Recovering Cosmic Structure with a Simple Physical Constraint

21cm Cosmology Workshop 2025 & Tianlai Collaboration Meeting, Xi'An, CN

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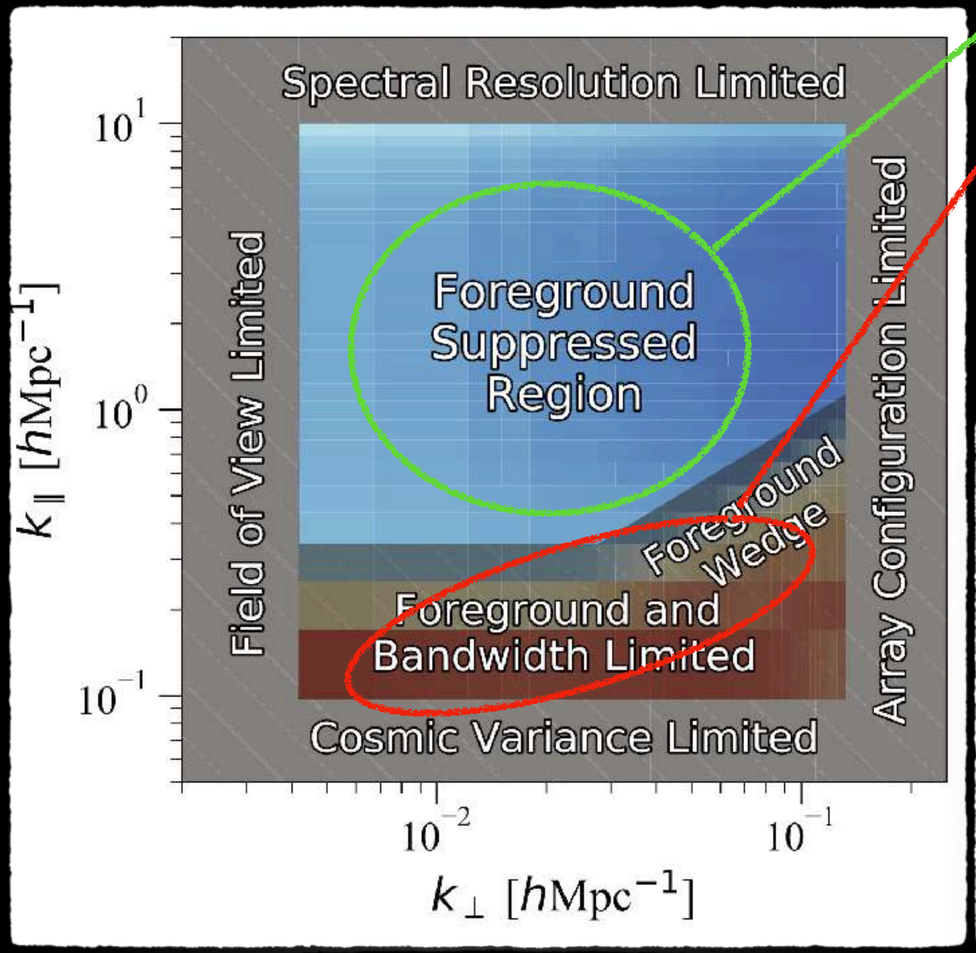
2025.7.16

arXiv: 2412.04021, 2503.20434

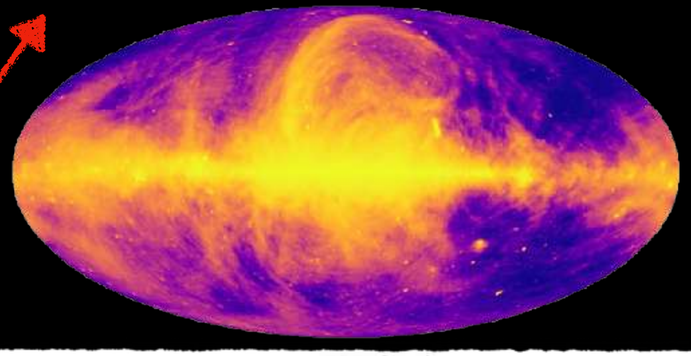
A pdf version of this prep can be download here

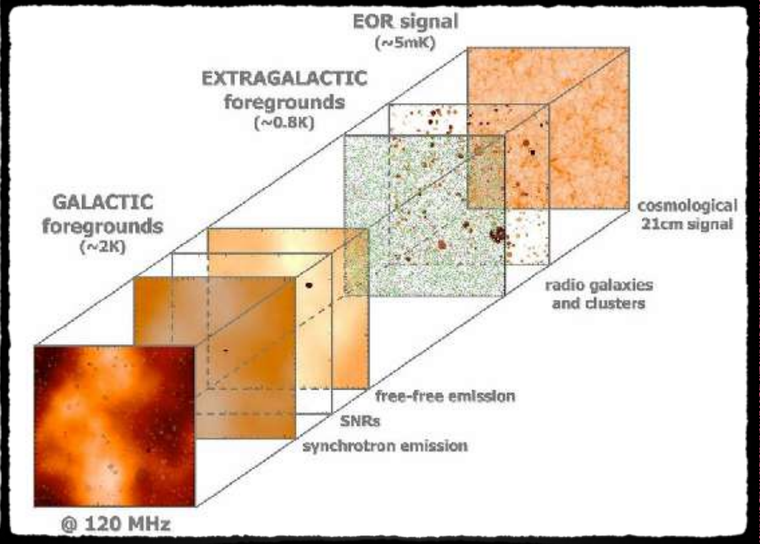
HI foreground: Mode mixing of the interferometer (foreground wedge)



EoR Window

Foreground & Wedge





DOI: 10.1088/1538-3873/ab5bfd

ImgCredit: V. Jeli'c

Biggest Challenge!

Solutions?
-> Foreground subtraction scheme

- Spectral smoothness

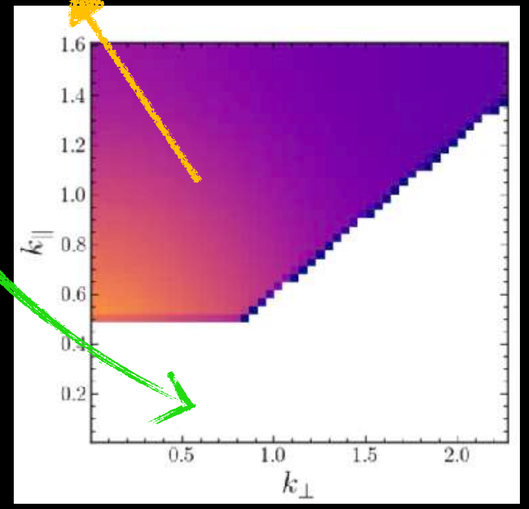
  Model-dependent
- Principal Component Analysis (PCA)

  Loss of vital info, subjective
- Independent Component Analysis (ICA)

  Model-dependent, complex
- Drop FG modes away···

  Conservative

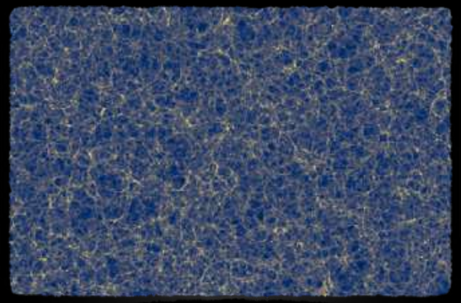
Extract LSS from SSS?



Solutions? -> From SSS to LSS

- Cosmic tidal reconstruction

Zhu et al., 2016, DOI: 10.1103/PhysRevD.93.103504



Quadratic estimator

Rely on 2LPT

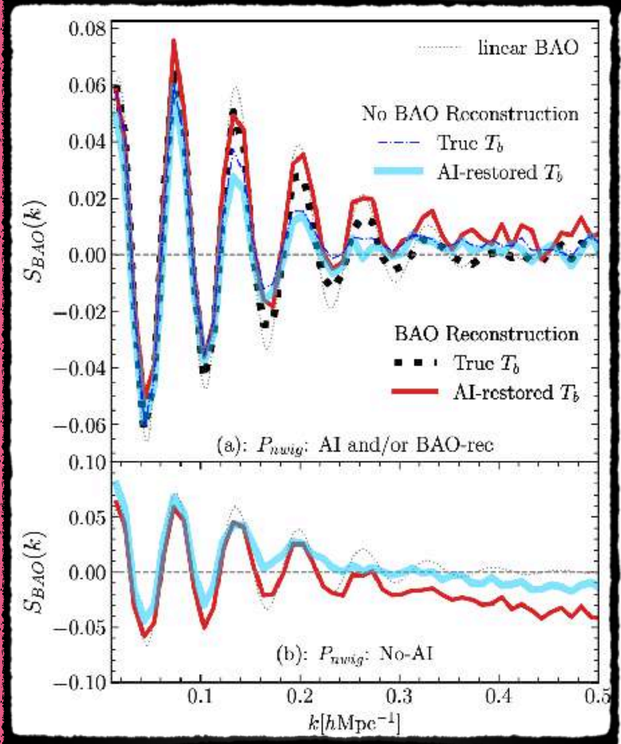
Complex

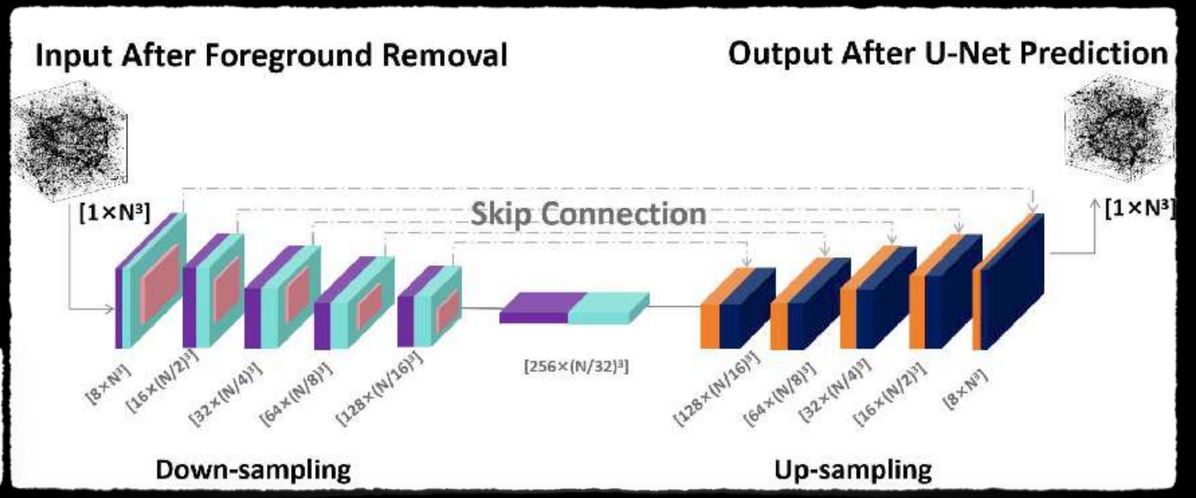
Sensitivity

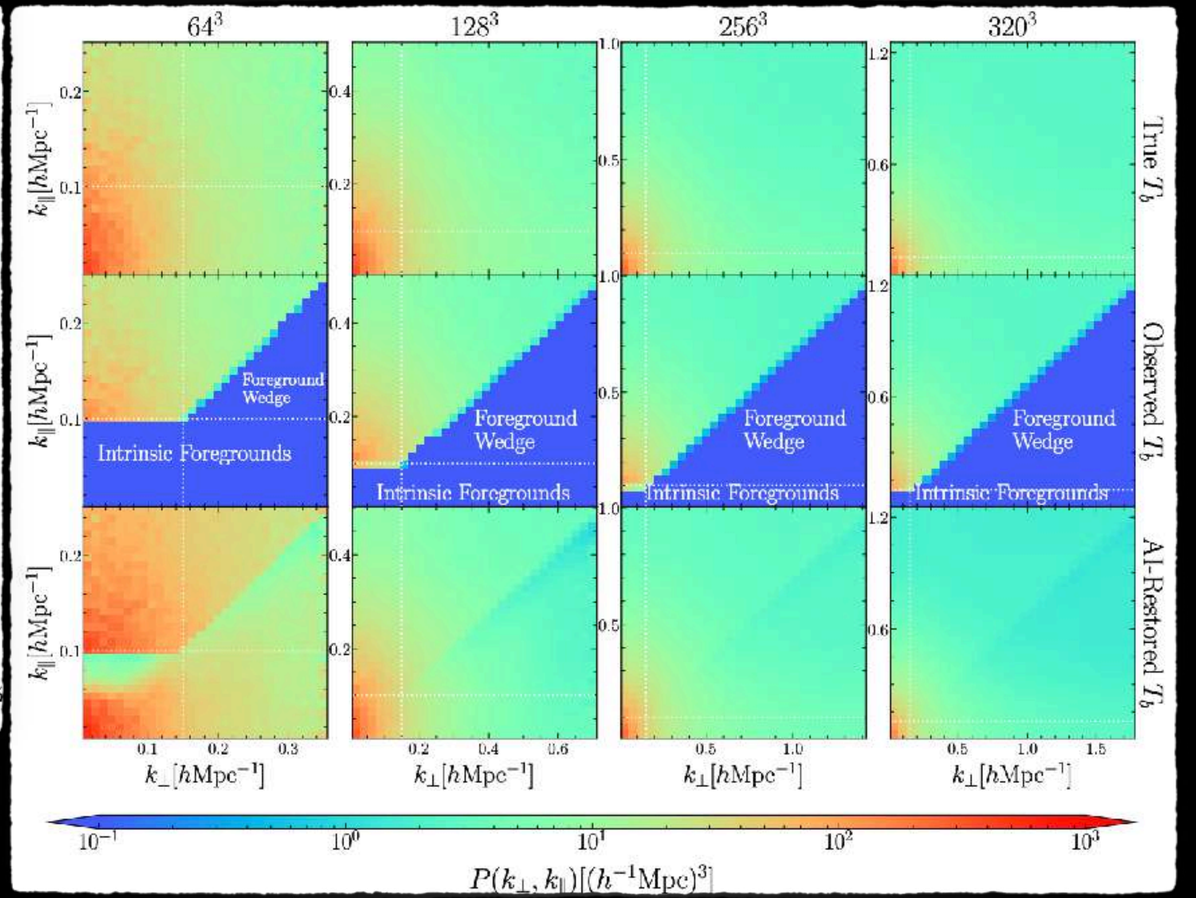
- Deep learning

Li, XW, Xiaodong Li, TCL et al., 2025, *JCAP*

$$\text{Loss} = \frac{1}{N}\sum_{i=1}^{N}\left(T_i^{\text{pred}} - T_i^{\text{true}}\right)^2$$







LSS is coupled with SSS ✌

Toy Model illustration

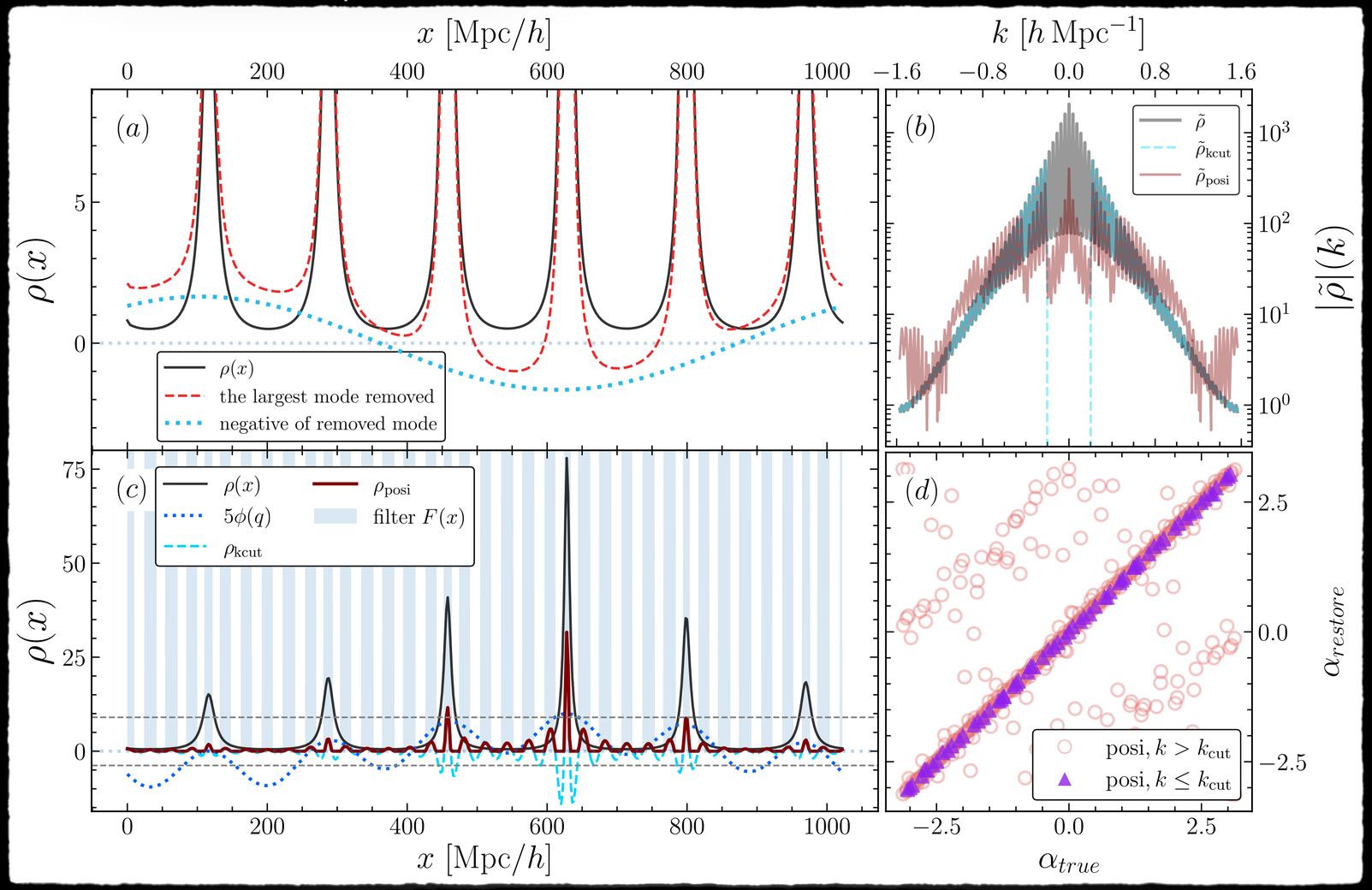
Positivization

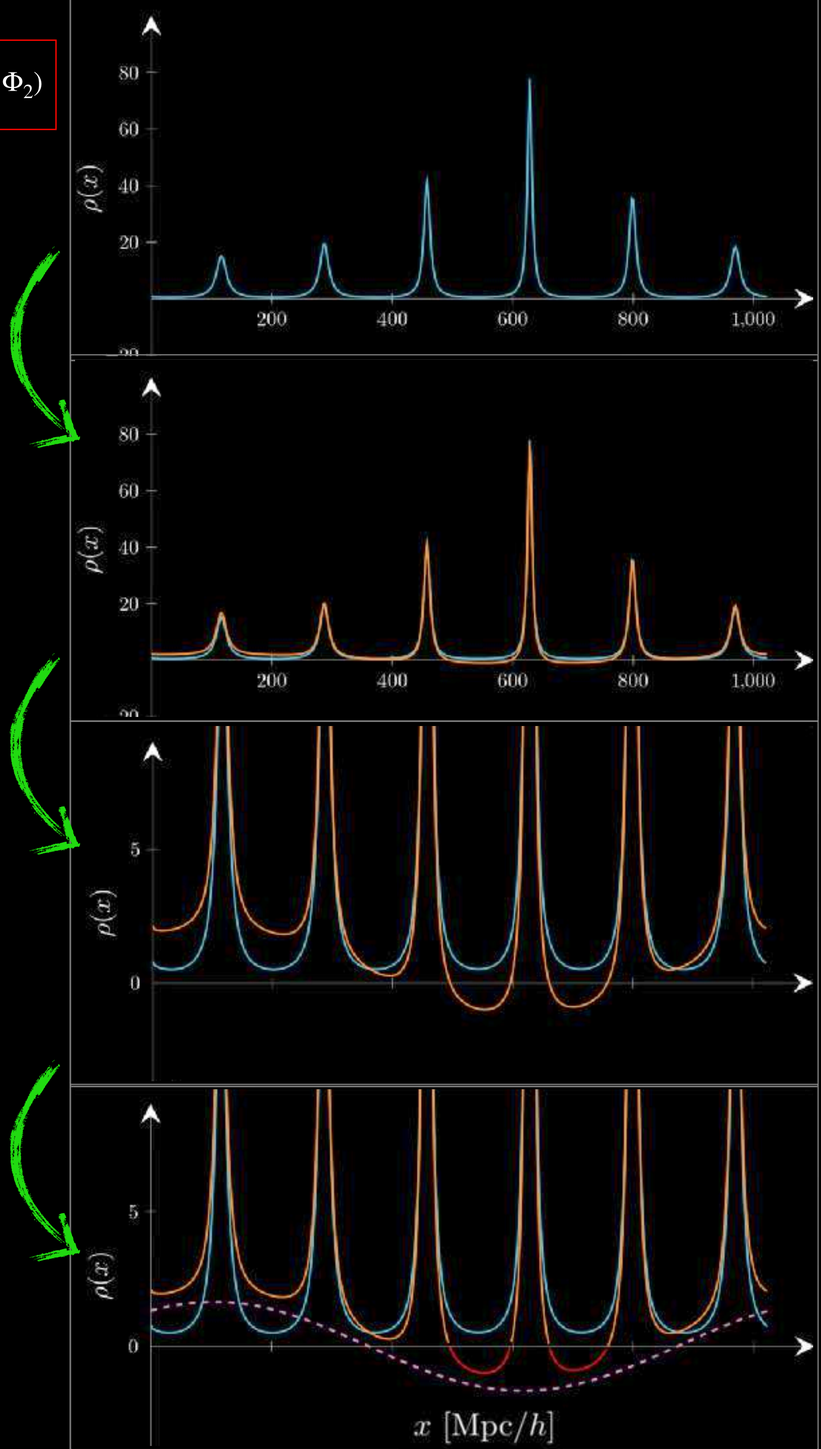
Displacement potential: $\phi = A\sin(\nu_1 x + \Phi_1) + A\sin(\nu_2 x + \Phi_2)$

Zel'dovich Approximation: $\mathbf{x} = \mathbf{q} + A(t)\nabla\phi$

Evolved density: $\rho(\mathbf{x}) = \dfrac{1}{1 + A(t)\nabla^2\phi}$

TCL, XW et al., 2025, *ApJ*

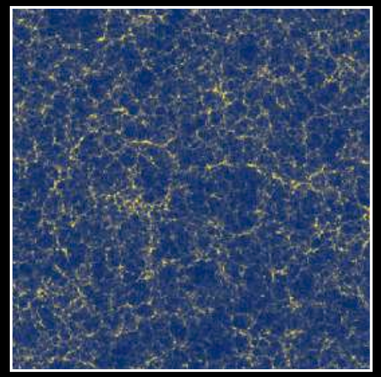


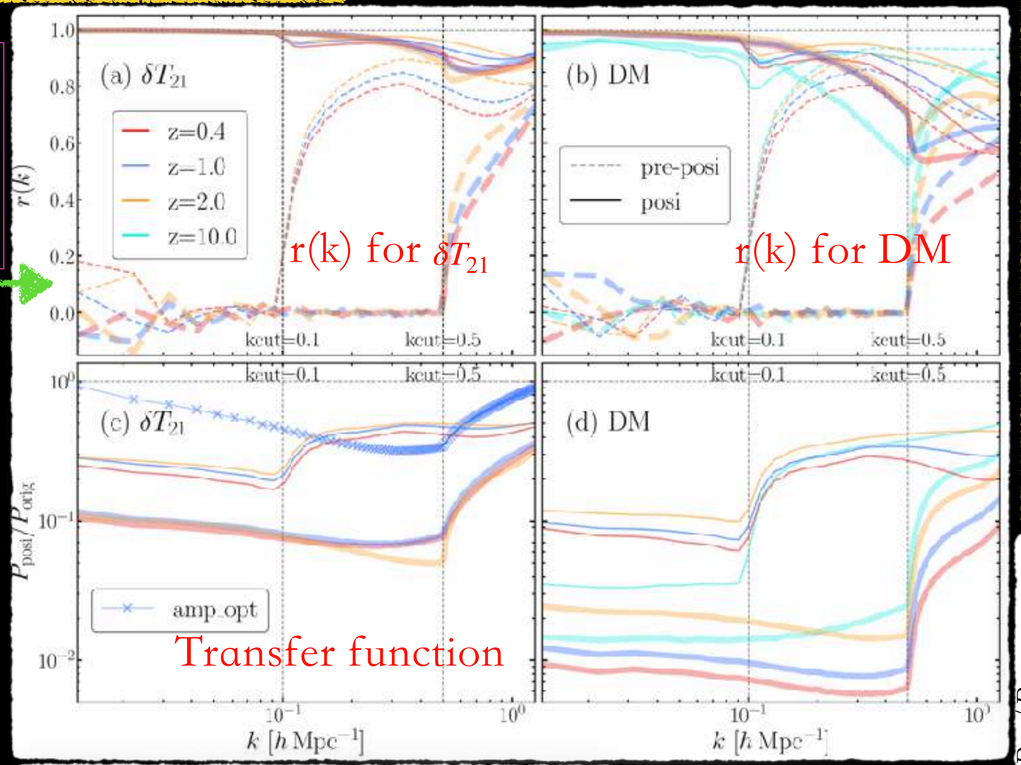


Application in 3D-cosmic sim

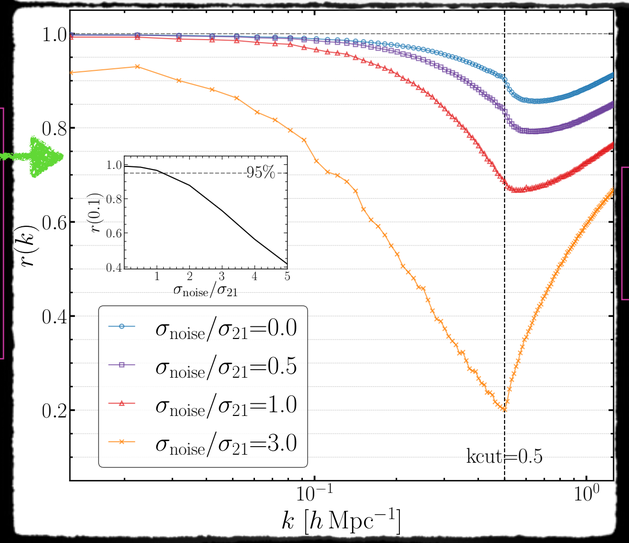
Recovering status on
- Phase
- Amplitude

$$r(\mathbf{k}) = \frac{P_{12}}{\sqrt{P_1 P_2}}(\mathbf{k}).$$

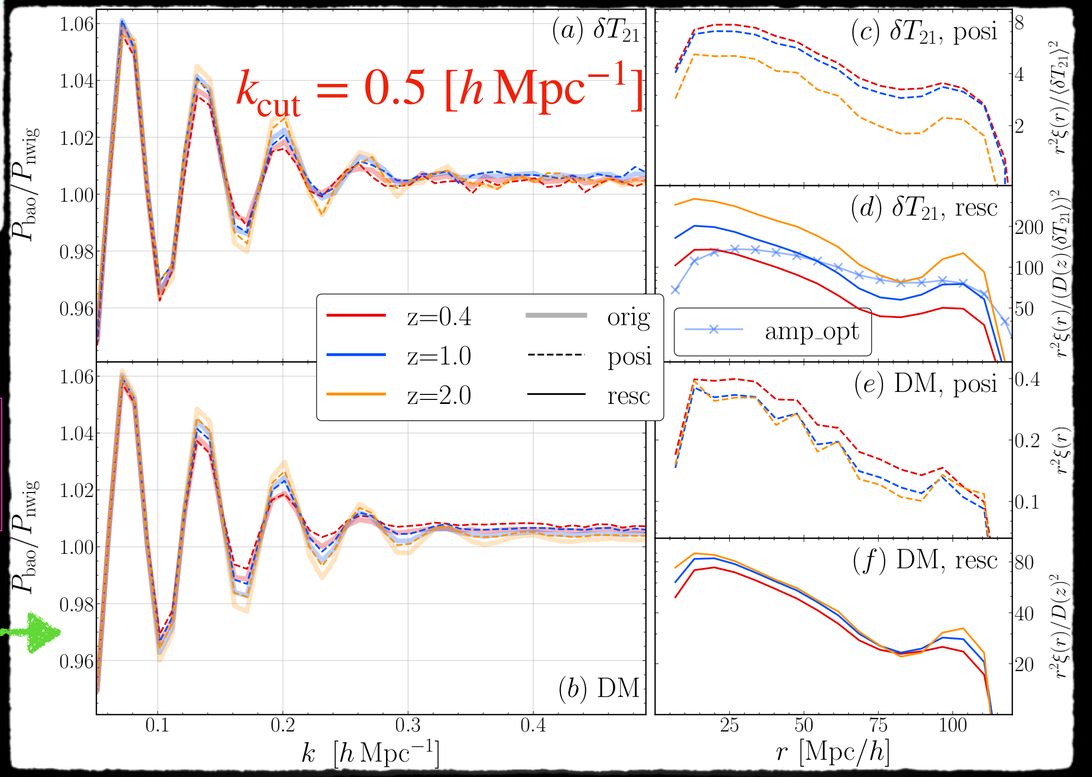




Impact of noise:
- Add different levels
  - [0.5, 1.0, 3.0] $\sigma_{\rm noise}/\sigma_{21}$
  - of Gauss thermal noise



Recovering status of BAO signal



Summary

From SSS to LSS:

Machine Learning:

Li, XW et al., 2025, *JCAP*

Positivizaiton:

TCL, XW et al., 2025, *ApJ*

Further:

in development, “better” than positivization..

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