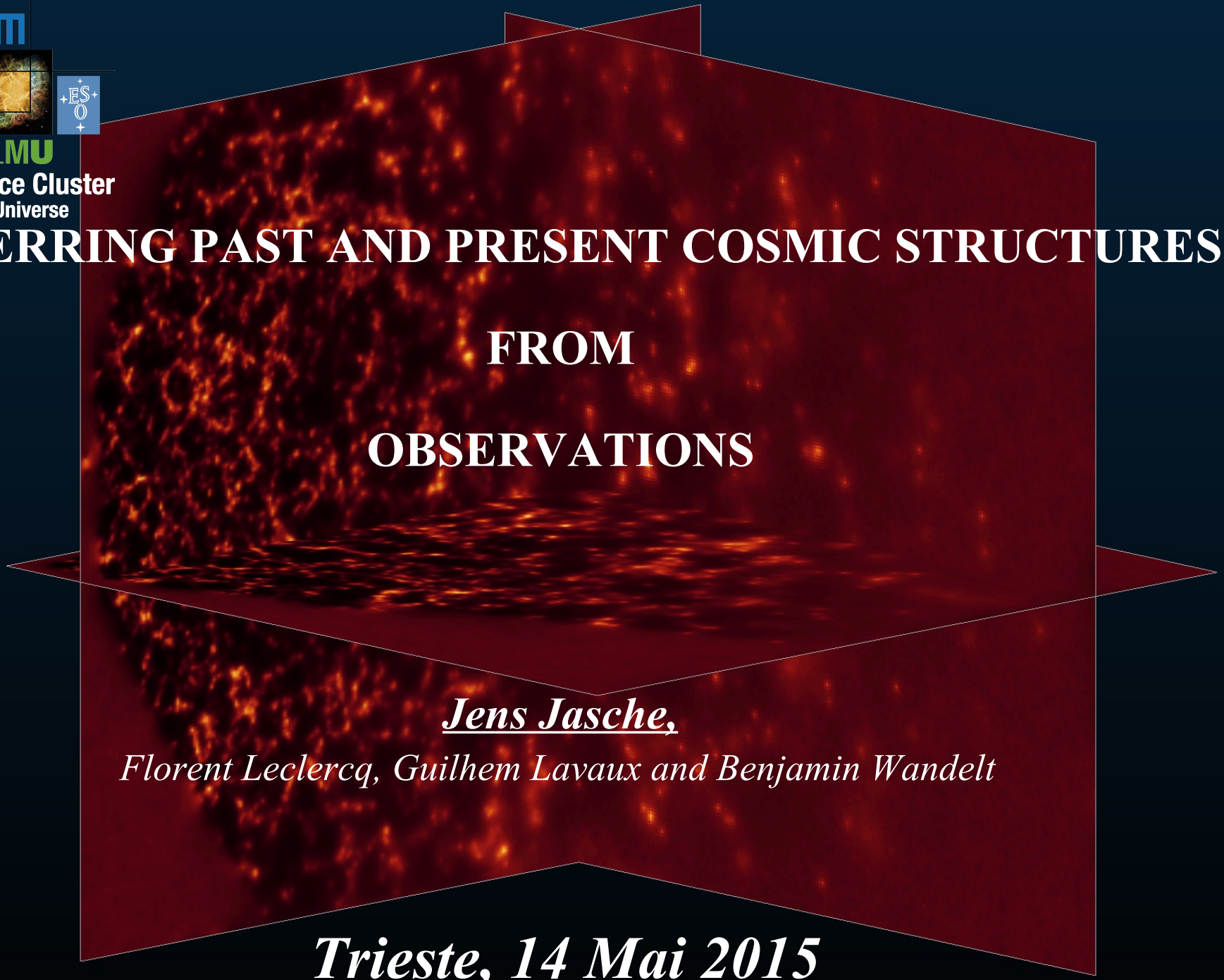


Excellence Cluster Universe

INFERRING PAST AND PRESENT COSMIC STRUCTURES

FROM

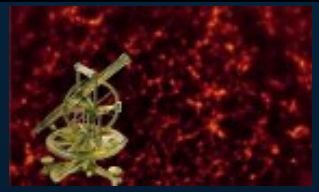
OBSERVATIONS

Jens Jasche,

Florent Leclercq, Guilhem Lavaux and Benjamin Wandelt

Trieste, 14 Mai 2015

What do we want to do?



- homogeneous vs. inhomogeneous Universe

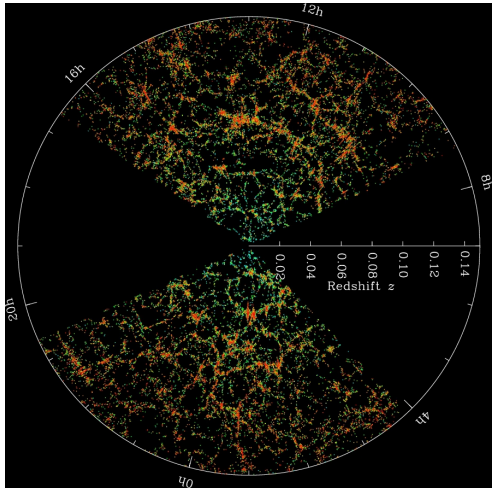
homogeneous Universe

~ 6 -10 parameter

inhomogeneous Universe

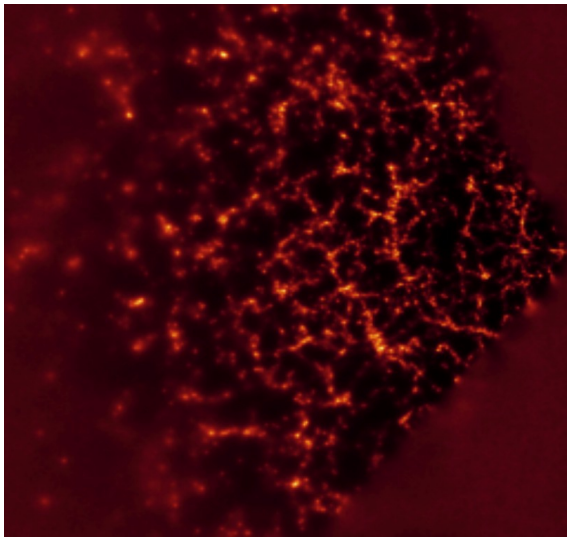
~ 10^7 parameter

Galaxy survey



Credit: M. Blanton and the Sloan Digital Sky Survey

3D density map



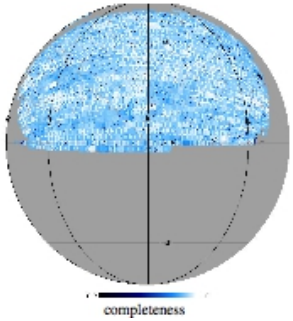
Jasche et al. (2010)

Why Bayesian Statistics?

- Inference of signals = ill-posed problem!

Noise

Incompleteness



Blurring

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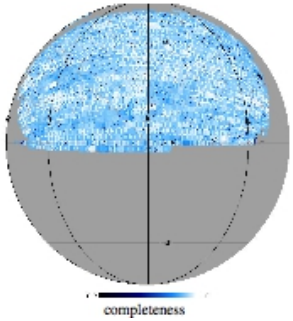

Blurring

No unique recovery! → Bayesian inference

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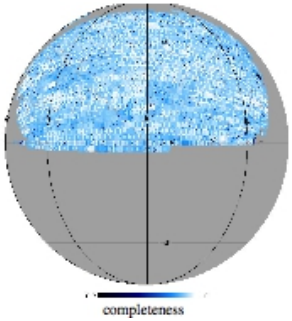

Blurring

No unique recovery! → Bayesian inference

$$\mathcal{P}(s|d) = \mathcal{P}(s)\,\frac{\mathcal{P}(d|s)}{\mathcal{P}(d)}$$

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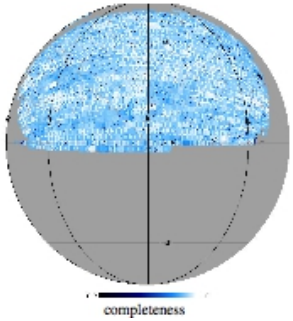
Noise

Incompleteness



Blurring

No unique recovery! → Bayesian inference

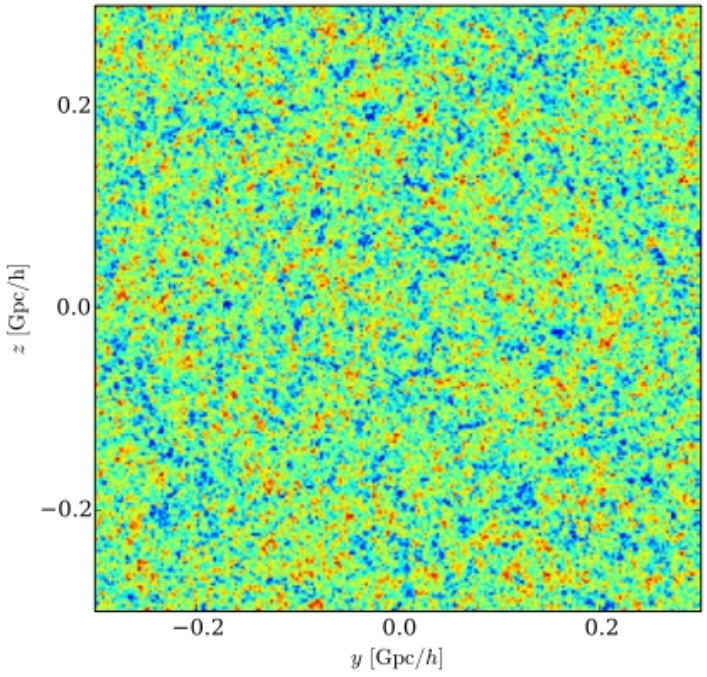
$$\mathcal{P}(s|d) = \mathcal{P}(s)\,\frac{\mathcal{P}(d|s)}{\mathcal{P}(d)}$$

Complex nonlinear statistics and extremely high dimensional!

Why 4D inference?

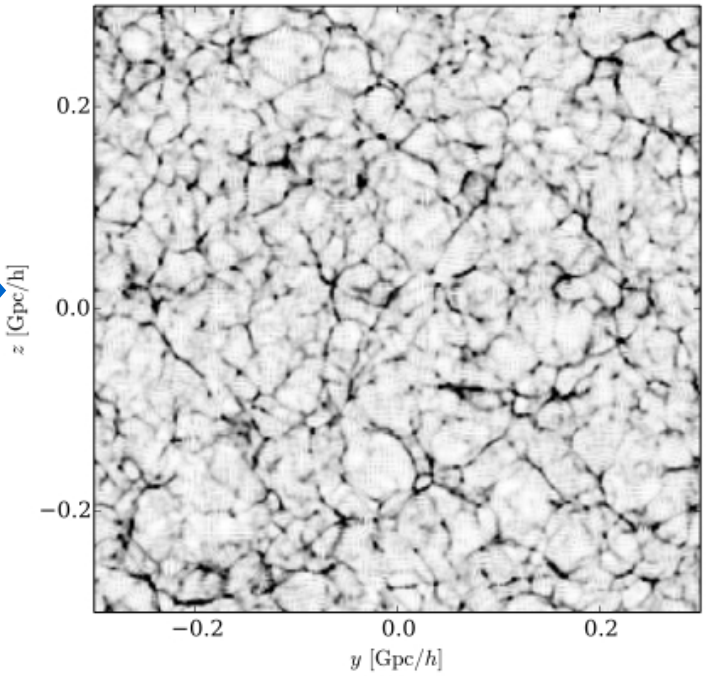
- Physical motivation
  - Complex final state
  - Simple initial state

Initial state



Gravity

Final state



Chrono-cosmography

- The naive approach:
  - We need a **very very very** large computer!

Chrono-cosmography

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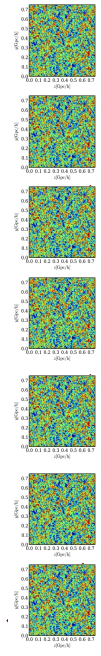

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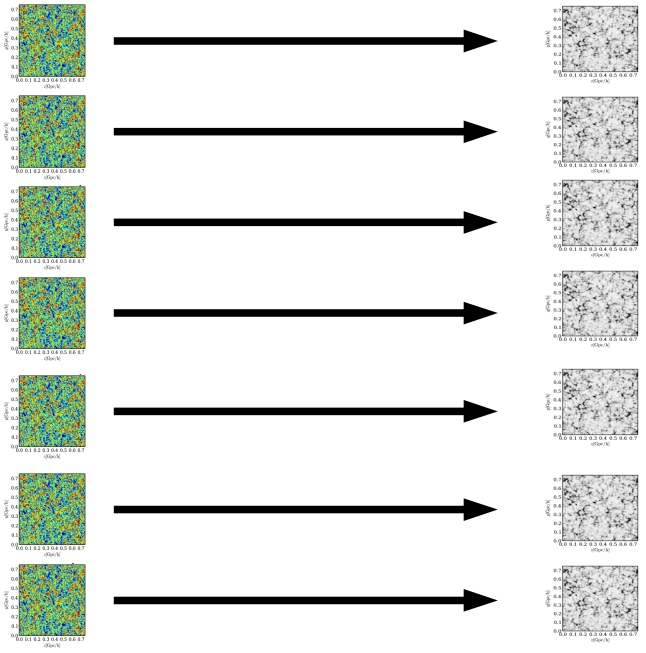

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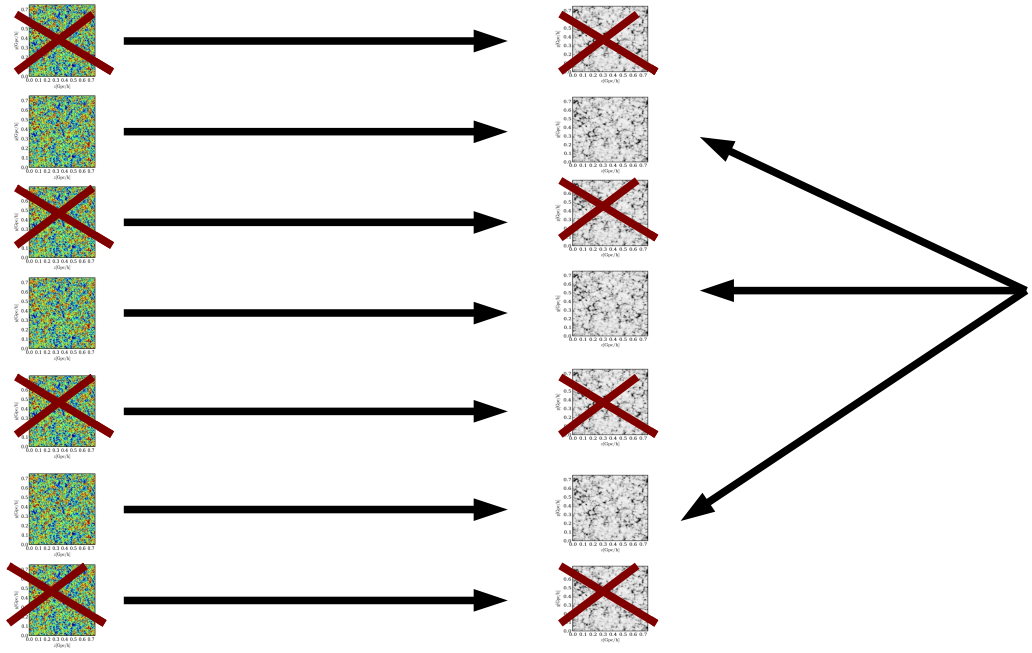
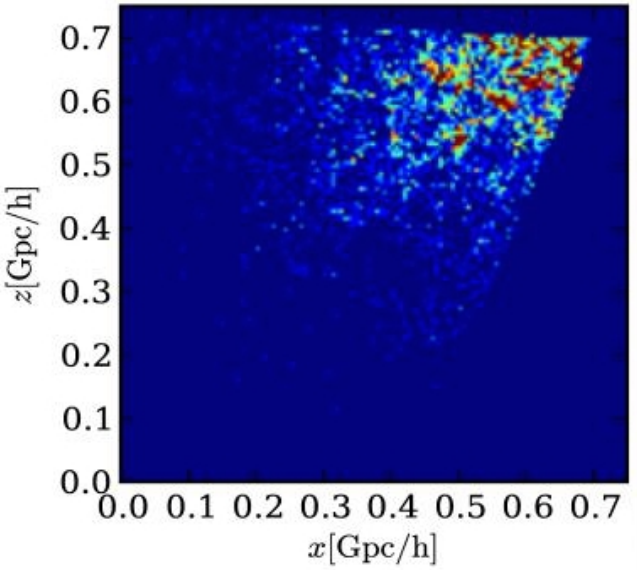


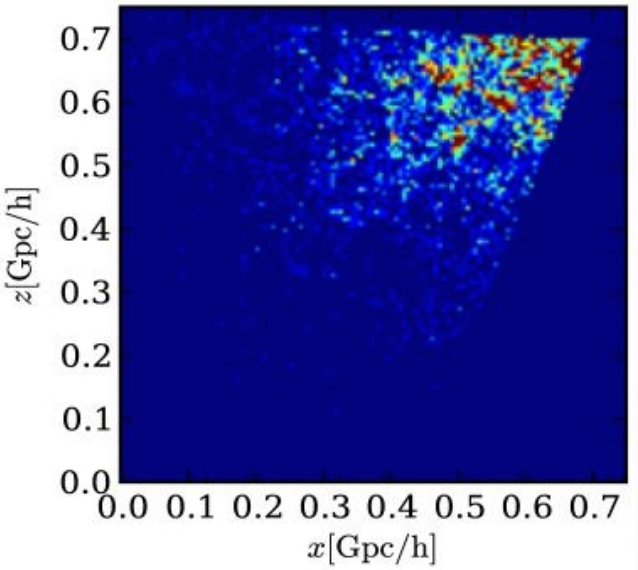


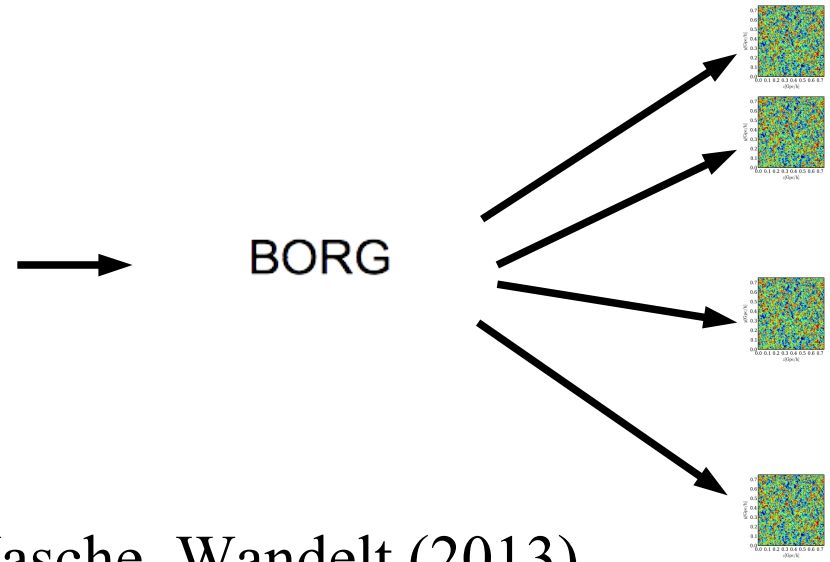
Not practical! Even with approximations!!!!

4D Bayesian inference

- BORG (Bayesian Origin Reconstruction from Galaxies)
  - Incorporate physical model into Likelihood
    - Approximate LSS formation model

    (Second order Lagrangian perturbation theory)
  - Initial conditions problem

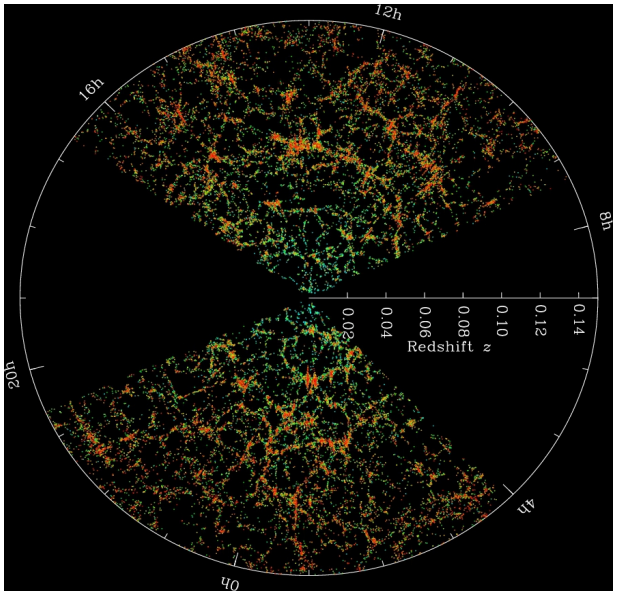




Jasche, Wandelt (2013)

4D analysis of the SDSS

- Analyzing the SDSS DR7 main sample
  - Explore a 2LPT-Normal-Poissonian distribution
  - 750 Mpc/h box
  - ~3 Mpc/h grid resolution
  - treatment of luminosity dependent bias (6 luminosity bins)
  - Automatic calibration of noise levels via sampling



Credit: M. Blanton and the Sloan Digital Sky Survey

4D analysis of the SDSS

4D analysis of the SDSS

- 3D ensemble mean fields from 10000 data constrained realizations

Initial density field

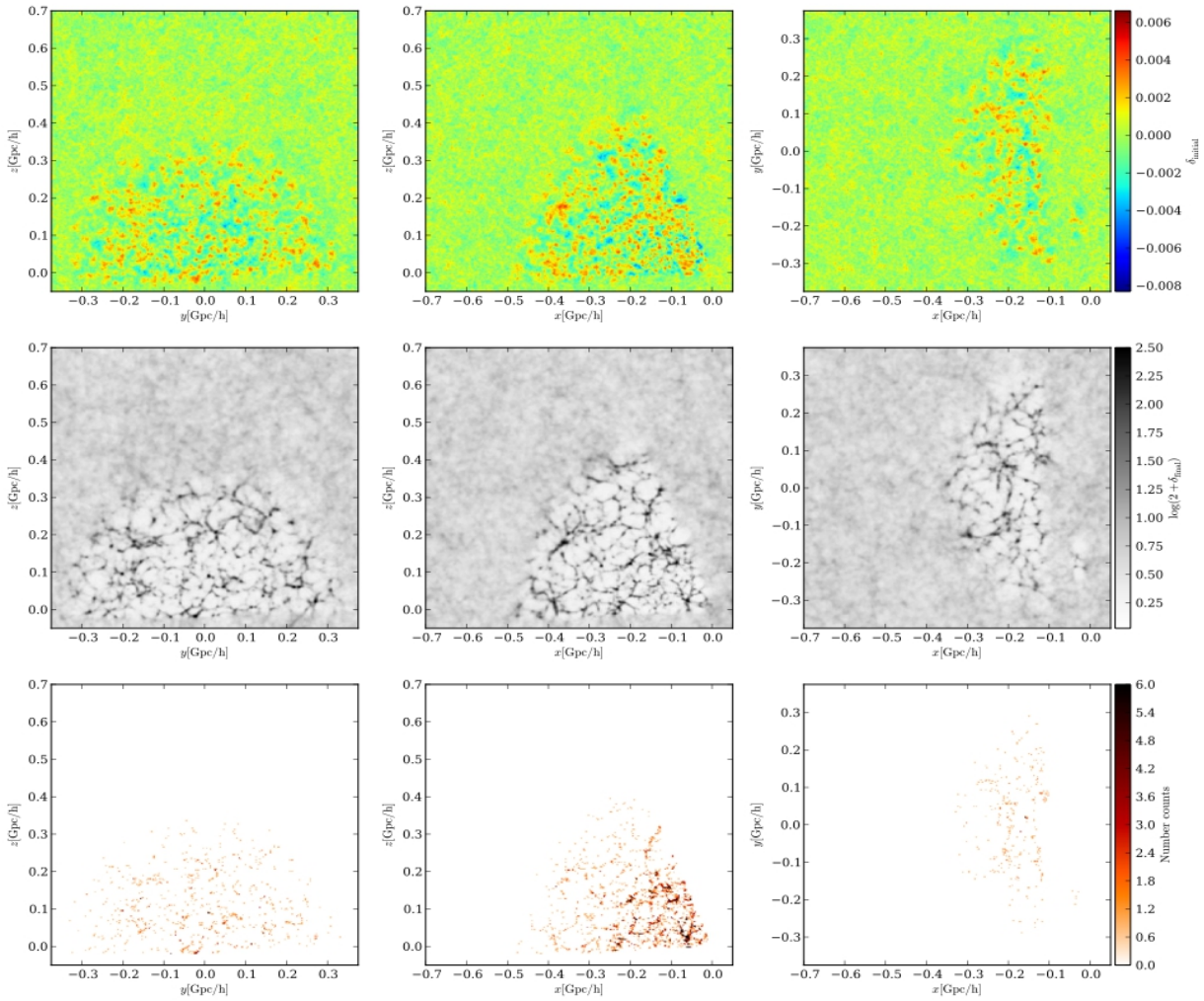
z = 1000

Final density field

z = 0

SDSS data

z = 0



4D analysis of the SDSS

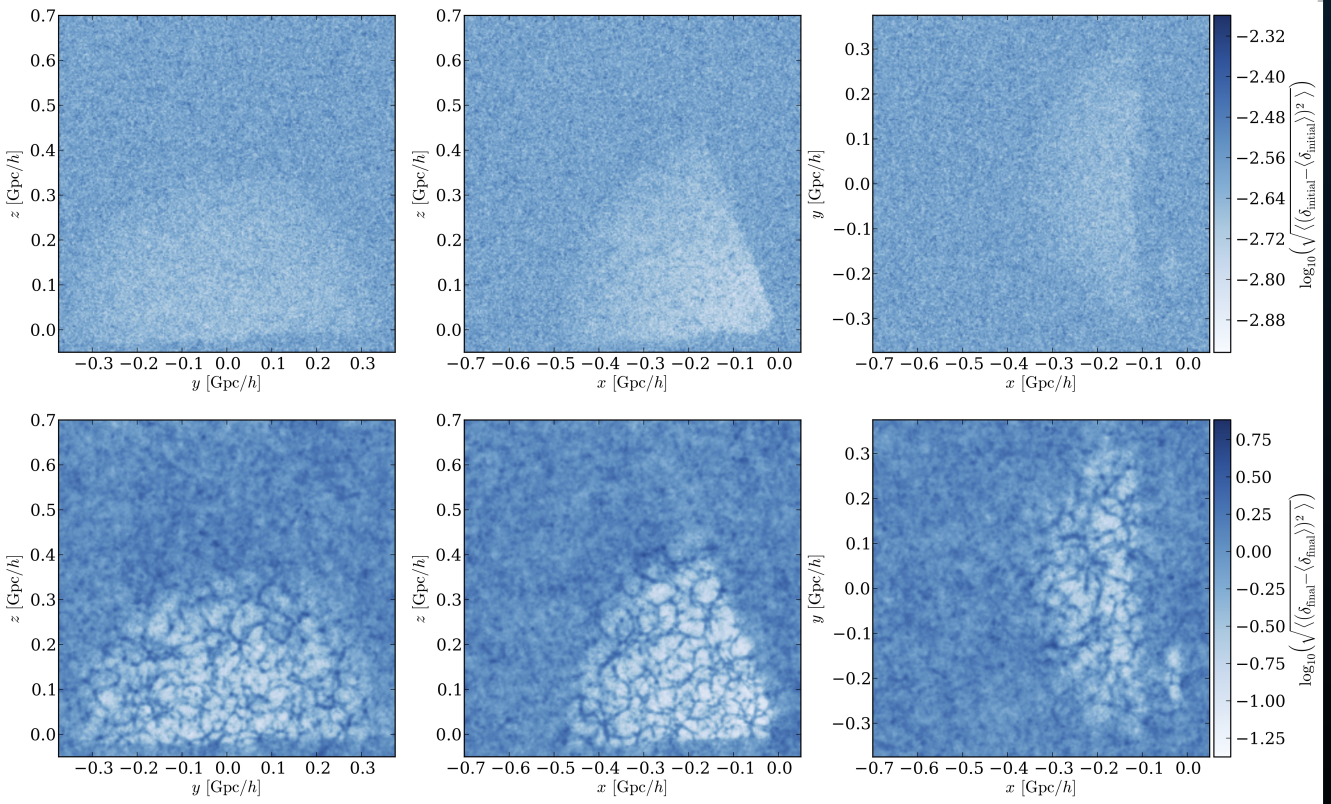
- Full non-linear and non-Gaussian uncertainty quantification
  - Example: voxel-wise standard deviations

Initial density field

z = 1000

Final density field

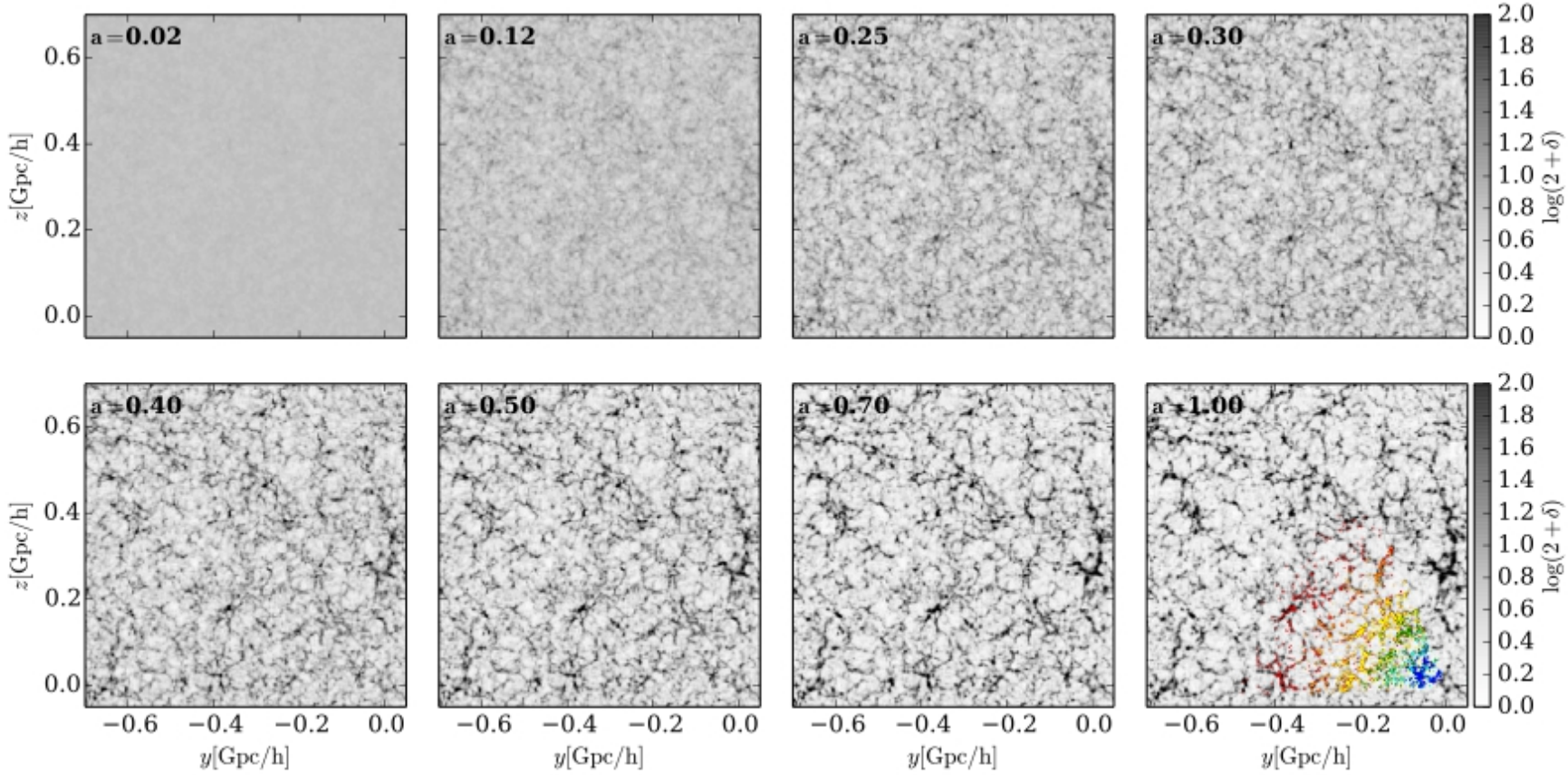
z = 0



Jasche et al. 2014 (arXiv:1409.6308)

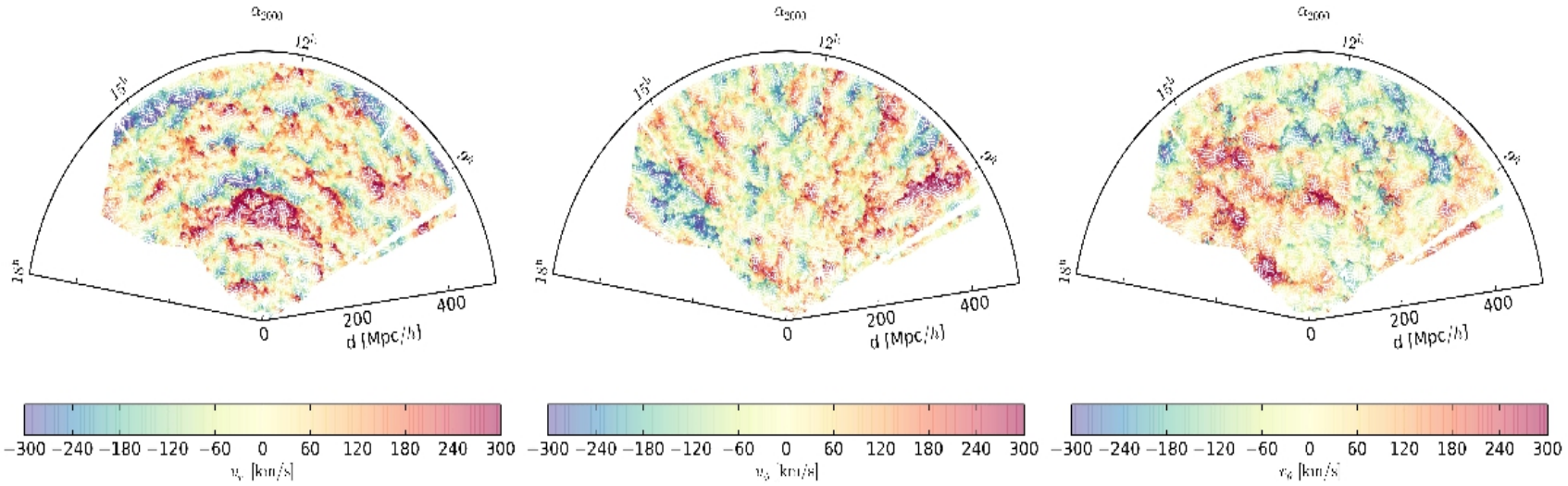
4D analysis of the SDSS

- Inference of plausible cosmic formation histories
  - From 3D to 4D inference



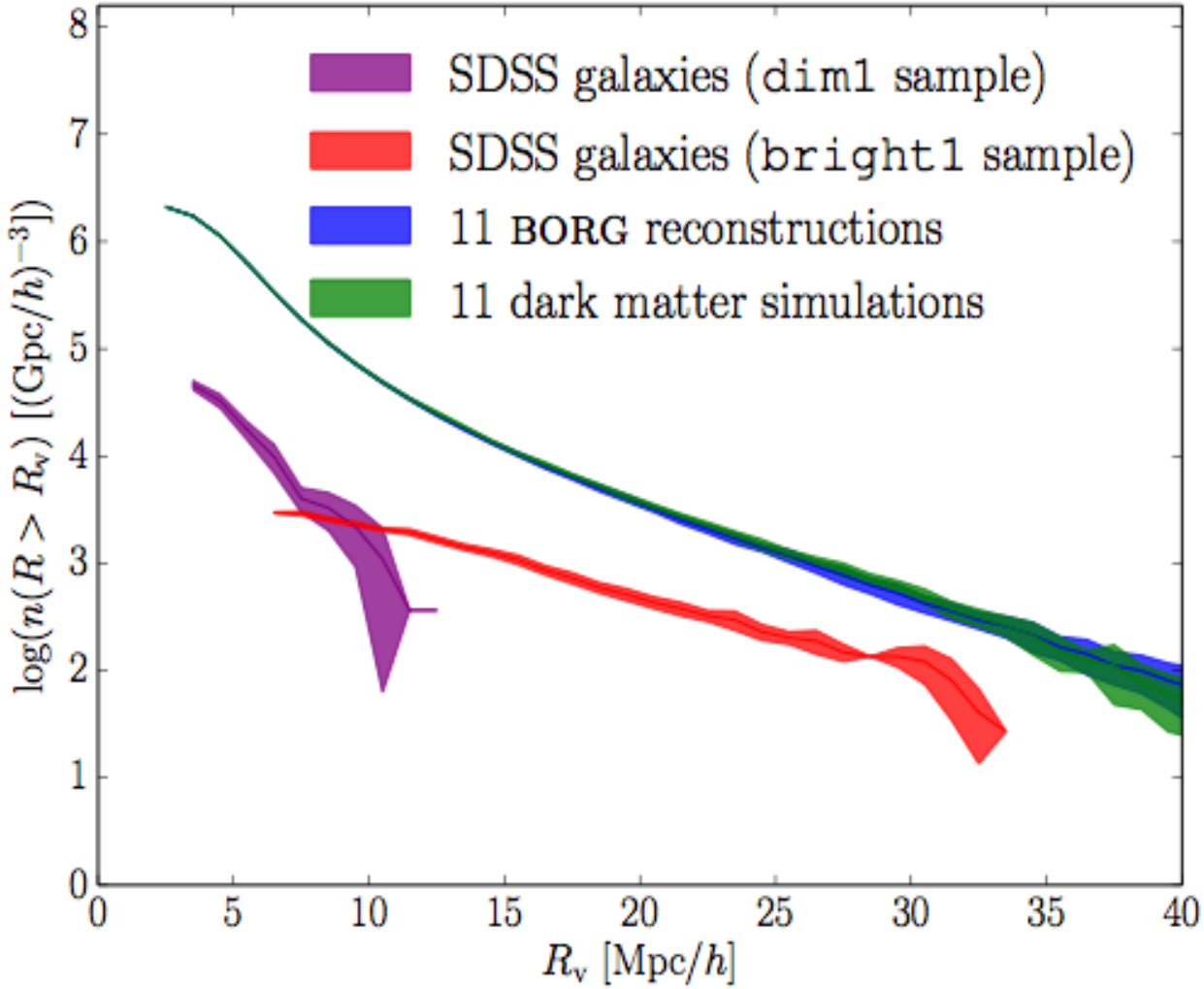
Dynamical information in the SDSS

- Inferred 3D velocity fields



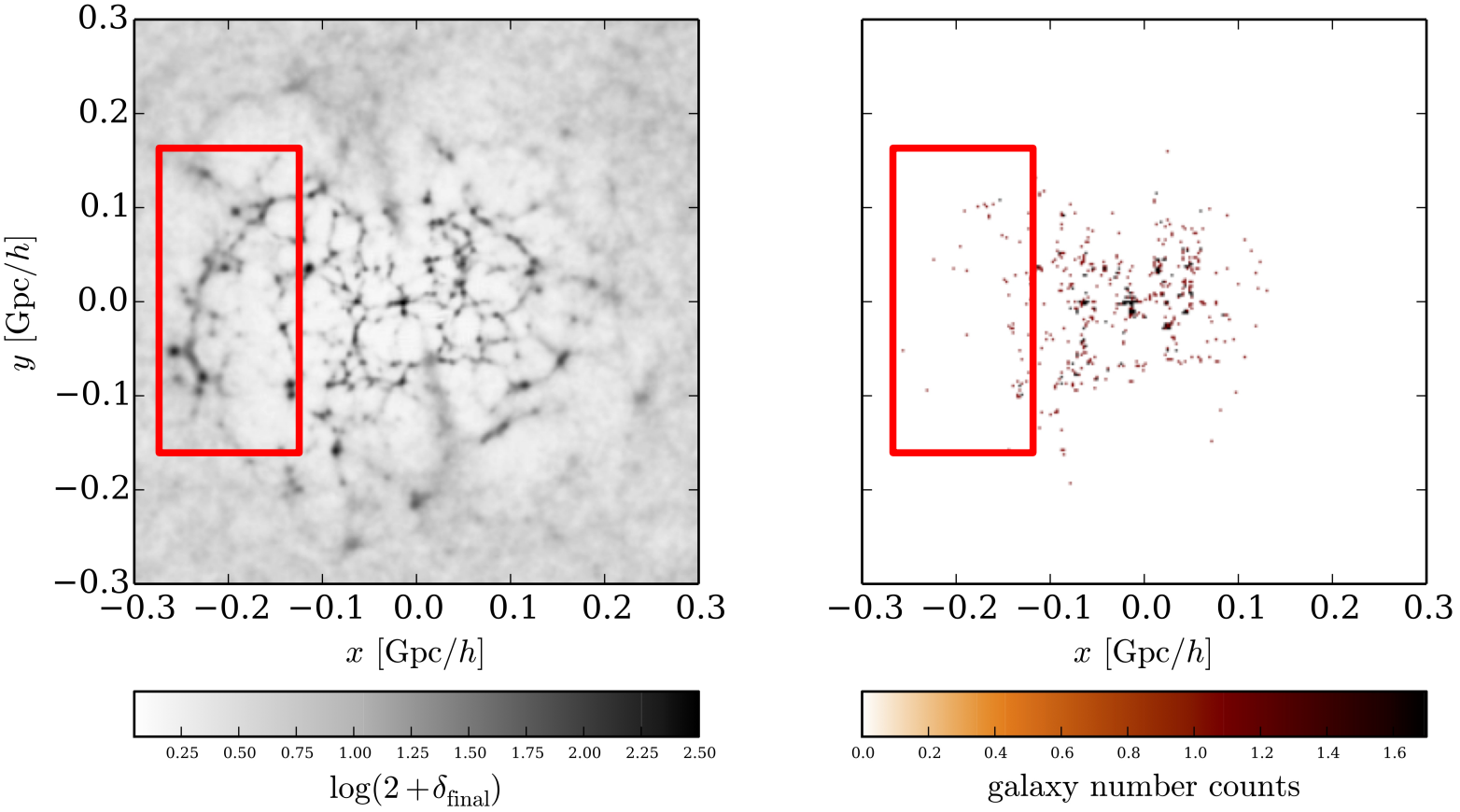
Jasche et al. 2014 (arXiv:1409.6308)

Dark matter void in the SDSS



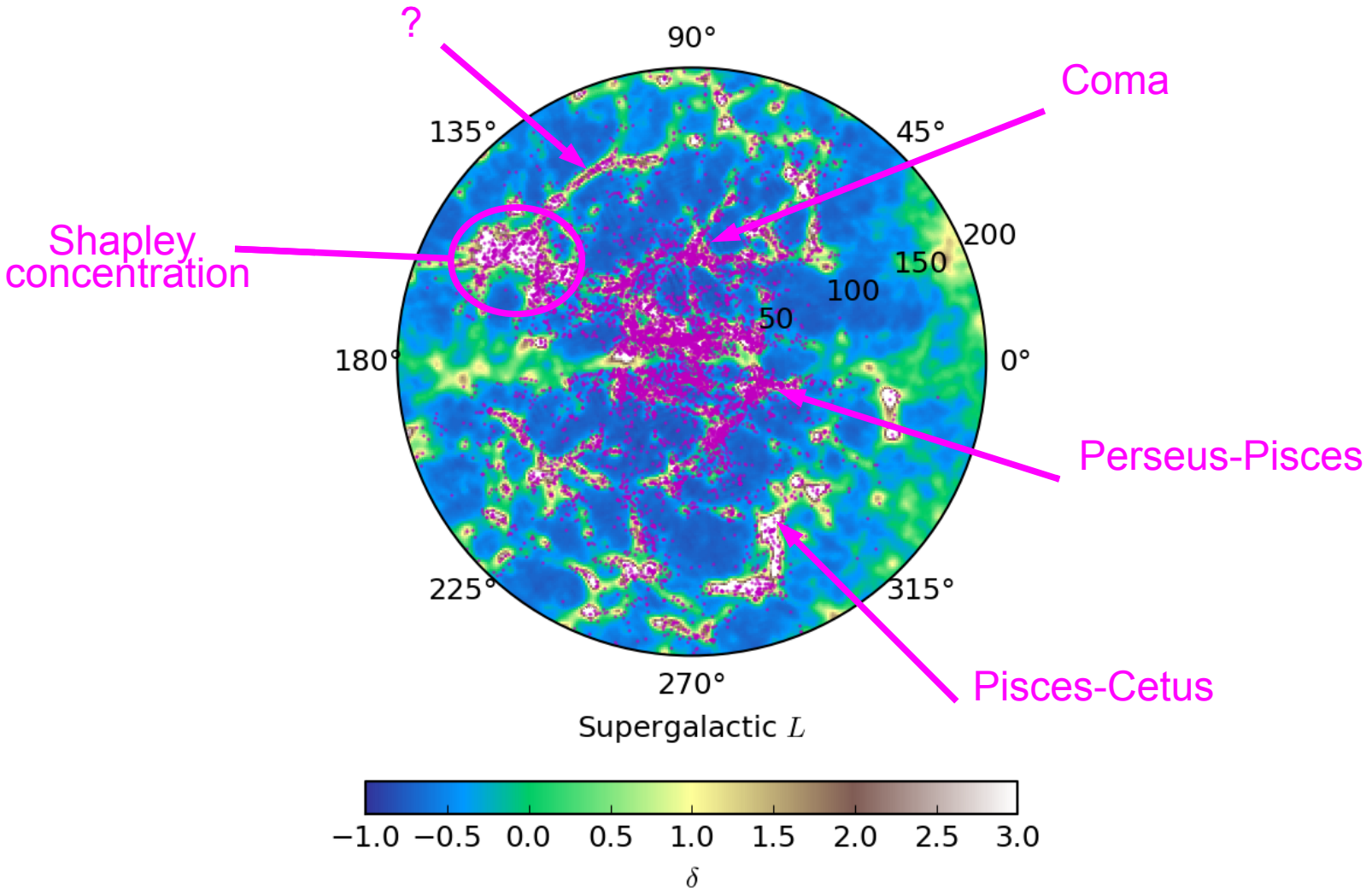
Leclercq et al. 2014 (arXiv:1410.0355)

4D analysis of the 2M++ survey



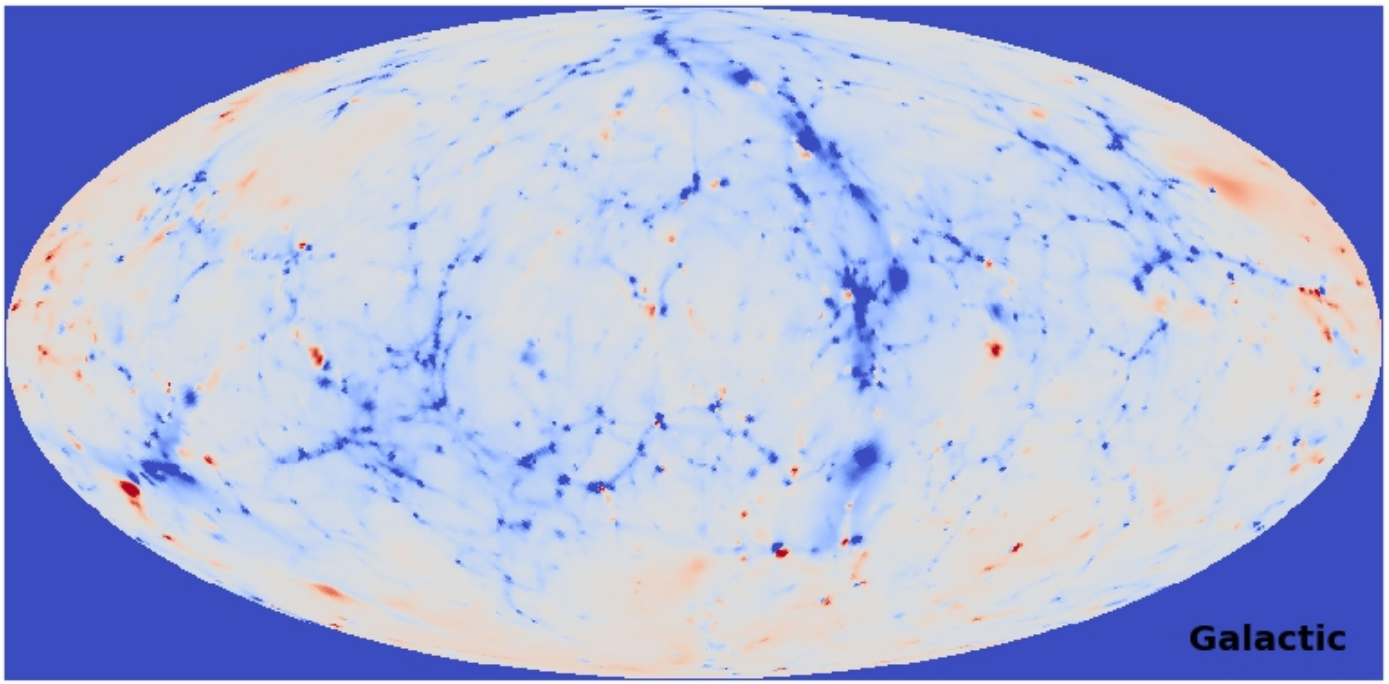
Lavaux and Jasche (in prep)

The Supergalactic plane



kSZ in the 2M++ survey

- Applying BORG to the 2M++ survey Lavaux (2011)
  - 600 Mpc/h Box (Full sky)
  - Construct kSZ Template



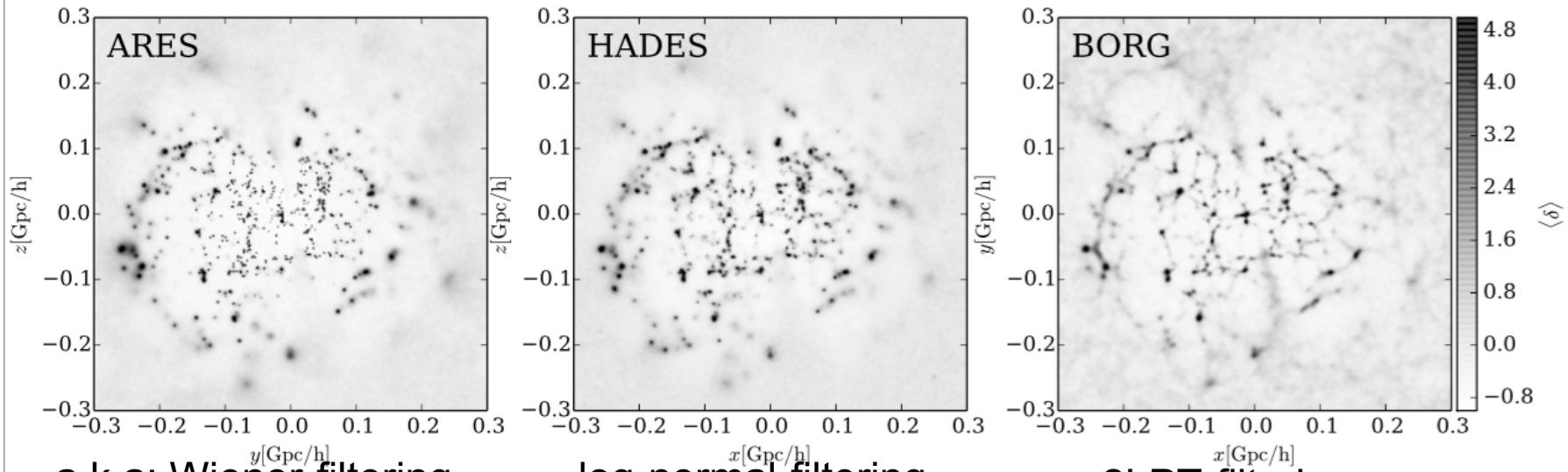
Lavaux and Jasche (in prep)

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

log-normal-filtering

Kitaura 2010
Jasche&Kitaura 2010

2LPT-filtering

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 statistics
  - Noise, survey geometry, selection effects and biases

- 4D Bayesian analyses of the SDSS and 2M++ survey
  - Characterization of initial conditions
  - Higher order statistics
  - Dynamic information, structure formation histories
  - Improved inference in noisy regimes (see Florent's Talk)
  - Predictions and test of physical effects (ISW, kSZ, weak lensing)

The End...

Thank You!