Probing primordial non-Gaussianity (PNG) by reconstructing the initial conditions with machine learning

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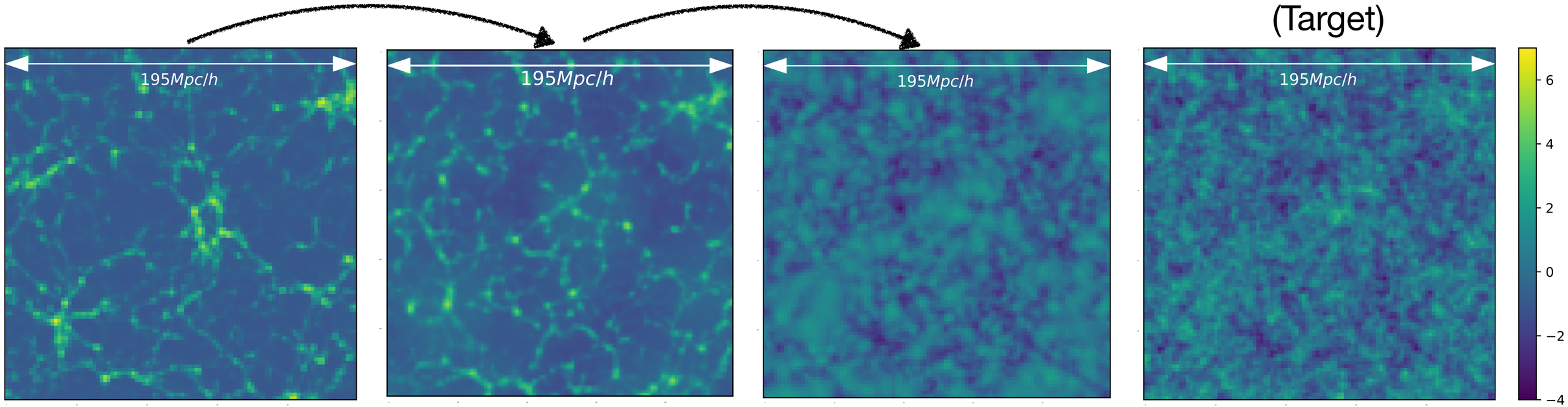
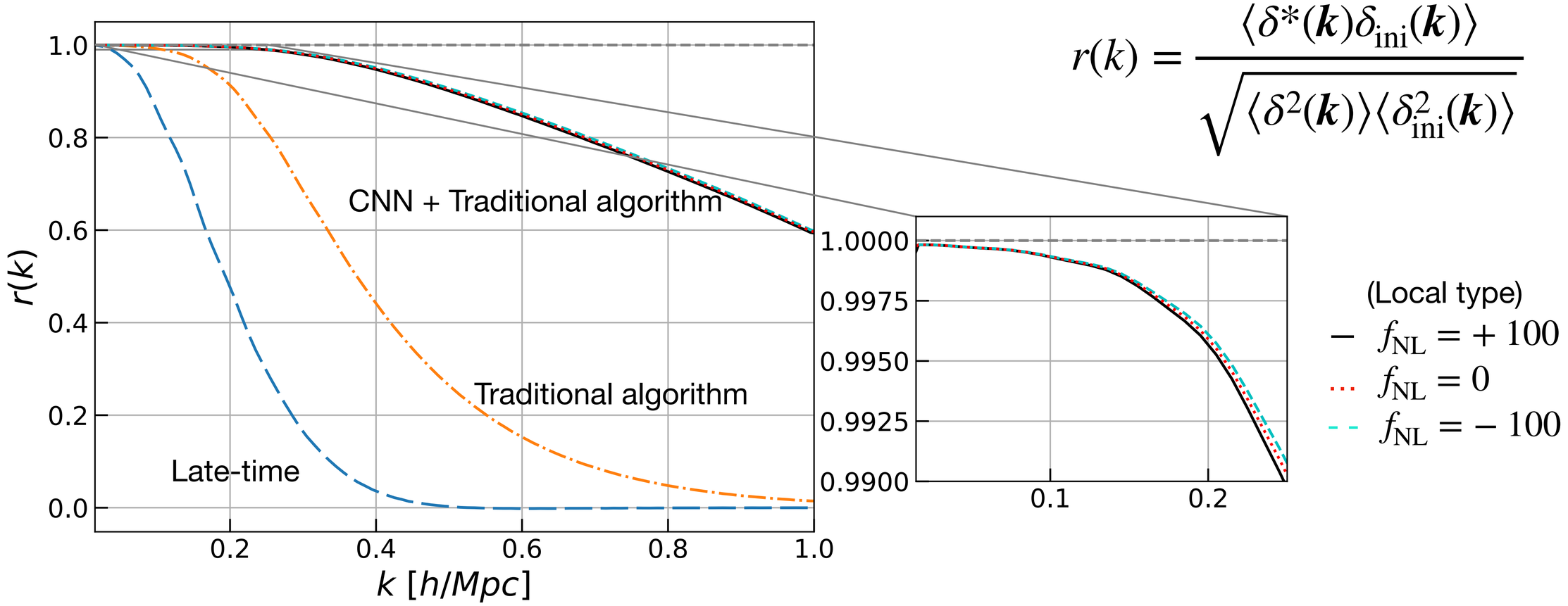
Image: D. Schlegel

Hybrid reconstruction method combining CNN with traditional algorithm significantly outperforms traditional algorithms



Normalized matter density fields at z=0, using Quijote simulations (Villaescusa-Navarro et al. 2020)

Model trained with no PNG works for PNG



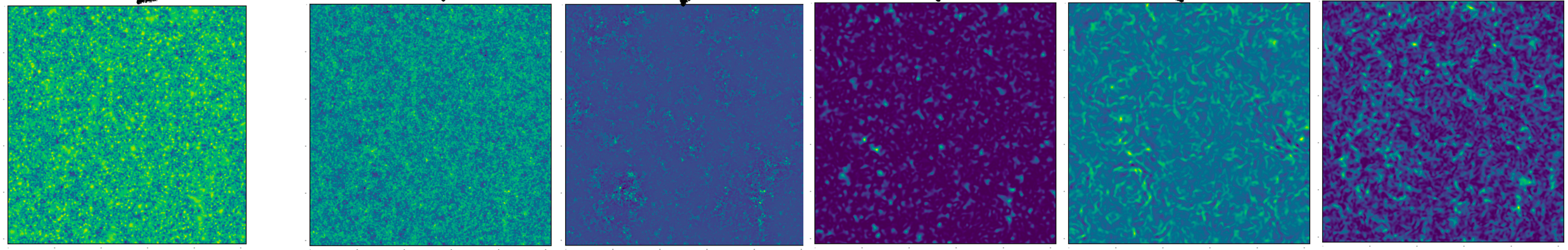
$$r(k) = \frac{\langle \delta^*(\boldsymbol{k}) \delta_{\rm ini}(\boldsymbol{k}) \rangle}{\sqrt{\langle \delta^2(\boldsymbol{k}) \rangle \langle \delta^2_{\rm ini}(\boldsymbol{k}) \rangle}}$$

Real space matter field z=0

Template fits give slightly biased fits but smaller $\sigma(f_{\rm NL})$

Gaussian Growth Shift Tidal

$$\delta_{\rm CNN} = b_G\delta_G + f_{\rm NL}\delta_{f_{\rm NL}} + b_2\delta^2 + b_{\nabla^2}\delta_{\nabla^2} + b_{s^2}\delta_{s^2} + \ldots$$



- δ_G=No PNG IC
- $\delta_{f_{\rm NL}} = \phi_G^2(k)M_\phi(k)$
- $\delta^2, \delta_{\nabla^2}, \delta_{s^2}$ all computed using δ_G

Fitting matter density field in 1 Gpc/h box in real space at z=0:

Post-(CNN) recon: $f_{\rm NL} = 100$: ~92±5, $f_{\rm NL} = -100$: ~-92±5

Pre-recon: $f_{\rm NL} = 100$: ~95±11, $f_{\rm NL} = -100$: ~-95±11

~2x improvement in error

For >2 Gpc survey volume (e.g. DESI):

$\sigma(f_{\rm NL}) \sim 1$

Takeaway

- Reconstruction with CNN+Traditional algorithm shows promising constraining power for PNG
  - **Significantly reduces gravity-induced nonlinearities**, and still **preserves most PNG and gives tighter constrains**
- Powerful approach to constrain PNG with large-scale structure surveys (e.g. DESI, *Euclid*, *Roman*)