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A MUSE tomography of J1000+0234: a galaxy protocluster core at z=4.5?

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IRyA's extragalactic group

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Outline

A. Extended Lya nebulae at high redshifts.

B. A rare combination: kpc-scale Lya emission around a dust-enshrouded starburst at 2<z<5

C. MUSE observations towards J1000+0234.

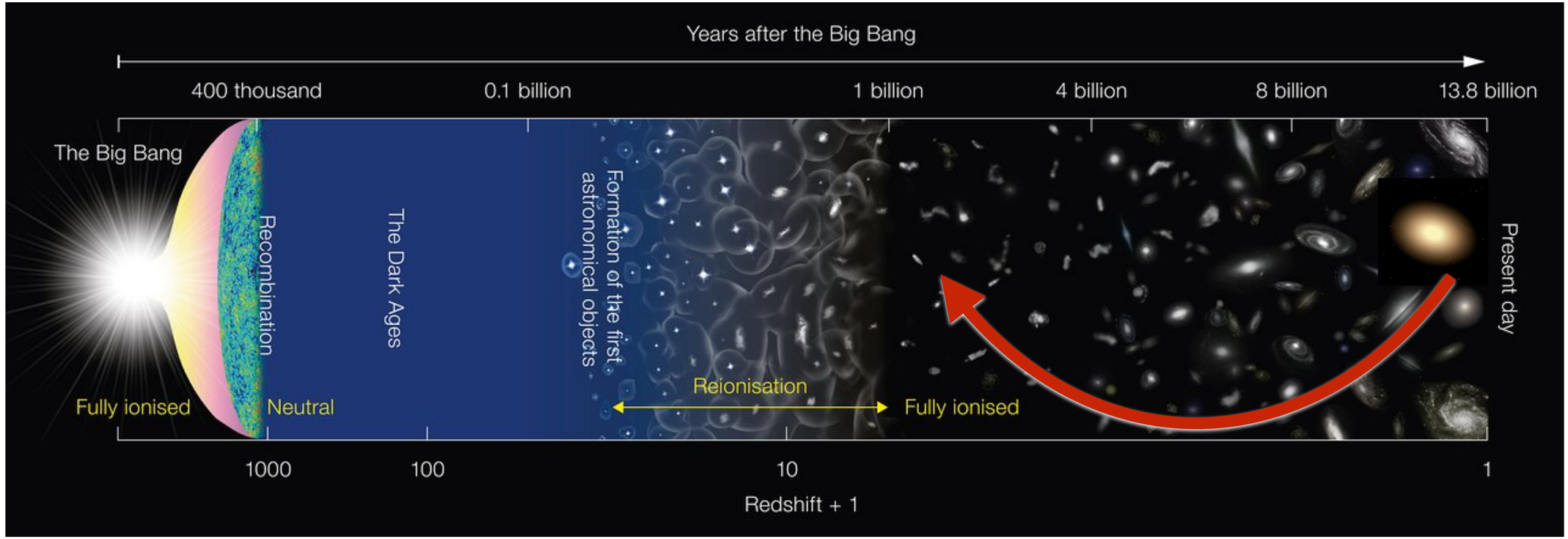
D. Ionization source, kinematics, and large-scale environment around J1000+0234.

F. Summary.

KEY MESSAGE:

J1000+0234 is an instructive example of a potential evolutionary link between extended Lya nebulae around dusty starbursts in overdense regions at z>3 and local elliptical galaxies that reside at the center of galaxy clusters.

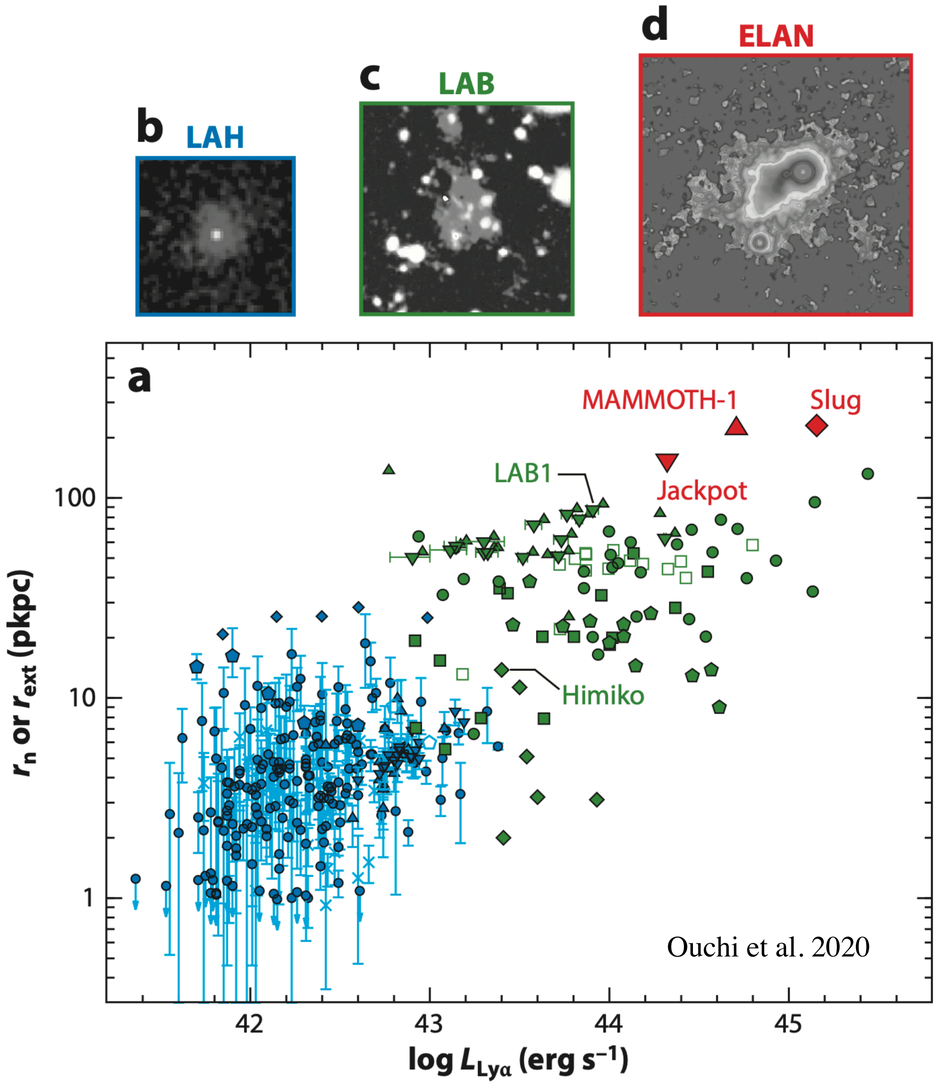
General open issue to be addressed here



Credit. NAOJ

Tracing the evolutionary path between the most massive starburst galaxies at $z>3$ with massive elliptical galaxies in the present epoch.

Extended Lya emission at high redshifts



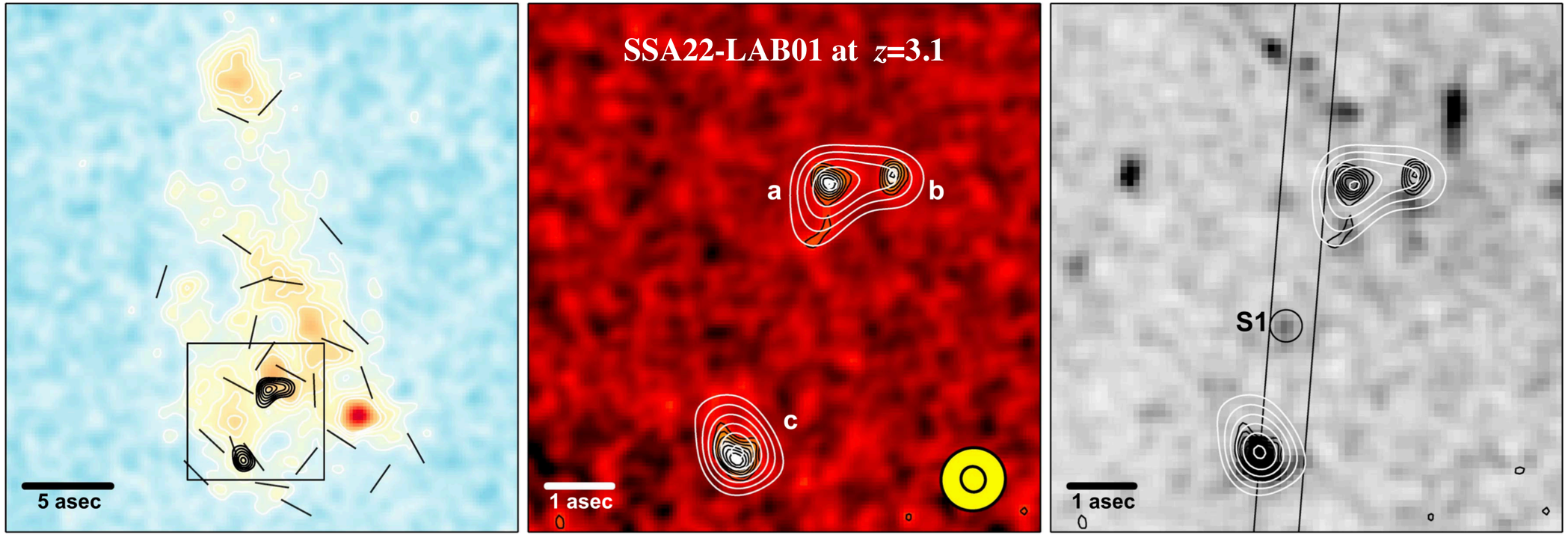
Extended nebulae of Lya emission are key observational signatures of high redshifts ($z > 2$) structures:

- **Extended Lyman Alpha Nebulae (ELAN):** Mainly associated with QSO. Tracers of Mpc-scale overdensities.
- **Lyman Alpha Blobs (LAB):** Associated with a wide range of galaxy populations (radio galaxies, quasars, QSO, etc). Tend to lie in galaxy overdensities.
- **Lyman Alpha Halos (LAH):** Ubiquitous in high-redshift star-forming galaxies (SFGs).

Steidel et al. 2000; Matsuda et al. 2004; Cantalupo et al. 2014; Shibuya et al. 2018; Wisotzki et al. 2018; Cantalupo et al. 2019

A rare combination: kpc-scale Lya emission around a dust-enshrouded starbursts

Particular emphasis is given to $z \sim 3$ LABs surrounding dusty, highly active SFGs selected at sub-mm wavelengths (Submillimeter Galaxies: SMGs).



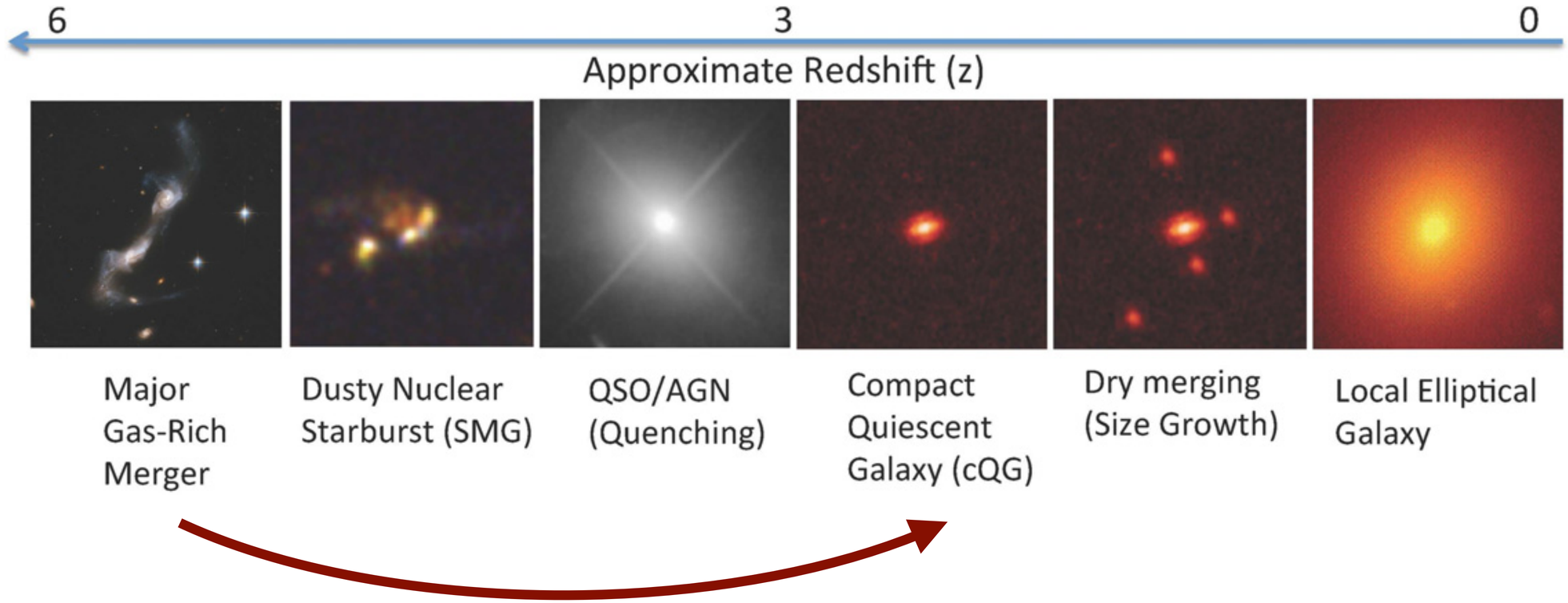
Geach et al. 2016

The rare population of LABs around dusty galaxies with infrared luminosities $\log(L_{IR}/L\odot)\sim12$ has a surface density of only ~0.1 deg^2 (Bridge et al. 2013).

Geach et al. 2005; Geach et al. 2014, 2016; Hine et al. 2016; Guaita et al. 2022

Evolutionary link between dusty starburst and elliptical galaxies

LABs around luminous SMGs might undergo a “short-lived", intense feedback phase that transforms high-redshift starbursts into mature/quenched systems.



To explore these scenarios, *an accounting of energetic processes and environment around SMGs within LABs is needed.*

Gobat et al. 2012; Glazebrook et al. 2017, Toft et al. 2014; Stach et al. 2021

Lya emission as an observational probe of high-z systems

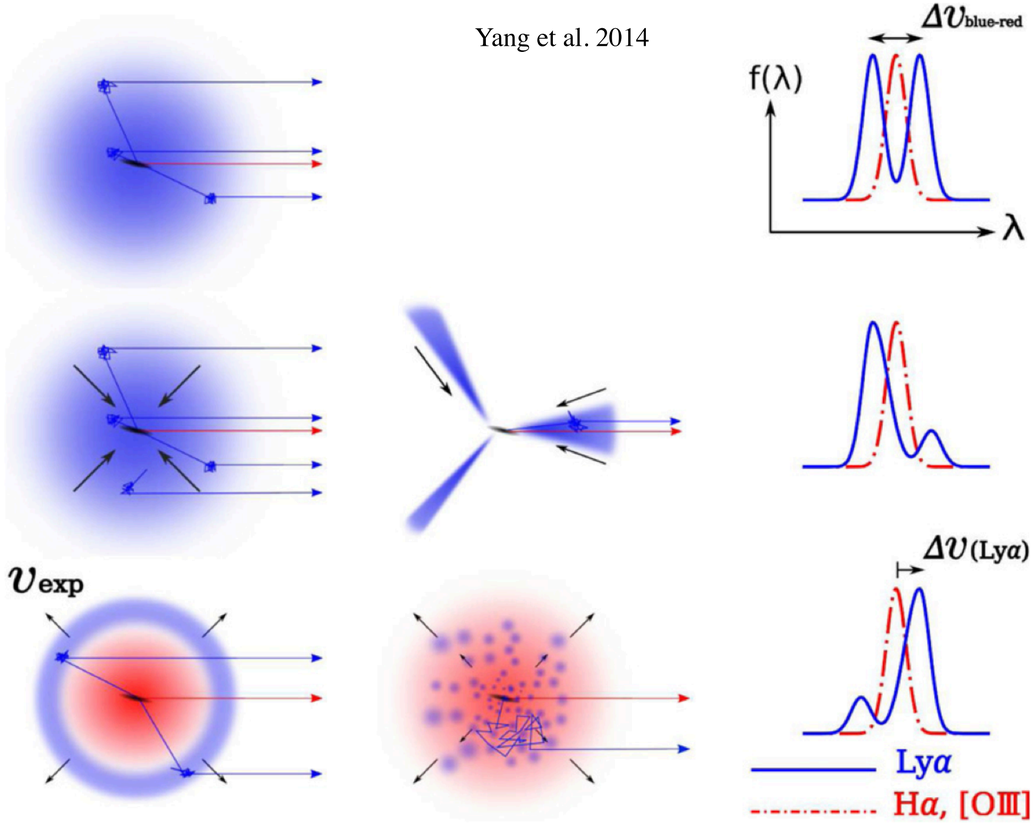
Why Lya?

Lya

- Workhorse diagnostic for high-z systems.
- Brightest UV line “easily” detected with ground-based optical telescopes.

BUT:

- It originates from several mechanisms (star formation, gravitational cooling radiation, Active Galactic Nuclei [AGN], shocks).
- Poor tracer of gas kinematics



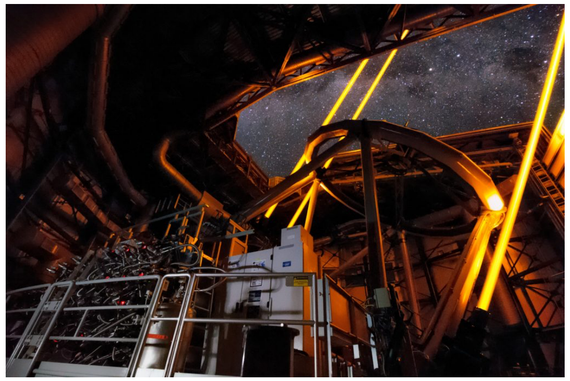
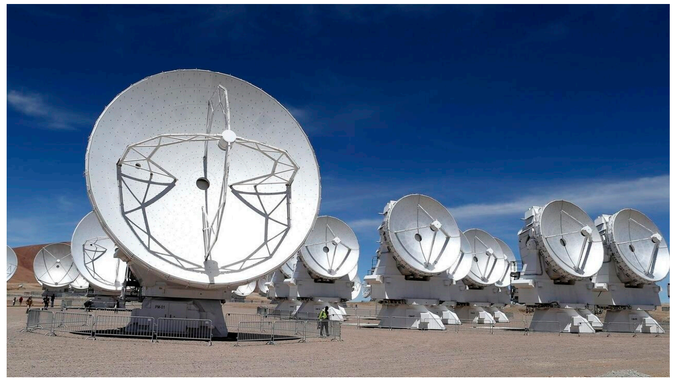
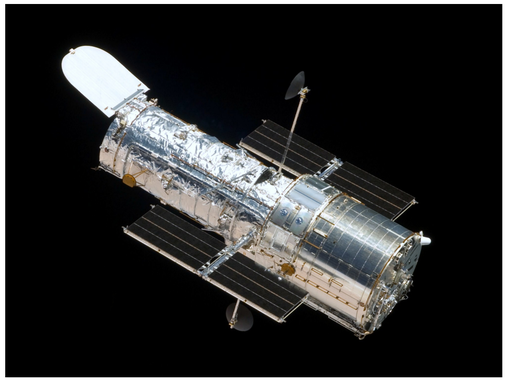
Lya is a resonant line—> line profile strongly depends on propagation effects.

Much fainter, yet vital, non-resonant lines are needed.

Goal of this project

To evaluate evolutionary links between luminous SMGs in rich environments at $z > 3$, LABs, and quiescent systems in the center of present-day galaxy clusters.

HOW?

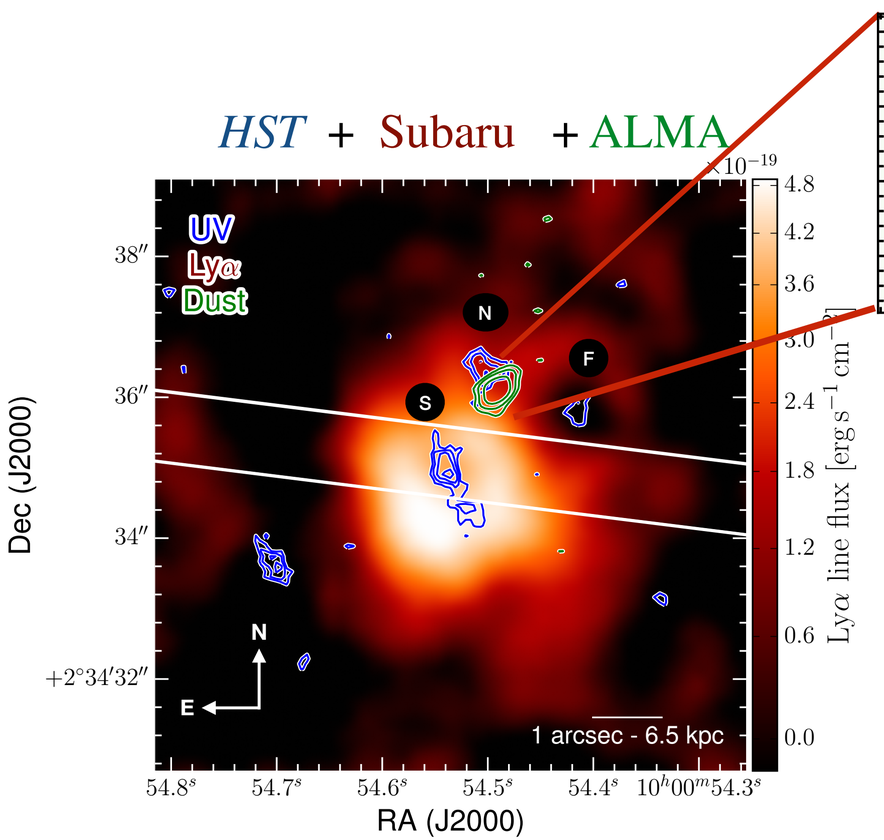




- By characterizing extended Lya 1216Å, CIV 1550Å, and HeII 1640Å emission around the z=4.5 SMG J1000+0234 and its companions.

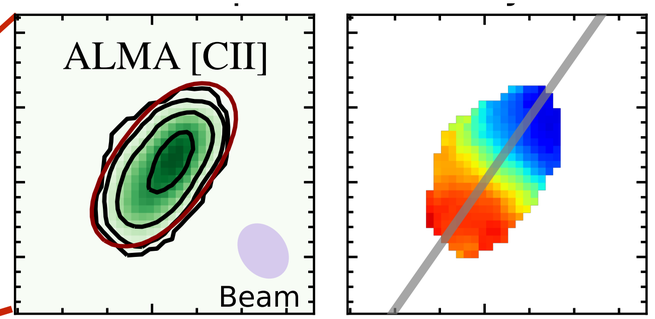
- By combining VLT/MUSE data with archival ALMA and *HST*/WFC3 observations, we study the ionizing mechanisms, kinematics, and large-scale environment of the LAB around J1000+0234

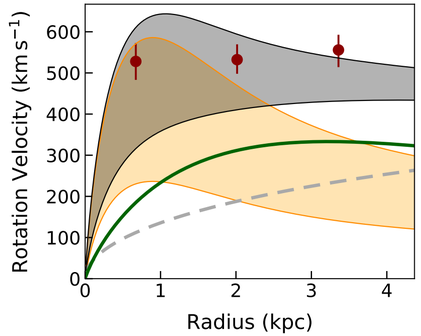
Key aspects of J1000+0234

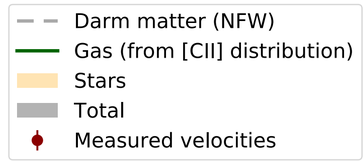
J1000+0234 is a galaxy pair at z=4.5: J1000+0234–S is a low-mass SFG (log(M⋆/M⊙)~9) neighboring the SMG J1000+0234–N.



Prominent Lyα emission is concentrically distributed around J1000+0234–S

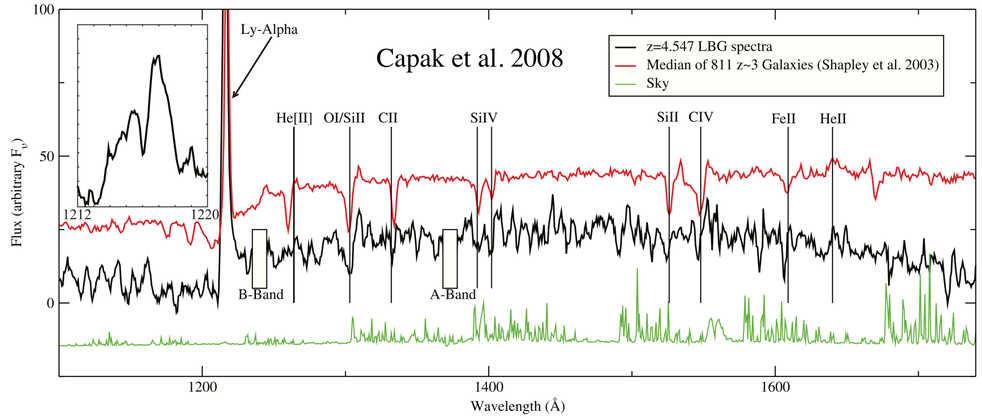






Fraternalli et al. 2020

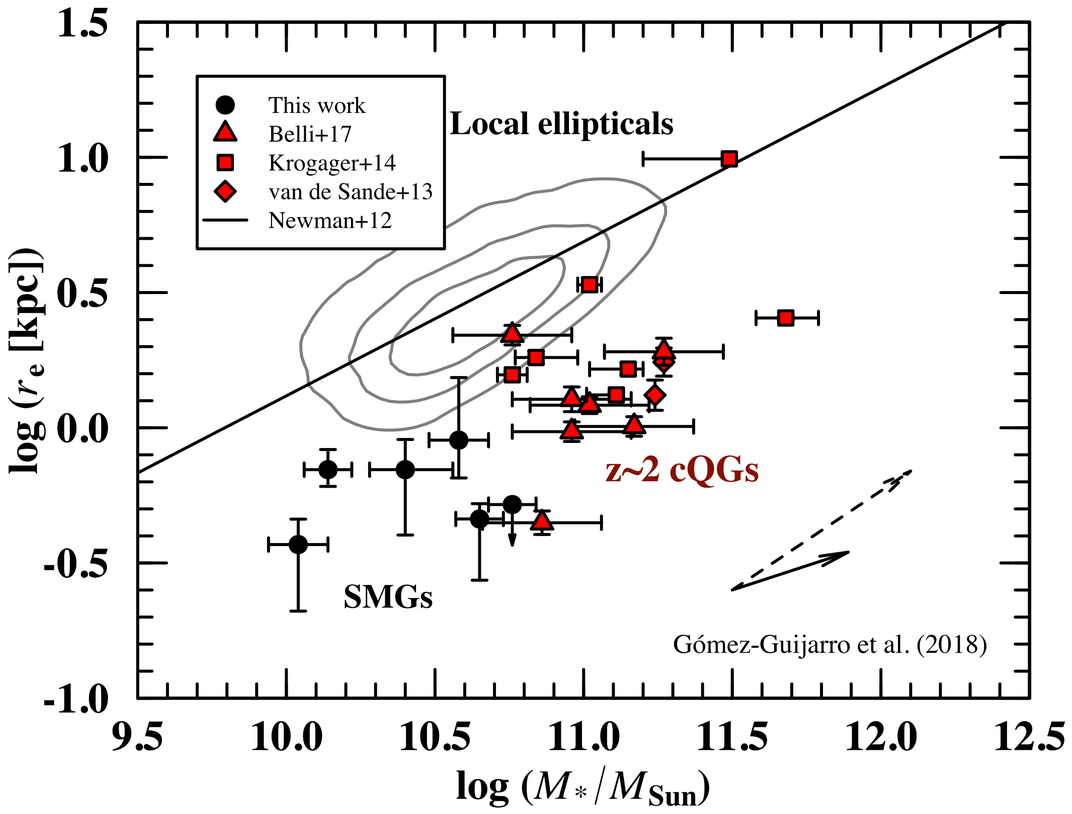
J1000+0234–N harbors a regularly rotating disk at z=4.5



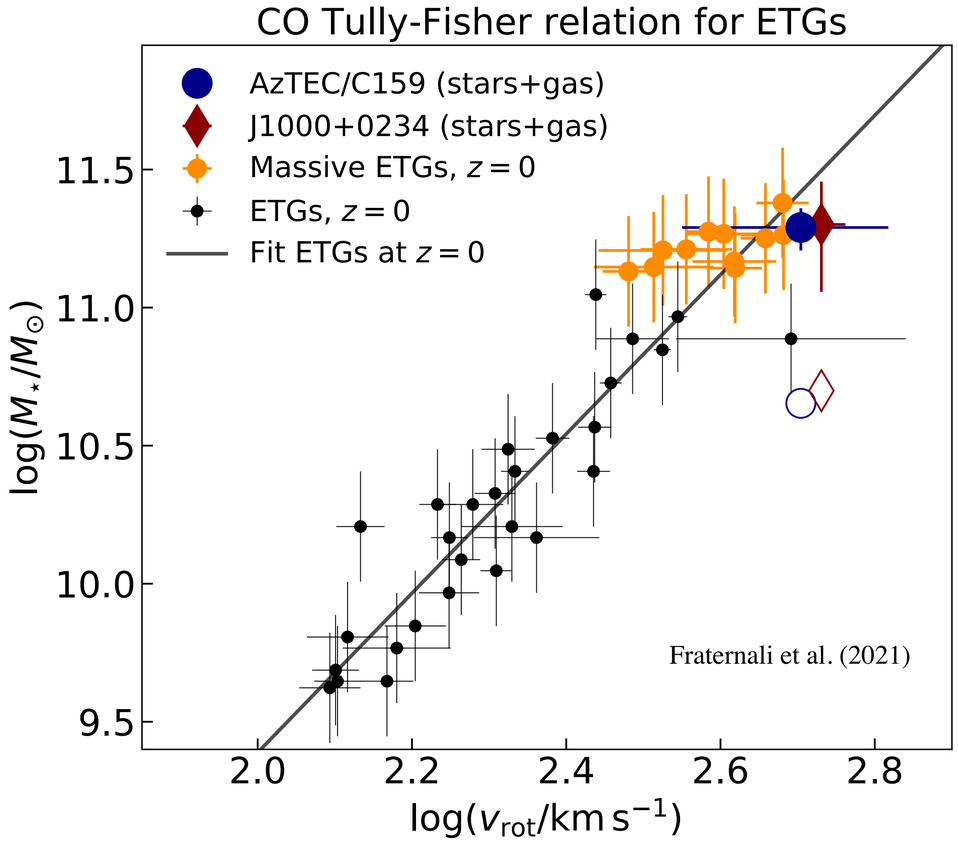
Asymmetric, multi-component Lya profile — galaxy-scale outflows? Evidence of supernovae feedback (expanding-shell) in J1000+0234–S?

Key aspects of J1000+0234

J1000+0234 will grow to a stellar mass and size typical of compact, quiescent galaxies at *z*~*2*: the progenitors of the local elliptical galaxies.



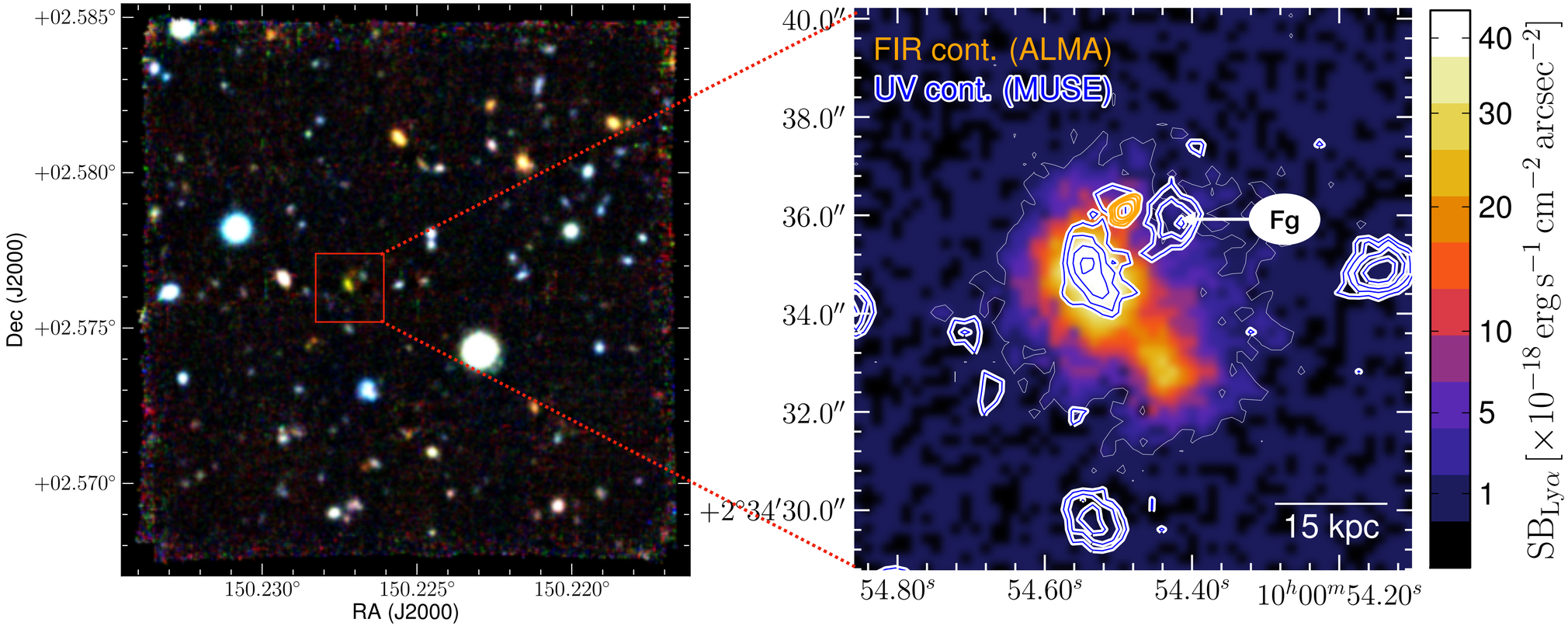
J1000+0234-N appears to have potential wells that are very similar to those of local massive ETGs.



The "birth" of a local quiescent galaxy caught in the act?

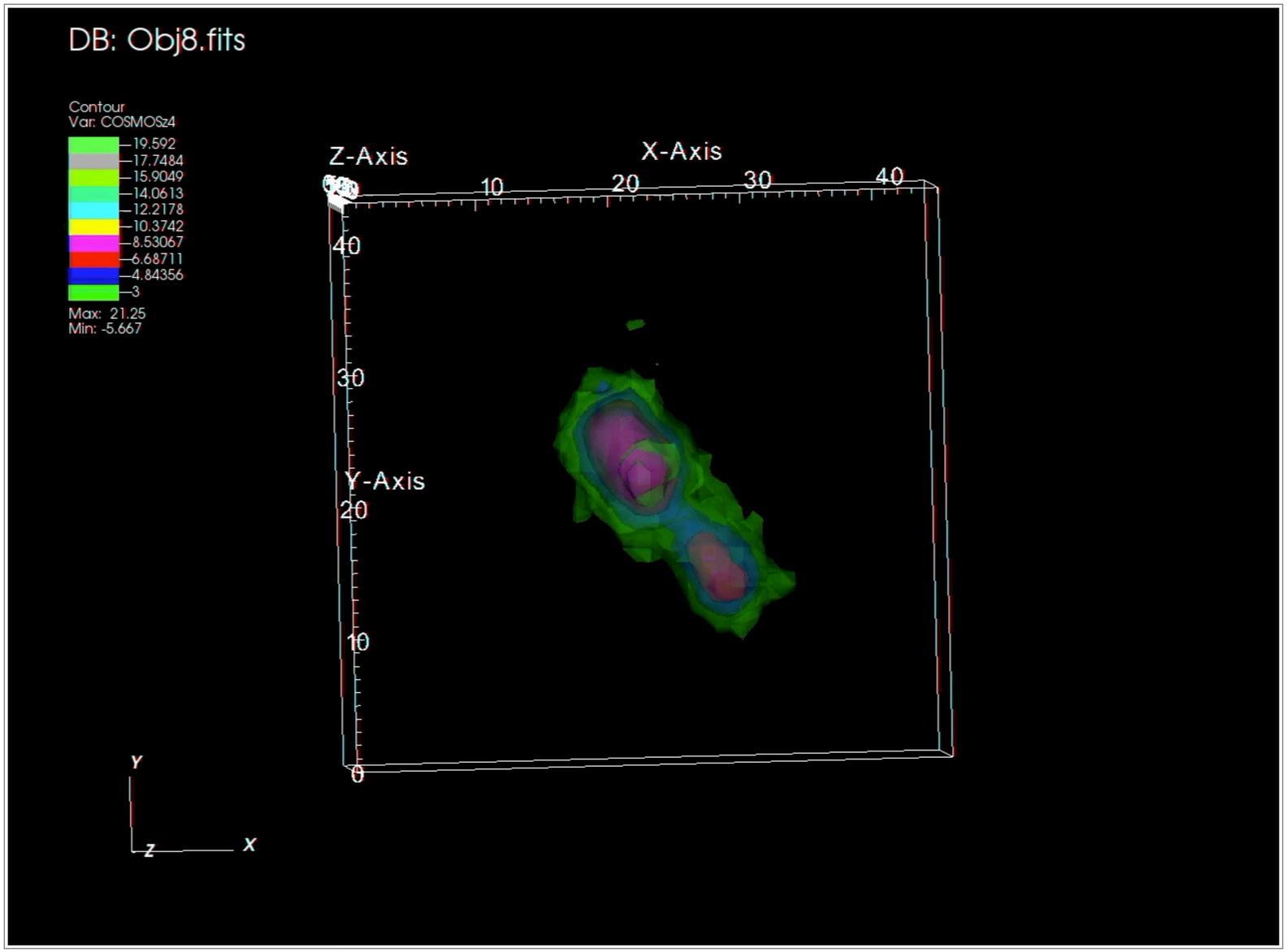
MUSE observations towards J1000+0234

4 hours of VLT/MUSE observations as part of the ESO GTO Program 0102.A-0448 (PIs: S. Cantalupo and S. Lilly).



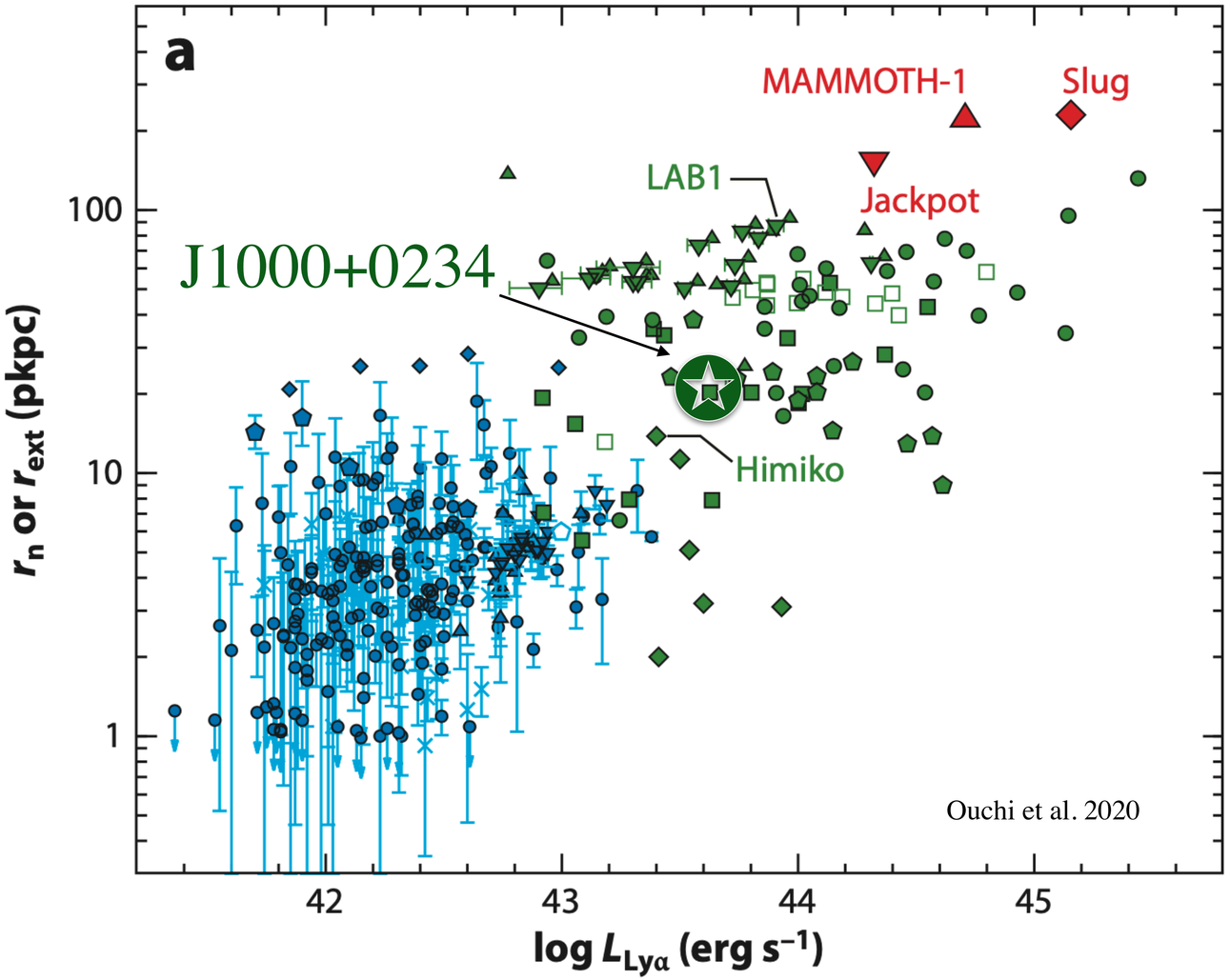
+ Serendipitous discovery of several $z > 3$ pairs of Lya emitters.

A tomography of Lya emission of the J1000+0234 nebula at z=4.5



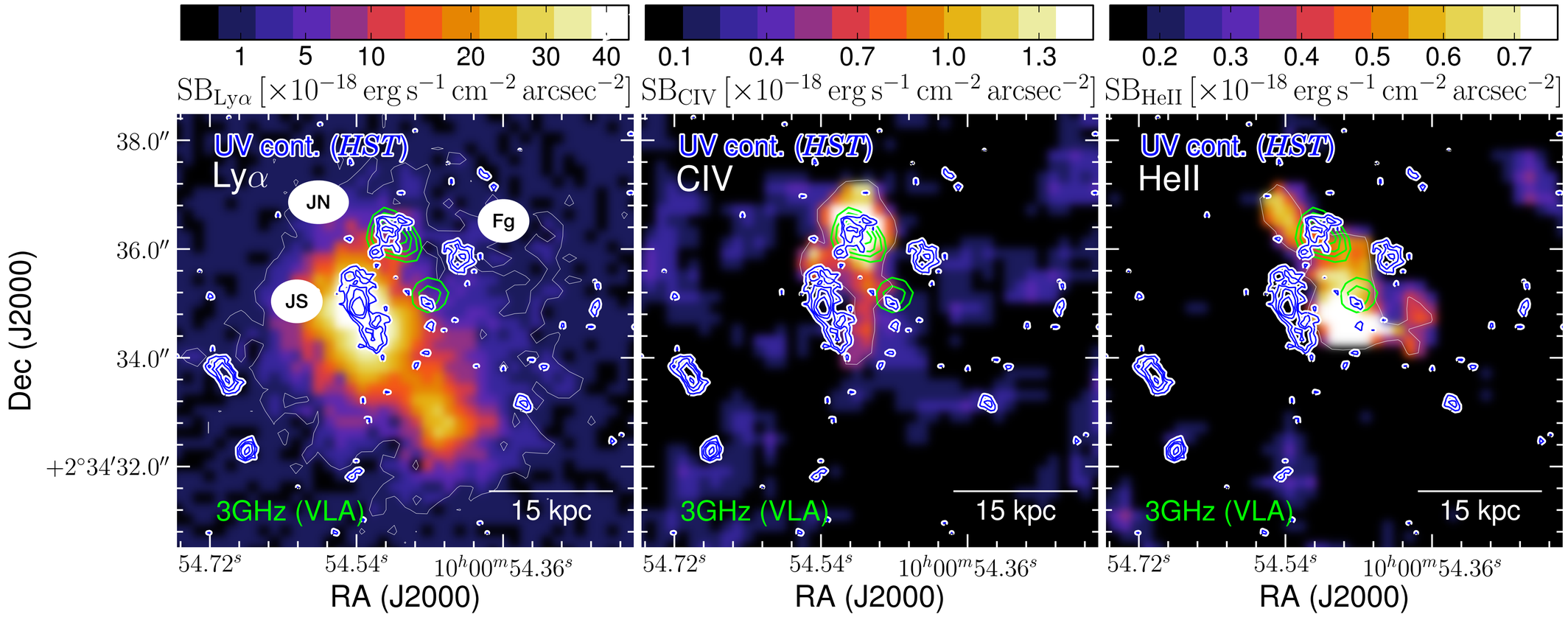
J1000+0234 in the context of the general population of Lya blobs

The Lya nebula around J1000+0234 has a total extent and luminosity typical of LABs.



This is unlikely to be an individual Lya halo around J1000+0234-S (our initial guess).

2D emission line maps



The brightest Lya region matches the locus of the low-mass SFG.

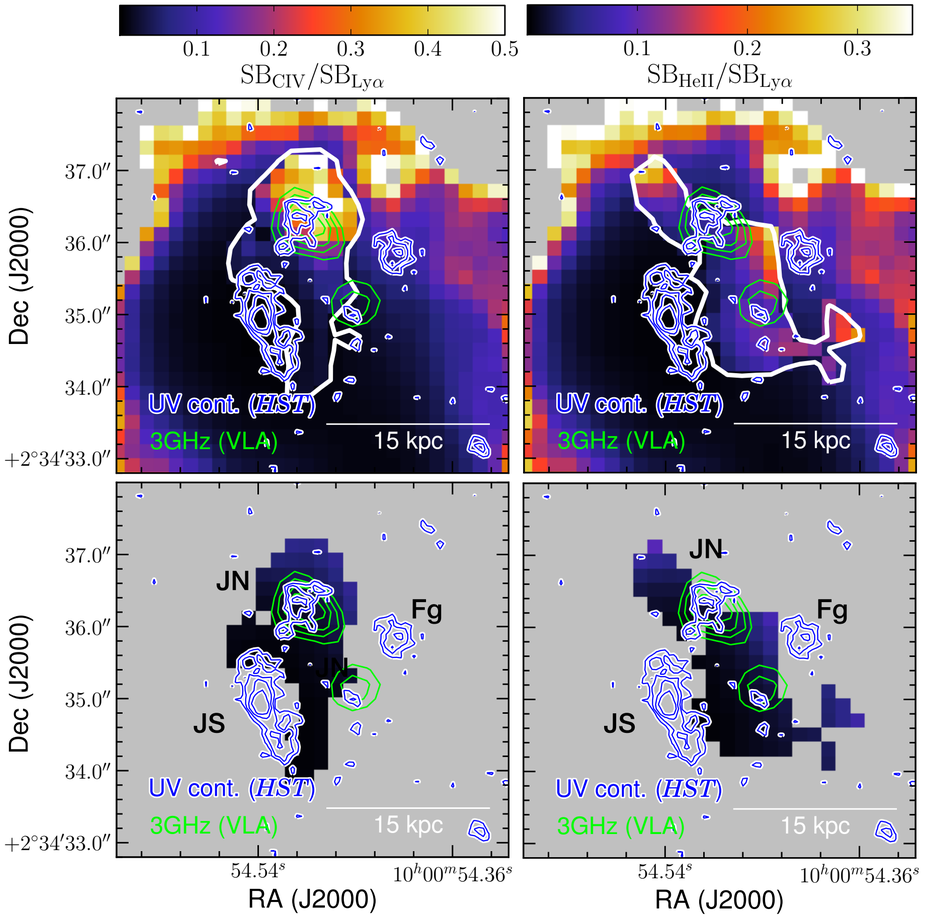
The brightest CIV region is coincident with the SMG position.

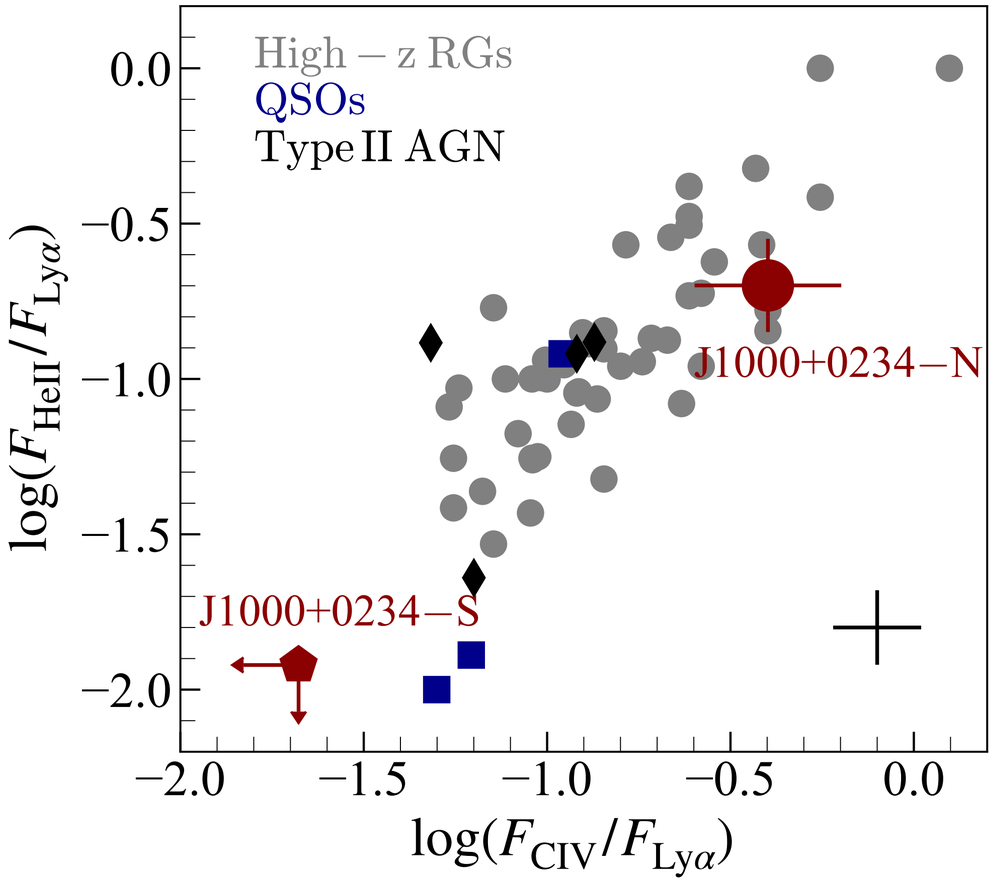
HeII emission is maximal at the position of a compact 3 GHz radio source that has a faint UV counterpart.

What is driving the LAB?

What is driving the extended Lya nebula?

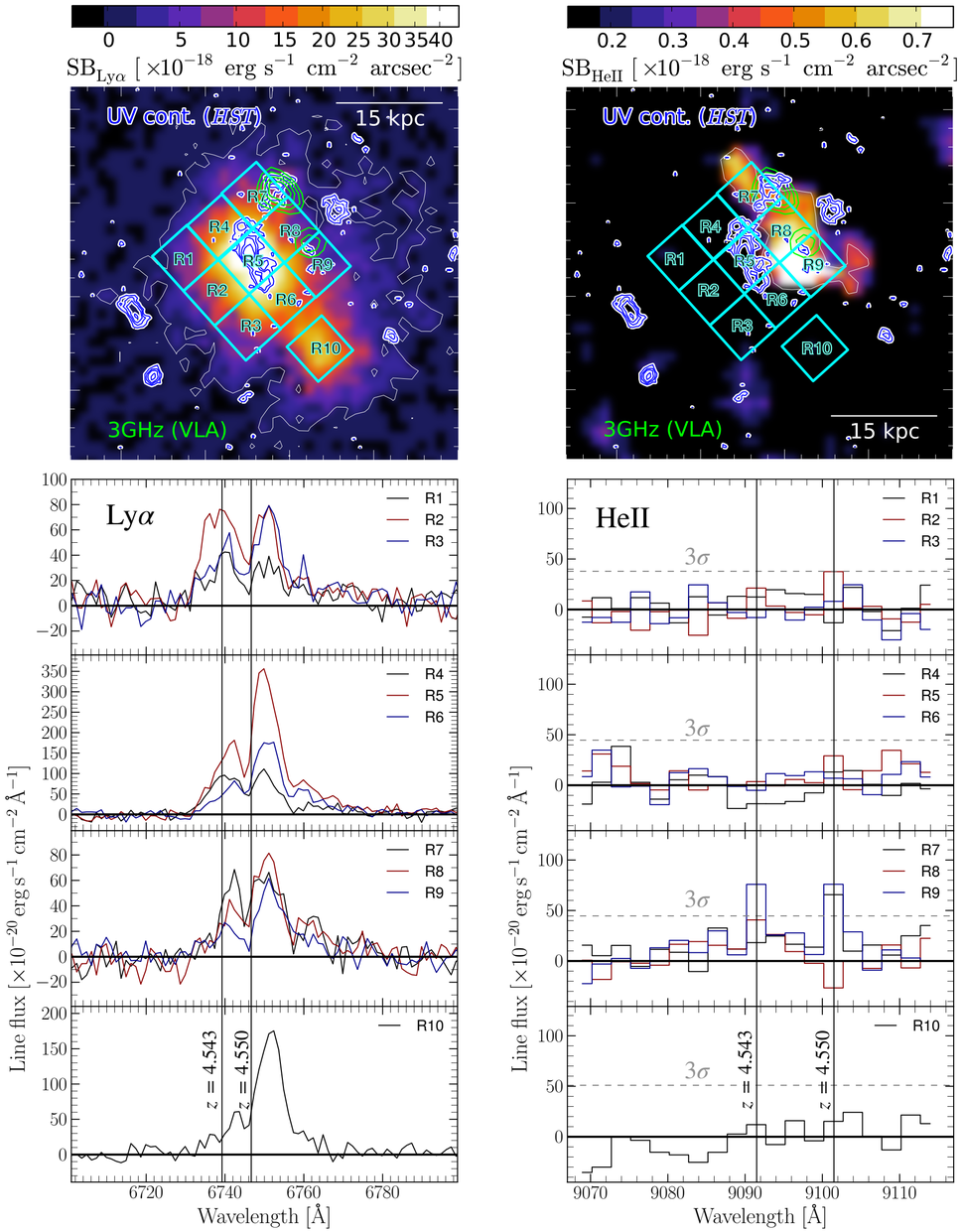
The line ratios are maximal in the vicinity of J1000+0234-N and are consistent with those observed in Type II AGN and high-redshift radio galaxies.





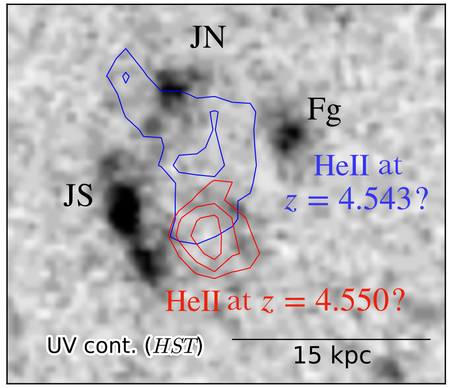
At the locus of J1000+0234-South no HeII nor CIV emission is detected—> the gas around J1000+0234-S does not receive enough incident flux from the AGN (too distant and/or broad density distribution of the intergalactic medium).

A single cloud or a complex system?



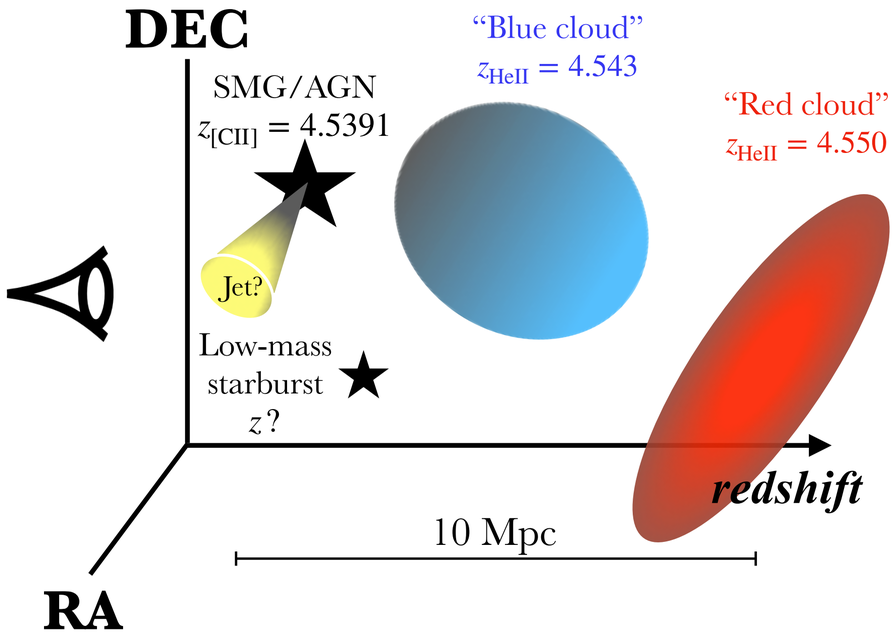
- There is marginal evidence for two peaks in the (non-resonant) HeII line profile separated by a velocity shift of ~330 km/s (similar to that observed in the Lya profile).

- The two peaks are spatially separated by 6kpc (projected on the sky plane).

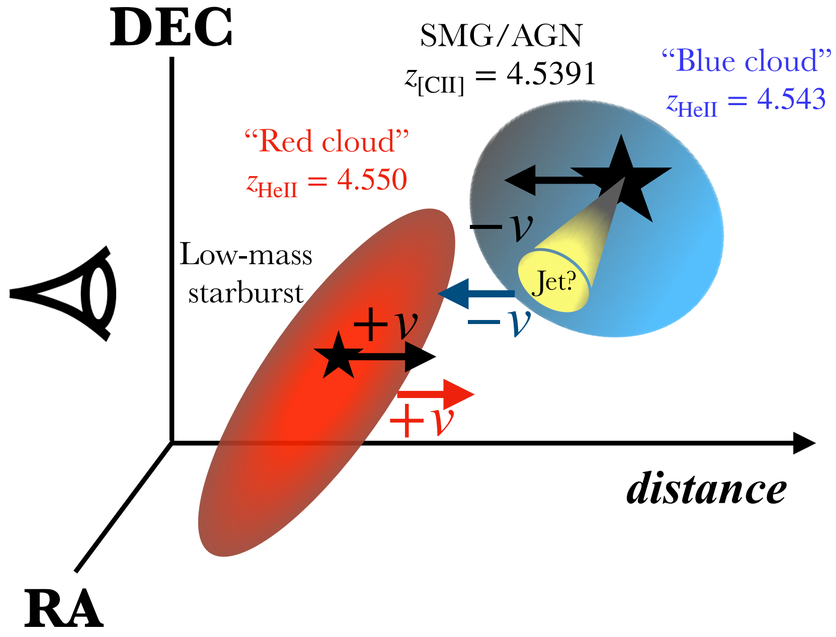


- This suggests the presence of two different clouds along the line of sight with redshifts 4.543 ± 0.002 and 4.550 ± 0.002.

The proposed scenario



No peculiar velocities

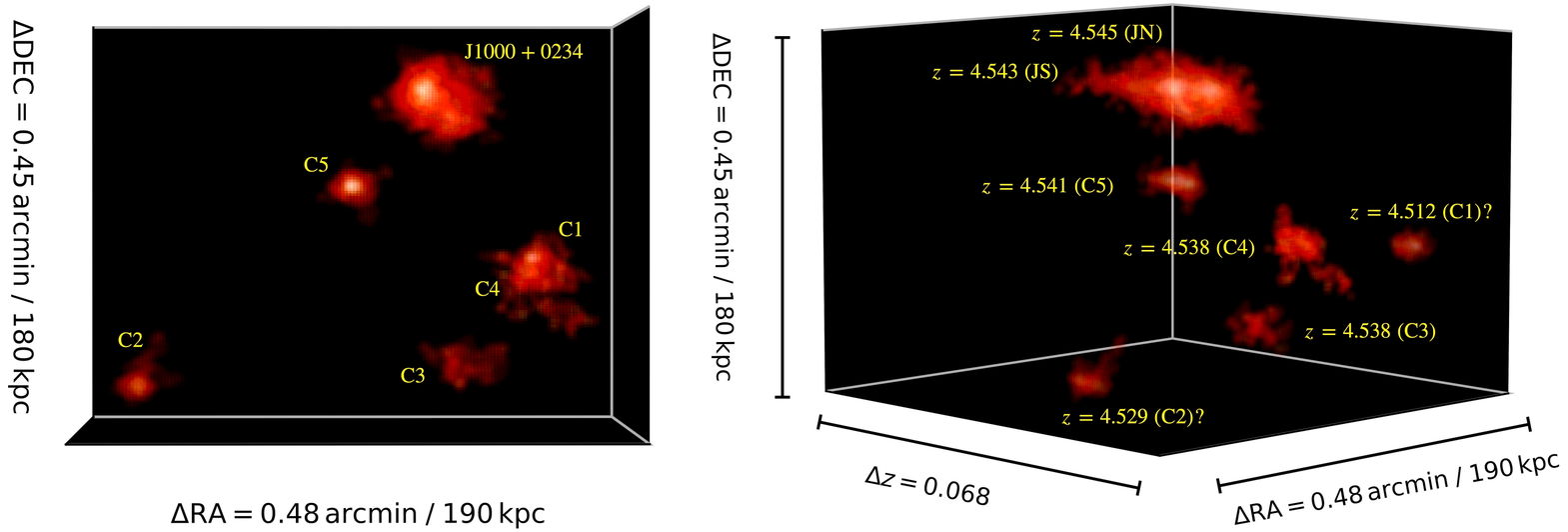


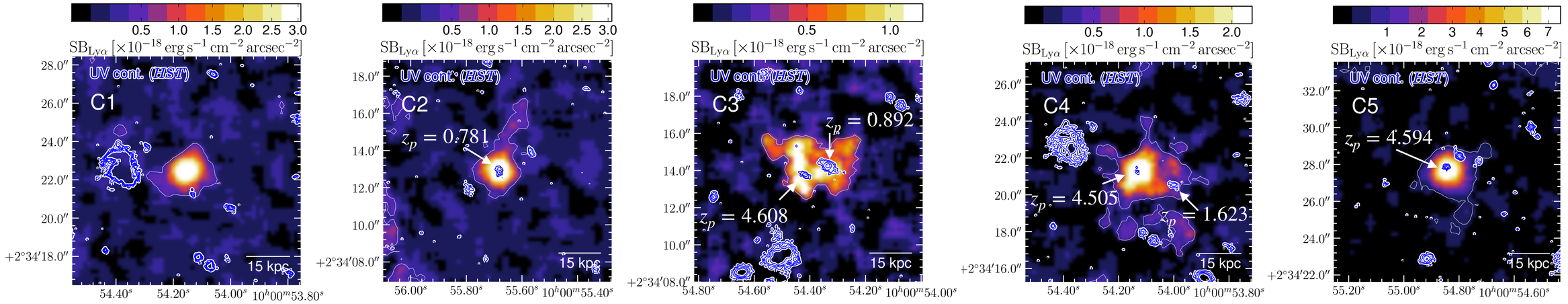
Considering peculiar velocities

The two emitting clouds surrounding J1000+0234-N and -S are likely on a collision course with a relative velocity of ~400 km/s.

Large-scale environment around J1000+0234

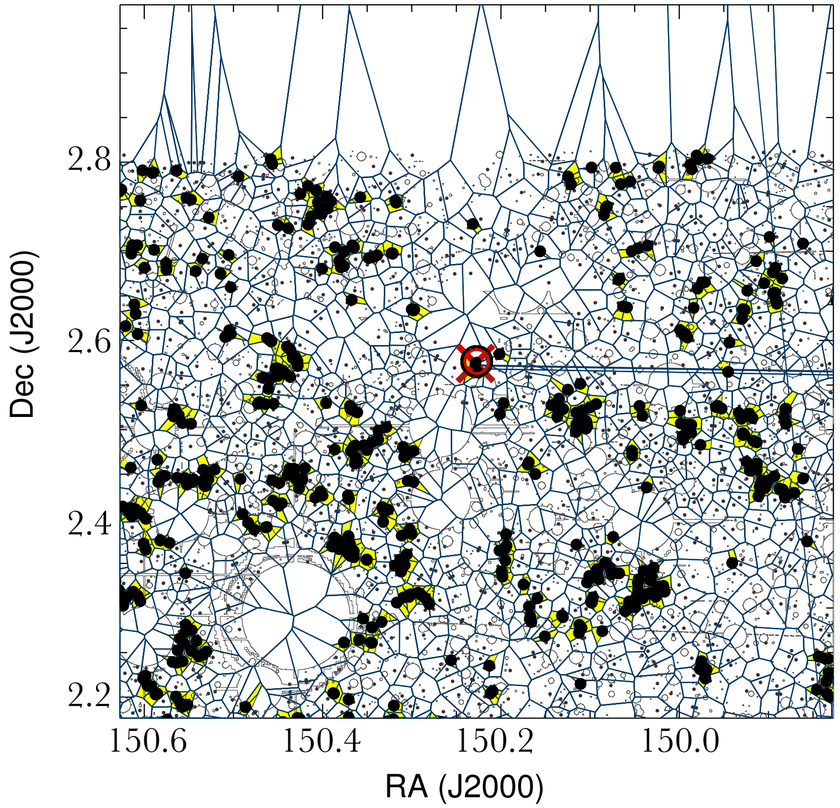
The serendipitous identification of three Lya emitters spanning over a redshift bin < 0.007 (i.e., 380 km/s) located at < 140kpc from J1000+0234.

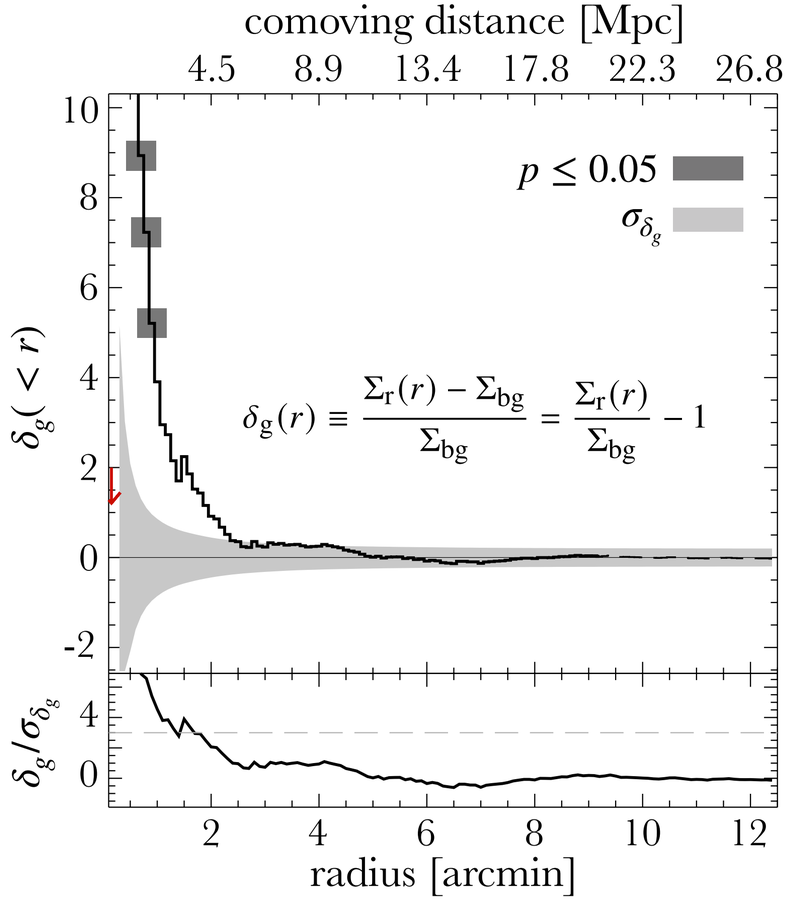




A Mpc-scale galaxy overdensity a z=4..5

A Voronoi tessellation analysis finds a galaxy overdensity around J1000+0234.



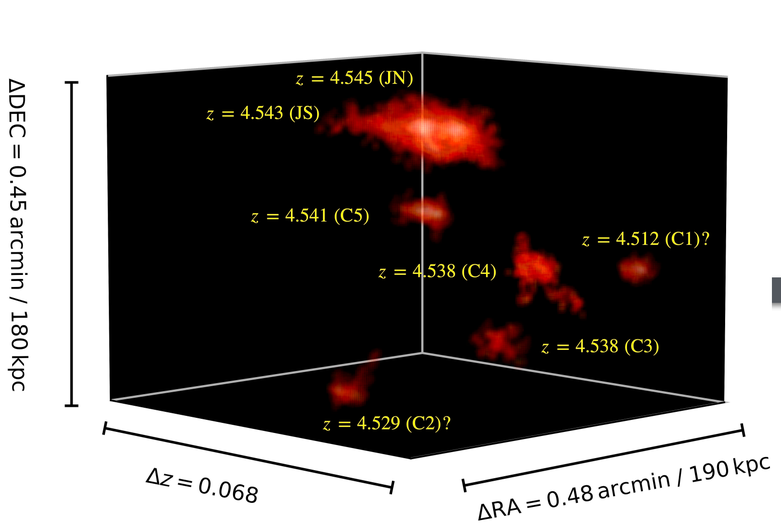


An overdensity is significantly detected out to a comoving radius of 5 Megaparsec (Mpc).

It is centered at only ~500 comoving kpc away from J1000+0234.

The fate of the J1000+0234 system

From previous studies: the gas dynamics and expected mass/size growth of J1000+0234 match those of quenched galaxies at $z<2$.



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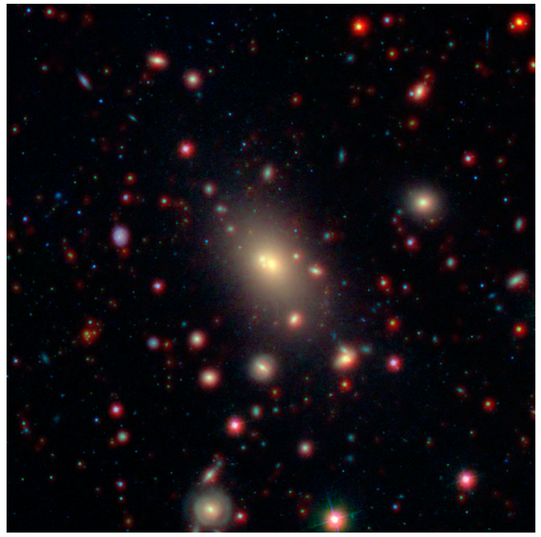

z=4.5 ***z=0***

What is new: Using Chiang et al. (2013) predictions, the overdensity around J1000+0234 at $z = 4.5$ has a low (20%) probability to evolve into a galaxy cluster with total mass of $10^{14}\,M_{\odot}$.

BUT, how to quench J1000+0234?

AGN heating and then mass quenching?

Summary

- LABs: observational signatures of galaxy over-densities at high redshifts, within which galaxy mergers can trigger intense star formation and AGN episodes.

- The clustering around J1000+0234 agrees with the proposed evolutionary link between SMGs in rich environments and local elliptical galaxies that reside at the center of galaxy clusters.

- The HeII line is key to study the gas kinematics within LABs. It helps to refute an expanding shell model and supports a scenario of overlapping clouds.

Status: draft submitted to MUSE consortium and COSMOS team for final round of suggestions…