Baryon Drift Effects at High Redshift

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Ramses User Meeting 2021

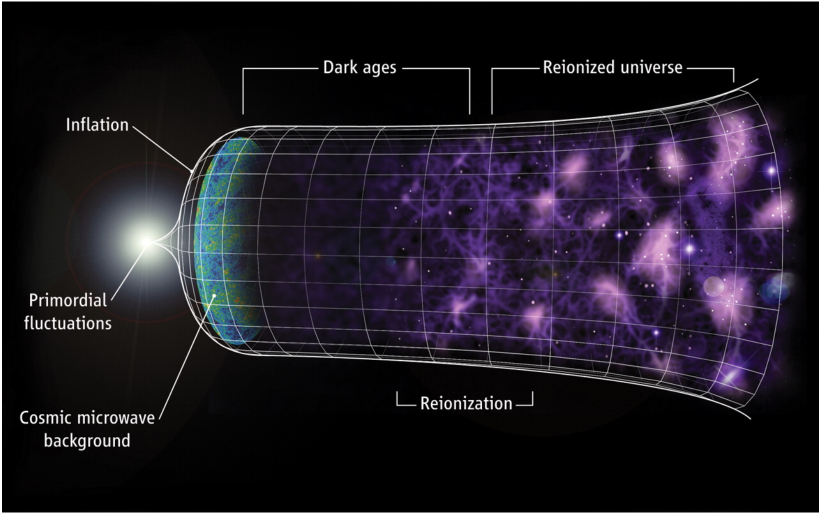


Figure: Faucher-Giguere+ (2008)

$z = 40$

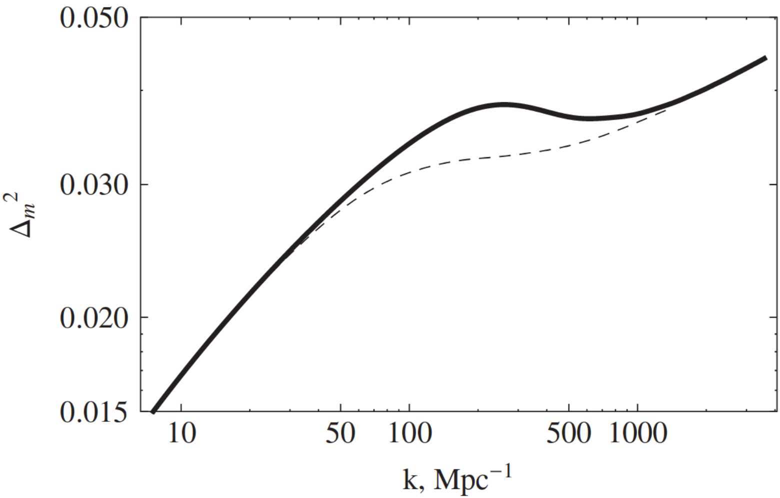


Figure: Tseliakhovich and Hirata (2010)

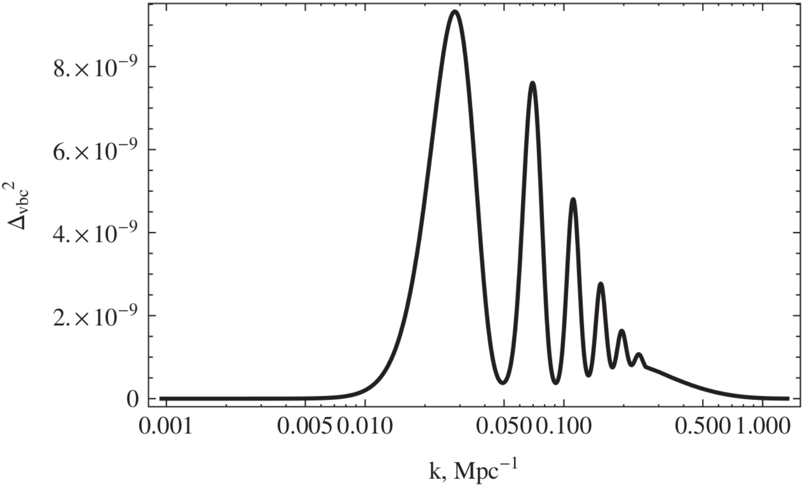


Figure: Tseliakhovich and Hirata (2010)

$$\mathcal{M} = v_{\rm bc}/c_s$$

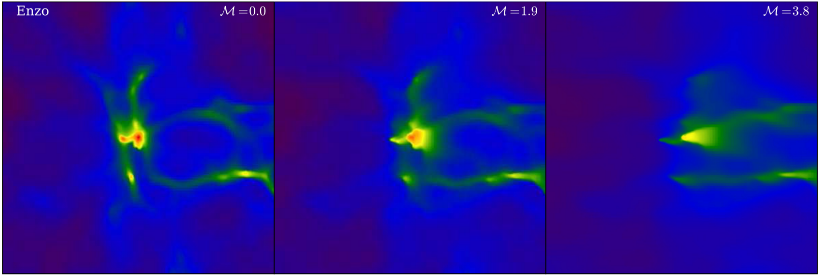
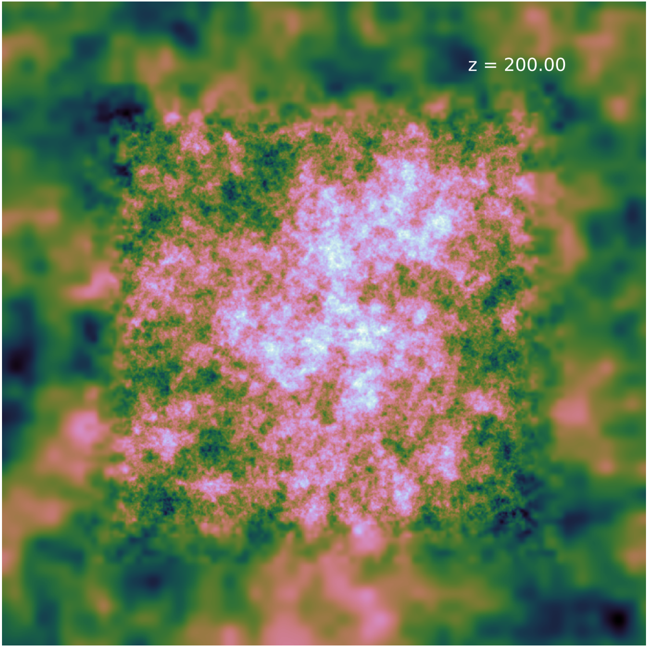


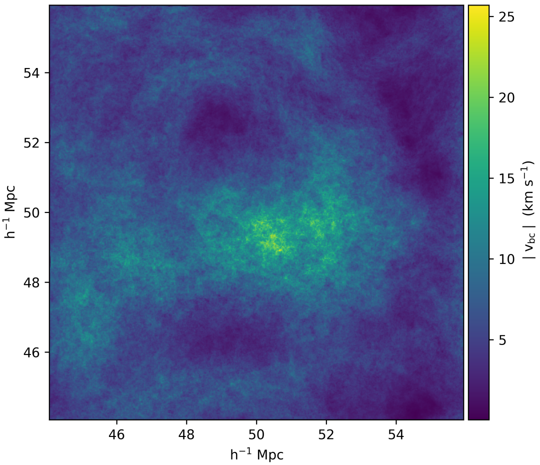
Figure: O'Leary and McQuinn (2012)

1. Generate initial conditions with MUSIC

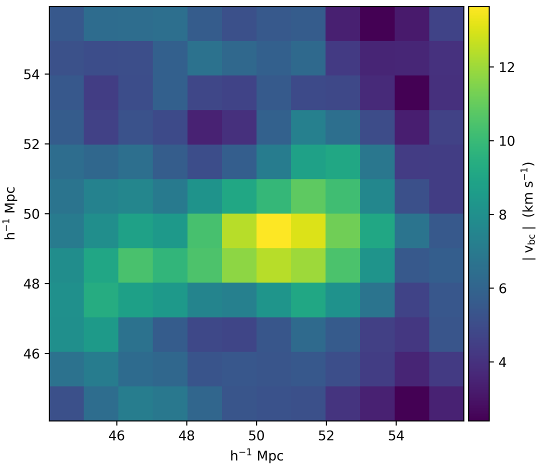

z = 200.00

1. Generate initial conditions with MUSIC
2. Calculate v_{bc} field

$$\mathbf{v_{bc} = v_b - v_c}$$

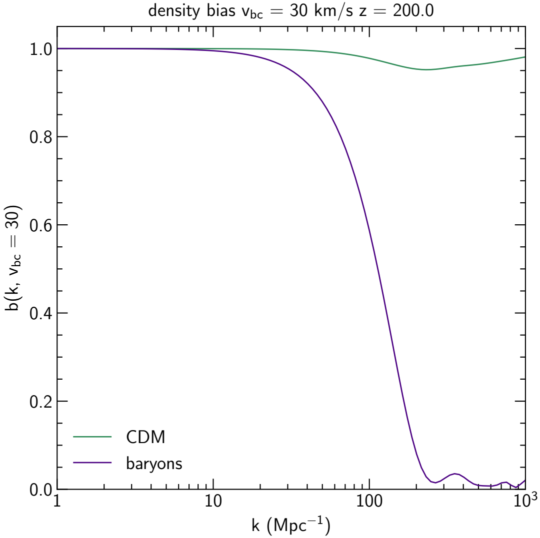


1. Generate initial conditions with MUSIC
2. Calculate v_{bc} field
3. Split initial conditions fields into patches

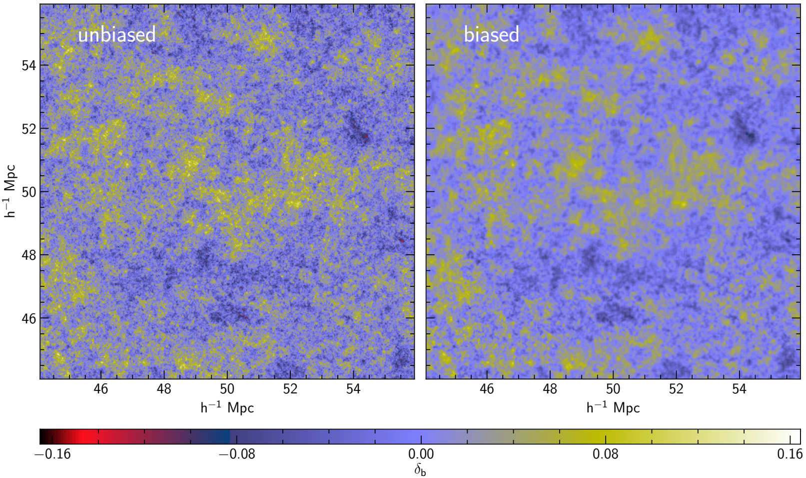


54
52
50
48
46
46
48
50
52
54
h^{-1} Mpc
h^{-1} Mpc
12
10
8
6
4
$|v_{bc}|$ (km s^{-1})

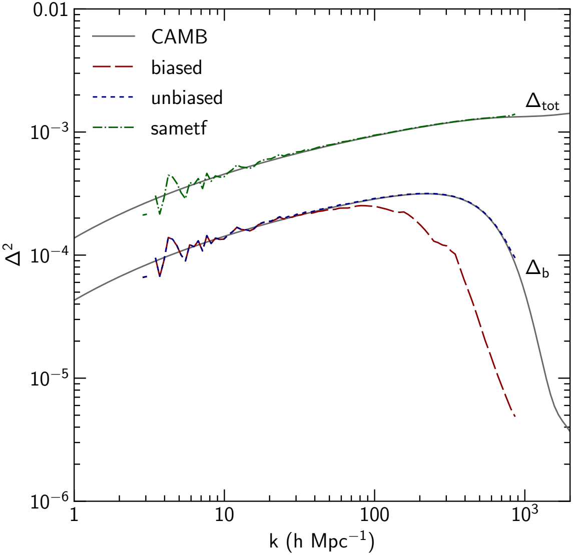
1. Generate initial conditions with MUSIC
2. Calculate v_{bc} field
3. Split initial conditions fields into patches
4. Calculate a scale-dependent bias $b(k, v_{\mathrm{bc}})$


density bias v_{bc} = 30 km/s z = 200.0
1.0
0.8
0.6
0.4
0.2
0.0
b(k, v_{bc} = 30)
1
10
100
10^3
k (Mpc^{-1})
CDM
baryons

1. Generate initial conditions with MUSIC
2. Calculate $v_{\rm bc}$ field
3. Split initial conditions fields into patches
4. Calculate a scale-dependent bias $b(k, v_{\rm bc})$
5. Convolve the bias with the patch



unbiased
biased
54
52
50
48
46
h^{-1} Mpc
46
48
50
52
54
h^{-1} Mpc
46
48
50
52
54
h^{-1} Mpc
−0.16
−0.08
0.00
0.08
0.16
δ_b



CAMB
biased
unbiased
sametf
Δ_{tot}
Δ_b
Δ^2
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1
10
100
10^3
k (h Mpc^{-1})

- 200 h^{-1} kpc box, $m_{\mathrm{DM}} = 35.1\ h^{-1}\ \mathrm{M}_{\odot}$
- Impose a constant value of v_{bc} across small-volume periodic box as

$$\begin{pmatrix} v_{\mathrm{b},x} \\ v_{\mathrm{b},y} \\ v_{\mathrm{b},z} \end{pmatrix} = \begin{pmatrix} v_{\mathrm{c},x} + v_{\mathrm{bc}} \\ v_{\mathrm{c},y} \\ v_{\mathrm{c},z} \end{pmatrix}$$

- Take $\sim 2\sigma$ value of v_{bc}, 12 km s^{-1} at $z = 200$

- Three sets of simulations

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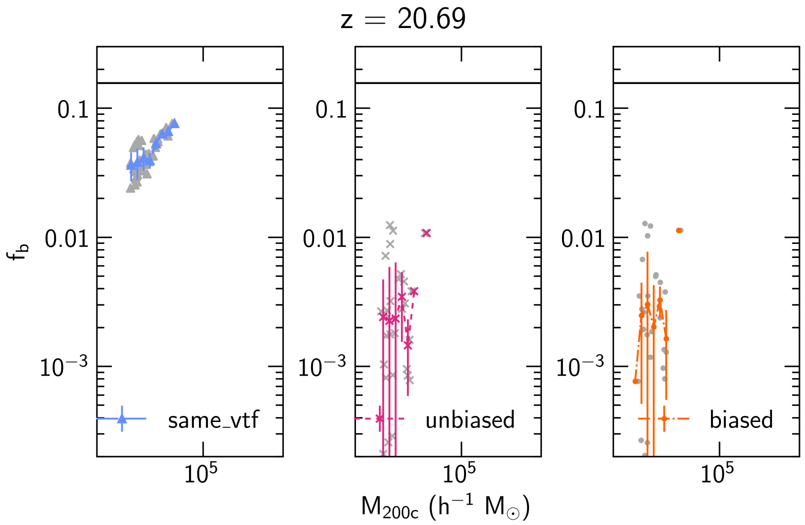
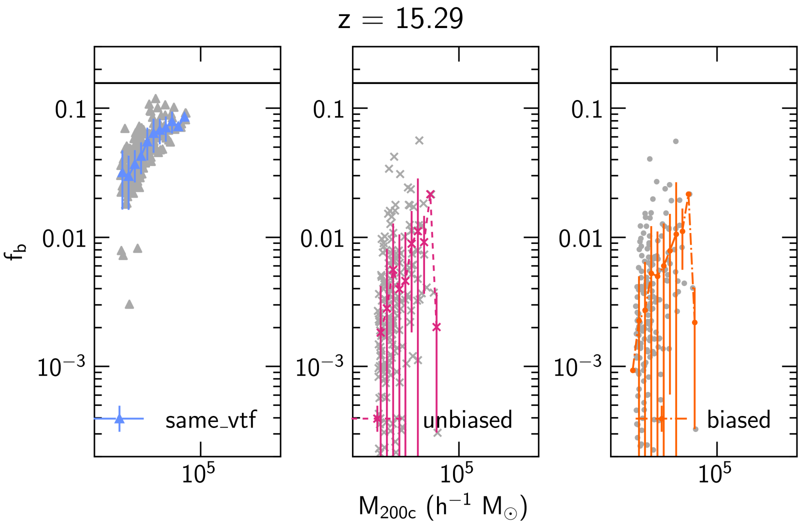
  - same_vtf: velocity field for both baryons and dark matter is that of the dark matter

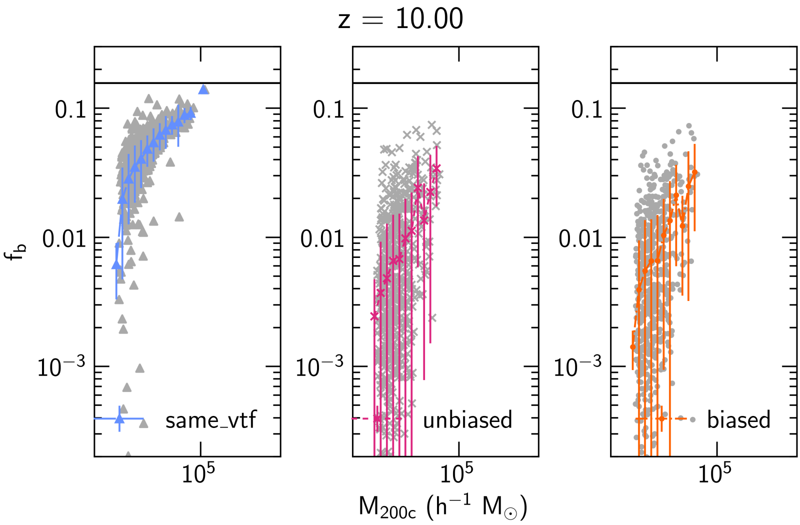
- Three sets of simulations
    - same_vtf: velocity field for both baryons and dark matter is that of the dark matter
    - unbiased: distinct velocity fields for baryons and dark matter

- Three sets of simulations
  - same_vtf: velocity field for both baryons and dark matter is that of the dark matter
  - unbiased: distinct velocity fields for baryons and dark matter
  - biased: distinct velocity fields for baryons and dark matter and incorporating the bias factor

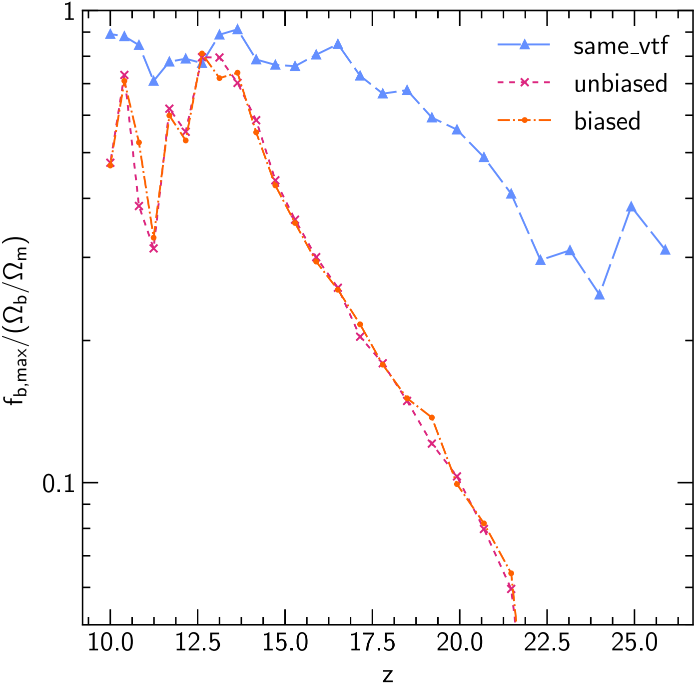

z = 20.69
f_b
0.1
0.01
10^{−3}
10^5
same_vtf
unbiased
biased
M_200c (h^{−1} M_⊙)



z = 15.29
0.1
0.01
10^{-3}
10^{5}
f_b
same_vtf
unbiased
biased
M_{200c} (h^{-1} $M_\odot$)



z = 10.00
0.1
0.01
10^−3
f_b
same_vtf
10^5
unbiased
biased
M_200c (h^−1 M_⊙)



1
0.1
$f_{b,max}/(\Omega_b/\Omega_m)$
10.0
12.5
15.0
17.5
20.0
22.5
25.0
z
same_vtf
unbiased
biased

- Relative velocities between dark matter and baryons can impact structure formation on small scales
- Our method agrees with the trend of previous works
- We can account for it self-consistently in zoom simulations (in progress)
- Any questions or comments, feel me free to contact me on Slack or `l.conaboy@sussex.ac.uk`

$$
\begin{aligned}
&\frac{\partial \delta_c}{\partial t} = -\theta_c, \\
&\frac{\partial \delta_b}{\partial t} = -\frac{i}{a}\mathbf{v}_{\rm bc} \cdot \mathbf{k}\delta_c - \theta_b, \\
&\frac{\partial \theta_c}{\partial t} = -\frac{3H^2}{2}(\Omega_c\delta_c + \Omega_b\delta_b) - 2H\theta_c, \\
&\frac{\partial \theta_b}{\partial t} = -\frac{i}{a}\mathbf{v}_{\rm bc} \cdot \mathbf{k}\theta_c - \frac{3H^2}{2}(\Omega_c\delta_c + \Omega_b\delta_b) - 2H\theta_b + \frac{k^2}{a^2}\frac{k_B\bar{T}}{\mu}(\delta_b + \delta \\
&\frac{\partial \delta_T}{\partial t} = \frac{2}{3}\frac{\partial \delta_b}{\partial t} - \frac{x_e}{a^4 t_\gamma}\frac{\bar{T}_\gamma}{\bar{T}}\delta_T
\end{aligned}
\tag{1}
$$

where θ_i is the velocity divergence.

- Solve evolution equations to calculate power spectra and calculate bias

$$b(k, v_{\mathrm{bc}}) = \frac{P(k, v_{\mathrm{bc}})}{P(k, v_{\mathrm{bc}} = 0)} \tag{2}$$

- Interpolate the bias onto a grid and use the convolution theorem to apply it

$$\hat{\delta}_{\mathrm{b}}(\mathbf{k}) = \hat{\delta}_{\mathrm{u}}(\mathbf{k})\sqrt{b(\mathbf{k}, v_{\mathrm{bc}})} \tag{3}$$

The power spectrum is defined as

$$P(\mathbf{k}) \propto |\hat{\delta}(\mathbf{k})|^2 \tag{4}$$

which means that our bias factor, calculated as the ratio of two power spectra is $\propto |\hat{\delta}(\mathbf{k})|^2$, hence when convolving with $\hat{\delta}(\mathbf{k})$ we take the square root.