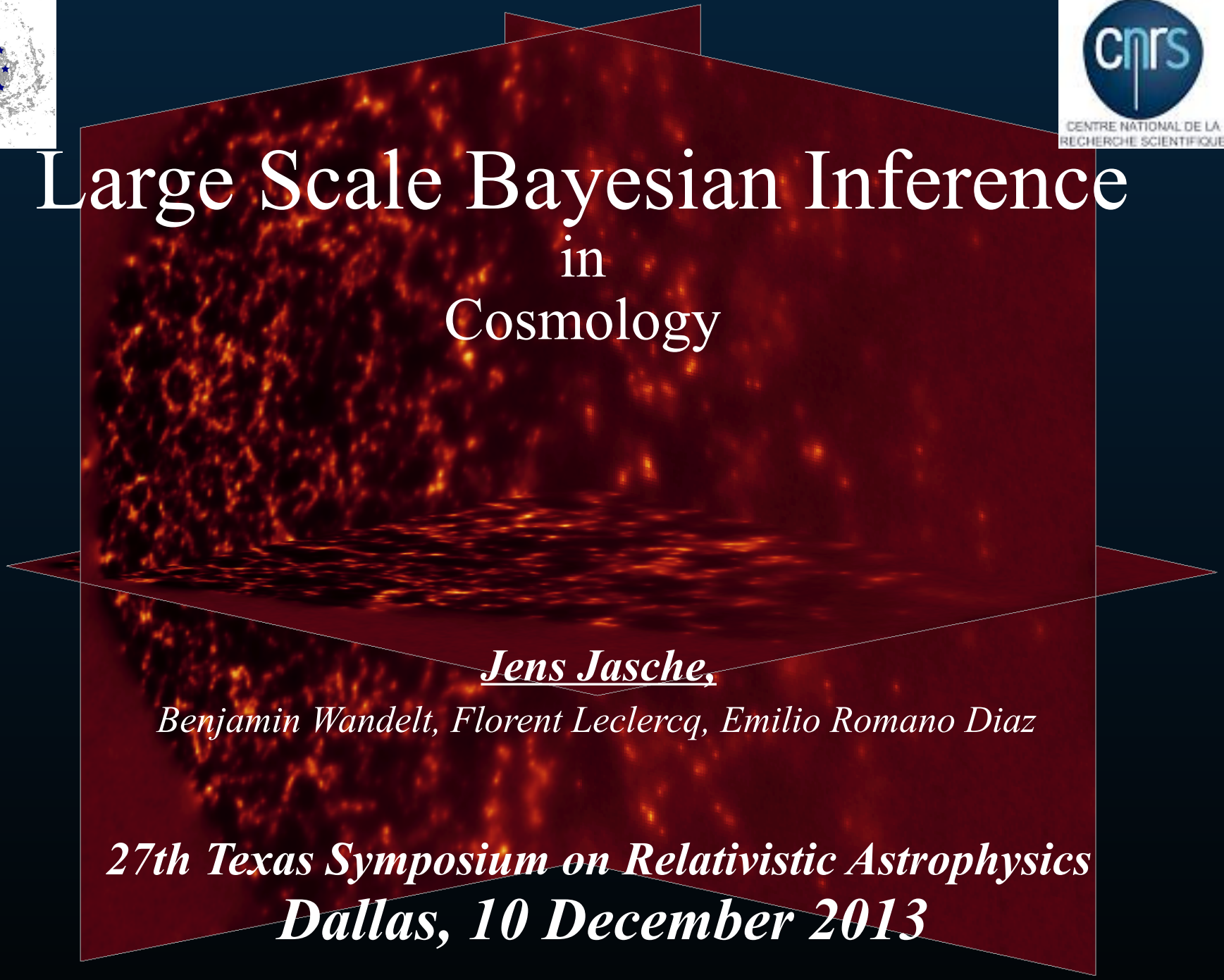


Large Scale Bayesian Inference in Cosmology

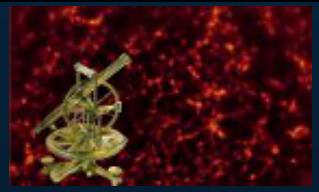
Jens Jasche,

Benjamin Wandelt, Florent Leclercq, Emilio Romano Diaz

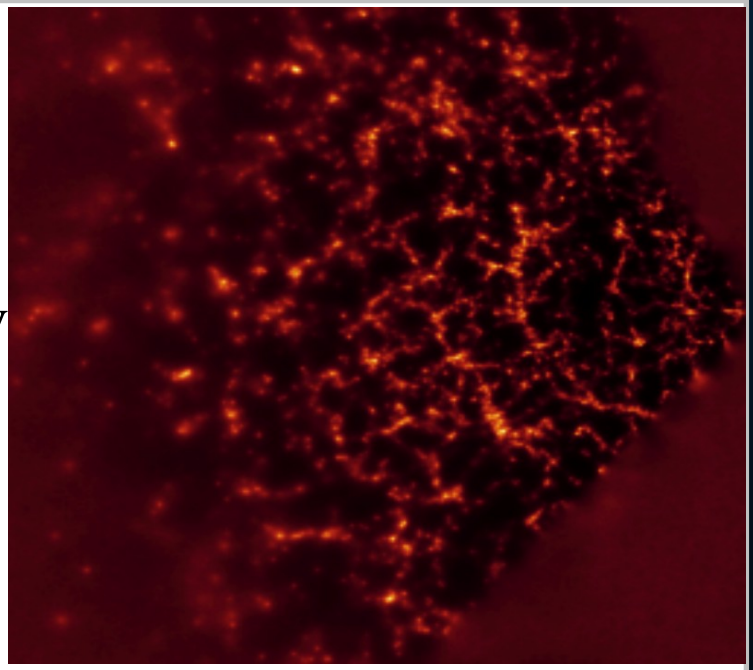
27th Texas Symposium on Relativistic Astrophysics

Dallas, 10 December 2013

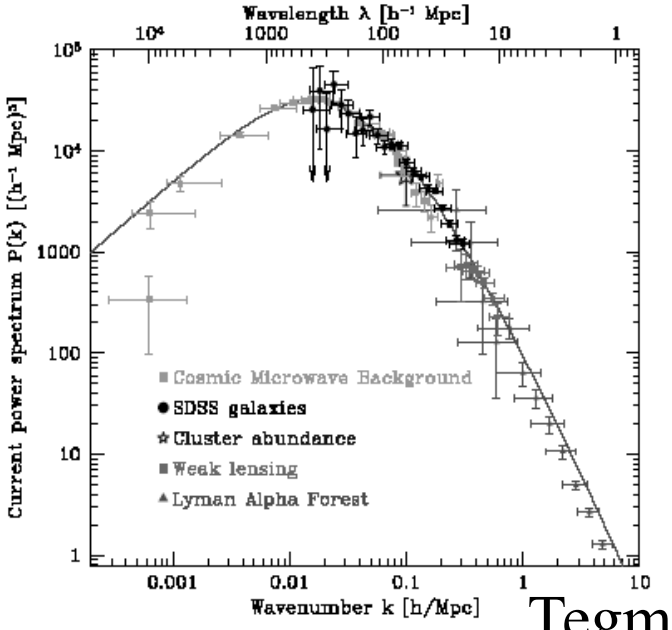
Introduction



- Cosmography
  - 3D density and velocity fields
  - Power-spectra, bi-spectra
  - Dark Energy, Dark Matter, Gravity
  - Cosmological parameters

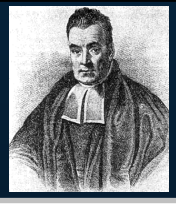


Jasche et al. (2010)



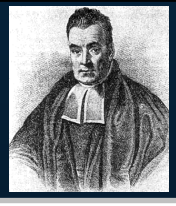
Tegmark et al. (2004)

Introduction



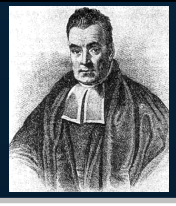
- Why do we need Bayesian inference?

Introduction

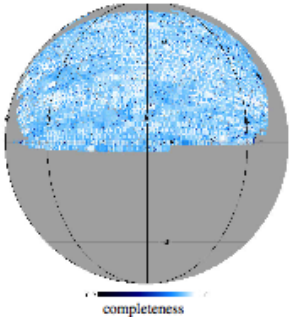


- Why do we need Bayesian inference?
  - Inference of signals = ill-posed problem

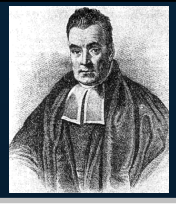
Introduction



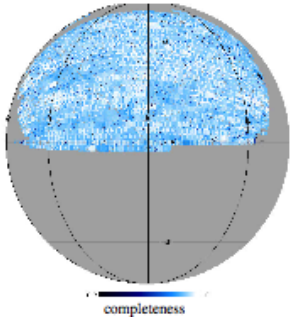
- Why do we need Bayesian inference?
  - Inference of signals = ill-posed problem
    - Noise
    - Incomplete observations
    - Systematics
    - Redshift uncertainties



Introduction



- Why do we need Bayesian inference?
  - Inference of signals = ill-posed problem
    - Noise
    - Incomplete observations
    - Systematics
    - Redshift uncertainties



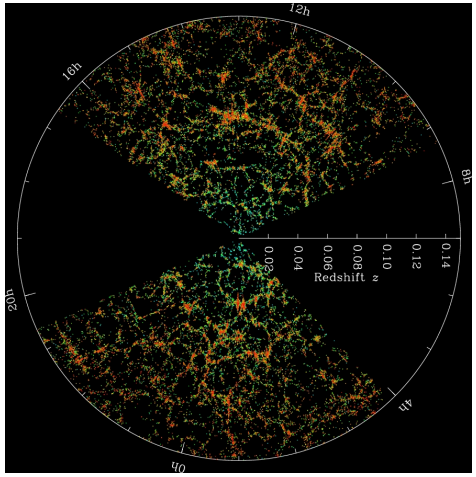
➡ Bayesian inference

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

Non-linear LSS inference

- Inference of the non-linear LSS
  - Non-linear density field
    - Log-normal prior

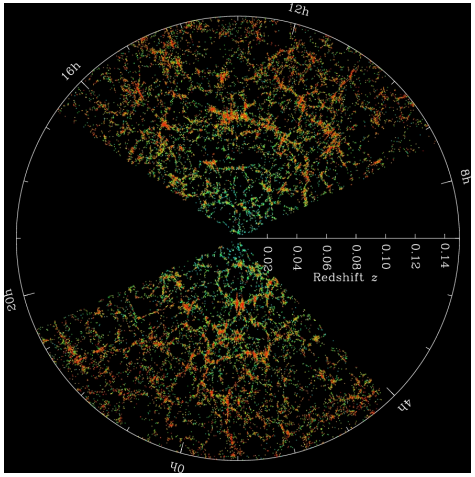
      See e.g. Coles & Jones (1991), Kayo et al. (2001)
  - Galaxy distribution
    - Poisson likelihood
    - Signal dependent noise



Credit: M. Blanton and the Sloan Digital Sky Survey

Non-linear LSS inference

- Inference of the non-linear LSS
  - Non-linear density field
    - Log-normal prior
      See e.g. Coles & Jones (1991), Kayo et al. (2001)
  - Galaxy distribution
    - Poisson likelihood
    - Signal dependent noise



Credit: M. Blanton and the Sloan Digital Sky Survey

Technically challenging in high dimensions!

- ~10^7 density amplitudes
- No reduction of problem size possible
- No analytic treatment of posterior distributions

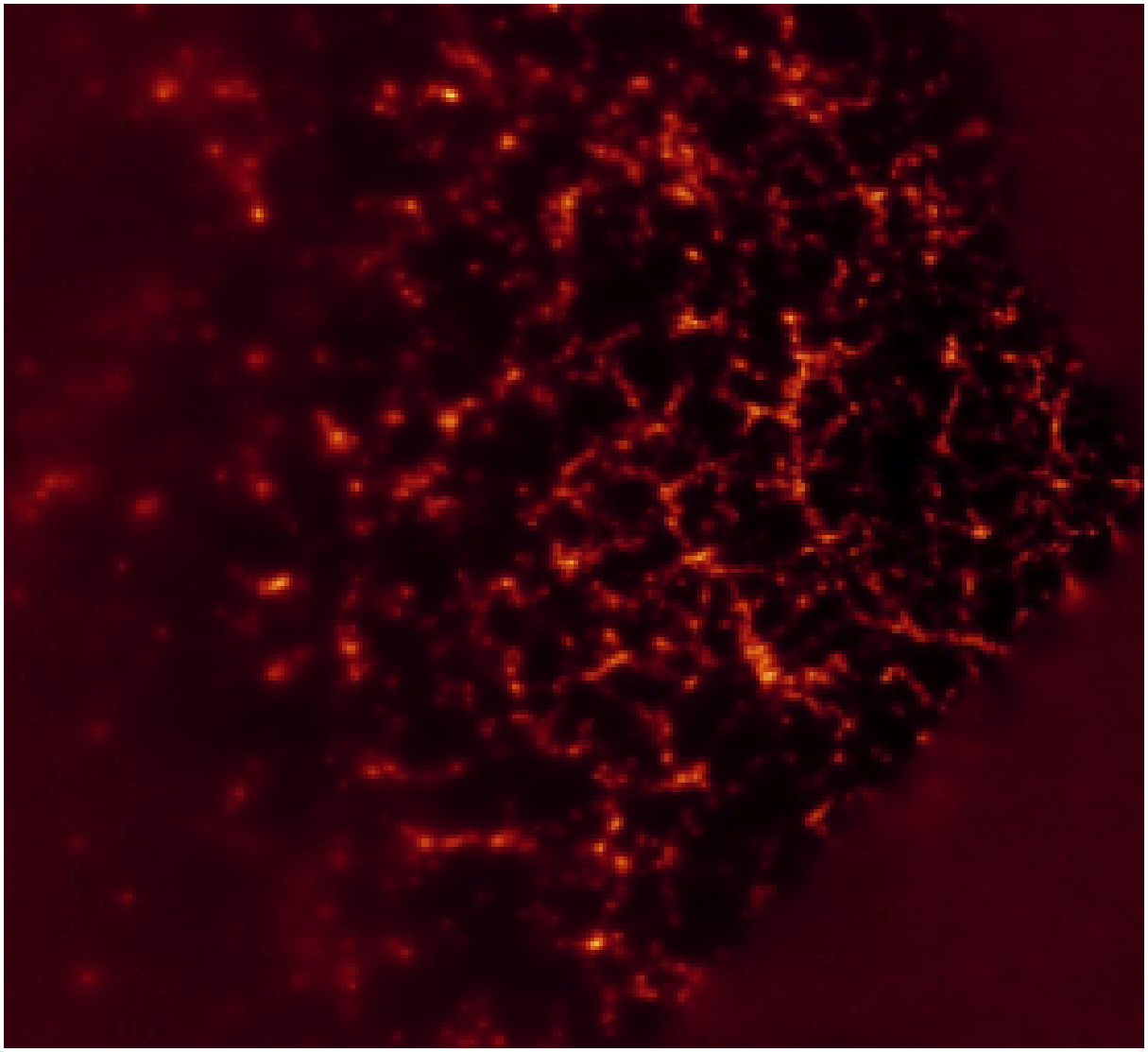
Non-linear LSS inference

- HADES (**H**amiltonian **D**ensity **E**stimation and **S**ampling)
  - Hybrid Monte Carlo sampling (dim ~ 10^7)
  - Data constrained LSS realizations
  - 3D Maps and uncertainty quantification

- HADES and the SDSS DR7
  - Cubic box (750 Mpc) with 3 Mpc grid resolution
  - 40000 density realizations (3 TB)
  - 3D Maps and uncertainty quantification

Jasche, Kitaura, Li, Enßlin (2010)

Non-linear LSS inference



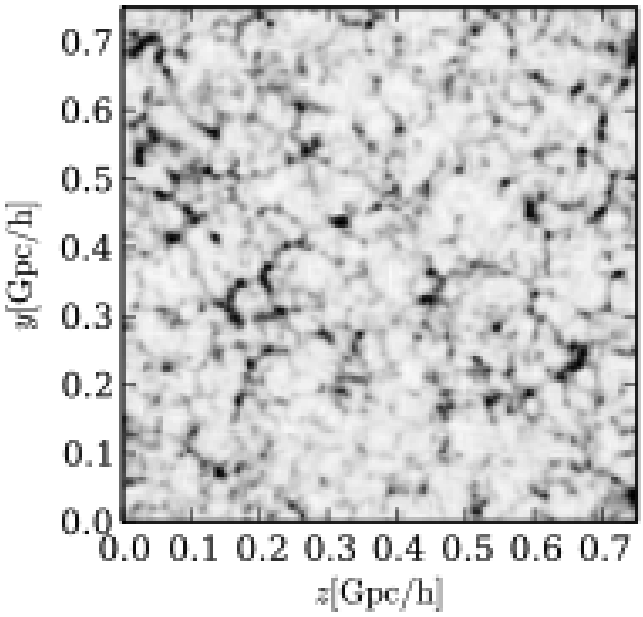
4D physical inference

- Physical motivation

4D physical inference

- Physical motivation
  - Complex final state

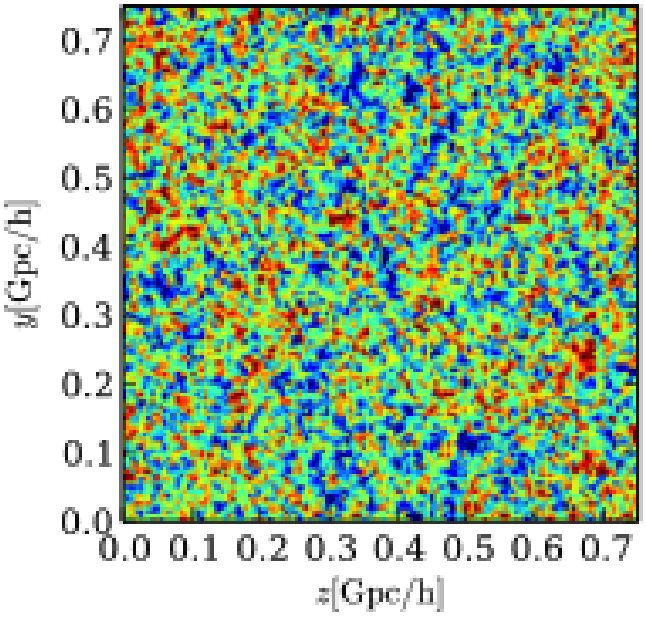
Final state



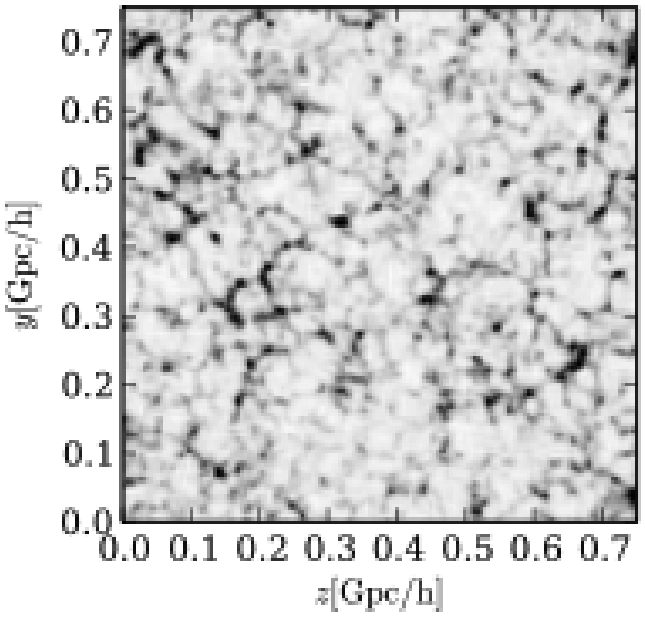
4D physical inference

- Physical motivation
  - Complex final state
  - Simple initial state

Initial state



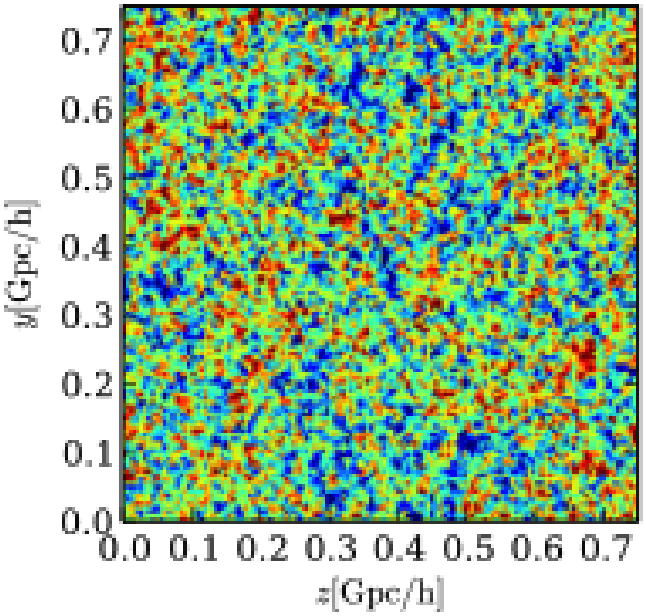
Final state



4D physical inference

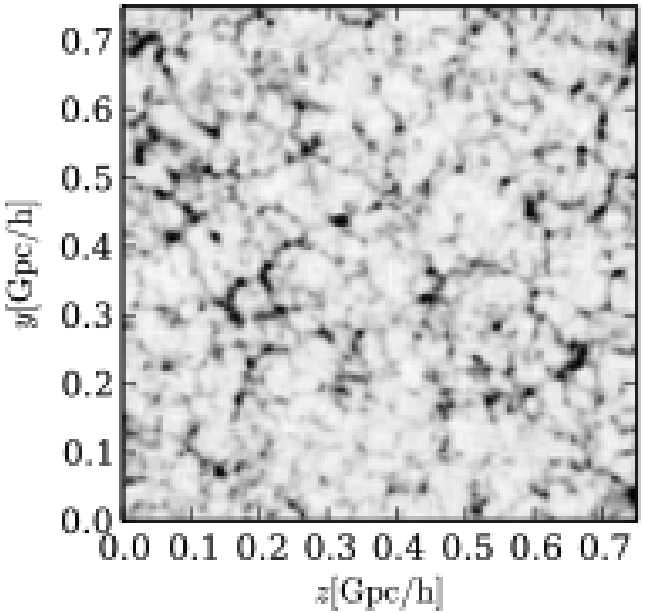
- Physical motivation
  - Complex final state
  - Simple initial state

Initial state



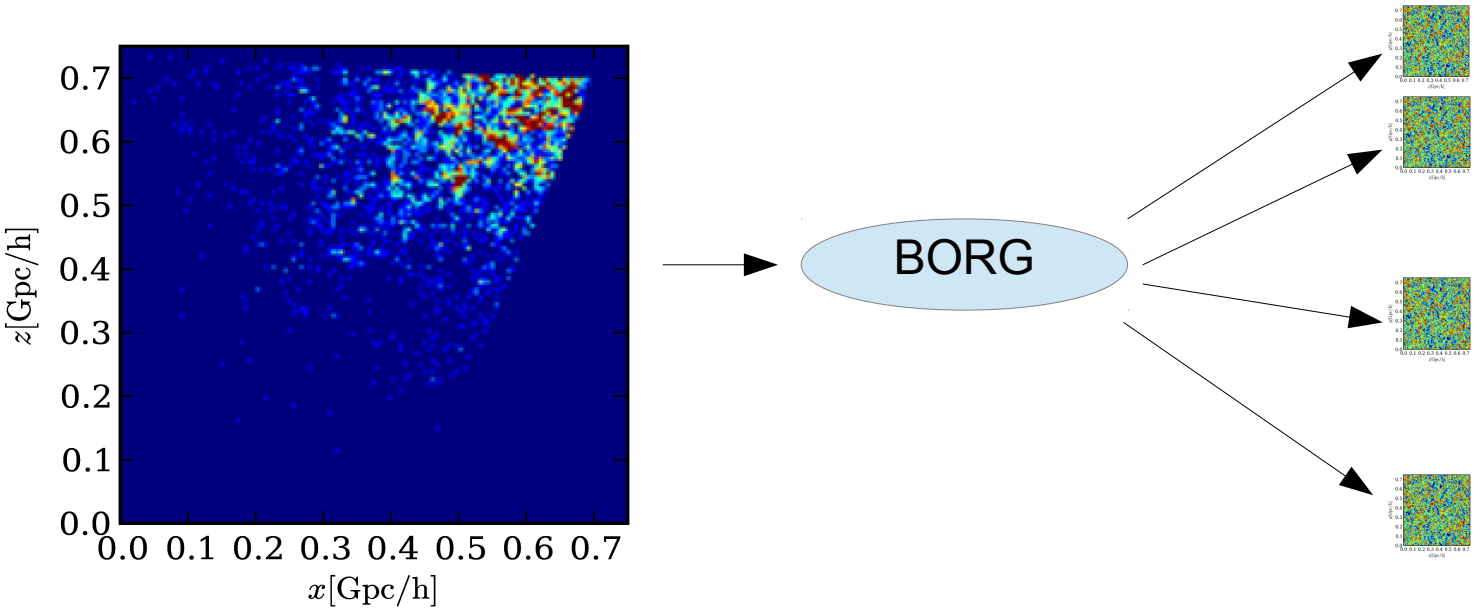
Gravity

Final state



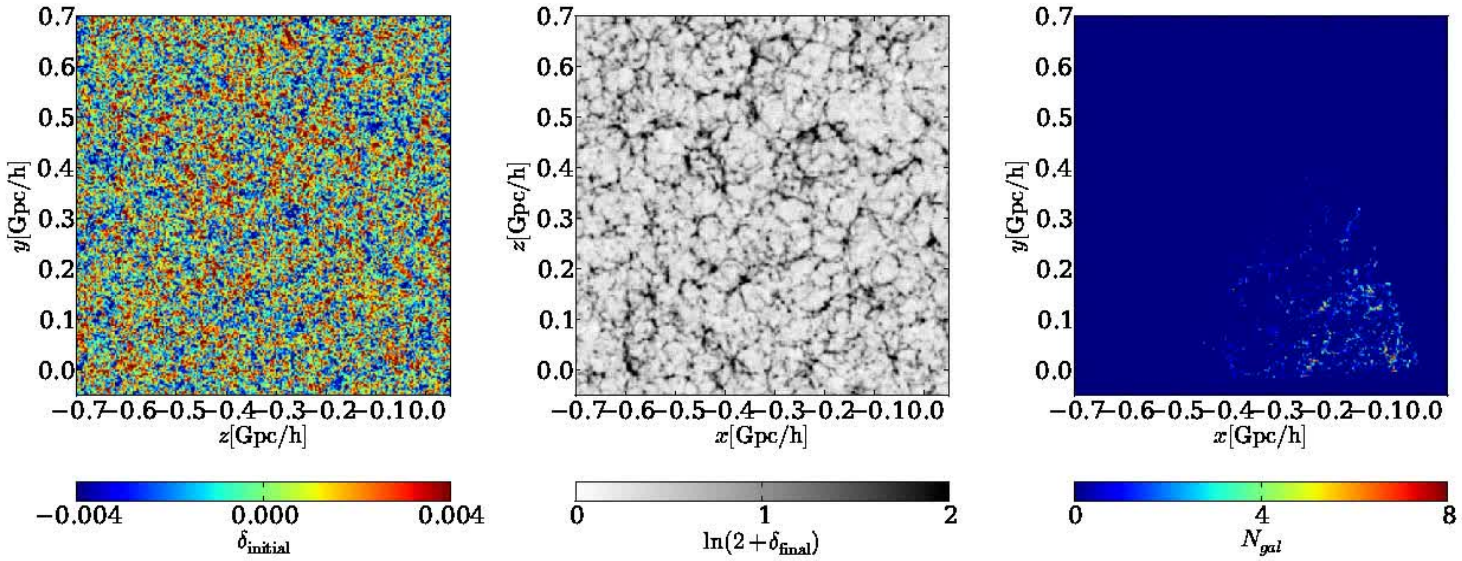
4D physical inference

- BORG (Bayesian Origin Reconstruction from Galaxies)
  - Hybrid Monte Carlo sampling
  - Second order Lagrangian perturbation theory

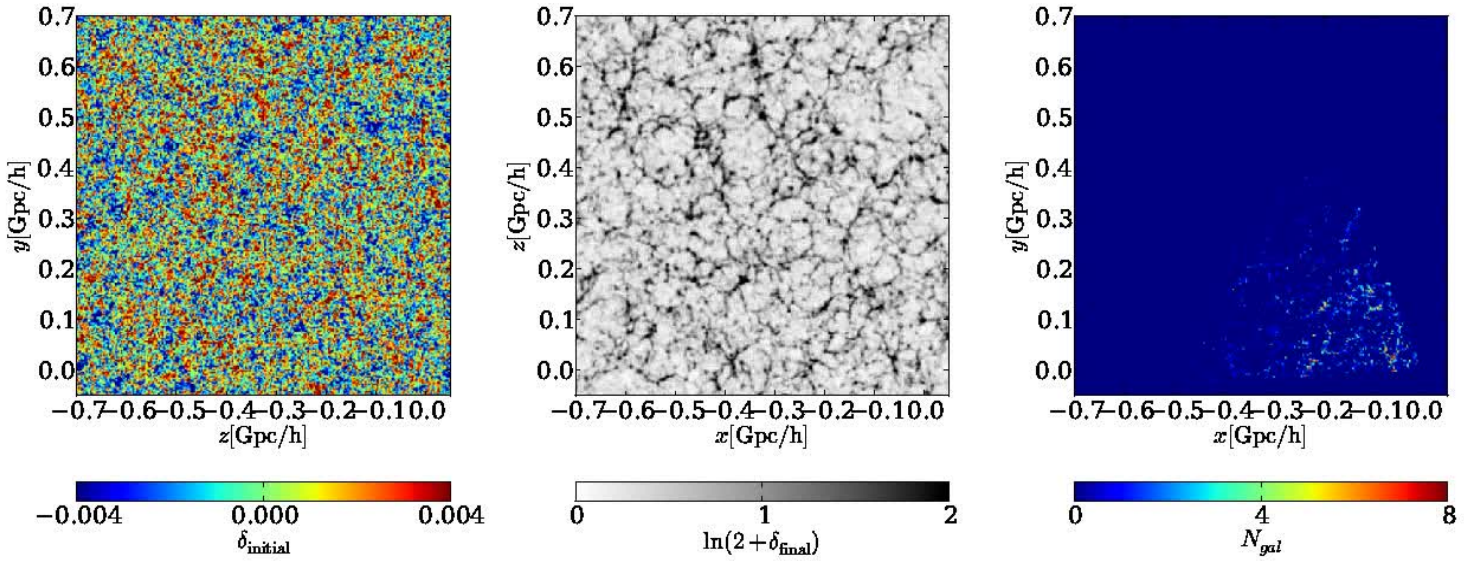


Jasche, Wandelt (2012)

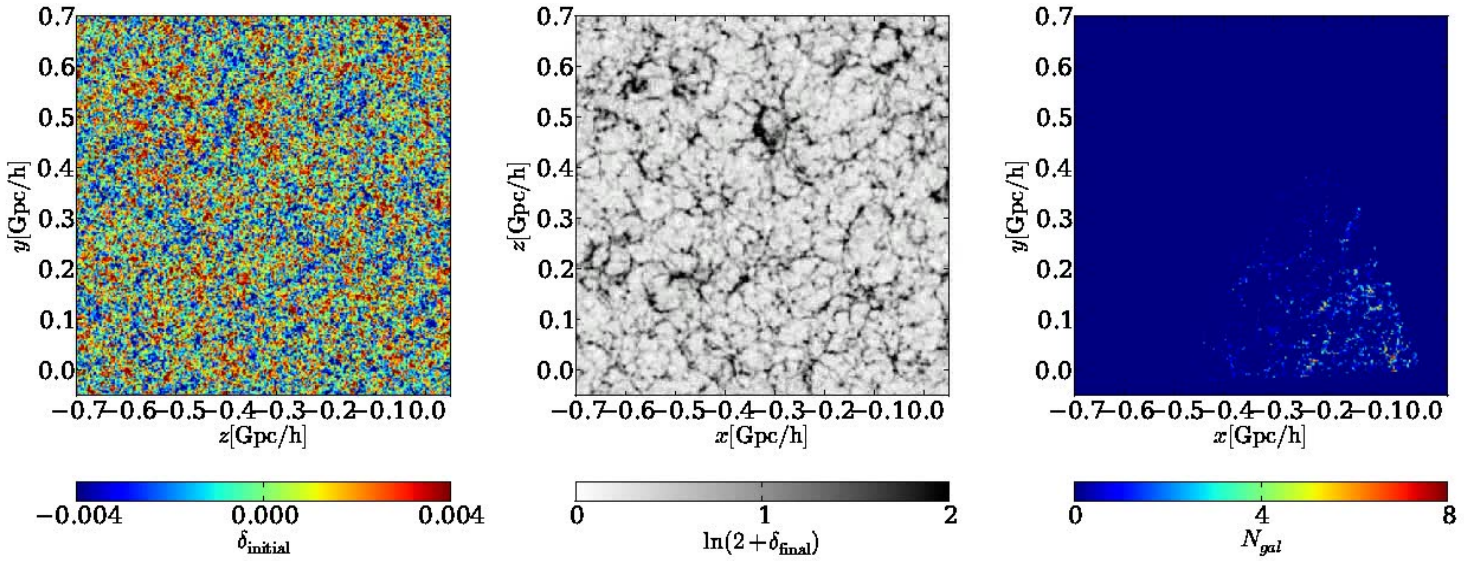
4D physical inference



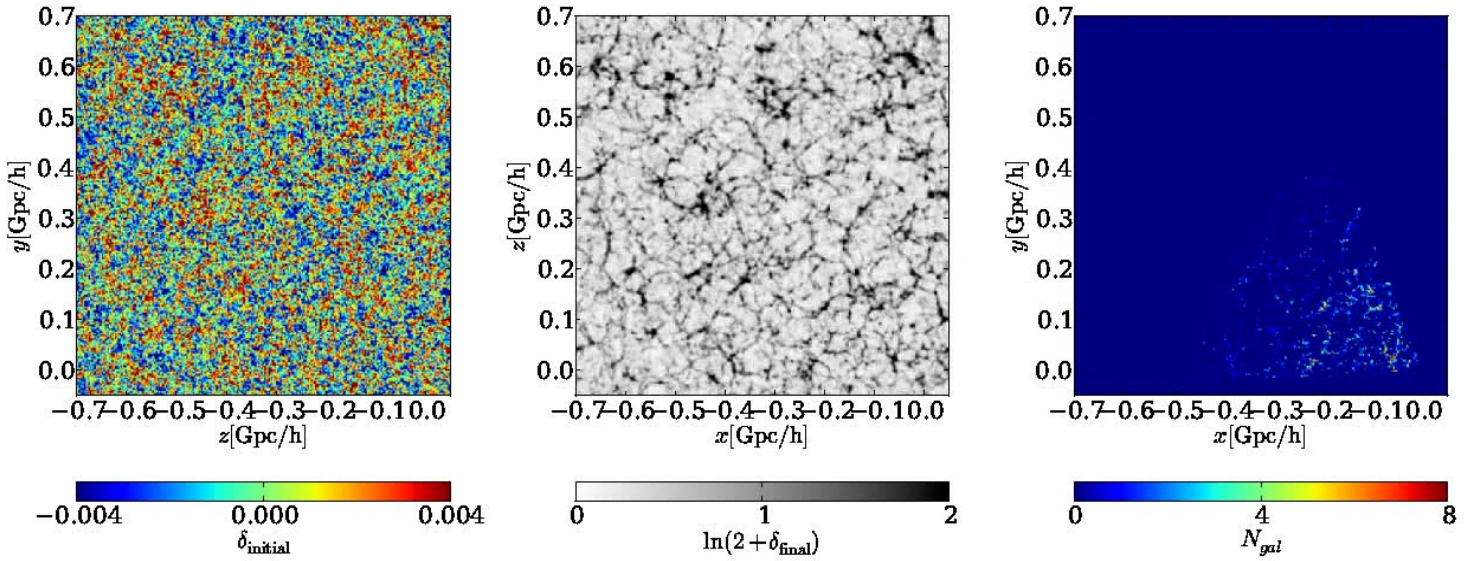
4D physical inference



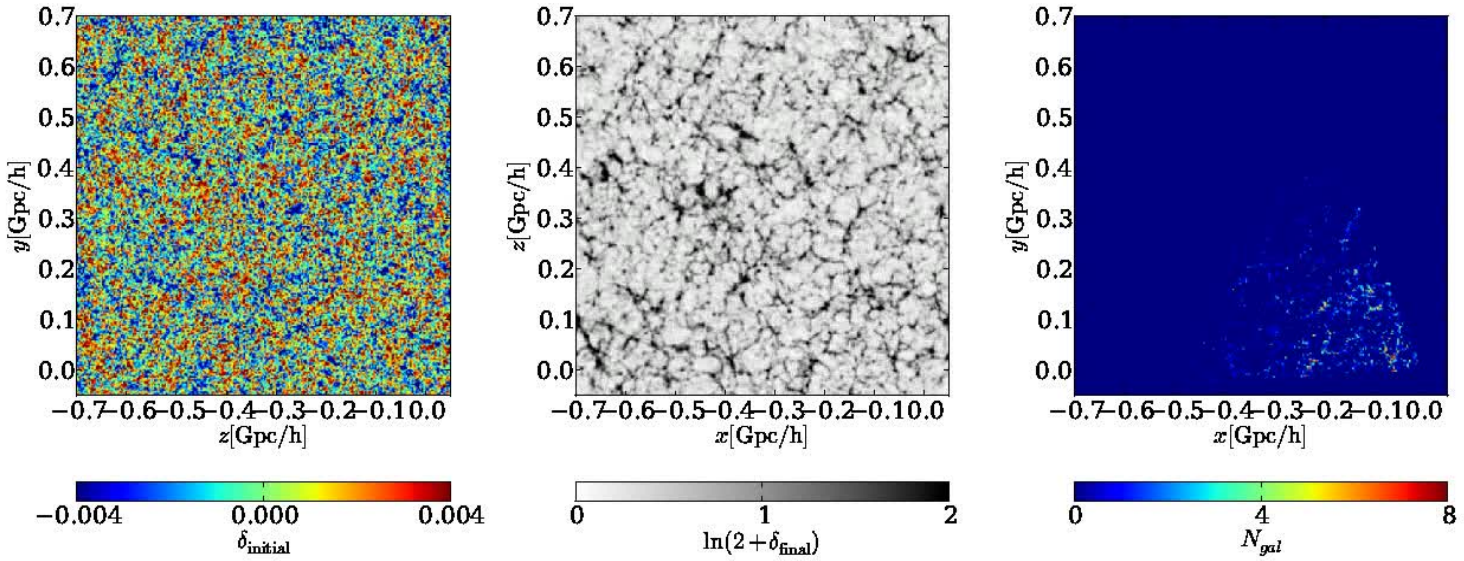
4D physical inference



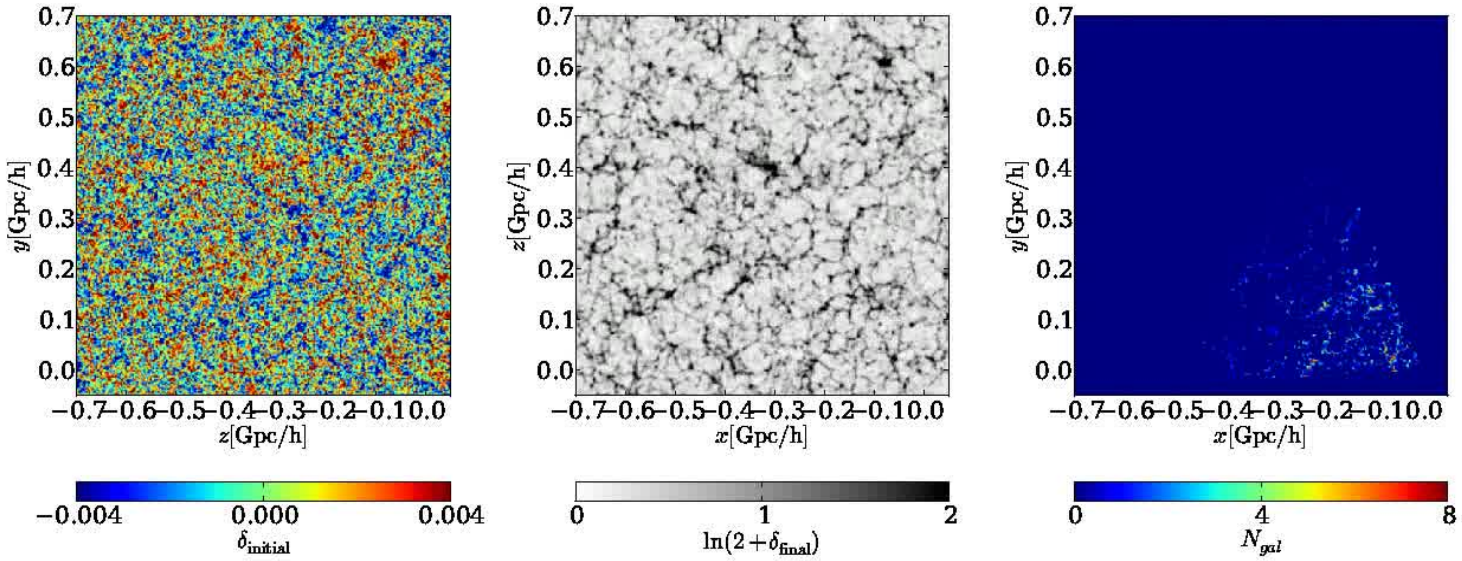
4D physical inference



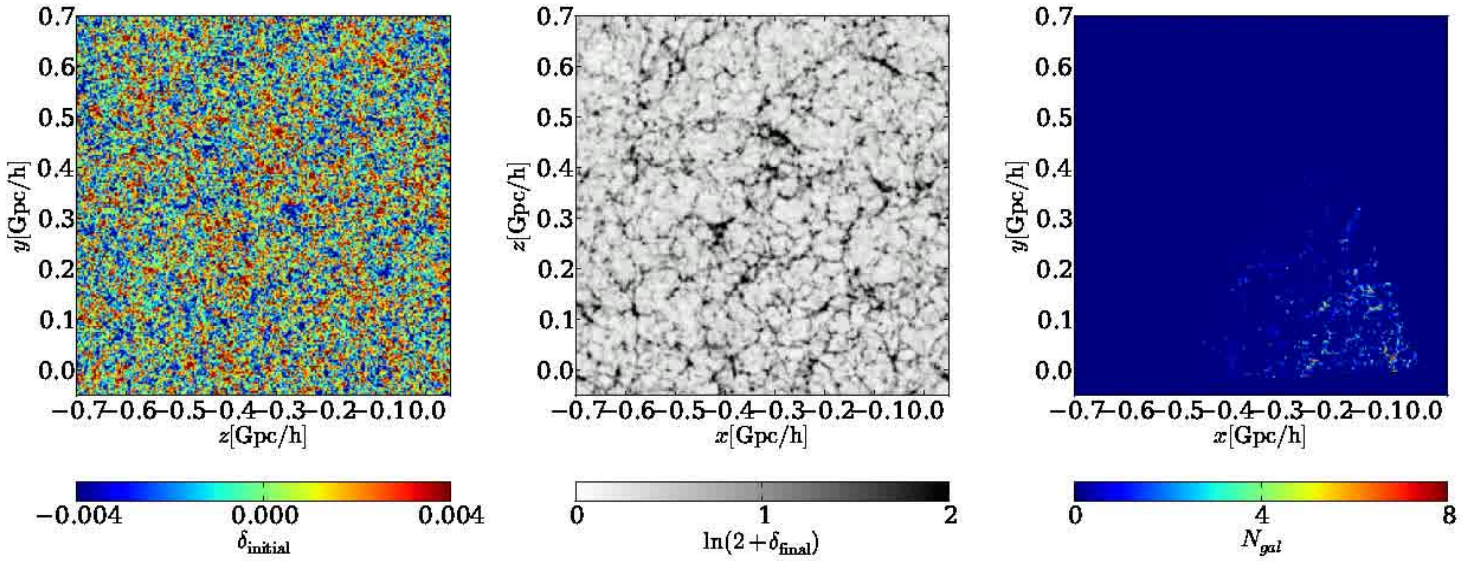
4D physical inference



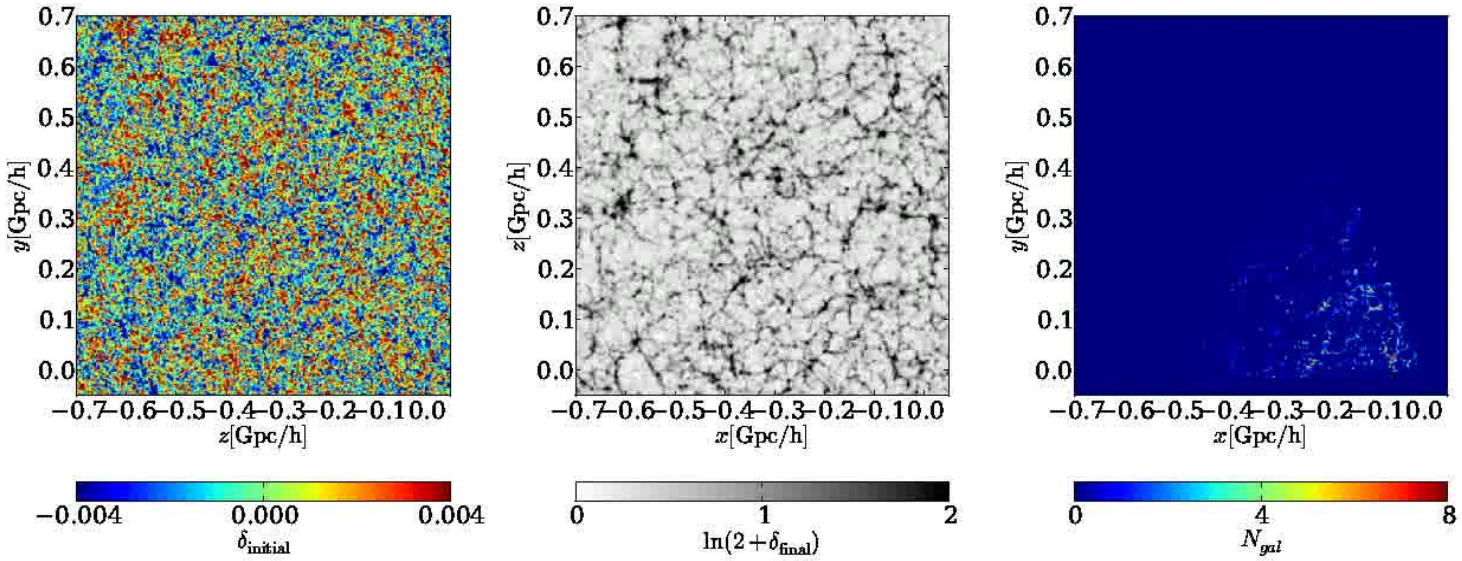
4D physical inference



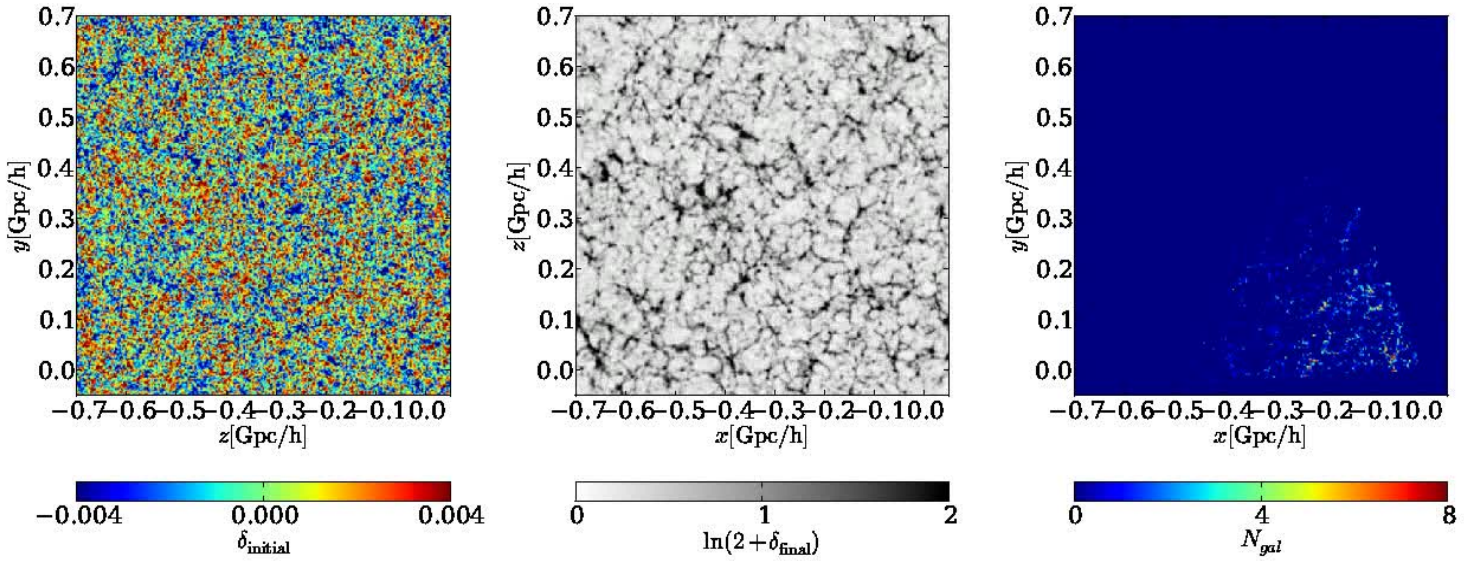
4D physical inference



4D physical inference



4D physical inference



- Cosmological applications:
  - Higher order statistics → primordial non-Gaussianity
  - 4D dynamic states → Dark Energy, ISW, kSZ
  - Physically joint analysis of data at different cosmic Epochs

Summary & Conclusion

- **Large scale Bayesian inference in ~10^7 dimensions is possible!**
  - Noise, survey geometry, selection effects and biases
  - Non-linear and non-Gaussian statistics
  - Uncertainty quantification
    - **MCMC via Hybrid Monte Carlo methods**

- Application to SDSS data
  - 3D density and velocity fields
  - Higher order statistics
  - Characterization of initial conditions
  - Dynamic information
  - Inference of structure formation history