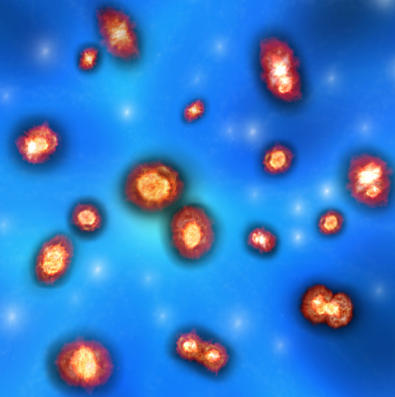


“A decade of discoveries with MUSE and beyond”  
Munich, Nov. 22, 2024

# Mpc-scale cosmic web filaments at a $z=3$ proto-cluster core



Hideki Umehata (Nagoya Univ.)



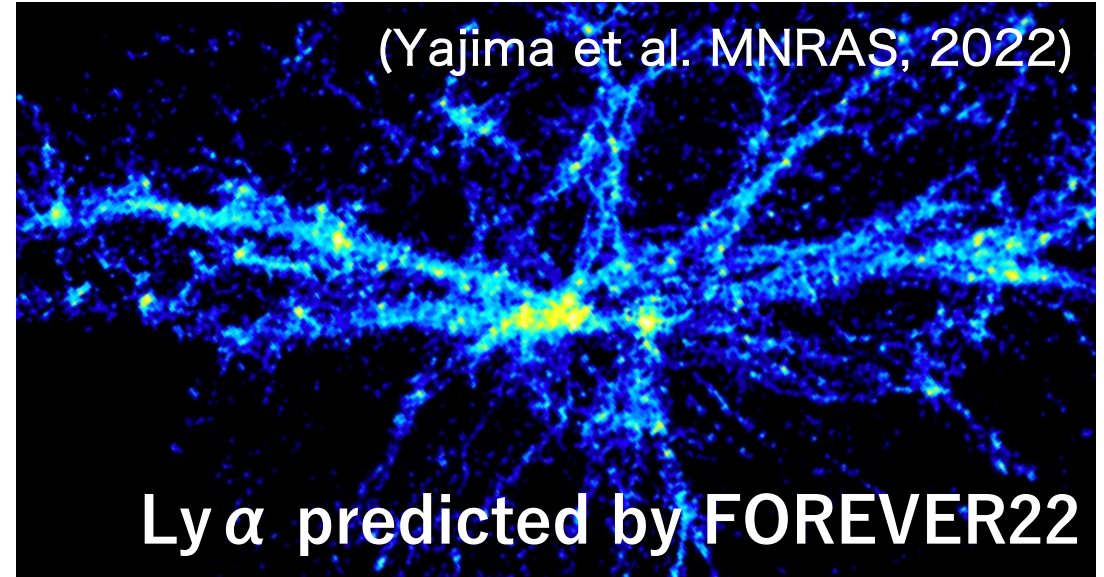
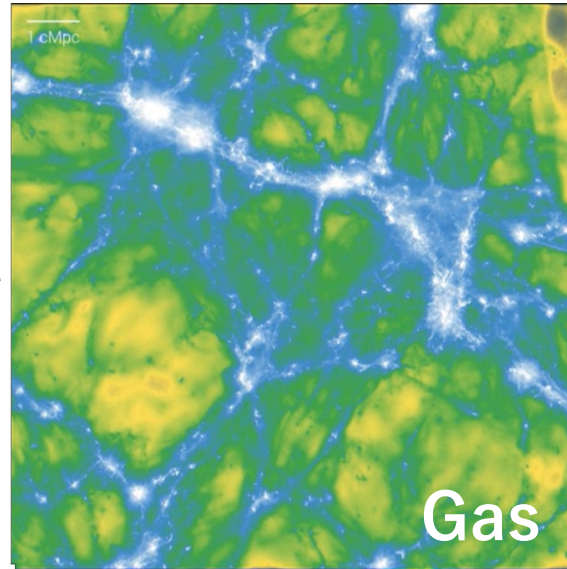
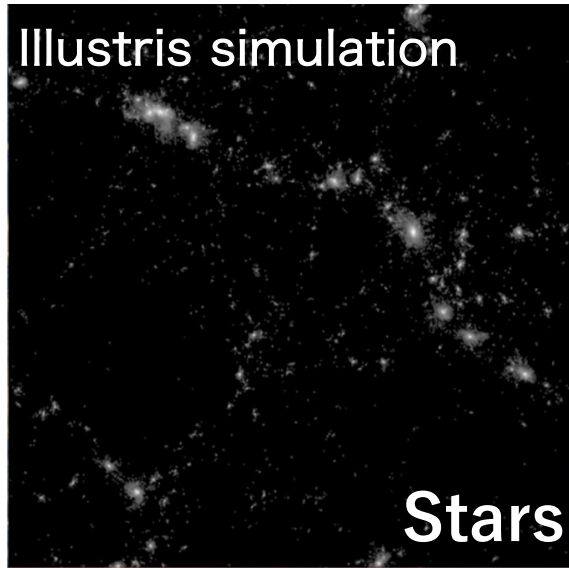
名古屋大学  
高等研究院



ADF22-WEB



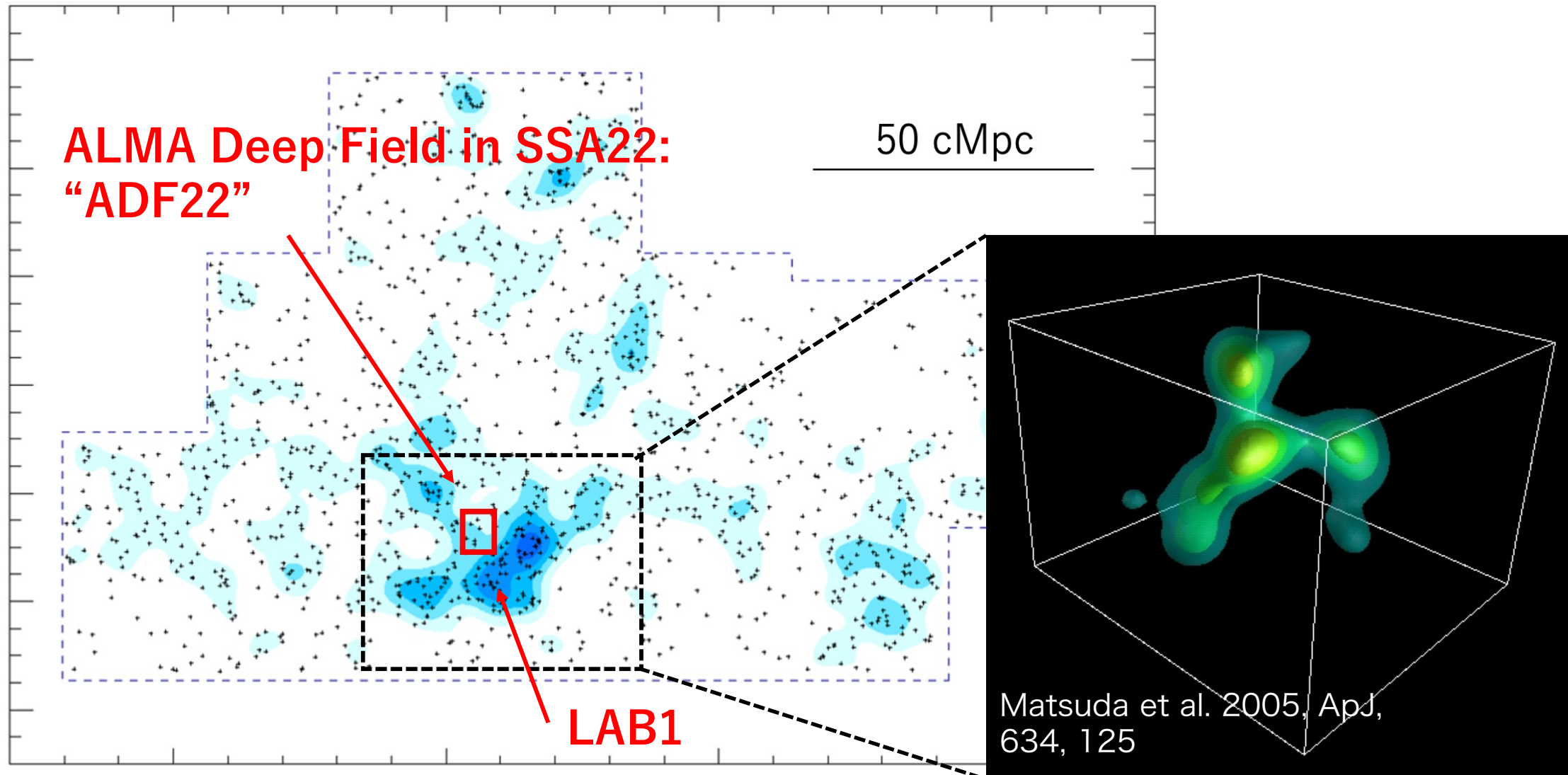
# Outline



- I. Discovery of the cosmic web filaments with MUSE/Subaru
- II. The nature of a giant Ly  $\alpha$  nebula revealed by MUSE/ALMA
- III. A giant barred spiral starburst galaxy in the filaments
- IV. Prospects: mapping the cosmic web filaments in 3D

# The SSA22 proto-cluster at $z=3.1$

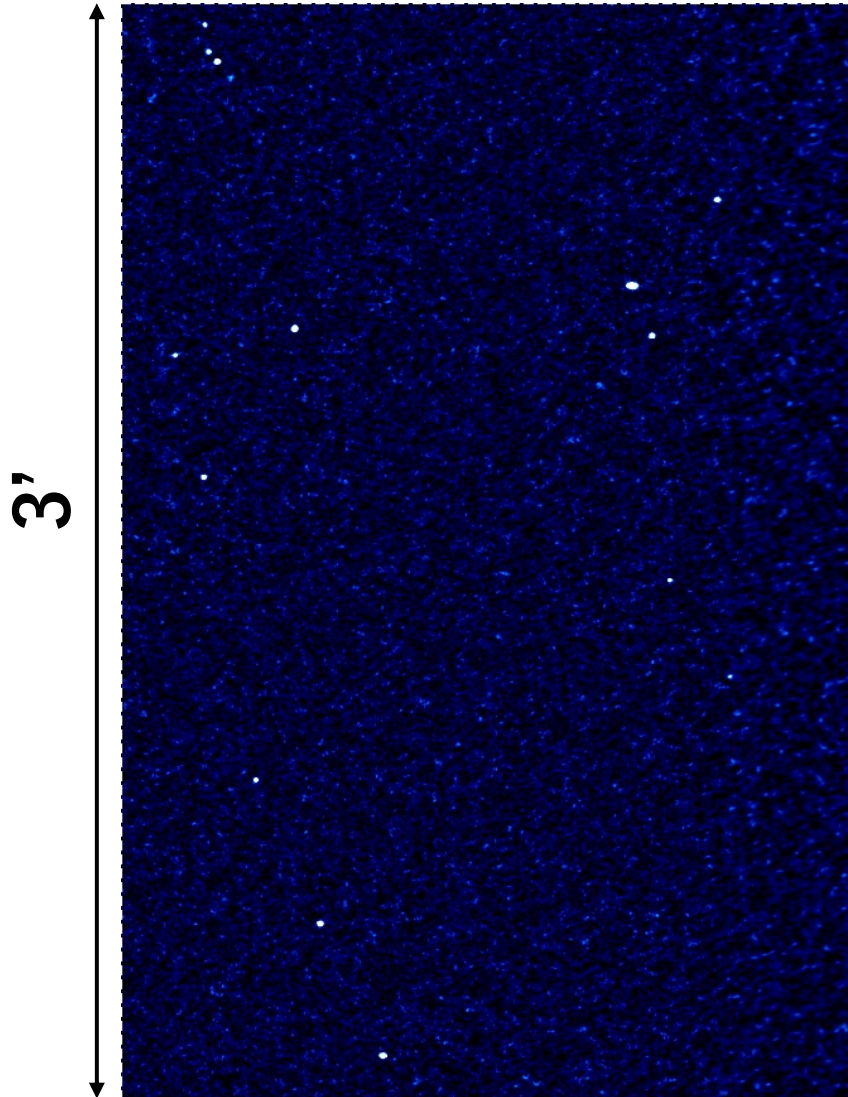
Yamada et al, 2012, AJ, 143, 79



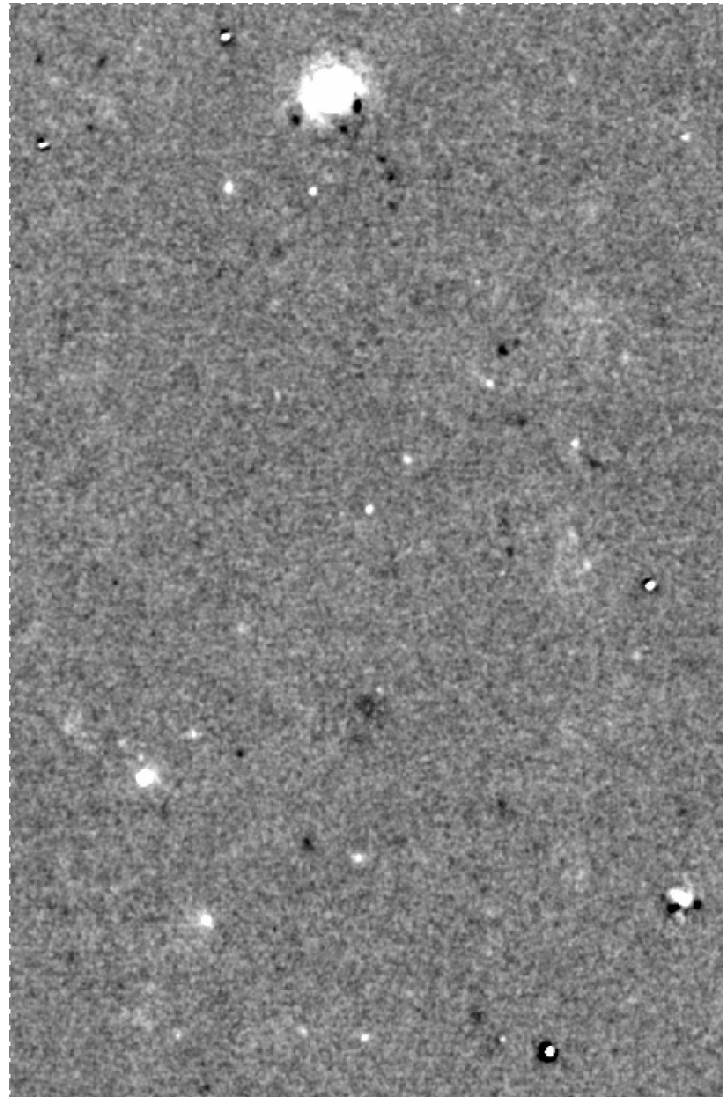


# History: Suprime-Cam to MUSE

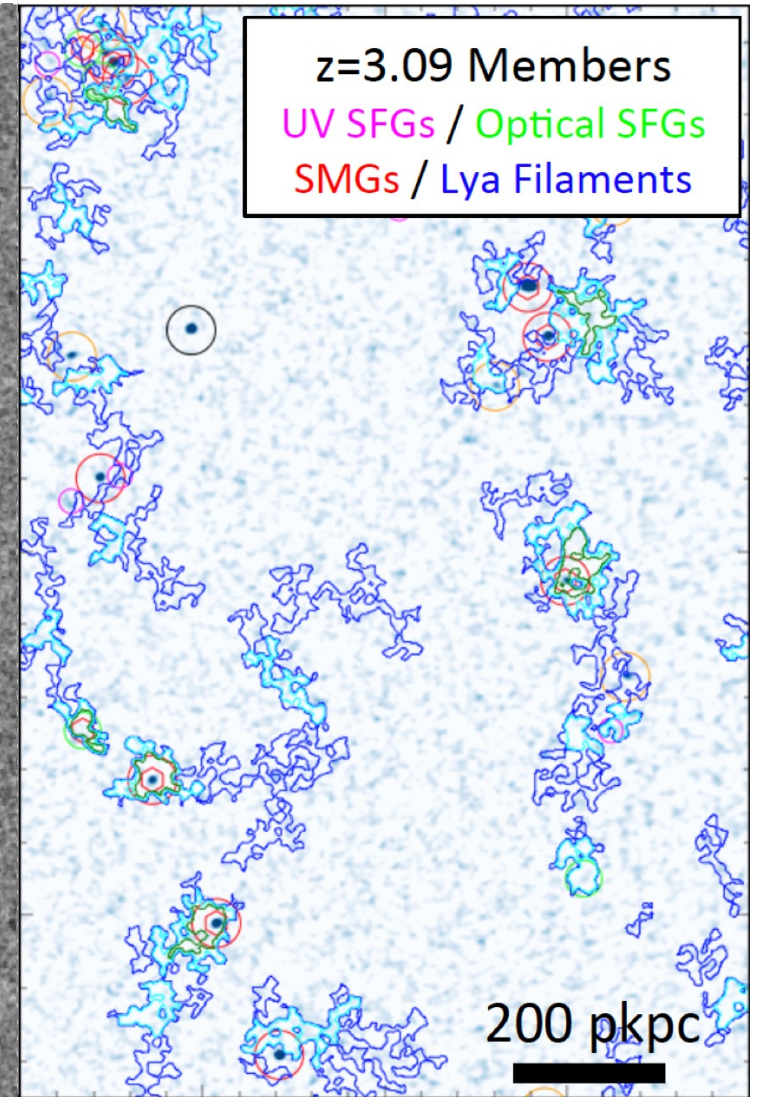
ALMA 1mm



Subaru Ly  $\alpha$

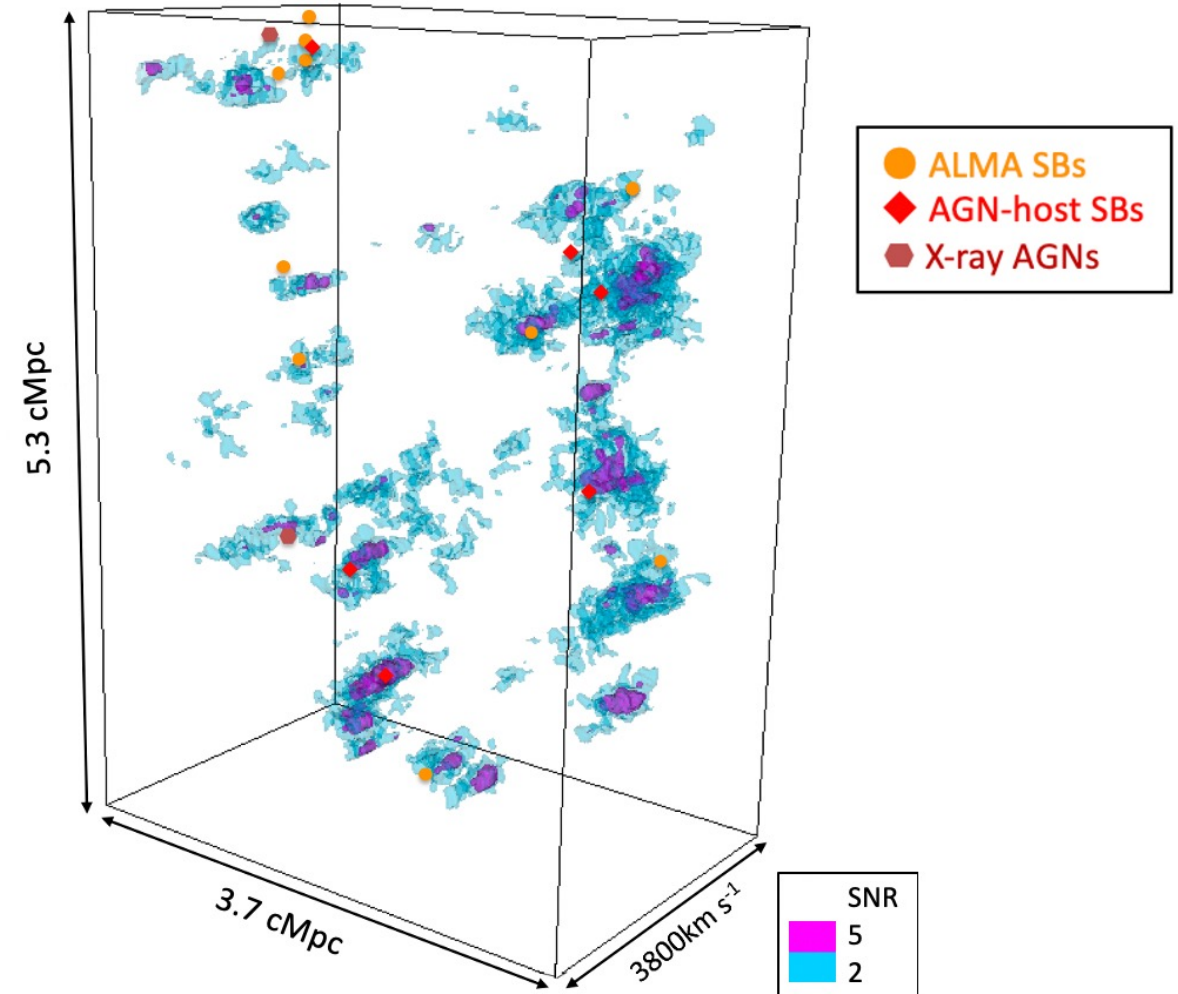
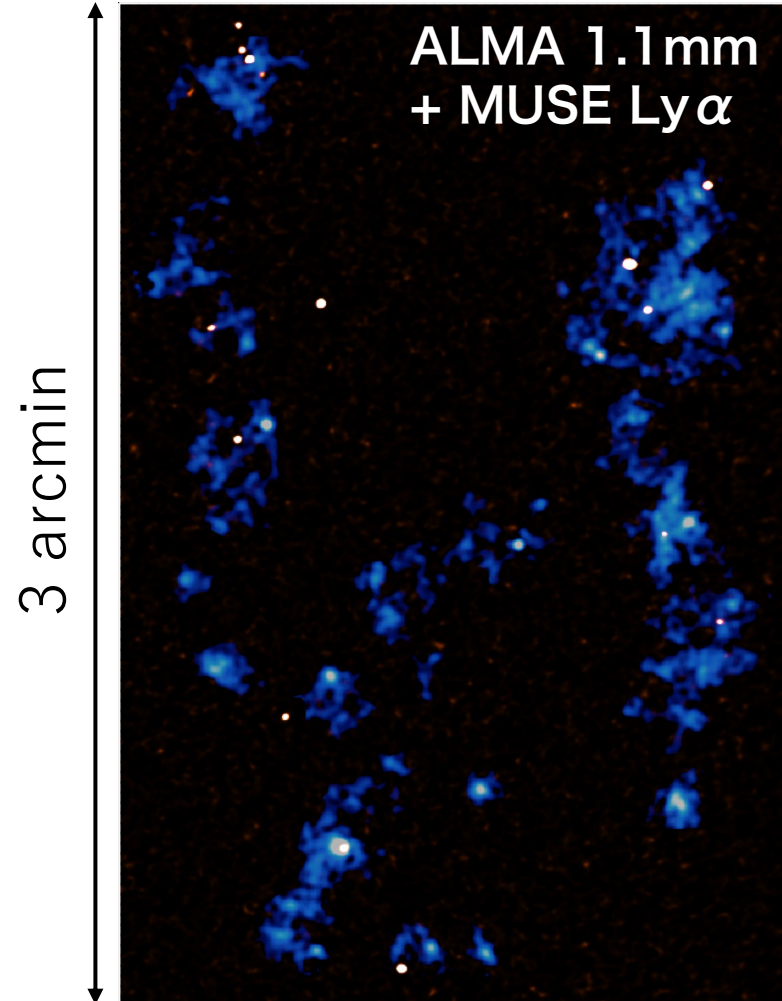


Filament Candidates





# Discovery of Mpc-scale Ly $\alpha$ filaments

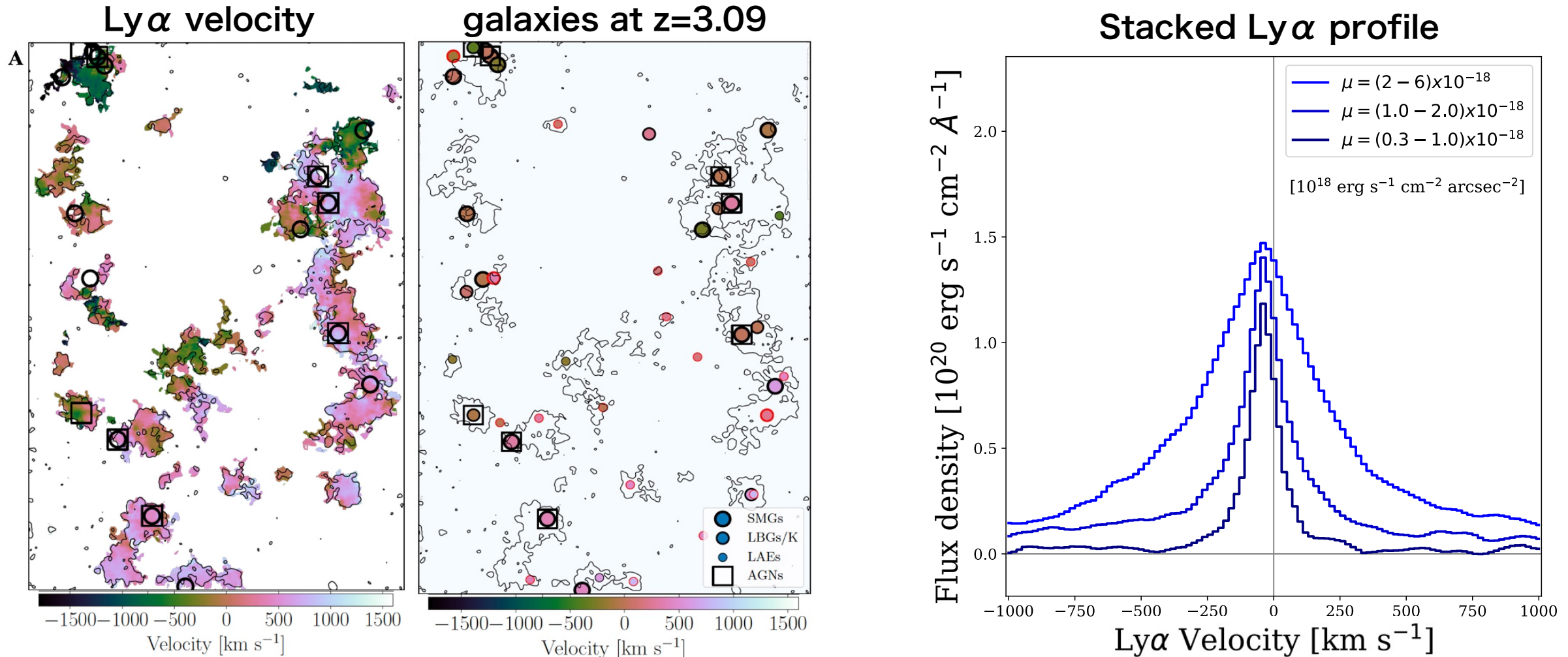


Umehata et al. 2019, *Science*, 366, 97

- All of DSFGs and X-ray AGNs are embedded within the Ly $\alpha$  filaments.
- The high-level activity is plausibly fueled by the cosmic web filaments.



# Discovery of Mpc-scale Ly $\alpha$ filaments

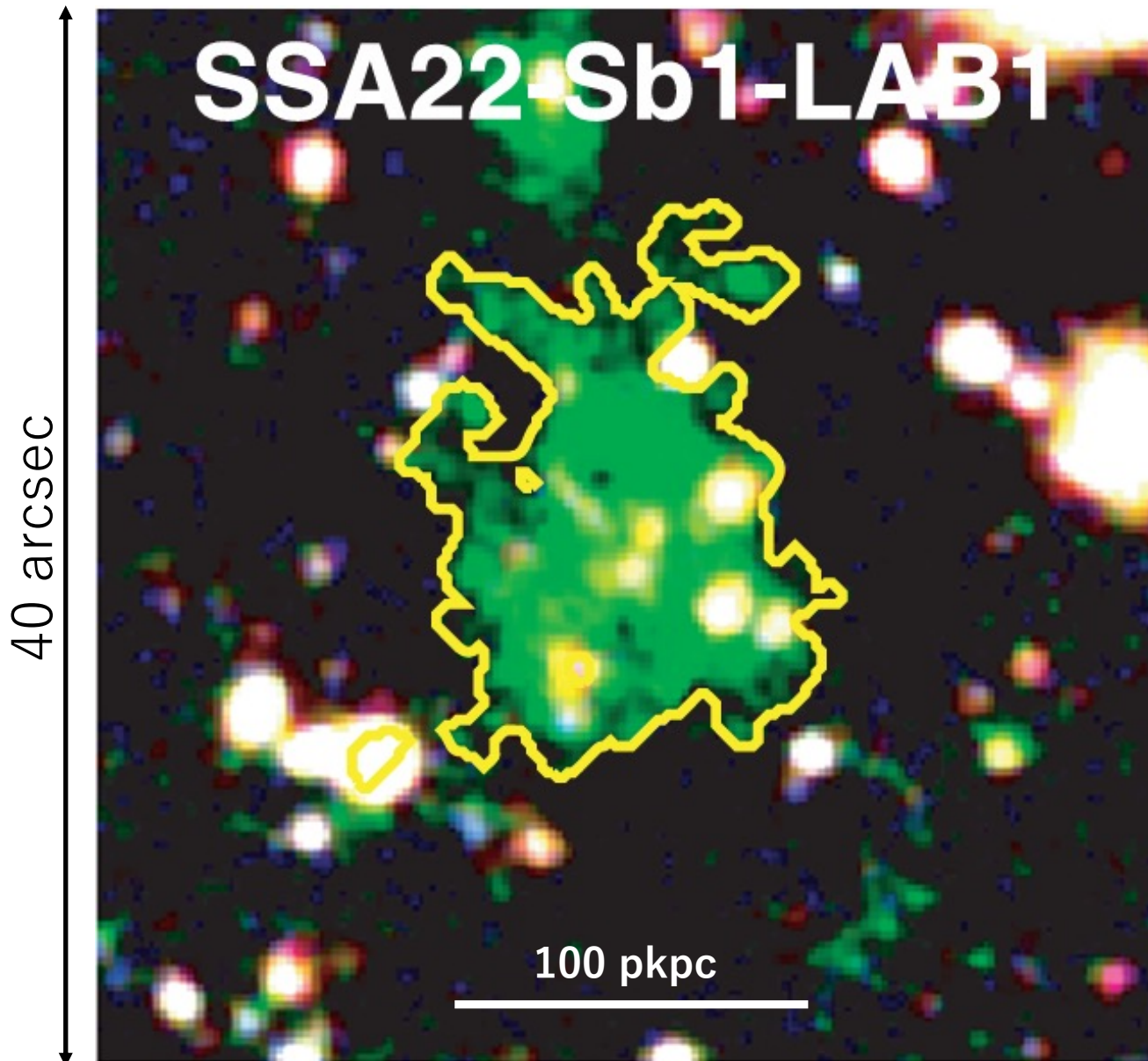


Umehata et al. 2019, *Science*, 366, 97

- Ly $\alpha$  emission is widely distributed into the intergalactic space.
- Fainter filaments are kinematically cooler.



# 3D views of a giant Ly $\alpha$ Blob, LAB1



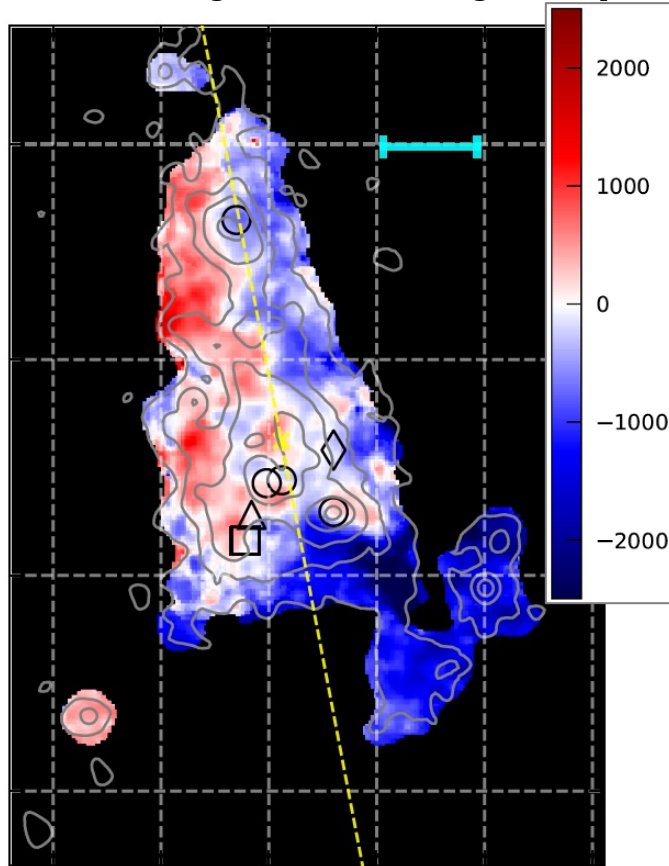
- LAB1 is one of the two brightest and largest LABs in the proto-cluster.
- There has been hot debates on the origins and power sources.

Matsuda et al, 2011, 410, L13  
(Steidel et al. 2000, ApJ, 532, 170)

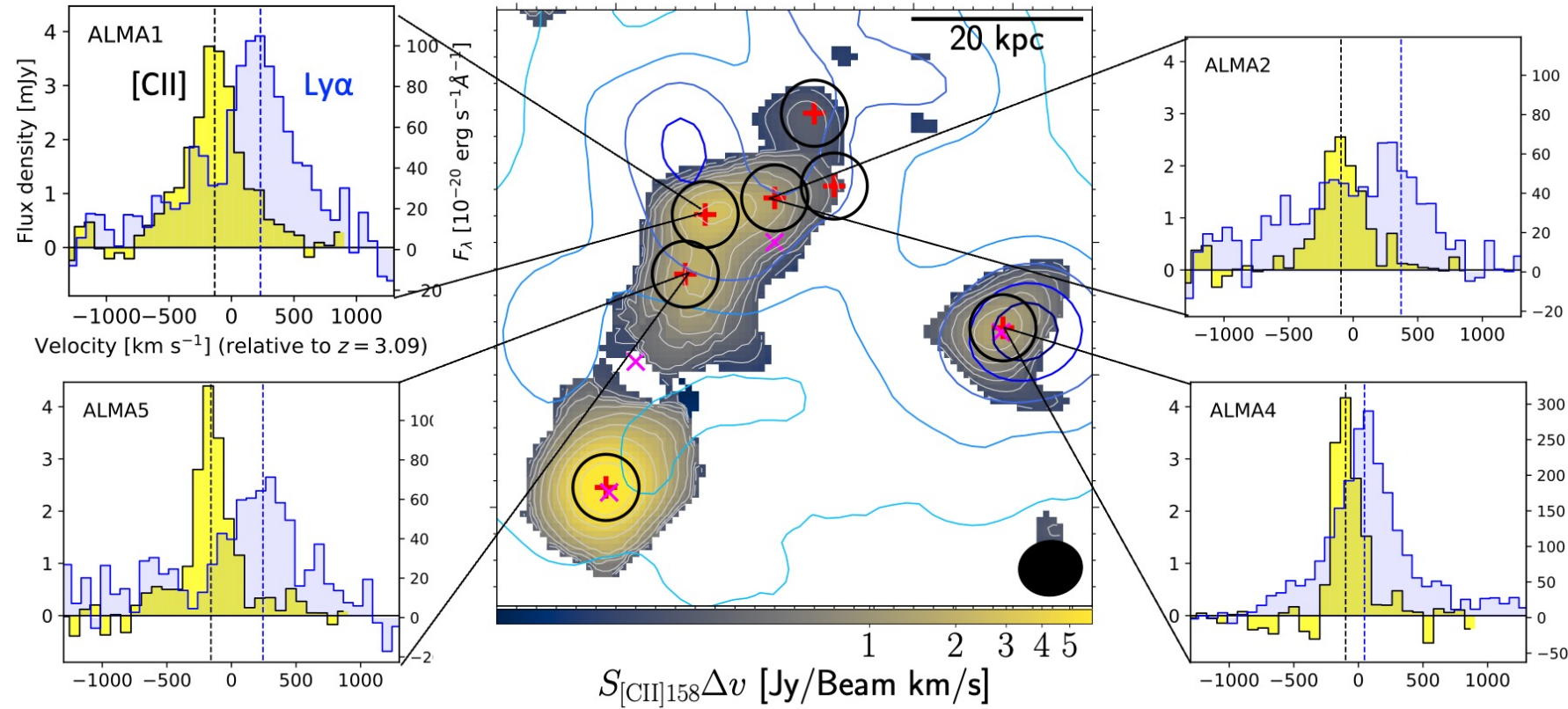


# 3D views of a giant Ly $\alpha$ Blob, LAB1

MUSE Ly $\alpha$  velocity map



[CII] 158 $\mu$ m + Ly $\alpha$  contours



Herenz et al. 2020, A&A, 642, 55  
(Geach et al. 2016, ApJ, 832, 37)

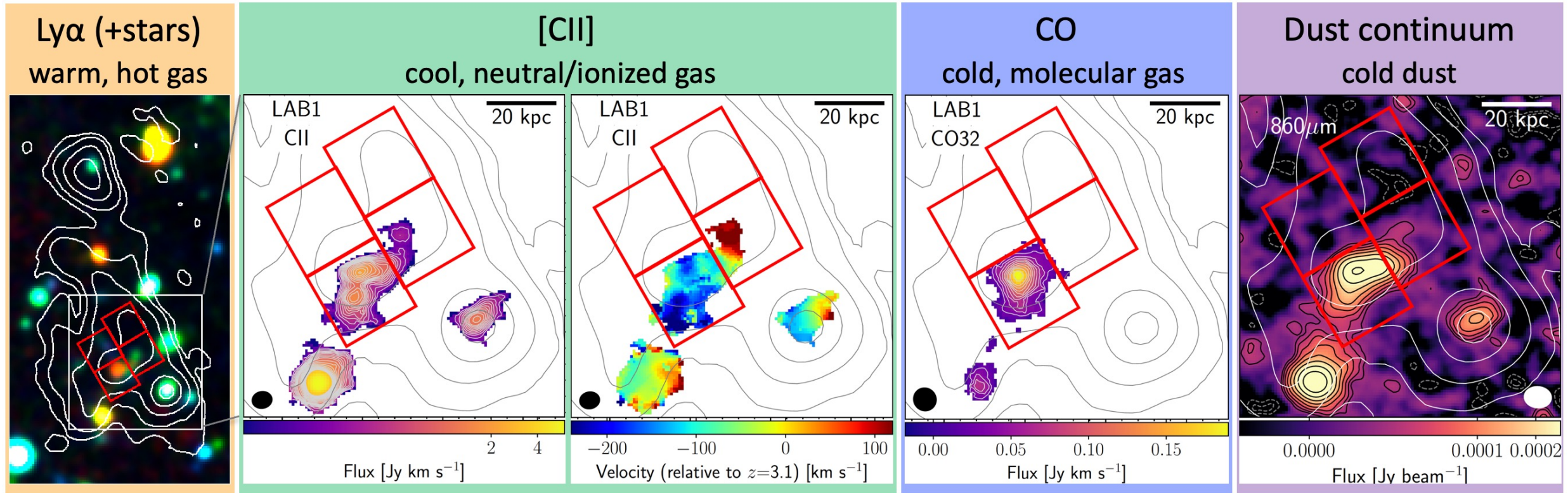
Umehata et al. 2021, ApJ, 918, 69

- Multi-phase gas kinematics are available by MUSE and ALMA.
- “central heating + scattering” may be a dominant (but not only) scenario.



# HORIZON: “H $\alpha$ Observation and Research of Intergalactic ZOnes and Networks”

# HORIZON

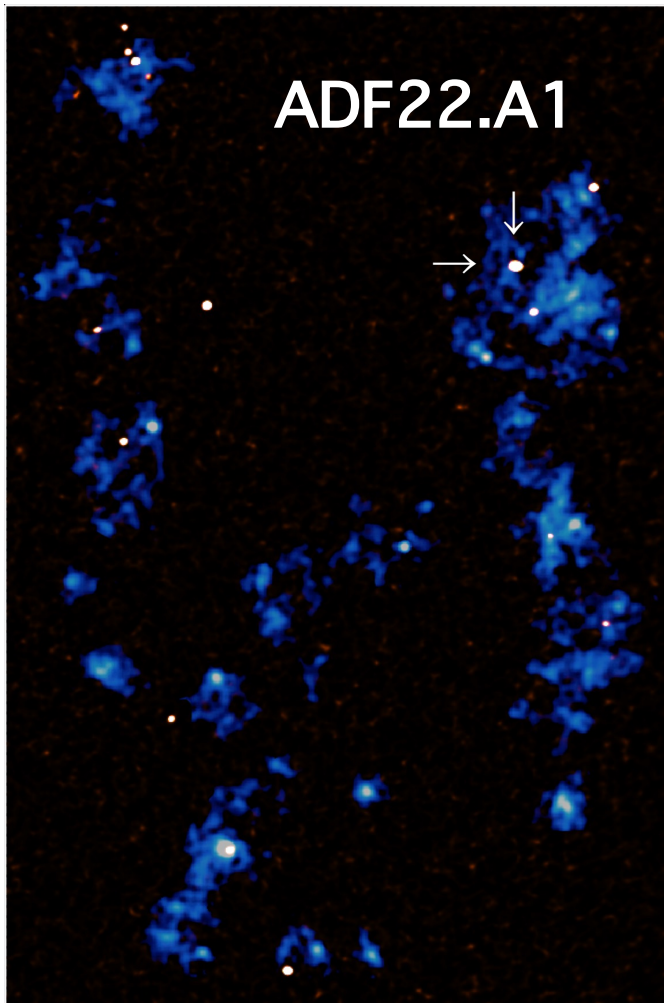


- 25 hrs NIRSpect-IFU observation of SSA22-LAB1 is scheduled (Pls. Umehata & Steidel).
- Spatially resolved H $\alpha$  mapping across the prototypical LAB at  $z=3$ .

# “ADF22-WEB” Project



**ADF22-WEB**



## MUSE (PI. Umehata)

- $\text{Ly}\alpha$ , CIV, H $\alpha$

## ALMA+JVLA (PI. Umehata)

- Dust continuum in B3, B6, B7, B8.
- CO(1-0), CO(3-2), CO(8-7), CO(9-8), CO(12-11), [CII], H<sub>2</sub>O, OH+, CH+, ...

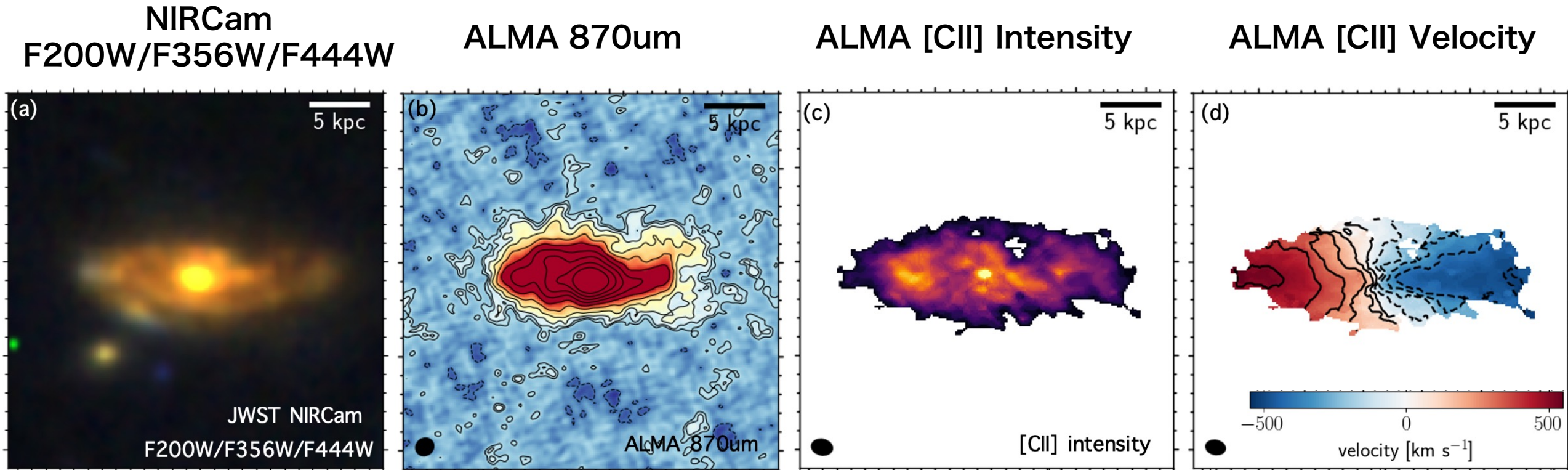
## JWST (PI. Umehata)

- NIRCam: F115W, F200W, F356W, F444W.
- MIRI: F770W, F2100W

+ HST/ACS, Chandra, Subaru, ...



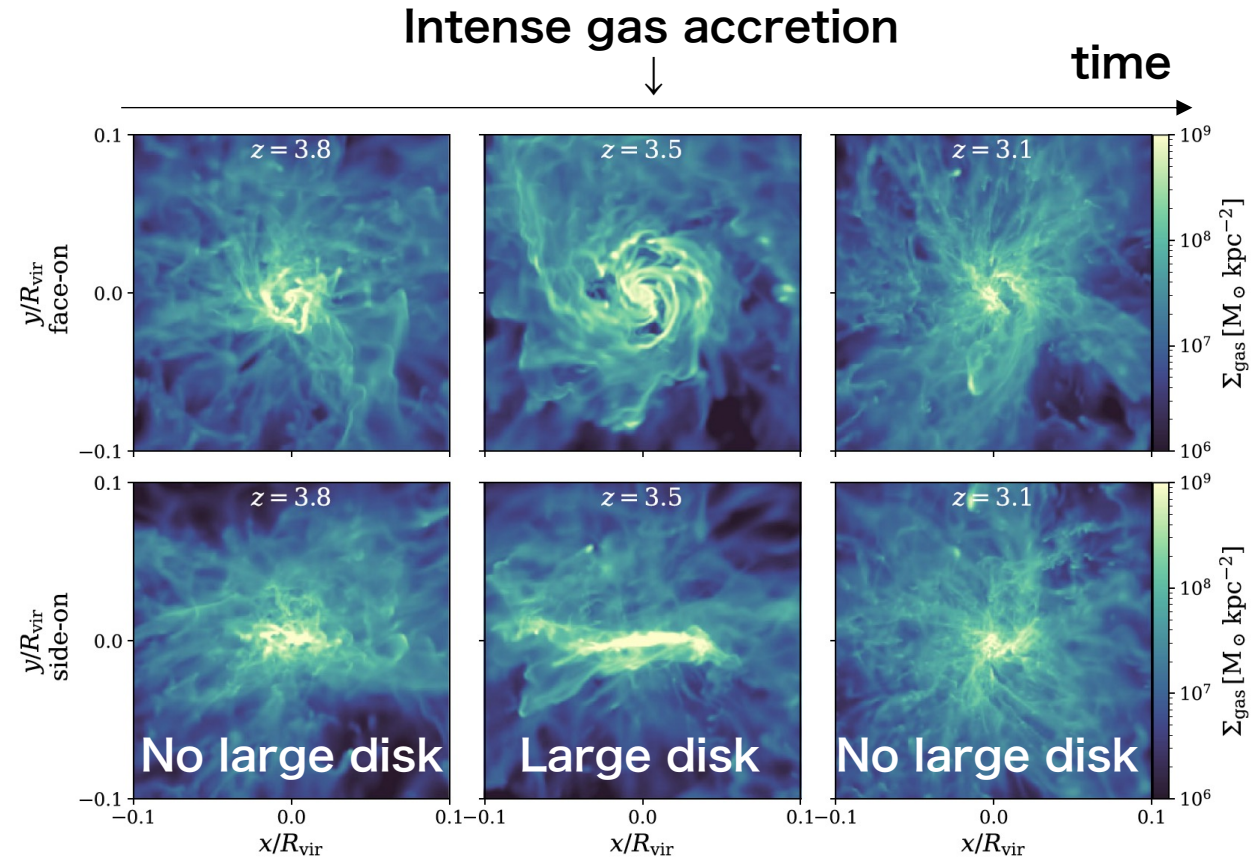
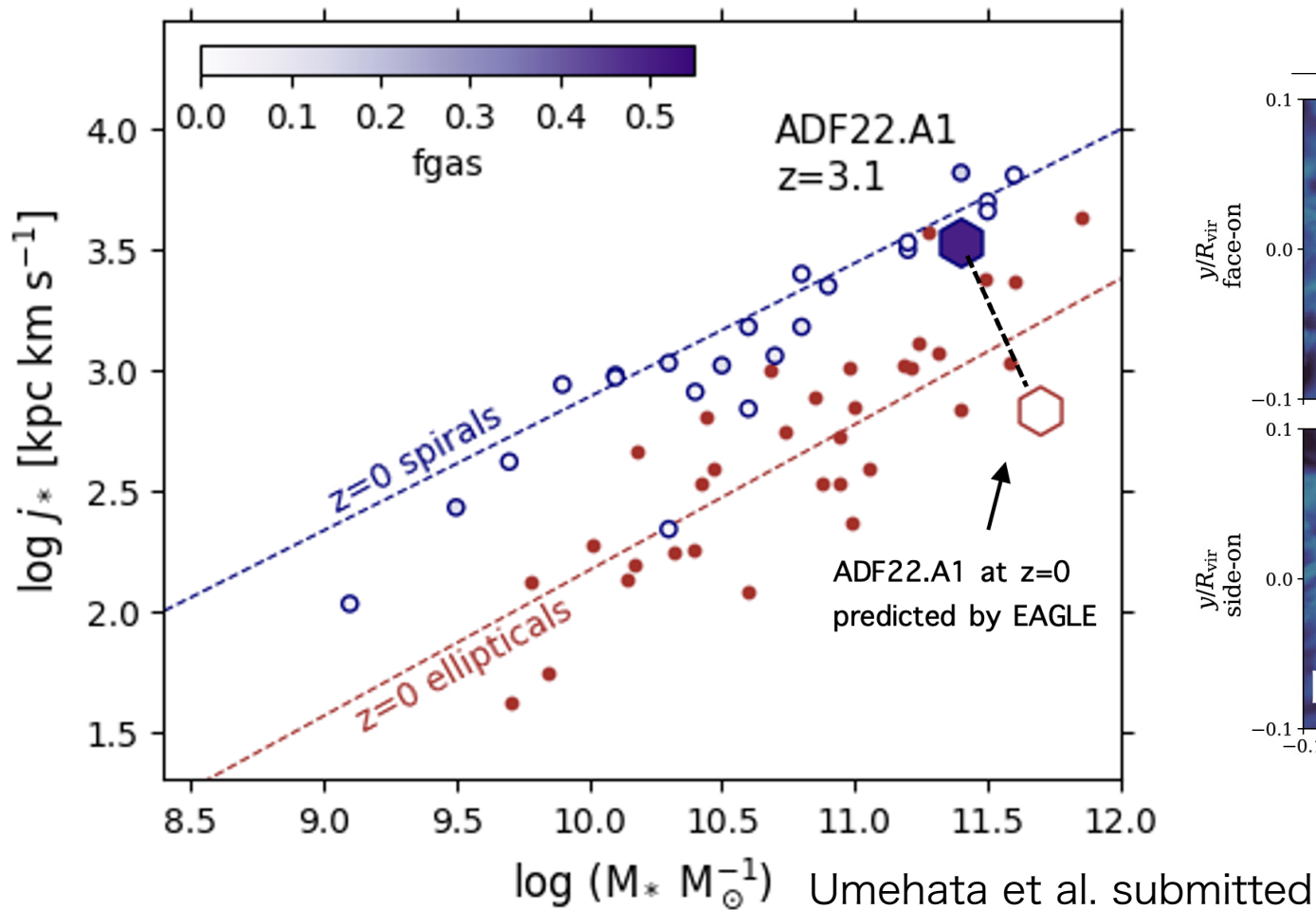
# Stars, Dust, Gas at kpc-scales at $z=3.1$



Umehata et al. submitted

- We have mapped stellar emission, dust continuum, and [CII] at  $\sim 0.2''$ .
- ADF22.A1 is a giant gas-rich spiral, while it is a brightest DSFG.

# Specific stellar angular momentum

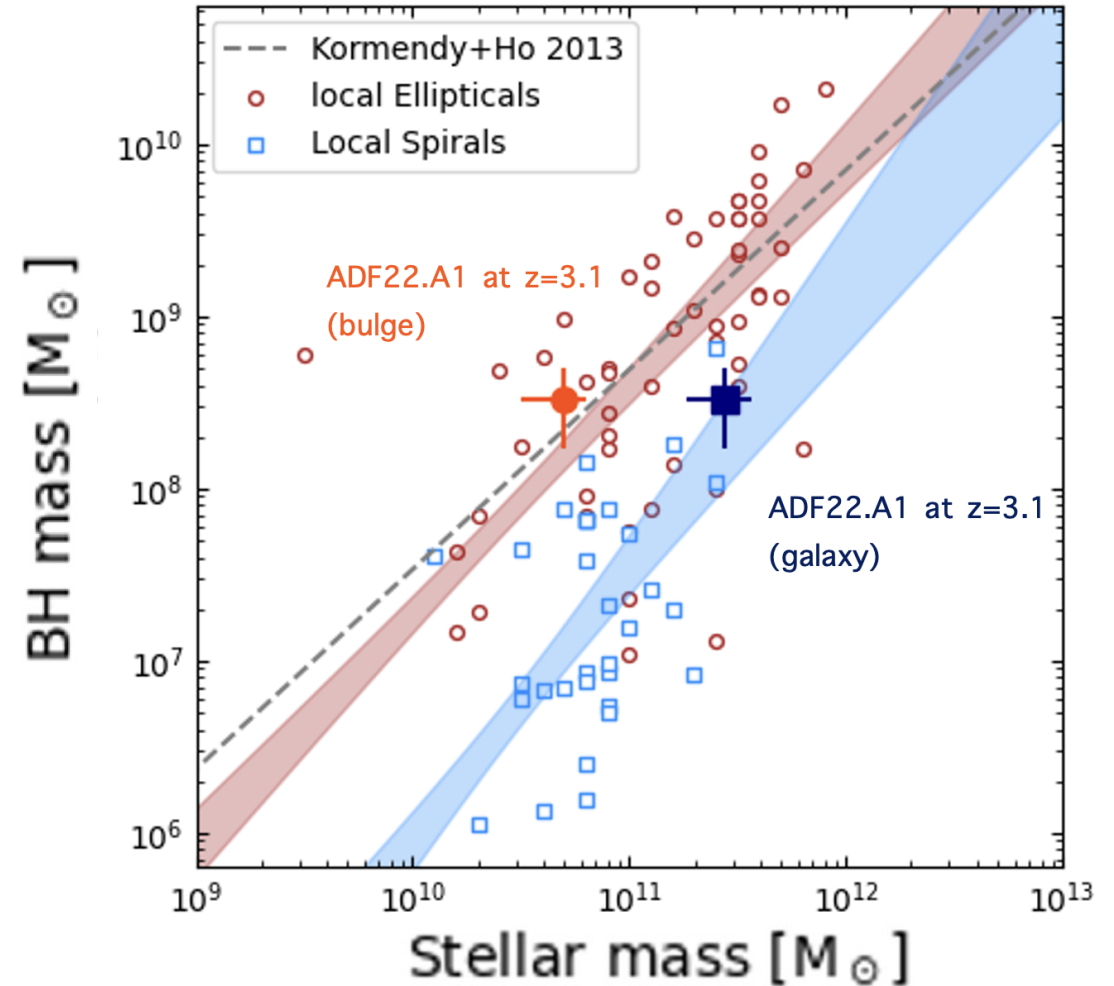
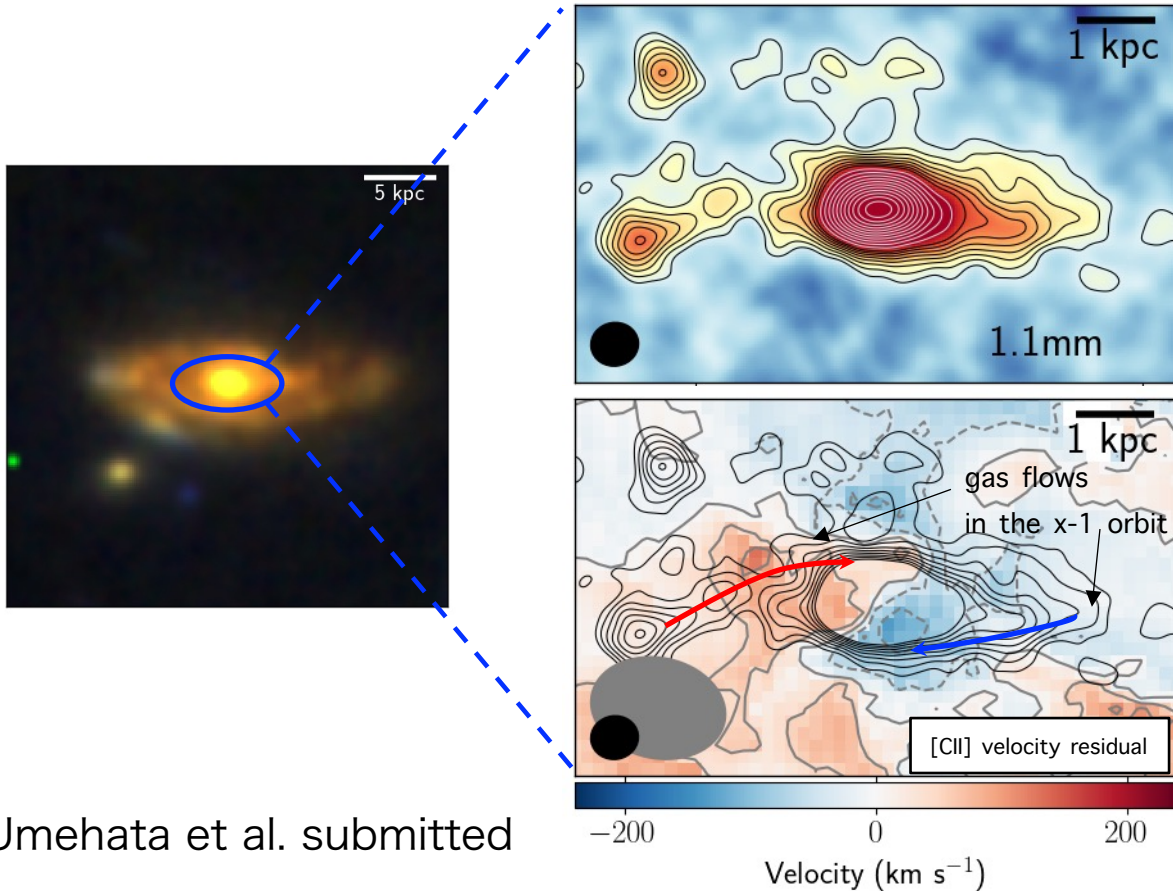


Kretschmer et al. 2022, MNRAS, 3266, 3275

- Intense accretion of co-planar, co-rotating gas via cold stream may be a key to make such a “giant, gas-rich spiral” at  $z > 3$ .
- Mergers can also contribute to increase the size and mass.



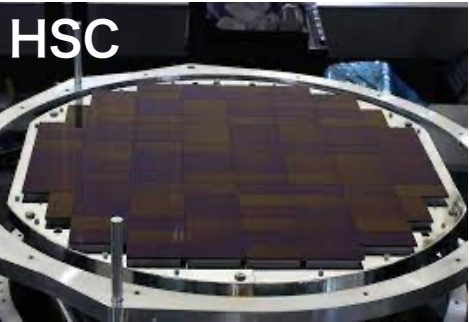
# Bar-driven co-evolution at $z=3$



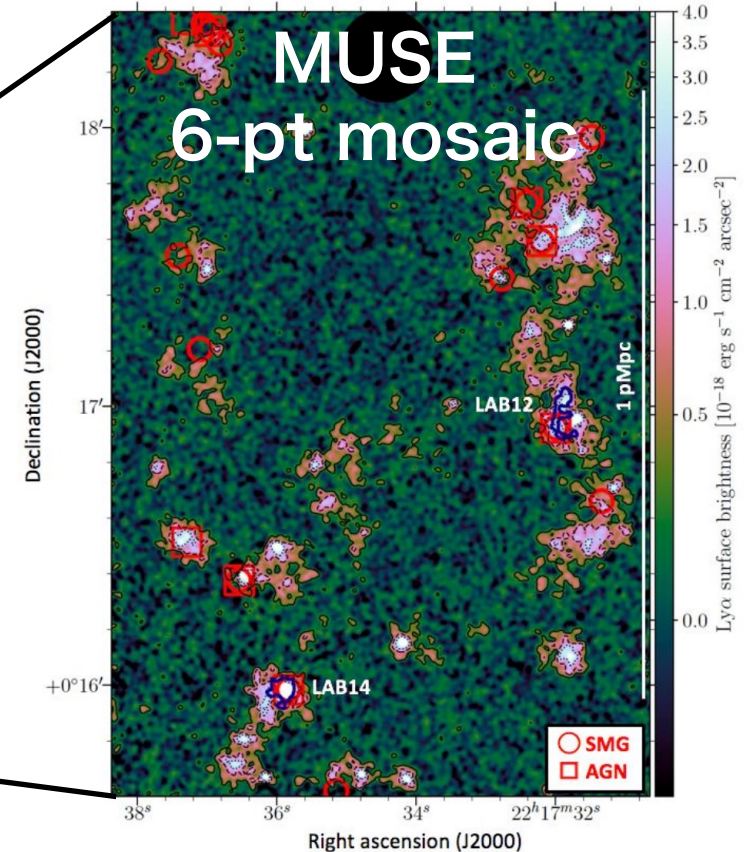
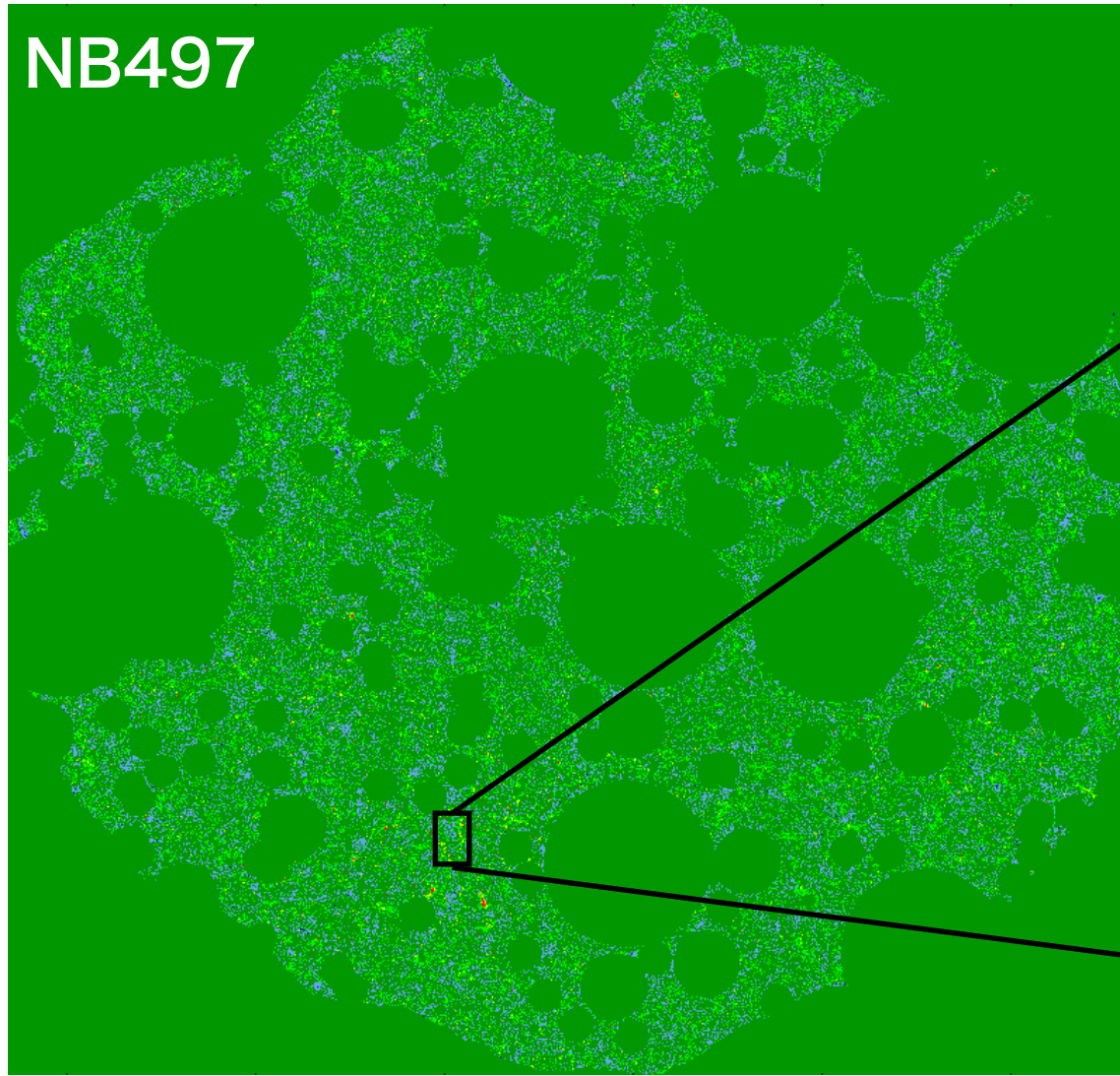
- A “hidden” dusty bar has been discovered by ALMA.
- $M_{\text{BH}}/M_{\text{bulge}}$  matches with the local relation, suggesting the emergence of the scaling relation at  $z>3$  driven by bars.

# MIRACLES: Ly $\alpha$ mapping on 100 cMpc scales

- Subaru Intensive Program (Pl. Y. Matsuda at NAOJ, ~100hrs)
- Deep and wide Ly $\alpha$  mapping in SSA22

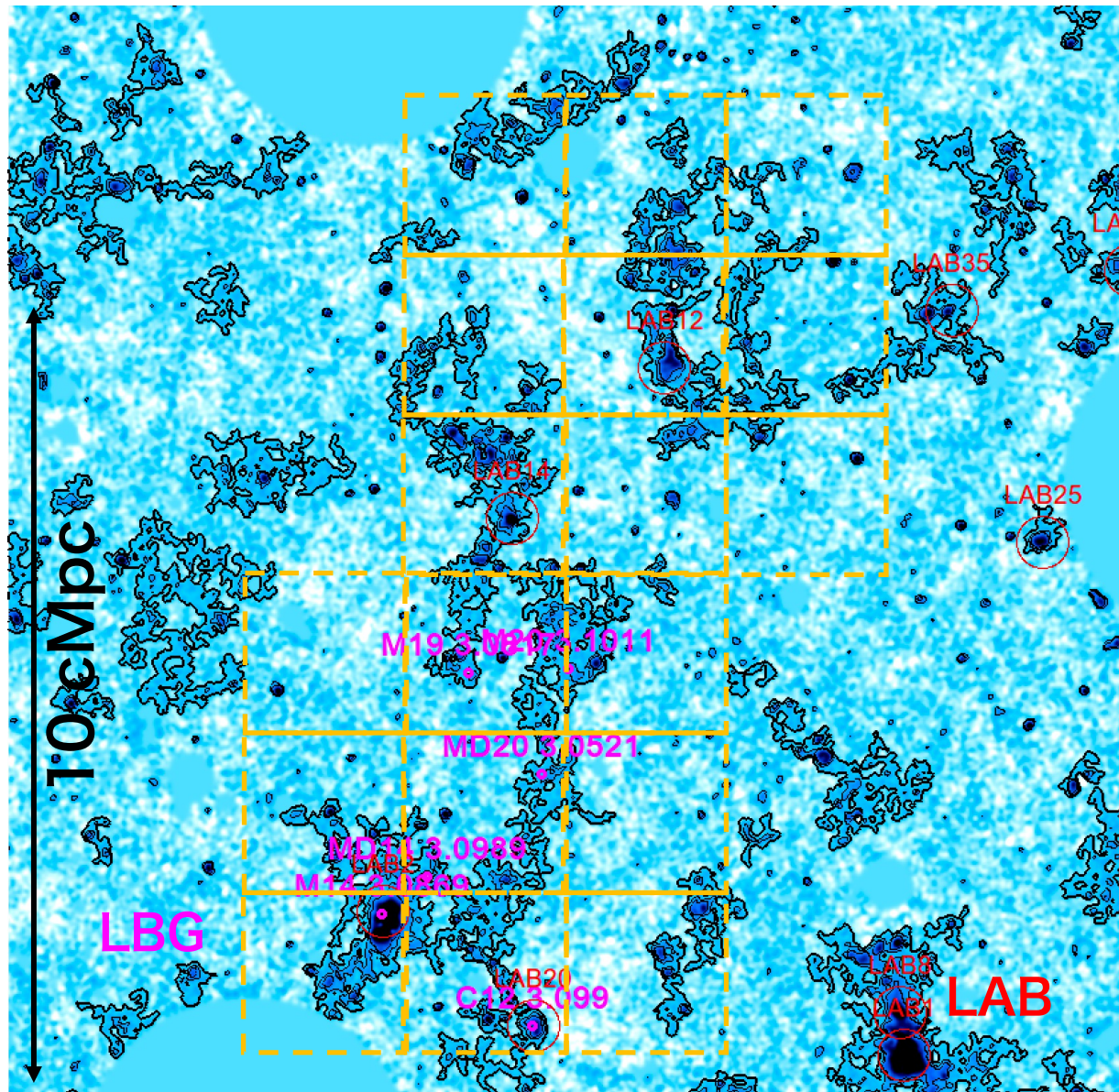


NB497





# Prospects for Blue-MUSE / WST

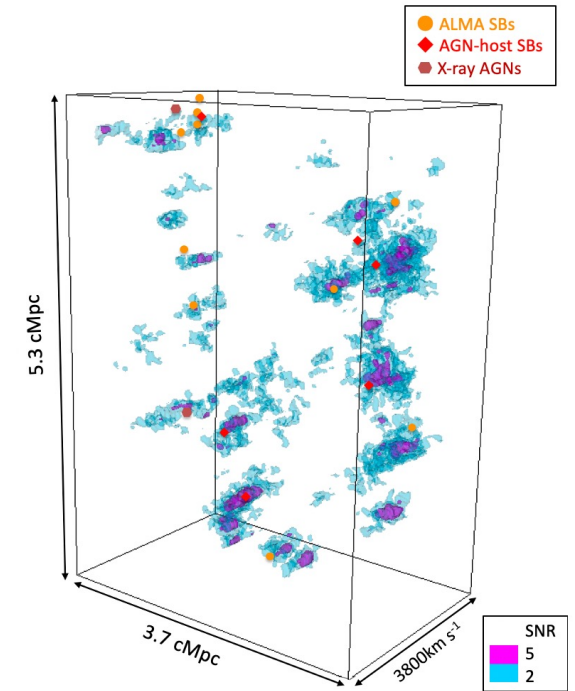


Umehata et al. in prep.

- Ly $\alpha$  filaments are being detected on a cosmological scale.
- Now we have a “map” to indicate distributions of baryons and ionizing photons.
- Blue-MUSE/WST will uncover 3D structures, kinematics, and physical/chemical conditions.

# Take-home messages

- The cosmic web filaments has been delineated by Ly $\alpha$  emission on scales of several-100 cMpc in the early universe.
- It is now possible to investigate how galaxies and SMBHs form and evolve within the cosmic web filaments.
- MUSE plays a key role. Blue-MUSE and WST must be essential to further develop such a research field.



**ADF22-WEB**