Perspectives of discoveries from Intergalactic Space

Matteo Viel *– INAF/OATs*

IPMU – Tokyo – Astrophysics of DM Workshop

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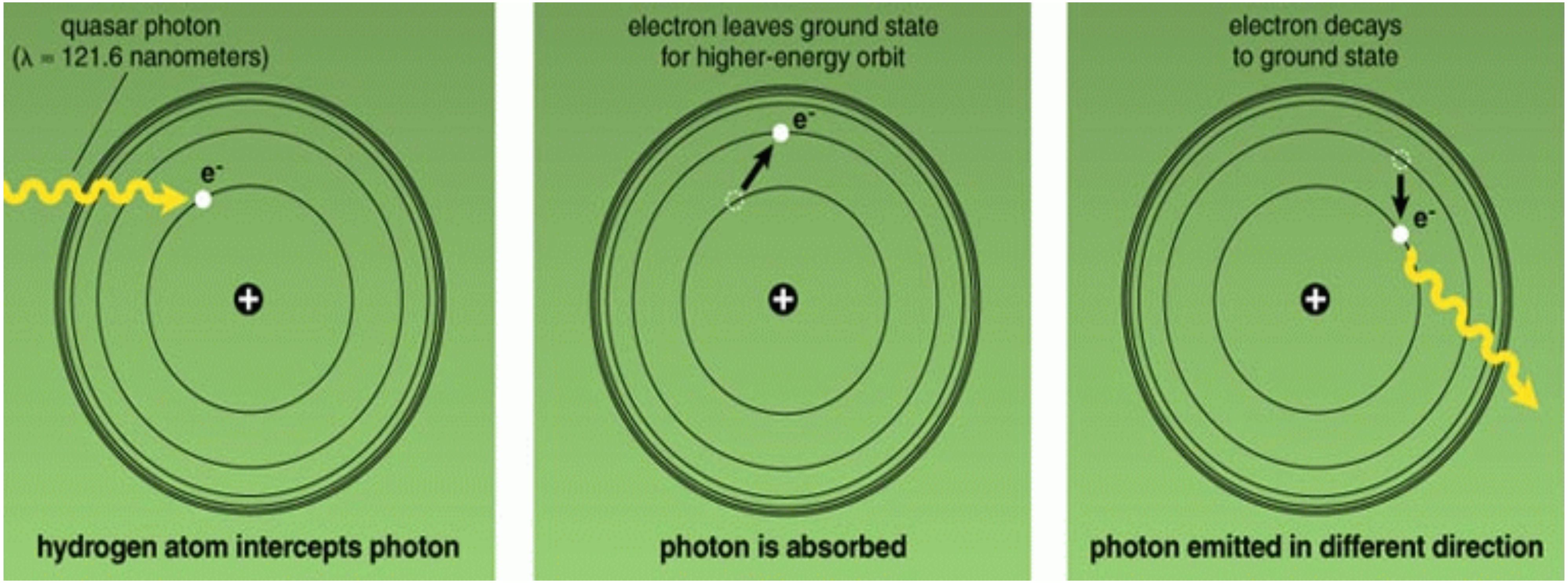
QUESTIONS

- Can we constrain the total neutrino mass using LSS data?
- How cold is cold dark matter?
- Can we use LSS tracers to probe WIMP scenarios?

TOPIC	DATA	THEORY	RESULTS
Cosmic neutrinos	IGM QSO Spectra low res	N-body/hydro sims	$\Sigma m_\nu < 0.12$ eV
Cold dark matter coldness	IGM QSO Spectra high res	N-body/hydro sims	$m_{WDM} > 3.3$ keV
WIMPS	Fermi/LAT diffuse background X LSS tracers (2MASS etc.)	Halo/HOD models	Constraints in the range 10-100 GeV signal compatible with DM

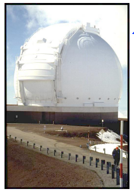
The Lyman-α forest

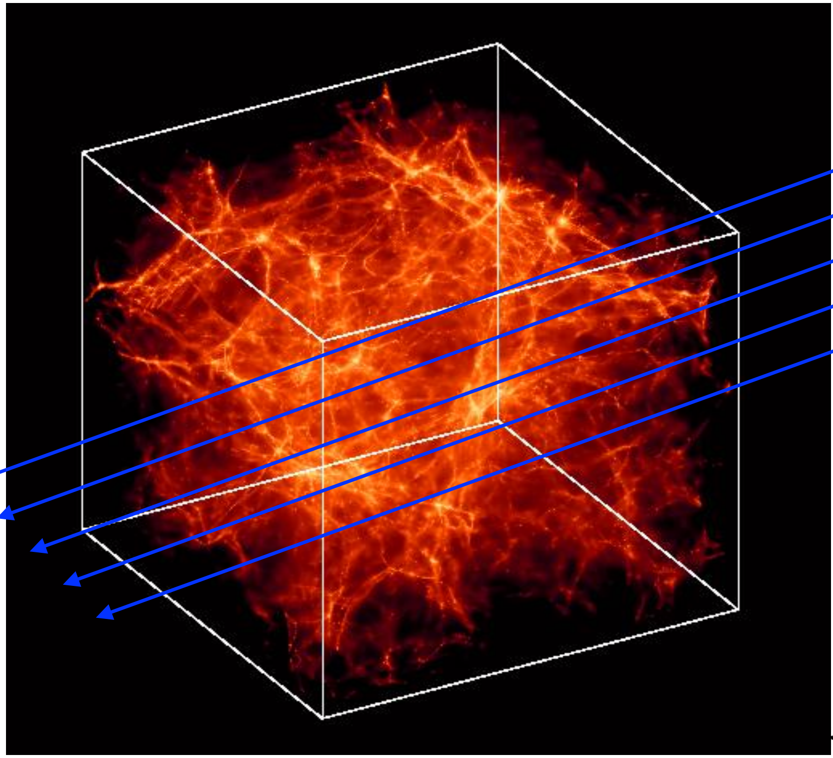
Lyman-α absorption is the main manifestation of the IGM

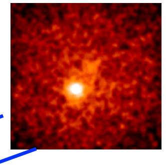


Tiny neutral hydrogen fraction after reionization…. But large cross-section

The Intergalactic Medium: Theory vs. Observations







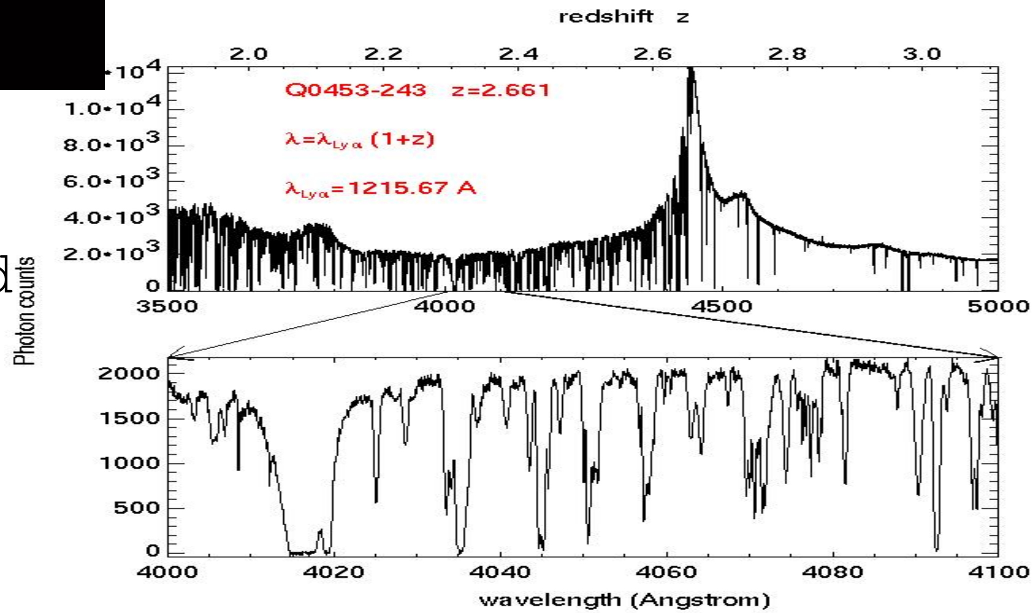
80% of the baryons at z=3 are in the **Lyman-α forest**

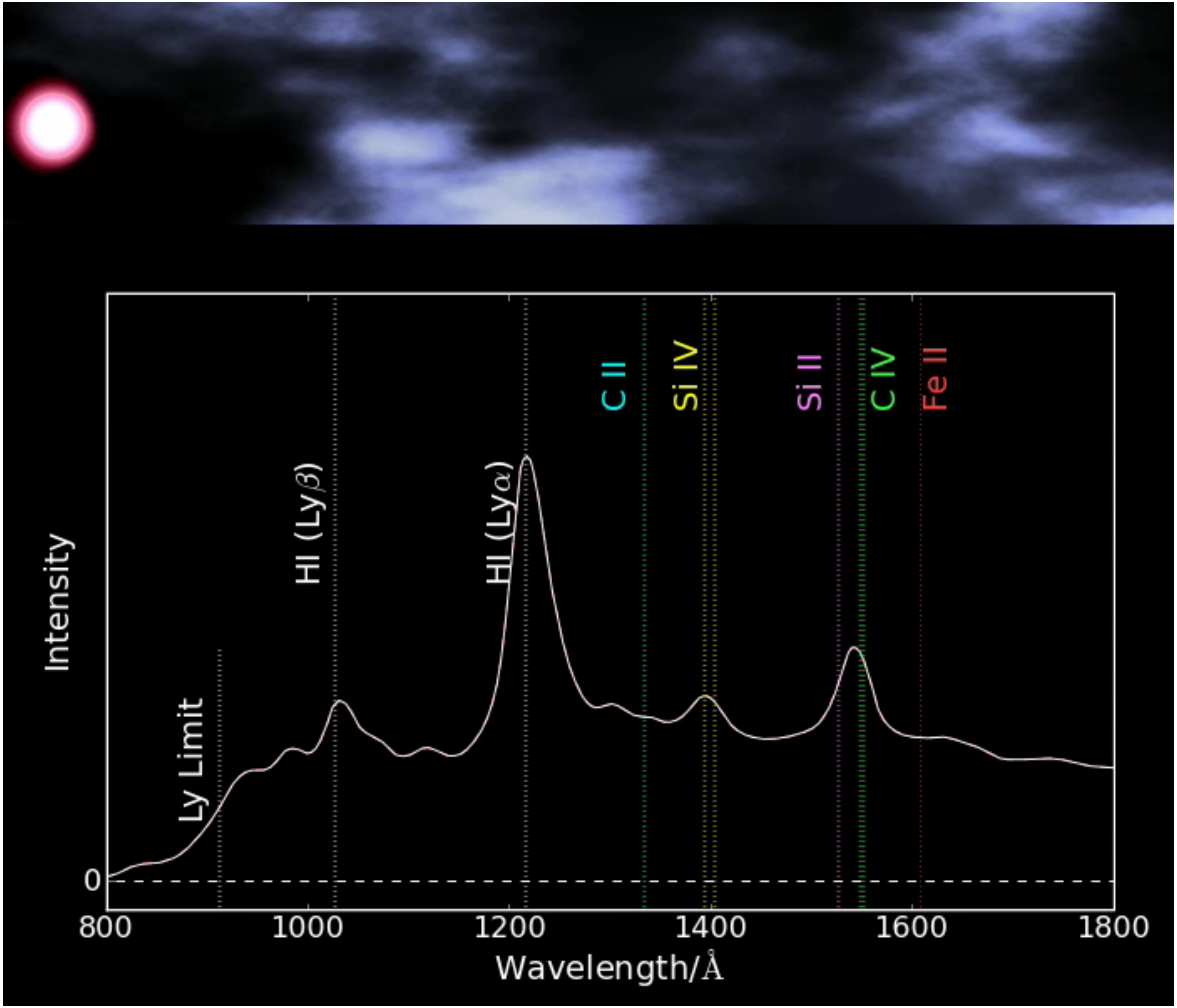
Bi & Davidsen (1997), Rauch (1998)
Review by Meiksin (2009)

baryons as tracer of the dark matter density field

$\delta_{IGM} \sim \delta_{DM}$

Croft+ 99,02
MV+ 04
McDonald+ 01,03




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

Modelling the IGM – I: Physics

Dark matter evolution: linear theory of density perturbation +
Jeans length $L_J \sim \mathrm{sqrt}(T/\rho)$ + mildly non linear evolution

Hydrodynamic processes: mainly gas cooling
cooling by adiabatic expansion of the universe
heating of gaseous structures (reionization)

- photoionization by a uniform Ultraviolet Background
- Hydrostatic equilibrium of gas clouds

dynamical time = $1/\mathrm{sqrt}(G\,\rho)$ ~ **sound crossing time**= size /gas sound speed

↓

Size of the cloud: > 100 kpc
Temperature: ~ 10^4 K
Mass in the cloud: ~ $10^9\ M_\odot$
Neutral hydrogen fraction: 10^{-5}

In practice, since the process is mildly non linear you need numerical simulations
To get convergence of the simulated flux at the percent level (observed)

Modelling the IGM – II: Analytical models for the Ly-a forest

(Bi 1993, Bi & Davidsen 1997, Hui & Gnedin 1998, Matarrese & Mohayaee 2002)

$$k_J^{-1}(z) \equiv H_0^{-1}\left[\frac{2\gamma k_B T_m(z)}{3\mu m_p \Omega_{0m}(1+z)}\right]^{1/2}$$

Jeans length

$$\delta_0^{\rm IGM}(\mathbf{k},z) = \frac{\delta_0^{\rm DM}(\mathbf{k},z)}{1+k^2/k_J^2(z)} \equiv W_{\rm IGM}(k,z)D_+(z)\delta_0^{\rm DM}(\mathbf{k})$$

Filtering of linear DM density field

$$\mathbf{v}^{\rm IGM}(\mathbf{k},z) = E_+(z)\frac{i\mathbf{k}}{k^2}W_{\rm IGM}(k,z)\delta_0^{\rm DM}(\mathbf{k})$$

Peculiar velocity

$$n_{\rm IGM}(\mathbf{x},z) = \overline{n}_{\rm IGM}(z)\exp\left[\delta_0^{\rm IGM}(\mathbf{x},z) - \frac{\langle(\delta_0^{\rm IGM})^2\rangle D_+^2(z)}{2}\right]$$

Non linear density field

$$T(\mathbf{x},z) = T_0(z)\,(1+\delta^{\rm IGM}(\mathbf{x},z))^{\gamma(z)-1}$$

'Equation-of-state'

$$\alpha(z,T(z))\,n_p n_e = J(z) n_{\rm HI}\ ,$$

Neutral hydrogen ionization equilibrium equation

$$\tau(u) = \frac{\sigma_{0,\alpha}\,c}{H(z)}\int_{-\infty}^{\infty} dy\, n_{\rm HI}(y)\,\mathcal{V}\left[u-y-v_{\parallel}^{\rm IGM}(y),\ b(y)\right]$$

Optical depth

Density Velocity Temperature

Linear fields: density, velocity

↓

Non linear fields + Temperature

↓

Spectra: Flux=exp(-τ)

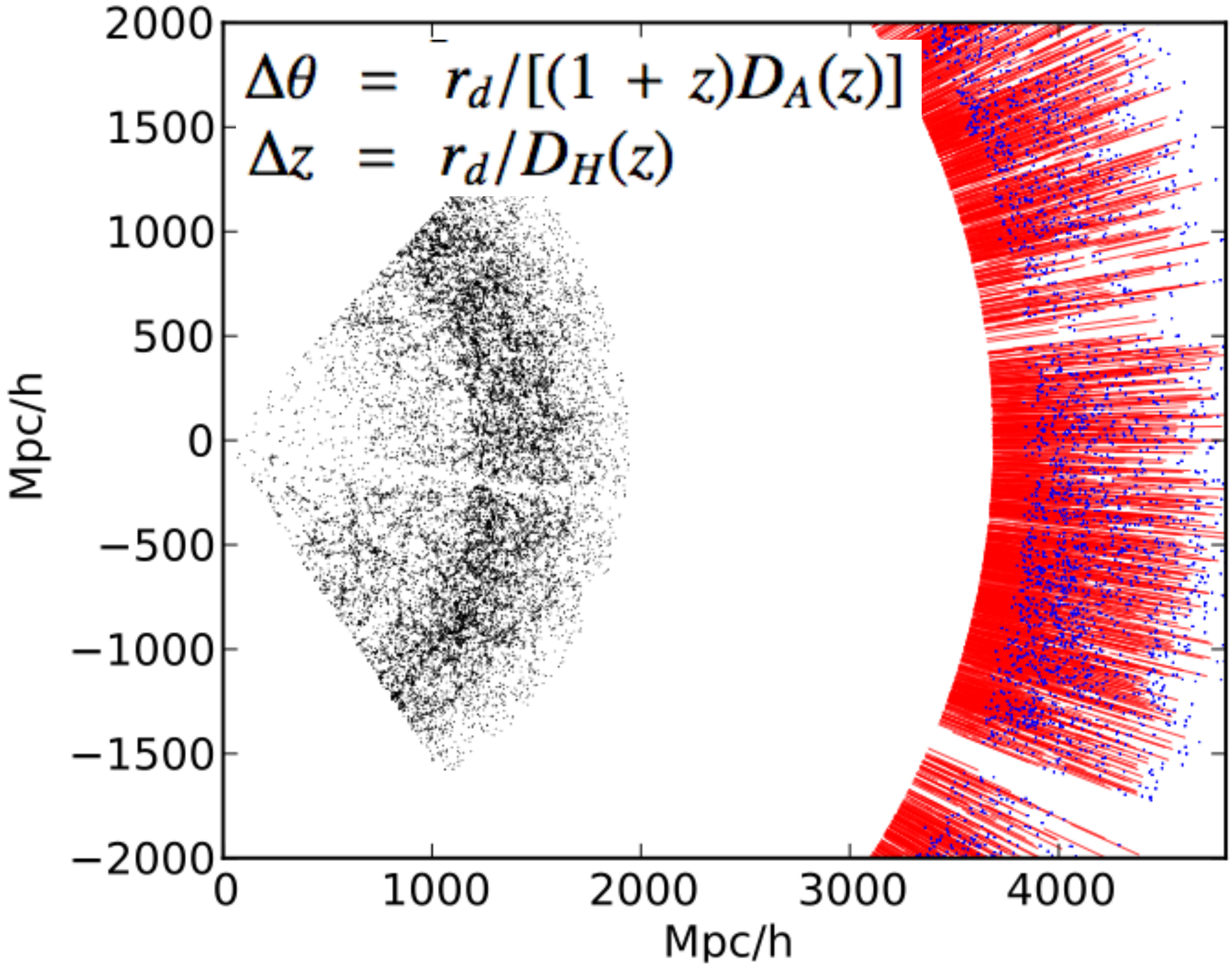
MV, Matarrese S., Mo HJ., Haehnelt M., Theuns T., 2002a, MNRAS, 329, 848

RESULTS FROM BOSS/SDSS-III

BAOs at z=2.3

SDSS- I

New regime to be probed with Lyman-α forest in 3D



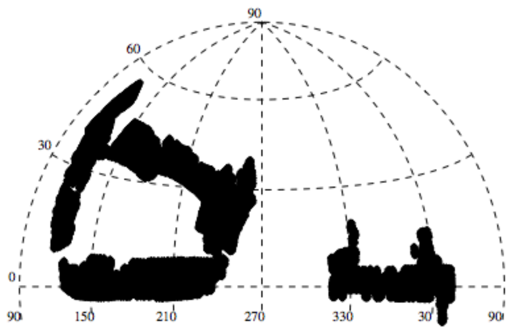
Slosar et al. 11
Busca et al. 13
Slosar et al. 13

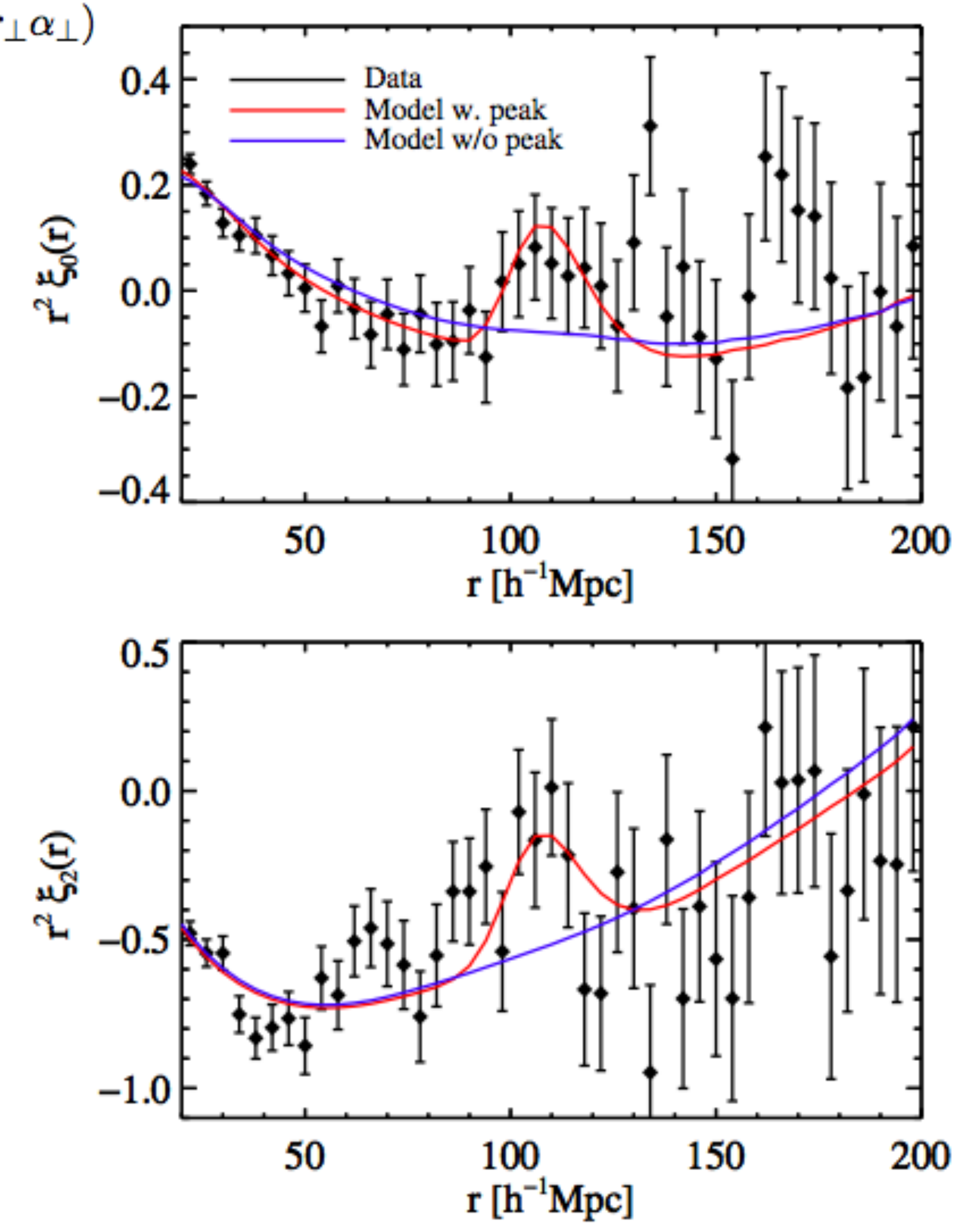
SDSS- II

Busca et al. 13

$$\xi_{\rm cosmo}(r_\parallel, r_\perp) = \xi_{\rm smooth}(r_\parallel, r_\perp) + a_{\rm peak} \cdot \xi_{\rm peak}(r_\parallel \alpha_\parallel, r_\perp \alpha_\perp)$$

$$\xi(r_\parallel, r_\perp) = \xi_{\rm cosmo}(r_\parallel, r_\perp, \alpha_\parallel, \alpha_\perp) + \xi_{\rm bb}(r_\parallel, r_\perp)$$



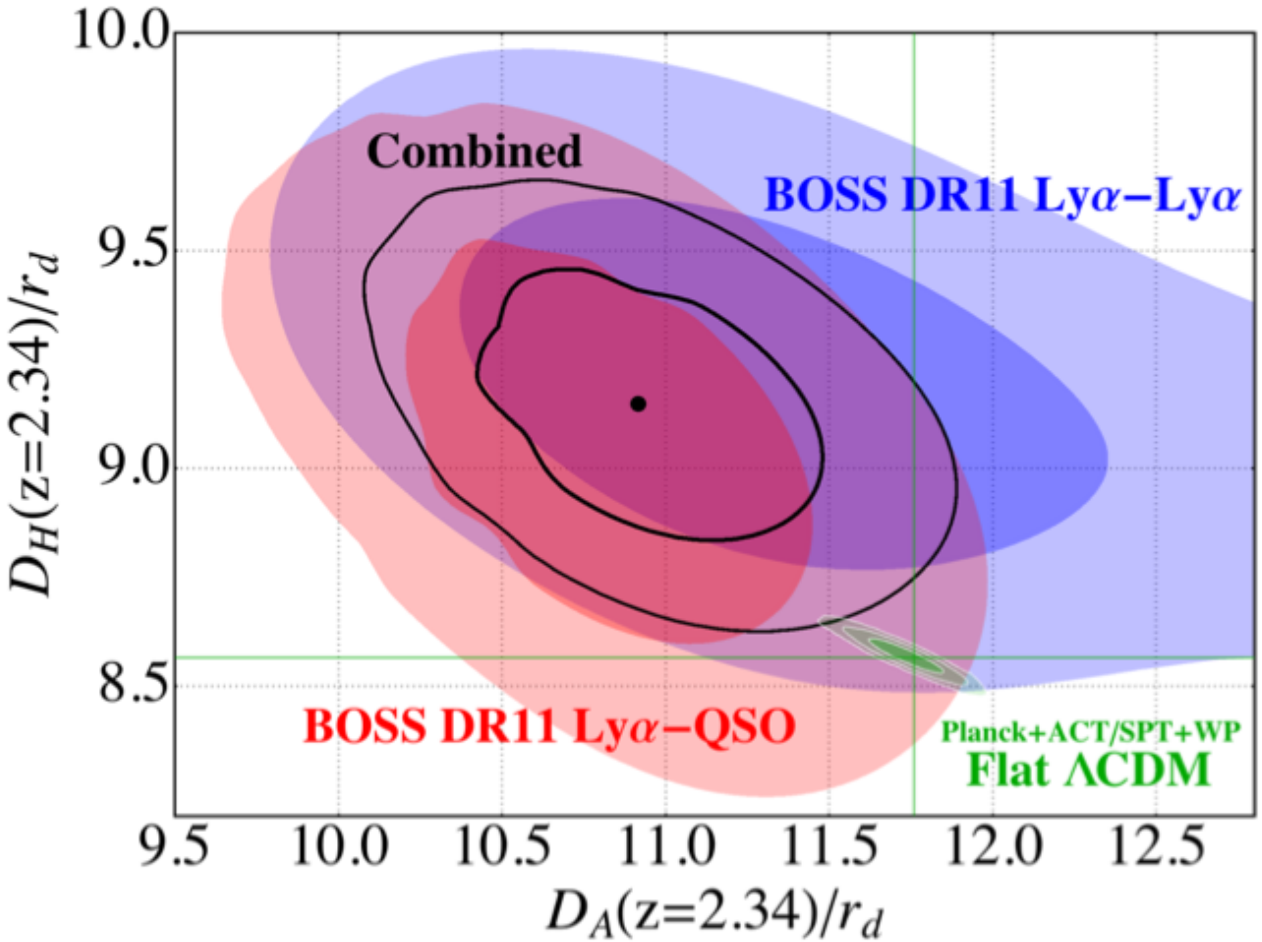


BAO feature detected at z=2.3
From 3000 deg^2, using 50000 QSOs
Significance of the detection at around 3σ

SDSS-III

$$P_{qF}(\mathbf{k}) = b_q \left[1 + \beta_q \mu_k^2\right] b_F \left[1 + \beta_F \mu_k^2\right] \; P(k)$$

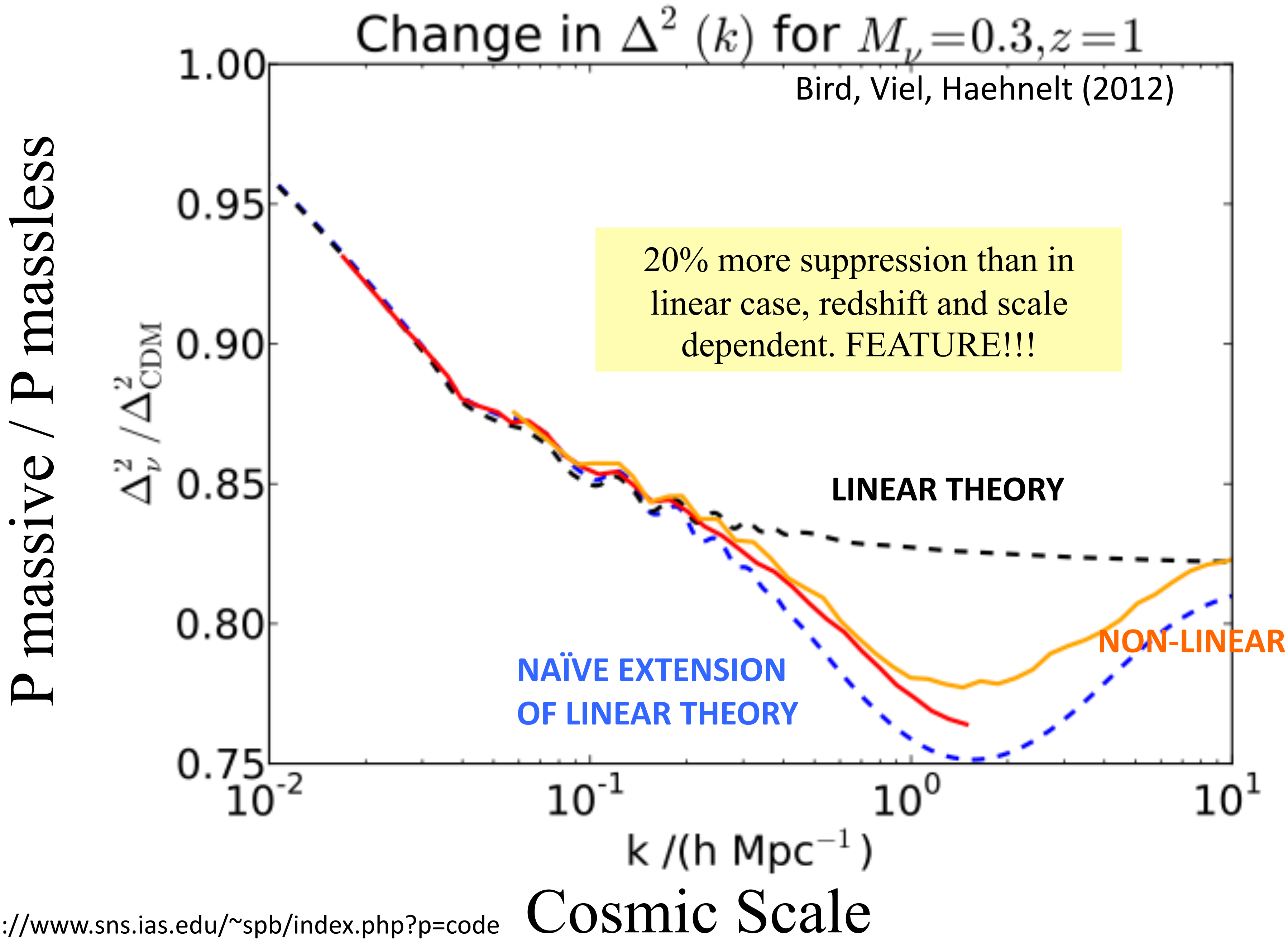
6% precision measurement of D_A/r_d
3% precision measurement of D_H/r_d



Delubac et al. 14

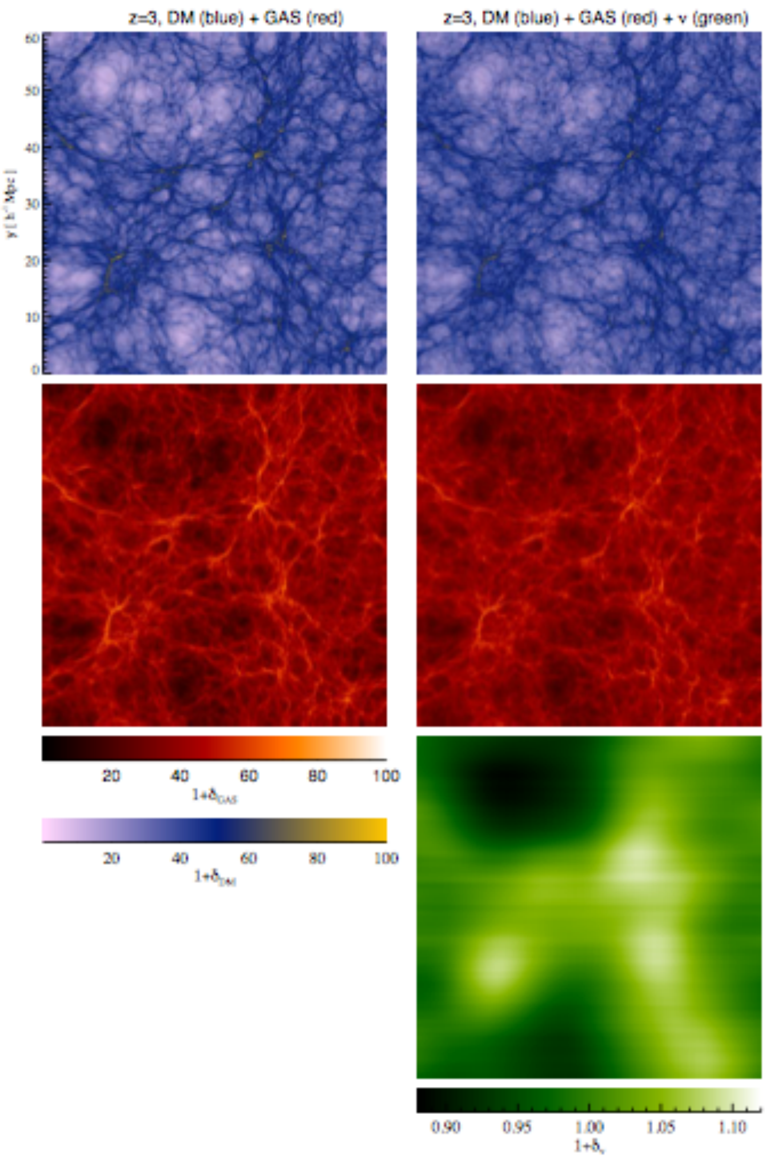
MASSIVE NEUTRINOS

COSMOLOGICAL NEUTRINOS: NON-LINEAR MATTER POWER



http://www.sns.ias.edu/~spb/index.php?p=code

NEUTRINOS IN THE IGM



N-body + hydro sims

Neutrino induced non-linear suppression understood and reproduced also with simple halo modelling (**Massara+ 15**)

Degeneracies with s8 are present

Neutrino induced effects on RSD (Marulli+11), BAOs (Peloso+15), mass functions and bias (Castorina+14) investigated

FROM IGM ONLY:

$$\Sigma m_{\nu} < 0.9 \text{ eV} (2\sigma)$$

Viel, Haehnelt, Springel 2010
Rossi+ 14, Villaescusa-Navarro+14

METHOD

DATA: thousands of low-res. Spectra for neutrino constraints. Few tens for cold dark matter coldness

SIMULATIONS: Gadget-III runs: 20 and 60 Mpc/h and (512^3,786^3,896^3)

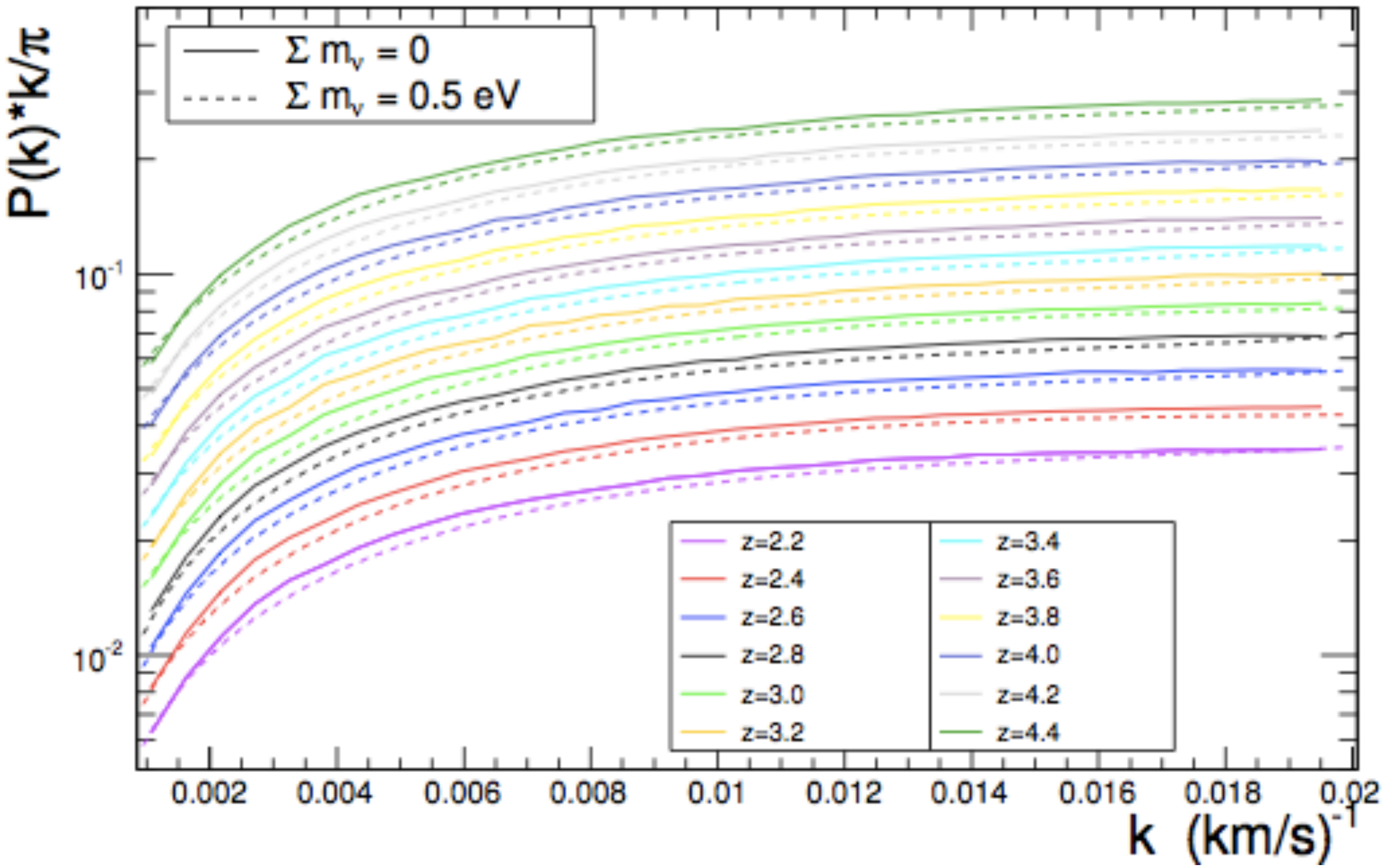
Cosmology parameters: σ_8, n_s, Ω_m, H_0, $m_{WDM,}$+ neutrino mass
Astrophysical parameters: z_{reio}, UV fluctuations, T_0, γ, <F>
Nuisance: resolution, S/N, metals

METHOD: Monte Carlo Markov Chains likelihood estimator + **very conservative assumptions** for the continuum fitting and error bars on the data

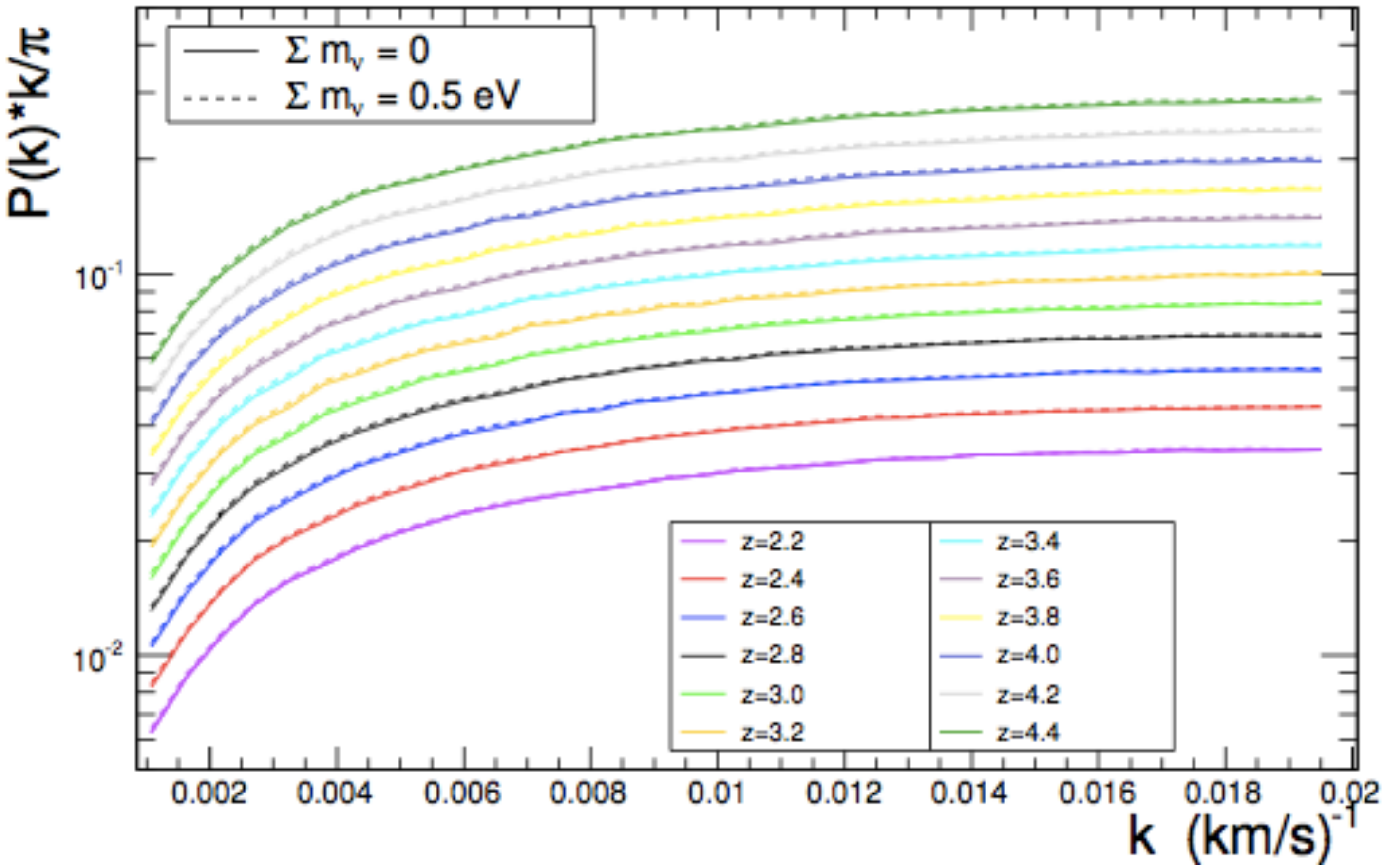
Parameter space: second order Taylor expansion of the flux power

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

NEUTRINO IMPACT - I



NEUTRINO IMPACT - II

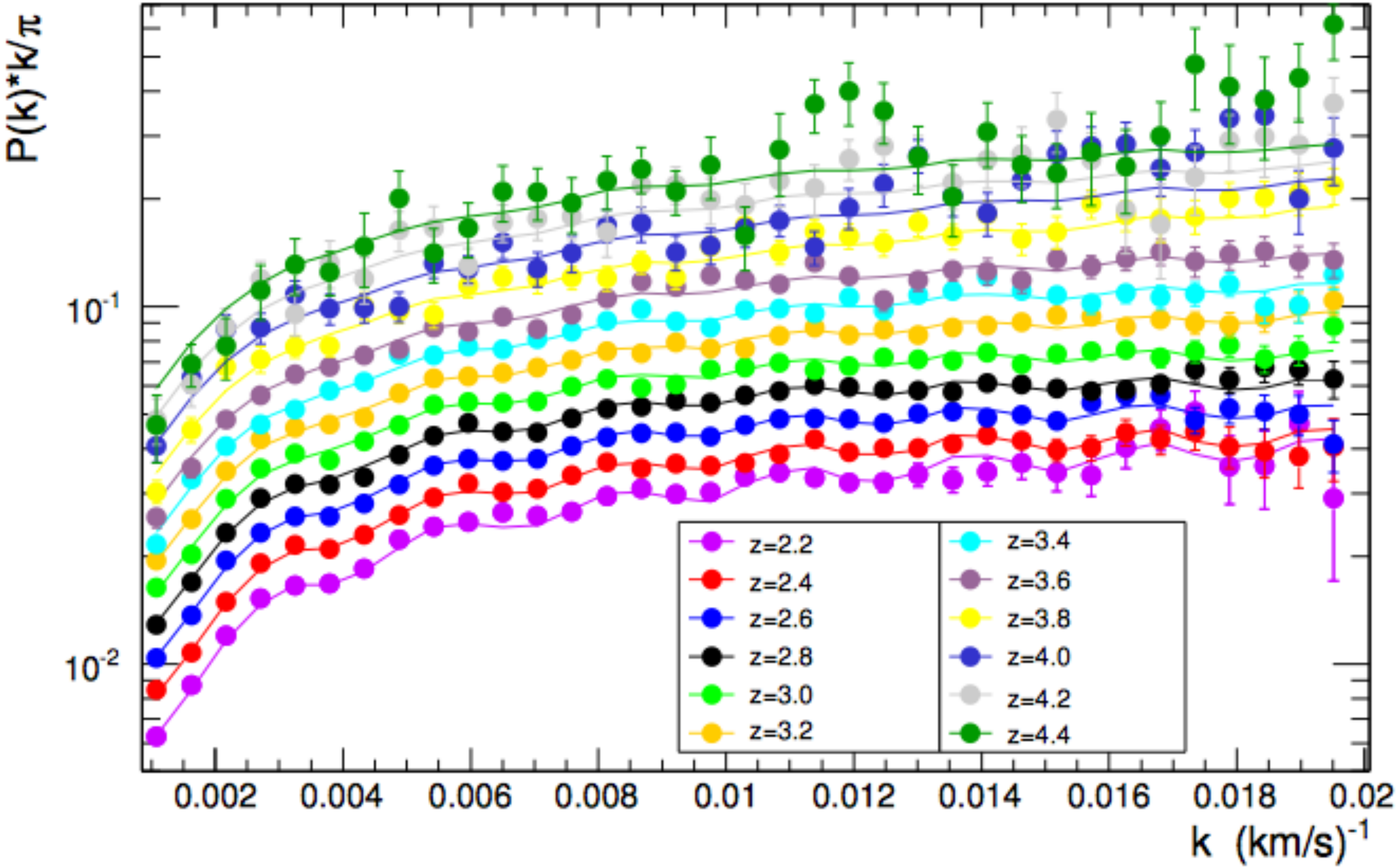


GROWTH OF STRUCTURES AT HIGH REDSHIFT

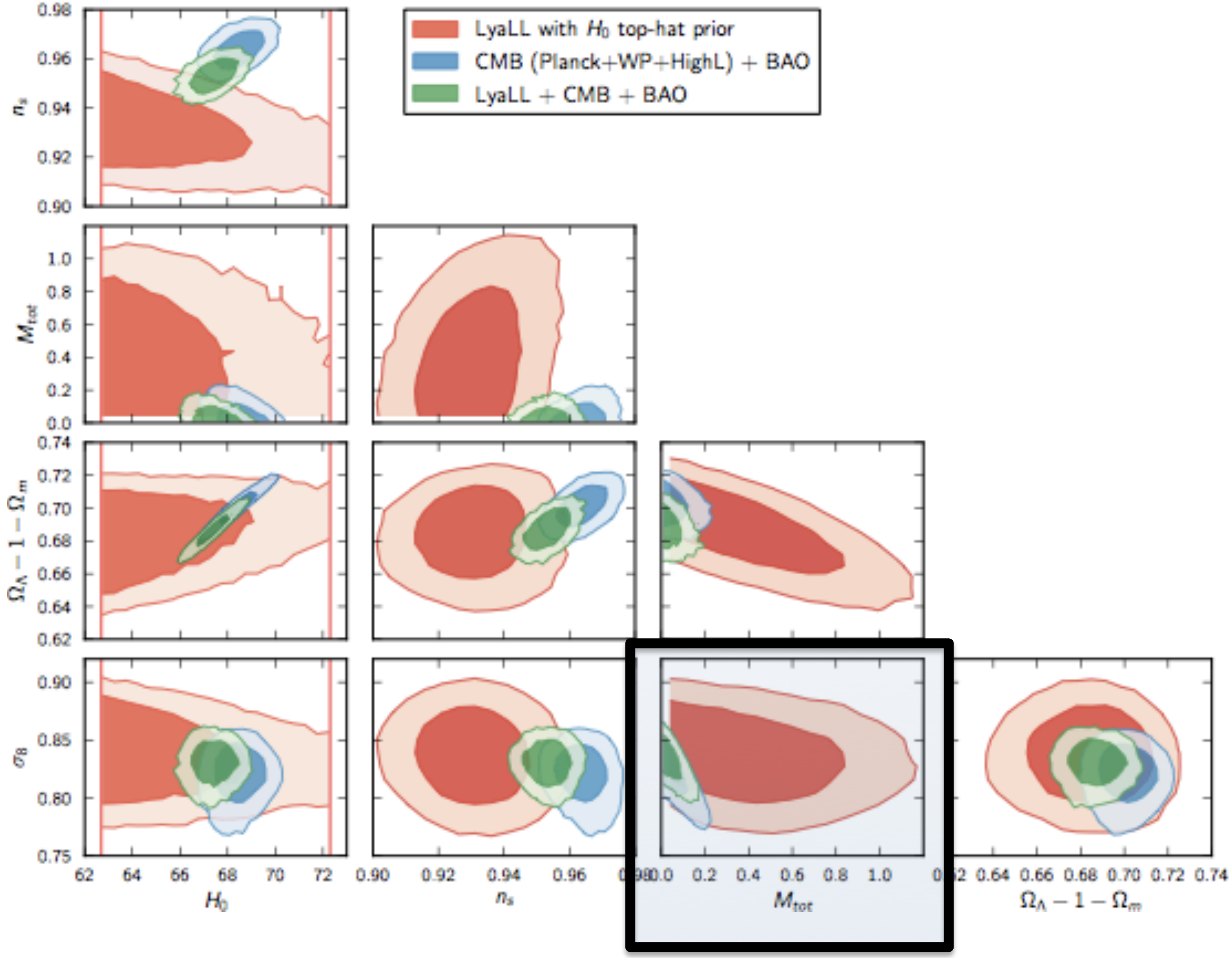
Constraint on neutrino masses from SDSS-III/BOSS Lyα forest and other cosmological probes

1D Flux power spectrum evolution

Nathalie Palanque-Delabrouille,[a,b] Christophe Yèche,[a] Julien Lesgourgues,[c,d,e] Graziano Rossi,[a,f] Arnaud Borde,[a] Matteo Viel,[g,h] Eric Aubourg,[i] David Kirkby,[j] Jean-Marc LeGoff,[a] James Rich,[a] Natalie Roe,[b] Nicholas P. Ross,[k] Donald P. Schneider,[l,m] David Weinberg[n]



BAYESIAN ANALYSIS



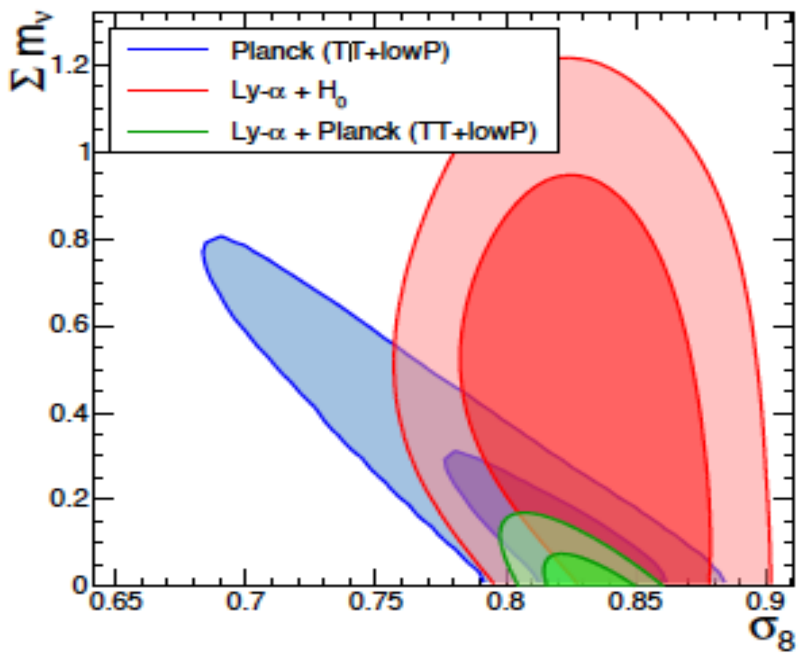
FINAL NUMBERS

Parameter	Lyα + H_0^{tophat} (62.5 ≤ H_0 < 72.5)	Lyα + CMB	Lyα + CMB + BAO	Lyα + CMB(A_L)
$10^9 A_s$	$3.2^{+0.5}_{-0.7}$	$2.20^{+0.05}_{-0.06}$	$2.20^{+0.05}_{-0.06}$	$2.18^{+0.05}_{-0.06}$
$10^2 \omega_b$	(fixed to 2.22)	2.20 ± 0.02	2.20 ± 0.02	2.22 ± 0.03
ω_{cdm}	$0.110^{+0.008}_{-0.013}$	$0.1200^{+0.0019}_{-0.0018}$	$0.1196^{+0.0015}_{-0.0014}$	0.1191 ± 0.002
τ_{reio}	(irrelevant)	$0.091^{+0.012}_{-0.013}$	$0.091^{+0.011}_{-0.013}$	$0.0871^{+0.012}_{-0.013}$
n_s	0.931 ± 0.012	0.953 ± 0.005	0.953 ± 0.005	$0.955^{+0.005}_{-0.006}$
H_0	< 70.9 (95%)	$67.2^{+0.8}_{-0.9}$	67.4 ± 0.7	$67.5^{+1.0}_{-1.1}$
$\sum m_\nu$ (eV)	< 0.98 (95%)	< 0.16 (95%)	< 0.14 (95%)	< 0.21 (95%)
A_L	(fixed to 1)	(fixed to 1)	(fixed to 1)	1.12 ± 0.10
σ_8	0.84 ± 0.03	$0.830^{+0.017}_{-0.013}$	$0.830^{+0.016}_{-0.012}$	$0.818^{+0.021}_{-0.014}$
Ω_m	$0.316^{+0.018}_{-0.021}$	0.316 ± 0.012	0.313 ± 0.009	0.312 ± 0.013

UPDATE using Planck 15

Palanque-Delabrouille+15 arxiv: 1506.05976, JCAP in press

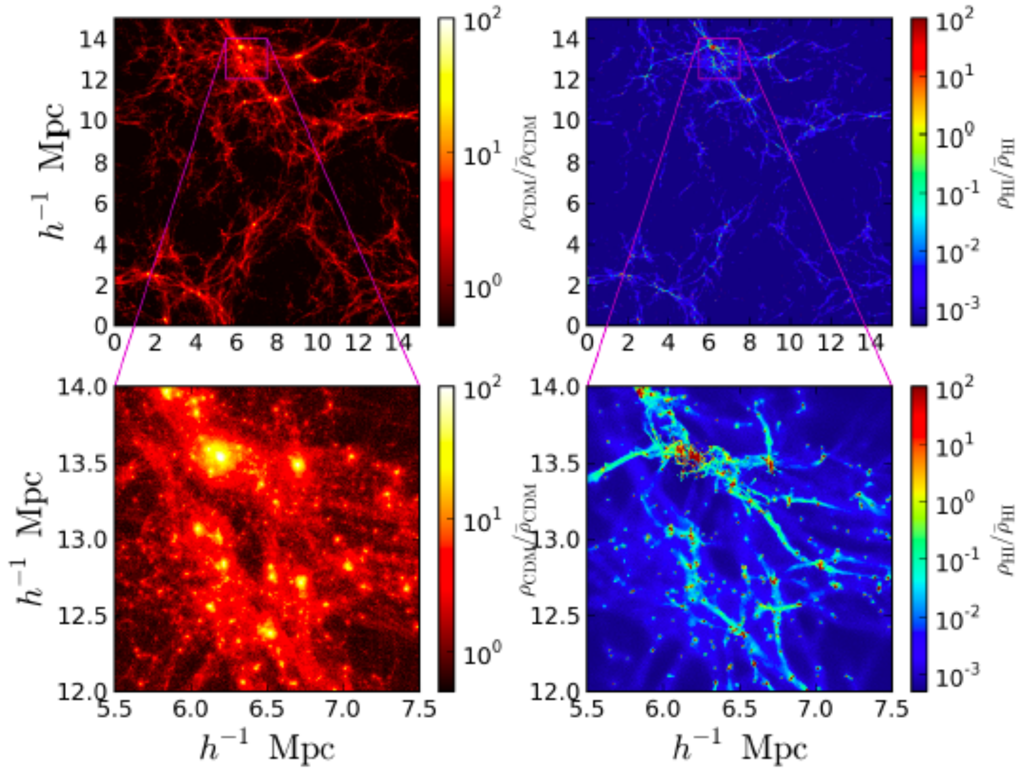
Parameter	(1) Lyα + $H_0^{\rm Gaussian}$ ($H_0 = 67.3 \pm 1.0$)	(2) Lyα + Planck TT+lowP	(3) Lyα + Planck TT+lowP + BAO	(4) Lyα + Planck TT+TE+EE+lowP + BAO
σ_8	0.831 ± 0.031	0.833 ± 0.011	0.845 ± 0.010	0.842 ± 0.014
n_s	0.938 ± 0.010	0.960 ± 0.005	0.959 ± 0.004	0.960 ± 0.004
Ω_m	0.293 ± 0.014	0.302 ± 0.014	0.311 ± 0.014	0.311 ± 0.007
H_0 (km s^{-1} Mpc^{-1})	67.3 ± 1.0	68.1 ± 0.9	67.7 ± 1.1	67.7 ± 0.6
$\sum m_\nu$ (eV)	< 1.1 (95% CL)	< 0.12 (95% CL)	< 0.13 (95% CL)	< 0.12 (95% CL)
Reduced χ^2	0.99	1.04	1.05	1.05



FROM ABSORPTION TO EMISSION - I

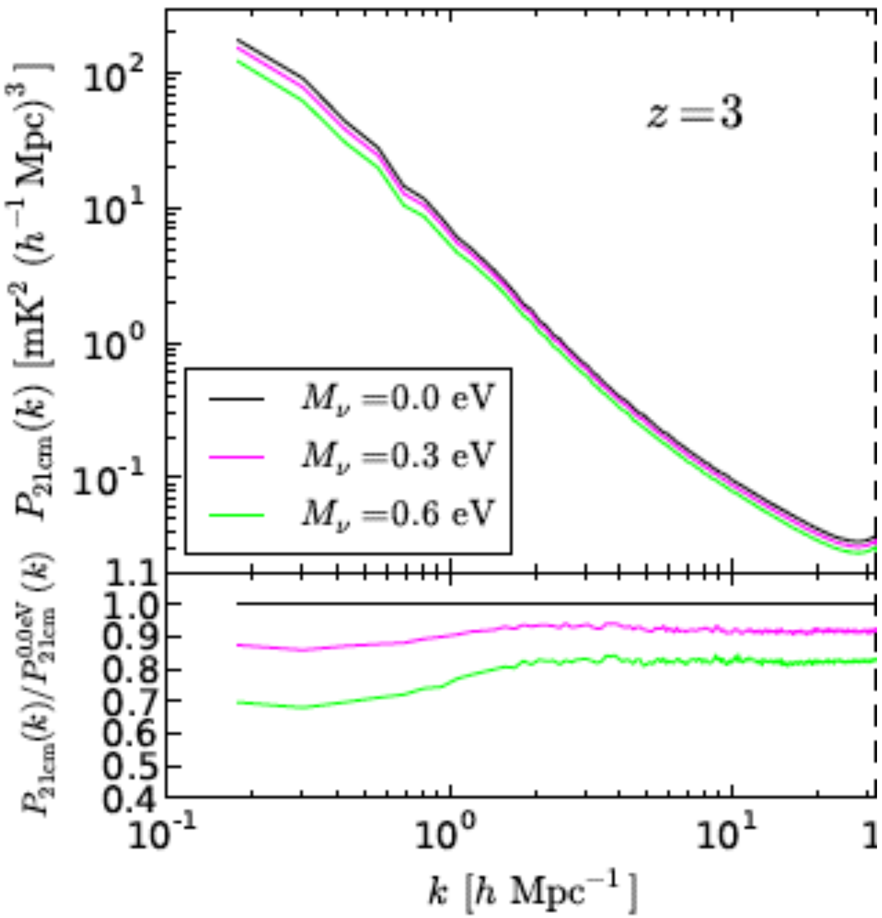
Villaescusa-Navarro, MV+ 2014

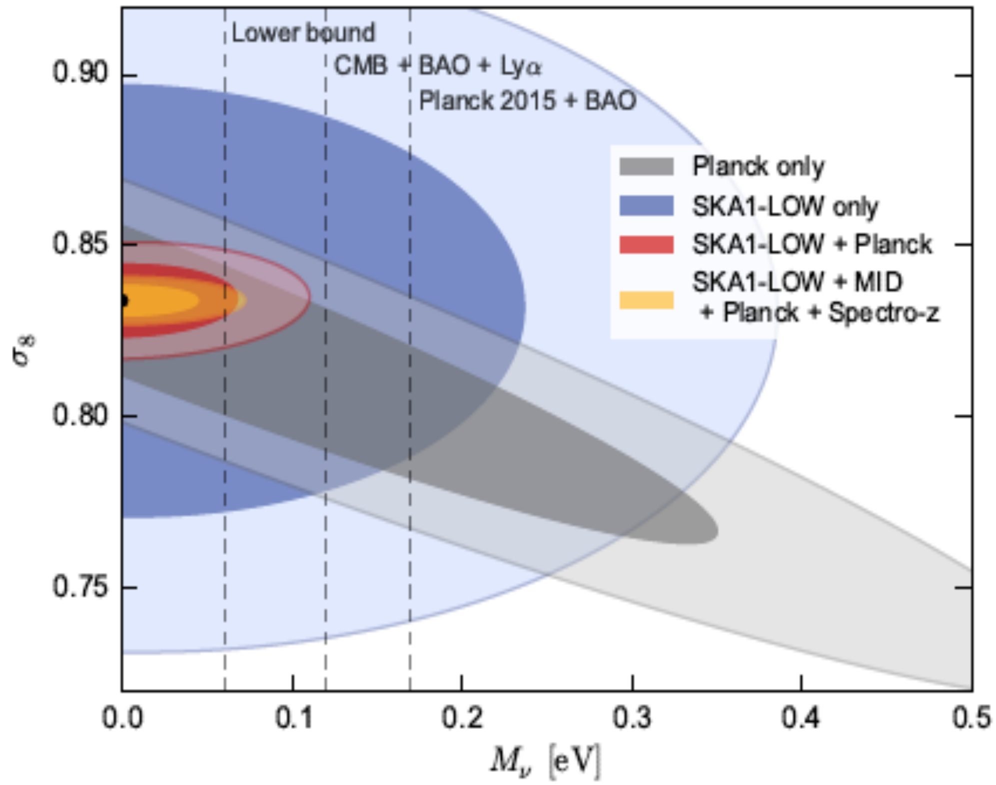
HI halo model	
Linear matter power spectrum	$P_m(k,z)$
Halo mass function	$n(M,z)$
Halo bias	$b(M,z)$
HI mass in halos	$M_{HI}(M,z)$
HI density profile in halos	$\rho_{HI}(r \mid M,z)$



FROM ABSORPTION TO EMISSION: NEUTRINOS in 21cm INTENSITY MAPPING with SKA

Villaescusa-Navarro, Bull, MV, arXiv: 1507.05102



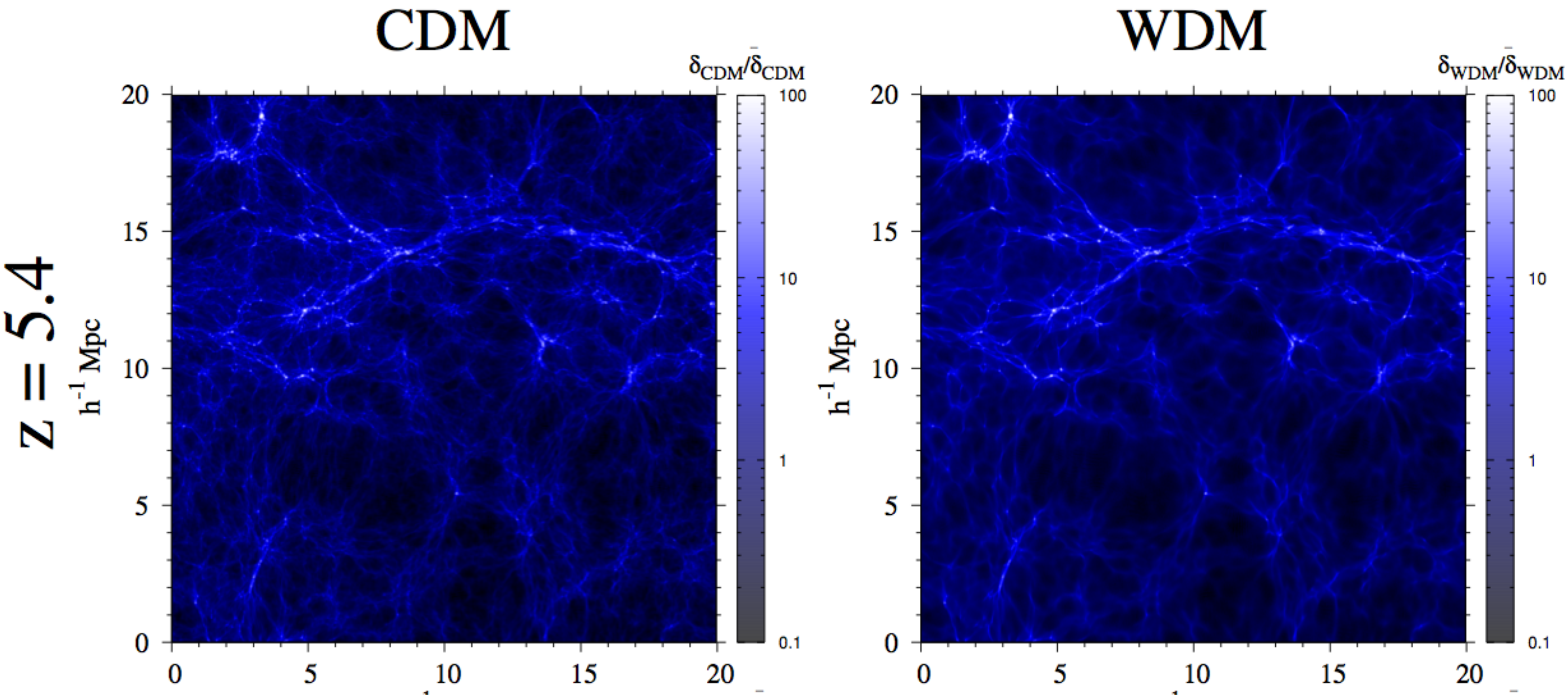


$\sigma(M_\nu) = 0.06$ eV (2σ error bar)

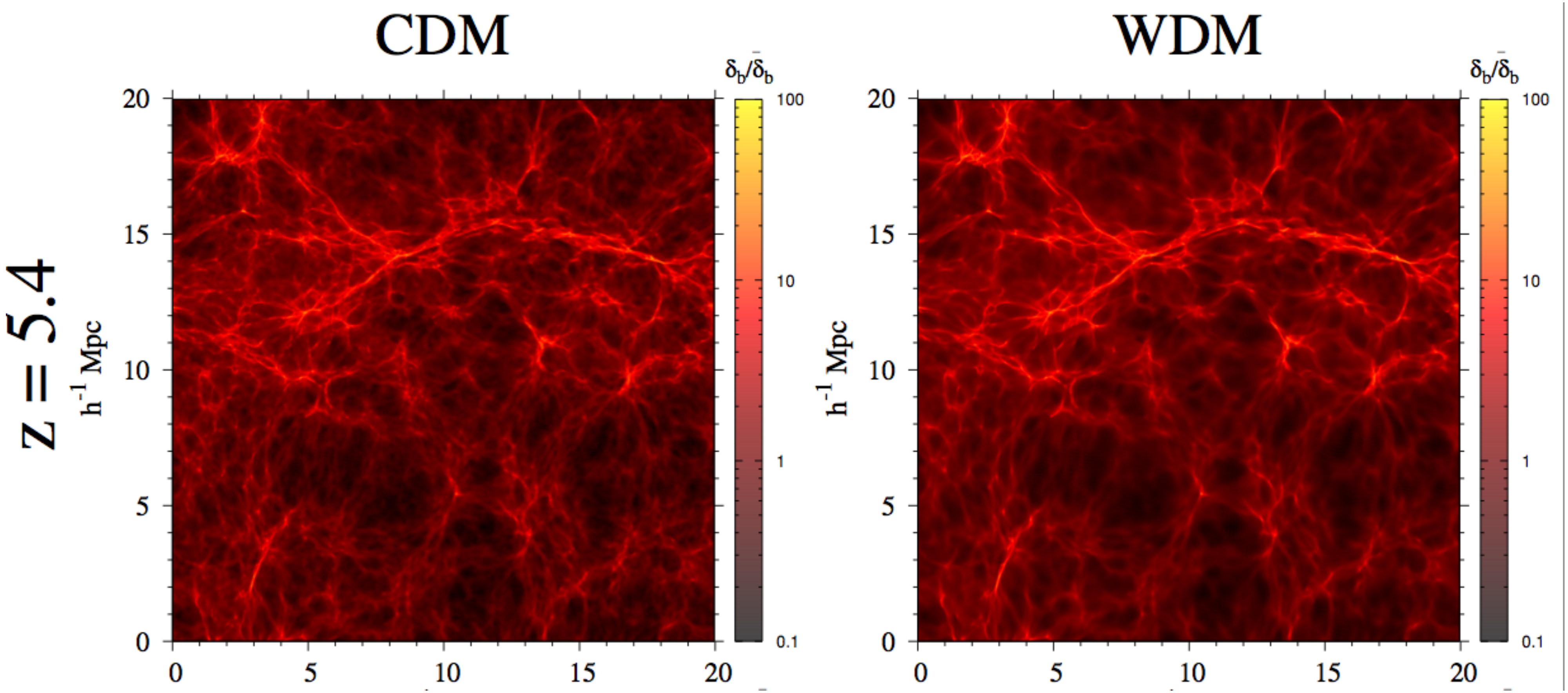
COLDNESS OF COLD DARK MATTER

Viel, Becker, Bolton, Haehnelt, 2013, PRD, 88, 043502

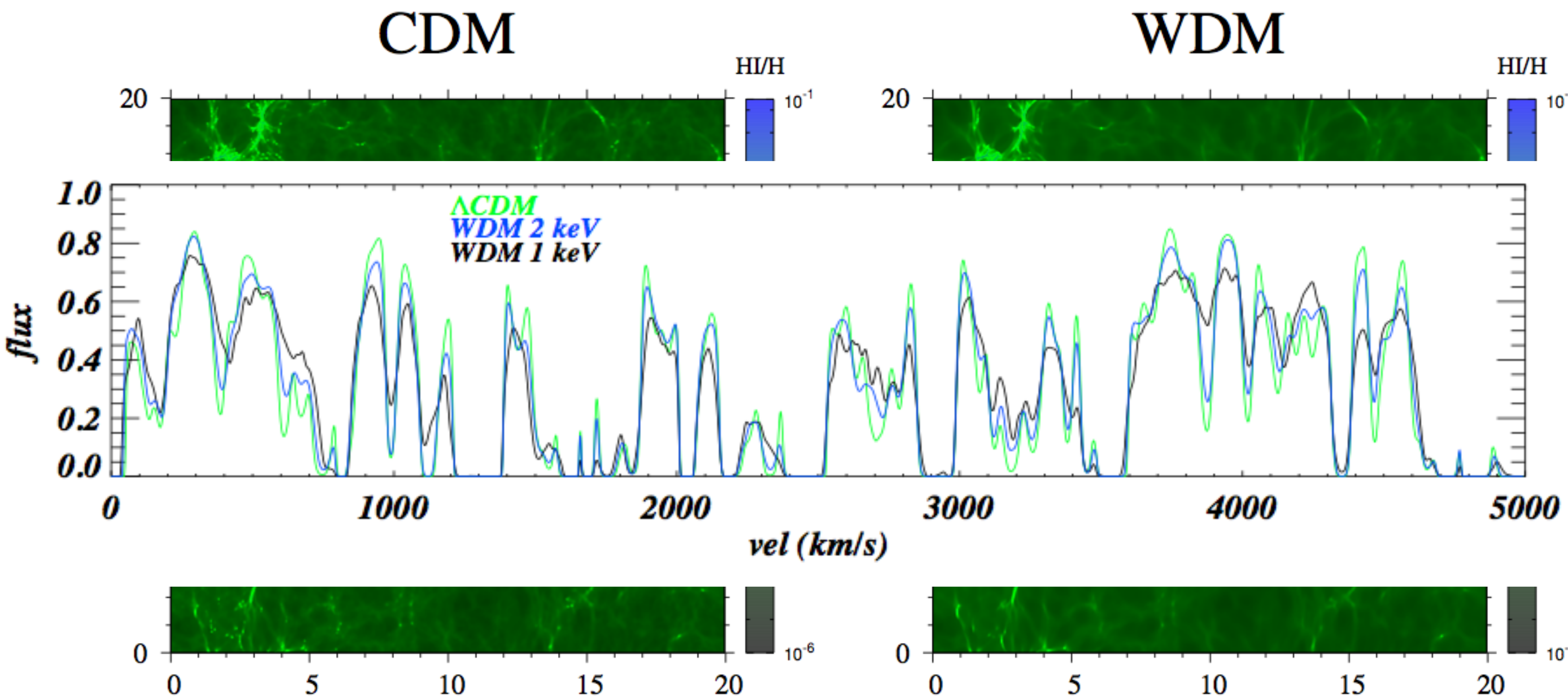
DARK MATTER DISTRIBUTION



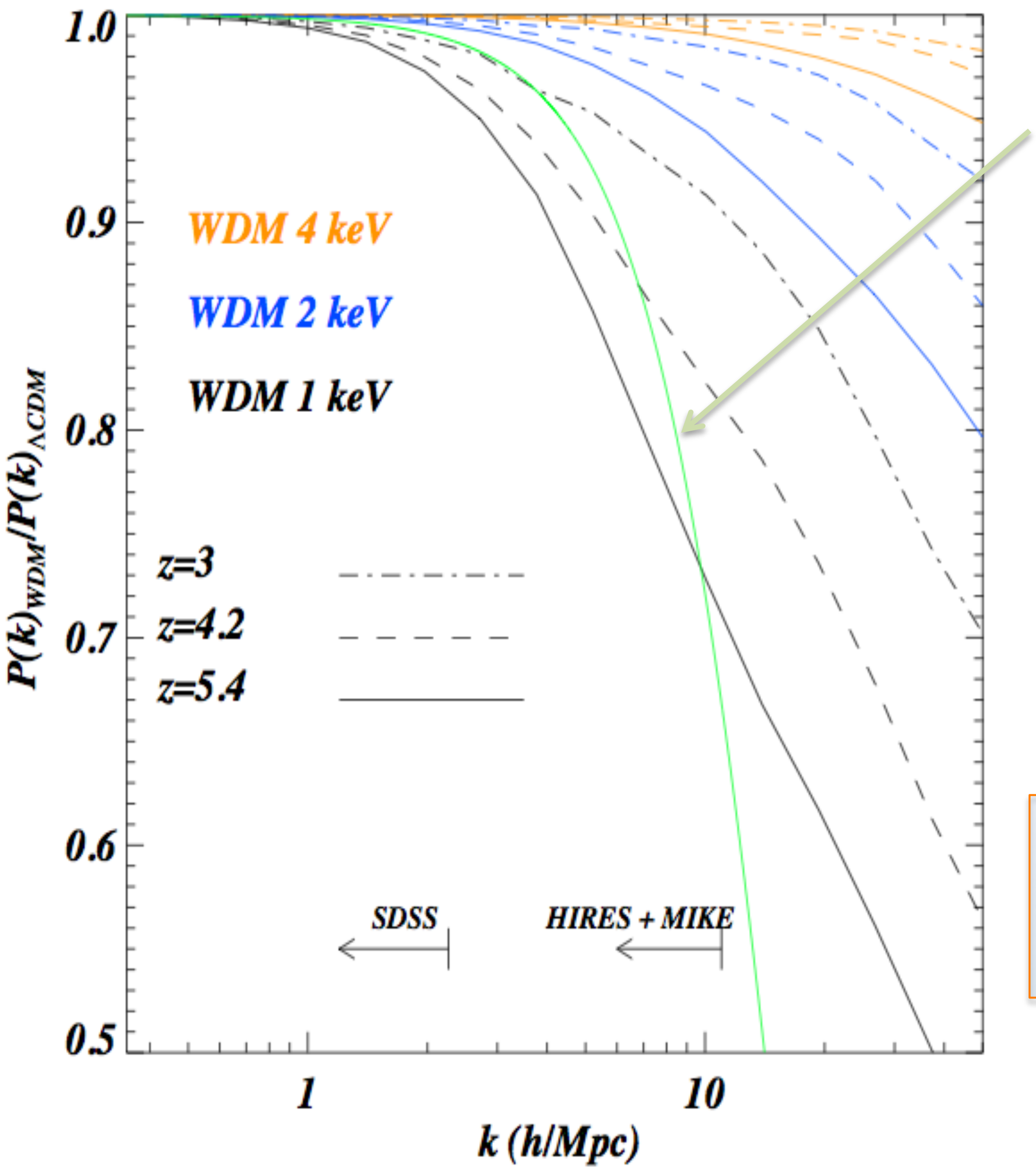
GAS DISTRIBUTION



HI DISTRIBUTION



THE WARM DARK MATTER CUTOFF IN THE MATTER DISTRIBUTION



Linear cutoff for WDM 2 keV

Linear cutoff is redshift independent

Fit to the non-linear cut-off

$$T^2_{\rm nl}(k) \equiv P_{\rm WDM}(k)/P_{\Lambda{\rm CDM}}(k) = (1+(\alpha\, k)^{\nu l})^{-s/\nu},$$

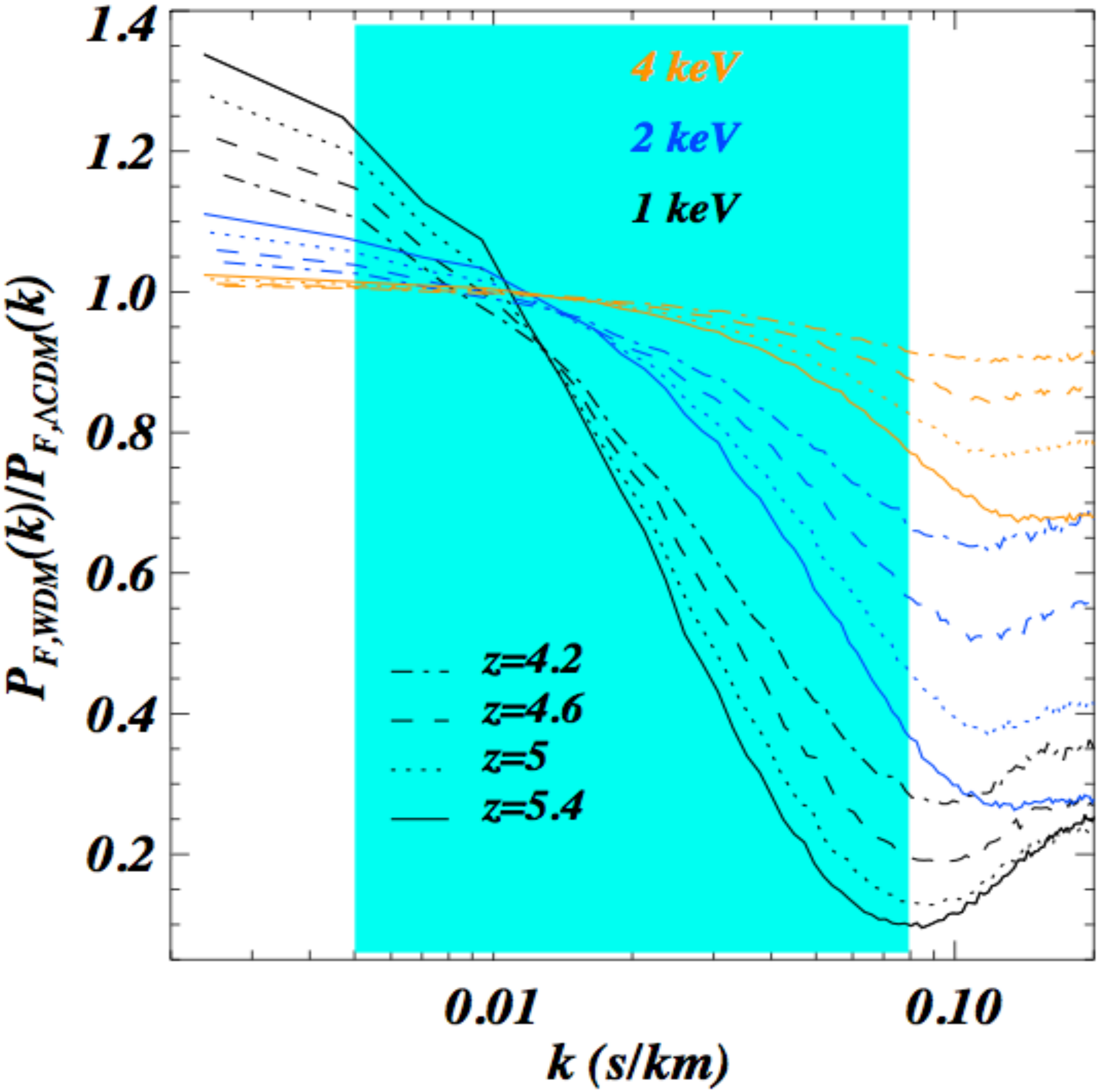
$$\alpha(m_{\rm WDM}, z) = 0.0476 \left(\frac{1{\rm keV}}{m_{\rm WDM}}\right)^{1.85} \left(\frac{1+z}{2}\right)^{1.3},$$

$\nu = 3$, $l = 0.6$ and $s = 0.4$.

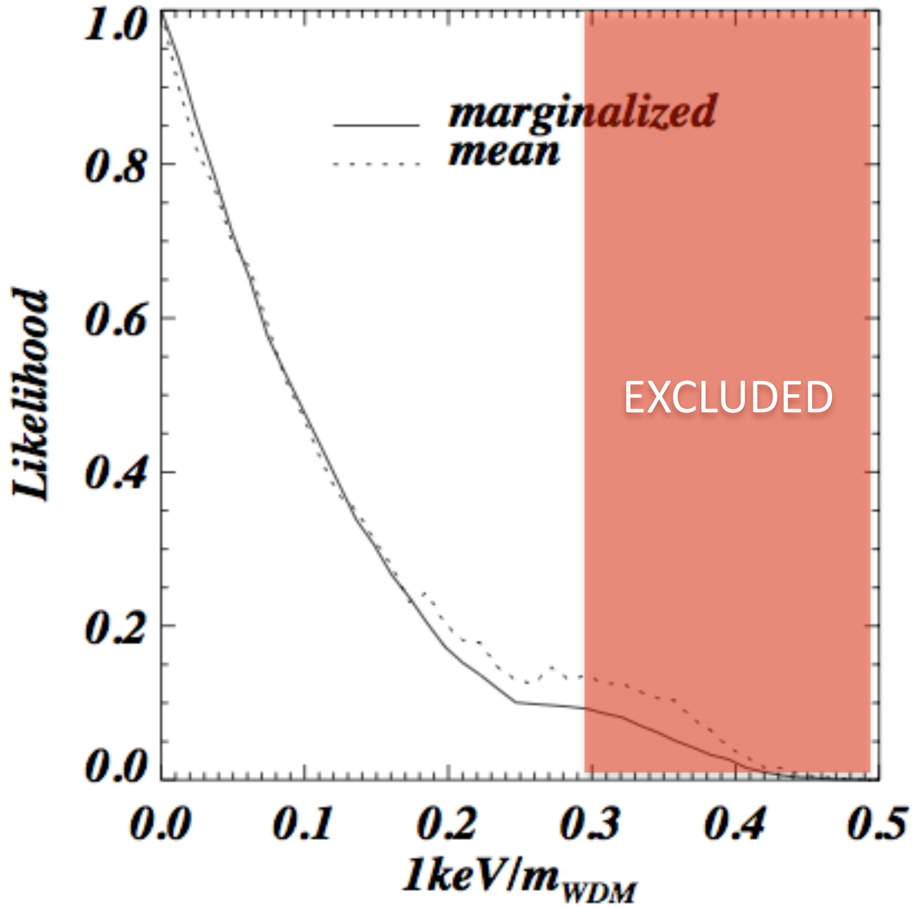
Viel, Markovic, Baldi & Weller 2013

THE HIGH REDSHIFT WDM CUTOFF

$\delta_F = F/\langle F\rangle - 1$



RESULTS FOR WDM MASS

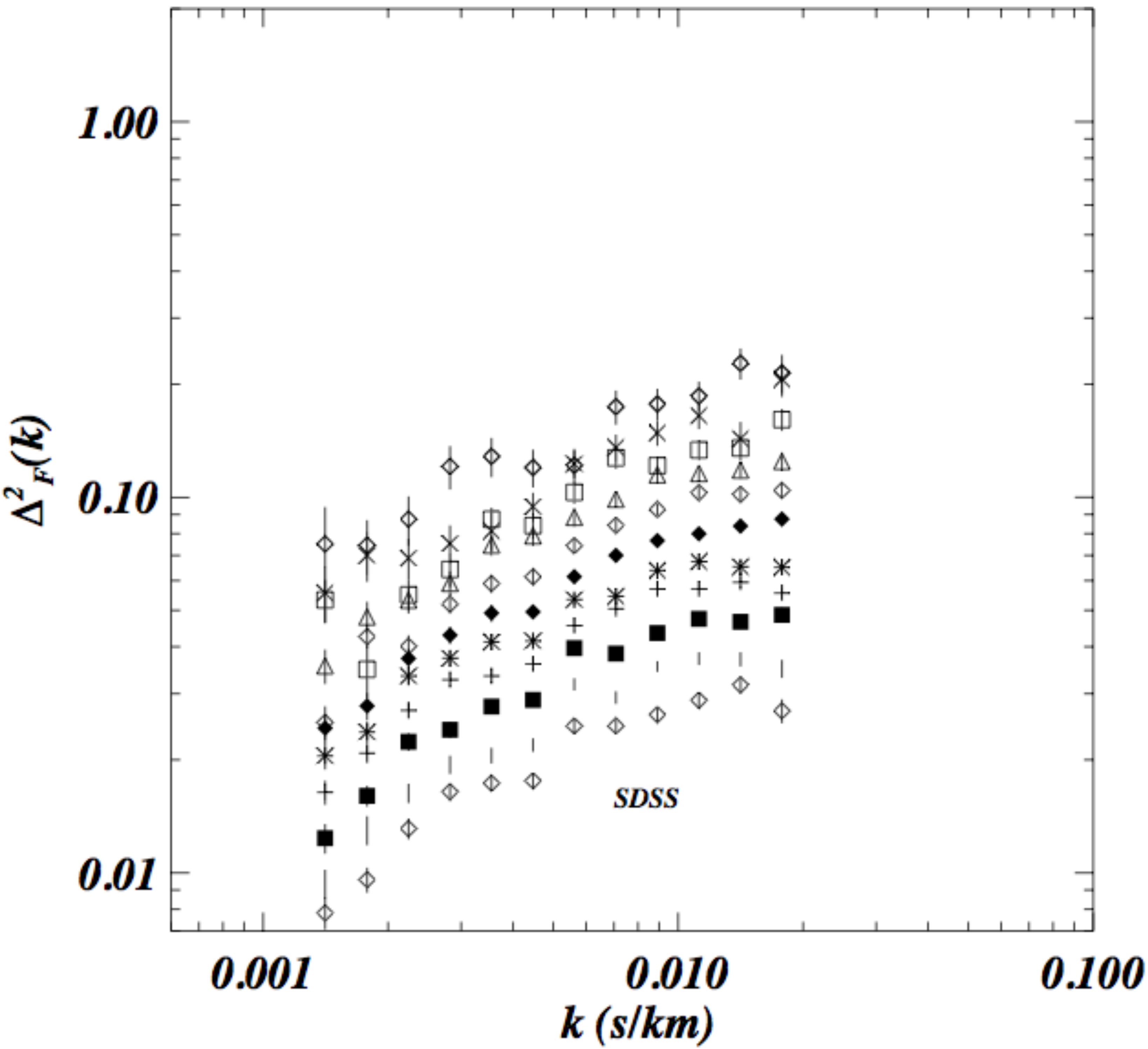


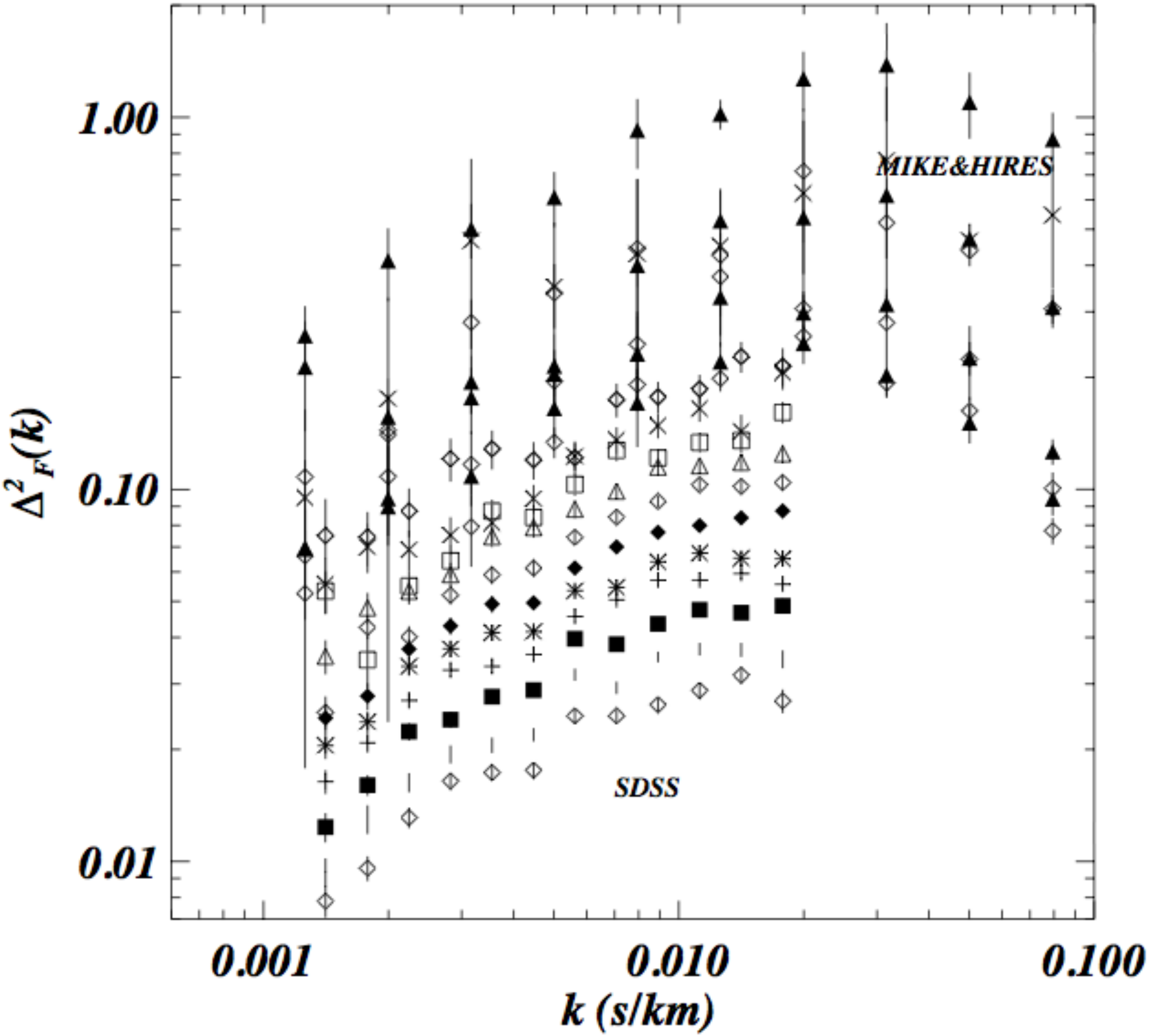
m > 3.3 keV (2σ)

SDSS + MIKE + HIRES CONSTRAINTS

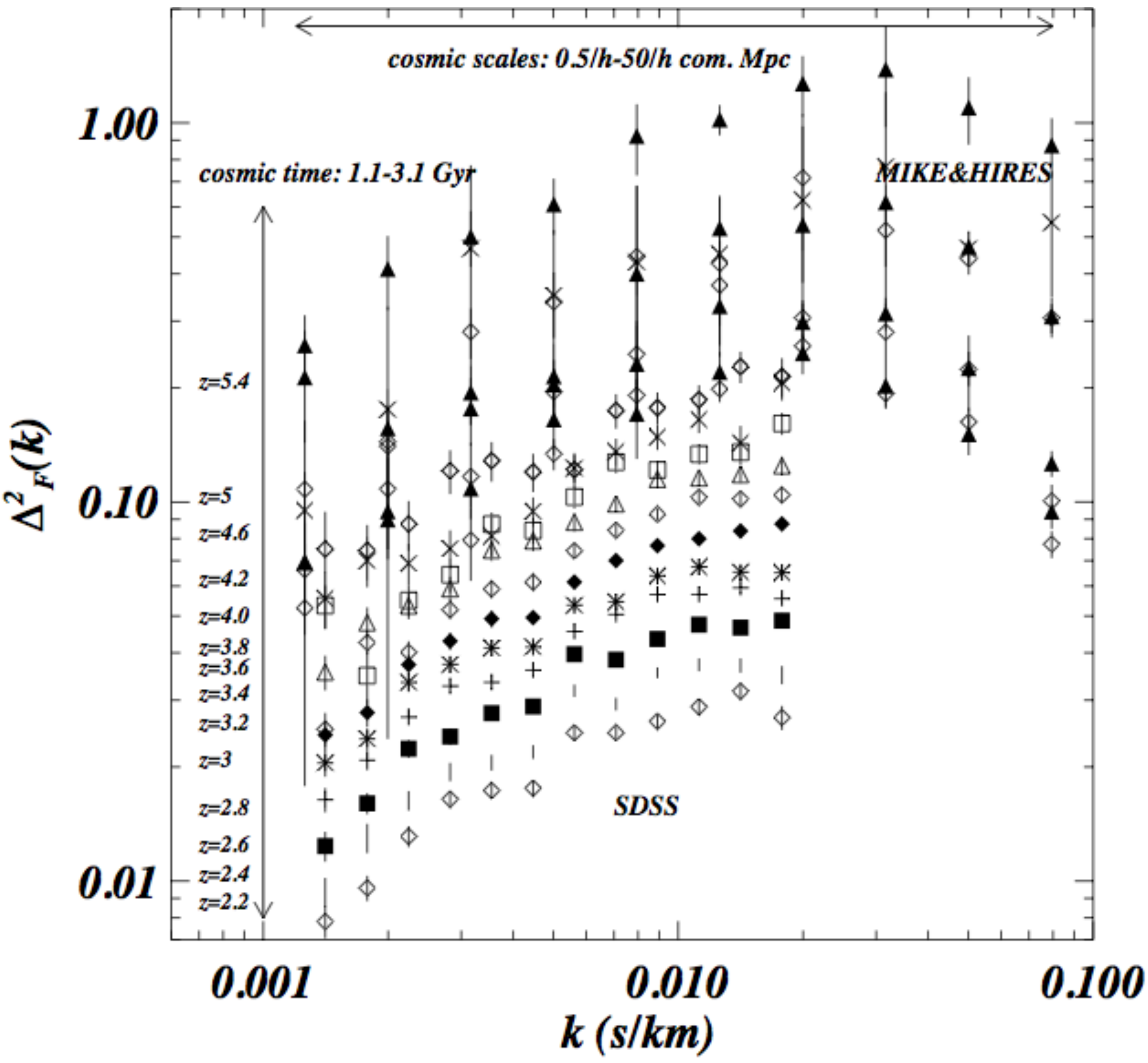
Joint likelihood analysis

SDSS data from McDonald05,06 not BOSS

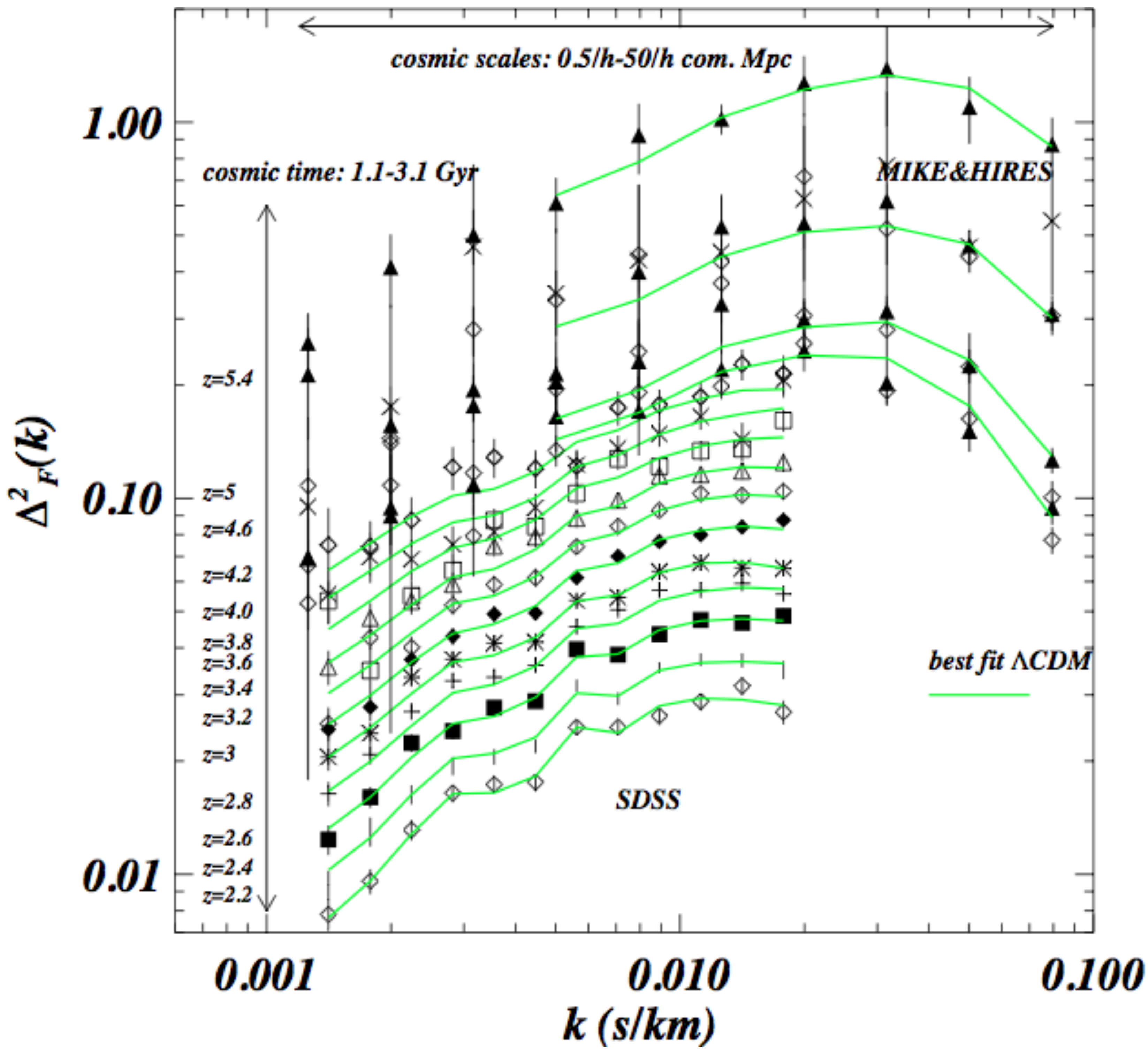

1.00
0.10
0.01
$\Delta^2_F(k)$
SDSS
0.001
0.010
0.100
k (s/km)

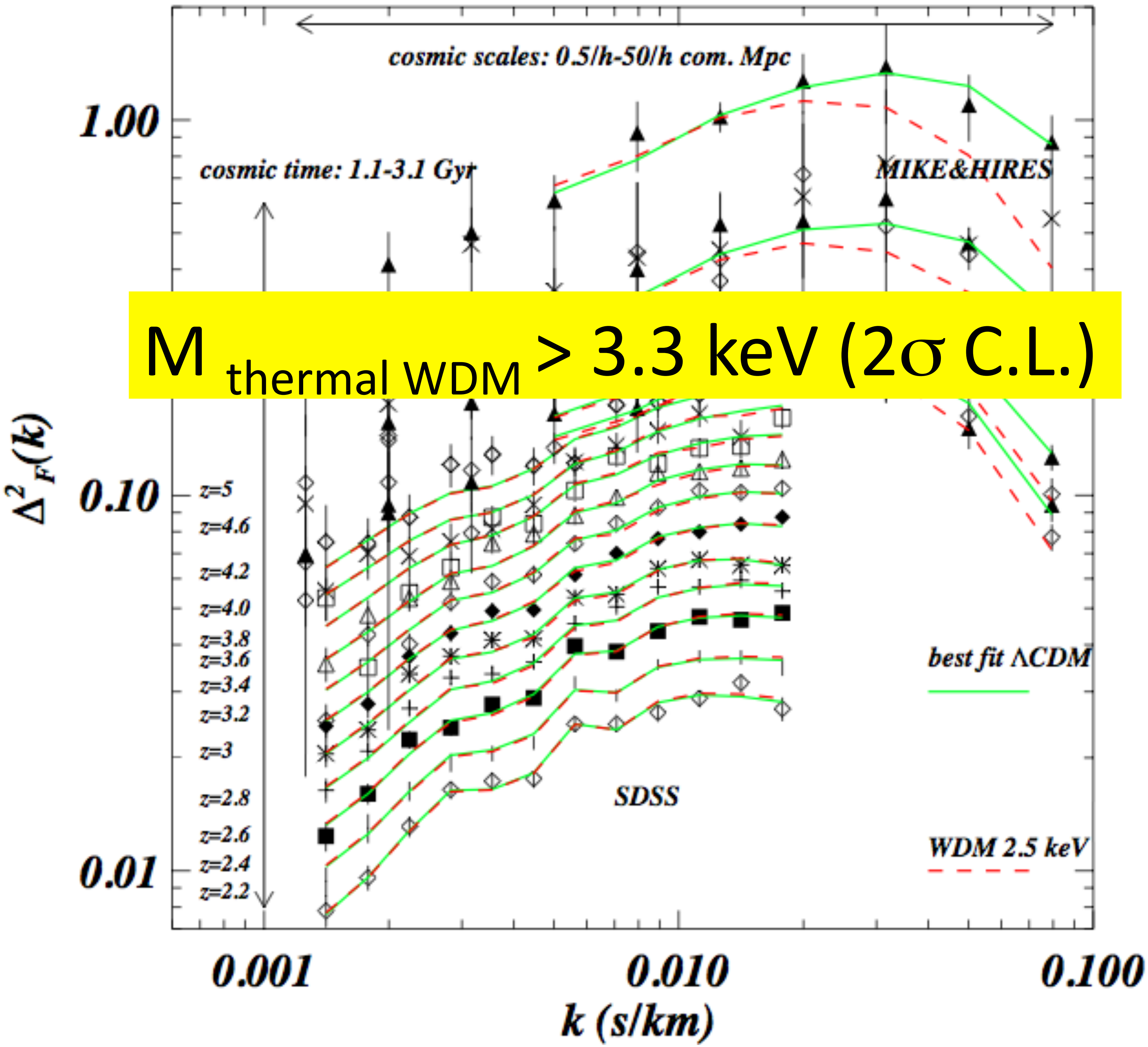


1.00
0.10
0.01
$\Delta^2_F(k)$
MIKE&HIRES
SDSS
0.001
0.010
0.100
k (s/km)



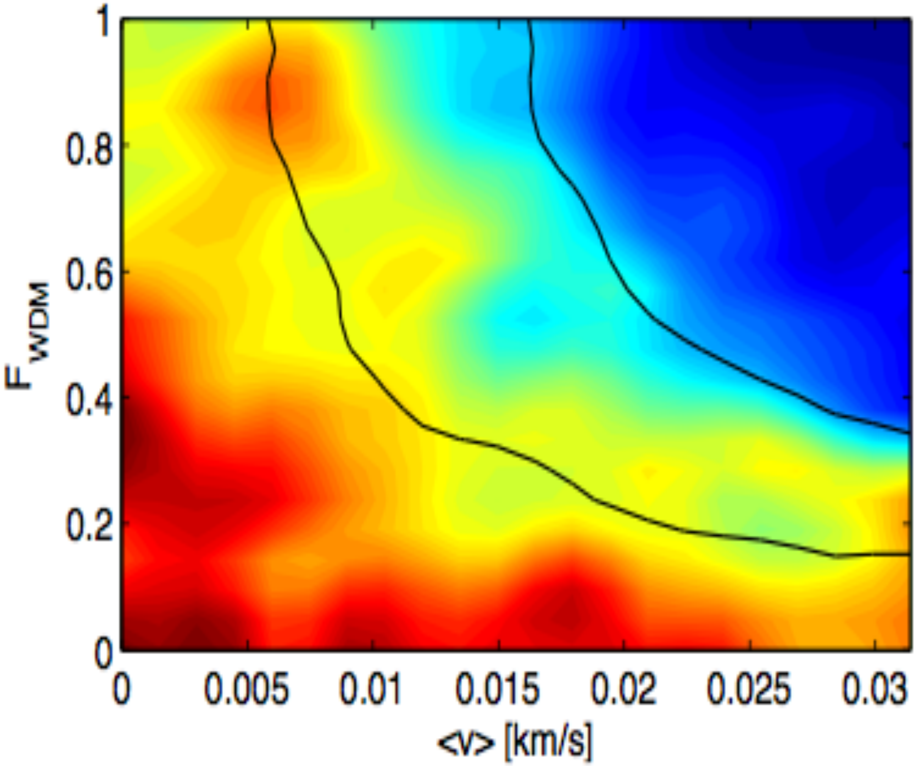
cosmic scales: 0.5/h-50/h com. Mpc
cosmic time: 1.1-3.1 Gyr
MIKE&HIRES
SDSS
z=5.4
z=5
z=4.6
z=4.2
z=4.0
z=3.8
z=3.6
z=3.4
z=3.2
z=3
z=2.8
z=2.6
z=2.4
z=2.2
1.00
0.10
0.01
0.001
0.010
0.100
$\Delta^2_F(k)$
k (s/km)

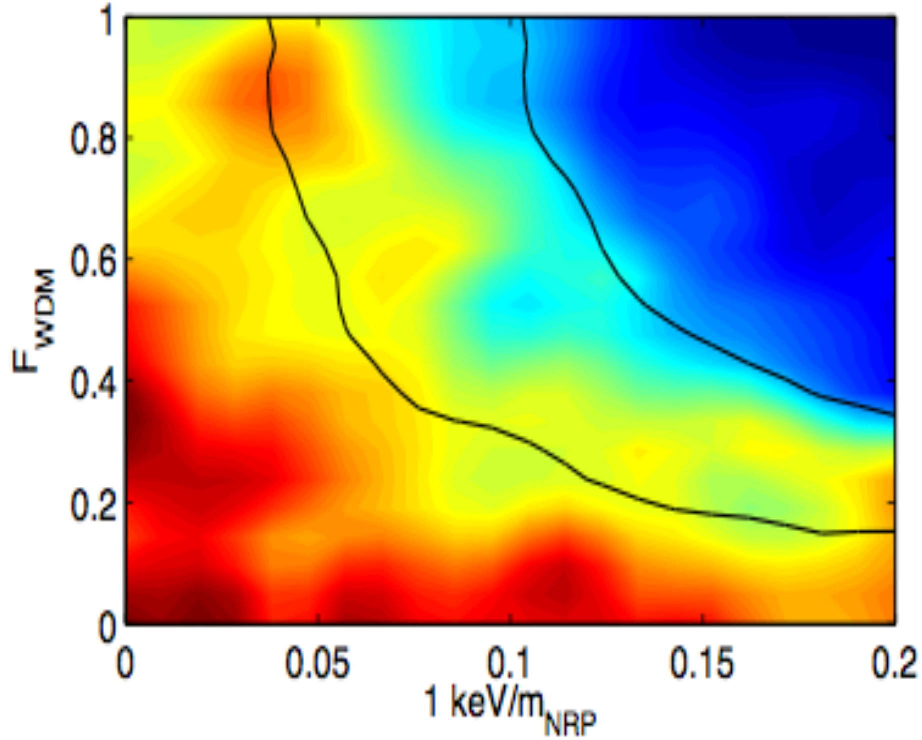

cosmic scales: 0.5/h-50/h com. Mpc
cosmic time: 1.1-3.1 Gyr
MIKE&HIRES
SDSS
best fit ΛCDM
z=5.4
z=5
z=4.6
z=4.2
z=4.0
z=3.8
z=3.6
z=3.4
z=3.2
z=3
z=2.8
z=2.6
z=2.4
z=2.2
1.00
0.10
0.01
0.001
0.010
0.100
Δ²F(k)
k (s/km)



cosmic scales: 0.5/h-50/h com. Mpc
cosmic time: 1.1-3.1 Gyr
MIKE&HIRES
SDSS
best fit ΛCDM
WDM 2.5 keV
z=5
z=4.6
z=4.2
z=4.0
z=3.8
z=3.6
z=3.4
z=3.2
z=3
z=2.8
z=2.6
z=2.4
z=2.2
1.00
0.10
0.01
0.001
0.010
0.100
$\Delta^2_F(k)$
k (s/km)
M thermal WDM > 3.3 keV (2σ C.L.)

<u>**CONSTRAINTS FROM SDSS vs UVES SPECTRA**</u>





m 2keV 1keV

Boyarsky, Ruchayasky, Lesguorgues, Viel, 2009, JCAP, 05, 012

WDM SUPPRESSION in 21cm INTENSITY MAPPING

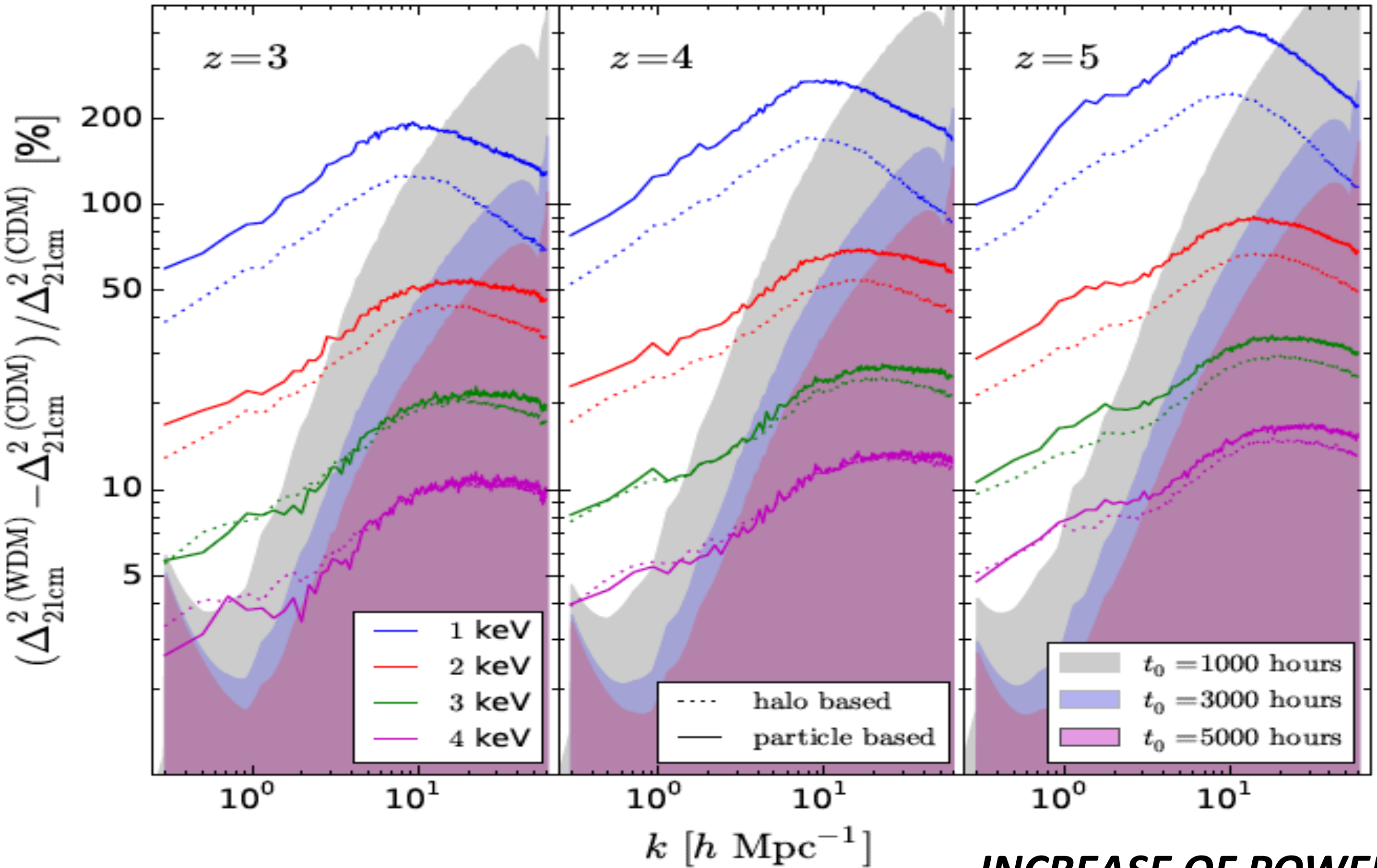
Carucci, Villaescusa, MV, Lapi 2015

$$\overline{\delta T_b}(z) = 23.88\ \bar{x}_{\rm HI}\left(\frac{\Omega_{\rm b}h^2}{0.02}\right)\sqrt{\frac{0.15}{\Omega_{\rm m}h^2}\frac{(1+z)}{10}}\ {\rm mK}$$

$$\delta T_b^s(\nu) = \overline{\delta T_b}(z)\left[\frac{\rho_{\rm HI}(\vec{s})}{\bar{\rho}_{\rm HI}}\right]$$

Contrary to Lyman-alpha forest HI in intensity mapping signal comes from haloes not filaments

REALISTIC SKA forecasts



INCREASE OF POWER!!!

UNDERSTANDING THE ISOTROPIC GAMMA RAY BACKGROUND WITH CROSS-CORRELATION TECHNIQUES

See works by Ackermann+14 from Fermi collaboration
Fornasa, Sanchez-Conde 15
Xia, Cuoco, Branchini, Viel 2011
Ando 14, Ando&Komatsu 13, Ando+14,
Shirasaki+14, Camera+14

IGRB – I: Catalogs and Astrophysical models

TOMOGRAPHY OF THE *FERMI*-LAT γ-RAY DIFFUSE EXTRAGALACTIC SIGNAL VIA CROSS-CORRELATIONS WITH GALAXY CATALOGS

JUN-QING XIA[1,2], ALESSANDRO CUOCO[3,4,5], ENZO BRANCHINI[6,7,8], AND MATTEO VIEL[9,10] ApJS, 2015, 217, 15

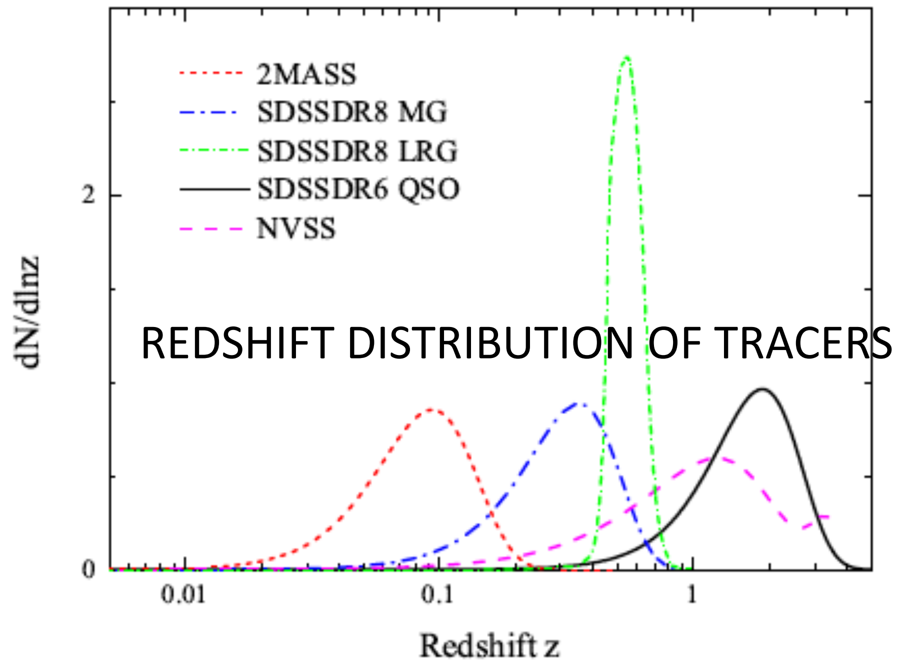
CATALOGS

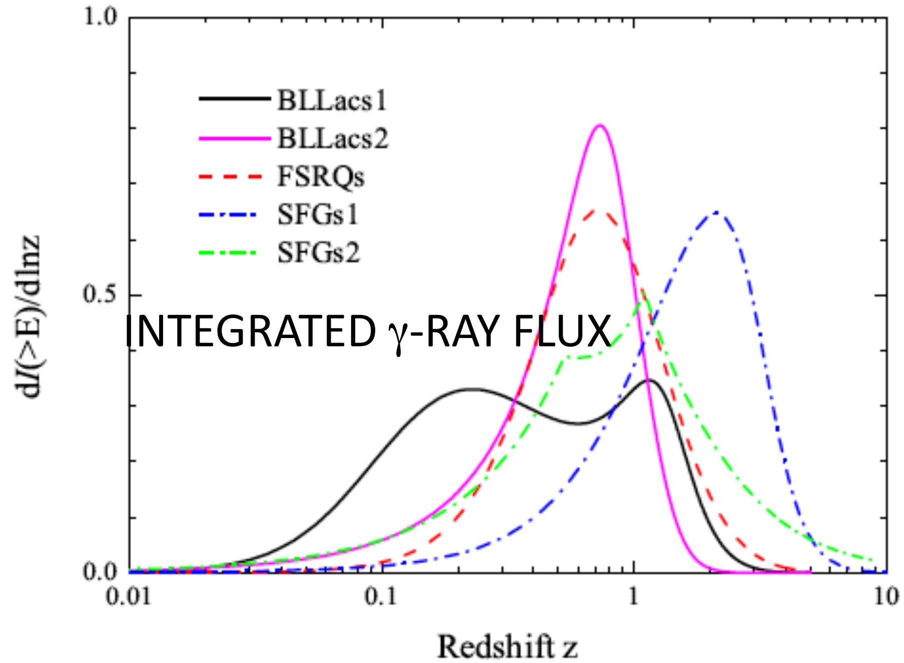
QSOs from SDSS DR6
Main galaxy sample SDSS DR8
Luminous Red Galaxies SDSS DR8
NVSS
2MASS

$$C_l^{I,j} = \frac{2}{\pi}\int k^2 P(k)[G_l^I(k)][G_l^j(k)]dk$$

SOURCES

BLLacs (2 models)
Star Forming Galaxies (2 models)
FSRQs
MAGNs also considered

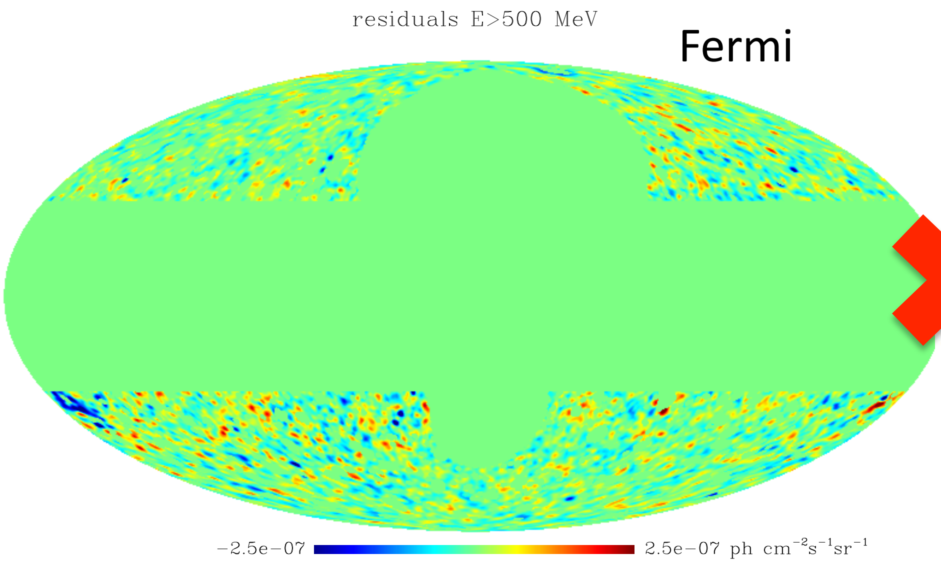


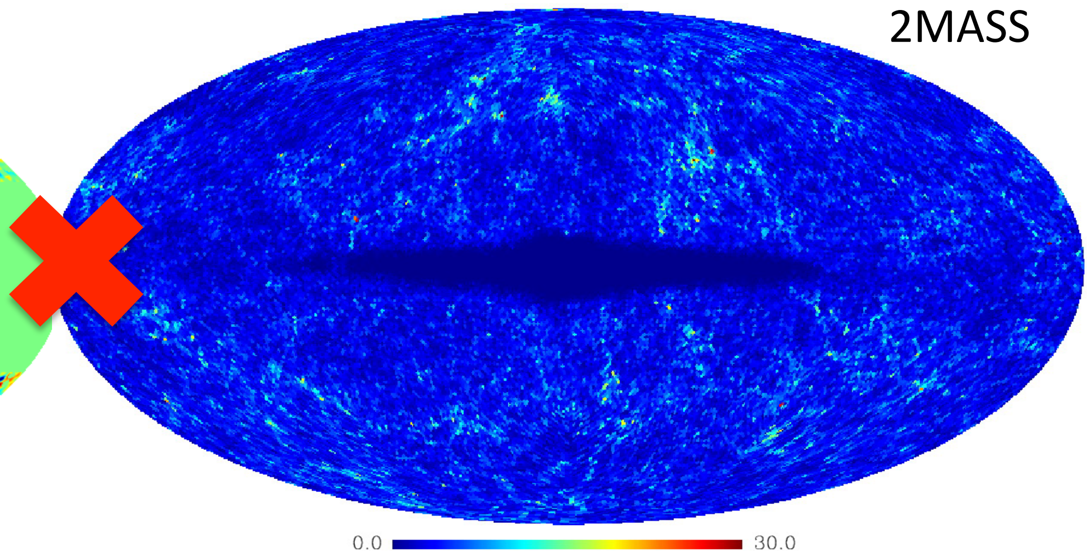


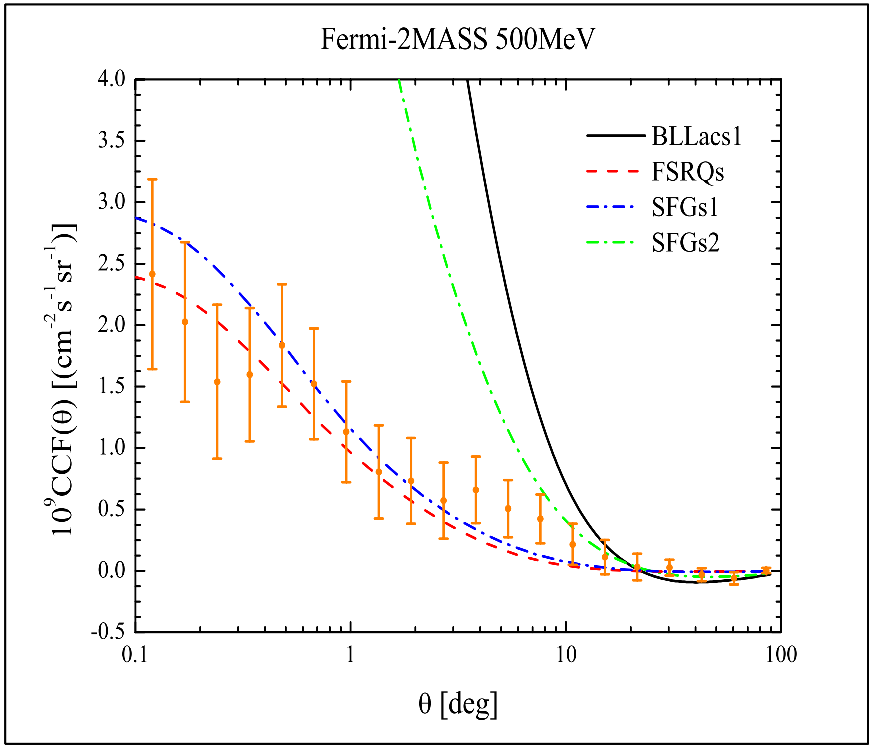
$$G_l^j(k) = \int \frac{dN(z)}{dz} b_j(z) D(z) j_l[k\chi(z)]dz.$$

$$G_l^I(k) = \int \rho_\gamma(z) b_\gamma(z) D(z) j_l[k\chi(z)]dz$$

IGRB – II: results from astro modelling







<u>Cross-correlations detected:</u>

2MASS: 3.5σ for θ<10° all energies

Main Galaxies: > 3σ at E>0.5,1 GeV

LRG: weak cross correlation

QSOs: 2-5σ

NVSS: strong cross corr. but likely to be syst.

<u>Main Result:</u>

Best fit when SFG are the main contributors 72^{+23}_{-37}% - Conclusions not sensitive to bias or dN/dz

BLLac contrib < 5%

FSRQs contrib < 10%

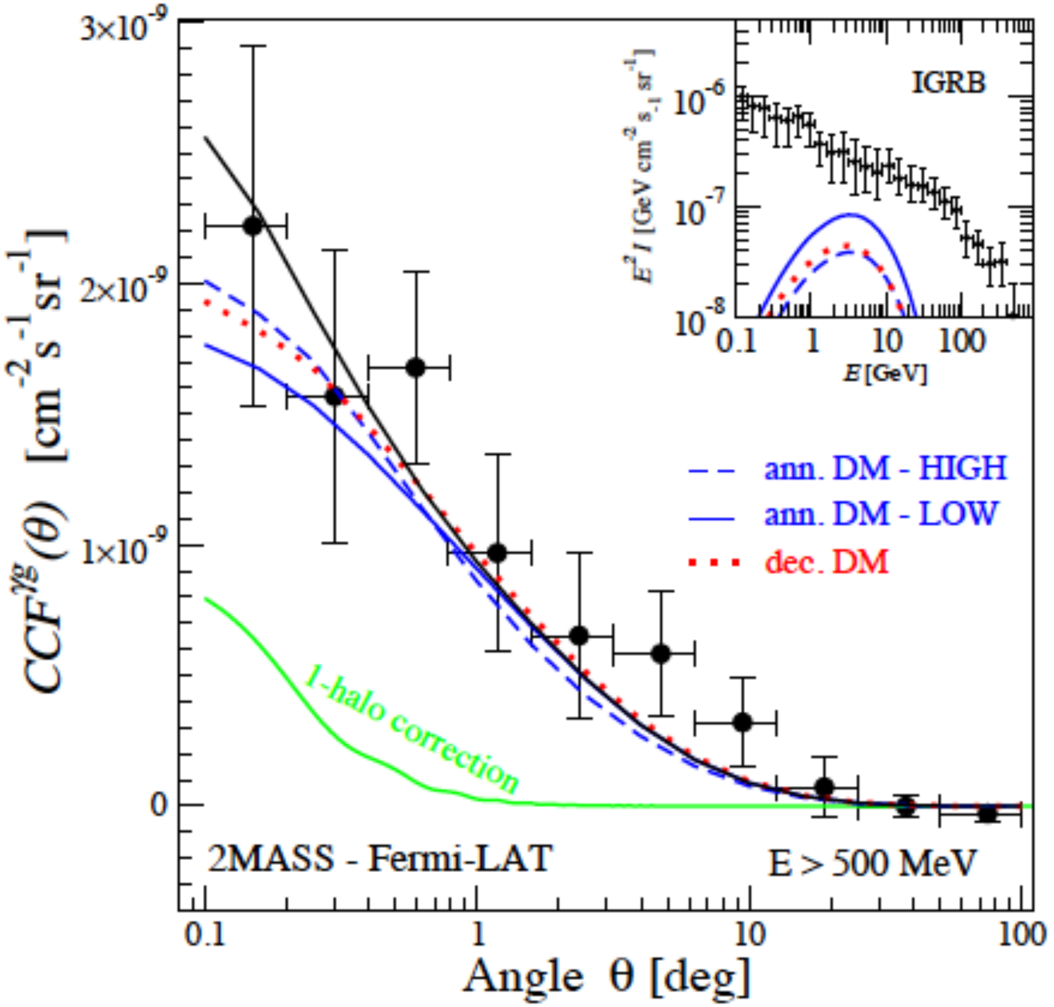
IGRB – III: dark matter contribution

Conservative assumption:
extra contribution due
to dark matter only

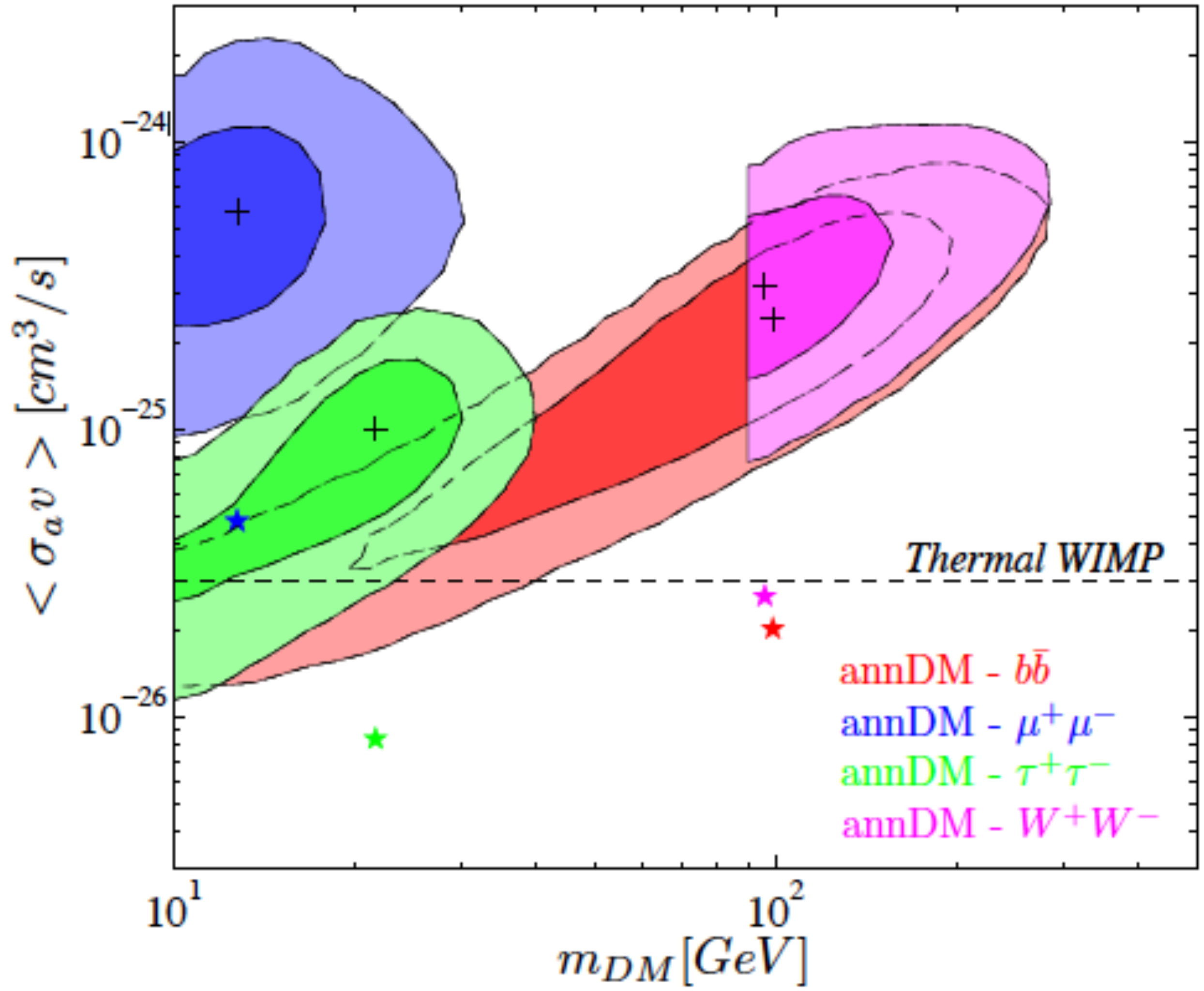
Annhil. $\propto \Omega_{DM}^2 \frac{\langle \sigma v \rangle}{2m_x^2} \int \rho^2(z) D(z) j_l[k\chi(z)] dz$

Decay $\propto \Omega_{DM} \frac{\Gamma_D}{2m_x}$

Regis, Xia, Cuoco, Branchini, Fornengo, MV PRL 2015

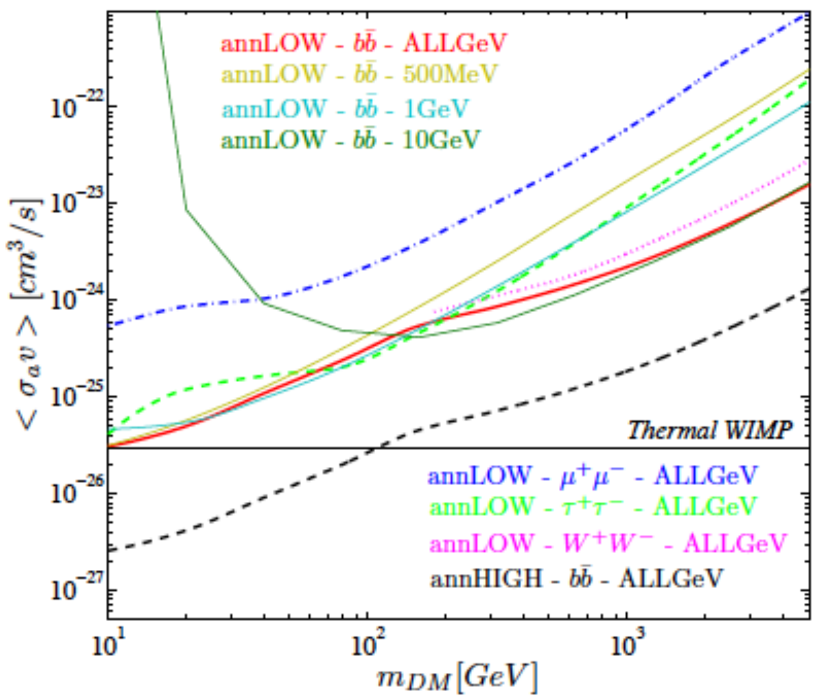


IGRB – IV: dark matter constraints

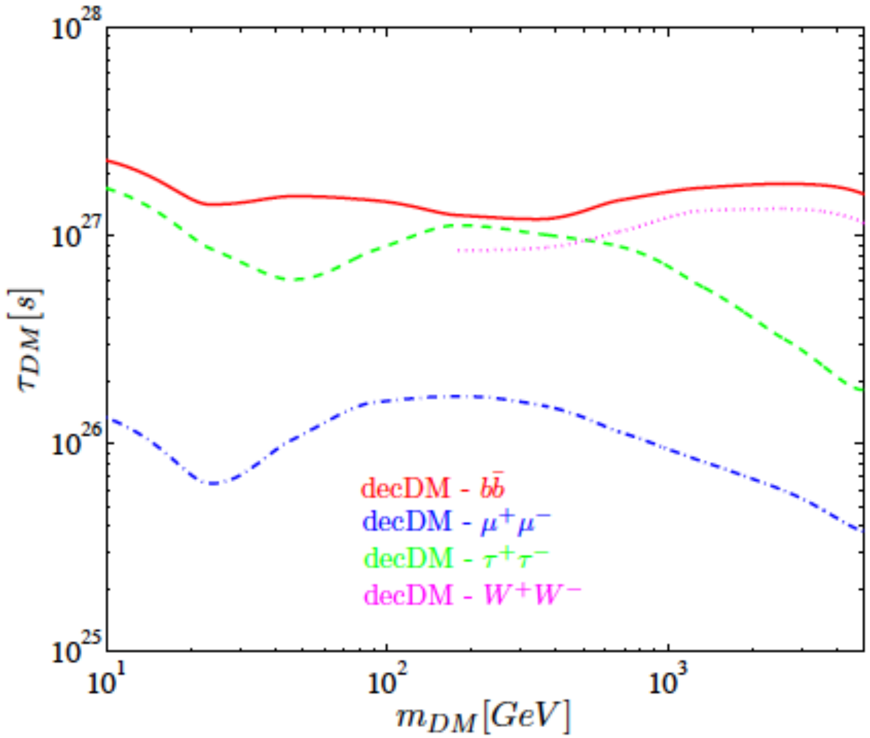


IGRB – IV: dark matter constraints

95% UPPER LIMITS ANNIHILATING DM



95% LOWER LIMITS DECAYING DM



Cross-correlation significantly (>5 times) more constraining than other extragalactic probes like clusters or auto-correlation of the IGRB or IGRB energy spectrum

Adding DM improves the fits

With modest substructure boost thermal WIMP cross sections up to few tens of GeV probed (i.e. ruled out)

CONCLUSIONS

NEUTRINOS:

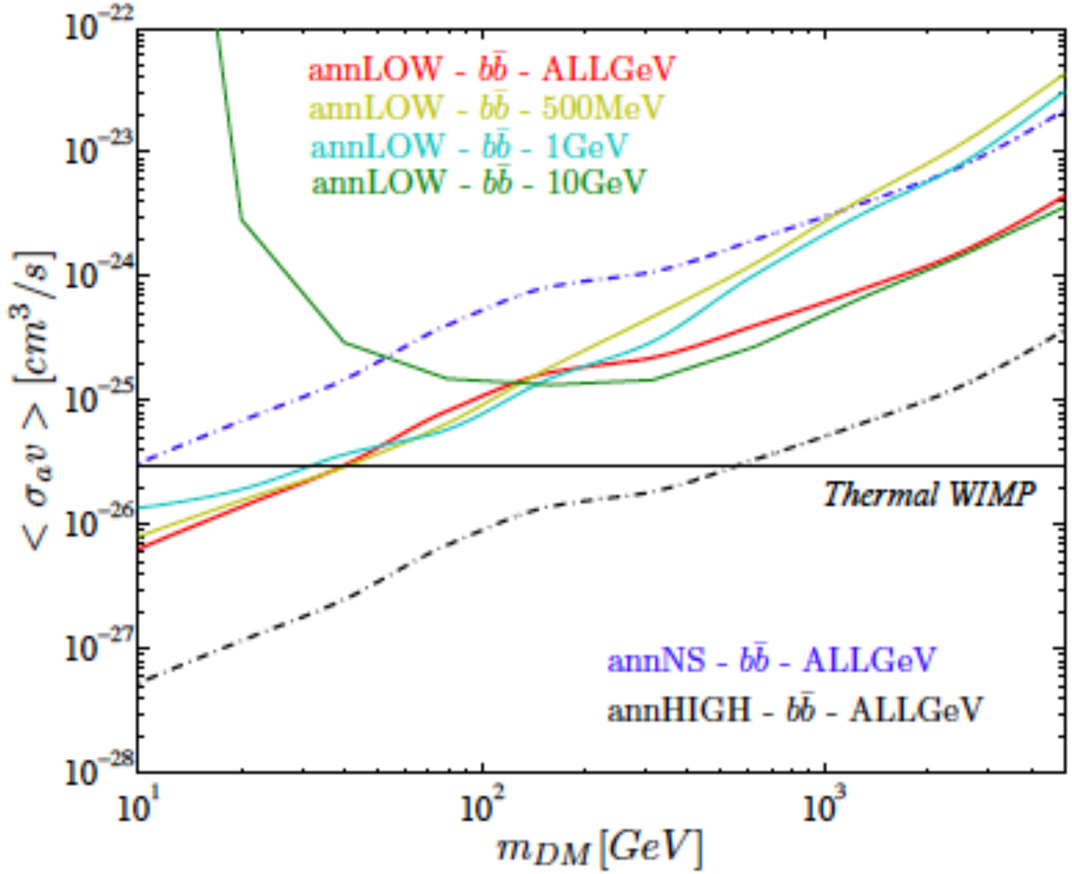
no support for non zero neutrino masses from IGM data total neutrino mass <0.12 eV 2s C.L.

WDM:

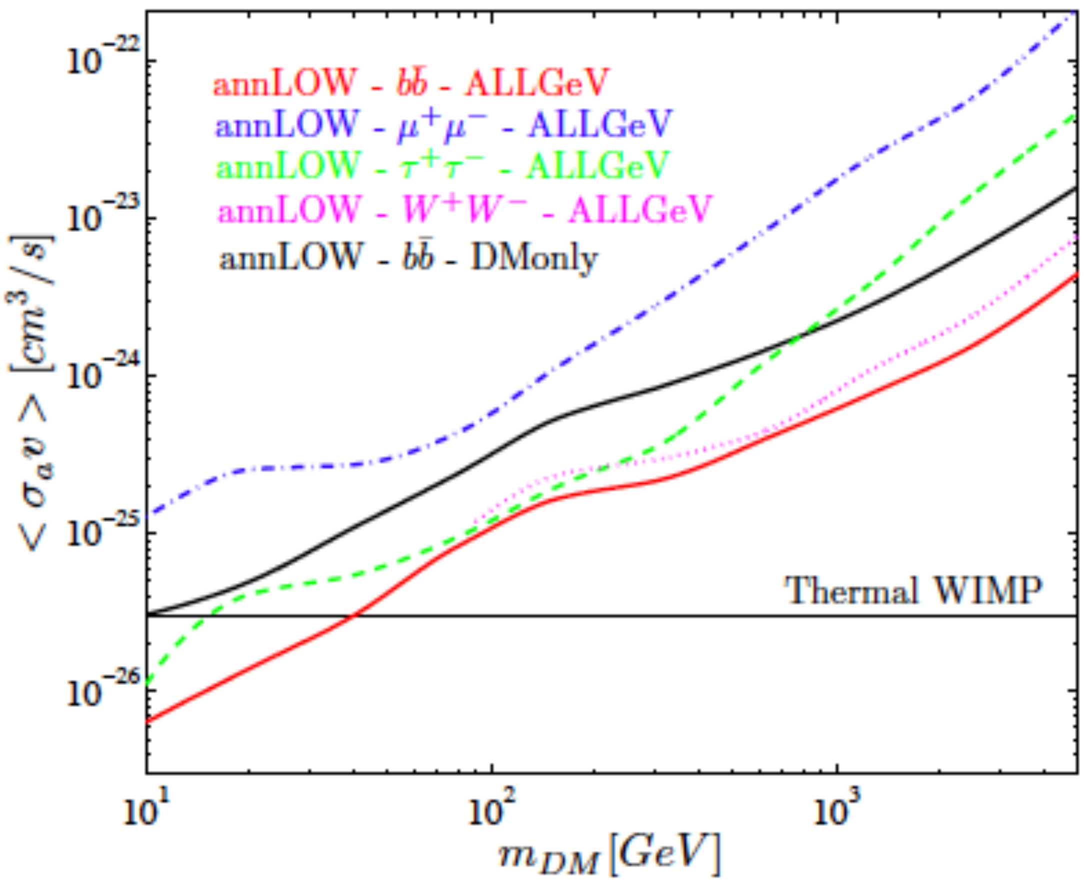
consistency with cold dark matter > 3.3 keV relics 2σ C.L.

IGRB:

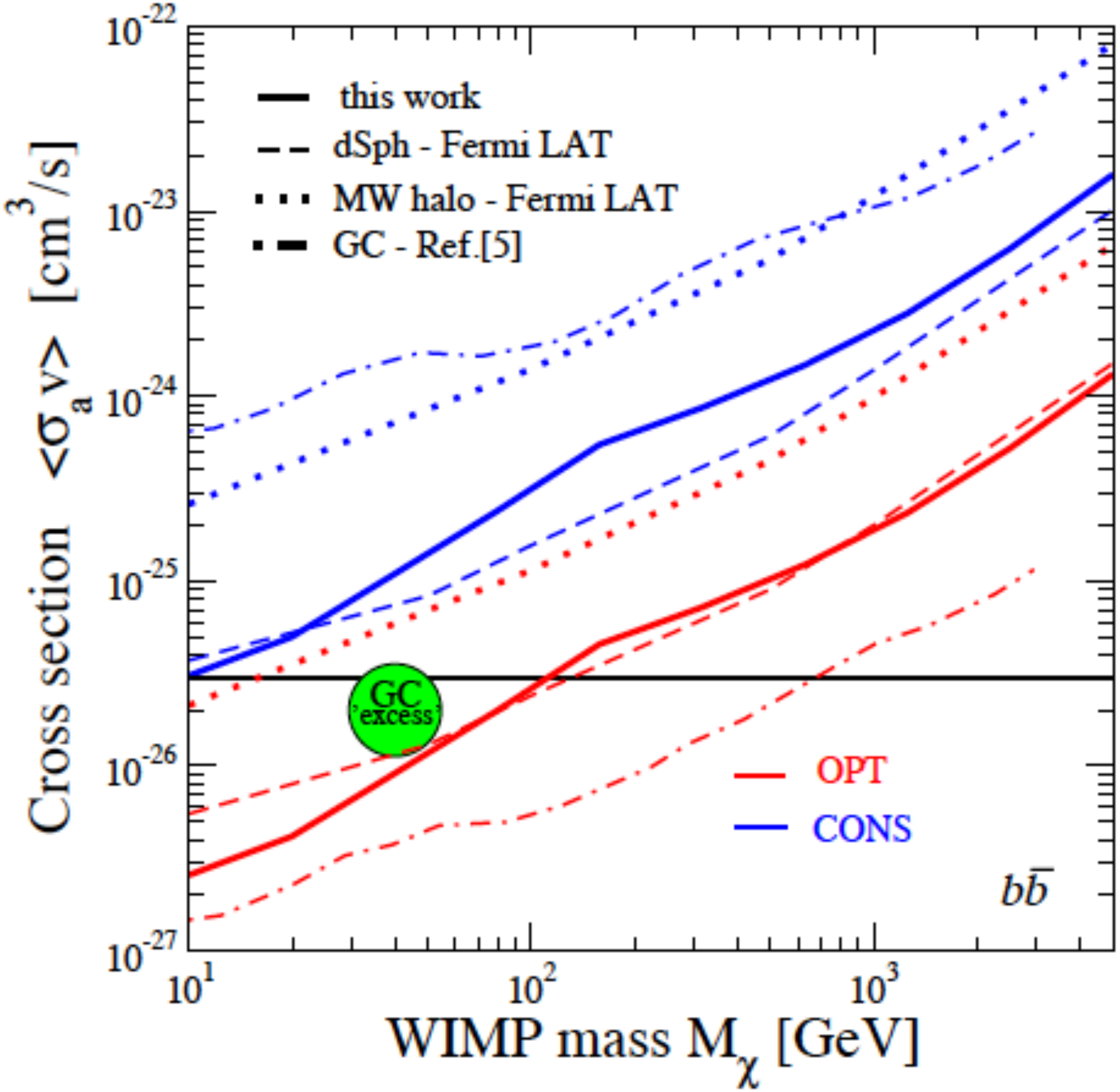
astro+DM modelling that probes thermal cross section



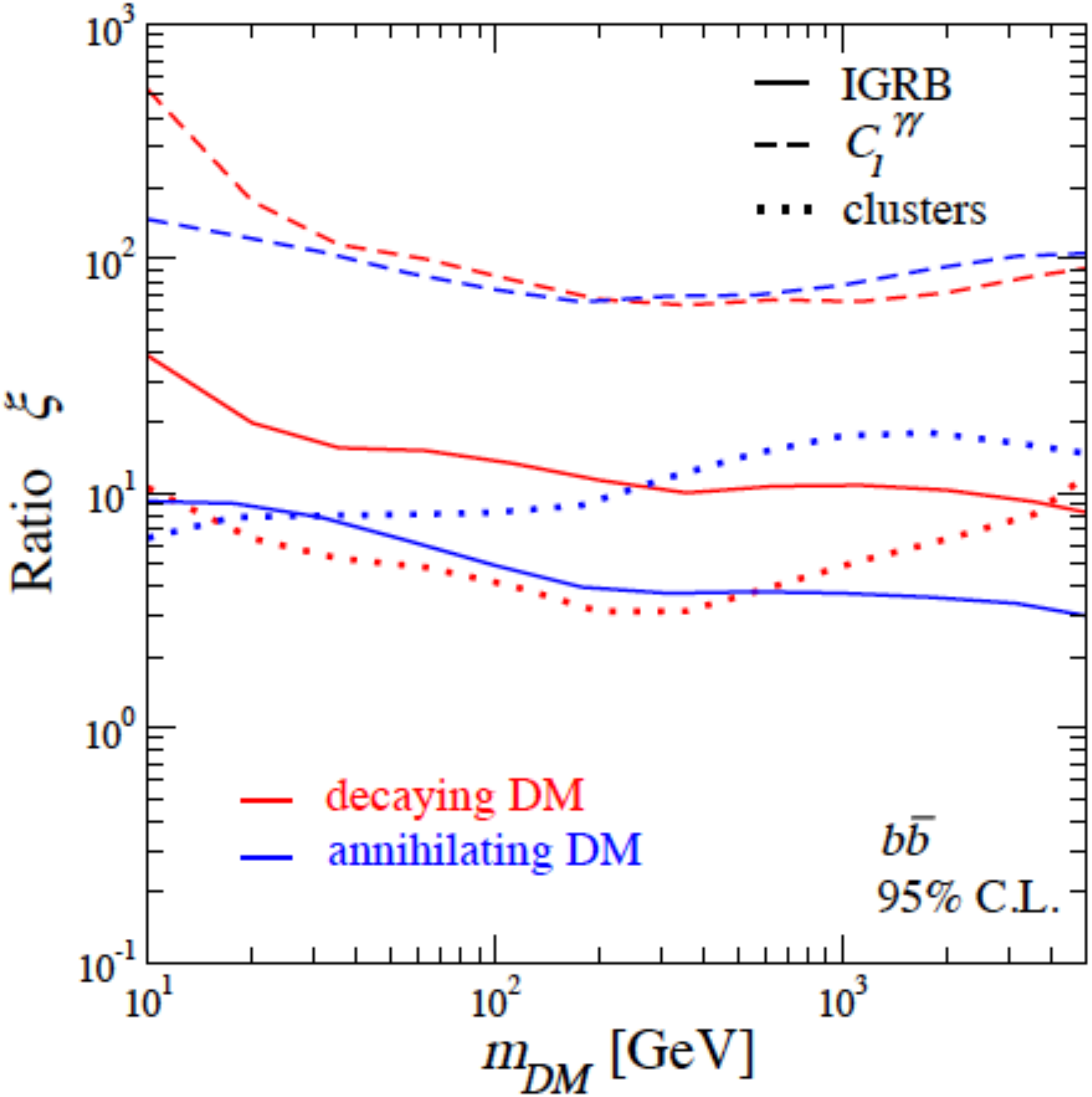
annLOW - $b\bar{b}$ - ALLGeV
annLOW - $b\bar{b}$ - 500MeV
annLOW - $b\bar{b}$ - 1GeV
annLOW - $b\bar{b}$ - 10GeV
Thermal WIMP
annNS - $b\bar{b}$ - ALLGeV
annHIGH - $b\bar{b}$ - ALLGeV
$< \sigma_a v > [cm^3/s]$
$m_{DM} [GeV]$
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^1
10^2
10^3



annLOW - $b\bar{b}$ - ALLGeV
annLOW - $\mu^+\mu^-$ - ALLGeV
annLOW - $\tau^+\tau^-$ - ALLGeV
annLOW - W^+W^- - ALLGeV
annLOW - $b\bar{b}$ - DMonly
Thermal WIMP
$< \sigma_a v > [cm^3/s]$
$m_{DM} [GeV]$



this work
dSph - Fermi LAT
MW halo - Fermi LAT
GC - Ref.[5]
GC 'excess'
OPT
CONS
$b\bar{b}$
Cross section $\langle\sigma_a v\rangle$ [cm^3/s]
WIMP mass M_χ [GeV]
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^1
10^2
10^3



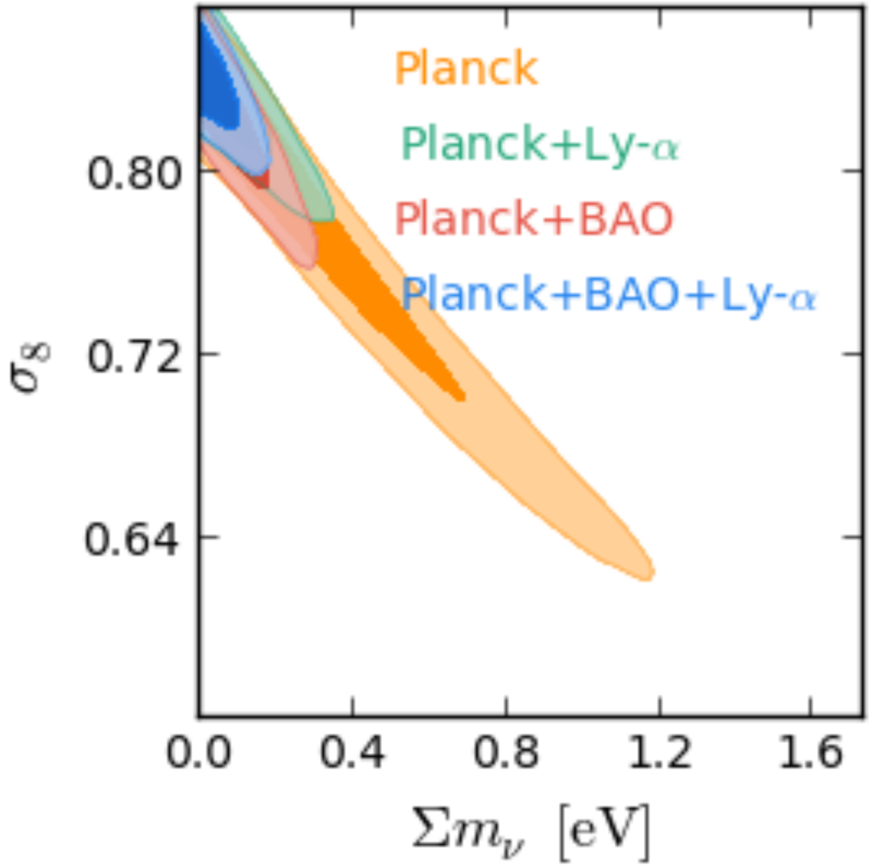
IGRB
$C_l^{\gamma\gamma}$
clusters
decaying DM
annihilating DM
$b\bar{b}$
95% C.L.
Ratio ξ
m_{DM} [GeV]
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

CONSTRAINTS on NEUTRINO MASSES FROM Planck13 + BAO +old Lya

"old Lya" here means 3000 QSO SDSS spectra
from McDonald+04,05, Seljak+06,07

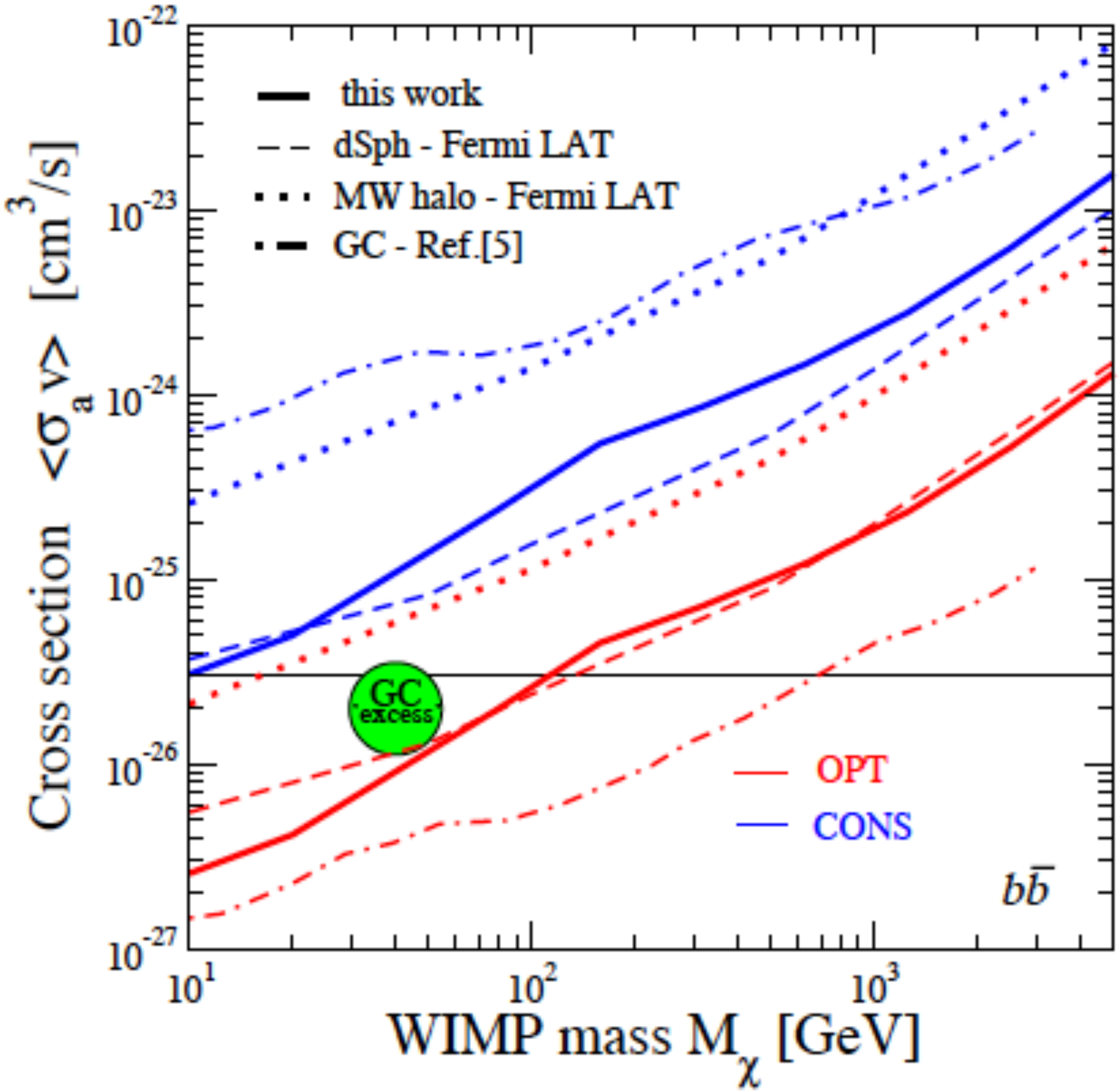
2σ upper limits

Planck:	$M_\nu < 0.93$ eV
Planck+Lya:	$M_\nu < 0.27$ eV
Planck+BAO:	$M_\nu < 0.24$ eV
Planck+BAO+Lyα:	$M_\nu < 0.14$ eV

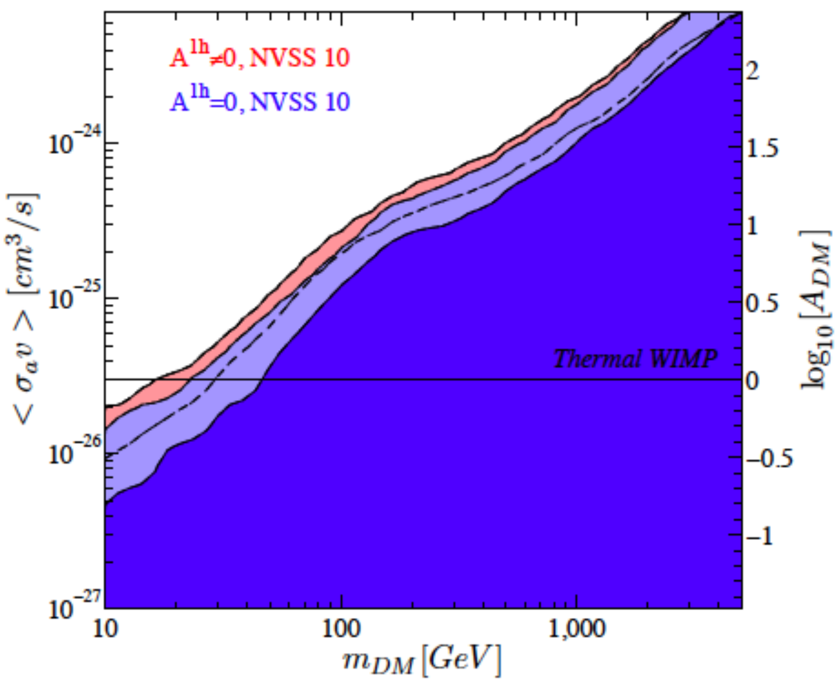


2 eV
29 eV
59 eV
.9 eV

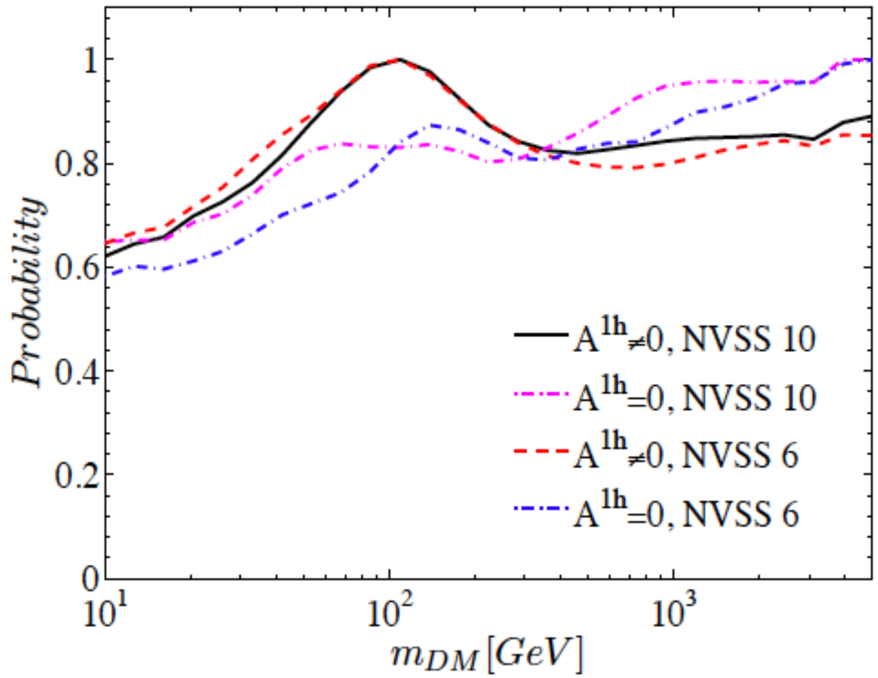
Costanzi, Sartoris, MV, Borgani (2014)



this work
dSph - Fermi LAT
MW halo - Fermi LAT
GC - Ref.[5]
GC excess
OPT
CONS
$b\bar{b}$
Cross section $<\sigma_a v>$ [cm^3/s]
WIMP mass M_χ [GeV]
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^1
10^2
10^3



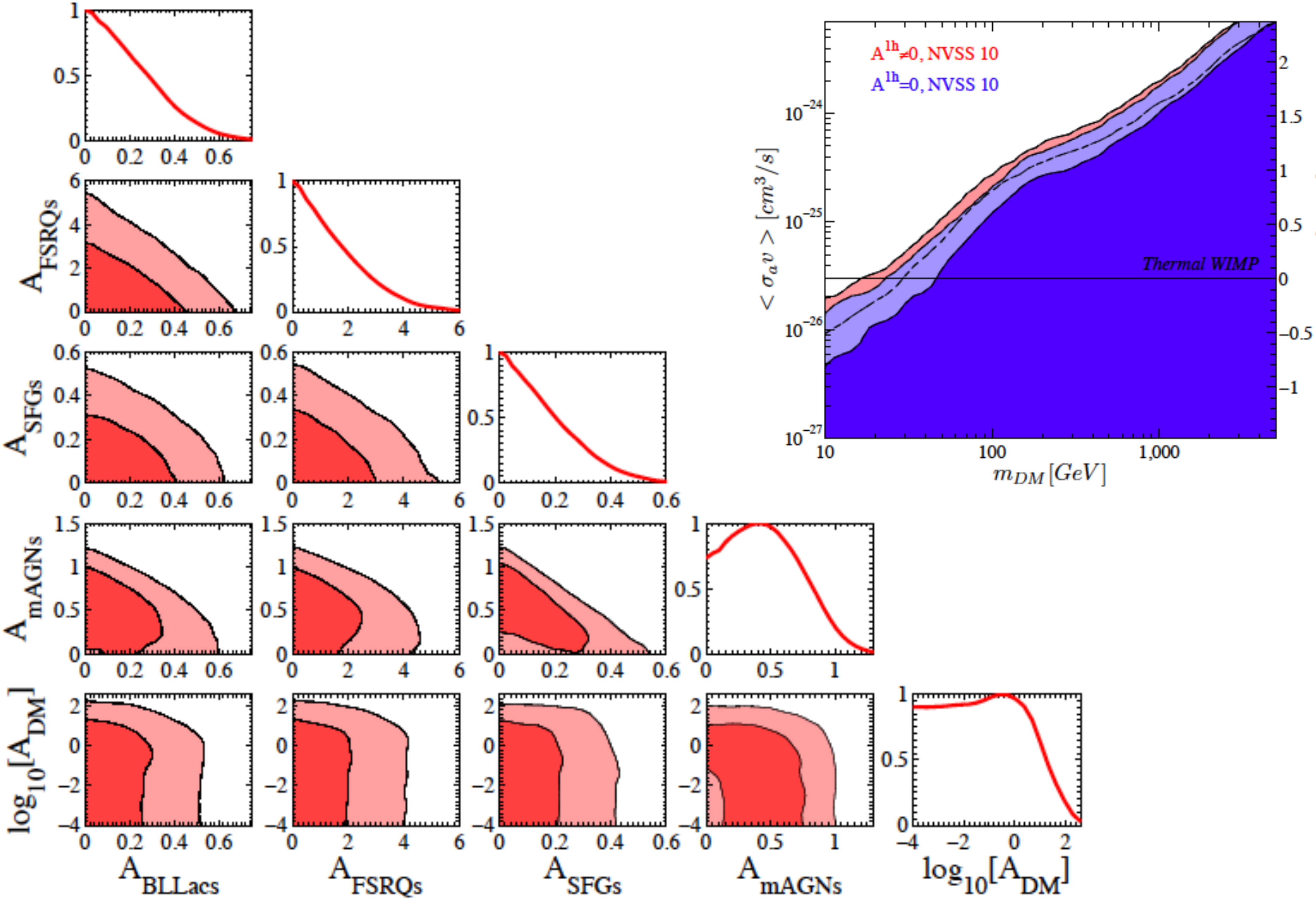
$A^{1h}\neq0$, NVSS 10
$A^{1h}=0$, NVSS 10
Thermal WIMP
$<\sigma_a v>$ $[cm^3/s]$
$\log_{10}[A_{DM}]$
$m_{DM}[GeV]$



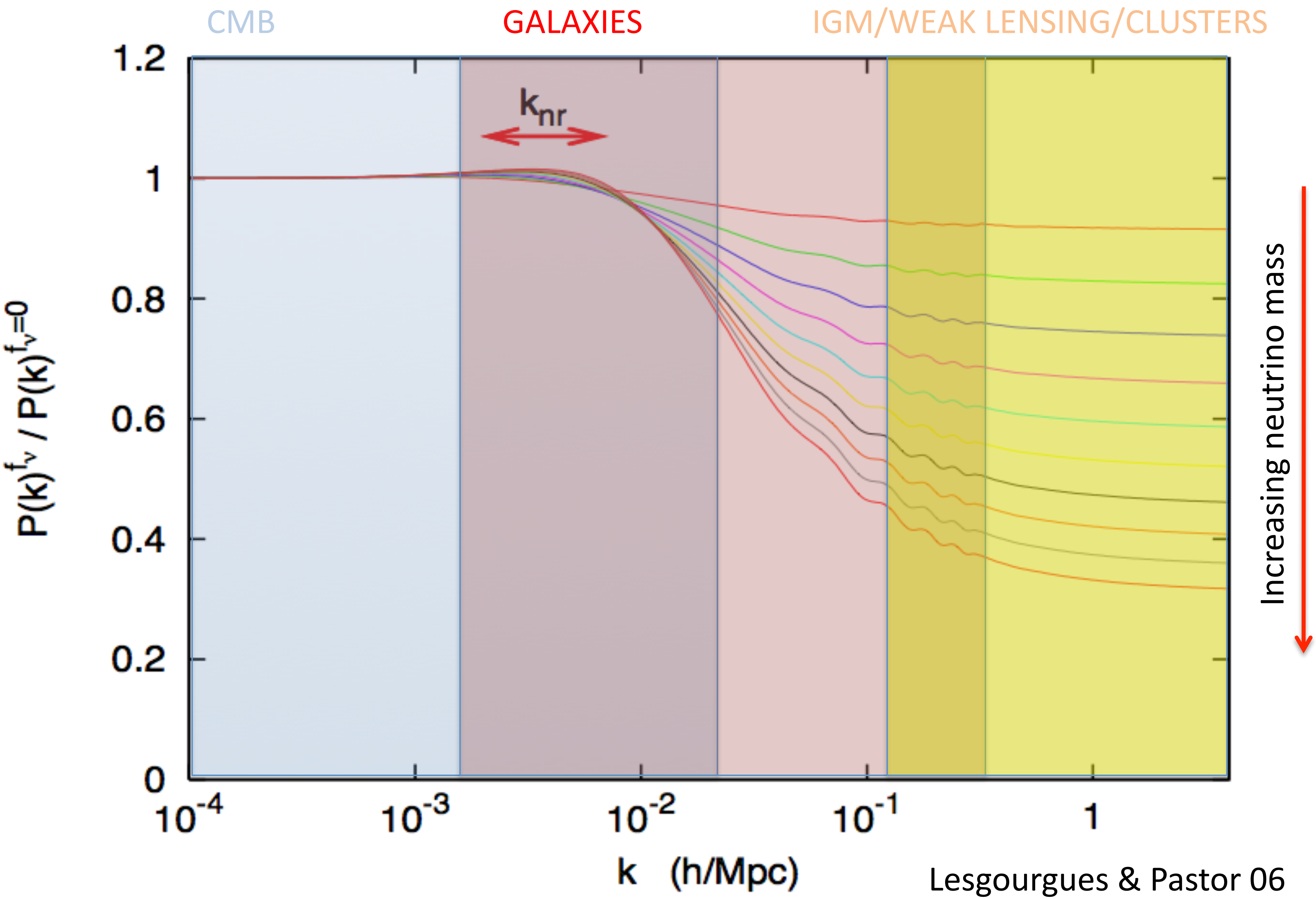
Probability
$m_{DM}[GeV]$
$A^{1h}\neq0$, NVSS 10
$A^{1h}=0$, NVSS 10
$A^{1h}\neq0$, NVSS 6
$A^{1h}=0$, NVSS 6

IGRB – V: dark matter + full astro

Cuoco+ 2015

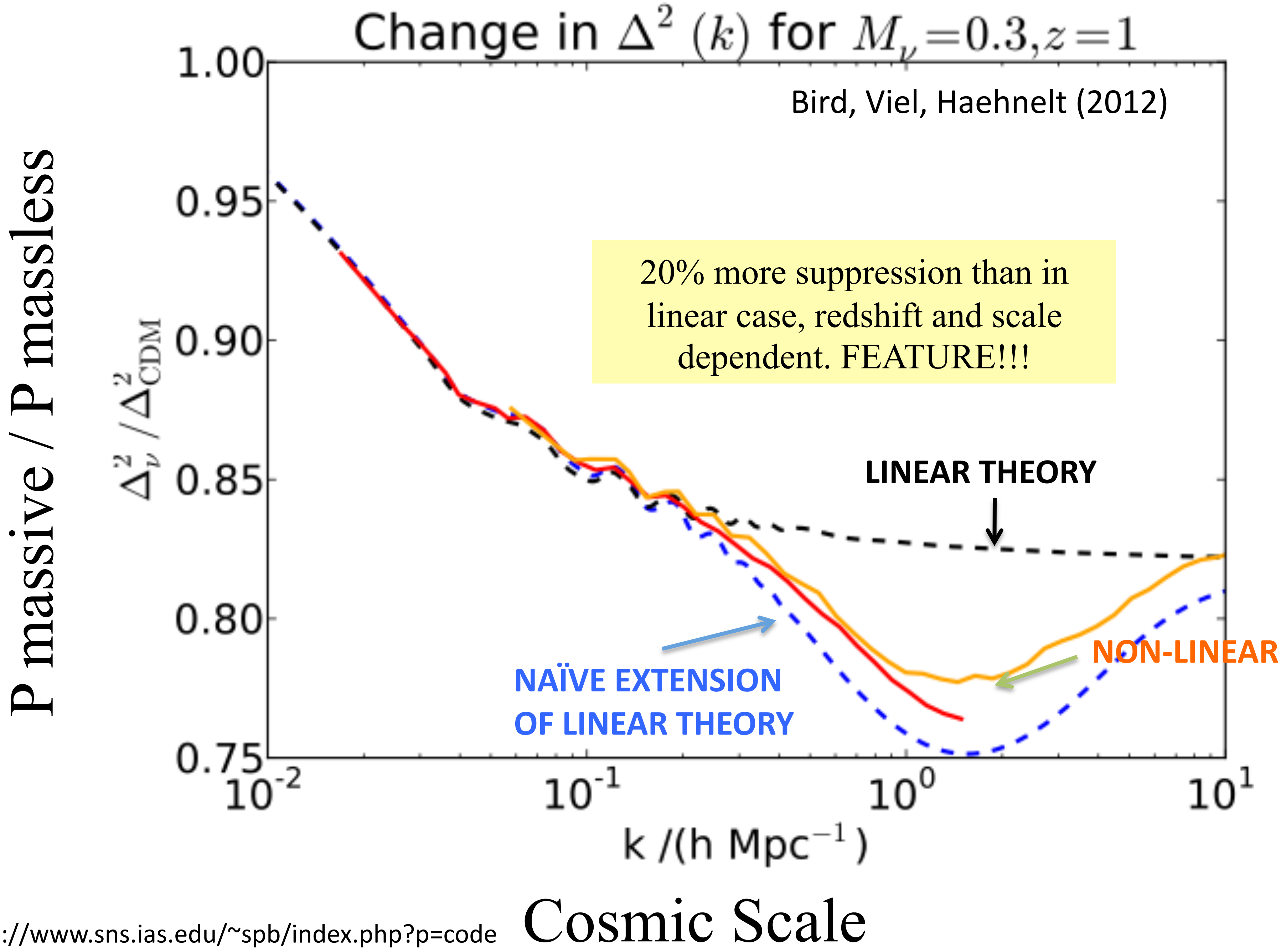


COSMOLOGICAL NEUTRINOS - I: LINEAR MATTER POWER



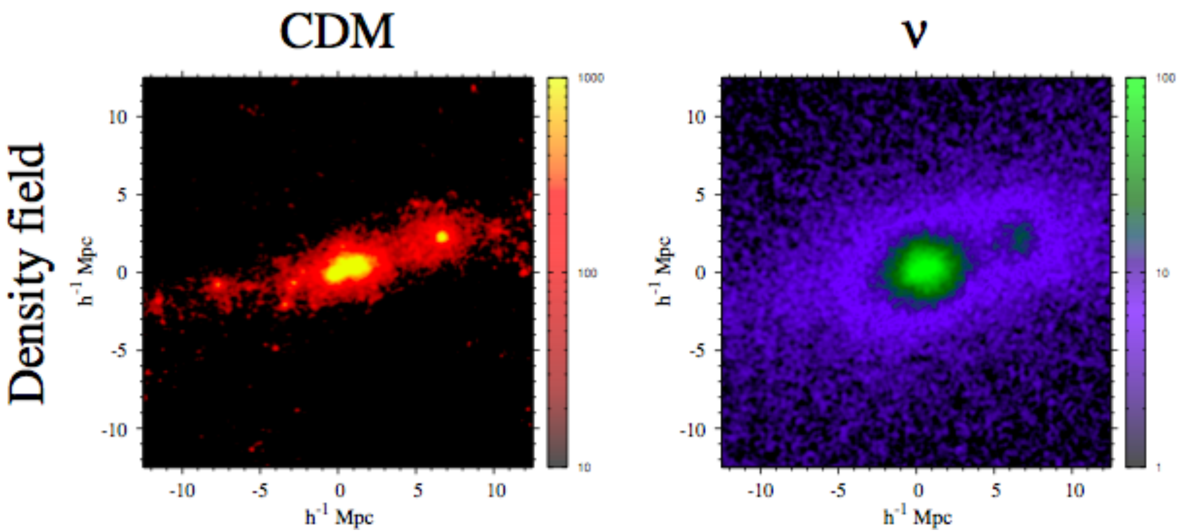
Lesgourgues & Pastor 06

COSMOLOGICAL NEUTRINOS- II: NON-LINEAR MATTER POWER

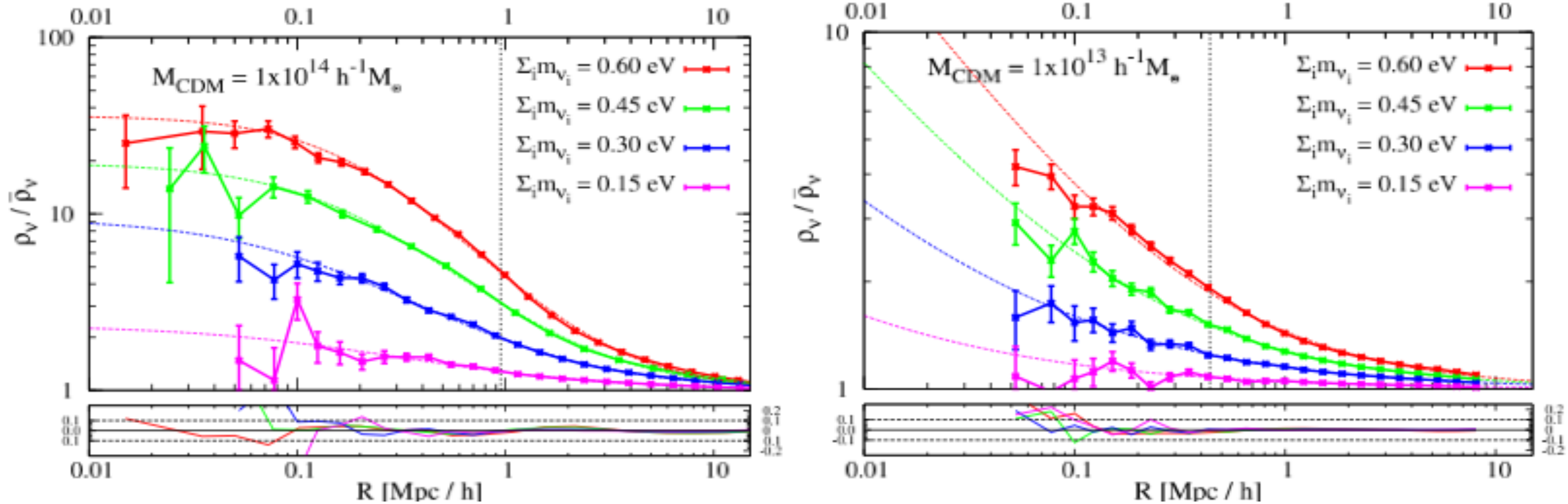


http://www.sns.ias.edu/~spb/index.php?p=code

COSMO NEUTRINOS –III: CHARACTERIZING THE NEUTRINO HALO



$$\delta_\nu(r) = \frac{\rho_\nu(r) - \overline{\rho}_\nu}{\overline{\rho}_\nu} = \frac{\rho_c}{1 + (r/r_c)^\alpha}$$



Villaescusa-Navarro, Bird, Garay, Viel, 2013, JCAP, 03, 019

Marulli, Carbone, Viel+ 2011, MNRAS, 418, 346

COSMO NEUTRINOS – IV: MODELLING NEUTRINOS *WITHOUT* N-BODY SIMS.

$$P(k) = \left(\frac{\bar\rho_c}{\bar\rho}\right)^2 P_c(k) + 2\,\frac{\bar\rho_c\bar\rho_\nu}{\bar\rho^2}\,P_{c\nu}(k) + \left(\frac{\bar\rho_\nu}{\bar\rho}\right)^2 P_\nu(k)$$

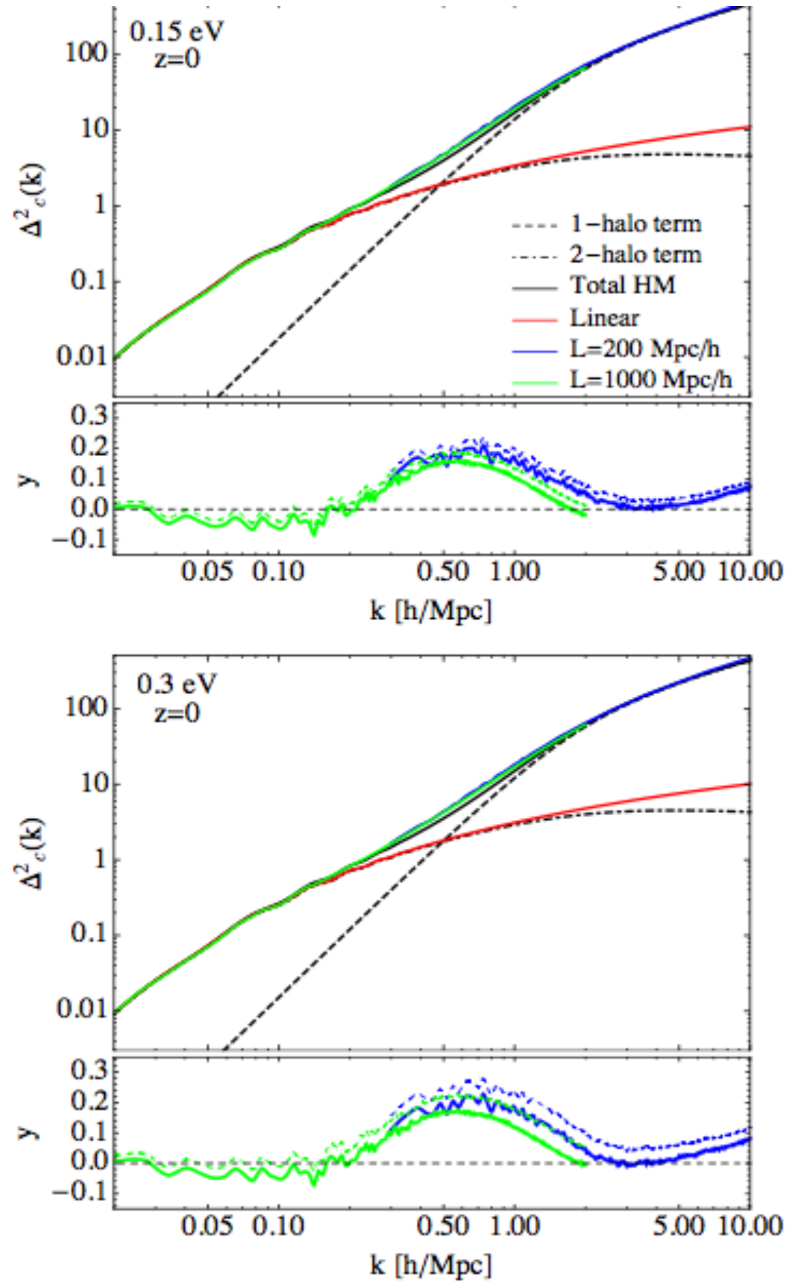
- Assumption: all matter within haloes 1h and 2h terms

- Simple modelling of non-linear power spectra (including cross-spectra)

- When used to predict ratios w.r.t. massless case it is as good as hydro/N-body to 2% level

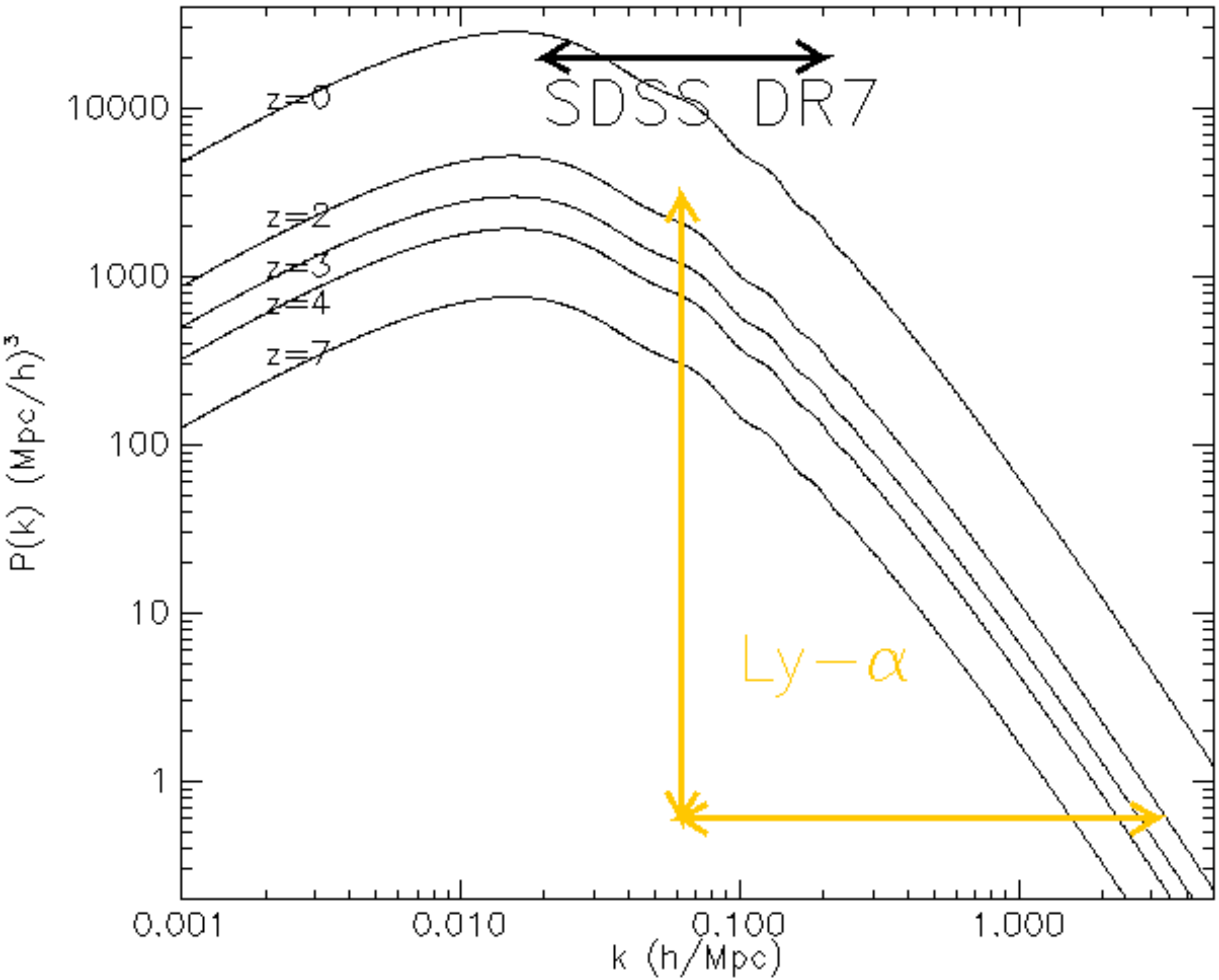
- When used to compute actual power it suffers from limitation and it is good at the 20% level

NON LINEAR POWER SPECTRA



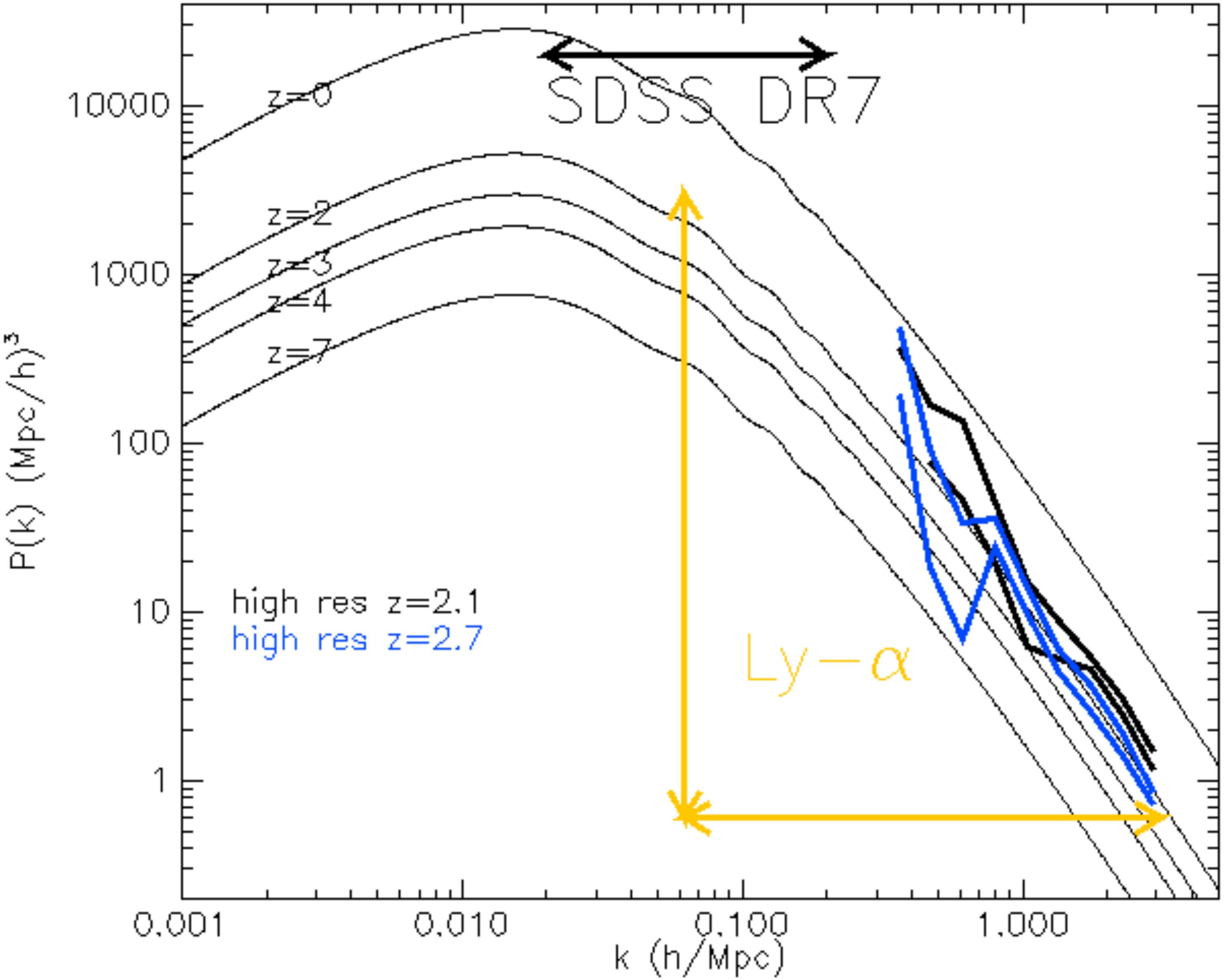
Massara, Villaescusa, MV (2014) – Castorina+ (2014) for bias and mass functions

DATA vs THEORY

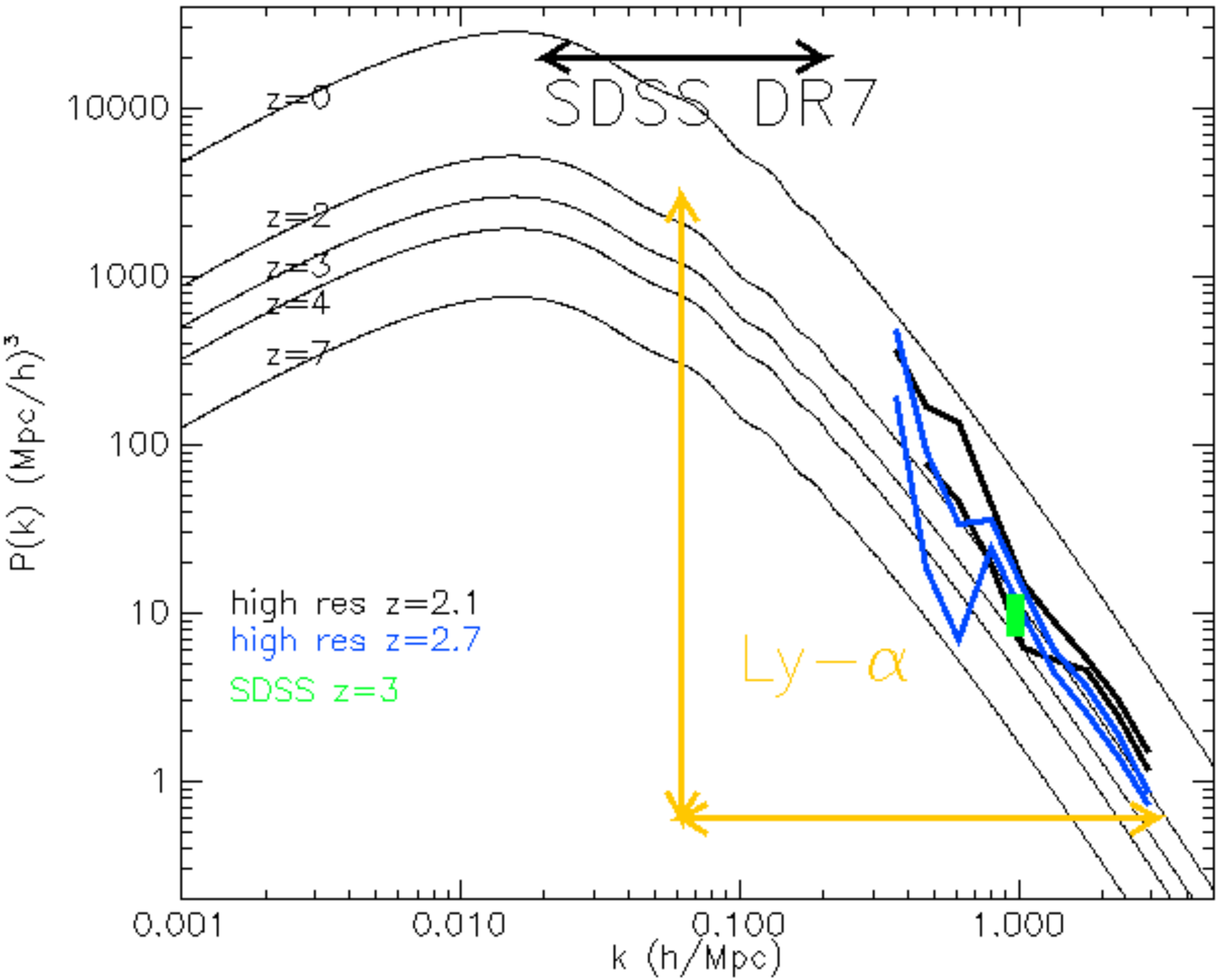


DATA vs THEORY

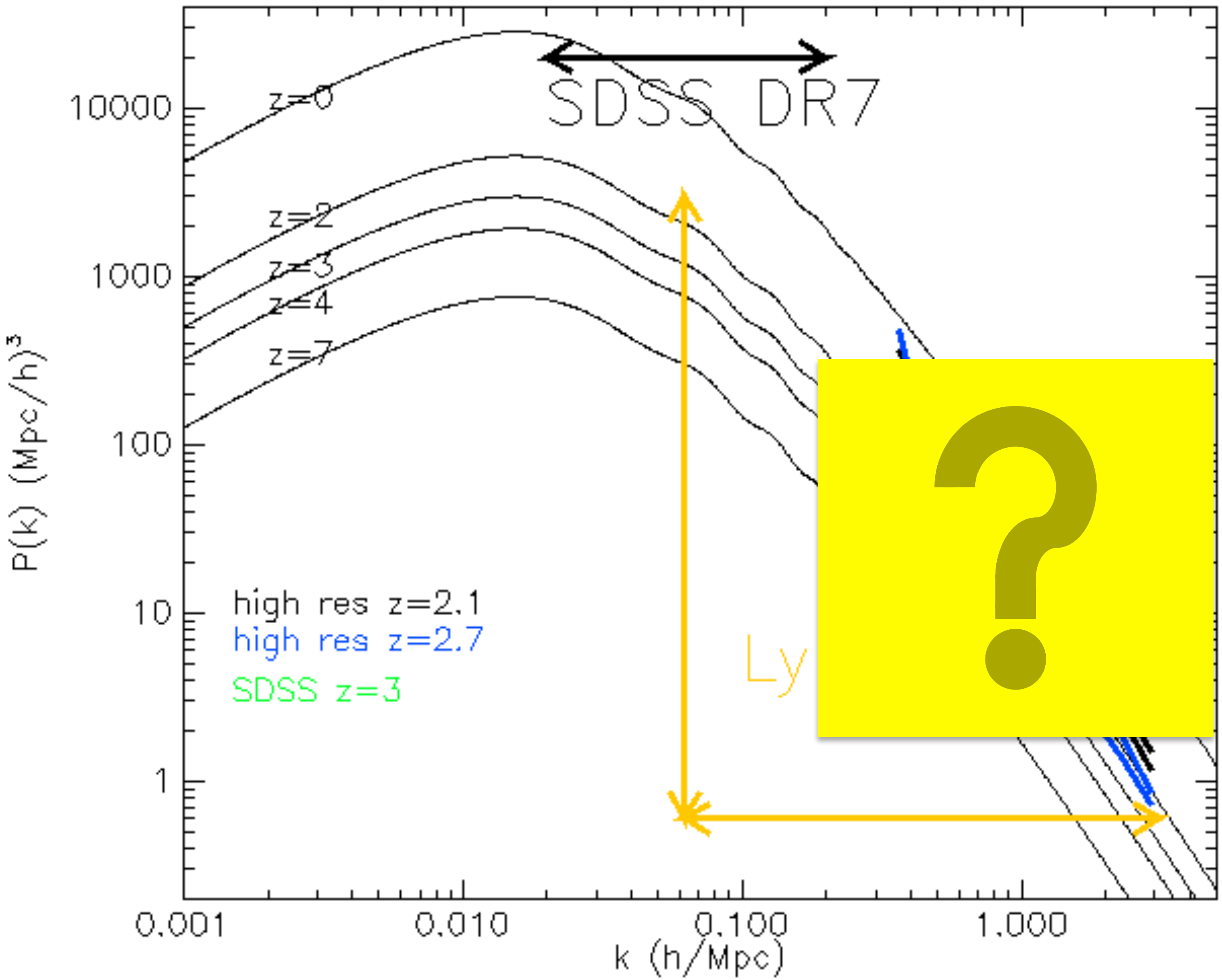
$P_{FLUX}(k,z) = bias^2(k,z) \times P_{MATTER}(k,z)$



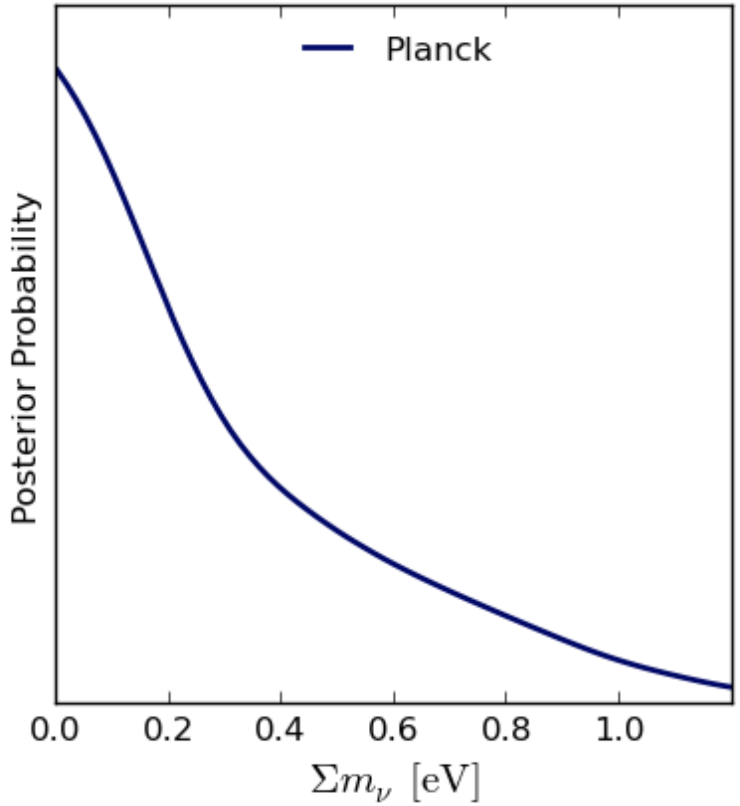
DATA vs THEORY



DATA vs THEORY



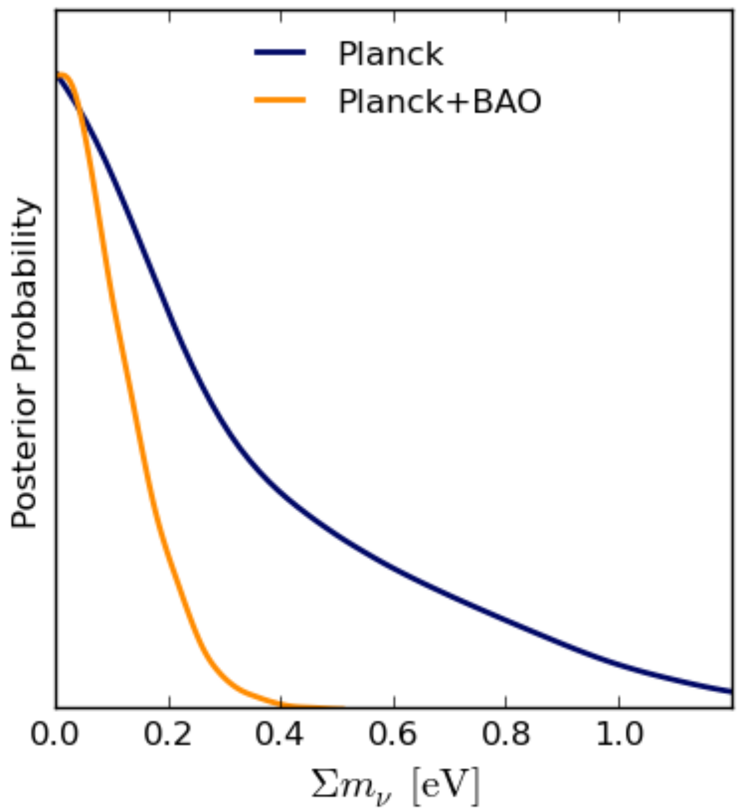
CONSTRAINTS on NEUTRINO MASSES FROM Planck: I



$$\Sigma m_\nu < 0.93 \text{ eV} (2\sigma)$$

Costanzi+ 2014, JCAP

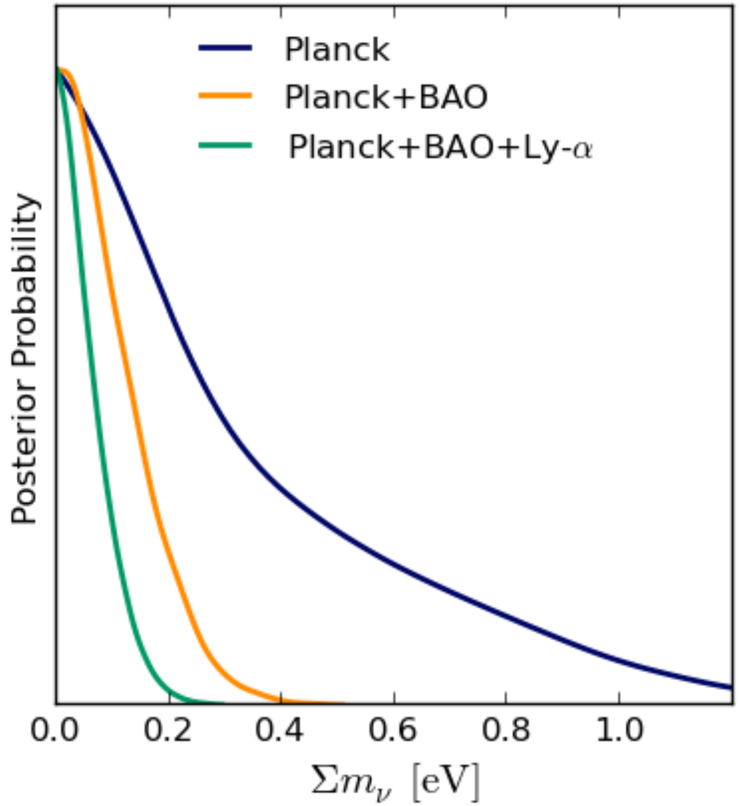
CONSTRAINTS on NEUTRINO MASSES FROM Planck+BAO: II



$$\Sigma m_\nu < 0.24 \text{ eV} (2\sigma)$$

Costanzi+ 2014

CONSTRAINTS on NEUTRINO MASSES FROM Planck+BAO+old Lya: III



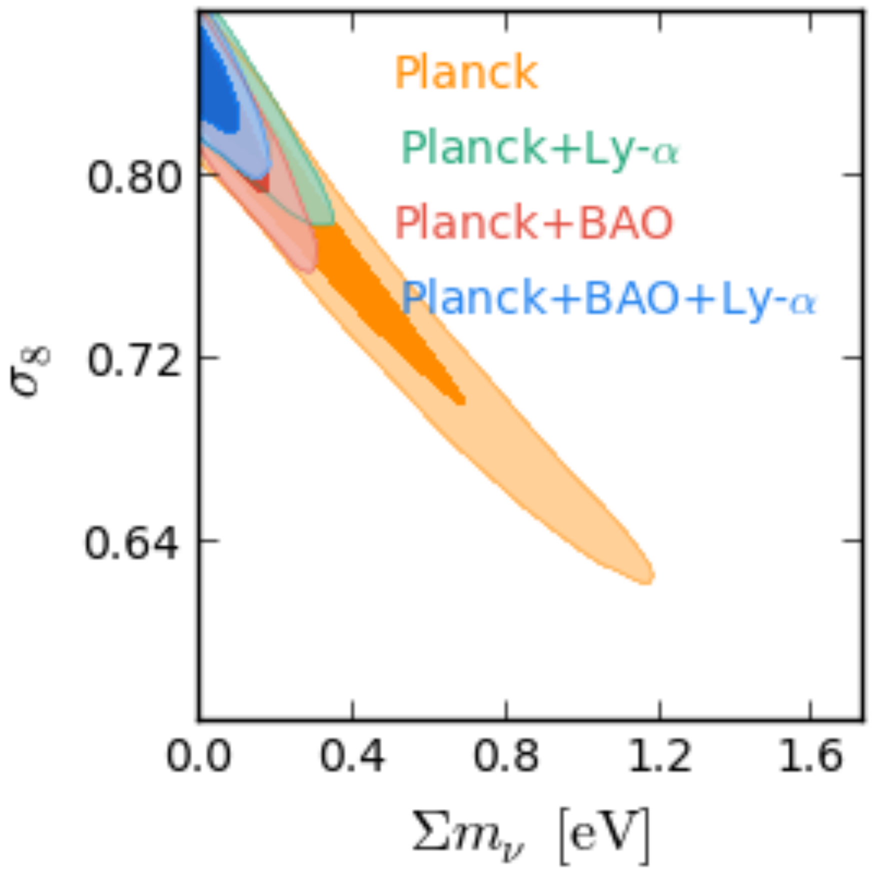
$$\Sigma m_{\nu} < 0.14 \text{ eV} (2\sigma)$$

Costanzi+ 2014

CONSTRAINTS on NEUTRINO MASSES FROM Planck+BAO+old Lya: IV

2σ upper limits

Planck:	$M_\nu < 0.93$ eV
Planck+Lya:	$M_\nu < 0.27$ eV
Planck+BAO:	$M_\nu < 0.24$ eV
Planck+BAO+Lyα:	$M_\nu < 0.14$ eV



2 eV
29 eV
59 eV
.9 eV

Costanzi, Sartoris, MV, Borgani (2014)

GRID OF HYDRODYNAMICAL SIMULATIONS

Cosmological Parameters

Astrophysical Parameter

Neutrino mass

Parameter	Central value	Range
n_s	0.96	± 0.05
σ_8	0.83	± 0.05
Ω_m	0.31	± 0.05
H_0	67.5	± 5
$T_0(z=3)$	14000	± 7000
$\gamma(z=3)$. .	1.3	± 0.3
A^τ	0.0025	± 0.0020
η^τ	3.7	± 0.4
$\sum m_\nu$ (eV)	0.0	0.4, 0.8

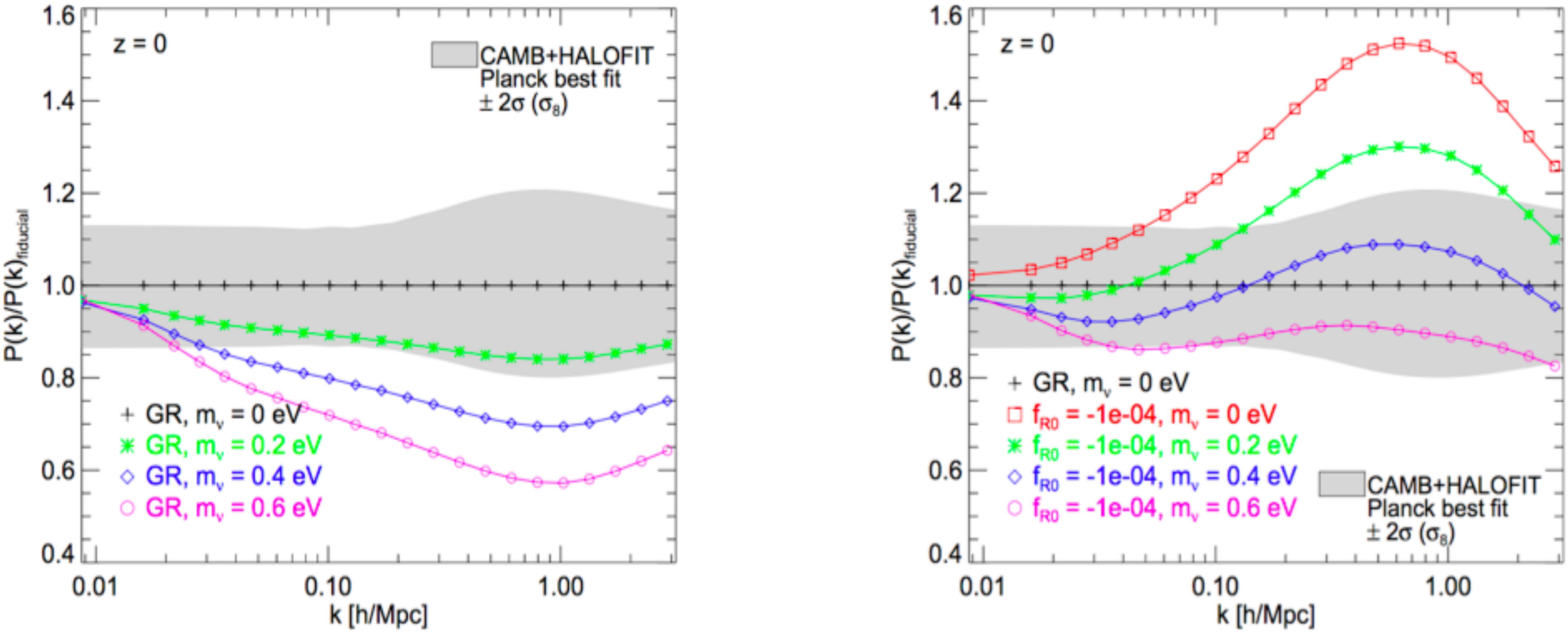
Astrophysics usually has a different redshift evolution compared to cosmology!

If my data cover a relatively wide redshift range then I can break the degeneracies

FINAL NUMBERS

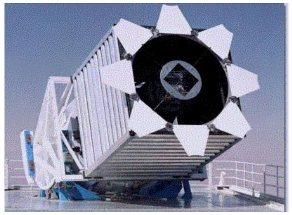
Parameter	Lyα + H_0^{tophat} ($62.5 \leq H_0 < 72.5$)	Lyα + CMB	Lyα + CMB + BAO	Lyα + CMB(A_L)
$10^9 A_s$	$3.2^{+0.5}_{-0.7}$	$2.20^{+0.05}_{-0.06}$	$2.20^{+0.05}_{-0.06}$	$2.18^{+0.05}_{-0.06}$
$10^2 \omega_b$	(fixed to 2.22)	2.20 ± 0.02	2.20 ± 0.02	2.22 ± 0.03
ω_{cdm}	$0.110^{+0.008}_{-0.013}$	$0.1200^{+0.0019}_{-0.0018}$	$0.1196^{+0.0015}_{-0.0014}$	0.1191 ± 0.002
τ_{reio}	(irrelevant)	$0.091^{+0.012}_{-0.013}$	$0.091^{+0.011}_{-0.013}$	$0.0871^{+0.012}_{-0.013}$
n_s	0.931 ± 0.012	0.953 ± 0.005	0.953 ± 0.005	$0.955^{+0.005}_{-0.006}$
H_0	< 70.9 (95%)	$67.2^{+0.8}_{-0.9}$	67.4 ± 0.7	$67.5^{+1.0}_{-1.1}$
$\sum m_\nu$ (eV)	< 0.98 (95%)	< 0.16 (95%)	< 0.14 (95%)	< 0.21 (95%)
A_L	(fixed to 1)	(fixed to 1)	(fixed to 1)	1.12 ± 0.10
σ_8	0.84 ± 0.03	$0.830^{+0.017}_{-0.013}$	$0.830^{+0.016}_{-0.012}$	$0.818^{+0.021}_{-0.014}$
Ω_m	$0.316^{+0.018}_{-0.021}$	0.316 ± 0.012	0.313 ± 0.009	0.312 ± 0.013

Cosmic Conspiracies?

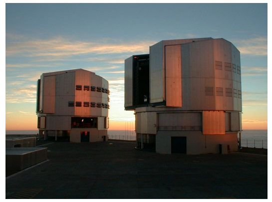


Baldi, Villaescusa-Navarro, Viel, Puchwein, Springel, Moscardini, 2014

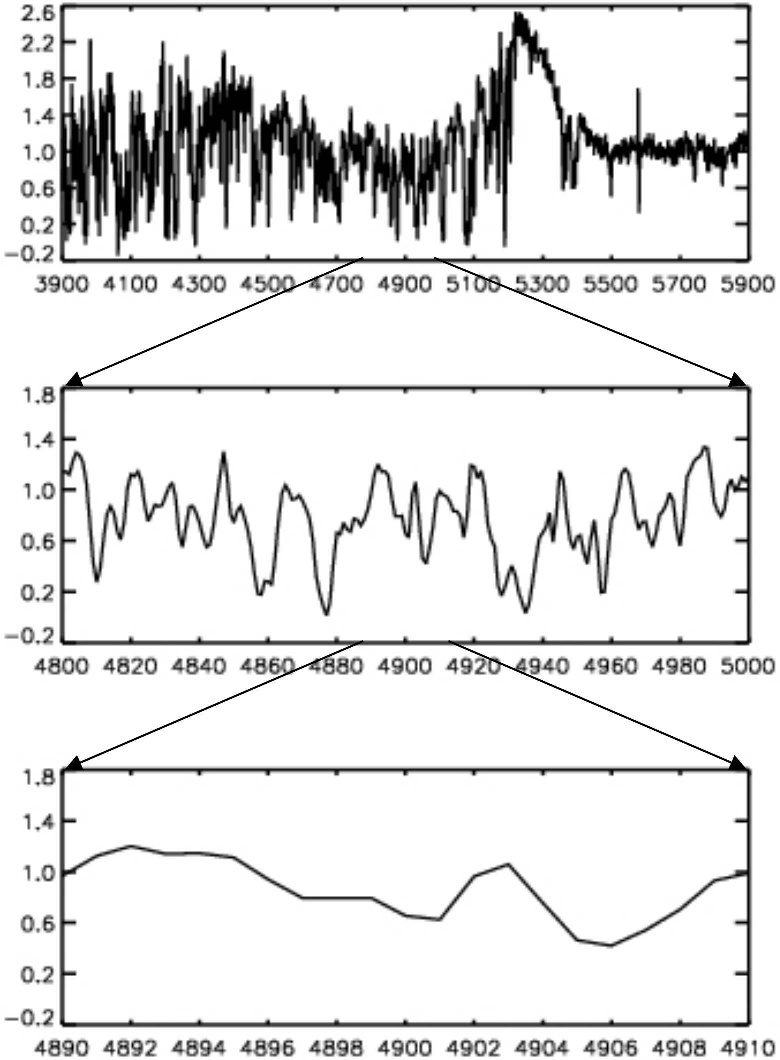
The data sets



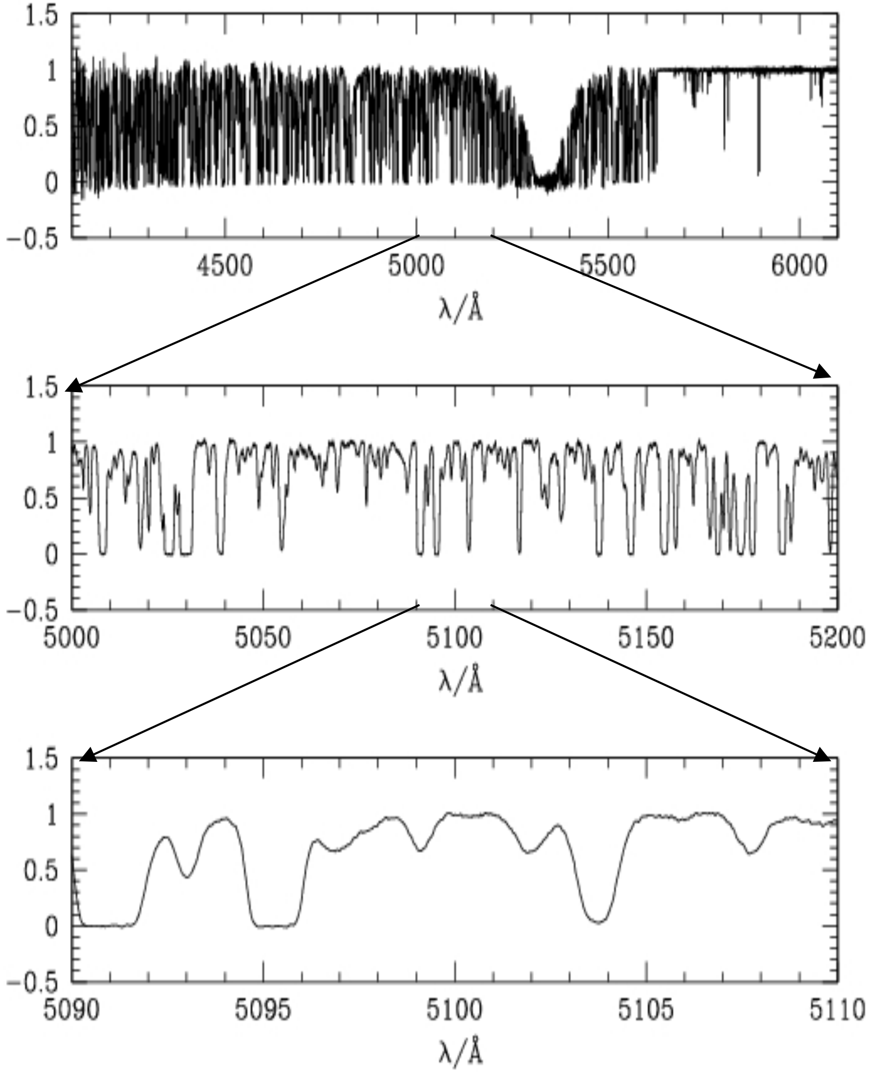
SDSS vs UVES



McDonald et al. 2005



Kim, MV+ 2004



SDSS
~10^4 LOW RESOLUTION LOW S/N

vs

UVES/KECK etc.
~10^2 HIGH RESOLUTION HIGH S/N