Non-linear bayesian inference of cosmic fields in SDSS3 and 2M++ and their application to Nearby cosmology

Guilhem Lavaux (IAP/CNRS)
and Aquila Consortium

eBOSS meeting 2018

From pictures… to physics of Universe at large

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In a handful of model parameters

Ultimately: we want to fit a model to this kind of picture, and the pixel by pixel spectrum

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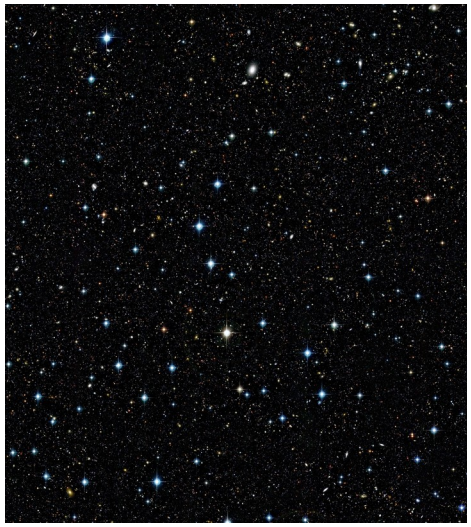
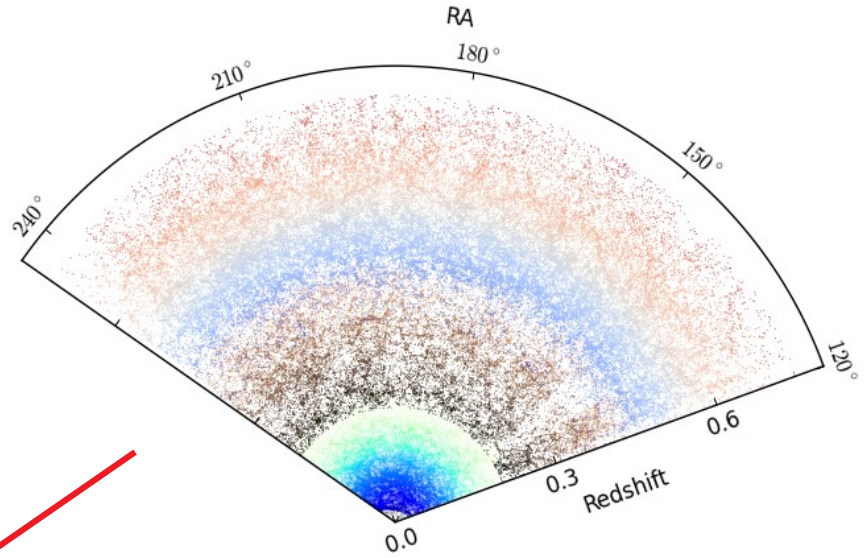
That’s very challenging, probably impossible → we reduce those datasets



Reduce



Ultimate BORG

Massage, adjust,
compute correlations

Ω

Cosmological parameters
Global cosmological properties

Fit model to
even further
reduced data

?

Do something

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)

… or IMNN

Charnock et al. (2018, PRD)

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

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Forward and adjoint model

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Easily exchangeable to try your favorite differentiable model

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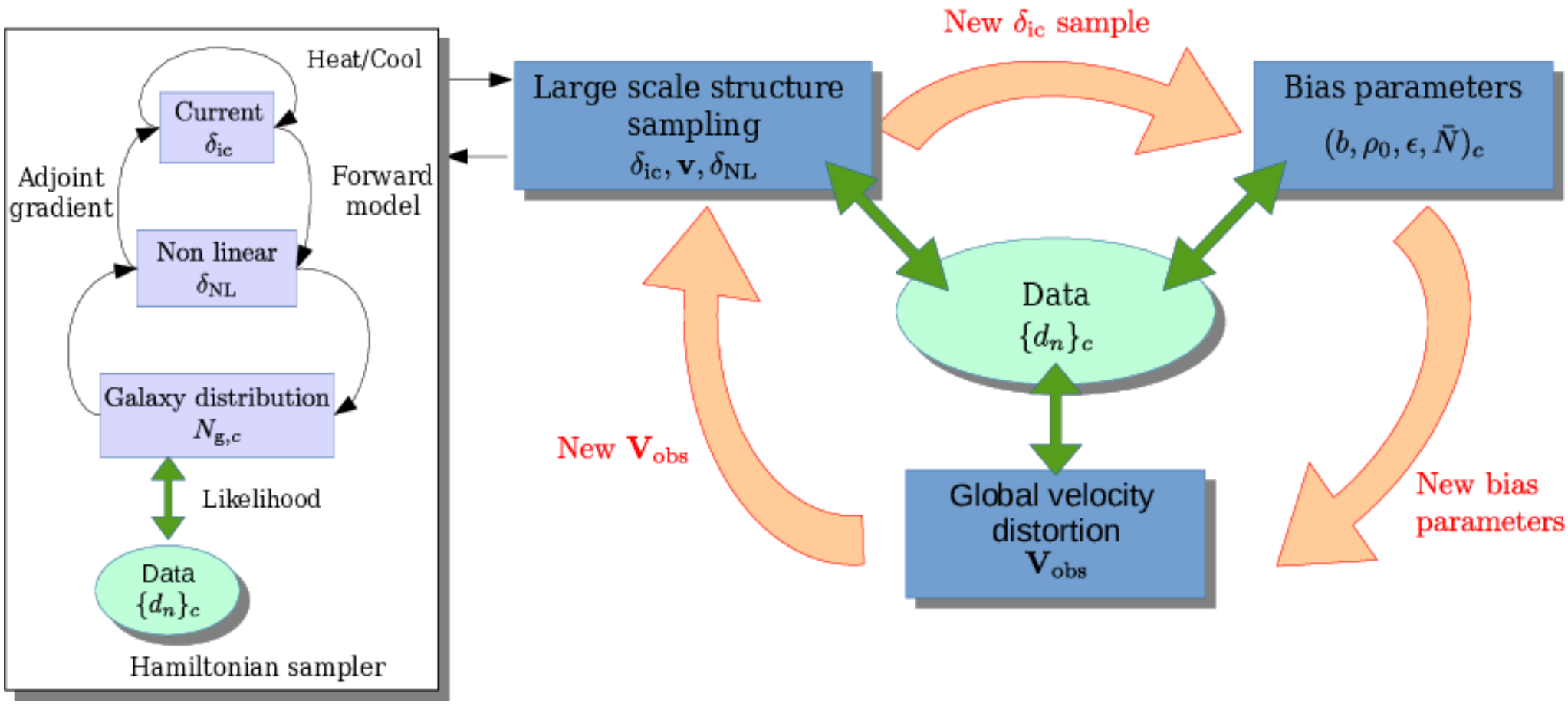
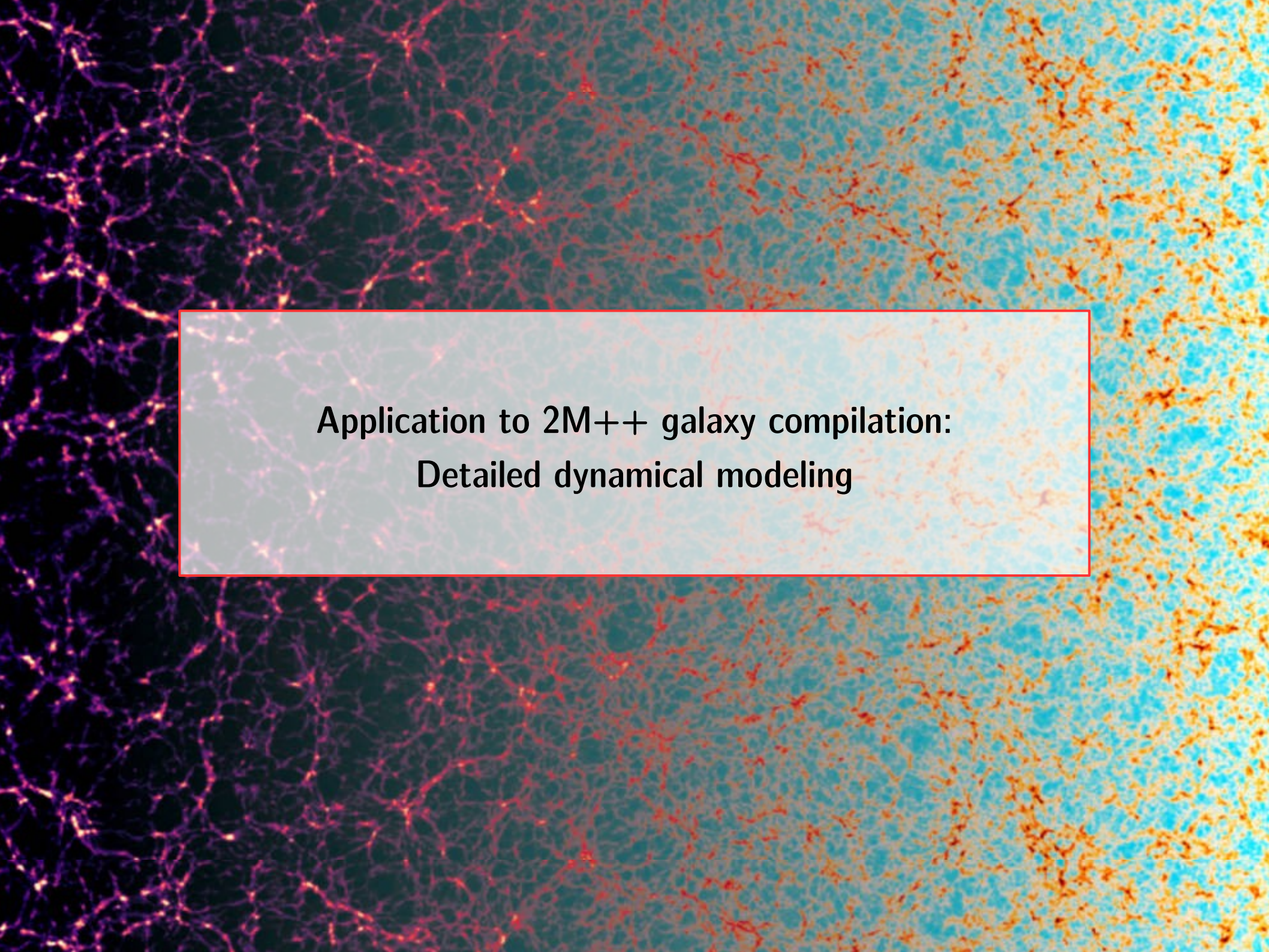
Encode survey systematic effects with expansions: $S(\hat{x}) = S_0(\hat{x}) \prod_{f=1}^{N} (1 + \alpha_f F_f(\hat{x}))$

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

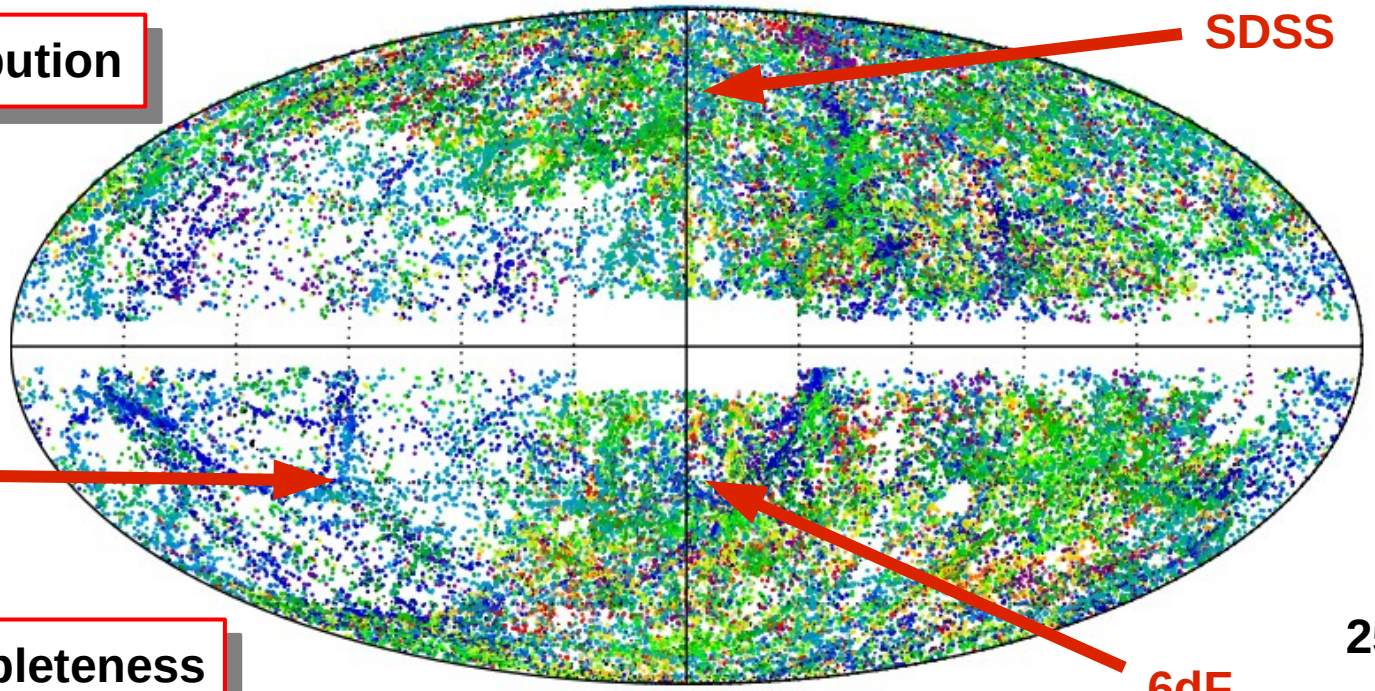
The BORG3 machine




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

The 2M++ galaxy compilation

Galaxy distribution

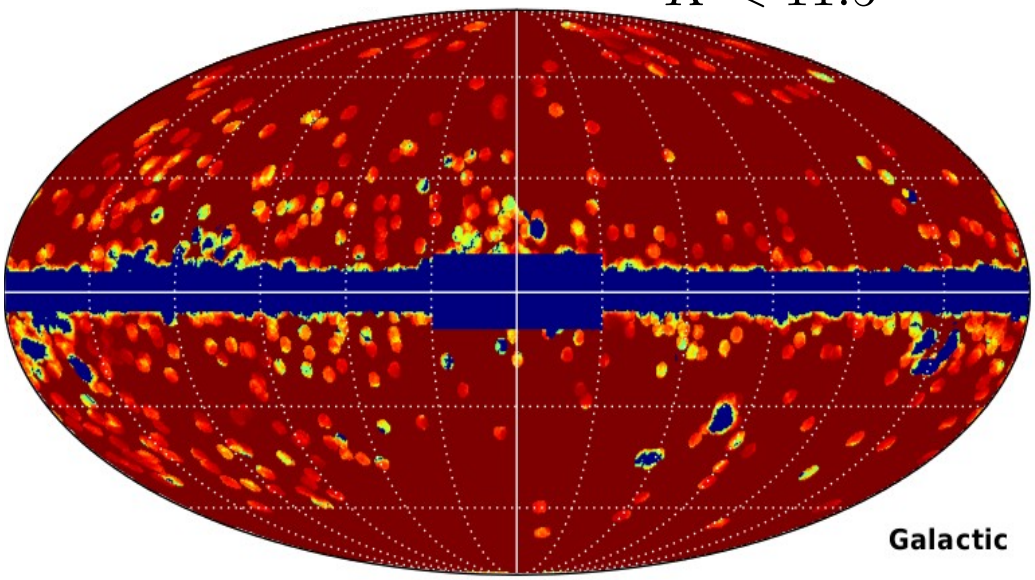


0 Mpc/h

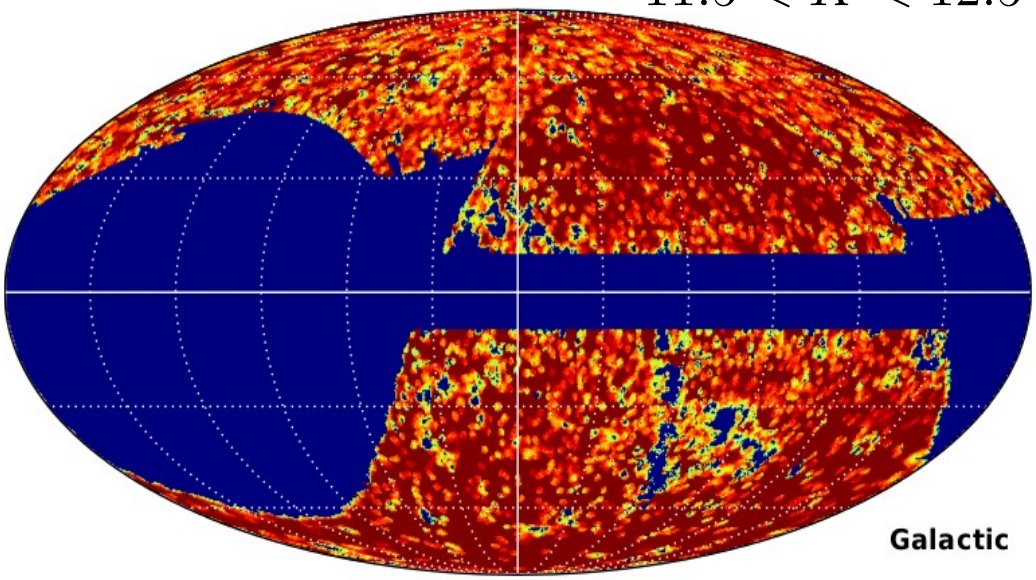
250 Mpc/h

Redshift completeness

$K < 11.5$



$11.5 < K < 12.5$

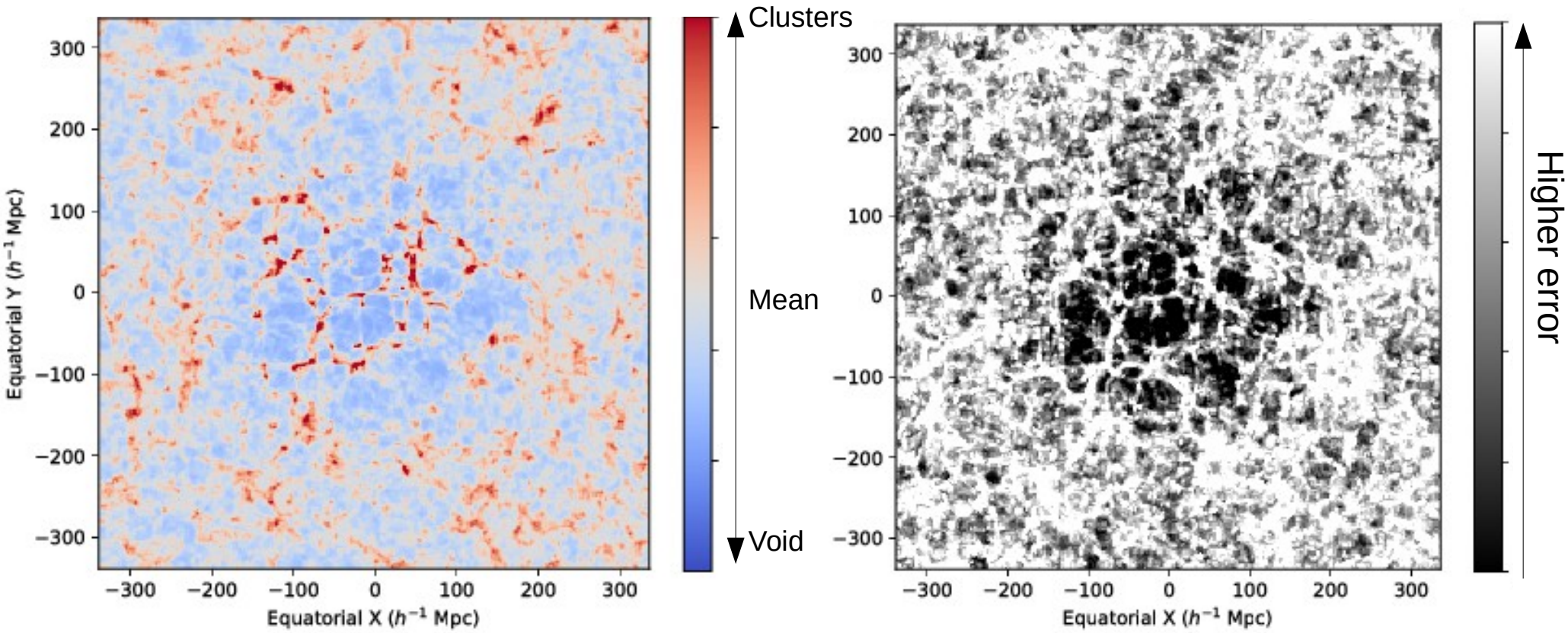


~70 000 galaxies

Lavaux & Hudson (MNRAS, 2011)

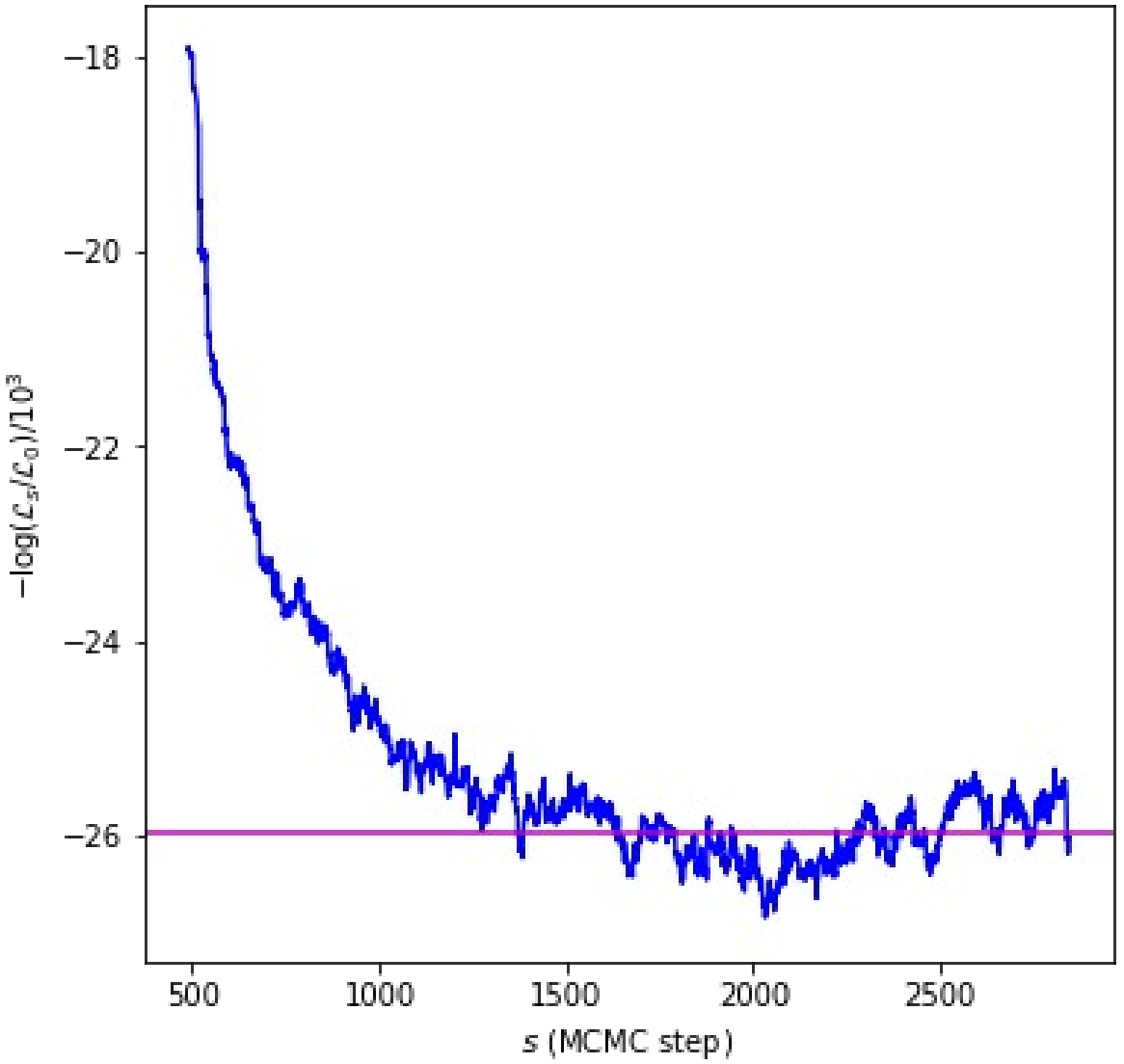
Inferred density fields

Ensemble average density fields at z=0



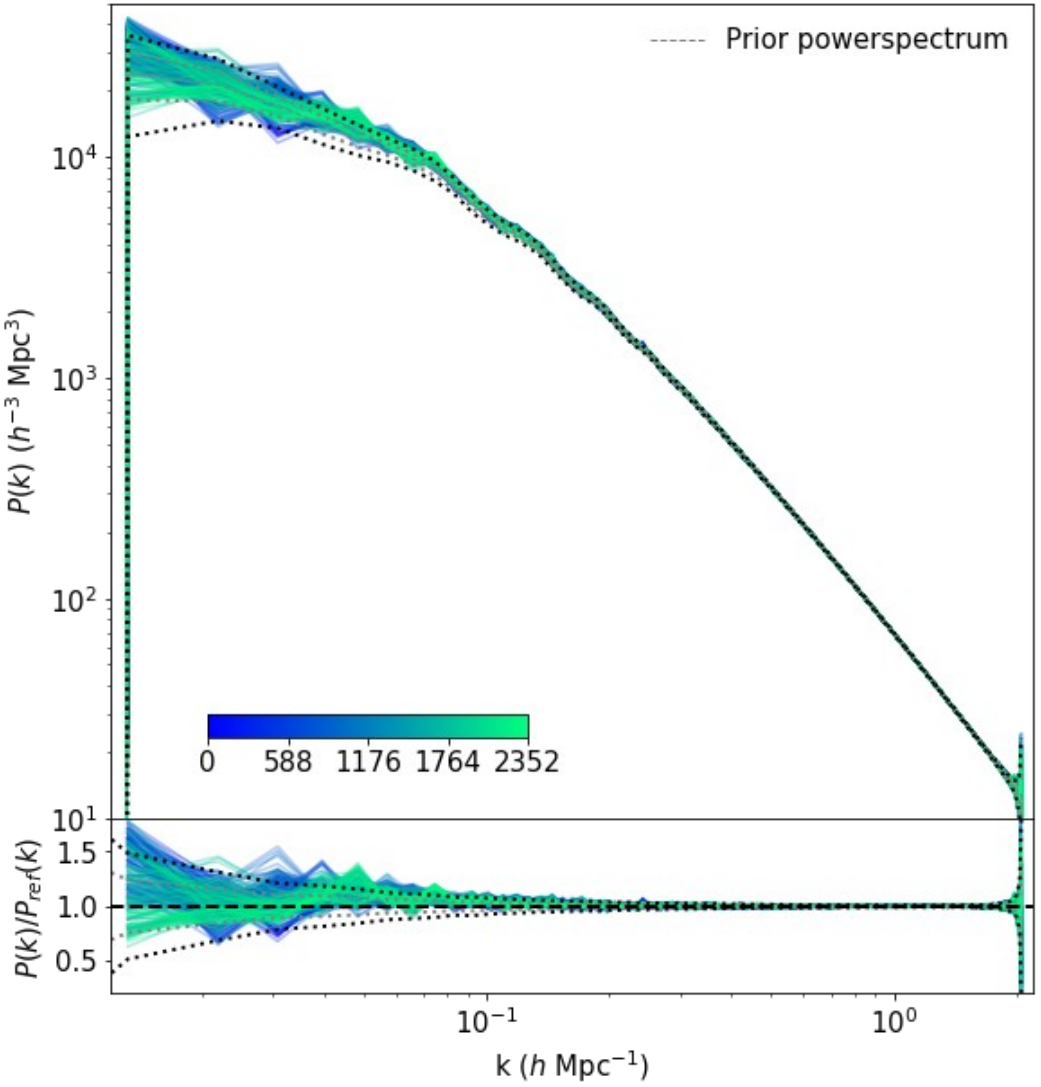
Jasche & Lavaux (2018, in prep.)

Performance aspect: burnin

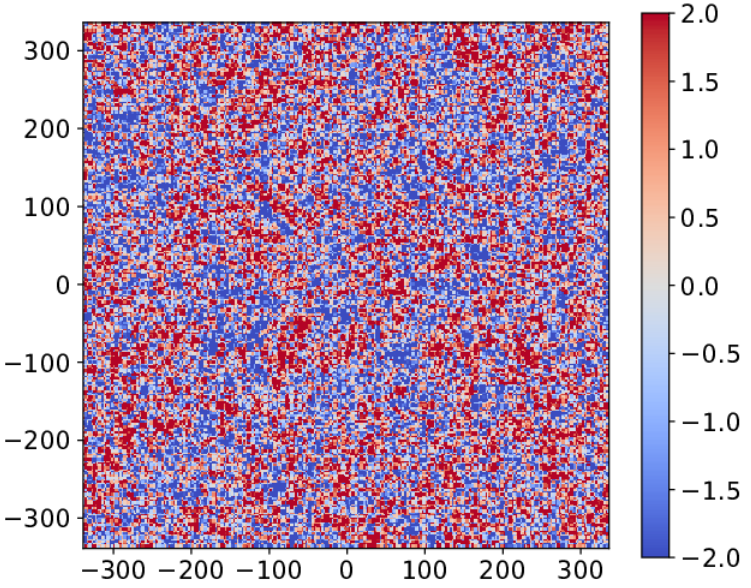


Jasche & Lavaux (2018, in prep.)

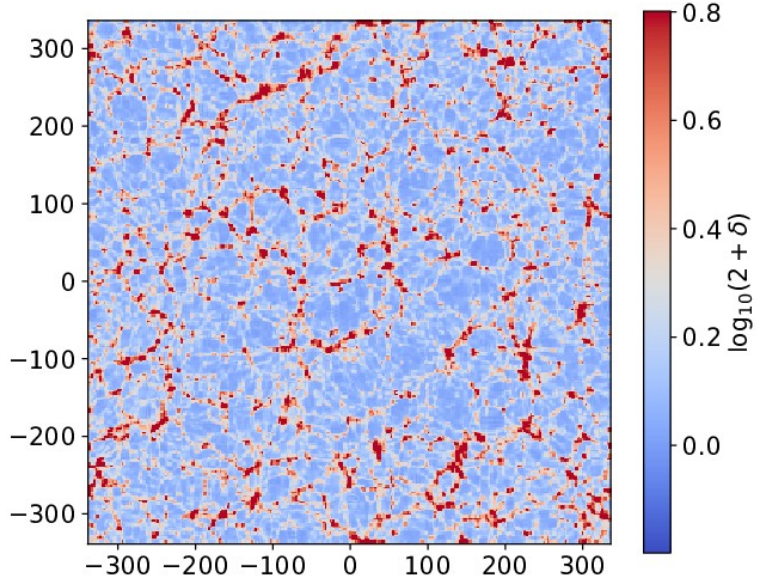
Initial condition powerspectrum



Initial conditions

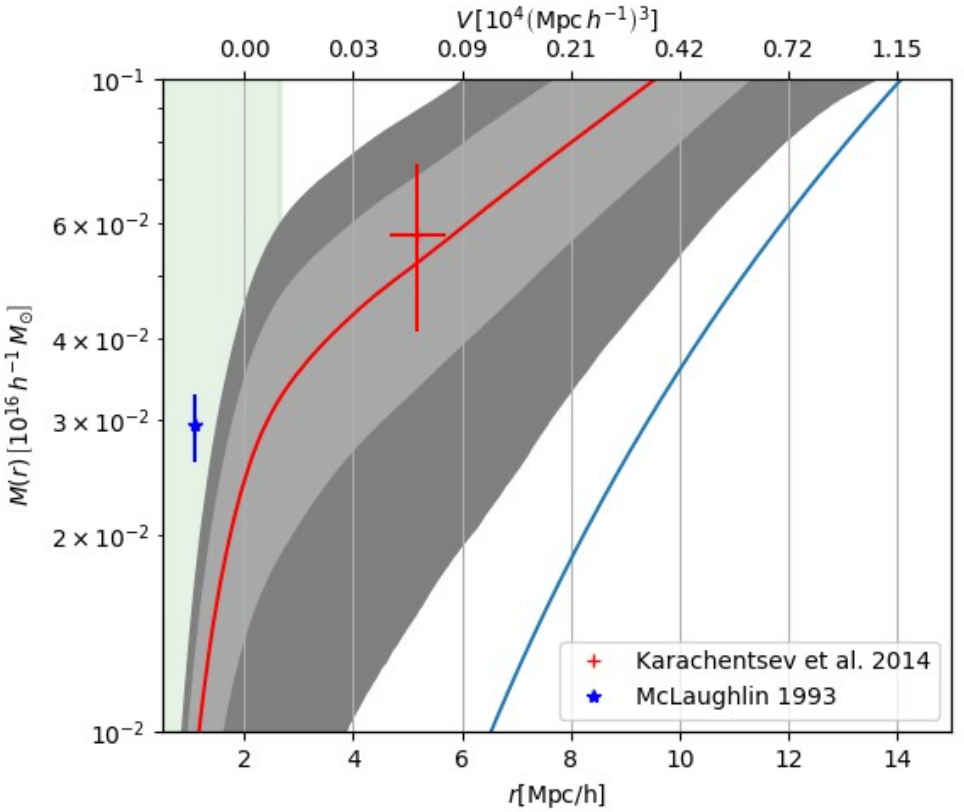


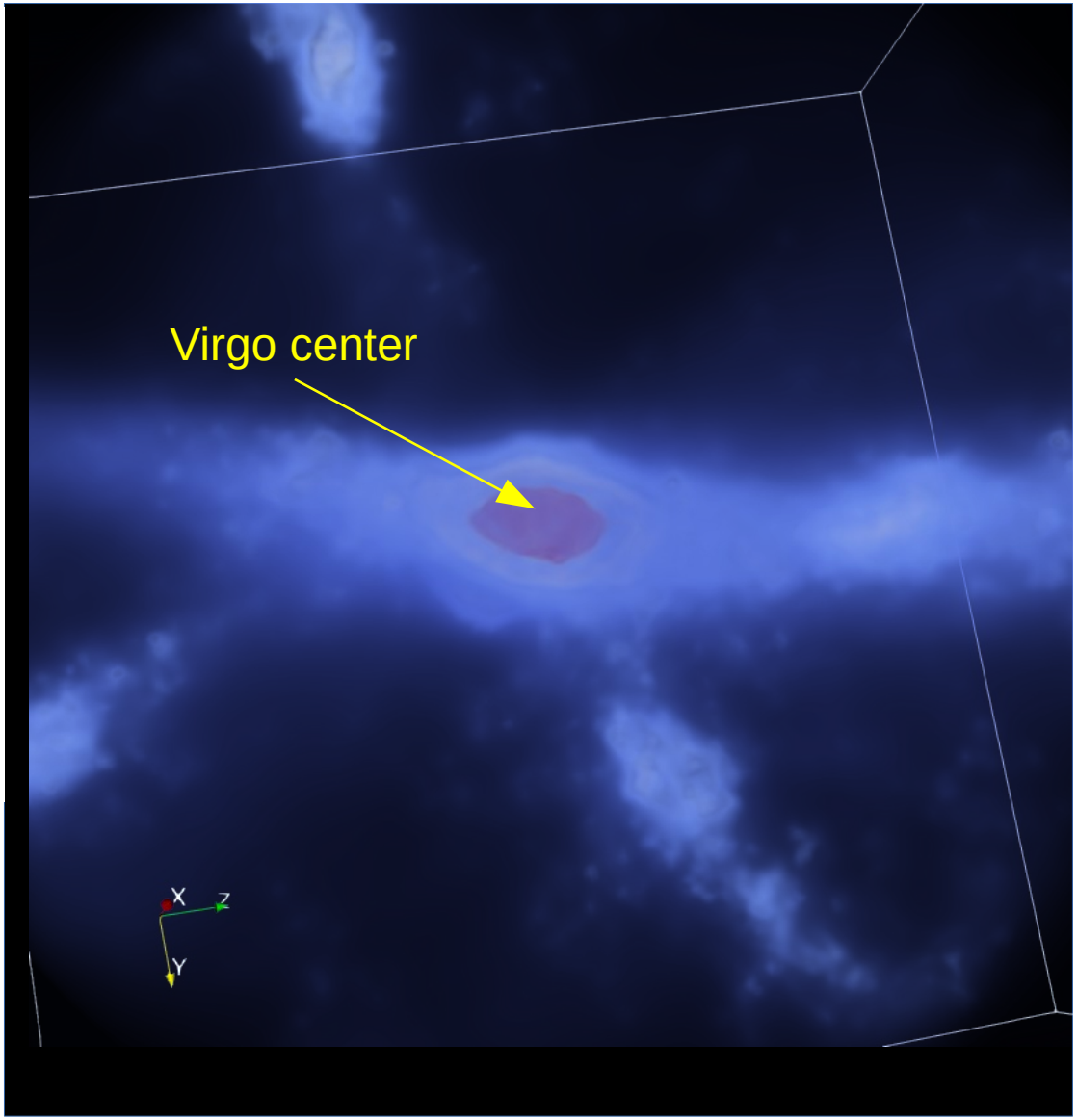
Post PM simulation



Jasche & Lavaux (2018, in prep.)

Virgo cluster



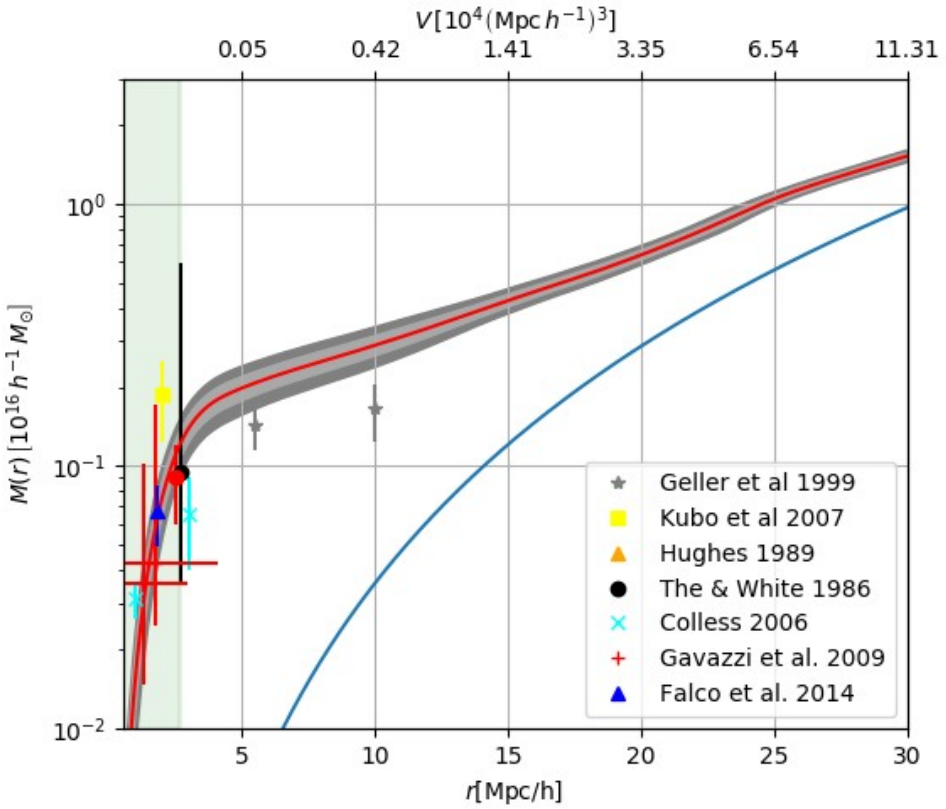


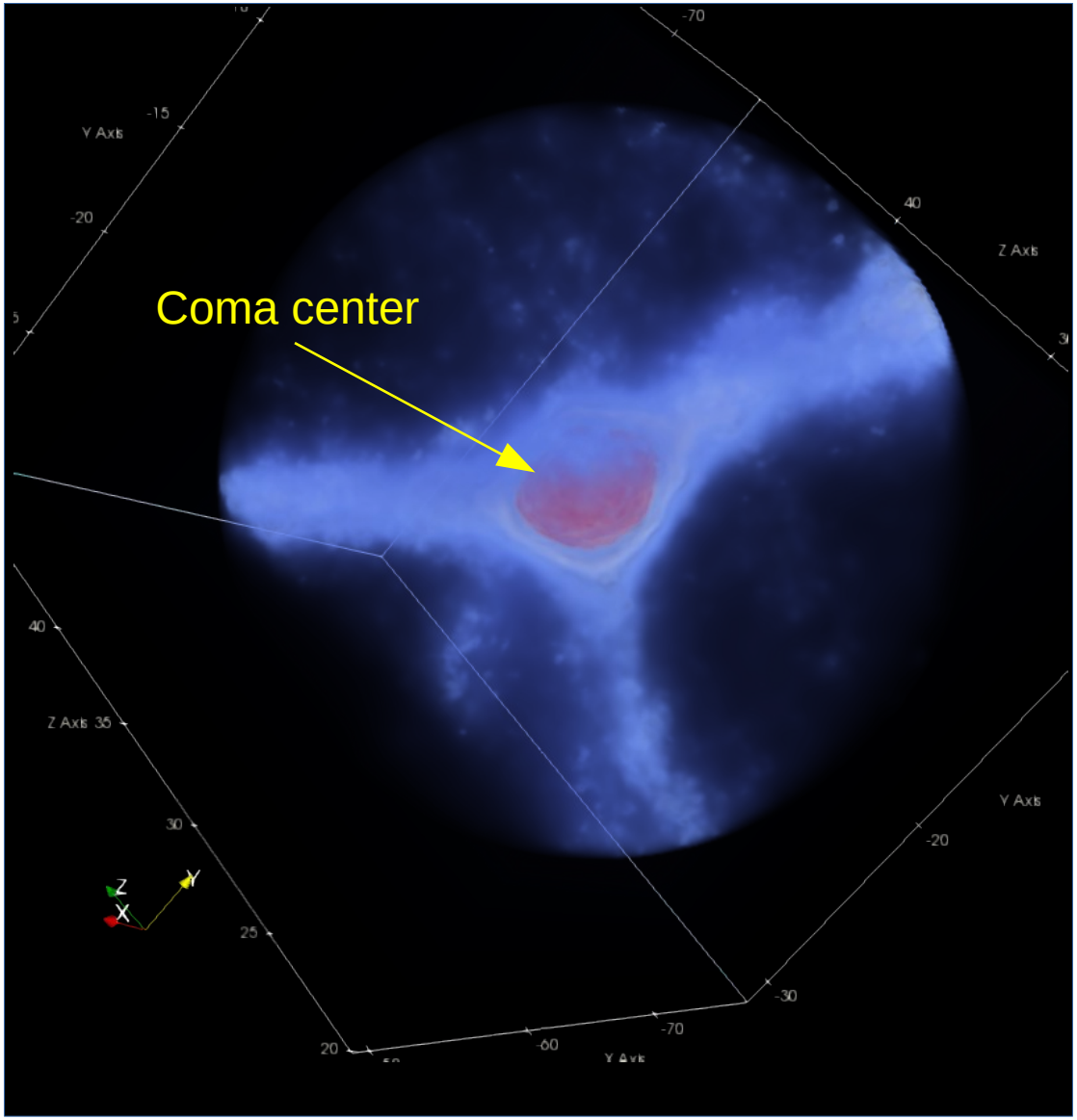
~30 Mpc/h

PLAY

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

Coma dynamical properties





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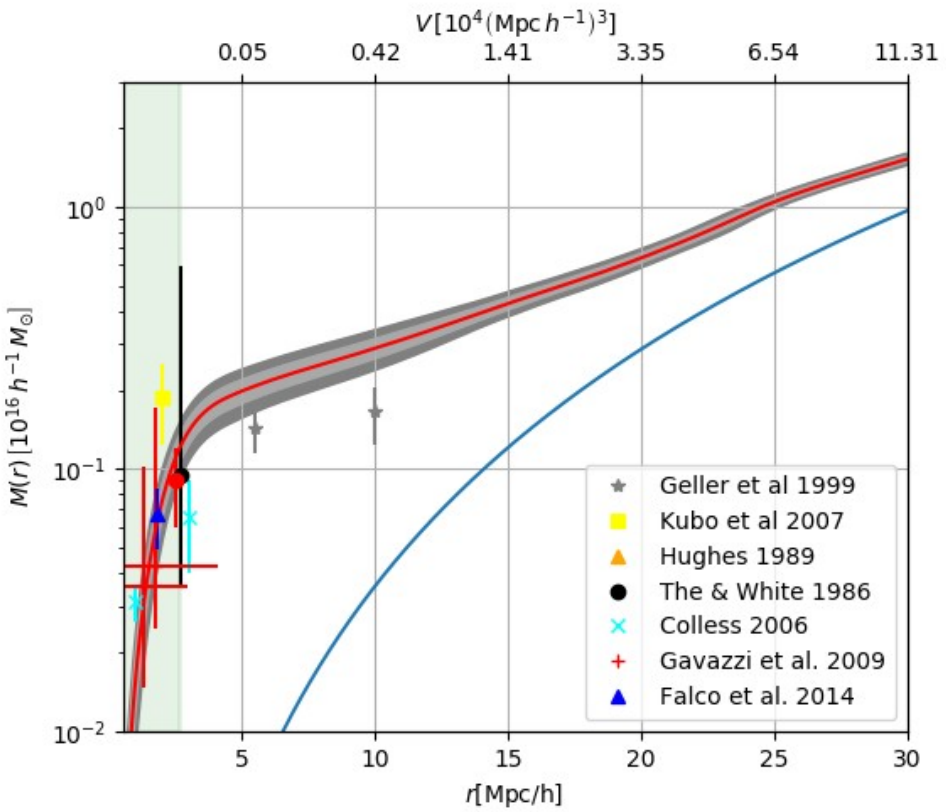
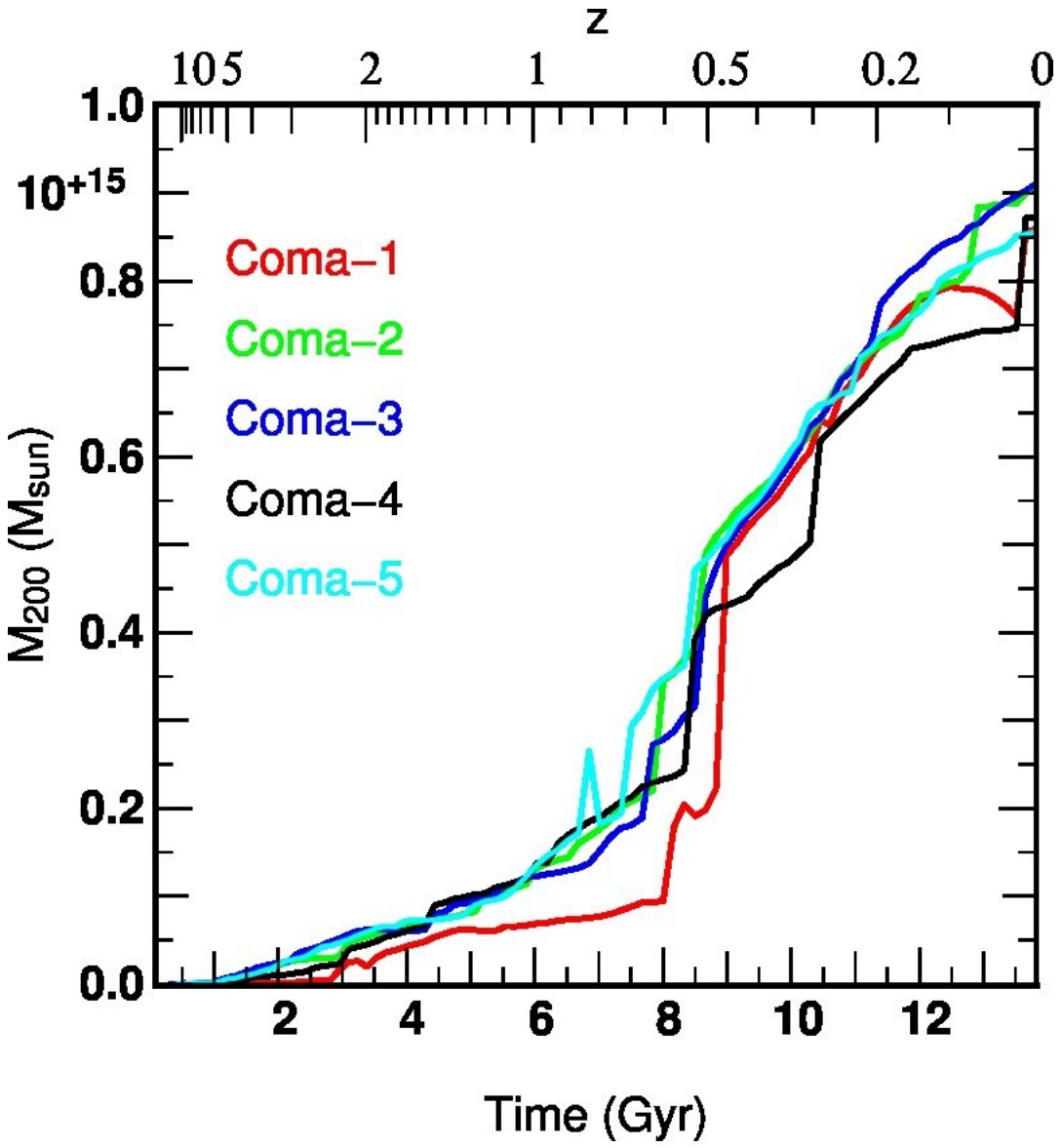




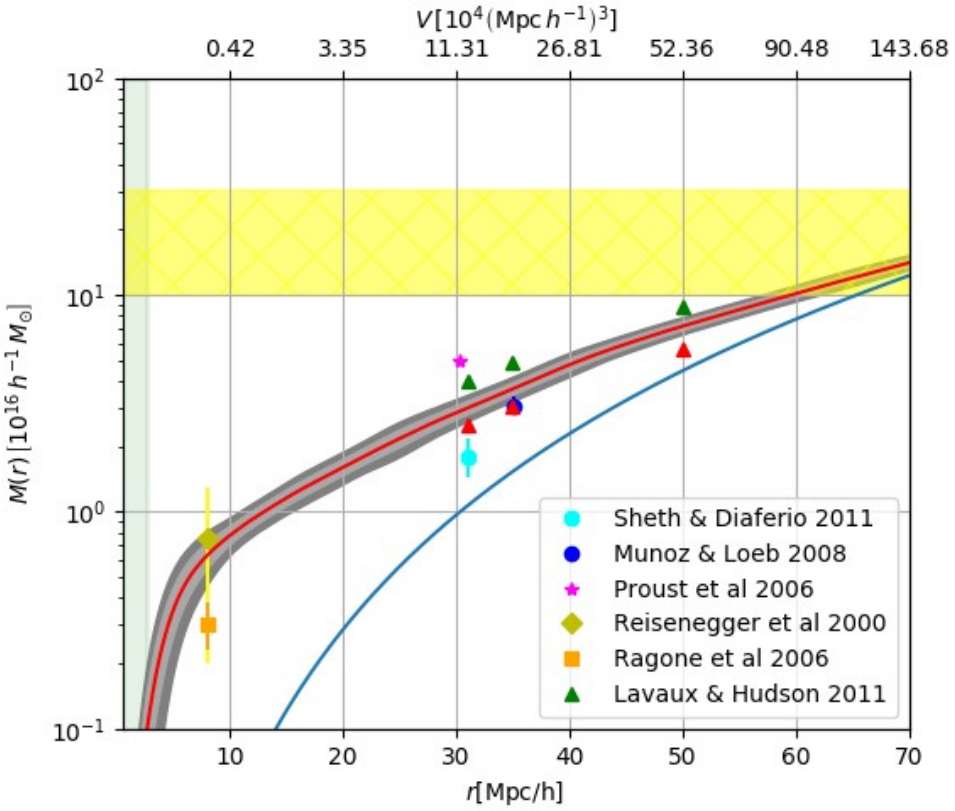
Zoom simulation on Coma
(~250 Mpart in zoom)

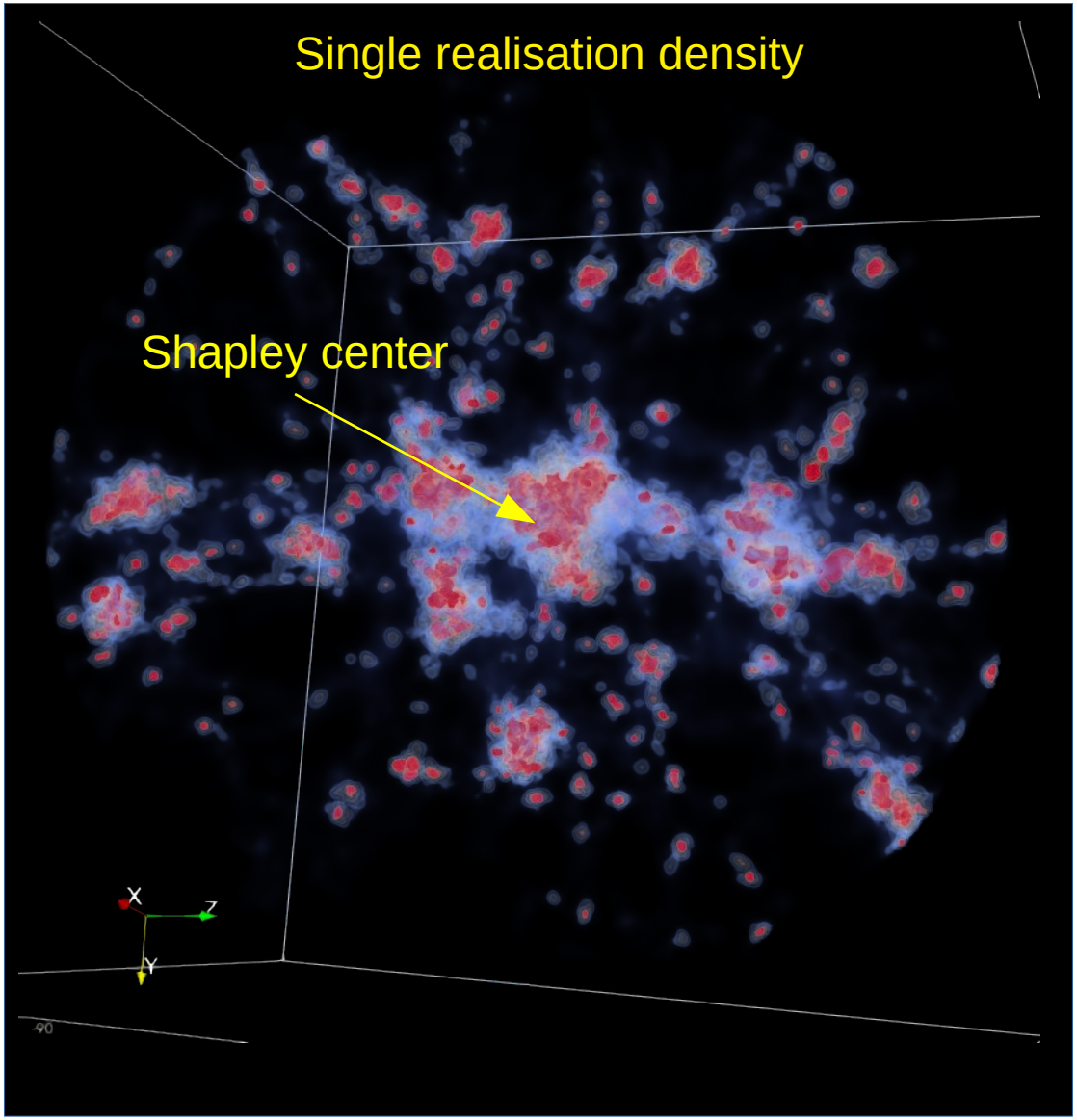
$$4 \times 10^7 h^{-1}\mathrm{M}_\odot/\mathrm{part}$$

PLAY

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

Shapley concentration





~60 Mpc/h

PLAY

Lavaux & Jasche (2018, in prep.)

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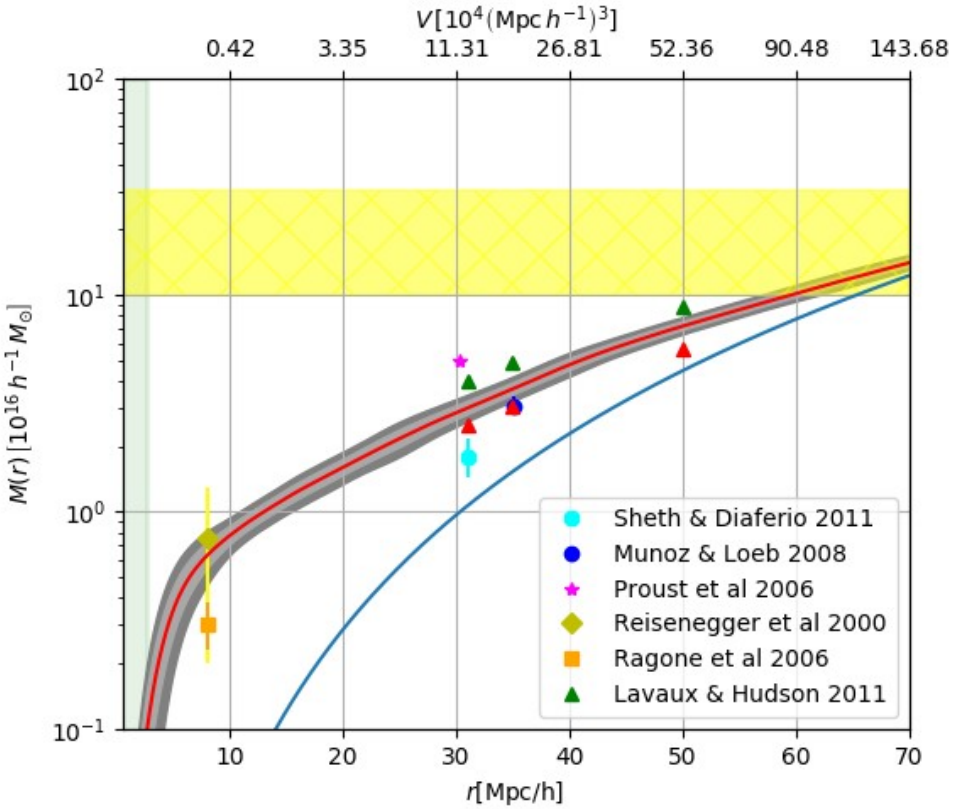

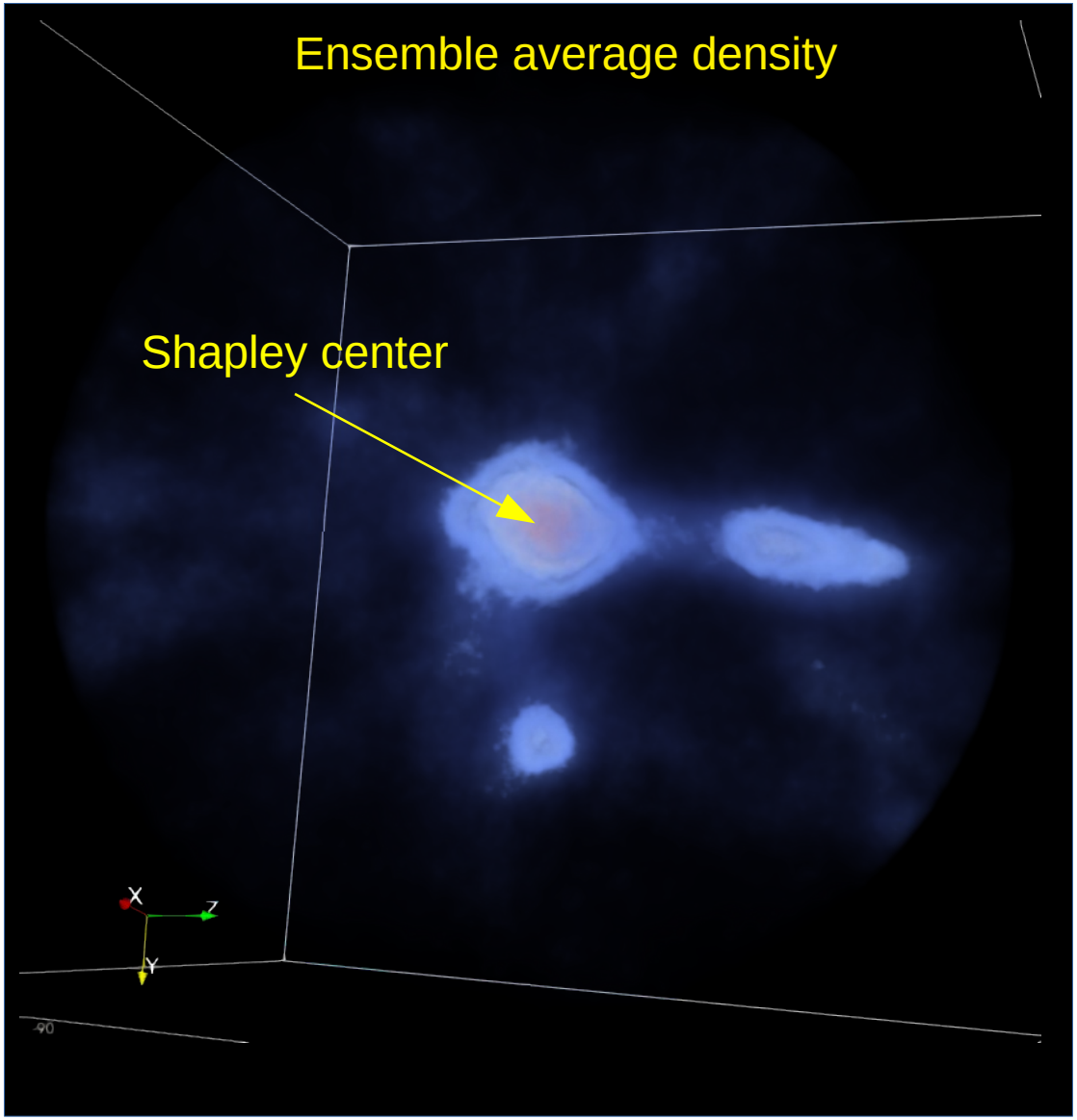

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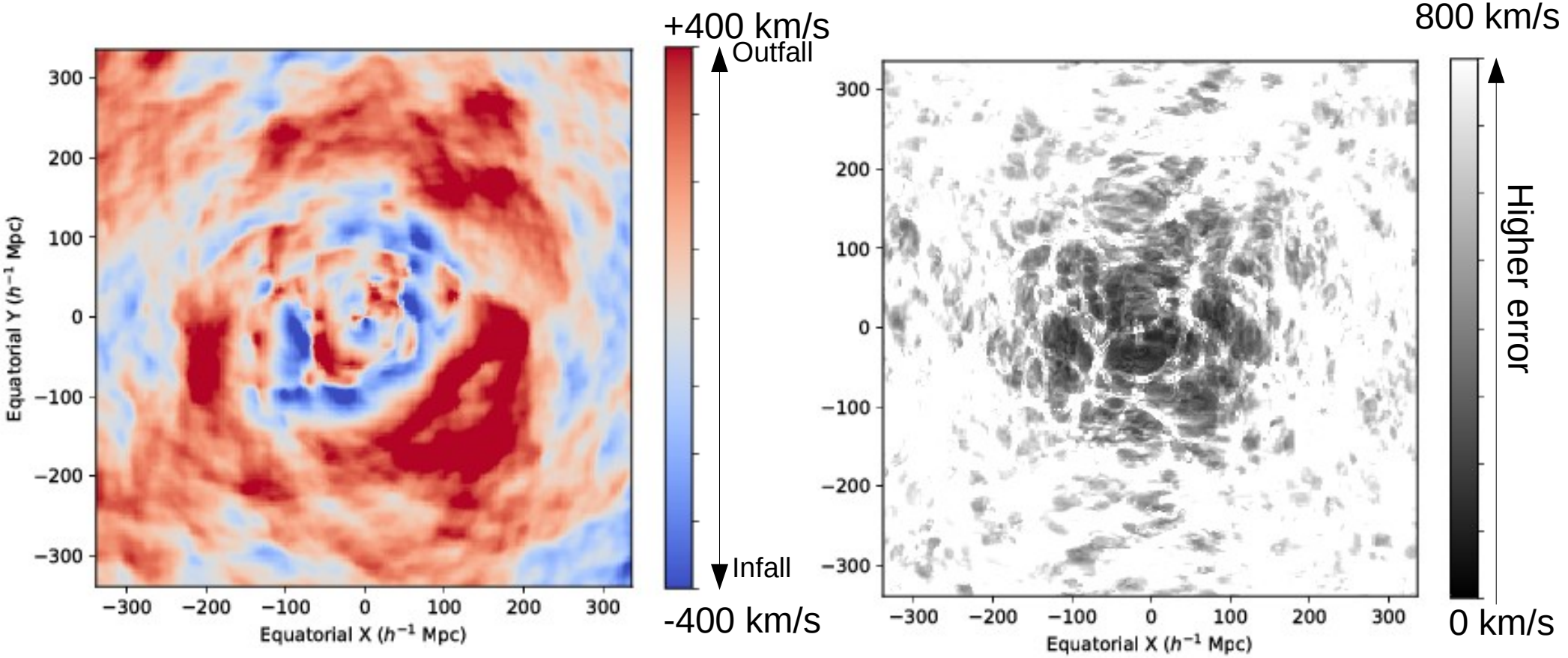
Lavaux & Jasche (2018, in prep.)

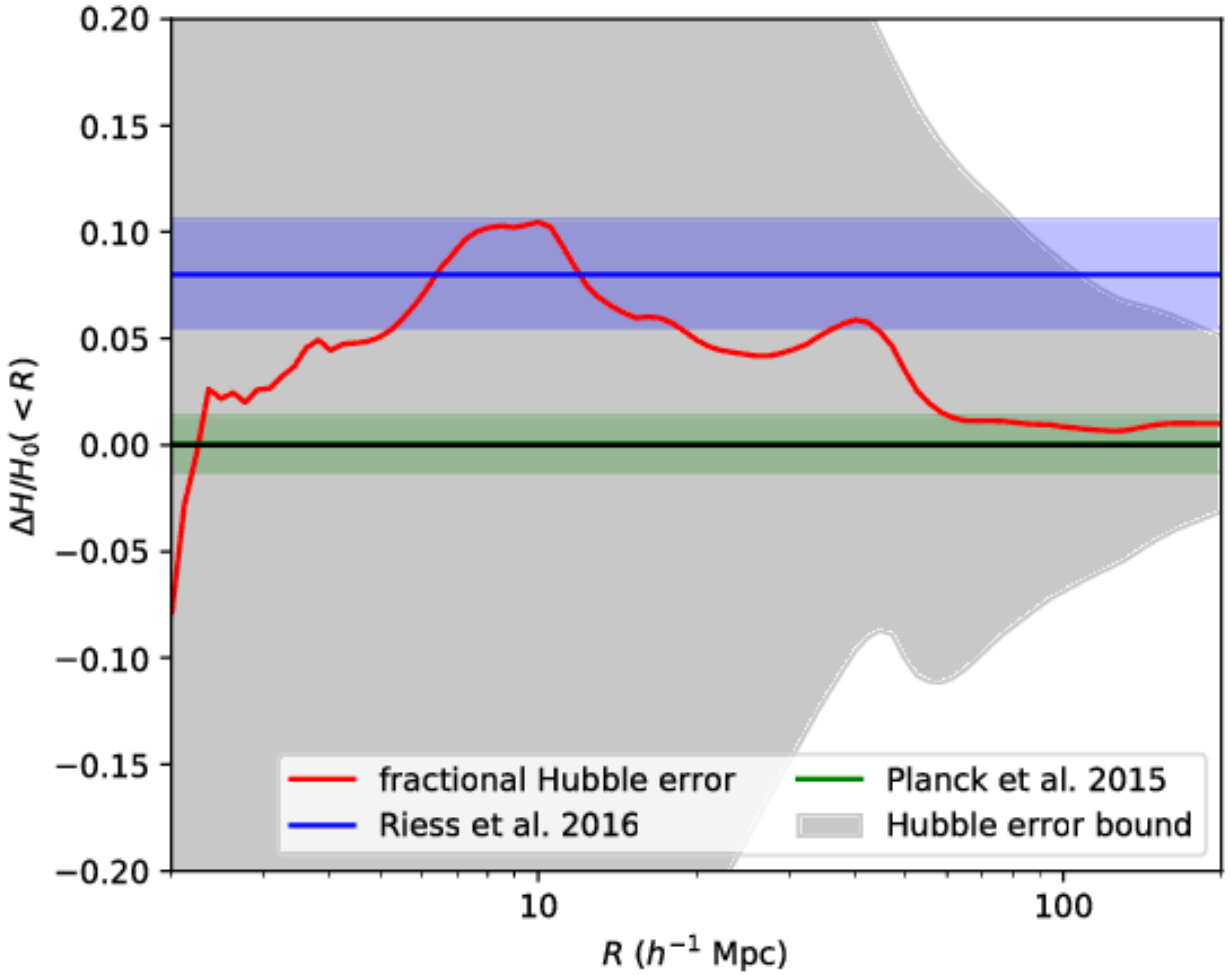
Inferred velocity fields



Jasche & Lavaux (2018, in prep.)

Velocity field and Hubble constant

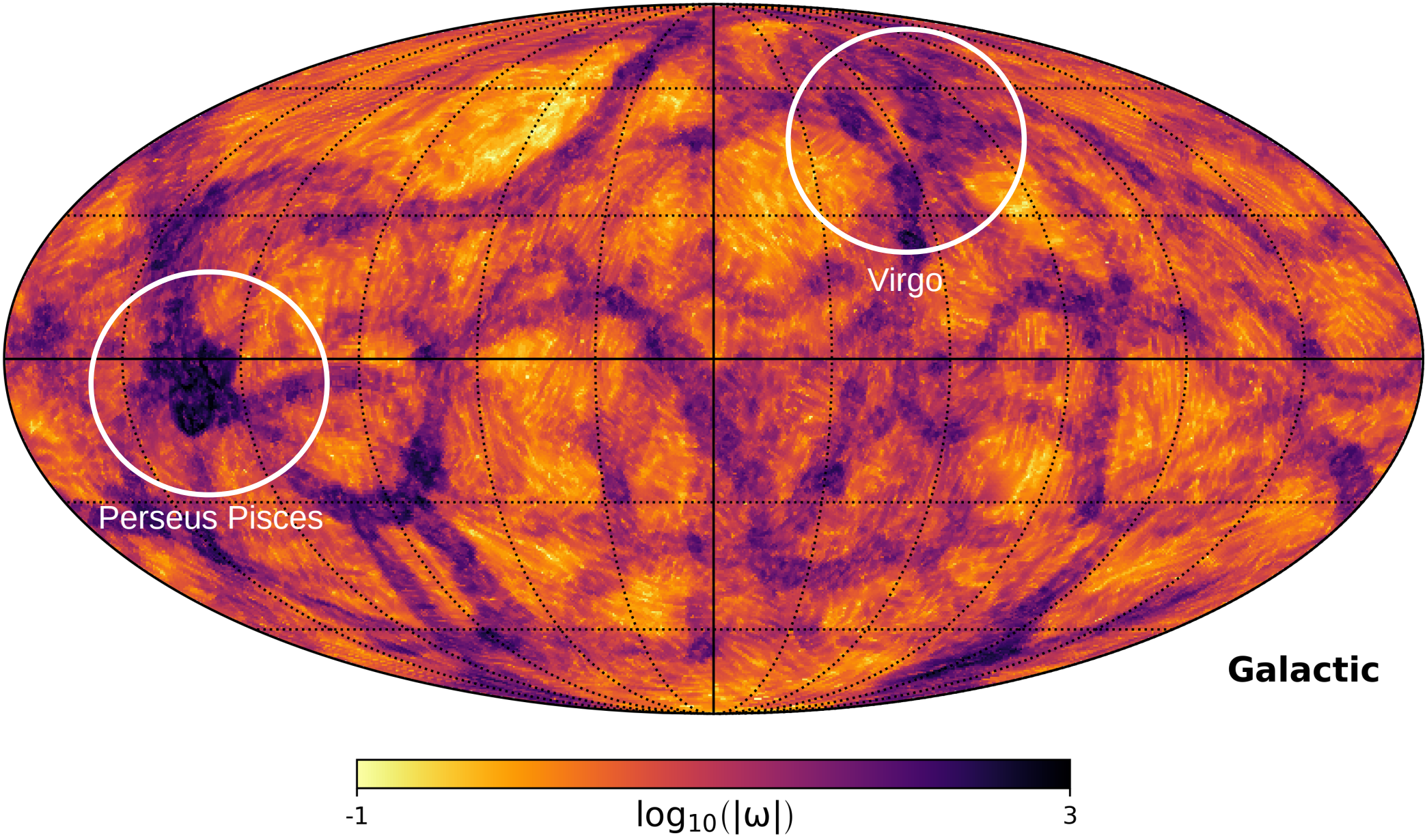
Mean error on Hubble measurement using tracers from observed large scale structures



TODO: Compare all the flow models

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

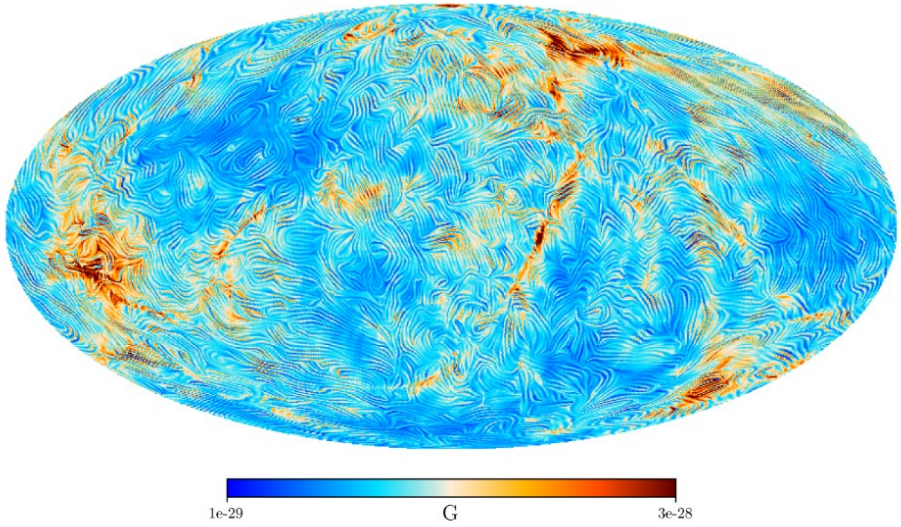
Peculiar velocity field vorticity



More applications

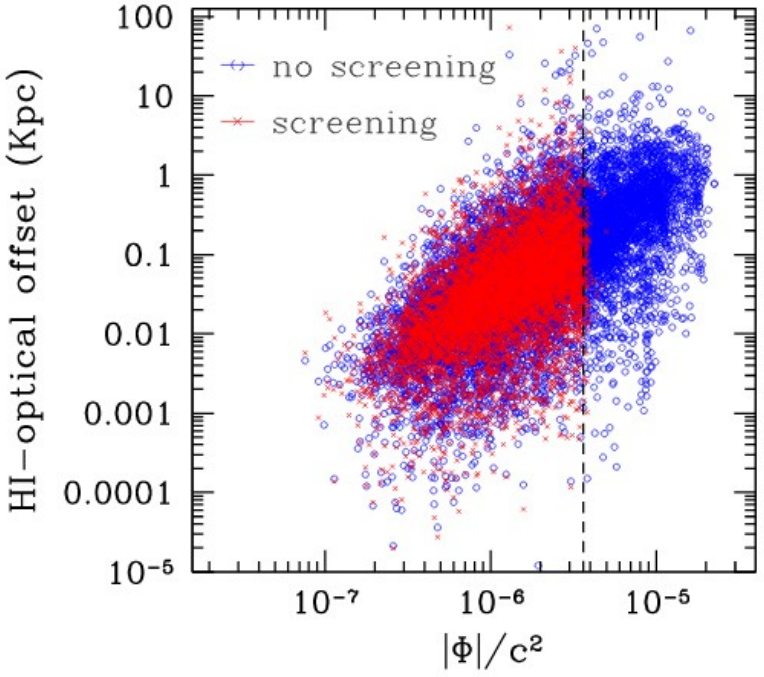
Magnetic field in our backyard generated by primordial mechanisms

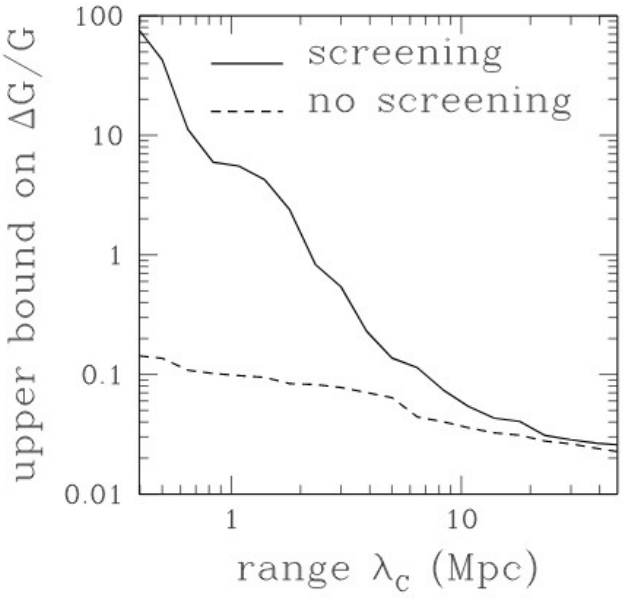
Hutschenreuter et al. (2018, CQG)

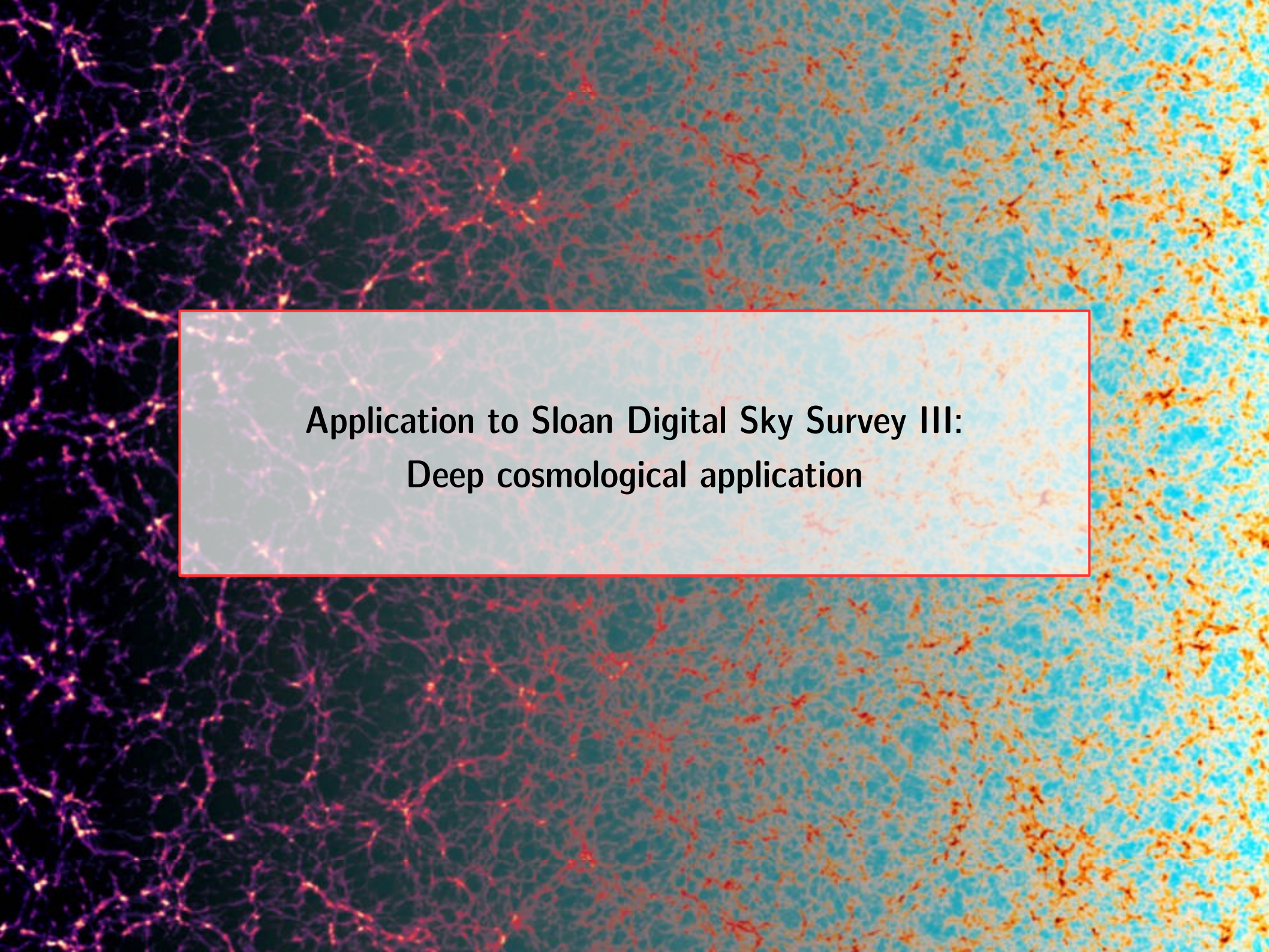


"Fifth-force" constraints

Desmond et al. (2018ab, PRD, PRL in review)

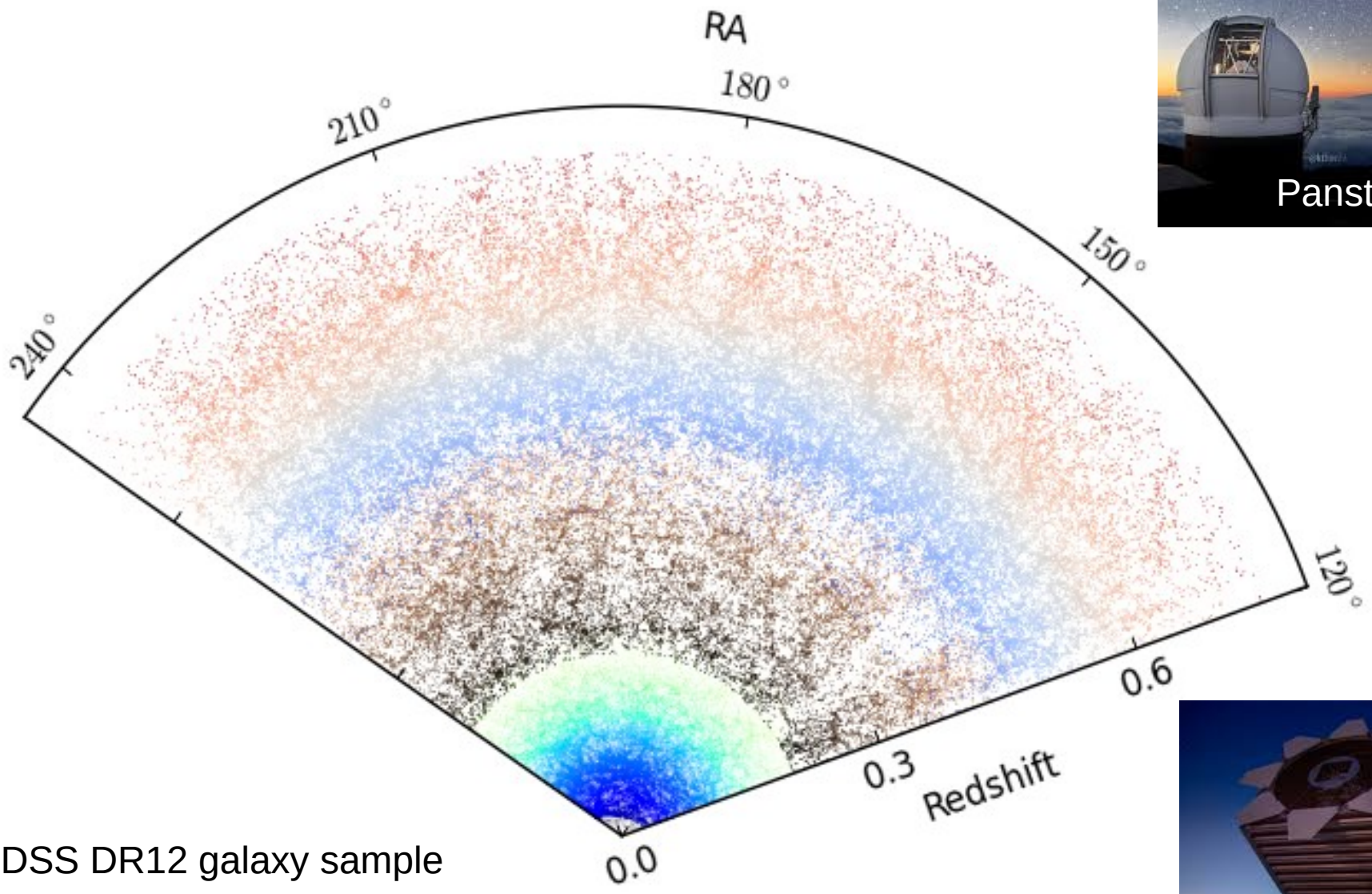






Application to Sloan Digital Sky Survey III: Deep cosmological application

SDSS3 data



SDSS DR12 galaxy sample

~1.6 millions of galaxies

Forward model becomes more complex

Cosmic expansion

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

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

→ Usual Hubble expansion at linear order

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

Cosmic growth of structures

Implemented so far for (2)LPT:

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

→ Evolving density contrasts

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

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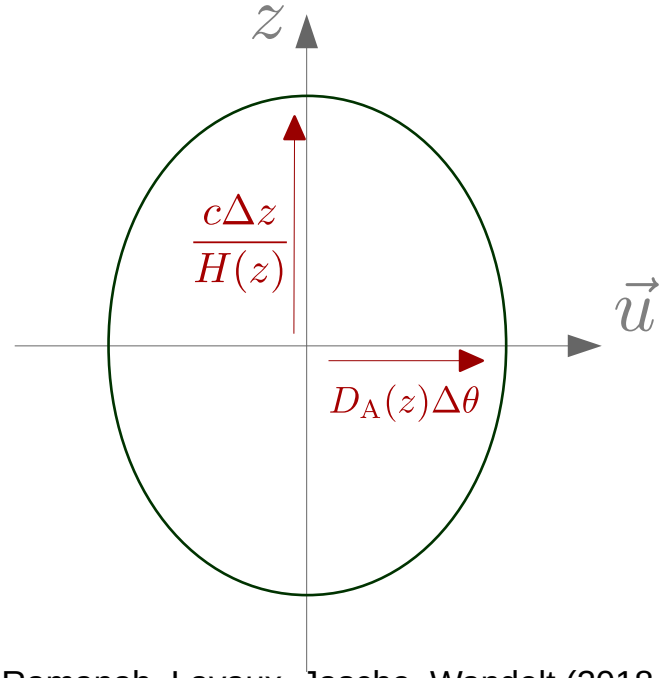
Do the ultimate Alcock-Pasczynski test!



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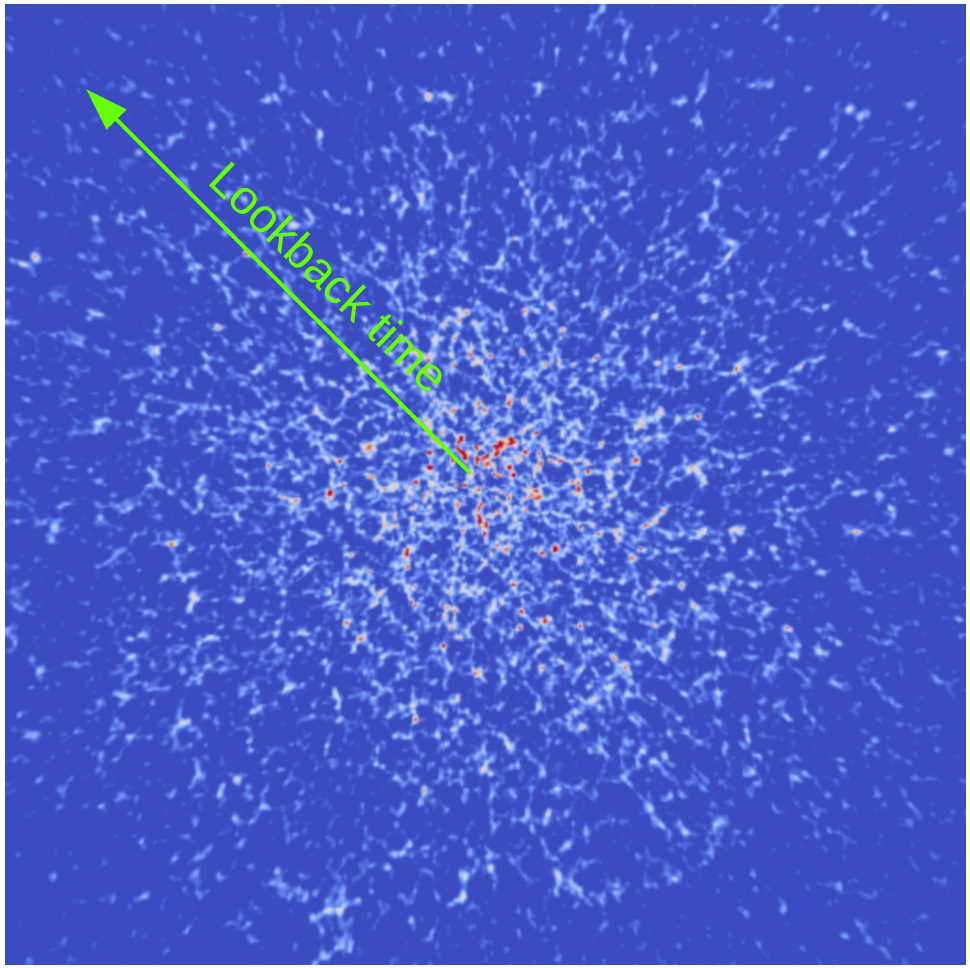

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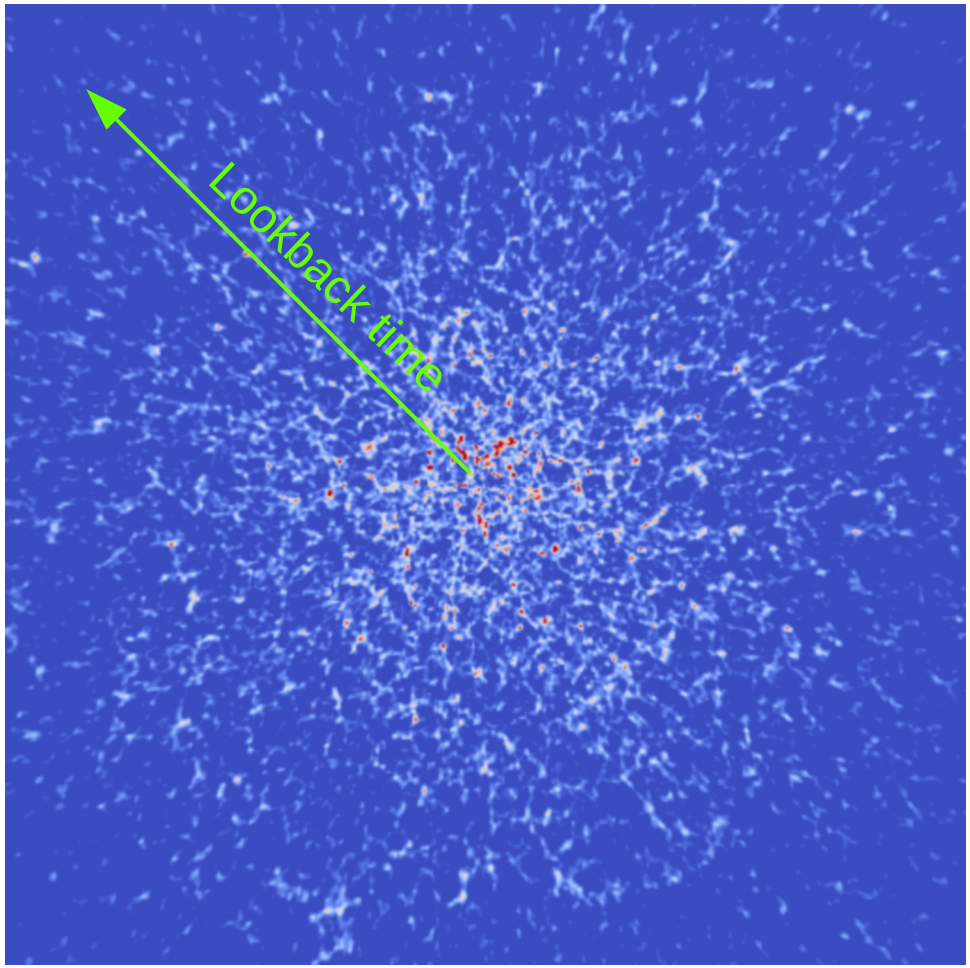

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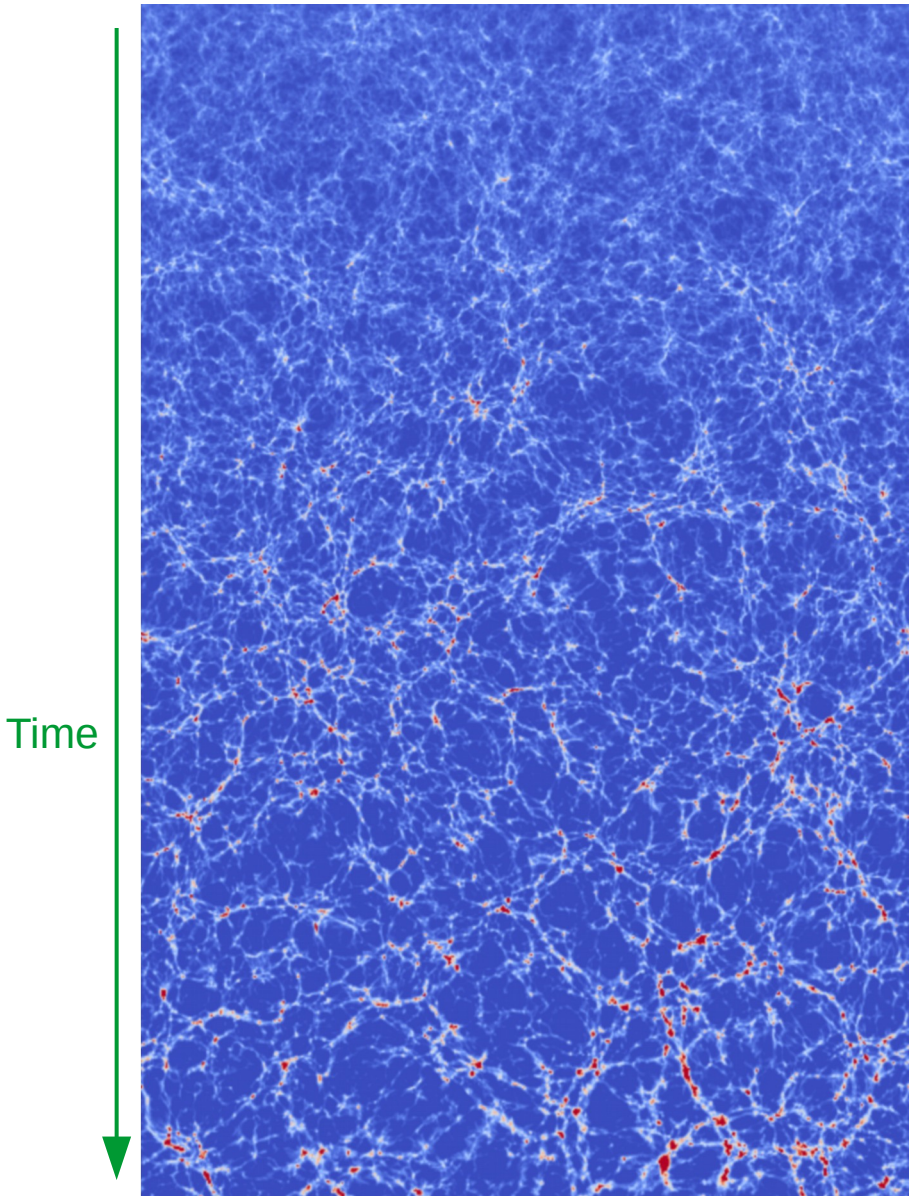
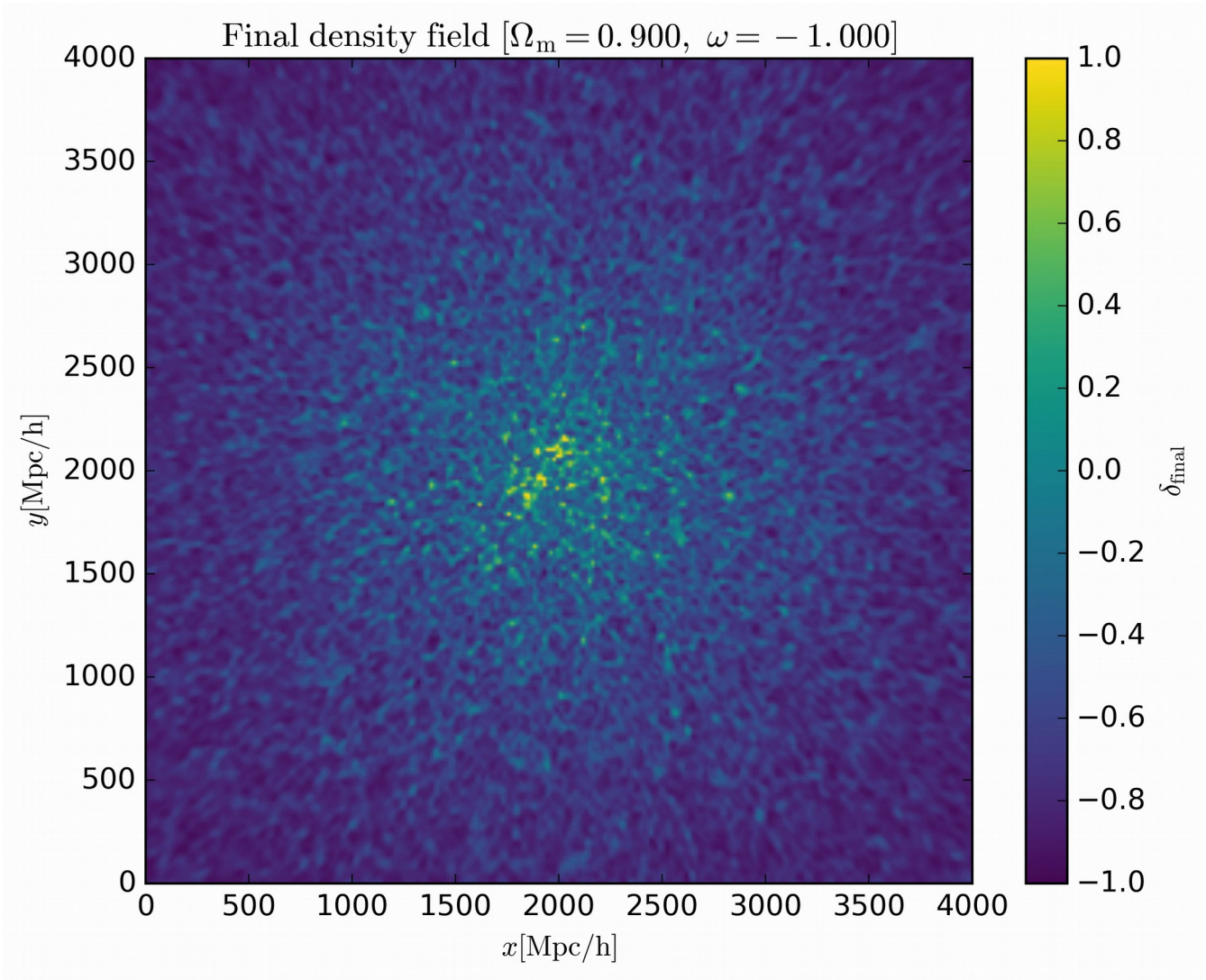
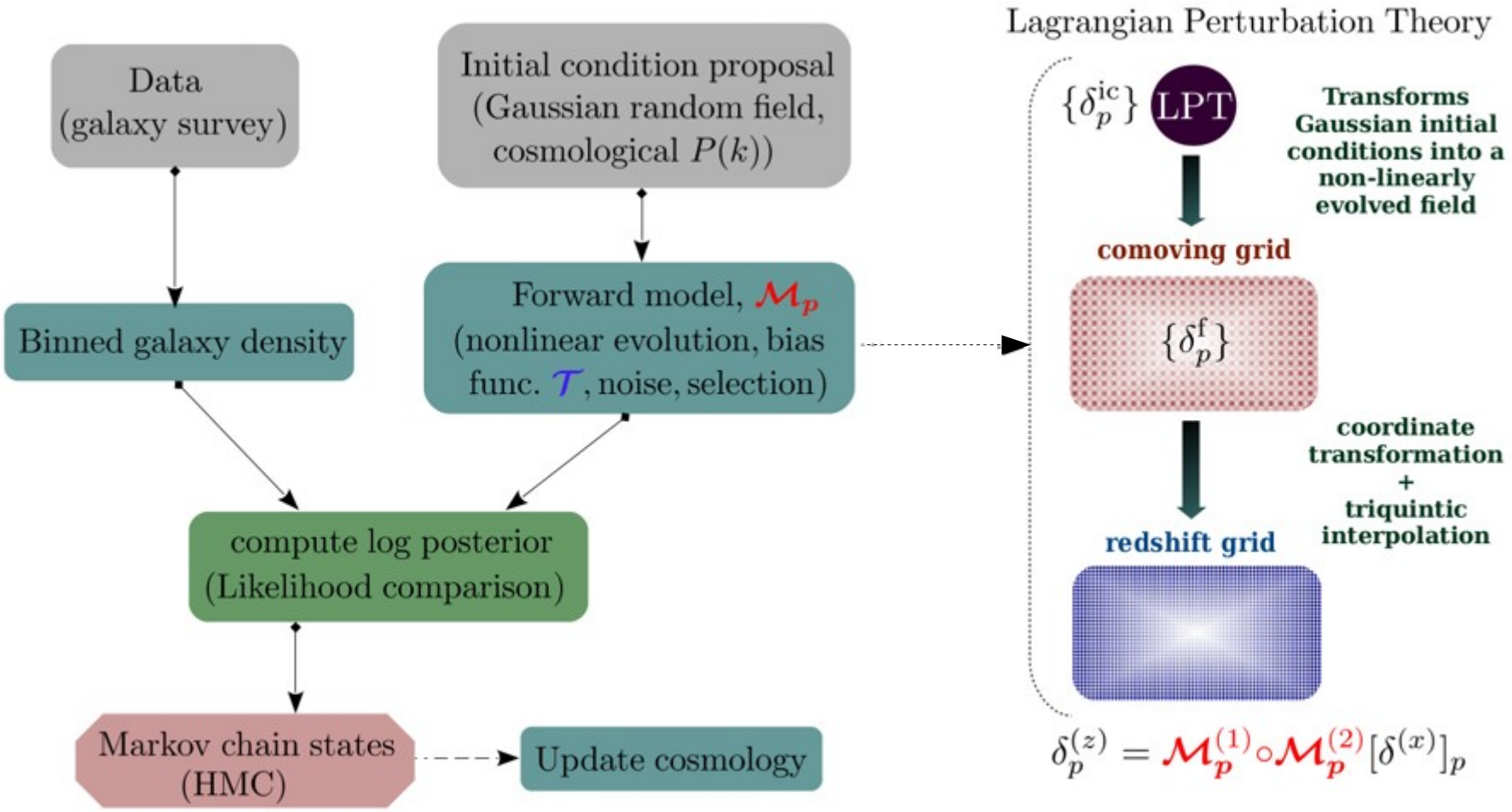


Kodi Ramanah, Lavaux, Jasche, Wandelt (2018, in prep.)

Impact of parameters on expansion



An updated scheme: more coordinates transform



Data model: $N_p^g = R(z_p)\bar{N}_p^g \mathcal{T}\left(1 + \mathcal{M}_p\{[\hat{\delta}_k]_{\tilde{p}}\}_p\right)$

Courtesy Doogesh Kodi Ramanah (Kodi Ramanah et al. 2018, in prep.)

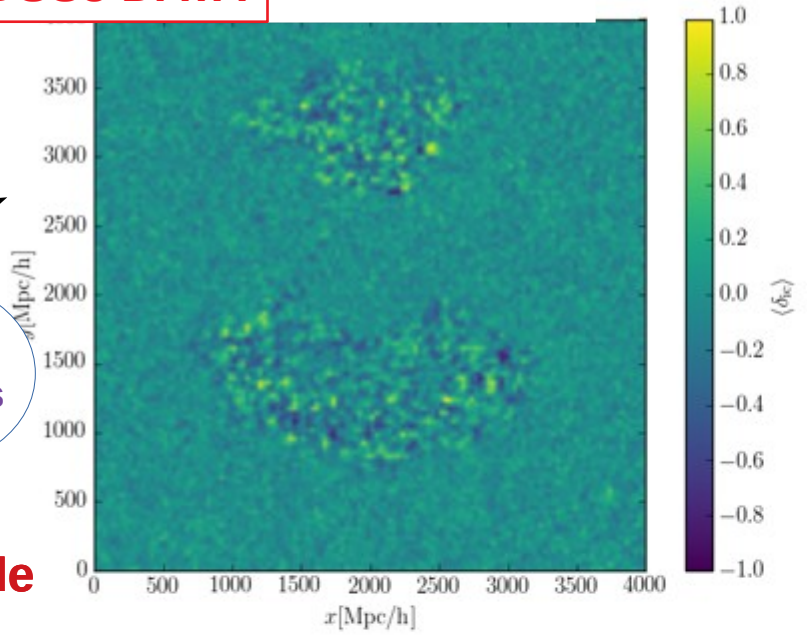
Inference with a freed light cone

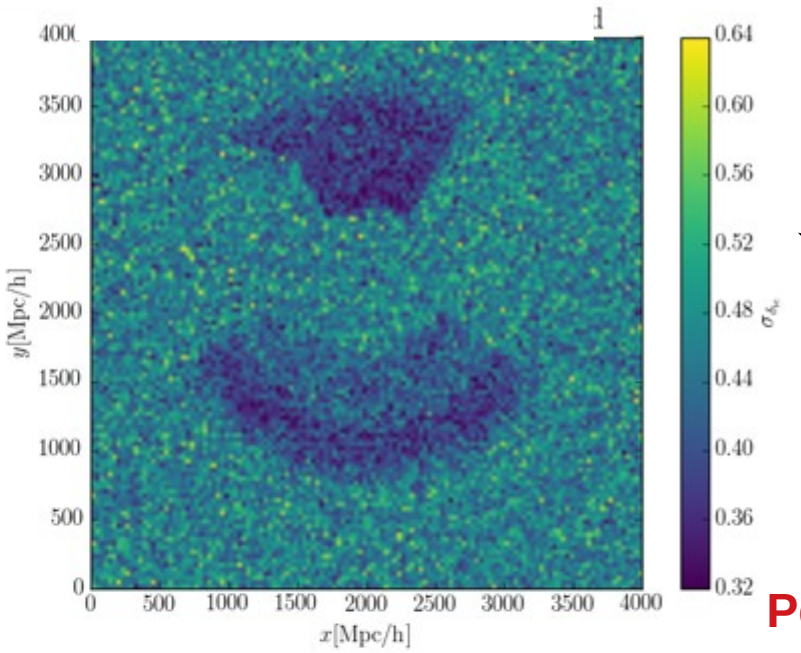
MOCK SDSS3 DATA

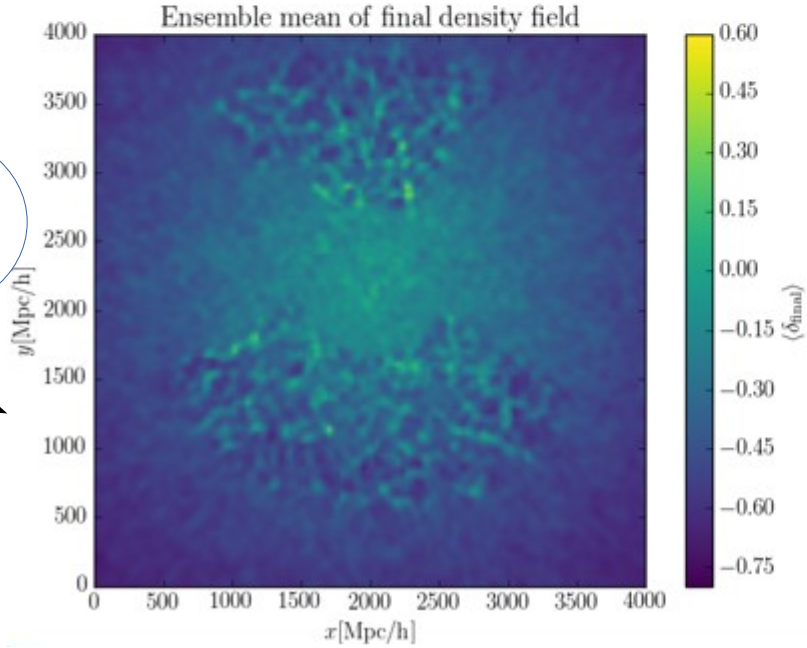
Initial conditions

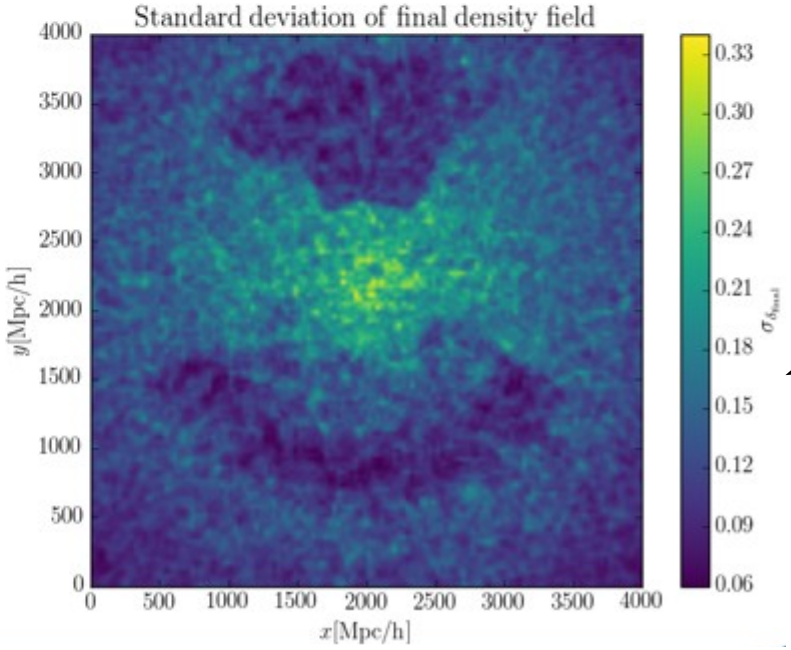
Ensemble mean density

Final conditions



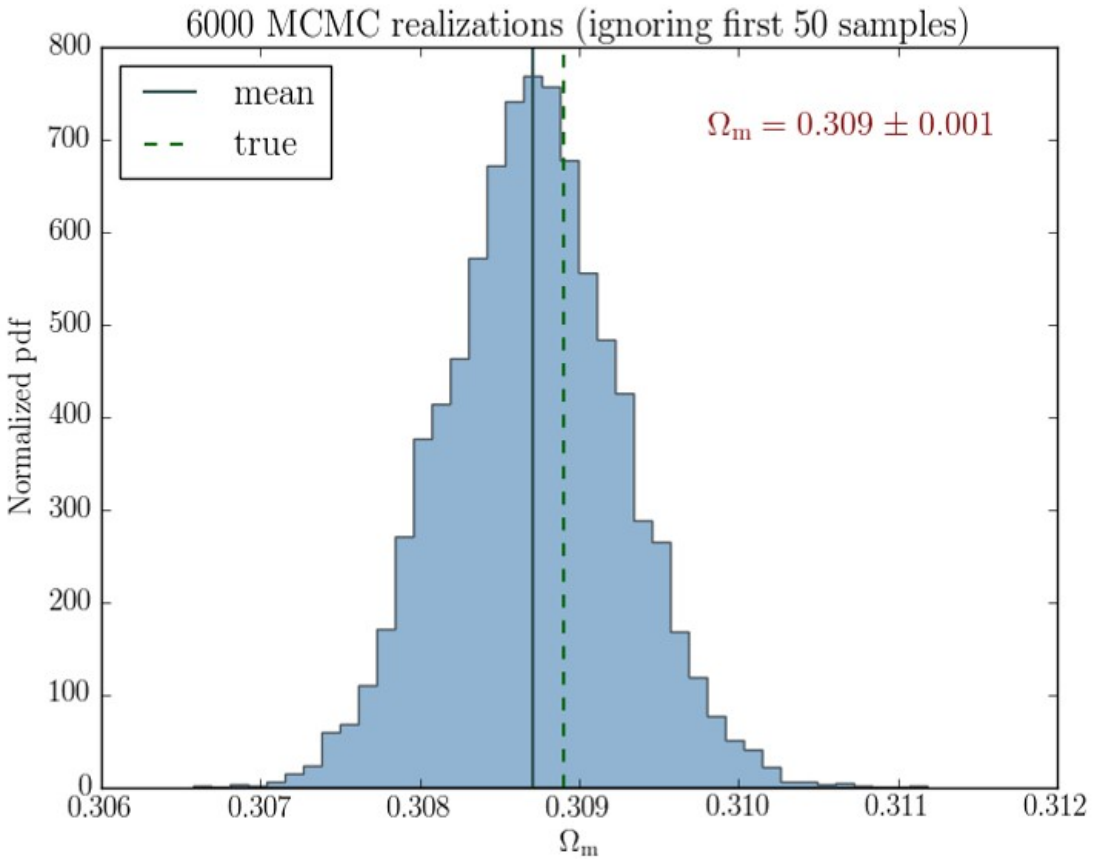






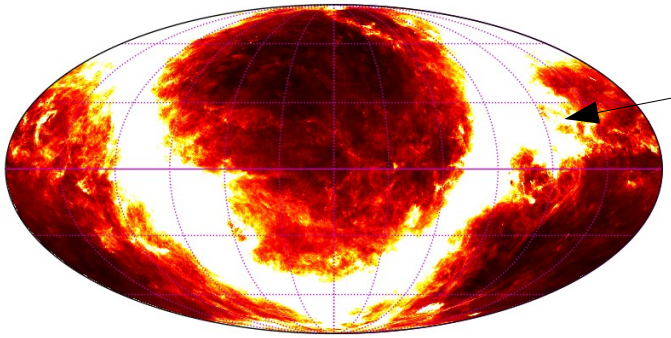
Per voxel error

Ultimate A/P: contraints on mean density



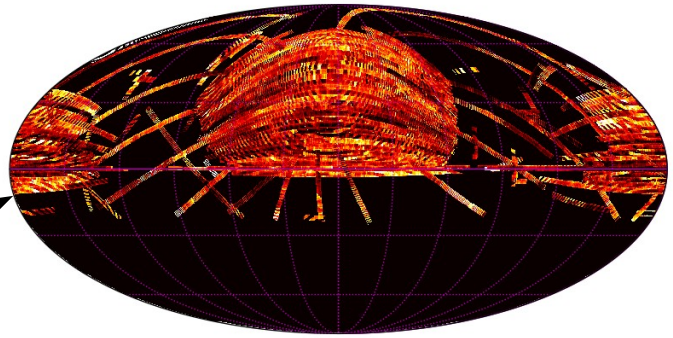
… and systematic cleaning…

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

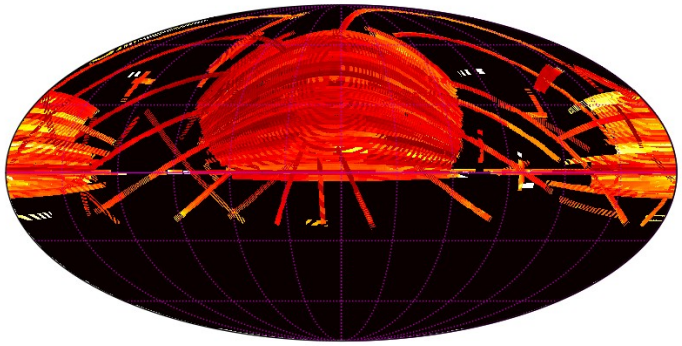


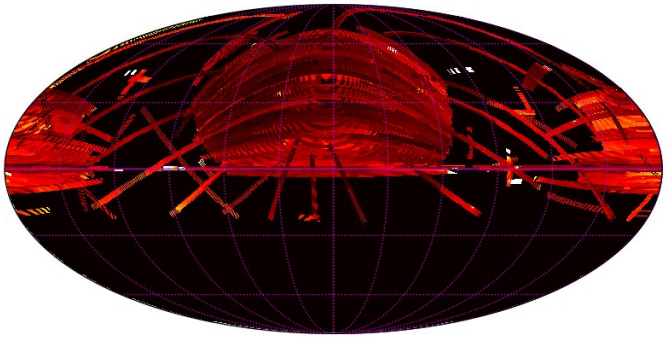
DUST

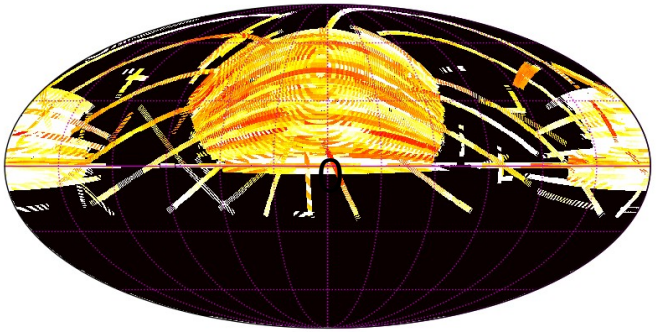
psfWidth



Sky fluxes

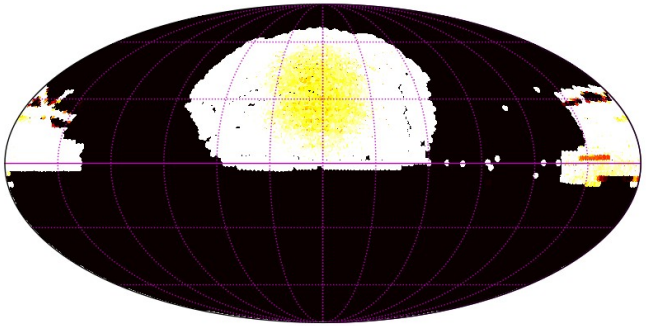


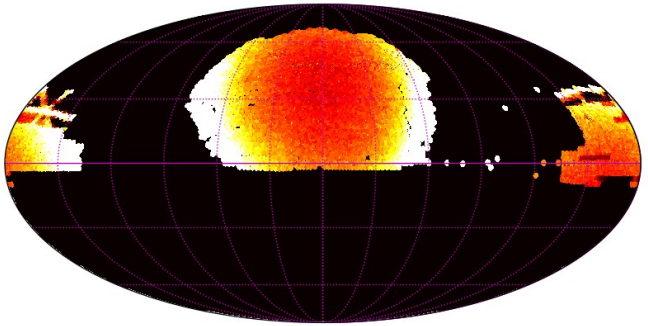


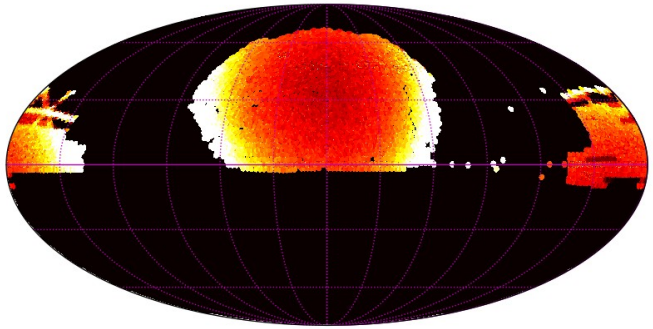


…

Star densities



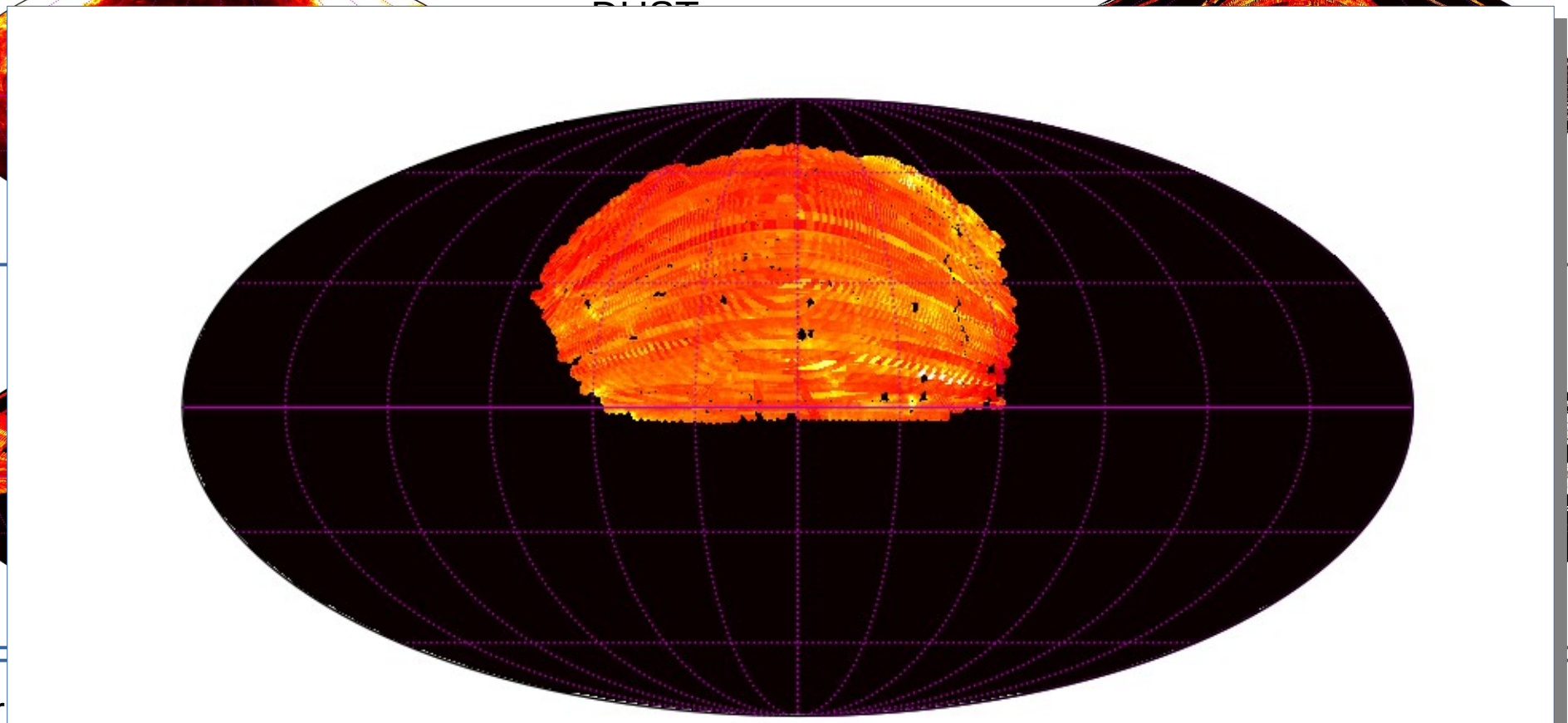




…

Example fitted composite...

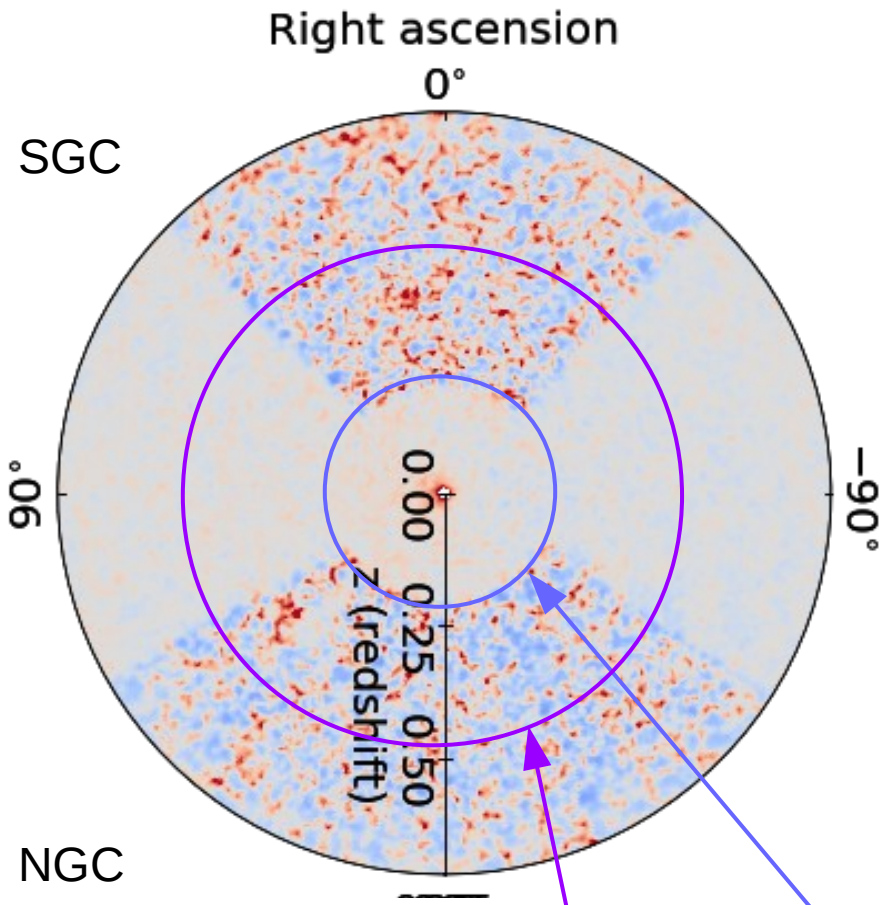
11 foregrounds (here only 8)… still much less than Leistedt & Peiris (2014) but improving



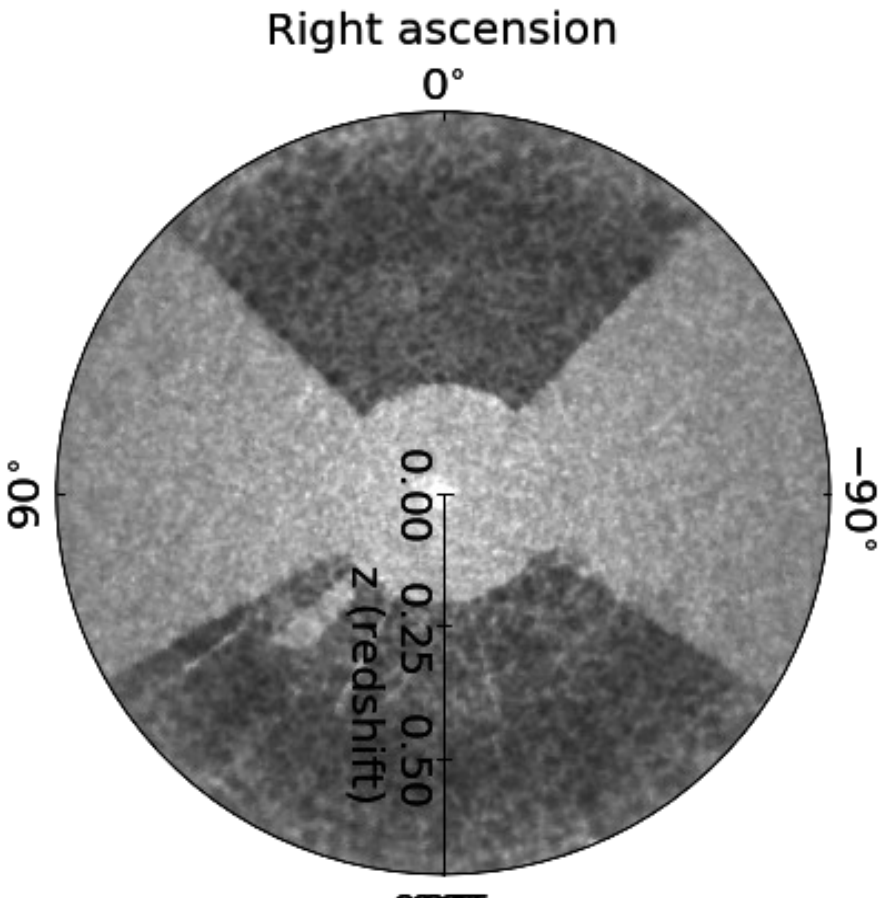
Preliminary

Stage 1: Inferred density of SDSS3

Ensemble density average



Error estimate from ensemble variance



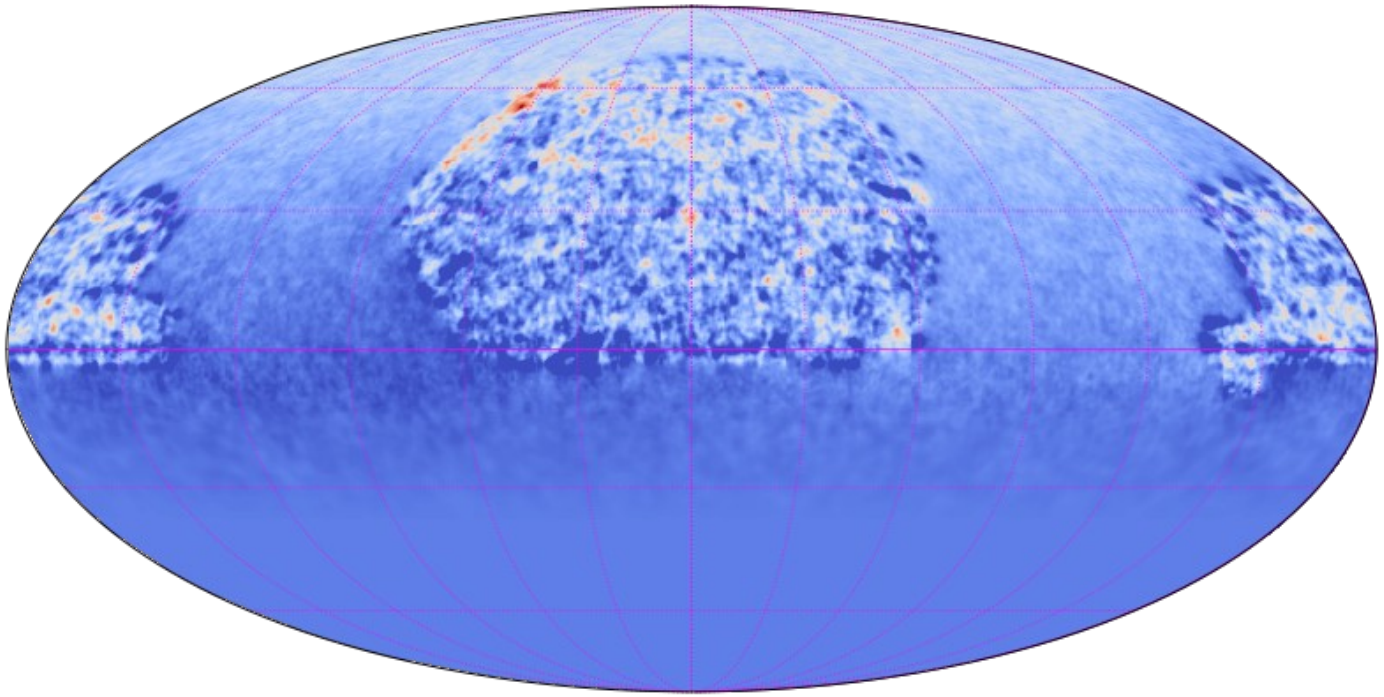
Main galaxy sample limit
(not included)

LOWZ limit

CMASS limit

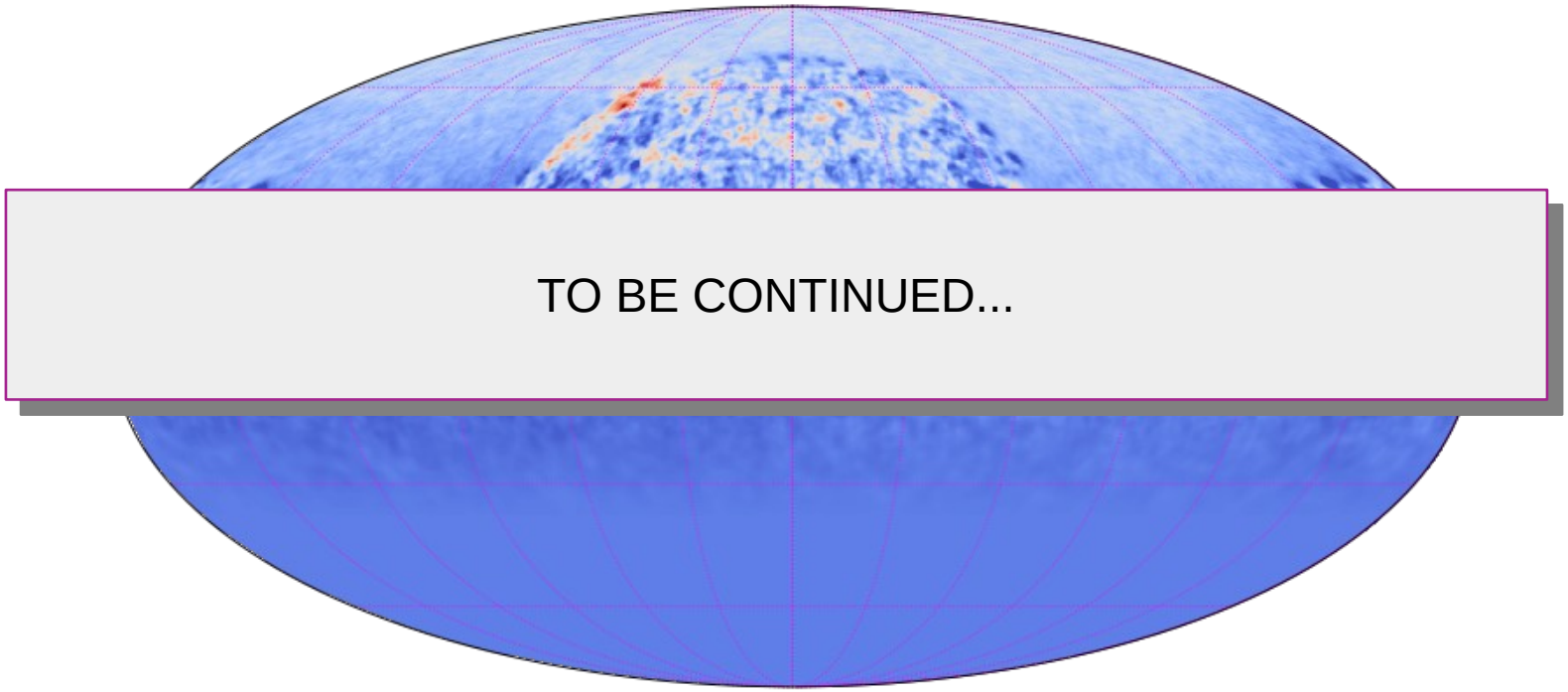
Preliminary

Sky density



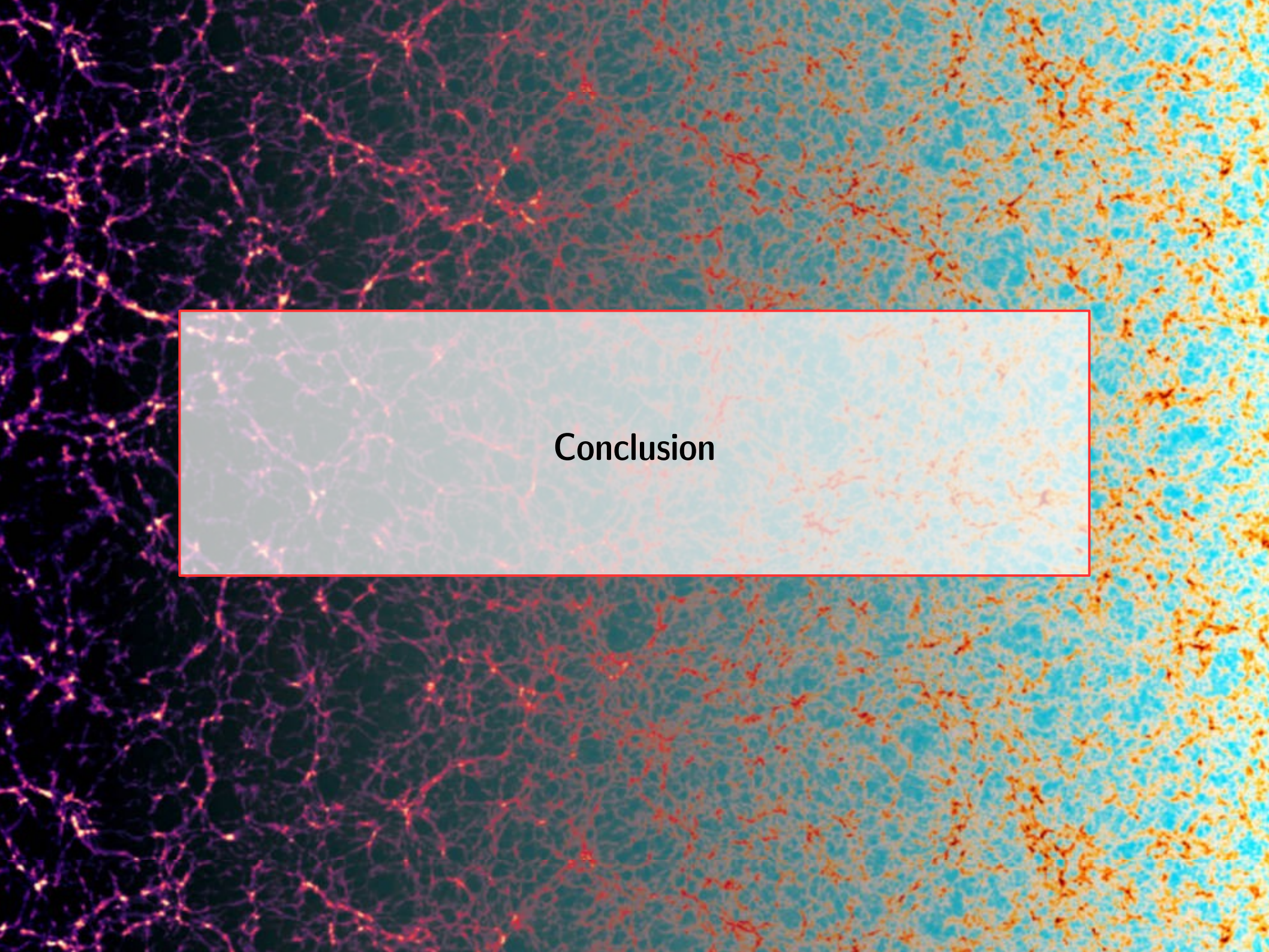
Preliminary

Sky density



TO BE CONTINUED...

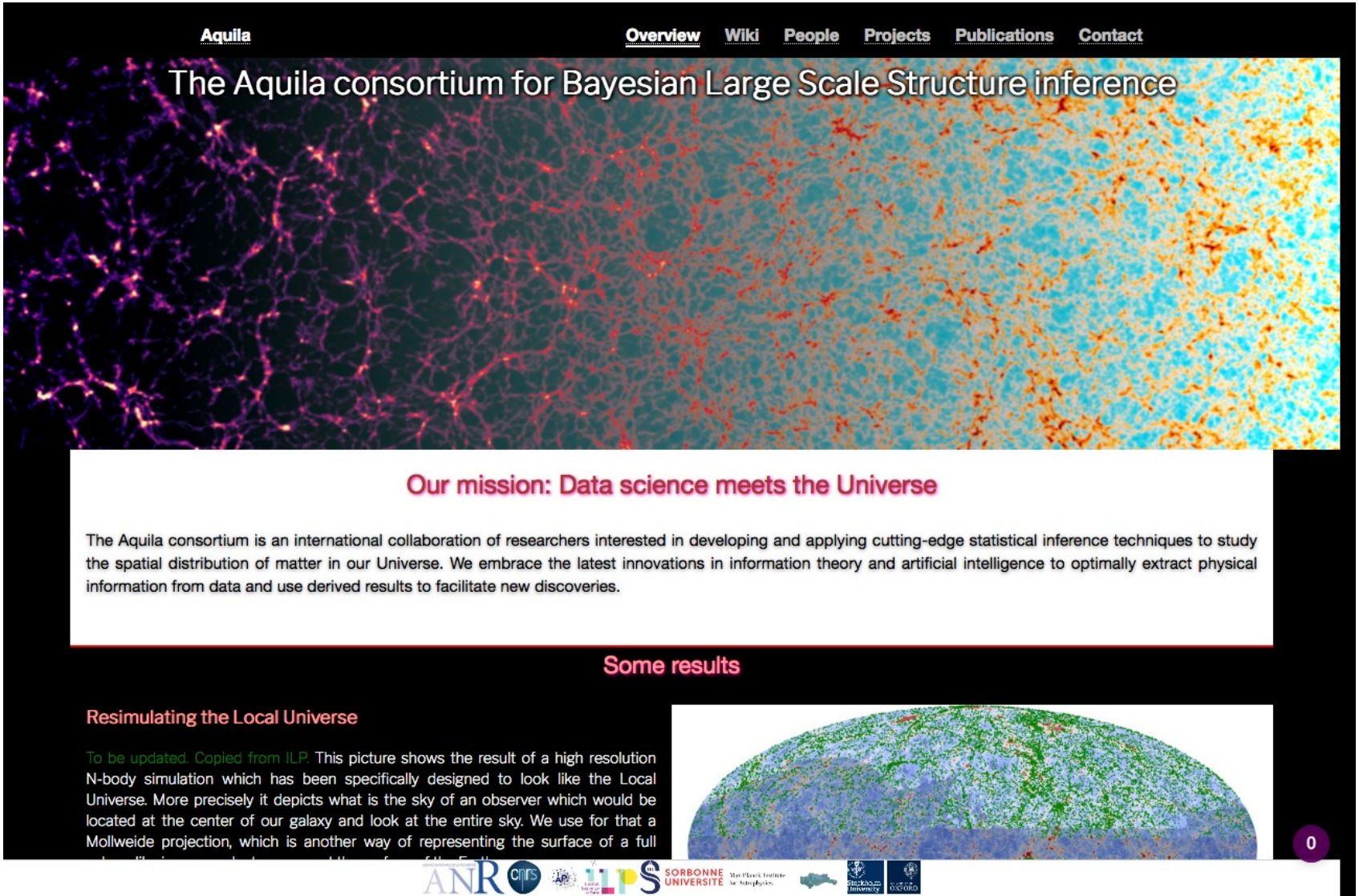
Preliminary


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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A biased list of Aquilians… check the website!

Natalia Porqueres

Minh Nguyen

Doogesh Kodi Ramanah

Tom Charnock

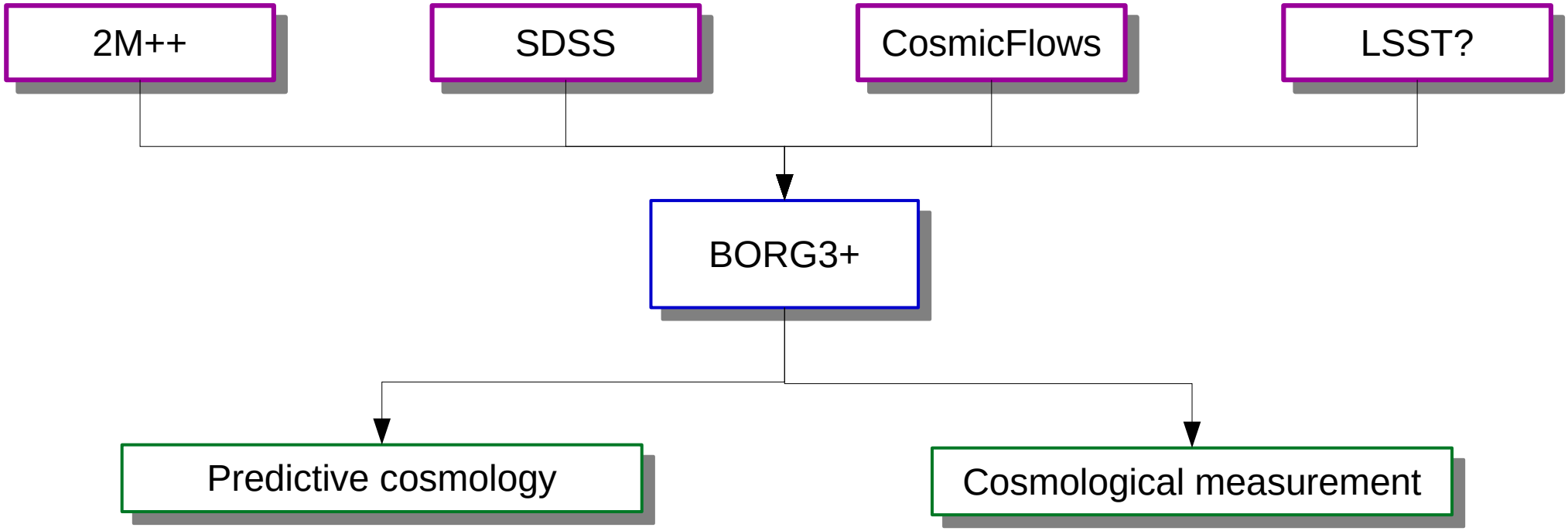
Harry Desmond

Franz Elsner

Florian Fuhrer

Florent Leclercq

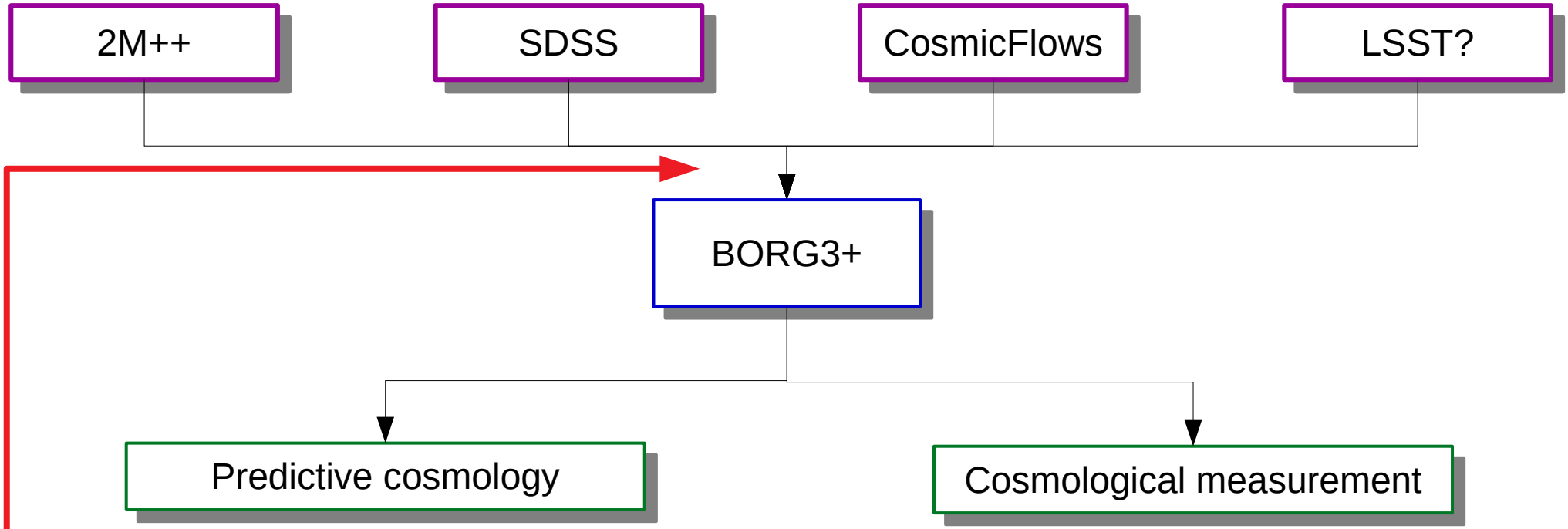
Conclusion: great future



- Velocity field (also VIRBIUS with F. Fuhrer)
- X-ray cluster emission
- Kinetic Sunyaev Zel'dovich
- Rees-Sciama
- Dark matter ?

- Cosmic expansion
- 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