Simulation framework for HI power spectrum measurement with CHIME

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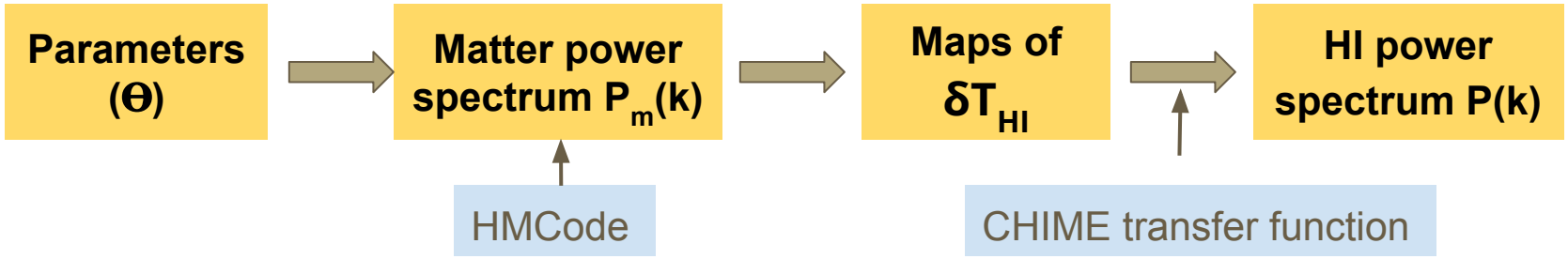
CHIME Collaboration

Outline

- Method for CHIME HI power spectrum interpretation
  - Simulation framework - this talk
  - Parameter inference framework - talk by Albin Joseph
  - *Application to data - currently in progress*
- Simulation of HI maps
- Power spectrum templates
- Summary

Simulations: Overview

Purpose: connect astrophysical model parameters to data power spectrum



We model the signal power spectrum using a set of "power spectrum templates" which account for CHIME-specific instrument characteristics & analysis choices.

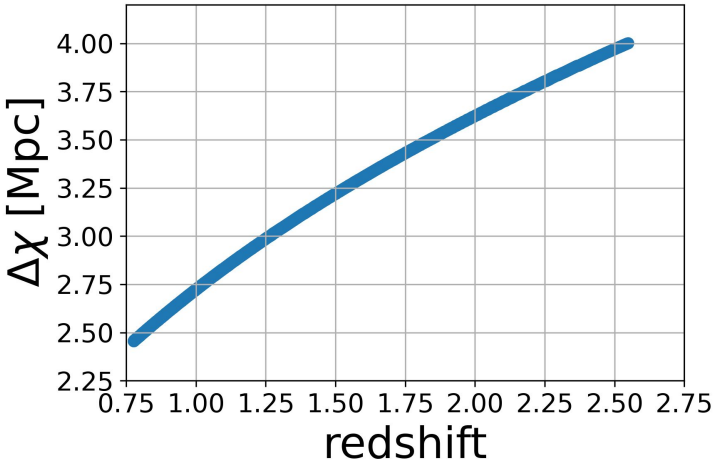
$$P^{(\mathrm{obs})}_{\mathrm{signal}}(k,\mu,z;\vec{\Theta}) = \sum_i \theta_i P^{(\mathrm{obs})}_i(k,\mu,z)$$

Similar to method in The CHIME Collaboration 2022, used for HI and galaxies stacking analysis.

Map simulation requirements for CHIME

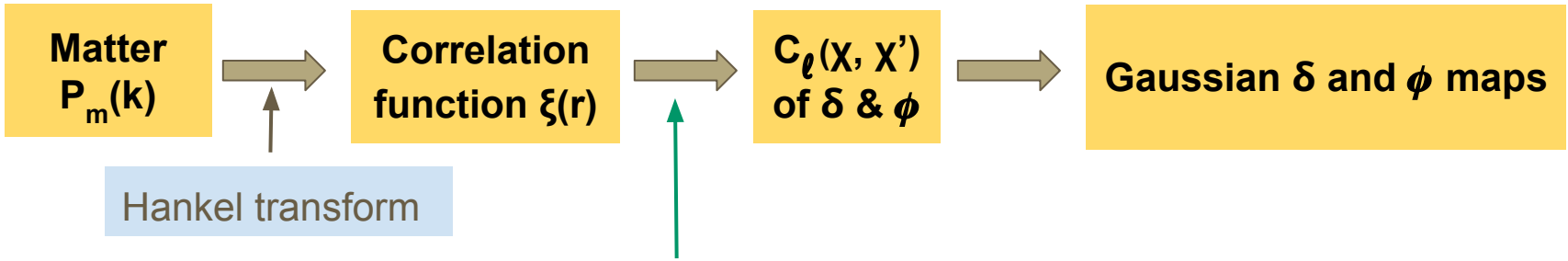
- Include required k-modes
  - k_{par} = 0.37 to 1.58 h/Mpc
  - k_{perp} = 0.08 to 0.40 h/Mpc
- Maps for different model parameters (required for the template method)
- Simulate multiple realizations
- ⇒ CORA
  - Gaussian maps of LSS tracers

Small width of CHIME channels in comoving distance



⇒ Limber approximation for $P_m(k) \rightarrow C_\ell$ not appropriate.

CORA Step-1: Simulation of LSS maps



$$C_\ell^{\chi\chi'} = 2\pi \int_{-1}^{1} \mathcal{L}_\ell(\mu) d\mu \left[\int d\chi W(\chi) \int d\chi' W(\chi') \xi(r) \right]$$

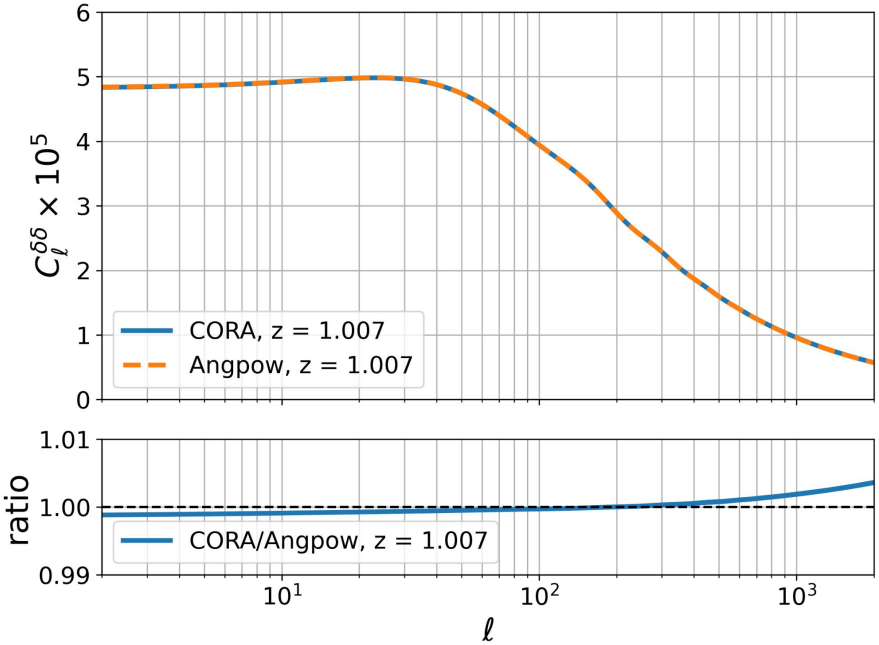
Legendre Polynomial

$$\mu = cos(\theta) \qquad r = \sqrt{\chi^2 + \chi'^2 - 2\chi\chi'\mu}$$

Additional smoothing due to finite channel width

Comparison of CORA output with a separate code

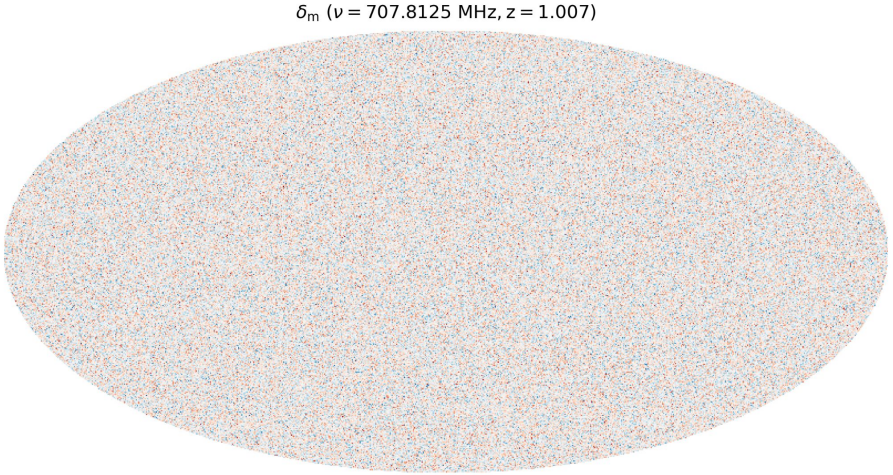
Angular power spectrum of matter overdensity



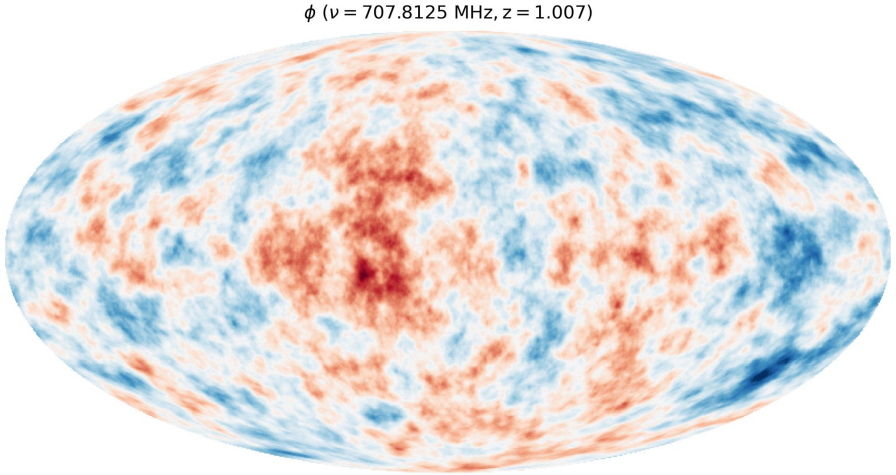
- We performed tests of convergence of CORA outputs.
- **Angpow** (Campagne et al., 2017): a code to obtain C_ℓ for the desired LSS tracer (with different integration techniques than those used in CORA).
- We find sub-percent level agreement between the output of the two codes.

Gaussian maps of density contrast (δ) and potential (ϕ)

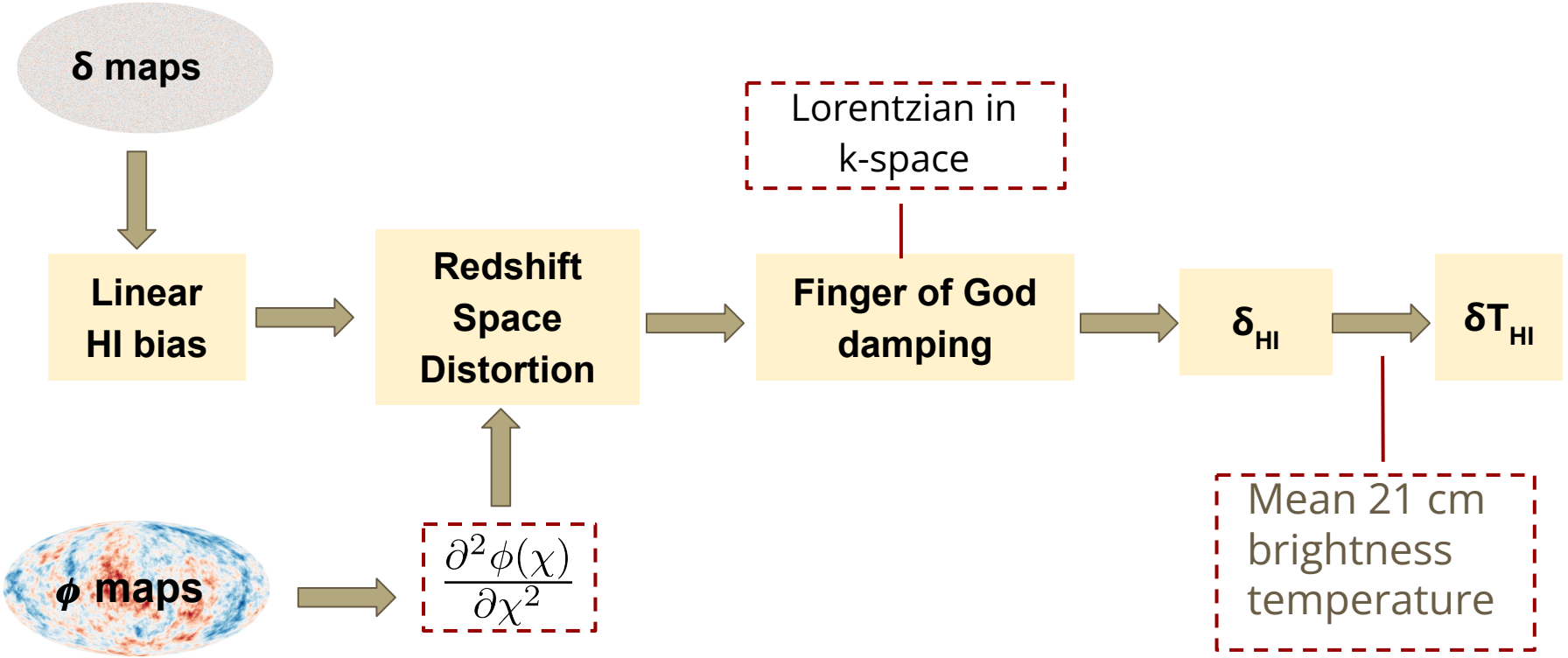
Matter density contrast (δ)



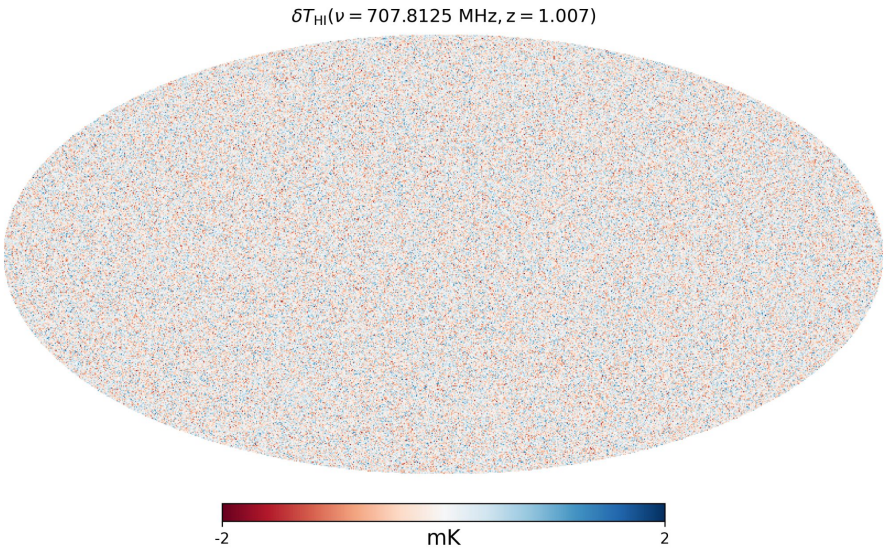
Gravitational potential (ϕ)

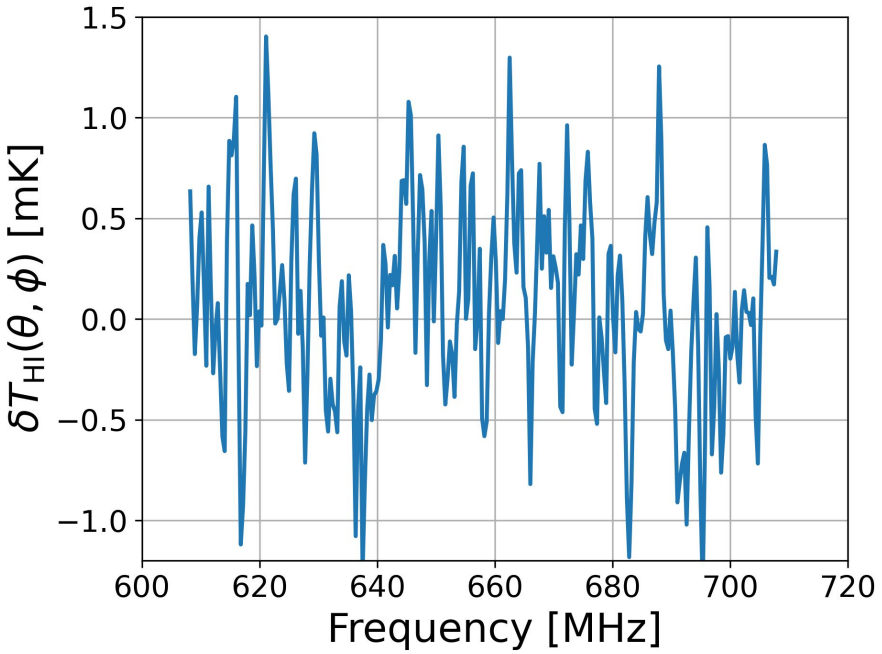


CORA Step-2: Simulation of δT_{HI} maps

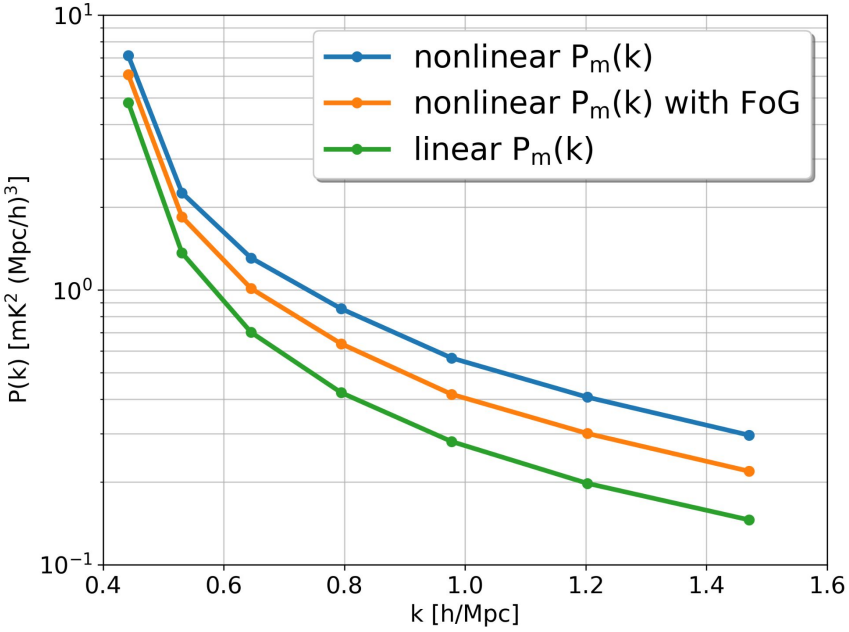


δT_{HI} maps: angular and LoS fluctuations





HI power spectrum [P(k)] templates for different $P_m(k)$



- Each P(k) template is obtained from a set of HI maps by passing it through CHIME analysis pipeline.
- Total time for one pipeline run to go from matter power spectrum to HI power spectrum: around 9 CPU hours (48 core, 187 GB node)
- **The template method is an efficient approach requiring fewer pipeline runs.**

Summary

- Gaussian simulations combined with template method is an efficient way to include the effect of instrument transfer function and analysis choices.
- CORA provides Gaussian δT_{HI} maps with sufficient accuracy.
- Modelling of clustering is approximate, however, it captures the effect of parameters of interest as required by the template method
- When required, incorporating more accurate modelling is possible
    - At the power spectrum level → highlighted in Albin's talk
    - At the map level, to include non-Gaussianity → see Tristan's talk

Thank you.