Cutoff in the Lyman-alpha forest power spectrum: warm IGM or warm dark matter?

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Thanks to: Matteo Viel

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Dark Matter exists

It must be a new particle:
neutrinos cannot be the dark matter, because they should be light in order to be the cosmological dark matter, but they would be too light to form dwarf galaxies

Resolution:

- particle that is either heavy

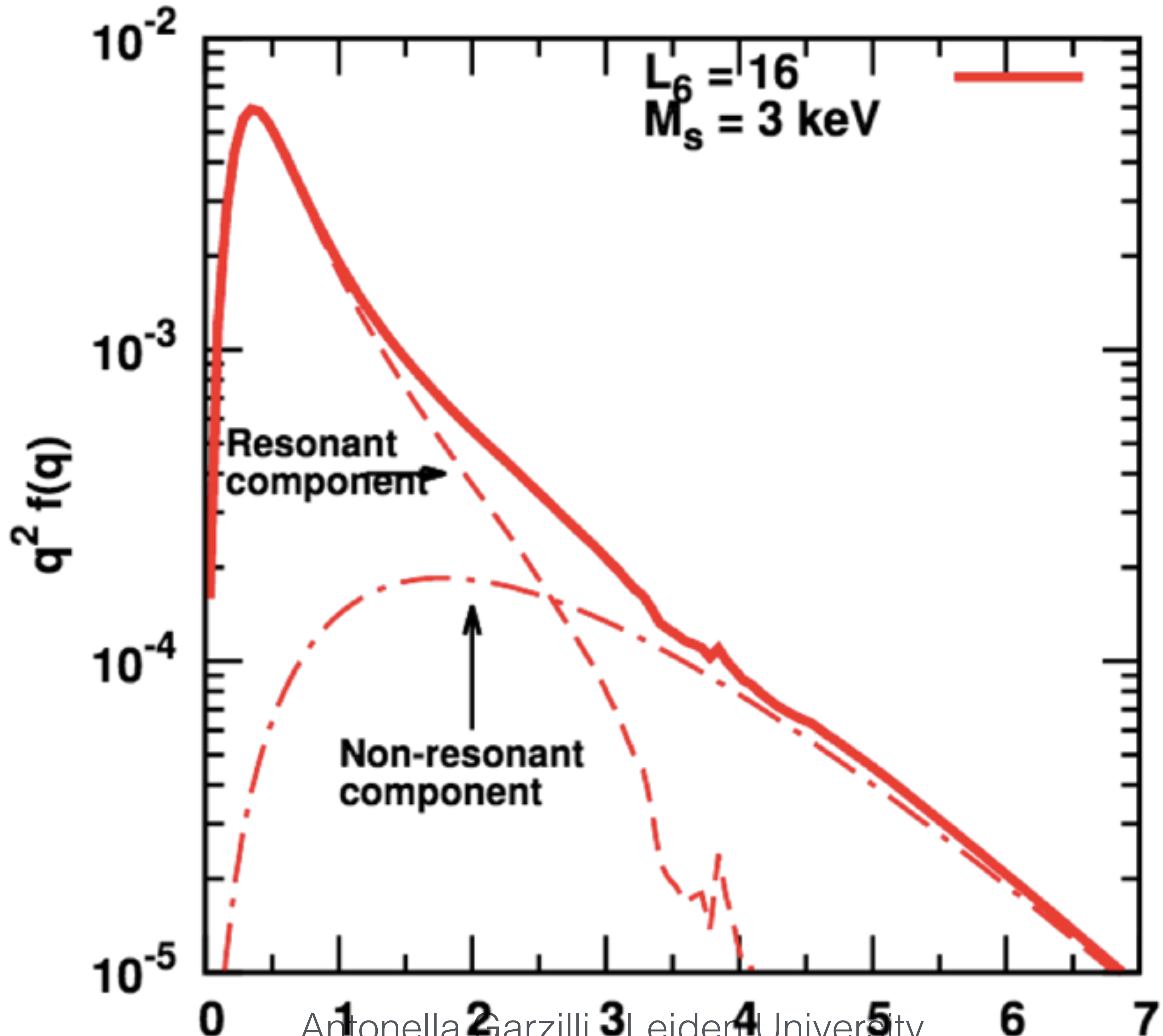
or

- interacts weaker than neutrinos

or

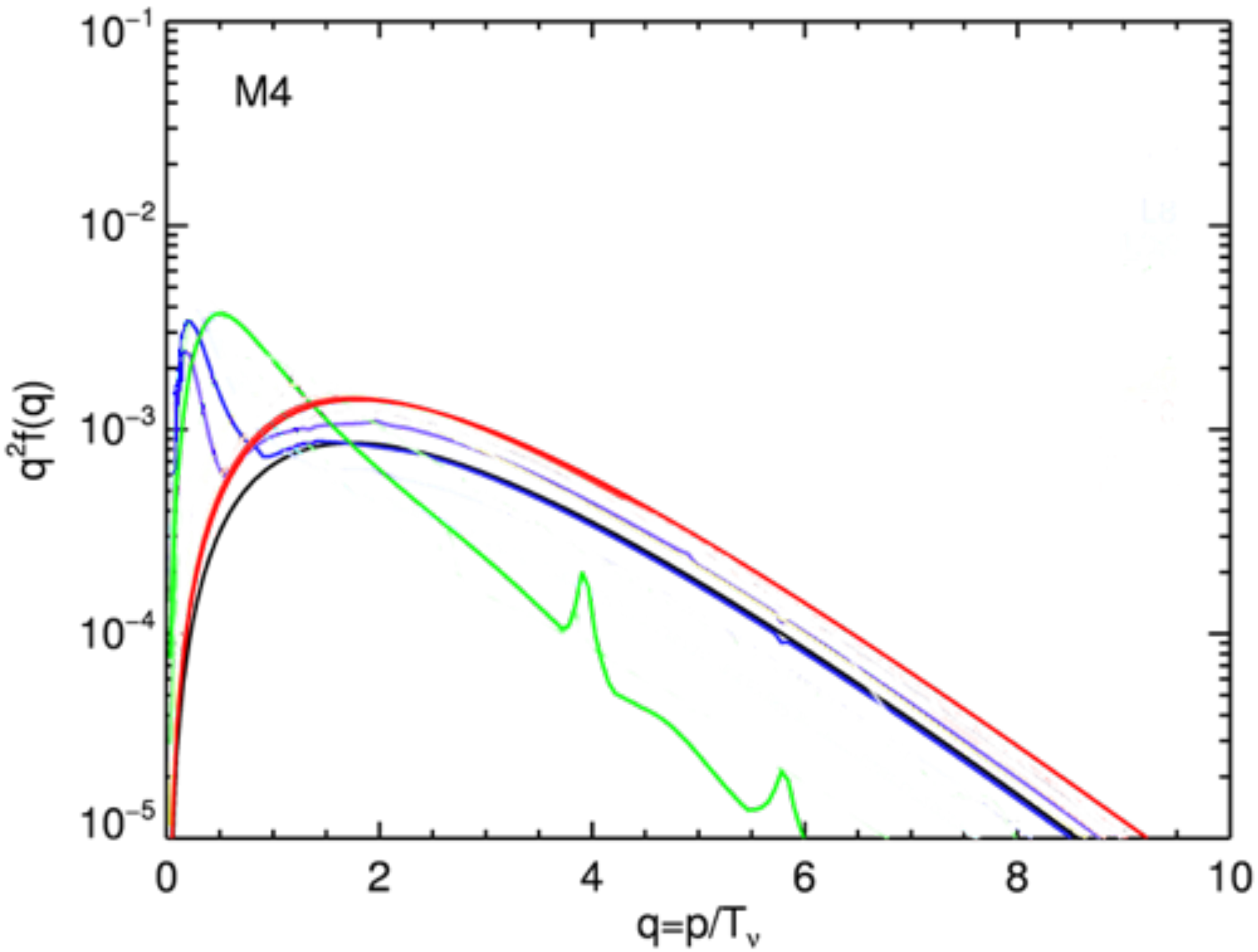
- be a boson like axions

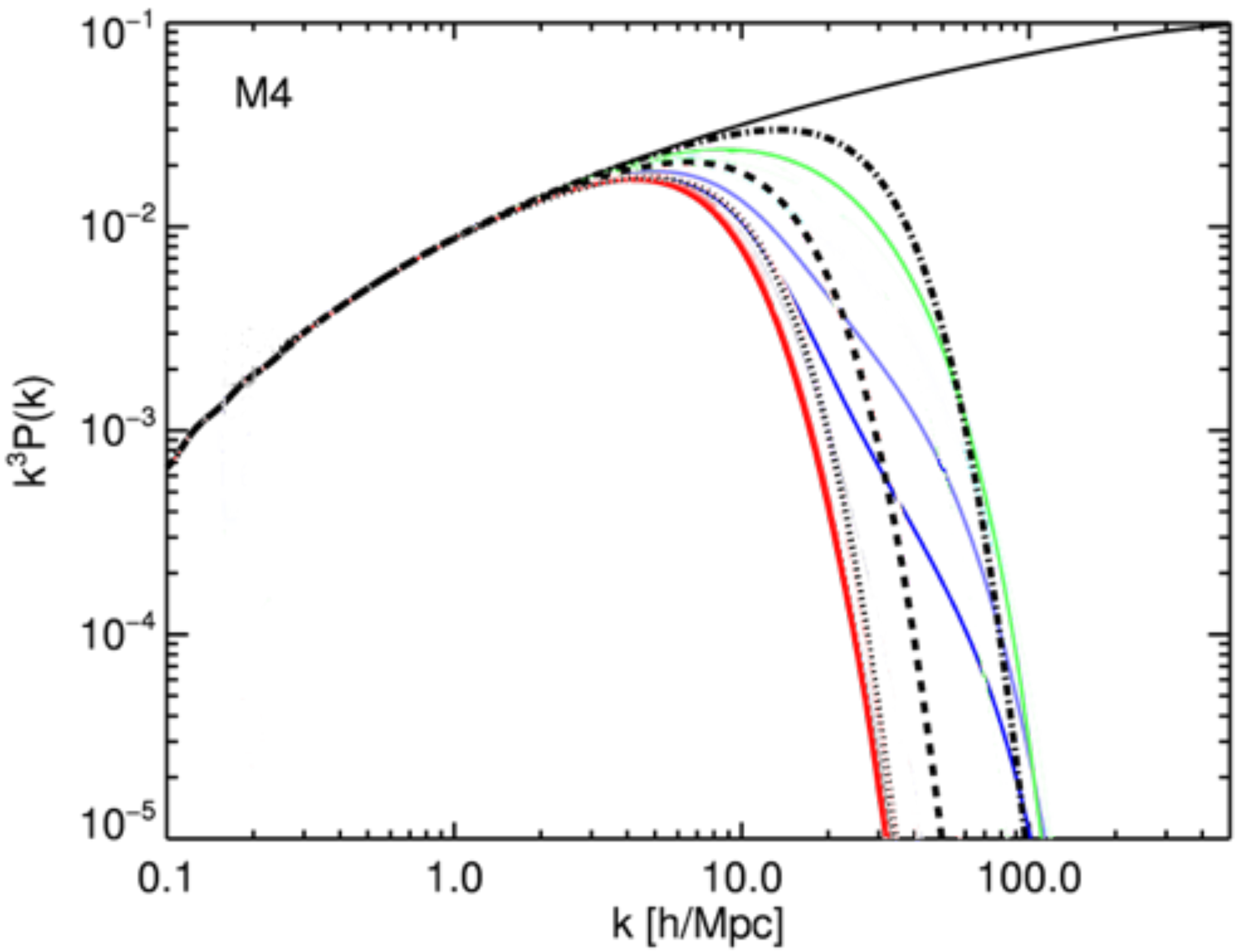
Sterile neutrinos production



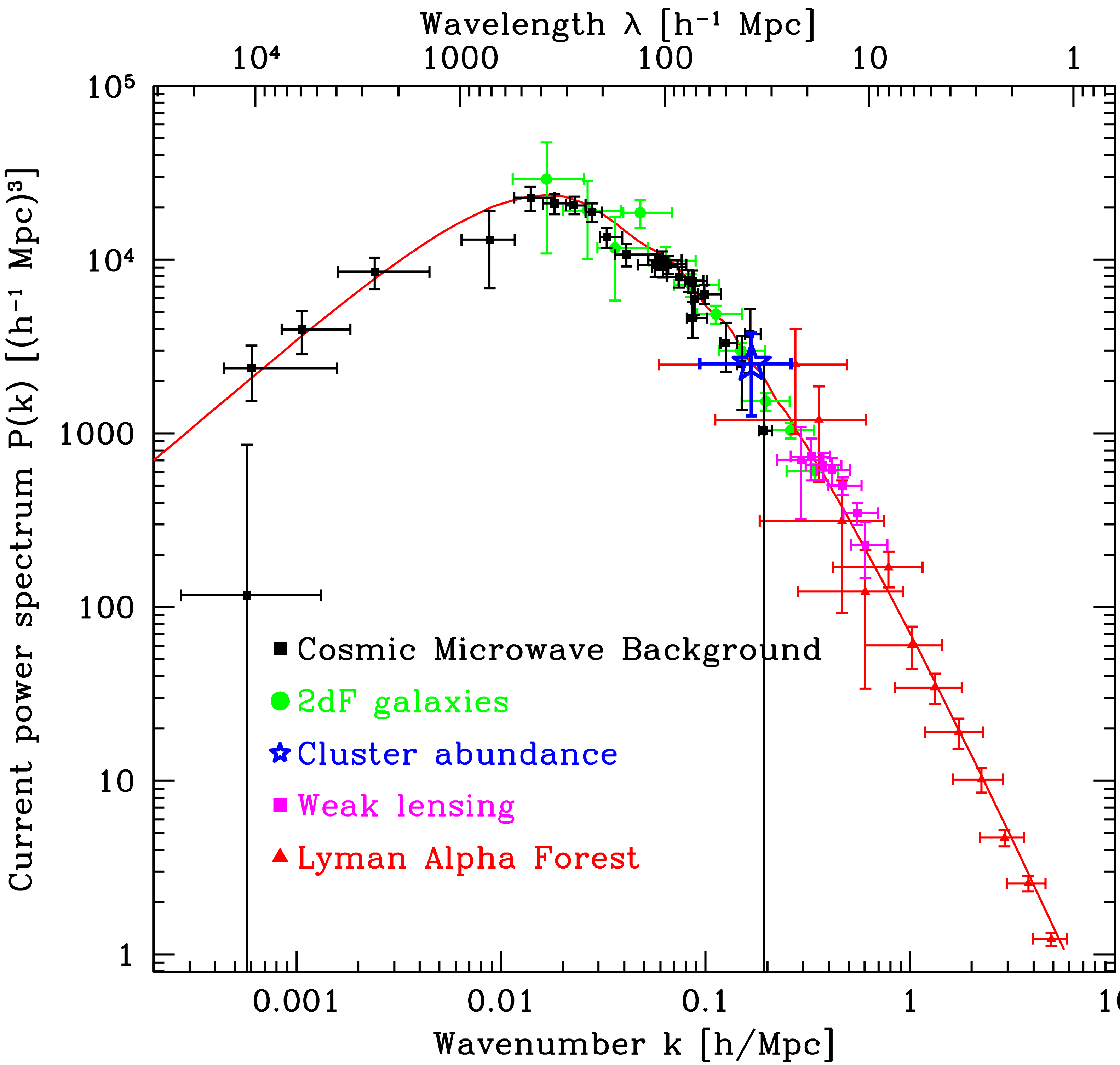
Warm Dark Matter and Sterile Neutrinos

(Laine & Shaposhnikov 2008)
(Mark Lovell)



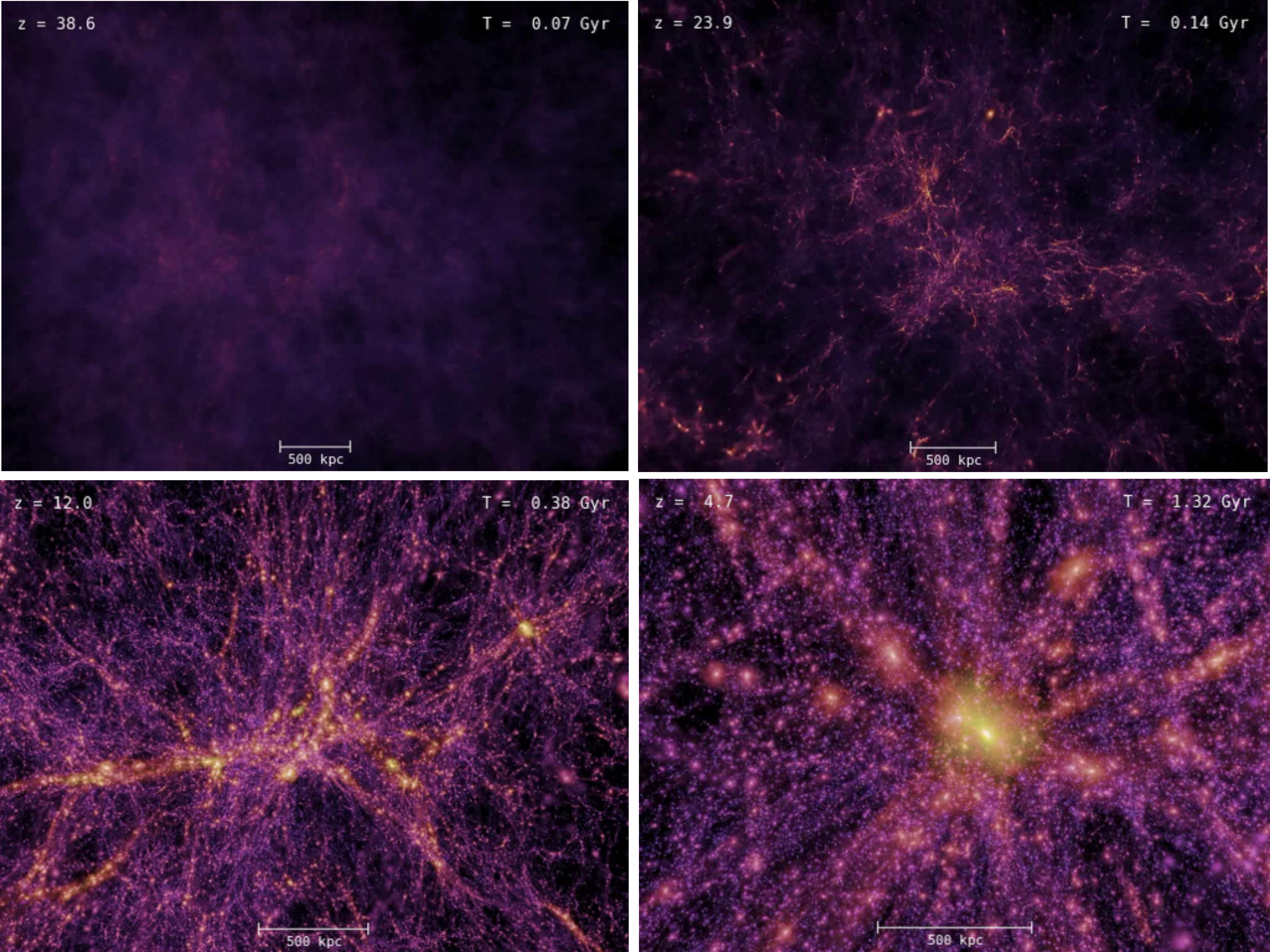


(Viel et al, 2005) $m^{NRP}_{\mathrm{sterile}\nu} = 4.43\,\mathrm{keV}\left(\frac{m_{\mathrm{thermal}}}{1\,\mathrm{keV}}\right)^{4/3}\left(\frac{0.12}{\Omega_\nu h^2}\right)^{1/3}$

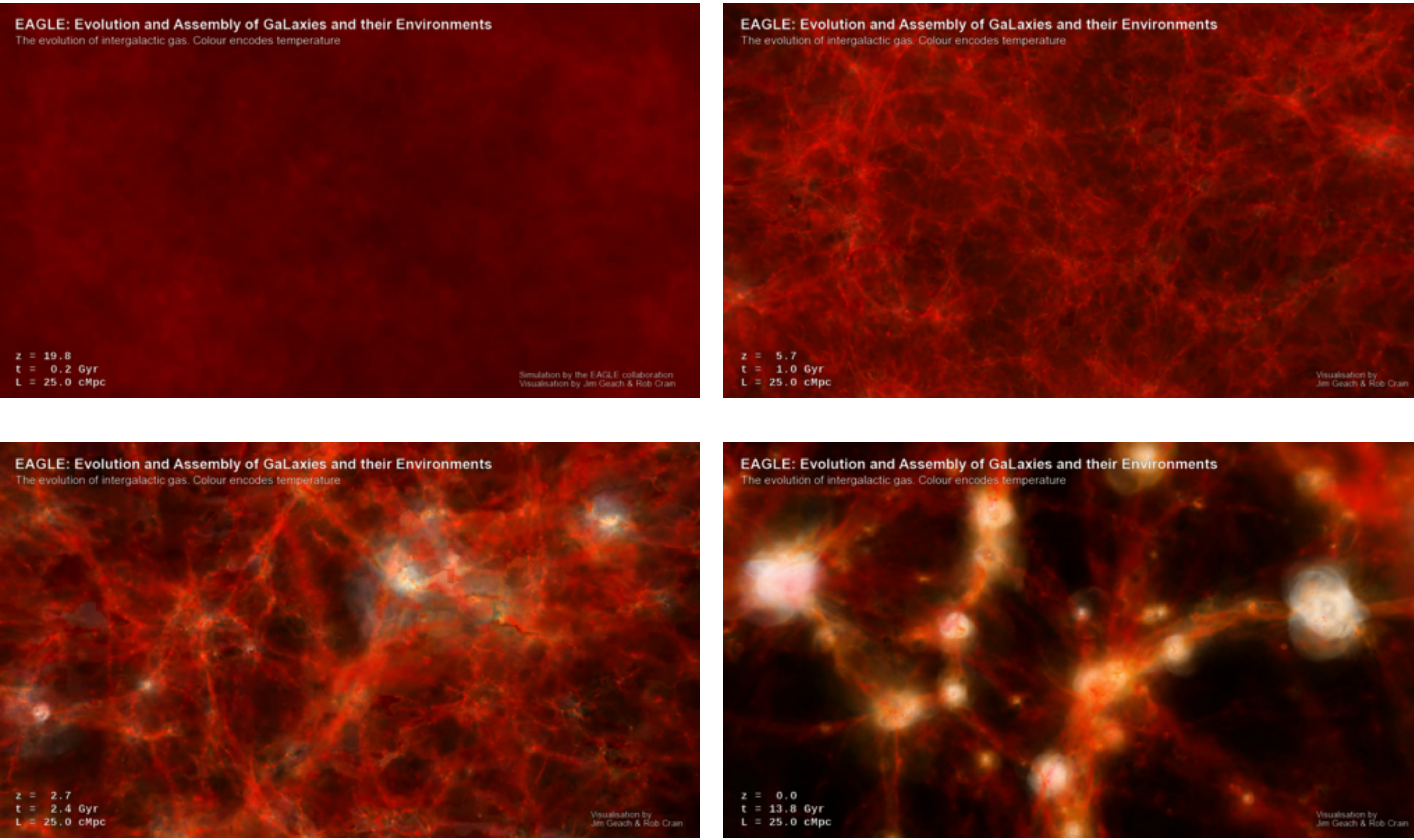


Wavelength λ [h⁻¹ Mpc]
10⁴
1000
100
10
1
10⁵
10⁴
1000
100
10
1
Current power spectrum P(k) [(h⁻¹ Mpc)³]
Cosmic Microwave Background
2dF galaxies
Cluster abundance
Weak lensing
Lyman Alpha Forest
0.001
0.01
0.1
1
10
Wavenumber k [h/Mpc]

(Tegmark)

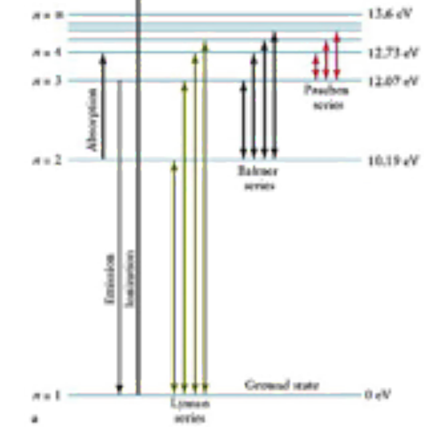

z = 38.6
T = 0.07 Gyr
500 kpc
z = 23.9
T = 0.14 Gyr
500 kpc
z = 12.0
T = 0.38 Gyr
500 kpc
z = 4.7
T = 1.32 Gyr
500 kpc

Baryons in cosmological simulations

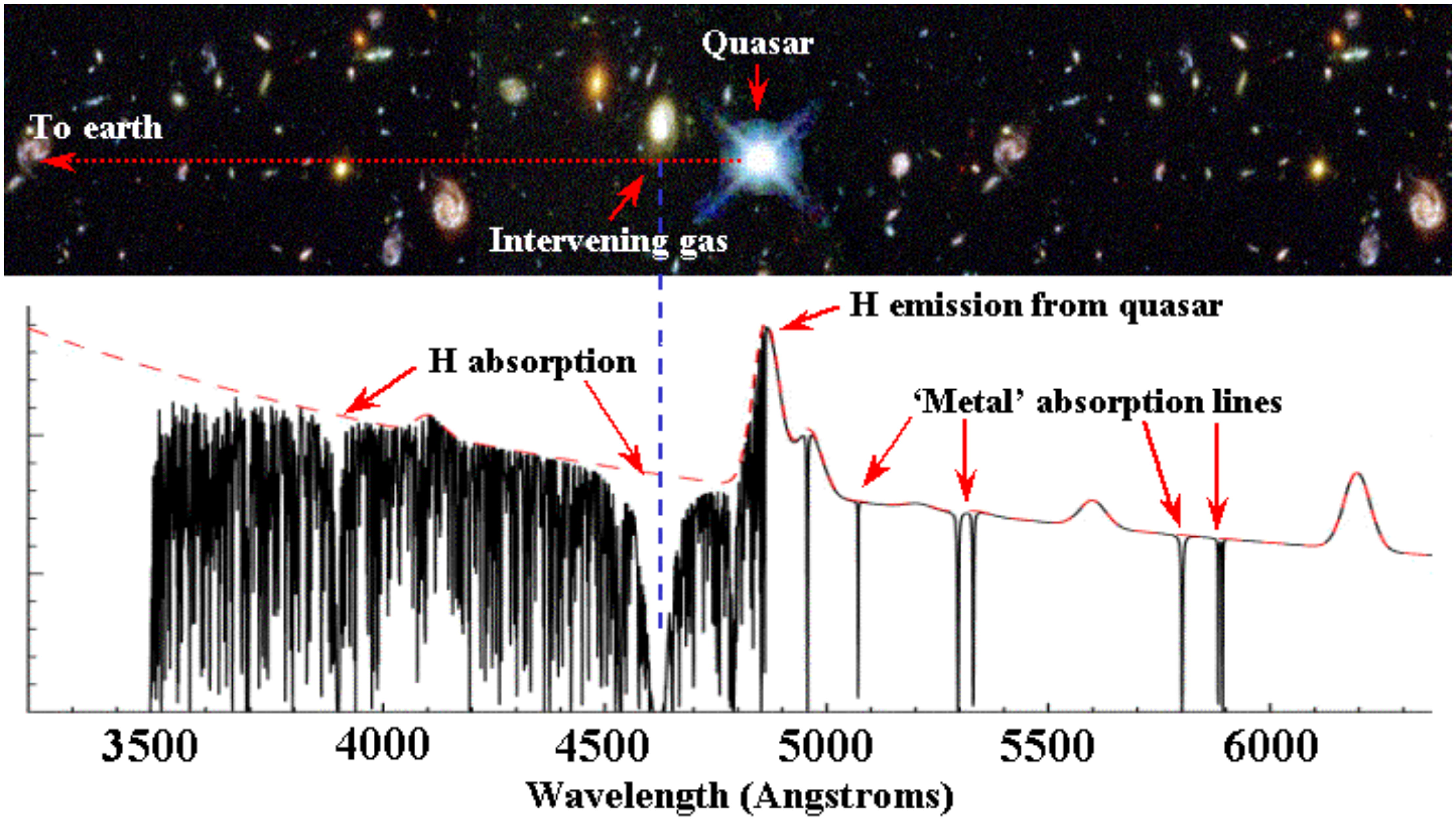


(Schaye et al 2015)

Lyman-α forest



$$\lambda_\alpha = 1216\text{Å}$$

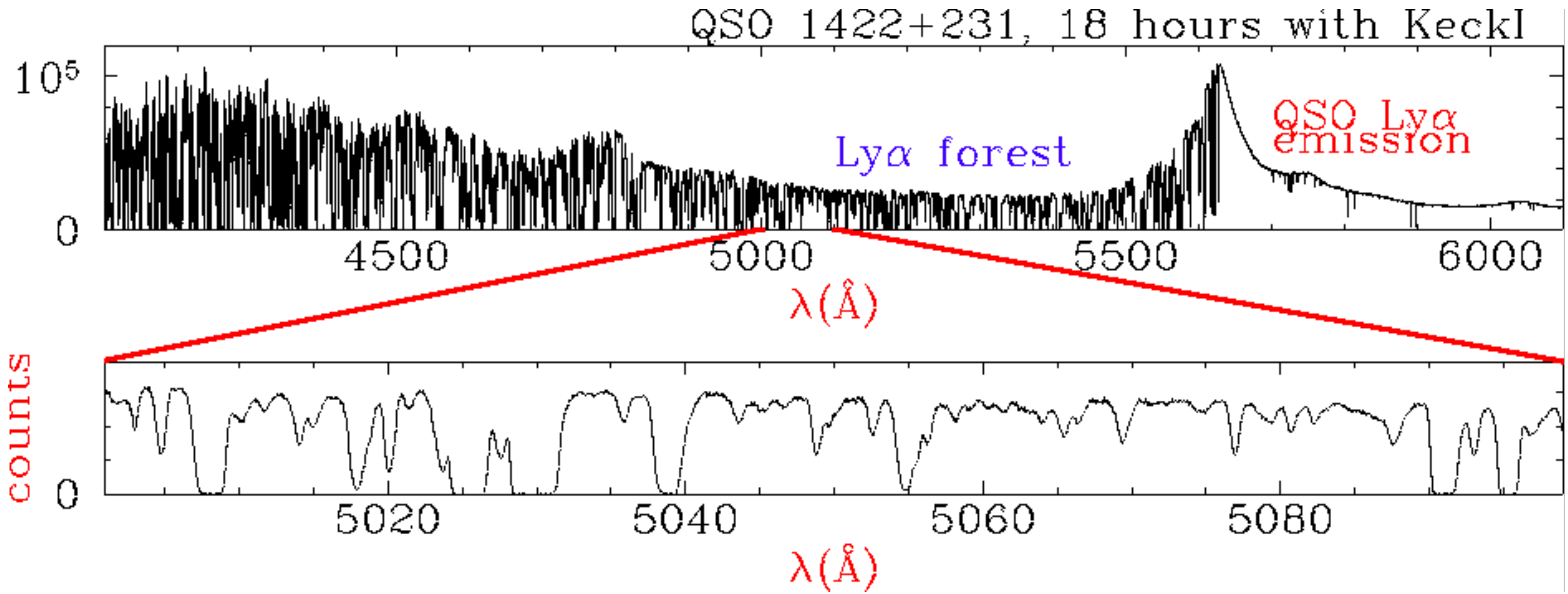


$$F = \exp(-\tau)$$

$$\tau_\nu = 1.191 \times 10^4 \frac{(1+z)^3}{[\Omega_m (1+z)^3 + \Omega_\Lambda]^{1/2}} \frac{\langle n_{\mathrm{HI}} \rangle}{\langle n_{\mathrm{H}} \rangle}$$

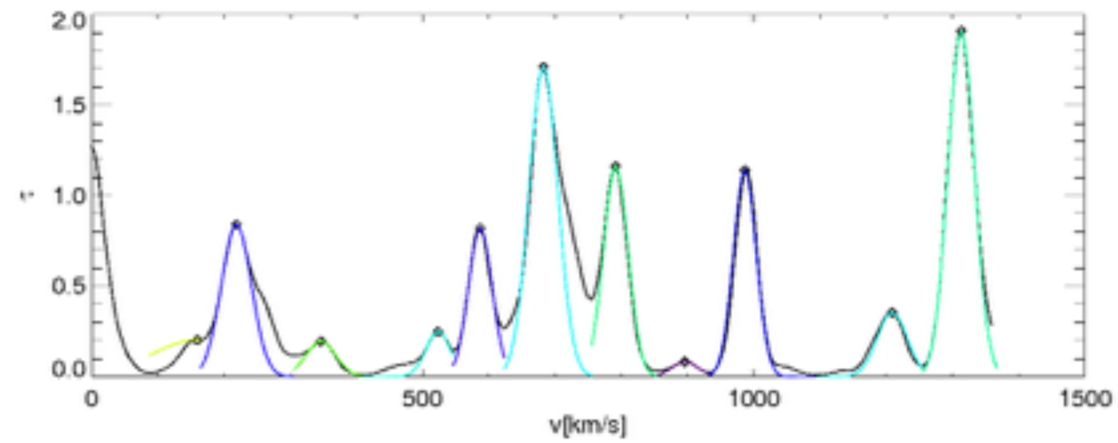
(Gunn et Peterson, 1965)

An example of high resolution quasar spectrum

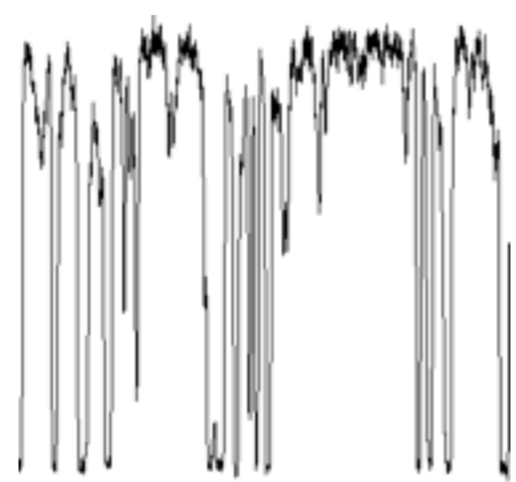


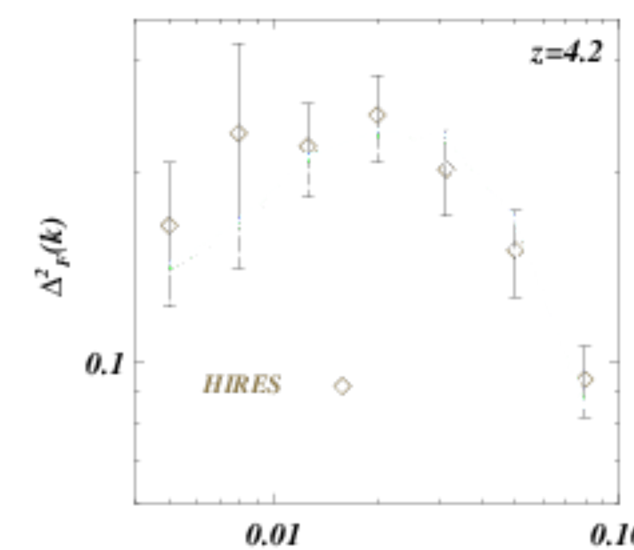
What can we measure in Lyman-α forest?

- Decomposition in absorption lines



- Flux power spectrum

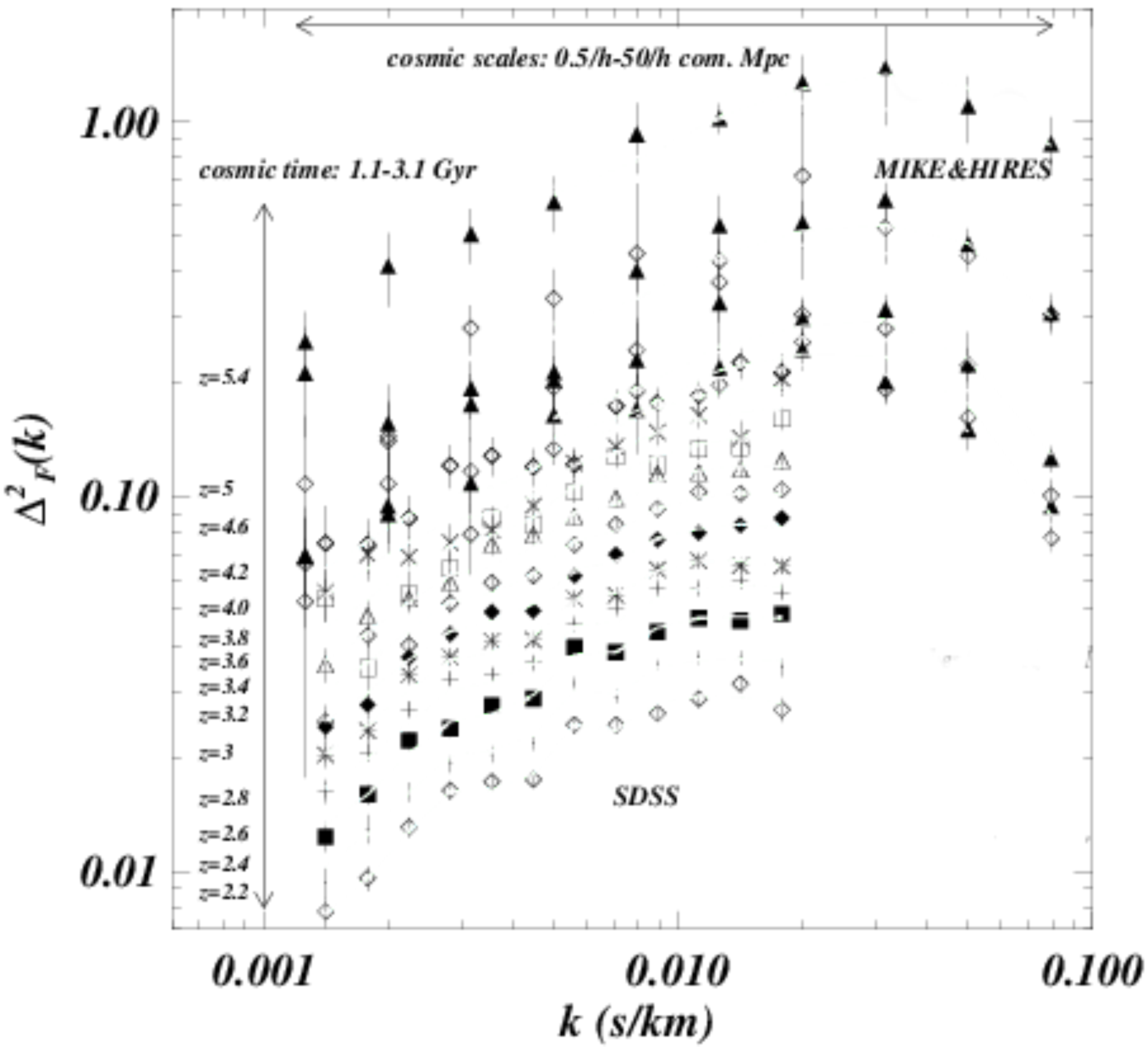




$$F \longrightarrow \Delta_F^2(k)$$

Previous constraints on WDM from the Lyman-α forest

(Viel et al, 2013)



SSDS
(Seljak et al, 2006)
(Boyarsky et al 2009)

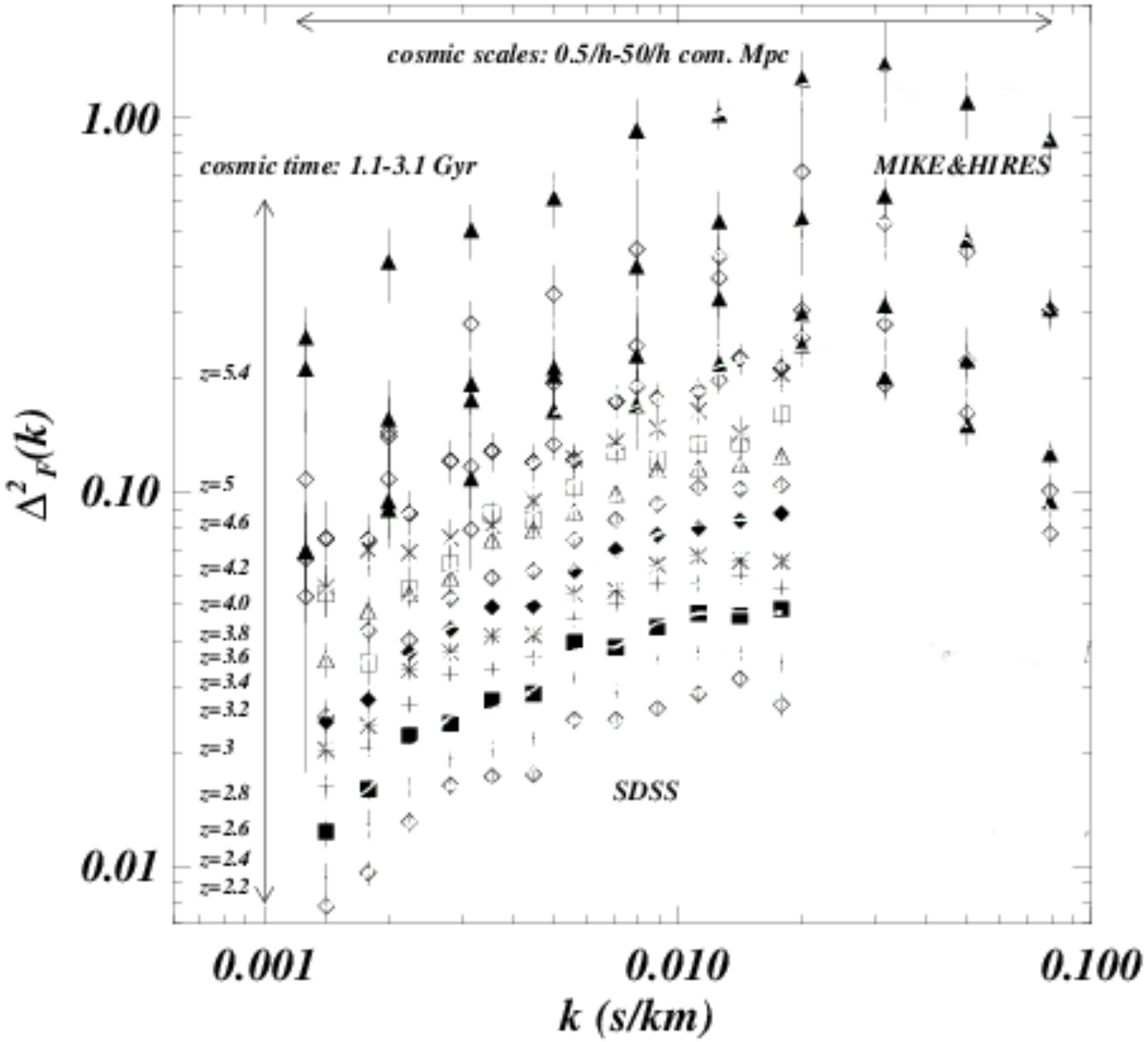
$$m_{\rm WDM} \gtrsim 2\,{\rm keV}$$

MIKE & HIRES
(Viel et al, 2013)

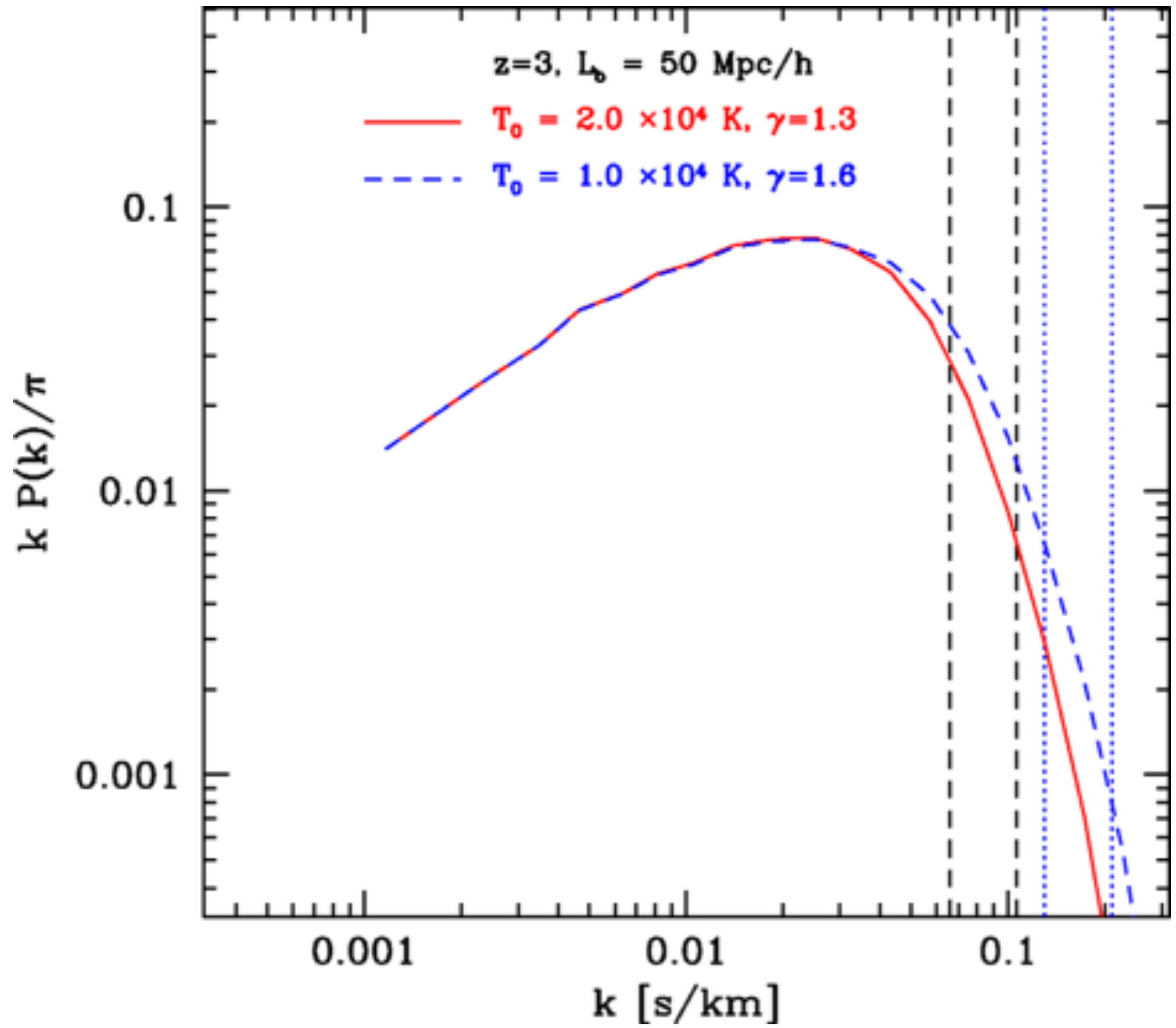
$$m_{\rm WDM} \gtrsim 3.3\,{\rm keV}$$

Degeneracy of WDM with baryonic physics

(Viel et al, 2013)



(Lidz et al 2010)

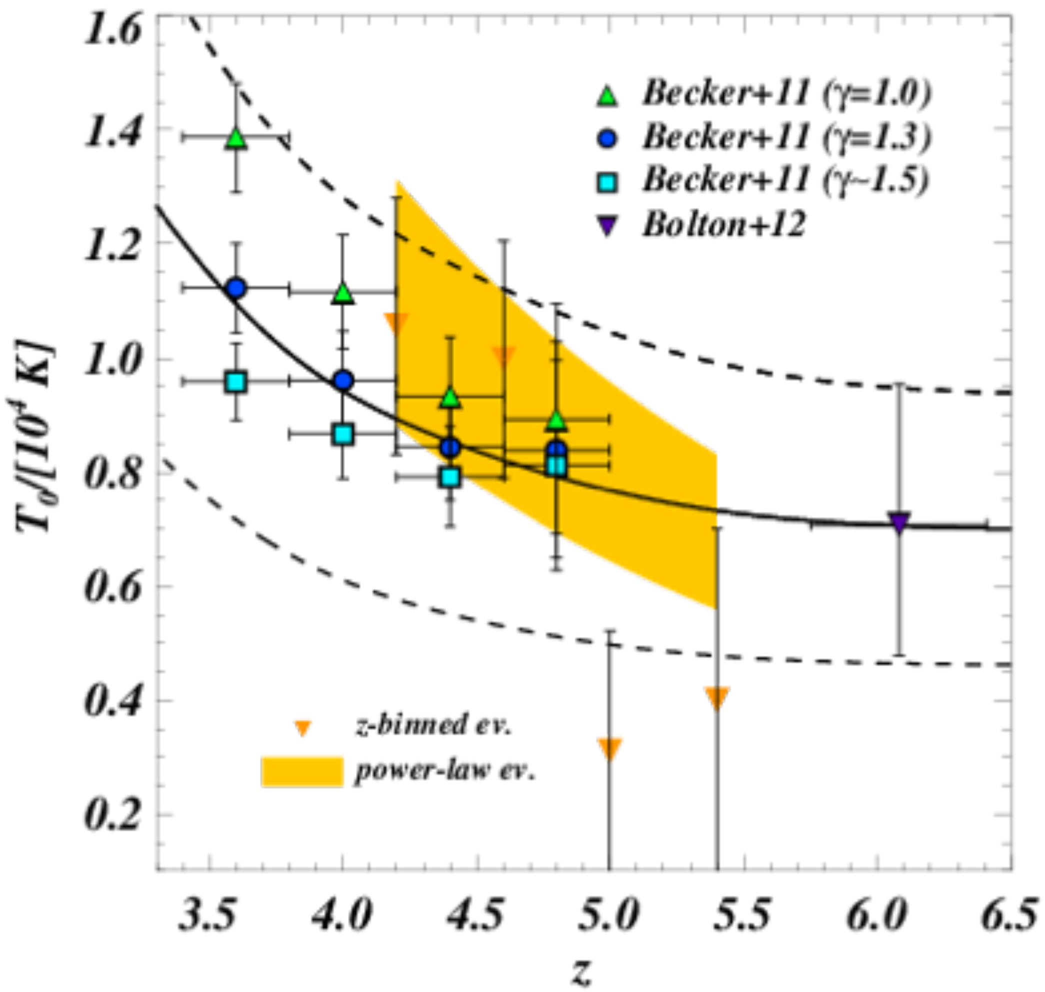


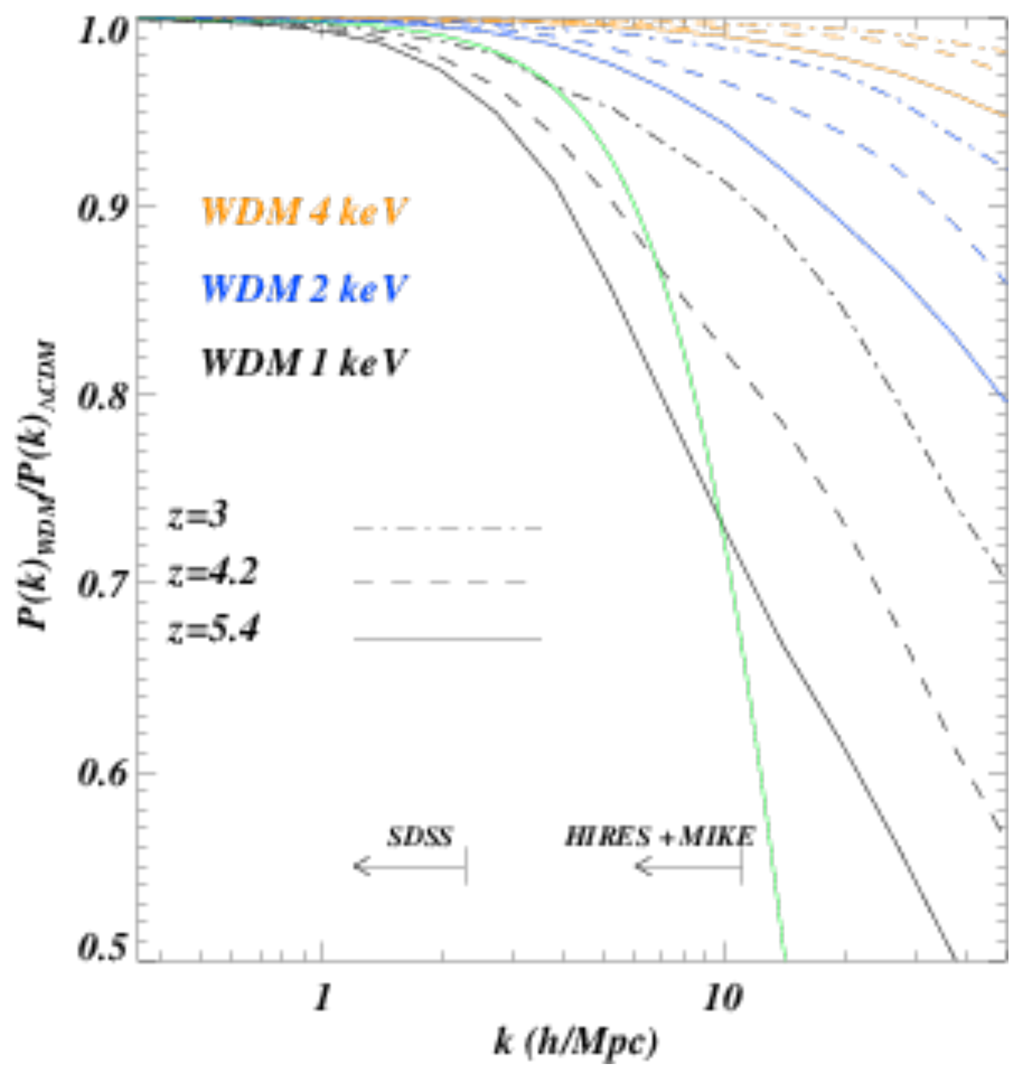
The flux power spectrum at small scales is affected by:

- temperature of the IGM (1D effect)
- pressure (3D)

(Gnedin & Hui 1998)
(Theuns, Schaye & Haehnelt 2000)

Analysis of Viel et al 2013





$$m_{\mathrm{WDM}} \gtrsim 3.3\,\mathrm{keV}$$

Assumption on IGM thermal history: power-law behaviour in z

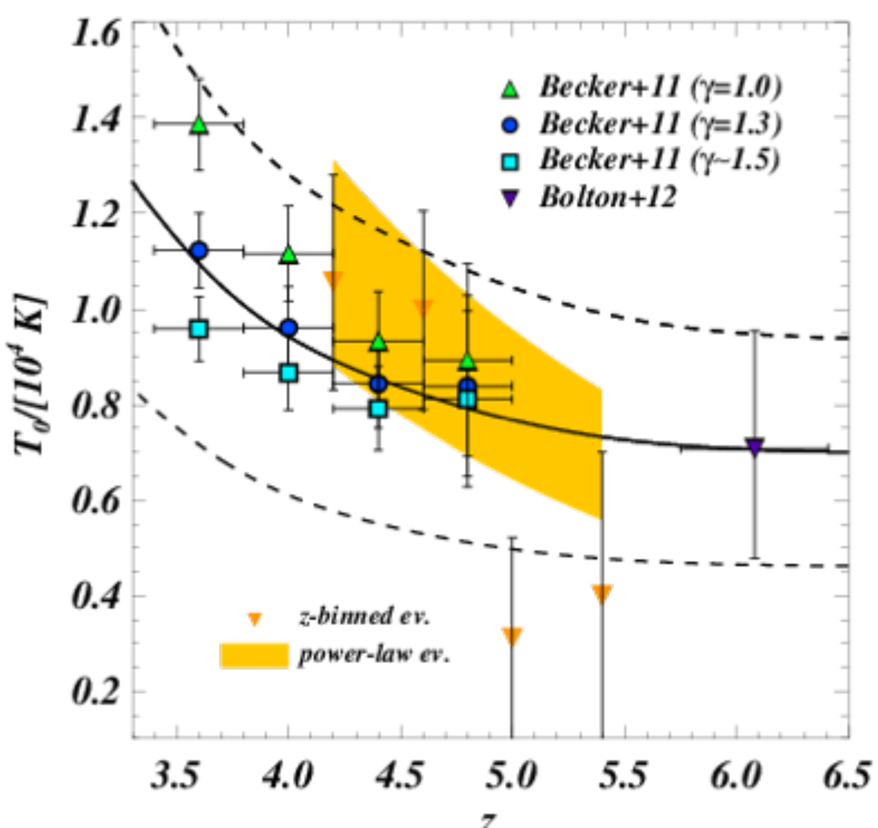
Low IGM temperature at high z …

- Missing satellite problem -> high redshift temperature $\sim 10^4\,\mathrm{K}$

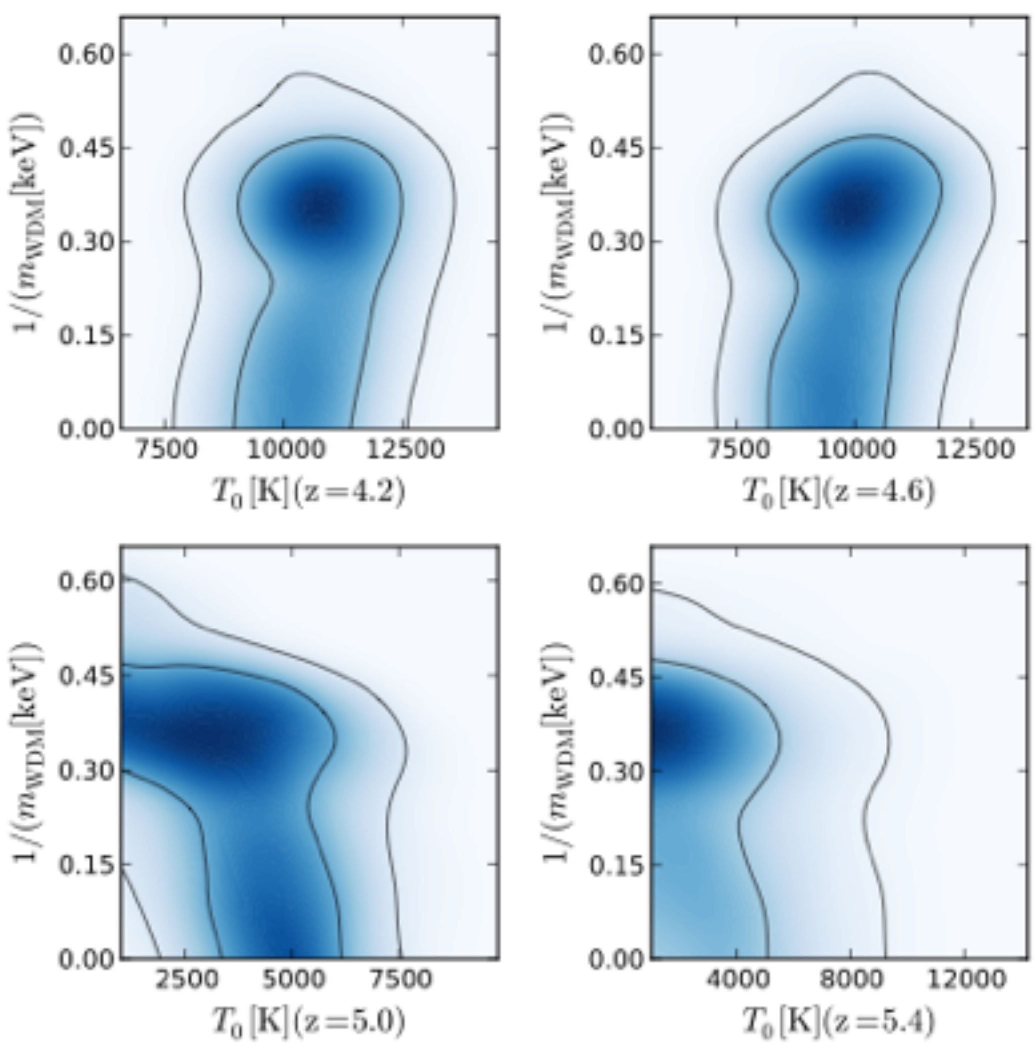
  WDM suppresses small structures
- Hardness of primordial stars

  We do not actually know how long they last
- Agreement with other measurements of IGM temperature

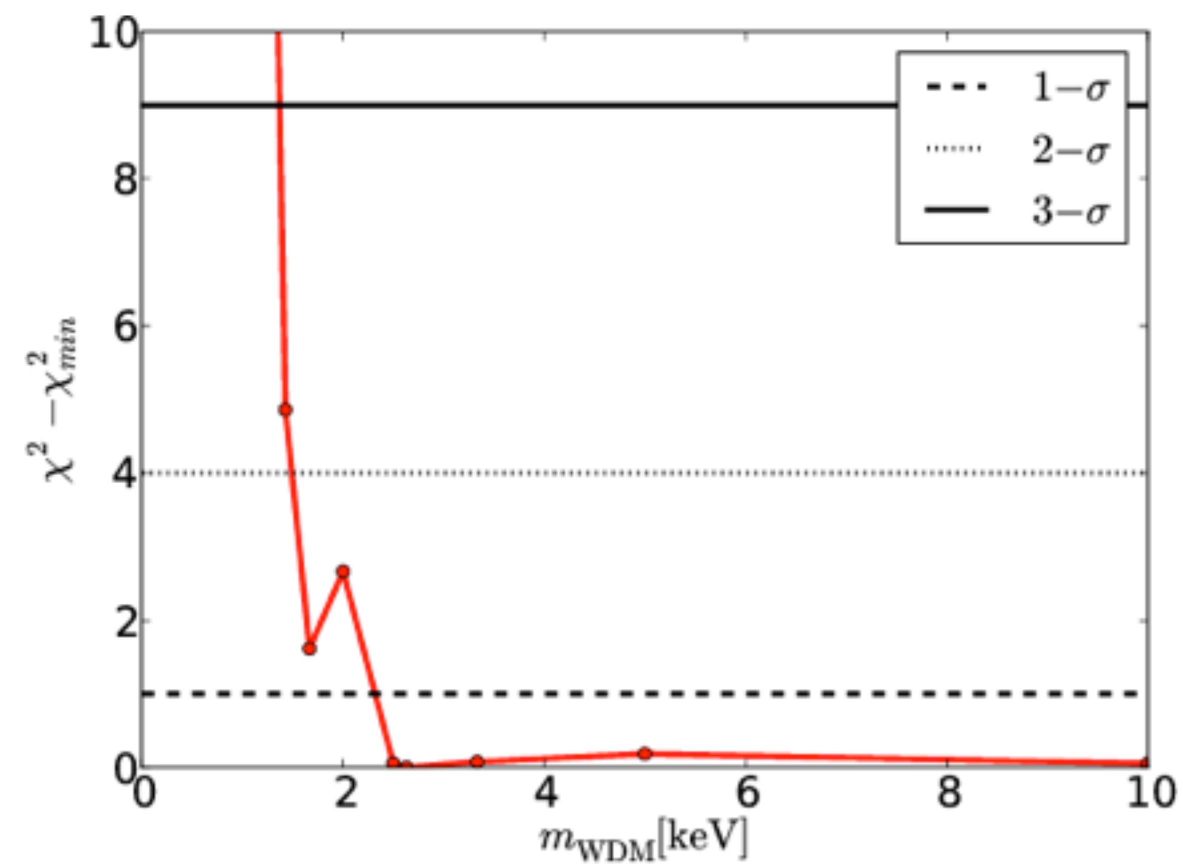
  We agree with a early HeII reionization



Our reanalysis of Viel et al 2013



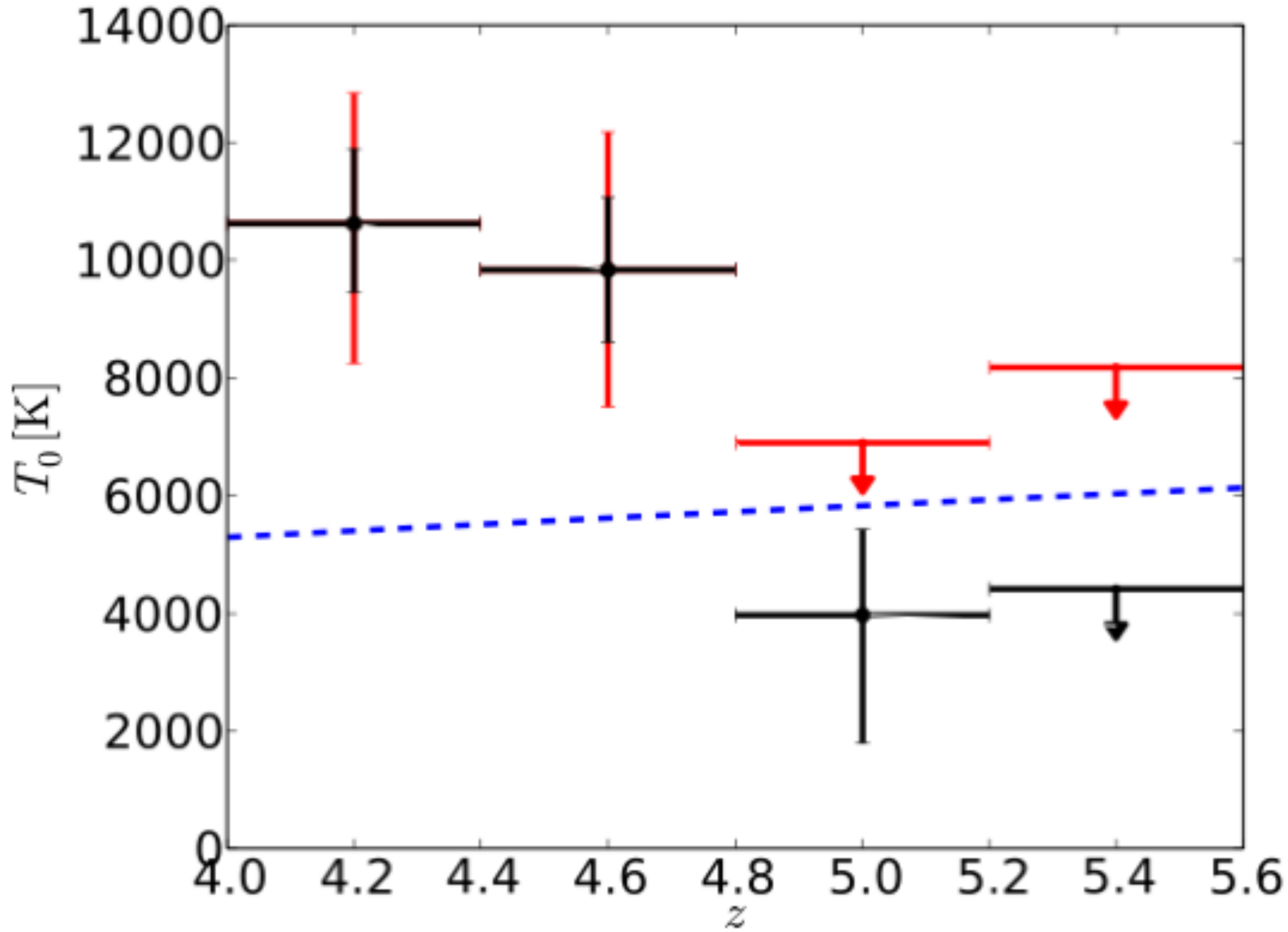
- Same Likelihood
- Different priors range



$$m_{\rm WDM} \gtrsim 2\,{\rm keV}$$

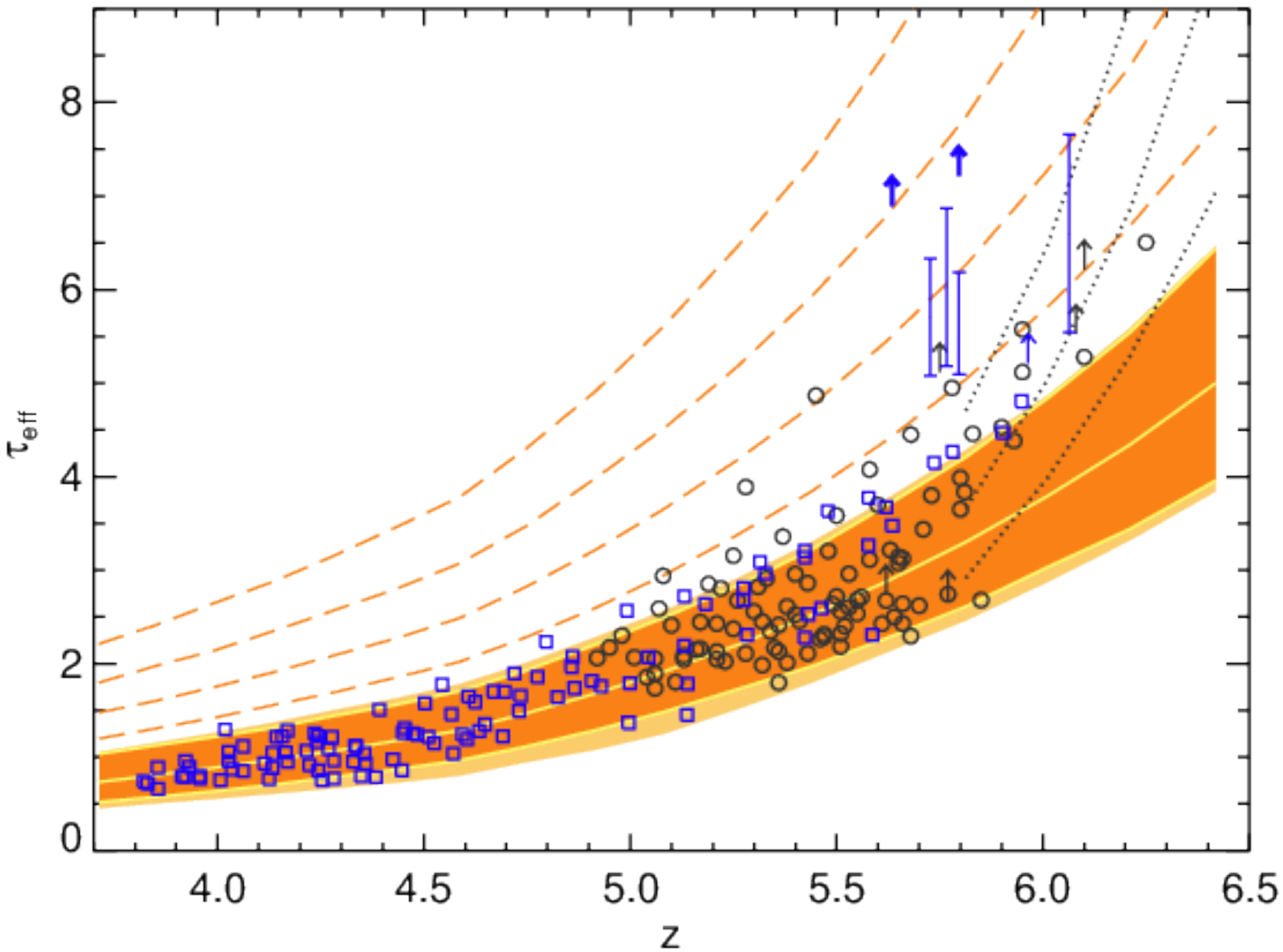
same limit as from SDSS

Low IGM temperature at high z …



CDM only: low IGM temperature at high redshift

…or unaccounted scatter in the optical depth



(Becker et al 2015) insufficient modelling of UVB fluctuations

What have we learnt about methodology?

In Bayesian analysis the result depends on the priors:

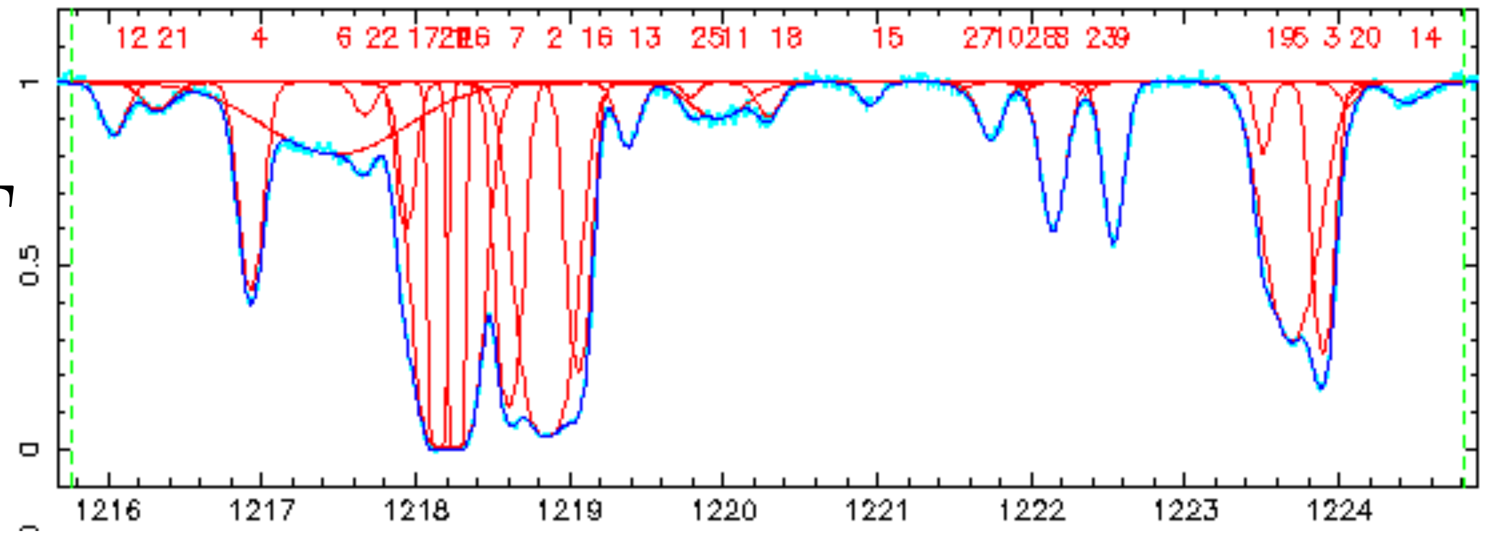
- power-law in temperature -> strong constraint on WDM
- no theoretical justification for such priors

If we believe that the estimated parameters are not realistic

We have to look for possible sources of bias

Line decomposition

F

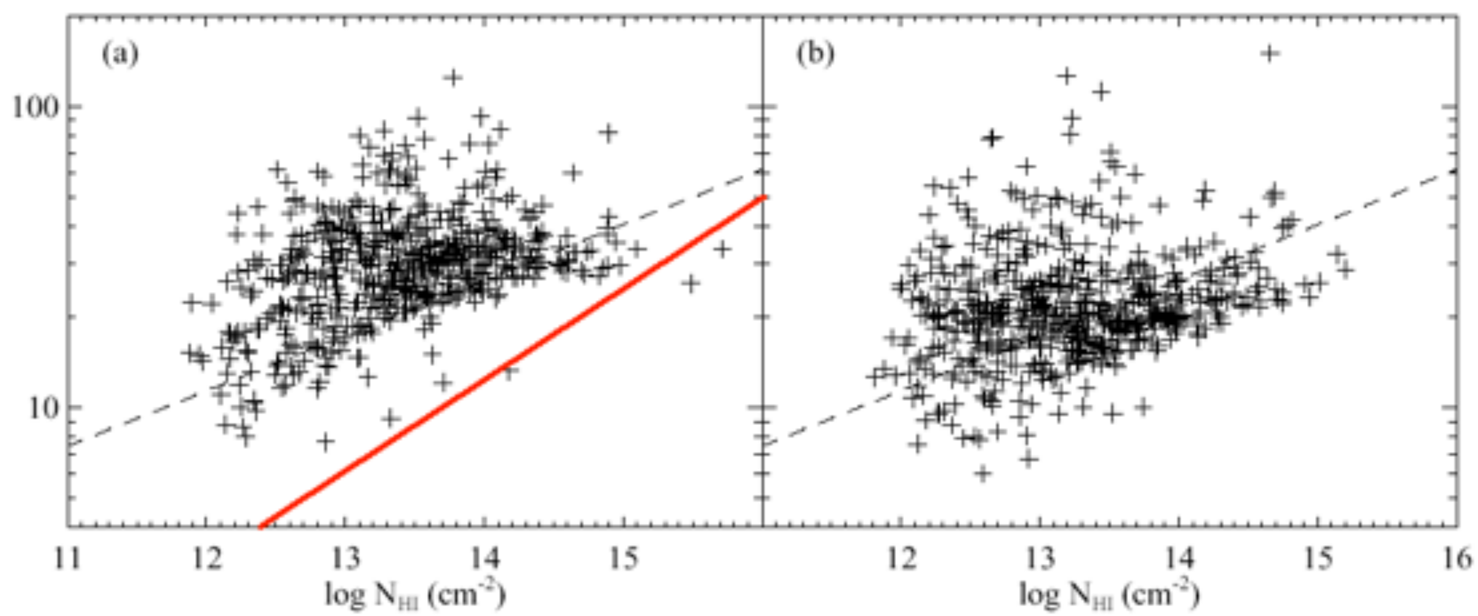


(b, N_{HI})

hot

cold

$b[\mathrm{km/s}]$

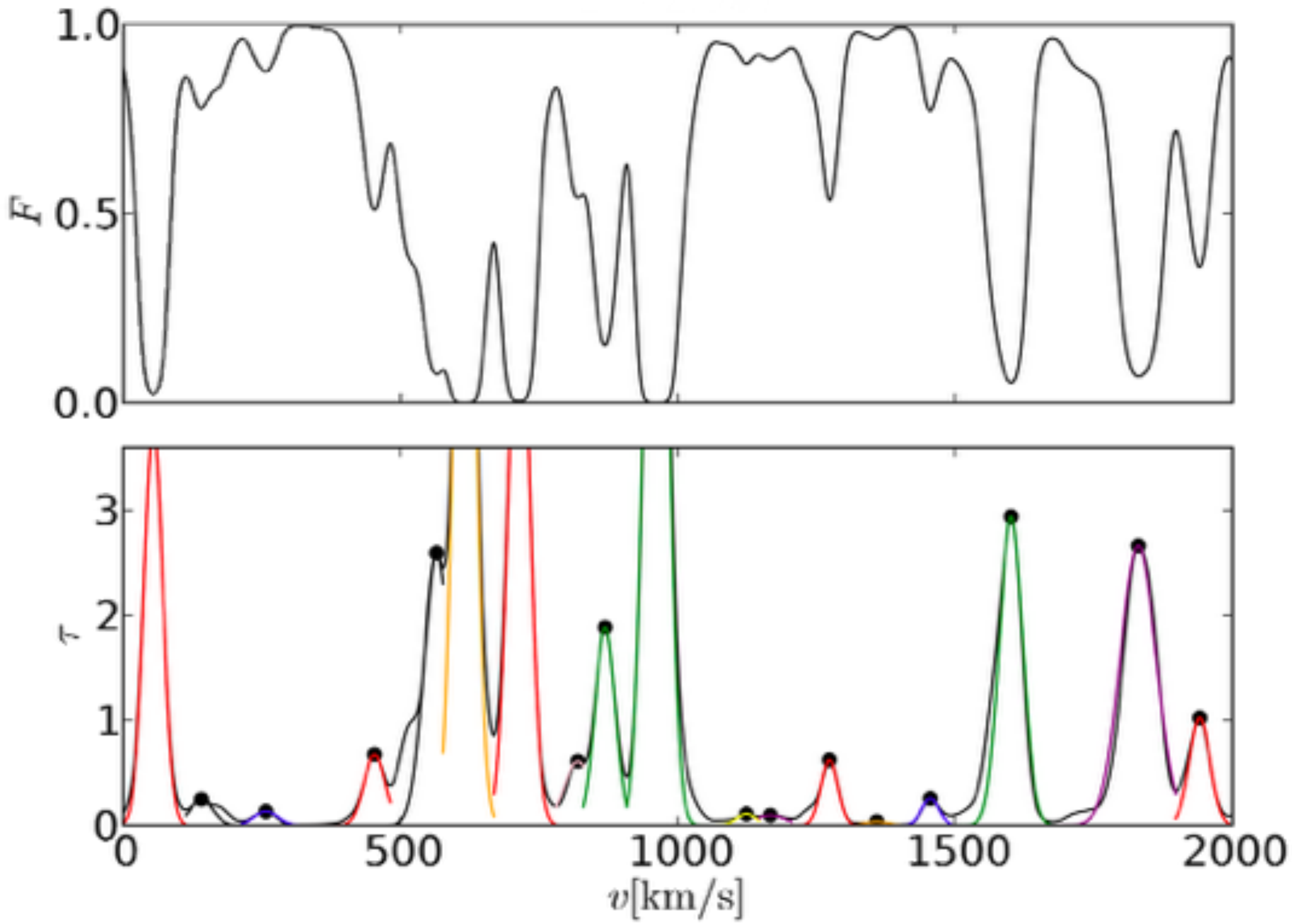


$$T = T_0 \Delta^{\gamma - 1}$$

$$b = \sqrt{\frac{2k_B T}{m_{\mathrm{H}}}}$$

Schaye et al 2000

IGM temperature from line broadening



$$F = \exp(-\tau)$$

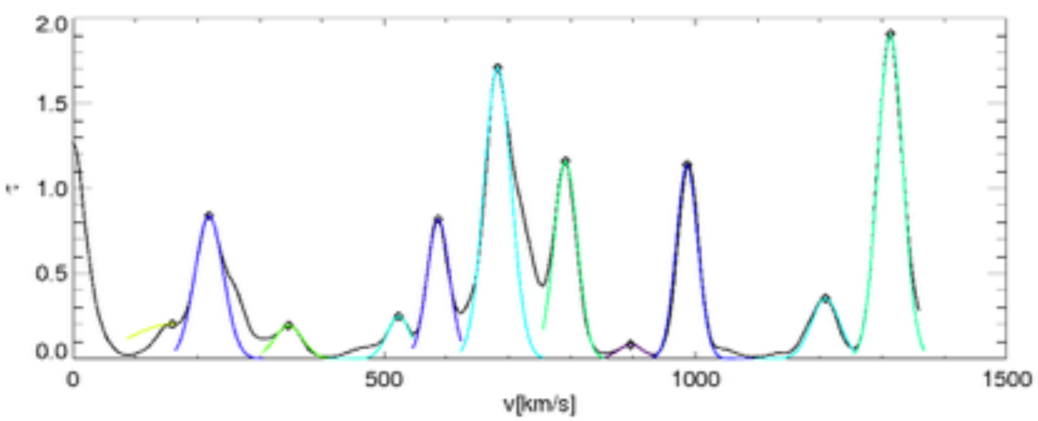
$$\tau(v) = \tau_0 e^{-(v-v_0)^2/b^2}$$

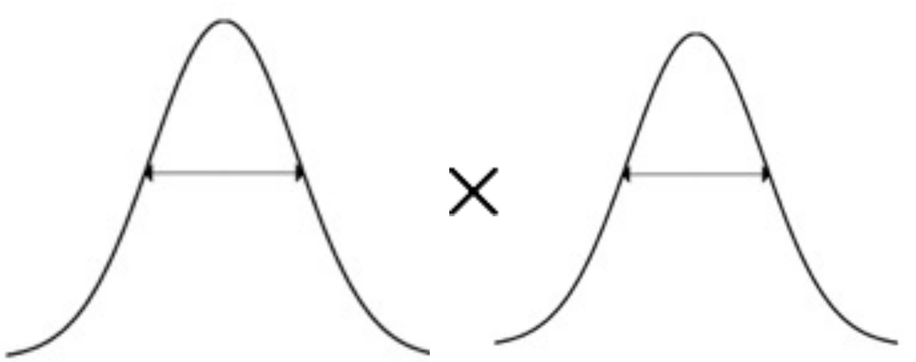
$$\tau_0 = \frac{\sigma_0 c}{\sqrt{\pi}} \frac{N_{\rm HI}}{b}$$

- Thermal Doppler broadening(1D): $\sqrt{\frac{2k_B T}{m_{\rm H}}}$
- Hubble Broadening(3D): $\sim H\lambda_F$

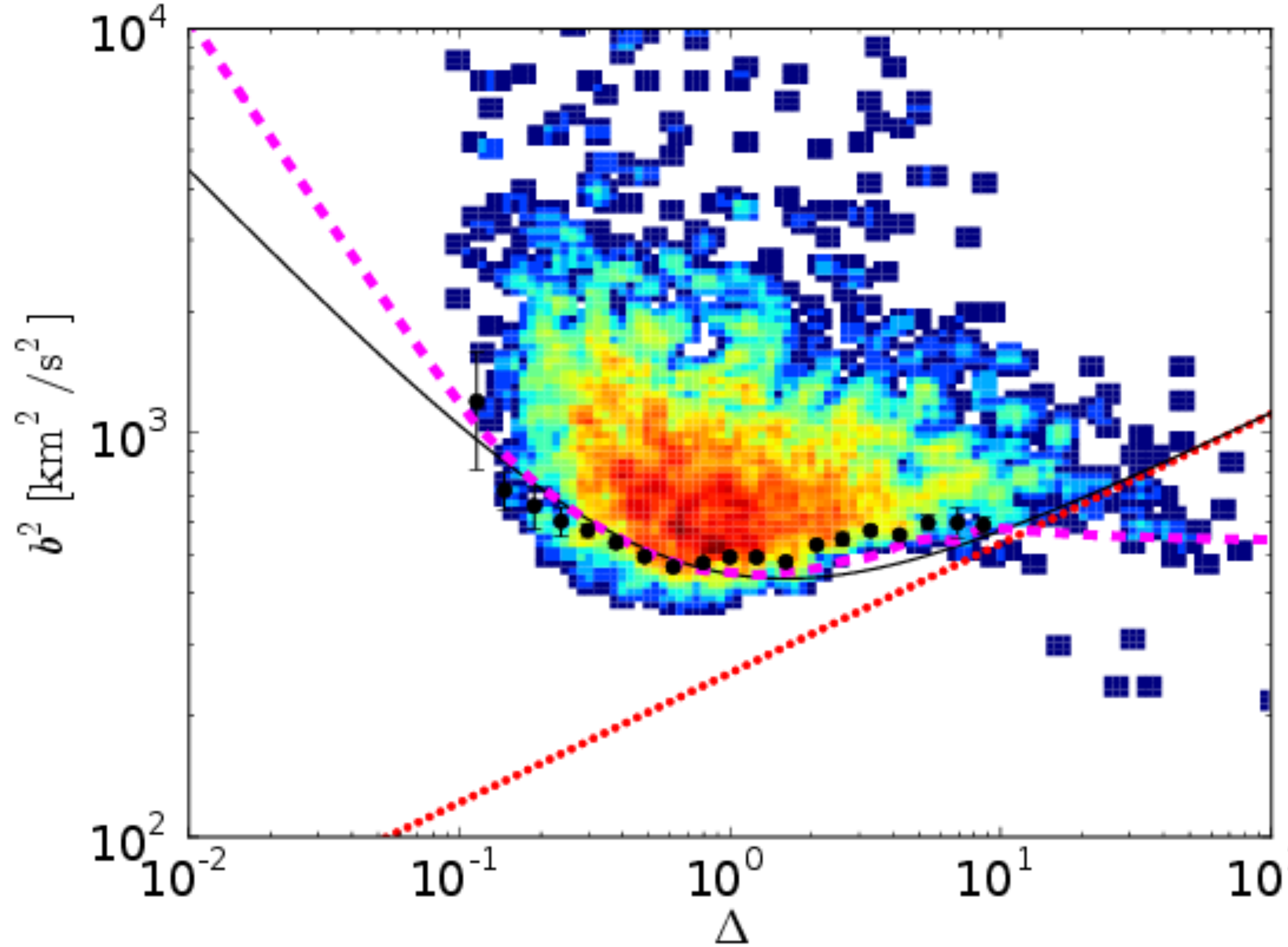
(Cen et al 1994)
(Gnedin & Hui 1998)
(Theuns, Schaye & Haehnelt, 2000)

IGM temperature from line broadening





$$\sqrt{\frac{2k_BT}{m_{\mathrm{H}}}} \qquad H(z)\lambda_F$$



Garzilli, Theuns, Schaye MNRAS 450, 2 (2015)

Plan for future simulations

SPH code (GADGET) has some limitations:

- poor information in low density regions
- poor resolution of shocks
- artificial viscosity

A new simulation scheme:

- AMR code (RAMSES)
- Radiative transfer code

Power spectra only WDM-like

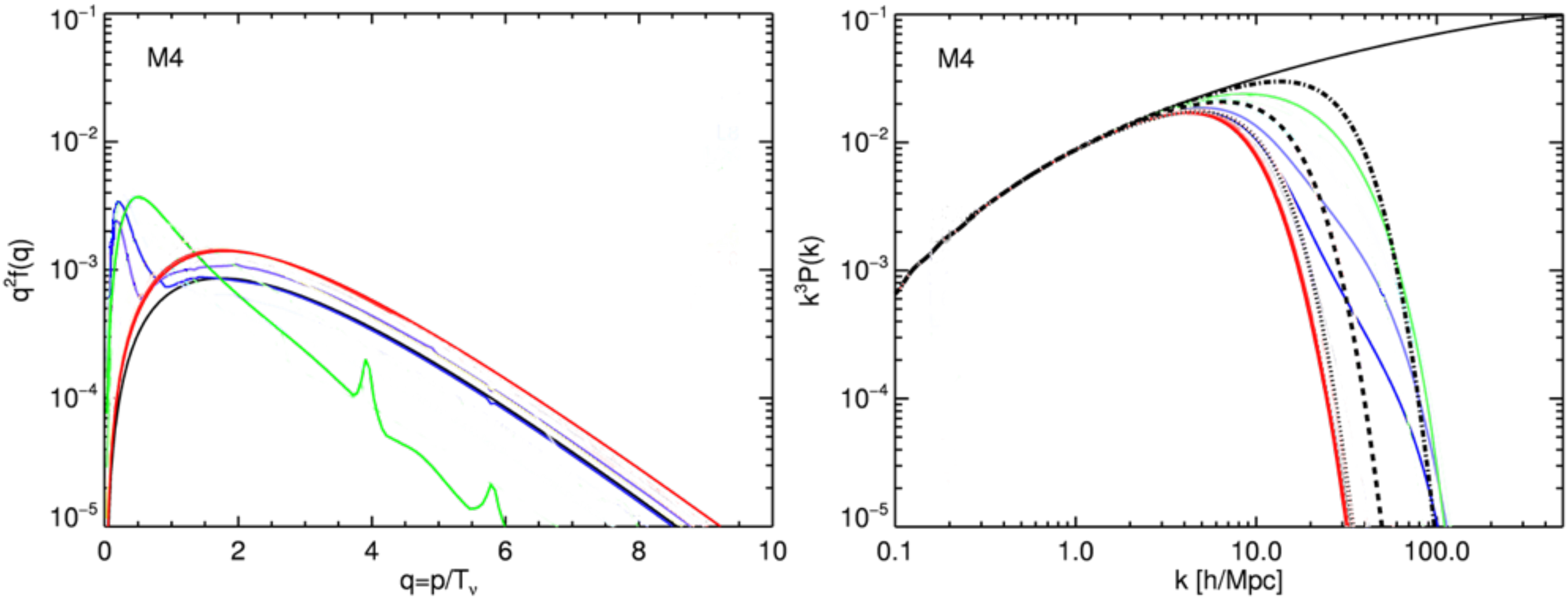
Realistic Sterile Neutrinos Power spectra

We can

- model of the Lyman-α forest in ~1 yr with WDM cosmologies
- lift the degeneracy between DM nature and gas properties

Warm Dark Matter and Sterile Neutrinos

(Laine & Shaposhnikov 2008)
(Mark Lovell)



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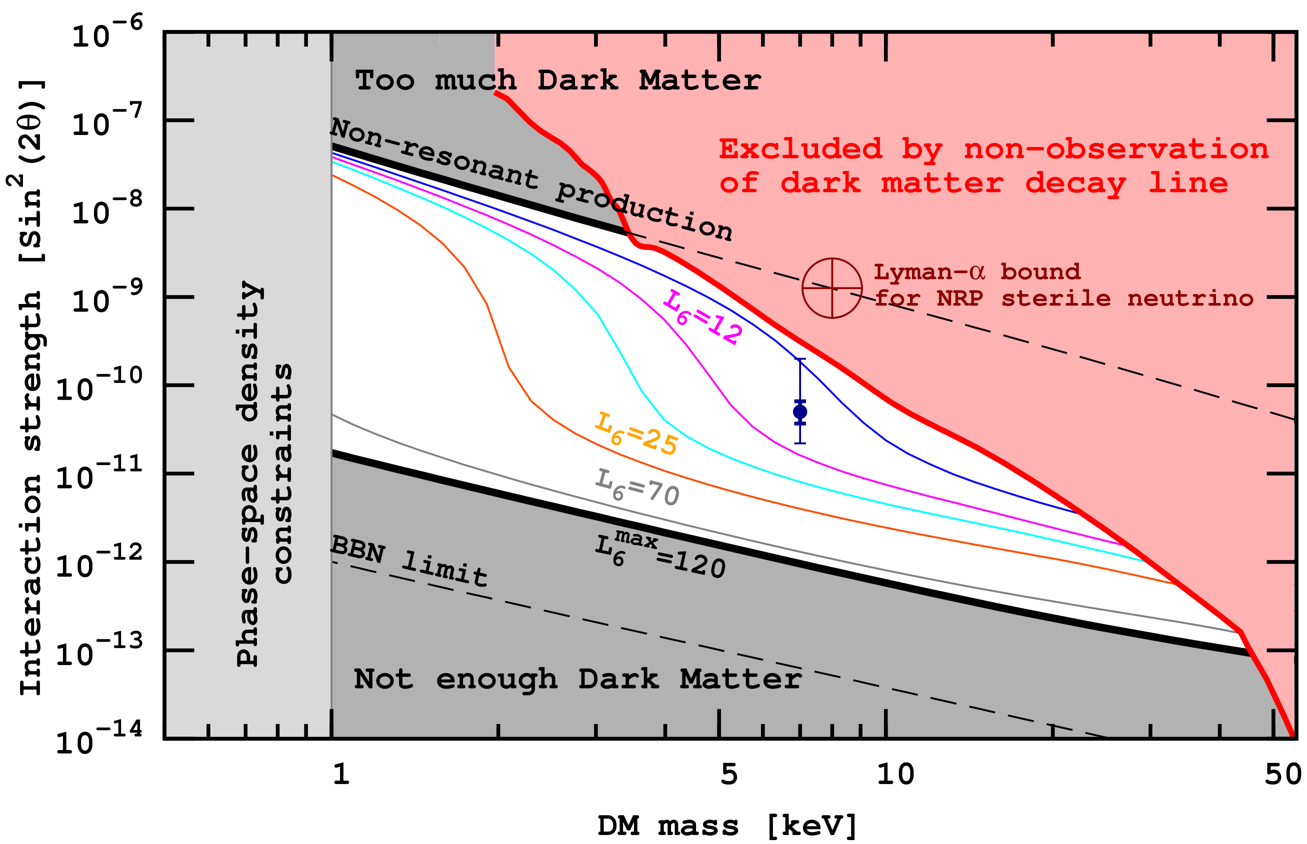
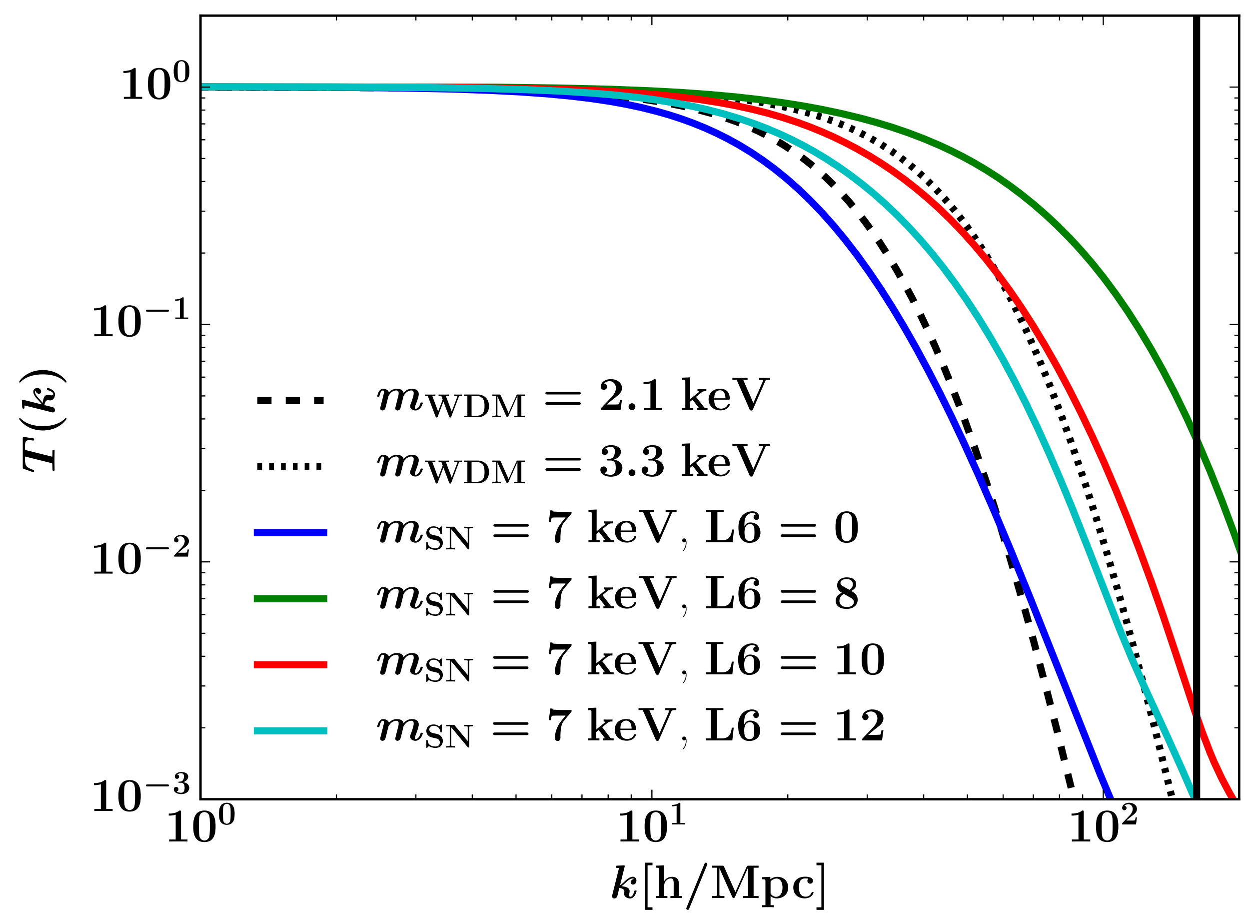
Implications for Sterile Neutrinos

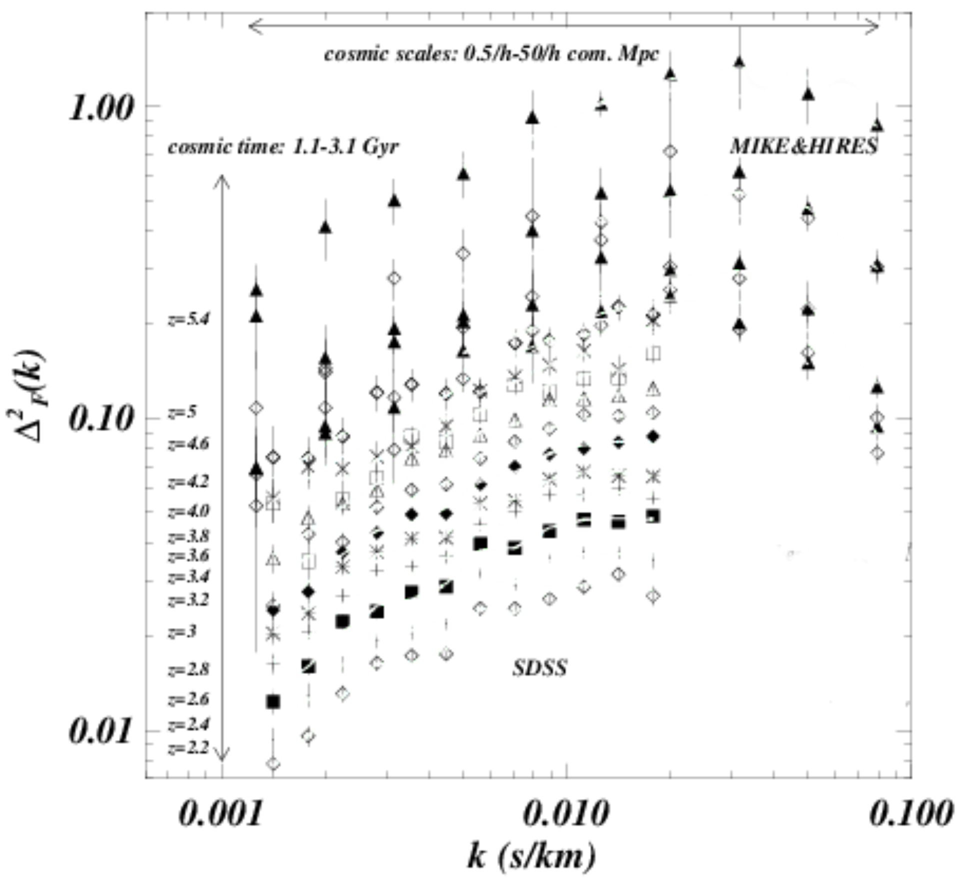


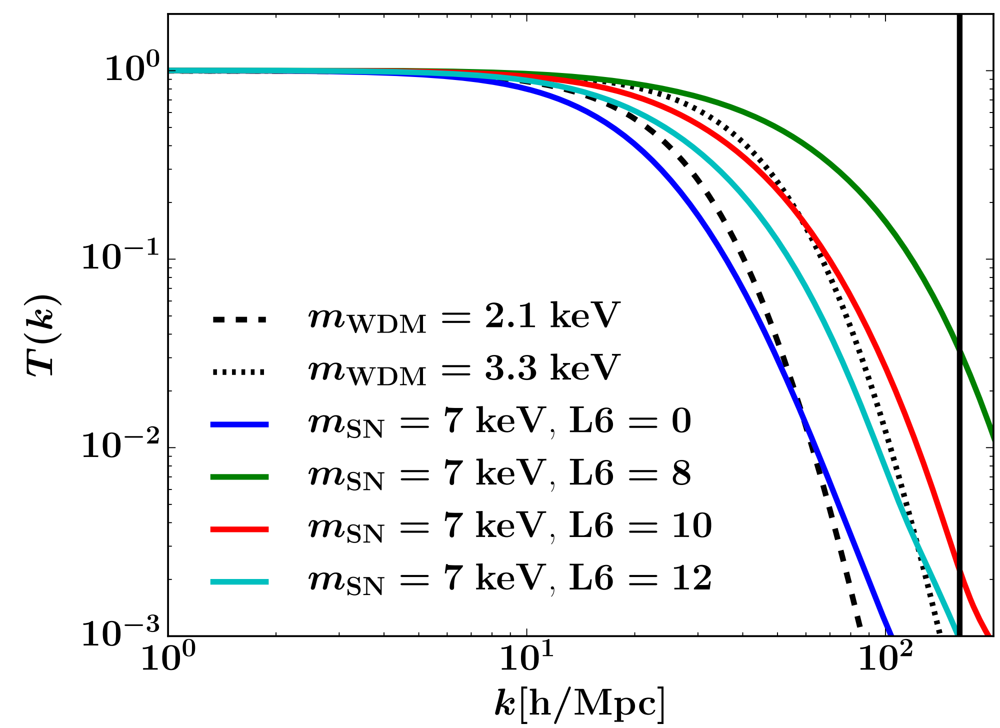


$m_{\rm SN} = 7\,{\rm keV}$ is motivated by the recent report of X-ray line at energy $E = 3.5\,{\rm keV}$

(Bulbul et al 2014)
(Boyarsky et al 2014)

Conclusions





- Lyman α high resolution data do not allow to put a stronger limit on WDM
- We need to solve the degeneracy between gas properties and warmness of dark matter
- in ~1yr we will be able to either:

detect WDM

or

putting strong constraints on WDM