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

Guilhem Lavaux (IAP/CNRS)
and Aquila Consortium

Cosmo21 – Valencia 2018

Aquila consortium (https://aquila-consortium.org)

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

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

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

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

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

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Initial conditions

Forward and adjoint model

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Easily exchangeable to try
your favorite differentiable model

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

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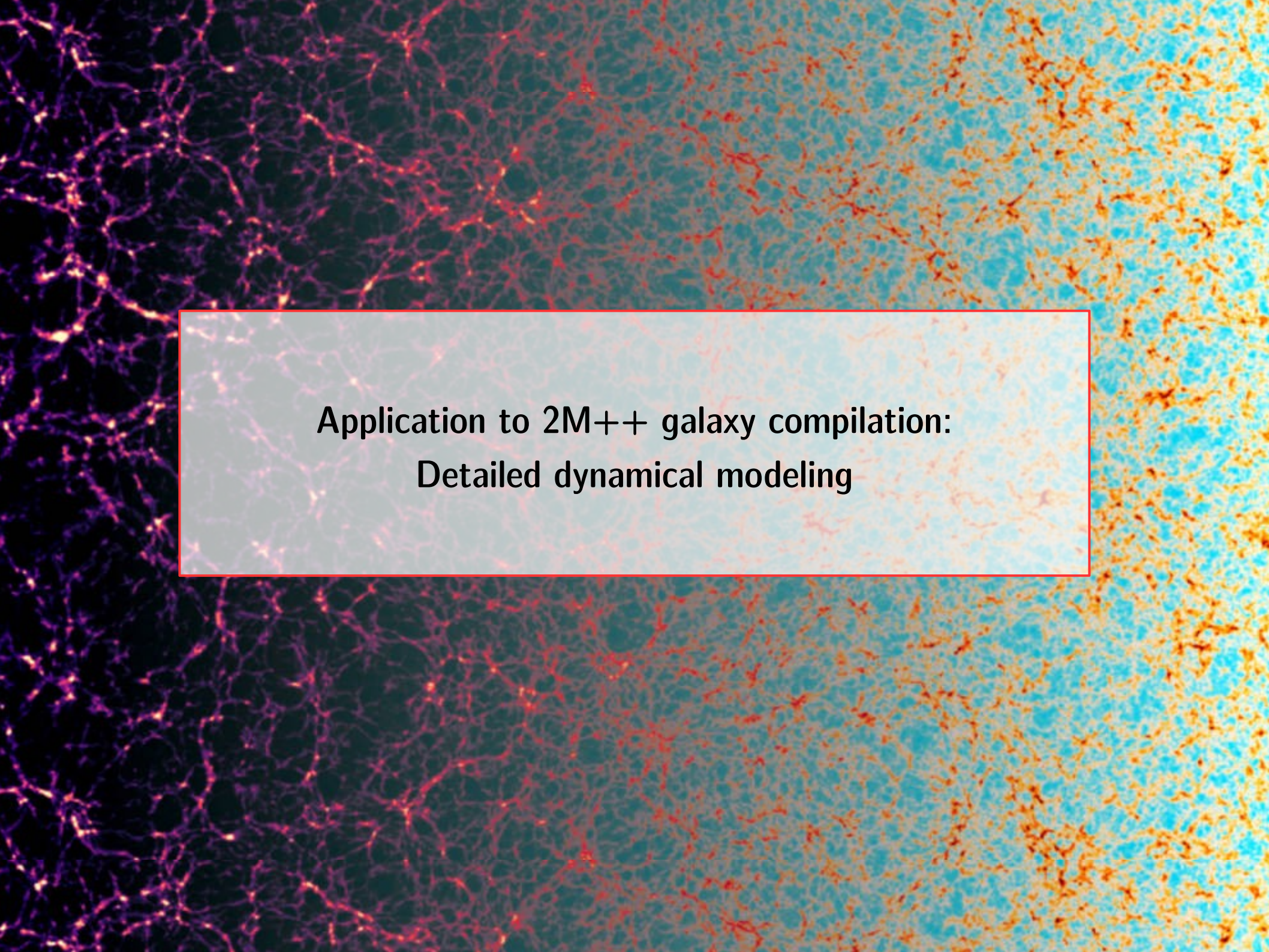
Random extraction $N_g^s \leftarrow \mathcal{P}(\rho_g^s)$ (Poisson, Negative binomial, ...)

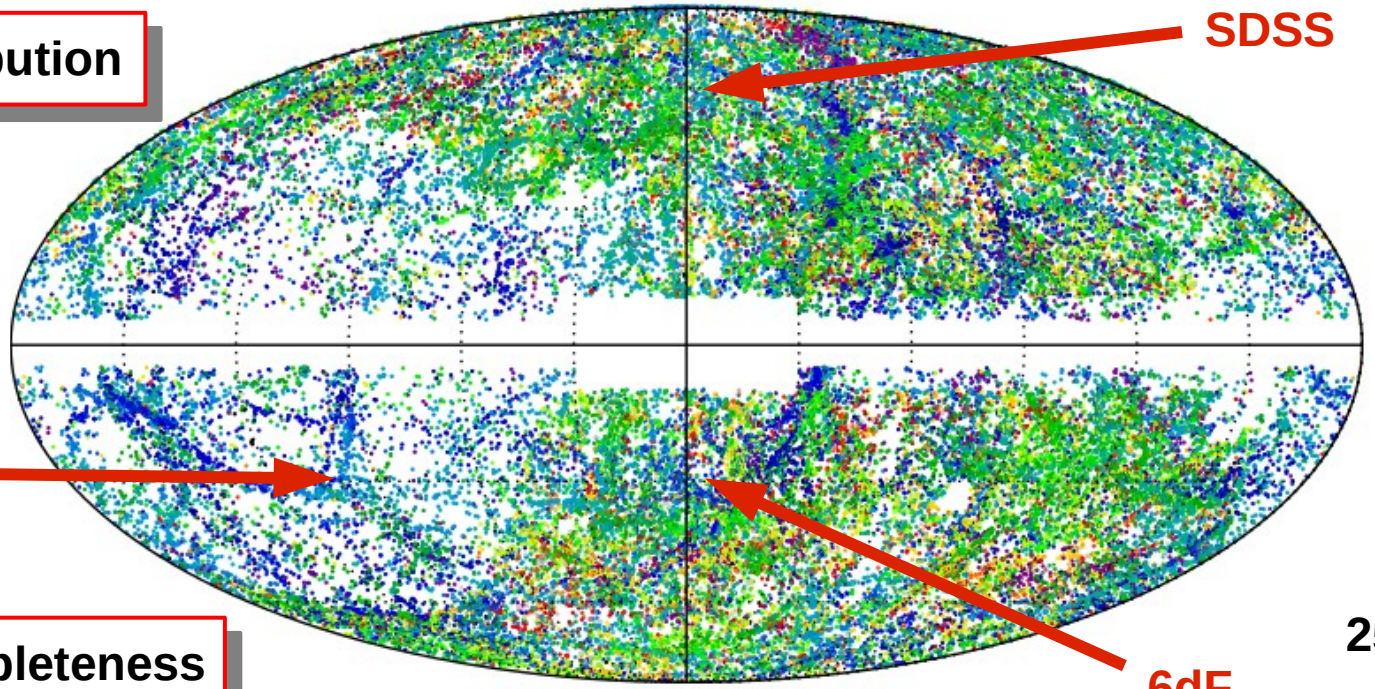
Encode survey systematic effects with expansions: $S(\hat{x}) = S_0(\hat{x}) \prod_{f=1}^{N} (1 + \alpha_f F_f(\hat{x}))$

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


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

The 2M++ galaxy compilation

Galaxy distribution

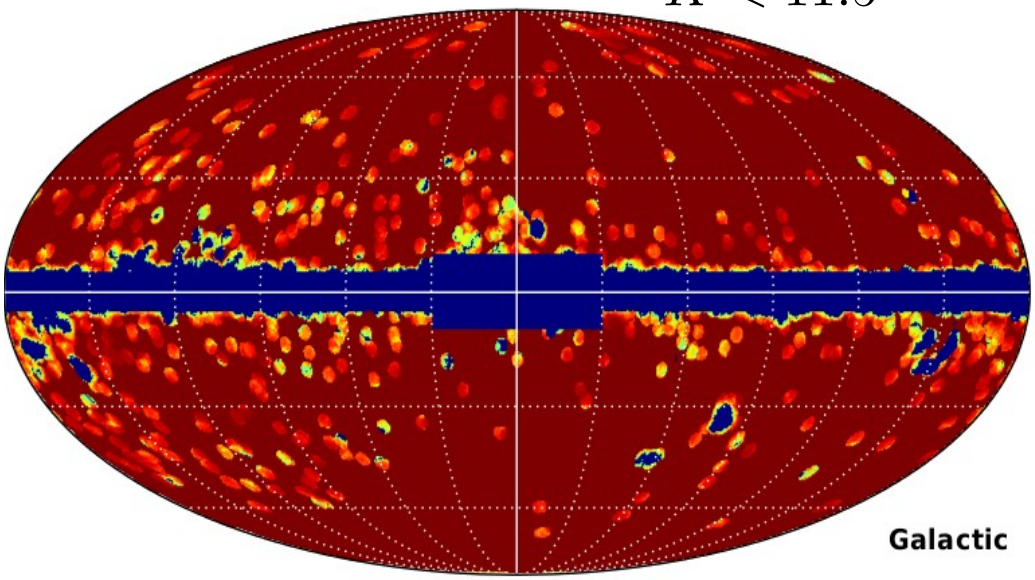


0 Mpc/h

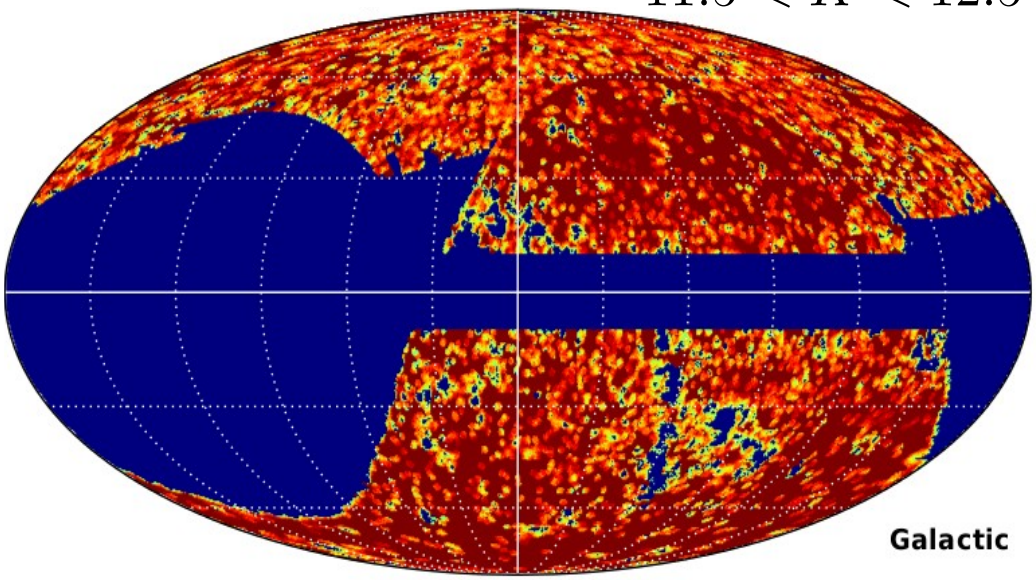
250 Mpc/h

Redshift completeness

$K < 11.5$



$11.5 < K < 12.5$

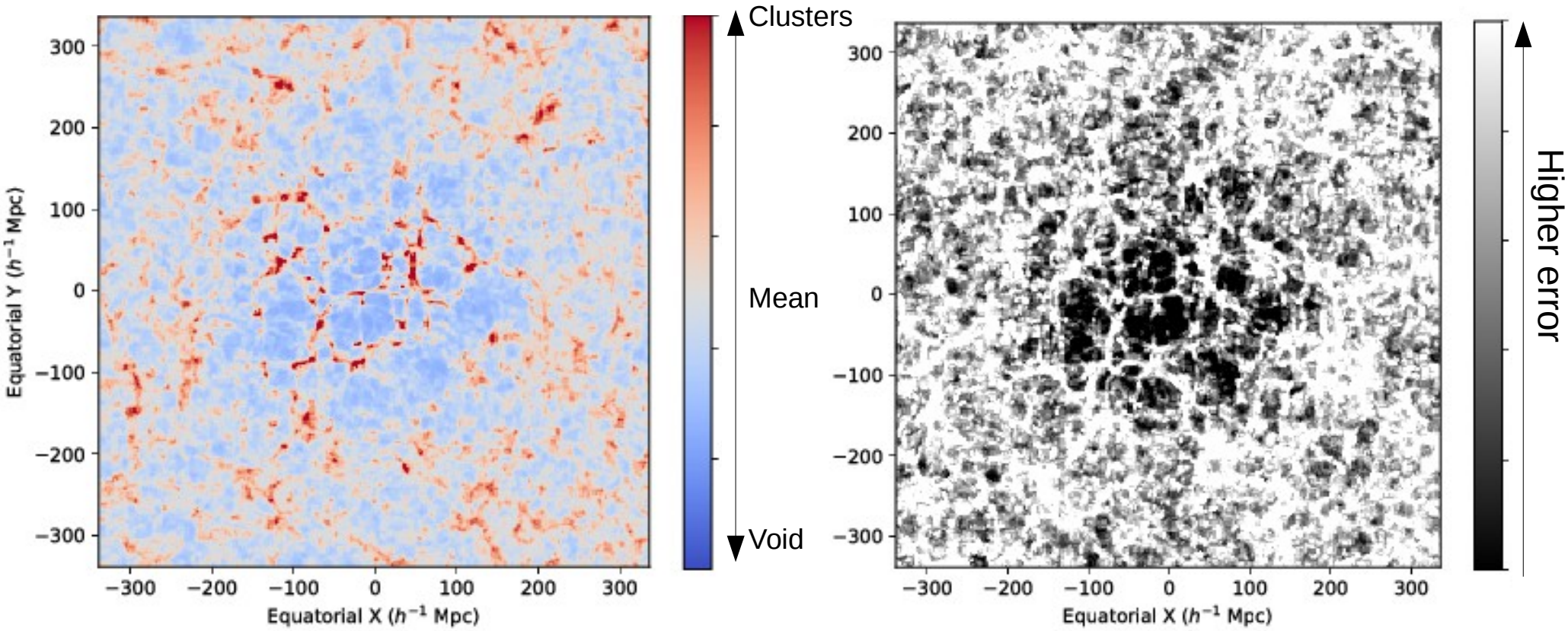


~70 000 galaxies

Lavaux & Hudson (MNRAS, 2011)

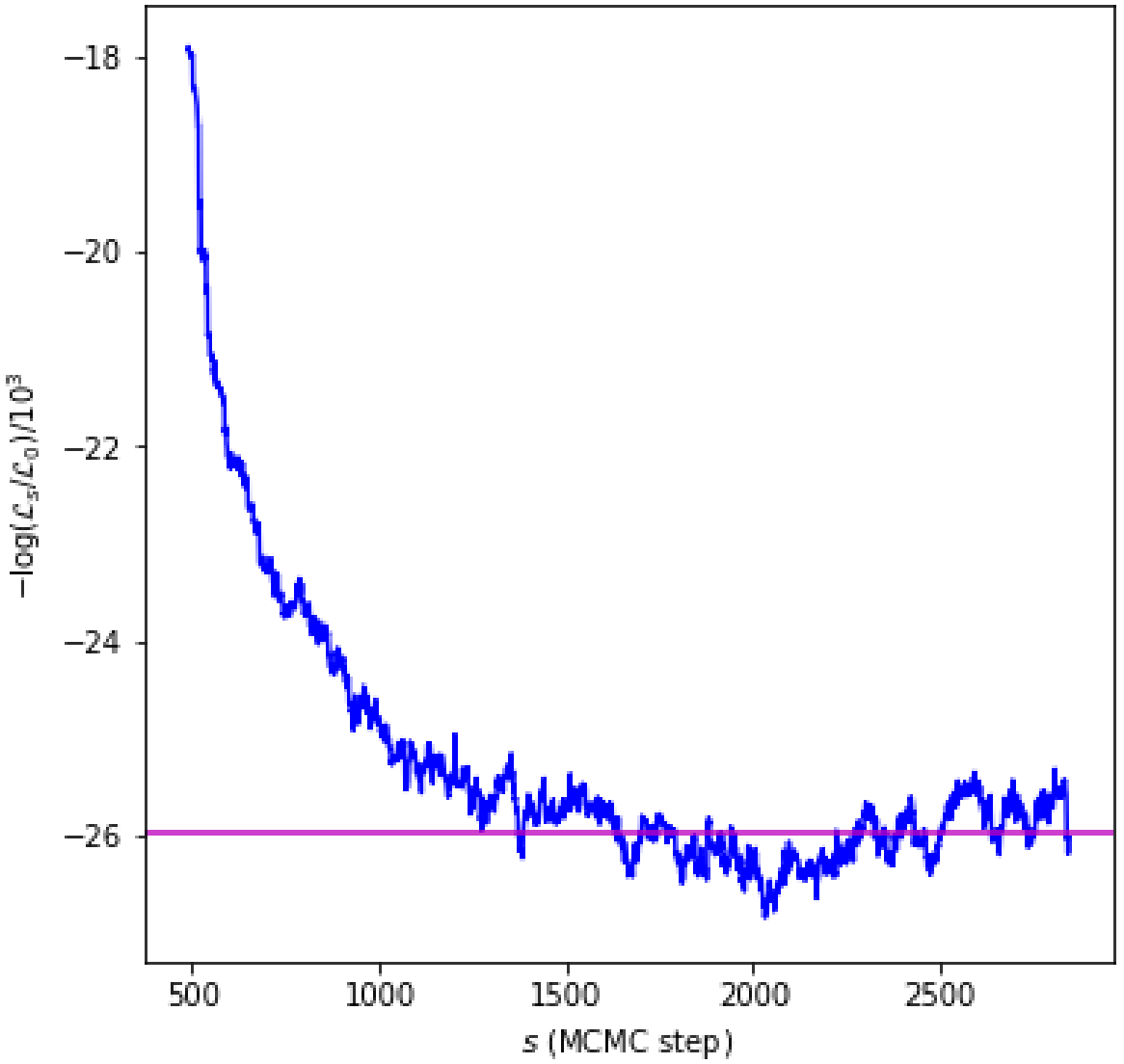
Inferred density fields

Ensemble average density fields at z=0



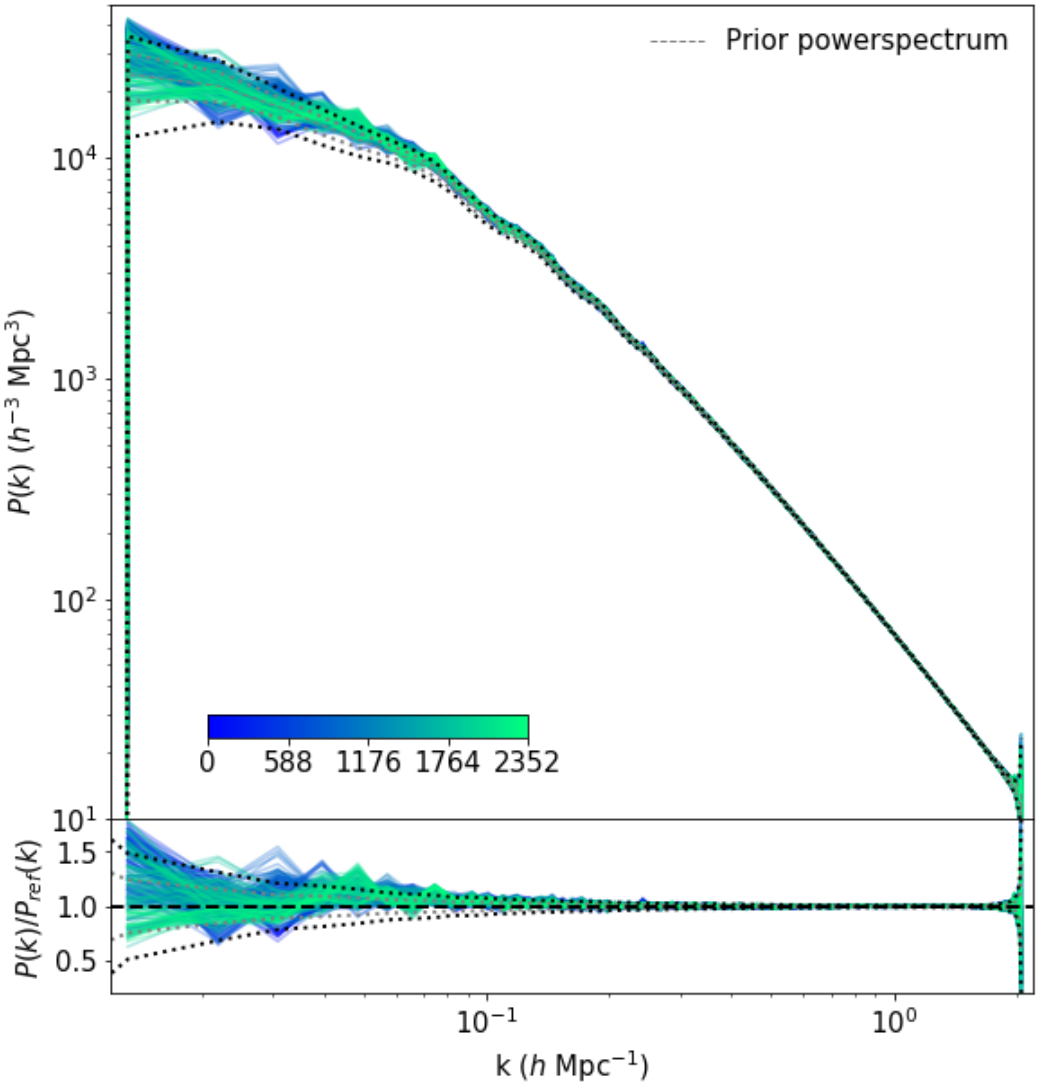
Jasche & Lavaux (2018, in prep.)

Performance aspect (2): burnin

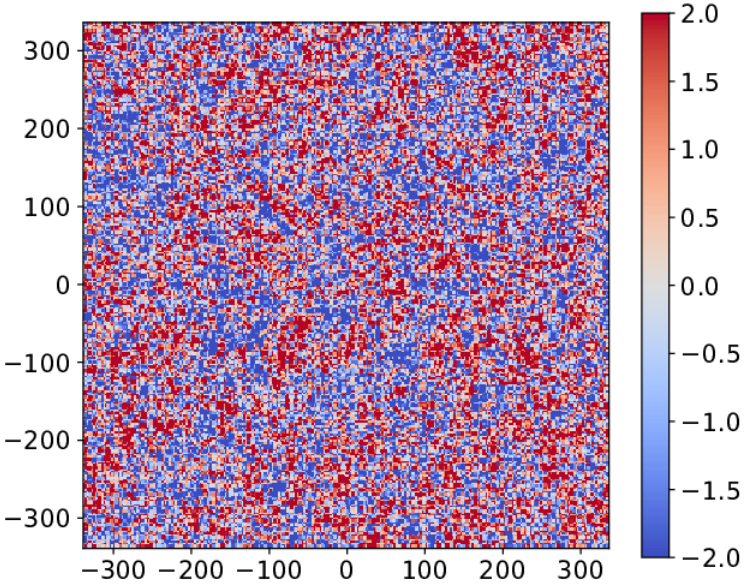


Jasche & Lavaux (2018, in prep.)

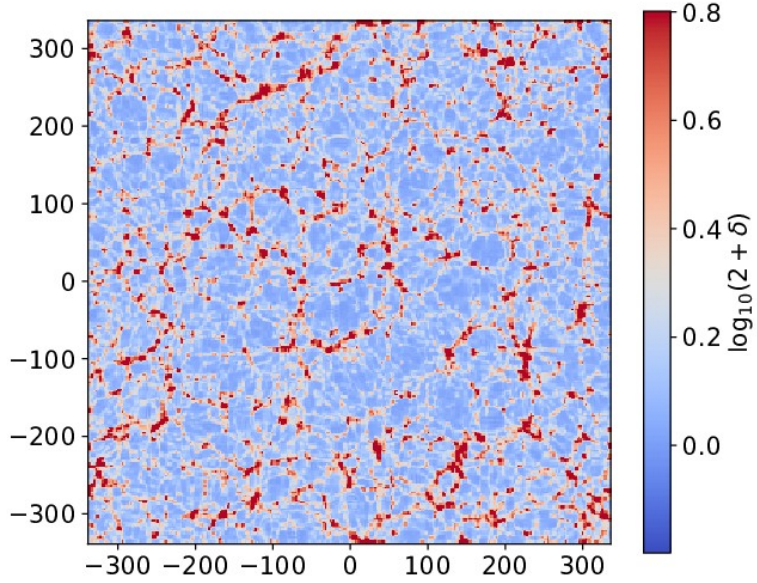
Initial condition powerspectrum



Initial conditions

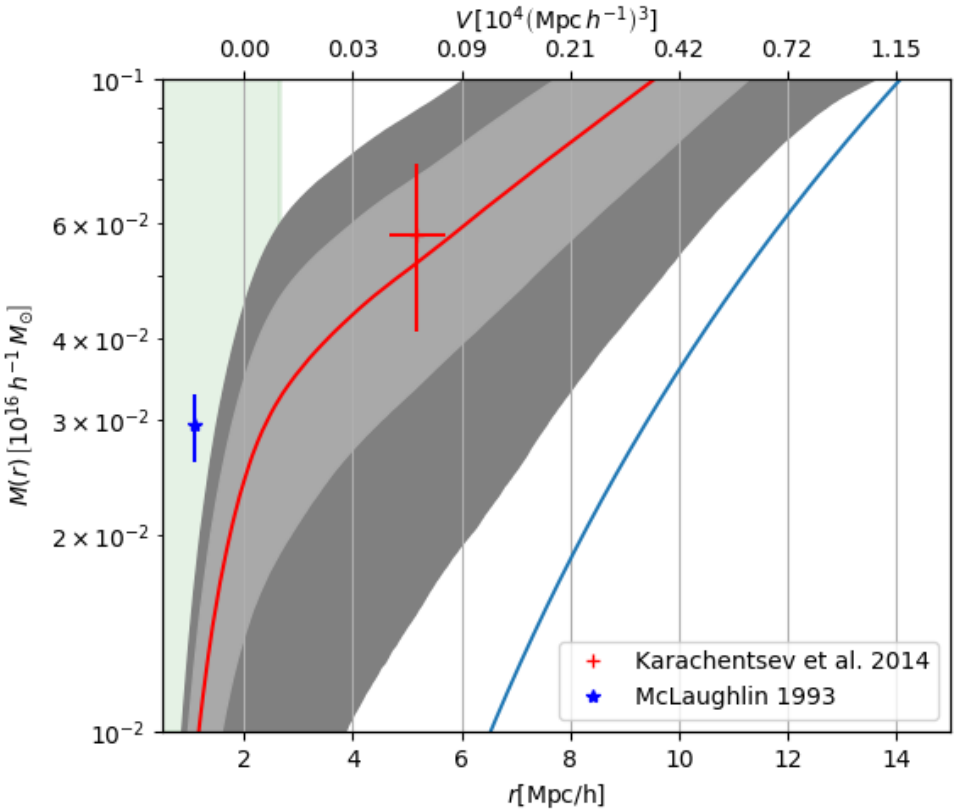


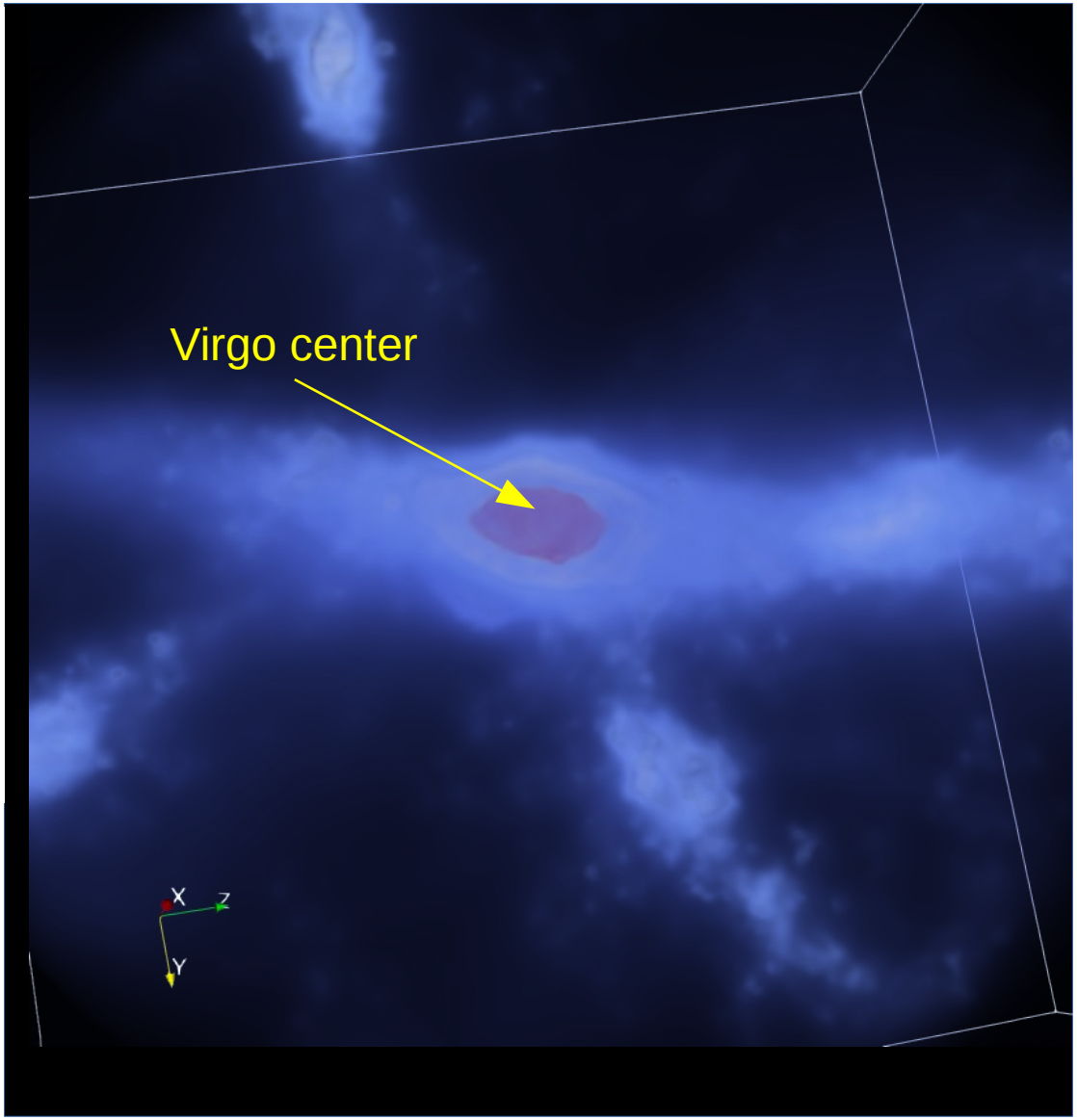
Post PM simulation



Jasche & Lavaux (2018, in prep.)

Virgo cluster

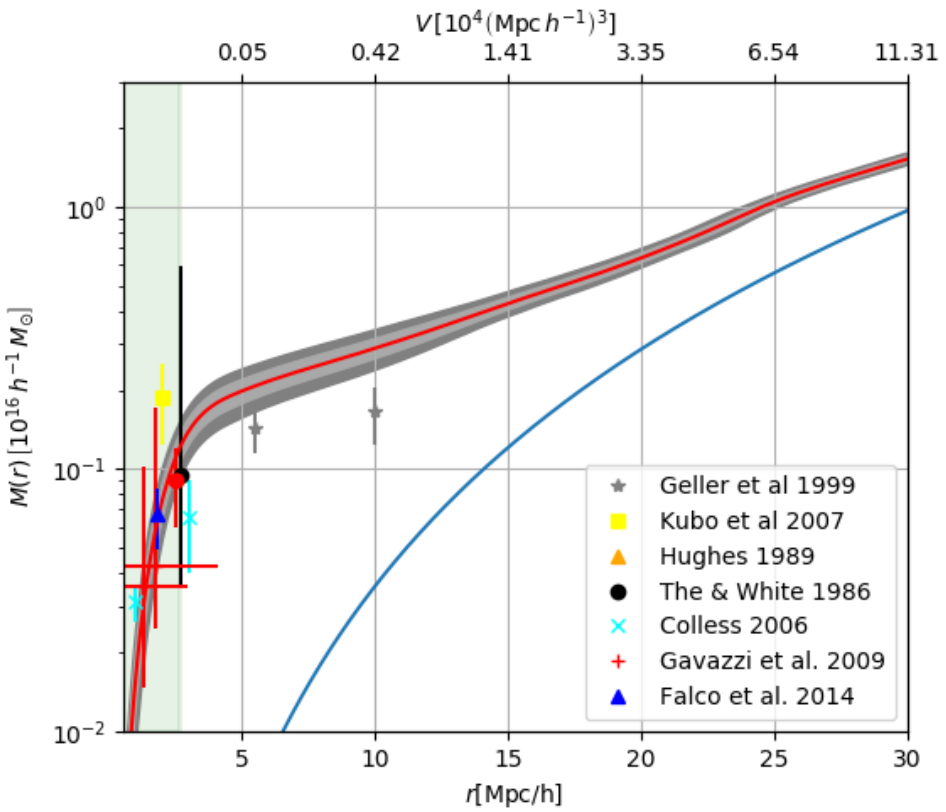


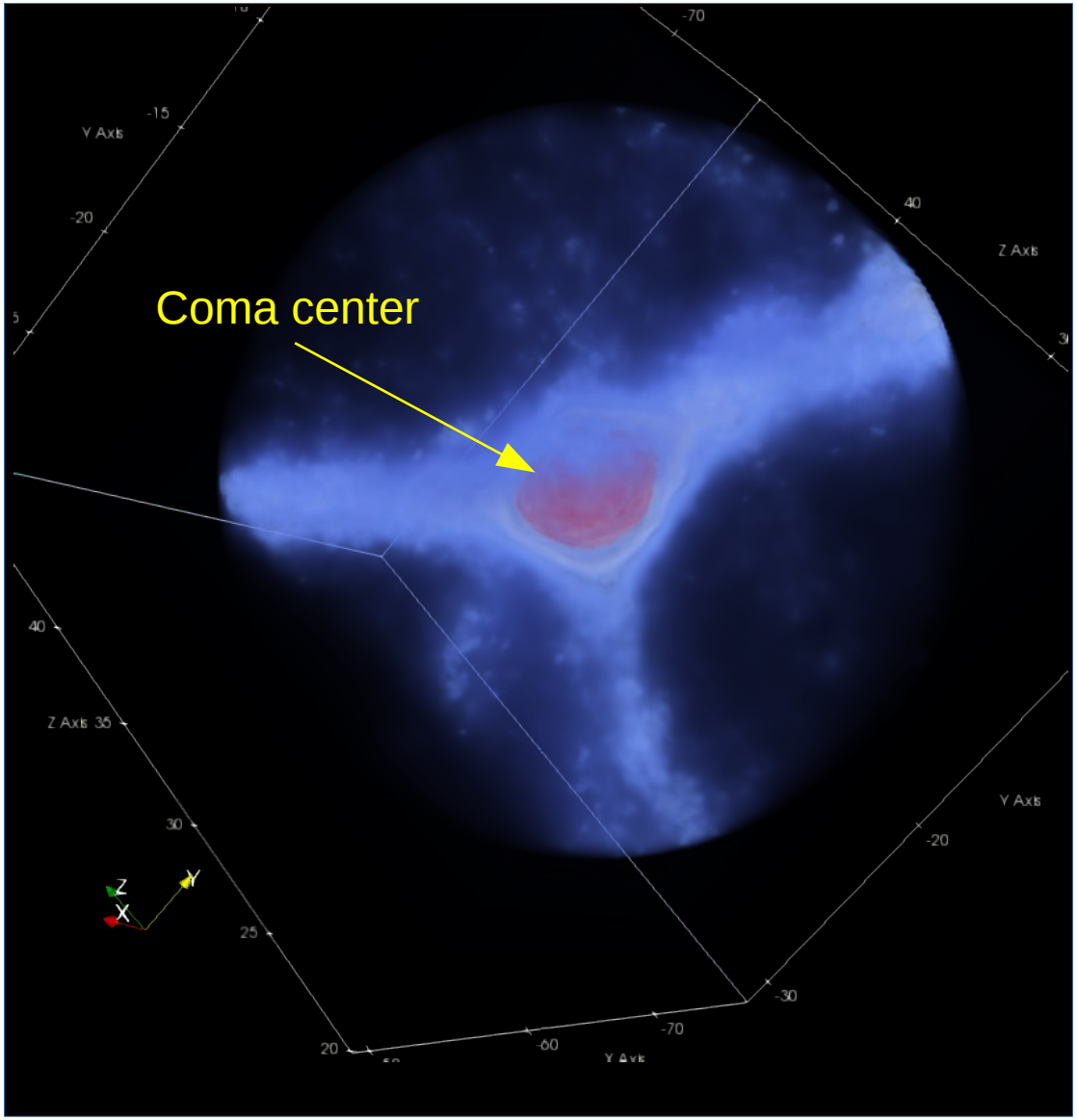


~30 Mpc/h

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

Coma dynamical properties





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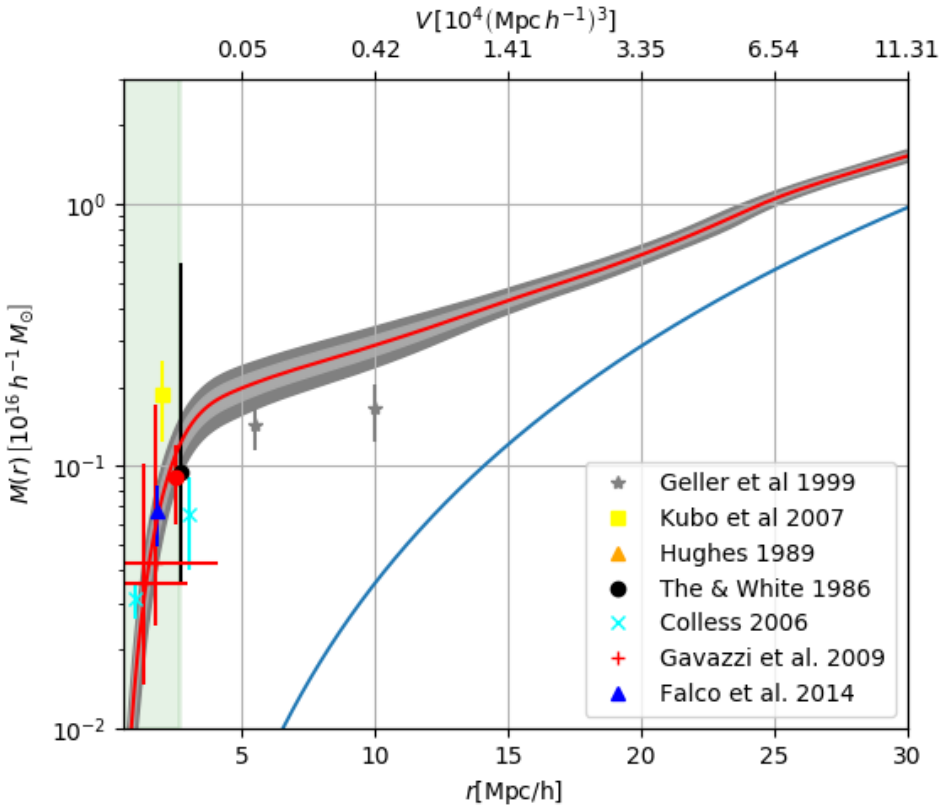
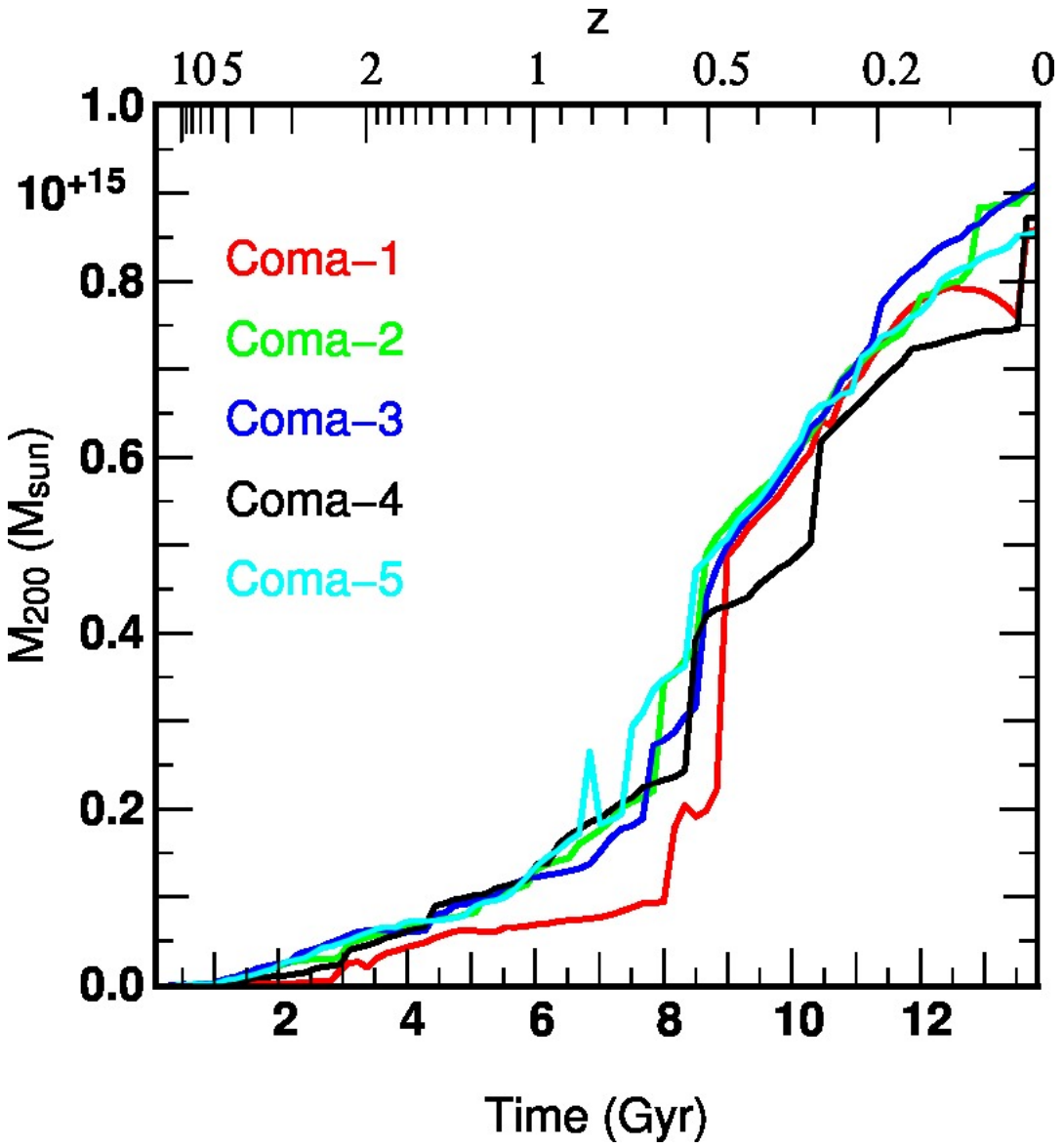


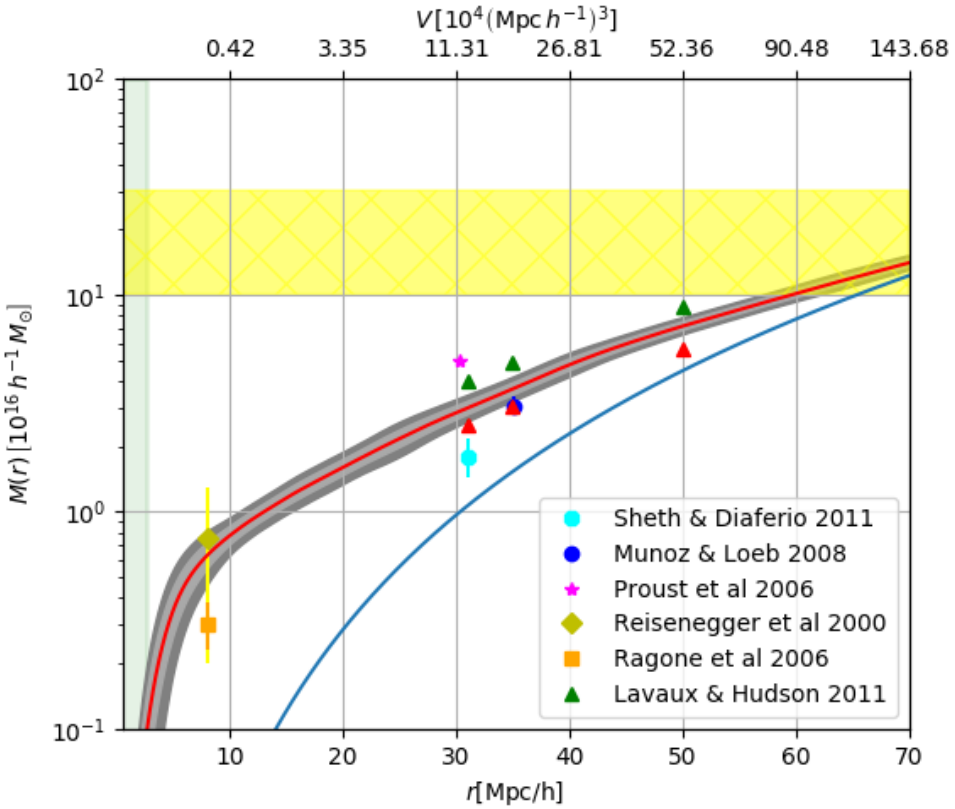


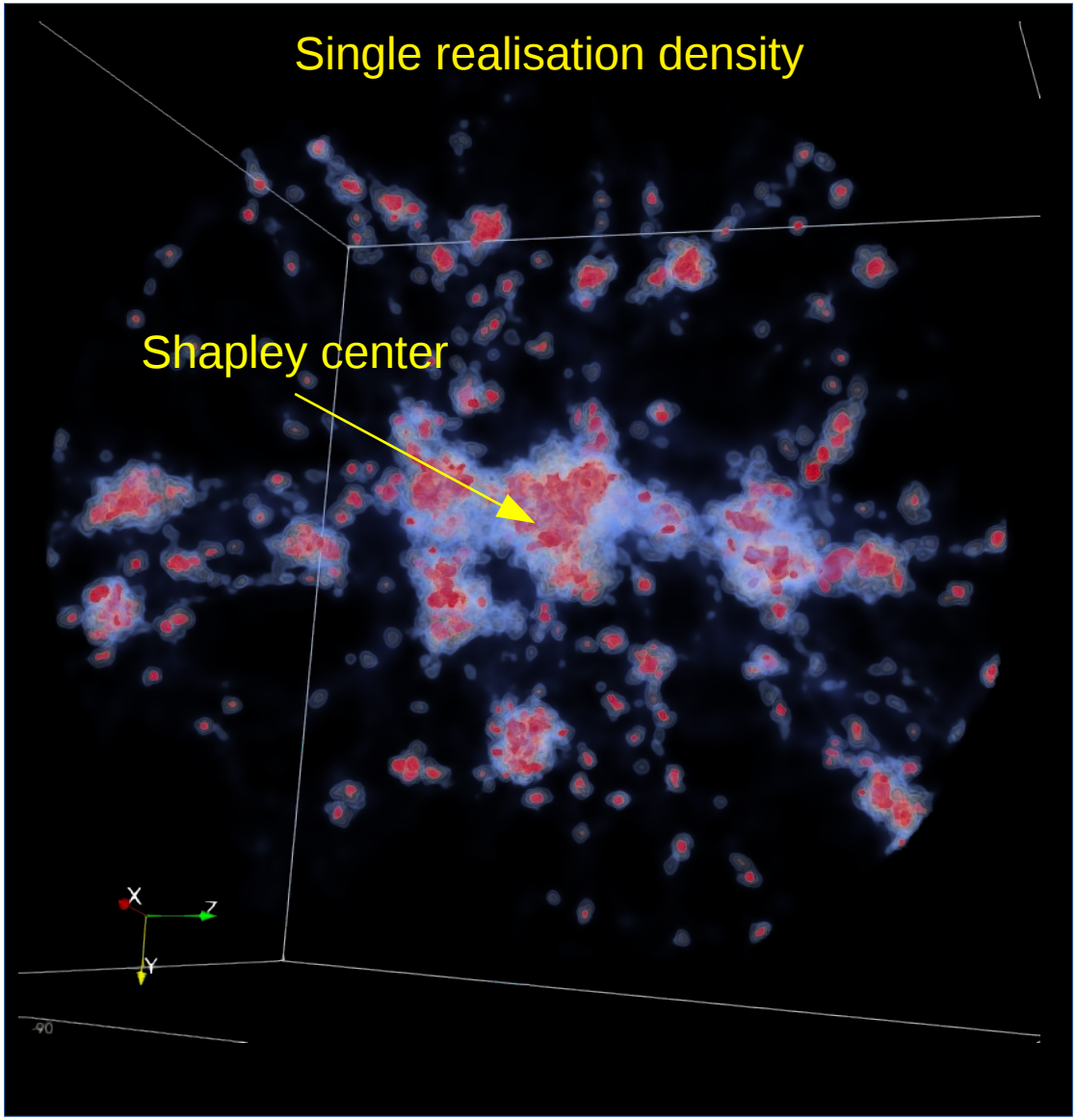
Zoom simulation on Coma
(~250 Mpart in zoom)

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

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

Shapley concentration





~60 Mpc/h

Lavaux & Jasche (2018, in prep.)

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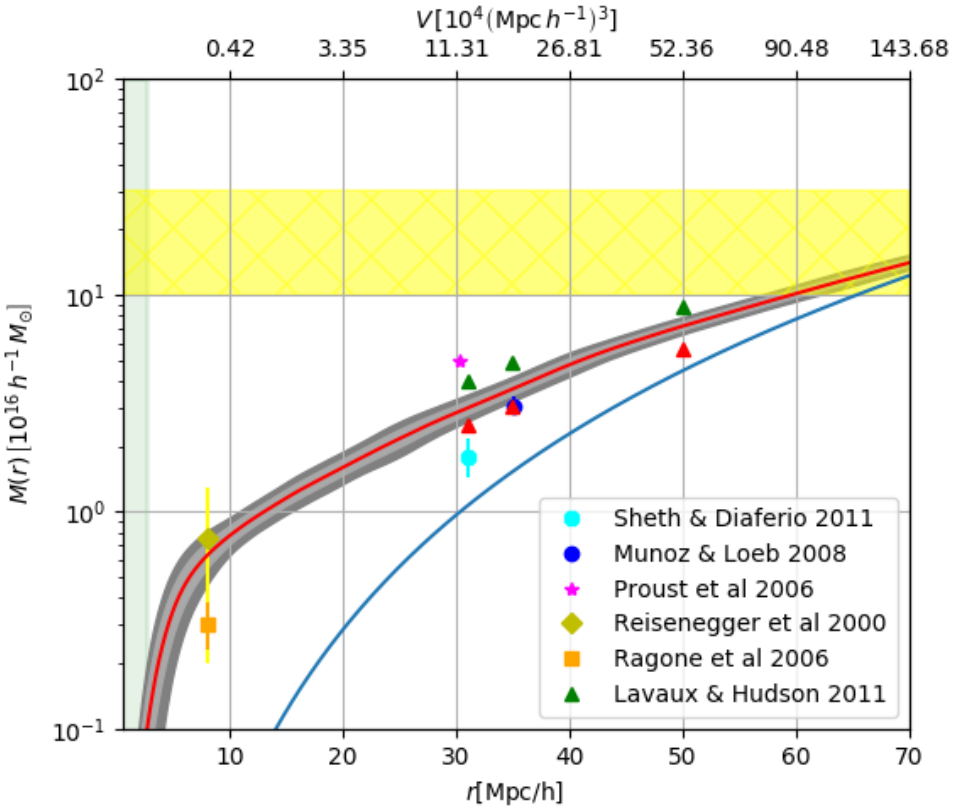

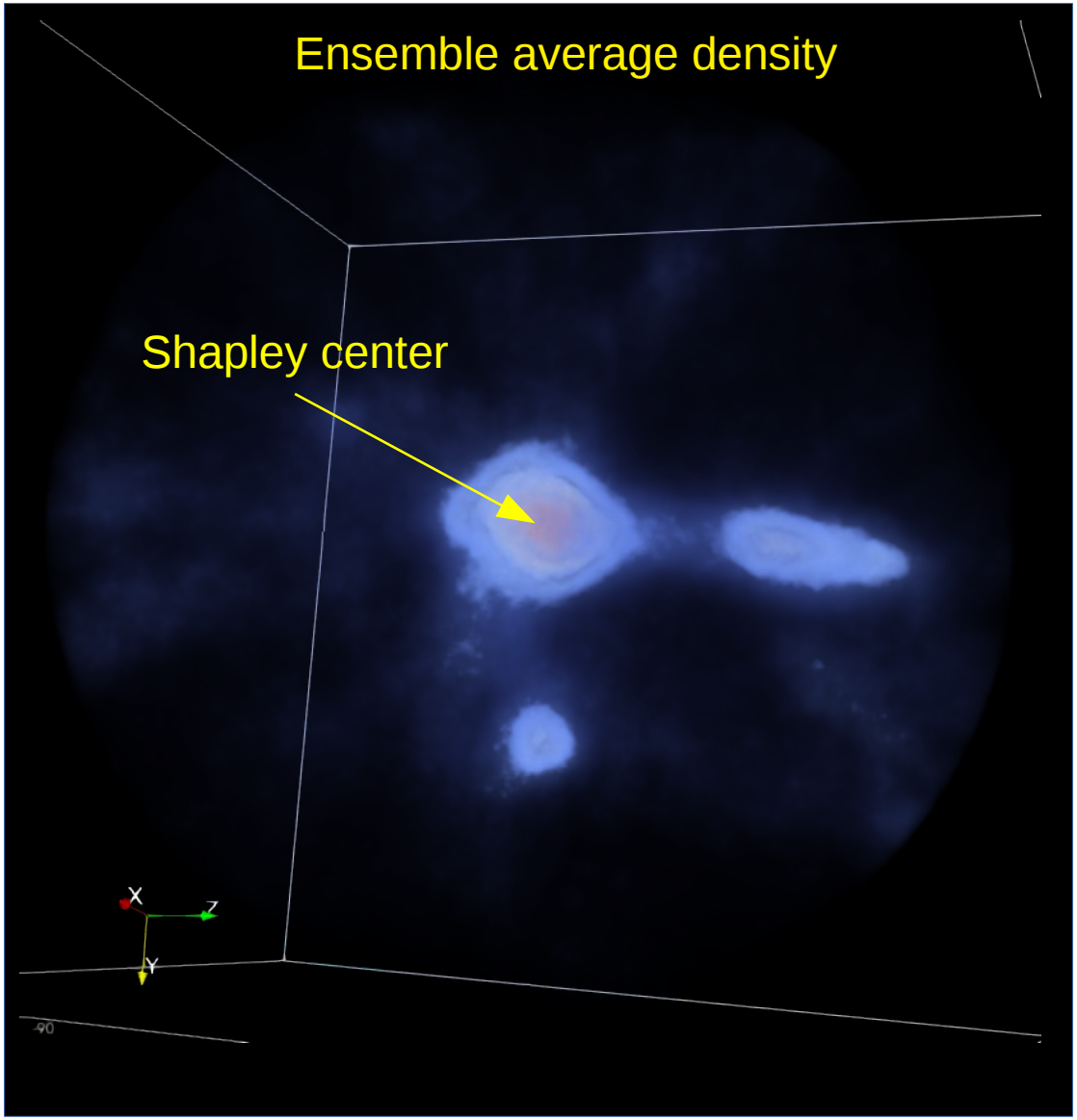

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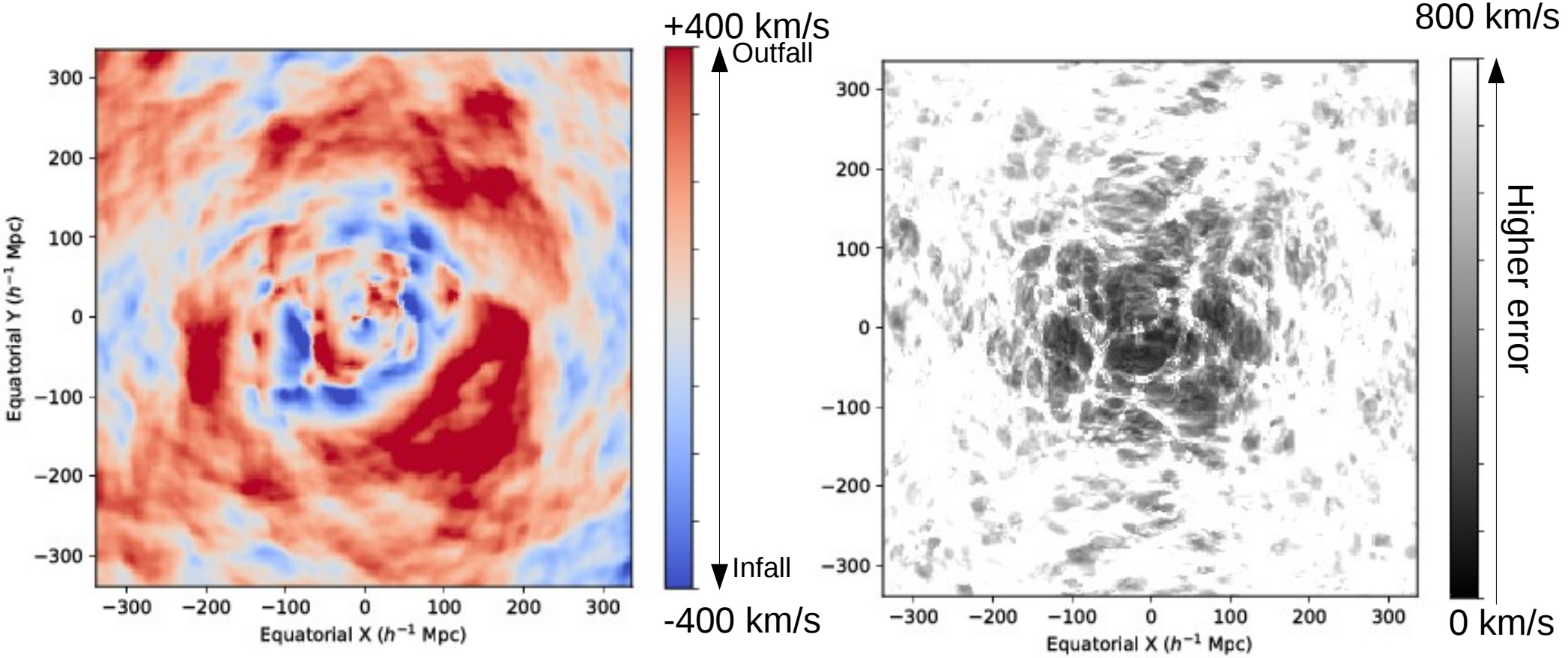
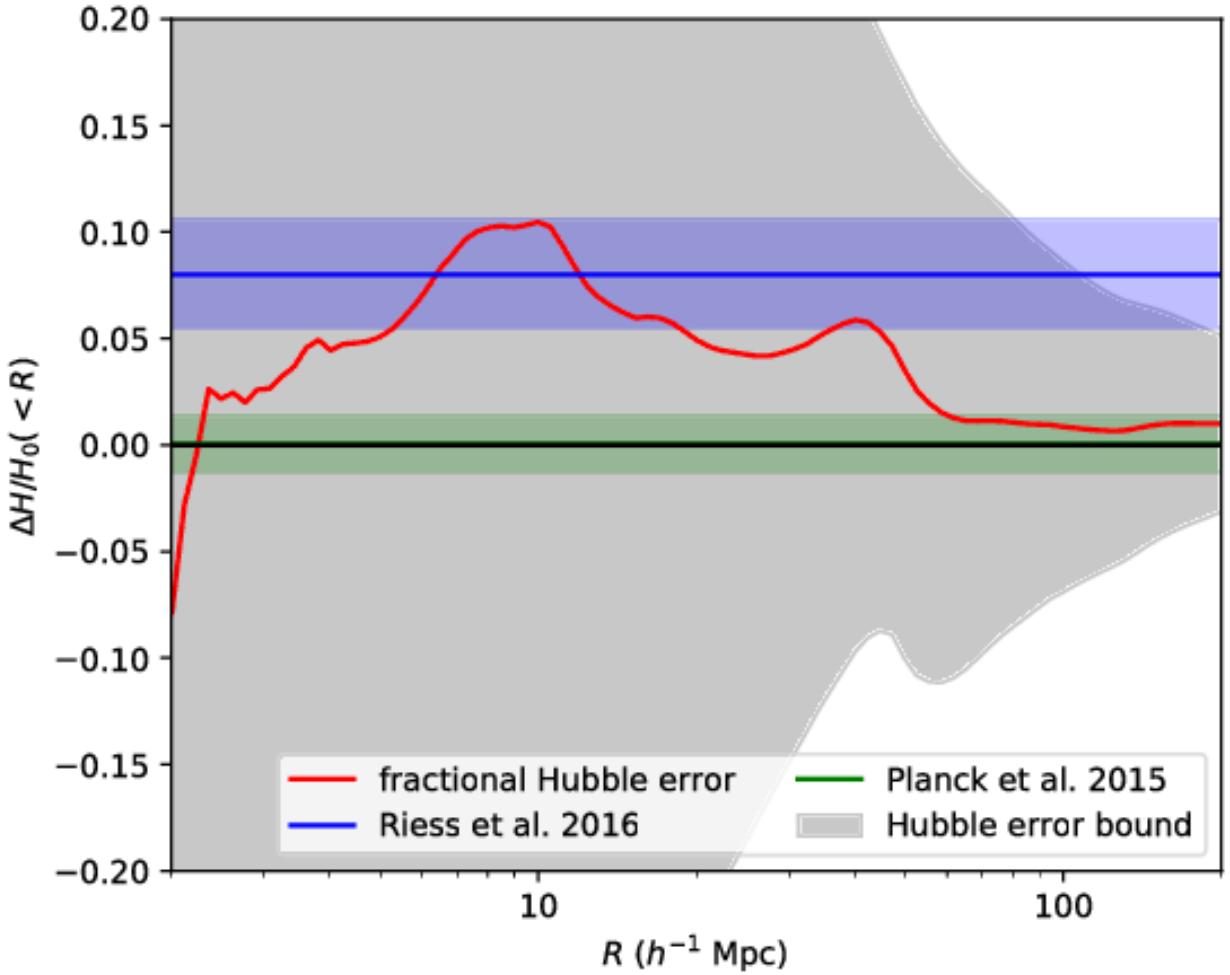
Inferred velocity fields



Jasche & Lavaux (2018, in prep.)

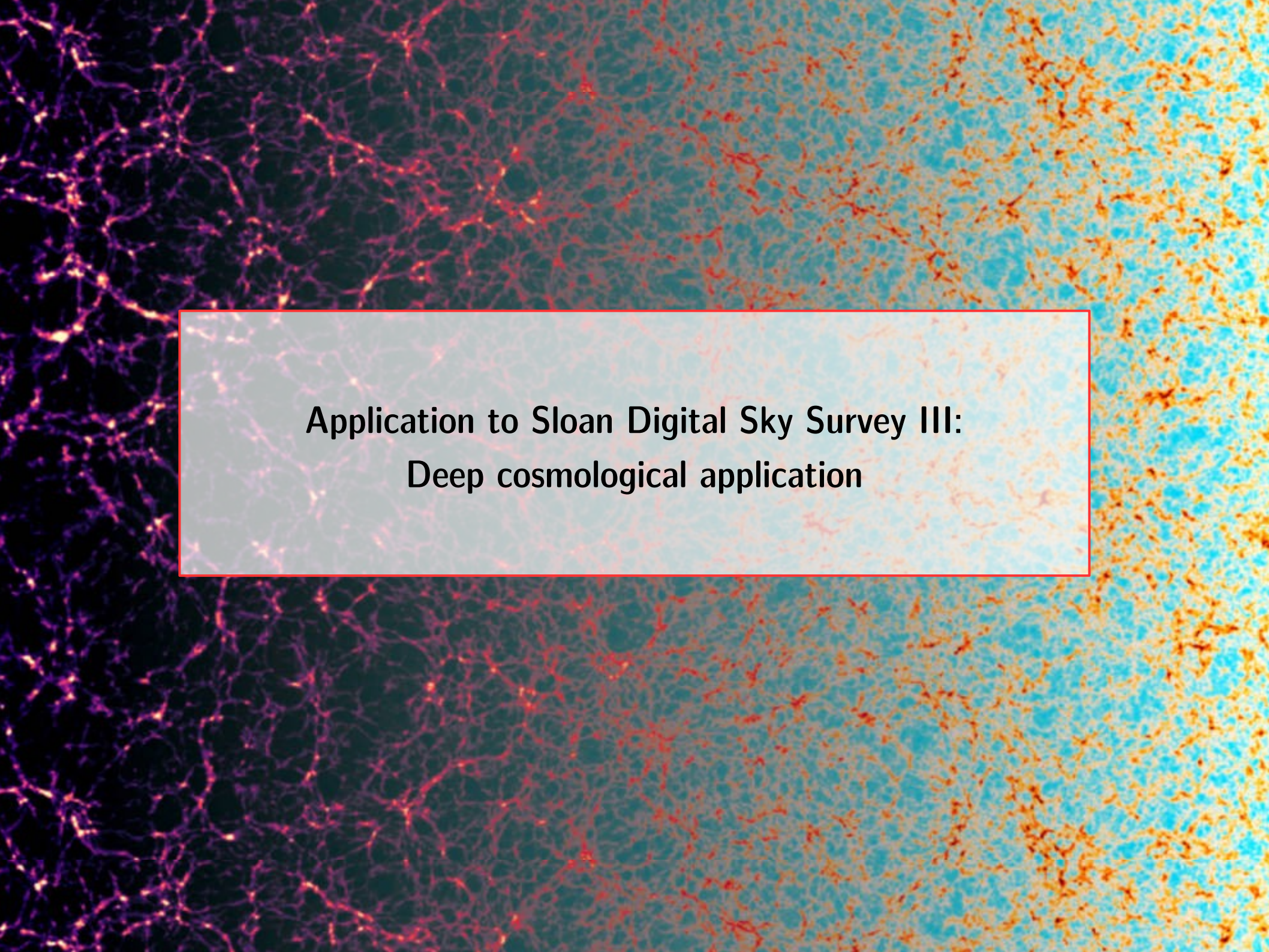
Velocity field and Hubble constant

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



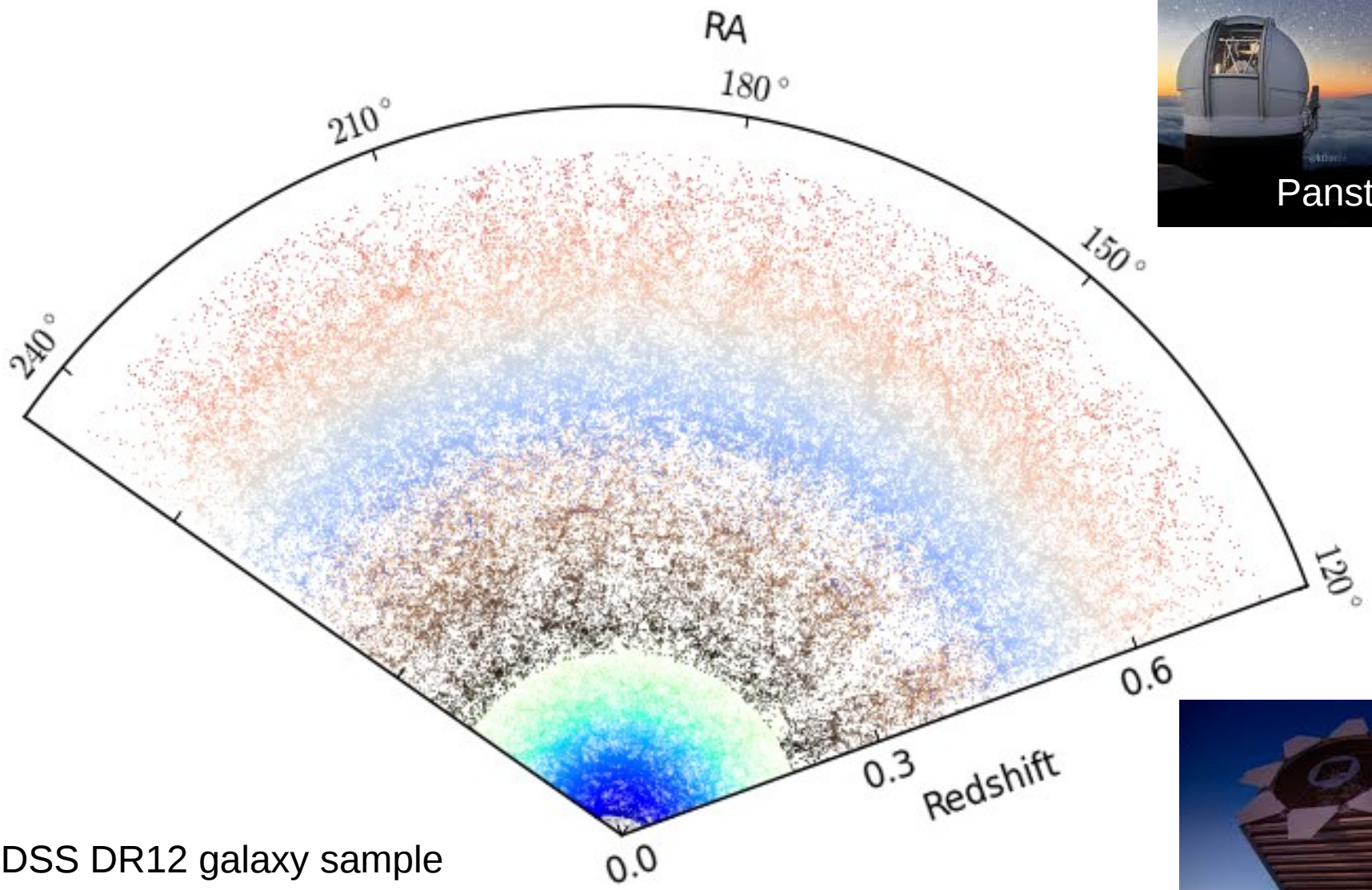
TODO: Compare all the flow models

Jasche & Lavaux (2018, in prep.), Lavaux & Jasche (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 expansion

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

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

$$f(|x|, ...) \simeq Hx + \mathrm{o}(x)$$

(see Doogesh' poster)

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

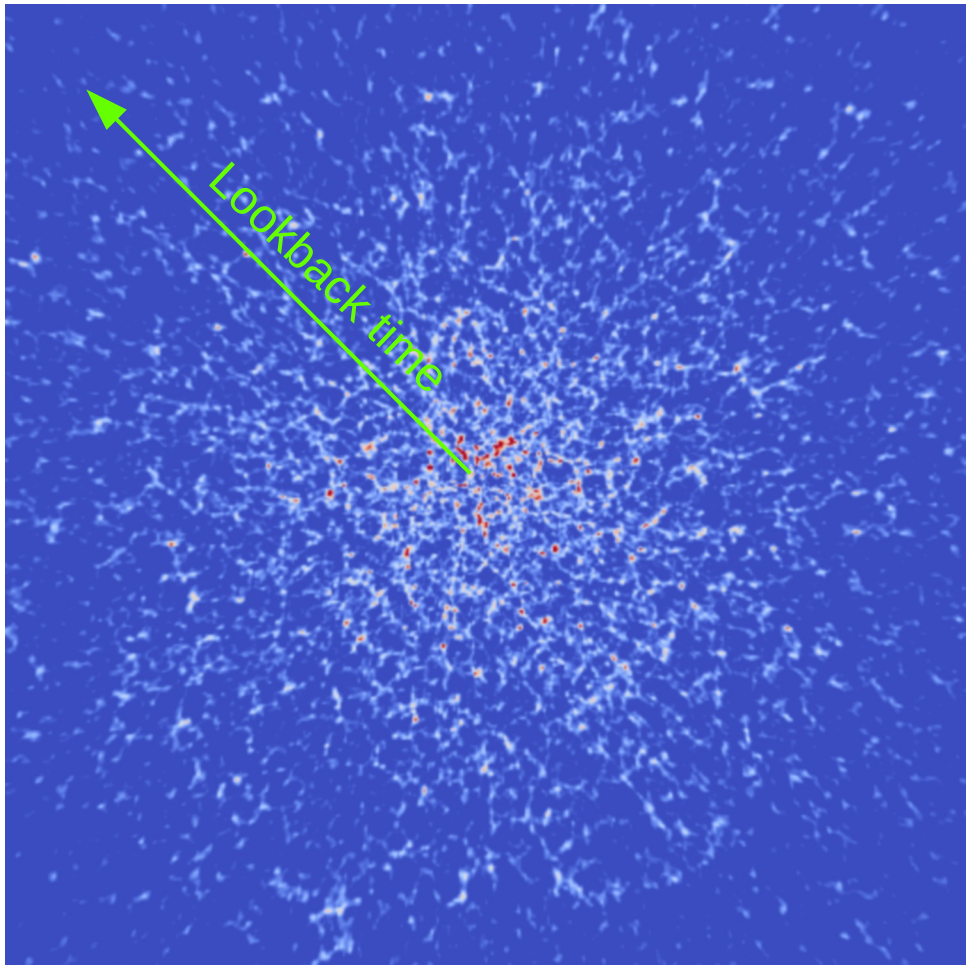
Cosmic growth of structures

Implemented so far for (2)LPT:

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

Forward model becomes more complex

Cosmic expansion



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

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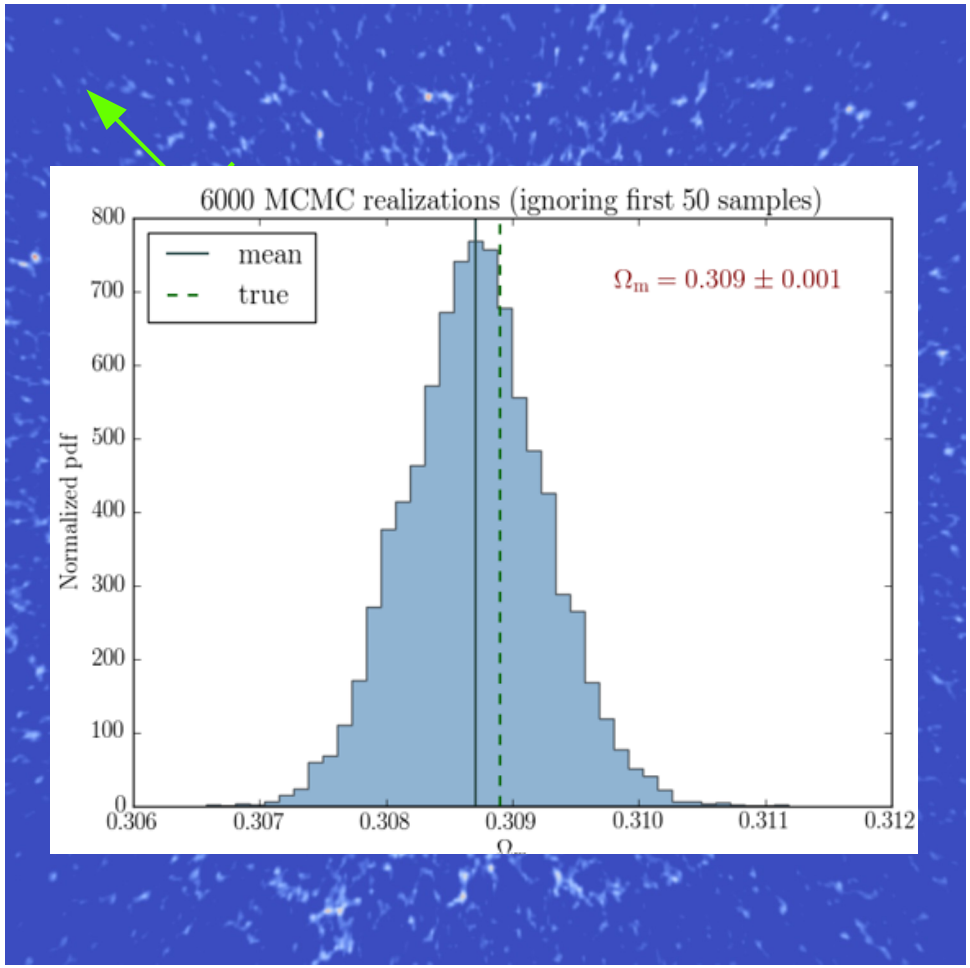

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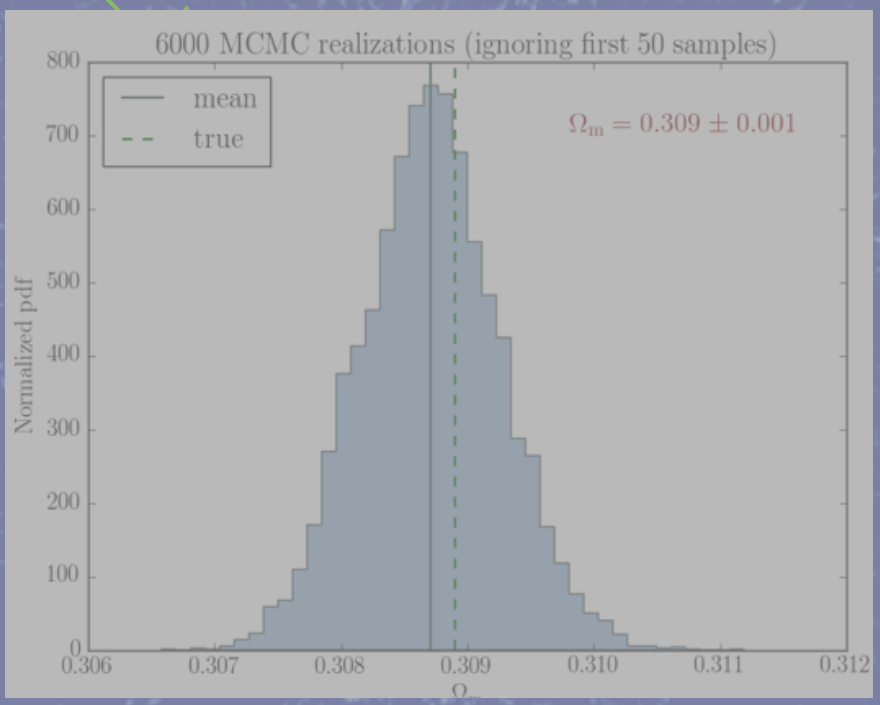

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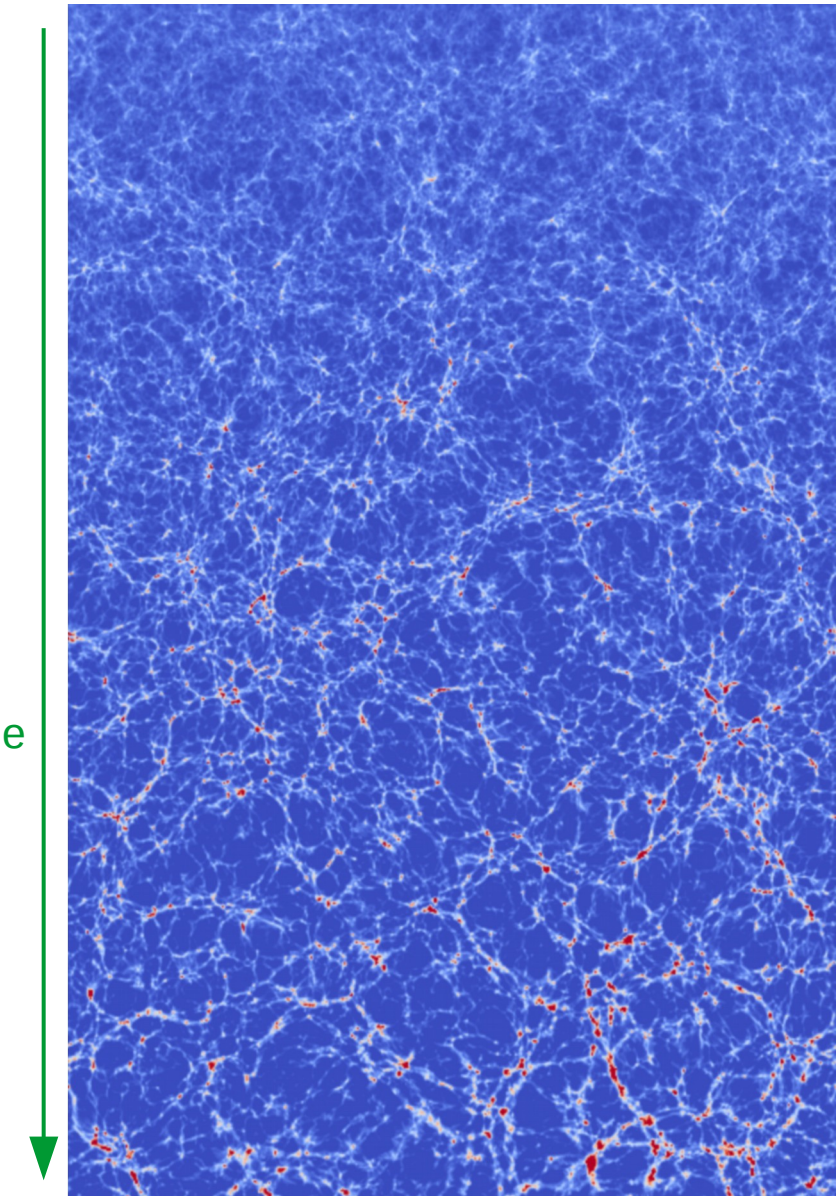
Kodi Ramanah, Lavaux, Jasche, Wandelt (2018, in prep.)

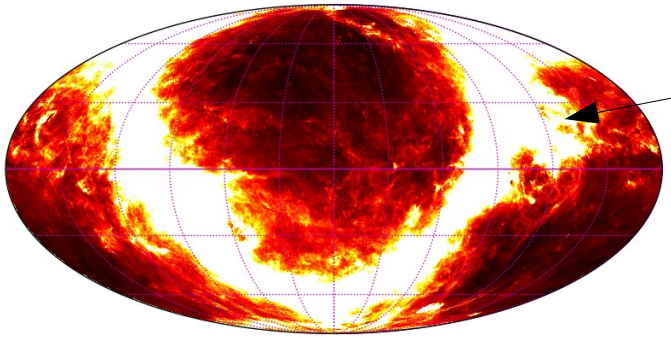
Cosmic growth of structures

Time



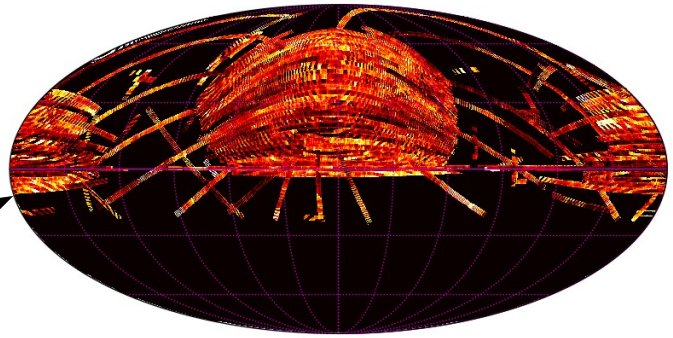
… and systematic cleaning…

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

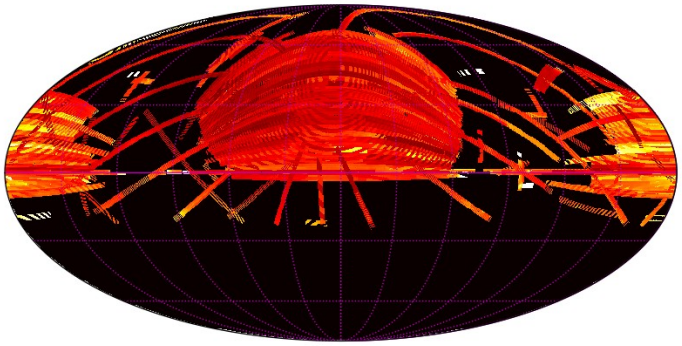


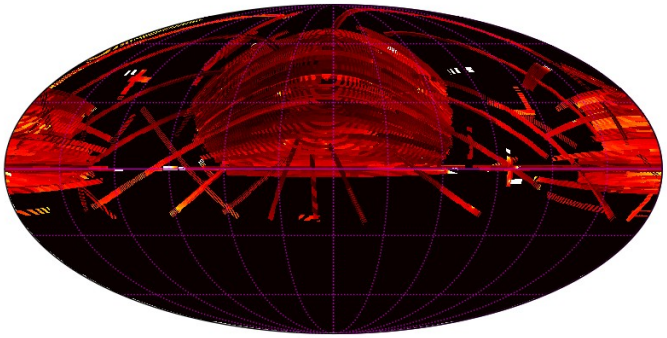
DUST

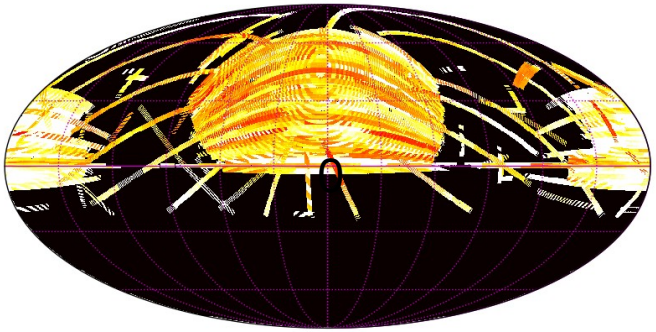
psfWidth



Sky fluxes

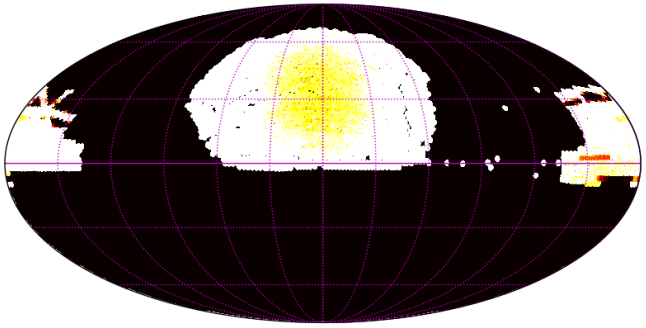


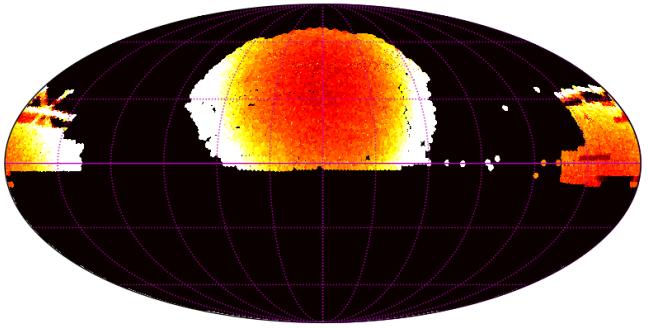


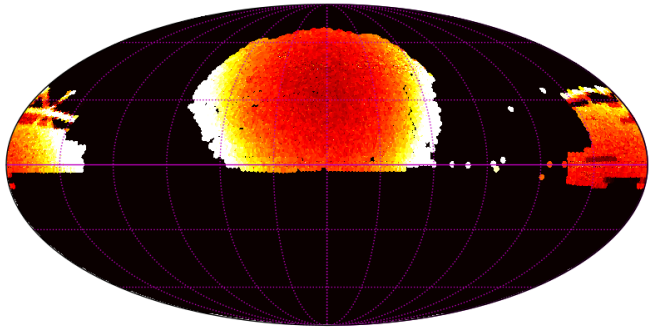


…

Star densities



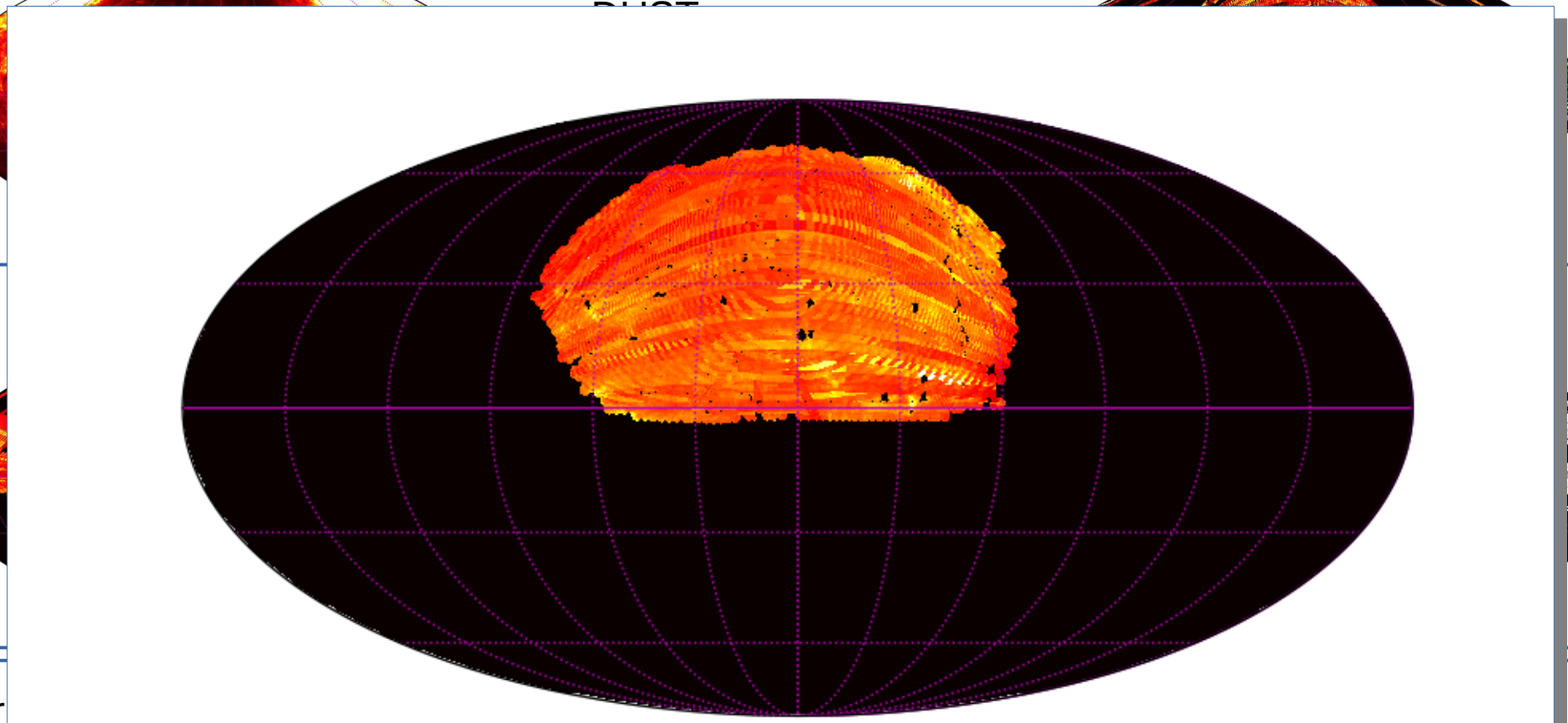




…

Example fitted composite...

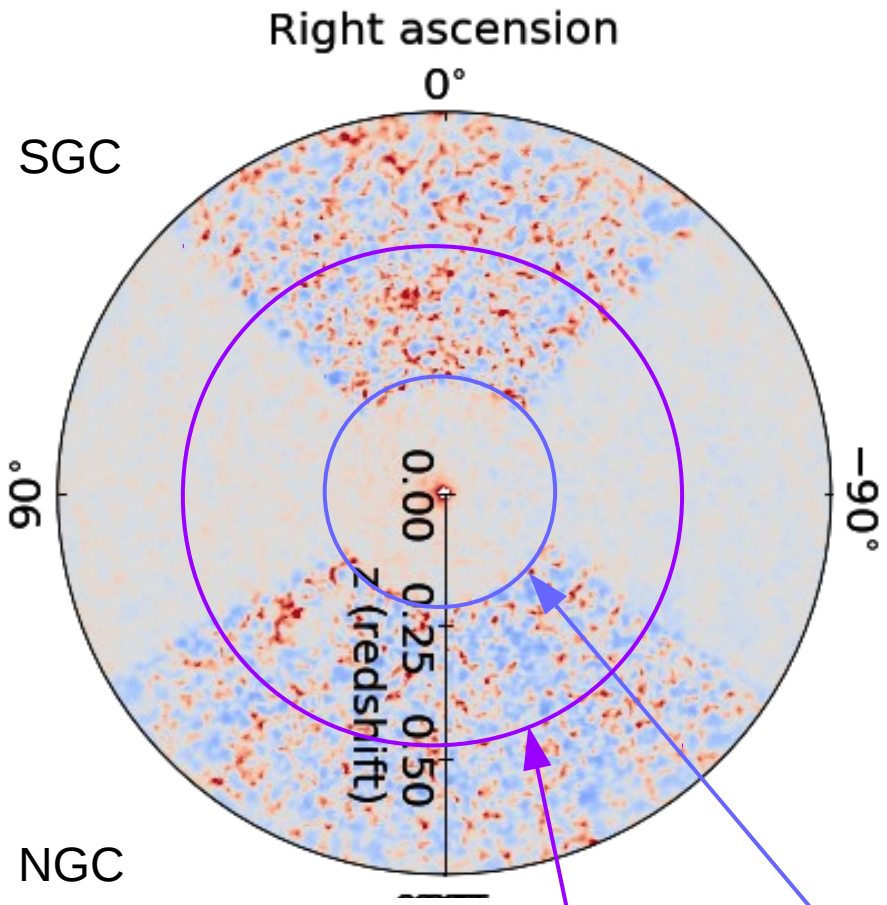
11 foregrounds (here only 8)… still much less than Leistedt & Peiris (2014) but improving



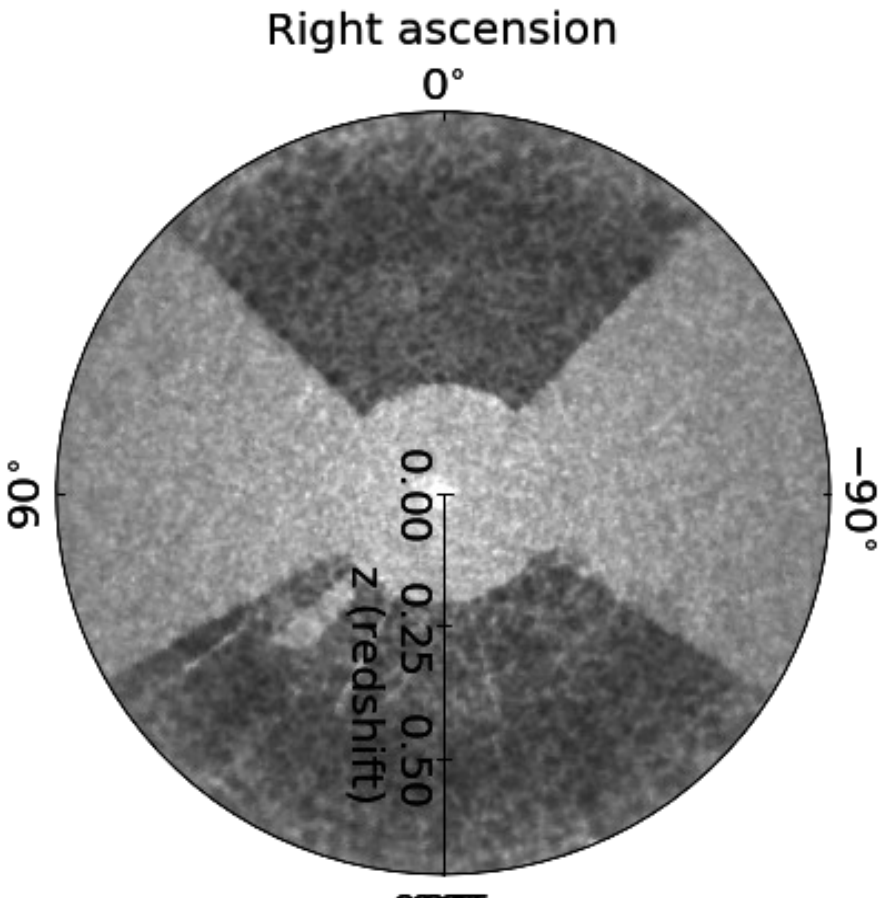
Preliminary

Inferred density of SDSS3

Ensemble density average



Error estimate from ensemble variance



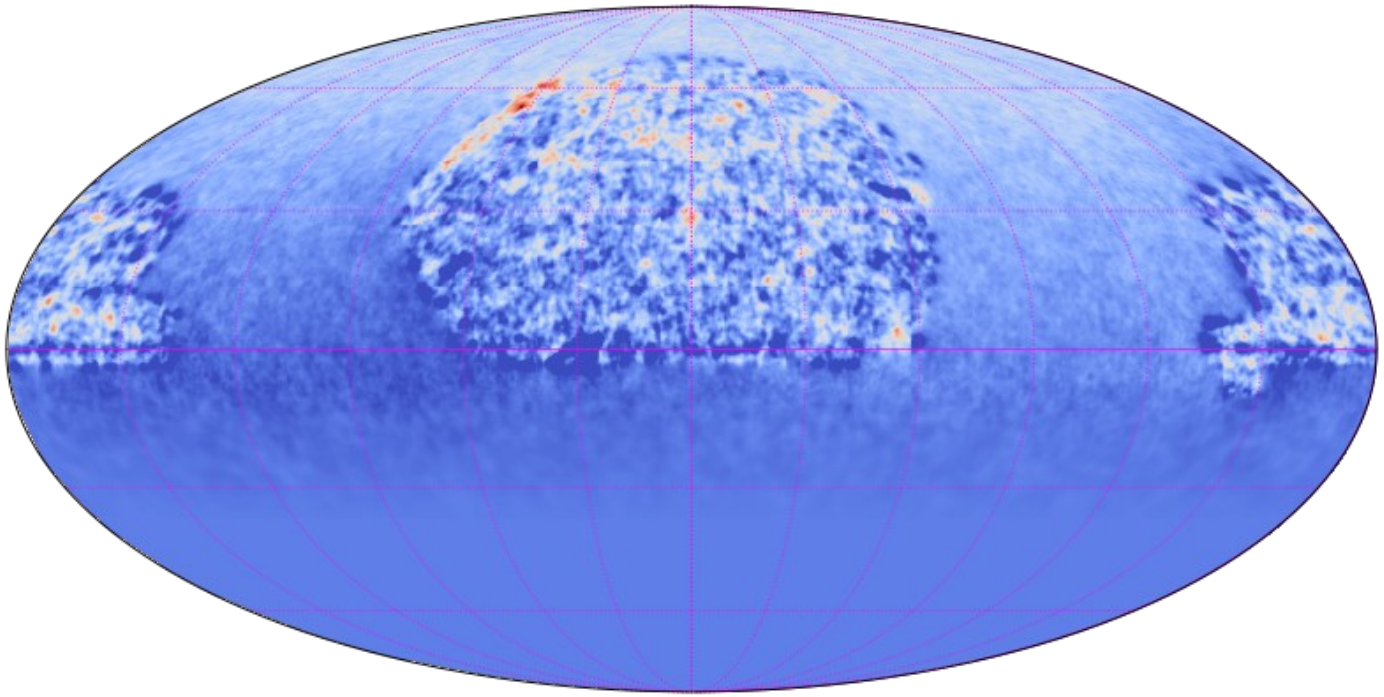
Main galaxy sample limit
(not included)

LOWZ limit

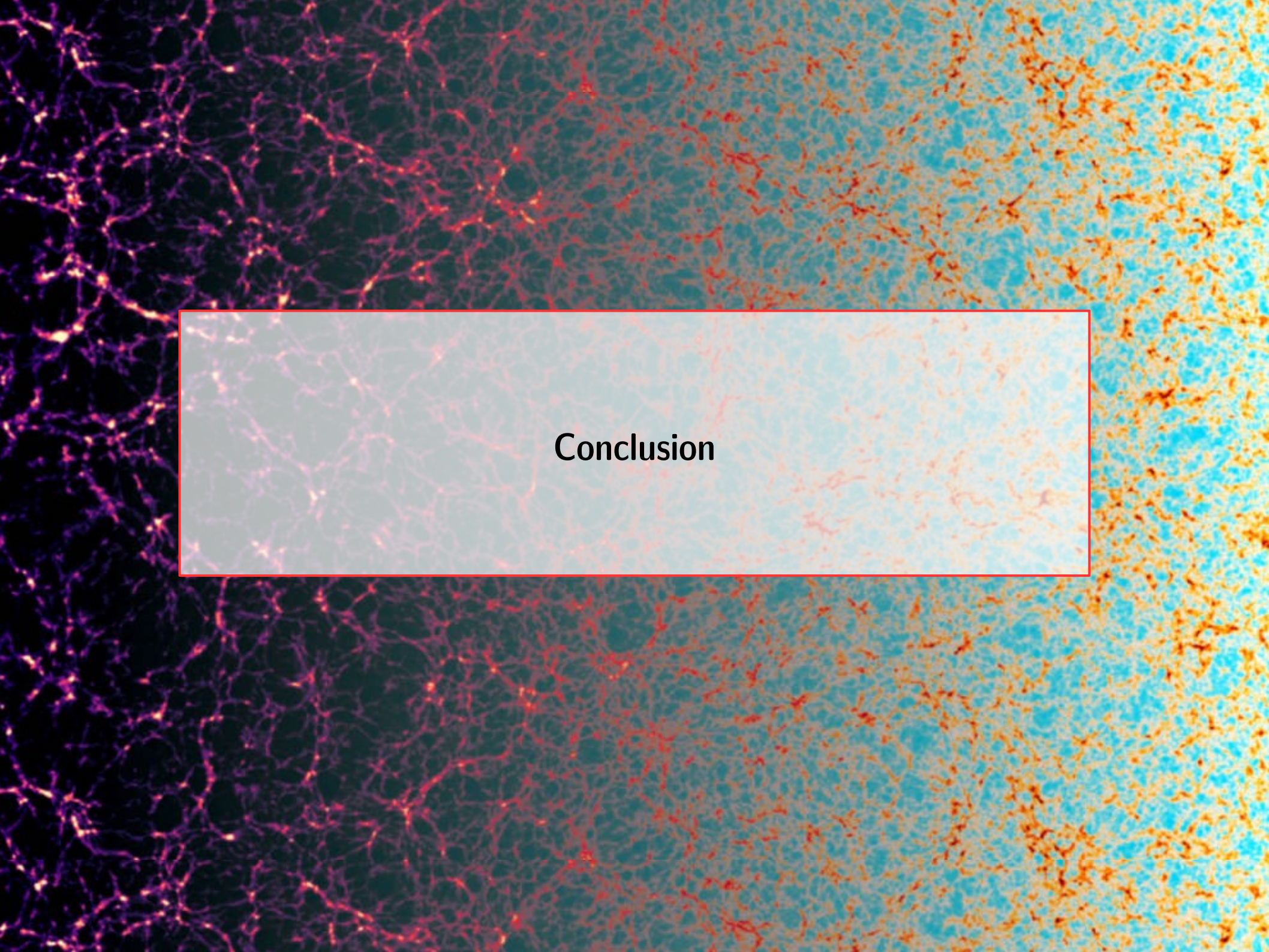
CMASS limit

Preliminary

Sky density



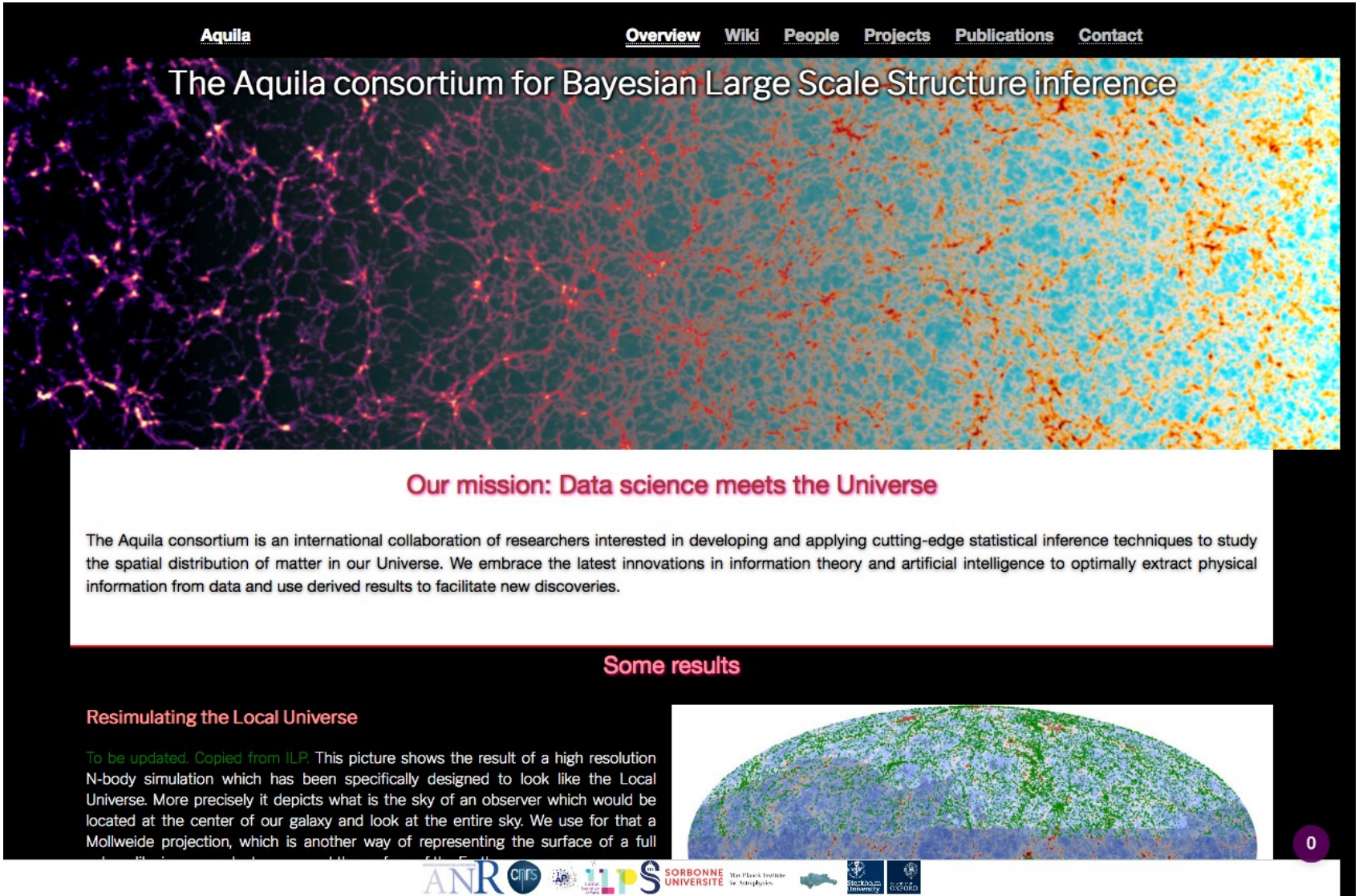
Preliminary


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/



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https://aquila-consortium.org/

A biased list of Aquilians… check the website!

Natalia Porqueres

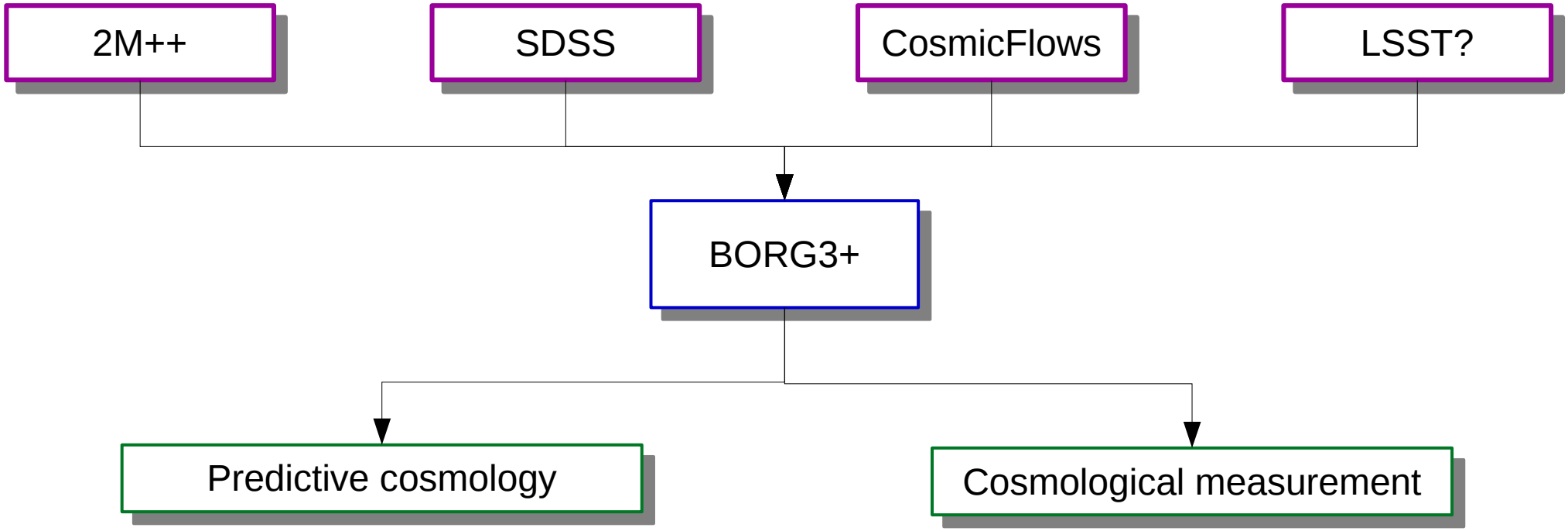
Minh Nguyen

Doogesh Kodi Ramanah

Tom Charnock

Florent Leclercq

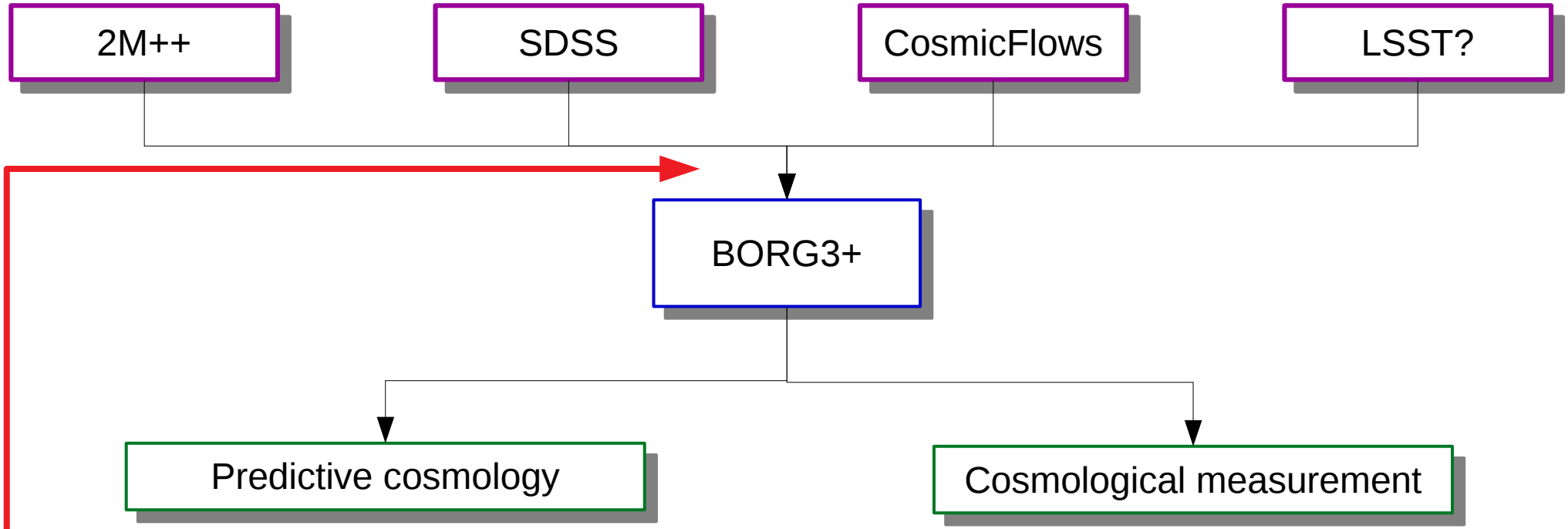
Conclusion: great future



- 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



- 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

Galaxy formation: bias and likelihood

Instrument modeling