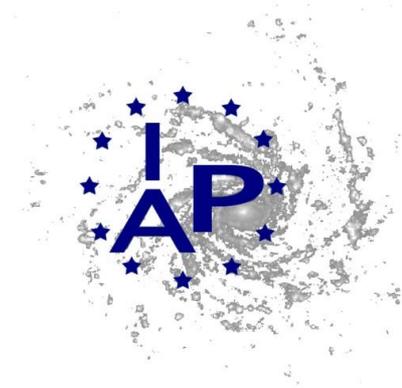


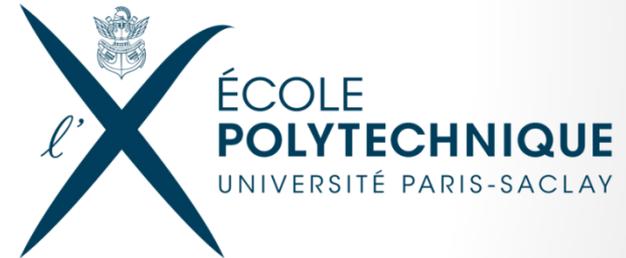
Bayesian large-scale structure inference and cosmic web analysis

Florent Leclercq

Institut d'Astrophysique de Paris
Institut Lagrange de Paris
École polytechnique ParisTech



March 5th, 2015



In collaboration with:

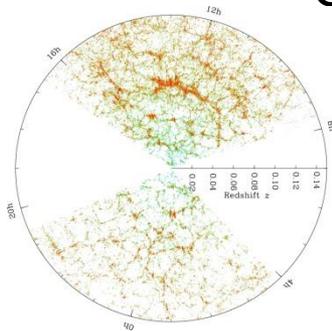
Héctor Gil-Marín (U. Portsmouth), Nico Hamaus (IAP), Jens Jasche (Excellence Cluster Universe Garching),
Alice Pisani (LAM/IAP), Emilio Romano-Díaz (U. Bonn), Paul M. Sutter (Trieste/IAP/Ohio State U.),
Benjamin Wandelt (IAP/U. Illinois), Matías Zaldarriaga (IAS Princeton)

BORG: *Bayesian Origin Reconstruction from Galaxies*

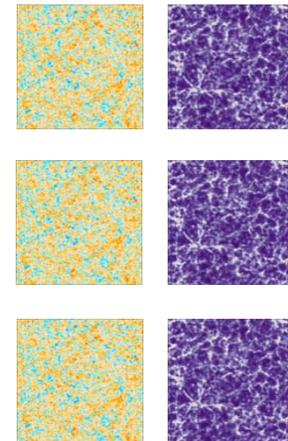
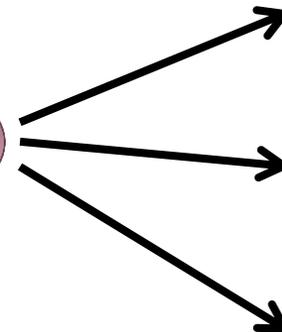


What makes the problem tractable:

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



Observations



Samples of possible 4D states

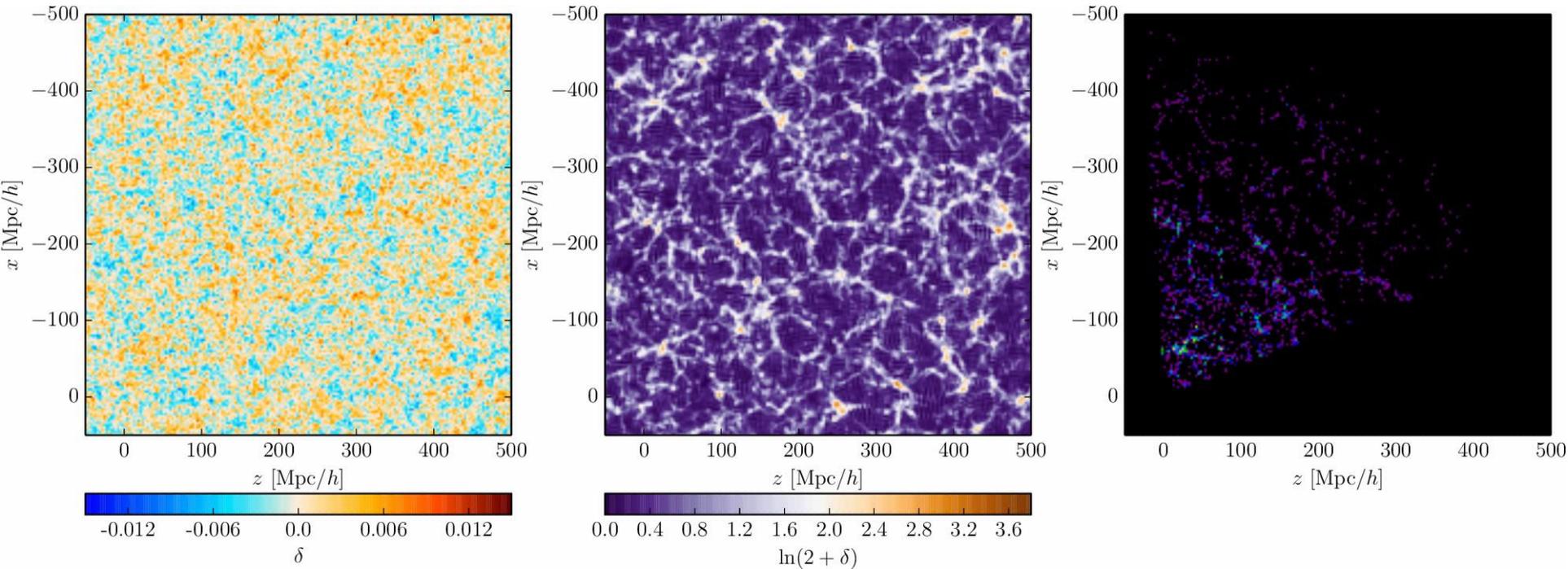
see also:

Kitaura 2013, arXiv:1203.4184

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

Jasche & Wandelt 2013, arXiv:1203.3639

BORG at work – chronocosmography



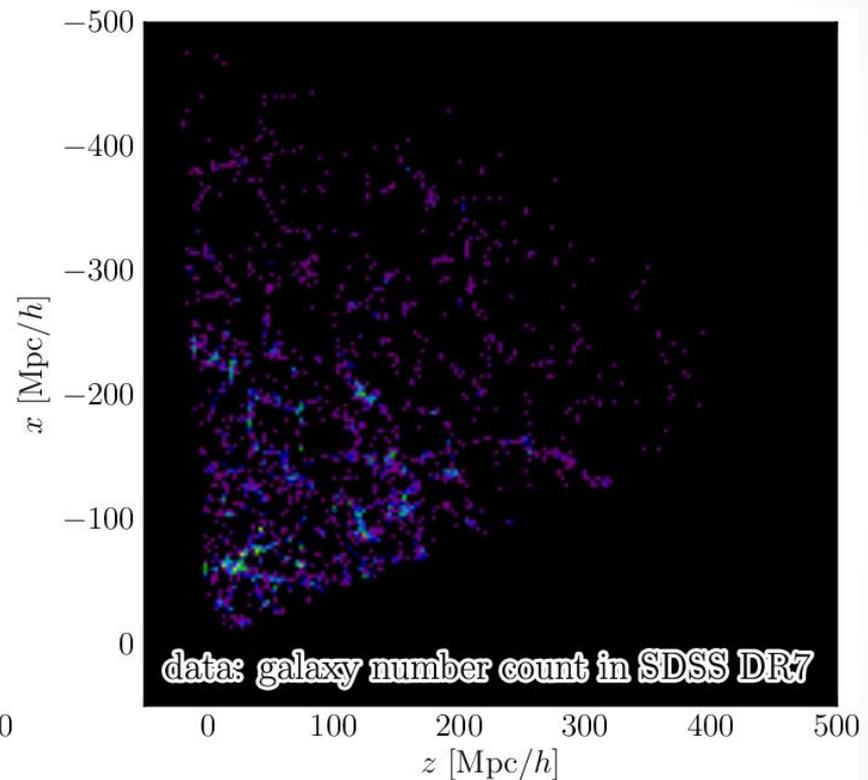
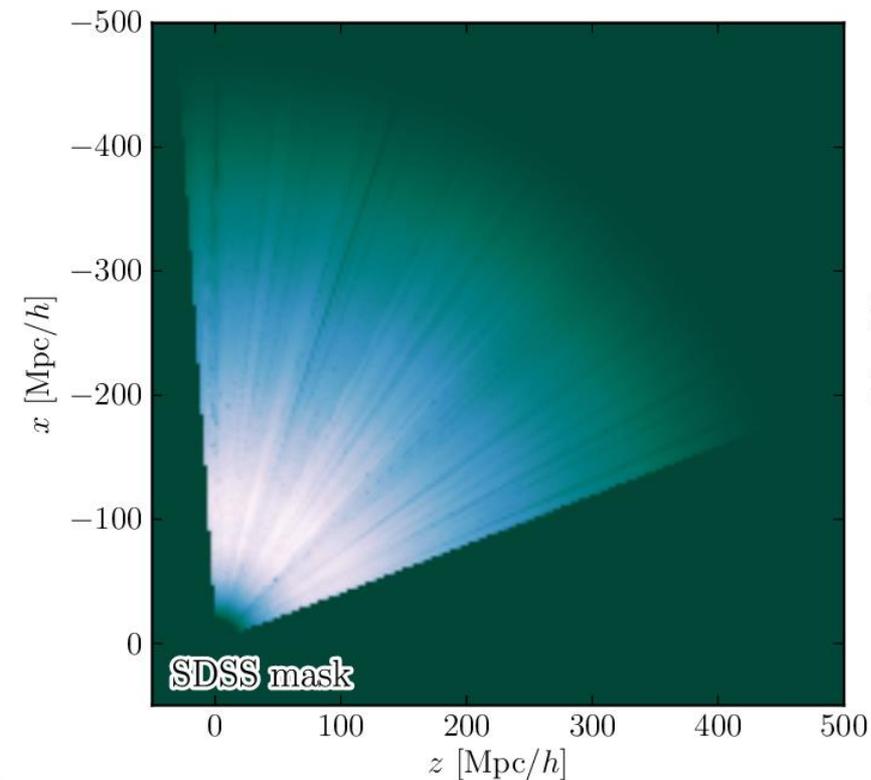
Initial conditions

Final conditions

Observations

Jasche, FL & Wandelt 2014, arXiv:1409.6308

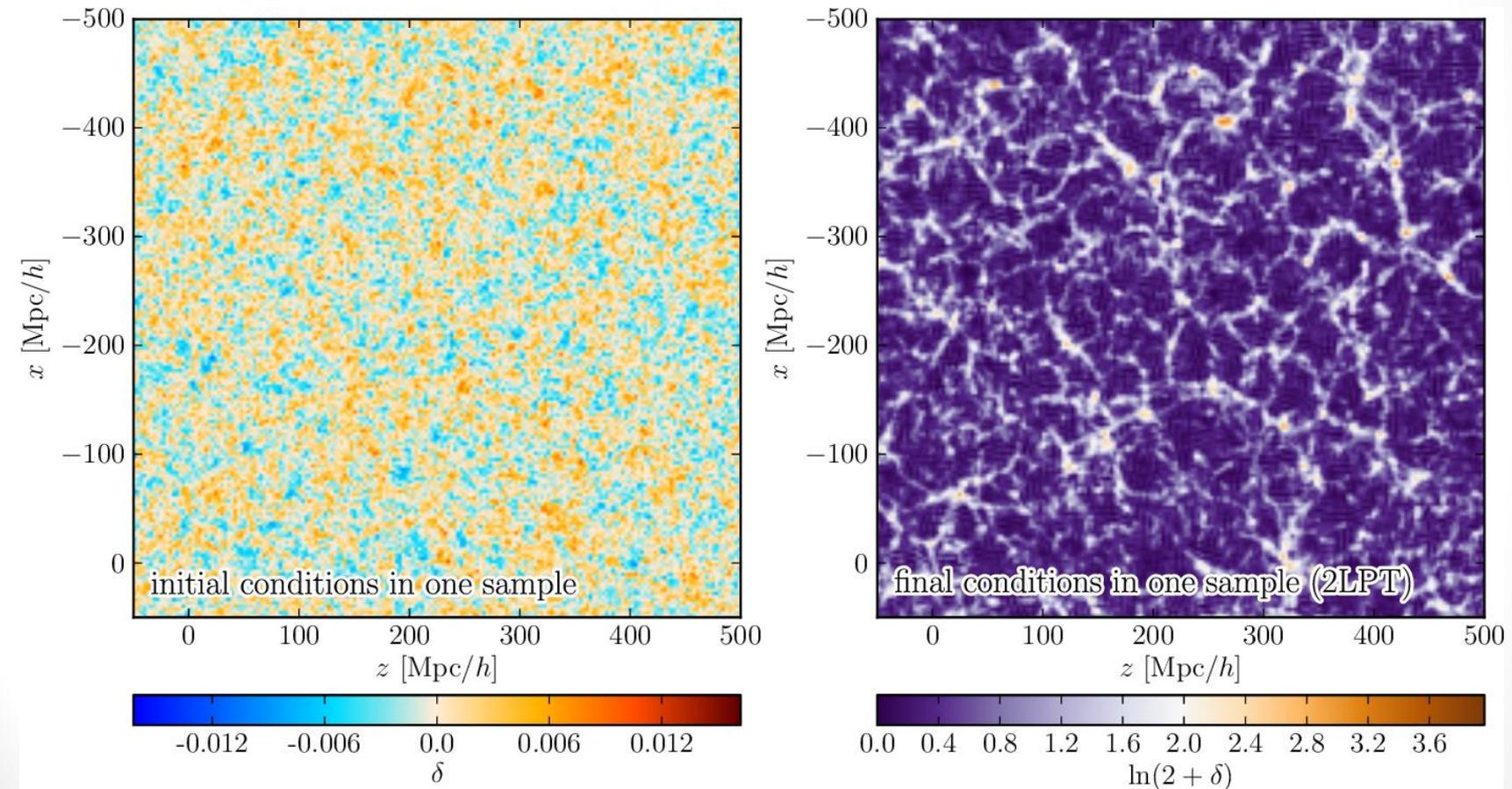
Bayesian chronocosmography from SDSS DR7



Jasche, FL & Wandelt 2014, arXiv:1409.6308

Data

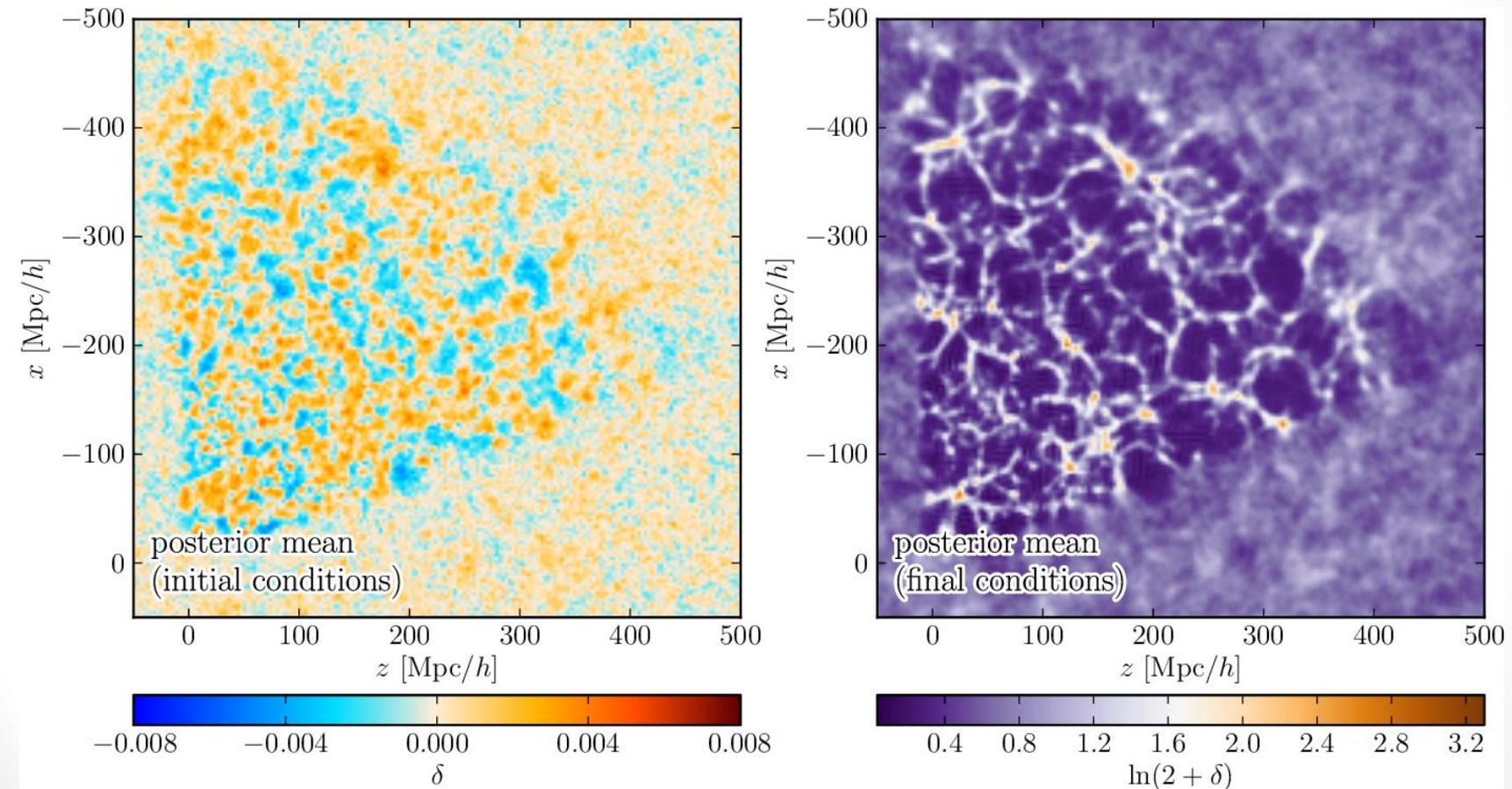
Bayesian chronocosmography from SDSS DR7



Jasche, FL & Wandelt 2014, arXiv:1409.6308

One sample

Bayesian chronocosmography from SDSS DR7



Jasche, FL & Wandelt 2014, arXiv:1409.6308

Posterior mean

Tidal shear analysis

- $\lambda_1, \lambda_2, \lambda_3$: eigenvalues of the tidal field tensor, the Hessian of the gravitational potential: $T_{ij} = \partial_i \partial_j \Phi$ $\lambda_1 + \lambda_2 + \lambda_3 = \delta$
 - 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.* 2007, arXiv:astro-ph/0610280

see also:

- Extensions:

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

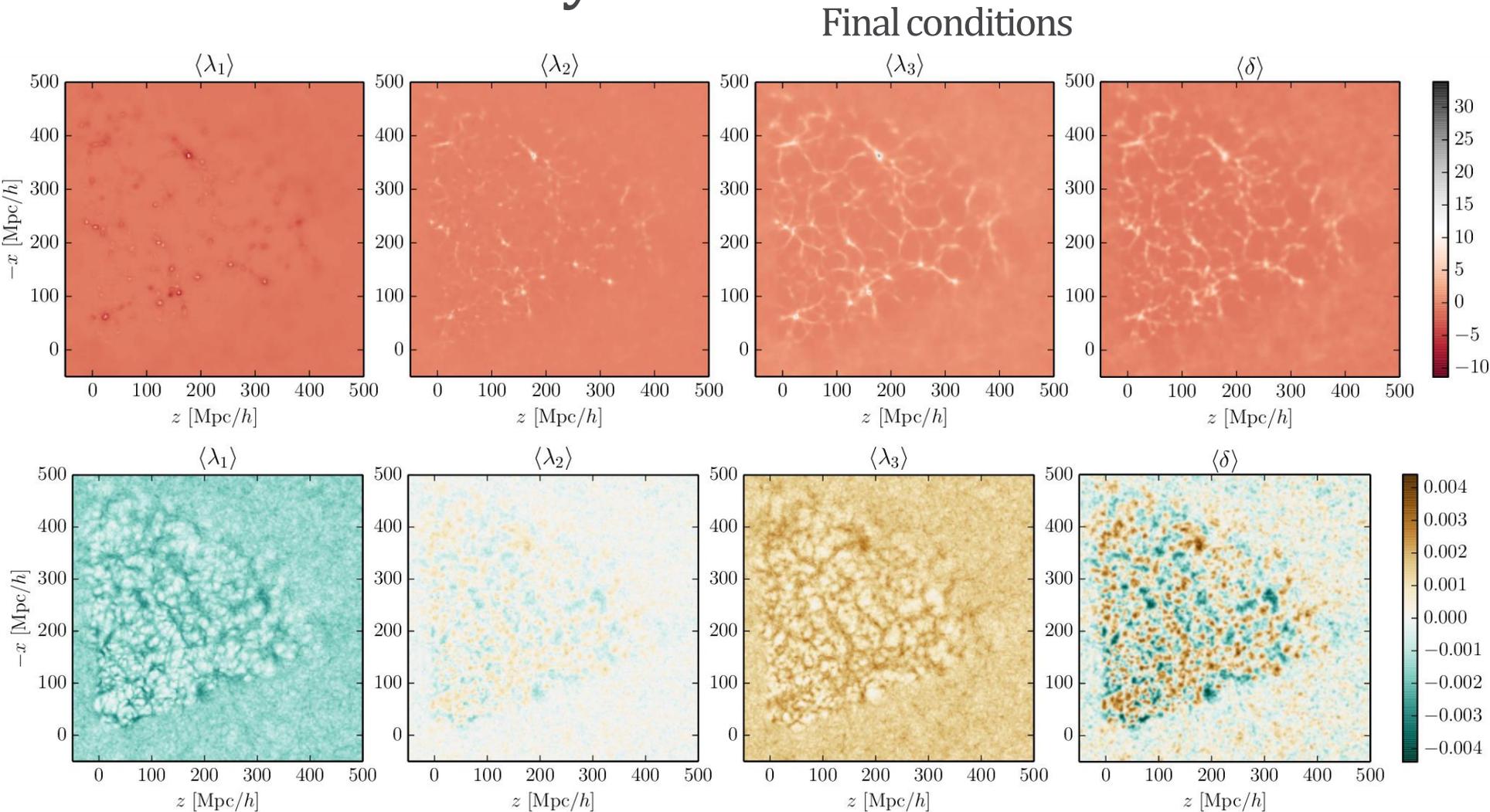
Hoffman *et al.* 2012, arXiv:1201.3367

- Similar web classifiers:

DIVA, Lavaux & Wandelt 2010, arXiv:0906.4101

ORIGAMI, Falck, Neyrinck & Szalay 2012, arXiv:1201.2353

Tidal shear analysis

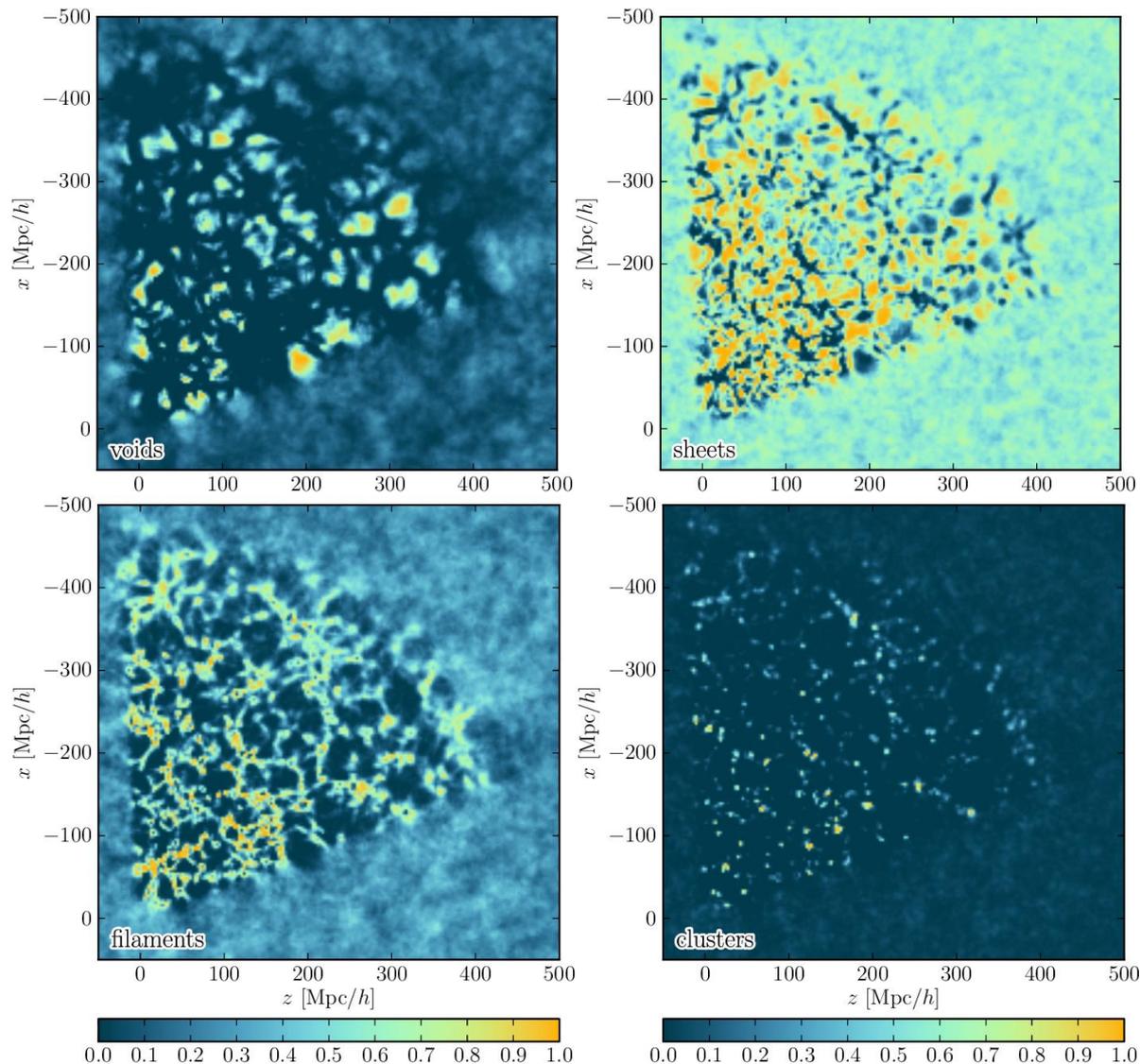


FL, Jasche & Wandelt 2015, arXiv:1502.02690

Initial conditions

Dynamic structures inferred by BORG

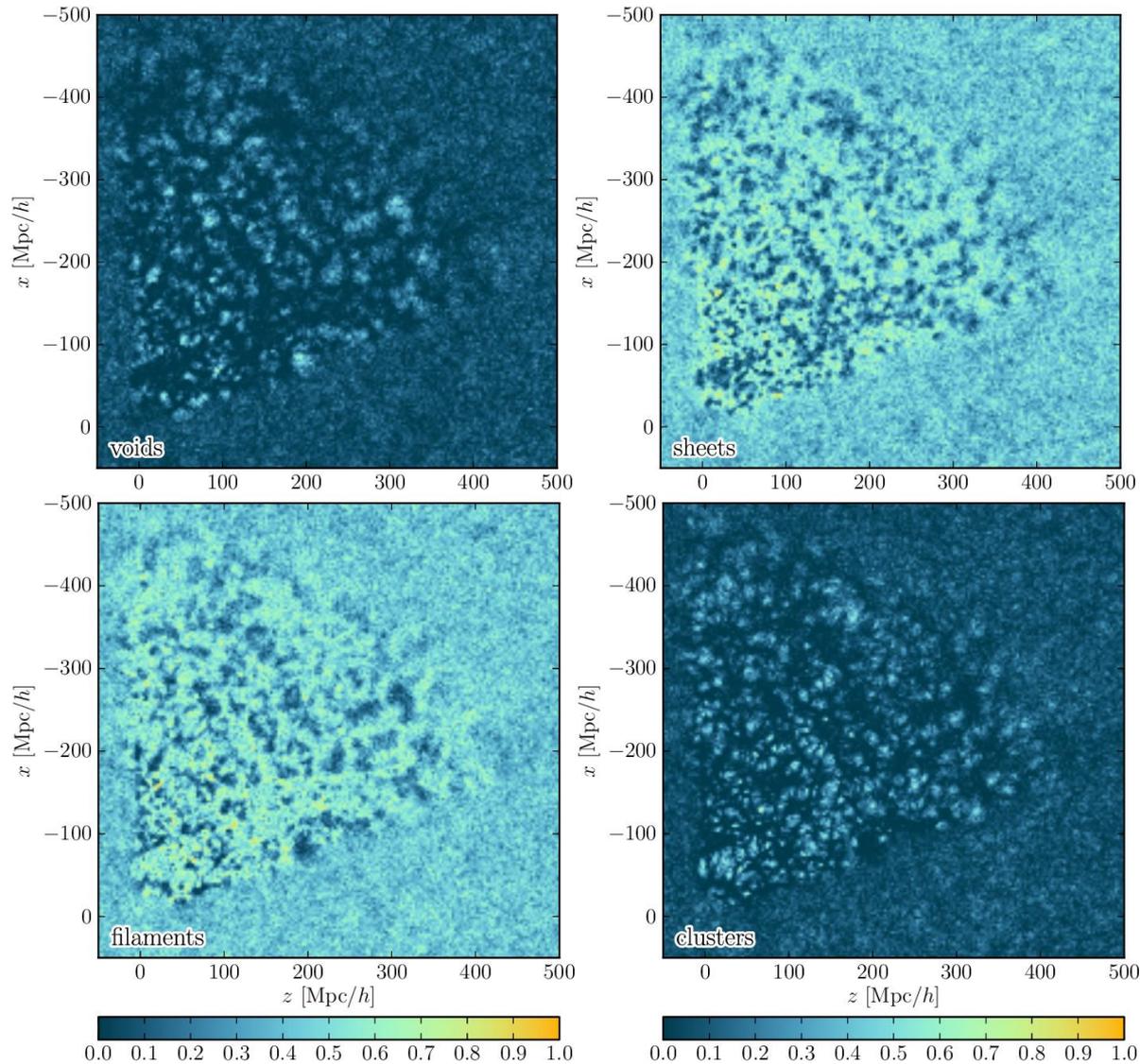
Final conditions



FL, Jasche & Wandelt 2015, arXiv:1502.02690

Dynamic structures inferred by BORG

Initial conditions



FL, Jasche & Wandelt 2015, arXiv:1502.02690

A decision rule for structure classification

- Space of “input features”:

$\{T_0 = \text{void}, T_1 = \text{sheet}, T_2 = \text{filament}, T_3 = \text{cluster}\}$

- Space of “actions”:

$\{a_0 = \text{“decide void”}, a_1 = \text{“decide sheet”}, a_2 = \text{“decide filament”}, a_3 = \text{“decide cluster”}, a_{-1} = \text{“do not decide”}\}$



A problem of **Bayesian decision theory**:

one should take the action which maximizes the utility

$$U(a_j(\vec{x}_k)|d) = \sum_{i=0}^3 G(a_j|T_i) \mathcal{P}(T_i(\vec{x}_k)|d)$$

- How to write down the gain functions?

Gambling with the Universe

- One proposal:

$$G(a_j | \mathbf{T}_i) = \begin{cases} \frac{1}{\mathcal{P}(\mathbf{T}_i)} - \alpha & \text{if } j \in \llbracket 0, 3 \rrbracket \text{ and } i = j & \text{“Winning”} \\ -\alpha & \text{if } j \in \llbracket 0, 3 \rrbracket \text{ and } i \neq j & \text{“Loosing”} \\ 0 & \text{if } j = -1. & \text{“Not playing”} \end{cases}$$

- Without data, the expected utility is

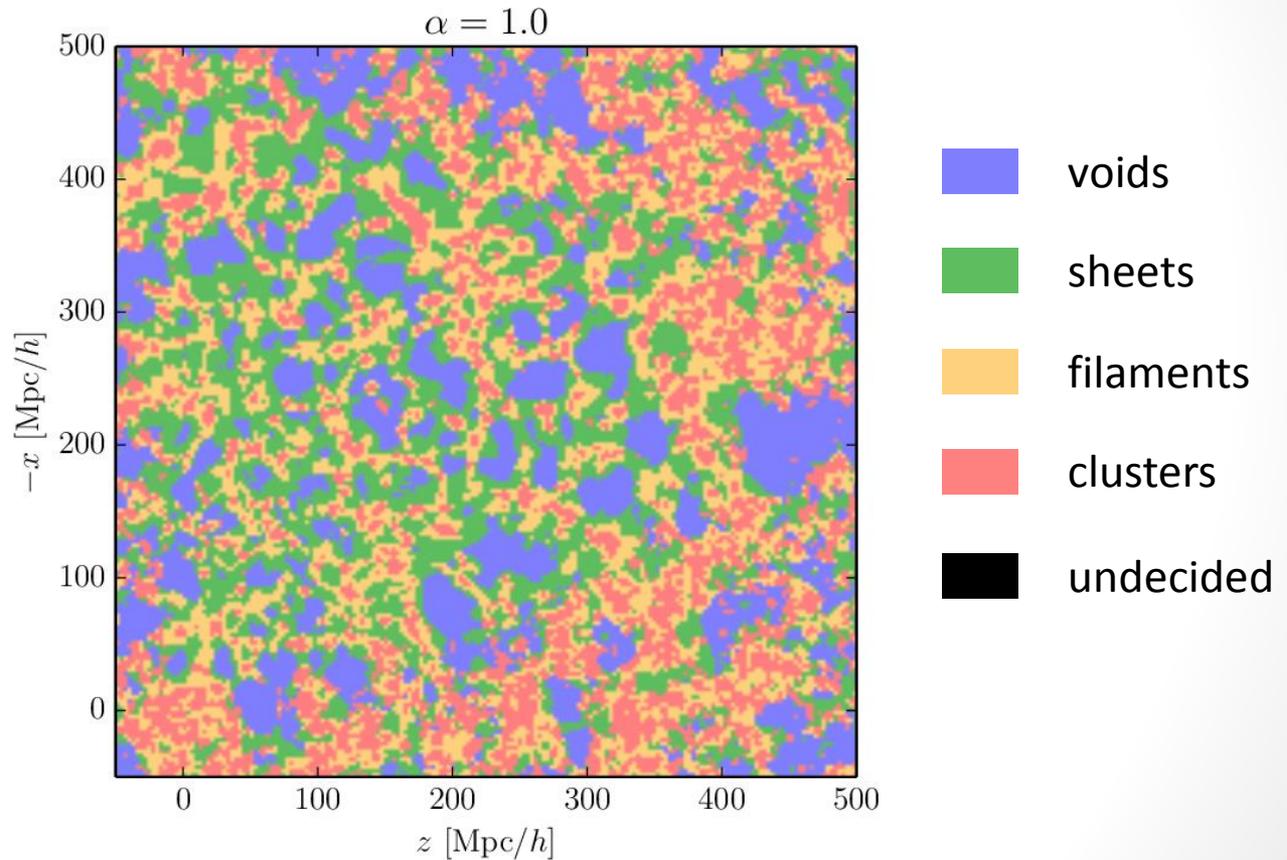
$$U(a_j) = 1 - \alpha \quad \text{if } j \neq -1 \quad \text{“Playing the game”}$$

$$U(a_{-1}) = 0 \quad \text{“Not playing the game”}$$

- With $\alpha = 1$, it's a *fair game* \Rightarrow always play \Rightarrow “speculative map” of the LSS
- Values $\alpha > 1$ represent an *aversion for risk* \Rightarrow increasingly “conservative maps” of the LSS

Playing the game...

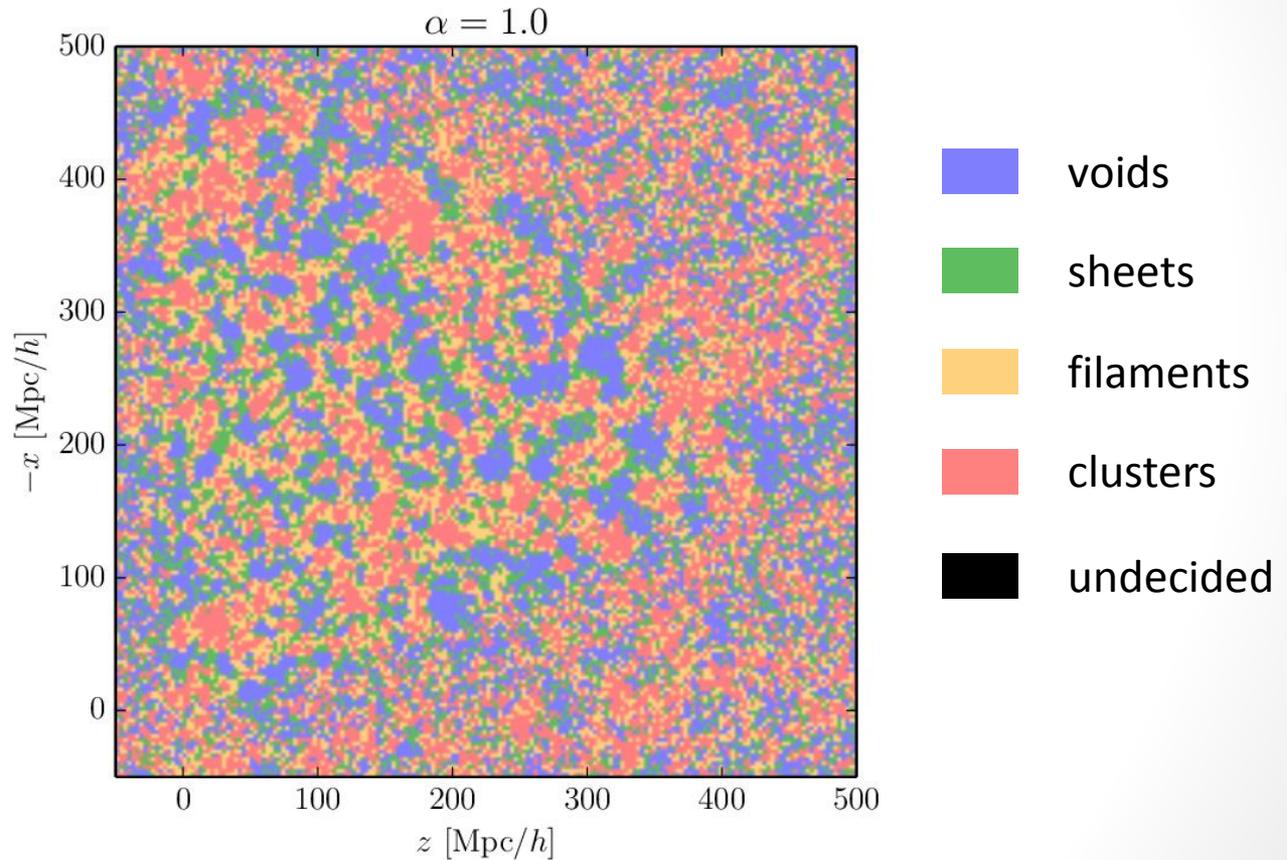
Final conditions



FL, Jasche & Wandelt 2015, arXiv:1503.00730

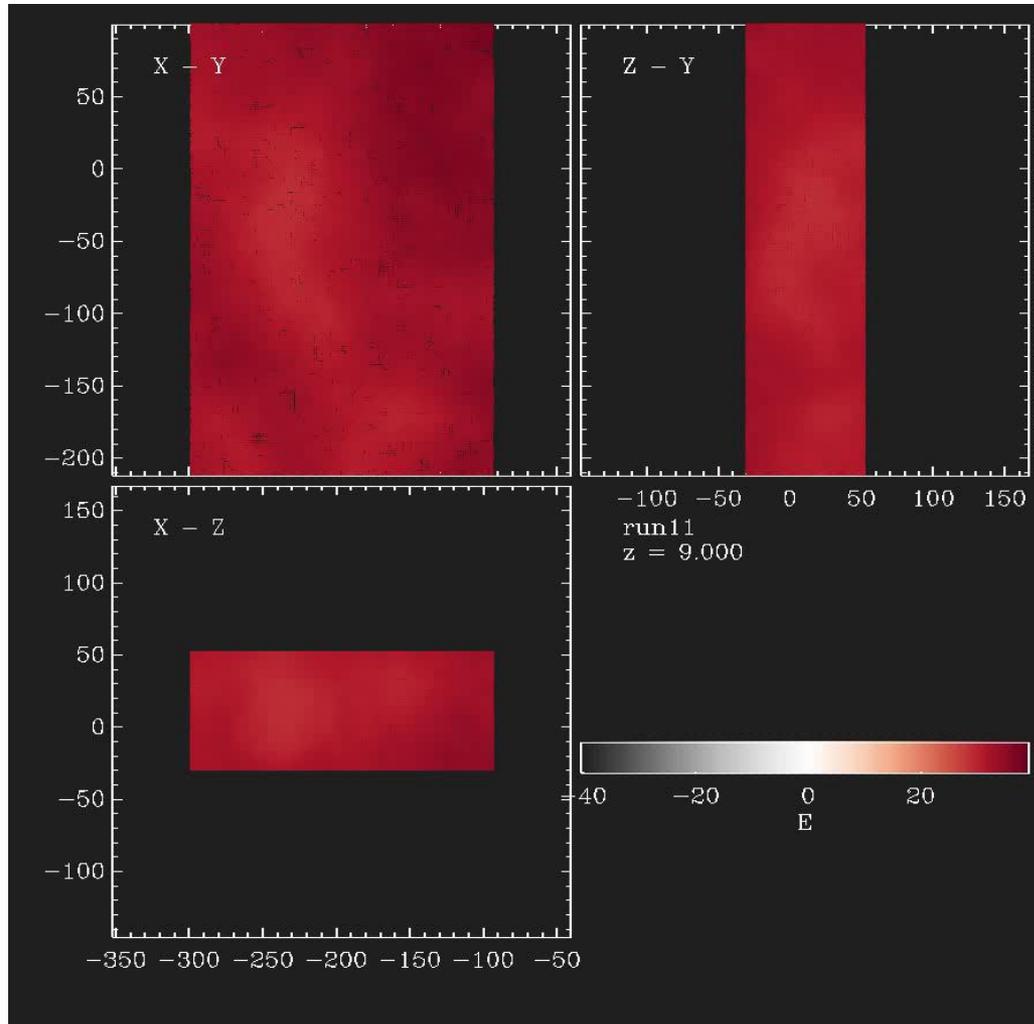
Playing the game...

Initial conditions



FL, Jasche & Wandelt 2015, arXiv:1503.00730

The Sloan Great Wall through Bayesian eyes



The Sloan Great Wall:

Gott *et al.* 2005, arXiv:astro-ph/0310571

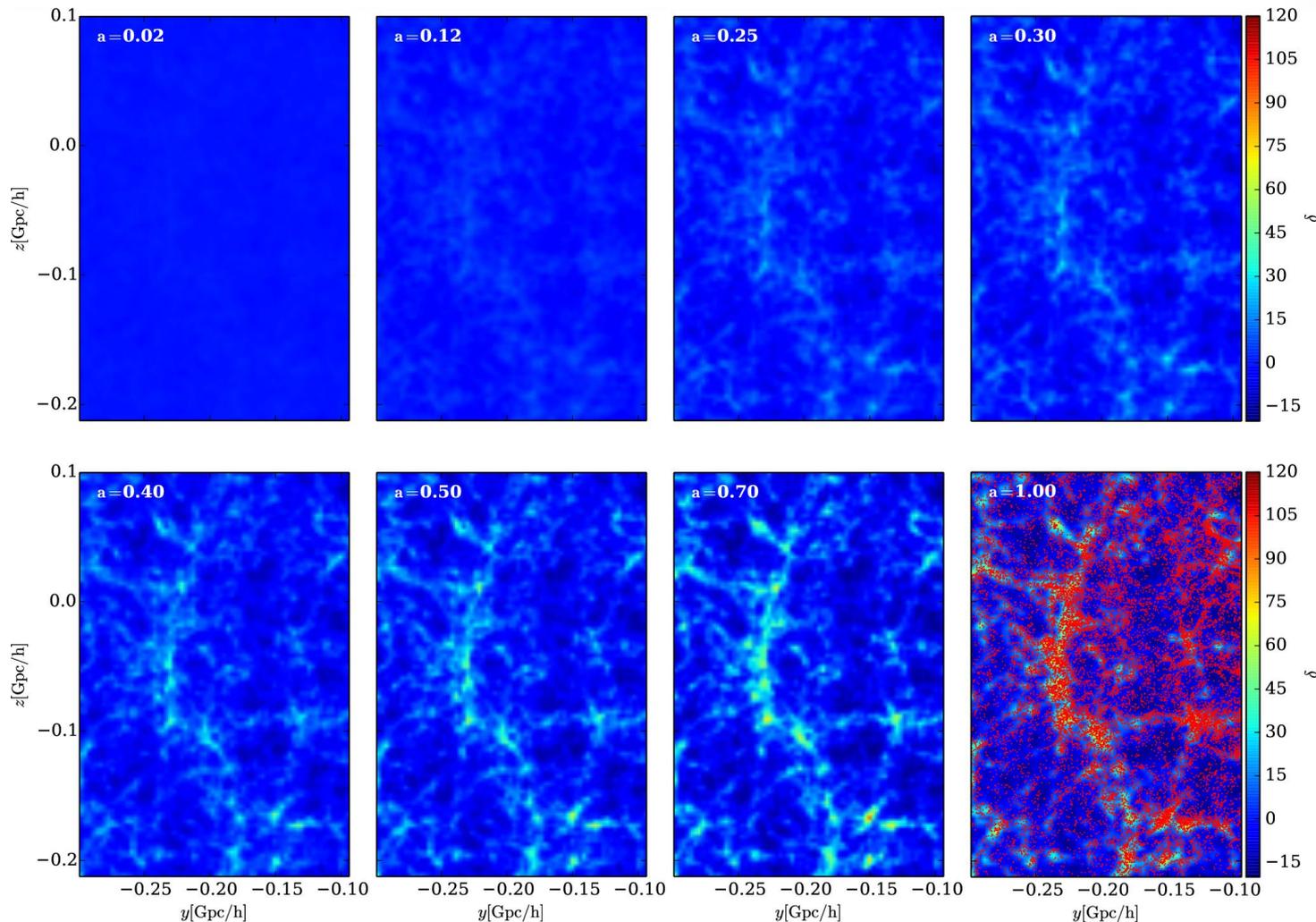
Nichol *et al.* 2006, arXiv:astro-ph/0602548

Einasto *et al.* 2010, arXiv:1007.4492

Einasto *et al.* 2011, arXiv:1105.1632

Jasche, Romano-Díaz, FL & Wandelt 2015, in prep.

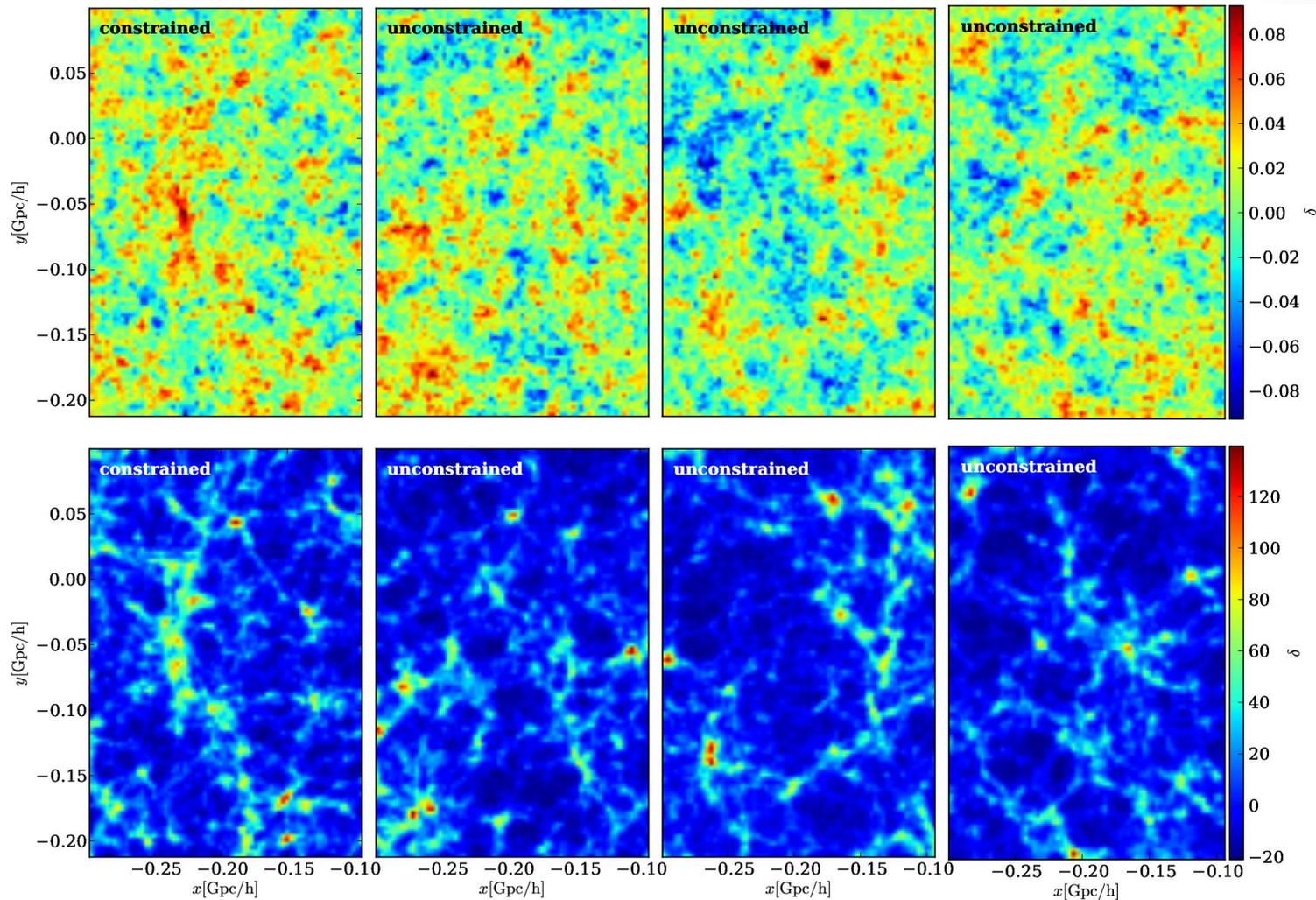
The formation history of the SGW



Jasche, Romano-Díaz, FL & Wandelt 2015, in prep.

Is the SGW special in Λ CDM?

Sylos Labini *et al.* 2009, arXiv:0909.0132



Jasche, Romano-Díaz, FL & Wandelt 2015, in prep.