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Optimal compression of the 21cm signal

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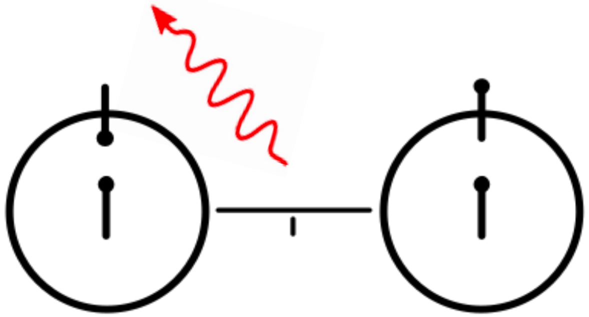
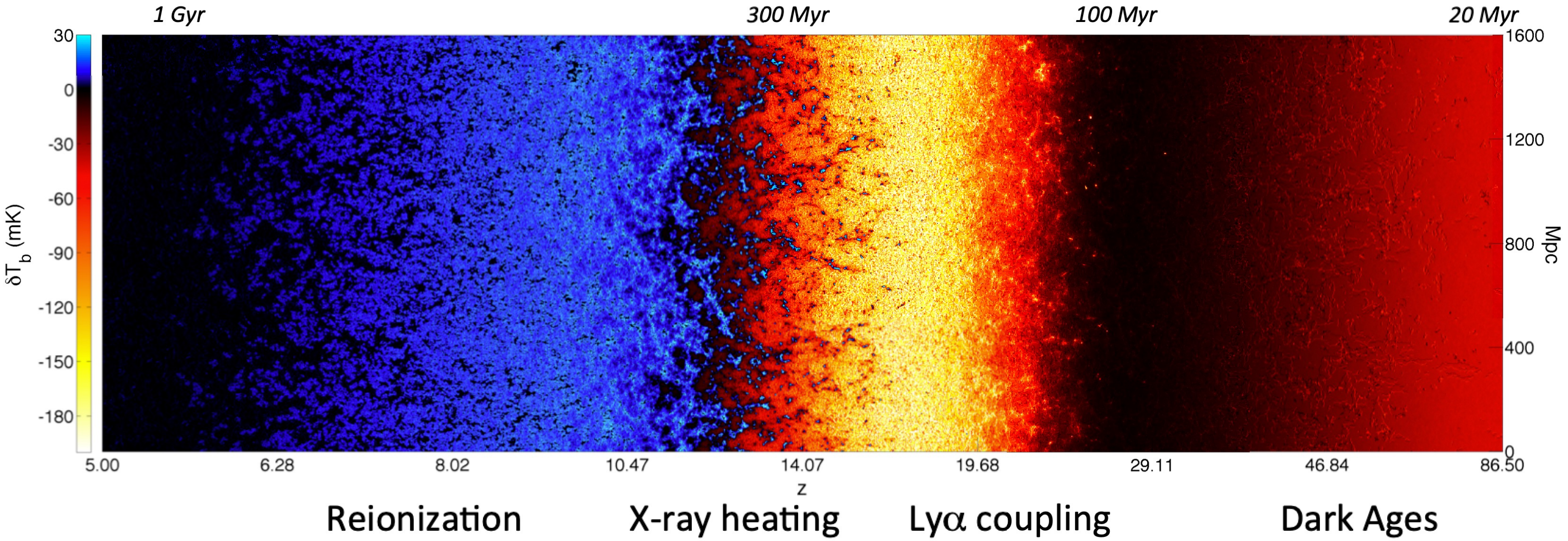
Cosmological 21cm signal



- cosmo. + astro.

$$\delta T_b \approx 30\, x_{\rm HI}\, \Delta \left(\frac{H}{dv_r/dr + H}\right)\left(1 - \frac{T_\gamma}{T_{\rm S}}\right)\left(\frac{1+z}{10}\,\frac{0.15}{\Omega_{\rm M} h^2}\right)^{1/2}\left(\frac{\Omega_b h^2}{0.023}\right)\,\mathrm{mK}$$

Mesinger+2016



How to infer properties?

(Non)Gaussianity – CMB example

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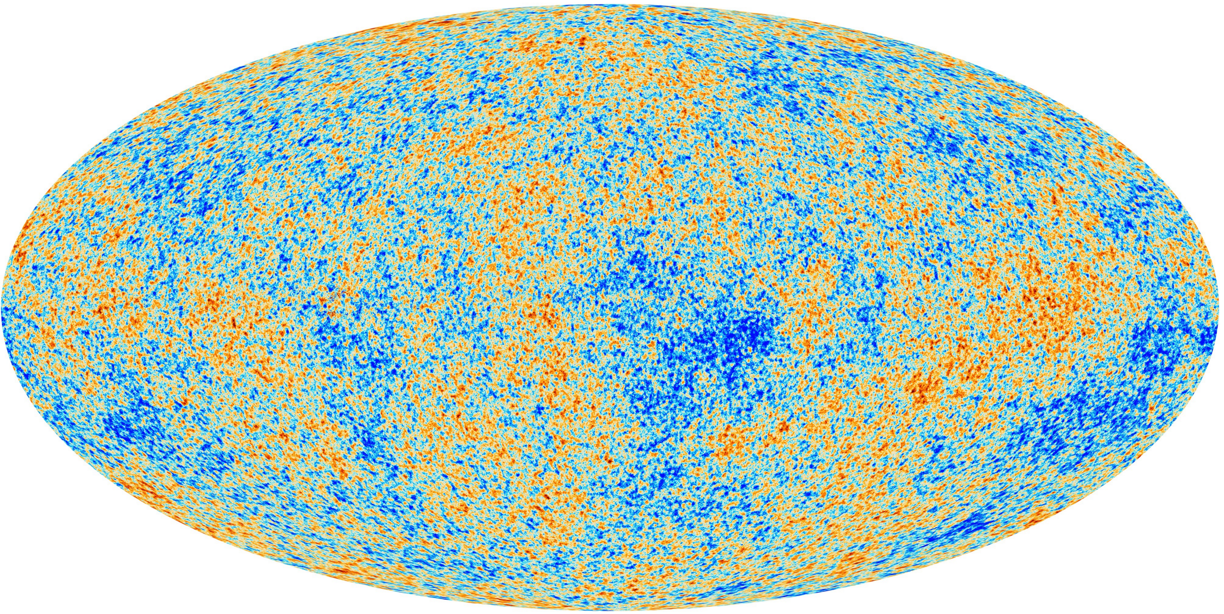
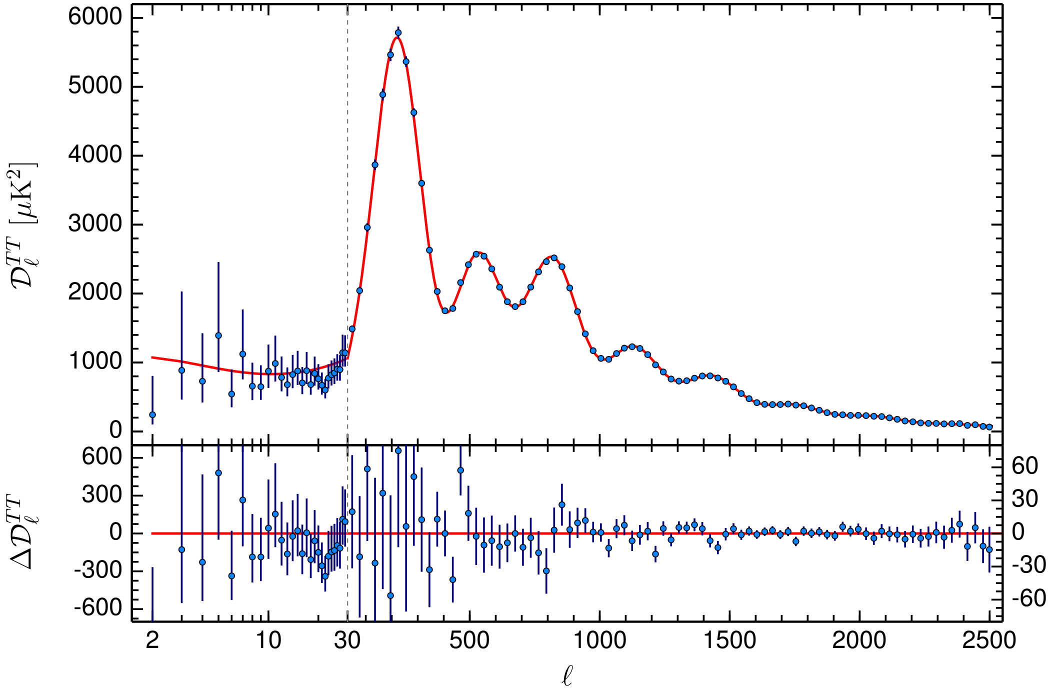
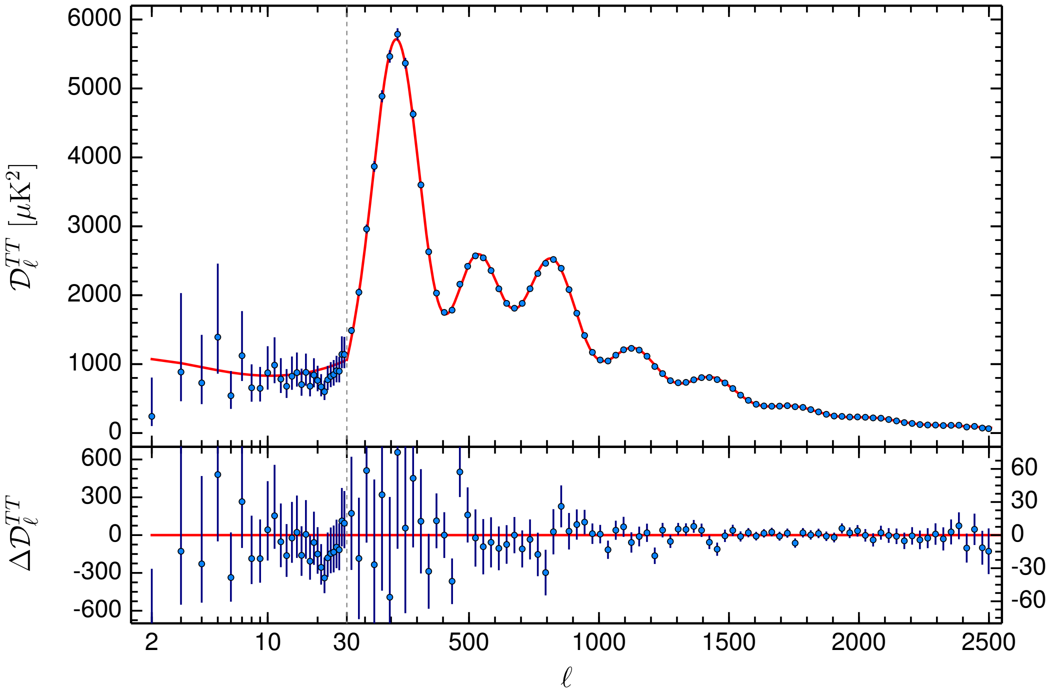


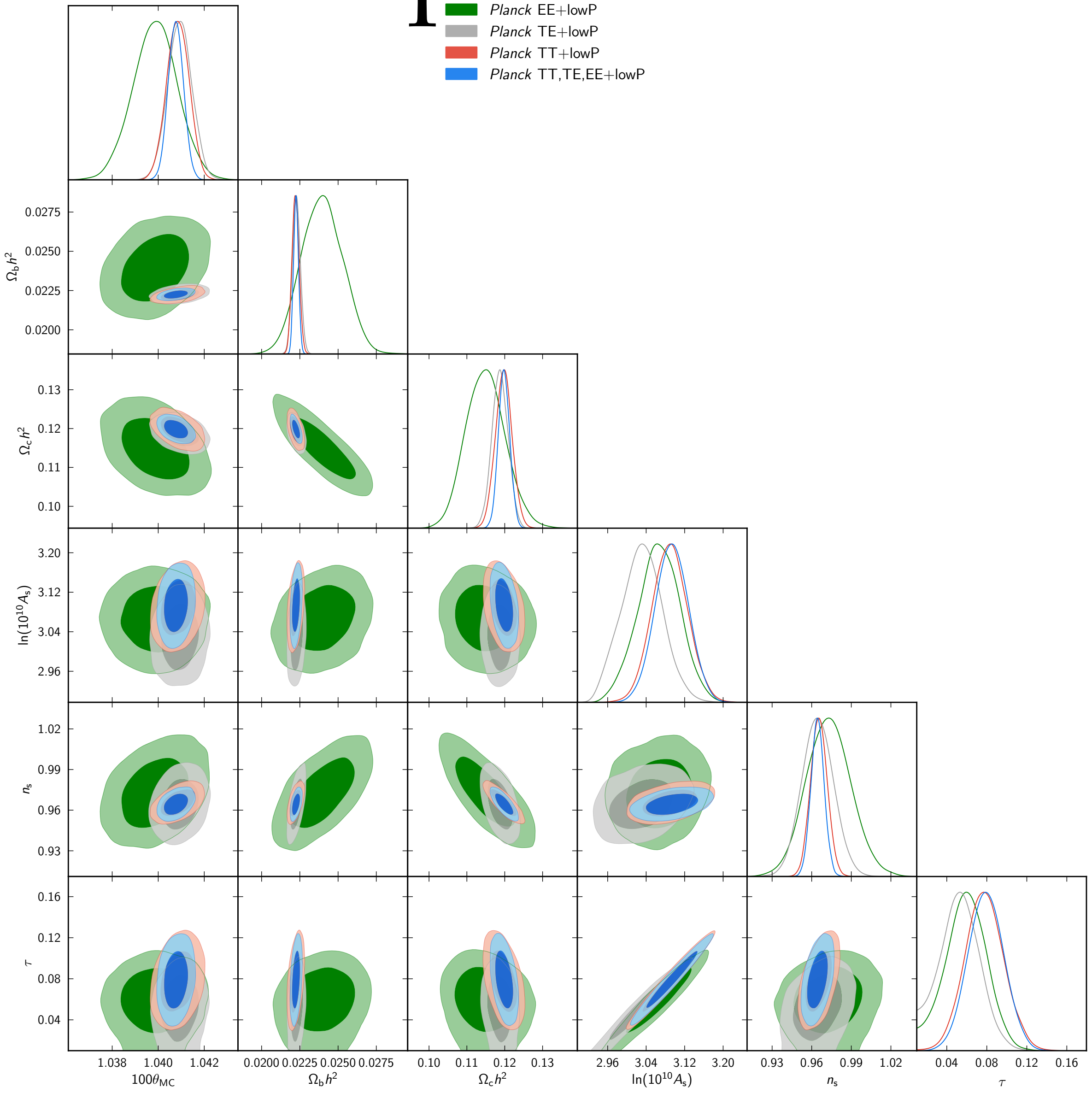


- Full sky map compressed to PS

Planck 2015

(Non)Gaussianity – CMB example

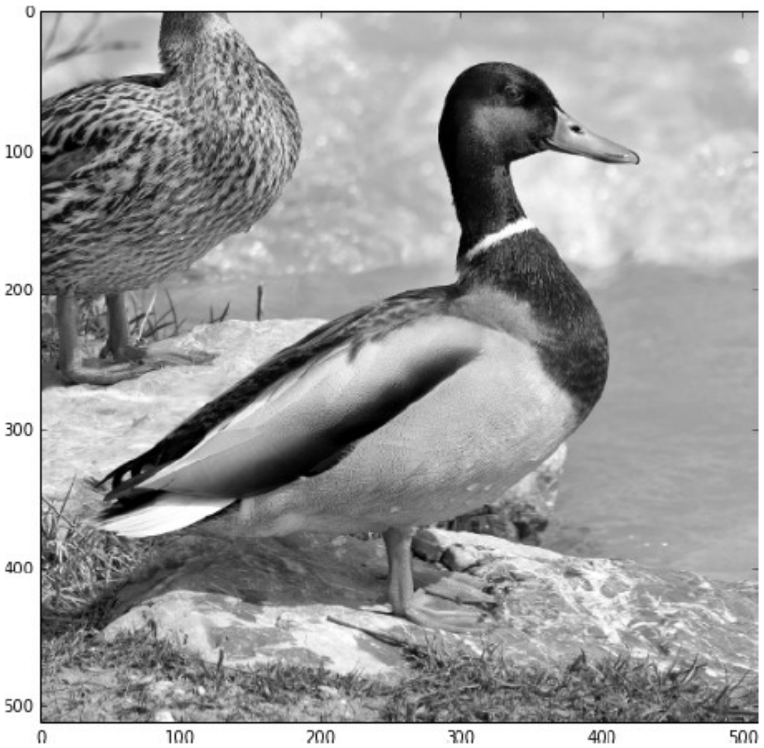




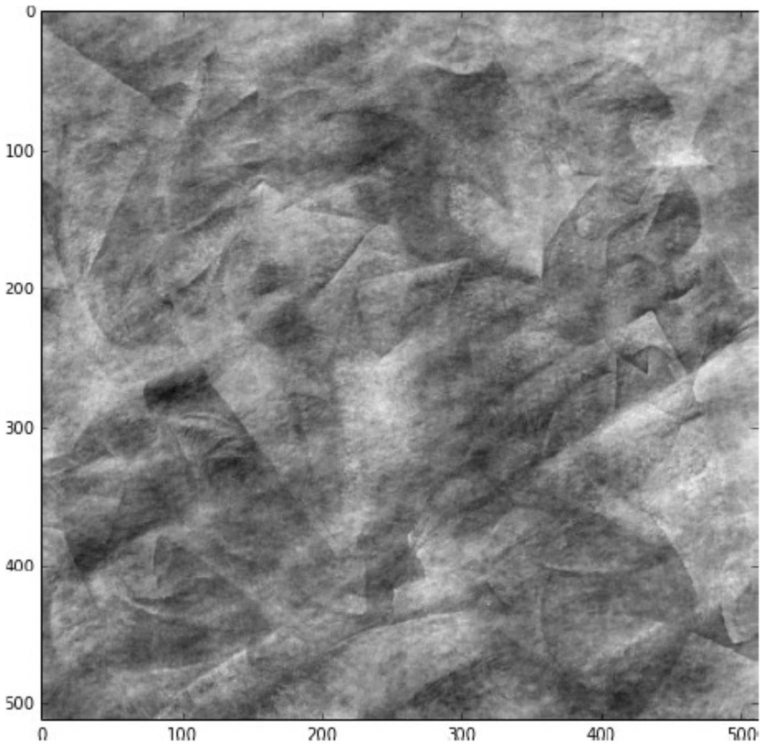
- Full sky map compressed to PS
- From it we infer the cosmology

Planck 2015

(Non)Gaussianity – duck example



change phases



- Same 2D PS
- Highly non-Gaussian

Credit: G. Bernardi

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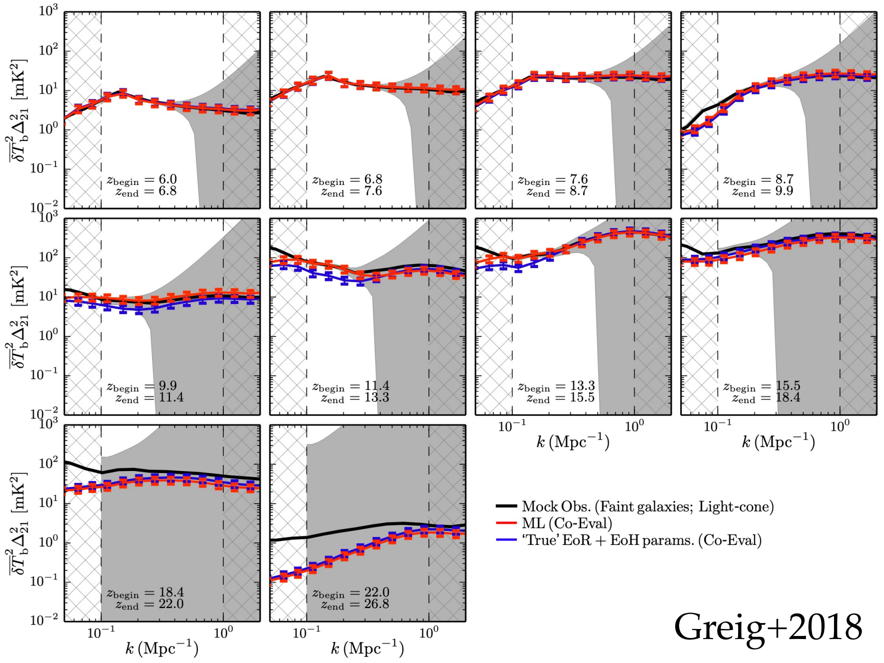
(Non)Gaussianity – 21cm

- Simpler than a duck
  - Power spectrum



Greig+2018

(Non)Gaussianity – 21cm

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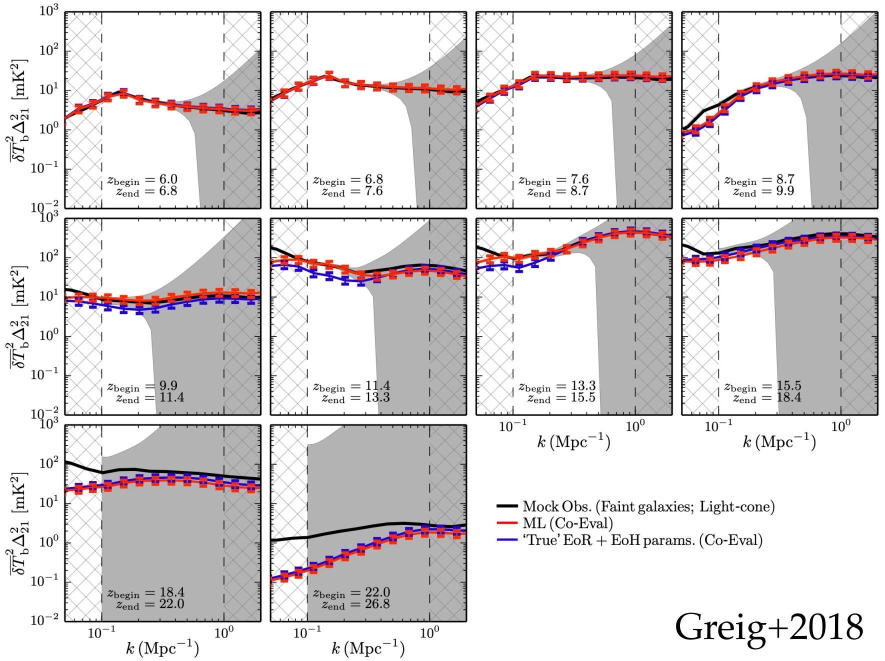

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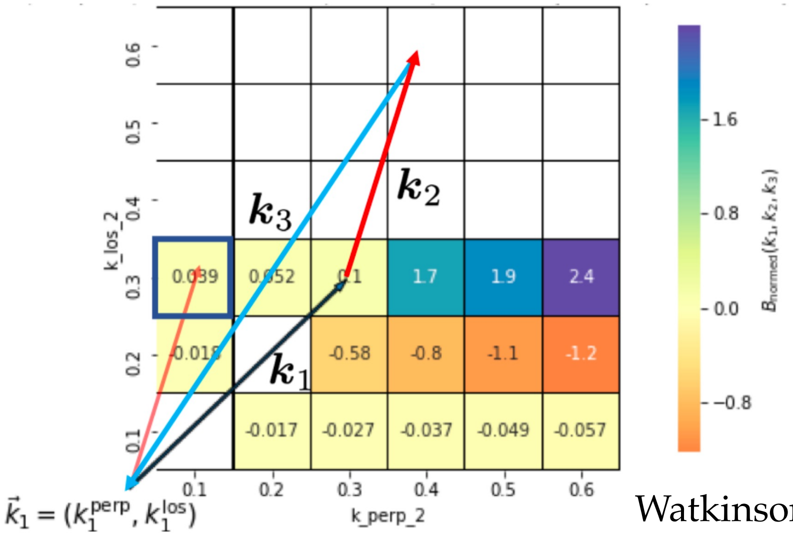
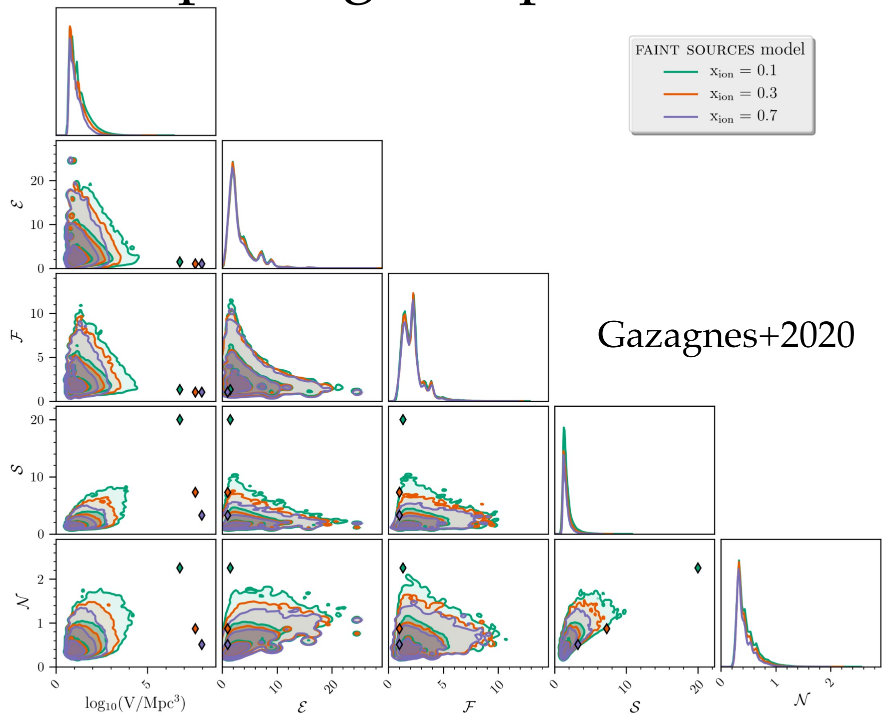


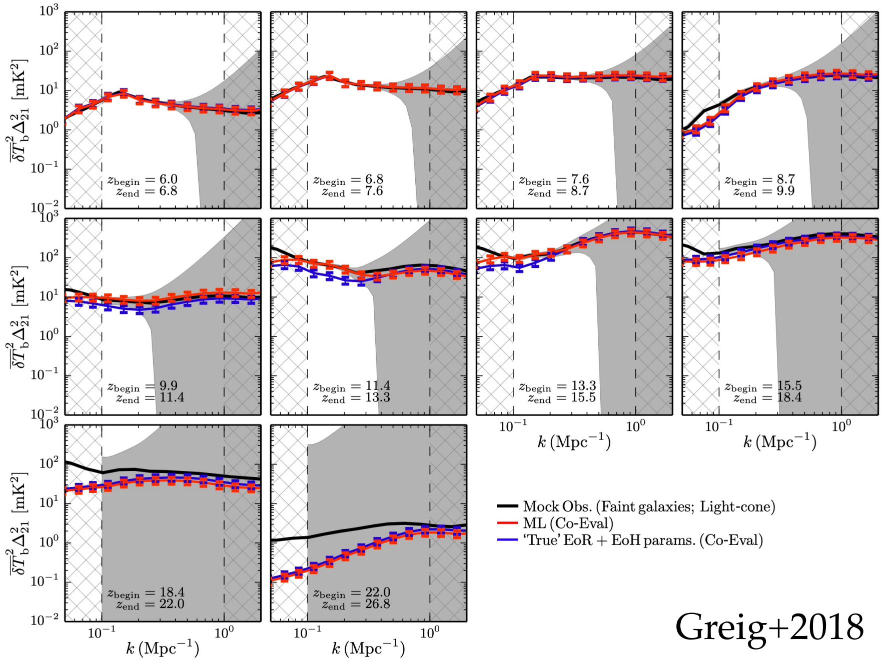
Watkinson+2020

(Non)Gaussianity – 21cm

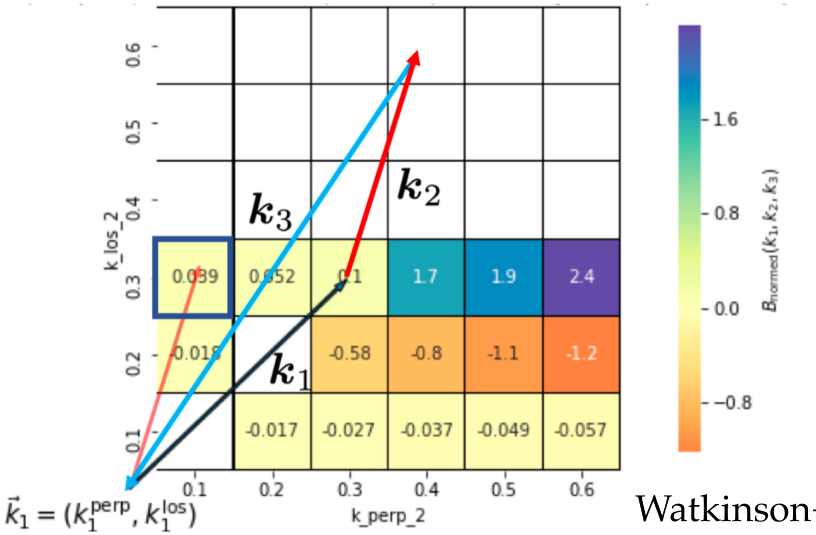
- Simpler than a duck
  - Power spectrum
  - Bispectrum
  - Morphological spectra



Gazagnes+2020



Greig+2018



Watkinson+2020

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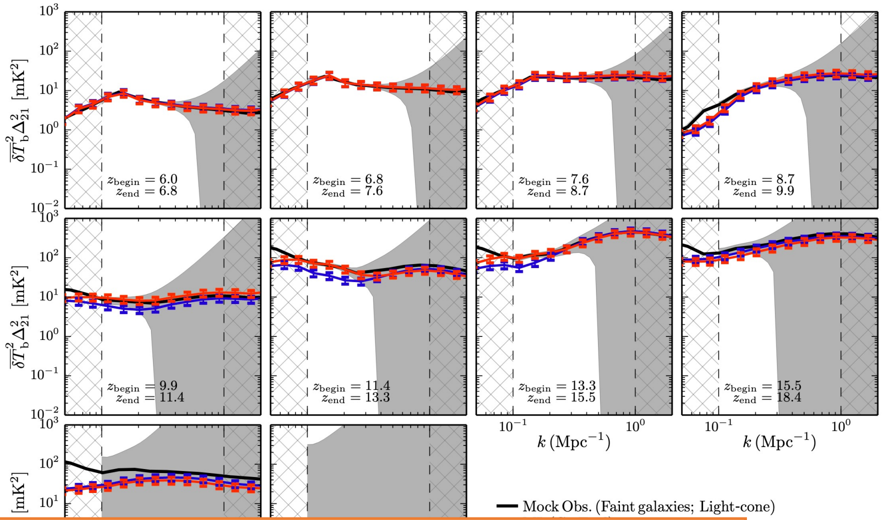
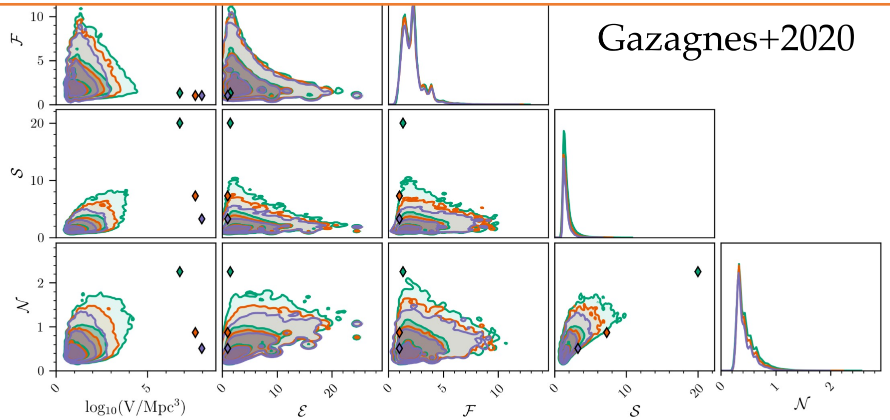
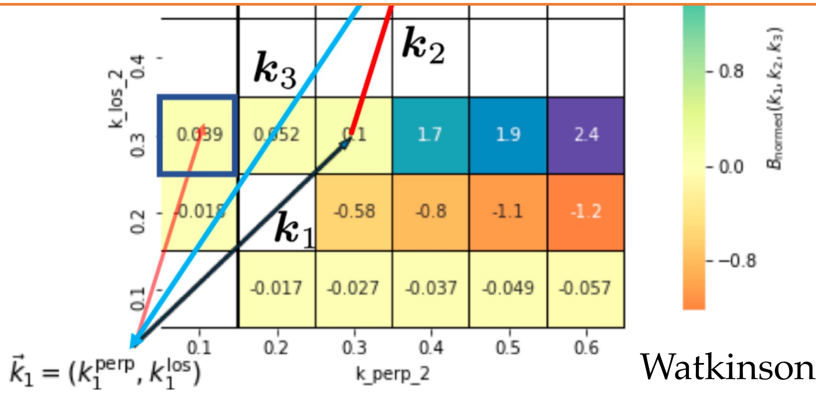


g+2018

Morphological (non-gaussian) statistics DO improve parameter inference!



Gazagnes+2020



Watkinson+2020

Statistics chosen relatively ad-hoc…

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- Without good a-priori physical motivation, we cannot know what is THE optimal summary statistic, i.e. providing tightest recovery of astrophysics and cosmology

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Statistics chosen relatively ad-hoc…

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Solution:

Let the machines figure it out for us!!

(Neural Network)

- Gillet+2018
- La Plante & Ntampaka 2019
- Makinen+2020
- Mangena+2020
- Hortúa+2020

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Neural Network Design?

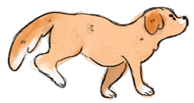
- Different problems require different NN design!

  What about the 21cm Lightcone?

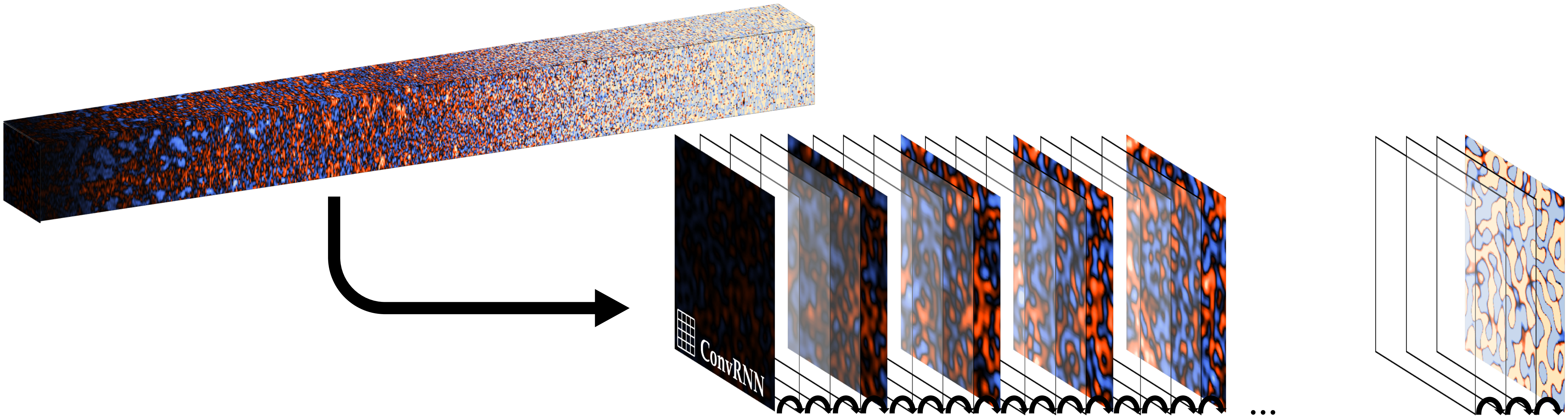
- Convolutional Neural Networks (CNN) – local correlations in images
  - Cats and Dogs

$f($  $) = \text{cat?}$

- Recurrent Neural Networks (RNN) – sequential data
  - Audio/video
  - Language processing

$f($  $) = \text{dog running?}$

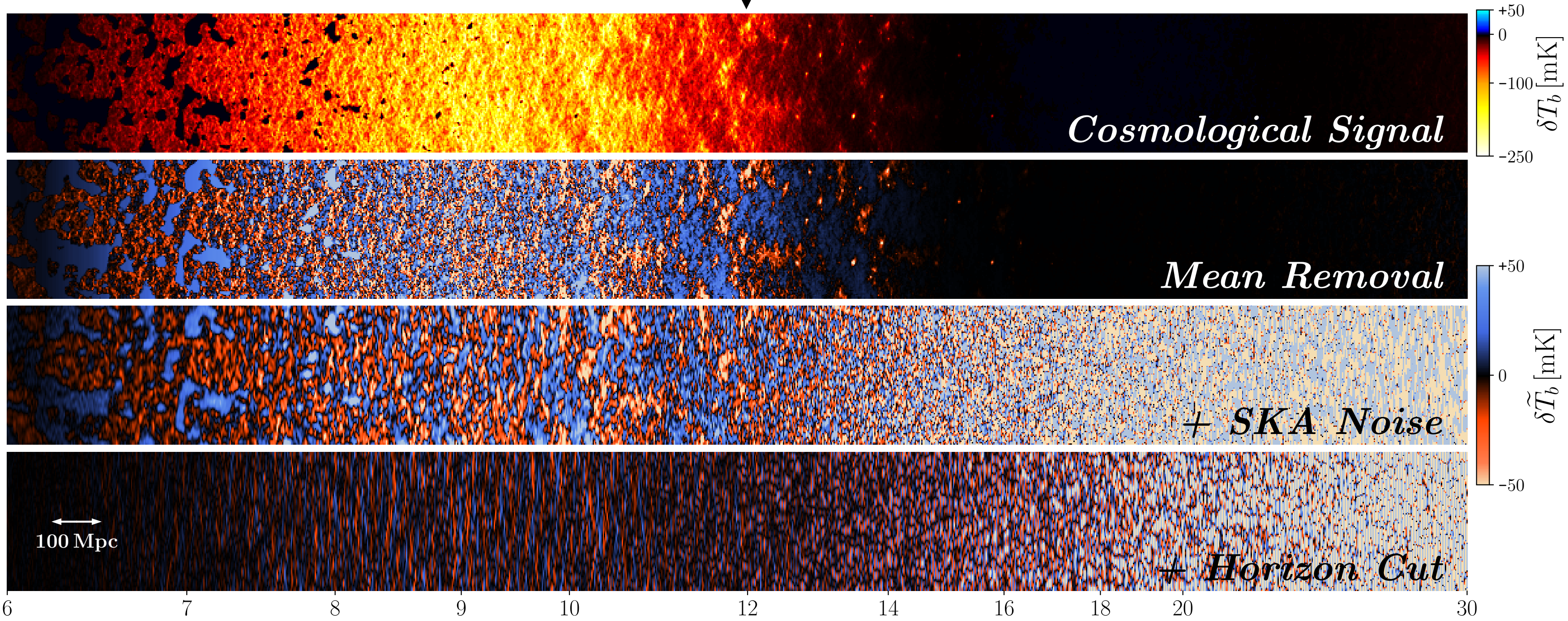
RNN for Lightcone



- RNN – encoding correlations across all frequency bins at once
- 2D Convolutional NN– local correlations in sky-plane

Procedure

10'000 21cmFAST simulations



Three levels of "contamination"

1. SKA not sensitive to global signal
2. UV coverage of SKA and its noise
3. Removing modes contaminated with foregrounds

All NN architectures trained on all three databases

$\zeta = 150,\ T_{vir} = 10^{5.7}\,\mathrm{K},\ L_X/\mathrm{SFR} = 10^{40}\,\mathrm{erg\,s^{-1}\,M_\odot^{-1}\,yr},\ E_0 = 1.2\,\mathrm{keV}$

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Astrophysical parameters

- ζ • UV ionizing efficiency of galaxies
  - timing of reionization
- L_X/SFR • Soft X-ray emmisivity
  - timing of heating
- E_0 • X-ray threshold for abs. by the galaxy
  - morphology of heating
- $T_{\rm vir}$ • Minimum virial temp. for SF galaxies
  - timing and morphology of ALL epochs

Simple, but showing important changes in timings and morphologies of the signal, making the inference robust

Minimum virial temperature for SF galaxies - $\log_{10}(\mathrm{T_{vir}}/1\ \mathrm{K}) \in [4-6]$

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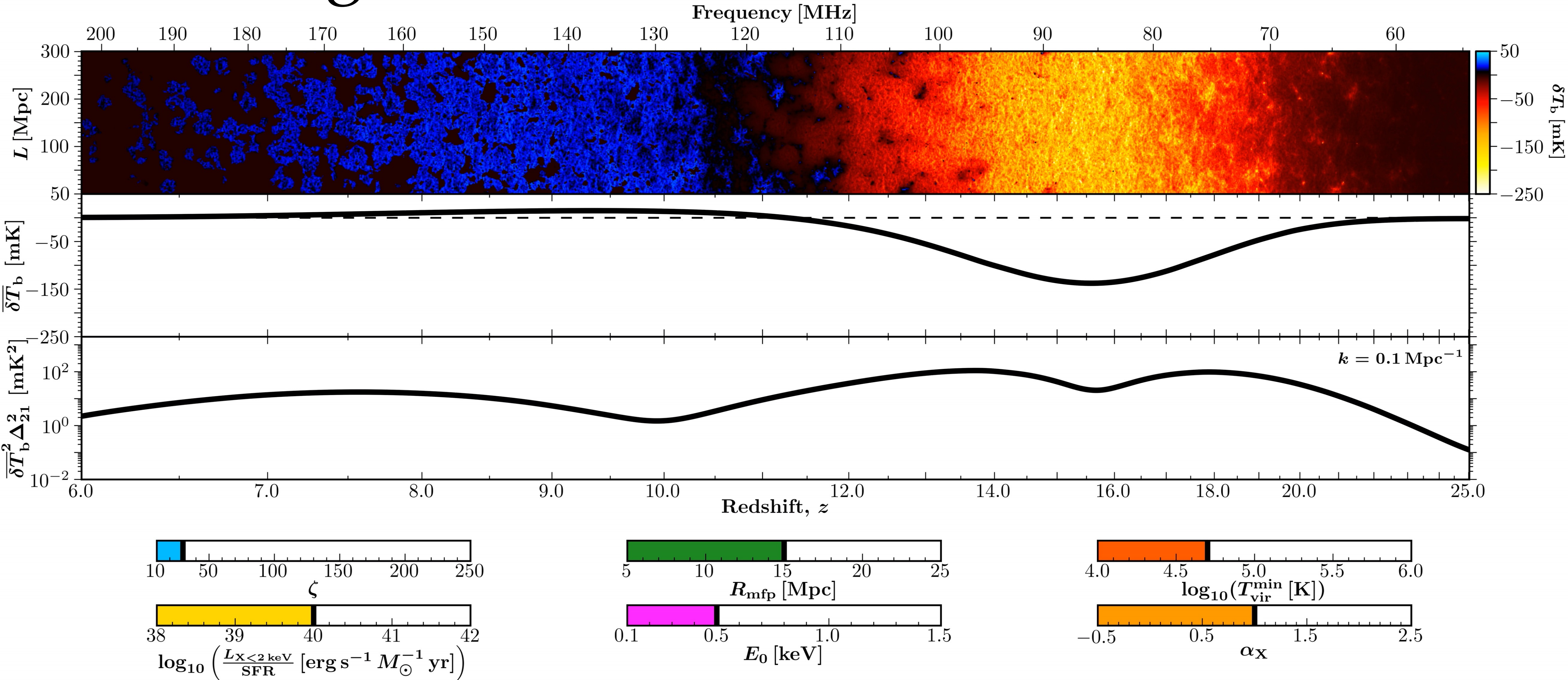

Mean Removal

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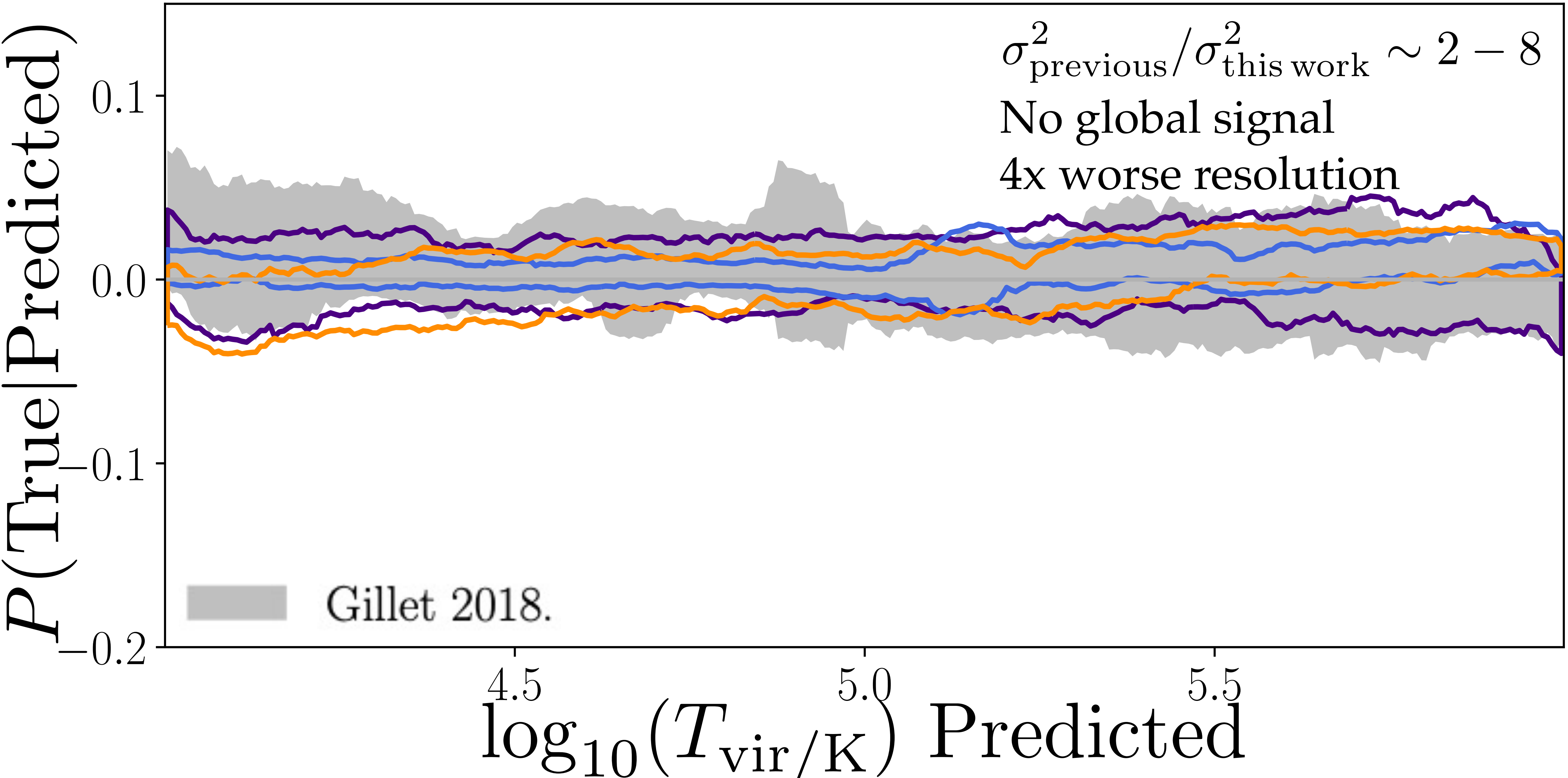
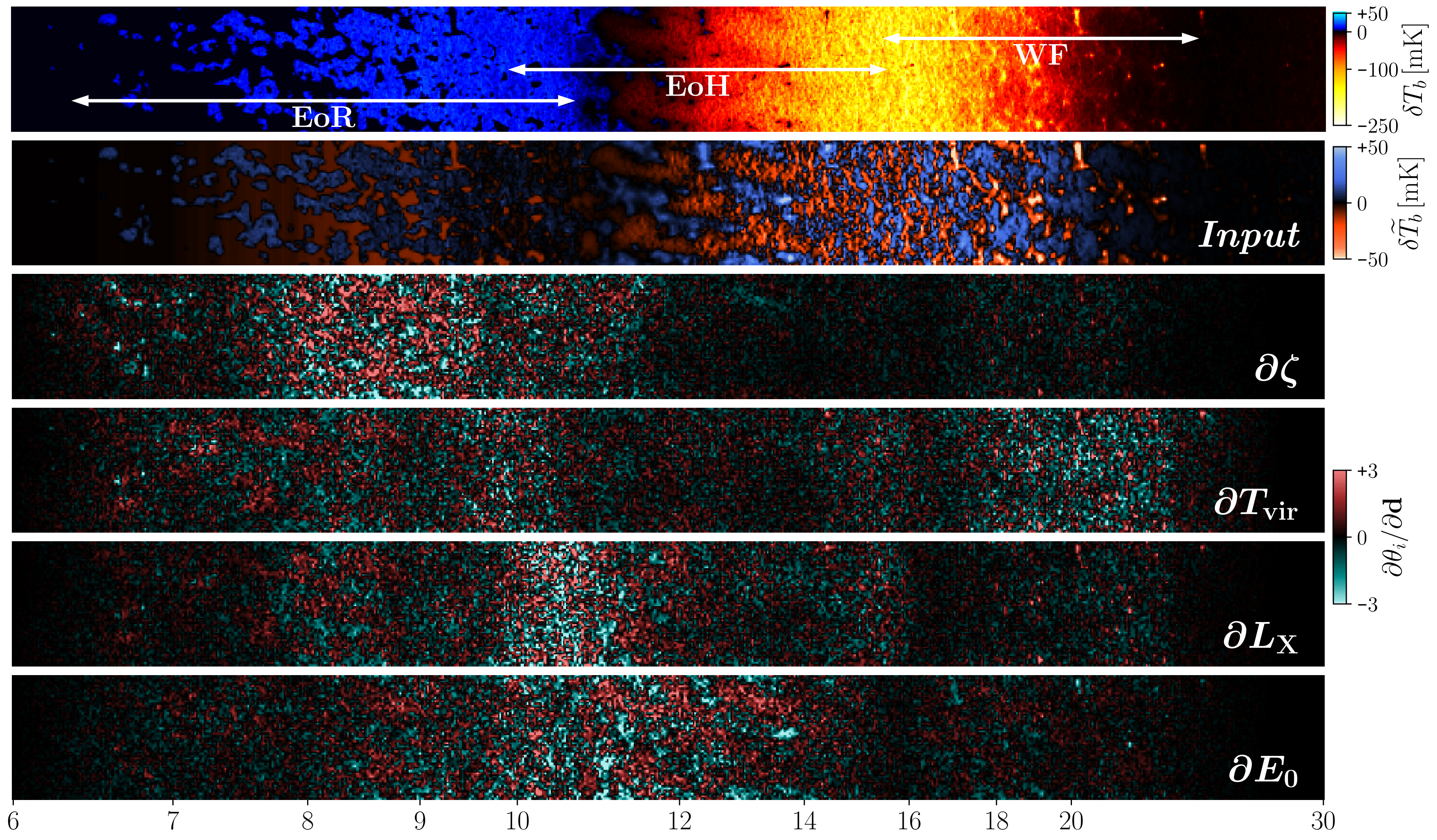


What does the network see?



- Saliency map:

$$\mathcal{J}_0 = \left\langle \frac{\partial \boldsymbol{\theta^p}}{\partial \mathbf{d}} \bigg|_{\mathbf{d}_0} \right\rangle$$

- changes in parameters influenced by underlying epochs

Conclusions

- RNN - optimally suited for the lightcone
- Factors of $\sim 2 - 8$ improvement in variance
- Network sees what it should
- Performance similar when including noise and wedge excision
  - Currently limited by dataset
  - For future improvements - better augmentation
    - Simulations of the signal, foregrounds, noise