My PhD cover thesis!

Relating the kinetic Sunyaev-Zel'dovich effect and the 21 cm signal

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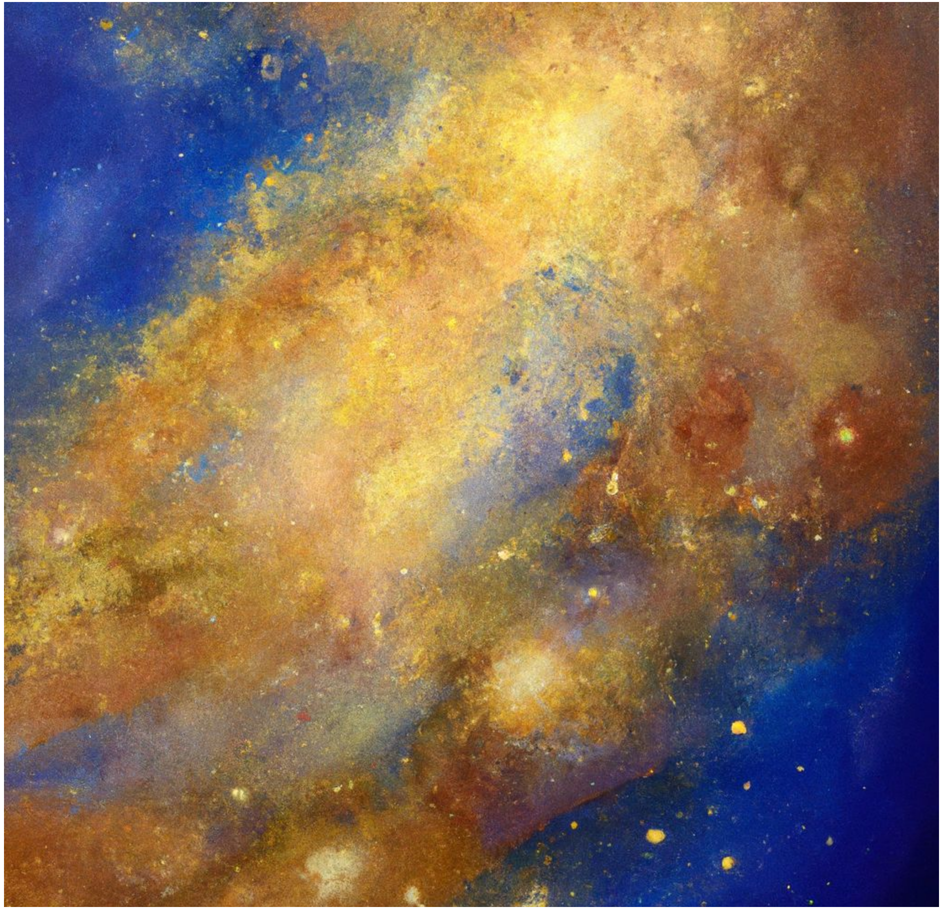
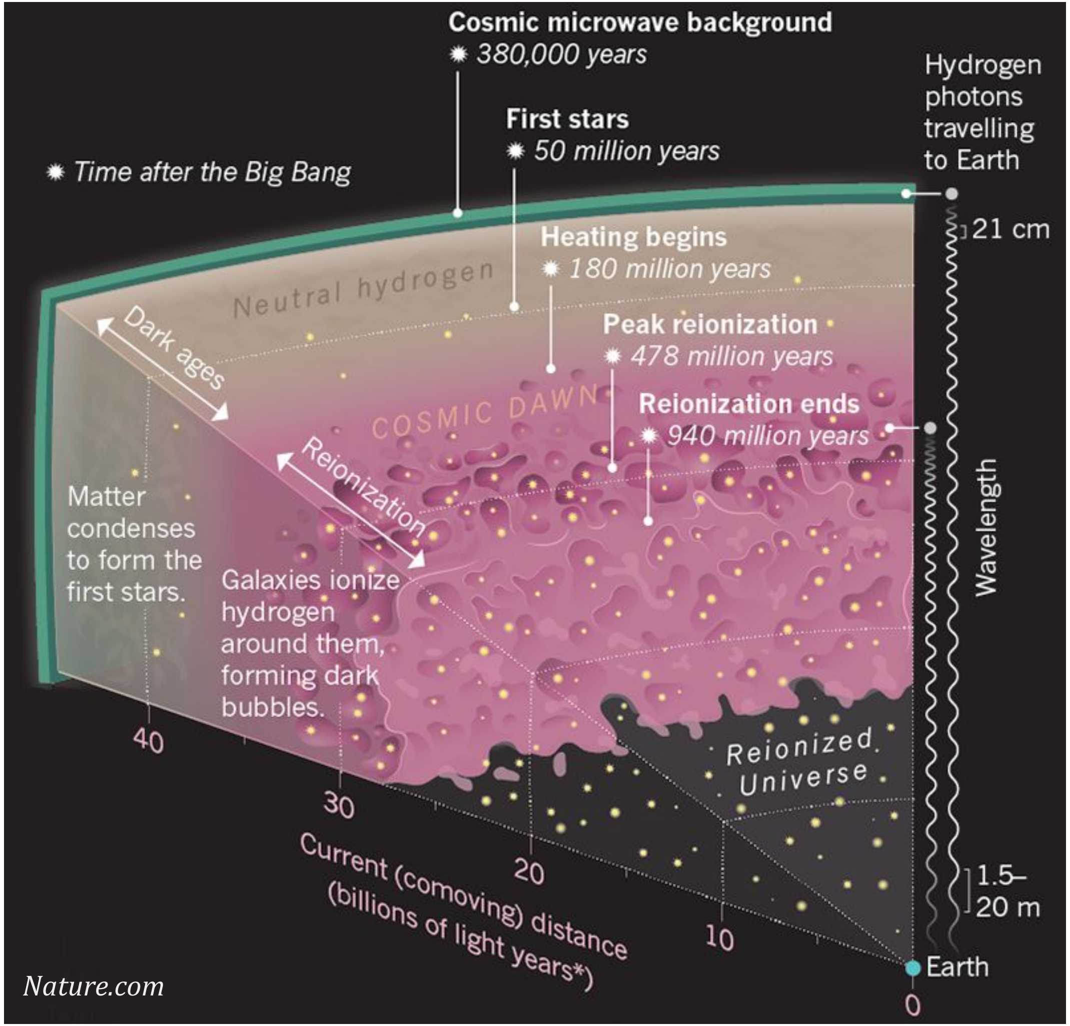


Goals and Motivation

The 21 cm from the IGM, particularly its power spectrum, is a promising probe of the EoR.

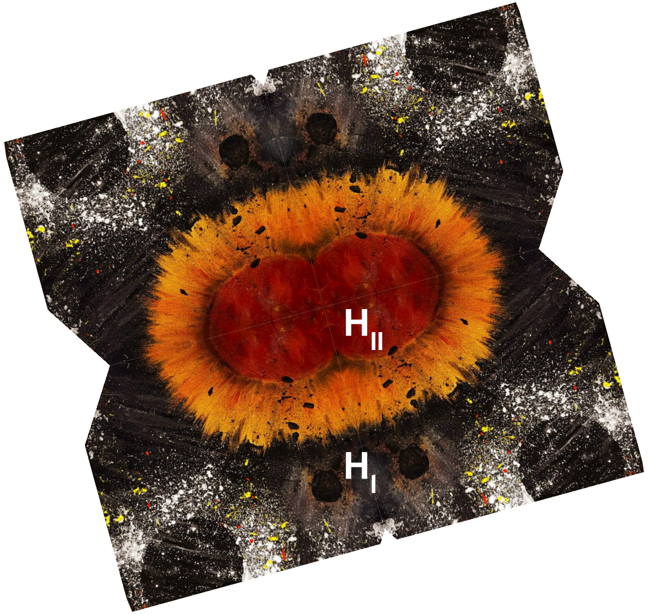
Yet, foreground noise and systematics make its detection and interpretation a difficult task.

Can we conduct a joint analysis of multiple probes of the EoR to infer its properties?



The Epoch of Reionisation

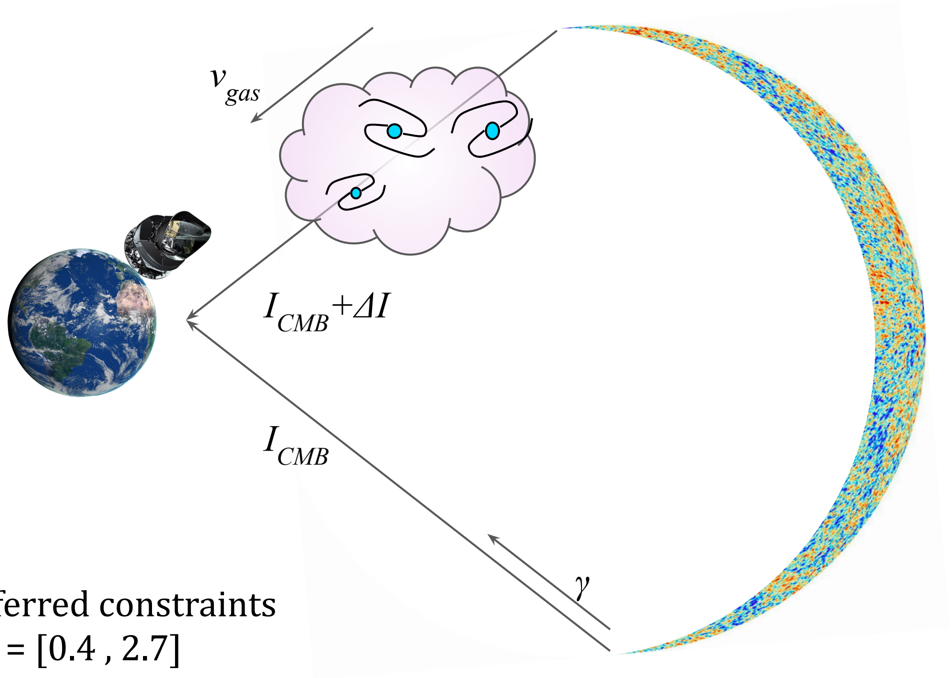
The Epoch of Reionisation (EoR) spans **astrophysical** & **cosmological scales**. The 21-cm signal contains **ionisation** and **density** information.

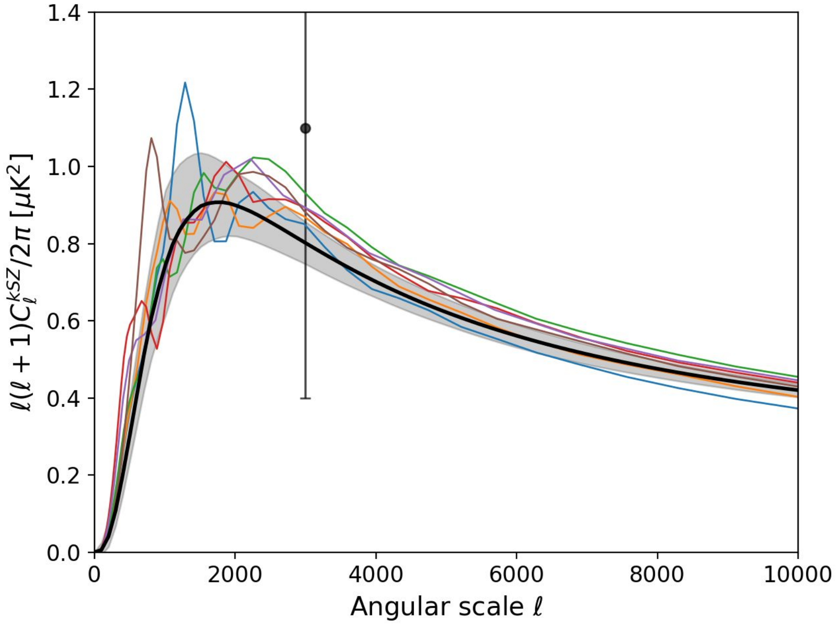


The patchy kinetic Sunyaev-Zel'dovich effect (pkSZ)

During EoR CMB photons **scatter off ionised bubbles** along the LOS.

The pkSZ will be **sensitive to the morphology of reionisation** (e.g. Reichardt+21).



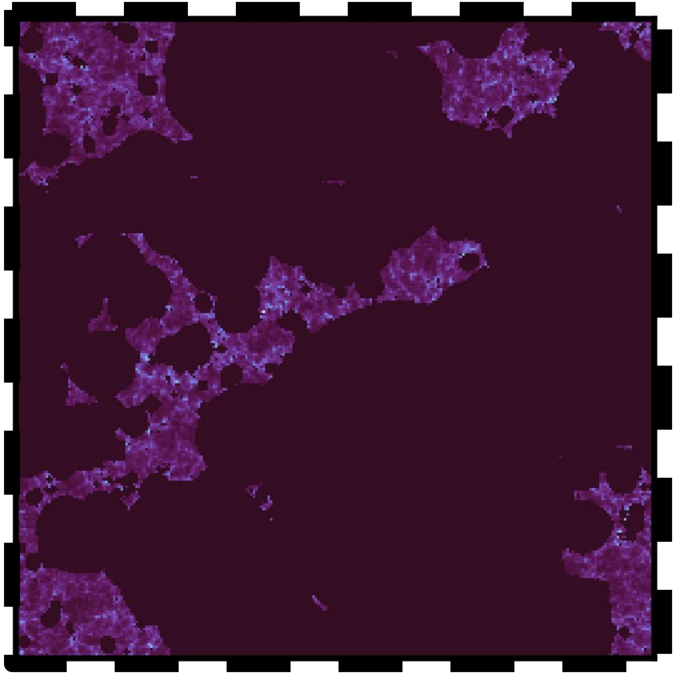


Inferred constraints
$\Delta z = [0.4 , 2.7]$
$\Delta z < 4.1$ (at 95%)

Gorce+20

Relating the 21-cm and the Electron Density Power Spectra

$$\frac{P_{21}(k,z)}{T_0(z)^2\overline{x}_{HIv}(z)^2} = P_{\delta_\rho,\delta_\rho}(k,z) + \overline{x}_{HIIm}(z)^2 P_{ee}(k,z) - 2\overline{x}_{HIIv}(z)\left[P_{\delta_\rho,\delta_\rho}(k,z) + P_{\delta_\rho,\delta_{xHII}}(k,z) + P_{\delta_\rho\delta_{xHII},\delta_\rho}(k,z)\right]$$



See 2110.13190 for the 21-cm Decomposition 😉.

Note that: $\Delta^2_{21cm}(k) = \frac{k^3 P_{\delta_{T_b},\delta_{T_b}}}{2\pi^2}$

Relating the 21-cm and the Electron Density Power Spectra

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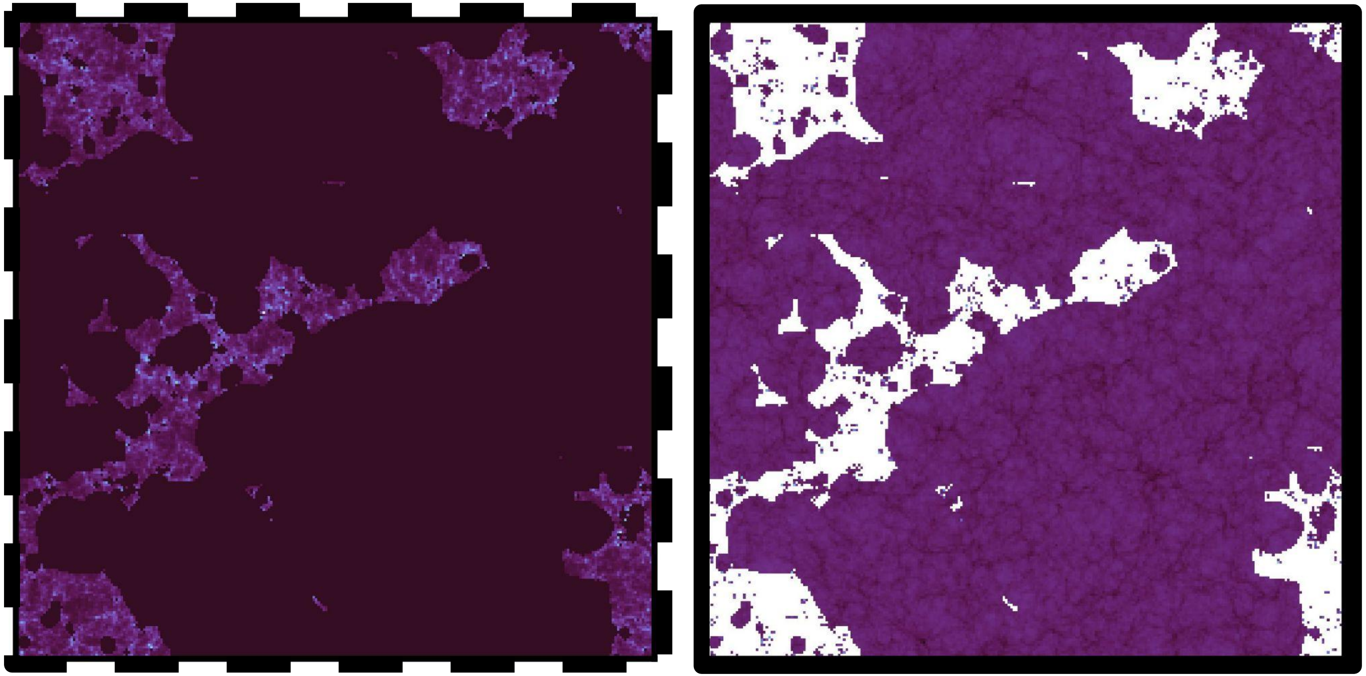

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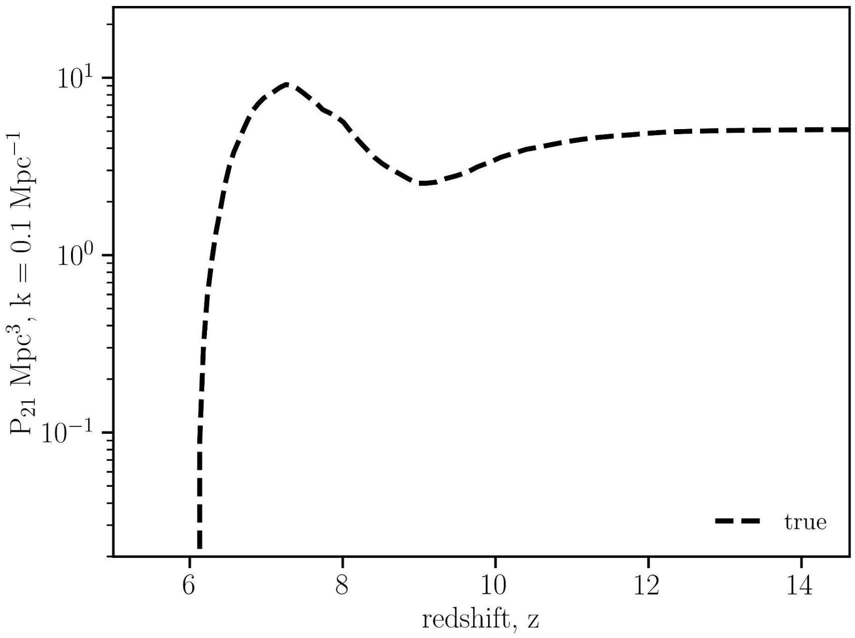

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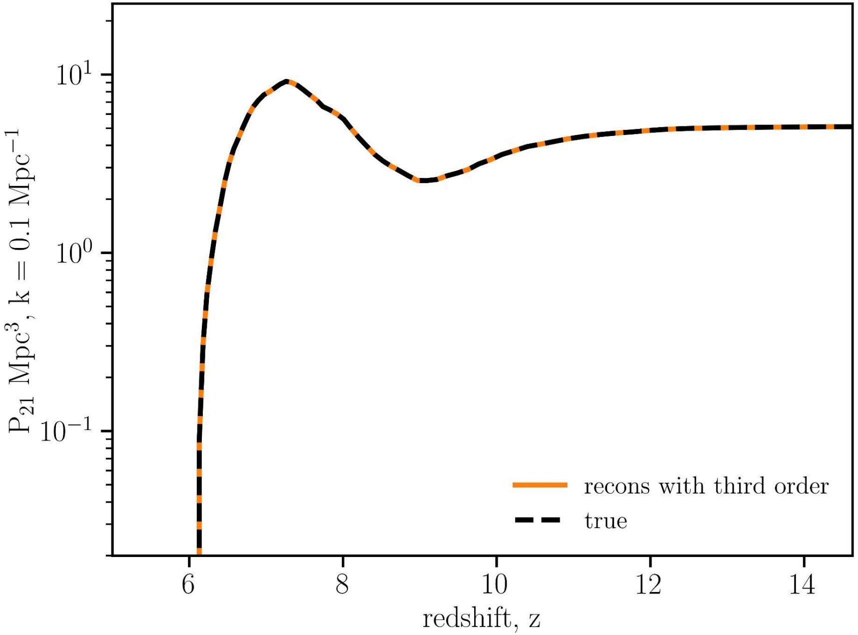
The full model matches the $\mathbf{P_{21}}$ amplitude and shape during the EoR.



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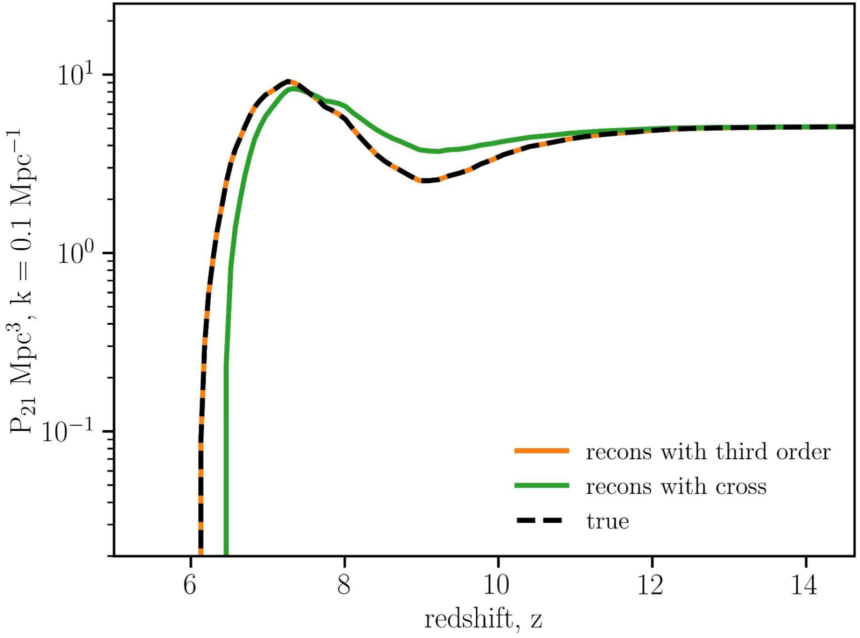
The green model only matches some of the $\mathbf{P_{21}}$ features and differs with *k*-scale.



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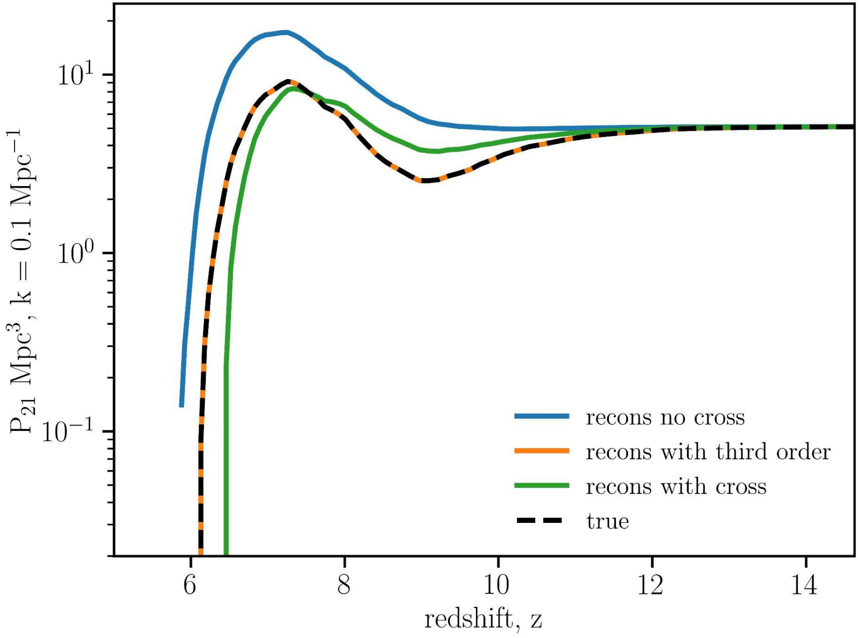
The Simplest model overestimates the $\mathbf{P_{21}}$ amplitude and duration of the EoR **but in a self-consistent manner.**



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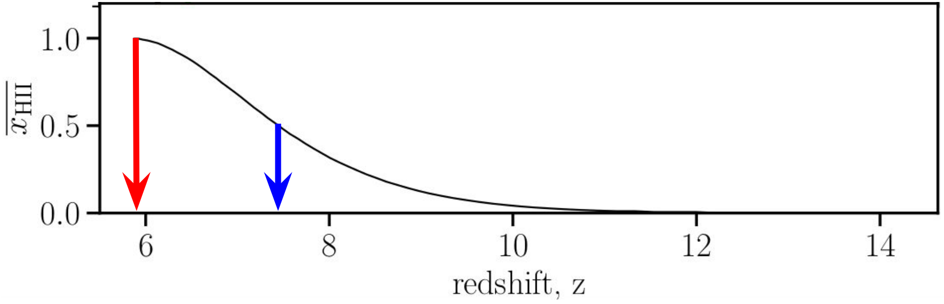
$$P_{ee}(k,z) = [f_{\mathrm{H}} - x_e(z)] \times \frac{\alpha_0\, x_e(z)^{-1/5}}{1 + [k/\kappa]^3 x_e(z)} + x_e(z) \times b_{\delta e}(k,z)^2 P_{\delta\delta}(k,z)$$

Gorce et al. 2020



x_{HII} fit from Douspis+2015

Forecast sample Parameters:

- z_{re}: middle of EoR,
- z_{end}: end of EoR,
- α_0: constant large-scale amplitude $\mathbf{P_{ee}}$ at high-z,
- κ: typical size of ionised regions during reionisation.

$$\frac{P_{21}(k,z)}{T_0(z)^2\overline{x}_{HIv}(z)^2} = P_{\delta_\rho,\delta_\rho}(k,z) + \overline{x}_{HIIm}(z)^2 P_{ee}(k,z) - 2\overline{x}_{HIIv}(z)\left[P_{\delta_\rho,\delta_\rho}(k,z) + P_{\delta_\rho,\delta_{xHII}}(k,z) + P_{\delta_\rho\delta_{xHII},\delta_\rho}(k,z)\right]$$

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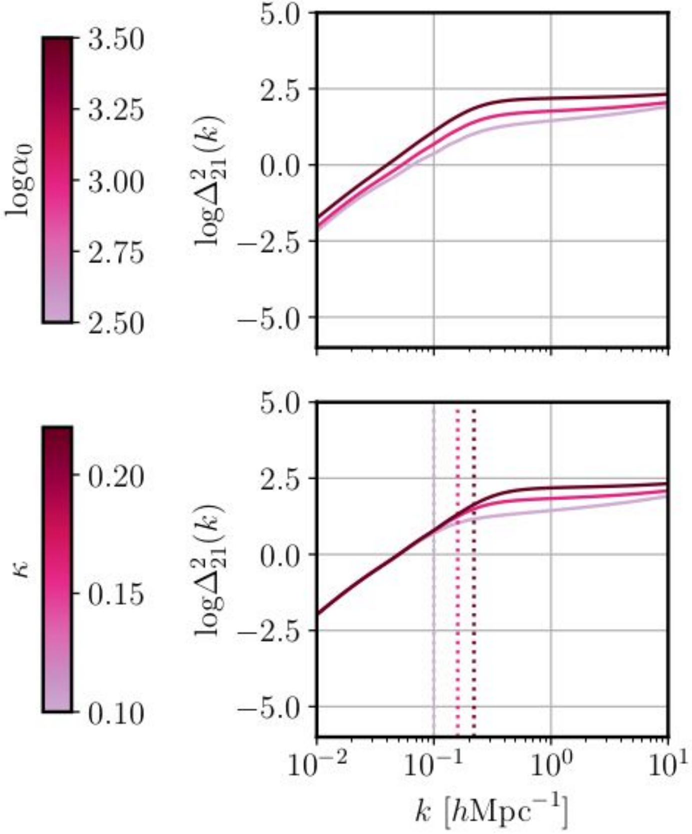
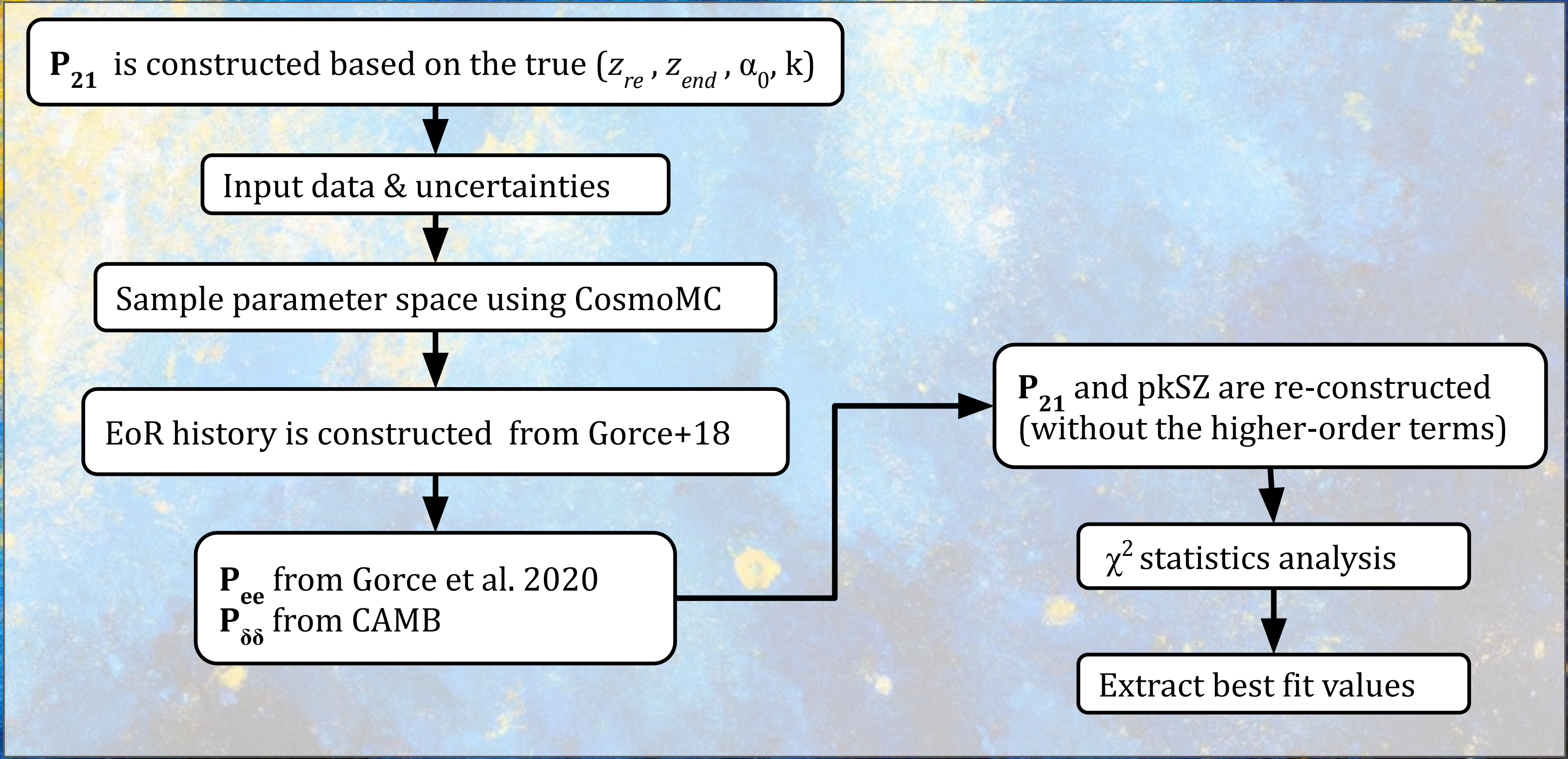


Forecast sample Parameters:

- α_0 constant large-scale amplitude $\mathbf{P_{ee}}$ at high-z,
- κ typical size of ionised regions during reionisation.

Forecast Overview



An Intuitive test of the forecast

We set our goal on early stage detections of $\mathbf{P_{21}}$.

$\mathbf{P_{21}}$ data points at z = 6.5, 7.8 for k = 0.5 Mpc^{-1} for 1000 h integration time with the SKA.

One patchy kinetic Sunyaev-Zel’dovich (**pkSZ**) data point at *l~3000* with a 10% uncertainty, motivated by the observation by Reichardt+21.

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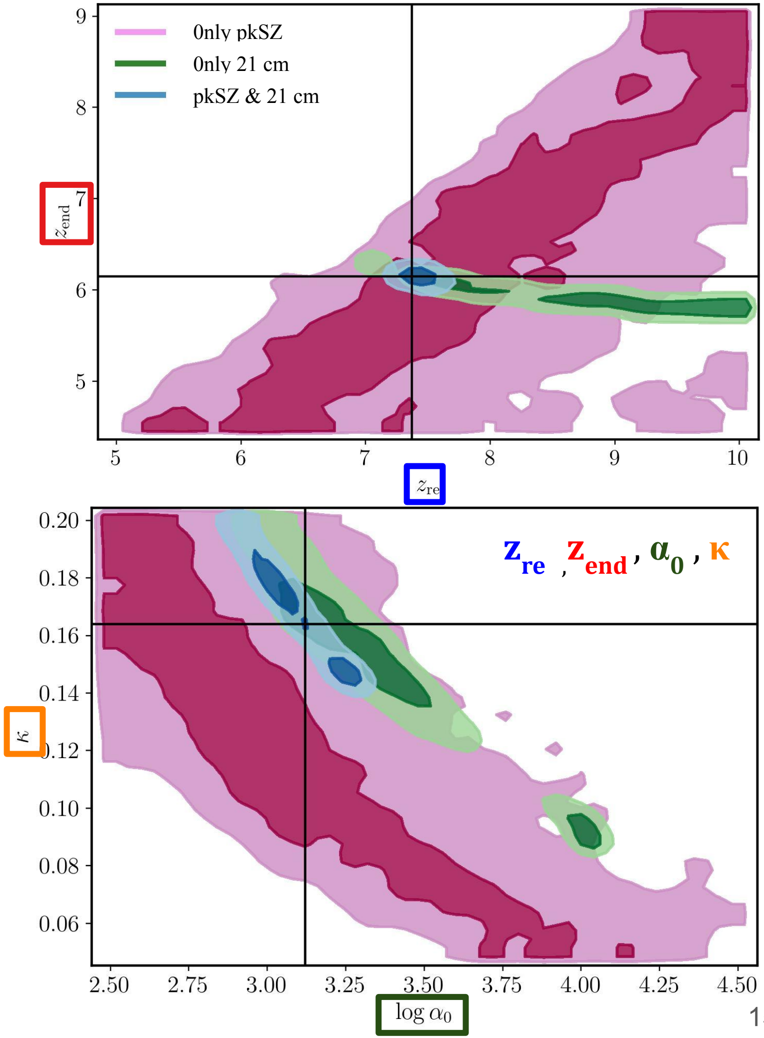
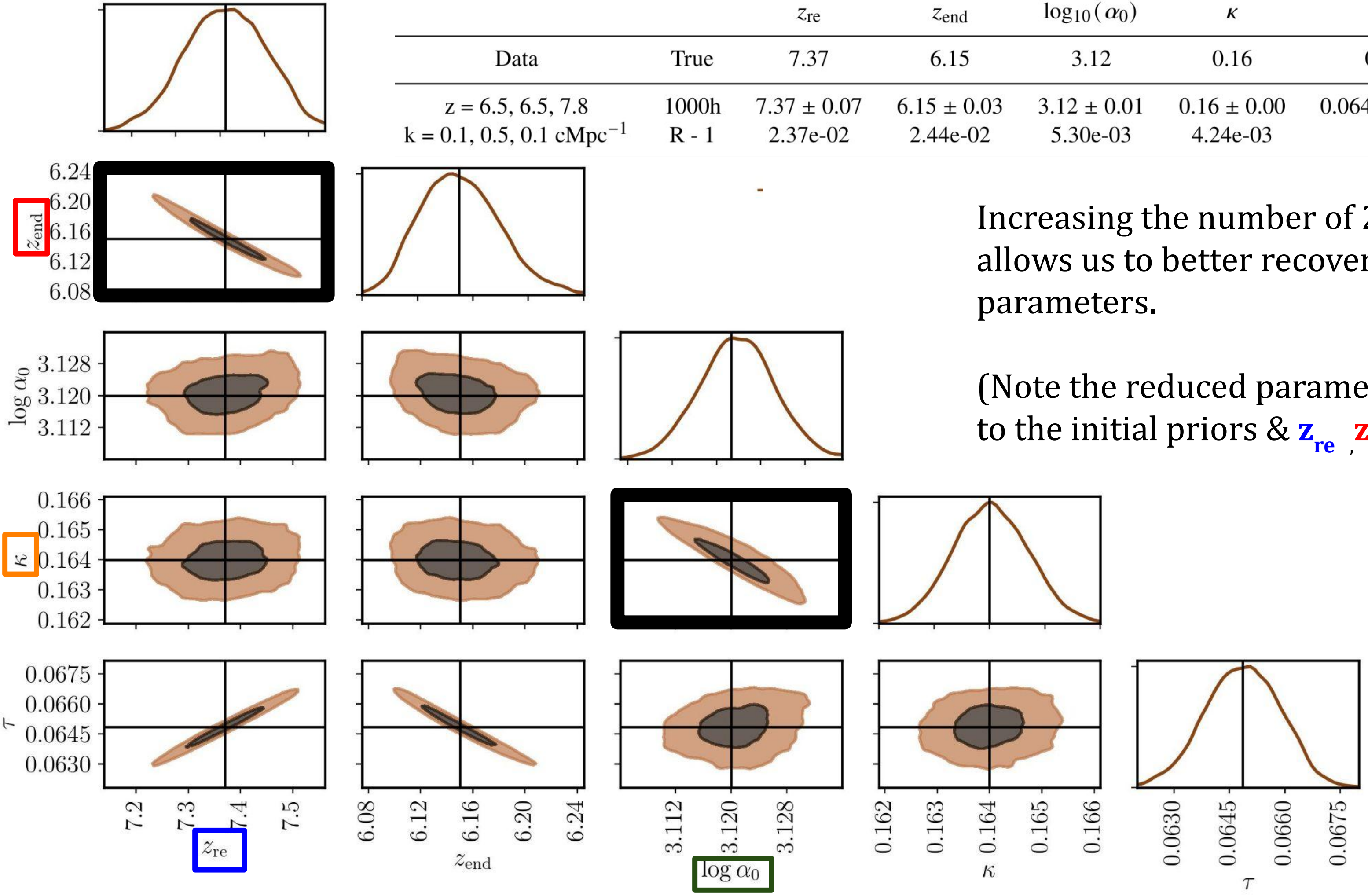
One **pkSZ** data point at *l~3000* with a 10% uncertainty, motivated by the observation by Reichardt+21.

The pkSZ only case sensitive to the duration of reionization.

The 21cm only case gives us upper limits on z_{end} and lower limits on z_{re}.



		z_{re}	z_{end}	$\log_{10}(\alpha_0)$	κ	τ	dz
Data	True	7.37	6.15	3.12	0.16	0.0649	1.22
z = 6.5, 6.5, 7.8 k = 0.1, 0.5, 0.1 $cMpc^{-1}$	1000h R - 1	7.37 ± 0.07 2.37e-02	6.15 ± 0.03 2.44e-02	3.12 ± 0.01 5.30e-03	0.16 ± 0.00 4.24e-03	0.0649 ± 0.0010 N/A	1.22 ± 0.10 N/A



Increasing the number of 21-cm data points allows us to better recover the EoR parameters.

(Note the reduced parameter space compared to the initial priors & z_{re} , z_{end} , α_0 , κ)

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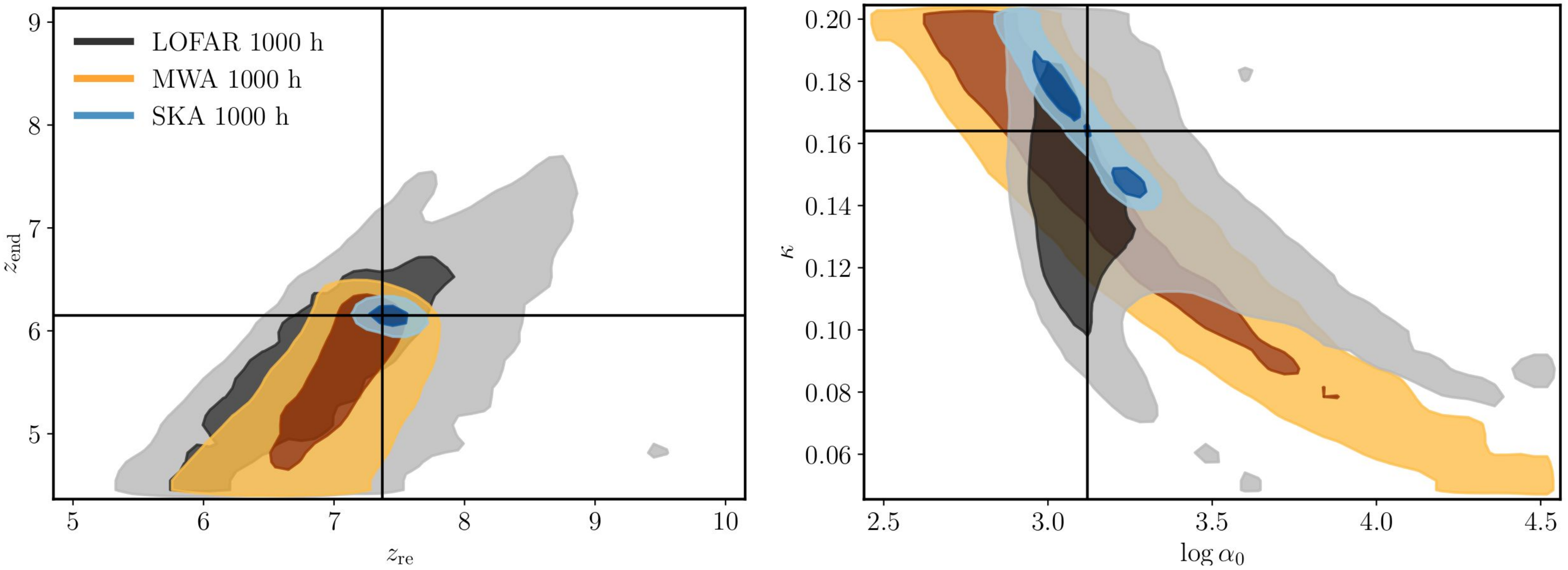
LOFAR-MWA Case



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I'm looking for the 21 cm signal from the EoR as well as postdoc opportunities. Have a chat with me if you're interested!

Summary and Conclusions

The natural connection between $\mathbf{P_{21}}$ and $\mathbf{P_{ee}}$ allows us to relate the patchy kSZ to the 21-cm signal from the EoR.

We built a forecast methodology to extract information on the nature of reionisation, given measurements of each data set.

The kSZ data allows us to verify inferences from the 21 cm data.

Thank you!

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A curious side note regarding cross-correlations

$$P_{eb}(k,z) \propto P_{bb}(k,z) + P_{bi}(k,z) + P_{bi,b}(k,z)$$

We can re-express the higher-order terms as the cross correlation between the electron and the density field

Interesting connection to the galaxy bias!

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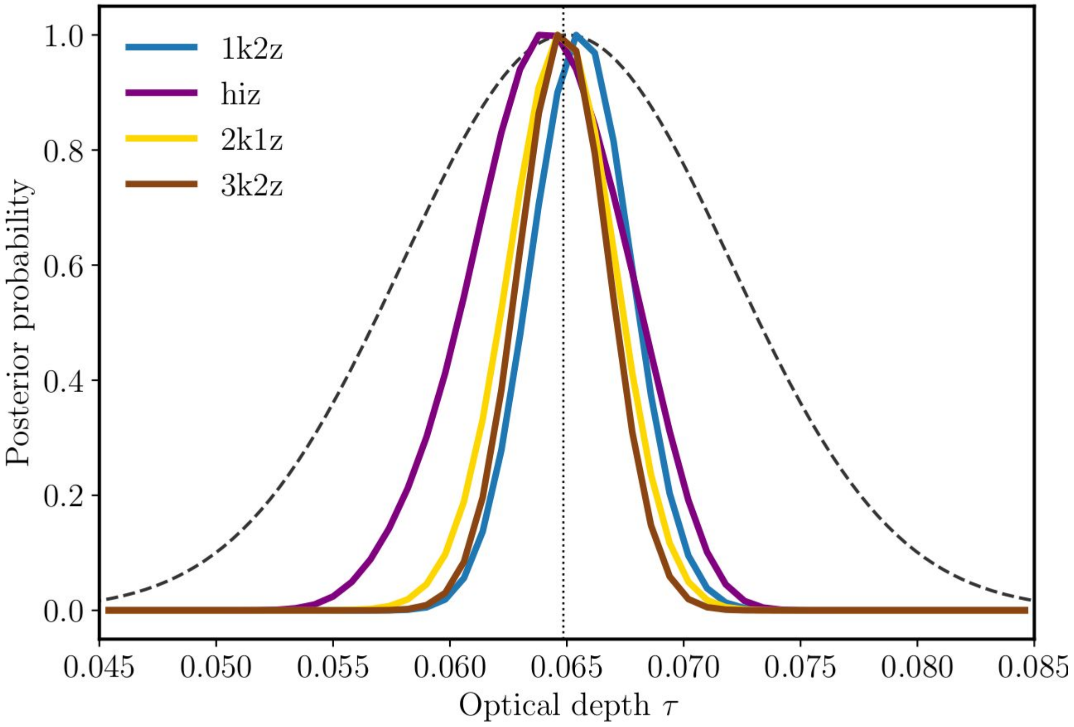
Constraining/Including the Thomson optical depth



The forecast is naturally complimented by constraints on τ.