

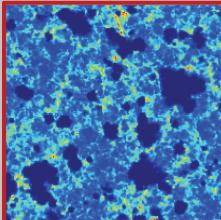
Statistics for signal extraction from the Epoch of Reionization

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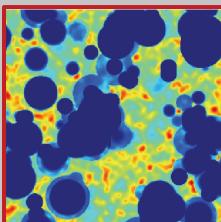
Summary

The study of 21cm radiation from the Epoch of Reionization (EoR) poses many observational and theoretical challenges. The first detection of the transition of the IGM from being mostly neutral to mostly ionized from radio interferometry is likely to be of a statistical nature. This raises the question of precisely which statistics to use. We suggest that the skewness of the cosmological 21cm signal may provide a route to a detection, and demonstrate the extraction of a signal from datacubes combining realistic models for the redshifted 21cm signal from the EoR, galactic and extragalactic foregrounds, the LOFAR instrumental response, and noise.

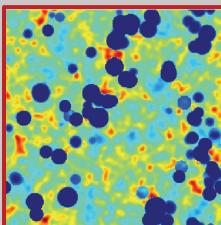
Cosmological signal simulations



1. Simulation f250C from Iliev et al. (2008), pictured here at $z=7.98$. Dark matter from PMFAST, radiative transfer using C²-RAY



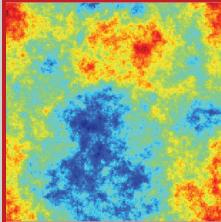
2. Reionization by QSOs, modelled using GADGET2 and a one-dimensional radiative transfer code (Thomas & Zaroubi 2008). Shown at $z=10.18$.



3. As above, but with reionization driven by stars rather than QSOs. Reionization is more gradual with more, smaller sources.

All our simulations have a comoving size of $100 h^{-1}$ Mpc and WMAP3-like parameters. Typical rms fluctuations are approx. 10 mK.

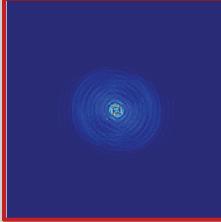
Foregrounds



Galactic and extragalactic foregrounds as described by Jelić et al. (2008), shown here at 150 MHz. The area of $5^\circ \times 5^\circ$ on the sky

corresponds to the area of one LOFAR EoR window. Typical rms fluctuations are approx. 2 K.

Instrumental response and noise

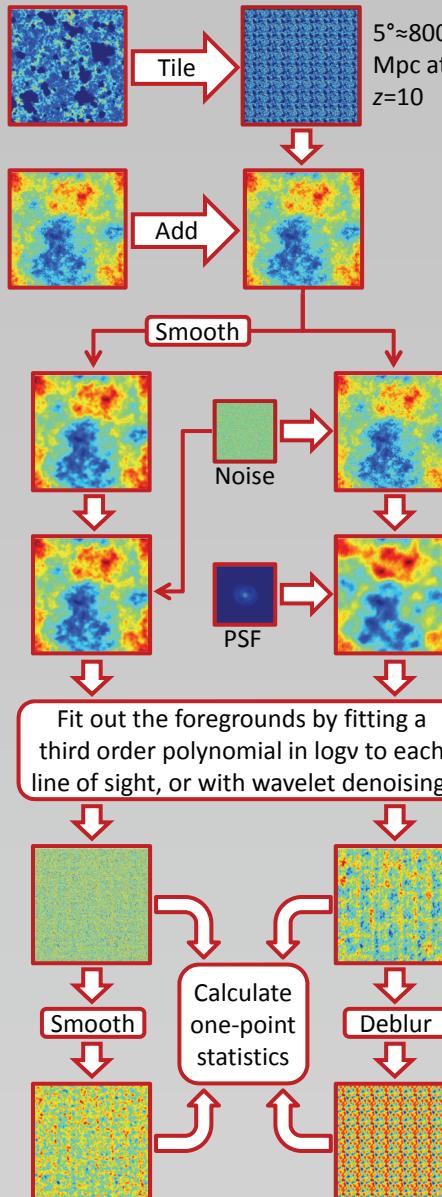


The sampling function, showing the expected density of measured points in the uv-plane for LOFAR. Because the noise on each

visibility is independent, this means that the noise in the image plane is correlated. Finding its precise properties requires a full inversion, but we study two simplified cases: uncorrelated noise in the image plane, and noise convolved with the PSF derived from the sampling function. The noise rms is approx. 50mK at 150 MHz.

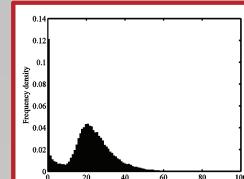
Method

All the steps below are illustrated for one frequency channel: slices are separated by 0.5 MHz and span the range 115-200 MHz.



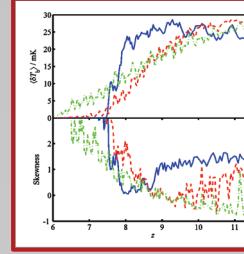
The case for uncorrelated noise is shown on the left. Smoothing here is done with a Gaussian kernel with the width of the LOFAR resolution. The more realistic case is shown on the right, though we do assume constant uv coverage with frequency. Deblurring (by Wiener deconvolution) requires knowledge of the correlation matrix of the signal and the noise.

Results

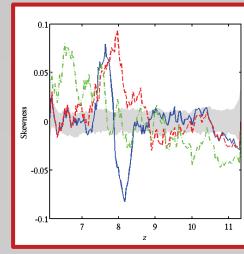


The one-point distribution of δT_b in simulation 1 at a redshift of 8.98.

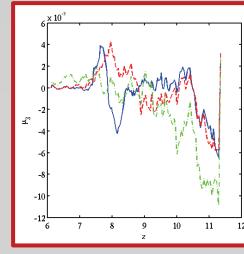
Note the positively skewed bulge of high- δT_b points and the δ -function at zero.



The evolution of the mean δT_b (top) and the skewness (bottom) in simulations 1 (solid blue line), 2 (dashed red line) and 3 (dot-dashed green line). The skewness exhibits a dip or minimum, followed by a rise at low redshift.



The evolution of skewness in the smoothed residuals for the case of uncorrelated noise, and polynomial fitting in logv. Line colours and styles are as described above. The grey area shows the errors, calculated using 100 realizations of a datacube with foregrounds and noise but no signal. We see similar results if the foregrounds are removed by filtering rather than fitting, and for the more realistic 'dirty' maps. Over-fitting means extraction using the variance is hard.



Similar to the last figure, but showing the unnormalized third moment of the distribution. At high z it is not suppressed by the increased variance.

Conclusions

One-point statistics, especially the third moment, will be useful for signal extraction as well as to distinguish different models of reionization. The skewness outperforms other statistics (including kurtosis and variance) in this respect, and is robust to errors in fitting and noise estimation.

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- References
Iliev I.T., Mellema G., Pen U.-L., Bond J.R., Shapiro P.R., 2008, MNRAS, 384, 863
Jelić V., Zaroubi S., Labropoulos P., Thomas R. M., Bernardi G., Brentjens M., de Bruyn G., Ciardi B., Harker G., Koopmans L.V.E., Pandey V., Schaye J., Yatawatta S., 2008, MNRAS, accepted (astro-ph/0804.1130)
Thomas R.M., Zaroubi S., 2008, MNRAS, 384, 1080



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