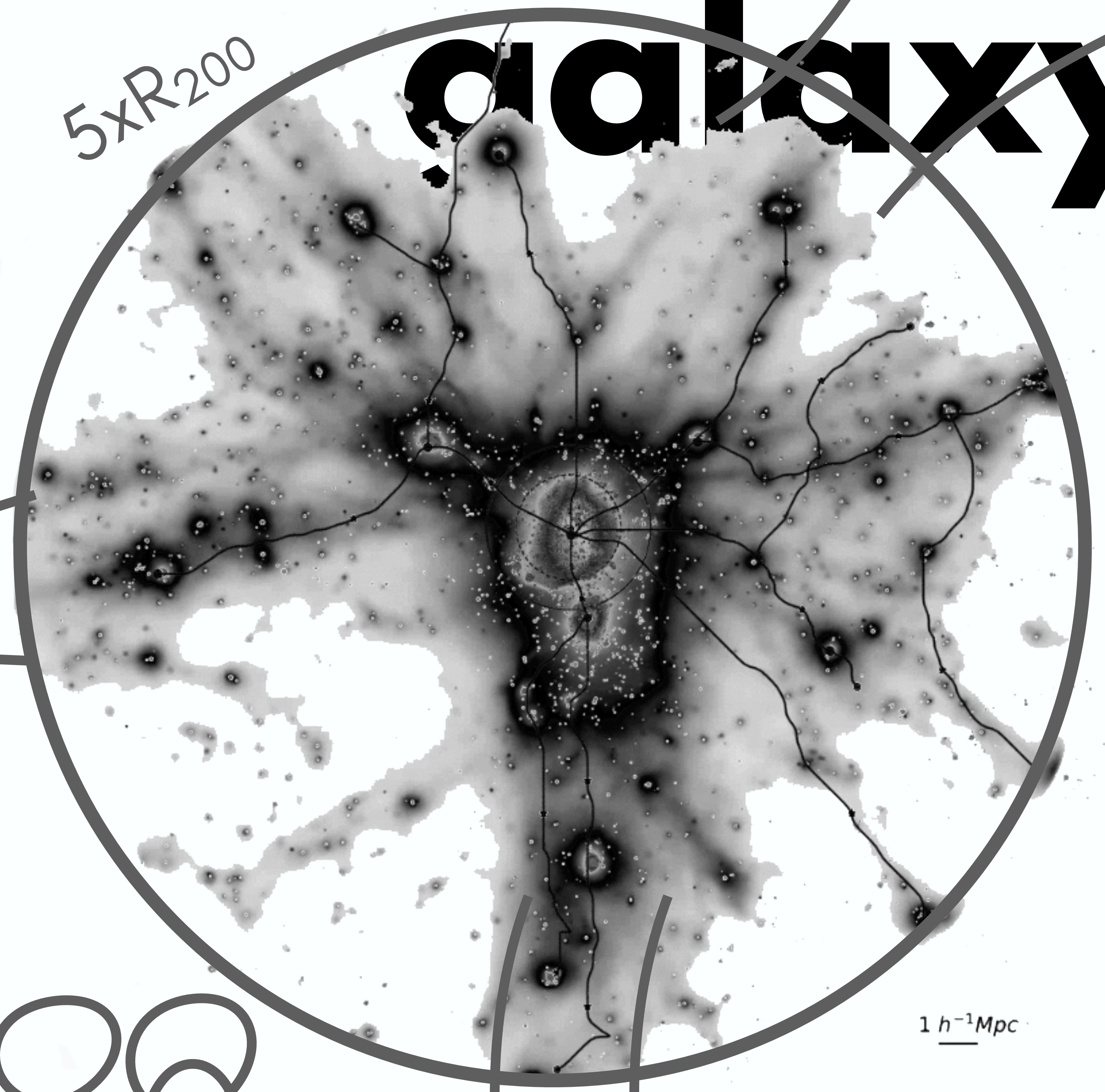
Pre-processing in galaxy cluster outskirts



Kuchner+2020 — 2020MNRAS.494.5473K
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Rost, Kuchner+2021 — 2021MNRAS.502…741R
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Merlin, .. Kuchner+2023 — 2022arXiv220912906E

Alfonso Aragón-Salamanca, Meghan Gray, Frazer Pearce

Ulrike Kuchner | University of Nottingham | KITP 08 Feb 2023

University of Nottingham UK | CHINA | MALAYSIA
The Three Hundred Project: Modelling Galaxy Clusters and Their Environment.
SPACE ECOLOGIES ART AND DESIGN
ITD Alliance
RS Digital Incubator for Museums
SURATÓMICA

Pre-processing in galaxy cluster outskirts

Problem analysis

Galaxy evolution in the CW

Pre-Processing

Decisions for observations

Approach analysis

Simulations: The 300

Observations: WEAVE 4MOST Euclid

Solution analysis

Preparations

Inventory

Characterisation

SIMULATION

The ThreeHundred: 324 mass complete DM + hydro zoom-in simulations (6 physics engines) of cluster volumes taken from MultiDark 1Gpc/h simulation, 128 snapshots from z=17 → 0.

OBSERVATION

WEAVE: new 1000-fiber optical MOS (FoV=2deg diameter, 1.3” fiber aperture) and IFUs (1 large ‘LIFU’ of 550 fibers and 20 small ‘mIFU’ of 37 fibers) on the Wiliam Herschel Telescope, R ~5000, R ~20000
first light: Dec 2022

Can we identify filaments in small areas around clusters? (Prep for survey)

Can we use velocities/redshifts as 3rd dimension info for reconstruction in redshift space?

1 Can we measure the proposed filaments spin?
2 What are the thermodynamical properties, shocks and gas dynamics of infall regions (over time)?
3 Can we use Disperse to identify groups in simulations?
4 What is the probability of correctly identifying a galaxy's environment as a function of stellar mass and clustercentric distance?
5 How well will we be able to recover the CW in Euclid?

What properties and structures do filaments have in cluster outskirts?

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How many galaxies do we expect in each environment? (Inventory: filaments, groups, cluster, backsplash)

What is the impact of the instrument? (Limitations)

What happens to galaxy groups and group galaxies during infall and backsplash?

How is star formation and gas content affected by the dynamical infall and backsplash?

WEAVE Survey paper introducing WWFCS

Can we measure morphologies for billions of galaxies in Euclid?

Can we measure photometry for billions of galaxies in Euclid?

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Pre-processing

the integrated effect of a range of processes that affects galaxies in cosmic **filaments and groups outside clusters** and can start the transformation well before their accretion into clusters (e.g., Zabludoff+1998, Fujita 2004).

Environmental mechanisms arising beyond the cluster virial radius:

- **Near cluster**: accretion shock
- **Further out**: galaxy groups (aka "substructure"). However, galaxy groups are not isolated entities but are embedded into the large-scale structure of the Universe and, during their growth, move along cosmic filaments.
- **Even further**: large-scale structure (aka cosmic filaments) see connection between cold gas accretion, disc spin orientation, and location of galaxies within filaments (e.g., Codis et al. 2012; Dubois et al. 2014; Kraljic et al. 2020).

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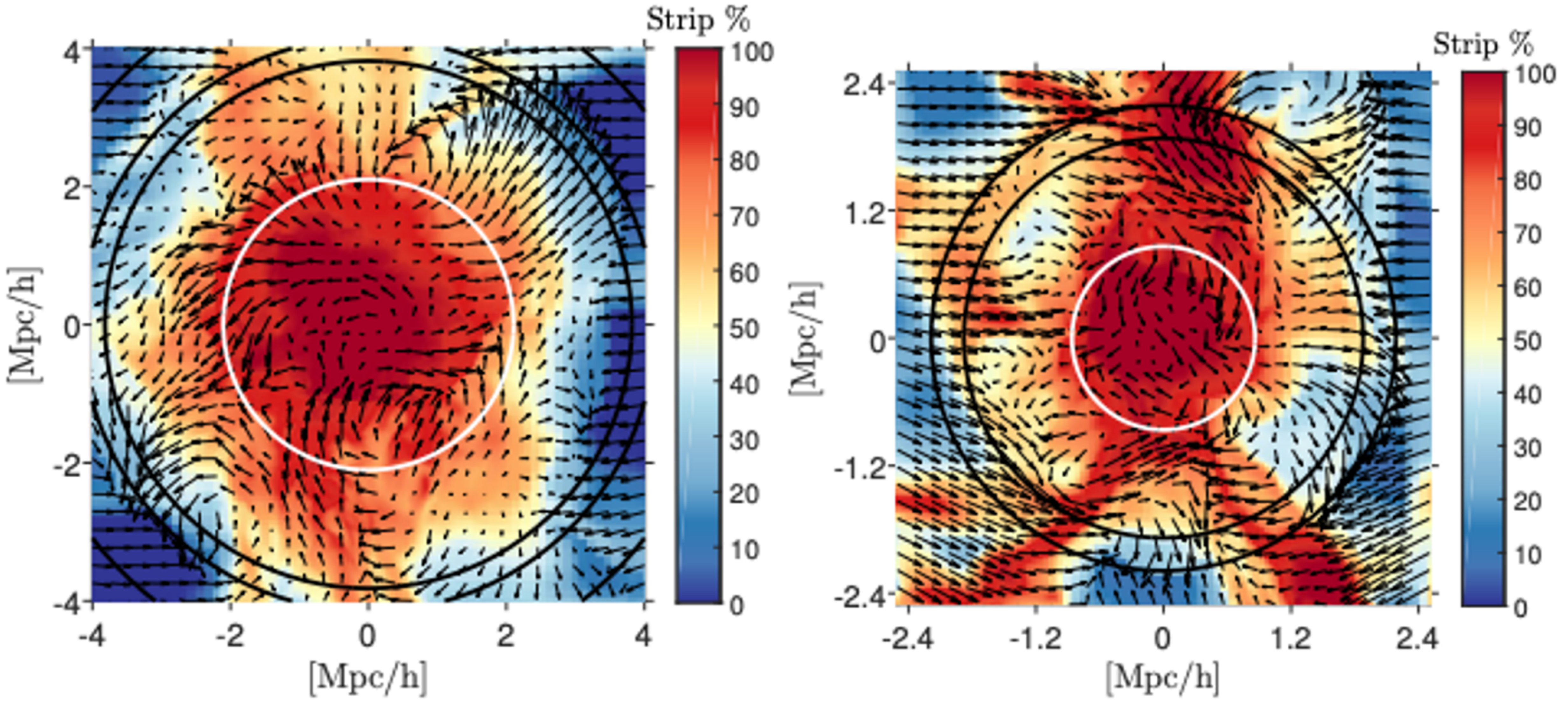
Zinger+2016: In the vicinity of the shock front the galaxy will be stripped of at least 30 per cent of its mass. At the virial radius of the cluster, the galaxy has lost between 70 and 90 per cent of its halo gas mass.



(a) Stripping of 10^{11} $M_\odot$ Satellite at $z = 0$

(b) Stripping of 10^{11} $M_\odot$ Satellite at $z = 0.6$

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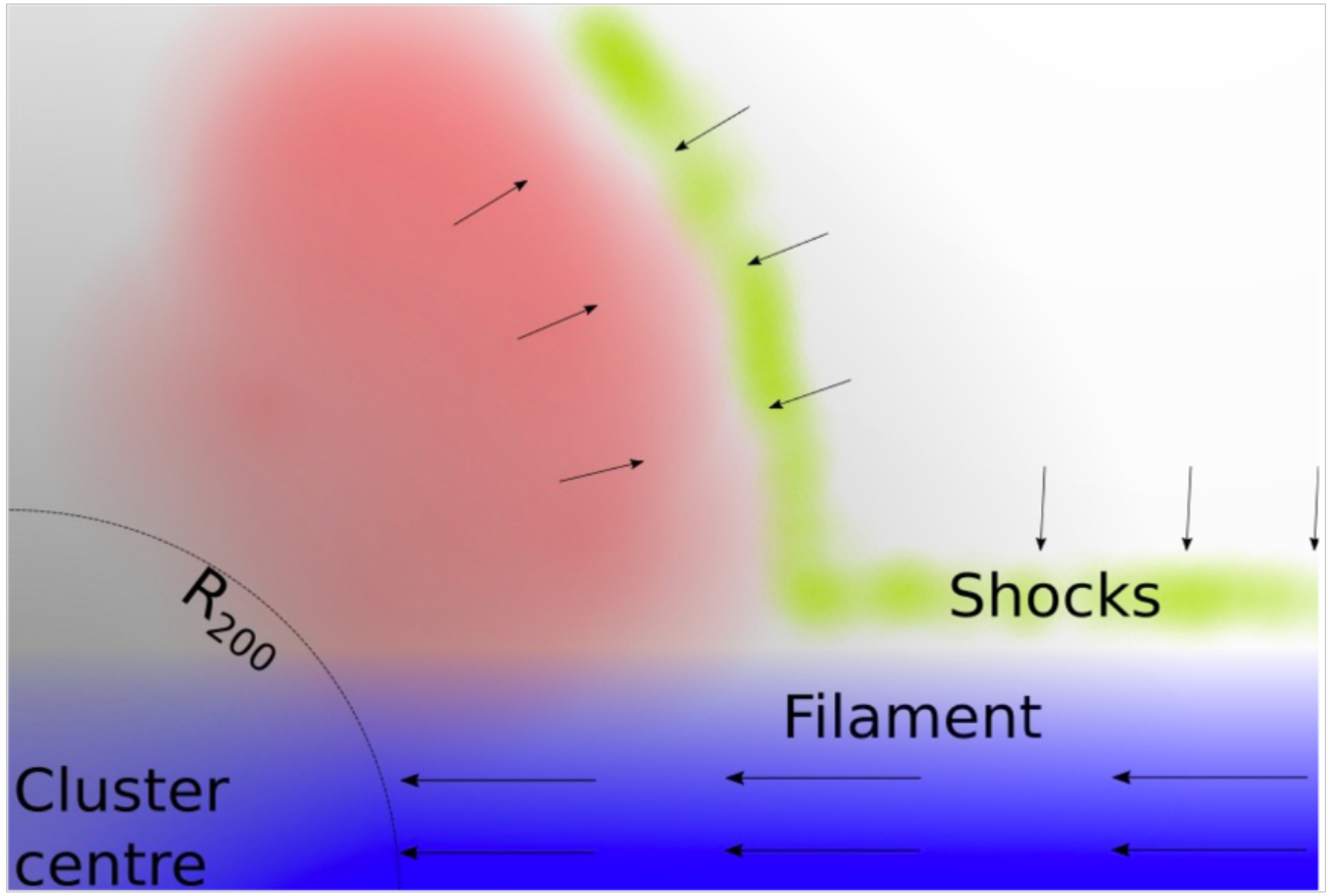
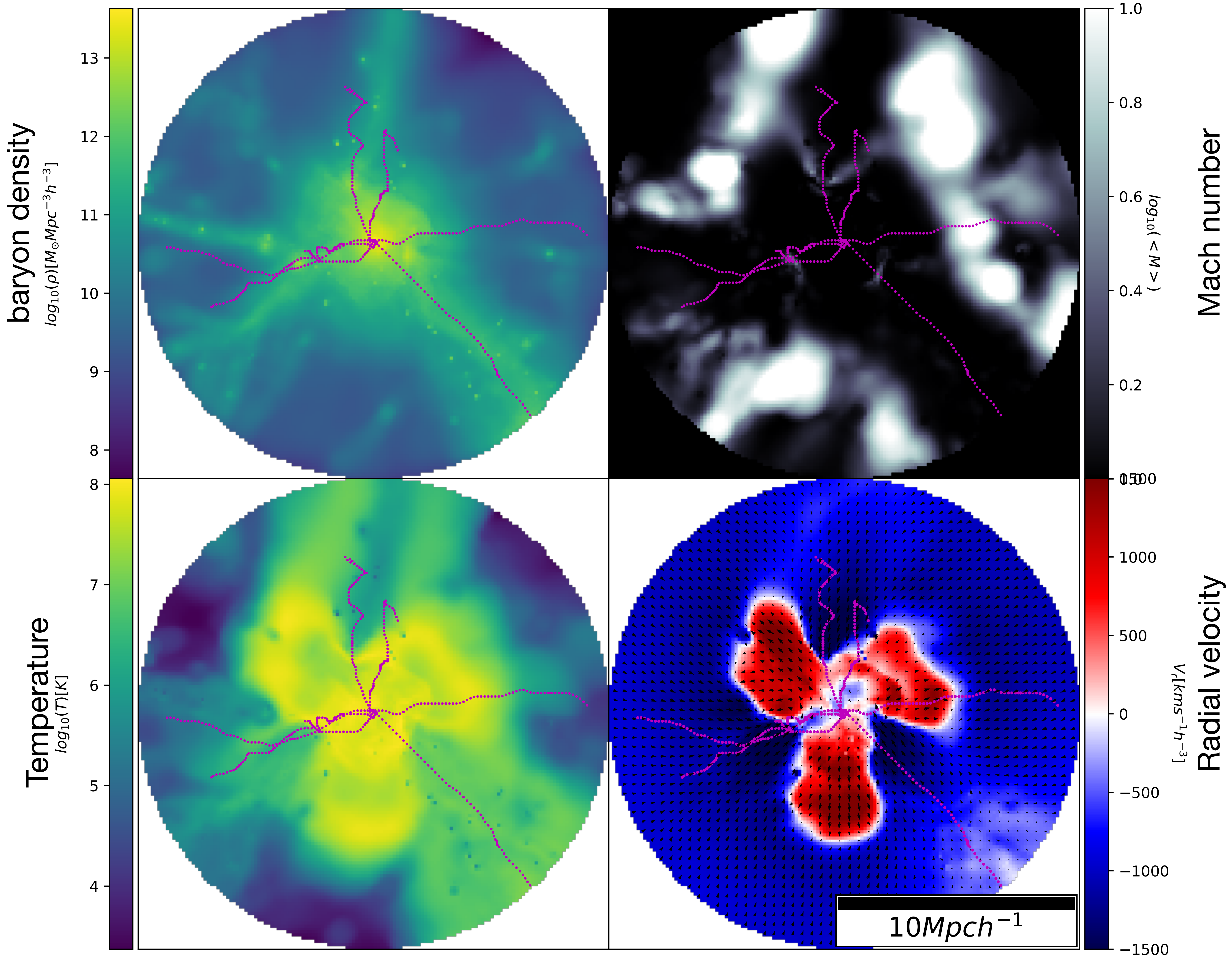


See also Charlotte Welker's talk after this!

Rost .. work in progress TBS

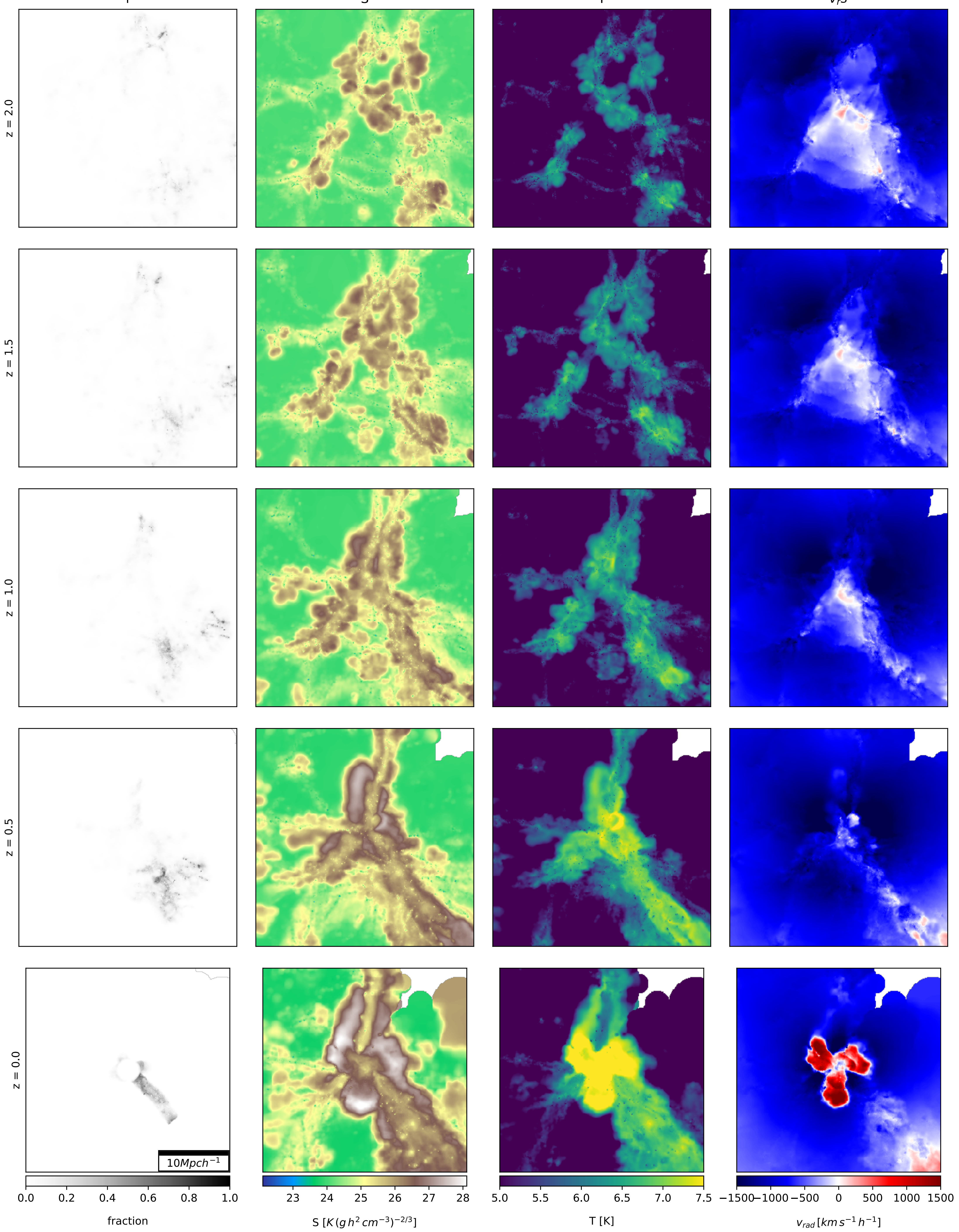


Gas distribution + feedback at $z = 0$ of a slice of 4 h^{-1} Mpc around a galaxy cluster centred in the simulated volume

*Hyunmi Song's talk later today!

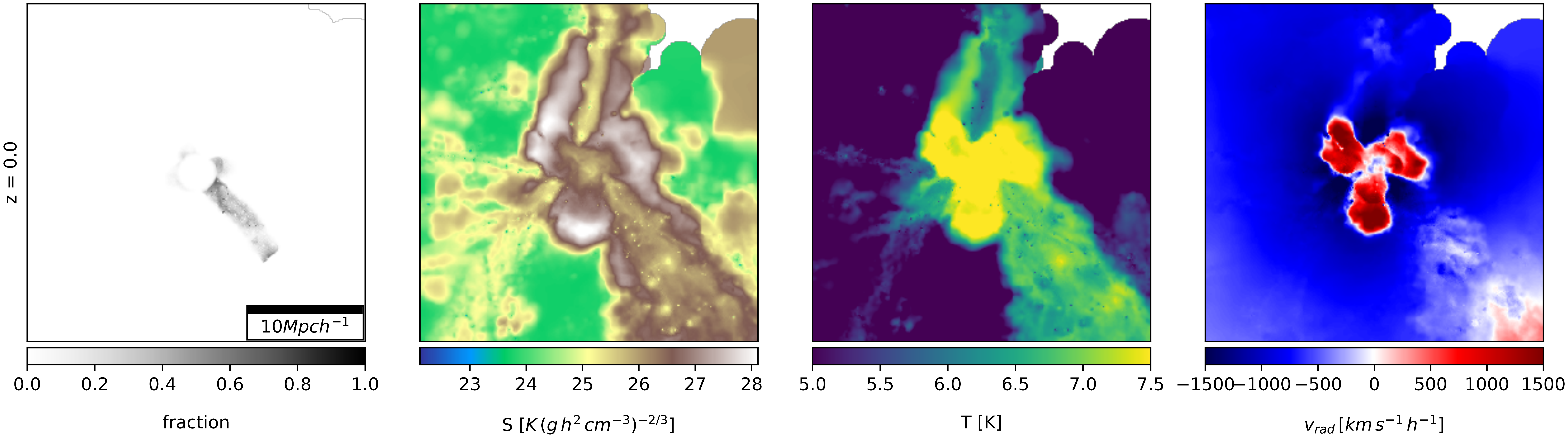
Rost .. TBS

Time evolution in a slice of 2 h^{-1} Mpc (comoving) thick in the simulated cluster region.



Galaxies are subject to shocks during their evolution. Start to think not only in the instantaneous environment of a galaxy but the environment it has experienced over its lifetime.

*Hyunmi Song's talk later today!



Material that belongs to a filament at $z = 0$, the entropic function of the gas, the gas temperature and the radial velocity towards the centre of the cluster.

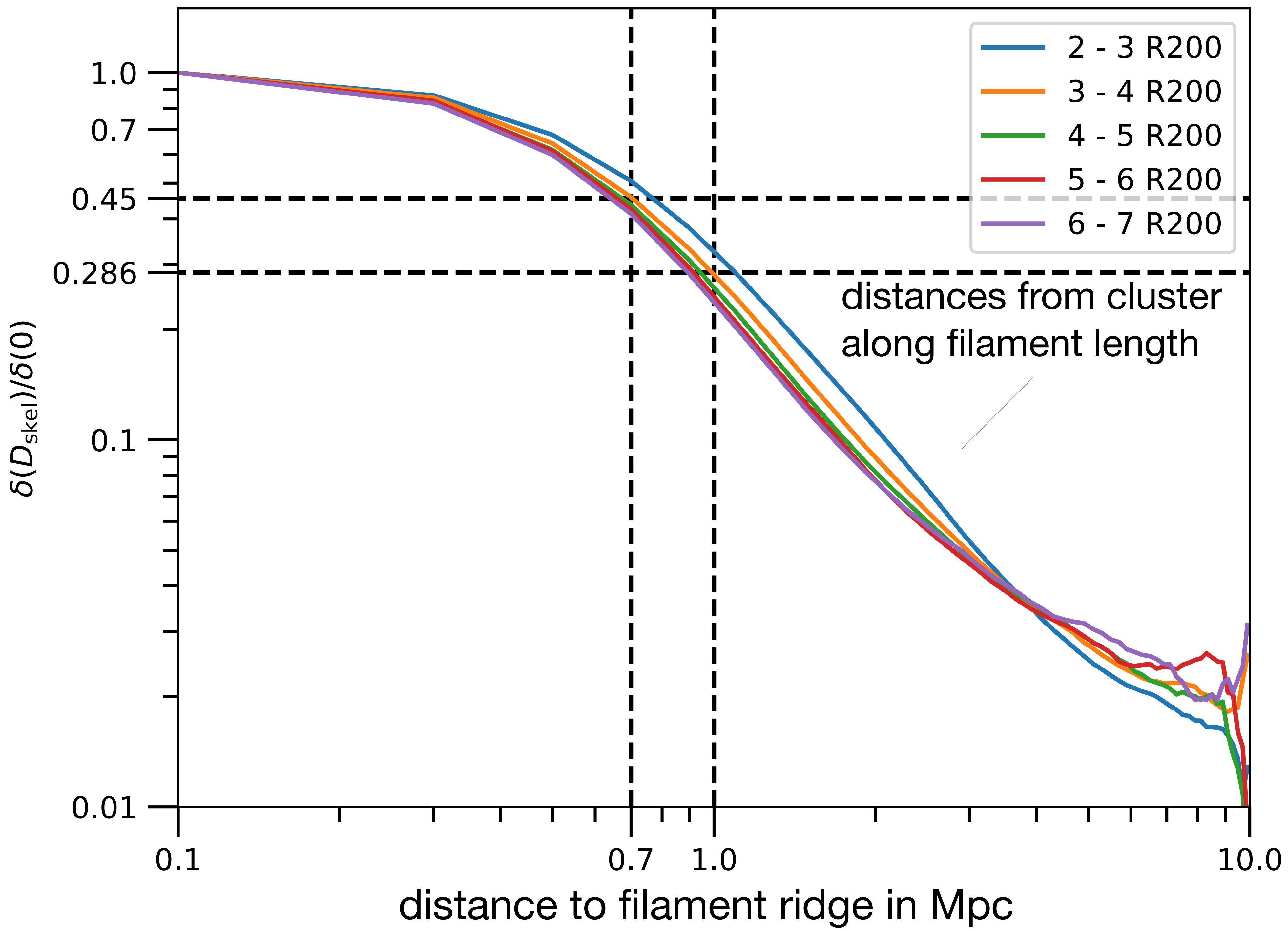
The stacked temperature profile of filaments is typically colder towards the spine, in line with the cosmological rarefaction of matter. Therefore, filaments are able to naturally protect their inner regions, keeping baryon properties.

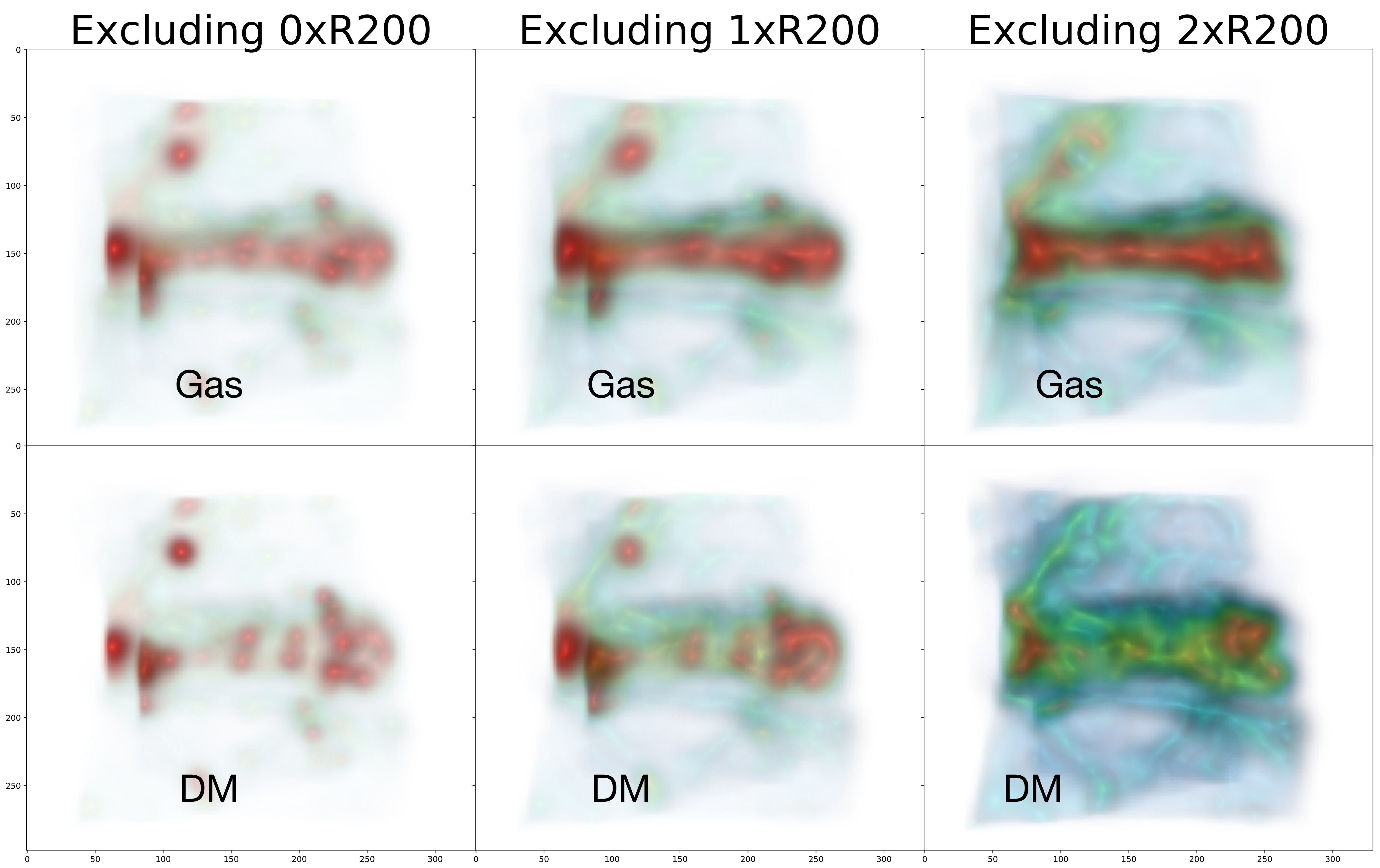
*Hyunmi Song's talk later today!

Rost+2022, see Han Aung’s talk later today

We trace gas filaments to define a characteristic width based on density.

We use this to associate galaxies to filaments.

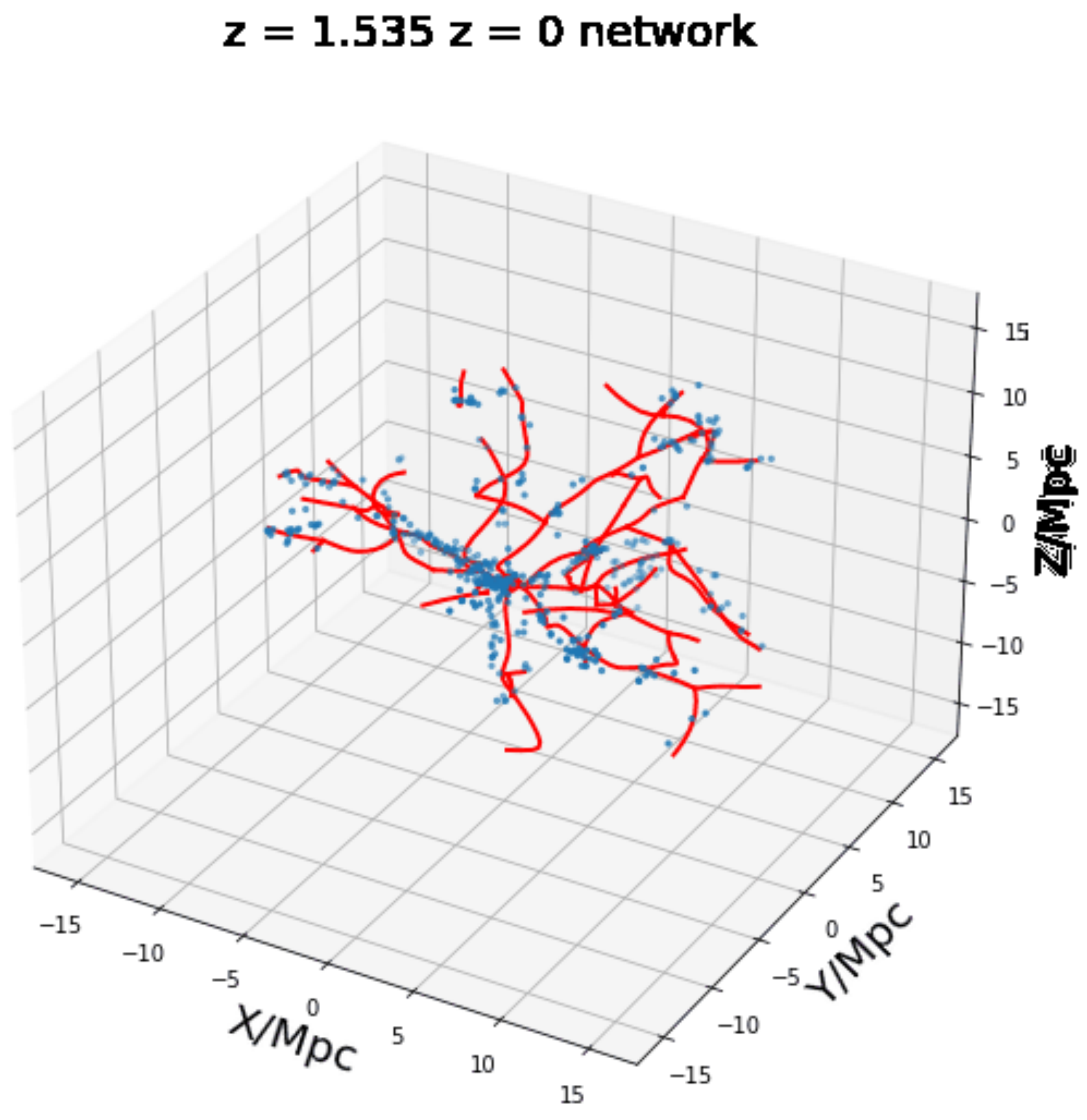


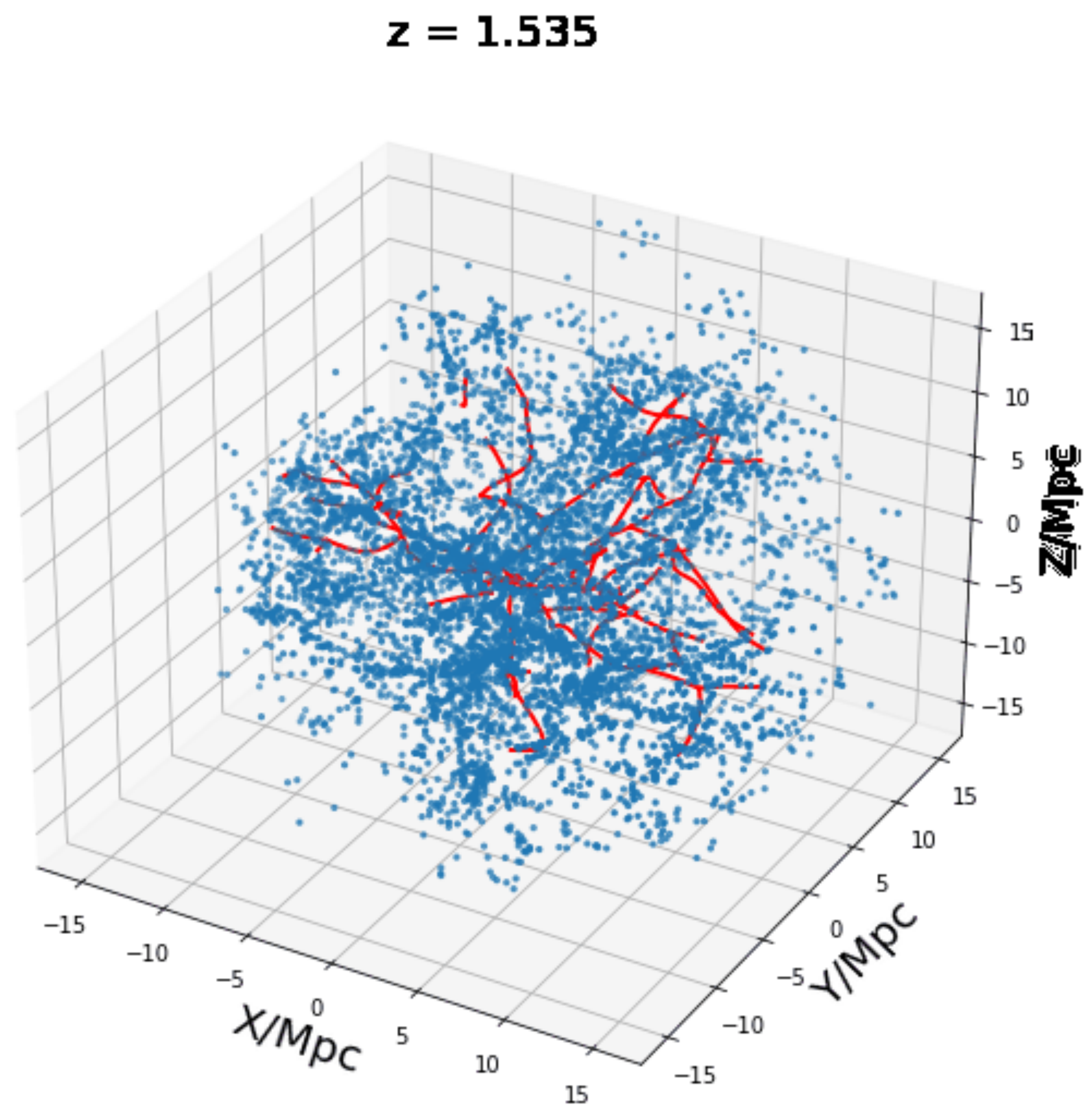


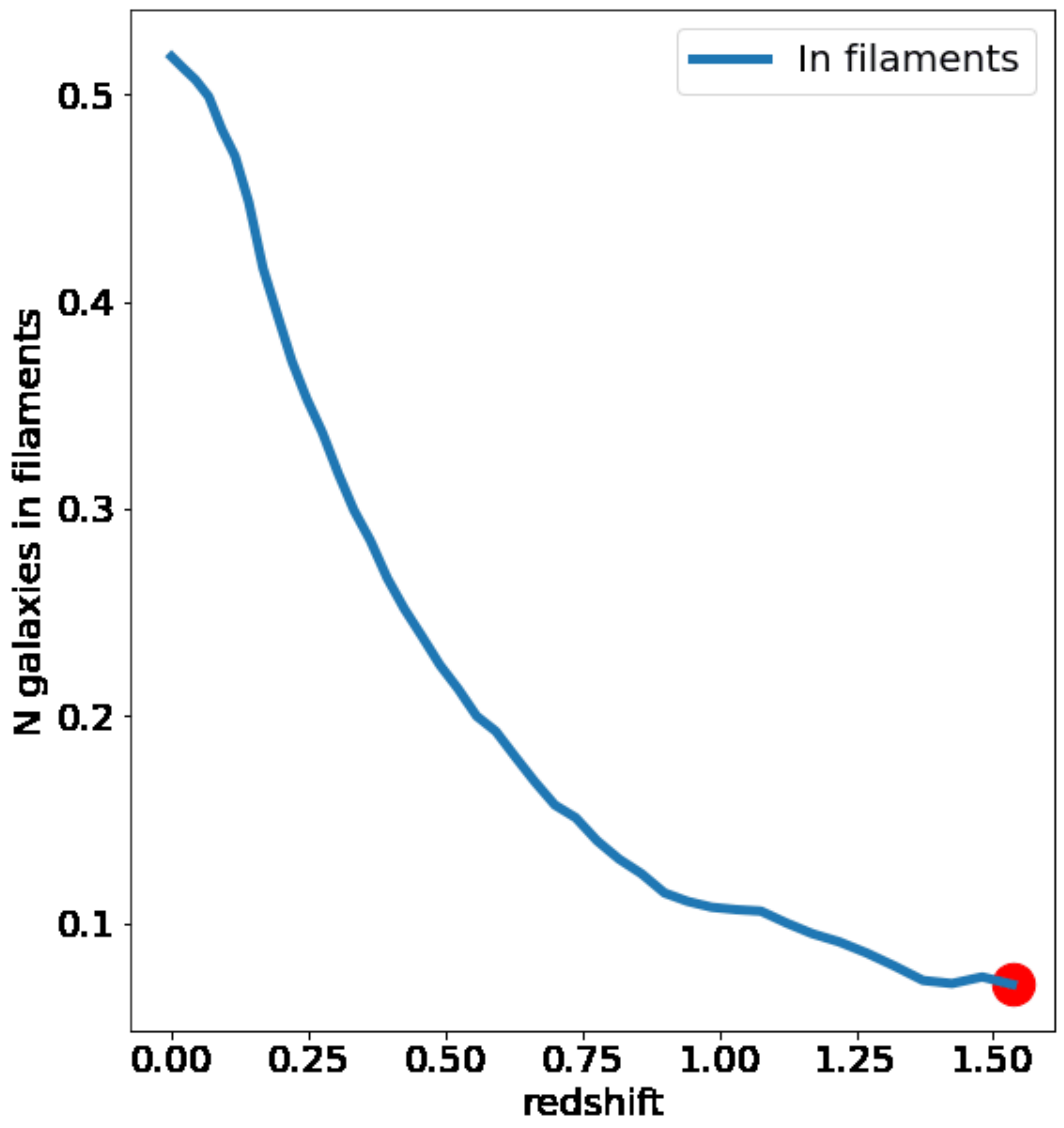
Gas density Entropy Pressure Temperature:

Rost+2023 TBS

Cornwell .. first glance

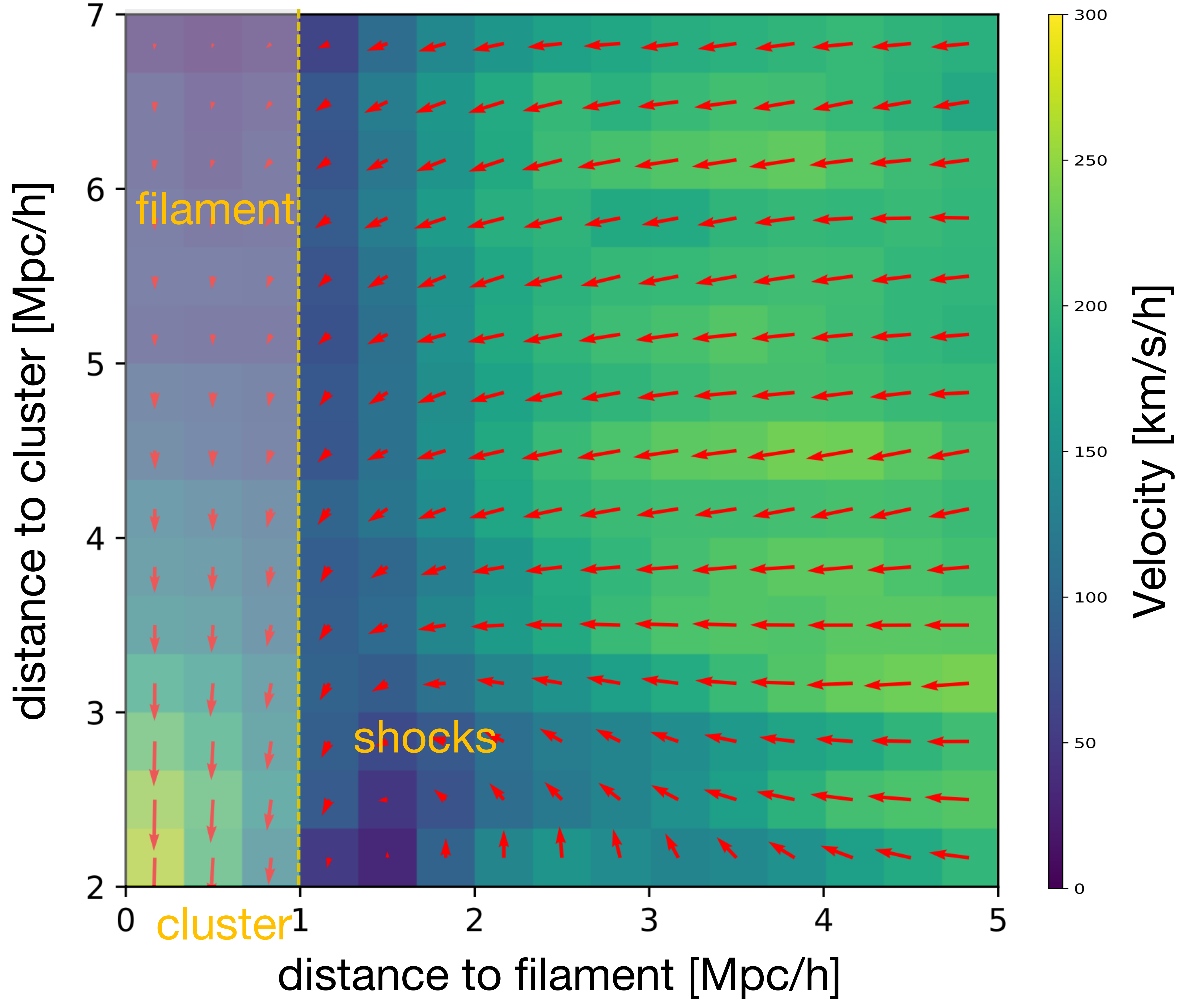






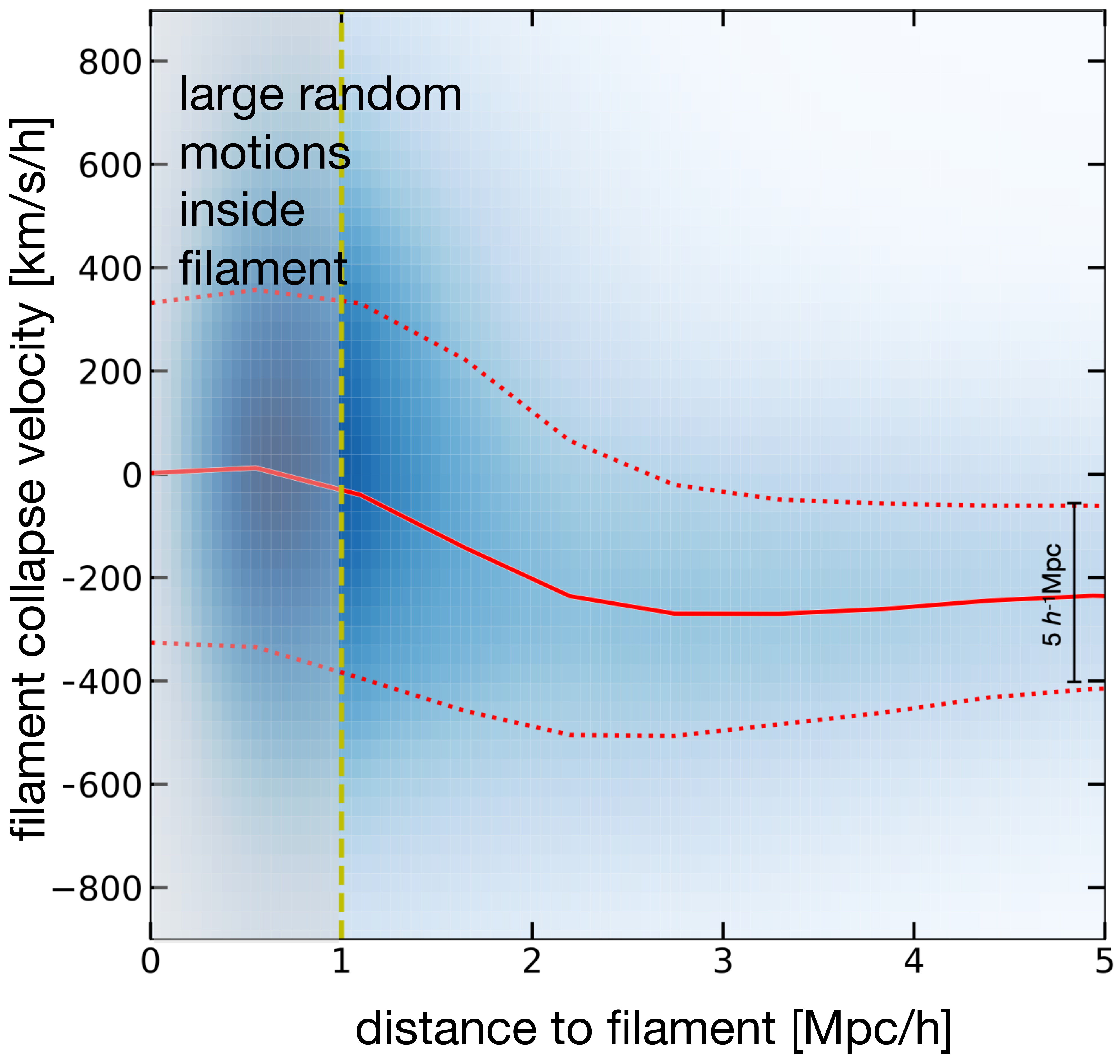
Filaments are gas highways for feeding clusters where gas and galaxies enter with high infall velocities.
Stacked velocity fields in cluster outskirts: collective motion of matter from low density regions towards filaments and nodes

GAS COLLAPSE TOWARDS FILAMENTS



Rost+2022

GALAXY COLLAPSE TOWARDS FILAMENTS



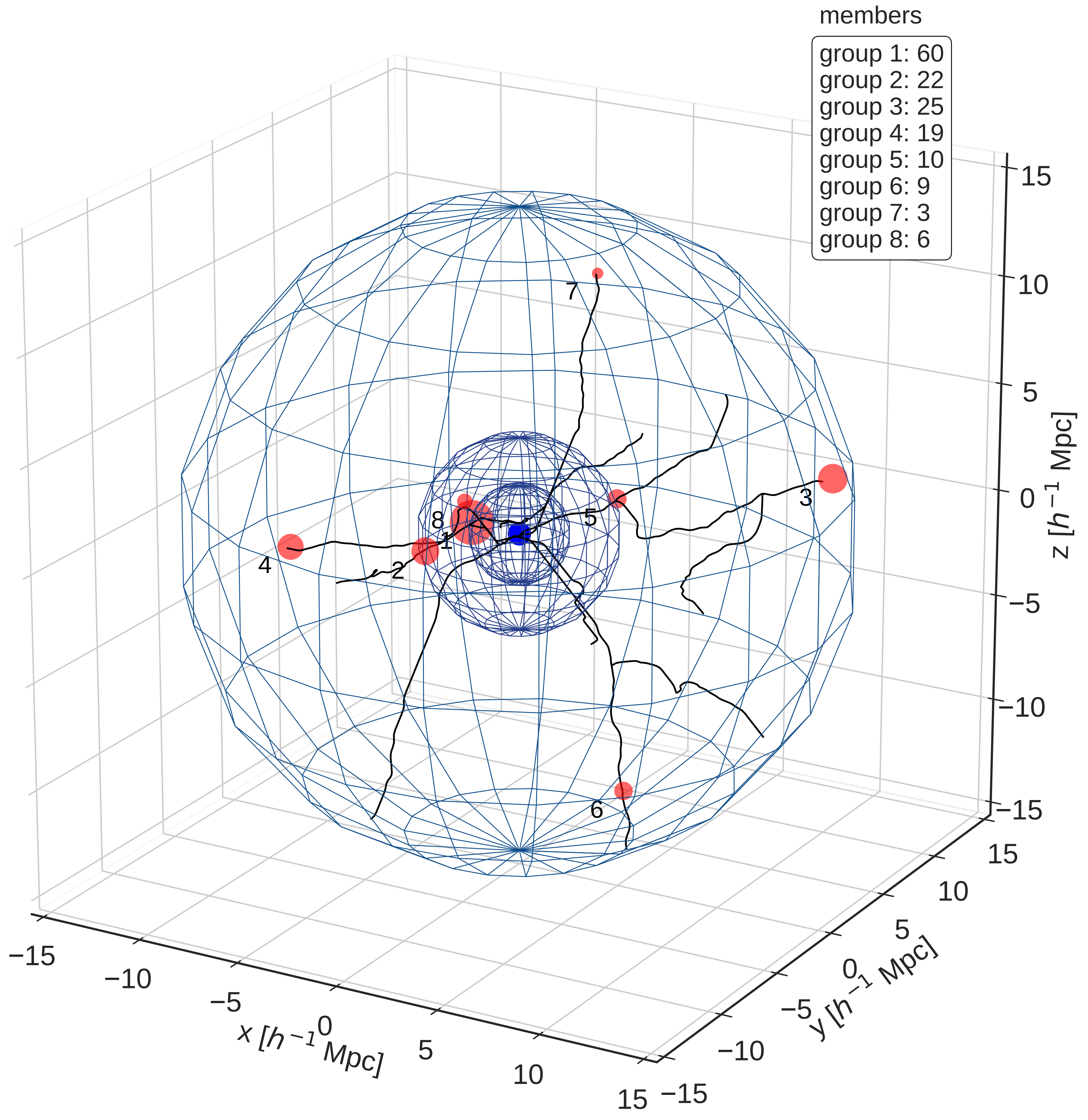
Kuchner+2022

Pre-processing

the integrated effect of a range of processes that affects galaxies in cosmic **filaments and groups outside clusters** and can start the transformation well before their accretion into clusters (e.g., Zabludoff+1998, Fujita 2004).

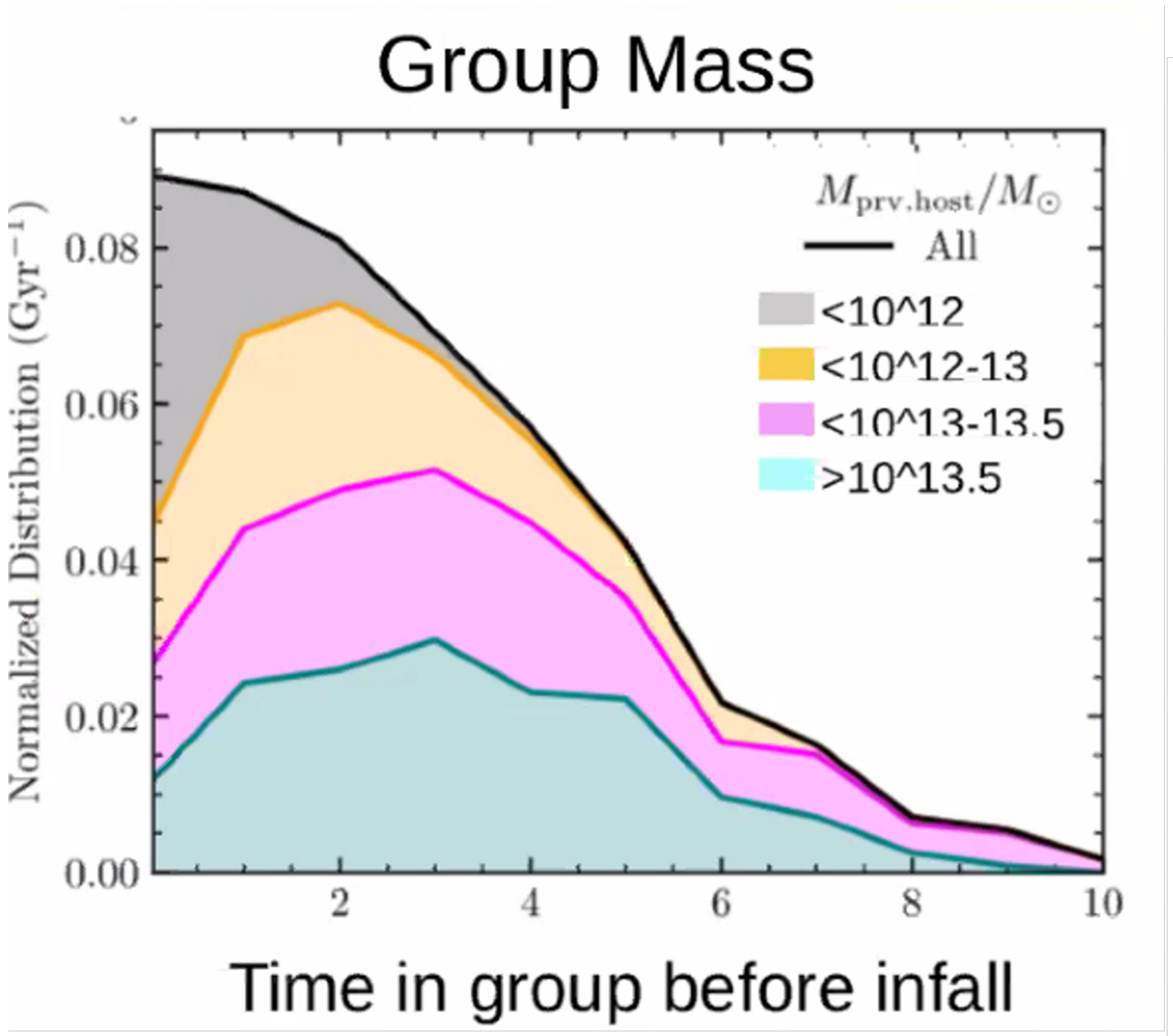
Environmental mechanisms arising beyond the cluster virial radius:

- **Near cluster**: accretion shock
- **Further out**: galaxy groups (aka "substructure"): literature often equals pre-processing with group membership. Reports of up to 50% of cluster members arrive via groups. Galaxy groups are not isolated entities but are embedded into the large-scale structure of the Universe and, during their growth, move along cosmic filaments.

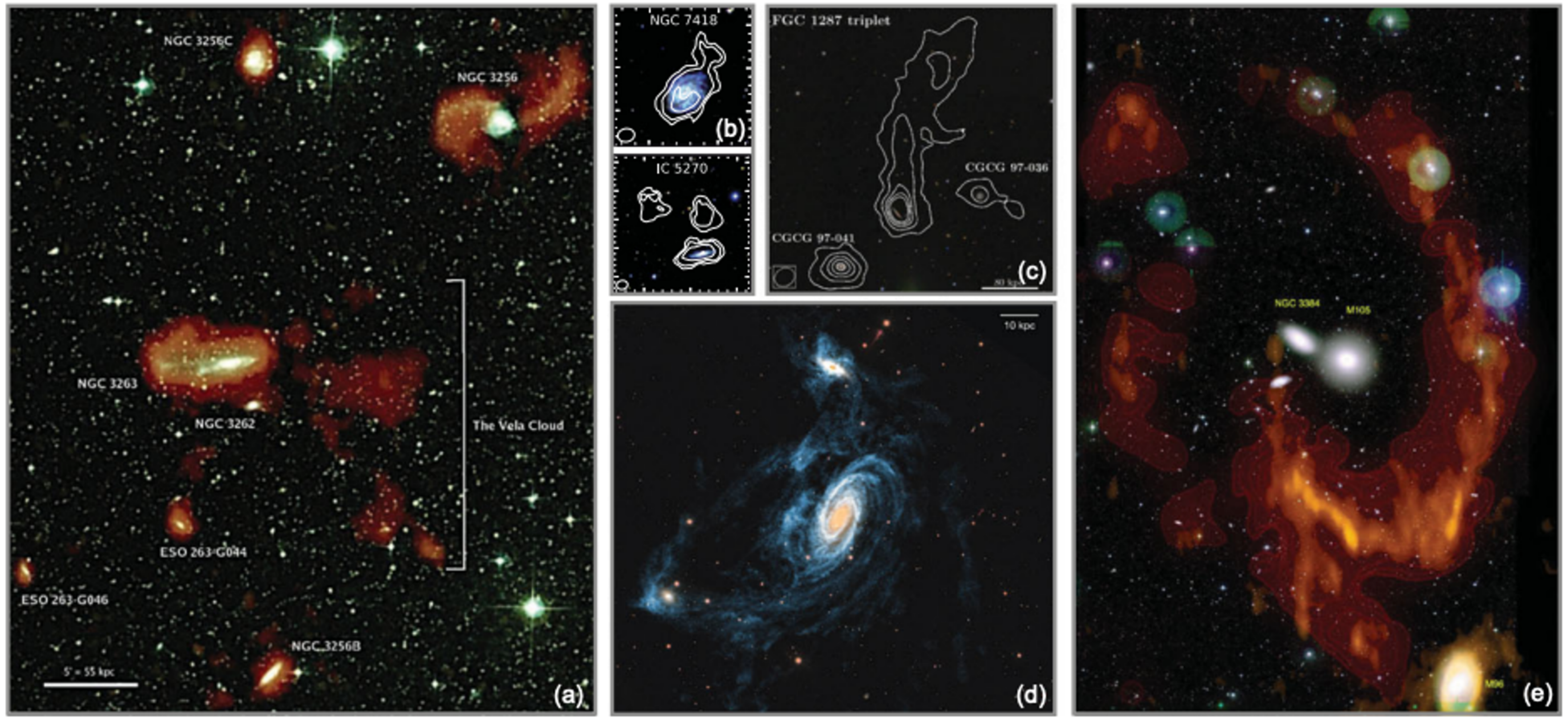


Groups *can* quench star formation in their massive satellites

- Massive galaxies are more likely to fall into clusters as group centrals than lower mass systems (De Lucia et al. 2012; Wetzel et al. 2013)
- The time spent as a satellite before infalling into the cluster varies (rom just ~0.1 to 8 Gyr or more) but is generally ~2–3 Gyr or less. This is similar to the typical delay time before the onset of the major quenching phase in satellites.
- Active stripping rarely appears sufficient to fully quench galaxies, unless all the cold gas is stripped during the first orbit through the centre of the parent halo. For a typical Milky Way-like galaxy, the inner parts of the cold disc remain bound to the galaxy and can continue to feed star formation for at least a few billion years longer.

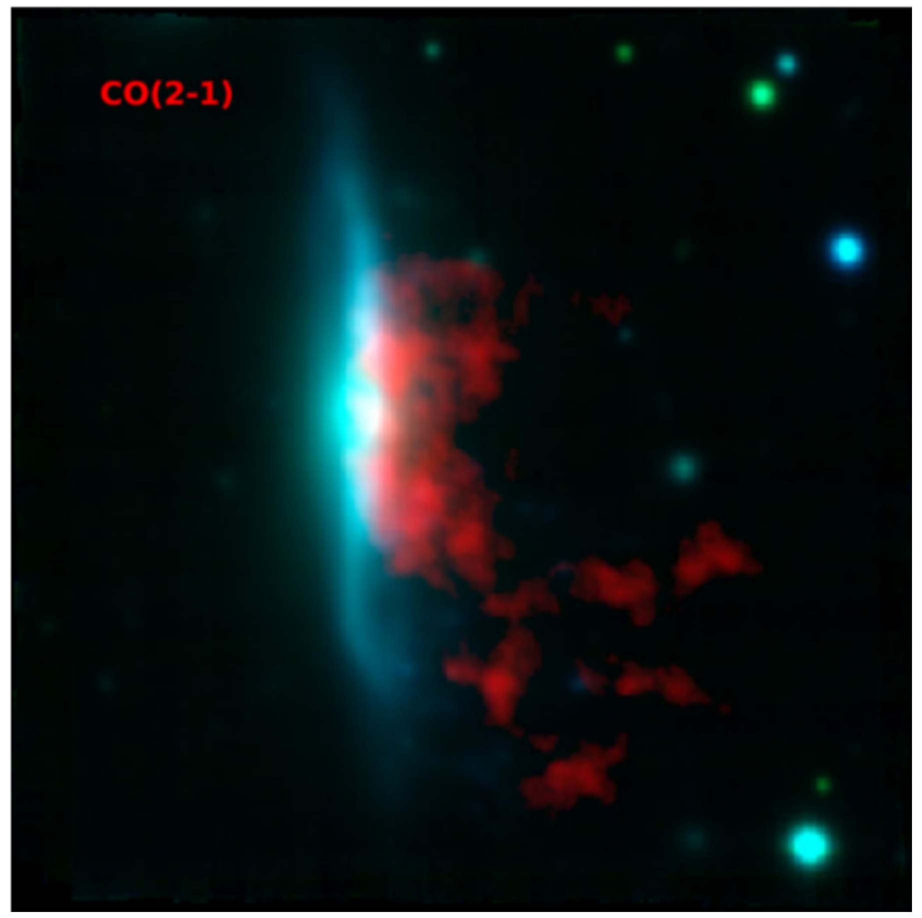


Han+2018



Examples of HI stripping in galaxy groups. prominent role of tidal forces in affecting both their gas and stellar distributions. prominent role of tidal forces in affecting both their gas and stellar distributions. Most are still actively star-forming and not HI deficient, however that is a selection effect.

Cortese+2021



Ram pressure Stripping in Groups. JW100 in Abel 2626, Moretti et al. 2020a

Approved MeerKAT + WEAVE

WHAT HAPPENS TO THE GALAXIES IN INFALLING GROUPS?

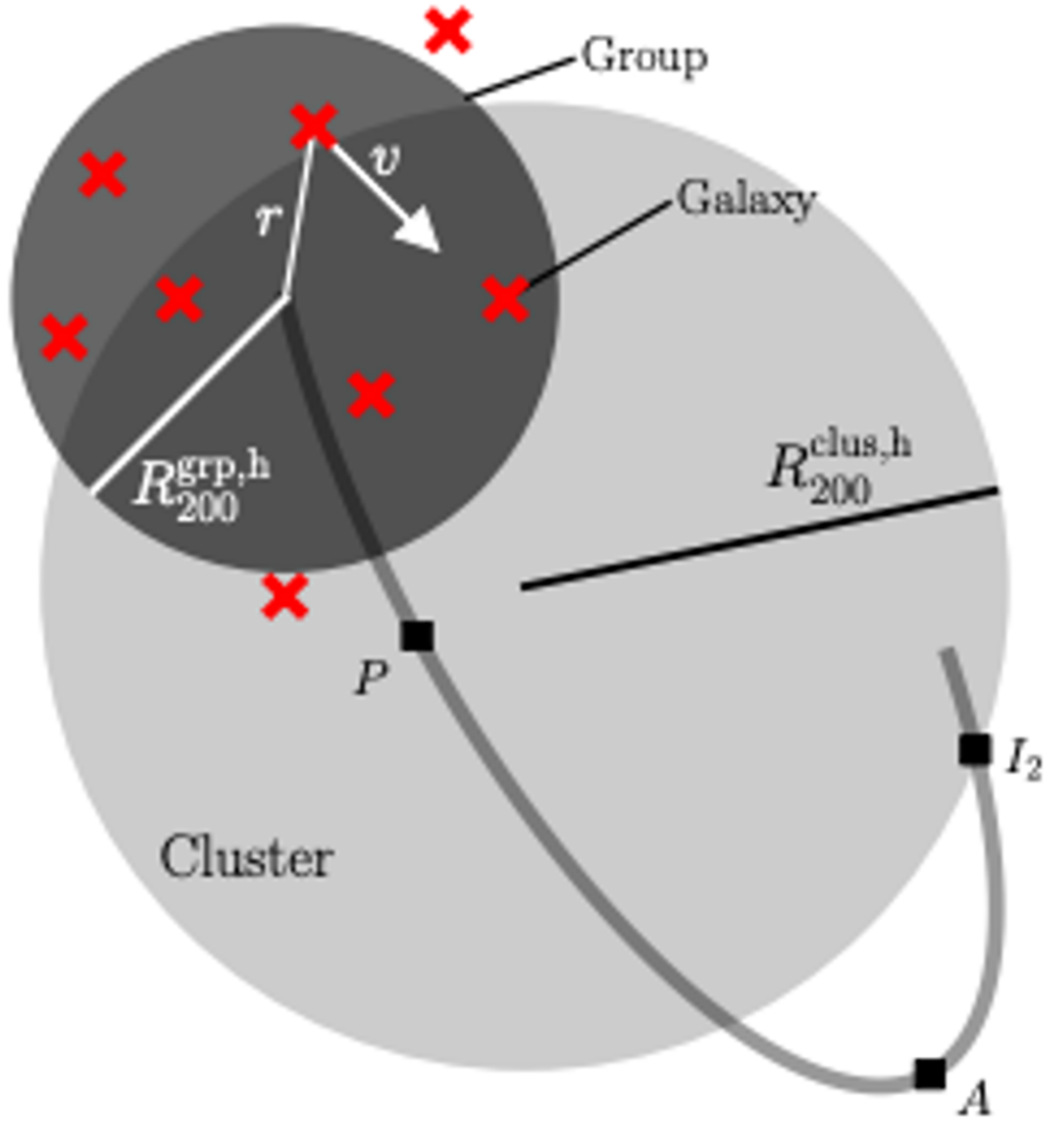
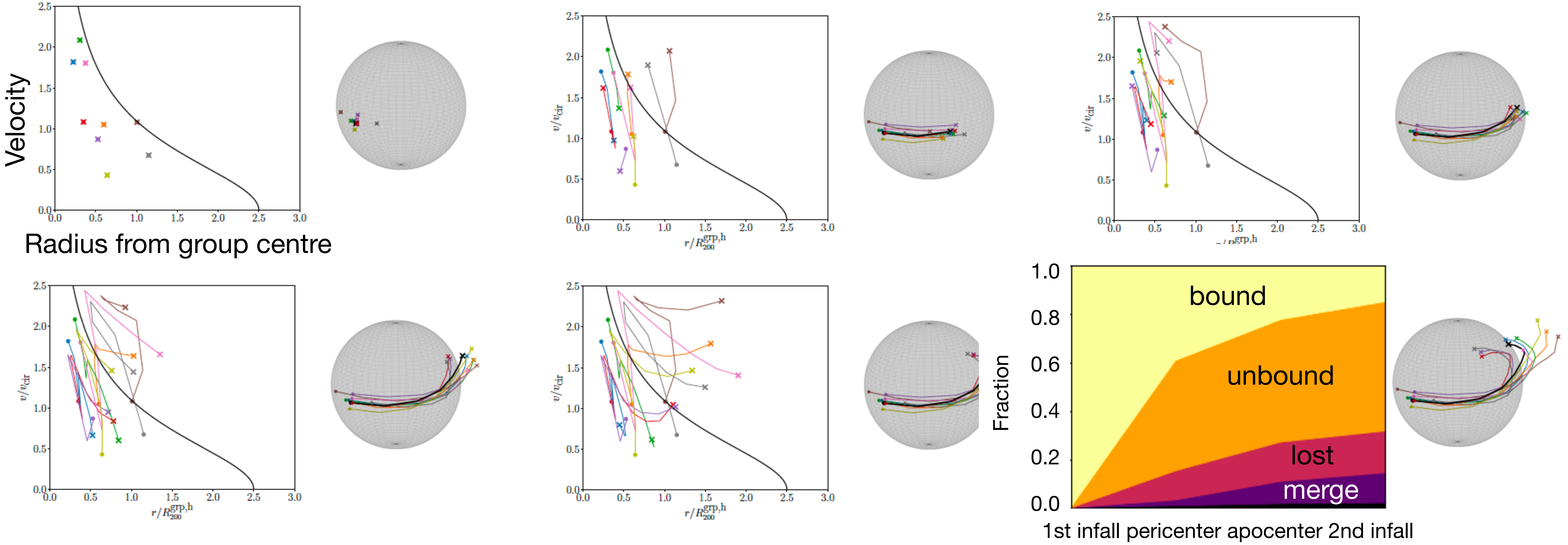


Figure 1. Schematic of a galaxy group halo (dark circle) passing within R_{200}^{clus} of a cluster (light circle) for the first time. Red crosses

Galaxy groups do not survive cluster infall

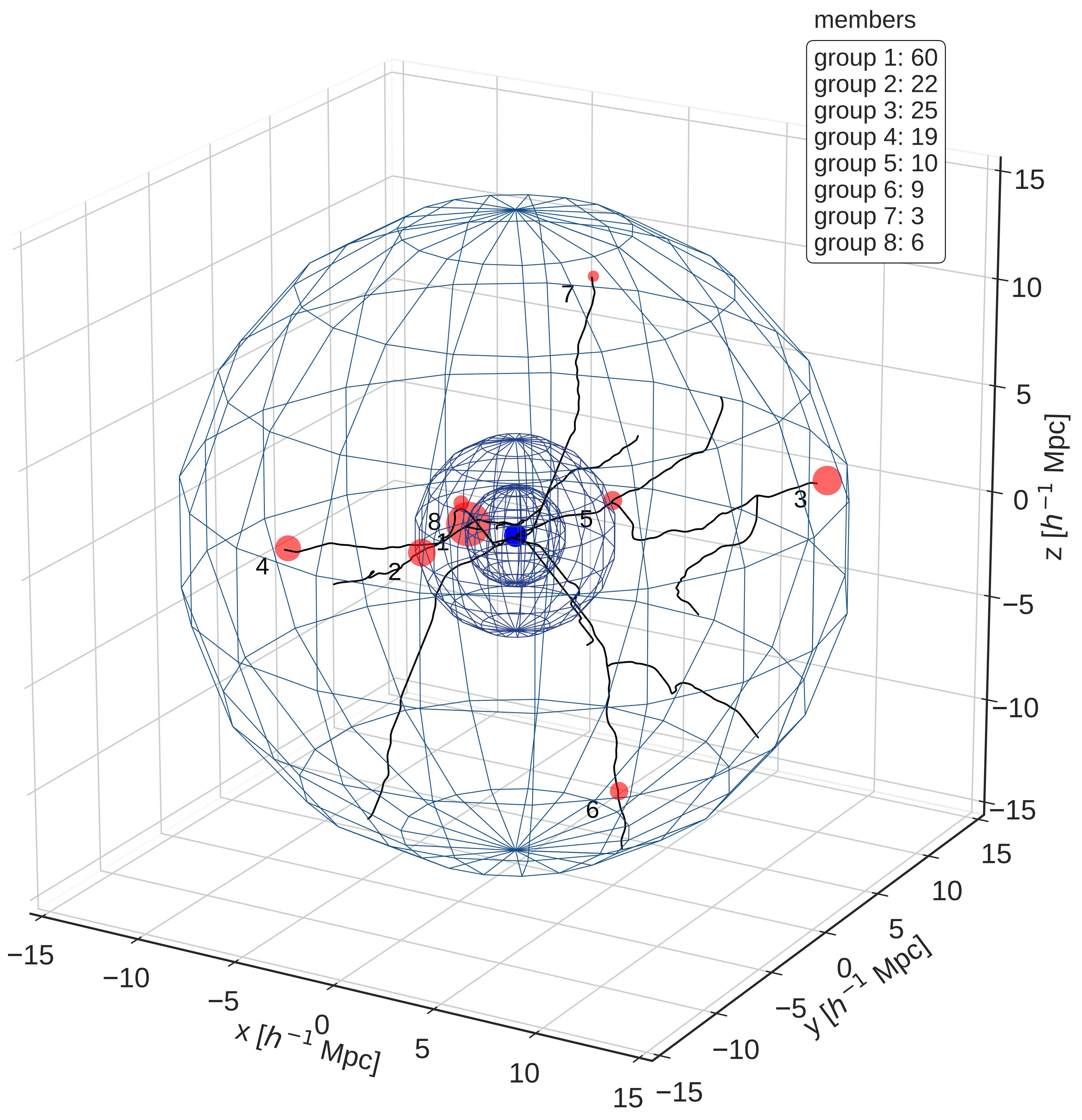
Haggar, Kuchner+2022

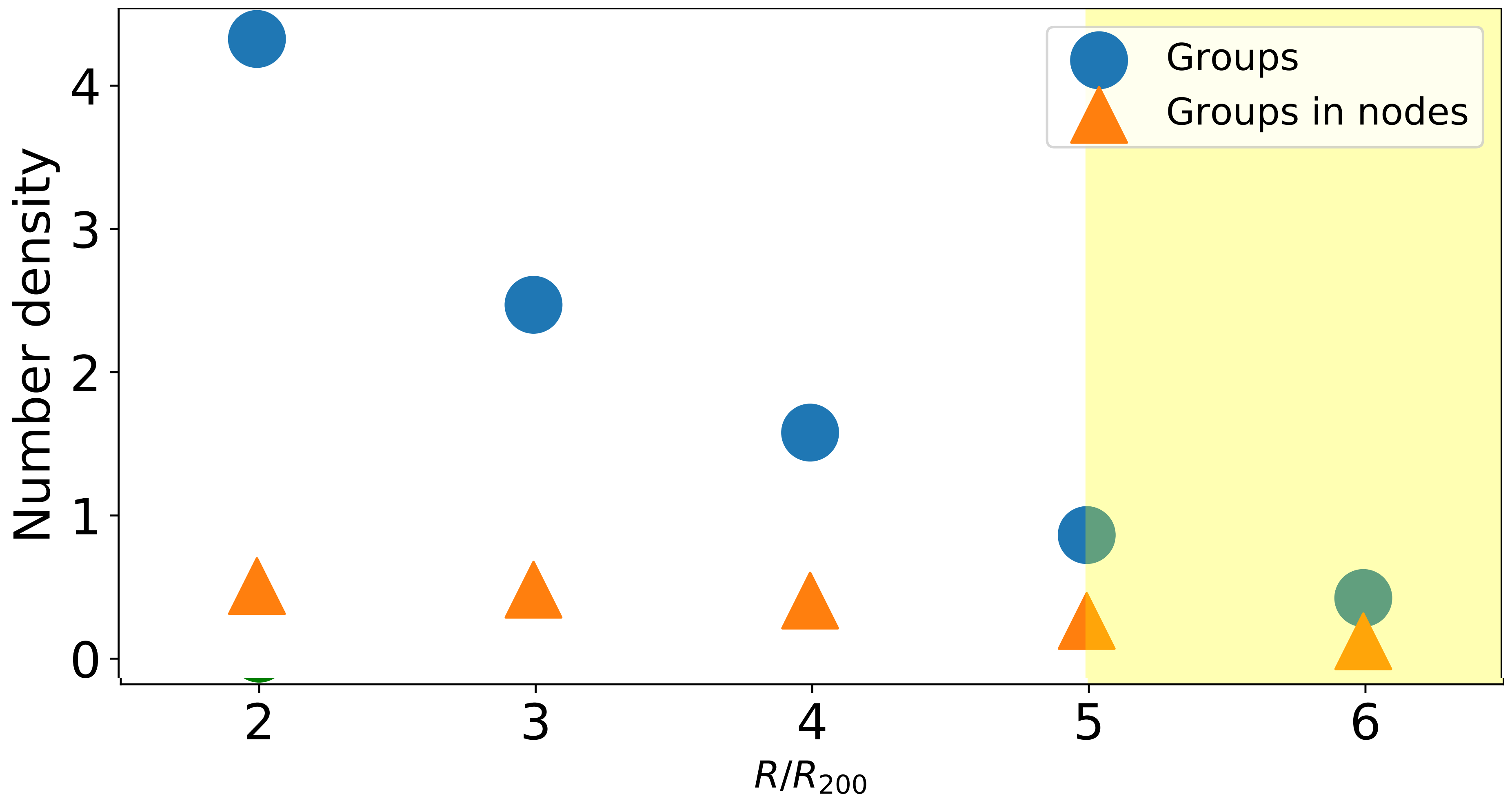


The overwhelming majority (> 99%) of groups that enter a cluster are doing so for the first time in their histories. Observationally, a group nearby to a cluster is very unlikely to have previously experienced a cluster environment.

There is no one/clear way to identify groups. It is a difficult problem in observations — especially near clusters.

Test inspired by Cohn+2022: can we identify groups near clusters with Disperse in observations?





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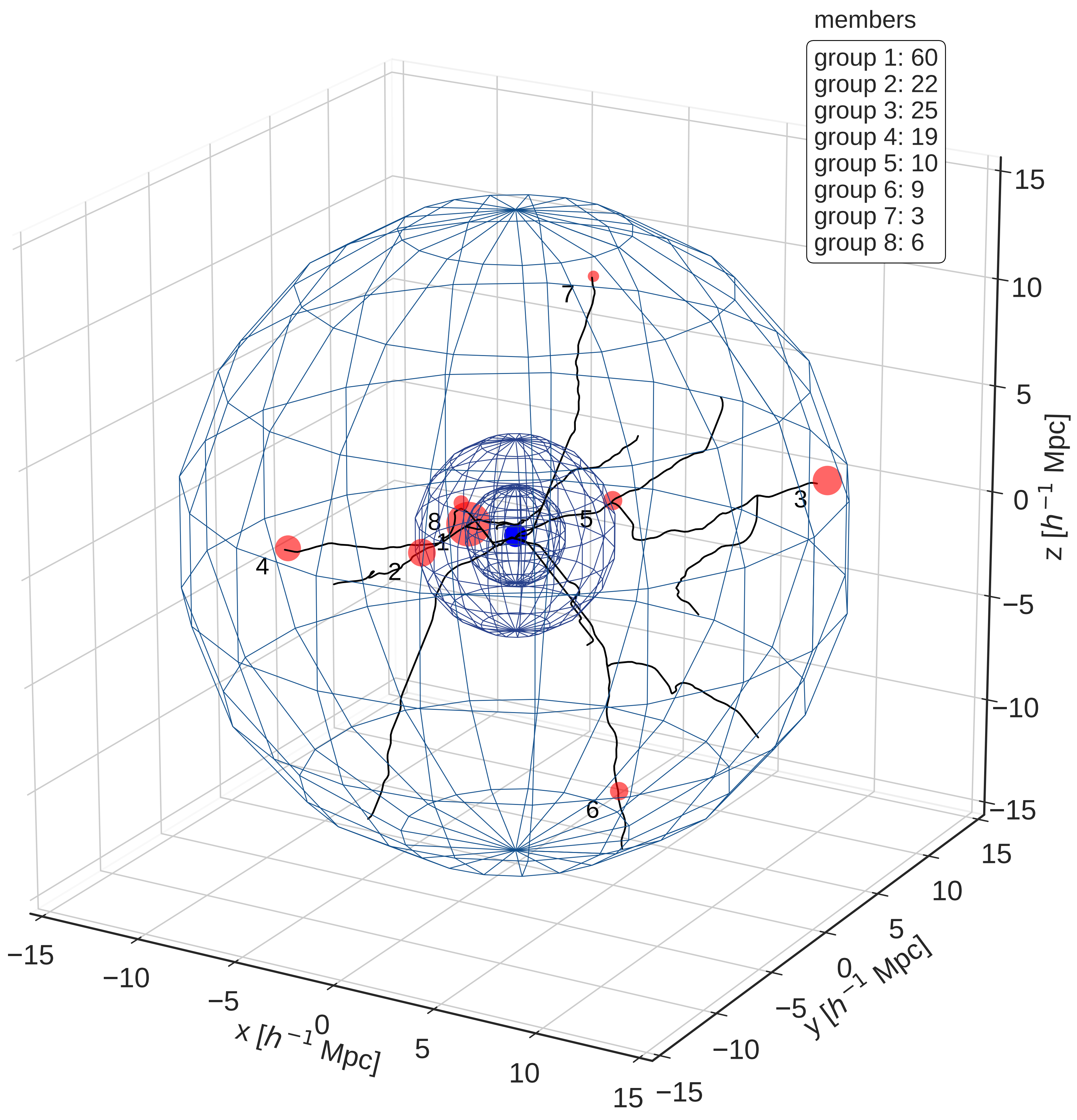
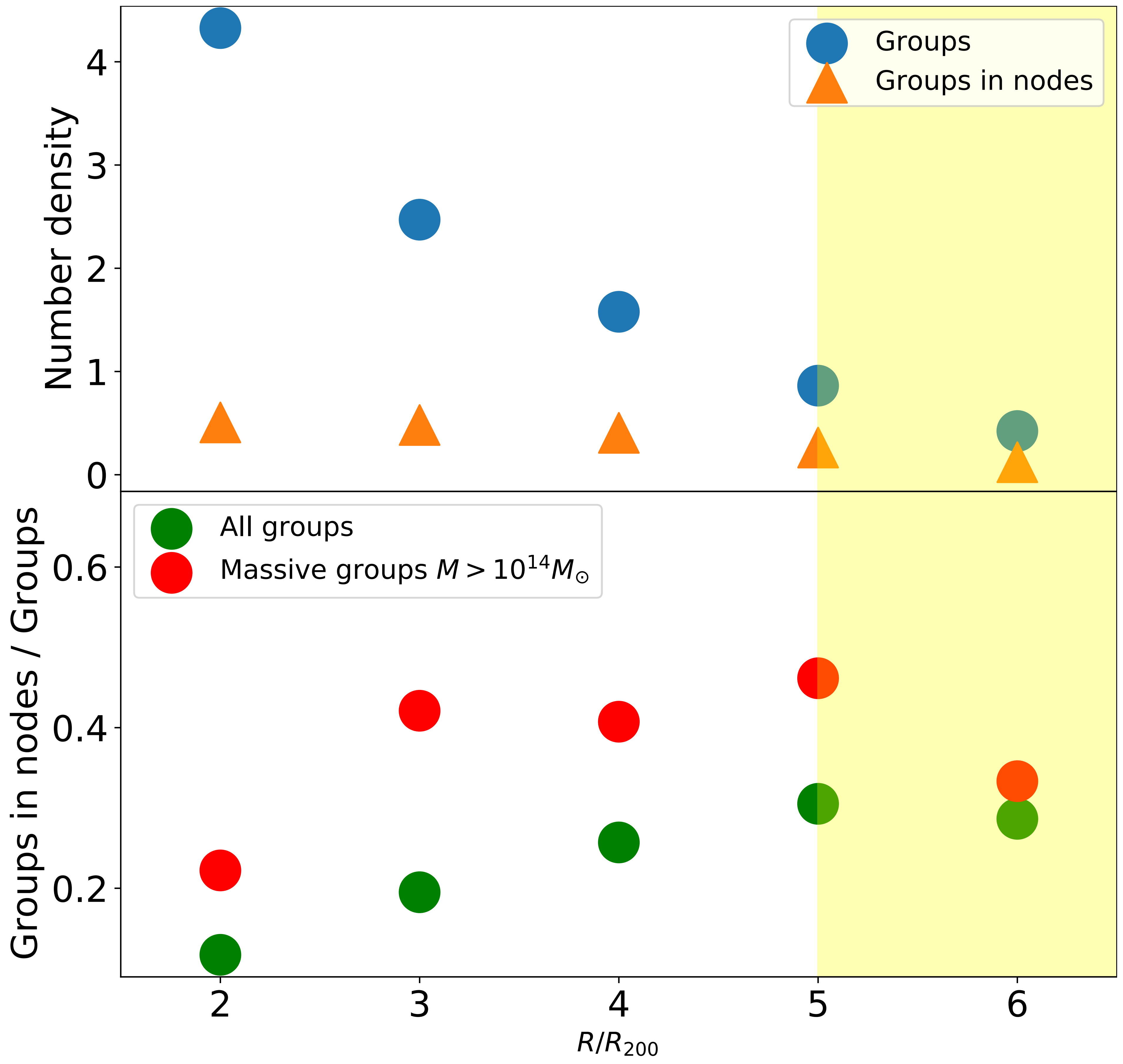
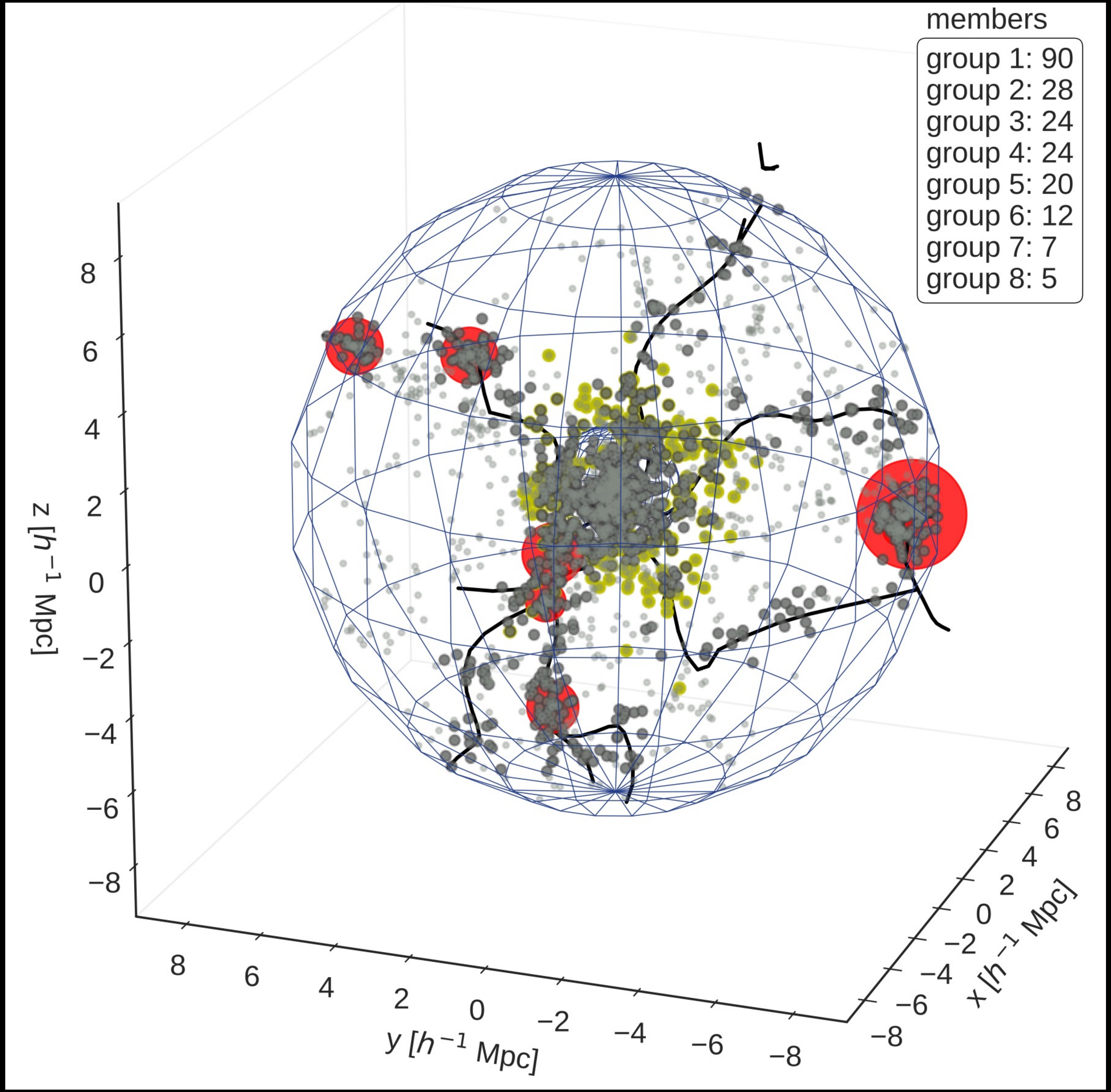
Test inspired by Cohn+2022: can we identify groups near clusters with Disperse in observations? — even harder in 2D





INVENTORY:
GALAXIES IN FILAMENTS

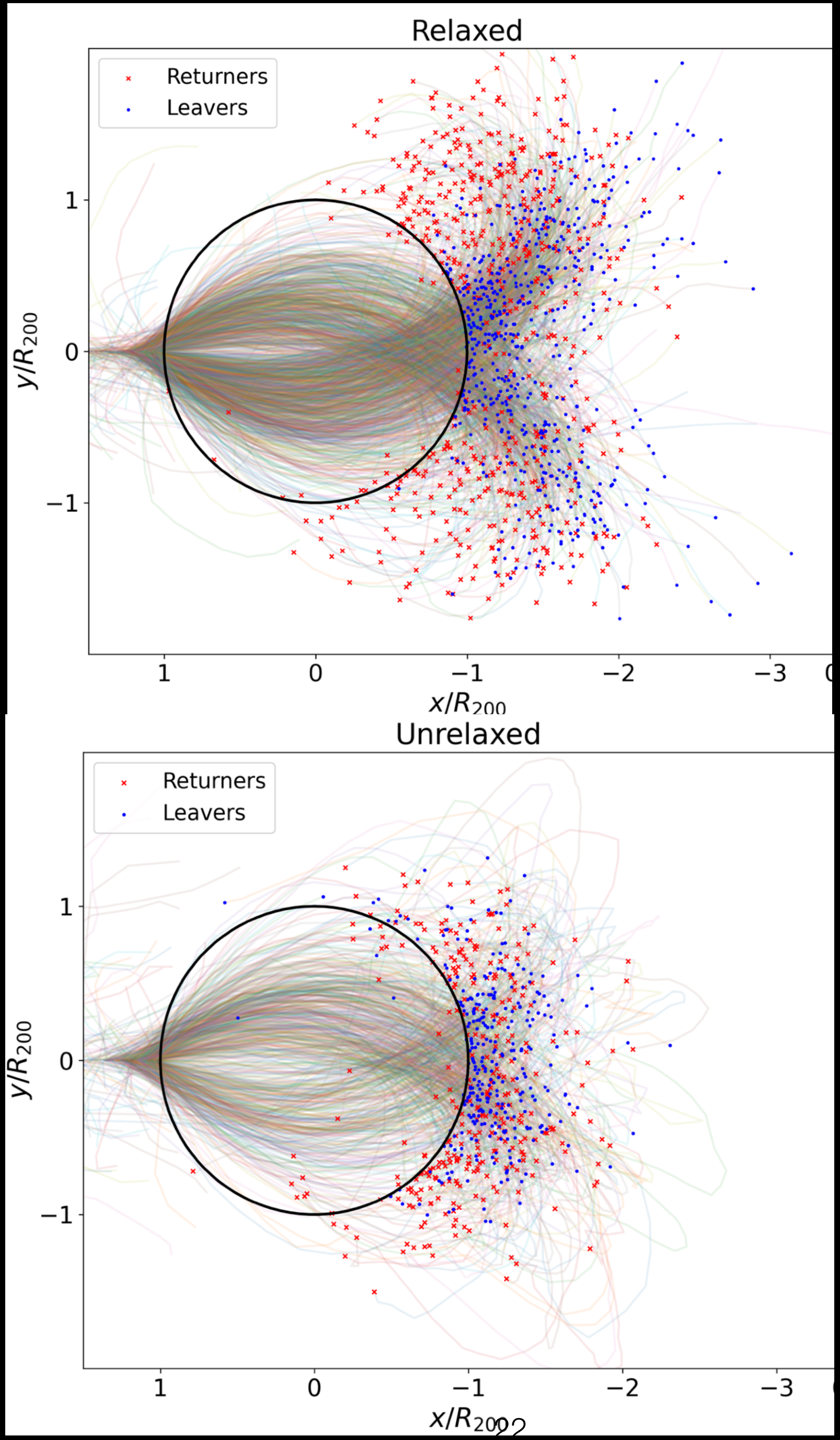


Galaxies feed clusters from a variety of evolving environments that pre-process them differently:

on their own (light gray),
via filaments (dark gray),
in groups (red),
as back-splash galaxies (yellow).

INVENTORY:

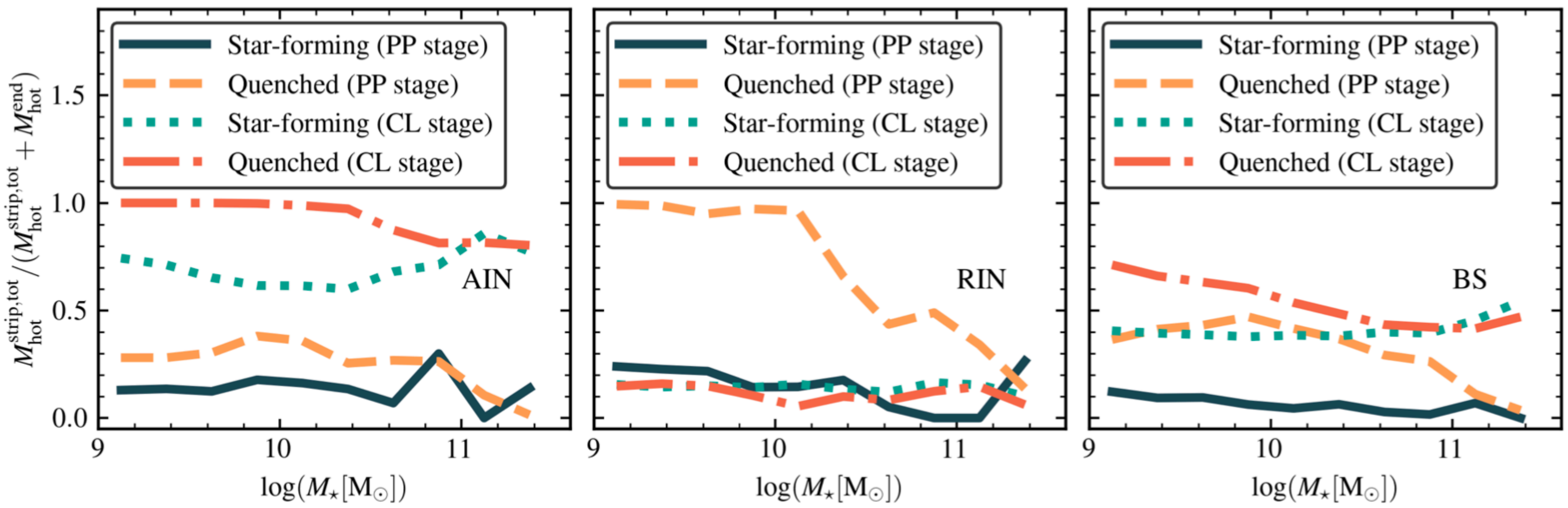
BACKSPLASH



Depending on the dynamical state of the cluster, backsplash galaxies are an **important ingredient** of the immediate cluster environment at z=0:

up to **60% of all galaxies between 1 and 2 R200** have already gone through the cluster and are on their second infall.

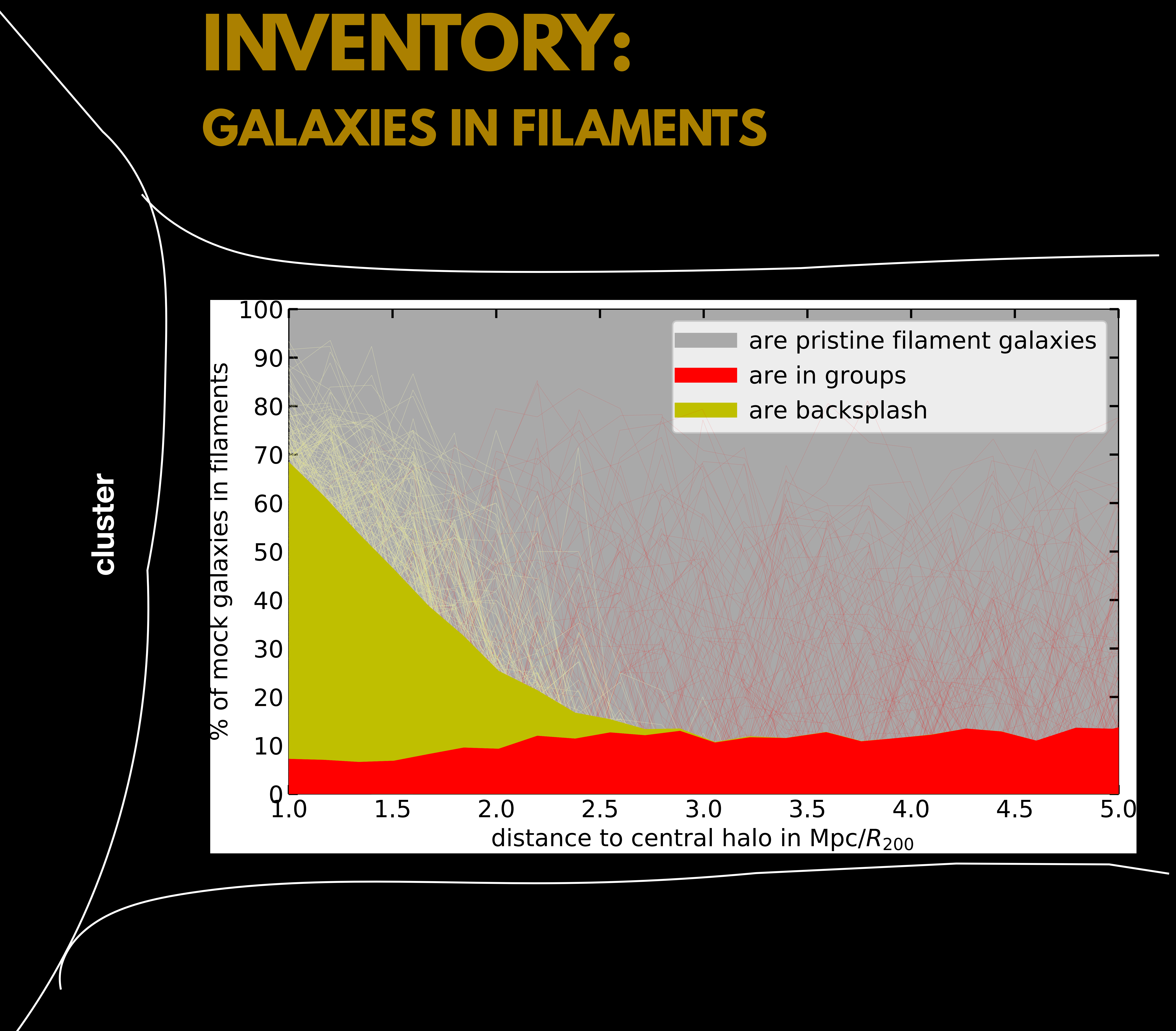
Gas removed by pre-processing



semi-analytic model of galaxy formation and evolution of 102 relaxed simulated galaxy clusters from The Three Hundred project

The majority of them quenches after the first pericentric passage, but a non-negligible fraction needs a second passage, specially galaxies with M* ≤ 1010.5 M . Recent infallers represent ~ 15 per cent of the quenched galaxies located inside the cluster and, on average, they contain a high proportion of hot and cold gas; moreover, pre-processing effects are the responsible for quenching the recent infallers prior to infall onto the main cluster progenitor. The ~ 65 per cent of quenched galaxies located around clusters are backsplash galaxies, for which the combination of RPS acting during a pre-processing stage and inside the cluster is necessary for the suppression of SF in this population.

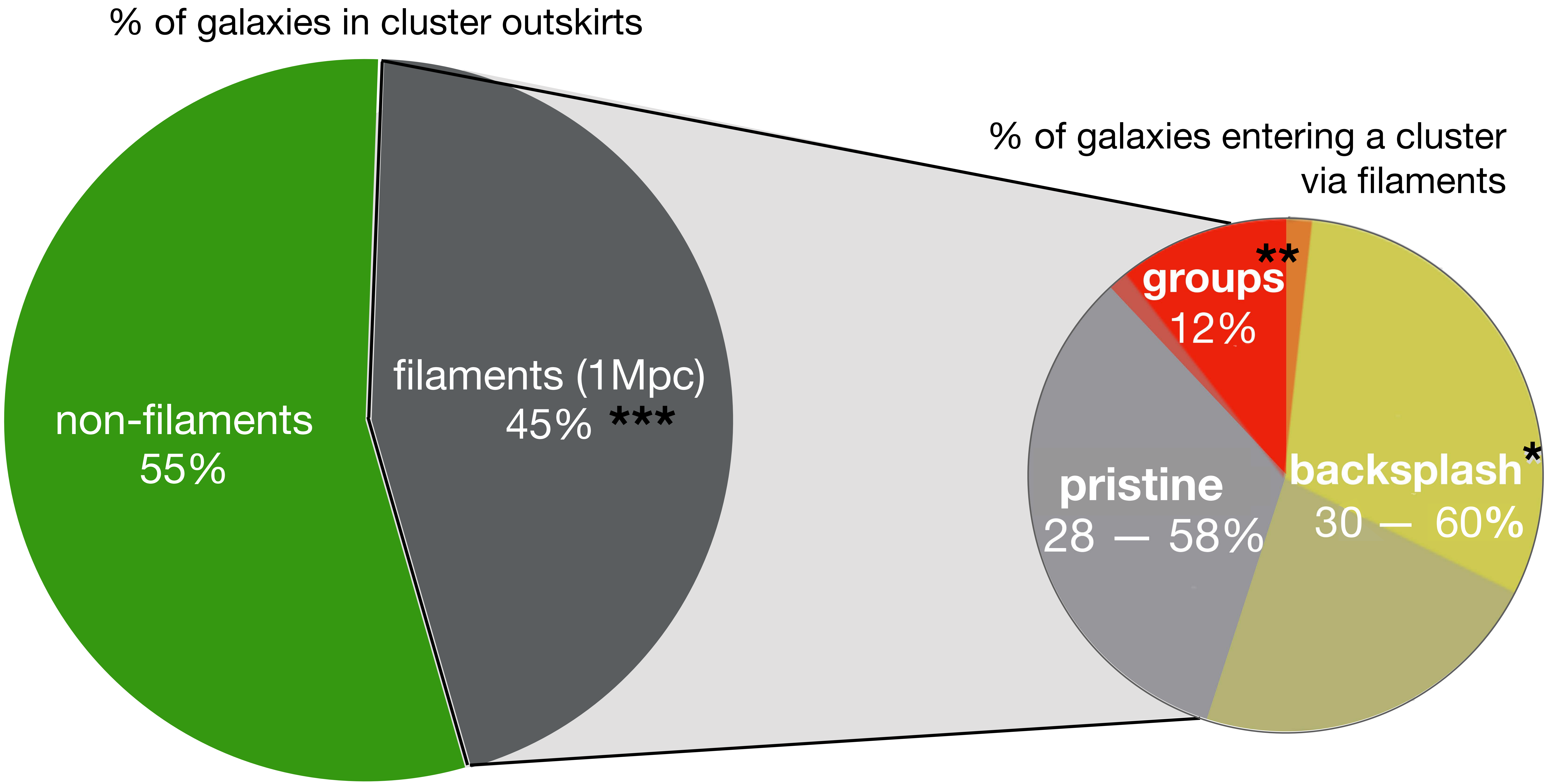
INVENTORY:
GALAXIES IN FILAMENTS



Filaments host galaxies of a mix of environments and environmental histories.

Only about 30% of all galaxies that fall into the cluster through filaments (*defined with constant thickness) are 'pristine'.

Kuchner+2022, 2022MNRAS.510..581K



* depends on dynamical state of the cluster

** >99% of the groups approaching clusters are falling in for the first time

*** depend on filament thickness, galaxy properties, way to identify filaments, distance from the cluster

Kuchner+2022, 2022MNRAS.510..581K

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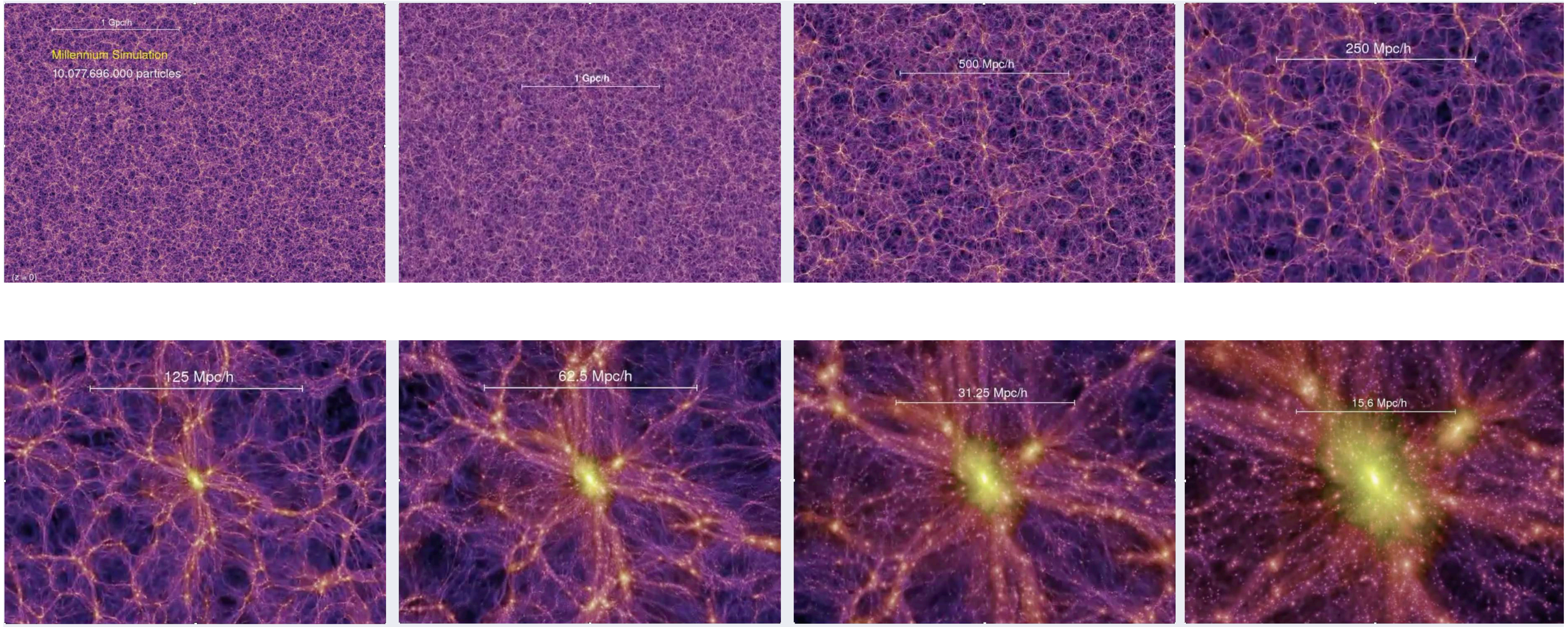
What is the problem?
Why does solving it matter and who does it matter to?



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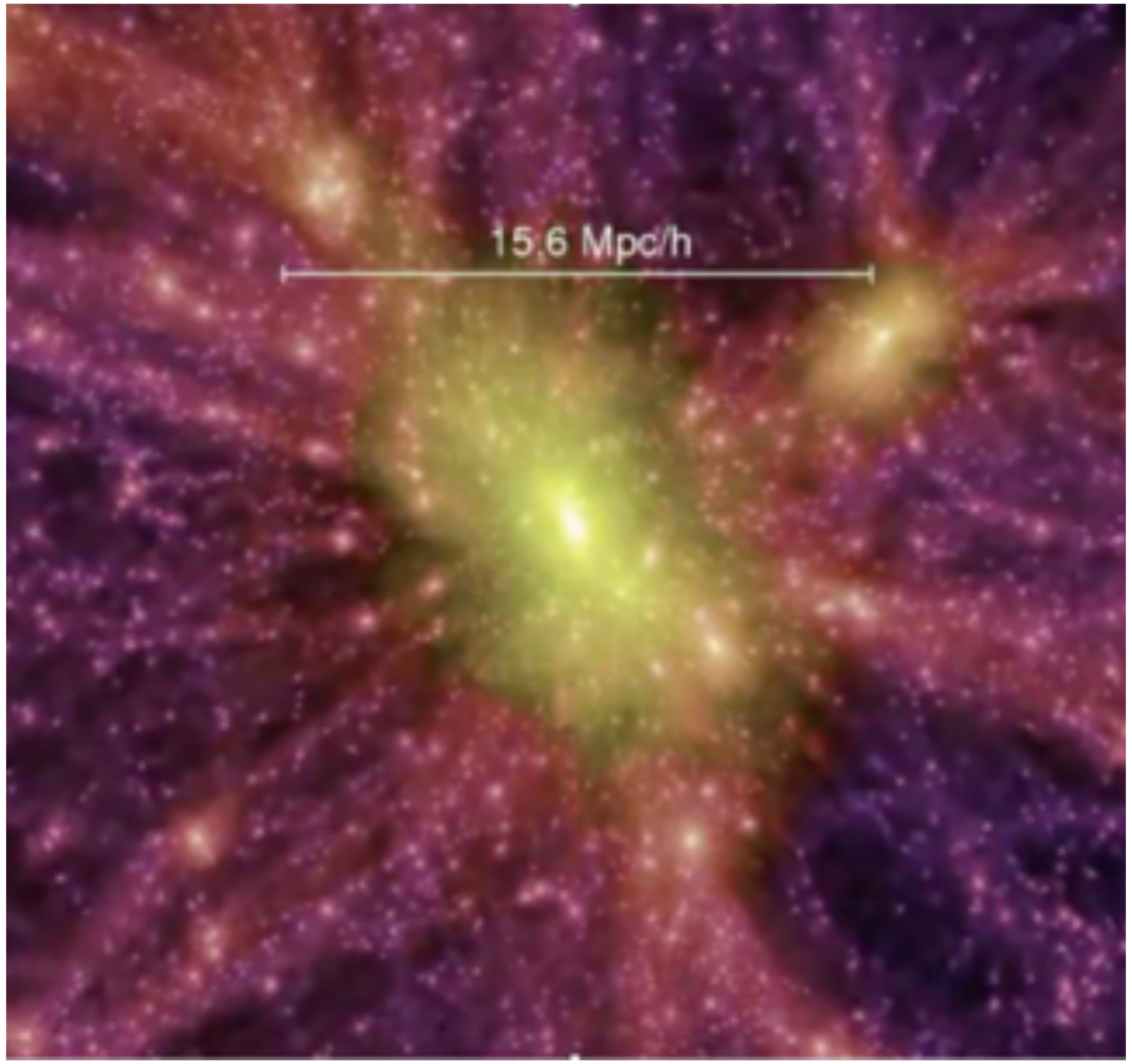
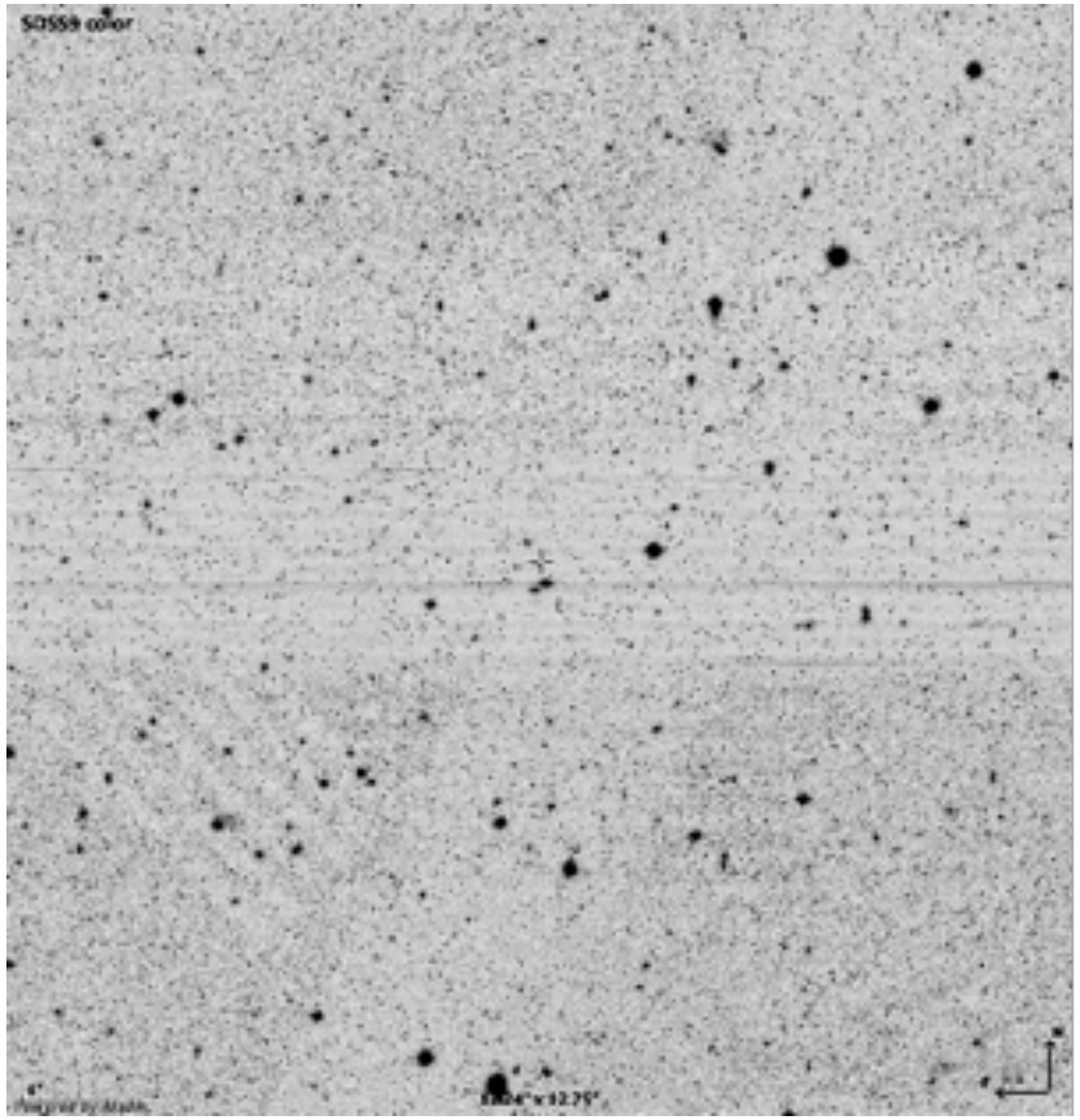
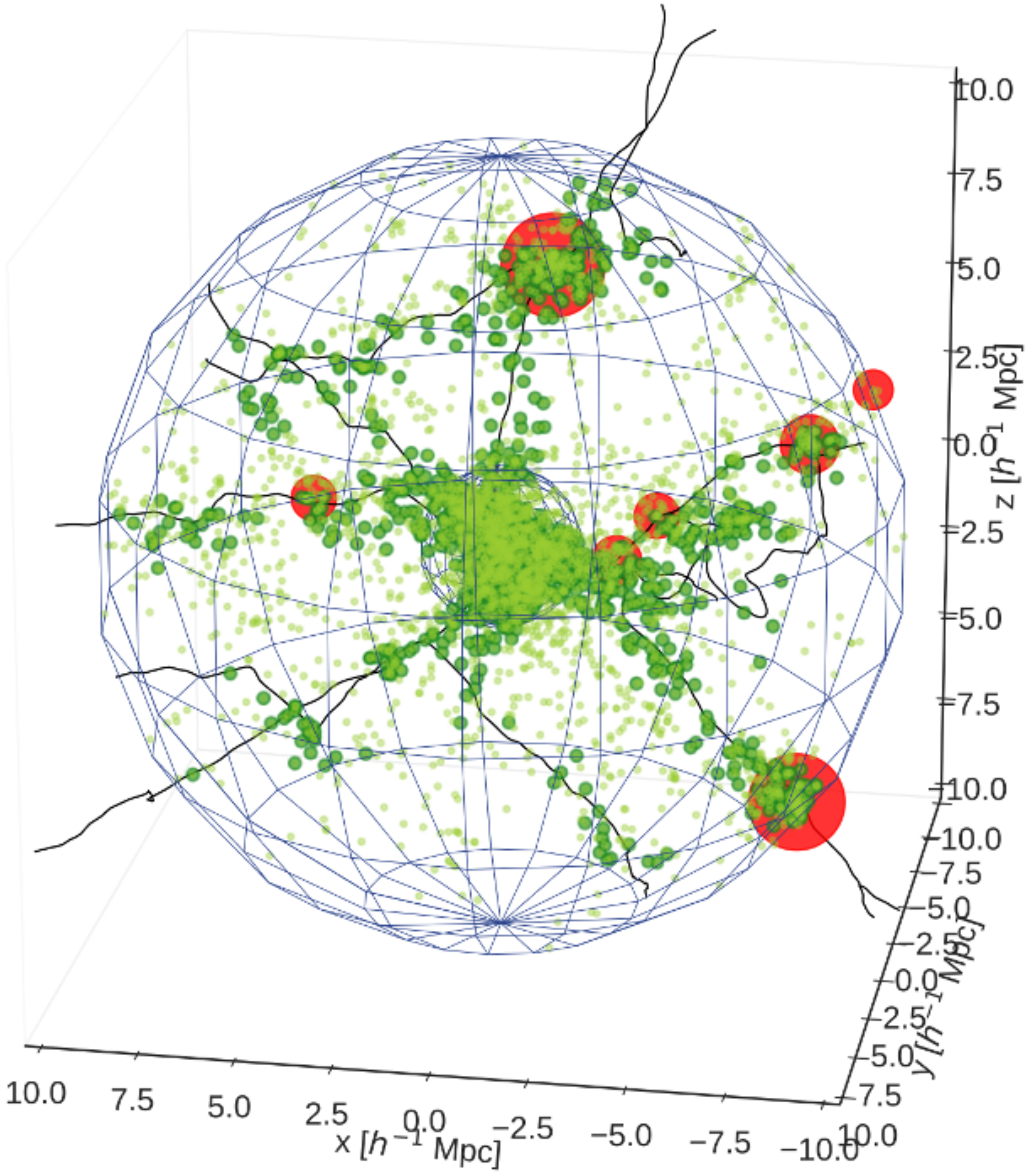


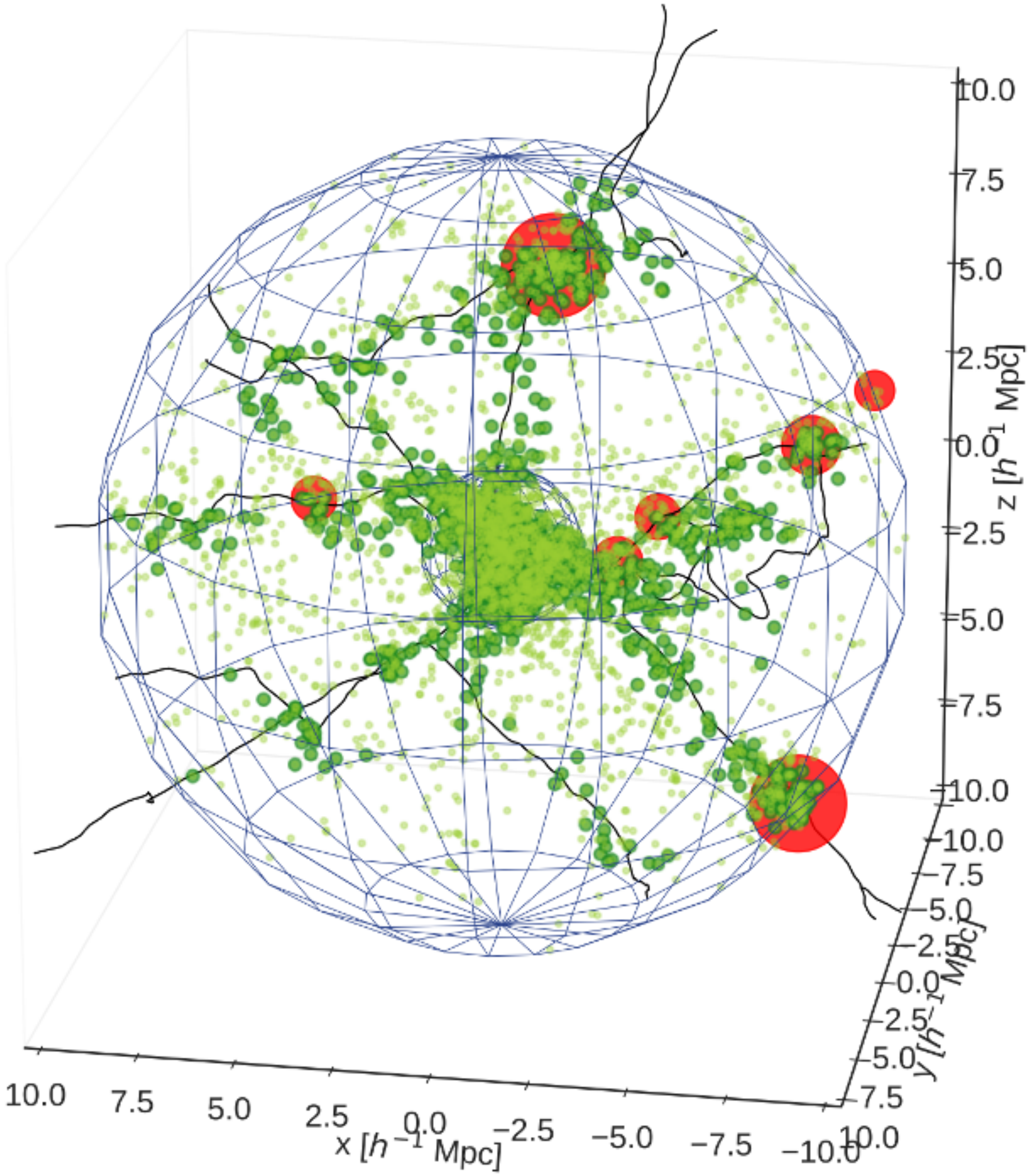


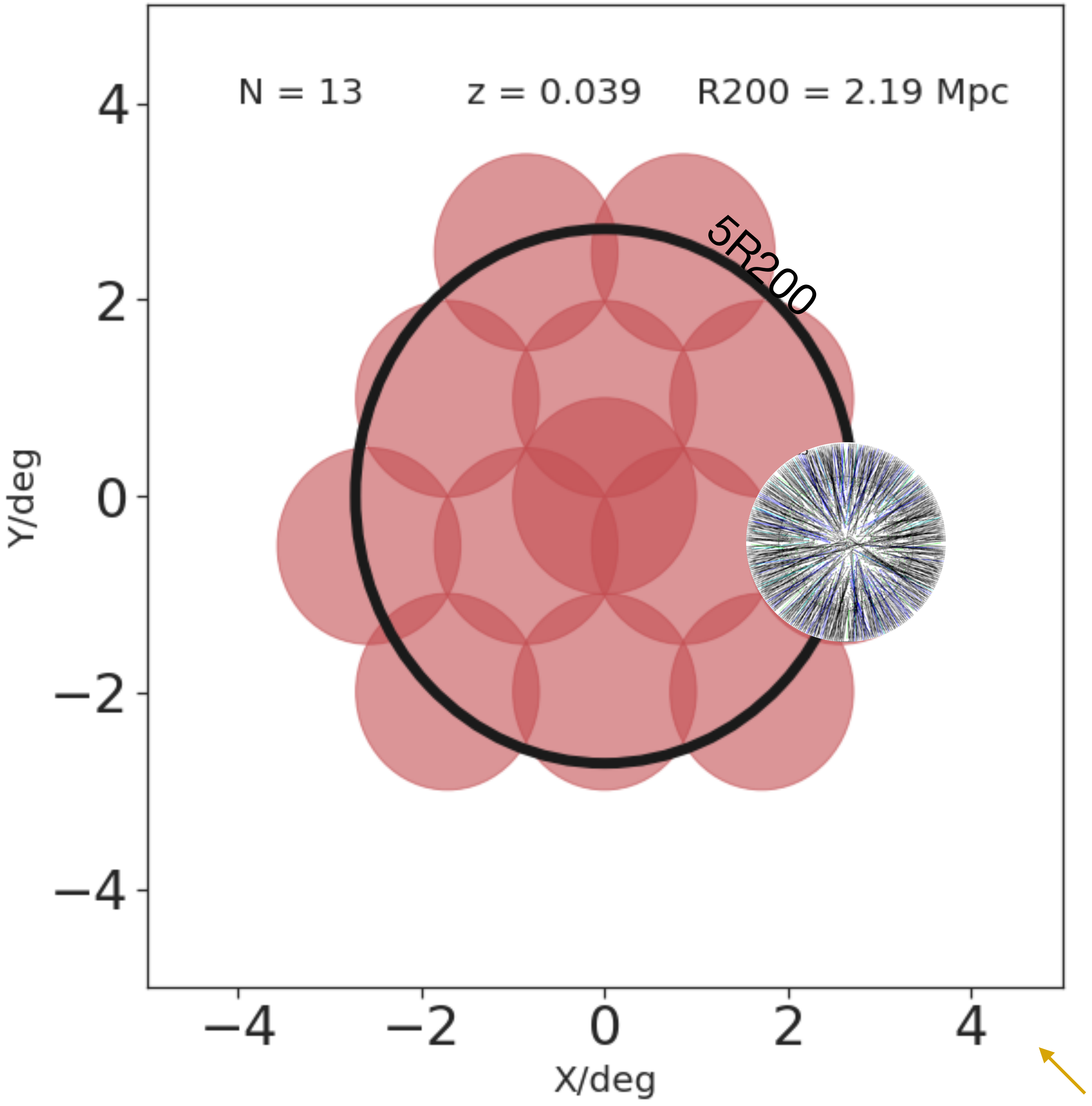
WEAVE - CLUSTERS

The **WEAVE Wide Field Cluster Survey** (WWFCS) will observe and map ~20 nearby (0.04<z<0.07) cluster structures out to 5R200.



Kuchner+2021, 2021MNRAS.503.2065K





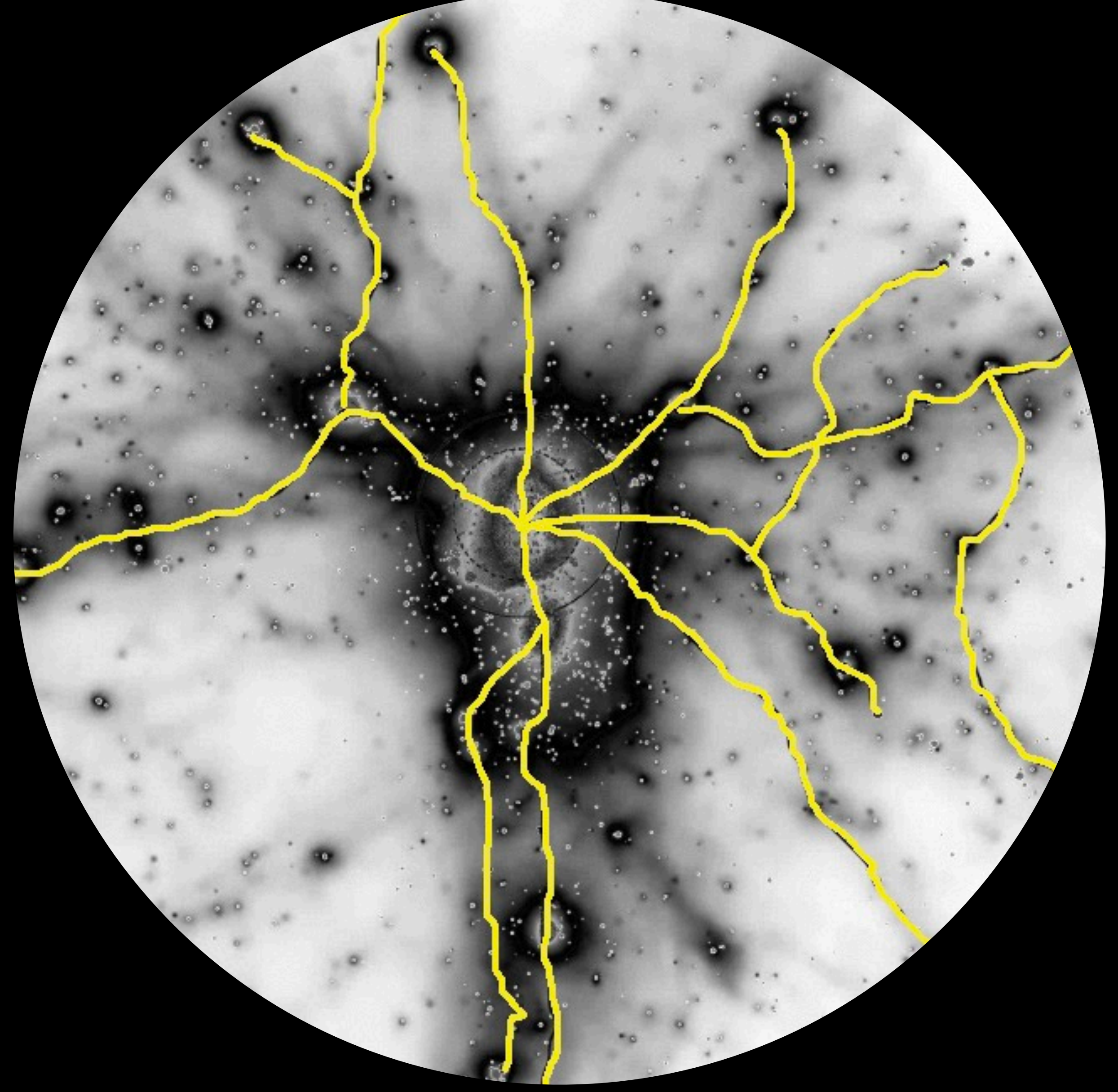
Cornwell+22 in prep

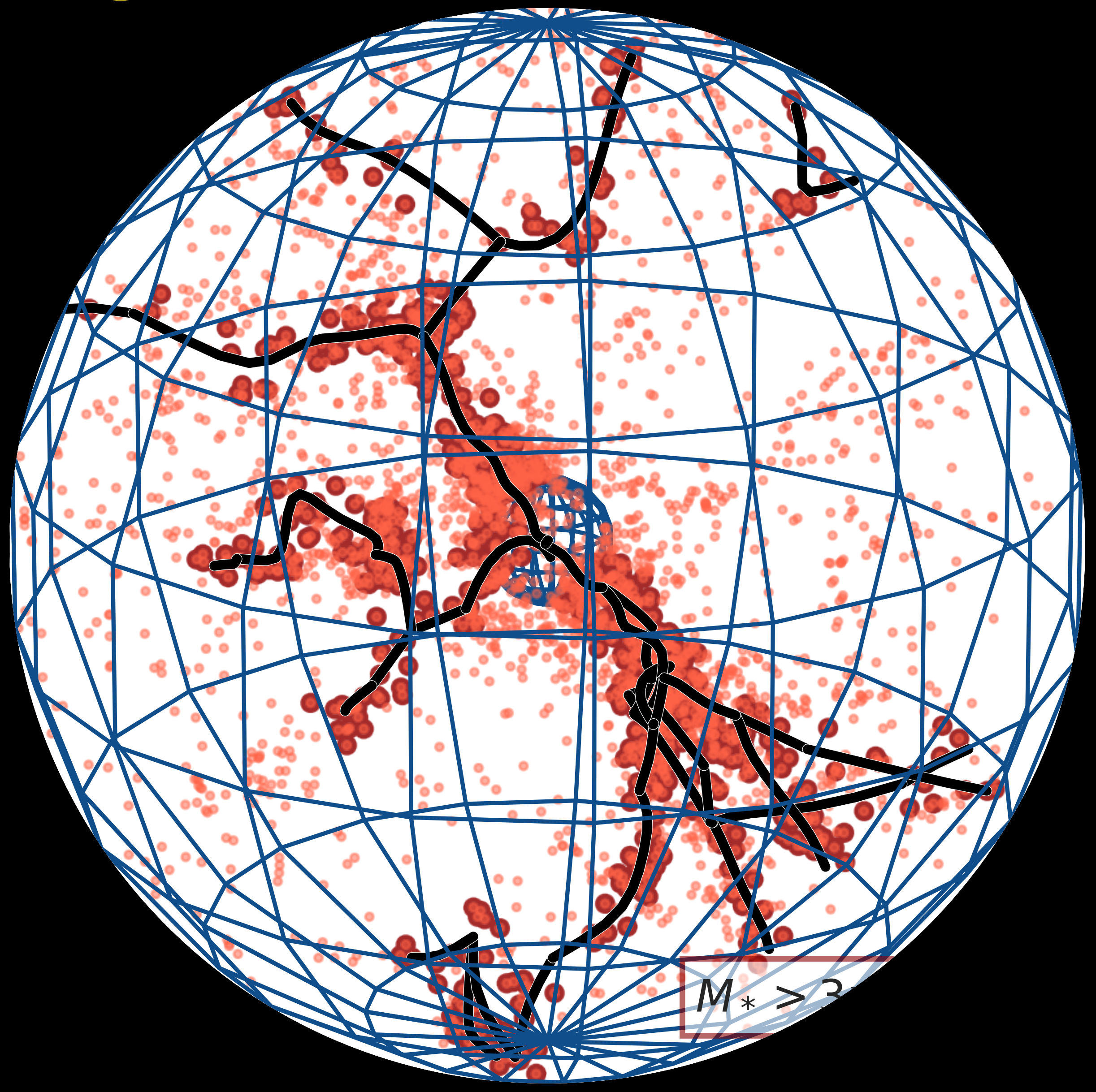
WEAVE Galaxy Clusters Survey

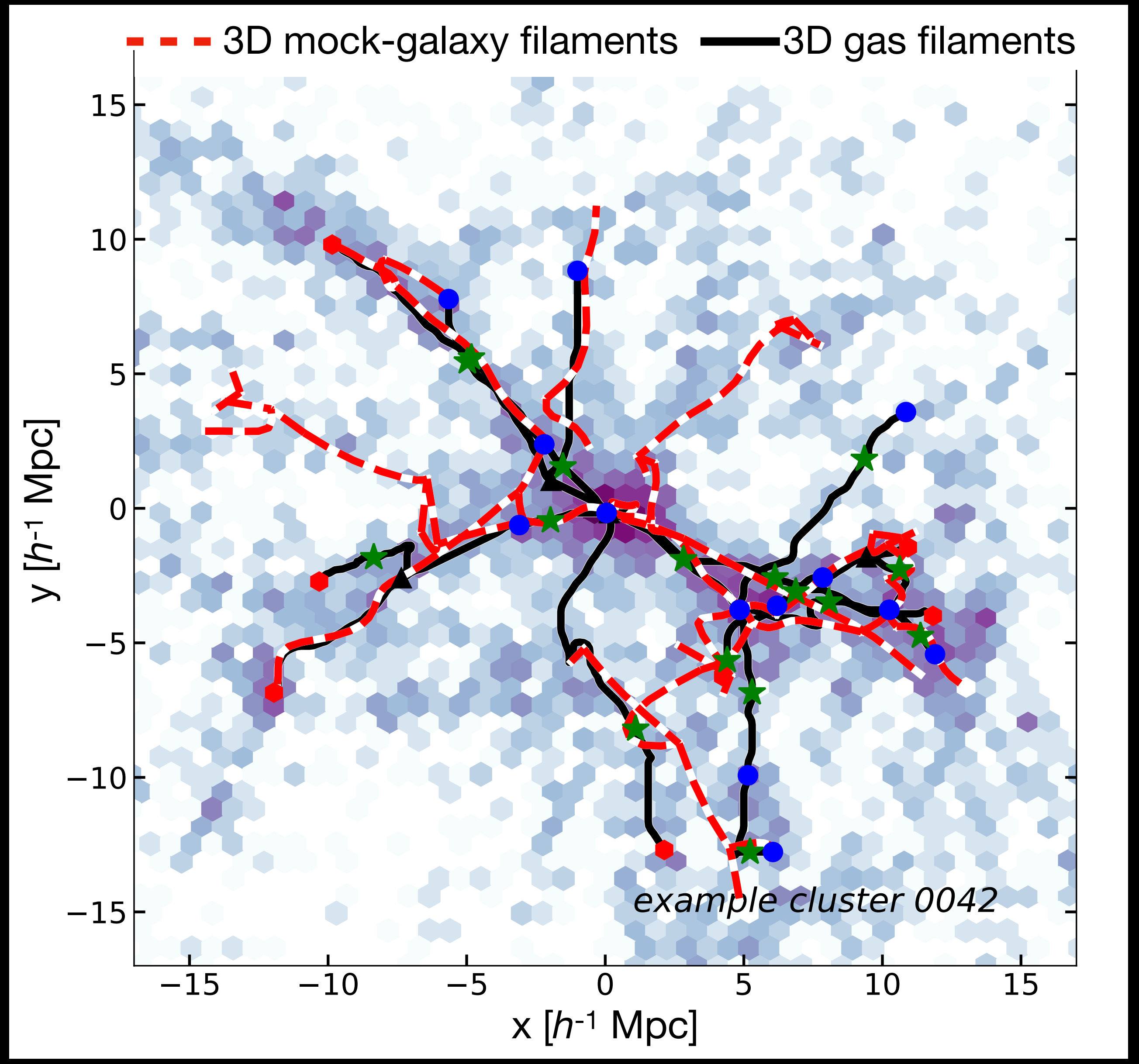
- WEAVE Nearby Clusters Survey
- WEAVE Wide Field Clusters Survey
- WEAVE Cosmological Clusters Survey

DECISIONS

How much information do we lose if we go from simulations to observations?







Reference filament network based on gas identified with **DiSperSE** (Sousbie+11)

Filament network based on **galaxies** and **galaxy associations** based on a **characteristic thickness** from gas density.

Several **selections** (according to detection limits and expected numbers for future surveys)

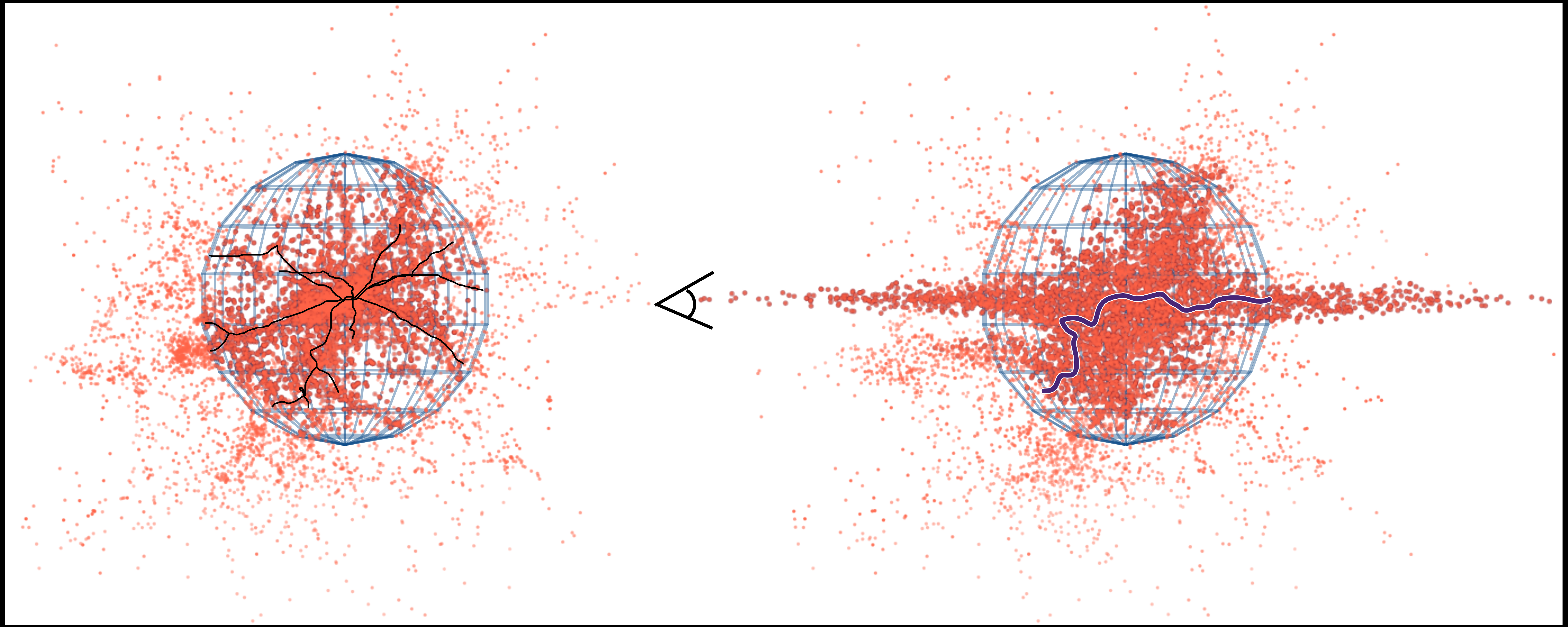
Compare filament networks

tailored to **WEAVE** (M*>3x10⁹Msol), also: **L*** galaxy, different **mass cuts**, gas and galaxies, **3D vs 2D**,..

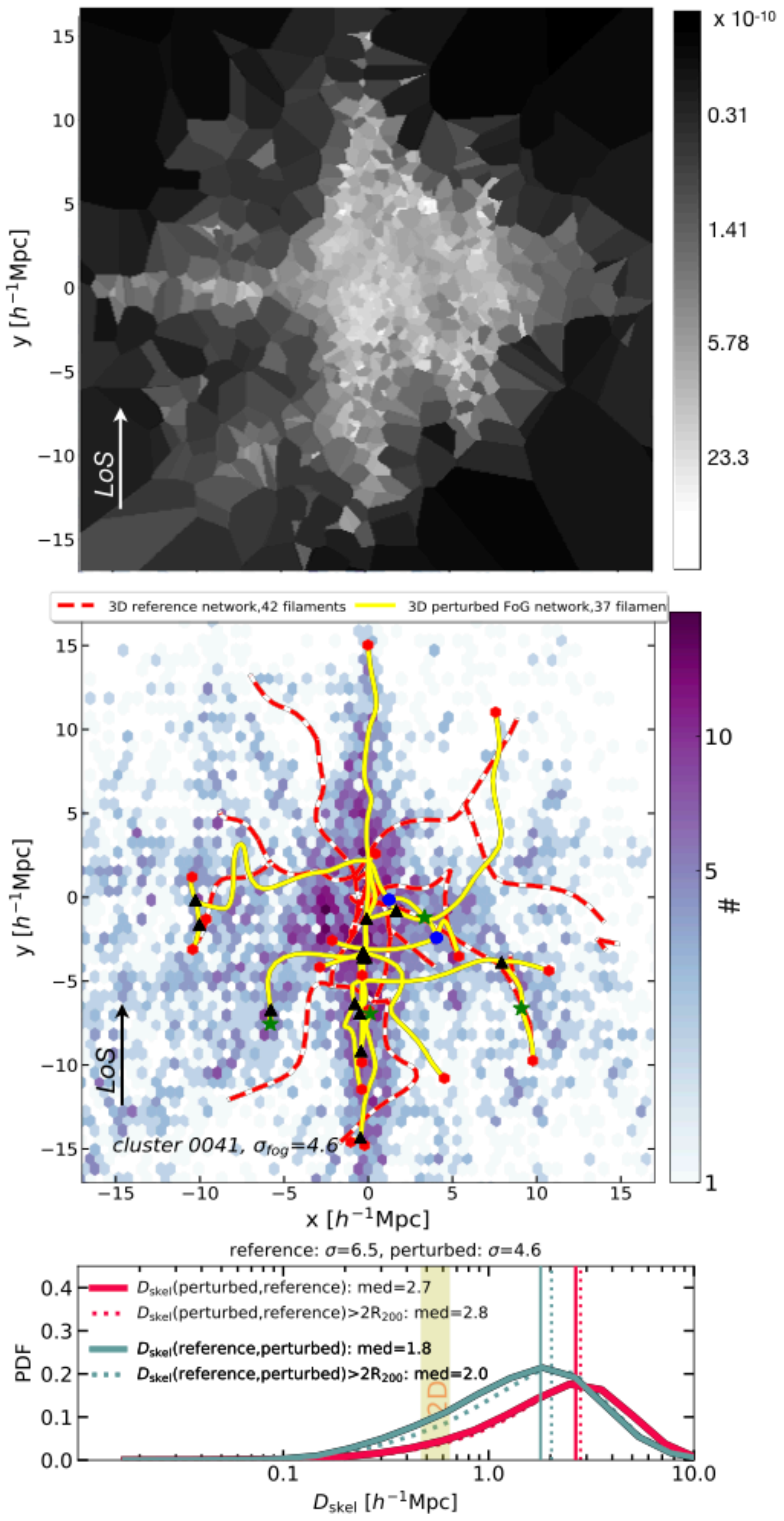
Cornwell+22: configured like observations: if only 75% of galaxies get fibres assigned, does this change the reconstruction? No.***

THE IMPACT OF FINGERS OF GOD

Can we find cluster-filaments in observations given the redshift space distortions caused by peculiar (non-Hubble) motions of galaxies?



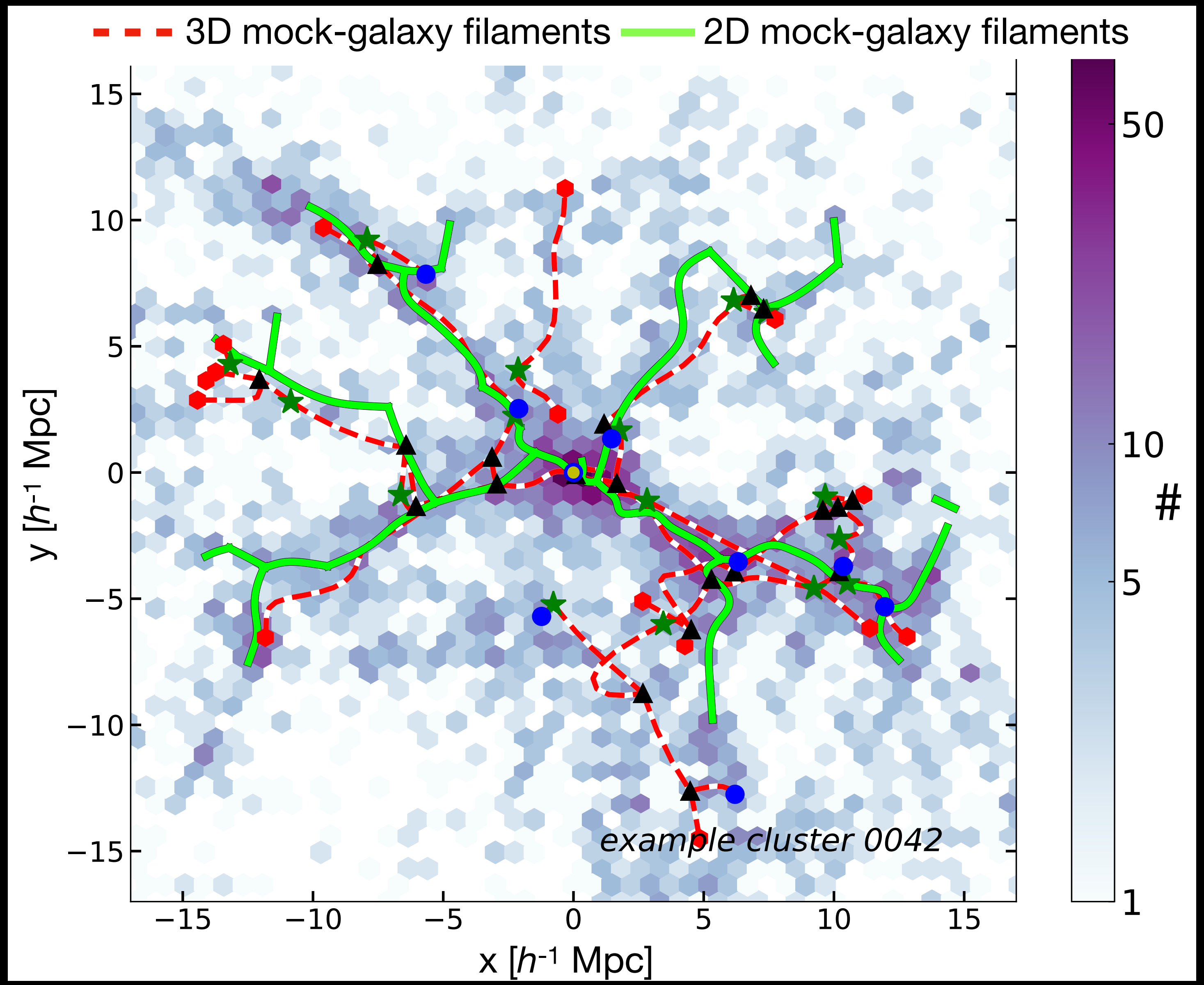
We tested network extractions after **compressing** distorted galaxies in **virialized structures** (cluster center and groups).

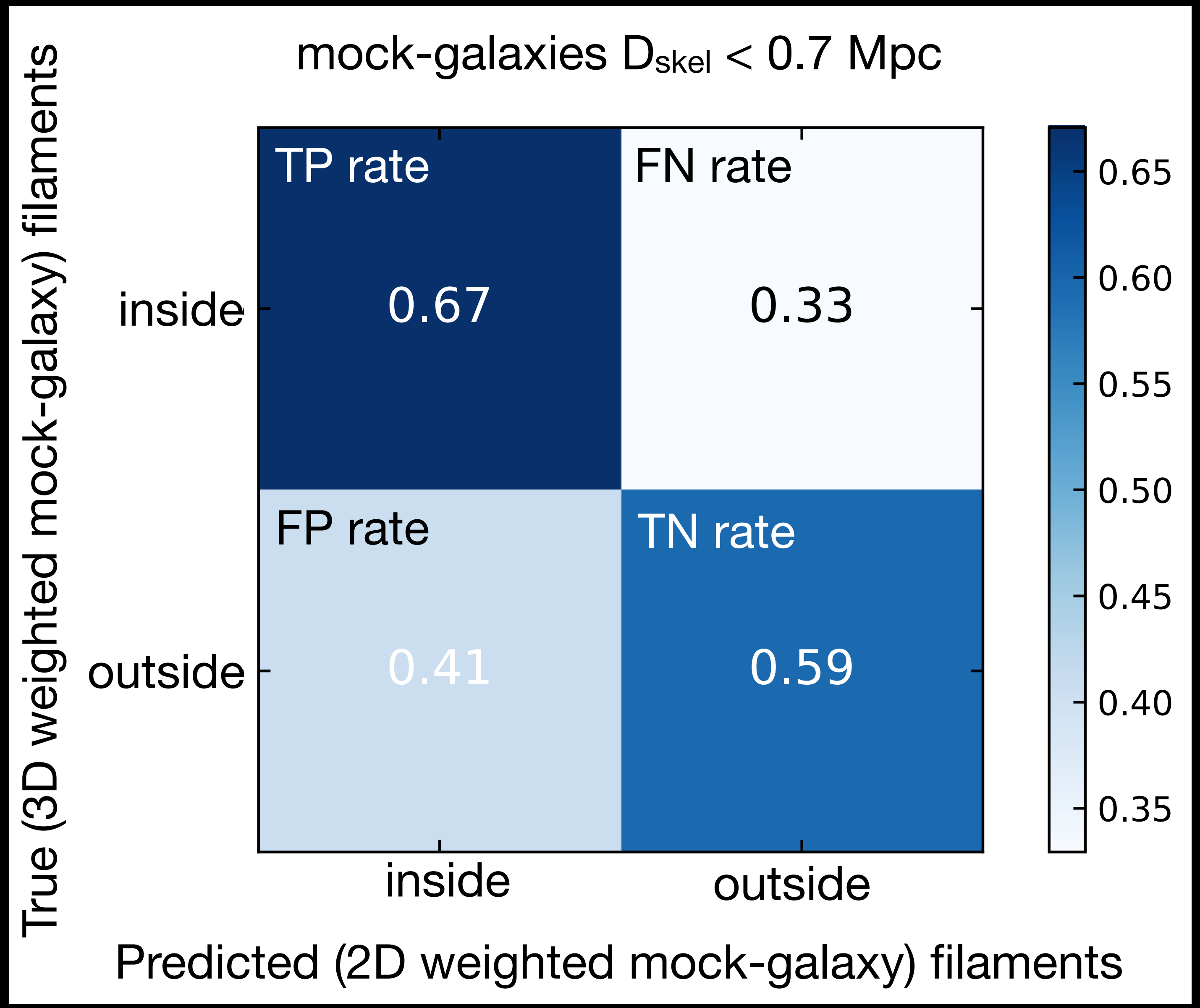


x 10-10
0.31
1.41
5.78
23.3
y [h^{-1}Mpc]
LoS
3D reference network,42 filaments
3D perturbed FoG network,37 filamen
cluster 0041, σ_{fog}=4.6
x [h^{-1}Mpc]
#
reference: σ=6.5, perturbed: σ=4.6
D_{skel}(perturbed,reference): med=2.7
D_{skel}(perturbed,reference)>2R_{200}: med=2.8
D_{skel}(reference,perturbed): med=1.8
D_{skel}(reference,perturbed)>2R_{200}: med=2.0
PDF
D_{skel} [h^{-1}Mpc]

FINGERS OF GOD (CLUSTER AND FILAMENTS)

Can we find cluster-filaments in observations given the redshift space distortions caused by peculiar (non-Hubble) motions of galaxies?

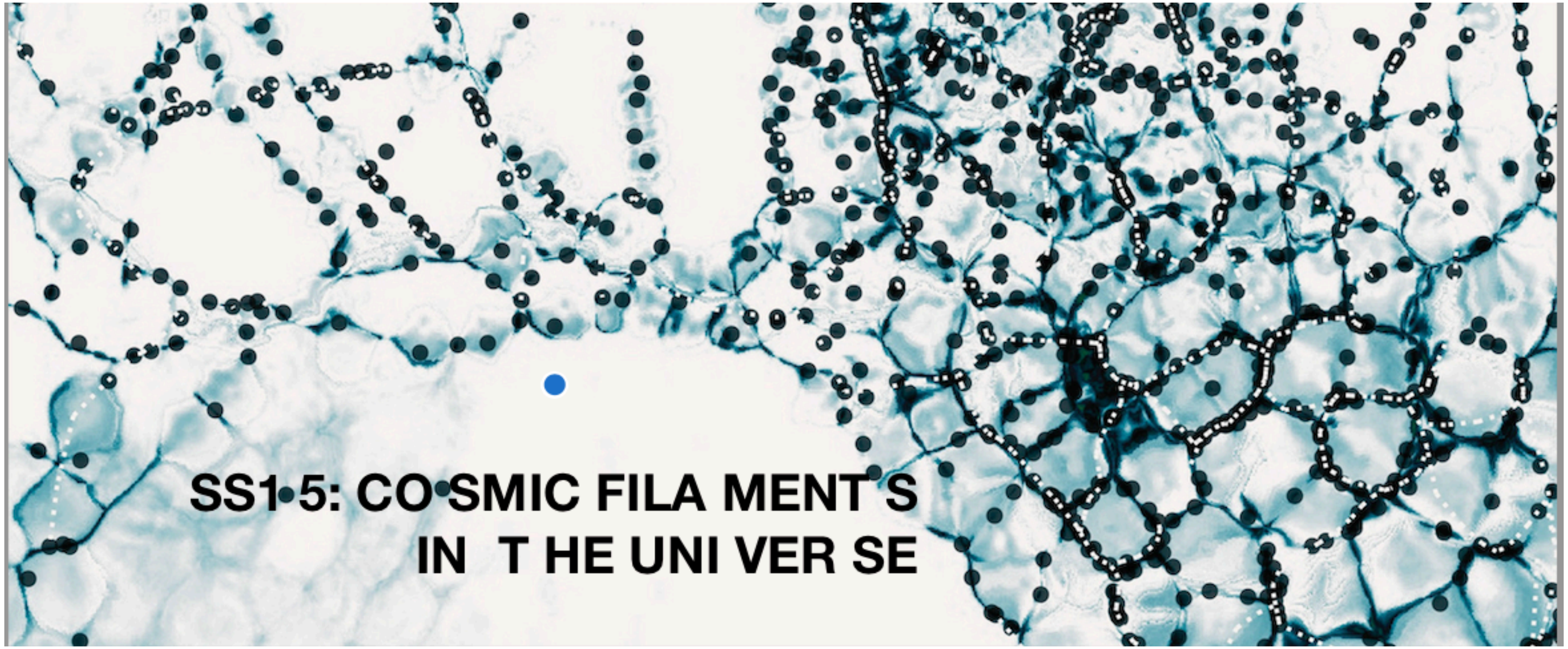




We found that **filaments extracted from the 2D projection of a spec-z defined volume** was more reliable than using velocities in small areas around clusters.

Kuchner+2020 , 2020MNRAS.494.5473K

EAS annual meeting in Krakow, Poland (10-14 July



Special Session 15: Cosmic Filaments in the Universe
Special Session 16: early results from WEAVE

16 Feb - 5 March 2023
SPACE Lab
[co-creative art-astronomy experiments]
Speculative artworks that respond to current research about the Universe co-created between astrophysicists and artists
Opening and Private Views: Thu 16 Feb 6 - 8pm
Sat 18 Feb 2 - 5pm
A·P·T Art in Perpetuity Trust Gallery
6, Creekside, Deptford
London, SE8 4SA
https://www.aptstudios.org/exhibitions2223-spacelab
Science and Technology Facilities Council
University of Nottingham UK | CHINA | MALAYSIA
ual: creative computing institute
WE ARE LEWISHAM
Monica LoCascio: Passenger III

Pre-processing in galaxy cluster outskirts

Problem analysis

Galaxy evolution in the CW

Pre-Processing

Decisions for observations

Approach analysis

Simulations: The 300

Observations: WEAVE 4MOST Euclid

Solution analysis

Preparations

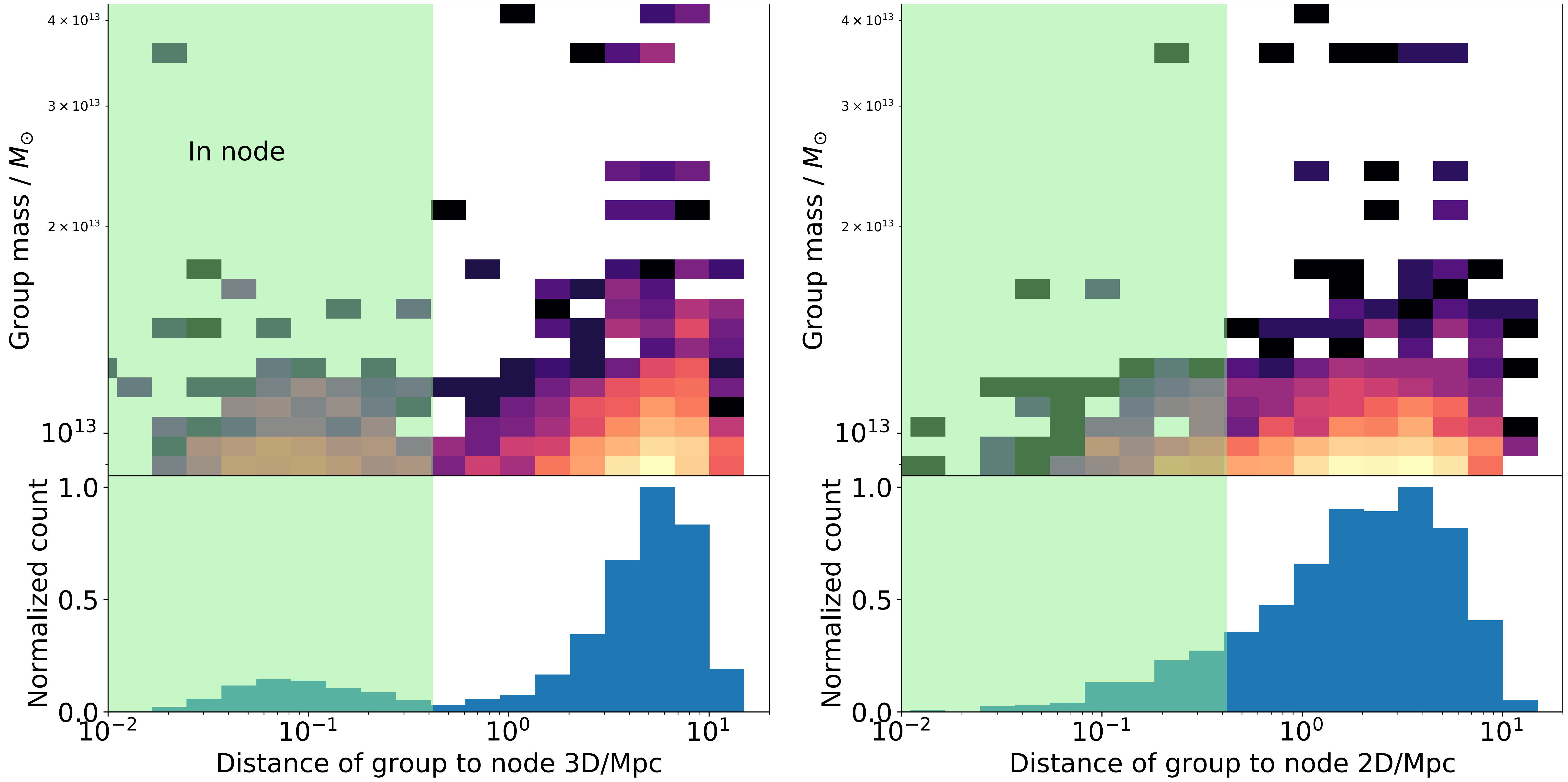
Inventory

Characterisation

Kuchner+2020 — 2020MNRAS.494.5473K
Kuchner+2021 — 2021MNRAS.503.2065K
Rost, Kuchner+2021 — 2021MNRAS.502…741R
Kuchner+2022 — 2022MNRAS.510…581K
Cornwell, Kuchner+2022 — 2022MNRAS.517.1678C
Haggar, Kuchner+2023 — 2023MNRAS.518.1316H
Hough, .. Kuchner+2023 — 2023MNRAS.518.2398H
Jin, …. Kuchner+2023 — 2022arXiv221203981J
Bretonniere, Kuchner+2023 — 2022arXiv220912907E
Merlin, .. Kuchner+2023 — 2022arXiv220912906E
Fereira, .. Kuchner+2022 — 2022ApJ.931…34…F

There is no one/clear way to identify groups. It is a difficult problem in observations — especially near clusters.

Test inspired by Cohn+2022: can we identify groups near clusters with Disperse **in observations (3D vs 2D)?**



hydrodynamic simulations with baryonic models:

GADGET-MUSIC (Sembolini et al. 2013): classic SPH method. Radiative cooling, star formation with both thermal and kinetic Supernove (SN) feedback.

GADGET-X (Murante et al. 2010): modern SPH with the Wendland C4 kernel. Gas cooling with metal contributions, star formation with chemical enrichment, SN feedback with AGB phase, and AGN feedback.

GIZMO-SIMBA: (Dave, et al 2019, Cui et al. 2022): Advanced BH/AGN models, dust model, 'calibrated' according stellar properties.

Latest re-calibration, with 3 observational relations: total stellar mass fraction, CCG stellar mass-halo mass relation, and satellite galaxy stellar mass function

SAMs from MultiDark-Galaxies:

Three different models GALACTICUS, SAG and SAGE (see Knebe et al. 2018 for details) are applied on the cosmological MultiDark simulation.

GALACTICUS (Benson 2012): no calibration. only orphan galaxy.

SAG (Cora et al. 2018): calibrated to observation. orphan galaxy + ICL.

SAGE (Croton et al. 2016): no calibration. no orphan galaxy, only ICL.

Notes: We select these catalogues from the same regions as the hydrodynamic simulations.

Why The300: **4. multi-wavelength mock observations**

GADGET-MUSIC GADGET-X GIZMO-SIMBA

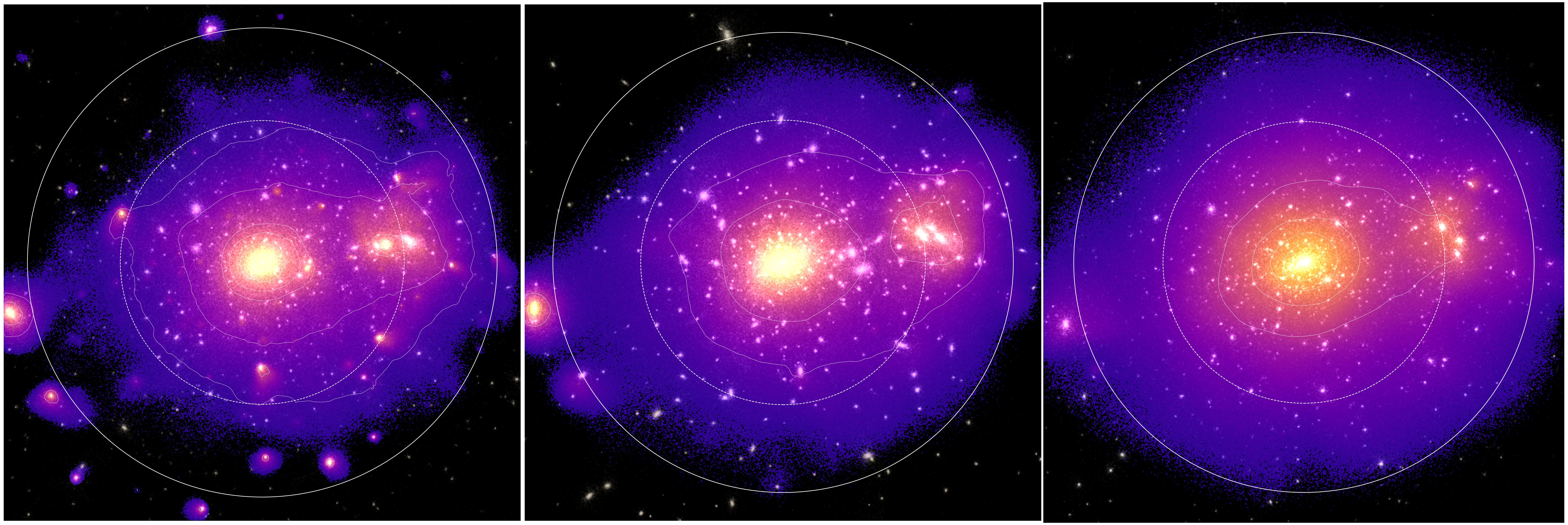
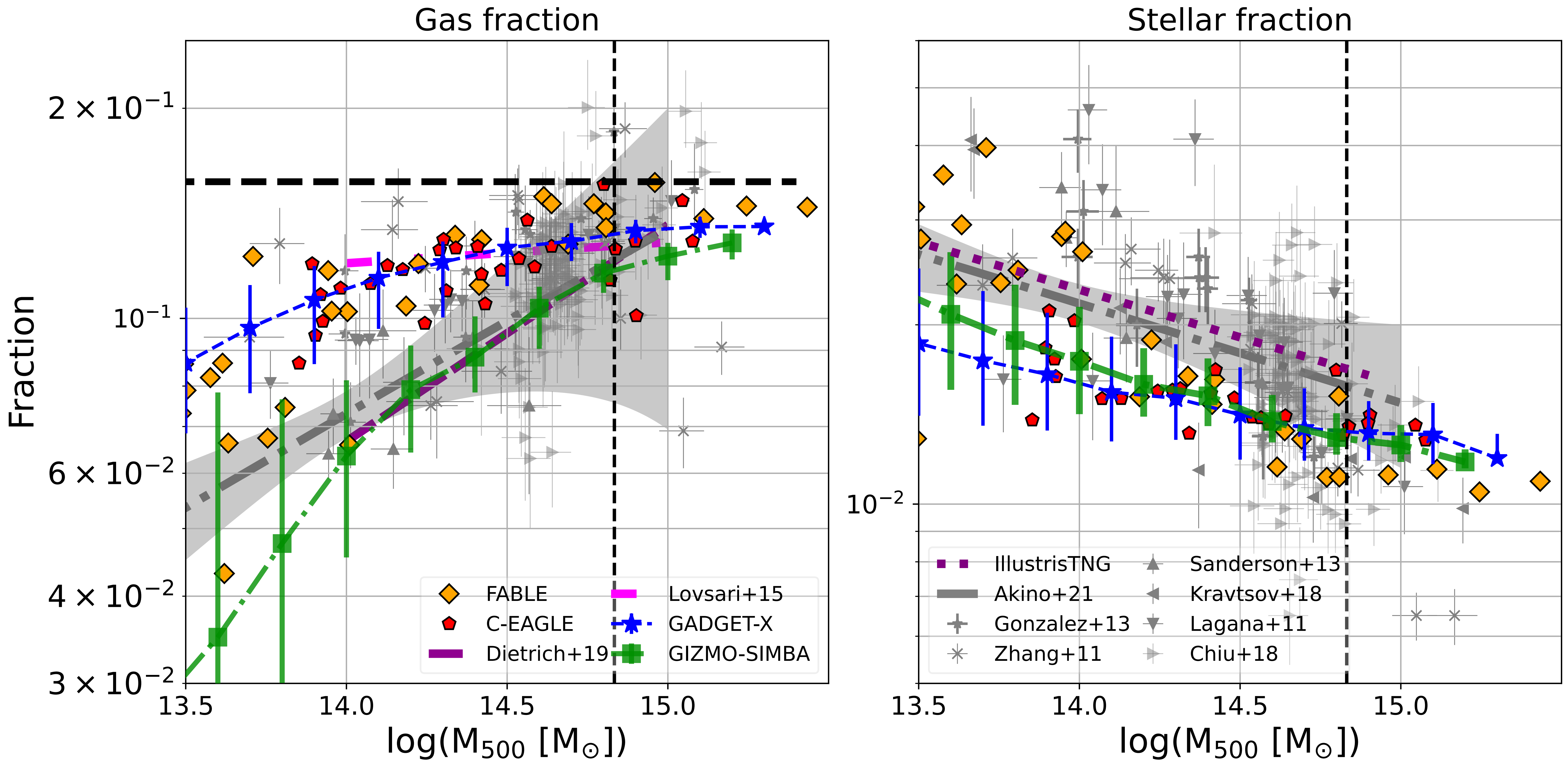


Figure: Mock multi-wavelength observations. From left to right, GADGET-MUSIC, GADGET-X, and GIZMO-SIMBA. Galaxies are shown by combining sdss u, g, r band images; X-ray photons is presented in colour map and SZ-y signal is highlight in contours. We also have **lensing maps** thanks to Carlo Giocoli.

Why SIMBA: *the "calibrated" stellar properties*

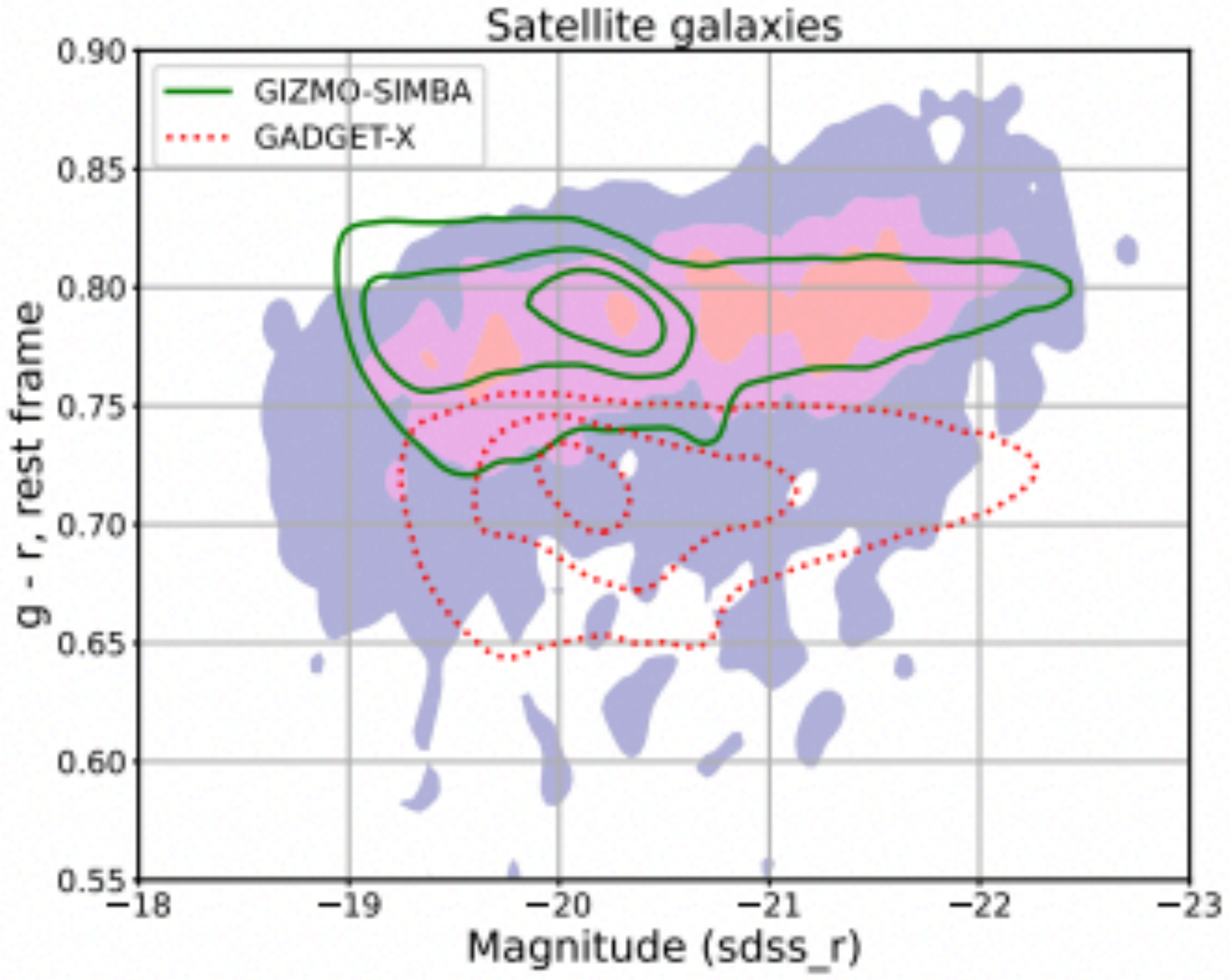
- The total stellar fractions

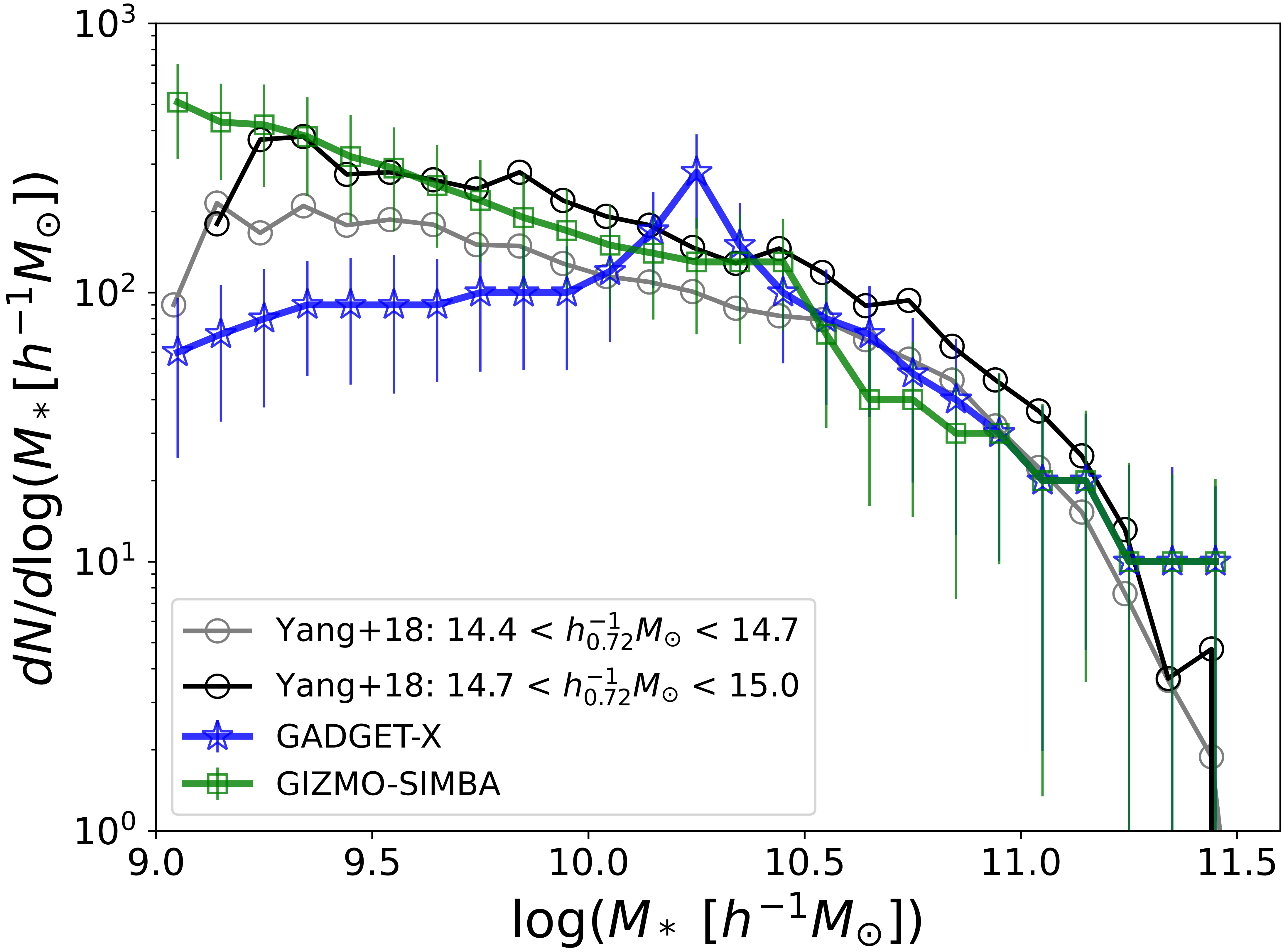


- satellite stellar mass function
- BCG-halo mass relation

Why SIMBA: *the "calibrated" stellar properties*

- The total stellar fractions
- satellite stellar mass function





- BCG-halo mass relation

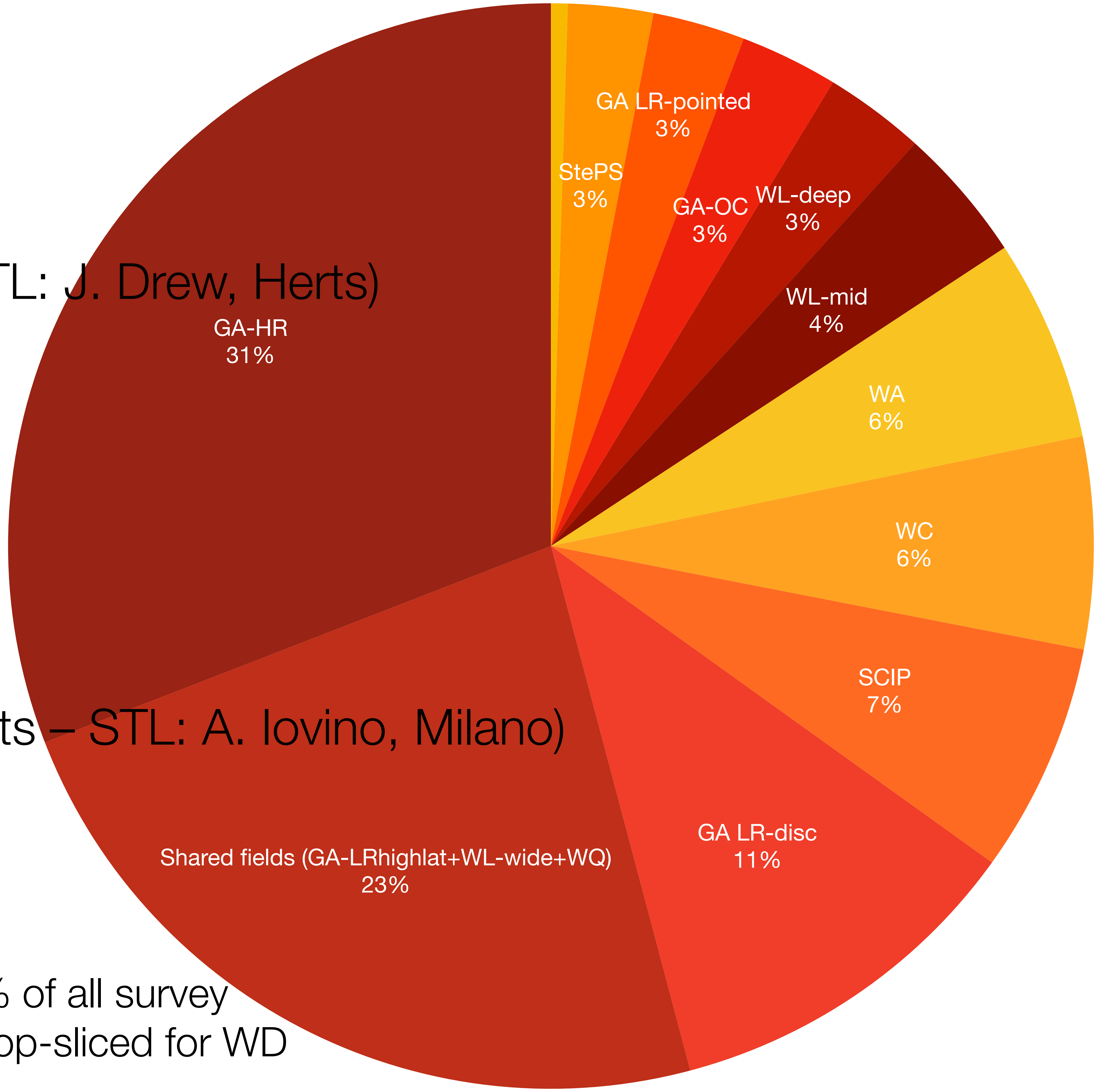
8 WEAVE SCIENCE SURVEYS

3 Galactic surveys:

- Galactic Archaeology (STL: V. Hill, OCA)
- SCIP (Stellar, Circumstellar, and Interstellar Physics – STL: J. Drew, Herts)
- White Dwarfs (STL: B. Gänsicke, Warwick)

5 Extragalactic surveys:

- WEAVE-Clusters (STL: J. A. Aguerri, IAC)
- WEAVE-Apertif (STL: J. Falcón Barroso, IAC)
- StePS (Stellar Population Survey at intermediate redshifts – STL: A. Iovino, Milano)
- WEAVE-LOFAR (STL: D. Smith, Herts)
- WEAVE-QSO (STL: M. Pieri, LAM)



Jin et al., MNRAS, accepted

PI: Gavin Dalton
Project Scientist: Scott Trager
Deputy Project Scientist: Shoko Jin

~1.5% of all survey time top-sliced for WD

WEAVE - CLUSTERS

Layer 1 Tracing the evolution of dwarf galaxies in clusters

>10^4 cluster dwarfs at R=5000 down to M_r<-16 with **MOS** mode + 10^3 cluster dwarfs with **mIFUs** for ***spatially resolved properties*** in 46 clusters at *z*~0.03

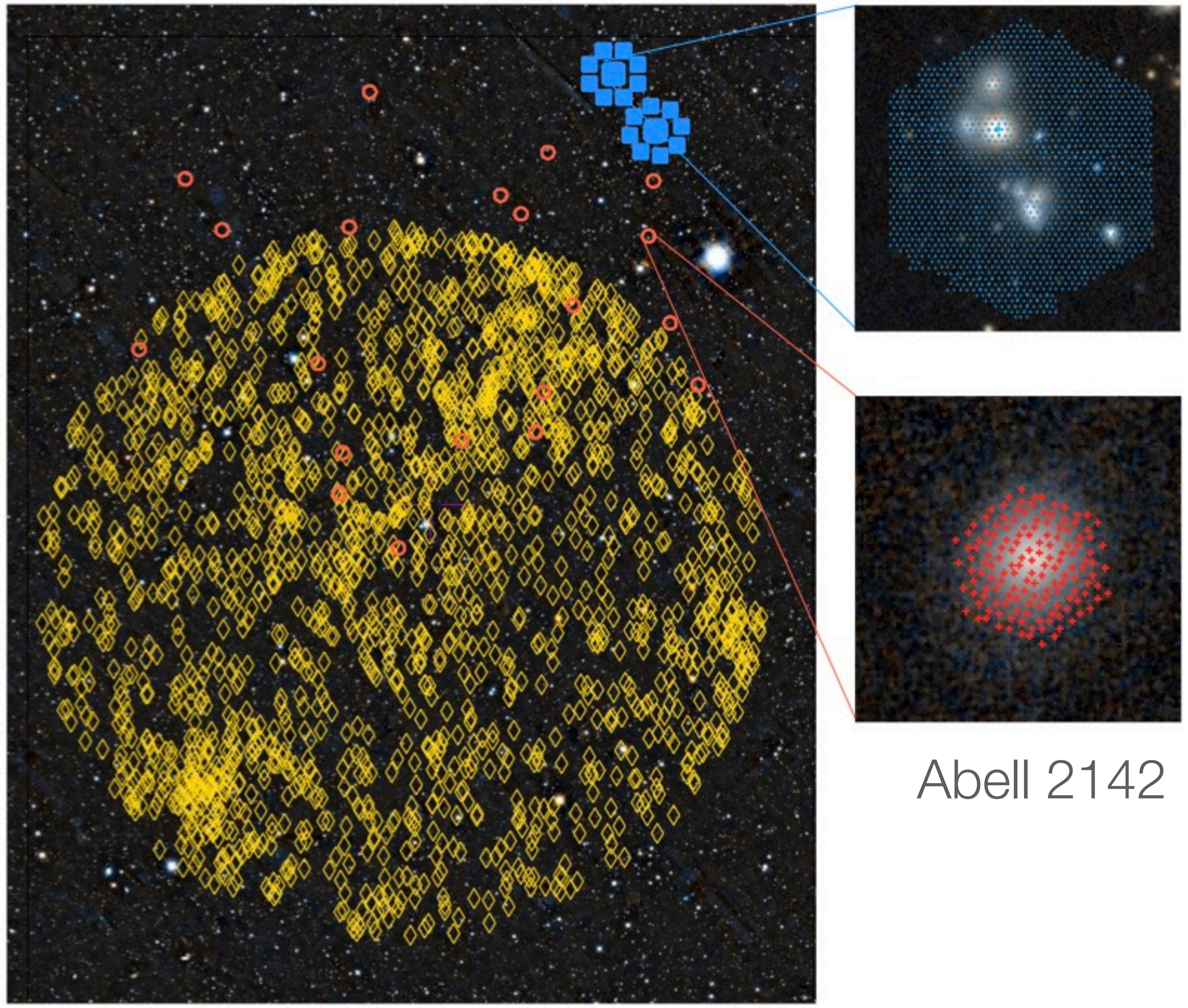
Layer 2 The infall regime

10^4 galaxies in ~20 clusters at *z*~0.05 ***out to 5R200*** at R=5000 to R<21 in **MOS** mode

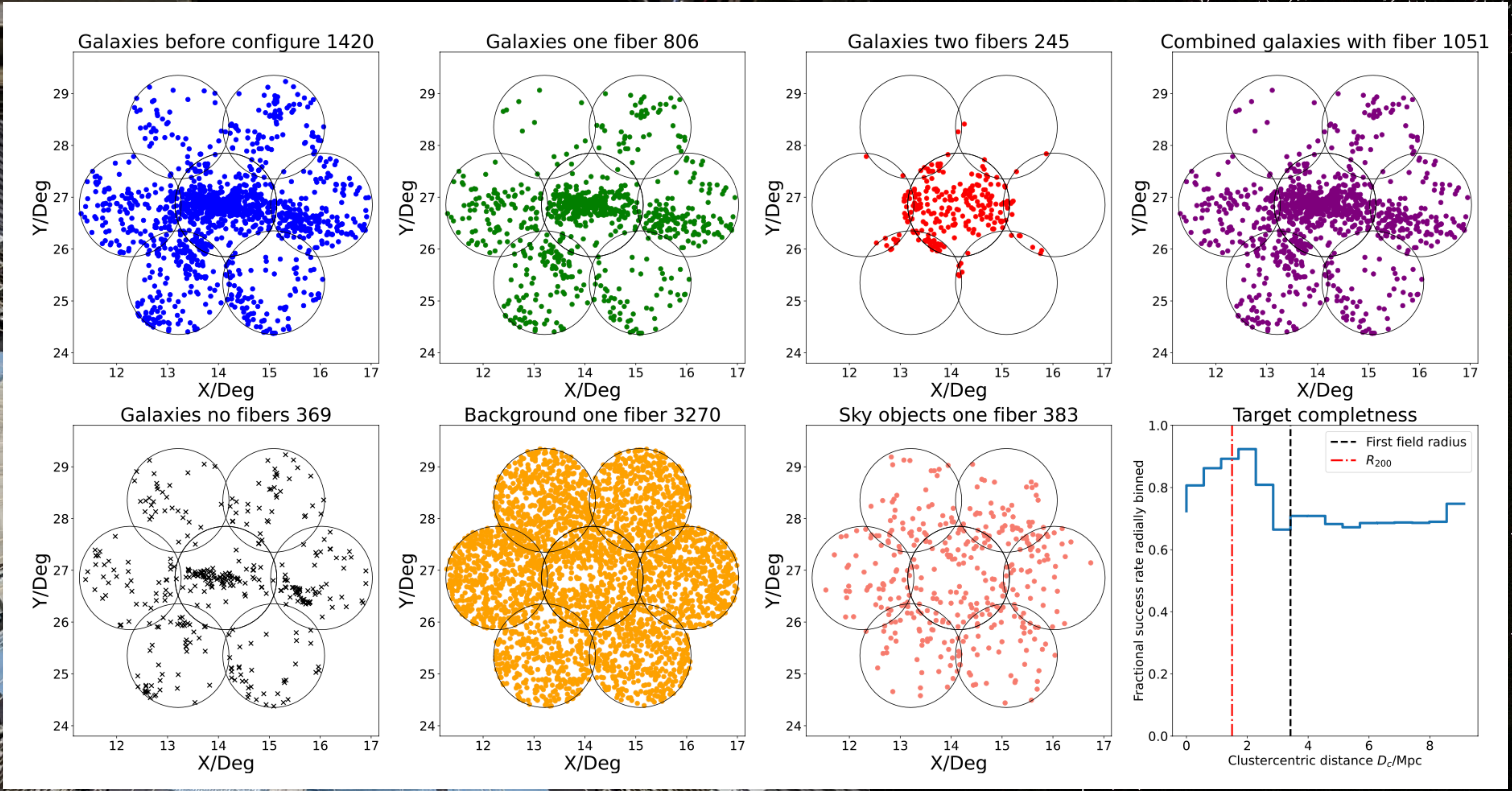
galaxy preselection driven by J-PLUS

Layer 3 The evolution of cluster galaxies and cluster masses at *z*<0.5

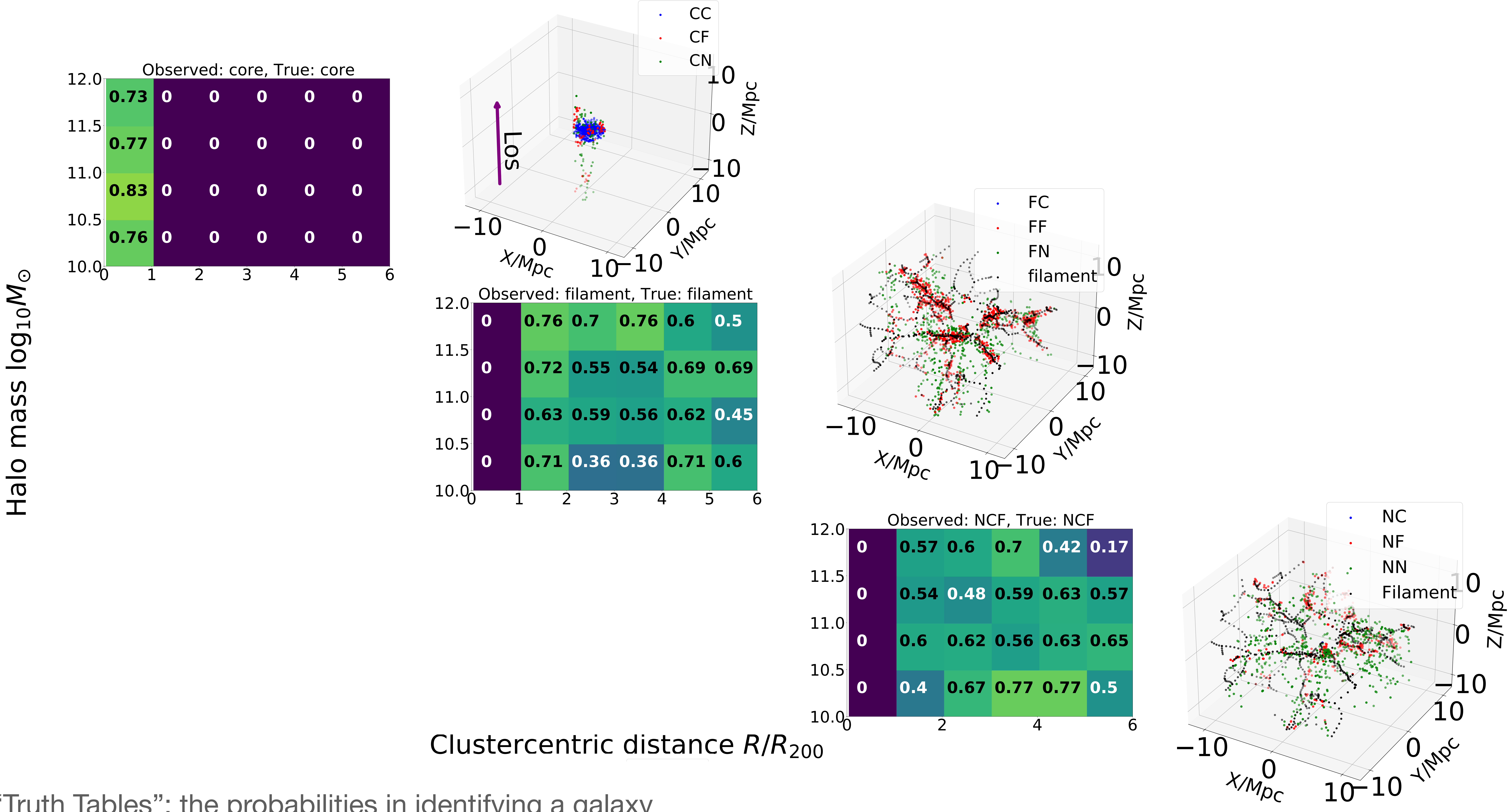
70 cluster cores/BCGs at *z*>0.3 with **LIFU** mode, 25 clusters at *z*<0.3 in **MOS** mode to determine stellar populations and cluster masses to compare with Sunyaev–Zeldovich decrements



Abell 2142



Cornwell+22, 2022MNRAS.517.1678C



"Truth Tables": the probabilities in identifying a galaxy
in different environments (cluster core, cosmic filaments or NCF (not core or filaments))