Nonlinear Reconstruction

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Nonlinear Reconstruction

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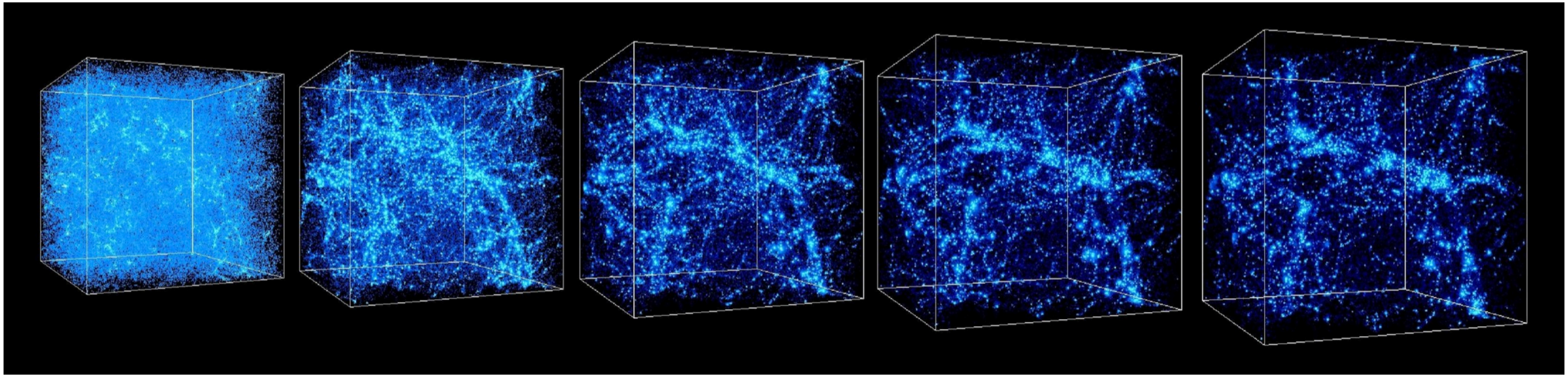
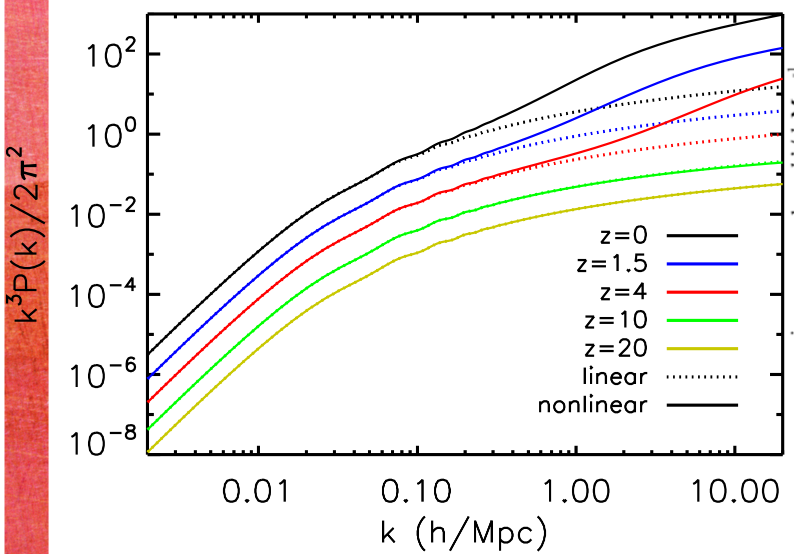
Outline

- Nonlinear evolution and standard reconstruction
- New reconstruction and performance
- Reconstruction with RSD effect
- In progress
- Conclusion

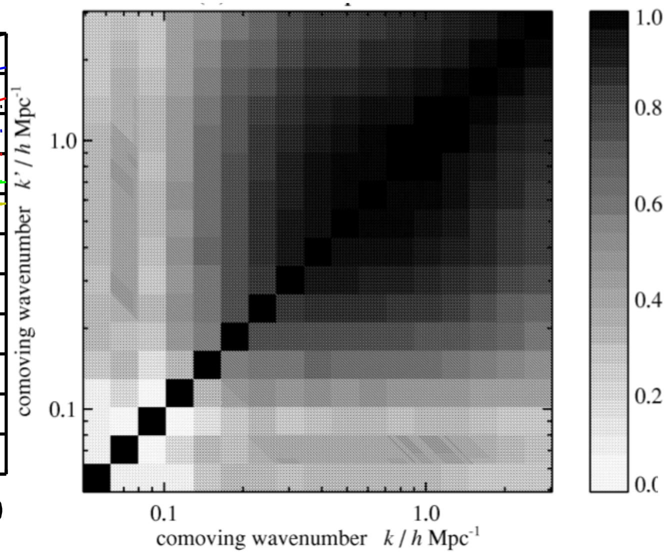
Nonlinear evolution



Boosted small scale power

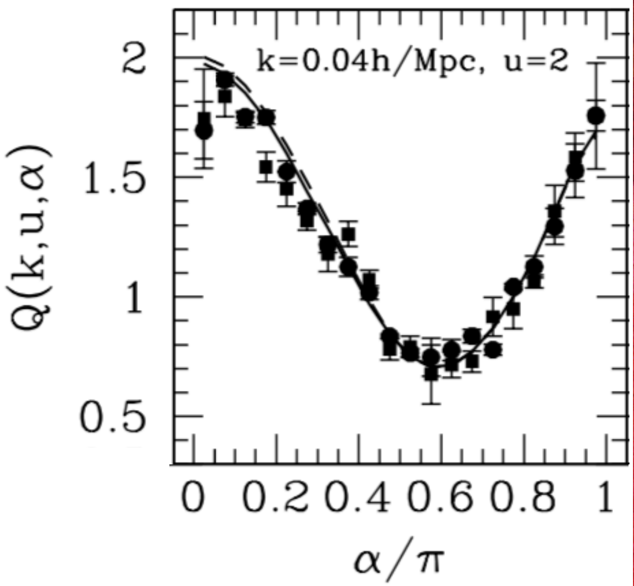


correlation between scales



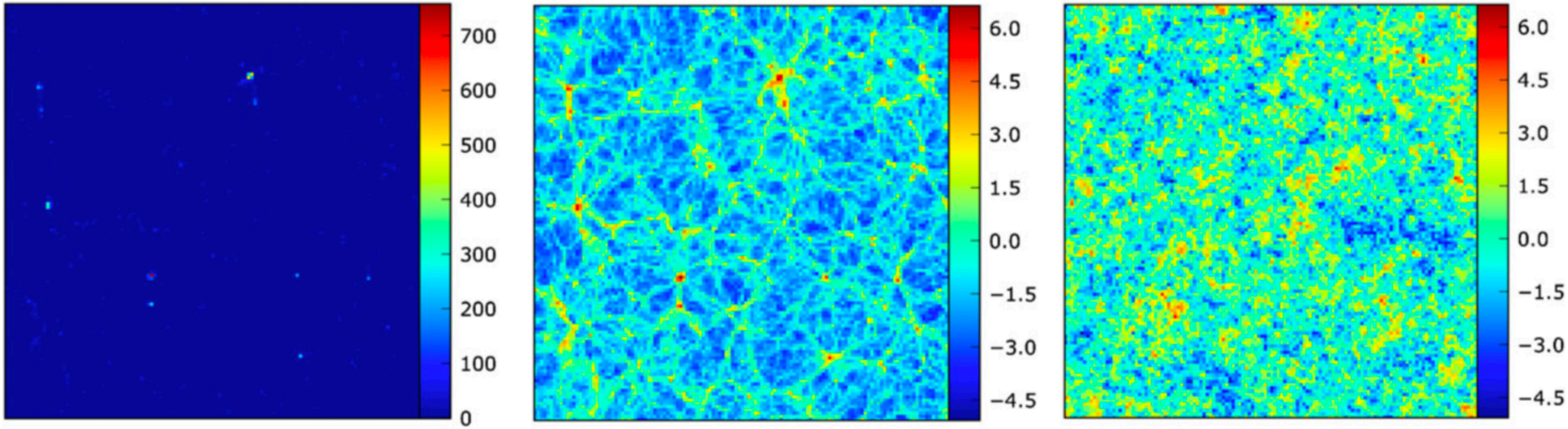
Rimes & Hamilton 2005

high-order statistics



Guo & Jing 2009

Local transform helps



δ $\qquad$ $\log(1+\delta)$ $\qquad$ $\delta_{\rm init}$

Local transforms are

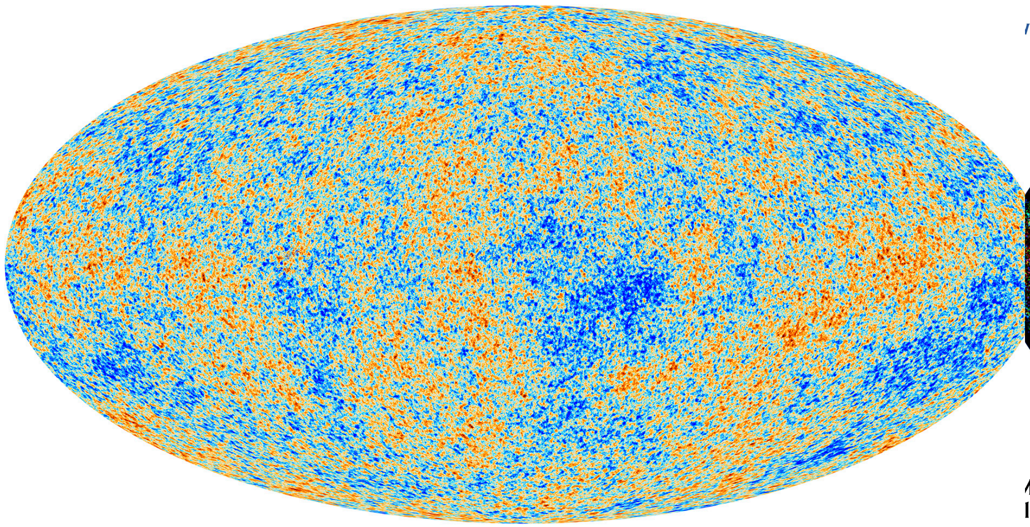
- Useful in analysis
- Useful in producing mocks (LogN)
- Useless in recovering the early state

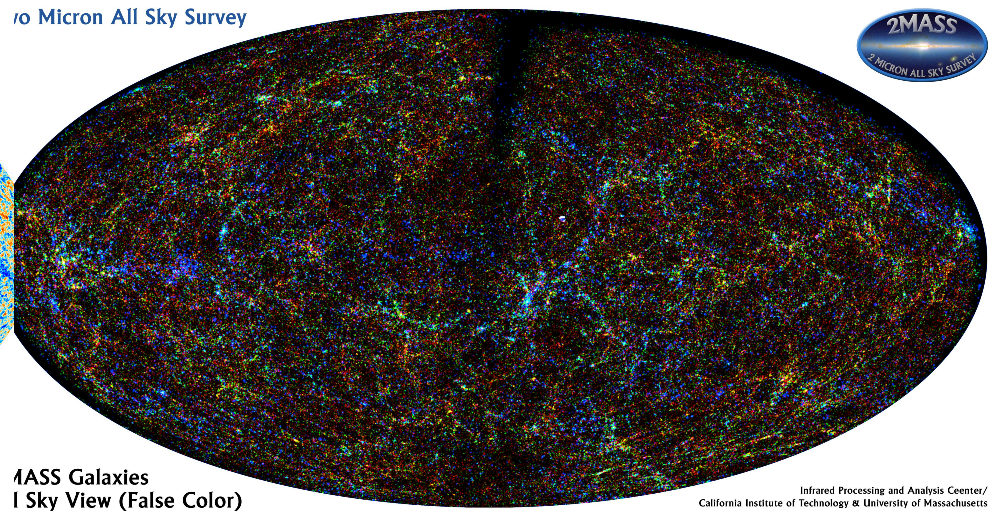
For weak lensing

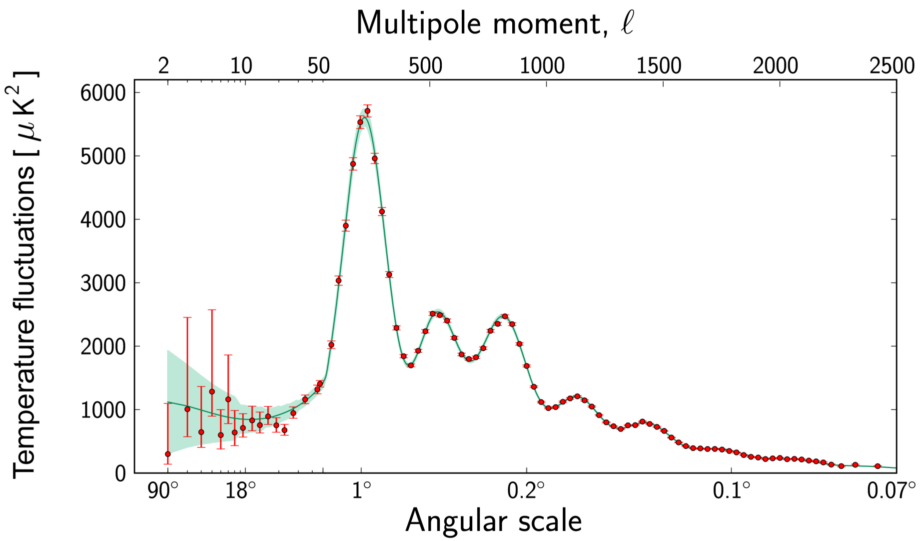
Yu et al. 2011, 2012

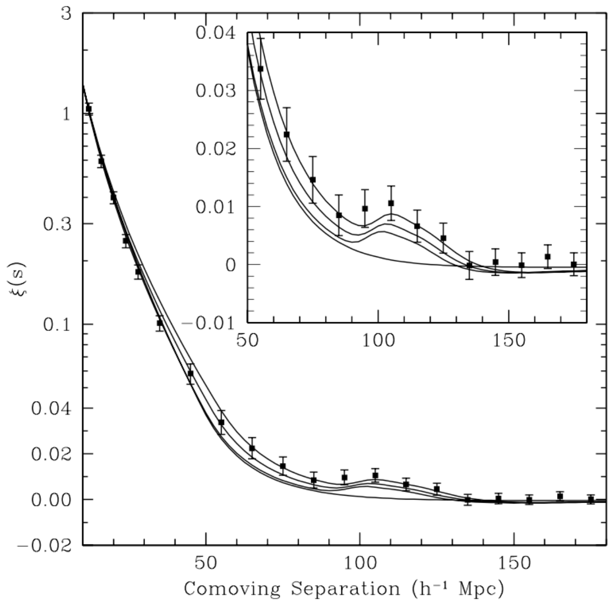
Yu et al. 2015

Nonlinear evolution





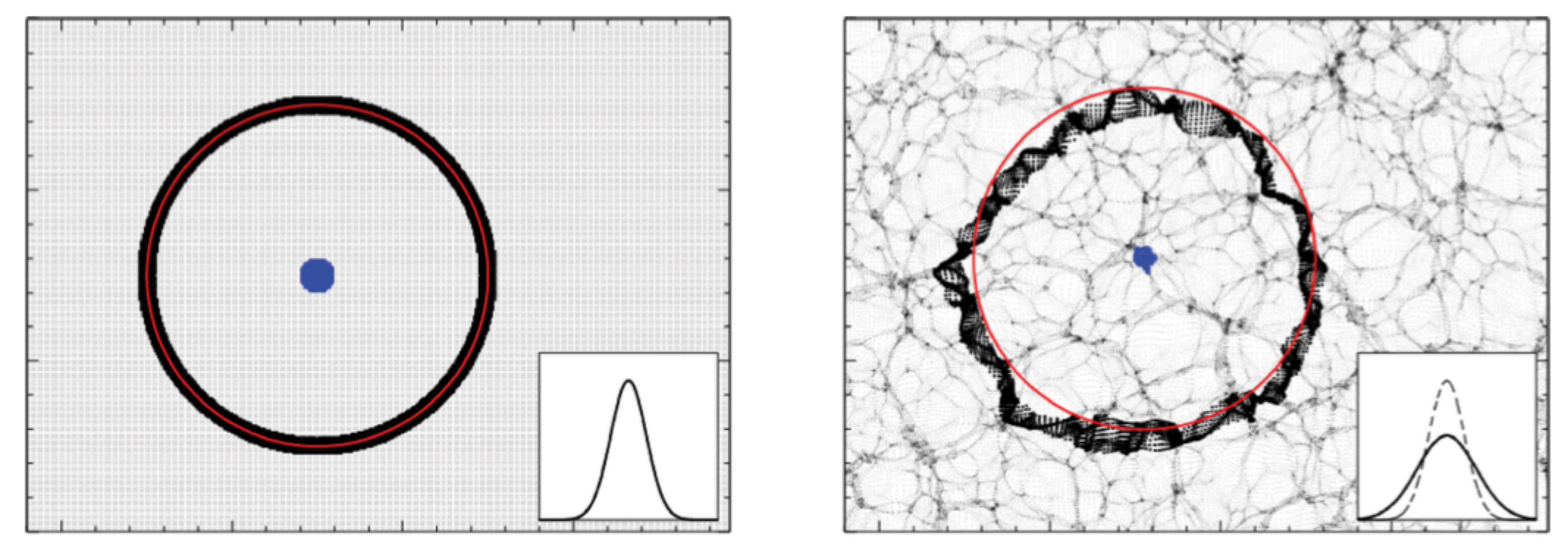




Planck 2013

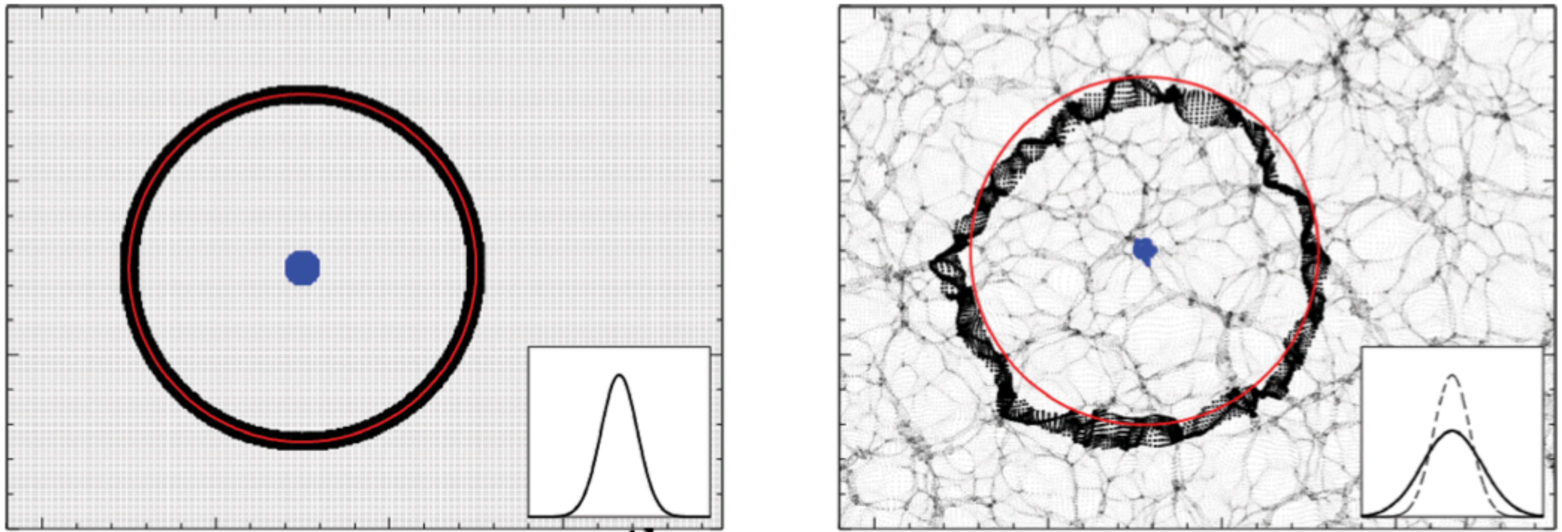
Eisenstein+ 2005

Baryon Acoustic Oscillation

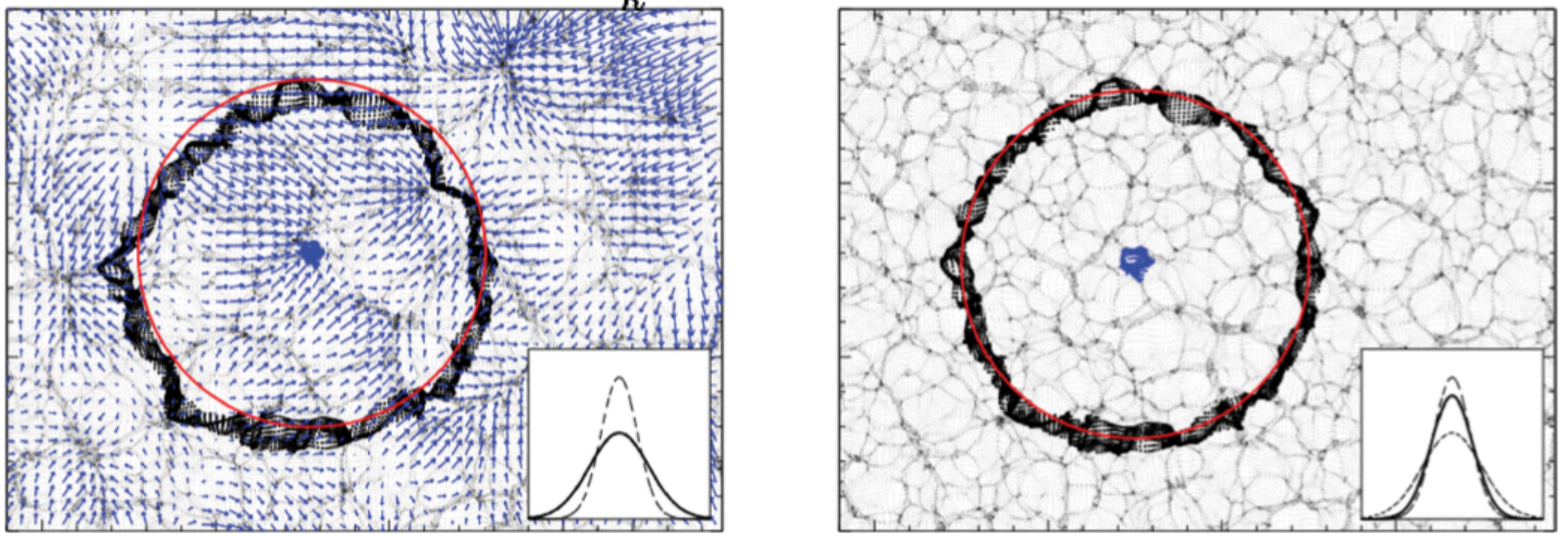


- bulk motion
- redshift space distortion
- nonlinear growth

Standard BAO reconstruction



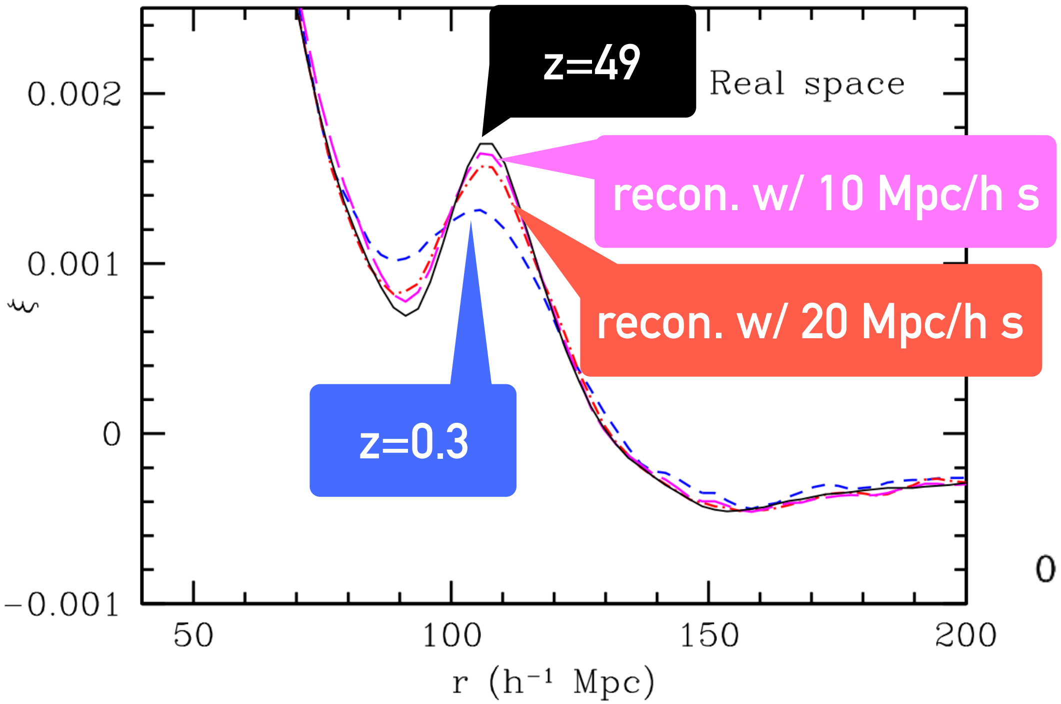
linear continuity equation $\boldsymbol{s}(\boldsymbol{k}) = -\frac{i\boldsymbol{k}}{k^2} S(k)\delta(k)$



Padmanabhan+ 2012

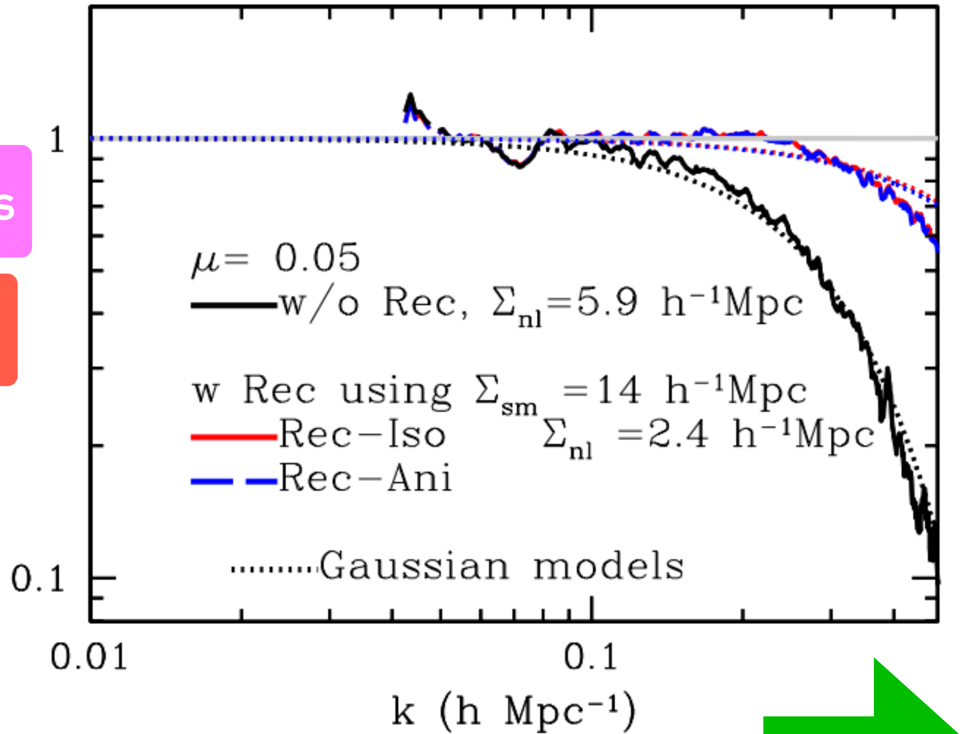
Standard BAO reconstruction

- Sharper peak / weaker damping



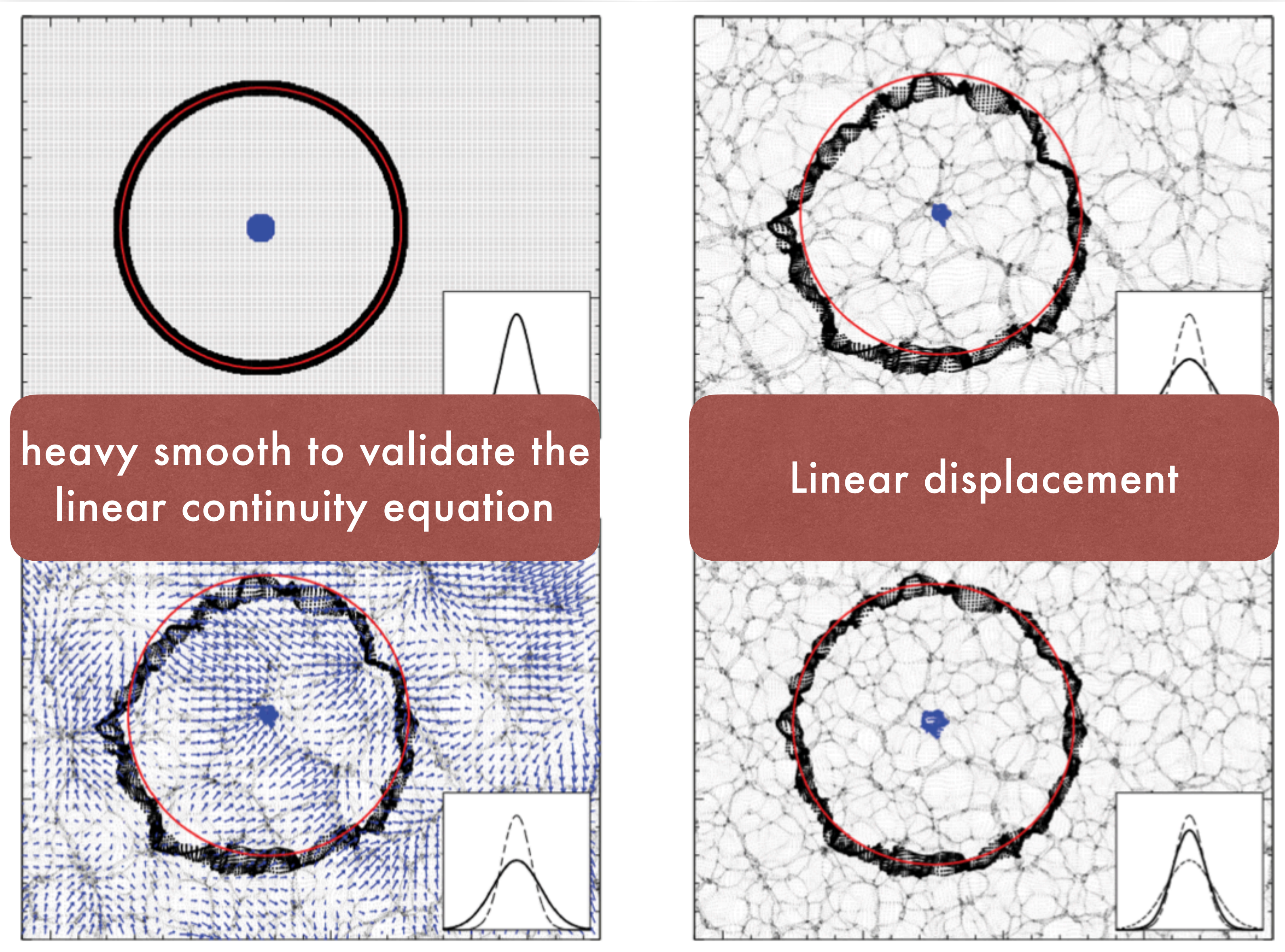
Eisenstein+ 2007

$$P(k) = D^2(k) P_L(k) + N(k)$$



Seo+ 2016

Standard BAO reconstruction



Padmanabhan+ 2012

Outline

- ➤ Nonlinear evolution and standard reconstruction
- ➤ New reconstruction and performance
- ➤ Reconstruction with RSD effect
- ➤ In progress
- ➤ Conclusion

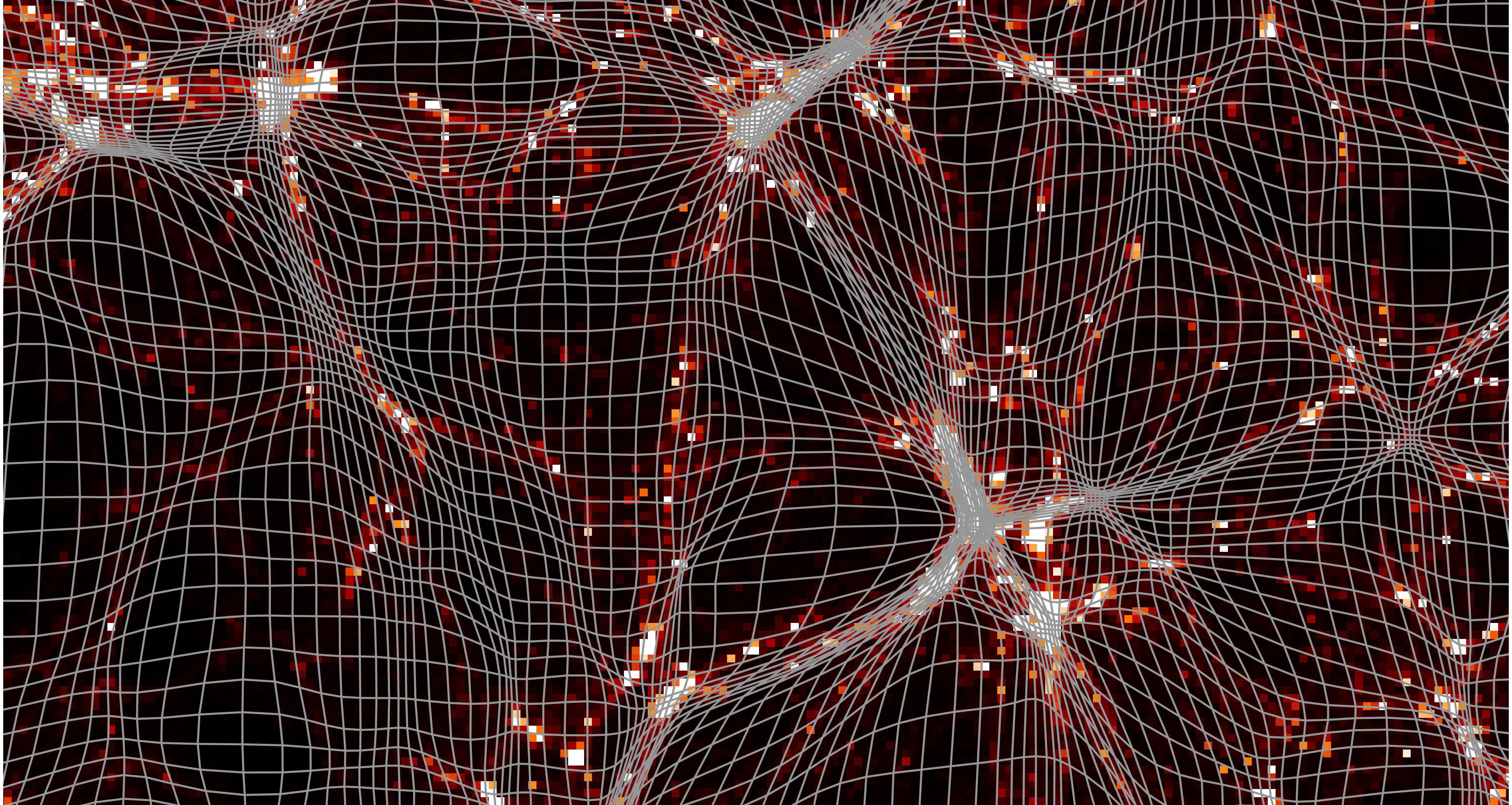
NEW reconstruction method

- The initial condition of our Universe is homogeneous, isotropic, and UNIFORM ($\sim 10^{-5}$ at z=1100).
- How about solving for a curvilinear coordinate, in which the mass per grid is constant.

$$\rho(\boldsymbol{x}) \qquad\qquad \rho(\boldsymbol{\xi})\mathrm{d}^3\boldsymbol{\xi} = \text{constant}$$

NEW reconstruction method

- solve for a curvilinear coordinate, in which the mass per grid is constant.



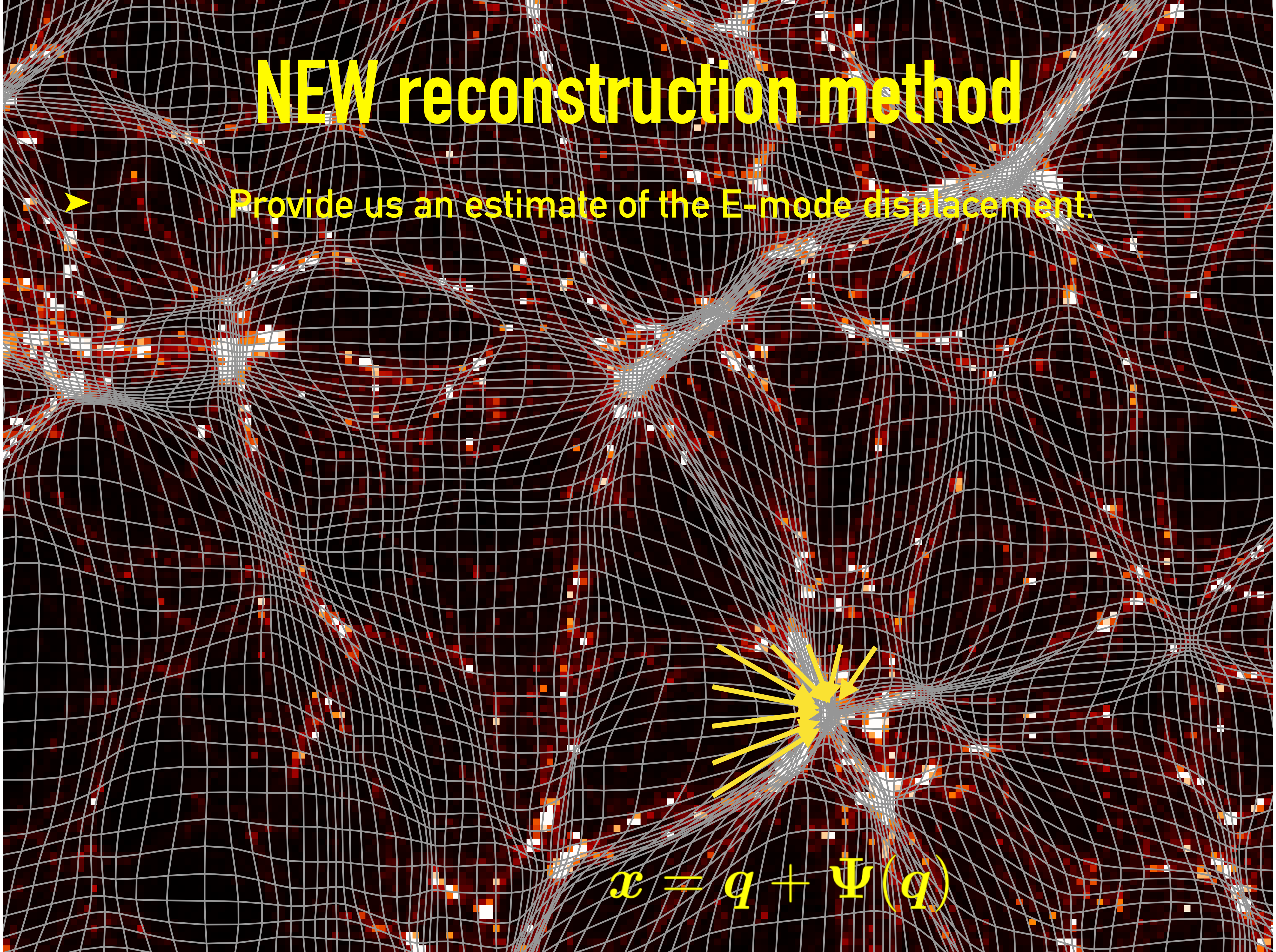
Algorithm

- Originally used in moving mesh simulation (N-body and hydrodynamic; see Pen 1995 & 1998)
  - solve for a mesh following the nonlinear density evolution at each time step
  - to keep (approximately) constant mass/energy resolution

- In our case, we need solve for a mesh consistent with the highly nonlinear density field, perturbatively and iteratively.
- POTENTIAL ISOBARIC GAUGE/COORDINATE

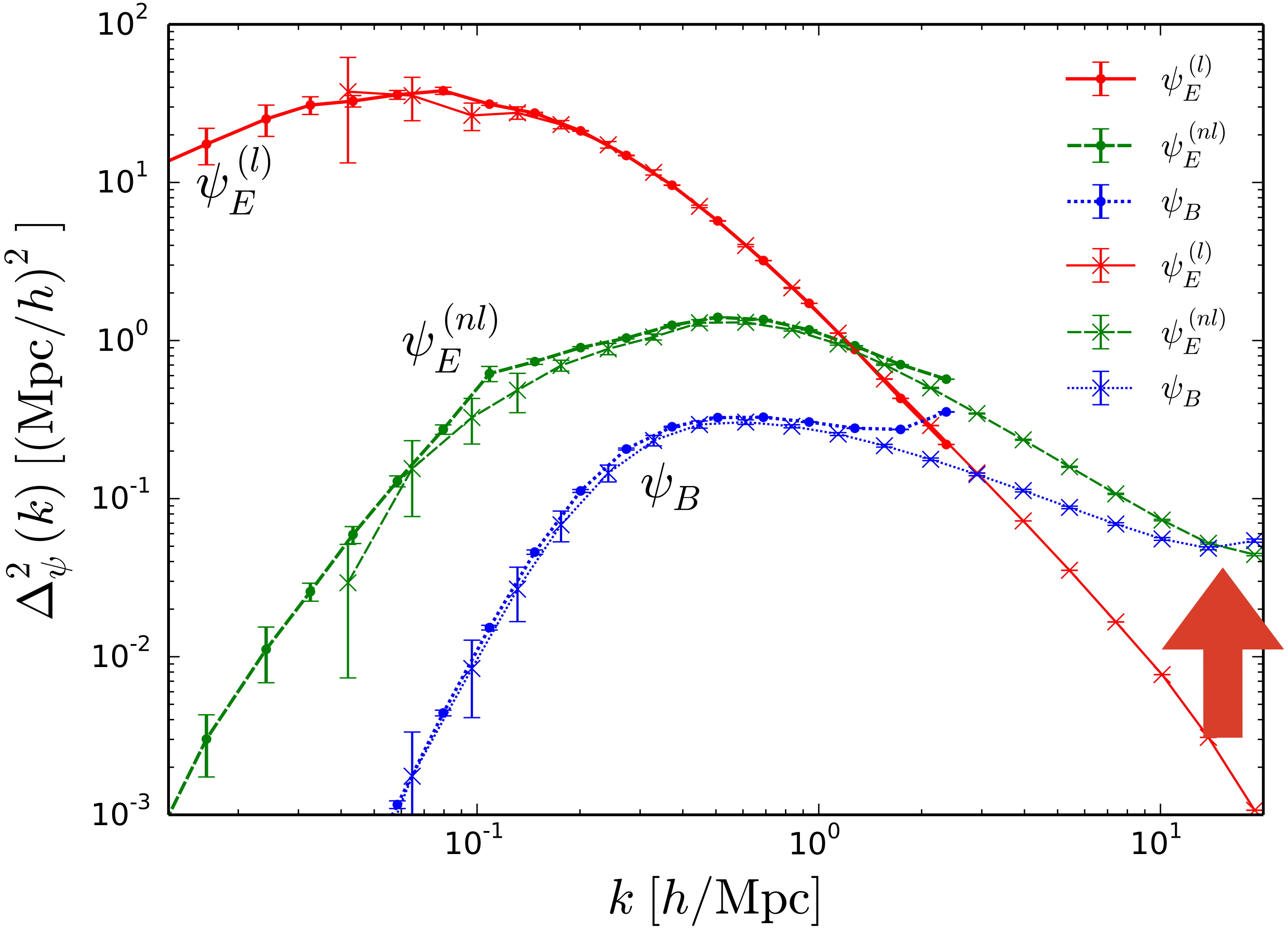
NEW reconstruction method

- Provide us an estimate of the E-mode displacement.



$$\boldsymbol{x} = \boldsymbol{q} + \boldsymbol{\Psi}(\boldsymbol{q})$$

Displacement components



$$\psi = \psi_E{}^{L} + \psi_E{}^{NL} + \psi_B$$

Definition

Reconstructed density field

$$\delta_R = -\nabla \cdot \Psi_R$$

Linear density field

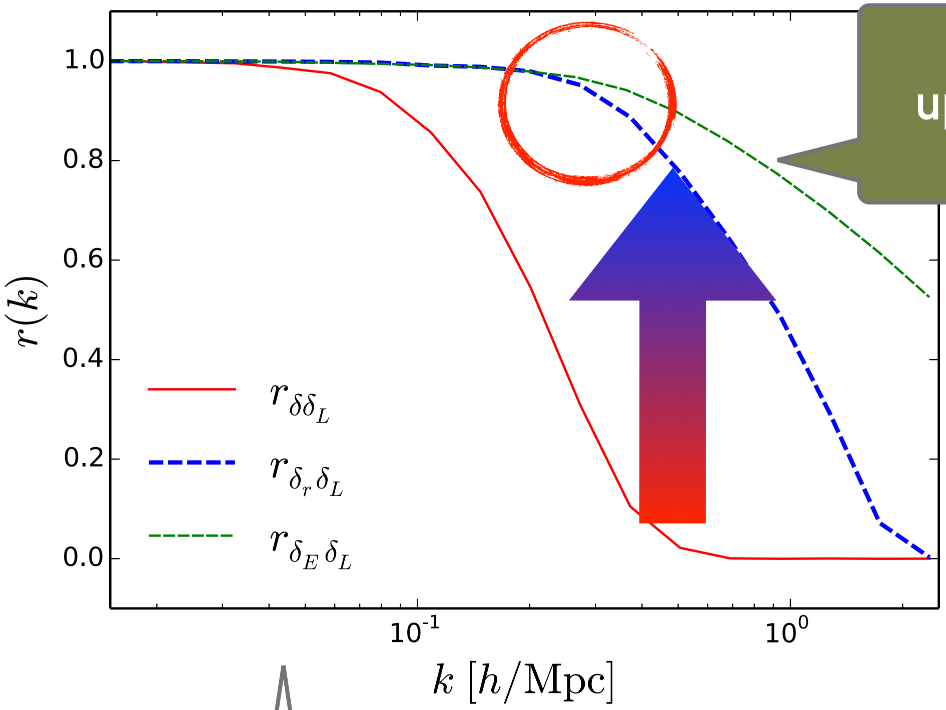
$$\delta_L$$

Reconstruction by real displacement

$$\delta_E = -\nabla \cdot \Psi_E$$

Correlation with initial condition

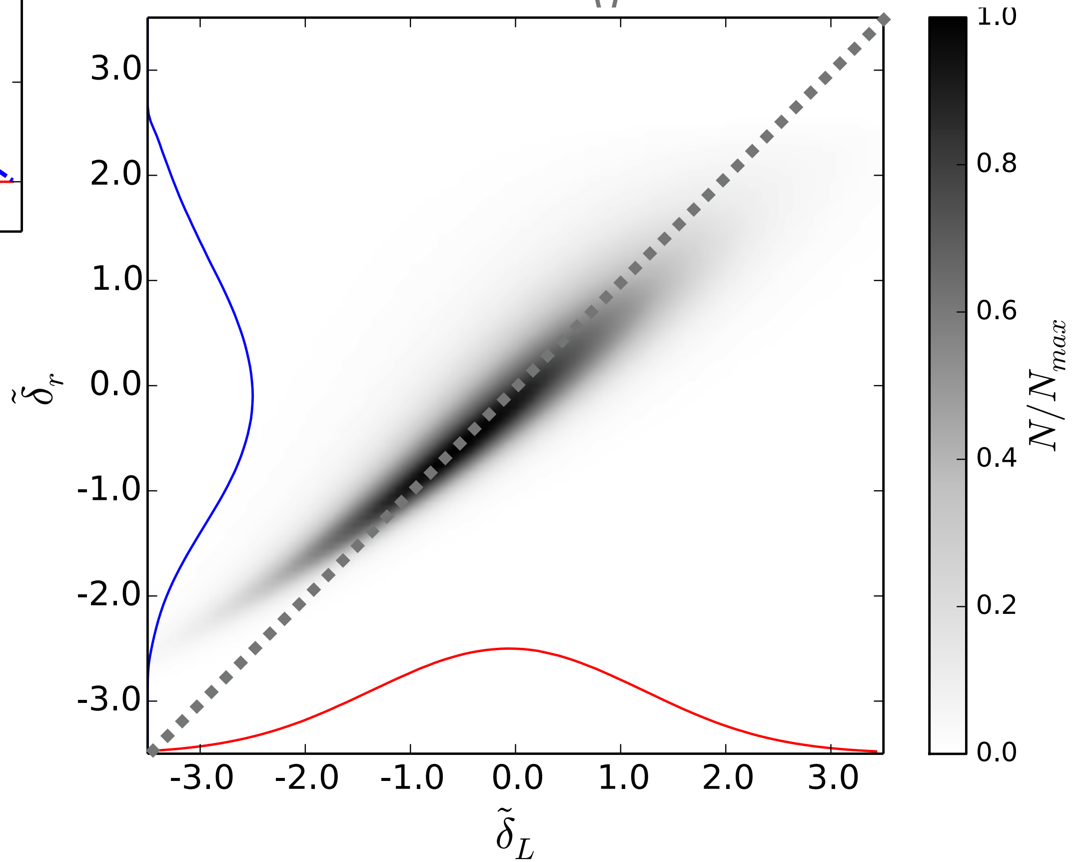
Zhu, YU and Pen (2016)



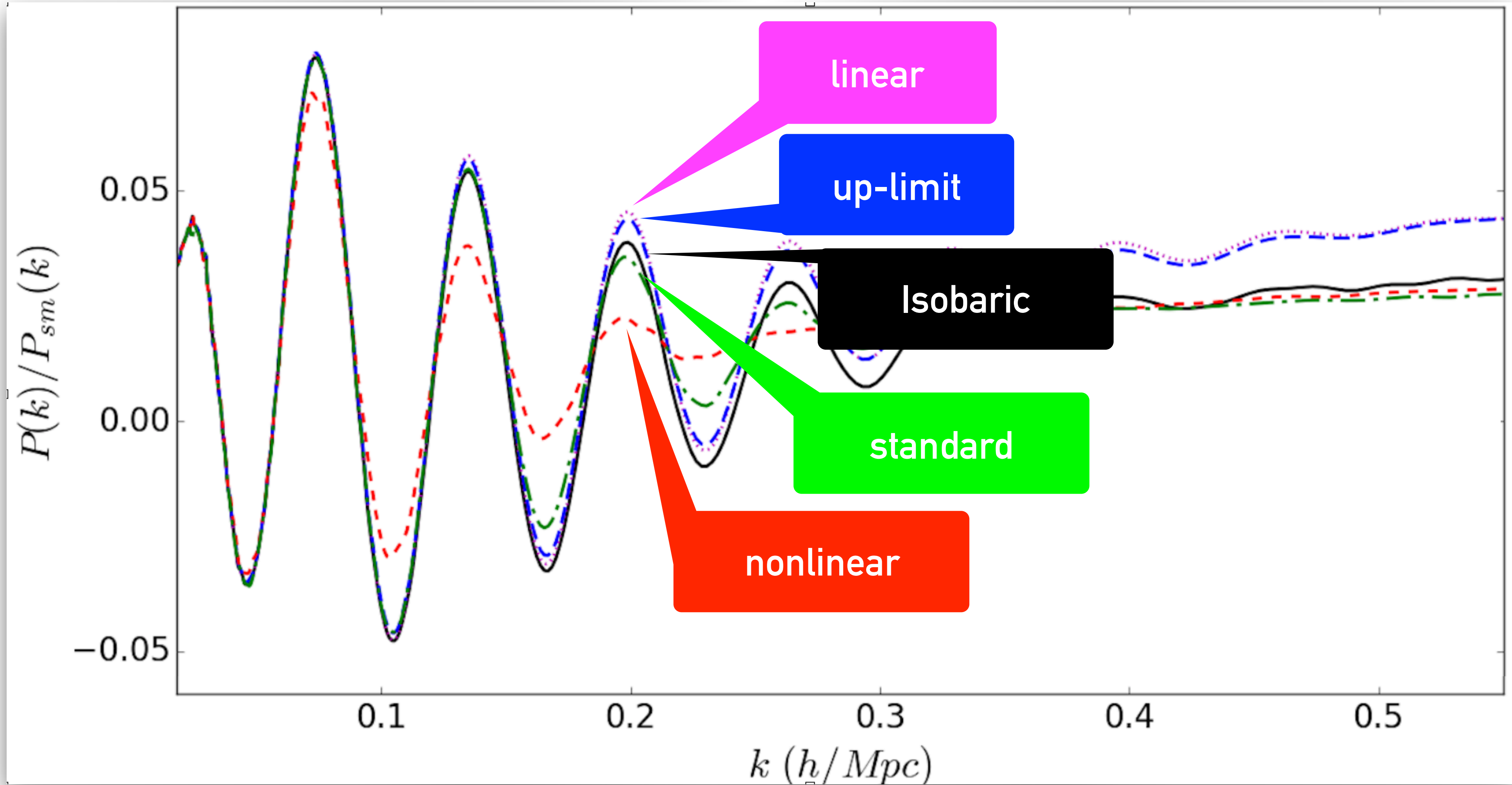
up-limit

Cross-correlation coefficient

point to point comparison

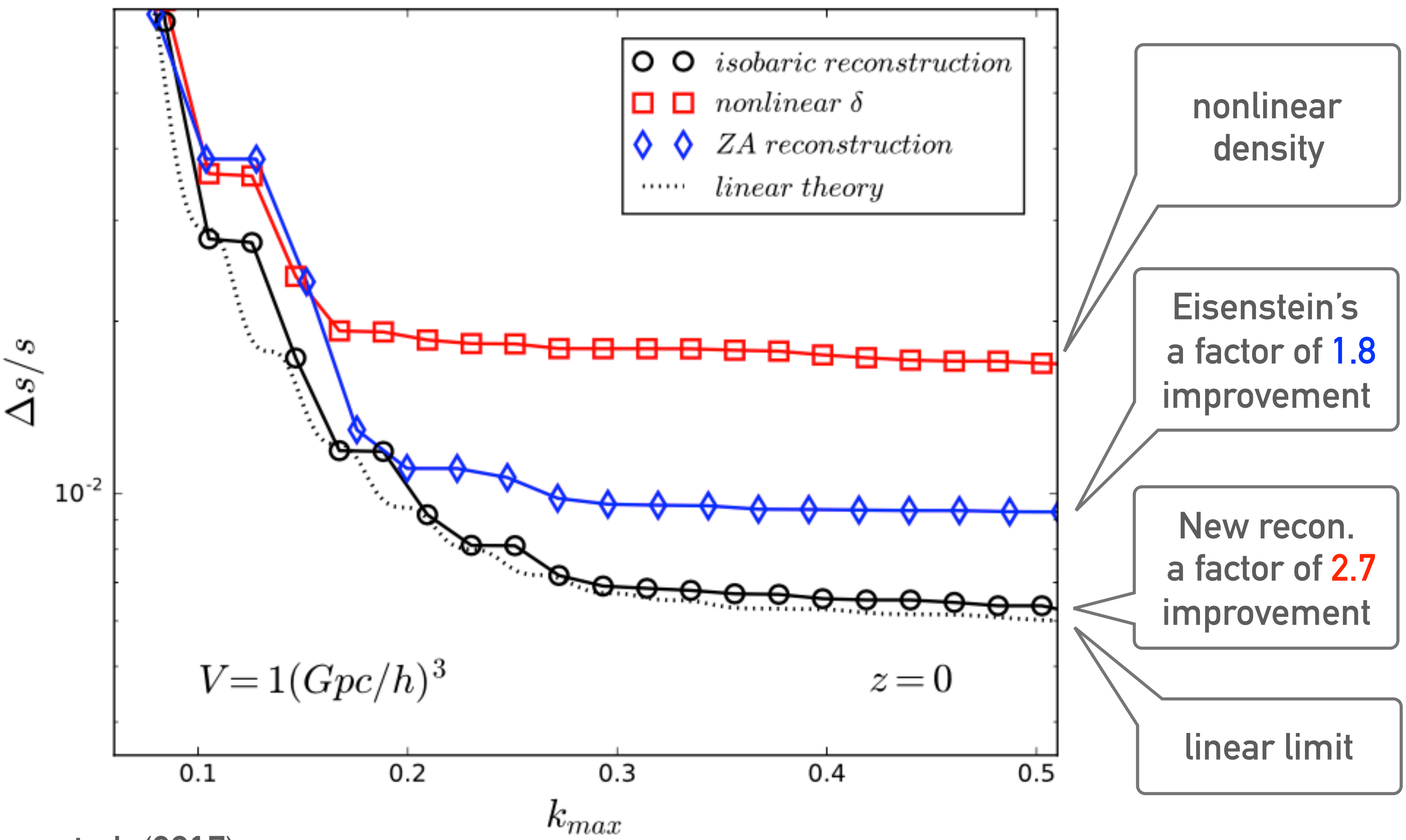


Acoustic peak recovery



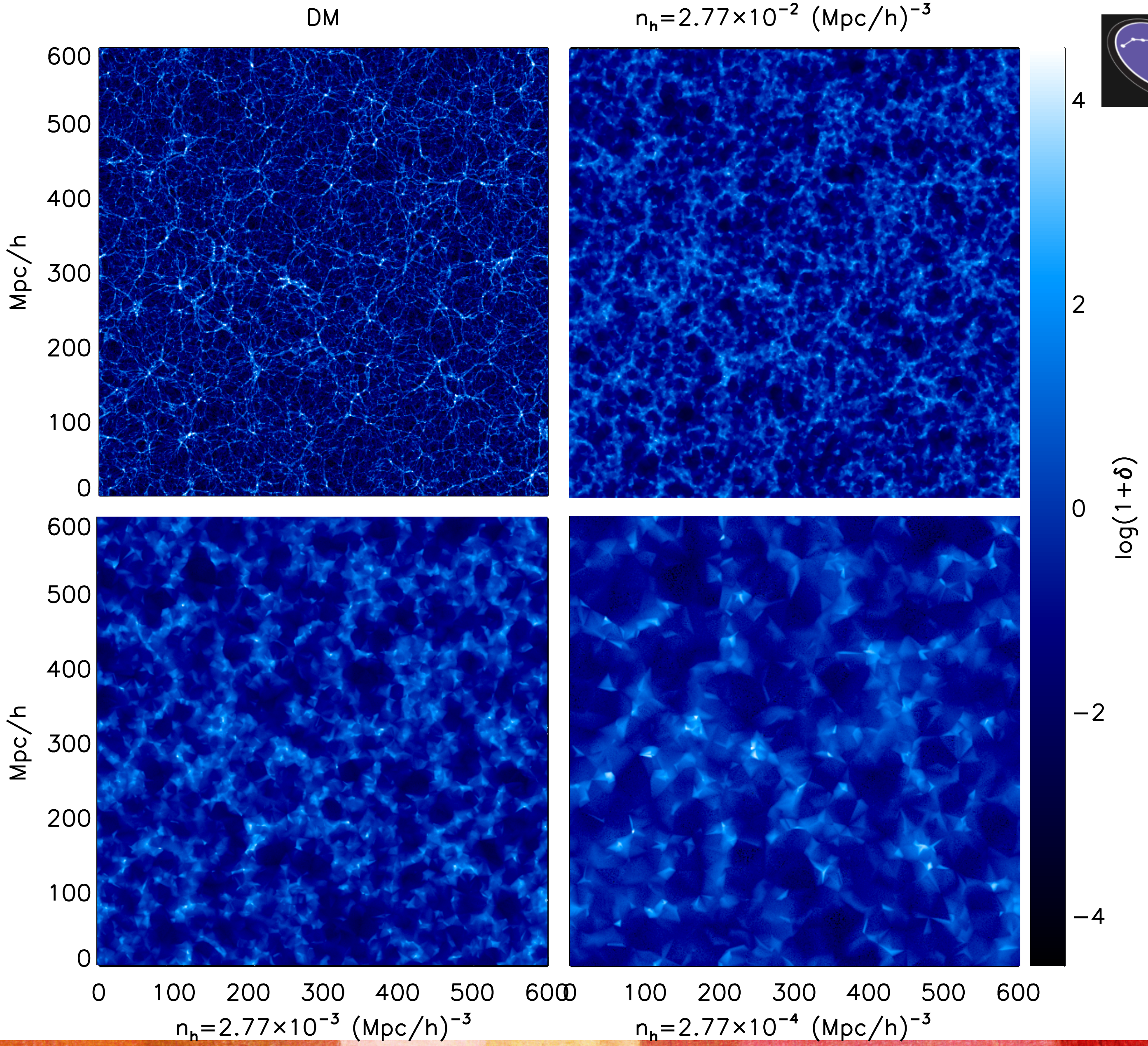
Wang et al. (2017)

Fractional error on the distance measurement



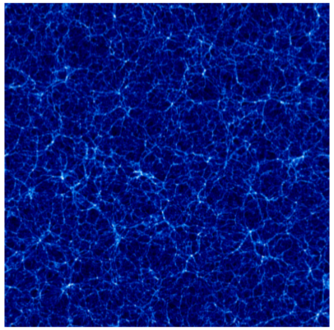
Wang et al. (2017)

Halo fields

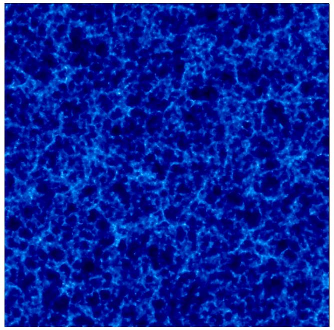


Yu et al. (2017)

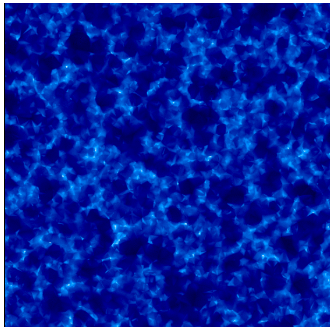
dark matter



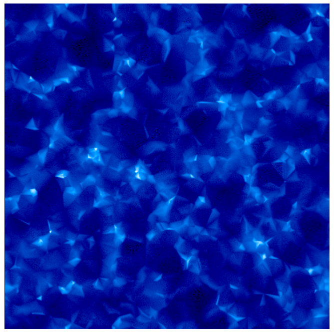
$n_h=2.77\times10^{-2}$ $(h/Mpc)^3$

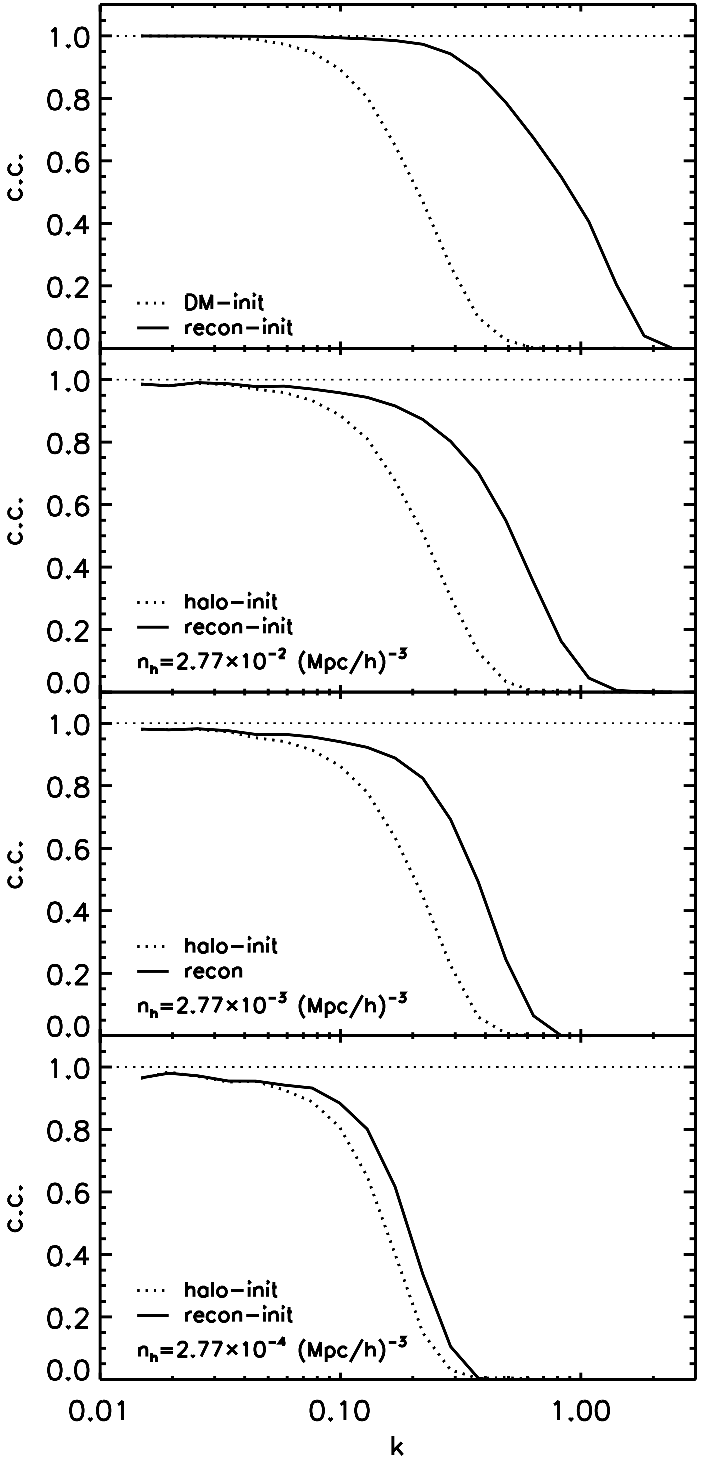


$n_h=2.77\times10^{-3}$ $(h/Mpc)^3$



$n_h=2.77\times10^{-4}$ $(h/Mpc)^3$

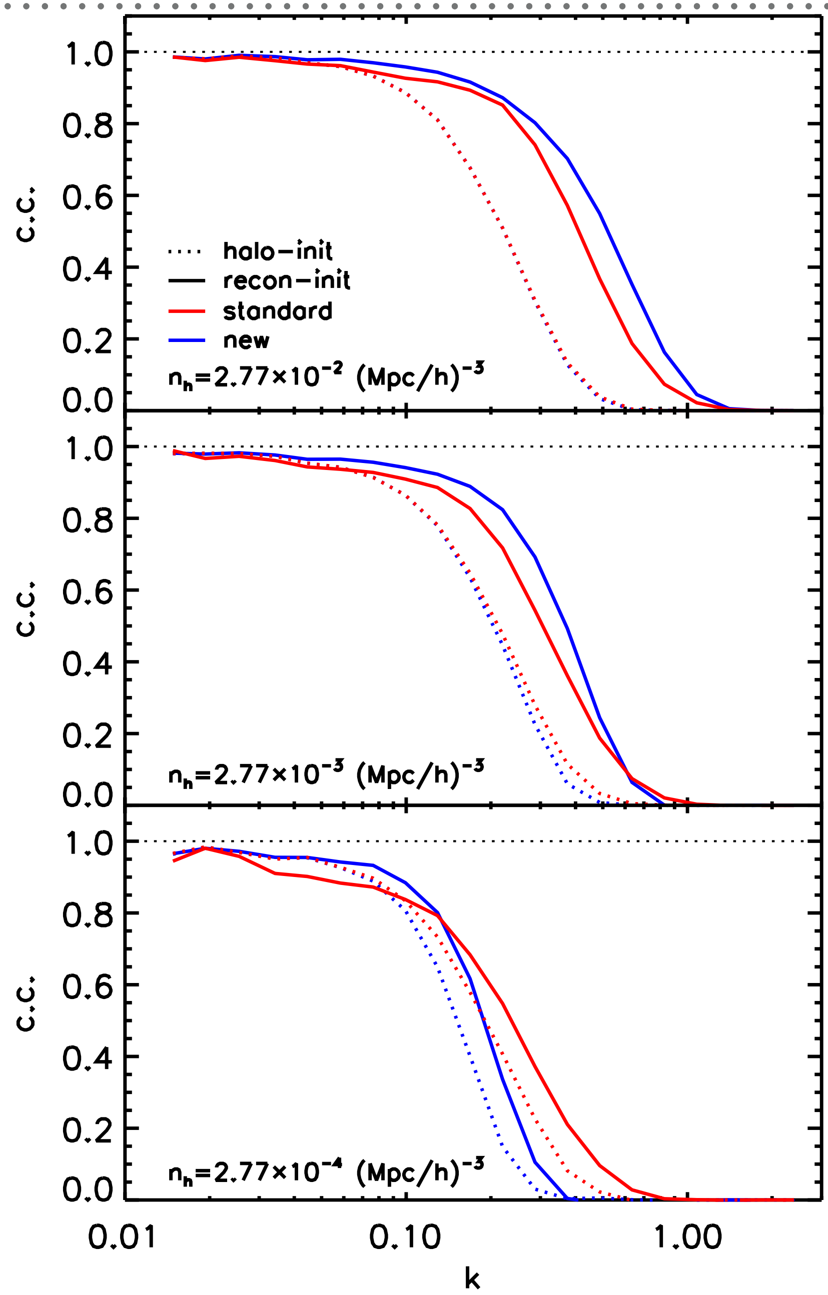




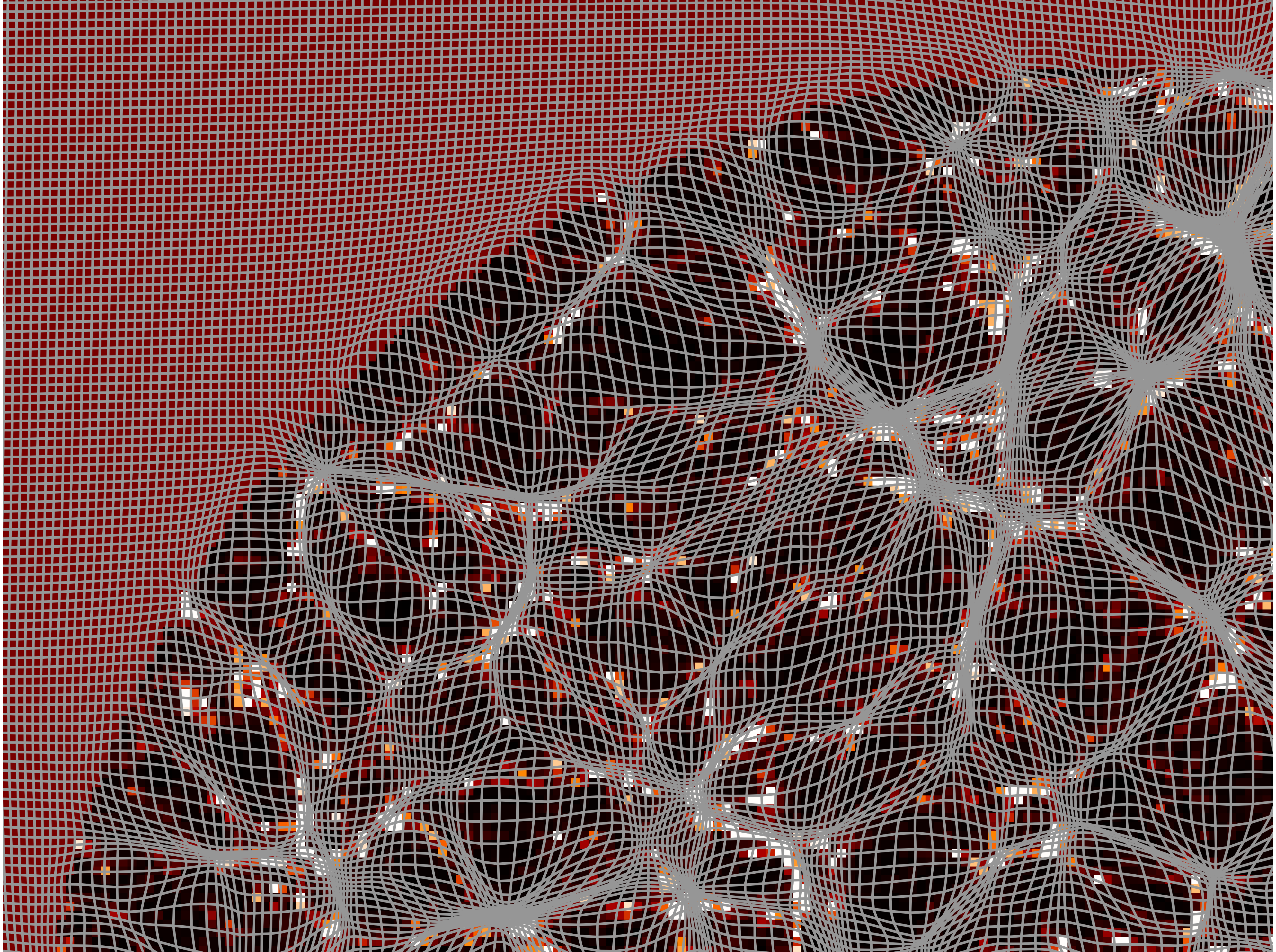
Cross-correlation coefficient

v.s. standard reconstruction

- indeed outperform over the standard BAO reconstruction method for dense sample ($n_g > 10^{-3} (Mpc/h)^{-3}$).



Yu et al. (2017)



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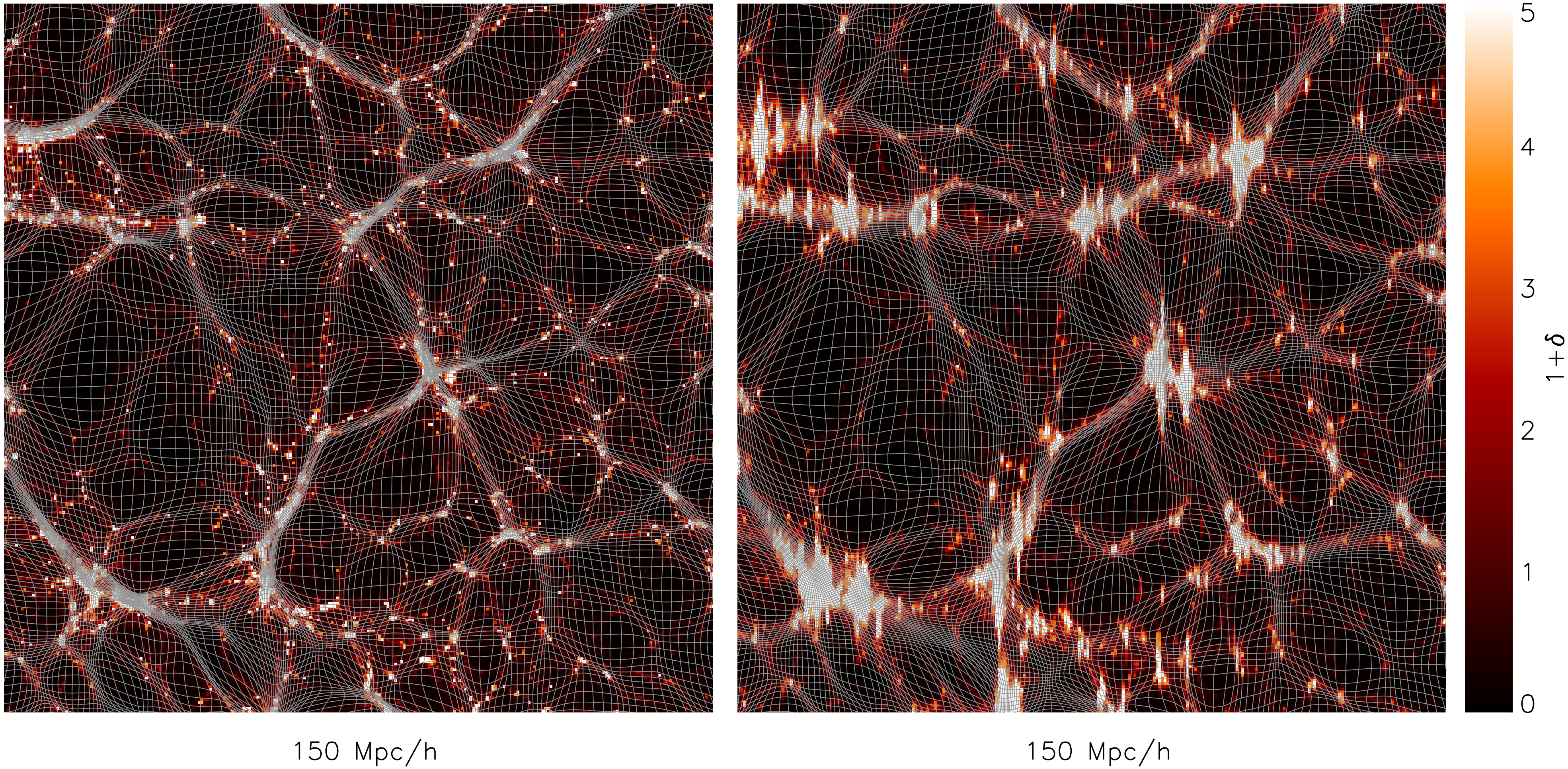
Reconstruction with RSD



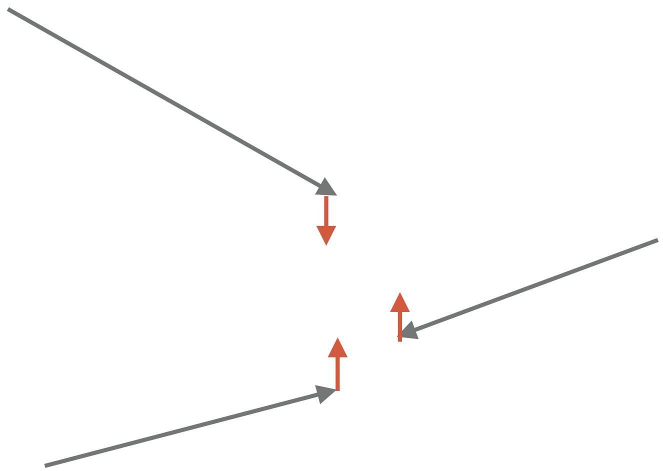
$$z^{\mathrm{obs}} = z^{\mathrm{hubble}} + z^{\mathrm{pv}}$$

Algorithm works with RSD

Reconstruction with RSD

$$\vec{x}(t) = \vec{q} + \vec{\Psi}(\vec{q}, t)$$

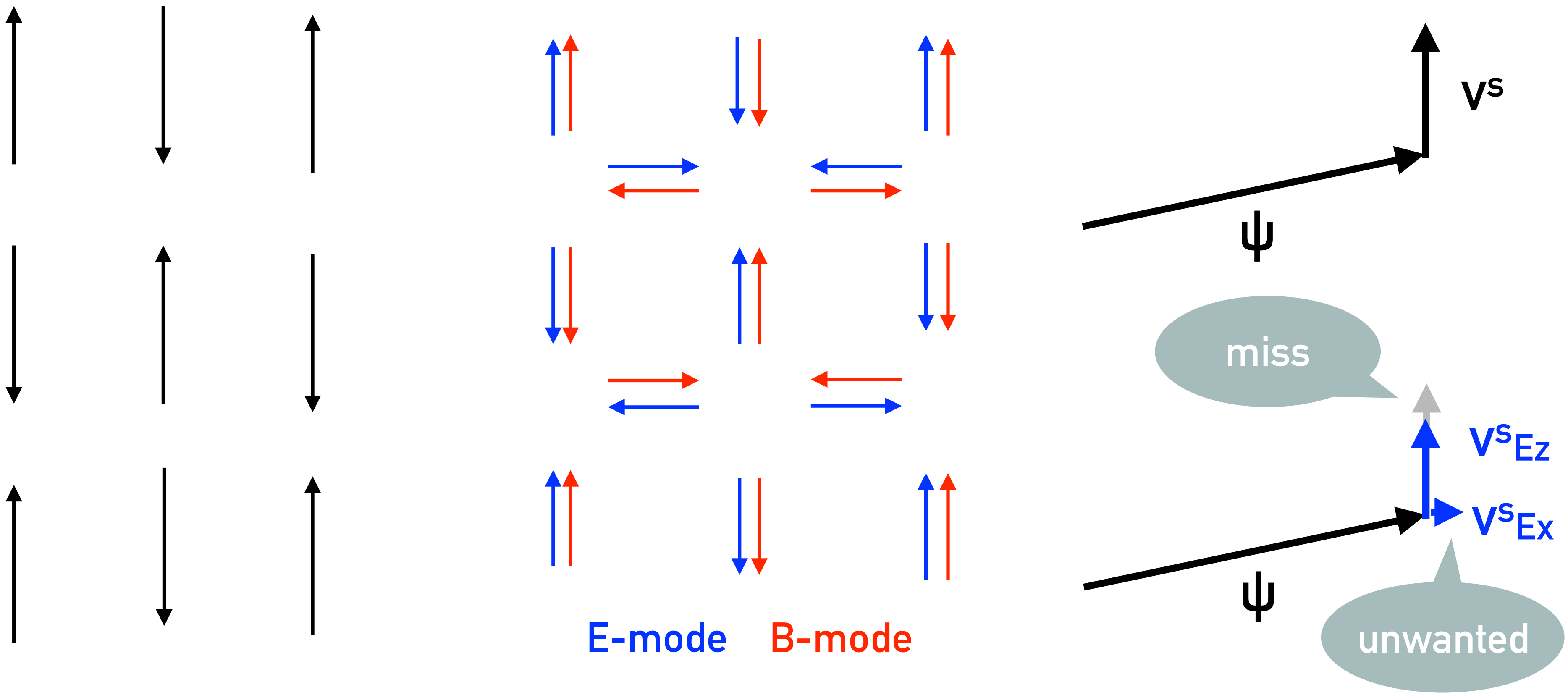
$$\vec{x}(t) = \vec{q} + \vec{\Psi}(\vec{q}, t) + v_z \vec{z}/aH$$



- Thus, RSD resides in the reconstructed density field.
- Before reconstruction: nonlinear density + nonlinear RSD
- After reconstruction: more linear density + more linear RSD?

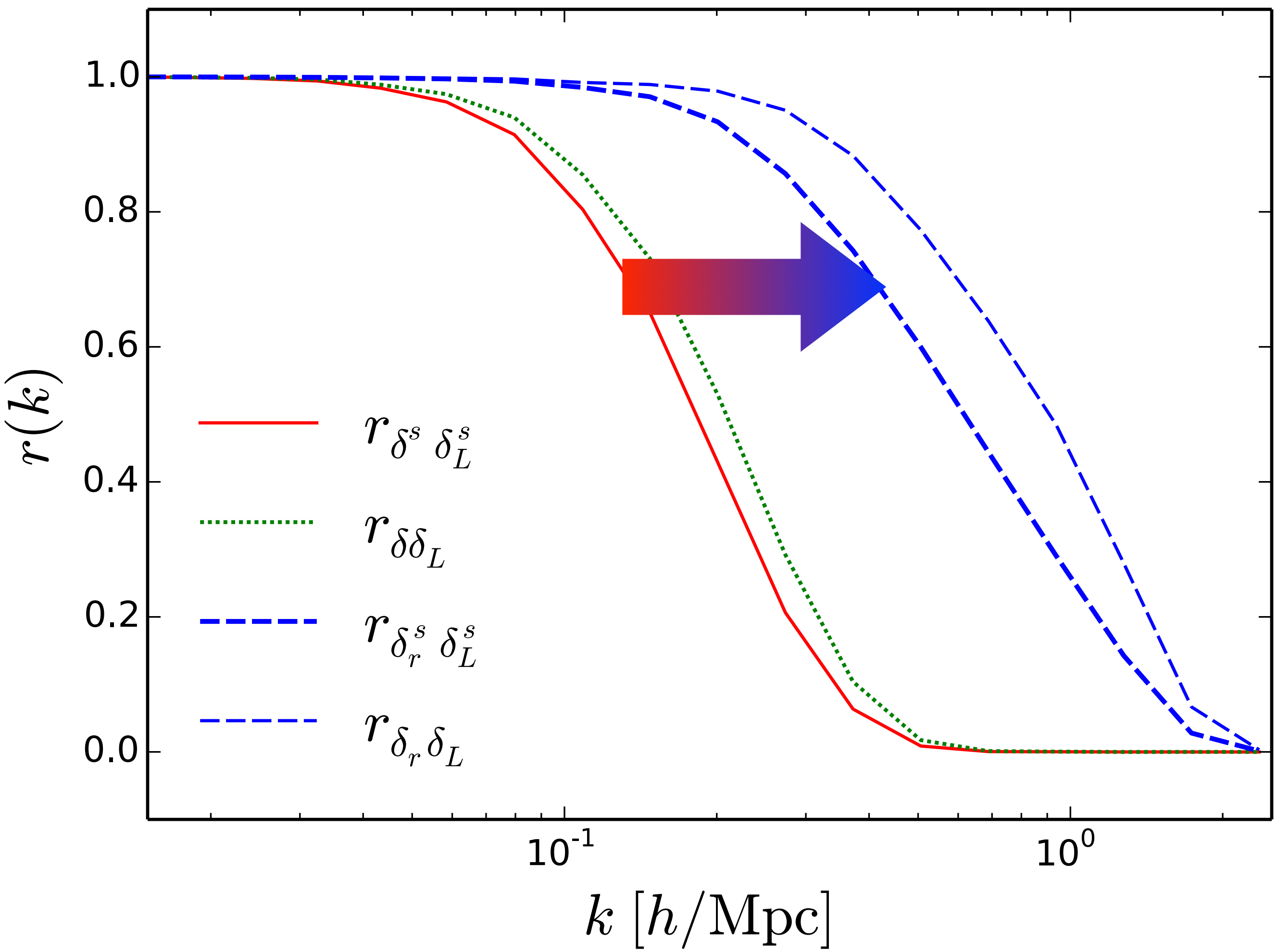
Shift velocity

$$v_z \vec{z} \equiv \vec{v}^s = \vec{v}^s_E + \vec{v}^s_B$$



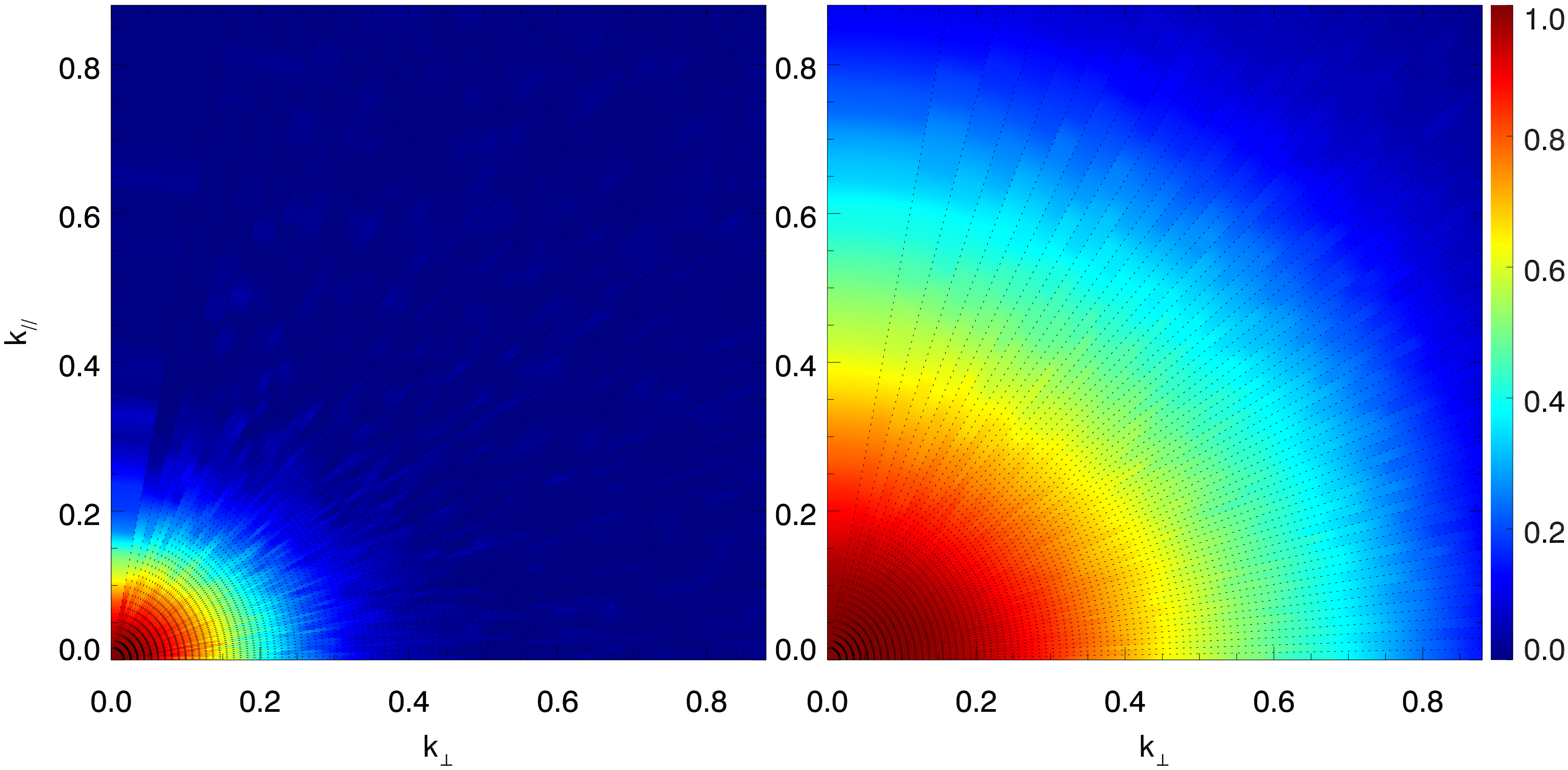
- The E-mode part of shift velocity could be reconstruction (v^s_{Ez}).
- Unwanted byproducts, v^s_{Ex}, v^s_{Ey}

1D Cross-correlation coefficient



➤ 1D cross-correlation coefficient with linear field + linear RSD, i.e., $<\delta_{NL}\,(1+f\mu^2)\delta_L>$ and $<\delta_{recon}\,(1+f\mu^2)\delta_L>$

2D Cross-correlation coefficient



- 2D cross-correlation coefficient with linear field + linear RSD, i.e., $<\delta_{NL}\ (1+f\mu^2)\delta_L>$ and $<\delta_{recon}\ (1+f\mu^2)\delta_L>$

Reconstruction with RSD

- Usually we use upto k=0.1 h/Mpc, since nonlinear RSD is not well understood.
- RSD is more linear in the reconstructed ANISOTROPIC density field.
- In principal, RSD could be modeled better. (not shown here)

- More linear RSD means more robust constraints on modified gravity?

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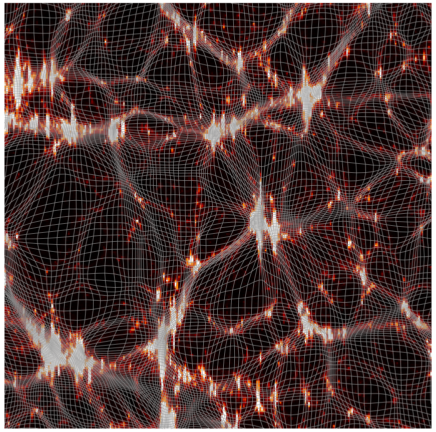
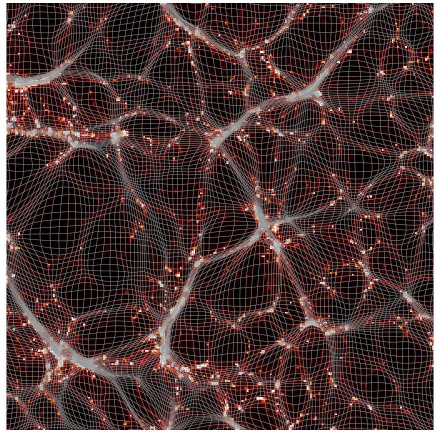
Multipole moments



150 Mpc/h

$$\delta^s(k) = \delta(k)(1 + \beta\mu^2)$$



150 Mpc/h

$$P_l^s(k) = \frac{2l+1}{2}\int_{-1}^{1} P(k,\mu)L_l(\mu)\mathrm{d}\mu$$

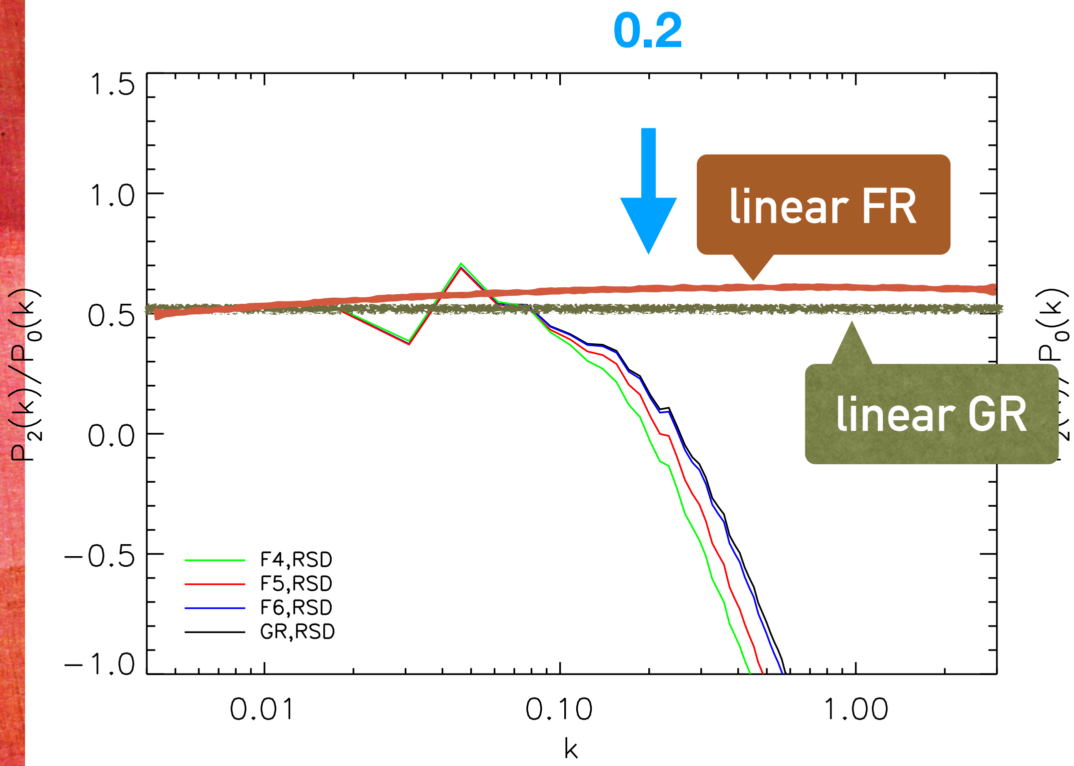
- l=0, 2, 4 (monopole, quadrupole, hexadecapole)

$$\begin{pmatrix} P_0(k) \\ P_2(k) \\ P_4(k) \end{pmatrix} = P_{\delta\delta}(k)\begin{pmatrix} 1 + \frac{2}{3}\beta + \frac{1}{5}\beta^2 \\ \frac{4}{3}\beta + \frac{4}{7}\beta^2 \\ \frac{8}{35}\beta^2 \end{pmatrix}$$

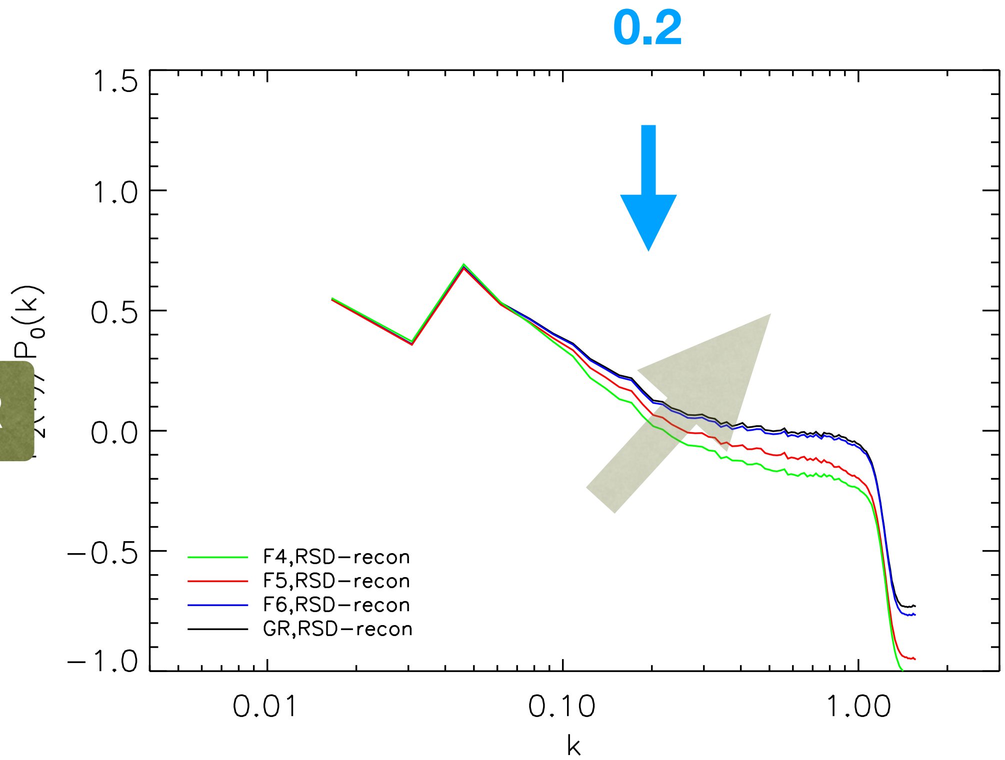
$P_2(k)/P_0(k)$ —> β

Multipole moments ratio

$P_2(k)/P_0(k)$

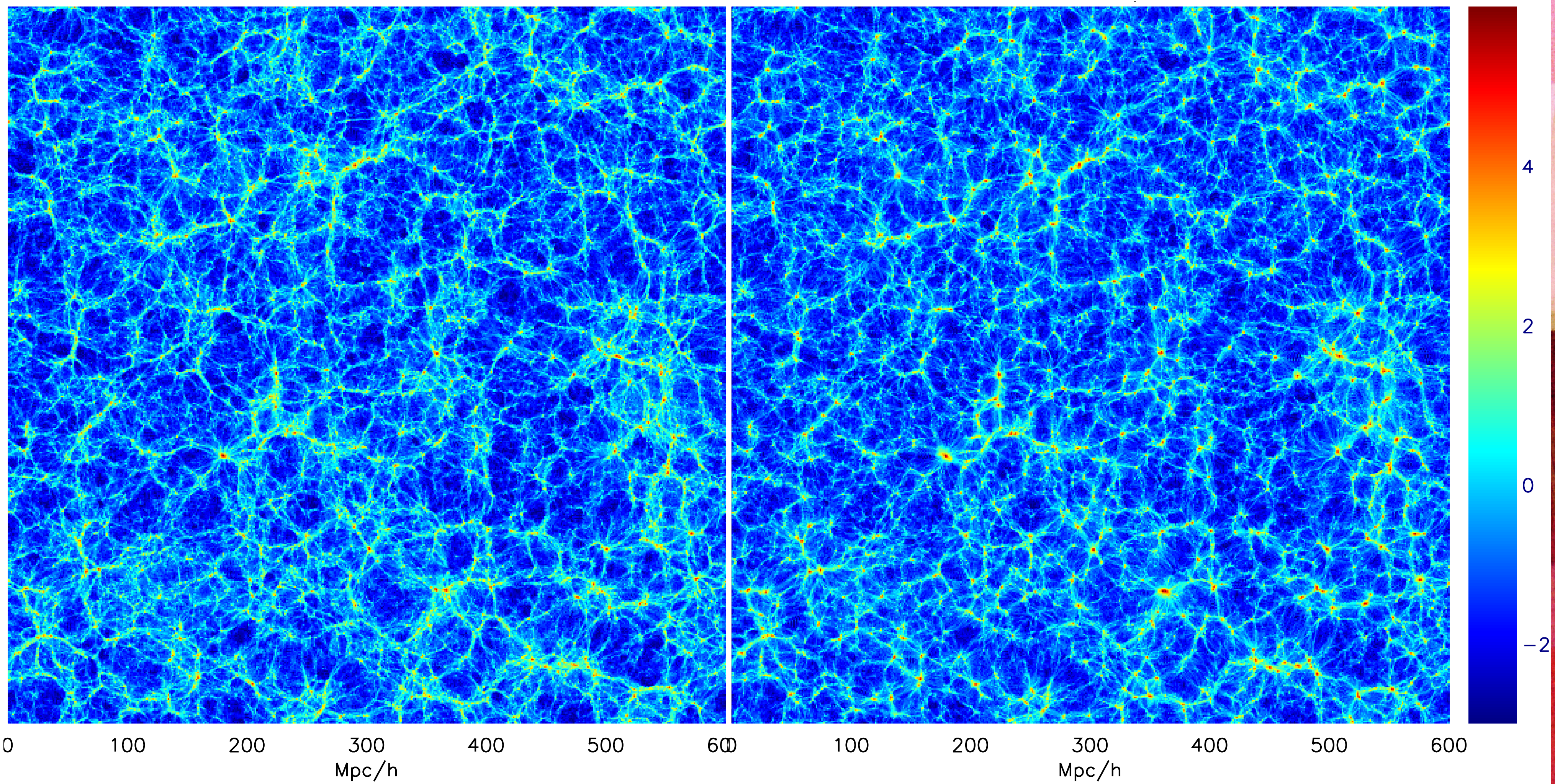


simulated



reconstructed

Constrained simulation



Original Simulation

Constrained Simulation

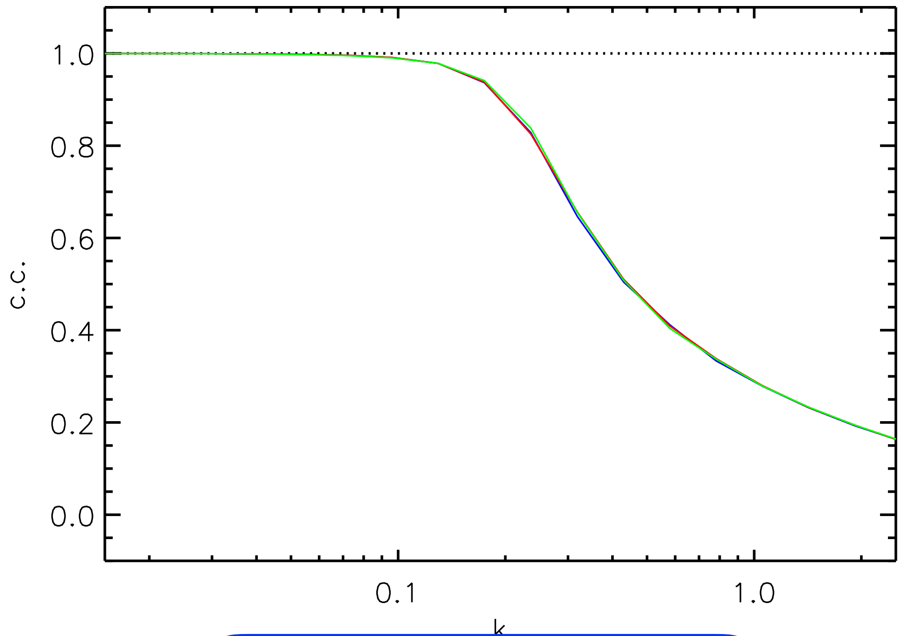
Velocity reconstruction

- Standard method: linear continuity equation

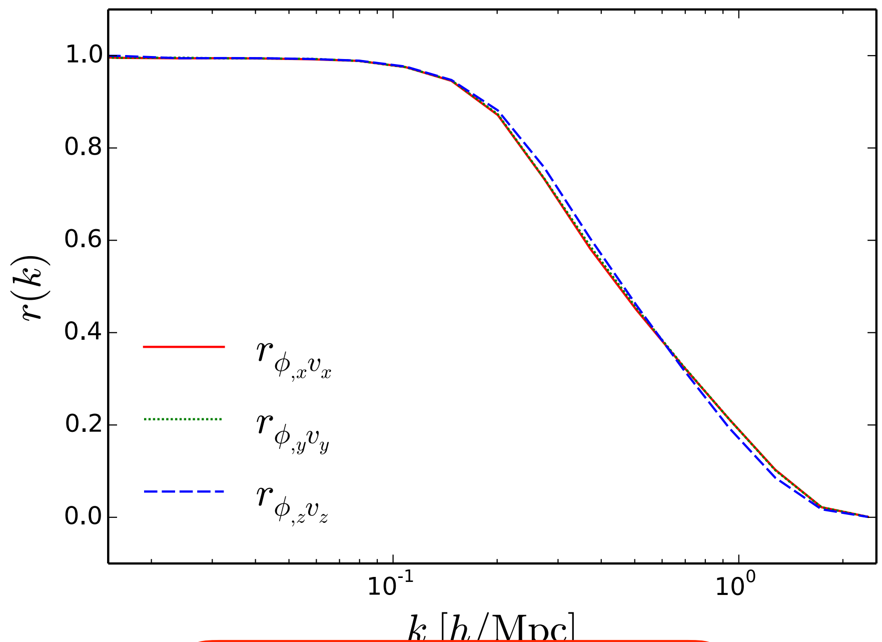
$$\boldsymbol{v}(\boldsymbol{k}) = aHf\frac{i\boldsymbol{k}}{k^2}\frac{\delta_S(\boldsymbol{k})}{b}$$

- Our attempts: relation with displacement

$$\boldsymbol{v} = \frac{\mathrm{d}\boldsymbol{x}}{\mathrm{d}t} = \frac{\mathrm{d}\boldsymbol{\Psi}}{\mathrm{d}t} \qquad \langle \boldsymbol{v}(\boldsymbol{q})\Psi(\boldsymbol{q})\rangle$$



v(q) v.s. Ψ(q)



v(q) v.s. Ψrecon(q)

Velocity reconstruction

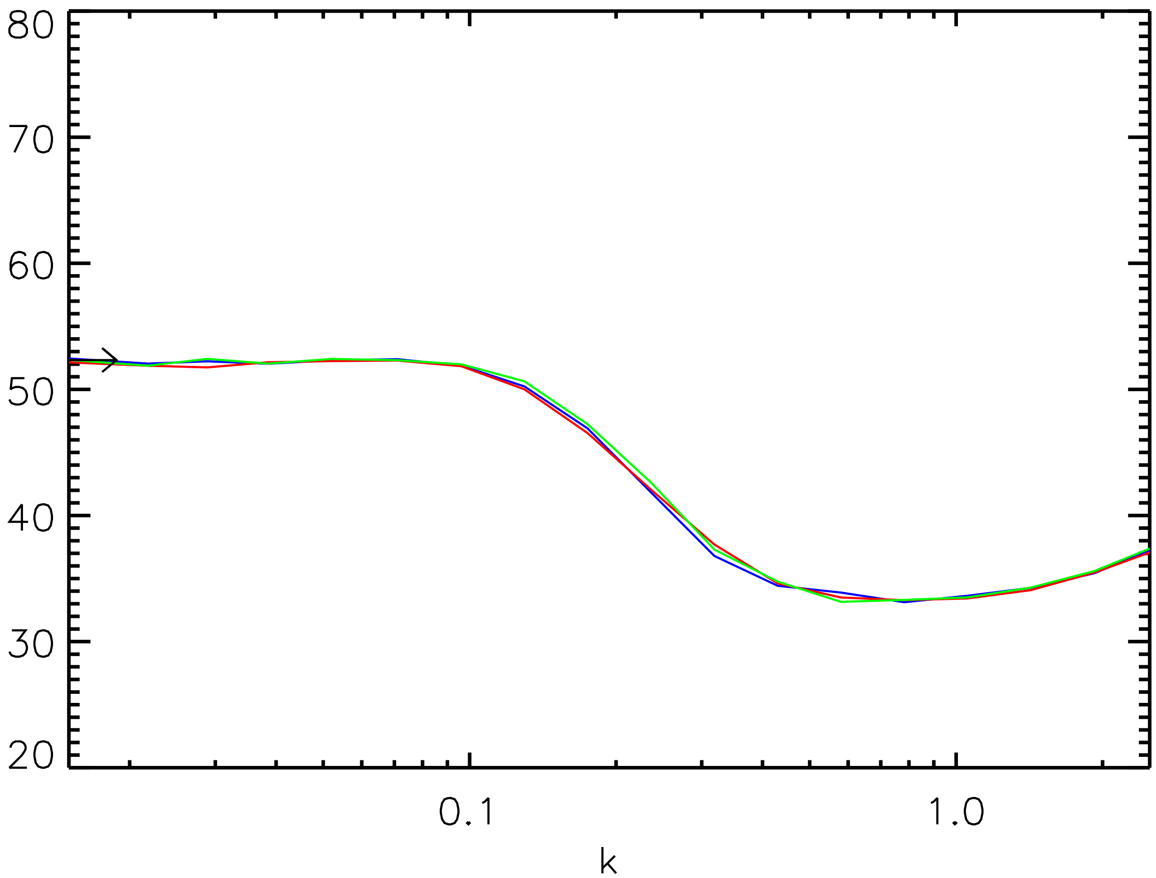
- Use the relation (transfer function) to convert the reconstructed displacement to the reconstructed velocity field.

$$\hat{v} = \frac{\langle \Psi v \rangle}{\langle \Psi \Psi \rangle} * \hat{\Psi}$$

Measured in simulation

recon from obs

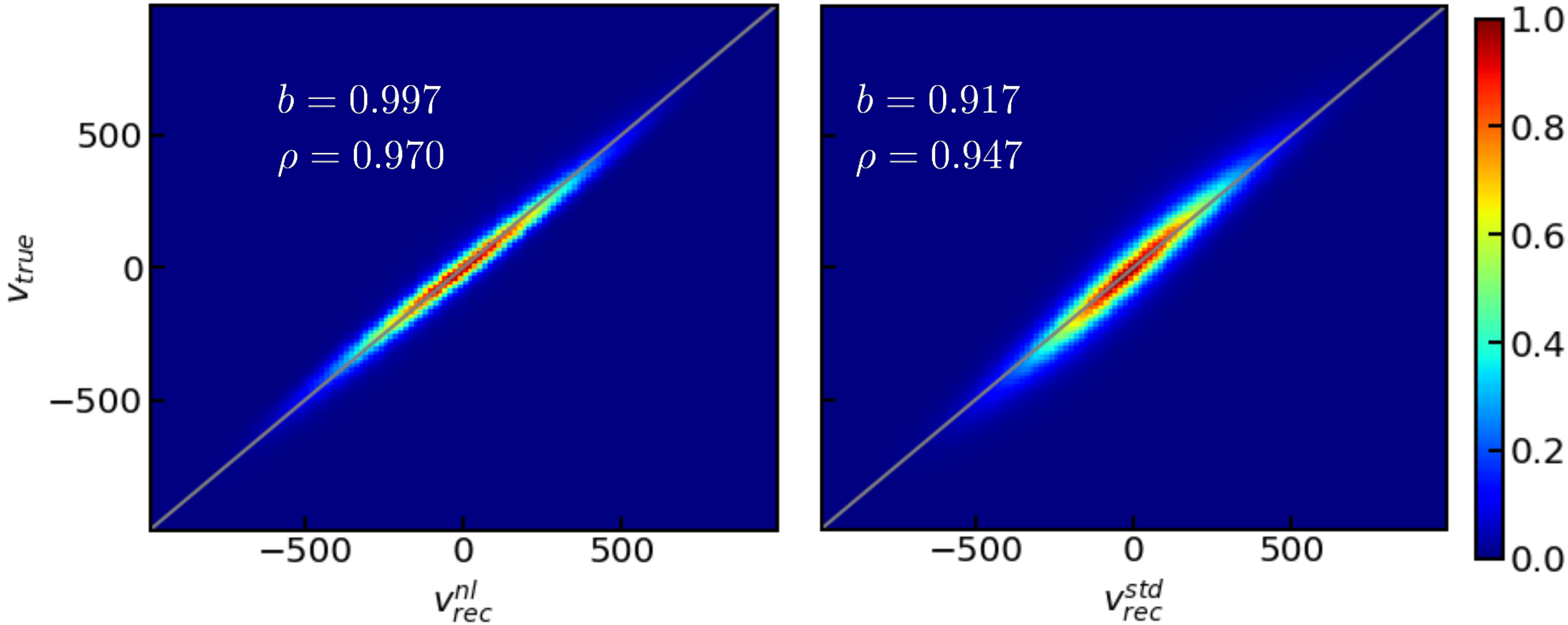
$$\frac{\langle \Psi v \rangle}{\langle \Psi \Psi \rangle}$$



Velocity reconstruction

$b = 1.040$

Nonlinear Recon.　　　Standard Recon.



Conclusion

- Nonlinear reconstruction is useful in
  - extracting BAO signal in low-redshift high-density survey
  - recovering more linear RSD effect

To explore

- Applying to real data (SDSS MGS, DESI BGS, 21cm IM, etc)
- improvement in differing gravity models ?
    - theoretical supporting for NR ?
    - quantification ($f\sigma_8$)
- reconstruction of the initial condition (v.s. HMC)
- velocity reconstruction performance ? (v.s. linear continuity equation)
- correspondence to halo displacement ?

上海交通大学天文系

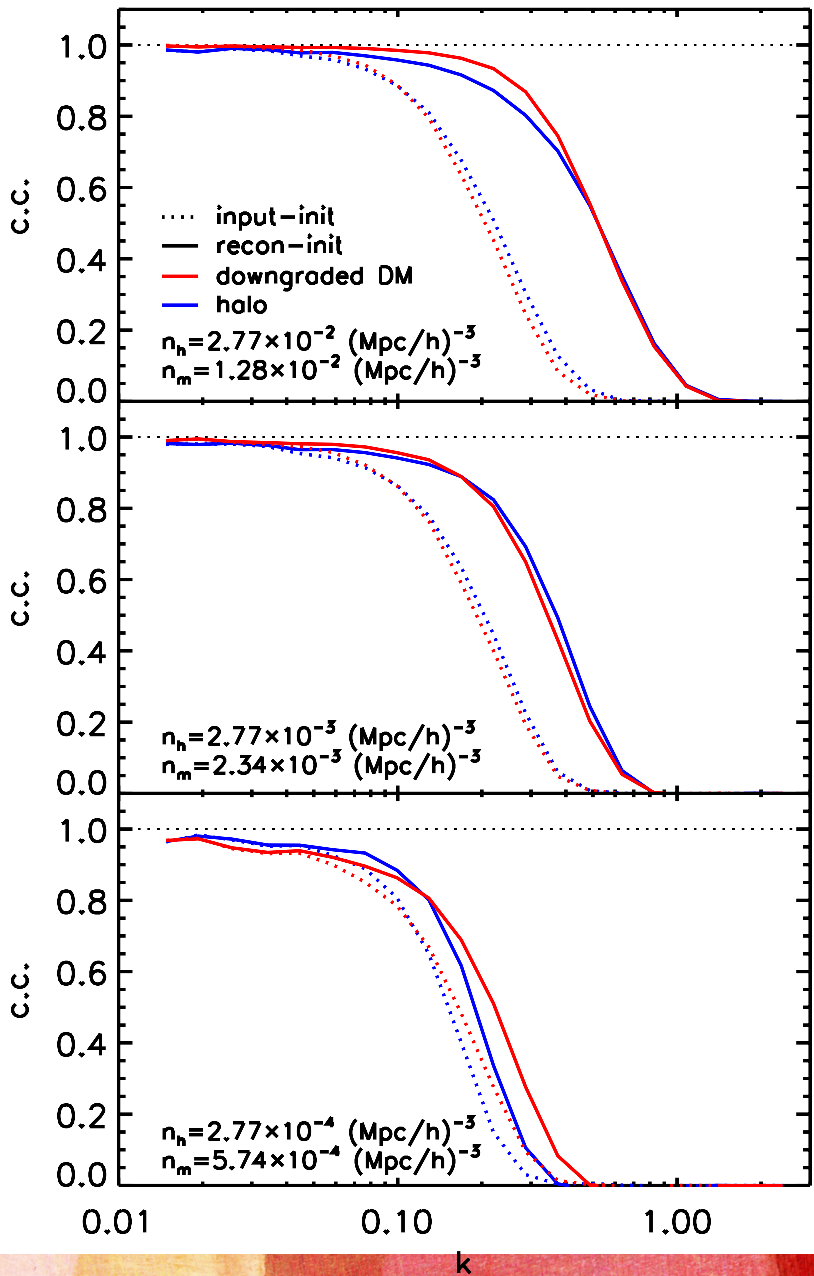
DEPARTMENT OF ASTRONOMY AT SJTU

THANK YOU

ご清聴ありがとうございました

halo v.s. downgraded DM

- $n_m = b^2 n_h$
- This downgraded DM sample shares the same effective shot noise as the halo sample
- This result tells us that the main limitation comes from the shot-noise.



Yu et al. (2017)

modeling of the power spectrum shape by transfer functions