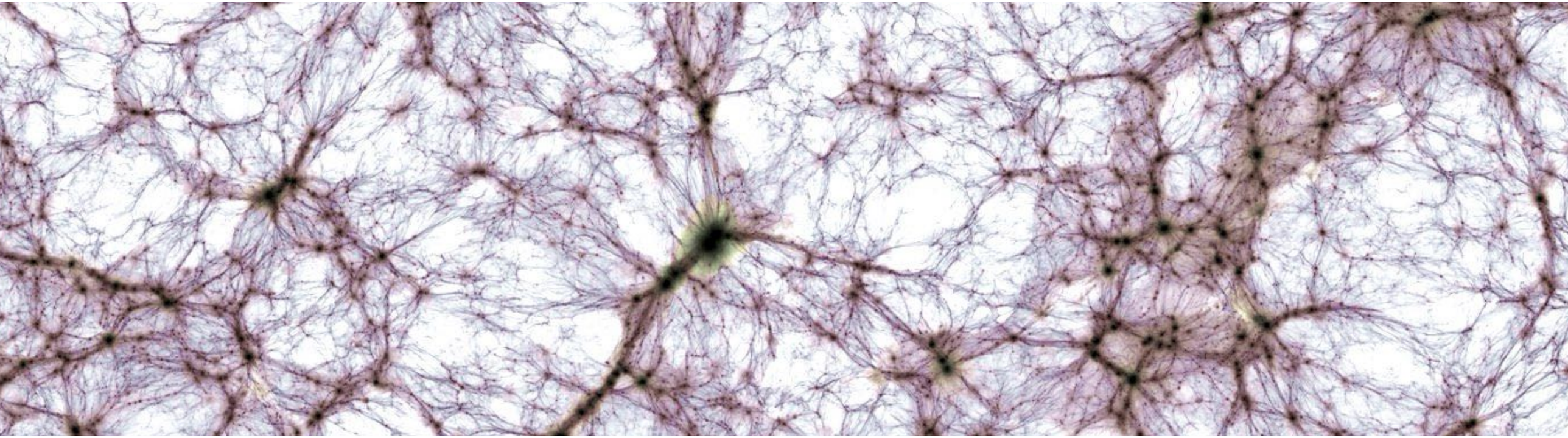
Impact of clusters' connectivity on their evolution and gas accretion



TNG simulation

Colloque national Action Dark Energy 2024 - 8ème édition

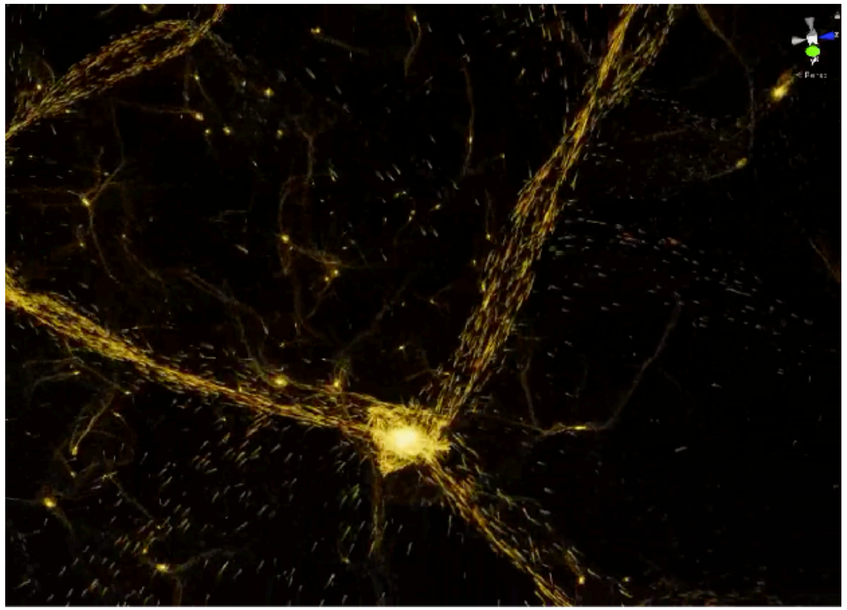
Gouin Celine, IAP, France

Collaborators: N.Aghanim (IAS), S.Gallo (IAS), D. Galarraga-Espinosa (MPA), M. Bonnemente (Univ. Alabama), C. Laigle (IAP), T. Bonnaire (ENS), C. Park (KIAS), S. Walker (Univ. Alabama), M. Mirakhor (Univ. Alabama)

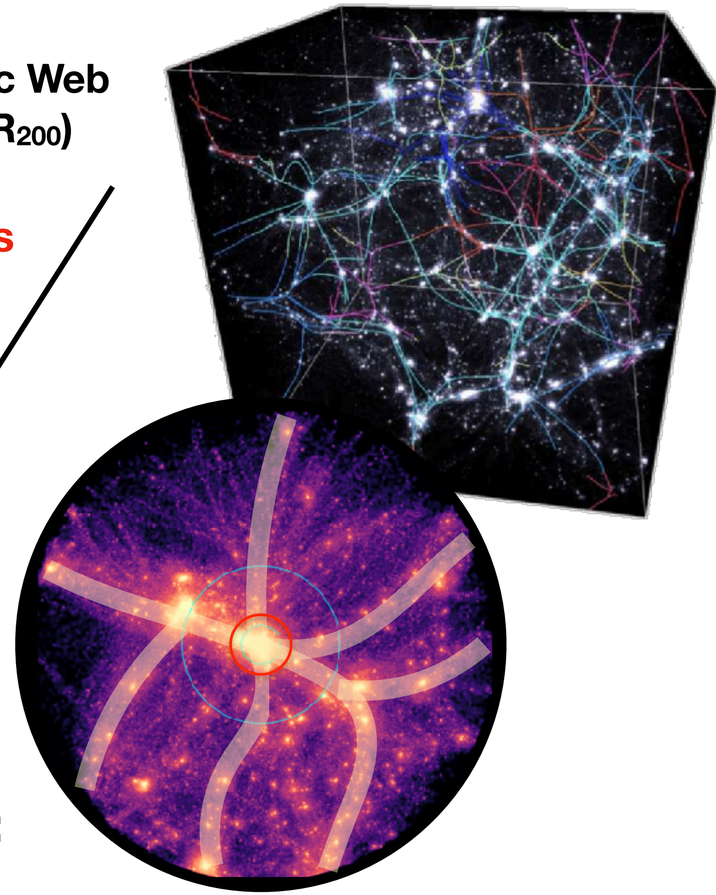
Introduction to galaxy clusters
Nodes of Cosmic web

Nodes of cosmic web:

- Located at the intersection of cosmic filaments
- Matter flow from void > wall > filaments > nodes



Credit to Miguel Aragon Calvo



Anisotropic infalling regions to probe:

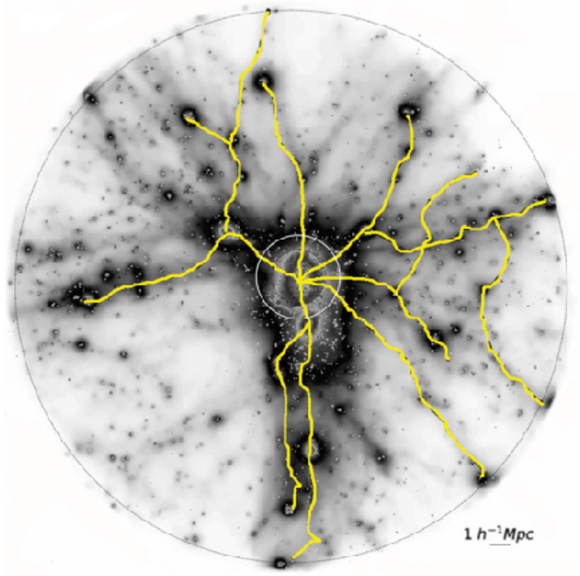
- Growth of massive structures
- Complex gas physics out-of-hydrostatic eq.
- Environmental driven galaxy evolution

I - Is cosmic web environments influencing cluster properties?

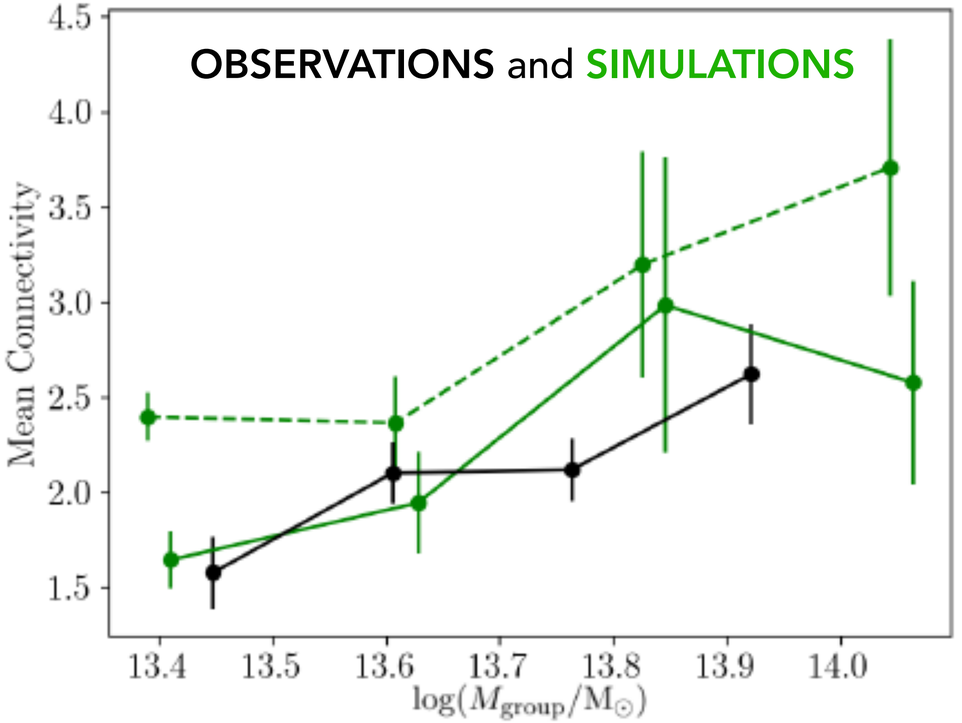
II - How gas is changing during it infall?

I - Is cosmic web environments influencing cluster properties ?

Connectivity
Number of connected cosmic filaments

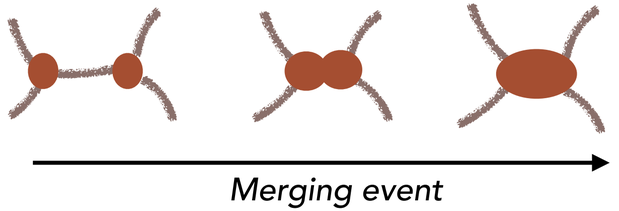


Kuchner, et al. 2020



Darragh Ford et al. 2019 (HorizonAGN and COSMOS)

More massive,
more connected to the cosmic web



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

One crucial property govern by the mass: the dynamical state

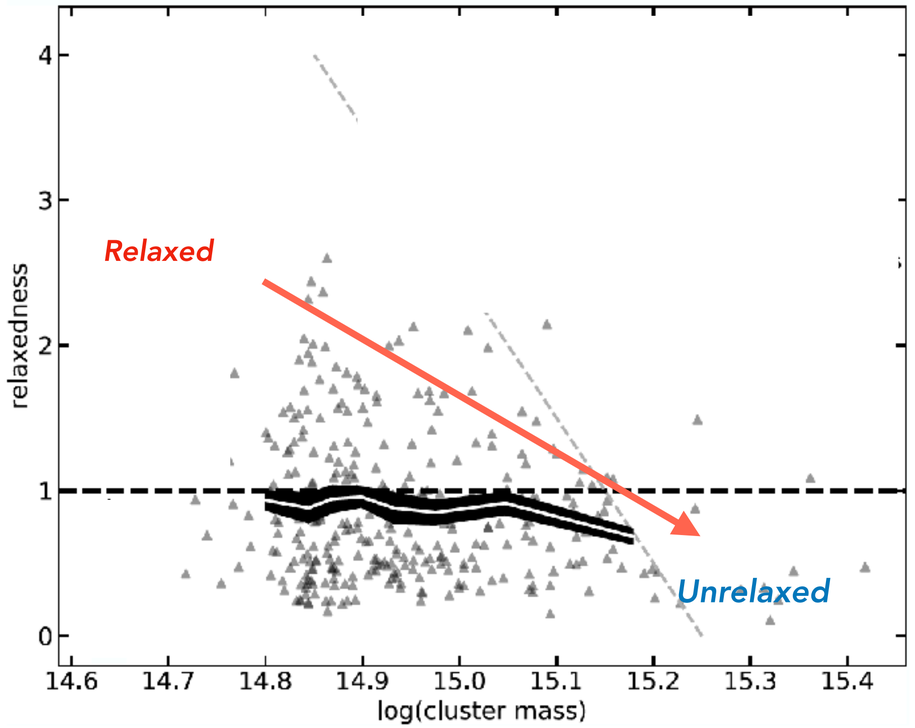
Dynamical state

Fraction of substructure

Center offset

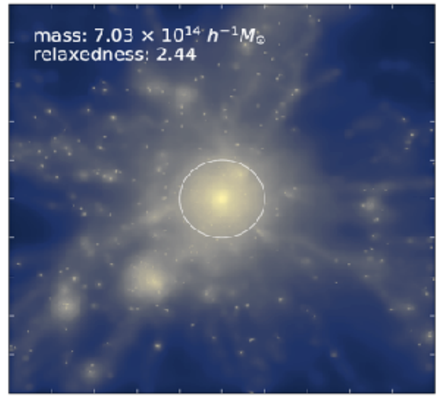
Virial ratio

Dynamical State fonction of mass

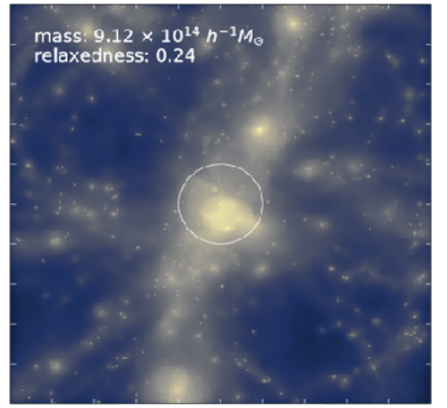


Kuchner, et al. 2020

ThreeHundred simulations



Relaxed



Unrelaxed

Kuchner, et al. 2020

I - Is cosmic web environments influencing cluster properties ?

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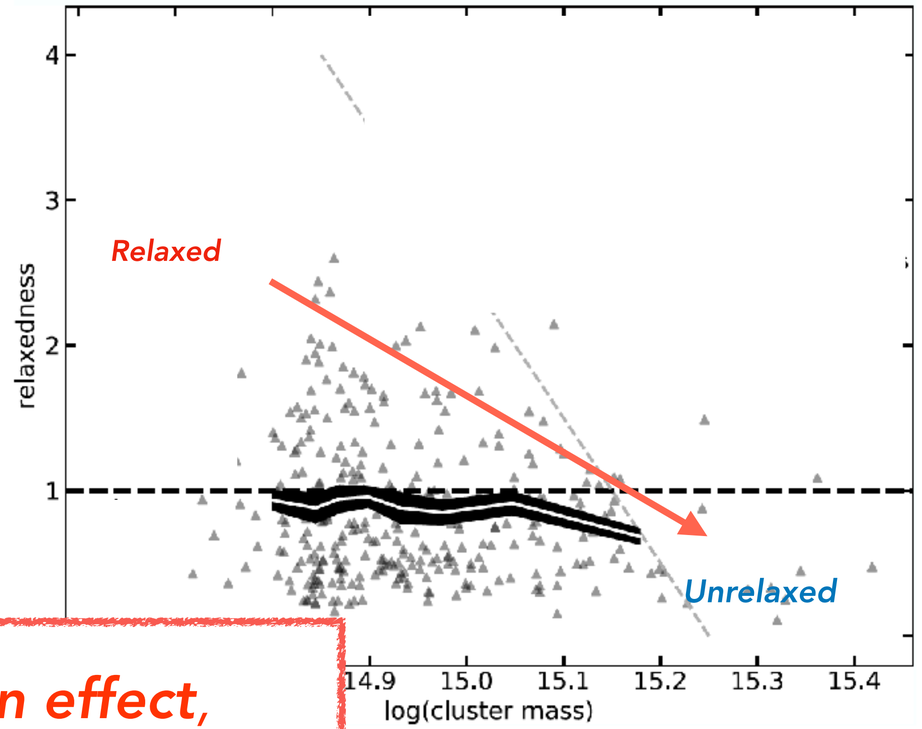
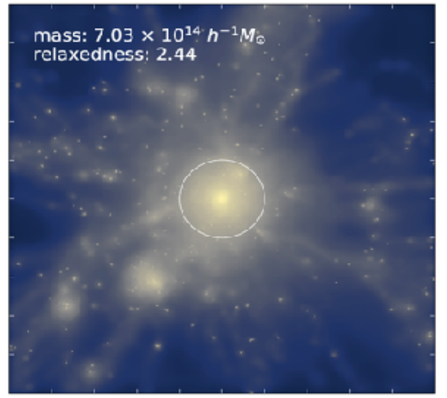


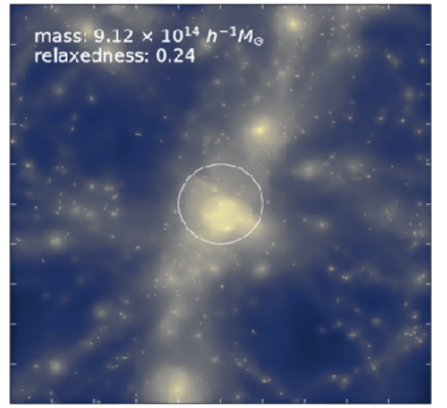
Kuchner, et al. 2020

Beyond this mass-driven effect,
are cluster properties affected by LSS?

ThreeHundred simulations



Relaxed

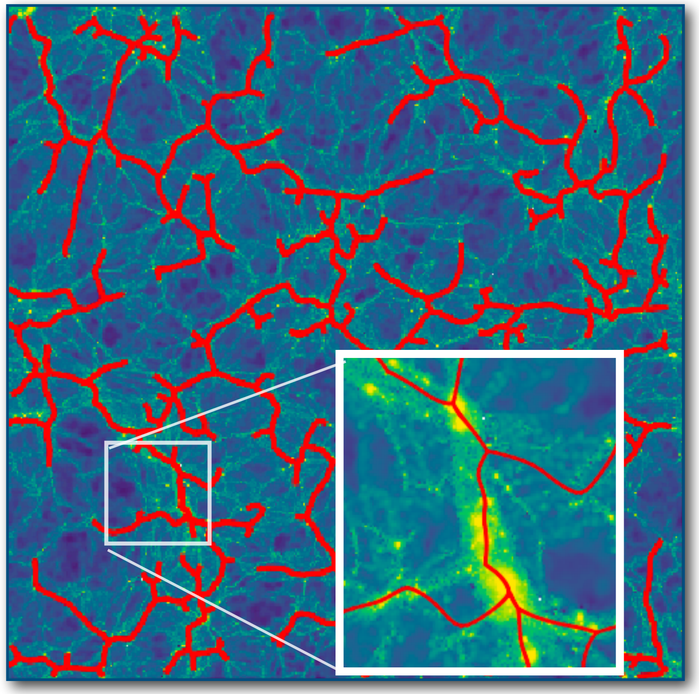


Unrelaxed

Kuchner, et al. 2020

I - Is cosmic web environments influencing cluster properties ?

Gouin+21



IllustrisTNG (z=0)

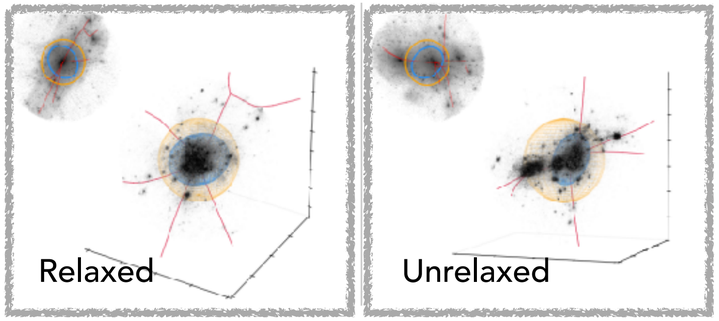
~2000 halos with
$M_{200}>10^{13}Mo/h$

Cosmic web skeleton

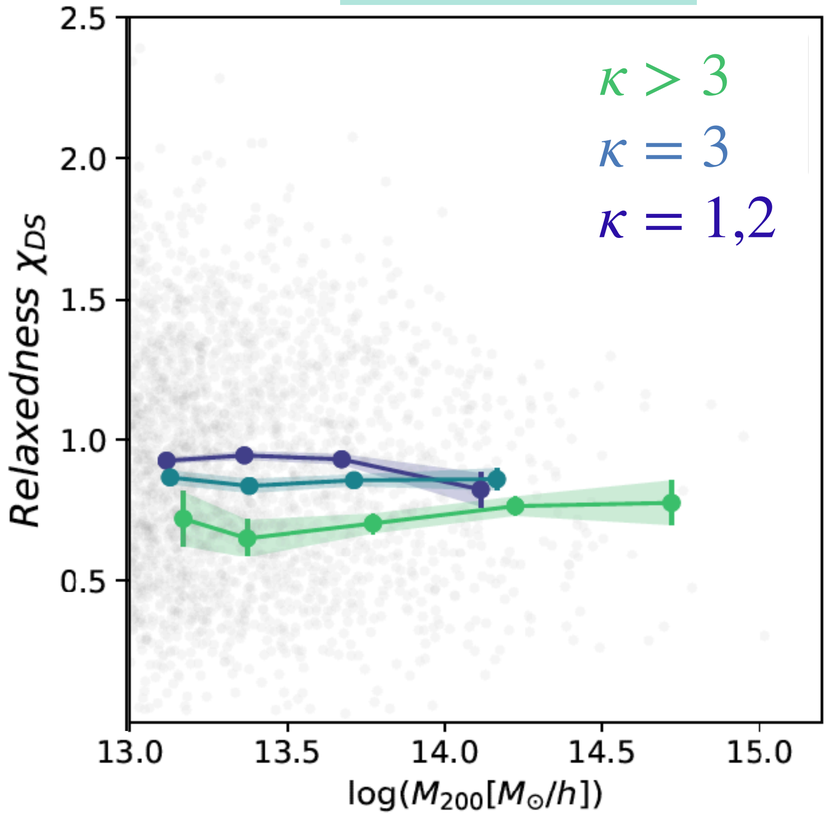
T-ReX algorithm
Bonnaire et al (2020)

Relaxedness

Substructure
Center offset
Virial ratio



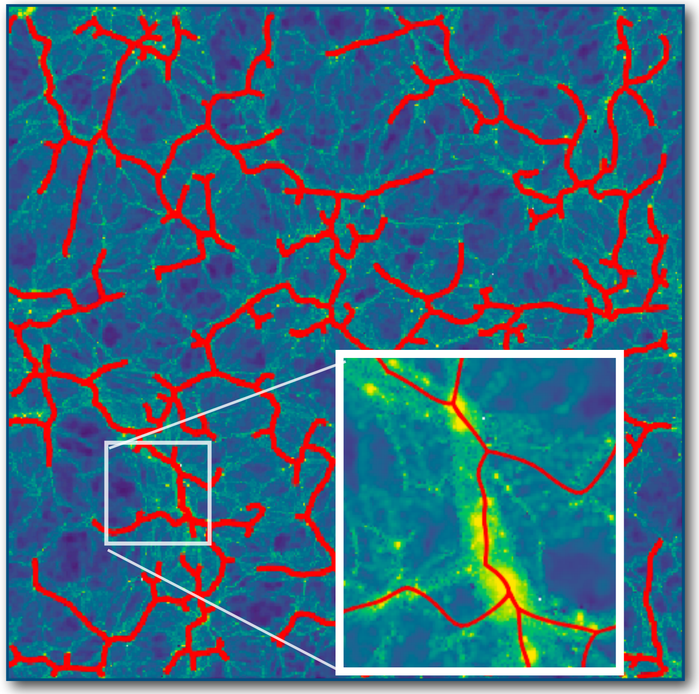
Dynamical State fonction of mass
and CONNECTIVITY



Highly connected clusters are less relaxed than low-connected clusters

I - Is cosmic web environments influencing cluster properties ?

Gouin+21



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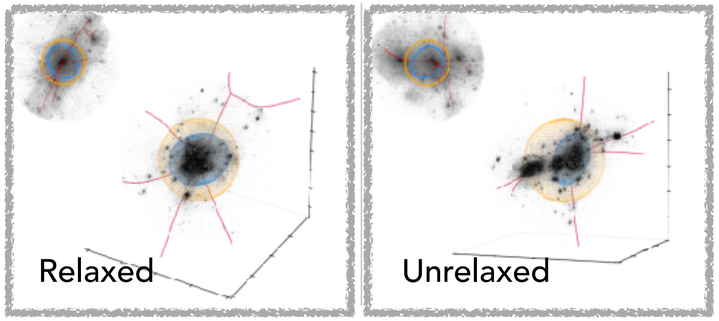


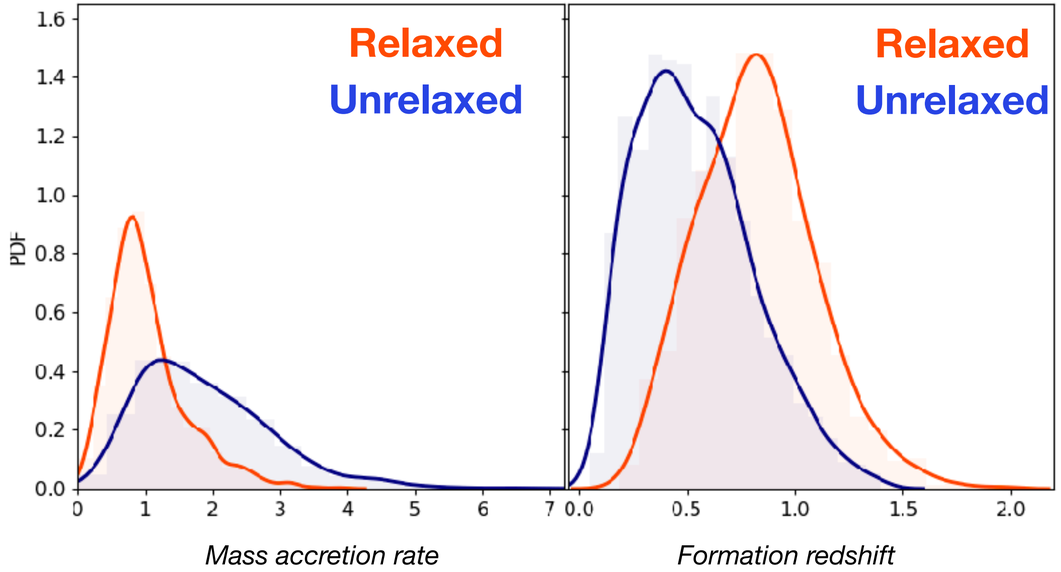
Mass assembly history proxies

Mass accretion rate

$$\Gamma = \frac{\Delta \log(M_{200m})}{\Delta a}$$

Formation redshift

$$M(z_{form}) = \frac{M(z=0)}{2}$$

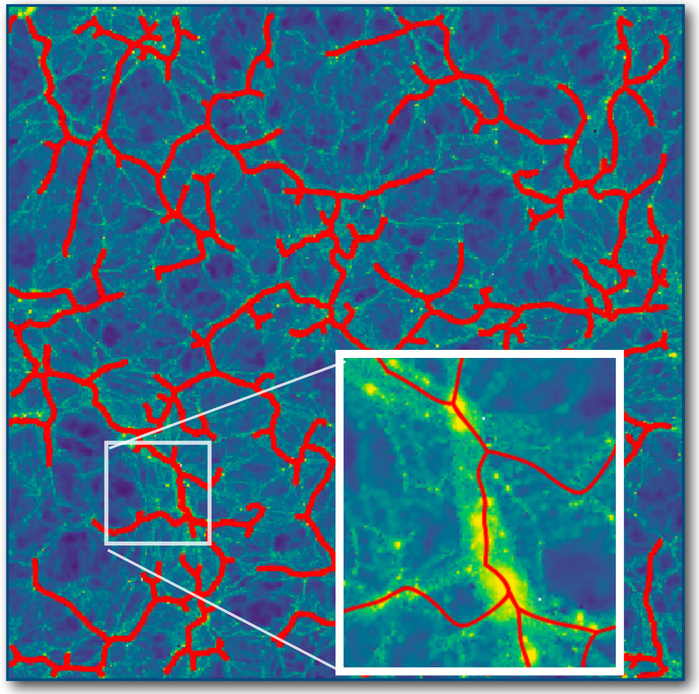


Unrelaxed halos are more recently formed and are in fast accreting phase

See also Power et al. (2012), Diemer et al (2014) Mostoghiu et al. (2019)

I - Is cosmic web environments influencing cluster properties ?

Gouin+21



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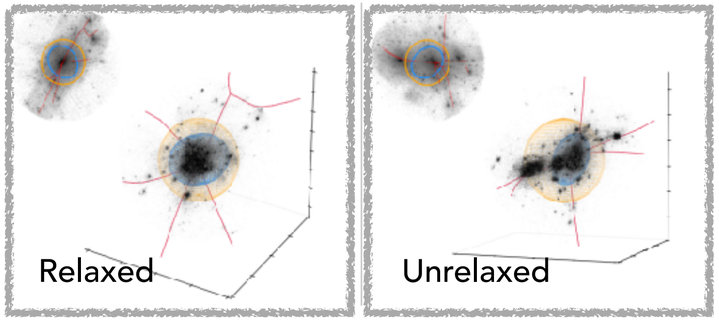

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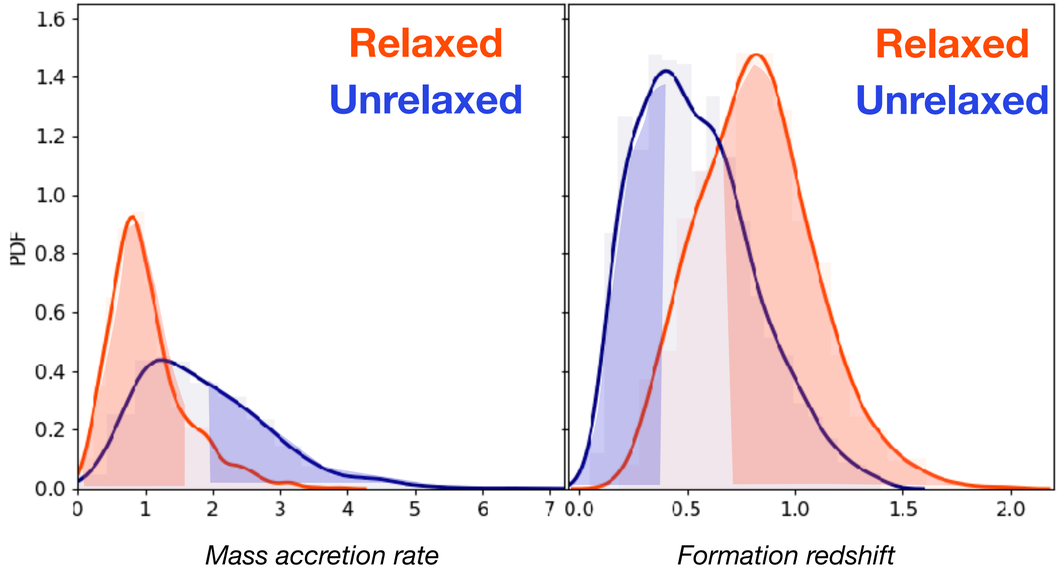


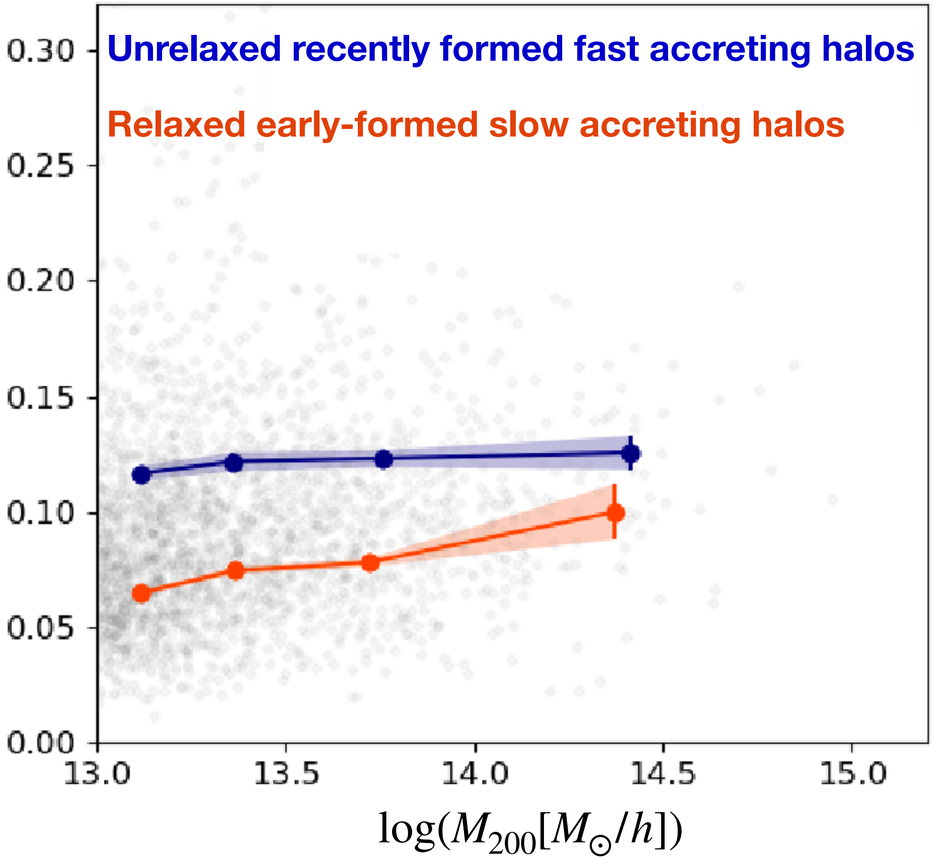
Unrelaxed recently formed fast accreting halos

Relaxed early-formed slow accreting halos

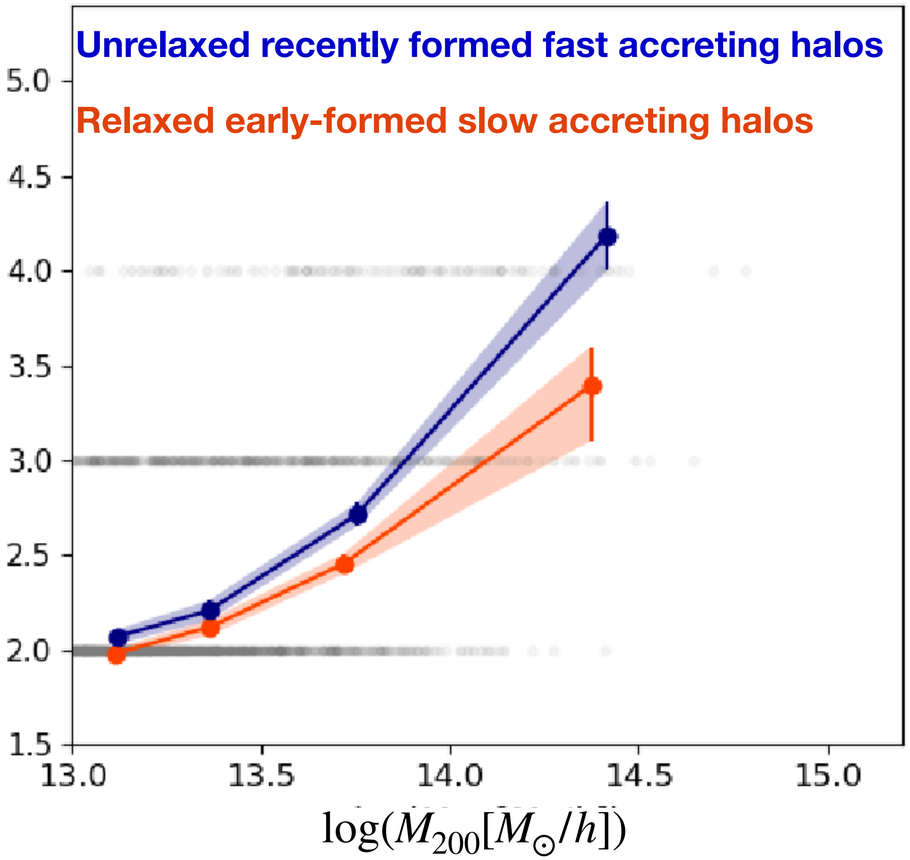
Gouin+21

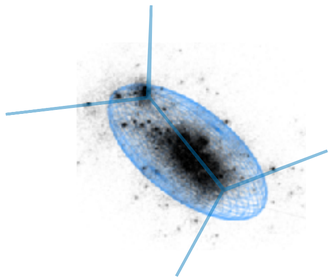
Cluster connectivity traduces different evolutionary state

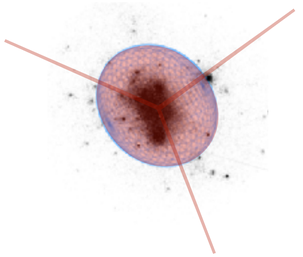
Ellipticity



Connectivity







See also Darragh Ford et al. 2019 (Connectivity & Merging events)

I - Is cosmic web environments influencing cluster properties ?

OBSERVATIONS

★ **A2142 cluster (Einasto et al. 2020)**

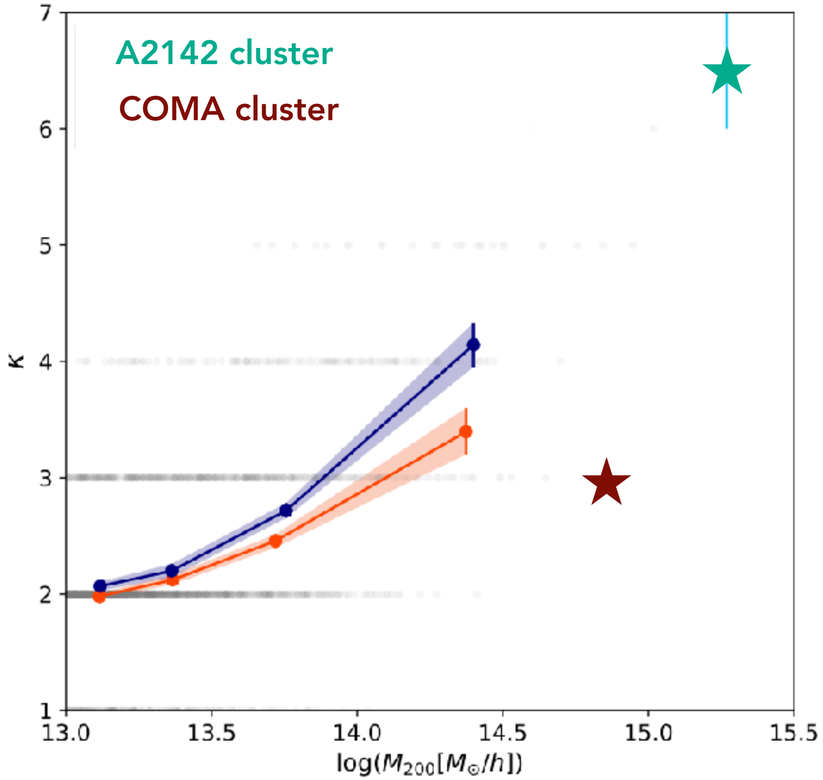
- elongated shape
- large number of substructures
- merging system

➡ **Recently formed type of objects**

★ **COMA cluster (Malavasi et al. 2020)**

- more spherical
- high concentration
  & low accretion rate

➡ **Early formed type of objects**

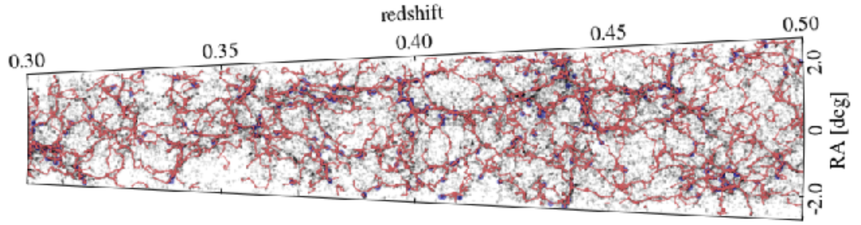


Need larger statistics of connectivity and dynamical state in observations

EUCLID - GAE SWG WP3 - Galaxy evolution in different environments

Detection of cosmic skeleton in 2D and 3D Euclid data / flackship mock

M. Maglioccheti, J. Sorce, Y. Bahé, K. kraljic, U. Kuchner, C. Laigle, F. Sarron, P. Jablonka, N. Malavasi, P. Jablonka, M. Balogh, F. Durret, C. Gouin

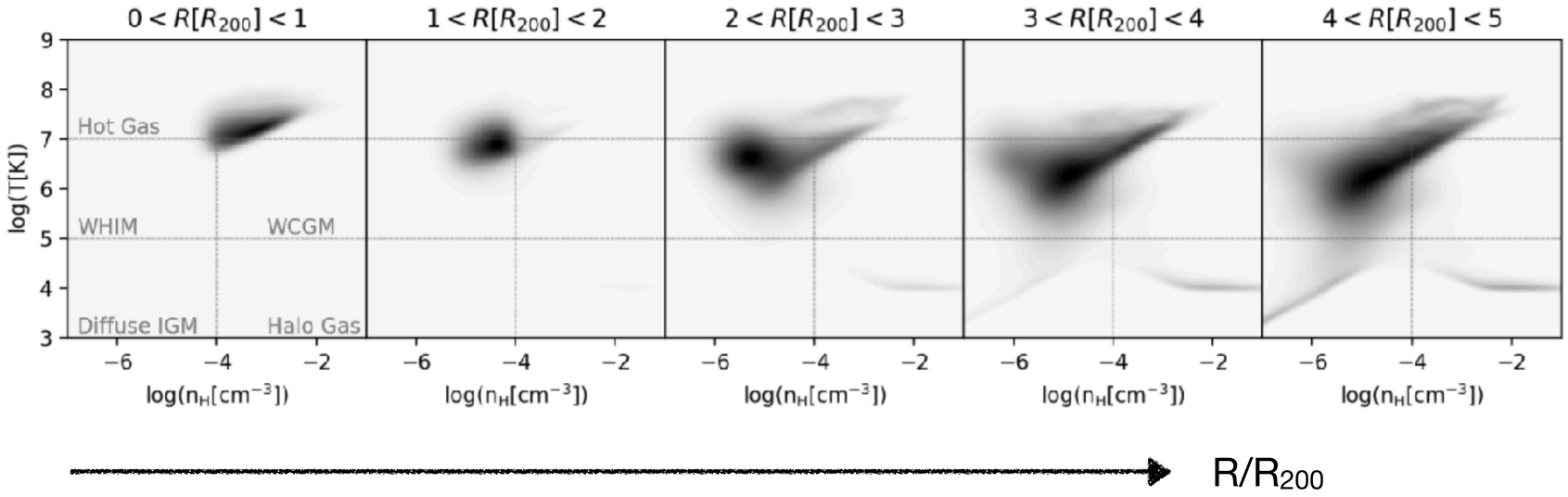


II - How gas is changing during it infall?

Gouin+22

From **HOT** gas inside clusters to **WHIM** gas out of clusters

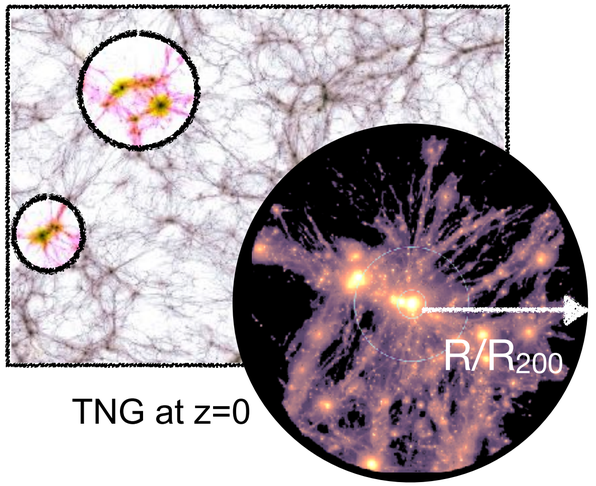
Phase space diagram



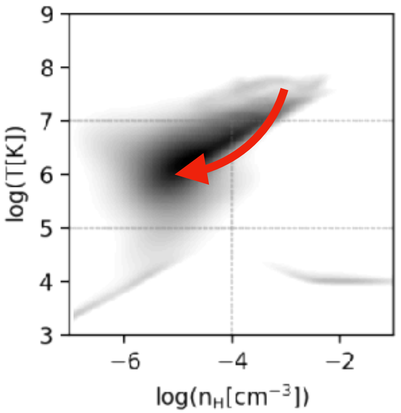
HOT Gas R < 1 R_{200} **WHIM R > 1 R_{200}**

Multi-phase environments

~400 clusters with M_{200}>5 x10^{13}Mo/h



TNG at z=0

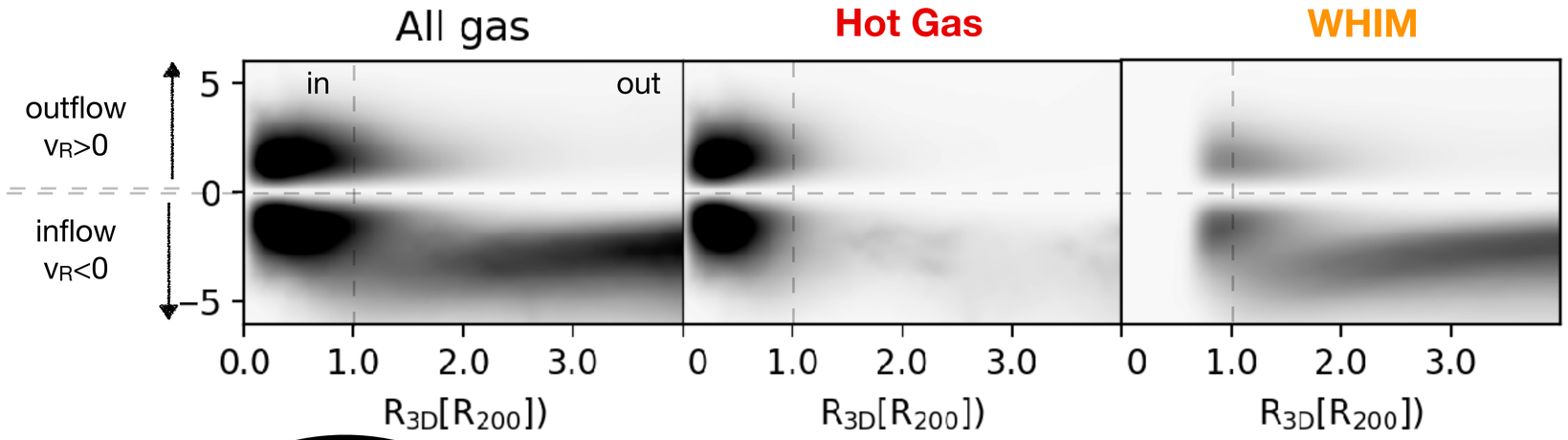


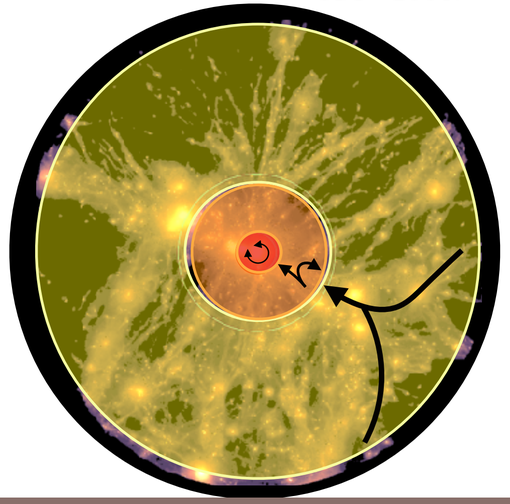
II - How gas is changing during it infall?

Gouin+22

From **HOT** gas inside clusters to **WHIM** gas out of clusters

Radial velocity of the in-falling gas





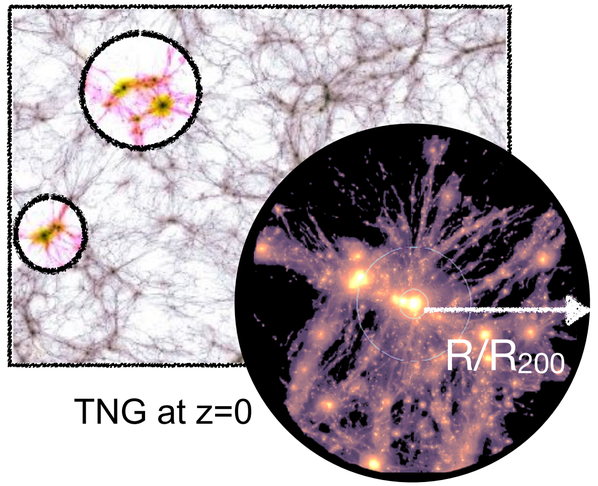
Accumulating ICM inside galaxy clusters

Slow inflow & ejected WHIM at cluster peripheries

Fast in-falling WHIM outside clusters

Multi-flow environments

~400 clusters with M_{200}>5 x10^{13}Mo/h



TNG at z=0

Comparison to other studies

Gas preferentially enters through filaments, and leaves clusters outside filaments

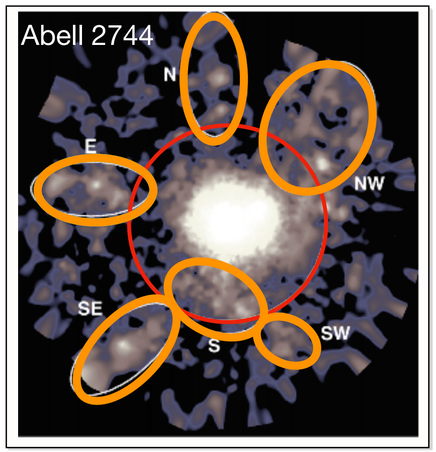
Rost+24 (TheThreeHundred)

See also Vurm+23 (C-EAGLE)

Gouin+21

Probing angular patterns beyond spherical symmetry = highlight asymmetries

Observation

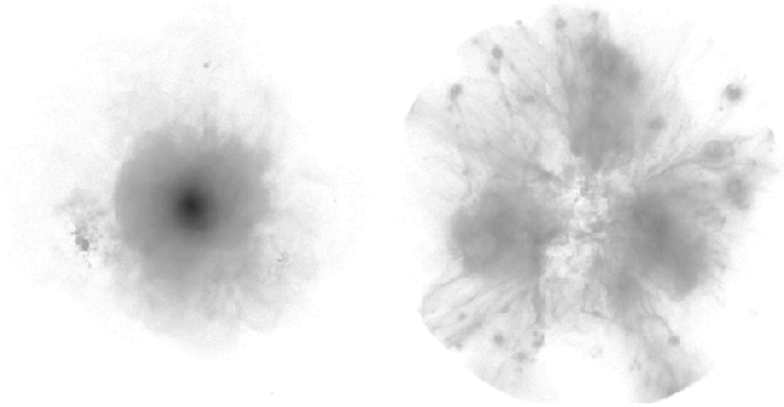


Eckert, et al. 2015

HOT GAS - Hot dense plama $T \sim 10^7$-10^8 K

WHIM - Low dense plasma $T \sim 10^5$-10^7 K

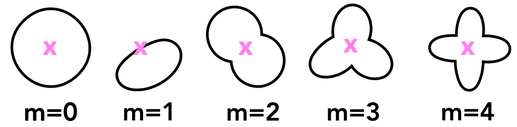
Simulation



HOT GAS **WHIM**

Decomposition in 2-D harmonic space

$$Q_m \propto \int e^{im\theta}\, \Sigma(\theta)\, d\theta$$



harmonic order m

Harmonic excess / circular symmetry

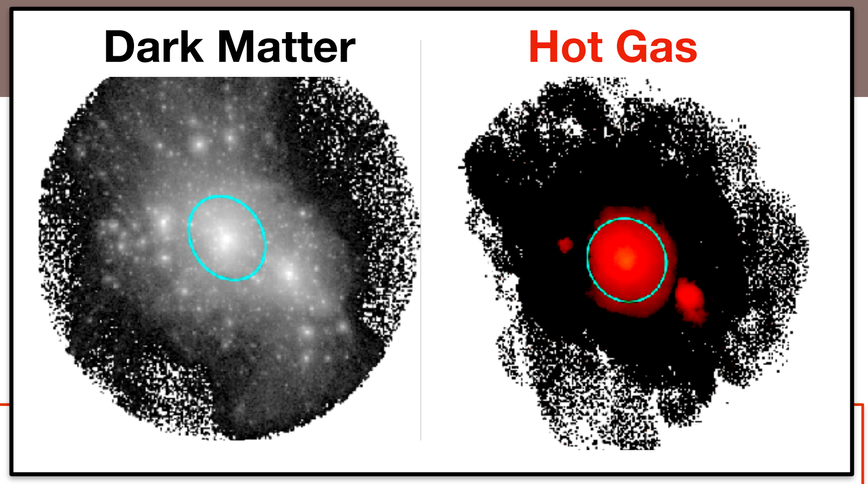
$$\beta \propto \sum_{m=1..4} \frac{Q_m}{Q_0}$$

DM distribution (Gouin et al. 2017, Codis et al 2017) and galaxy distribution (Gouin et al. 2020)

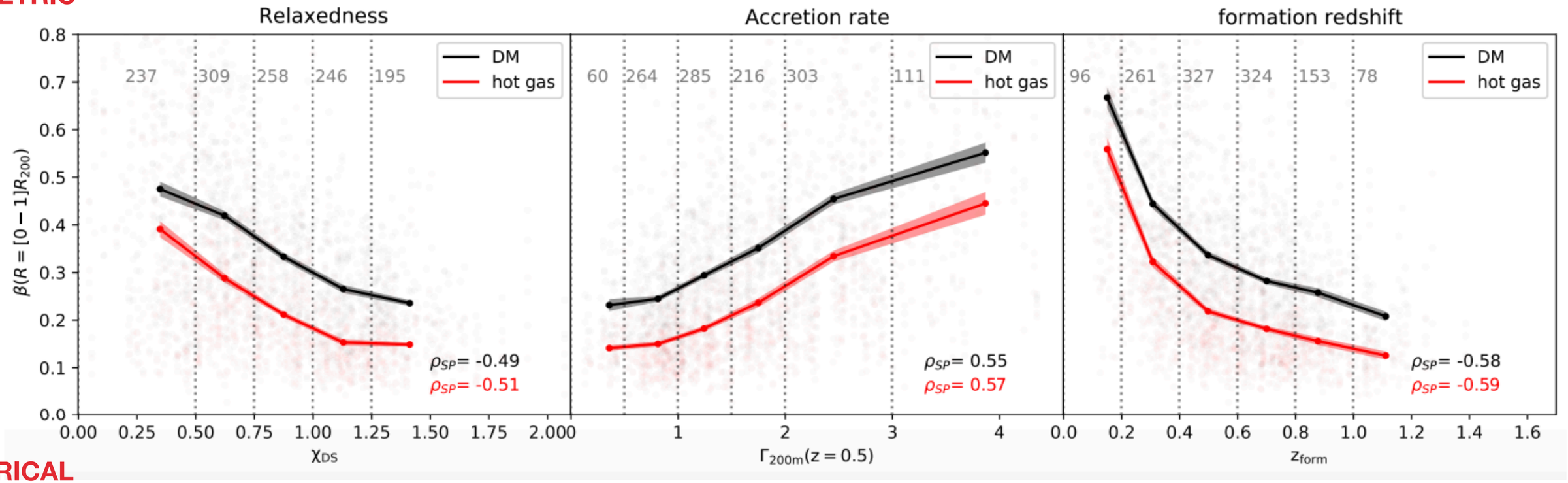
II - How gas is changing during it infall?

ICM asymmetries = tracer of cluster evolution

More asymmetric = Unrelaxed, fast accretion, recently formed



ASYMETRIC

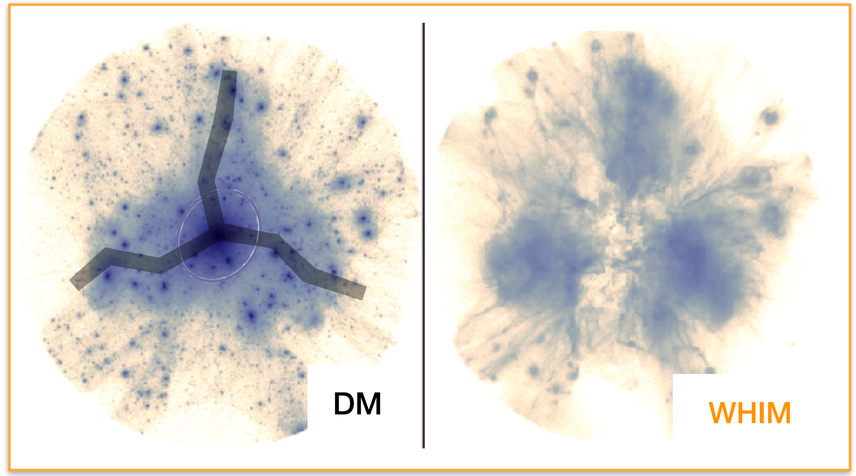


SPHERICAL

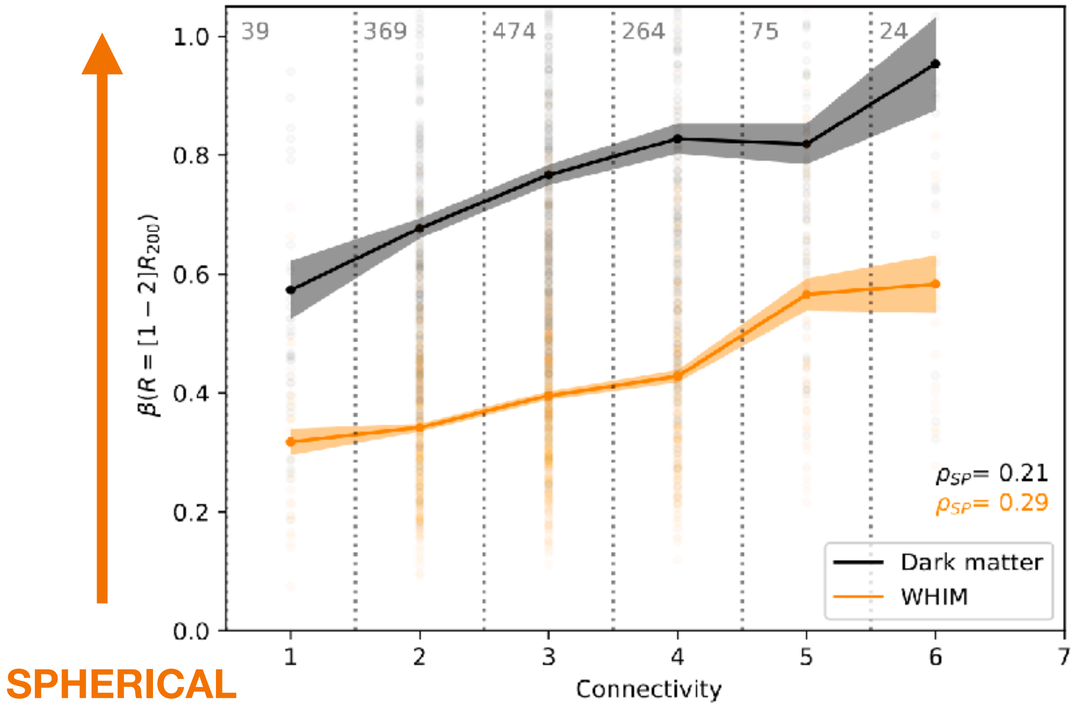
Gouin+22

WHIM asymmetries = tracer of connectivity

DM filamentary patterns

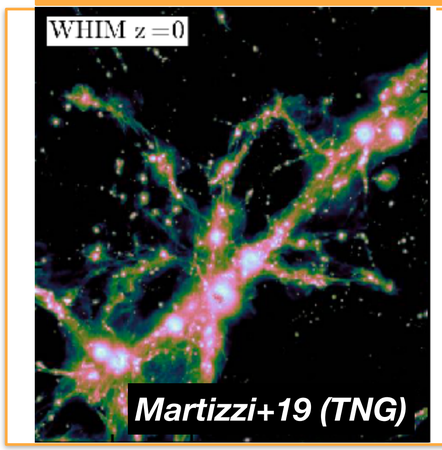


ASYMETRIC



SPHERICAL

Comparison to other studies



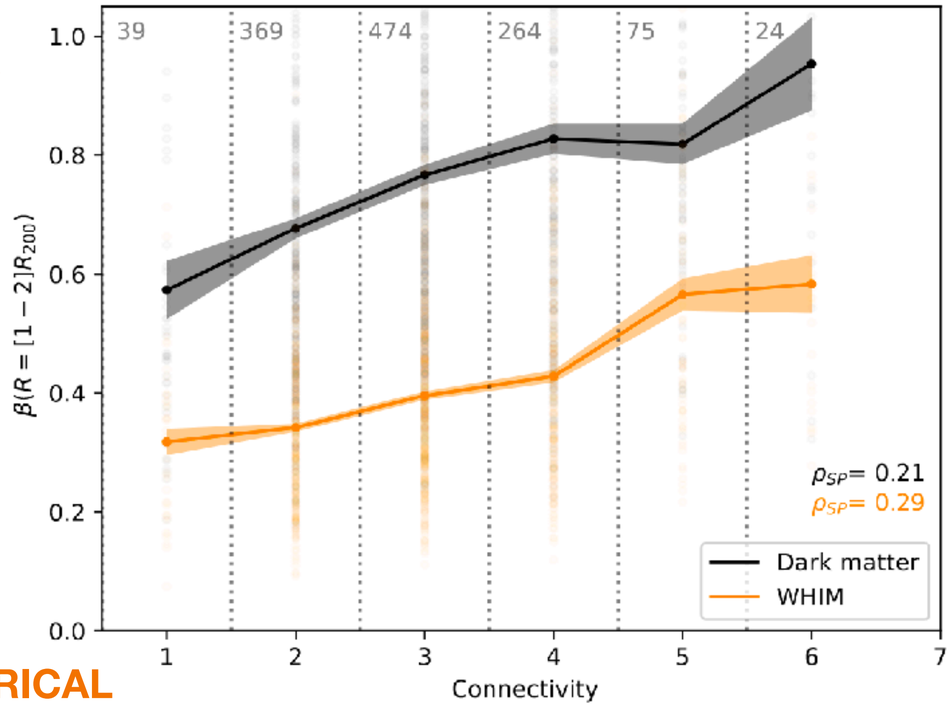
WHIM gas phase is tracing large scale cosmic filaments

Martizzi+19 (TNG),
Galarraga-Espinosa+21 (TNG),
Tuominen+21 (EAGLE)…

Gallo+24

WHIM gas asymmetries is tracing the DM filamentary patterns

ASYMETRIC

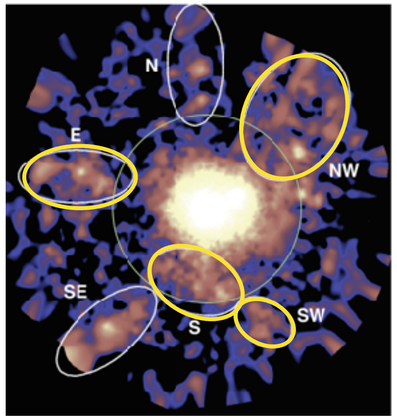


SPHERICAL

Application to the X-ray observations of A2744

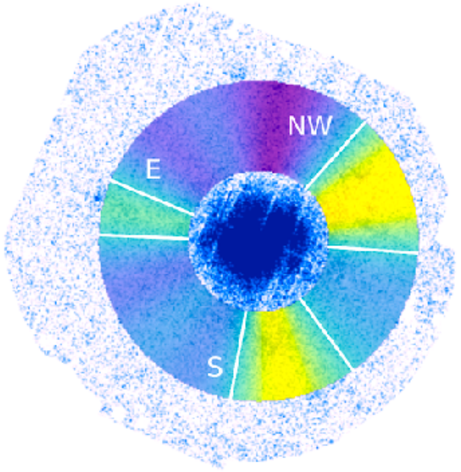
Gallo, Aghanim, Gouin, Eckert, et al., 2024

Stefano Gallo
past PhD IAS

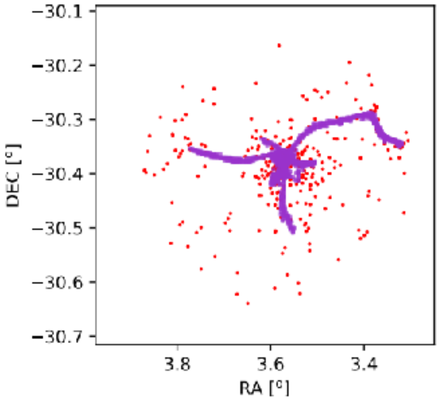


Eckert + 2015

First detection by eyes

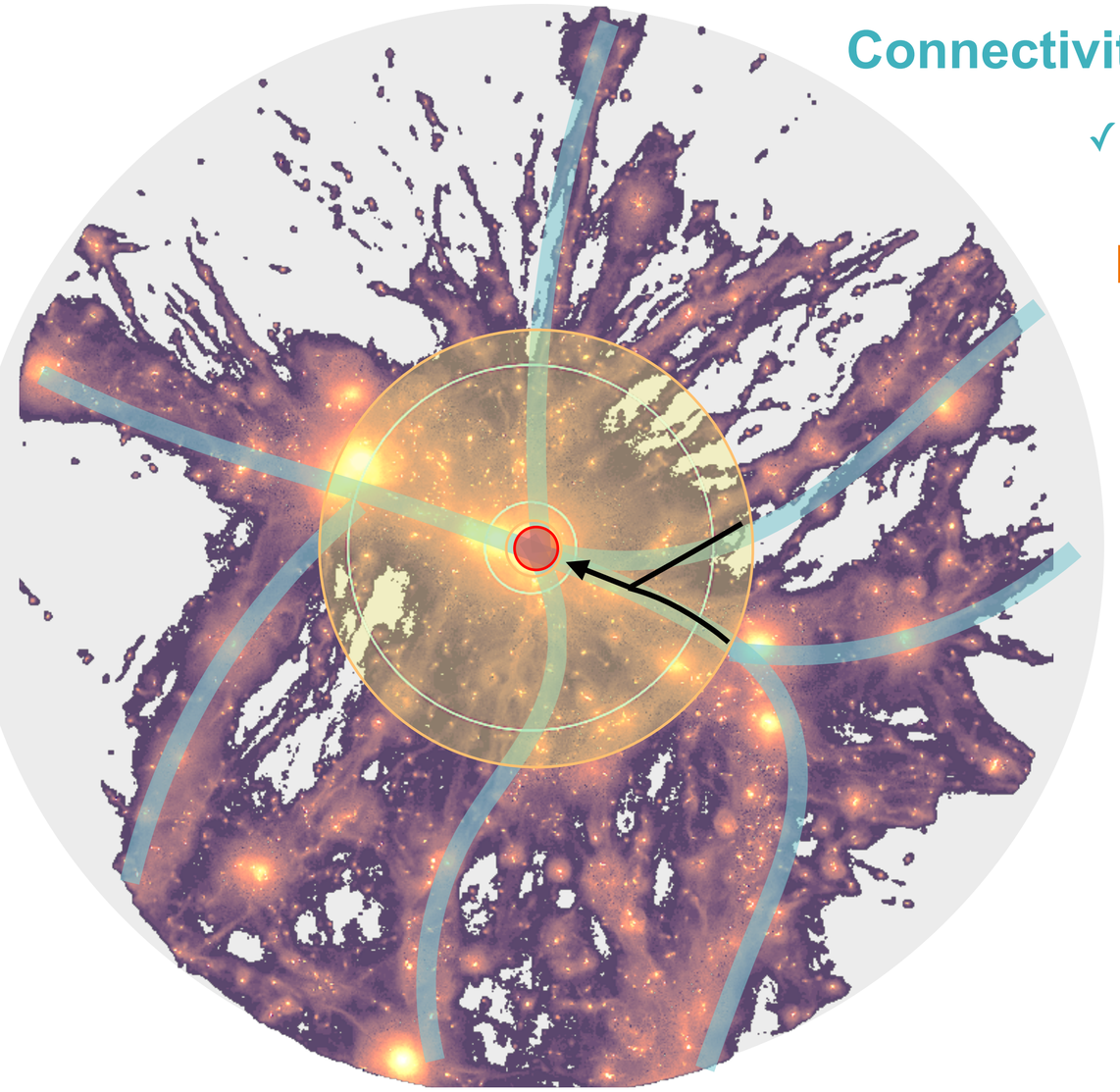


Harmonic detection on X map



TREX detection on galaxies

Cluster environnements : from cosmic filaments to cluster cores



Connectivity affect the cluster dynamical states

✓ *Tracing mass assembly history* — *Gouin+21*

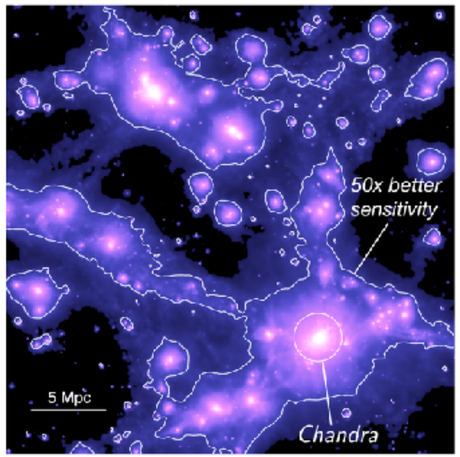
From WHIM, to HOT gas phase

✓ *Multi-phase, multi flow, and asymmetric*

✓ *Asymmetries trace cluster mass assembly* — *Gouin+22*

✓ *Apply on Abell 2744 X-ray observations* — *Gallo+24*

To be continued …



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eROSITA, XRISM, NewAthena

Thank you !