

# Non-linear bayesian inference of cosmic fields in SDSS3 and 2M++

Guilhem Lavaux (IAP/CNRS)  
and Aquila Consortium

Statistical Challenge for large-scale structure in the era of LSST  
(Oxford 2018)

# Outline



**The statistical framework**



**The 2M++ compilation**

**(presentation, clusters, velocity fields, applications)**



**SDSS3 BOSS**

**(more modeling challenges, density field)**



**Conclusion**

# From theory to observations...

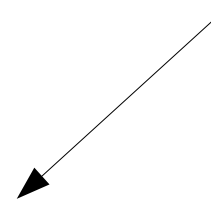
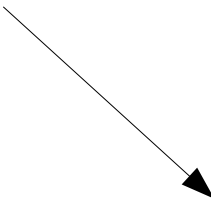
## Model

- Perfect
- Complete description
- Full knowledge of physics
- Did I say perfect ?

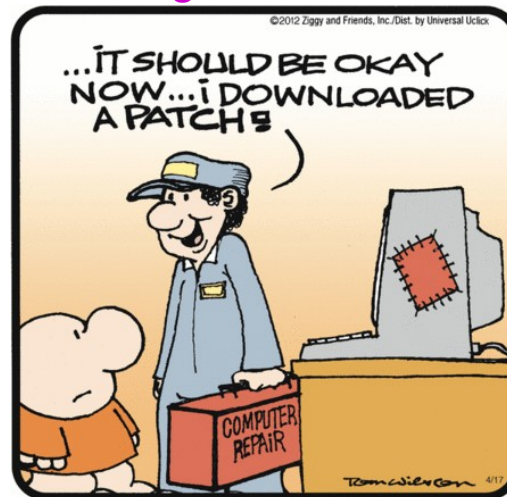


## Observations

- Great but messy
- We do not understand the physics
- Systematics not fully known
- Good attempt by observers to seemingly make our life easier end up bad



Various hacking to make sense of data



# From theory to observations...

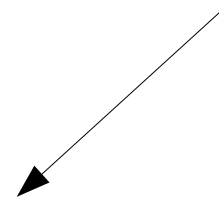
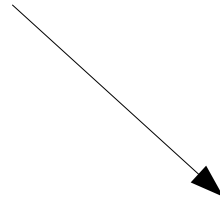
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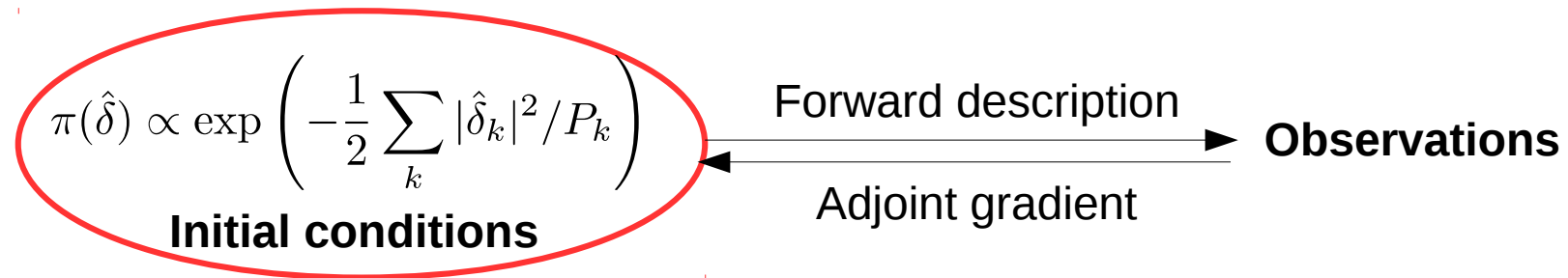
**BORG3**

Still far too perfect though... (see later)



Another perspective to automatically solve this problem: see Tom Charnock's talk

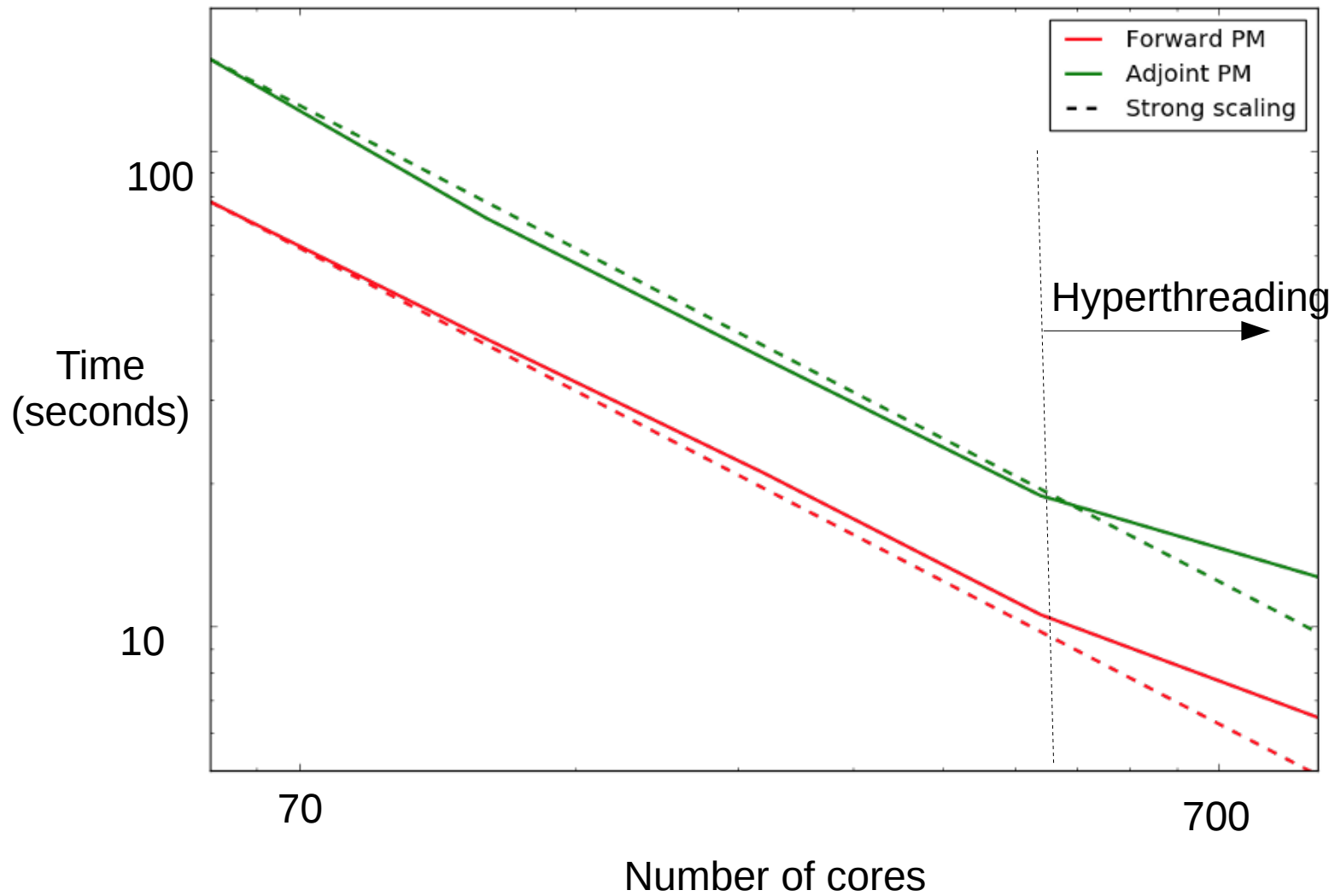
# The BORG3 inference framework



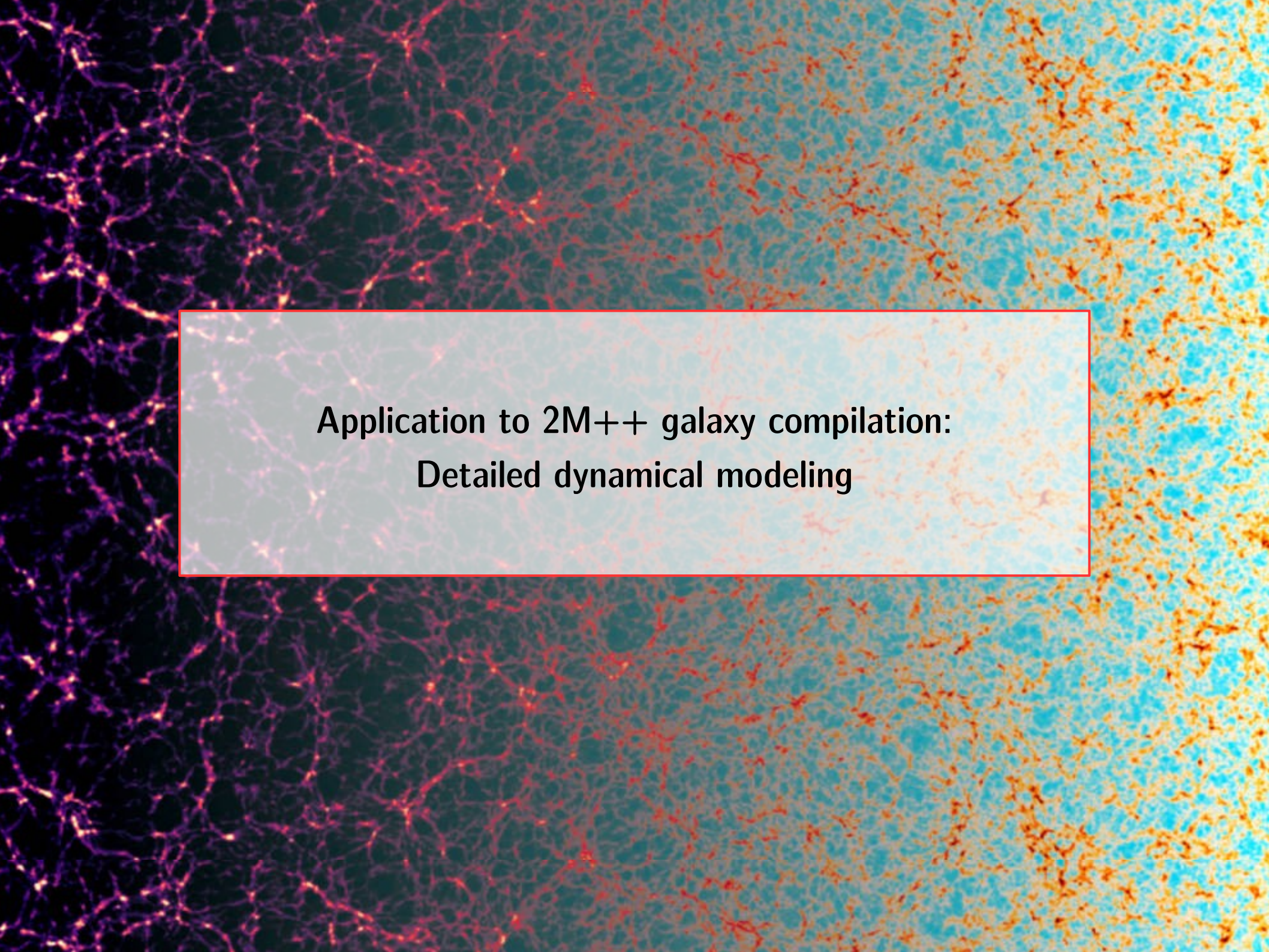
Encode survey systematic effects  
with expansions:

$$S(\hat{x}) = S_0(\hat{x}) \prod_{f=1}^N (1 + \alpha_f F_f(\hat{x}))$$

# BORG-PM Performance aspect

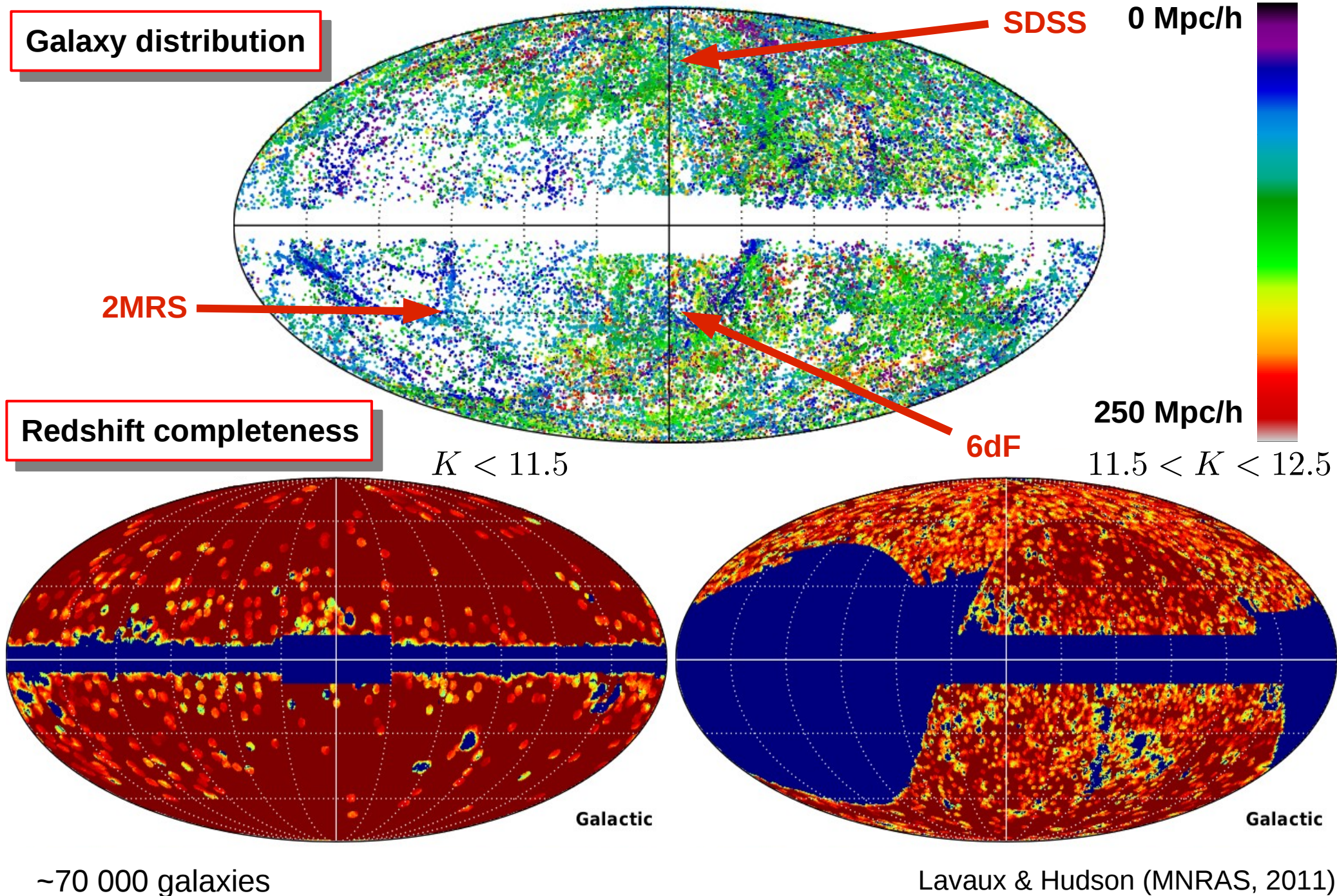


BORG-(2)LPT is ~20 times faster

A visualization of the cosmic web, showing a complex network of filaments and nodes. The filaments are colored in shades of purple, red, and orange, while the nodes are bright yellow and white. The background is a gradient of blue and cyan.

**Application to 2M++ galaxy compilation:  
Detailed dynamical modeling**

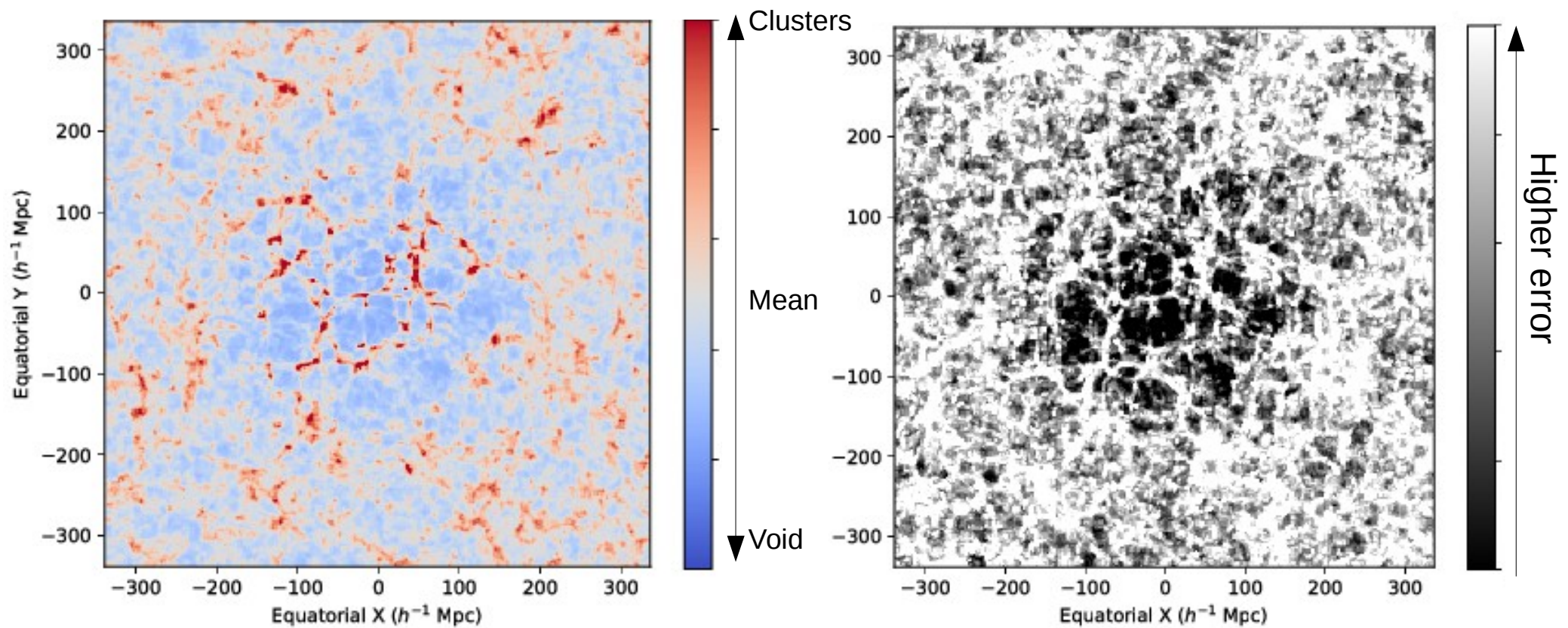
# The 2M++ galaxy compilation



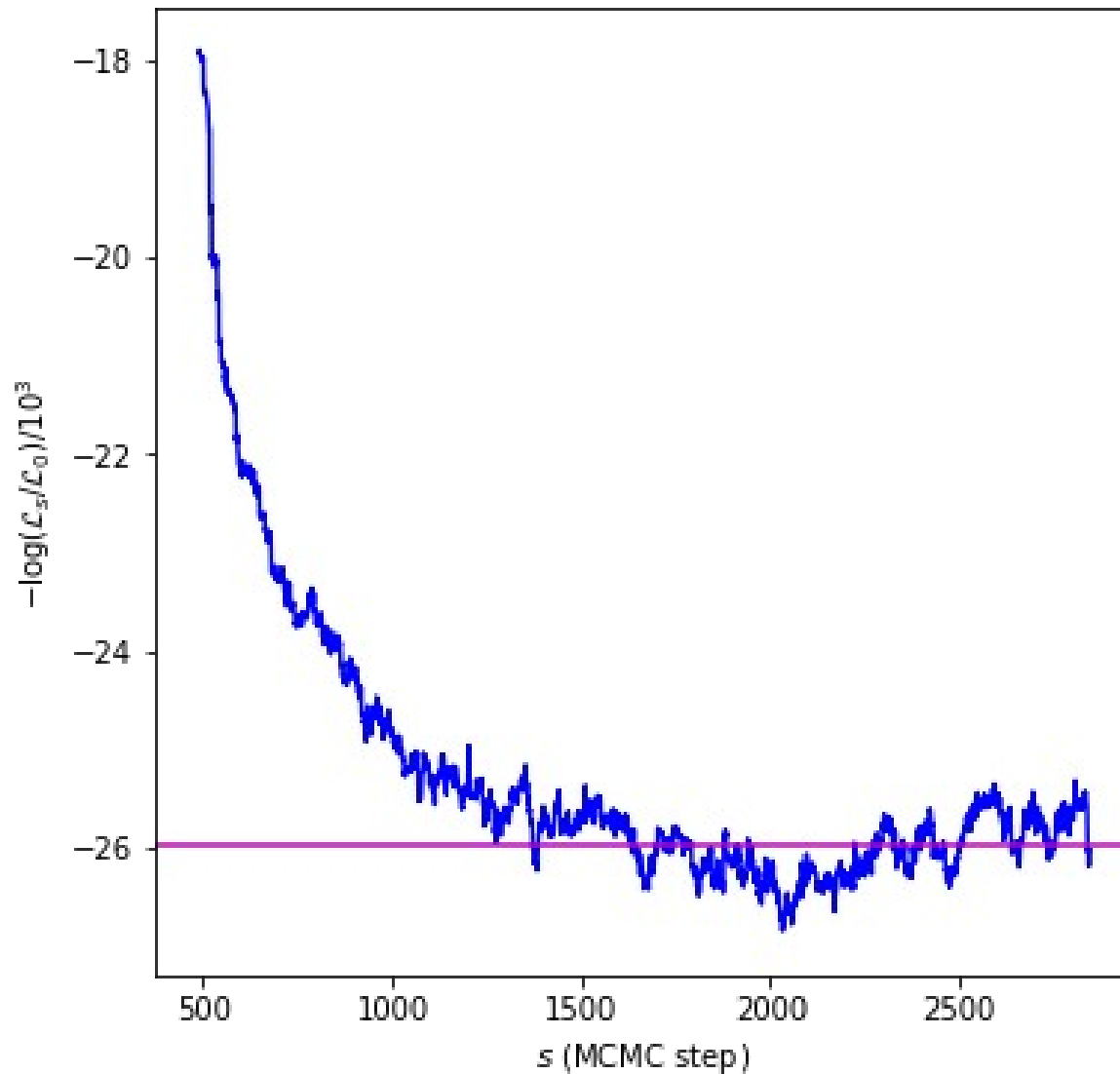


# Inferred density fields

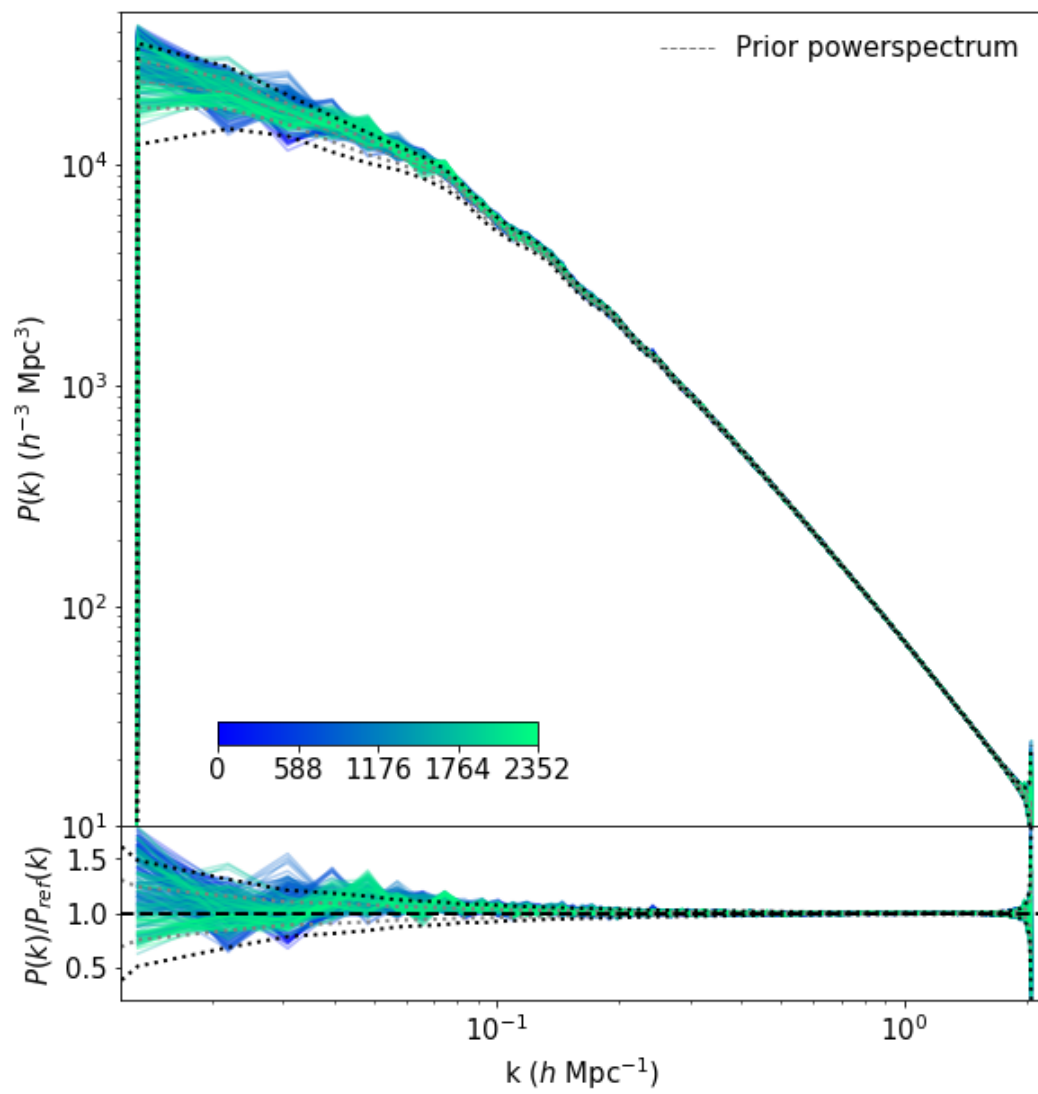
Ensemble average density fields at  $z=0$



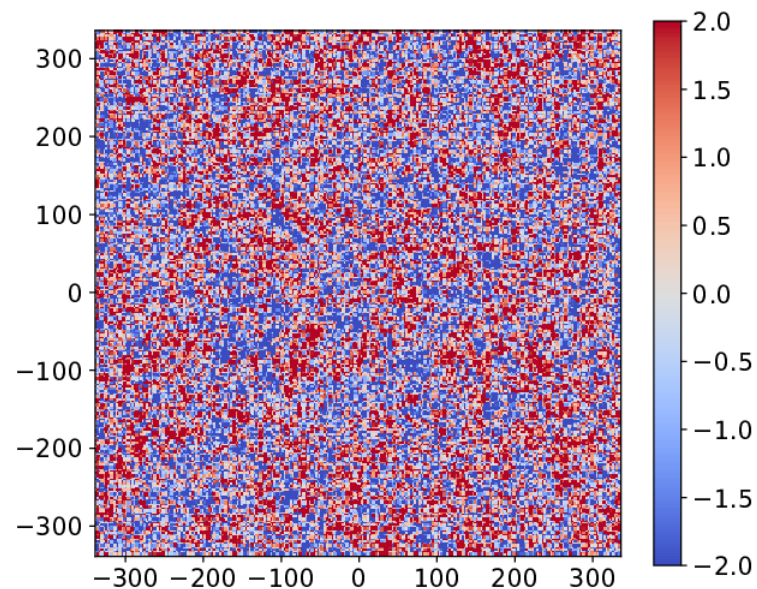
# Performance aspect (2): burnin



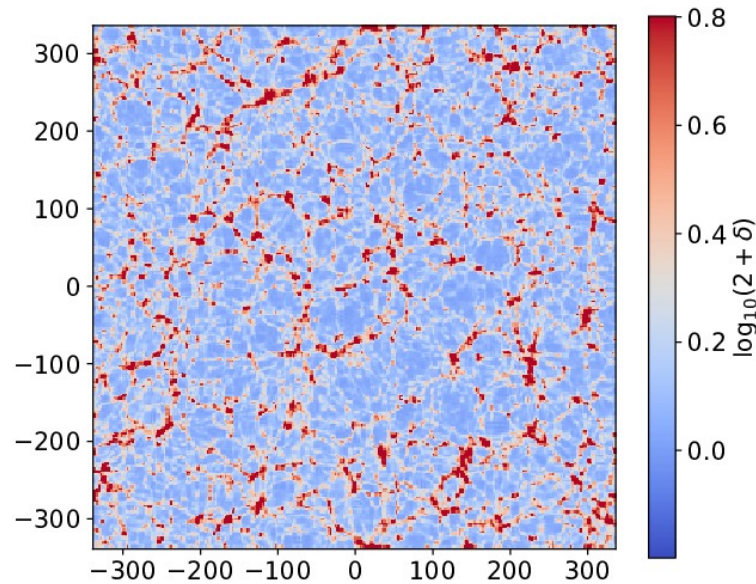
# Initial condition powerspectrum



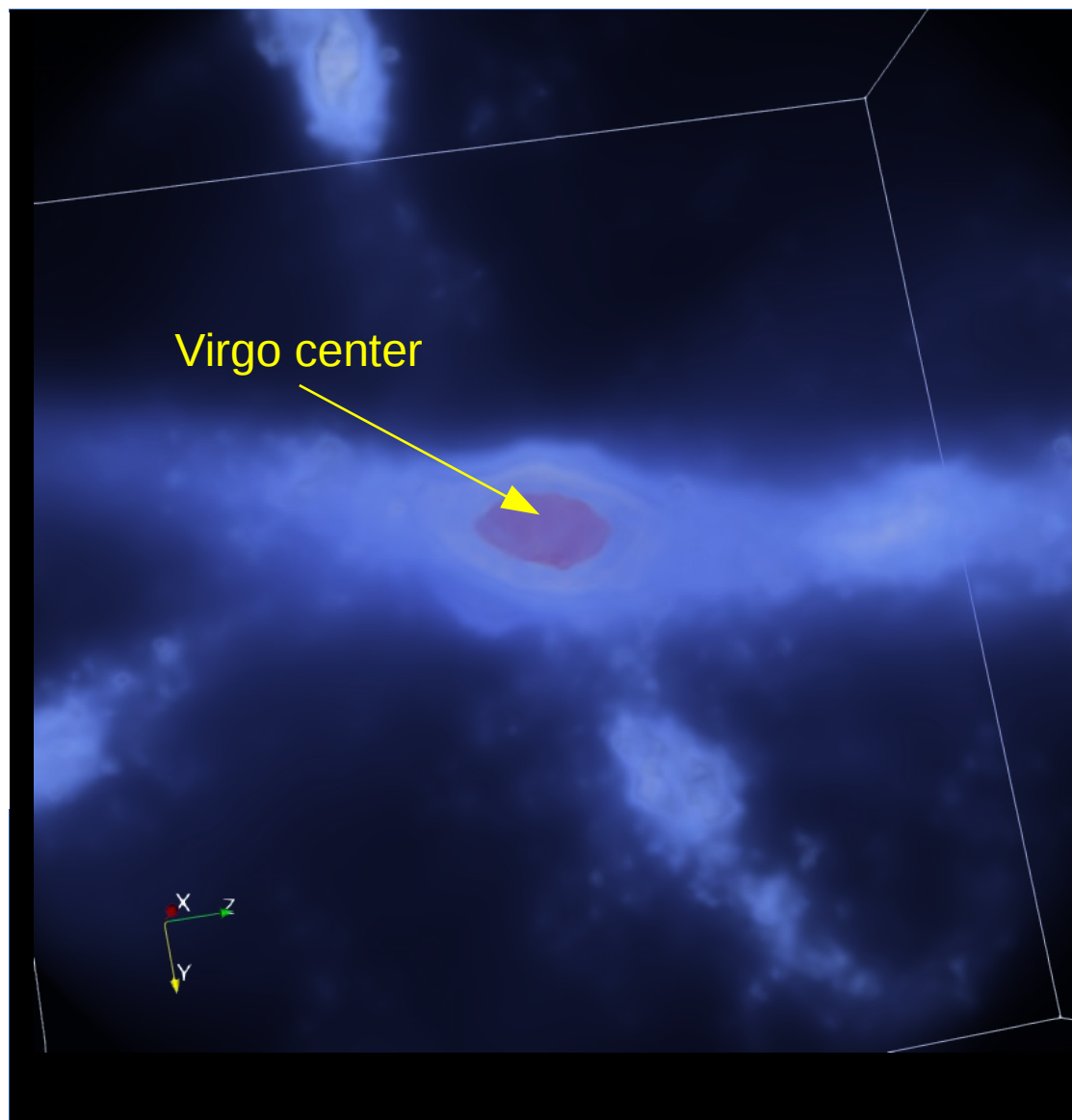
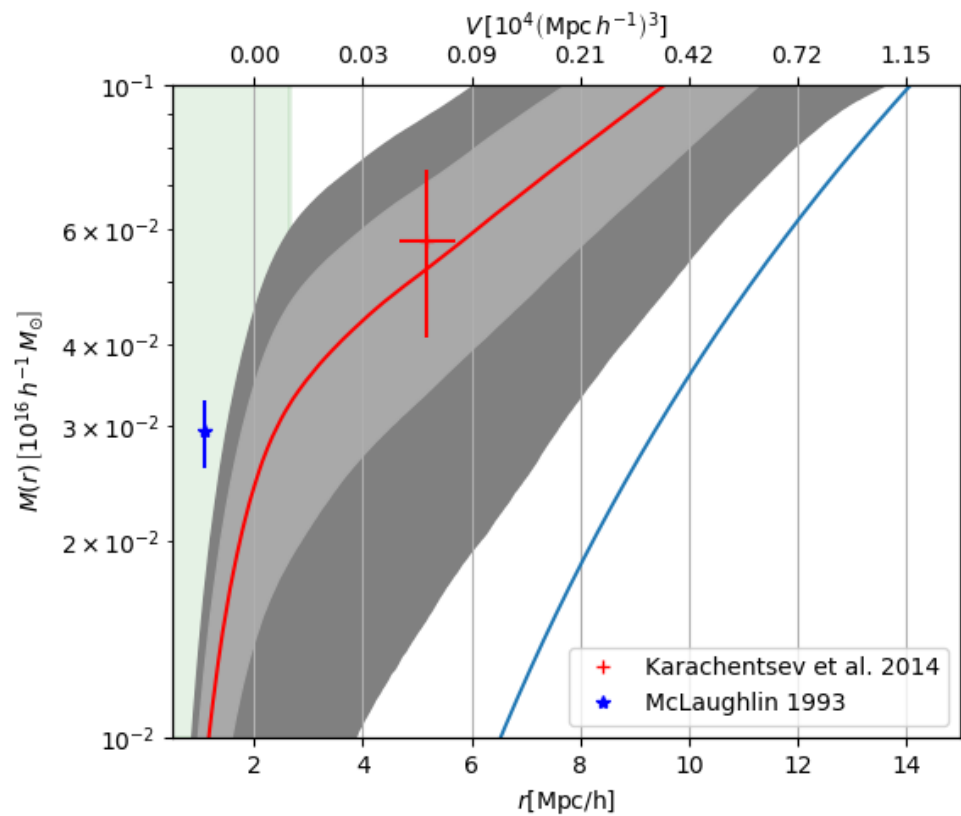
Initial conditions



Post PM simulation

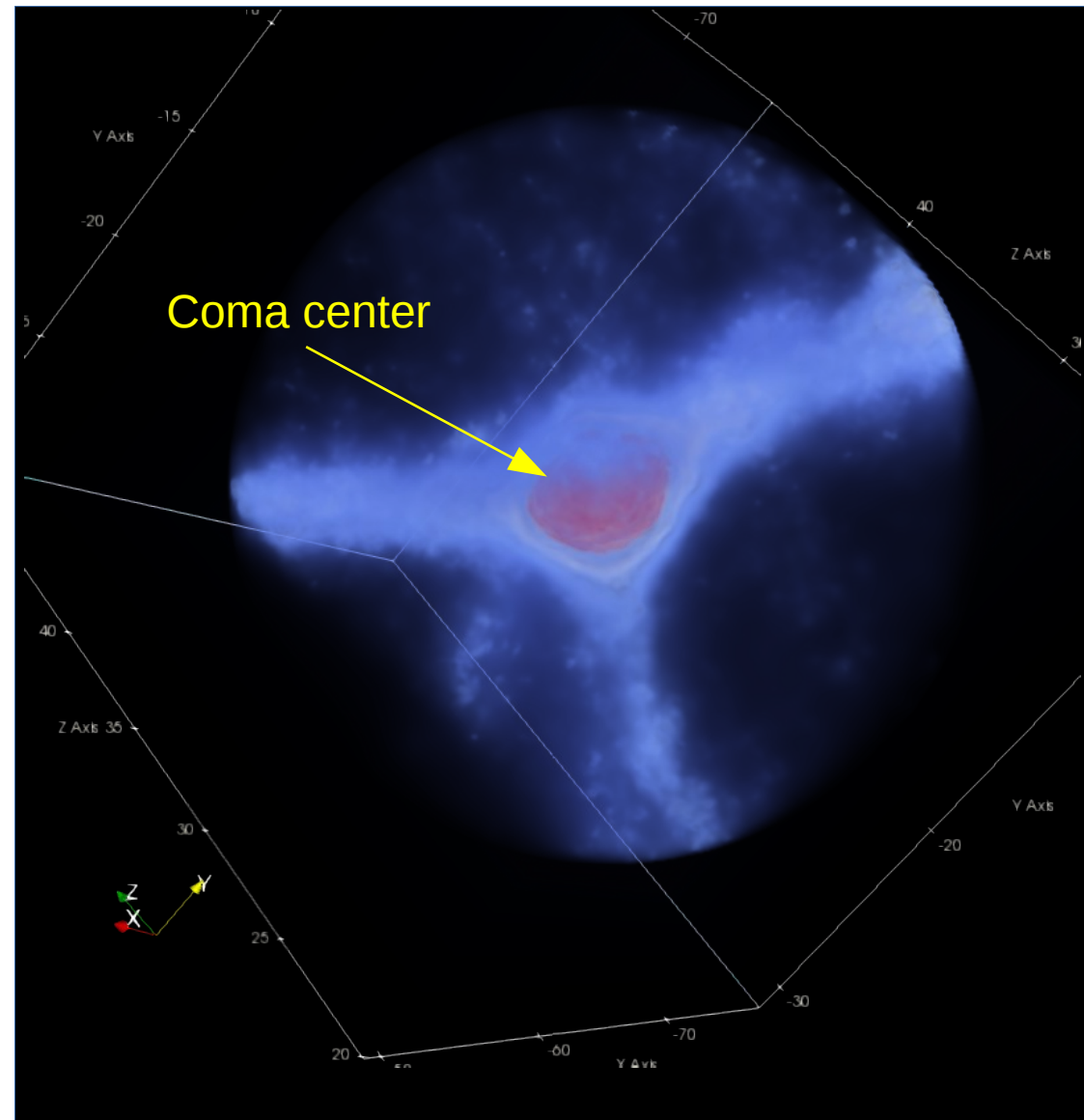
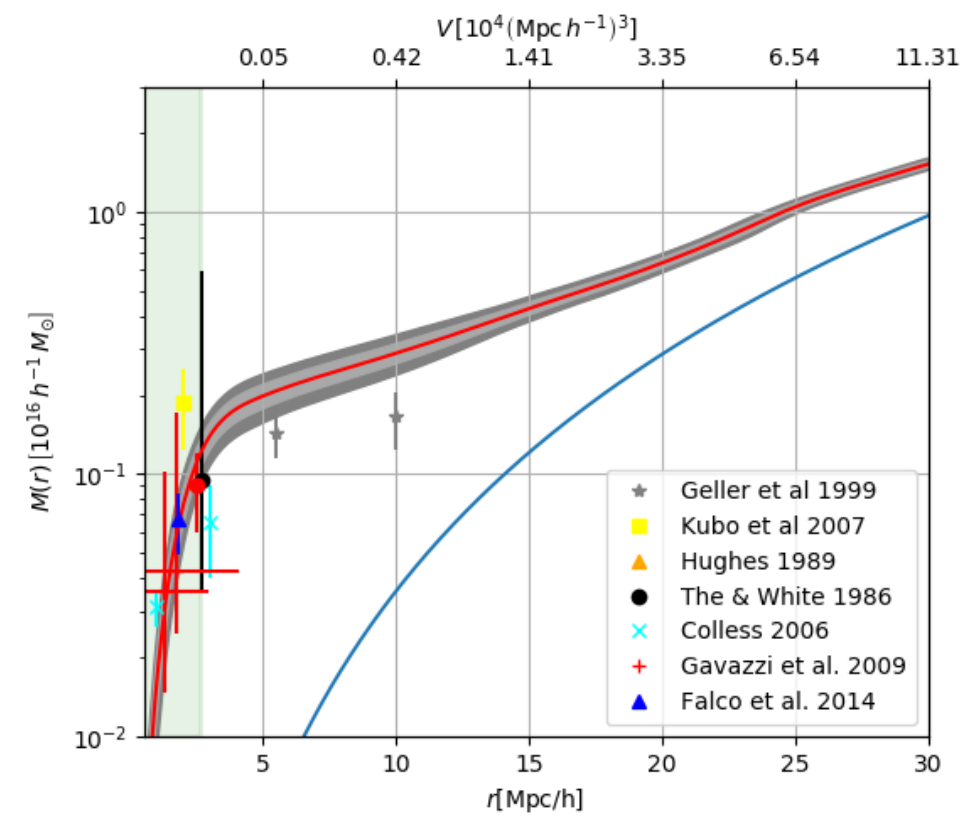


# Virgo cluster

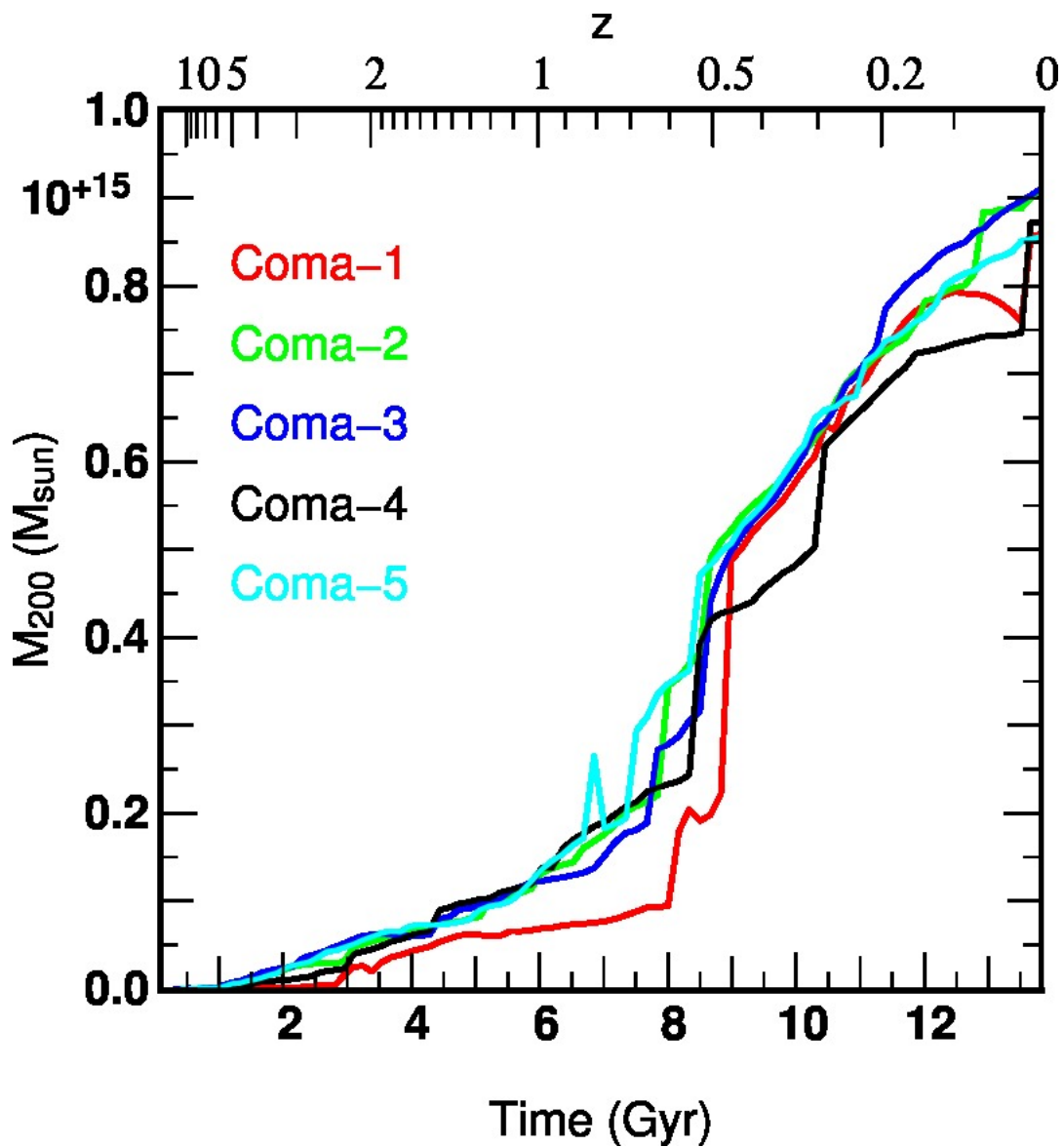
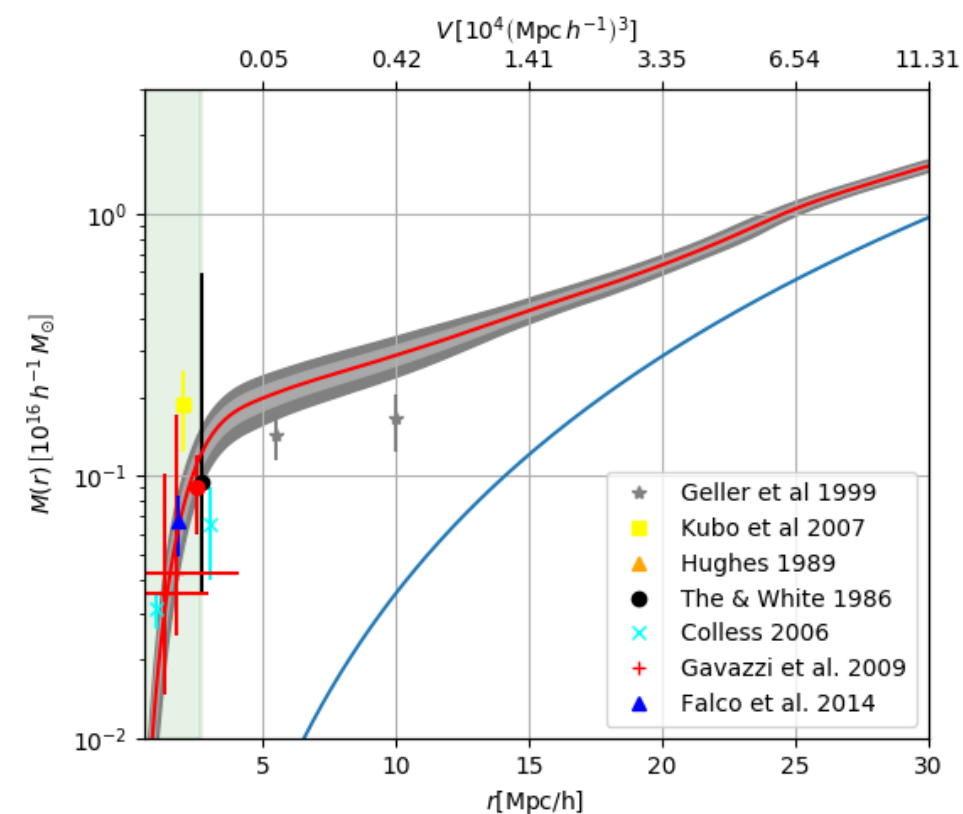


~30 Mpc/h

# Coma dynamical properties



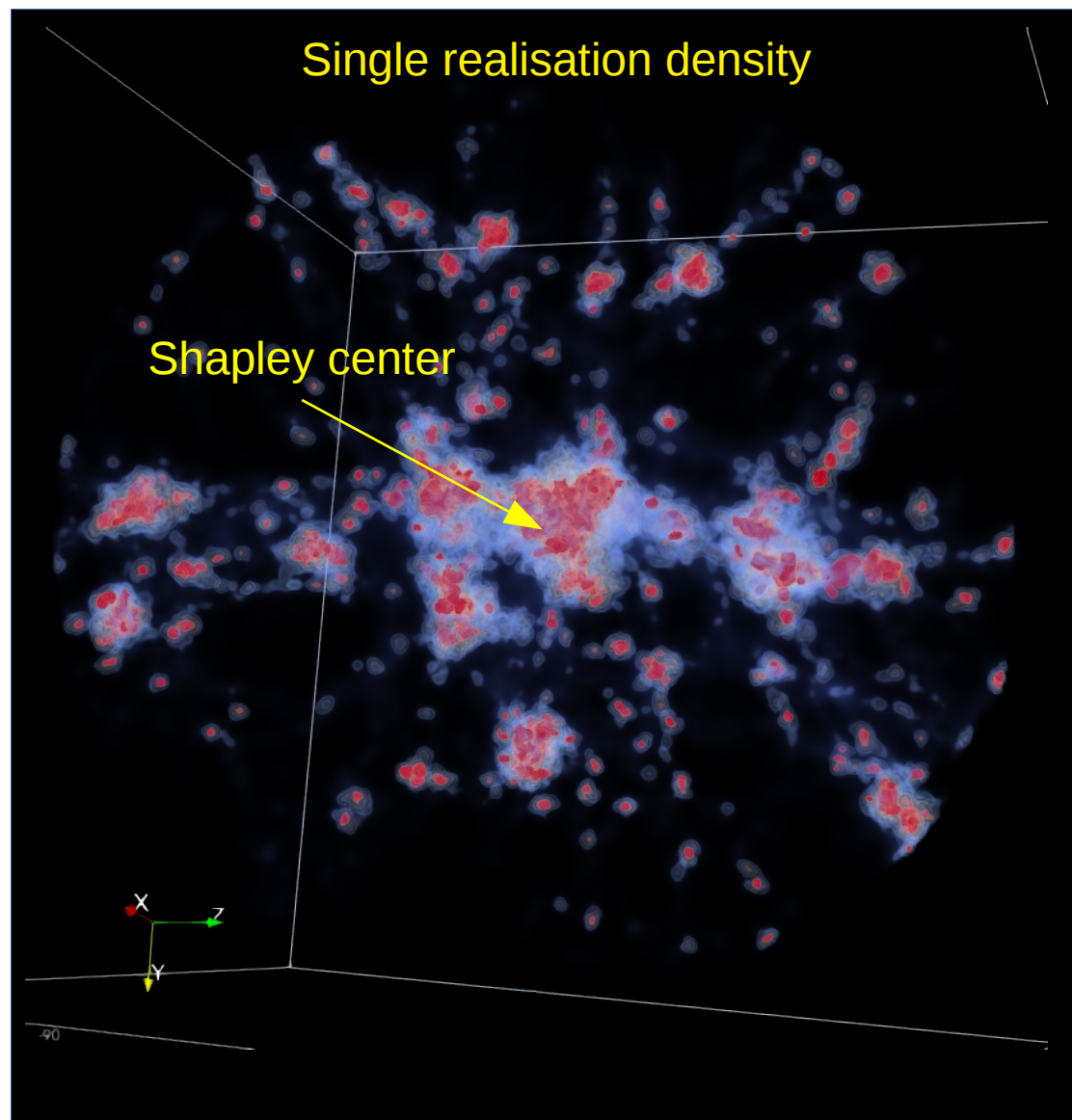
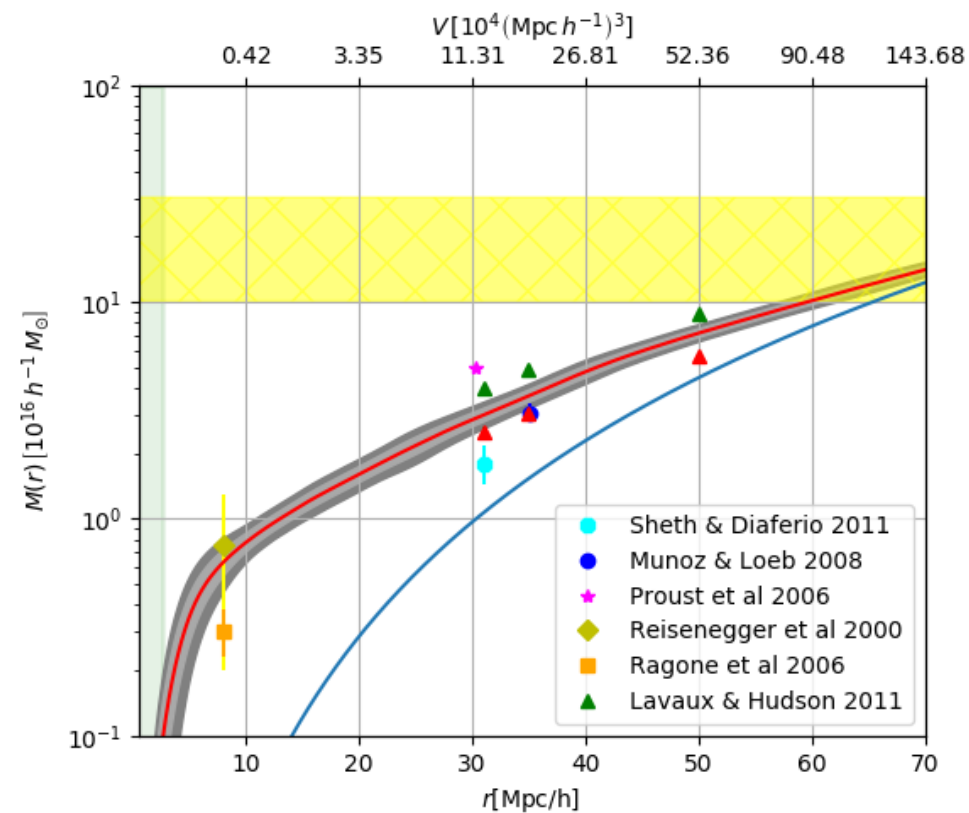
# Coma dynamical properties



Zoom simulation on Coma  
 (~250 Mpart in zoom)

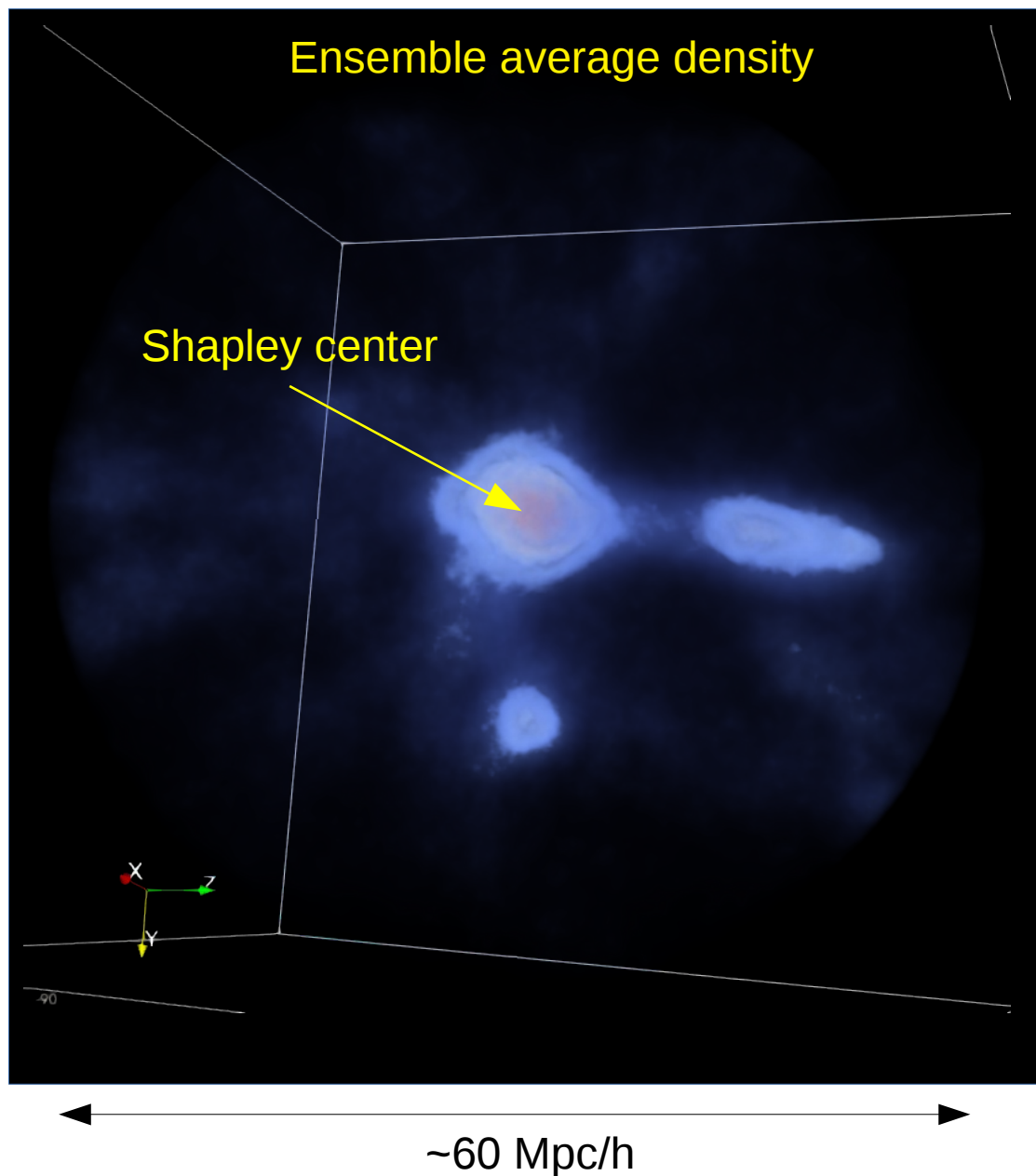
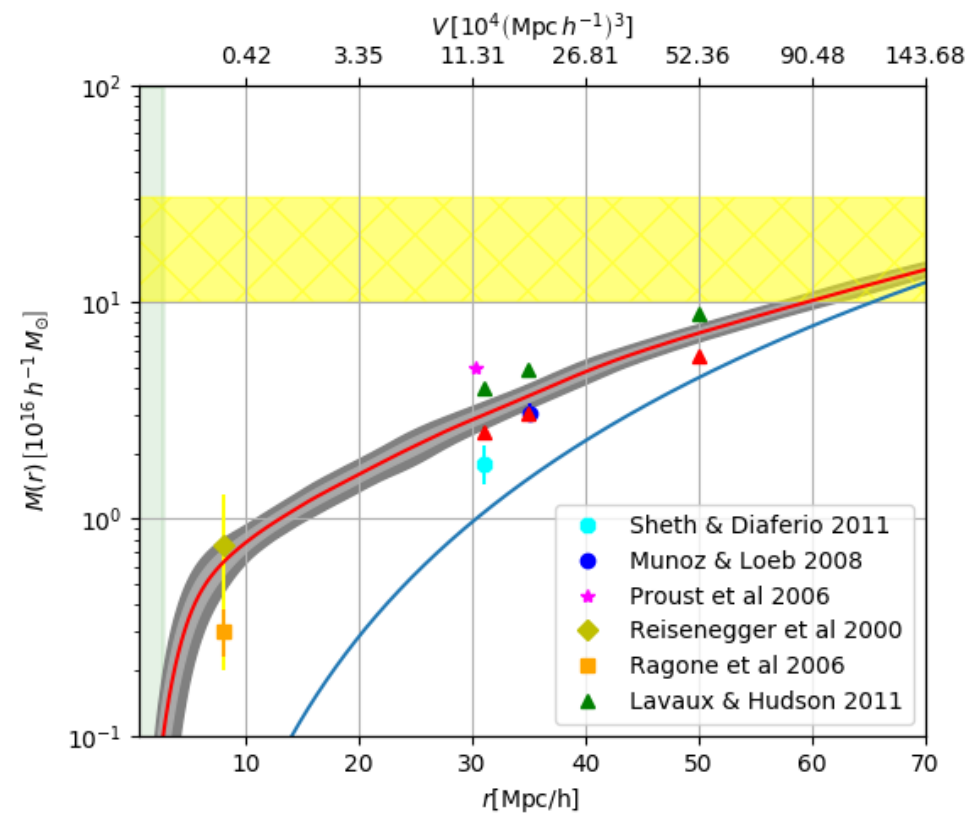
$$4 \times 10^7 h^{-1} M_{\odot} / \text{part}$$

# Shapley concentration



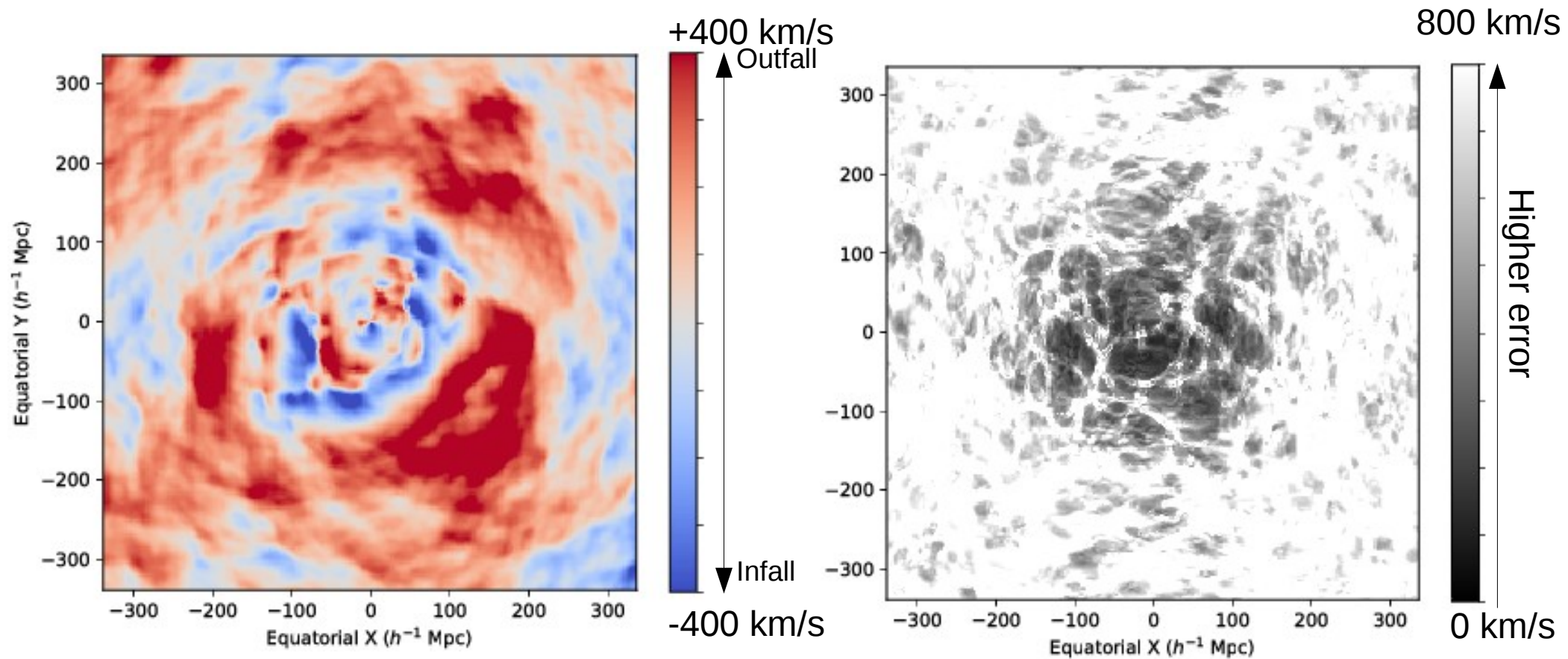
~60 Mpc/h

# Shapley concentration



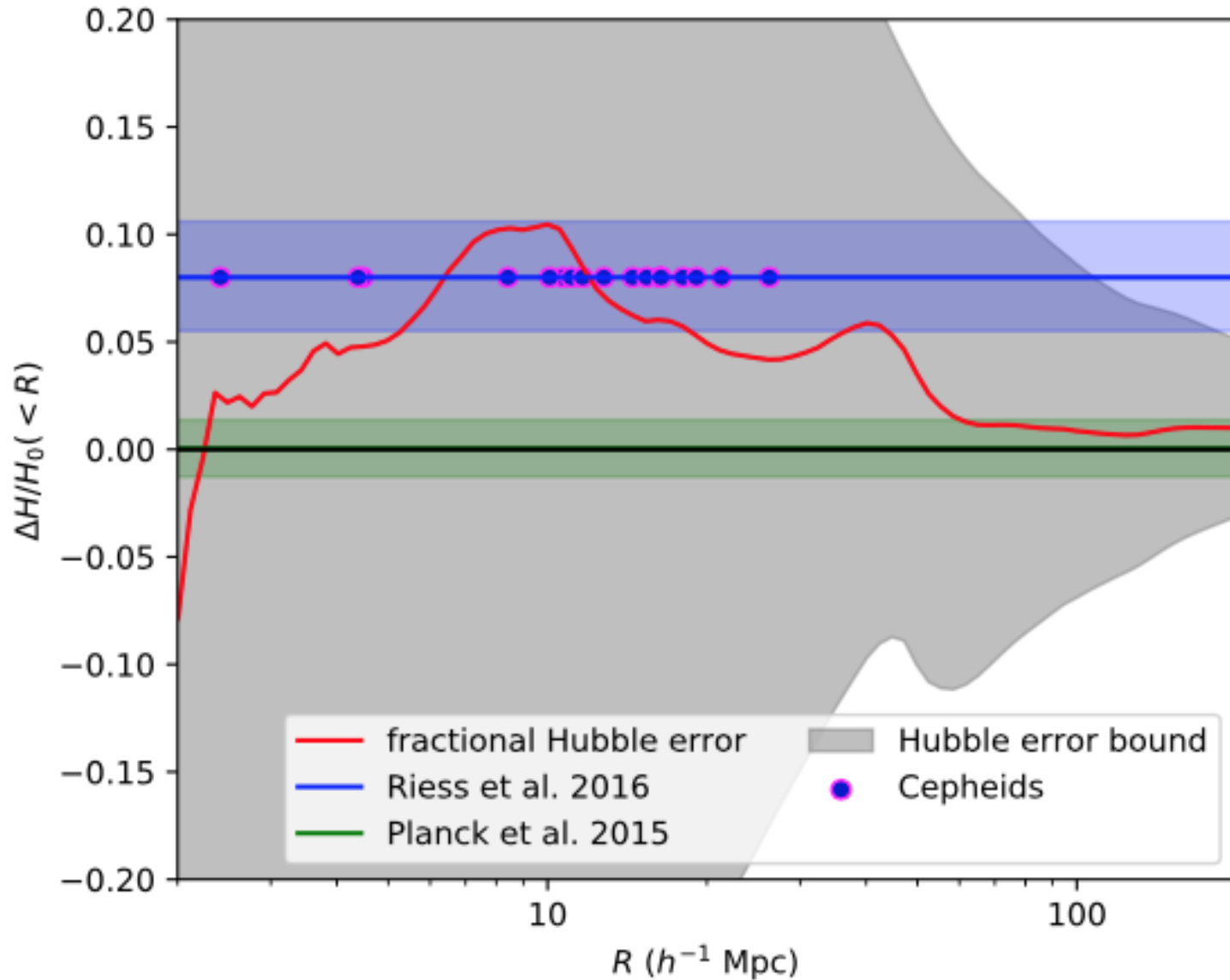


# Inferred velocity fields



# Velocity field and Hubble constant

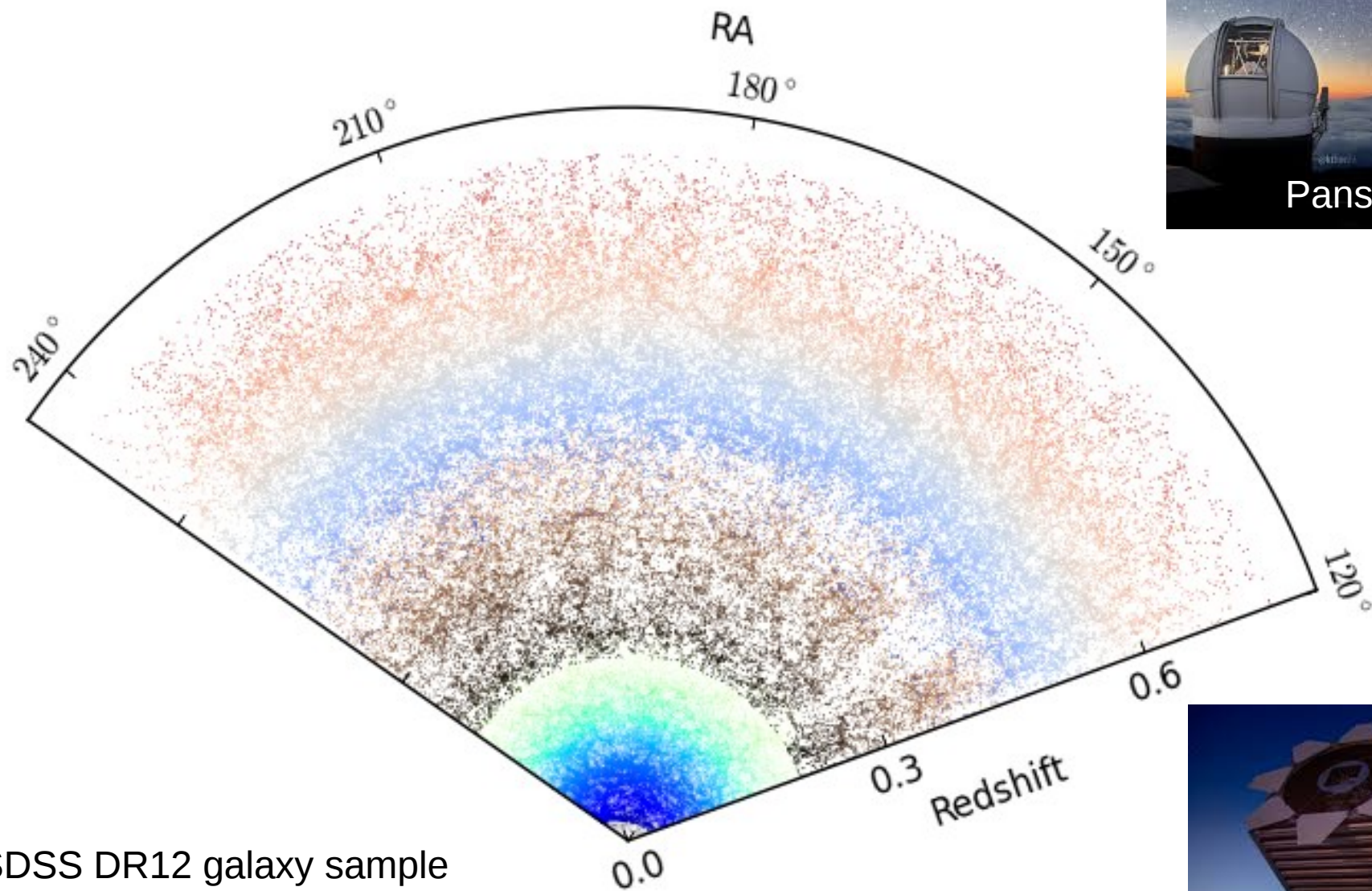
Mean error on Hubble measurement using tracers from observed large scale structures



A visualization of the cosmic web, showing a complex network of filaments and nodes. The left side is dark purple and black, transitioning to red and orange filaments, and finally to a bright cyan and yellow background on the right. A semi-transparent white box with a red border is centered in the middle.

**Application to Sloan Digital Sky Survey III:  
Deep cosmological application**

# SDSS3 data



SDSS DR12 galaxy sample  
~1.6 millions of galaxies



# Forward model becomes more complex

## Cosmic growth of structures

Implemented so far for (2)LPT:

$$\vec{x}(\vec{q}, t) = \vec{q} + \Psi(\vec{q}, t) \underset{LPT}{\simeq} \vec{q} + D(t)\Psi(\vec{q})$$

## Cosmic expansion

Non-linear density remapping:  $\vec{x} \rightarrow \vec{z}$

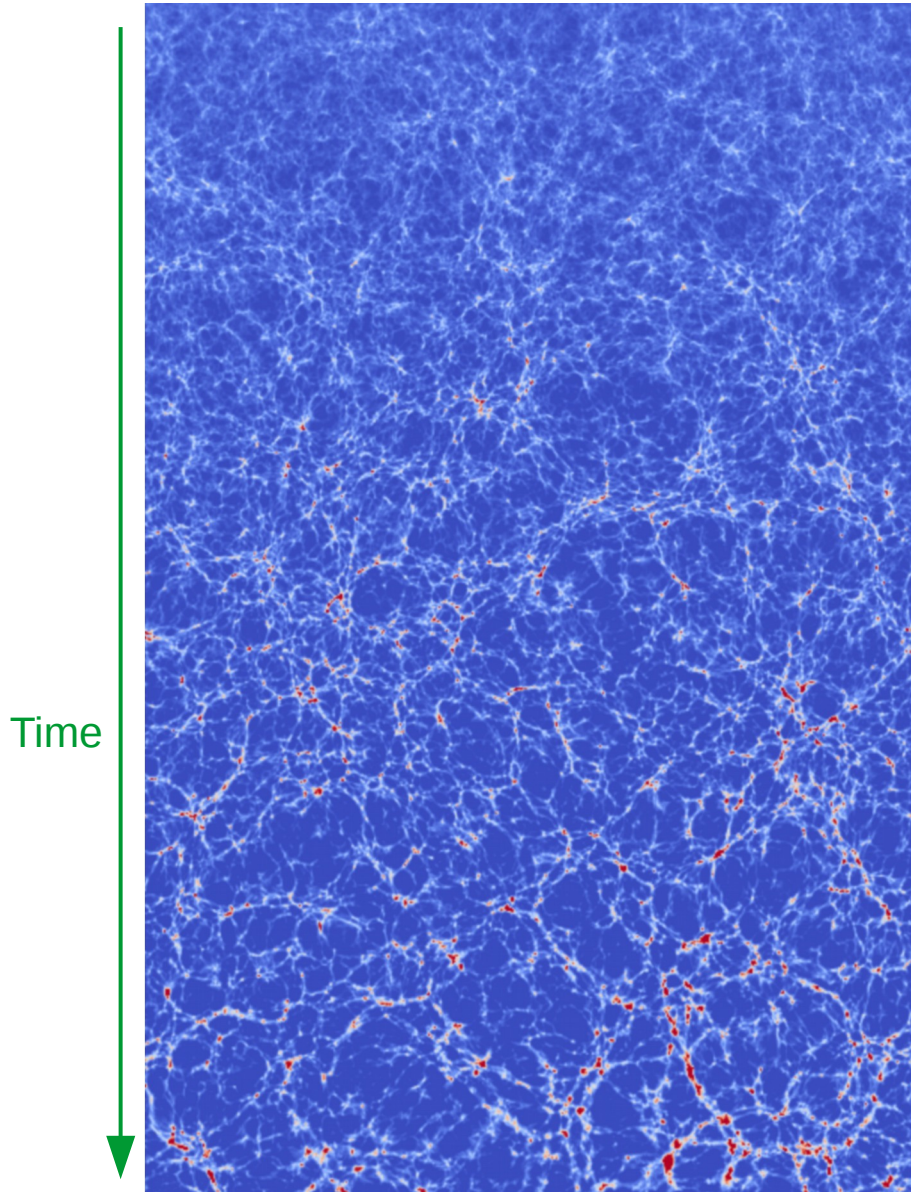
$$\vec{z}(\vec{x}) = f(|\vec{x}|, \text{cosmology}) \times \vec{x}$$

$$f(|x|, \dots) \simeq Hx + o(x)$$

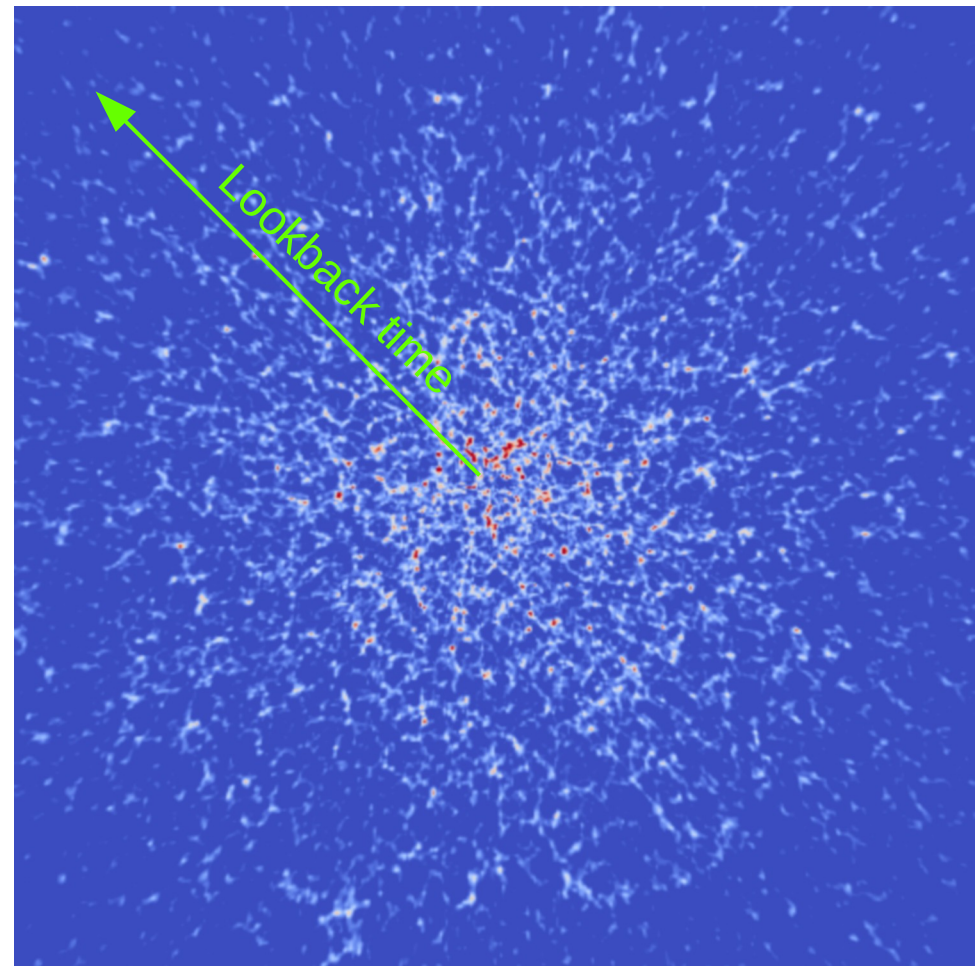
(see Doogesh' talk)

# Forward model becomes more complex

Cosmic growth of structures



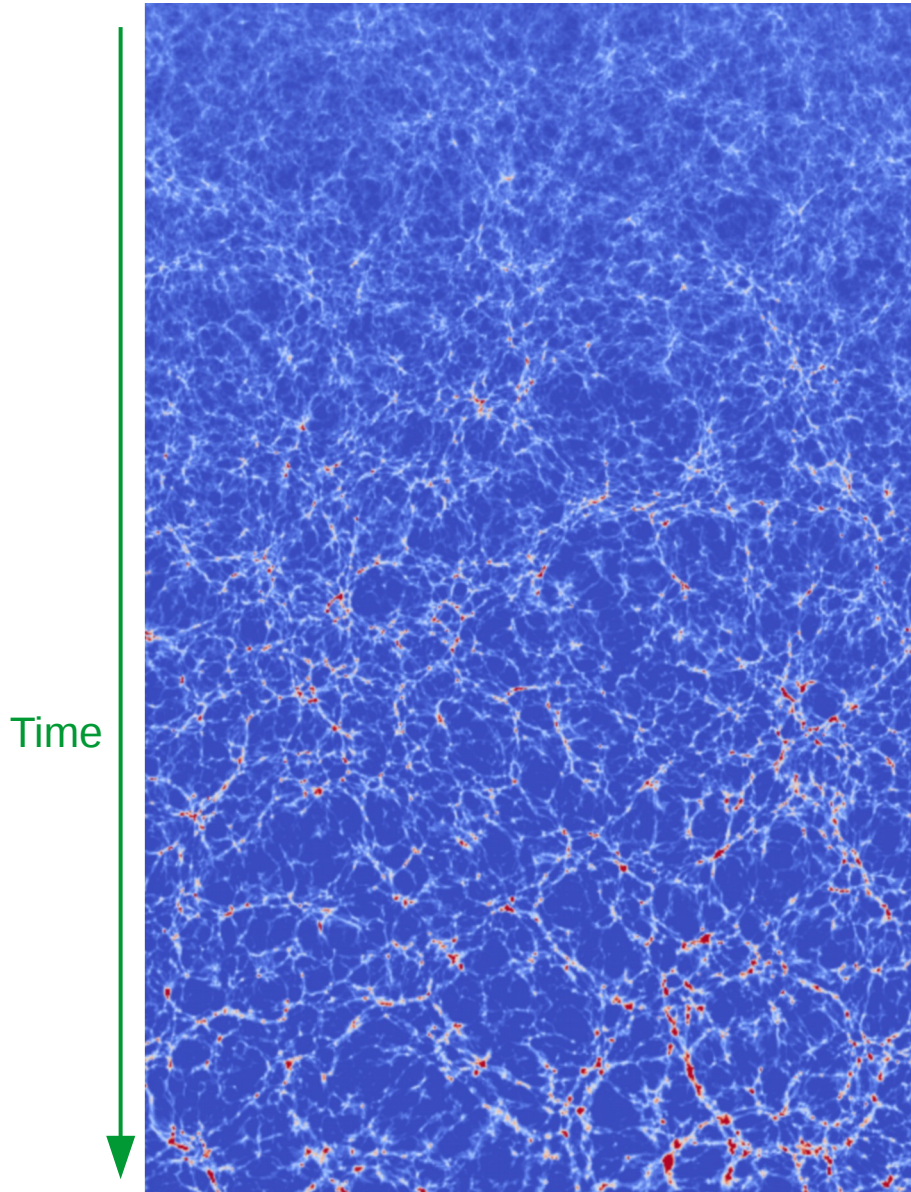
Cosmic expansion



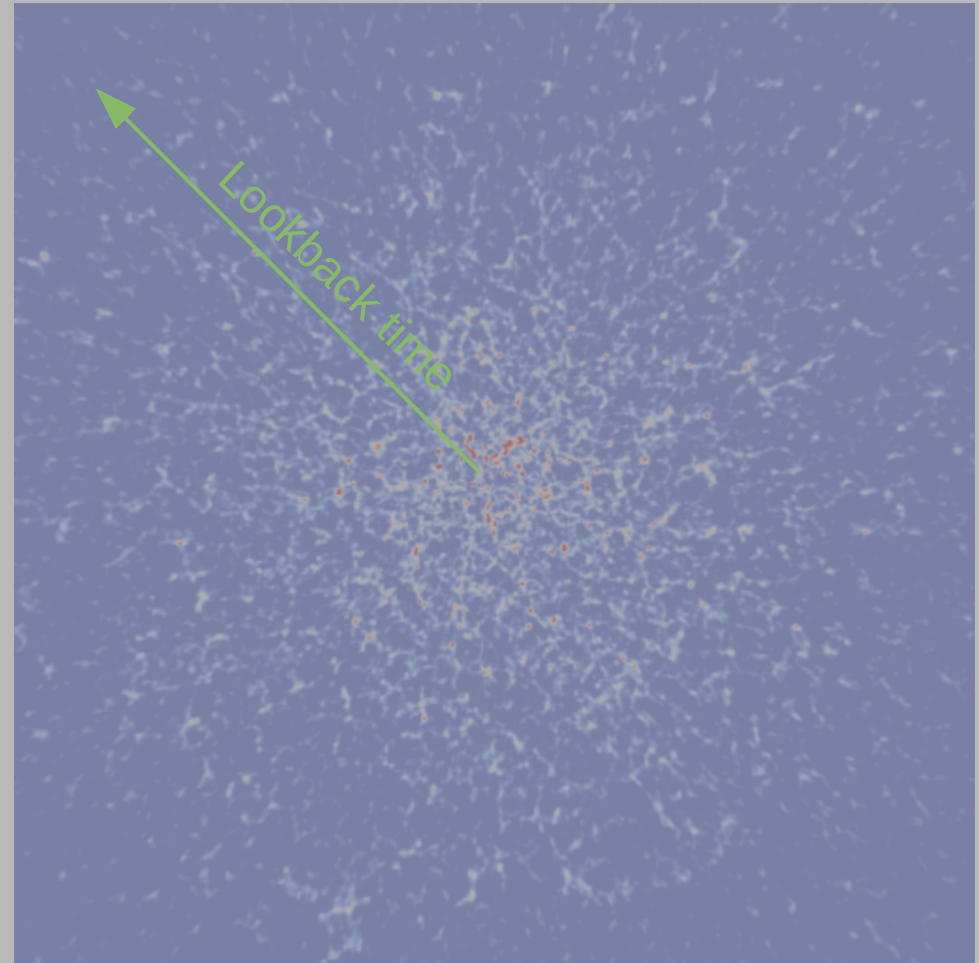
(see Doogesh' talk)

# Forward model becomes more complex

Cosmic growth of structures



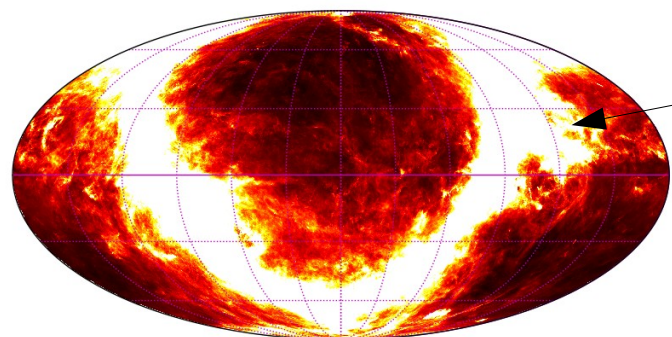
Cosmic expansion



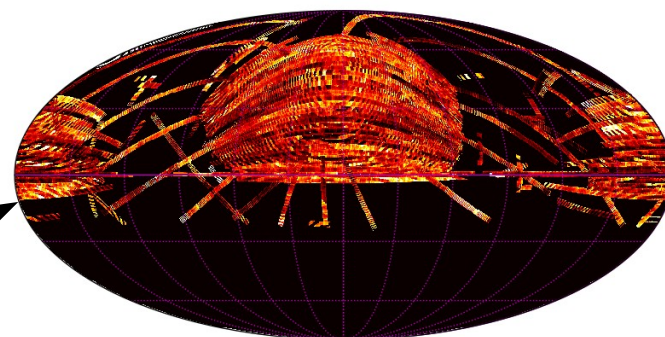
(see Doogesh' talk)

# Some systematic cleaning...

11 foregrounds (here only 8)... still much less than Leistedt & Peiris (2014) but improving

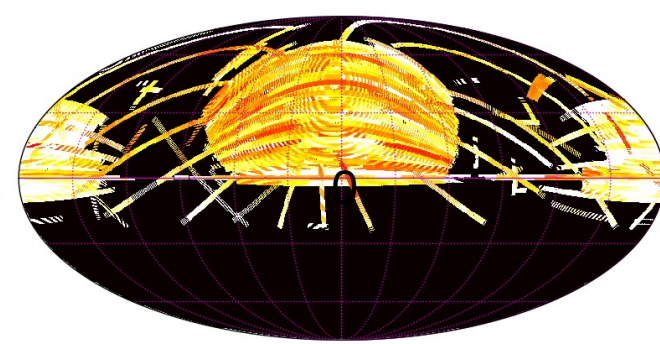
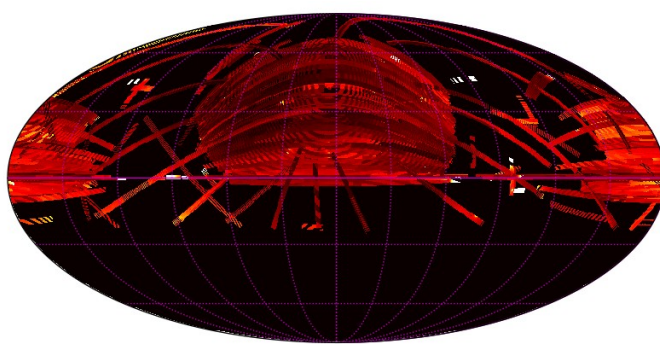
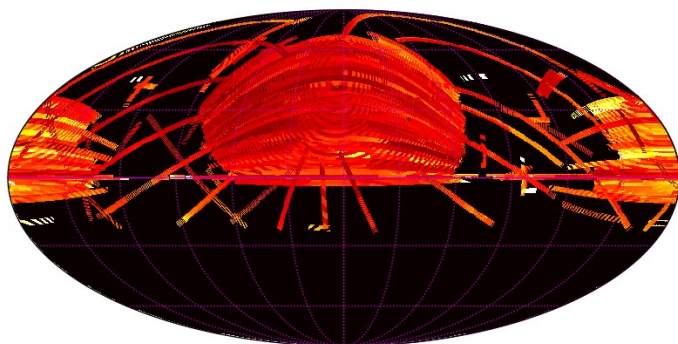


DUST



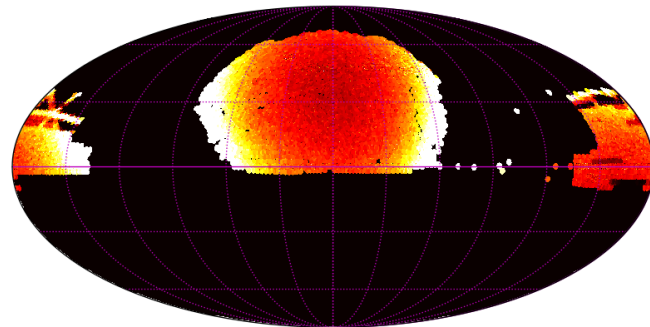
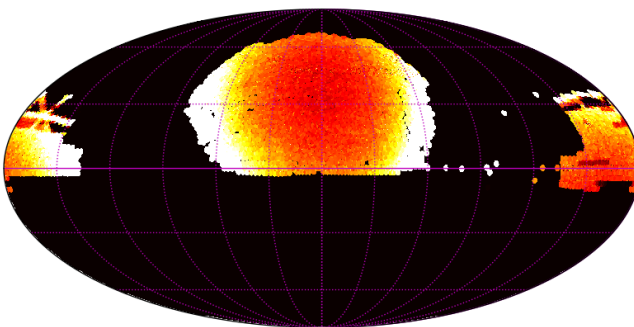
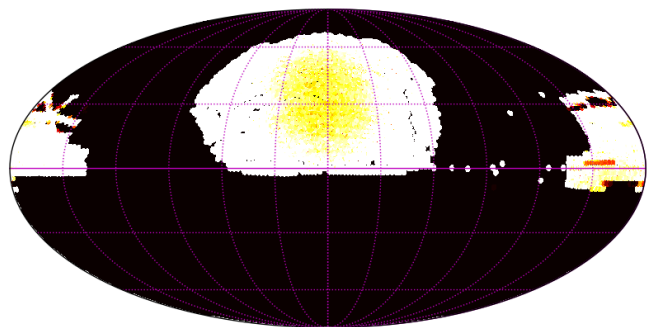
psfWidth

Sky fluxes



...

Star densities

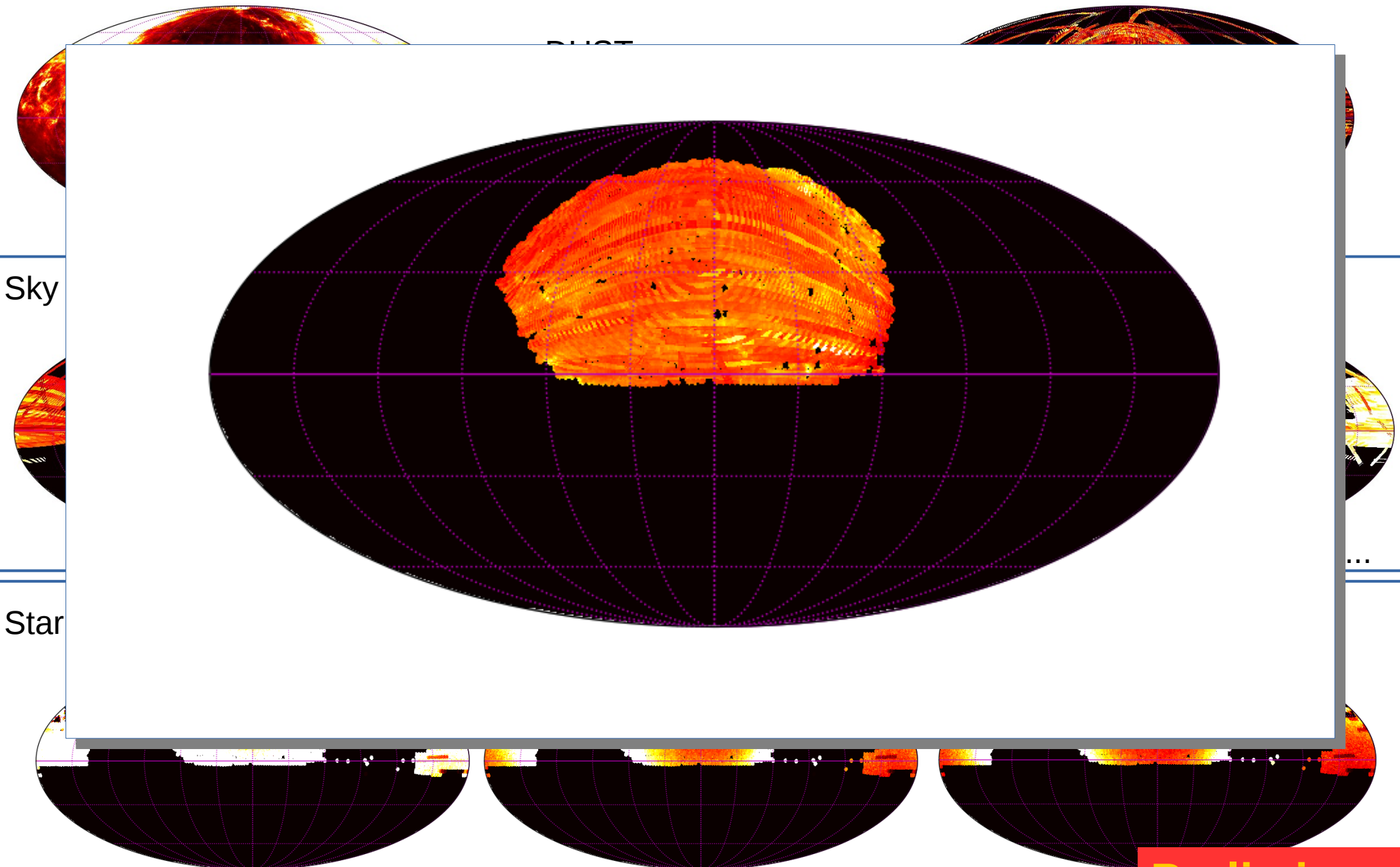


...



# Example fitted composite...

11 foregrounds (here only 8)... still much less than Leistedt & Peiris (2014) but improving



Sky

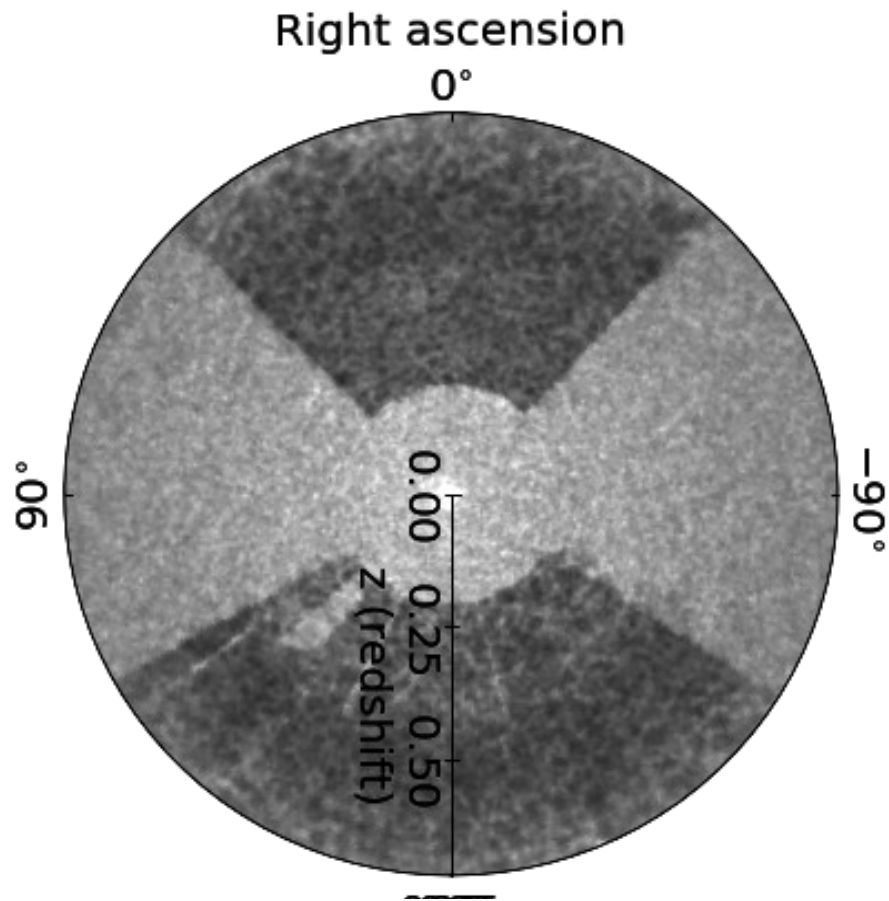
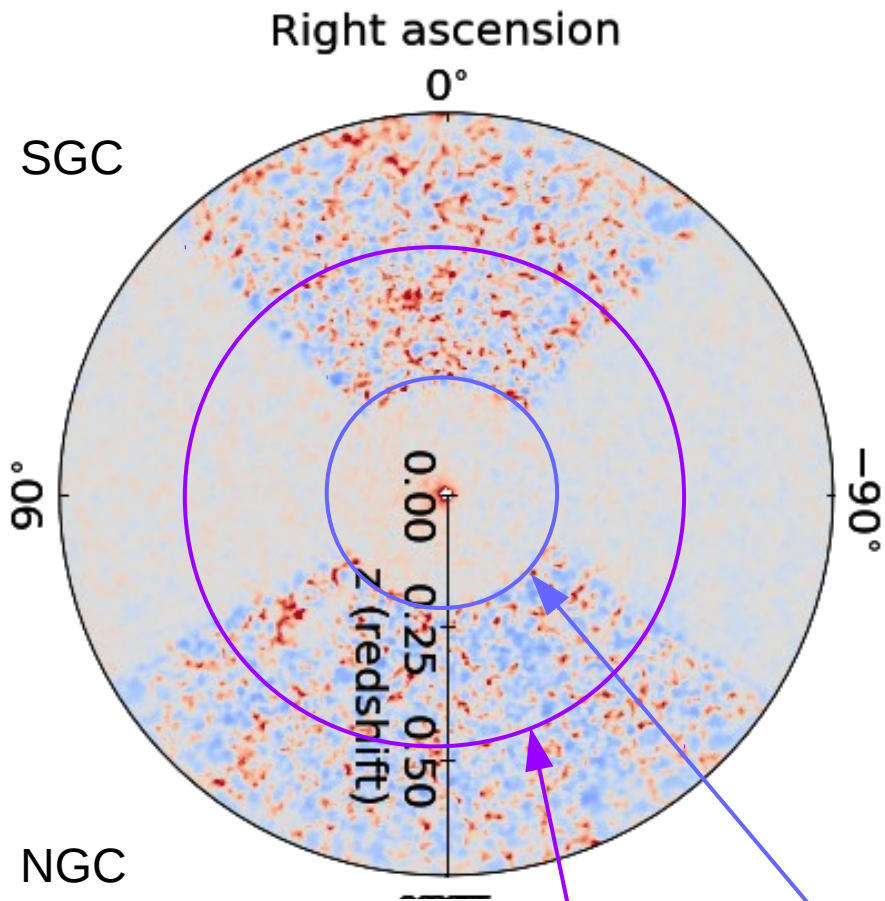
Star

Preliminary

# Inferred density of SDSS3

Ensemble density average

Error estimate from ensemble variance



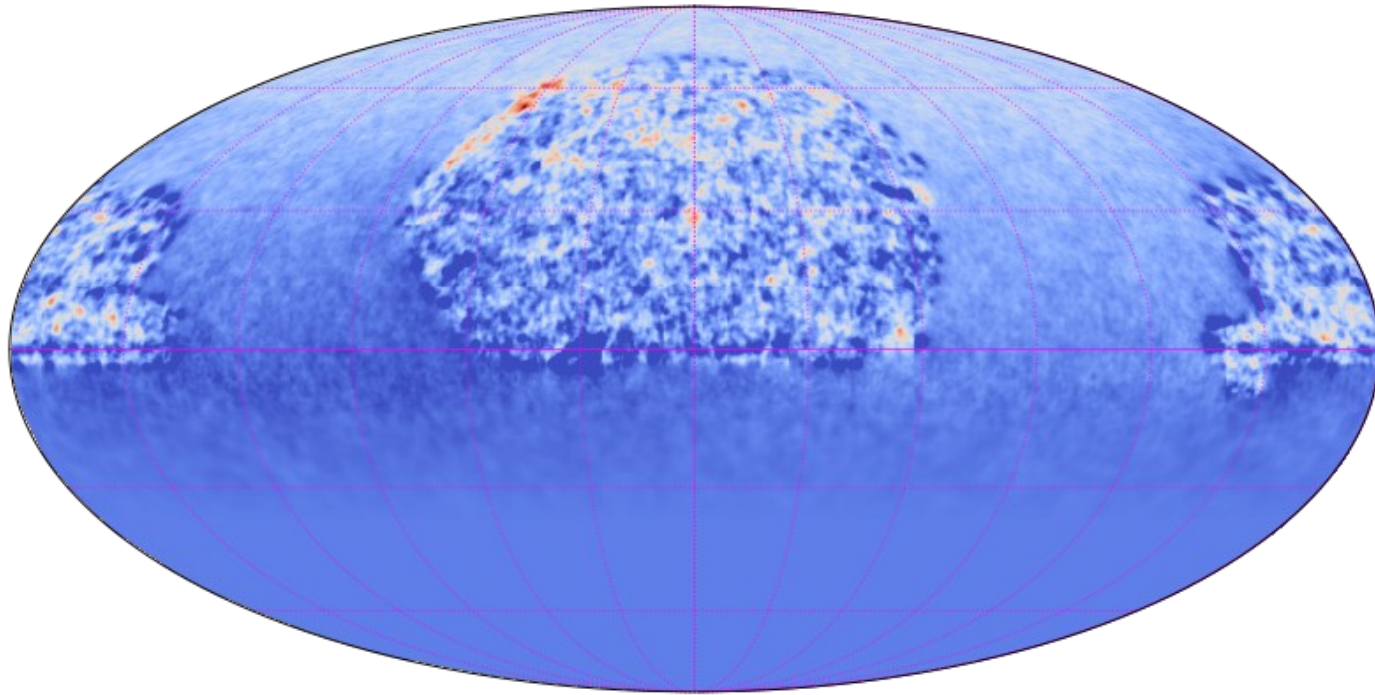
Main galaxy sample limit  
(not included)

LOWZ limit

CMASS limit

**Preliminary**

# Sky density



Preliminary

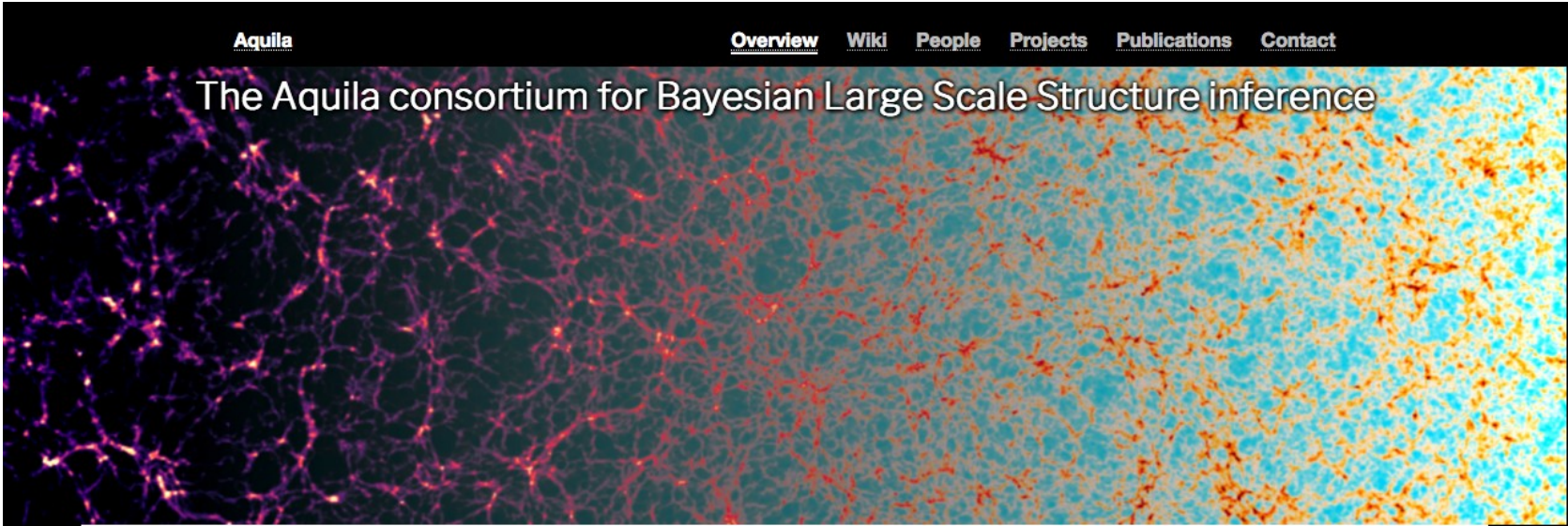
The background of the slide is an abstract, textured pattern. It features a dense network of thin, interconnected lines and shapes. The color palette is diverse, ranging from deep purples and magentas on the left side to bright blues and cyan on the right, with various shades of red and orange interspersed throughout. The overall effect is reminiscent of a microscopic view of a complex material or a digital data visualization.

**Conclusion**

# The Aquila consortium

- Founded in 2016
- Gather people interested in working with each other on developing the Bayesian pipelines and run analysis on data.

<https://aquila-consortium.org/>



**Aquila** [Overview](#) [Wiki](#) [People](#) [Projects](#) [Publications](#) [Contact](#)

## The Aquila consortium for Bayesian Large Scale Structure inference

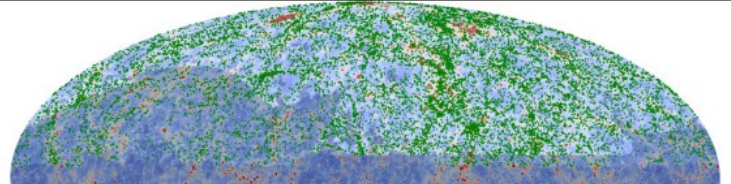
**Our mission: Data science meets the Universe**

The Aquila consortium is an international collaboration of researchers interested in developing and applying cutting-edge statistical inference techniques to study the spatial distribution of matter in our Universe. We embrace the latest innovations in information theory and artificial intelligence to optimally extract physical information from data and use derived results to facilitate new discoveries.

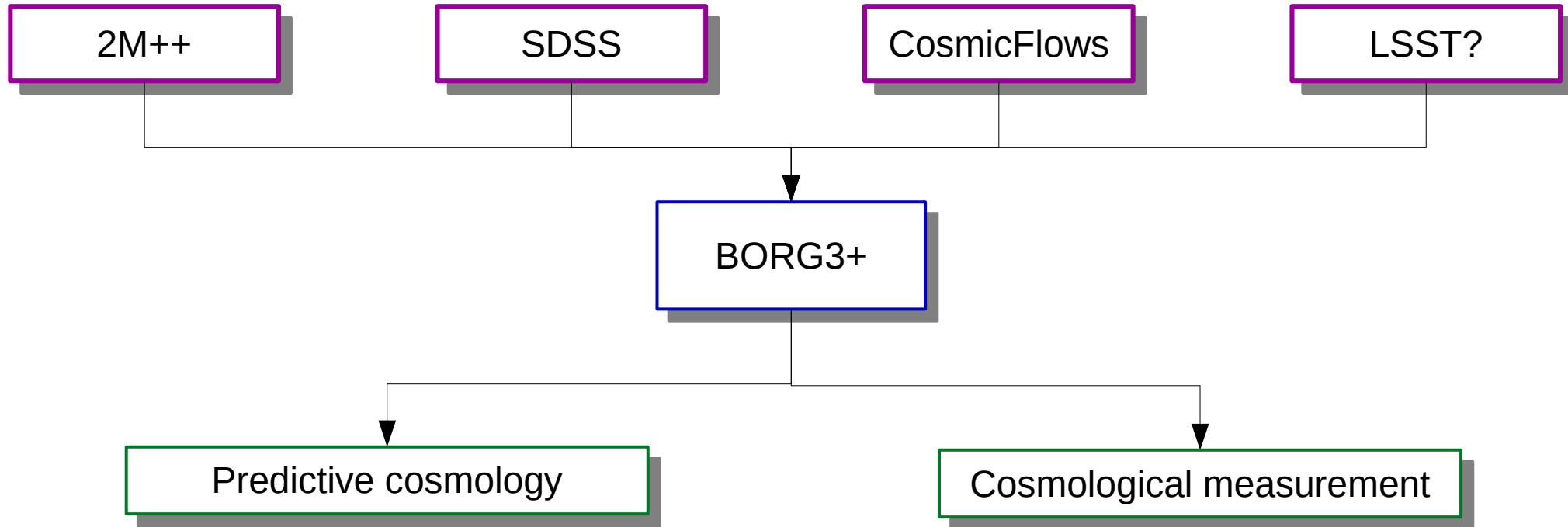
**Some results**

### Resimulating the Local Universe

To be updated. Copied from ILP. This picture shows the result of a high resolution N-body simulation which has been specifically designed to look like the Local Universe. More precisely it depicts what is the sky of an observer which would be located at the center of our galaxy and look at the entire sky. We use for that a Mollweide projection, which is another way of representing the surface of a full



# Conclusion: great future



- Velocity field (also VIRBIUS with F. Fuhrer)
  - X-ray cluster emission
  - Kinetic Sunyaev Zel'dovich
  - Rees-Sciama
  - Dark matter ?
- Cosmic expansion (see Doogesh's talk)
  - Power spectrum (and governing parameters)
  - Gaussianity tests of initial conditions
  - Direct probe of dynamics

# Conclusion: great future and challenges

