

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

Guilhem Lavaux (IAP/CNRS)
and Aquila Consortium

Cosmo21 – Valencia 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...

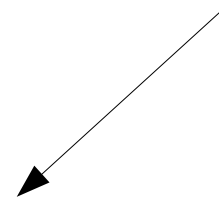
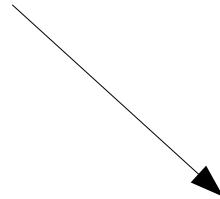
Model

- 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...

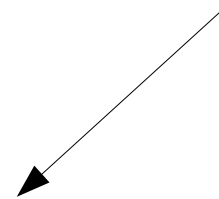
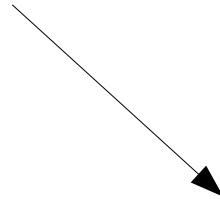
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BORG3

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



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

The BORG3 inference framework

$$\pi(\hat{\delta}) \propto \exp\left(-\frac{1}{2} \sum_k |\hat{\delta}_k|^2 / P_k\right)$$

Initial conditions

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Total evolved matter density $\rho_m = \mathcal{F}[\delta]$

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Biased galaxy distribution

$$\rho_g \propto \rho_m^\alpha \exp\left(-(\rho_m/\rho_0)^{-\epsilon}\right)$$

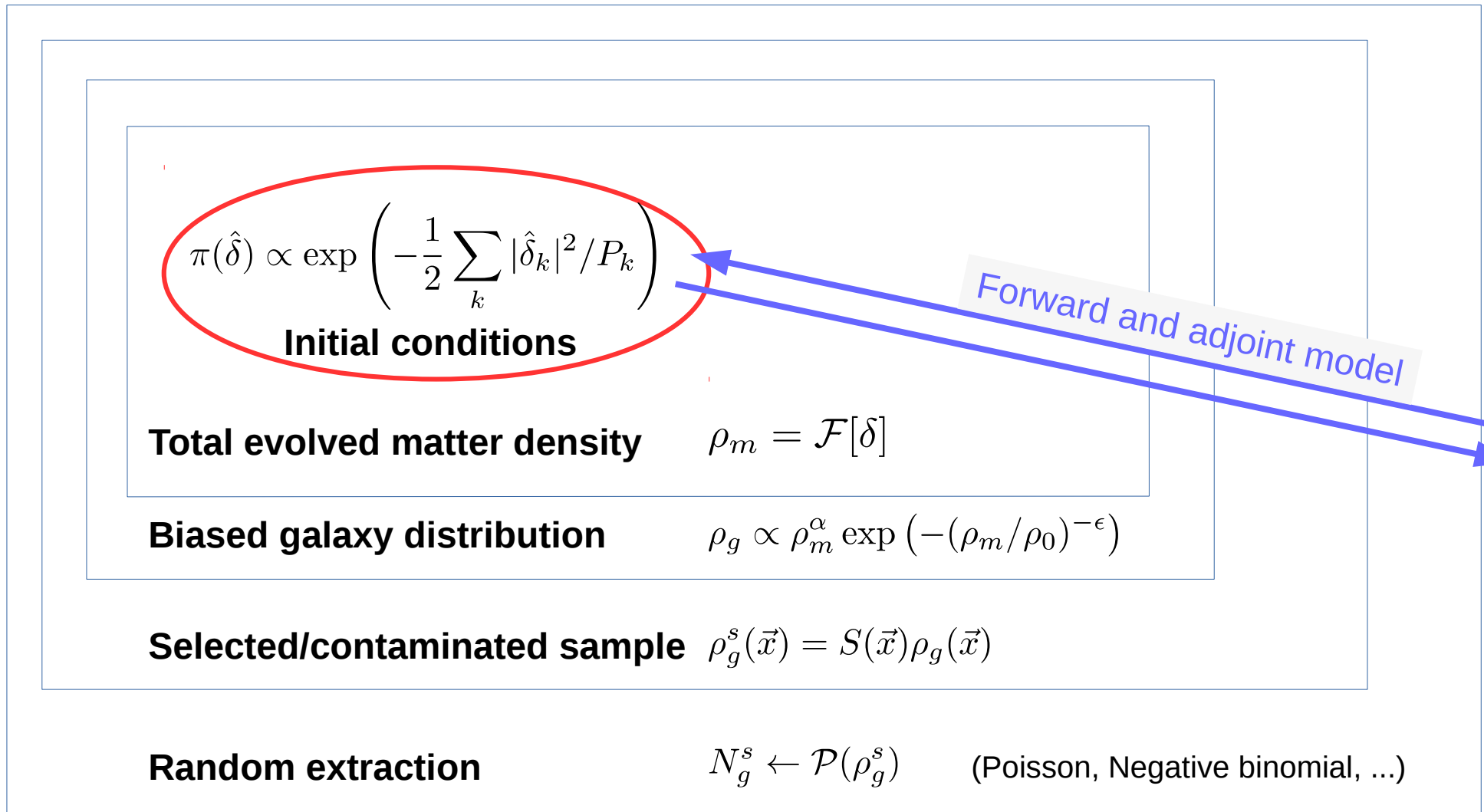
Selected/contaminated sample

$$\rho_g^s(\vec{x}) = S(\vec{x})\rho_g(\vec{x})$$

Random extraction

$$N_g^s \leftarrow \mathcal{P}(\rho_g^s) \quad (\text{Poisson, Negative binomial, ...})$$

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Easily exchangeable to try
your favorite differentiable model

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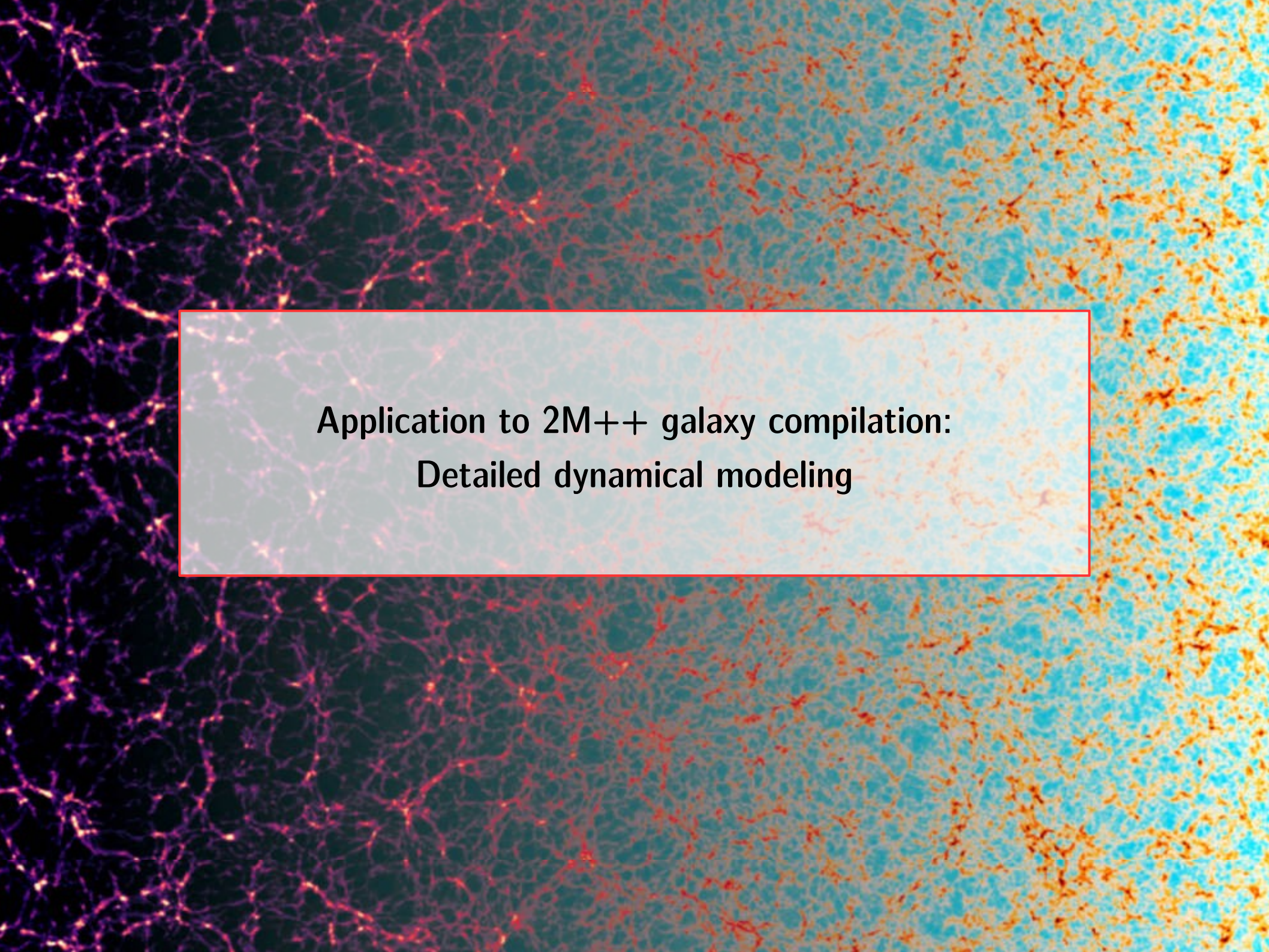
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Encode survey systematic effects with expansions:

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

A visualization of the cosmic web, showing a complex network of filaments and nodes. The left side is dominated by dark purple and blue filaments, while the right side transitions into a lighter blue and yellowish-orange background with more diffuse, filamentary structures.

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

The 2M++ galaxy compilation

Galaxy distribution

SDSS 0 Mpc/h

2MRS

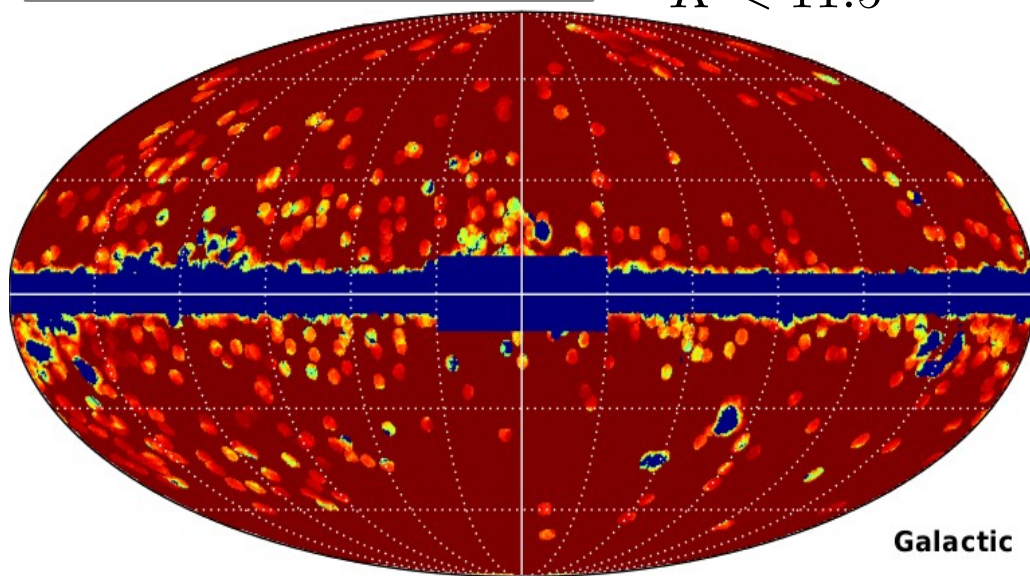
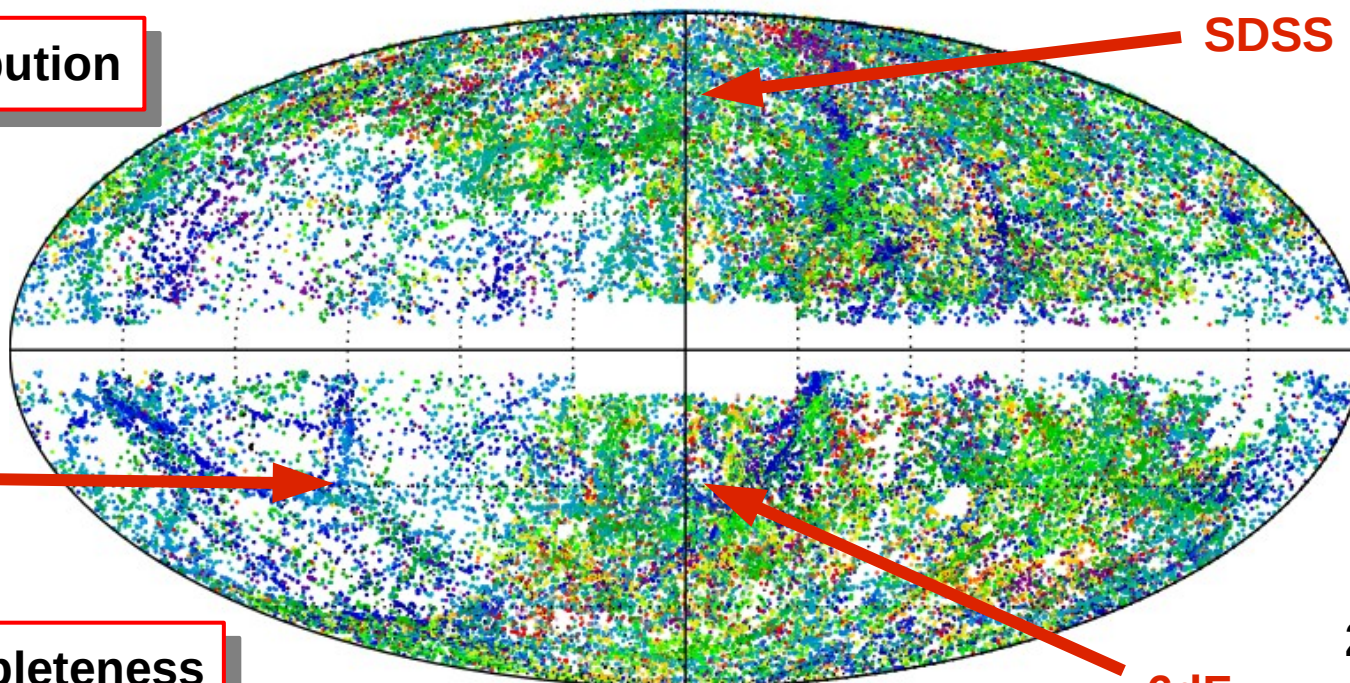
6dF

Redshift completeness

$K < 11.5$

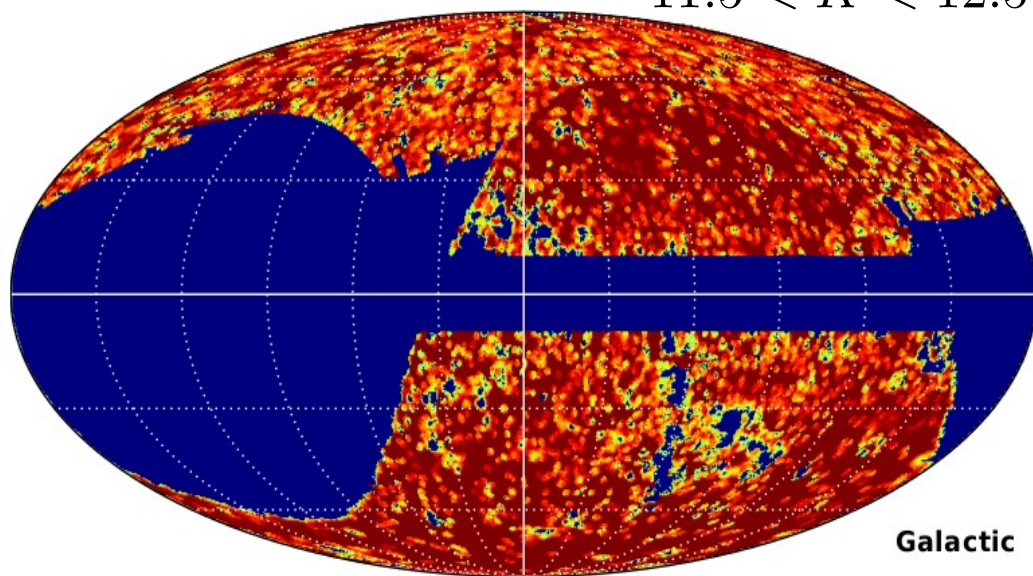
250 Mpc/h

$11.5 < K < 12.5$



Galactic

~70 000 galaxies

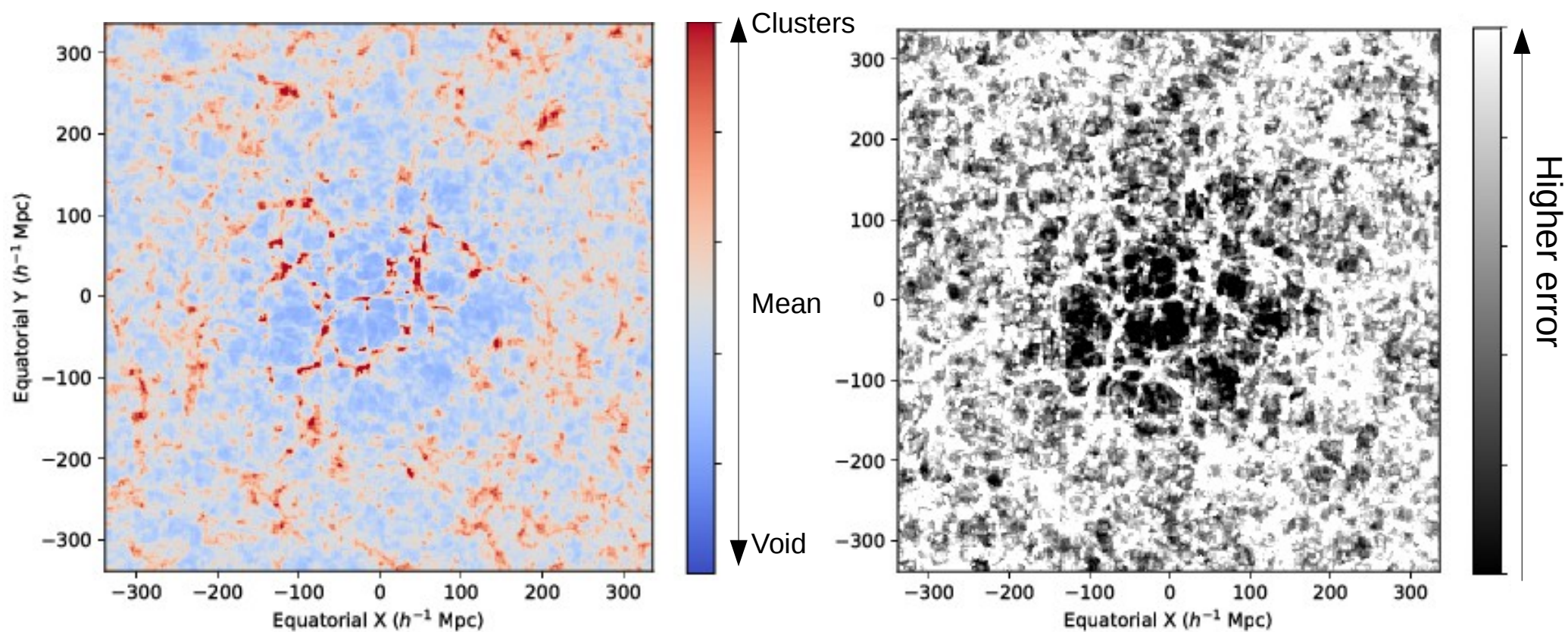


Galactic

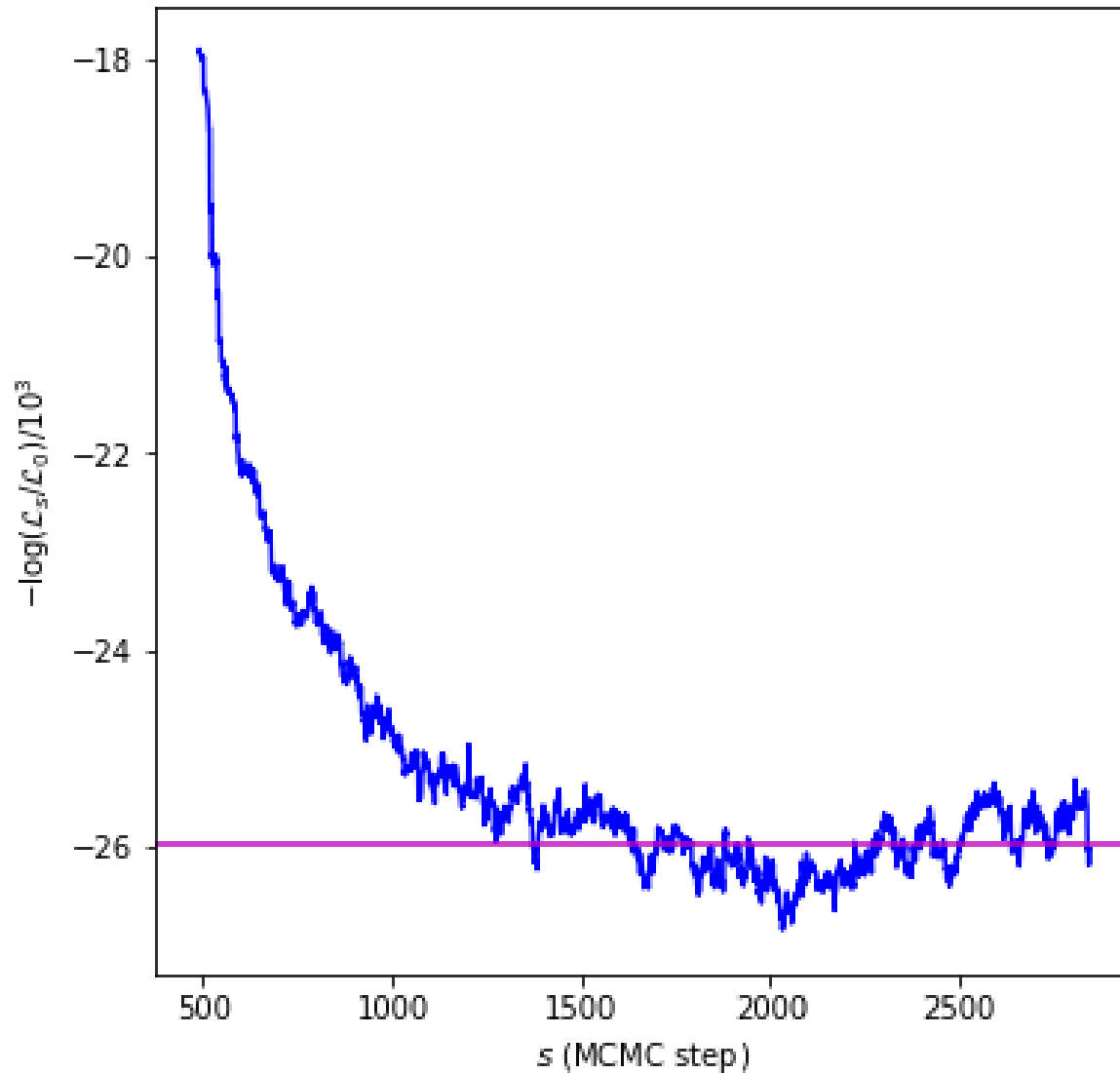
Lavaux & Hudson (MNRAS, 2011)

Inferred density fields

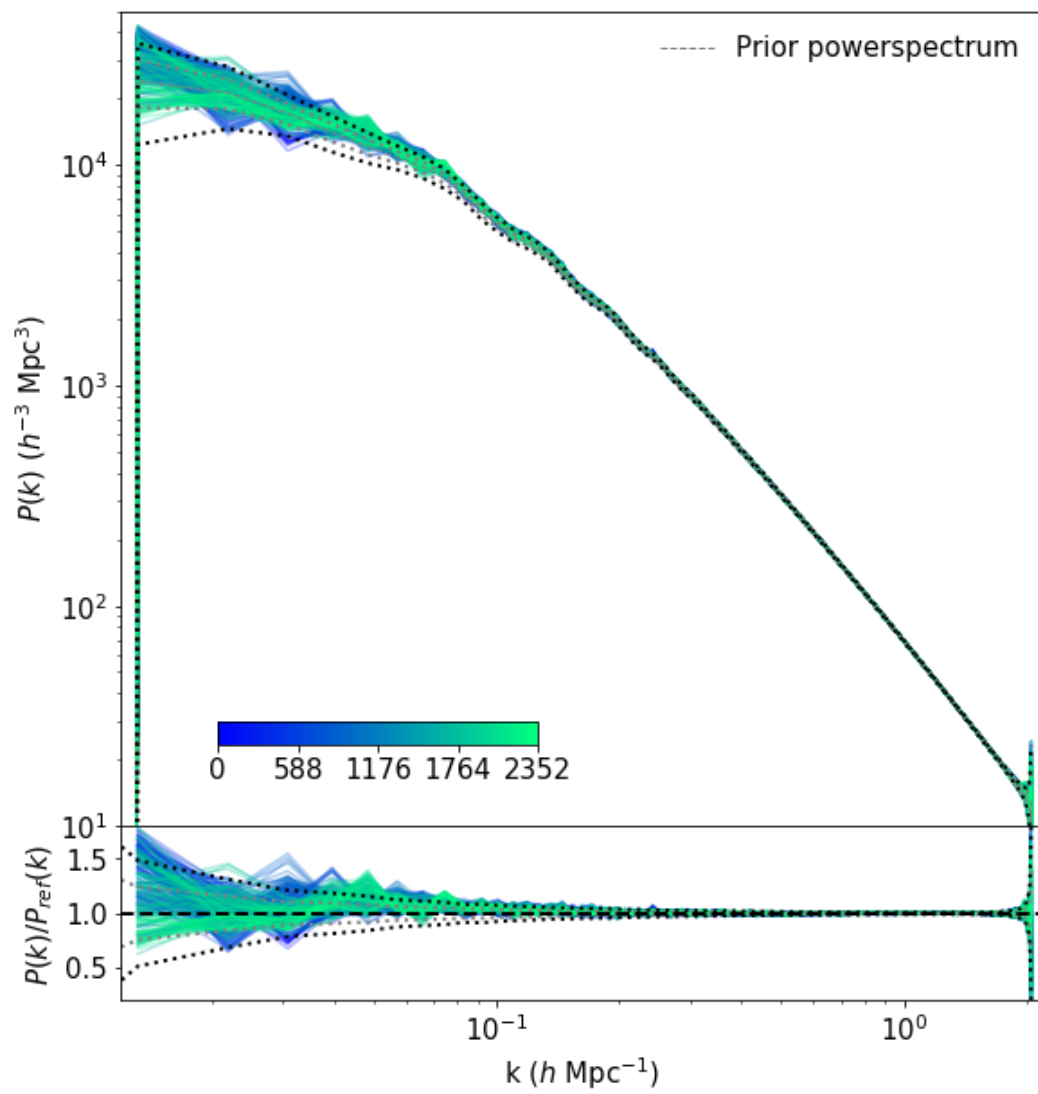
Ensemble average density fields at $z=0$



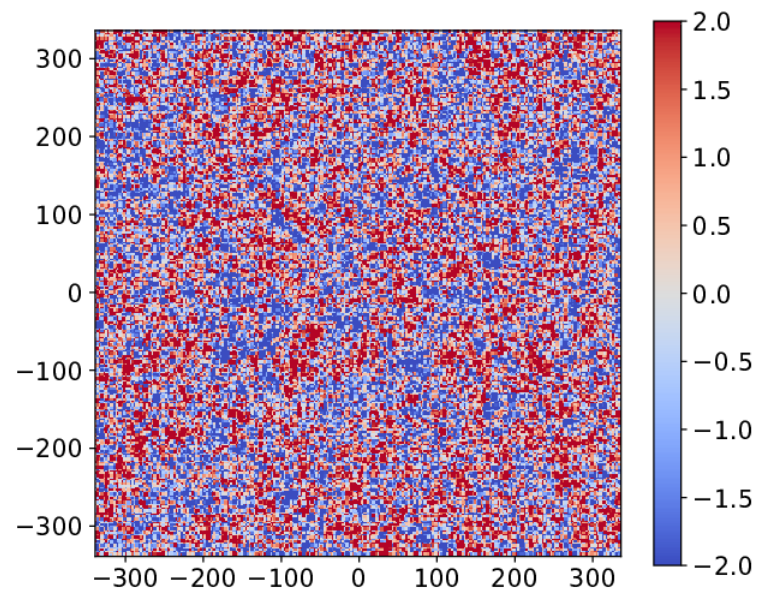
Performance aspect (2): burnin



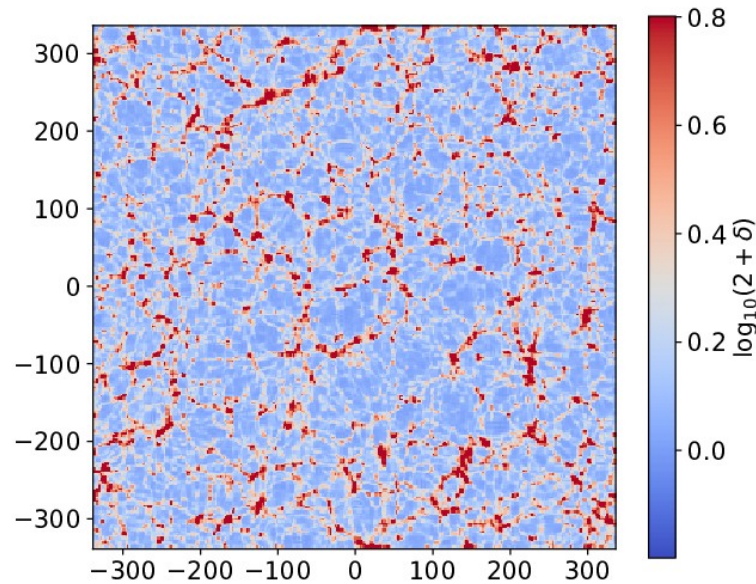
Initial condition powerspectrum



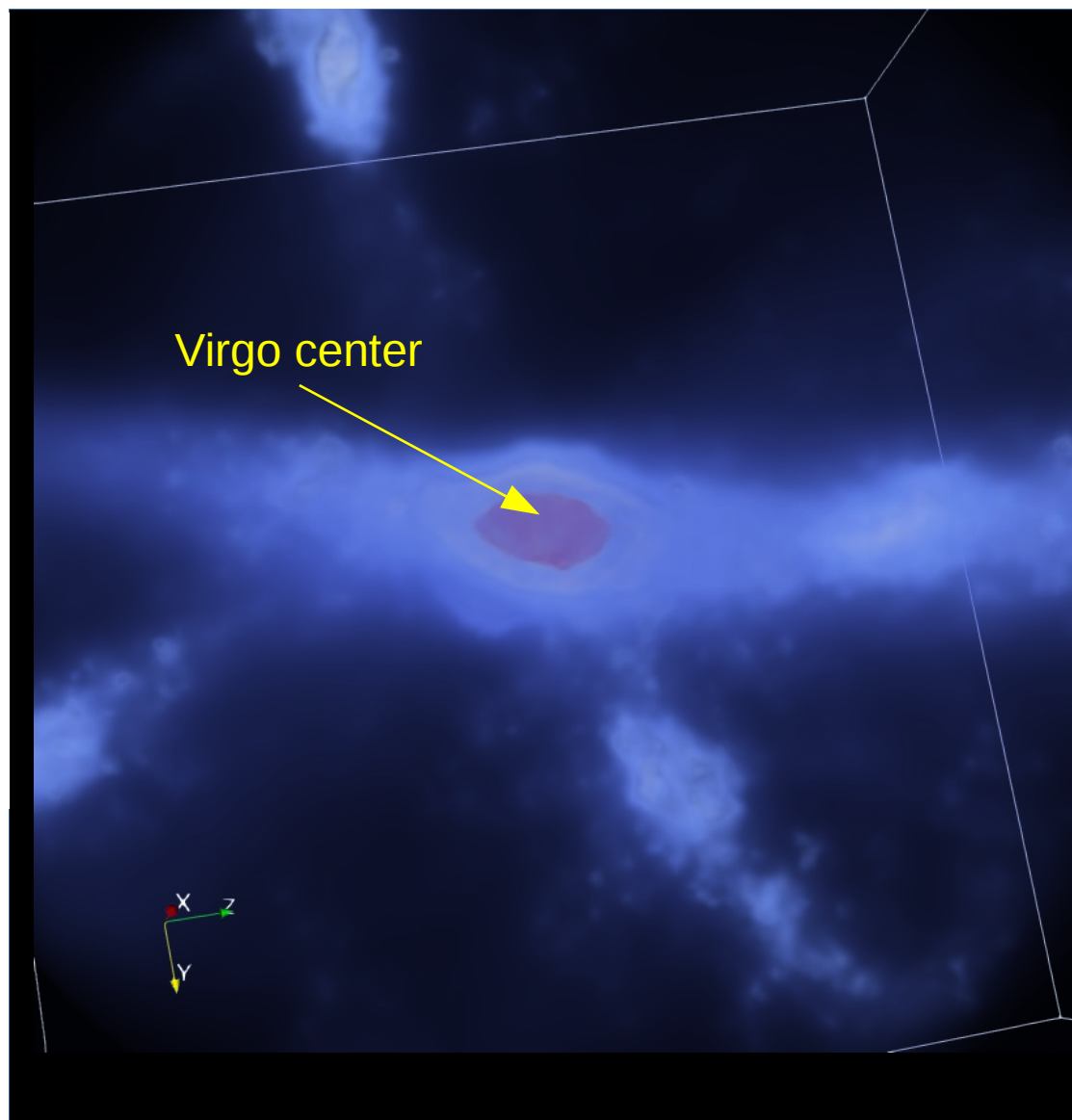
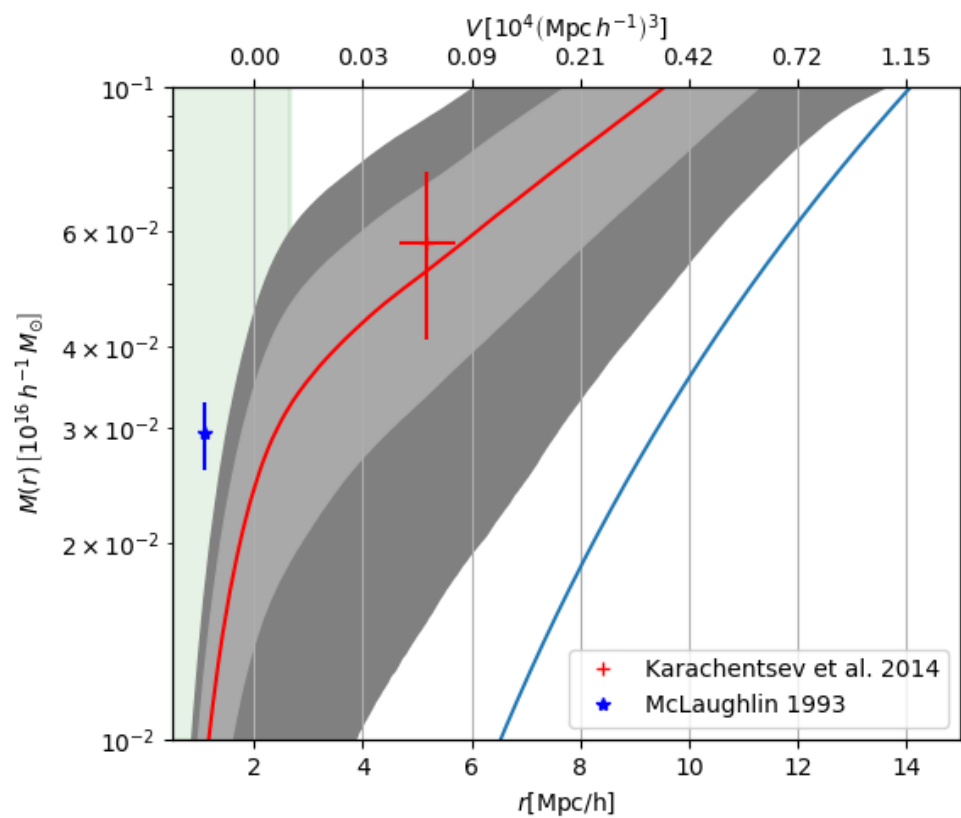
Initial conditions



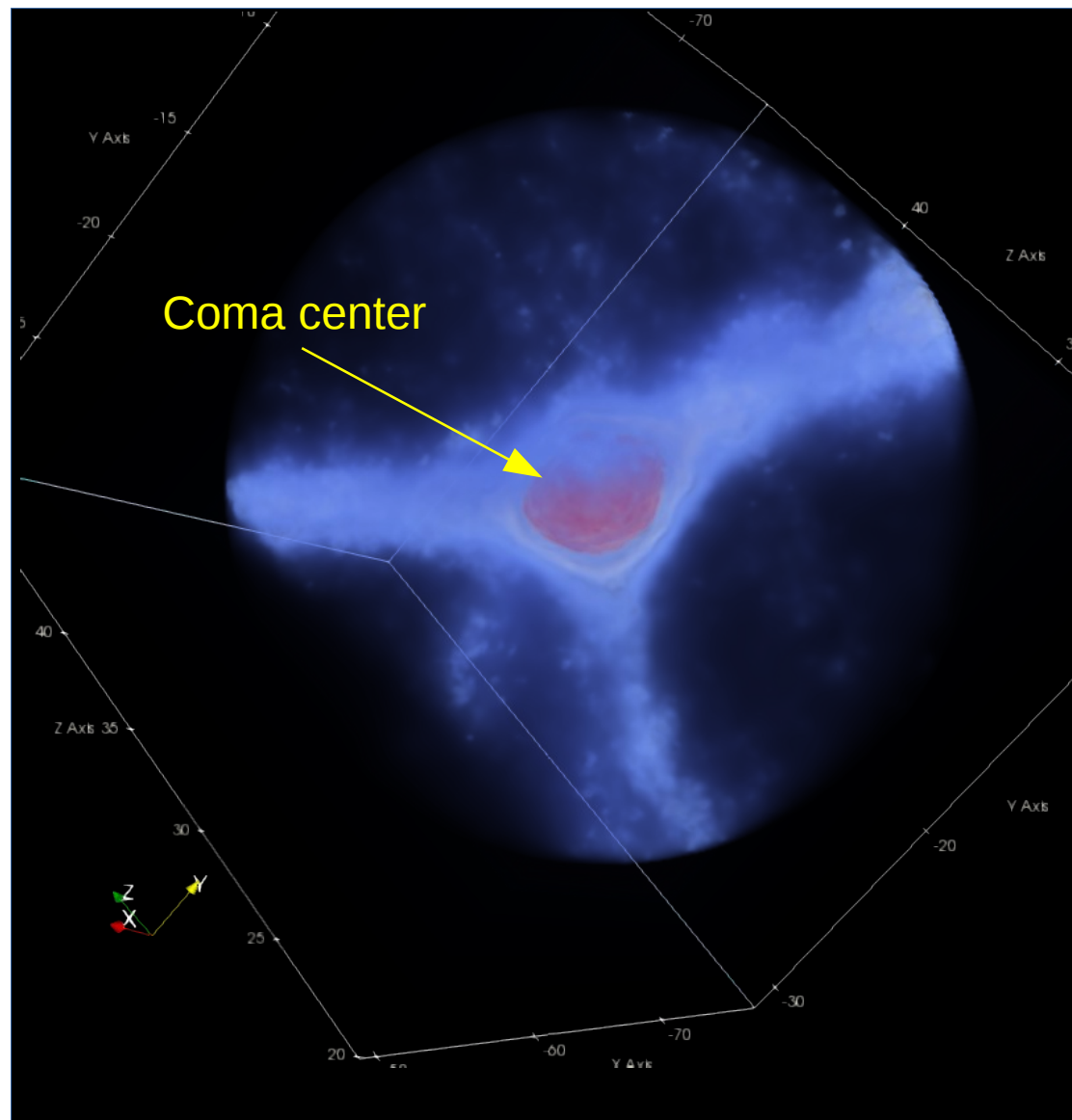
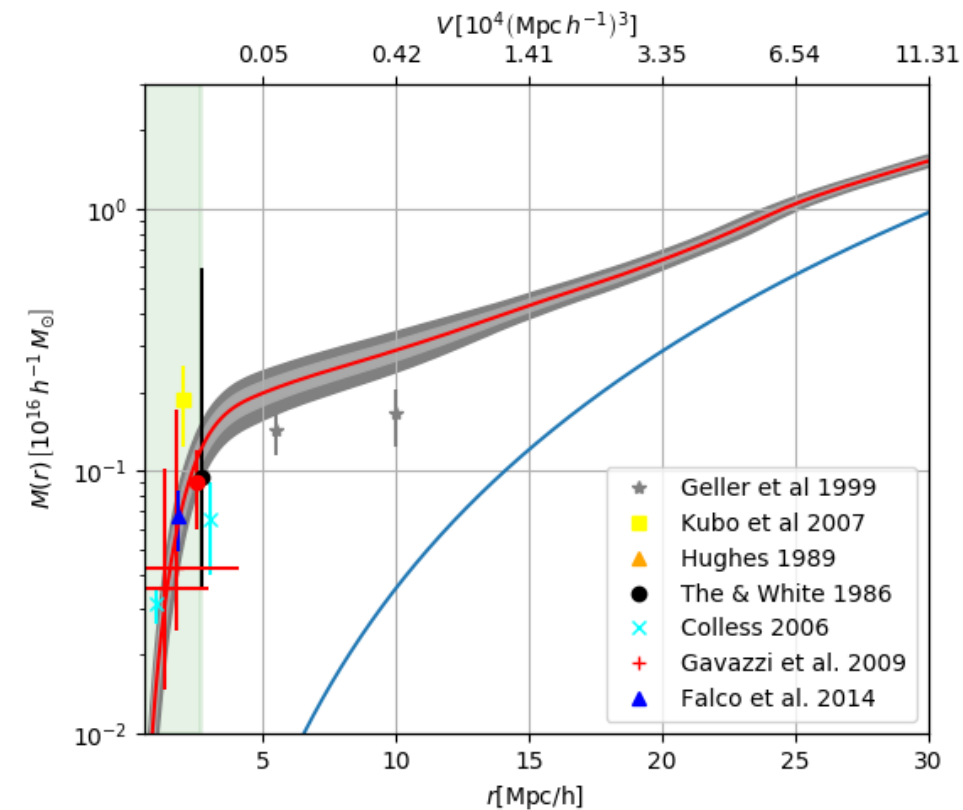
Post PM simulation



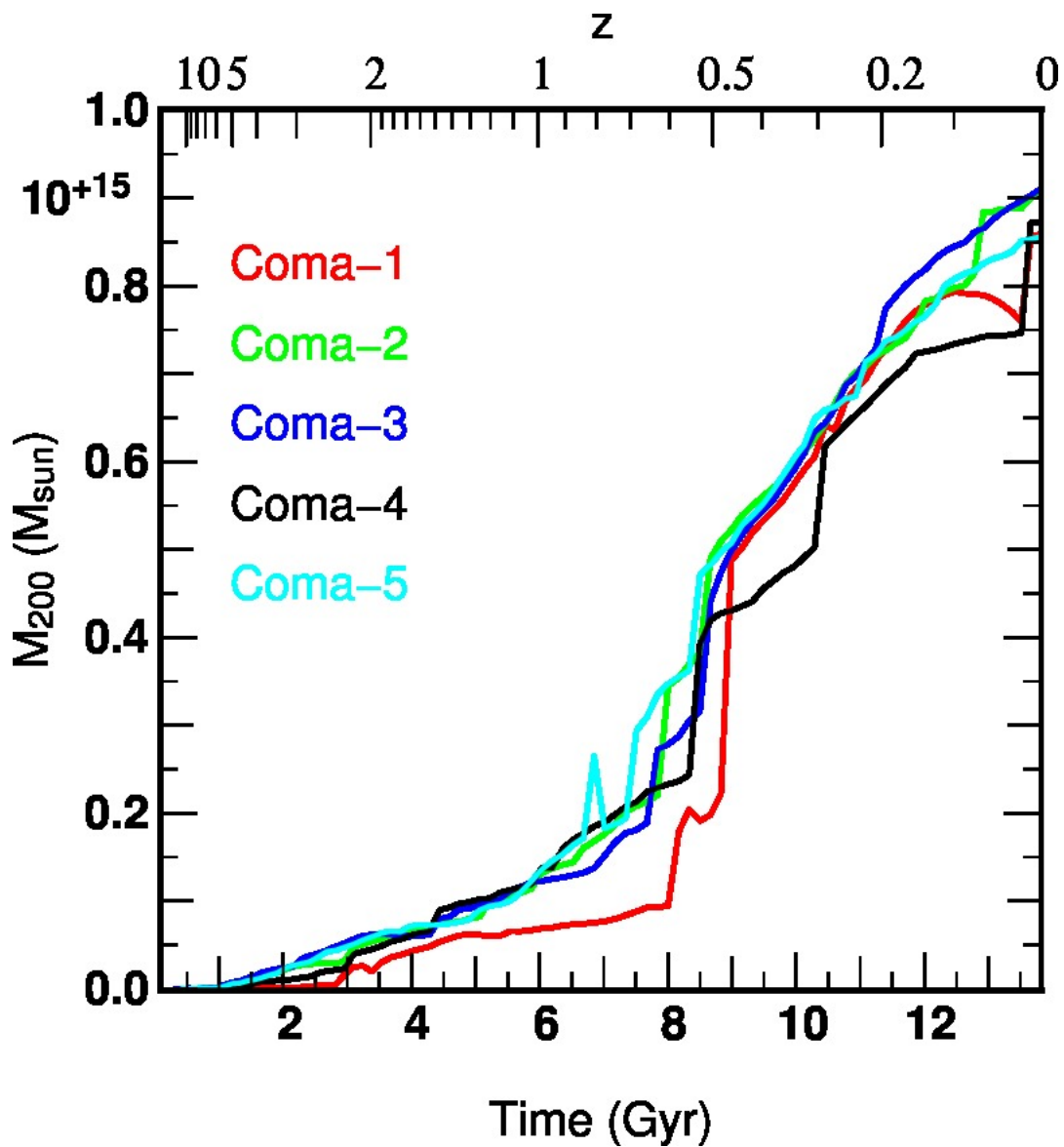
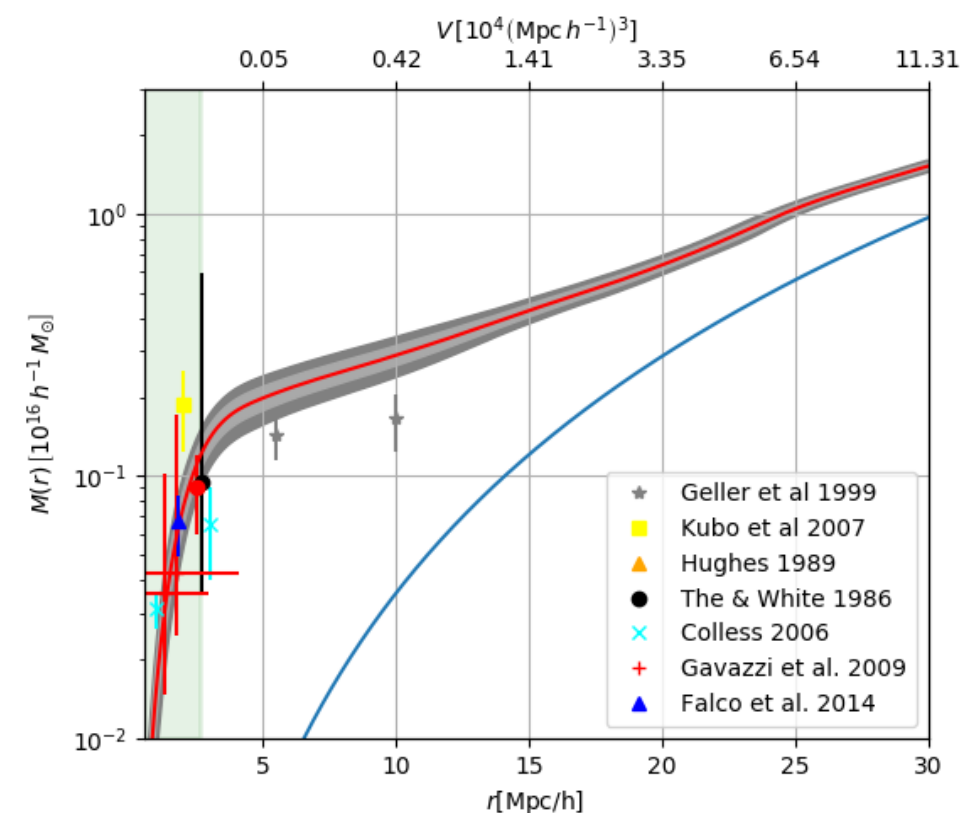
Virgo cluster



Coma dynamical properties



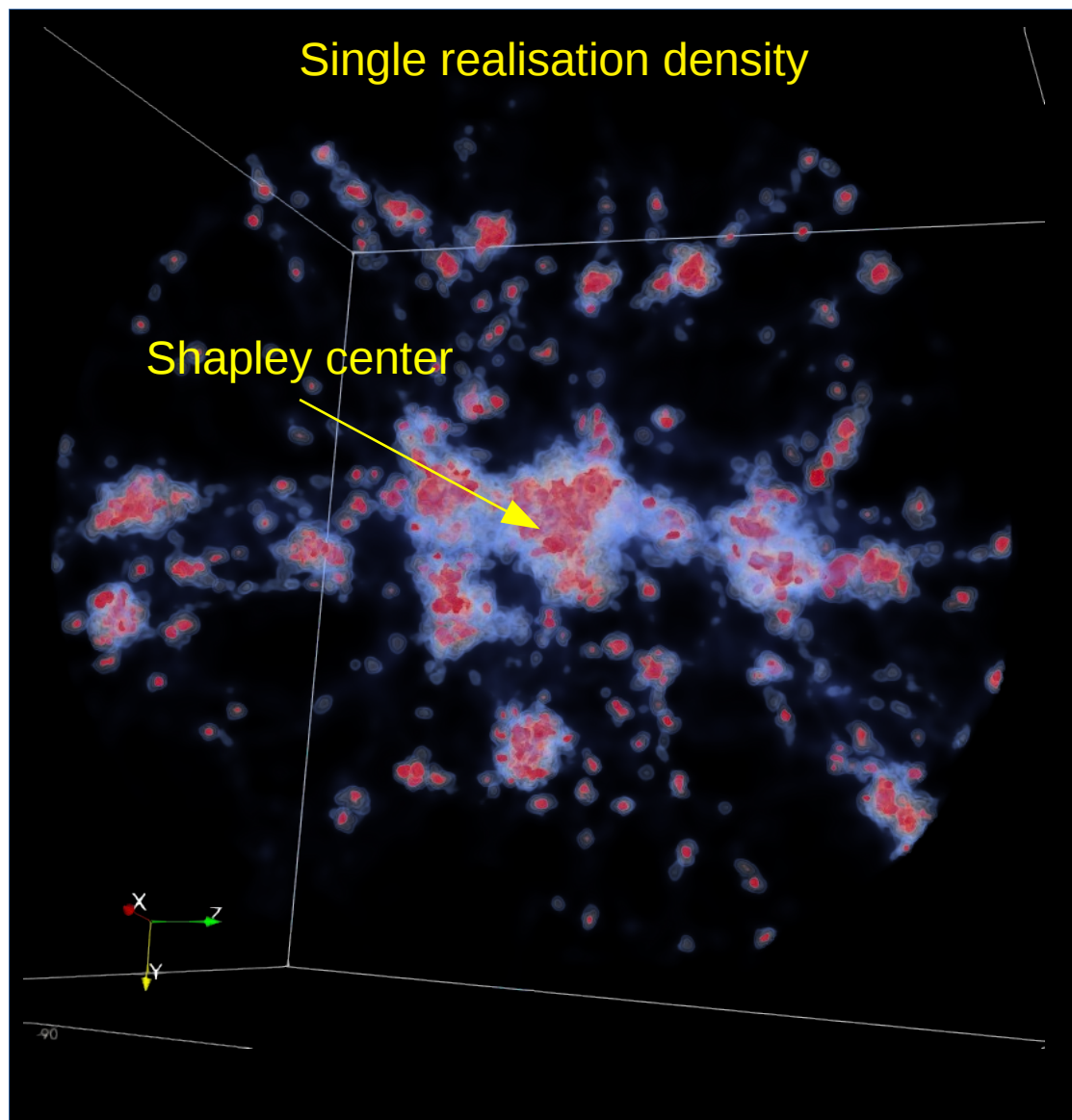
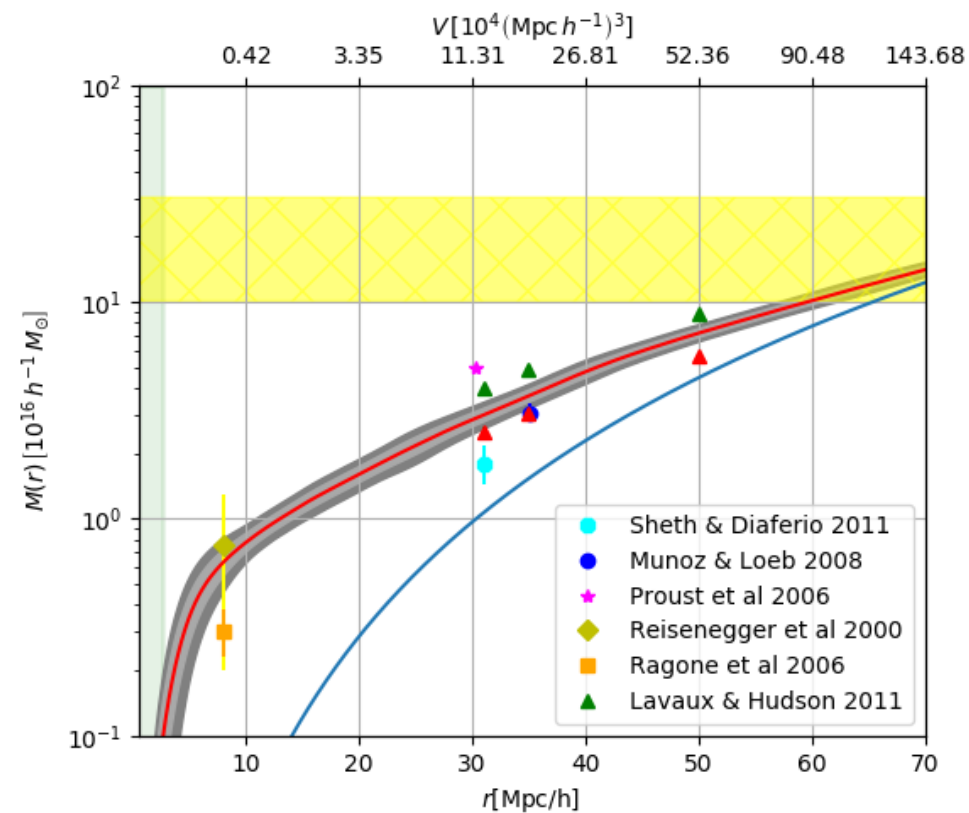
Coma dynamical properties



Zoom simulation on Coma
 (~250 Mpart in zoom)

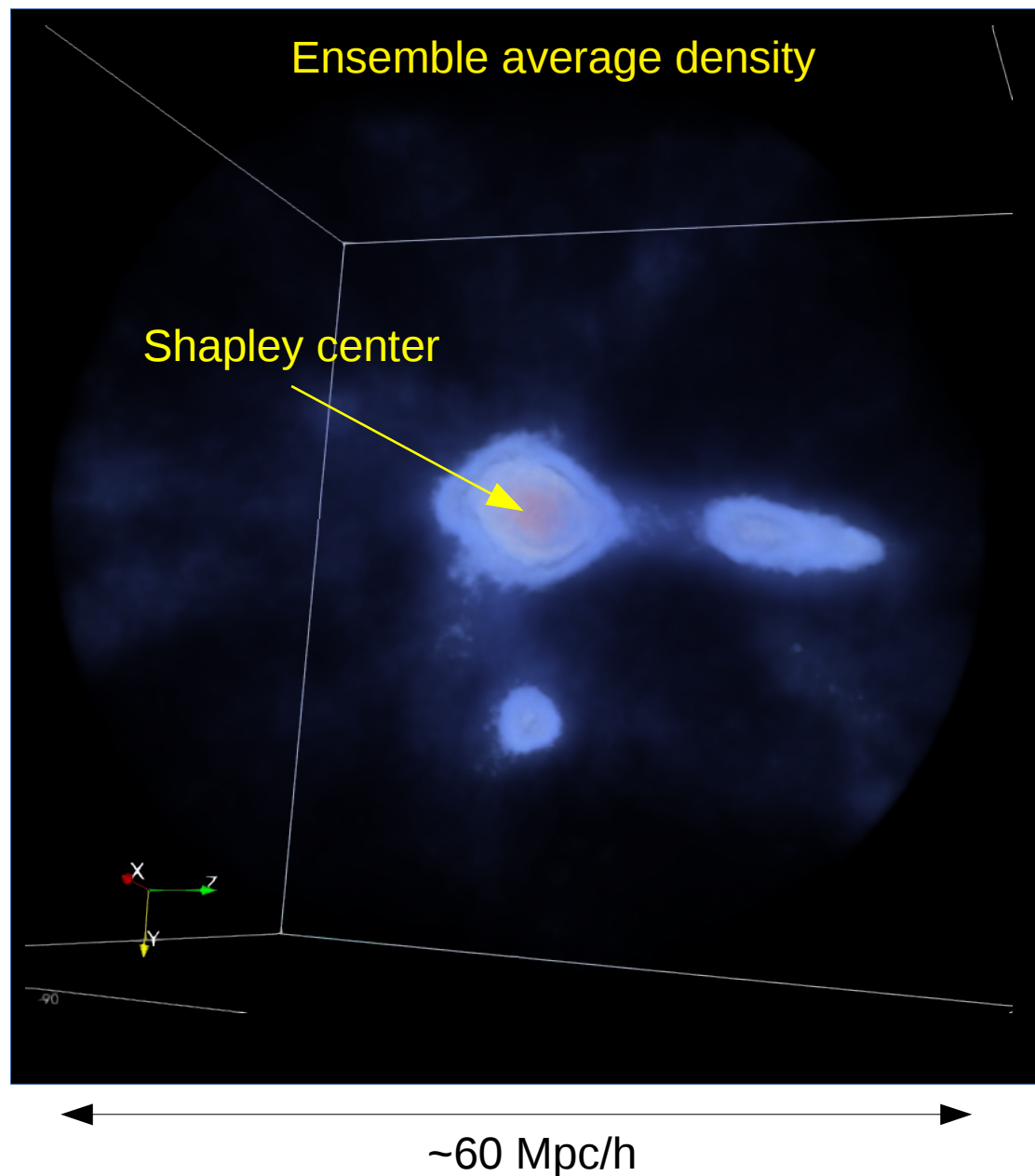
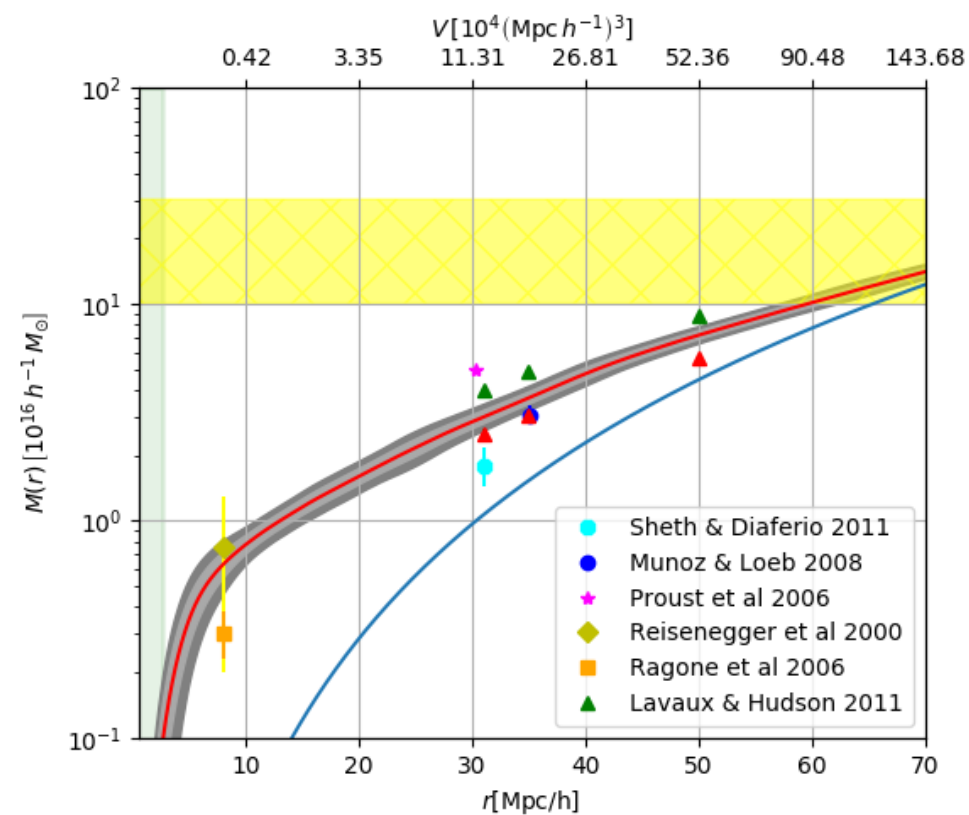
$4 \times 10^7 h^{-1} M_{\odot} / \text{part}$

Shapley concentration

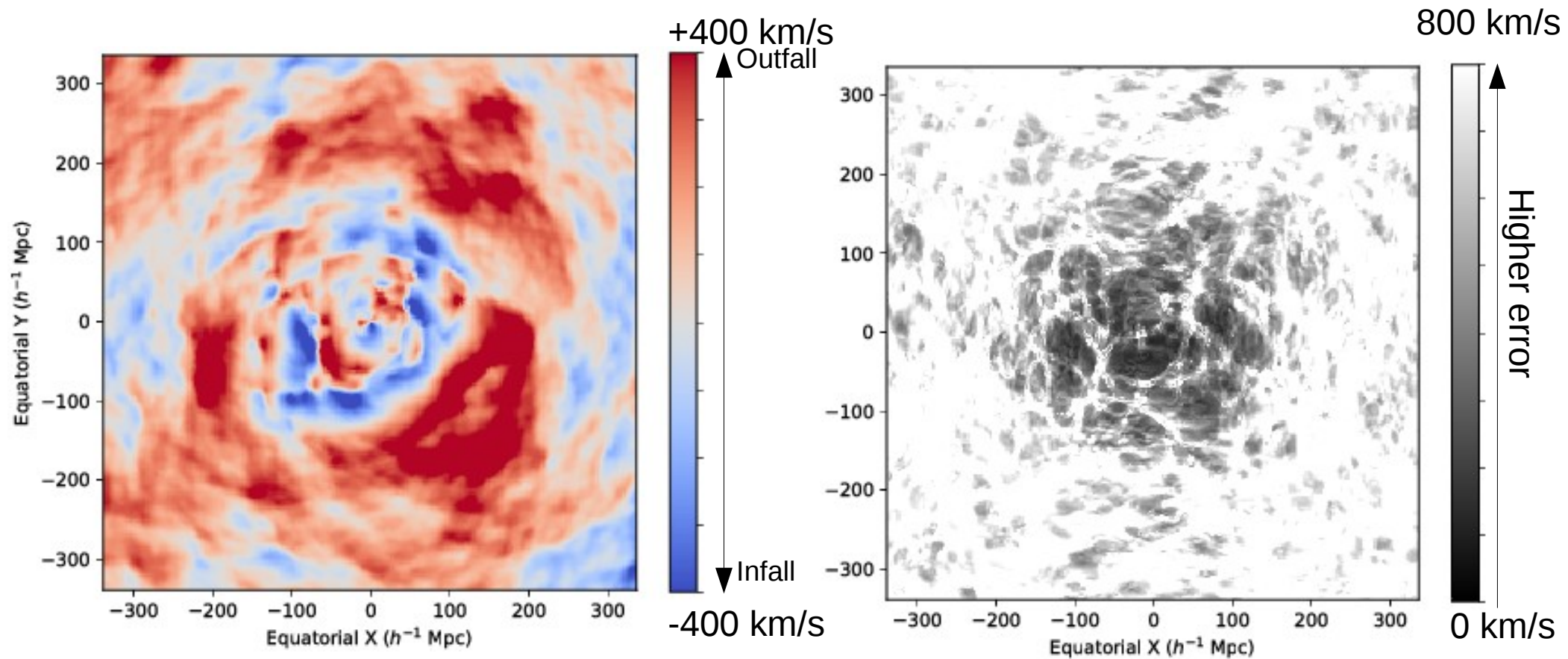


~60 Mpc/h

Shapley concentration

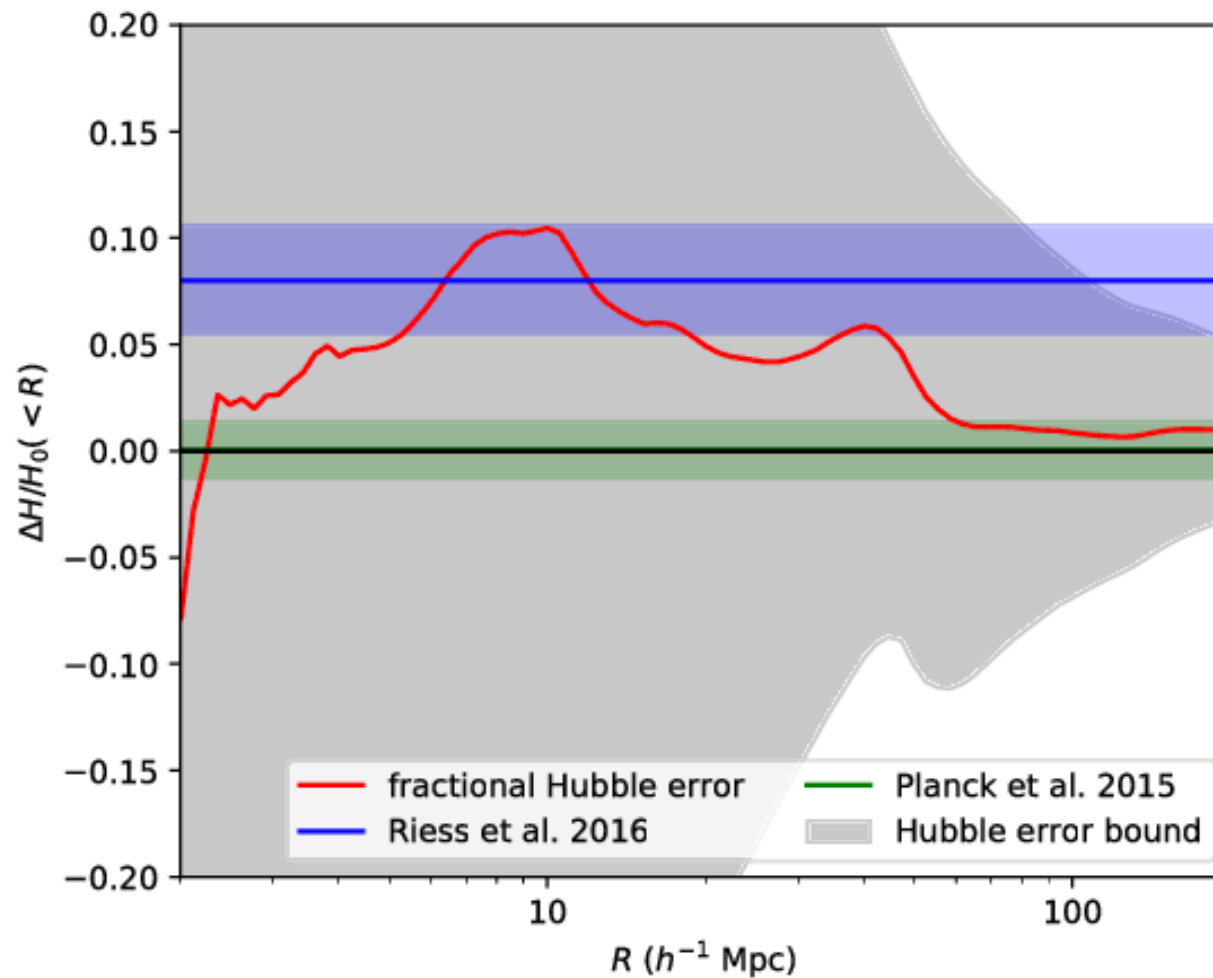


Inferred velocity fields



Velocity field and Hubble constant

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

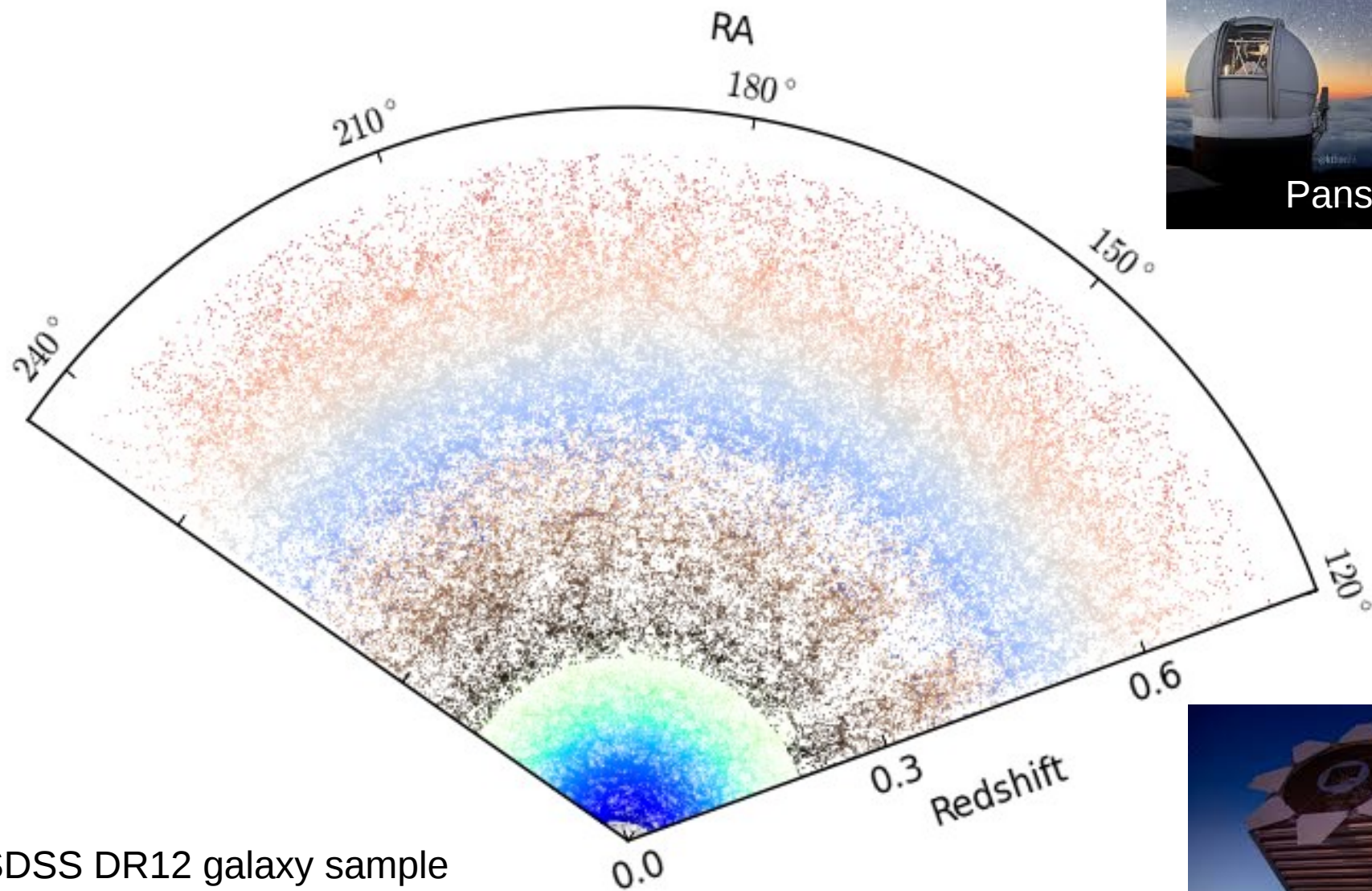


TODO: Compare all the flow models

A visualization of the cosmic web, showing a complex network of filaments and nodes. The left side is dark purple and black, transitioning to a bright cyan and yellow on the right. The filaments are thin and interconnected, forming a web-like structure.

**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 expansion

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

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

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

Cosmic growth of structures

Implemented so far for (2)LPT:

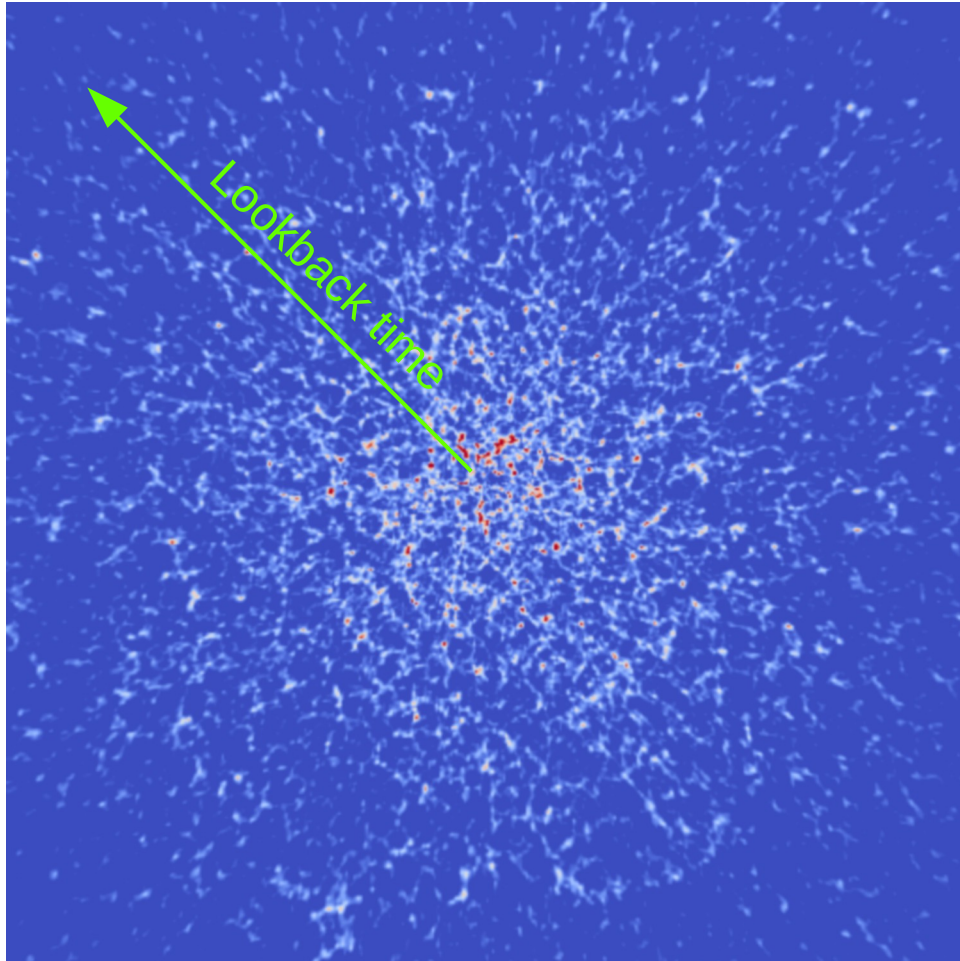
$$\vec{x}(\vec{q}, t) = \vec{q} + \Psi(\vec{q}, t) \underset{LPT}{\simeq} \vec{q} + D(t)\Psi(\vec{q})$$

(see Doogesh' poster)

Kodi Ramanah, Lavaux, Jasche, Wandelt (2018, in prep.)

Forward model becomes more complex

Cosmic expansion

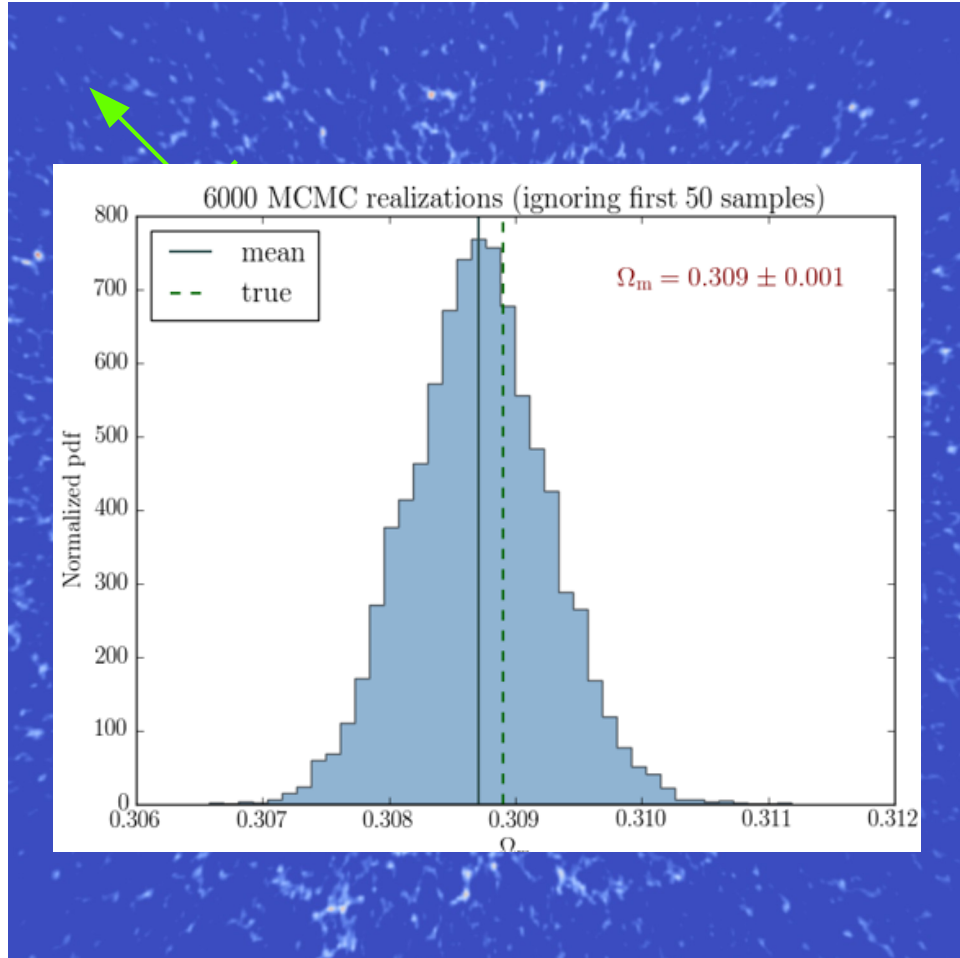


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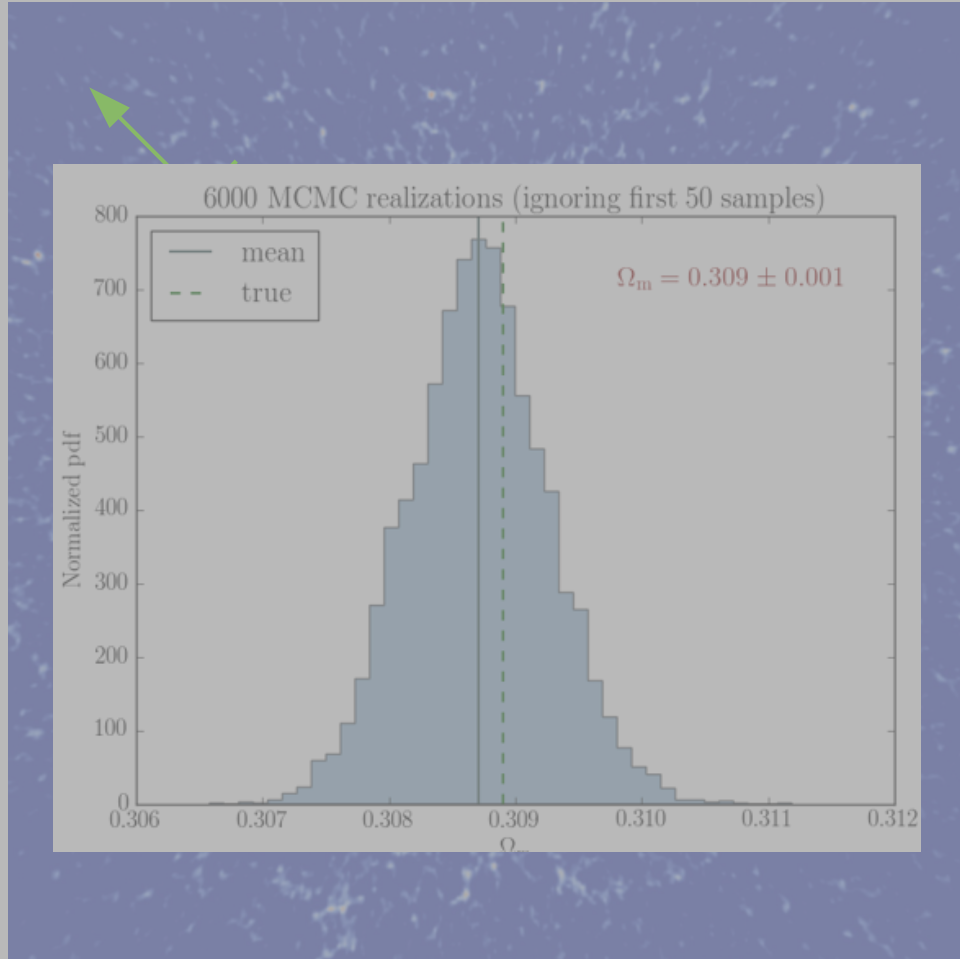


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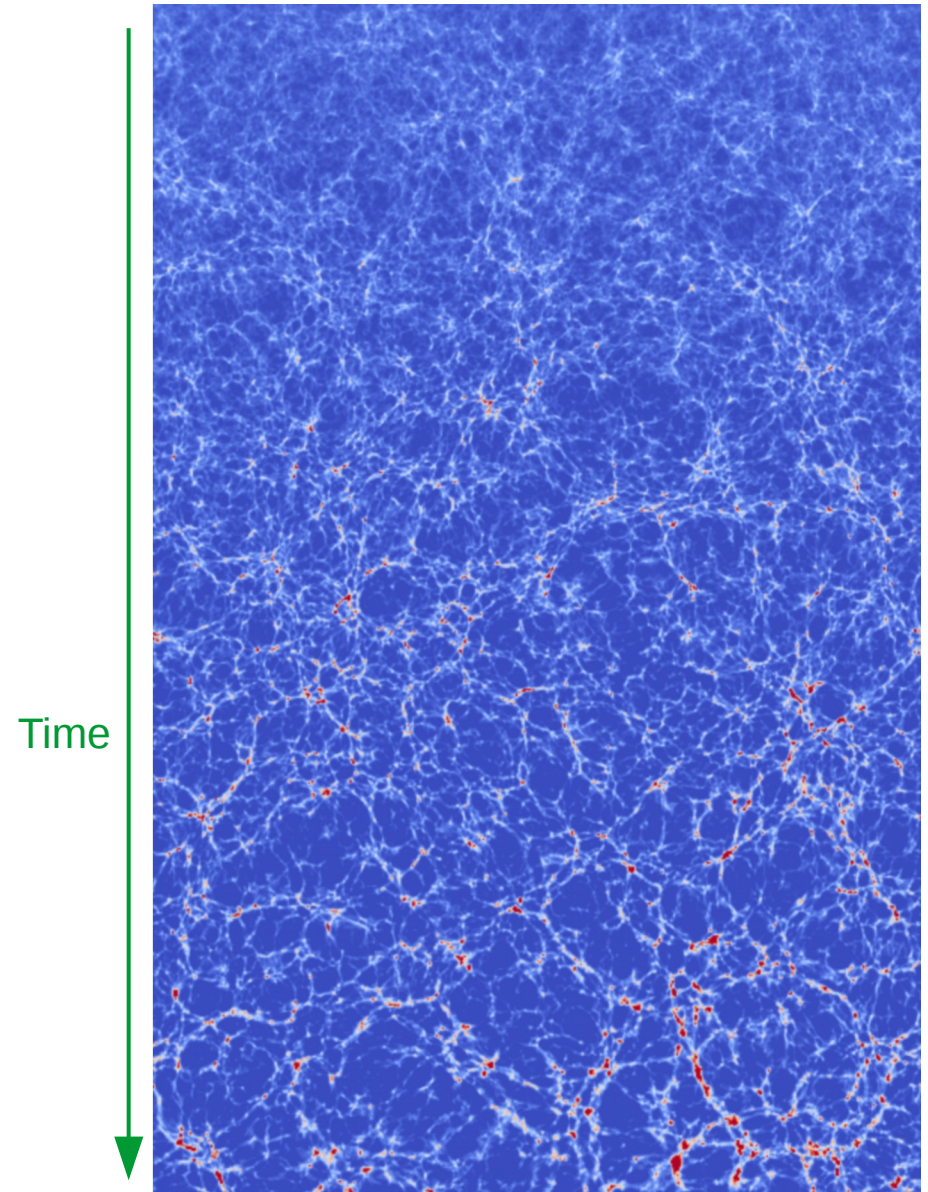
Cosmic expansion



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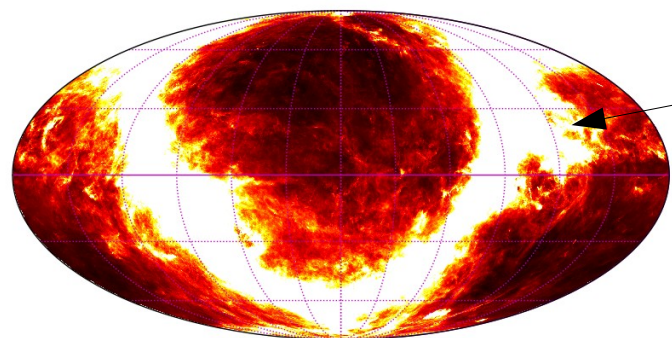
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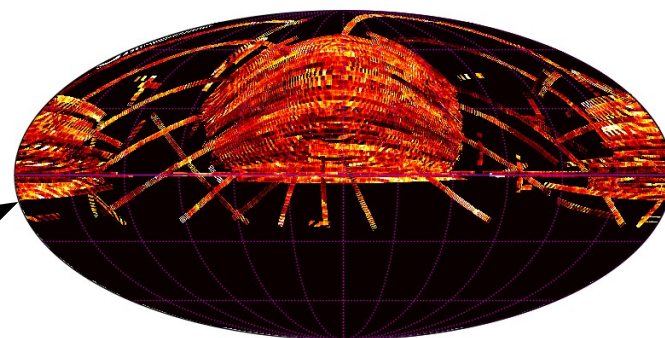


... and systematic cleaning ...

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

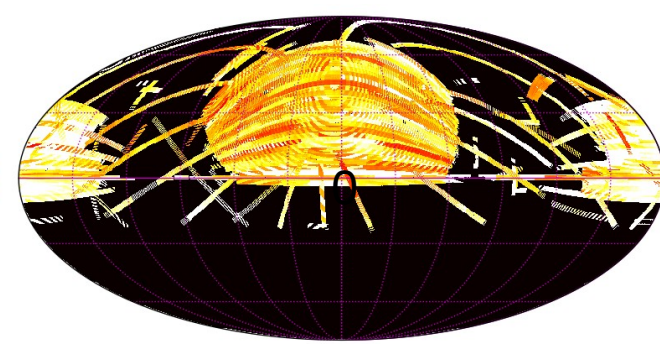
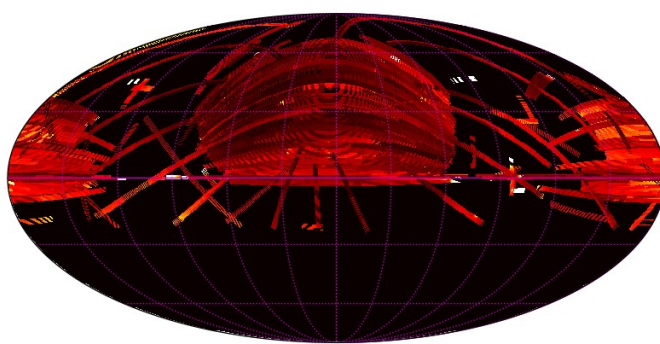
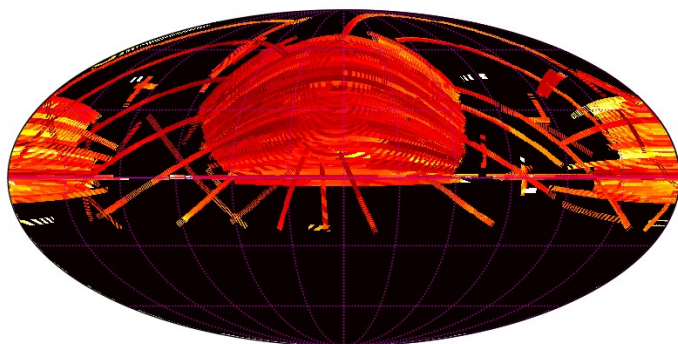


DUST



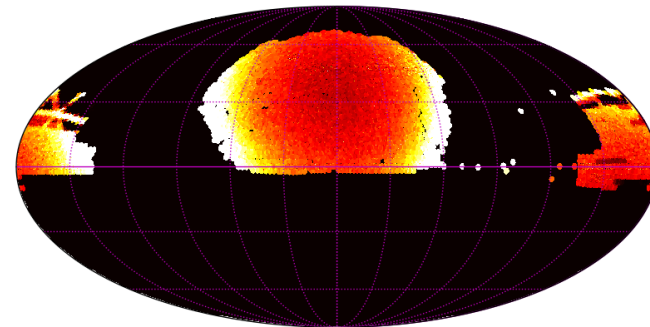
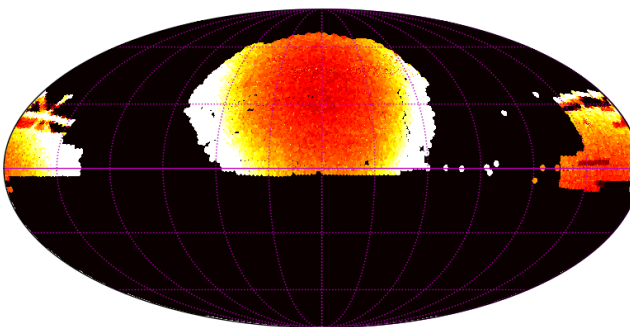
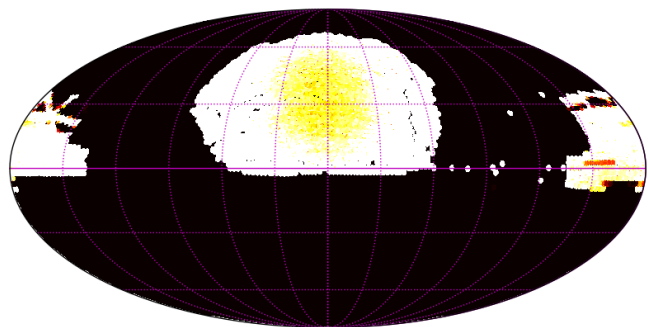
psfWidth

Sky fluxes



...

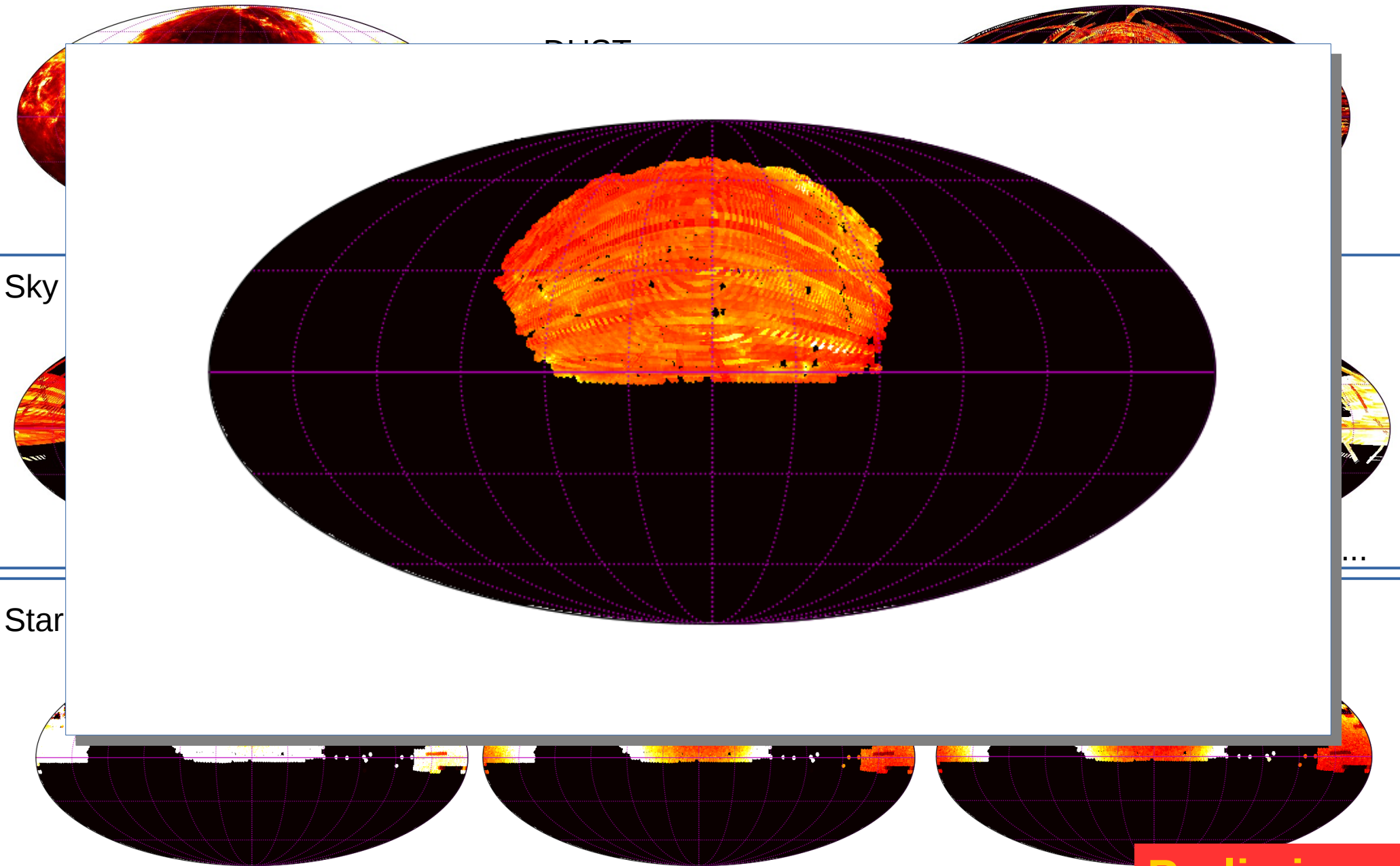
Star densities



...

Example fitted composite...

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

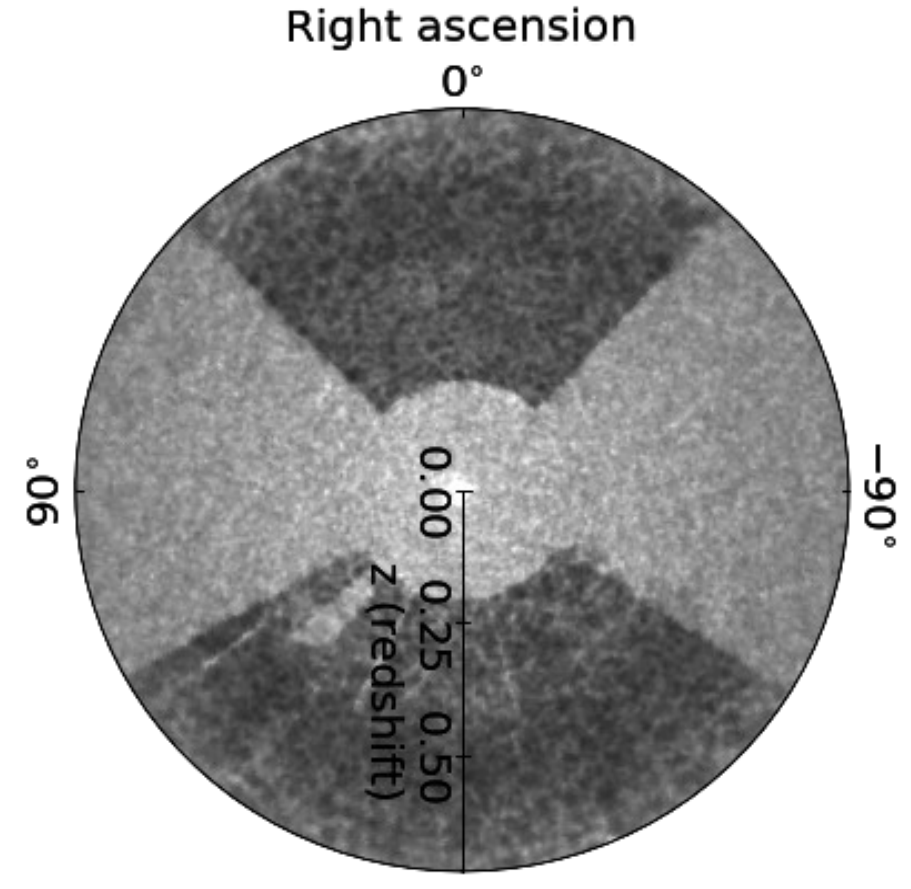
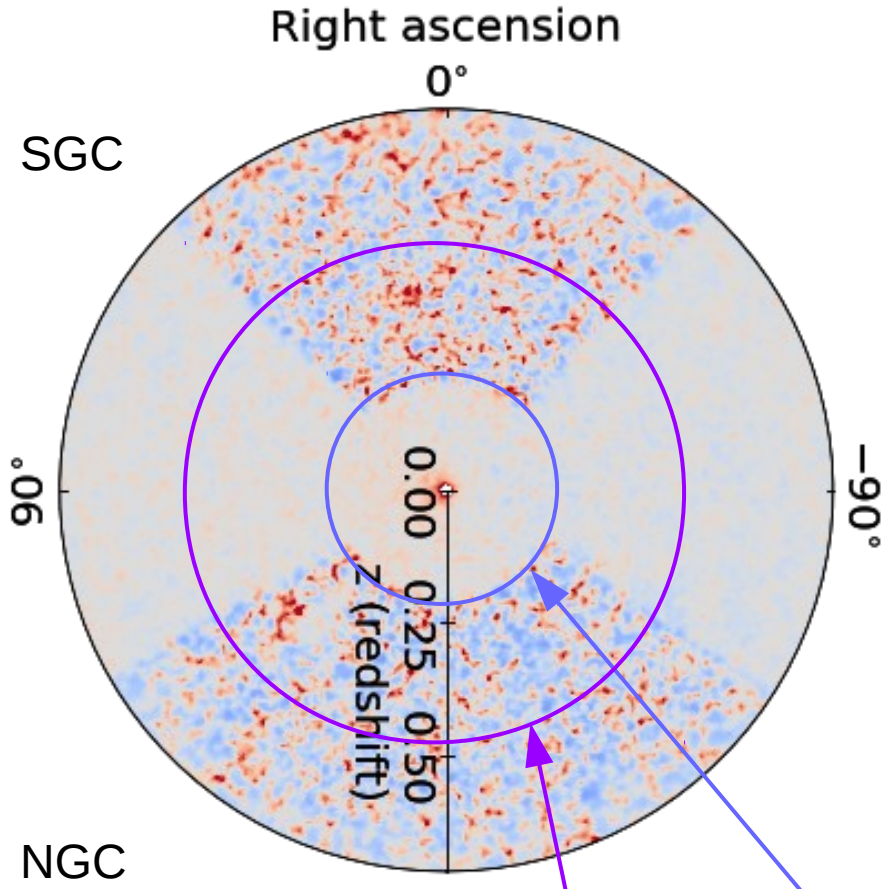


Preliminary

Inferred density of SDSS3

Ensemble density average

Error estimate from ensemble variance



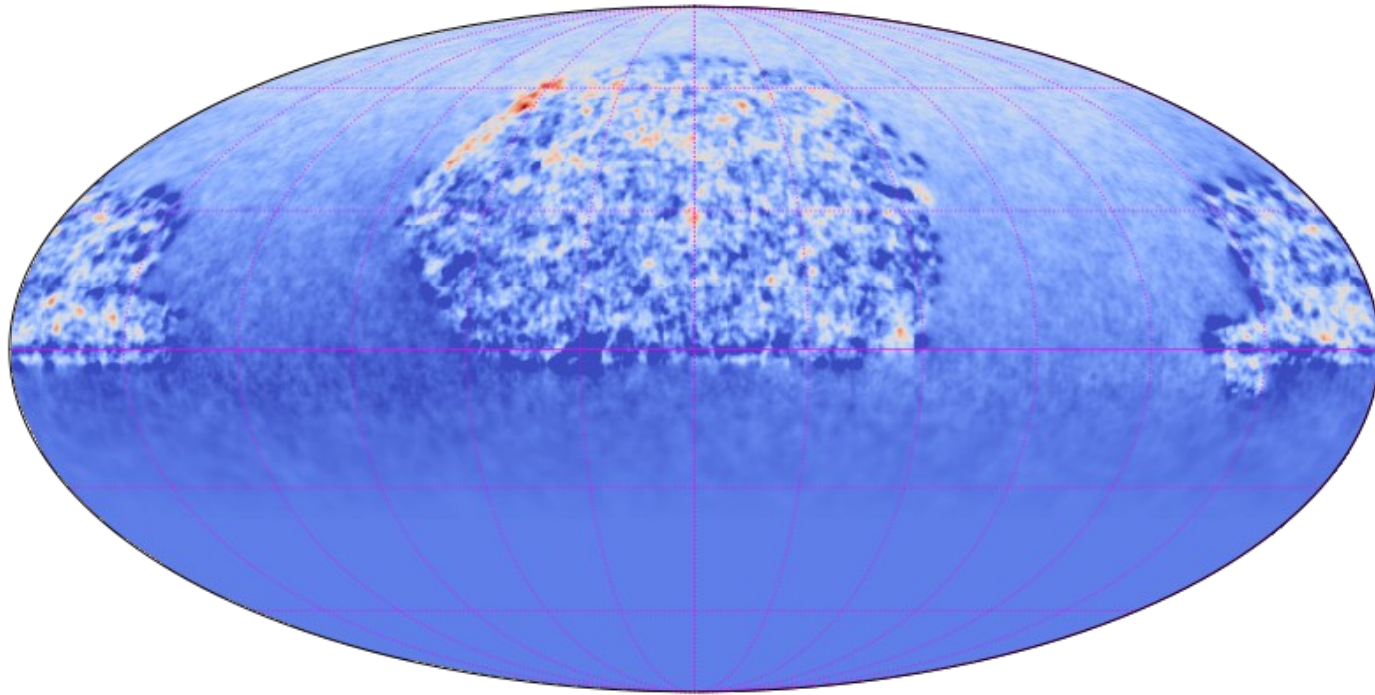
Main galaxy sample limit
(not included)

LOWZ limit

CMASS limit

Preliminary

Sky density



Preliminary

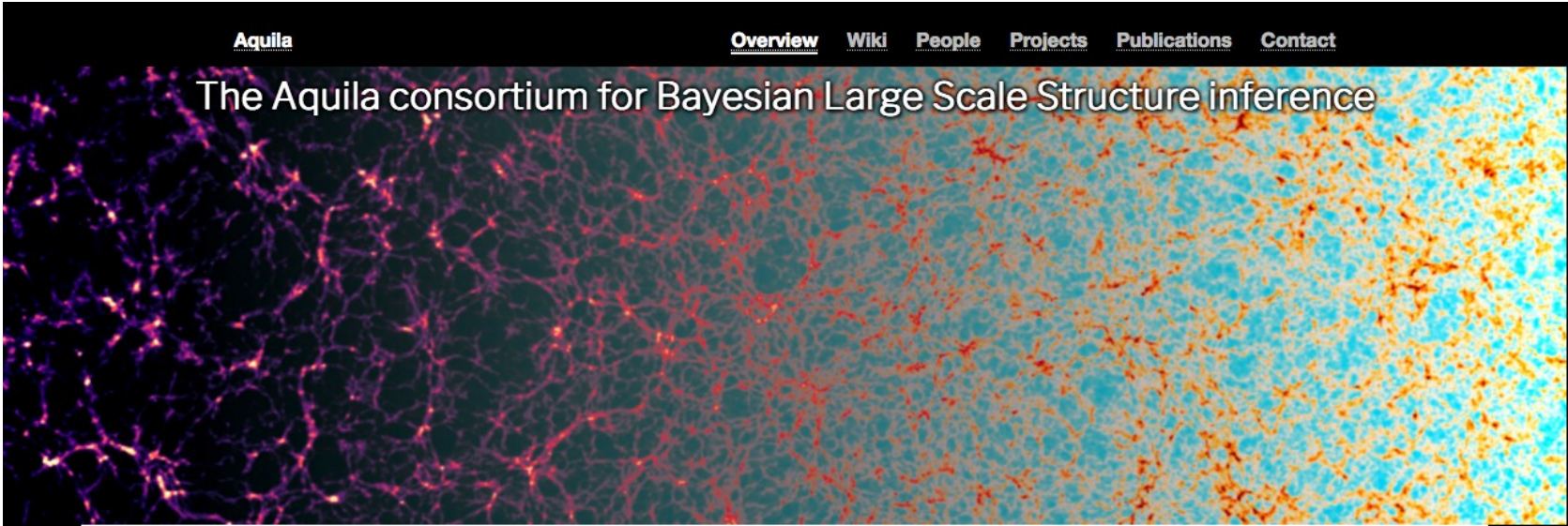


Conclusion

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

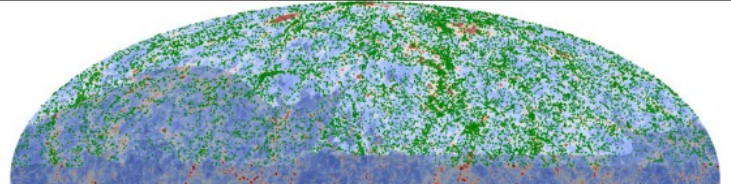
Our mission: Data science meets the Universe

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



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

A biased list of Aquilians... check the website!



Natalia Porqueres



Minh Nguyen



Doogesh Kodi Ramanah

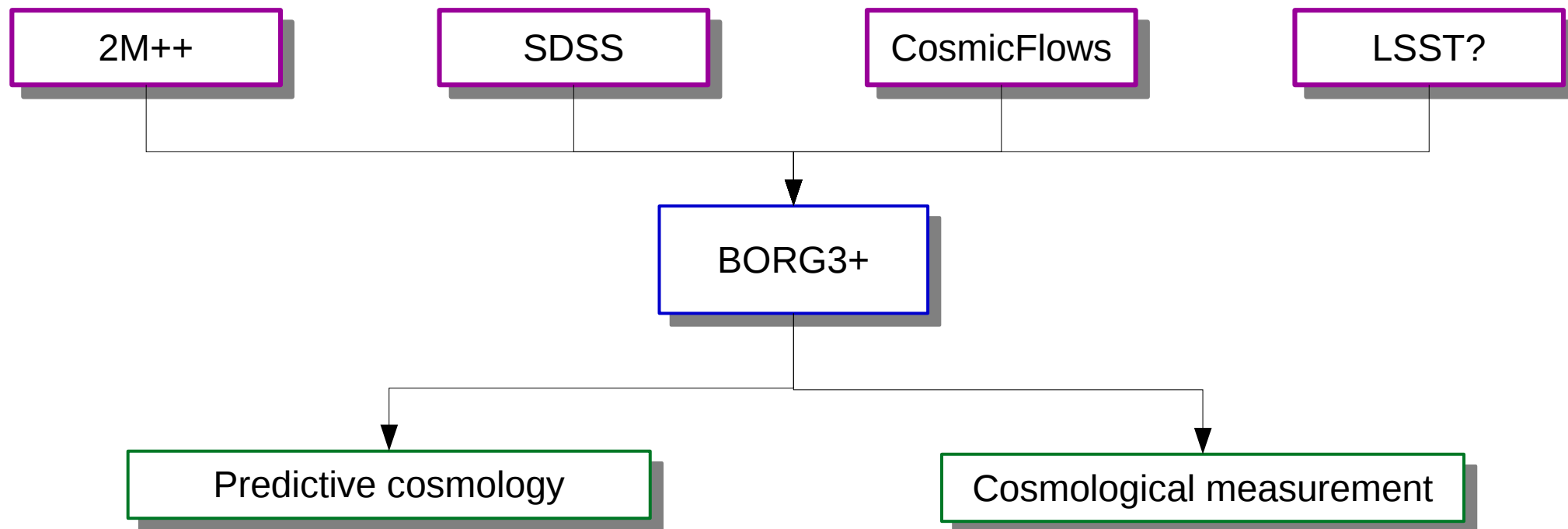


Tom Charnock



Florent Leclercq

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

