

Perspectives of discoveries from Intergalactic Space

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LSS 2015 - Garching (Germany)

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This project has received funding from the European Union's Seventh *Framework* Programme for research, technological development and demonstration under grant agreement no 257670

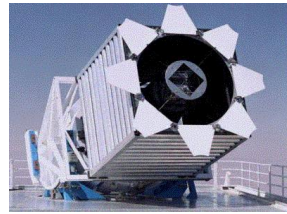


QUESTIONS

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

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

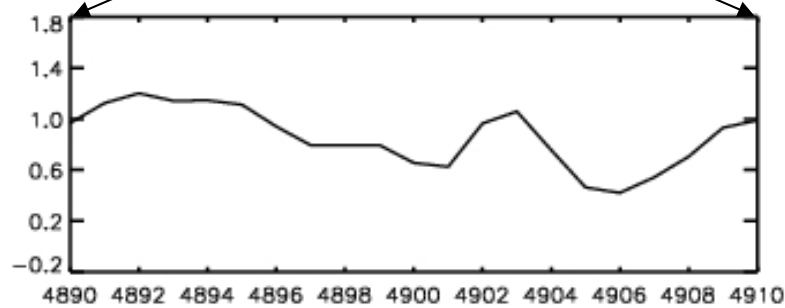
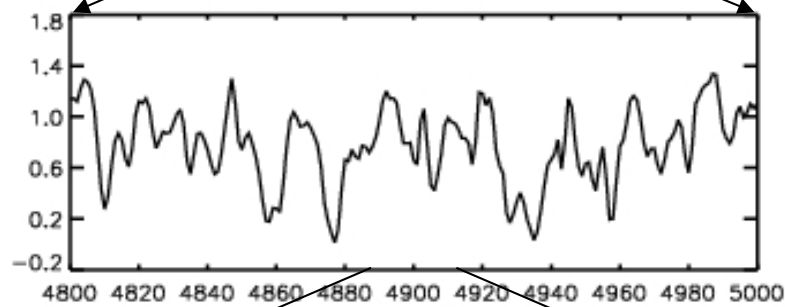
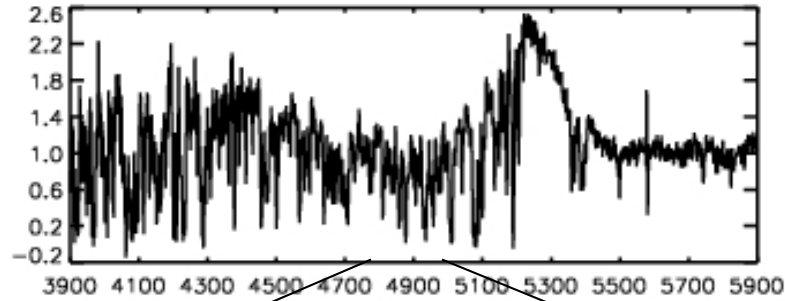
The data sets



SDSS vs UVES



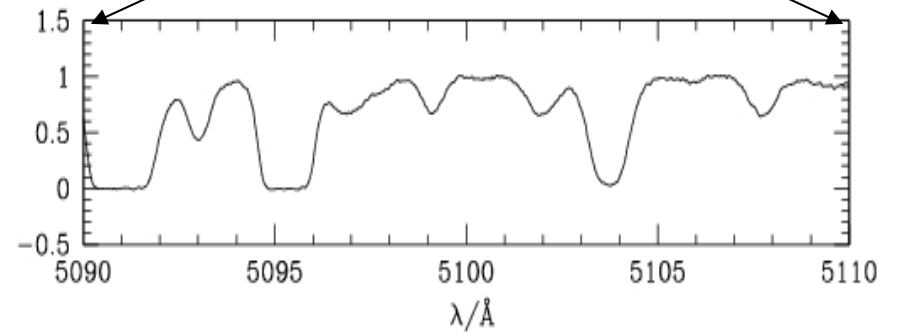
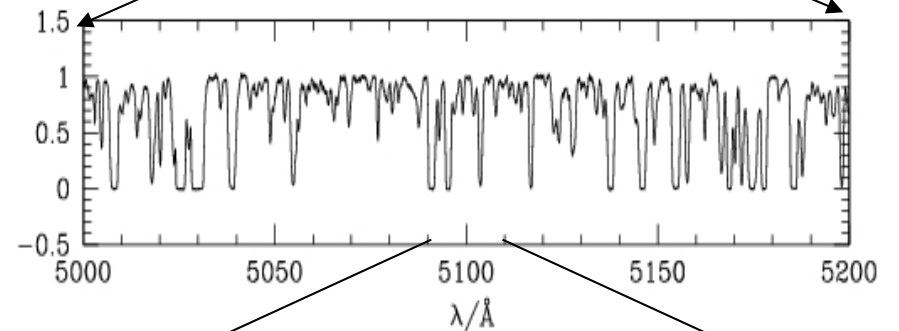
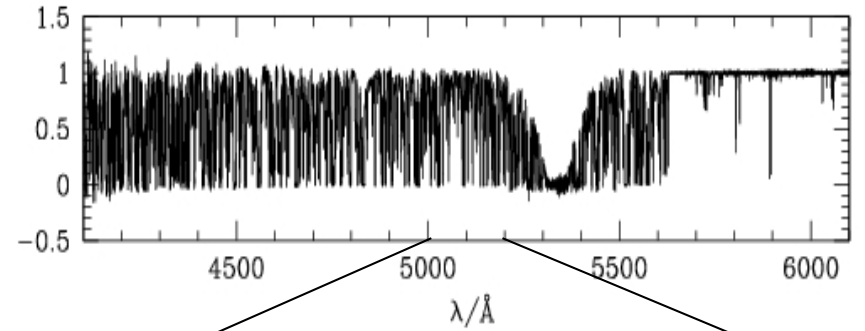
McDonald et al. 2005



SDSS

$\sim 10^4$ LOW RESOLUTION LOW S/N

Kim, MV+ 2004

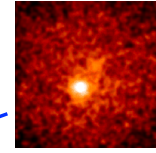
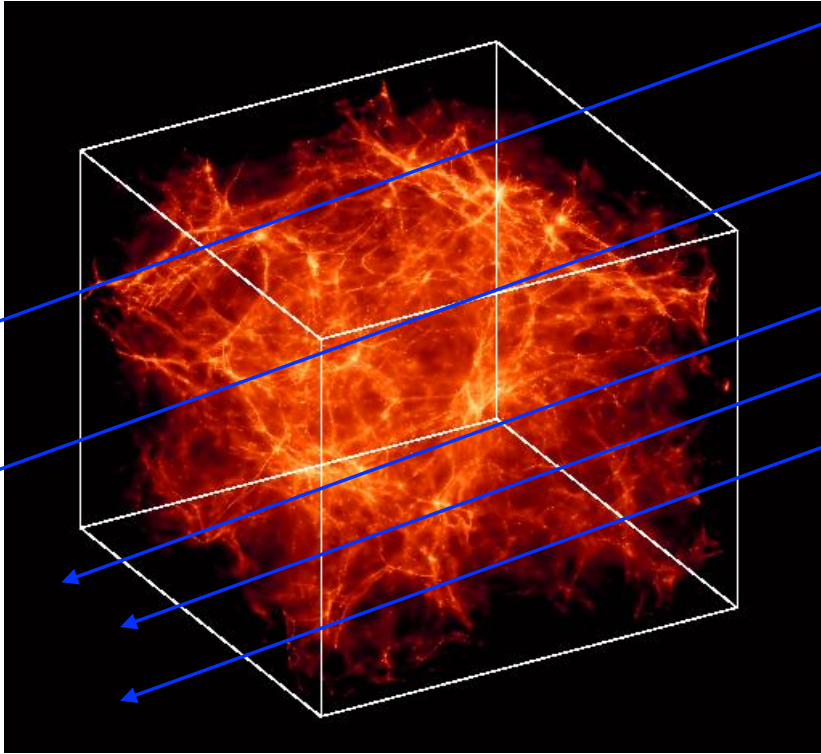


UVES/KECK etc.

$\sim 10^2$ HIGH RESOLUTION HIGH S/N

vs

The Intergalactic Medium: Theory vs. Observations



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

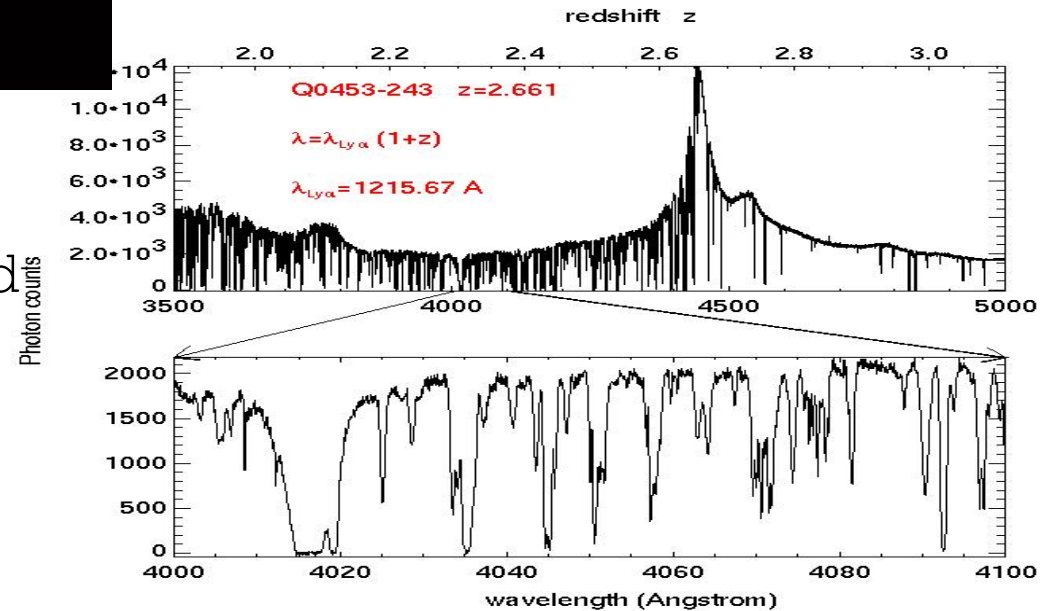
Bi & Davidsen (1997), Rauch (1998)
Review by Meiksin (2009)



baryons as tracer of the dark matter density field

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

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



COSMIC NEUTRINOS

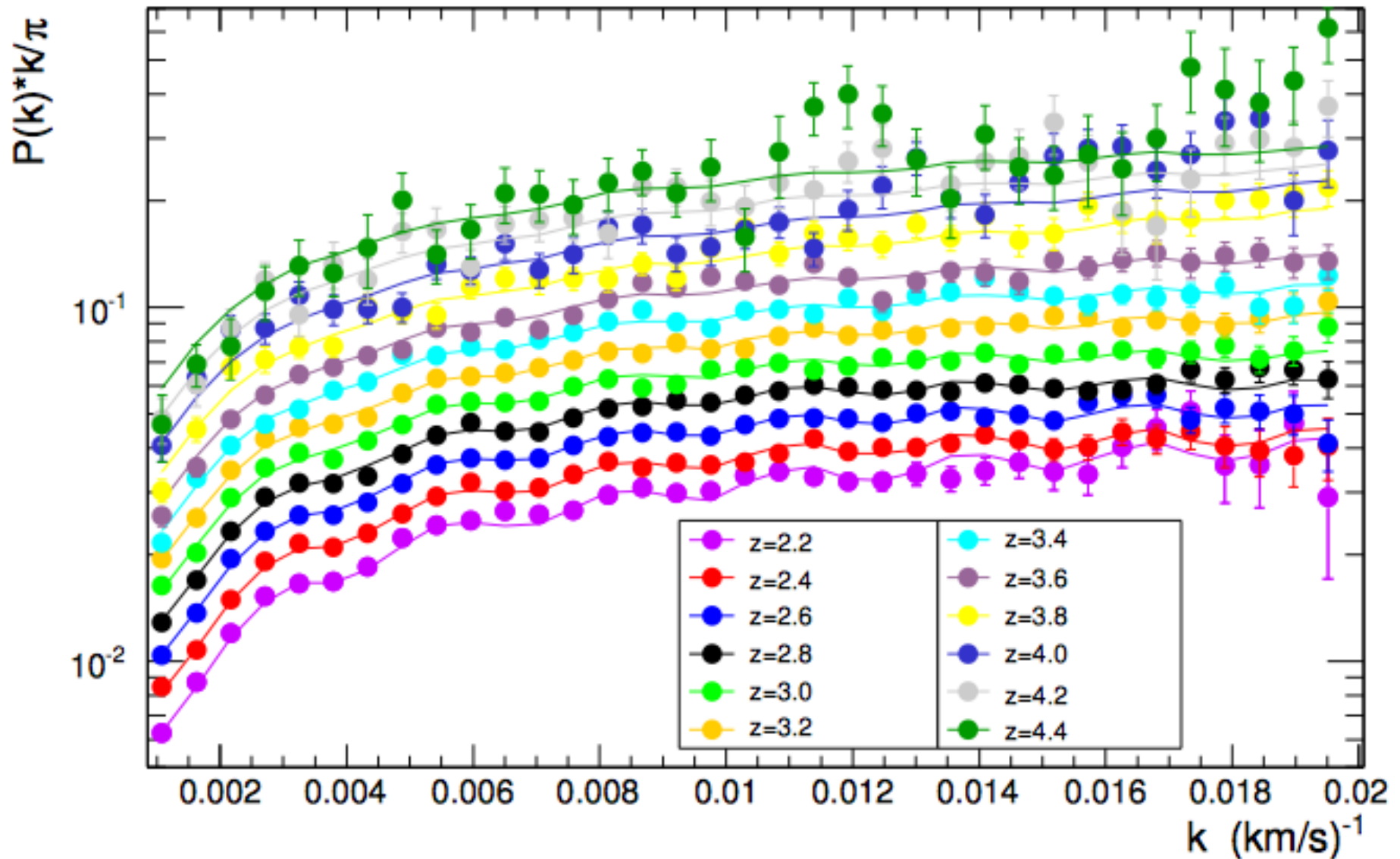
Palanque-Delabrouille+ 15a, 15b
BOSS/SDSS-III Ly-alpha group

GROWTH OF STRUCTURES AT HIGH REDSHIFT

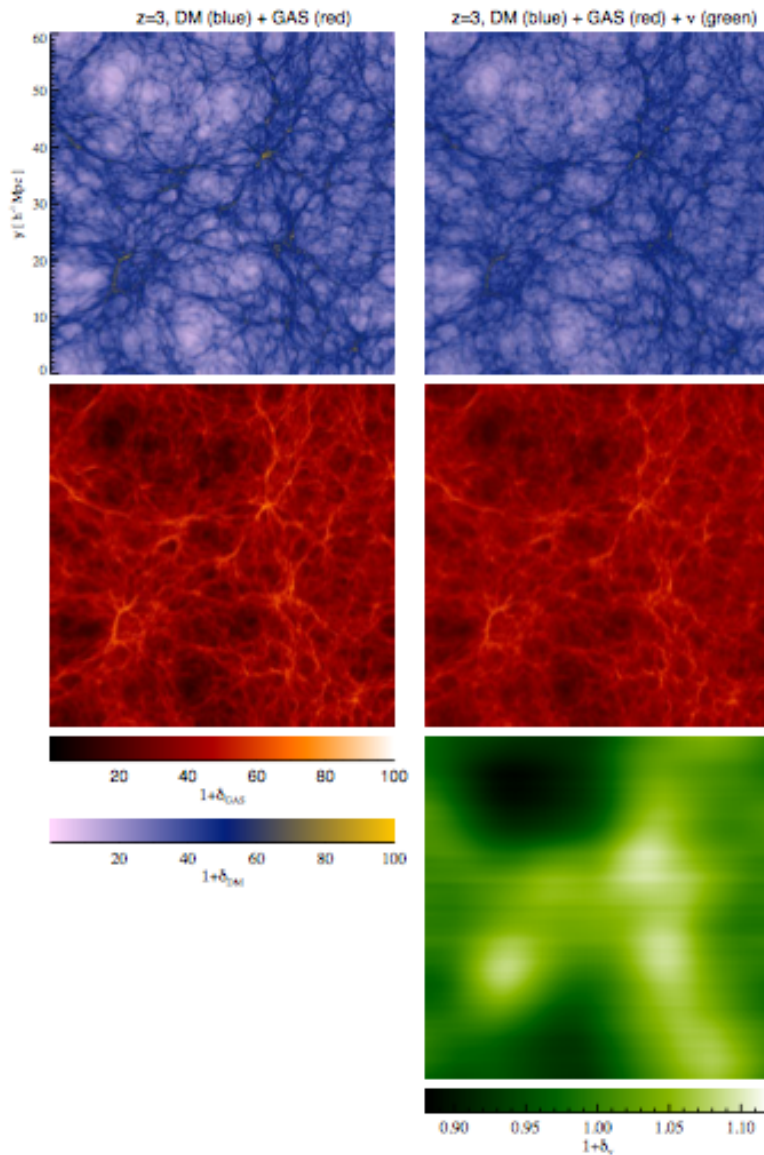
Constraint on neutrino masses from SDSS-III/BOSS Ly α forest and other cosmological probes

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^a



NEUTRINOS IN THE IGM



N-body + hydro sims

Neutrino induced non-linear suppression understood and reproduced also with simple halo modelling (**Massara's poster**)

Degeneracies with σ_8 are present (but not perfect)

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

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 , $\langle F \rangle$

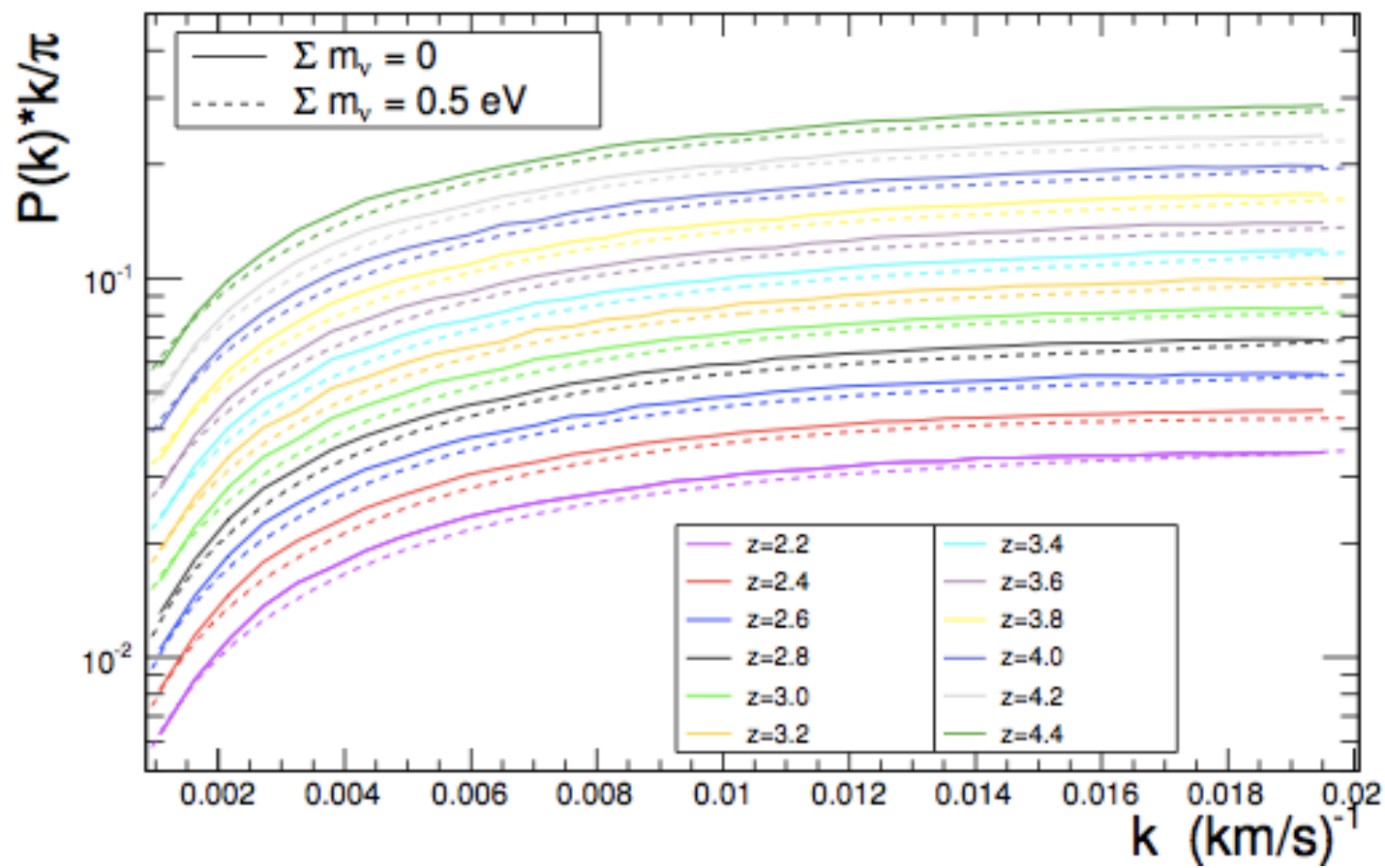
Nuisance: resolution, S/N, metals

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

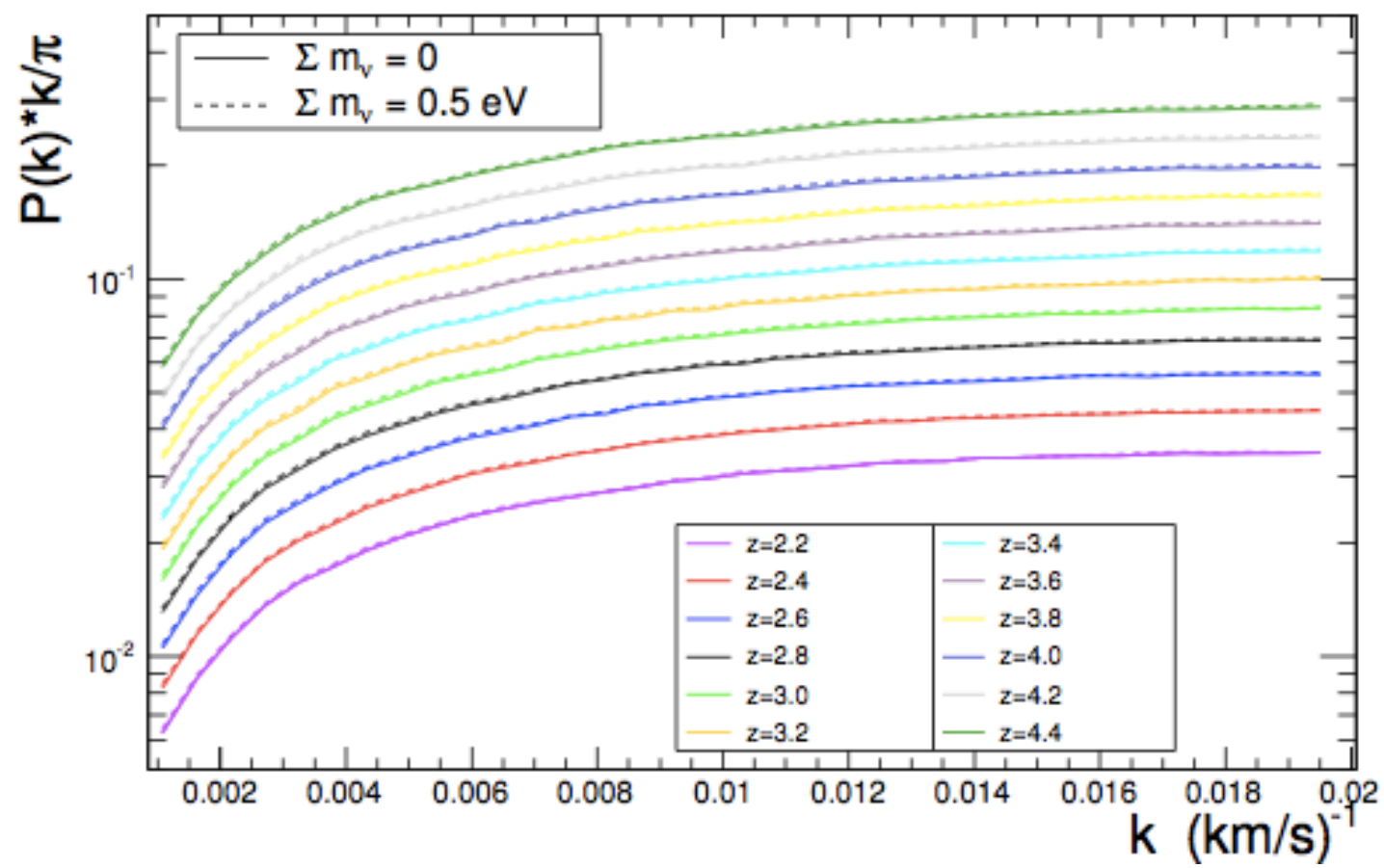
Parameter space: second order Taylor expansion of the flux power

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

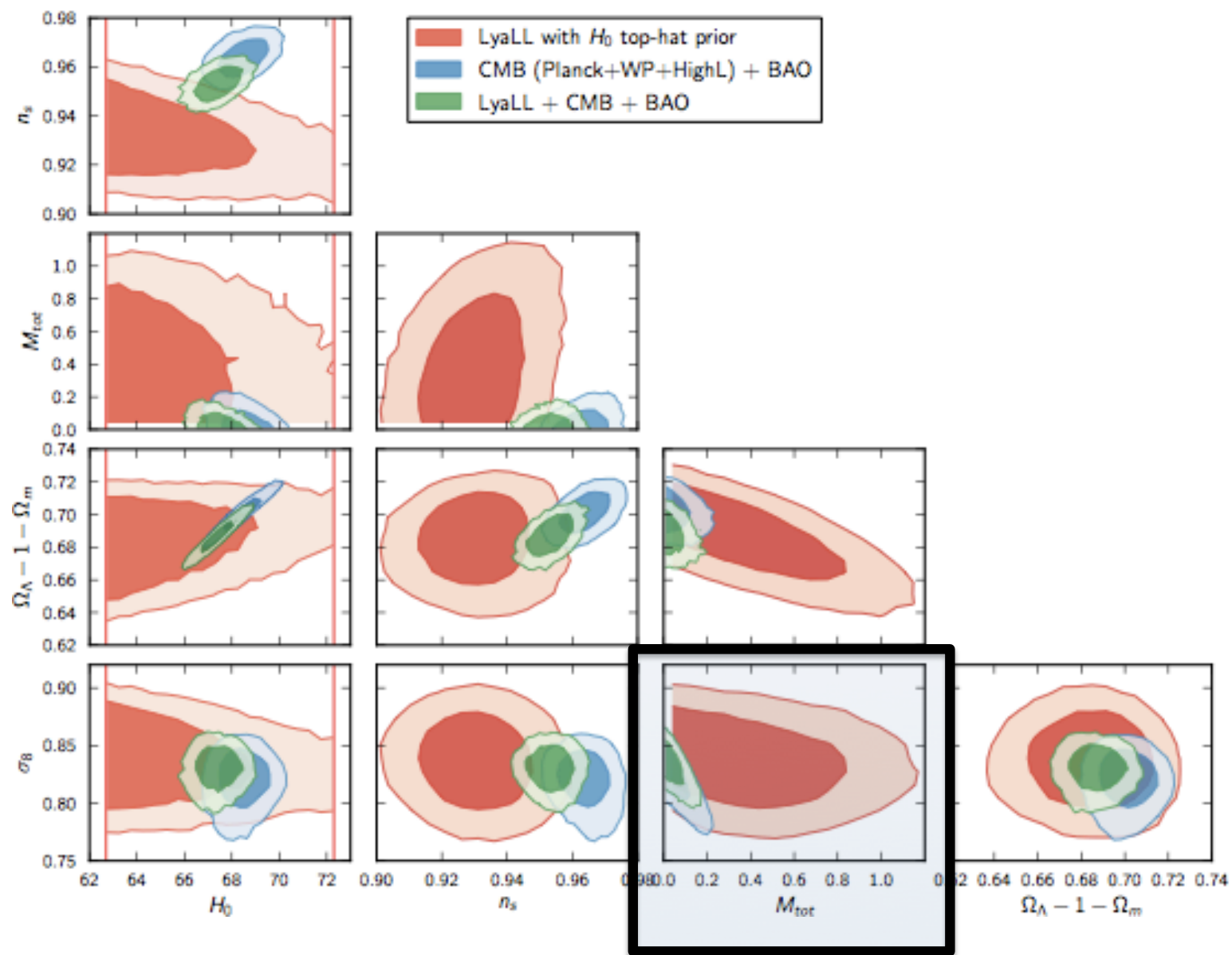
NEUTRINO IMPACT - I



NEUTRINO IMPACT - II



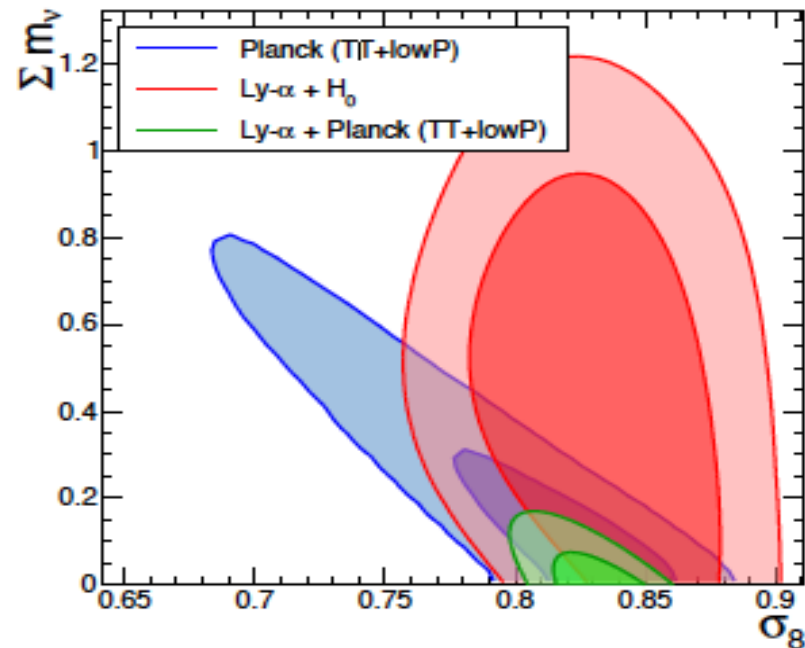
BAYESIAN ANALYSIS



FINAL NUMBERS

Parameter	$Ly\alpha + H_0^{\text{tophat}}$ ($62.5 \leq H_0 < 72.5$)	$Ly\alpha + \text{CMB}$	$Ly\alpha + \text{CMB}$ + BAO	$Ly\alpha + \text{CMB}(A_L)$
$10^9 A_s$	$3.2^{+0.5}_{-0.7}$	$2.20^{+0.05}_{-0.06}$	$2.20^{+0.05}_{-0.06}$	$2.18^{+0.05}_{-0.06}$
$10^2 \omega_b$	(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

Parameter	(1) Ly α + H_0^{Gaussian} ($H_0 = 67.3 \pm 1.0$)	(2) Ly α + Planck TT+lowP	(3) Ly α + Planck TT+lowP + BAO	(4) Ly α + 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

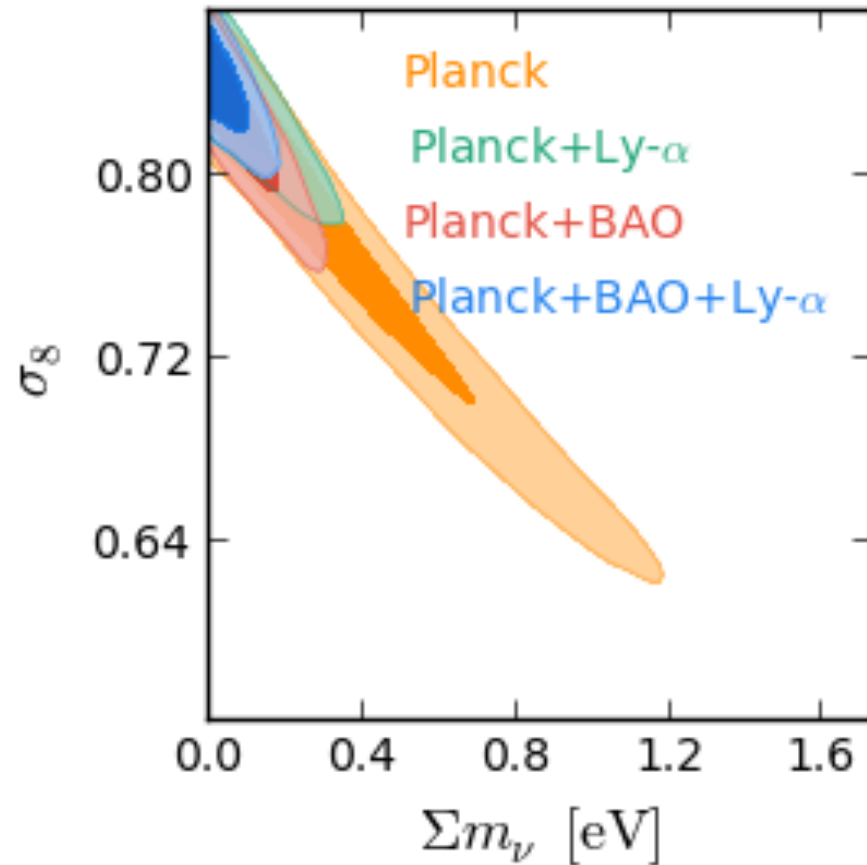


CONSTRAINTS on NEUTRINO MASSES FROM Planck13 + BAO +old Lya

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

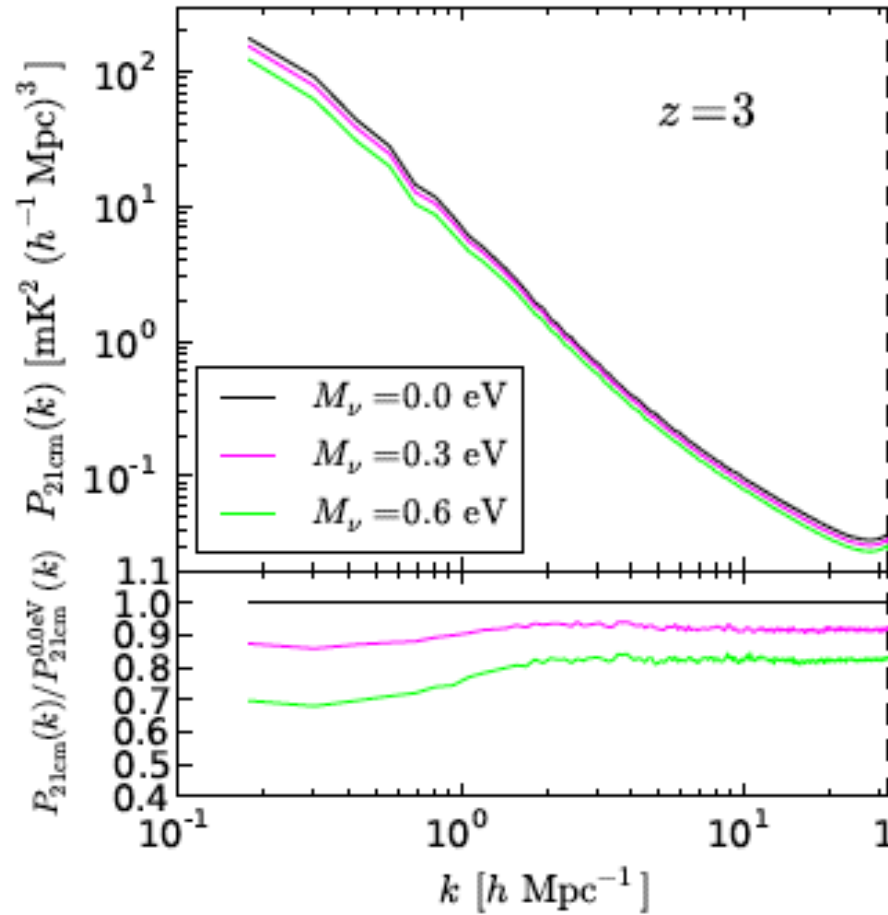
2 σ upper limits

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



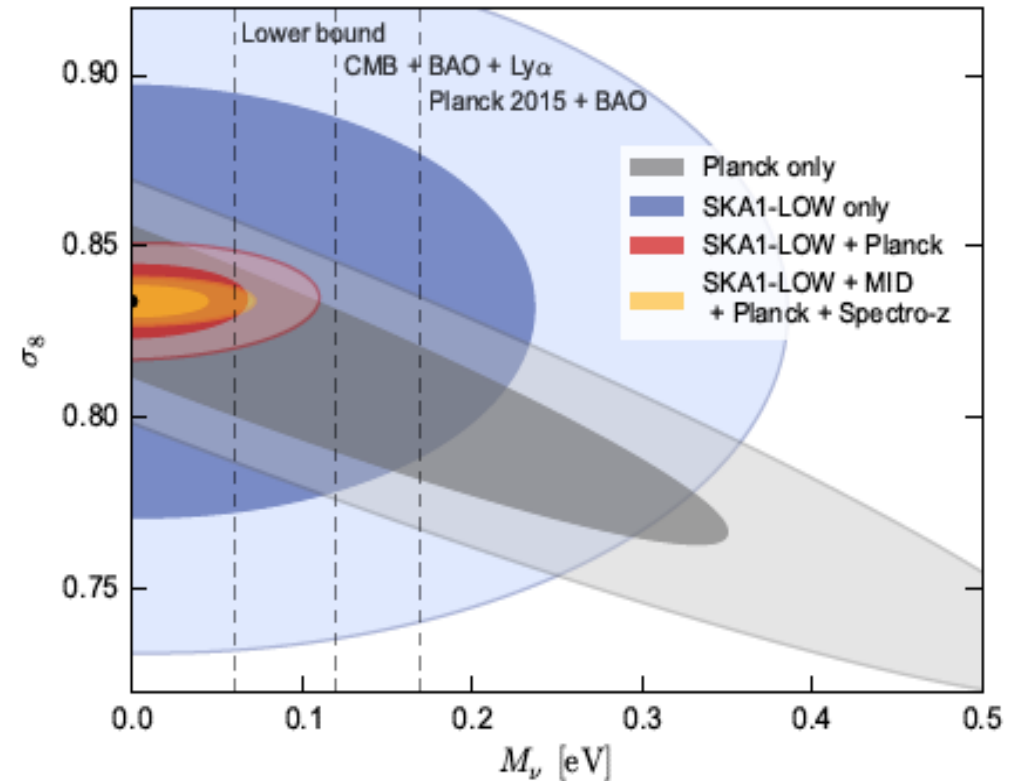
2 eV
29 eV
59 eV
9 eV

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



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

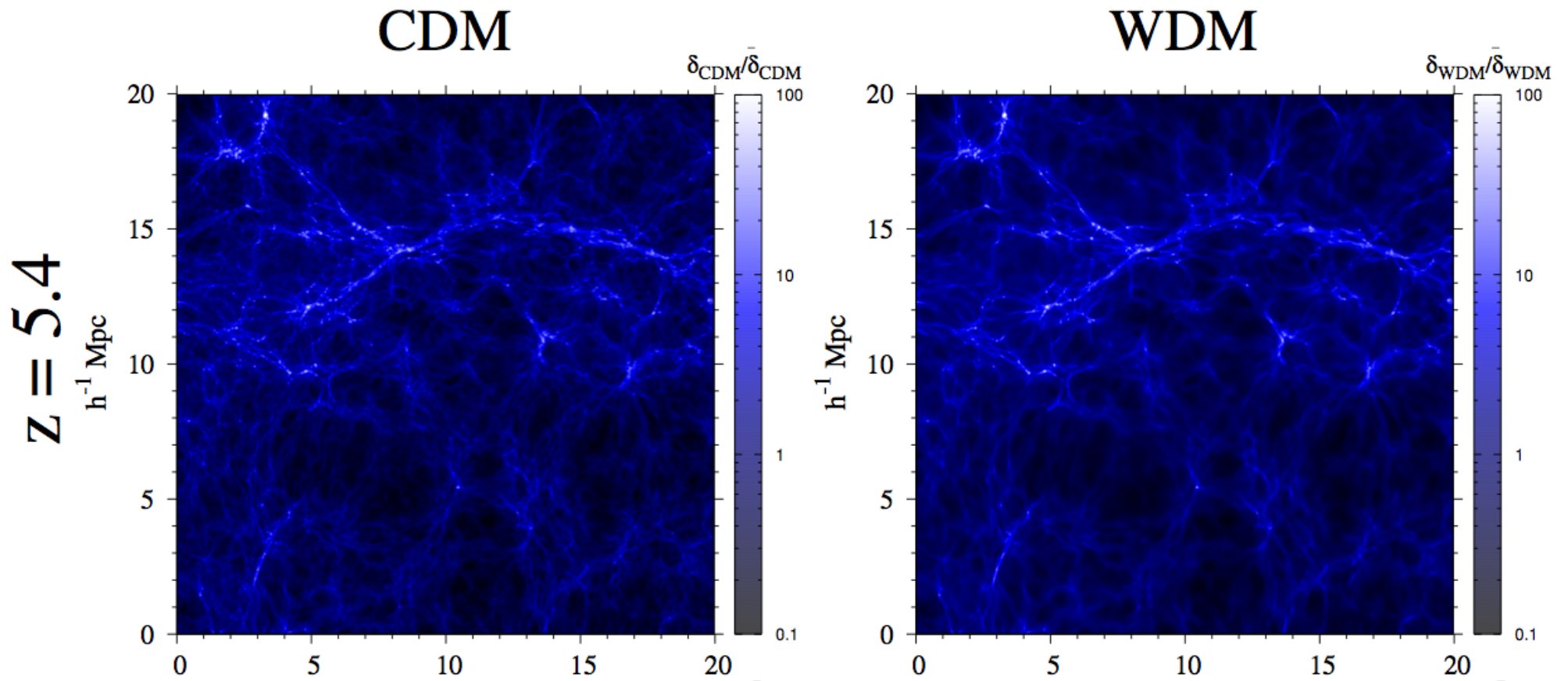
Villaescusa-Navarro, Bull, MV, arXiv: 1507.05102



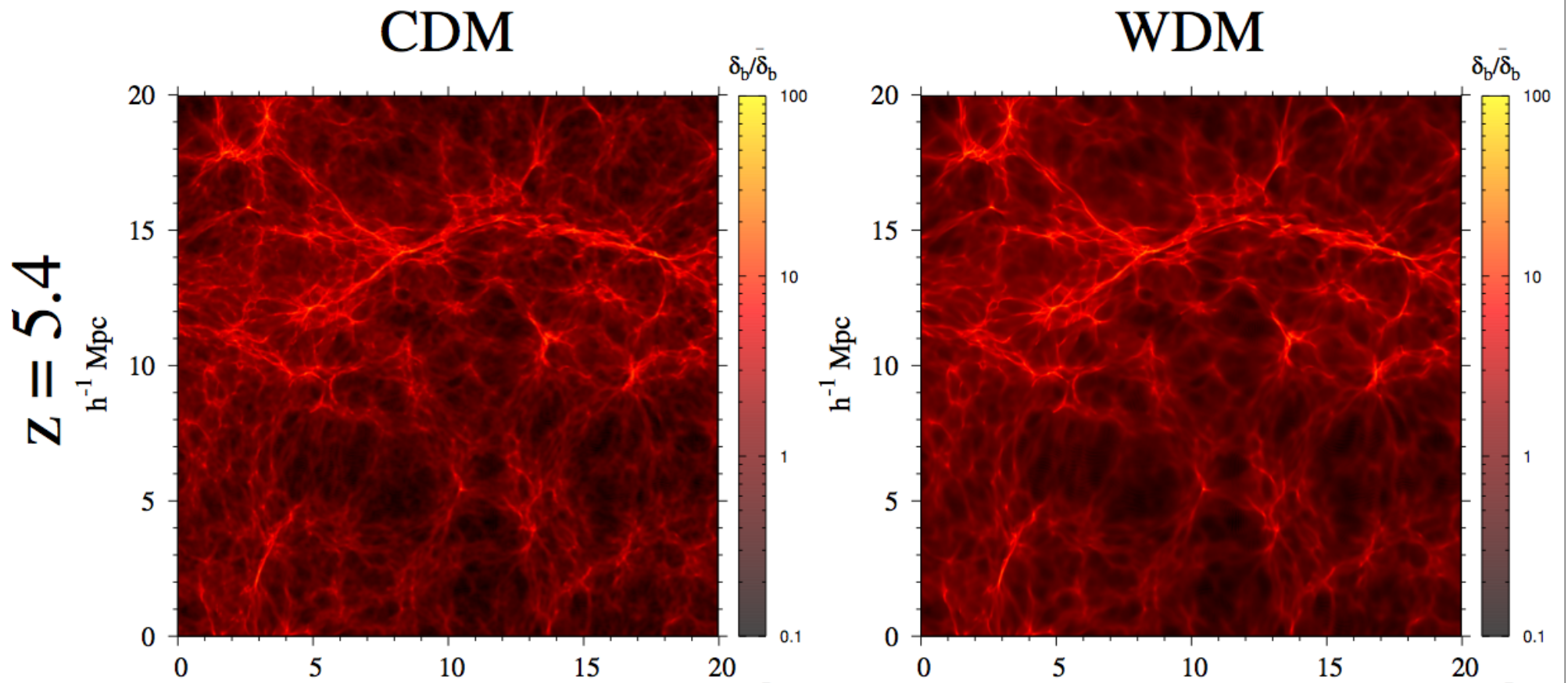
COLDNESS OF COLD DARK MATTER

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

DARK MATTER DISTRIBUTION



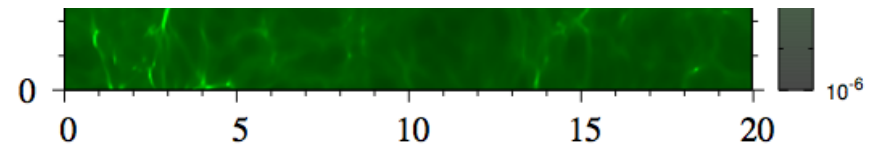
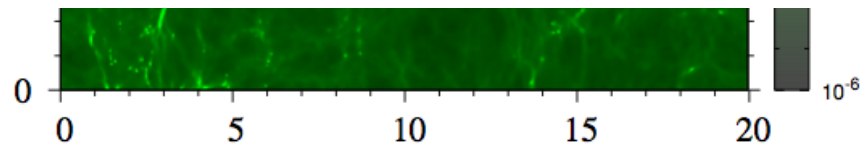
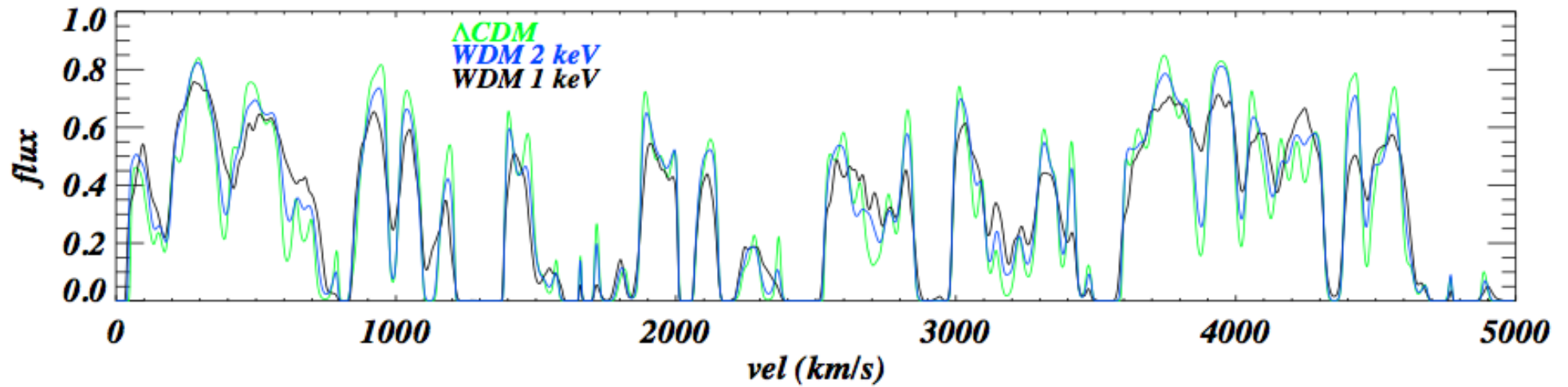
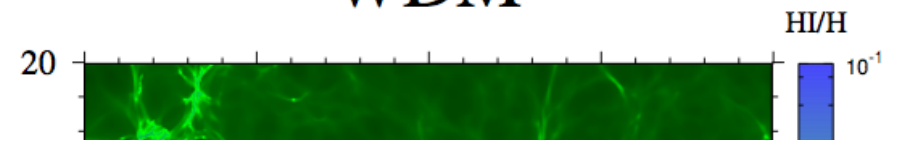
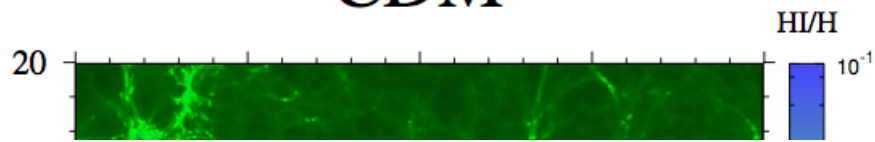
GAS DISTRIBUTION



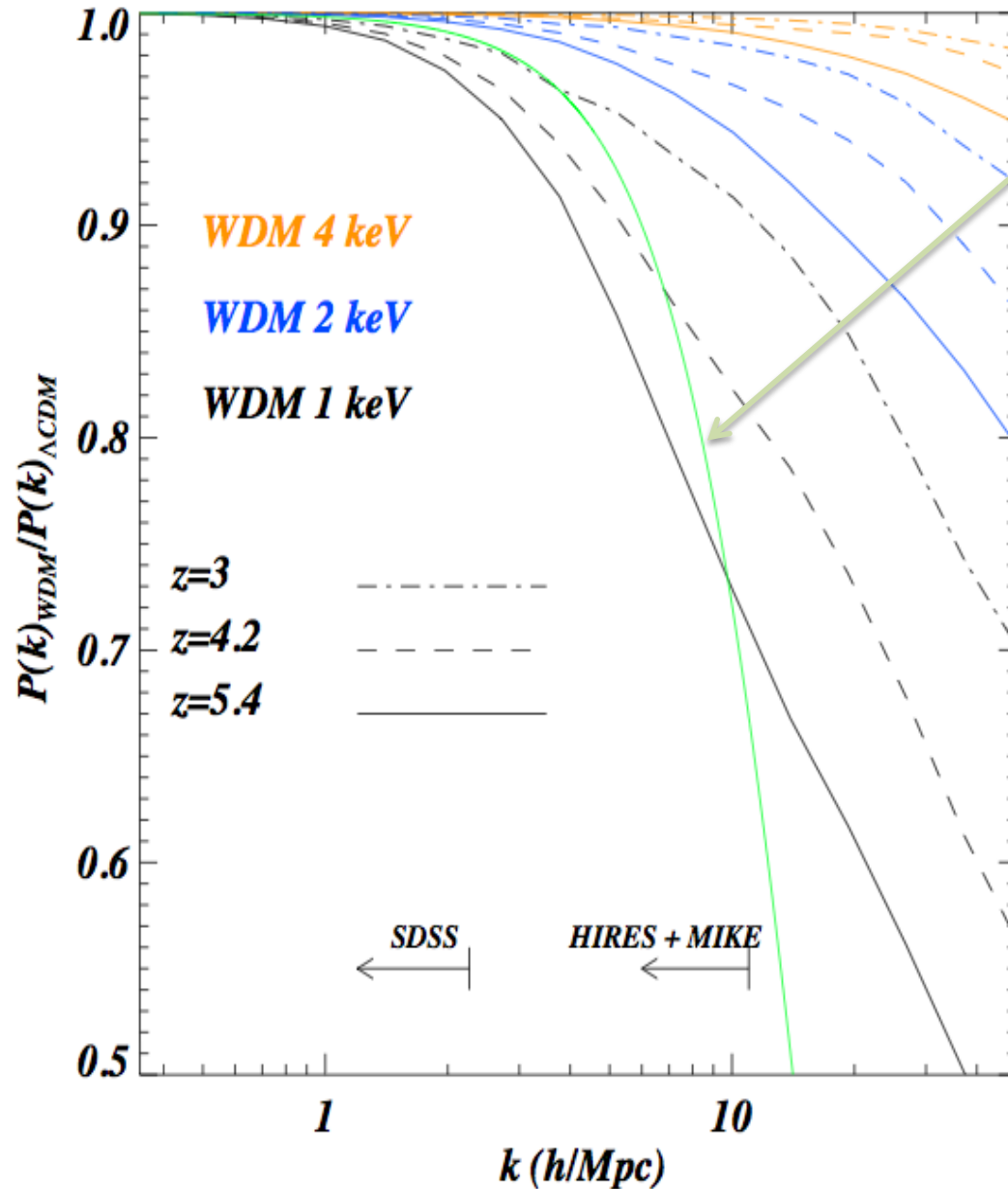
HI DISTRIBUTION

CDM

WDM



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

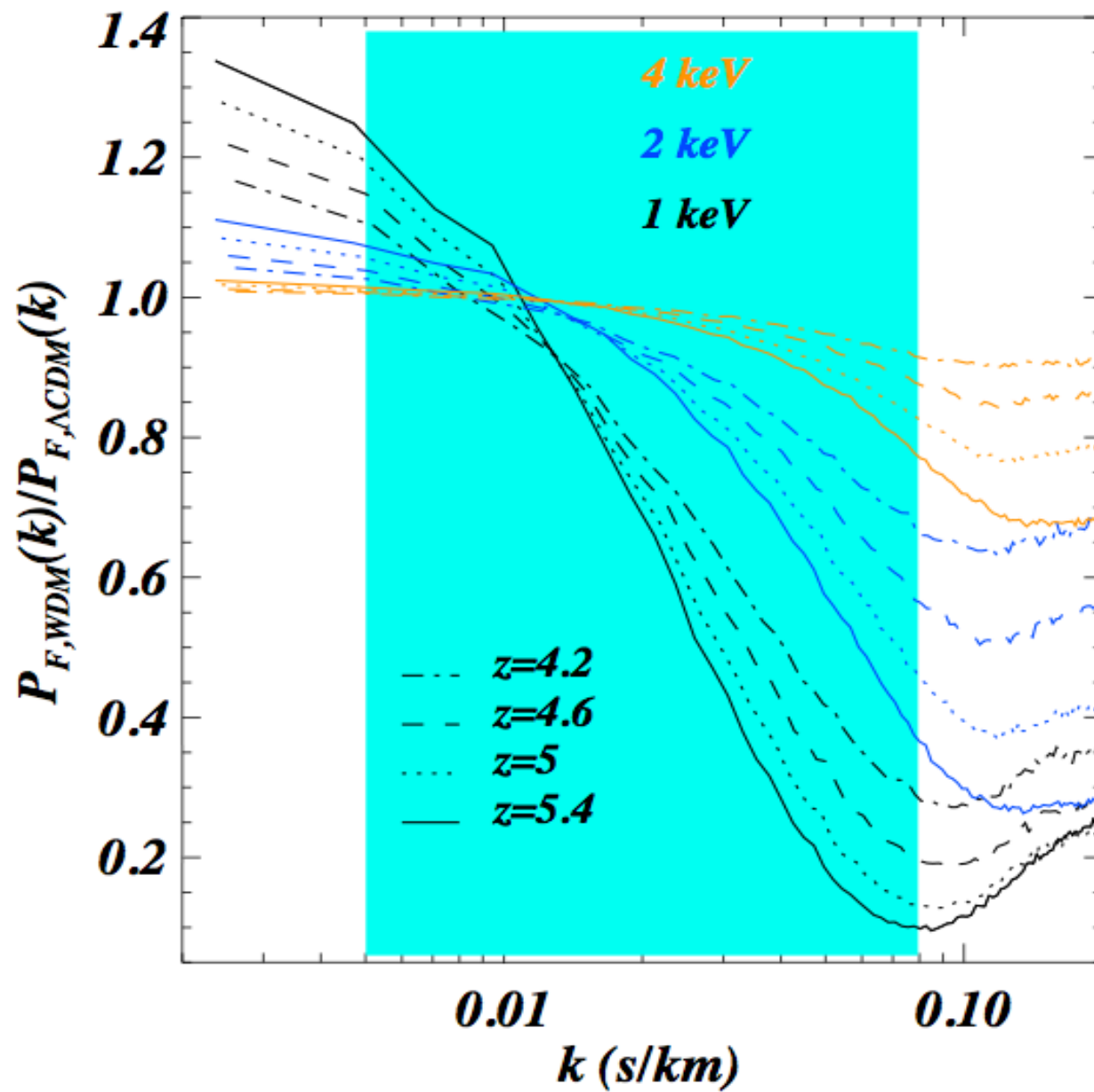
$$T_{nl}^2(k) \equiv P_{WDM}(k)/P_{\Lambda CDM}(k) = (1 + (\alpha k)^{\nu l})^{-s/\nu},$$

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

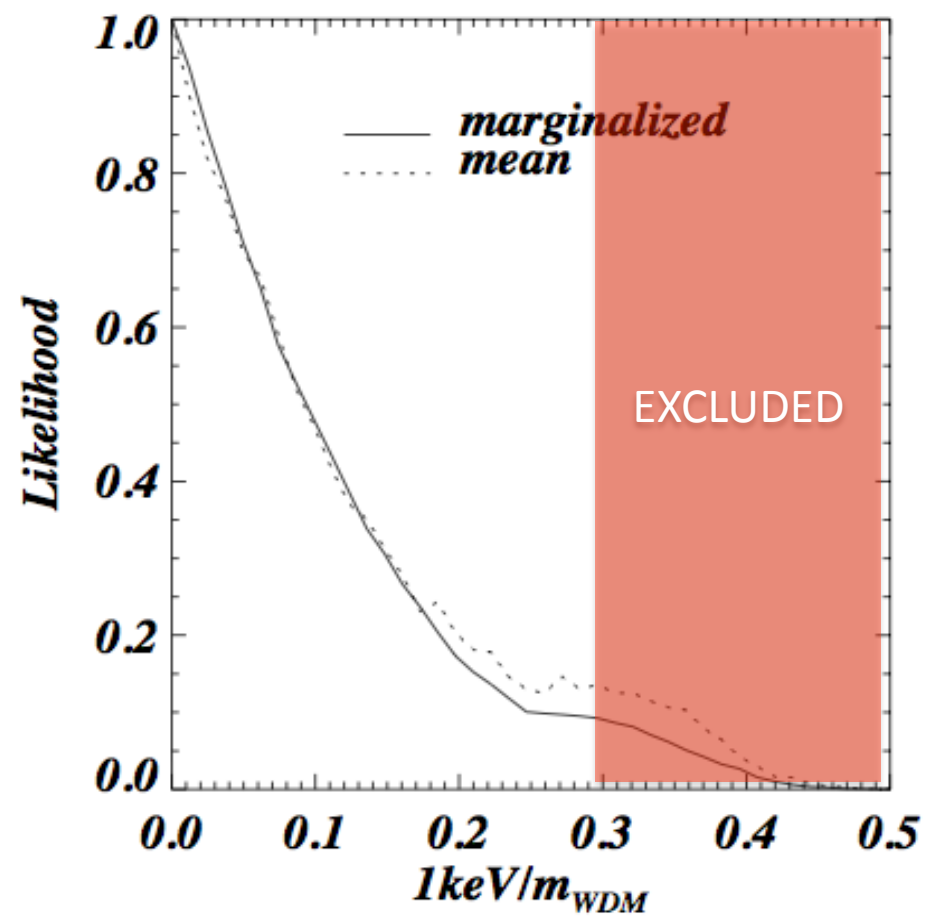
$\nu = 3, l = 0.6$ and $s = 0.4$.

THE HIGH REDSHIFT WDM CUTOFF

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



RESULTS FOR WDM MASS

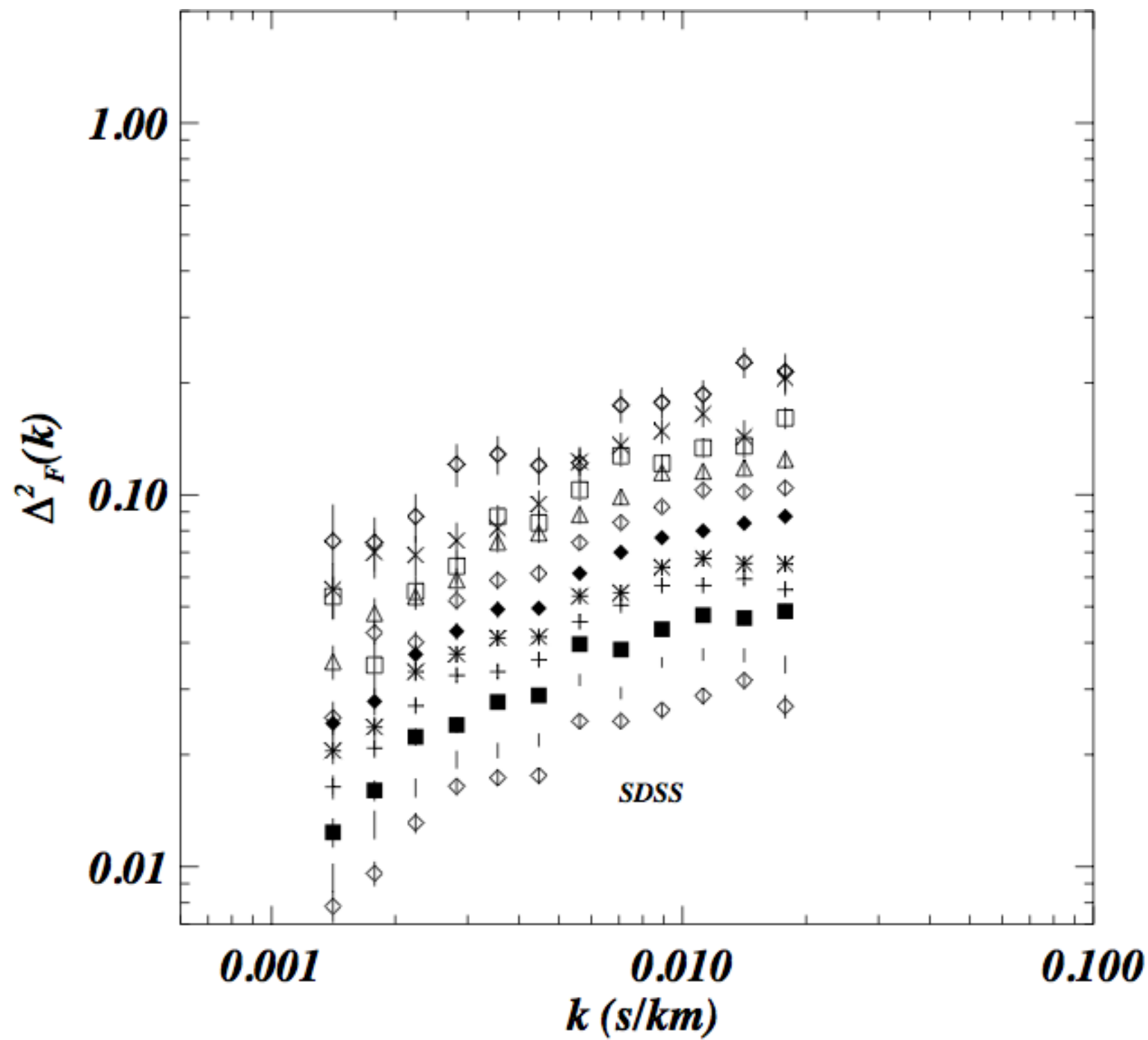


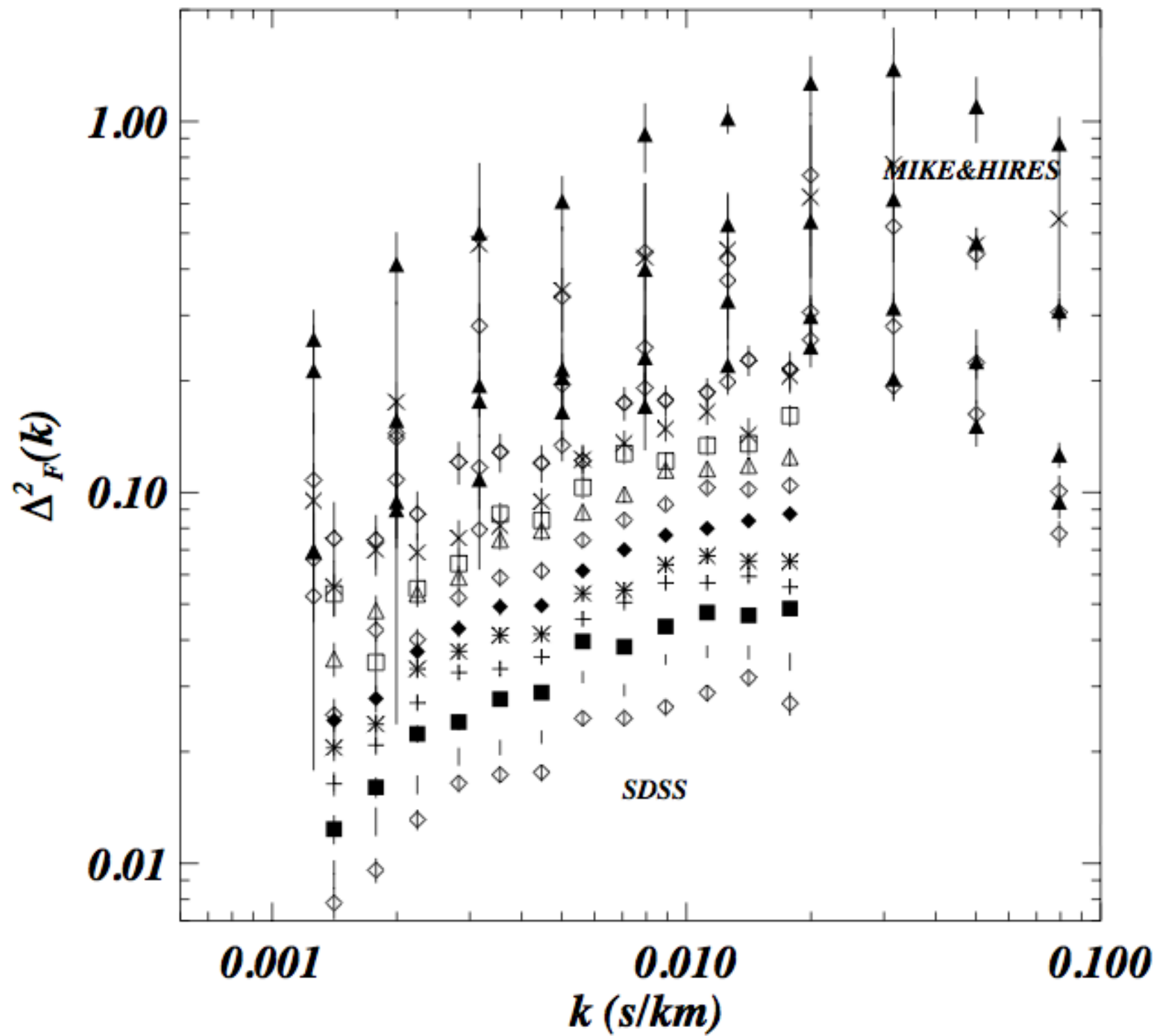
$m > 3.3 \text{ keV} (2\sigma)$

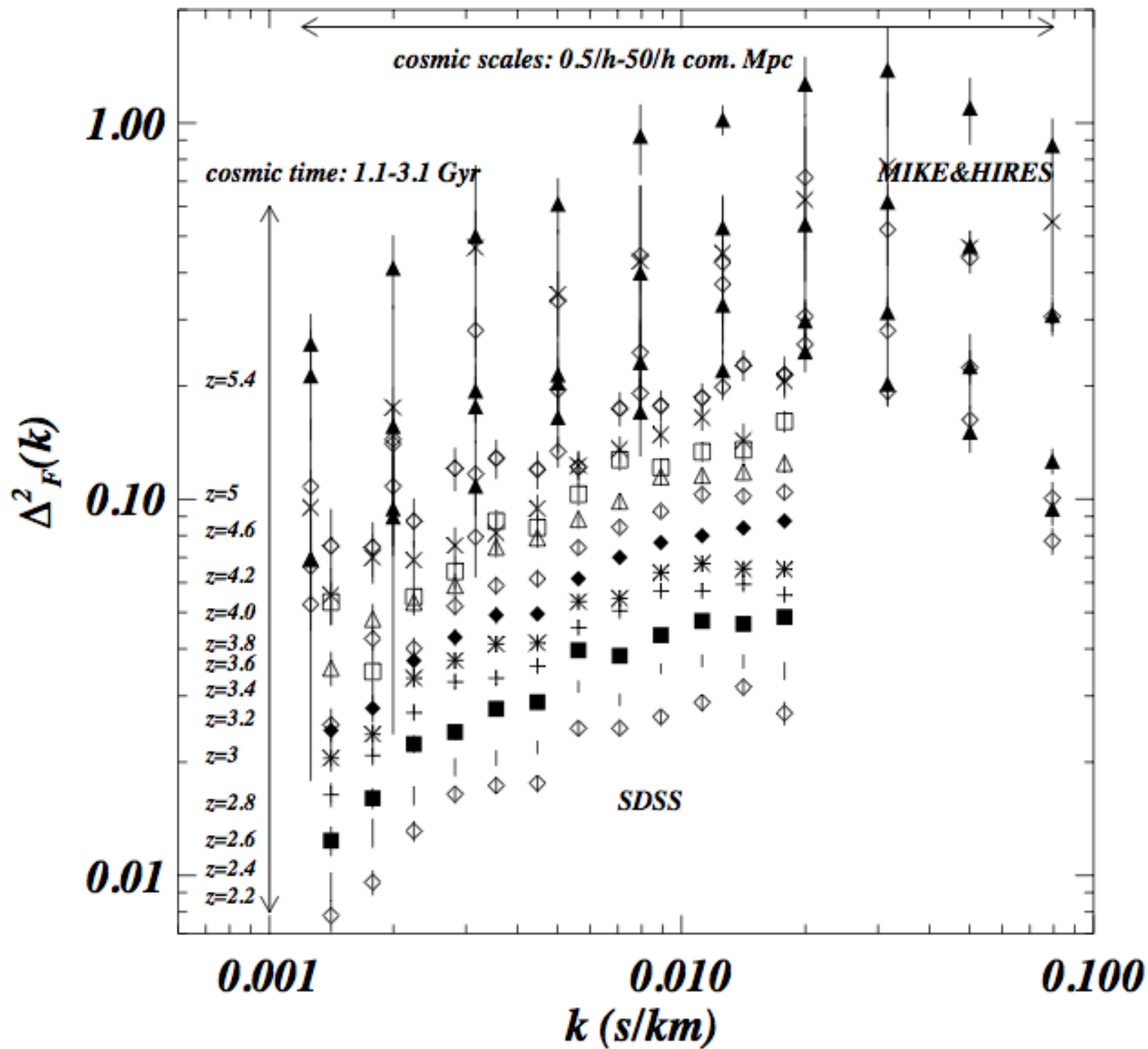
**SDSS + MIKE + HIRES
CONSTRAINTS**

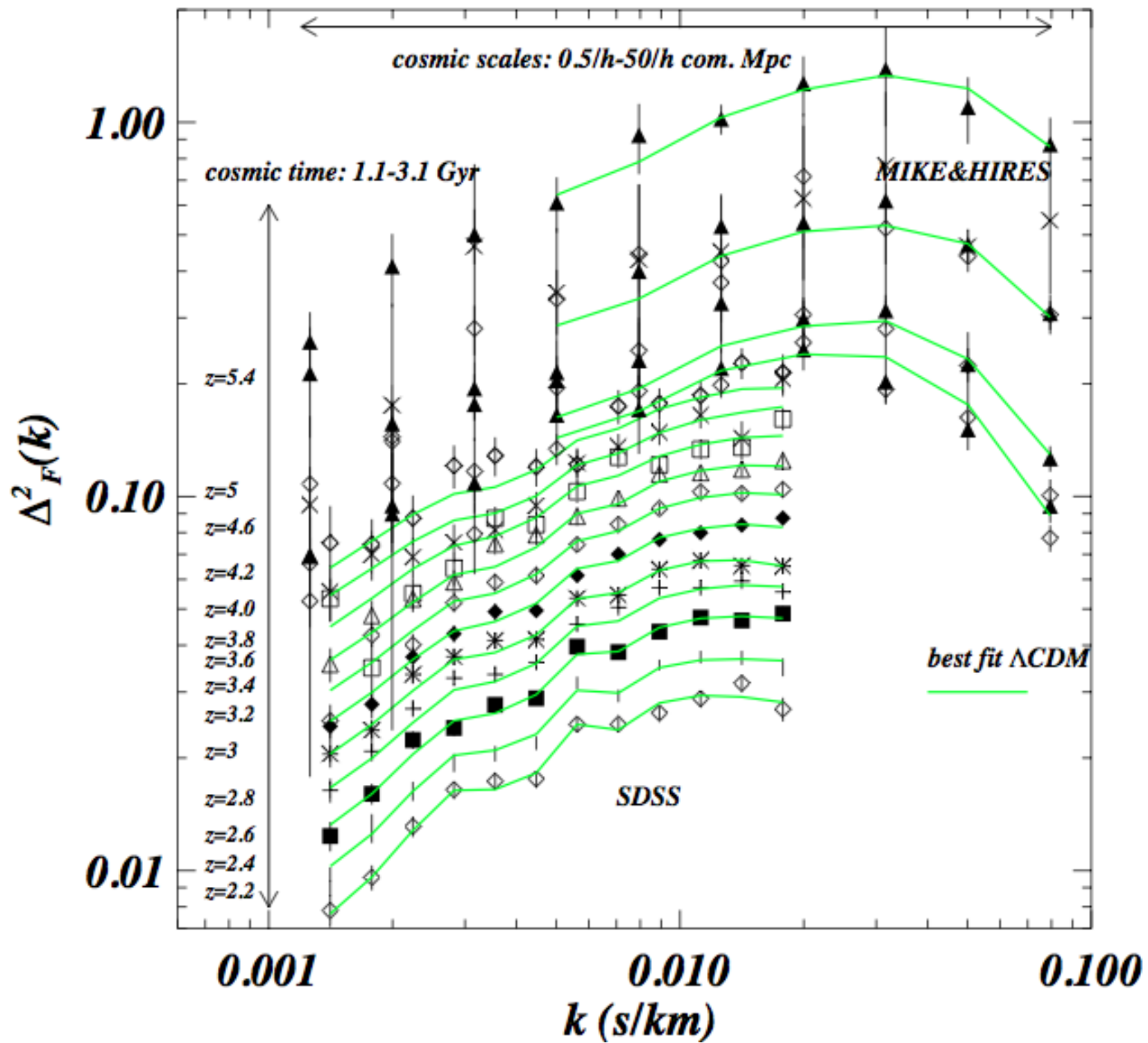
Joint likelihood analysis

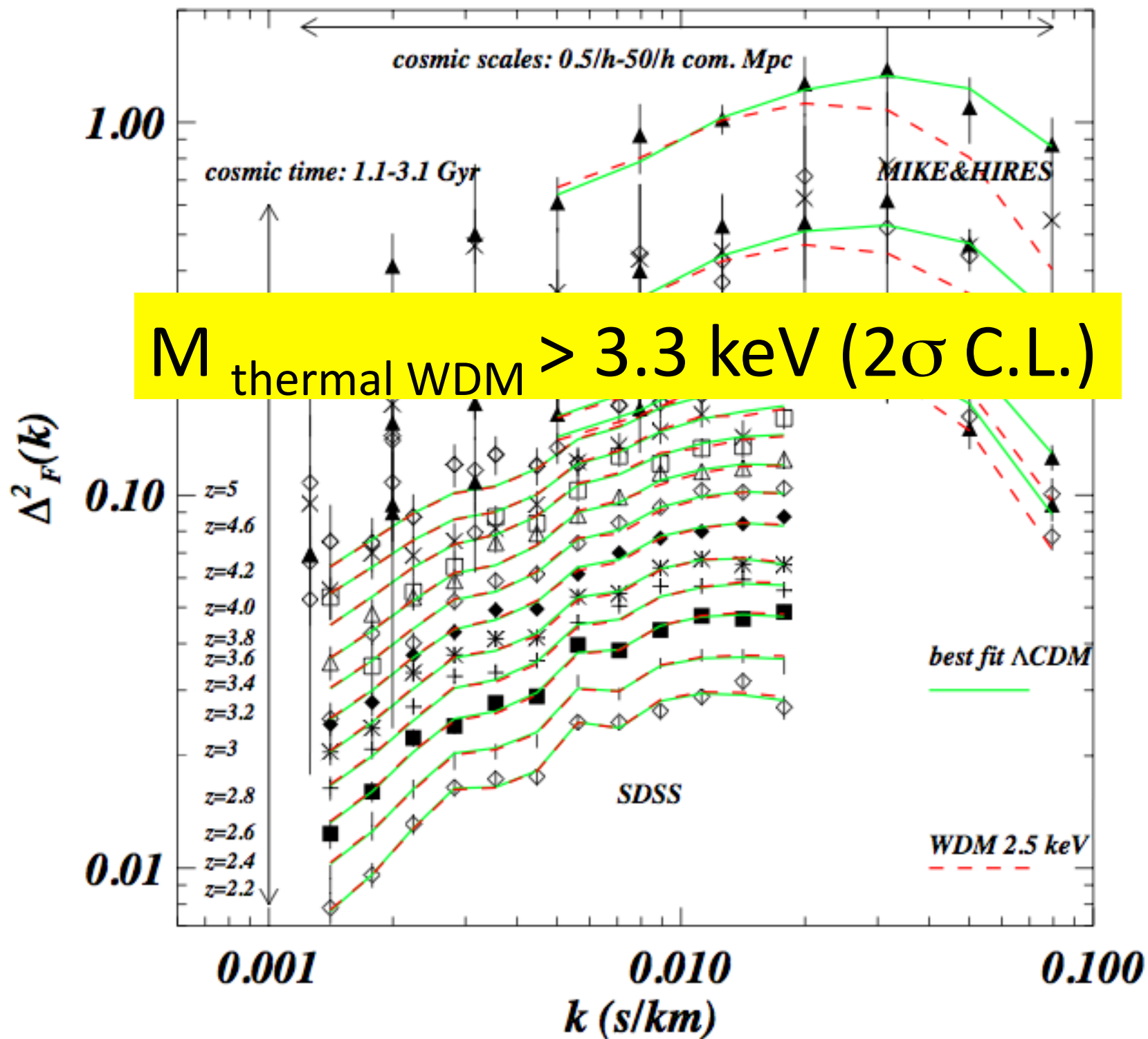
SDSS data from McDonald05,06 not BOSS











WDM SUPPRESSION in 21cm INTENSITY MAPPING

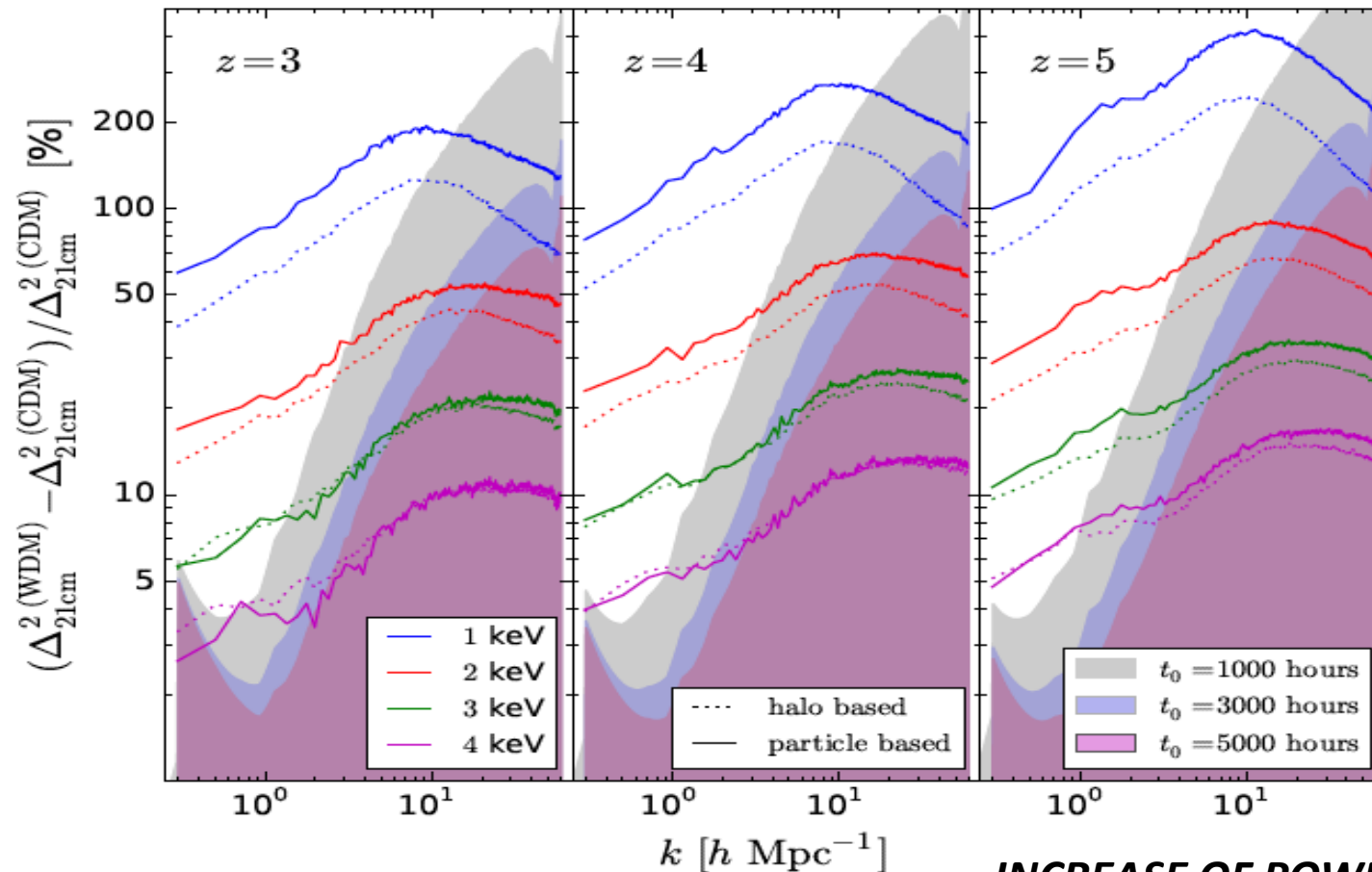
Carucci, Villaescusa, MV, Lapi 2015

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

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

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

REALISTIC SKA forecasts



INCREASE OF POWER see Carucci's poster

**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

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

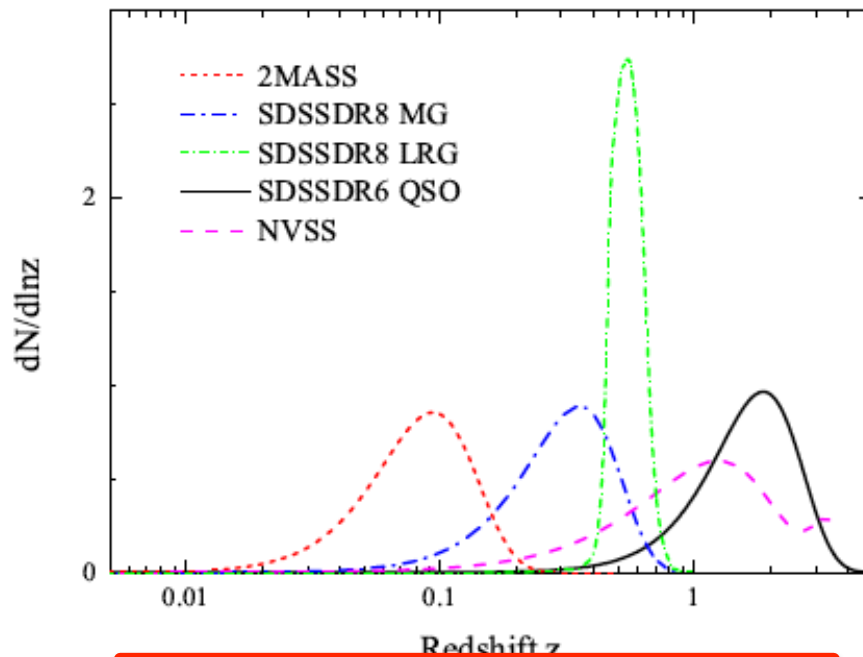
CATALOGS

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

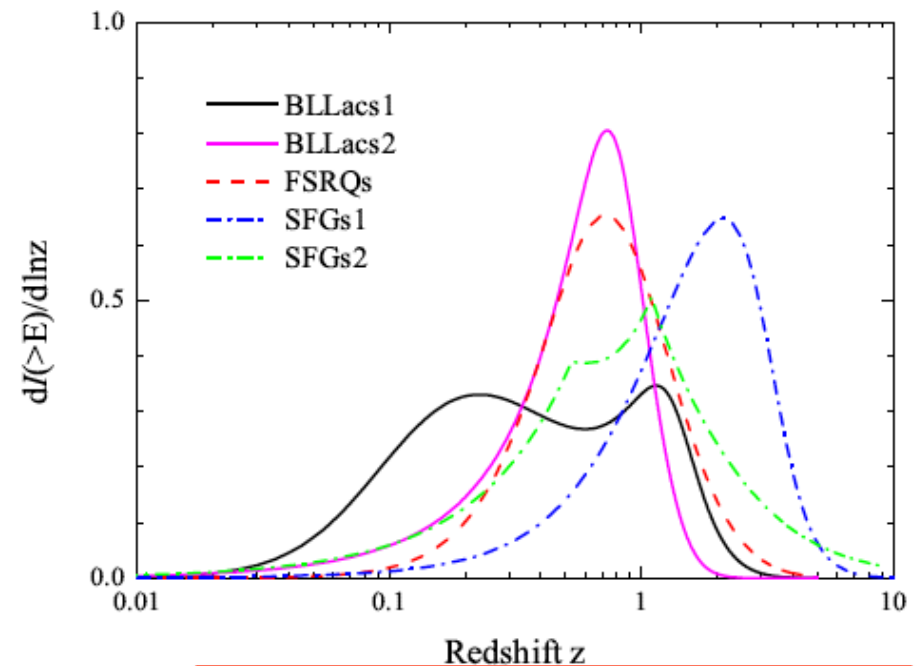
$$C_l^{I,j} = \frac{2}{\pi} \int k^2 P(k) [G_l^I(k)] [G_l^j(k)] dk$$

SOURCES

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

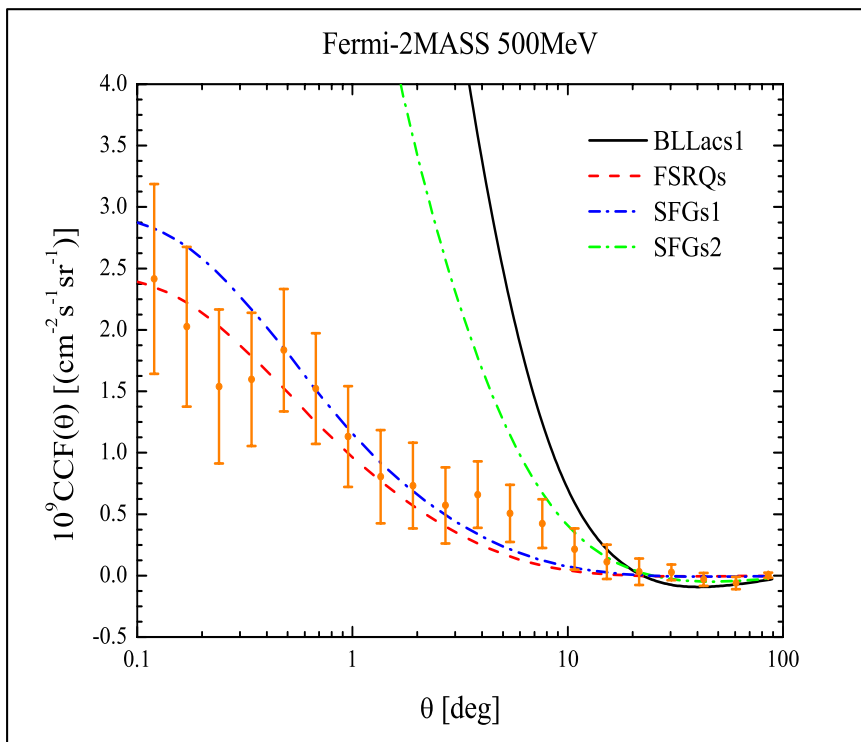
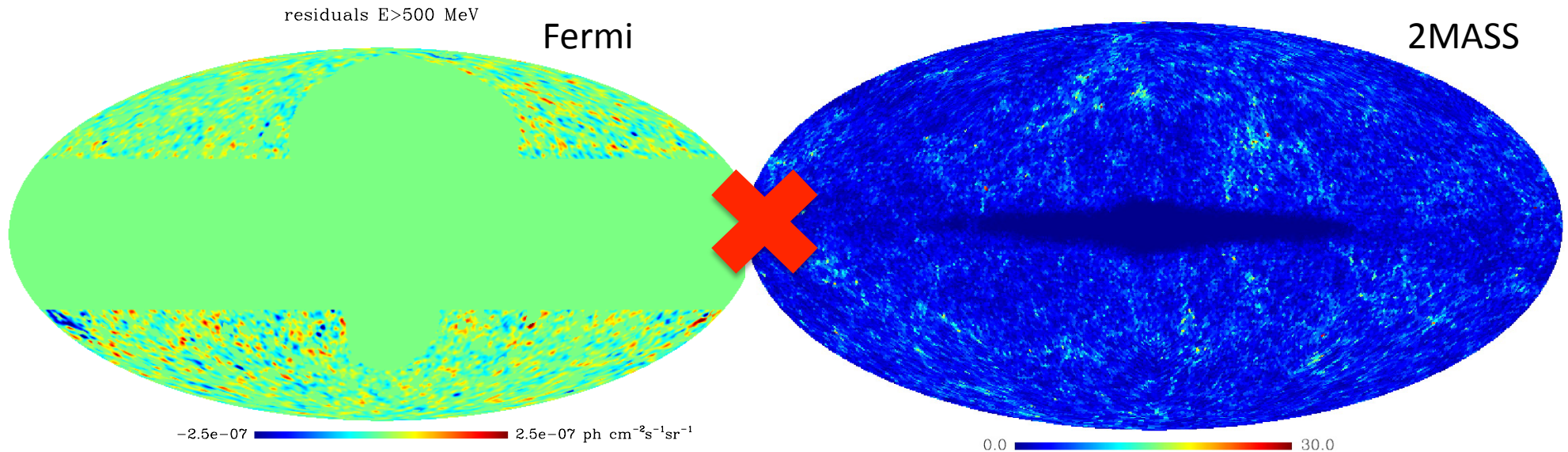


$$G_l^j(k) = \int \frac{dN(z)}{dz} b_j(z) D(z) j_l[k\chi(z)] dz$$



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

IGRB - II: results from astro modelling



Cross-correlations detected:

2MASS: 3.5σ for $\theta < 10^\circ$ all energies

Main Galaxies: $> 3\sigma$ at $E > 0.5, 1$ GeV

LRG: weak cross correlation

QSOs: $2-5\sigma$

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

Main Result:

Best fit when SFG are the main contributors

$72^{+23}_{-37}\%$ - Conclusions not sensitive to bias or dN/dz

BLLac contrib $< 5\%$

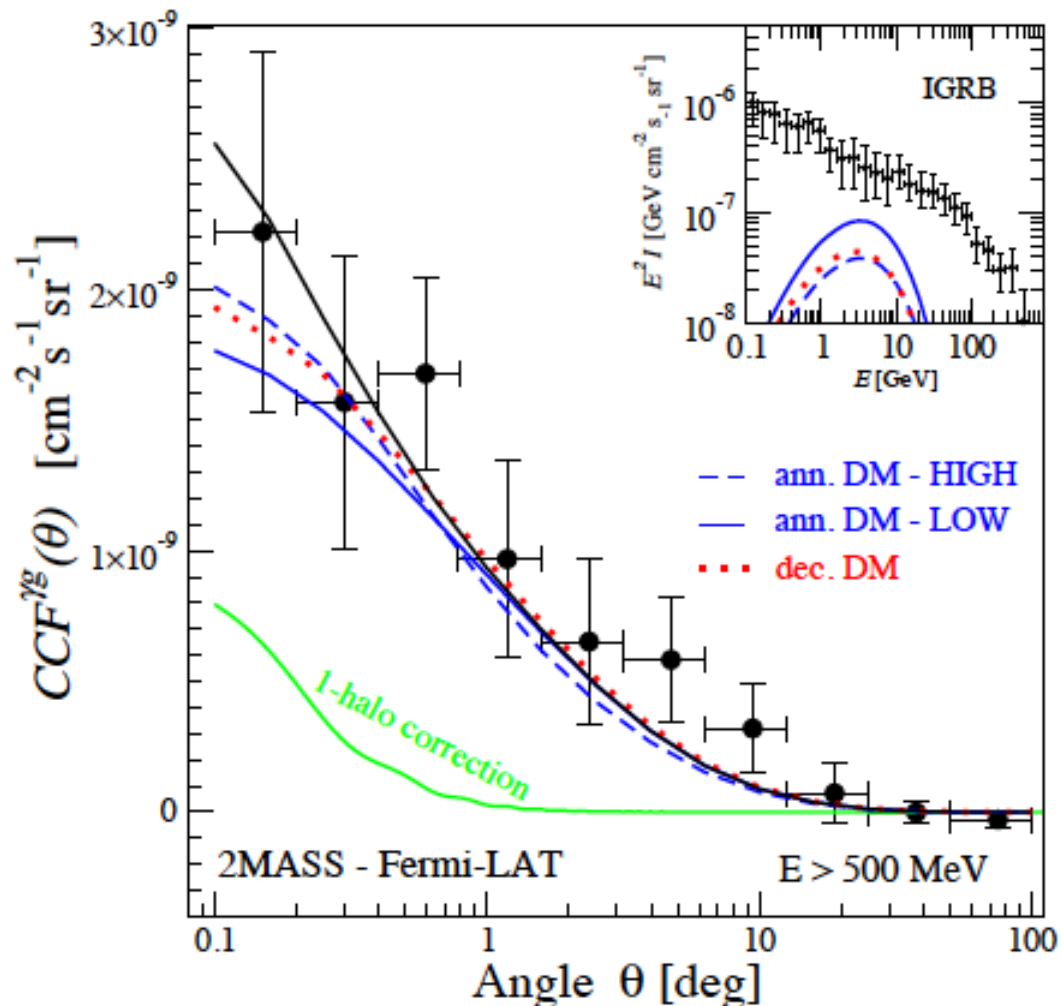
FSRQs contrib $< 10\%$

IGRB - III: dark matter contribution

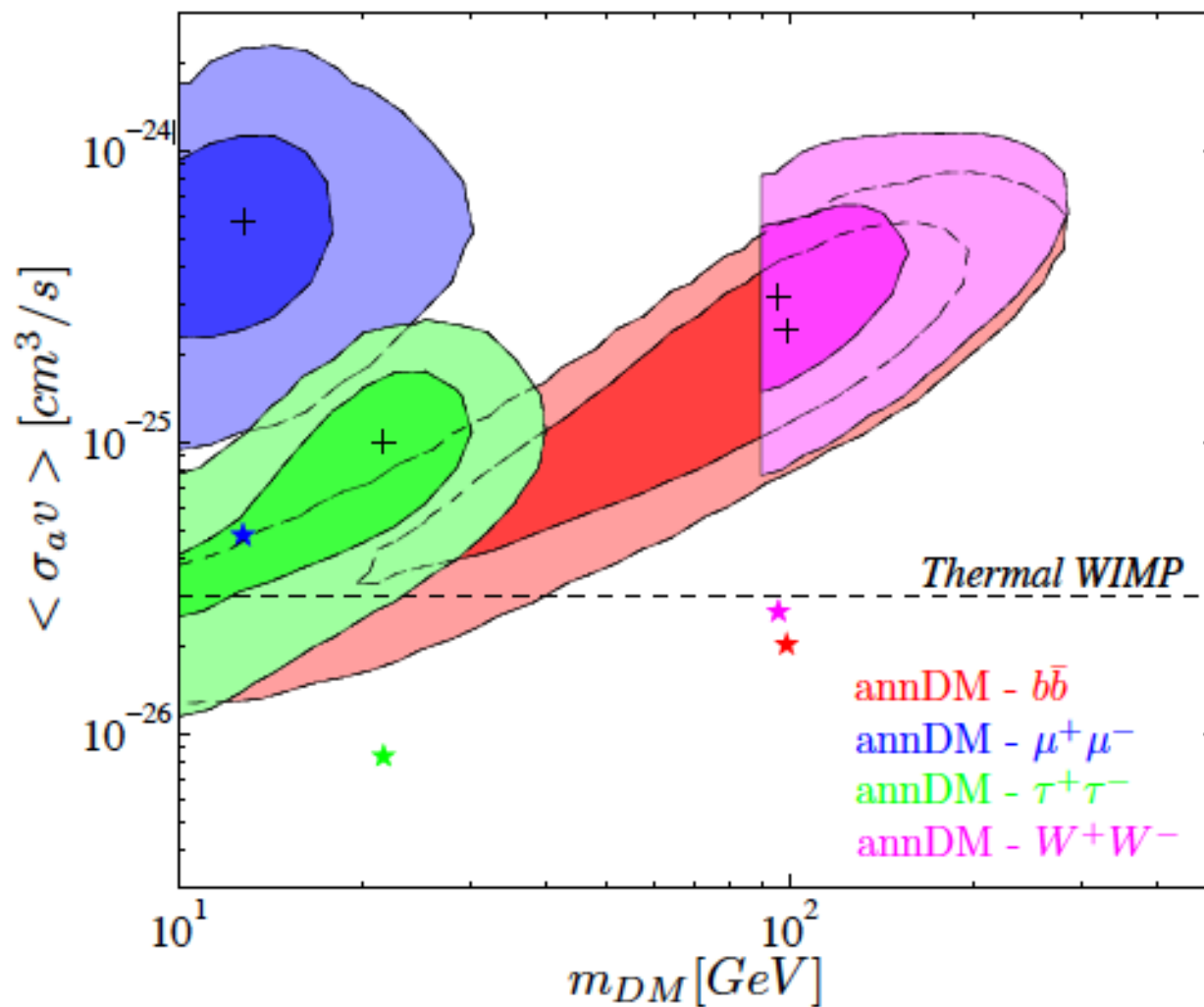
Conservative assumption:
extra contribution due
to dark matter only

$$\begin{aligned} &\text{Annihil.} \propto \Omega_{DM}^2 \frac{\langle \sigma v \rangle}{2m_x^2} \int \rho^2(z) D(z) j_l[k\chi(z)] dz \\ &\text{Decay} \propto \Omega_{DM} \frac{\Gamma_D}{2m_x} \end{aligned}$$

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

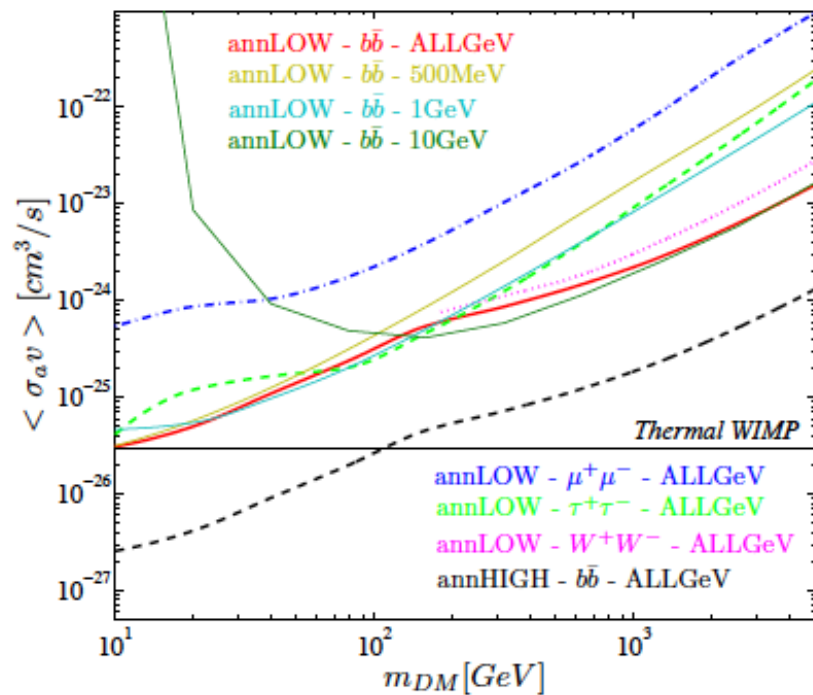


IGRB - IV: dark matter constraints

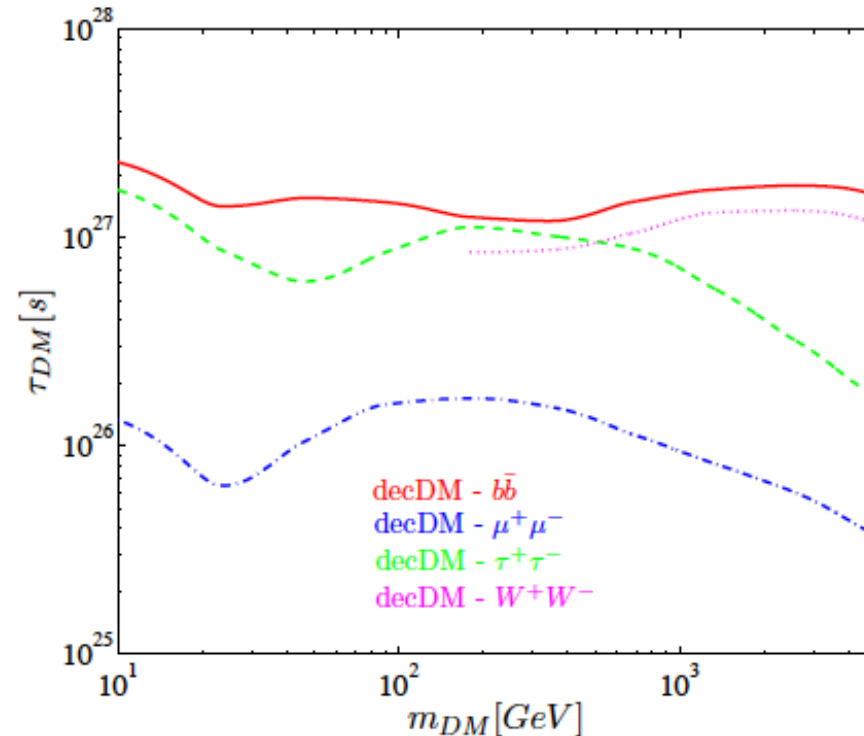


IGRB - IV: dark matter constraints

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

CONCLUSIONS

NEUTRINOS:

no support for non zero neutrino masses from
IGM data total neutrino mass $< 0.12 \text{ eV}$ 2σ C.L.

TIGHTEST CONSTRAINT

WDM:

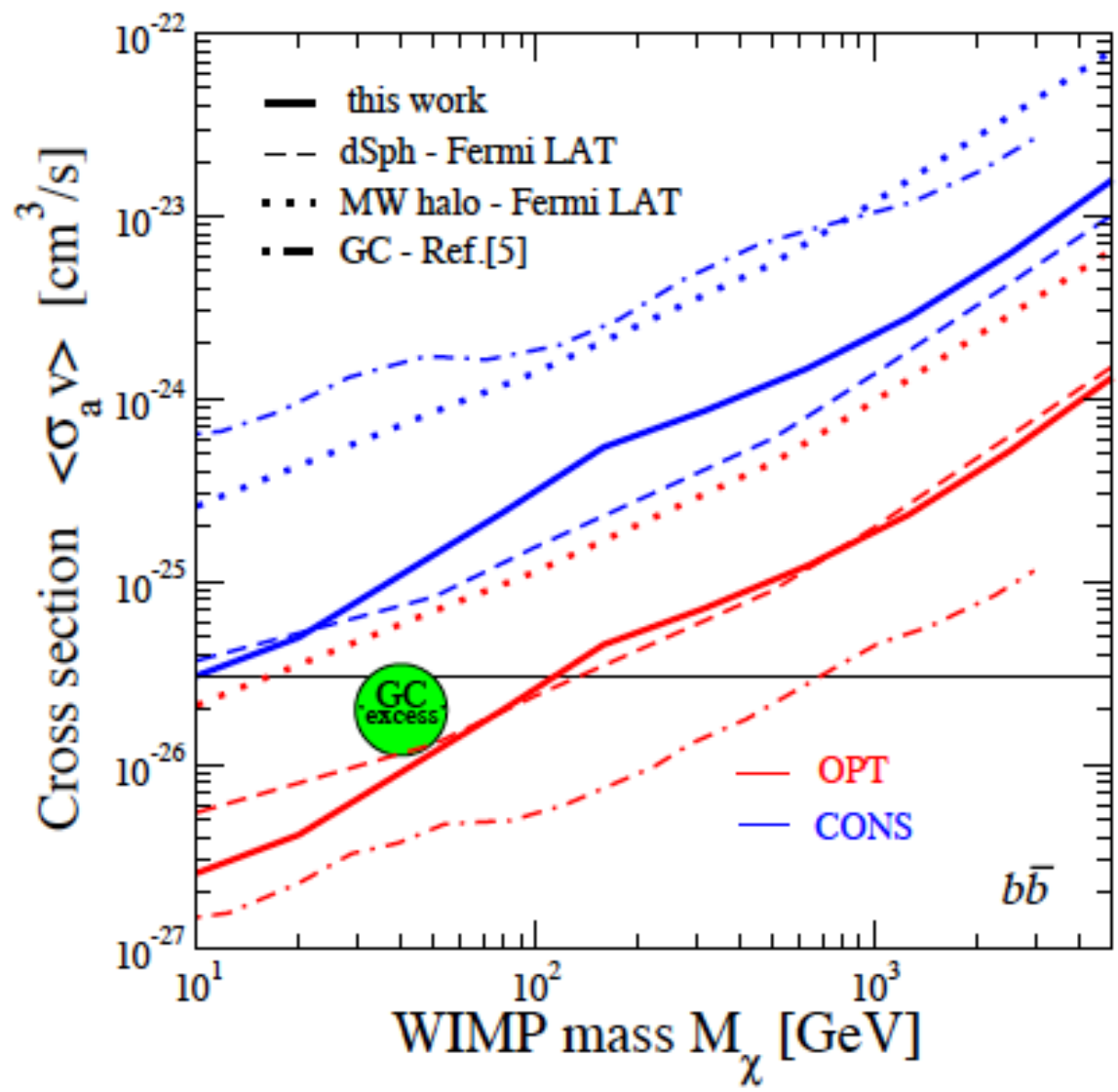
consistency with cold dark matter $> 3.3 \text{ keV}$
relics 2σ C.L.

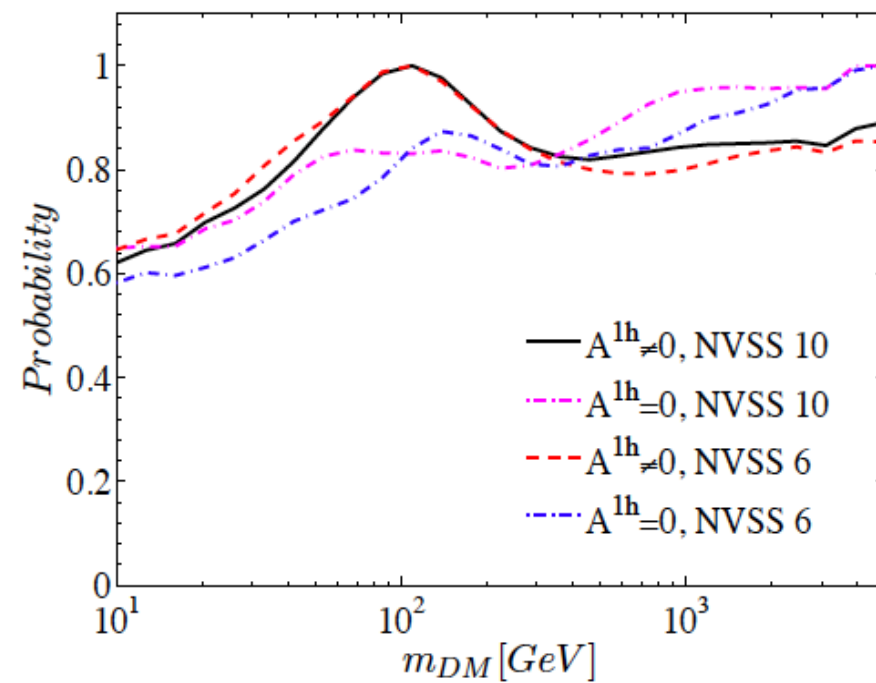
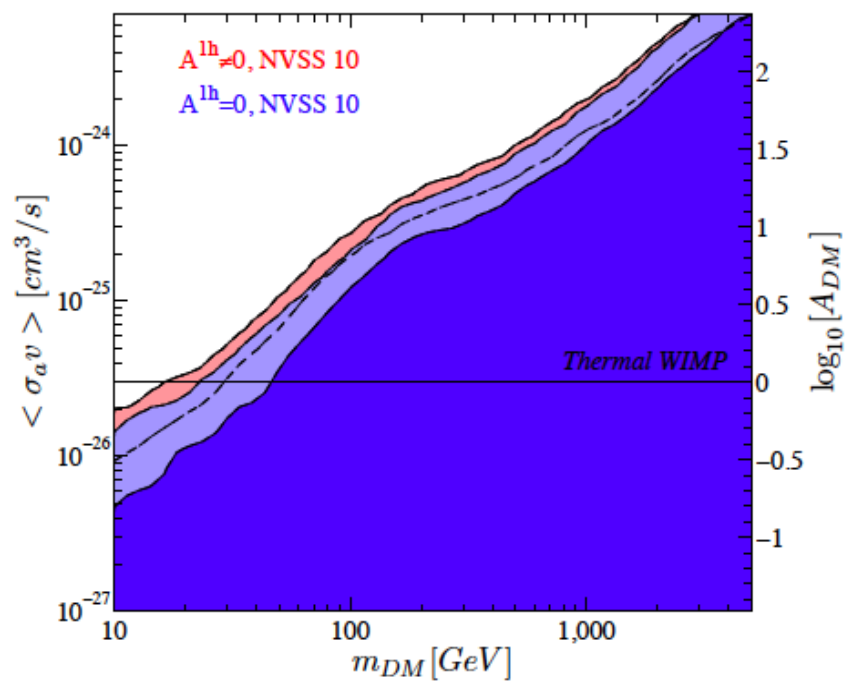
TIGHTEST CONSTRAINT

IGRB:

astro+DM modelling that probes thermal cross
section

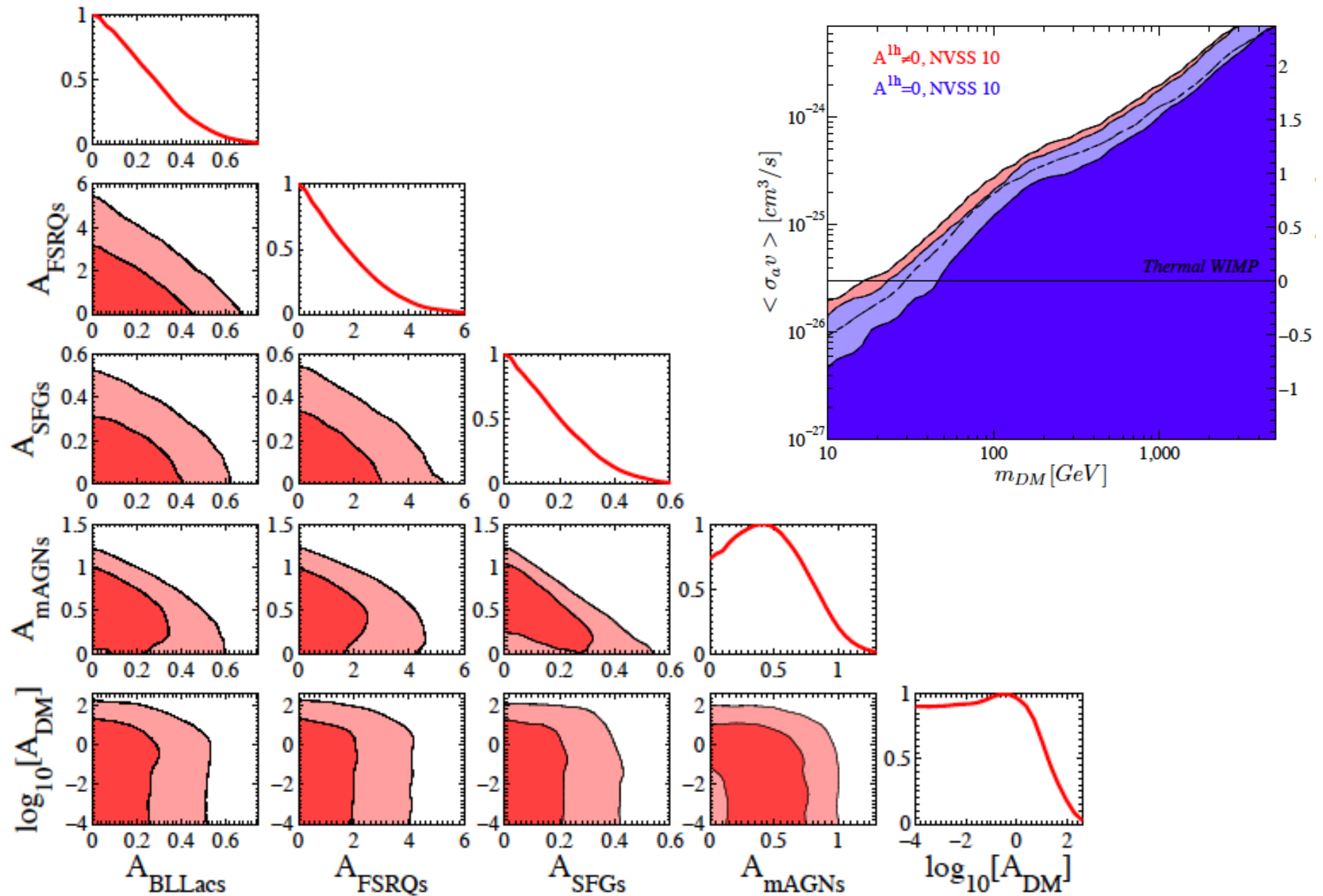
TIGHTEST CONSTRAINT



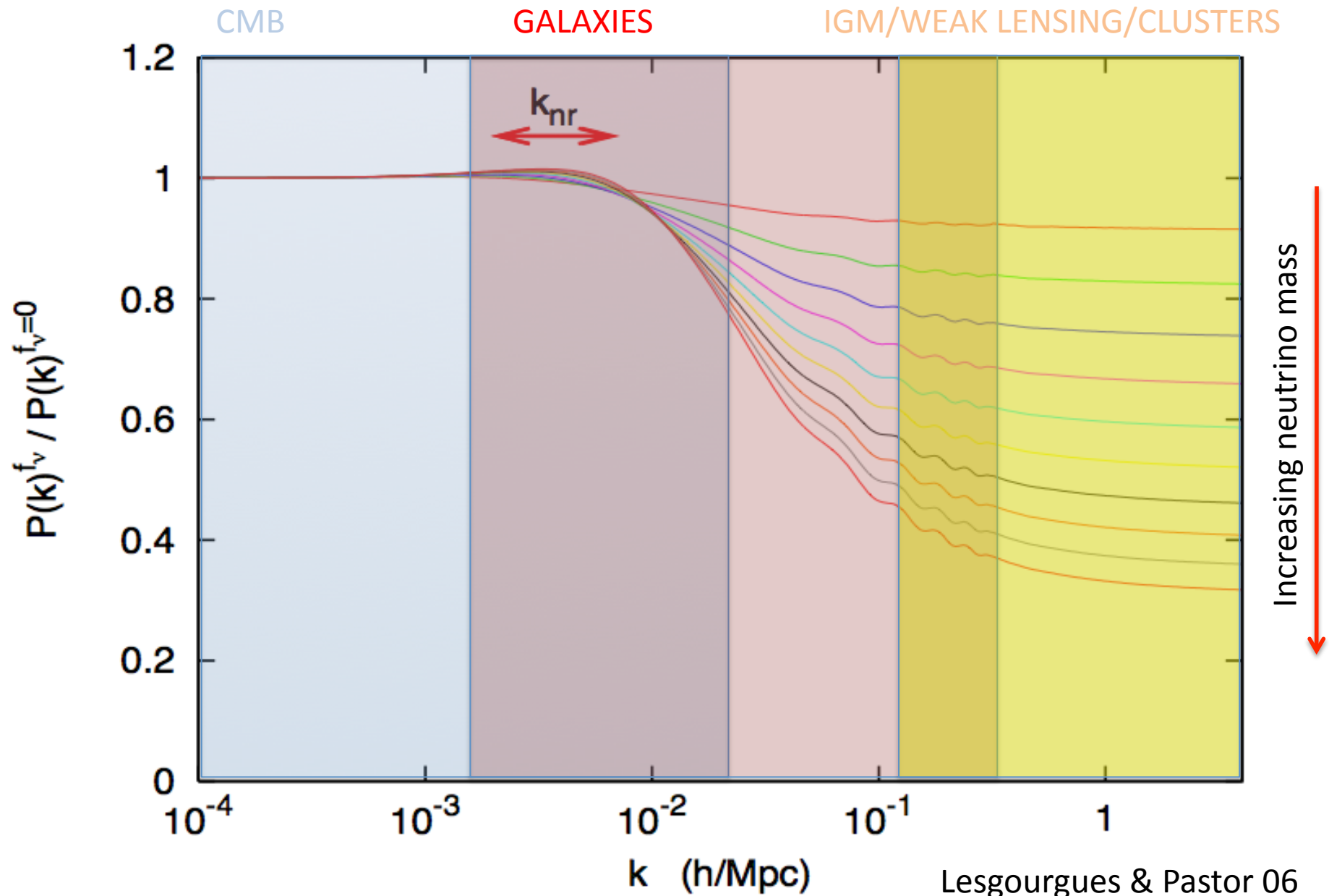


IGRB - V: dark matter + full astro

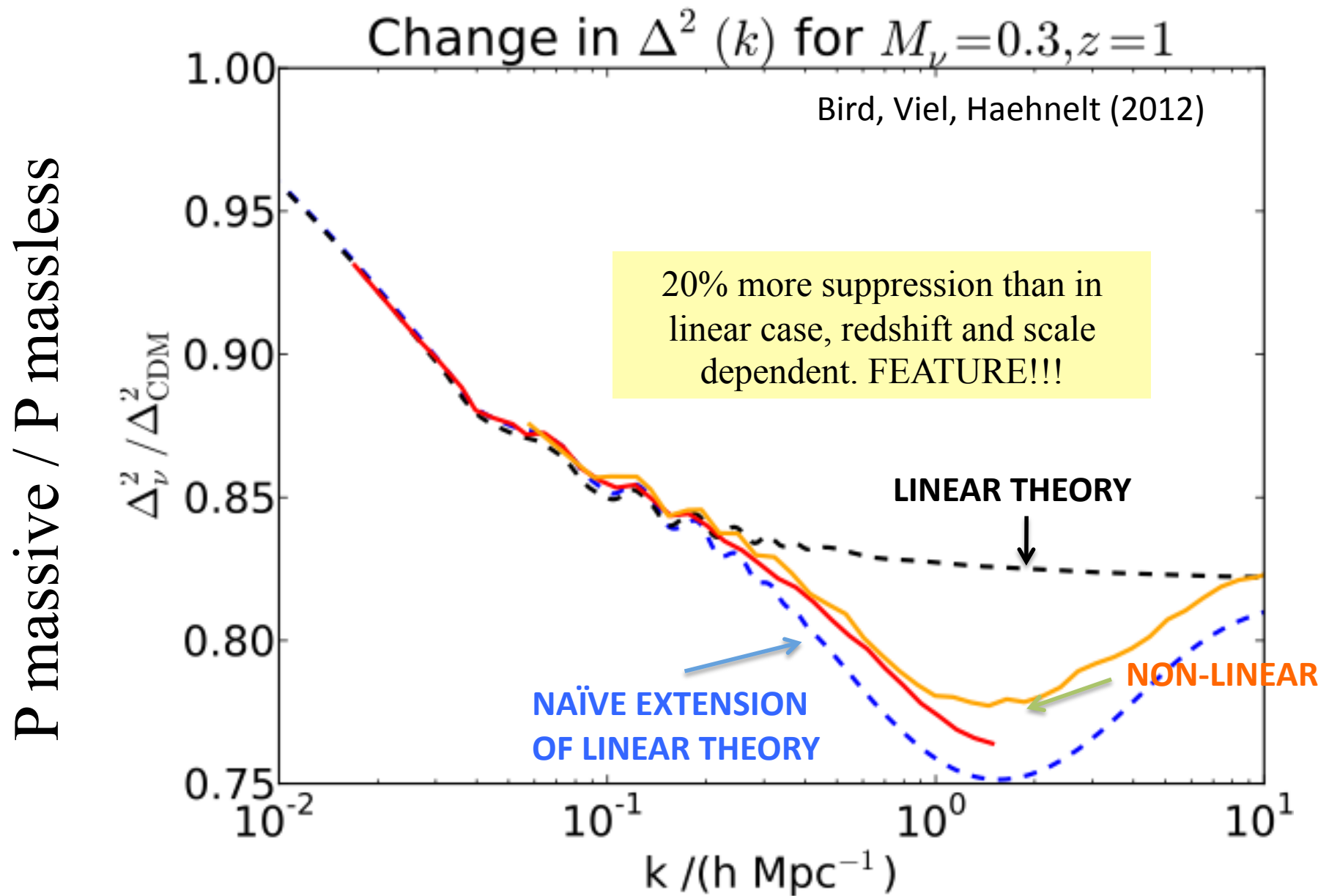
Cuoco+ 2015



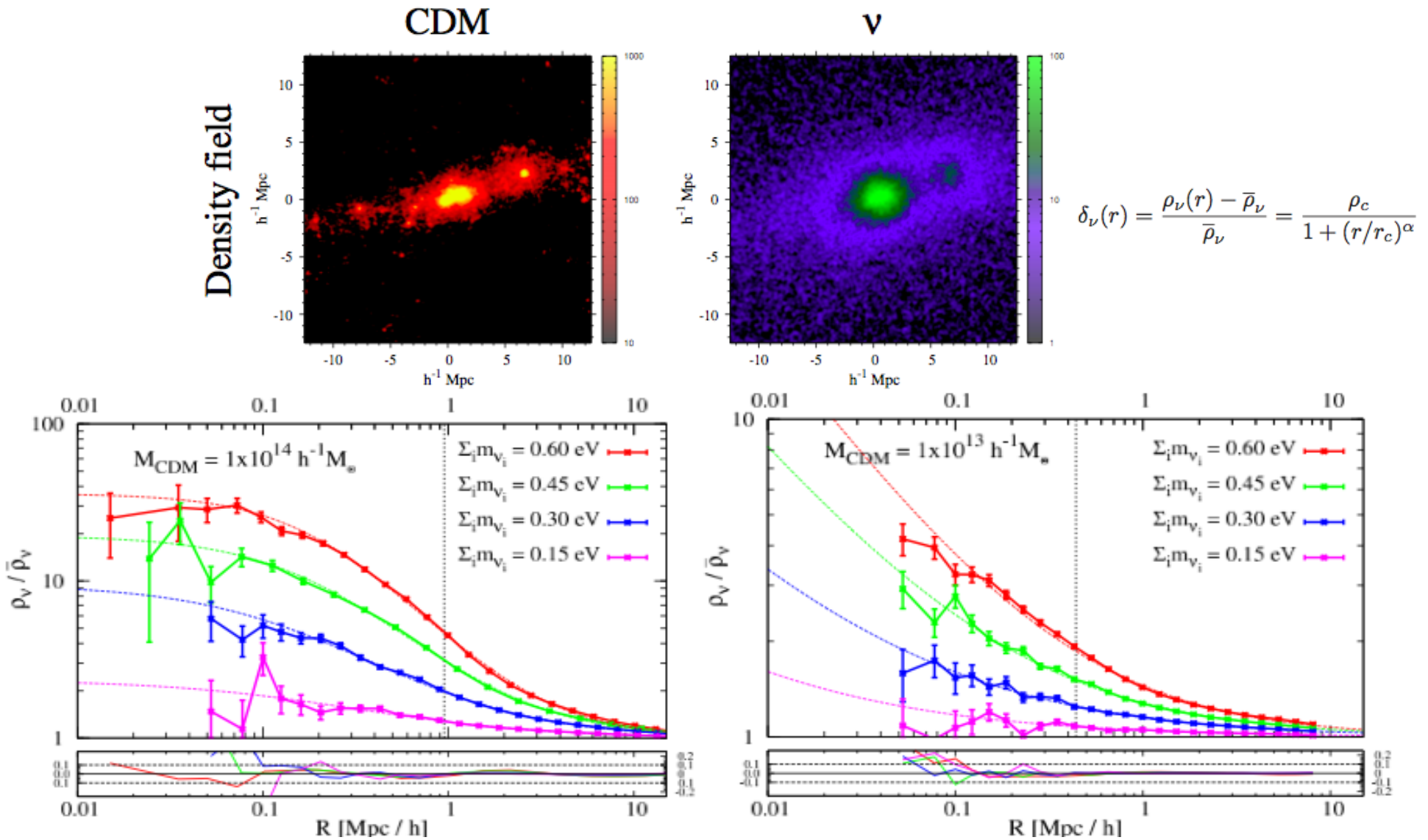
COSMOLOGICAL NEUTRINOS - I: LINEAR MATTER POWER



COSMOLOGICAL NEUTRINOS- II: NON-LINEAR MATTER POWER



COSMO NEUTRINOS –III: CHARACTERIZING THE NEUTRINO HALO



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

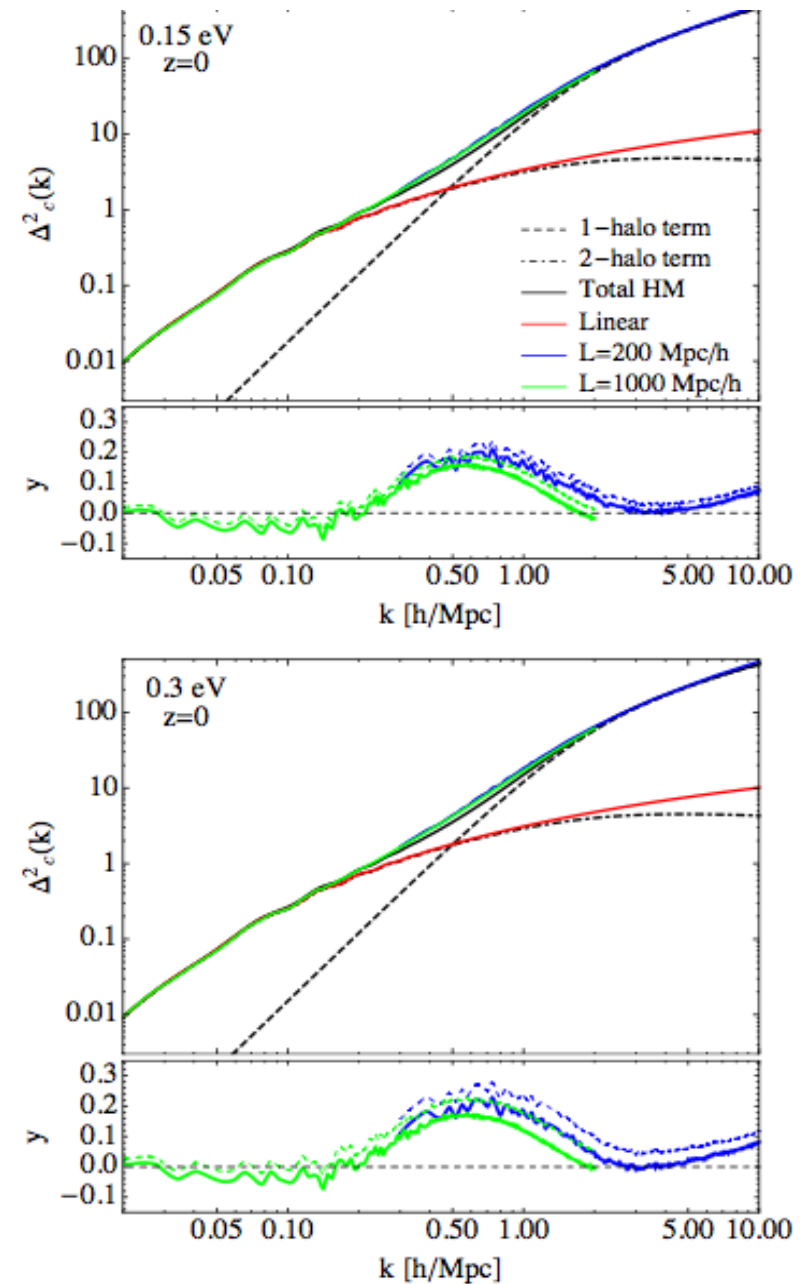
Marulli, Carbone, Viel+ 2011, MNRAS, 418, 346

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

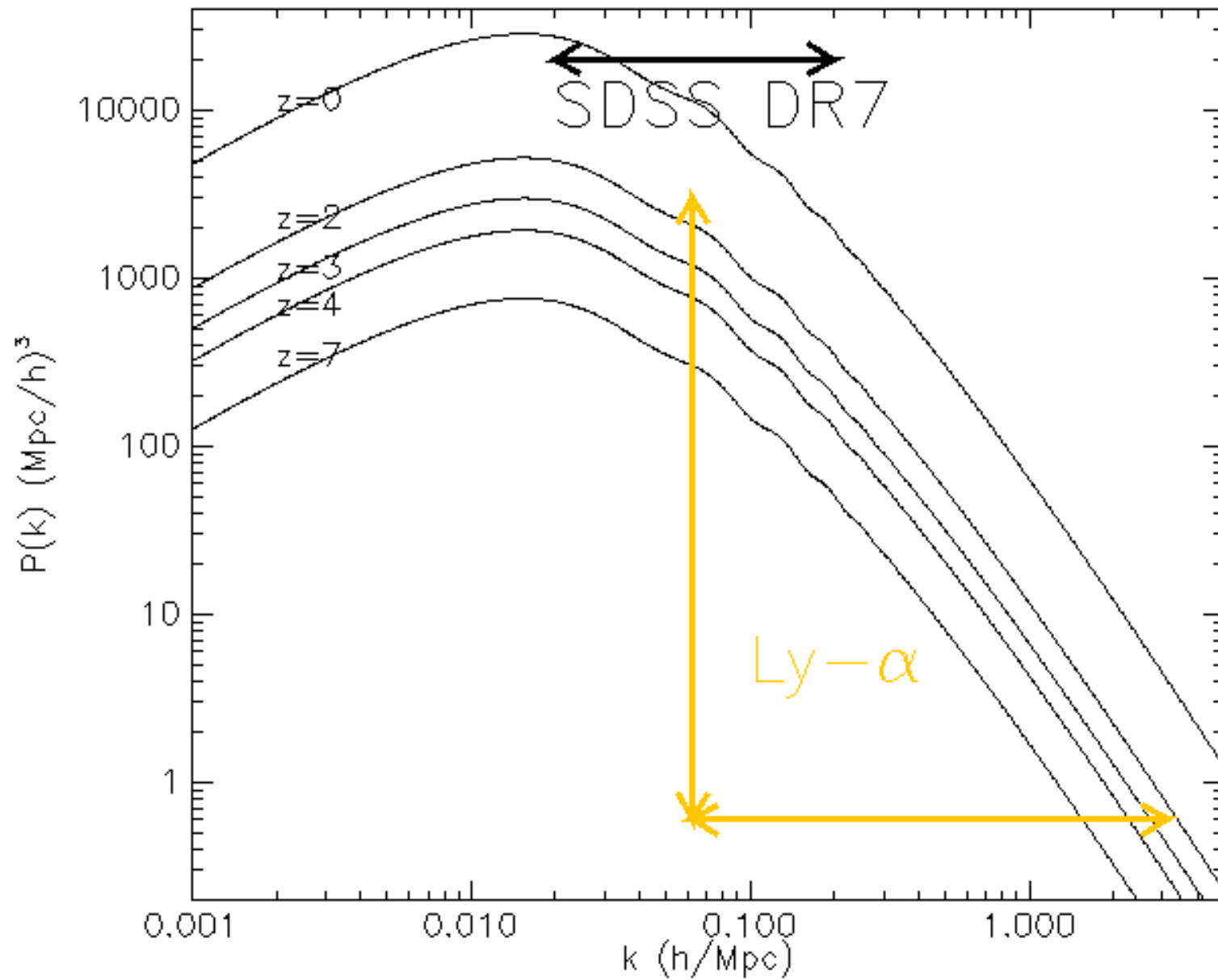
$$P(k) = \left(\frac{\bar{\rho}_c}{\bar{\rho}}\right)^2 P_c(k) + 2 \frac{\bar{\rho}_c \bar{\rho}_\nu}{\bar{\rho}^2} P_{c\nu}(k) + \left(\frac{\bar{\rho}_\nu}{\bar{\rho}}\right)^2 P_\nu(k)$$

- 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

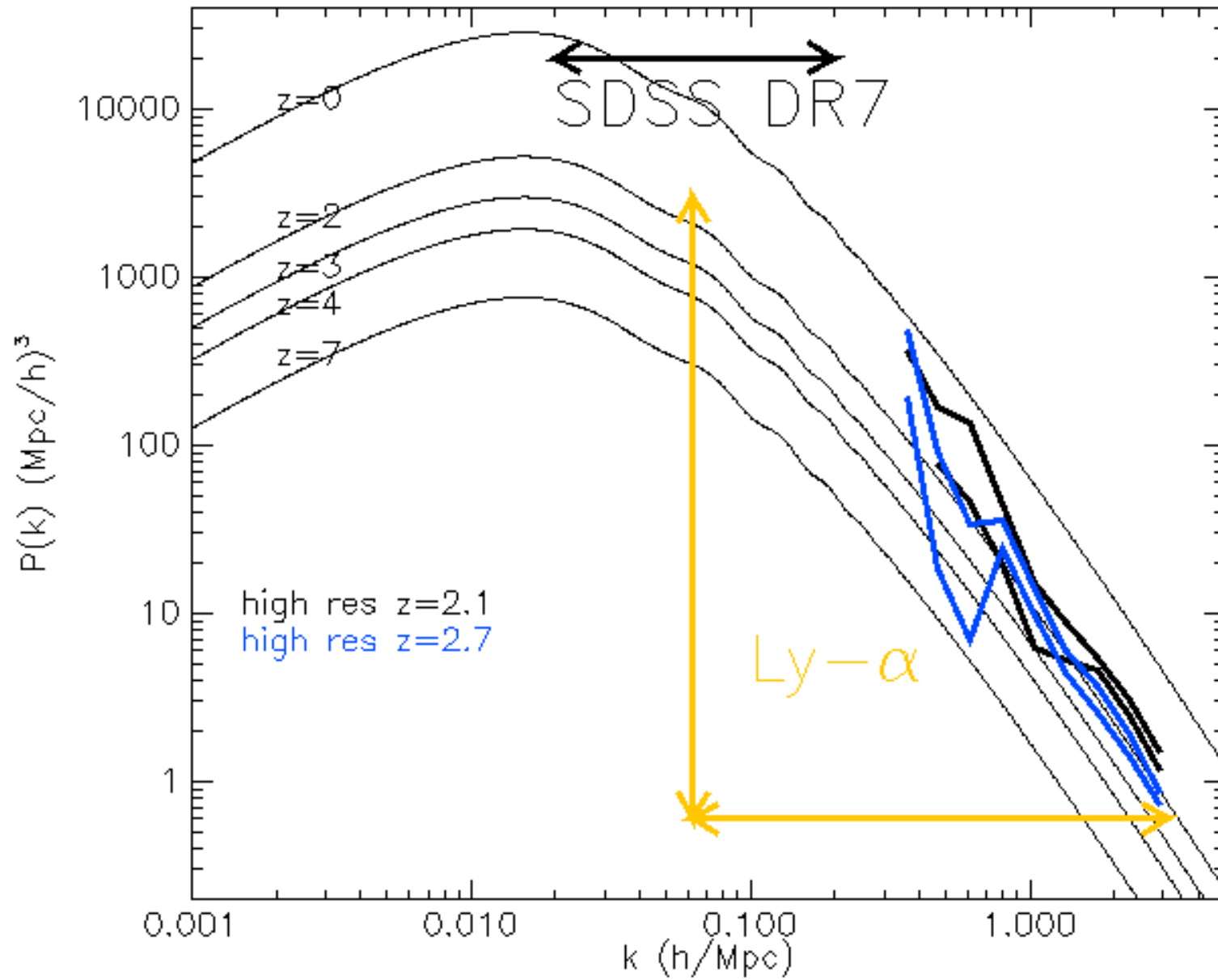


DATA vs THEORY

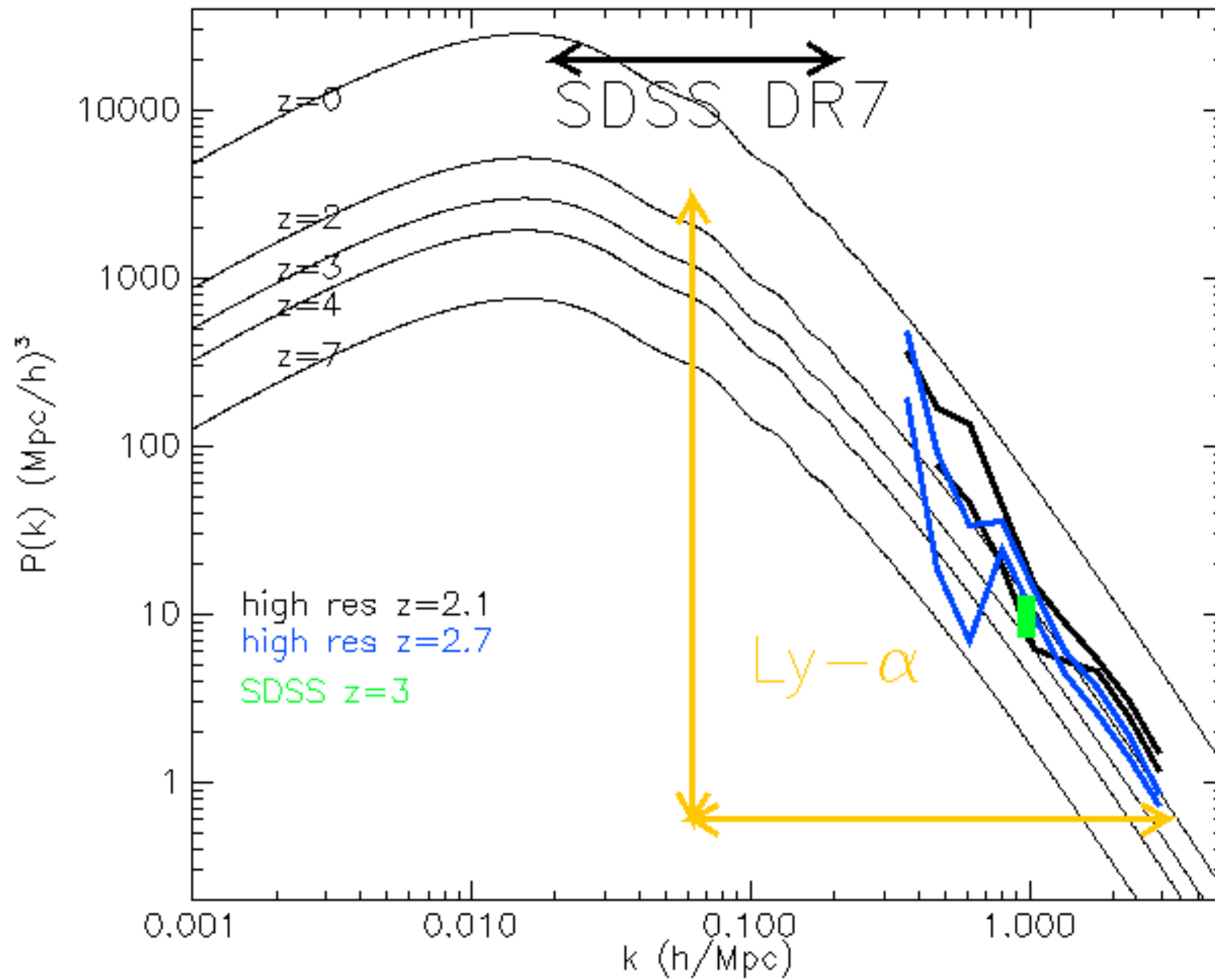


DATA vs THEORY

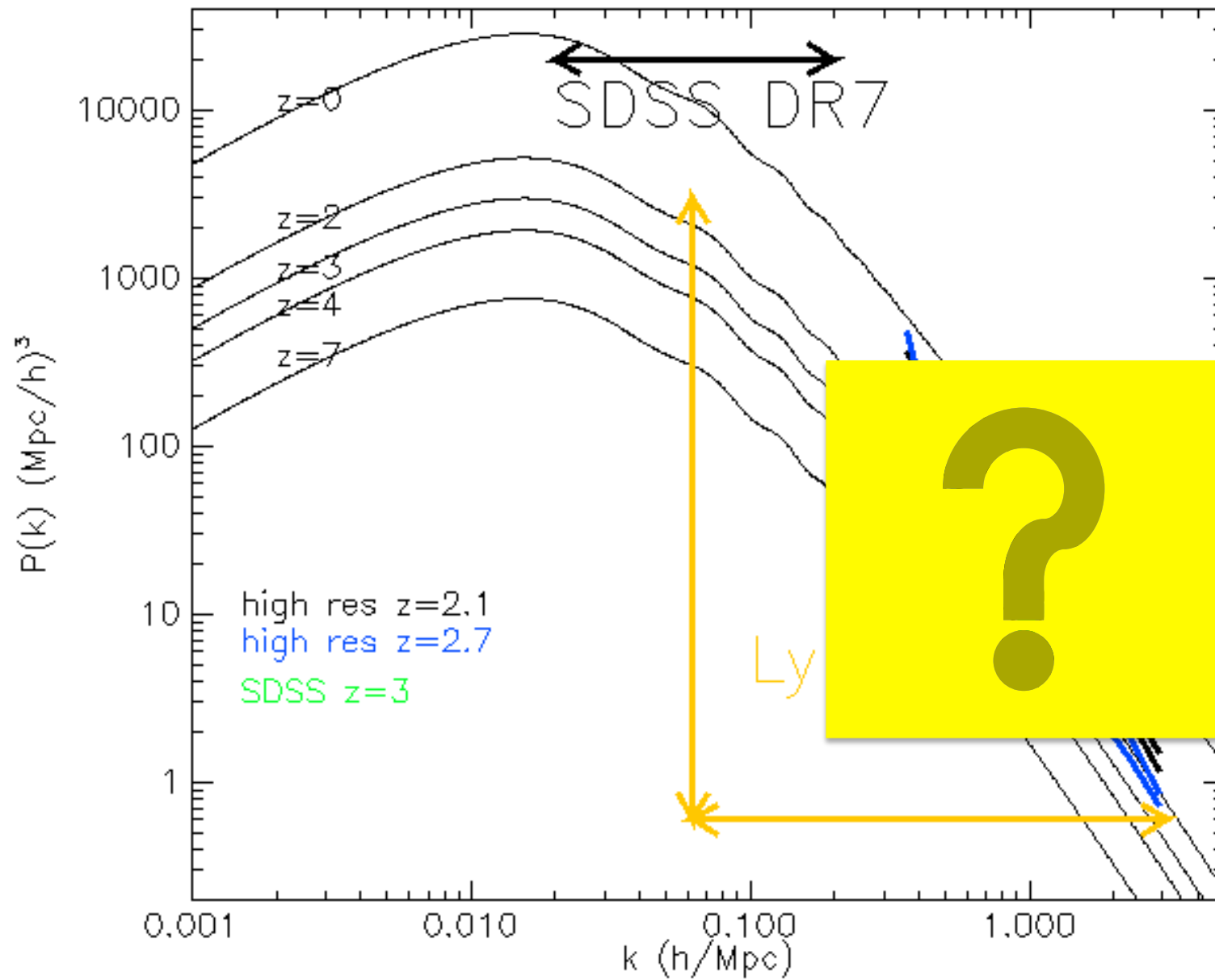
$$P_{\text{FLUX}}(k,z) = \text{bias}^2(k,z) \times P_{\text{MATTER}}(k,z)$$



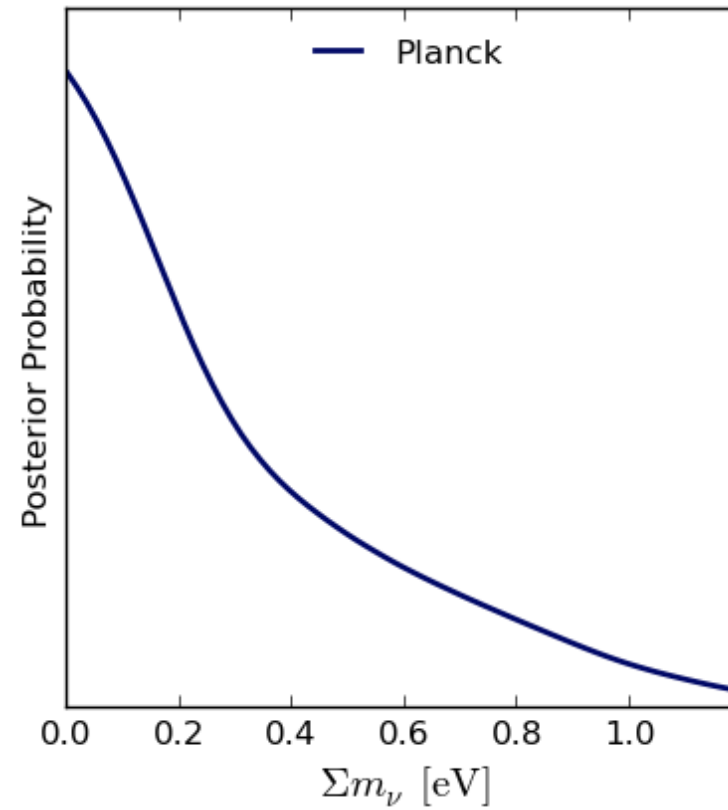
DATA vs THEORY



DATA vs THEORY

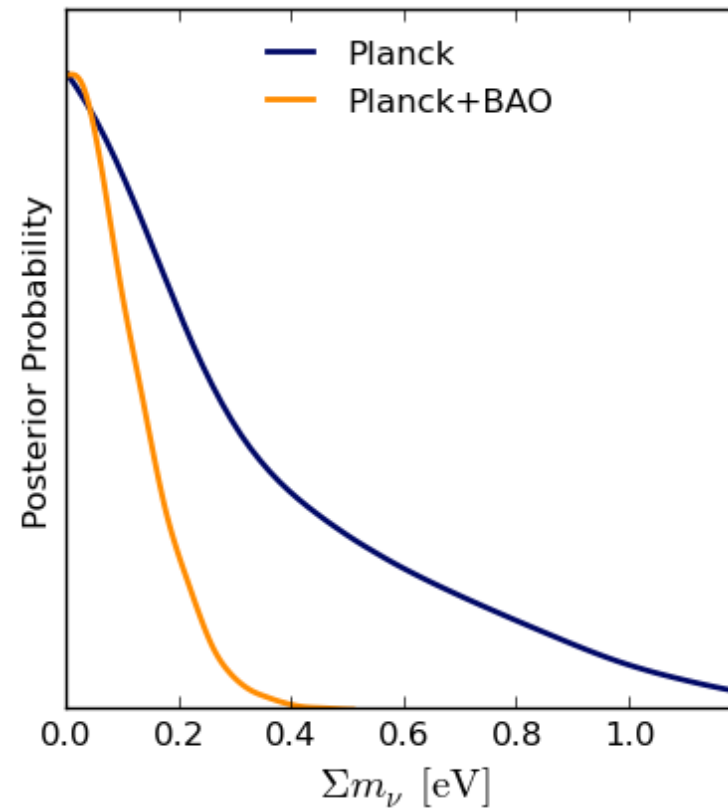


CONSTRAINTS on NEUTRINO MASSES FROM Planck: I



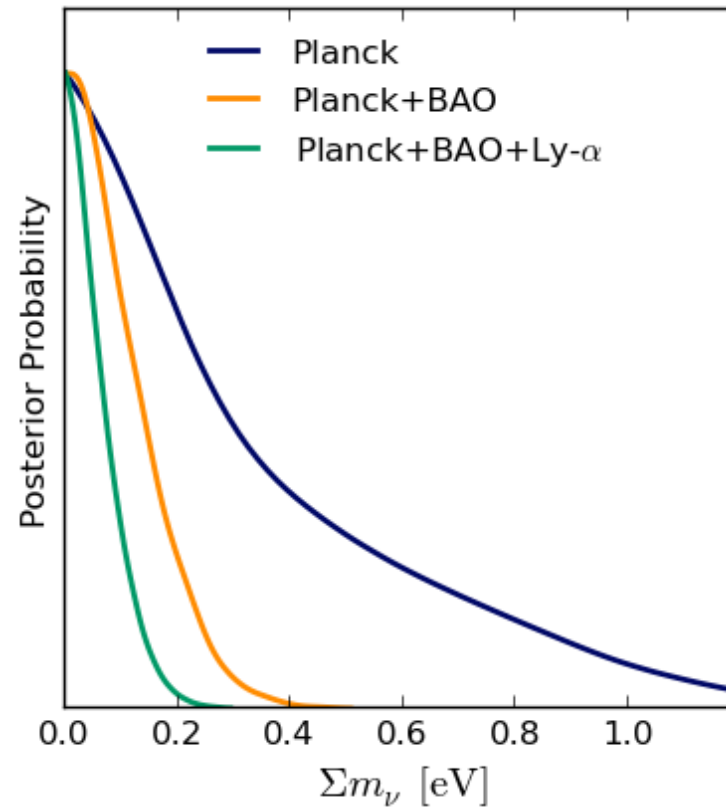
$$\Sigma m_\nu < 0.93 \text{ eV} (2\sigma)$$

CONSTRAINTS on NEUTRINO MASSES FROM Planck+BAO: II



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

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

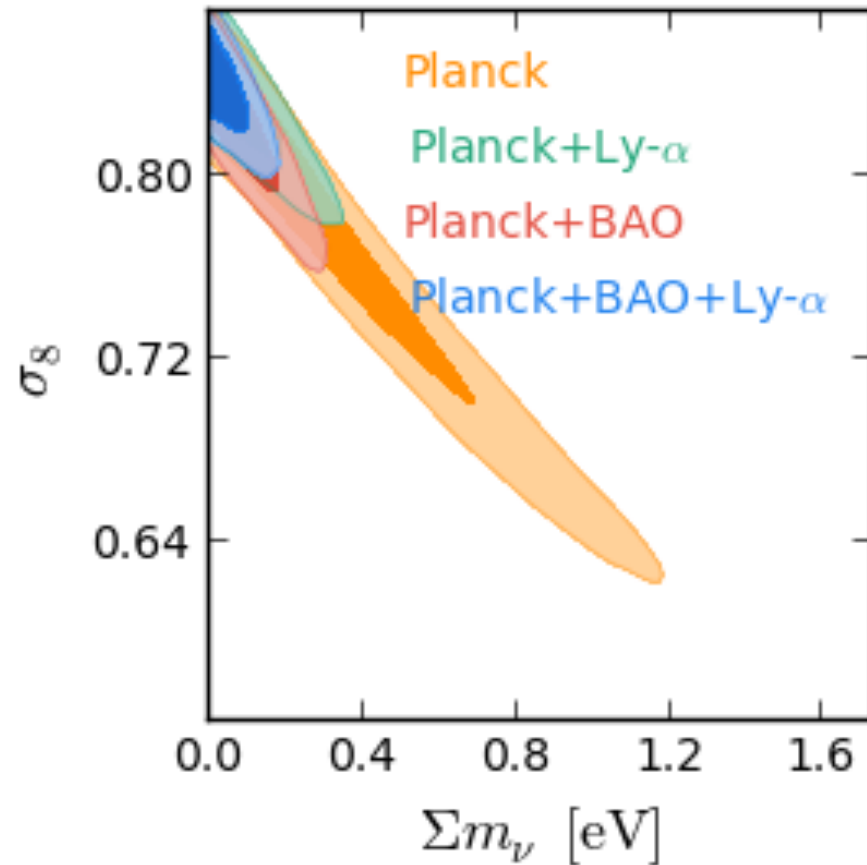


$$\Sigma m_\nu < 0.14 \text{ eV} (2\sigma)$$

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

2 σ upper limits

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



2 eV
29 eV
59 eV
9 eV

GRID OF HYDRODYNAMICAL SIMULATIONS

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

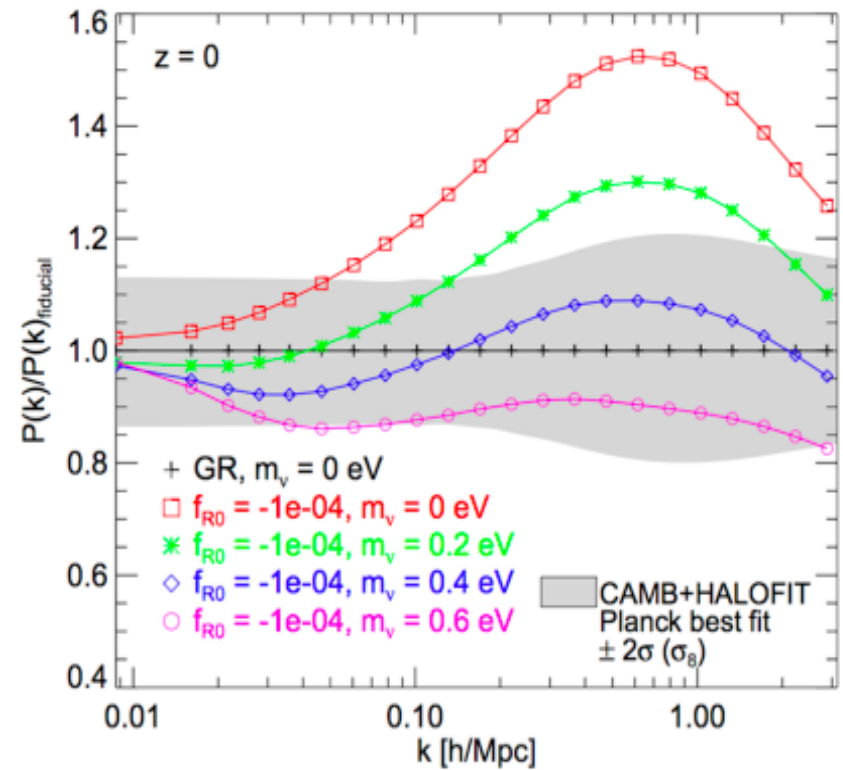
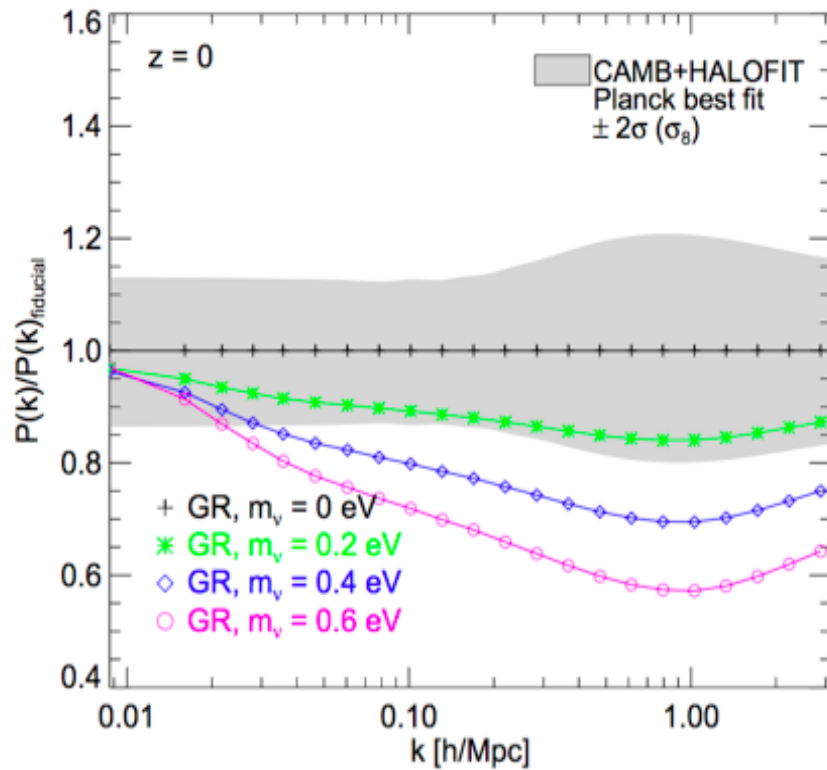
Astrophysics usually has a different redshift evolution compared to cosmology!

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

FINAL NUMBERS

Parameter	$Ly\alpha + H_0^{\text{tophat}}$ ($62.5 \leq H_0 < 72.5$)	$Ly\alpha + \text{CMB}$	$Ly\alpha + \text{CMB}$ + BAO	$Ly\alpha + \text{CMB}(A_L)$
$10^9 A_s$	$3.2^{+0.5}_{-0.7}$	$2.20^{+0.05}_{-0.06}$	$2.20^{+0.05}_{-0.06}$	$2.18^{+0.05}_{-0.06}$
$10^2 \omega_b$	(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