Modeling HI at the field level

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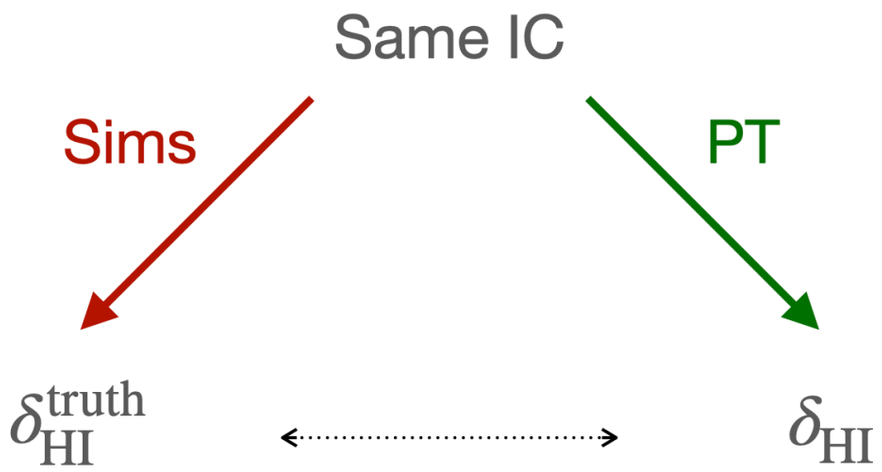
Motivation

- 21cm IM surveys will be mainly sensitive to perturbative scales
- Test perturbation theory (PT) + HI bias models at the field level (Schmittfull+18)
- Explore HI noise properties
- Generate fast and accurate HI mocks at the field level

Field level approach

Advantages

- Pixel-by-pixel agreement → agreement of all summary statistics
- No overfitting
- Easy to isolate and study noise
- No cosmic variance for same IC, no need for large hydro sims.



PT model

Hybrid Lagrangian and Eulerian scheme, bulk flows included, only linear fields

$$\delta_{\rm HI}(\mathbf{k}) = \beta_1(k)\tilde{\delta}_1(\mathbf{k}) + \beta_2(k)\tilde{\delta}_2^{\perp}(\mathbf{k}) + \beta_{\mathcal{G}_2}(k)\tilde{\mathcal{G}}_2^{\perp}(\mathbf{k}) + \ldots + \text{noise}$$

Transfer functions

Matches 1-loop EFT & CLPT power spectrum

Goal: minimise mean-squared difference/residuals:

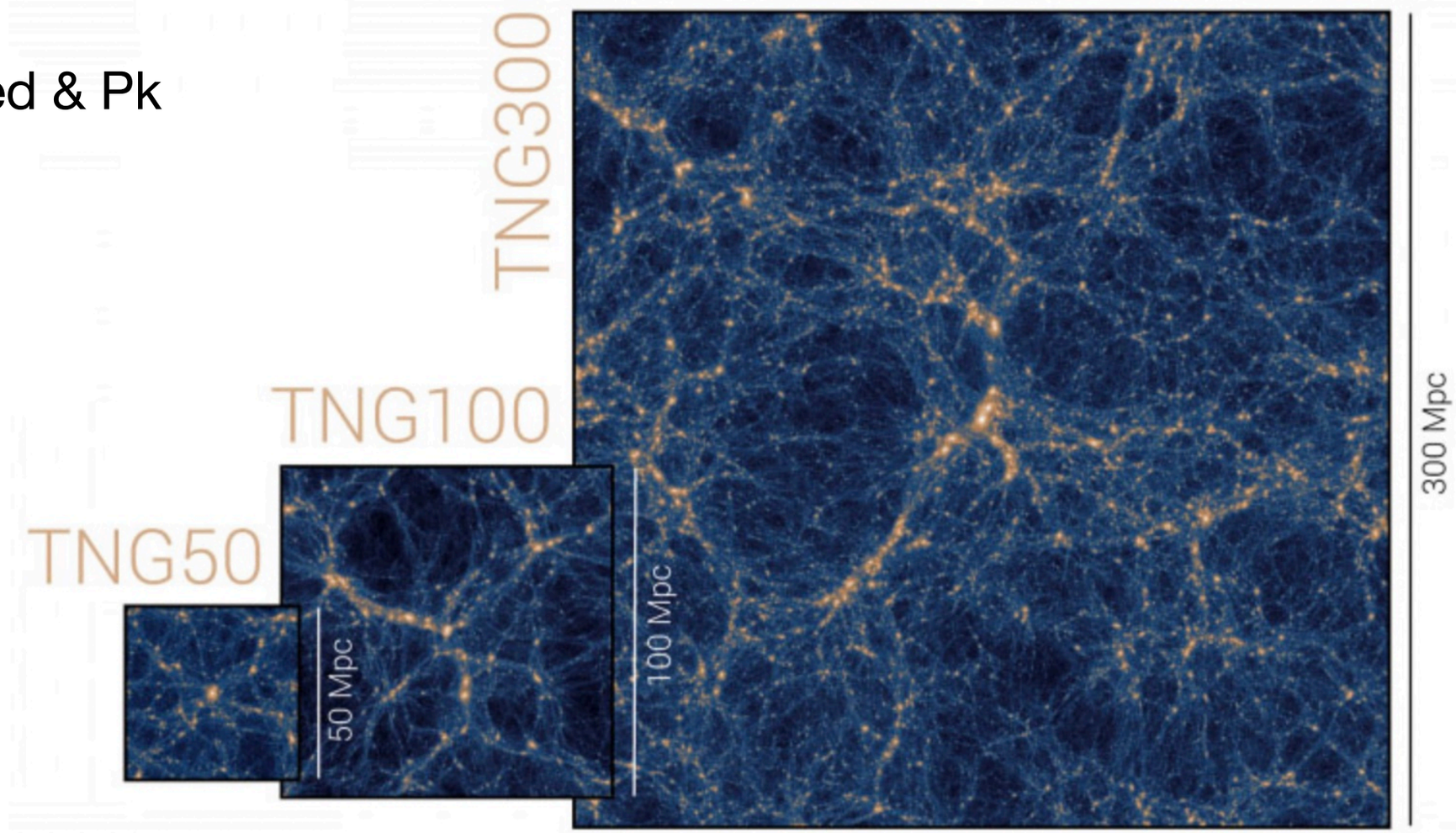
$$P_{\rm err}(k) \equiv \langle\, |\, \delta_{\rm HI}^{\rm truth}(\mathbf{k}) - \delta_{\rm HI}^{\rm model}(\mathbf{k})\, |^2 \,\rangle$$

by doing least-squares in each k-bin

$$\beta_i = \langle \mathcal{O}_i^{\perp} \delta_{\rm HI}^{\rm truth*} \rangle / \langle\, |\, \mathcal{O}_i^{\perp}\, |^2 \,\rangle$$

Simulated HI – “truth”

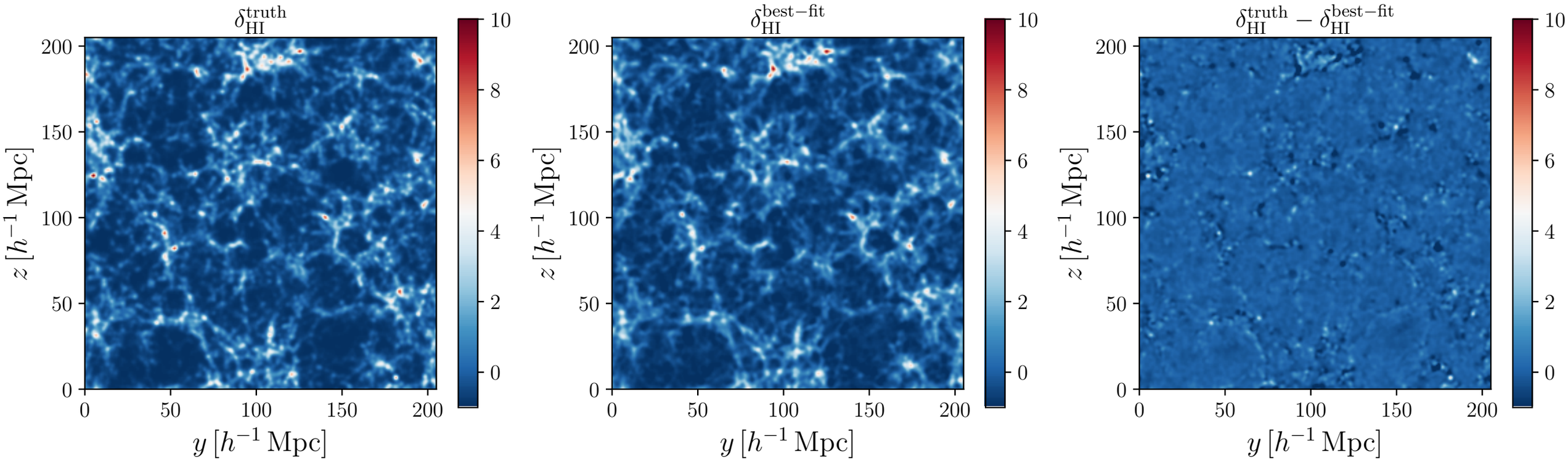
- Application to full hydro simulation
- Illustris TNG300-1 ($L = 205\,h^{-1}\mathrm{Mpc}$)
- HI in post-processing (Villaescusa+18)
- Same IC: random seed & Pk



Results

$z = 1$, real space

$$\delta_{\rm HI}(\mathbf{k}) = \beta_1(k)\tilde{\delta}_1(\mathbf{k}) + \beta_2(k)\tilde{\delta}_2^{\perp}(\mathbf{k}) + \beta_{\mathscr{G}_2}(k)\tilde{\mathscr{G}}_2^{\perp}(\mathbf{k}) + \beta_3(k)\tilde{\delta}_3^{\perp}(\mathbf{k}) + \ldots + \text{noise}$$

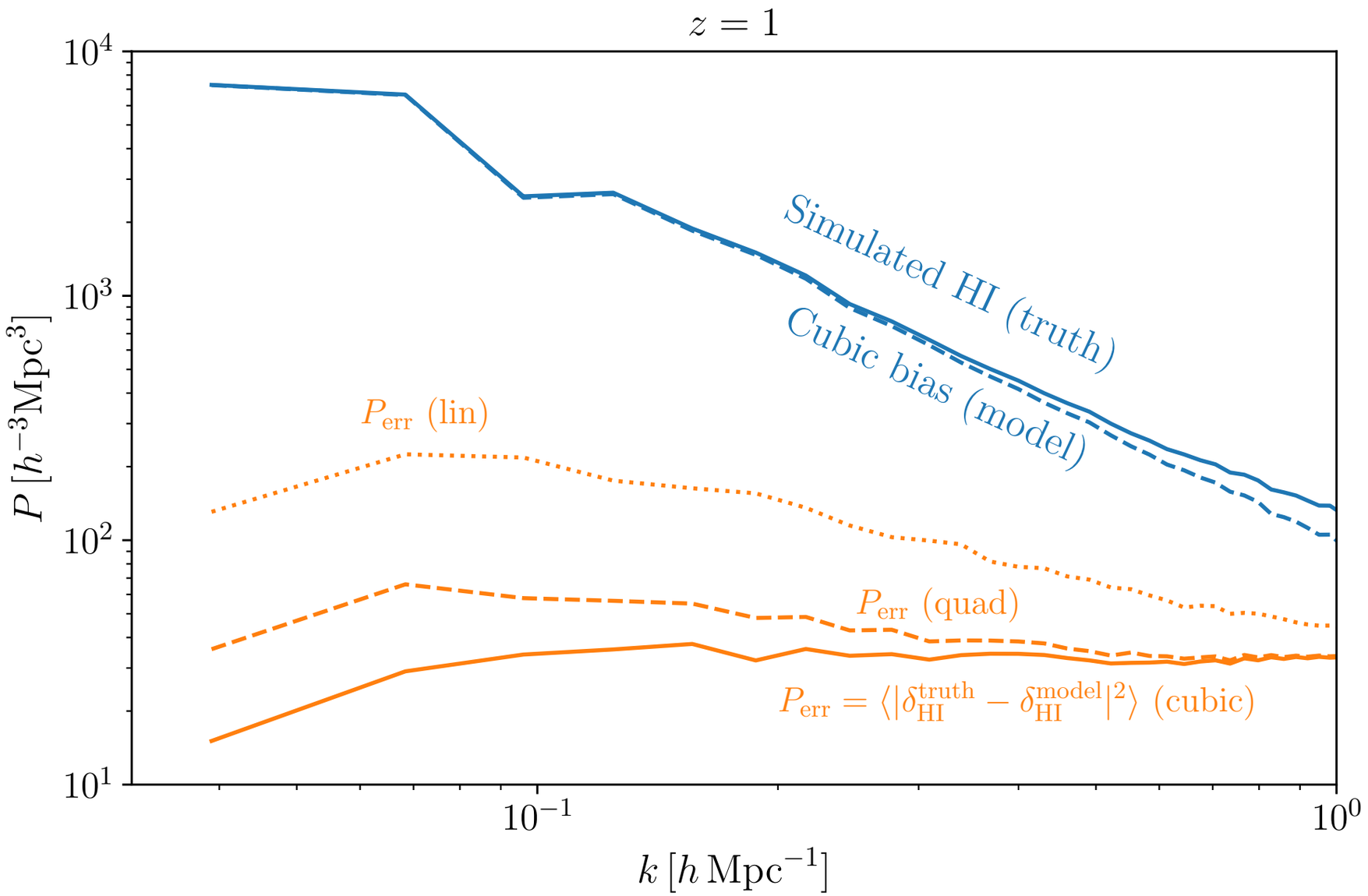


Slice depth 20 Mpc/h, smoothed 1 Mpc/h Gaussian

Results – power spectrum

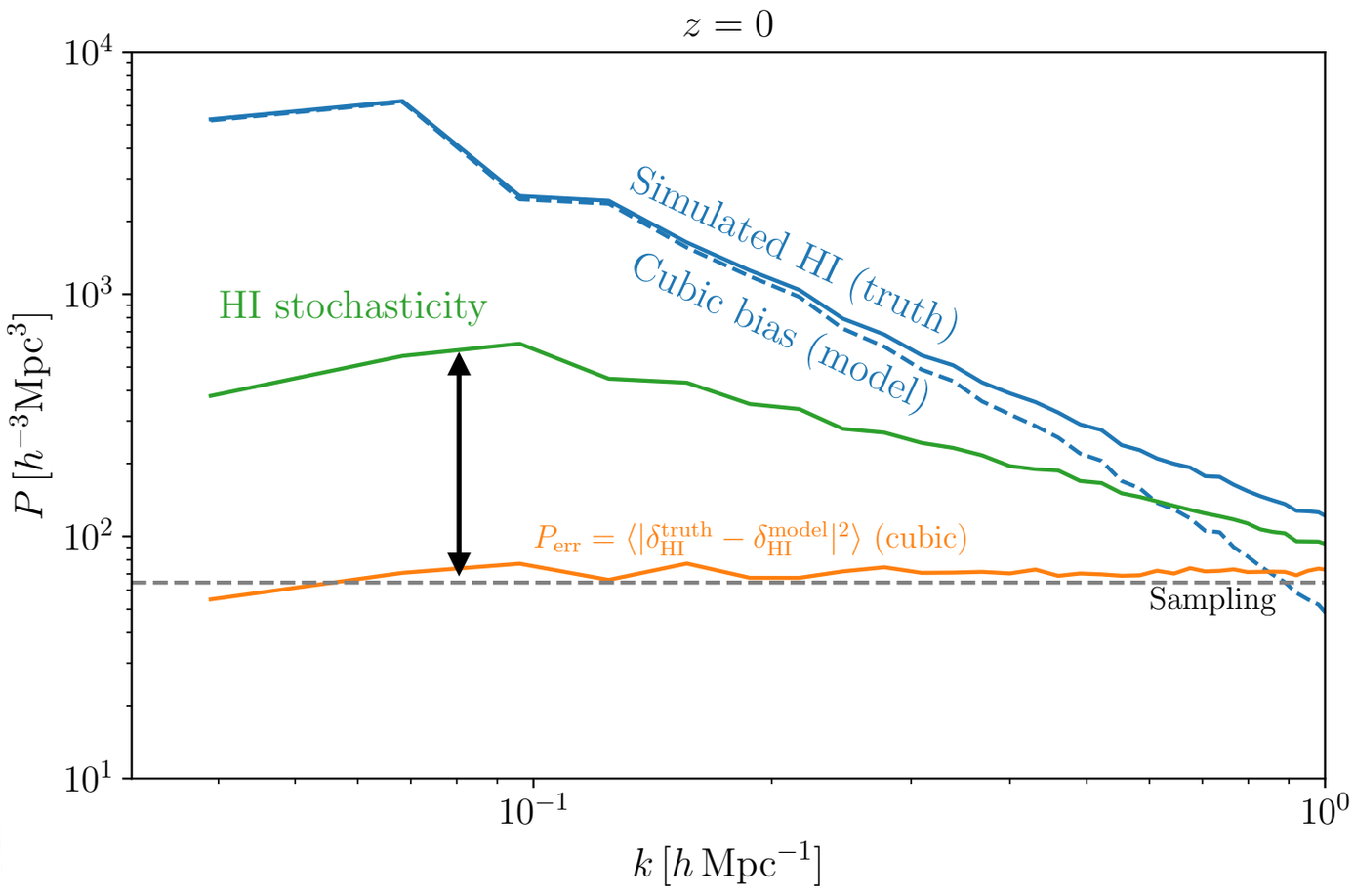
$z = 1$, real space

$$\delta_{\rm HI}(\mathbf{k}) = \beta_1(k)\tilde{\delta}_1(\mathbf{k}) + \beta_2(k)\tilde{\delta}_2^{\perp}(\mathbf{k}) + \beta_{\mathscr{G}_2}(k)\tilde{\mathscr{G}}_2^{\perp}(\mathbf{k}) + \beta_3(k)\tilde{\delta}_3^{\perp}(\mathbf{k}) + \ldots + \text{noise}$$



HI noise properties

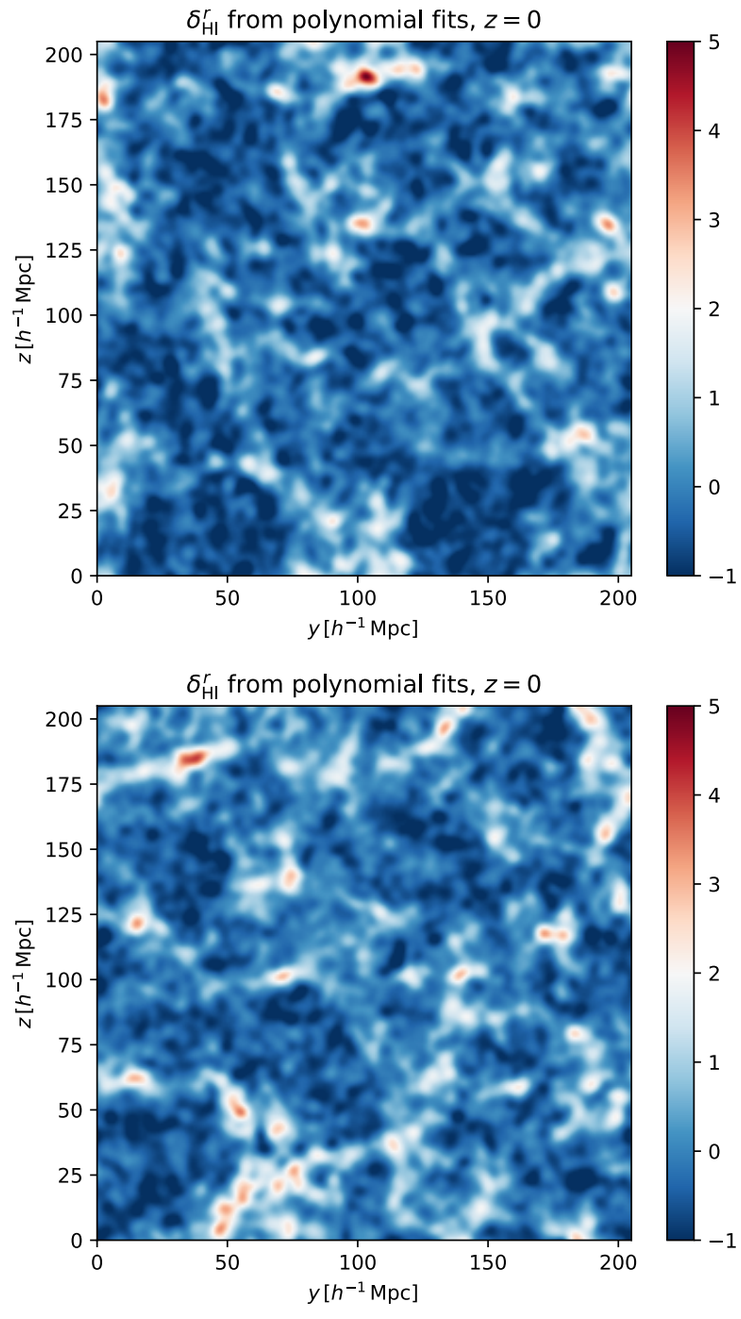
- $P_{\rm err}$ flat
- Comparable to sampling noise
- HI noise smaller than higher order terms at low-k
- Stochasticity should enter the Fisher Pk covariance, not the sampling noise
- Field level may do better than Pk!



Hi-Fi mocks

https://github.com/andrejobuljen/Hi-Fi_mocks

- Generate fast 3D HI field (Hi-Fi) level mocks
- ~2 min. on a modern laptop
- Real & redshift space at z=0,1 (more soon…)
- Tuned to TNG HI clustering (k=0.03-1h/Mpc)
- Variables: IC seed, BoxSize…
- **Publicly available, give it a try!**



TNG and random IC seed at z=0

Conclusions

- HI is a biased tracer of the matter field
- Cubic bias model 1% up to $k = 0.4\ (0.3)\ h/\mathrm{Mpc}$ in real (redshift) space

- HI noise flat & lower than stochasticity
- Higher order terms dominant at low-k, opposite to galaxies
- Case where field level analysis could be worthwhile (future work)

- We provide code to generate HI field level mocks: **Hi-Fi mocks**
- Improve future data analysis
- Useful for forecasts, mocks, covariances…

Thank you!