

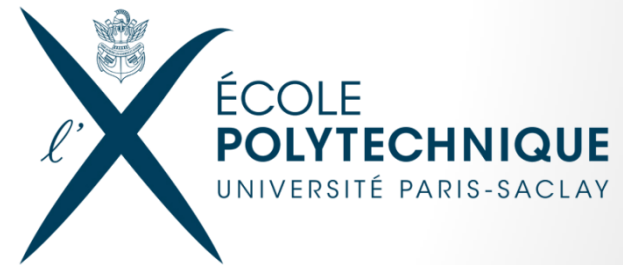
Bayesian inference of the initial conditions from large-scale structure surveys

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In collaboration with:

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Some specificities of cosmology

- **Unicity**. The experience is unique and irreproducible by physical experimentation. There is no exteriority nor anteriority. The properties of the Universe cannot be determined statistically on a set.
- **Energy**. The energy scales at stake in the early Universe are orders of magnitude higher than anything we can reach on Earth.
- **Arrow of time**. Reasoning in cosmology is "bottom-up". The final state is known and the initial state has to be inferred.

➔ The **initial conditions** of the Universe have a **particular status**.

Why Bayesian inference?

- Why do we need Bayesian inference?

Inference of signals = ill-posed problem

- Incomplete observations: survey geometry, selection effects
- Noise, biases, systematic effects
- Cosmic variance



➔ No unique recovery is possible!

“What are the initial conditions of the Universe?”

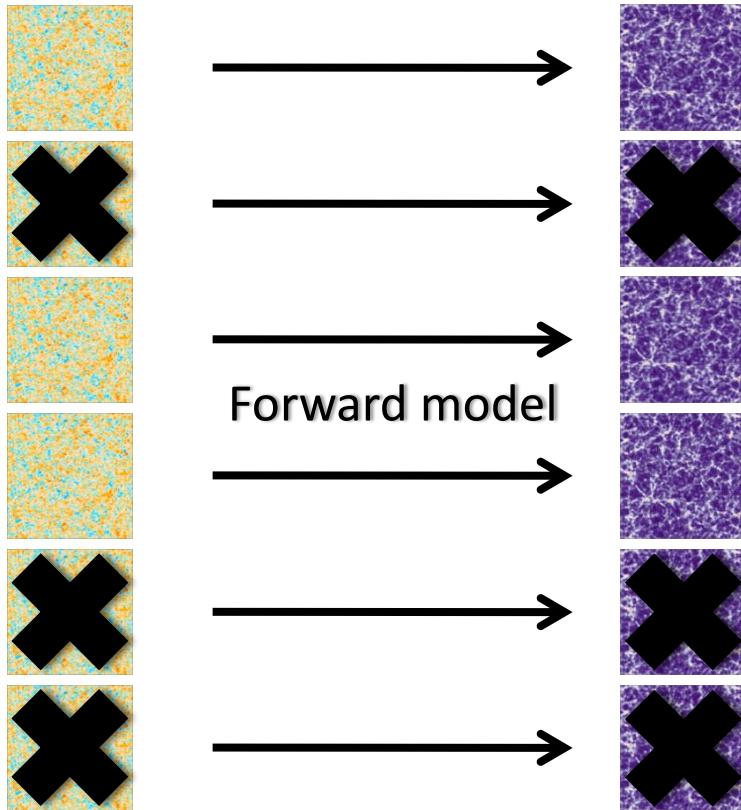


“What is the probability distribution of possible initial conditions (signals) compatible with the observations?”

$$p(s|d)p(d) = p(d|s)p(s)$$

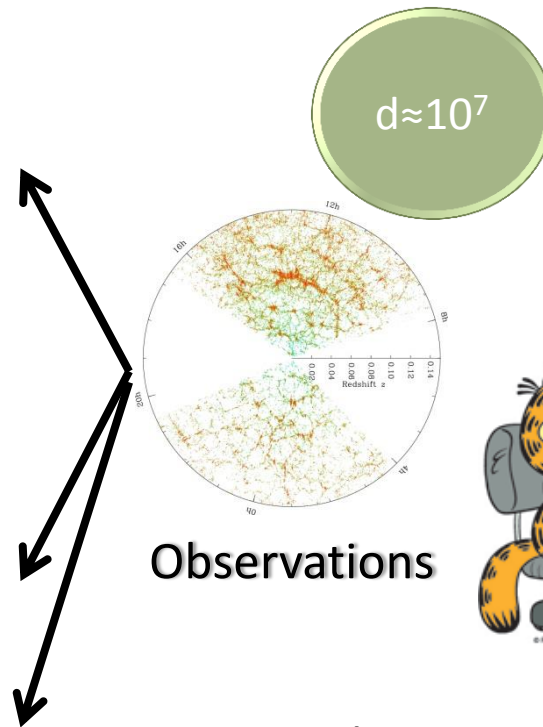
Bayesian forward modeling: the ideal scenario

Forward model = N-body simulation + Halo occupation +
Galaxy formation + Feedback + ...

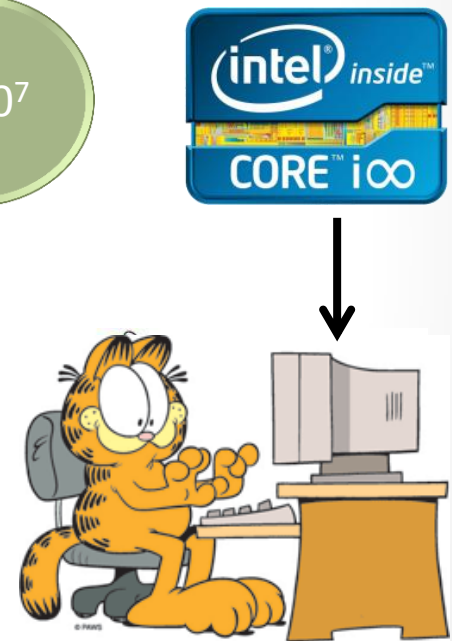


All possible ICs

All possible FCs



Observations



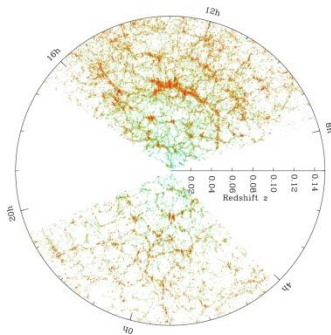
We need a *very, very, very*
big computer!

BORG: *Bayesian Origin Reconstruction from Galaxies*

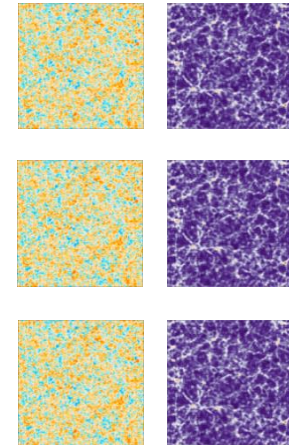


What makes the problem tractable:

- **Sampler**: Hamiltonian Markov Chain Monte Carlo method
- **Physical model**: Second-order Lagrangian perturbation theory (2LPT)



Observations



Samples of possible 4D states

see also:

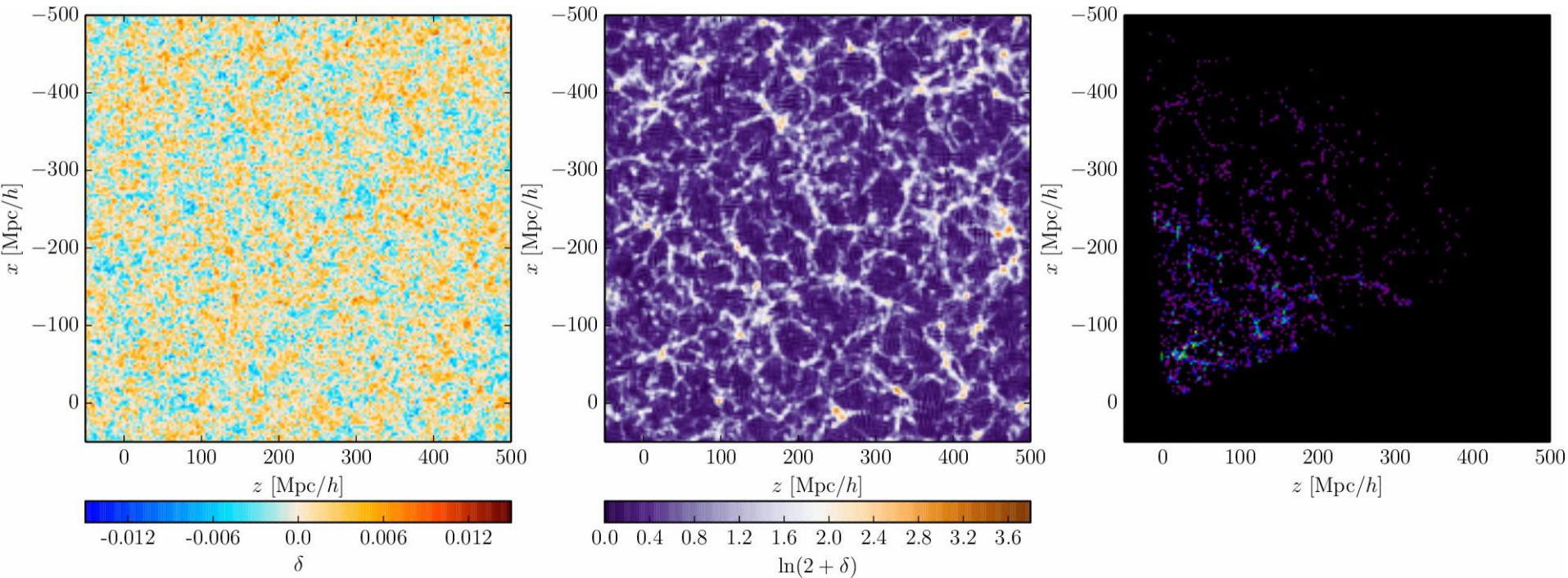
Kitaura 2013, arXiv:1203.4184

Wang, Mo, Yang & van den Bosch 2013, arXiv:1301.1348

See Francisco Kitaura's talk

Jasche & Wandelt 2013, arXiv:1203.3639

BORG at work – chronocosmography



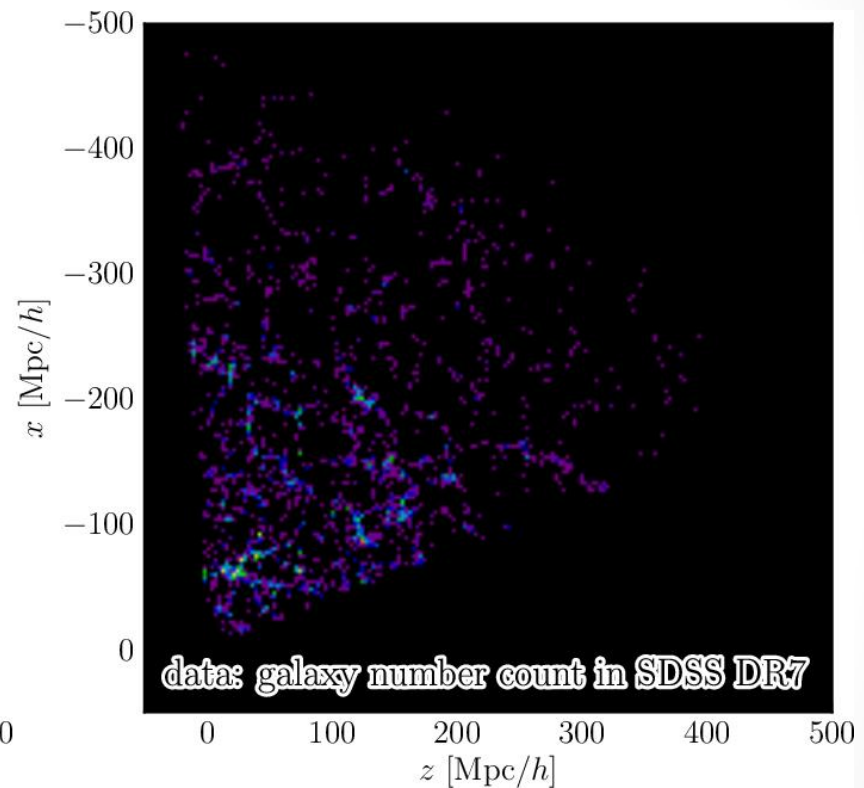
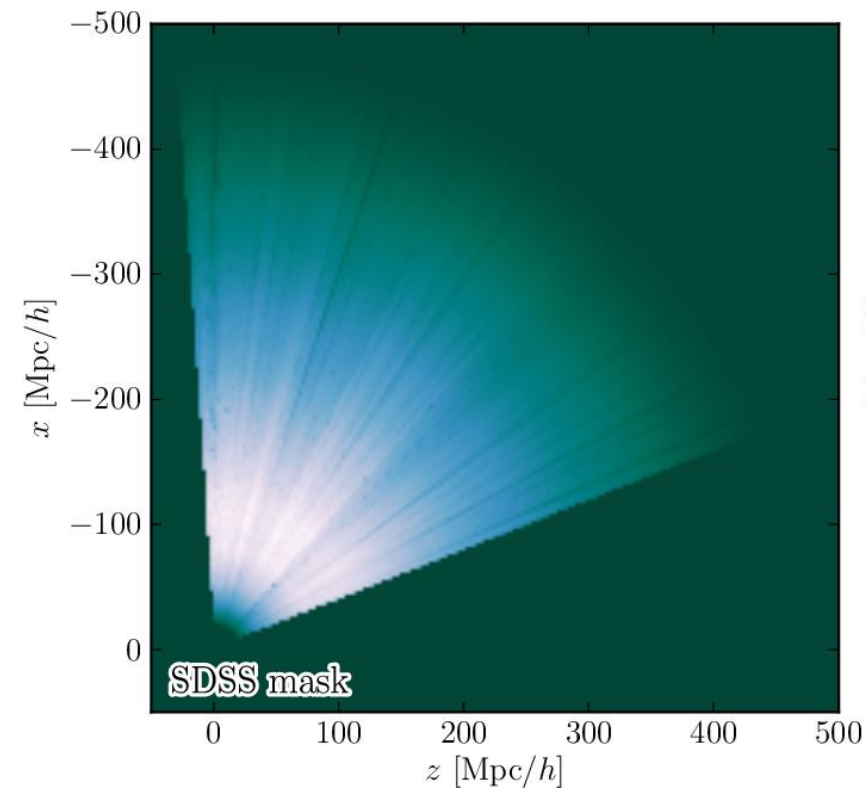
Initial conditions

Final conditions

Observations

Jasche, FL & Wandelt, in prep.

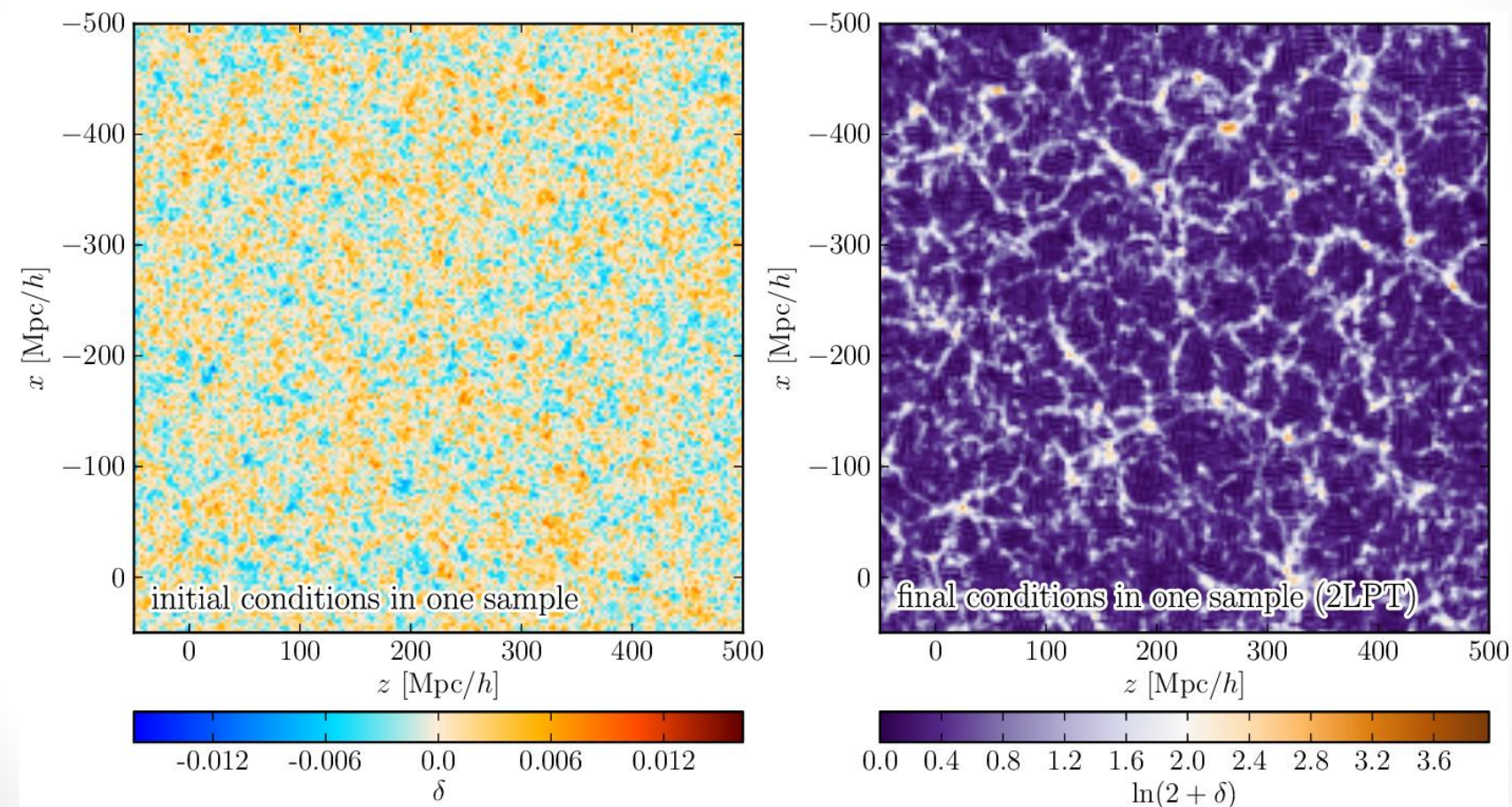
Bayesian chronocosmography from SDSS DR7



Jasche, FL & Wandelt, in prep.

Data

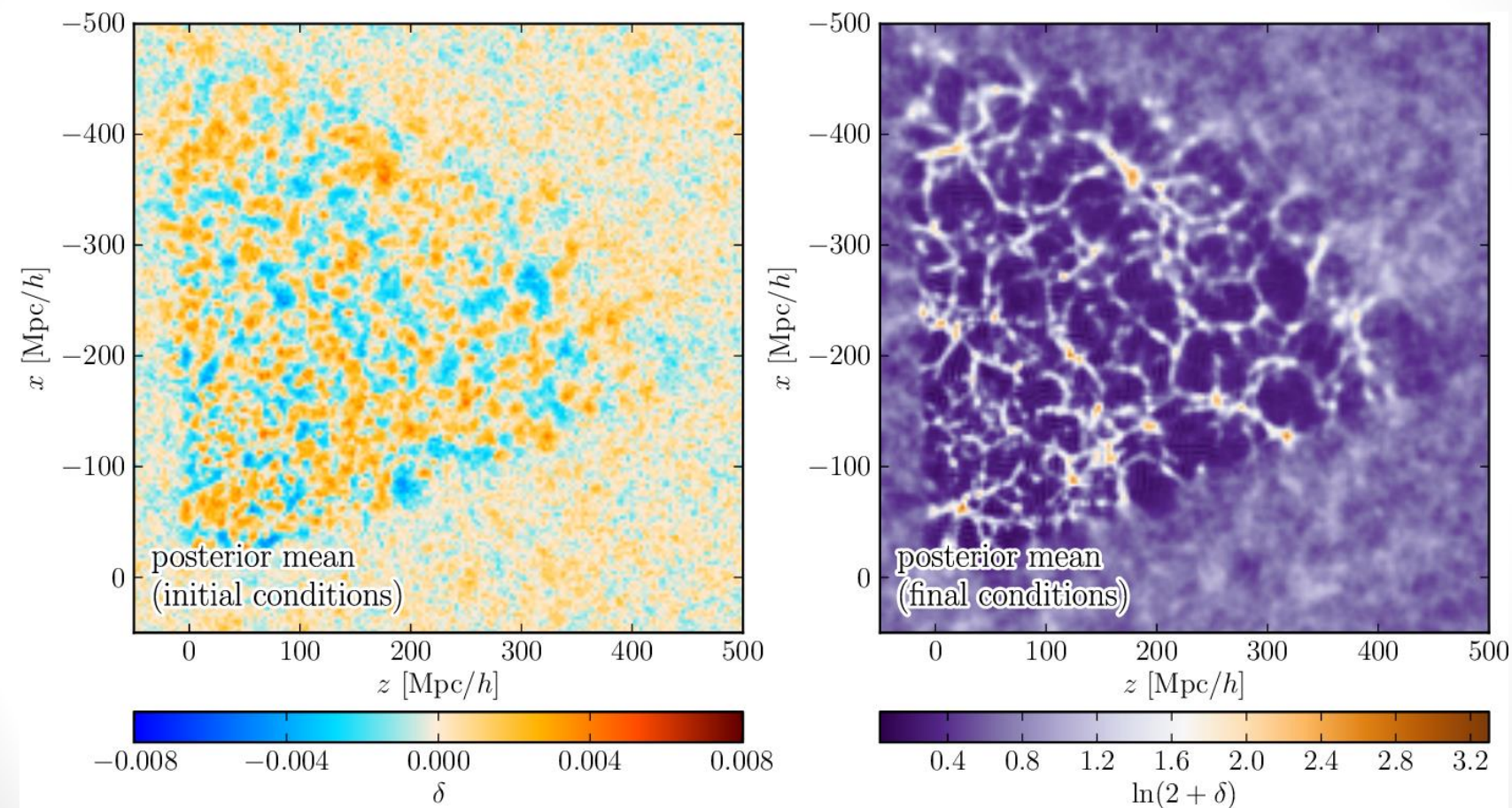
Bayesian chronocosmography from SDSS DR7



Jasche, FL & Wandelt, in prep.

One sample

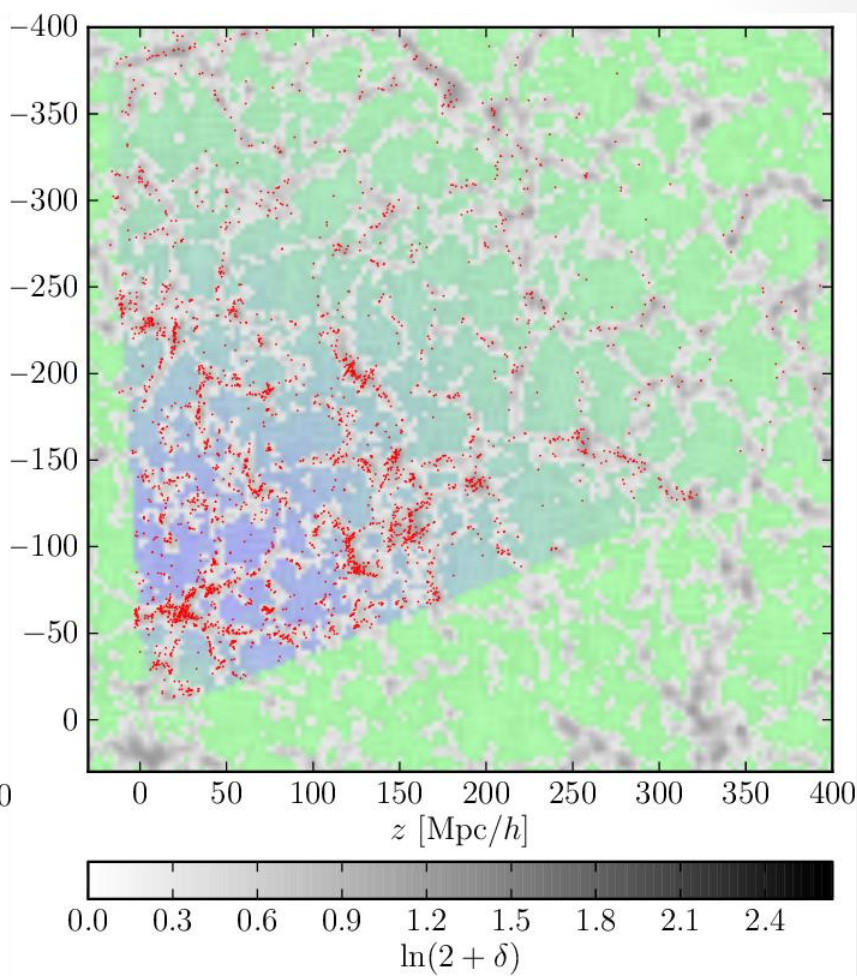
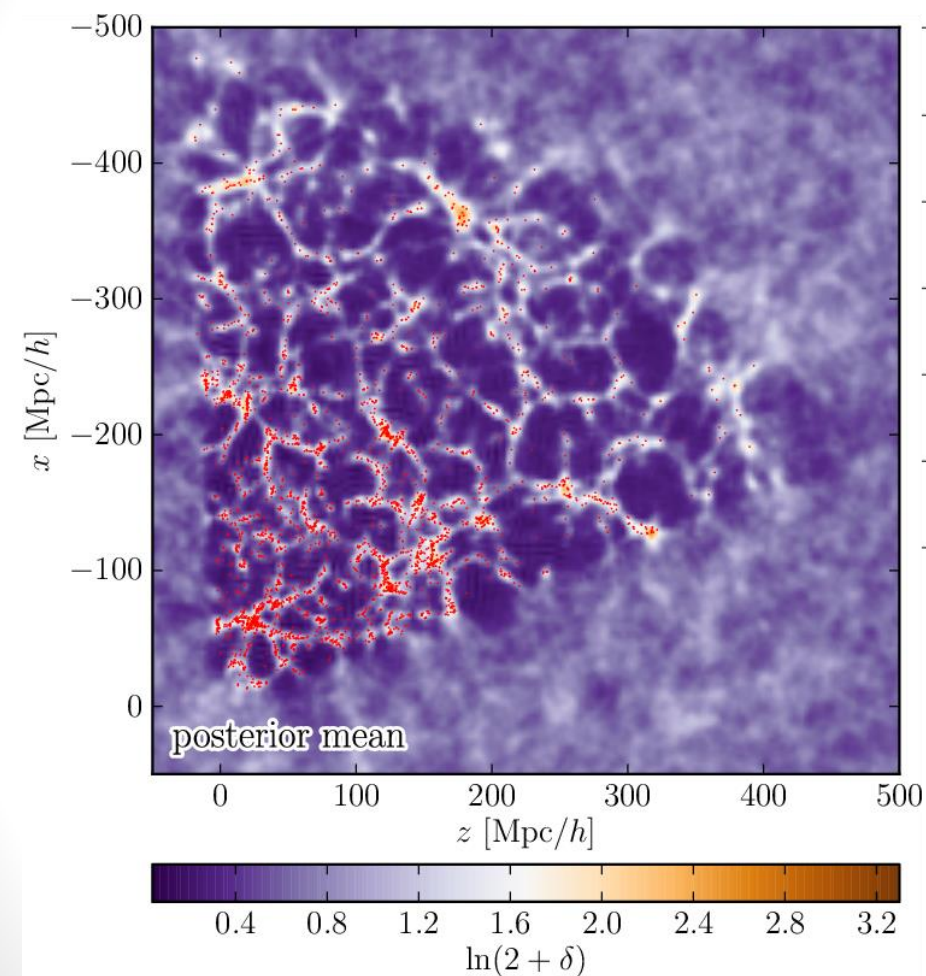
Bayesian chronocosmography from SDSS DR7



Jasche, FL & Wandelt, in prep.

Posterior mean

Dark matter voids in the SDSS



FL, Jasche, Sutter, Hamaus & Wandelt, in prep.

VIDE pipeline: see Paul Sutter's talk

Tidal shear analysis

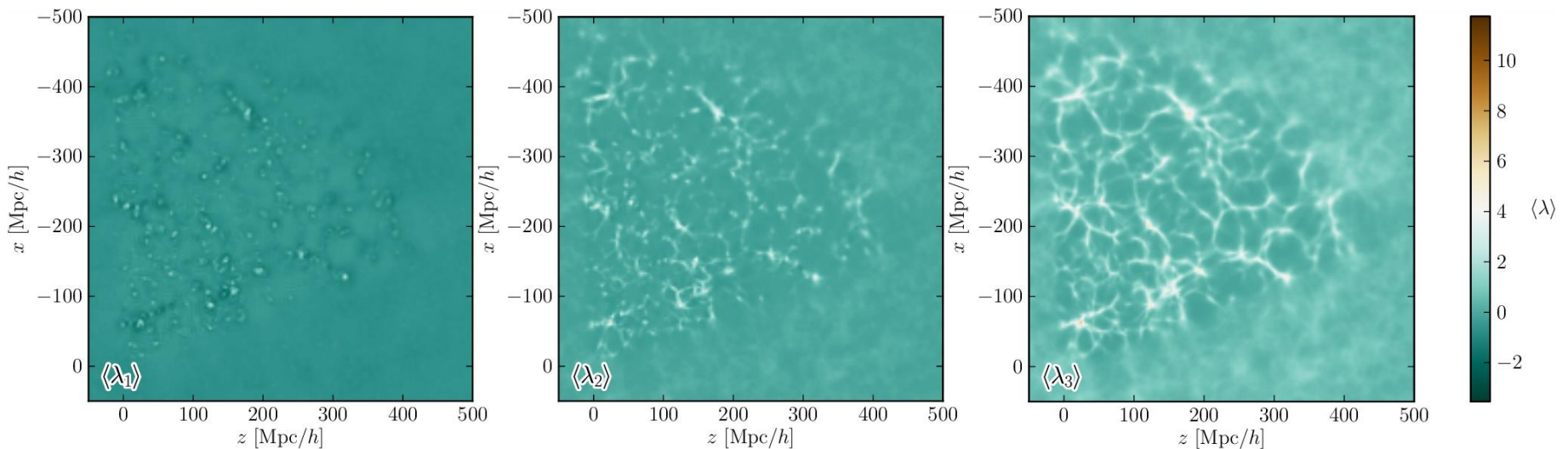
- $\lambda_1, \lambda_2, \lambda_3$: eigenvalues of the tidal field tensor, the Hessian of the gravitational potential: $T_{ij} = \partial_i \partial_j \Phi$
 - Voids: $\lambda_1, \lambda_2, \lambda_3 < 0$
 - Sheets: $\lambda_1 > 0$ and $\lambda_2, \lambda_3 < 0$
 - Filaments: $\lambda_1, \lambda_2 > 0$ and $\lambda_3 < 0$
 - Clusters: $\lambda_1, \lambda_2, \lambda_3 > 0$

Hahn *et al.* 2006, arXiv:astro-ph/0610280

see also:

Forero-Romero *et al.* 2008, arXiv:0809.4135

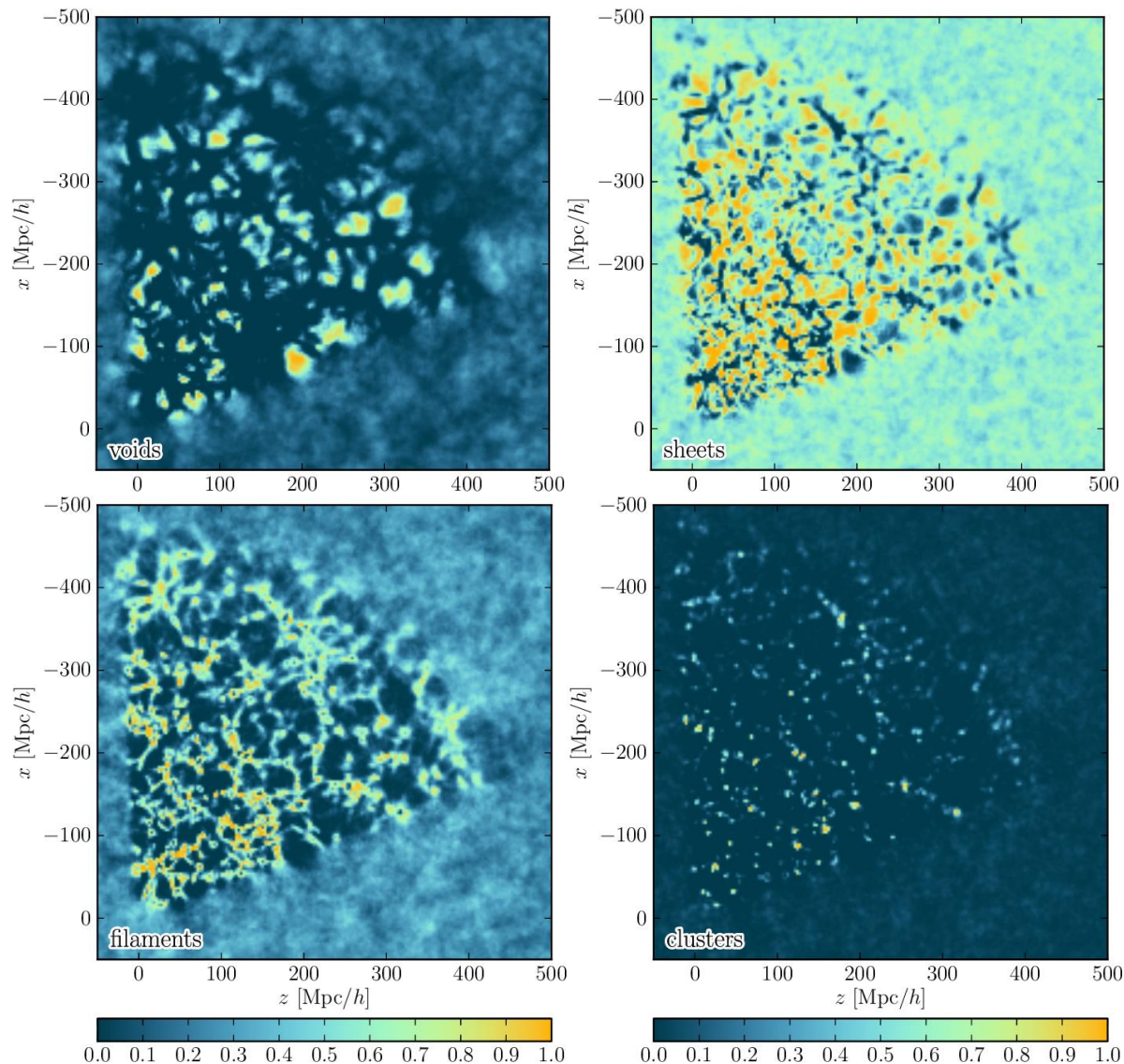
Hoffman *et al.* 2012, arXiv:1201.3367



FL, Jasche, Chevallard & Wandelt, in prep.

Dynamic structures inferred by BORG

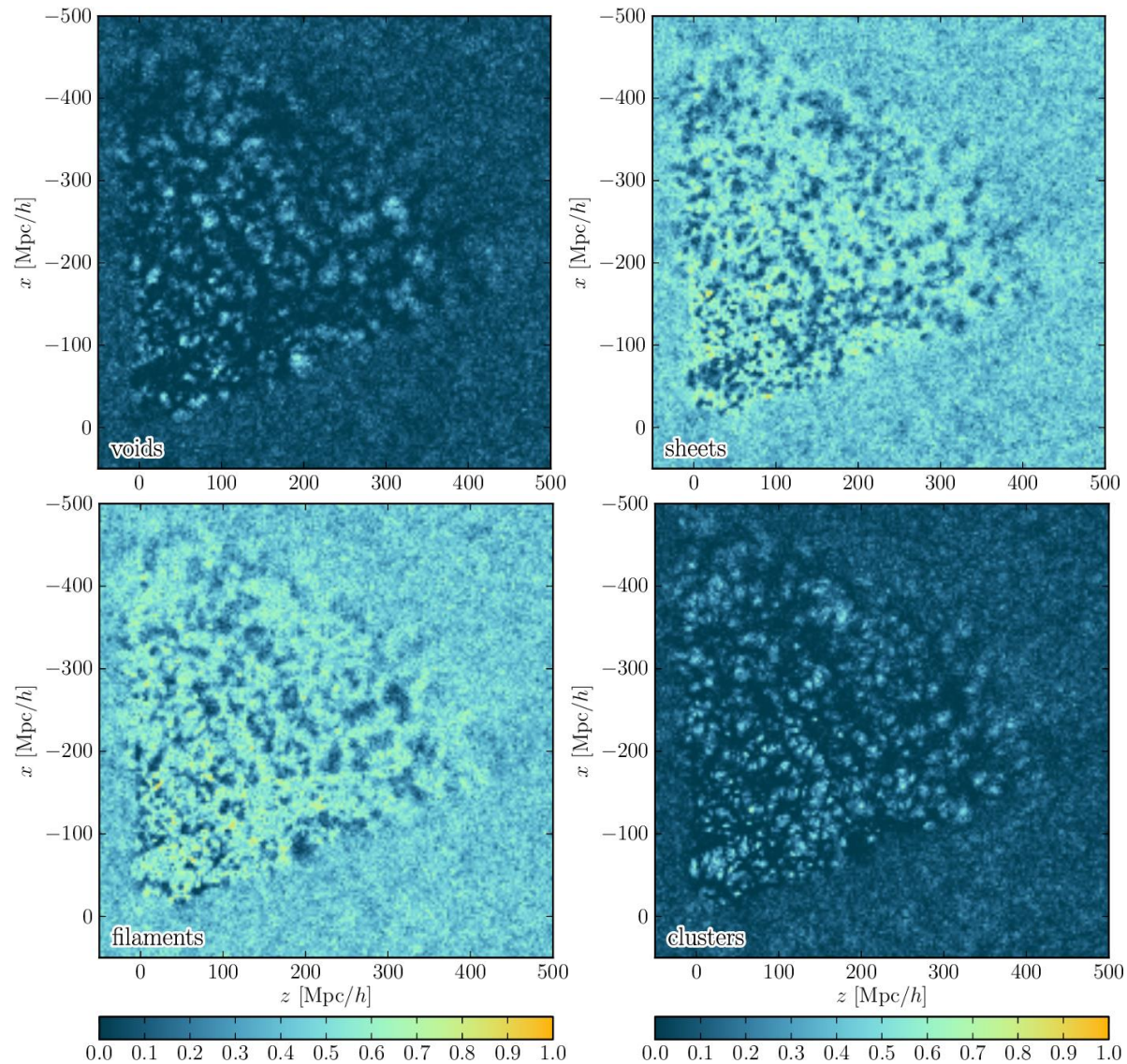
Final conditions



FL, Jasche, Chevallard & Wandelt, in prep.

Dynamic structures inferred by BORG

Initial conditions



FL, Jasche, Chevallard & Wandelt, in prep.

Summary & Conclusions

- Bayesian large-scale structure inference in 10 millions dimensions is possible!
 - Non-linear and non-Gaussian inference
 - Uncertainty quantification (noise, survey geometry, selection effects and biases)
- Application to data: four-dimensional **chronocosmography**
 - Characterization of the cosmic web in the present-day Universe
 - Physical reconstruction of the initial conditions