Dynamical Reconstruction of Linear Universe

Preliminary results

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McWilliams Center for Cosmology

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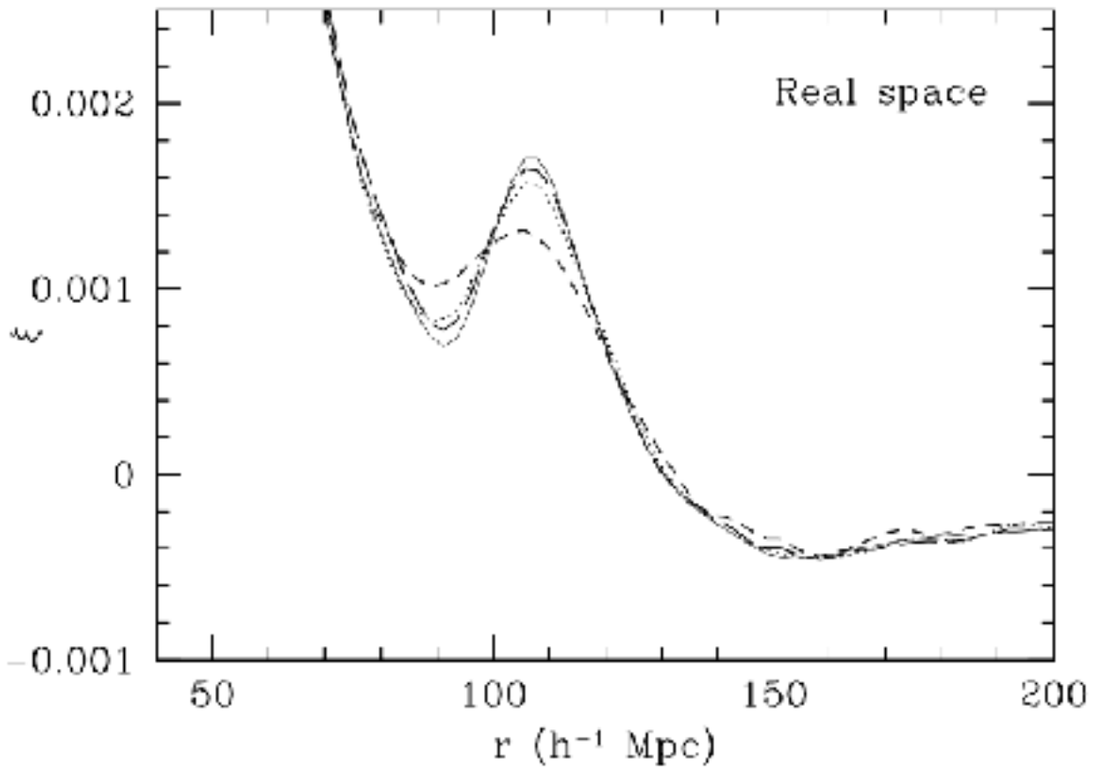
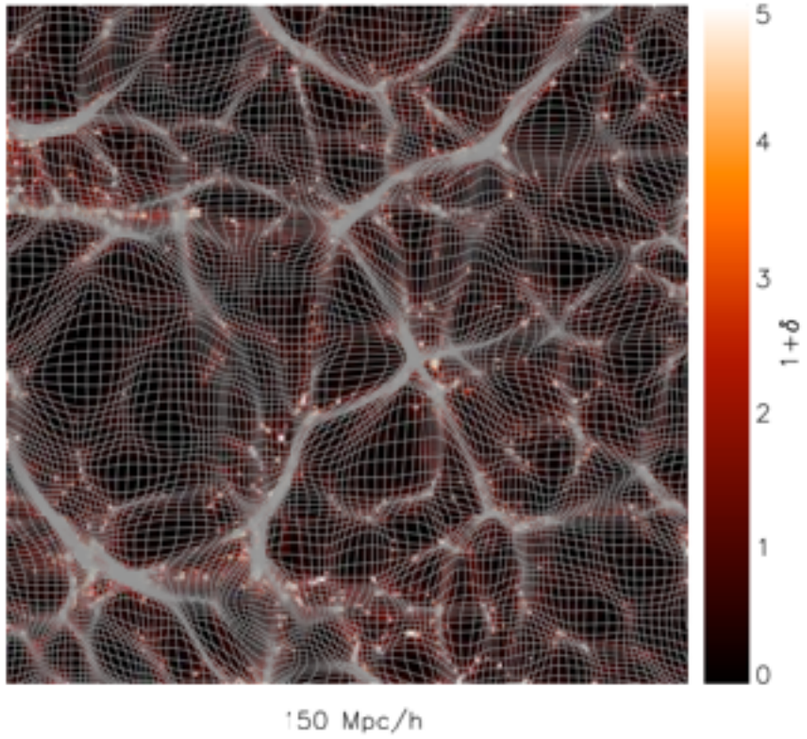
Current Status

- Lagrangian Reconstruction Algorithm (Eisenstein, Seo et al. 2007)
- Eulerian Reconstruction Algorithm (Schmittfull et al. 2015)
- Non-linear Reconstruction Method (Zhu et al. 2017)
- …



Eisenstein, Seo et al. Astrophys. J. 2007



Zhu et al. ArXiv Eprint 1611.09638 2017

Dynamical Reconstruction: Theory

- Theory

	Forward in time	Back in time
Initial condition	$\mathbf{x}_i$, $\mathbf{v}_i$ at early time	
Governing Equation	$\nabla^2\phi = 4\pi G\rho$ $\frac{d\mathbf{r}}{dt} = +\mathbf{u}, \quad \frac{d\mathbf{u}}{dt} = -\nabla\phi$	
Output	$\mathbf{x}_0$, $\mathbf{v}_0$ at late time	

Dynamical Reconstruction: Theory

- Theory

	Forward in time	Back in time
Initial condition	$\mathbf{x}_i$, $\mathbf{v}_i$ at early time	$\mathbf{x}_0$, $-\mathbf{v}_0$ at late time
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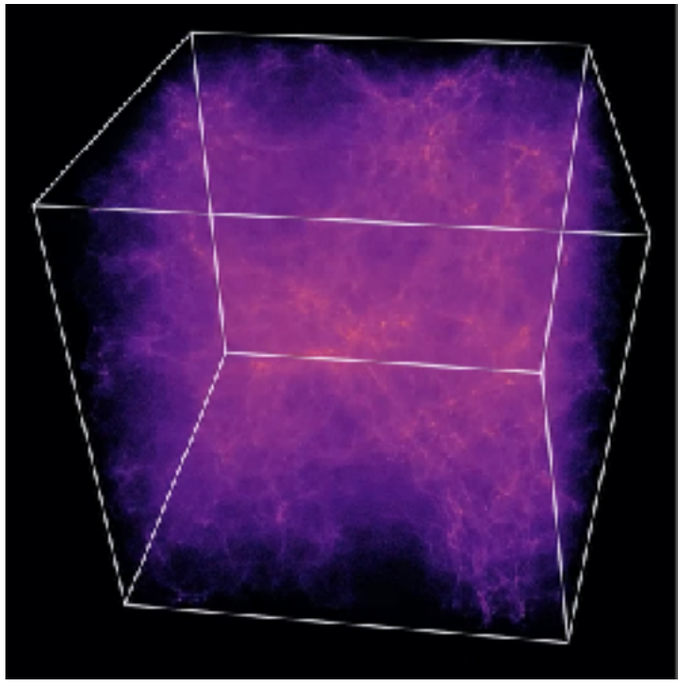
Output	$\mathbf{x}_0$, $\mathbf{v}_0$ at late time	$\mathbf{x}_i$, $-\mathbf{v}_i$ at early time

Dynamical reconstruction in action



$$\nabla^2\phi = 4\pi G\rho$$

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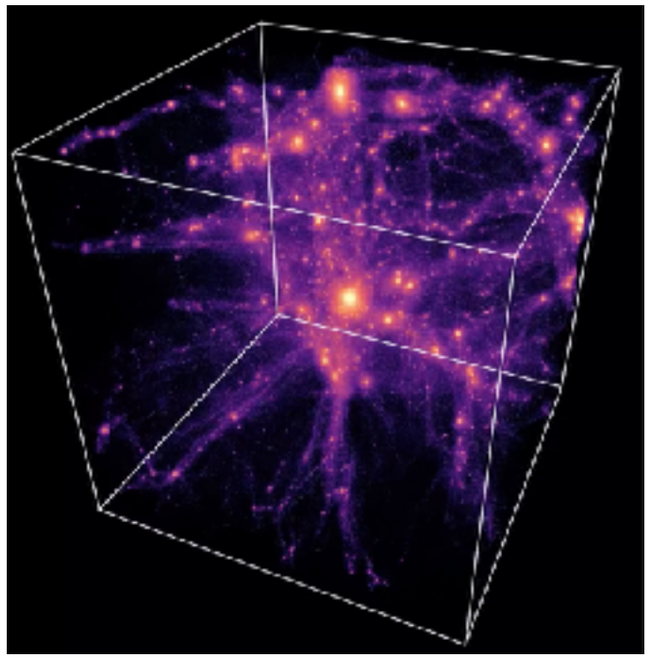
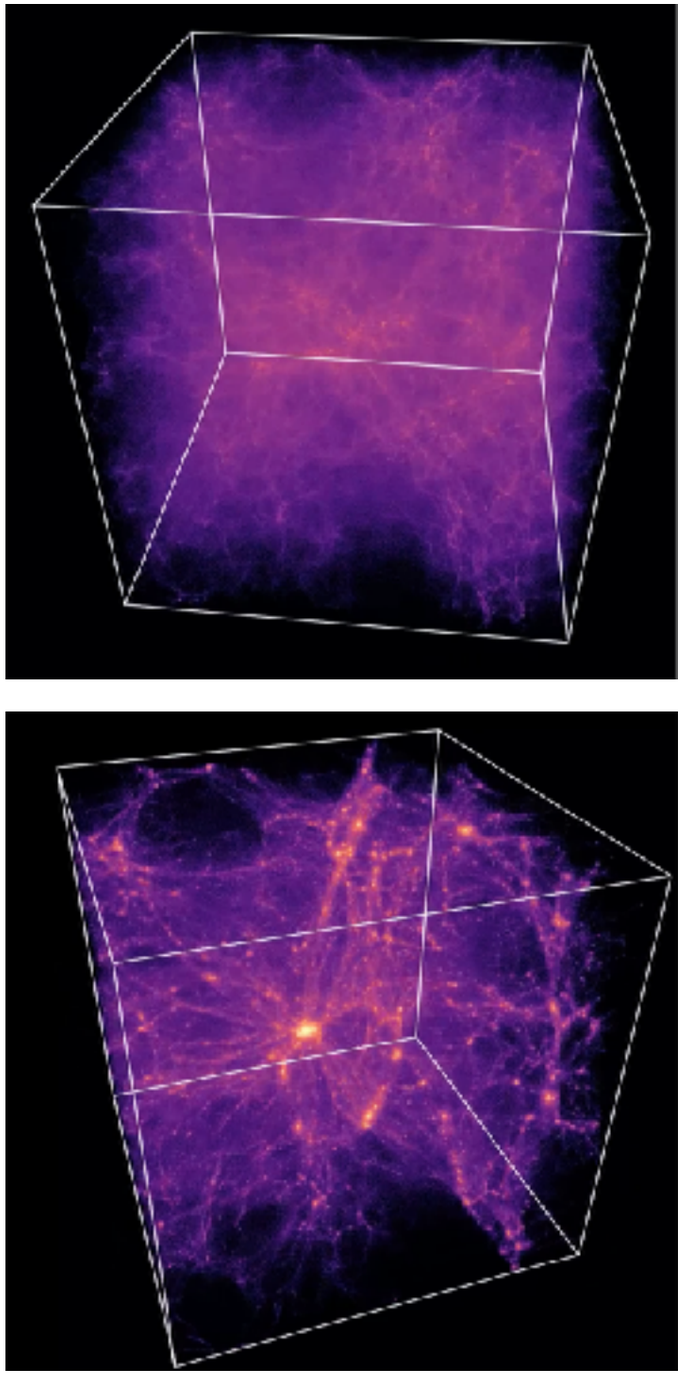


plot credited to EAGLE simulation

Dynamical reconstruction in action



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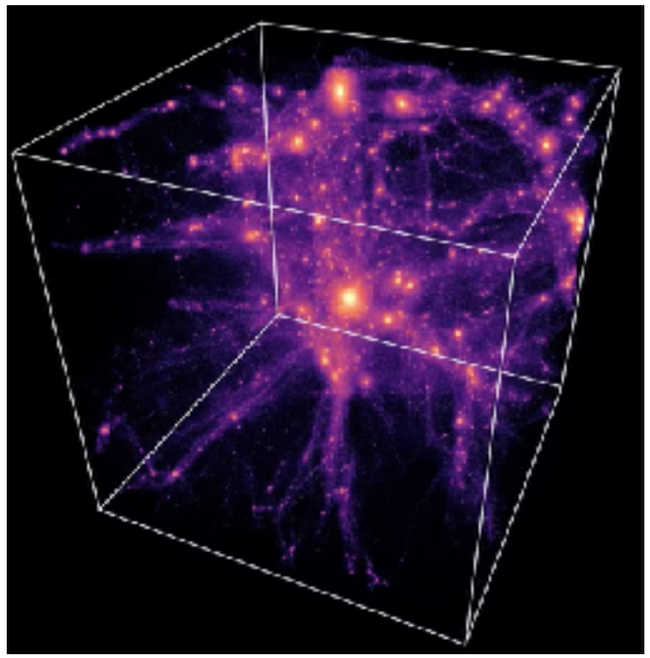

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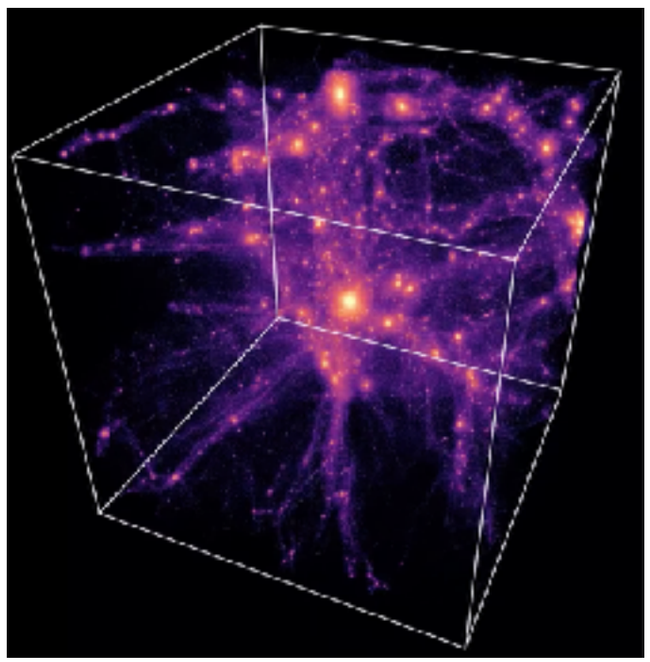

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Dynamical Reconstruction: Theory

- Theory

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Output	$\mathbf{x}_0$, $\mathbf{v}_0$ at late time	$\mathbf{x}_i$, $-\mathbf{v}_i$ at early time

- What is this good for?
  - Accessing more linear modes by moving the observation to earlier times
  - BAO reconstruction

Dynamical Reconstruction: Challenges

- incomplete phase space information
  - Velocity reconstruction at late time

$$\mathbf{x}(t) = \mathbf{q} + \Psi(\mathbf{q}, t)$$ ← Lagrangian Point of view

$$\nabla \cdot \Psi = -\delta \qquad \mathbf{v} = aHf\Psi$$

↑ Zeldovich Approximation

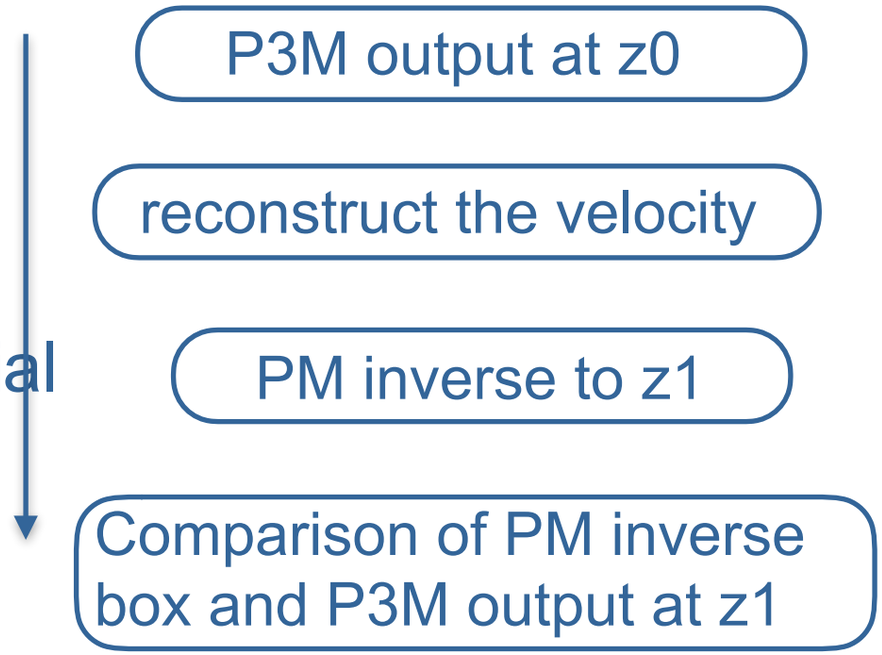
  - Decaying modes

$$\delta(\mathbf{x}, t) = A(\mathbf{x}, t)D_1(t) + B(\mathbf{x}, t)D_2(t)$$

$$D_1(t) \propto t^{2/3} \propto a, \quad D_2(t) \propto t^{-1} \propto a^{-3/2} \quad (\Omega_m = 1)$$

Dynamical Reconstruction: Method

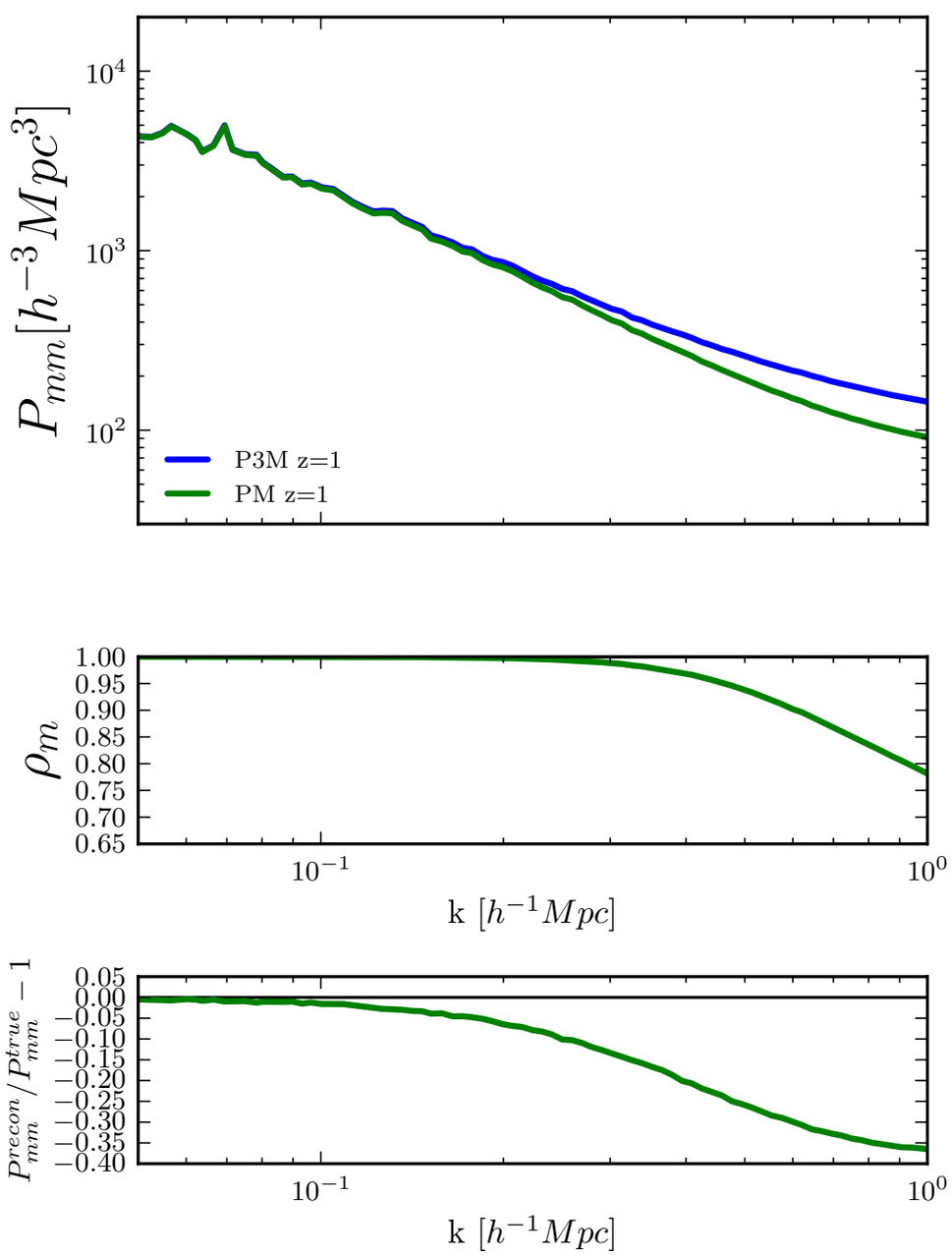
- Simulation
  - Algorithm: P3M; Parameters: Planck
  - Box size: 512^3 Mpc/h
  - Number of particles: 128^3
- Algorithm of dynamical reconstruction
  - Zeldovich reconstruction of velocity at initial redshift
  - Inverse particle mesh code
- Accuracy Checks
  - Matter (velocity) power spectrum
  - Matter (velocity) correlation coefficient

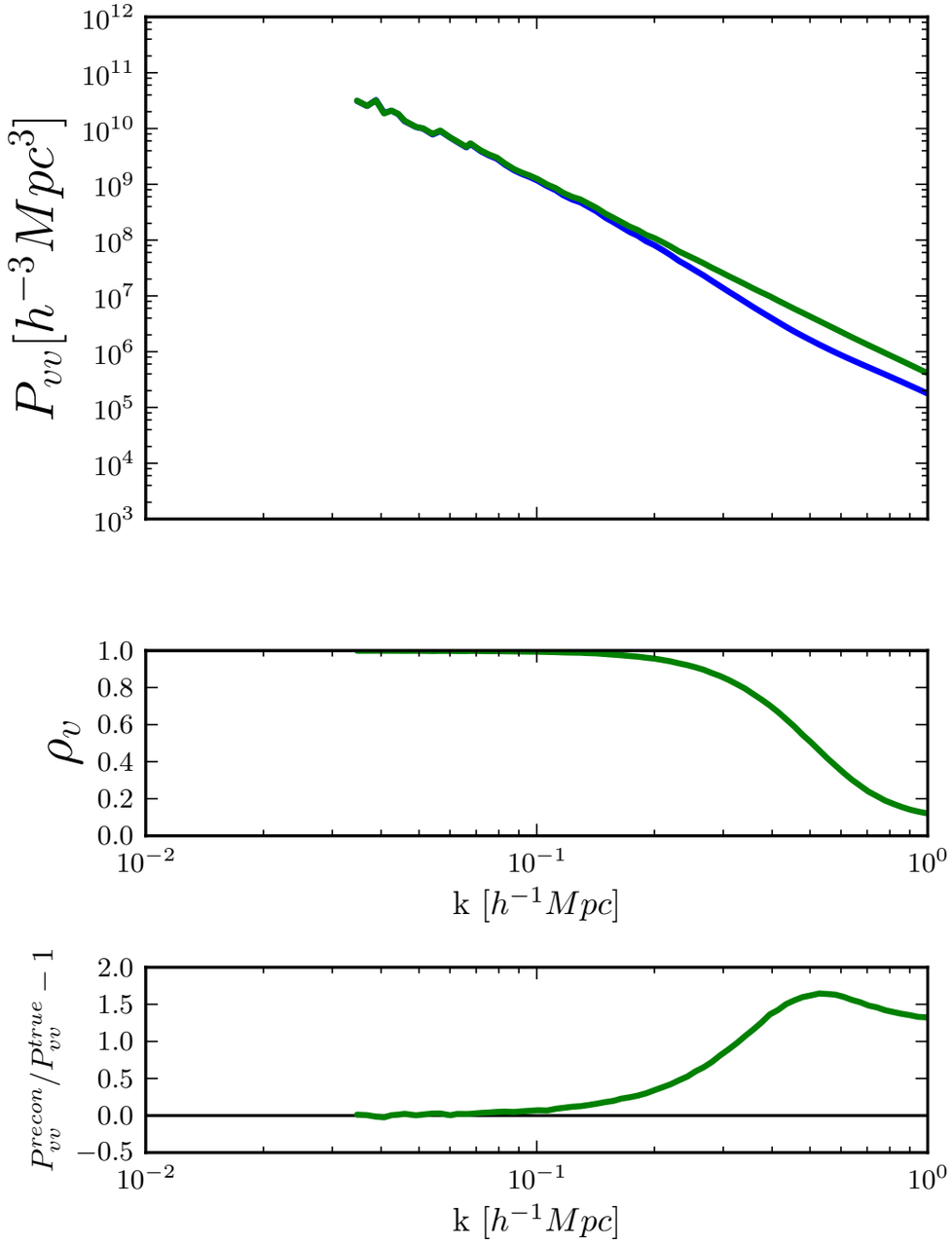


$$\rho_m = \frac{P_{mm}(k)_{true\times recon}}{\sqrt{P_{mm}(k)_{true}P_{mm}(k)_{recon}}}$$

$$\rho_v = \frac{P_{vv}(k)_{true\times recon}}{\sqrt{P_{vv}(k)_{true}P_{vv}(k)_{recon}}}$$

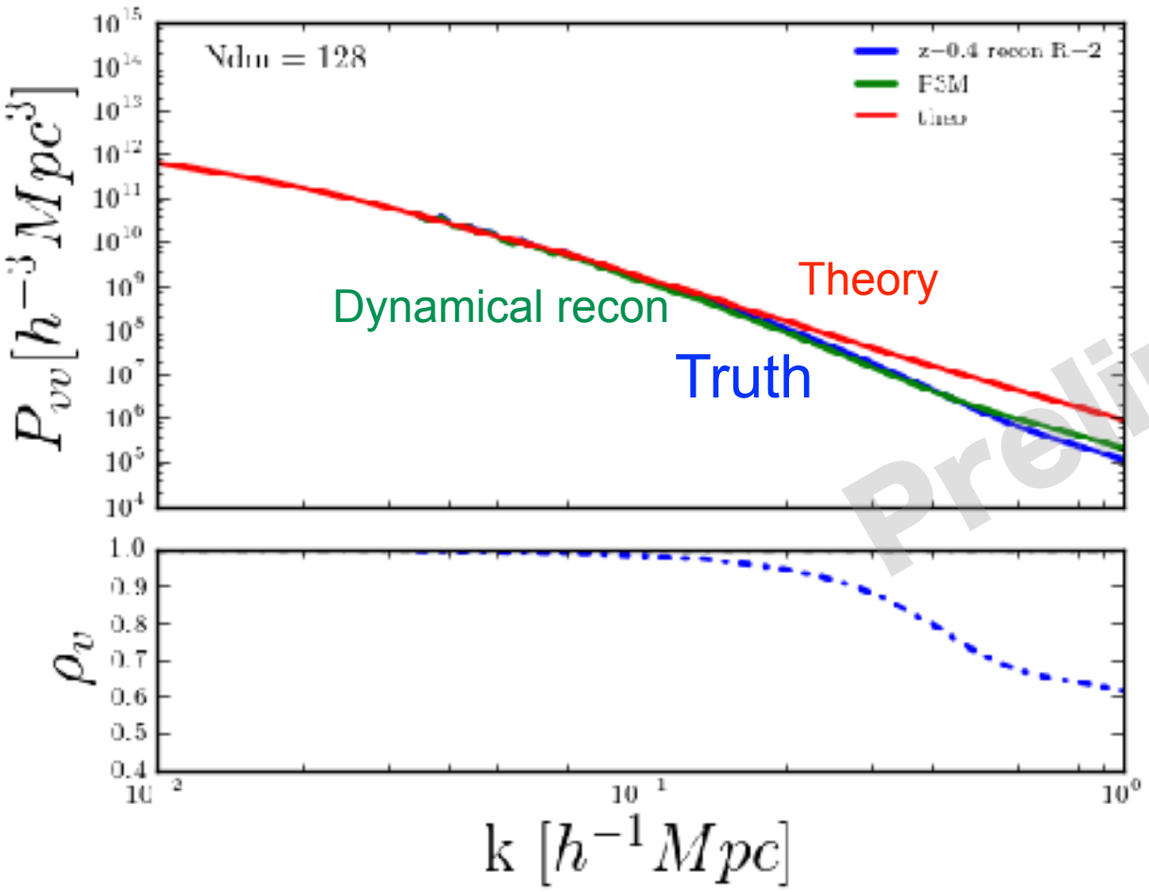
Dynamical Reconstruction: simple test

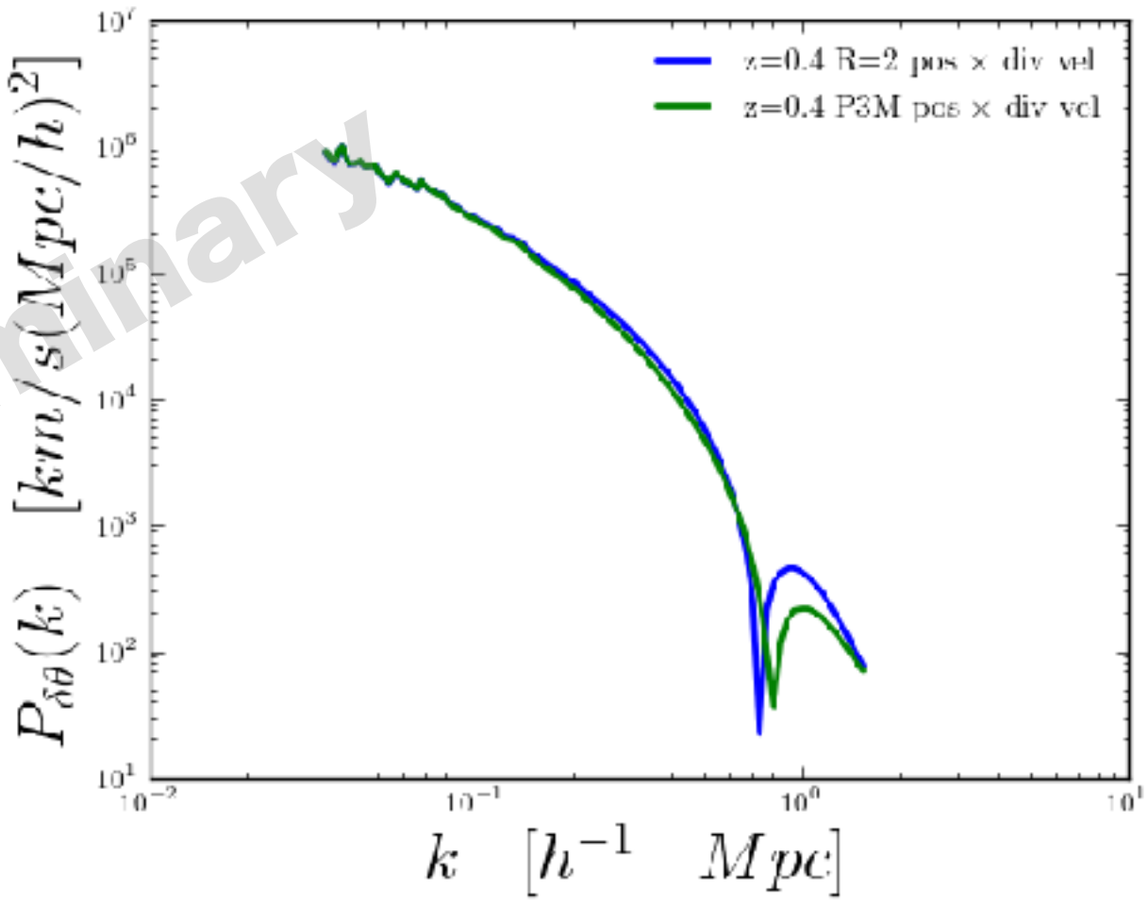




Dynamical Reconstruction Step 1: Velocity reconstruction at initial redshift

- velocity reconstruction at z = 0.4





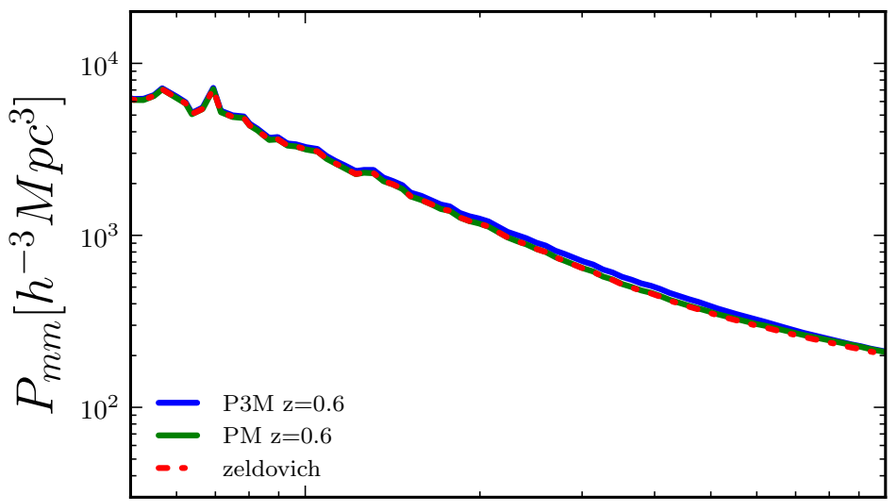
Preliminary

- R: smoothing scale for density
- Linear theory: $p_{vv}(k) = a^2 H^2 f^2 P_{mm}(k)/k^2$

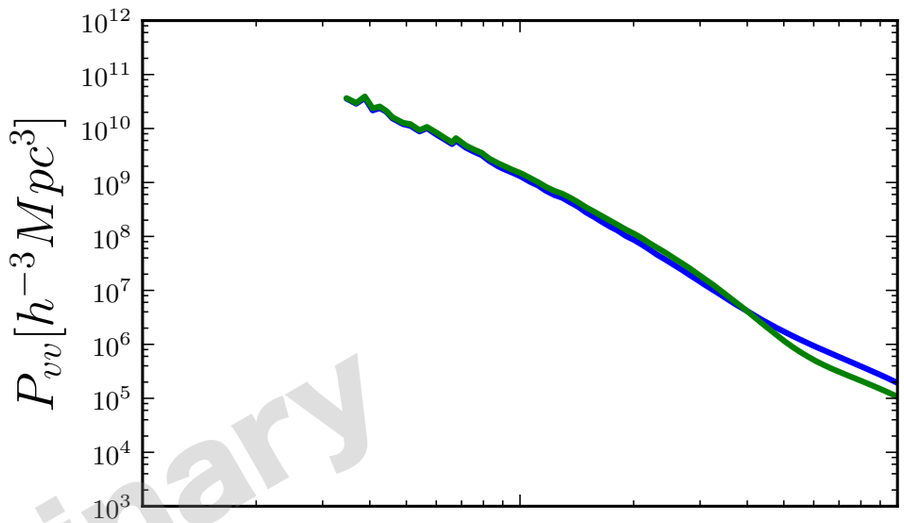
$$p_{\delta\theta}(k) = aHfP_{mm}(k)/k^2 \quad (\theta = \nabla \cdot \mathbf{v})$$

Dynamical Reconstruction step 2:
Moving from z=0.4 to 0.6 (Move back 1.43 Gyr)

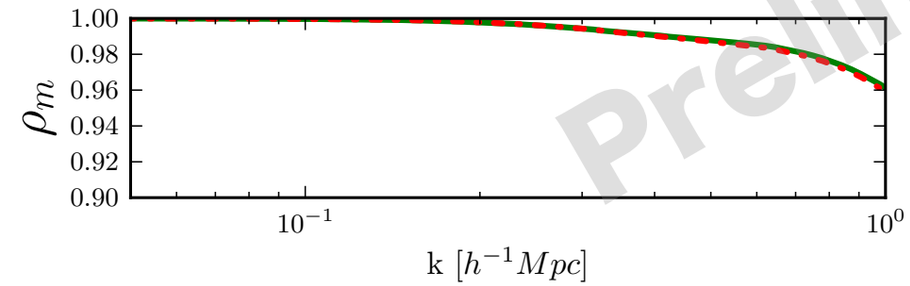
Matter Power-spectrum

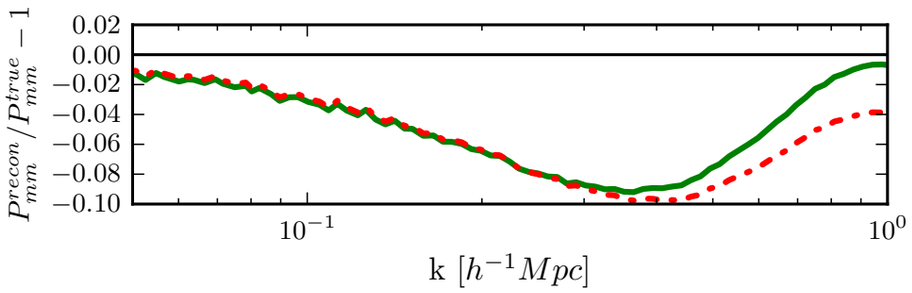


Velocity Power-spectrum

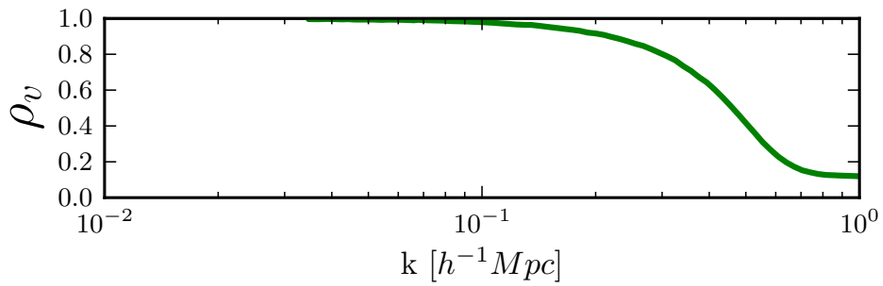


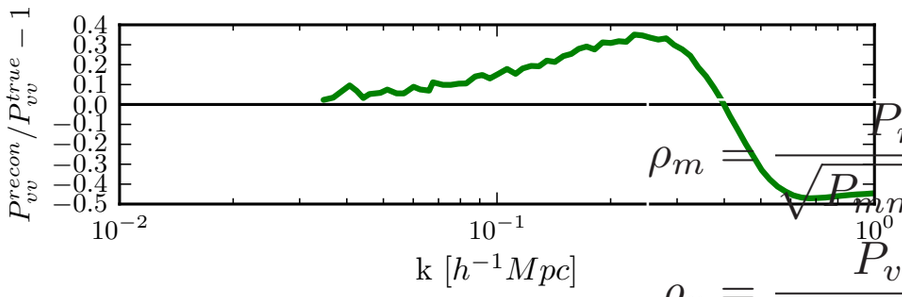
Matter Correlation coefficient





Velocity Correlation coefficient





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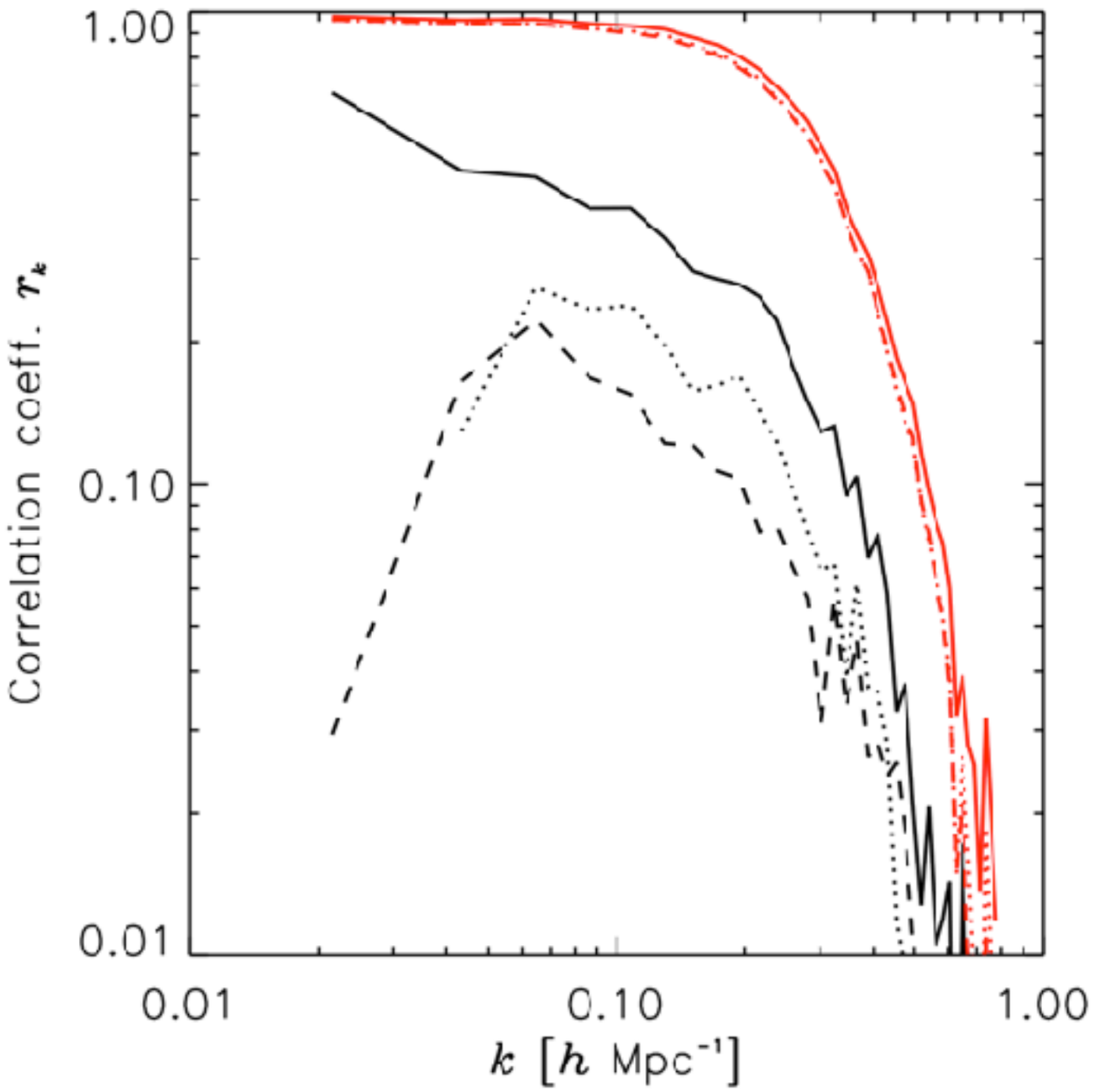
Preliminary

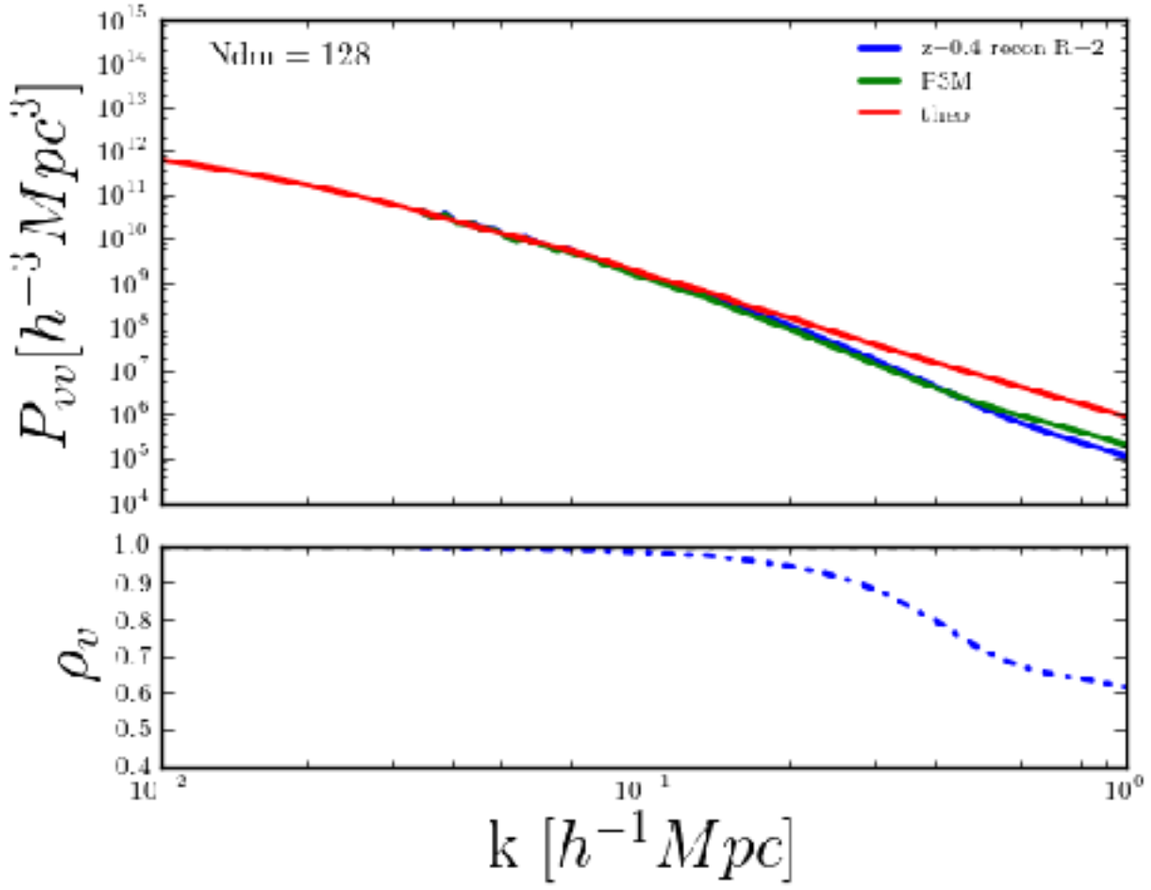
98% reconstruction at k=0.5 h/Mpc

Dynamical Reconstruction: how to improve?

- Smoothing scales, mesh size
- number of particles
- leap frog algorithm
- ……

Dynamical Reconstruction: velocity construction comparison





Planck intermediate results. XXXVII 2015

Future direction of dynamic reconstruction project

- theory paper
  - parameters check: smoothing scales, mesh size, number of particles
  - comparison with previous reconstruction paper
    - BAO reconstruction
    - velocity reconstruction
- data paper
  - test with galaxies
  - apply to real data
    - doing cosmology analysis with more linear fields
    - velocity reconstruction
    - BAO reconstruction
  - relative velocity between dark matter and baryons