Toward Precision Cosmology with the 1D Power Spectrum from Lyα Forests

Solène Chabanier (CEA Paris Saclay)
Nathalie Palanque-Delabrouille, Frédéric Bournaud

Toward Precision Cosmology with the 1D Power Spectrum from Lyα Forests

I - The Lya Forest in Cosmology

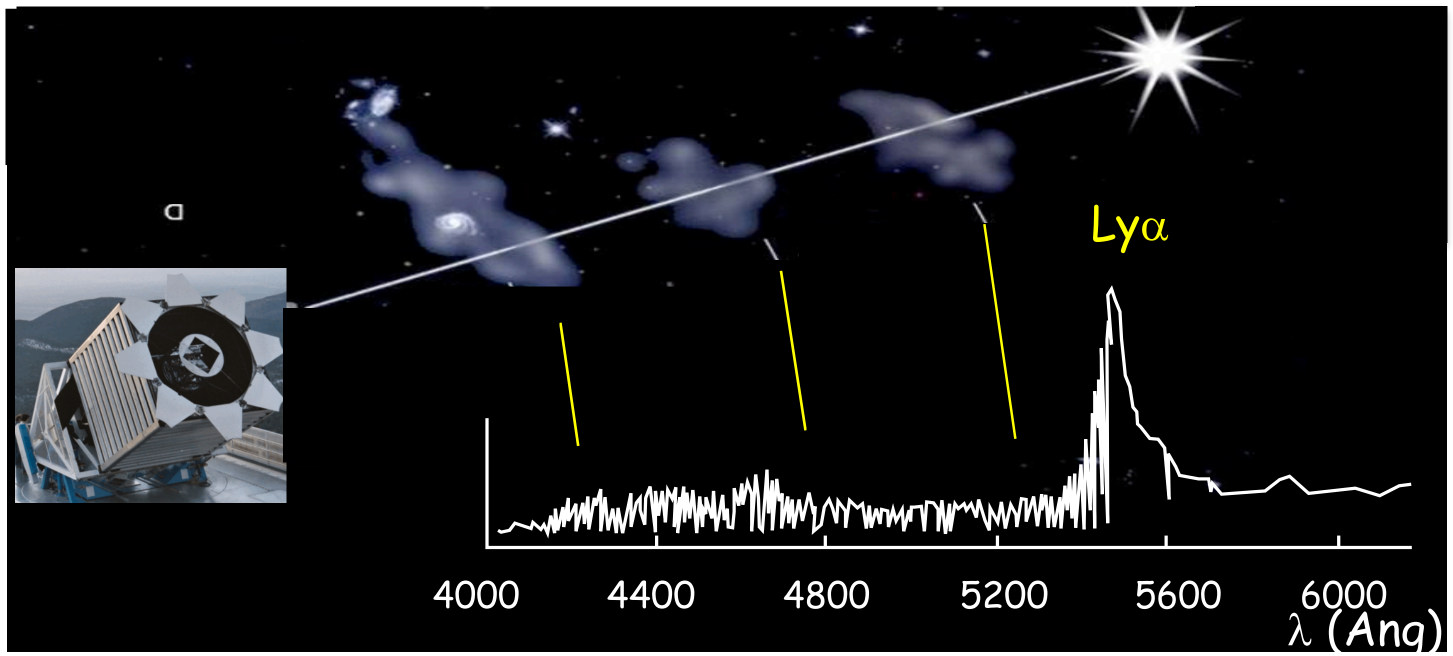
II- 1D Power Spectrum Analysis

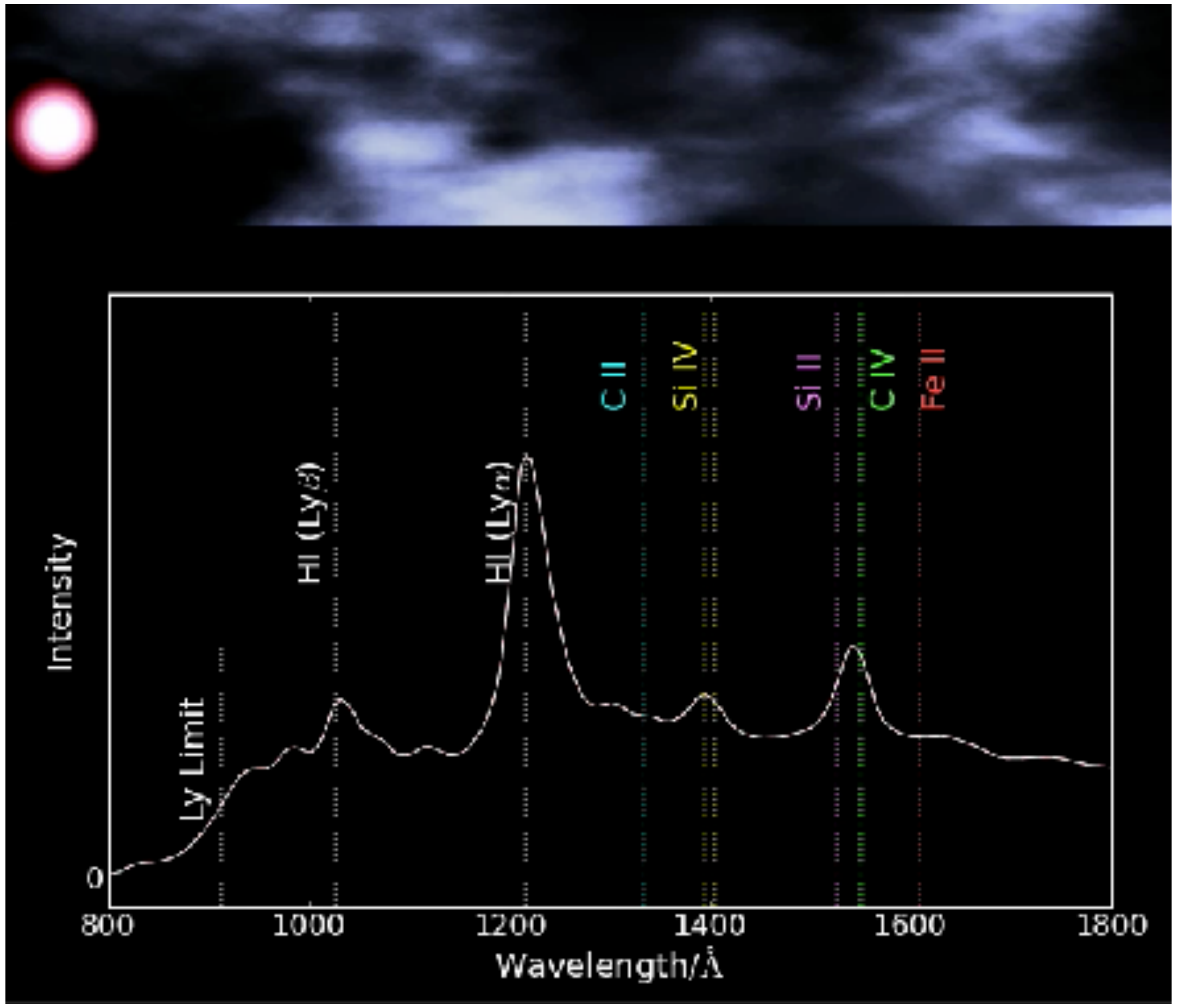
III- AGN feedback impact

IV- Cosmological analysis

1- The Lyα Forest

- Neutral hydrogen absorptions in the IGM along the line of sight of high redshift QSOs





1- The Lyα Forest

- Neutral hydrogen absorptions in the IGM along the line of sight of high redshift QSOs
- Low density IGM acts as a **proxy of dark matter density**

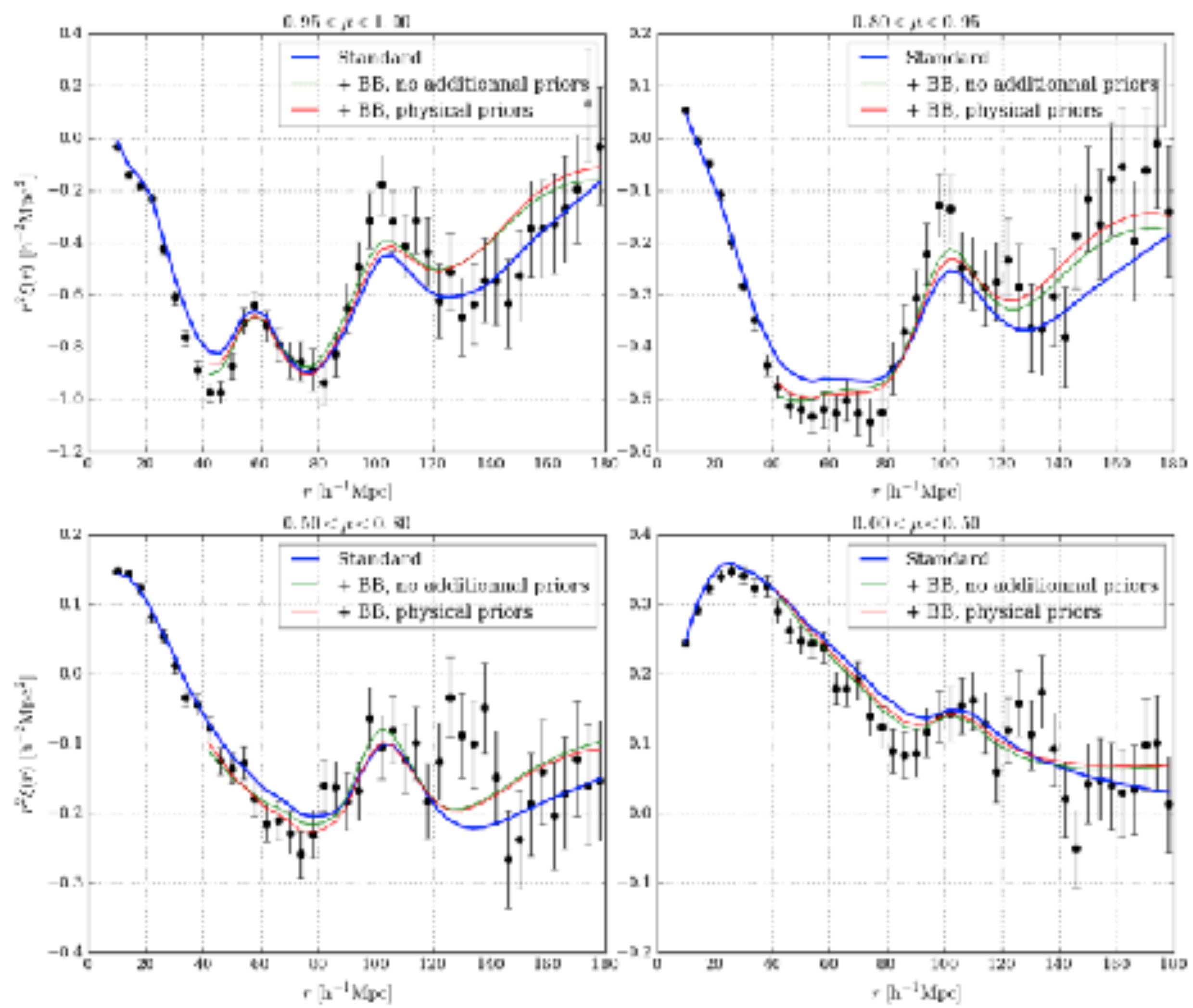
→ Lyα forest is useful for cosmology

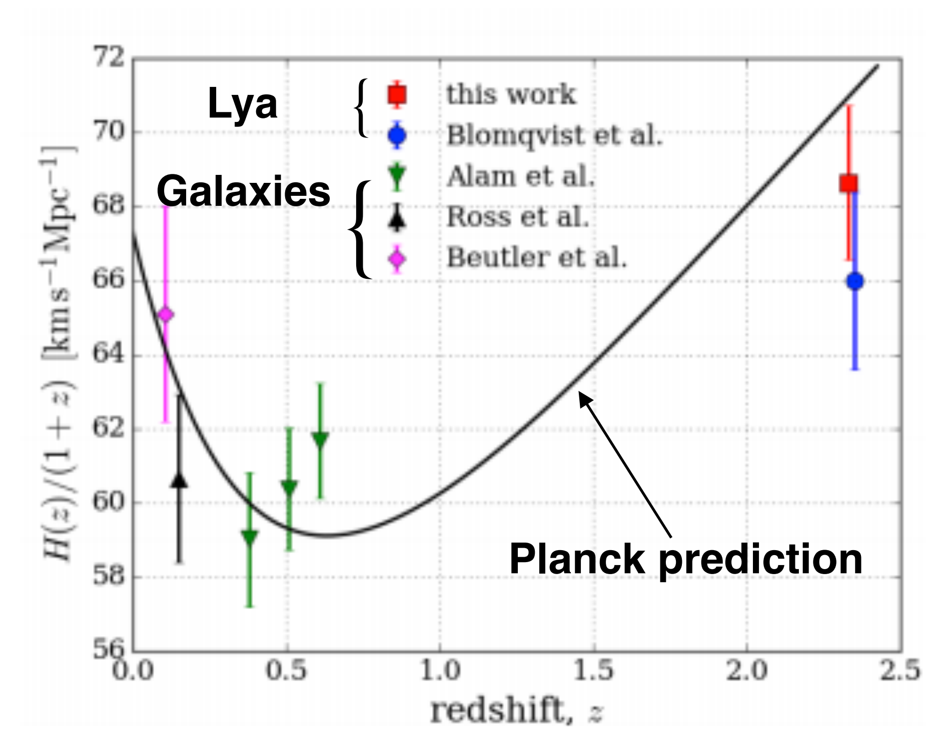
1- The Lyα Forest

- Neutral hydrogen absorptions in the IGM along the line of sight of high redshift QSOs
- Low density IGM acts as a proxy of dark matter density

→ Lyα forest is useful for cosmology

3D correlation (large scales $\sim 100\, Mpc/h$ **)** → sensitive to BAO





De Sainte-Agathe et al. 2019

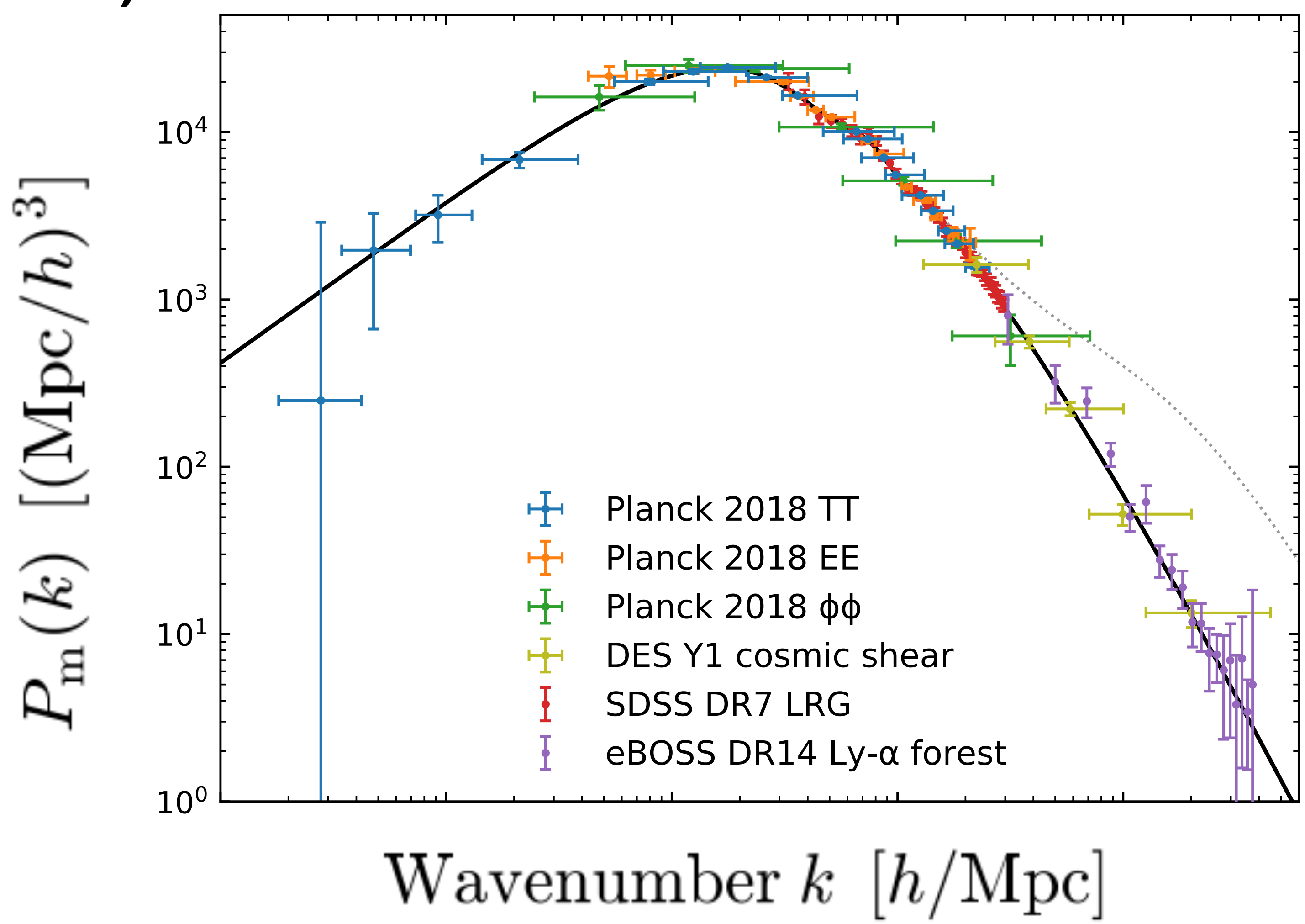
1- The Lyα Forest

- Neutral hydrogen absorptions in the IGM along the line of sight of high redshift QSOs
- Low density IGM acts as a proxy of dark matter density

→ Lyα forest is useful for cosmology

Chabanier, Millea, Palanque-Delabrouille 2019

1D correlation (small scales $\sim 1 Mpc/h$**)**

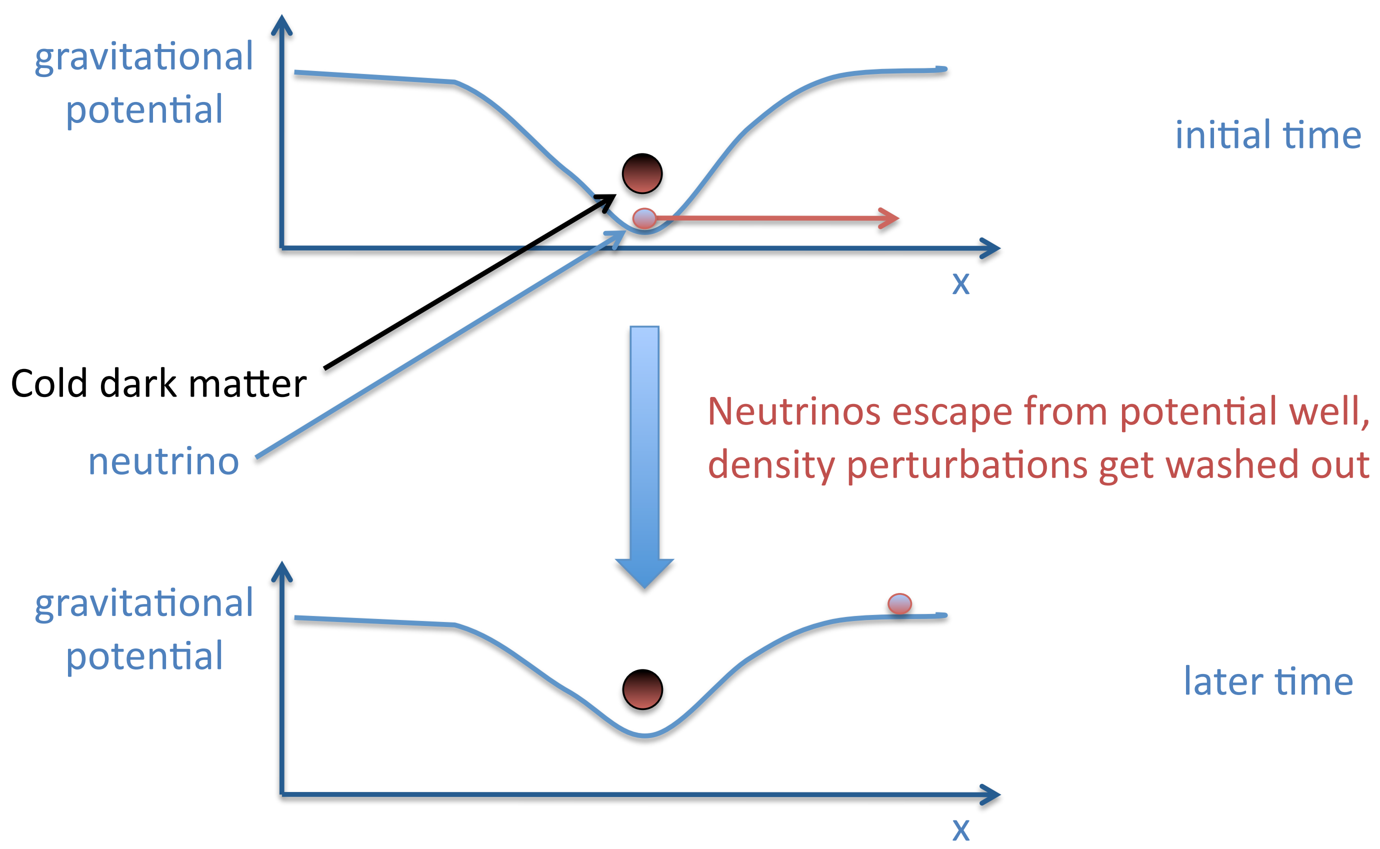


1- The Lyα Forest

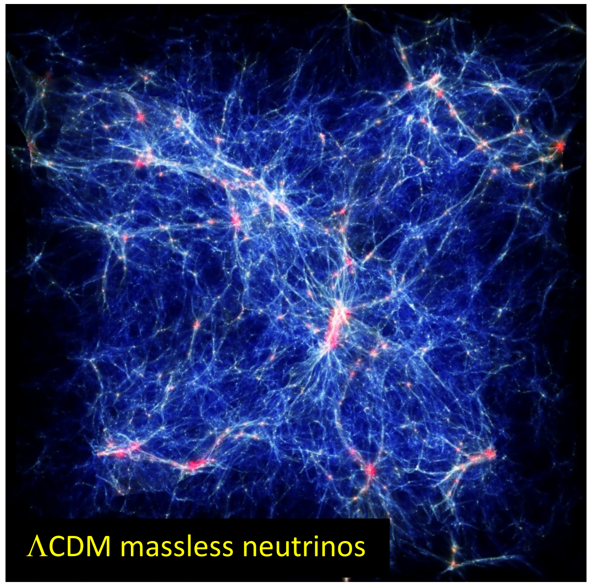
- Neutral hydrogen absorptions in the IGM along the line of sight of high redshift QSOs
- Low density IGM acts as a proxy of dark matter density

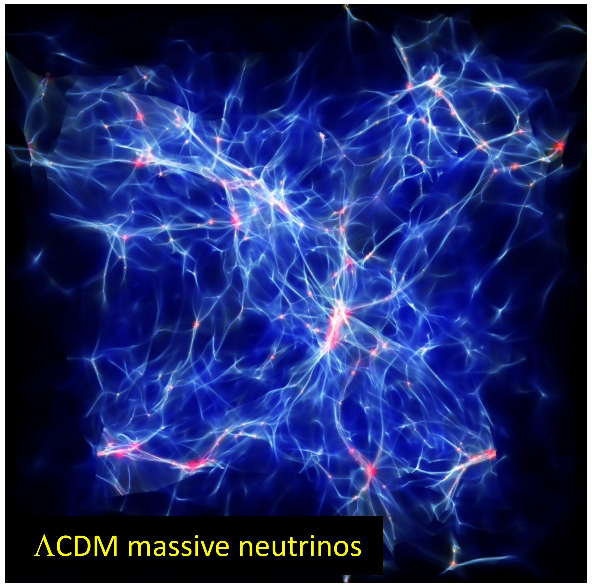
→ Lyα forest is useful for cosmology

1D correlation (small scales $\sim 1 Mpc/h$) → sensitive to smoothing



Suppression of small scales



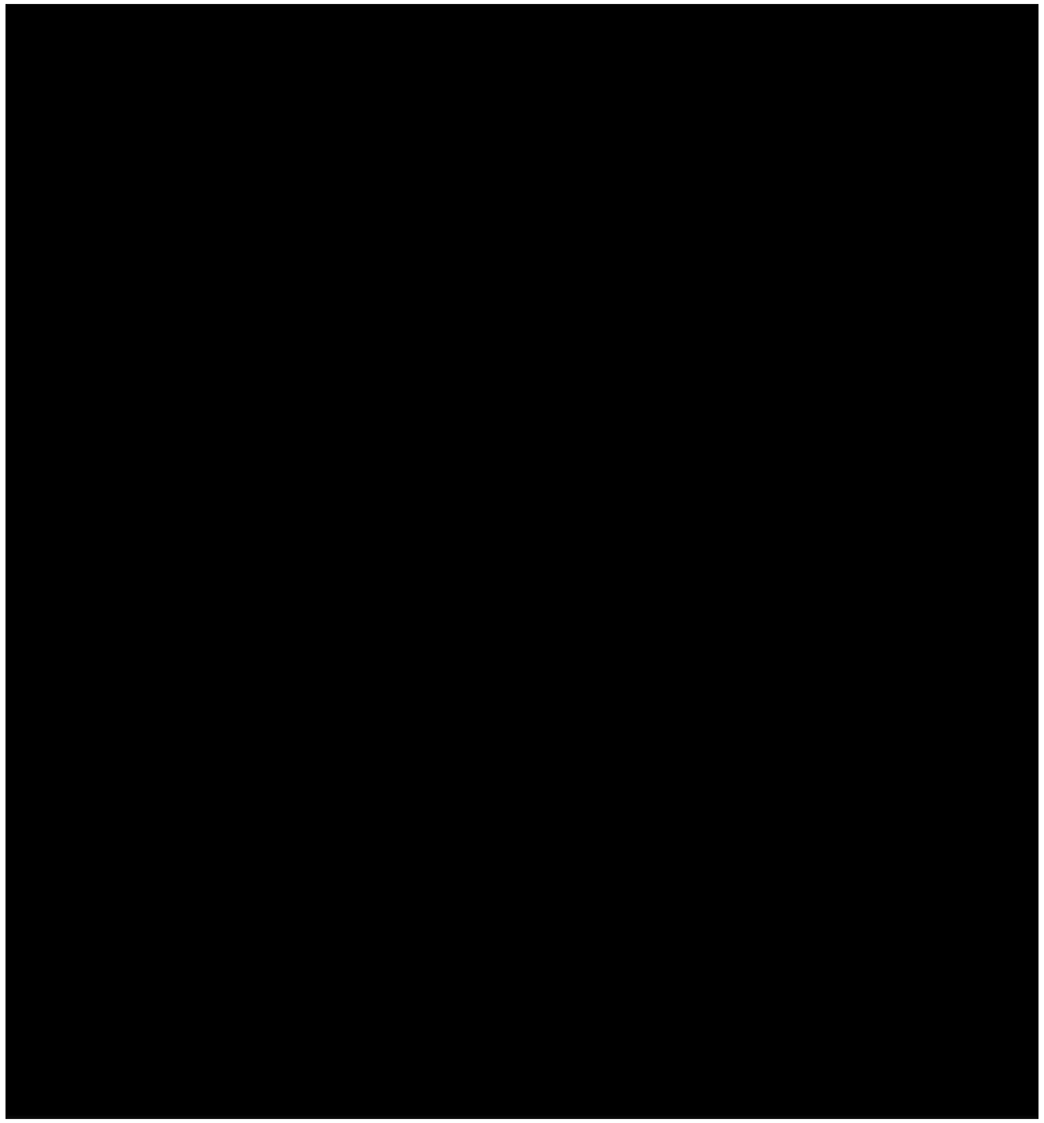


1- The Lyα Forest

- Neutral hydrogen absorptions in the IGM along the line of sight of high redshift QSOs
- Low density IGM acts as a proxy of dark matter density

→ Lyα forest is useful for cosmology

1D correlation (small scales $\sim 1 Mpc/h$**)**



Credits: A. Borde

1- The Lyα Forest

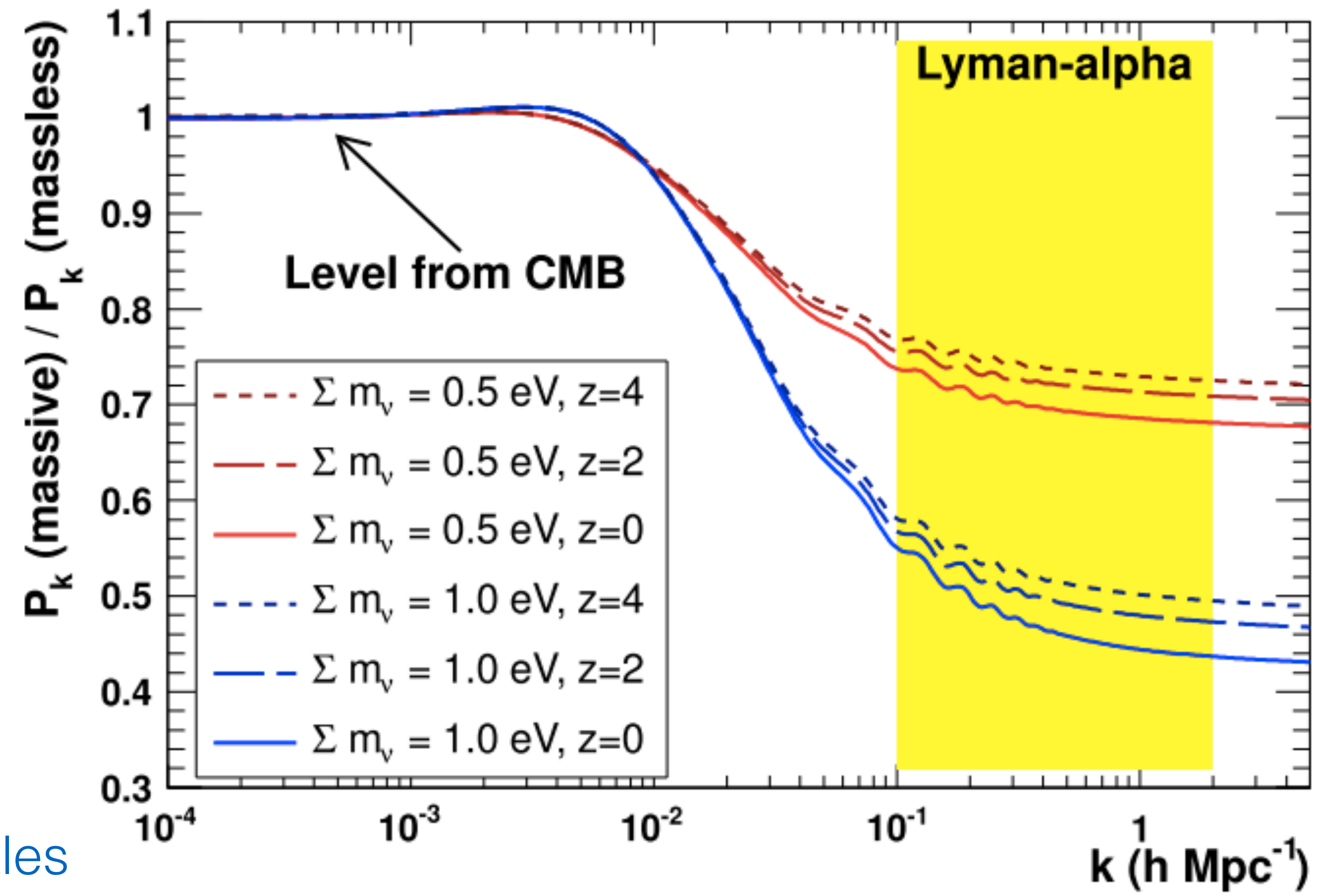
- Neutral hydrogen absorptions in the IGM along the line of sight of high redshift QSOs
- Low density IGM acts as a proxy of dark matter density

→ Lyα forest is useful for cosmology

1D correlation (small scales $\sim 1 Mpc/h$**)**

→ upper limit on $\sum m_\nu$

Step-like power suppression with active neutrinos



Large scales

Small scales

$\sum m_\nu$ increases

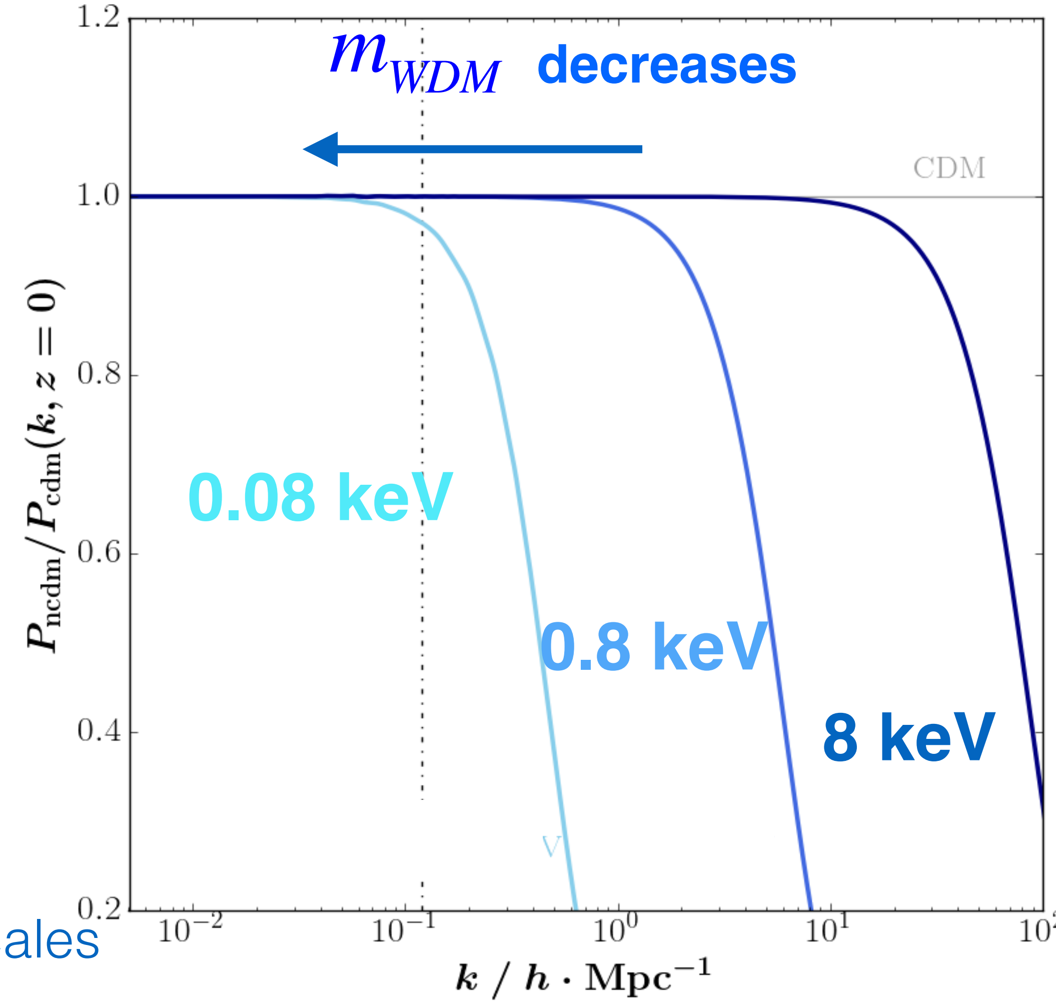
1- The Lyα Forest

- Neutral hydrogen absorptions in the IGM along the line of sight of high redshift QSOs
- Low density IGM acts as a proxy of dark matter density

→ Lyα forest is useful for cosmology

1D correlation (small scales $\sim 1 Mpc/h$ **)**

Power cut-off with warm dark matter



Large scales

Small scales

→ lower limit on m_{WDM}

Toward Precision Cosmology with the 1D Power Spectrum from Lyα Forests

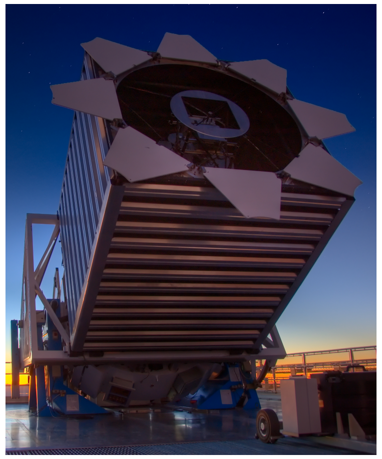
I - The Lyα Forest in Cosmology

II- 1D Power Spectrum Analysis

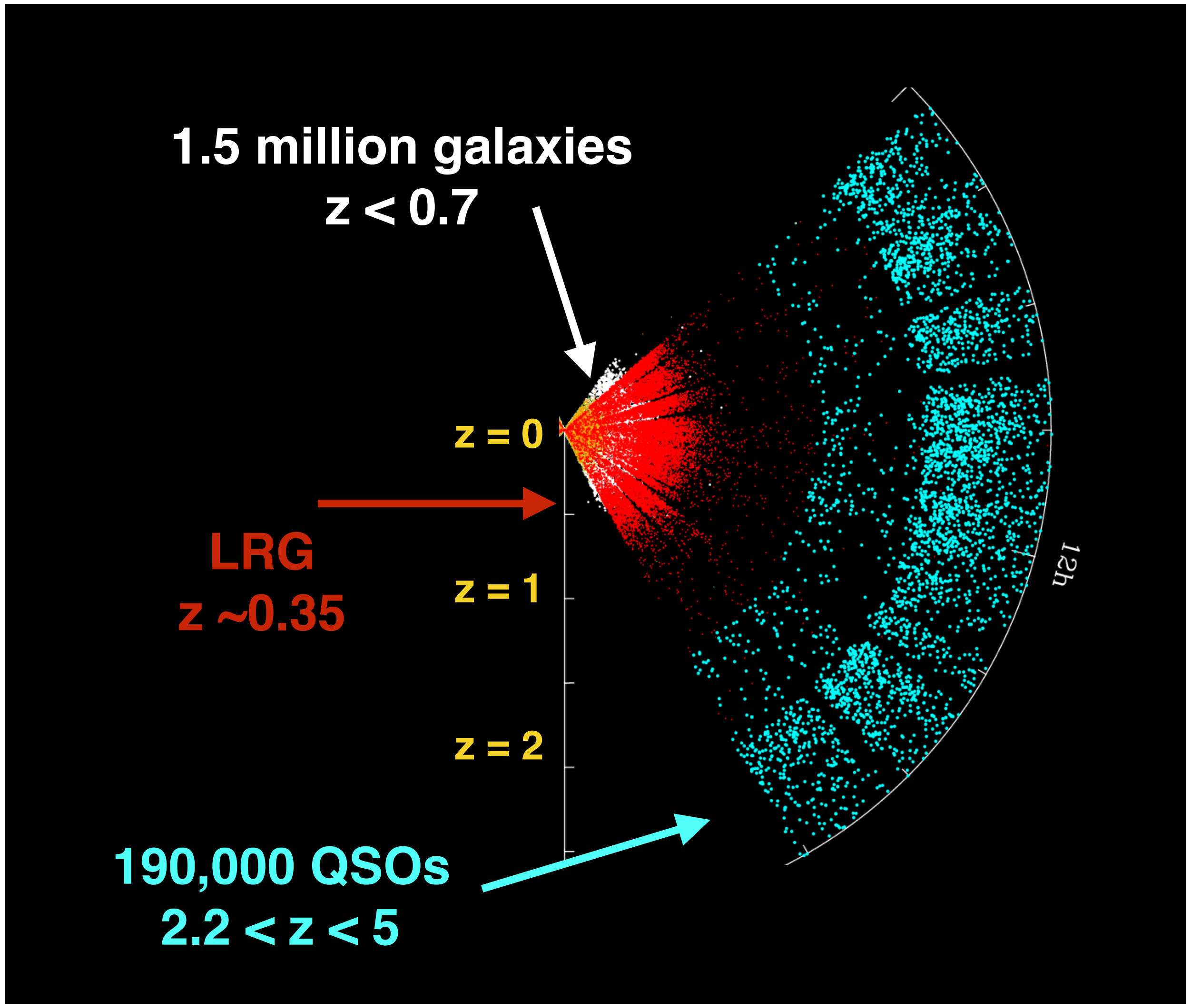
III- AGN feedback impact

IV- Cosmological analysis

The SDSS BOSS/eBOSS spectroscopic surveys

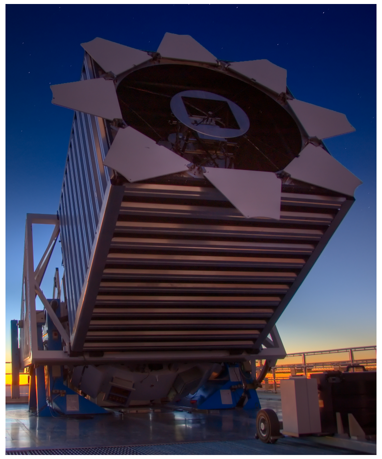


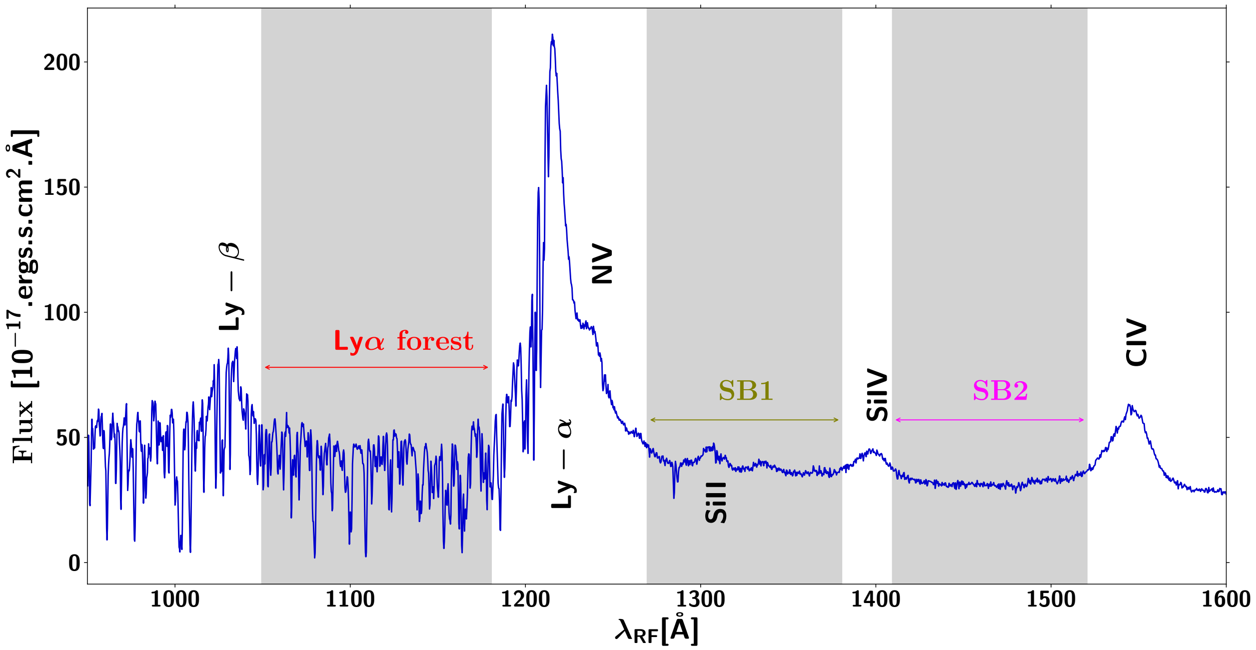
- 2.5m Sloan telescope (New Mexico)
- Survey area: $10{,}000\,\mathrm{deg}^2$

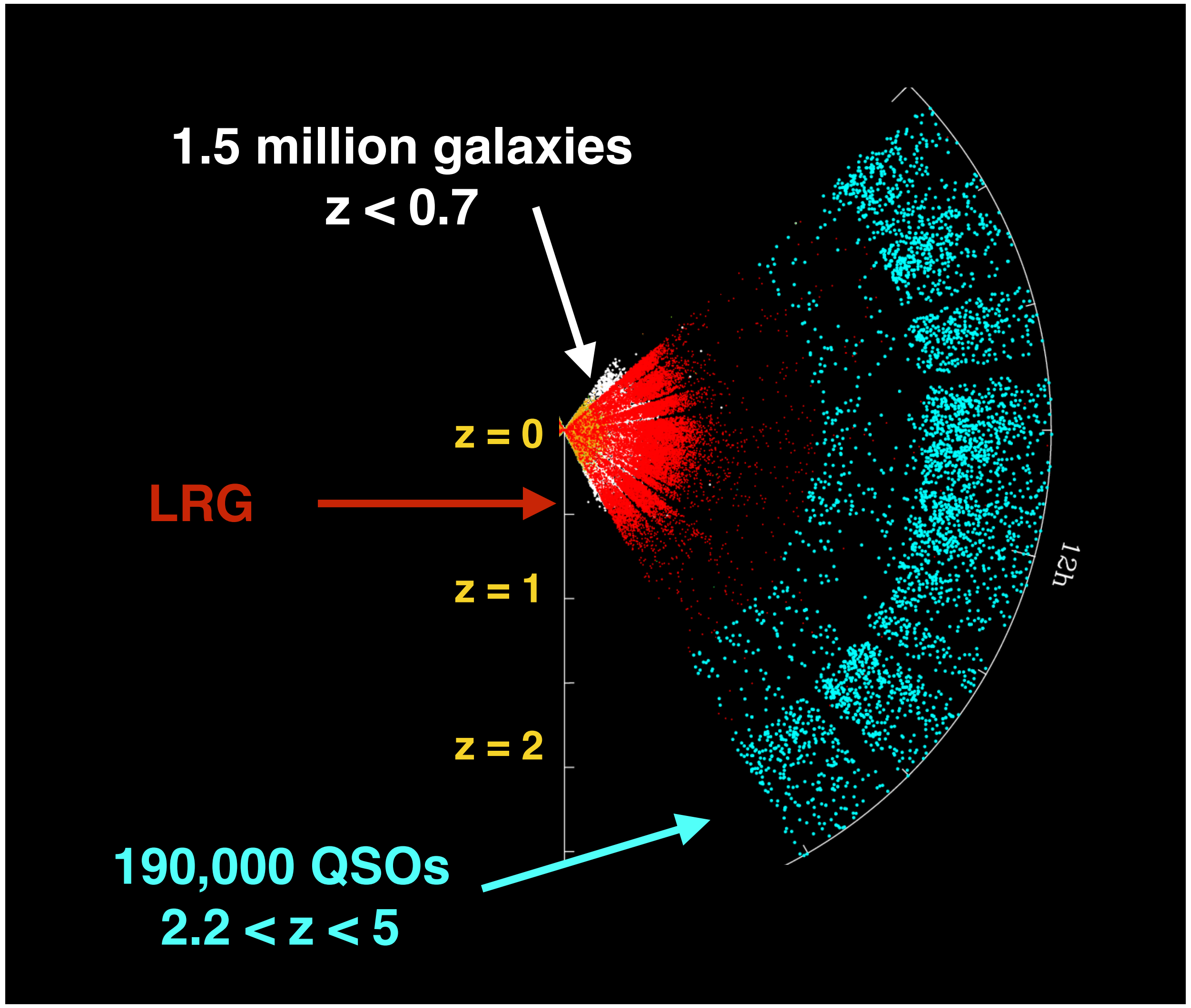


2- The 1D Power Spectrum of the Lyα Forest Analysis

The SDSS BOSS/eBOSS spectroscopic surveys



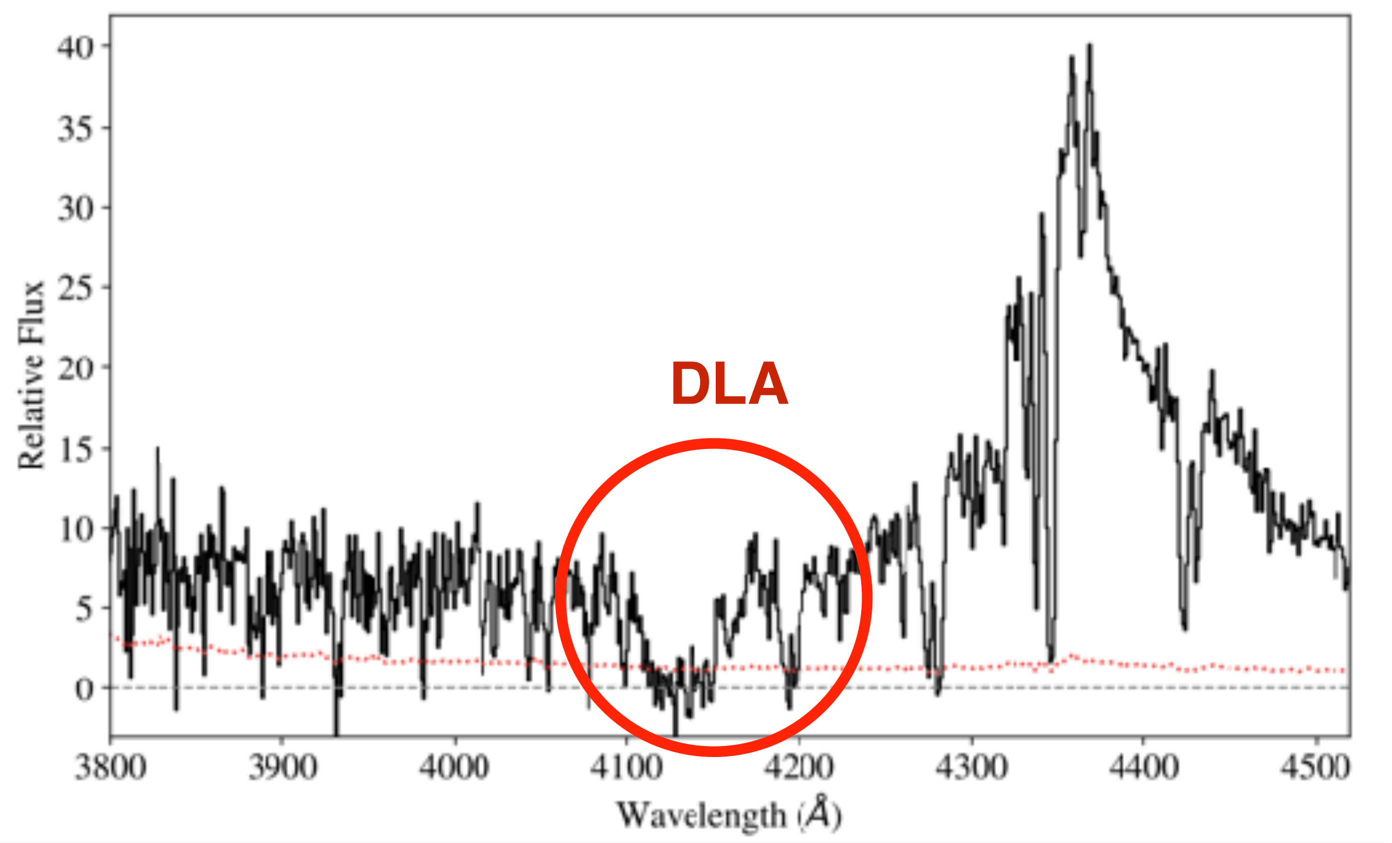




2- The 1D Power Spectrum of the Lyα Forest Analysis

Data selection

- 43,000 spectra out of 190,000 of DR14 eBOSS
- Selected over
  - SNR to reduce statistical uncertainty
  - Resolution < 85 km/s
  - quality (no high density absorbers)



2- The 1D Power Spectrum of the Lyα Forest Analysis

Method

McDonald 2006

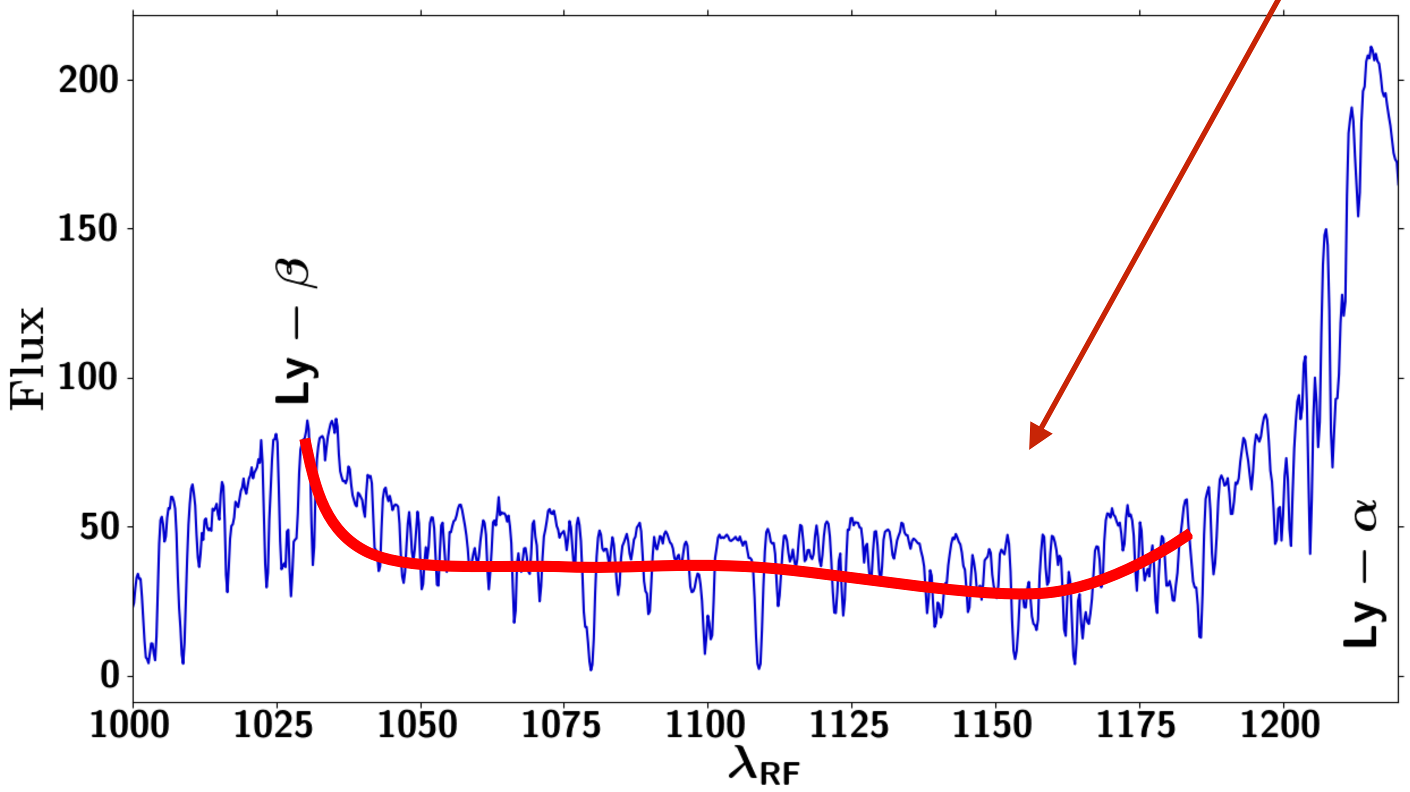
$$P_{raw} = FFT^2(\delta)$$

Flux absorption field

Absorbed spectrum

$$\delta(\lambda) = \frac{f(\lambda)}{C_q(\lambda)\bar{f}(z)} - 1$$

Quasar continuum = unabsorbed spectrum

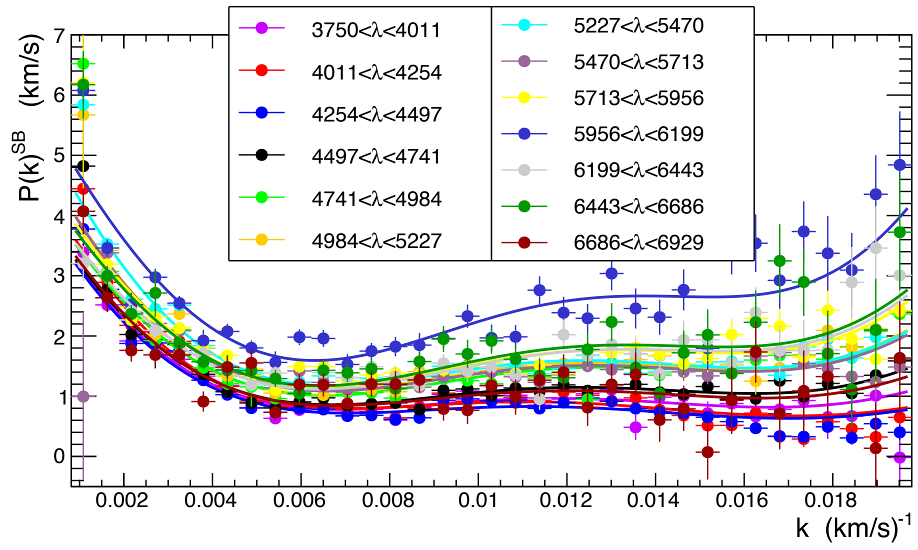


2- The 1D Power Spectrum of the Lyα Forest Analysis

Method

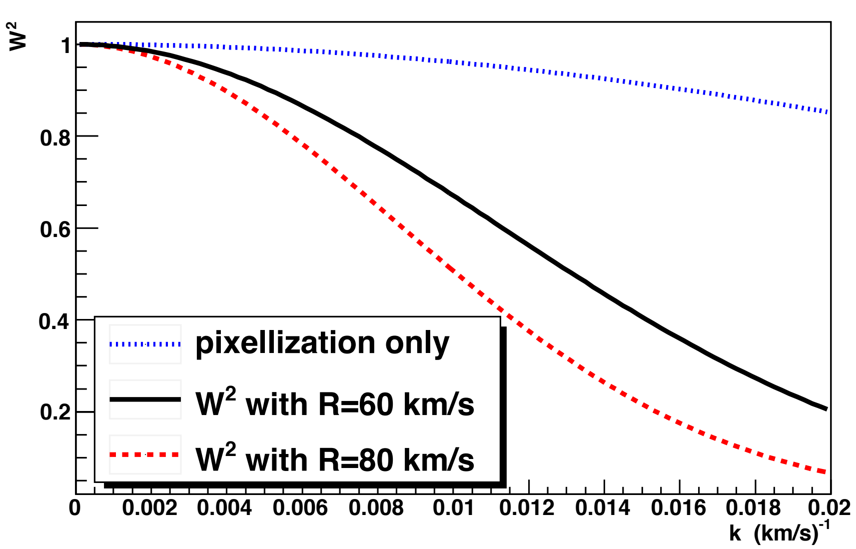
$$P_{raw} = FFT^2(\delta)$$

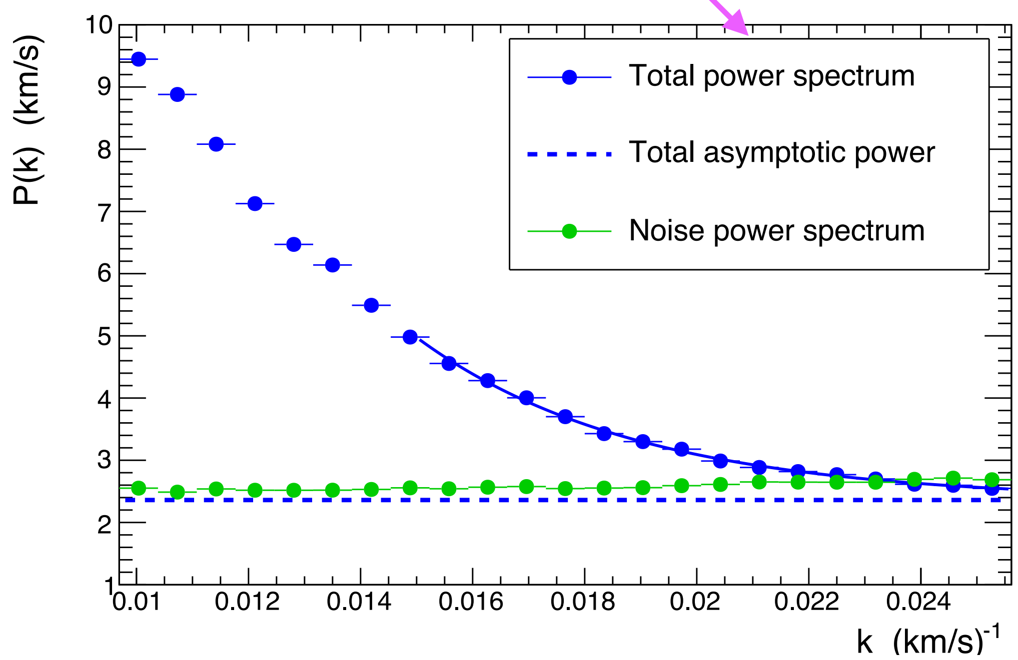
MacDonald 2006



$$P_{raw}(k) = [P_{Ly\alpha}(k) + P_{HI-Si3}(k) + P_{metals}(k)].W^2(k) + P_{noise}(k)$$

W = resolution + pixellisation



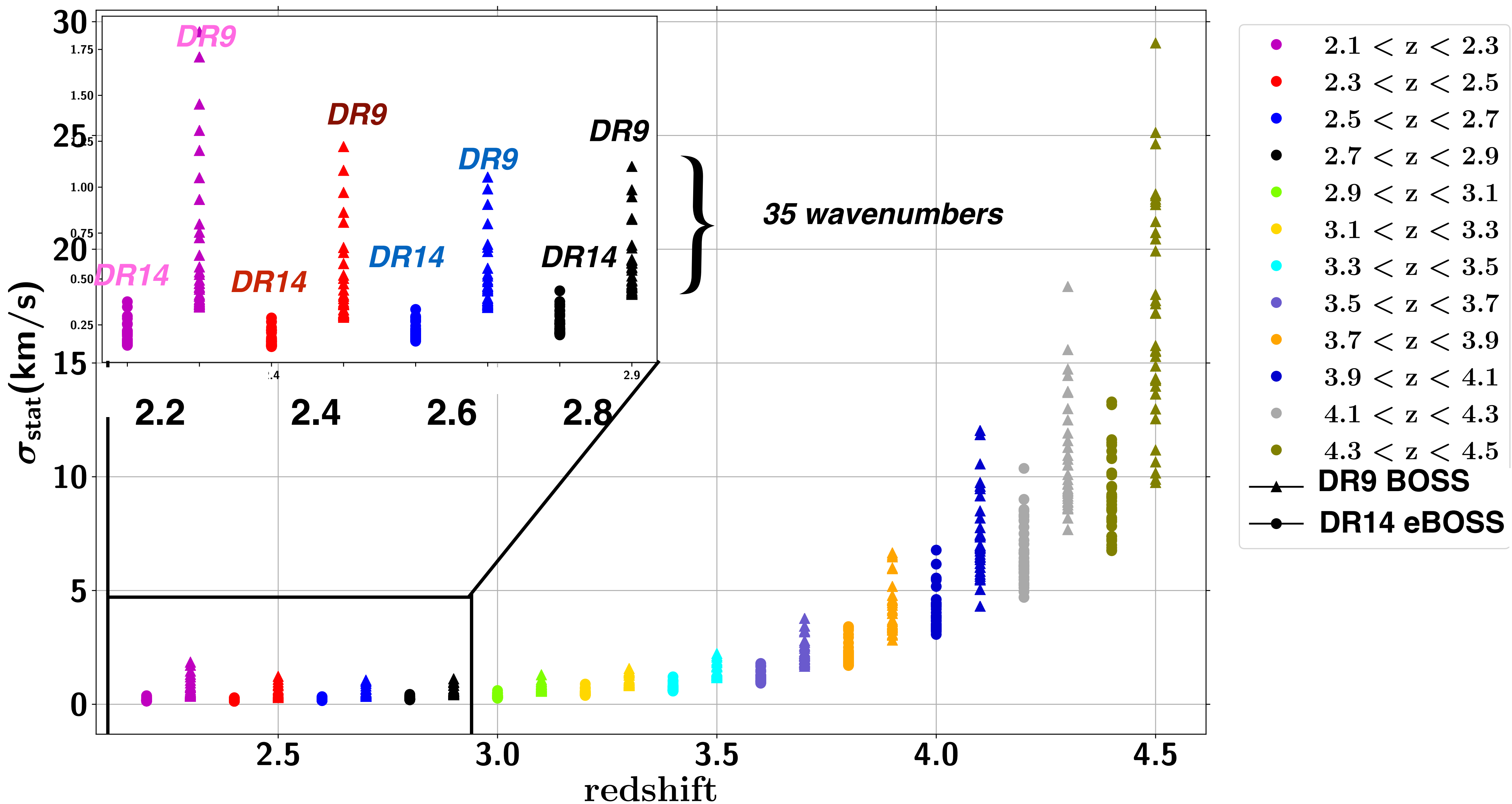


2- The 1D Power Spectrum of the Lyα Forest Analysis

Statistical uncertainties

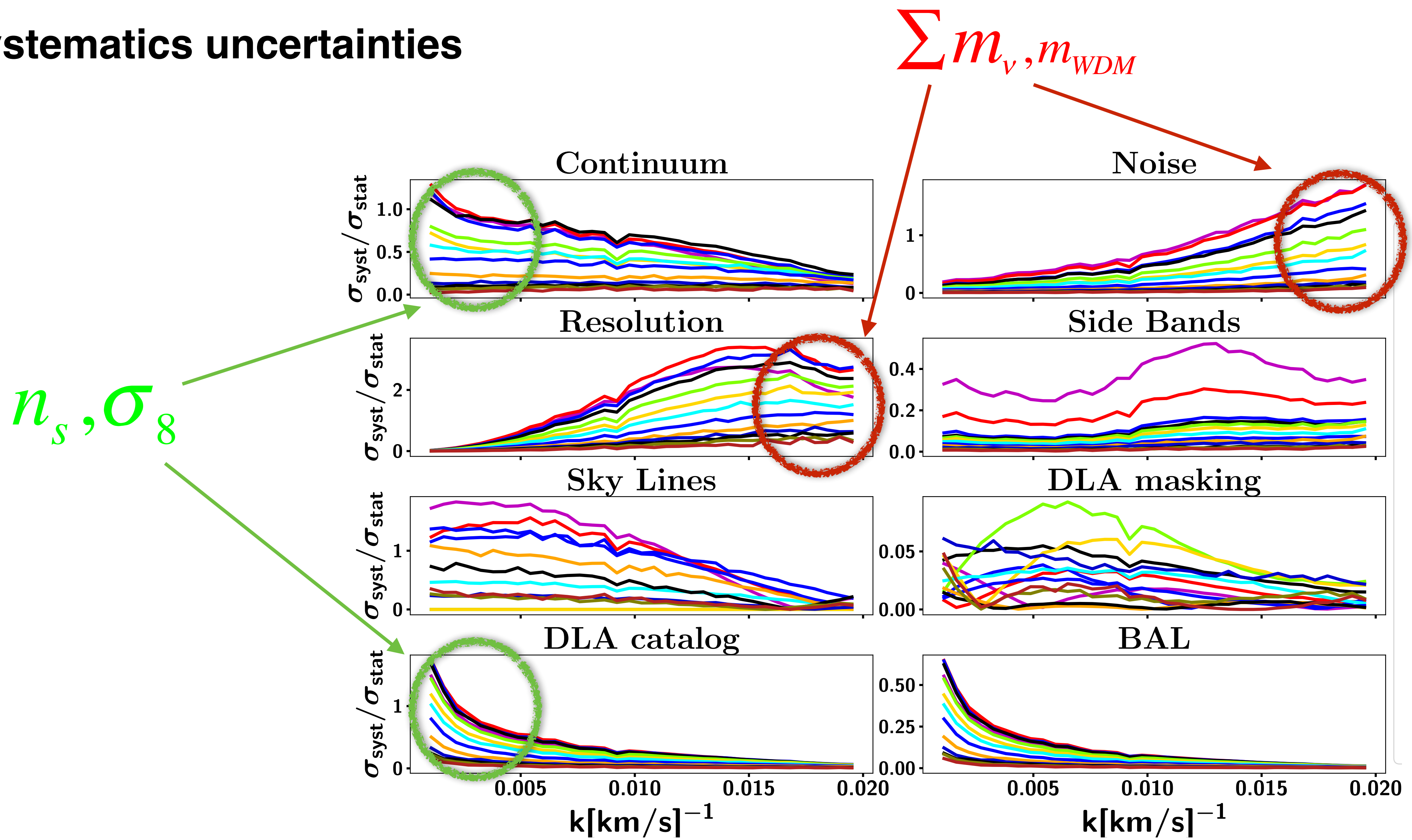
DR9: 13,000 QSOs

DR14: 43,000 QSOs



2- The 1D Power Spectrum of the Lyα Forest Analysis

Systematics uncertainties

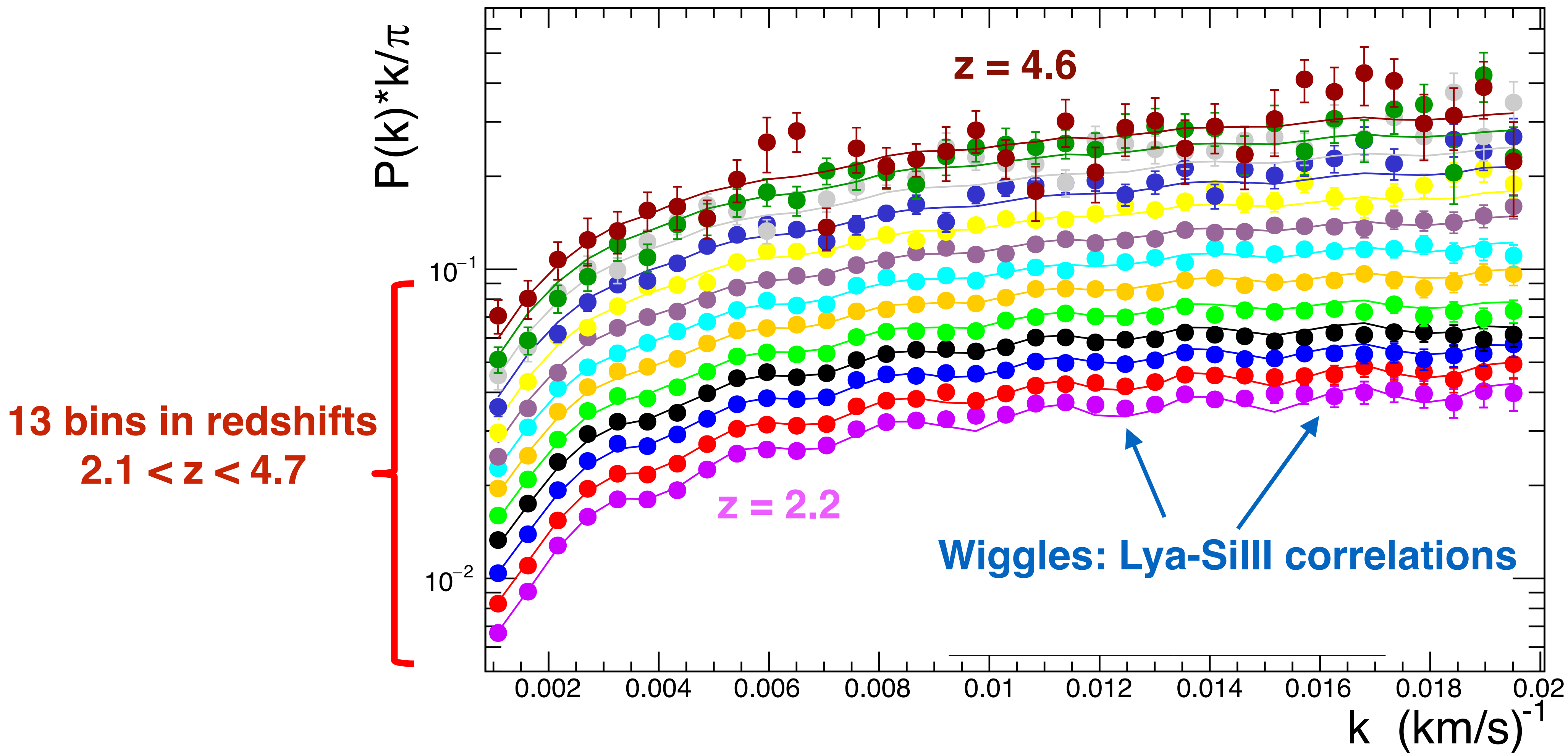


We are now systematic limited

2- The 1D Power Spectrum of the Lya Forest Analysis

Final measurements DR14 eBOSS

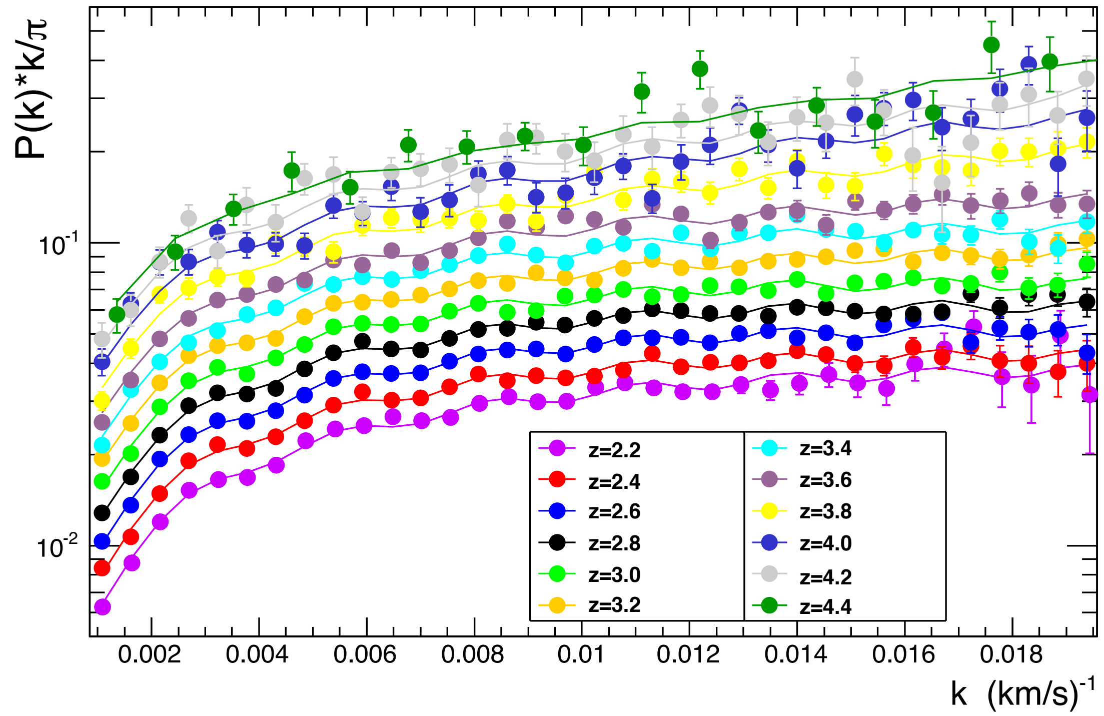
Chabanier, Palanque-Delabrouille, Yèche et al. 2019

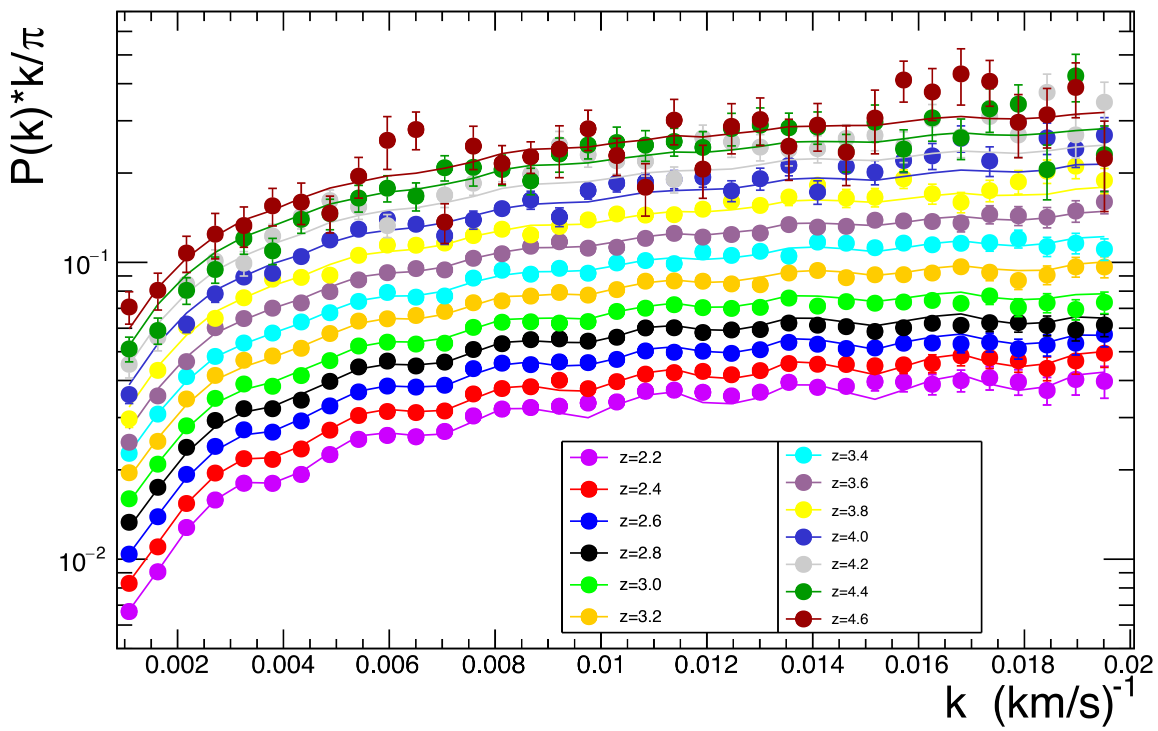


Comparison DR14 eBOSS / DR9 BOSS

- Significant decrease of data-related uncertainties
  - **gain of 2 on statistical power**
  - **improved census of systematics**
- One extra redshift bin

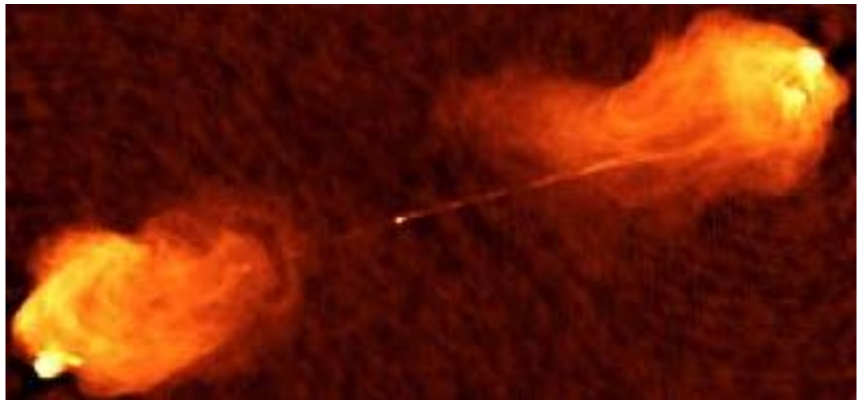
DR9 BOSS → **DR14 eBOSS**



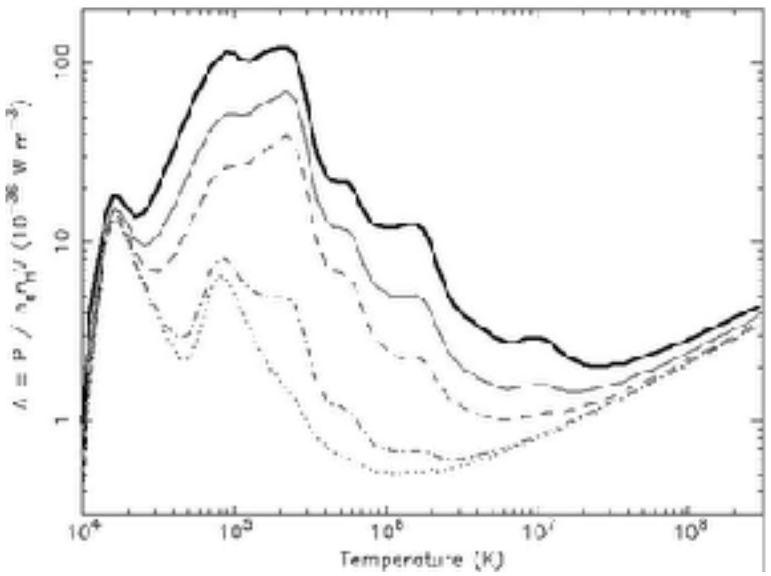


Significant decrease of data-related uncertainties…

→ **we need an improvement of theoretical predictions from simulations**

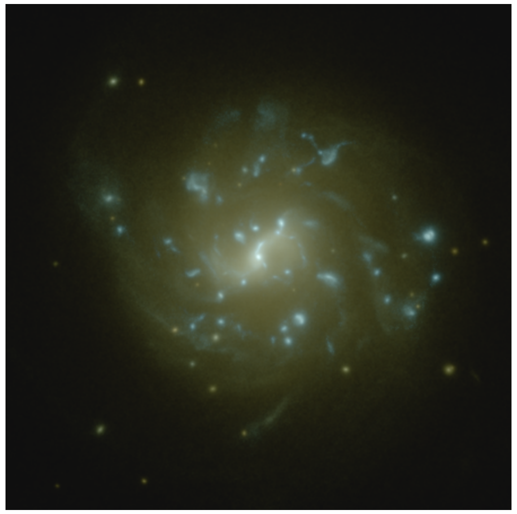


AGN feedback



gas cooling

star formation



galactic winds

Toward Precision Cosmology with the 1D Power Spectrum from Lyα Forests

I - The Lya Forest in Cosmology

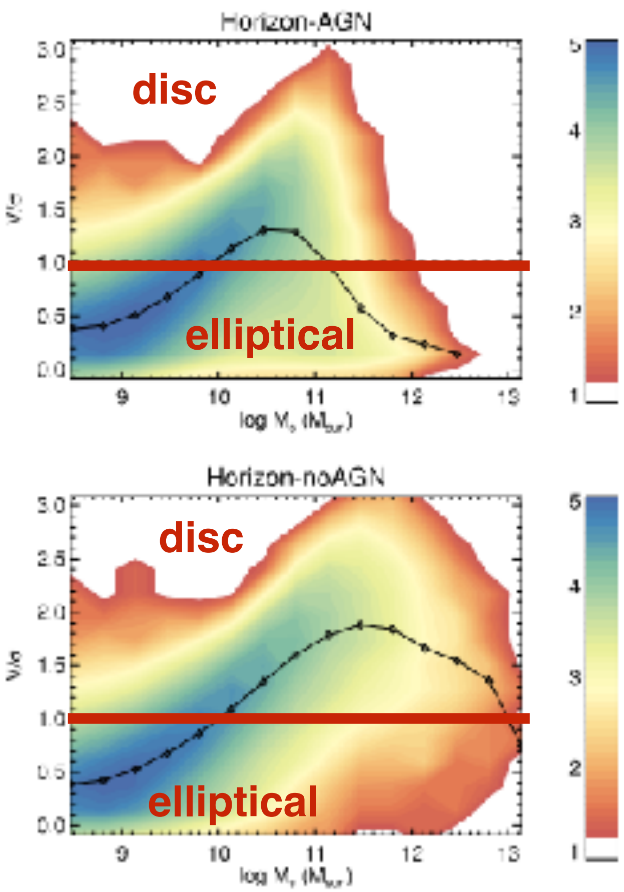
II- 1D Power Spectrum Analysis

III- AGN feedback impact

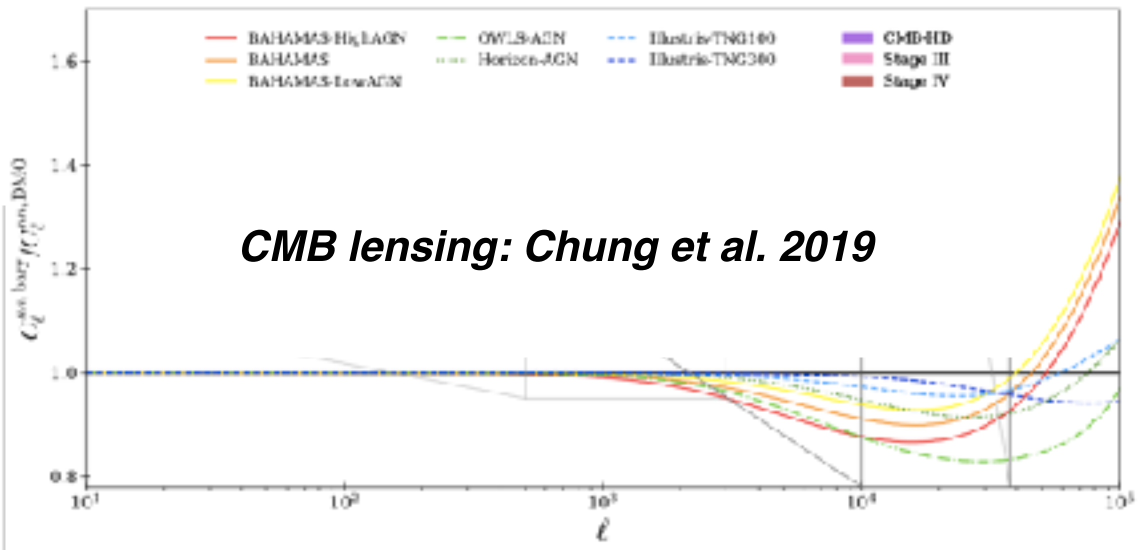
IV- Cosmological analysis

3- AGN Feedback Impact

AGN feedback

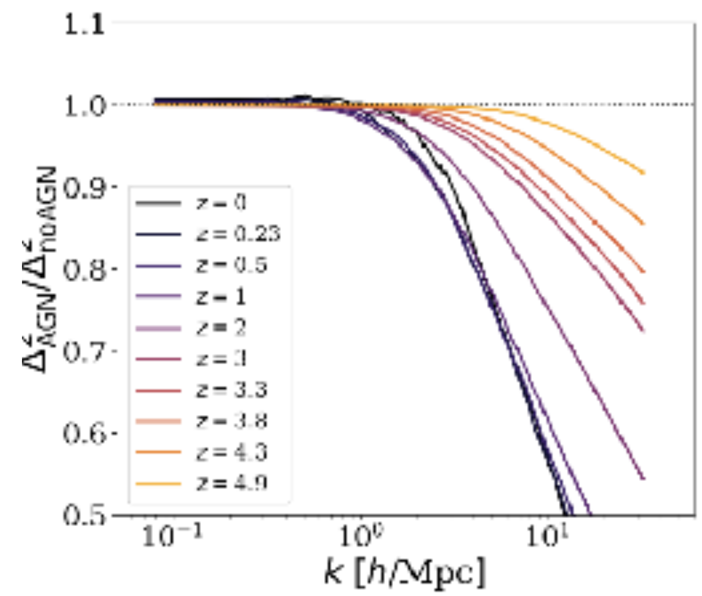


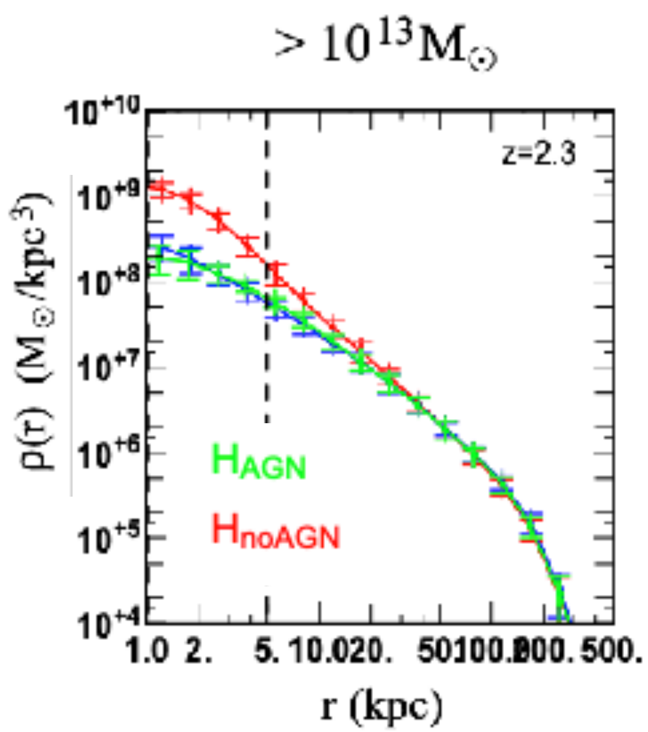
Morphology of galaxies: Dubois et al. 2014



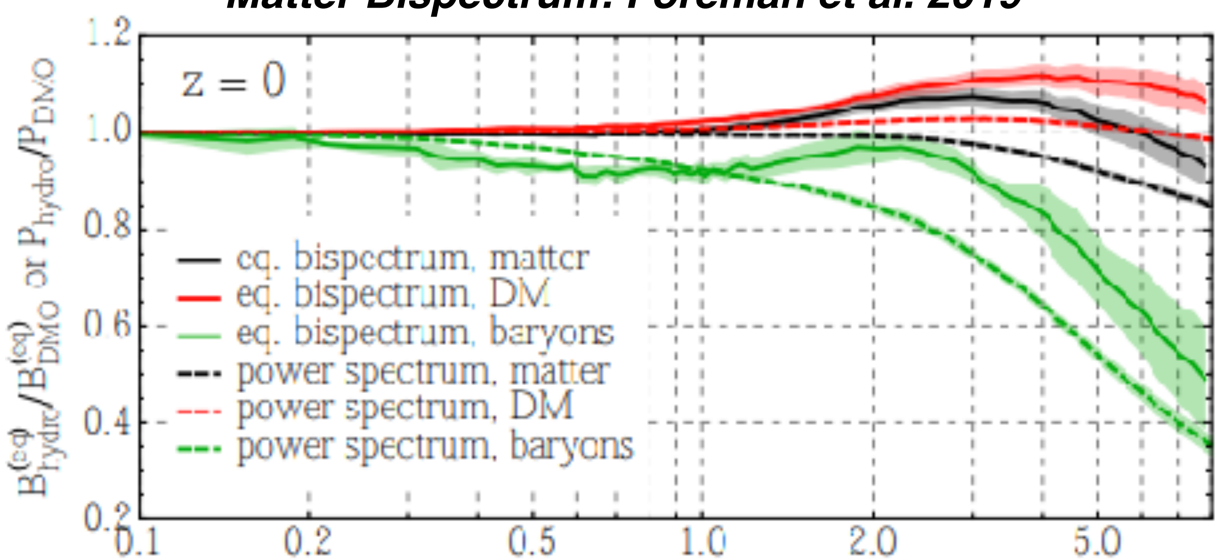
CMB lensing: Chung et al. 2019

Matter Power Spectrum: Chisari et al. 2018





Matter Bispectrum: Foreman et al. 2019

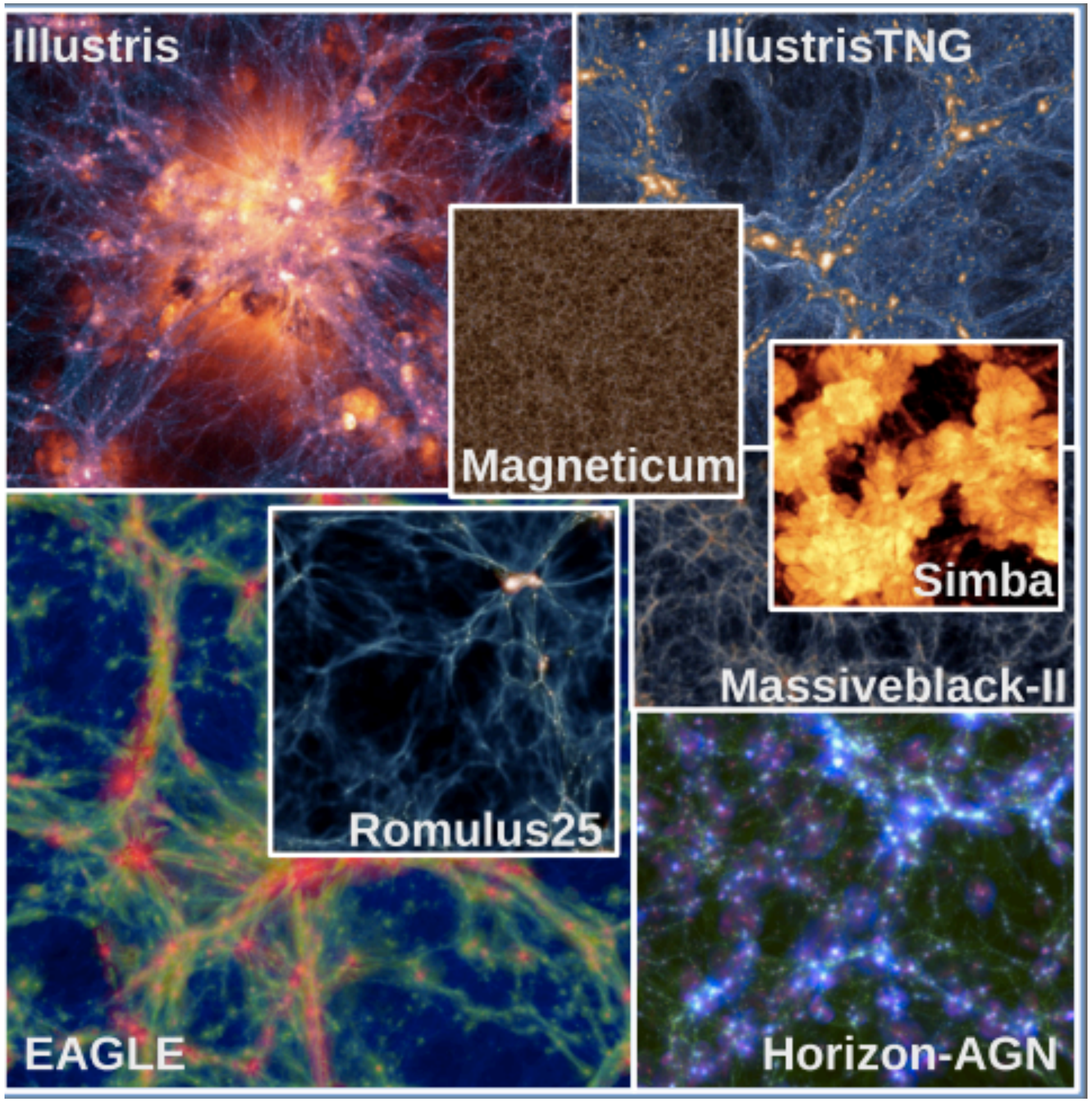


DM density profile: Peirani et al. 2017

3- AGN Feedback Impact

Hydrodynamical cosmological simulations

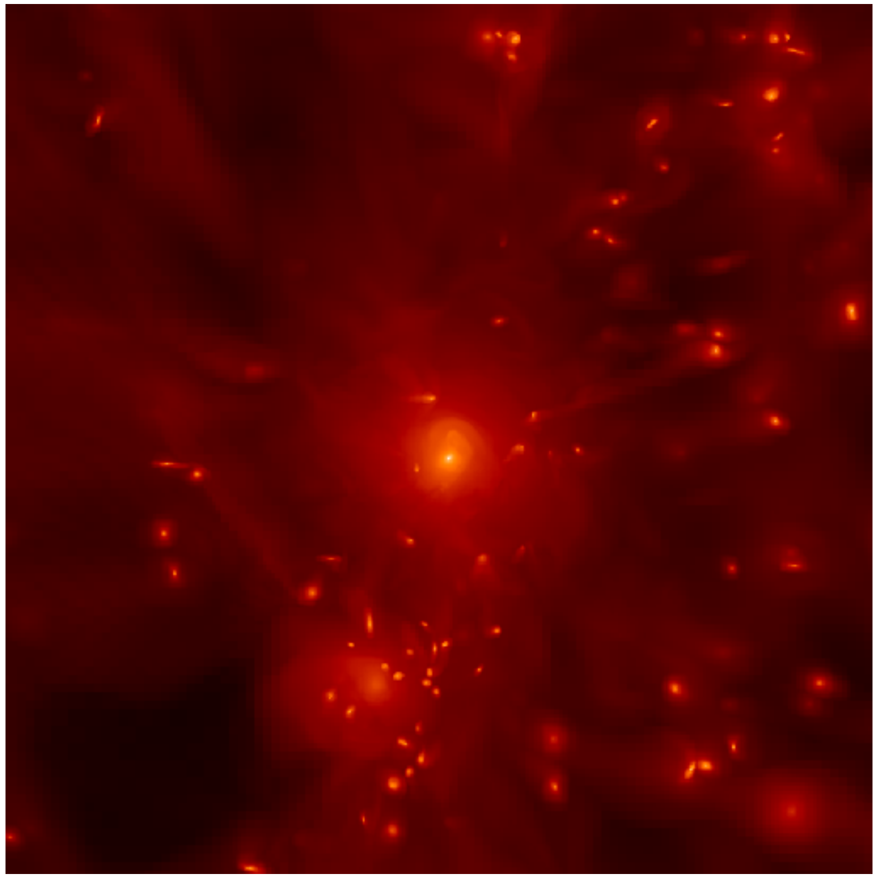
Vogelsberger et al. 2019



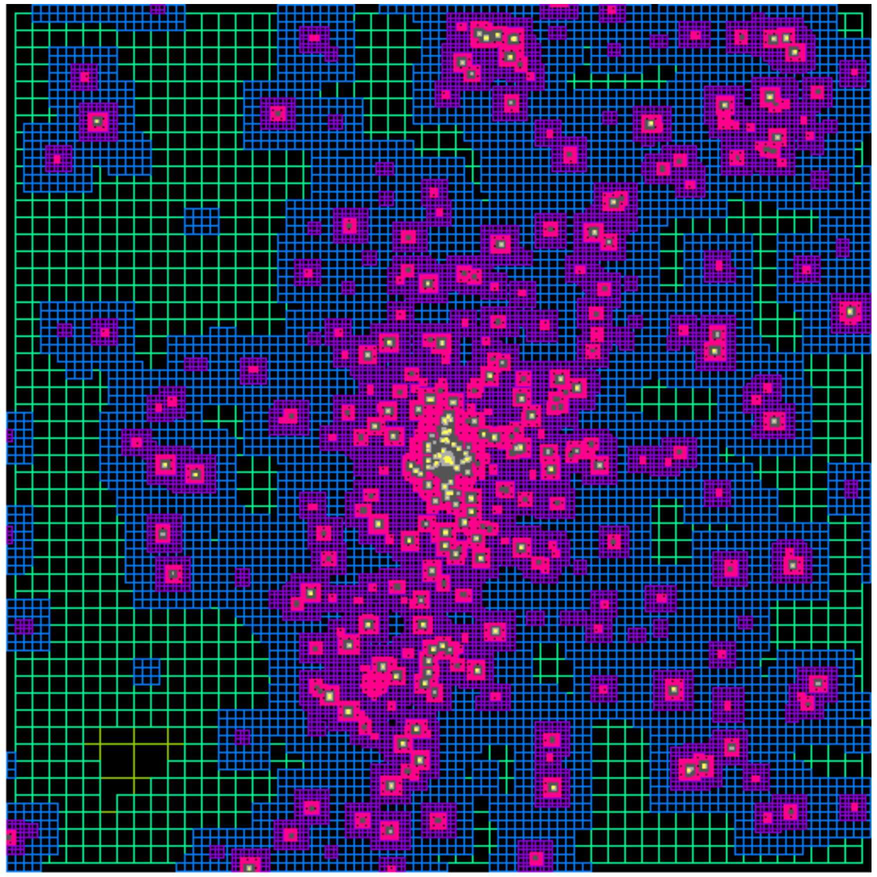
The HorizonAGN simulation

- Cosmological hydrodynamical simulation run with the Adaptative Mesh Refinement (AMR) code RAMSES *(Teyssier 2002)*

gas density



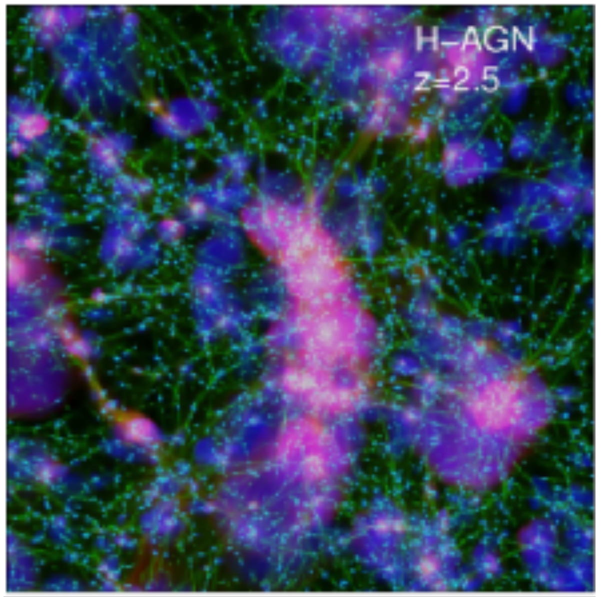
Grid

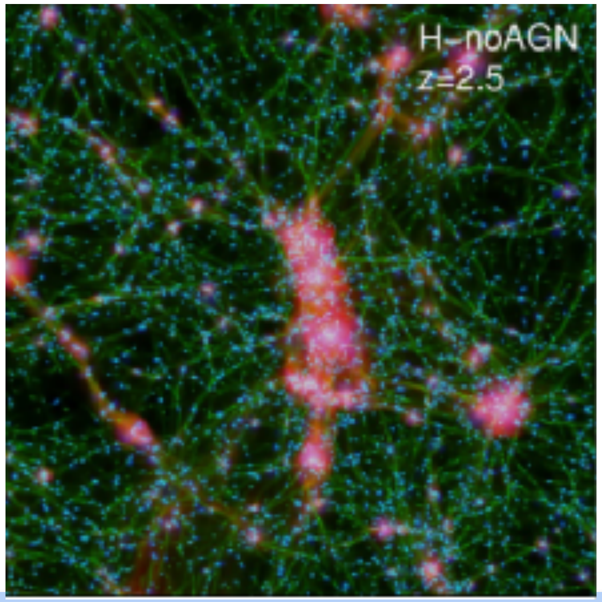


3- AGN Feedback Impact

The HorizonAGN simulation

- Cosmological hydrodynamical simulation run with the Adaptative Mesh Refinement (AMR) code RAMSES *(Teyssier 2002)*
- Run to z = 0.2 using 4 Million CPU hours
- Box size: $L_{box} = 100\,Mpc.h^{-1}$ with WMAP 7 cosmology
- Cell size = $1\,kpc.h^{-1}$ to $100\,kpc.h^{-1}$
- Included physics: - Gas cooling with contribution from metals
  - Heating from a uniform UV background
  - Stellar formation
  - Stellar feedback: release mass, energy and metals
  - AGN feedback
- Companion simulation Horizon-noAGN





gas density
temperature
gas metallicity

3- AGN Feedback Impact

The AGN feedback in the HorizonAGN simulation

- Black hole are sink particles which can accrete gas at the Bondi-Hoyle accretion rate:

$$\dot{M}_{BH} = \frac{4\Pi\alpha G^2 M_{BH}^2 \bar{\rho}}{(\bar{c}_s^2 + \bar{u}^2)^{3/2}}$$

α boost factor, accounts for not resolving the accretion disk

$$\begin{cases} (\rho/\rho_0)^2 & \text{if} \quad \rho > \rho_0 \\ 1 & \text{otherwhise} \end{cases}$$

3- AGN Feedback Impact

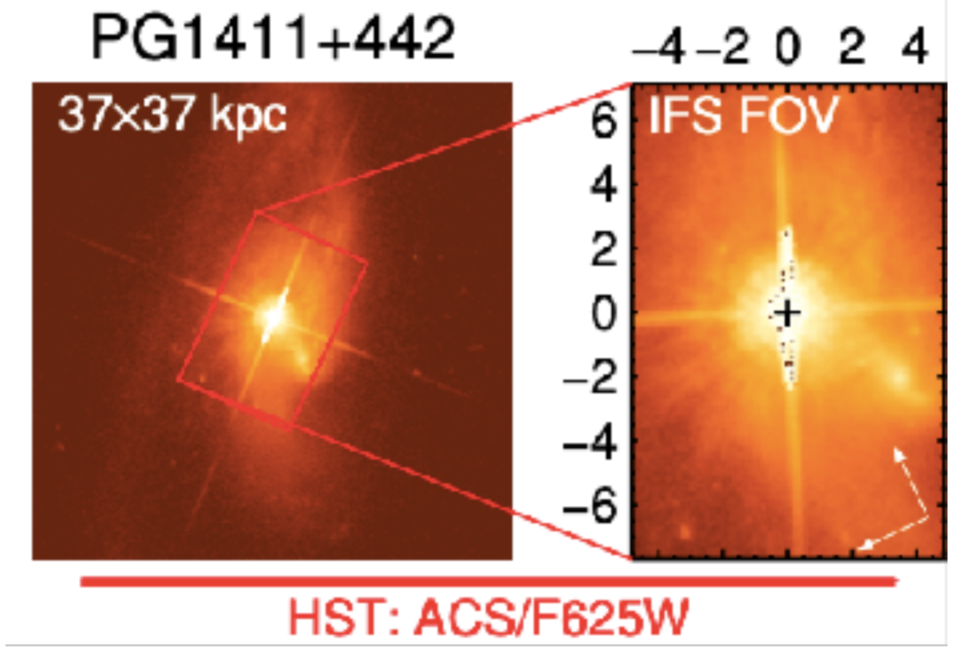
The AGN feedback in the HorizonAGN simulation

- Black hole are sink particles which can accrete gas the Bondi-Hoyle accretion rate:

$$\dot{M}_{BH} = \frac{4\Pi\alpha G^2 M_{BH}^2 \bar{\rho}}{(\bar{c}_s^2 + \bar{u}^2)^{3/2}}$$

- AGN feedback proceeds in two modes:
  - *Quasar mode:* high-z universe, emit large amount of radiations, photo-ionize and heat gas
    → Injection of **thermal energy** in a sphere of radius $r_{AGN} = \Delta x$

Rupke et al. 2017



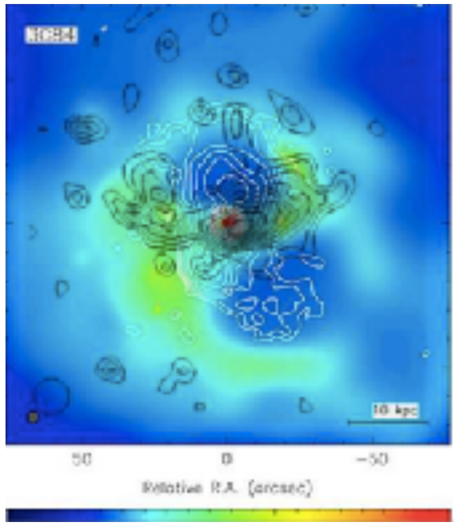
3- AGN Feedback Impact

The AGN feedback in the HorizonAGN simulation

- Black hole are sink particles which can accrete gas the Bondi-Hoyle accretion rate:

$$\dot{M}_{BH} = \frac{4\Pi\alpha G^2 M_{BH}^2 \bar{\rho}}{(\bar{c}_s^2 + \bar{u}^2)^{3/2}}$$

- AGN feedback proceeds in two modes:
  - *Quasar mode:* high-z universe, emit large amount of radiations, photo-ionize and heat gas
    → Injection of **thermal energy** in a sphere of radius $r_{AGN} = \Delta x$
  - *Radio mode:* low-z universe, creation of inflated cavities with strong magnetic fields
    → Injection of **kinetic energy** in jets of length $r_{AGN} = \Delta x$



3- AGN Feedback Impact

The AGN feedback in the HorizonAGN simulation

- Black hole are sink particles which can accrete gas the Bondi-Hoyle accretion rate:

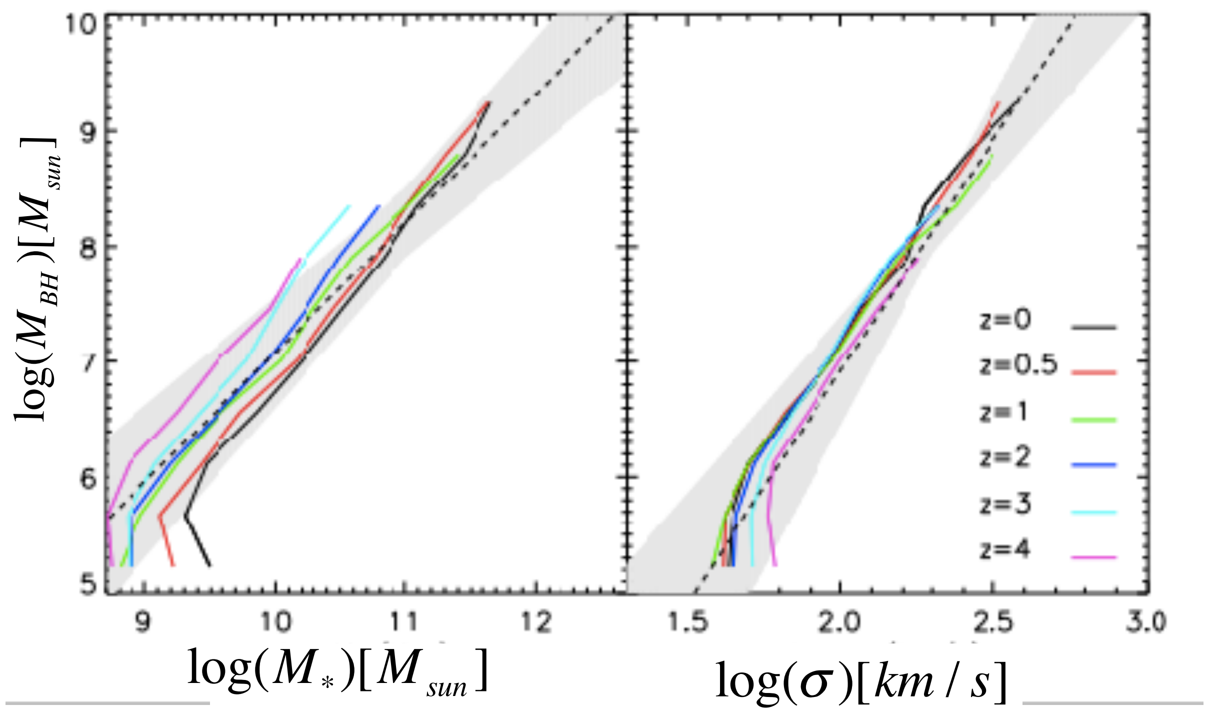
$$\dot{M}_{BH} = \frac{4\Pi\alpha G^2 M_{BH}^2 \bar{\rho}}{(\bar{c}_s^2 + \bar{u}^2)^{3/2}}$$

- AGN feedback proceeds in two modes:
  - *Quasar mode:* high-z universe, emit large amount of radiations, photo-ionize and heat gas
    → Injection of **thermal energy** in a sphere of radius $r_{AGN} = \Delta x$
  - *Radio mode:* low-z universe, creation of inflated cavities with strong magnetic fields
    → Injection of **kinetic energy** in jets of length $r_{AGN} = \Delta x$
- A fraction ϵ_f of the radiated energy L_r is injected to the medium $\Delta E_{IGM} = \epsilon_f L_r$

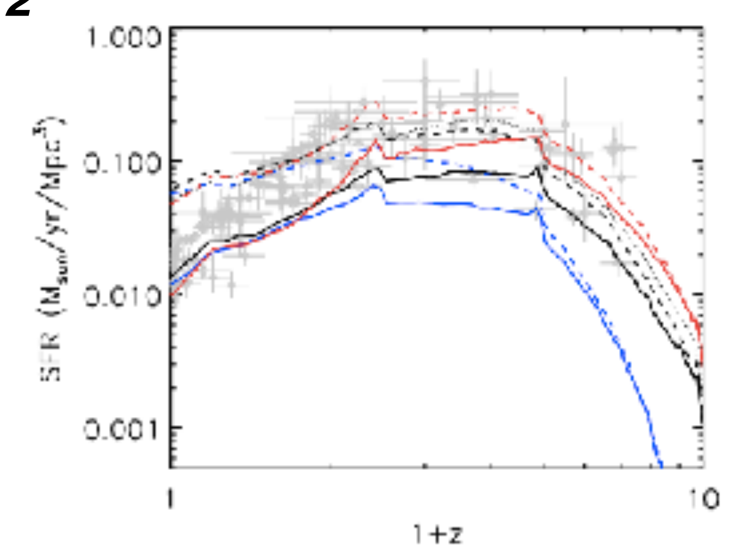
3- AGN Feedback Impact

The AGN feedback in the HorizonAGN simulation

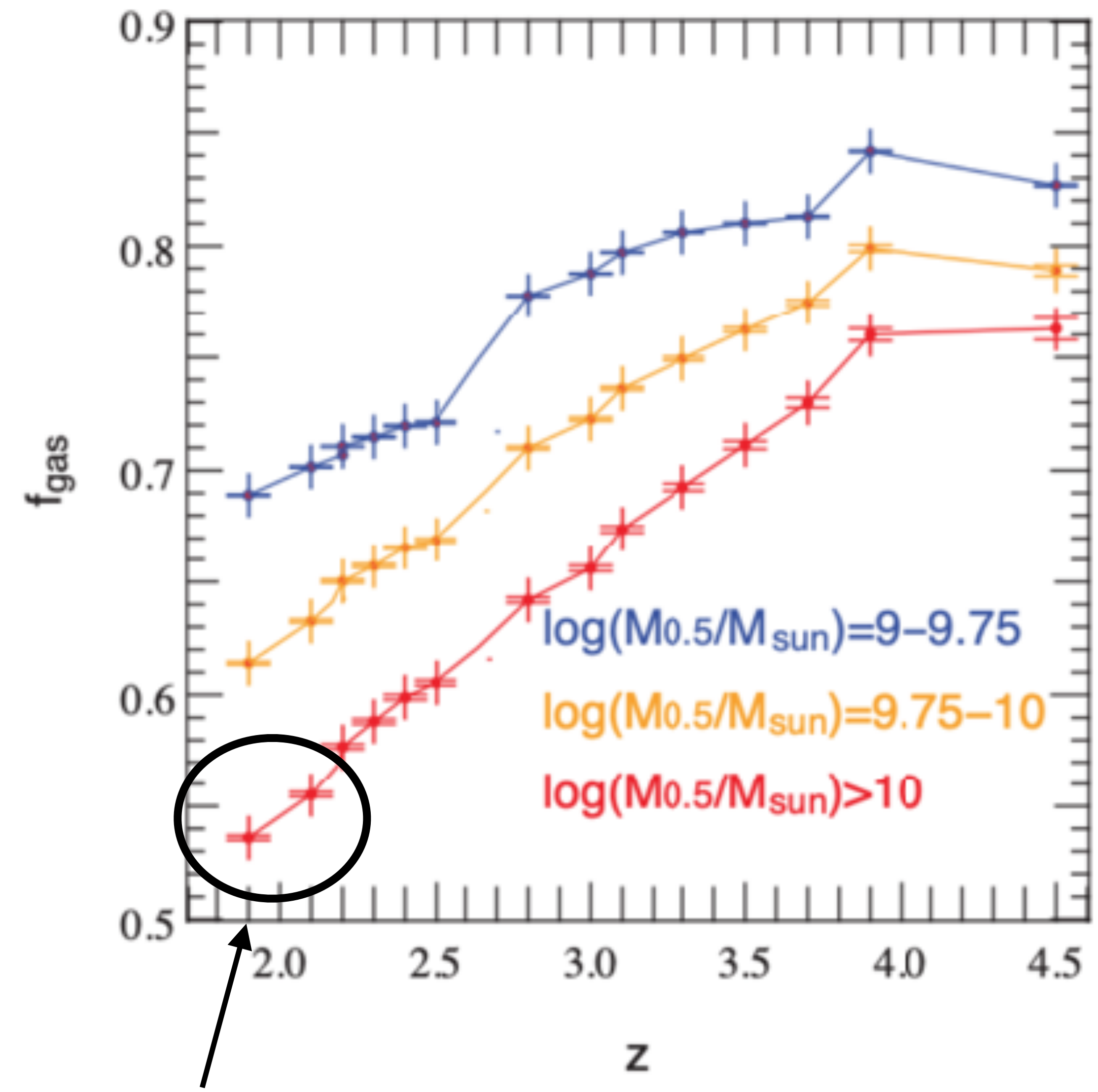
- Reproduce well scaling relations, **mean fraction of gas** in galaxies



Dubois et al. 2012

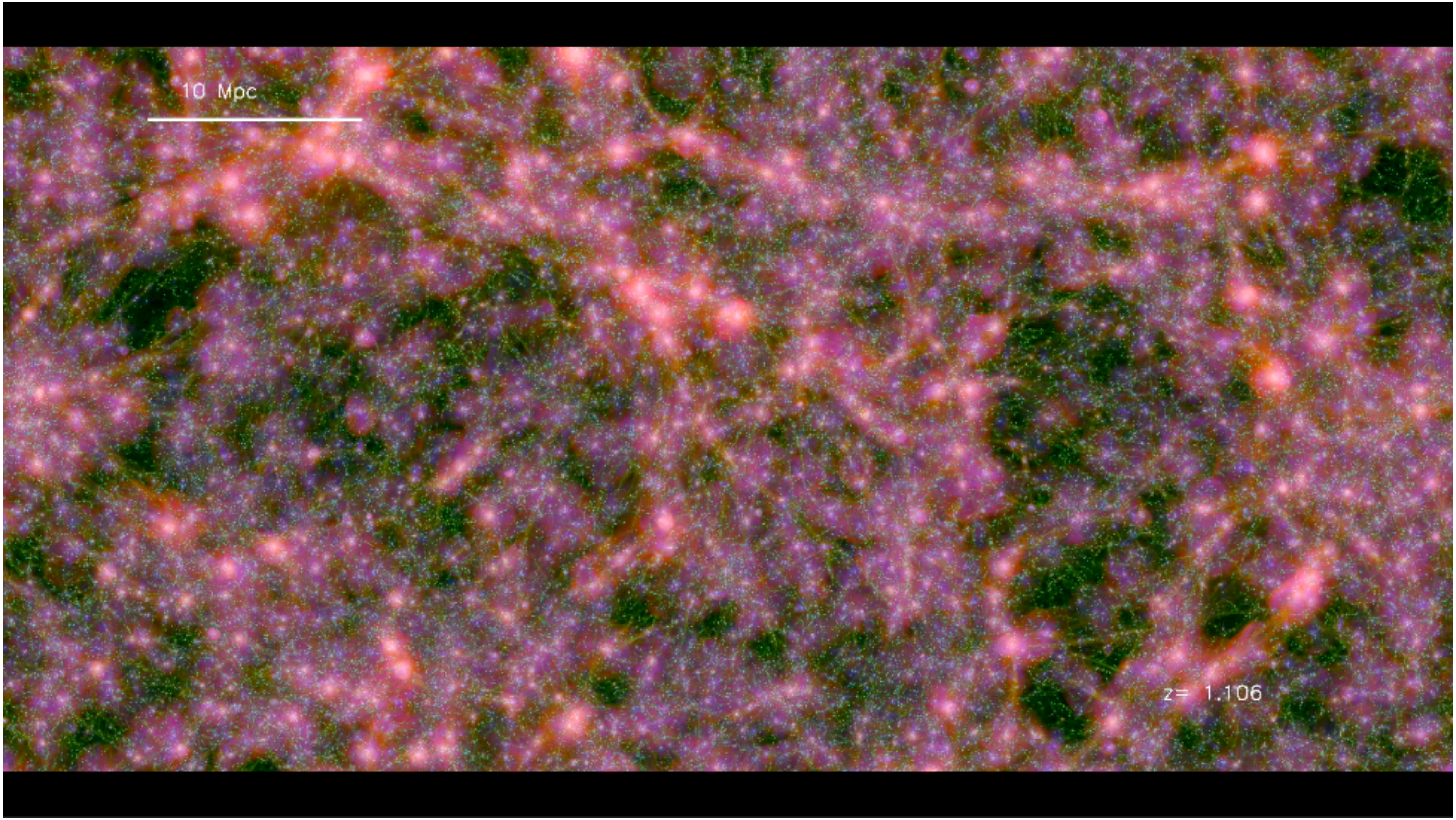


Welker et al. 2017



observations give 50%

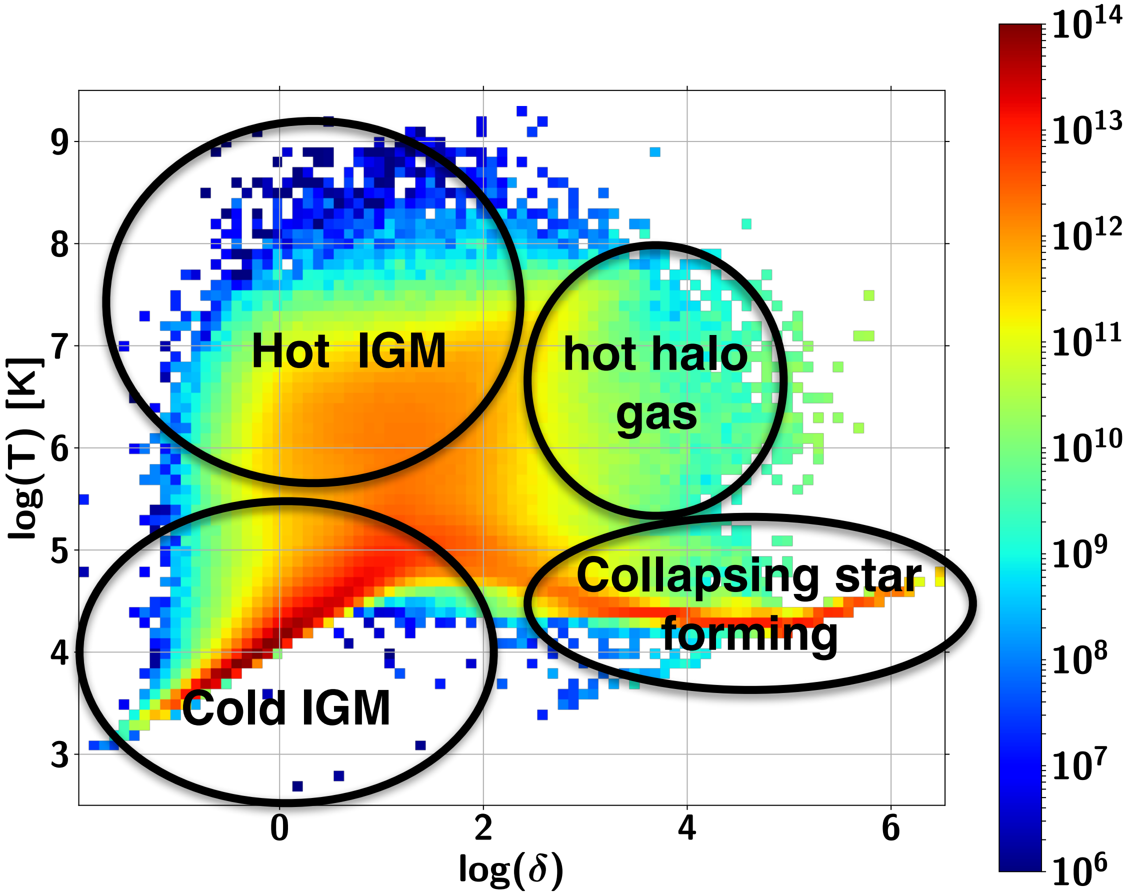
3- AGN Feedback Impact

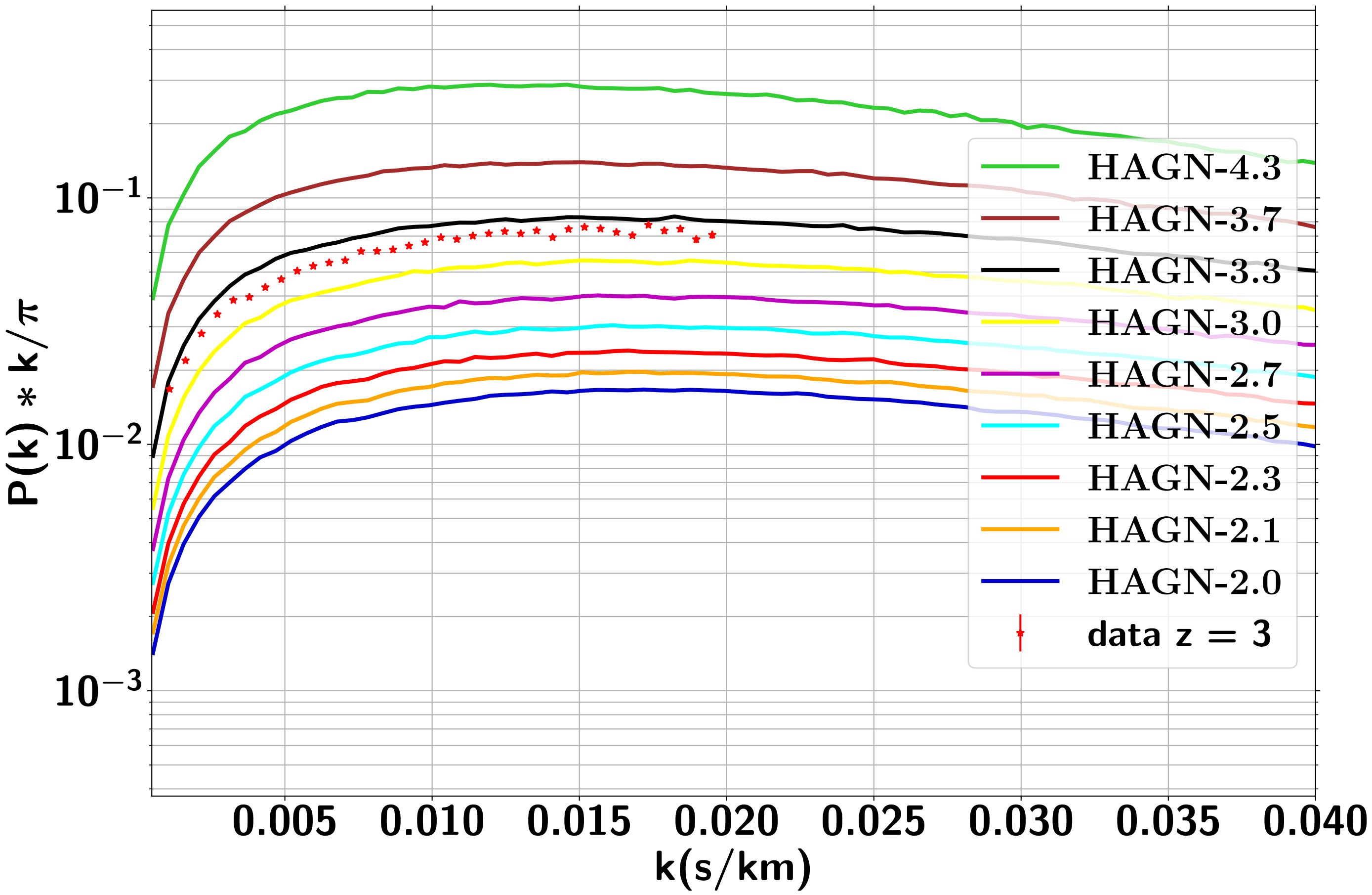


Credits: Y. Dubois

3- AGN Feedback Impact

The Lyα forest in the HorizonAGN simulation





3- AGN Feedback Impact

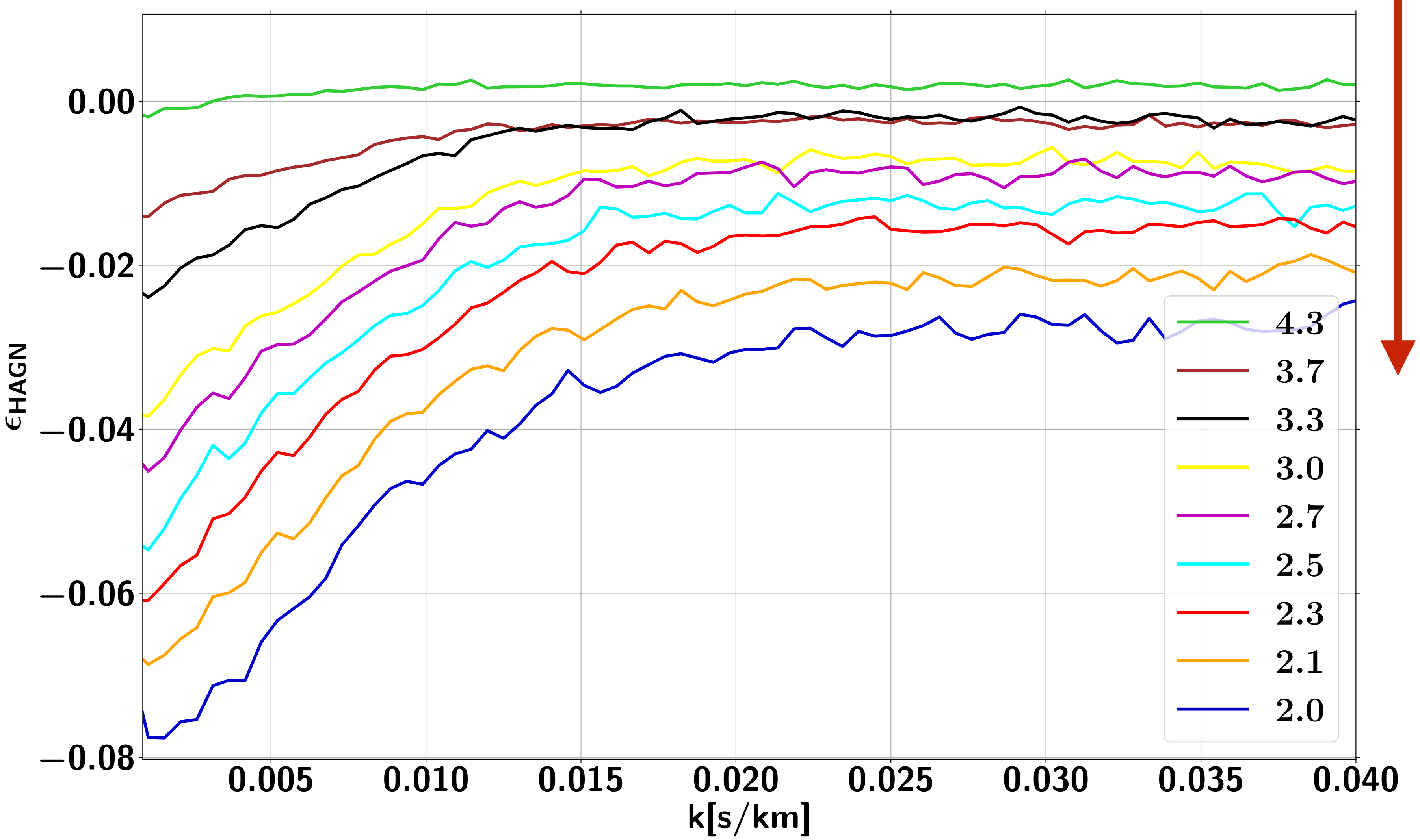
AGN feedback effect on the P1D

$$\frac{P_{Ly\alpha}(HAGN)}{P_{Ly\alpha}(HnoAGN)} = 1 + \epsilon_{HAGN}$$

Suppression increases with..

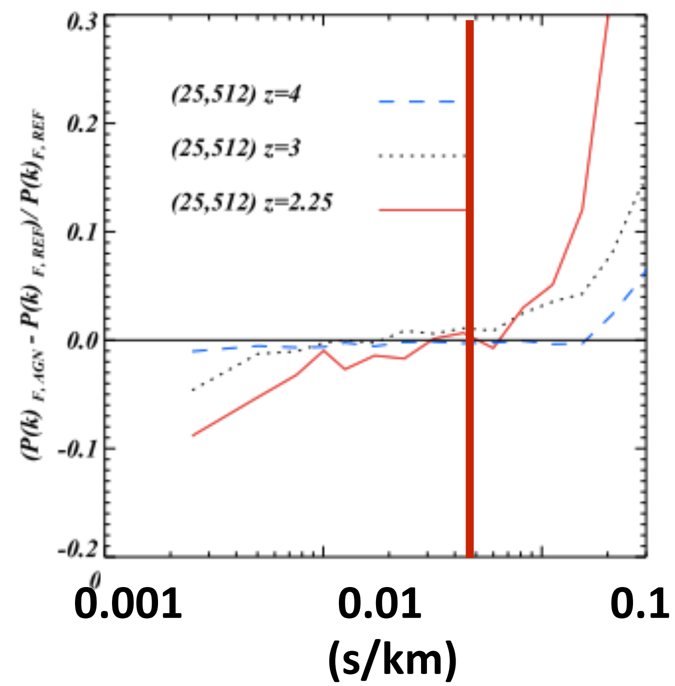
.. increasing scales

.. decreasing redshift



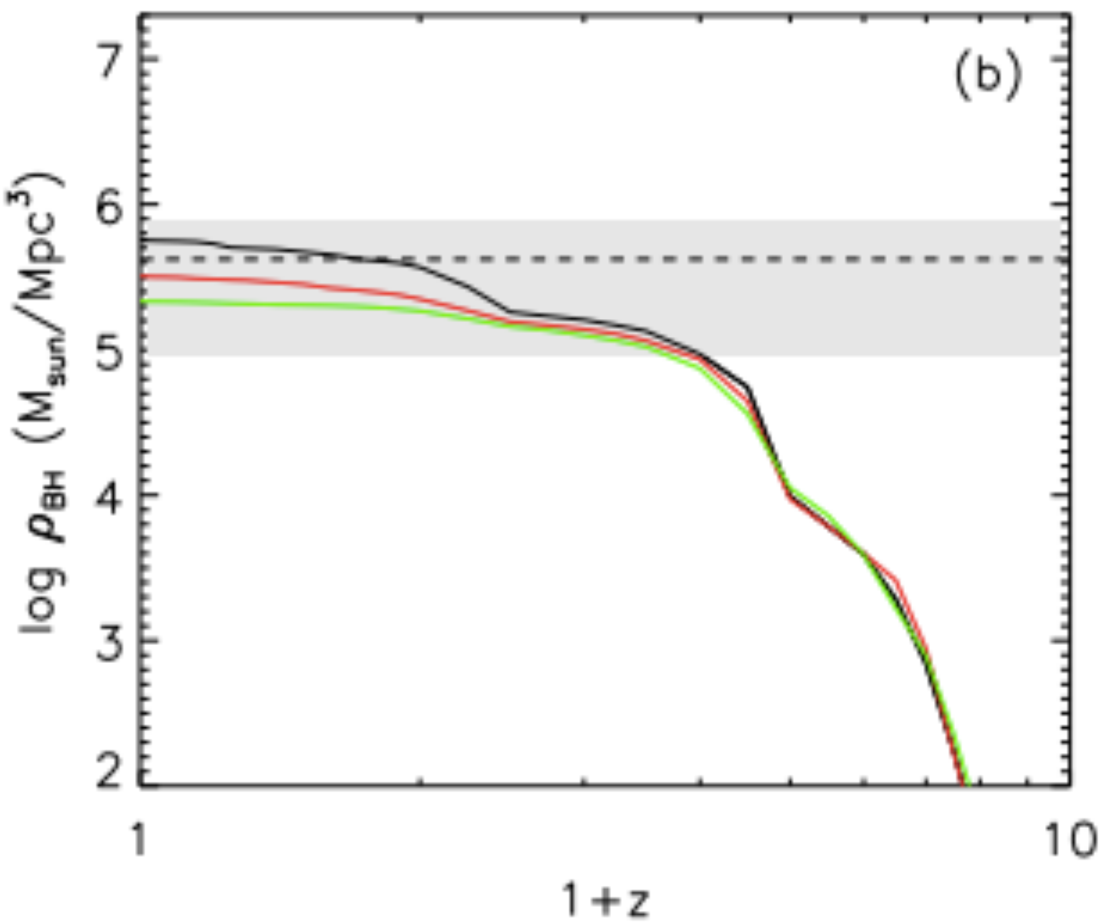
Chabanier et al. in prep

Viel et al. 2013

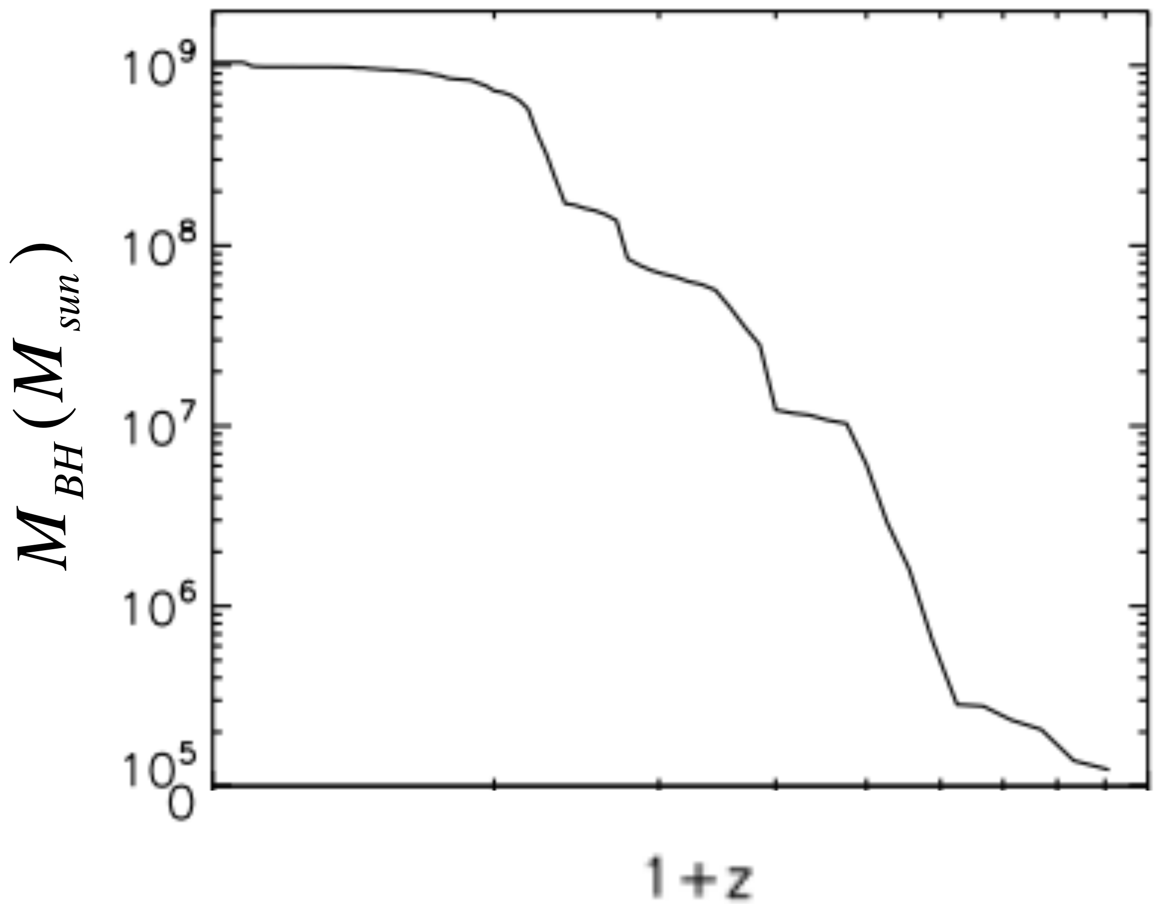


AGN feedback effect on the P1D: redshift dependence

Comoving black hole mass density

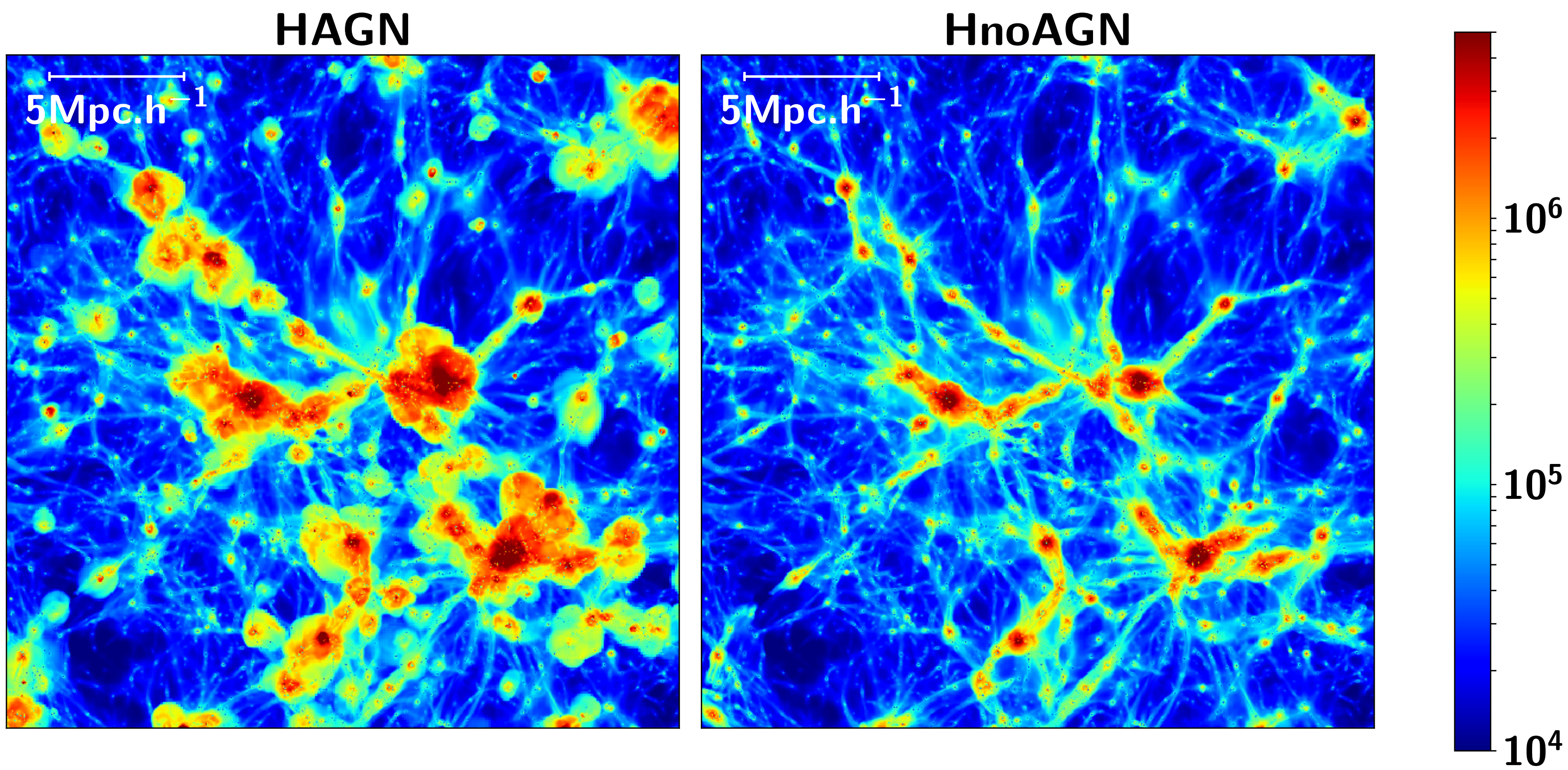


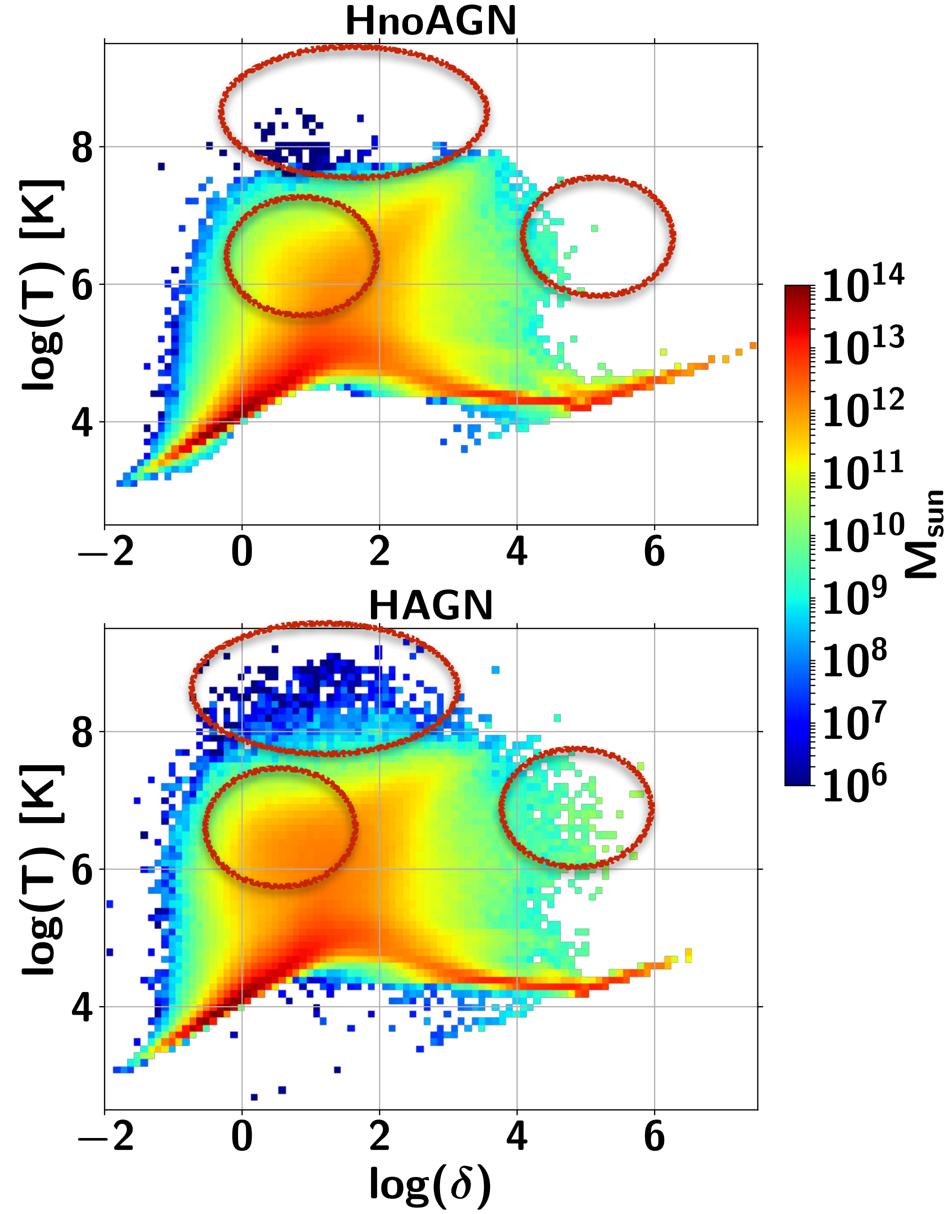
black hole mass



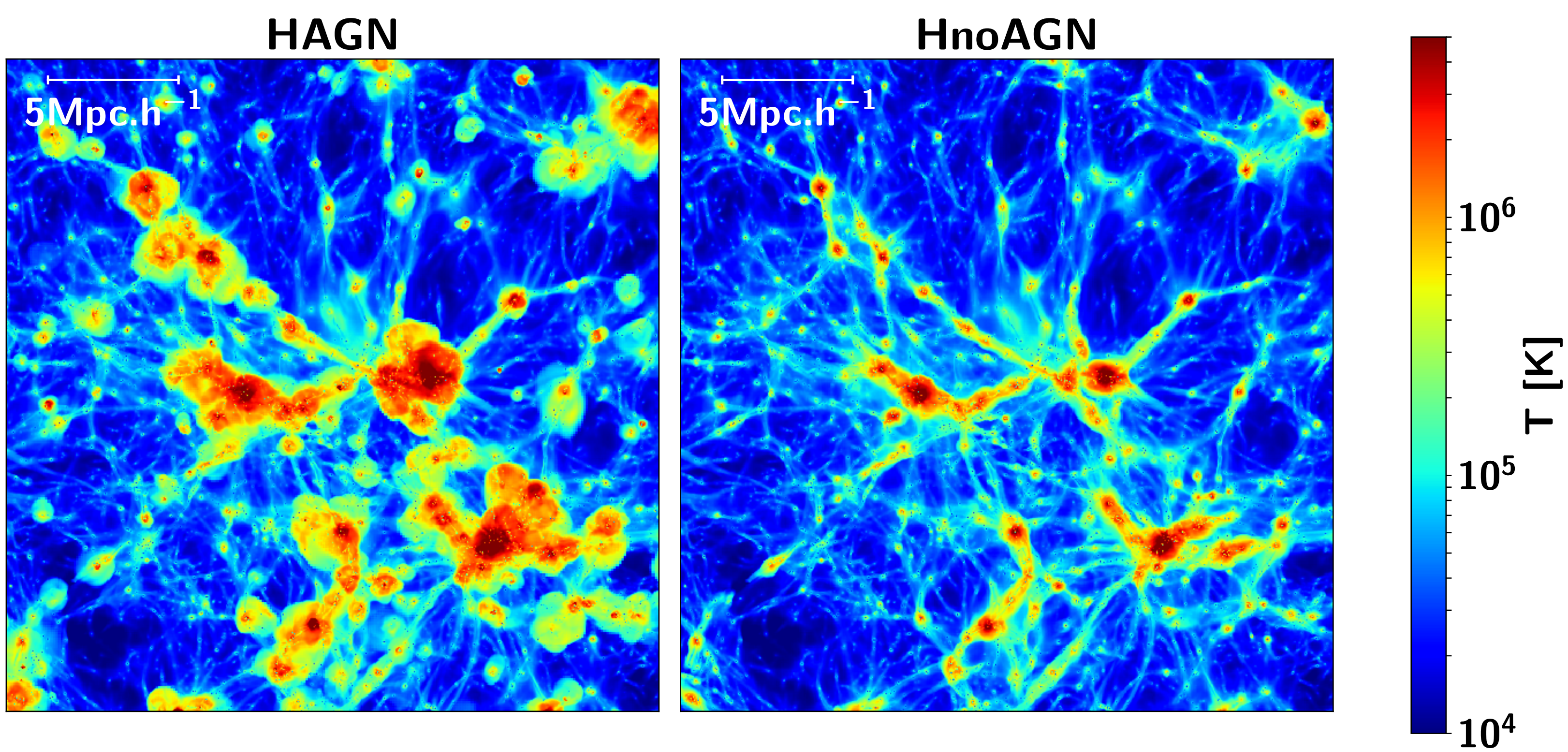
Dubois et al. 2012

AGN feedback effect on the P1D: heating

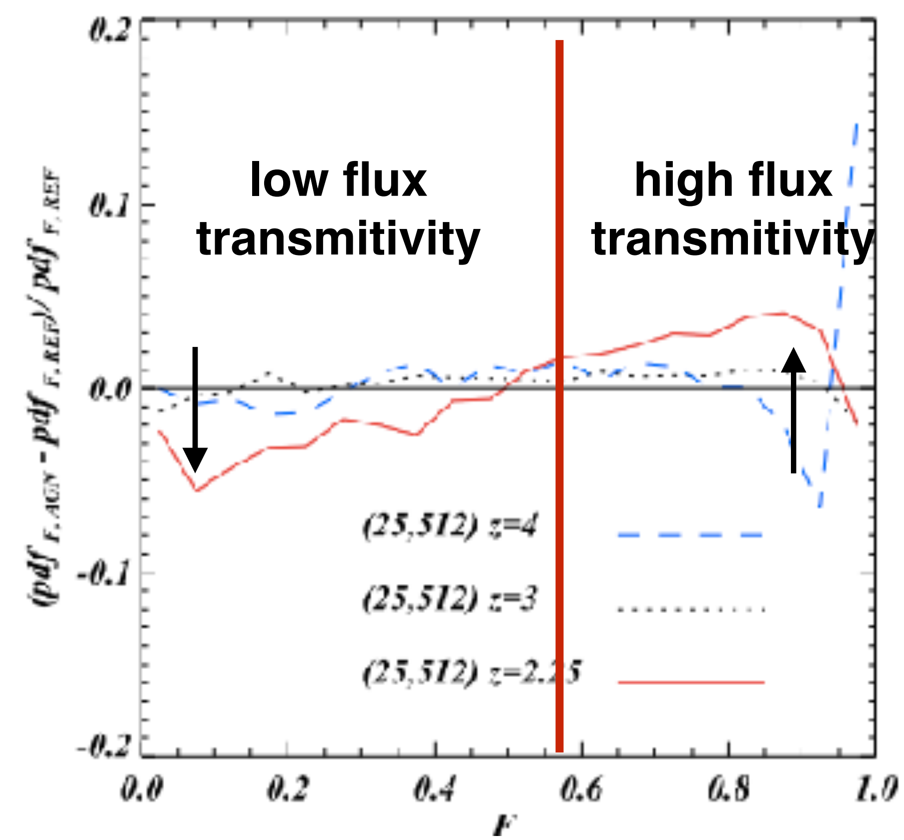




AGN feedback effect on the P1D: heating



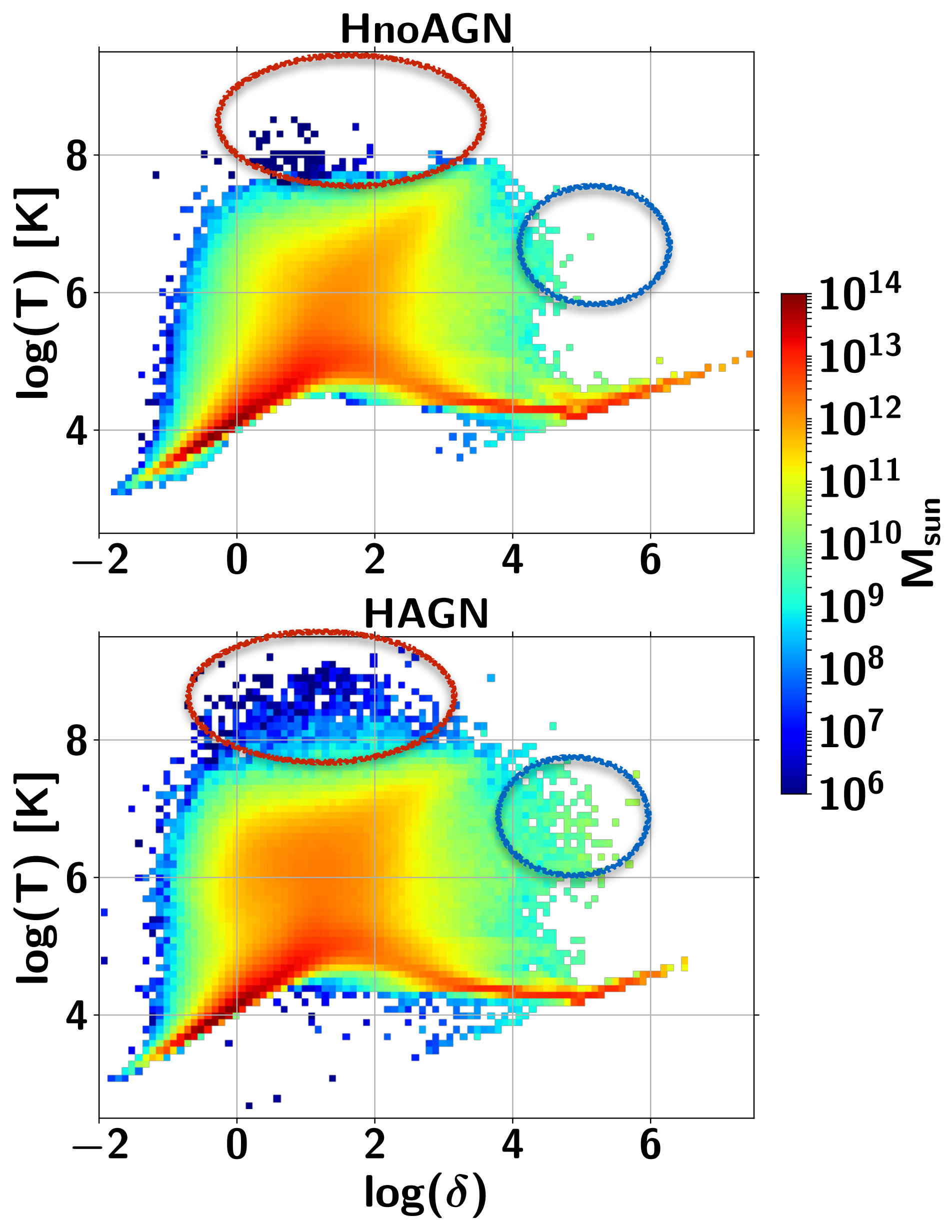
Viel et al. 2013



Heating → ionization → suppression of power

3- AGN Feedback Impact

AGN feedback effect on the P1D: heating



Large scales:

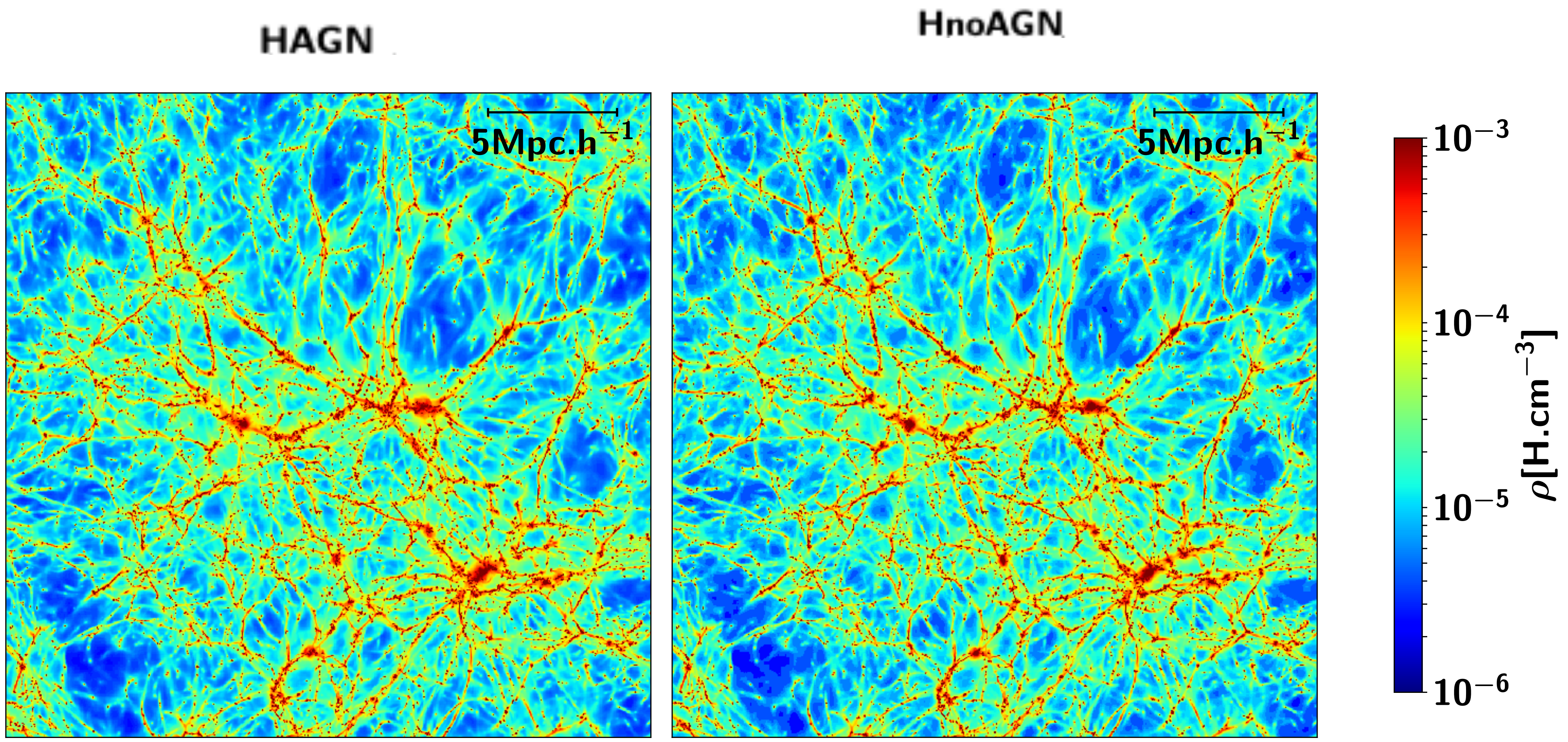
diffuse
very efficiently heated } **stays ionized**

Small scales:

dense
midly heated } **recombine easily**

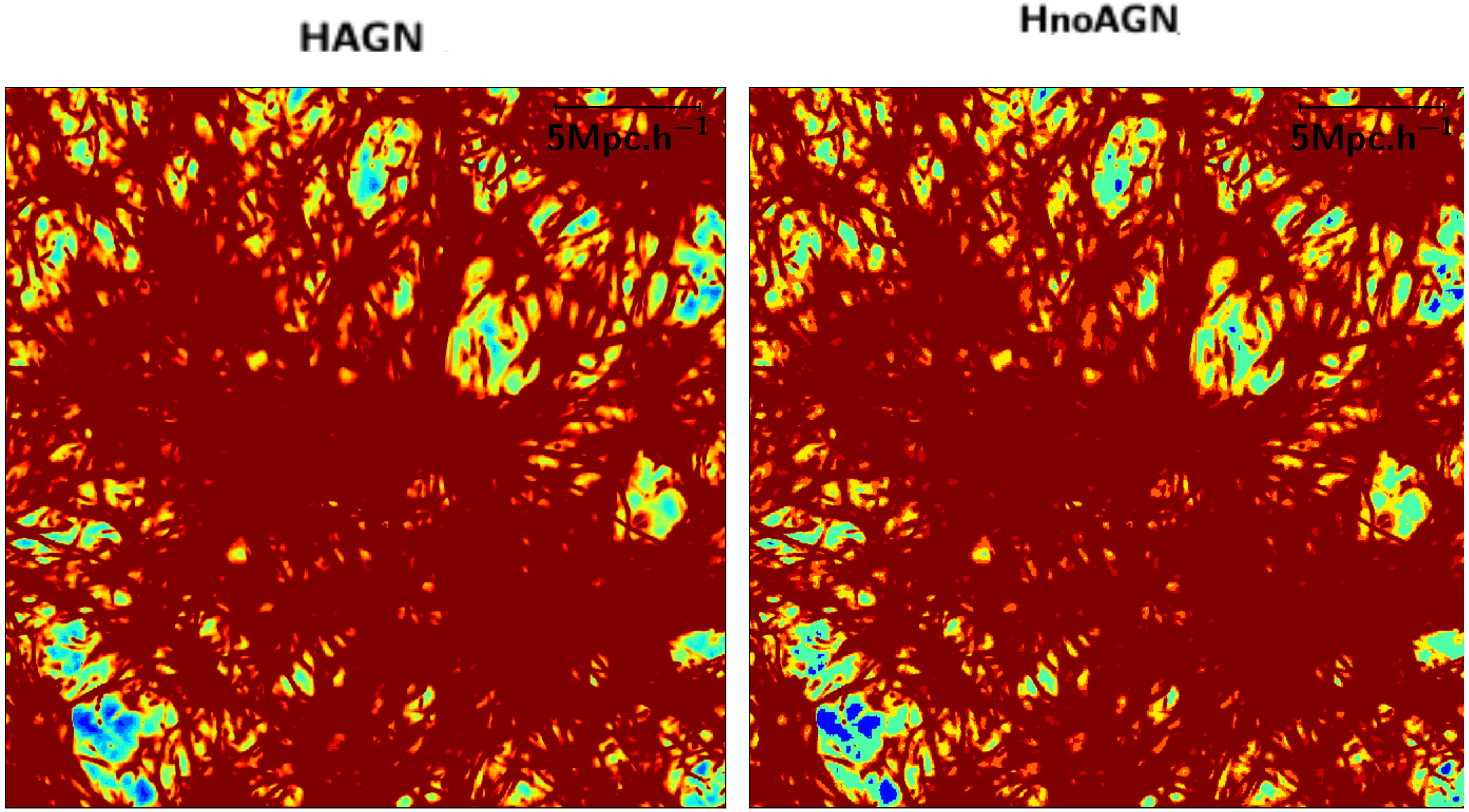
3- AGN Feedback Impact

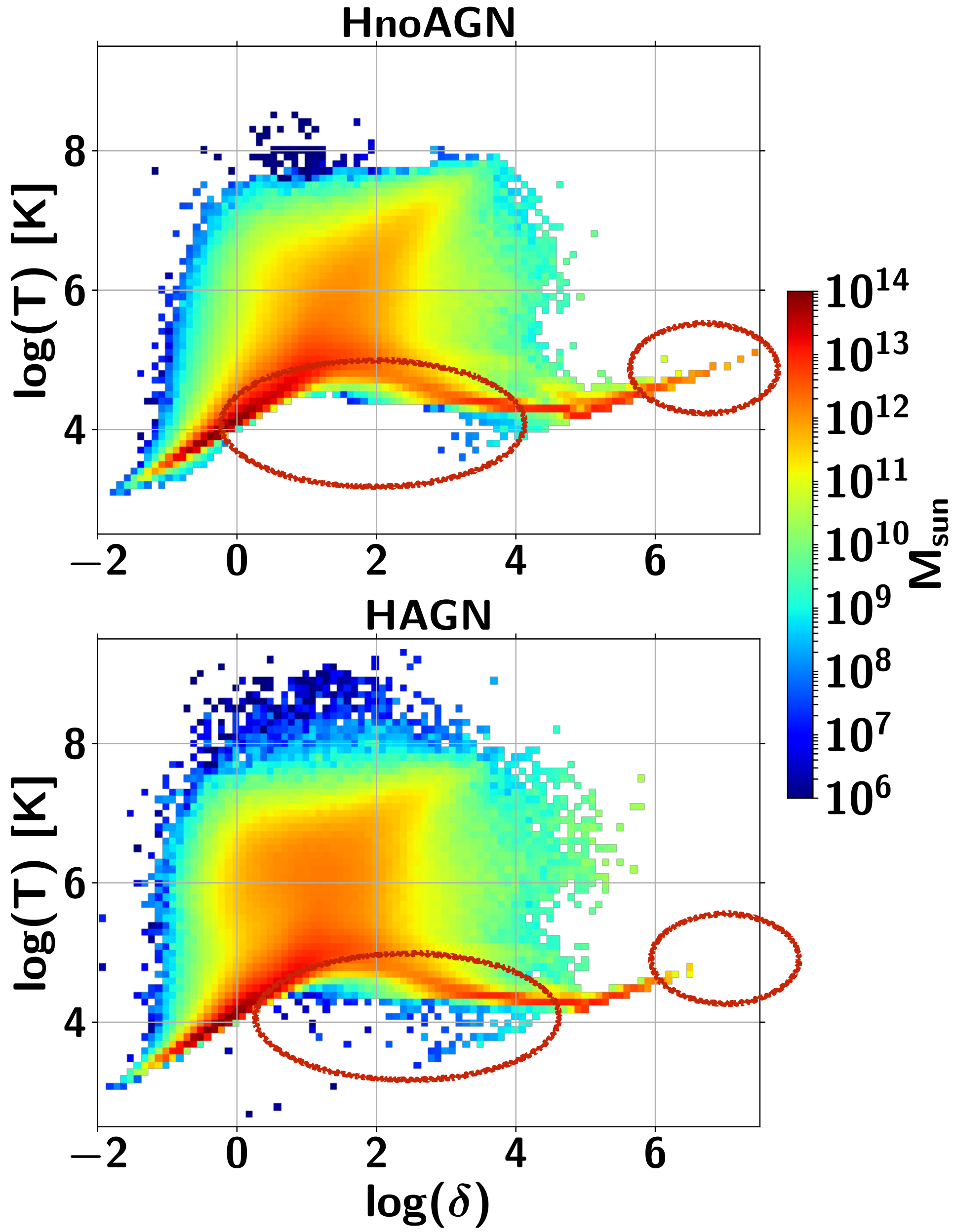
AGN feedback effect on the P1D: gas redistribution



3- AGN Feedback Impact

AGN feedback effect on the P1D: gas redistribution

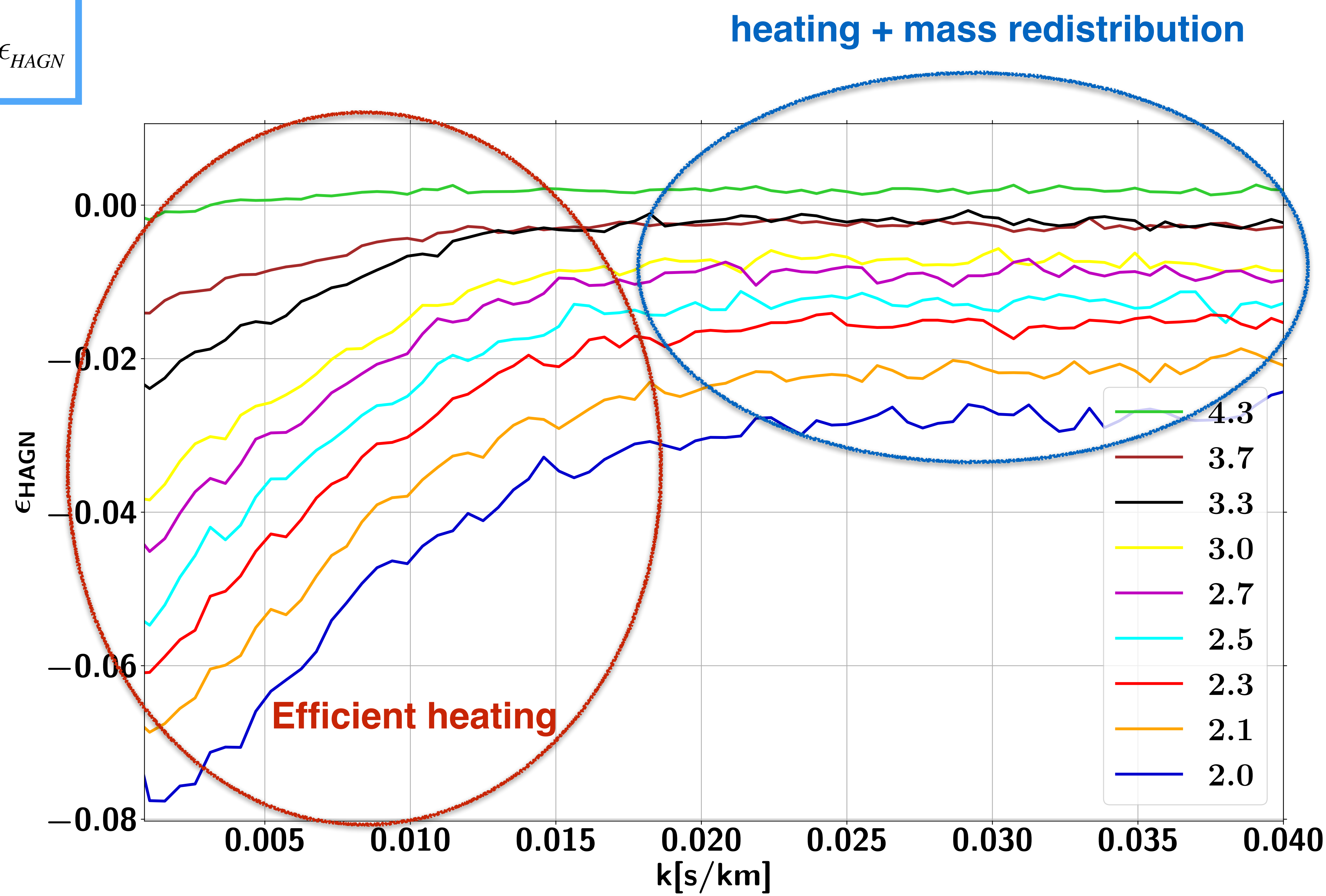




3- AGN Feedback Impact

AGN feedback effect on the P1D

$$\frac{P_{Ly\alpha}(HAGN)}{P_{Ly\alpha}(HnoAGN)} = 1 + \epsilon_{HAGN}$$



The set of additional simulations

Simulation	α	r_{AGN}	ϵ_f
HAGN	$\begin{cases} (\rho/\rho_0)^2 & \text{if } \rho > \rho_0 \\ 1 & \text{otherwhise} \end{cases}$	Δx	$\begin{cases} 0.1 & \text{if radio mode} \\ 0.15 & \text{if quasar mode} \end{cases}$
HAGNclp10	10% of the time: $10\alpha_{HAGN}$	$r_{AGN,HAGN}$	$\epsilon_{f,HAGN}$
HAGNclp100	1% of the time: $100\alpha_{HAGN}$	$r_{AGN,HAGN}$	$\epsilon_{f,HAGN}$
HAGNr+	α_{HAGN}	$2\Delta x$	$\epsilon_{f,HAGN}$
HAGNr−	α_{HAGN}	$0.5\Delta x$	$\epsilon_{f,HAGN}$
HAGNϵ+	α_{HAGN}	$r_{AGN,HAGN}$	$\begin{cases} 3 & \text{if radio mode} \\ 0.45 & \text{if quasar mode} \end{cases}$
HAGNϵ−	α_{HAGN}	$r_{AGN,HAGN}$	$\begin{cases} 0.33 & \text{if radio mode} \\ 0.05 & \text{if quasar mode} \end{cases}$

3- AGN Feedback Impact

The set of additional simulations

Stochasticity in the accretion rate

$$\dot{M}_{BH} = \frac{4\Pi \alpha G^2 M_{BH}^2 \bar{\rho}}{(\bar{c}_s^2 + \bar{u}^2)^{3/2}}$$

Simulation	α	r_{AGN}	ϵ_f
HAGN	$(\rho/\rho_0)^2$ if $\rho > \rho_0$; 1 otherwhise	Δx	0.1 if radio mode; 0.15 if quasar mode
HAGNclp10	10% of the time: $10\alpha_{HAGN}$	$r_{AGN,HAGN}$	$\epsilon_{f,HAGN}$
HAGNclp100	1% of the time: $100\alpha_{HAGN}$	$r_{AGN,HAGN}$	$\epsilon_{f,HAGN}$
HAGNr+	α_{HAGN}	$2\Delta x$	$\epsilon_{f,HAGN}$
HAGNr−	α_{HAGN}	$0.5\Delta x$	$\epsilon_{f,HAGN}$
HAGNϵ+	α_{HAGN}	$r_{AGN,HAGN}$	3 if radio mode; 0.45 if quasar mode
HAGNϵ−	α_{HAGN}	$r_{AGN,HAGN}$	0.33 if radio mode; 0.05 if quasar mode

3- AGN Feedback Impact

The set of additional simulations

<u>radius of energy deposition</u>

Simulation	α	r_{AGN}	ϵ_f
HAGN	$\begin{cases} (\rho/\rho_0)^2 & \text{if } \rho > \rho_0 \\ 1 & \text{otherwhise} \end{cases}$	Δx	$\begin{cases} 0.1 & \text{if radio mode} \\ 0.15 & \text{if quasar mode} \end{cases}$
HAGNclp10	10% of the time: $10\alpha_{HAGN}$	$r_{AGN,HAGN}$	$\epsilon_{f,HAGN}$
HAGNclp100	1% of the time: $100\alpha_{HAGN}$	$r_{AGN,HAGN}$	$\epsilon_{f,HAGN}$
HAGNr+	α_{HAGN}	$2\Delta x$	$\epsilon_{f,HAGN}$
HAGNr−	α_{HAGN}	$0.5\Delta x$	$\epsilon_{f,HAGN}$
HAGNϵ+	α_{HAGN}	$r_{AGN,HAGN}$	$\begin{cases} 3 & \text{if radio mode} \\ 0.45 & \text{if quasar mode} \end{cases}$
HAGNϵ−	α_{HAGN}	$r_{AGN,HAGN}$	$\begin{cases} 0.33 & \text{if radio mode} \\ 0.05 & \text{if quasar mode} \end{cases}$

The set of additional simulations

Simulation	α	r_{AGN}	ϵ_f
HAGN	$\begin{cases} (\rho/\rho_0)^2 & \text{if } \rho > \rho_0 \\ 1 & \text{otherwhise} \end{cases}$	Δx	$\begin{cases} 0.1 & \text{if radio mode} \\ 0.15 & \text{if quasar mode} \end{cases}$
HAGNclp10	10% of the time: $10\alpha_{HAGN}$	$r_{AGN,HAGN}$	$\epsilon_{f,HAGN}$
HAGNclp100	1% of the time: $100\alpha_{HAGN}$	$r_{AGN,HAGN}$	$\epsilon_{f,HAGN}$
HAGNr+	α_{HAGN}	$2\Delta x$	$\epsilon_{f,HAGN}$
HAGNr−	α_{HAGN}	$0.5\Delta x$	$\epsilon_{f,HAGN}$
HAGNϵ+	α_{HAGN}	$r_{AGN,HAGN}$	$\begin{cases} 3 & \text{if radio mode} \\ 0.45 & \text{if quasar mode} \end{cases}$
HAGNϵ−	α_{HAGN}	$r_{AGN,HAGN}$	$\begin{cases} 0.33 & \text{if radio mode} \\ 0.05 & \text{if quasar mode} \end{cases}$

Efficiency parameter

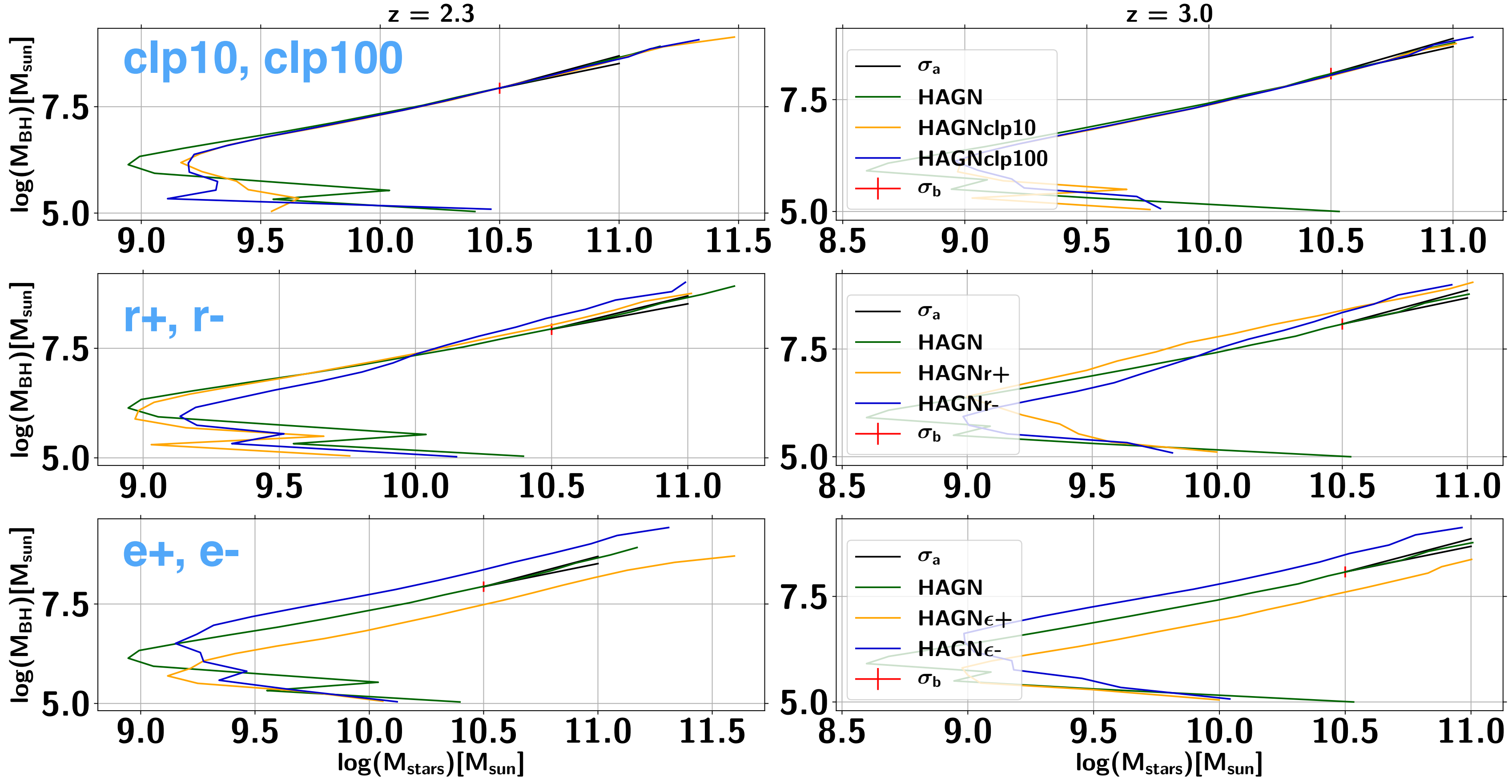
$$\Delta E_{IGM} = \epsilon_f L_r$$

3- AGN Feedback Impact

The set of additional simulations

Parameters chosen to span observational uncertainties

$$M_{BH} - M_*$$



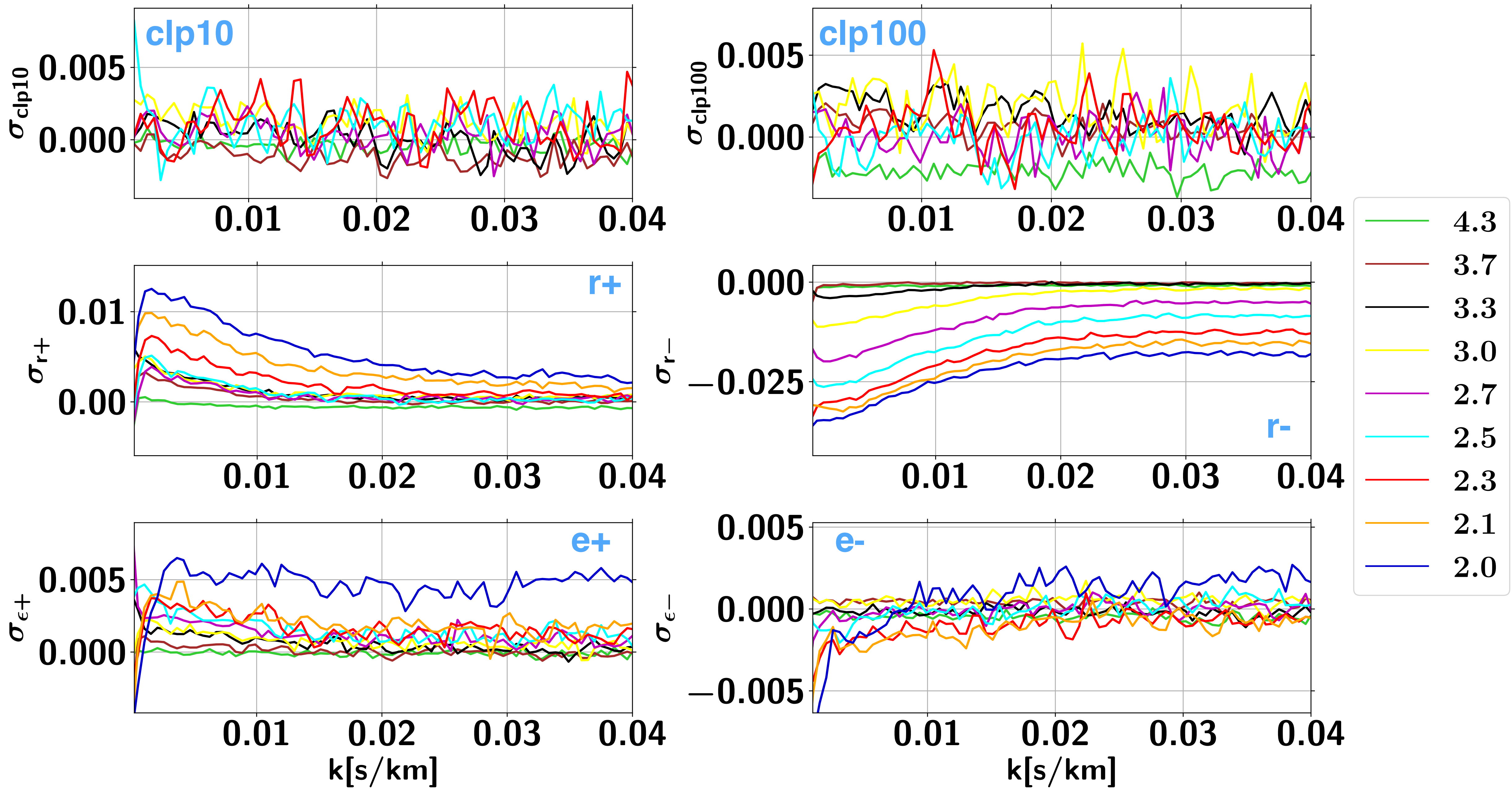
Mean fraction of gas in galaxies

		f_{gas}	Δf_{gas}
	HAGN	0.46	0.0
1σ	HAGNclp10	0.45	$< \sigma_f$
	HAGNclp100	0.42	σ_f
3σ	HAGNr+	0.36	$3\sigma_f$
	HAGNr−	0.57	$2.7\sigma_f$
3σ	HAGNϵ+	0.38	$2.3\sigma_f$
	HAGNϵ−	0.56	$2.5\sigma_f$

→ **our set covers a wide range of realistic feedback models**

3- AGN Feedback Impact

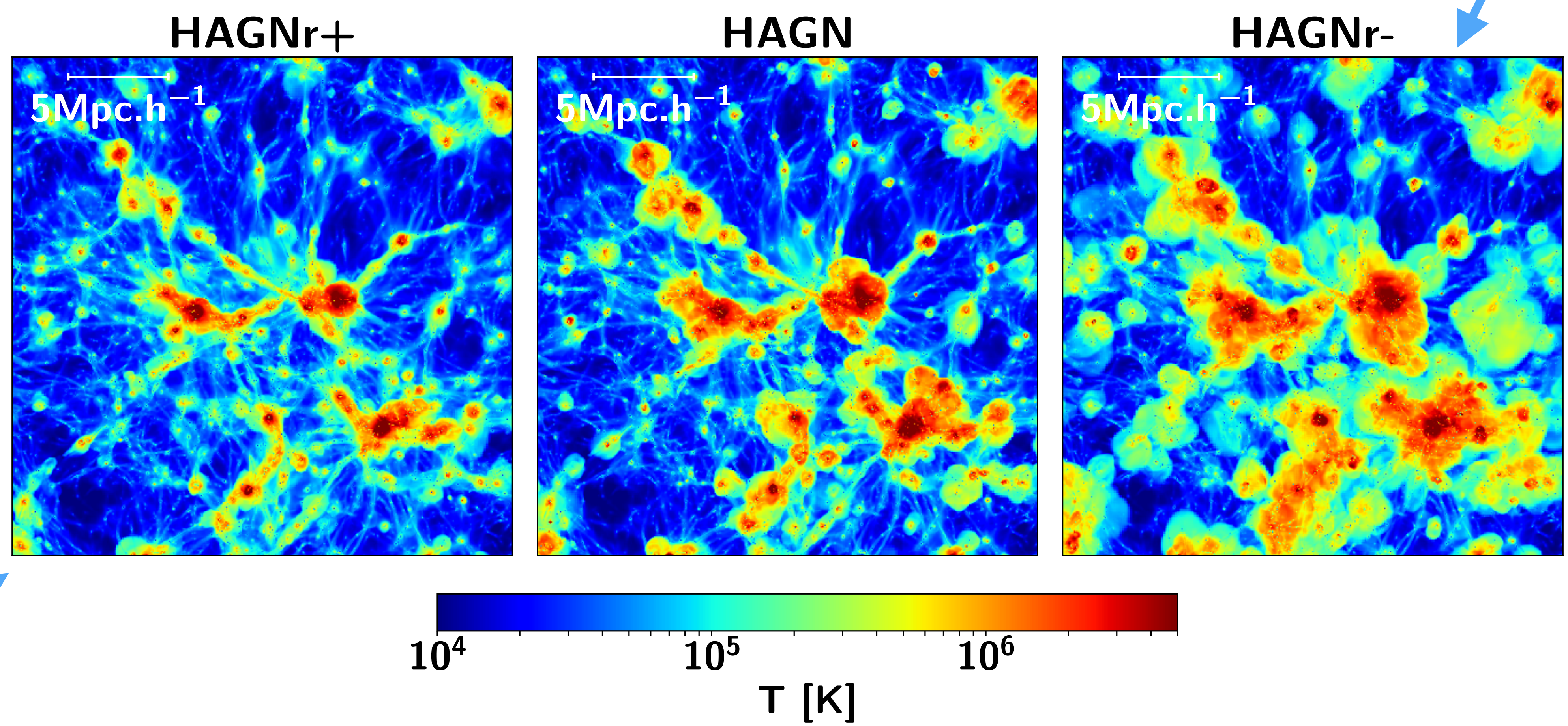
Uncertainties in the feedback model



3- AGN Feedback Impact

Uncertainties in the feedback model

Efficiently heats the gas $(>10^7, 10^8 K)$



injects energy to larger scales

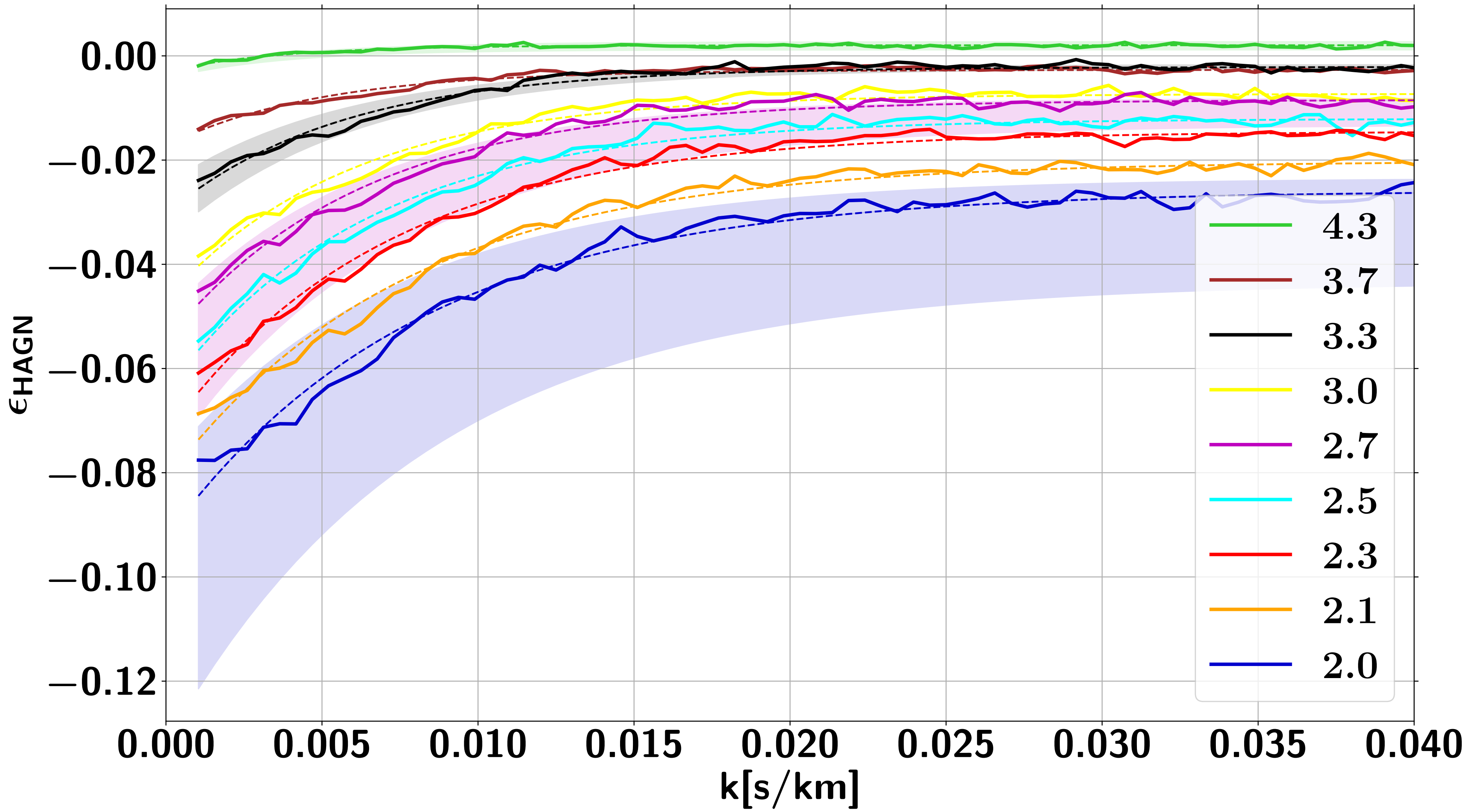
feedback efficiency

lowering r_{AGN} → stronger feedback because **total amount of injected energy is conserved**

Uncertainties in the feedback model

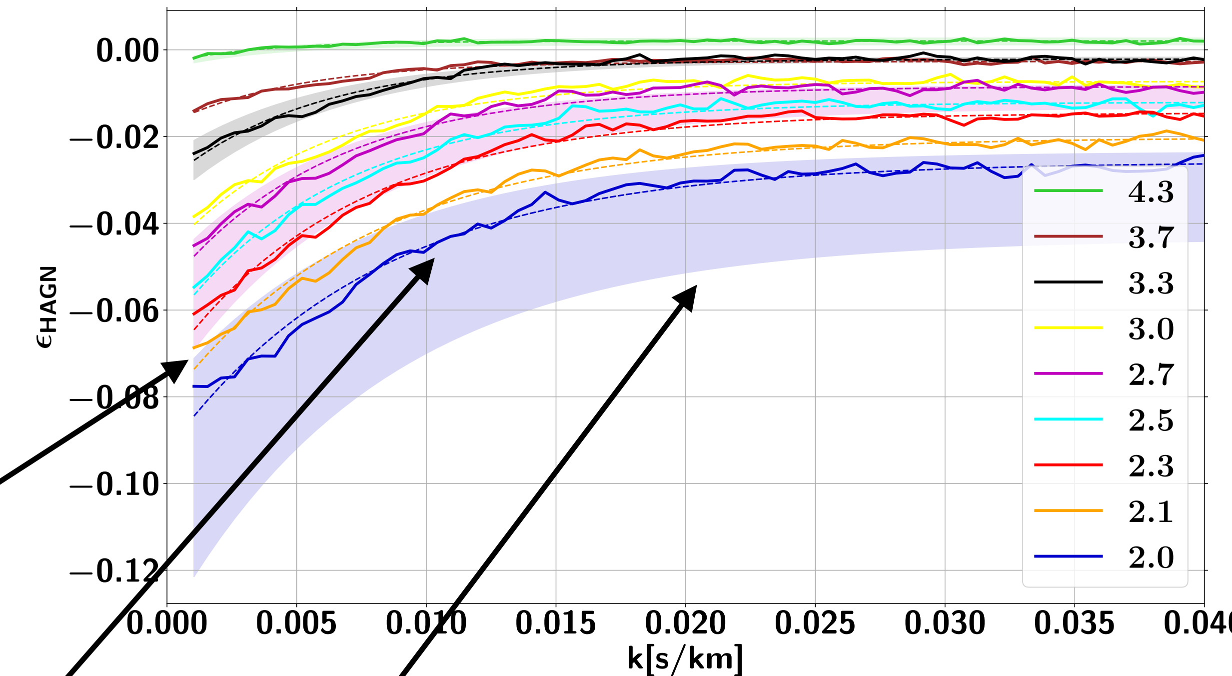
$$\frac{P_{Ly\alpha}(HAGN)}{P_{Ly\alpha}(HnoAGN)} = 1 + \epsilon_{HAGN}$$

Chabanier et al. in prep



3- AGN Feedback Impact

Impact on cosmological parameters

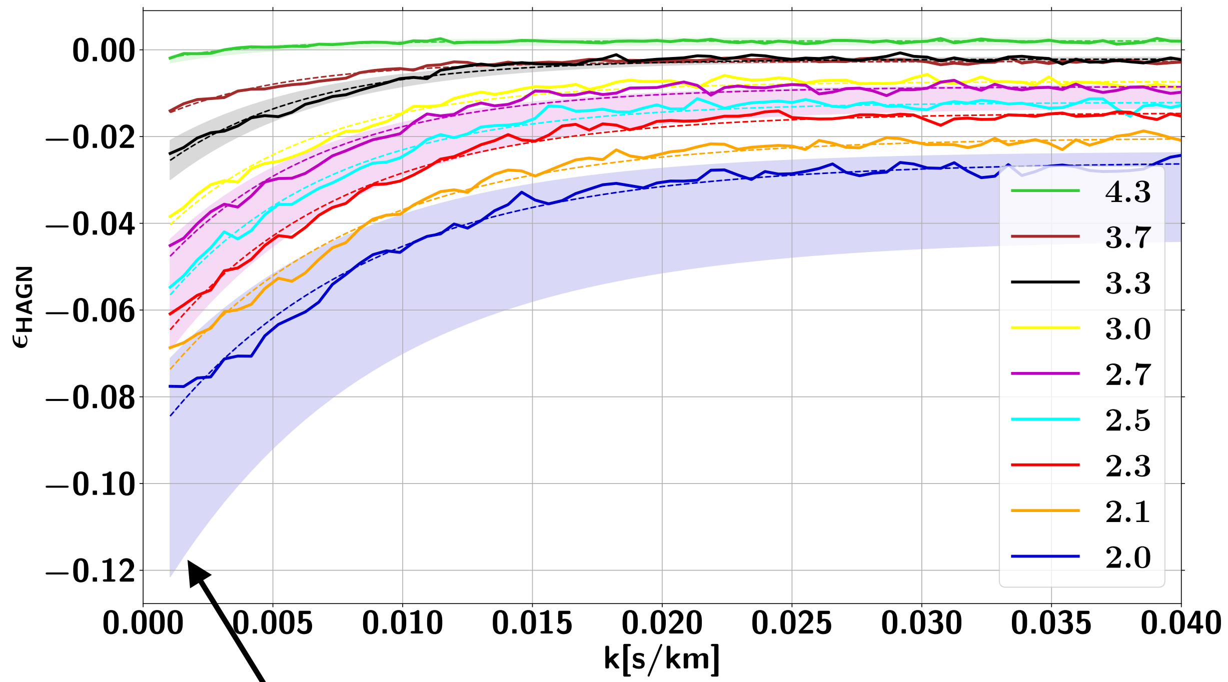


$\epsilon = 0$

	noAGN	weakAGN	fidAGN	strongAGN	
σ_8	0.820 ± 0.020	0.830 ± 0.022	0.831 ± 0.020	0.835 ± 0.019	cosmology
n_s	0.958 ± 0.005	0.950 ± 0.005	0.949 ± 0.005	0.946 ± 0.005	
Ω_m	0.268 ± 0.009	0.269 ± 0.009	0.270 ± 0.009	0.269 ± 0.009	
$T_0(z=3)$ (10^3 K)	8.55 ± 2.0	8.59 ± 1.8	8.64 ± 1.9	8.66 ± 1.2	IGM temperature
γ	0.917 ± 0.132	0.950 ± 0.125	0.934 ± 0.140	0.975 ± 0.150	
A^τ (10^{-3})	2.33 ± 0.06	2.37 ± 0.06	2.38 ± 0.06	2.40 ± 0.06	optical depth
η^τ	3.83 ± 0.03	3.83 ± 0.03	3.84 ± 0.03	3.84 ± 0.03	

3- AGN Feedback Impact

Impact on cosmological parameters



$\epsilon = 0$

	noAGN	weakAGN	fidAGN	strongAGN
σ_8	0.820 ± 0.020	0.830 ± 0.022	0.831 ± 0.020	0.835 ± 0.019
n_s	0.958 ± 0.005	0.950 ± 0.005	0.949 ± 0.005	0.946 ± 0.005
Ω_m	0.268 ± 0.009	0.269 ± 0.009	0.270 ± 0.009	0.269 ± 0.009
$T_0(z=3)$ (10^3 K)	8.55 ± 2.0	8.59 ± 1.8	8.64 ± 1.9	8.66 ± 1.2
γ	0.917 ± 0.132	0.950 ± 0.125	0.934 ± 0.140	0.975 ± 0.150
A^τ (10^{-3})	2.33 ± 0.06	2.37 ± 0.06	2.38 ± 0.06	2.40 ± 0.06
η^τ	3.83 ± 0.03	3.83 ± 0.03	3.84 ± 0.03	3.84 ± 0.03

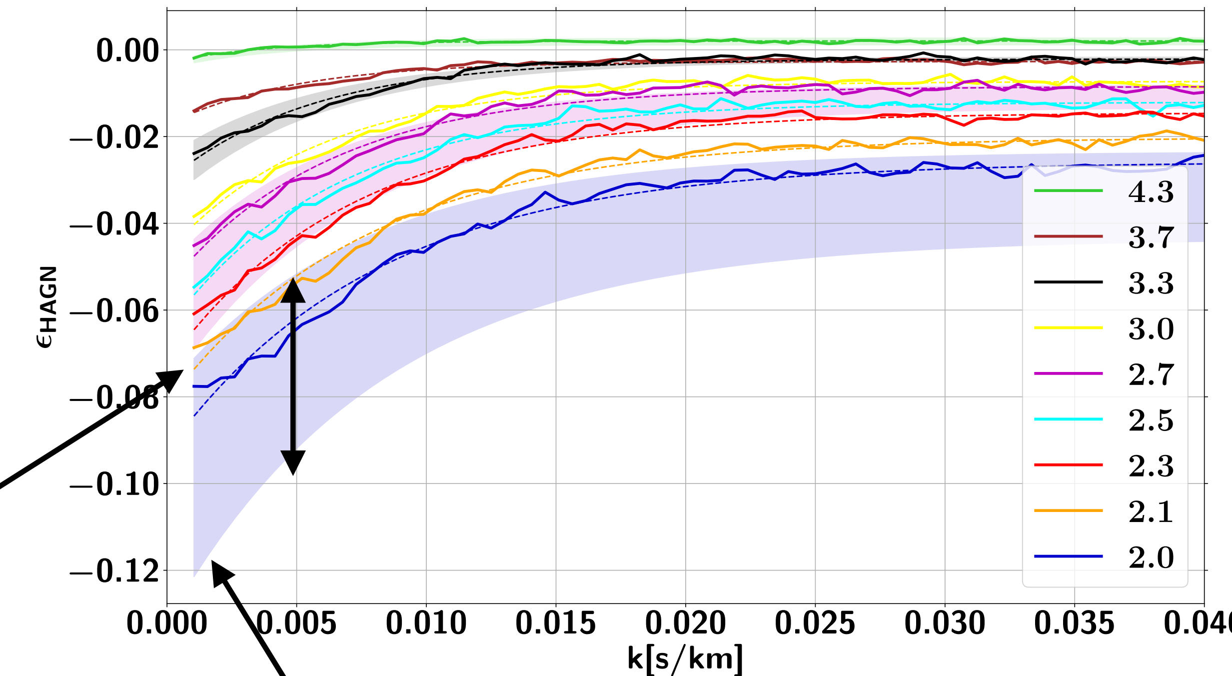
bias up to 2%

bias up to 6%

bias up to 3%

3- AGN Feedback Impact

Impact on cosmological parameters

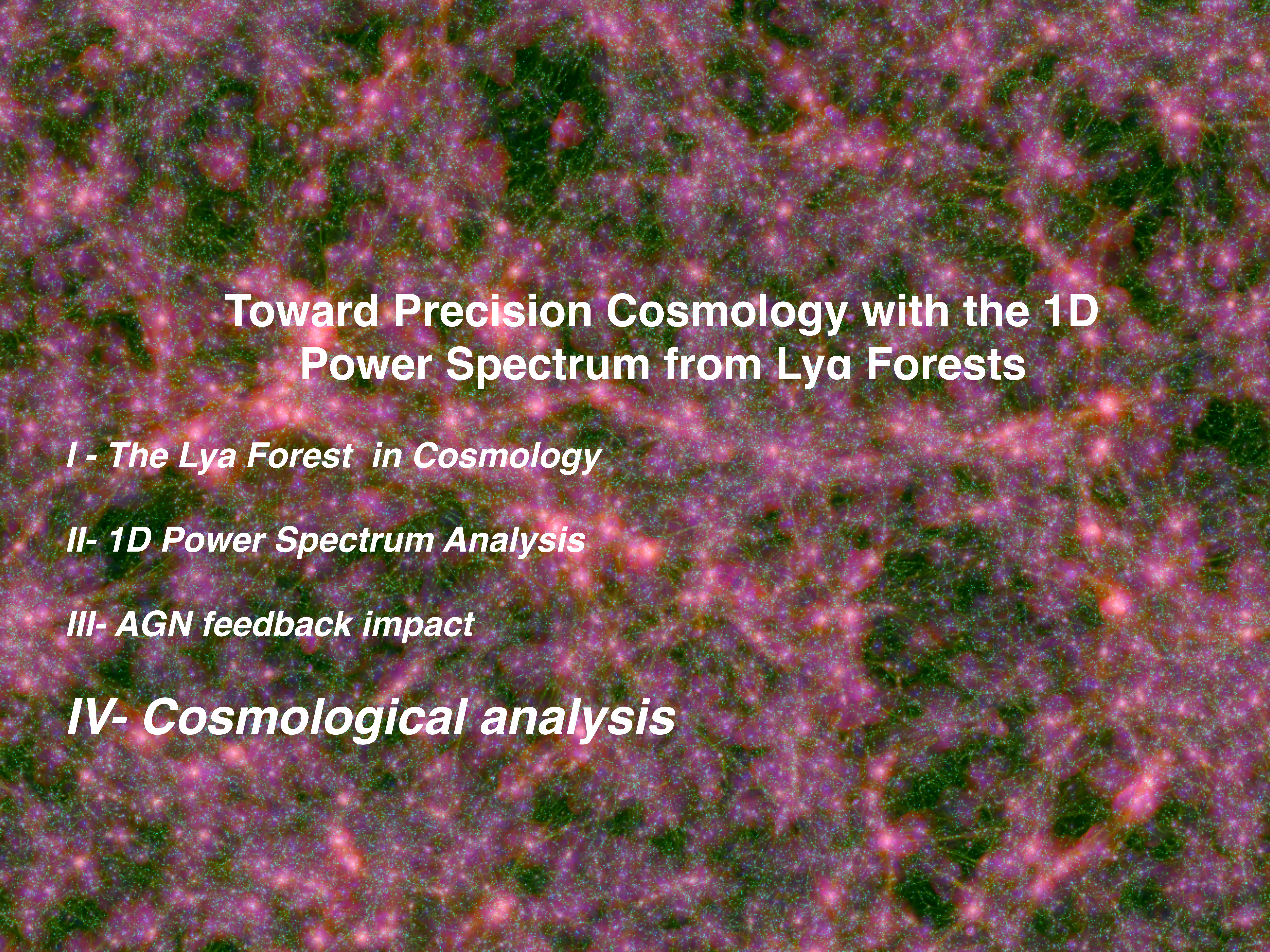


	noAGN	weakAGN	fidAGN	strongAGN
σ_8	0.820 ± 0.020	0.830 ± 0.022	0.831 ± 0.020	0.835 ± 0.019
n_s	0.958 ± 0.005	0.950 ± 0.005	0.949 ± 0.005	0.946 ± 0.005
Ω_m	0.268 ± 0.009	0.269 ± 0.009	0.270 ± 0.009	0.269 ± 0.009
$T_0(z=3)$ (10^3 K)	8.55 ± 2.0	8.59 ± 1.8	8.64 ± 1.9	8.66 ± 1.2
γ	0.917 ± 0.132	0.950 ± 0.125	0.934 ± 0.140	0.975 ± 0.150
A^τ (10^{-3})	2.33 ± 0.06	2.37 ± 0.06	2.38 ± 0.06	2.40 ± 0.06
η^τ	3.83 ± 0.03	3.83 ± 0.03	3.84 ± 0.03	3.84 ± 0.03

bias << 1%

2%

1%



Toward Precision Cosmology with the 1D Power Spectrum from Lyα Forests

I - The Lyα Forest in Cosmology

II- 1D Power Spectrum Analysis

III- AGN feedback impact

IV- Cosmological analysis

4- Cosmological Analysis

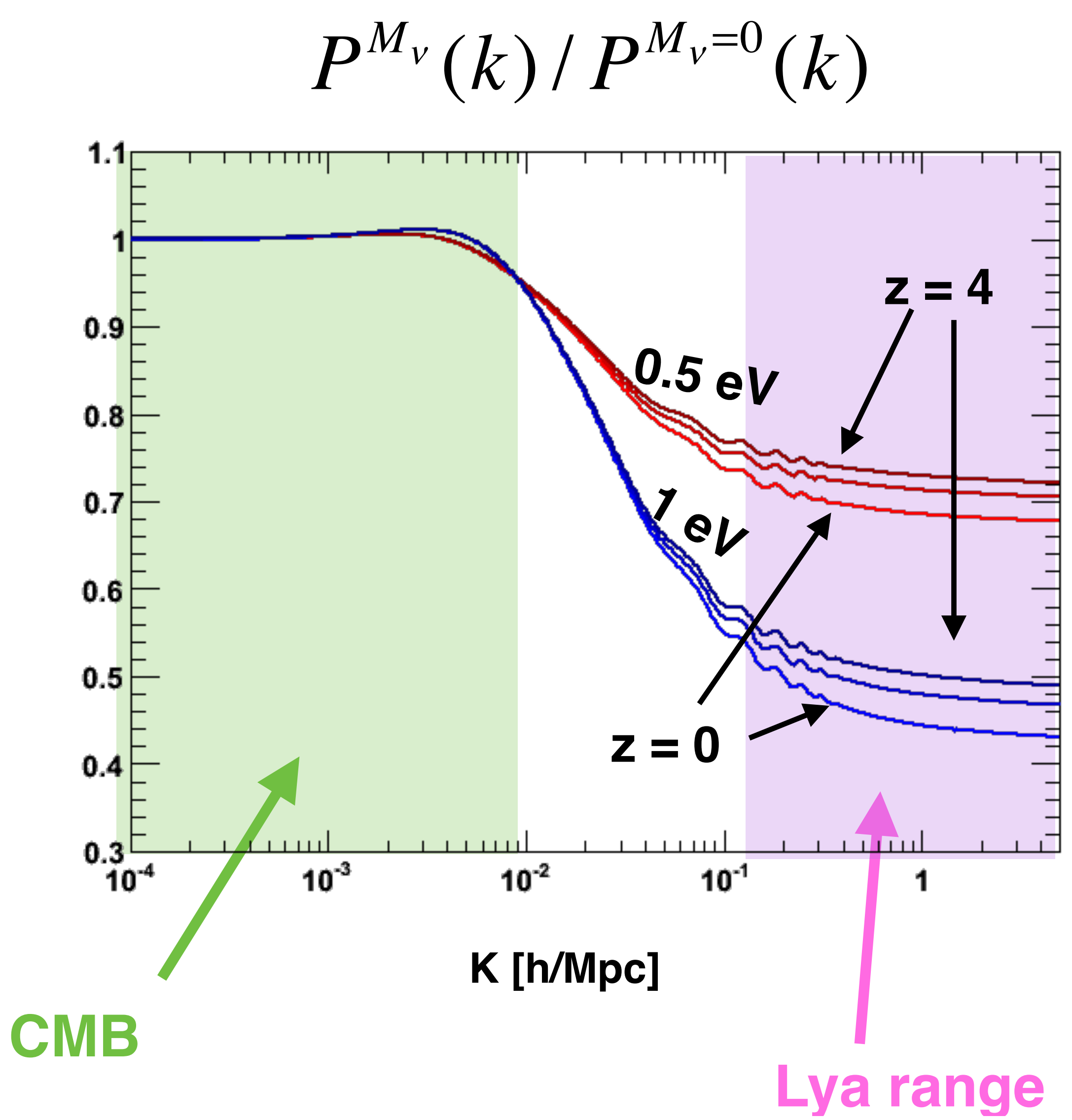
Active neutrinos constraints

- Lya alone: power suppression + z-dependence

but large degeneracy $\sigma_8 - M_\nu$

- Lya + CMB: sensitive to amplitude suppression

→ **break degeneracy**

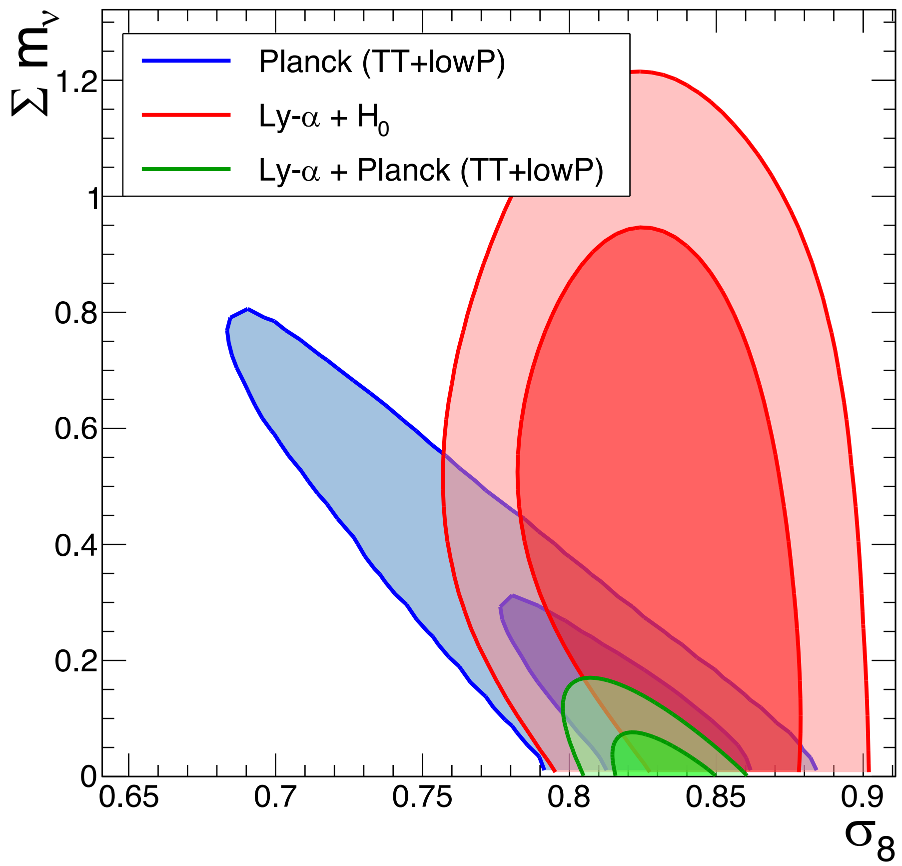


4- Cosmological Analysis

Active neutrinos constraints

DR9 BOSS results

Parameter	[1] Lyα + H_0^{Gaussian} ($H_0 = 67.3 \pm 1.0$)	[2] Lyα + Planck TT+lowP
σ_8	0.831 ± 0.031	0.833 ± 0.011
n_s	0.938 ± 0.010	0.960 ± 0.005
Ω_m	0.293 ± 0.014	0.302 ± 0.014
H_0 (km s^{-1} Mpc^{-1})	67.3 ± 1.0	68.1 ± 0.9
$\sum m_\nu$ (eV)	< 1.1 (95% CL)	< 0.12 (95% CL)



Palanque-Delabrouille et al. 2015b

Expected DR14 eBOSS + CMB constraints (preliminary results)

$$\sum m_\nu < 0.105$$ **(ev) @95% CL**

4- Cosmological Analysis

Thermal relics constraints

DR9 BOSS results

Data set	Lower bound on $\frac{m_X}{\text{keV}}$
Ly-α + H_0 ($z \leq 4.5$)	4.09

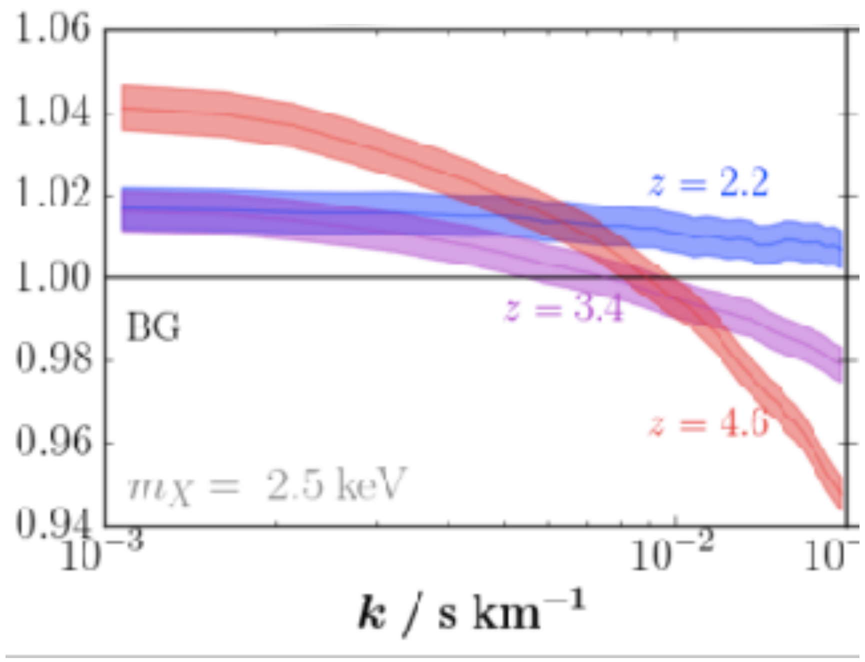
Factor > 2: - reduced uncertainties

- addition of the z = 4.6 redshift bin

Expected DR14 eBOSS constraints (preliminary results)

$m_X > 10$ **(kev) @95% CL**

$P_{WDM}(k) / P_{DM}(k)$



m_X most constrained by highz

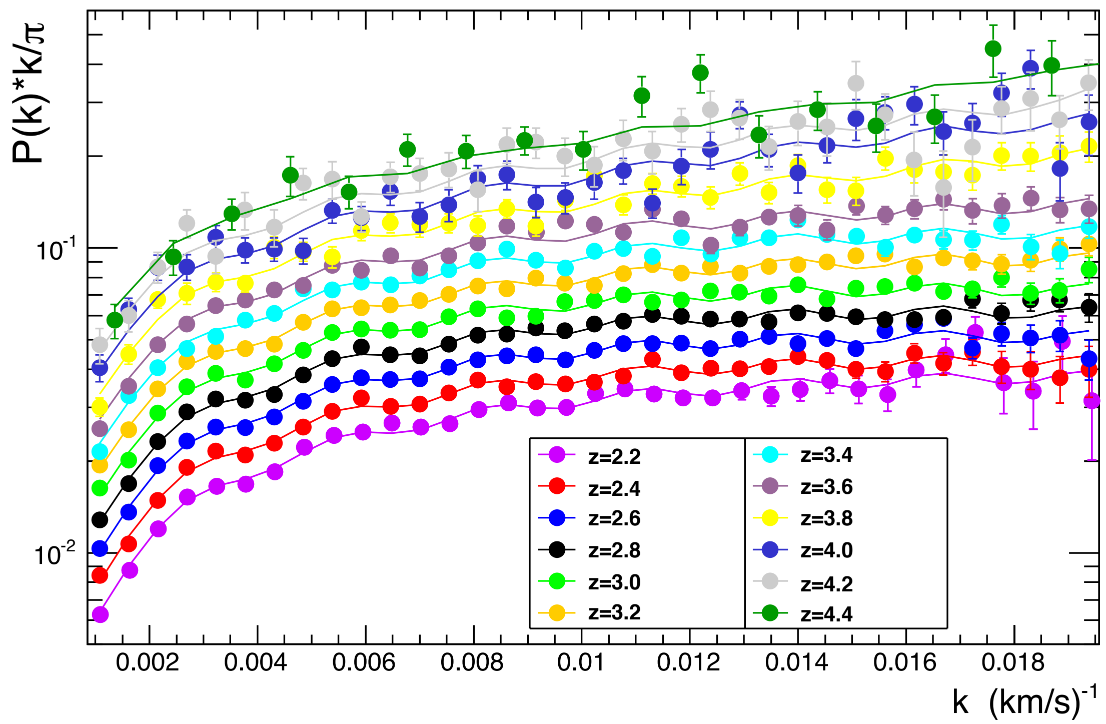
Conclusion

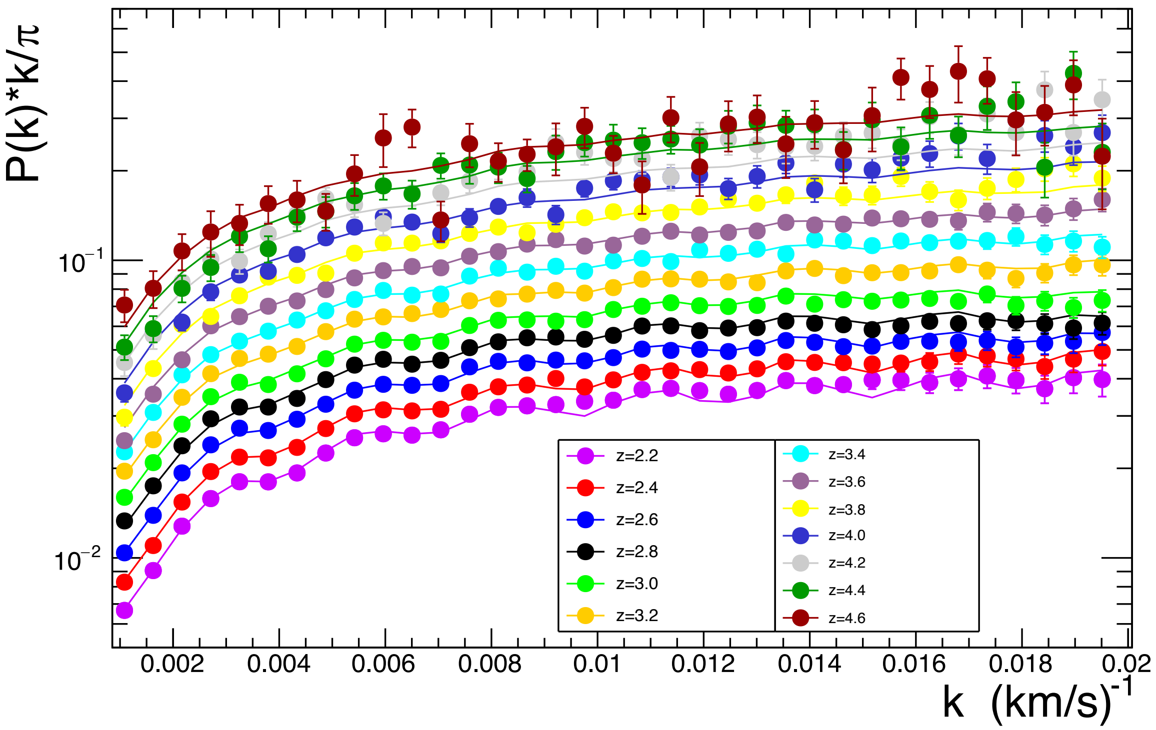
- High potential of Lya forest
  - 3D correlations: expansion
  - **1D correlations: sensitive to smoothing i.e.** $\sum m_\nu$ m_{WDM}

- Significant decrease of data-related uncertainties
  - **gain of 2 on statistical power**
  - **improved census of systematics**

→ improvement of theoretical predictions from simulation is needed !

DR9 BOSS → **DR14 eBOSS**





Conclusion

- High potential of Lya forest
  - 3D correlations: expansion
  - **1D correlations: sensitive to smoothing i.e.** $\sum m_\nu$ m_{WDM}

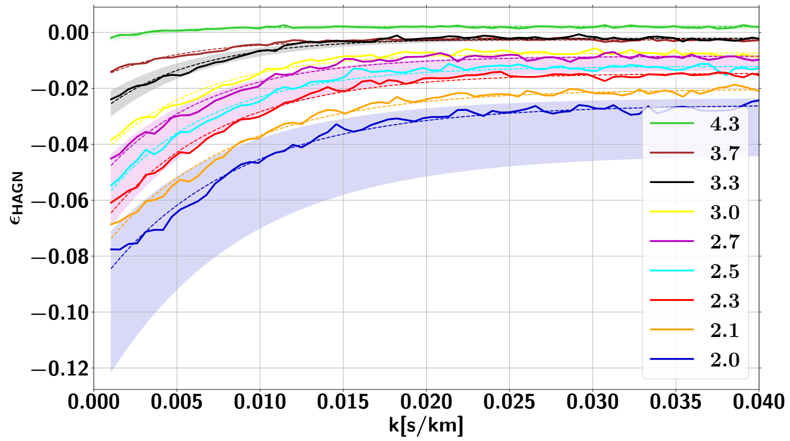
- Significant decrease of data-related uncertainties
  - **gain of 2 on statistical power**
  - **improved census of systematics**

→ improvement of theoretical predictions from simulation is needed !

- AGN feedback correction with uncertainty interval spanning a wide range of plausible models

→ *suppresses power due to: efficient heating (large scales)*
heating + mass redistribution (small scales)

→ *Induces 2% bias on* n_s



Conclusion

- High potential of Lya forest
  - 3D correlations: expansion
  - **1D correlations: sensitive to smoothing i.e.** $\sum m_\nu$ m_{WDM}

- Significant decrease of data-related uncertainties
  - **gain of 2 on statistical power**
  - **improved census of systematics**

→ improvement of theoretical predictions from simulation is needed !

- AGN feedback correction with uncertainty interval spanning a wide range of credible models

→ *suppresses power due to: efficient heating (large scales)*
heating + mass redistribution (small scales)

→ *Induces 2% bias on* n_s

- Preliminary works give:
  - $\sum m_\nu < 0.105$ ev @95% CL → slight preference for NH
  - $m_X > 10$ kev @95% CL → factor 2 because of additional zbin and reduced uncertainties


Thank you for your attention