Inferring past and present cosmic structures from observations

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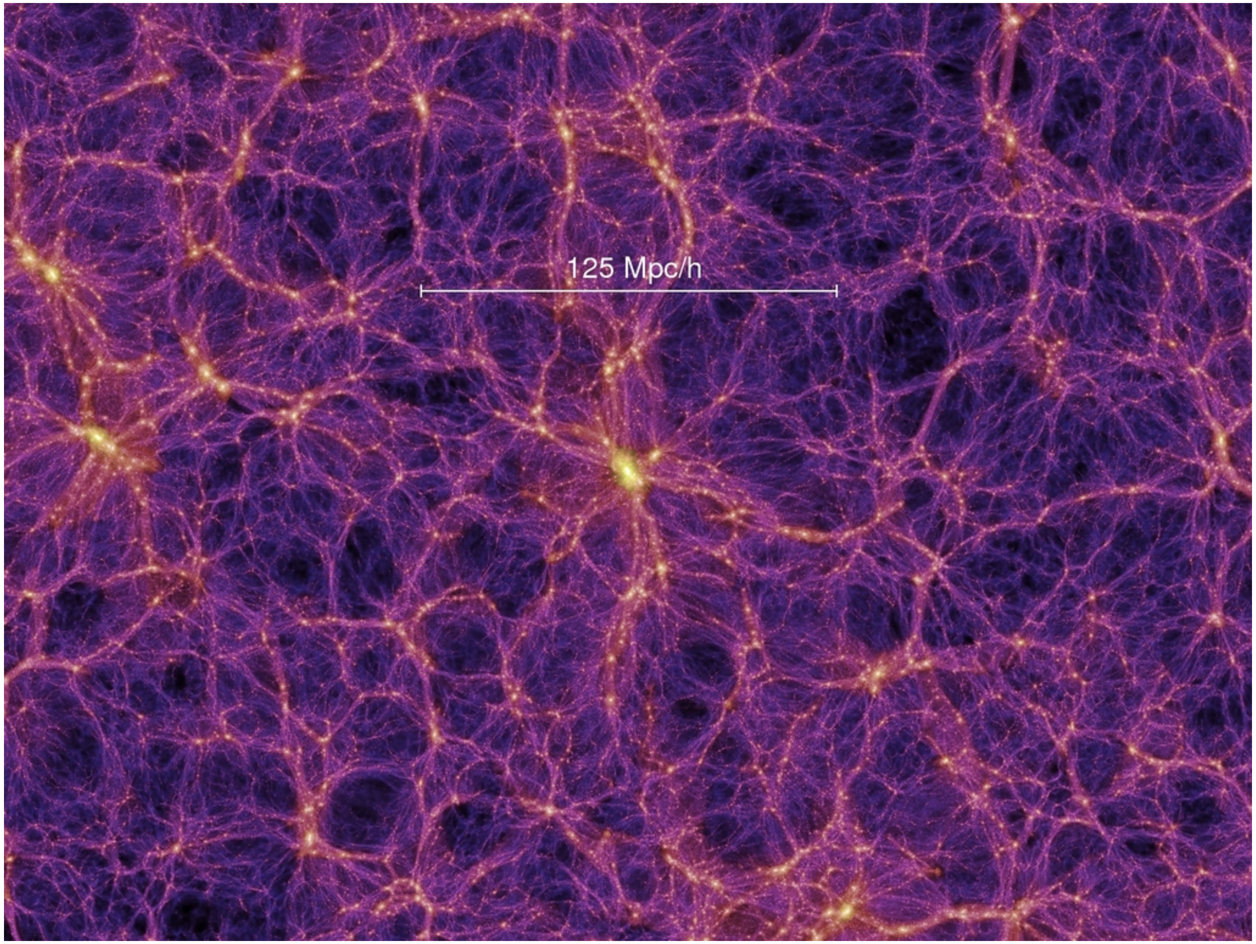
Garching, 22 July 2015

Excellence Cluster Universe

The cosmic large scale structure...

... A source of knowledge!



- Cosmological parameter
- Geometry of the Universe
- Constituents of the Universe
- Tests of Gravity
- Galaxy formation
- fundamental physics

Image credit: Volker Springel
for the Millenium Simulation, MPA Garching

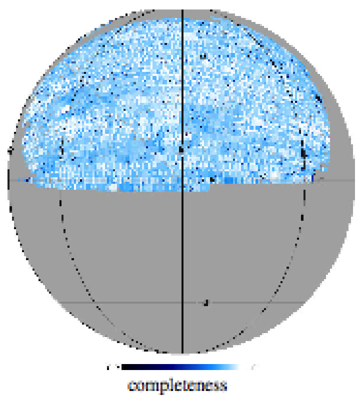
The need for statistics

"If your experiment needs statistics, you ought to do a better experiment."

Lord Ernest Rutherford

Inference of signals = Ill-posed problem

Cosmic variance
Noise



Survey geometry
Selection effects
Foregrounds
Galaxy bias

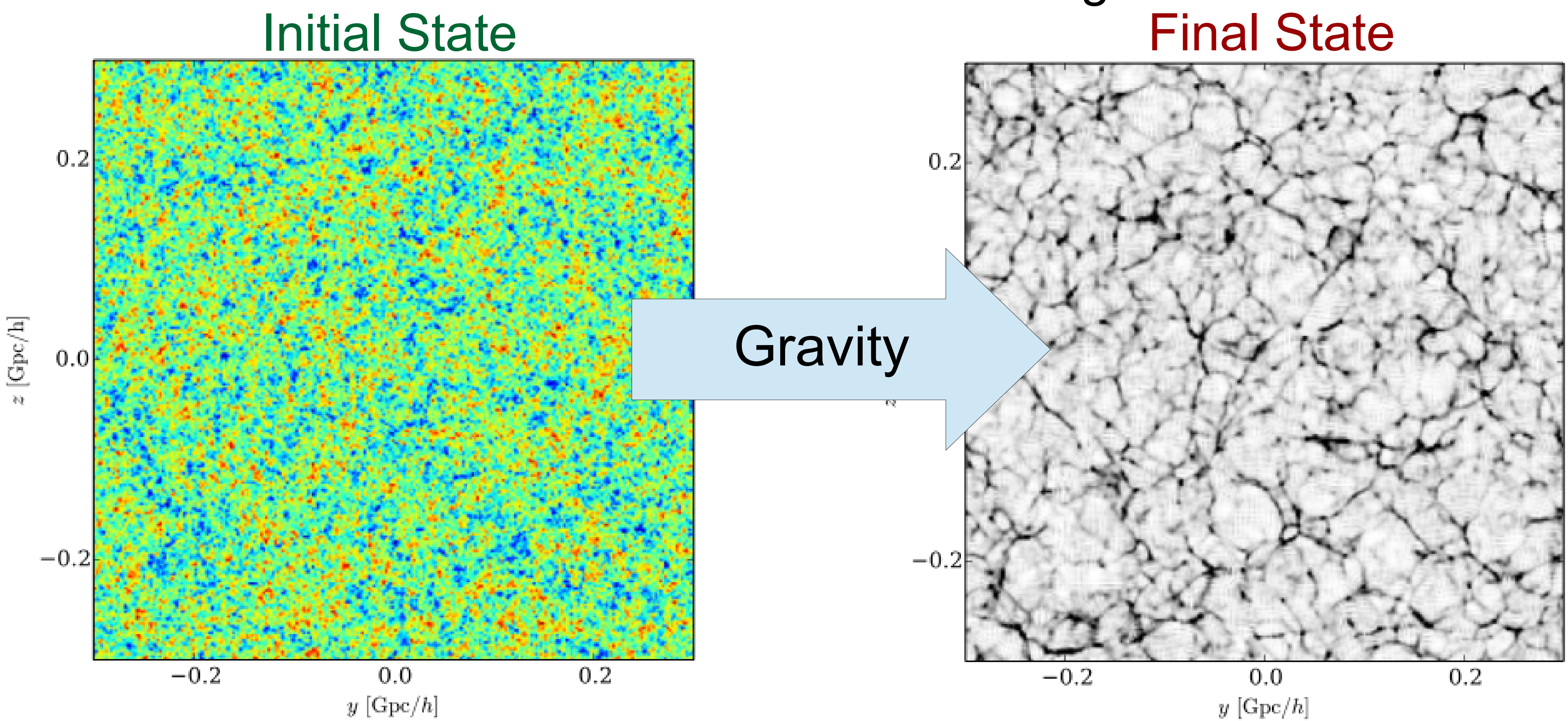
Finite resolution of telescope
Redshift distortions
Photometric uncertainties

No unique recovery! → We need statistics!

4D Bayesian Inference

Bayesian physical inference

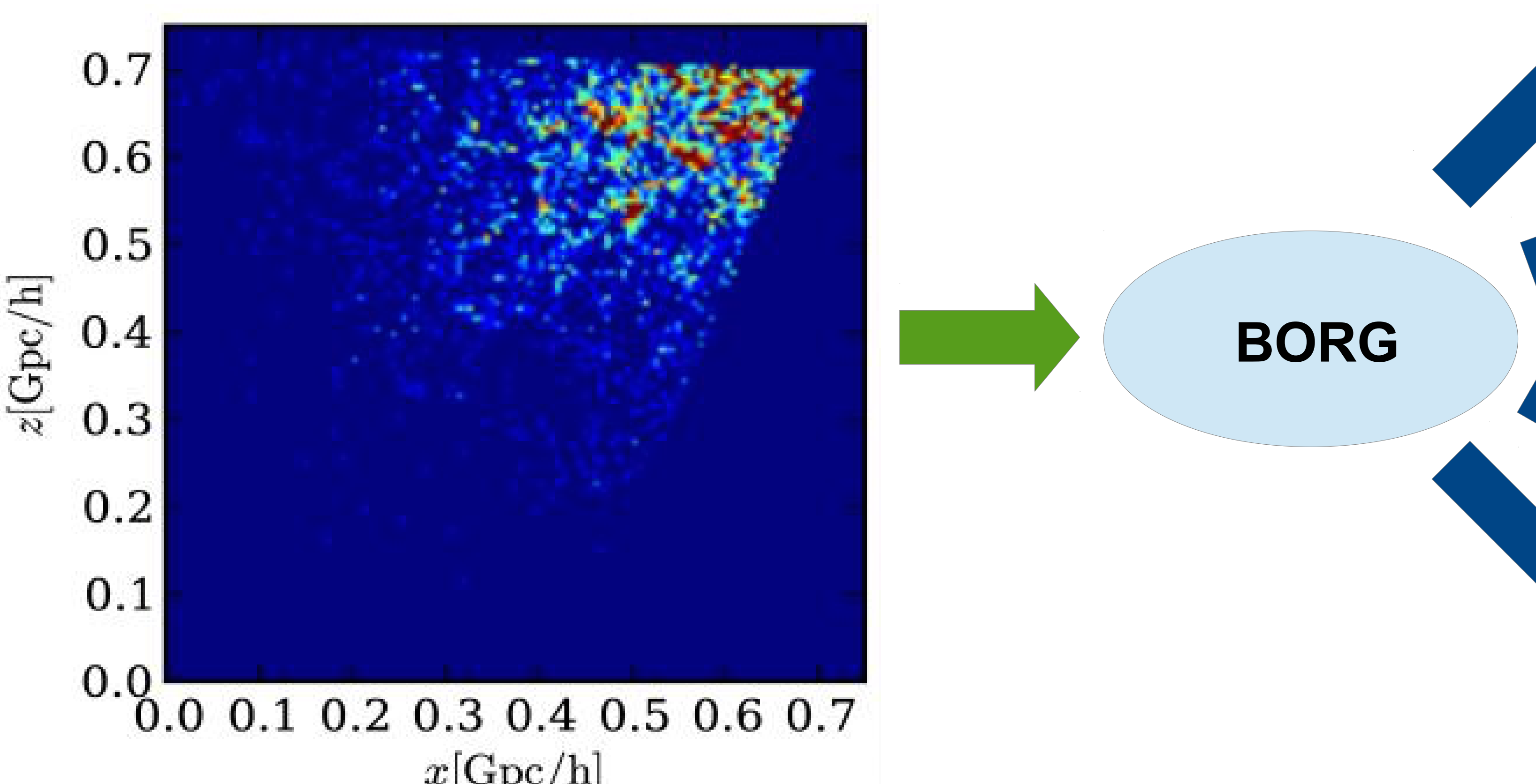
- Statistically complex final state
- Statistically simple initial state
- Solve inverse Problem via forward modeling

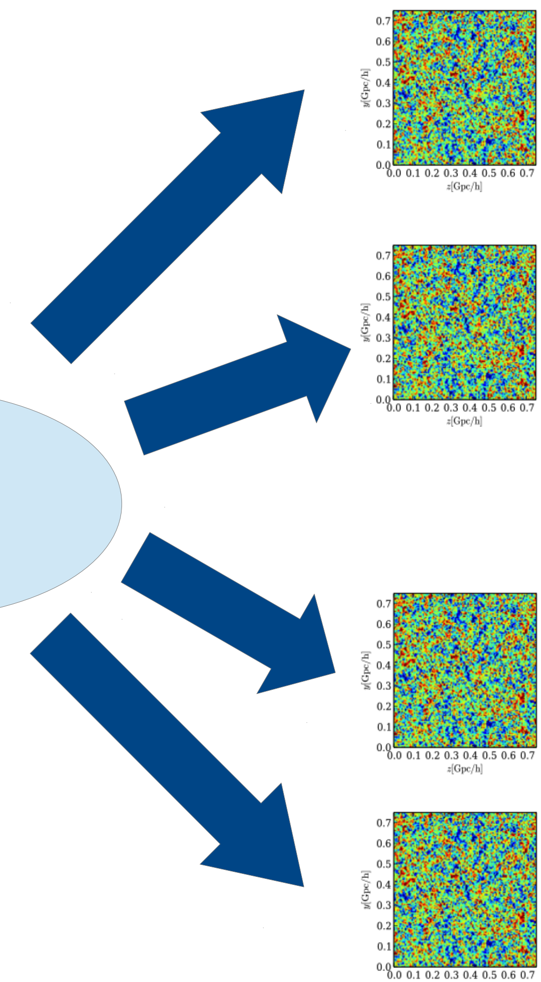


4D Bayesian Inference

BORG (**B**ayesian **O**rigin **R**econstruction from **G**alaxies)

- Incorporates physical model into Likelihood
- Approximate LSS formation model (2LPT)
- Uses HMC to solve initial conditions problem



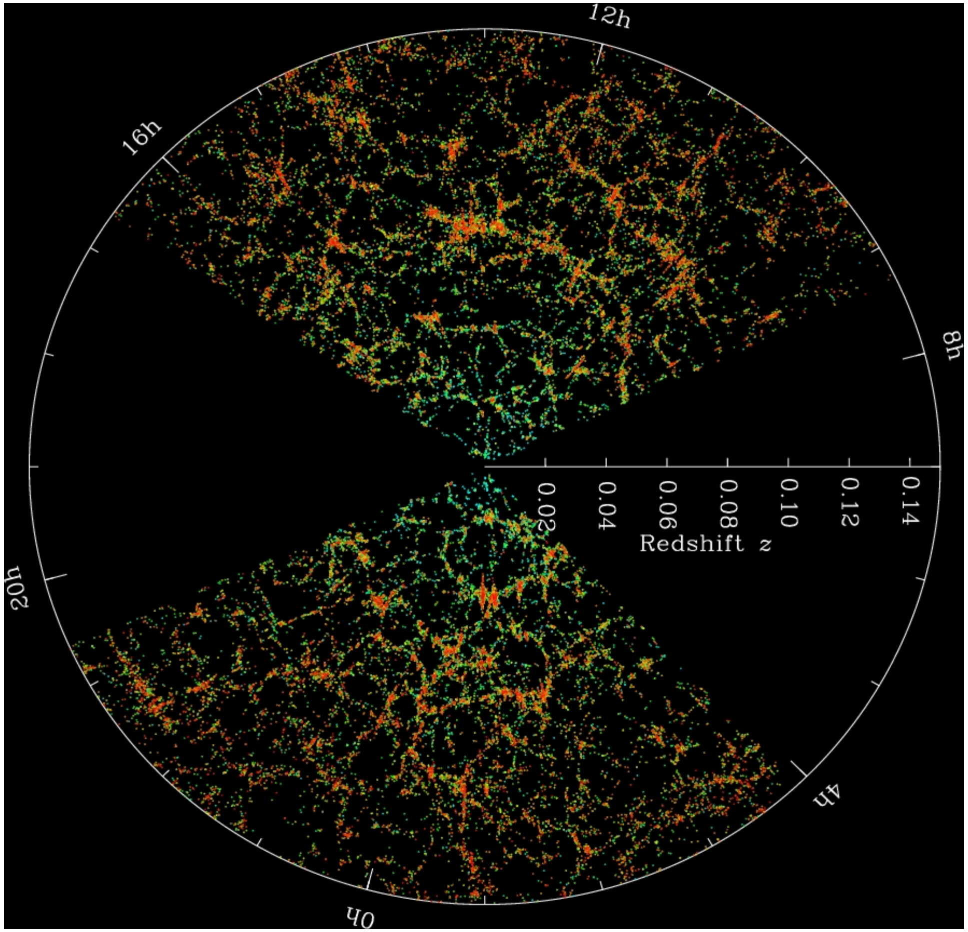


Jasche, Wandelt (2013)

Data application

Analyzing the SDSS DR7 main sample

- 750 Mpc/h box
- ~3 Mpc/h grid resolution
- Treatment of luminosity dependent bias
- Automatic noise calibration

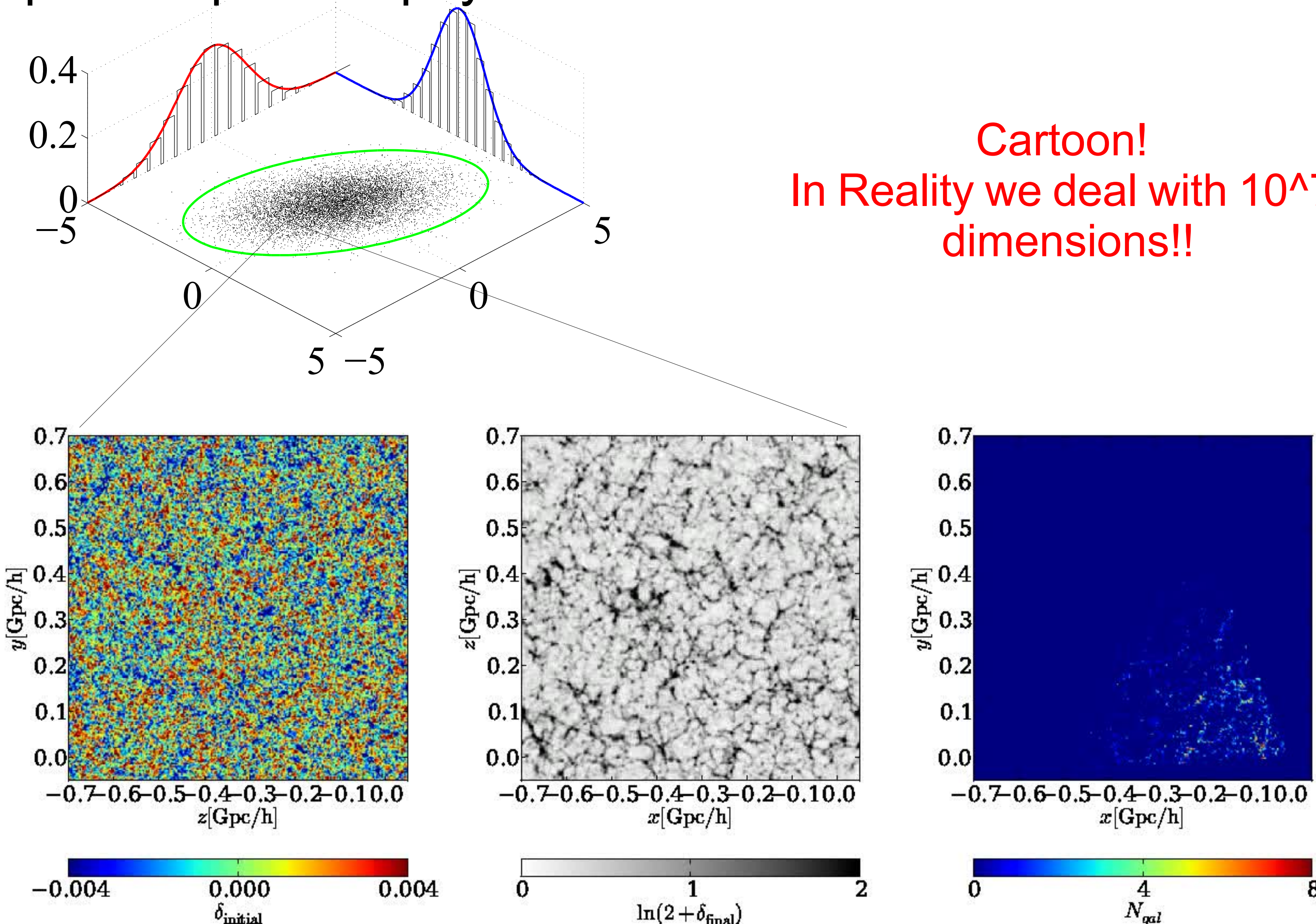


Credit: M. Blanton and the Sloan Digital Sky Survey

4D Bayesian inference

BORG performs MCMC sampling

- Explores space of physical 3D initial conditions



Cartoon!
In Reality we deal with 10^7 dimensions!!

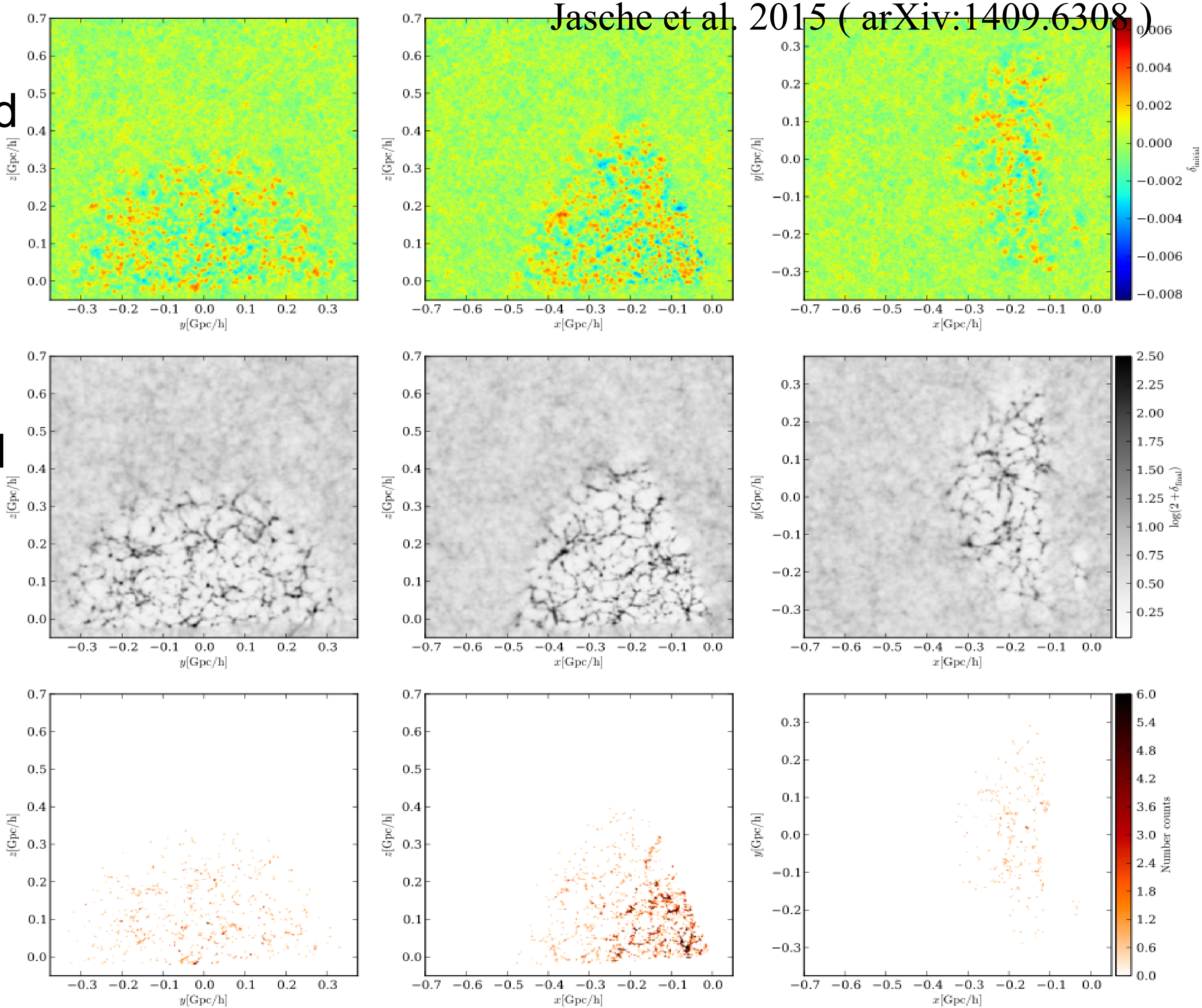
4D analysis of the SDSS

Jasche et al. 2015 (arXiv:1409.6308)

Initial density field
z ~ 1000

final density field
z=0

SDSS
number counts
z=0

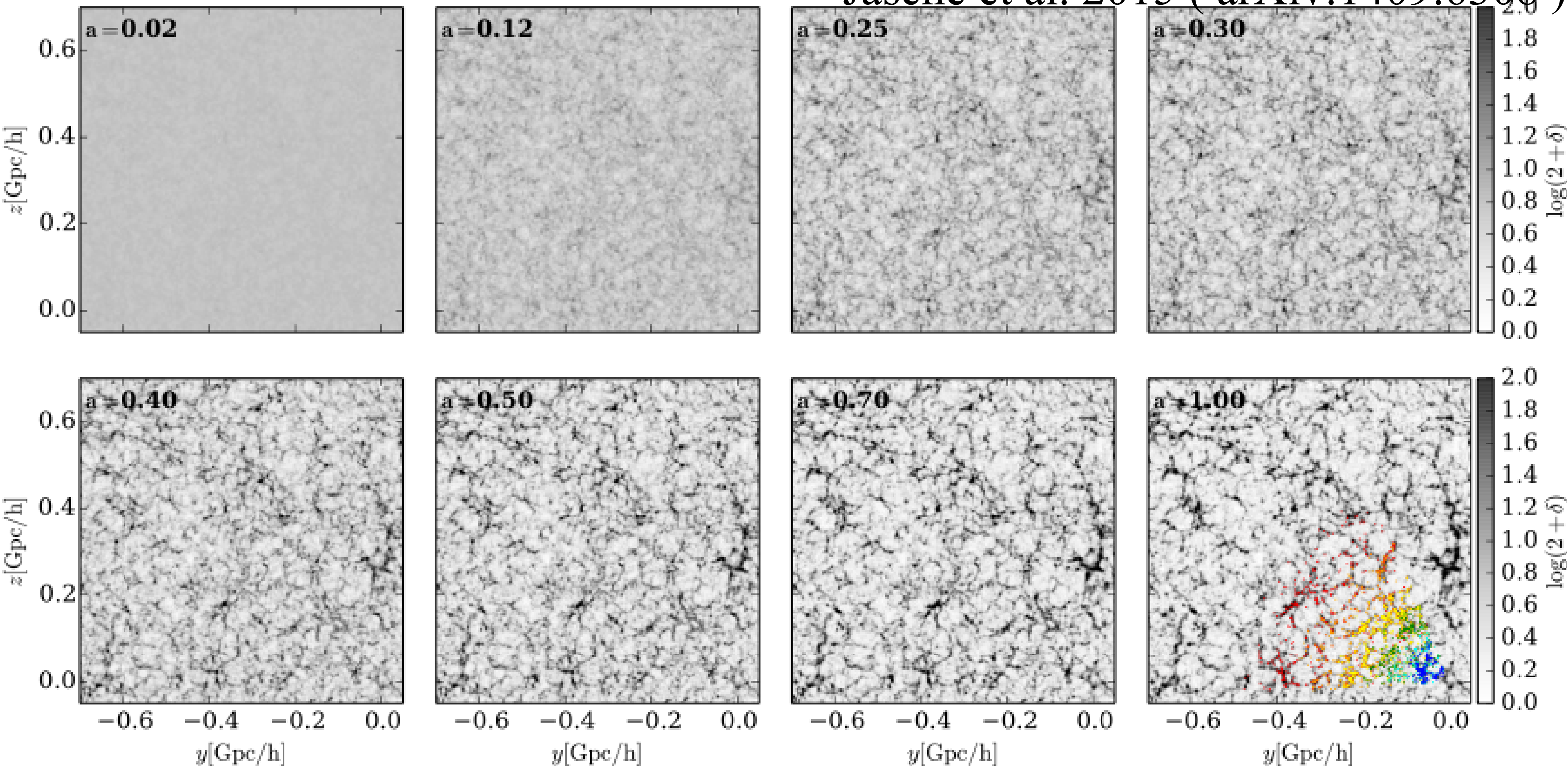


4D analysis of the SDSS

Dynamic Information

- Plausible LSS formation history

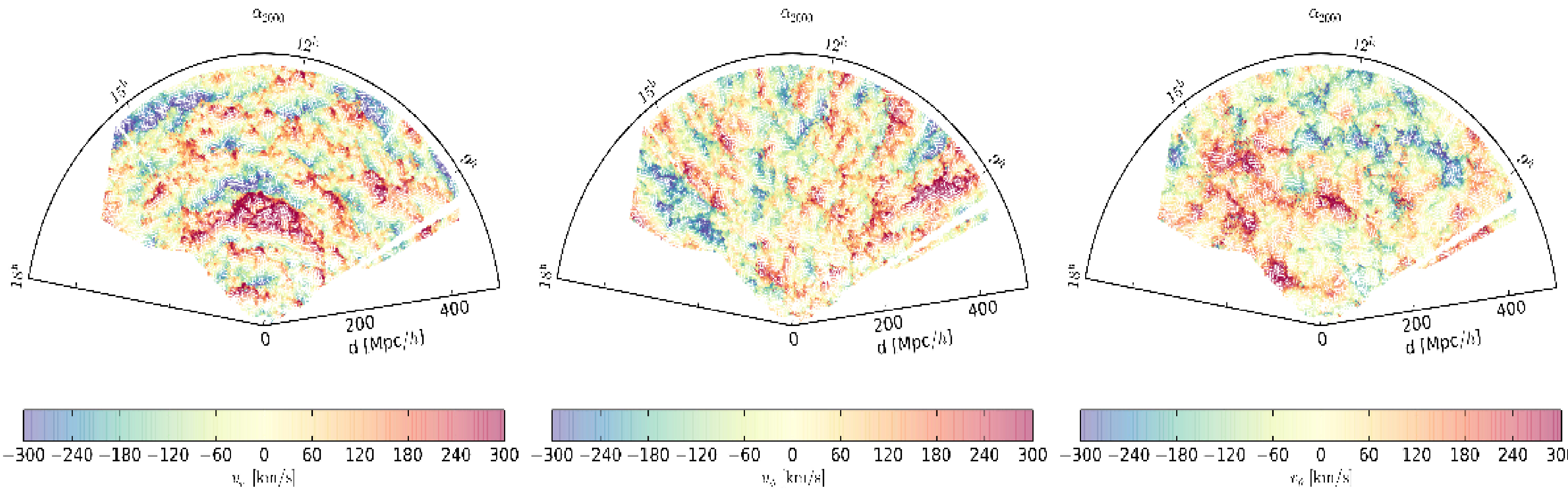
Jasche et al. 2015 (arXiv:1409.6308)



4D analysis of the SDSS

Dynamic Information

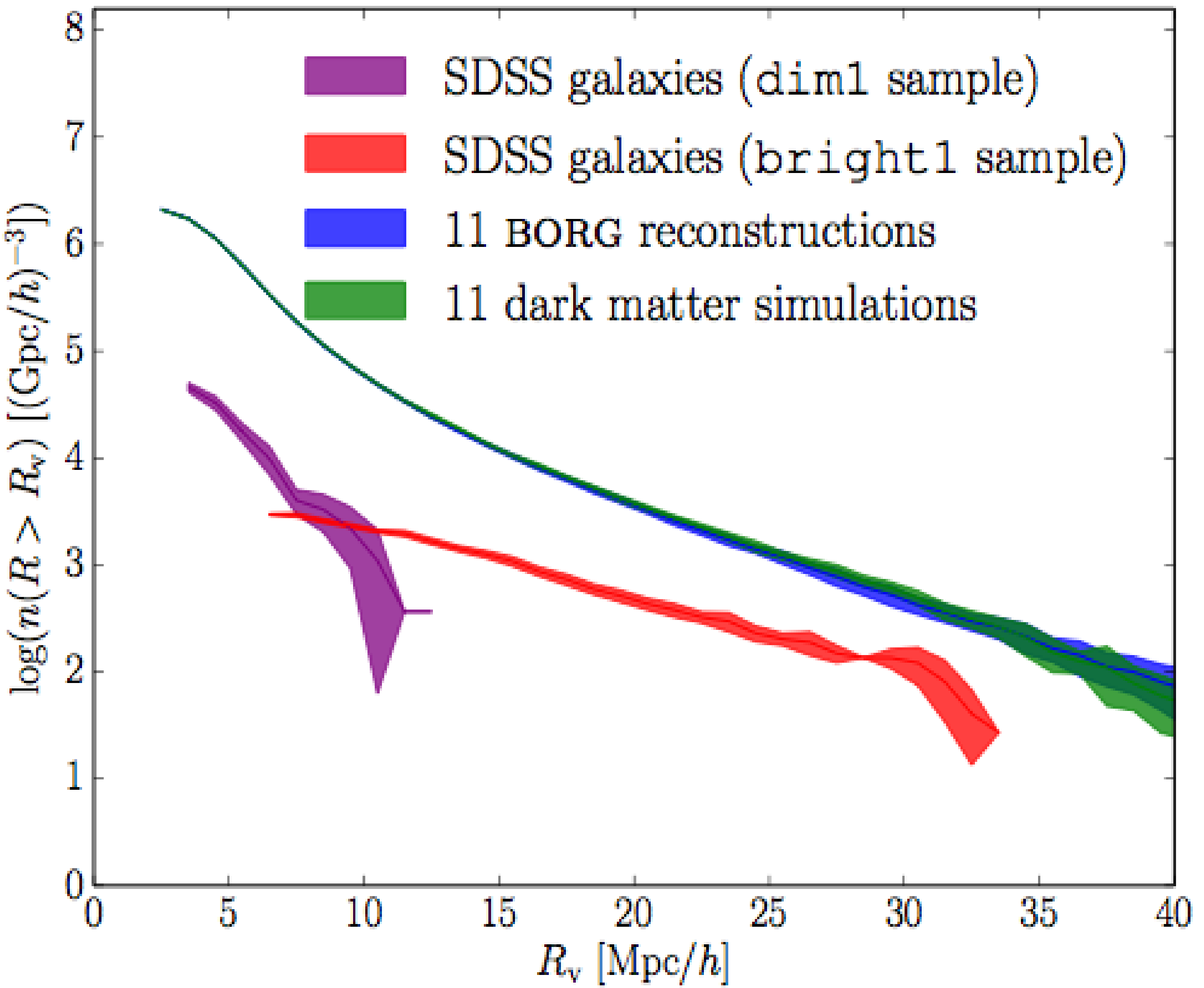
- Inference of 3D velocity fields



Jasche et al. 2015 (arXiv:1409.6308)

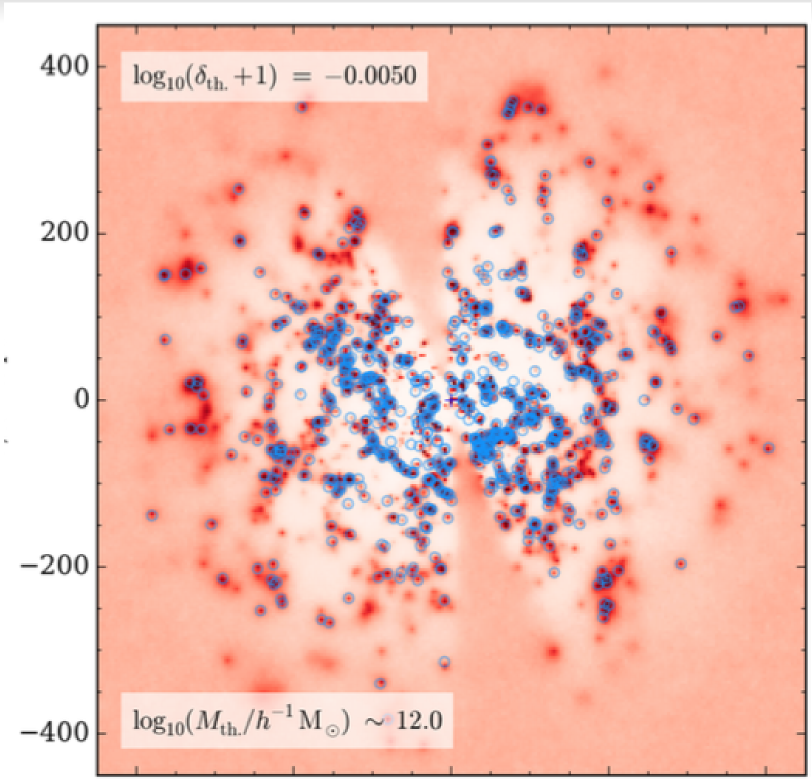
Dark matter voids in the SDSS

Cumulative void number functions



Leclercq et al. 2015 (arXiv:1410.0355)

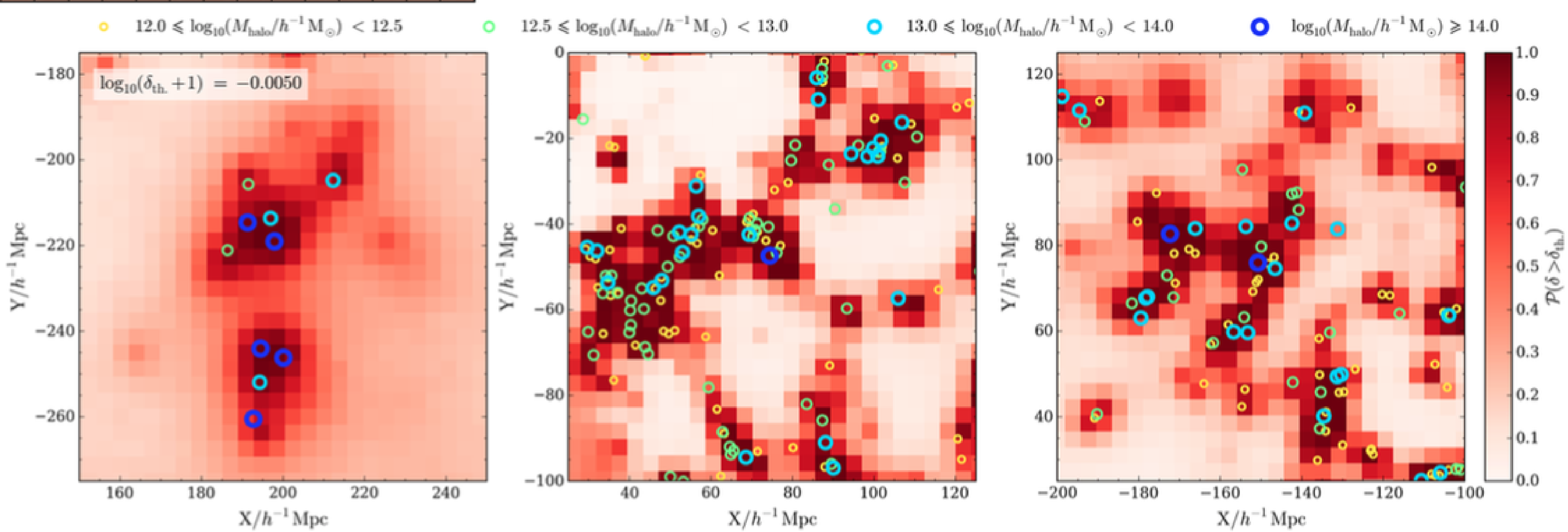
Halo detection in noisy data



Proof of concept!

Merson et al. 2015 (arXiv 1505.03528)

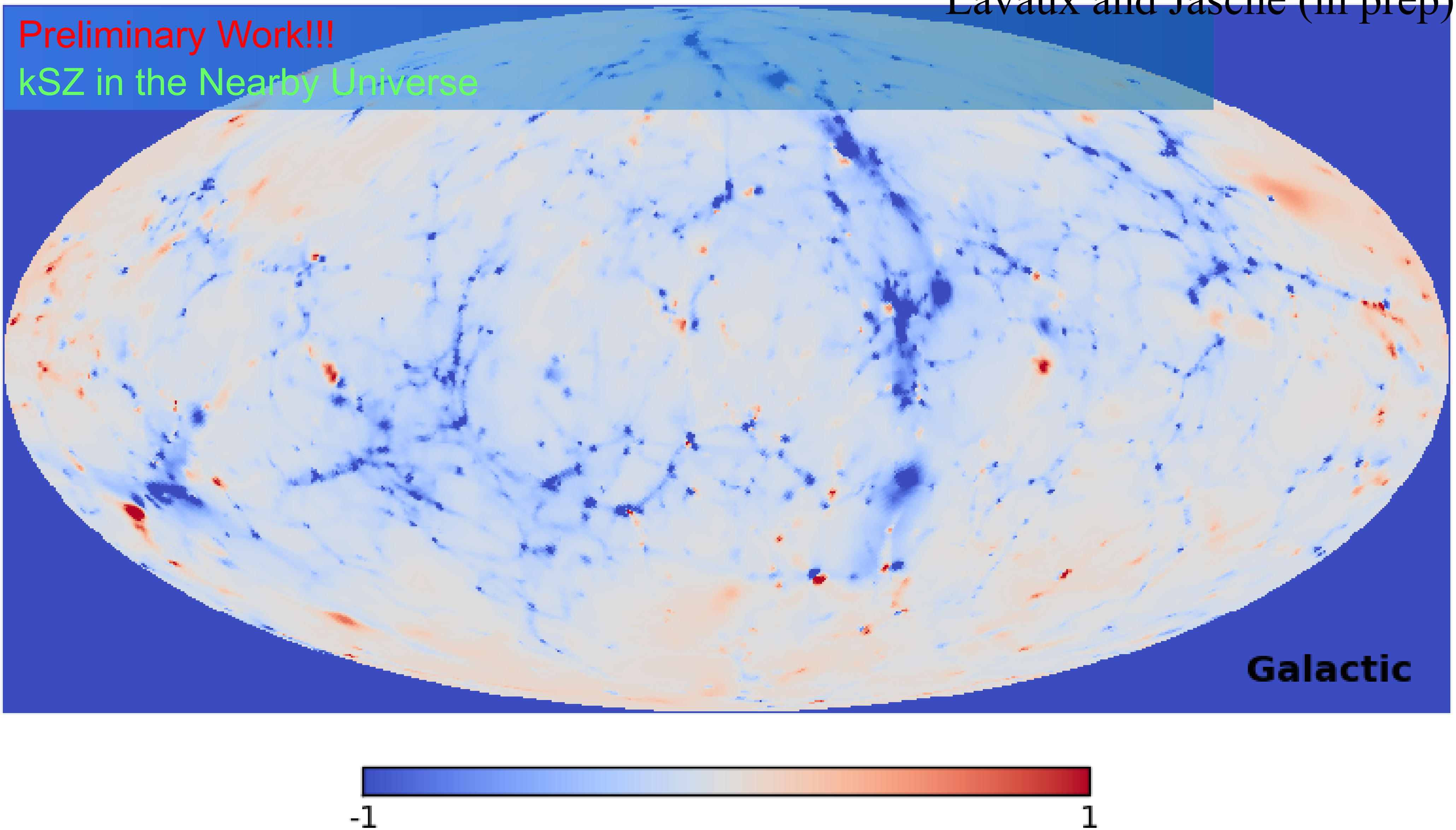
Will also work with photometric data-sets!



Template generation

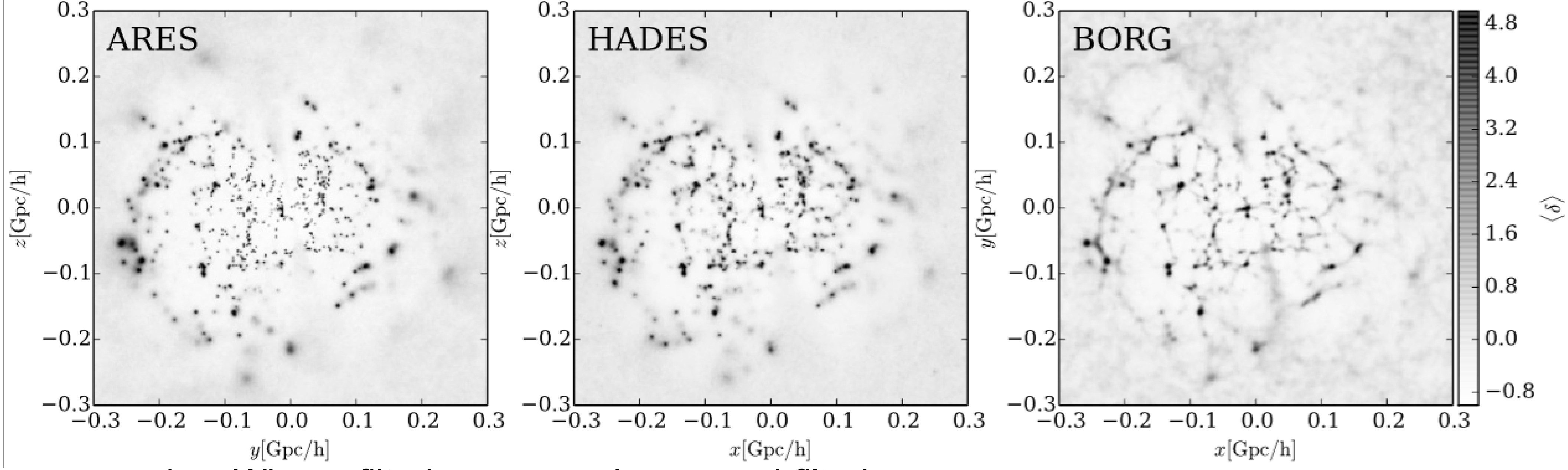
Predicting physical phenomena

Lavaux and Jasche (in prep)



Comparing inference schemes

Gaussian | Log-normal-Poisson | 2LPT-Poisson



a.k.a: Wiener-filtering

Zaroubi et al. 1994
Erdogdu et al. 2004
Kitaura & Ensslin 2008
Grannet et al. 2015

log-normal-filtering

Kitaura 2010
Jasche&Kitaura 2010

Jasche&Wandelt 2012

Which scheme performs best?

Ask the data!

$$A_{ij} = \ln\left(\mathcal{P}(d|\delta_i)\right) - \ln\left(\mathcal{P}(d|\delta_j)\right)$$

	ARES	HADES	BORG
ARES	0	-219580.31	-383482.25
HADES	219580.31	0	-163901.94
BORG	383482.25	163901.94	0.

Jasche & Lavaux (in prep)

Summary & Conclusion

4D Bayesian inference

- From 3D to 4D (Spatio-Temporal inference)
- Non-linear, non-Gaussian
- Handling of noise, bias, selection effects, survey geometries etc.

Scientific results

- Characterization of initial conditions
- Higher order statistics
- Dynamic information, Structure formation
- Predictions of physical phenomena (kSZ, ISW, weak lensing)
- Greatly improved reconstructions of LSS

The end...

Thank You!

4D Bayesian inference

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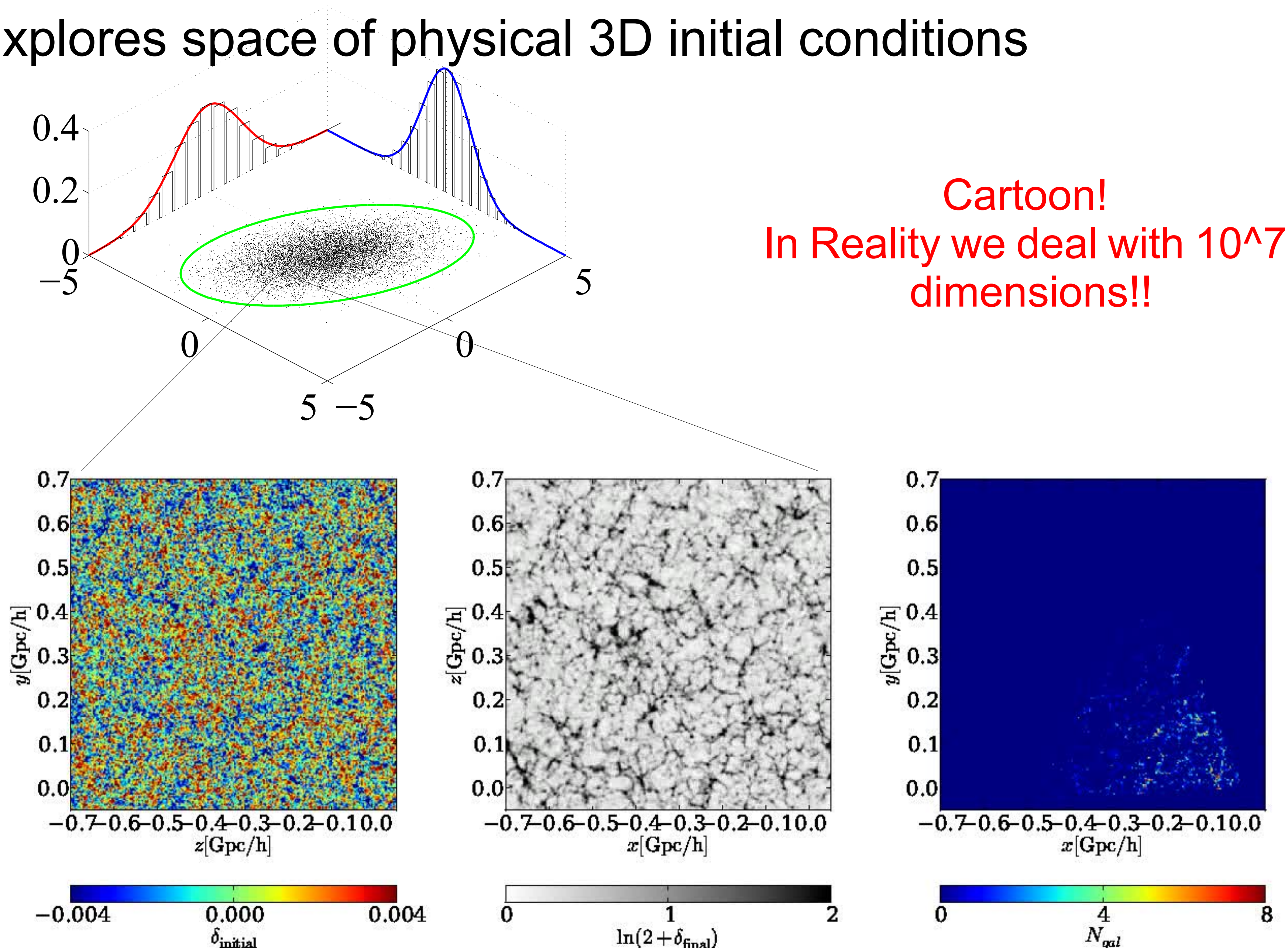
- Explores space of physical 3D initial conditions



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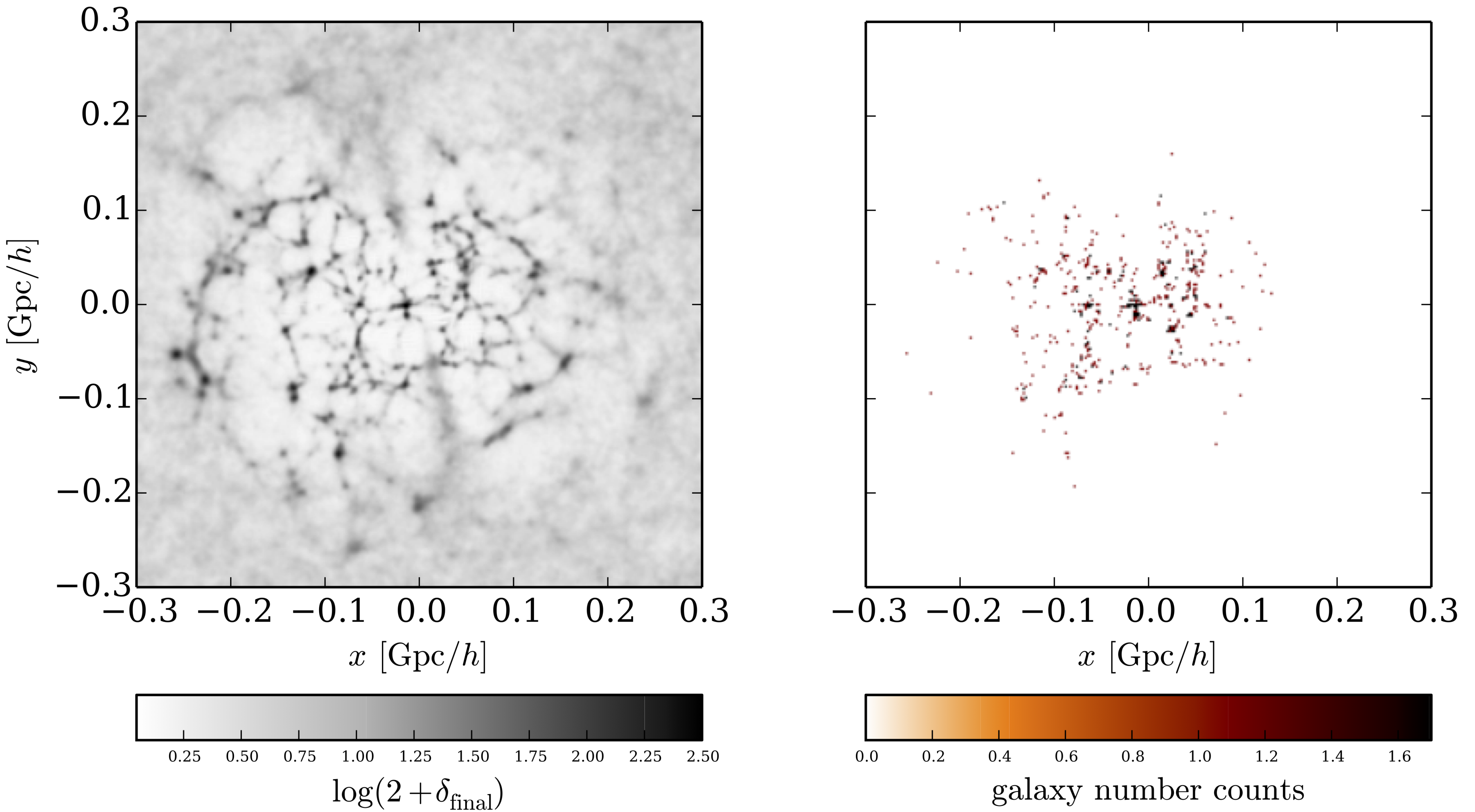
4D Bayesian inference



Lavaux and Jasche (in prep.)

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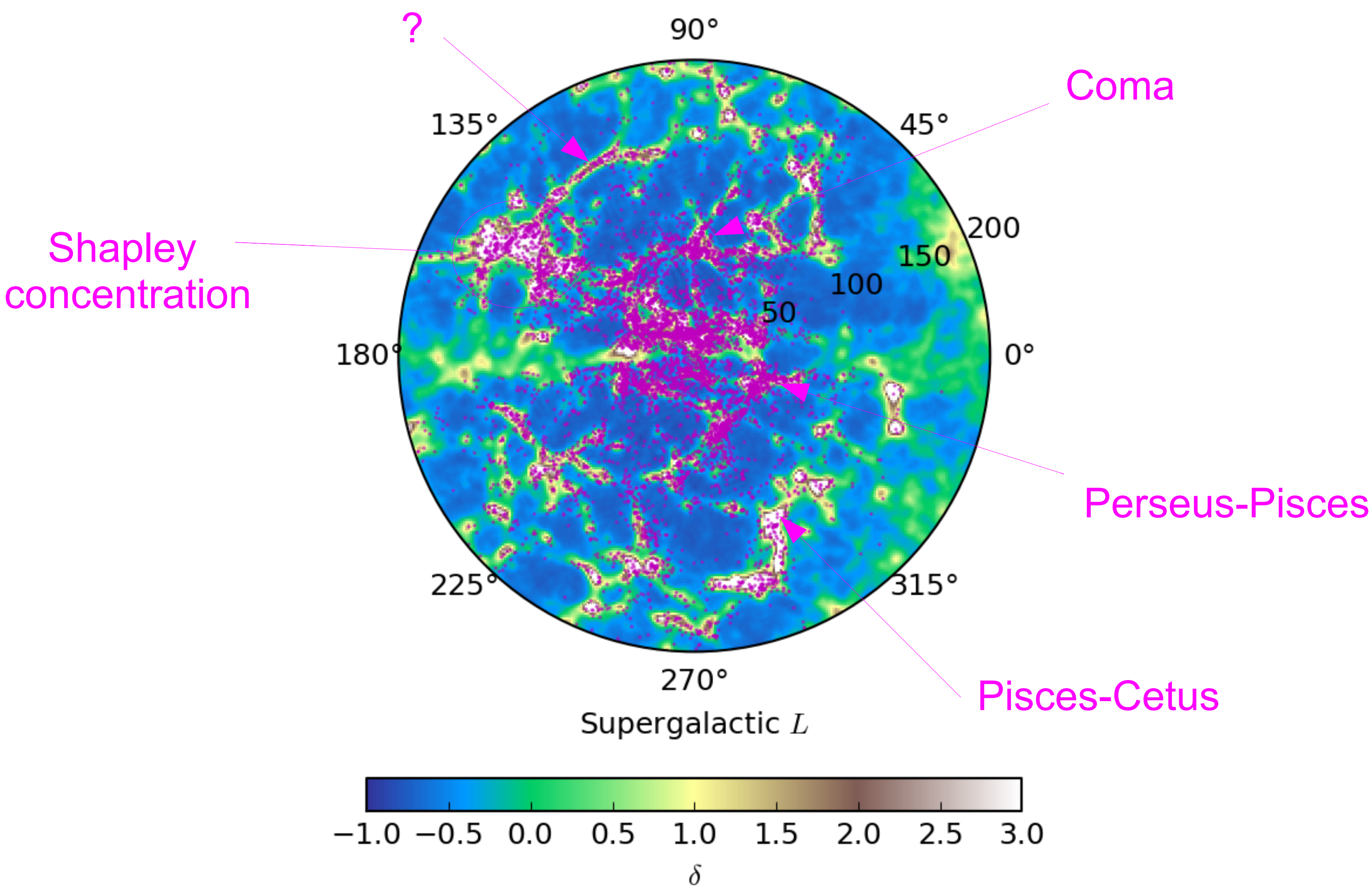

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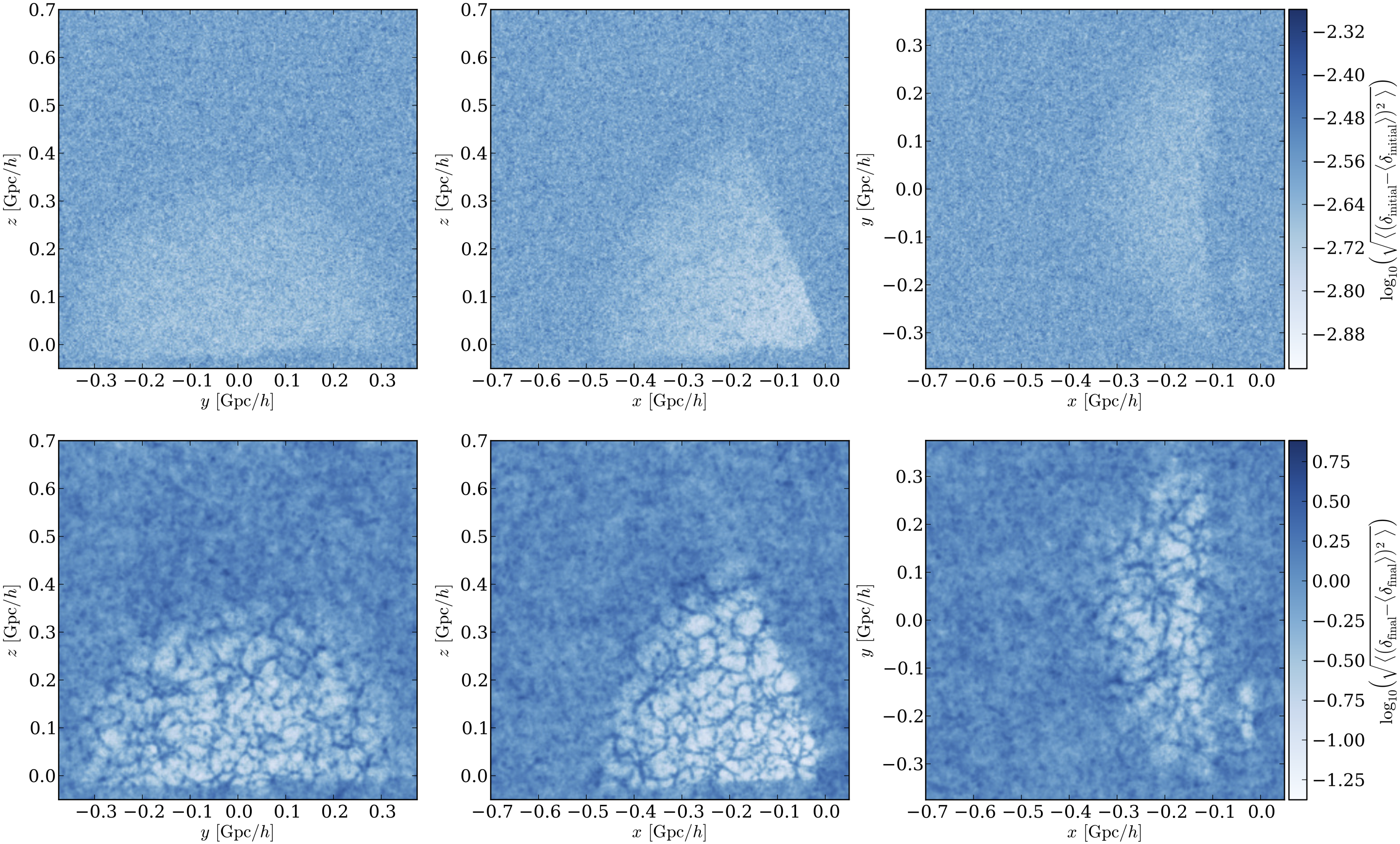
4D Bayesian inference

Uncertainty quantification

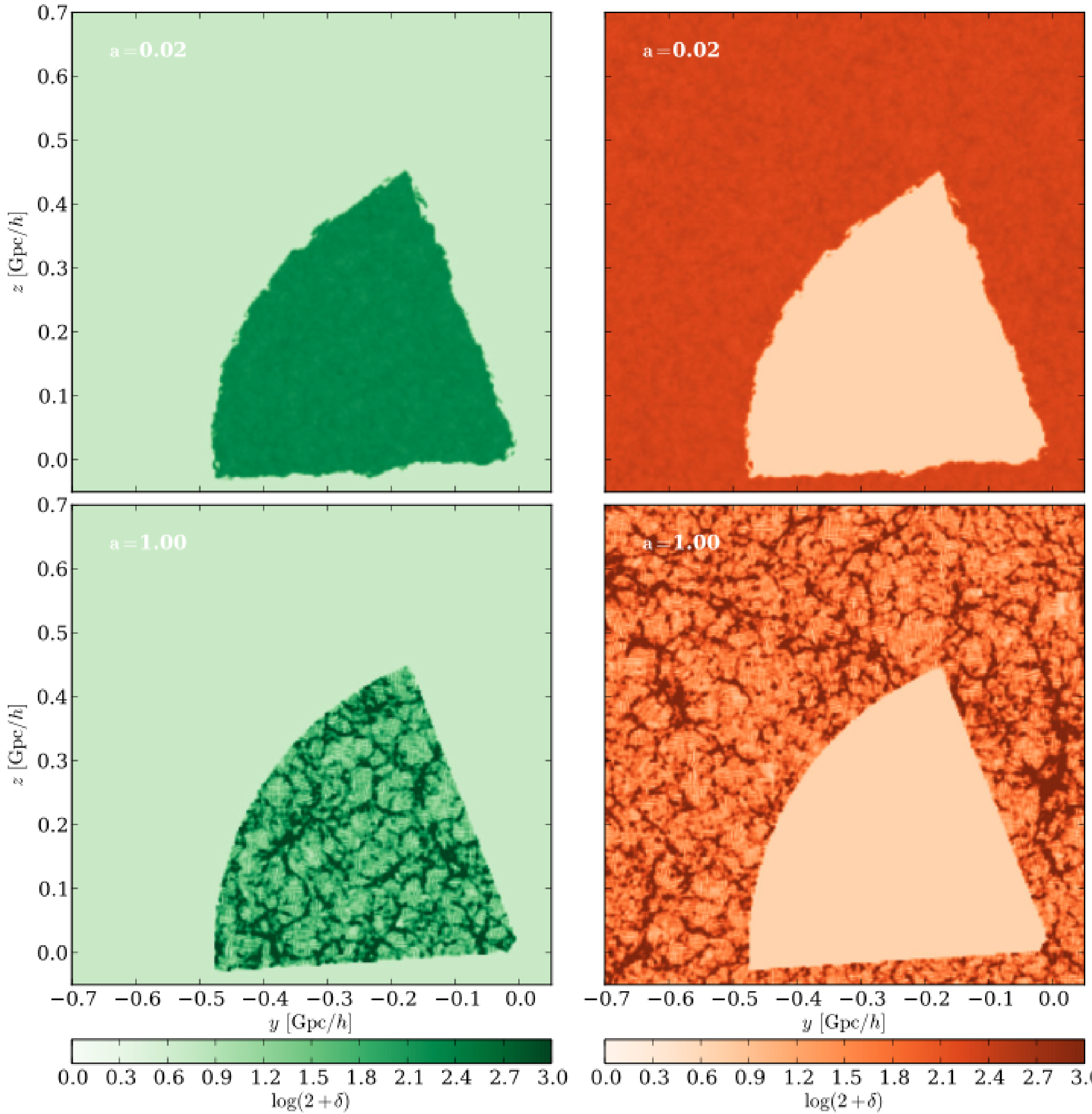
- Voxel-wise standard deviations for initial and final states



Jasche et al. 2015 (arXiv:1409.6308)

4D Bayesian inference

Non-local propagation of information



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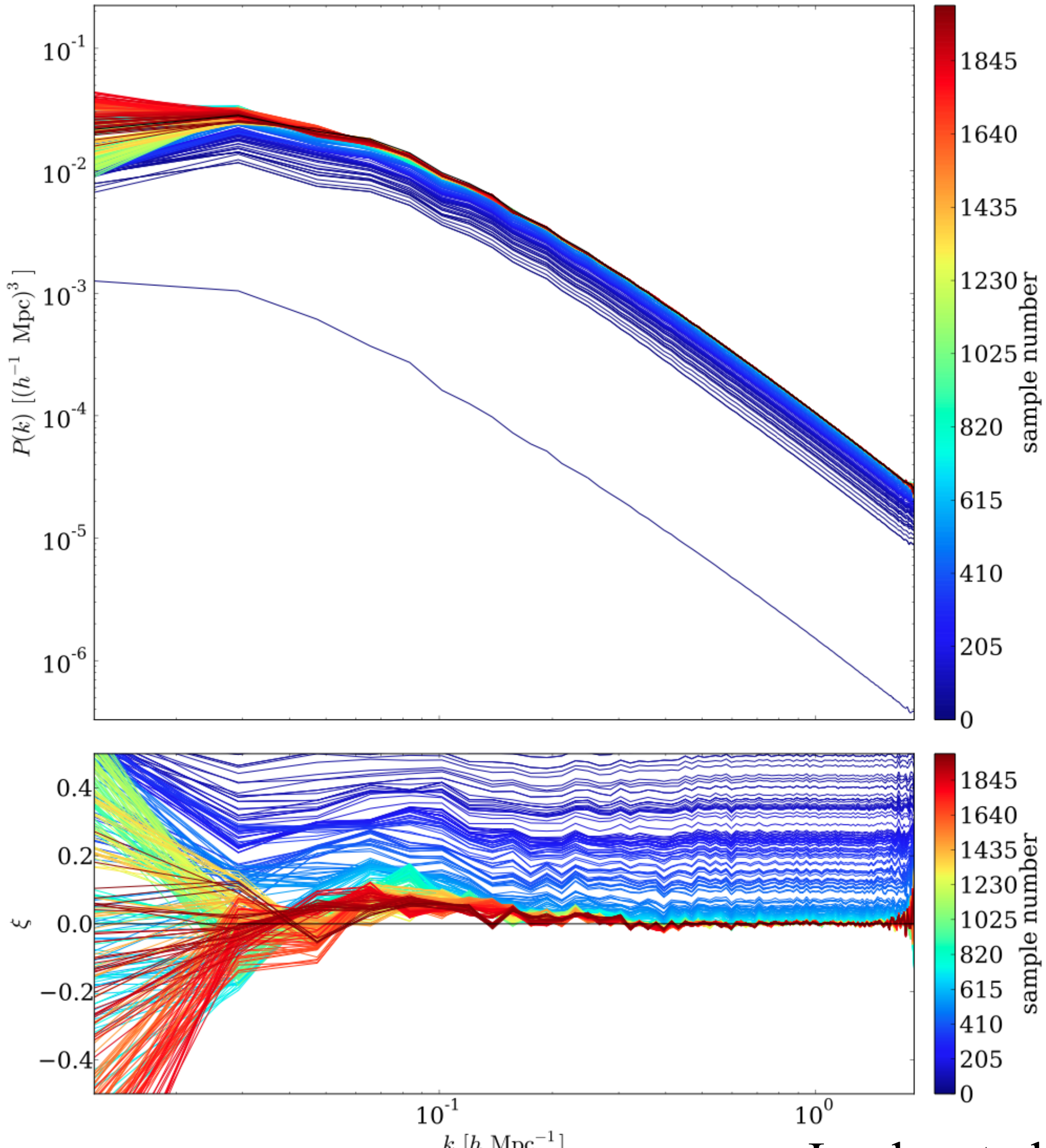
4D Bayesian inference

Burn-in power-spectra

- Unbiased physical reconstruction of initial conditions



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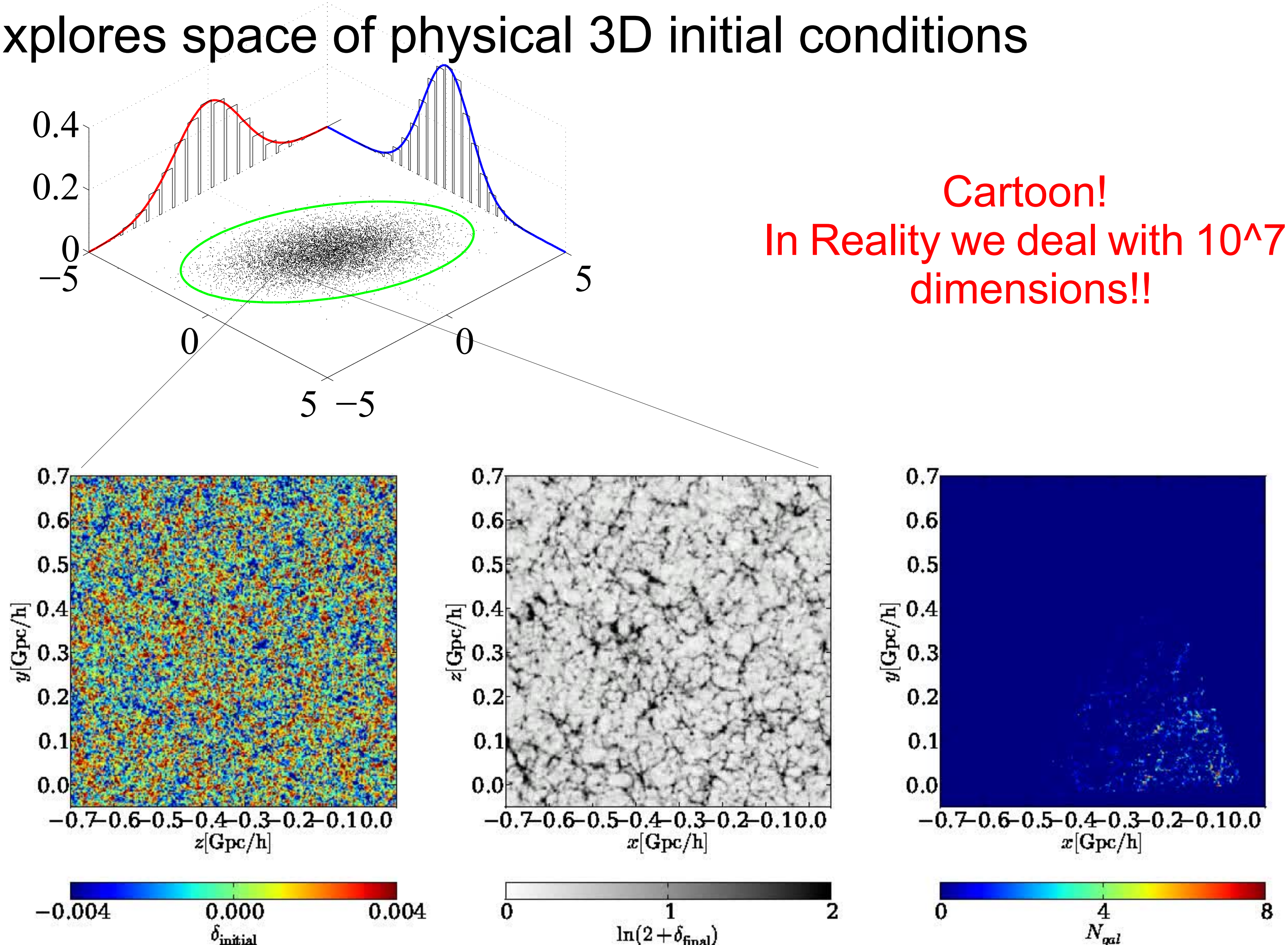

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