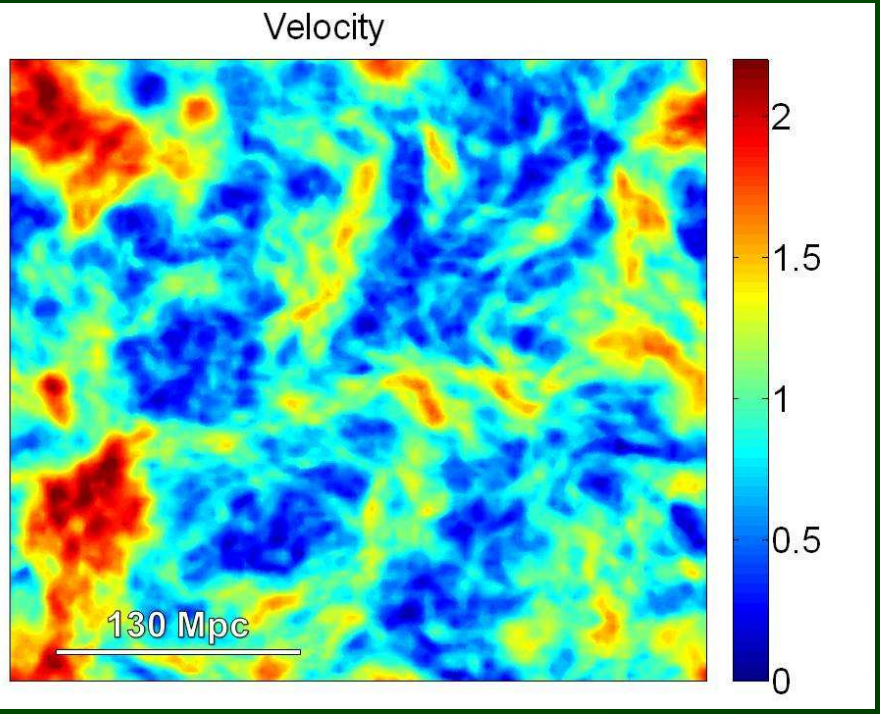
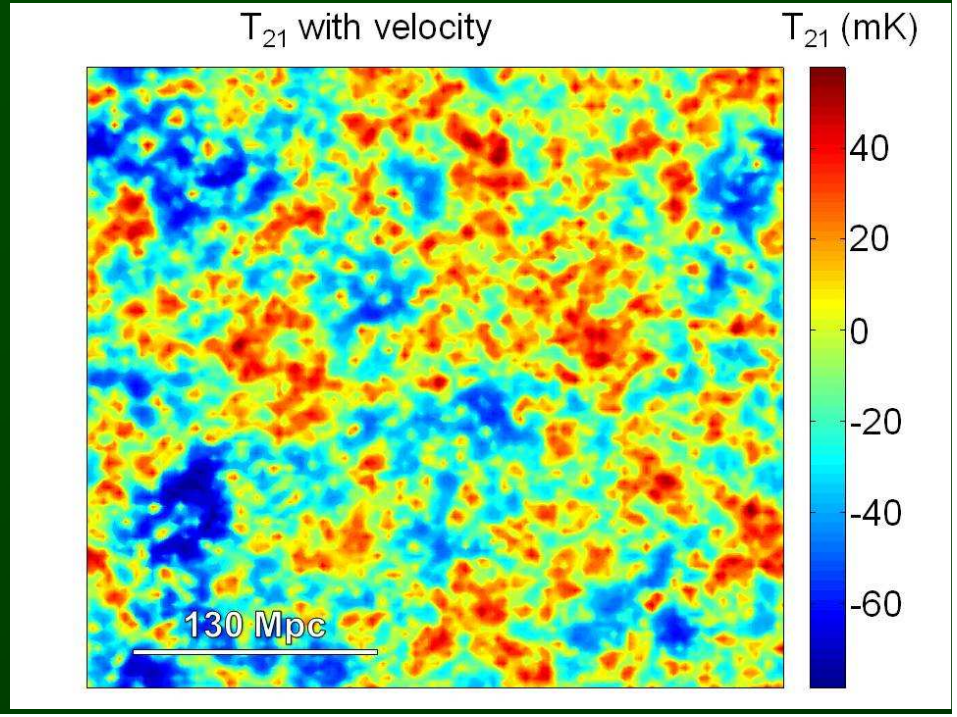
Detecting the First Stars at Redshift 20

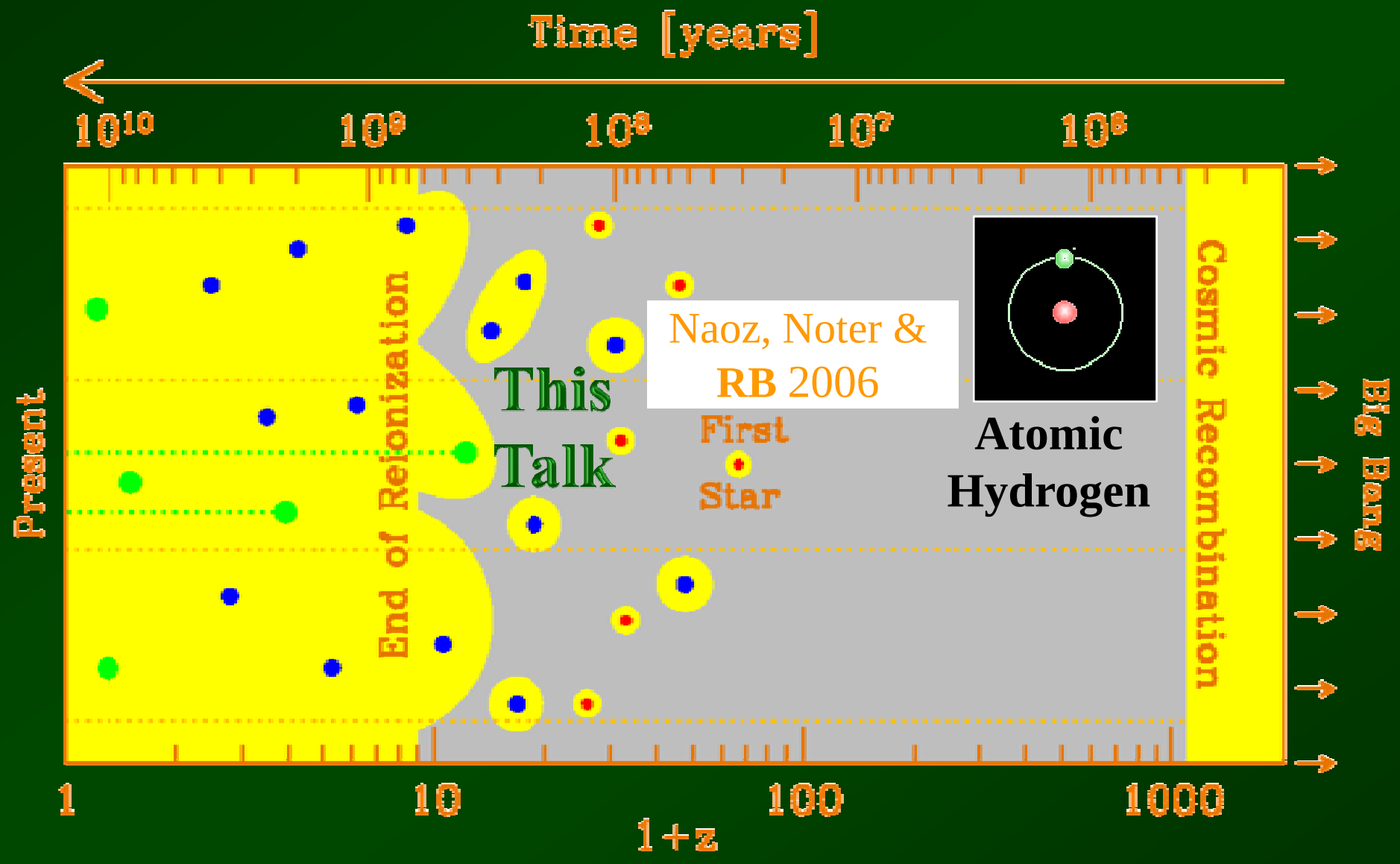
Rennan Barkana רנן ברקנא

TEL AVIV UNIVERSITY אוניברסיטת תל-אביב



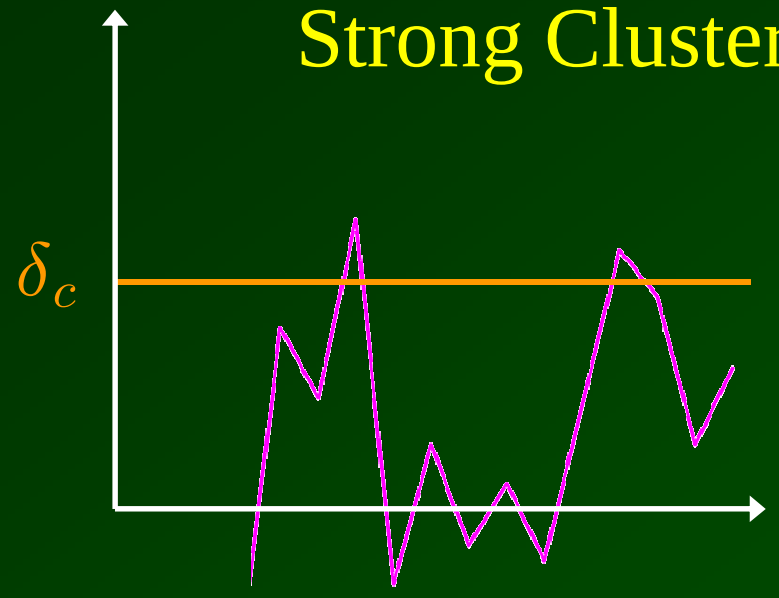


Cosmic History



RB 2006, Science

Strong Clustering of Early Galaxies



Extended Press-Schechter
Peak-Background Split

Press & Schechter 1974

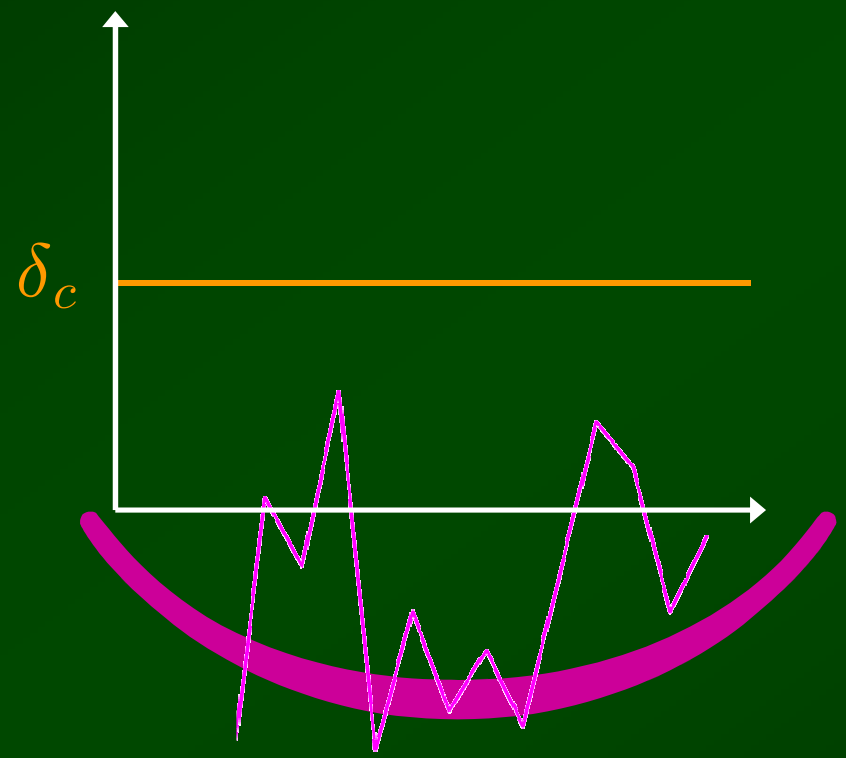
Bardeen, Bond,
Kaiser, & Szalay 1986

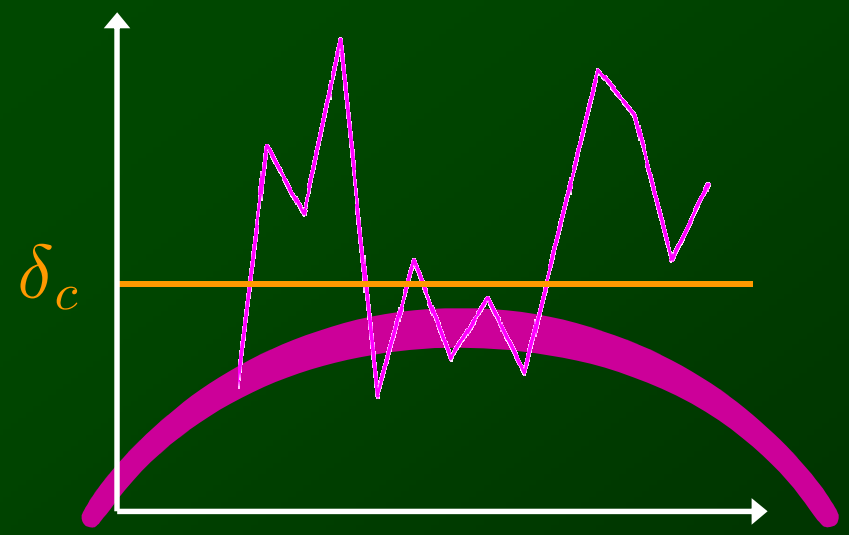
Kaiser 1984

Bond, Cole, Efstathiou, & Kaiser 1991

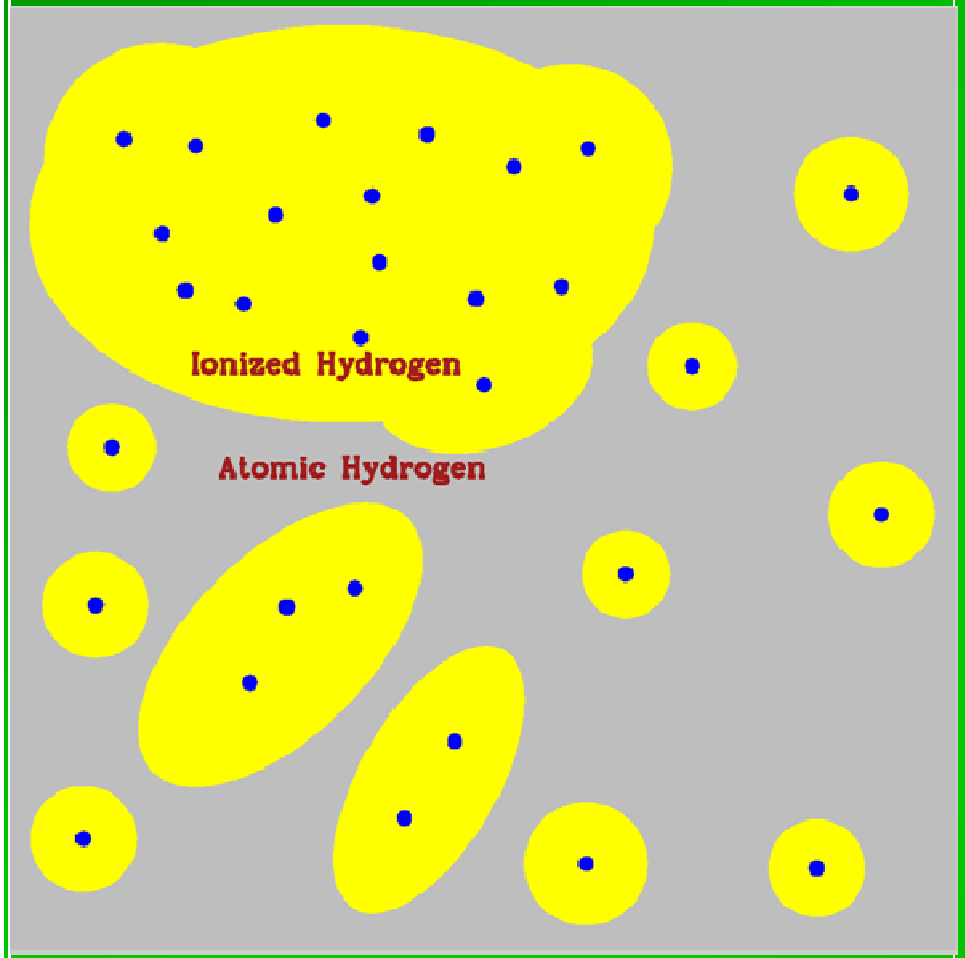
Cole & Kaiser 1989

Mo & White 1996

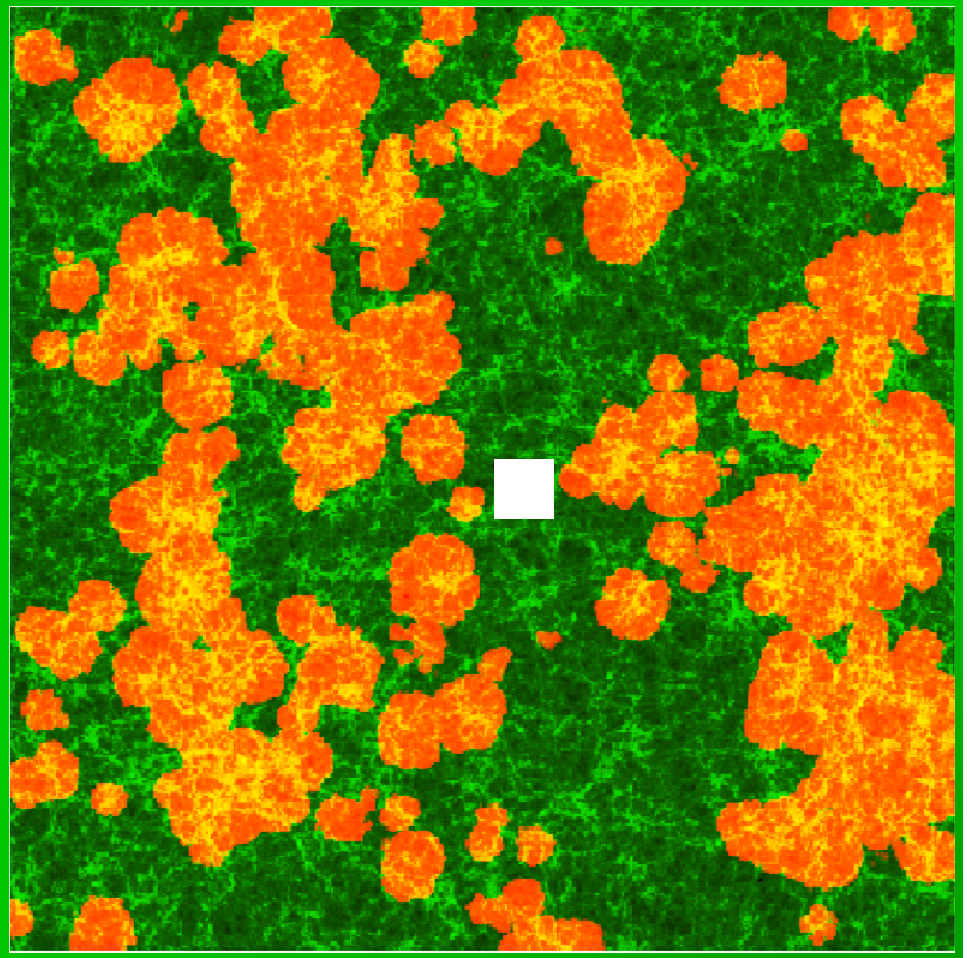




Cosmic Reionization



RB & Loeb 2004

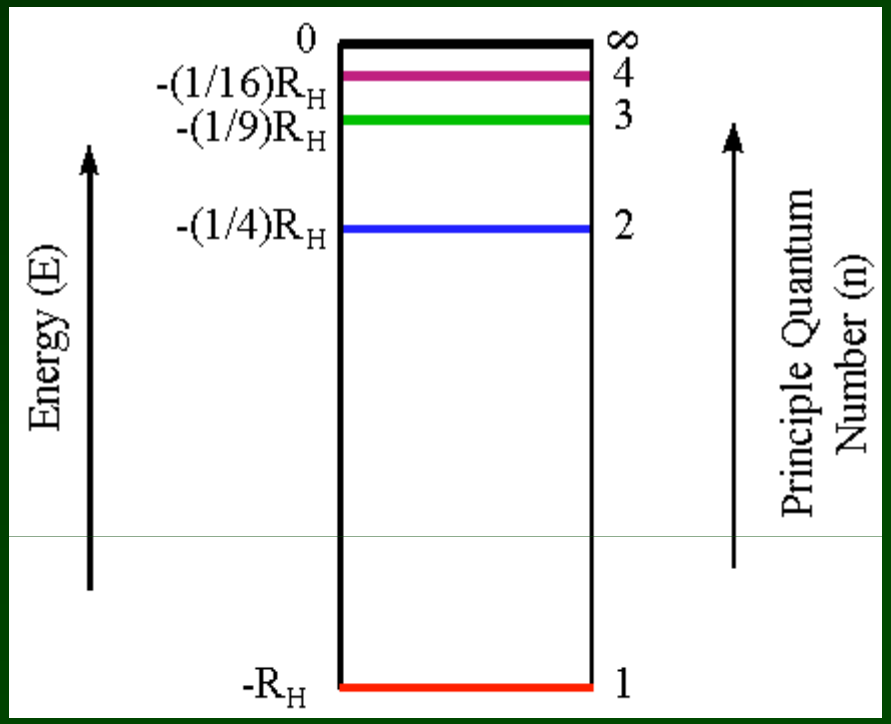


← 100/h Mpc = 0.5° →

Mellema et al. 2006

Furlanetto, Zaldariagga, Hernquist 2004

The Lyman-α flux



$$\mathrm{LLimit}: \quad 13.6 \ \ \mathrm{eV}$$

$$\mathrm{Ly}\alpha: \quad \tfrac{3}{4}\mathrm{LL} = 10.2 \ \ \mathrm{eV}$$

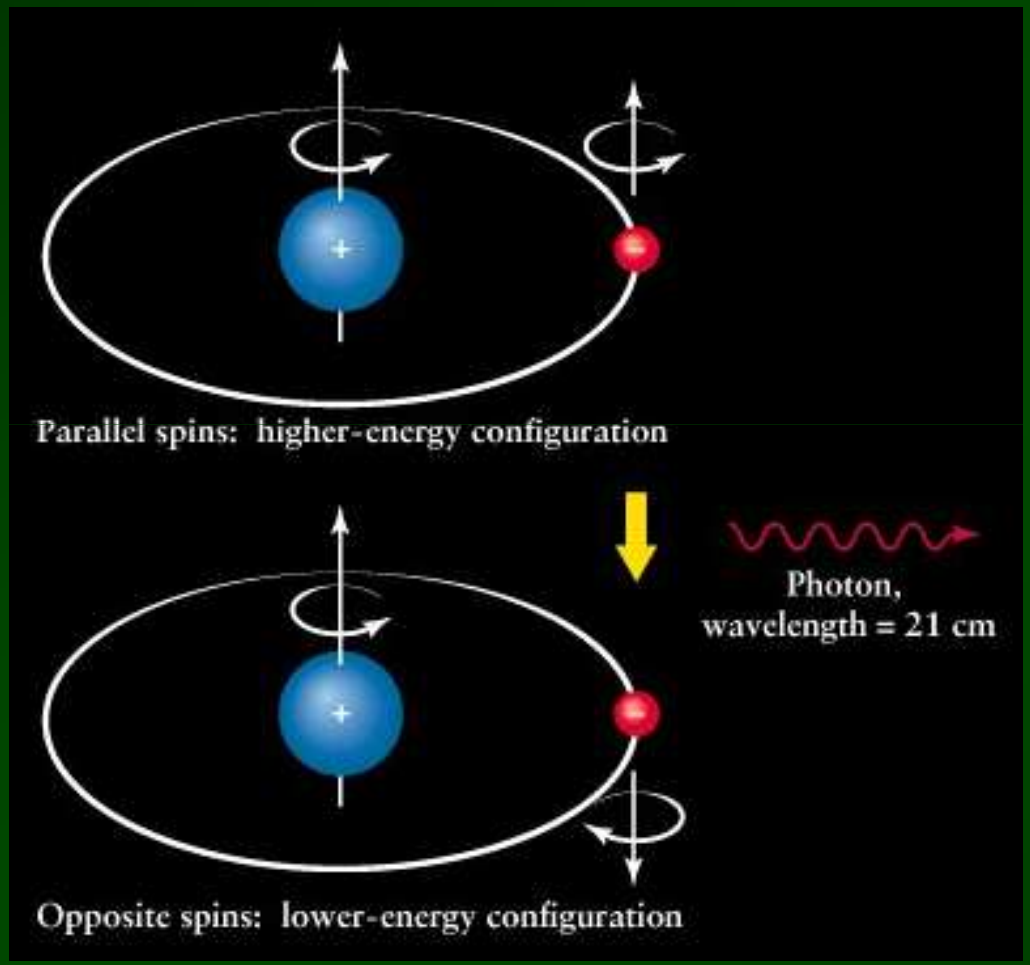
Madau, Meiksin & Rees 1997:
Lyman-α and X-ray heating

Ly-α Fluctuations

RB & Loeb 2005

X-ray heating: Pritchard & Furlanetto 2007

21-cm Cosmology: The Spin Temperature



$$\lambda = 21\,\mathrm{cm}$$

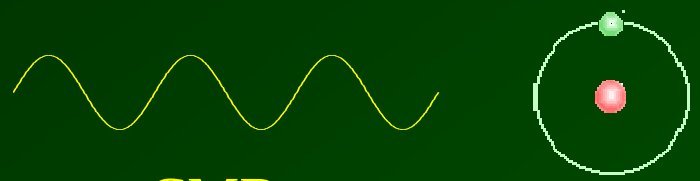
$$\nu = 1420\,\mathrm{MHz}$$

$$E = 5.9 \times 10^{-6}\,\mathrm{eV}$$

$$\frac{E}{k_B} = T_* = 0.068\,\mathrm{K}$$

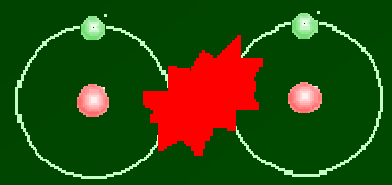
$$\frac{n_1}{n_0} = 3\exp\left\{-\frac{T_*}{T_S}\right\}$$

What determines T_S?

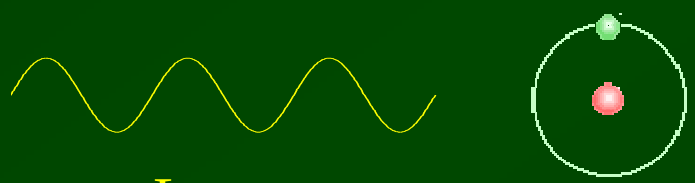


CMB

$$T_S \rightarrow T_{\mathrm{CMB}}$$



$$T_S \rightarrow T_{\mathrm{gas}}$$

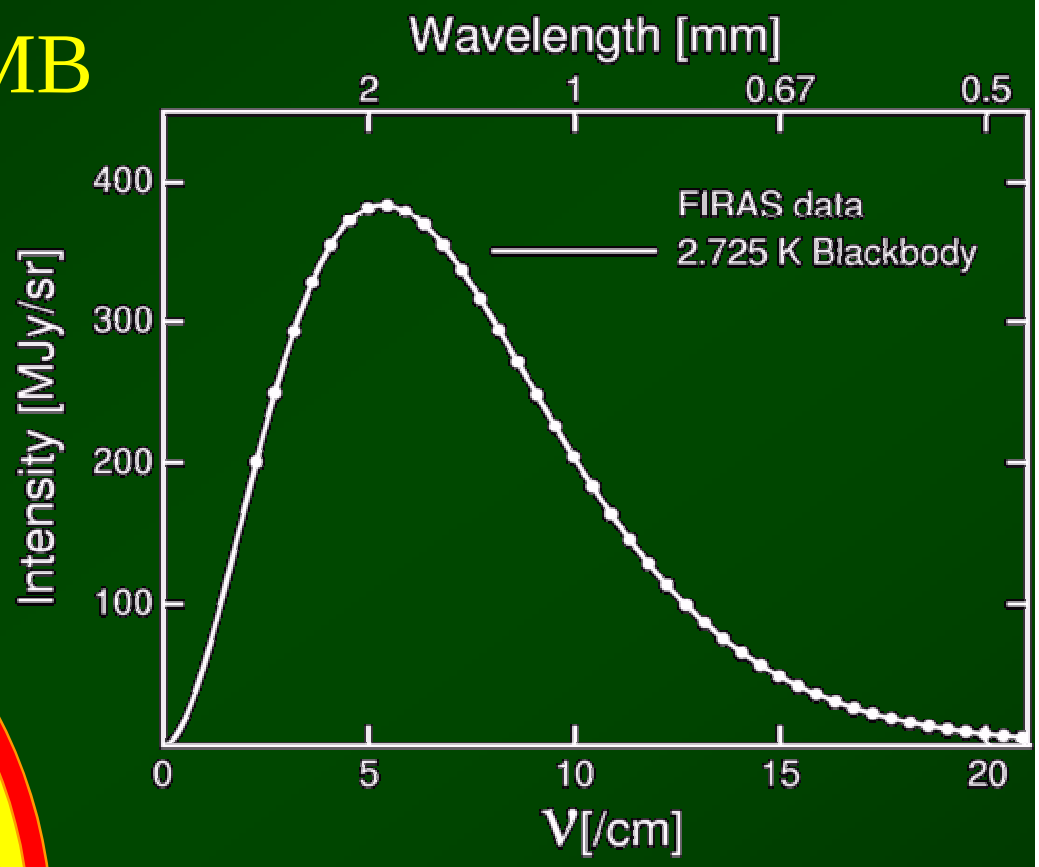


Lyα

$$T_S \rightarrow T_{\mathrm{gas}}$$

Wouthuysen 1952
Field 1958

Diffuse Source: The CMB



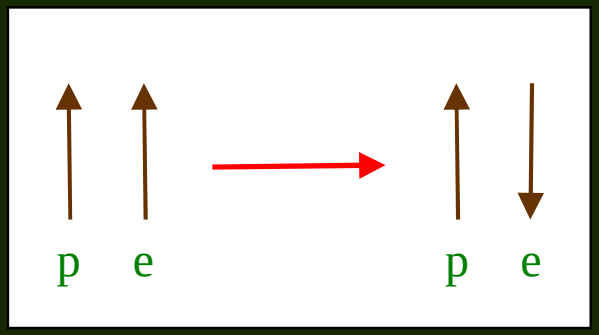
The CMB

Edge of the observable universe

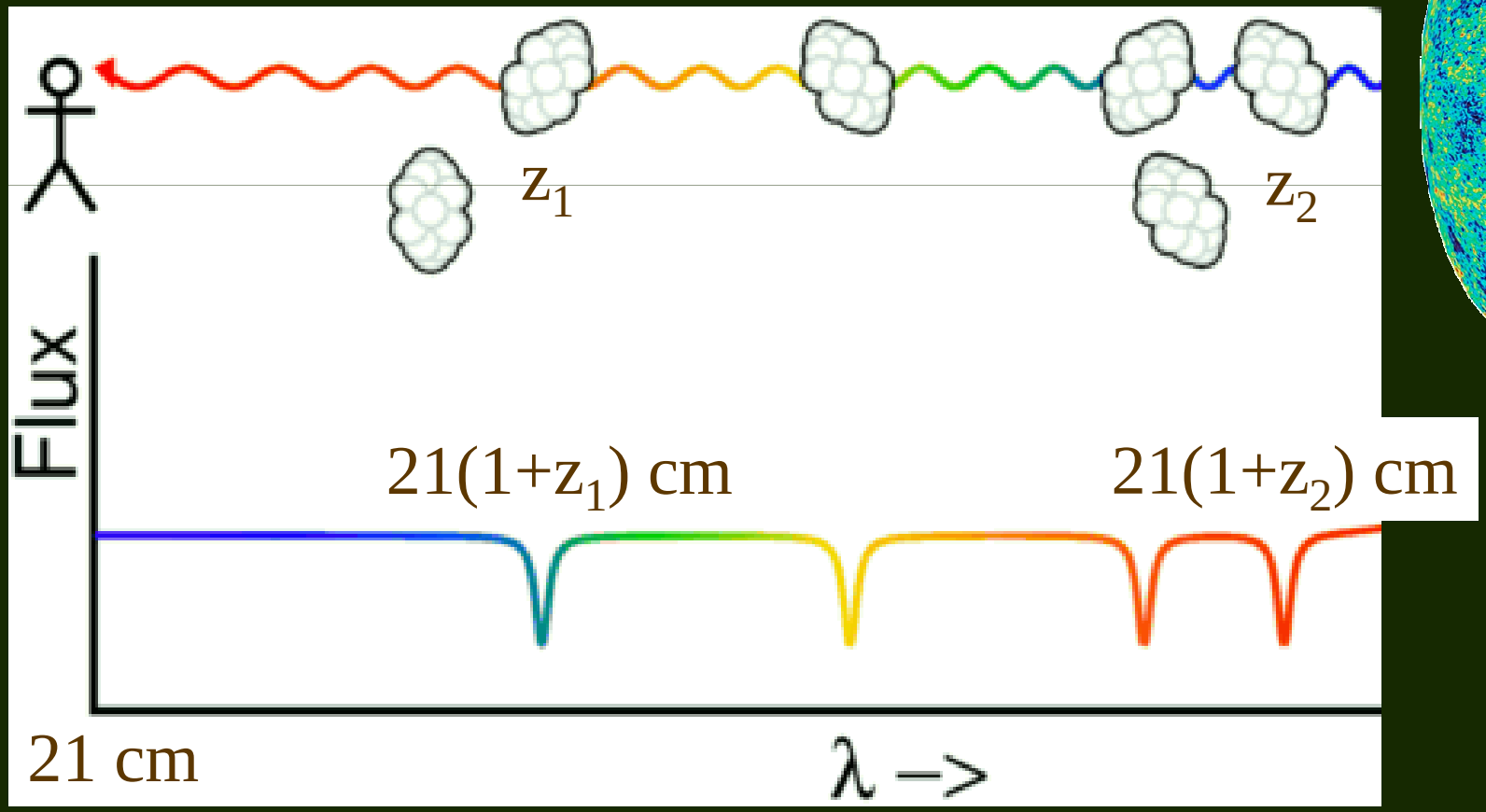
$$h\nu \ll k_B T$$

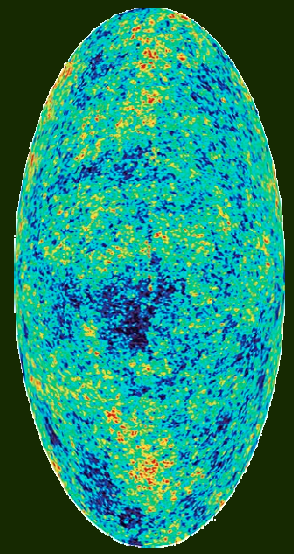
$$I_\nu = 2k_B T \nu^2 / c^2$$

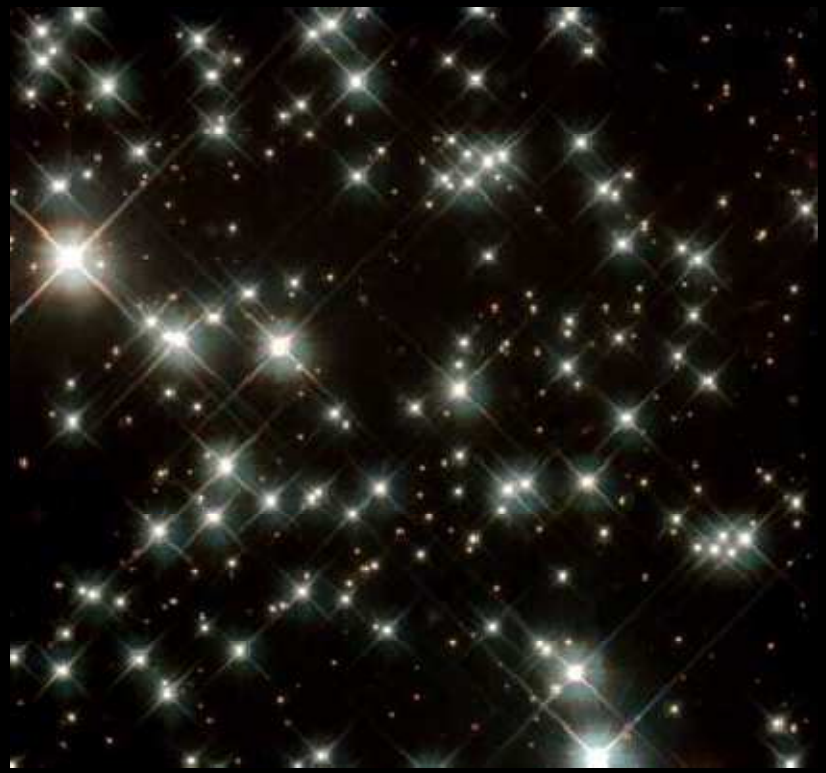
21-cm Spectra



Resonance Line +
Cosmological Redshift



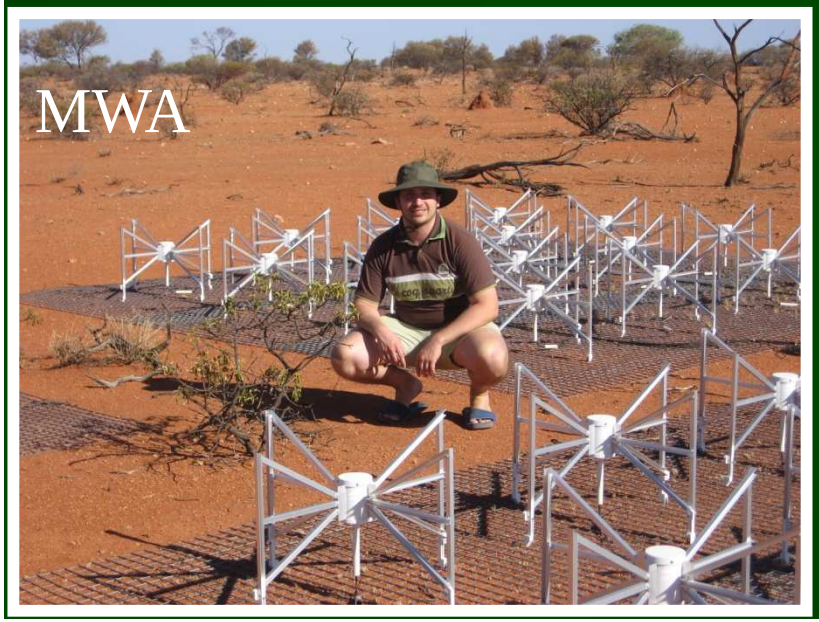


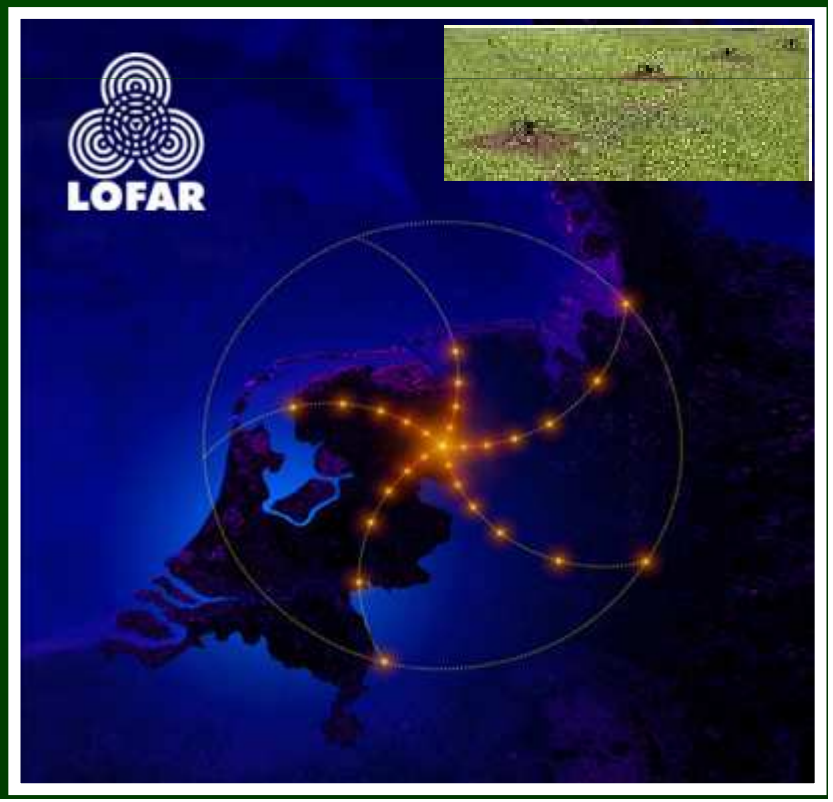


21-cm → 3D map of HI at 7 < z < 200

Can we see the first stars at z ~ 20?

Experiments (Fluctuations)



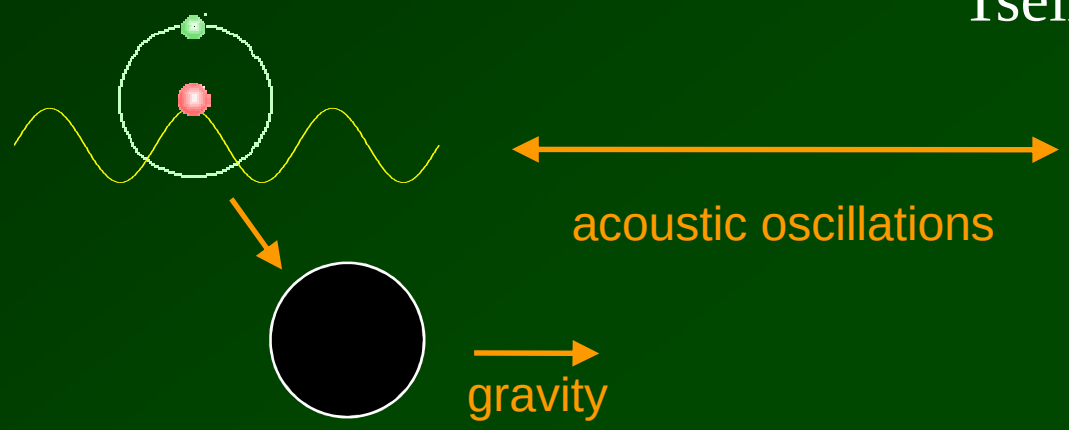


The SKA (Square Kilometer Array)

The first stars can be probed.
Do not need a km² !

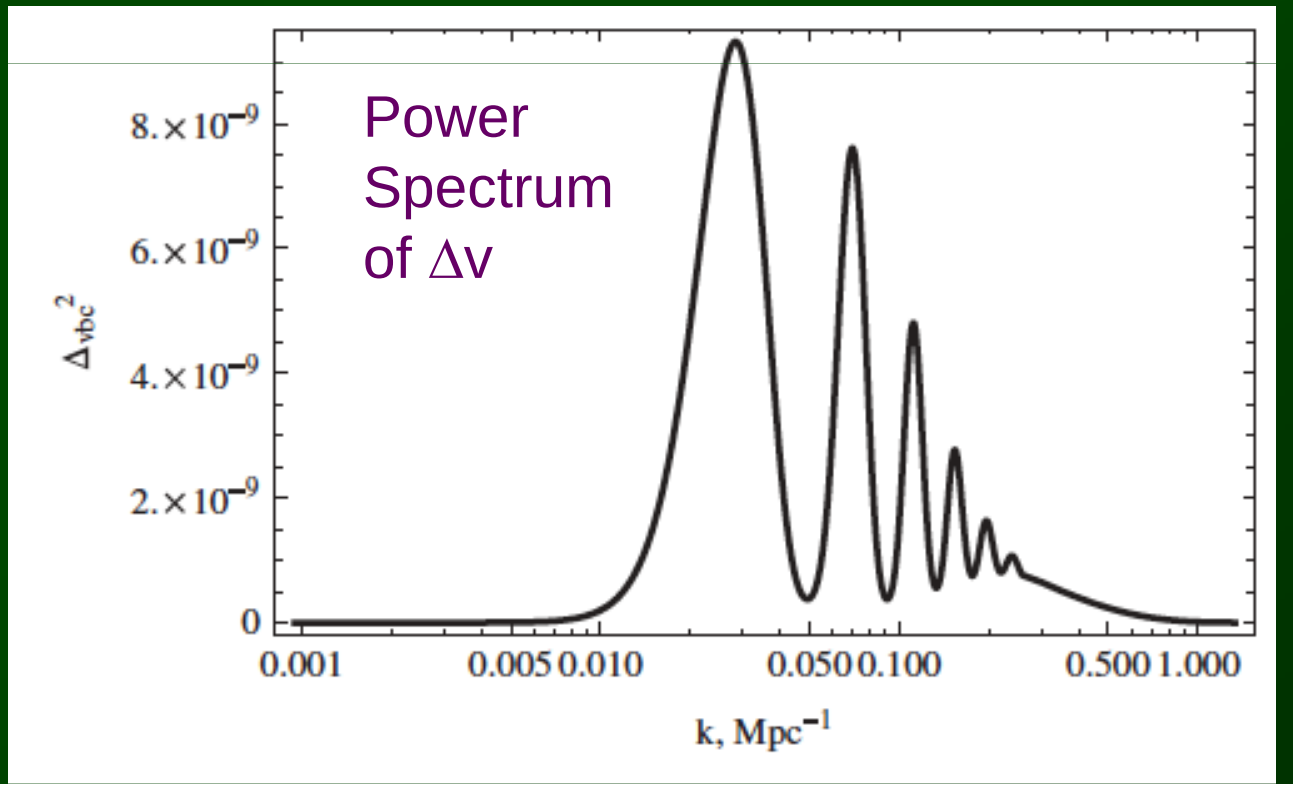
Baryon – Dark Matter Relative (Streaming) Velocity

Tseliakhovich & Hirata 2010



$|V_b - V_{cdm}|^{r.m.s.} \sim$
30 km/s at z_{rec}
$\sim 5\ c_s$

1. Split the scales
2. BAOs



Suppression of Early Galaxies

Previously missed…But is it important?

Halo abundance

Tseliakhovich & Hirata 2010

Halo baryon fraction

Dalal, Pen, & Seljak 2010

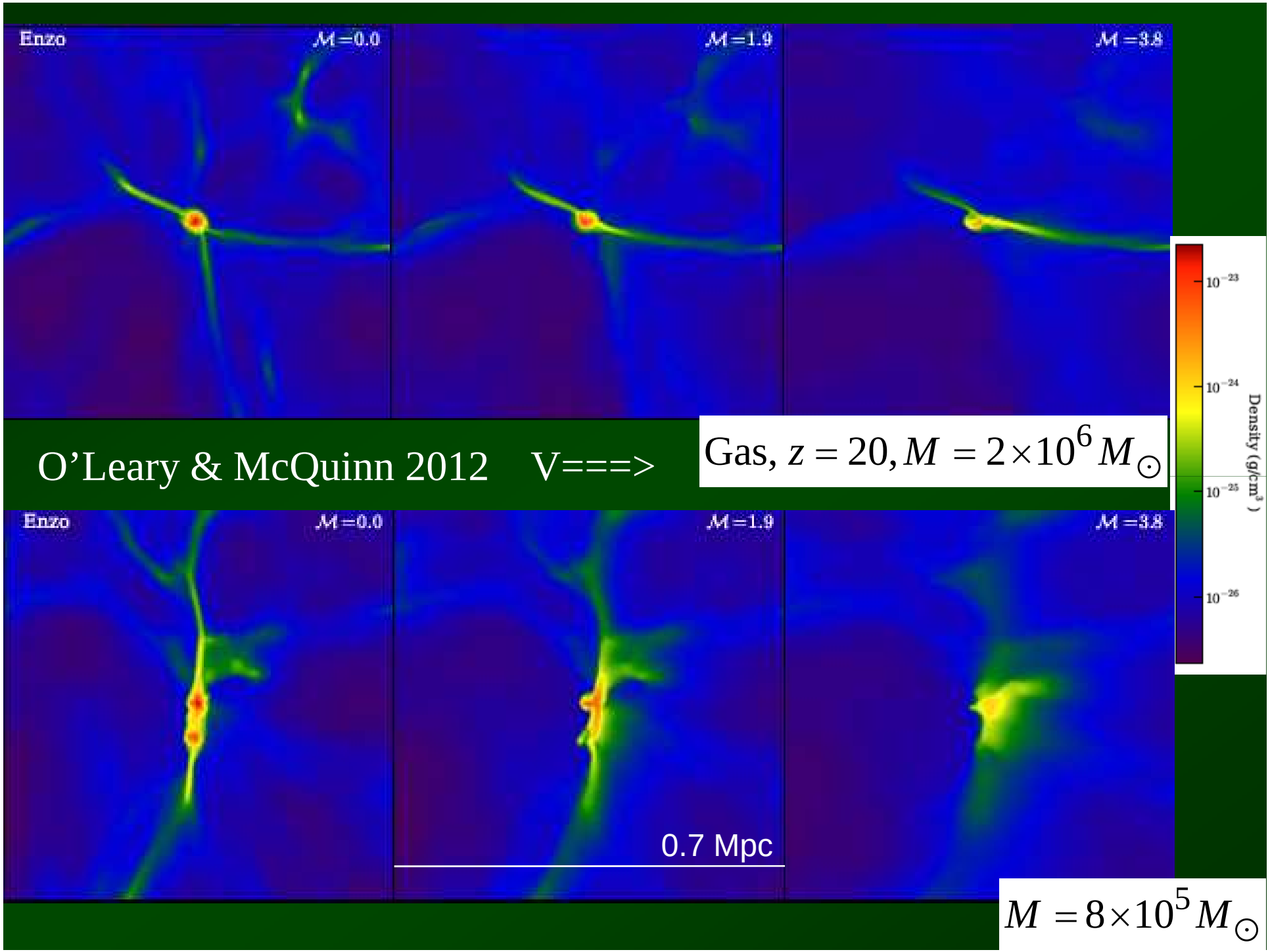
Minihalos: Tseliakhovich, **RB** & Hirata 2011

Simulations

Maio, Koopmans & Ciardi 2011; Stacy, Bromm & Loeb 2011; Greif, White, Klessen, Springel 2011; Naoz , Yoshida, Gnedin 2011; O'Leary & McQuinn 2012

Minimum cooling mass increases

Fialkov, **RB**, Tseliakhovich, & Hirata 2012


Enzo
$\mathcal{M}=0.0$
$\mathcal{M}=1.9$
$\mathcal{M}=3.8$
O'Leary & McQuinn 2012 V===>
Gas, $z=20, M=2\times10^6 M_\odot$
Enzo
$\mathcal{M}=0.0$
$\mathcal{M}=1.9$
$\mathcal{M}=3.8$
0.7 Mpc
$M=8\times10^5 M_\odot$
10^{-23}
10^{-24}
10^{-25}
10^{-26}
Density (g/cm^3)

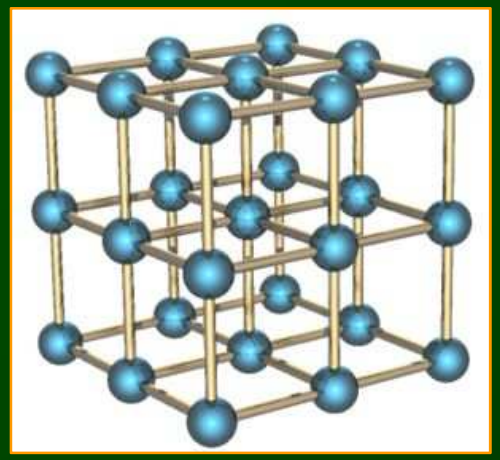
Visbal, **RB**, Fialkov, Tseliakhovich, & Hirata

Nature 2012

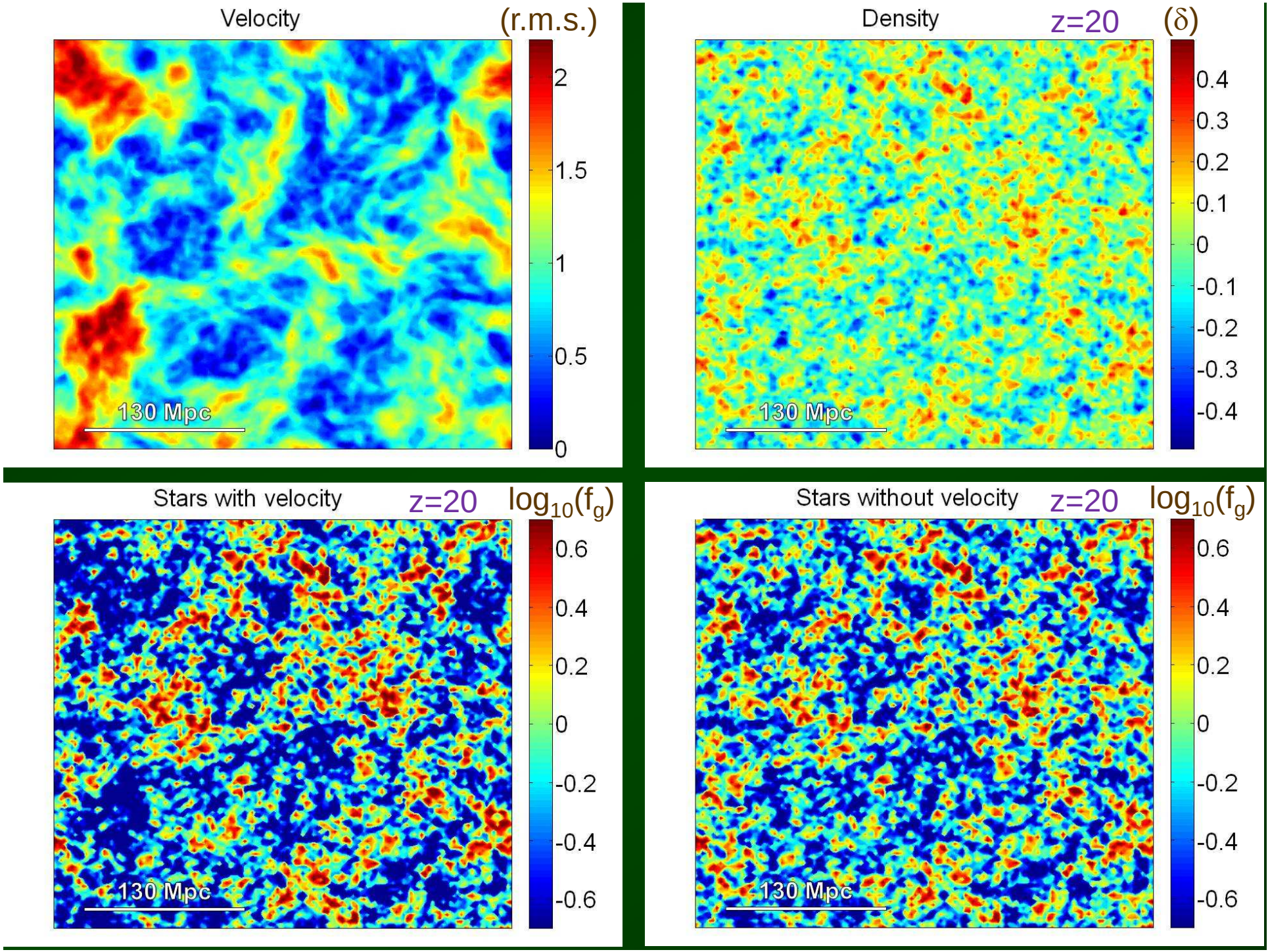
1) 400 Mpc box

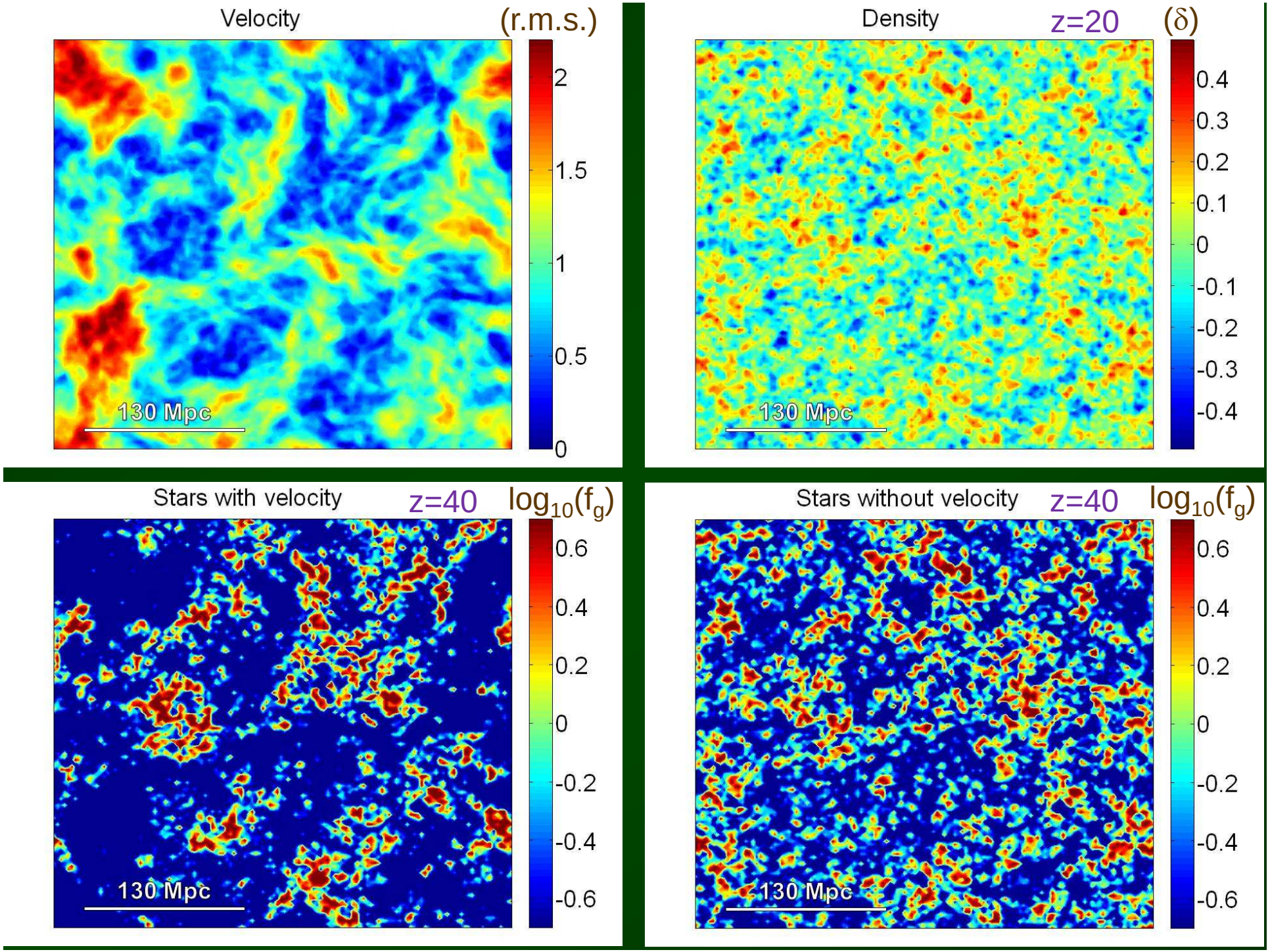
2) Hybrid simulation method

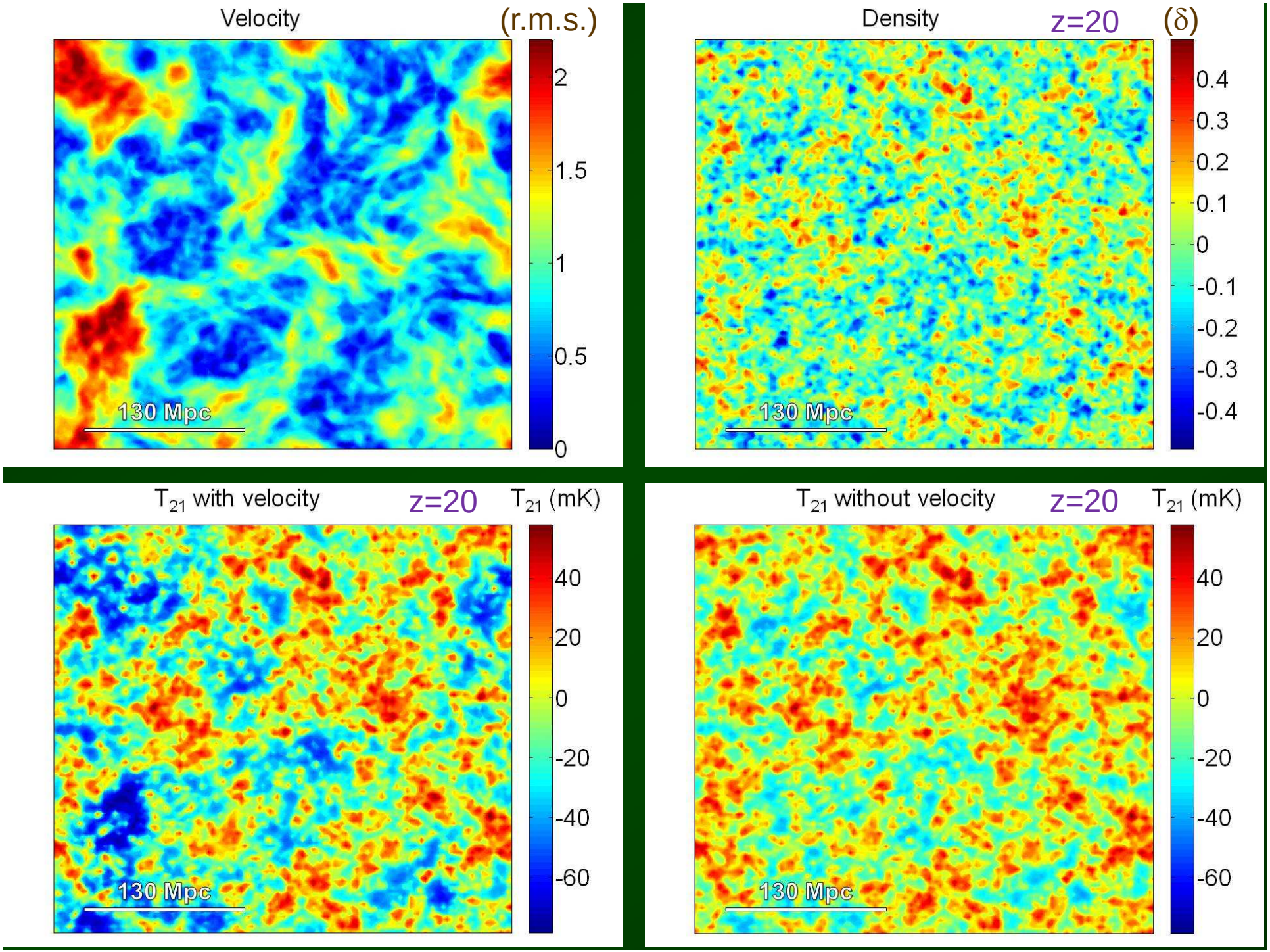
3) X-ray heating

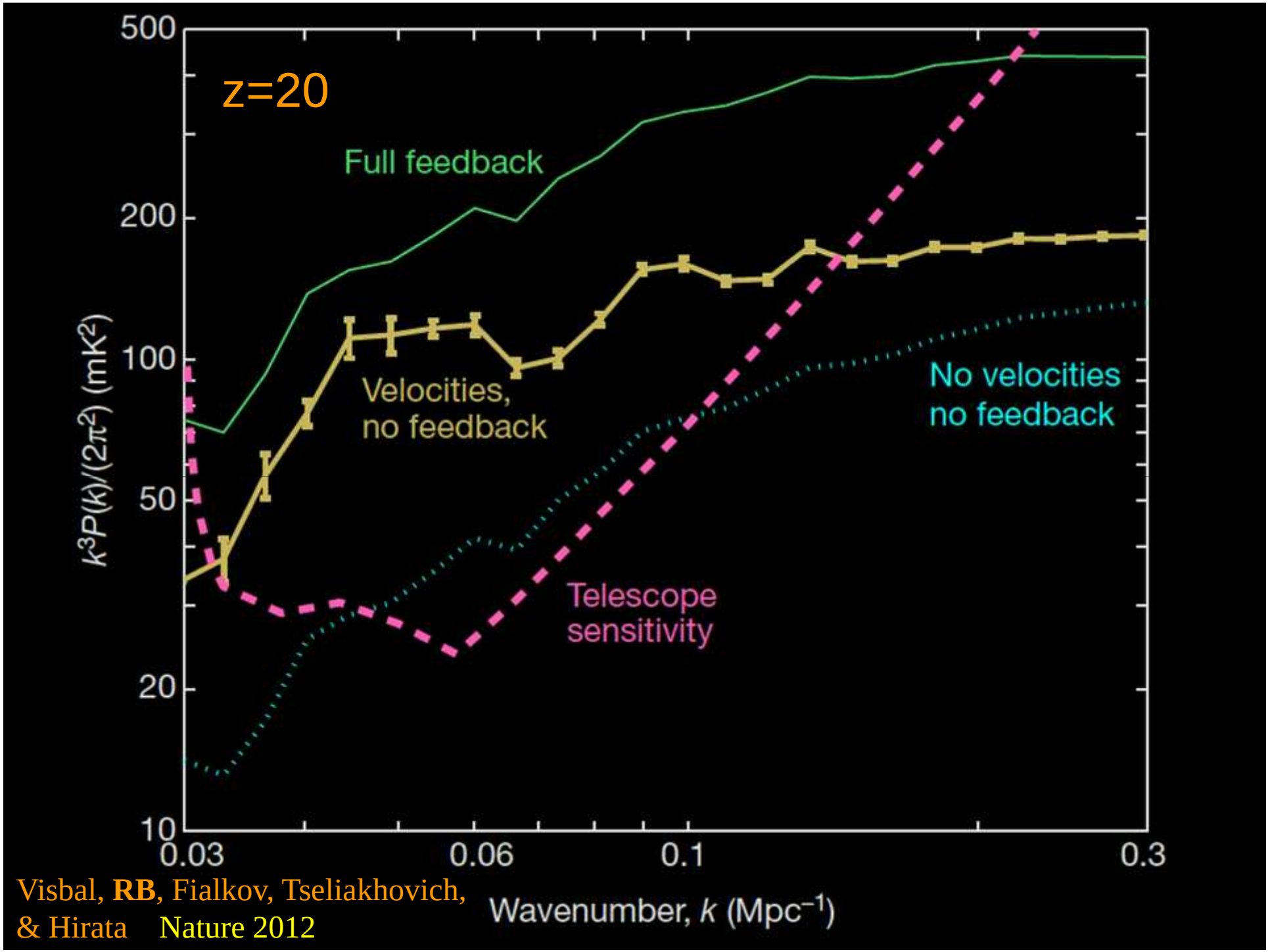


$$T_b = 40\,(1+\delta)\left(1-\frac{T_{\mathrm{CMB}}}{T_{\mathrm{gas}}}\right)\sqrt{\frac{1+z}{21}}\ \mathrm{mK}$$


Velocity
(r.m.s.)
2
1.5
1
0.5
0
130 Mpc
Density
z=20
(δ)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
130 Mpc
Stars with velocity
z=20
log10(fg)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
130 Mpc
Stars without velocity
z=20
log10(fg)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
130 Mpc


Velocity
(r.m.s.)
2
1.5
1
0.5
0
130 Mpc
Density
z=20
(δ)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
130 Mpc
Stars with velocity
z=40
log10(fg)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
130 Mpc
Stars without velocity
z=40
log10(fg)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
130 Mpc

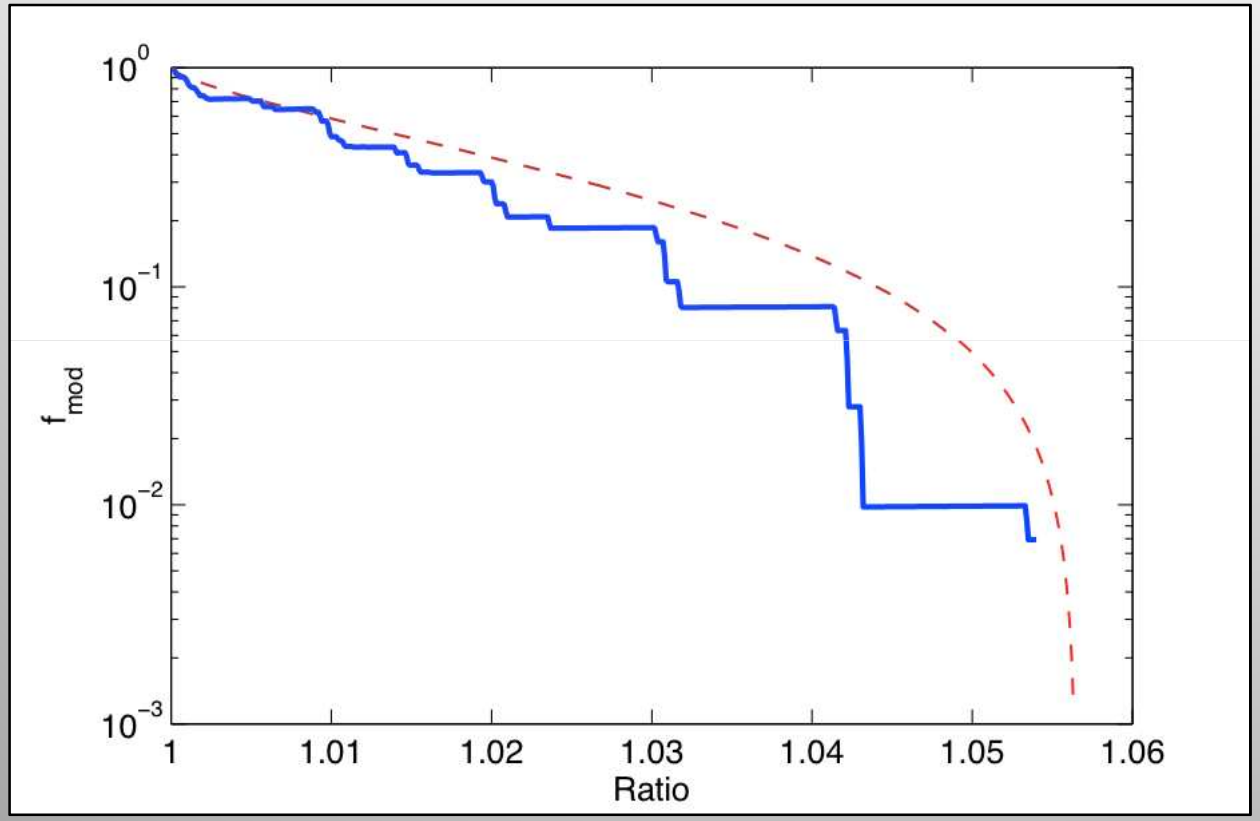

Velocity
(r.m.s.)
2
1.5
1
0.5
0
130 Mpc
Density
z=20
(δ)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
130 Mpc
T21 with velocity
z=20
T21 (mK)
40
20
0
-20
-40
-60
130 Mpc
T21 without velocity
z=20
T21 (mK)
40
20
0
-20
-40
-60
130 Mpc



Visbal, **RB**, Fialkov, Tseliakhovich, & Hirata Nature 2012

Including the negative LW feedback

Machacek et al 2001; Wise & Abel 2007; O'Shea & Norman 2008

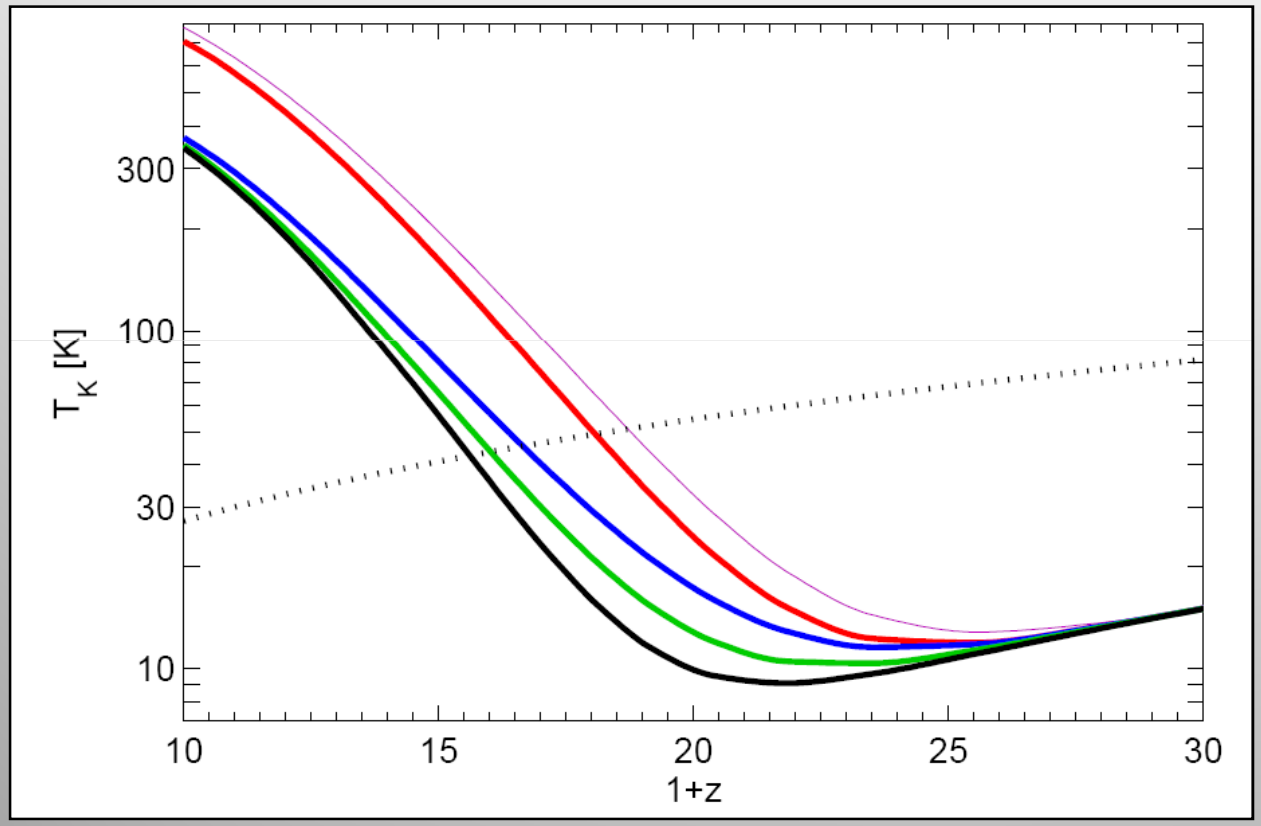


Relative LW absorption vs. λ ratio

Haiman, Rees, & Loeb 1997

Fialkov, **RB**, Visbal, Tseliakhovich, & Hirata submitted

The heating history



No v_{bc}, no feedback

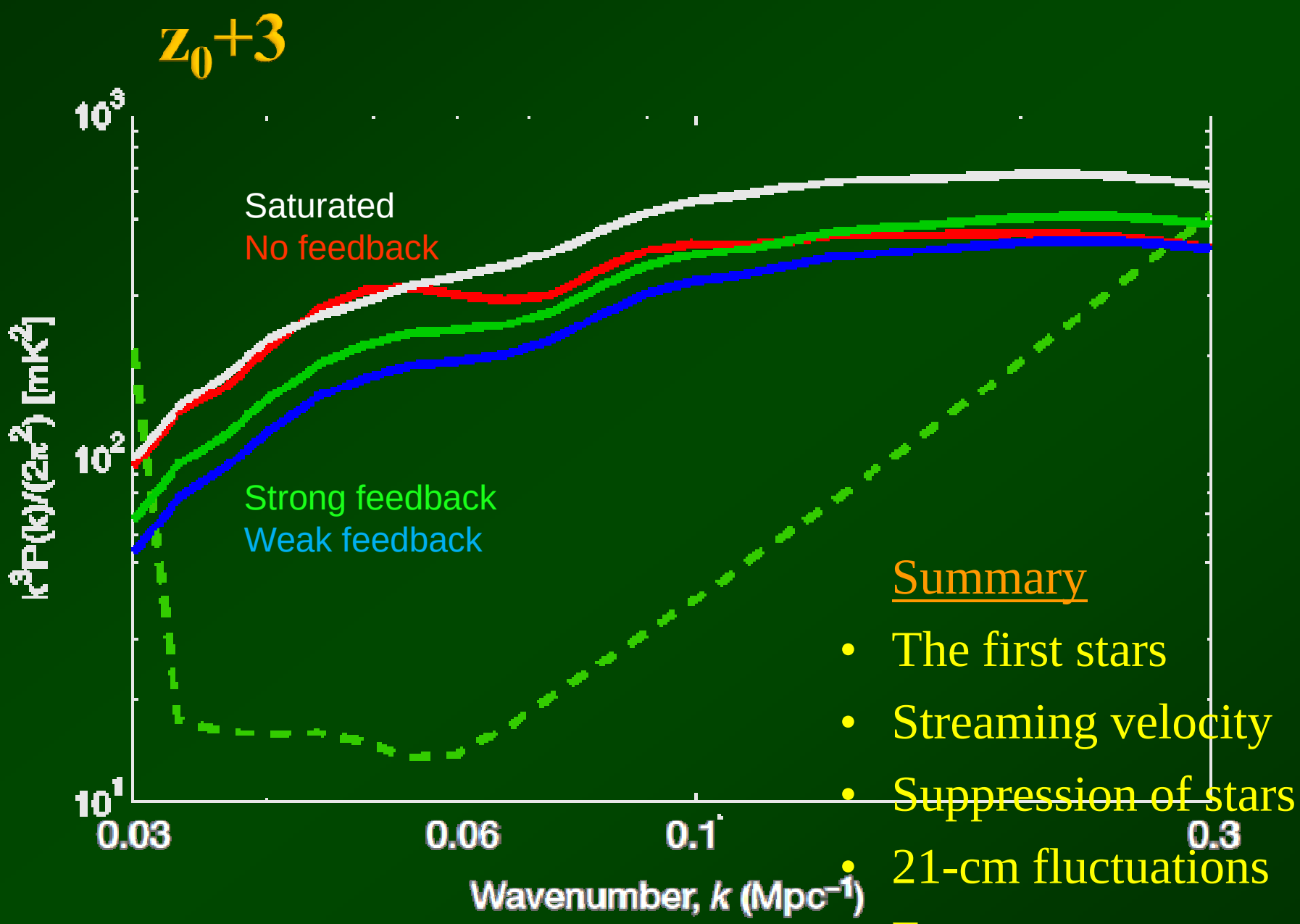
v_{bc}, no feedback

v_{bc} weak feedback

v_{bc} strong feedback

v_{bc} saturated feedback

Fialkov, **RB**, Visbal, Tseliakhovich, & Hirata submitted



Summary

- The first stars
- Streaming velocity
- Suppression of stars
- 21-cm fluctuations
- Future