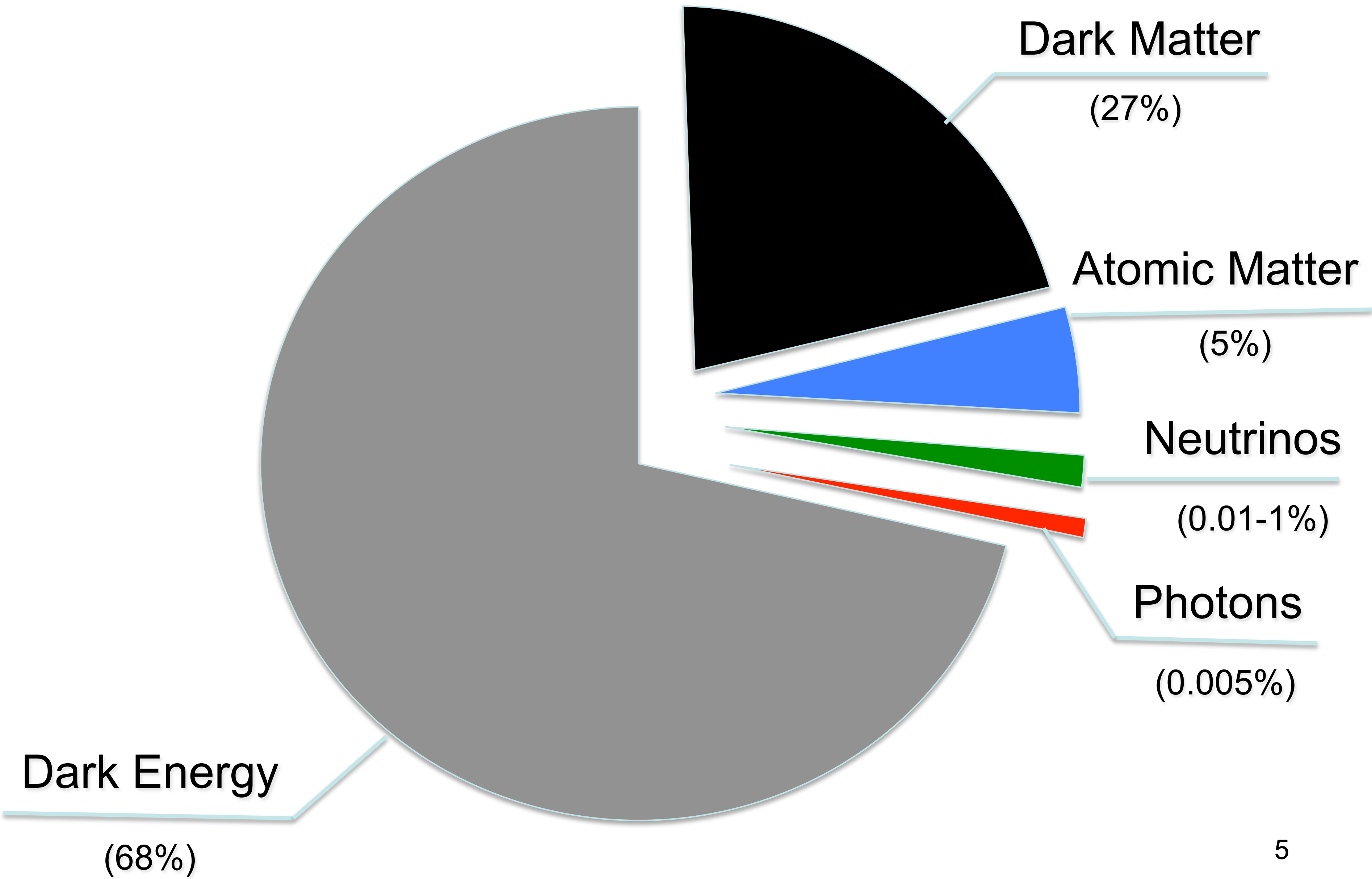
- 62 temporary snapshots per simulation: ~0.54 TB/snap (CDM+ ν)
- 10 halo-catalogs per simulation
- 10 sub-halo catalogs per simulation
- Matter power-spectra for all the 62 snapshots
- 62 temporary gravitational potential grids of size 4096^3 (for CMB weak-lensing)
- 62 temporary grids of size 4096^3 for the derivative of the gravitational potential (for ISW/Rees-Sciama)
- 90 TB of data in total per simulation

DEMNUni simulations

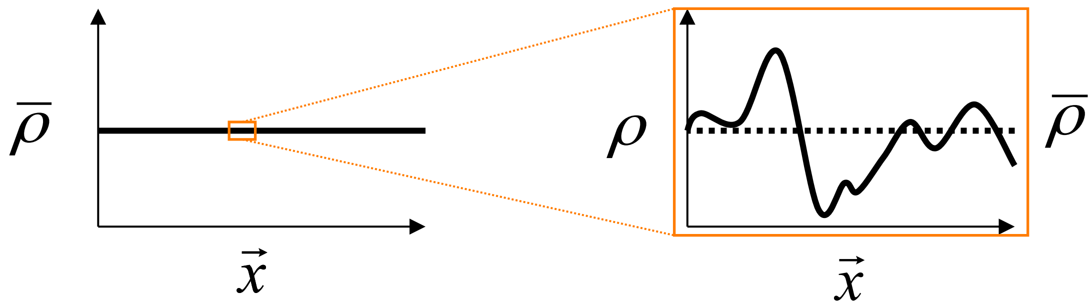


Comparison between the DEMNUni runs and previous, recent simulations of massive neutrino cosmologies in terms of cold dark matter mass resolution and comoving volume

The concordance model of cosmology:



3) Dynamics of the inhomogeneous universe



Homogeneous Background *Deviations on smaller scales*

$$\delta(t,\vec{x}) = \frac{\rho(t,\vec{x}) - \bar{\rho}(t)}{\bar{\rho}(t)}$$

Fluid approximation in the Newtonian limit:

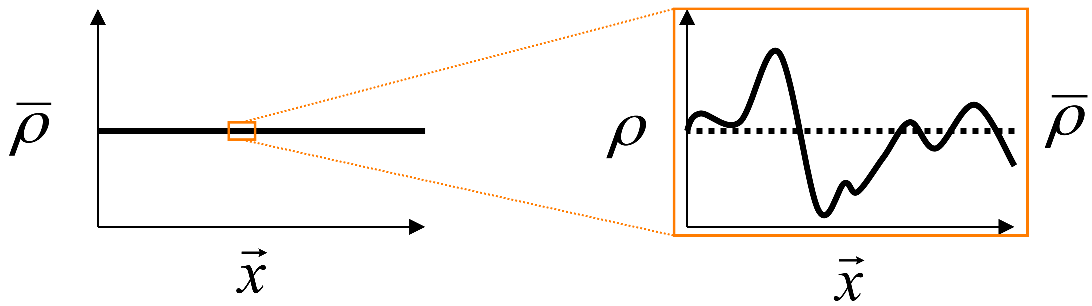
$$d\tau \equiv \frac{dt}{a}$$

$$\frac{\partial \delta}{\partial \tau} + \vec{\nabla} \cdot \vec{v} = -\vec{\nabla} \cdot (\delta \vec{v})$$ *(Continuity)*

$$\frac{\partial \vec{\nabla} \cdot \vec{v}}{\partial \tau} + aH\vec{\nabla} \cdot \vec{v} + \Delta\phi = -\vec{\nabla} \cdot [(\vec{v} \cdot \vec{\nabla})\vec{v}]$$ *(Momentum conservation)*

$$\Delta\phi - \frac{3}{2}\Omega_m (aH)^2 \delta = 0$$ *(Poisson equation)*

3) Dynamics of the inhomogeneous universe



Homogeneous Background

Deviations on smaller scales

$$\delta(t,\vec{x}) = \frac{\rho(t,\vec{x}) - \bar{\rho}(t)}{\bar{\rho}(t)}$$

Linear evolution of fluctuations:

(In Newtonian approximation)

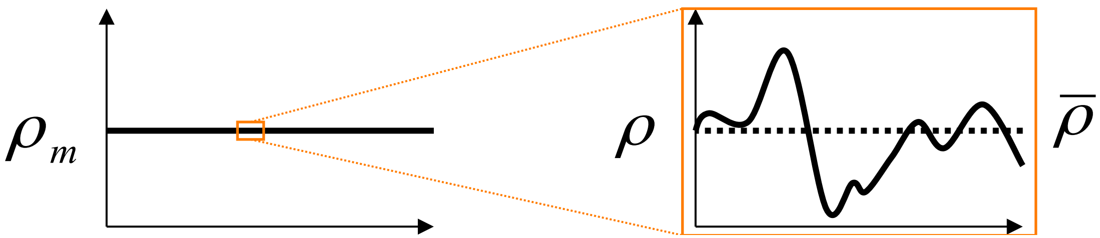
$$\frac{d^2\delta}{d\tau^2} + aH\frac{d\delta}{d\tau} - \frac{3}{2}\Omega_m H^2\delta = 0$$

Velocity fluctuations: $\vec{\nabla}\cdot\vec{v} = -aHf\,\delta(t,\vec{x})$

Growth rate: $f \equiv \dfrac{d\ln\delta}{d\ln a}$

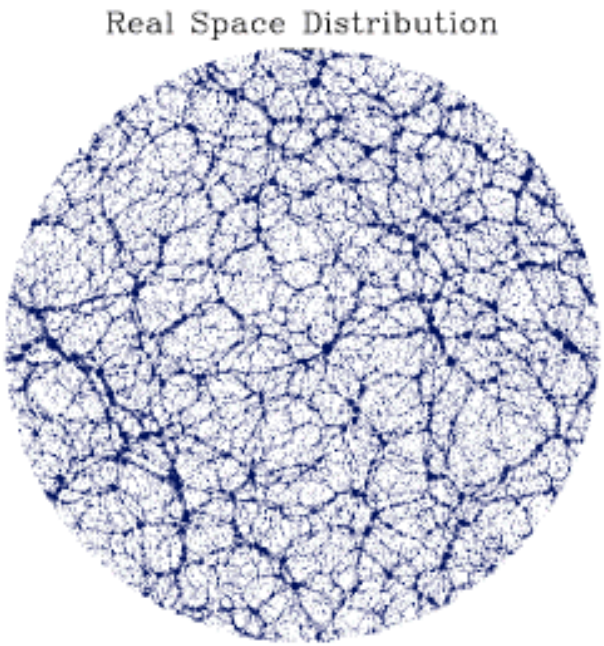
$$z_o = z_c + \frac{\vec{v}\cdot\vec{e}_{los}}{c}$$

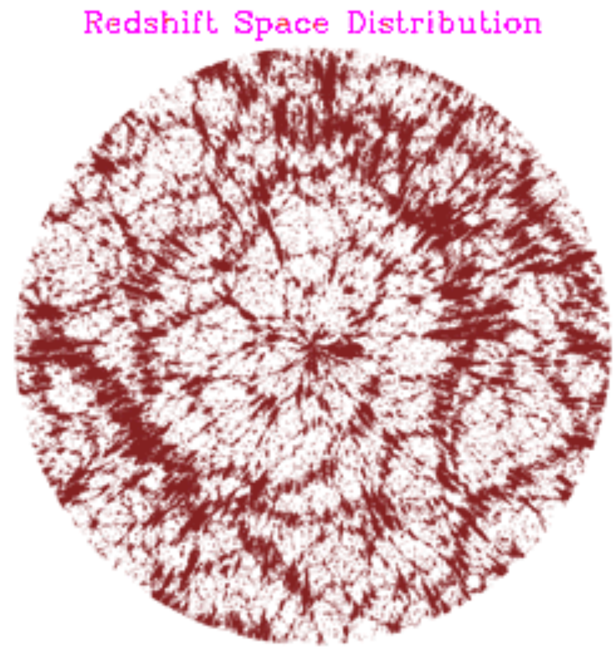
3) Dynamics of the inhomogeneous universe



$$\delta(t,\vec{x}) = \frac{\rho(t,\vec{x}) - \bar{\rho}(t)}{\bar{\rho}(t)}$$

Homo





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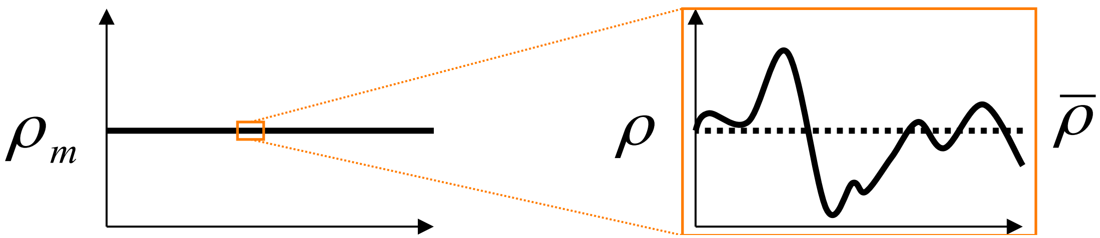
3) Dynamics of the inhomogeneous universe



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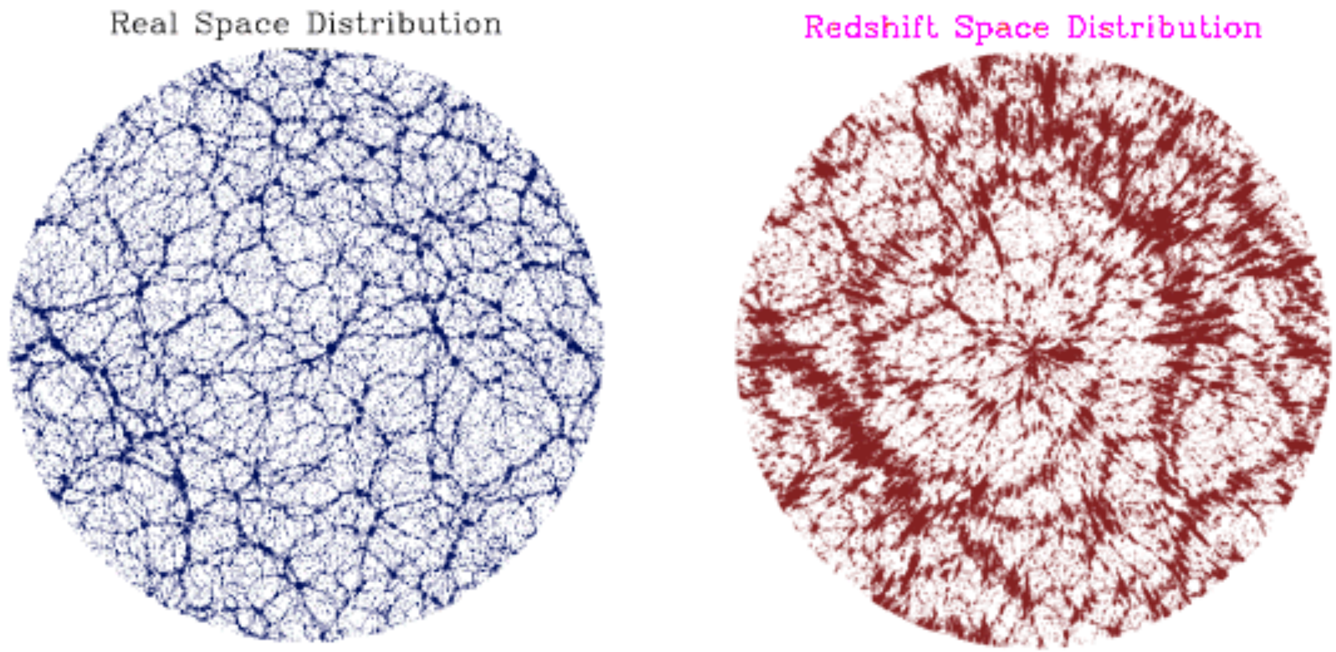


f is directly related to observations

Massive neutrinos

Experiments on oscillations of neutrinos of different flavours: Masse difference

WHAT IS THEIR ABSOLUTE MASSE ?

Fermi-Dirac momentum distribution $\rho_\nu \propto T^4 \int_0^\infty \frac{q^2\sqrt{q^2+(m/T)^2}}{1+e^q}$

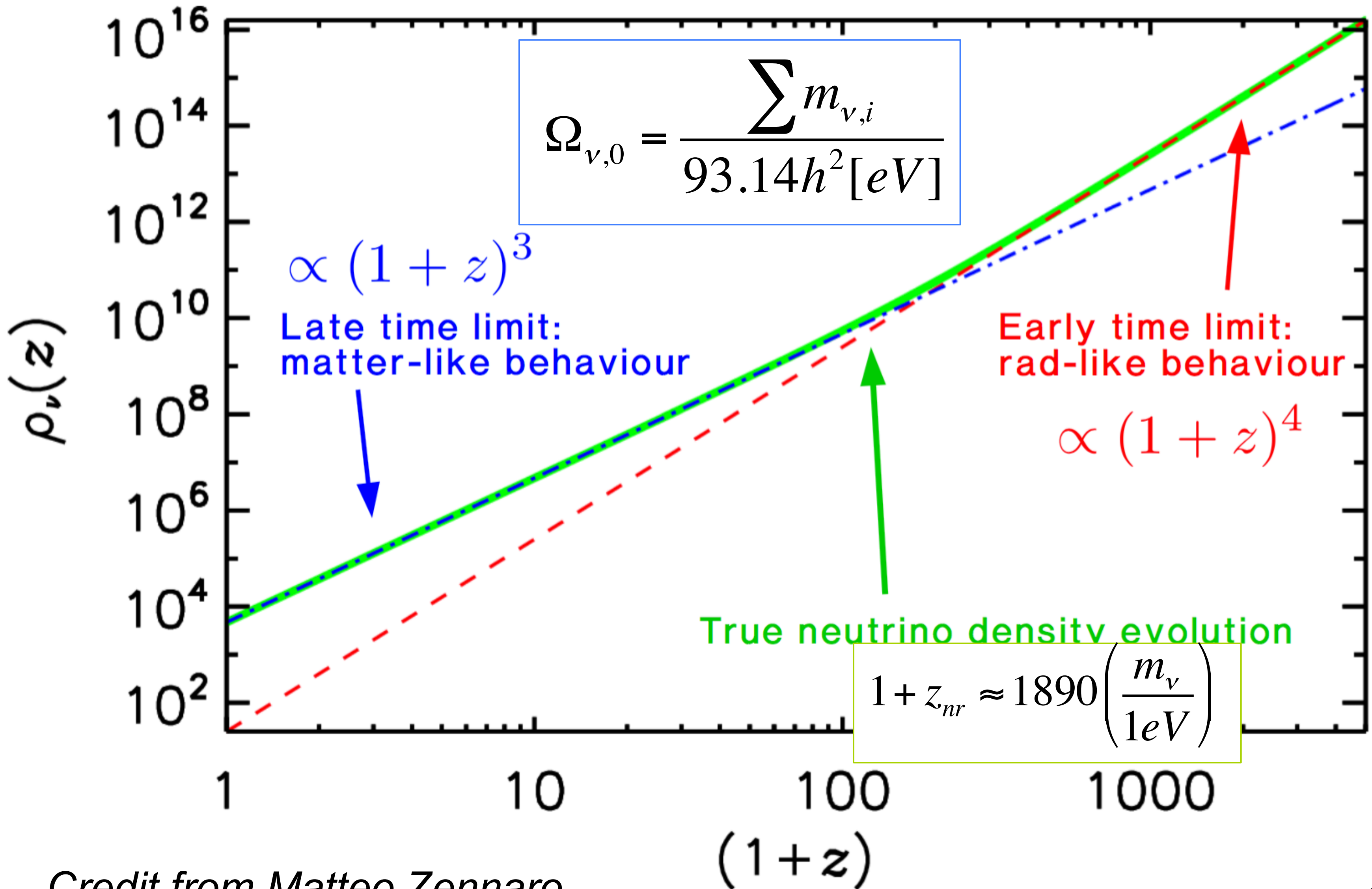
High redshift: $\rho_\nu \propto (1+z)^4$

Low redshift: $\rho_\nu \propto (1+z)^3$

-At high redshift they behave as radiation

-At low redshift they are indistinguishable from matter

Massive neutrinos



Credit from Matteo Zennaro

Massive neutrinos

Non-negligible velocity dispersion:

$$\frac{\partial \delta_\nu}{\partial \tau} + \vec{\nabla} \cdot \vec{v}_\nu = 0$$ (Continuity equation for neutrinos)

$$\frac{\partial \delta_c}{\partial \tau} + \vec{\nabla} \cdot \vec{v}_c = 0$$ (Continuity equation for CDM)

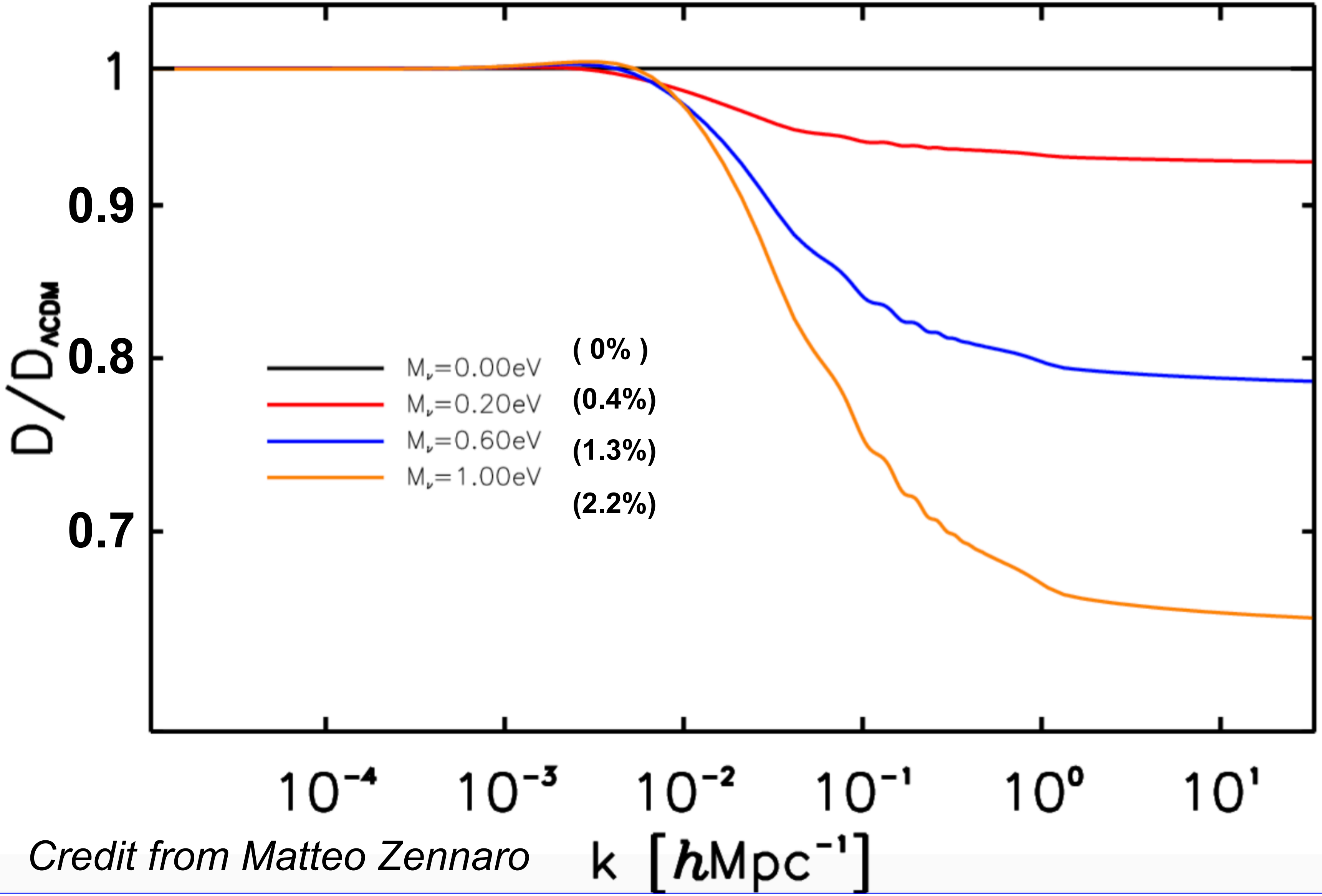
$$\frac{\partial \vec{\nabla} \cdot \vec{v}_\nu}{\partial \tau} + aH\vec{\nabla} \cdot \vec{v}_\nu + \frac{2}{3}\Omega_m (aH)^2 [(1-\nu)\delta_c + \nu\delta_\nu] \boxed{- c_{eff}^2 \Delta\delta_\nu} = 0$$

(Eq. of motions)

$$\frac{\partial \vec{\nabla} \cdot \vec{v}_c}{\partial \tau} + aH\vec{\nabla} \cdot \vec{v}_c + \frac{2}{3}\Omega_m (aH)^2 [(1-\nu)\delta_c + \nu\delta_\nu] = 0$$

(Blas et al. 2014)

Massive neutrinos



Credit from Matteo Zennaro

DEMNUni (Phase I)

The DEMNUni cosmology:

$$h = 0.67$$
$$\Omega_\Lambda = 0.68$$
$$\Omega_m = 0.32$$
$$\Omega_b = 0.05$$
$$n_s = 0.96$$

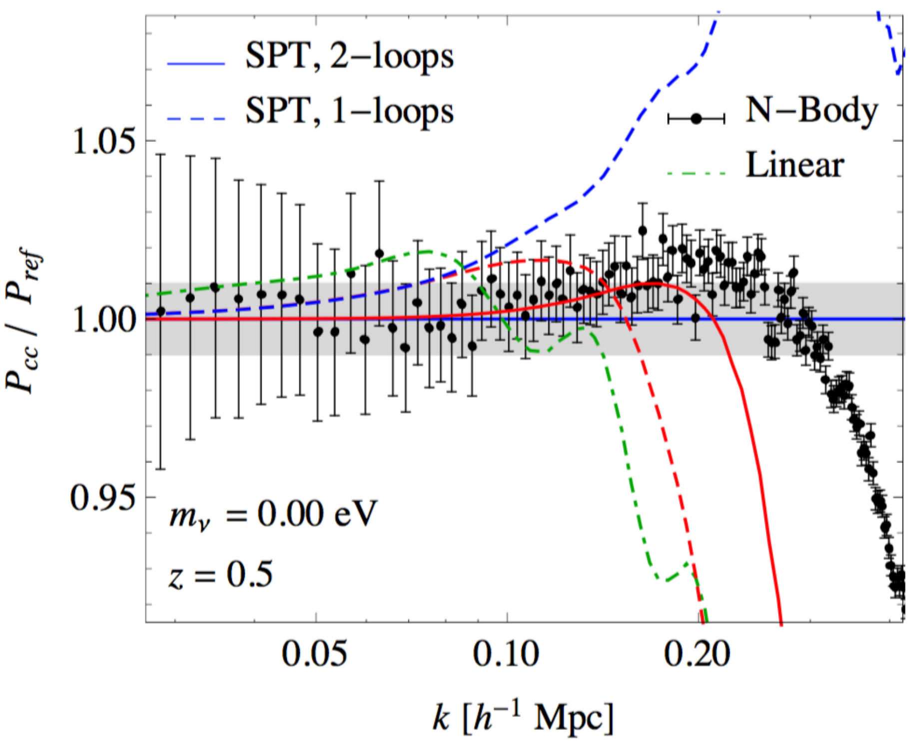
$$M_\nu = 0, \quad 0.17, \quad 0.3, \quad 0.53eV$$

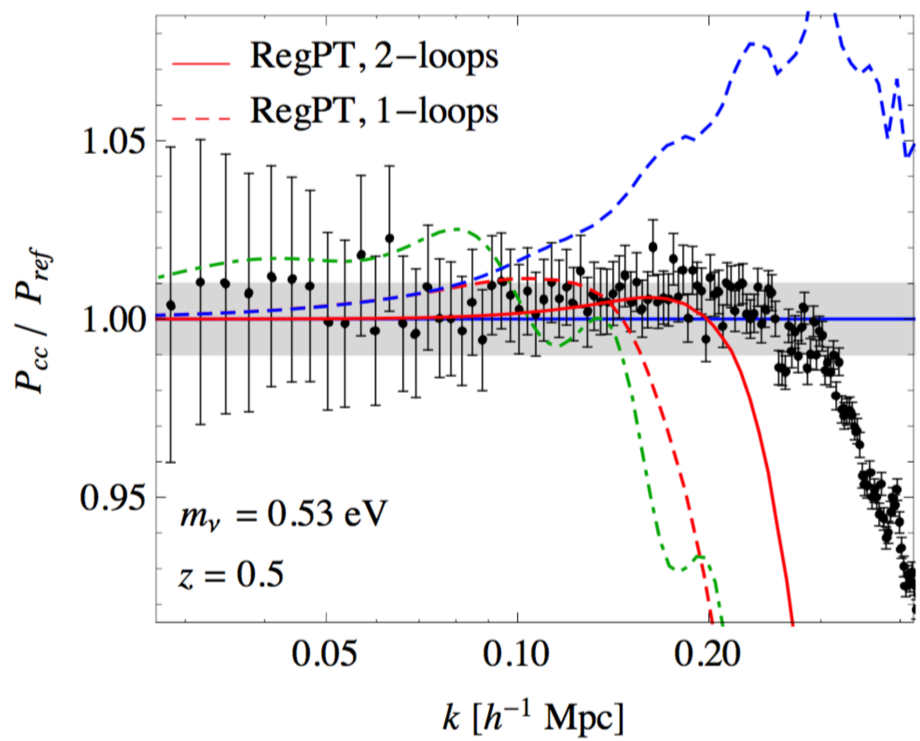
$$\sigma_{8,m} = 0.85, \quad 0.80, \quad 0.77, \quad 0.72$$ (total matter)

$$\sigma_{8,c} = 0.85, \quad 0.81, \quad 0.79, \quad 0.74$$ (cold dark matter)

DEMNUni (Phase I)

Comparison with perturbation theory:

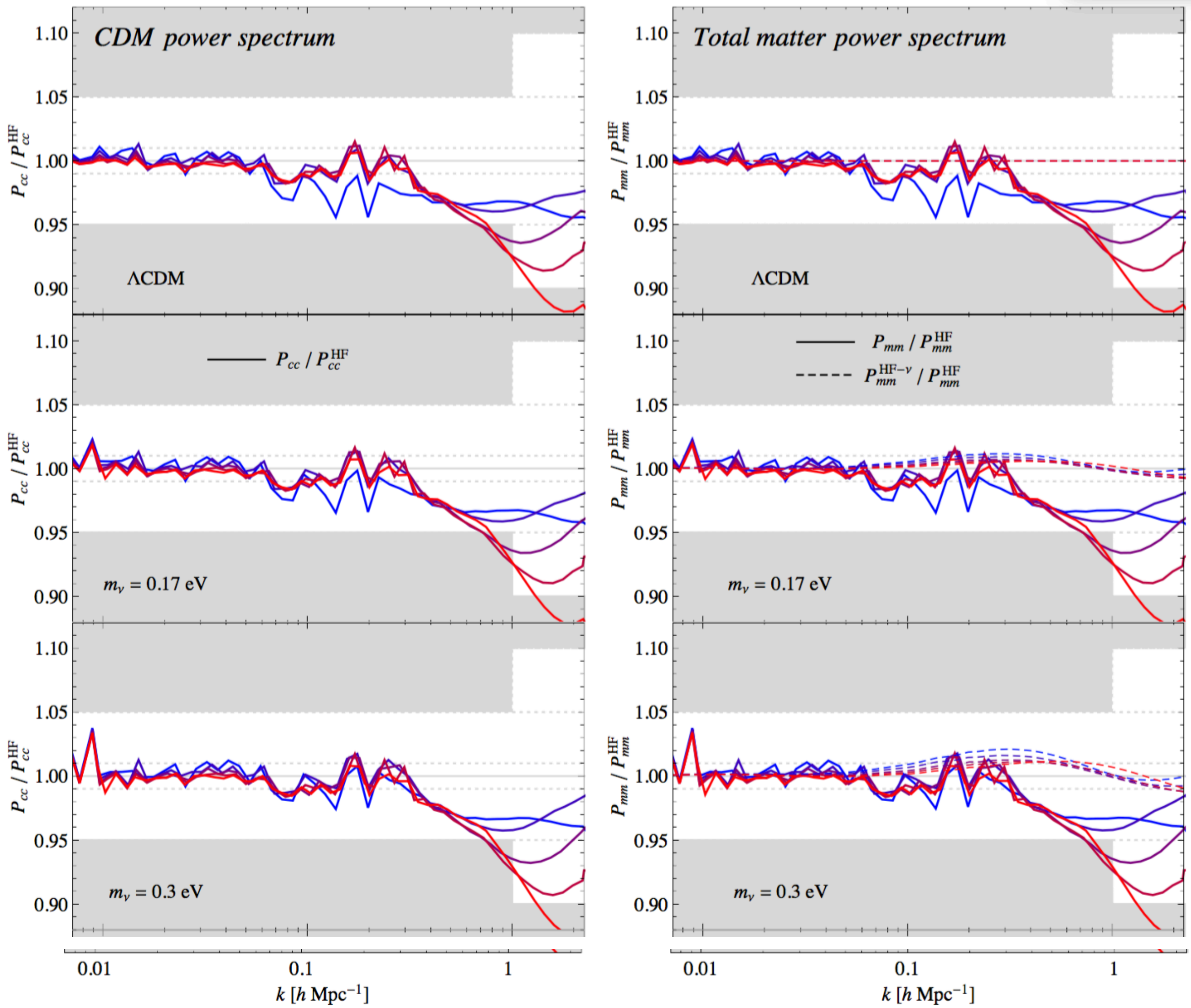




Castorina et al. (2015)

DEMNUni (Phase I)

Comparison with Halofit:



Castorina et al. (2015)

DEMNUni: velocity spectra (in preparation)

DEMNUni (LCDM):

$h = 0.70$

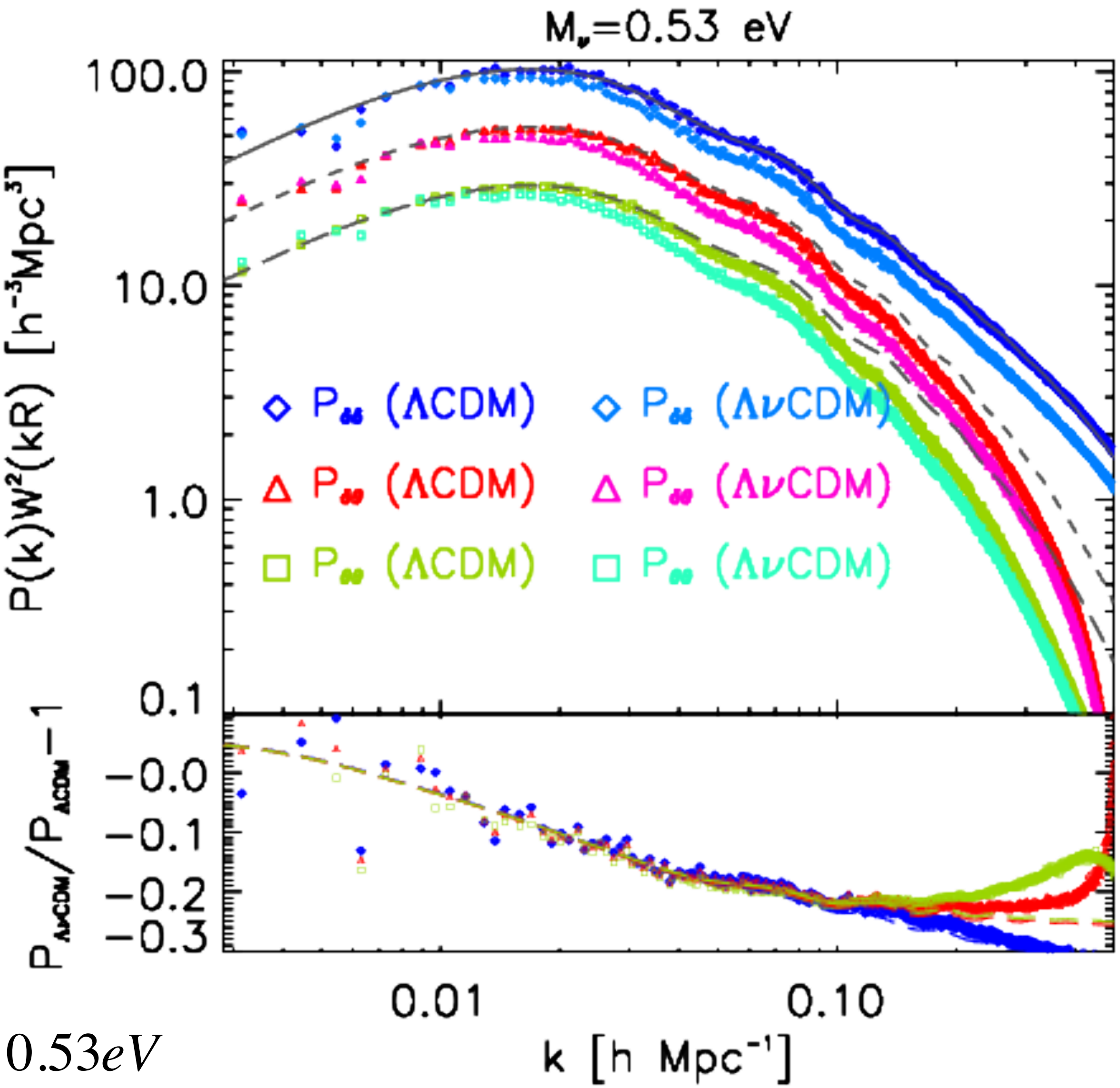
$\Omega_\Lambda = 0.68$

$\Omega_m = 0.32$

$\Omega_b = 0.044$

$\sigma_8(0) = 0.80$

$n_s = 0.95$



$m_p \approx 8 \times 10^{10} h^{-1} M_{sol}$

$M_\nu = 0,\quad 0.17,\quad 0.3,\quad 0.53 eV$

2048^3 particles in a **2000**^{3} $h^{-3}Mpc^3$ box

Conclusions

- We learned from DEMNUni (Phase I)

- We developed a prescription to set initial conditions in neutrino simulations

- Non matter density non linearities can be taken into account by applying any perturbative scheme or fitting prescriptions (Halofit) to the CDM component only

- Phase II is starting so we have freedom in the choice of the dark energy models and the neutrino masses that we want to investigate