

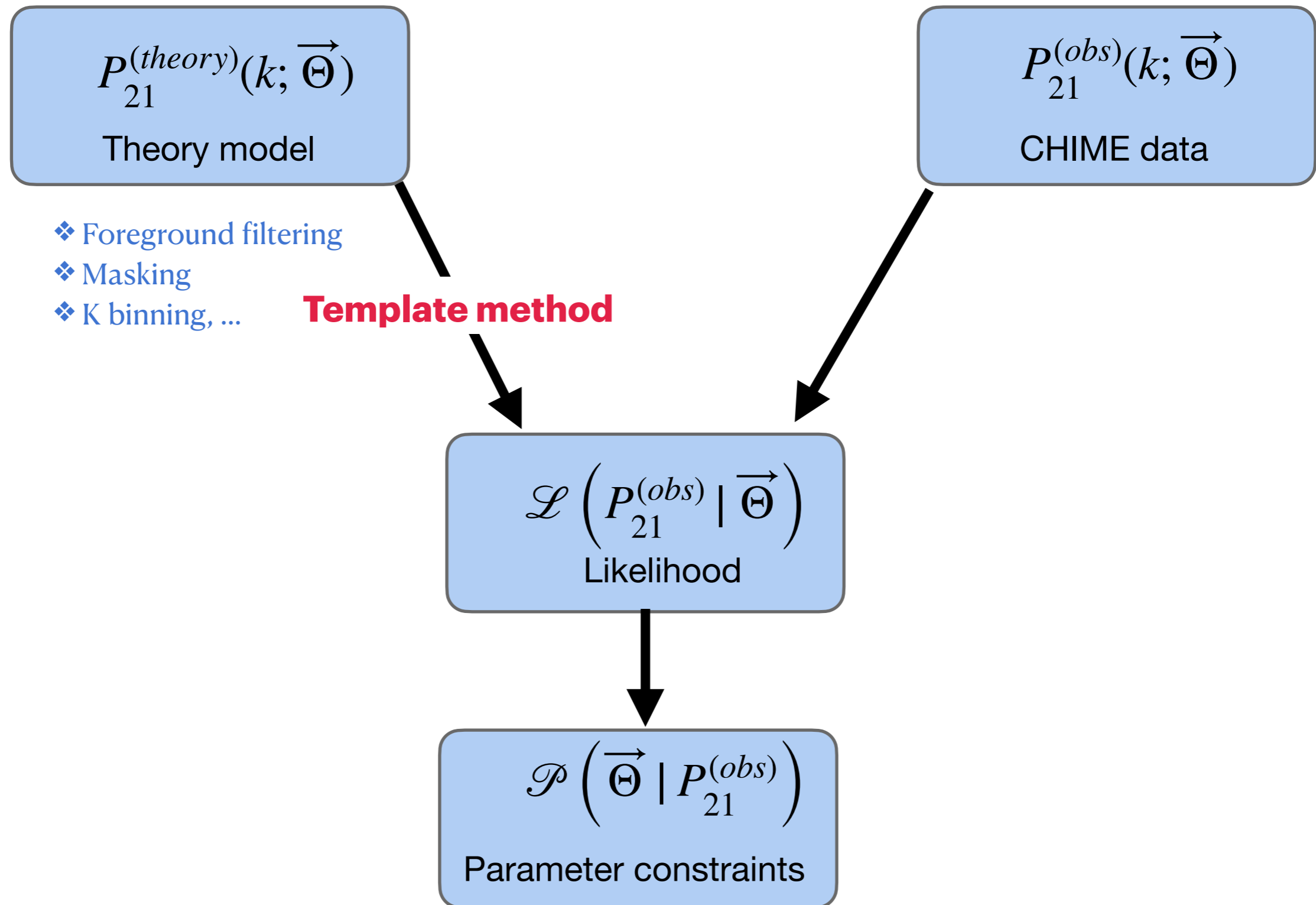
Framework for the Physical Interpretation of HI Power Spectrum Measurement with CHIME

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CHIME Collaboration

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Framework for physical interpretation



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.

- ★ Simulation framework validated at sub-percent accuracy via comparison with **Angpow** (Campagne et al., 2017)



Simon Foreman



Shabbir Shaikh

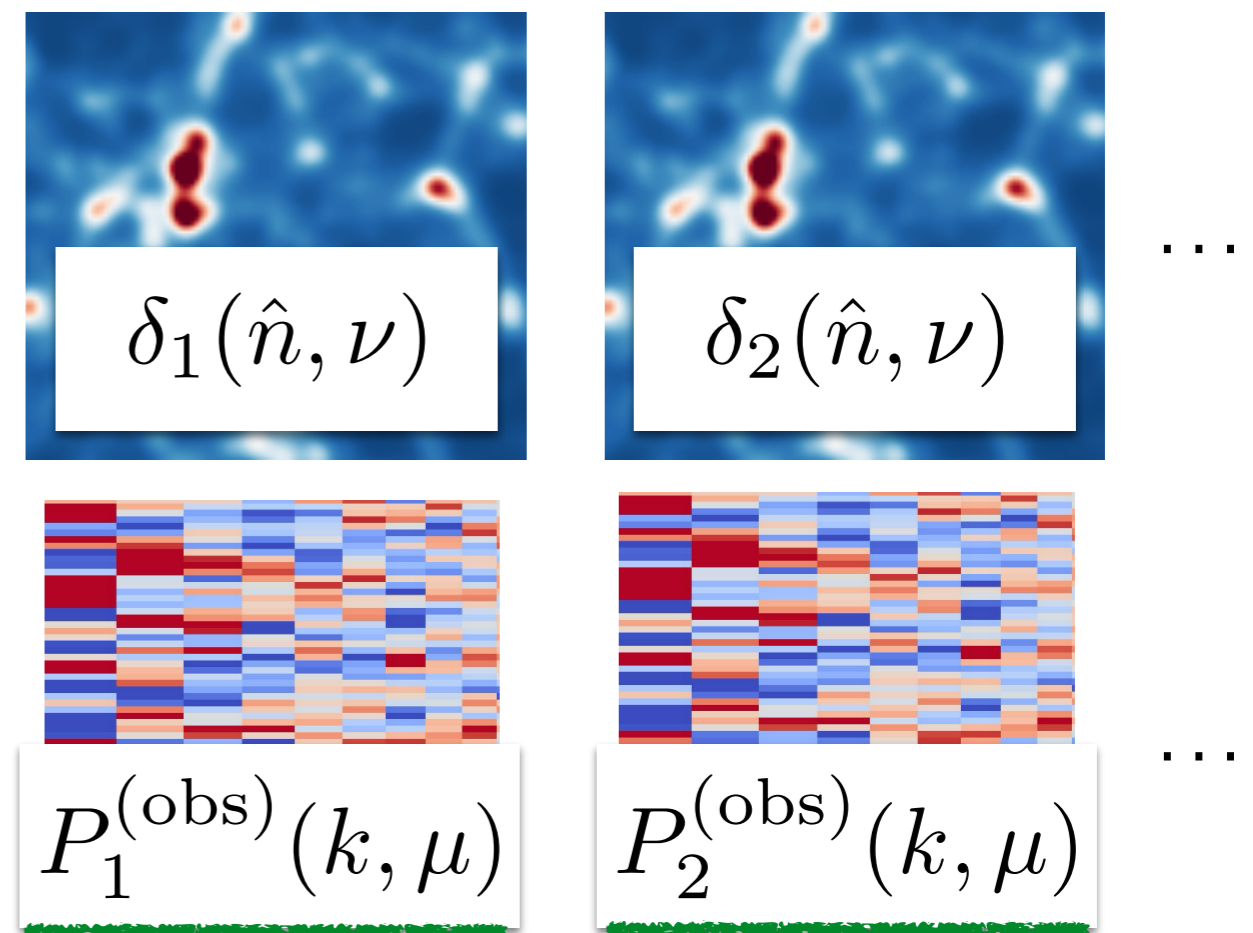


1. Choose $P_{\text{signal}}^{(\text{theory})}$ model with simple (linear, quadratic) dependence on model parameters, e.g.

$$P_{\text{signal}}^{(\text{theory})}(k, \mu, z; \vec{\Theta}) = \sum_i \theta_i P_i^{(\text{theory})}(k, \mu, z)$$

theory templates

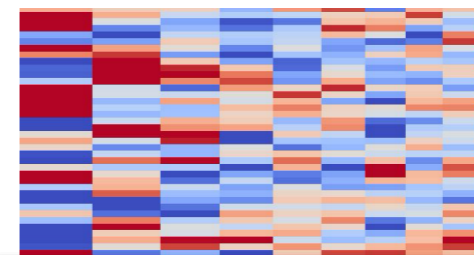
2. Simulate sky maps from each theory template
3. Propagate maps through sim+analysis pipelines, to obtain **obs. templates**



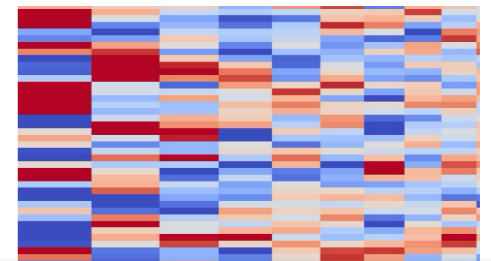
NB: Pipeline must be linear!

Template method

- Propagate maps through sim+analysis pipelines, to obtain **obs. templates**



$$P_1^{(\text{obs})}(k, \mu)$$



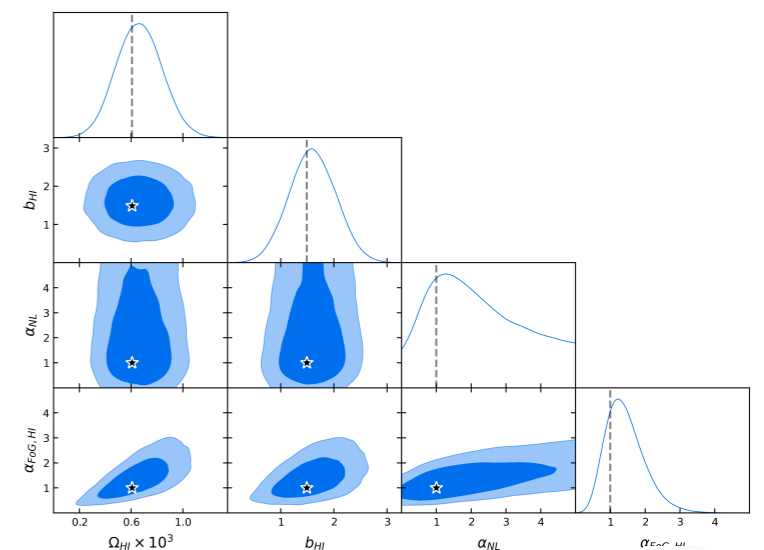
$$P_2^{(\text{obs})}(k, \mu)$$

...

- Observed power spectrum is linear combination of obs. templates

$$P_{\text{signal}}^{(\text{obs})}(k, \mu; \vec{\Theta}) = \sum_i \theta_i P_i^{(\text{obs})}(k, \mu)$$

- Sample likelihood to obtain posterior for $\vec{\Theta}$



$P_{21}^{(theory)}$ model

$$P_{21}^{(theory)}(k, \mu, z) = T_b(z)^2 [b_{HI}(z) + f\mu^2]^2 D_{FoG}(k\mu, z)^2 \times \left[\alpha_{NL} P_m^{(nonlin)}(k, z) + (1 - \alpha_{NL}) P_m^{(lin)}(k, z) \right]$$

Matter power spectrum; α_{NL} interpolates between linear and nonlinear models (at fixed cosmology)

b_{HI} = linear HI bias

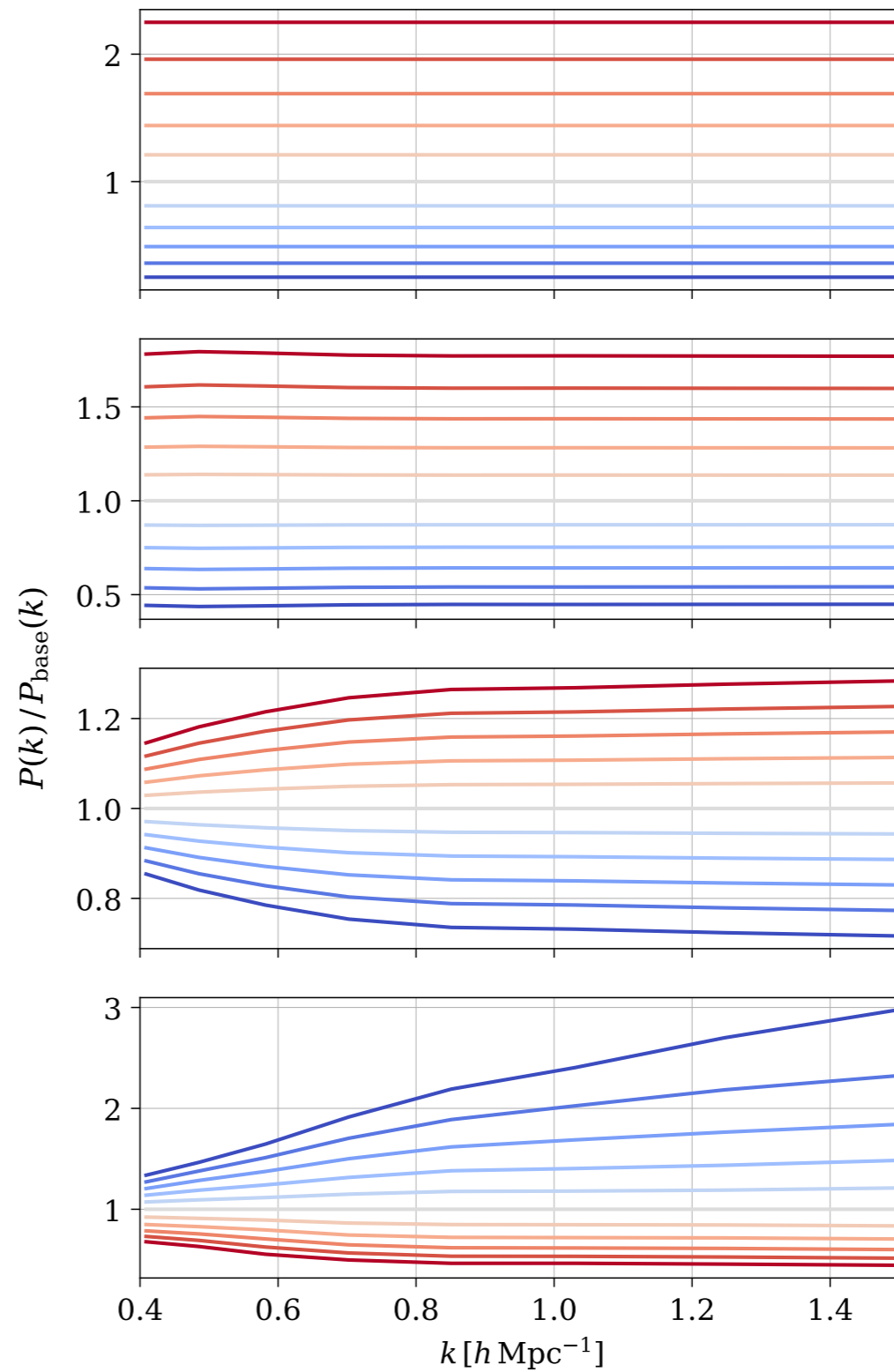
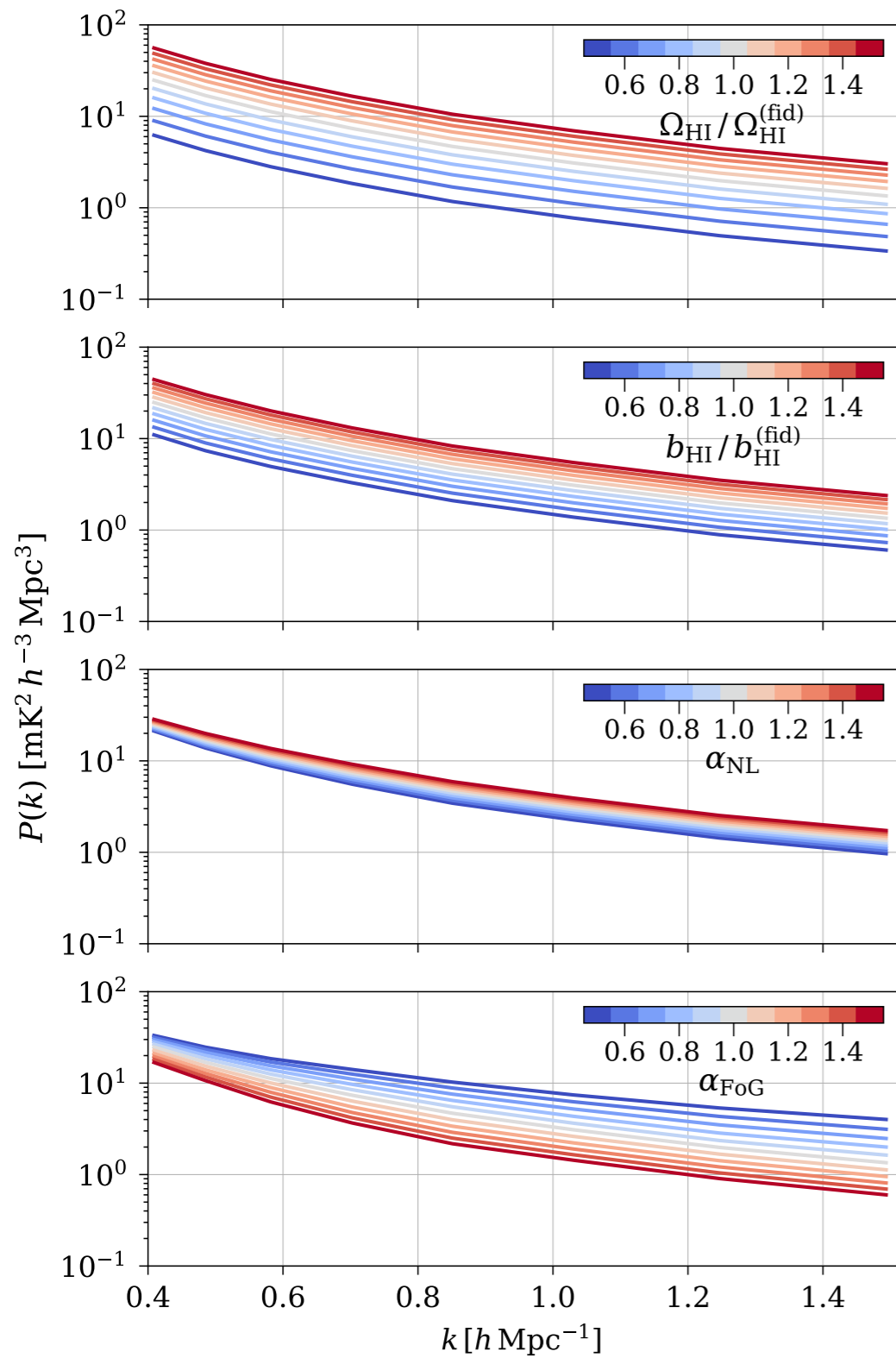
$f\mu^2$ = redshift-space distortions on large scales (“kaiser”)

D_{FoG} = RSD on small scales (“Finger of God”) $\longrightarrow \frac{1}{1 + \frac{1}{2}k^2\mu^2\sigma_{FoG}^2}$

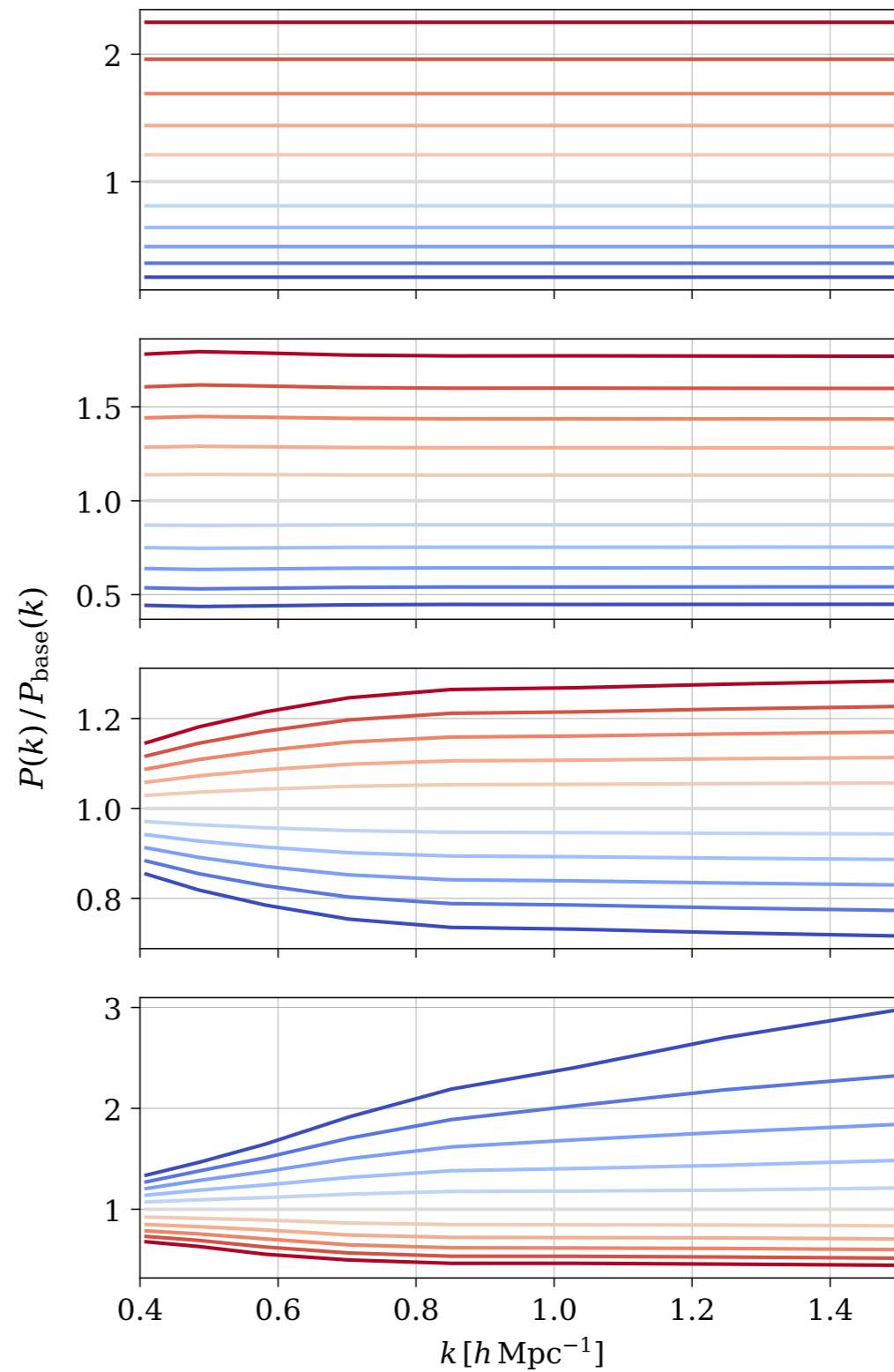
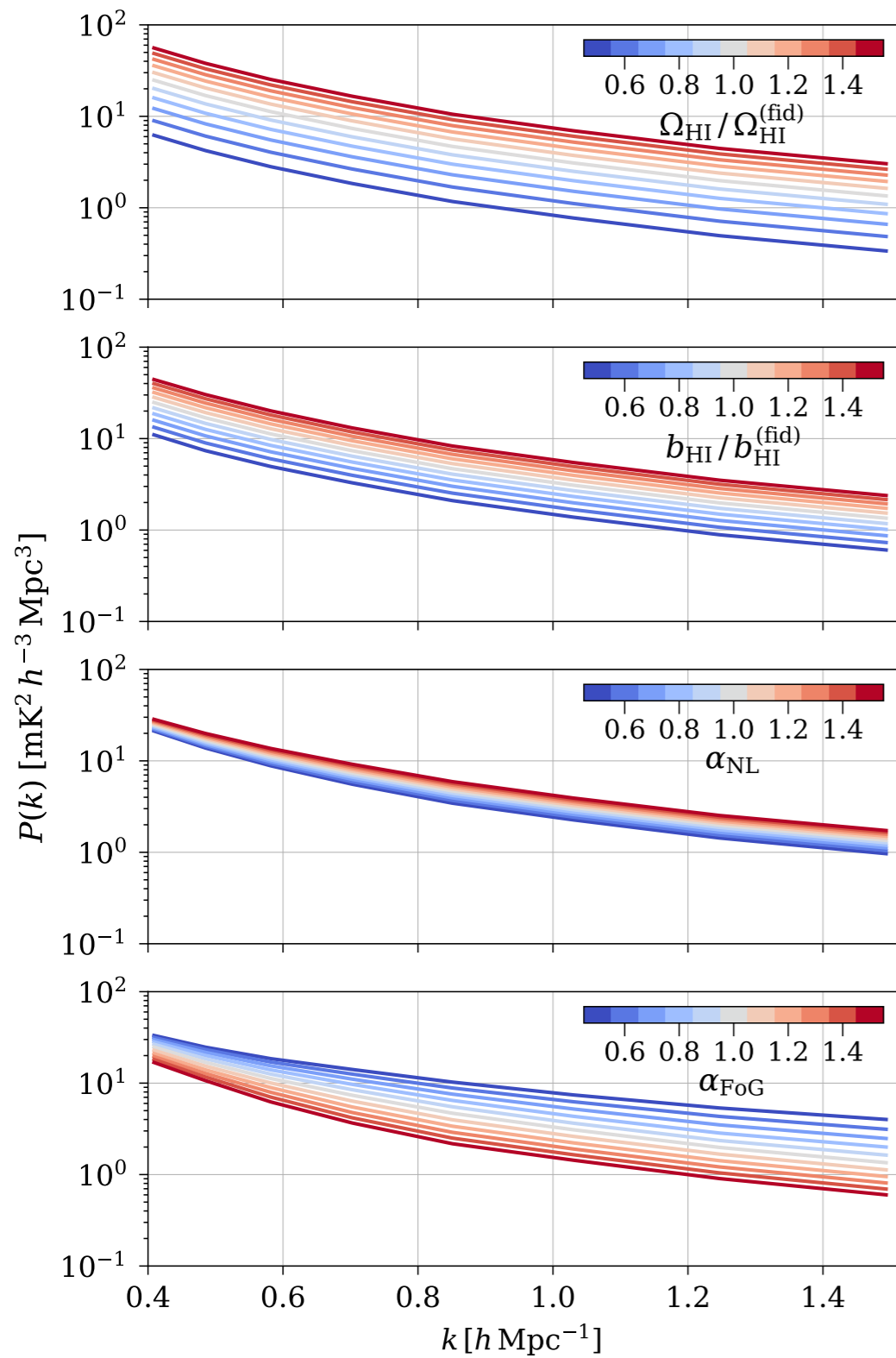
T_b = mean 21cm brightness temperature, $\propto \Omega_{HI}$

★ We parameterize the shape of the nonlinear power spectrum using nuisance parameters that are marginalized over to constrain Ω_{HI} and b_{HI}

Parameter sensitivity

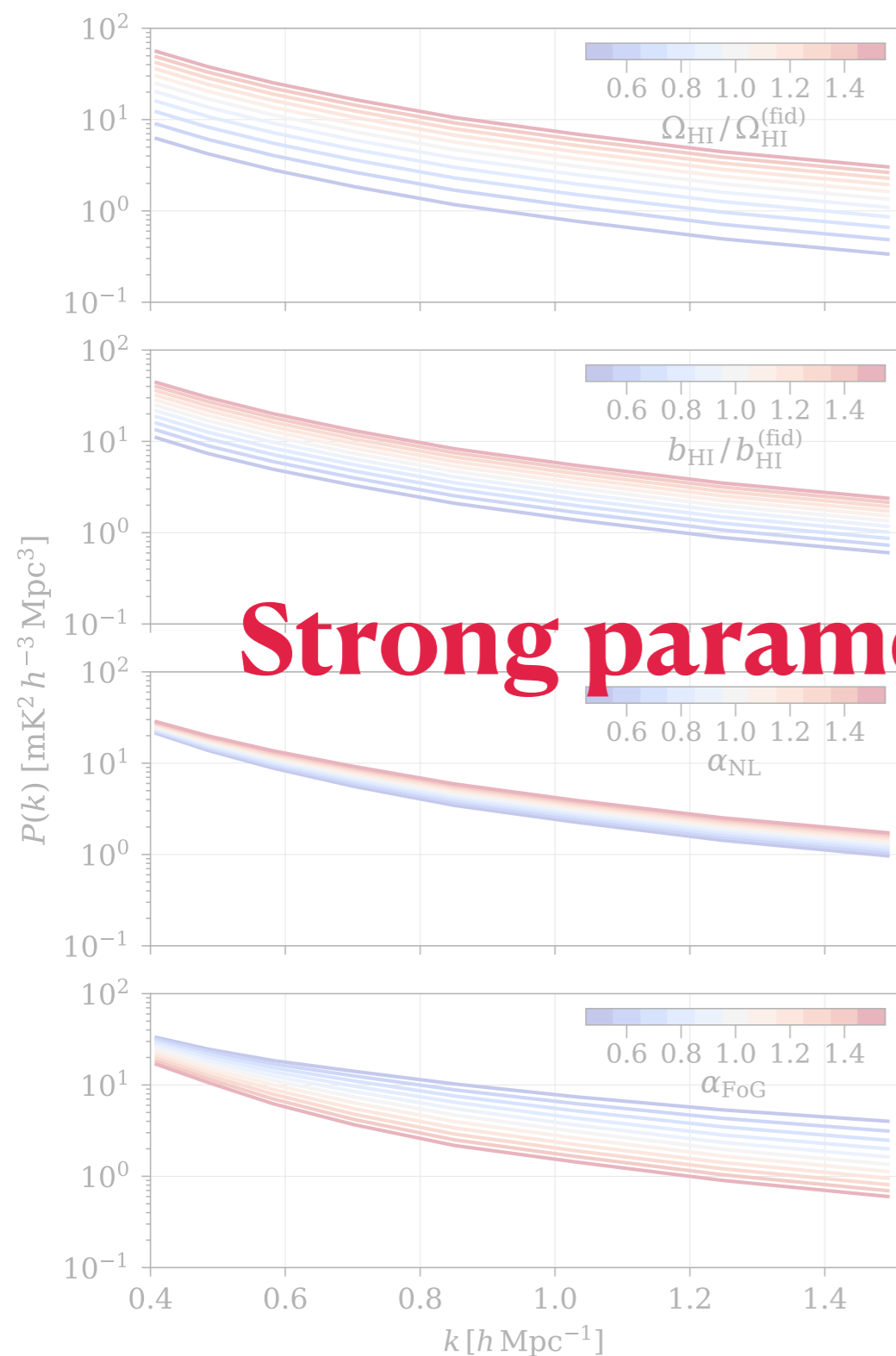


Parameter sensitivity



Increases overall amplitude

Parameter sensitivity



Strong parameter degeneracies!



Parameter degeneracies

$$P_{21}^{(theory)} \propto \Omega_{HI}^2 [b_{HI} + f\mu^2]^2$$



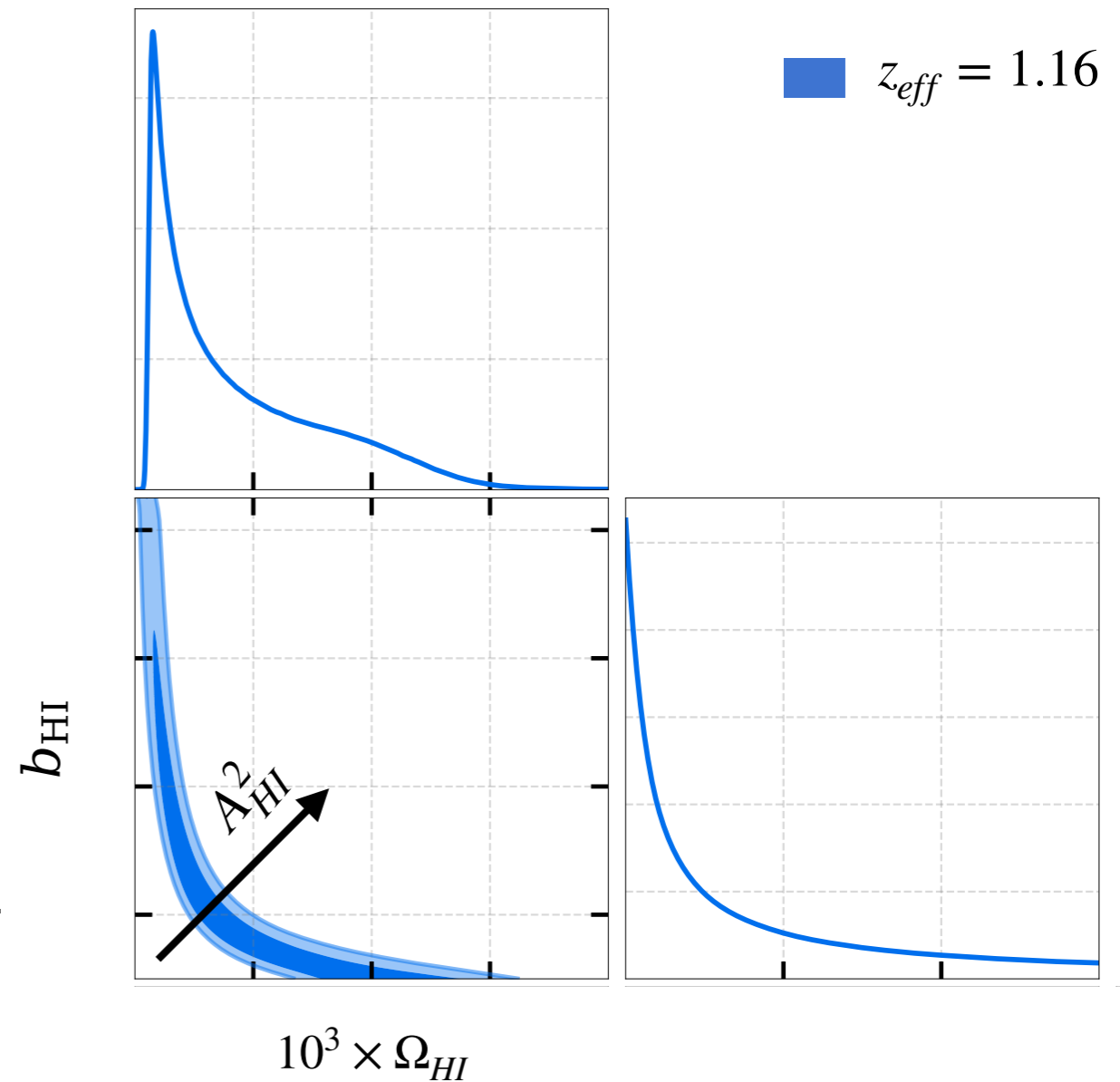
Degeneracy



Constrain $A_{HI}^2 = 10^6 \Omega_{HI}^2 (b_{HI} + \langle f\mu^2 \rangle)^2$

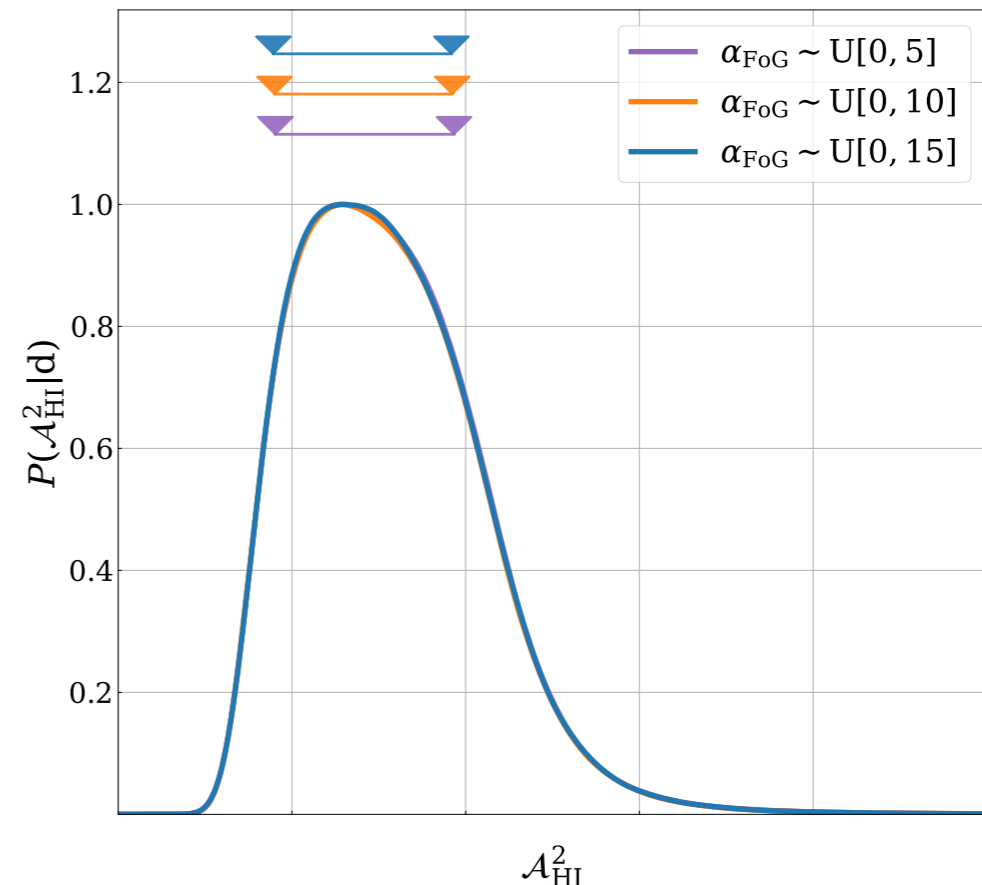
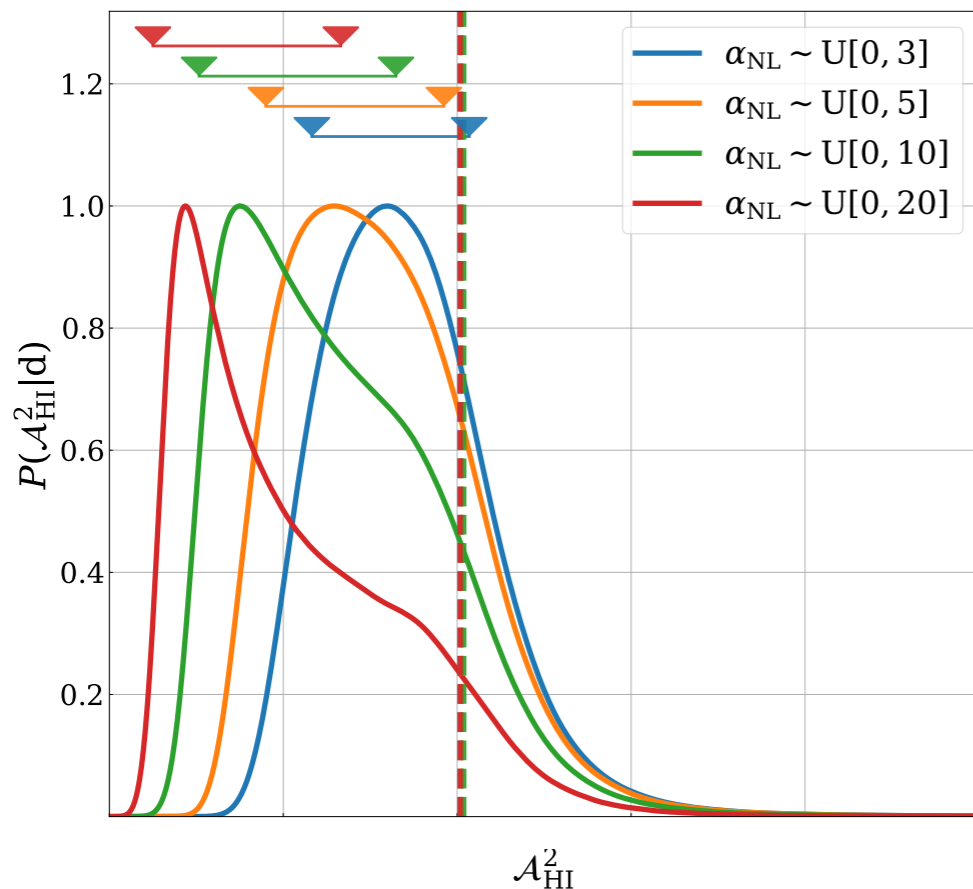
Nuisance parameters

$$\alpha_{FoG}, \alpha_{NL} \quad \text{where} \quad \alpha_{FoG} = \frac{\sigma_{FoG}(z)}{\sigma_{FoG}^{fid}(z_{eff})}$$



Impact of Priors

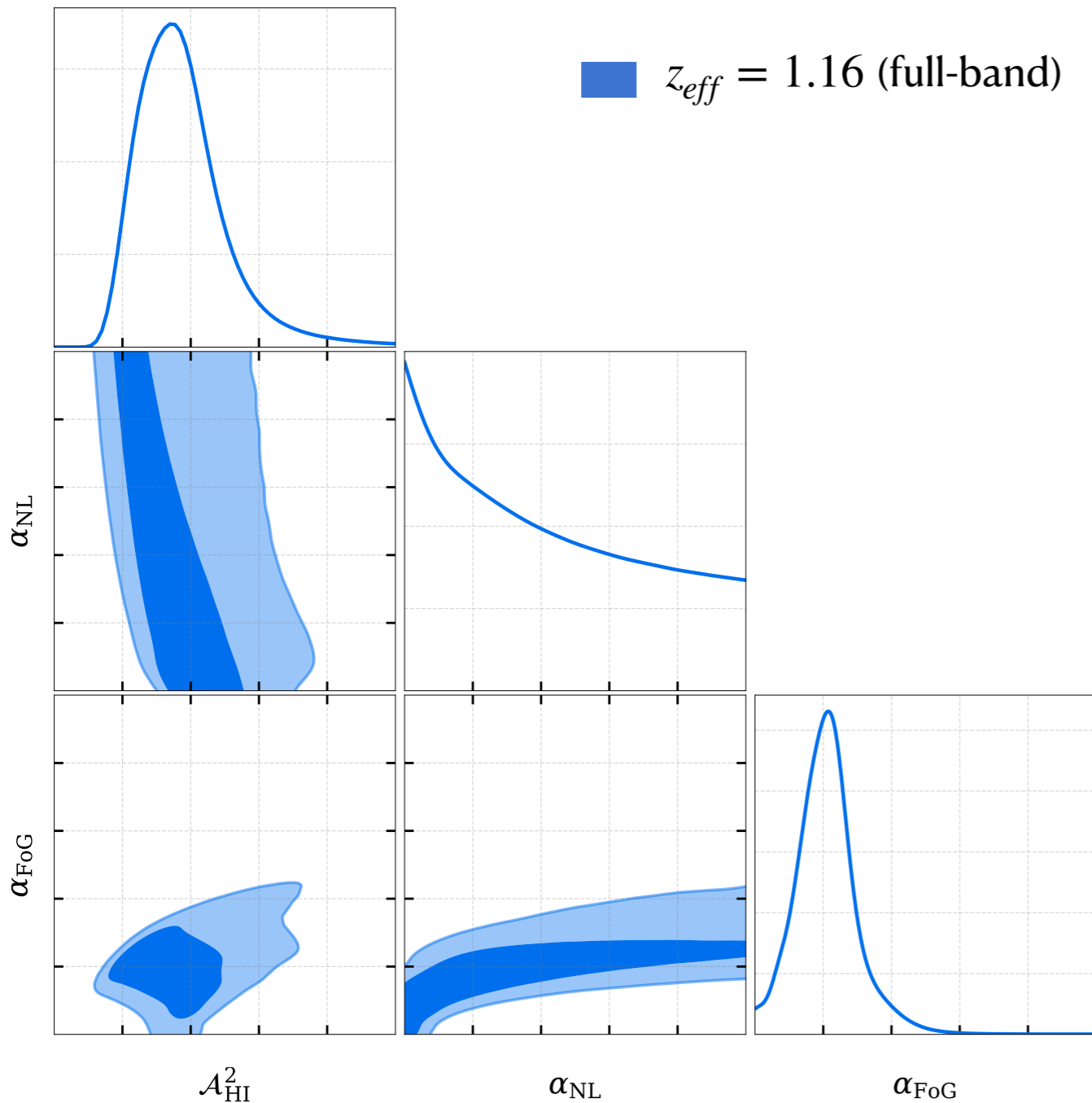
- ★ Low S/N and strong parameter degeneracies lead to prior-volume effects
- ★ The marginalized posterior of A_{HI}^2 shifts with the prior range of α_{NL} , indicating prior-volume effects



How did we deal with prior volume effects ??

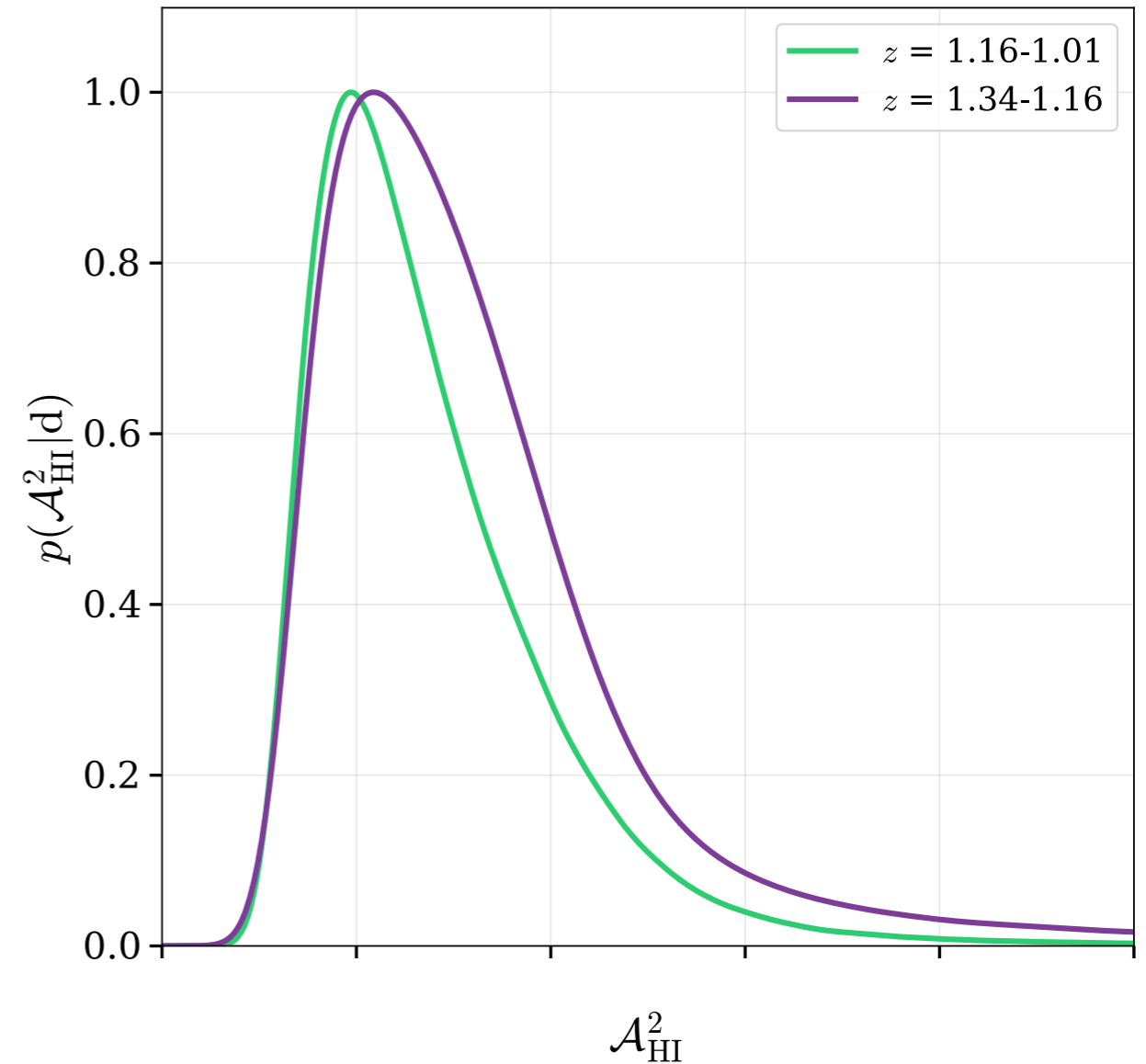
- ★ Using 20 validation simulations at Latin-hypercube sampled points in parameter space.
- ★ Is true value of A_{HI}^2 is within 68% CL from MCMC fitting for each simulations?
- ★ This test identifies stable priors for our analysis

Parameter constraints: Full-band and sub-bands



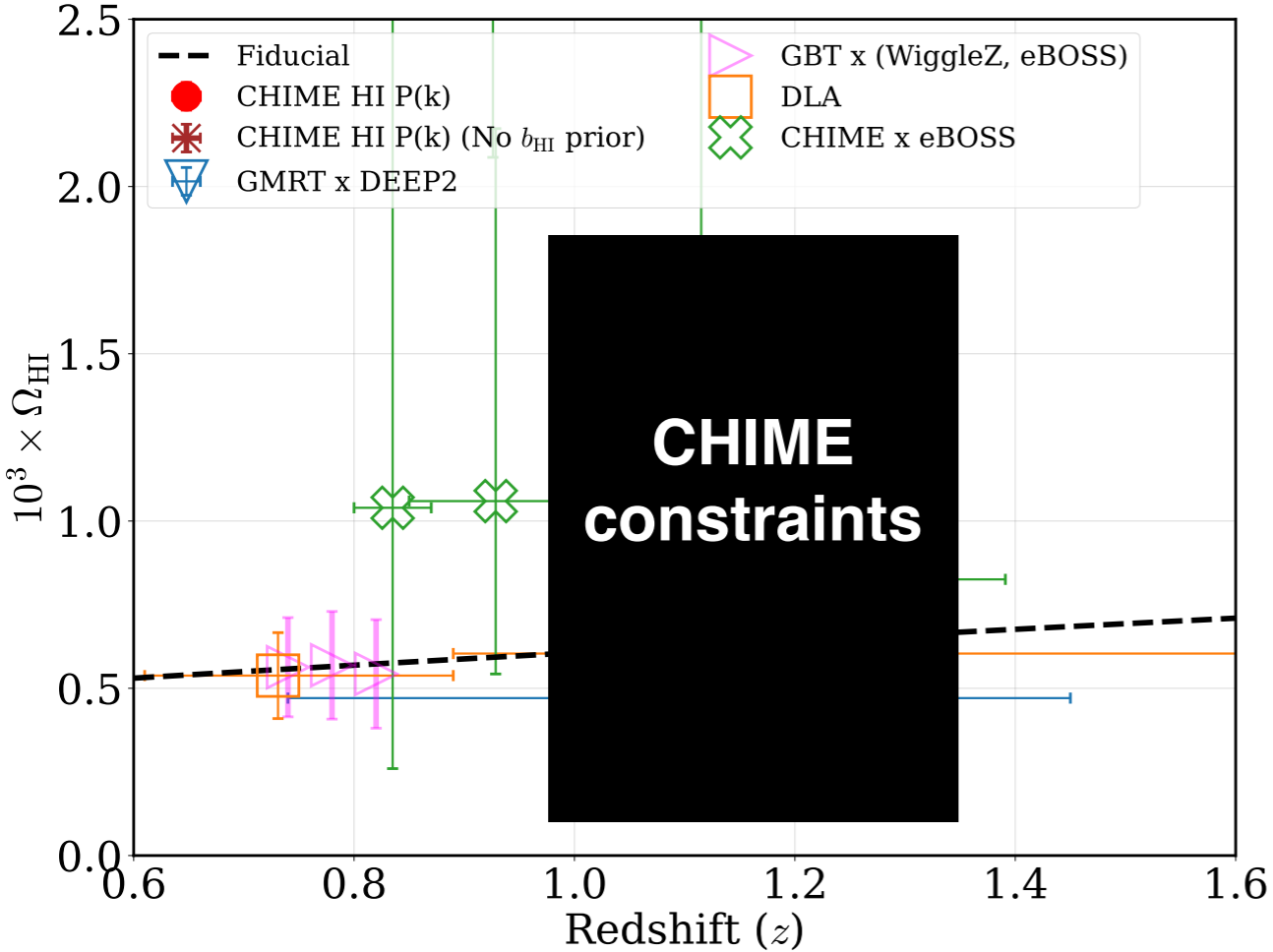
Strong constraint on A_{HI}^2

Consistency of A_{HI}^2 between independent sub-bands



Current SNR insufficient to prove redshift evolution

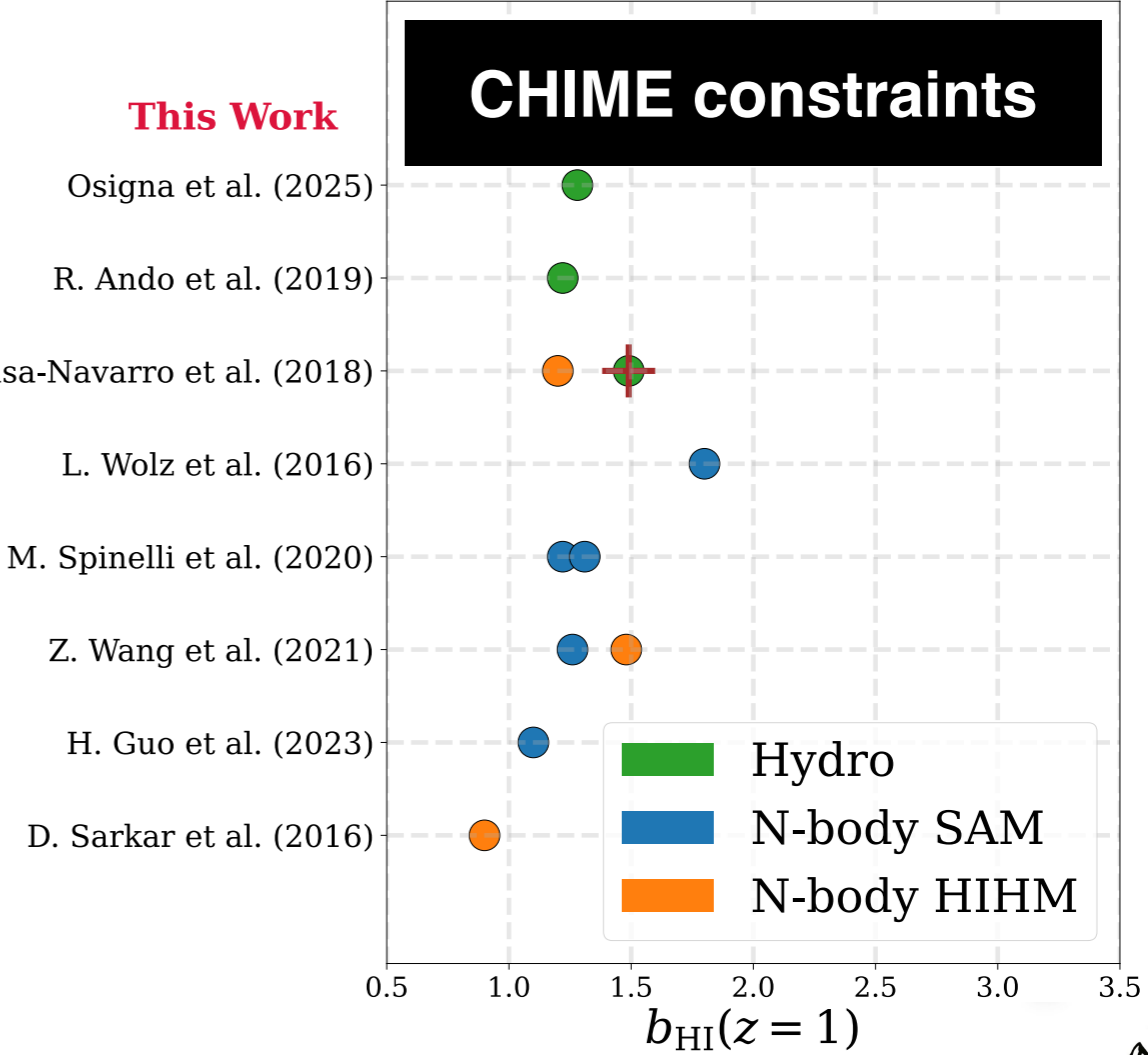
Constraints: Mean density and linear HI bias



Shabbir Shaikh

Place prior on b_{HI} and examine constraint on Ω_{HI} (and vice versa)

In arXiv soon!



Summary

- We use simulation-based pipeline to bridge theoretical HI power spectrum model to CHIME observations
- Our model includes Ω_{HI} , b_{HI} , and nuisance parameters α_{FoG} and α_{NL} characterizing small-scale physics
- Strong degeneracy exists between Ω_{HI} and b_{HI} , limiting individual parameter constraints
- We address this by constraining the amplitude parameter A_{HI}^2 , which remains well-determined
- Coming soon: Constraints on Ω_{HI} and b_{HI} using power spectrum model

Ongoing work: Transfer function framework

- ★ The current analysis uses **template-based signal model**
- ★ We are developing a **transfer function approach** that maps the true HI power spectrum to the observed spectrum

$$P_{21}^{obs}(k_{\perp}, k_{\parallel}) = \sum_{k'_{\perp}, k'_{\parallel}} T(k_{\perp}, k'_{\perp}; k_{\parallel}, k'_{\parallel}) P_{21}^{true}(k'_{\perp}, k'_{\parallel})$$

- ★ This will allow us to constrain more general models for the HI power spectrum, including:
 - ▶ predictions from **cosmological simulations**
 - ▶ **HI halo models**

Thank You