Distant groups and clusters with BlueMUSE: targeting their giant Lya nebulae to study cold gas flows

AIM CEA Paris-Saclay

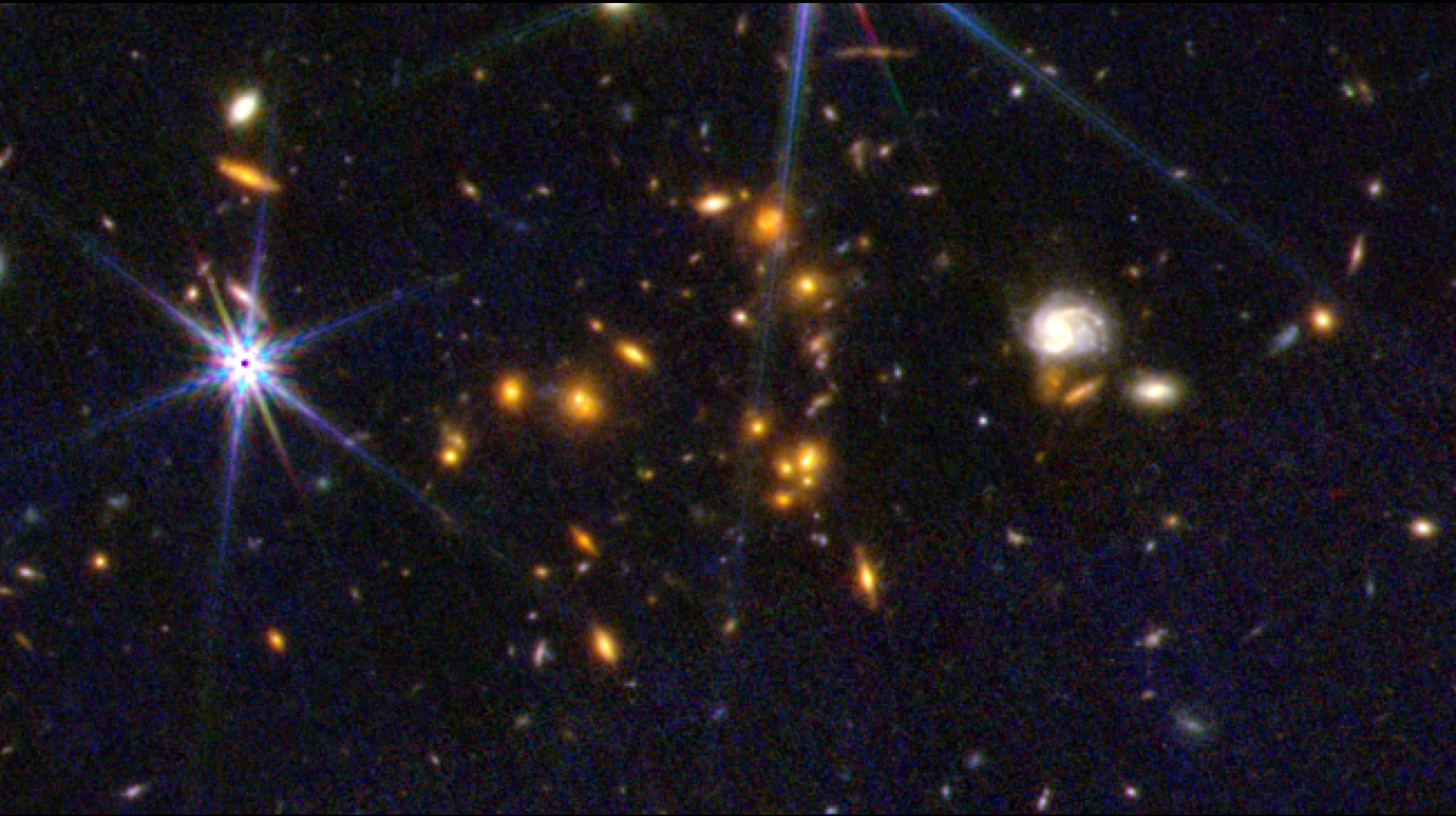
Daddi E., Elbaz D., Bournaud F., Correa C., Pratt G., Melin JB., Magnelli B., Guo S.

KCWI work in collaboration M. Rich (UCLA) et al.

Recent MUSE work by Sicen Guo (PhD)

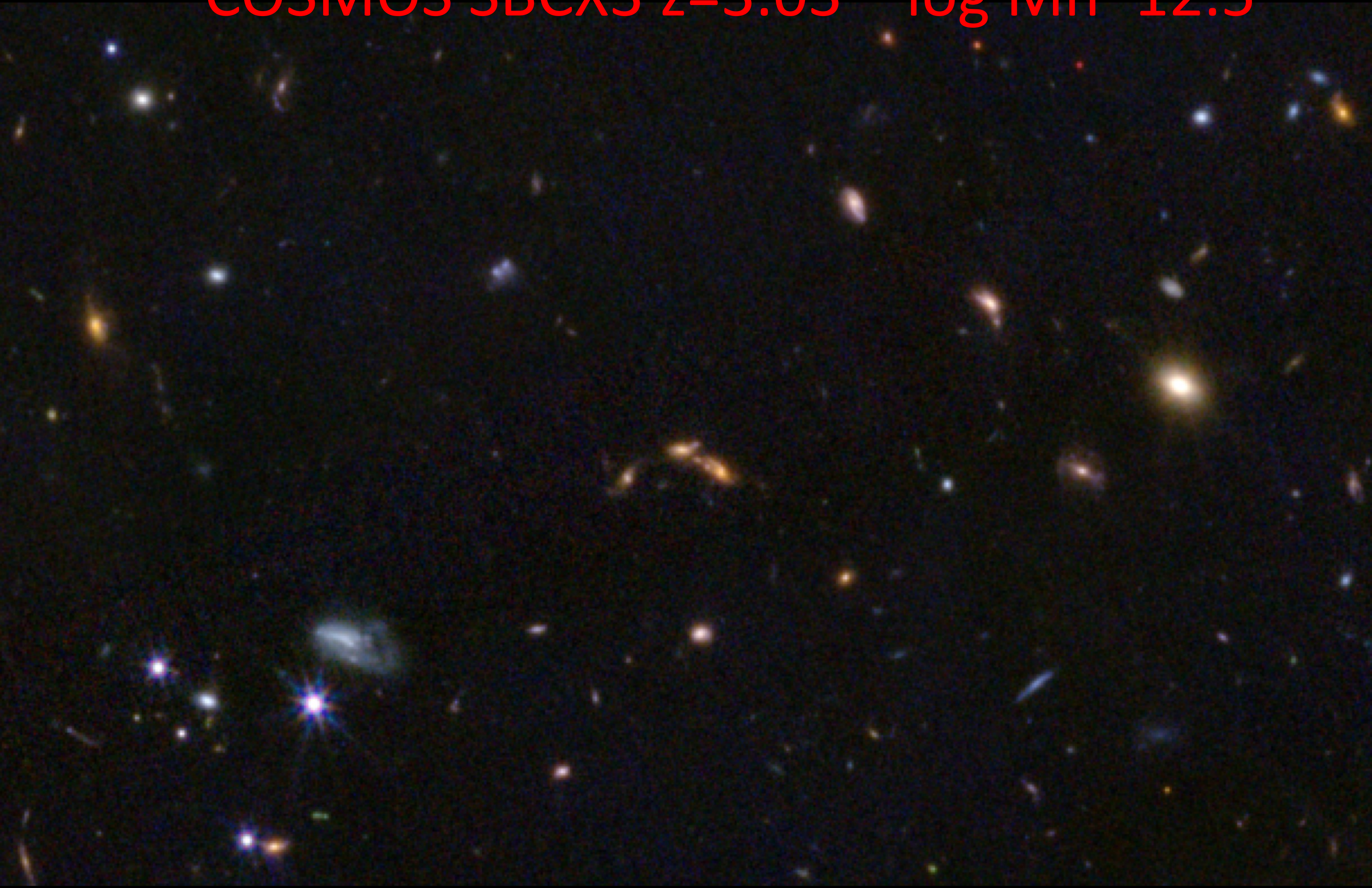
BlueMUSE Science meeting online; April 25th 2024

COSMOS Cl1001 z=2.51 log Mh~13.8



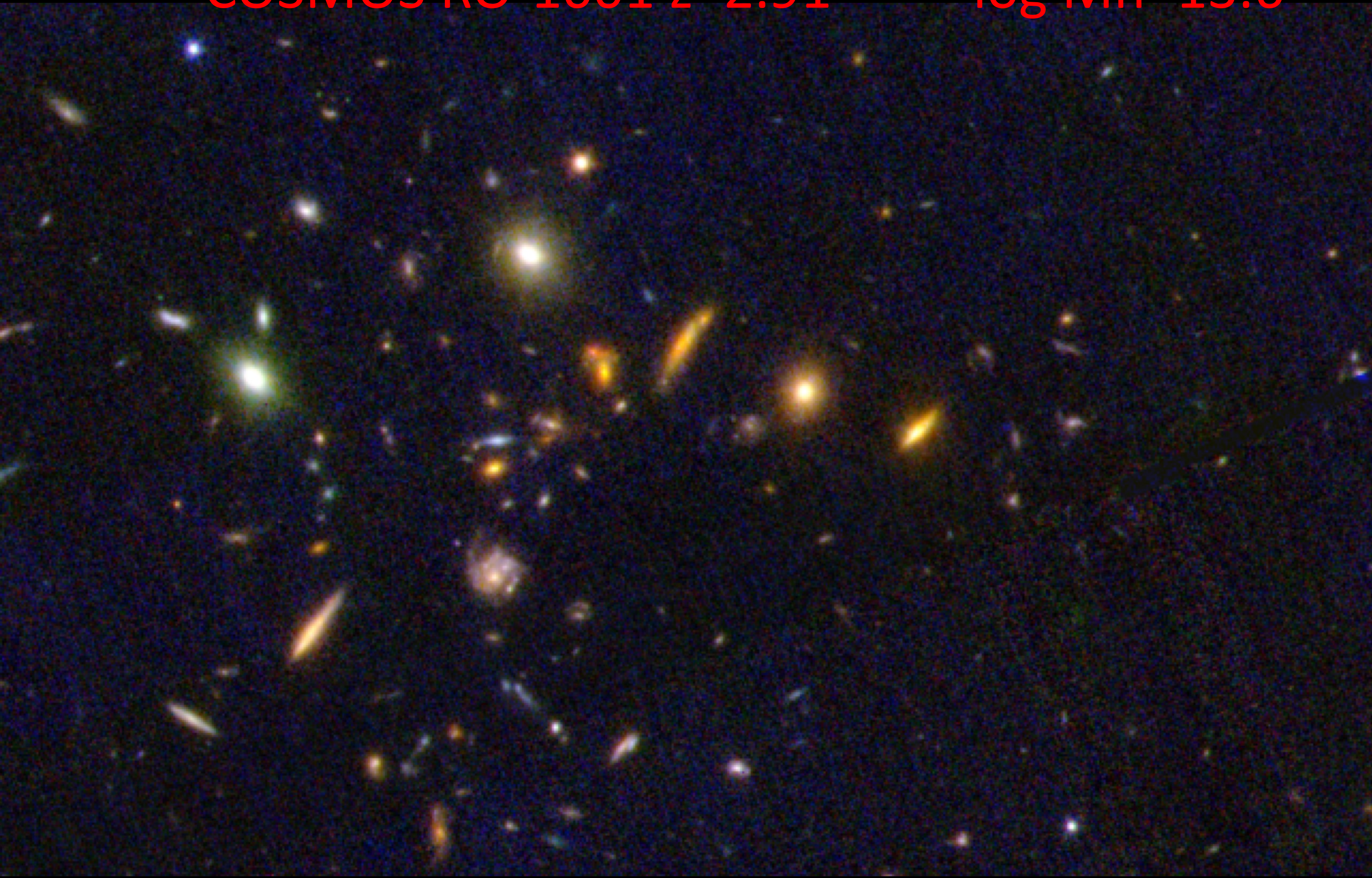
Wang et al. 2016; 2018; 2024; Daddi et al. 2017

COSMOS SBCX3 z=3.03   log Mh~12.5



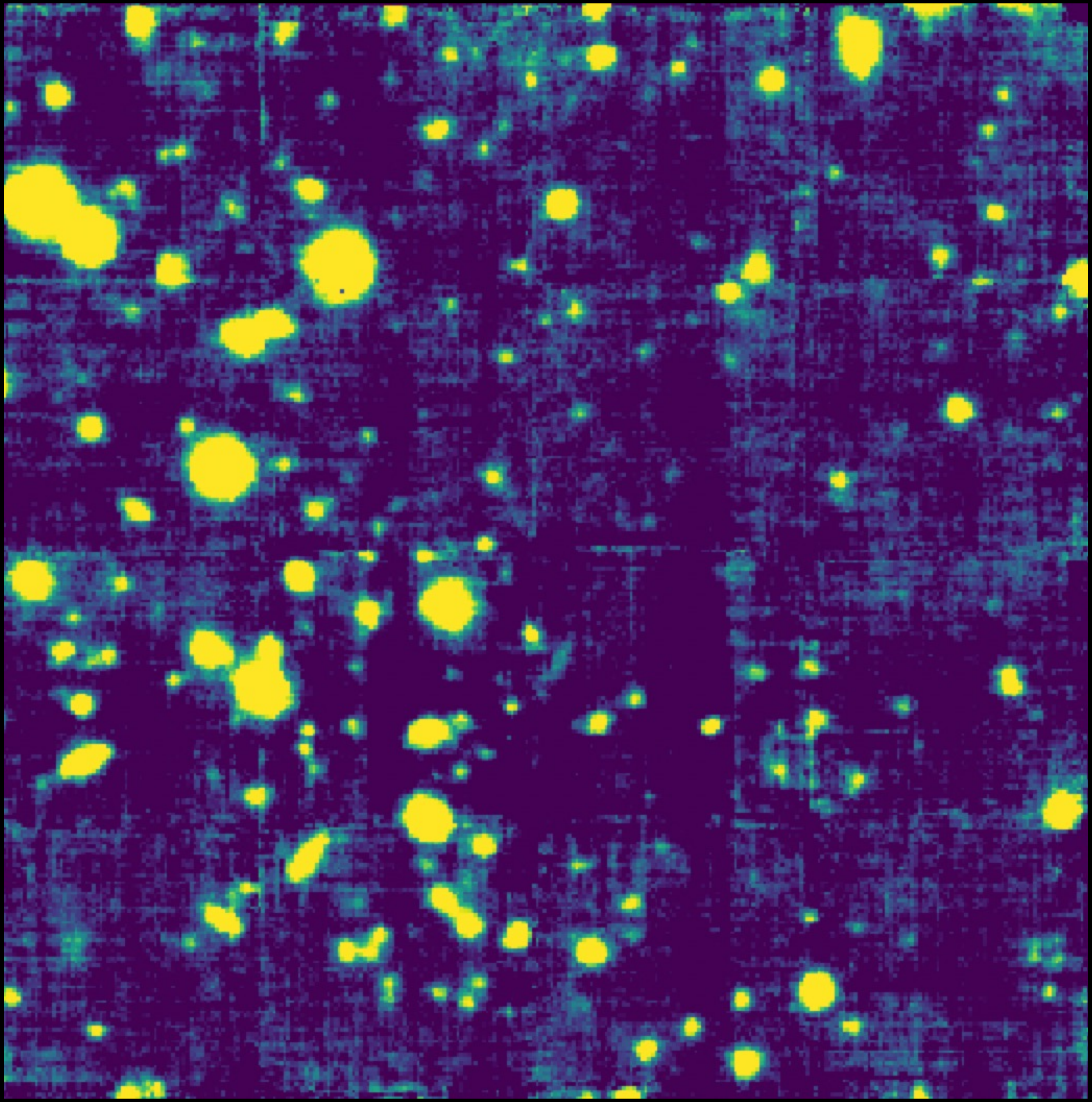
Sillassen et al. 2024 in prep

COSMOS RO-1001 z=2.91 log Mh~13.6

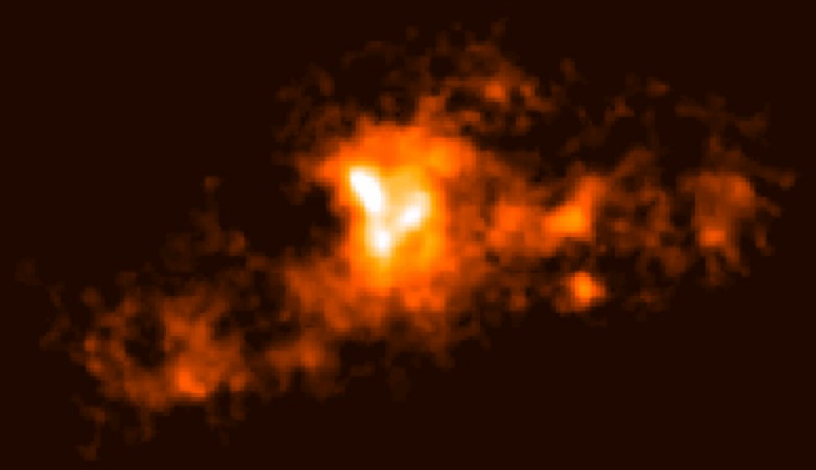


Daddi et al 2021; 2022; Kalita et al 2021; 2022

The group GALAXIES are NOT our primary BlueMUSE targets

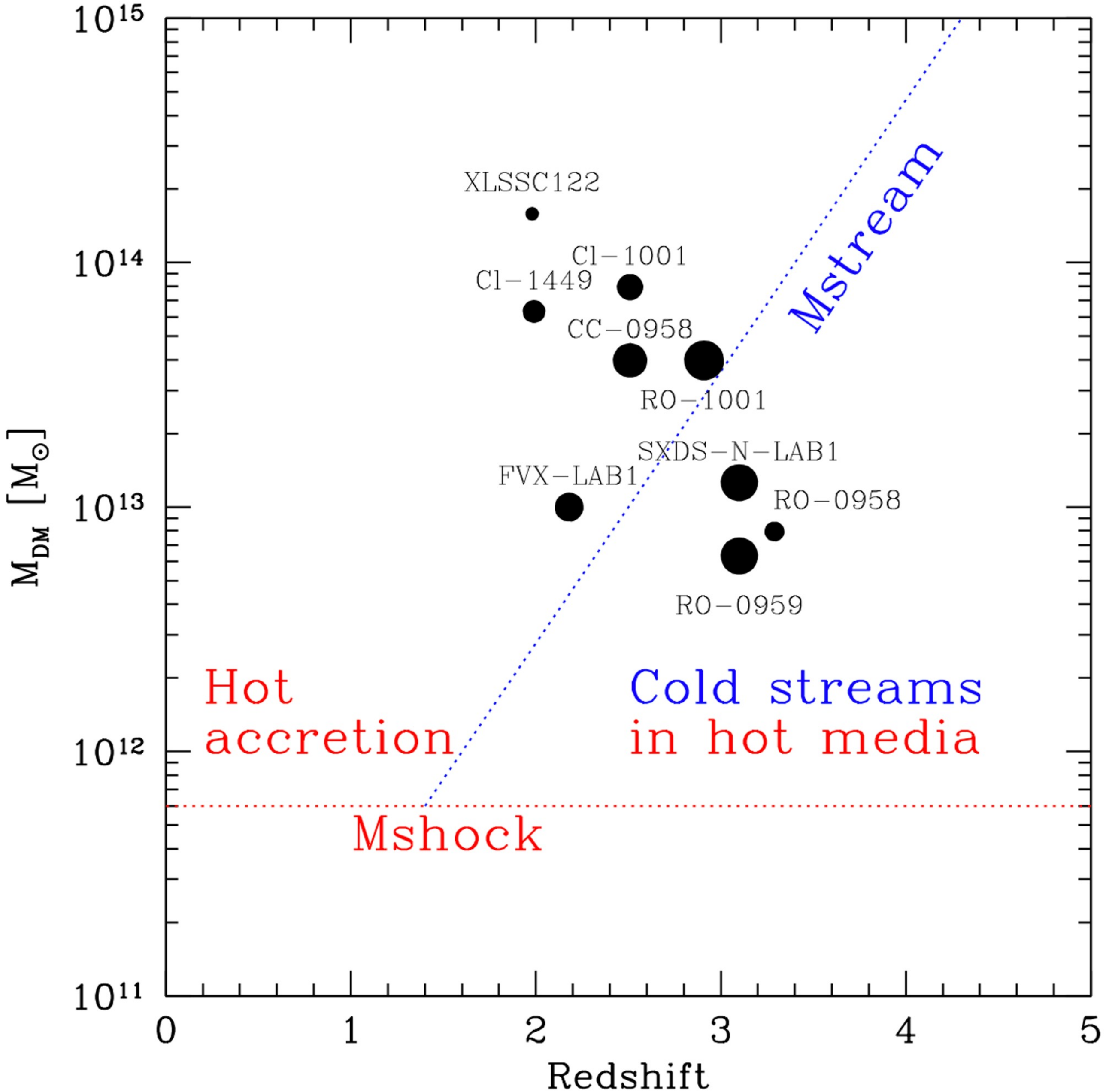


BlueMUSE will look at the cold gas around groups/clusters
Not the cluster galaxies…

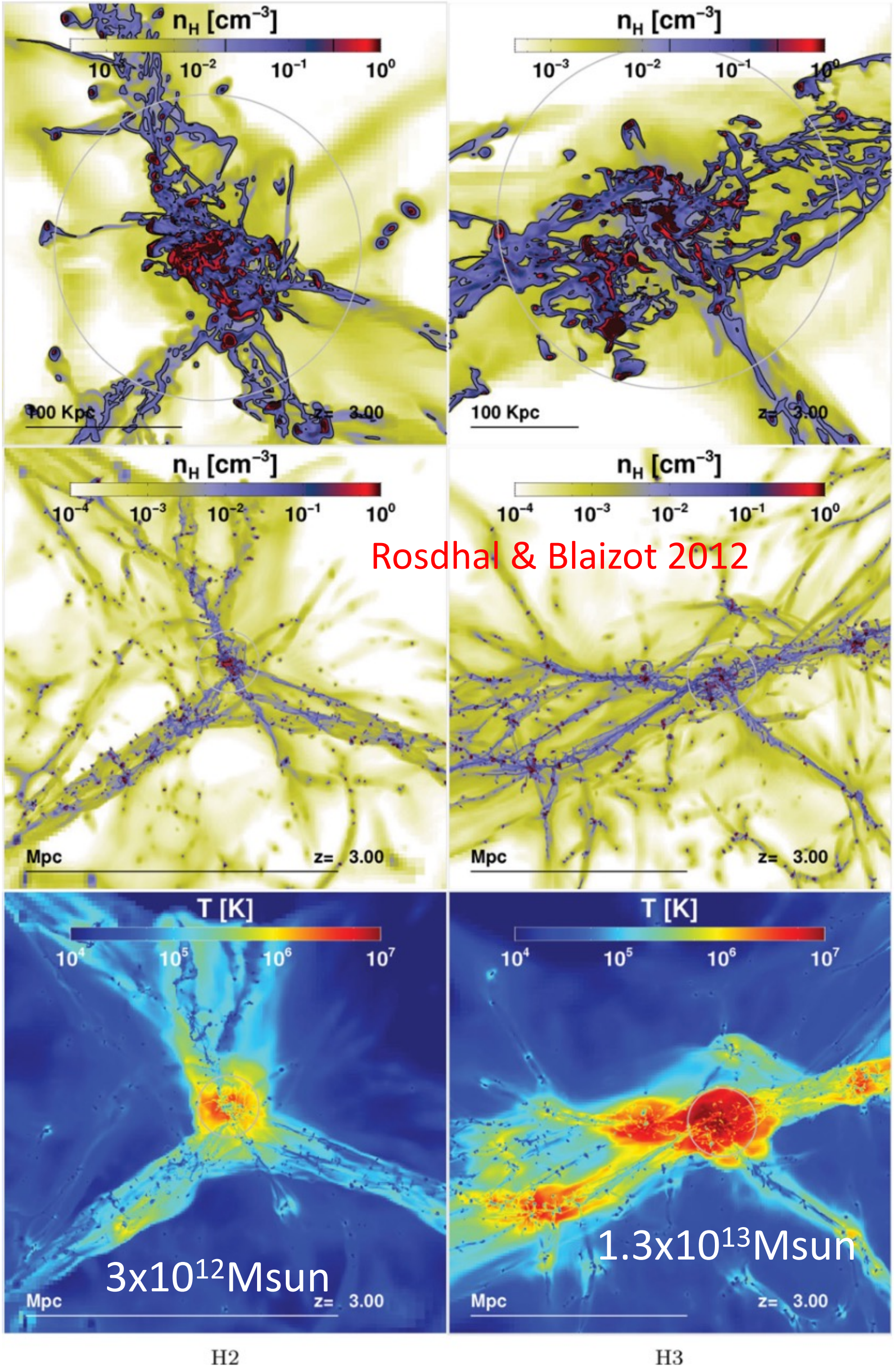


Notice the nicely matched field of view (MUSE here)

Cold accretion depends on Mh and redshift (theory)



Dekel et al 2009



Cold accretion streams

We have a lot from theory.
But do they really exist ?

Lya can come from photoionization (from AGN and SF), scattering

Can we detect collisionally excited Lya (which could be from streams/outflows) ?

Can we identify any galaxy observable that is aware of the theory (i.e. Mstream) ?

Astro2020 priority: Cosmic web → gas feeding

Worlds and Suns in Context

Priority Area: Pathways to Habitable Worlds

Understanding the connections between stars and the worlds that orbit them, from nascent disks of dust and gas through formation and evolution, is an important scientific goal for the next decade. The effort to identify habitable Earth-like worlds in other planetary systems and search for the biochemical signatures of life will play a critical role in determining whether life exists elsewhere in the universe.

KEY RECOMMENDATIONS:

New Messengers and New Physics

Priority Area: New Windows on the Dynamic Universe

Over the next decade, a range of complementary observations—from radio to gamma rays, gravitational waves, neutrinos, and high-energy particles—will enable investigations into the most energetic processes in the universe and address larger questions about the nature of dark matter, dark energy, and cosmological inflation. These growing capabilities will enable closer study of neutron stars, white dwarfs, black hole collisions, stellar explosions, and the birth of our universe.

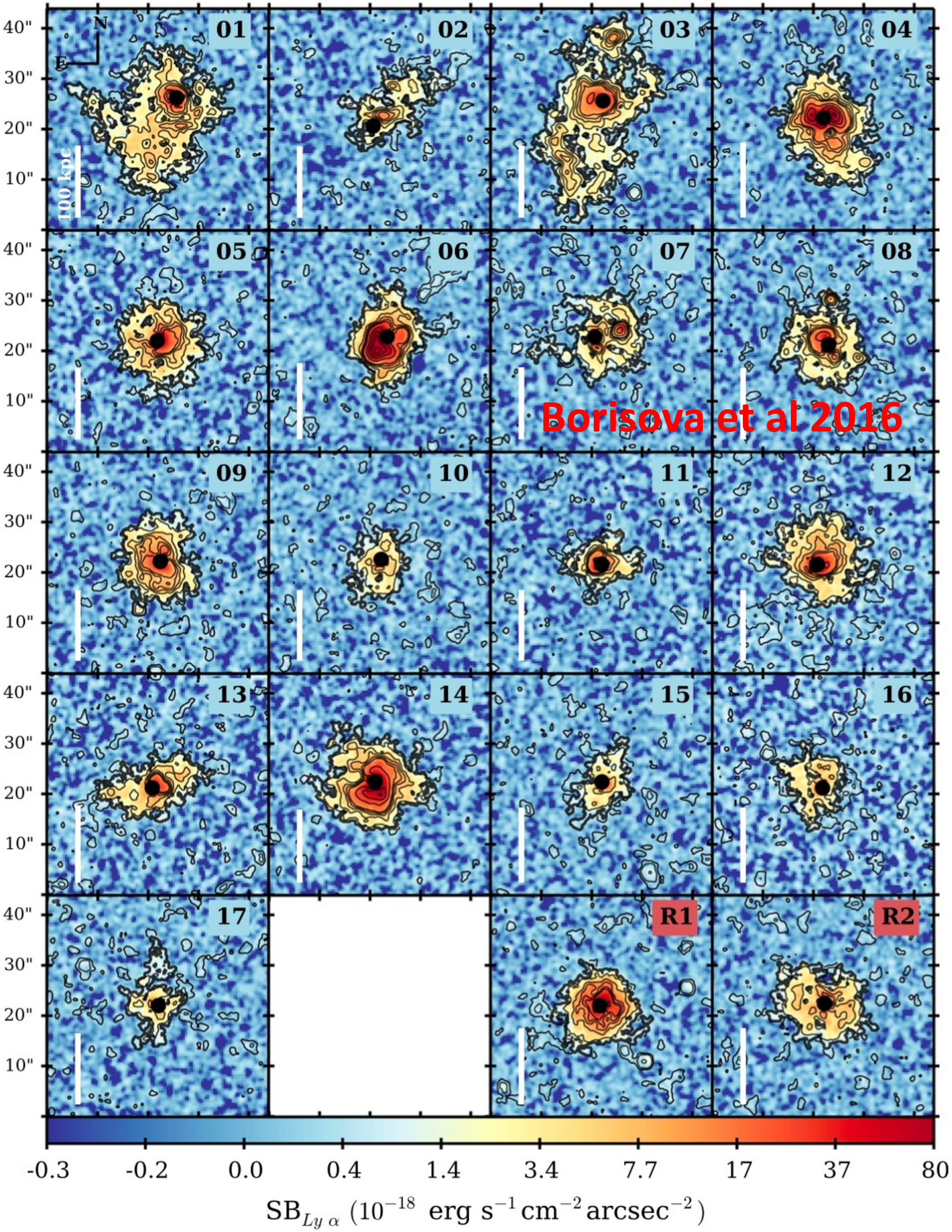
KEY RECOMMENDATIONS:

Cosmic Ecosystems

Priority Area: Unveiling the Drivers of Galaxy Growth

Research in the coming decade will revolutionize our understanding of the origins and evolution of galaxies, from the cosmic webs of gas that feed them to the formation of stars. New observational capabilities across the electromagnetic spectrum along with computation and theory will help resolve the rich workings of galaxies on all scales.

KEY RECOMMENDATIONS:



We see plenty of Lya halos at high redshift, e.g. around QSOs

Their typical hosting masses are low ~10^{12} Msun (close to the Mshock boundary)

They are certainly powered by QSO photoionization

Cold gas might come from giant outflows from the QSO

Difficult to use QSO nebulae to study accretion of cold gas

→ Observe Lya from massive halos, lacking bright QSOs, to test accretion theory across the Mstream boundary

Why studying this in massive halos (groups/clusters) at high-z ?
Shouldn't we just do 'the field', normal galaxies ?

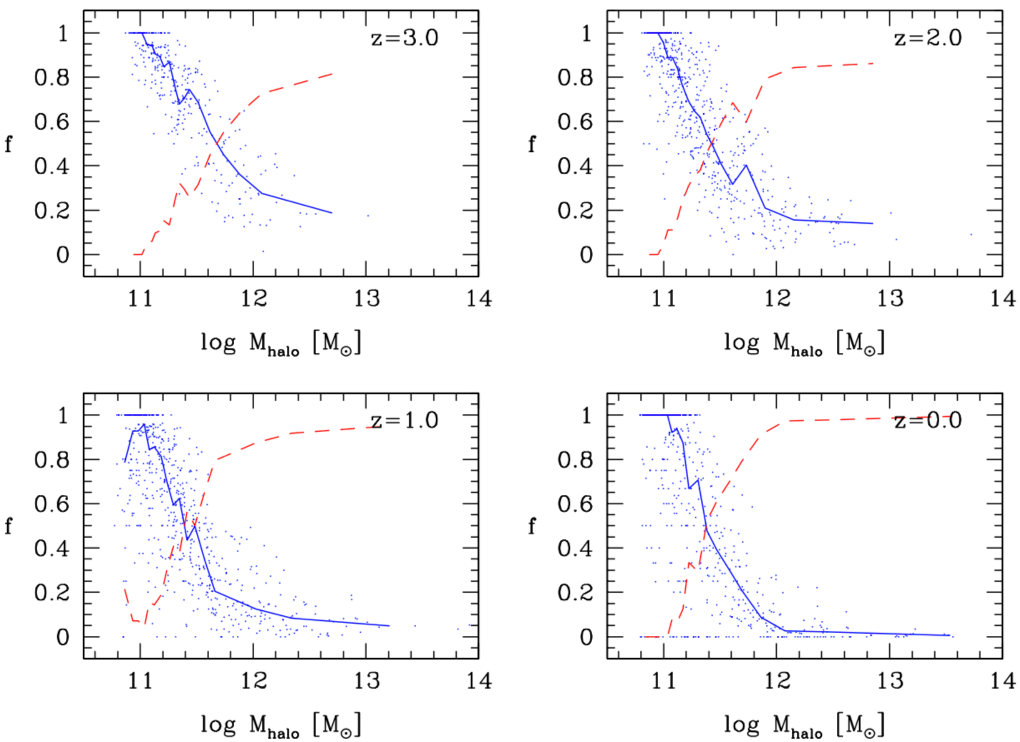
1) We can estimate halo masses
2) Accretion rate rising with M_{DM} and z (and can be estimated)

$$BAR \simeq 137\left(\frac{M_{DM}}{10^{12}M_\odot}\right)^{1.15}\left(\frac{(1+z)}{(1+3)}\right)^{2.25} M_\odot yr^{-1}$$

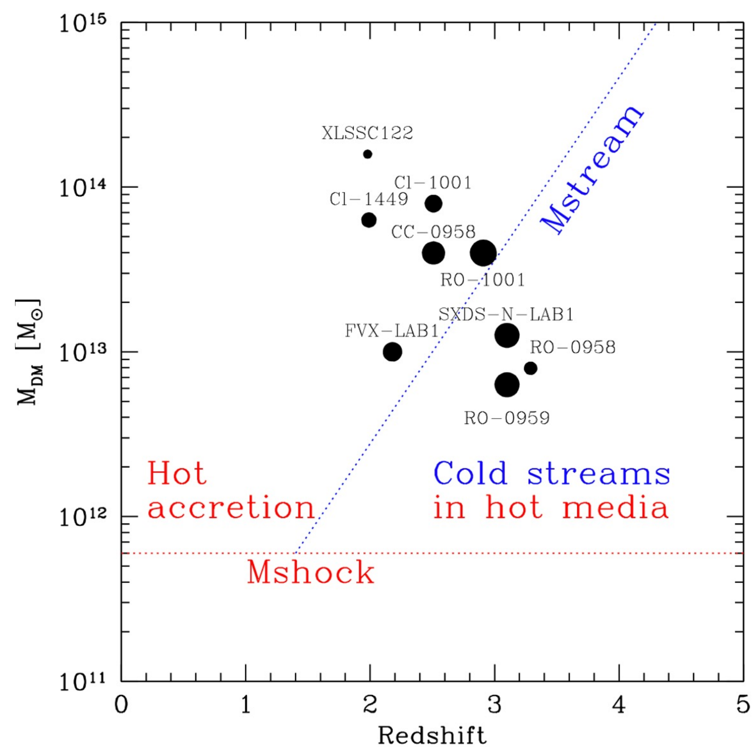
Not all BAR will remain cold as crossing the Mstream boundary

Goerdt et al 2010

Models suggest: Lya ~ BAR_{cold}



Keres et al 2005

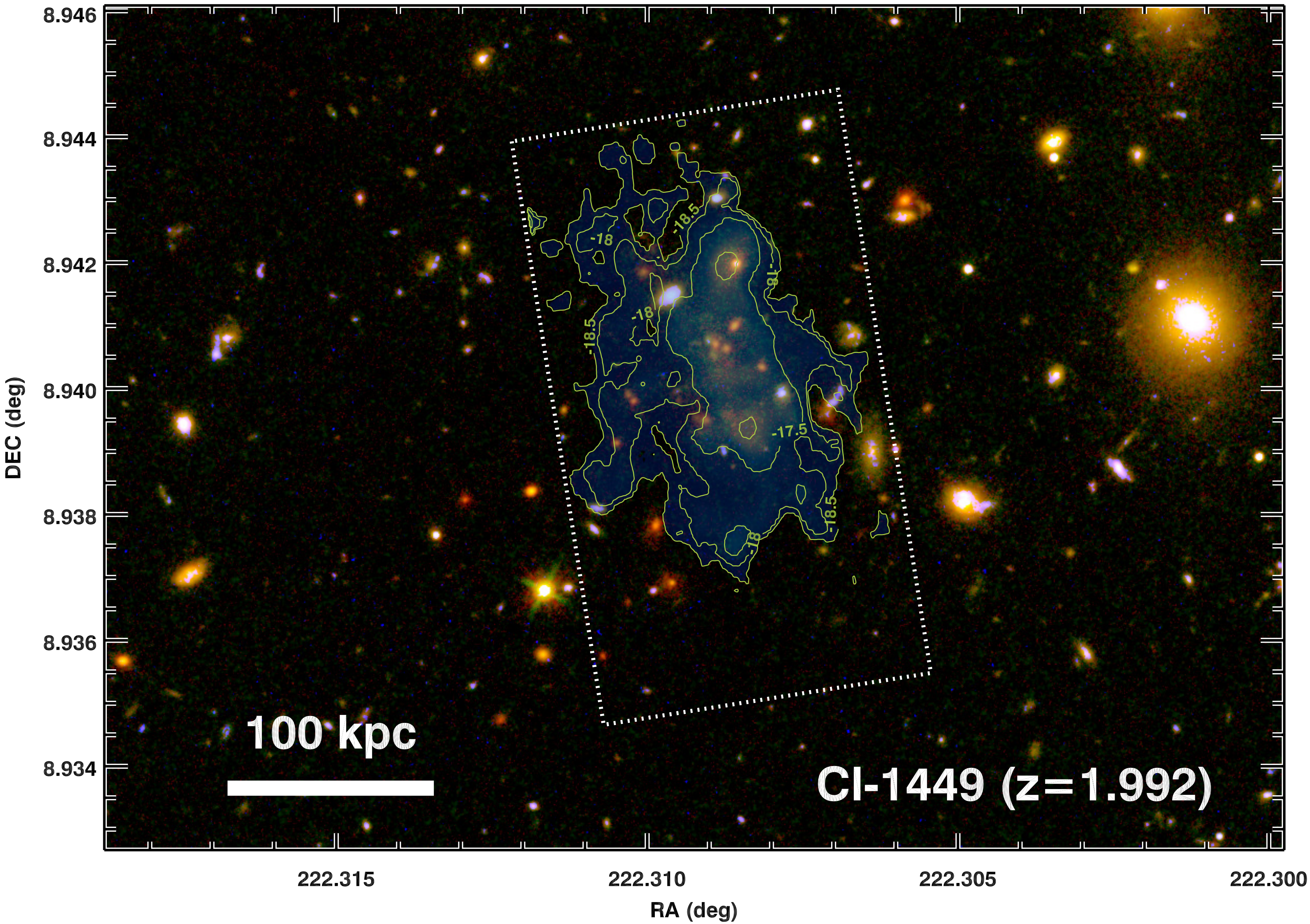


What have we learned so far

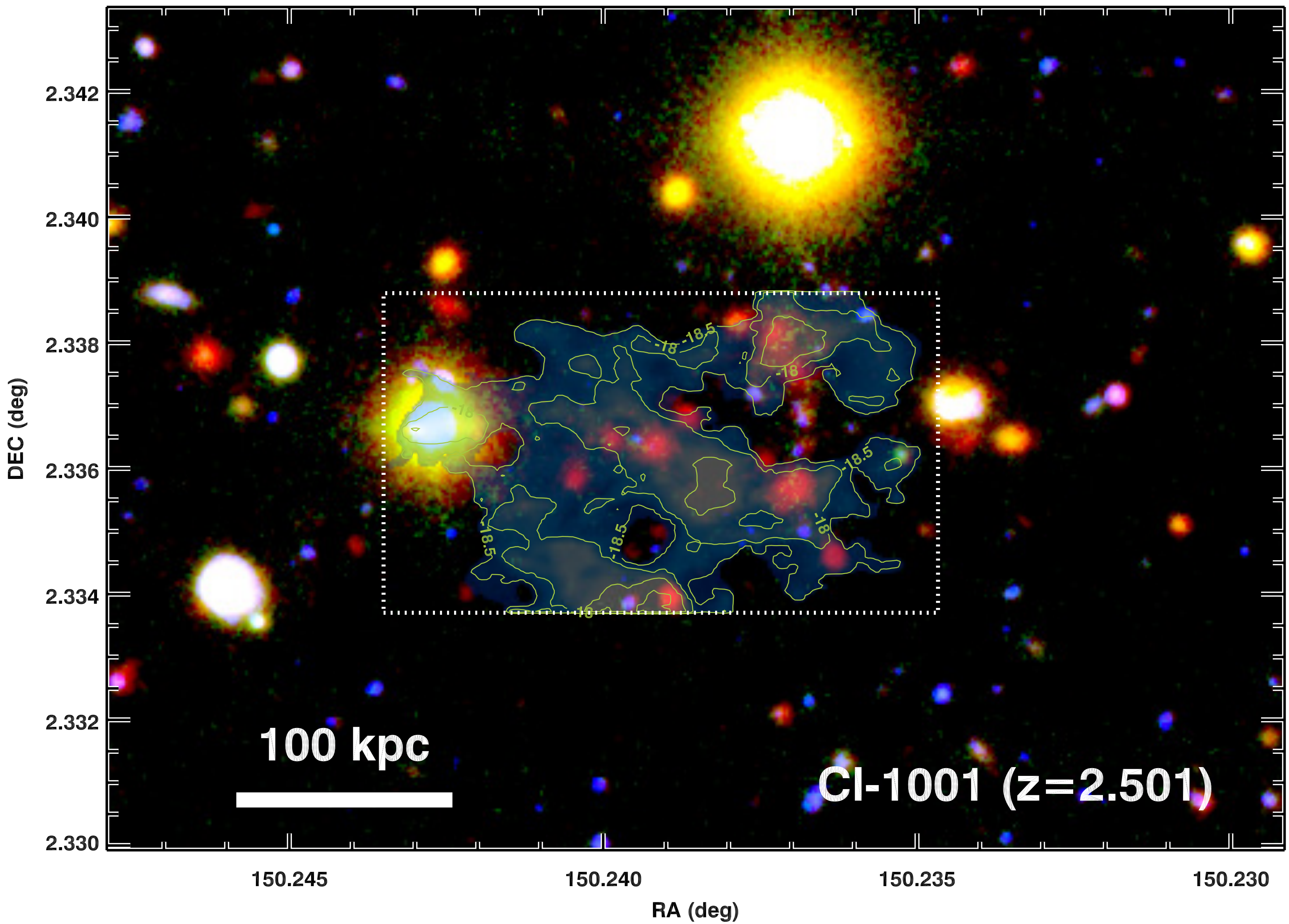
1) **Groups and clusters z>2, logMh>~13 are virtually all hosting giant Lya halos**

Genuine single halo structures, not ‘proto-clusters’

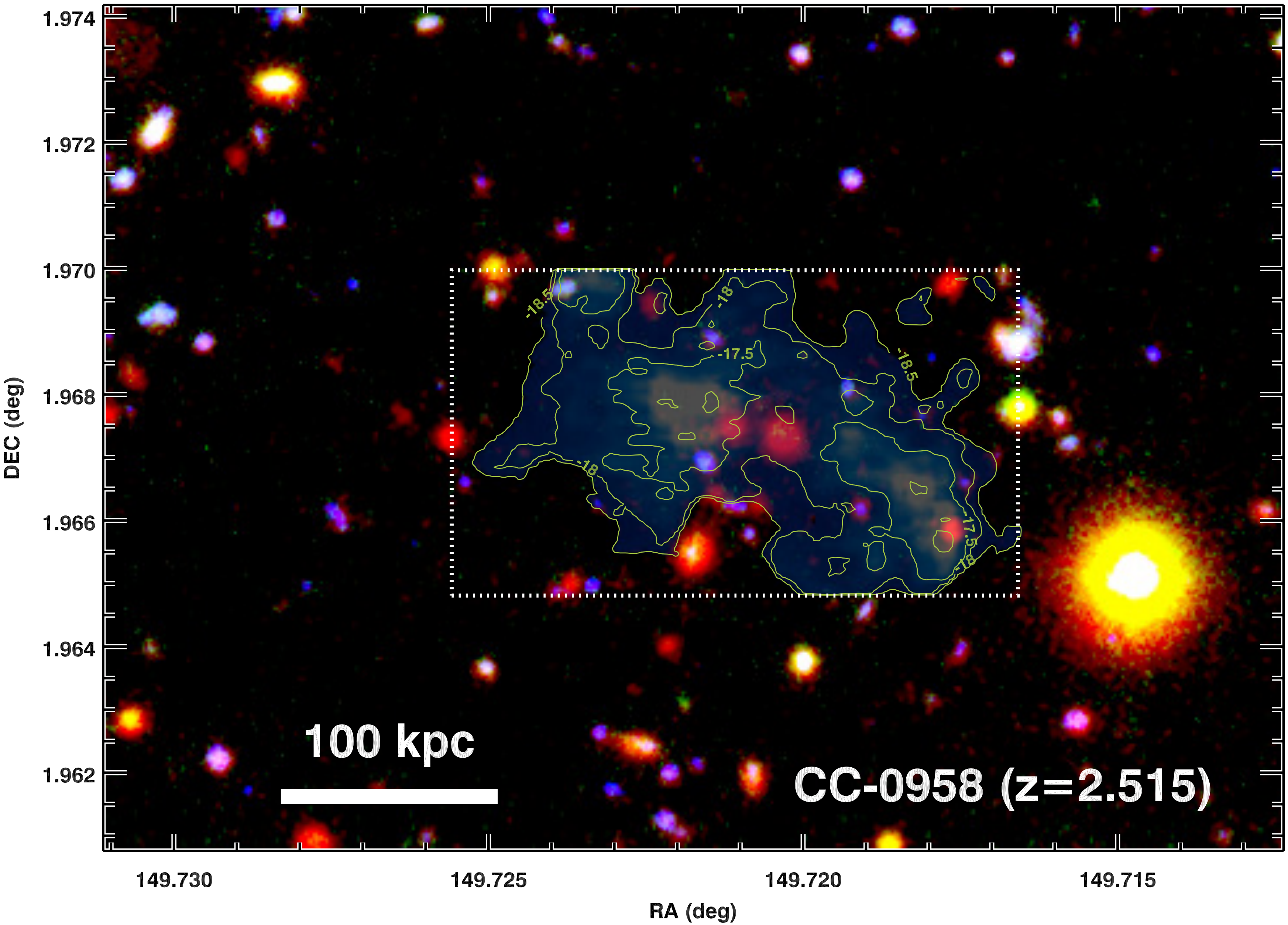
First Lya halo in cluster detection (Valentino+2016)



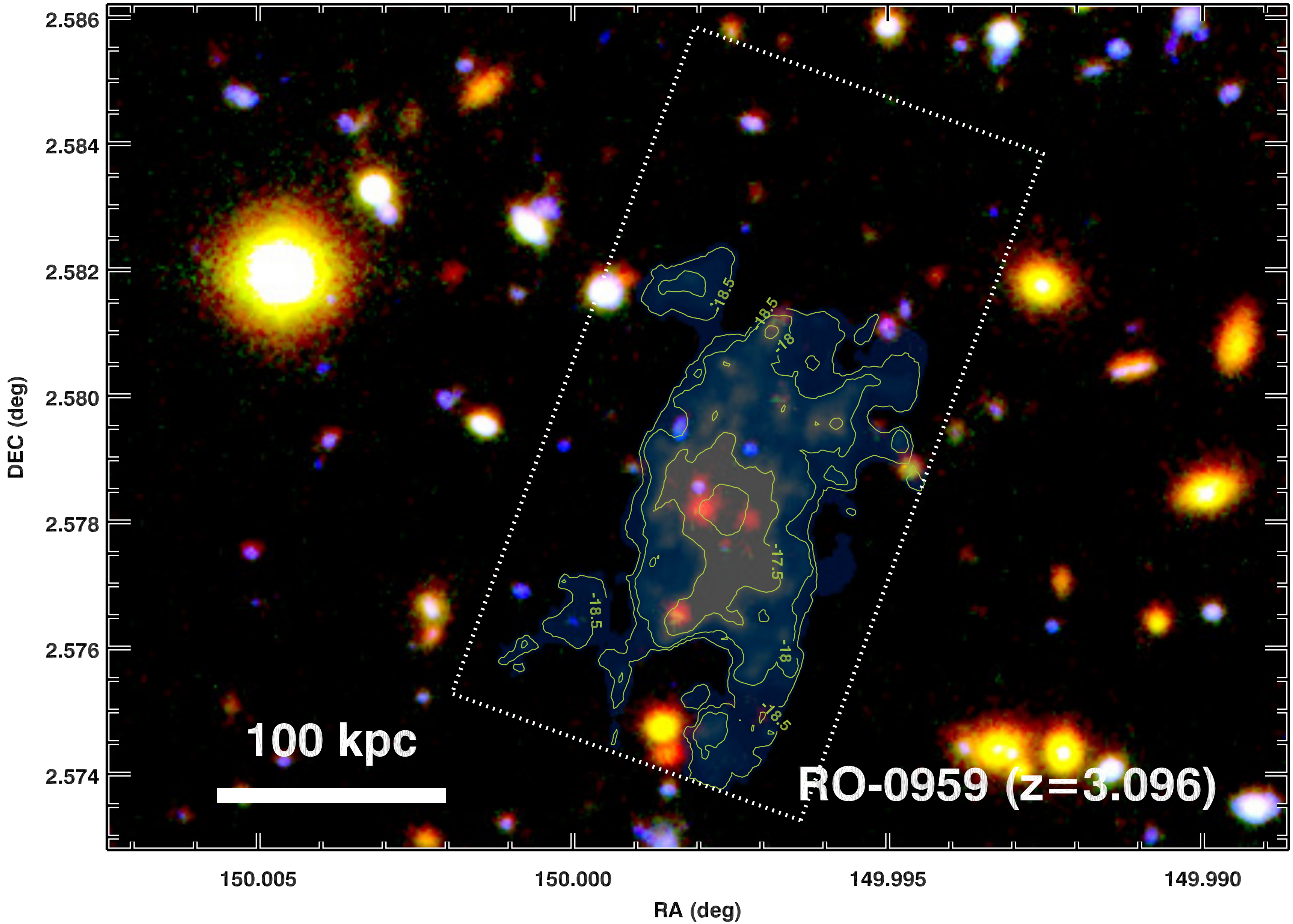
Cl1449 (Gobat et al., Strazzullo et al., Valentino et al., Coogan et al., Kalita et al., etc)



Cluster from Wang et al. 2016

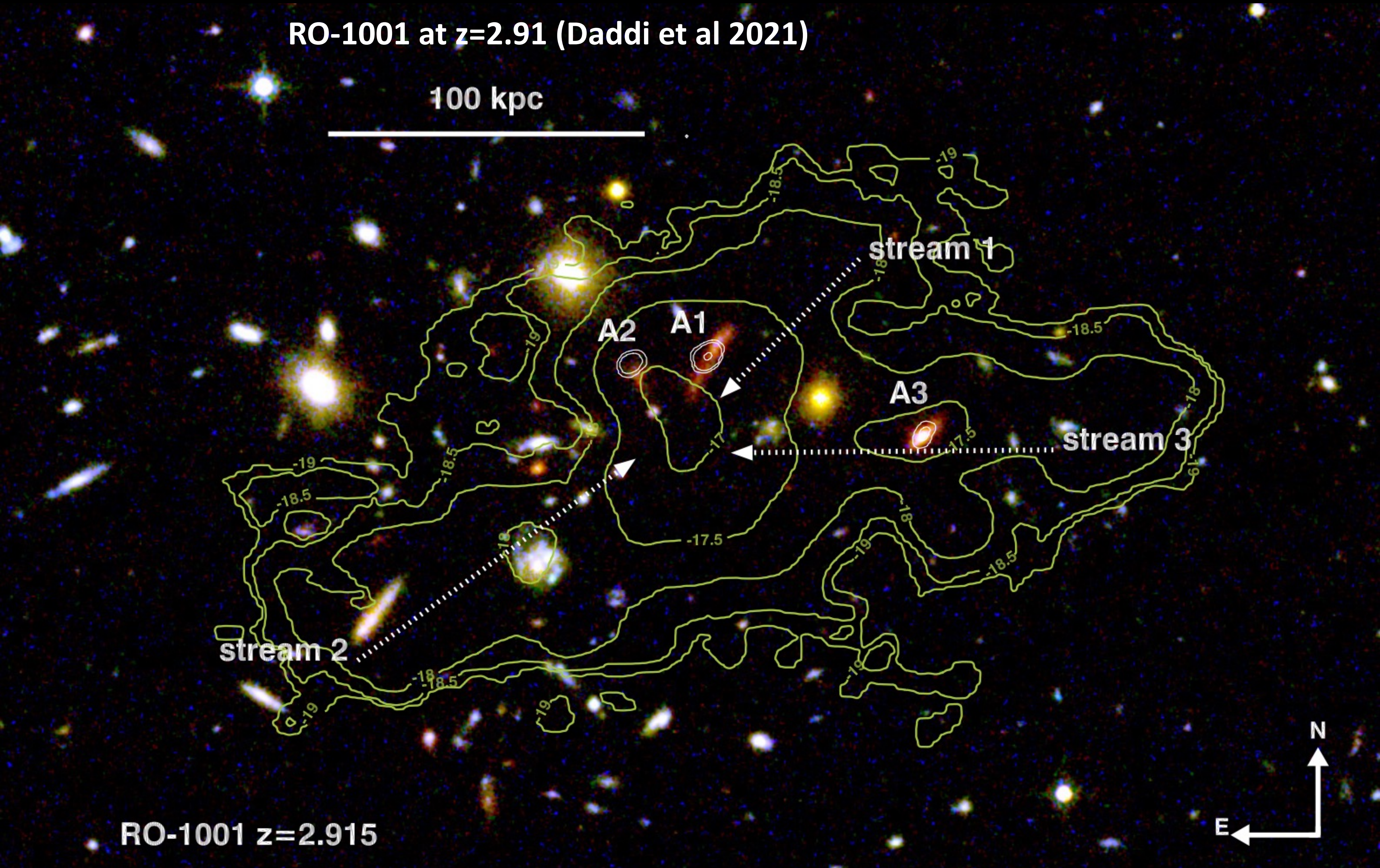


Cluster from Strazzullo et al. 2015



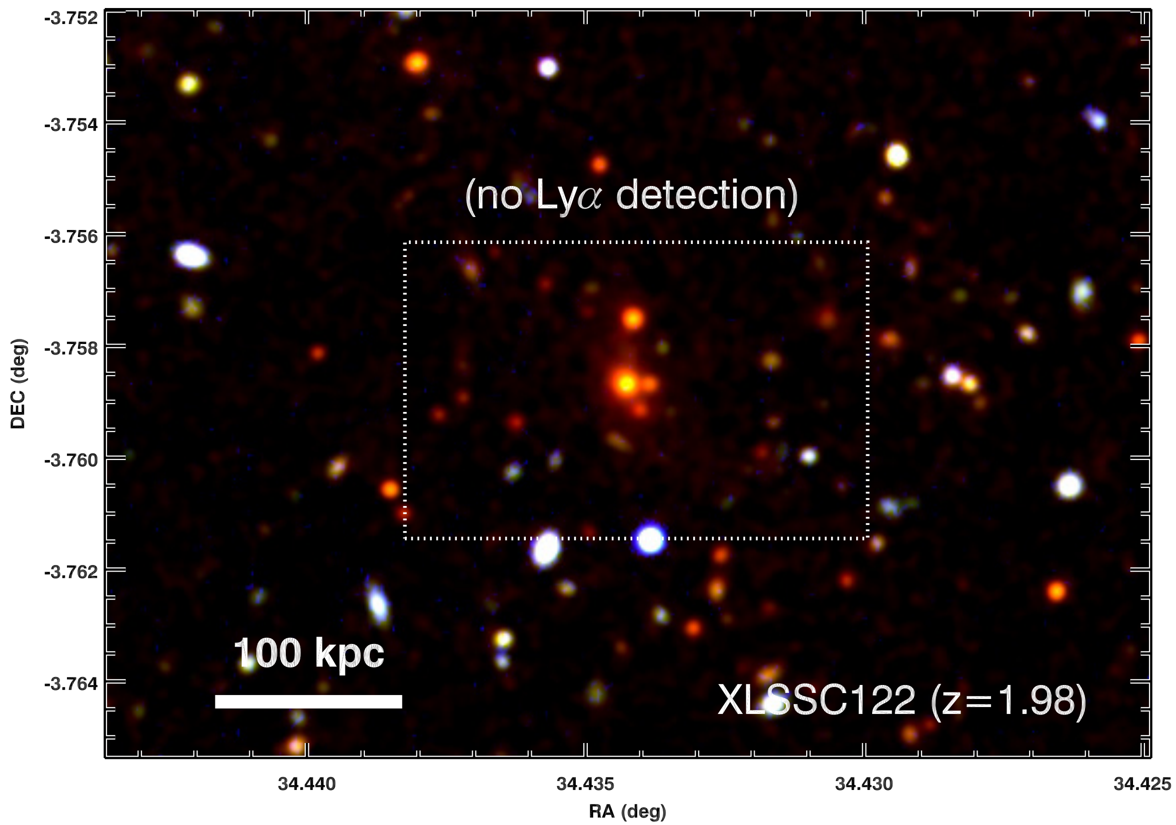
A radio selected group (following the Daddi et al. 2017 method)

RO-1001 at z=2.91 (Daddi et al 2021)

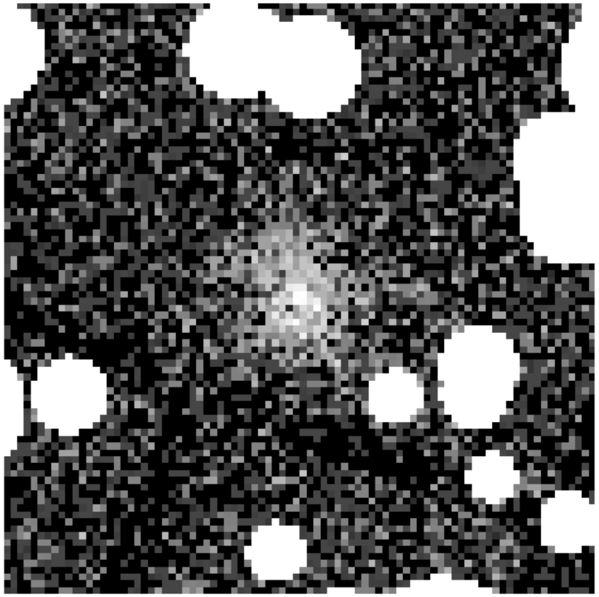


M~4x10^{13}Msun

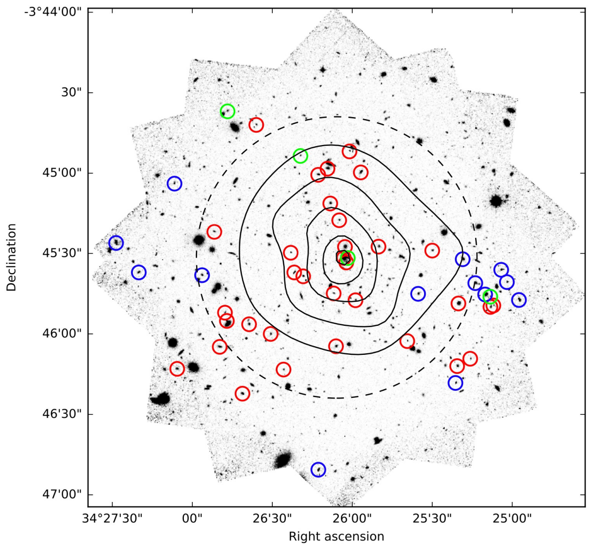
9 structures, only 8 detected in Lya



No Lya in the most massive and evolved cluster @z=2



Mantz et al. 2018 z=1.98
Very massive, X-ray, SZ bright



Willis et al 2020 (Nature)

What have we learned so far

2) Lya luminosities seem to ‘know’ about Mstream,
In a similar way that galaxies also ‘know’

Based on a sample of 9 Lya halos in groups from 2022…

We might look for a modulation post boundary defining a two-step function

$$\frac{L_{Ly\alpha}}{BAR} \simeq \begin{cases} C_{Ly\alpha}\left(\frac{M_{\rm stream}}{M_{\rm DM}}\right)^{\alpha_{Ly\alpha}} & M_{\rm DM} > M_{\rm stream} \\ C_{Ly\alpha} & M_{\rm DM} \lesssim M_{\rm stream} \end{cases}$$

1) $\alpha = 0$ → nothing happens at the boundary (theory wrong ?)

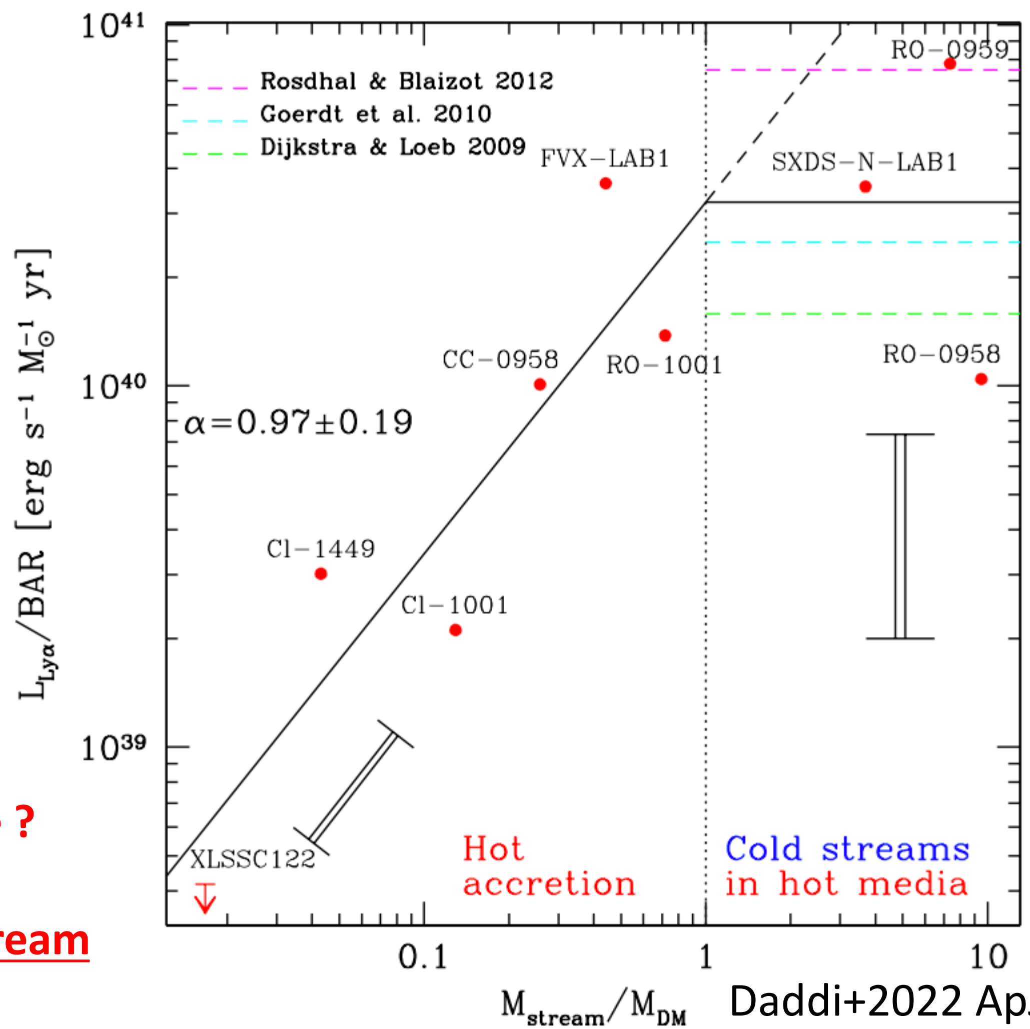
2) α = infinity → perfect boundary, 3σ cold accretion beyond $M_{\rm stream}$

3) Finite α → measure modulation

Lya seems to follow well the theory prediction

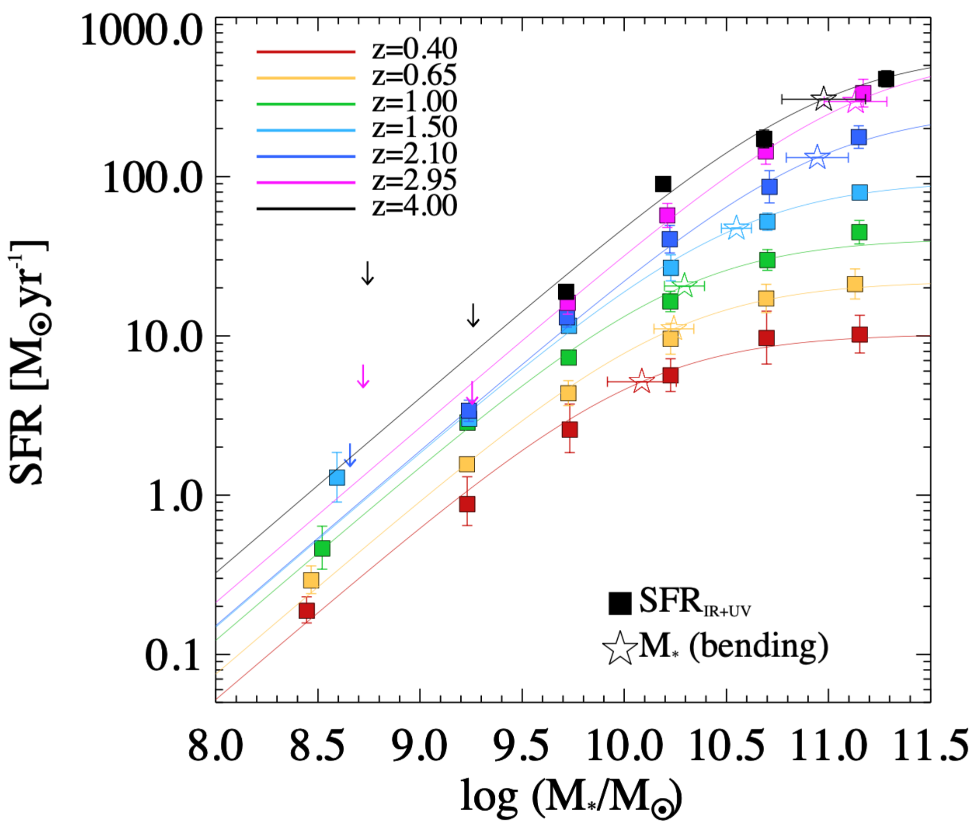
Can we identify any observable that is affected by the Mstream mass scale ?

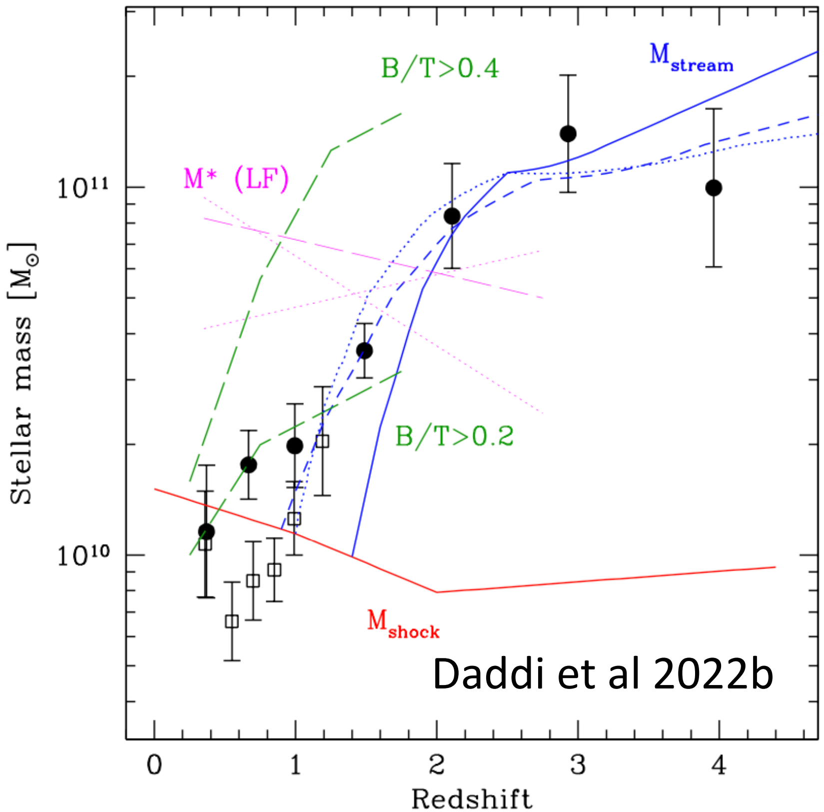
→ yes, Lya seems to know about Mstream



Daddi+2022 ApJL

Modulation of gas accretion in massive halos is also causing the bending of the MS
There is not such a thing as ‘starvation’, only a softening in gas suppression





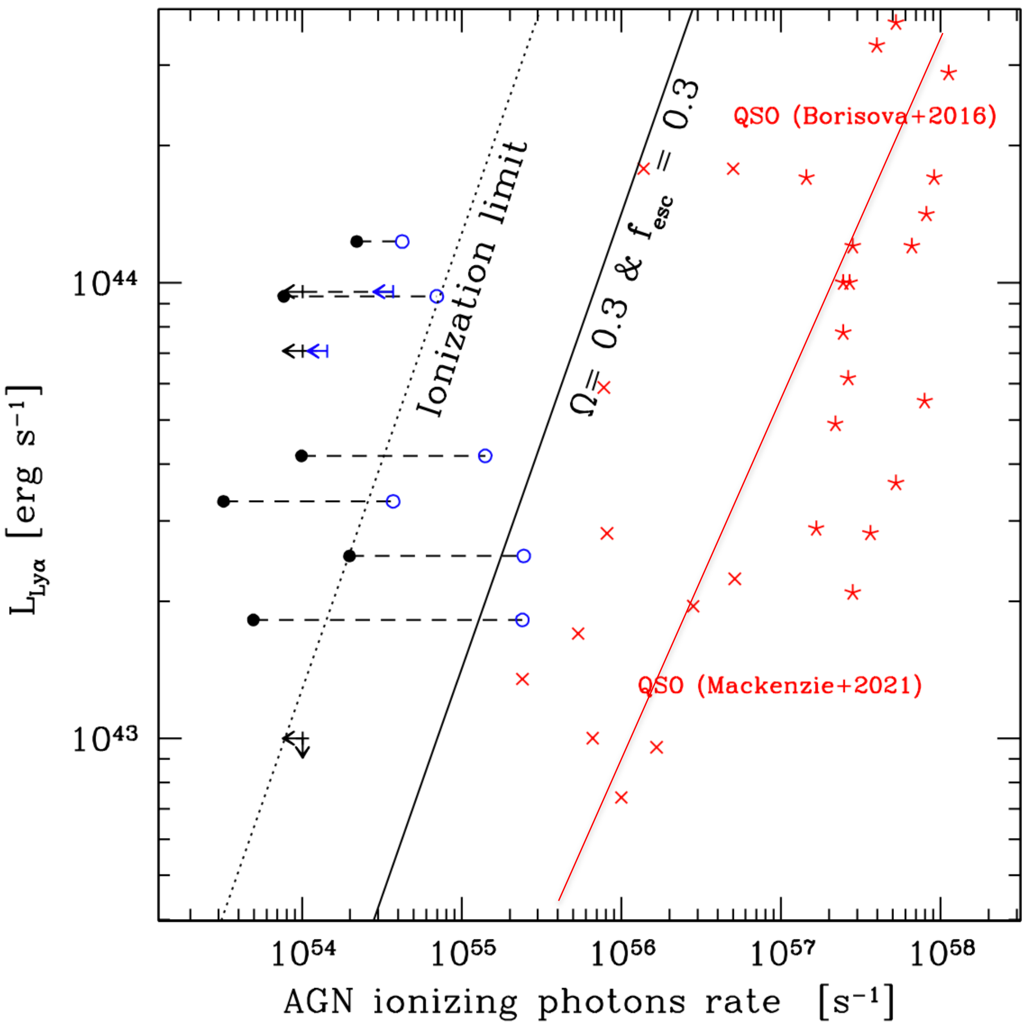
→ 1) The bending of the MS at high-z supports the cold stream paradigm.
Shows close interdependence of galaxies properties vs halos and environment

→ 2) This allows a revision of the Dekel+06 Mstream line (flatter and rising earlier)
Recent state of the art modeling from Mandelker+2020 provides a remarkably similar ‘fiducial’ prediction

What have we learned so far

3) Evidence growing that Lya is from collisions

What is the source of Lya luminosity for giant nebulae in groups/clusters ?



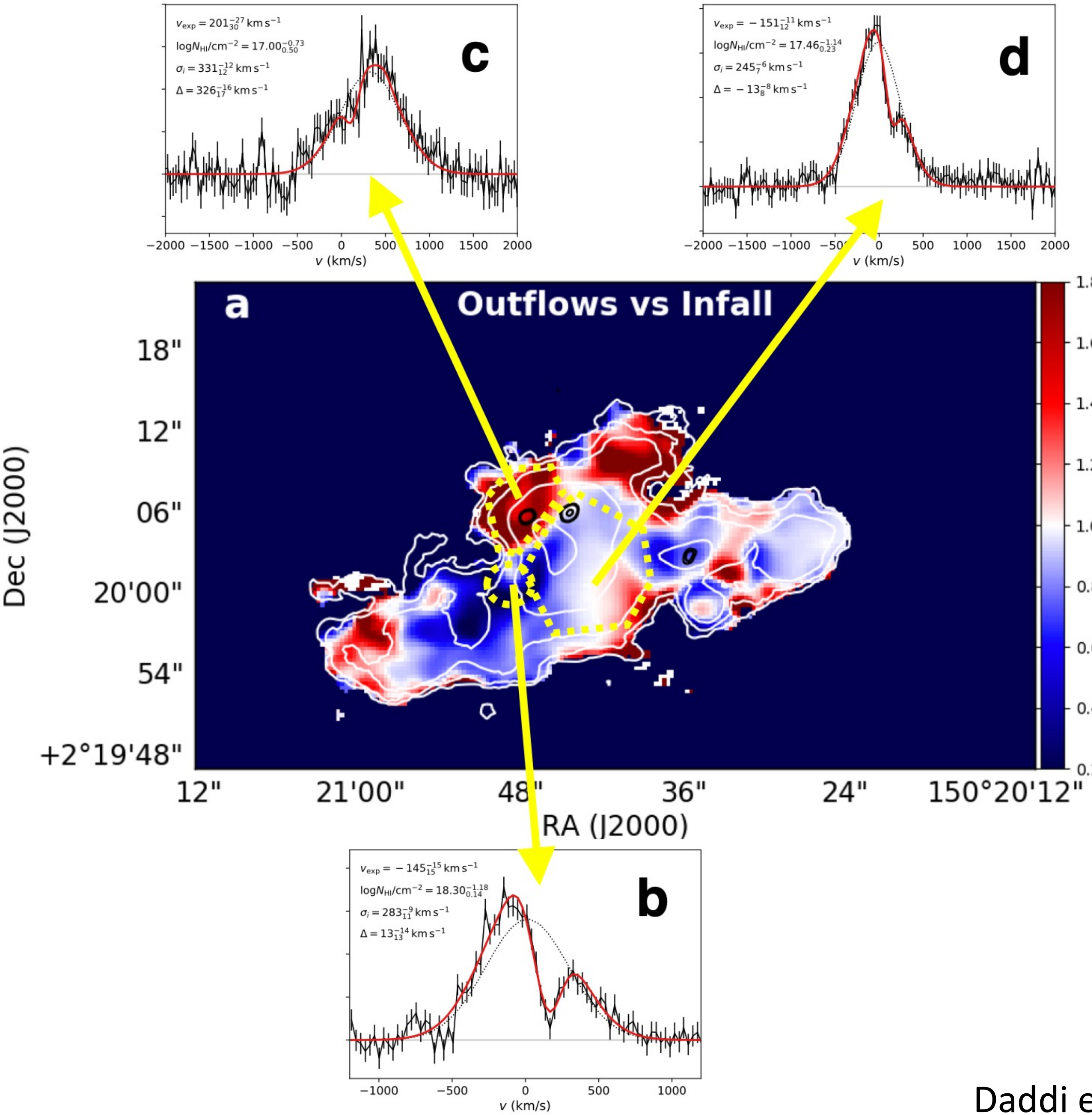
AGNs are 10^3-10^4 weaker than in QSOs

In many cases AGNs are not enough to explain the Lya emission, at least not known ones

AGN unification at z=2—3 ?
Lyman continuum escape ?

However, SFR and AGNs are in a way regulated by accretion, so the probe might be valid even if indirect

Daddi+2022 ApJL



Blue-shifted Lya profiles with little HI absorption (negligible scattering) support presence of infall

Similar blue-skewed spectra from Ao et al 2020 and Li, Steidel et al 2021 on Lya blobs

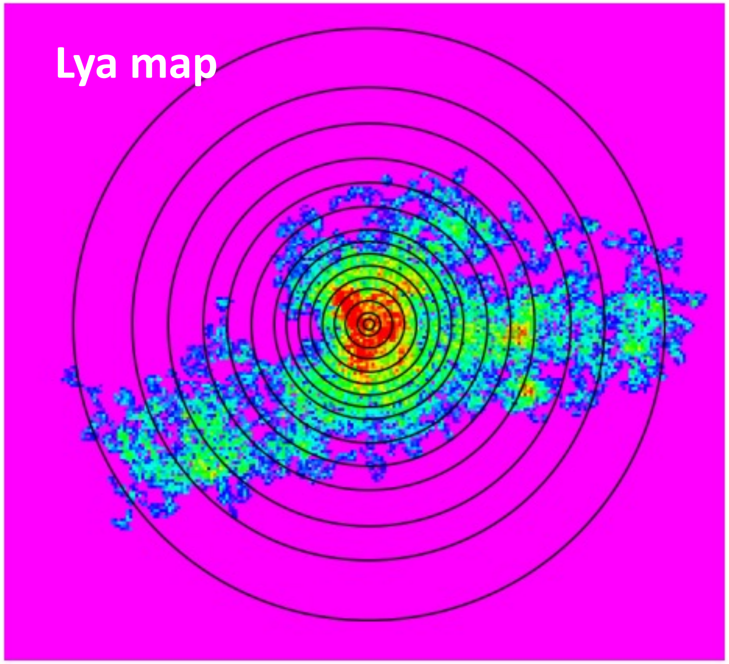
Daddi et al 2021

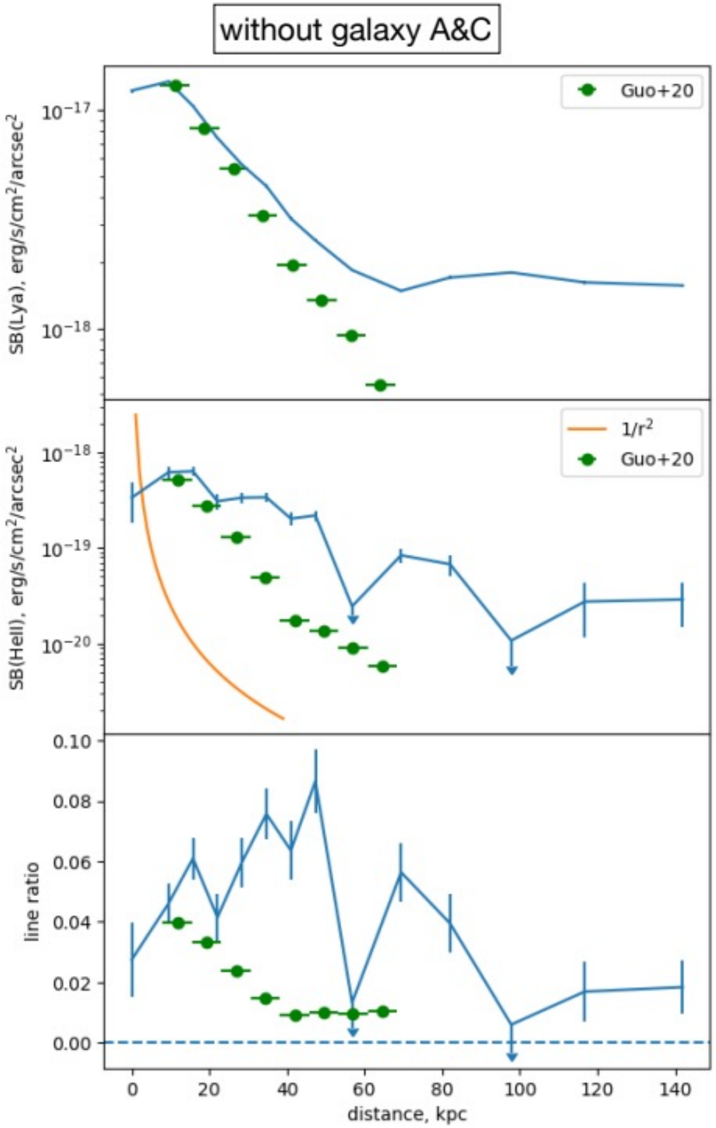
HeII is weak but everywhere (we also see CIV1550+CIII1909 → not pristine)

→ Exclude SF ionization

Nearly flat ratio to Lya with radius

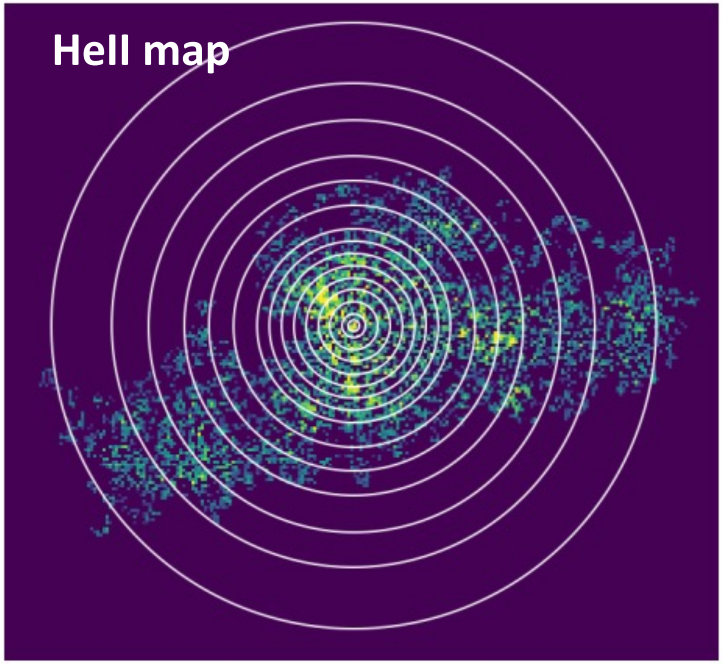
→ Hardly compatible with ionization from the weak AGNs





Sicen GUO

PhD's work

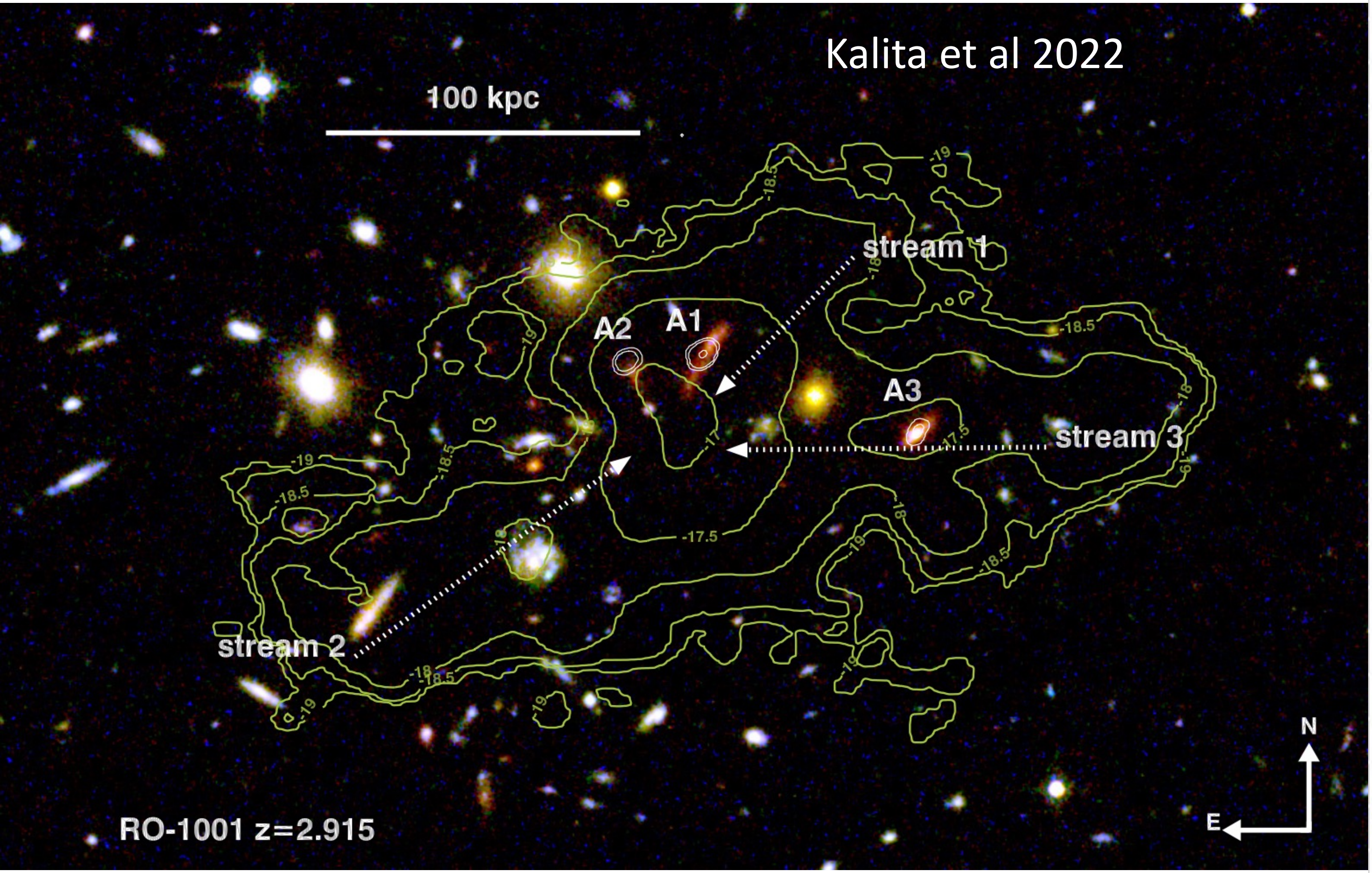


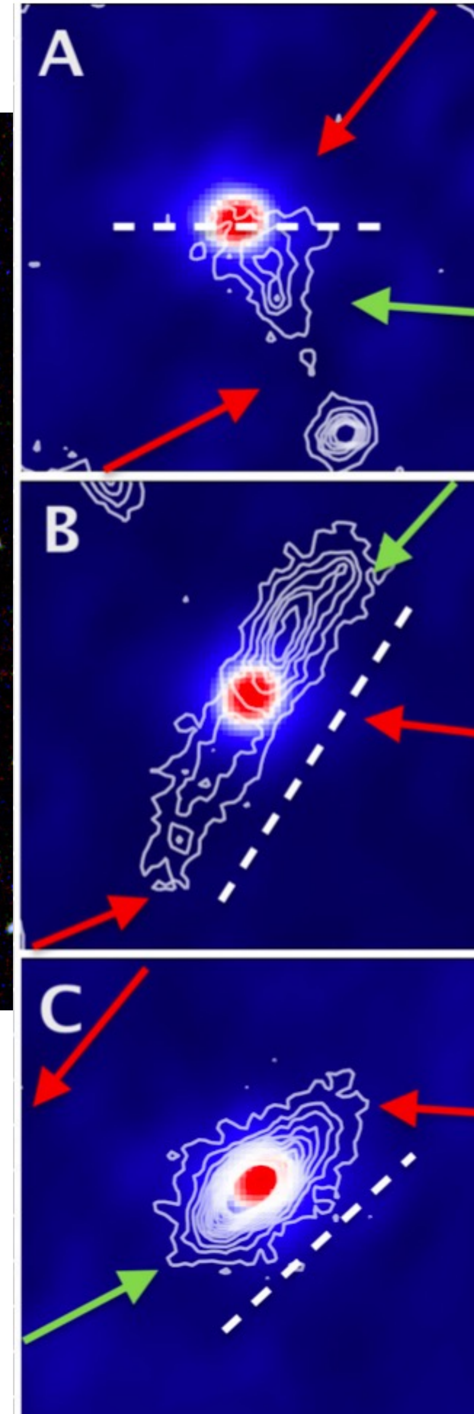
Guo et al in prep

What have we learned so far

4) Accretion might affect galaxies properties

Galaxies in stream-fed halos: star forming





Lopsidedness

Compact starbursting nuclei

Orientation of the disks connected to the filaments

OK, so BlueMUSE, 2032+

opens up Lya@1.87--2.9 that cannot be seen by MUSE
Larger FOV than KCWI@keck
Higher spectral resolution (in wide field) than KCWI@keck
Much better spatial resolution (recall the 0.29’’x1.35’’ KCWI pixels)
Much better flat-fielding accuracy

OK, so BlueMUSE, 2032+ opens up Lya@1.87--2.9

8 more years, 8 years ago we published the first cluster z=2 (2016)

This science will evolve until 2032+, but here some considerations:

A) Statistical samples, build sample size (11 Lya halos as of today…)

B) Few test-case studies to constrain the physics/filaments/etc
+ (MUSE also needed for z>2.53 to see HeII at >5800A)

C) Needs the best targets (with Mh), to be built (Euclid/JWST?)

D) Sinergy with multi-lambda facilities, build sample quality
+ for hot gas (Athena) but also galaxies (JWST/ELTs?)

E) Establish simulation set to enable understanding/diagnostics