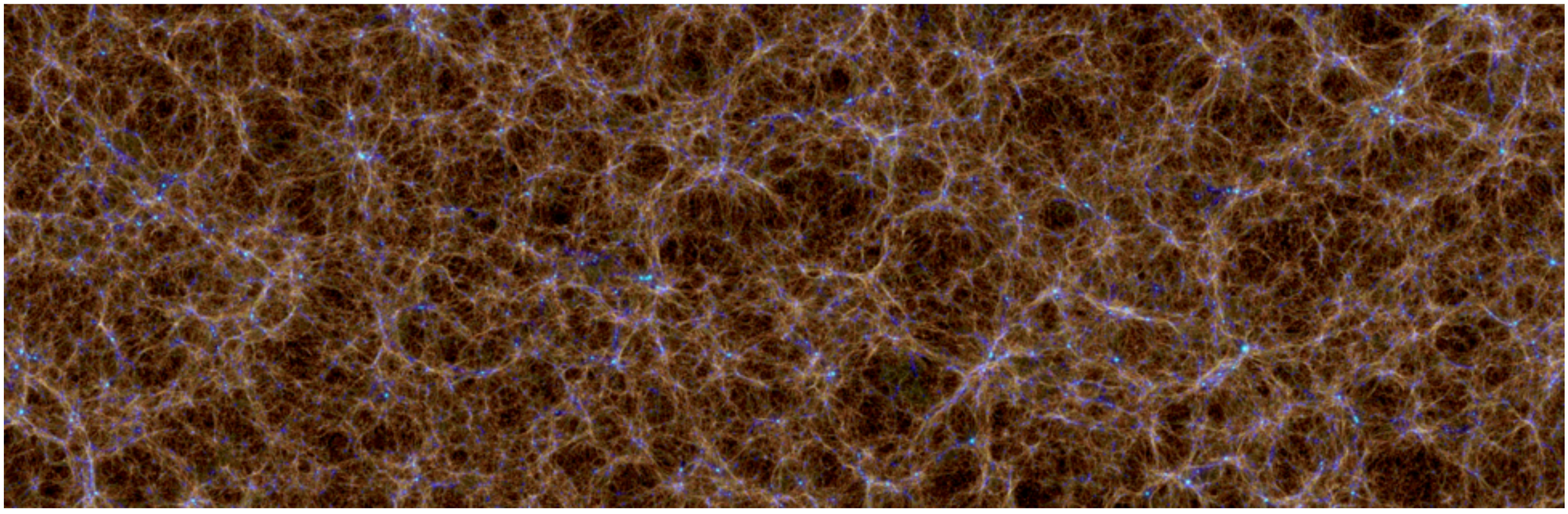
Probing the azimuthal environment of galaxies around clusters from cluster core to cosmic filaments

Gouin C., Aghanim N., Bonjean V., Douspis M. (2020)



Céline Gouin
Korean Institute for Advanced Study

From galaxies to cosmology with large spectroscopic surveys
A tribute to Olivier Le Fèvre

06/07/2022

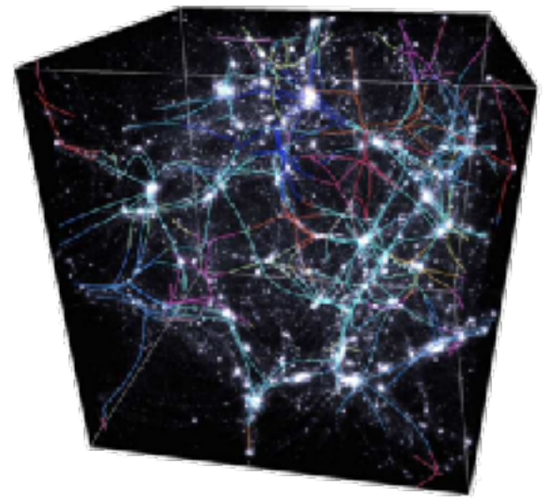
Introduction - *the filamentary structure around clusters*

- Located at the intersection of cosmic filaments

- Most recently formed structures

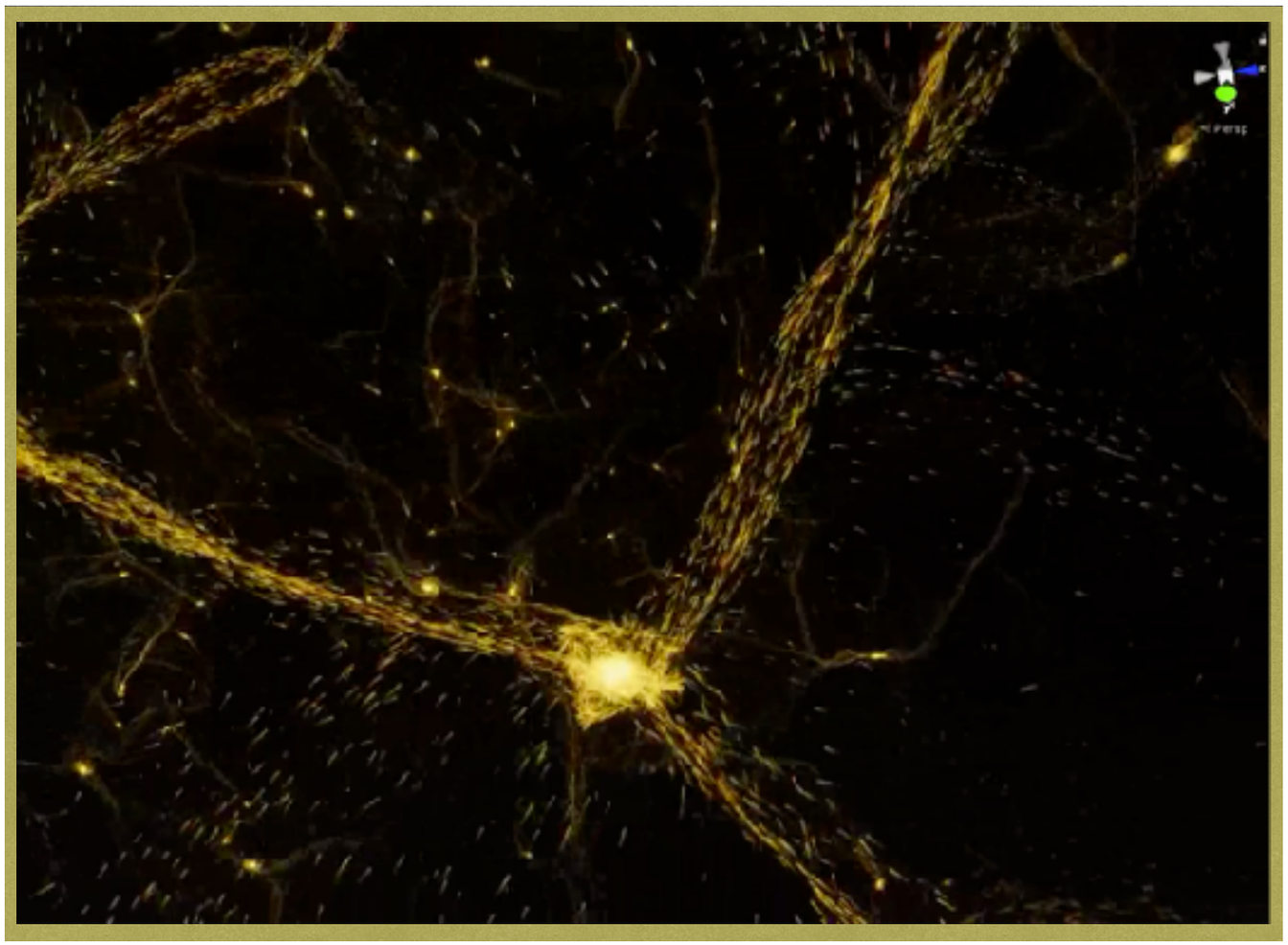
- Matter flow from void to wall, then via filaments into clusters

SIMULATIONS



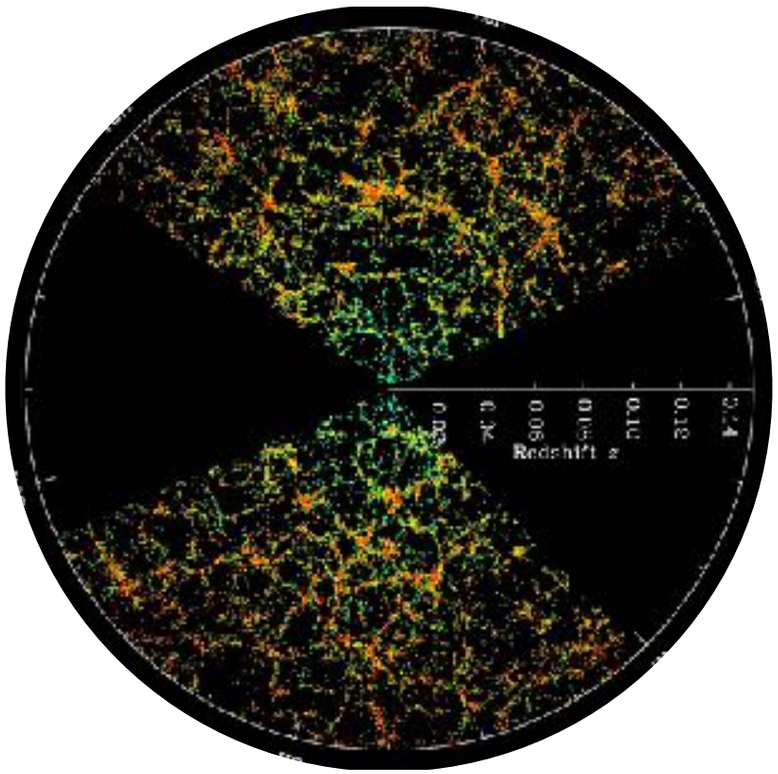
Pichon et al, 2009

ANNISOTROPE ACCRETION



Credit to Miguel Aragon Calvo

OBSERVATIONS



Crédit. SDSS

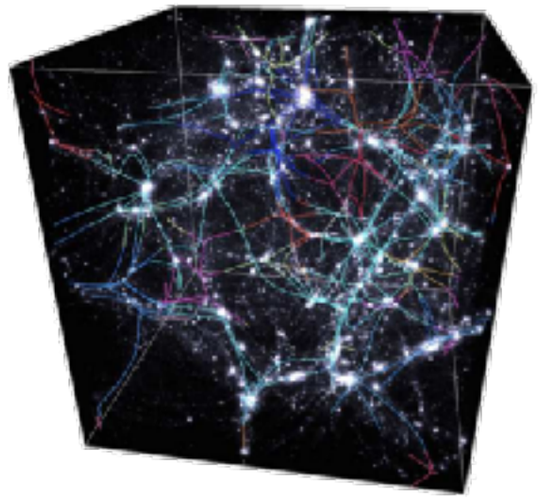
Introduction - *the filamentary structure around clusters*

SIMULATIONS

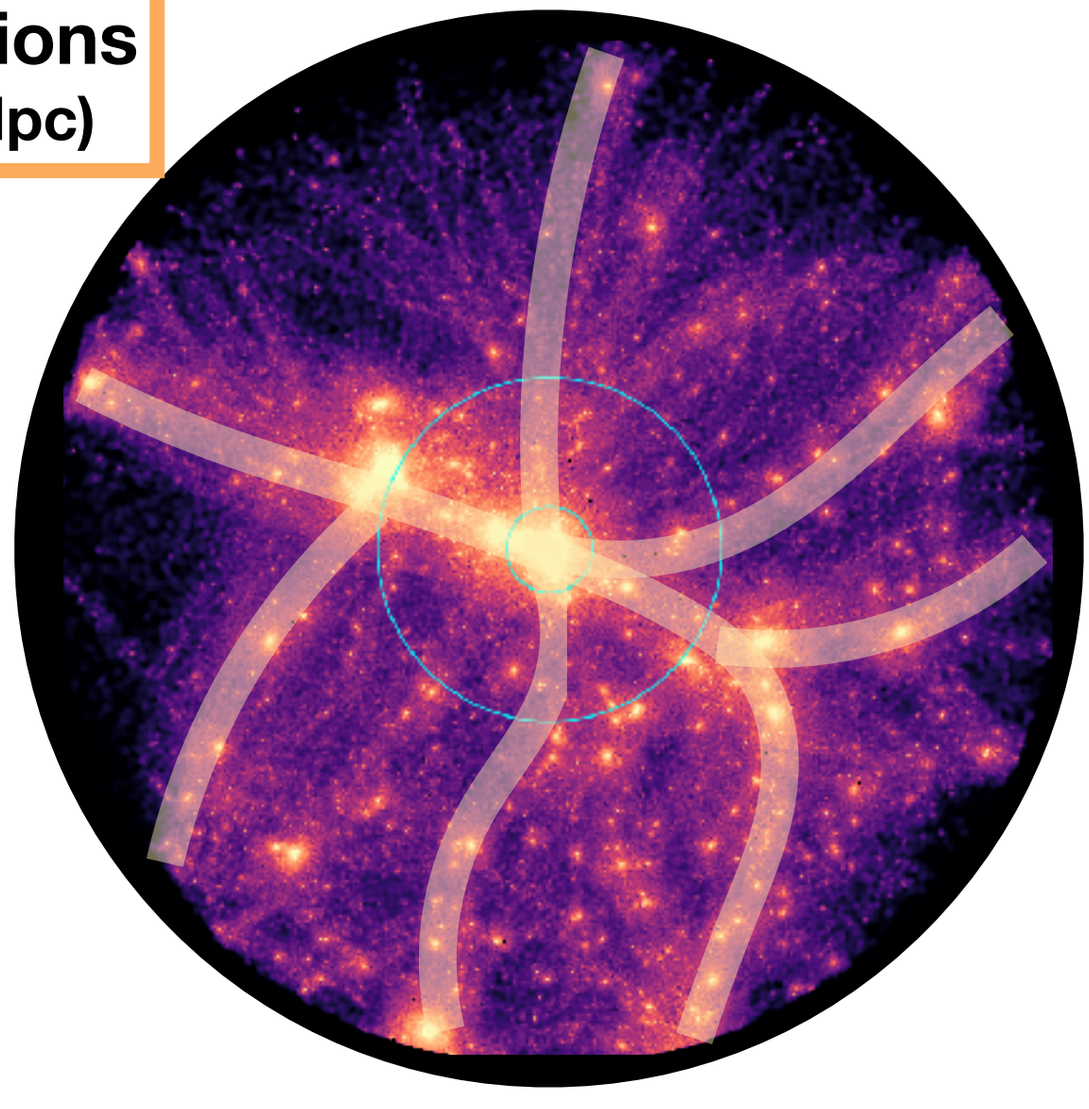
Ideal places to probe

- Geometry of the cosmic web
- Structure formation/evolution
- Galaxy evolution

Cosmic Web
(> 4 R_{200})



In-falling regions
(1-4 Rvir < 8 Mpc)



Galaxy clusters
(~1 R_{200})

How can we quantify the anisotropy of the density field around clusters?

What are the impacts of such anisotropic environments on galaxy properties?

Probing the azimuthal environment of galaxies around clusters from cluster core to cosmic filaments

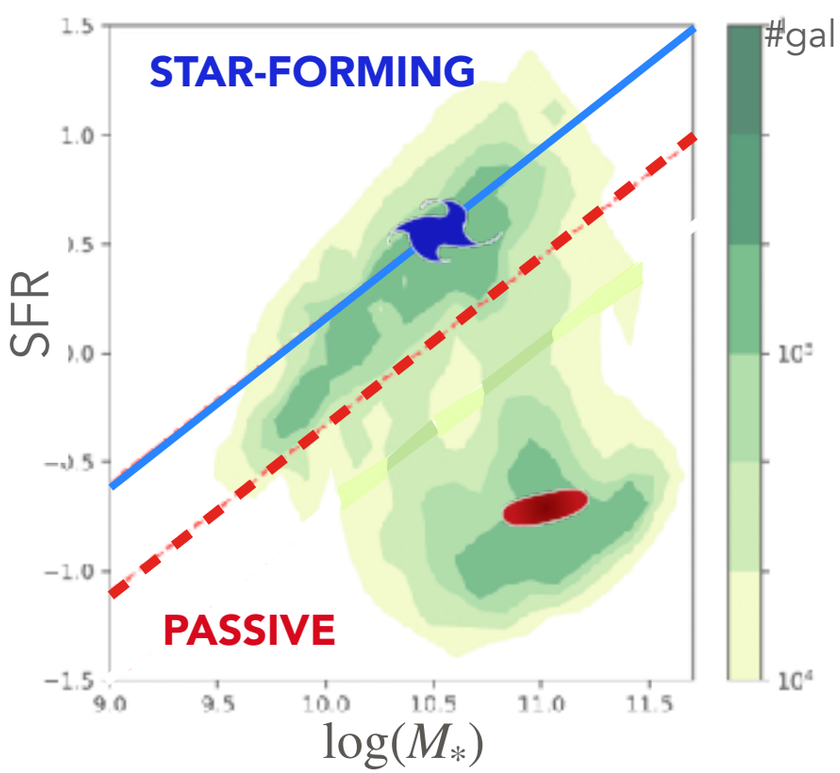
Data & Method - *Statistical analysis of galaxy distribution around clusters*

Data & Method - *Galaxies around clusters*

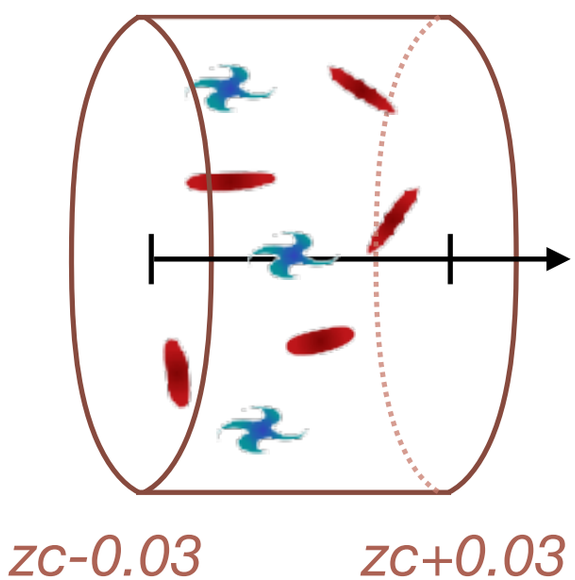
Case 1 ▸ Observational dataset for low-z clusters

- ➡ Galaxies form Wise X SCOSMOS between 0.1<z<0.3 (Bilicki et al, 2016)
- ➡ ~6400 Clusters from SDSS - 0.1<z<0.3 - $M_{200}>10^{14}$ Mo/h (Wen et al, 2012)

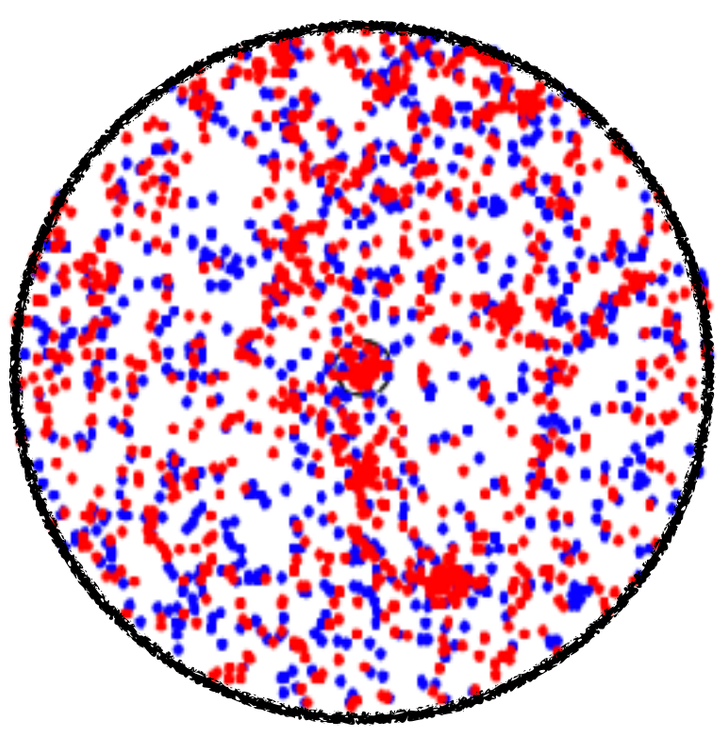
Passive VS Star-forming



Redshift slices around clusters



Projection along the LOS



Data & Method - *Galaxies around clusters*

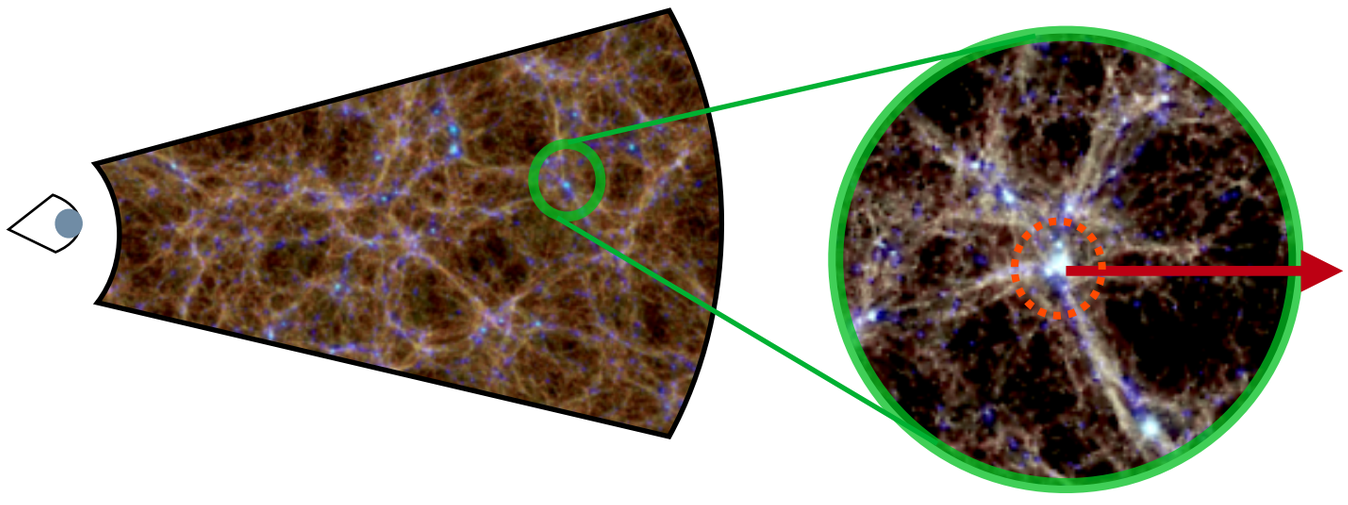
Case 1

- **Observational dataset for low-z clusters**

Case 2

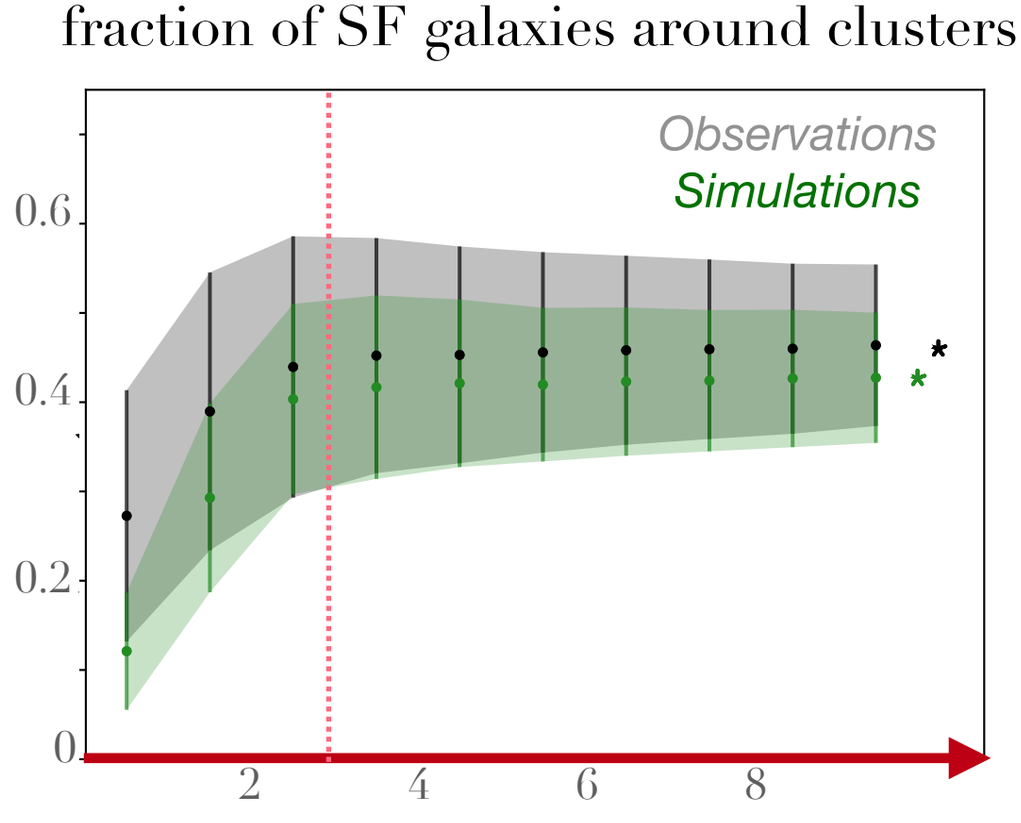
- **Identical cluster & galaxy selection in simulation**

Light-cone of Magneticum



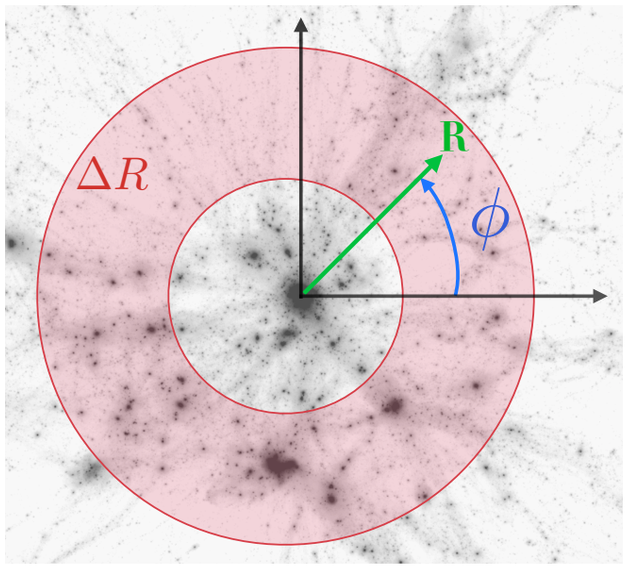
1/8 th of the sky

Hirschmann et al. (2014) and Dolag et al. (2015)



Data & Method - *Statistical method for filamentary pattern detection*

Multipole moments of galaxy distribution around clusters



A decomposition of 2-D galaxy distribution around galaxy clusters (Schneider et al, 1997)

$$Q_m(\Delta R) = \int_{\Delta R} R\, dR \int_0^{2\pi} d\phi\, e^{im\phi}\, \Sigma_g(R, \phi)$$

to characterize angular asymmetries/patterns

Projection on the sky

Multipole order m

- **Galaxies are used as a tracer of the underlying density field around clusters**

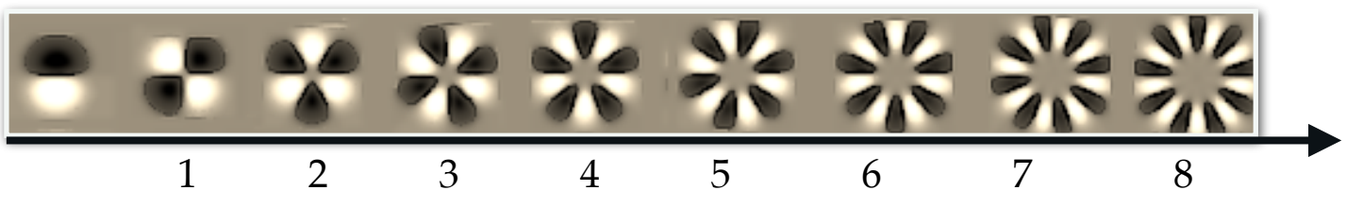
- Method previously applied on DM particles in simulation (Gouin et al, 2017), and on GRF in theoretical point of view (Codis et al, 2017).

Data & Method - *Statistical method for filamentary pattern detection*

Harmonic power Average over a larger number of cluster

$$Q_m \longrightarrow \langle |Q_m|^2 \rangle = \frac{1}{N_{clusters}} \sum_i |Q_m|_i^2$$

to statistically probe the anisotropies



1 2 3 4 5 6 7 8 ….Multipole orders

Data & Method - *Statistical method for filamentary pattern detection*

Harmonic power Average over a larger number of cluster

$$Q_m \longrightarrow \langle |Q_m|^2 \rangle = \frac{1}{N_{clusters}} \sum_i |Q_m|^2_i$$

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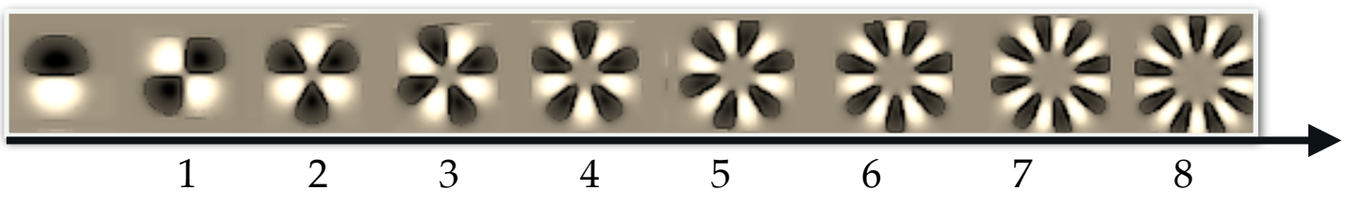
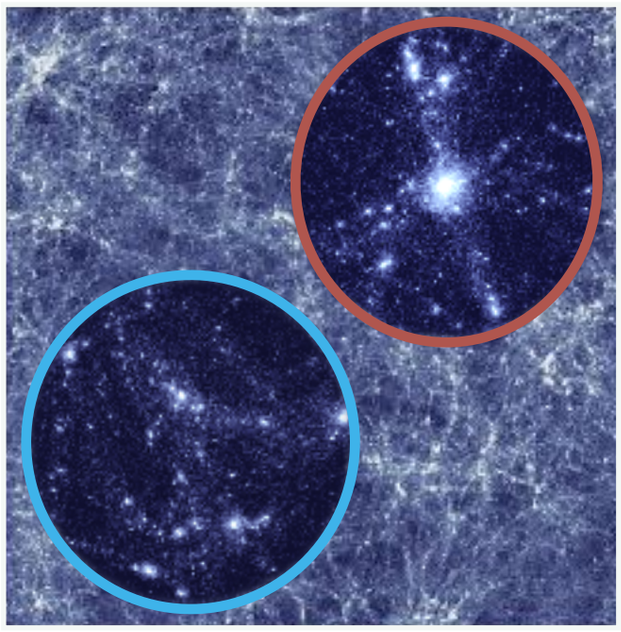




Harmonic power excess

What are in excess to ***background density field ?***

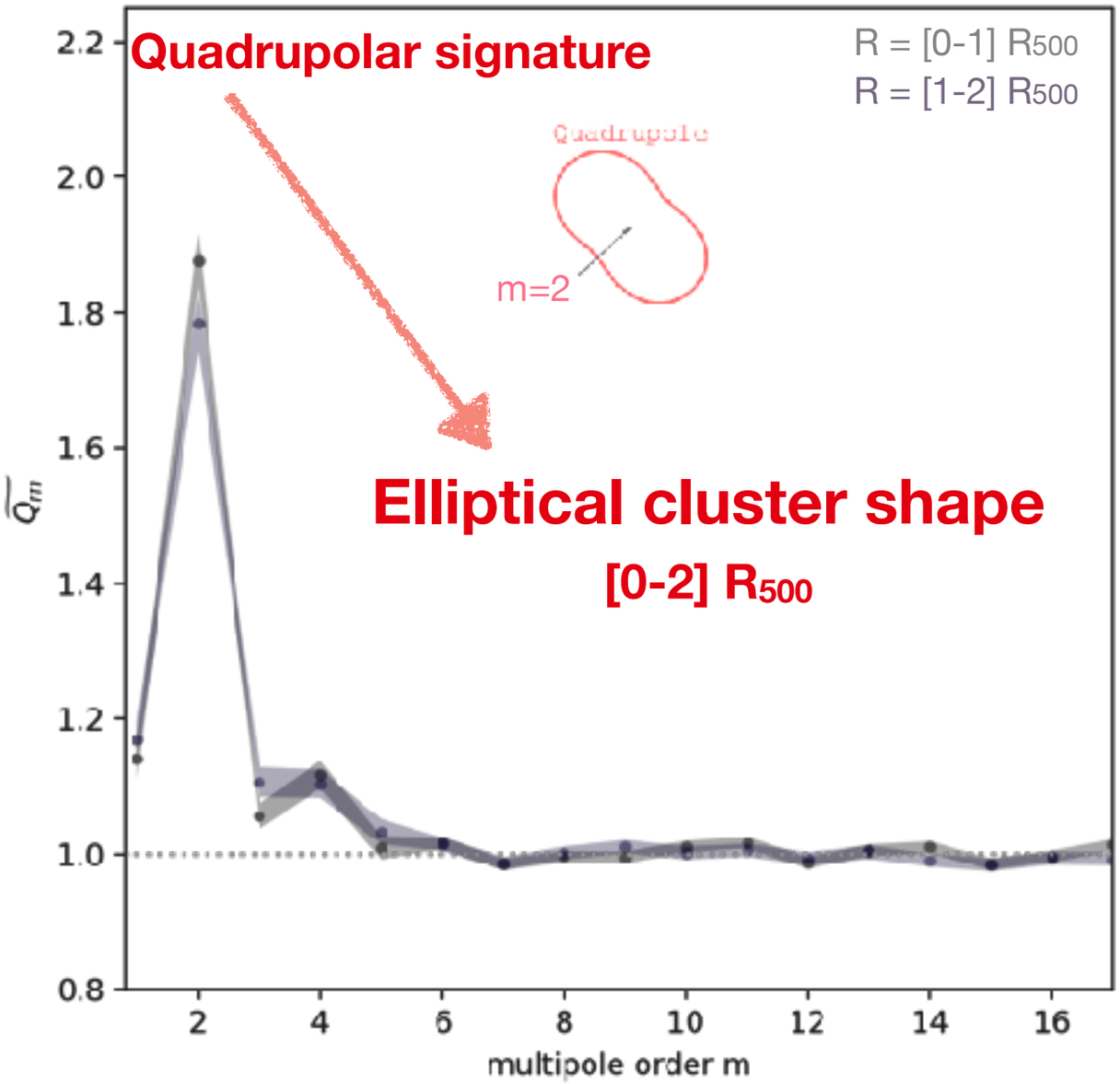
$$\tilde{Q}_m \propto \frac{\langle |Q_m|^2 \rangle_{\textbf{clusters}}}{\langle |Q_m|^2 \rangle_{\textbf{randoms}}}$$

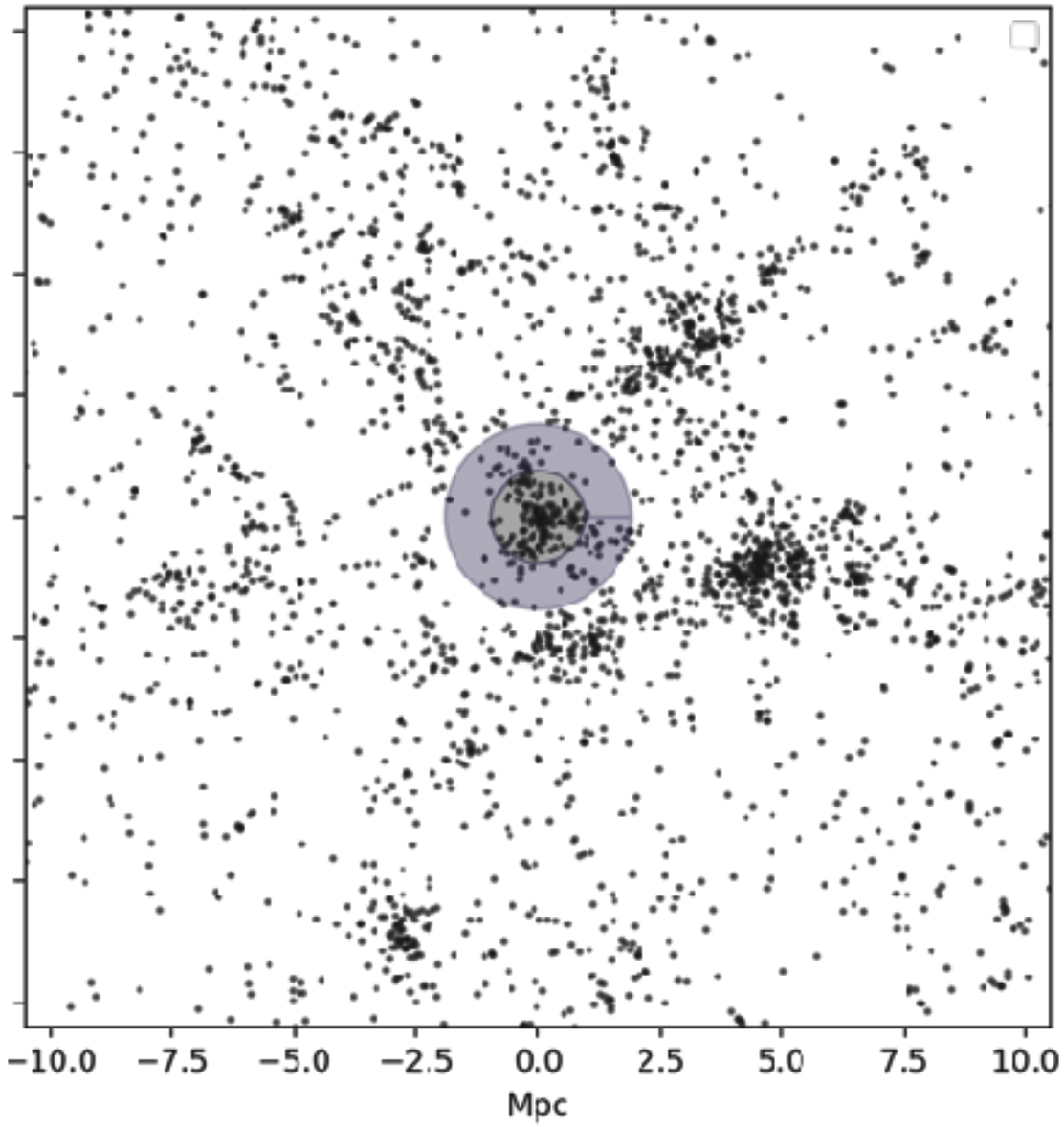
Probing the azimuthal environment of galaxies around clusters from cluster core to cosmic filaments

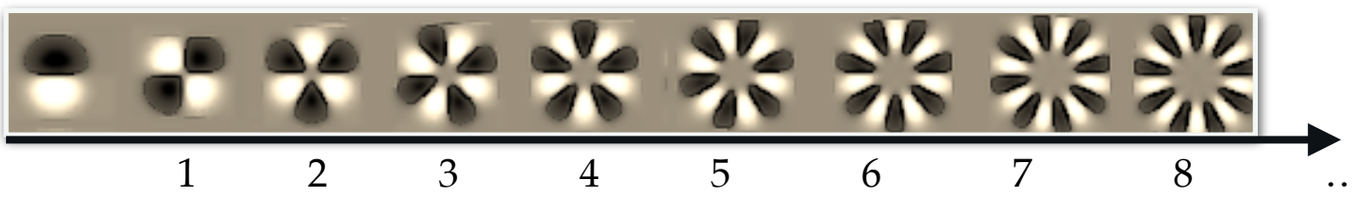
Results in observations & simulations

Results - 1. Radial evolution of asymmetries around clusters

Simulations

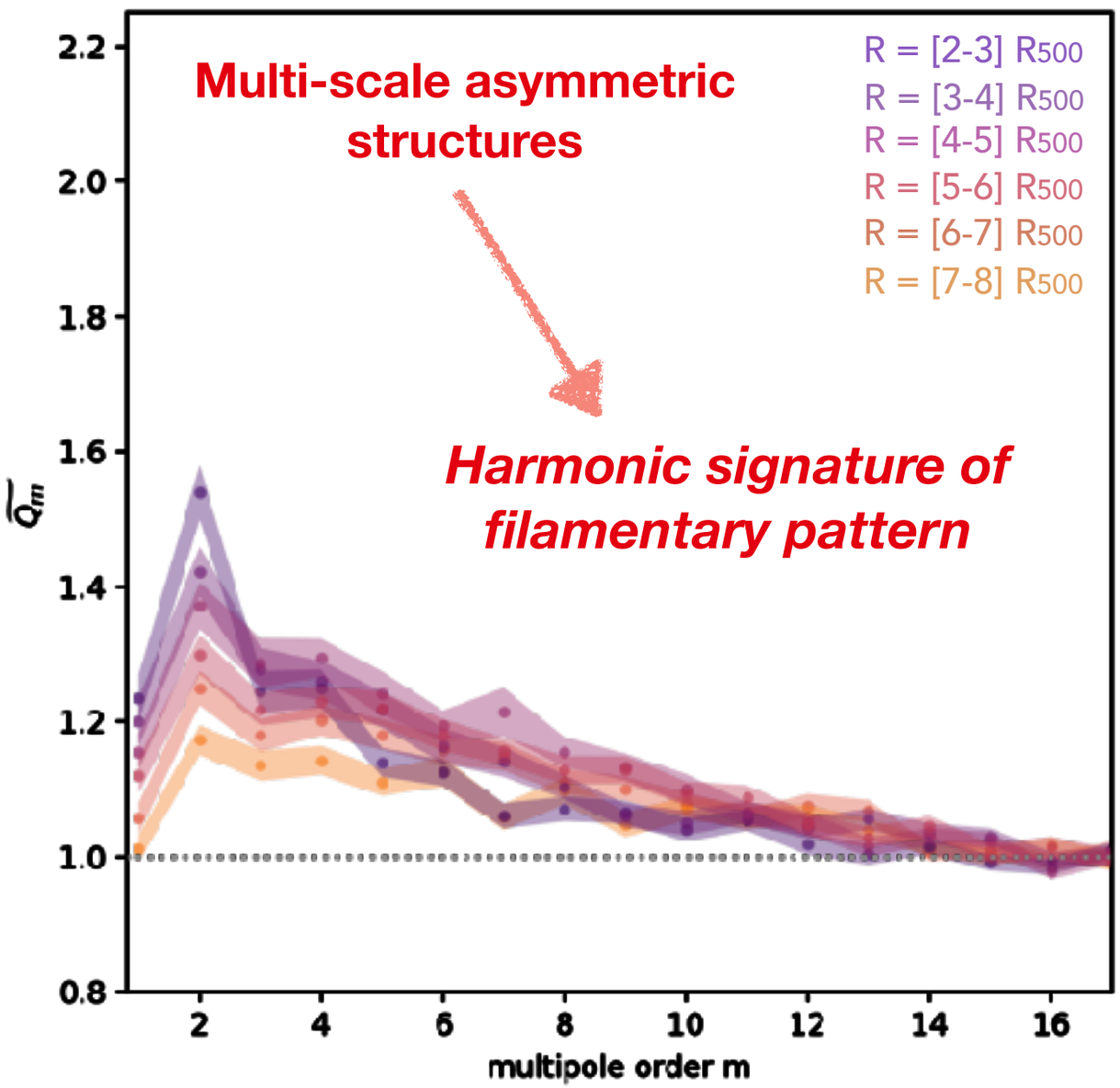


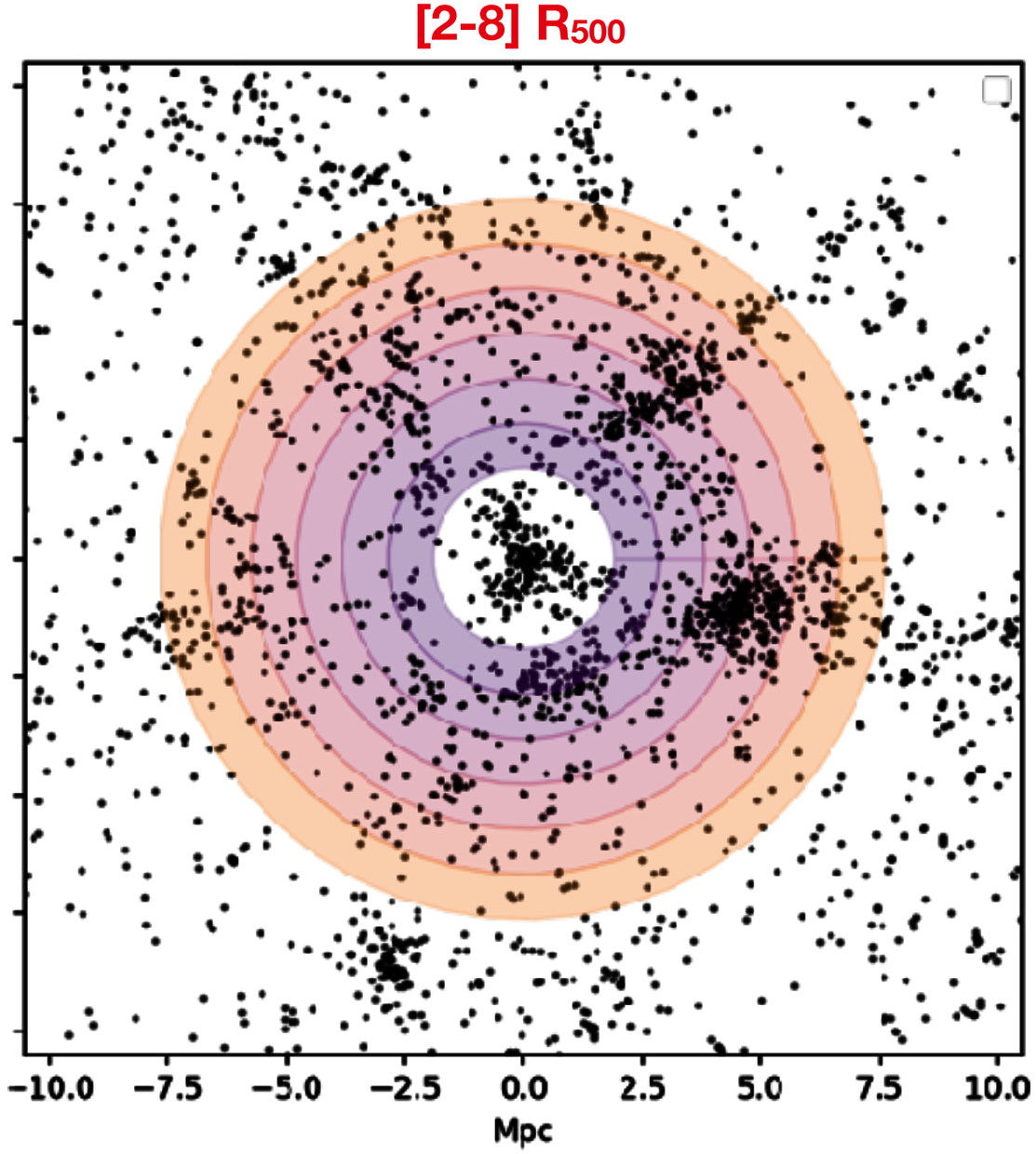


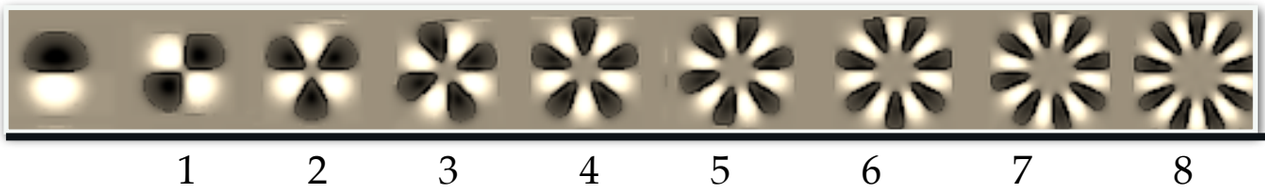


Results - 1. Radial evolution of asymmetries around clusters

Simulations

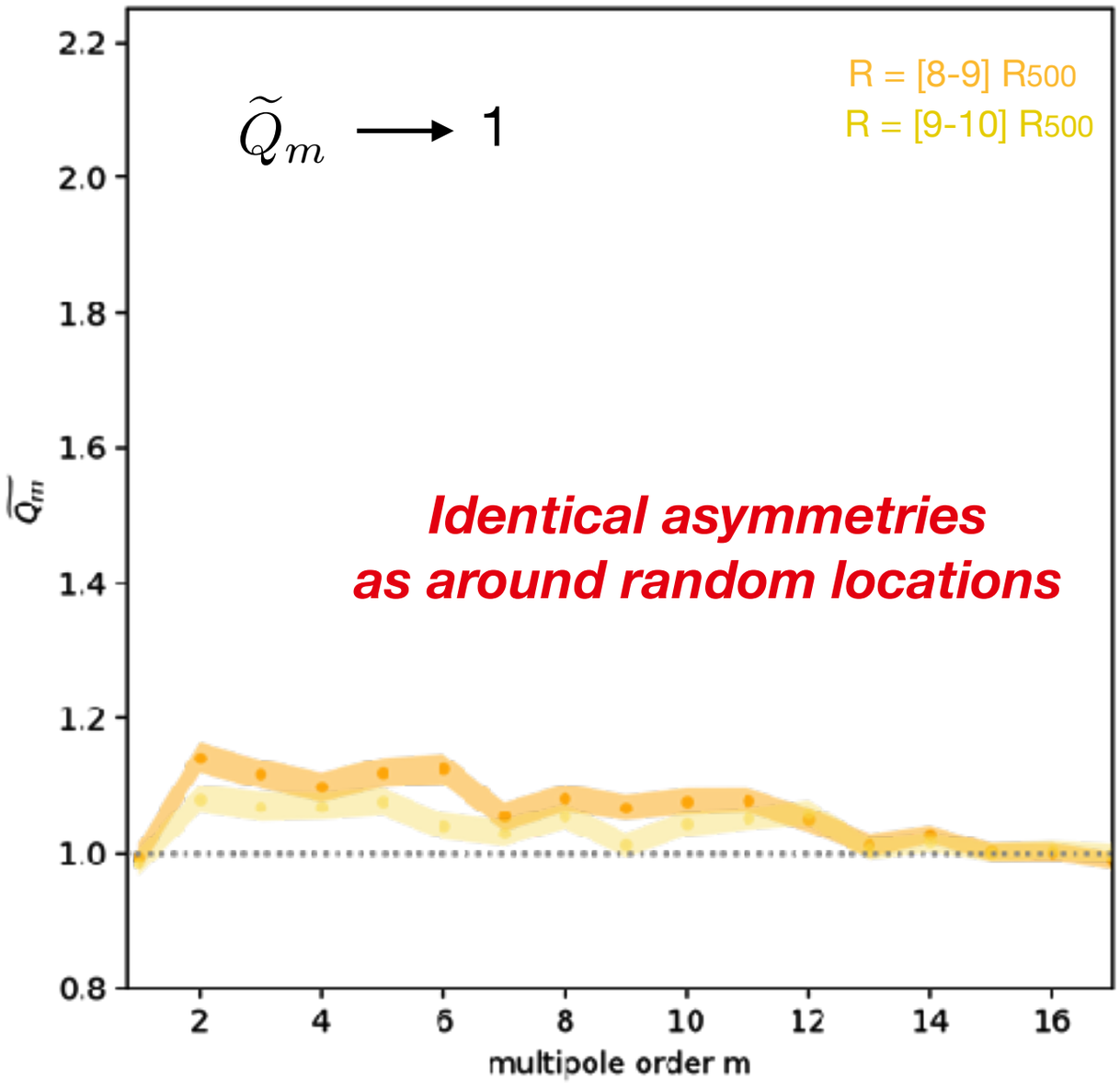


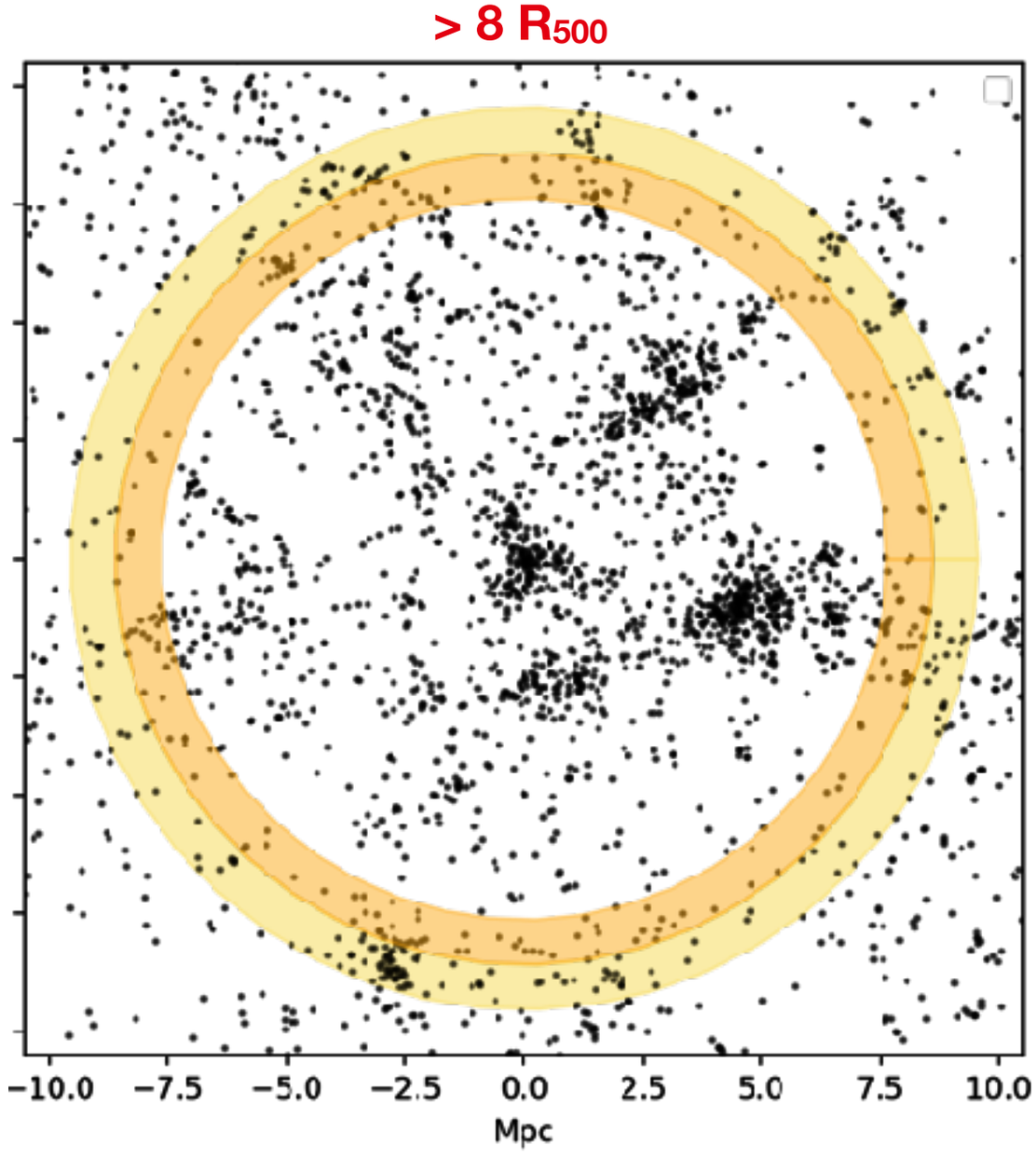


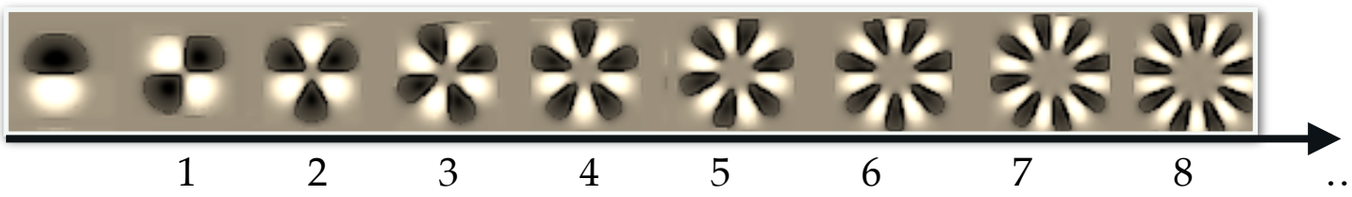


Results - 1. Radial evolution of asymmetries around clusters

Simulations



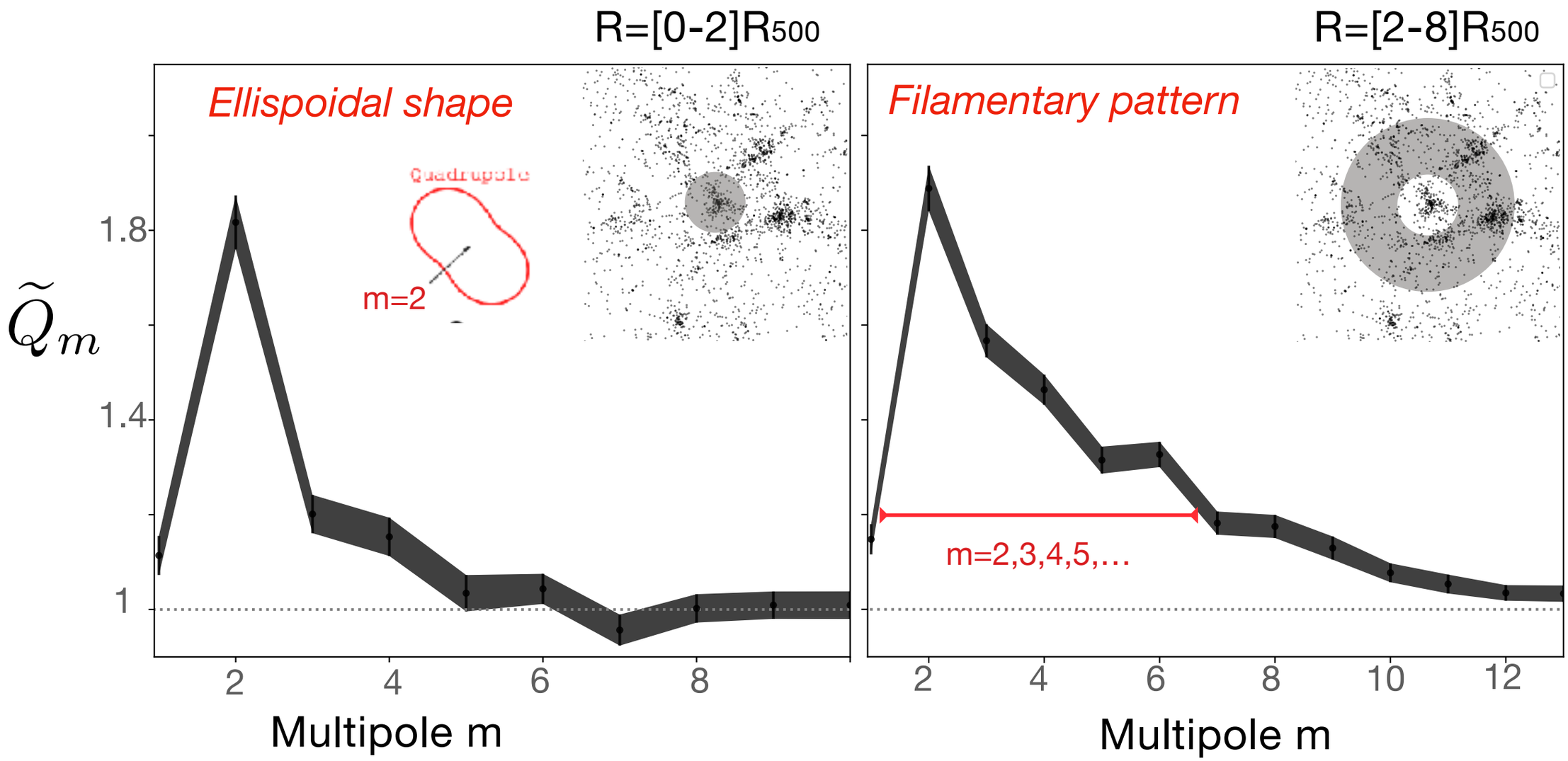


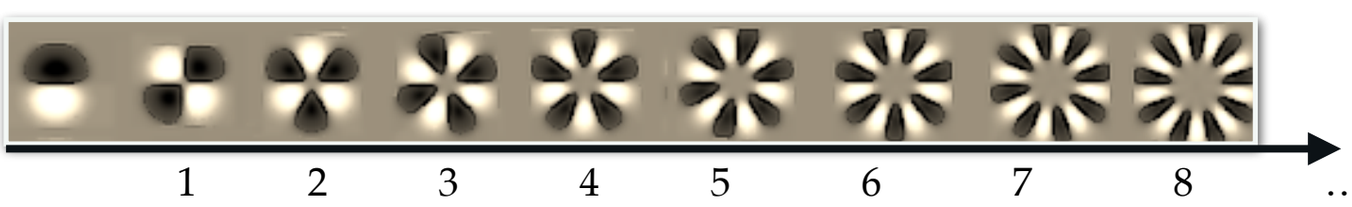


$$\widetilde{Q}_m \propto \frac{\langle |Q_m|^2 \rangle_{\text{clusters}}}{\langle |Q_m|^2 \rangle_{\text{randoms}}}$$

Results - 1. Radial evolution of asymmetries around clusters

Observations





Results - 1. Radial evolution of asymmetries around clusters

Observations

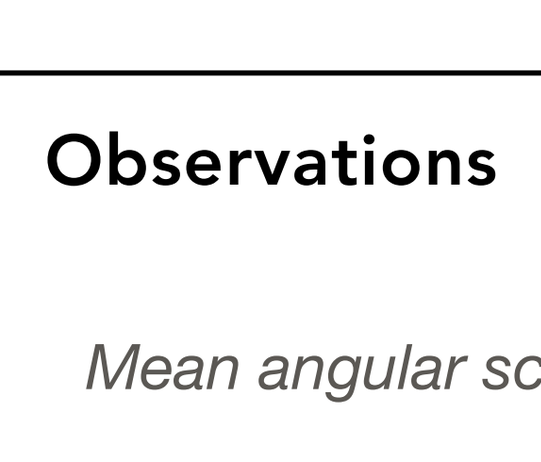
Mean angular scale

→ $m_{mean} = 4.20 \pm 0.09$

Median angular scale

⇢ $m_{median} = 3.13 \pm 0.10$

Connectivity



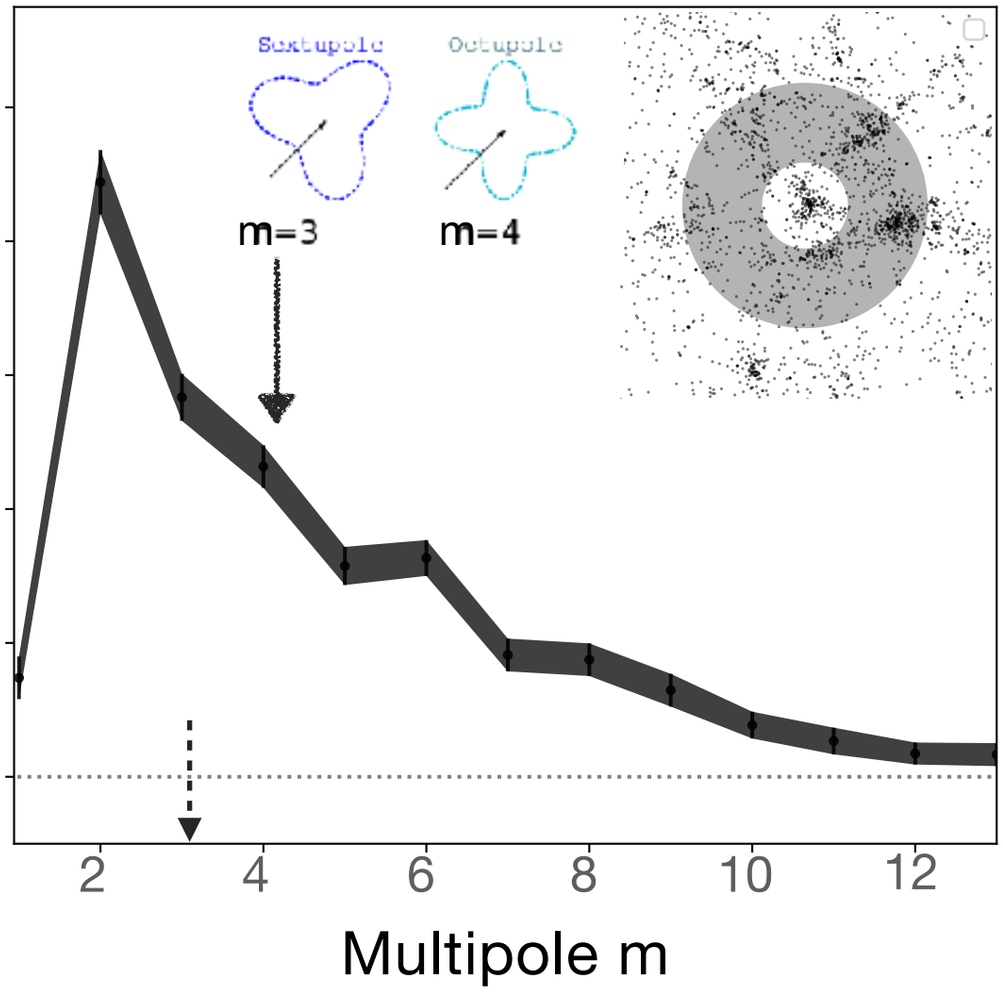
Disperse filaments

~1 Rvir

~3.7 in DM simulation
(Codis et al., 2018)

~3 - 4 in observations

(Sarron 2019,
Malavasi 2019,
Darragh-Ford 2019)



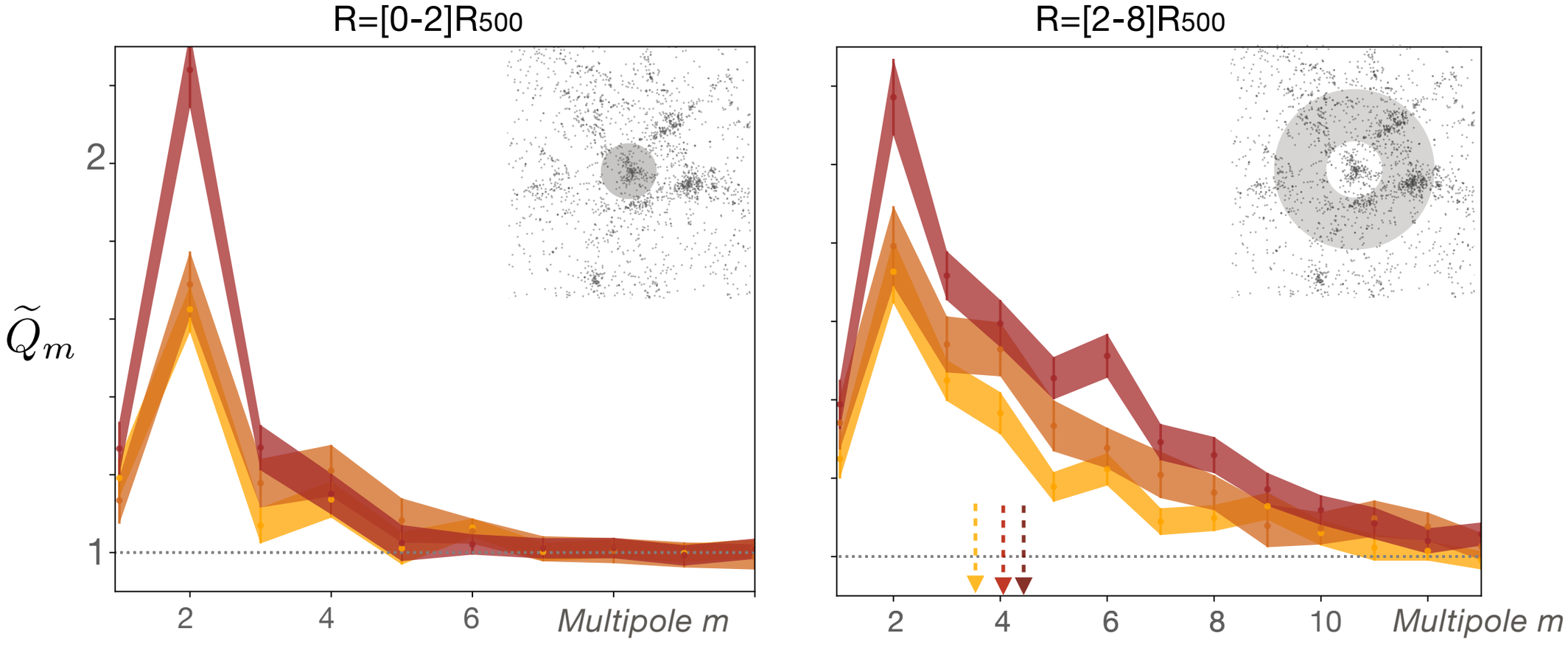
Results - 2. Cluster mass dependency

$20 < richness \leq 25$ $M_{200} \sim 1.2 \times 10^{14} M_\odot$

$25 < richness \leq 30$ $M_{200} \sim 1.6 \times 10^{14} M_\odot$

$richness > 30$ $M_{200} \sim 2.7 \times 10^{14} M_\odot$

$m_{mean} = 4.38 \pm 0.13$
$m_{mean} = 4.01 \pm 0.20$
$m_{mean} = 3.63 \pm 0.27$



The elliptical shape is more marked in richer clusters

(See also Despali et al, 2014)

Richer clusters present a stronger filamentary pattern, and higher *connectivity (mean angular scale)*

Results - 2. Cluster mass dependency

$20 < richness \leq 25$ $M_{200} \sim 1.2 \times 10^{14} M_{\odot}$

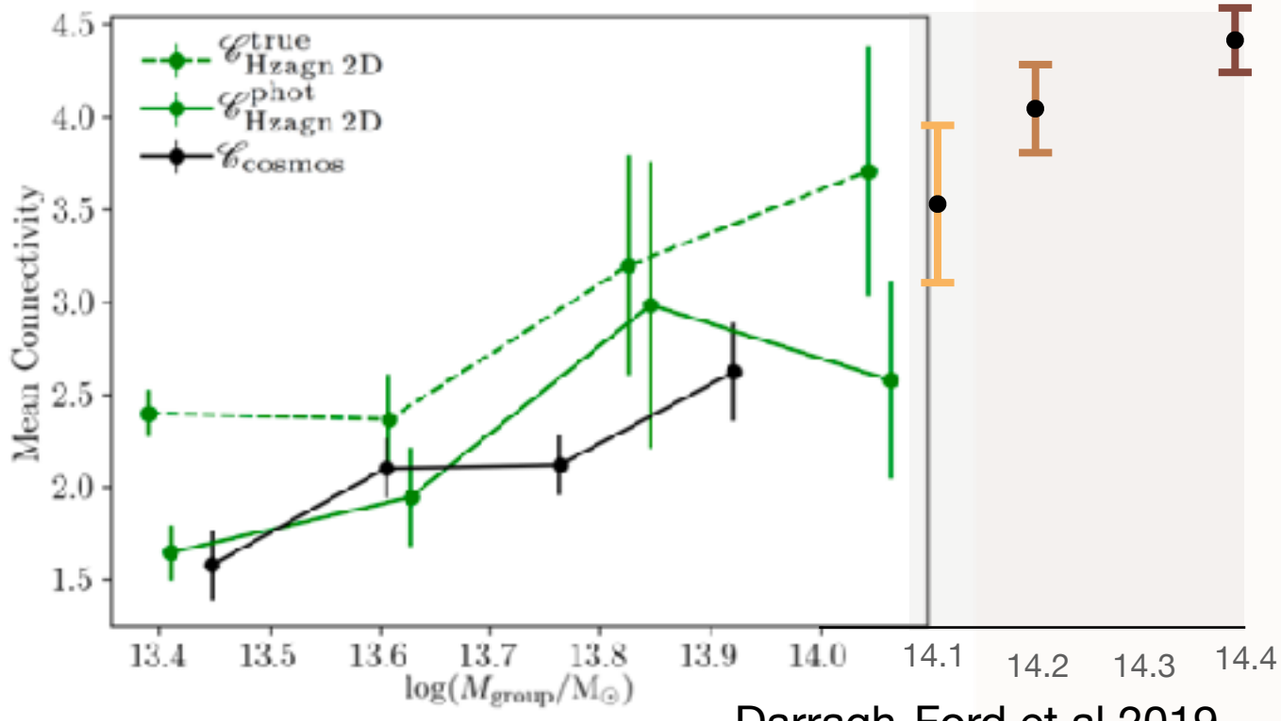
$25 < richness \leq 30$ $M_{200} \sim 1.6 \times 10^{14} M_{\odot}$

$richness > 30$ $M_{200} \sim 2.7 \times 10^{14} M_{\odot}$

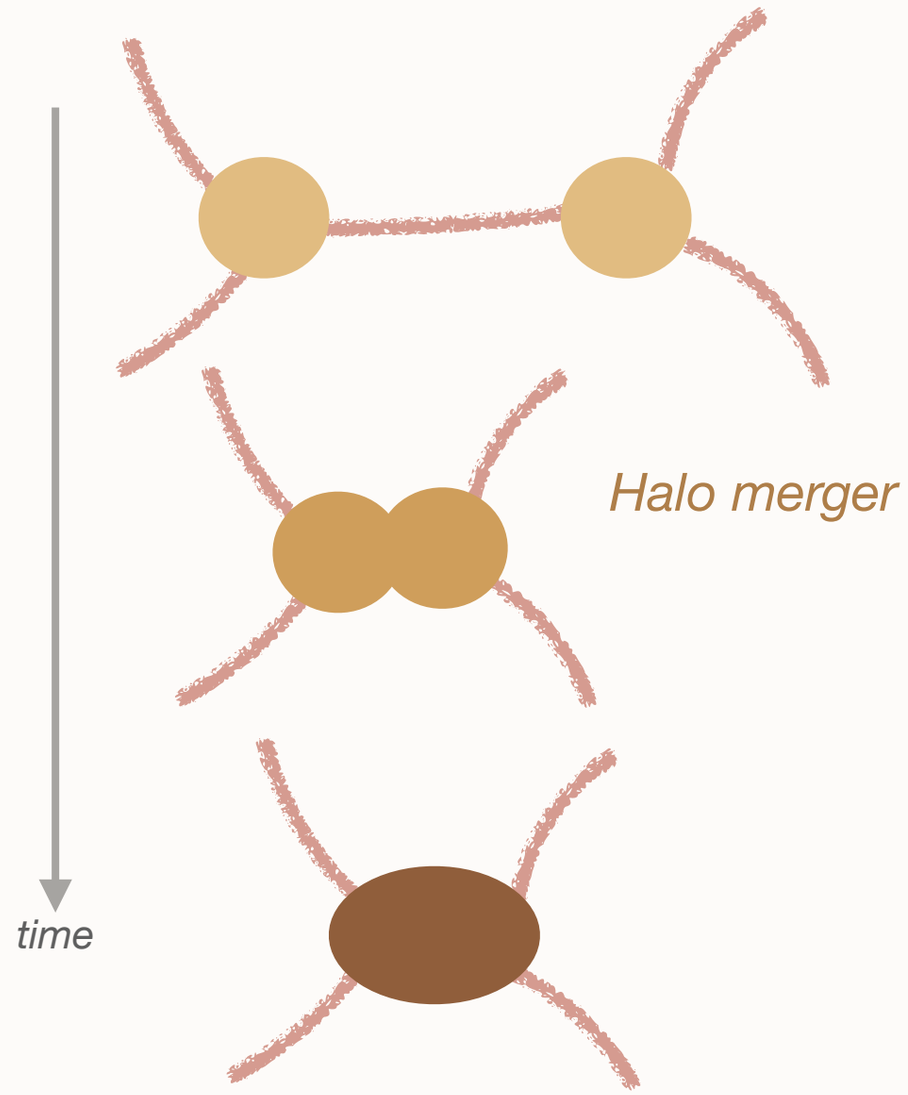
$m_{mean} = 4.38 \pm 0.13$
$m_{mean} = 4.01 \pm 0.20$
$m_{mean} = 3.63 \pm 0.27$

In agreement with current studies
massive objects more connected than low-mass one

Local connectivity of groups with 0.5<z<1.2



Darragh-Ford et al 2019



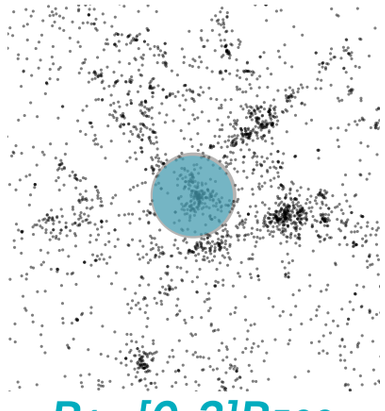
theoretically, see Aragón-Calvo et al. 2010; Pichon et al. 2010; Codis et al. 2018

Observational study, see also Sarron et al 2019

Results - 3. Radial aperture correlation

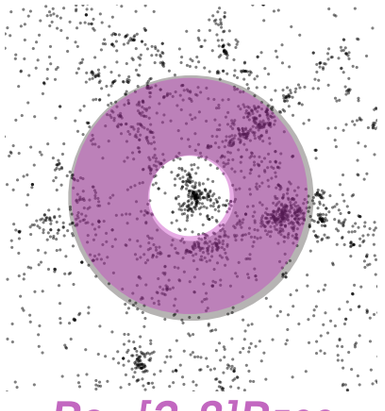
Are the filamentary structures preferentially orientate with the cluster core ?

Correlation between



$R_1=[0\text{-}2]R_{500}$

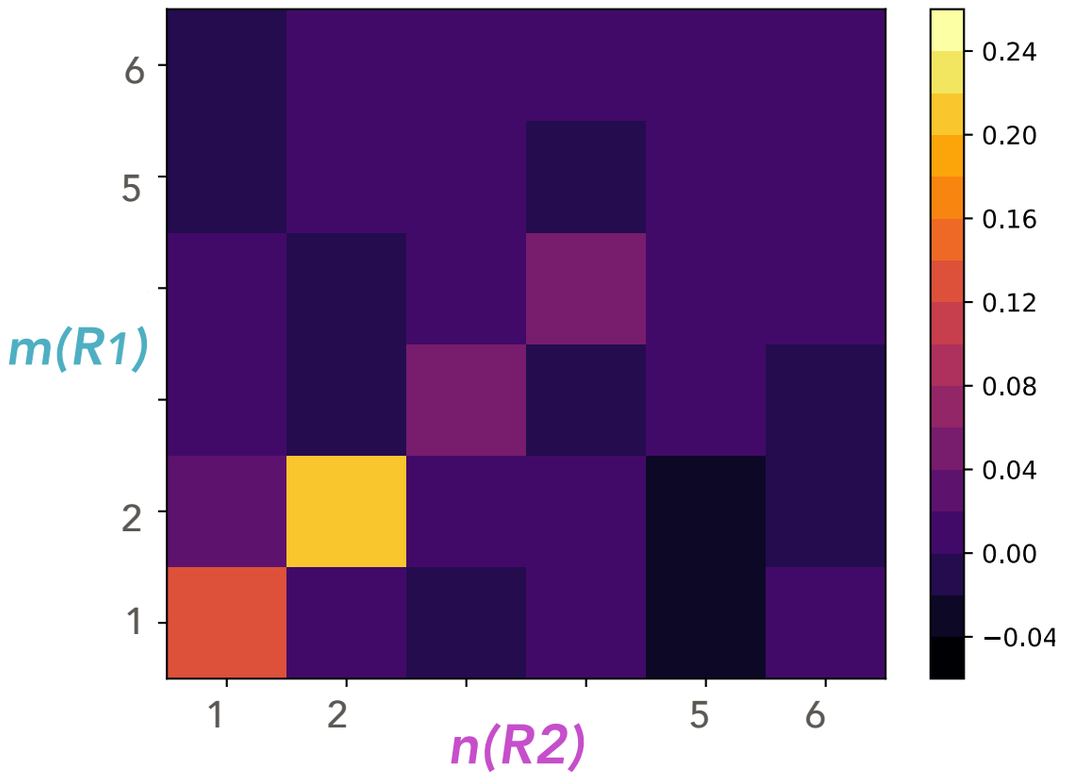
and



$R_2=[2\text{-}8]R_{500}$

?

Correlation coefficients of multipole moments between R1 & R2

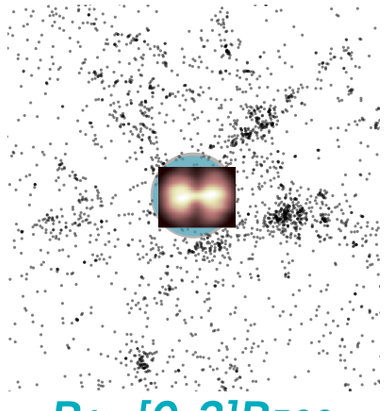
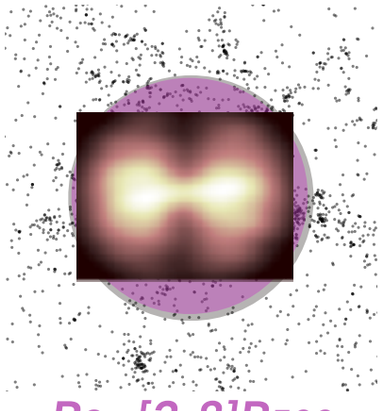


Cross power spectrum between R1 and R2

$$\mathcal{C}_{m,n}(R_1, R_2) = \mathcal{R}e\left(\frac{\langle Q_m(R_1)Q_n^*(R_2)\rangle}{\sigma_{Q_m}(R_2)\sigma_{Q_n}(R_2)}\right)$$

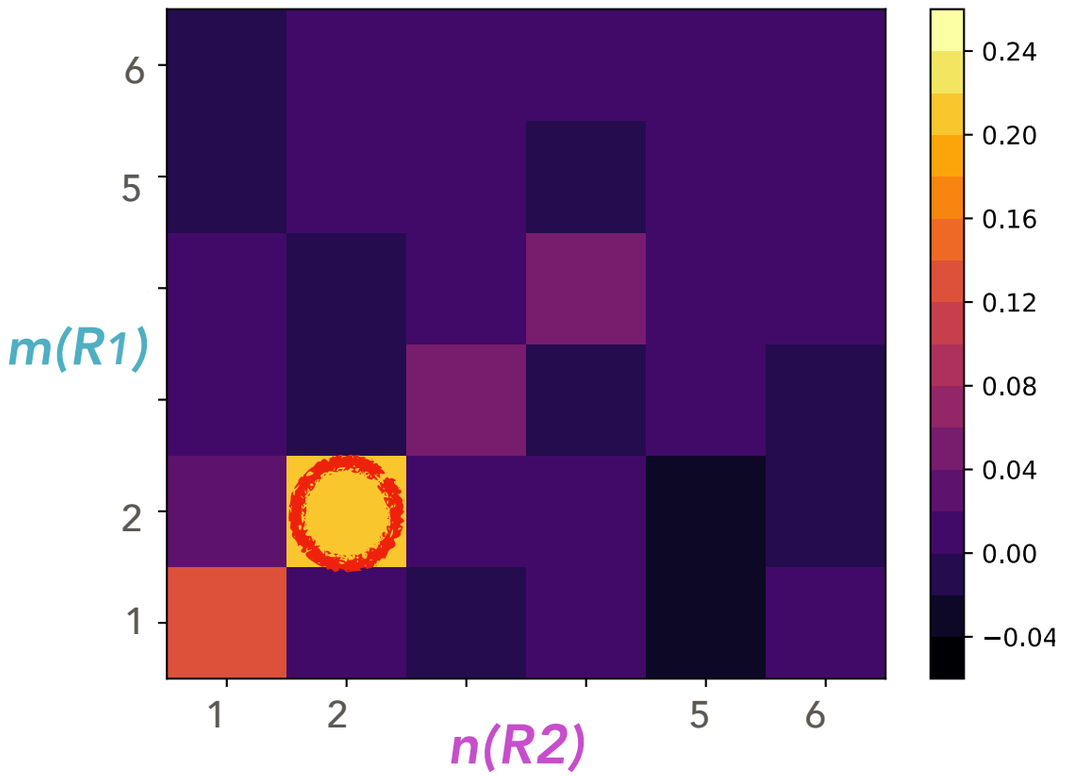
Results - 3. Radial aperture correlation

Are the filamentary structures preferentially orientate with the cluster core ?

Correlation between  and  ?

$R_1=[0\text{-}2]R_{500}$ $R_2=[2\text{-}8]R_{500}$

Correlation coefficients of multipole moments between R1 & R2



Significative correlation at m=n=2

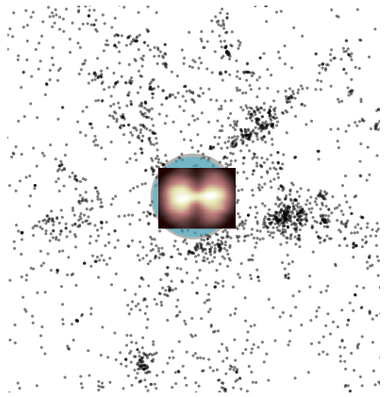
Cross power spectrum between R1 and R2

$$\mathcal{C}_{m,n}(R_1,R_2) = \mathcal{R}e\left(\frac{\langle Q_m(R_1)Q_n^*(R_2)\rangle}{\sigma_{Q_m}(R_2)\sigma_{Q_n}(R_2)}\right)$$

Results - 3. Radial aperture correlation

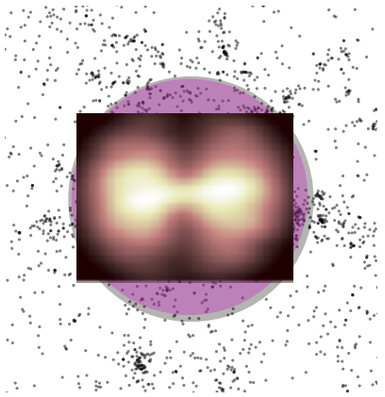
Are the filamentary structures preferentially orientate with the cluster core ?

Correlation between



$R_1=[0\text{-}2]R_{500}$

and



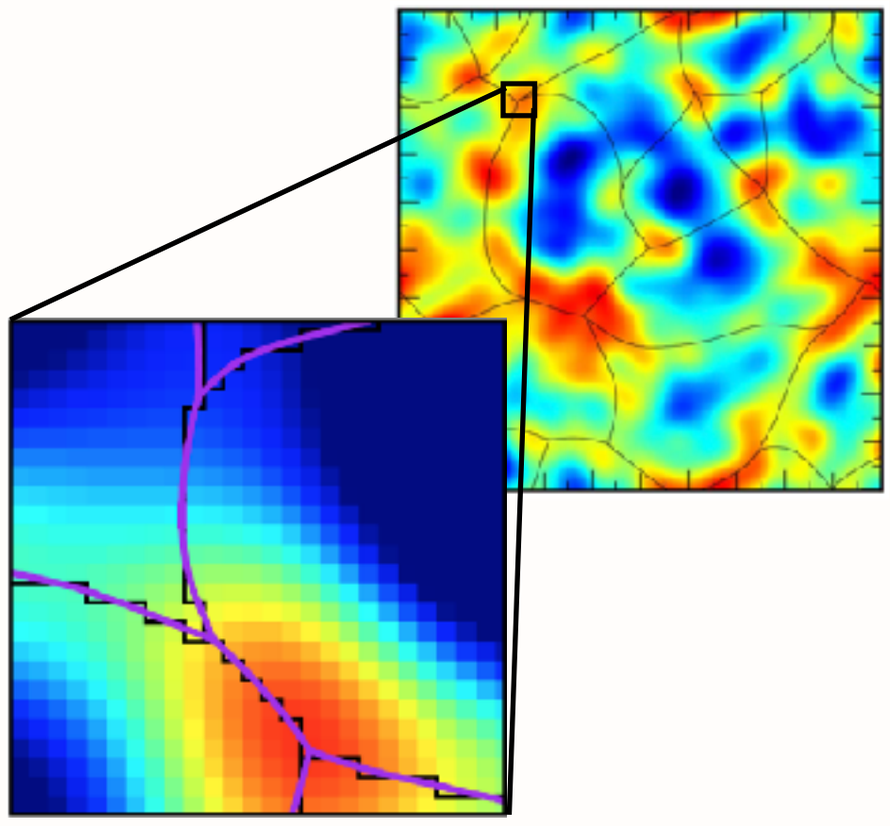
$R_2=[2\text{-}8]R_{500}$

?

Correlation between clusters nodes and large scale structure

Very locally **a density peak** is elliptical and has two ridges

But further away, the **skeleton bifurcates and number of filaments** increases with the distance to the peak

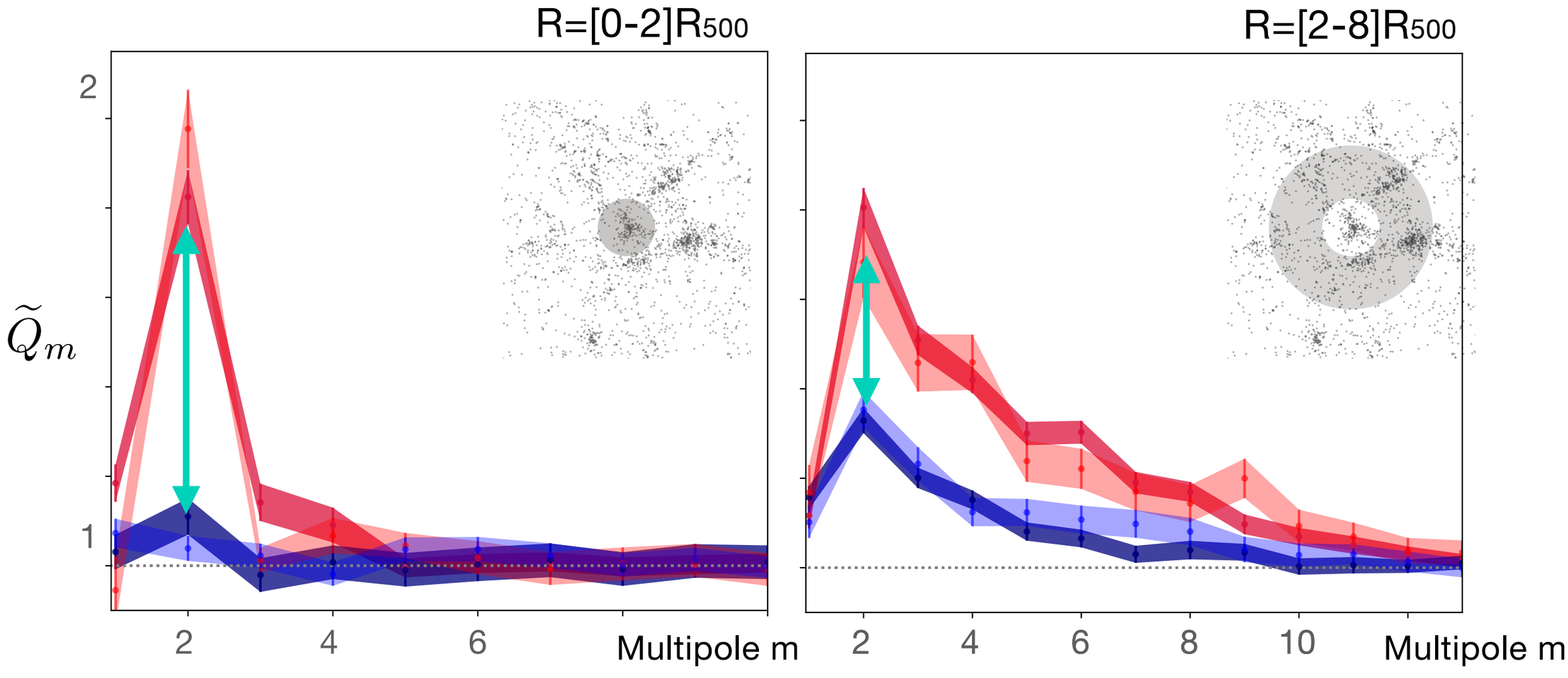


Codis et al (2018)

Results - 4. Galaxy type - different tracer?

Which type of galaxy trace the asymmetries in galaxy distribution?
The role of cluster environment ?

Passive and **star-forming** from observations & simulation



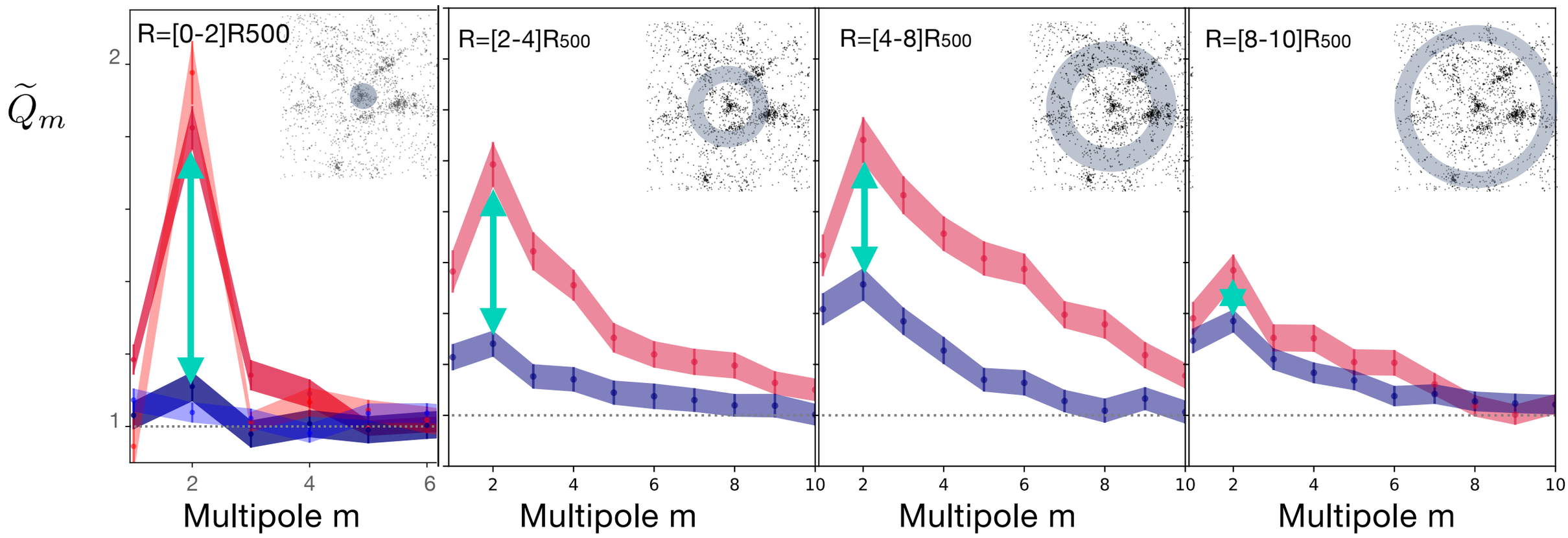
The contribution of SF galaxies increases with cluster distance

A gradient of SF activity in anisotropic structures, from cluster centre to the filaments?

Results - 4. Galaxy type - different tracer?

Which type of galaxy trace the asymmetries in galaxy distribution?
The role of cluster environment ?

Passive and **star-forming** from observations & simulation



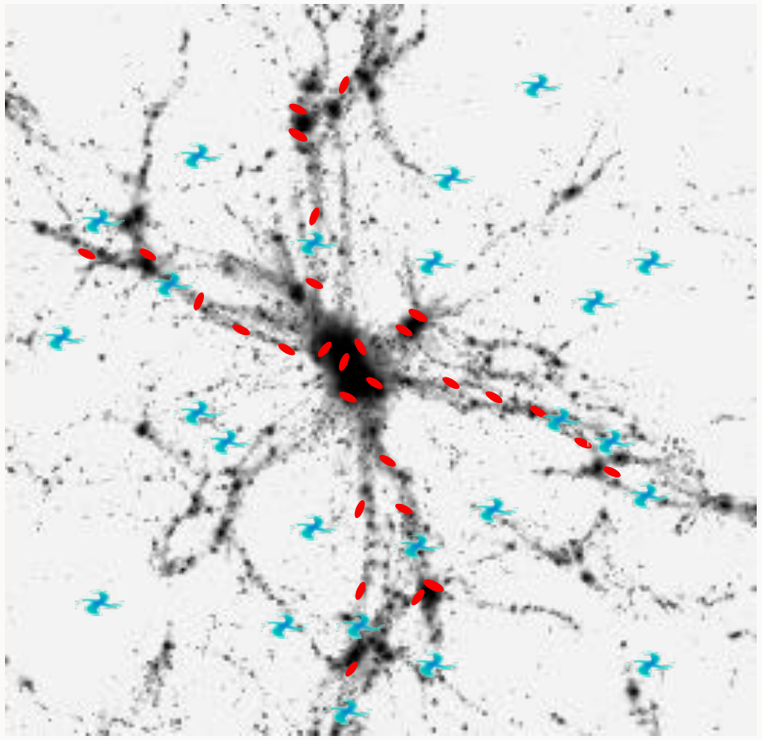
The contribution of SF galaxies increases with cluster distance

An gradient of SF activity in asymmetric structures from cluster centre to the LSS

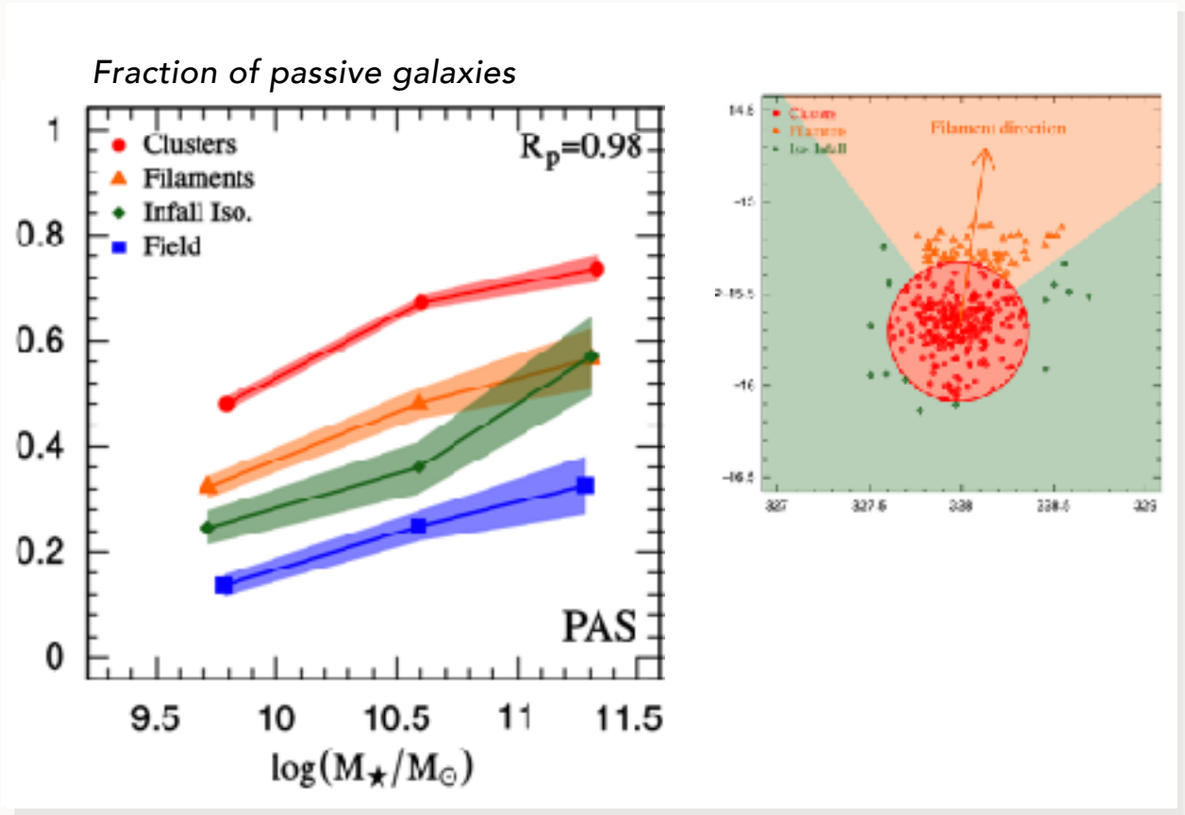
Results - 4. Galaxy type - different tracer?

Which type of galaxy trace the asymmetries in galaxy distribution?
The role of cluster environment ?

Galaxies are pre-processed inside filaments before entering into clusters?



Galaxies in filaments are systematically more quenched than their counterparts infalling from other directions



Salerno et al. (2020)

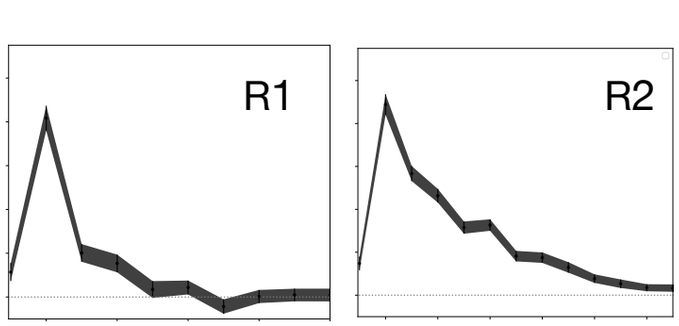
An gradient of SF activity in asymmetric structures from cluster centre to the LSS

Probing the azimuthal environment of galaxies around clusters from cluster core to cosmic filaments

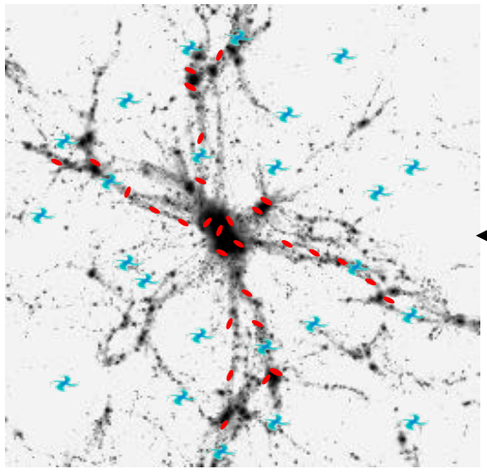
Gouin C., Aghanim N., Bonjean V., Douspis M. (2020)

Main conclusions

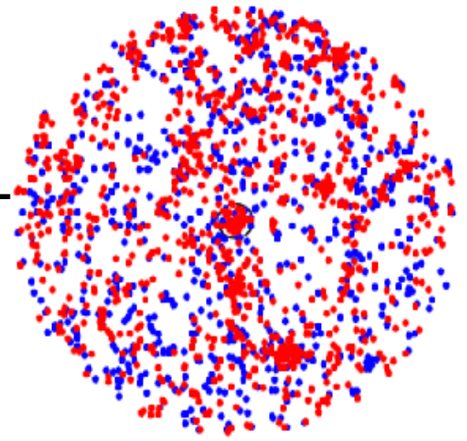
Elliptical core and **filamentary patterns** in harmonic space



Pre-processing of galaxies by filaments before entering into clusters ?



?



In agreement with DM predictions

- Correlate with the connectivity from in simulations (Gouin+22)
- Euclid prediction for harmonic decomposition on shear map (Gouin+17)

New investigations

LSS investigation on spectroscopic galaxies around 200 clusters (MMT/Hectospec and SDSS)