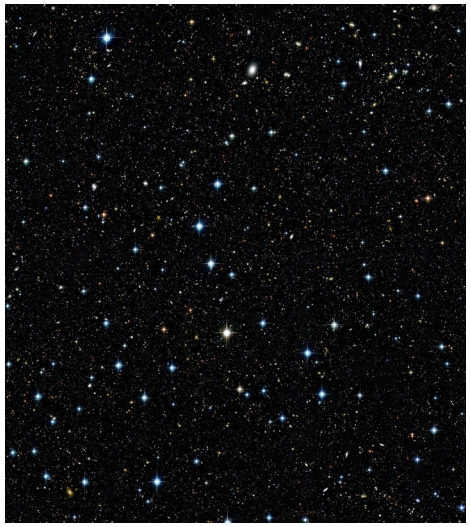
Inference of mass of clusters of galaxies with BORG

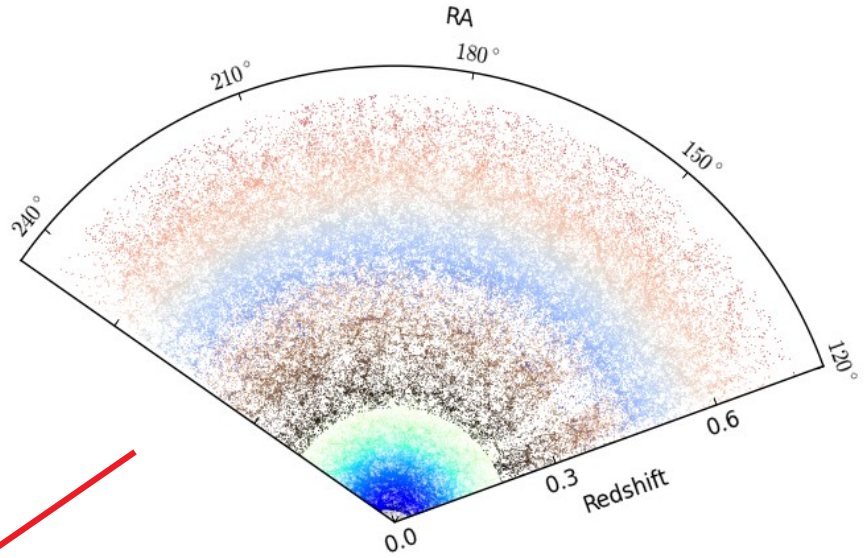
Guilhem Lavaux (IAP/CNRS)
for the Aquila Consortium

Atelier amas, December 11th 2020

These are our observables! Everything else is data compression.



Reduce



BORG

Massage, adjust, compute correlations

Ω

Cosmological parameters
Global cosmological properties
Mass of clusters

Fit model to even further reduced data

?

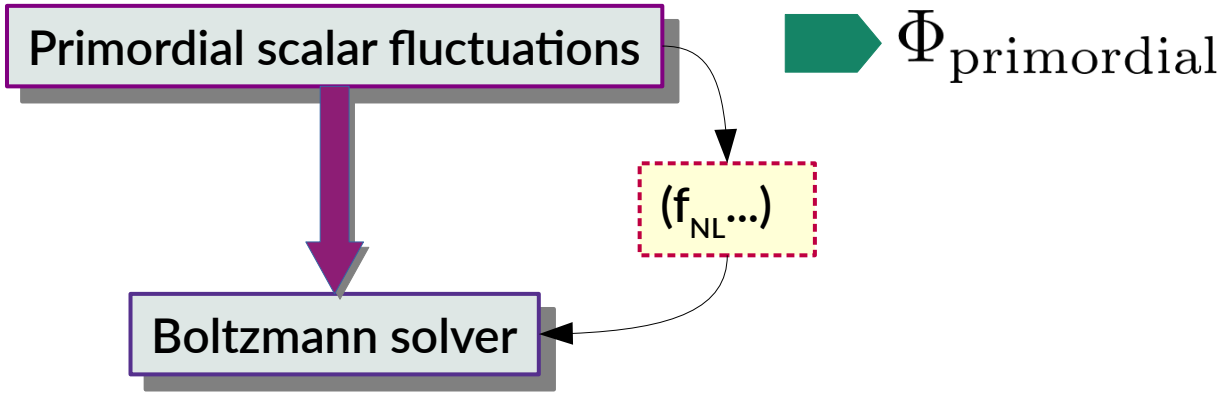
Do something

In practice...

Galaxy spatial data → Global density inference → MCMC of initial conditions

Image credits: Paramount Pictures

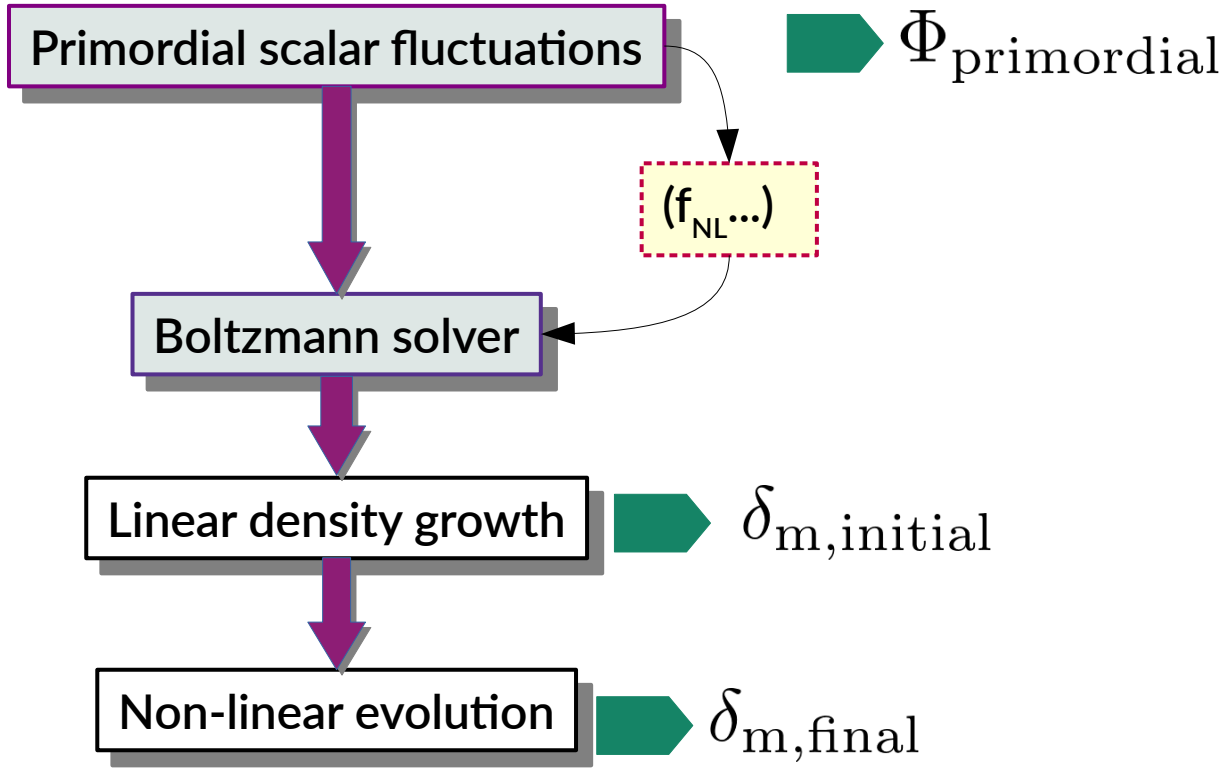
A data model for galaxy clustering



$N^{(G)}_{i,j,k}, \gamma_i, \ldots$

Data / catalogs

A data model for galaxy clustering



$N^{(G)}_{i,j,k}, \gamma_i, \ldots$

Data / catalogs

A data model for galaxy clustering

Primordial scalar fluctuations

$\Phi_{\rm primordial}$

(f_{NL}...)

Boltzmann solver

Linear density growth

$\delta_{\rm m,initial}$

Non-linear evolution

$\delta_{\rm m,final}$

Tracer "biasing"

$n_{\rm tracer}$

Selection effects

Redshift space distortions

+

Expansion

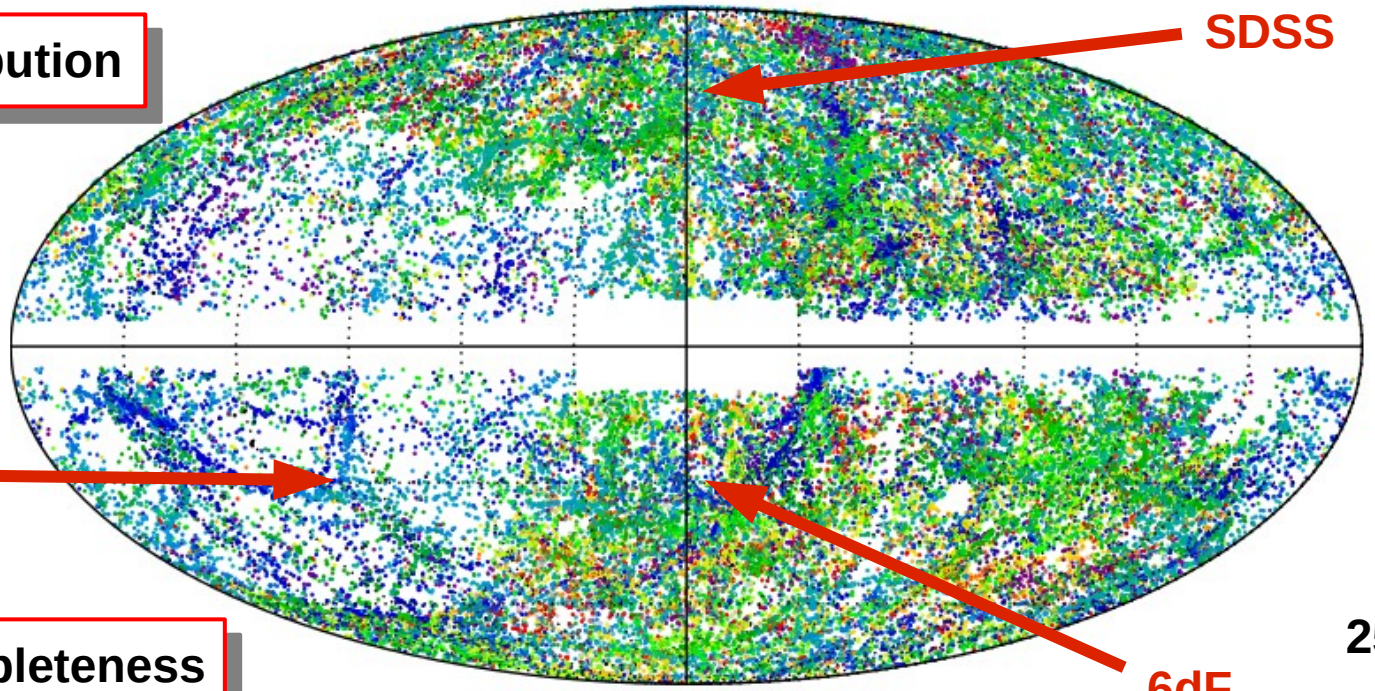
$N^{(G)}_{i,j,k}, \gamma_i, \ldots$

Data / catalogs

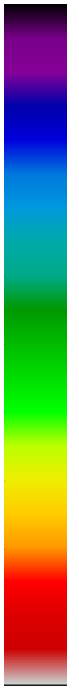
Likelihood

The 2M++ galaxy compilation

Galaxy distribution



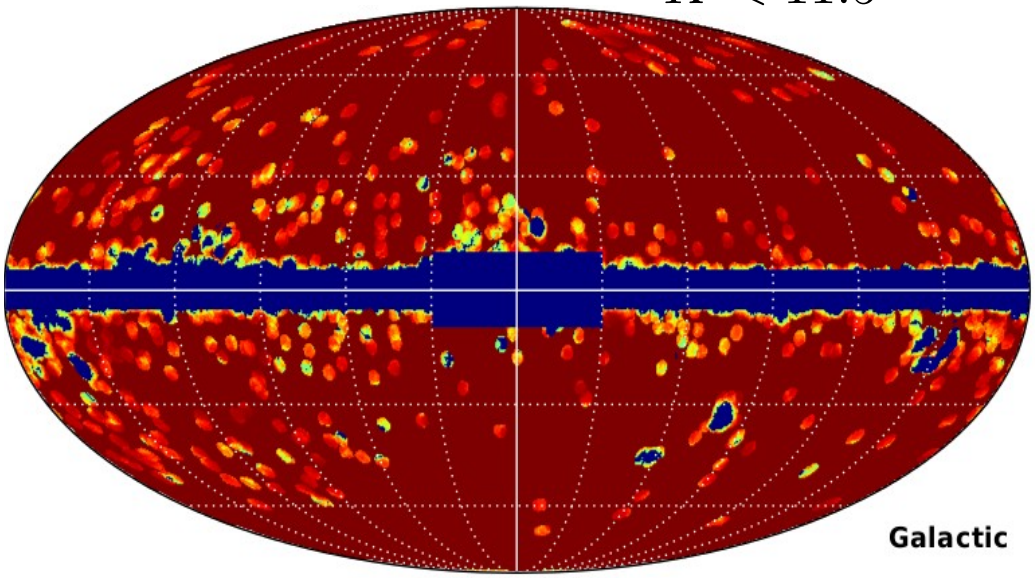
0 Mpc/h



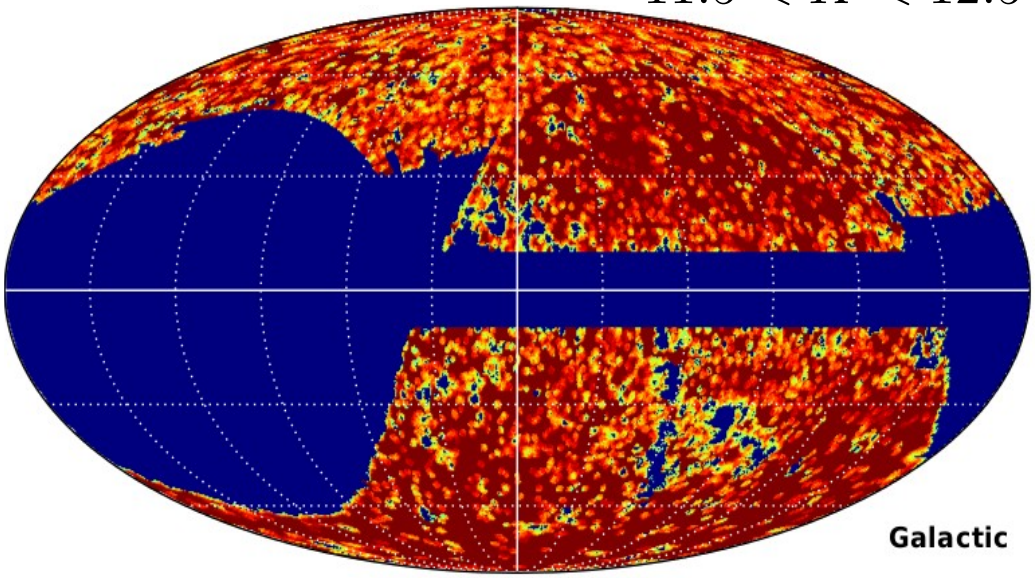
250 Mpc/h

Redshift completeness

$K < 11.5$



$11.5 < K < 12.5$

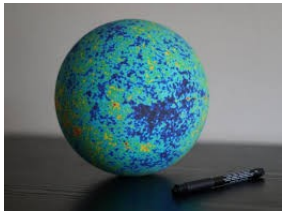


~70 000 galaxies

Lavaux & Hudson (MNRAS, 2011)

The model

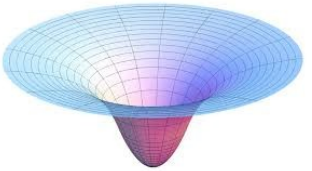
ΛCDM Universe with Planck+15 cosmological parameters



Box of $(677.7\ \mathrm{Mpc}/h)^3$
256^3 initial condition elements
512^3 particles

Particle mesh solver

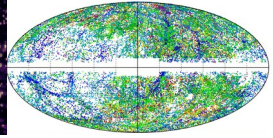
Redshift space distortions derived from particle simulations



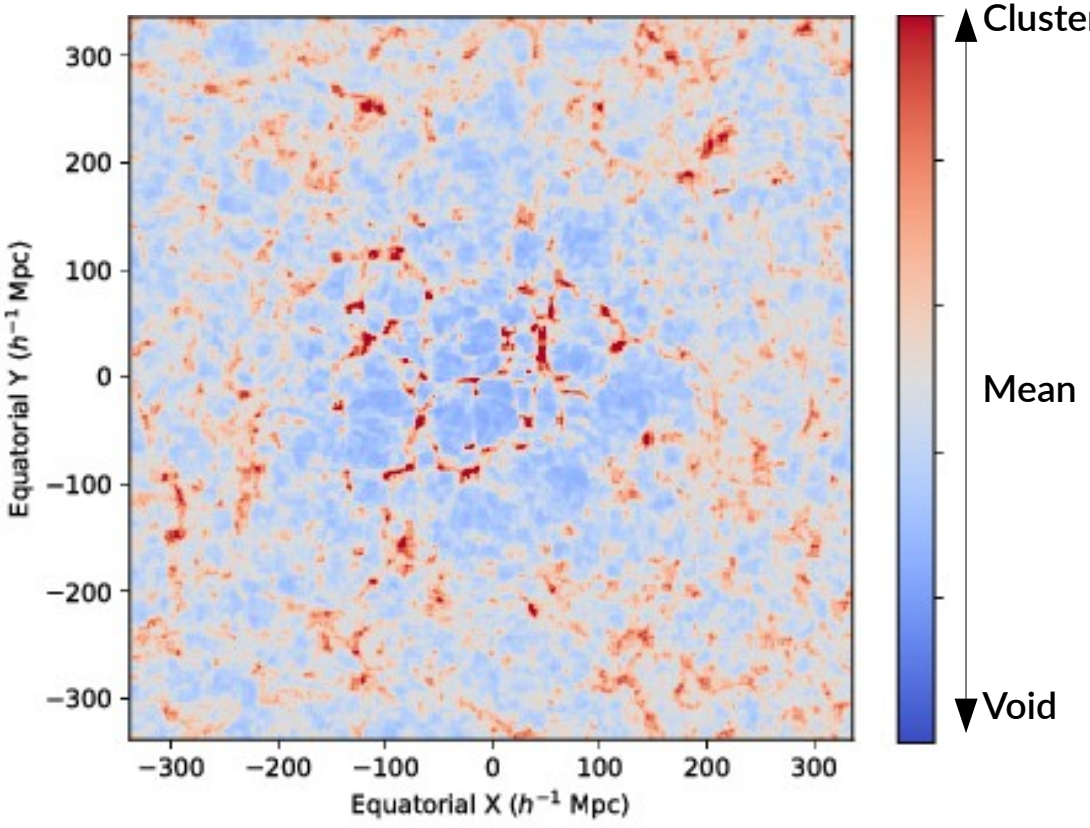
Bias model: $\rho_g \propto \rho_m^{\alpha} \exp\left(-(\rho_m/\rho_0)^{-\epsilon}\right)$

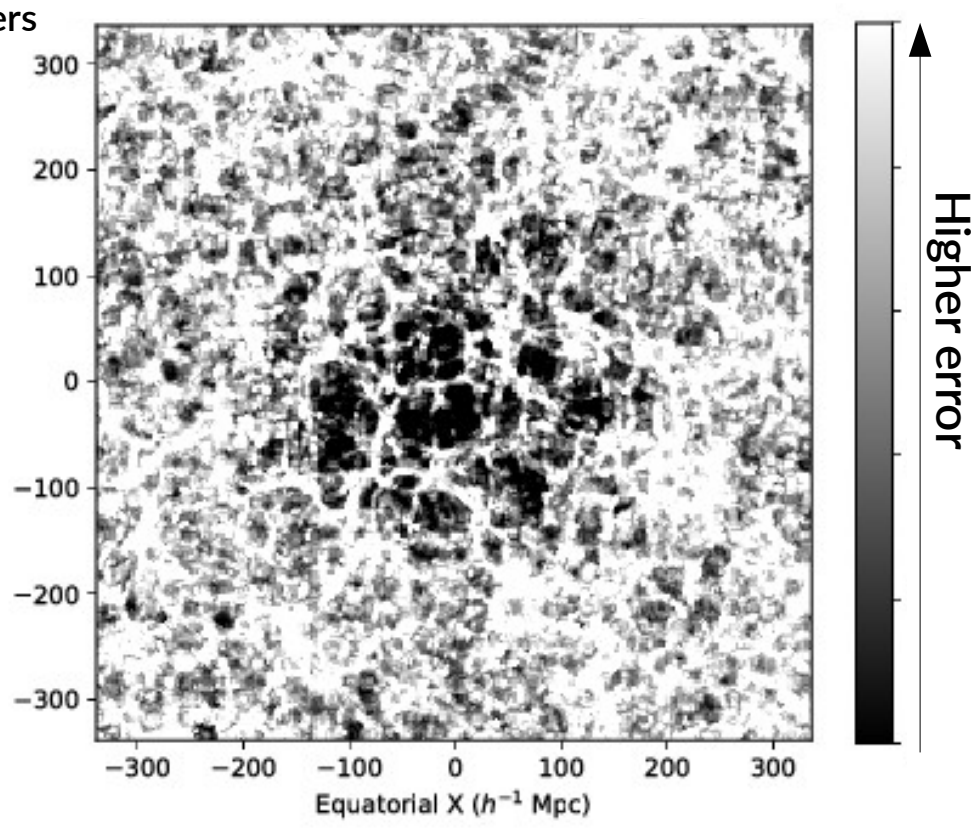
Selection derived from Schechter luminosity function

Inferred density fields



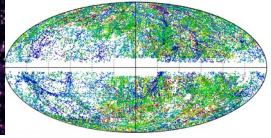
Ensemble average density fields at z=0

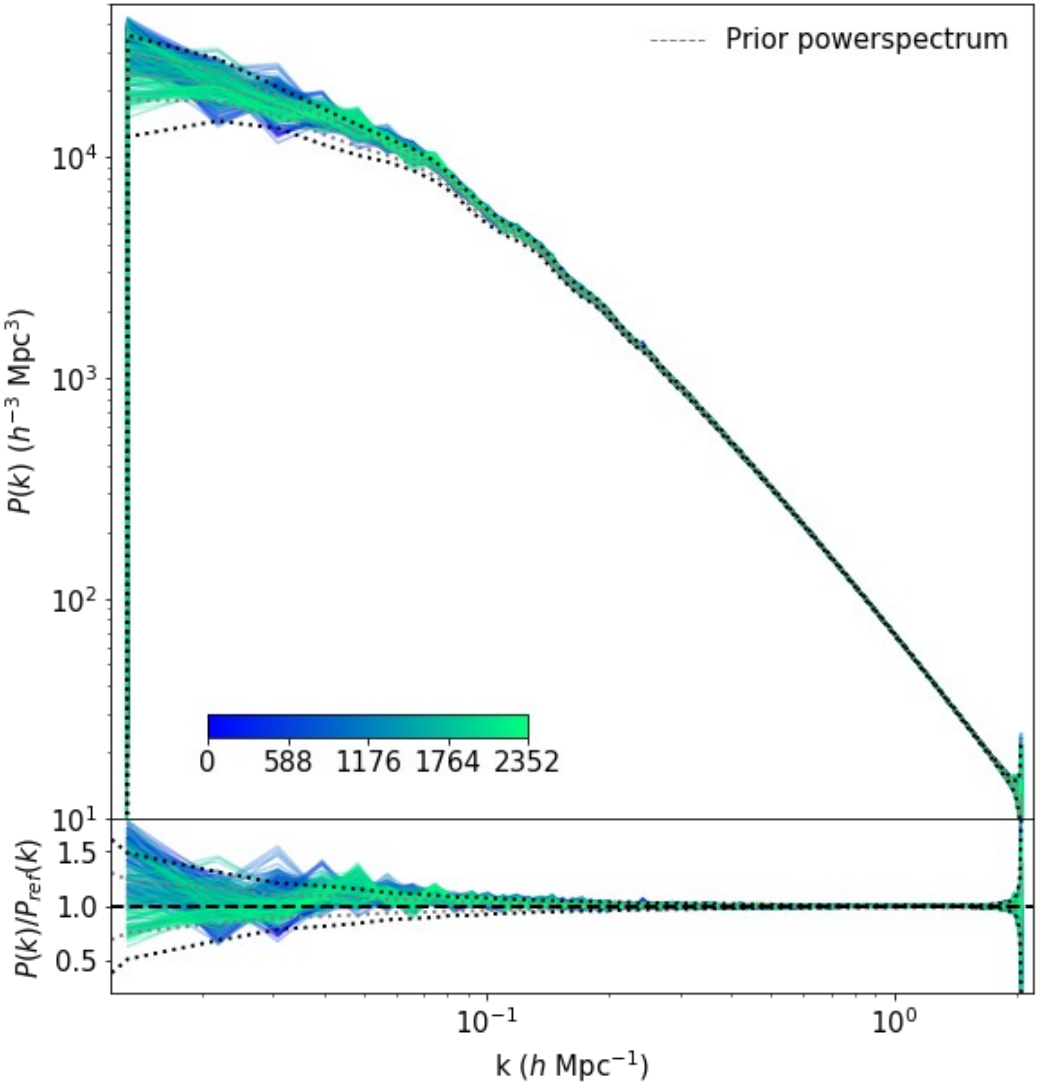




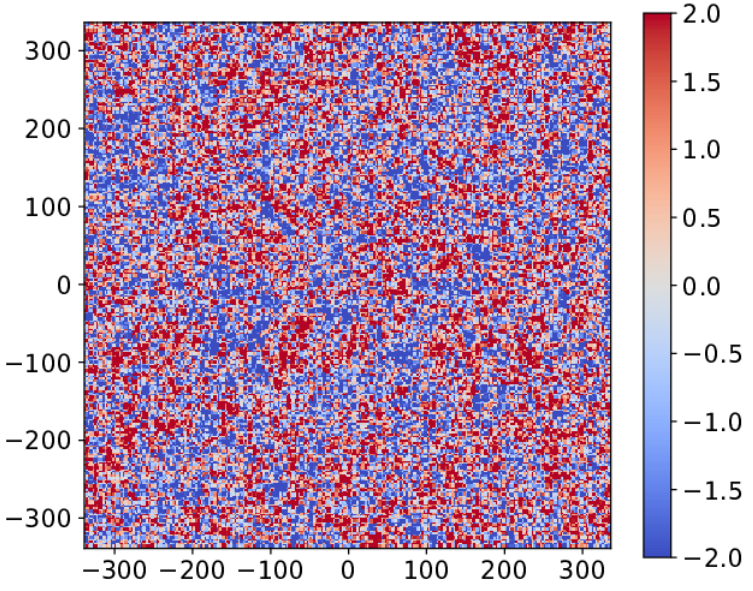
Jasche & Lavaux (2019, A&A)

Initial condition powerspectrum

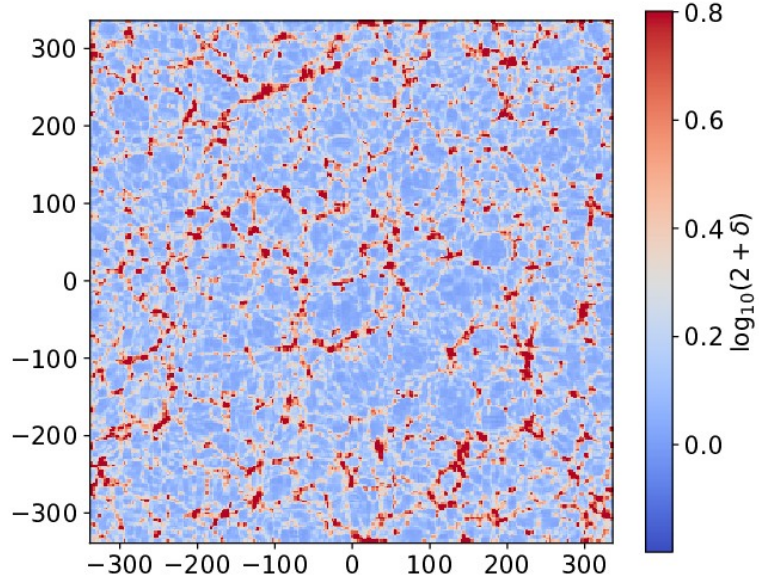




Initial conditions

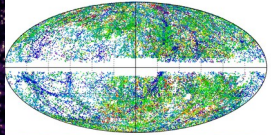


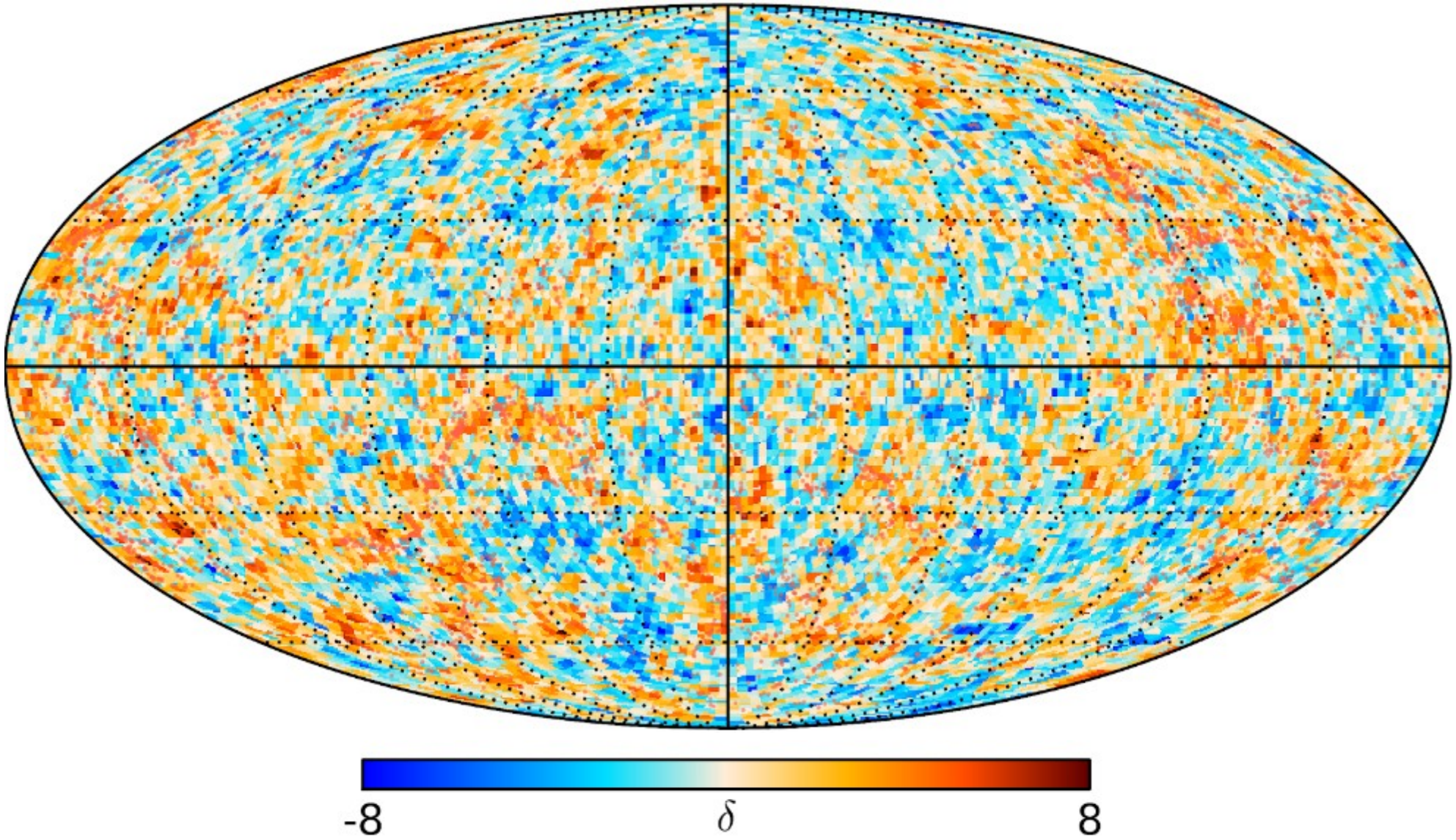
Post PM simulation



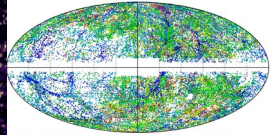
Jasche & Lavaux (2019, A&A)

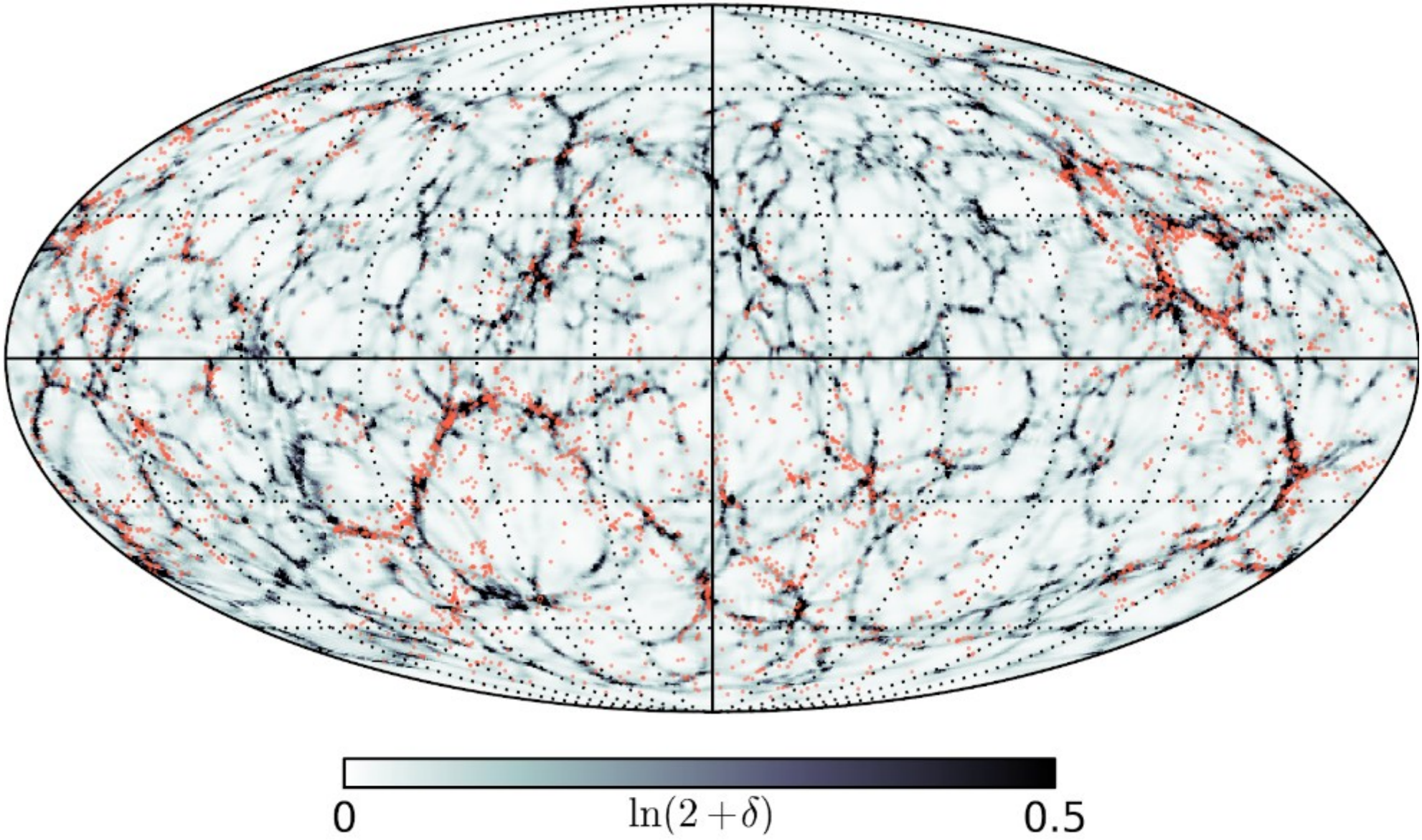
Primordial fluctuations on the sphere



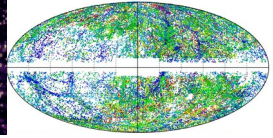


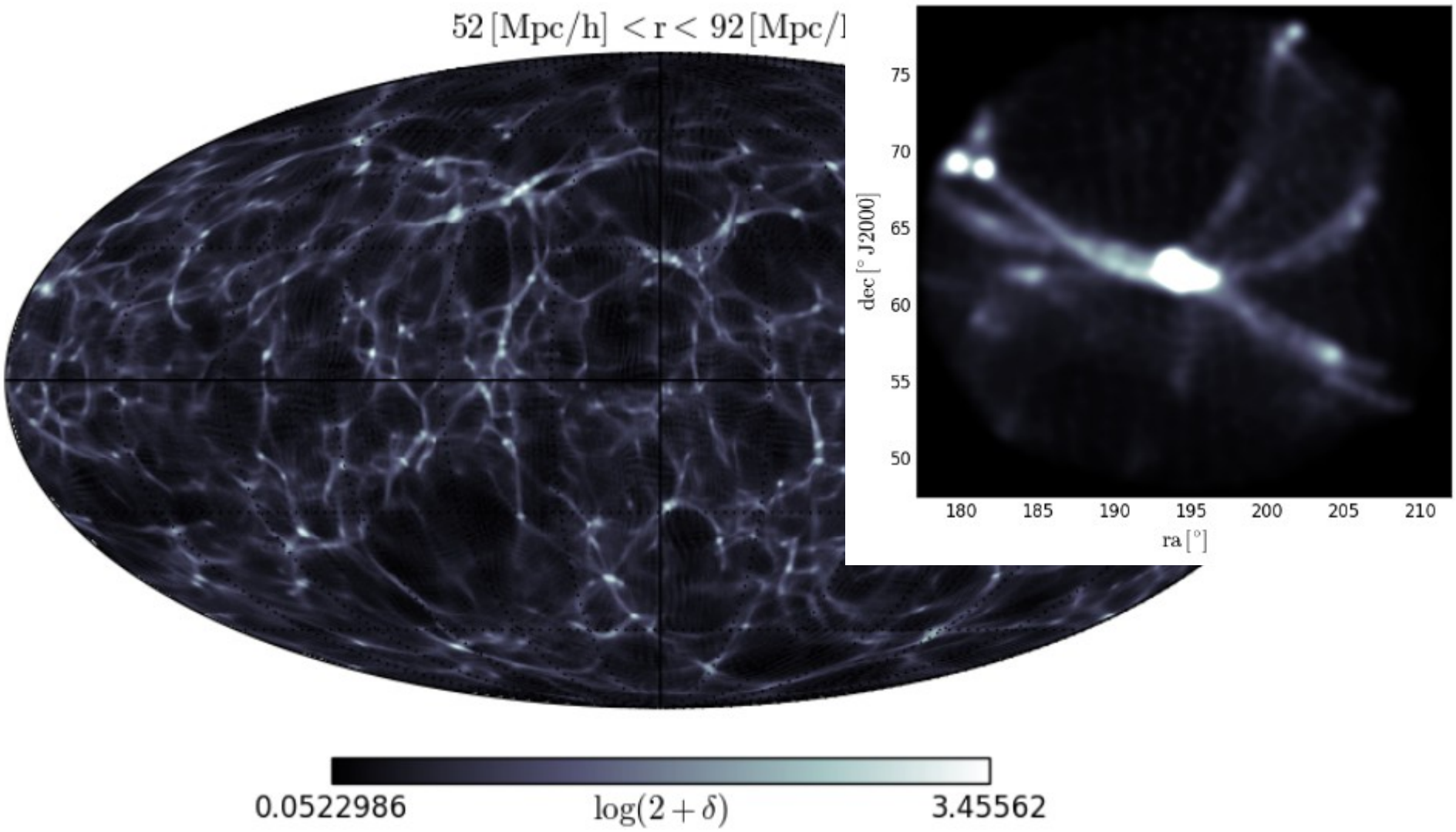
Comparing to actual galaxy distribution





Focusing on COMA





Locating and measuring mass profile

Algorithm to relate clusters to our constrained realizations:

1) Density field / particle simulation built for each MCMC file
2) Provide an approximate observed position (from NED)
3) Find the local maximum peak by iterating the barycenter position with decreasing spherical volume
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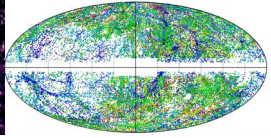
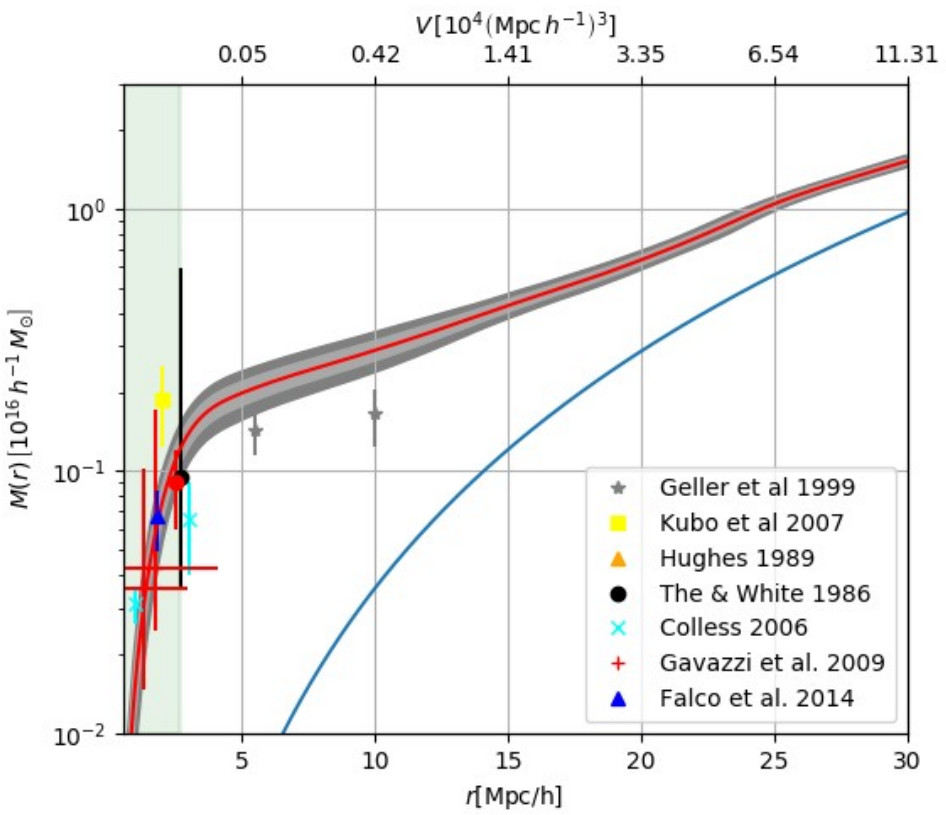
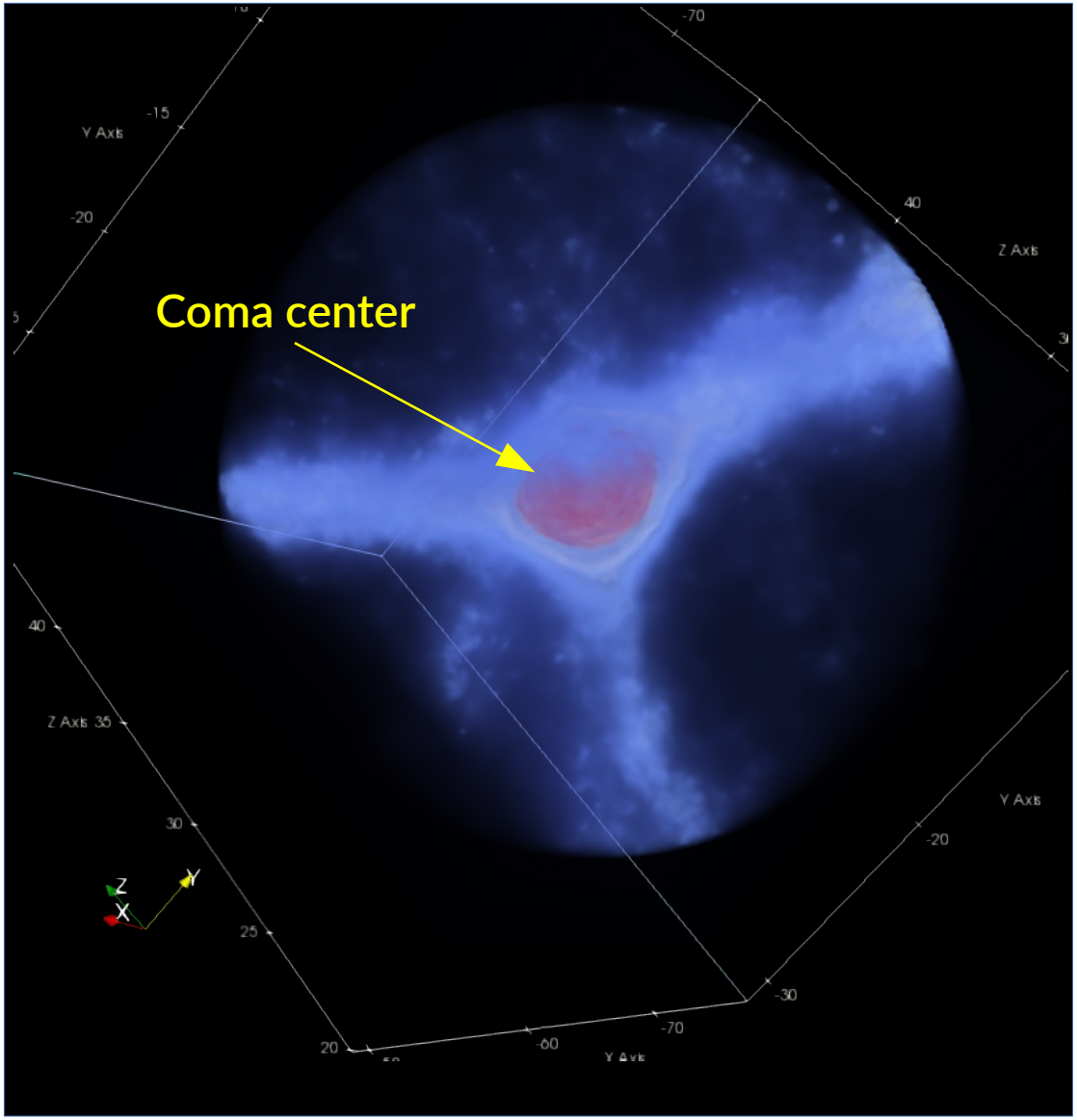
Examples!

Coma dynamical properties

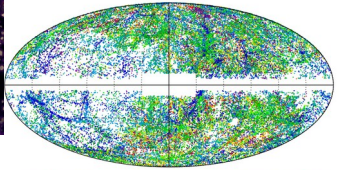


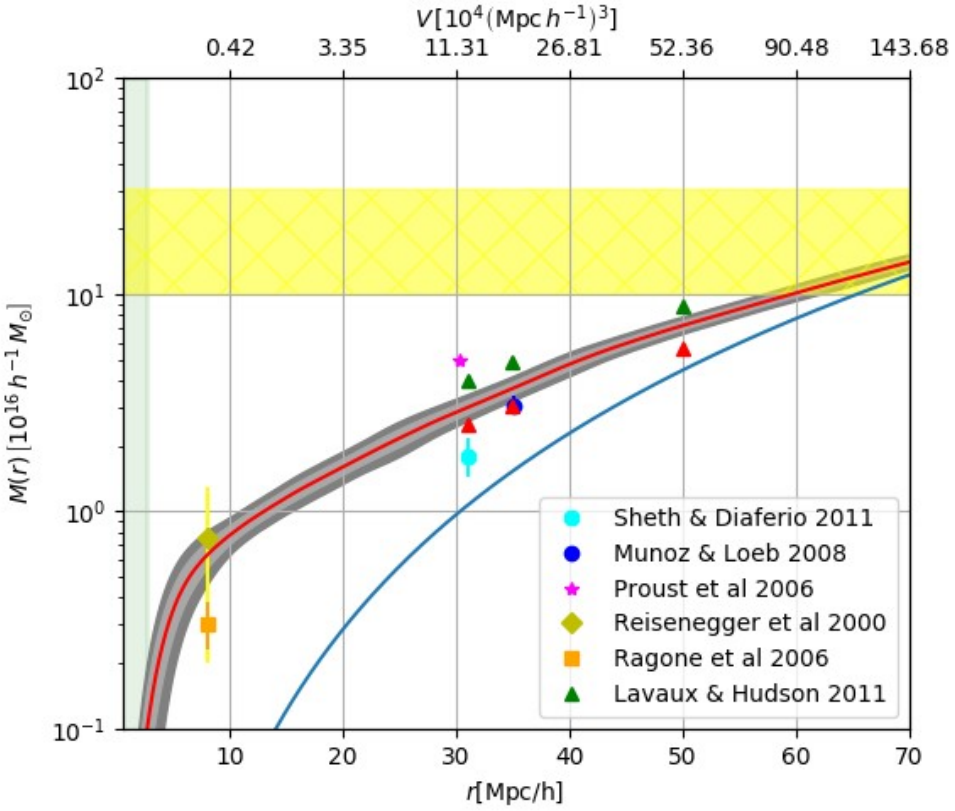


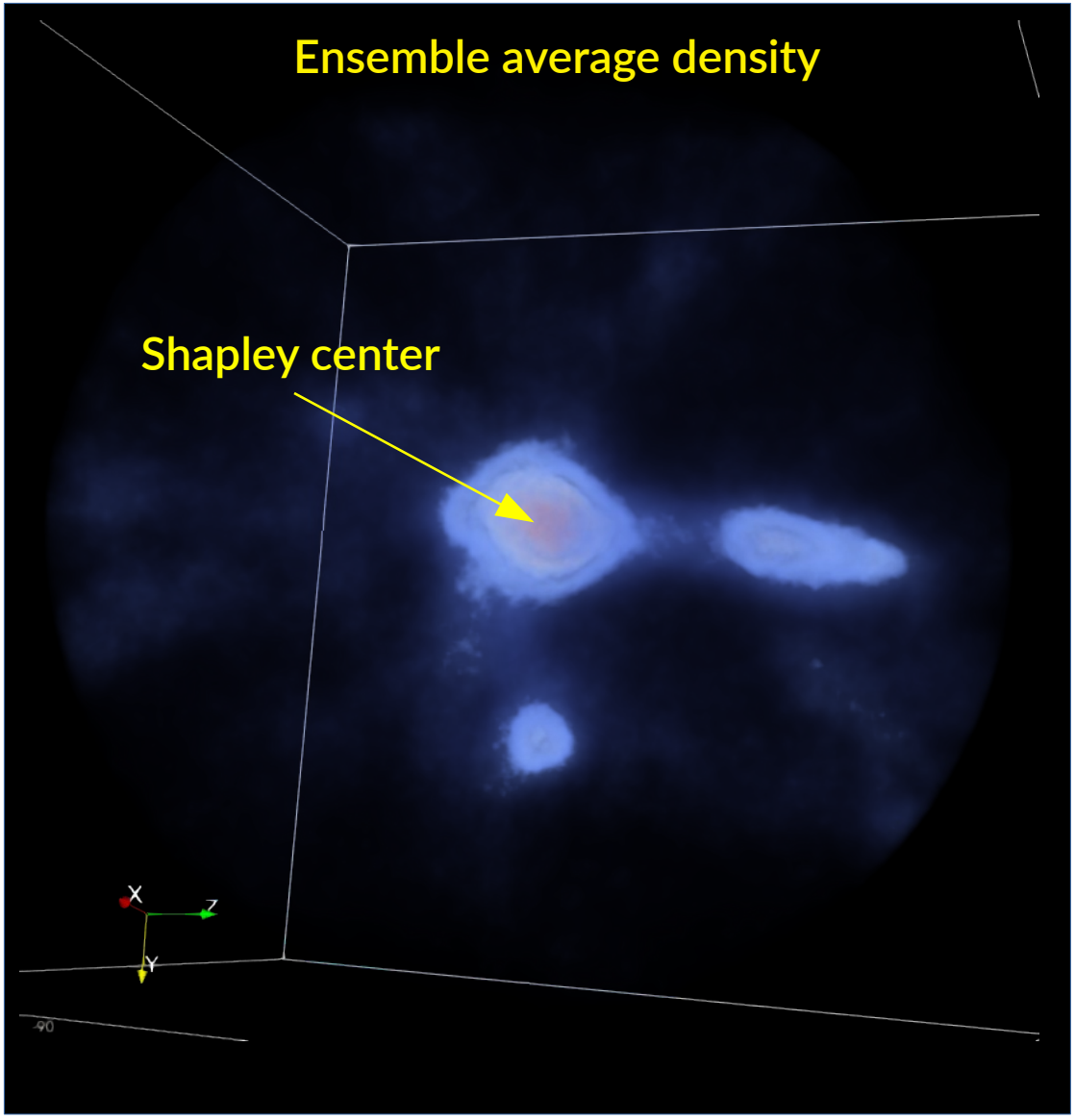


Jasche & Lavaux (2019 A&A); Peirani, Lavaux & Jasche (2019, in prep.)

Shapley concentration







~60 Mpc/h

Lavaux & Jasche (2018, in prep.)

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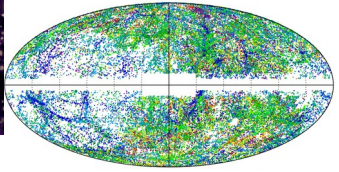
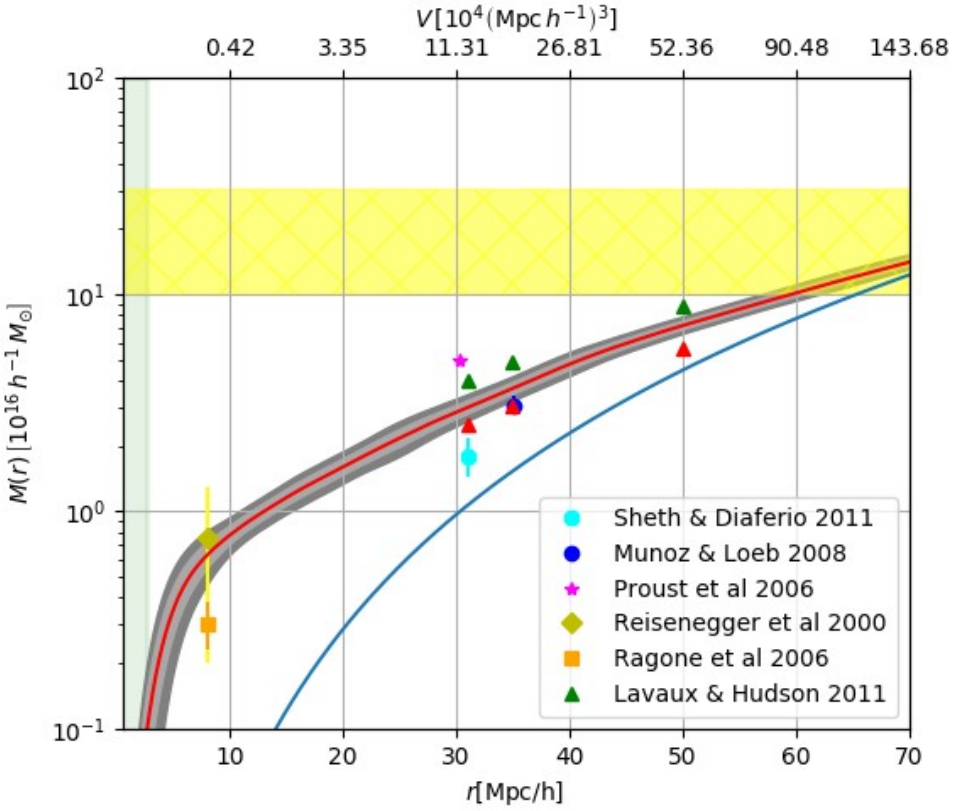
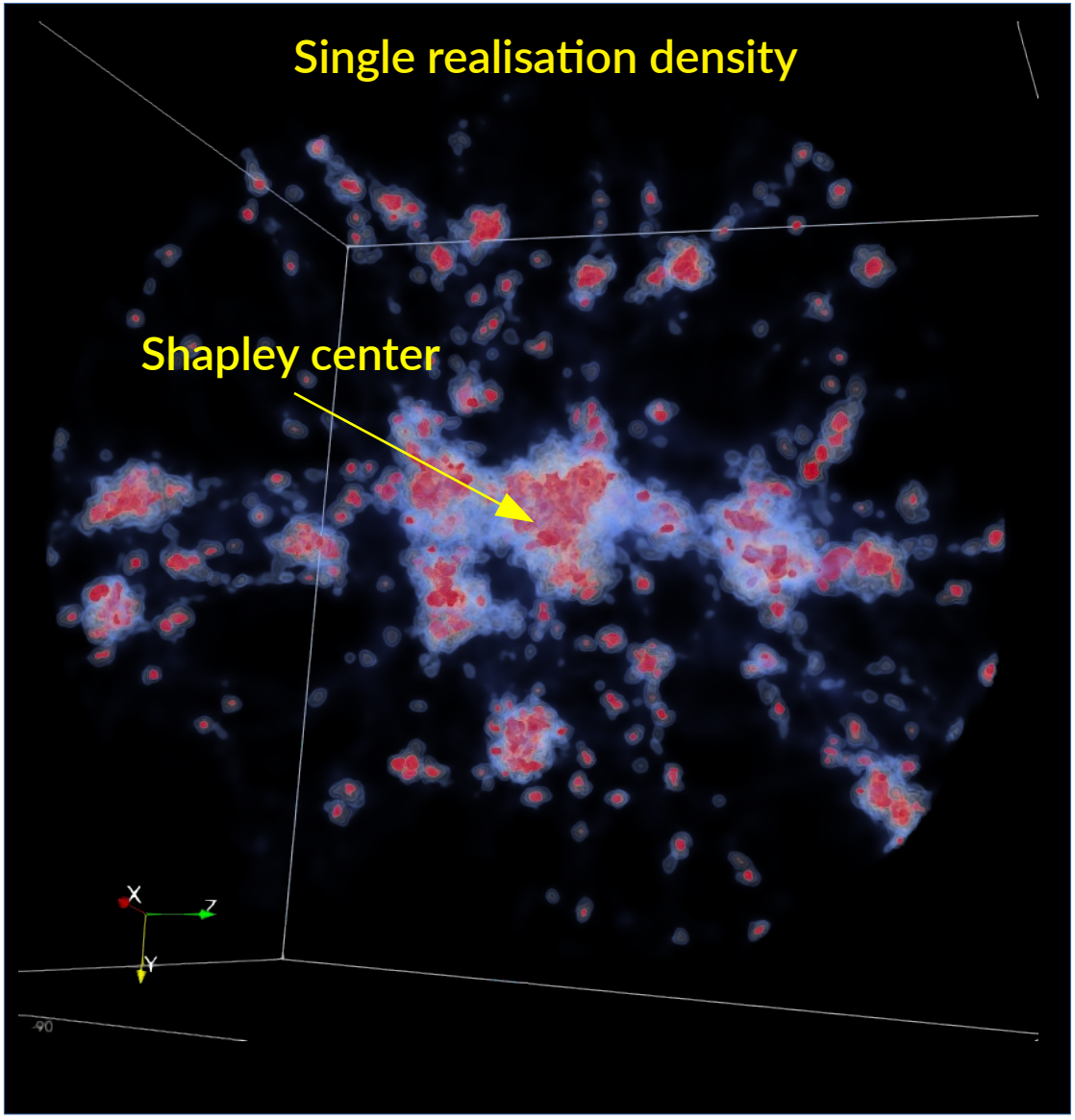




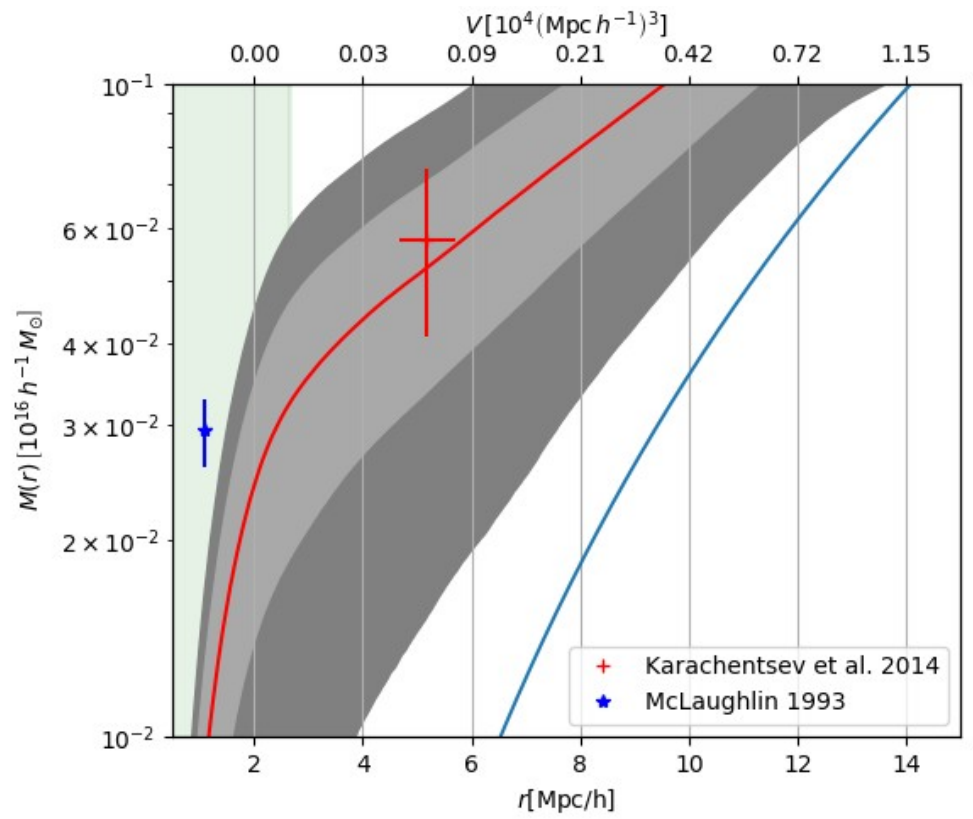


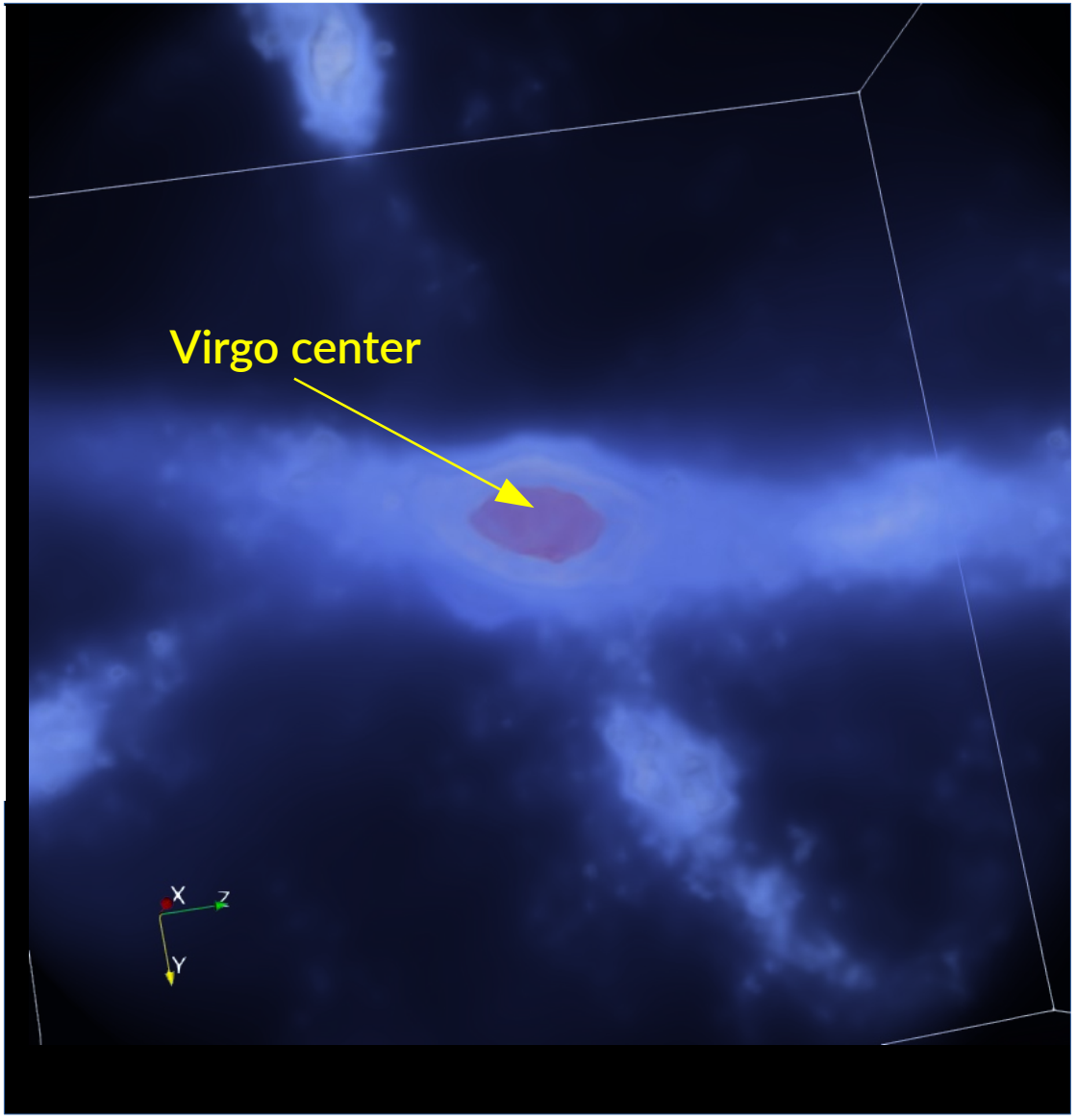
~60 Mpc/h

PLAY

Lavaux & Jasche (2018, in prep.)

Virgo cluster





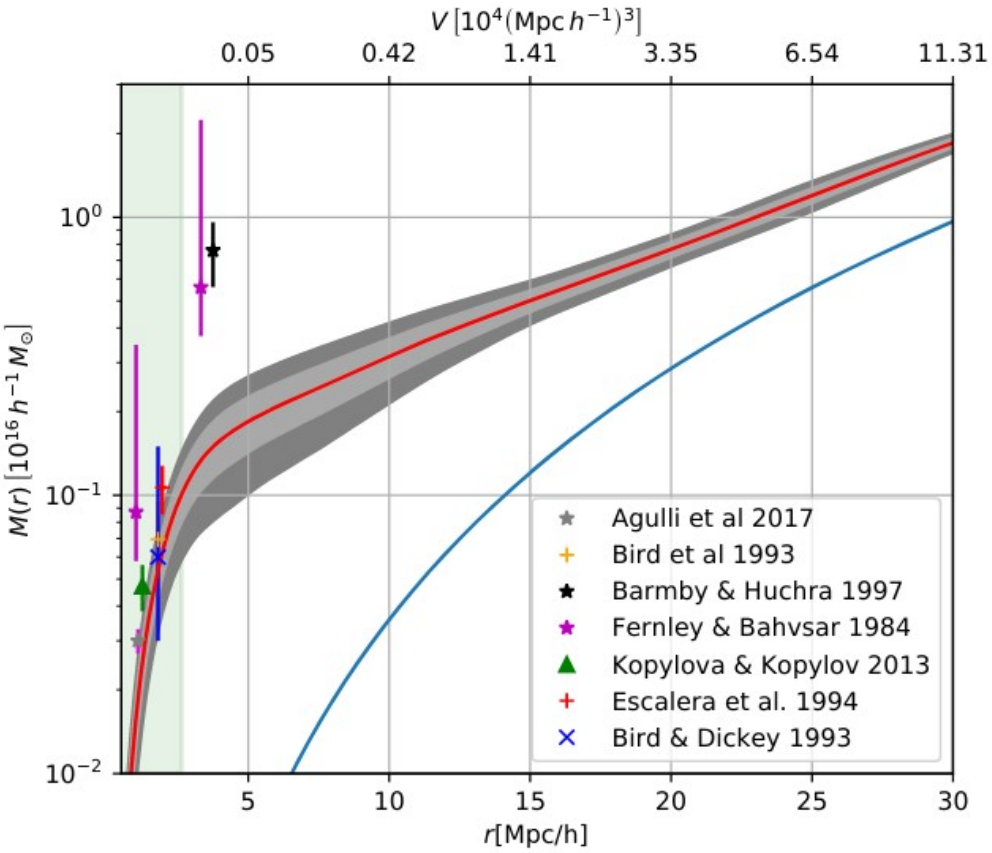
~30 Mpc/h

PLAY

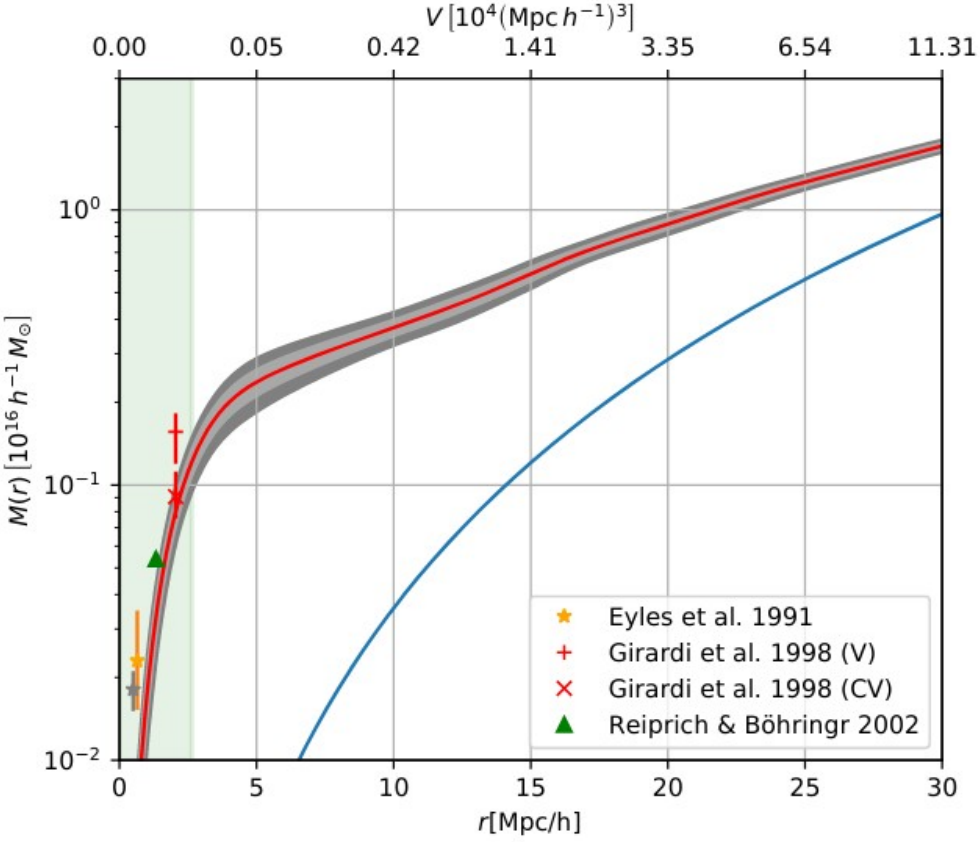
Jasche & Lavaux; Lavaux & Jasche; Peirani, Lavaux & Jasche (2018, in prep.)

Some more clusters

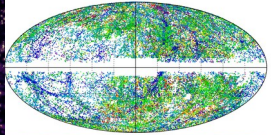
Hercules cluster

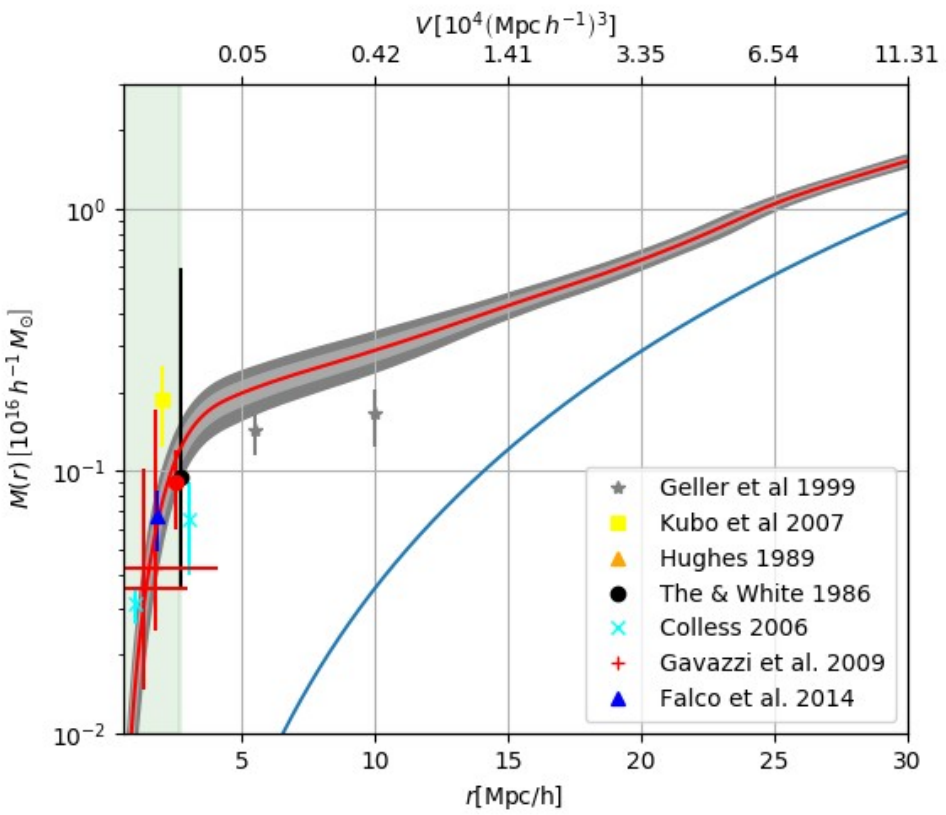


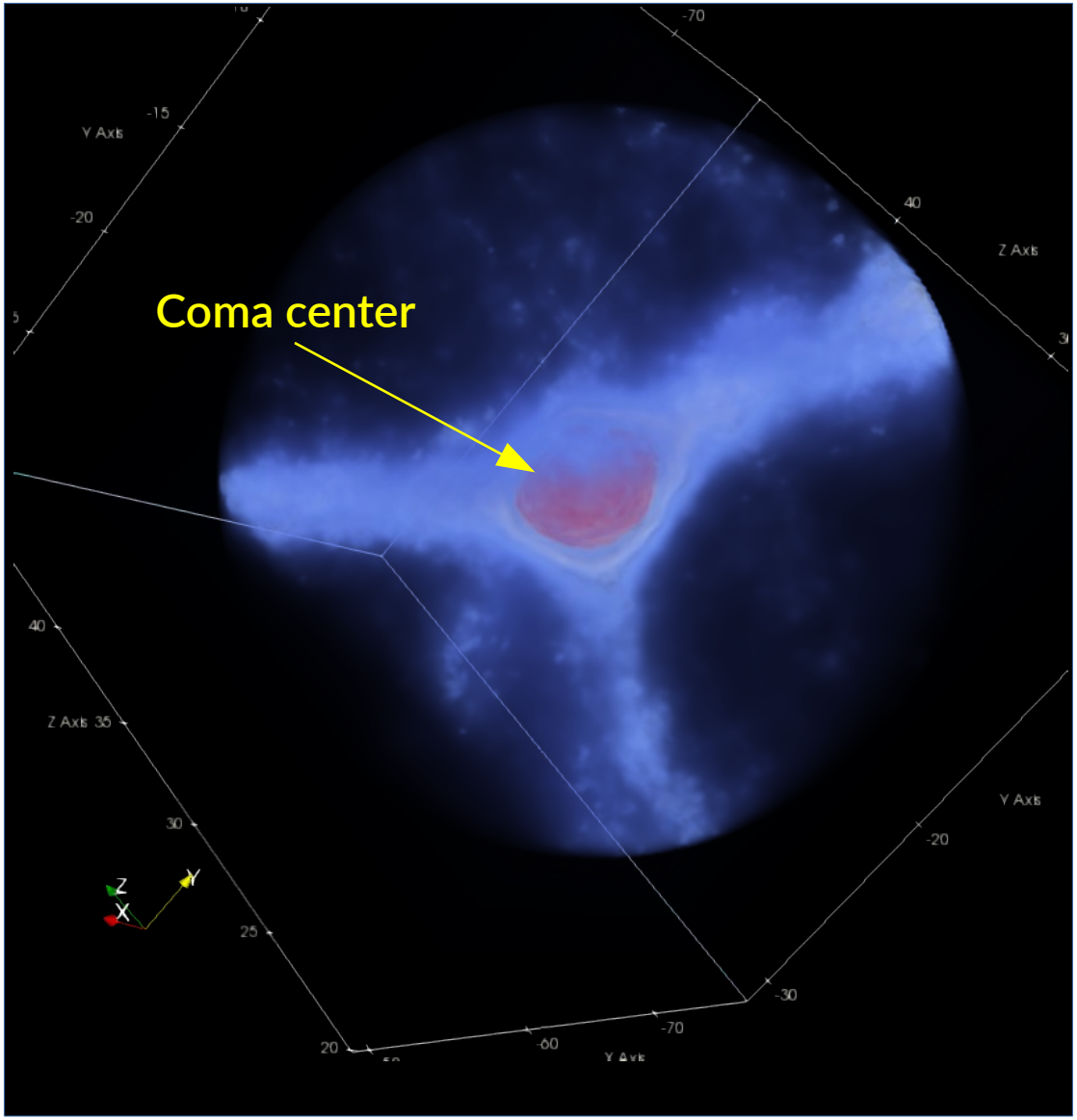
Perseus cluster



Coma dynamical properties







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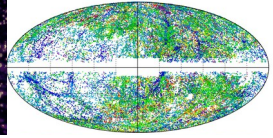
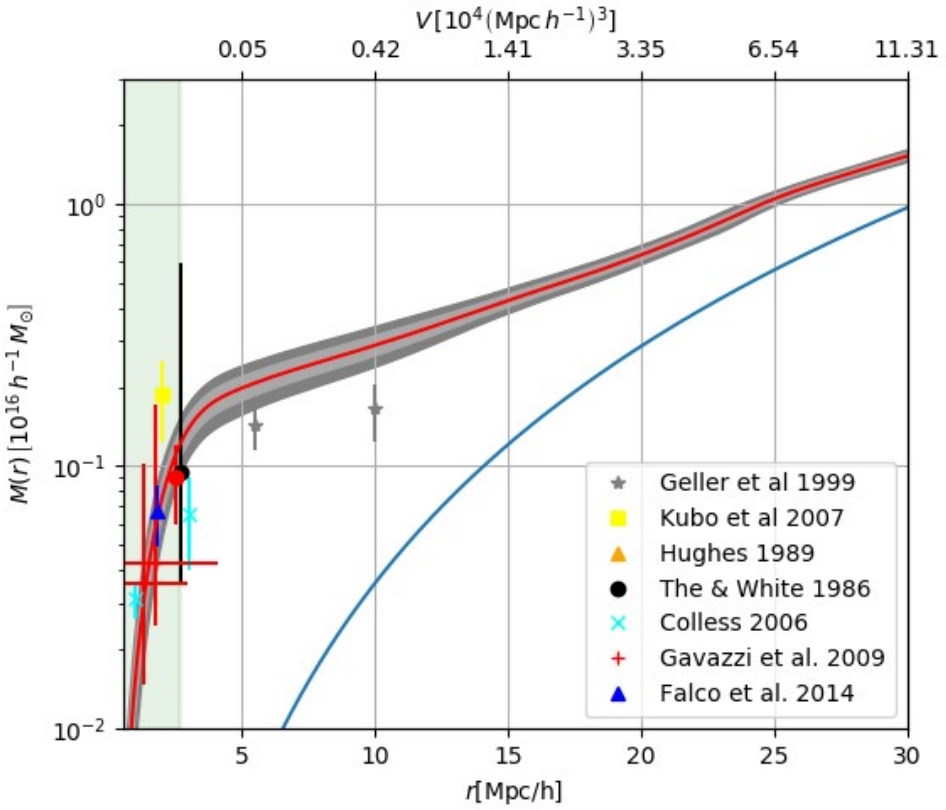
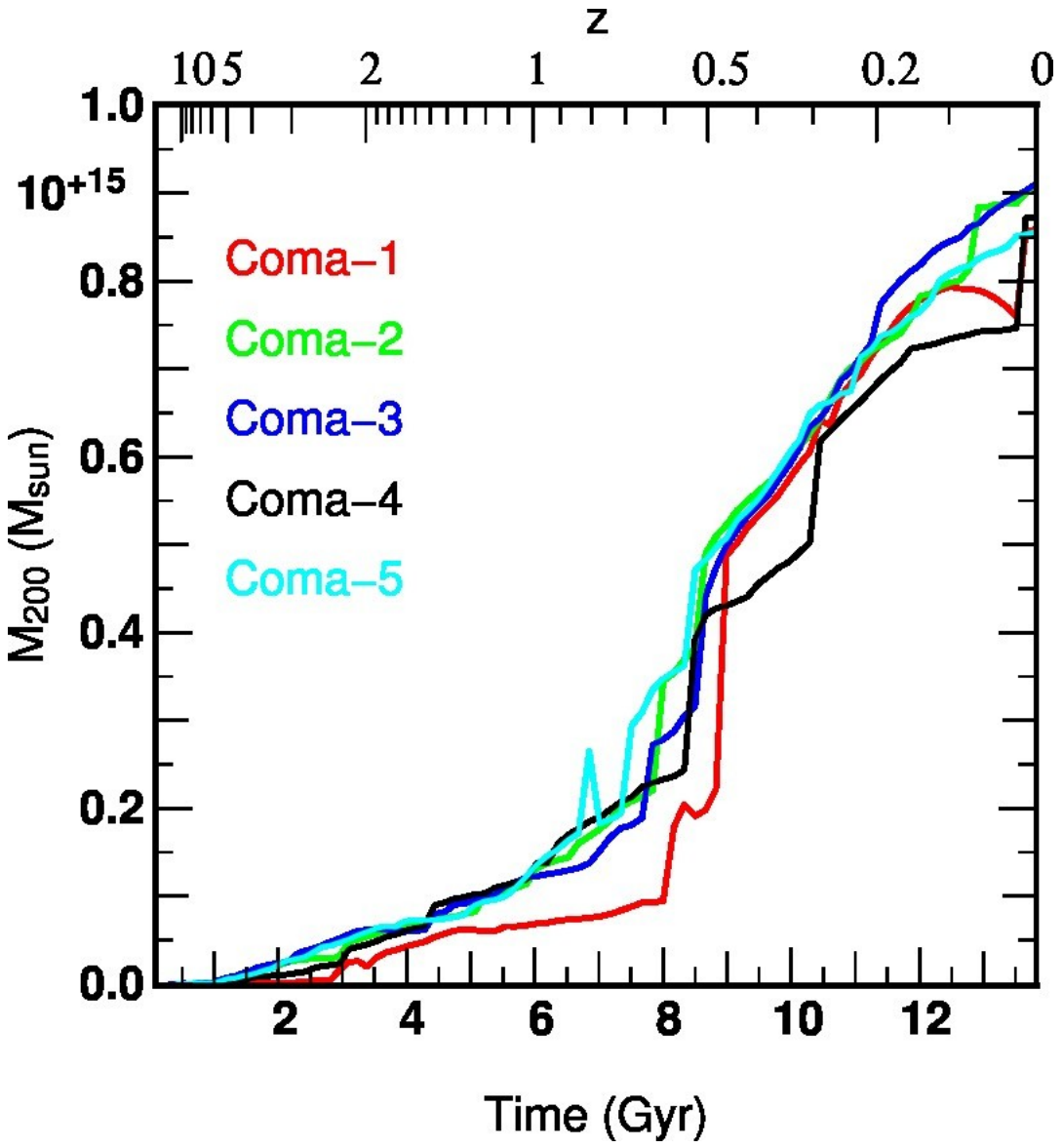






Zoom simulation on Coma
(~250 Mpart in zoom)

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

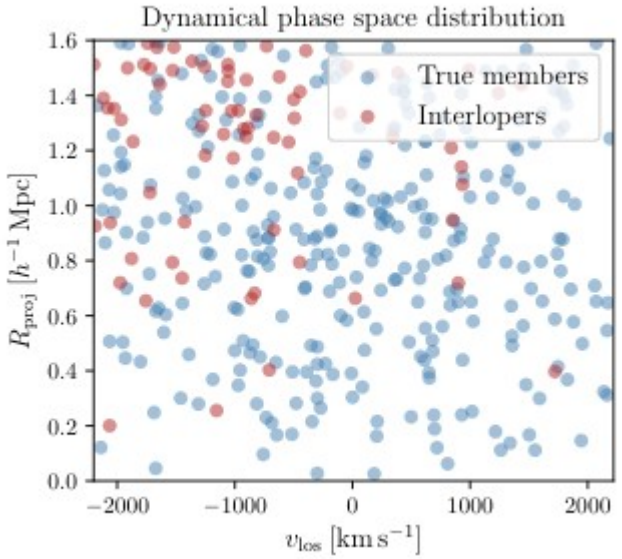
Jasche & Lavaux (2019 A&A); Peirani, Lavaux & Jasche (2019, in prep.)

Other recent techniques

Deep learning based techniques to relate observations to mass:

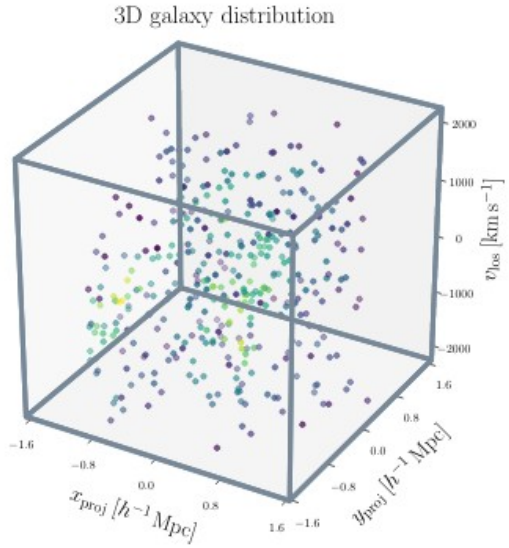
Ramanah et al. (2020, 2003.05951)

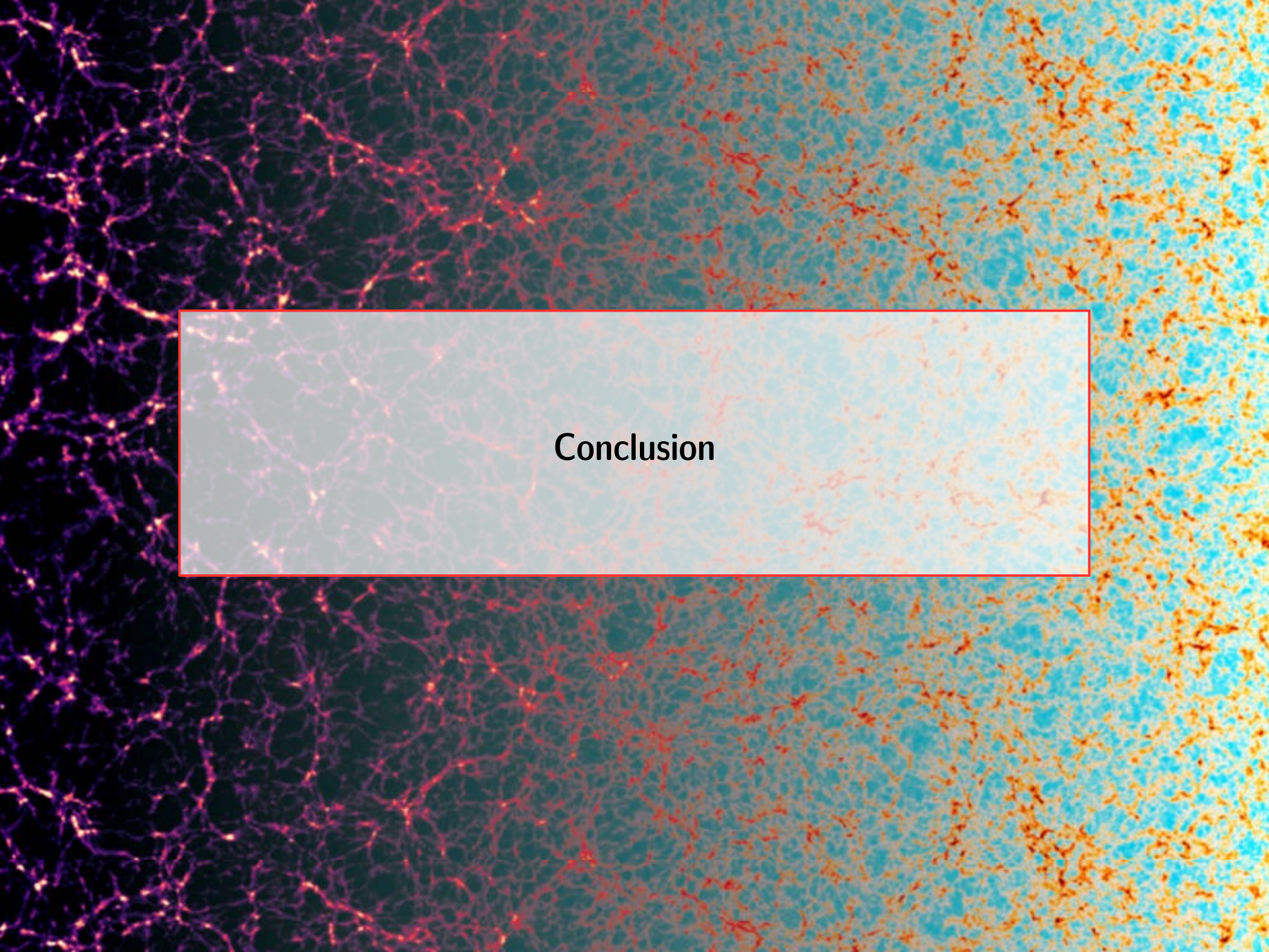
- Use Normalizing flows on 2d phase space distribution



Ramanah et al. (2020, 2009.03340)

- Use Convolutional Neural Network on 3d phase space distribution




Conclusion

Conclusion

Holistic dynamical inference of the Local Universe is maturing

Several checks point to unbiased reconstruction

- Individual mass of clusters (Coma, Virgo, Hercules, Shapley concentration, Perseus)
- Cosmological power spectrum
- Velocity field

More work required: some P(k) features

Interactive visualization
https://big4.iap.fr/index.php?n=Main.BorgVisu