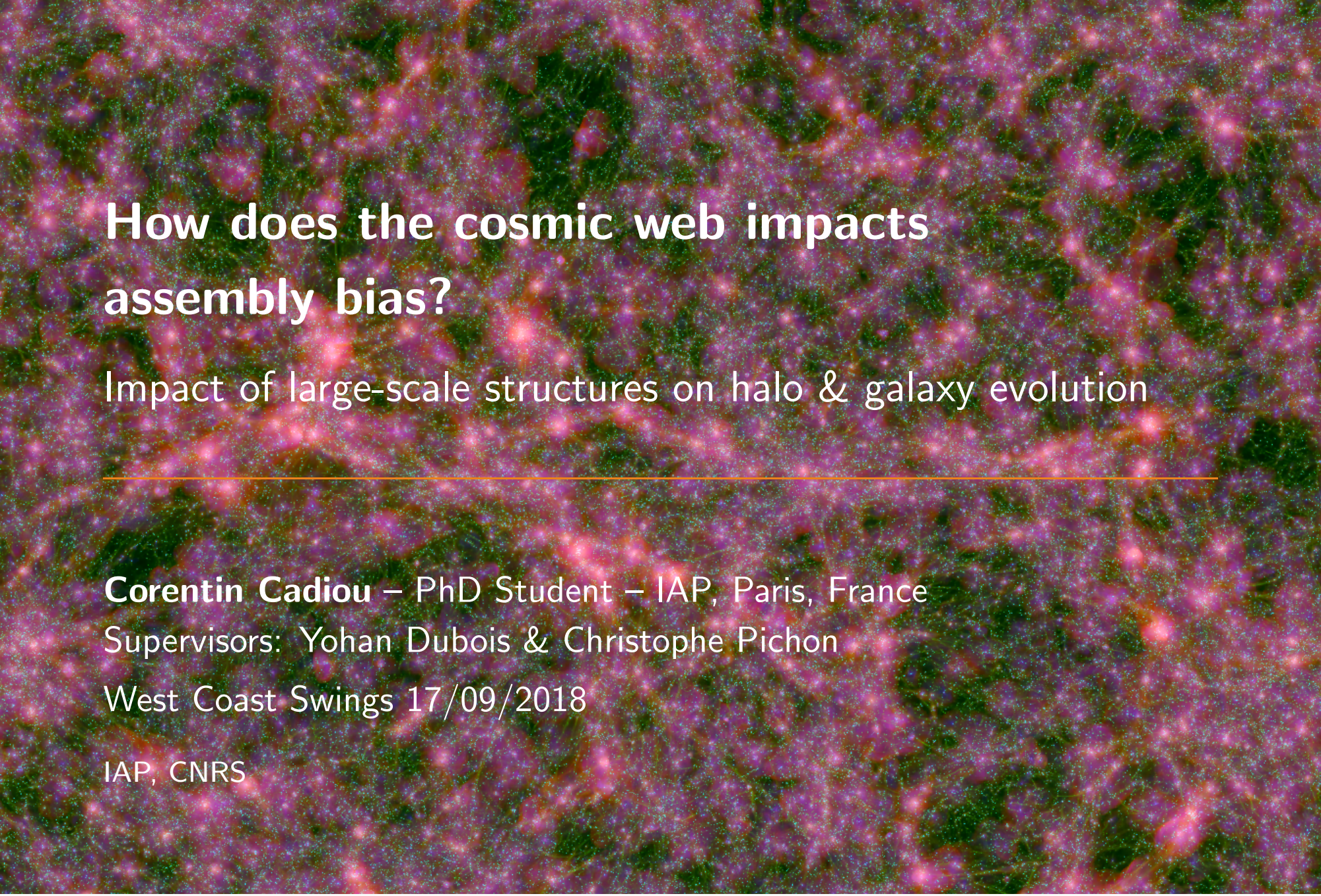

How does the cosmic web impacts assembly bias?

Impact of large-scale structures on halo & galaxy evolution

Corentin Cadiou – PhD Student – IAP, Paris, France
Supervisors: Yohan Dubois & Christophe Pichon

West Coast Swings 17/09/2018

IAP, CNRS

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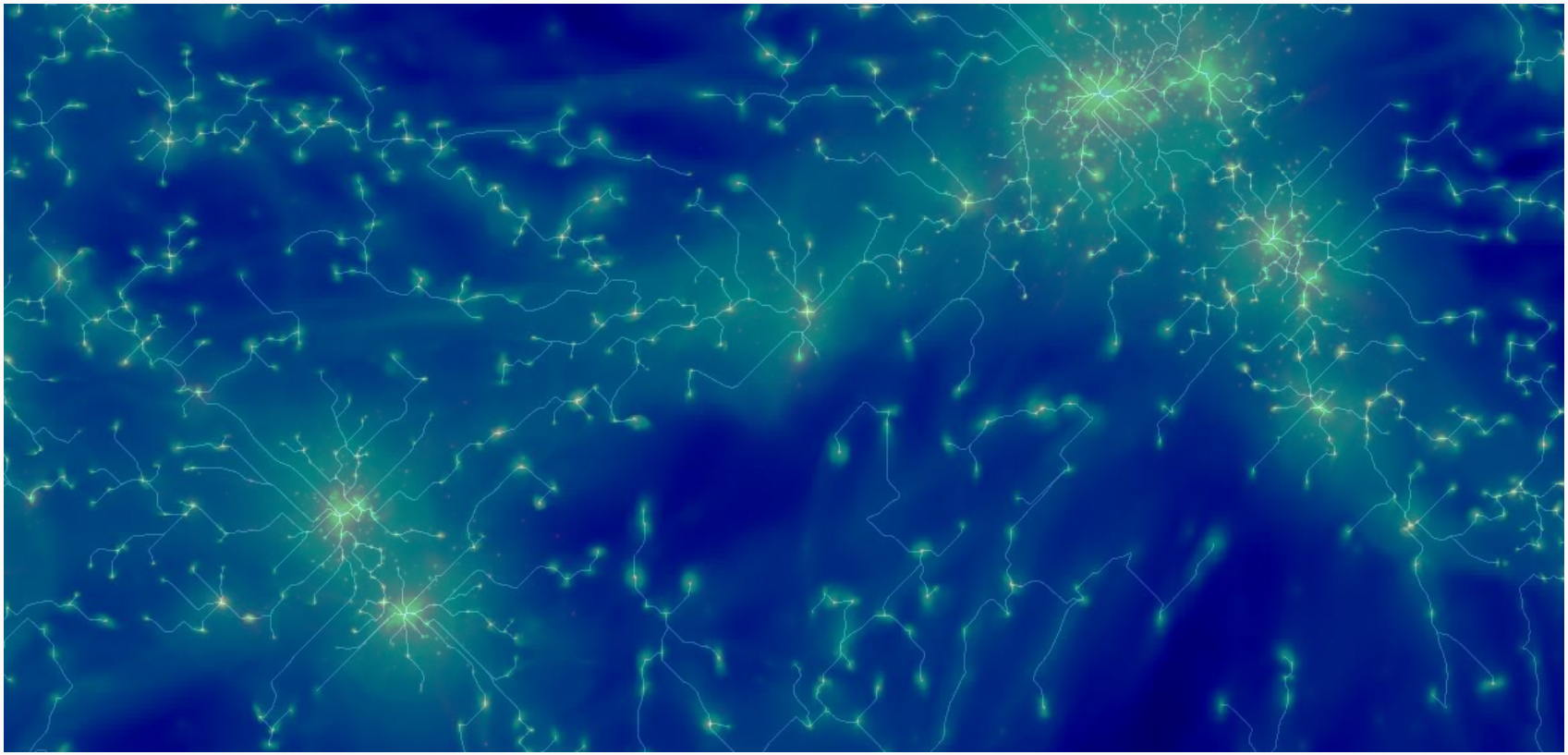
Introduction

What's the link between galaxy/halo formation and large-scale structures?

DM/Galaxy properties

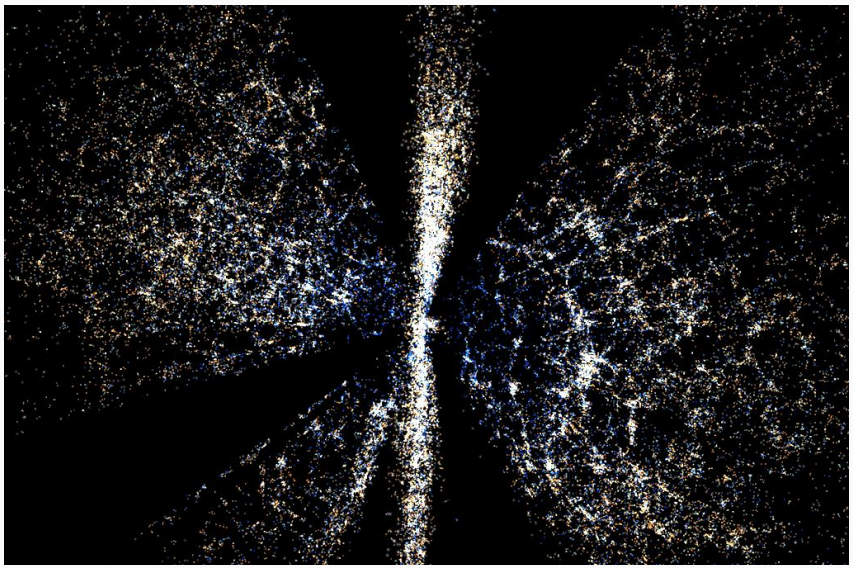


Horizon-AGN simulation with skeleton, Dubois+12

DM Halo & Galaxy properties **change with cosmic time** and location w.r.t. **the cosmic web** (see e.g. K. Kraljic+2017)!

Cosmic Web

- Geometry of the density/potential field
- Voids, walls, filaments, peaks (resp. 3, 2, 1, 0D)



Cosmic Web

- Geometry of the density/potential field
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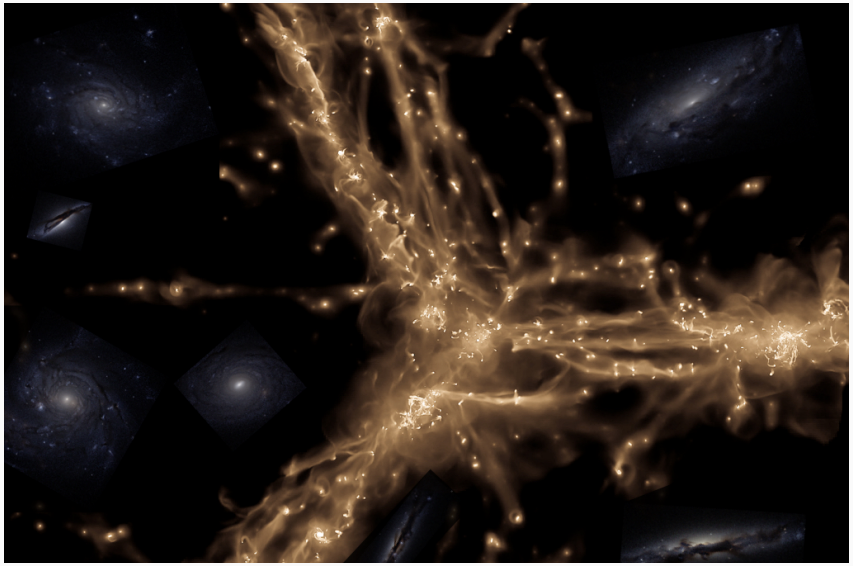
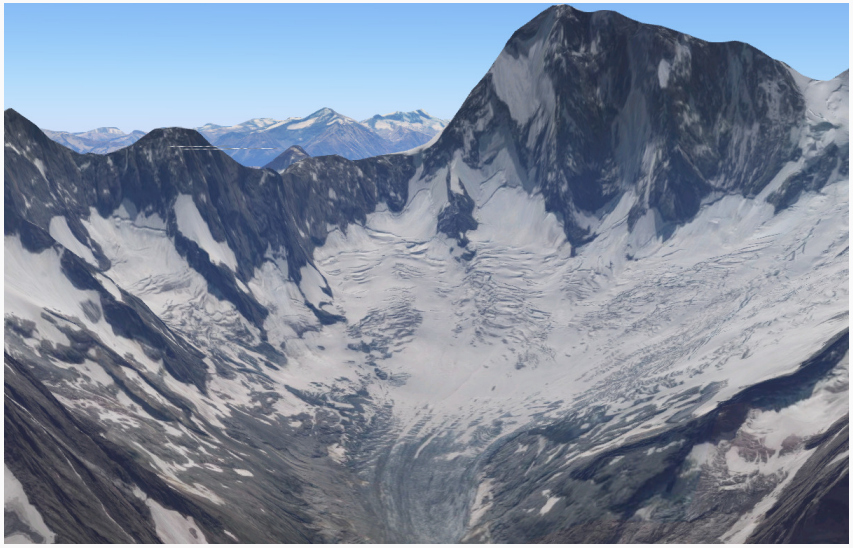


Cosmic Web

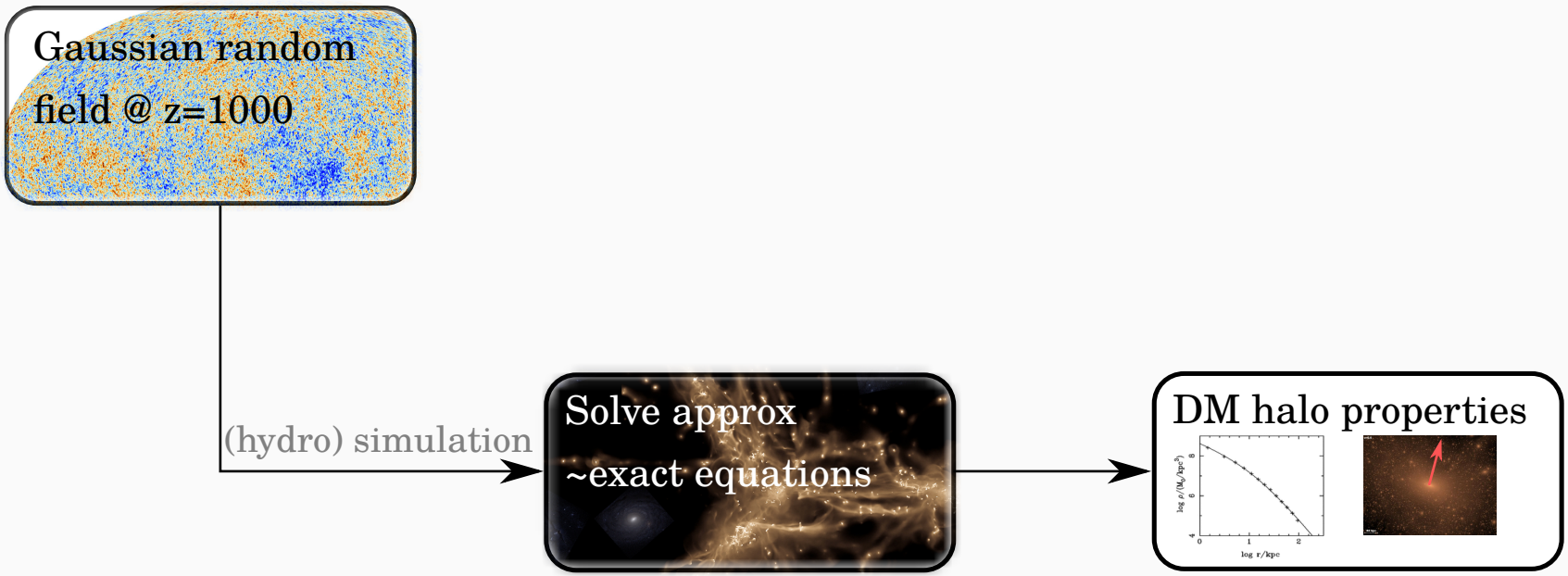
- Geometry of the density/potential field
- Voids, walls, filaments, peaks (resp. 3, 2, 1, 0D)

  or
- Critical points (0D, minima, saddle points and maxima)

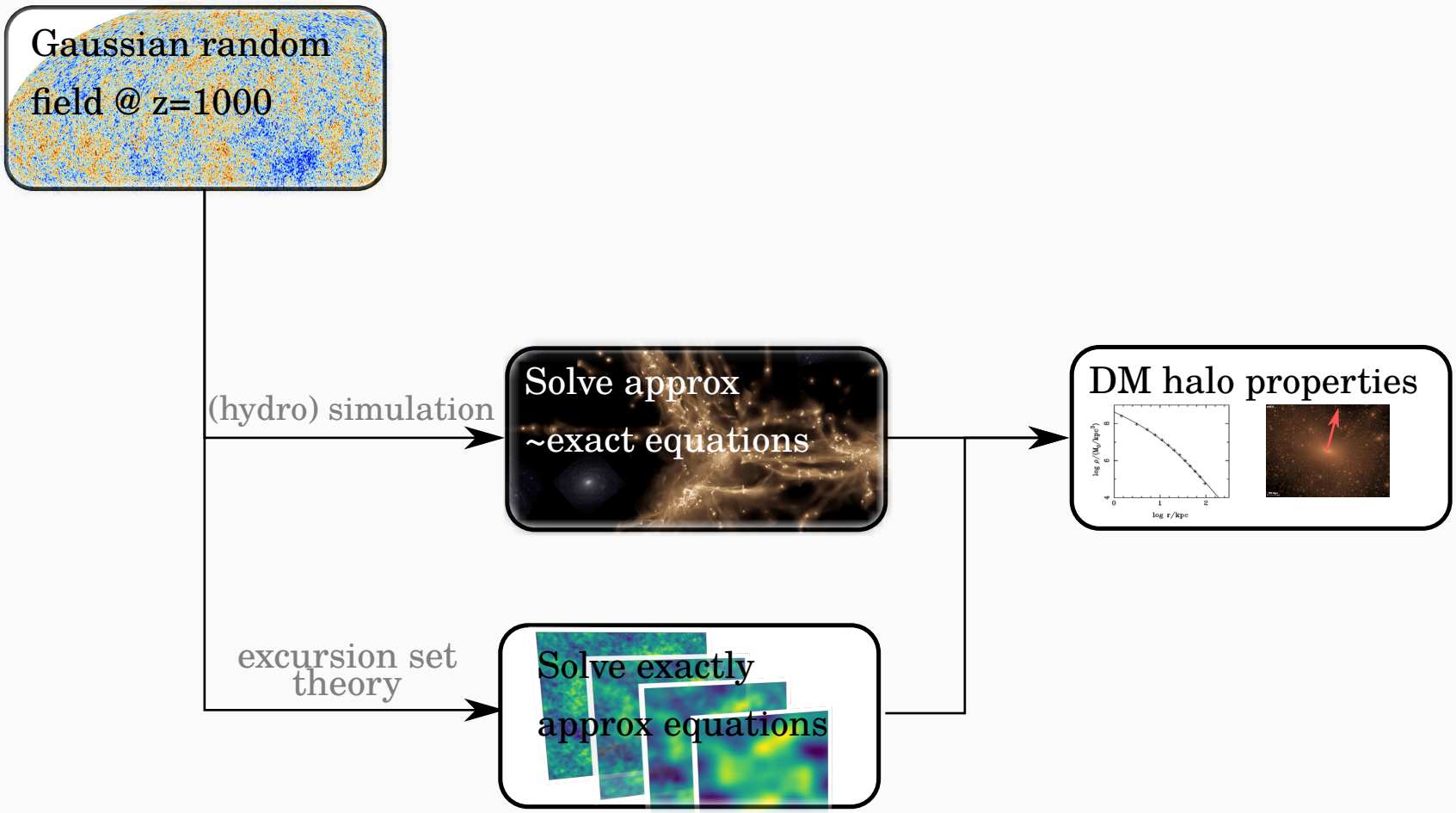


Quick intro to Excursion Set Theory

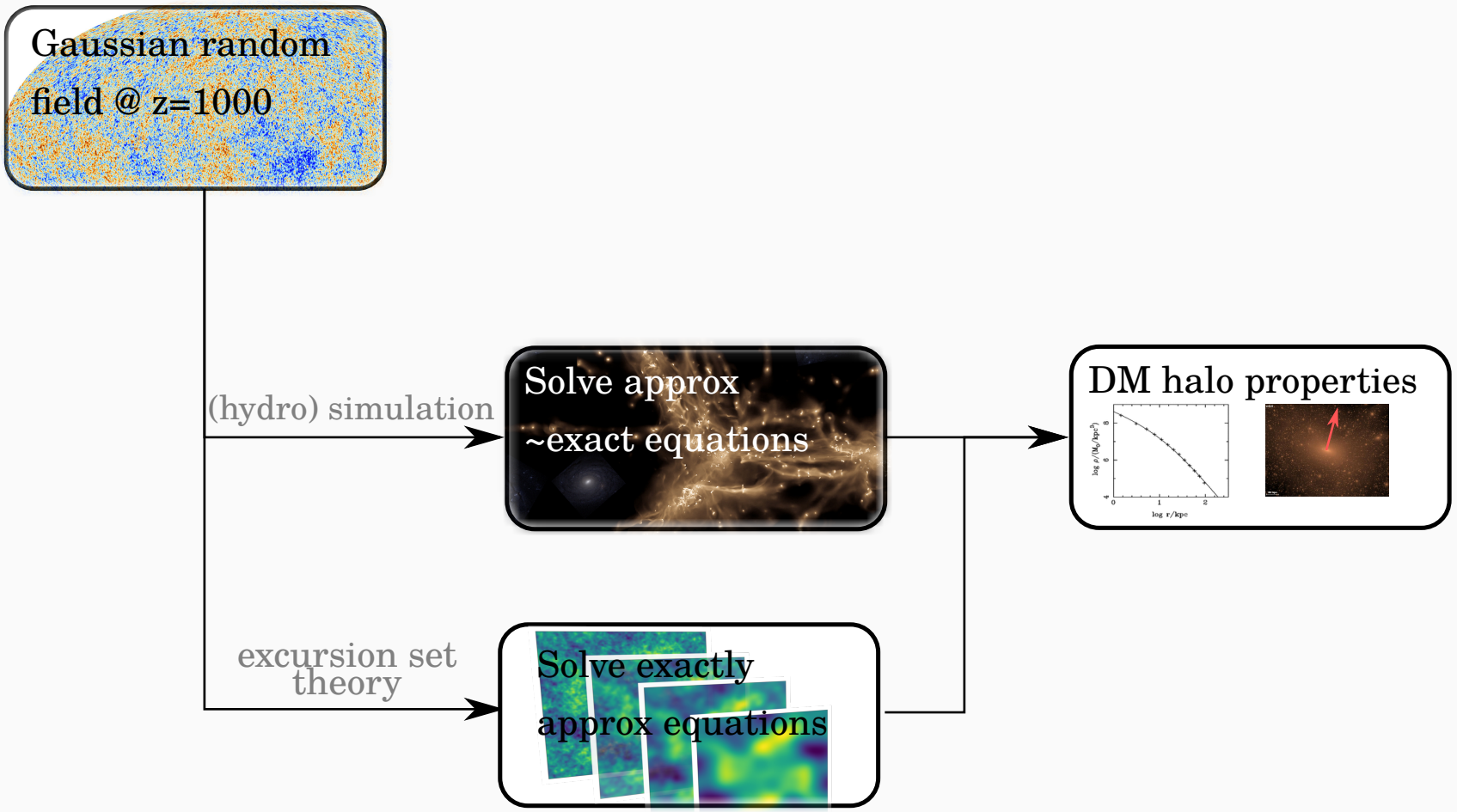
Excursion set theory – saving a few M CPU.hrs



Excursion set theory – saving a few M CPU.hrs



Excursion set theory – saving a few M CPU.hrs

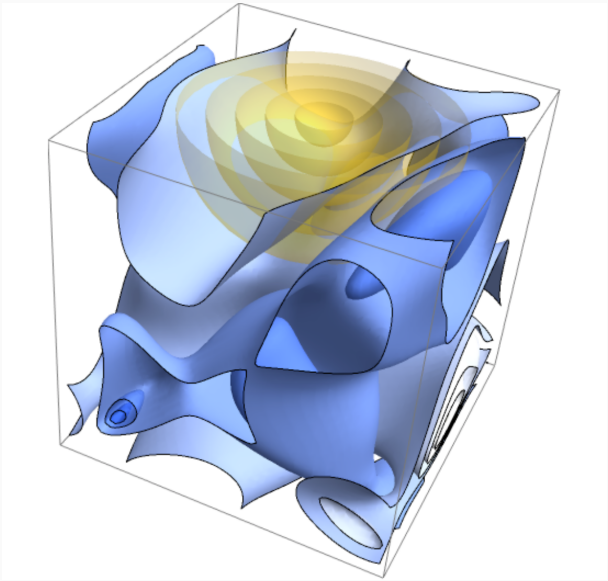


Press&Schechter 74, Bond+91, ...

Theoretical setup

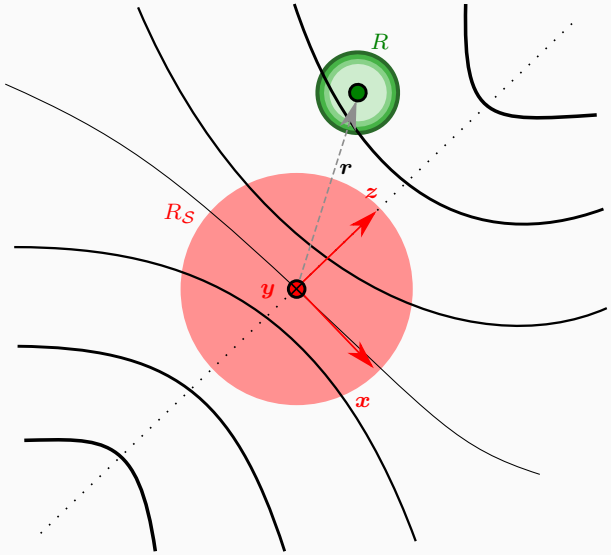
Excursion set theory
Halo properties & evolution from initial conditions

$\Rightarrow$ Find largest mass that will collapse by z at given location

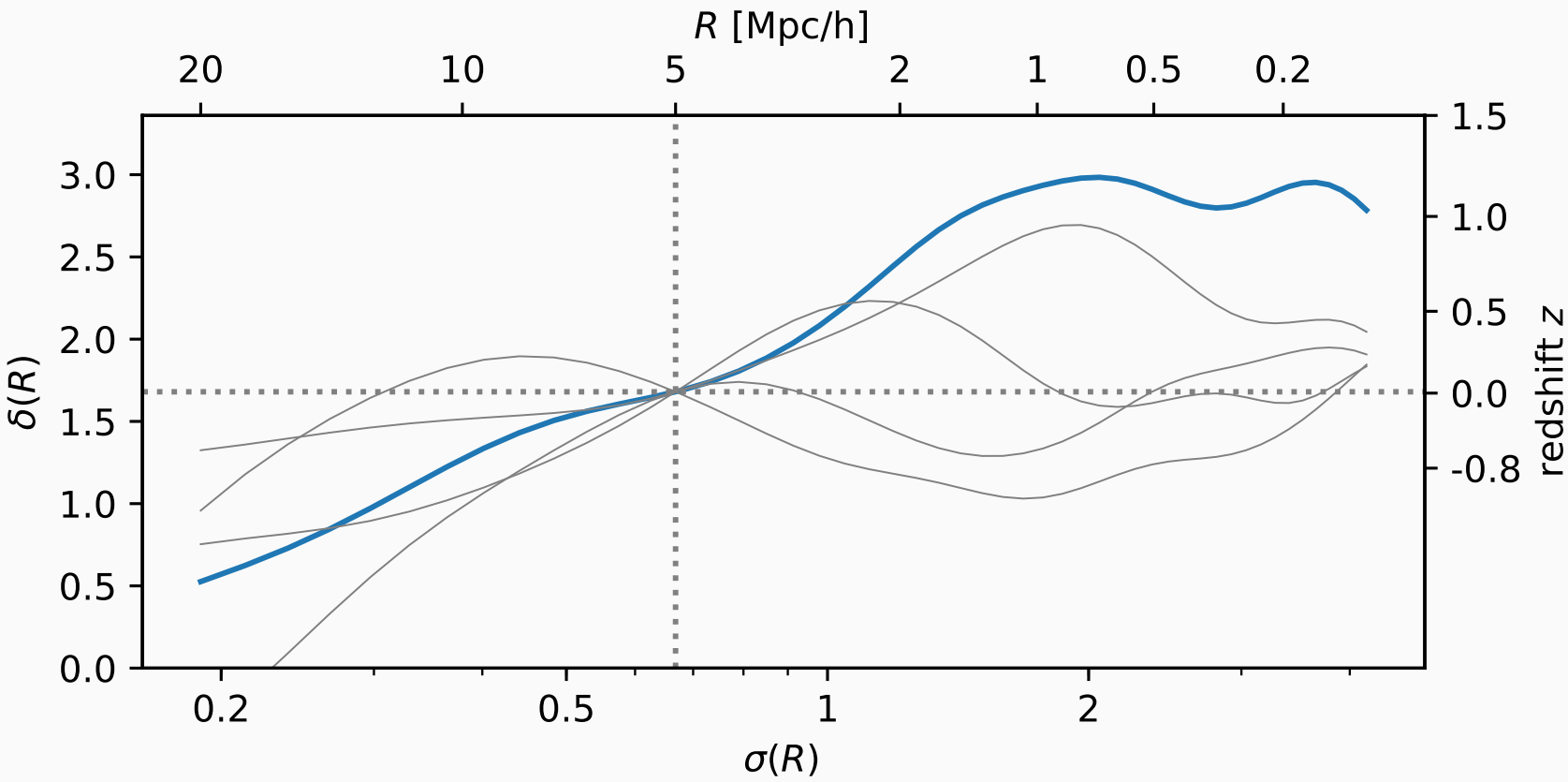


Courtesy of C. Pichon

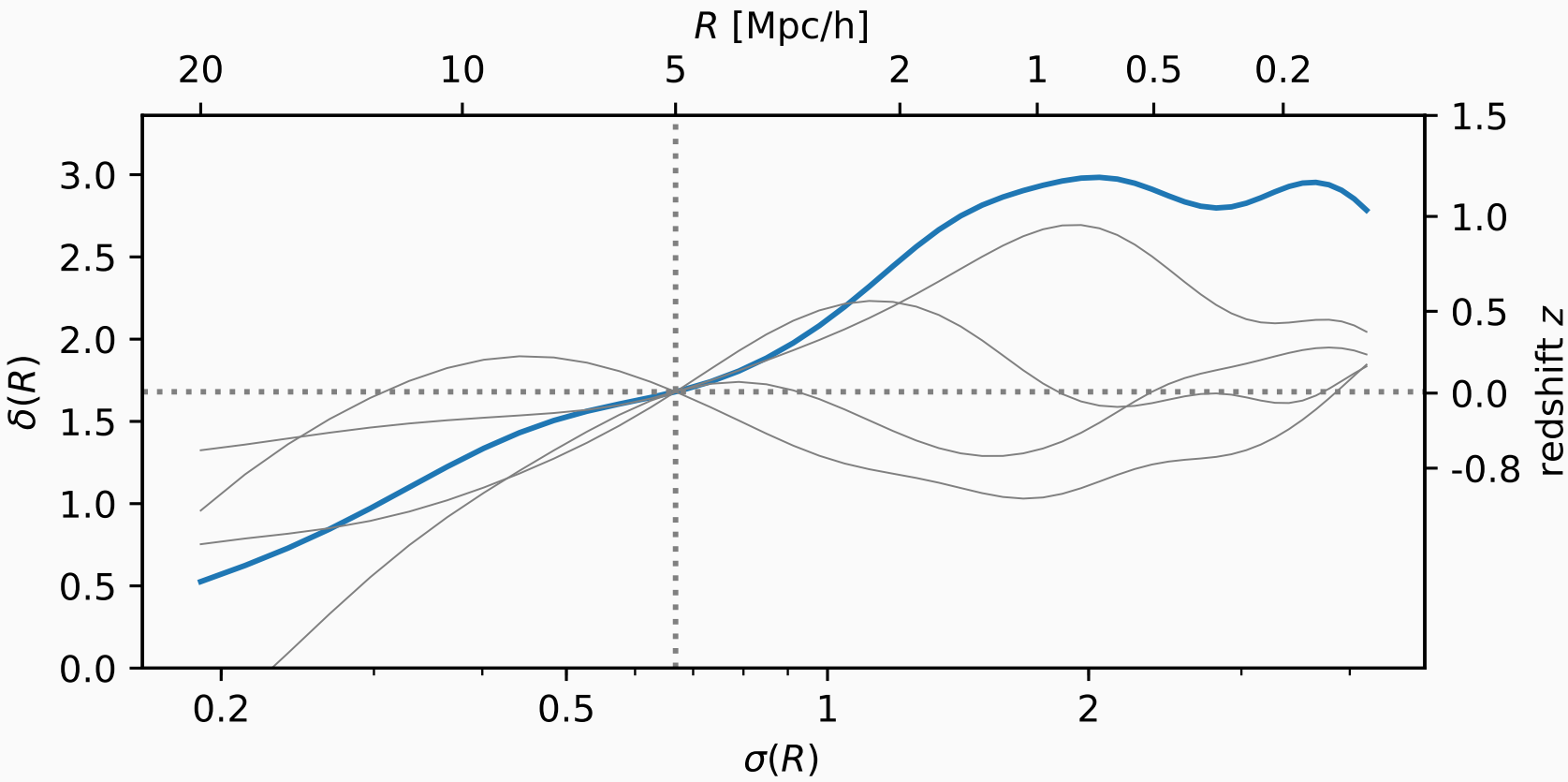
Simulation	Theory
M	R
z, t	$\delta = \frac{\rho - \bar{\rho}}{\bar{\rho}}$



Excursion Set illustrated



Excursion Set illustrated

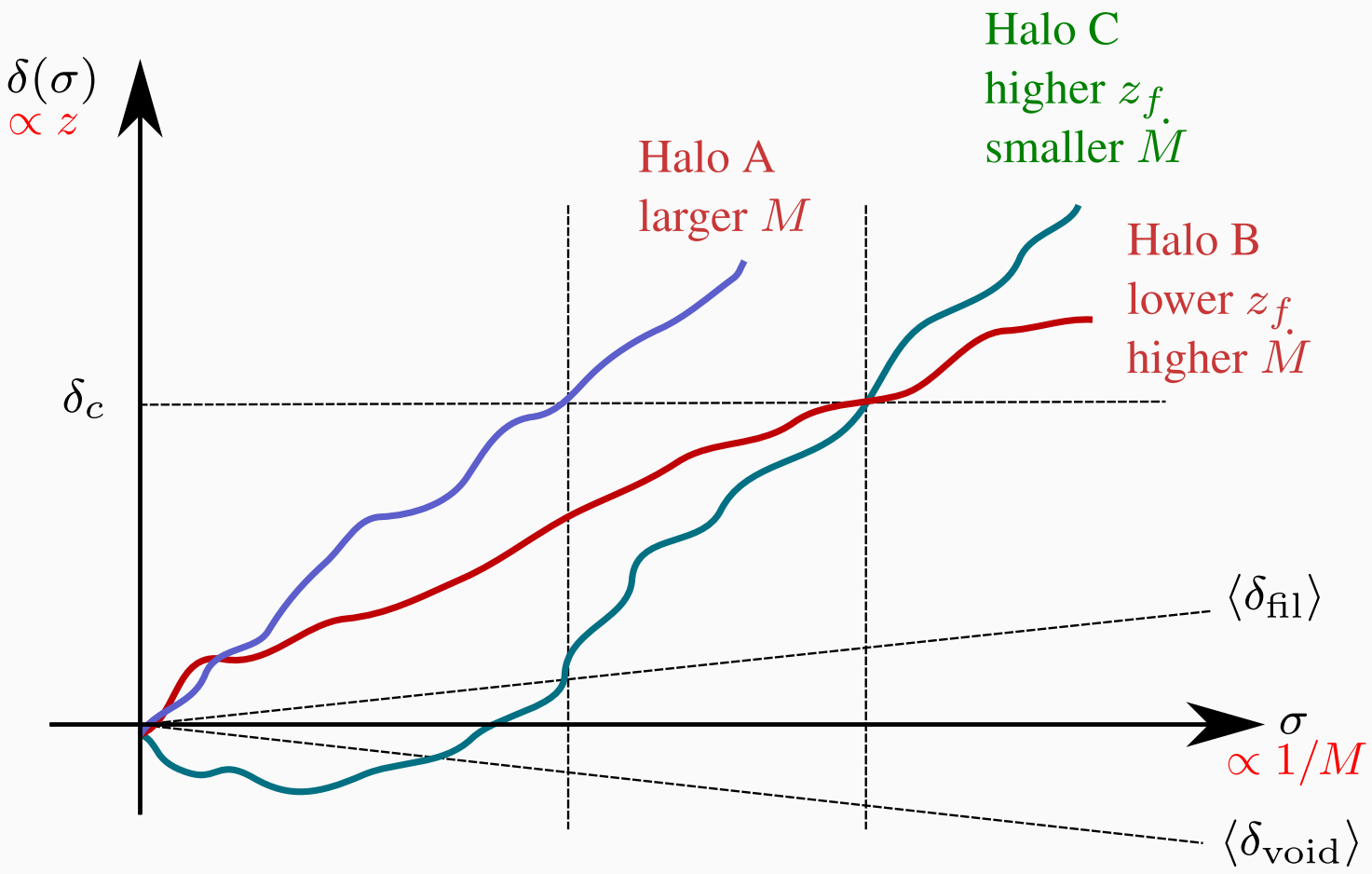


High density $\rightarrow$ early collapse

Large smoothing scale $\rightarrow$ large mass

Large slope $\rightarrow$ small accretion rate

Schematical picture



Red: in filament, green: in void

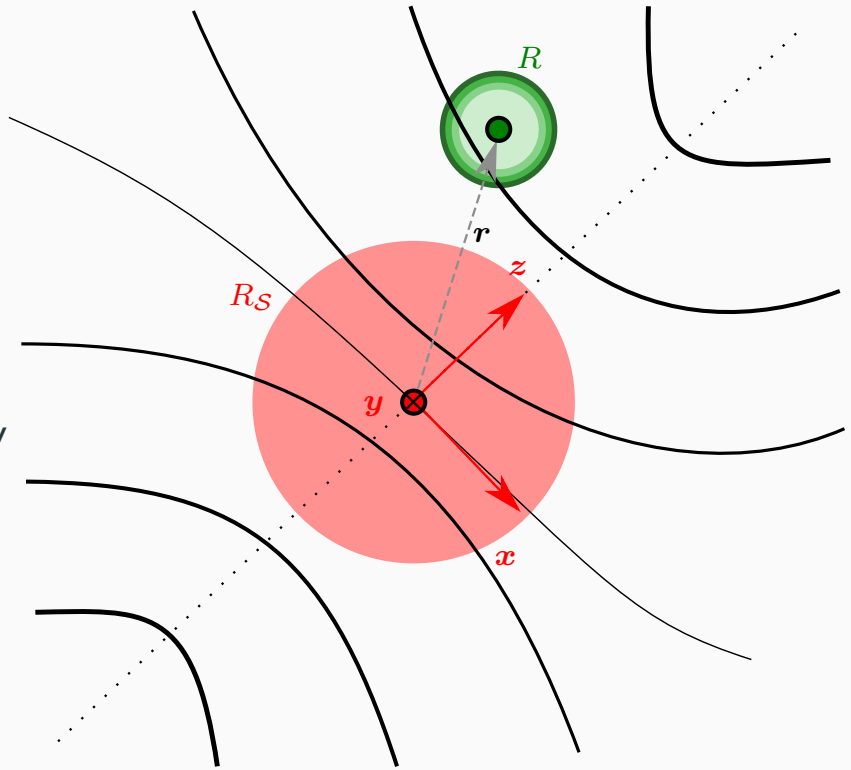
Including filaments

Anisotropy encoded in the Hessian of tidal tensor

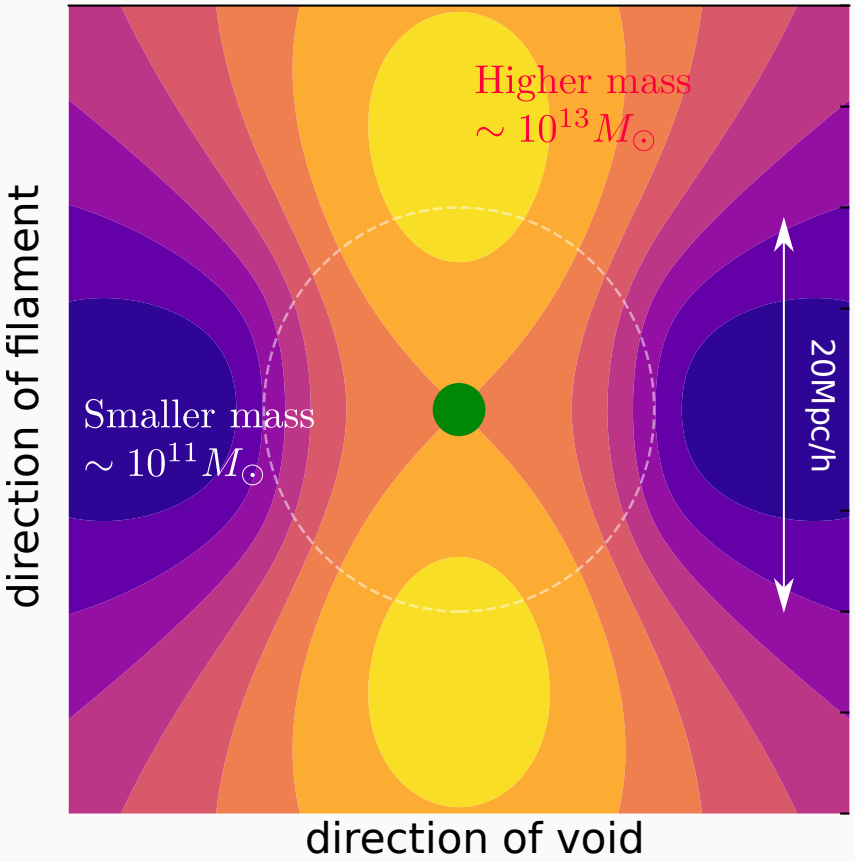
$$q_{ij} = \underbrace{\left(\phi_{ij} - \frac{\nu}{3}\delta_{ij}\right)}_{\bar{q}_{ij} \equiv \text{traceless part} \rightarrow \text{anisotropy}} + \underbrace{\frac{\nu}{3}\delta_{ij}}_{\text{density}}$$

via

$$\mathcal{Q} = \frac{r_i \bar{q}_{ij} r_j}{r_i r_j}$$



Typical mass of DM halo



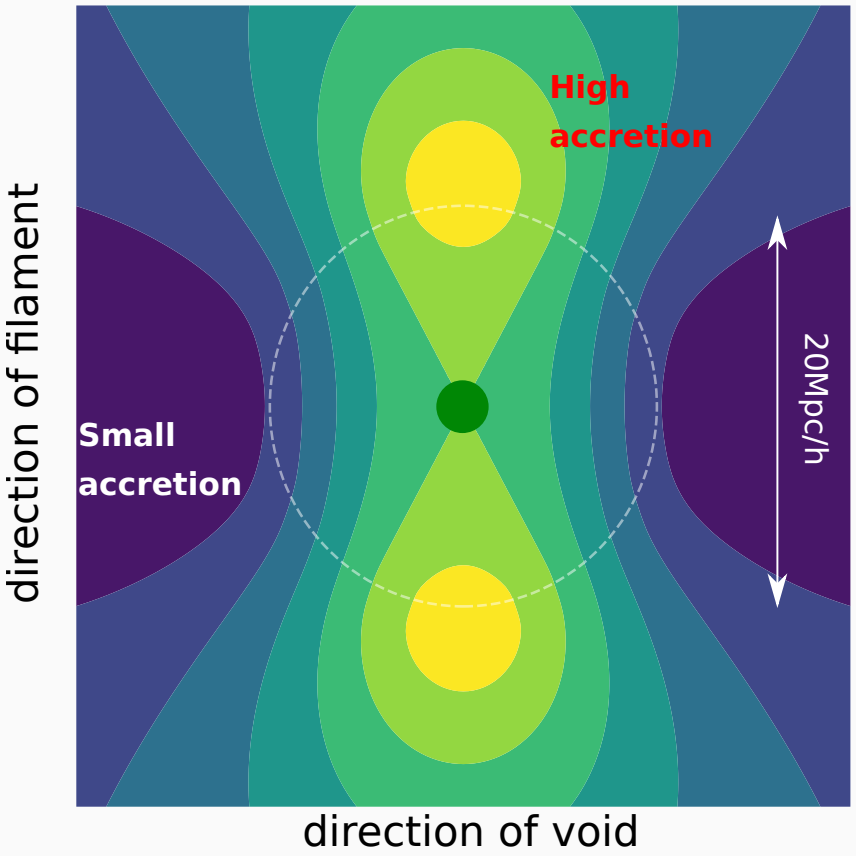
The typical mass at $z = 0$.

1. Larger galaxies in nodes
2. Smaller galaxies in voids

In agreement with *n*-body simulations.

M. Musso, C. Cadiou *et al.*, MNRAS

Effect on (DM) accretion rate



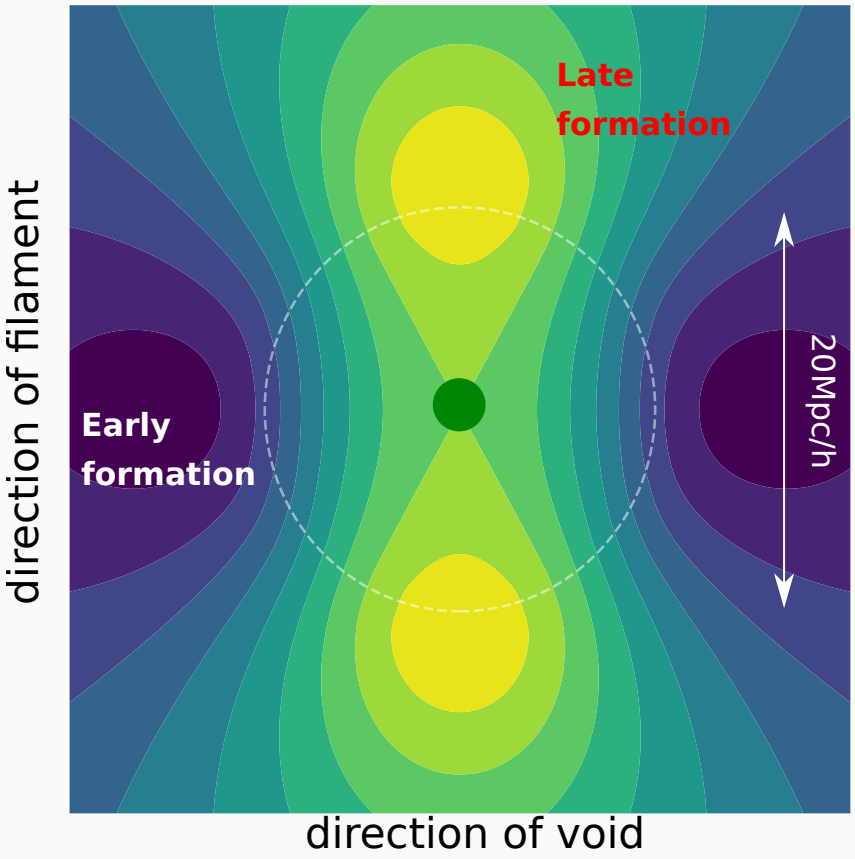
Accretion rate at **fixed** final mass

$$M \simeq 3 \times 10^{11}\,\mathrm{M}_{\odot}.$$

M. Musso, C. Cadiou *et al.*, MNRAS

1. High accretion rate in node
2. Small accretion rate in voids

Effect of halo formation time

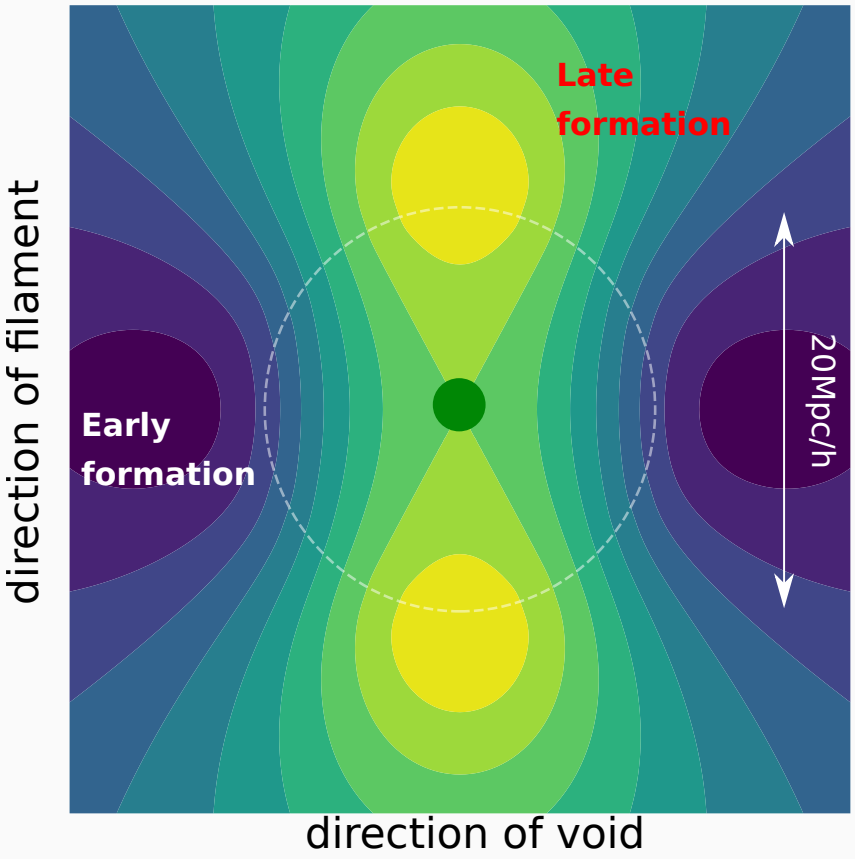


Formation time at **fixed** final mass $M \simeq 3 \times 10^{11}\,\mathrm{M}_{\odot}$.

1. Late formation in node (low z)
2. Early formation in voids (high z)

M. Musso, C. Cadiou *et al.*, MNRAS

Effect of halo formation time



Formation time at **fixed** final mass $M \simeq 3 \times 10^{11}\,\mathrm{M}_{\odot}$.

1. Late formation in node (low z)
2. Early formation in voids (high z)

Tension with observations?

M. Musso, C. Cadiou *et al.*, MNRAS

Trying to fill gap with galaxy formation

Theory

Higher DM accretion + late formation:

blue central galaxy?

Observations

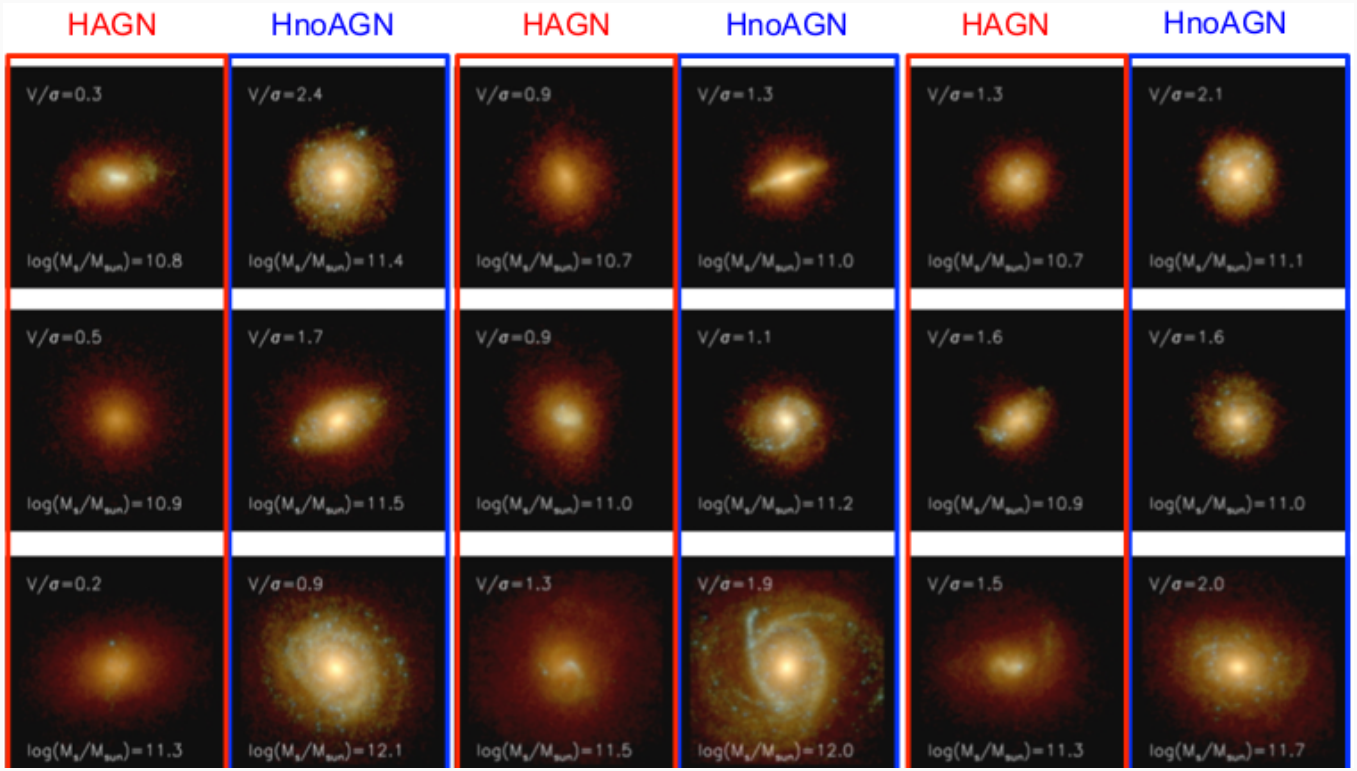
Massive red central galaxies

Trying to fill gap with galaxy formation

Theory
Higher DM accretion + late formation:

blue central galaxy?

Observations
Massive red central galaxies



Take home message

Assembly variables are functions of

- mass
- density

This is a non local effect! (to balance with e.g. Paranjape+18, Alam+18)

Take home message

Assembly variables are functions of

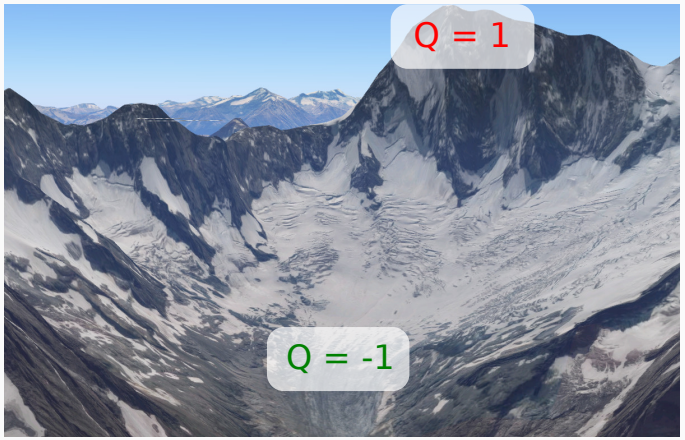
- mass
- density
- anisotropy, induced by saddle

Encoded by

$$\mathcal{Q} = \frac{r_i \bar{q}_{ij} r_j}{r^2} = \text{anisotropy}$$

$$+$$

$$r = \text{distance}$$



This is a non local effect! (to balance with e.g. Paranjape+18, Alam+18)

How does that compare to reality?

How does that compare to reality?

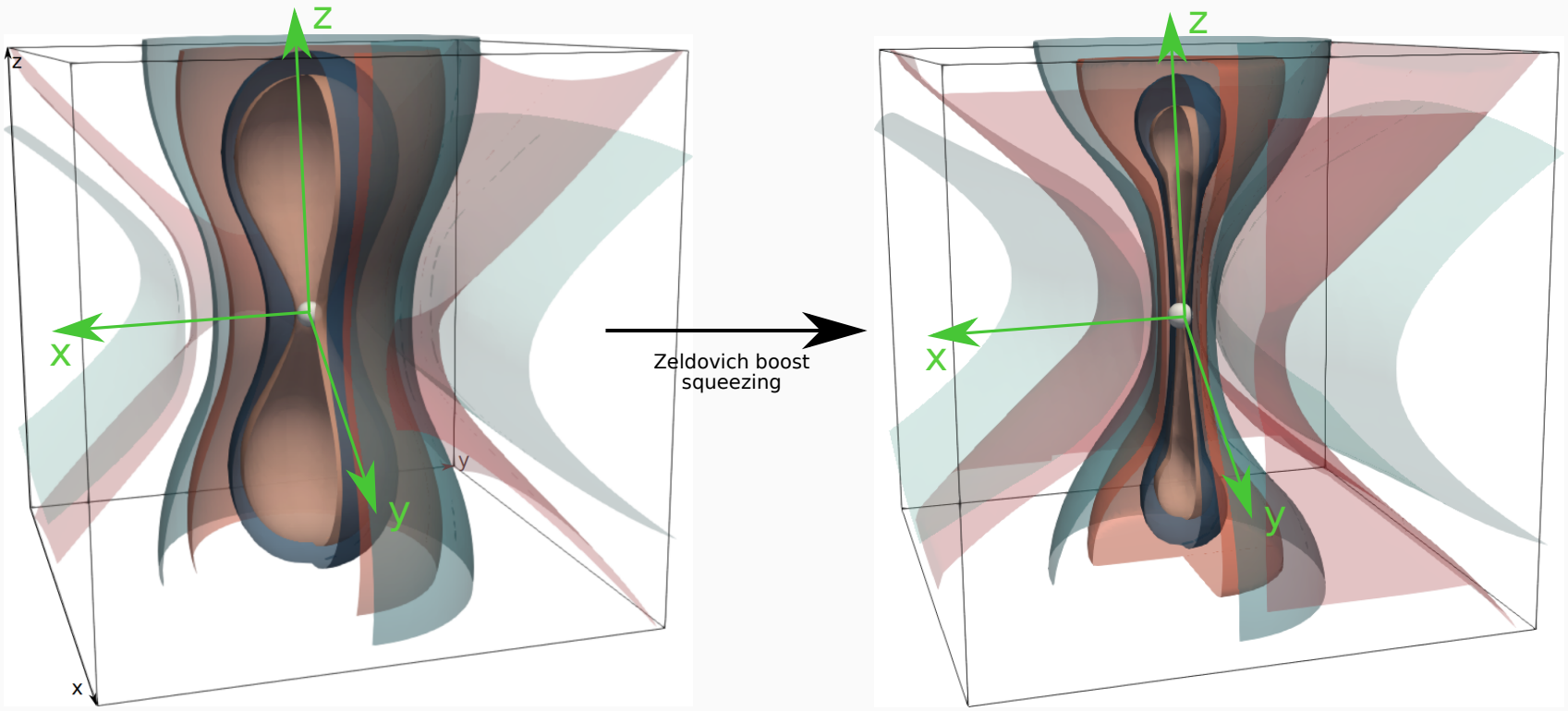
like observation

How does that compare to reality?

like observation

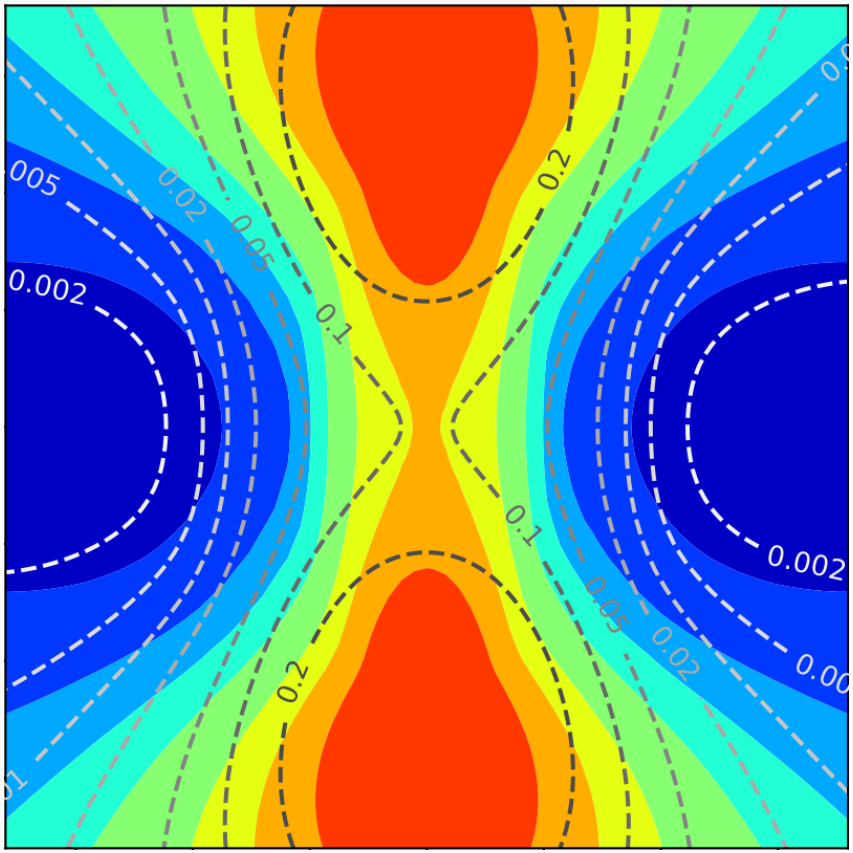
or actually simulations

Link to observation



Need to map Lagrangian space (theoretical space) to Eulerian space (simulation/observation space).

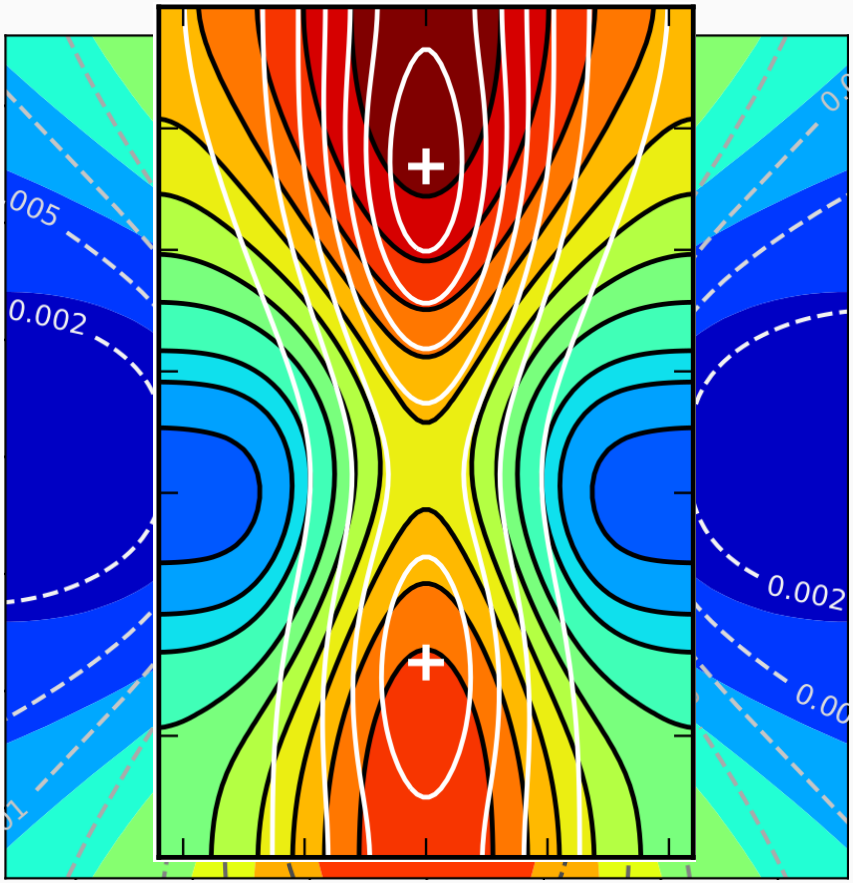
Link to simulations



Typical halo mass (in $10^{11}\,M_\odot$) theory vs. simulation

Kraljic+, submitted.

Link to simulations



Typical halo mass (in $10^{11}\,M_\odot$) theory vs. simulation

Kraljic+, submitted.

Where to go now?

Theoretical improvements

1. Improve model by including **local** corrections spherical $\rightarrow$ ellipsoidal collapse (Castorina+16, Paranjape+18, Alam+18).

Numerical improvements

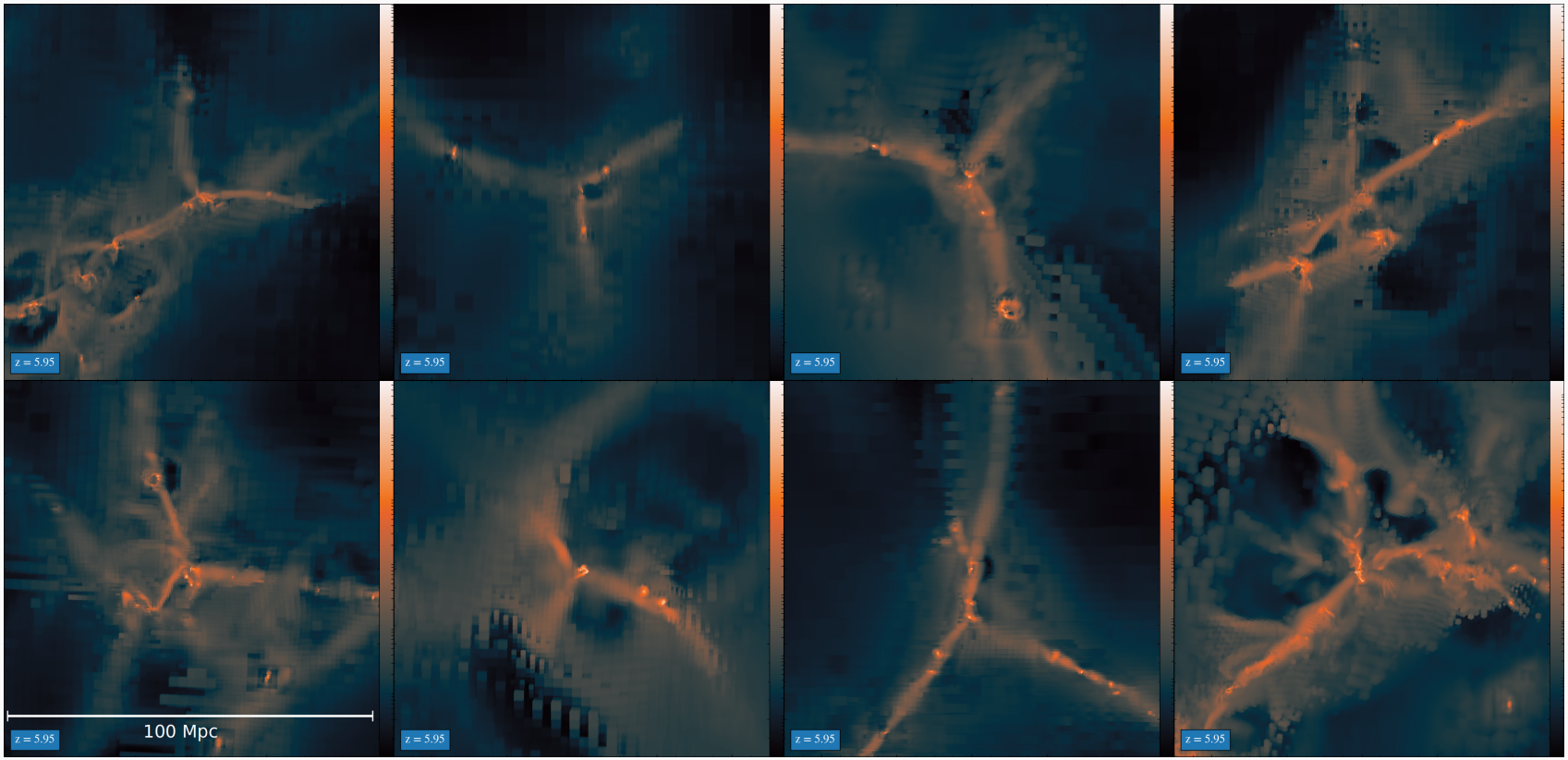
Study connection between...

1. large scale DM structures and cold filaments (baryons)
2. cold filaments and angular momentum buildup?

WIP with Y. Dubois, method paper coming up soon, simulations running. Come to me for questions!

Filamentary accretion at high z

From simulations



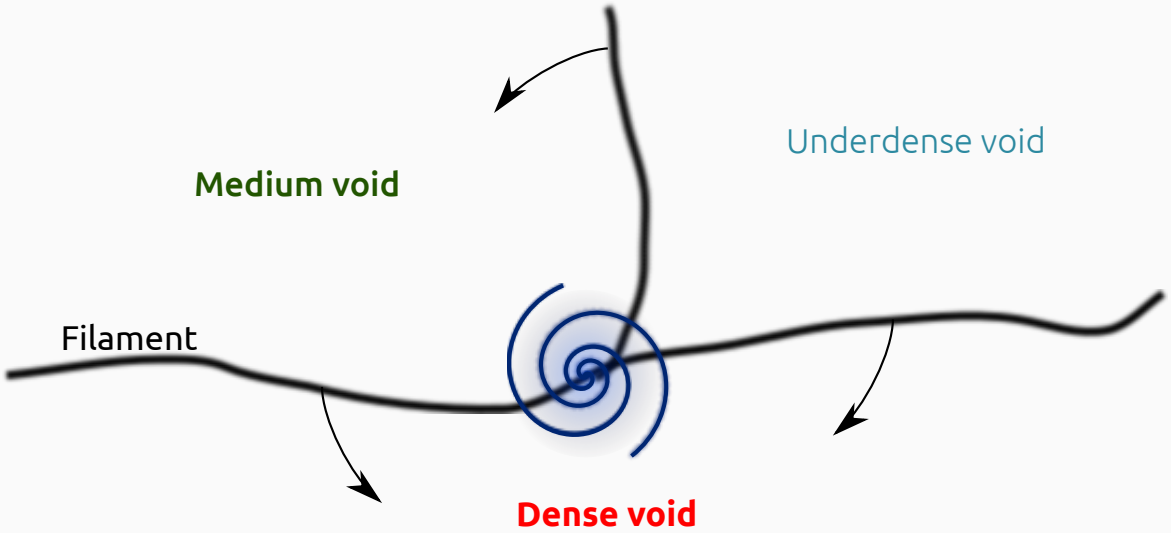
Density maps of galaxies from New Horizon simulation @ $z = 6$, Dubois+, in prep.

Typical setup: planar with 3 filaments

2D model

Open questions

- Net torque on filaments?
- Galaxy spin-up or down?
- Typical coherence scale?



C. Cadiou, C. Pichon & S.Codis, in prep

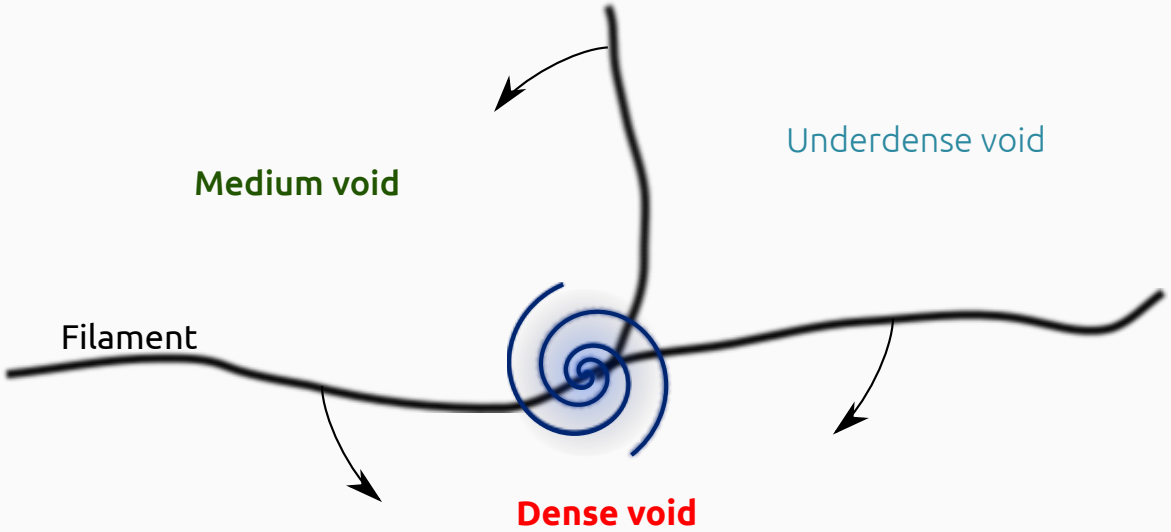
2D model

Open questions

- Net torque on filaments?
- Galaxy spin-up or down?
- Typical coherence scale?

Model

- Planar (2D)
- 3 voids $\rightarrow$ 3 filaments
- 1 central peak

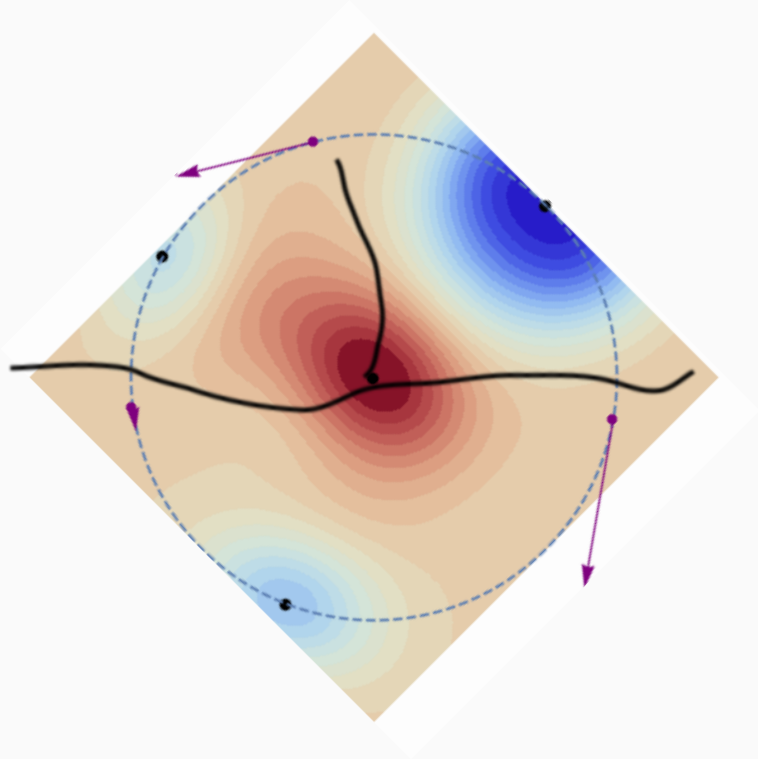


C. Cadiou, C. Pichon & S.Codis, in prep

Predicting the torque

Using constrained theory + Λ-CDM power spectrum

Voids are pushing filaments



C. Cadiou, C. Pichon & S.Codis, in prep

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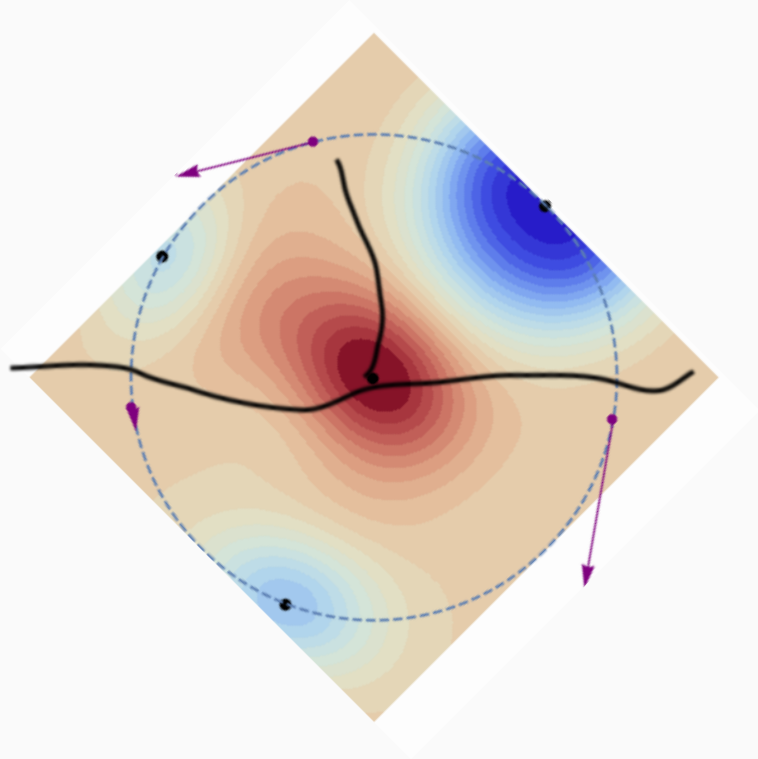
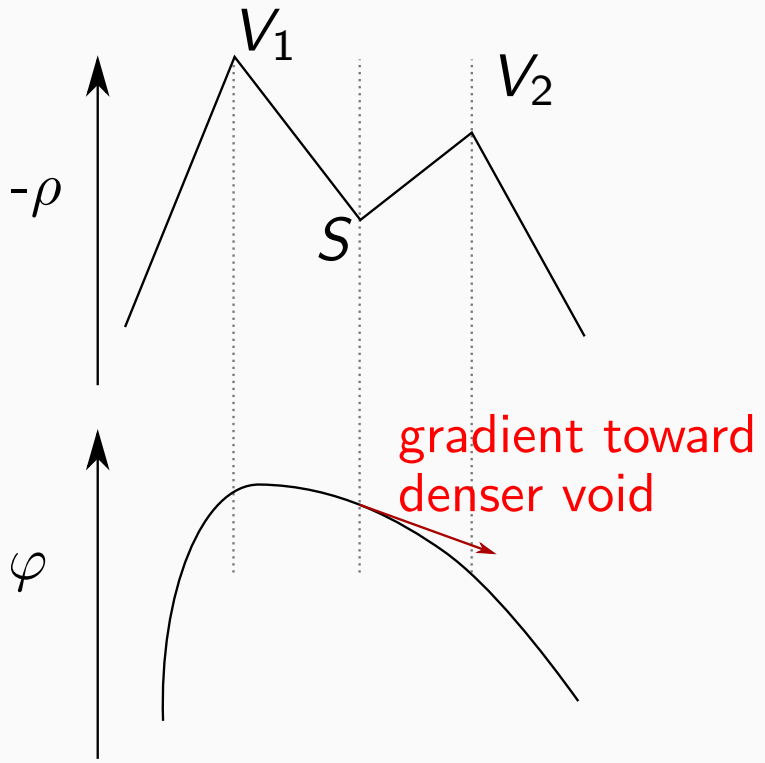
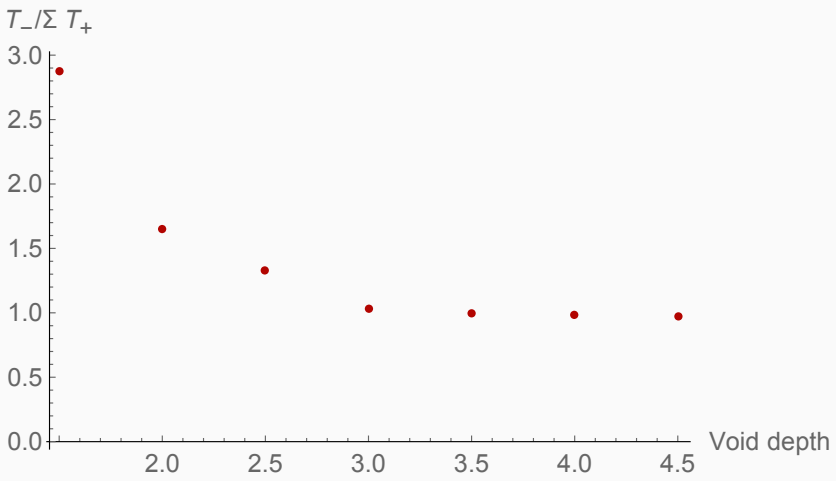
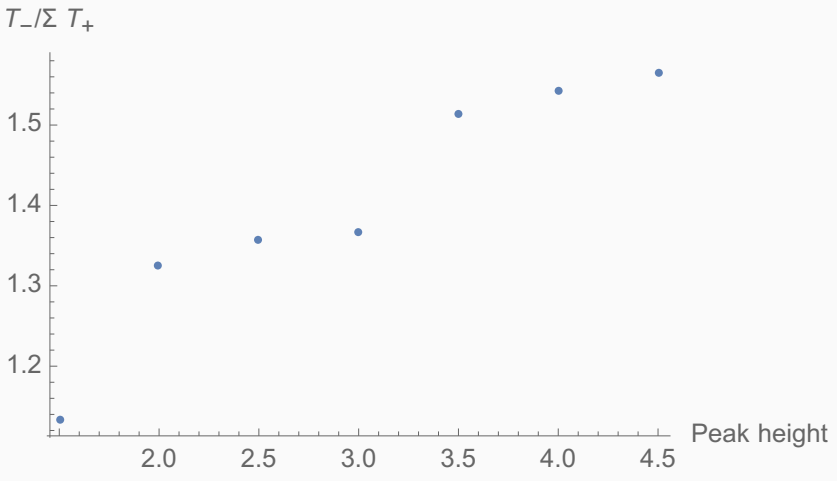


C. Cadiou, C. Pichon & S.Codis, in prep



Preliminary results





1. Void depth decreases relative torque effect.
2. Peak height (rarity) increases relative torque effect.

Improvement to the model

Improvements

- Use real power spectrum instead of (2D) power law
- Assess validity of model on baryons/DM

Conclusions

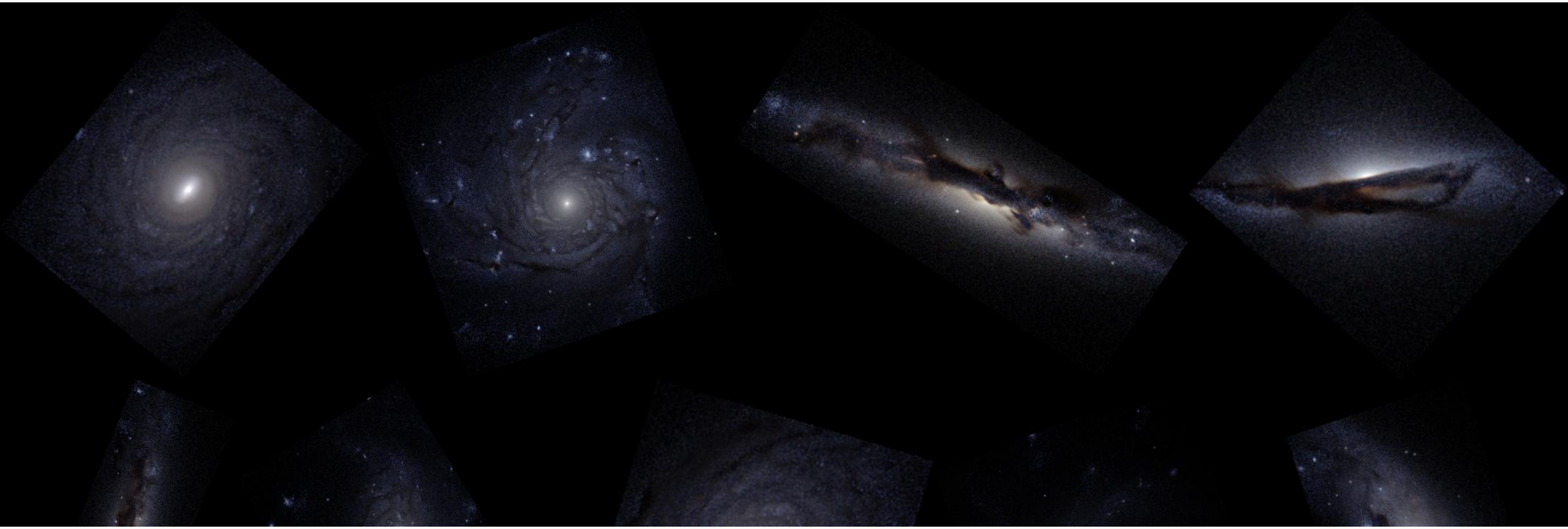
Conclusions

Assembly of DM halo

- Influenced by LSS
- Recovers *n*-body sim
- Still need baryonic physics

Torque on filament

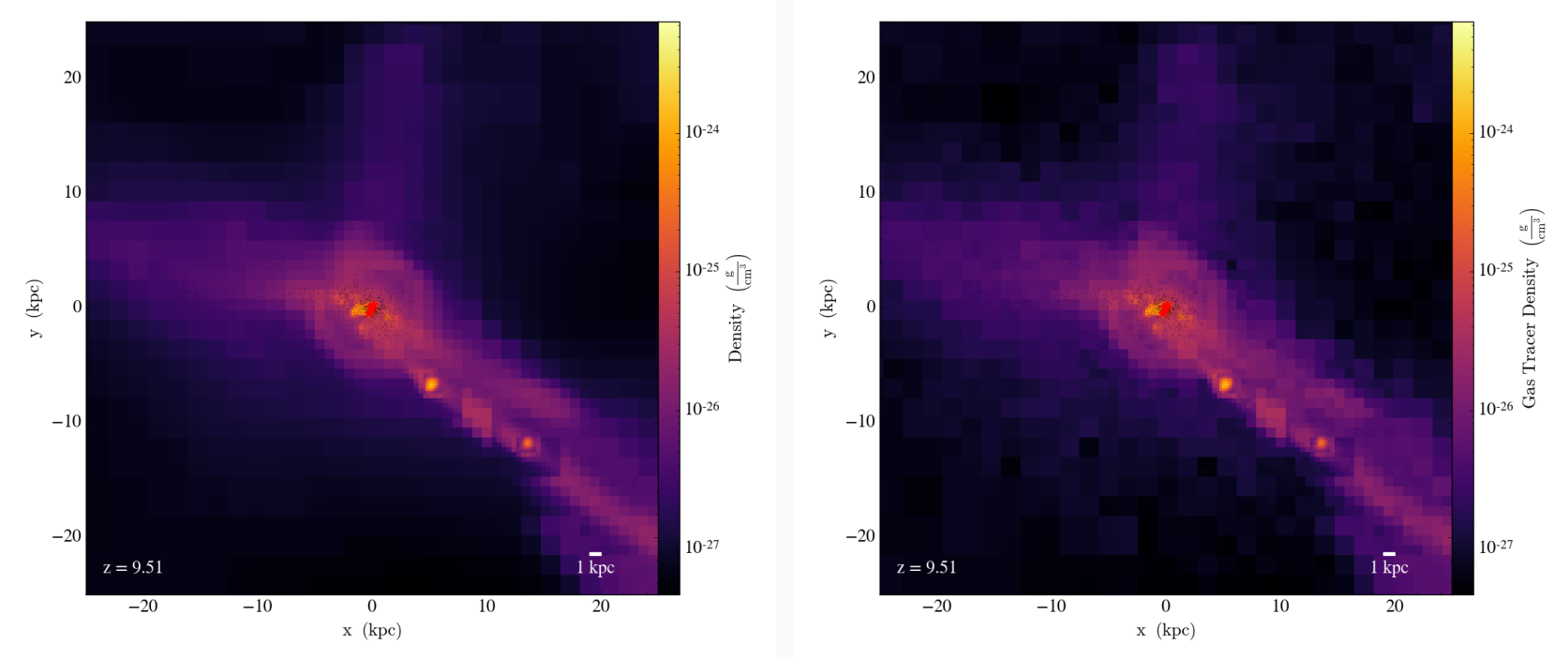
- Expect torque on filament
- Quantitative results
- Compare with simulations?



Thank you!

What's next?

Study of interaction cold flows/disk

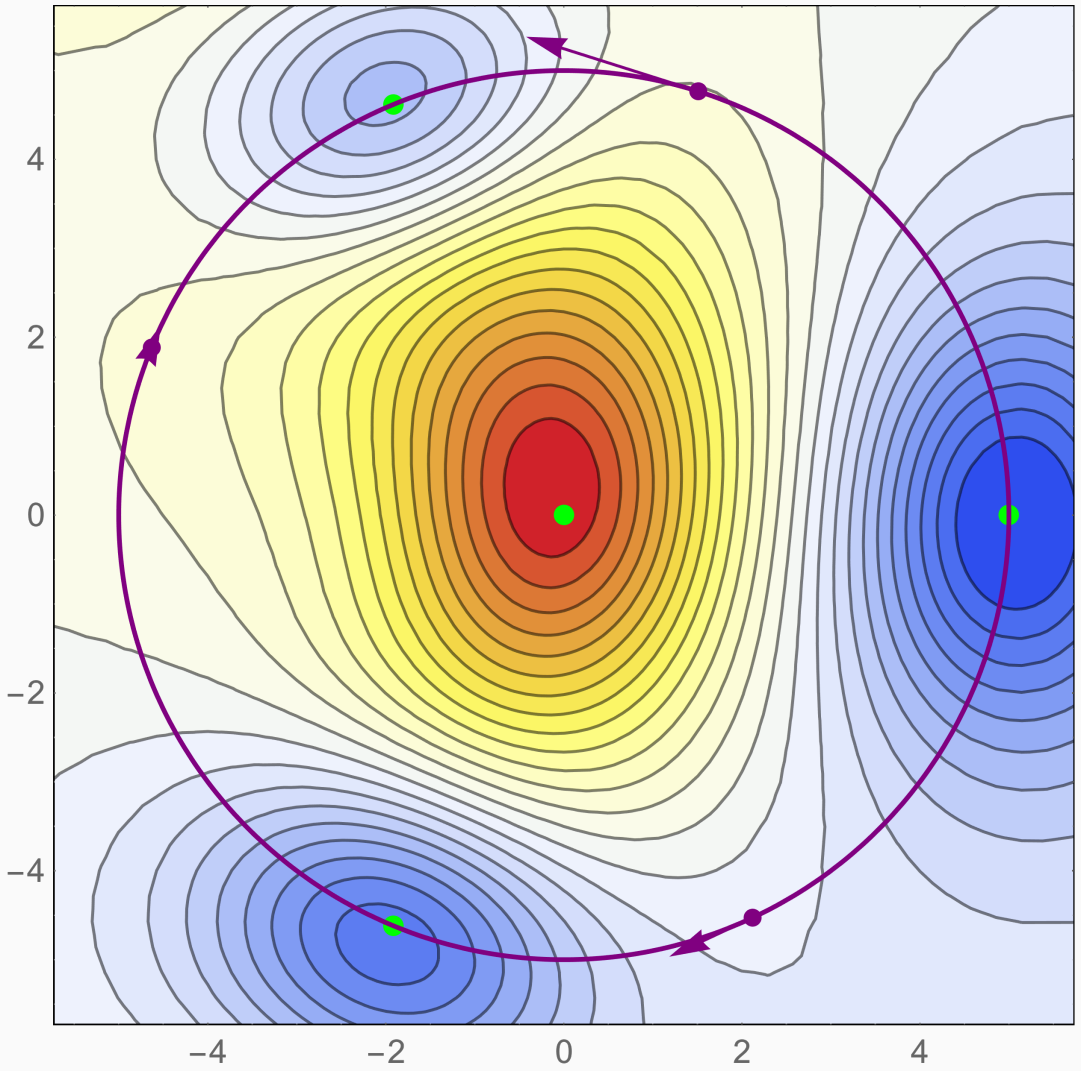


"Lagrangian in Eulerian code", see Genel+13

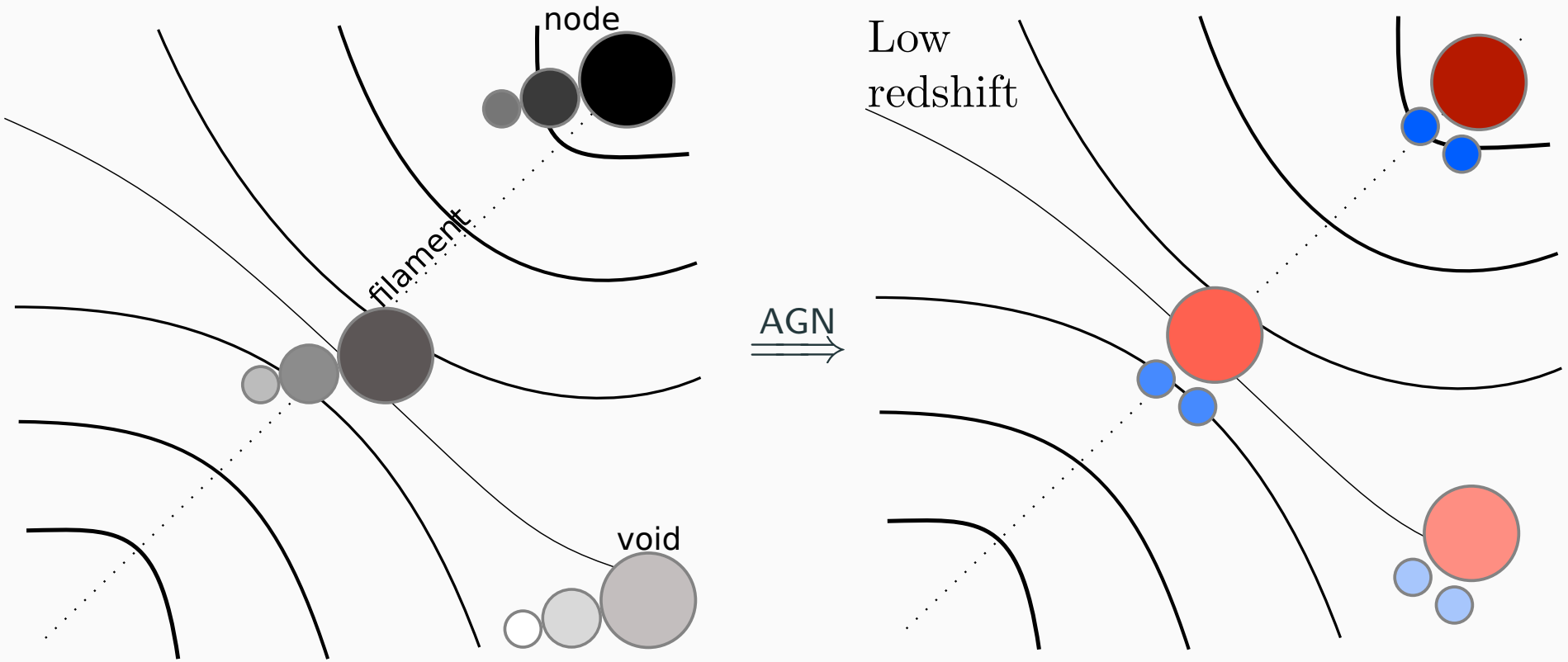
Fill the gap between large scale (filaments) and galaxy properties

More torque plots

Torque on filament



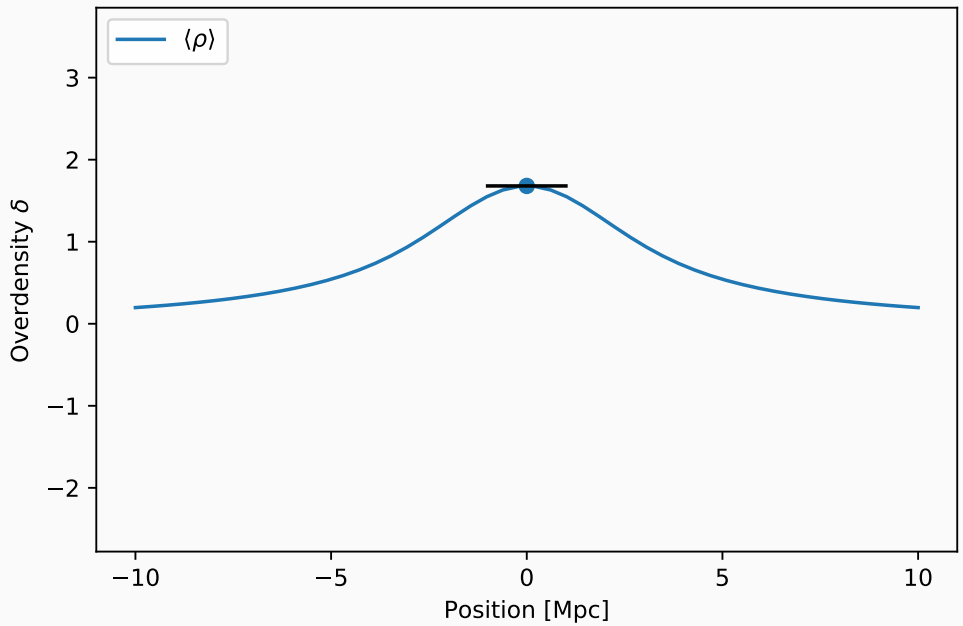
Effect of AGN



Beyond Mass-Density

4 parameters dictate mass/accretion/formation time/. . . :

- mean density δ
- mean derived density $\delta' = \frac{\mathrm{d}\delta}{\mathrm{d}R}$

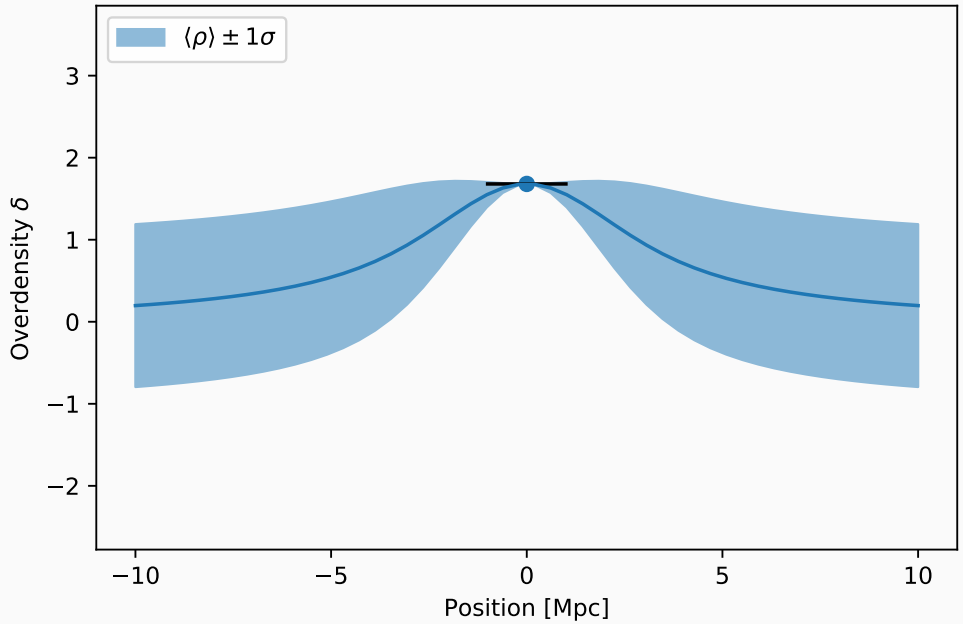


Environments with different variance do not behave the same: what matters is $(\delta - \langle\delta\rangle)/\sqrt{\mathrm{Var}(\delta)}$

Beyond Mass-Density

4 parameters dictate mass/accretion/formation time/. . . :

- mean density δ
- mean derived density $\delta' = \frac{\mathrm{d}\delta}{\mathrm{d}R}$
- variance of density
- variance of accretion

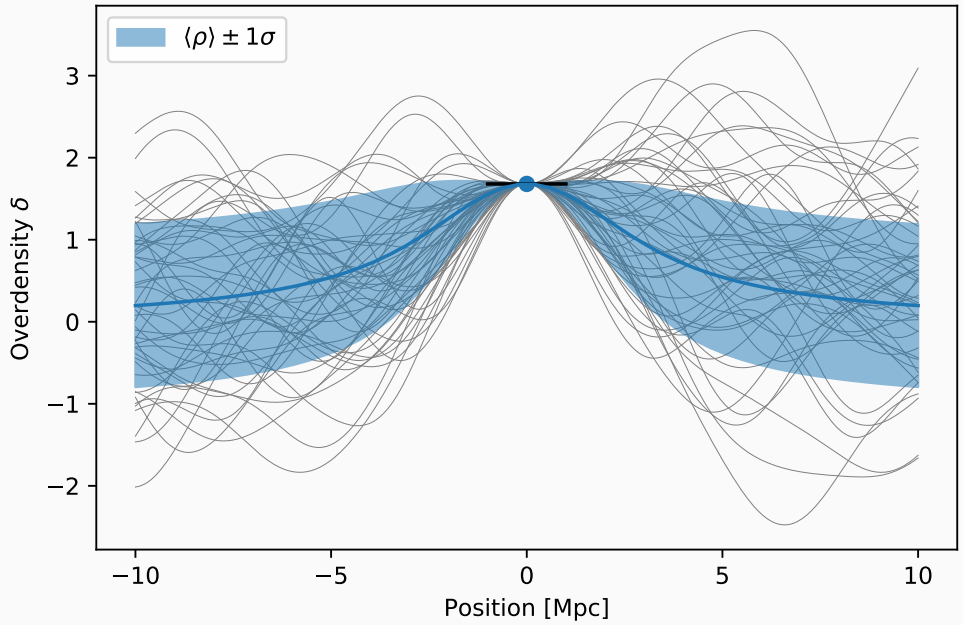


Environments with different variance do not behave the same: what matters is $(\delta - \langle\delta\rangle)/\sqrt{\mathrm{Var}(\delta)}$

Beyond Mass-Density

4 parameters dictate mass/accretion/formation time/...:

- mean density δ
- mean derived density $\delta' = \frac{\mathrm{d}\delta}{\mathrm{d}R}$
- variance of density
- variance of accretion



Environments with different variance do not behave the same: what matters is $(\delta - \langle\delta\rangle)/\sqrt{\mathrm{Var}(\delta)}$

Tension with other results?

Tension with other results?

Hahn+2009: less accretion due to tidal effects from neighboring large halo

$\Rightarrow$ extra effect in large tide limit (halo-halo interaction)