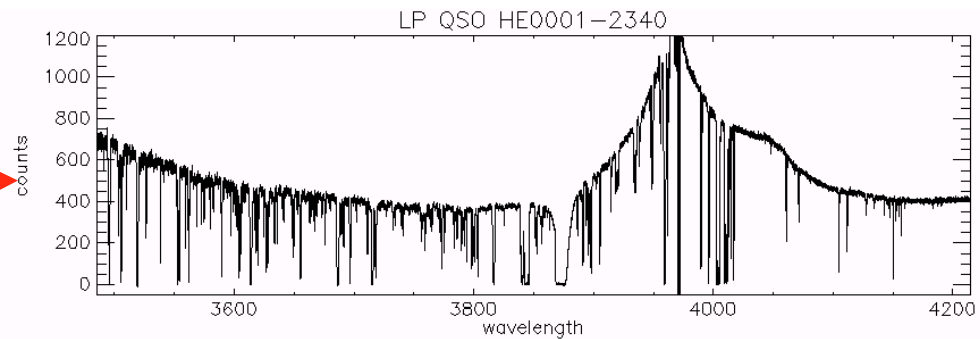
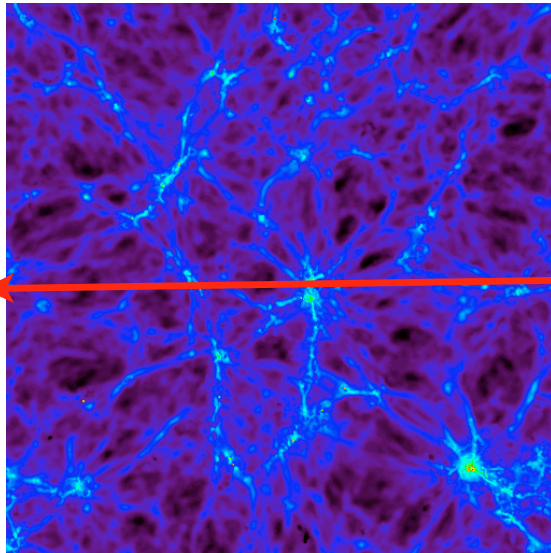
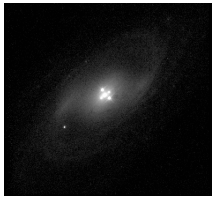


Observing and simulating the Lyman-alpha forest

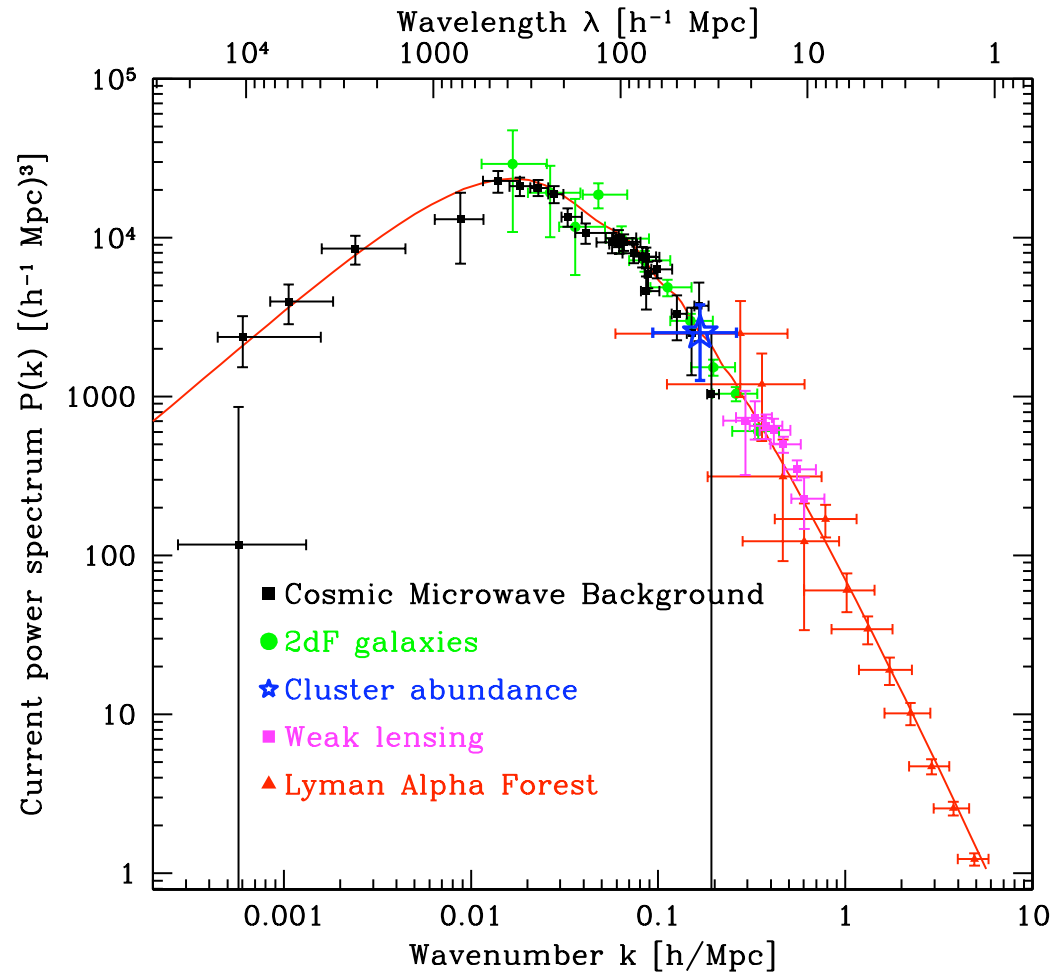
Tom Theuns

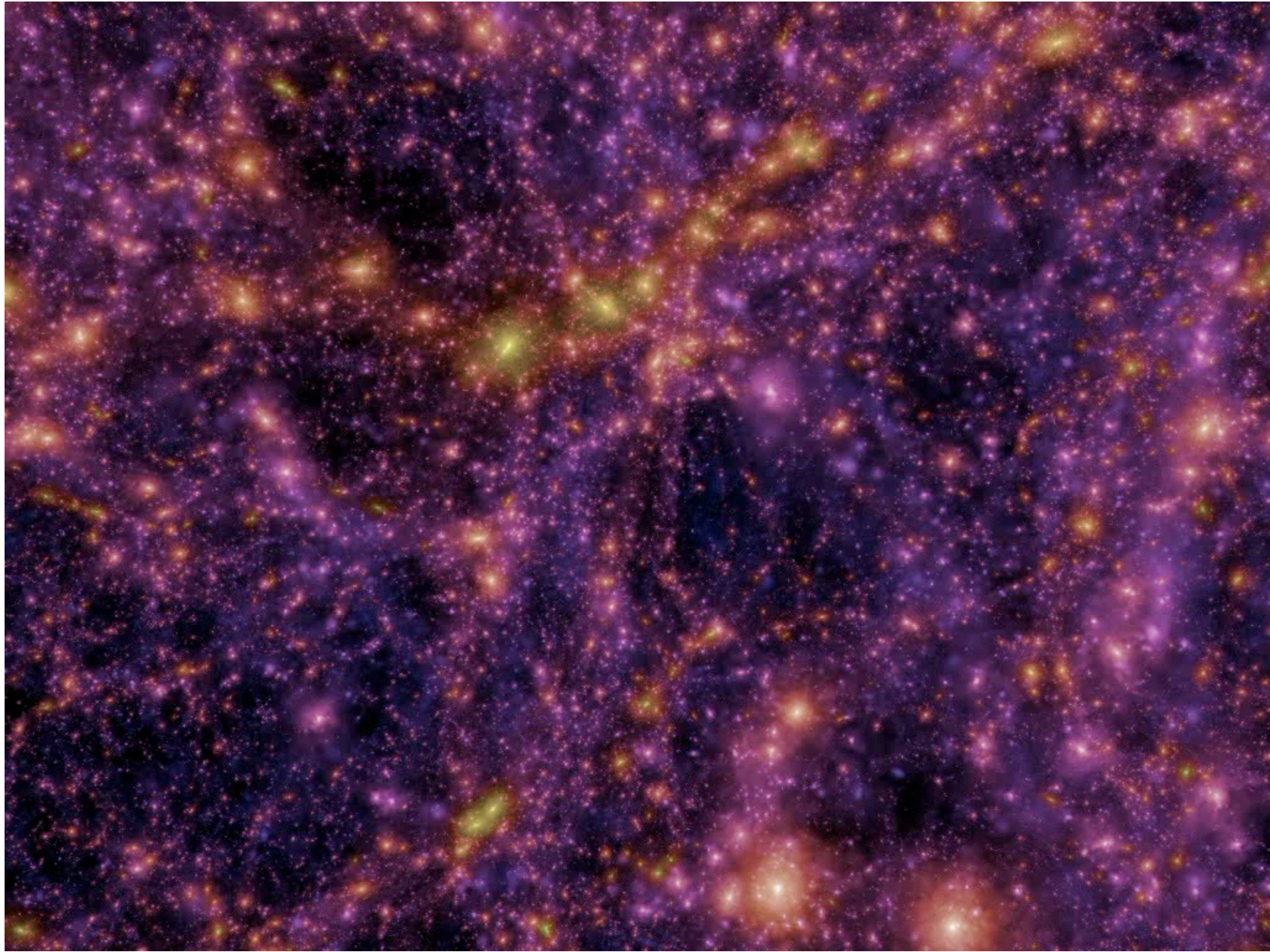


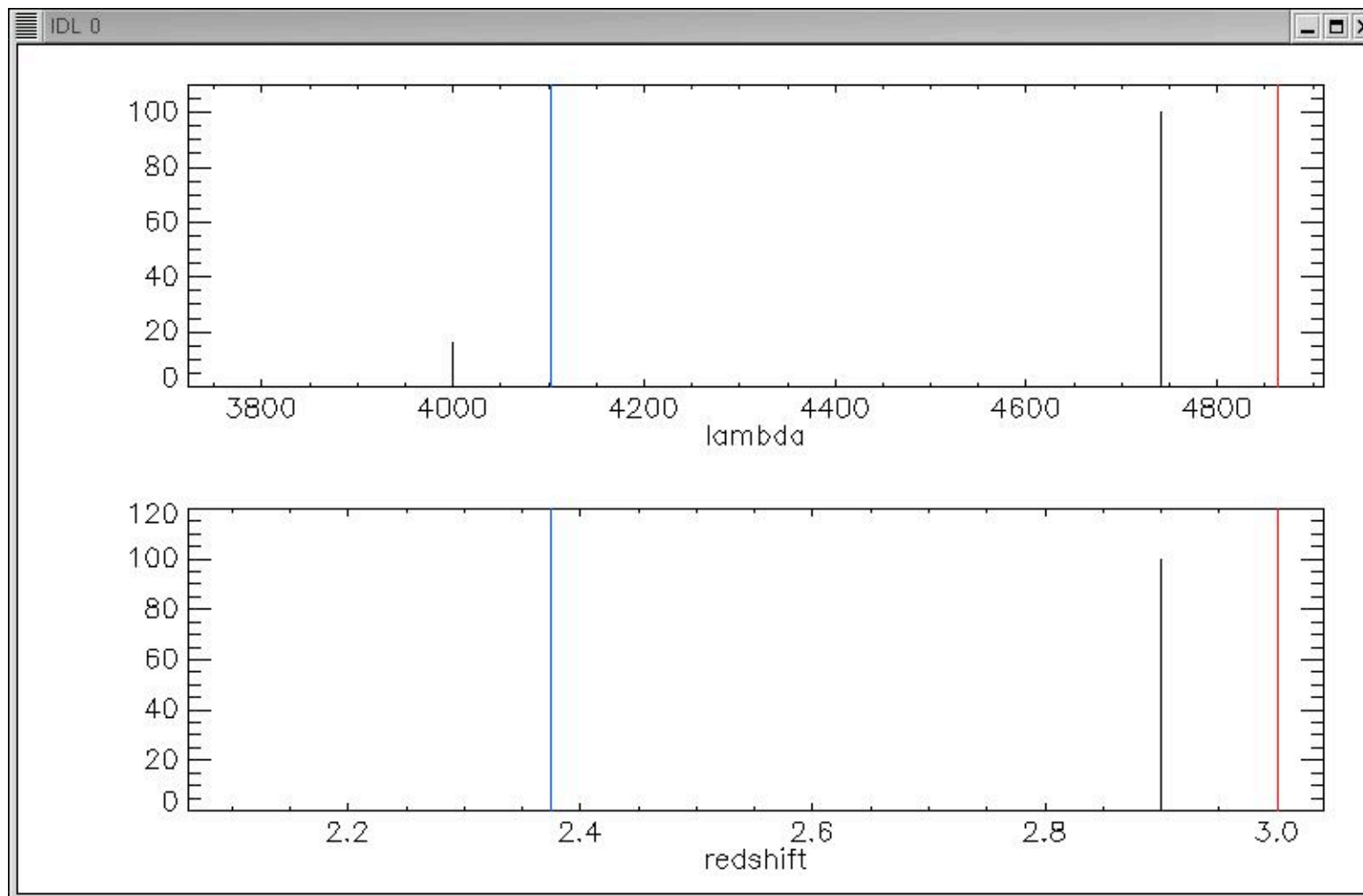
- Introduction
- Current observations
- Simulating the forest

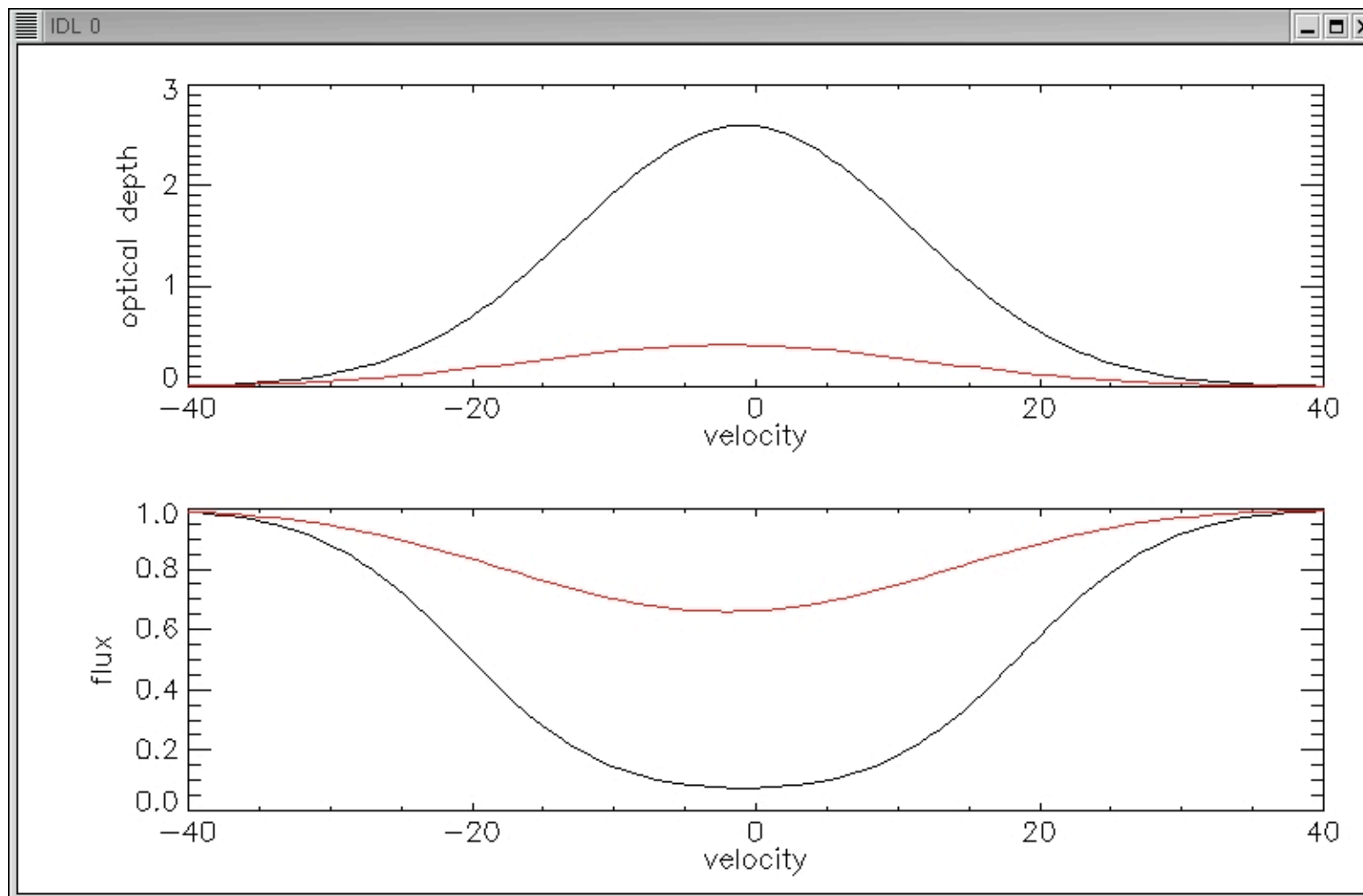
Separating the Early Universe from the Late Universe: cosmological parameter estimation beyond the black box

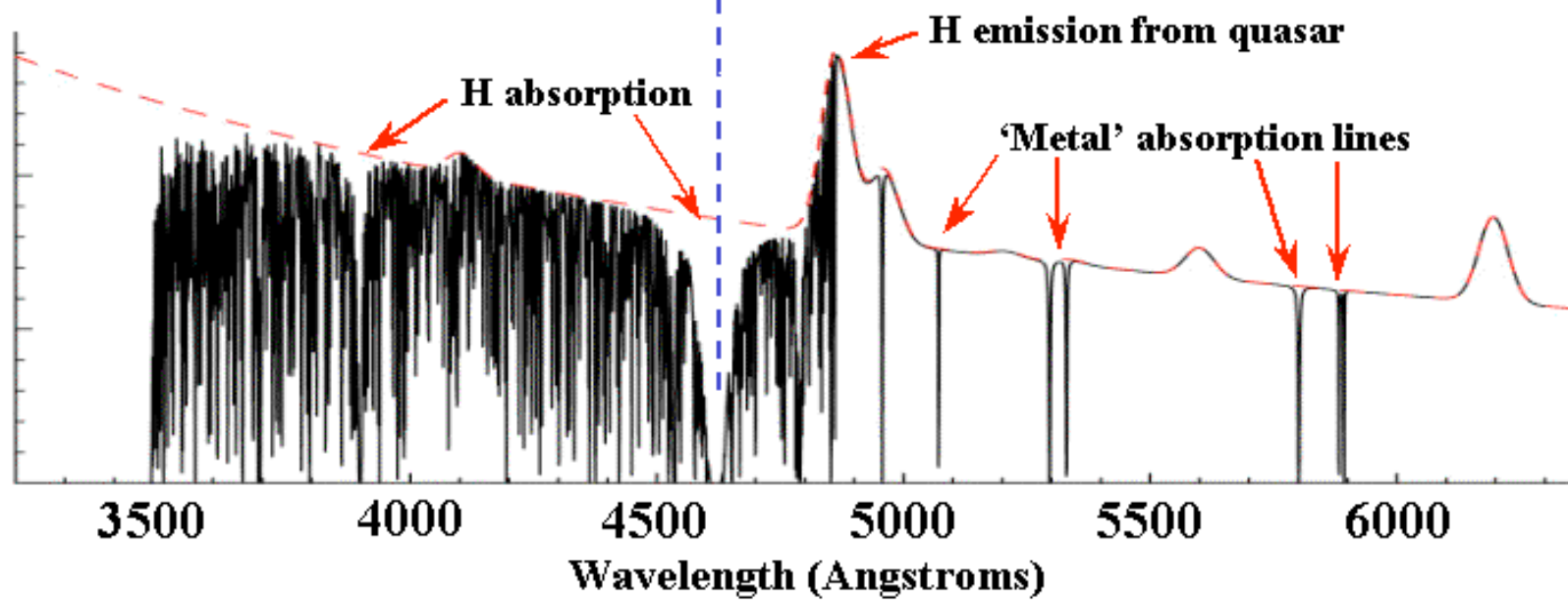
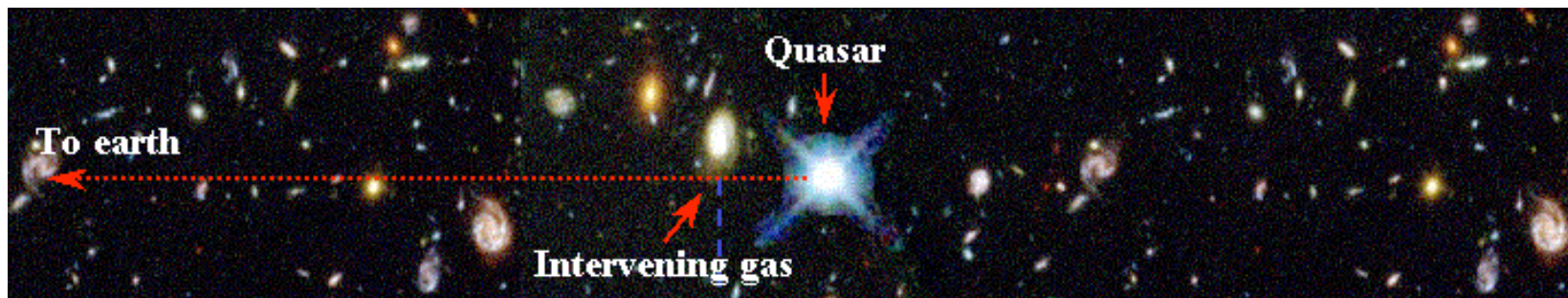
Max Tegmark¹ & Matias Zaldarriaga^{2,3}

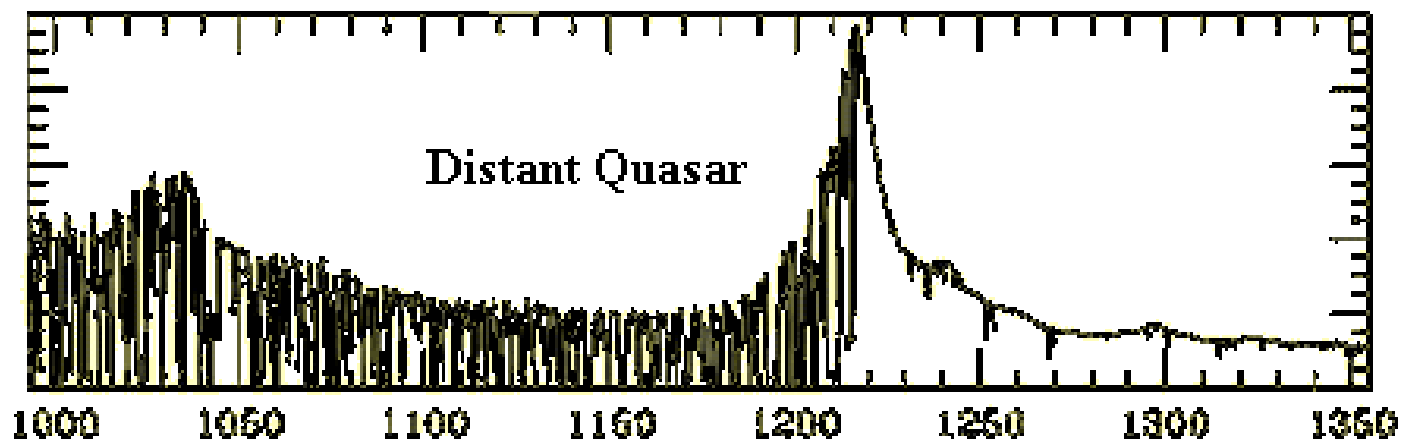
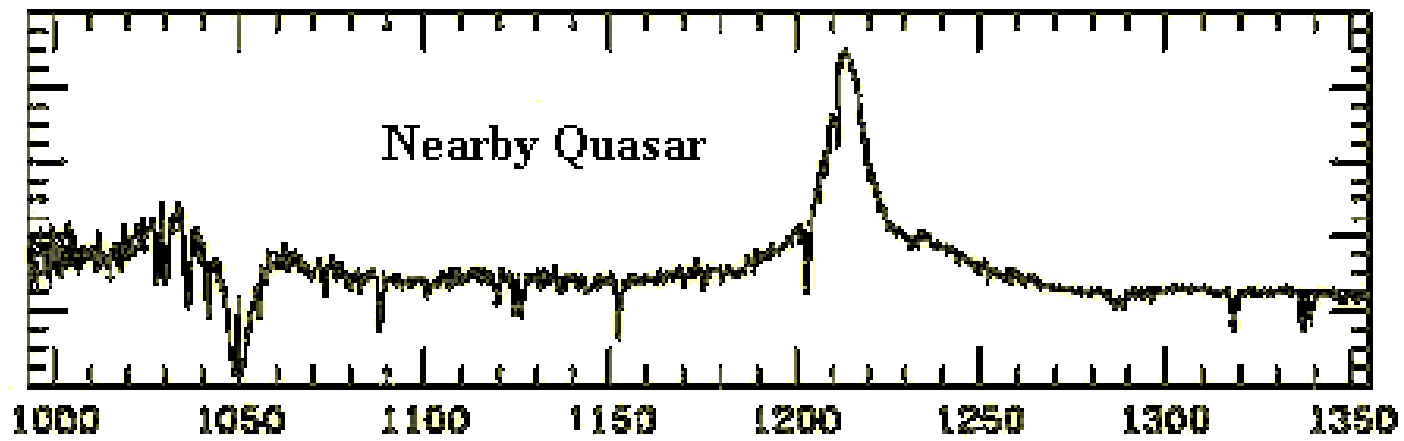




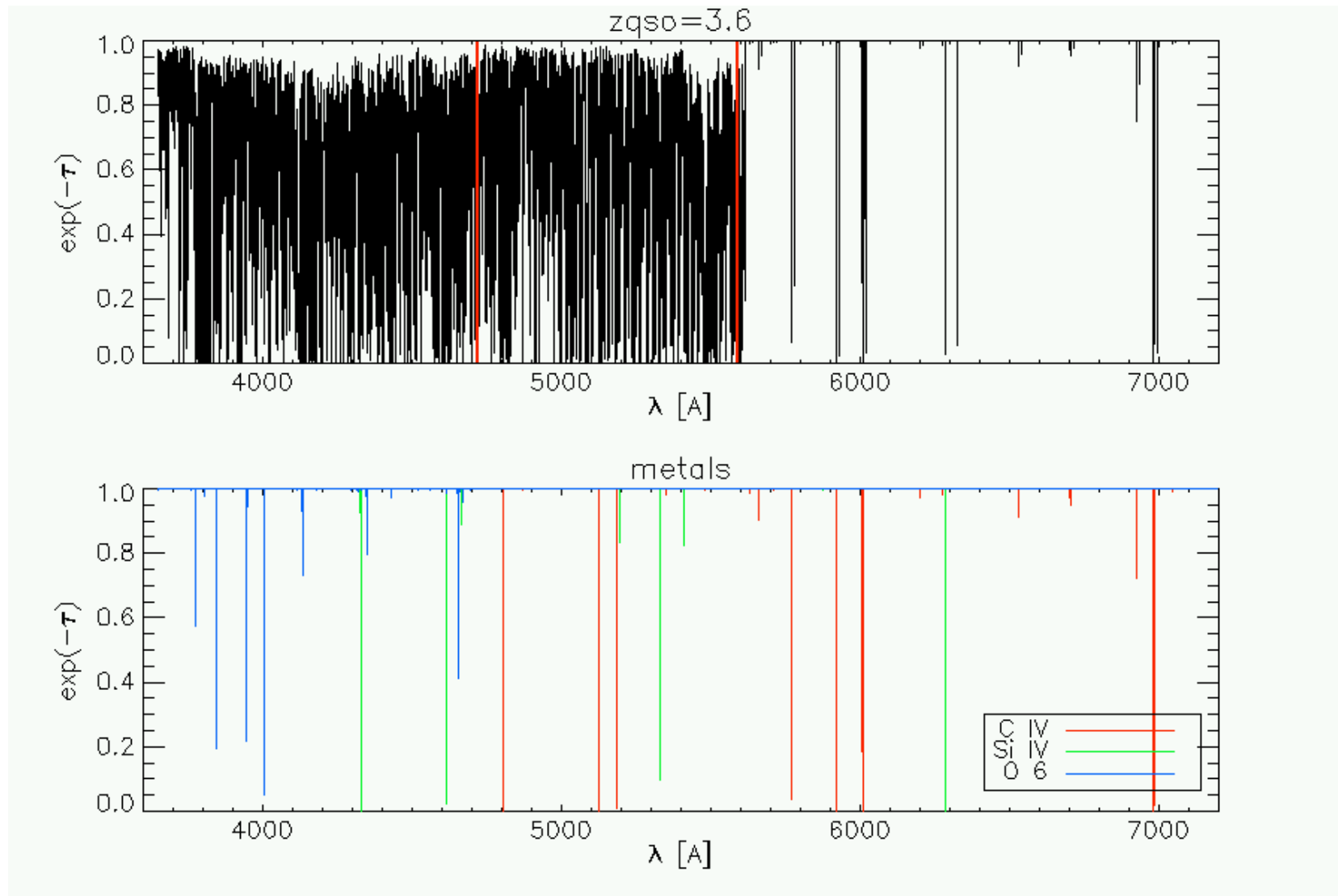




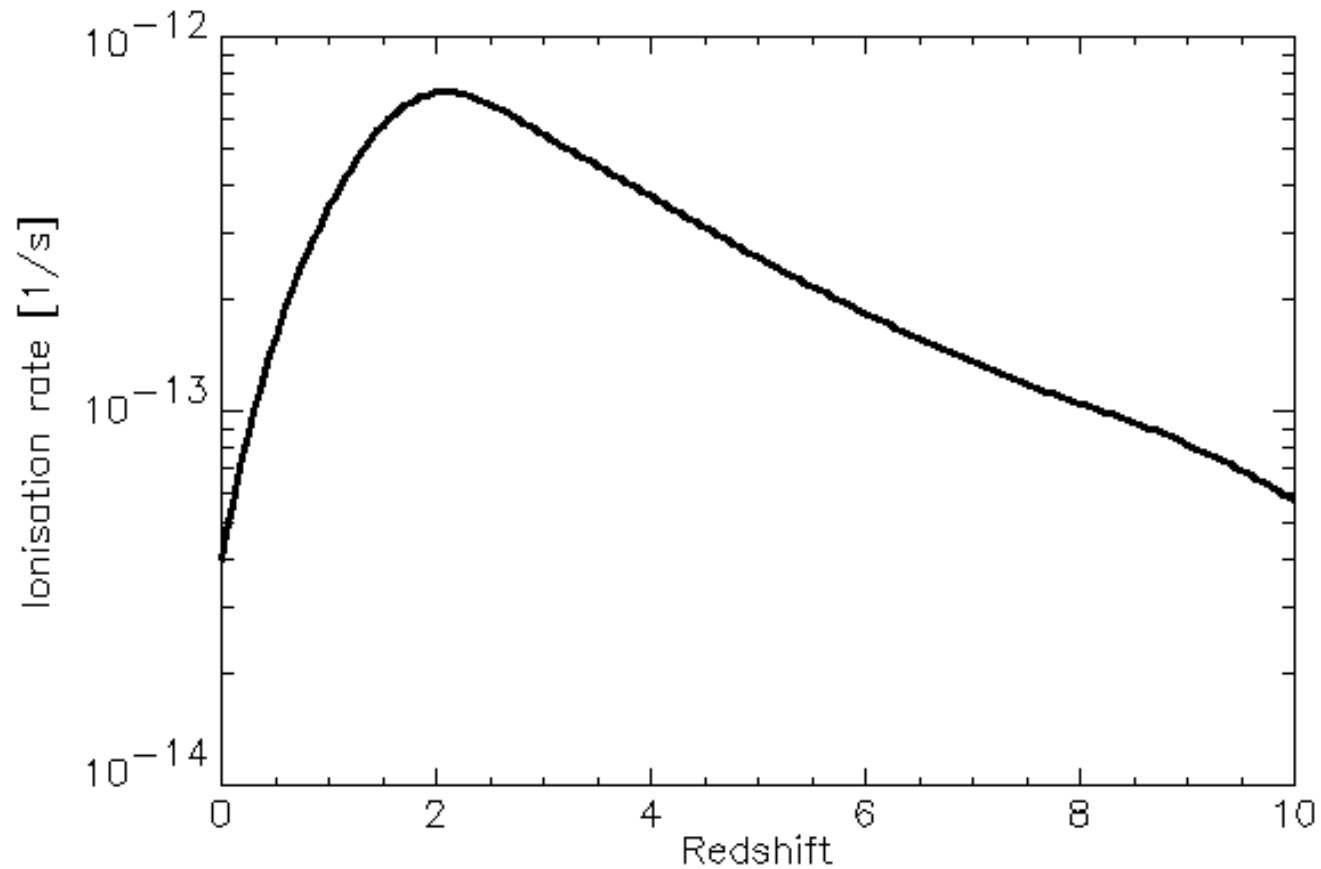




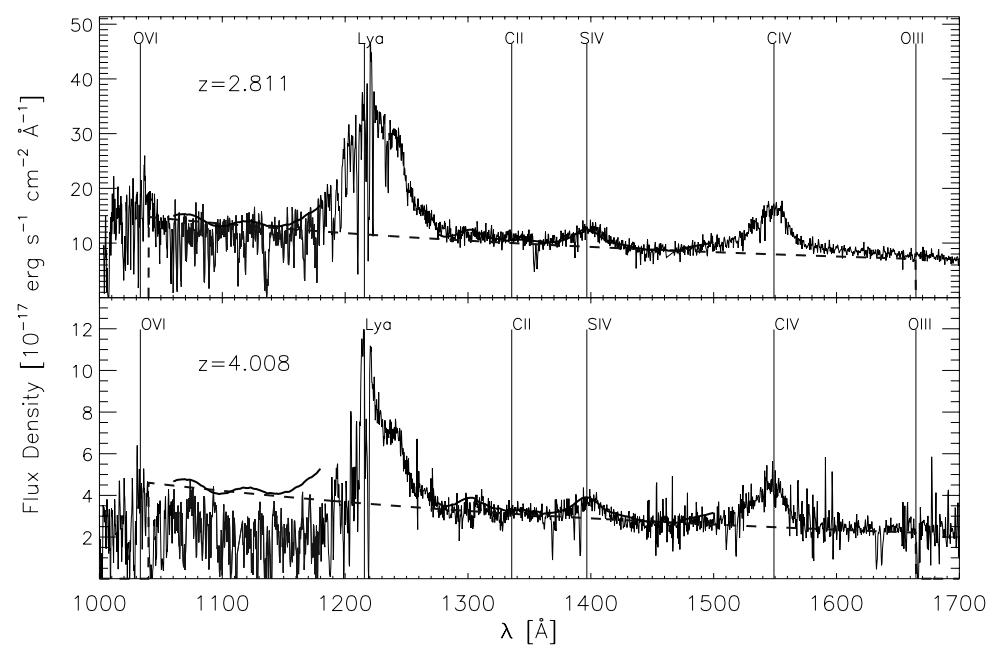
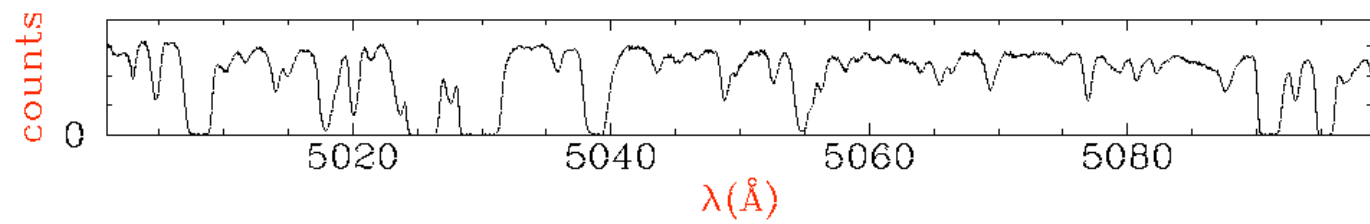
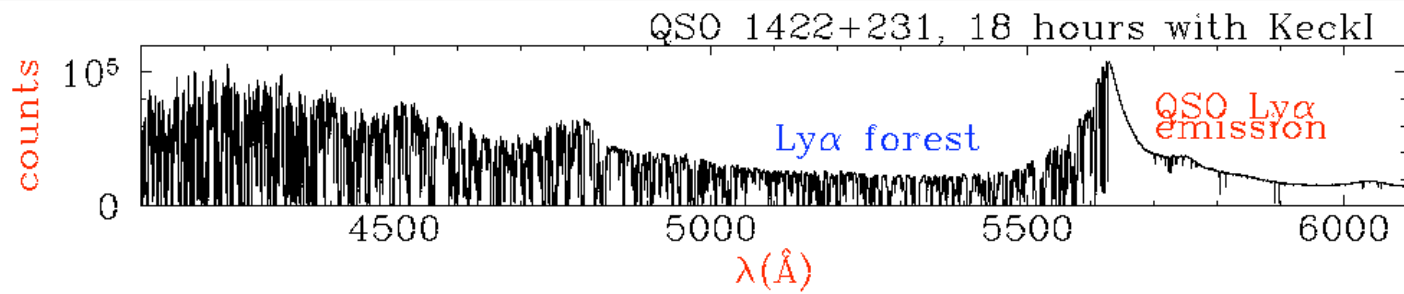
Simulated absorption spectrum



The IGM is highly ionized



Ionization rate from galaxies & QSOs as
computed by Haardt & Madau 2001



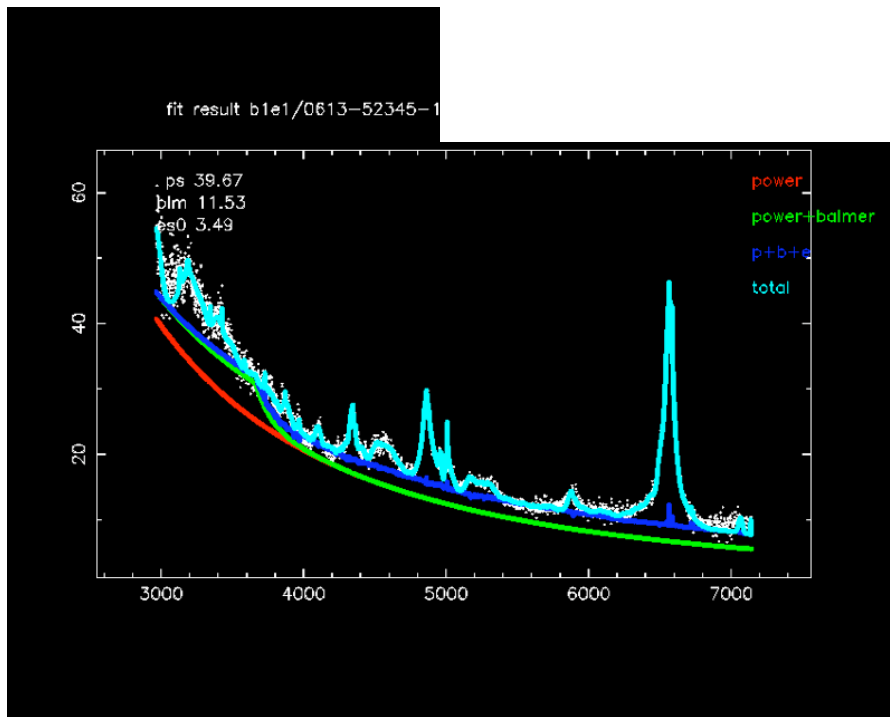
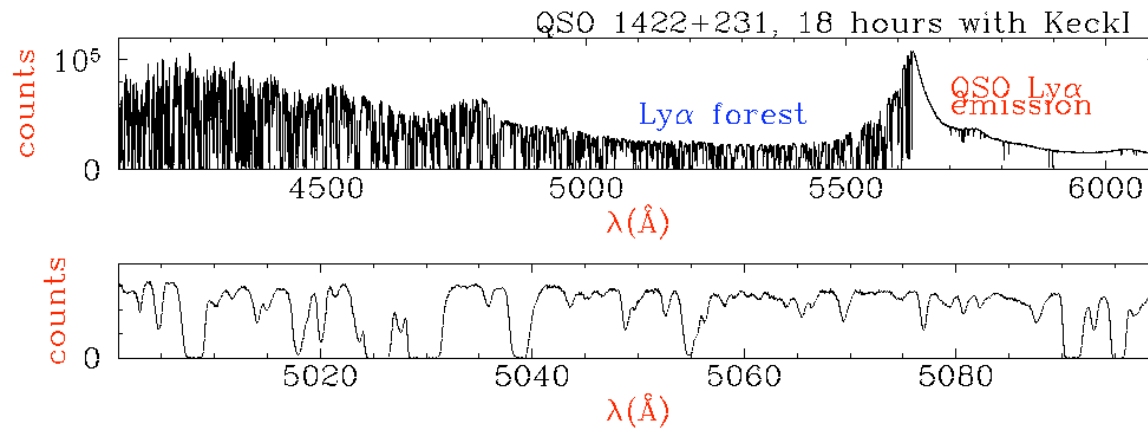
High-resolution
(Keck, VLT)

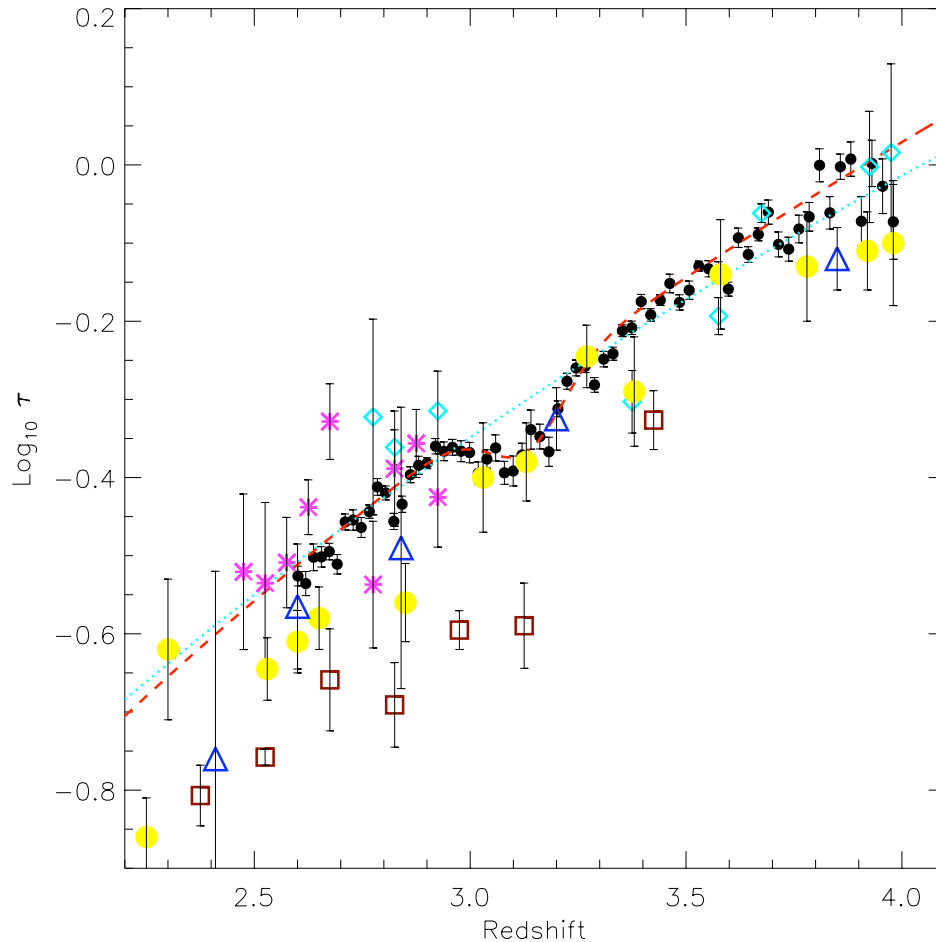
Low-resolution
(SDSS)

Some Issues:

- Continuum fitting
- Noise properties
- Are all lines Hydrogen?
- Are all lines cosmological?

Continuum fit



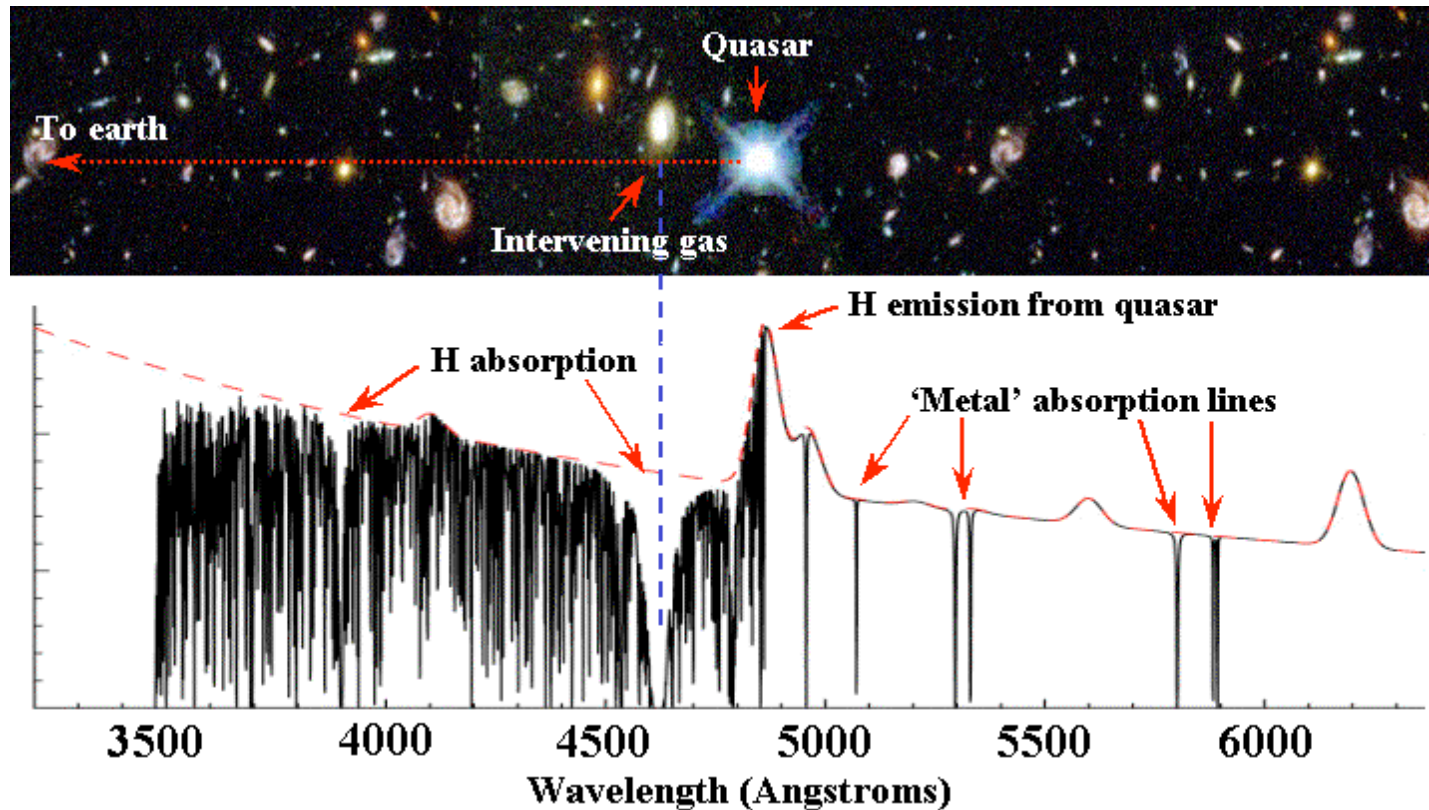


Mean amount
of absorption?

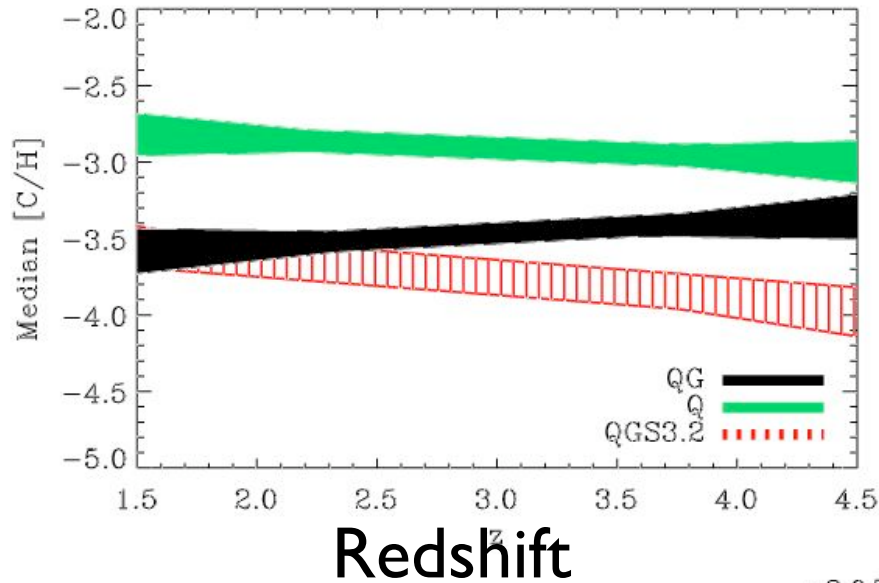
Bernardi et al 02

Fig. 13.— Comparison of measurements of the evolution of the effective optical depth in the Ly α forest. Stars, diamonds, squares and small filled circles show measurements from 42 low resolution spectra by Sargent, Steidel & Bocksenberg (1989), 33 from Schneider, Schmidt & Gunn (1991), 42 from Zuo & Lu (1993), and the subset of 796 QSOs in the SDSS sample which had $S/N > 4$ and were studied in this paper. Triangles and large filled circles show measurements in ~ 10 higher resolution spectra by McDonald et al. (2000) and Schaye et al. (2000). Dotted line shows the evolution reported by Press, Rybicki & Schneider (1993), and dashed line shows the evolution given in Table 1.

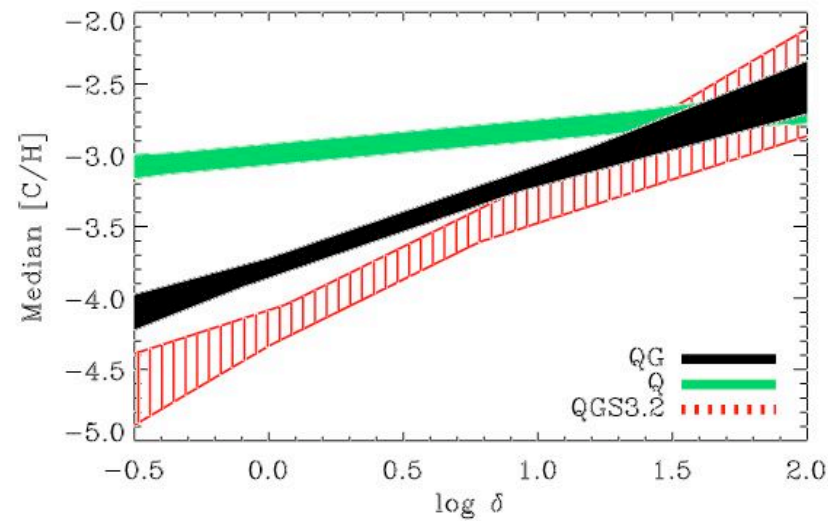
Are all lines Hydrogen lines? Are they cosmological?



Delta = 3



z=3



Schaye et al 03

Density

- Current observations

Measurements of the flux power-spectrum

$$\exp(-\tau) \equiv \frac{\text{Observed counts}}{\text{Emitted counts}}$$

$$\frac{d\lambda}{\lambda} = \frac{dv}{c}$$

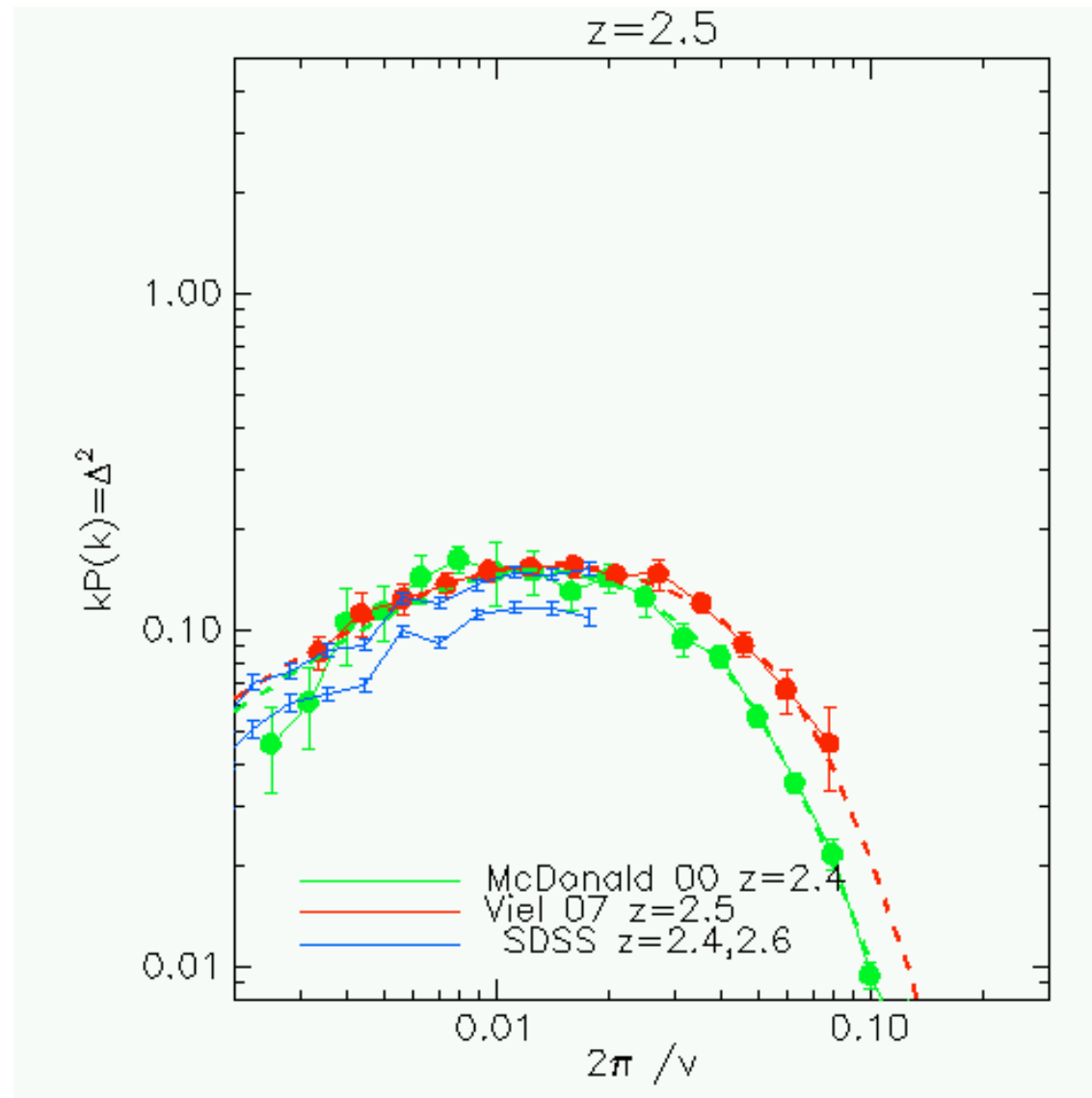
$$\log\left(\frac{\lambda}{\lambda_0}\right) = \exp(v/c)$$

$$k = \frac{2\pi}{v} \quad \text{has dimensions of s km}^{-1}$$

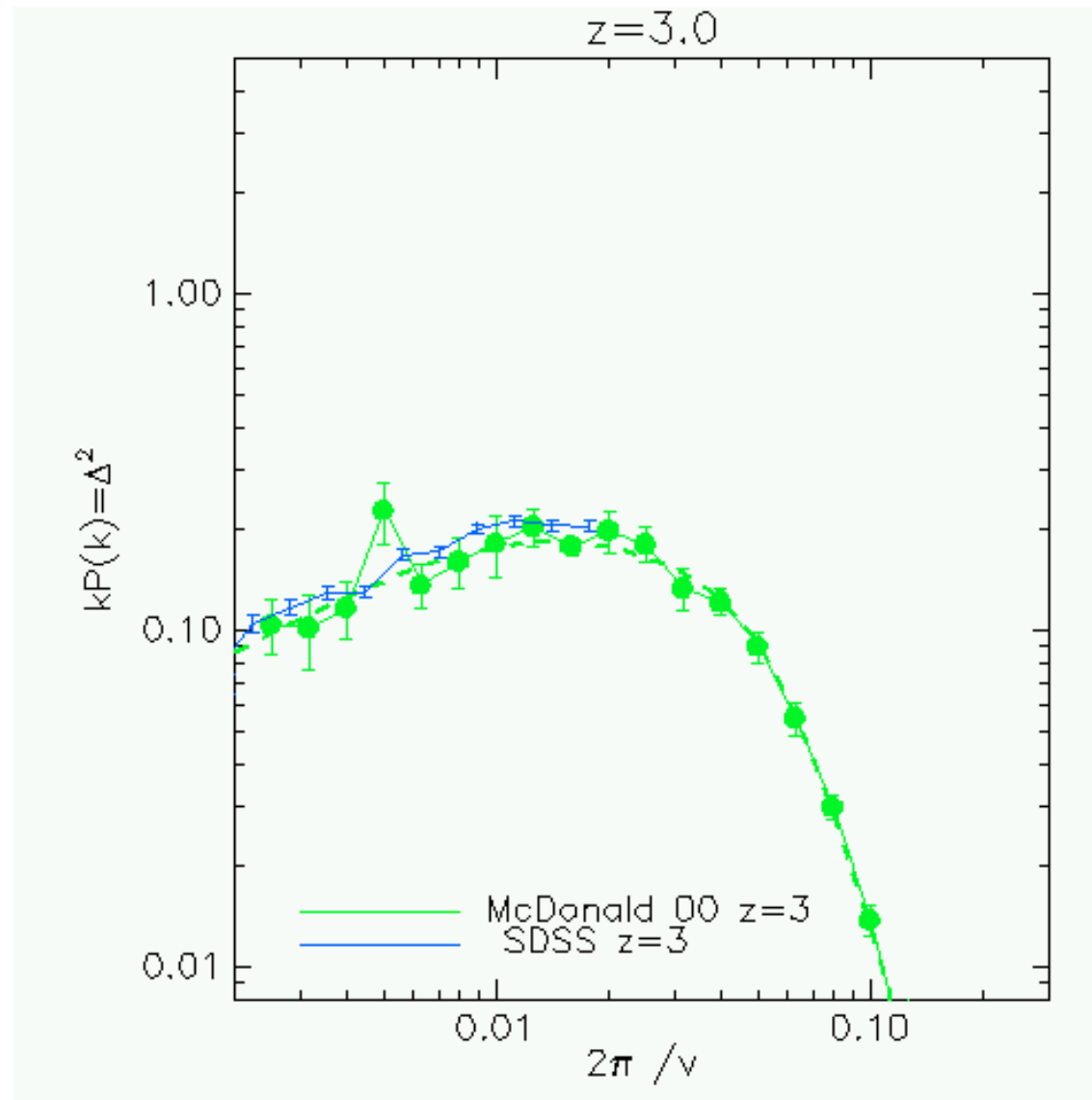
$$P(k) = \text{power spectrum of } \exp(-\tau)$$

$$kP(k) = \Delta^2(k) \quad \text{is dimensionless}$$

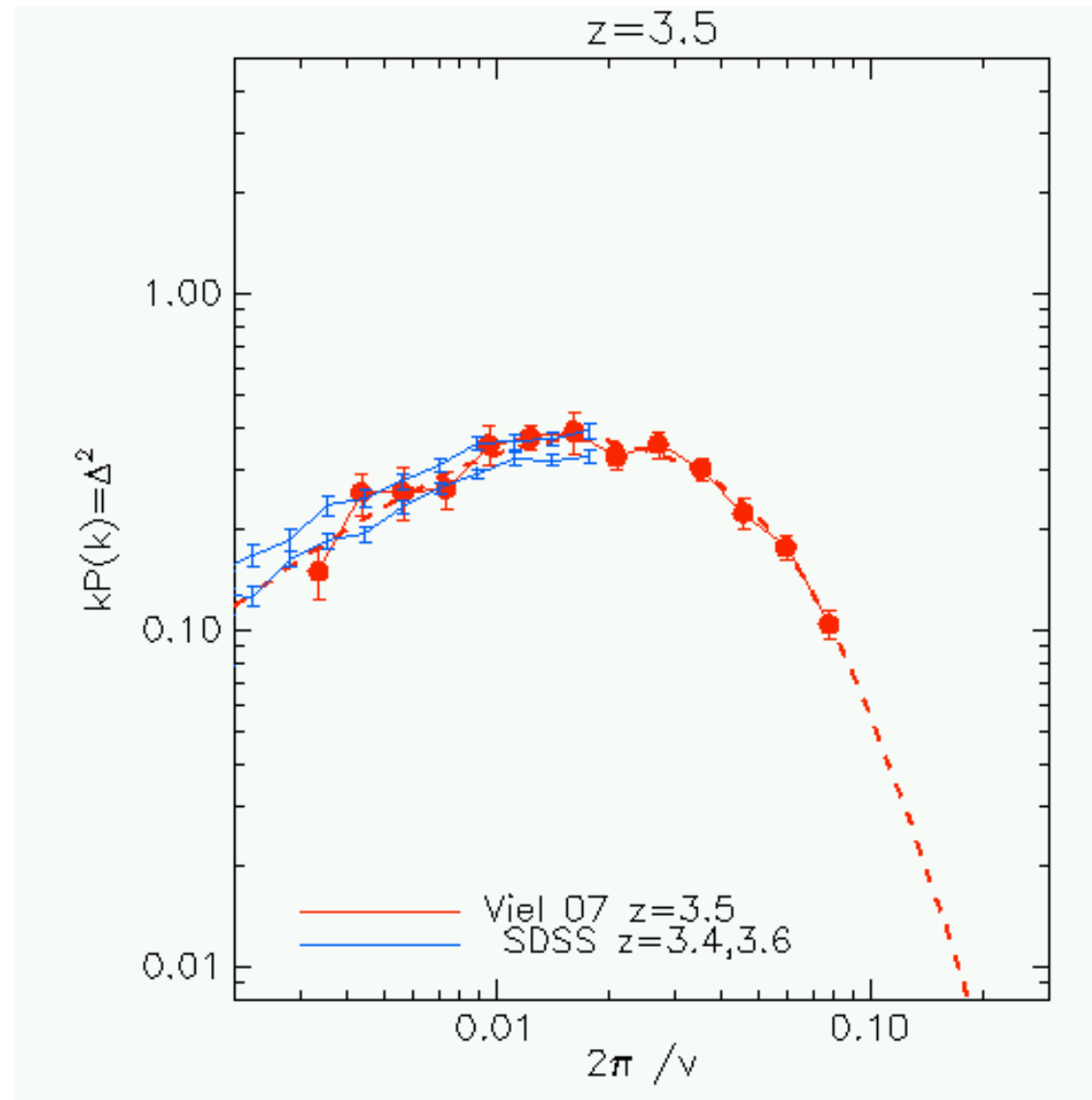
Observations: Mcdonald HiRes / Viel / Mc Donald SDSS



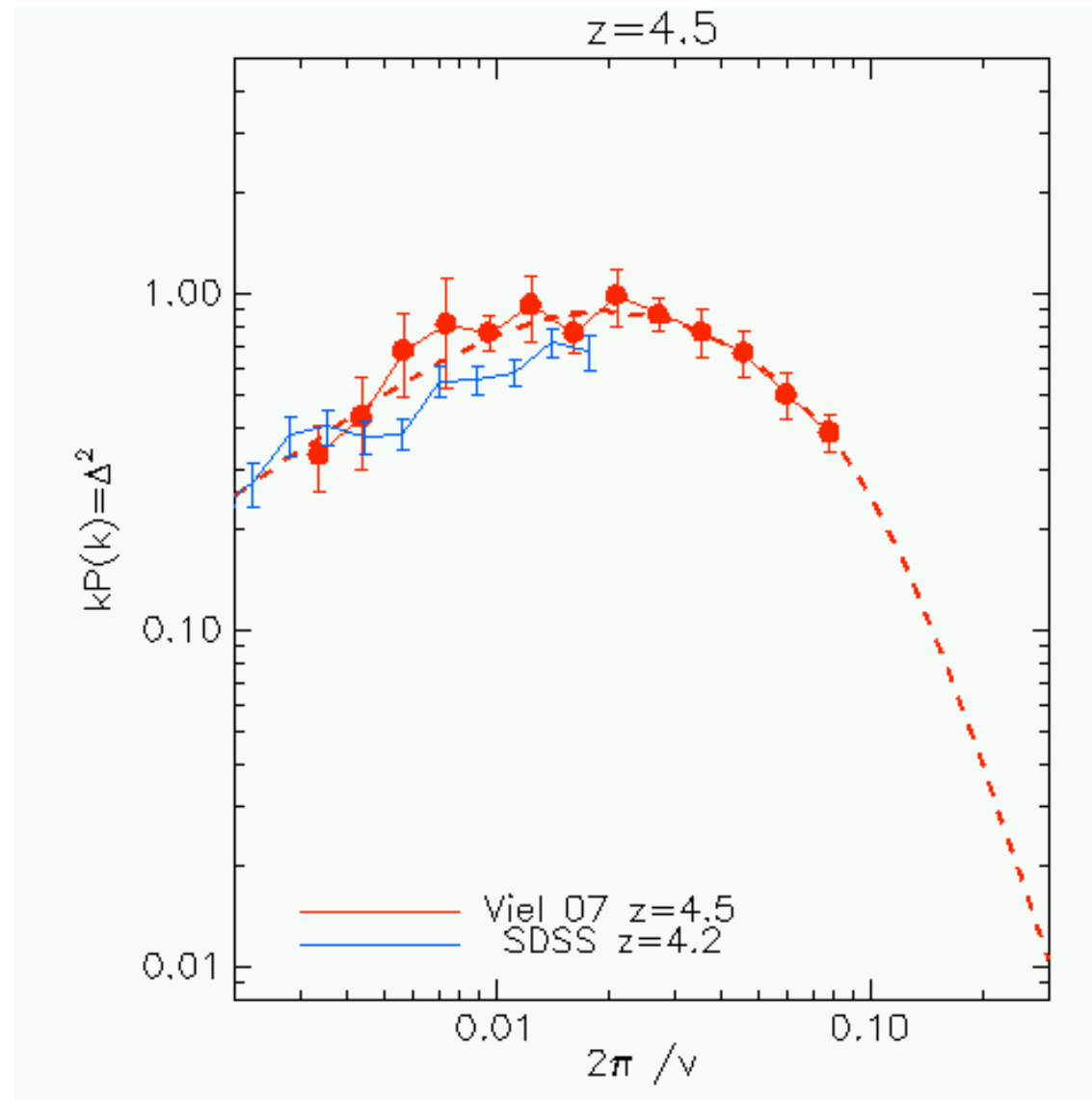
Observations: McDonald HiRes / Viel / McDonald SDSS



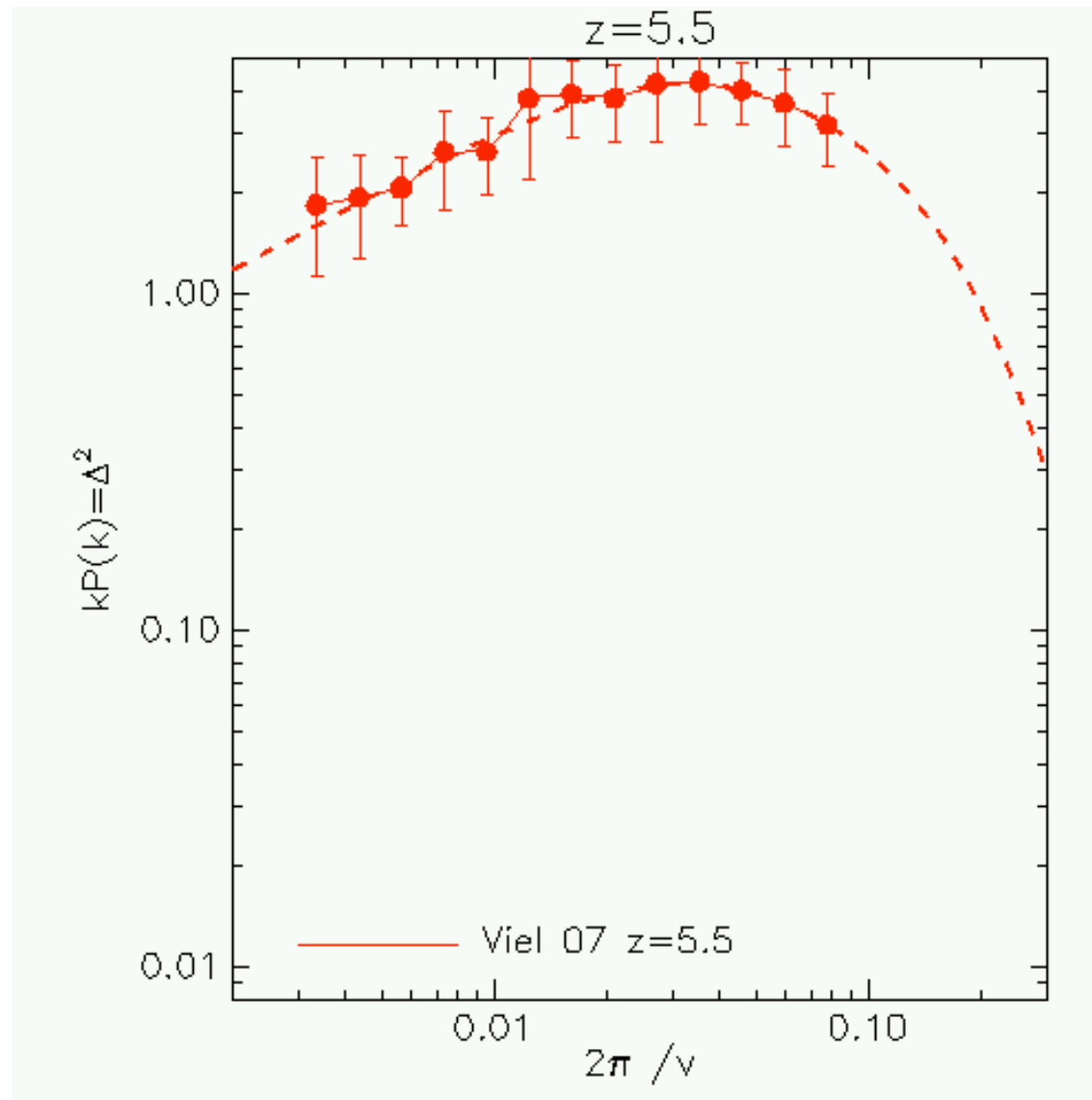
Observations: Mcdonald HiRes / Viel / McDonald SDSS



Observations: Mcdonald HiRes / Viel / Mc Donald SDSS



Observations: Mcdonald HiRes / Viel / McDonald SDSS



• Simulating the forest

Leiden:
Claudio Dalla Vecchia
Joop Schaye



Trieste:
Luca Tornatore



MPA:
Volker Springel



Aims:

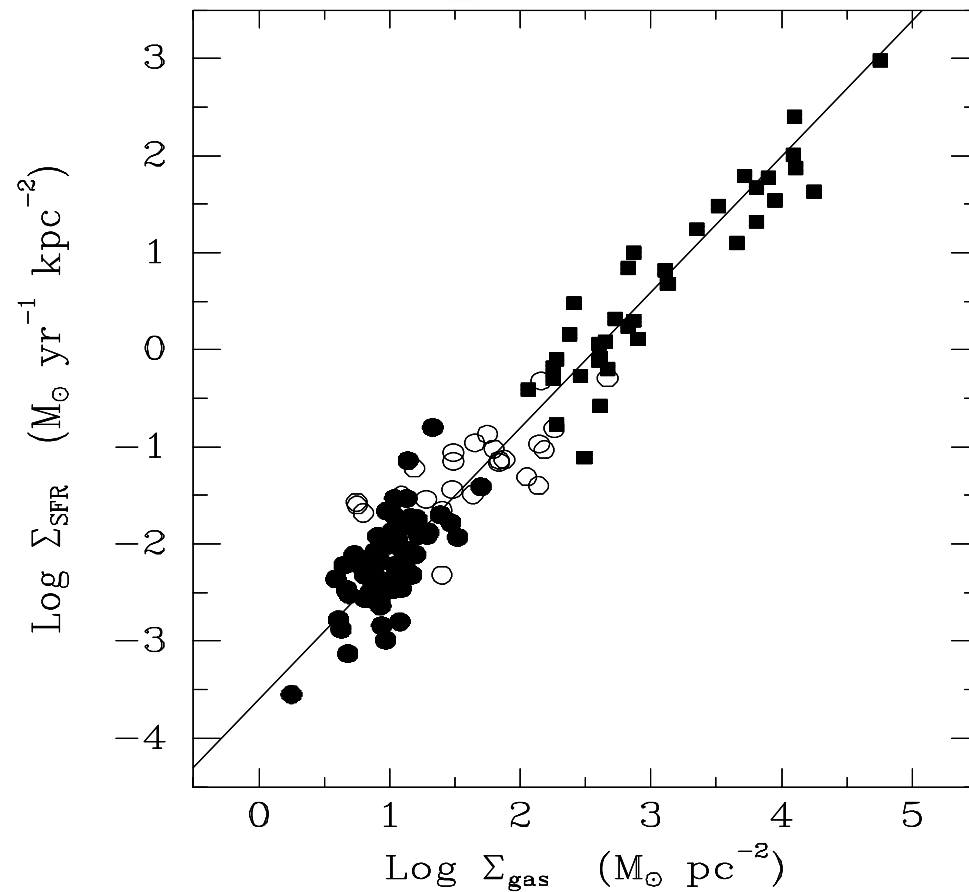
- simulate IGM and galaxies together
- investigate numerical/physical uncertainties

- Gadget 3
- Star formation guarantees Schmidt law
- Stellar evolution
- Winds
- Metal-dependent cooling

Observed star formation:

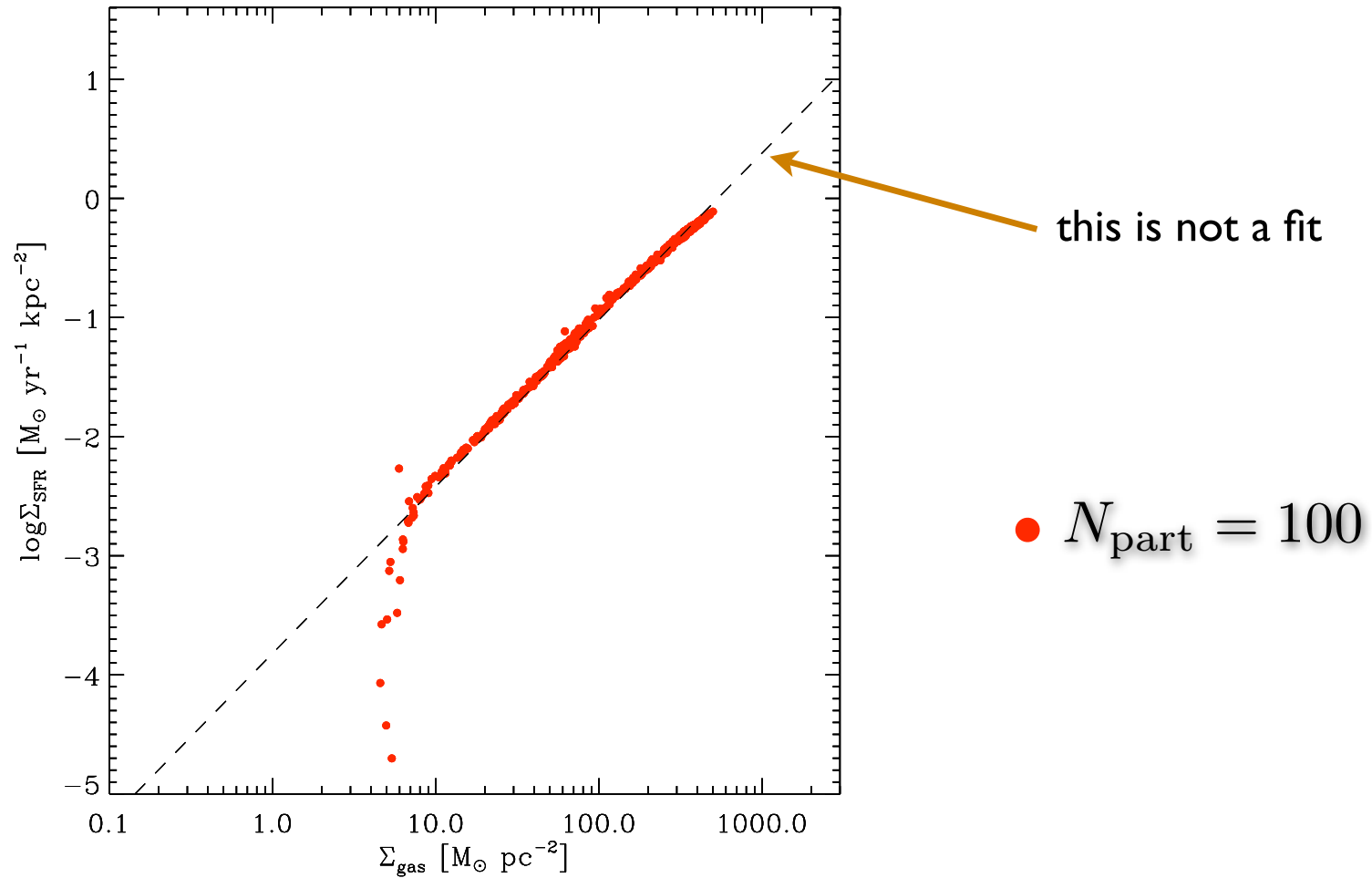
Schmidt law

$$\Sigma_{\text{SFR}} \propto \Sigma_{\text{gas}}^n \quad (n = 1.4 \pm 0.15)$$



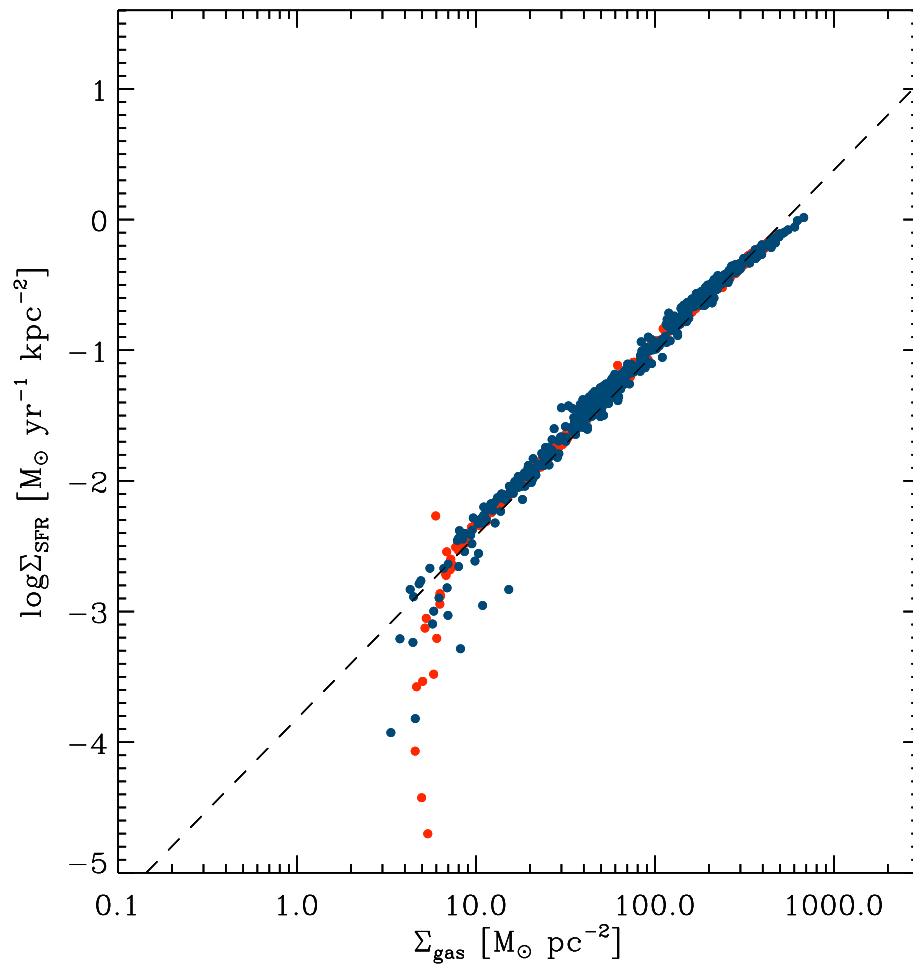
(Kennicutt 1989)

Simulated star formation:



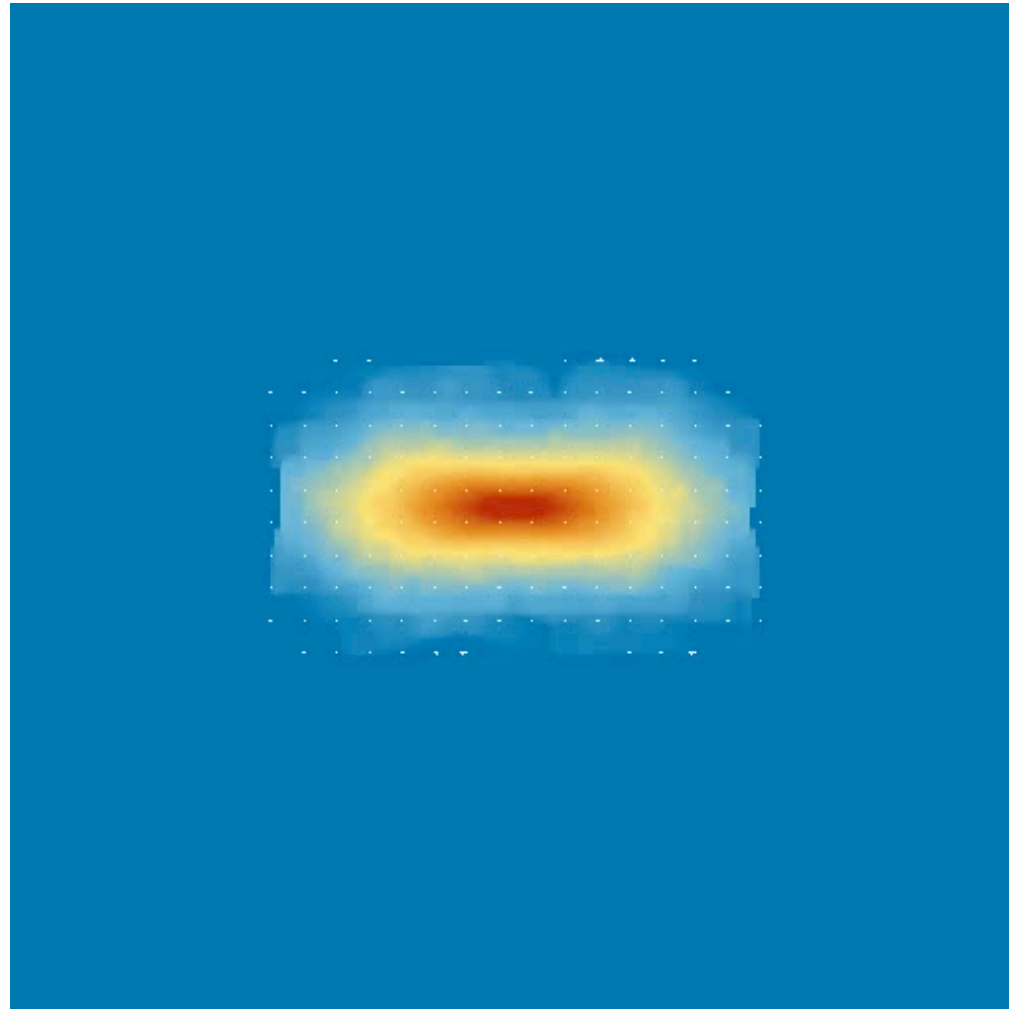
Simulated star formation:

“resolution independent”



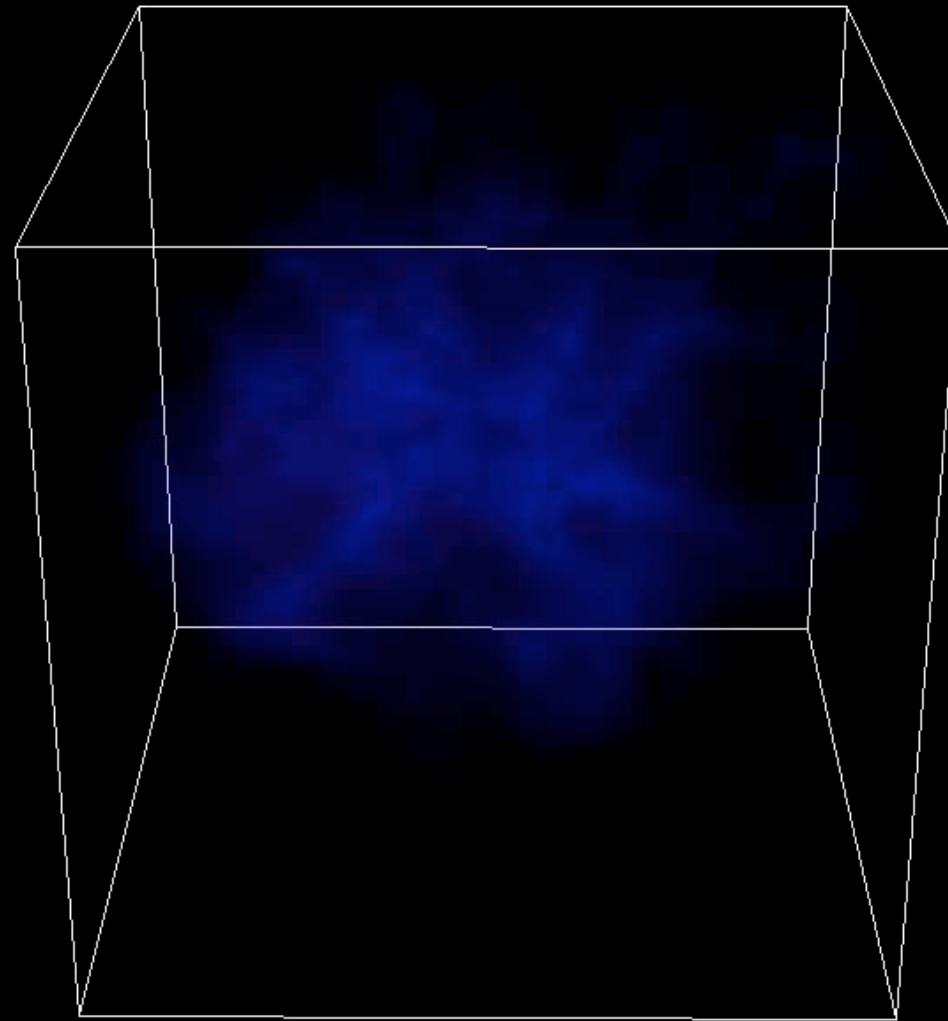
● $N_{\text{part}} = 100$

● $N_{\text{part}} = 12$



Dwarf galaxy with GIMIC/OWLS code

log (Gas density) in [$M_{\text{sun}}/h / (\text{Mpc}/h)^3$]

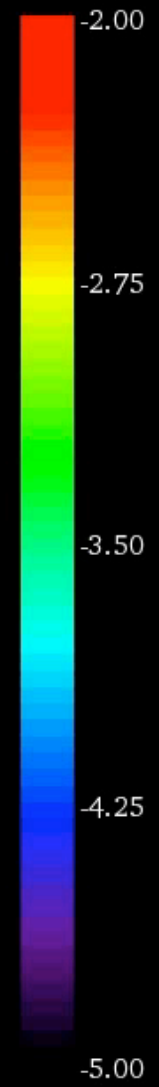
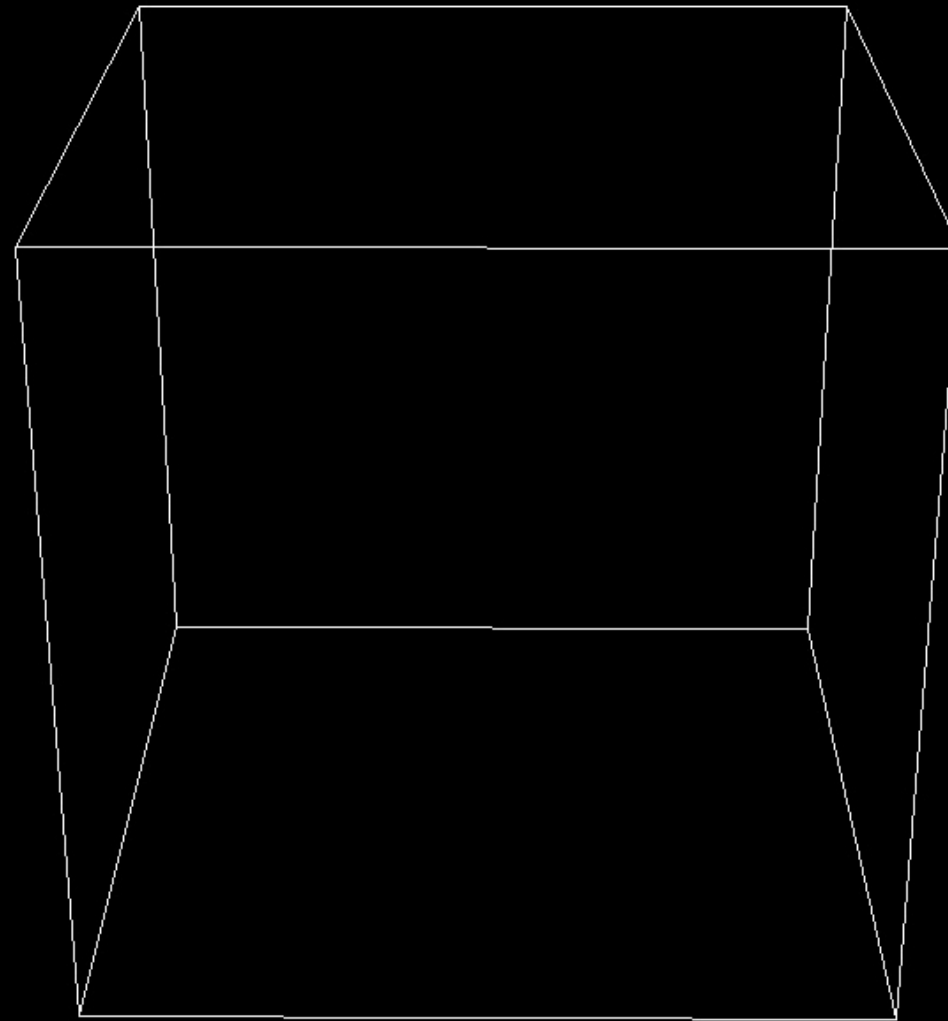


$z = 29.888$

$L = 0.999 \text{ Mpc}/h$

Dwarf galaxy with GIMIC/OWLS code

$\log(Z)$



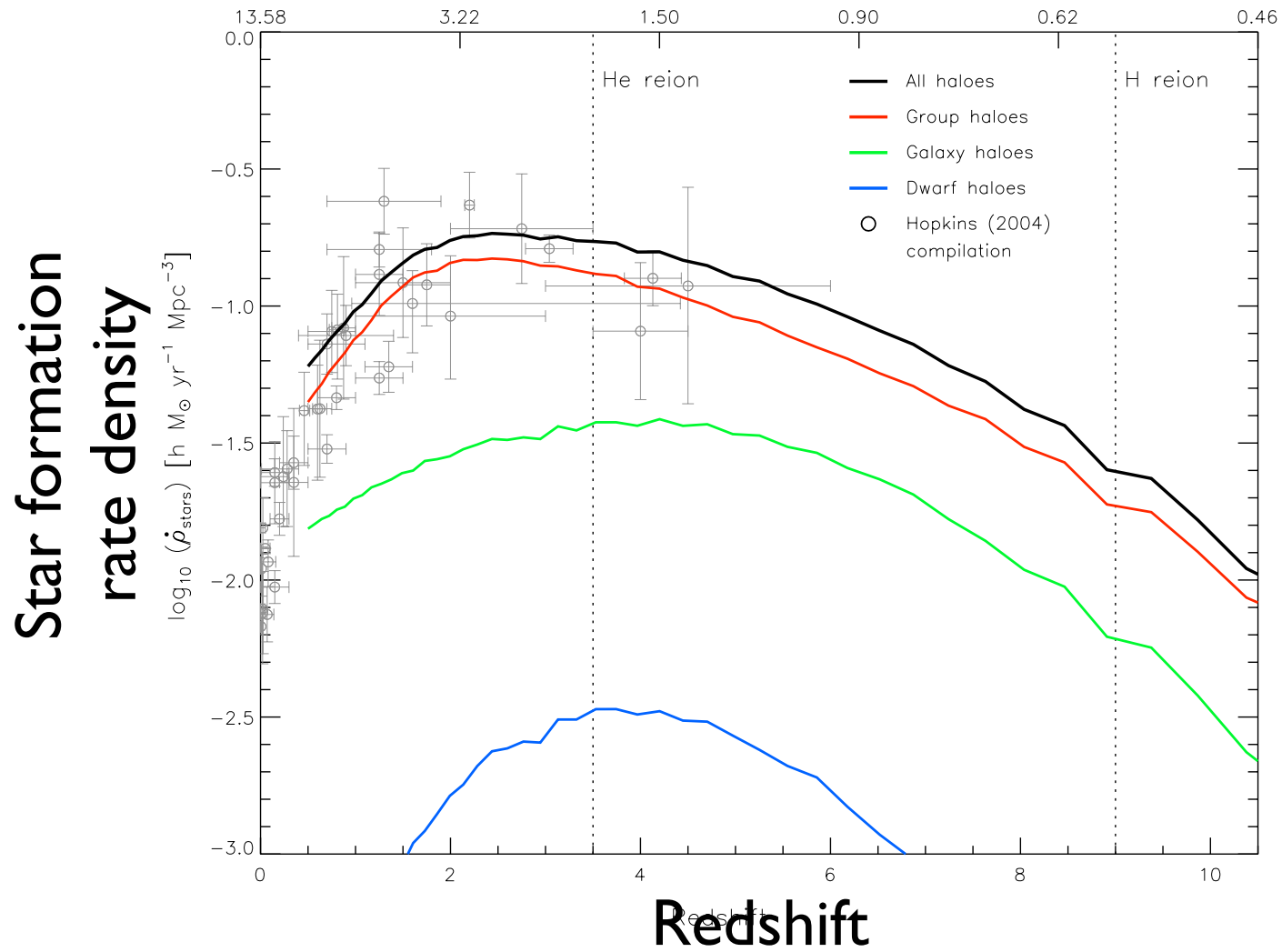
$z = 29.888$

$L = 0.999 \text{ Mpc}/h$

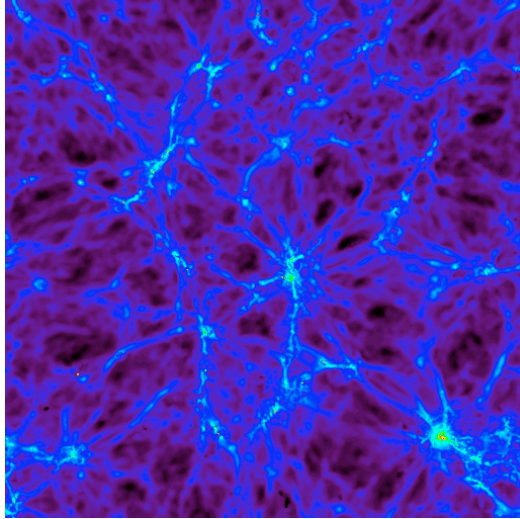
Suite of simulations varying:

- Star formation parameters
- Wind implementation
- Resolution
- Box size
- Cosmology
- Reionization history

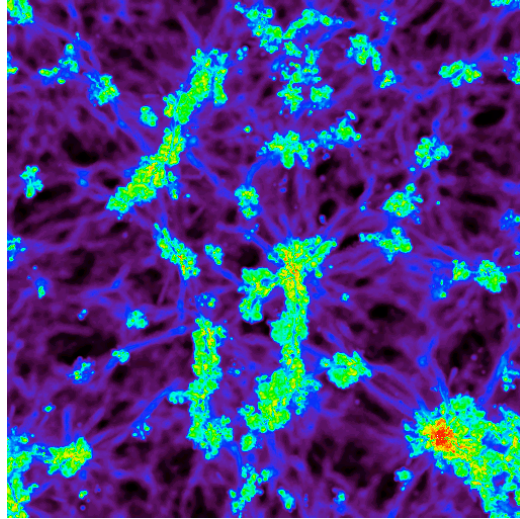
Star formation history



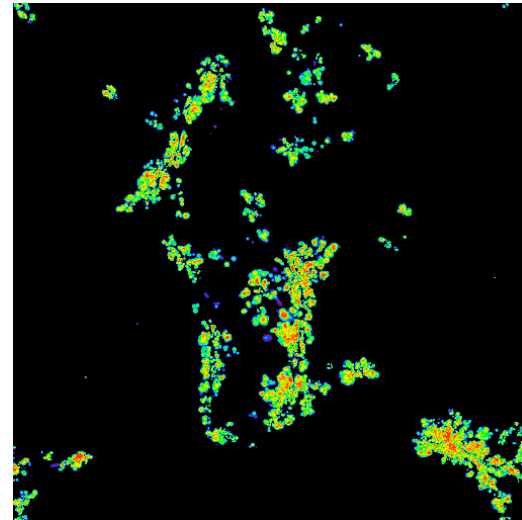
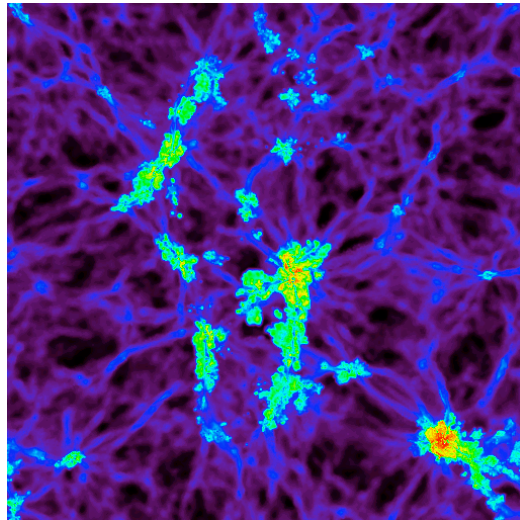
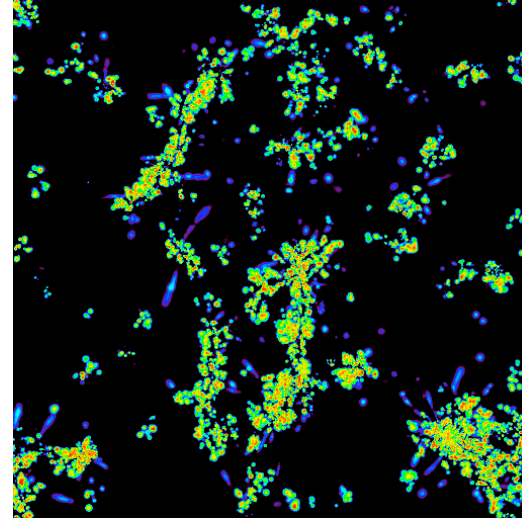
Density

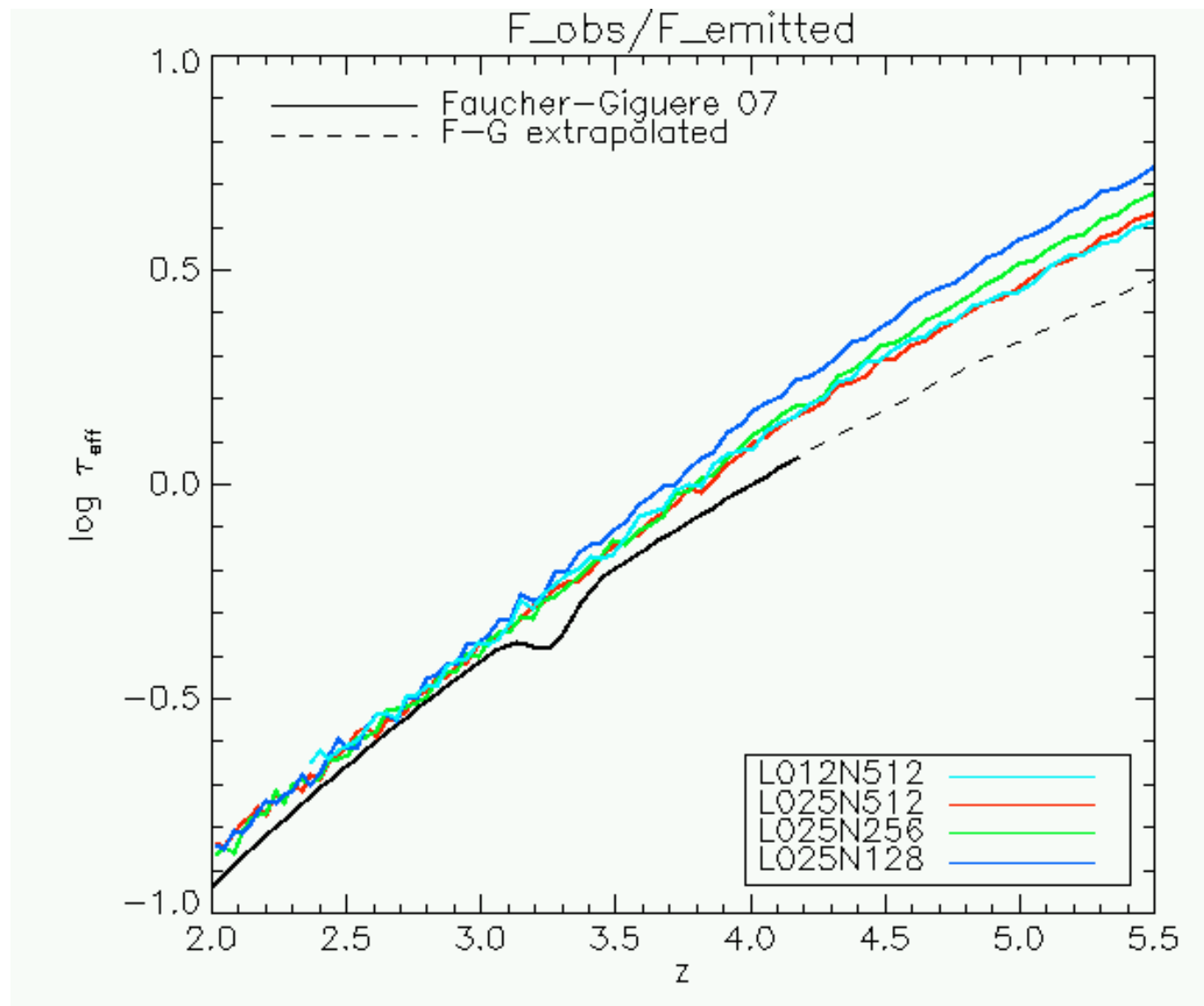


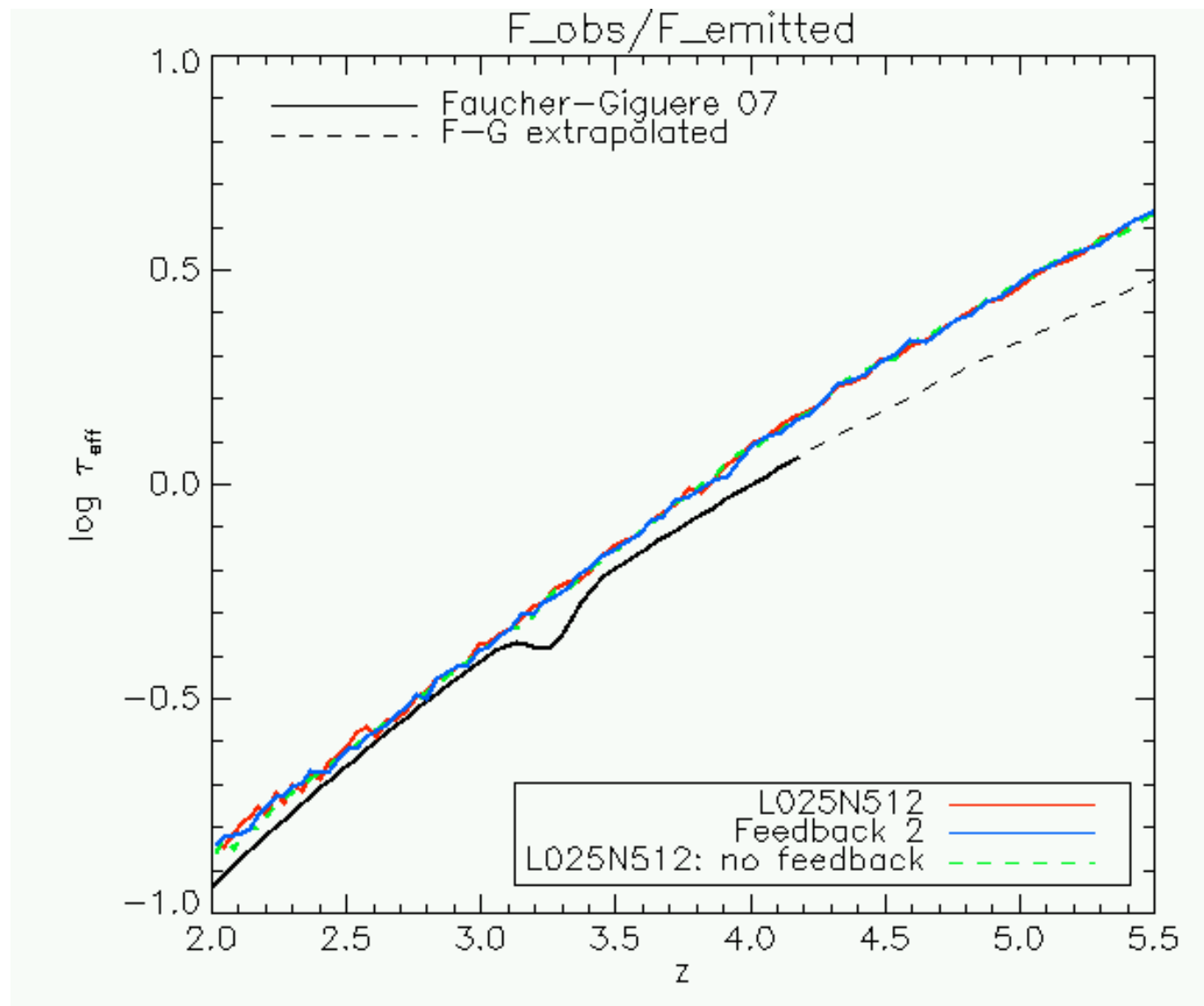
Temperature

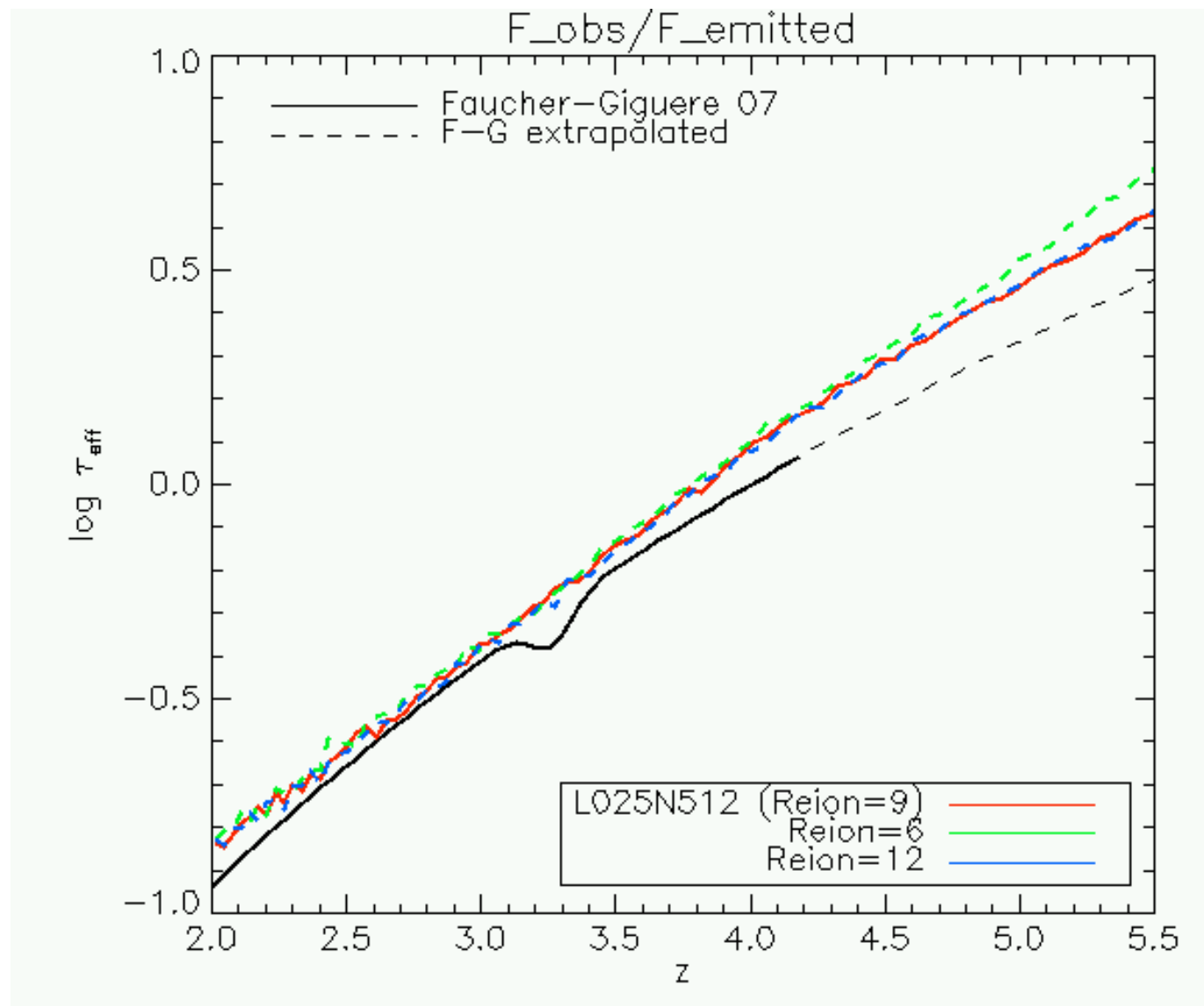


Metallicity

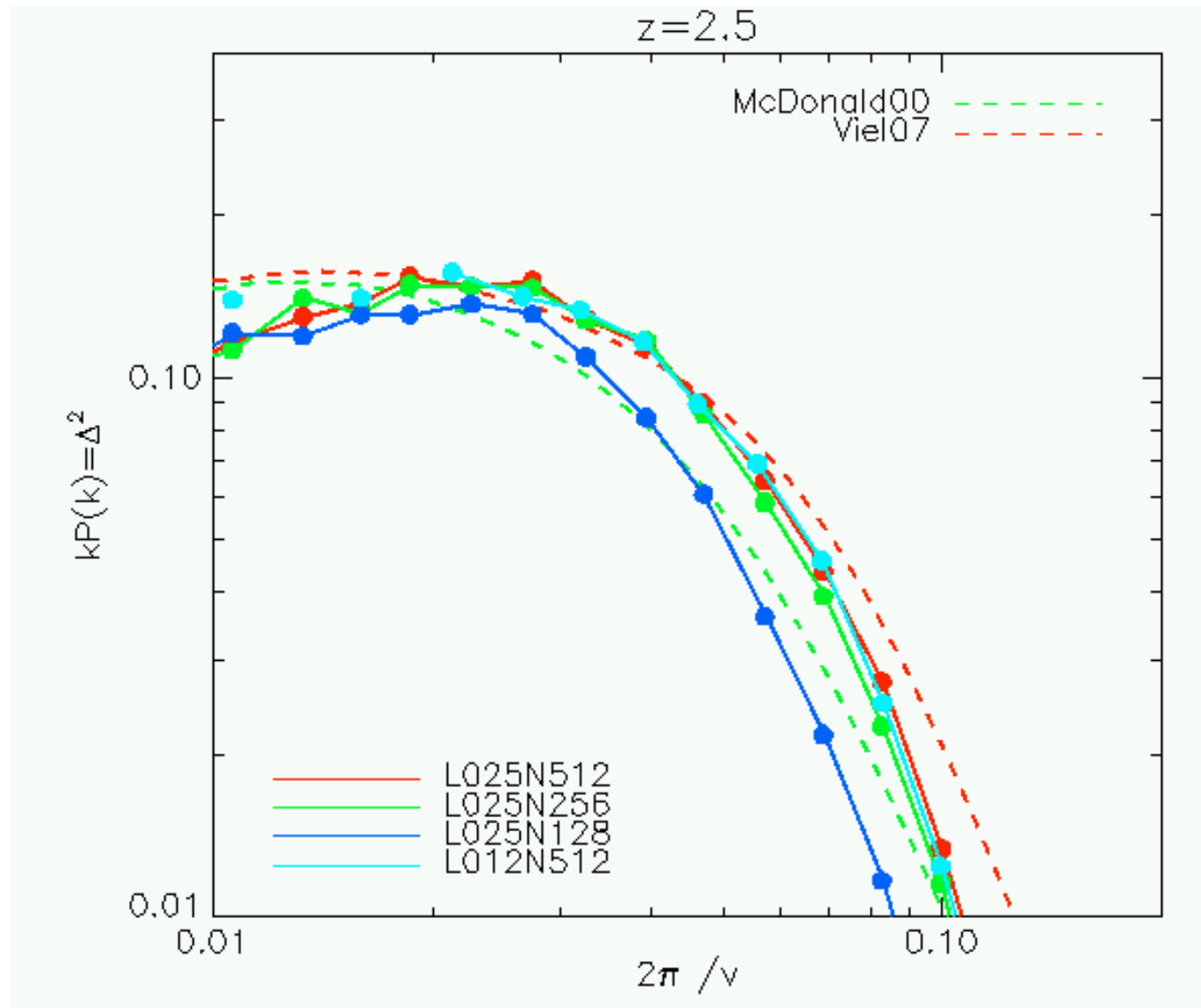




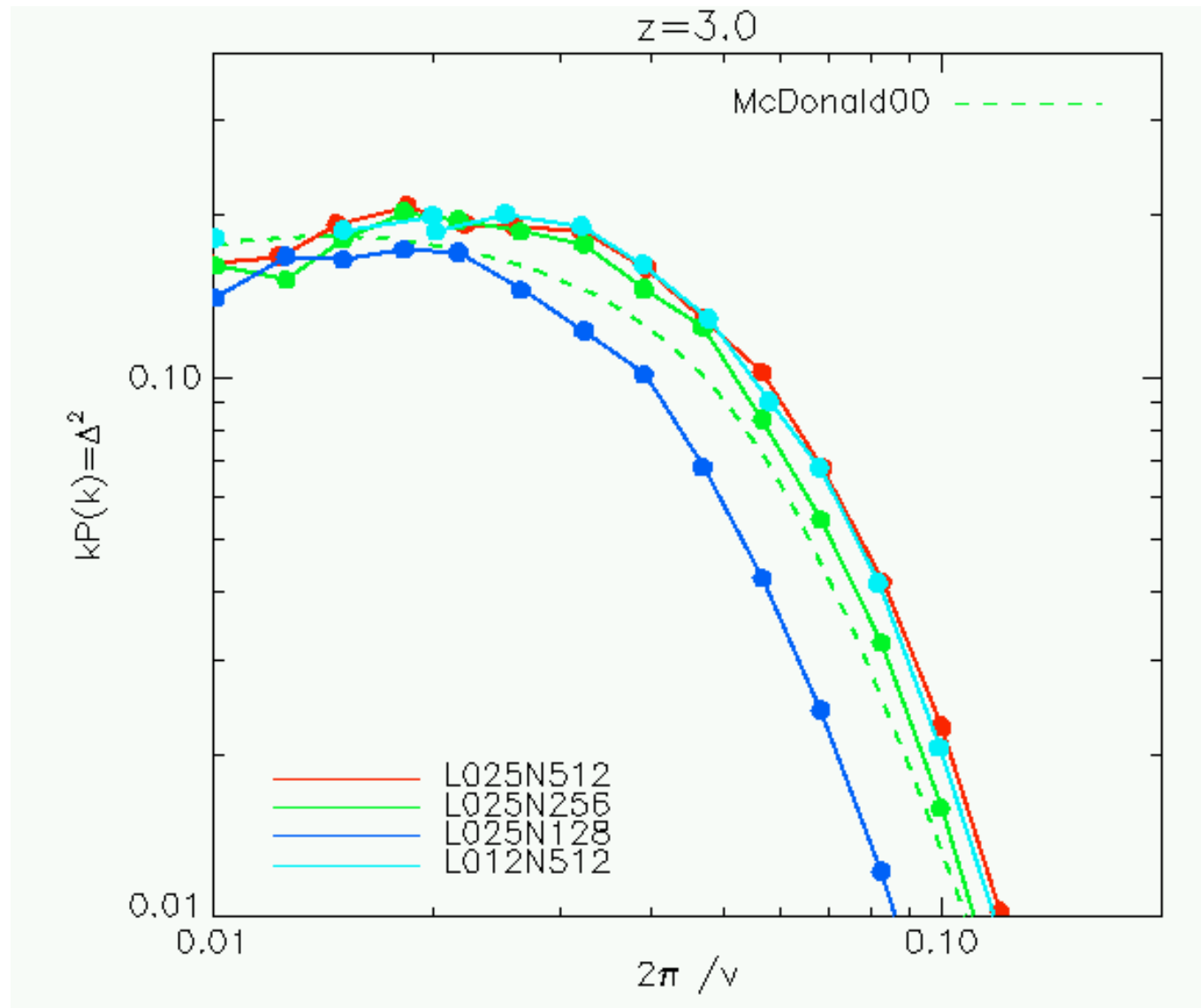




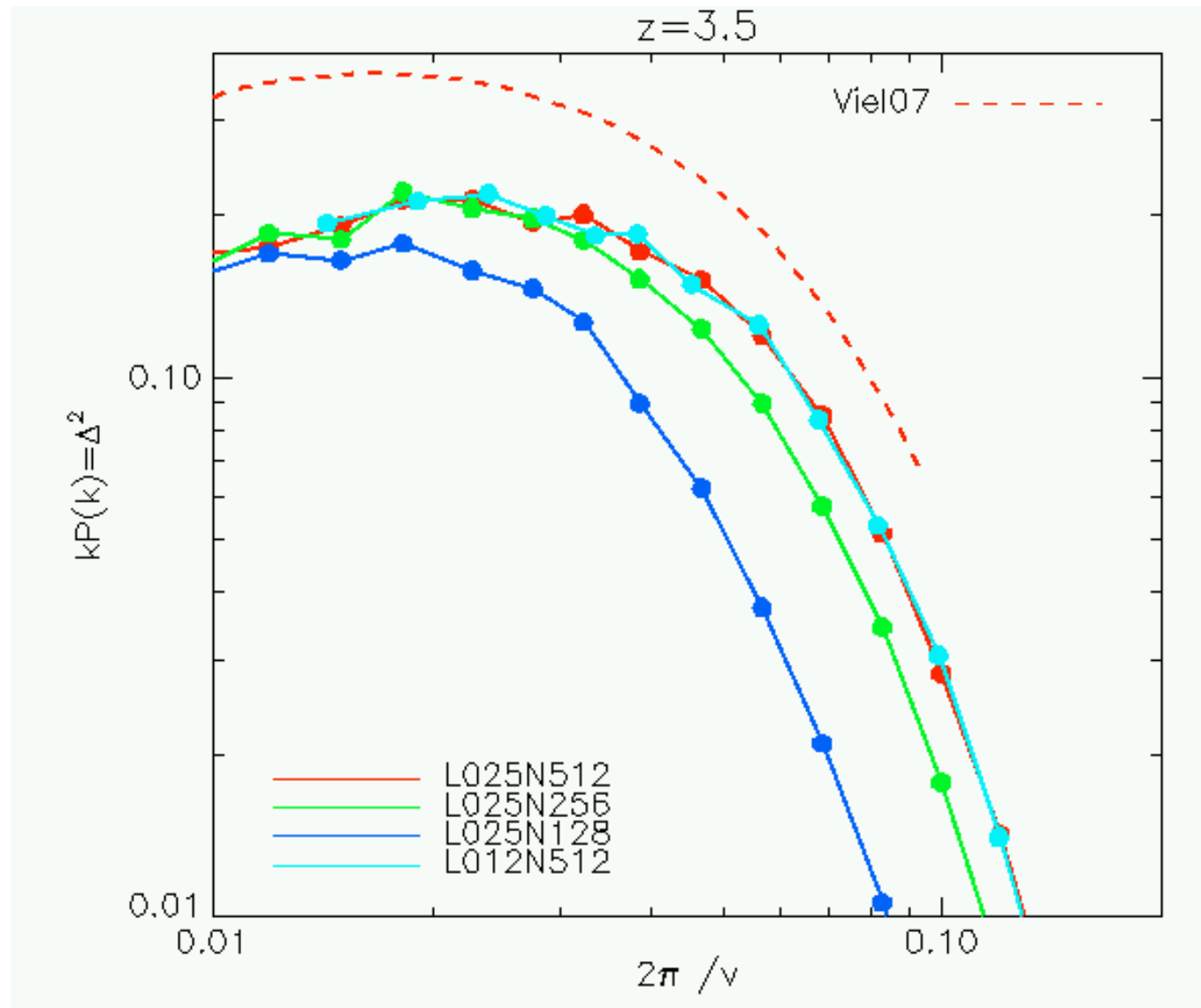
Resolution: low / medium / high / very high



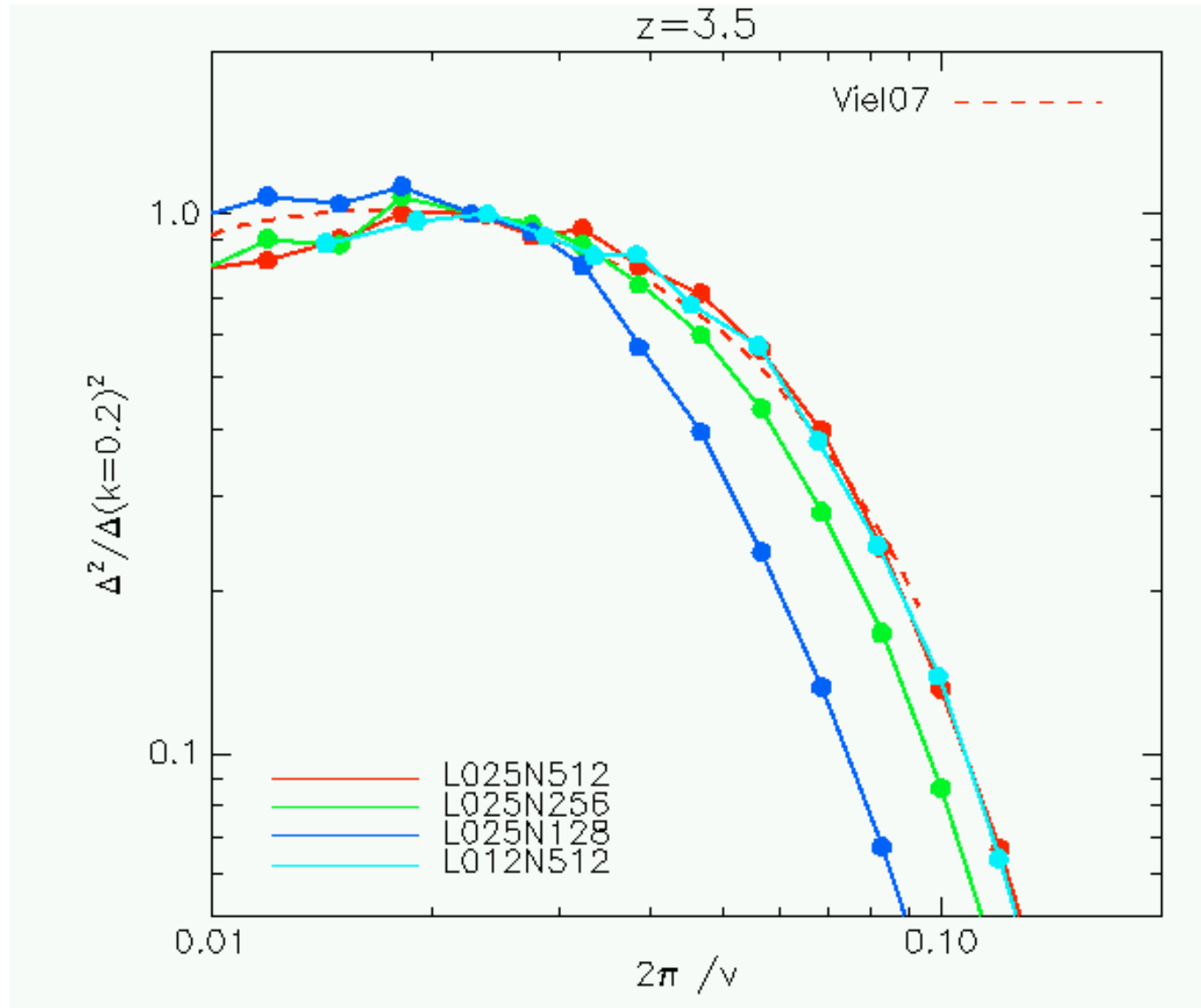
Resolution: low / medium / high / very high



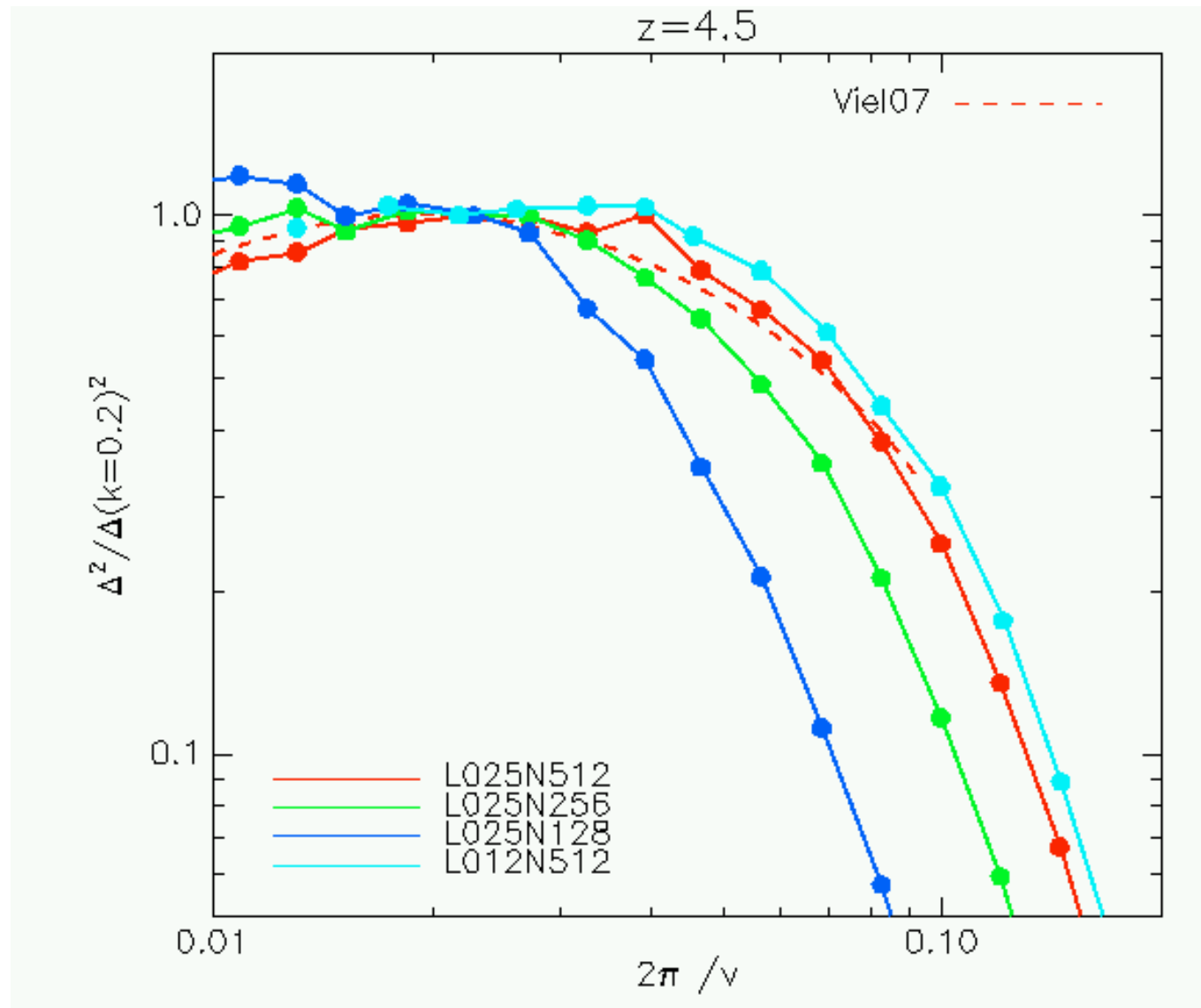
Resolution: low / medium / high / very high



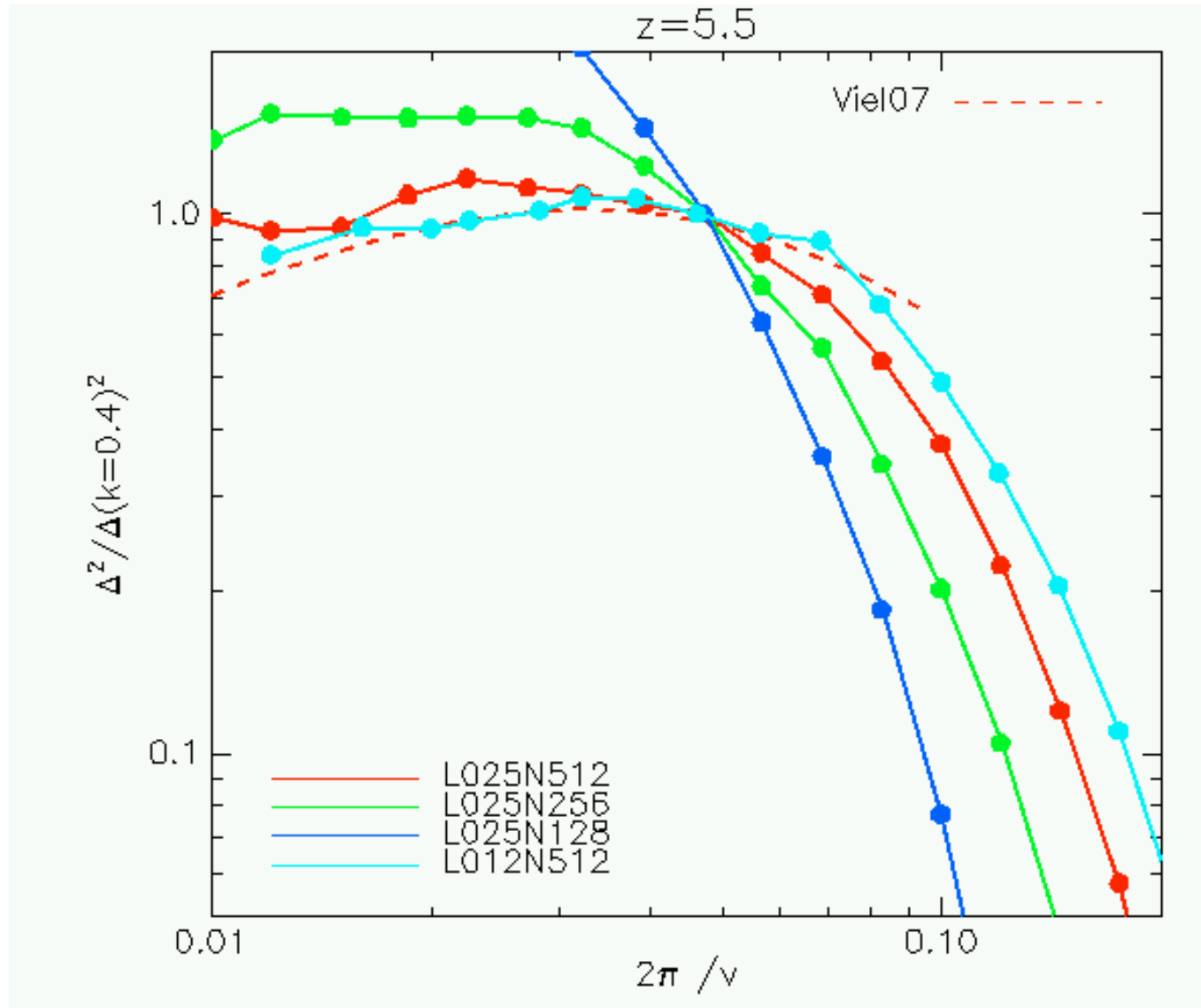
Resolution: low / medium / high / very high



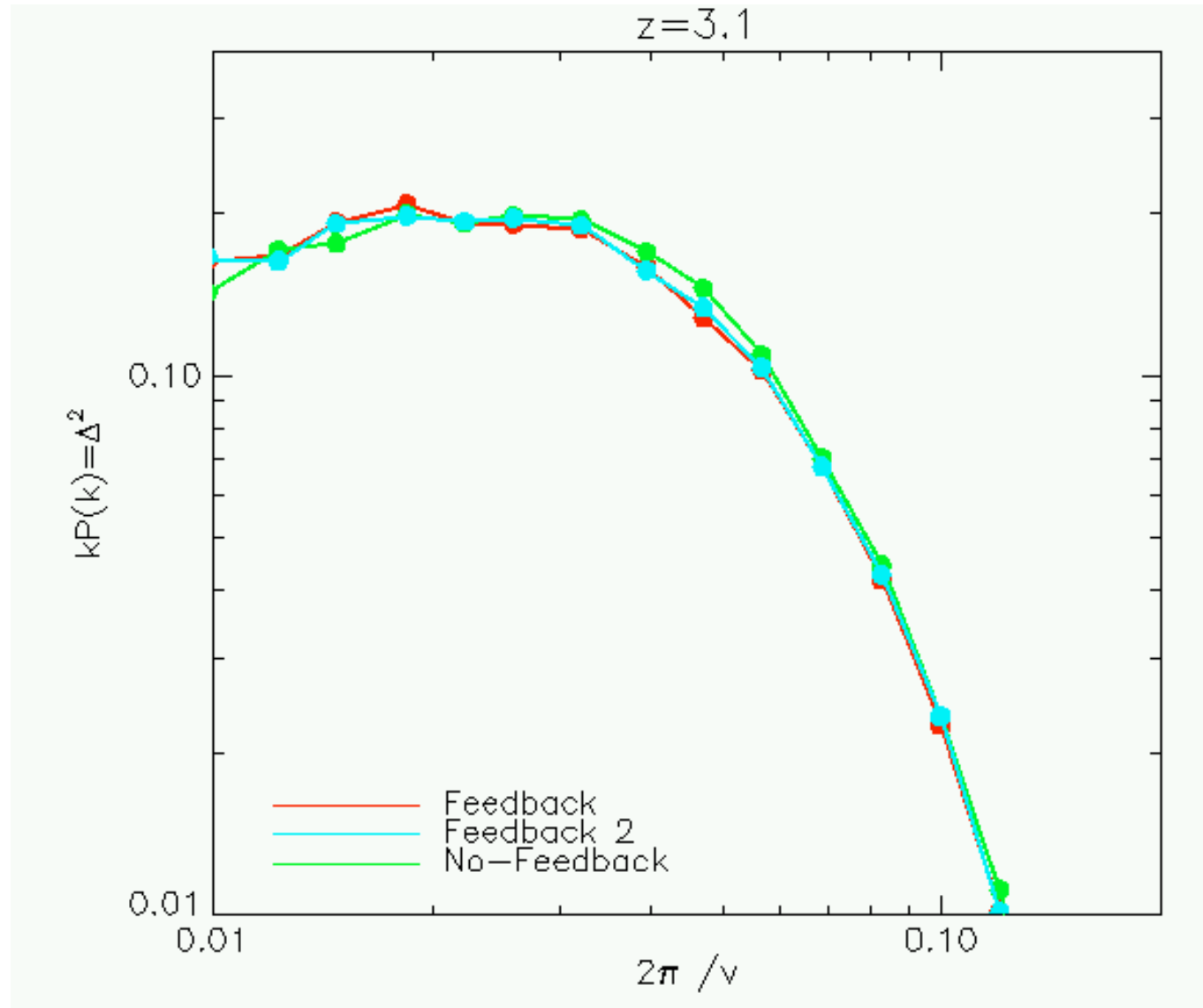
Resolution: low / medium / high / very high



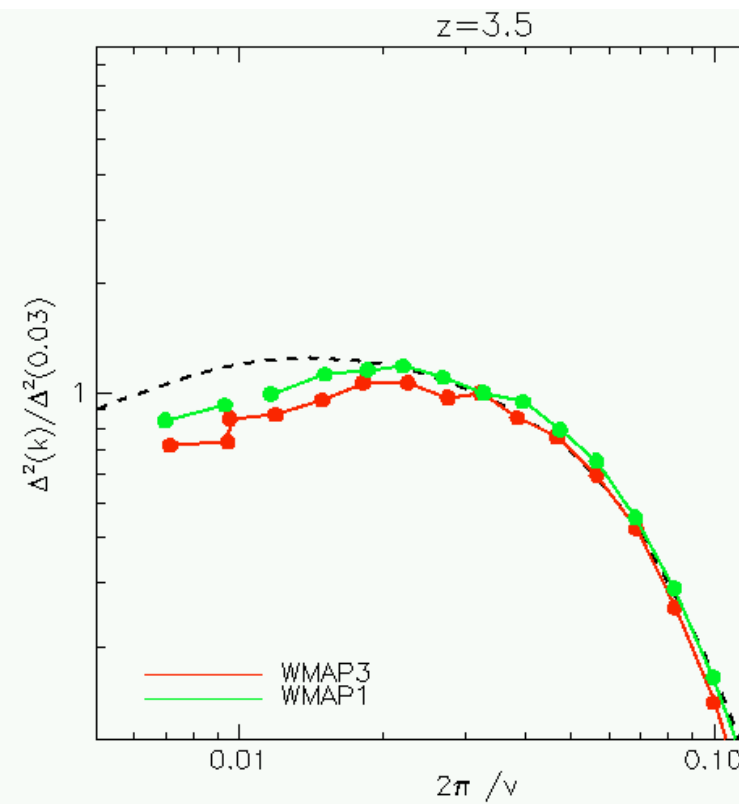
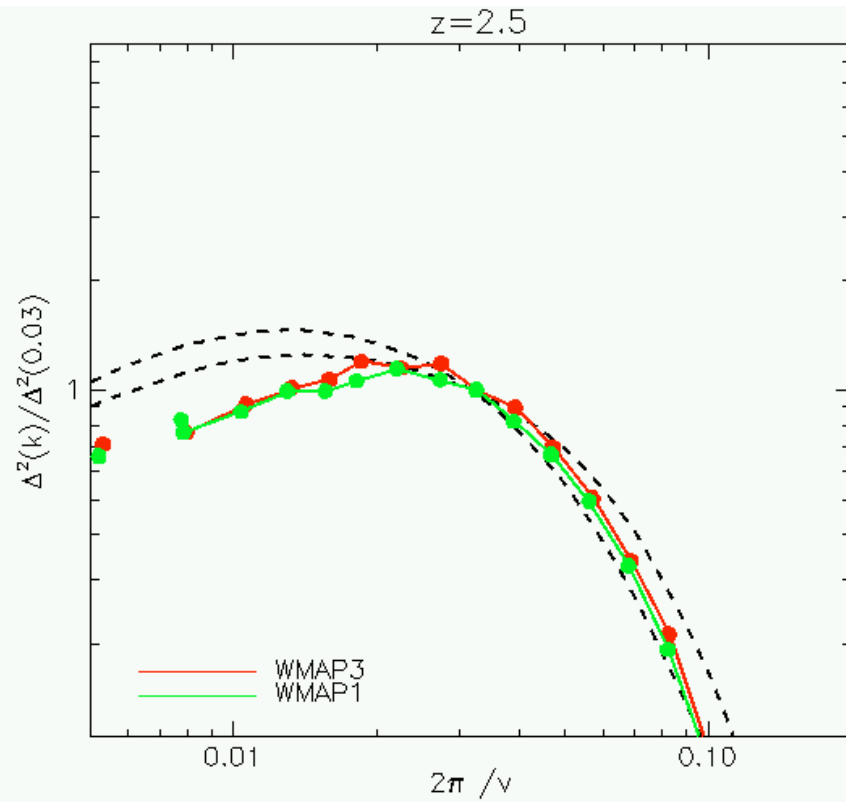
Resolution: low / medium / high / very high



Feedback / Feedback2 / No-Feedback



cosmology: WMAP3/WMAP1

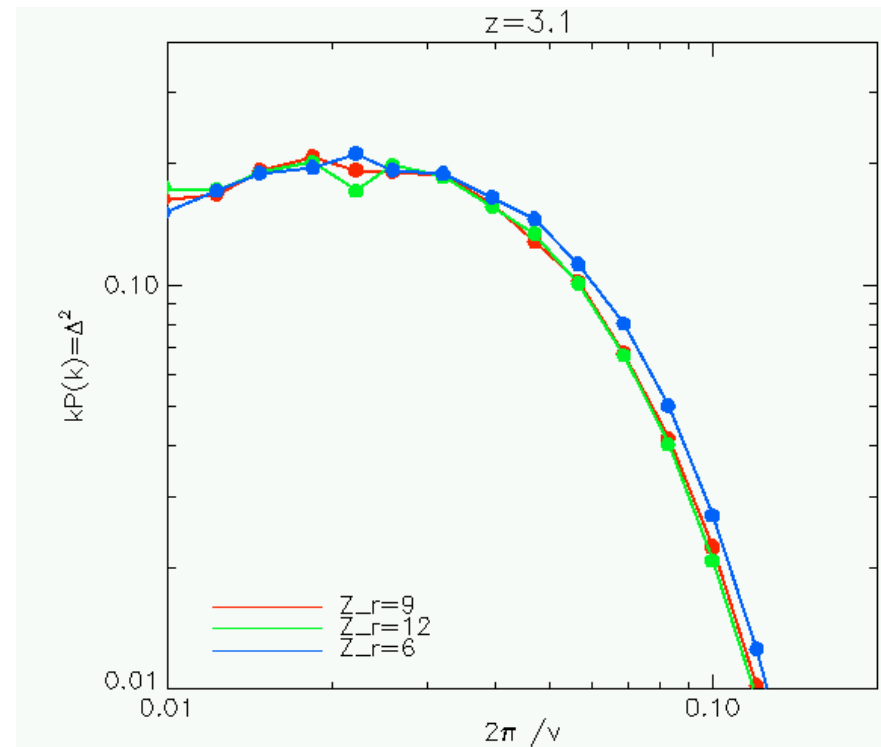
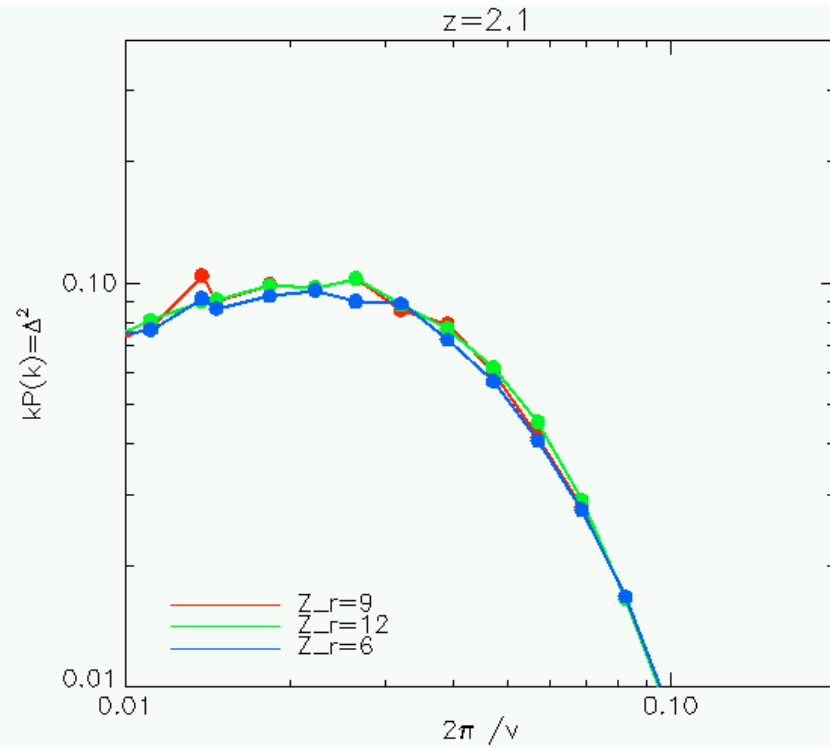


Epoch of HI reionization:

$Z_{\text{reion}}=6/$

$Z_{\text{reion}}=9/$

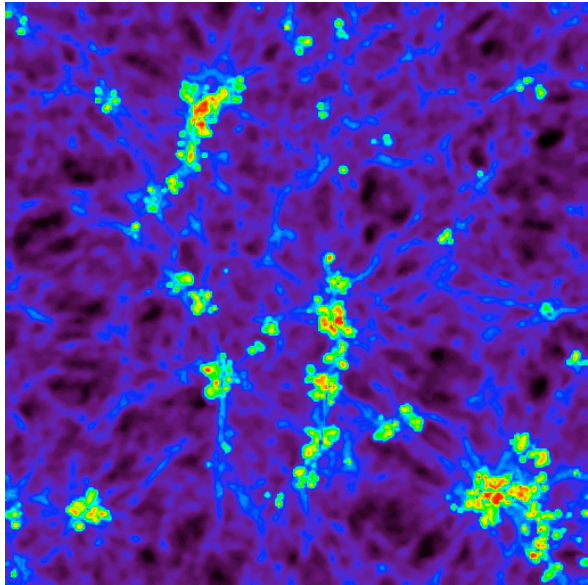
$Z_{\text{reion}}=12$



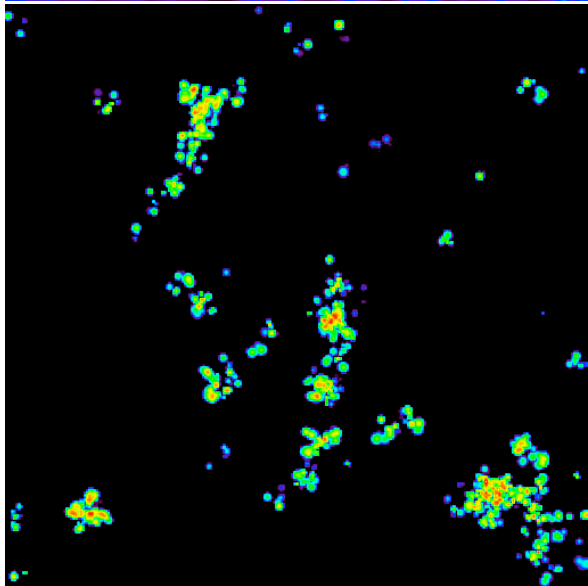
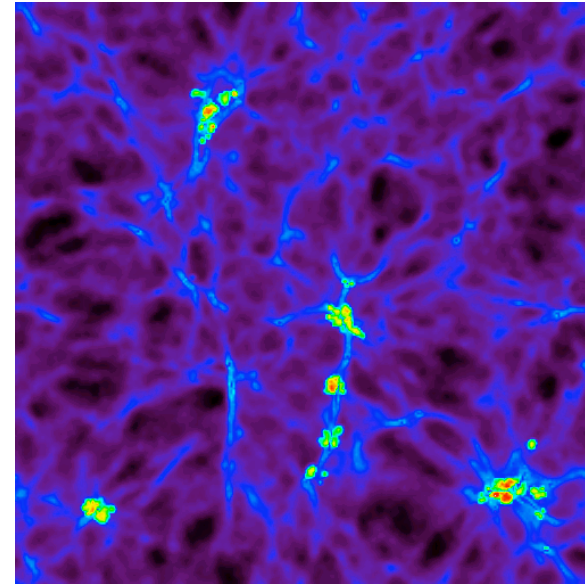
7 keV

WDM

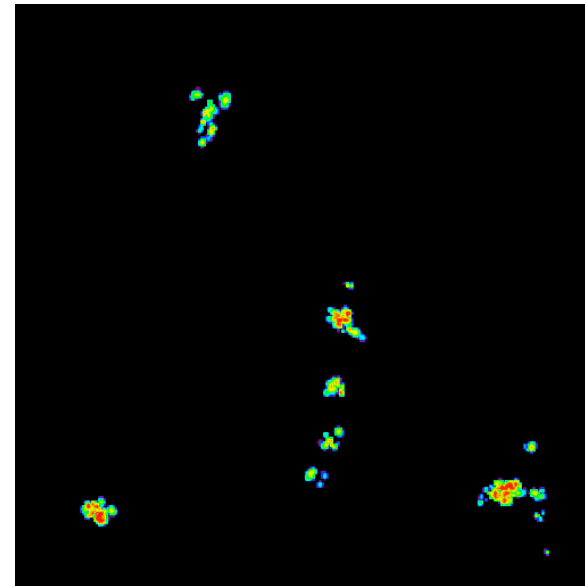
1 keV



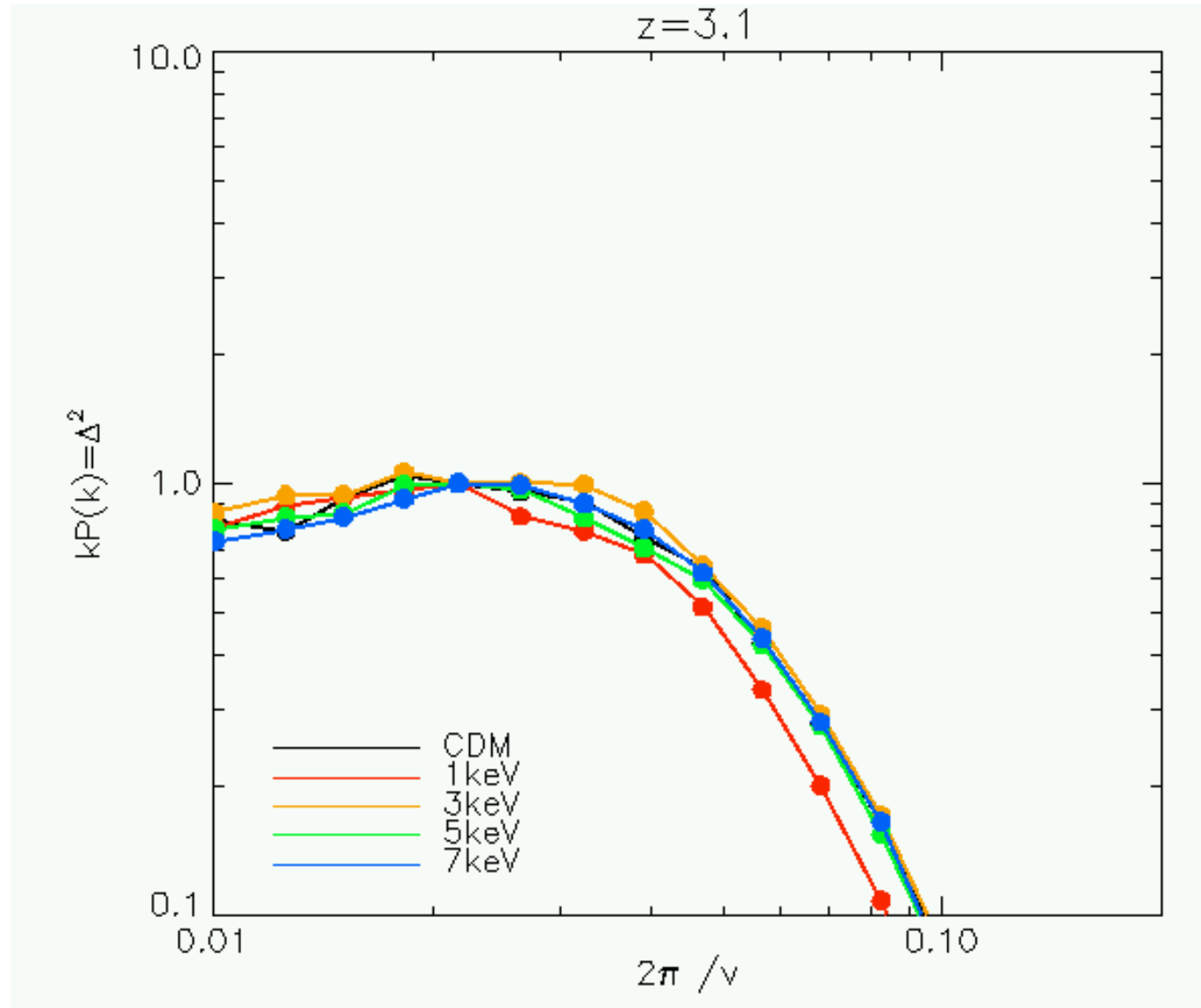
temperature



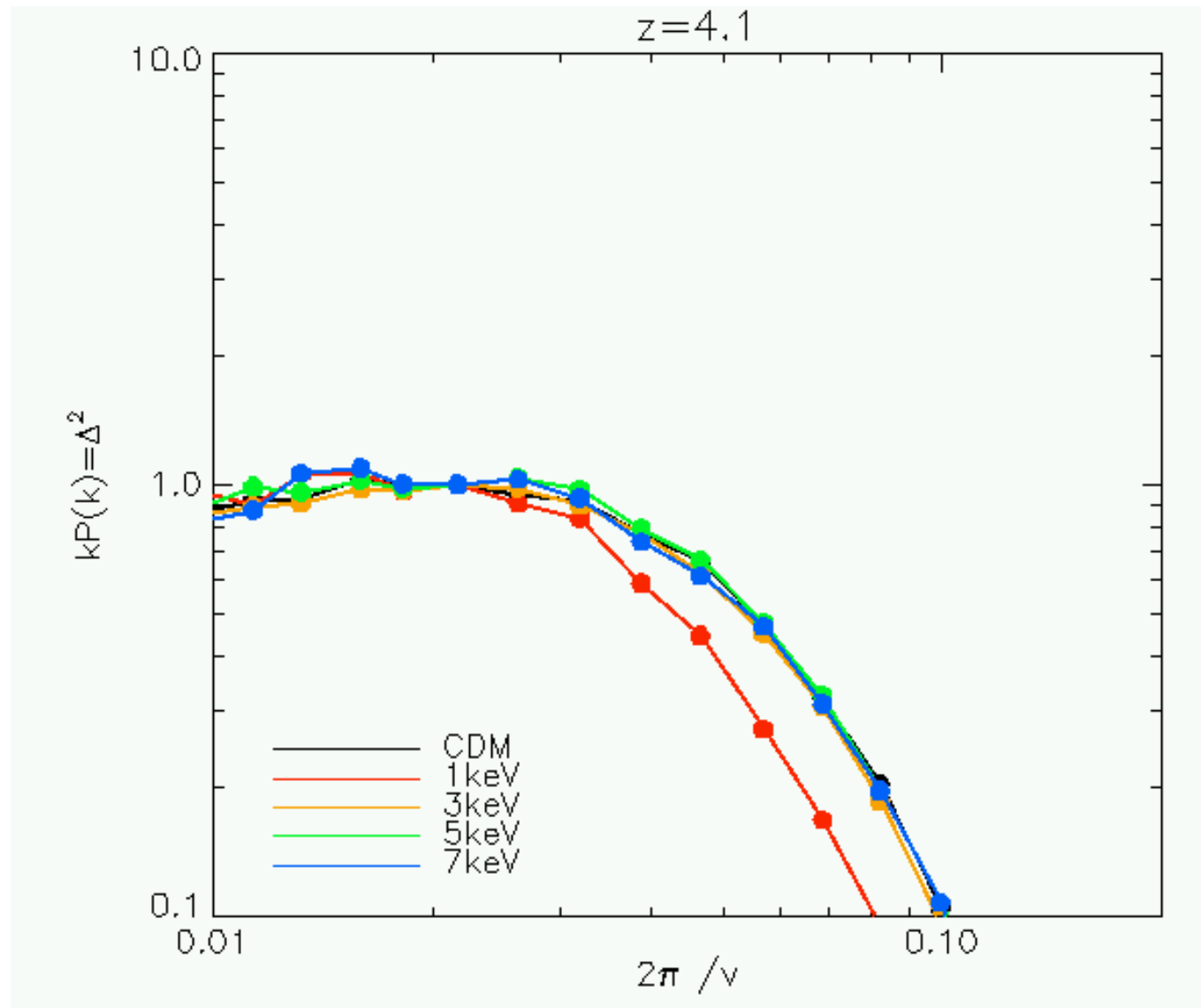
metallicity



dark matter: 1keV / 3 keV / 5keV / 7keV / CDM



dark matter: 1keV / 3 keV / 5keV / 7keV / CDM



dark matter: 1keV / 1keV including WDM velocities

