Rethinking the statistical parameters of a large-scale reionization model

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Epoch of Reionization (EoR)

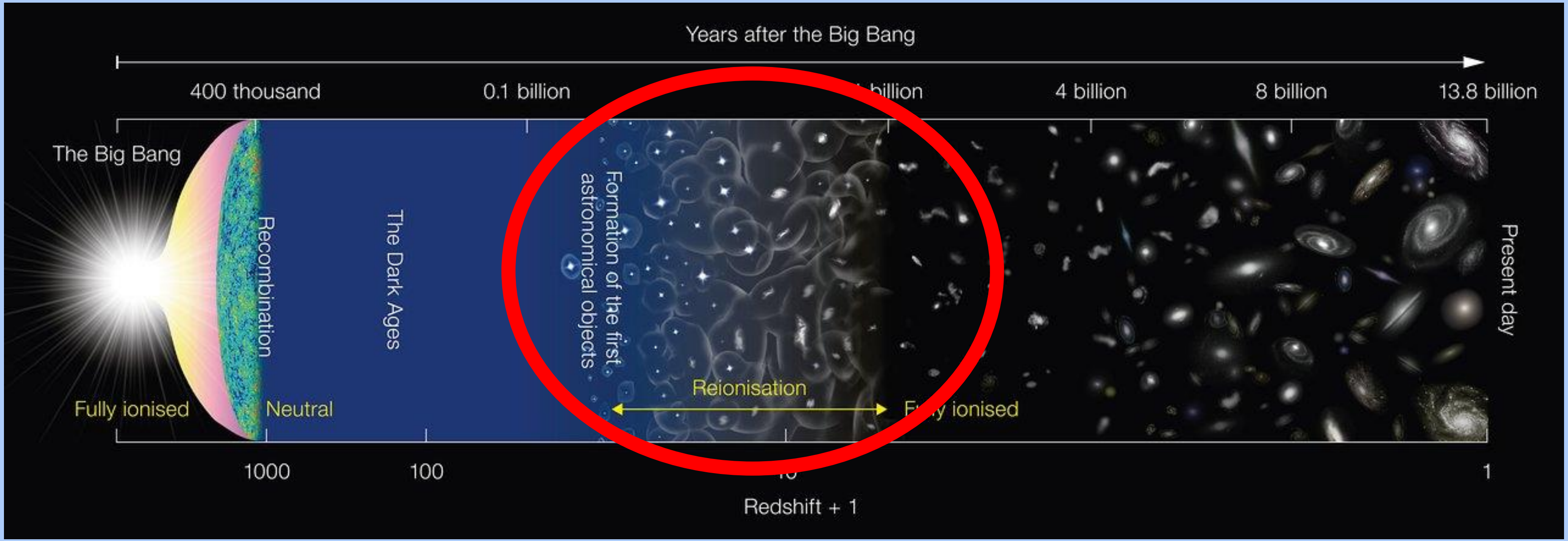
After the Big Bang, the universe was a quickly cooling soup of fundamental particles.

Approximately 300 000 years later, the soup cooled enough for protons and electrons to combine to form neutral hydrogen (Recombination).

Stayed neutral for about 250 million years (Dark ages).

The birth of the first star ionized the neutral hydrogen of the intergalactic medium (Epoch of Reionization).

Redshift can be use as a measure of time (ex: EoR is from redshifts 20 to 6 -> 250M years to 1G year).

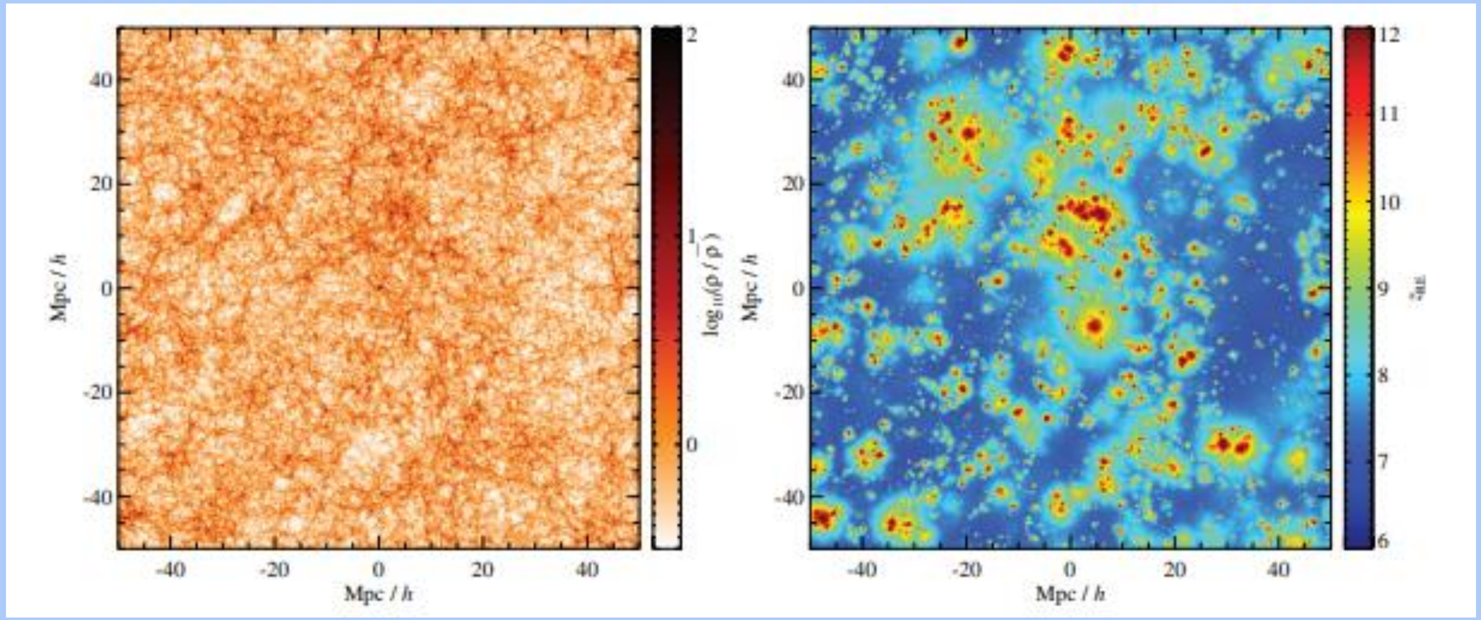


Credit : European Southern Observatory

Why is it so important?

- As the hydrogen in the IGM represents 98% of the early universe, Understanding the correlation between its reionization and the density of the universe is key to understanding the physics that drives our universe.

Density field Redshift of reionization field



Credit : Battaglia et al. 2013

Motivation (1/2)

- Before *Battaglia et al.* 2013, the redshift of reionization field was either produce in short-scale ($\leq Mpc^{-1}h)^3$ by models including radiative transfer and hydrodynamic simulations, or in large-scale ($\geq Gpc^{-1}h)^3$ by semi-analytical models.
- The Battaglia model proposes a large-scale model including these physical elements. To do so, they compute a linear bias factor linking the density field to the redshift or reionization field on small scales.

$$\tilde{\delta}_{\mathrm{z_{re}}}(k) = b_{mz}(k)\ \tilde{\delta}_{\mathrm{m}}(k)$$

where

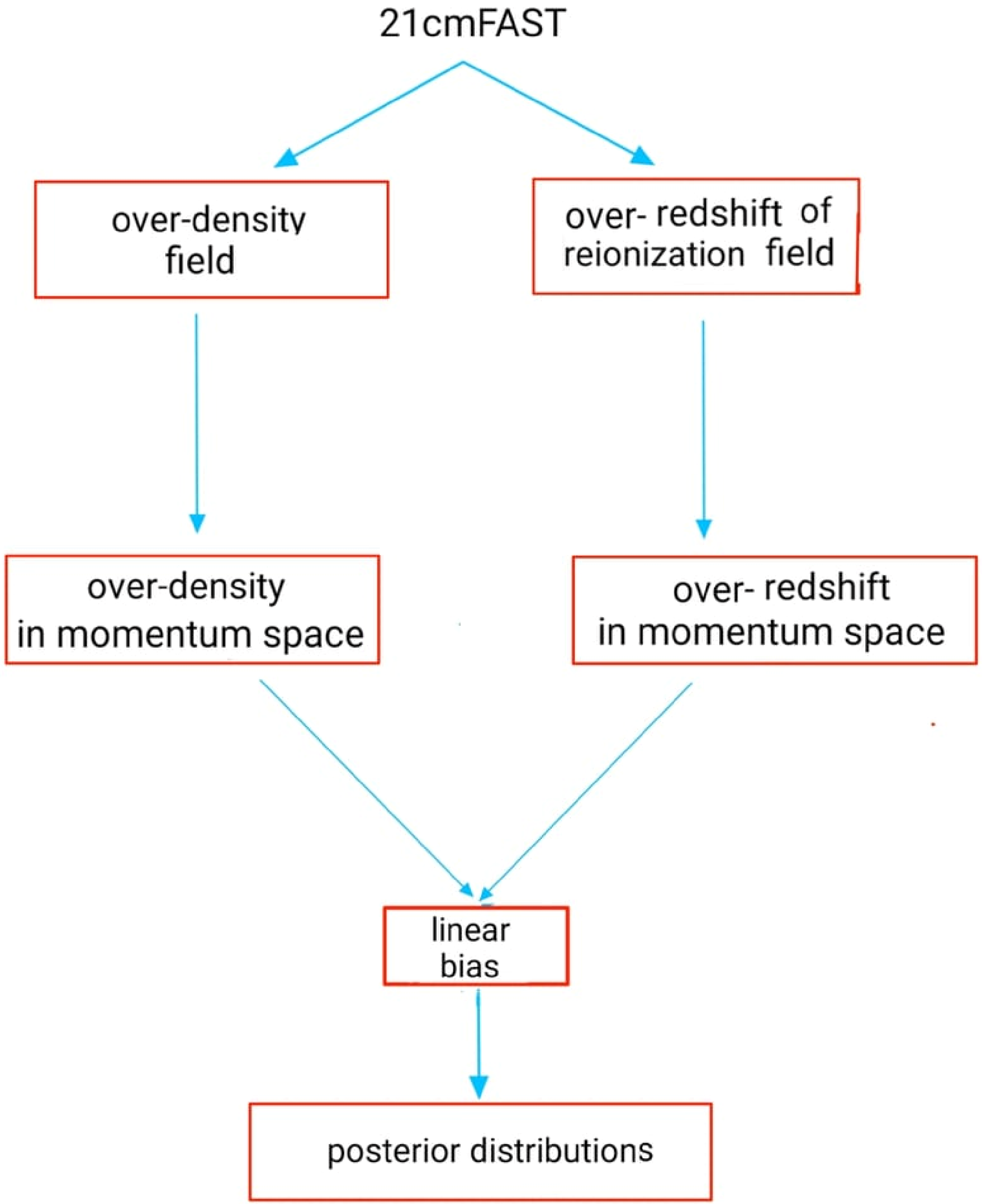
$$b_{\mathrm{mz}}(k) = \frac{b_0}{(1+k/k_0)^{\alpha}}$$

Motivation (2/2)

- This approach allows the production of reionization redshift field on a large scale with models including radiative transfer and hydrodynamic simulations.
- Problem: Since the linear bias factor is purely mathematical, its lack of physical meaning makes it hard to use.
- Another semi-numerical model, **21cmFAST**, uses physical process (with approximations) to independently compute the redshift of the reionization field and the density field.

Objectives

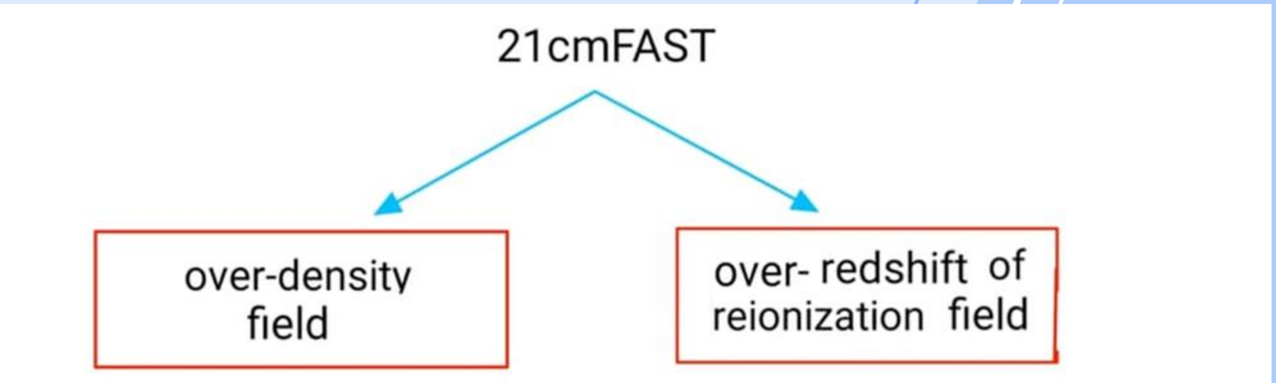
Construct an algorithm to link 21cmFast and the linear bias factor of Battaglia et al., and verify that the linear bias equation fits the 21cmFAST data.



Methods

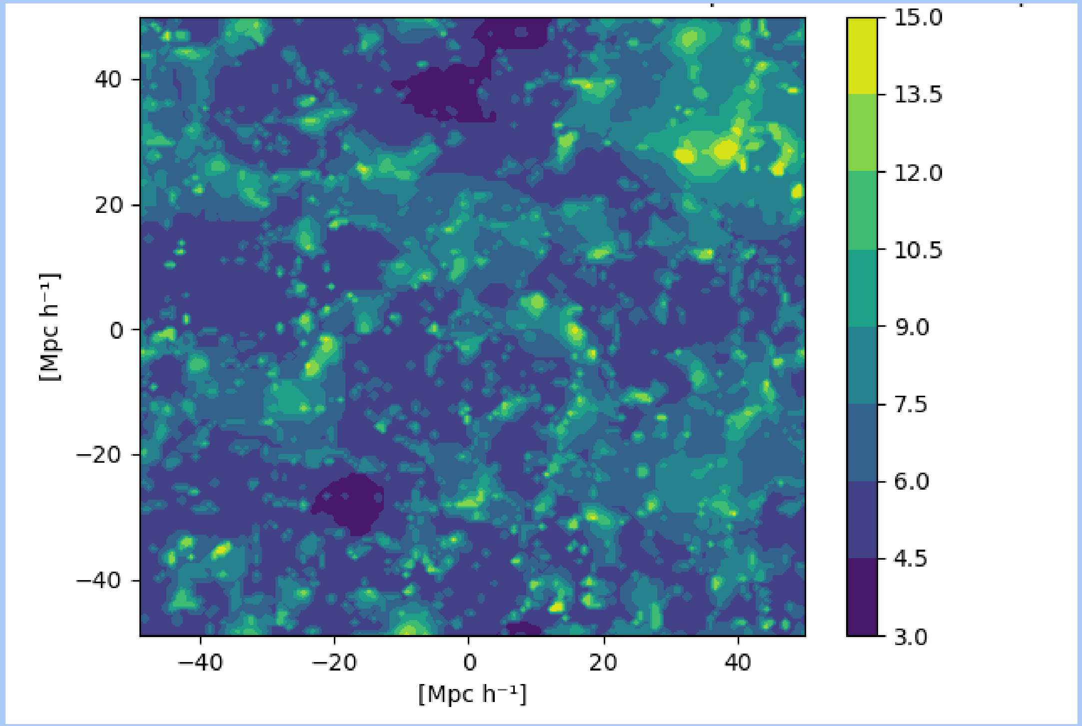
- With 21cm fast, generate density field and redshift of reionization field.
- Repeat the Battaglia model process.

Step 1 the fields



Computing the redshift of reionization

Field obtained with 21cmFast



- 21cmFAST computes the density field directly.
- 21cmFAST computes reionization field at define redshift.
- Compute the redshift of reionization field from several redshifts.
- Brighter zone ionized earlier.

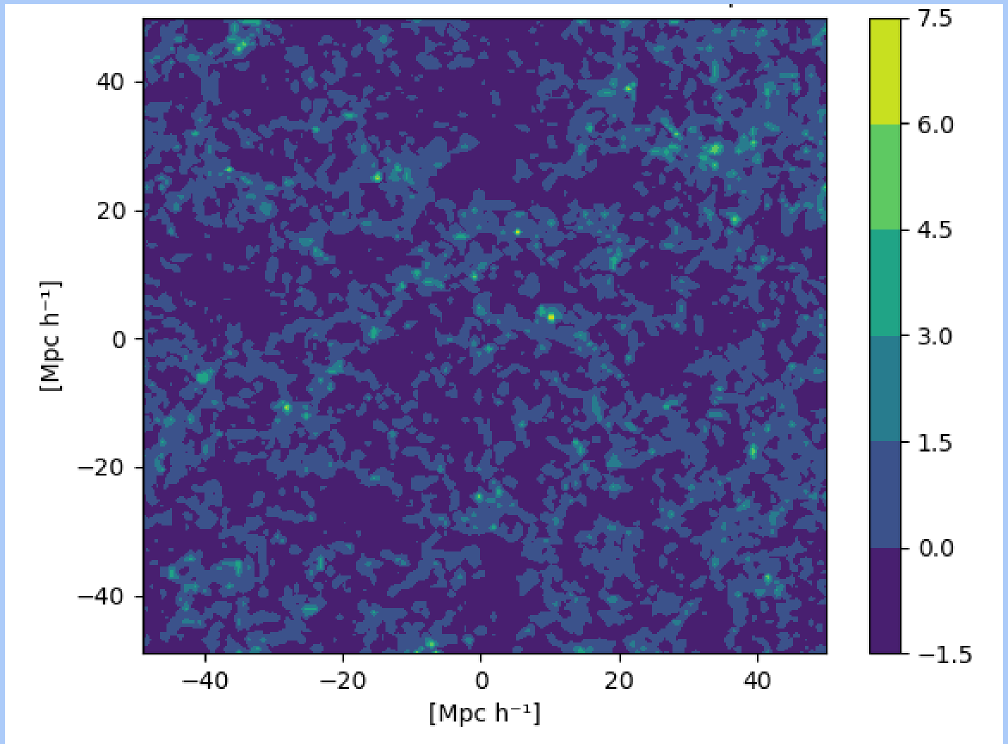
Difference from average

- Both field have a resolution of 1 Mpc/h (pixel size).
- The fields Exhibit similar pattern (similar dark/bright zones).

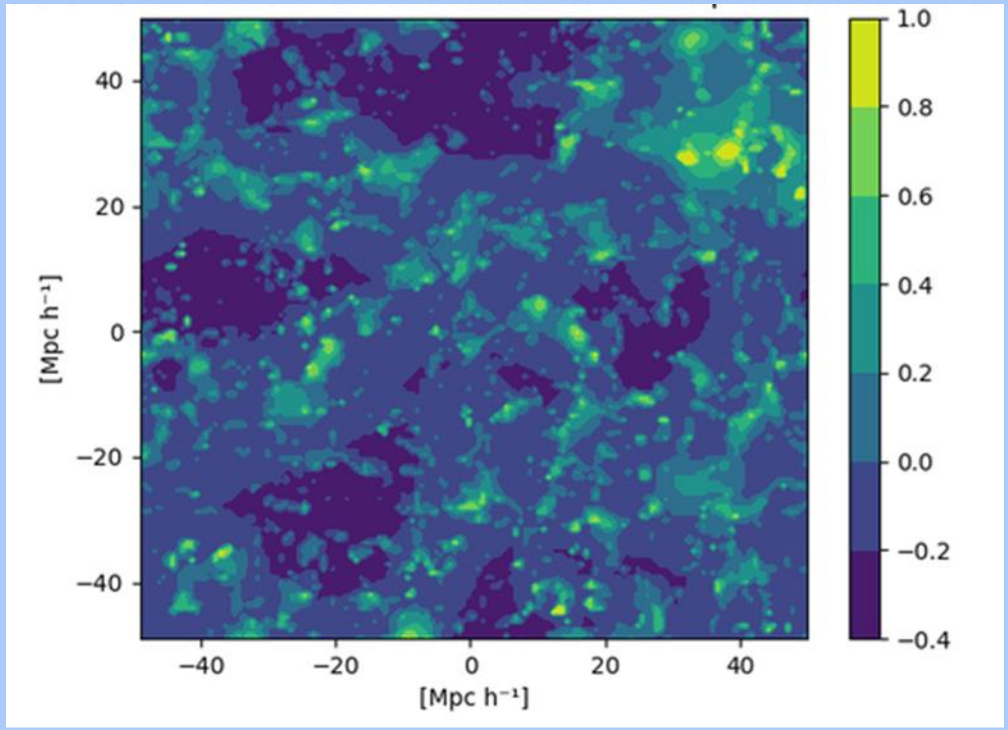
$$\delta_{\mathrm{m}}(\mathbf{x}) \equiv \frac{\rho(\mathbf{x}) - \bar{\rho}}{\bar{\rho}}$$

$$\delta_z(\mathbf{x}) \equiv \frac{[1+z_{\mathrm{RE}}(\mathbf{x})]-[1+\bar{z}]}{1+\bar{z}}$$

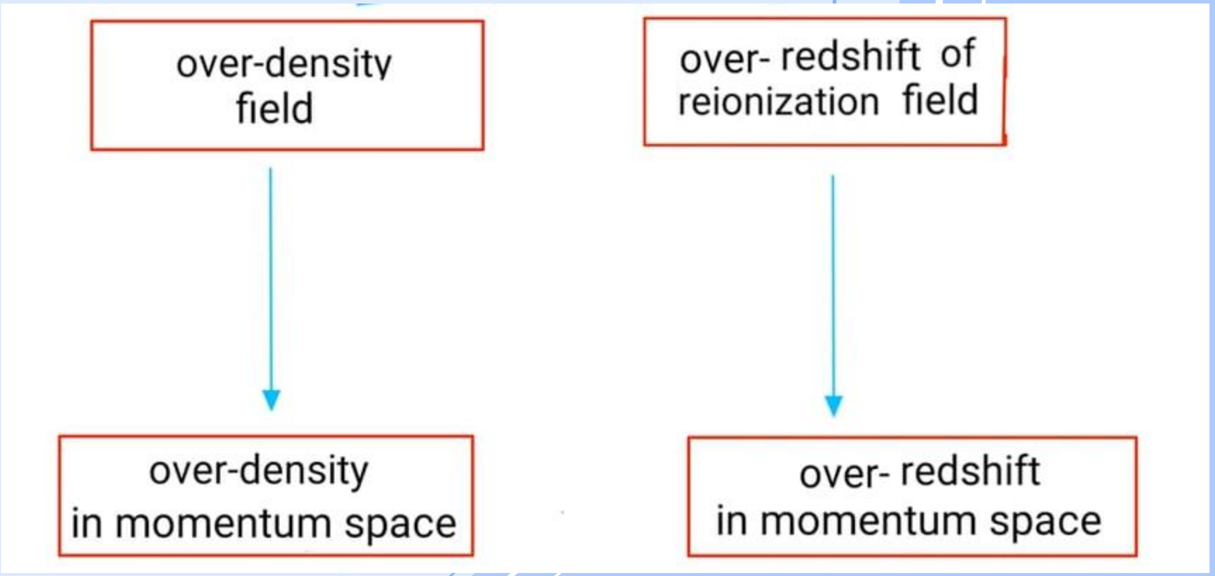
Over-density field obtained from 21cmFAST



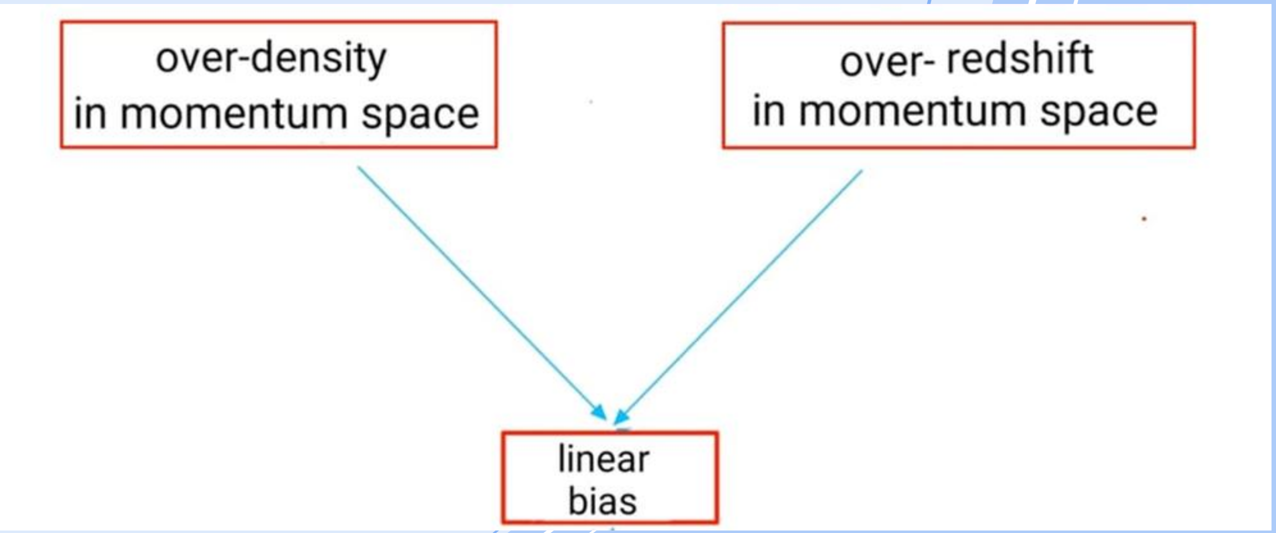
Over-redshift of reionization field obtained from 21cmFAST



Step 2 Fourier transform



Step 3 Computing the linear bias



Computing the linear bias

The linear bias is defined as:

$$b_{\mathrm{mz}}(k) = \sqrt{\frac{P_{\mathrm{zz}}(k)}{P_{\mathrm{mm}}(k)}}$$

And that the power spectrums (correlation function in momentum space) are defined as:

$$\left\langle |\widetilde{\delta_m}(\mathbf{k})|^2 \right\rangle \propto P_{mm}(\mathbf{k})$$

$$\left\langle |\widetilde{\delta_z}(\mathbf{k})|^2 \right\rangle \propto P_{zz}(\mathbf{k})$$

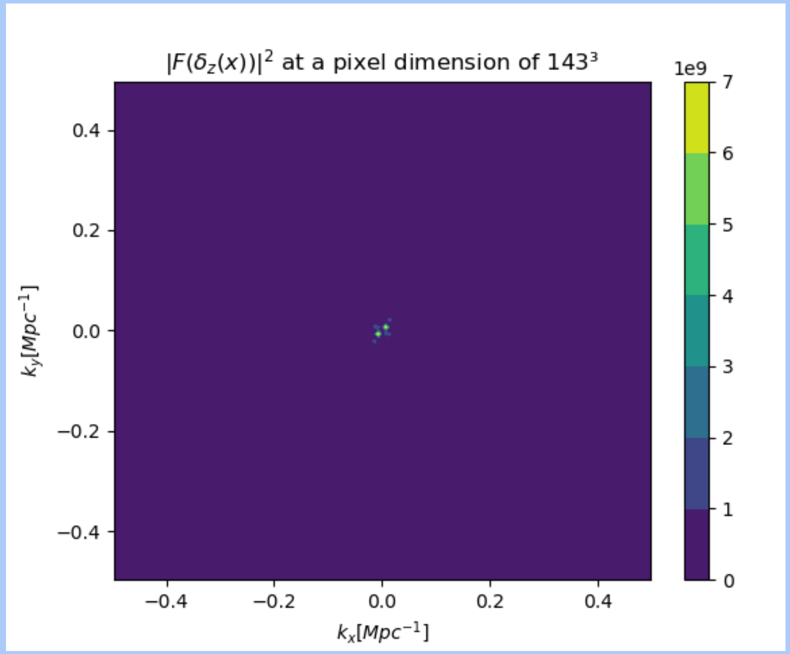
The magnitude square of the fields in momentum space are taken.

The brackets denotes an average

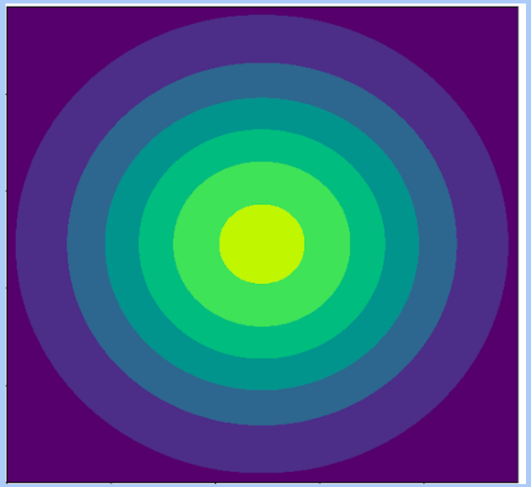
Fields as a function of k

- Averaging the field over “shells” (theta and phi) makes the field only a function of k, where the errors are the standard deviation of the averaged shell.

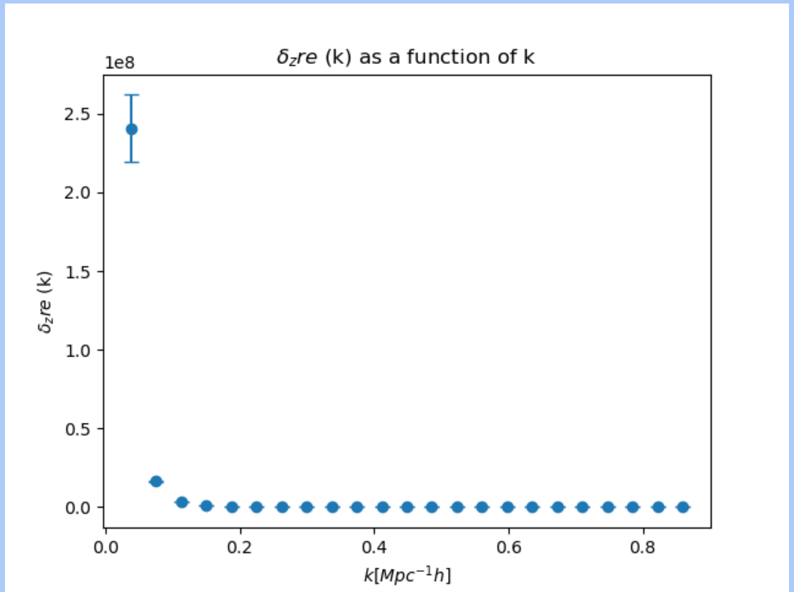
Over-redshift of reionization in k space (3d)



Averaging over



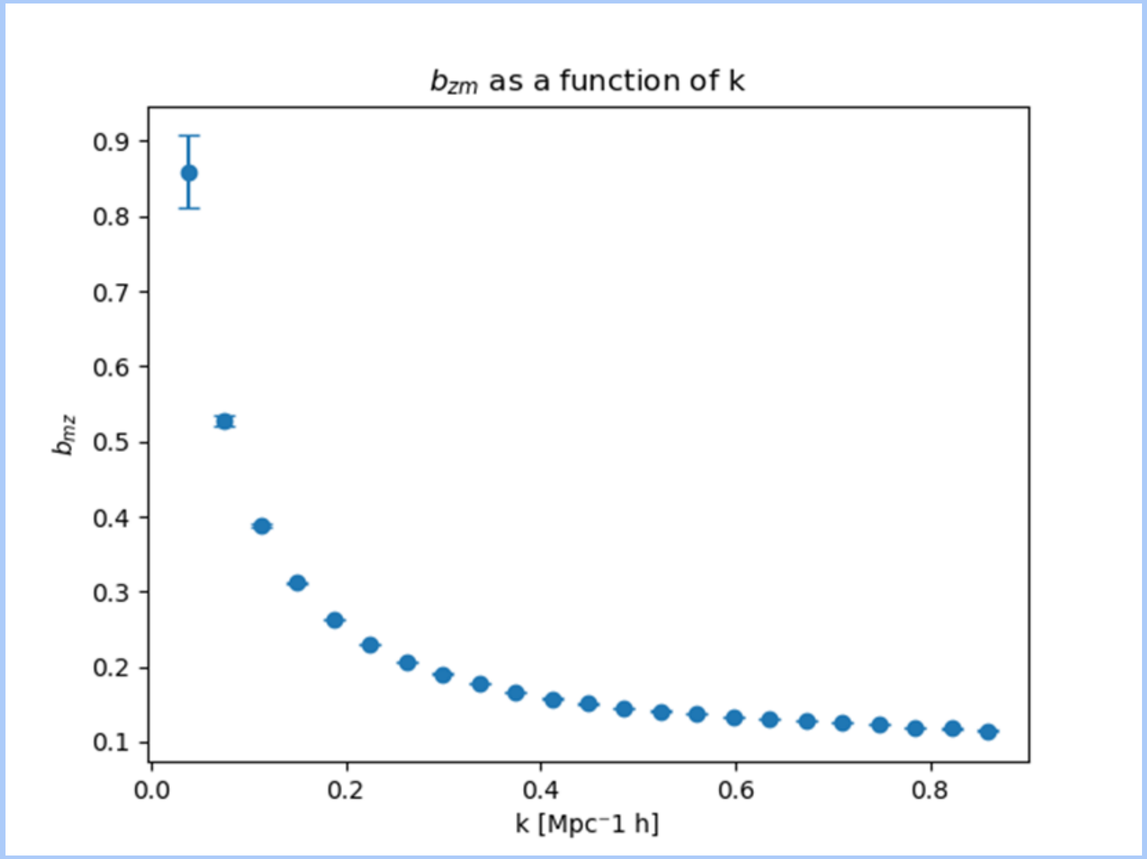
Over-redshift of reionization as a function of k (1d)



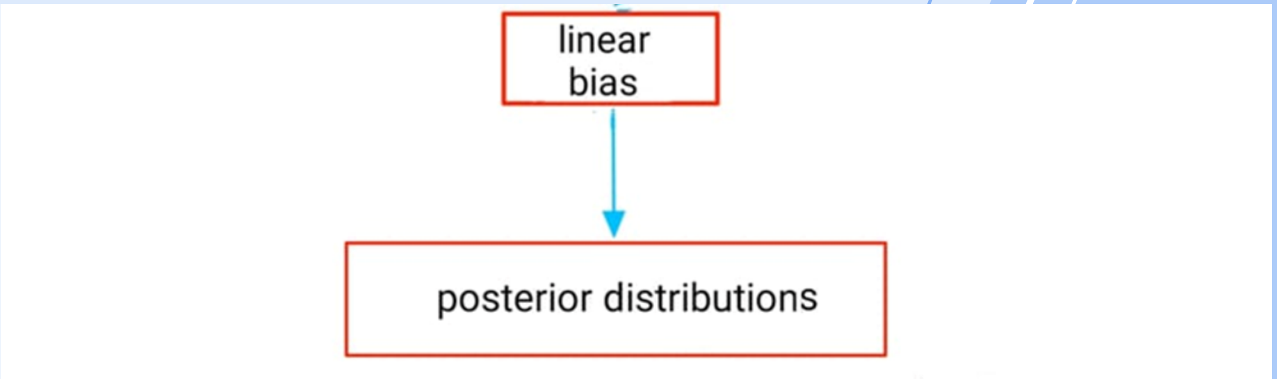
Linear bias computed with 21cmFAst

$$b_{\mathrm{mz}}(k) = \sqrt{\frac{P_{\mathrm{zz}}(k)}{P_{\mathrm{mm}}(k)}}$$

$$b_{\mathrm{mz}}(k) = \frac{b_0}{(1+k/k_0)^{\alpha}}$$



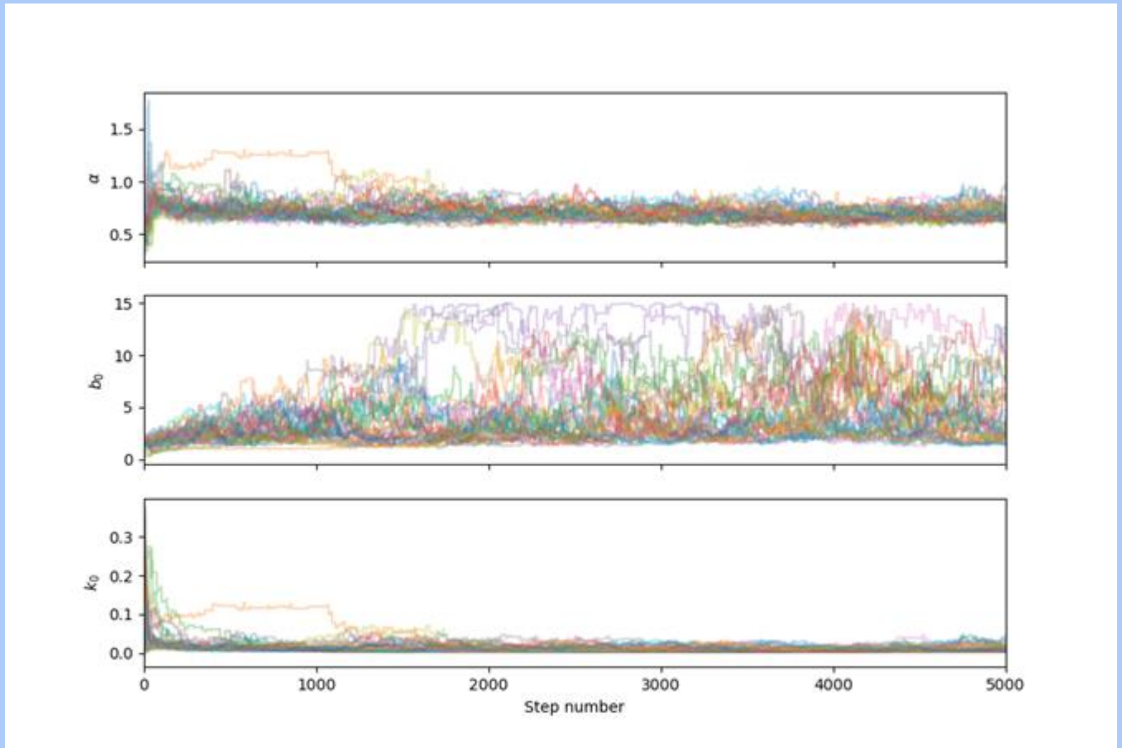
Step 4 Fitting for the parameters



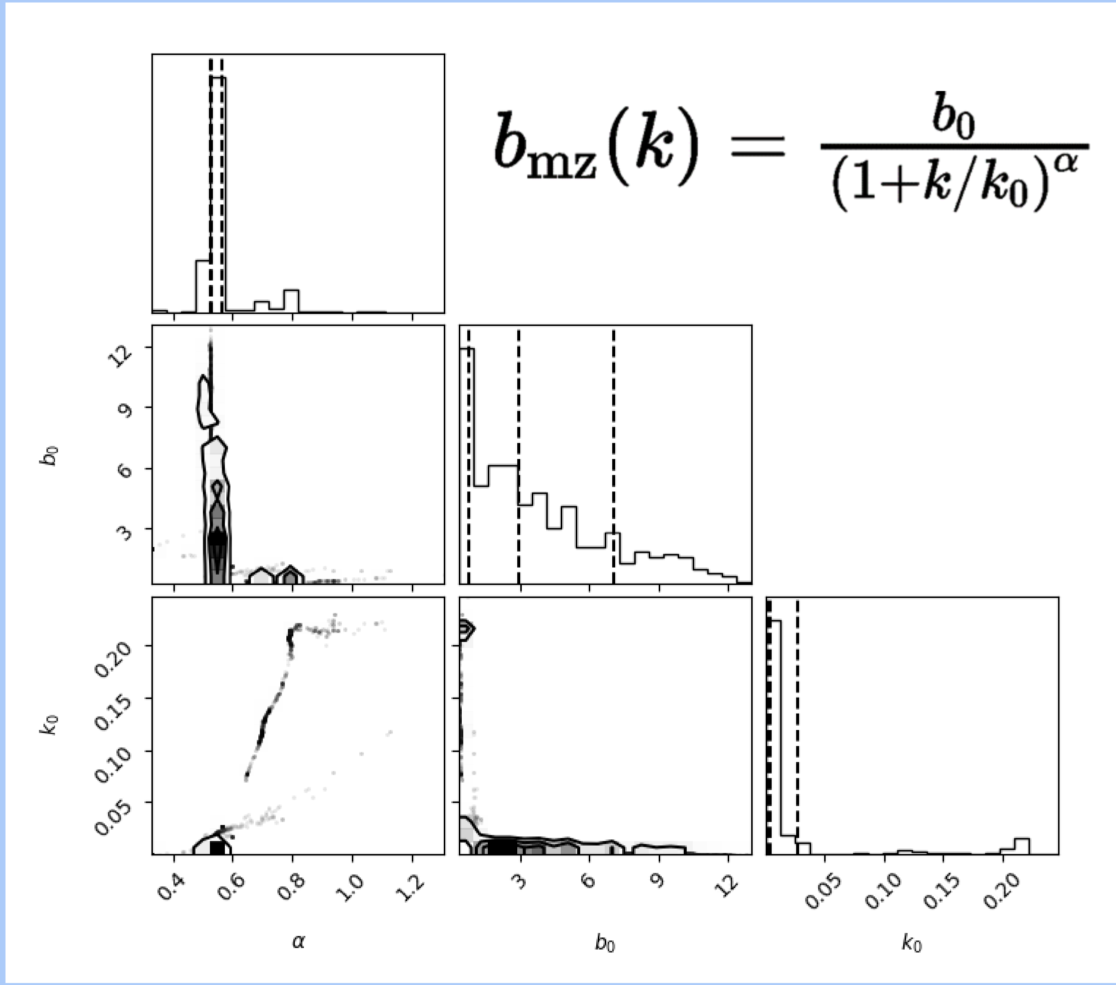
Markov Chain Monte Carlo (MCMC)

- Use of Bayesian statistics
- Sampling probability regions
- Continuous probability spectrum for the fitted parameters

Walkers behaviour



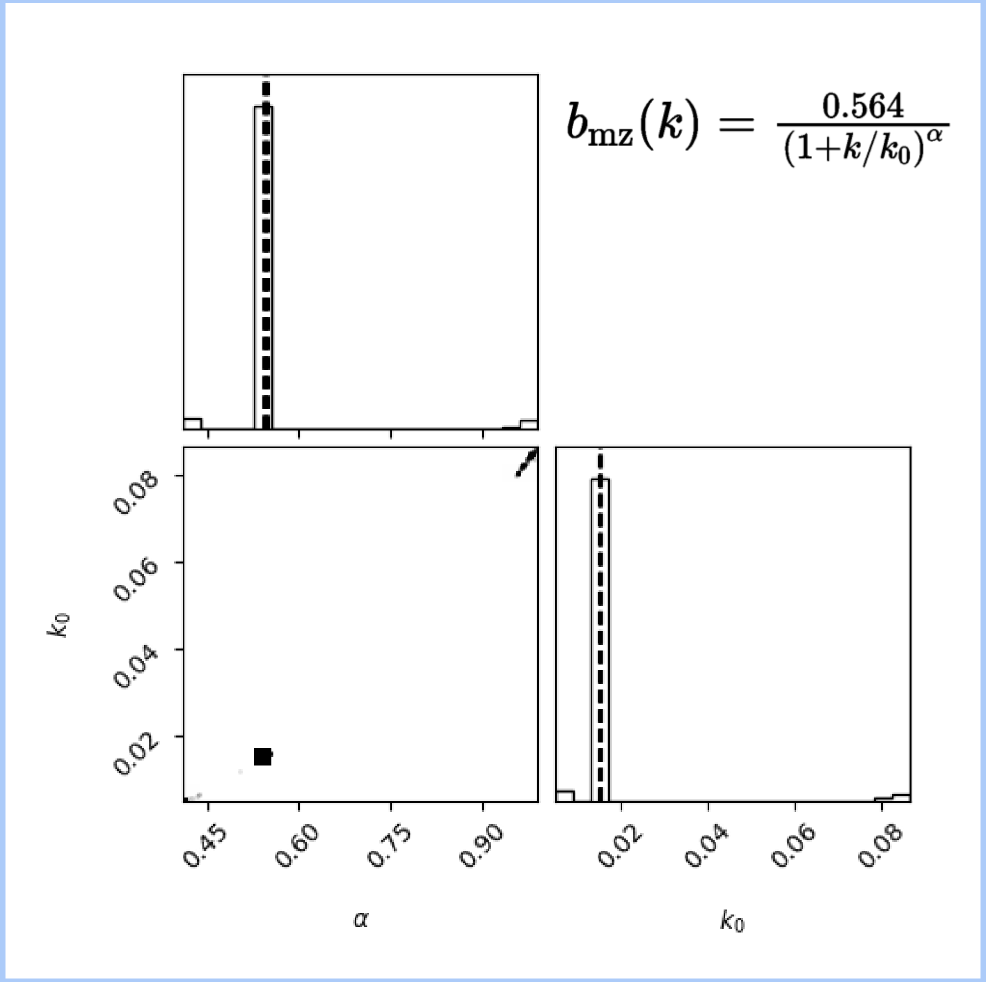
Probability distribution of the parameters



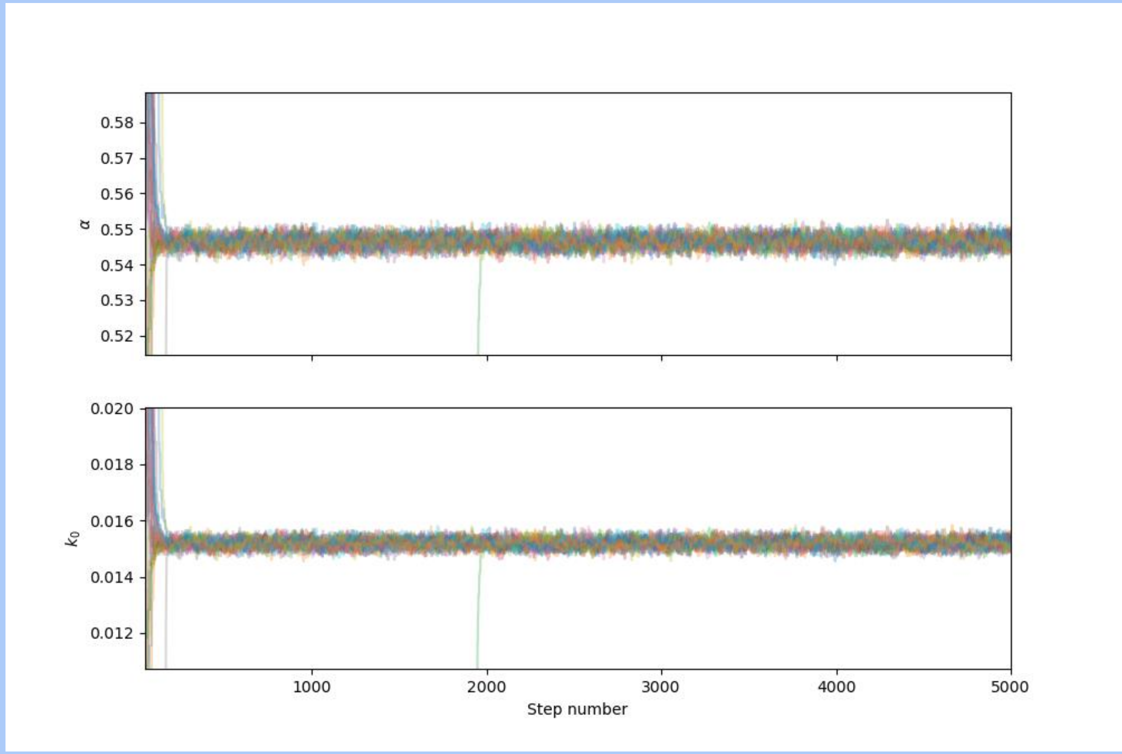
Notice the non-Gaussian posterior distribution for b_0?
Let's try fitting with only 2 parameters

Setting a fix b_0 parameter

Probability distribution of the parameters

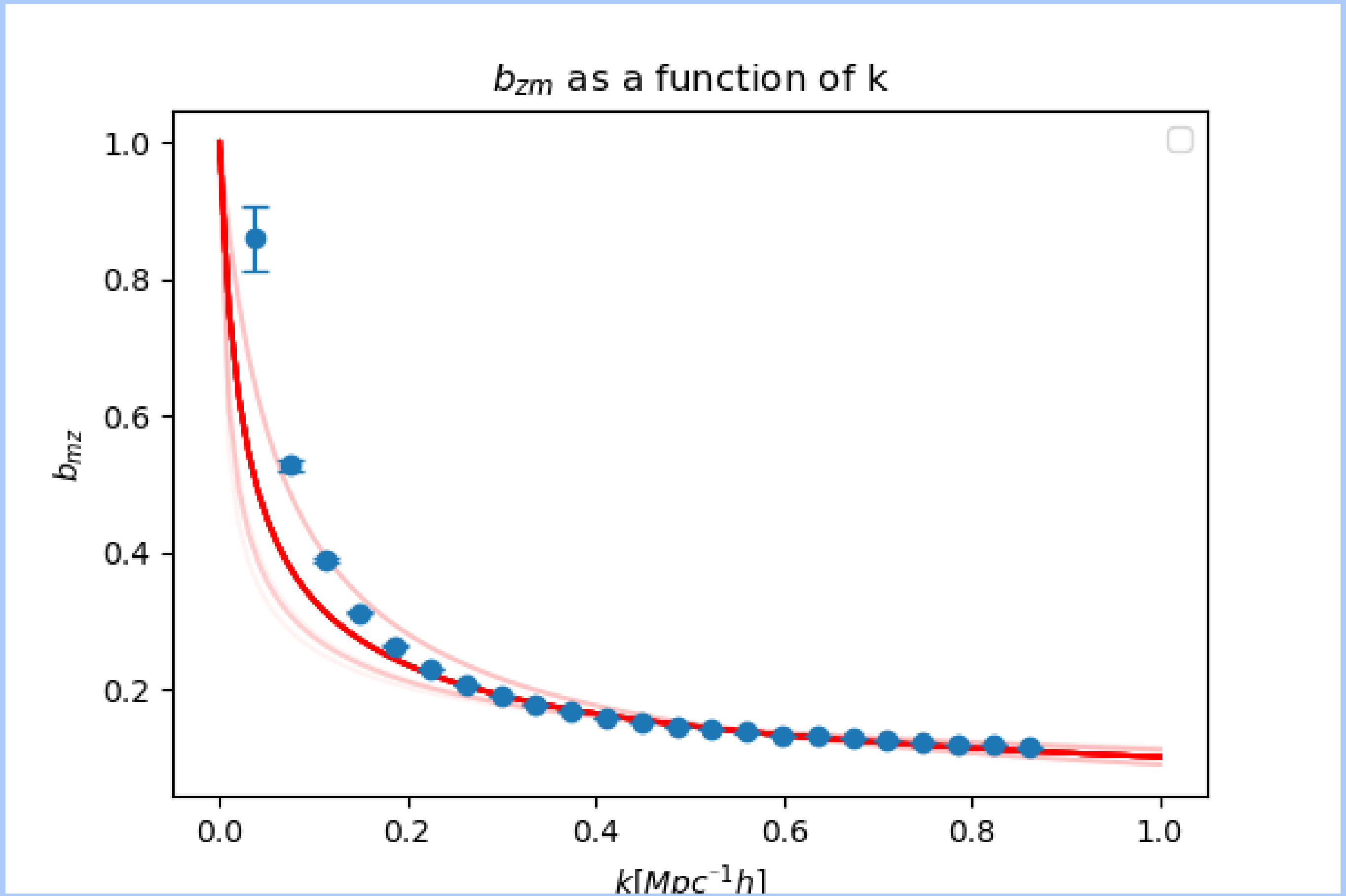


walkers



Where b0 = critical over-density threshold = 0.564

Best fit for 2 parameters



This is only a sample of the walkers

Conclusion

- The algorithm constructed successfully links 21cmFAST with the Battaglia model.

- The Battaglia model's linear bias equation fits well the data of 21cmFAST.

Next steps

- Explore the effect of the variation of 21cmFAST cosmological parameters on these bias parameters (ex. Turnover mass and ionization efficiency)

Questions?

Thank you for your attention!