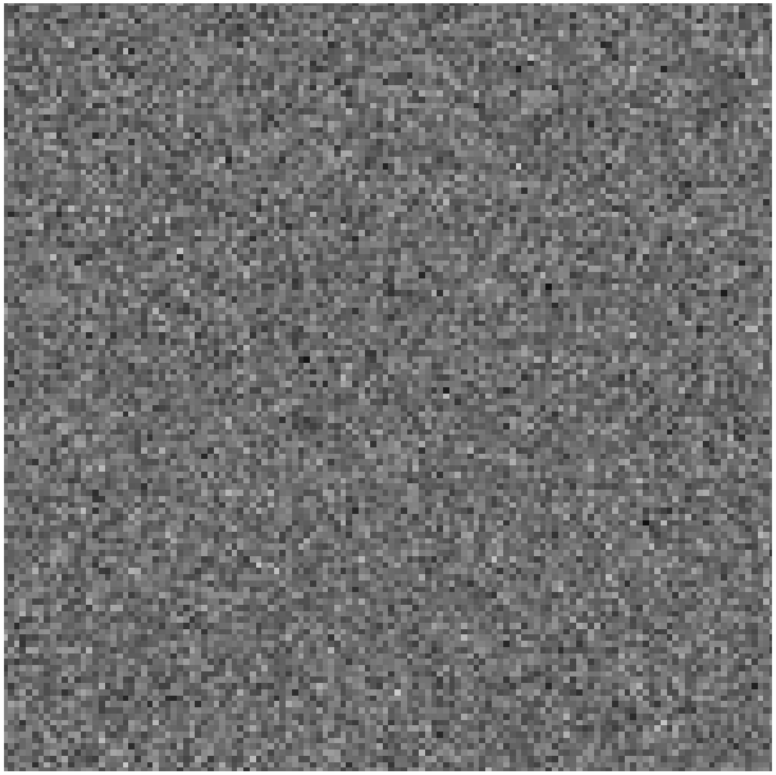
Two complementary approaches to cosmic variance:



Big volume simulations *and* **constrained Simulations**

Steffen Heß

Leibniz-Institut für Astrophysik Potsdam AIP

With

Gustavo Yepes, Anatoly Klypin, Francisco Prada

Francisco Kitaura and Stefan Gottlöber

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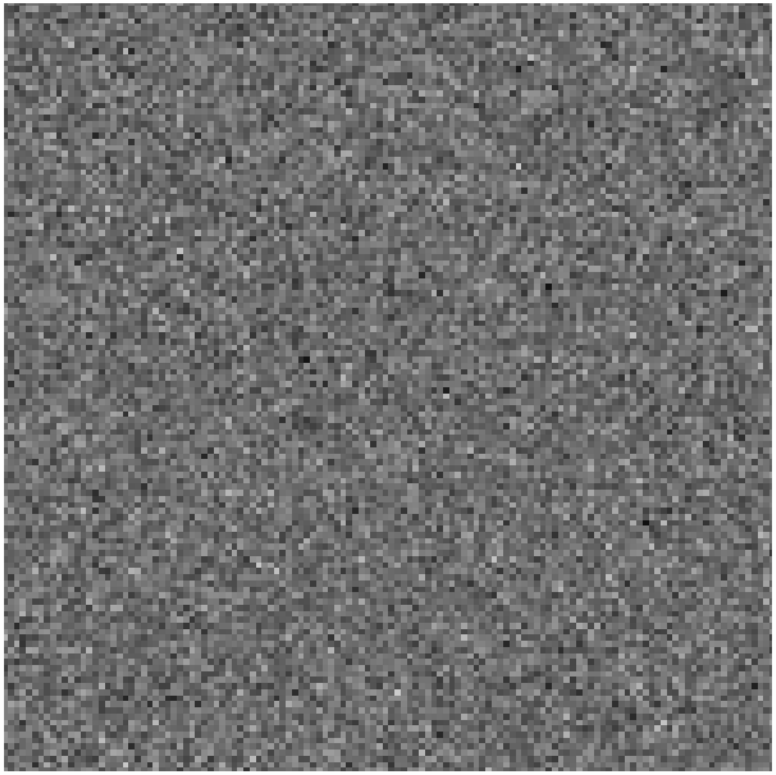

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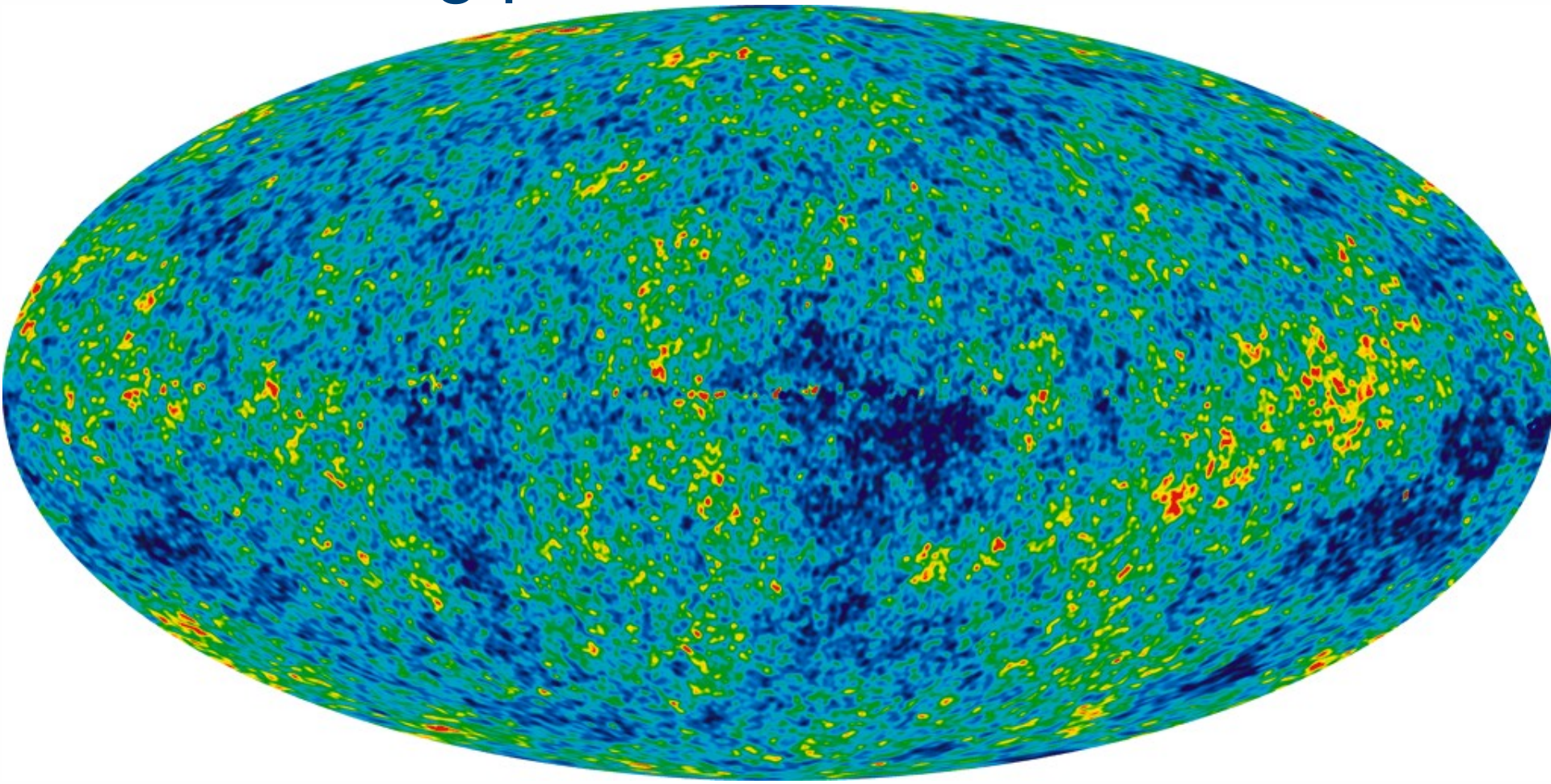
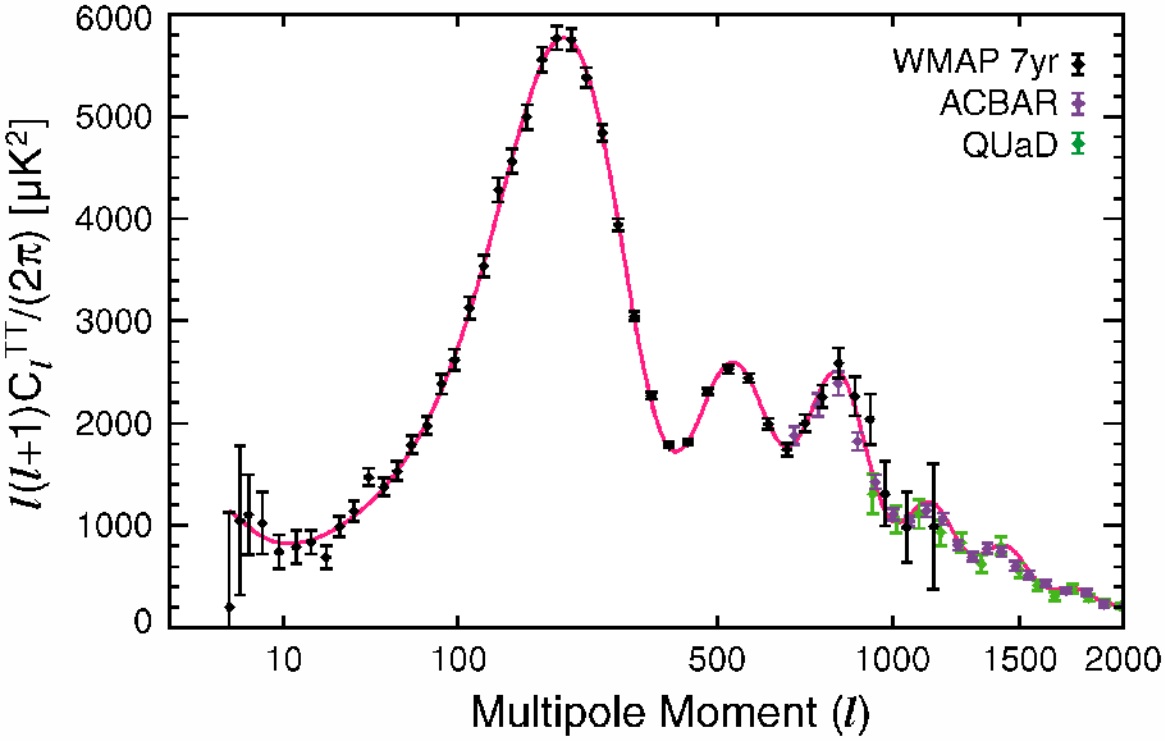
Starting point



- Cosmological simulations as a Cauchy problem

Actual starting point

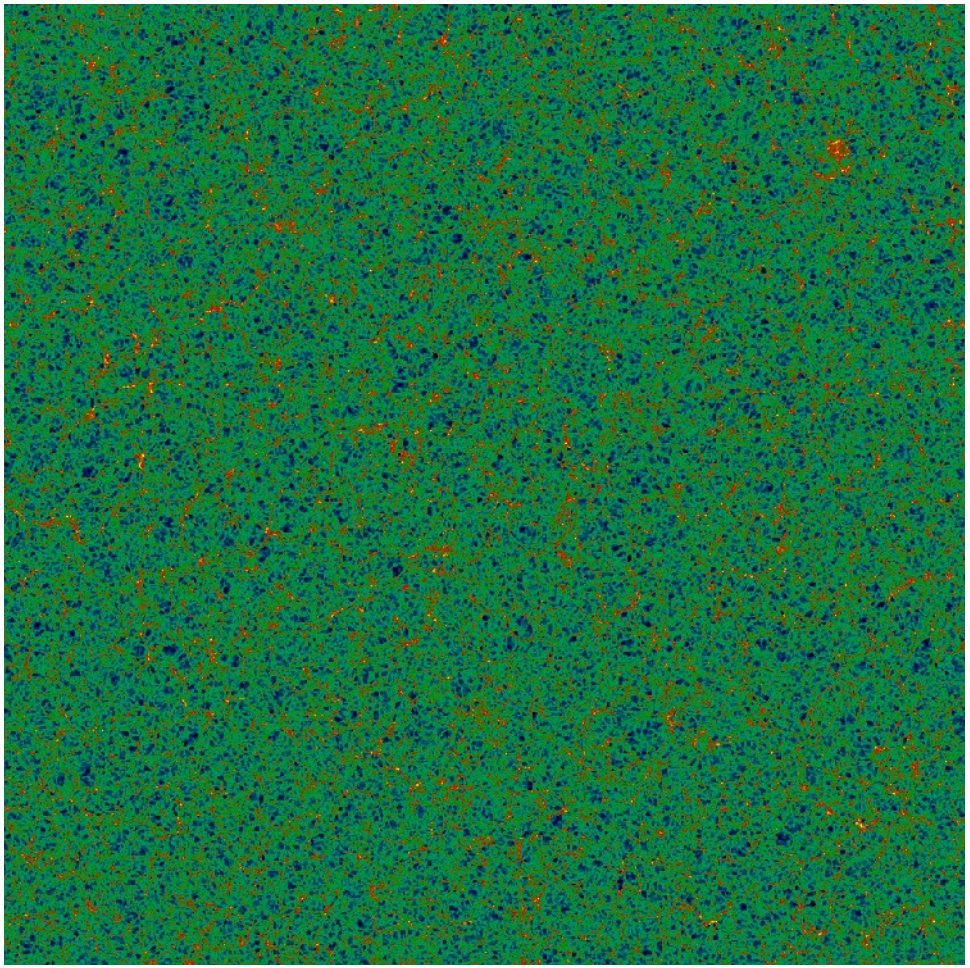


- No Phase information is used

What about Cosmic variance?

The Mdark runs

- **2.5 Gpc/h**
- Varying cosmology



AIP

Can we disentangle structure formation?

AIP

Can we disentangle structure formation?

For the ONE universe That we can observe?

We want to constrain the **phases** of the initial perturbations such,

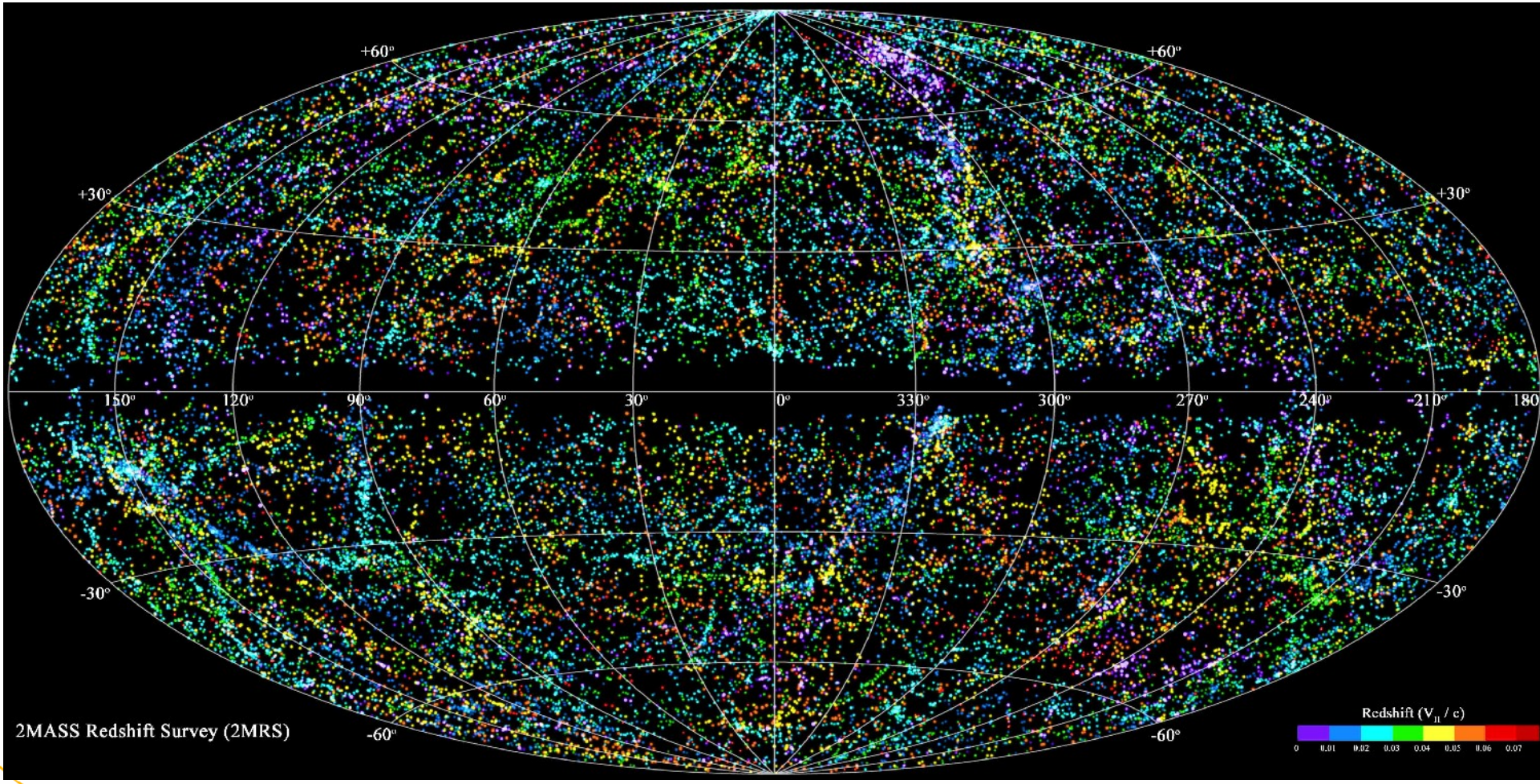
that we **reproduce structures** as they are observed

Observational challenges

First:

- Observe structures
  - The more data the better
  - Ideally:
    volume-limited full-sky redshift survey

2MRS



http://wise2.ipac.caltech.edu/staff/jarrett/2mrs/2mrs.html

- 91% of the sky

$$\delta_G(z)\{z_G\}$$

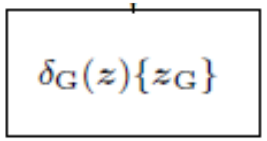
nonlocal and nonlinear **mode-coupling** between large and small scales **has hidden the initial phase information**

$$\delta_G(z)\{z_G\}$$

KIGEN algorithm

KIGEN-code
(KInetic GENeration of the initial conditions, jap. origin)
(*Kitaura 2012*)

nonlocal and nonlinear **mode-coupling** between large and small scales **has hidden the initial phase information**

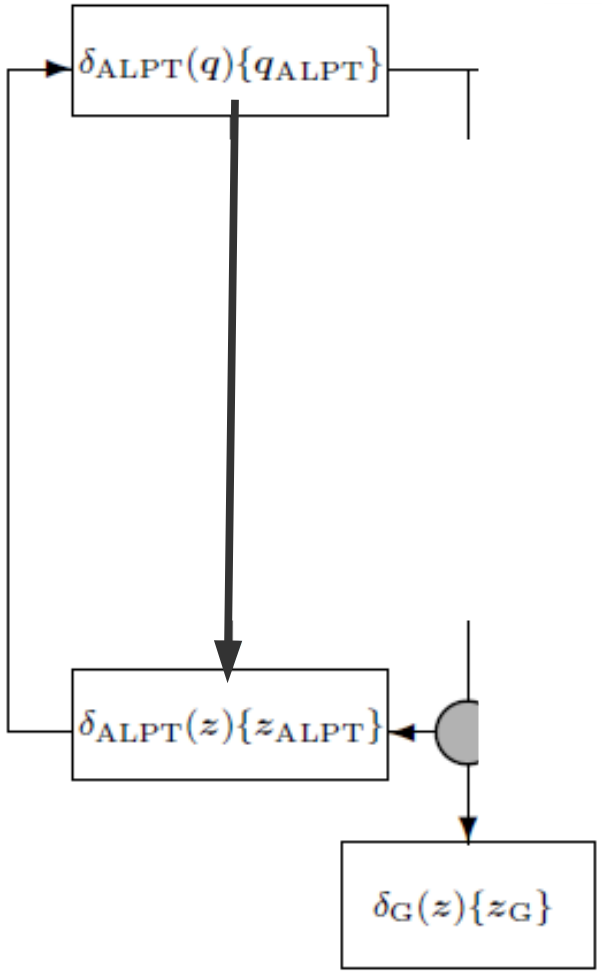


KIGEN algorithm

$\delta(\{q\}) \leftarrow P(\delta(\{q\}) \mid \{q\})$

$\{q\} \leftarrow P(\{q\} \mid \{x_G\}, \delta(\{q\}))$

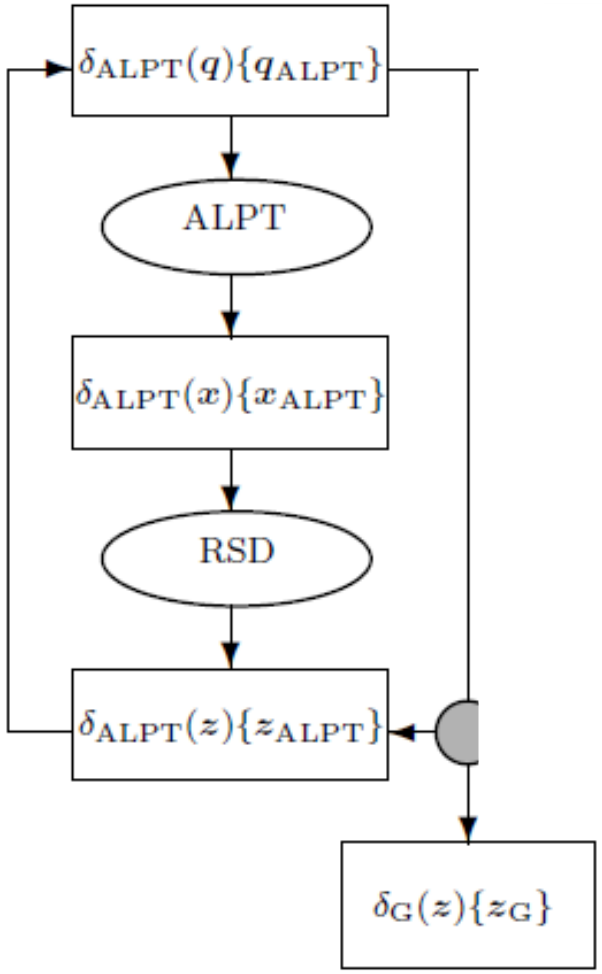
- Sampling the Gaussian field given a set of matter tracers at z_{init}, given a prior P(k)
- Propagate the set of matter tracers



KIGEN algorithm

Propagate the set of matter tracers:

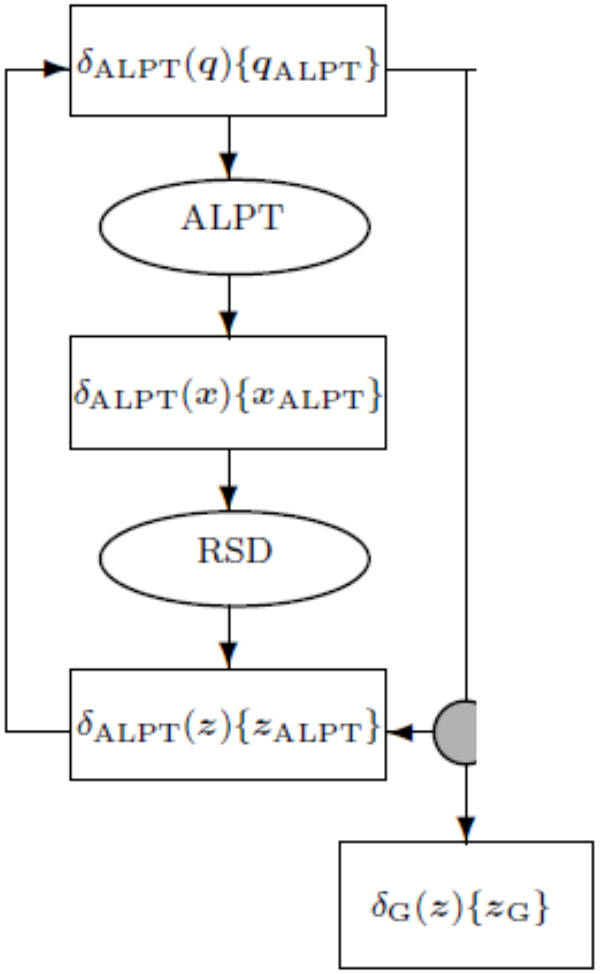
- ALPT combines:
  - 2LPT on large
  - Spherical collapse on small scale



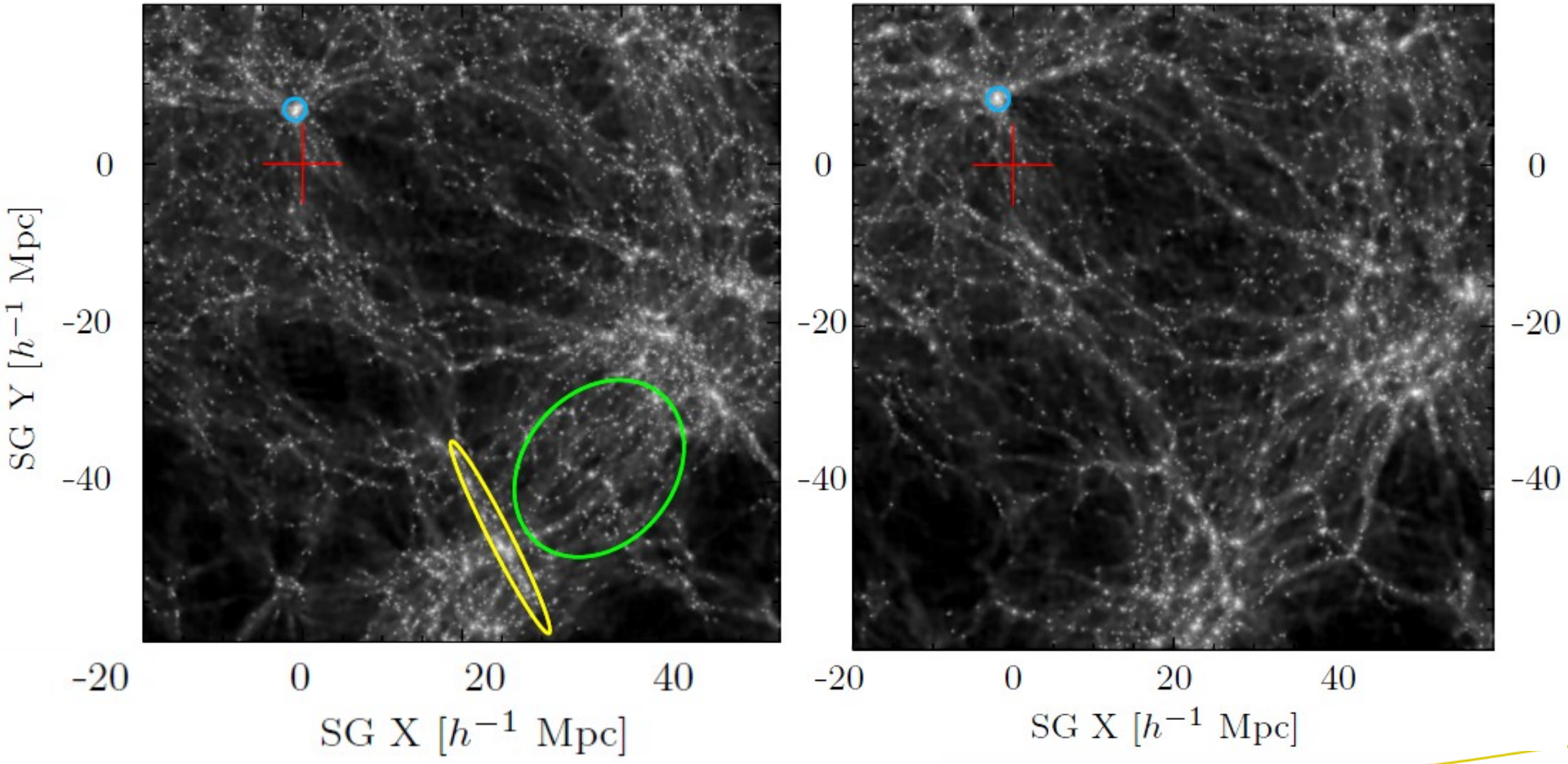
KIGEN algorithm

Propagate the set of matter tracers:

- Model RSD:
  - Coherent flow is modeled by 2LPT
  - Fingers-of-god NOT compressed BUT modeled as dispersion term



Fingers-of-god modeling



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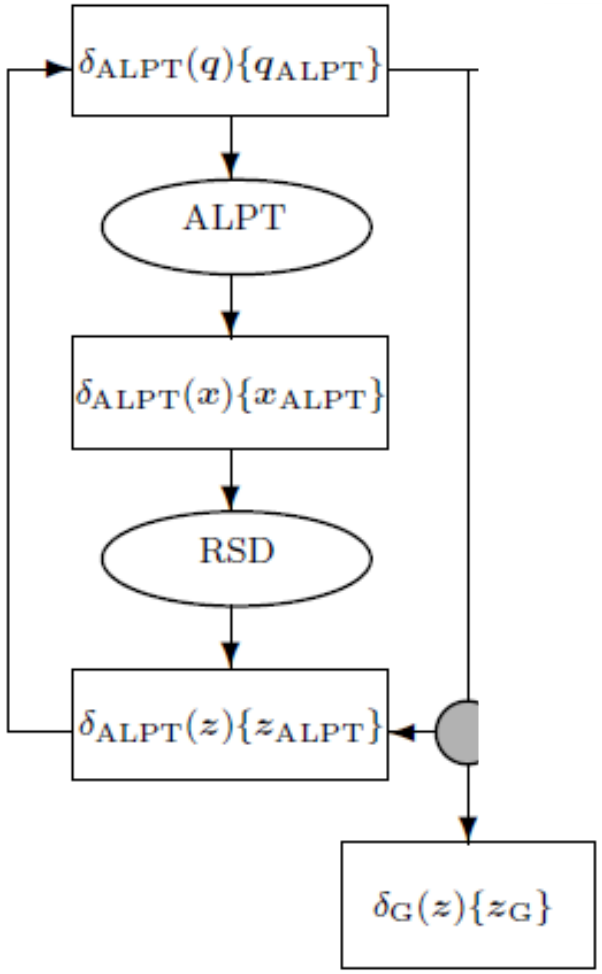
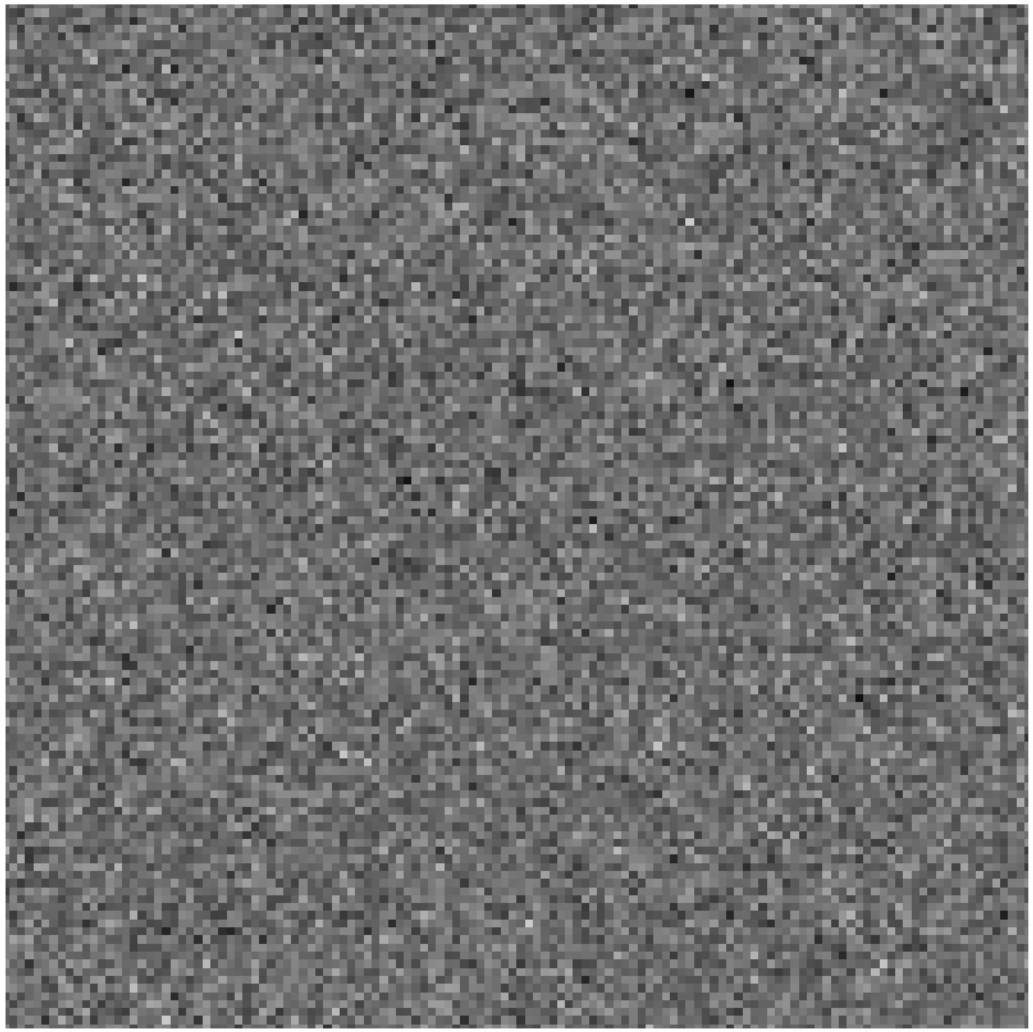
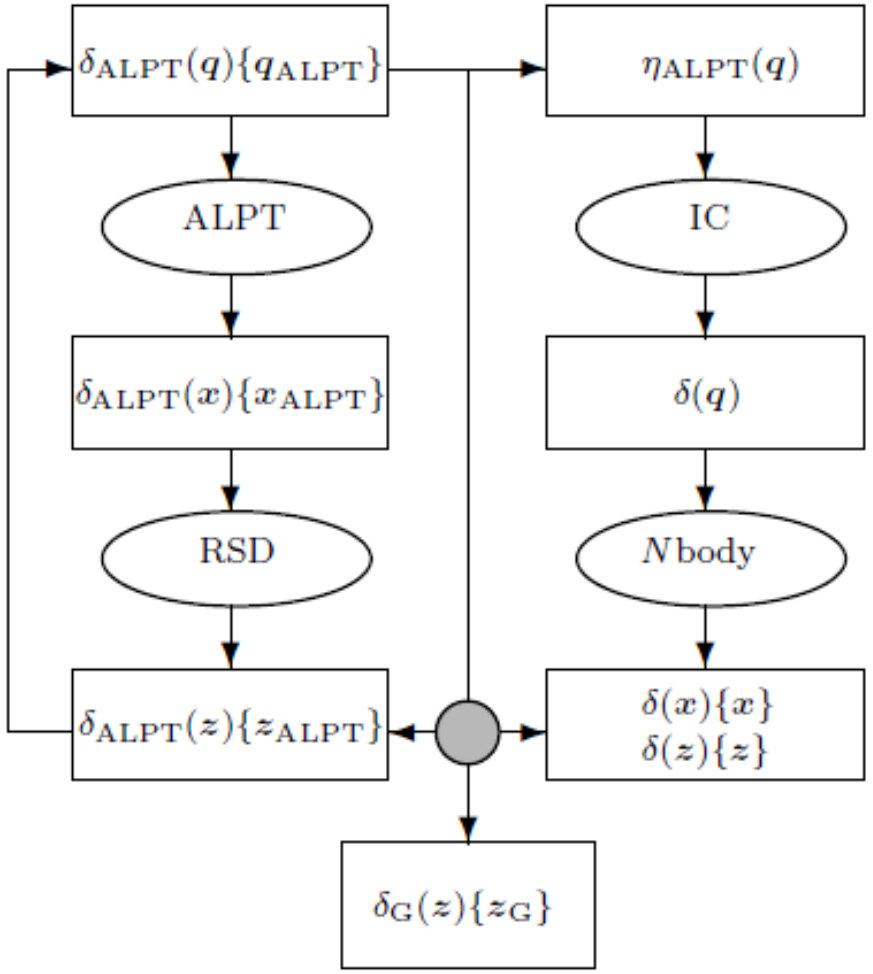


White noise



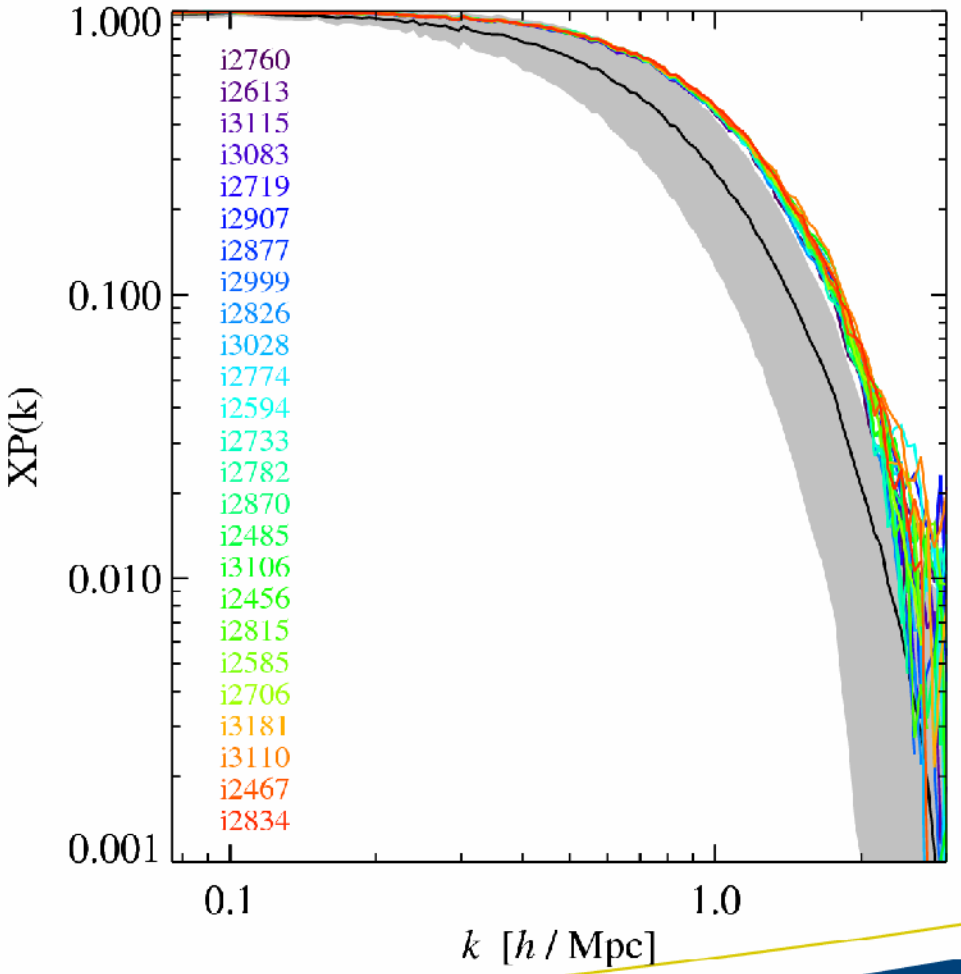
Nbody simulations

- Selecting *good* reconstruction
- Adding random small scale modes
- Propagating matter with a **fully non-linear** scheme
- Formation of **halos**



Selecting an ensemble

- From ~1200 iterations
- We impose a threshold of XP(k=1) > 0.43
- This sample of 25 realisations is superior on all scales

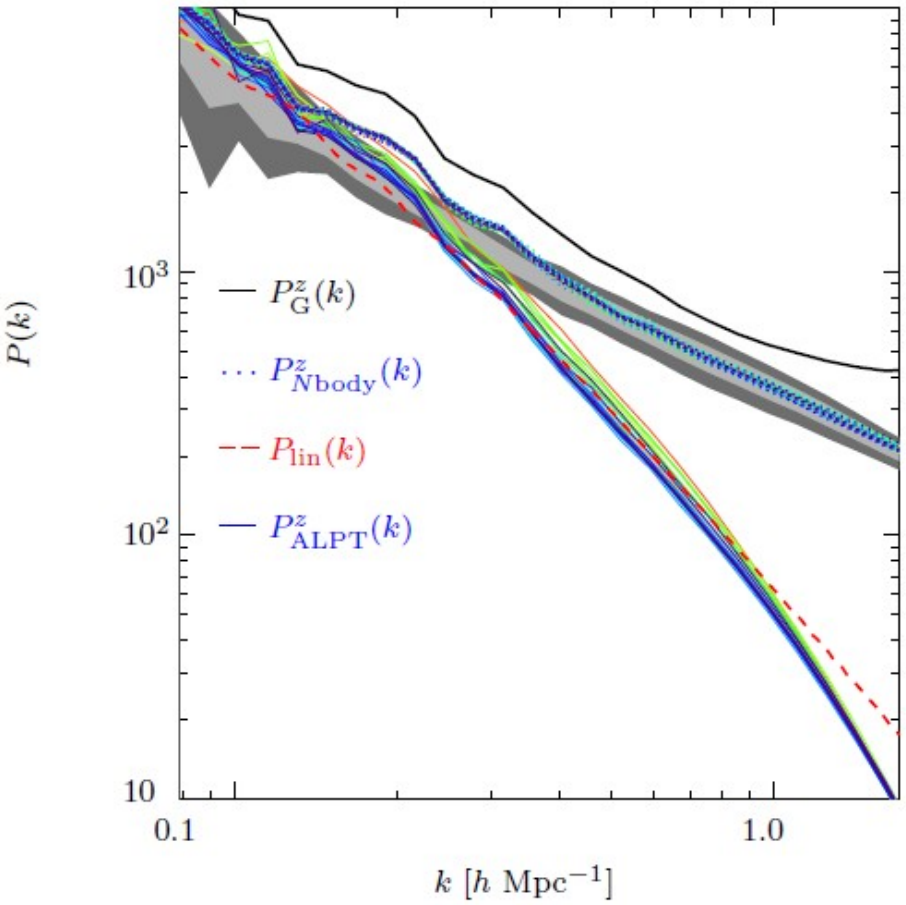


Properties of the simulations

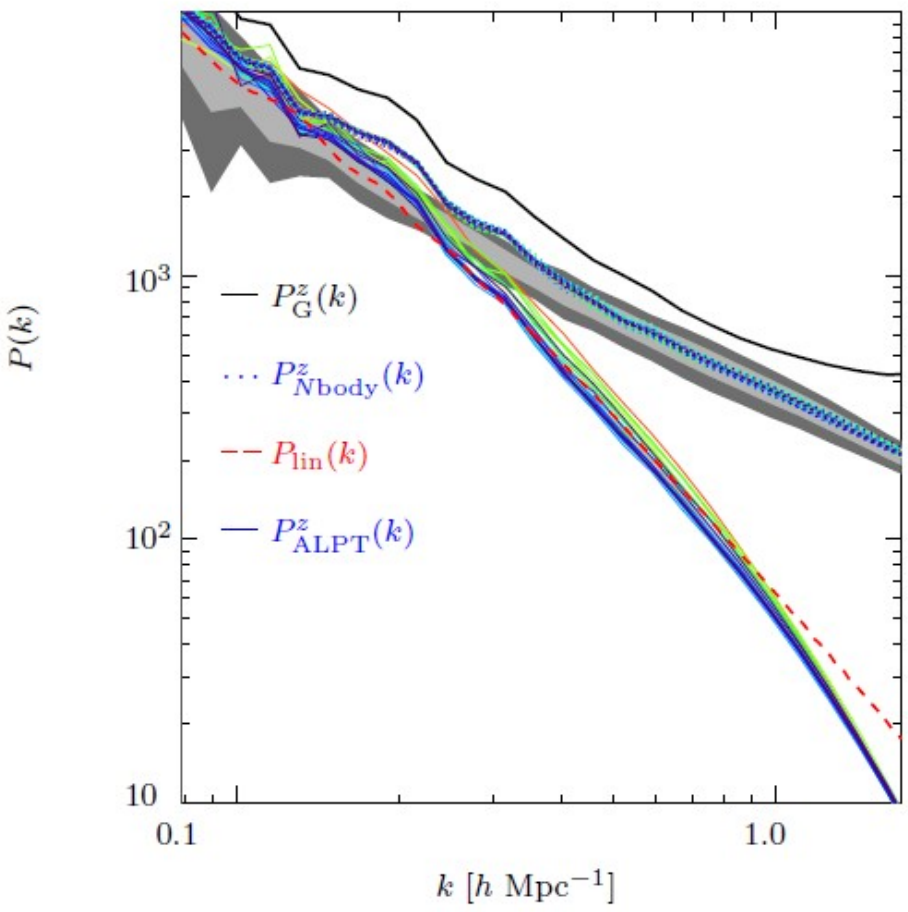
- Boxsize
- Particles
- Mass resolution
- Different realisations

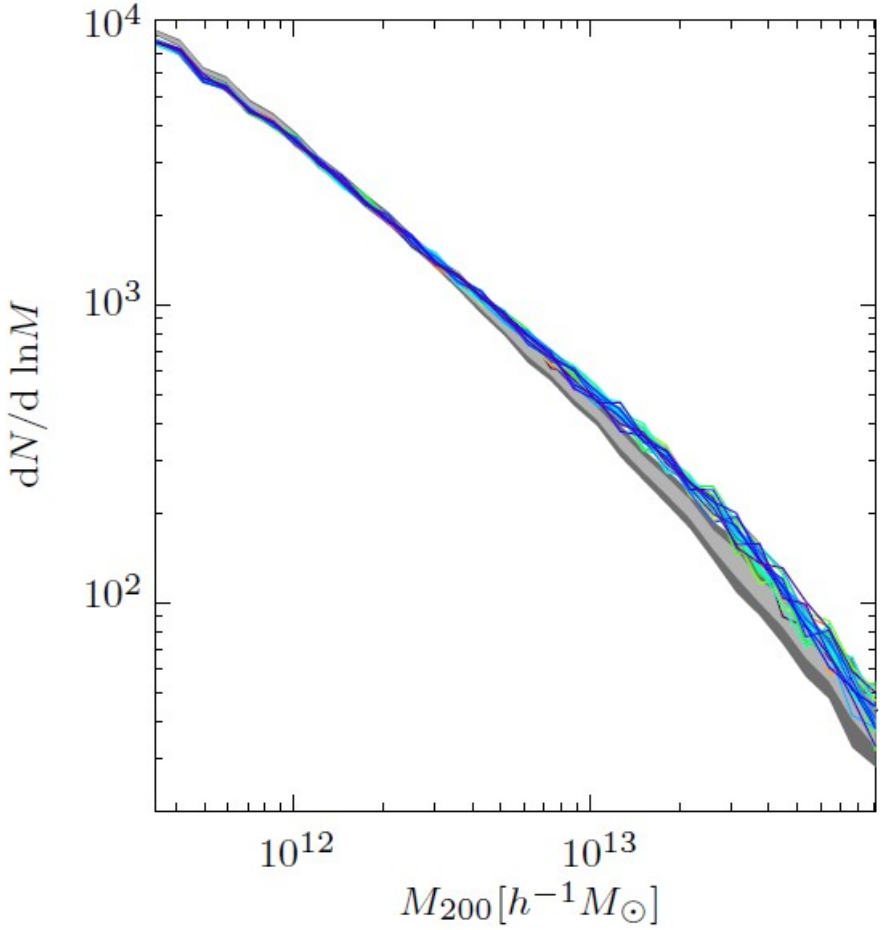
- 180 h^{-1} Mpc
- 384^3
- 7.8 10^9 M_{sun}
- 25

Main characteristics

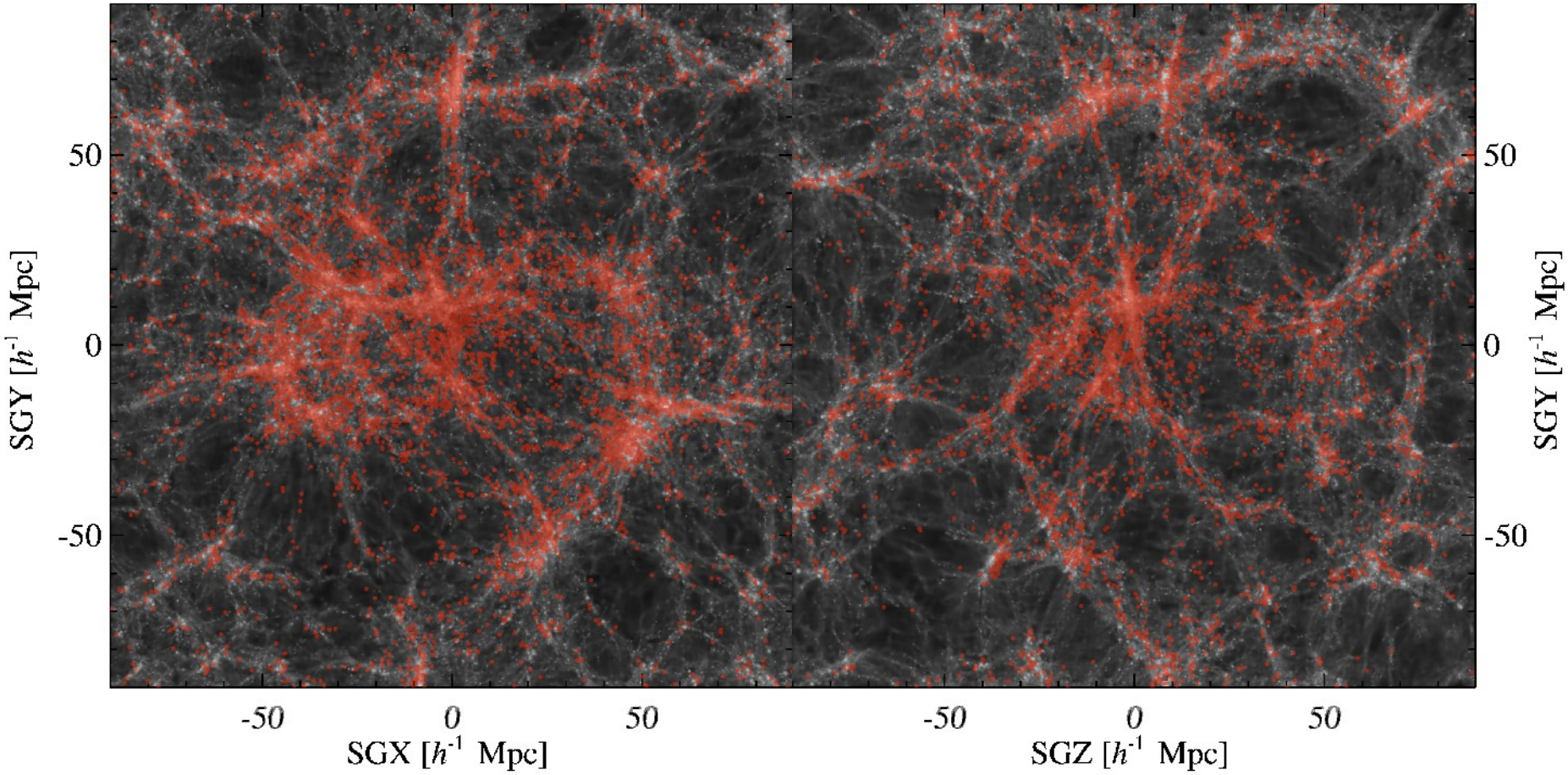


Main characteristics



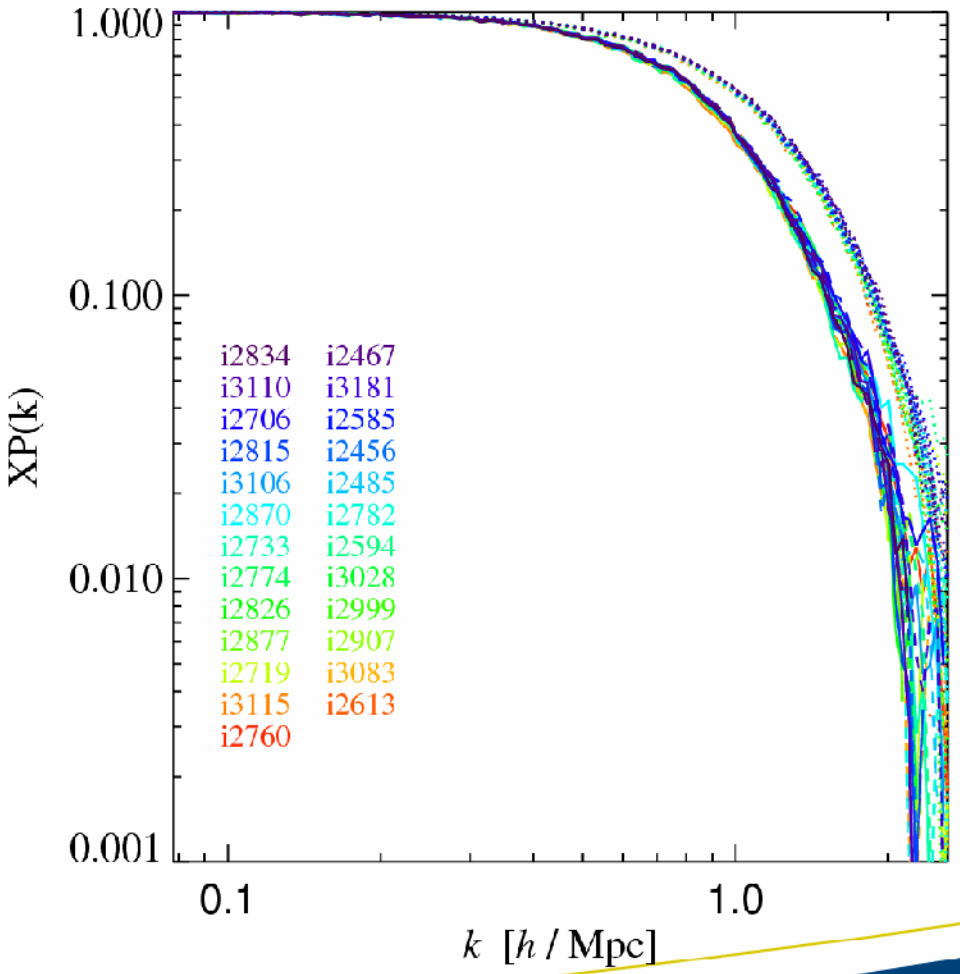


z-space

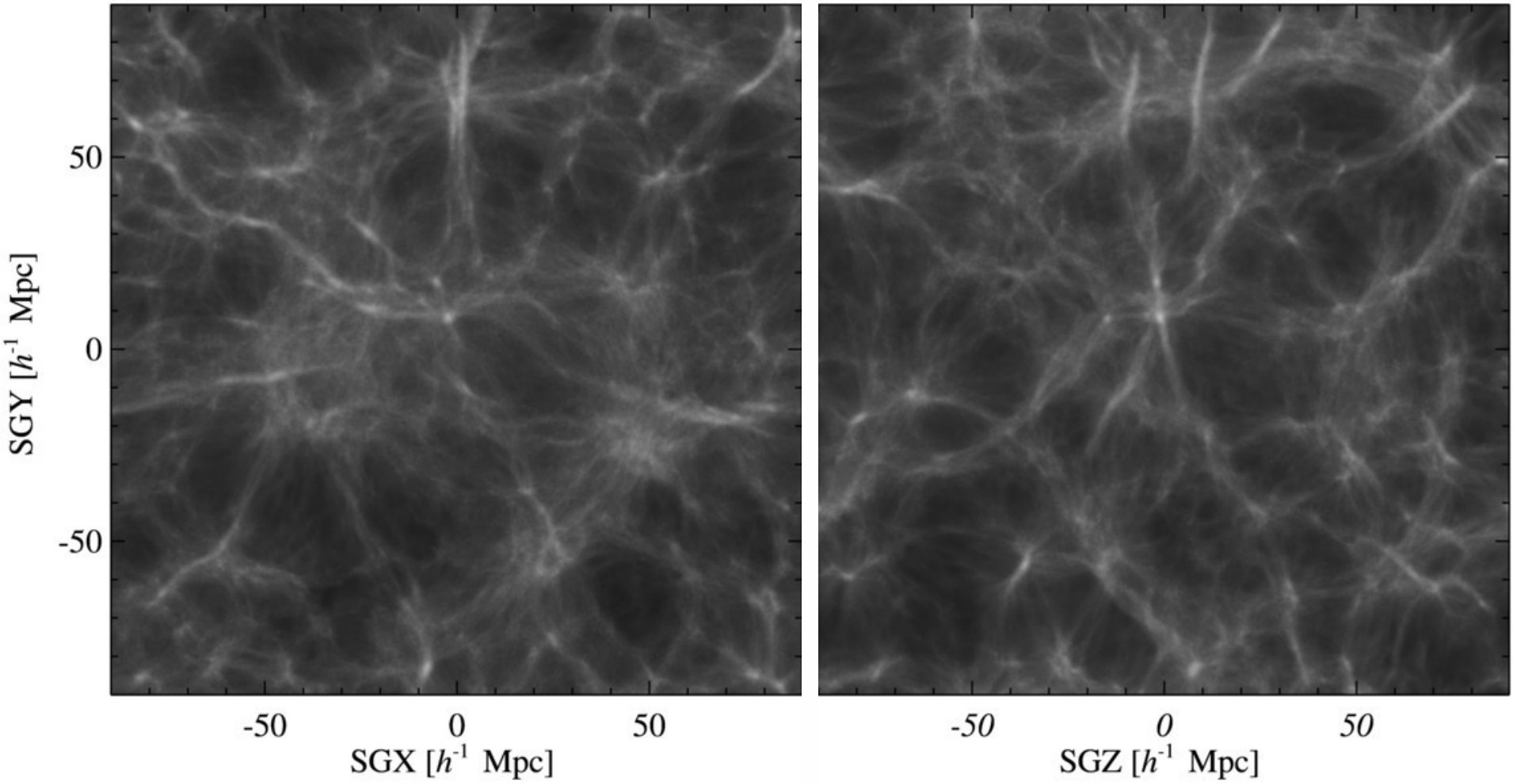

50
0
-50
SGY [h^{-1} Mpc]
-50
0
50
SGX [h^{-1} Mpc]
-50
0
50
SGZ [h^{-1} Mpc]
50
0
-50
SGY [h^{-1} Mpc]

Cross-power of the ensemble

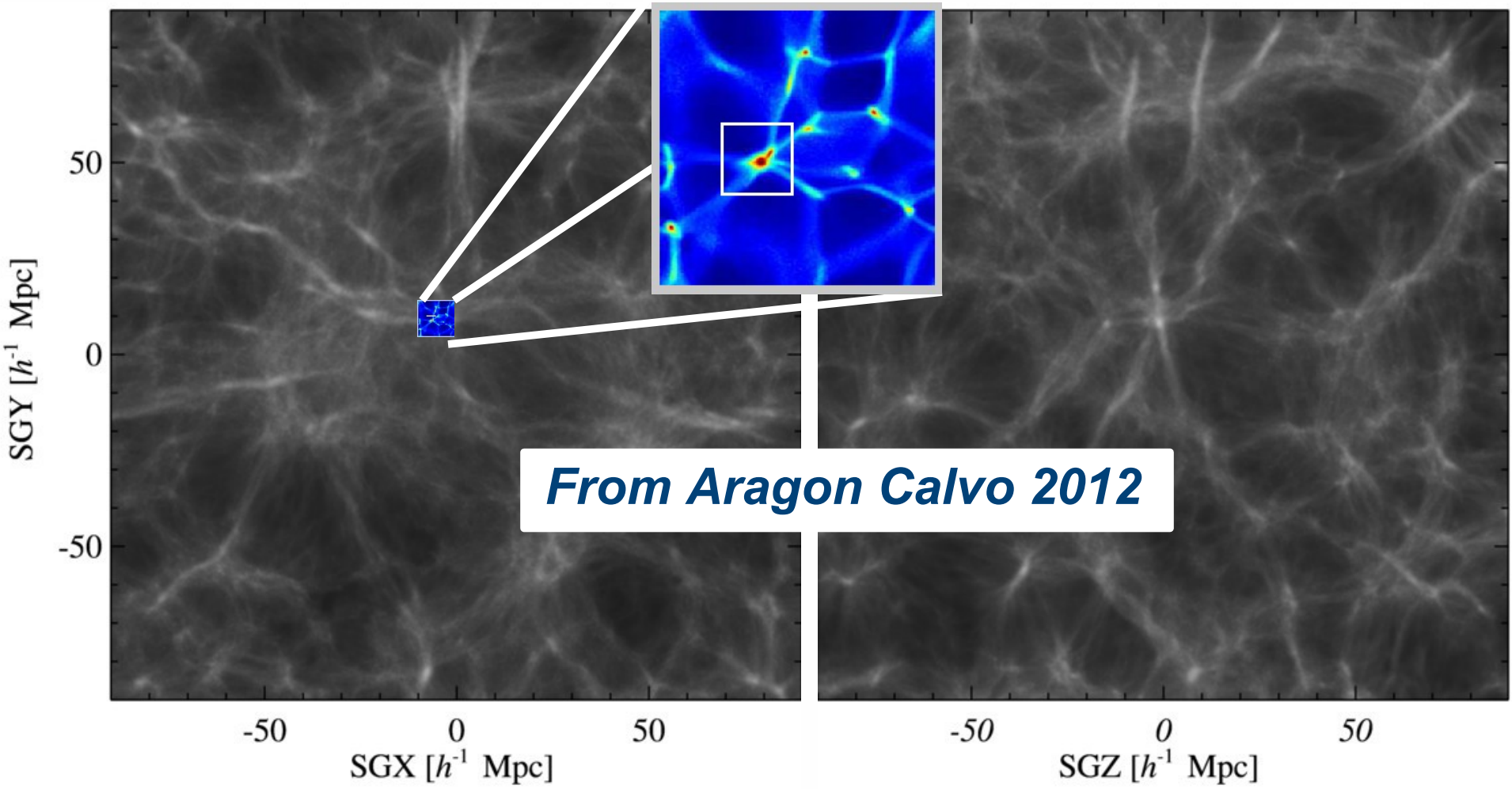
- Small spread between realisations
- Constraining to scales: 2.6±0.2 Mpc/h
- At k=1 XP > 38%



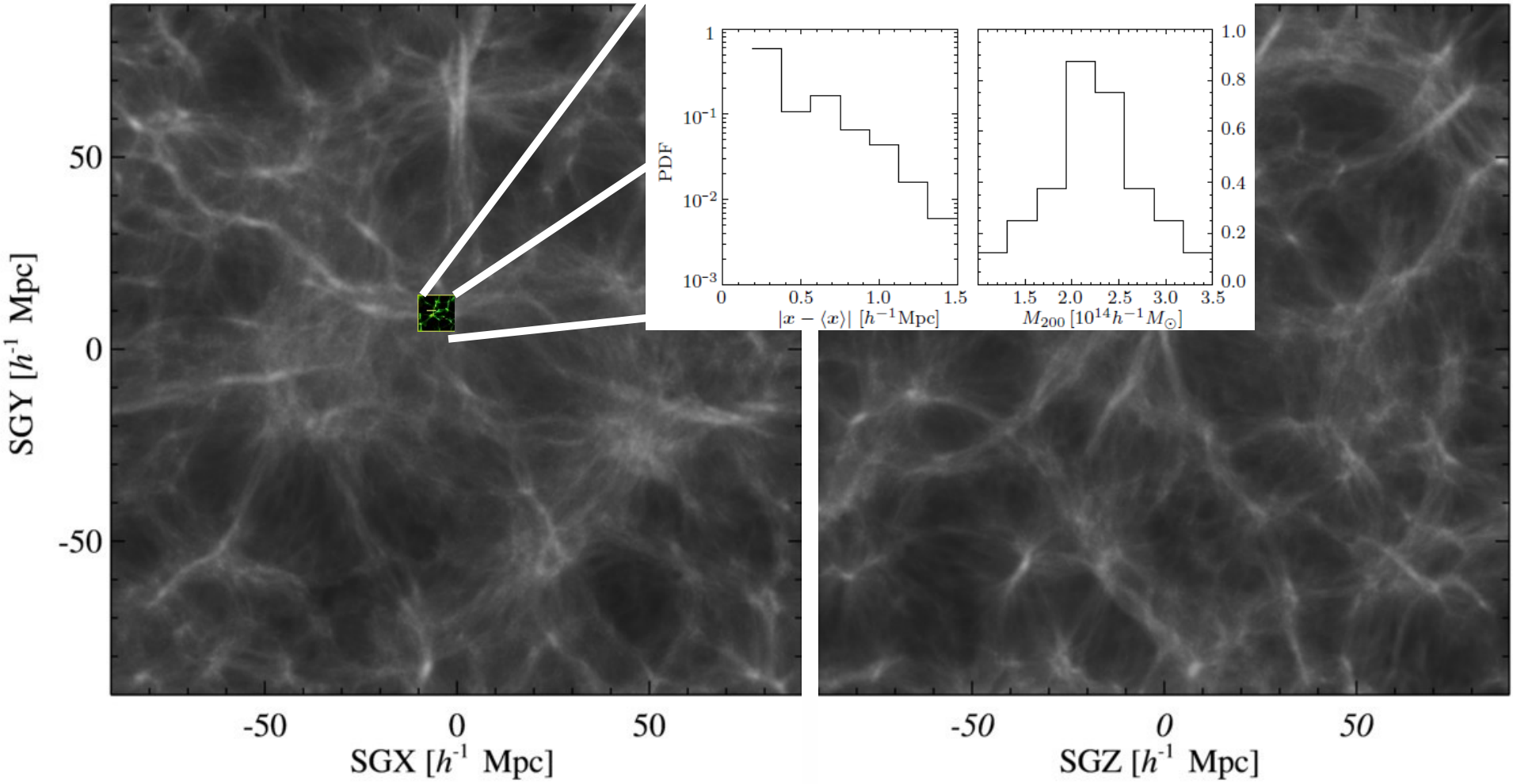
Average of ensemble



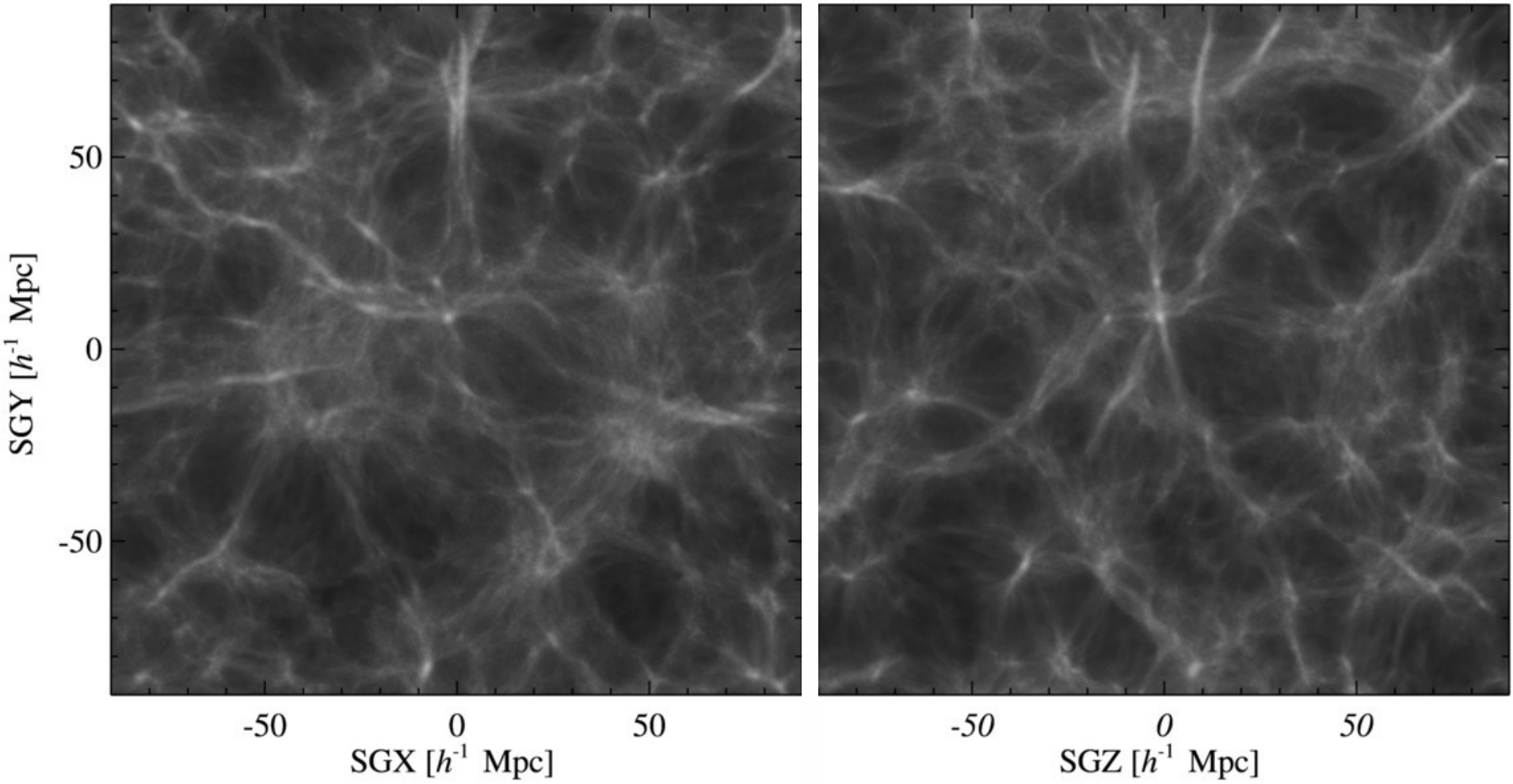
Average of ensemble



Average of ensemble

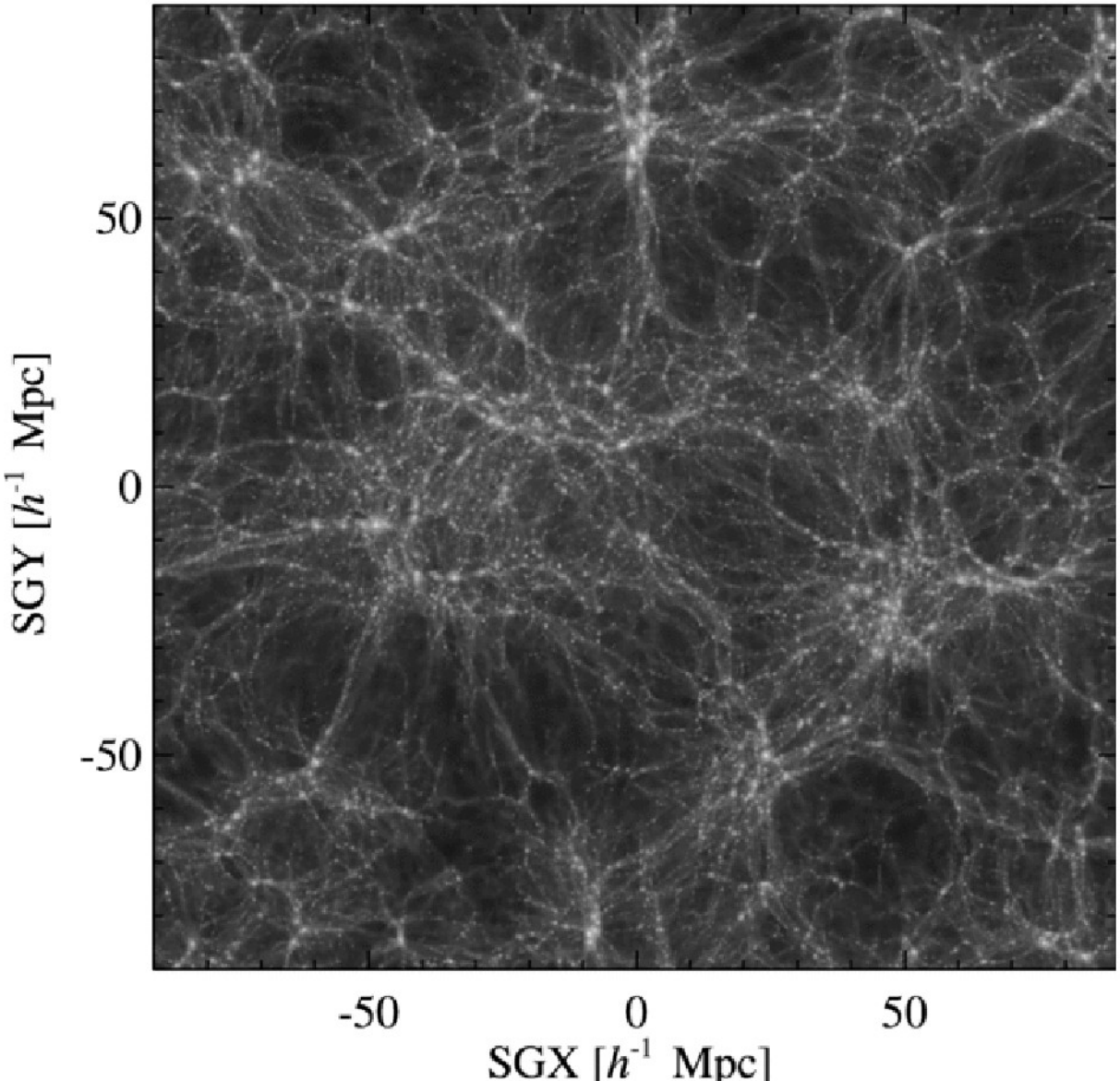


Average of ensemble



AIP

The heart of this talk



Possiblities with new Simulations

- Big volume simulations offer high-number statistics for rare objects
- Apply our method to other surveys
- Study cosmic variance in the Local Universe
  - Isotropy, homogeneity, velocities, gravitational potential
- **Qualitative change in constraints ~2.6 Mpc/h**

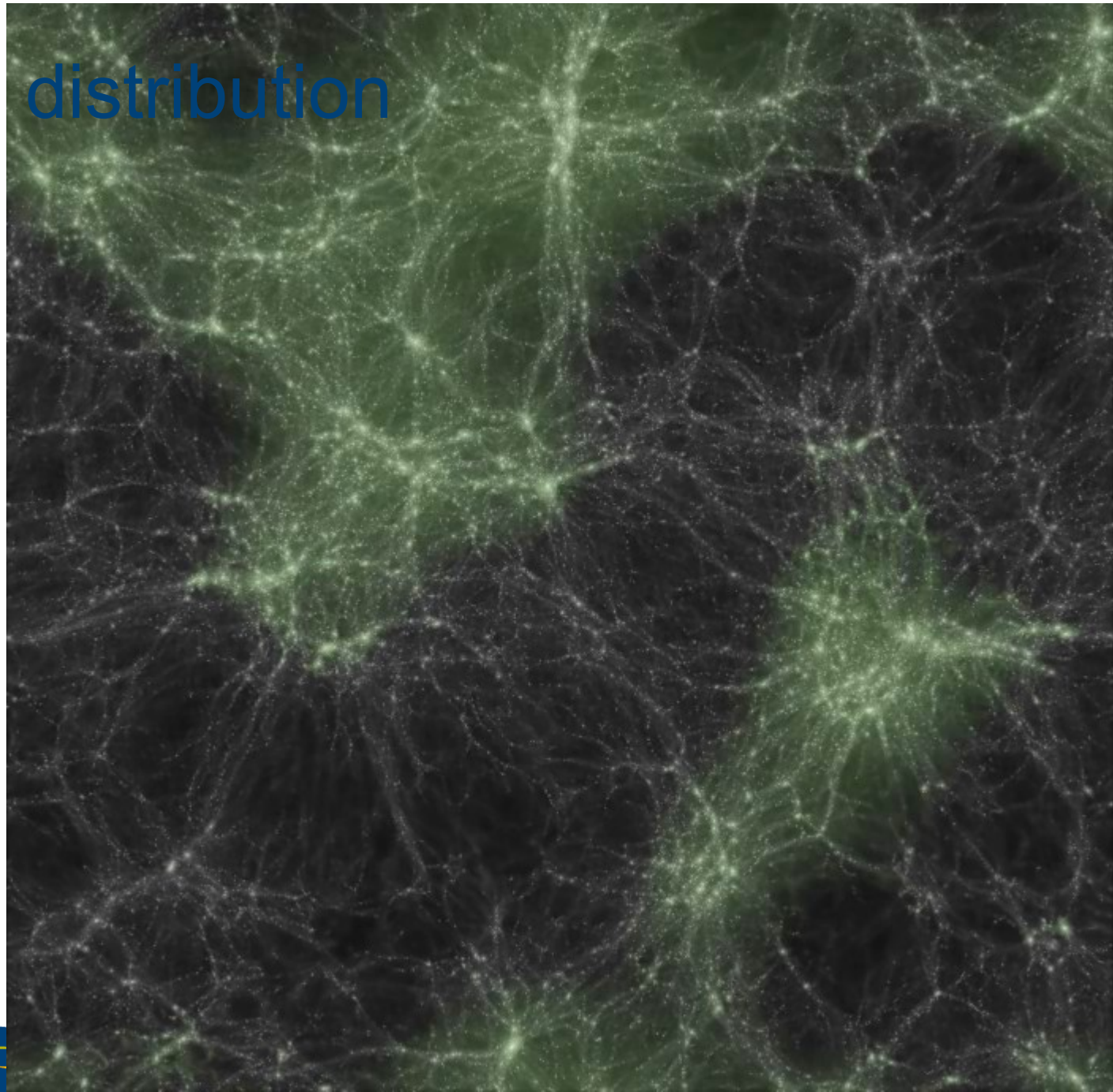
  => Environmental studies of nearby clusters
  - Virgo, Coma

  => Environmental studies of the local group

  also with our hydrodynamics VPH (see Hess&Springel 2010)

AIP

DM distribution

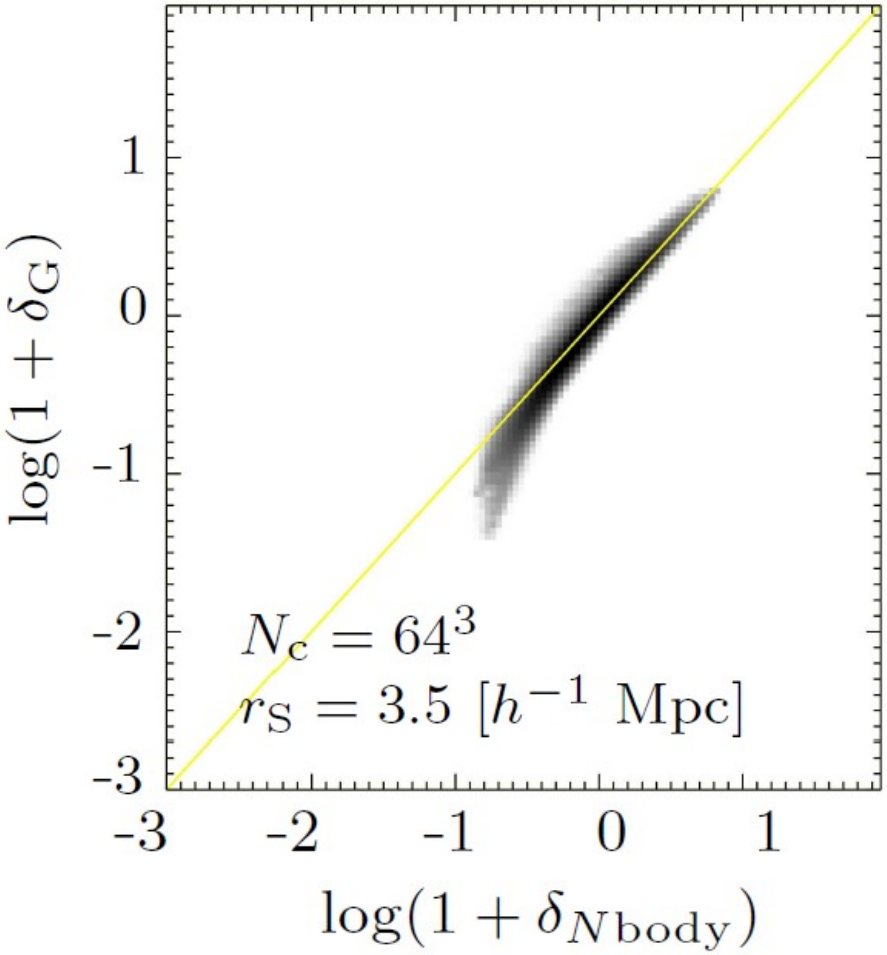


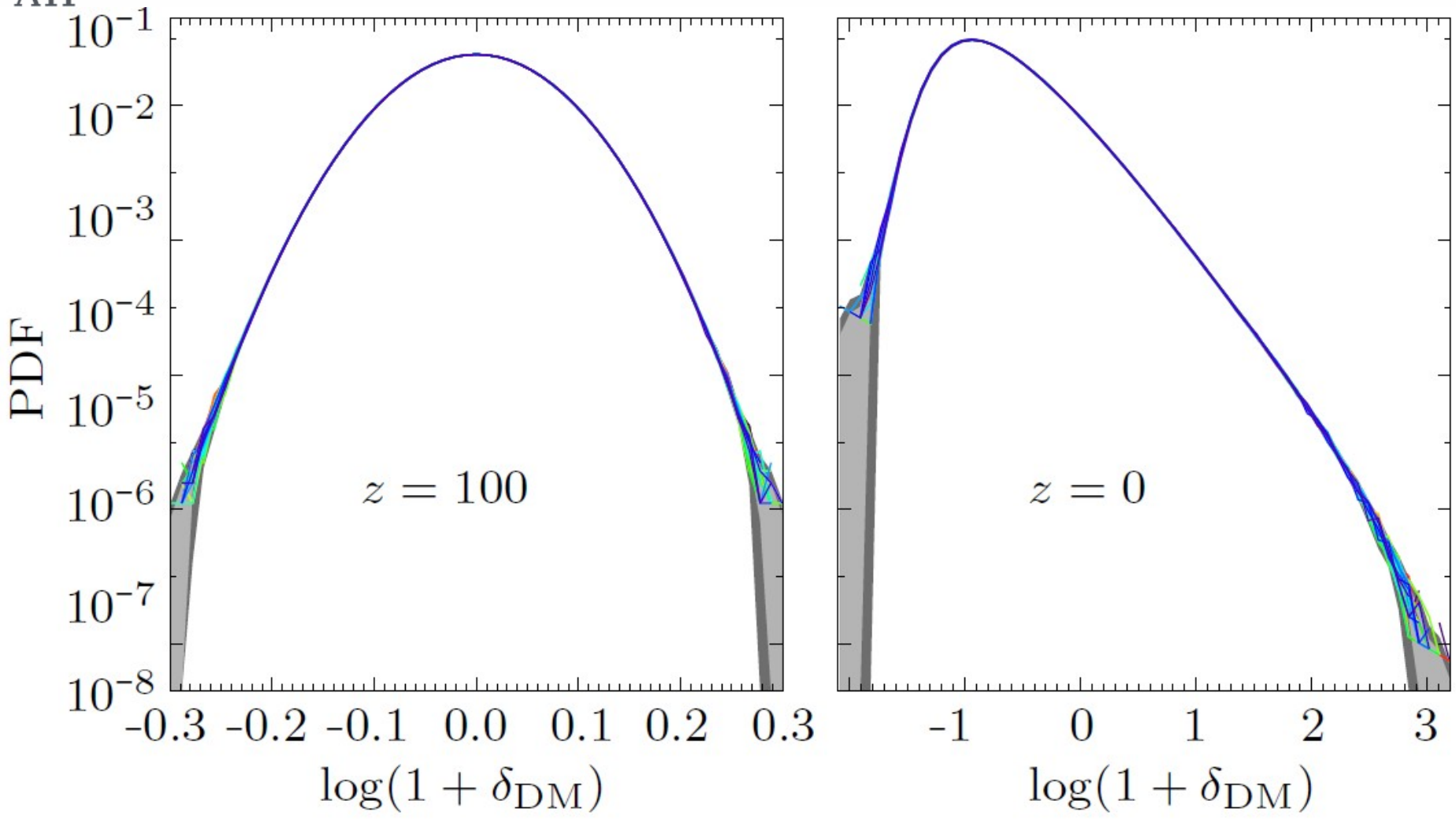
AIP

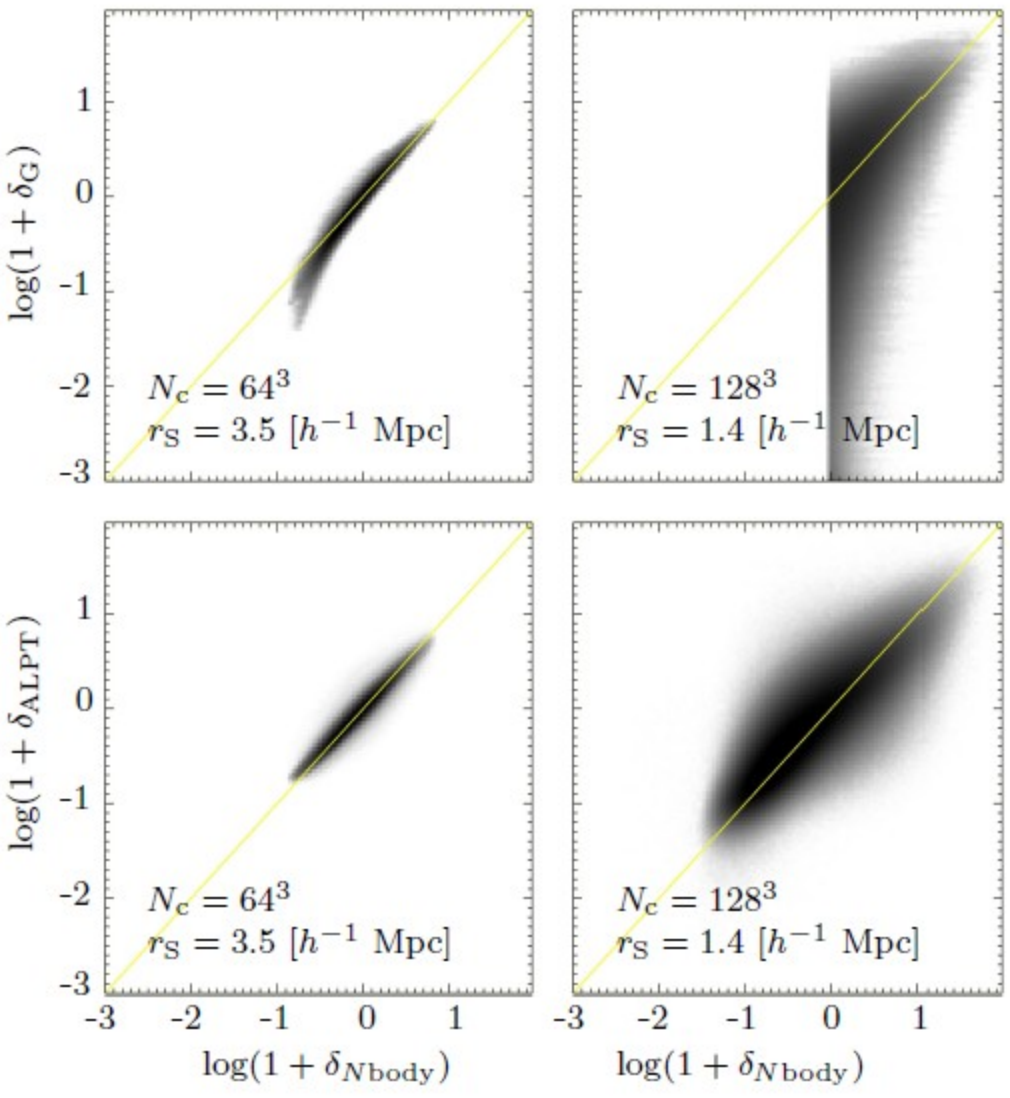
What is the drag?

Sparse sampling of galaxies at 128^3

- Better with 64^3 and gaussian smoothing
- Overall correlation 98%




PDF
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
$z = 100$
$z = 0$
-0.3 -0.2 -0.1 0.0 0.1 0.2 0.3
-1 0 1 2 3
$\log(1 + \delta_{\rm DM})$
$\log(1 + \delta_{\rm DM})$


$\log(1+\delta_{\rm G})$
$\log(1+\delta_{\rm ALPT})$
$\log(1+\delta_{N\rm body})$
$\log(1+\delta_{N\rm body})$
$N_{\rm c}=64^3$
$r_{\rm S}=3.5\ [h^{-1}\ {\rm Mpc}]$
$N_{\rm c}=128^3$
$r_{\rm S}=1.4\ [h^{-1}\ {\rm Mpc}]$
$N_{\rm c}=64^3$
$r_{\rm S}=3.5\ [h^{-1}\ {\rm Mpc}]$
$N_{\rm c}=128^3$
$r_{\rm S}=1.4\ [h^{-1}\ {\rm Mpc}]$
-3
-2
-1
0
1