Dark Matter Halos Assembly in the Frame of the Saddle Points of the Cosmic Web

or how does the cosmic web impacts assembly bias

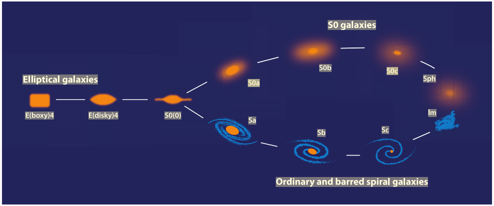
Corentin Cadiou – PhD Student – IAP, Paris, France
Supervisors: C. Pichon & Y. Dubois

KIAS, October 30, 2017

Introduction

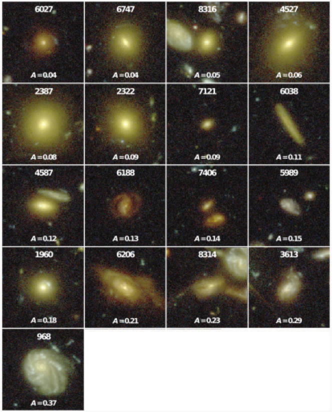
Describing galaxies?

Theory



+ star forming?
+ bulge?
+ mass?
+ DM halo mass?
+ DM profile?
+ ...

Observations (HDF)



Describing galaxies?

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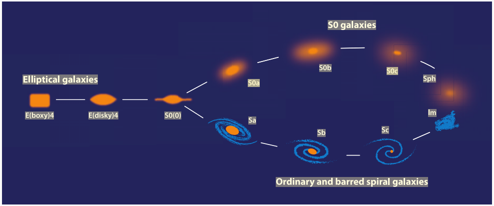

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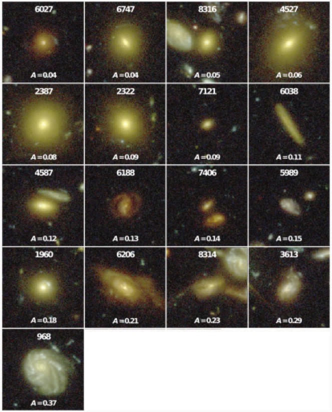
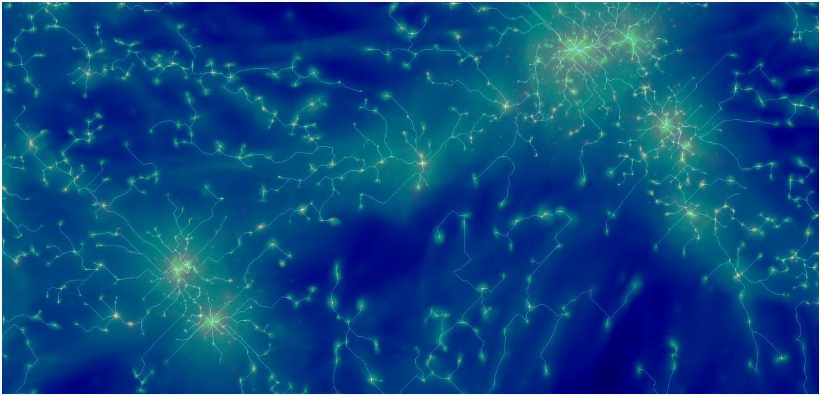


And all the properties **change with cosmic time**...

The Cosmic Web



Horizon-AGN simulation with skeleton, Dubois+12

And all the properties **change with cosmic time** and location w.r.t. **the cosmic web**!

Today: DM halo <u>assembly</u> in the <u>frame of the cosmic web</u>

DM Halo – motivation 1

Gravitational only $\rightarrow$ theoretical predictions

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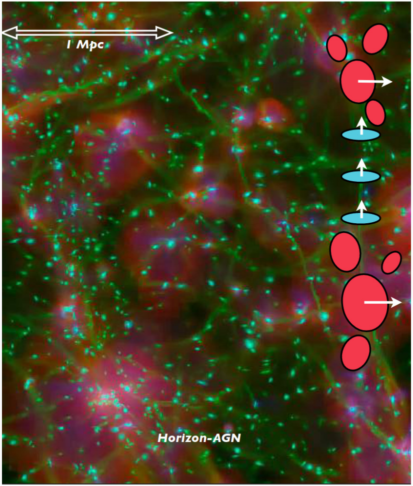
Gravitational only $\rightarrow$ theoretical predictions

How much of galaxy formation is due to DM (gravitational only) effects?

1. *Predict DM halo properties*
2. Infer galactic properties
3. Measure non explained signal

DM Halo – motivation 2

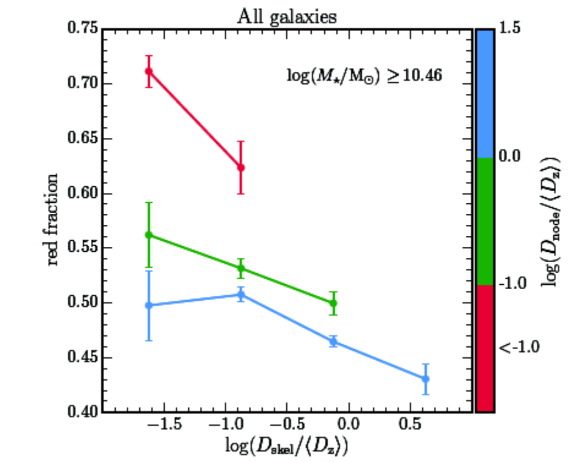


S. Codis

To understand *theoretically* weak lensing:

1. intrinsic alignment (see e.g. Codis+12);
2. galactic properties (mass, morphology, color,. . .).

Observed gradients



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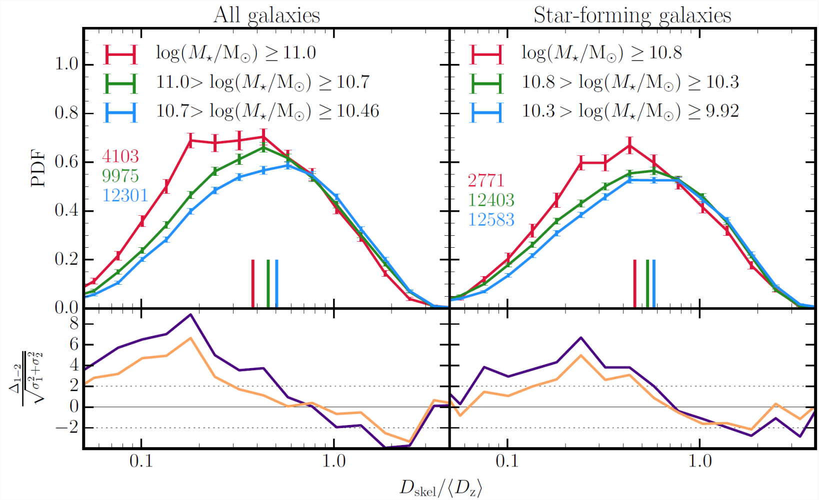
From void to filament
From filament to node
More massive, red and dead

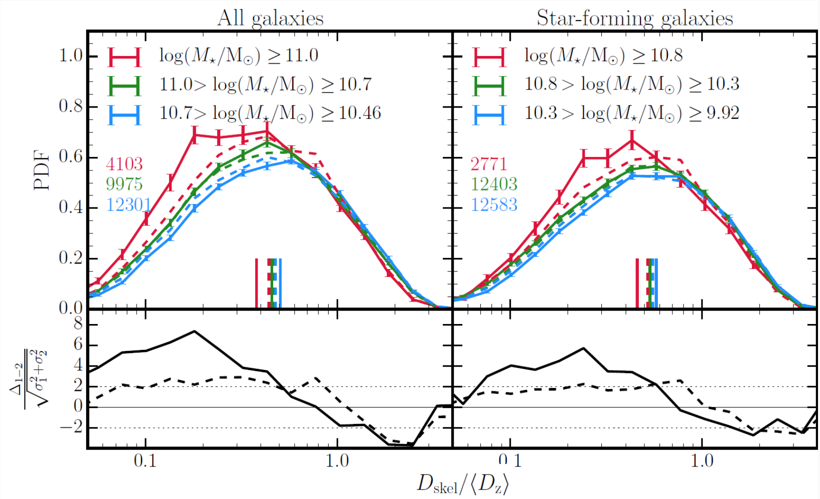
Advanced explanations

- Mass effect (not only)



Advanced explanations

- Mass effect (not only)
- Density effect (not only)



Need to take into account large-scale environment

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For 2nd order effects

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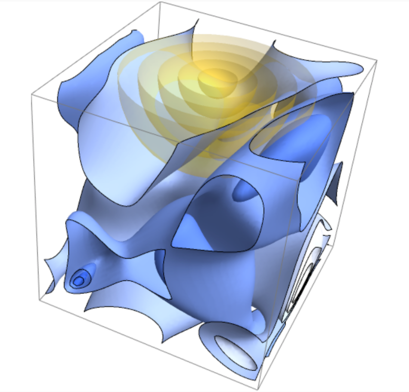
For 2nd order effects

How?

Excursion set

Excursion set in a nutshell – spherical collapse

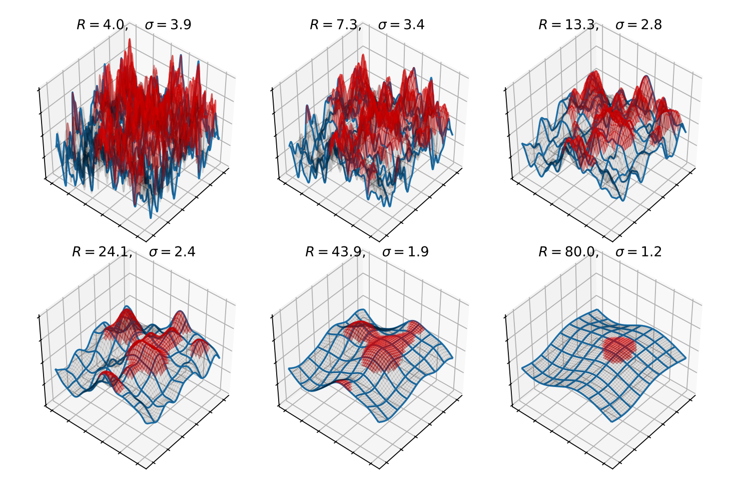


Christophe Pichon

- Gaussian random field
  (initial conditions $\leftrightarrow$ CMB)
- Over-density $\delta \equiv \dfrac{\rho - \bar{\rho}}{\bar{\rho}}$
- $\delta = \delta_c / D(z) \Rightarrow$ spherical collapse at $z = 0$
  (a DM halo will form)

Excursion set in a nutshell – mass

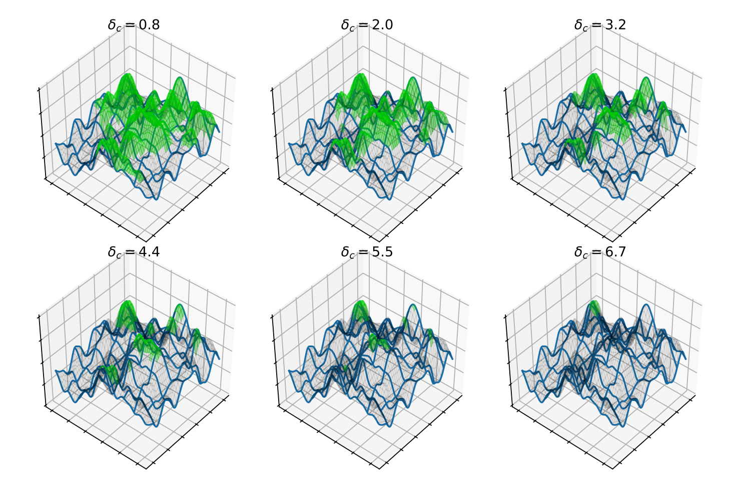
Small mass/radius, high σ $\longrightarrow$



$\longrightarrow$ large mass/radius, small σ

Excursion set in a nutshell – time

Low δ_c, late time, low z $\longrightarrow$



$\longrightarrow$ high δ_c, early time, high z

Excursion set in a nutshell

Mass proxy

At given z_0, R such that

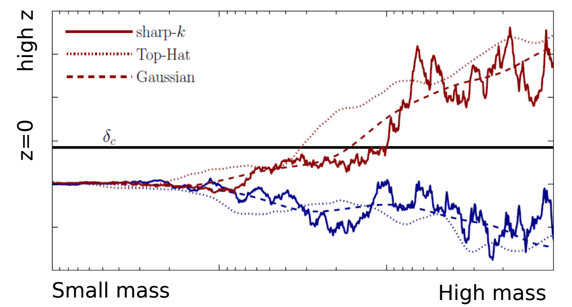
$$\delta(R) = \delta_c/D(z_0)$$

Time proxy

At a given R_0, z such that

$$\delta(R_0) = \delta_c/D(z)$$

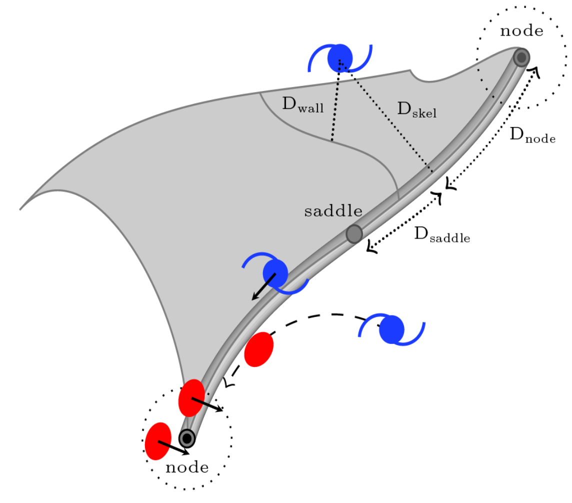
Time and mass evolution: **assembly of DM halo**



Desjacques, Jeong, Smith 16

Describing filaments with saddle point

Google Maps in the cosmic web



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Filament
Wall type filament
Jungfraujoch
Mönch
Landschaftspark Binntal
Jungfrau-Aletsch-Bietschhorn
Premia
Bettmeralp
Riederalp
Termen
Naters
CANTON OF BERN
Google

What's a saddle point?

Saddle point of ρ

- Direct access *via* number density, ...
- Probe scales $k^2 P(k)$ (small scale)

Saddle point of φ

- Access *via* e.g. grav. lensing
- Proba scales $P(k)$ (large scale)
- Theoretically tractable

How do we define it?

1. Critical point

$$\nabla\varphi \equiv -\mathbf{g}_{\mathcal{S}} = 0 \quad \text{no acceleration.}$$

2. Saddle point constrain (in frame of saddle point)

$$\nabla_i\nabla_j\varphi \equiv q_{ij} = \begin{pmatrix} q_{xx} & 0 & 0 \\ 0 & q_{yy} & 0 \\ 0 & 0 & q_{zz} \end{pmatrix} \quad \text{and} \quad q_{xx} < 0 < q_{yy} < q_{zz}.$$

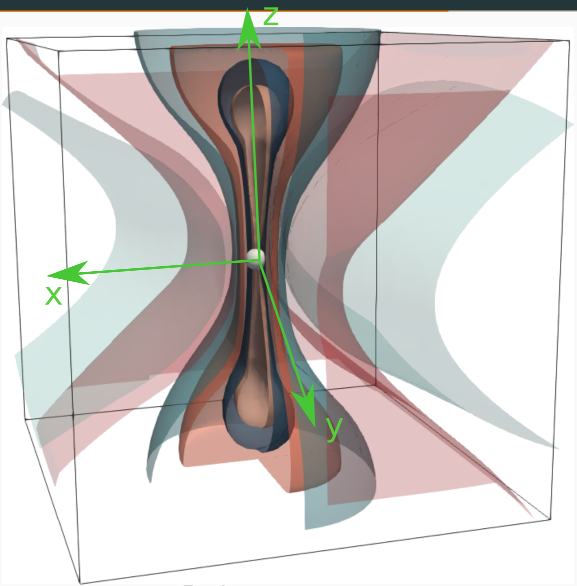
Physically: local maximum in y, z directions, local minimum in x direction.

3. Heigth of the saddle point

$$\delta_{\mathcal{S}} \equiv \frac{\rho - \bar{\rho}}{\bar{\rho}}$$

smoothed at scale $R_{\mathcal{S}}$.

Saddle Point Frame



3D density contours

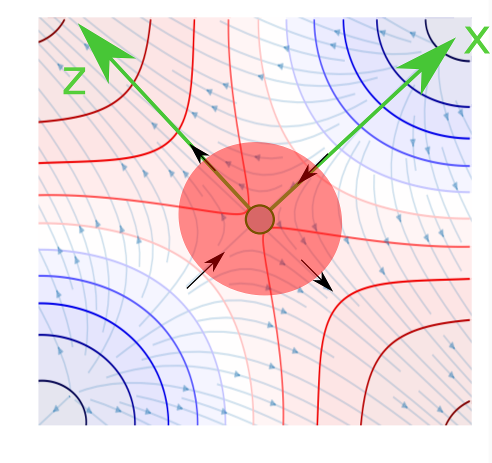
Directions

- x: toward void
- y: toward wall
- z: toward node

Filament

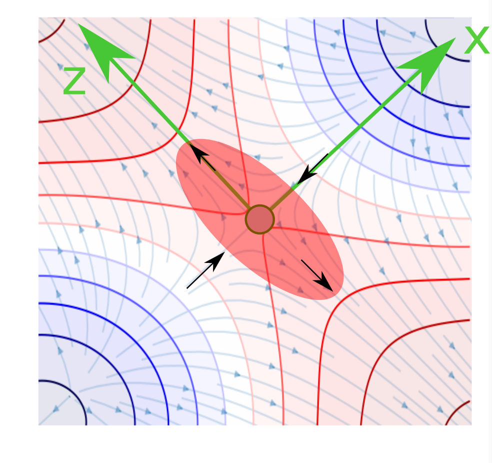
- x dir. collapsed (Zel'dovich)
- z dir. of filament

Flow Around Saddle Point



Saddle point is stationary (critical point of the "streamlines")

Flow Around Saddle Point



Saddle point is stationary (critical point of the "streamlines")

Description of the saddle point

Variables

- $R_{\mathcal{S}}$ the smoothing scale
- $\delta_{\mathcal{S}}$ the overdensity
- $\mathbf{g}_{\mathcal{S}}$ the acceleration
- q_{ij} (next slide)

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Variables

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- q_{ij} (next slide)

Values

- e.g. $10\,\mathrm{Mpc/h}$
- ~ 1.2
- $(0, 0, 0)$
- q_{ij}

A few words about q_{ij}...

$$q_{ij} = \nabla_i \nabla_j \varphi \tag{1}$$

q_{ij} is a tensor of order 2 describing the *tides at the saddle point*.

A few words about q_{ij}...

$$q_{ij} = \nabla_i \nabla_j \varphi \sim -\nabla_i \nabla_j \delta \tag{1}$$

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Signature	Type of point
$+++$	peak
$-++$	filament-type saddle point
$--+$	wall-type saddle point
$---$	void

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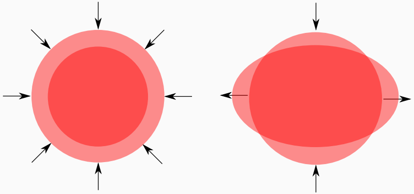
A few words about q_{ij} [Stephane's slide]

$$q_{ij} = \underbrace{\frac{\delta_{\mathcal{S}}}{3}\begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}}_{\text{density}} + \underbrace{\begin{pmatrix} \bar{q}_{11} & \bar{q}_{12} & \bar{q}_{13} \\ & \bar{q}_{22} & \bar{q}_{23} \\ & & \bar{q}_{33} \end{pmatrix}}_{\text{tides}} \tag{2}$$



Information in $\mathbf{Tr}(q_{ij})$ ("diagonal" part)

$$\mathrm{Tr}(q_{ij}) = \frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} + \frac{\partial^2 \varphi}{\partial z^2}$$

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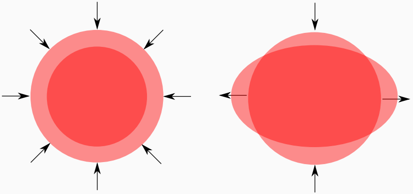

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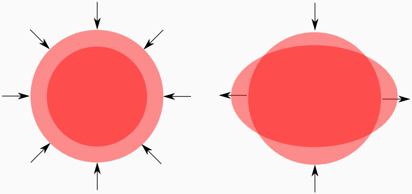

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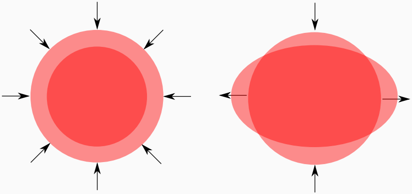

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A few words about q_{ij}... [continued]

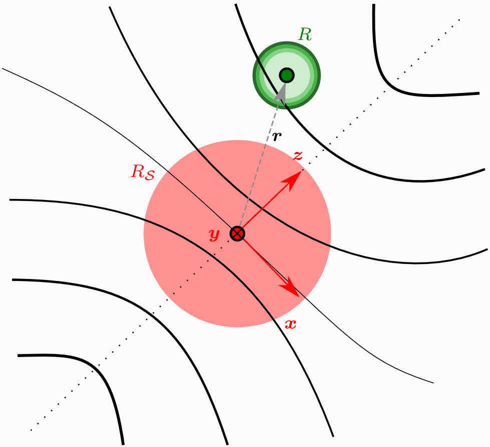
$$\bar{q}_{ij} \equiv \text{traceless part of } q_{ij} = q_{ij} - \frac{\delta_{\mathcal{S}}}{3}\mathbb{I}_{ij} \tag{3}$$

Why do we care about $\bar{q}_{ij}$?

- contains *geometric* information
- no information on *local density*
- probe for LSS

$\Rightarrow$ from theory: seem like good way to measure large scale environment

Saddle point frame



- Distance $\mathbf{r} = (r_x, r_y, r_z)$ from saddle point
- Scale $R \sim 1\,\mathrm{Mpc/h} \ll R_{\mathcal{S}}$

Angular variable

$$\mathcal{Q} = \sum_i \sum_j \frac{r_i \bar{q}_{ij} r_j}{\|\mathbf{r}\|^2} \tag{4}$$

- Filament: $\mathcal{Q} = \bar{q}_{zz} \sim 1$
- Void: $\mathcal{Q} = \bar{q}_{xx} \sim -1$

Angular variable

$$\mathcal{Q} = \sum_i \sum_j \frac{r_i \bar{q}_{ij} r_j}{\|\mathbf{r}\|^2} \tag{4}$$

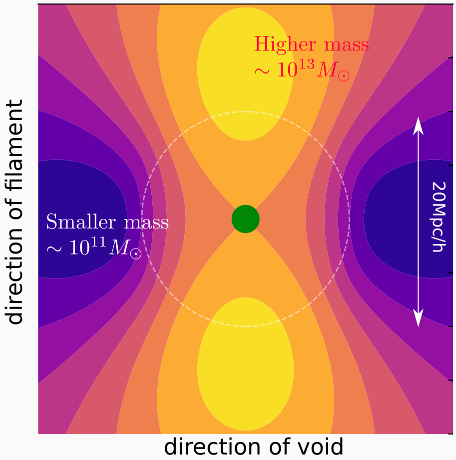
- Filament: $\mathcal{Q} = \bar{q}_{zz} \sim 1$
- Void: $\mathcal{Q} = \bar{q}_{xx} \sim -1$

In practice: all results are functions of r and $\mathcal{Q}$.

$\mathcal{Q}$ is *the* variable encoding **anisotropic** environmental effects

Effect on assembly history

Typical mass

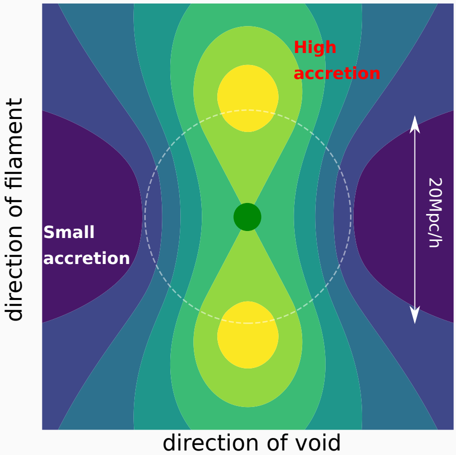


$$\Delta M_\star(\mathbf{r}) \propto \delta_{\mathcal{S}} \xi_{20}(r) \mathcal{Q}$$

ξ_{20}: corr. density-tide + density

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

Accretion rate @ $\approx 3 \times 10^{11}\,\mathrm{M}_\odot$ & $z = 0$

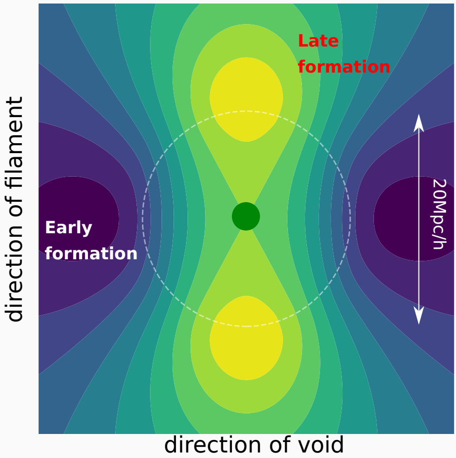


$$\Delta \dot{M}(\mathbf{r}) \propto \left[\xi'_{20} - \frac{\sigma - \xi'_I \xi_I}{\sigma^2 - \xi^2}\xi_{20}\right]\mathcal{Q}$$

ξ'_{20}: corr. slope-tide + variance of field

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

Formation time @ $\approx 3 \times 10^{11}\,\mathrm{M}_\odot$ & $z = 0$



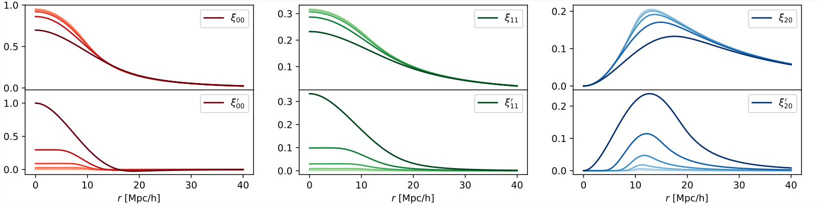
$$\Delta z_\star(\mathbf{r}) \propto M\xi_{20}(r)\mathcal{Q}$$

higher mass: later formation time

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

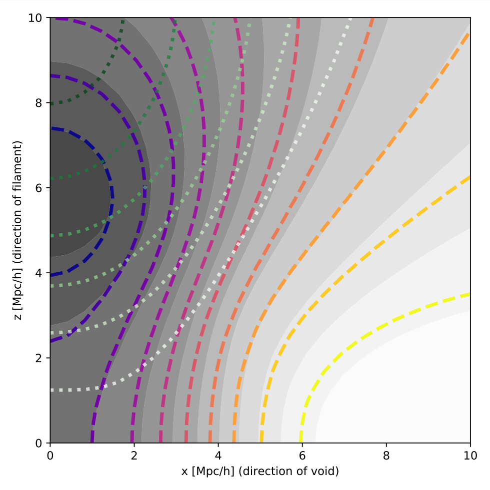
ξ functions

$\xi_{00} \propto \langle \delta \delta_{\mathcal{S}} \rangle$ $\xi_{11} \propto \langle \delta g_i \rangle$ $\xi_{20} \propto \langle \delta \bar{q}_{ij} \rangle$



$\xi'_{00} \propto \langle \delta' \delta_{\mathcal{S}} \rangle$ $\xi'_{11} \propto \langle \delta' g_i \rangle$ $\xi'_{20} \propto \langle \delta' \bar{q}_{ij} \rangle$

Gradient alignment



- background: ρ
- dotted M
- dashed $\dot{M}$

K. Kraljic, S. Arnouts, C. Pichon, C. Laigle, S. de la Torre, D.Vibert, C. Cadiou et al., MNRAS

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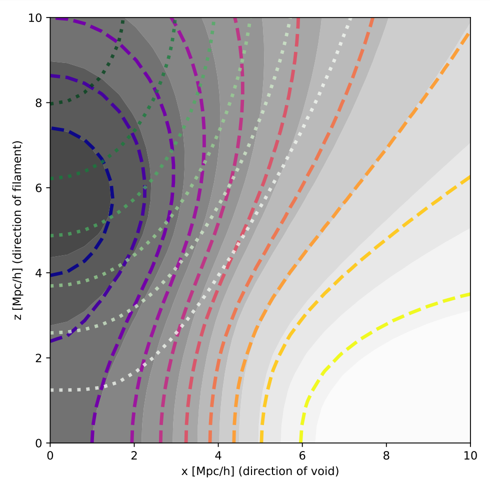

- background: ρ
- dotted M
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$\Rightarrow$ different gradients

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(Temporary) conclusions

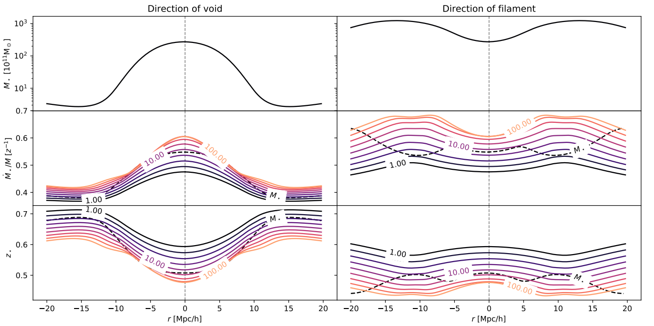
Halos in nodes . . .

- form later,
- are accreting more,
- typically more massive,

compared to those in filaments (and same from voids to filaments).

In agreement with results from n-body simulations + hint for different assembly w.r.t. cosmic web.

Quantitative results



Voids to filaments

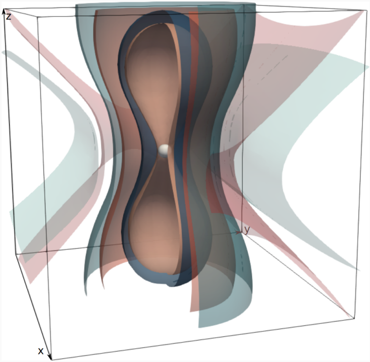
- $M \times 10^2$
- $\dot{M}/M + 30\%$
- $z_f - 15\%$

Filaments to nodes

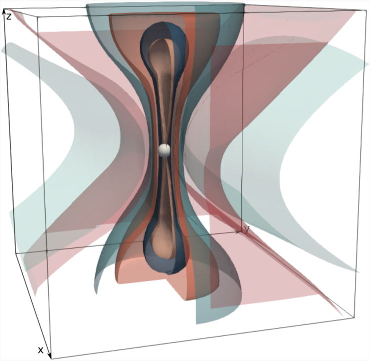
- $M \times 5$
- $\dot{M}/M + 10\%$
- $z_f - 5\%$

Expected observations?

Need to take into account Zel'dovich-boost

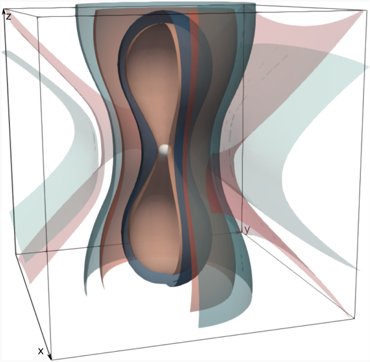


$\xRightarrow[\text{boost}]{\text{Zel'}}$

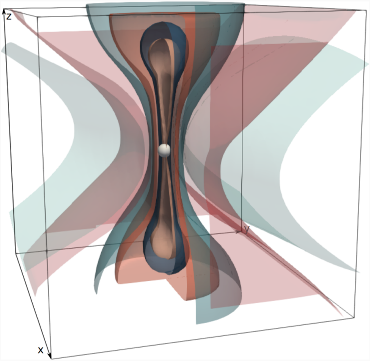


Effect of Zel'dovich

Need to take into account Zel'dovich-boost



$\xrightarrow[\text{boost}]{\text{Zel'}}$



- gradients align
- information attenuated

Origin of differences?

Variance vs. mean

The saddle affects both the **mean** and the **variance** of δ and δ', at a given distance r:

$$\begin{aligned} X(r) = X[\mathcal{S},\mathcal{Q}] = F\Big[& \langle \delta \mid \mathcal{S},\mathcal{Q} \rangle, \mathrm{Var}(\delta \mid \mathcal{S},\mathcal{Q}), \\ & \left\langle \delta' \mid \mathcal{S},\mathcal{Q} \right\rangle, \mathrm{Var}\left(\delta' \mid \mathcal{S},\mathcal{Q}\right), \\ & \left\langle \delta_{1/2} \mid \mathcal{S},\mathcal{Q} \right\rangle, \mathrm{Var}\left(\delta_{1/2} \mid \mathcal{S},\mathcal{Q}\right), \\ & \left\langle \delta'_{1/2} \,\middle|\, \mathcal{S},\mathcal{Q} \right\rangle, \mathrm{Var}\left(\delta'_{1/2} \,\middle|\, \mathcal{S},\mathcal{Q}\right) \Big] \end{aligned}$$

Relevant quantities: not only mean but also variance!

Conclusion

Conclusion

Results

- Different gradients for different quantities
- Effects beyond mass & local density
- DM halo in nodes (resp. filaments)
    - form later
    - accrete more
    - are more massive

  than in filaments (resp. voids)

Open questions / WIP

- Link DM halo to galaxy
- Take into account non-spherical collapse
- Build more proxies (e.g. merger rate)?

Thank you!

Thank you!

M. Musso, C. Cadiou et al 2017 (theory)

K. Kraljic et al 2017 (observations)

Effect of large scale