NEUTRINOS AND
LARGE SCALE STRUCTURES

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INAF & INFN – Trieste

PADOVA 18th May 2011 – Scuola Neutrini in Cosmologia

OUTLINE

- Quantifying the impact of neutrinos on cosmological observables

- Simulating neutrinos beyond linear theory: neutrinos and LSS

- Review of (tightest) constraints on neutrino masses

- Sterile neutrinos and the coldness of cold dark matter at small scales

EVOLUTION of COSMOLOGICAL LSS – I: methods

Linear theory -- use popular codes like CAMB http://camb.info/

Non-linear evolution -- approximations (e.g. Lognormal modelling /Peacock & Dodds,PT etc.) or N-body/hydrodynamic/adaptive mesh refinement techniques

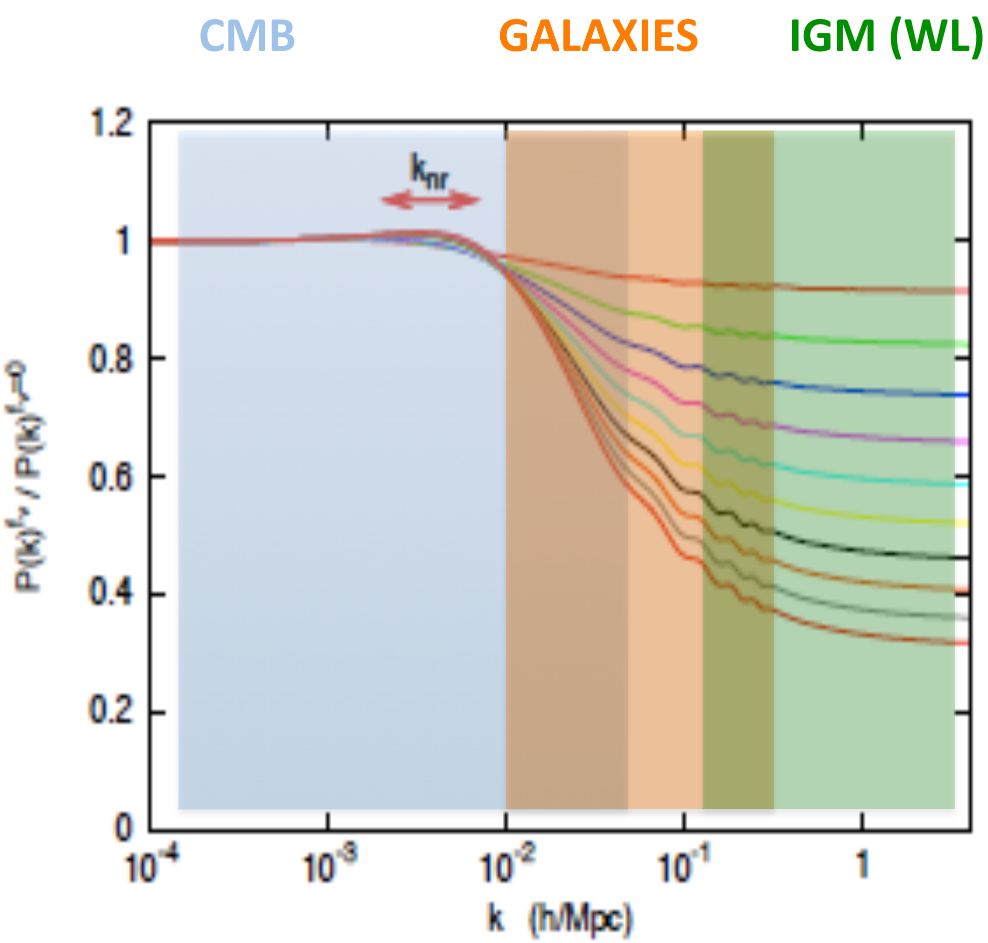
Early simulations: **direct summation** method for the gravitational N-body problem (still useful for stellar systems) Holmberg 1941, Aarseth 1979, Peebles, White etc.

Improvement made in the 90s to compute large scale force via Fourier/**mesh techniques**
Tree algorithms arrange particles in groups and compute forces by summing over multipole expansions.

These two have been combined into **Tree+PM** codes, that could include hydrodynamic processes using for example the smoothed particle hydrodynamics (**SPH**, Lucy 1977) .

Hydrodynamic processes are important at small scales

EVOLUTION of LSS –II : dynamics in the linear regime

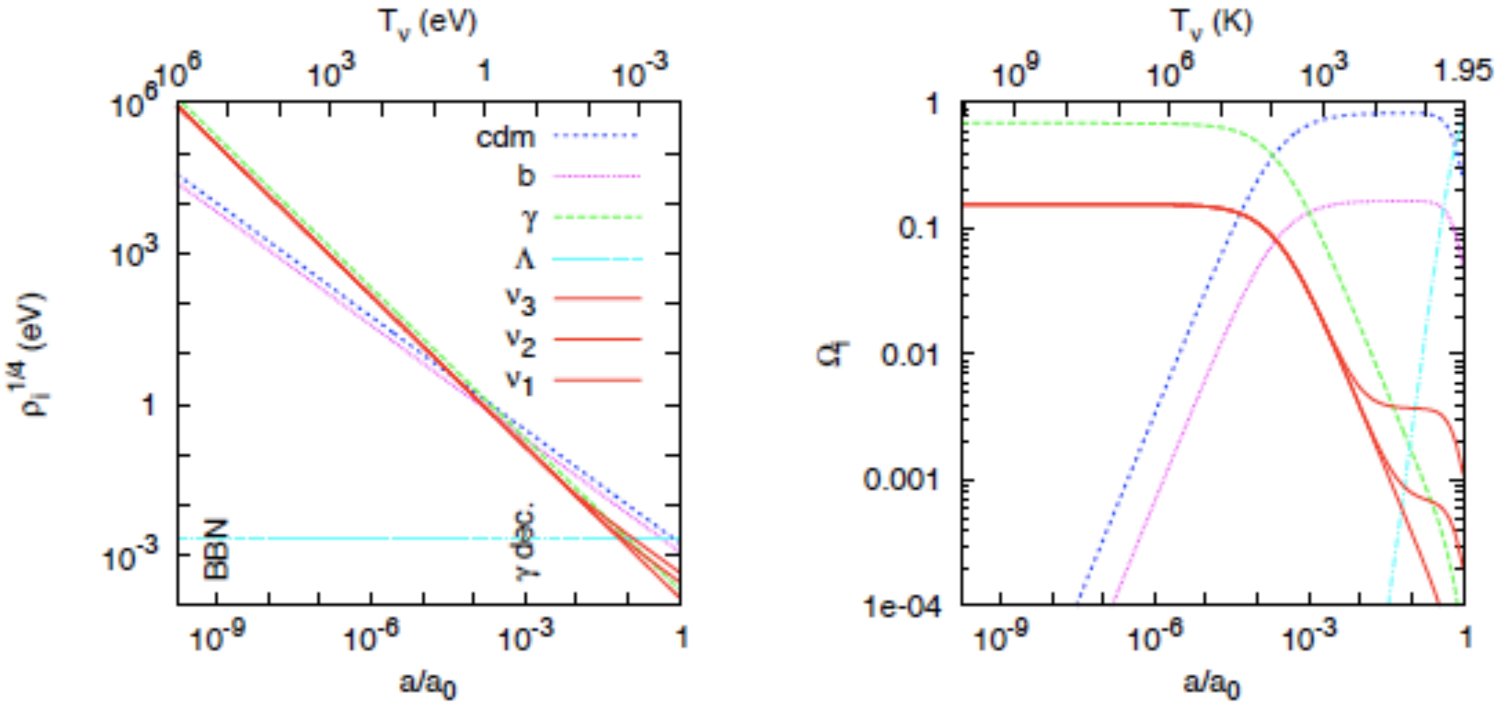


Effects in terms of matter clustering,
Hubble constant,
Energy density

(see Lesgourgues & Pastor 2006)

Different evolution in terms of **dynamics** and **geometry** as compared to massless neutrino universes

EVOLUTION of LSS – III : background evolution



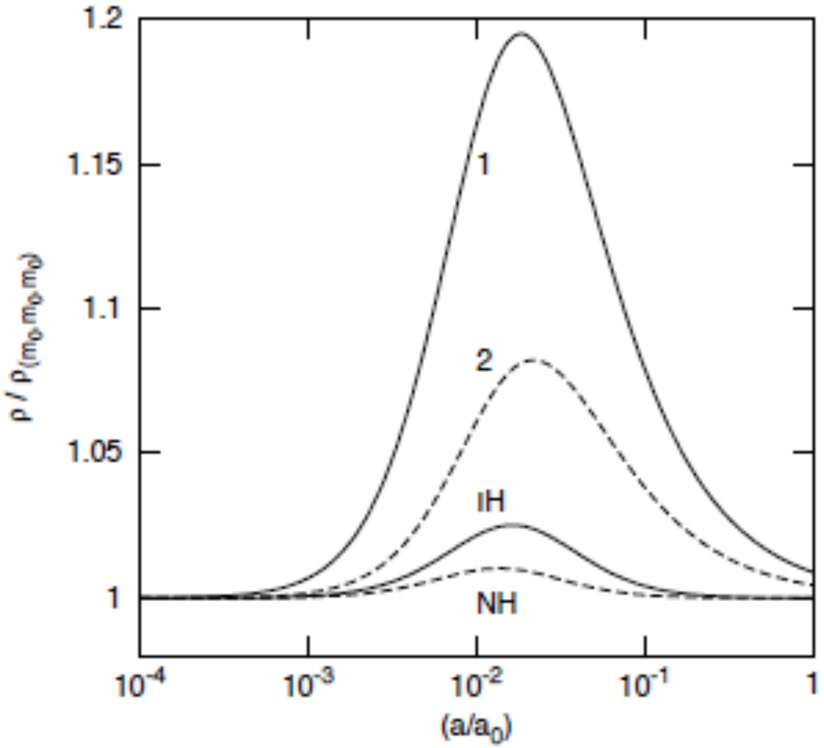
$$H(a) = H_0 \left[\frac{\Omega_m}{a^3} + \frac{\Omega_r}{a^4} + \frac{\Omega_k}{a^2} + \frac{\Omega_\Lambda}{a^{3(1+w_{\rm eff}(a))}} \right]^{1/2}$$

$$\Omega_r = \Omega_\gamma \left(1 + 0.2271 N_{\rm eff}\right)$$

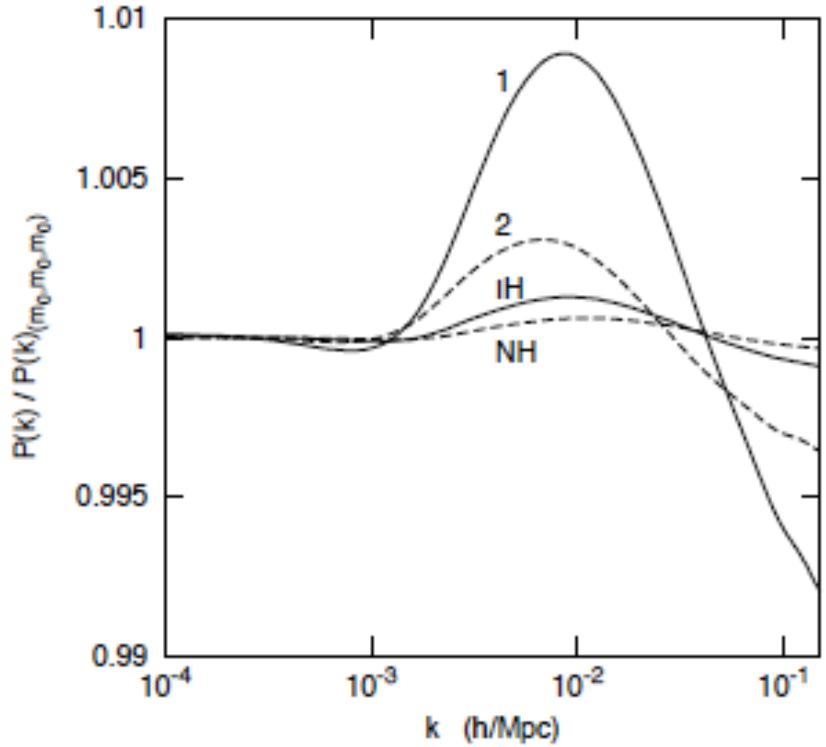
Note that the equation above is not exact
but it is a good approximation (e.g. Komatsu et al 11)

EVOLUTION of LSS - IV: individual neutrino masses do matter

Lesgourgues & Pastor 2006



GEOMETRY



DYNAMICS

SIMULATION of LSS – I: basic equations

$f(\mathbf{r}, v, t)$

DM

$$\frac{df}{dt} \equiv \frac{\partial f}{\partial t} + \mathbf{v}\frac{\partial f}{\partial \mathbf{x}} - \frac{\partial \Phi}{\partial \mathbf{r}}\frac{\partial f}{\partial \mathbf{v}} = 0$$

Collisionless Boltzmann Equation

$$\nabla^2 \Phi(\mathbf{r}, t) = 4\pi G \int f(\mathbf{r}, \mathbf{v}, t)\, d\mathbf{v}$$

Poisson equation

N-body problem: follow the Newton's equation of motions for a large number of particles under their own self-gravity

GAS

$$\frac{d\rho}{dt} + \rho \nabla \cdot \mathbf{v} = 0$$

Continuity

$$\frac{du}{dt} = -\frac{P}{\rho}\nabla \cdot \mathbf{v} - \frac{\Lambda(u, \rho)}{\rho}$$

Energy

$$\frac{dv}{dt} = -\frac{\nabla P}{\rho} - \nabla\Phi,$$

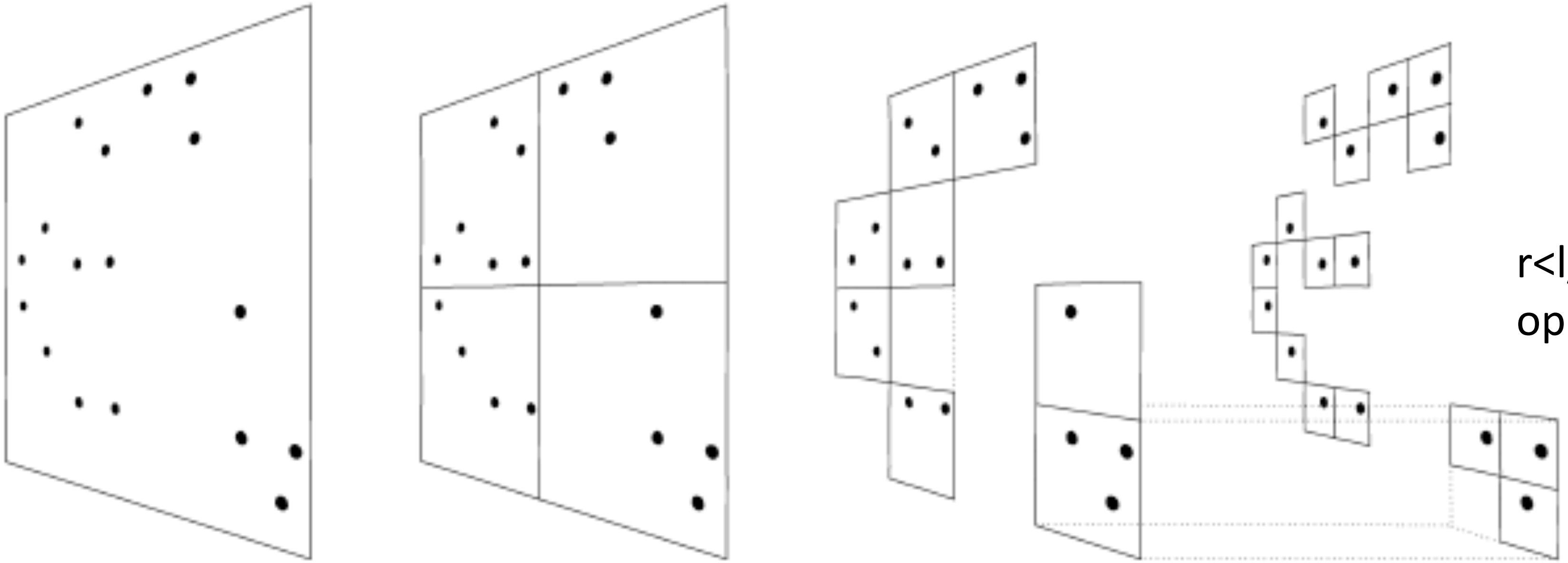
Euler

$$P = (\gamma - 1)\rho u$$

Gas eq.of state

SIMULATION of LSS – II: basic equations for DM

Tree method – expansion of the gravitational potential in multipoles



r<l/θ then
open the node

$$\Phi(r) = G\int_{V'} \frac{\rho(r')dV'}{|\vec{r}'-\vec{r}|}$$

$$\frac{1}{|r'-r|} \approx \frac{1}{r} + \sum_i r_i' \frac{\partial(1/r)}{\partial r_i} + \frac{1}{2}\sum_i\sum_j r_i' r_j' \frac{\partial^2(1/r)}{\partial r_i \partial r_j} - \frac{1}{6}\sum_i\sum_j\sum_k r_i' r_j' r_k' \frac{\partial^3(1/r)}{\partial r_i \partial r_j \partial r_k}$$

$$\Phi(r) = \left\{ M(1/r) - \vec{P} \bullet \nabla(1/r) + \frac{1}{2}\mathbf{Q} : \nabla\nabla(1/r) - \frac{1}{6}\bar{\mathbf{S}} \,\therefore\, \nabla\nabla\nabla(1/r) + \cdots + \right\}$$

P dipole moment, Q tensor quadropole moment, S usually not considered

SIMULATION of LSS – III: historical background

1980: Bond et al. 1980 – linear theory (also Russian school with Zeldovich)
1983: Bond et al. – Evolution of Boltzmann-Einstein equations. Clustering properties of galaxies not reproduced if the universe is dominated by neutrinos (White et al. 1983) – numerical experiment

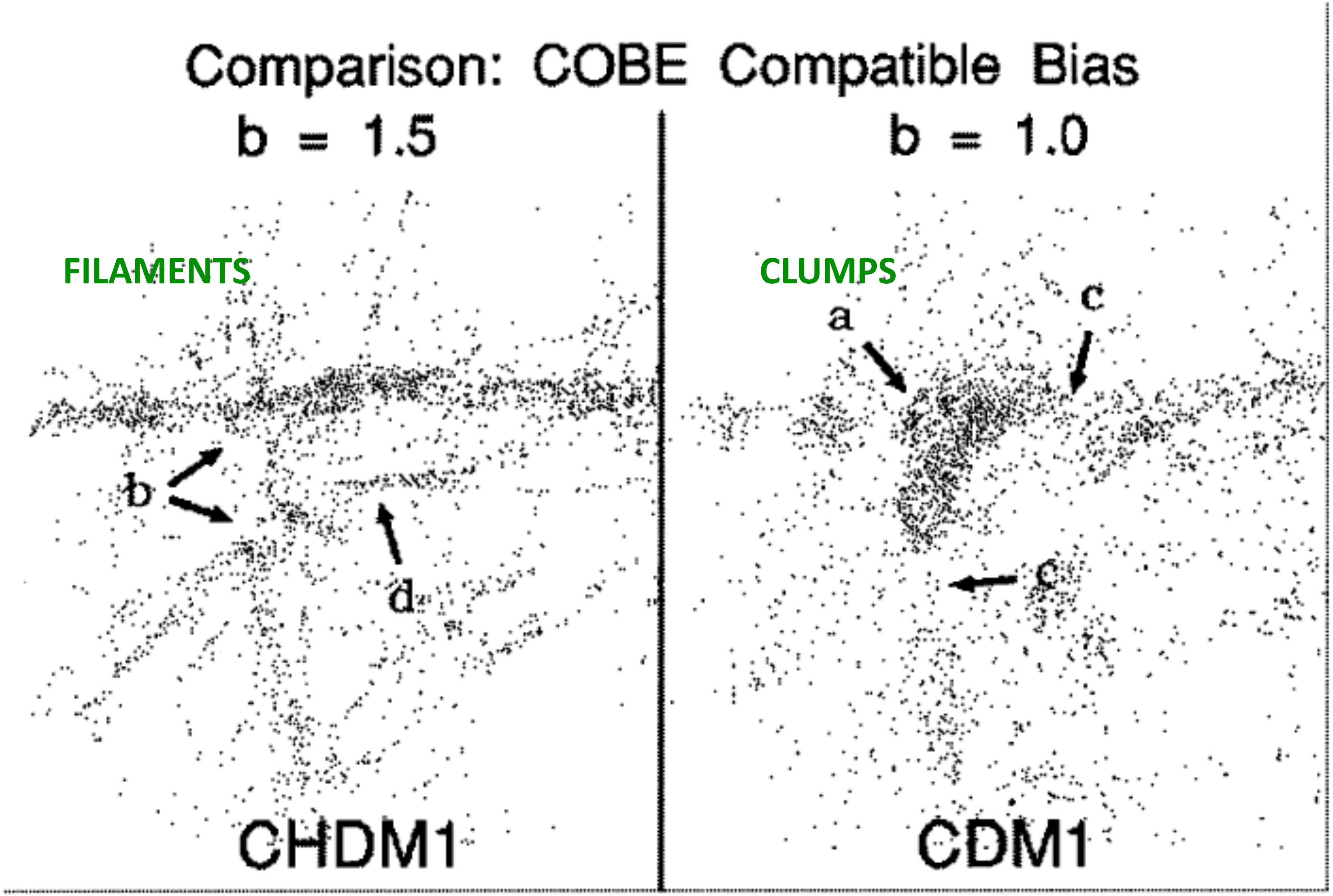
1992: Davis et al. HDM or CHDM models P3M codes with neutrino particles placed as the dark matter ones (same CDM spectrum + velocities): 32^3 particles

1993: Klypin et al. 2 x 128^3 particles at z_IC=14 with the right power spectrum

1994: Ma & Bertschinger approximate linear scheme evolved at z=13 and after that pure N-body

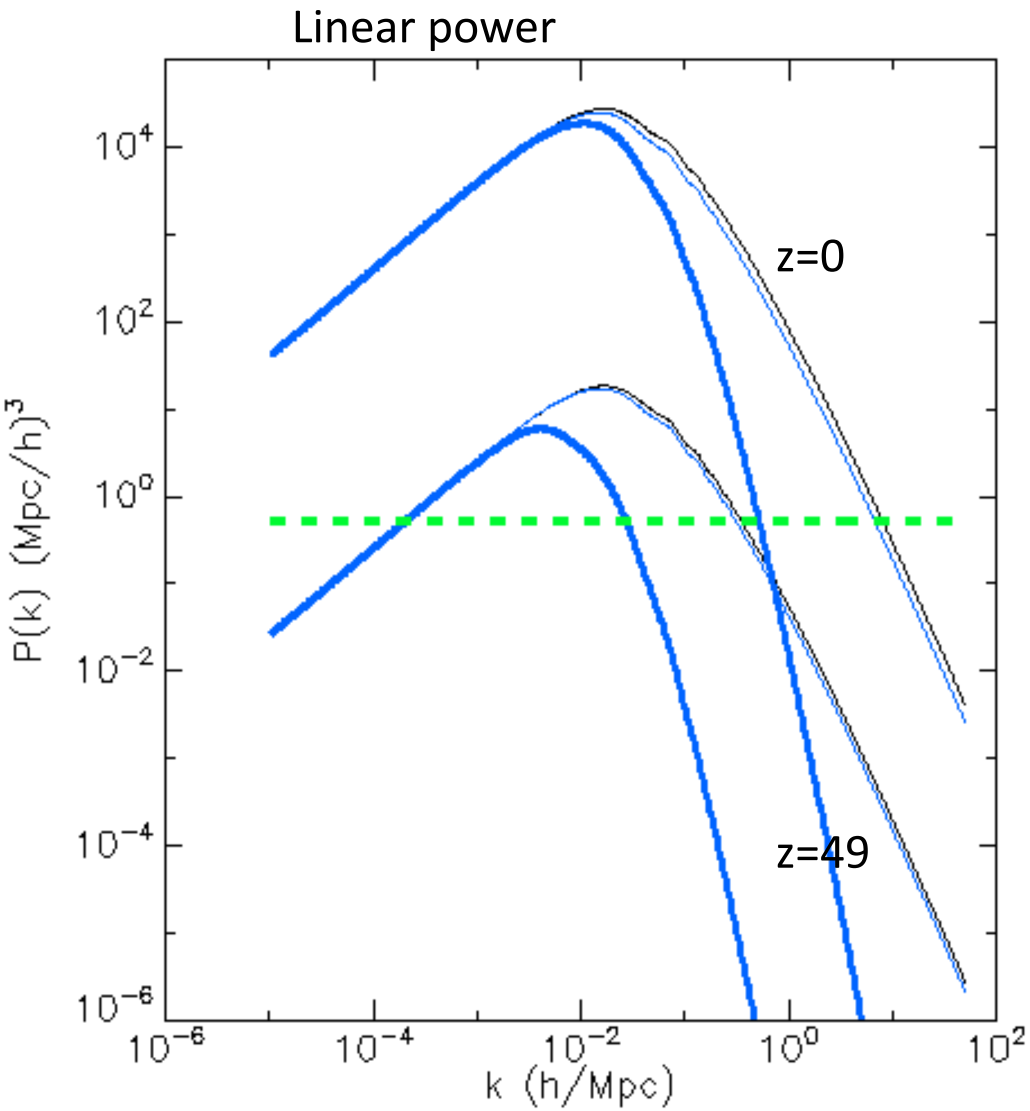
SIMULATION of LSS – IV: the distribution of matter

Pure HDM not allowed. However CHDM is still viable and impacts on the cosmic web



Brodbeck et al. 98

SIMULATION of LSS – V: Initial Conditions



Black is matter power

Blue is matter power in neutrino simulations

Thick blue is neutrino power

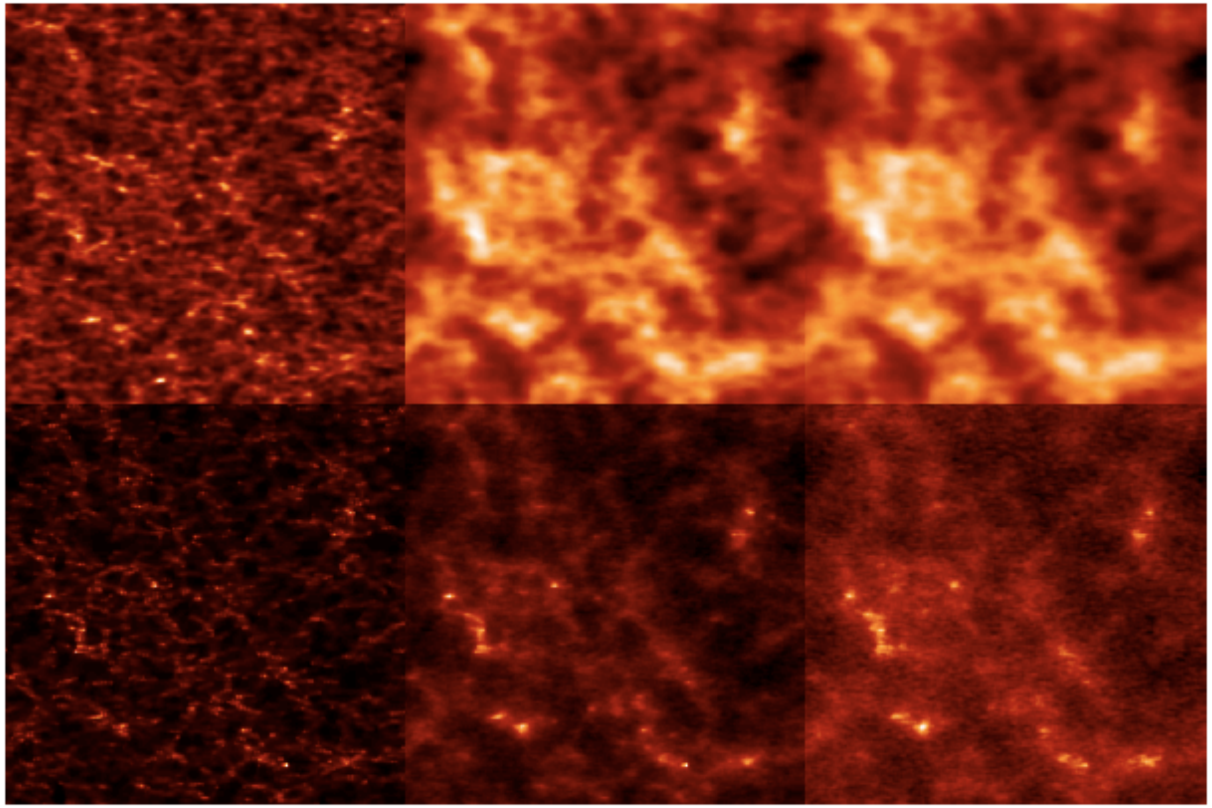
Green dashed is shot noise level for a typical run

Zeldovich displacement of the particles

$$\boldsymbol{x}(\boldsymbol{q}, z) = \boldsymbol{q} + D_+(z)\nabla_{\boldsymbol{q}}\phi_{\rm f}(\boldsymbol{q})$$

$$\phi_{\rm i}(\boldsymbol{x}) = -\frac{3}{2} H^2 a^3 \Phi_{\rm i}(\boldsymbol{x})$$

N-body simulations – I: particles

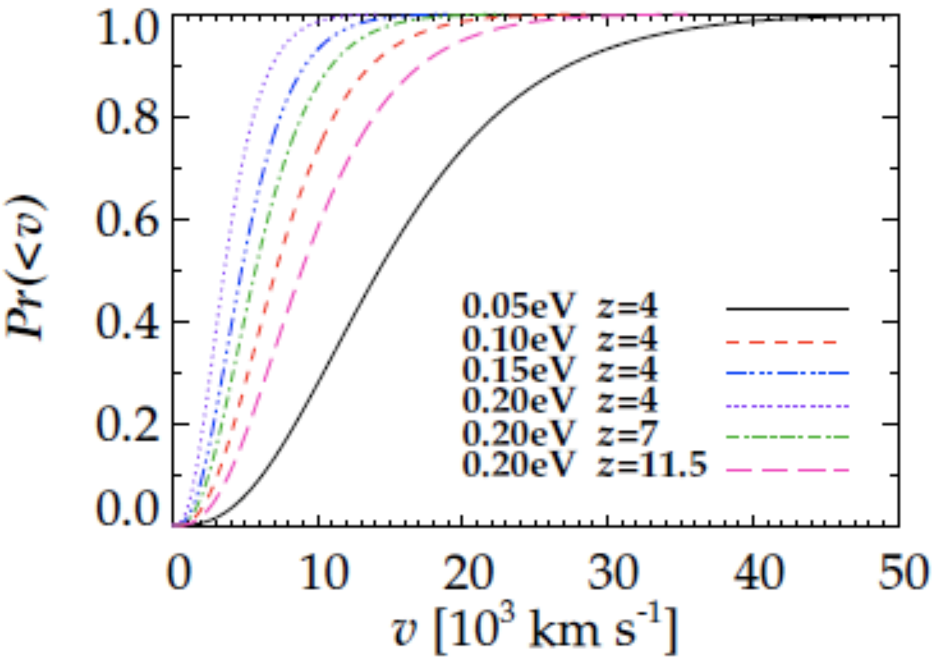


COLD DM NEUTRINOS 0.6 eV NEUTRINOS 0.3 eV

Simulation of neutrinos as an independent set of particles that interact gravitationally

Brandbyge et al 08

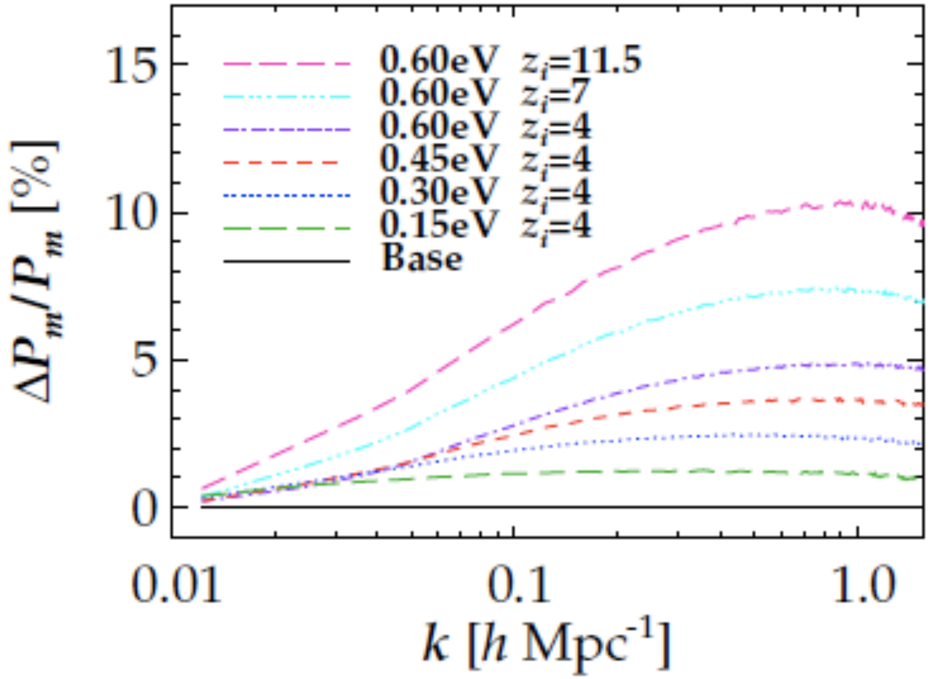
N-body simulations – II: velocities



$$T_\nu \simeq T_\gamma (4/11)^{1/3}$$

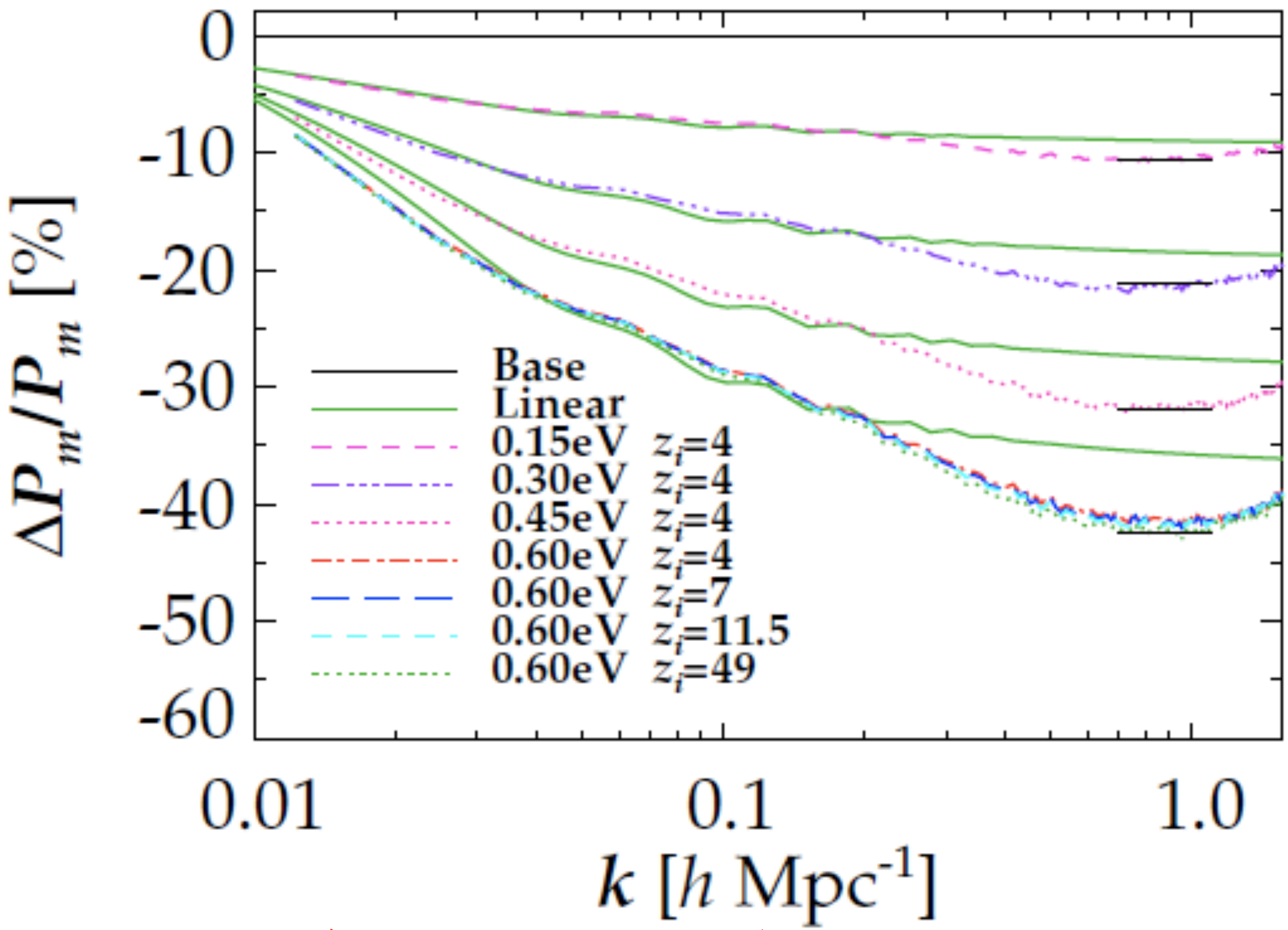
$$Pr(<p) = N \int_0^p \frac{p'^2}{e^{p'c/k_b T_\nu} + 1} dp'$$

Draw velocity from Fermi-Dirac distribution



Brandbyge et al 08a

N-body simulations – III: effects in terms of non-linear power



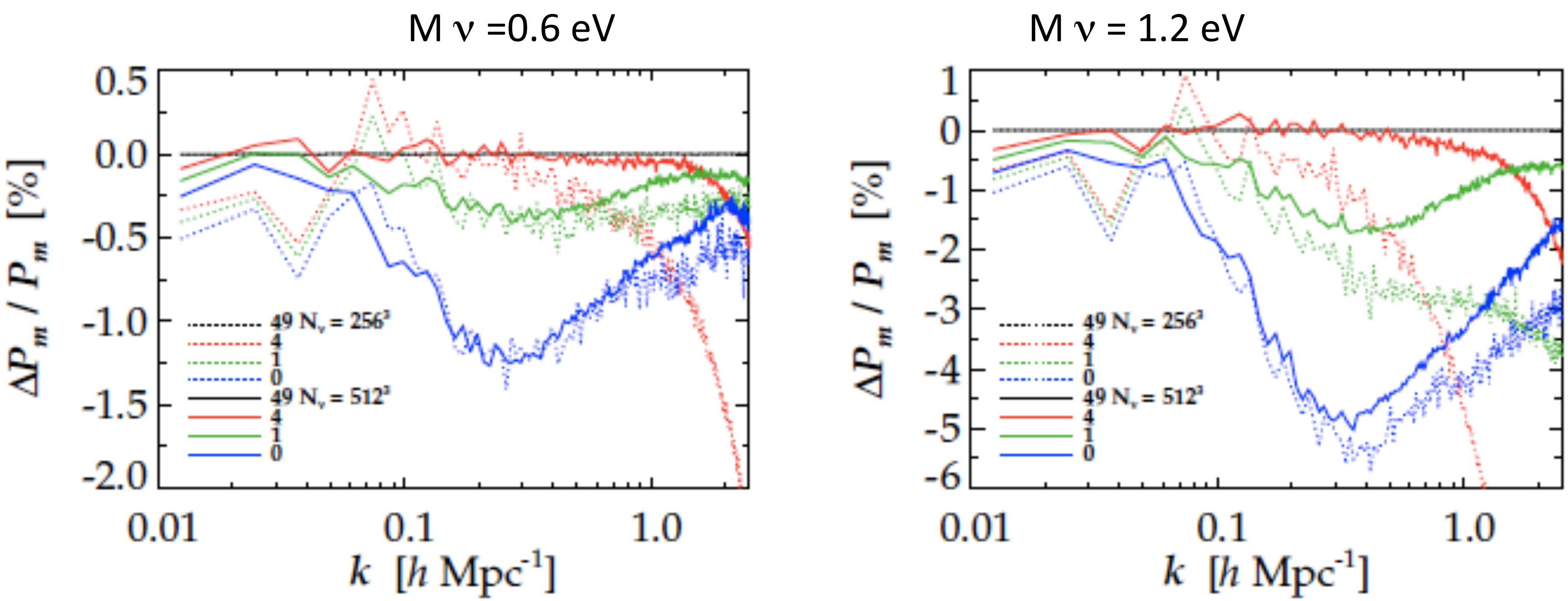
Brandbyge et al 08

$$\left.\frac{\Delta P}{P}\right|_{\max} \sim -8\frac{\Omega_\nu}{\Omega_m} \quad\rightarrow\quad \left.\frac{\Delta P}{P}\right|_{\max} \sim -9.8\frac{\Omega_\nu}{\Omega_m}$$

N-body simulations – IV: mesh method

Computing the neutrino gravitational potential on the PM grid and summing up its contribution to the total matter gravitational potential

COMPARISON GRID VS PARTICLES



Brandbyge et al 08b

N-body simulations – V: a hybrid approach

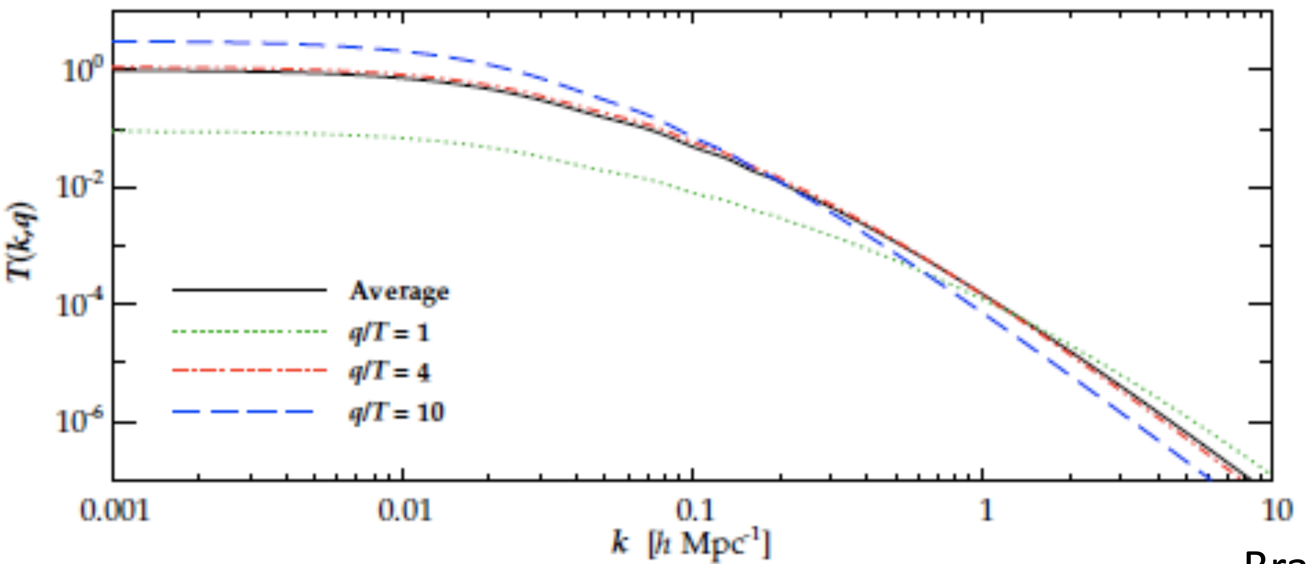
$$f = f_0 + \frac{\partial f_0}{\partial T}\delta T = f_0(1+\Psi) \qquad f_0(q) = \frac{1}{e^{q/T}+1}$$

After neutrino decoupling CBE

$$\frac{df}{d\tau} = \frac{\partial f}{\partial \tau} + \frac{dx^i}{d\tau}\frac{\partial f}{\partial x^i} + \frac{dq}{d\tau}\frac{\partial f}{\partial q} + \frac{dn_i}{d\tau}\frac{\partial f}{\partial n_i} = 0$$

$$\delta\rho_\nu(k) = 4\pi a^{-4}\int q^2 dq \epsilon f_0 \Psi_0 \qquad \epsilon = (q^2 + a^2 m^2)^{1/2}$$

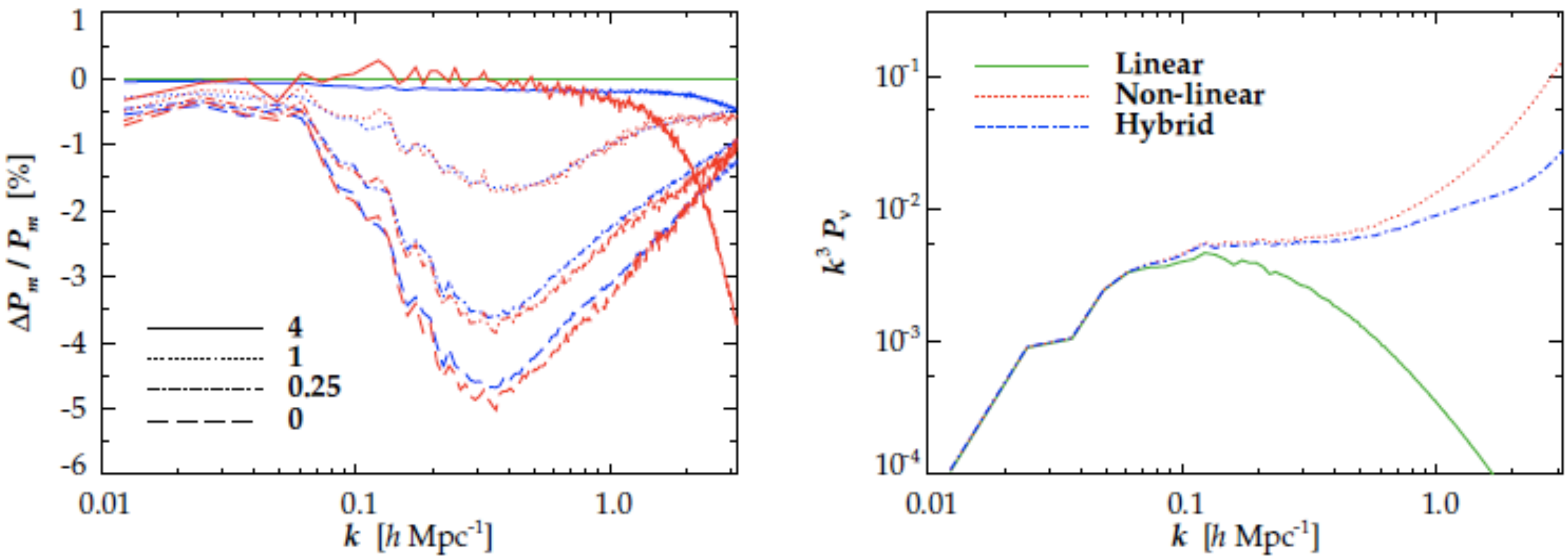
$$\dot{\Psi}_0 = -\frac{qk}{3\epsilon}\Psi_1 - \dot{\phi}\frac{d\ln f_0}{d\ln q},$$
$$\dot{\Psi}_1 = \frac{qk}{\epsilon}\left(\Psi_0 - \frac{2}{5}\Psi_2\right) - \frac{\epsilon k}{q}\psi\frac{d\ln f_0}{d\ln q},$$
$$\dot{\Psi}_l = \frac{qk}{\epsilon}\left(\frac{l}{2l-1}\Psi_{l-1} - \frac{l+1}{2l+3}\Psi_{l+1}\right), \; l \geq 2$$



$$\Psi_0(k,q,z) = T(k,q,z)\Psi_0^I(k,q)$$

Brandbyge & Hannestad 09

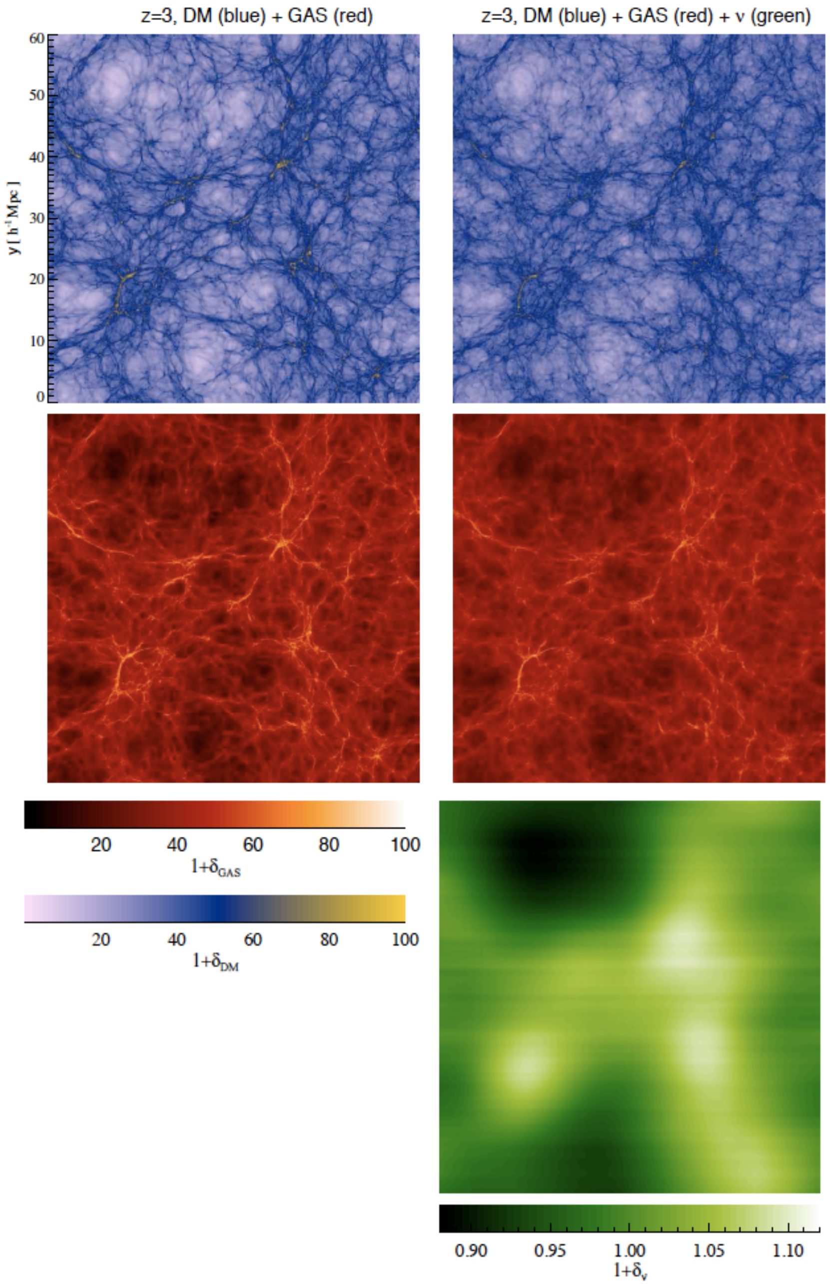
N-body simulations – VI: comparison



PARTICLES: accurate non-linear sampling but prone to shot-noise errors

GRID: fast and accurate but no phase mixing (i.e. non-linear regime suppression maybe it is less than it should be)

N-body + Hydro simulations – I: slices

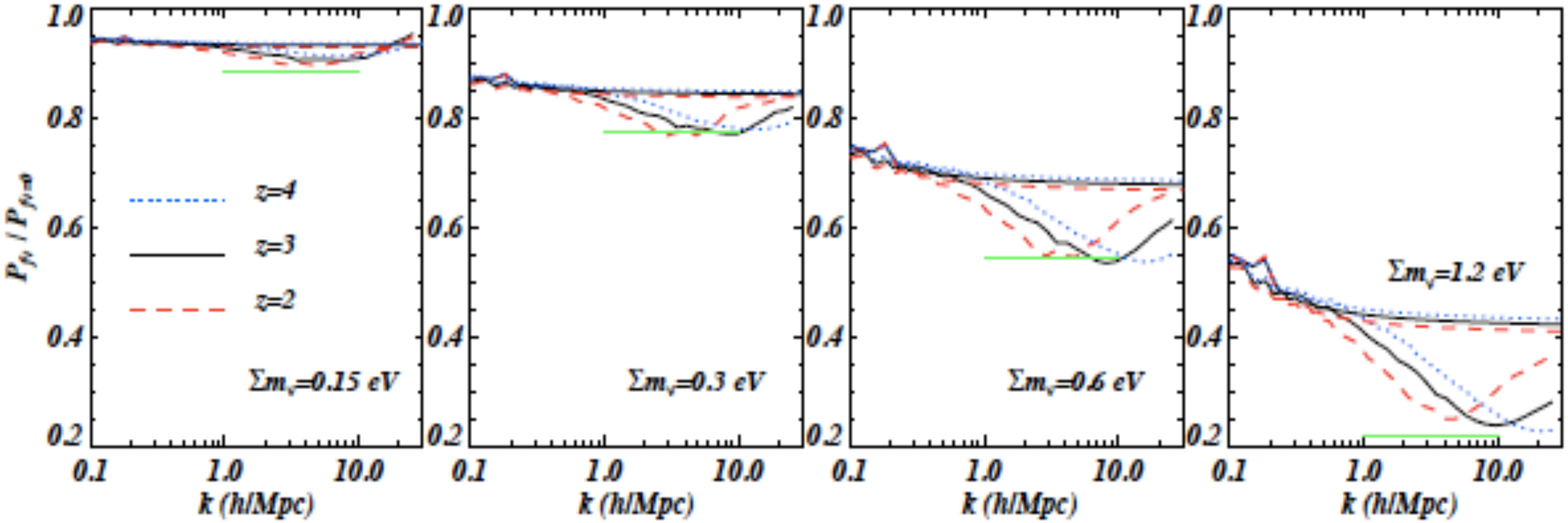


TreeSPH code Gadget-III
follows DM, neutrinos, gas and star particles in a cosmological volume

Viel, Haehnelt & Springel 2010, JCAP, 06 ,15

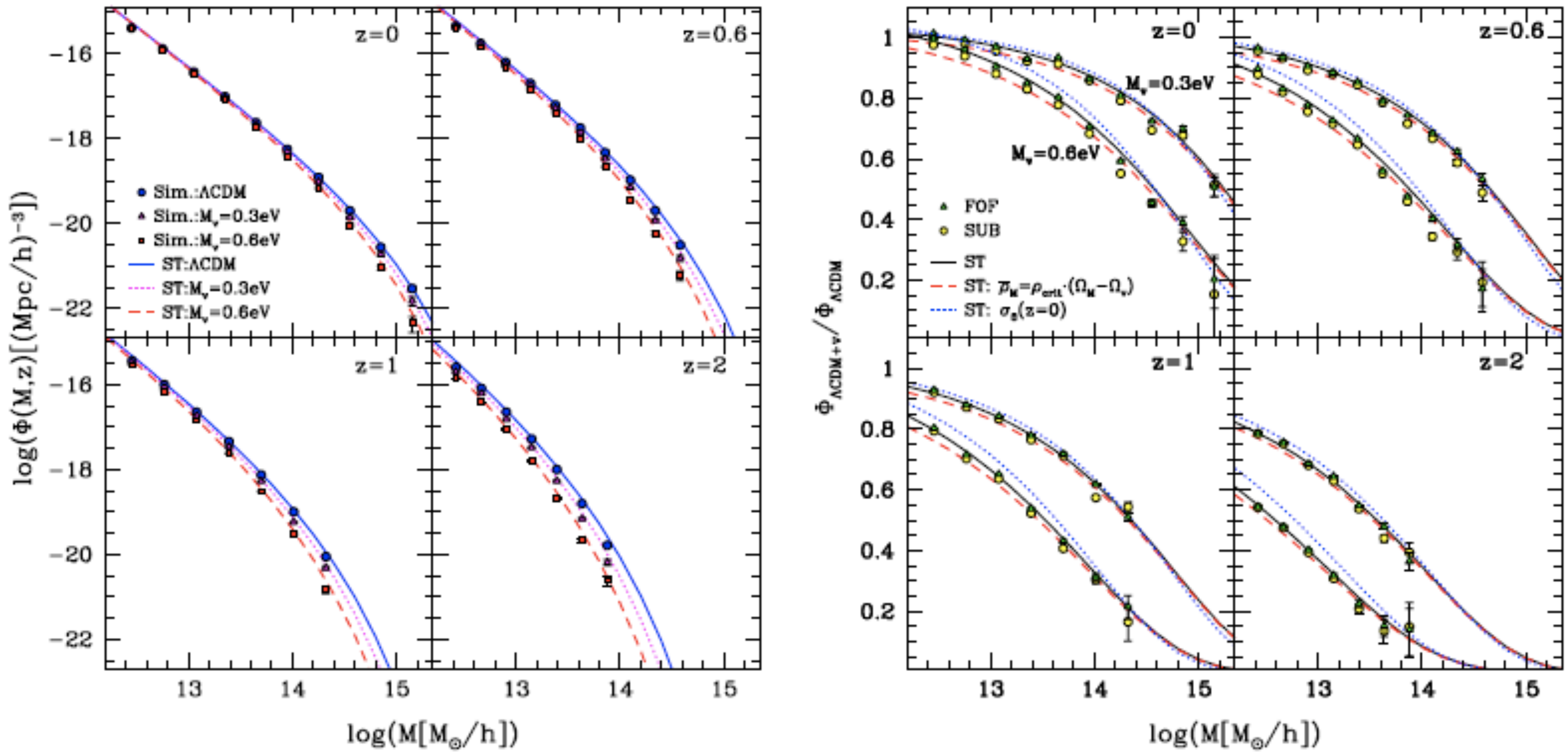
Hydro simulations – II: redshift/scale dependence of non-linear power

Full hydro simulations: gas physics does impact at the <10 % level at scales k < 10 h/Mpc



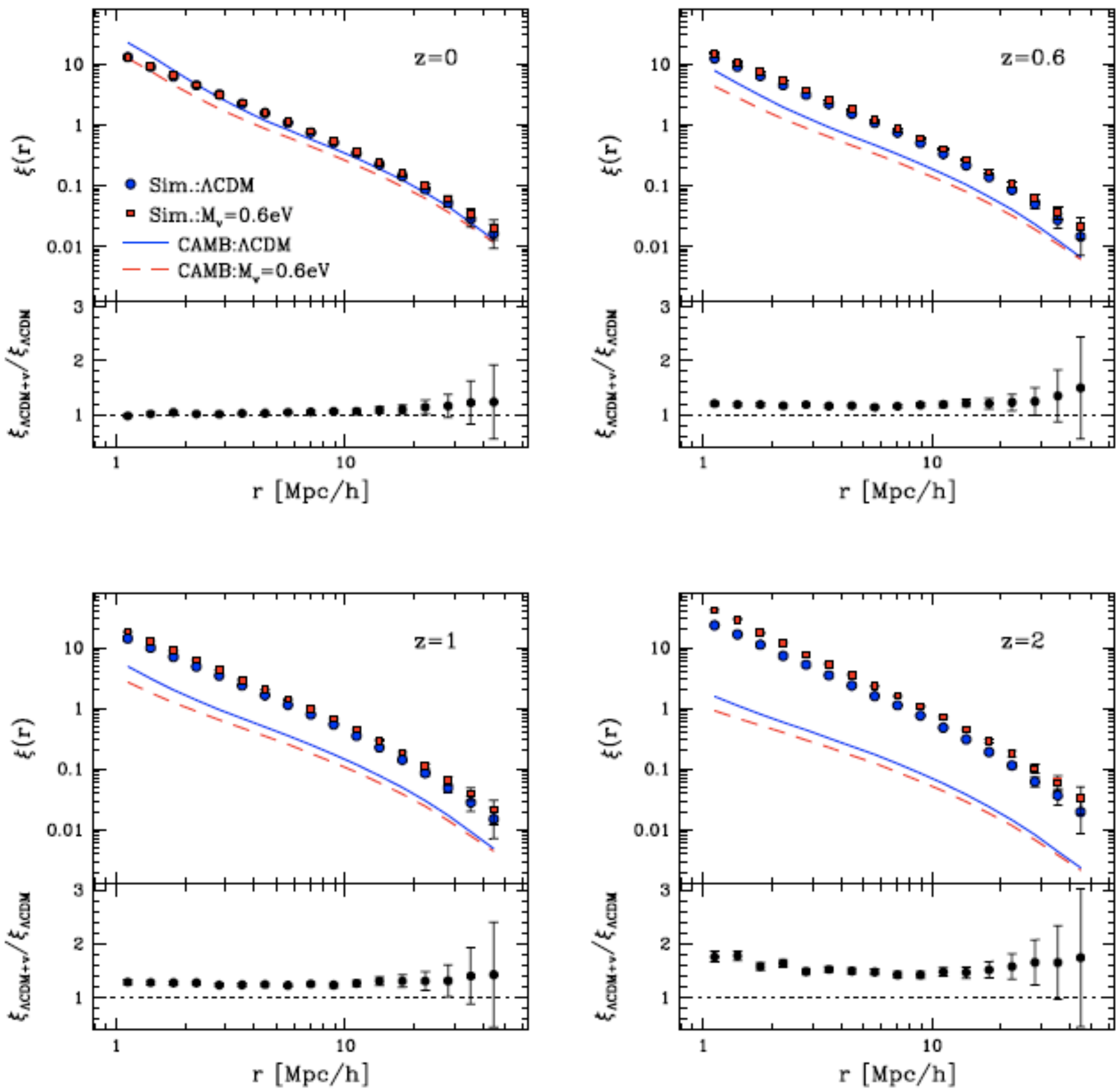
Viel, Haehnelt & Springel 2010, JCAP, 06 ,15

Hydro simulations – III: halo mass functions



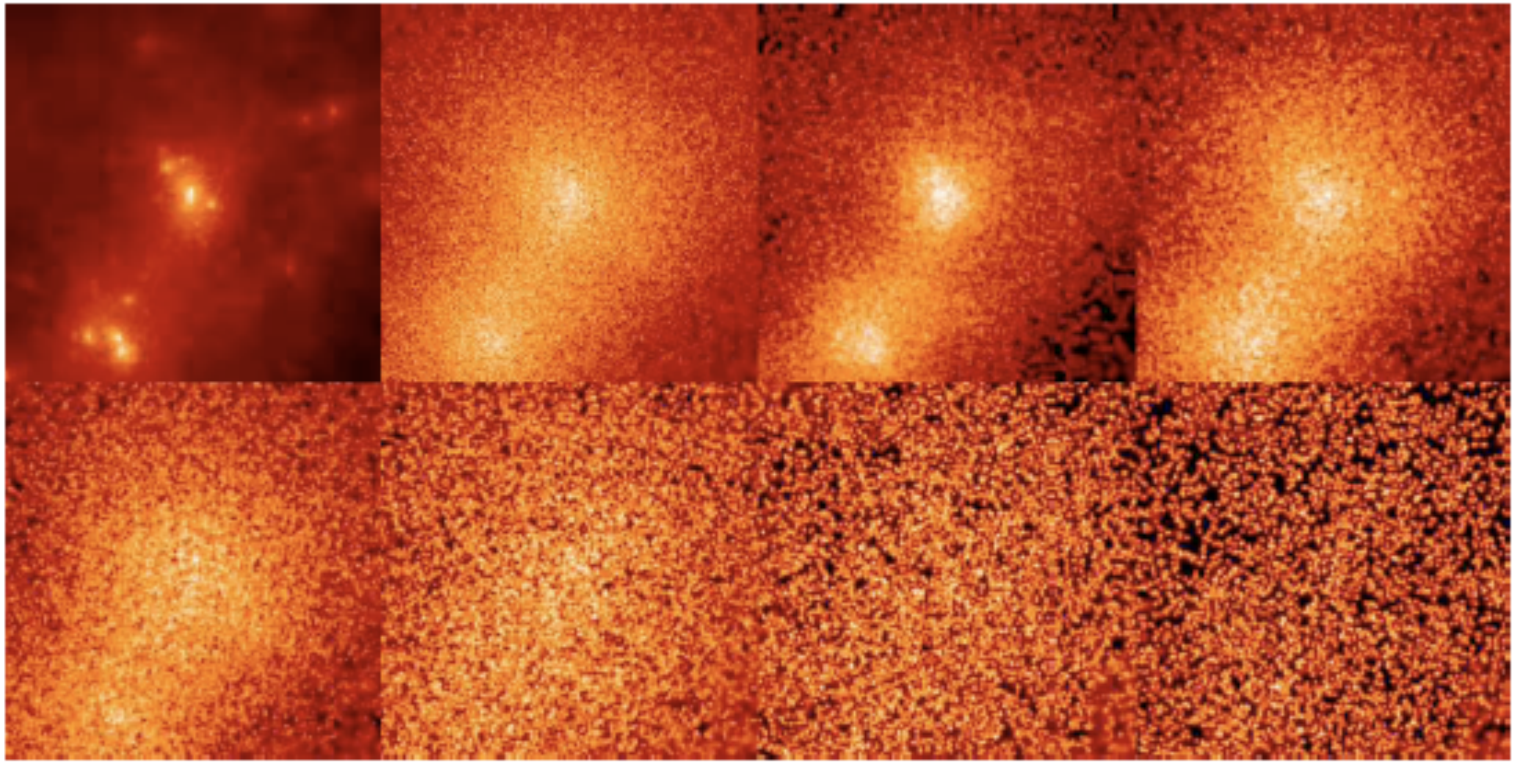
Marulli, Carbone, MV, Moscardini e Cimatti 2011 arxiv: 1103.0278

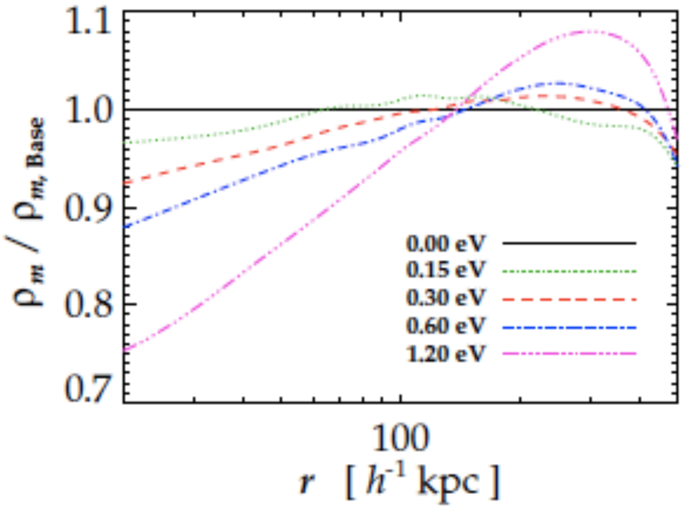
Hydro simulations – IV: matter and halo clustering



Marulli, Carbone, MV, Moscardini e Cimatti 2011 arxiv: 1103.0278

N-body simulations – V: halo density profile

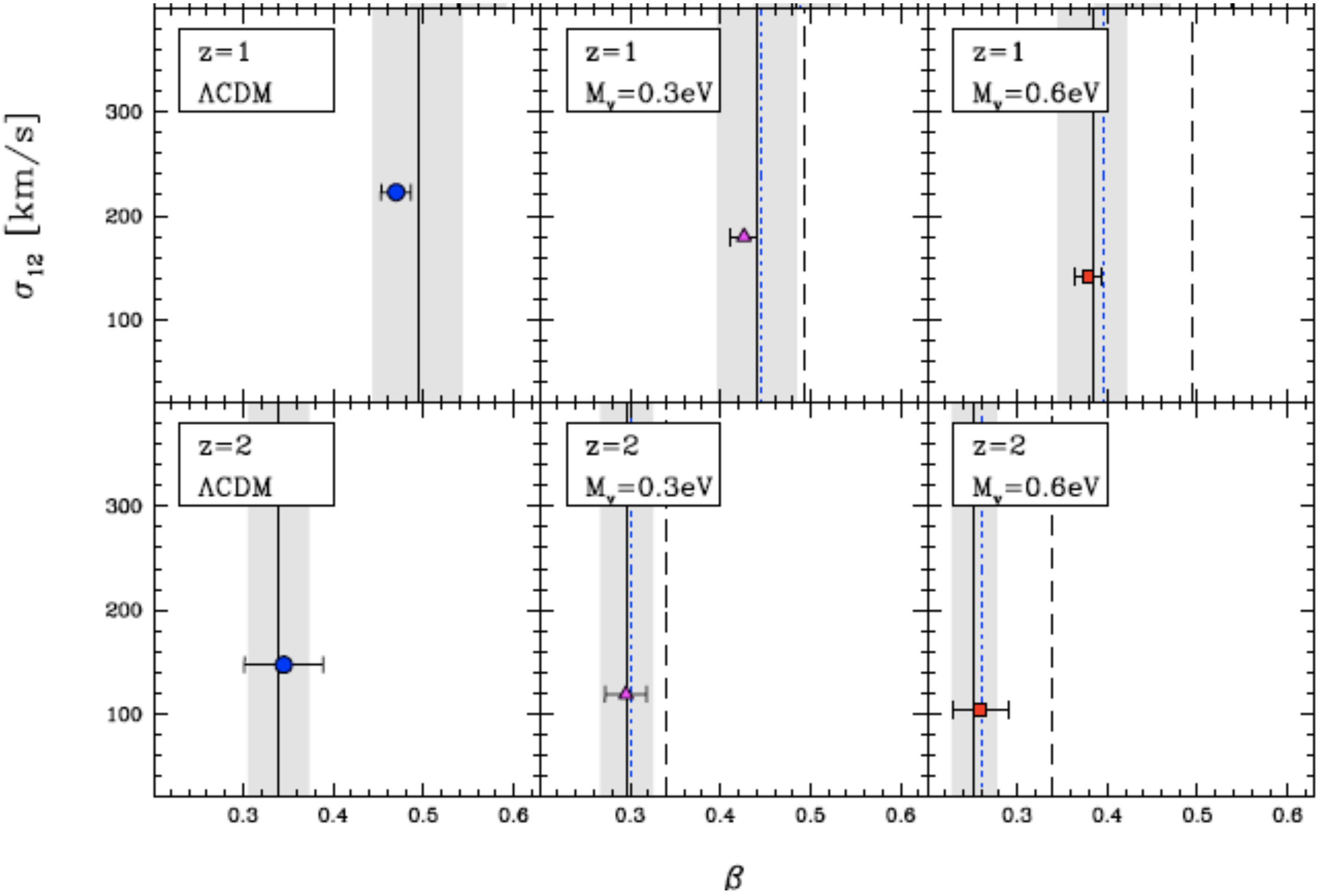




Brandbyge et al. 2010

Hydro simulations – VI: redshift space distortions

$$\xi(s_\perp, s_\parallel) = \int_{-\infty}^{\infty} dv\, f(v)\, \xi(s_\perp, s_\parallel - v/H(z)/a(z))$$

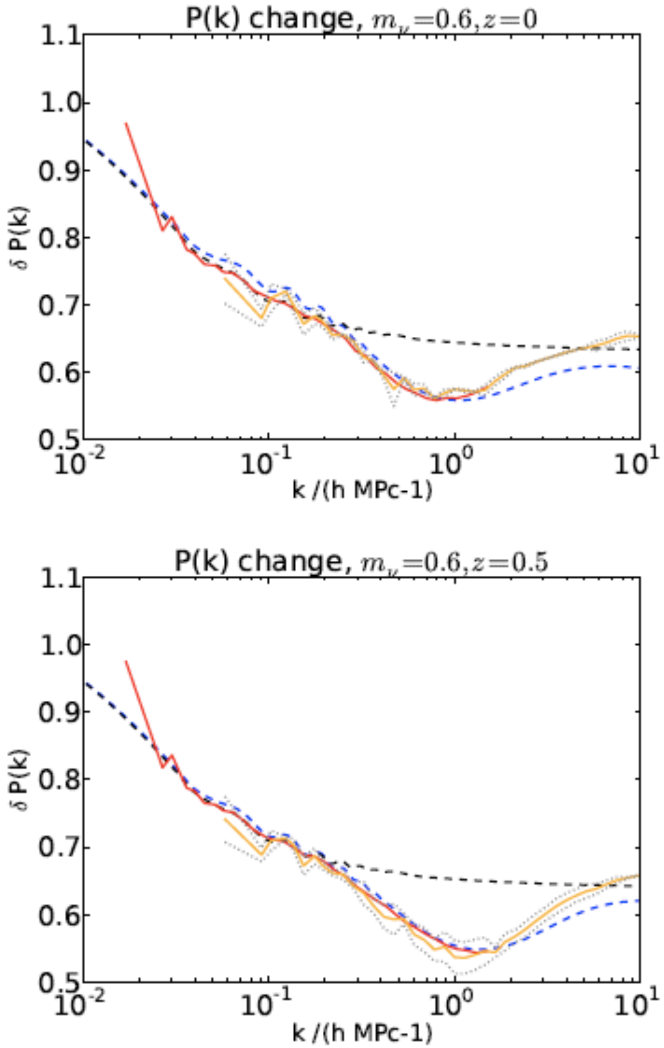


$$f_{\exp}(v) = \frac{1}{\sigma_{12}\sqrt{2}} \exp\left(-\frac{\sqrt{2}|v|}{\sigma_{12}}\right)$$

$$P(k) = (1 + \beta\mu^2)^2 P_{\rm lin}(k)$$

Marulli, Carbone, MV, Moscardini e Cimatti 2011 arxiv: 1103.0278

Hydro simulations – VII: very non-linear regime comparison with halofit



Bird, MV et al 011

IGM

Ordinary baryonic matter that fills the space between galaxies

Dark matter evolution and baryon evolution – I

linear theory of density perturbation +

Jeans length $L_J \sim \mathrm{sqrt}(T/\rho)$ + mildly non linear evolution

$$x_b \equiv \frac{1}{H_0}\left[\frac{2\gamma k T_m}{3\mu m_p \Omega(1+z)}\right]^{1/2}$$

Jeans length: scale at which gravitational forces and pressure forces are equal

$$\delta_0(x) \equiv \frac{1}{4\pi x_b^2}\int \frac{\delta_{\rm DM}(x_1)}{|x-x_1|}\, e^{-|x-x_1|/x_b}\, dx_1$$

$$\delta_0(k) \equiv \frac{\delta_{\rm DM}(k)}{1+x_b^2 k^2}\,,$$

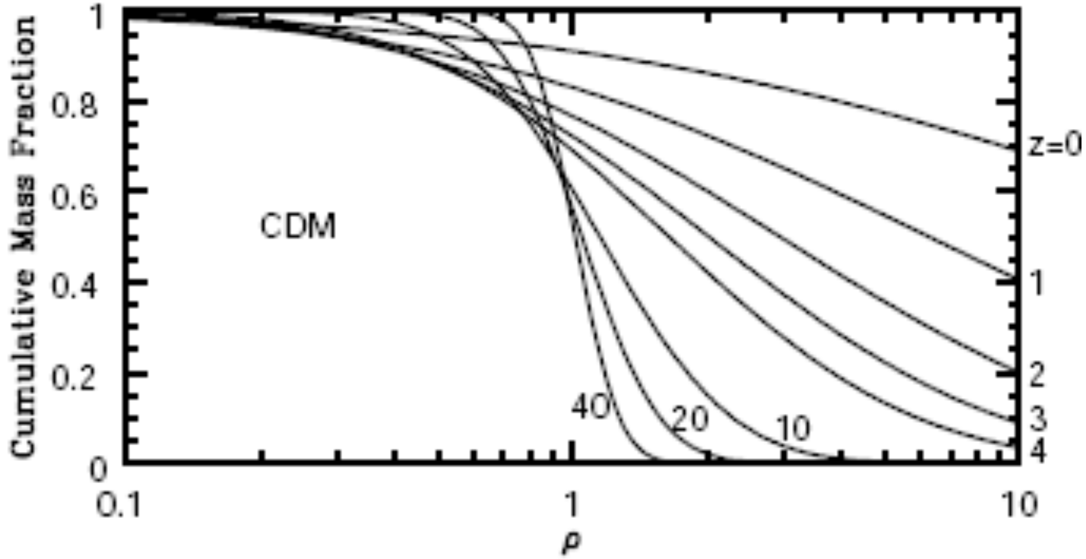
Density contrast in real and Fourier space

$$n(x) = n_0 \exp\left[\delta_0(x) - \frac{\langle \delta_0^2 \rangle}{2}\right]$$

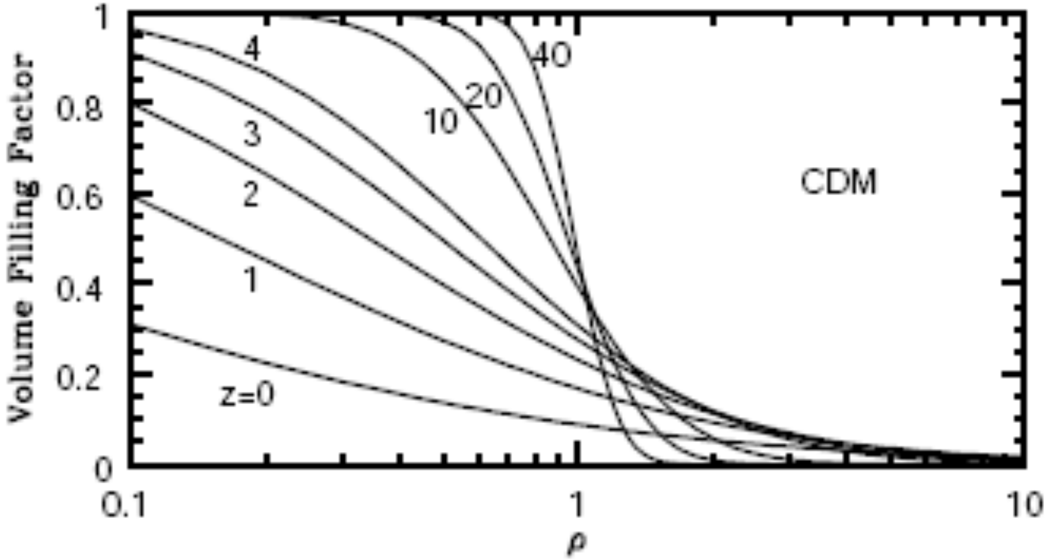
Non linear evolution lognormal model

Bi & Davidsen 1997, ApJ, 479, 523

Dark matter evolution and baryon evolution –II

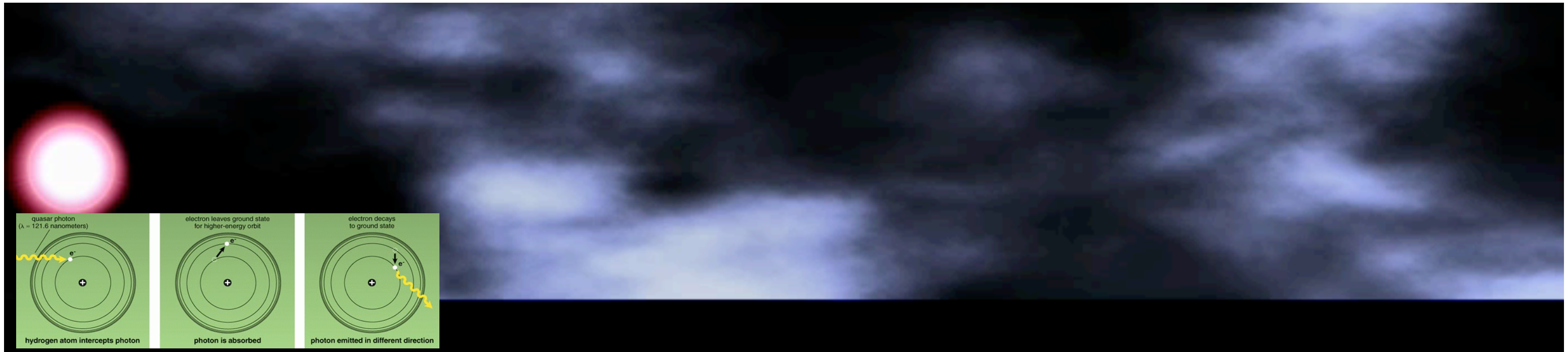


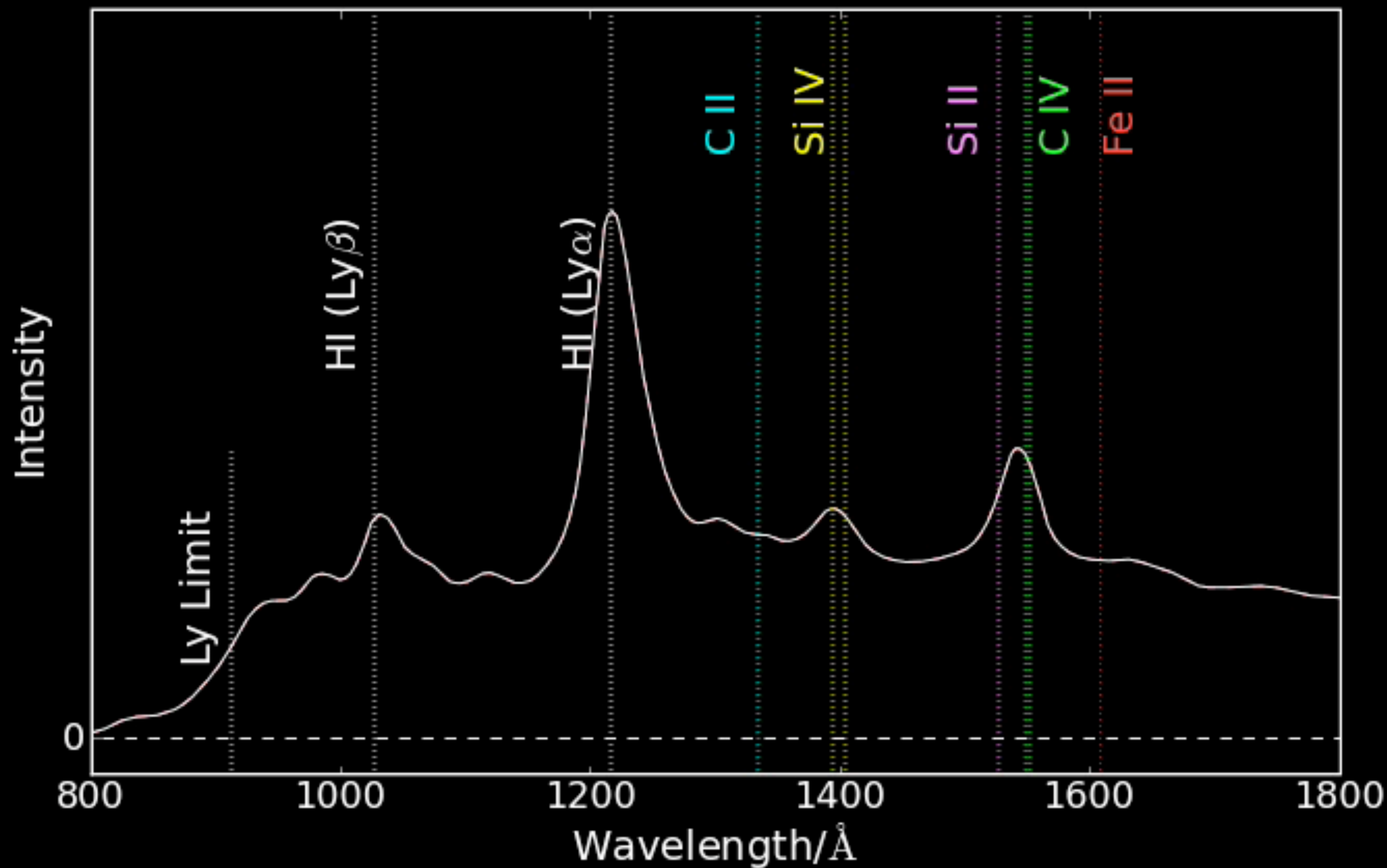
M (> ρ)



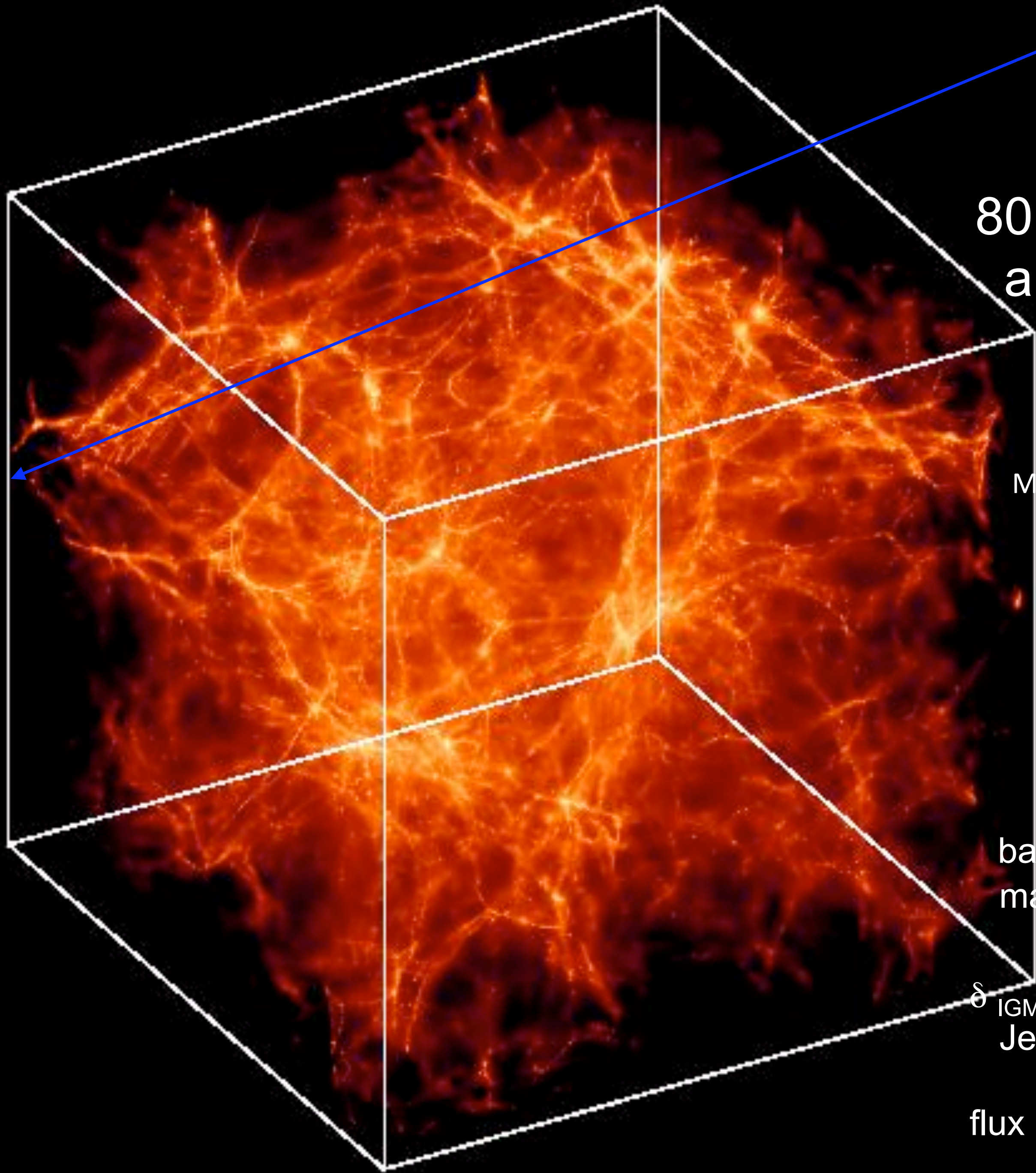
V (> ρ)

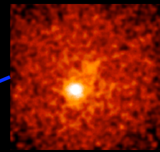
Bi & Davidsen 1997, ApJ, 479, 523

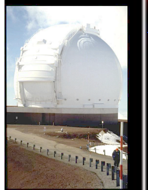

quasar photon
(λ = 121.6 nanometers)
hydrogen atom intercepts photon
electron leaves ground state
for higher-energy orbit
photon is absorbed
electron decays
to ground state
photon emitted in different direction


Intensity
0
Ly Limit
HI (Lyβ)
HI (Lyα)
C II
Si IV
Si II
C IV
Fe II
800
1000
1200
1400
1600
1800
Wavelength/Å

THEORY: GAS in a LCDM universe







80 % of the baryons at z=3 are in the Lyman-α forest

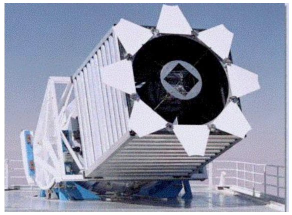
Meiksin's review (2007)

baryons as tracer of the dark matter density field

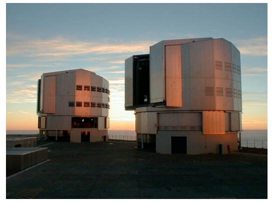
$\delta_{IGM} \sim \delta_{DM}$ at scales larger than the Jeans length ~ 1 com Mpc

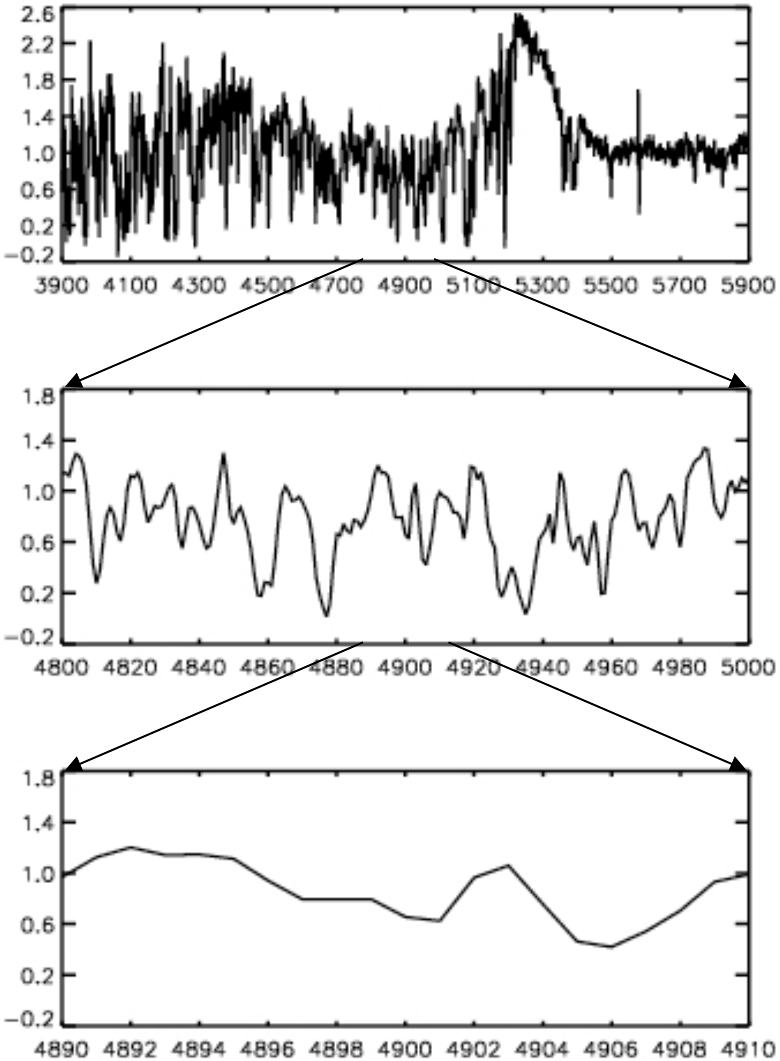
flux = $\exp(-\tau) \sim \exp(-(\delta_{IGM})^{1.6}\, T^{-0.7})$

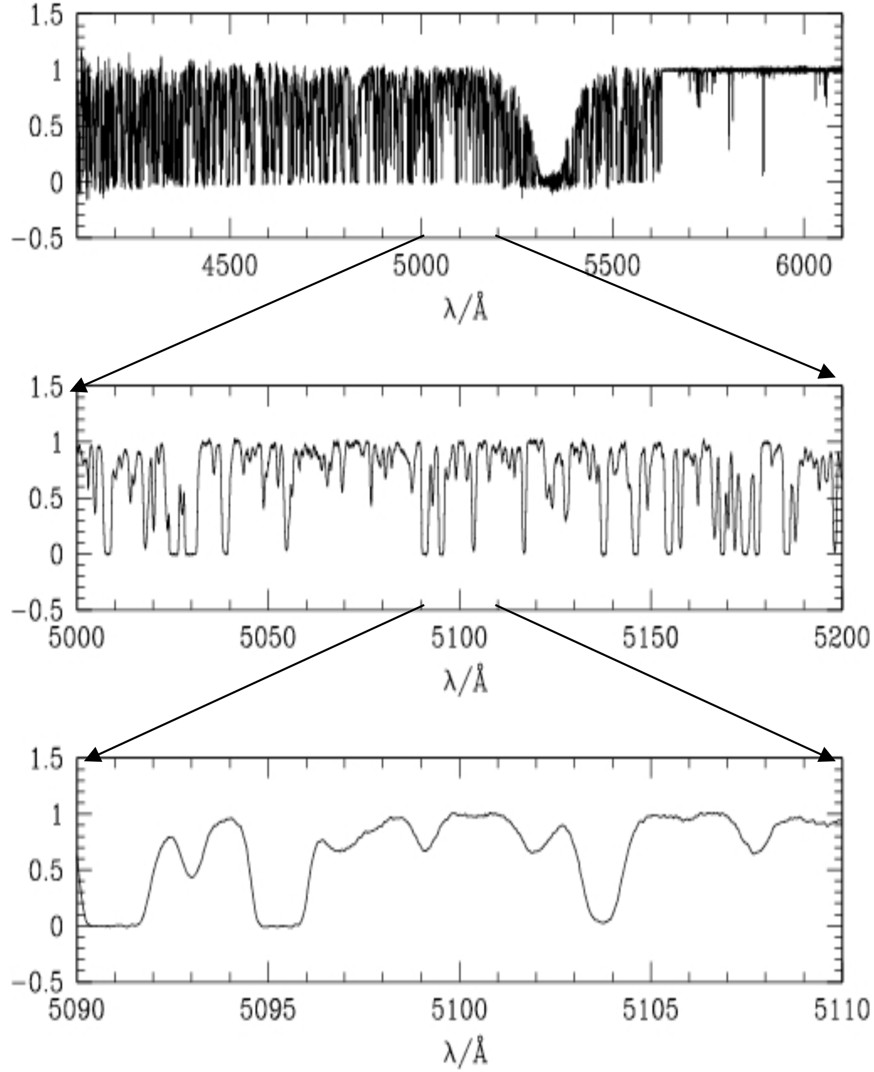
The data sets



SDSS vs UVES







SDSS
3035 LOW RESOLUTION LOW S/N

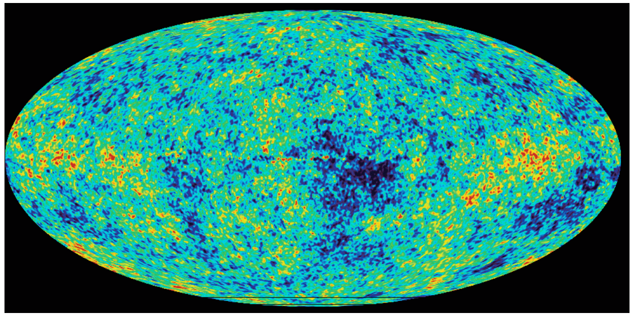
vs

LUQAS
30 HIGH RESOLUTION HIGH S/N

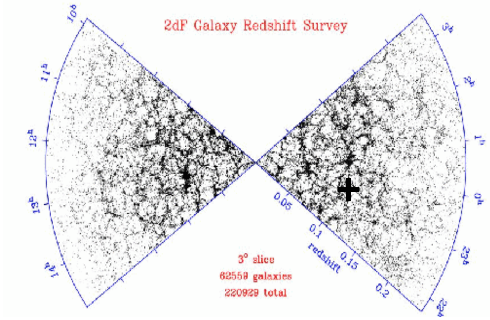
The interpretation: full grid of sims - I

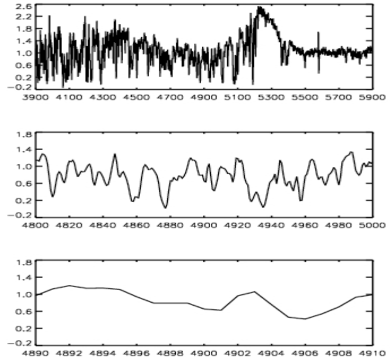
SDSS power analysed by forward modelling motivated by the huge amount of data with small statistical errors

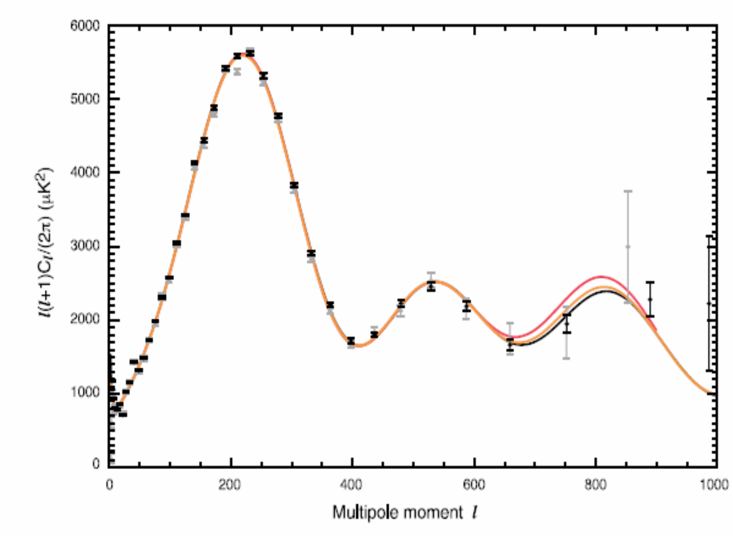
CMB: Spergel et al. (05) Galaxy P(k): Sanchez & Cole (07) Flux Power: McDonald (05)

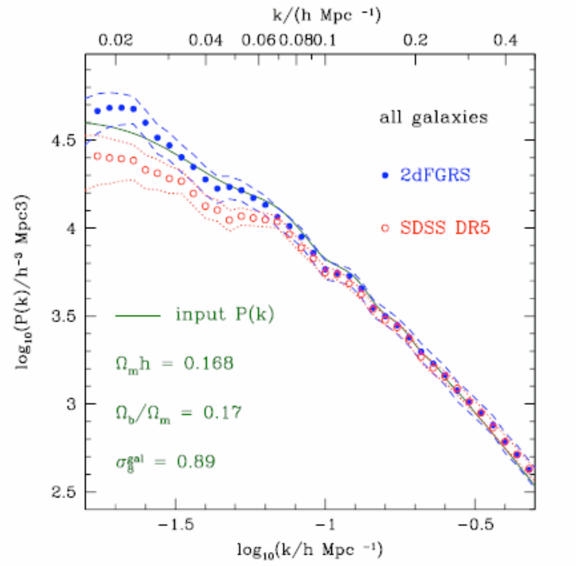


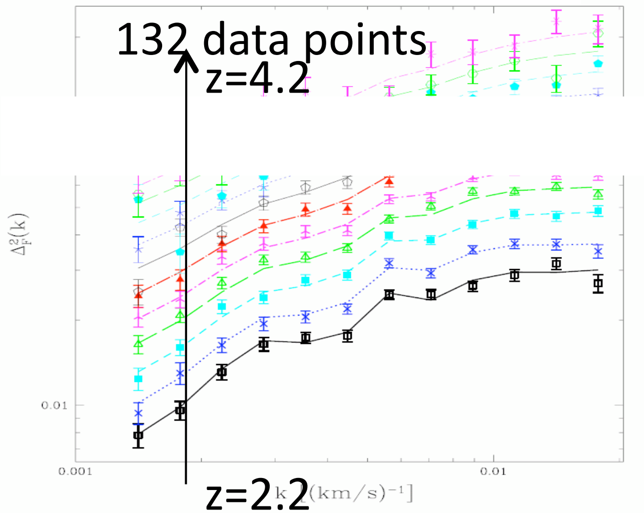
+







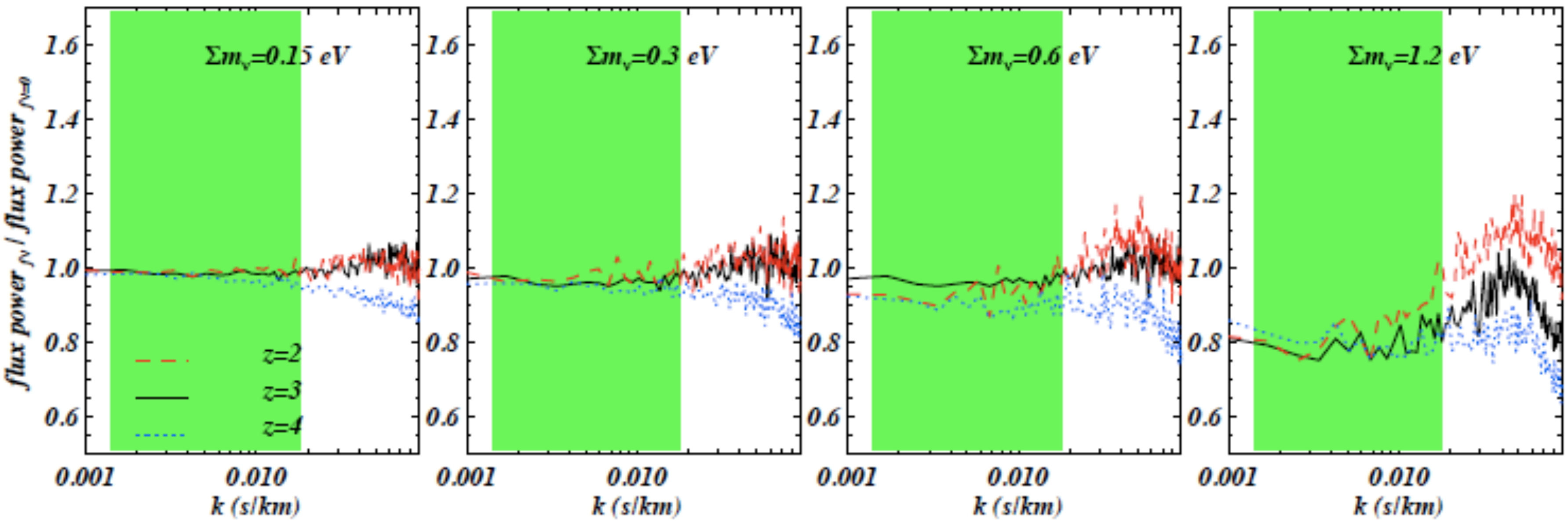




Cosmological parameters + e.g. bias + Parameters describing IGM physics

Hydro simulations – VI: redshift/scale dependence of flux power

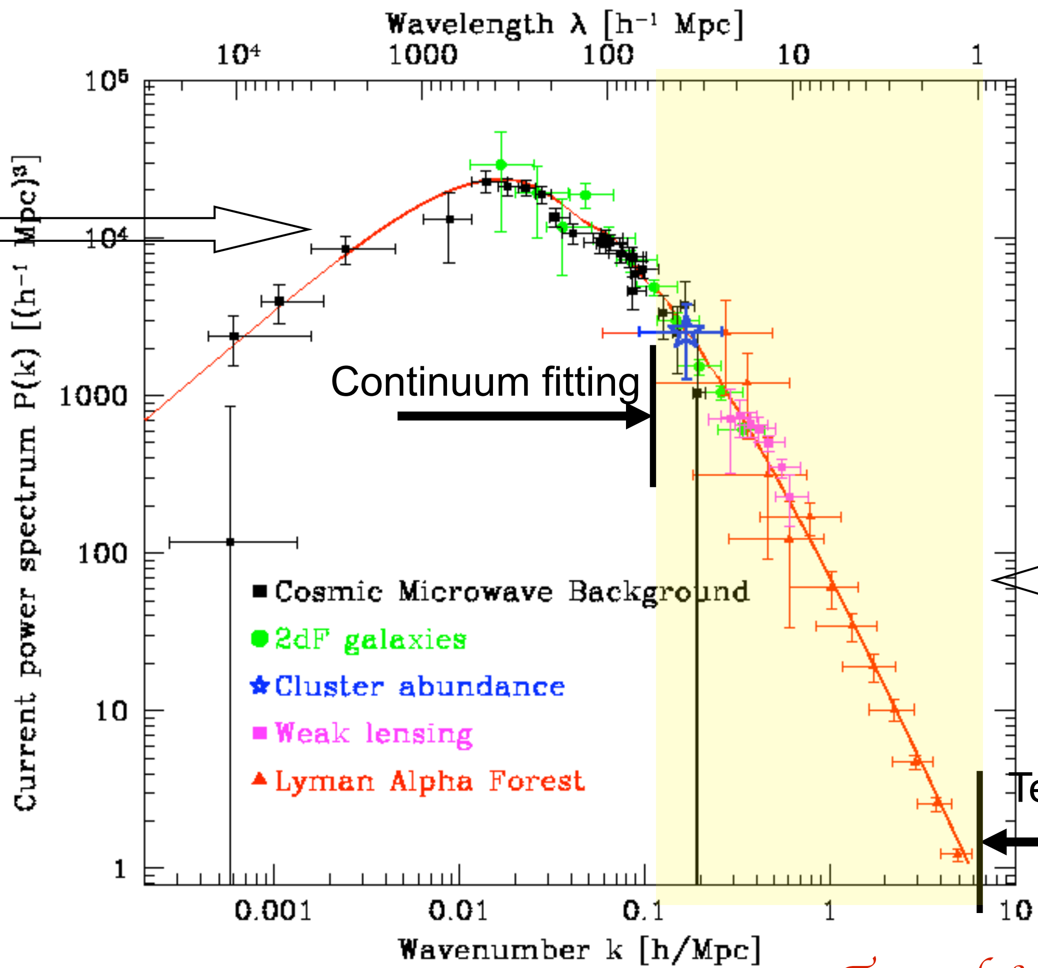
Effect on flux power observables is smaller than matter power



Viel, Haehnelt & Springel 2010, JCAP, 06 ,15

GOAL: the primordial dark matter power spectrum from the observed flux spectrum (filaments)

CMB physics
z = 1100
dynamics



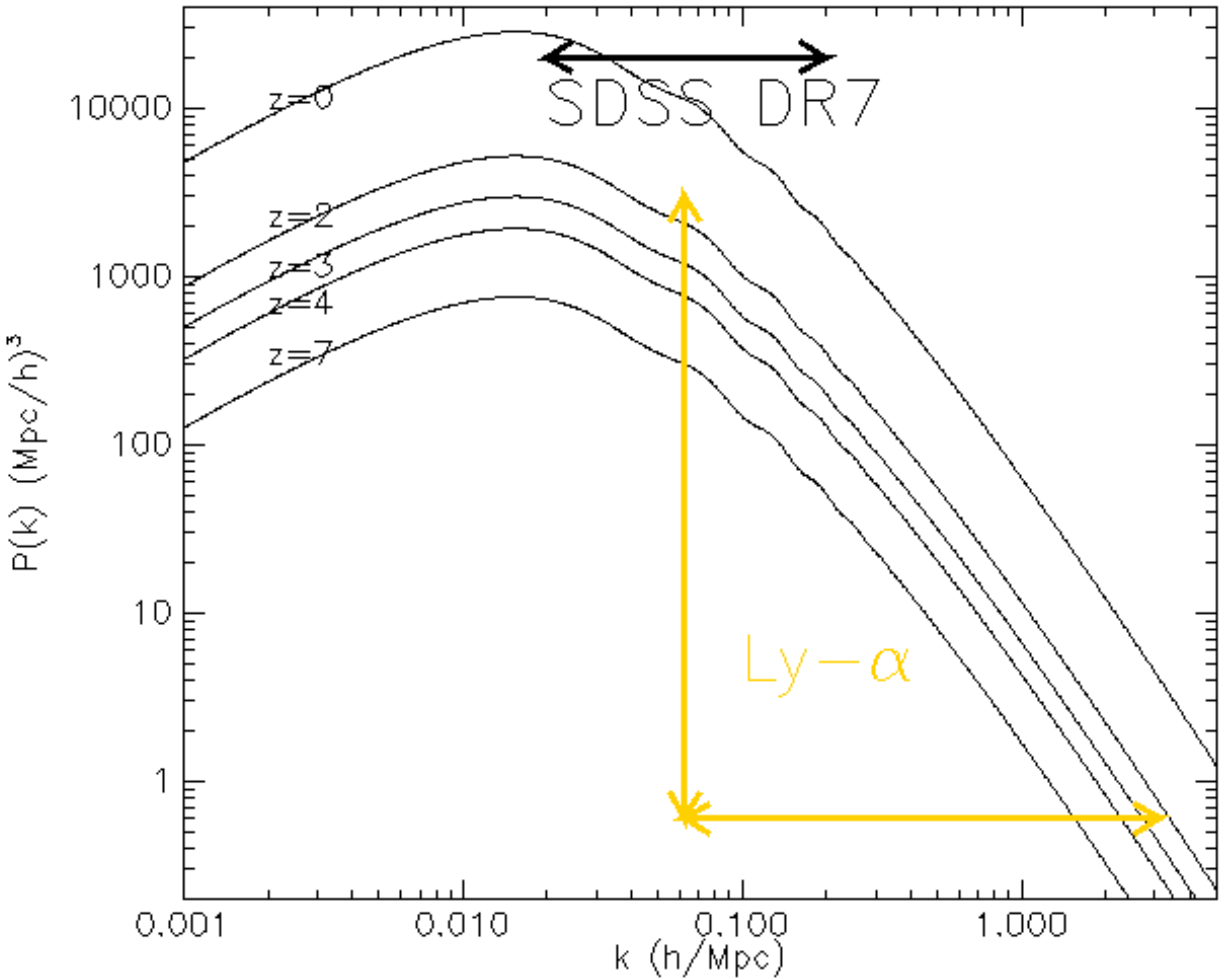
Lya physics
z < 6
dynamics
+
termodynamics

Tegmark & Zaldarriaga 2002

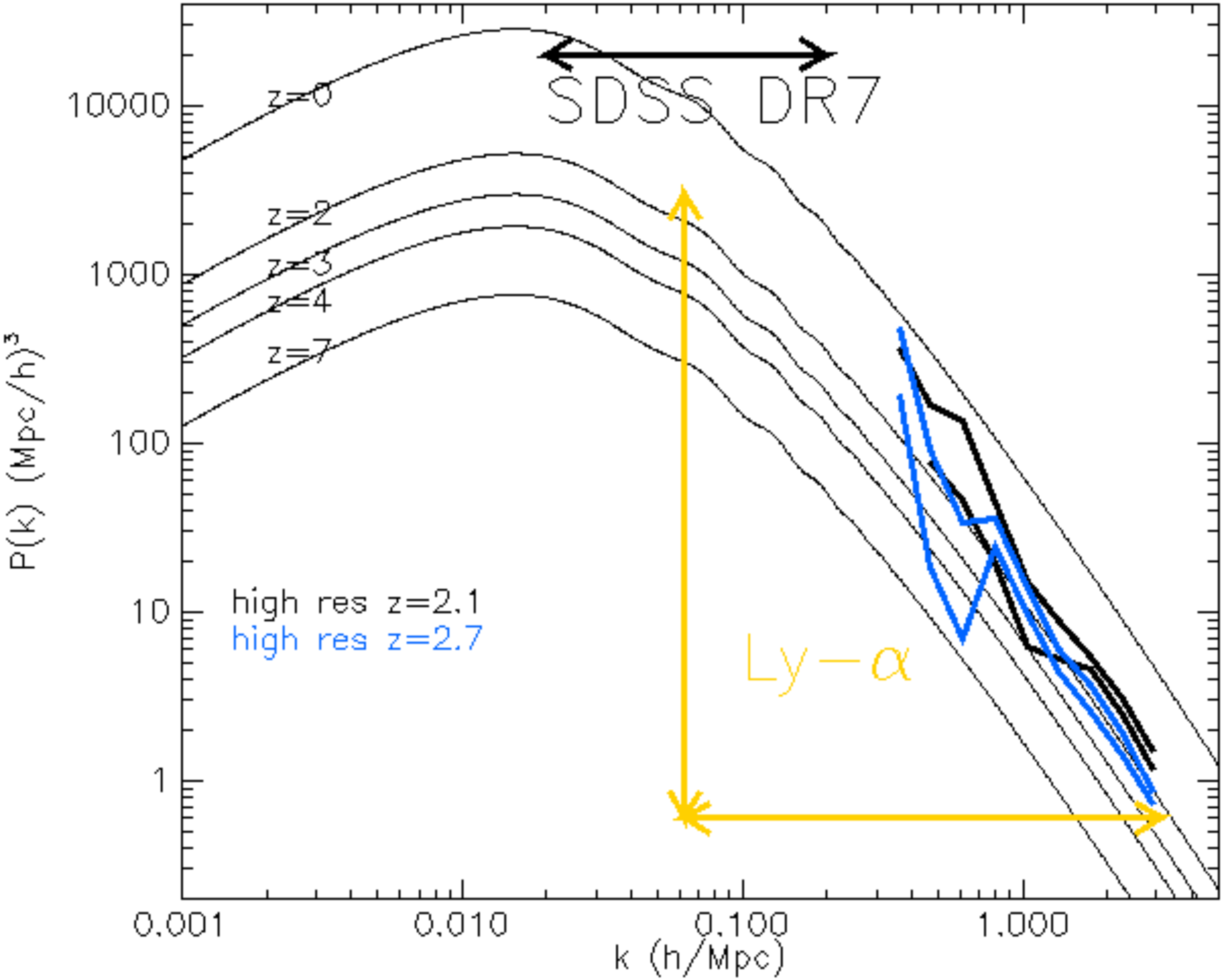
CMB + Lyman a → Long lever arm

Constrain spectral index and shape

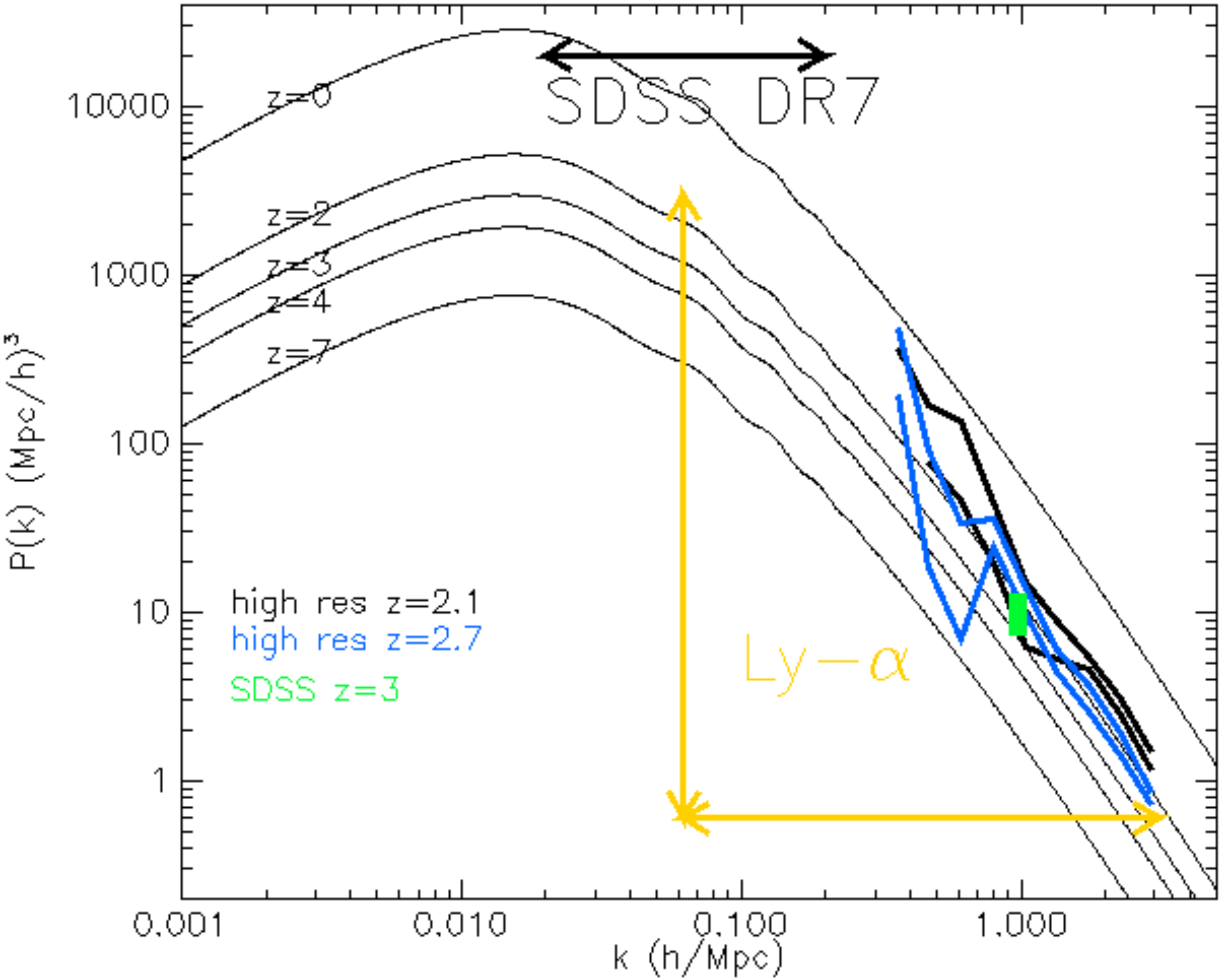
Relation: $P_{FLUX}(k)$ - $P_{MATTER}(k)$??



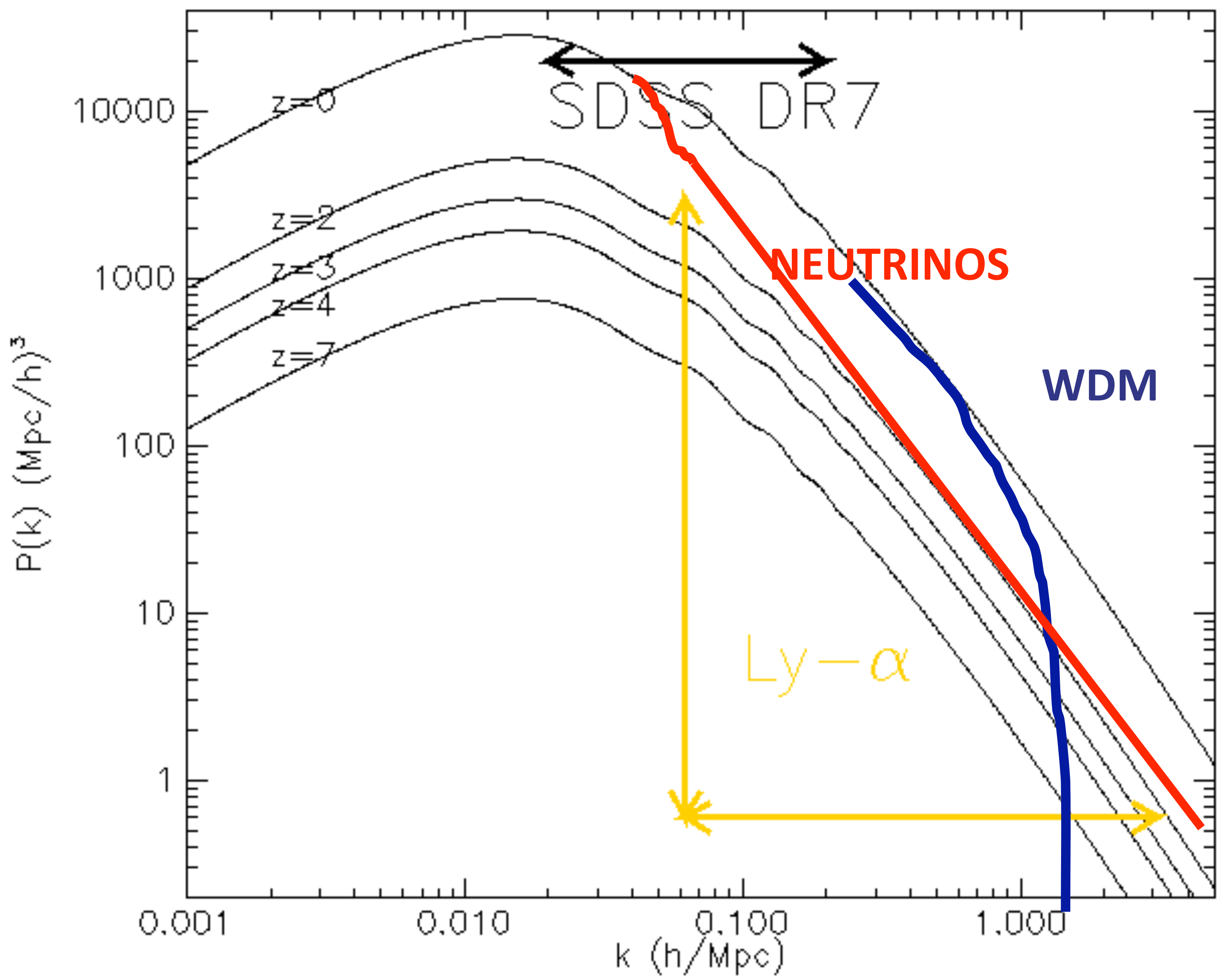
SDSS DR7
z=0
z=2
z=3
z=4
z=7
Ly−α
10000
1000
100
10
1
P(k) (Mpc/h)³
0.001
0.010
0.100
1.000
k (h/Mpc)



SDSS DR7
z=0
z=2
z=3
z=4
z=7
10000
1000
100
10
1
P(k) (Mpc/h)^3
high res z=2.1
high res z=2.7
Ly−α
0.001
0.010
0.100
1.000
k (h/Mpc)



SDSS DR7
z=0
z=2
z=3
z=4
z=7
10000
1000
100
10
1
P(k) (Mpc/h)^3
high res z=2.1
high res z=2.7
SDSS z=3
Ly−α
0.001
0.010
0.100
1.000
k (h/Mpc)


SDSS DR7
NEUTRINOS
WDM
Ly−α
z=0
z=2
z=3
z=4
z=7
10000
1000
100
10
1
0.001
0.010
0.100
1.000
k (h/Mpc)
P(k) (Mpc/h)³

The interpretation: flux derivatives

Analysis of SDSS flux power

The flux power spectrum is a smooth function of k and z

Flux power

$$P_F(k, z; \mathbf{p}) = P_F(k, z; \mathbf{p}^0) + \sum_{i=1,N} \left. \frac{\partial P_F(k, z; p_i)}{\partial p_i} \right|_{\mathbf{p} = \mathbf{p}^0} (p_i - p_i^0)$$

Best fit

p: astrophysical and cosmological parameters

but even resolution and/or box size effects if you want to save CPU time

Summary (highlights) of results from the high-res and low-res data

Why Lyman-α ? Small scales
High redshift
Most of the baryonic mass is in this form
Quasars sample 75% of the age of the universe

1. Measurement of matter power spectrum McDonald et al. 05,06 Viel et al. 04, 06

2. Tightest constraints to date on neutrino masses and running of the spectral index

   Seljak, Slosar, McDonald JCAP (2006) 10 014

3. Tightest constraints to date on the coldness of cold dark matter

   MV et al., Phys.Rev.Lett. 100 (2008) 041304

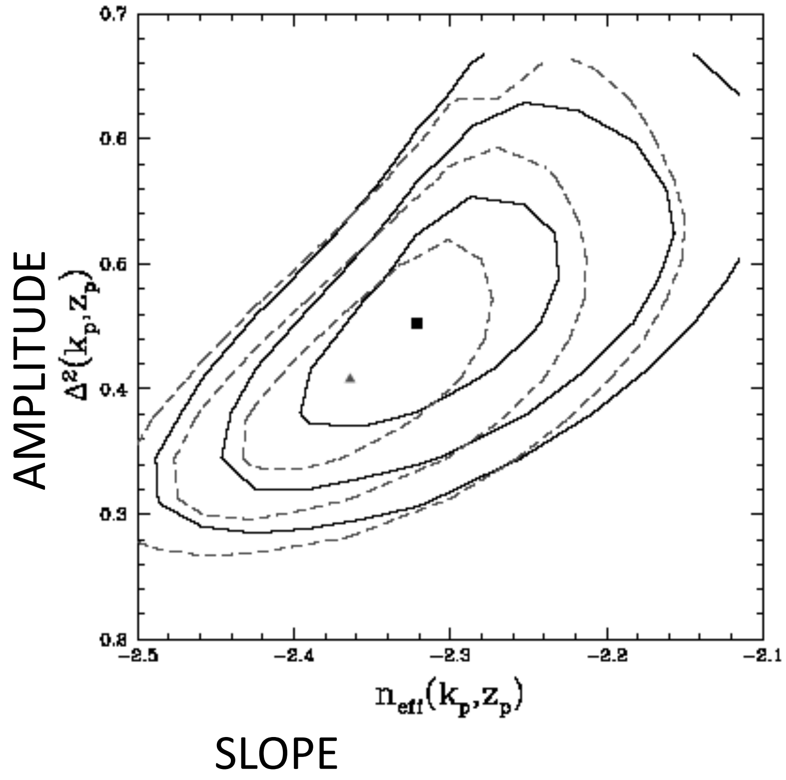
Results Lyman-α only: amplitude and slope of matter power

$$\Delta^2_L(k,\ z) \simeq \left[\frac{D(z)}{D(z_p)}\right]^2 \Delta^2_L(k_p,\ z_p) \quad \times \left[\frac{k}{k_\star(z)}\right]^{3+n_{\rm eff}(k_p,z_p)+(1/2)\alpha_{\rm eff}(k_p,z_p)\,\ln[k/k_\star(z)]}$$

χ^2 likelihood code distributed with COSMOMC

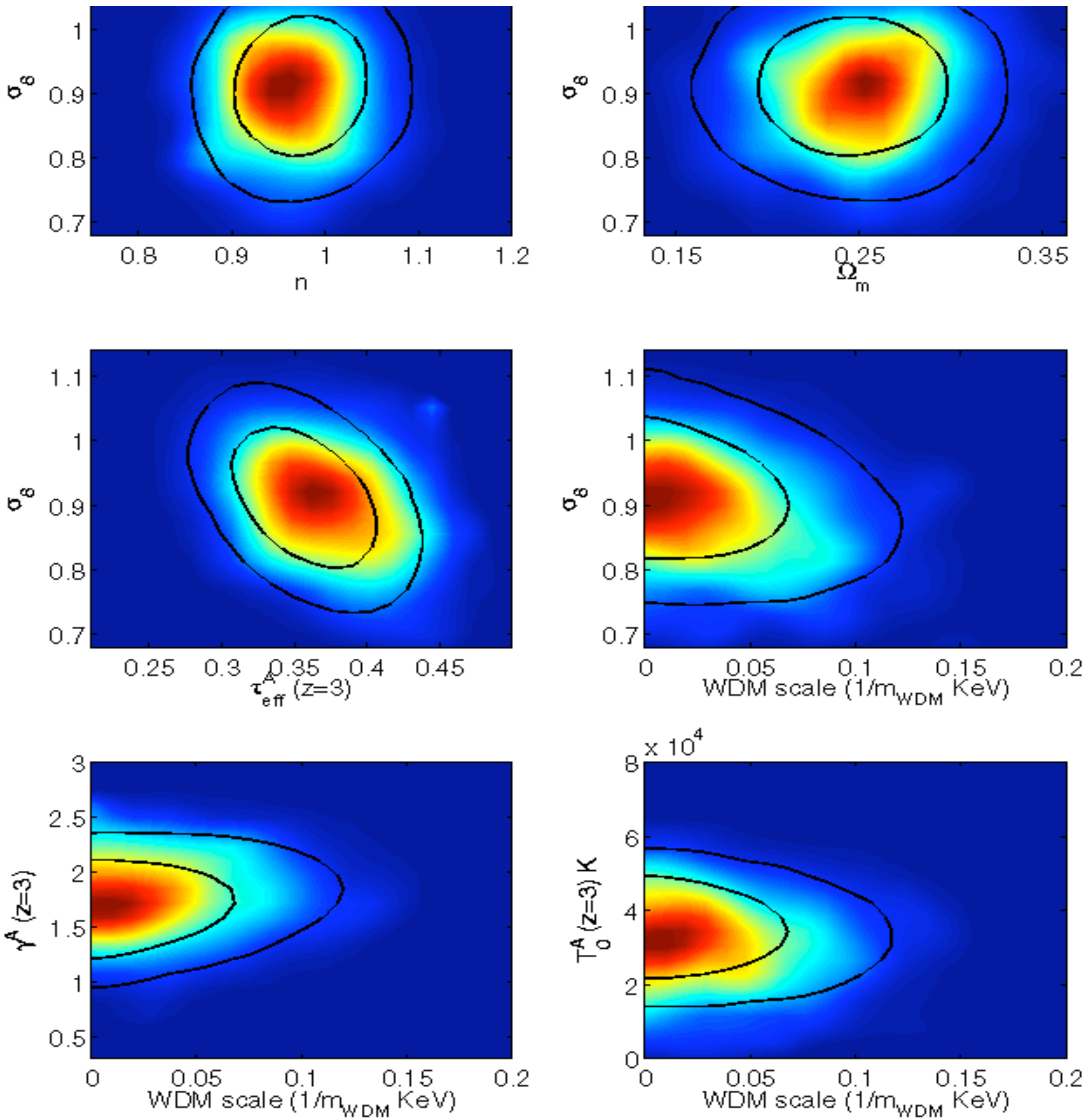
McDonald et al. 05

Croft et al. 98,02 40% uncertainty
Croft et al. 02 28% uncertainty
Viel et al. 04 29% uncertainty
McDonald et al. 05 14% uncertainty



Redshift z=3 and k=0.009 s/km corresponding to 7 comoving Mpc/h

Results Lyman-α only with flux derivatives: correlations



Fitting SDSS data with GADGET-2
this is SDSS Ly-α only !!

FLUX DERIVATIVES

SDSS data only

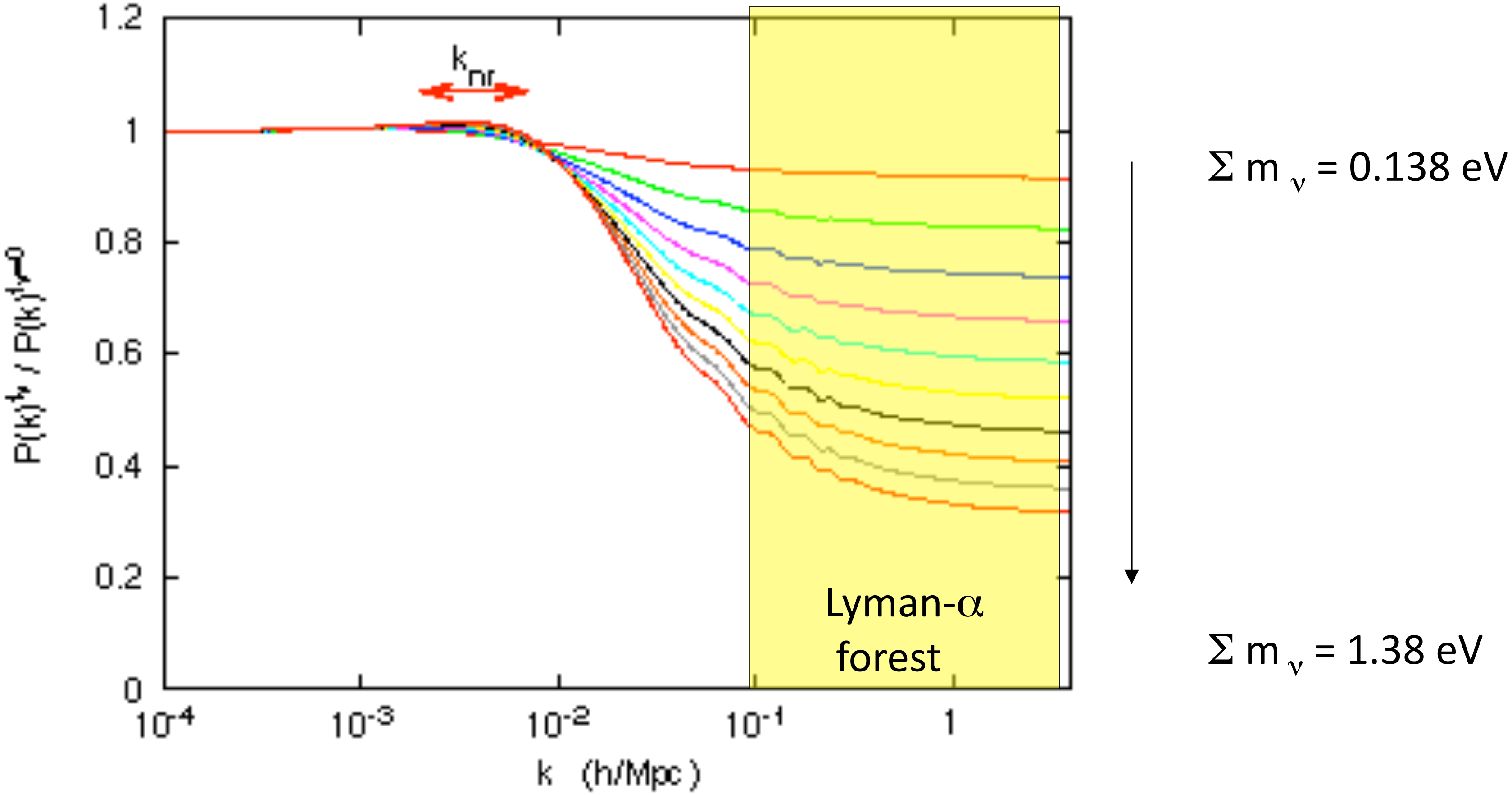
$\sigma_8 = 0.91 \pm 0.07$

$n = 0.97 \pm 0.04$

Active neutrinos – I: the effect

$$k_{\rm nr} \simeq 0.018\ \Omega_{\rm m}^{1/2} \left(\frac{m}{1\,{\rm eV}}\right)^{1/2} h\,{\rm Mpc}^{-1}$$

Lesgourgues & Pastor Phys.Rept. 2006, 429, 307

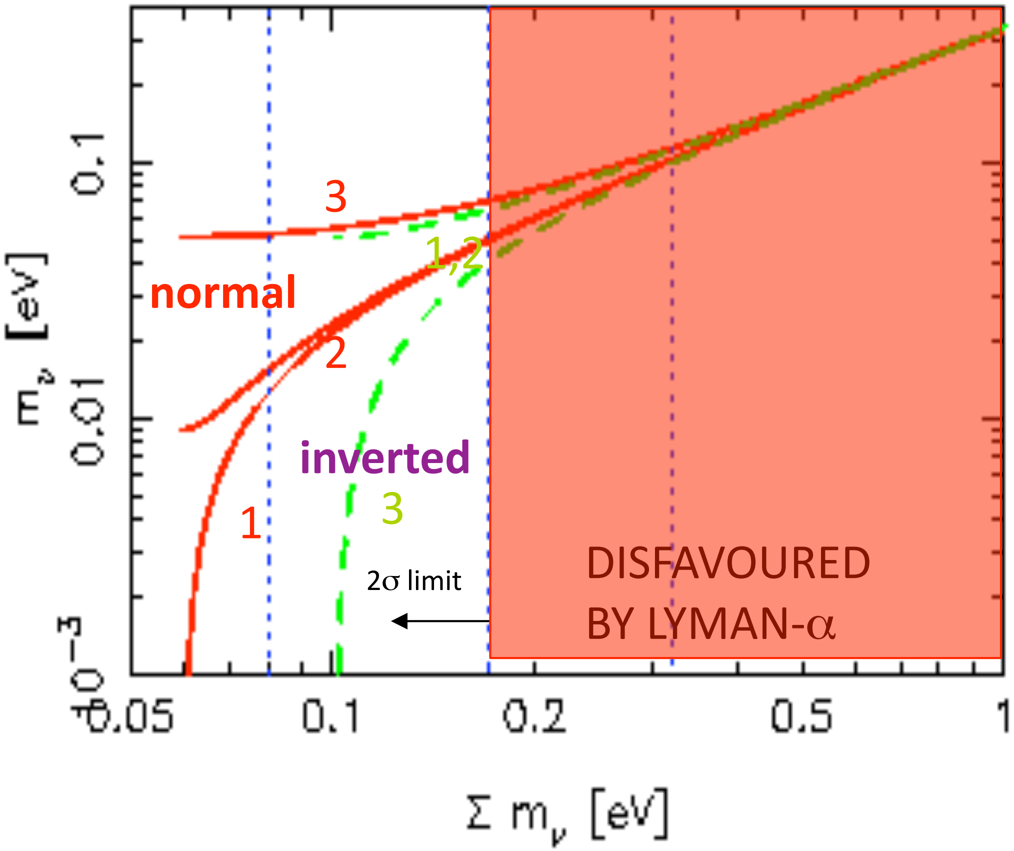


$$v_{\rm th} \equiv \frac{\langle p \rangle}{m} \simeq \frac{3T_\nu}{m} = \frac{3T_\nu^0}{m}\left(\frac{a_0}{a}\right) \simeq 150(1+z)\left(\frac{1\,{\rm eV}}{m}\right) {\rm km\,s^{-1}}$$

$$k_{FS}(t) = \left(\frac{4\pi G\bar{\rho}(t)a^2(t)}{v_{\rm th}^2(t)}\right)^{1/2}, \qquad \lambda_{FS}(t) = 2\pi\frac{a(t)}{k_{FS}(t)} = 2\pi\sqrt{\frac{2}{3}}\frac{v_{\rm th}(t)}{H(t)}$$

Active neutrinos – II: constraints

Seljak, Slosar, McDonald, 2006, JCAP, 0610, 014



Tight constraints because data are marginally compatible

$\Sigma m\nu$ (eV) < 0.17 (95 %C.L.), **< 0.19 eV (Fogli et al. 08)**

r < 0.22 (95 % C.L.)

running = -0.015 ± 0.012

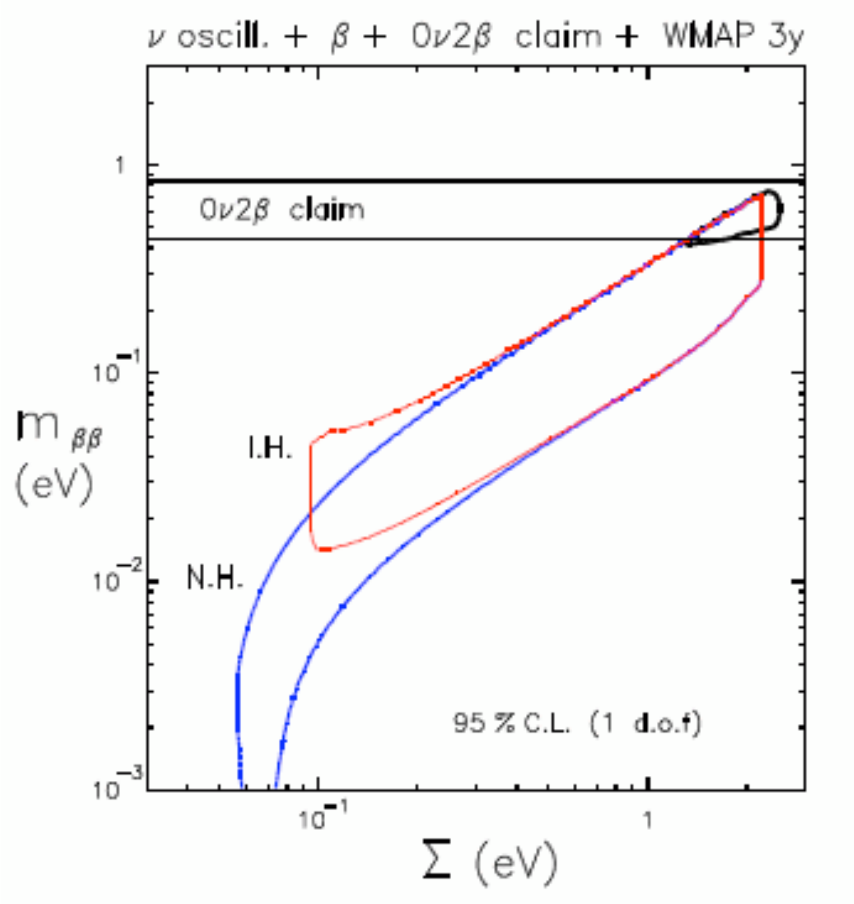
Neff = 5.2 (3.2 without Ly α)

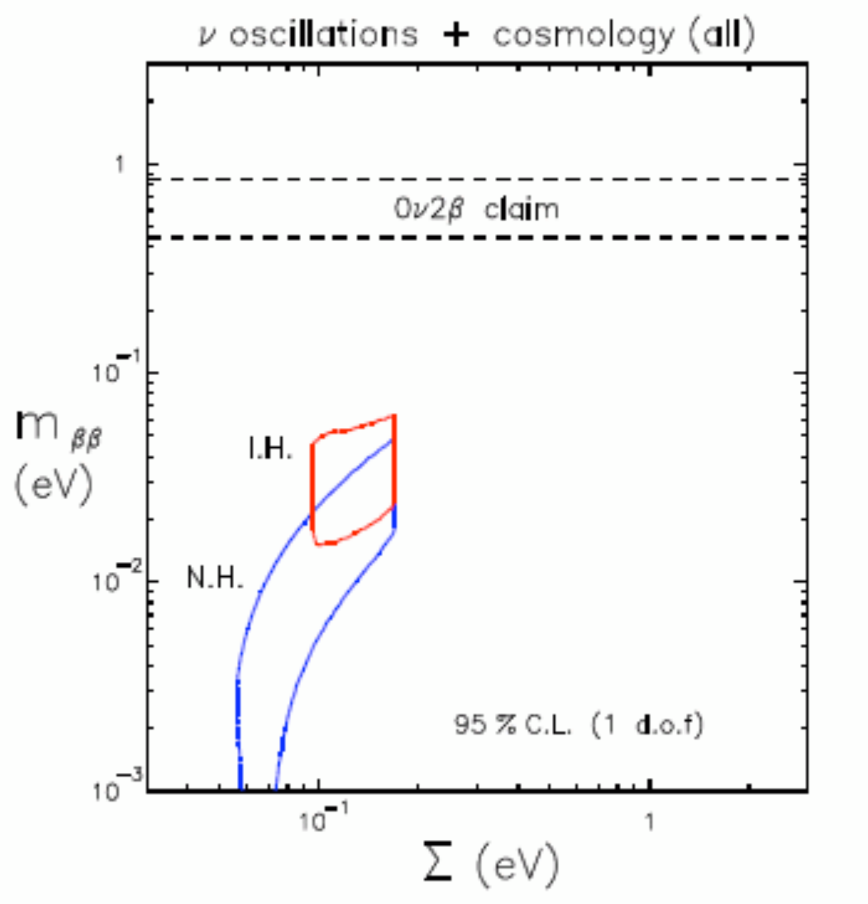
CMB + SN + SDSS gal+ SDSS Ly-α

Goobar et al. 06 get upper limits 2-3 times larger……

for forecasting see Gratton, Lewis, Efstathiou 2007

Active neutrinos – III: comparison with other constraints





Fogli, Lisi, Marrone, Melchiorri, Palazzo, Serra, Silk, Slosar, PhysRevD, 2007, 75, 0533001

RESULTS

WARM DARK MATTER

Or if you prefer.. How cold is cold dark matter?

(Some) Motivations

★ Some problems for cold dark matter at the small scales: 1- too **cuspy cores**, 2- too **many satellites**, 3- **dwarf galaxies** less clustered than bright ones (e.g. Bode, Ostriker, Turok 2001)

Although be aware that 1- **astrophysical processes** can act as well to alleviate these problems (feedback); 2- number of **observed satellites** is increasing (SDSS data); 3- galaxies along filaments in warm dark matter sims is probably a **numerical artifact**

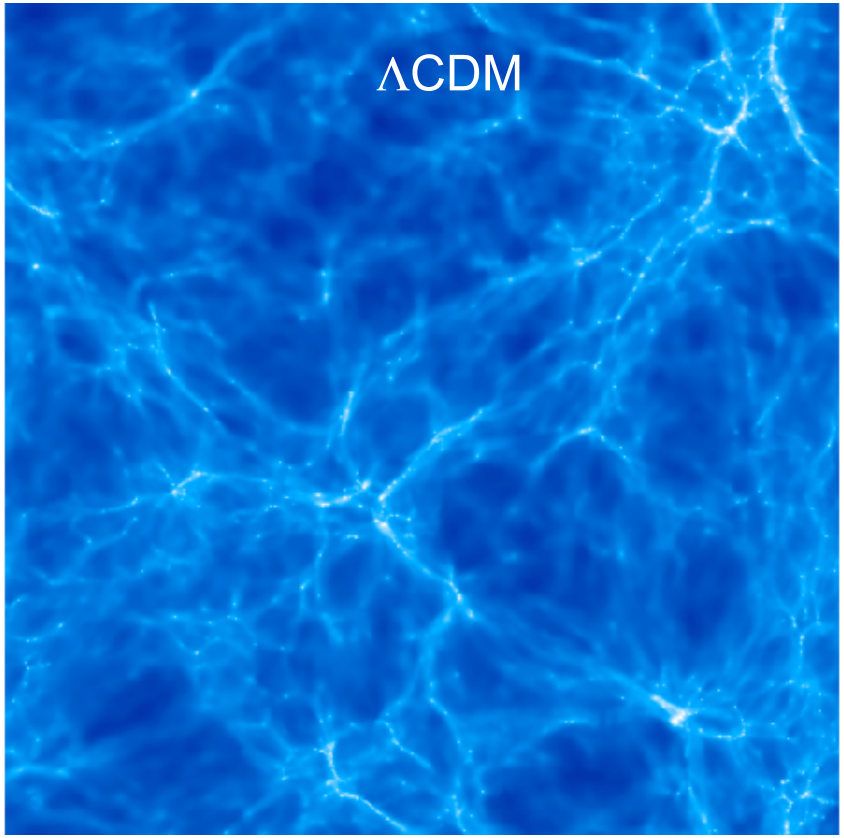
★ **Minimal extension of the Standard Model** for particle physics that accommodates neutrino oscillations naturally

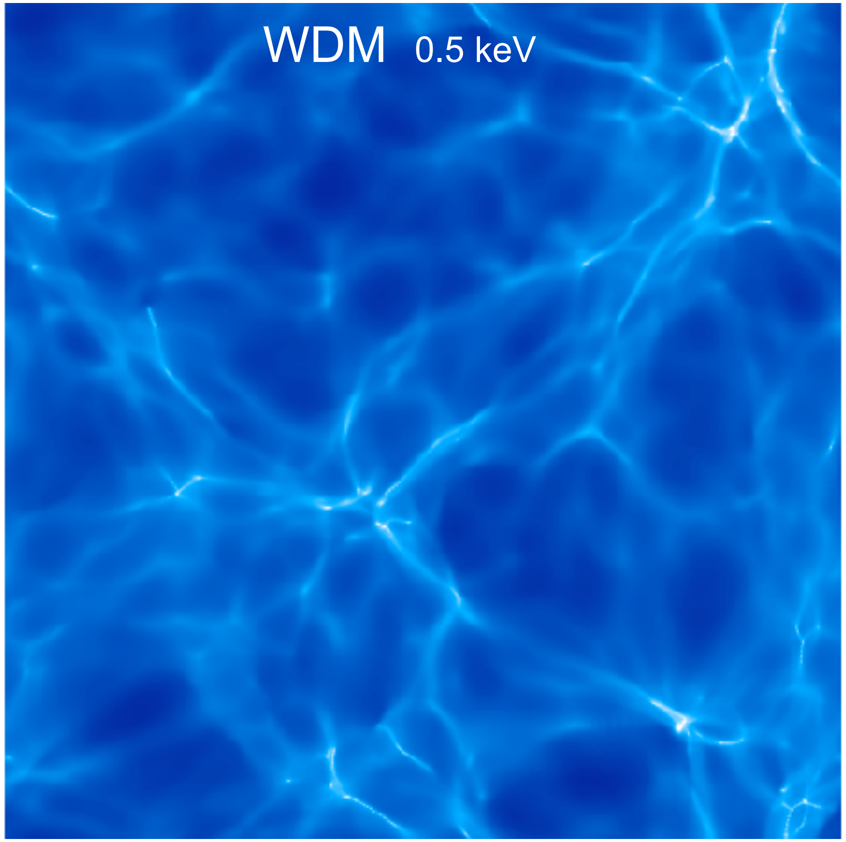
Hints of a sterile sector: LSND experiment prefers a sterile neutrino $m_{\nu} < 1$ eV
but Lyman-α data $m_{\nu} < 0.26$ eV
and best fit N eff (active) = 5.3

The LSND result has been rejected by MiniBoone

Although be aware that LSND results are controversial and that Lyman-α data that wish to probe the subeV limits are prone to systematic effects

Lyman-α and Warm Dark Matter - I





30 comoving Mpc/h z=3

See Bode, Ostriker, Turok 2001
Abazajian, Fuller, Patel 2001

In general

$k_{FS} \sim 5\ T_\nu/T_x\ (m_x/1\text{keV})\ \text{Mpc}^{-1}$

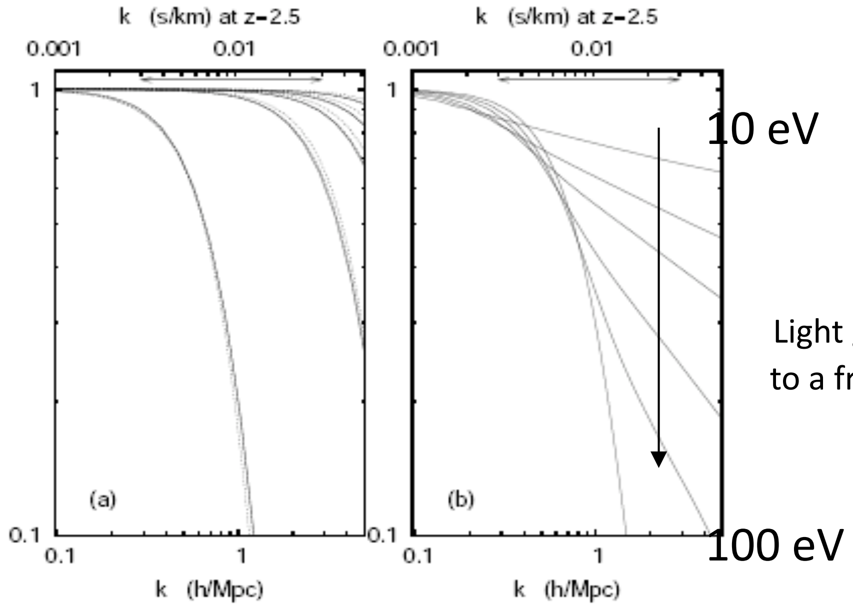
Set by relativistic degrees of freedom at decoupling

MV, Lesgourgues, Haehnelt, Matarrese, Riotto, PRD, 2005, 71, 063534

Lyman-α and Warm Dark Matter - II

$P(k) = A\, k^n\, T^2\,(k)$

$[P\,(k)_{WDM}/P\,(k)_{CDM}]^{1/2}$

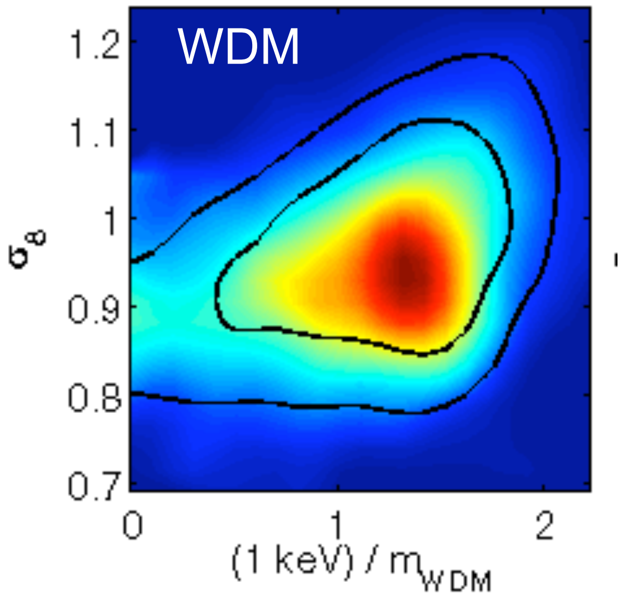


Light gravitino contributing to a fraction of dark matter

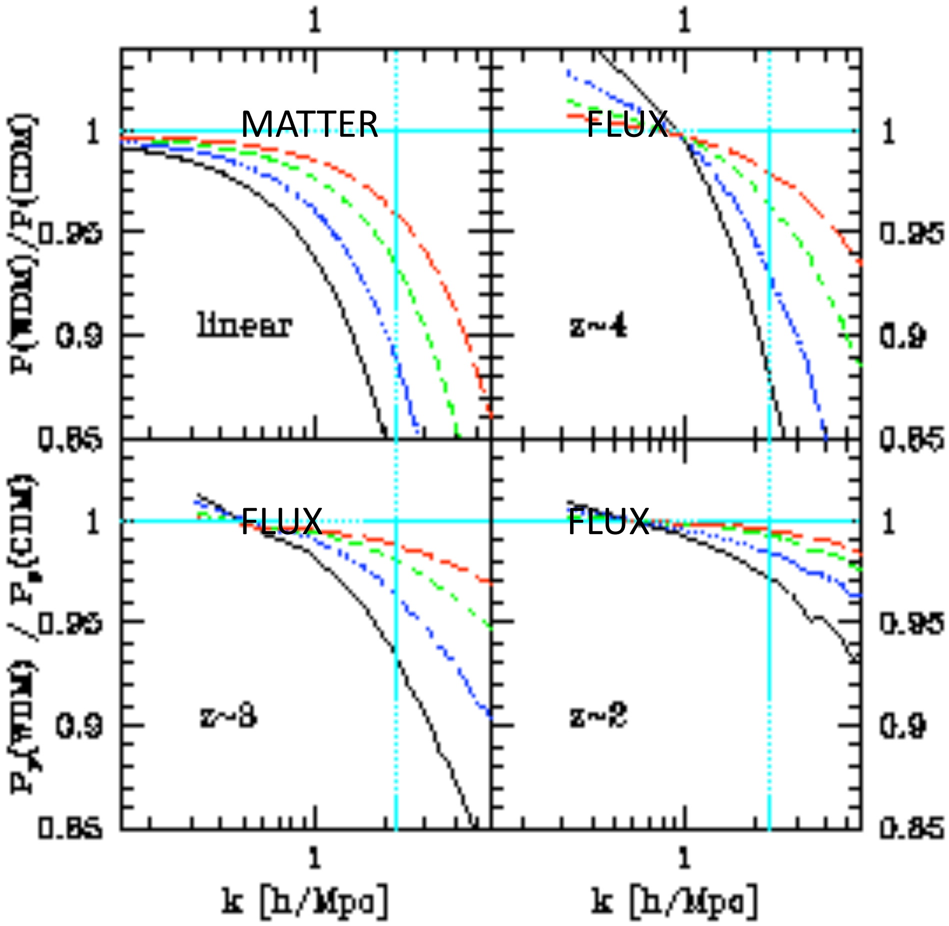
$$\frac{T_x}{T_\nu} = \frac{10.75^{1/3}}{g\,(T_D)^{1/3}}$$

MV, Lesgourgues, Haehnelt, Matarrese, Riotto, PRD, 2005, 71, 063534

Lyman-α and Warm Dark Matter - III



m_{WDM} > 550 eV thermal
> 2keV sterile neutrino
< 16 eV gravitino



Viel et al. (2005)from high-res

$$\Lambda_{susy} \simeq \left(\sqrt{3} m_{3/2} M_p\right)^{1/2} \lesssim 260\,\mathrm{TeV}$$

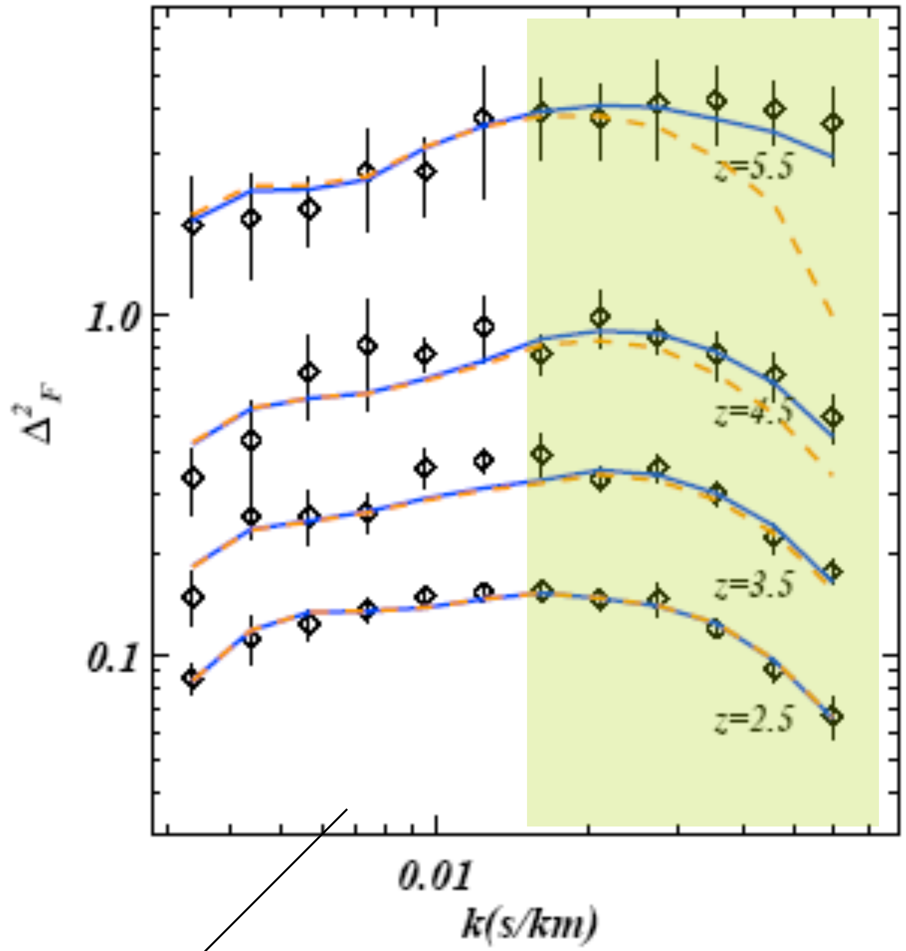
m_{WDM} > 1.5-2 keV thermal
> 10-14 keV sterile neutrino

Seljak, Makarov, McDonald, Trac, PhysRevLett, 2006, 97, 191303

MV, Lesgourgues, Haehnelt, Matarrese, Riotto, PhysRevLett, 2006, 97, 071301

Lyman-α and Warm Dark Matter - IV

MV et al., Phys.Rev.Lett. 100 (2008) 041304



SDSS range

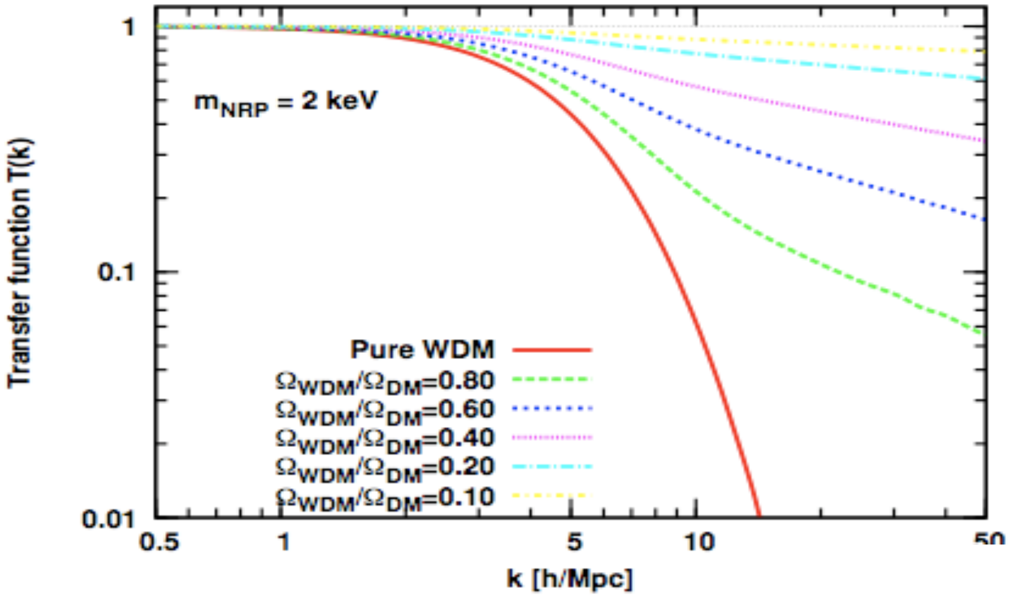
SDSS + HIRES data

Tightest constraints on mass of WDM particles to date:

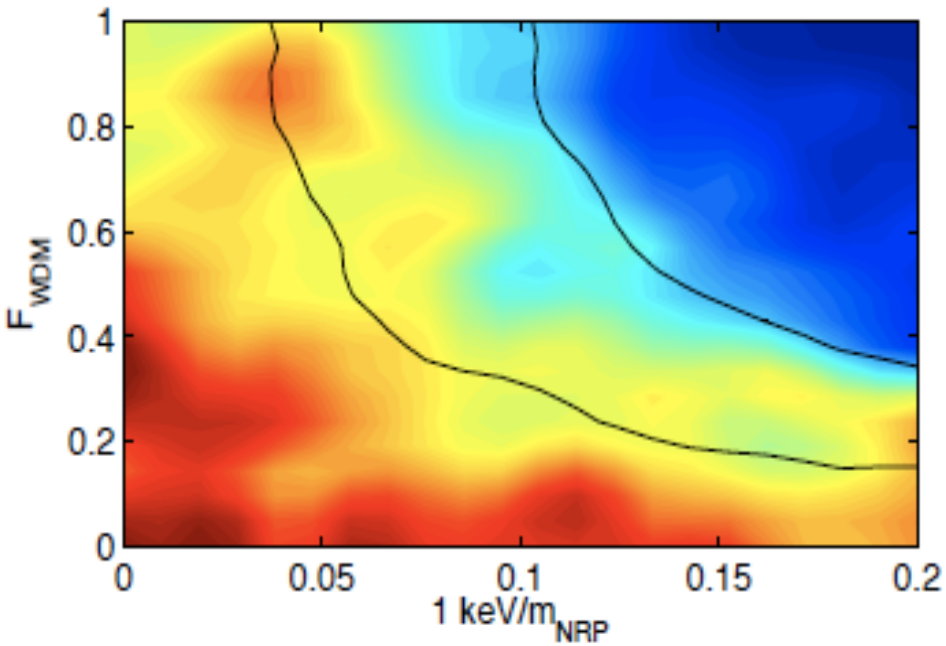
m_{WDM} > 4 keV (early decoupled thermal relics)

$m_{sterile}$ > 28 keV

Lyman-α and sterile neutrinos - V

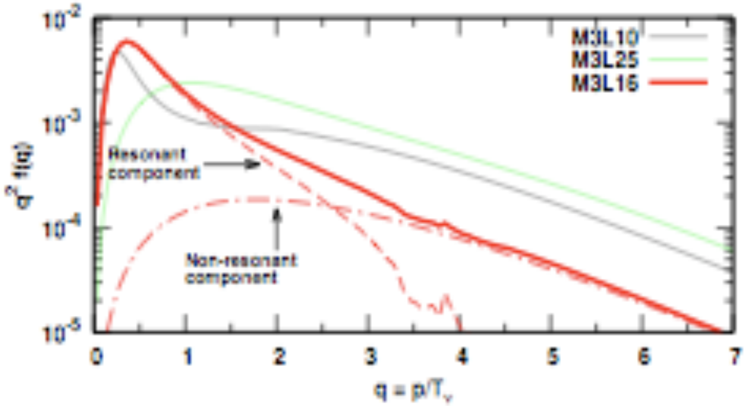


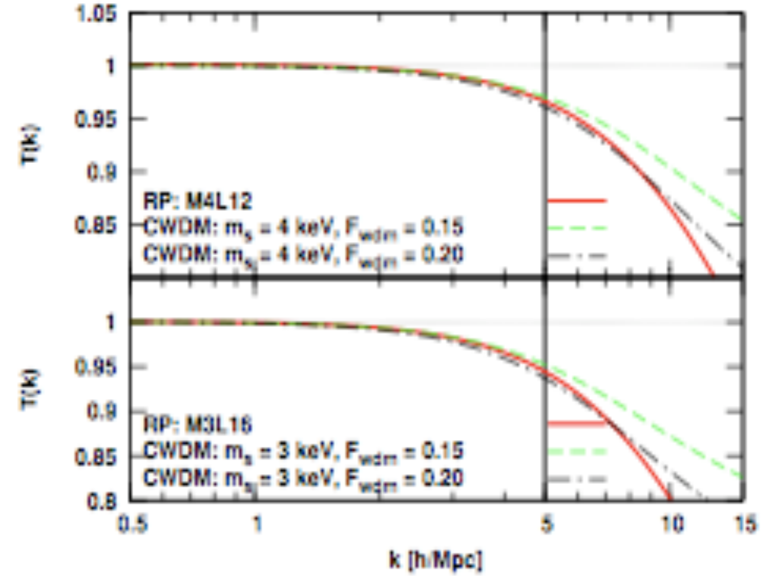
SDSS+WMAP5

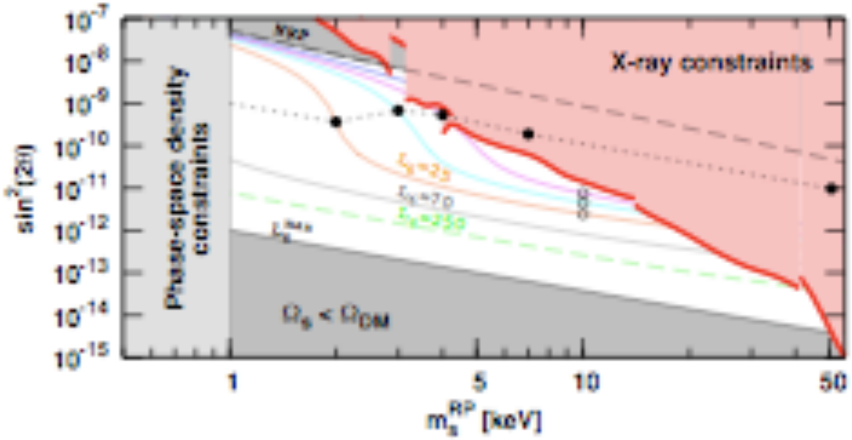


Boyarsky, Lesgourgues, Ruchayskiy, Viel, 2009, JCAP, 05, 012– REVIEW!

Lyman-α and resonantly produced sterile neutrinos -VI

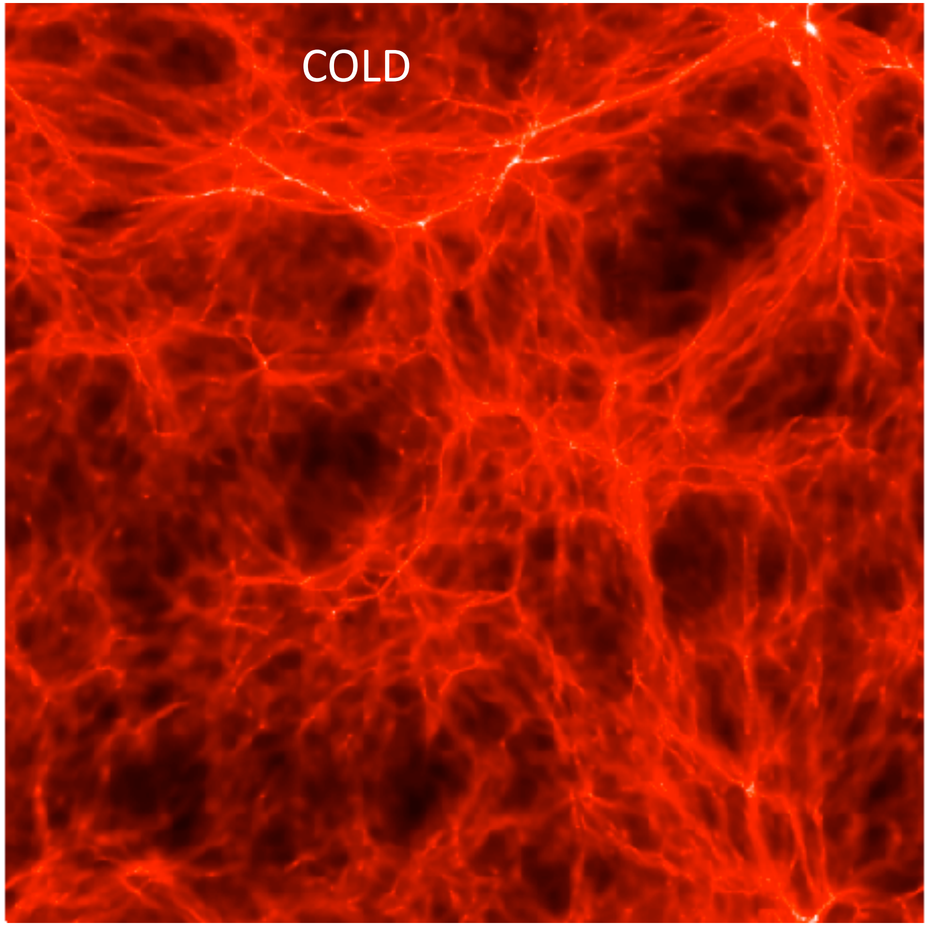


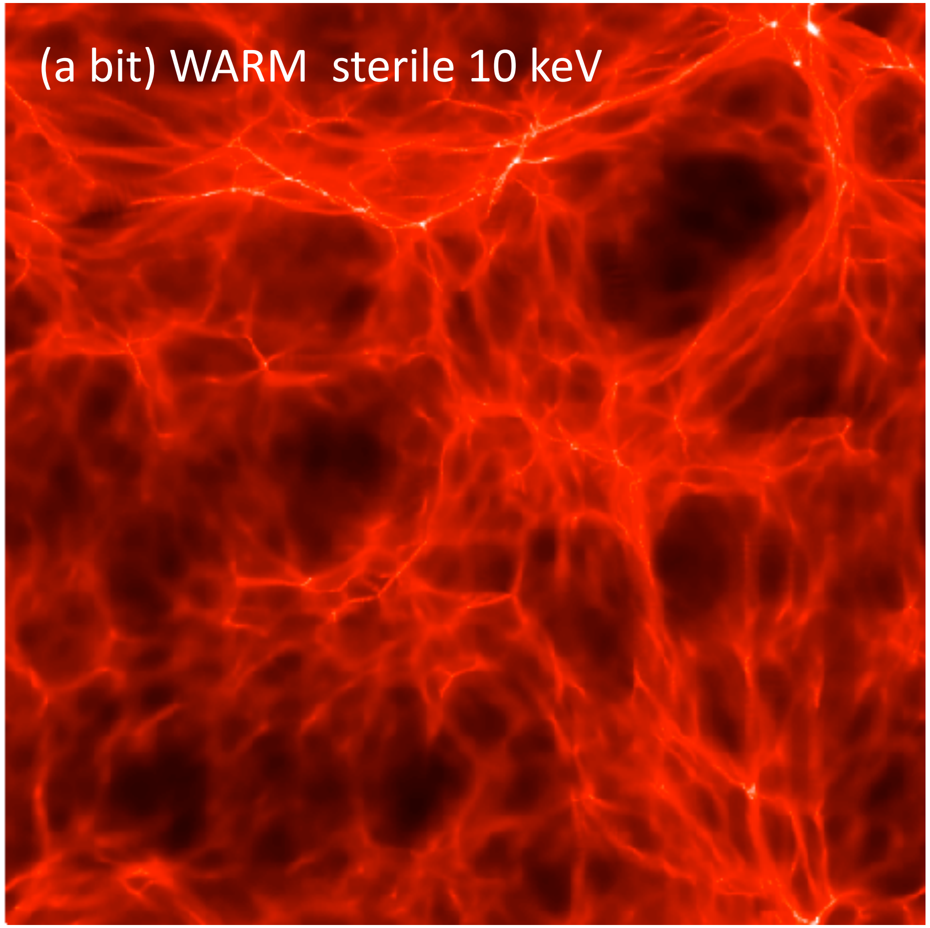




Boyarsky, Lesgourgues. Ruchayski, Viel, 2009, PRL, 102, 201304

Little room for warm dark matter…… at least in the standard DW scenario
…the cosmic web is likely to be quite “cold”





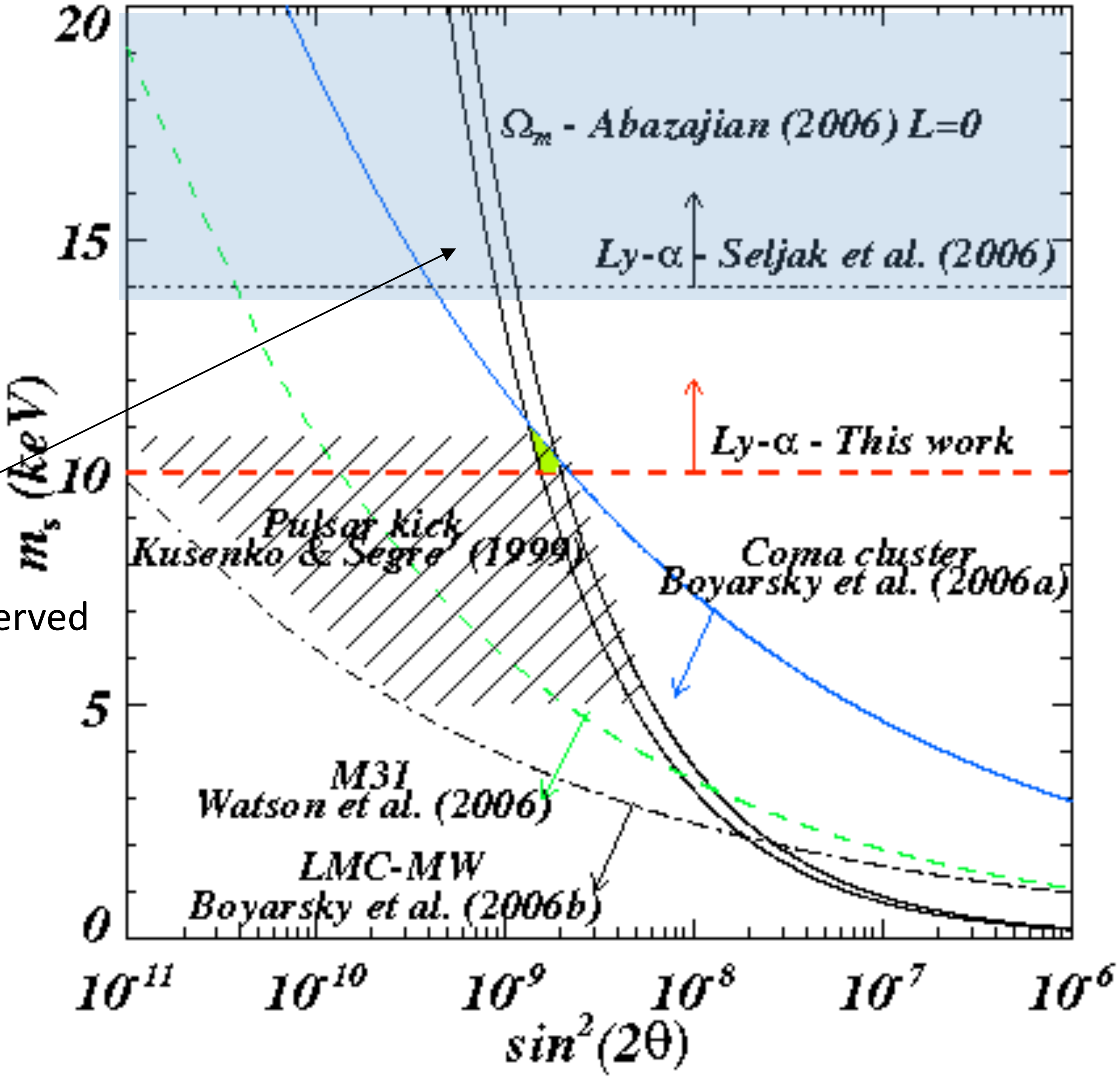
To constrain the sterile neutrino particle we need two parameters:

1) Neutrino mass $\mathbf{m_s}$

2) Mixing angle θ that describes the interaction between active and sterile neutrino families

Lyα-WDM VII: analysis with flux derivatives

$L_\nu = 0$
Leptonic number is conserved



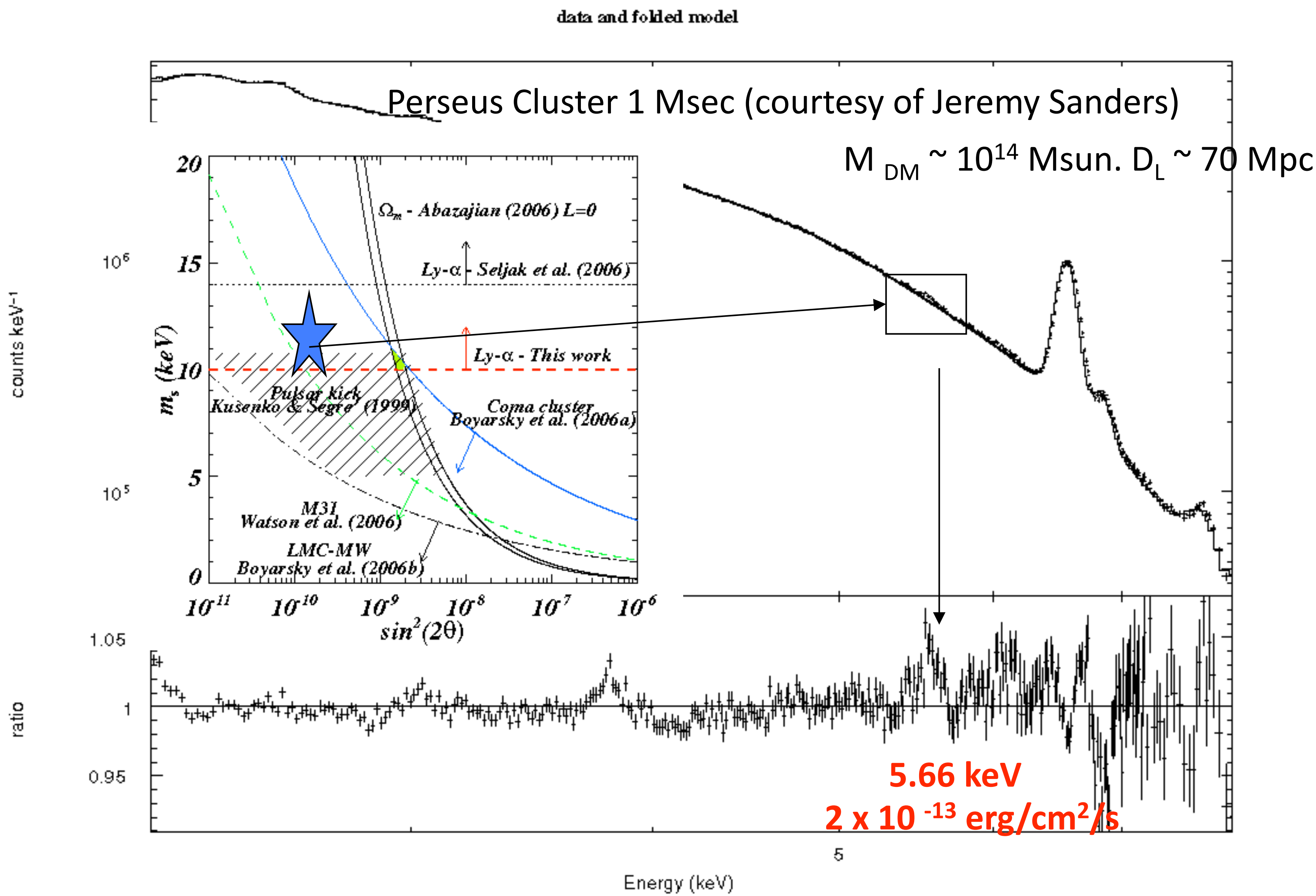
Radiative decay channel at a rate that depends on its mass and the mixing angle with active neutrinos

$\Gamma \sim \sin^2 2\theta \; m_{sterile}^5$

Viel, Lesgourgues, Haehnelt, Matarrese, Riotto, Phys.Rev.Lett., 2006, 97, 071301

Fabian, Sanders and coworkers…..

Decaying channel into photons and active neutrinos line with $E=m_s/2$ (X-band)



Line flux ~ 5×10^{-18} erg cm $^{-2}$ s $^{-1}$ $(D_L/1\text{Mpc})^{-2}$ $(M_{DM}/10^{11} M_{sun})$ $(\sin^2 2\theta/10^{-10})$ $(m_s/1\text{kev})^5$

ESA Portal – XMM–Newton reveals the origin of elements in galaxy clusters – Web Browser

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XMM-Newton reveals the origin of elements in galaxy clusters

10 May 2006

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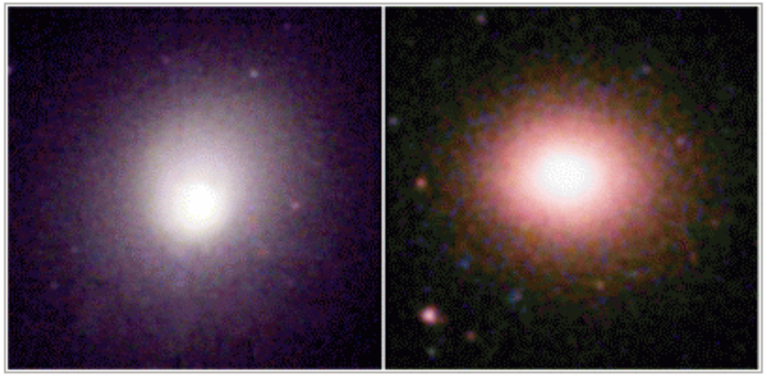

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These X-ray images of the clusters of galaxies 'Sersic 159-03' (right) and '2A 0335+096' (left) were taken by the European Photon Imaging Camera (EPIC) on-board ESA's XMM-Newton, in November 2002 and August 2003 respectively. Thanks to these observations, astronomers could determine the abundances of nine chemical elements in the clusters 'plasma' – a gas containing charged particles such as ions and electrons. These elements include oxygen, iron, neon, magnesium, silicon, argon, calcium, nickel, and - detected for the first time ever in a galaxy cluster - chromium. The distribution of silicon (produced by 'type Ia' and 'core collapse' supernova types) relative to iron (mainly produced by 'type Ia' supernovae) in these two clusters is very different, showing that they had a different evolution.

Credits: ESA and the XMM-Newton EPIC consortium

More about...
- XMM-Newton overview

Related articles
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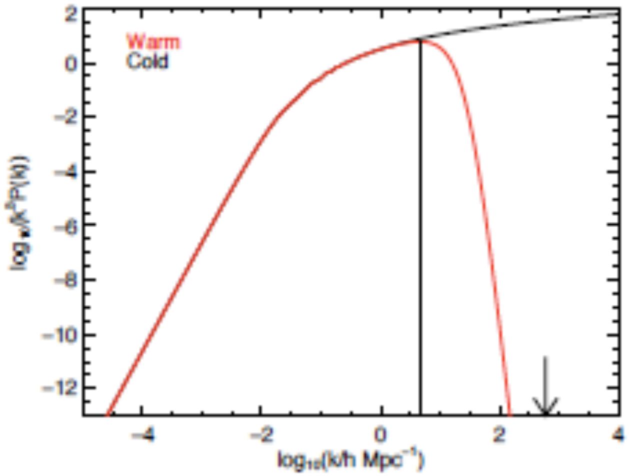
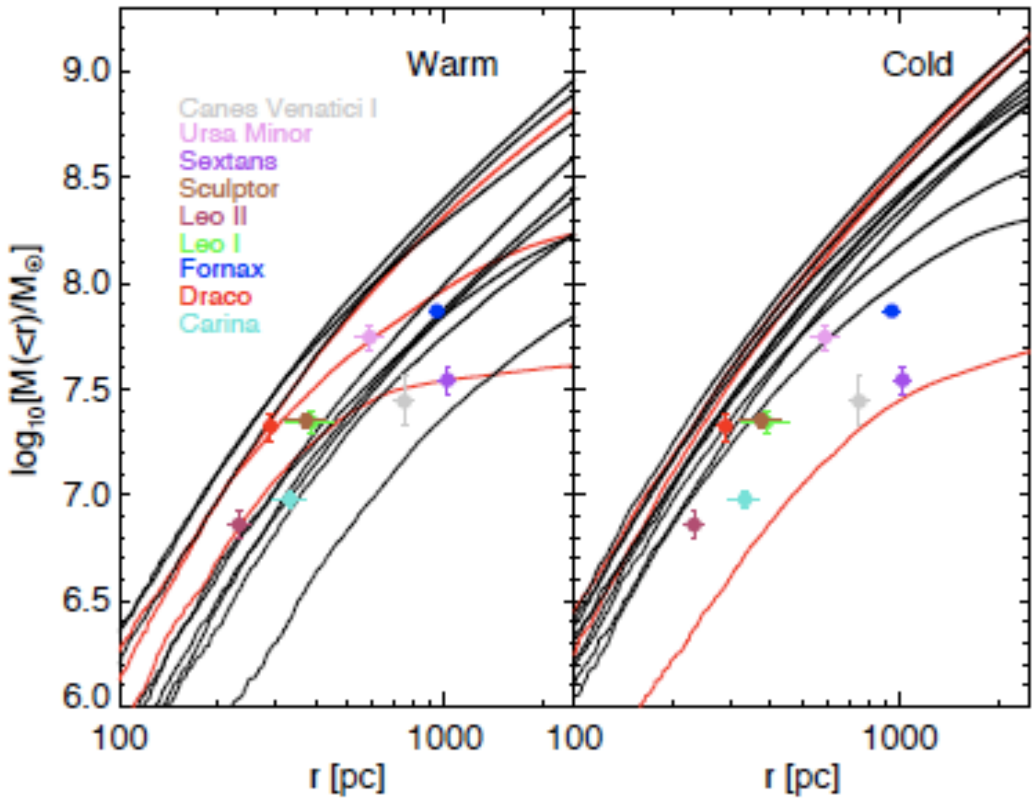
- XMM-Newton probes formation of galaxy clusters
- XMM-Newton's fifth anniversary in orbit

5.66 keV !!!

Satellites of the Milky Way and Warm Dark Matter





Lovell et al. 11

CONCLUSIONS

- Neutrinos do impact on the LSS at a level which is very much constrained by present data sets. The effect is small and **systematic effects** should be addressed at an unprecedented level of precision. Modelling the power spectrum at the 1 % level at small scales is difficult: **relevant physical processes and numerics** should be modelled and under control.

-Among different observables I outlined the important role of the **IGM**, which is currently providing the tightest constraints on the mass (0.17 eV – 2σ upper limit); **weak lensing** and **galaxy redshift surveys** are likely to provide interesting results

-Coldness of cold dark matter at small scales is a fundamental observable since possible deviations from the standard model can be measured or a candidate can show up. At present the constraints on the **sterile neutrinos** are tight (especially from IGM data) and are 14 keV (2σ lower bound) in the non-resonantly production mechanism or about 2 keV (2σ lower bound) in the resonant production scenario.

- Tools to investigate these topics beyond the linear regime are **N-body simulations** (and others)

Science http://adlibitum.oats.inaf.it/viel/cosmoIGM

→Postdoctoral positions in Trieste

COSMOLOGY

IGM as a tracer of the large scale structure of the universe: tomography of IGM structures; systematic/statistical errors; sinergies with other probes – IGM unique in redshift and scales

cosmoIGM

IGM as a probe of fundamental physics: dark matter at small scale; neutrinos; coldness of dark matter; fundamental constants; cosmic expansion

PARTICLE PHYSICS

Galaxy/IGM interplay: metal enrichment and galactic feedback; impact on the cosmic web and metal species; the UV background; the temperature of the IGM

GALAXY FORMATION

Lyman-α and Warm Dark Matter - III

55 HIRES spectra QSOs z=2-6.4
from Becker, Rauch, Sargent (2006)

Masking of DLAs and metal lines associated to the DLAs, or identified from other lines outside the forest (so there could be still some metal contamination)

Unexplored part of the flux power spectrum which is very sensitive to:

Temperature,
Metals,
Noise,
Galactic winds,
Ionizing fluctuations,
Damping wings….
…and maybe more

Power Spectrum **Covariance Matrix**