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...

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

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

Forward description →

Observations

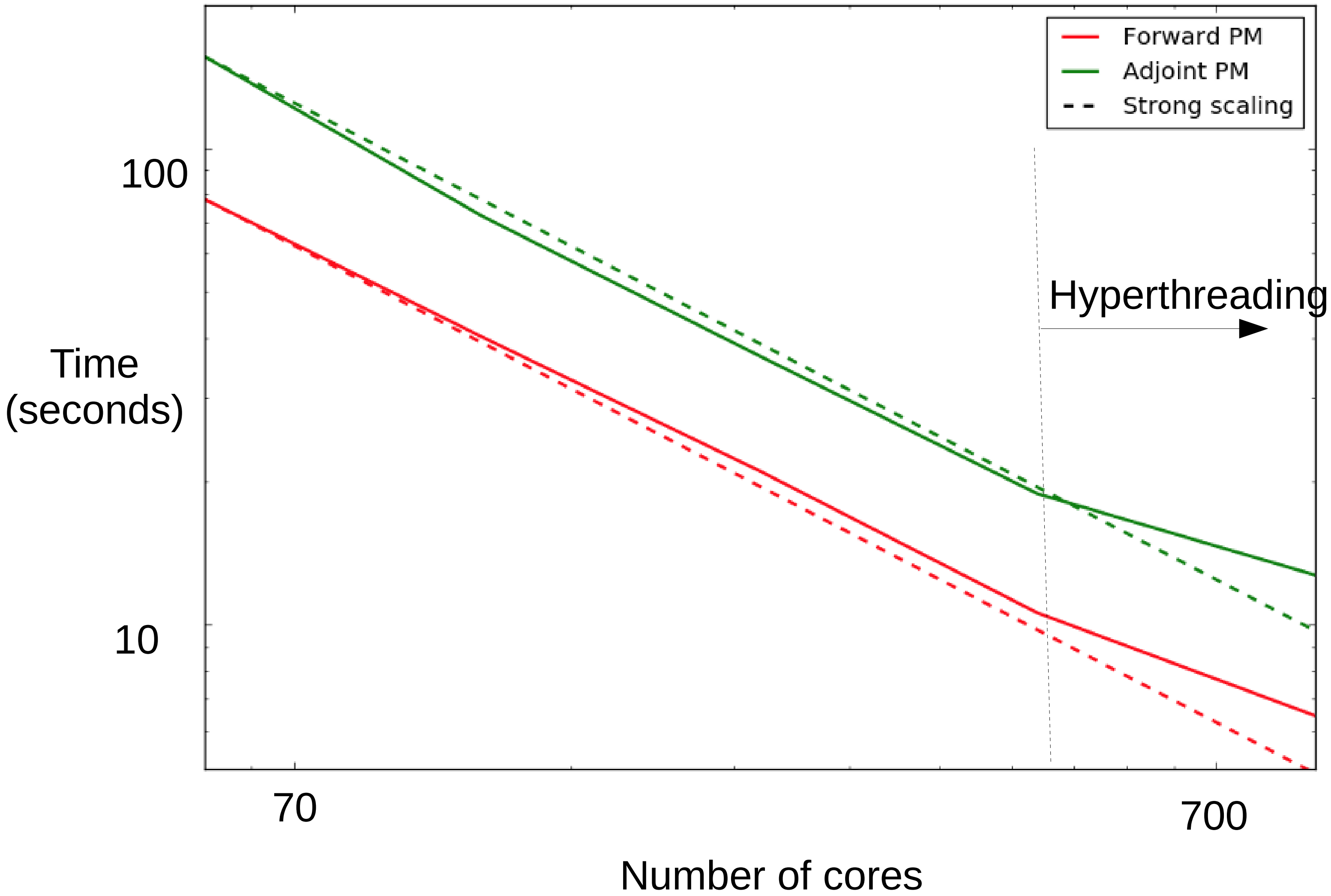
← Adjoint gradient

Encode survey systematic effects with expansions:

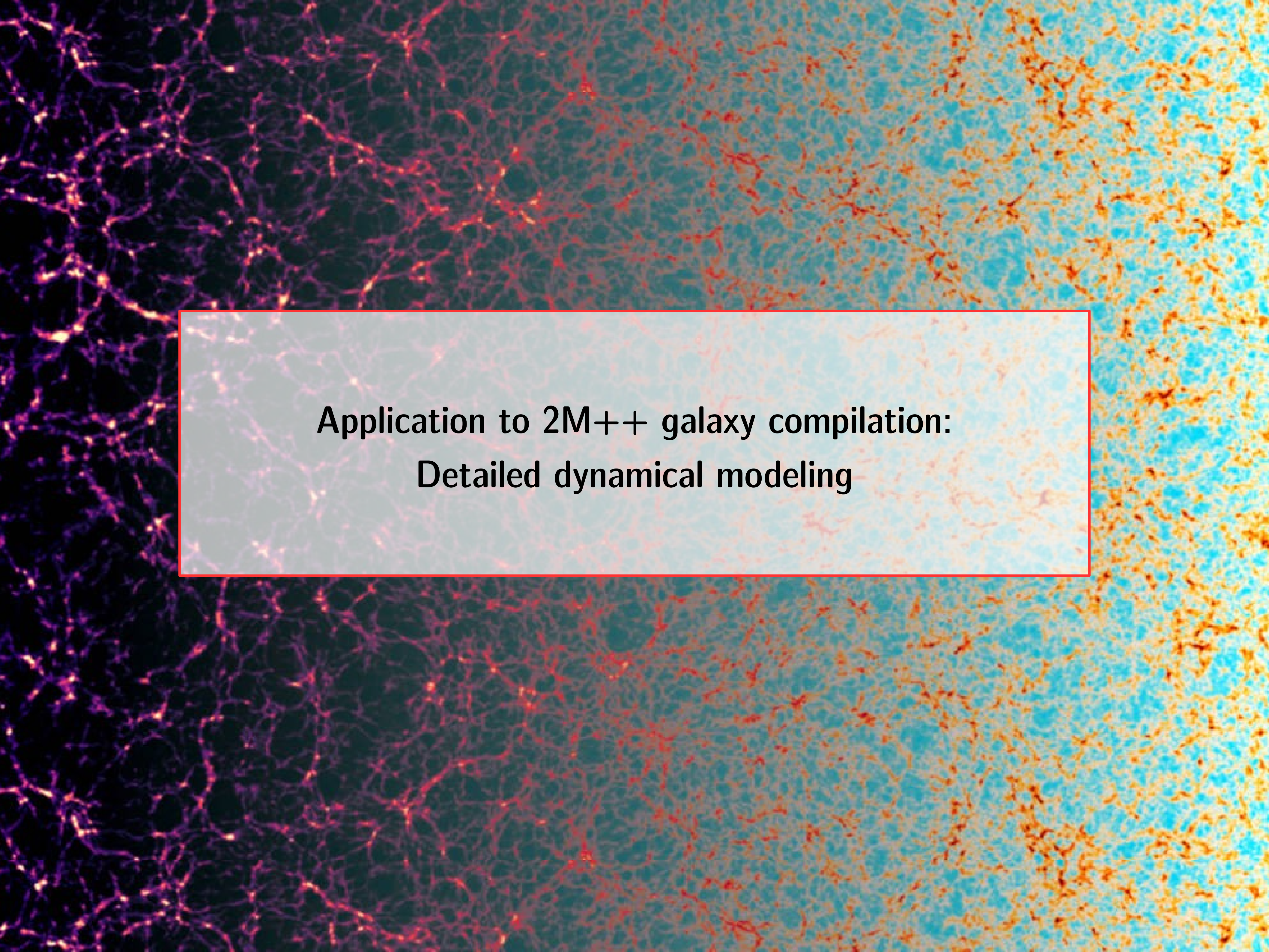
$$S(\hat{x}) = S_0(\hat{x}) \prod_{f=1}^{N} (1 + \alpha_f F_f(\hat{x}))$$

Jasche et al. (2010), Jasche & Wandelt (2013), Lavaux & Jasche (2016), Jasche & Lavaux (2017, 2018)

BORG-PM Performance aspect



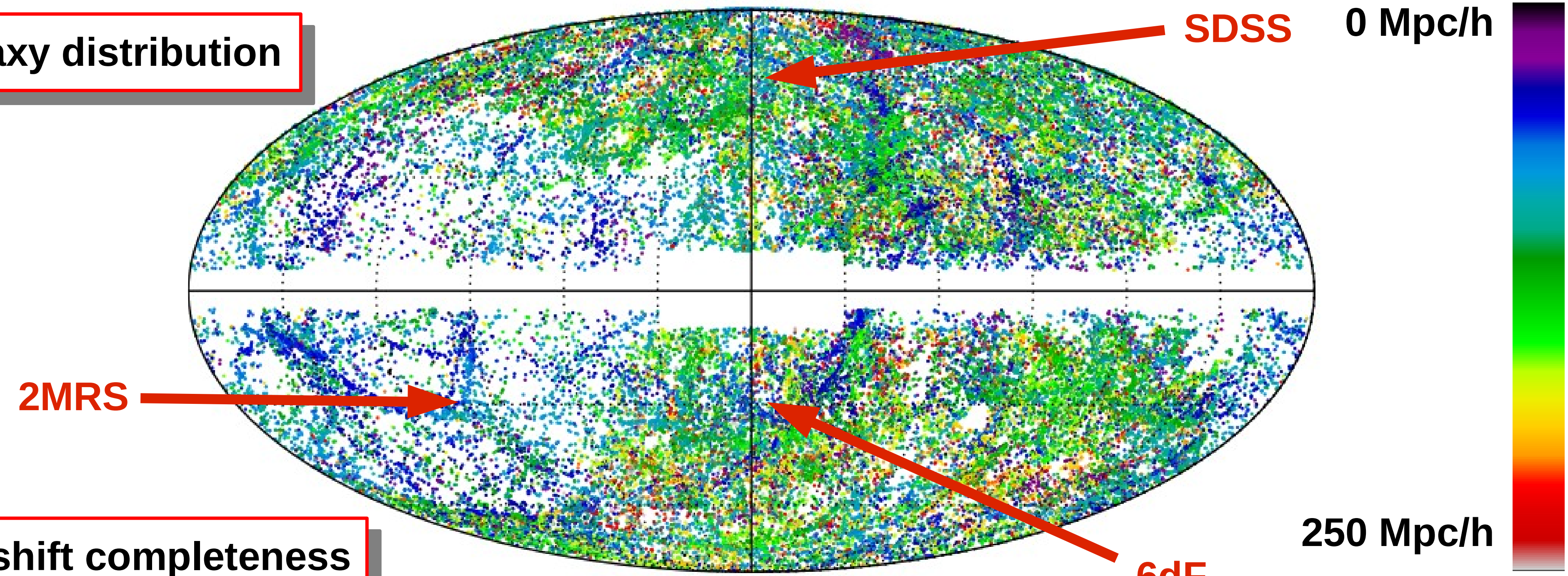
BORG-(2)LPT is ~20 times faster



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

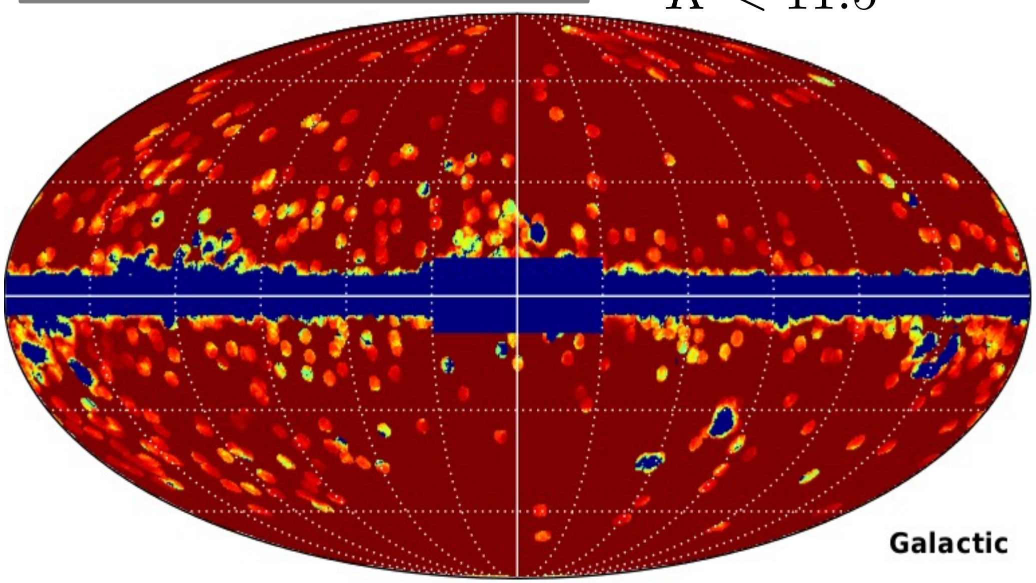
The 2M++ galaxy compilation

Galaxy distribution

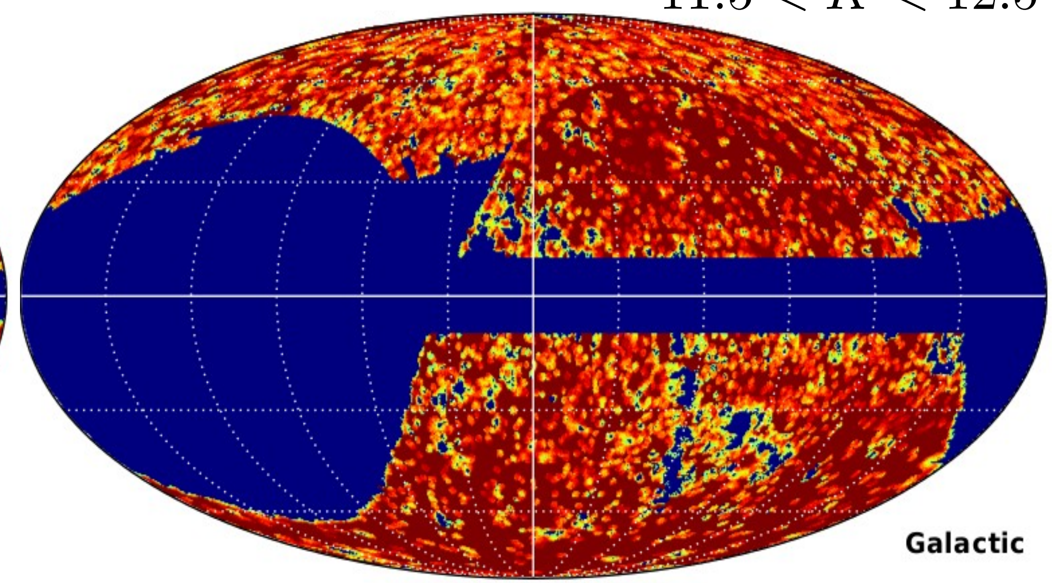


Redshift completeness

$K < 11.5$



$11.5 < K < 12.5$

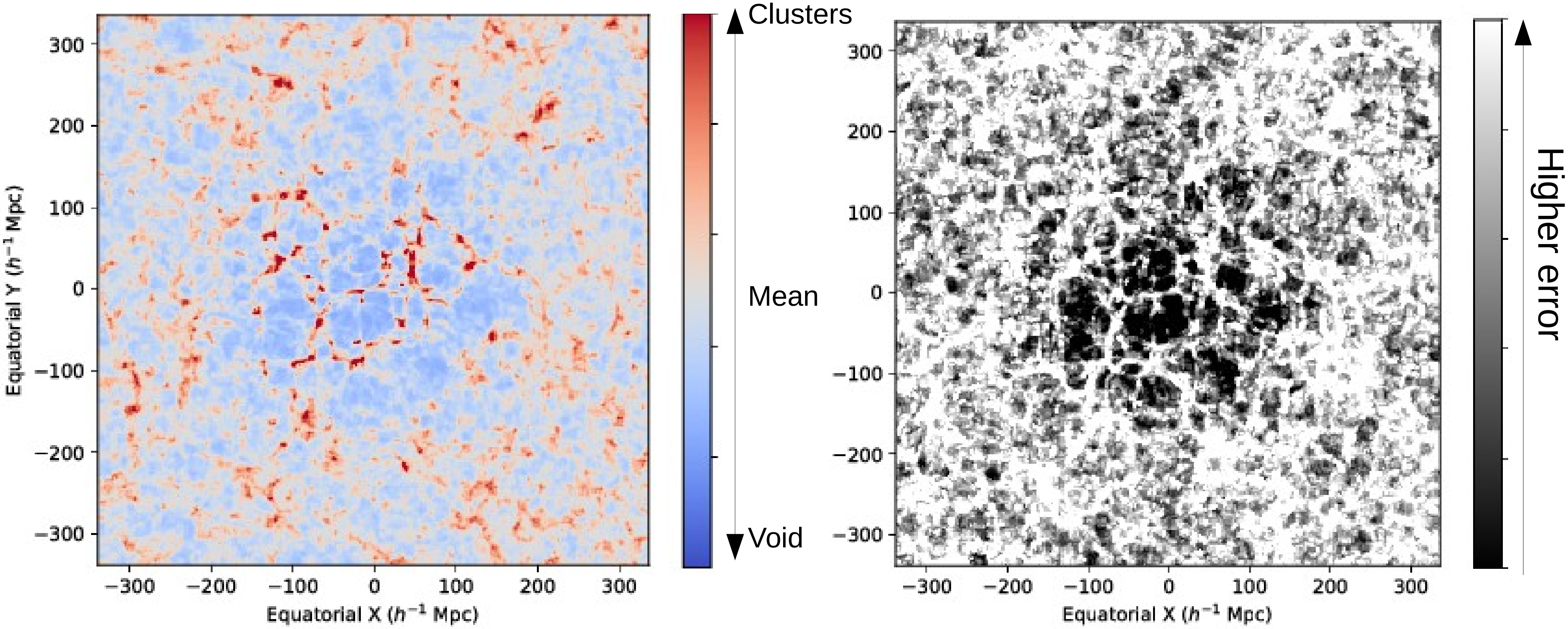


~70 000 galaxies

Lavaux & Hudson (MNRAS, 2011)

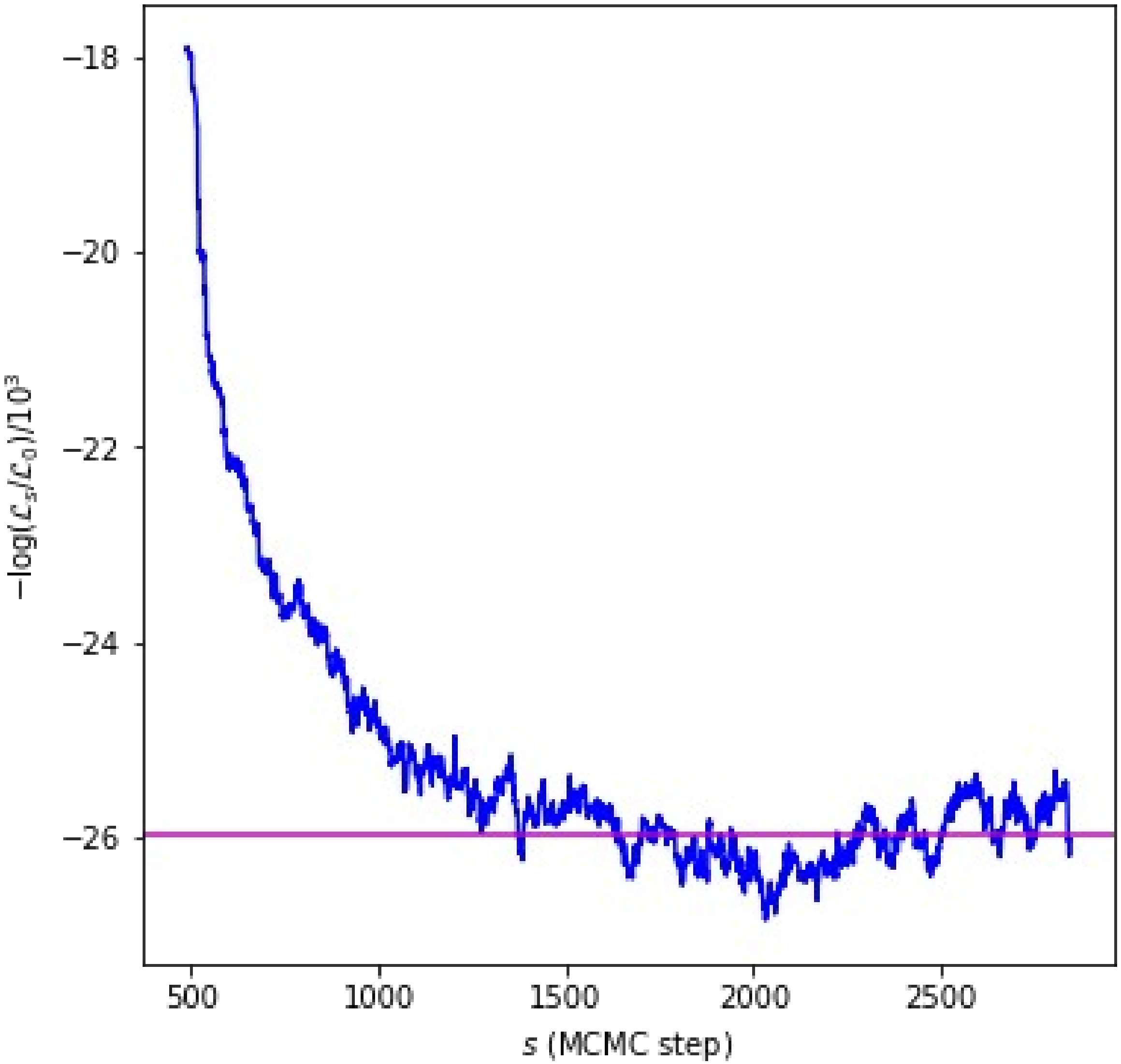
Inferred density fields

Ensemble average density fields at z=0



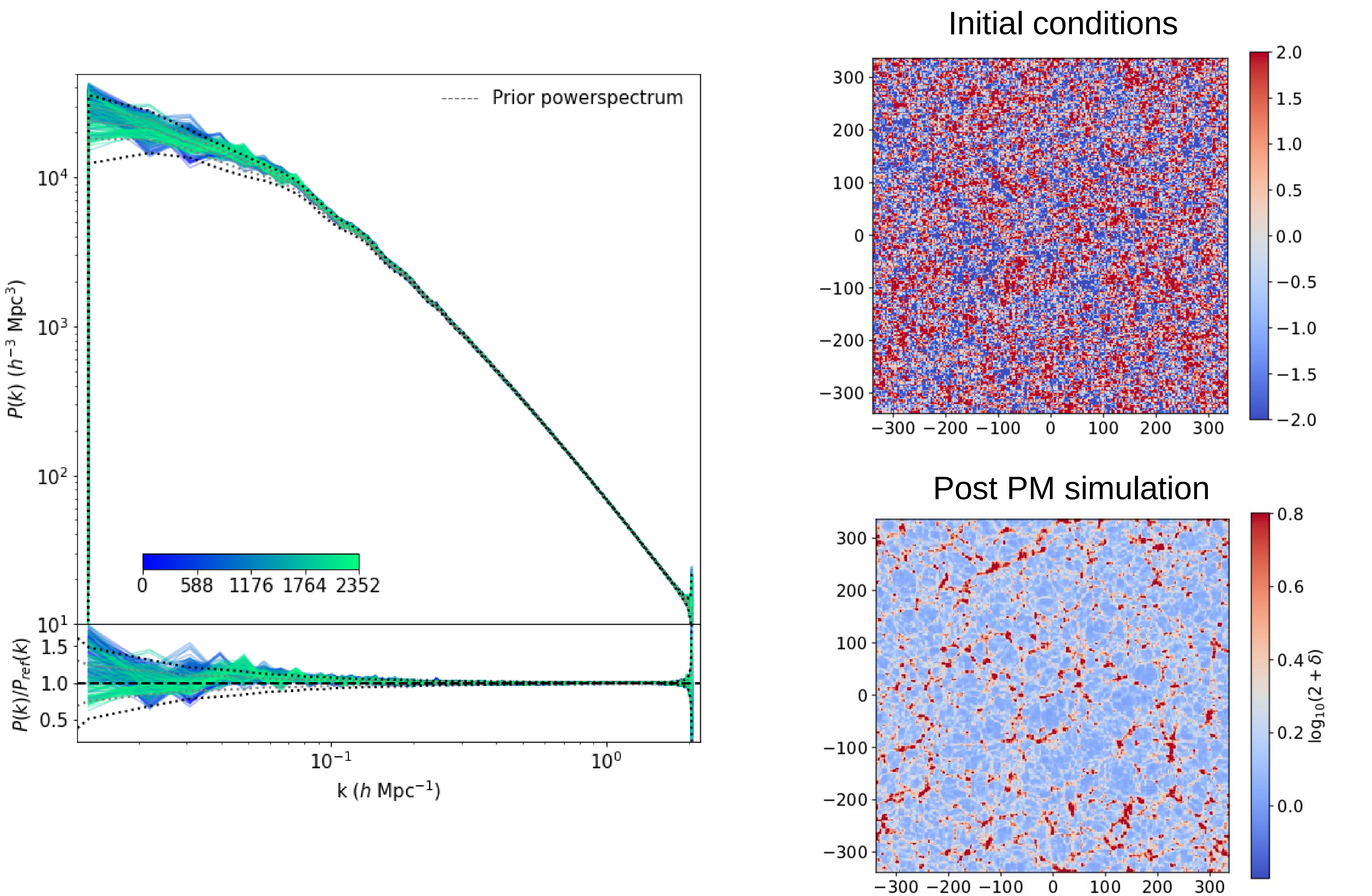
Jasche & Lavaux (2018, in prep.)

Performance aspect (2): burnin



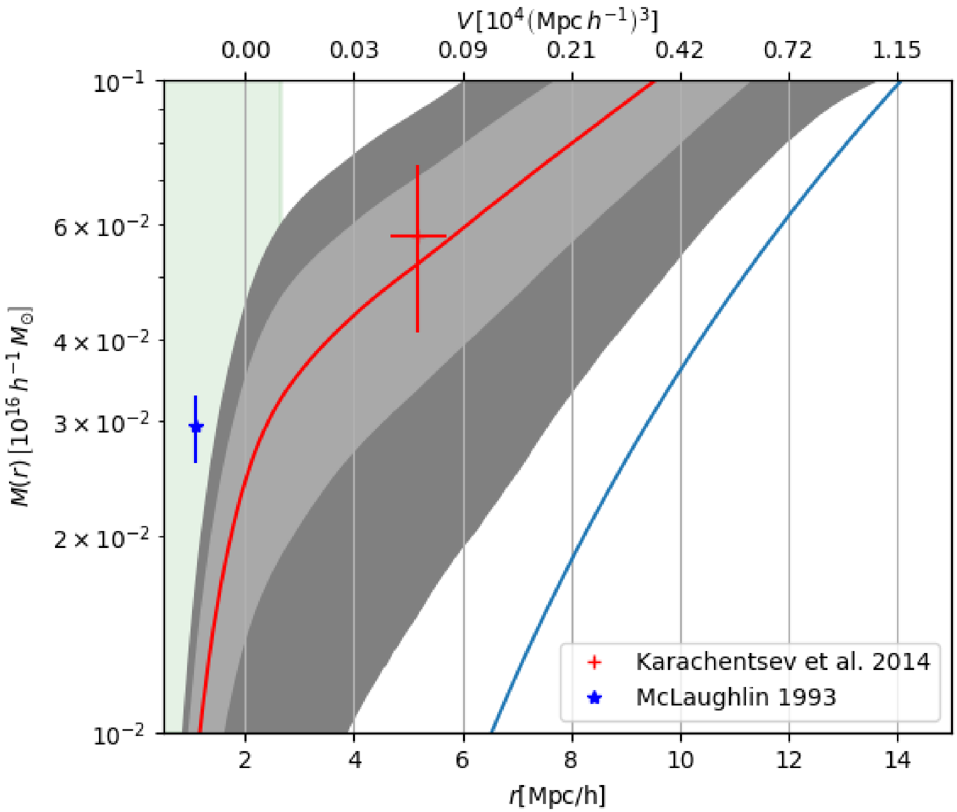
Jasche & Lavaux (2018, in prep.)

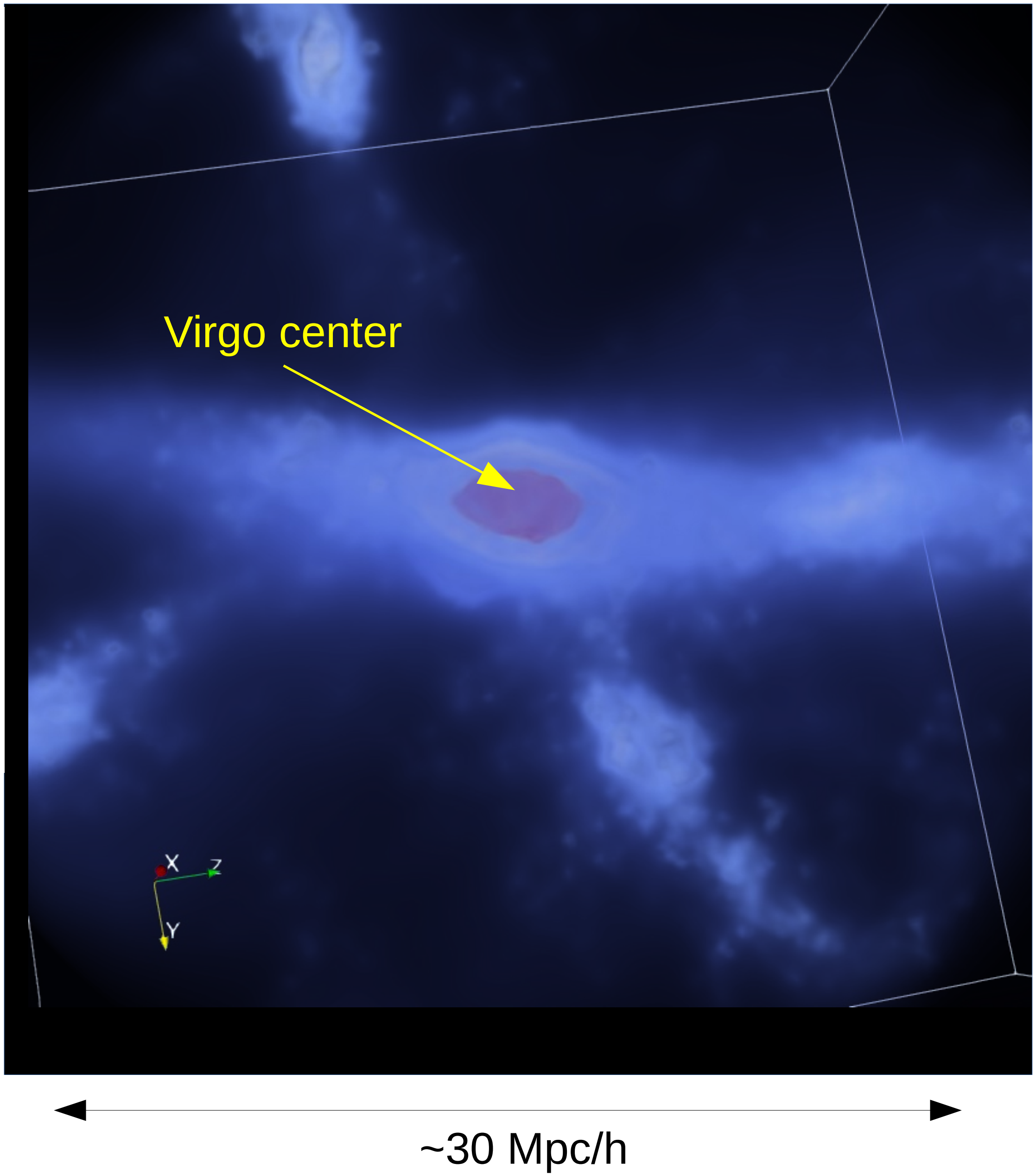
Initial condition powerspectrum



Jasche & Lavaux (2018, in prep.)

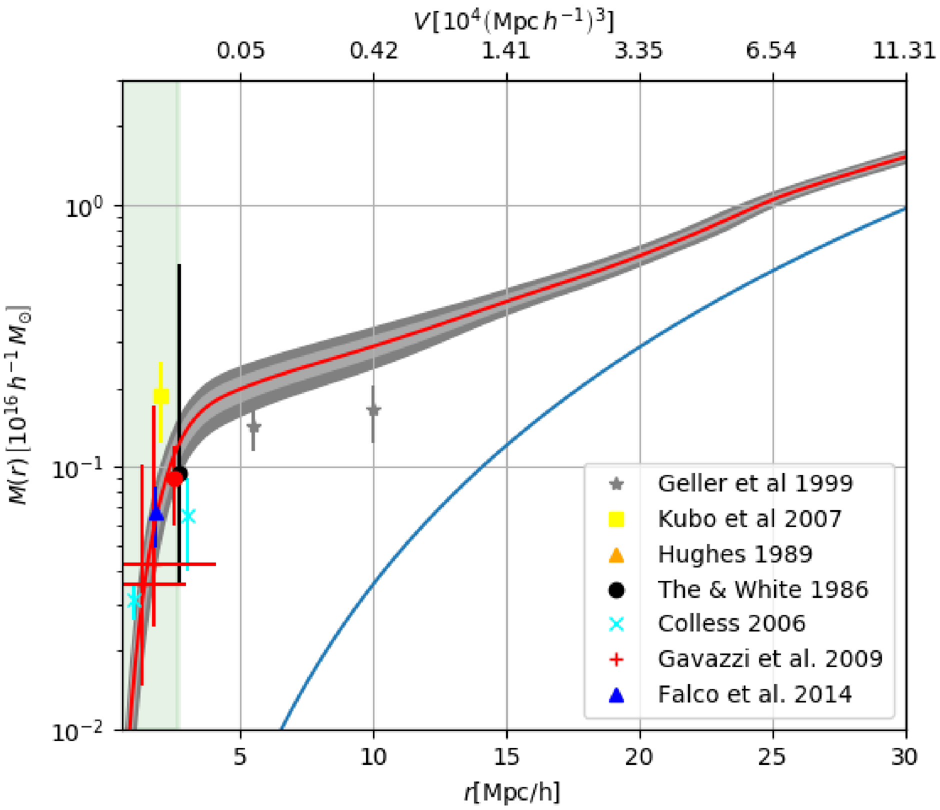
Virgo cluster

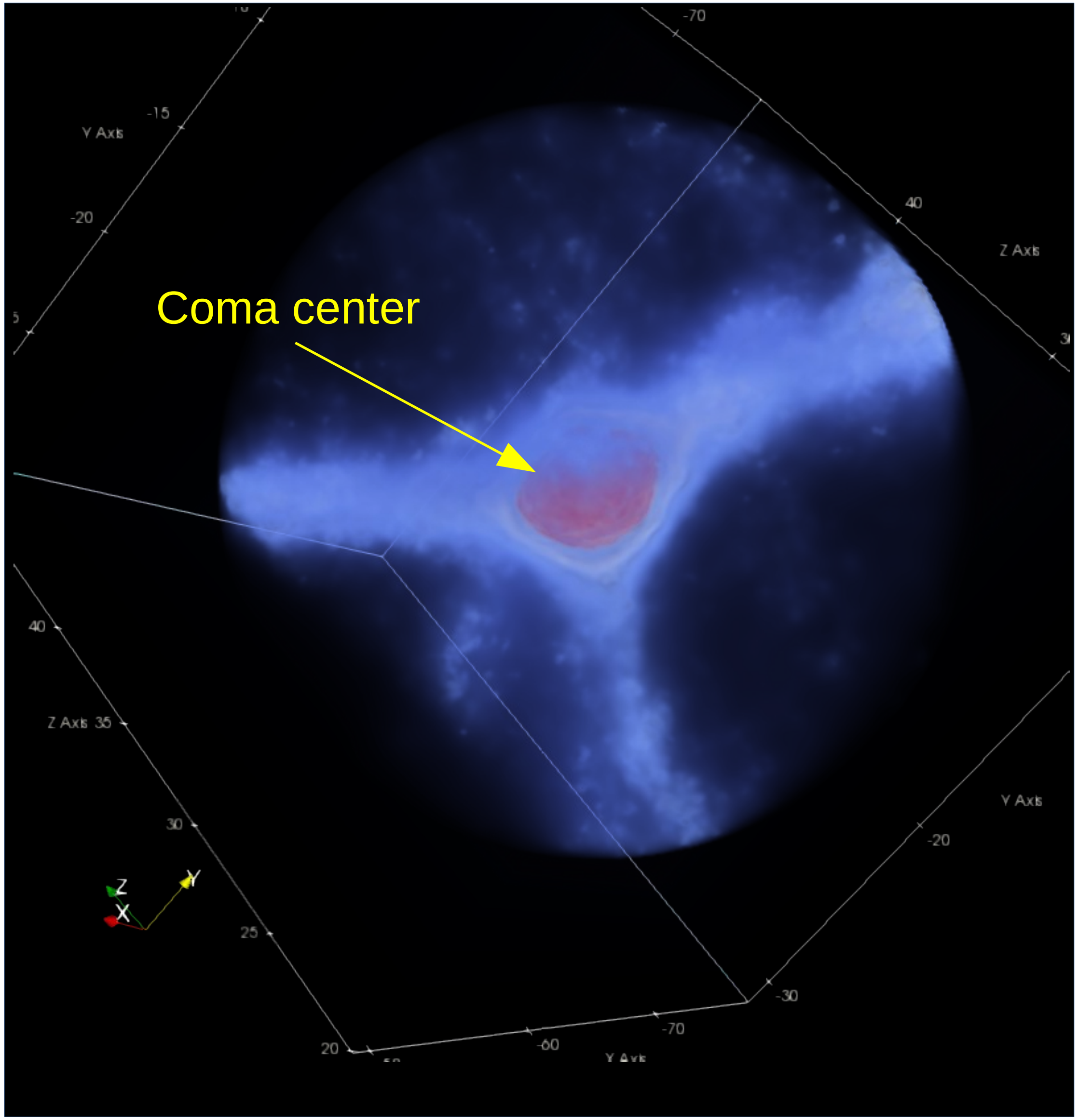




Jasche & Lavaux; Lavaux & Jasche; Peirani, Lavaux & Jasche (2018, in prep.)

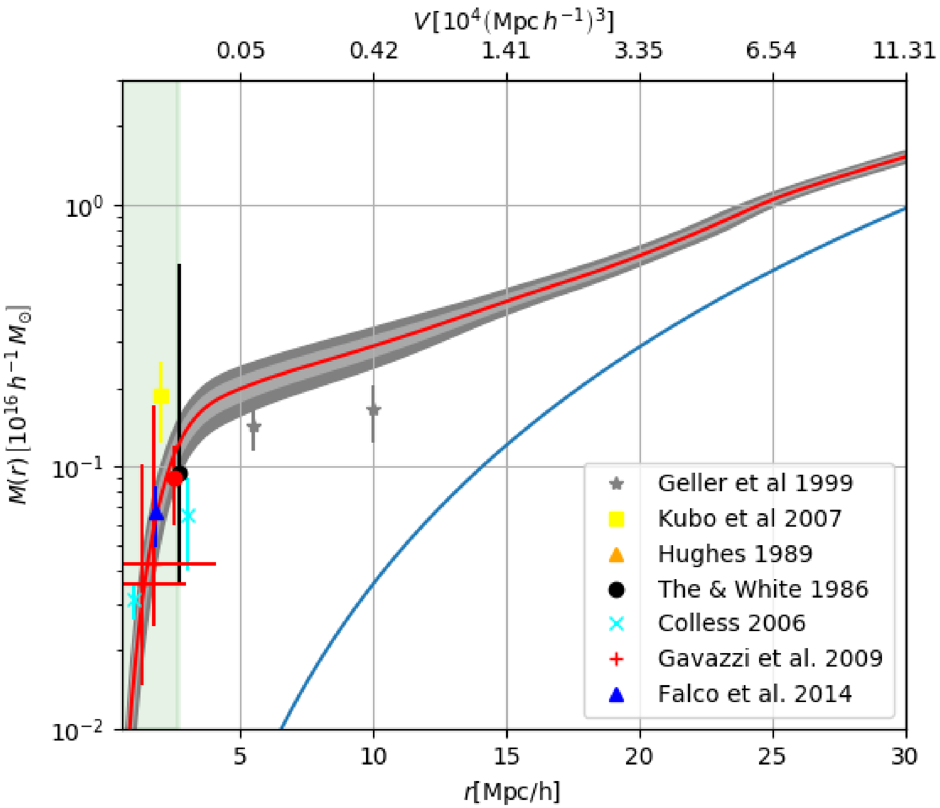
Coma dynamical properties

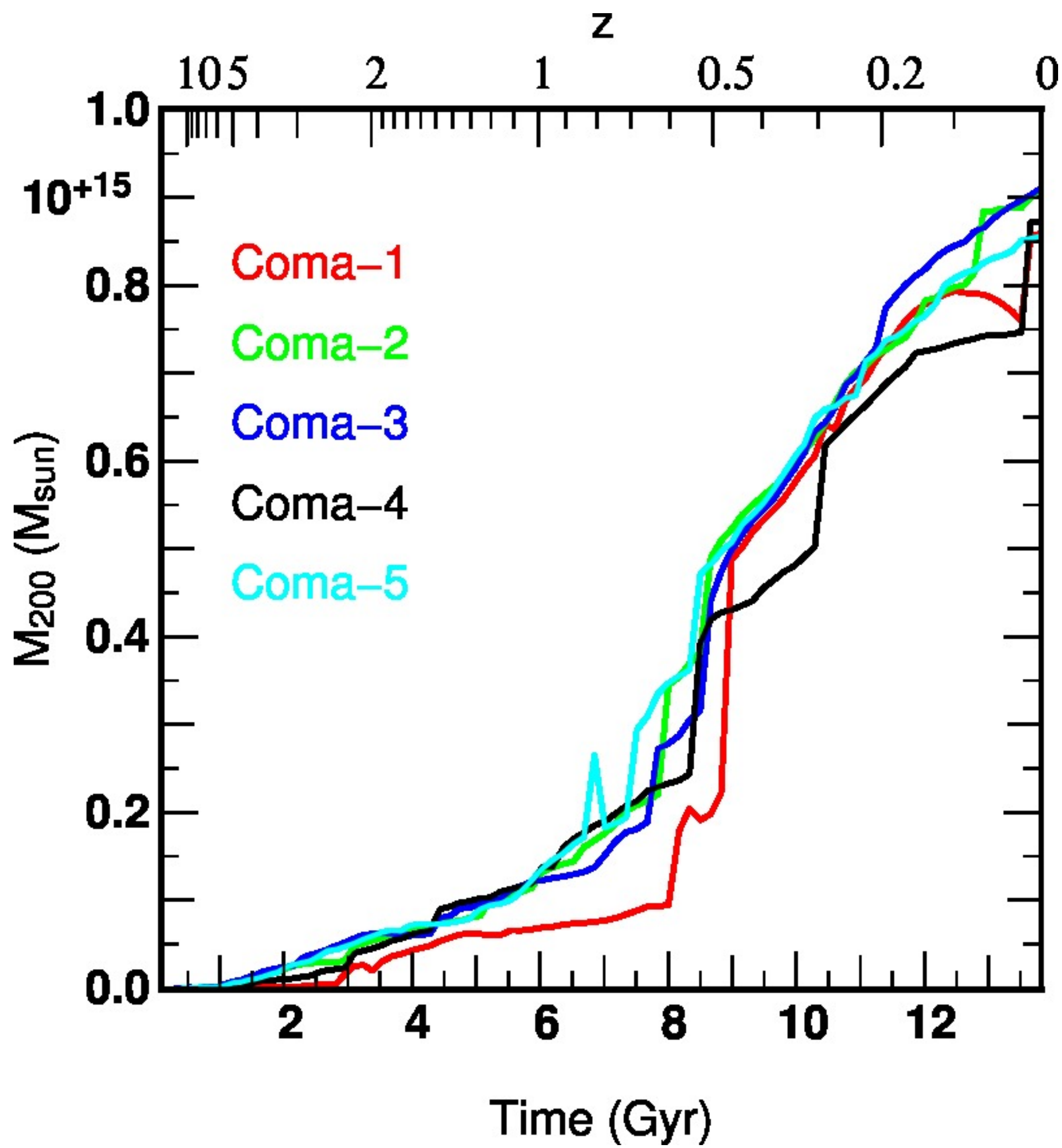




Jasche & Lavaux; Lavaux & Jasche; Peirani, Lavaux & Jasche (2018, in prep.)

Coma dynamical properties



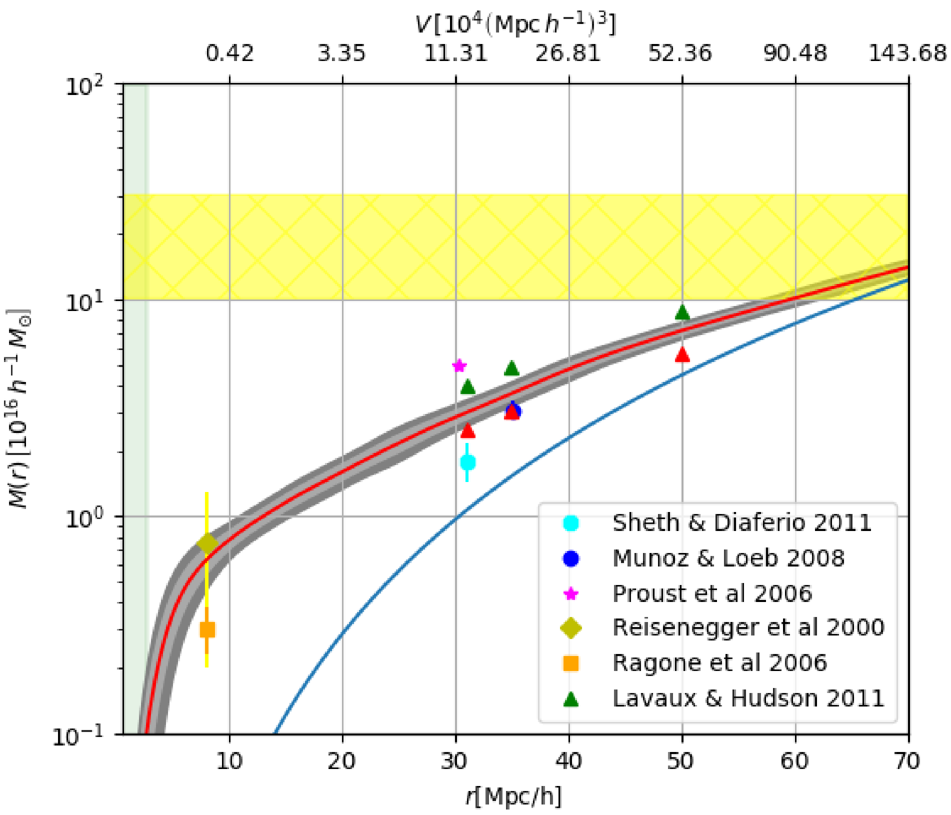


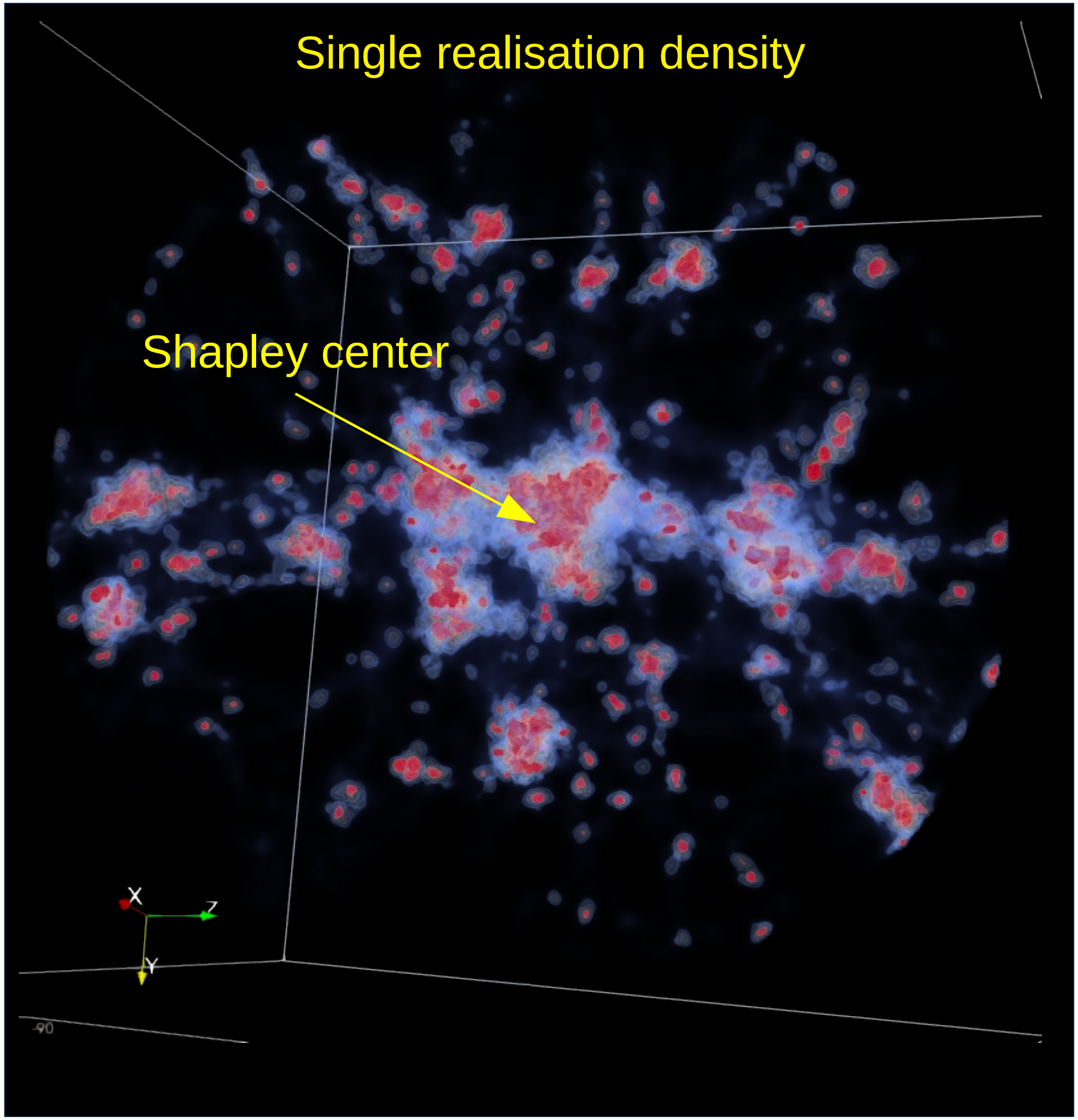
Zoom simulation on Coma
(~250 Mpart in zoom)

$4 \times 10^7 h^{-1} \mathrm{M}_\odot/\mathrm{part}$

Jasche & Lavaux; Lavaux & Jasche; Peirani, Lavaux & Jasche (2018, in prep.)

Shapley concentration

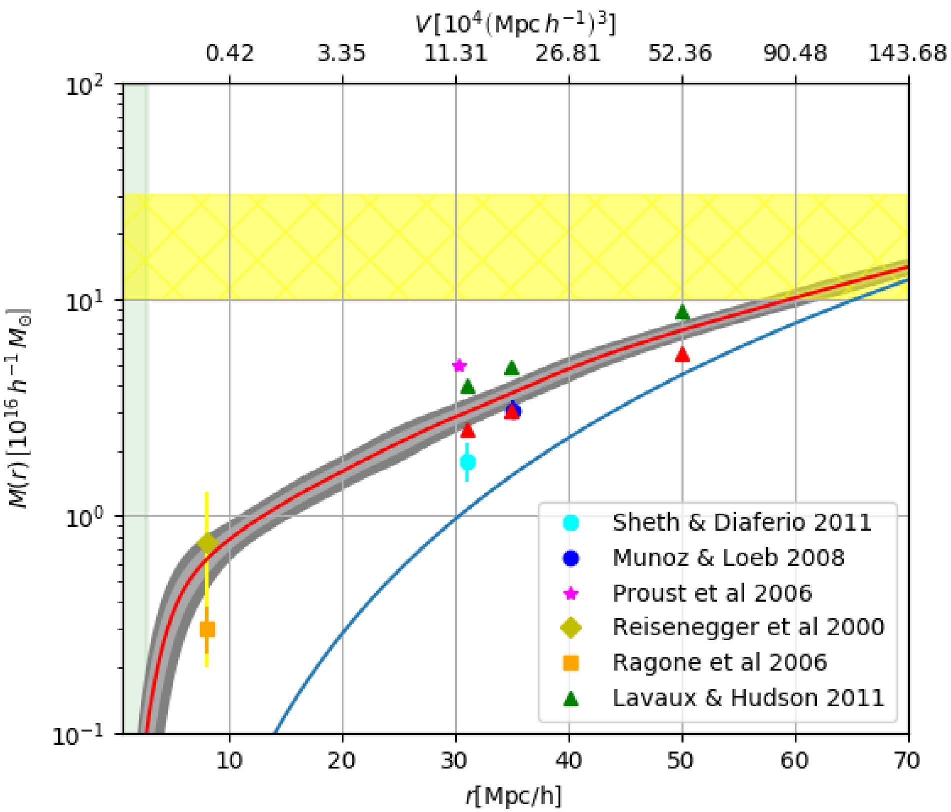


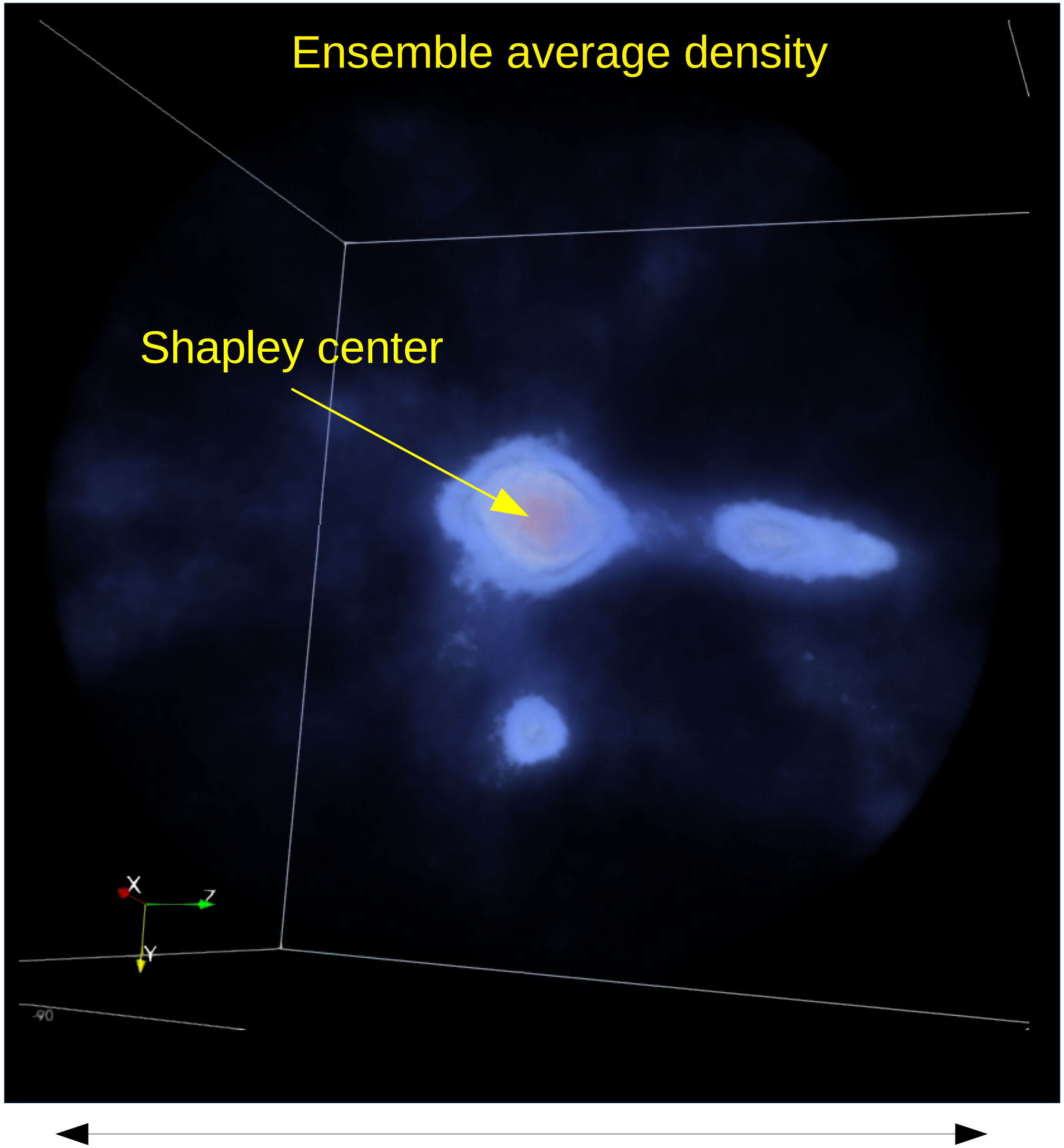


~60 Mpc/h

Lavaux & Jasche (2018, in prep.)

Shapley concentration

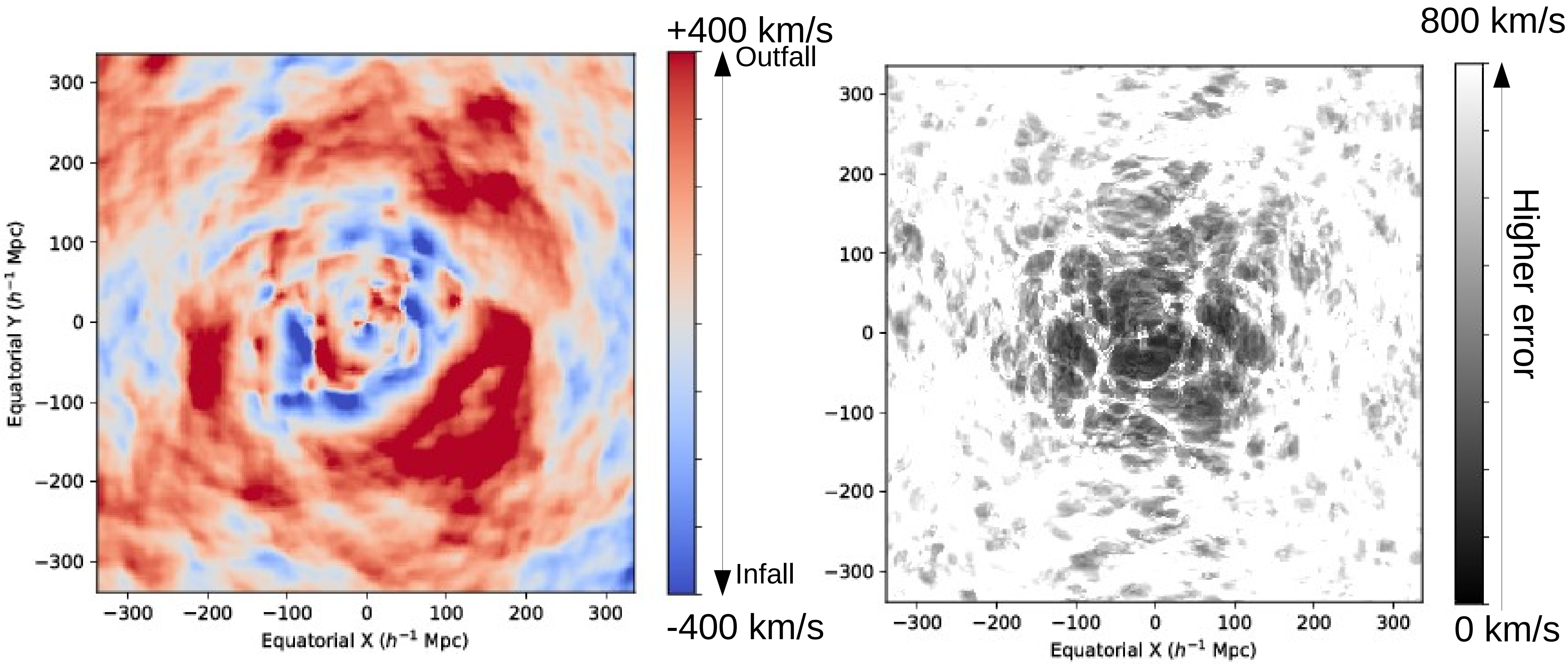




~60 Mpc/h

Lavaux & Jasche (2018, in prep.)

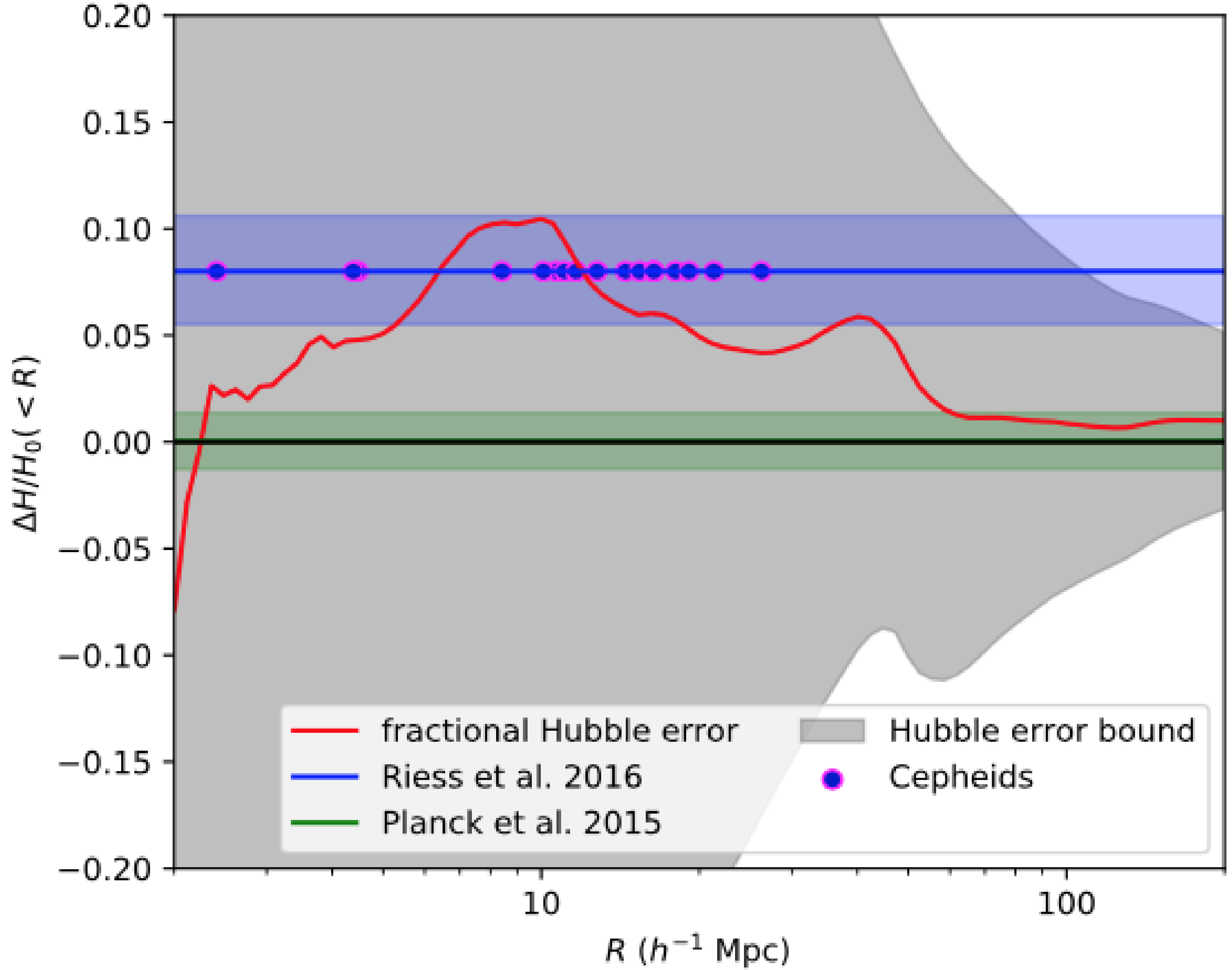
Inferred velocity fields



Jasche & Lavaux (2018, in prep.)

Velocity field and Hubble constant

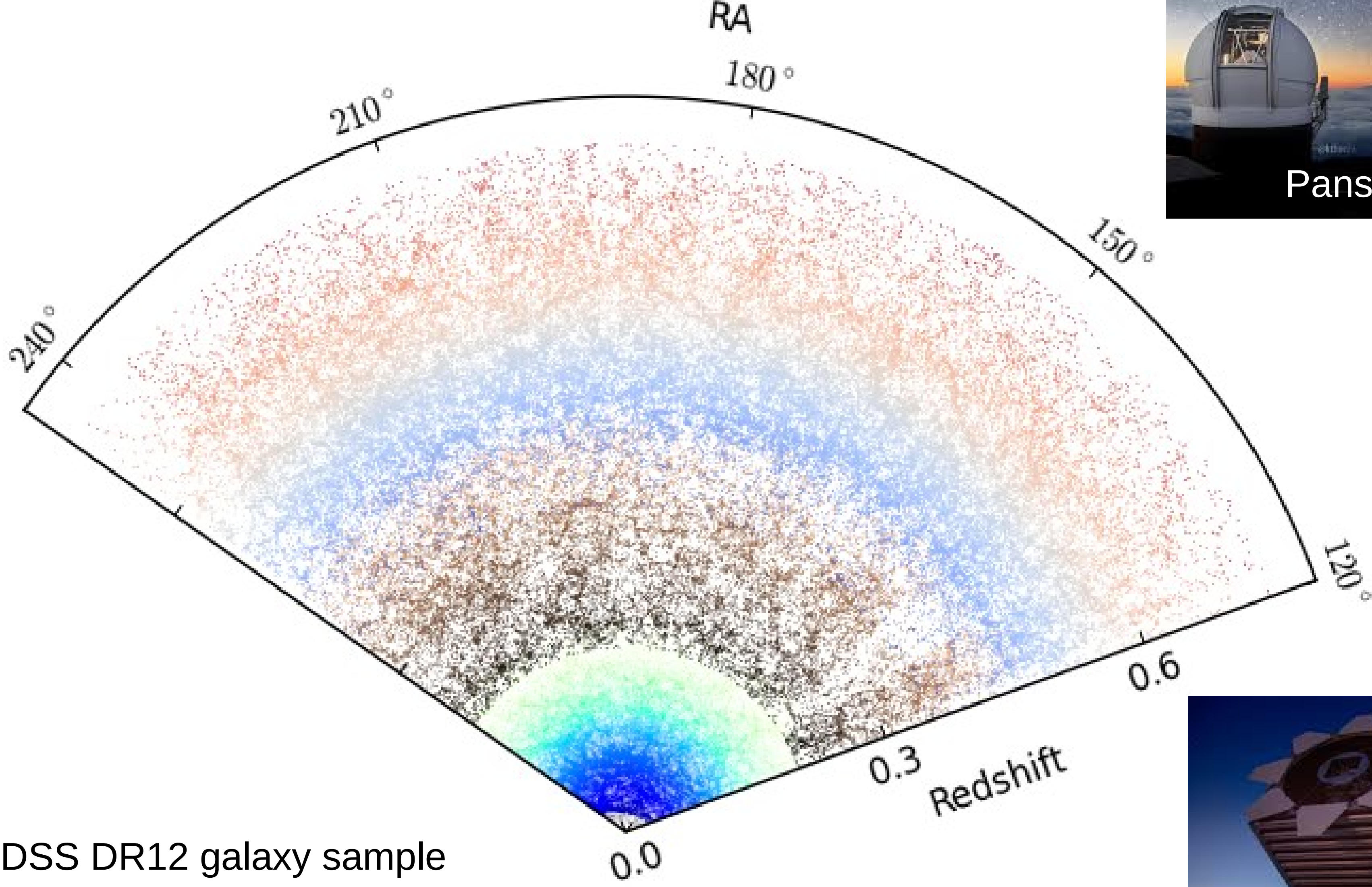
Mean error on Hubble measurement using tracers from observed large scale structures



Jasche & Lavaux (2018, in prep.)

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: $\vec{x} \rightarrow \vec{\mathfrak{z}}$

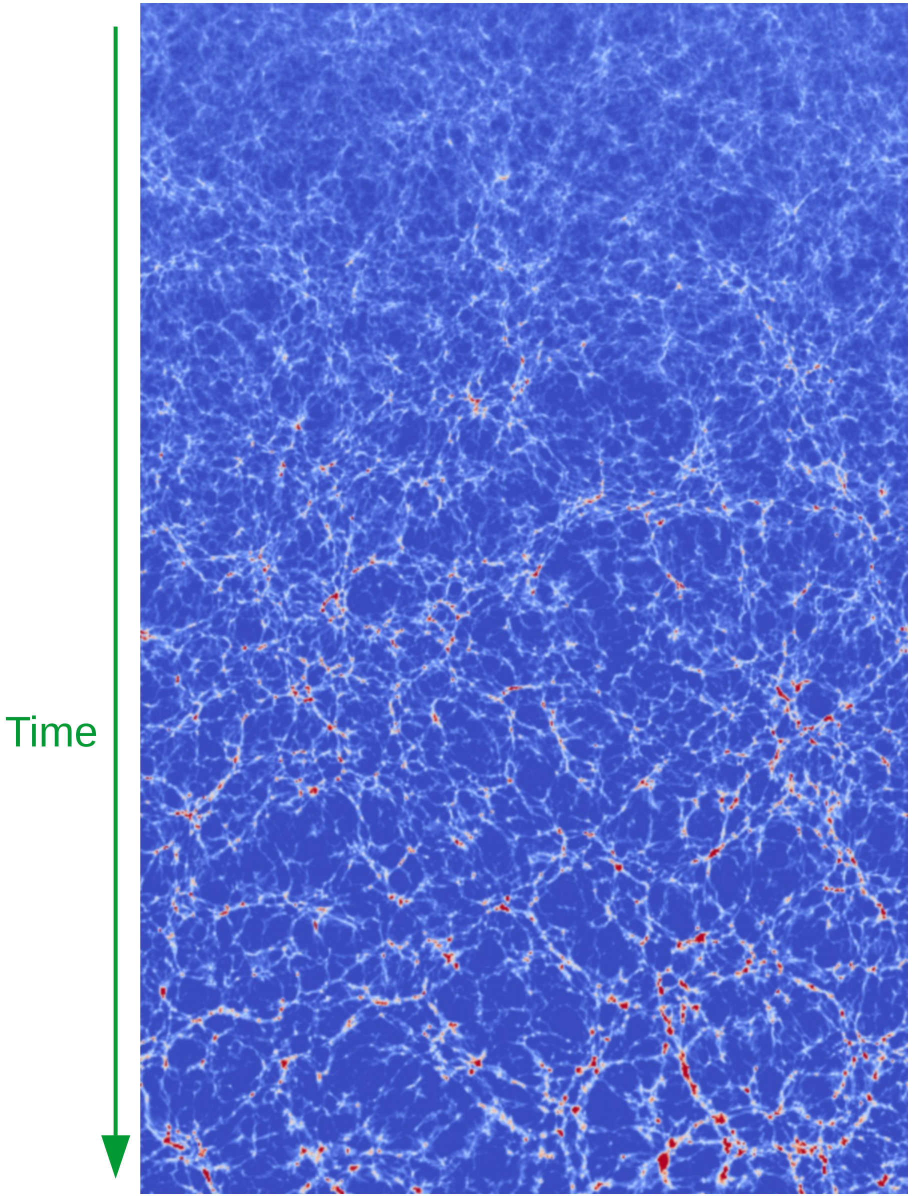
$$\vec{\mathfrak{z}}(\vec{x}) = f\left(|\vec{x}|, \mathrm{cosmology}\right) \times \vec{x}$$

$$f\left(|x|, \ldots\right) \simeq Hx + o(x)$$

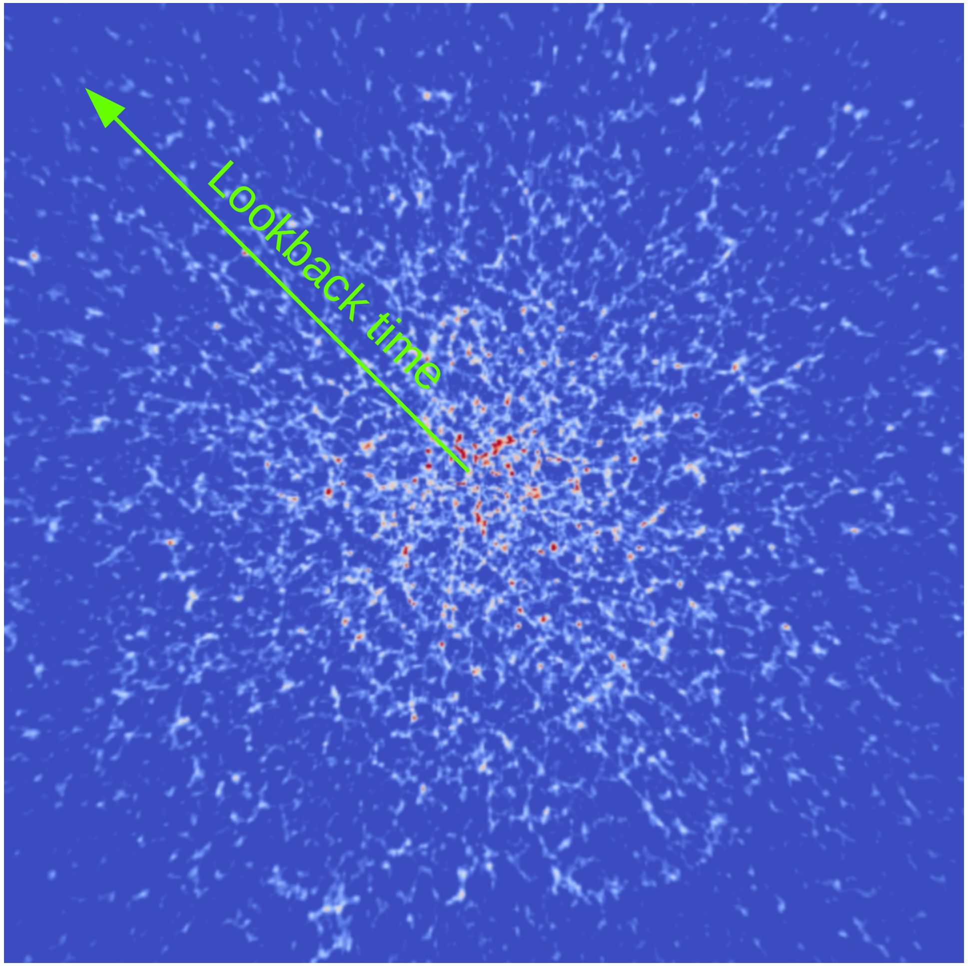
(see Doogesh' talk)

Forward model becomes more complex

Cosmic growth of structures



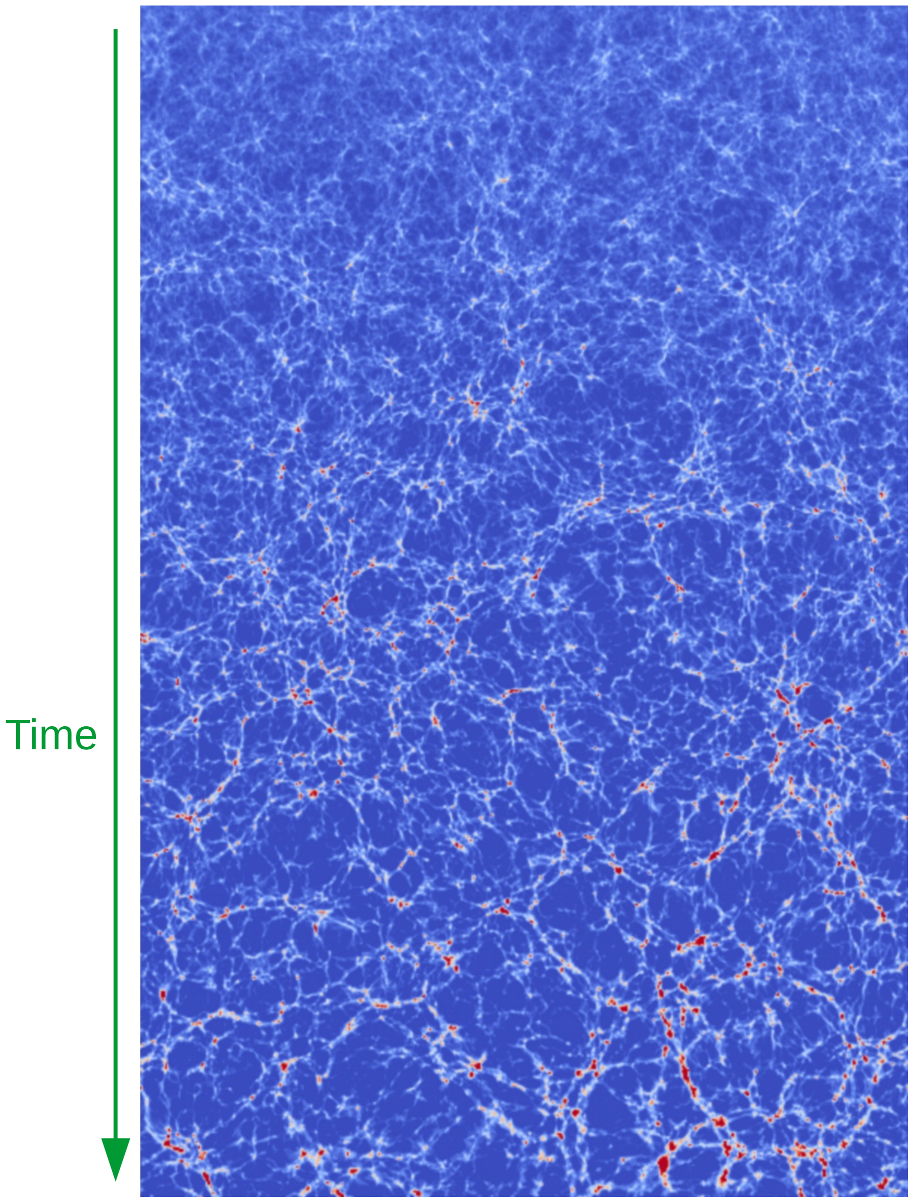
Cosmic expansion



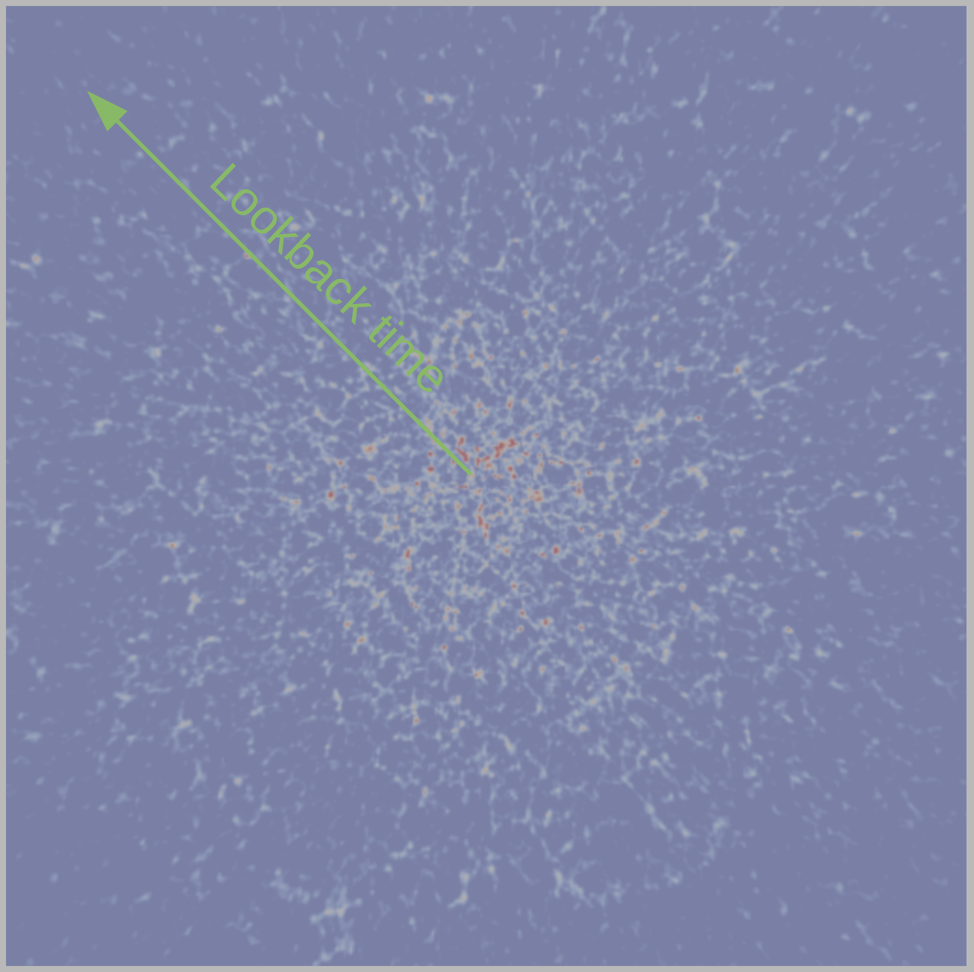
(see Doogesh' talk)

Forward model becomes more complex

Cosmic growth of structures



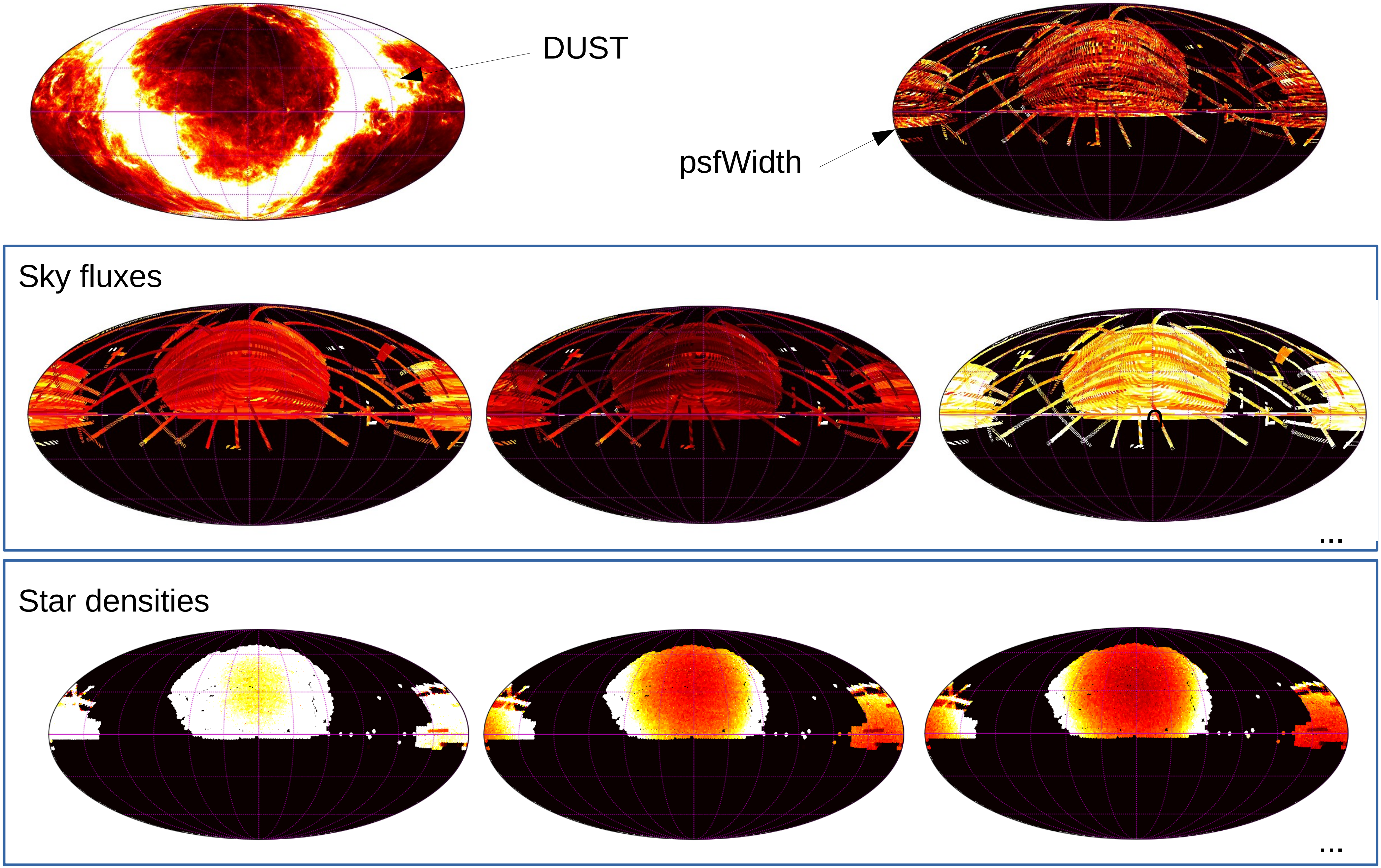
Cosmic expansion



(see Doogesh' talk)

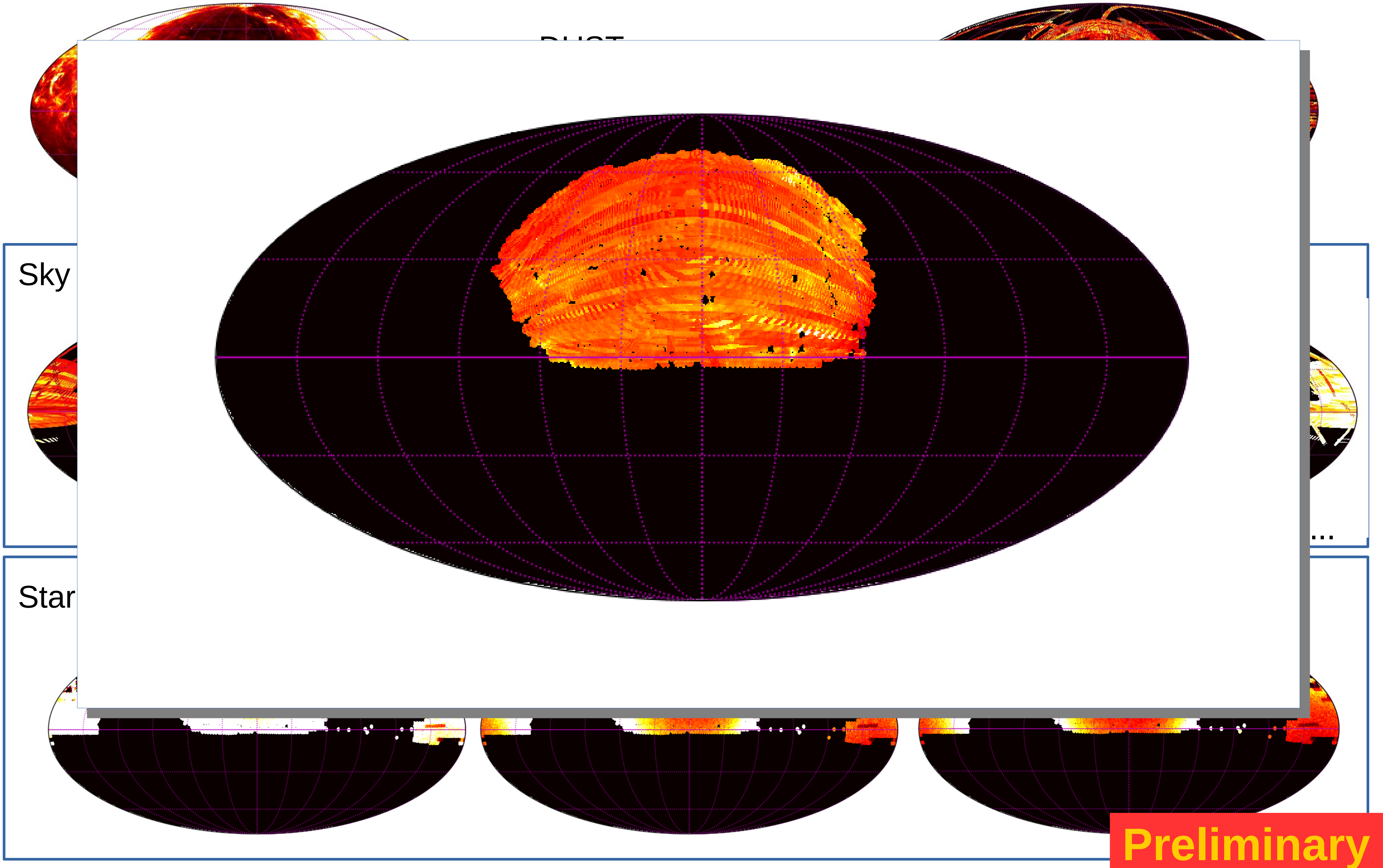
Some systematic cleaning…

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



Example fitted composite...

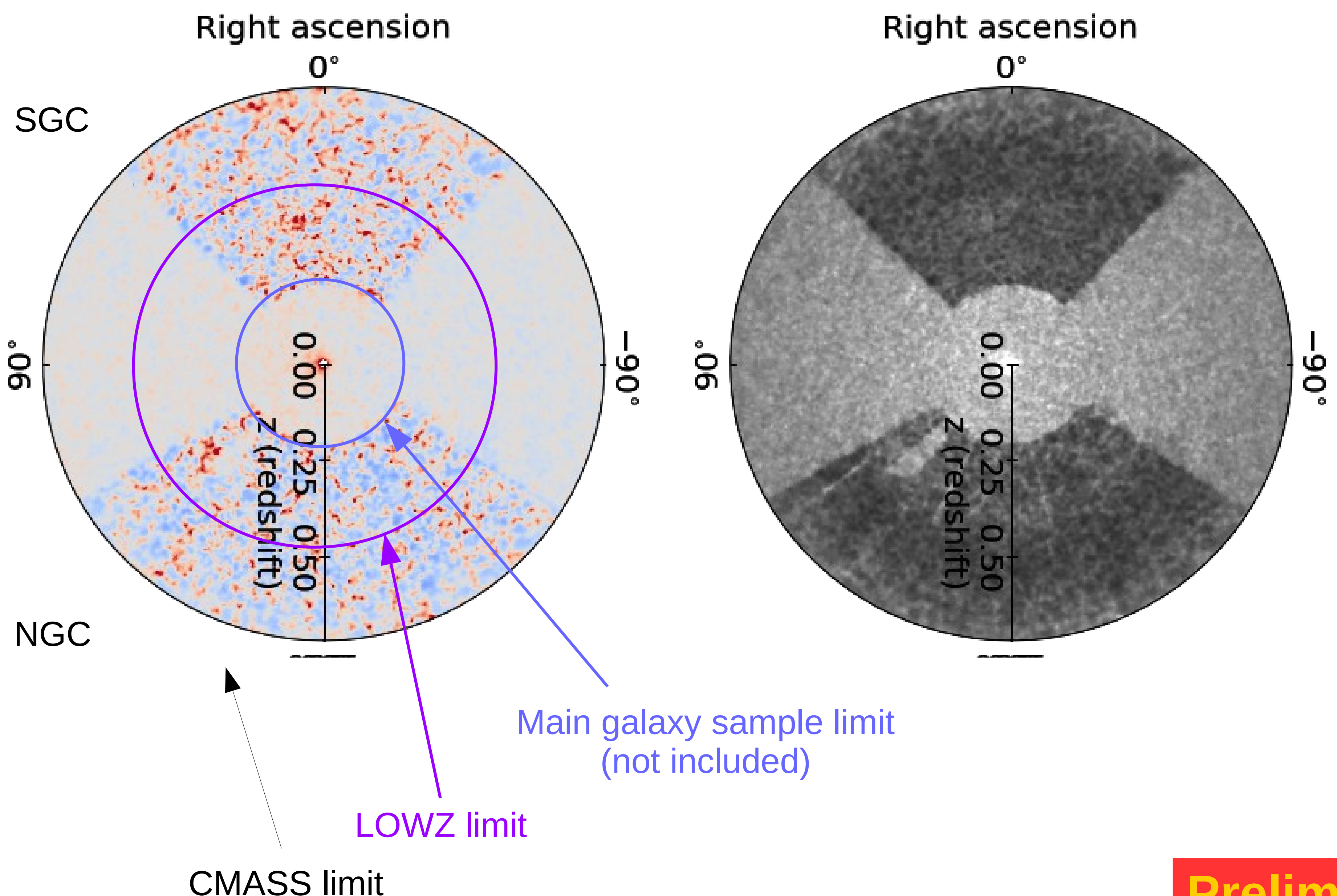
11 foregrounds (here only 8)… still much less than Leistedt & Peiris (2014) but improving



Inferred density of SDSS3

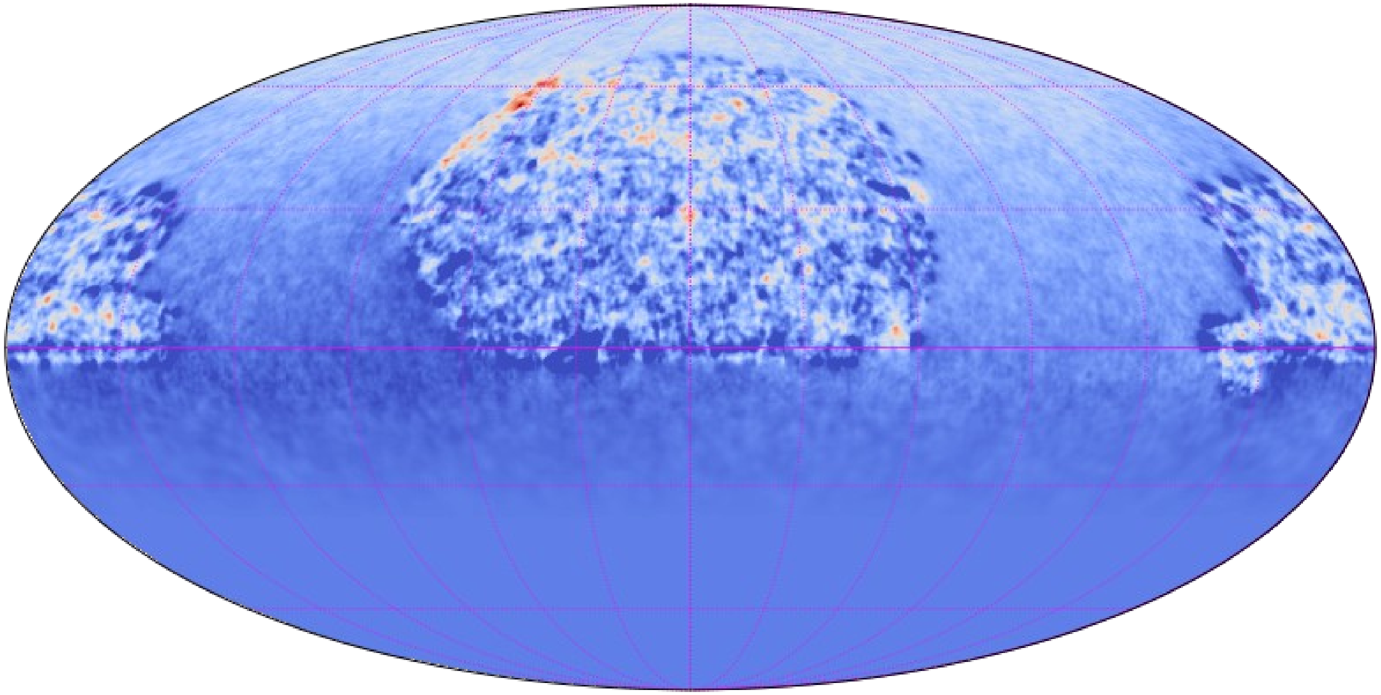
Ensemble density average

Error estimate from ensemble variance

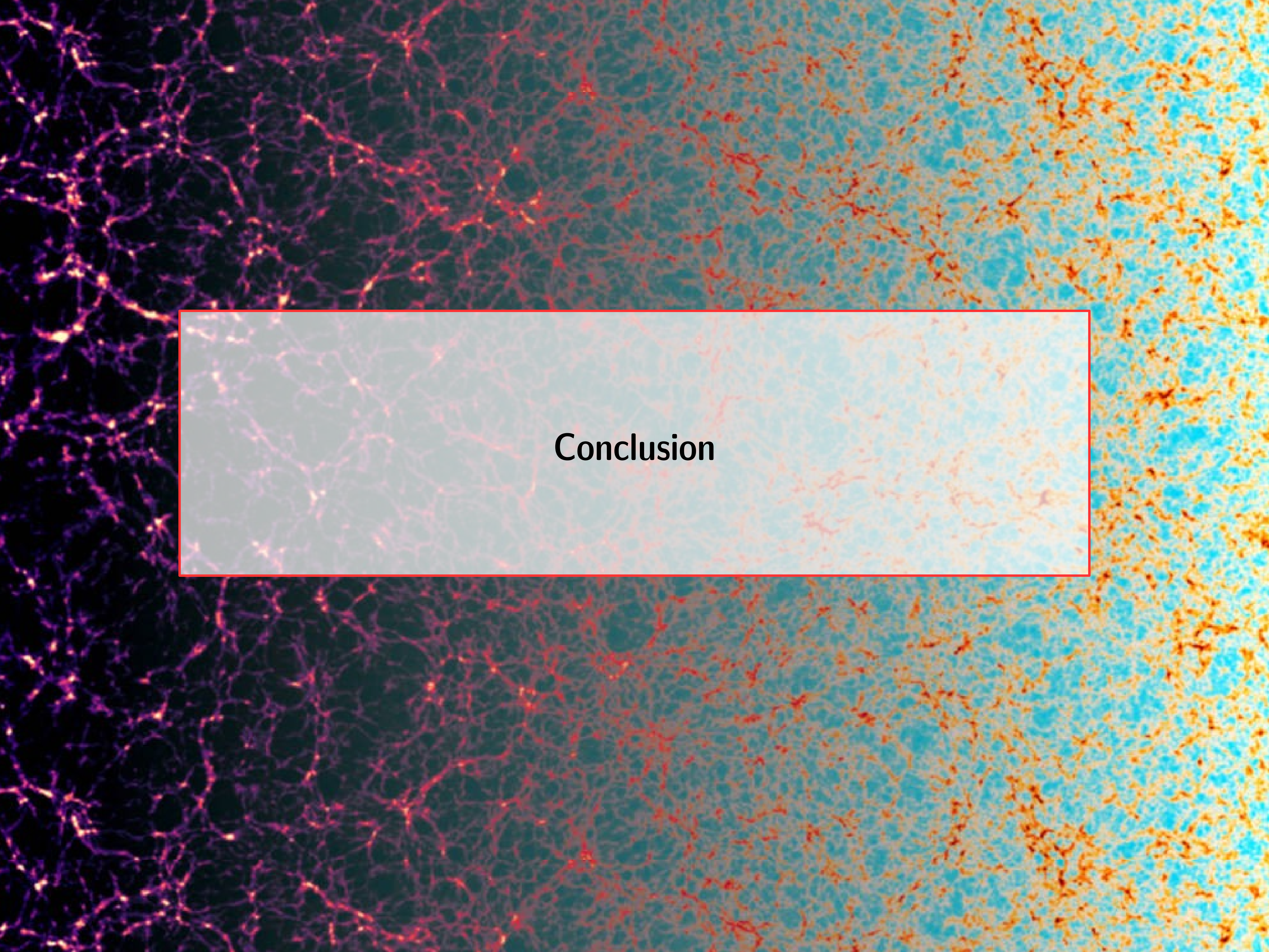


Preliminary

Sky density



Preliminary

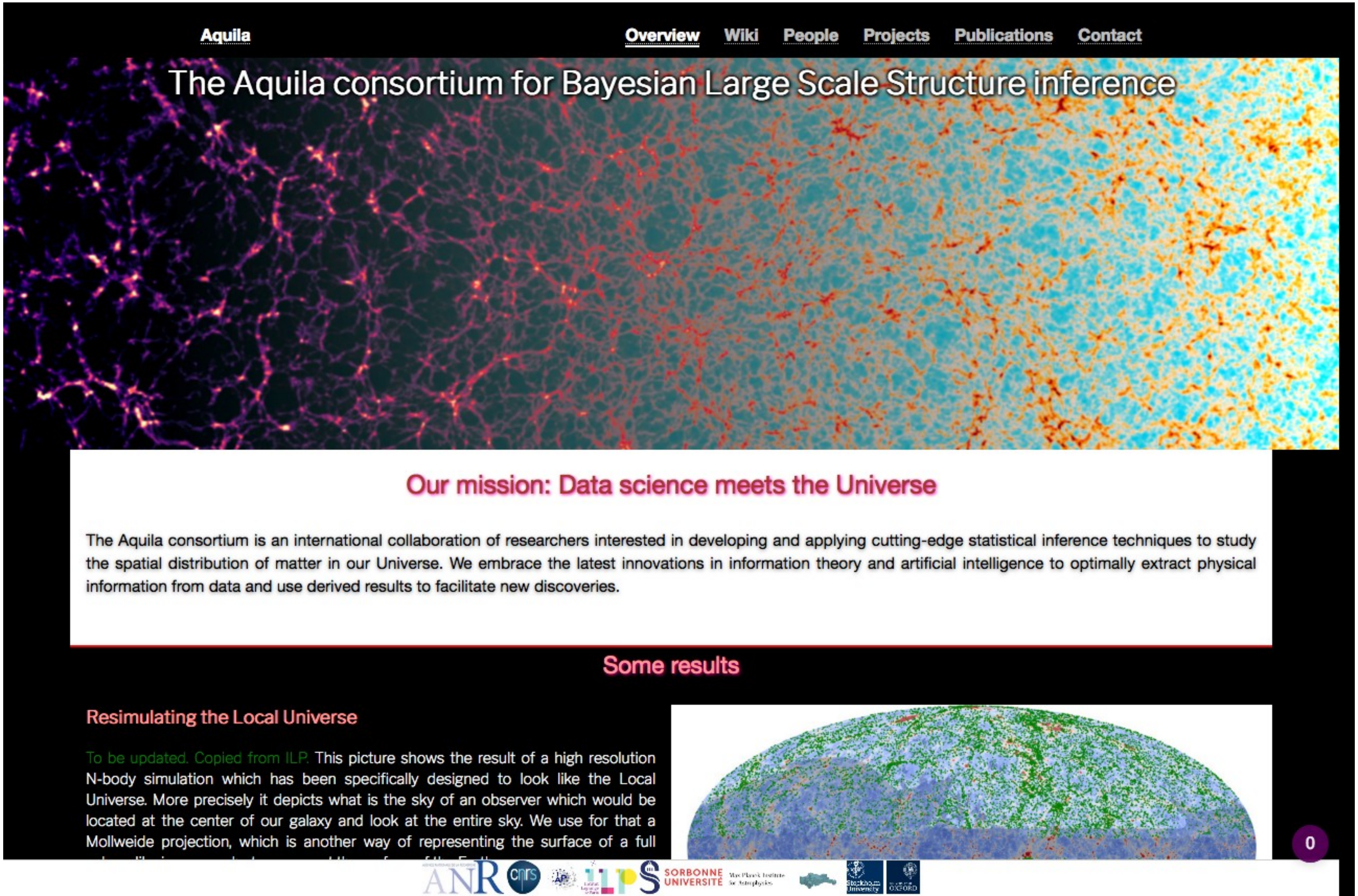


Conclusion

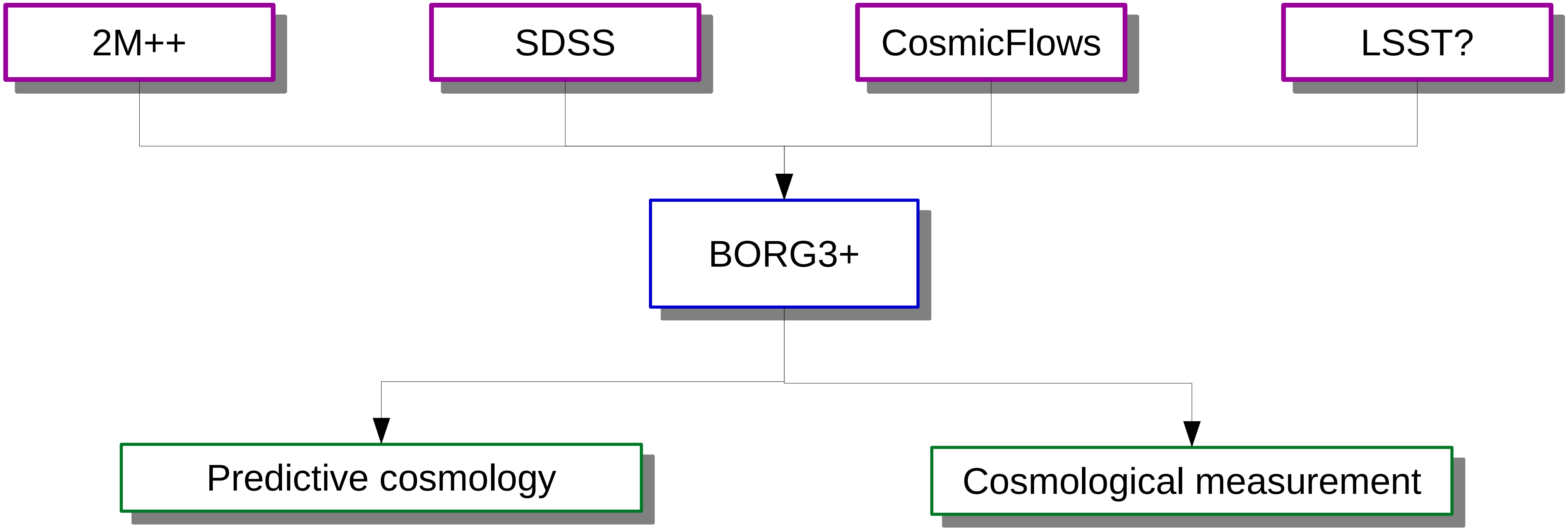
The Aquila consortium

- 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/



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