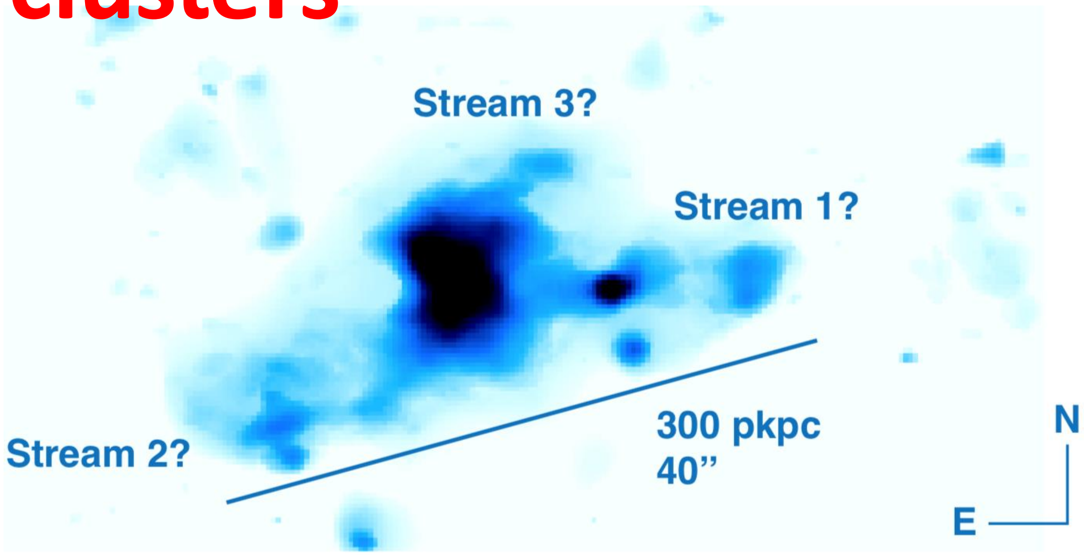
A KCWI study of Lya nebulae in high redshift clusters



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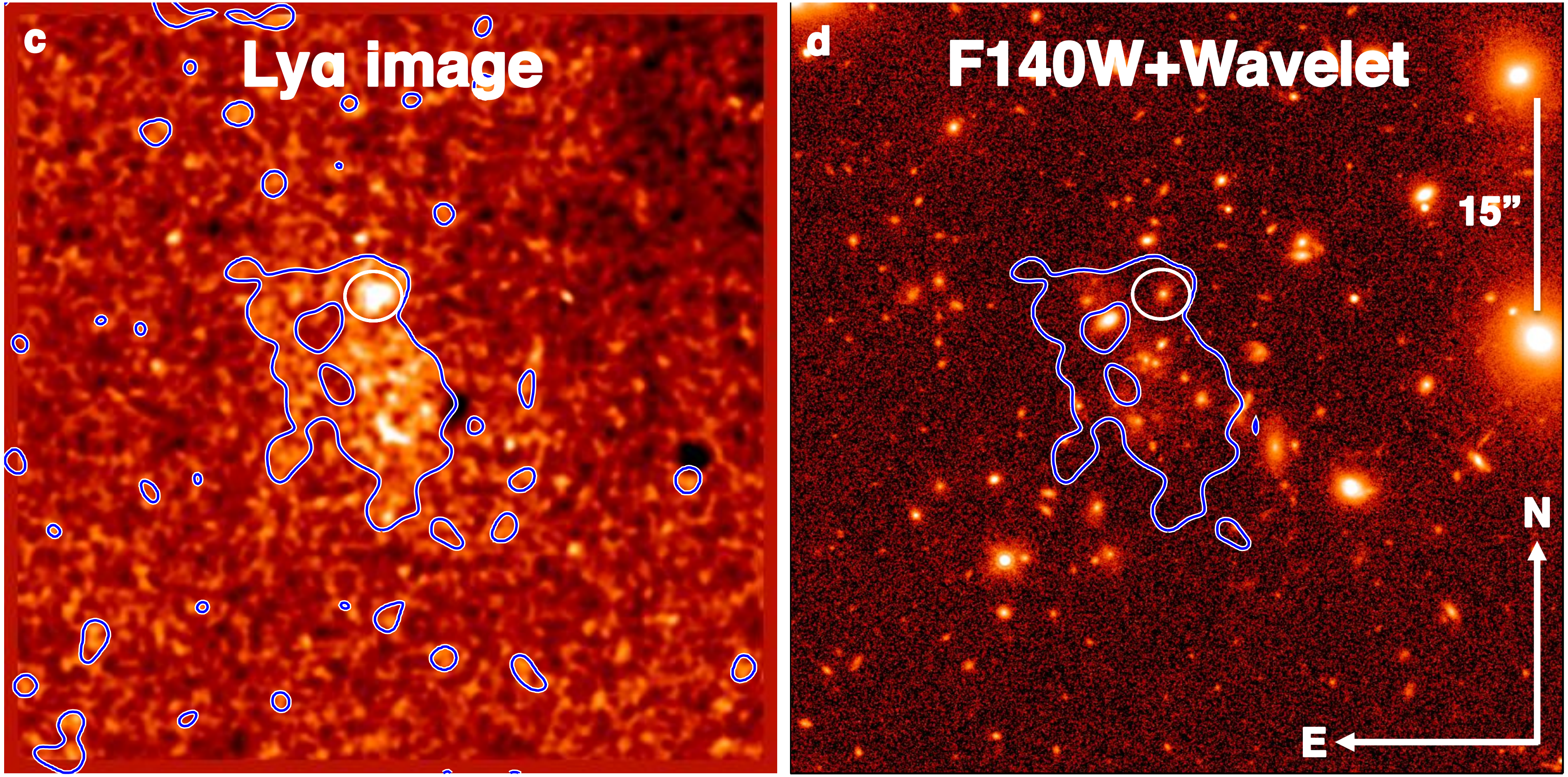
F. Valentino (Dawn)

Finoguenov, O'Sullivan, Neill, Martin, Verhamme, Marchal, Bournaud, Elbaz, Schinnerer, Cantalupo, Gobat, Jin, Liu, Calabro, Delvecchio, Strazzullo, Wang, Kalita, Coogan, Puglisi, DEugenio

Subaru 20

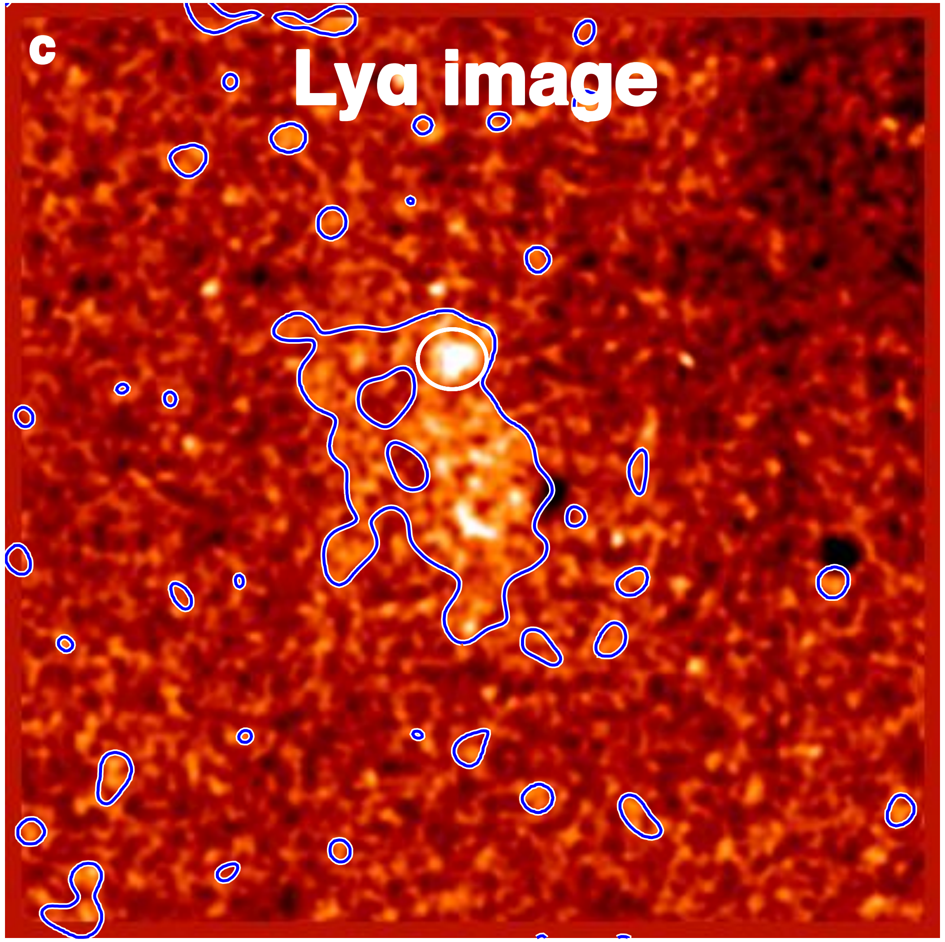
Back in 2016: surprise:
a Lya nebula, over the cluster core



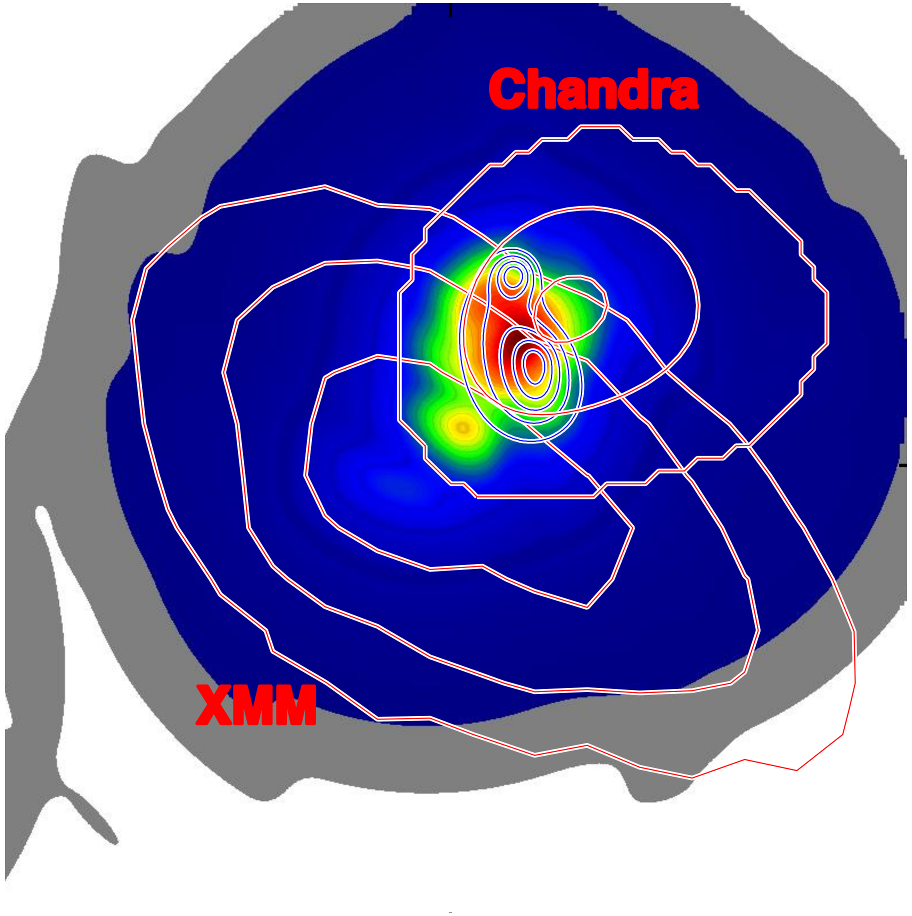
Valentino et al 2016

Cold gas co-existing with hot gas

Valentino et al 2016



Cold 10^4 K plasma



Hot 10^7 K plasma

Cold accretion required from understanding of SFR evolution

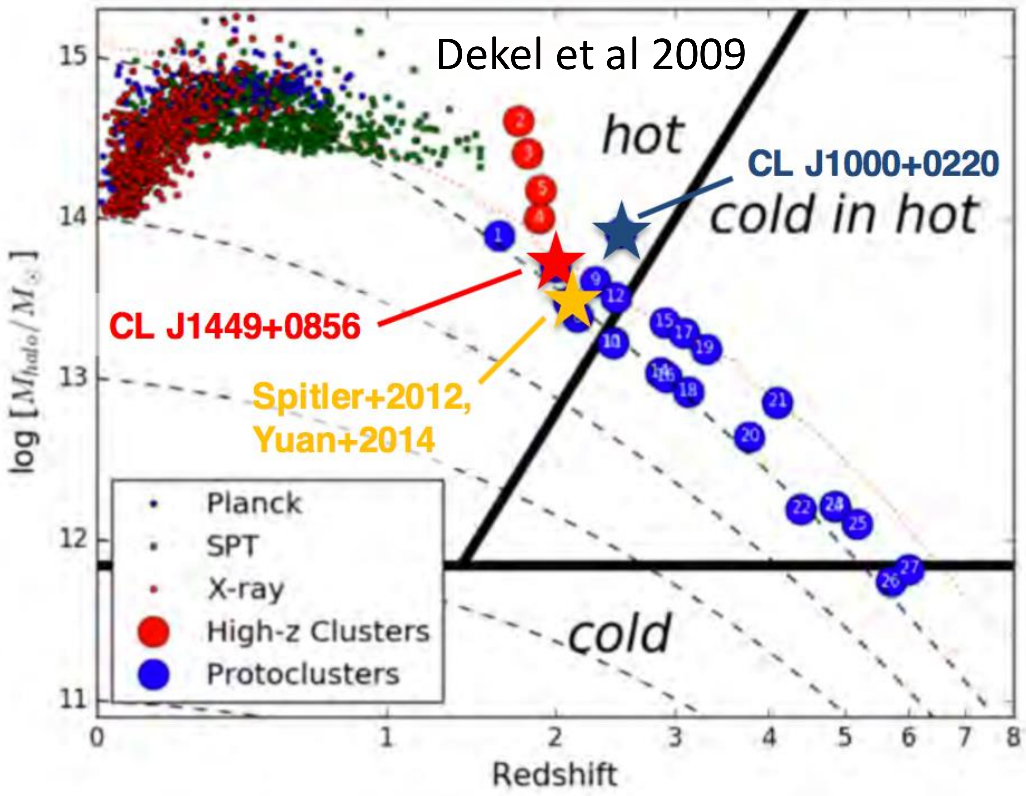
Galaxies have gas consumption times ~0.5-1 Gyr but keep going for x10 longer

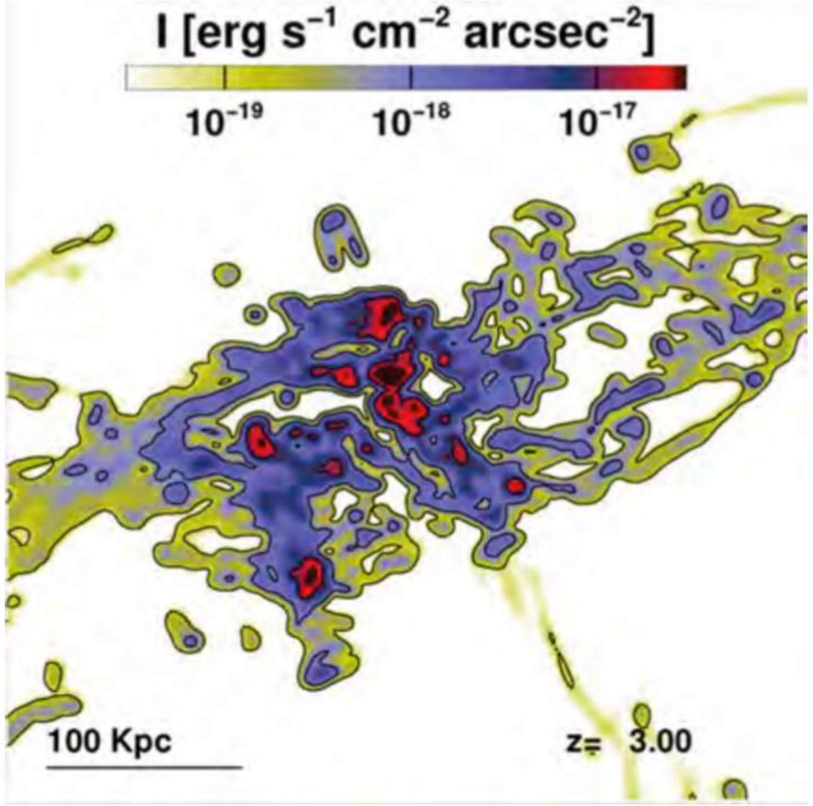
→ Need fueling and replenishment, otherwise cannot work

→ Postulate 'cold flows' accretion to maintain the 'steady state'

(predicted by theory, never convincingly/definitively observed so far)

Rosdahl & Blaizot 2012





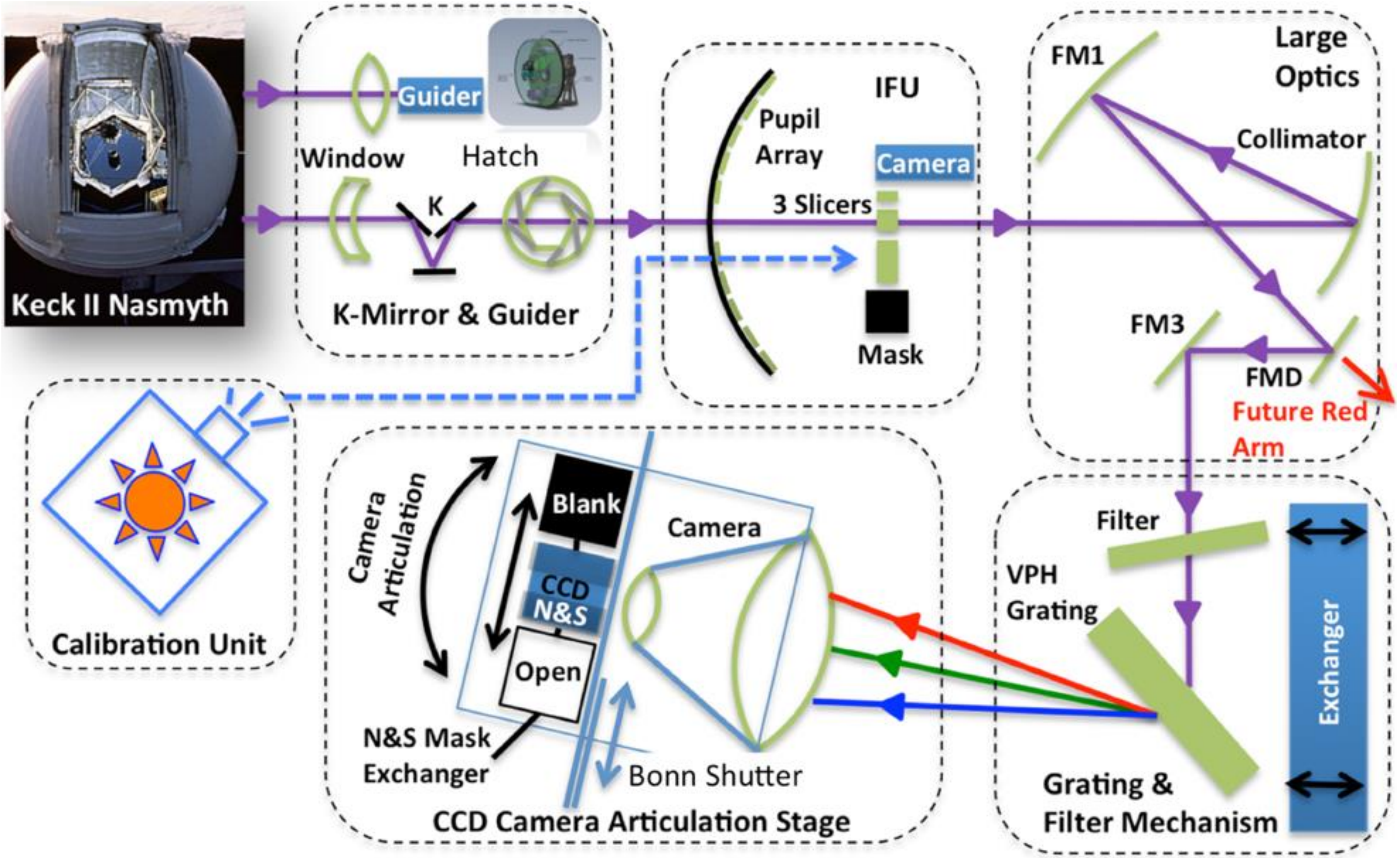
Valentino et al 2015; 2016; Overzier et al 2016

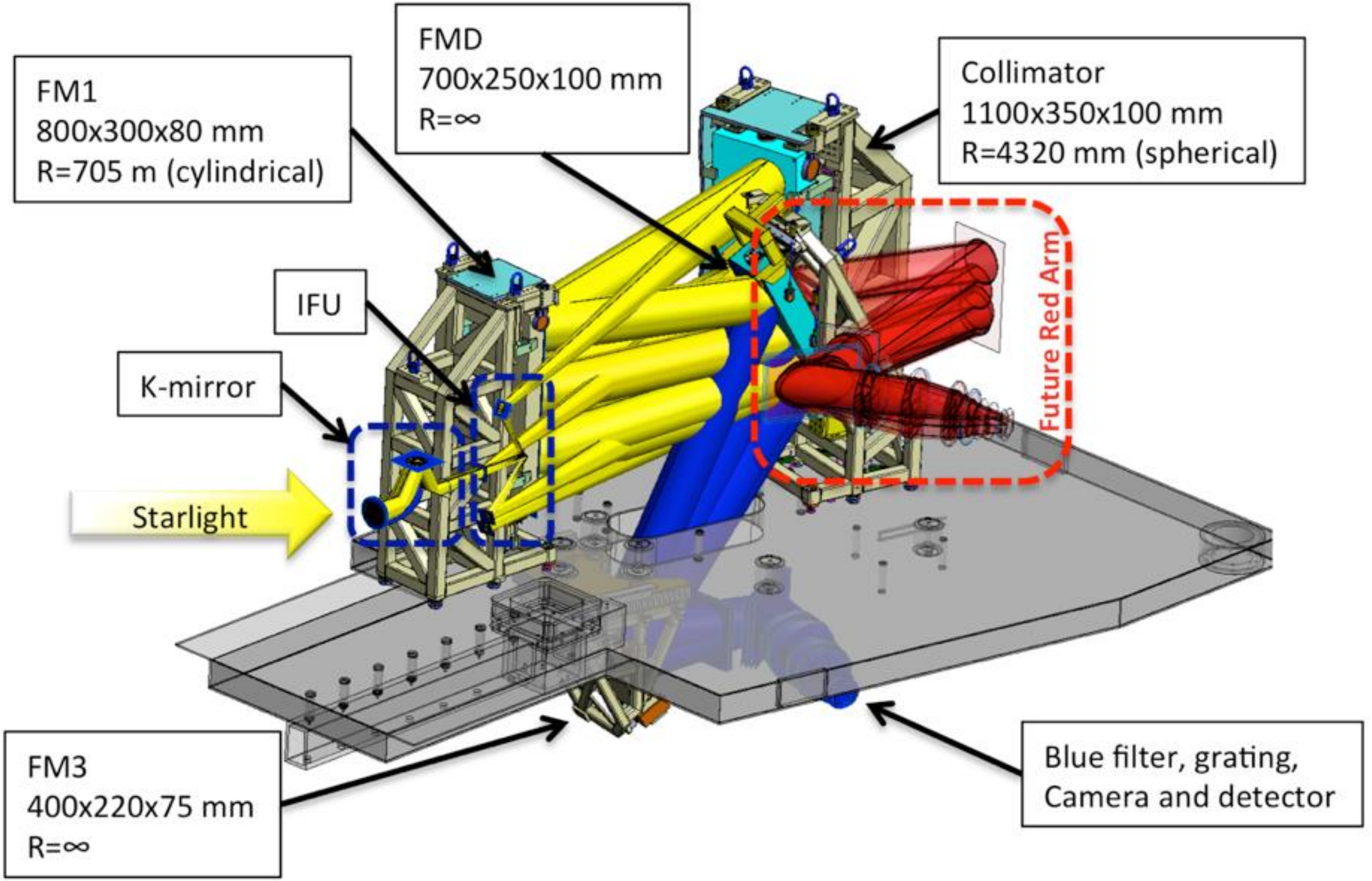
Cluster environment a place to search for lyman alpha nebulae.. However...

- Nearly all giant lyman alpha nebulae are known to be associated with high redshift quasars (e.g. Cantalupo et al.)
- The QSO provides the source of photoionization

- As member of Keck Cosmic Web imager science team, seeking out exciting science for KCWI
- Emanuele Daddi notes that MUSE cannot go blueward of 4500A; - an opportunity
- Observations in 2018 January and 2019 February

Keck Cosmic Web Imager is an integral field unit




FMD
700x250x100 mm
R=∞
FM1
800x300x80 mm
R=705 m (cylindrical)
Collimator
1100x350x100 mm
R=4320 mm (spherical)
IFU
K-mirror
Future Red Arm
Starlight
FM3
400x220x75 mm
R=∞
Blue filter, grating,
Camera and detector

	Instrument Configuration			
Science Objective	**IFU Slicer**	**Grating**	**NAS mask in/out**	**Central wavelength**
Field of view	Large 33” x 20” Medium 16” x 20” Small 8” x 20”			
Spectral resolution	Small: 4R0 Medium: 2R0 Large: R0	BH R0~4500 BM R0~2000 BL R0~900		Slight variation
Spatial sampling	Small 0.35” Medium 0.70” Large 1.35”			
Bandpass (Instantaneous)		BL ~ 2000Å BM ~ 850Å BH ~ 400Å	NAS Out DI NAS In DI/4	Slight variation
Low Surface Brightness Extended Emission Sensitivity & Sky Subtraction Accuracy	Large slicer is best [more sky around object, faster sky measurement] Small slicer is worst	If emission line then best sensitivity when line is resolved.	NAS IN Recommended if extended emission <few % sky and/or significant fraction of FOV	
Efficiency	Small slicer has slight vignetting	BL has best efficiency, BM close, BH slightly lower but comparable except for BH3	Requires 4 x longer to obtain same Poisson S/N plus some overhead.	Some variation (10-20% relative)

SLICER

			Large	Medium	Small
			|| x ⊥ dispersion		
		Field of View	33″ x 20.4″	16.5″ x 20.4″	8.4″ x 20.4″
		Slice width	1.35″	0.69″	0.35″
Grating	Parameter				
		Bandpass/Dispersion			
BL	R (central)	0.625Å/pixel	900	1800	3600
	Δλ (total)	350-560 nm			
	Δλ (instantaneous)	200 nm			
	Δλ (NAS)	50 nm			
BM	R (central)	0.28Å/pixel	2000	4000	8000
	Δλ (total)	350-550 nm			
	Δλ (instantaneous)	80-90 nm			
	Δλ (NAS)	20-22 nm			
BH3	R (central)	0.125Å/pixel	4500	9000	18,000
	Δλ (total)	470-560 nm			
	Δλ (instantaneous)	47-53 nm			
	Δλ (NAS)	12 nm			
BH2	R (central)	0.125Å/pixel	4500	9000	18,000
	Δλtotal)	400-480 nm			
	Δλ (instantaneous)	37-44 nm			
	Δλ (NAS)	10 nm			
BH1	R (central)	900	4500	9000	18,000
	Δλ (total)	350-410 nm			
	Δλ (instantaneous)	~40 nm			
	Δλ (NAS)	~10 nm			

KCWI extends reach to z=2 by getting the blue

- MUSE cutoff about 4700 A
- z>2.9
- KCWI especially efficient in blue, reaches z=1.7
- KCRM on the way; will reach to 1um

New KCWI results (Daddi, Valentino, Rich et al. 2018) R01001 z=2.9 (COSMOS field)

More Successful Detections of 6/7 clusters

FV_X z=2.18
Strazz2 z=2.51
R1001 z=2.91
R0958 z=3.04
R0959 z=3.09
Wang z=2.50

and also

Gobat cluster at 14h50 +09 z=1.99

RO-1001 nebula at z=2.91 No powering AGN identified

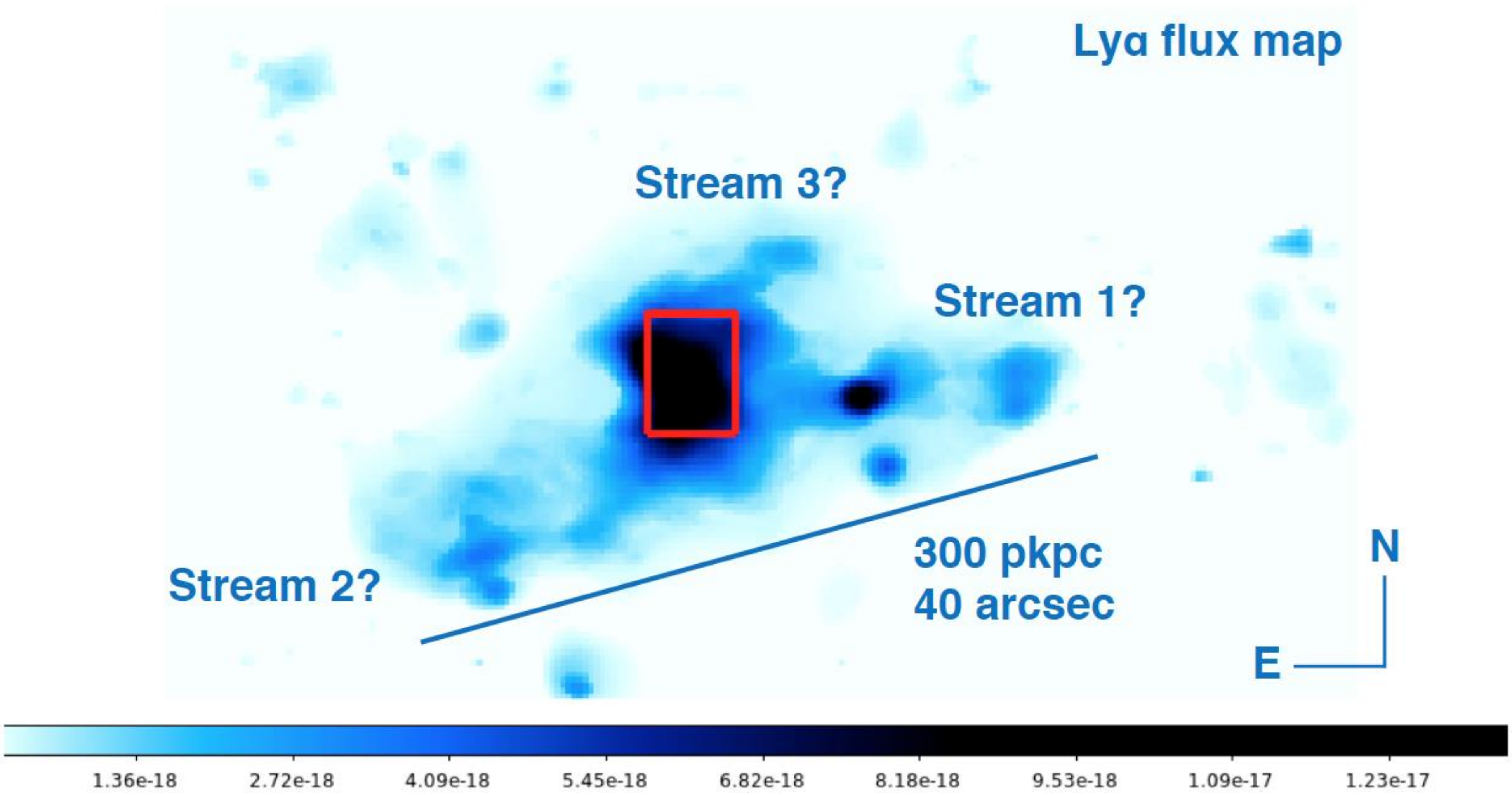


Figure 2: Lyα flux map (i.e., moment 0) of the RO-1001 nebula, reconstructed from adaptive smoothing. Three quite clear filaments/streams are detected outwards of the central bright core. The color bar at the bottom shows the Lyα surface brightness scale (SB), ranging from a few 10^{-17} erg cm^{-2} s^{-1} $arcsec^{-2}$ at the center to 10× lower SB in the filaments. The field of view shown is the same in all figures. **The red rectangle shows the GMOS IFU field.**

RO-1001 z=2.91 10^{13} Msun possible cosmological cold flows

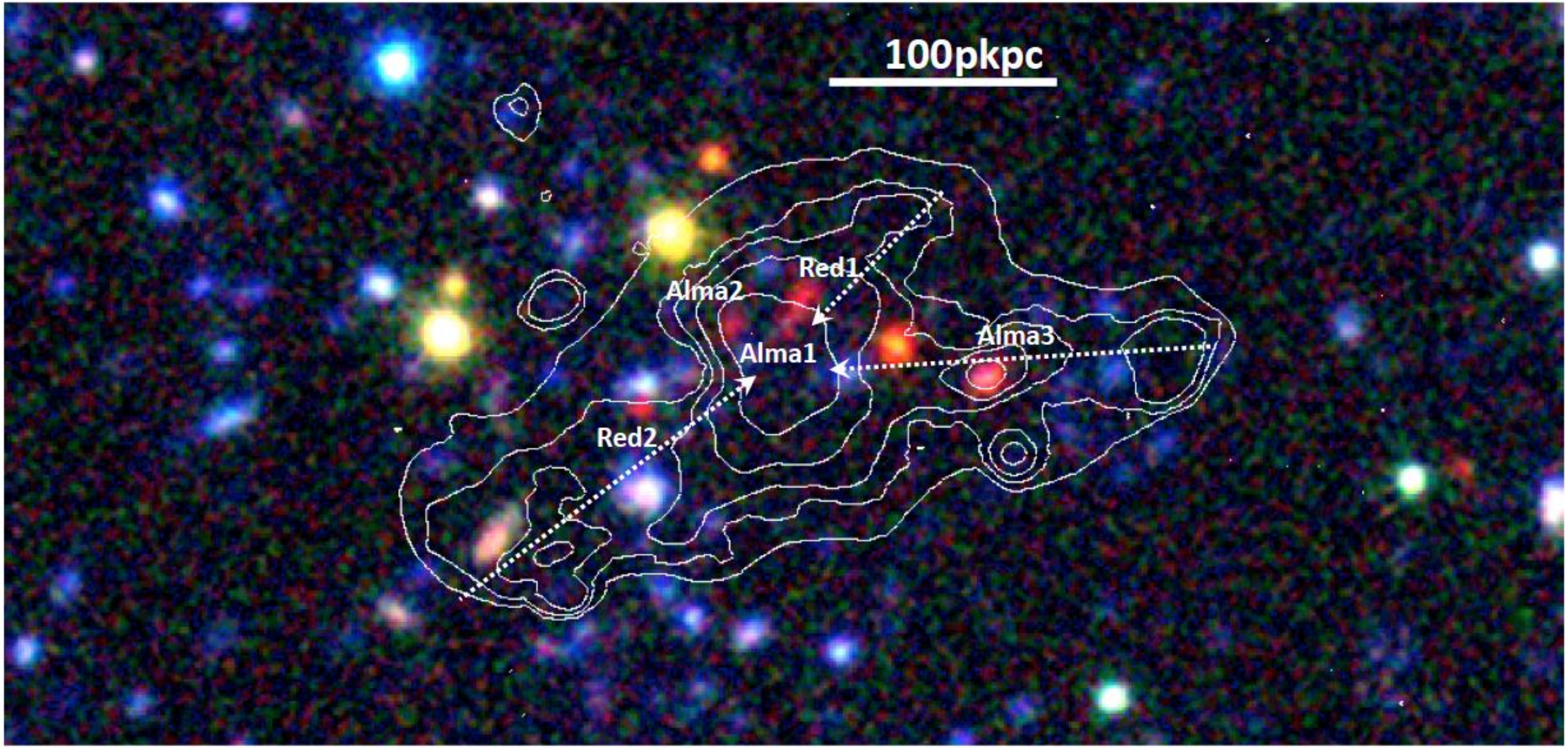
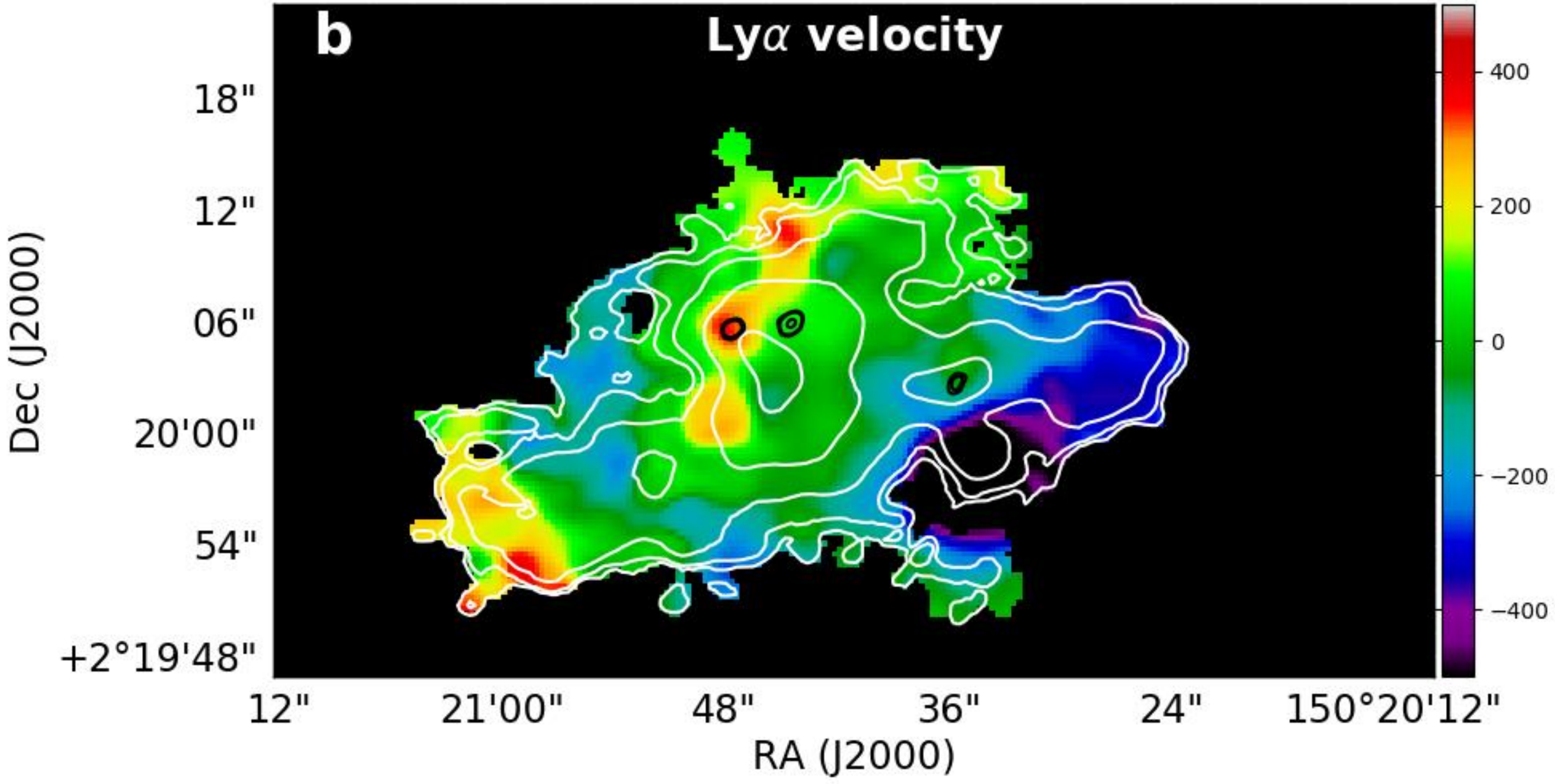


Figure 1: Deep imaging of the RO-1001 cluster from ULTRA-Vista K and J (red and green) and Subaru HSC g-band (blue). The 5 massive $>10^{11}M_{\odot}$ galaxies are labeled. The white contours show the Lyα surface brightness scale (SB) from Figure 2, from a few 10^{-17} erg cm^{-2} s^{-1} arcsec^{-2} (center) to x10 lower SB (filaments). Arrows show stream directions.

Kinematics from centroids of Lya peak velocities



Thanks to A. Marchal et al 2019
ROSHA code → 2D

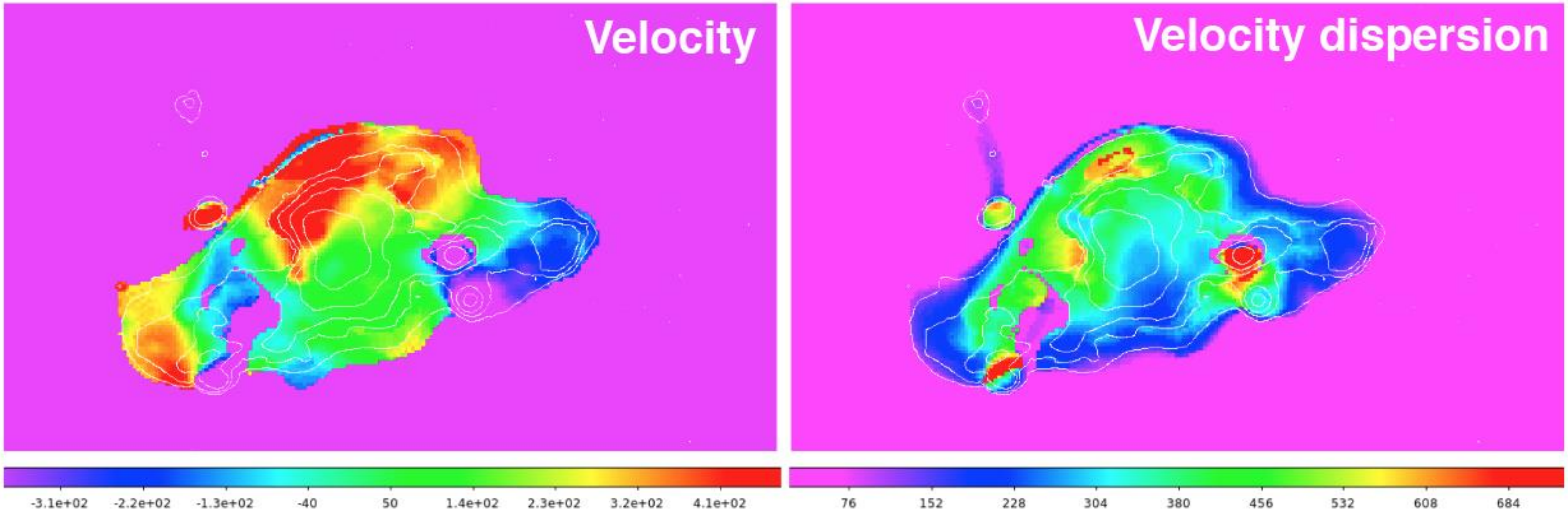
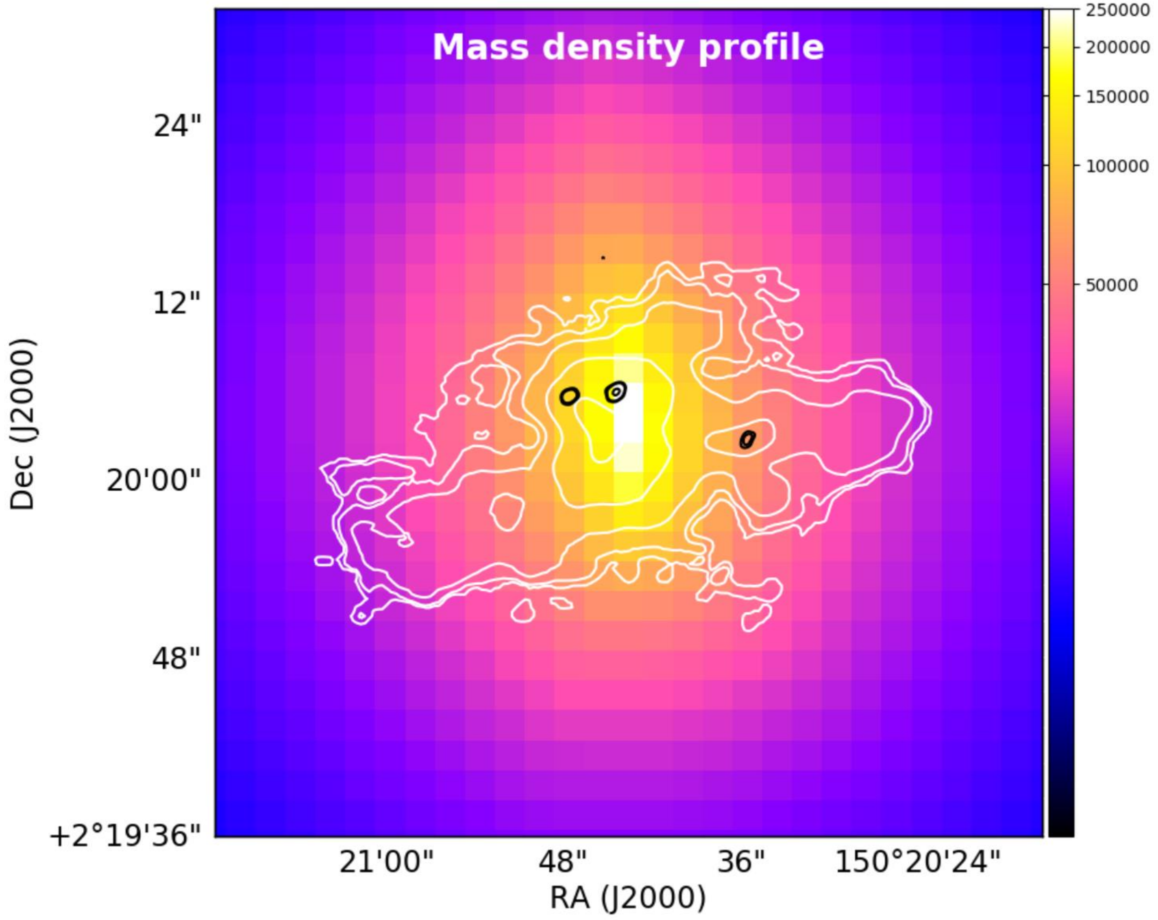


Figure 3: Velocity (moment1, left) and velocity dispersion (moment 2, right) maps of the RO-1001 nebula. The color bars at the bottom show the velocity scales in km s^{-1}. The white contours show the Lyα SB levels from Figure 2.

Lya nebula sitting at the center
Of the potential well of massive halo



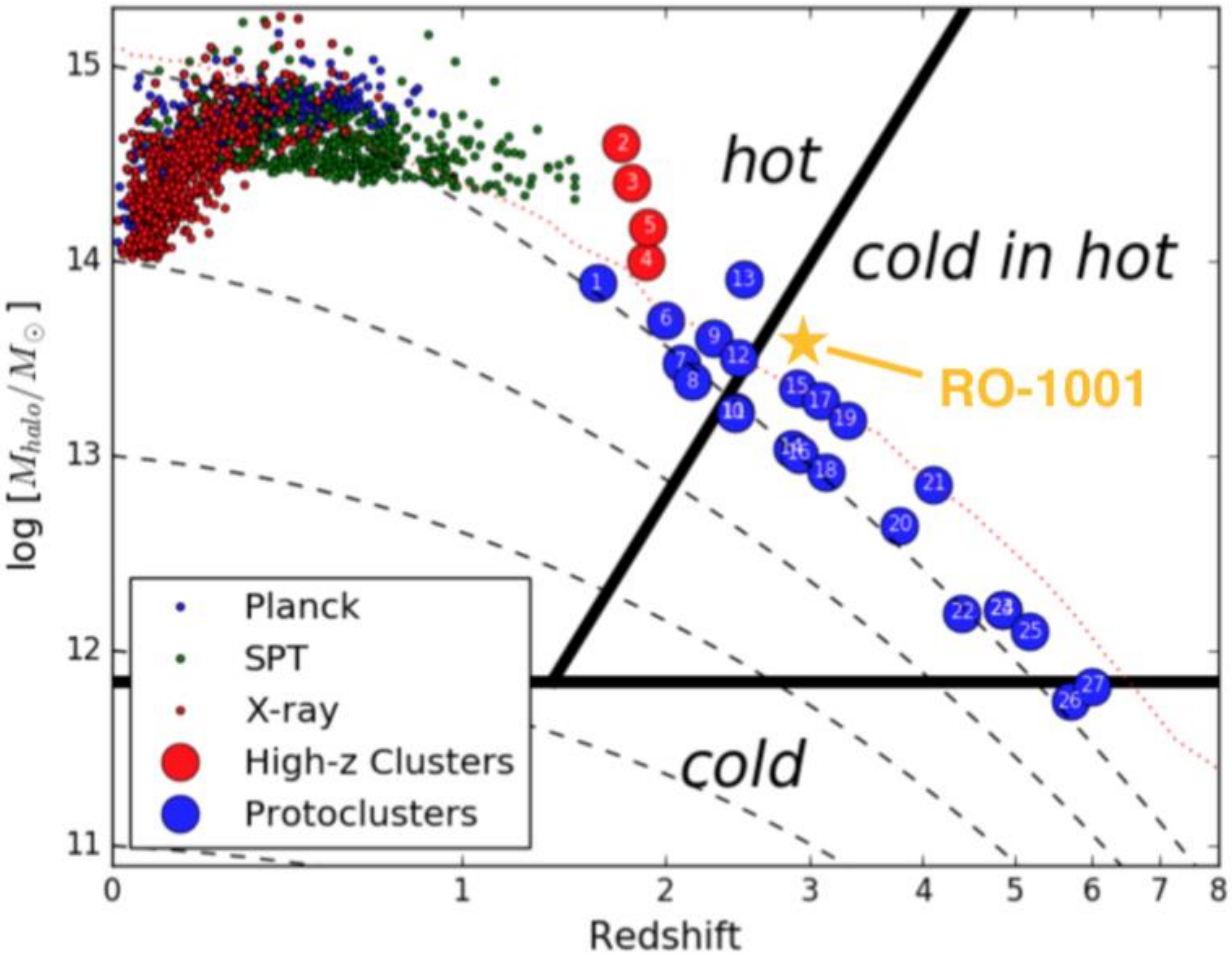
M_{DM}~4x10^{13}Msun @z=2.91

1) Stellar mass content
2) SFR integrated (Herschel, ALMA)
3) 3σ X-ray detection

10^{11} Msun HI by modeling L alpha emission (phase I SKA detectable)

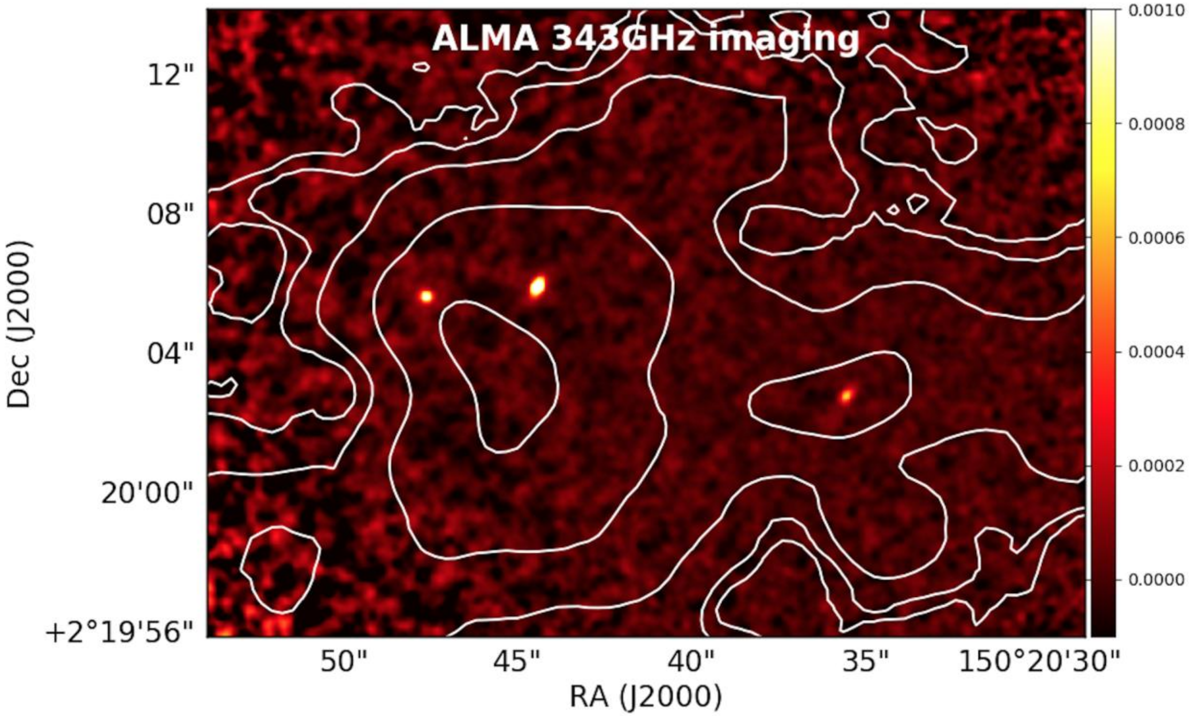
1200 Msun/yr of SFR

RO-1001 falls in the cosmological cold flow regime

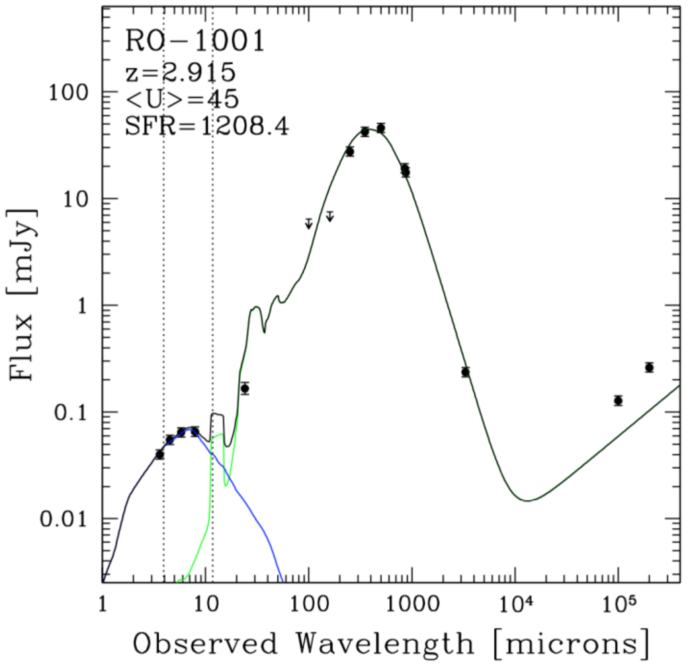


Overzier+2016

What is the source of the ionization ? photons ?



ALMA half light radii ~500pc



No sign of AGN from IR

No X-ray AGNs (soft/hard)
$L_x < 5\times10^{43}$ from 8-40keV rest

No way to get enough ionizing photons

AGNs weak if any, and VERY obscured
SF extremely obscured

Diffuse SF/AGN in many objects rejected from EW (no continuum), unlike Spider Web z=2.1

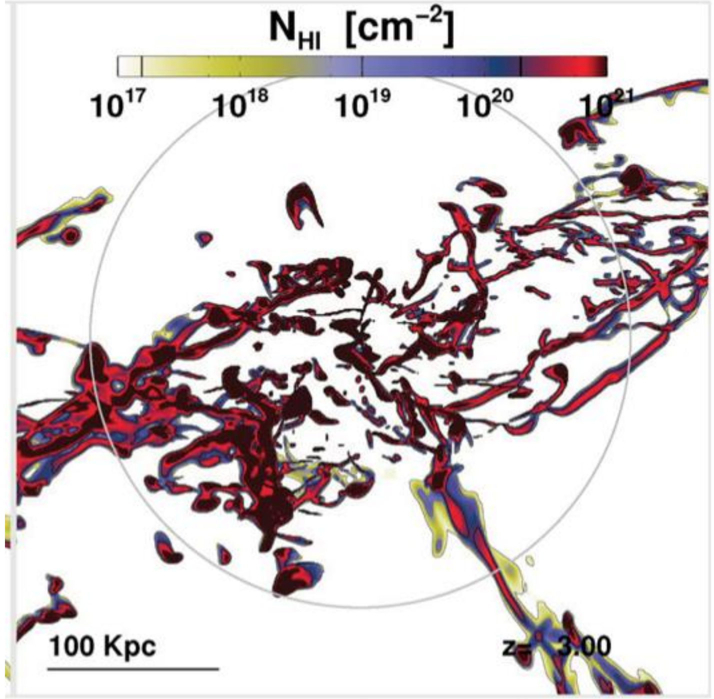
RO-1001 vs QSO nebulae
Lya ~ 2×10^{44} erg/s

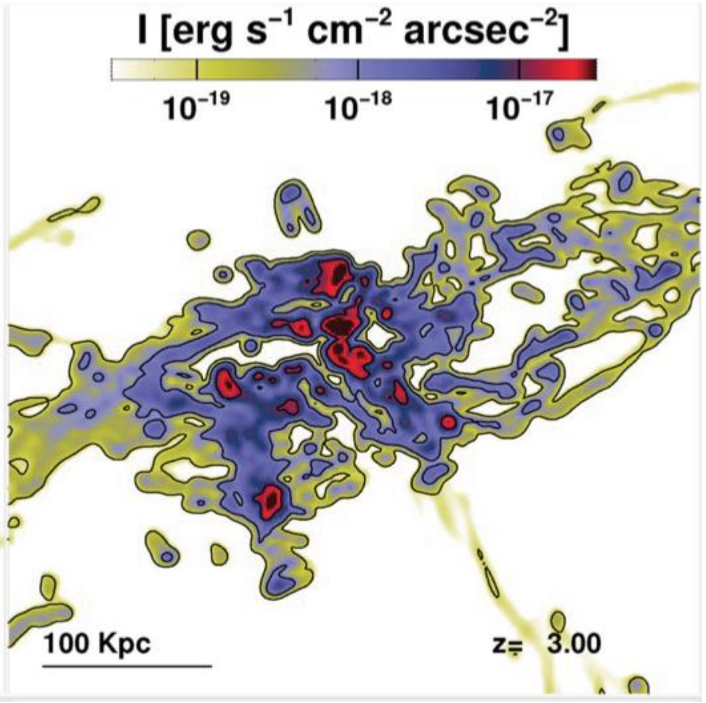
	RO-1001 nebula			QSO nebulae		
Energy source	Constrain	Total	Effective	Constrain	Total	Effective
AGN photo.	$L_{AGN} \lesssim 2\times10^{45}$ erg s^{-1}	$\lesssim 60\%$	$< 20\%$	$L_{AGN} \sim 10^{47}$ erg s^{-1}	**40**	≈ 1 ?
SF photo.	$1200 M_\odot yr^{-1}$	5	$< 1\%$	$120 M_\odot yr^{-1}$	0.5	< 0.5
AGN outflows	$\lesssim 200 M_\odot yr^{-1}$	30%	$<<10\%$	$8000 M_\odot yr^{-1}$	**20**	≈ 1 ?
SF outflows	$1200 M_\odot yr^{-1}$	1	$<10\%$	$120 M_\odot yr^{-1}$	negl.	negl.
Gravity	$M_{DM}=4\times10^{13} M_\odot$	**160**	≈ 1 ?	$M_{DM}=3\times10^{12} M_\odot$	≈ 1	$<1\%$?

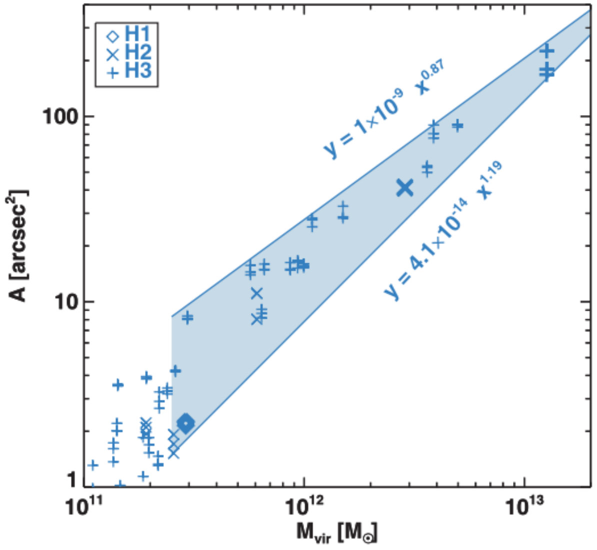
1) Energy source, gravity vs photoionization ? 4 orders of mag difference

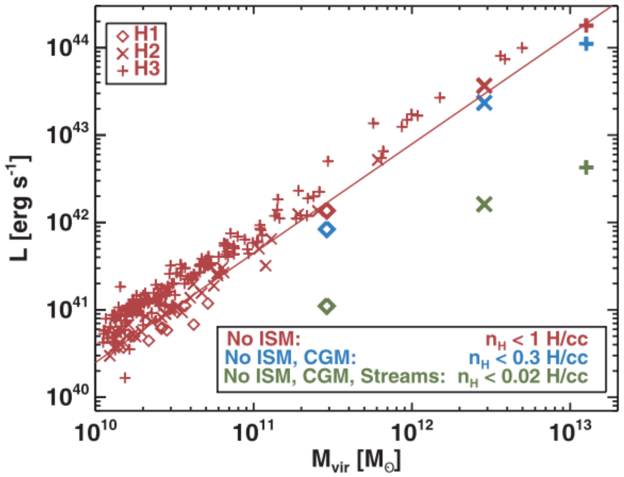
2) Where is cold gas from, infall or outflows ? >2 orders of mag difference

Comparing to Rosdhal & Blaizot 2012 simulations (see also Goerdt+2010)









- ✓ Luminosity
- ✓ SB distribution
- ✓ Area
- ✓ 3 filaments
- ✓ Velocities
- ✓ Column density

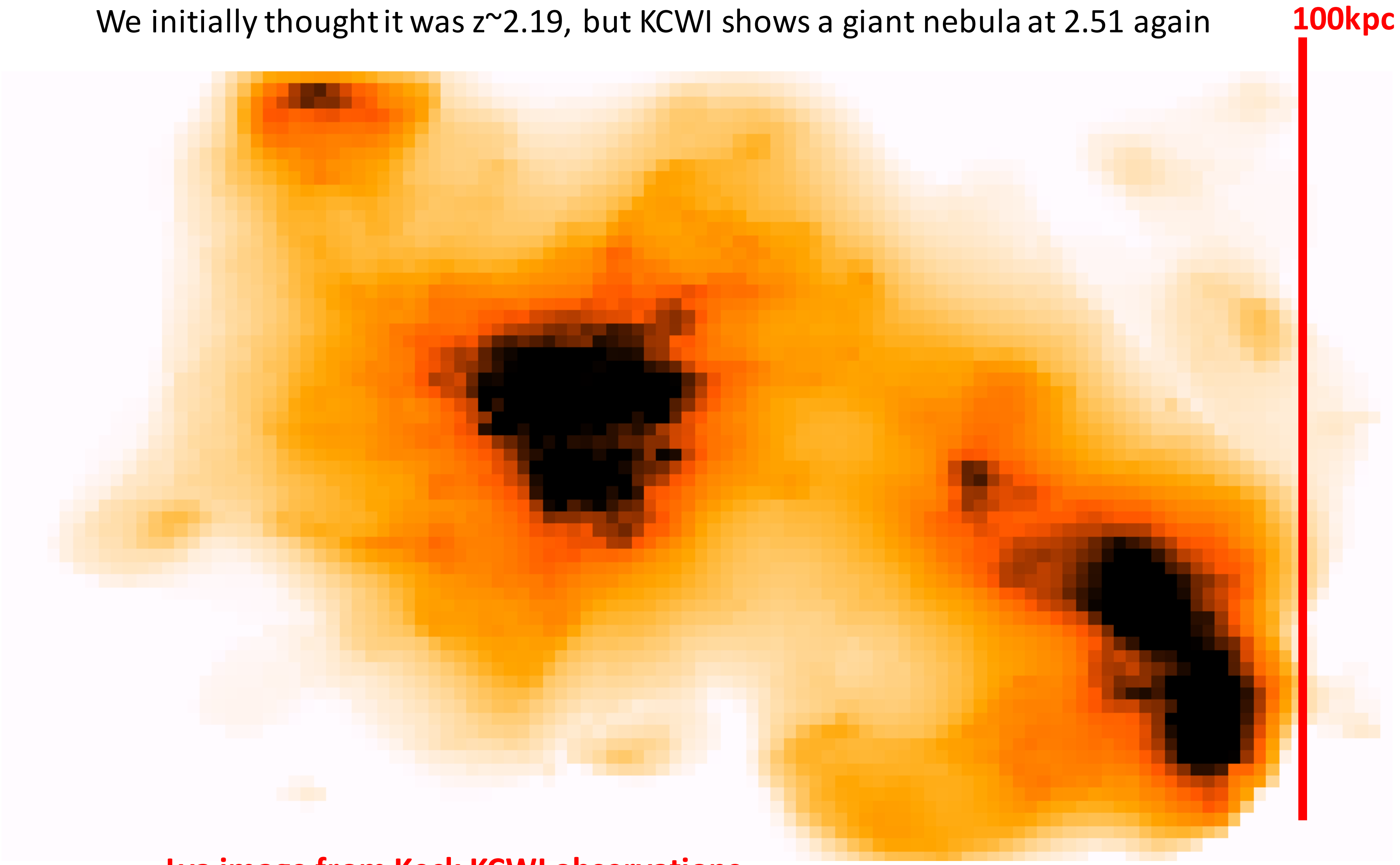
All informed with M_{DM} knowledge

→ Excellent quantit. agreement with predictions

More where that came from!

The highest redshift 'passive galaxy selected' cluster from Strazzullo et al 2015

We initially thought it was z~2.19, but KCWI shows a giant nebula at 2.51 again



Lya image from Keck KCWI observations

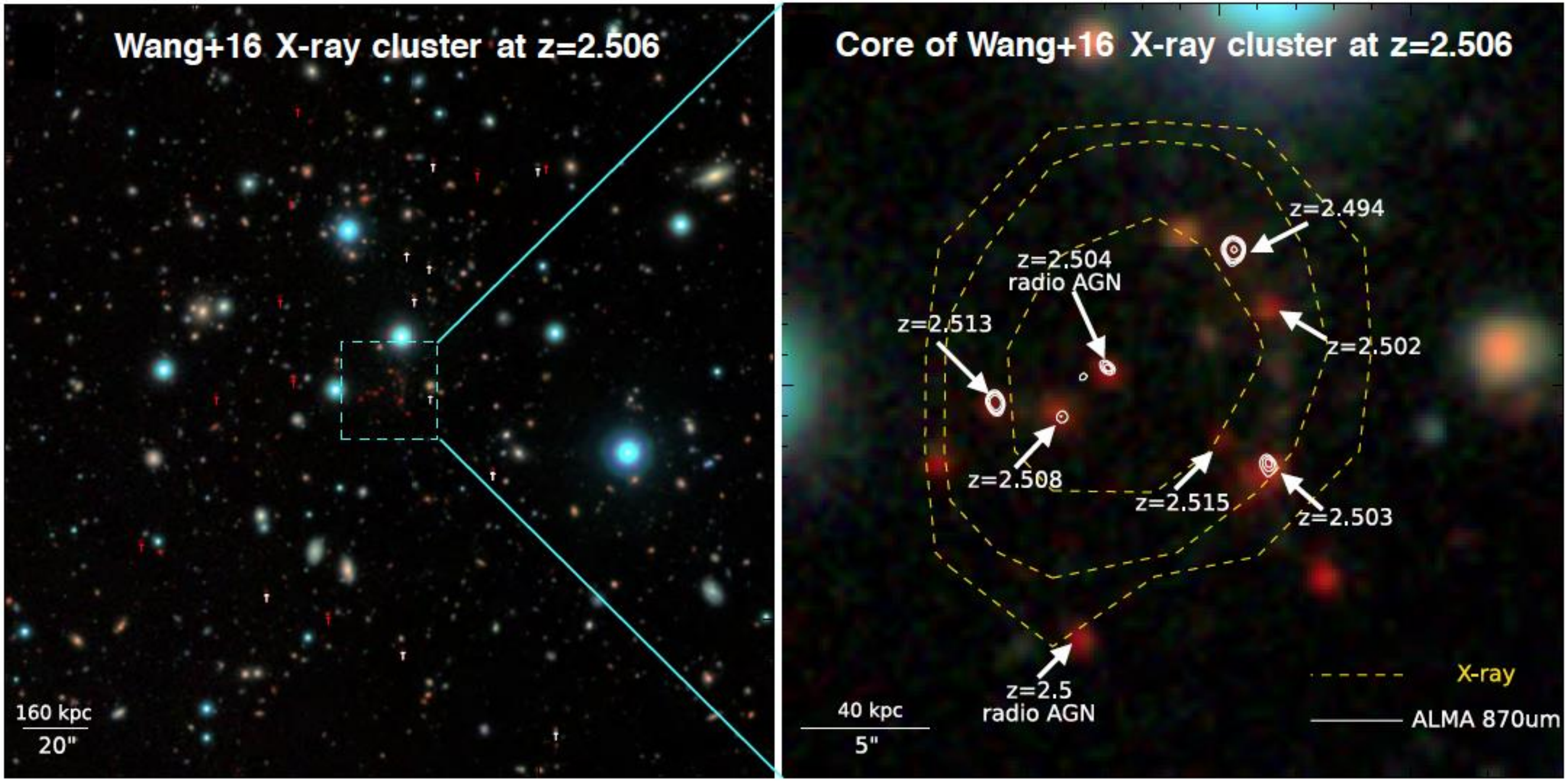
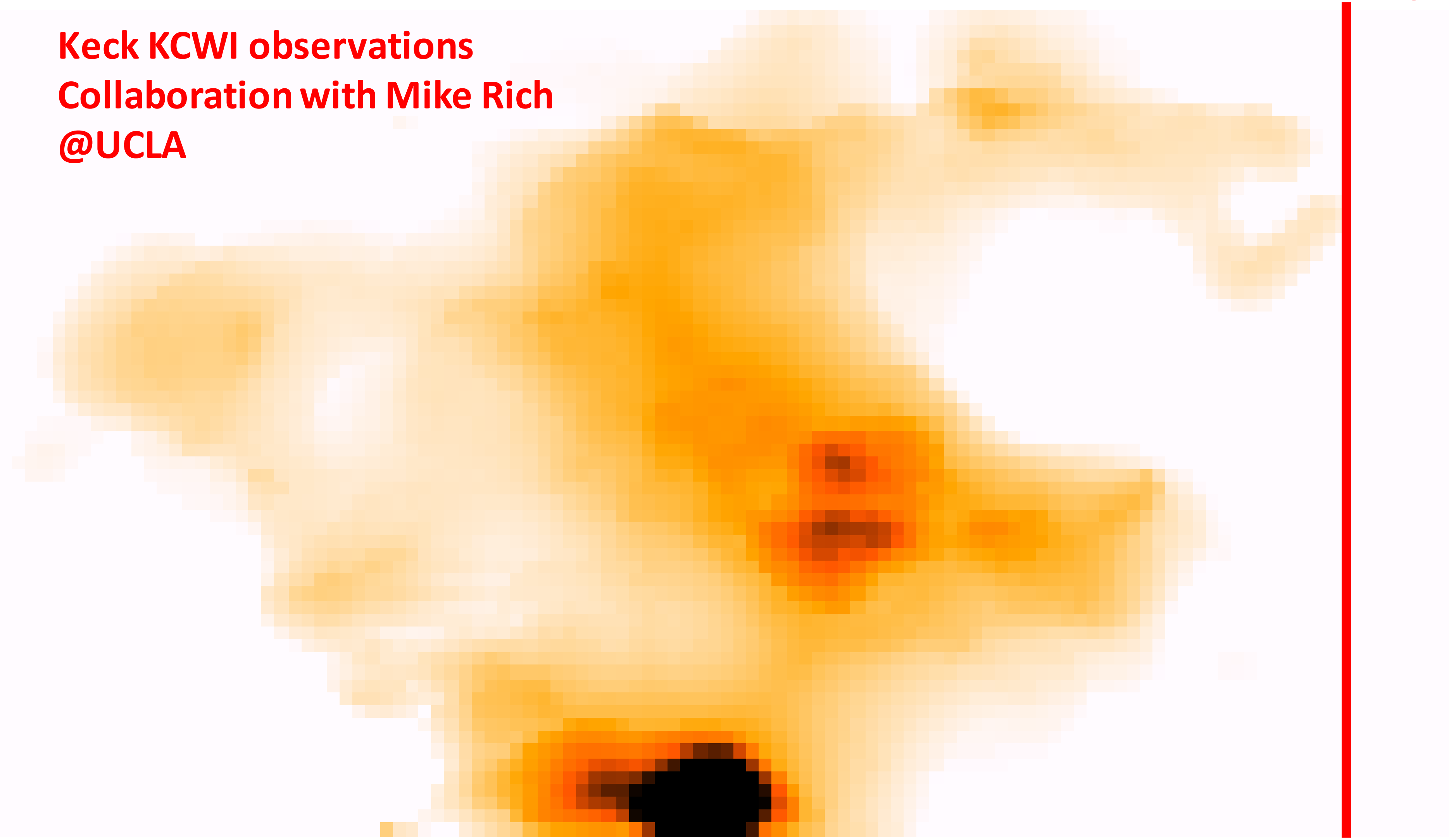


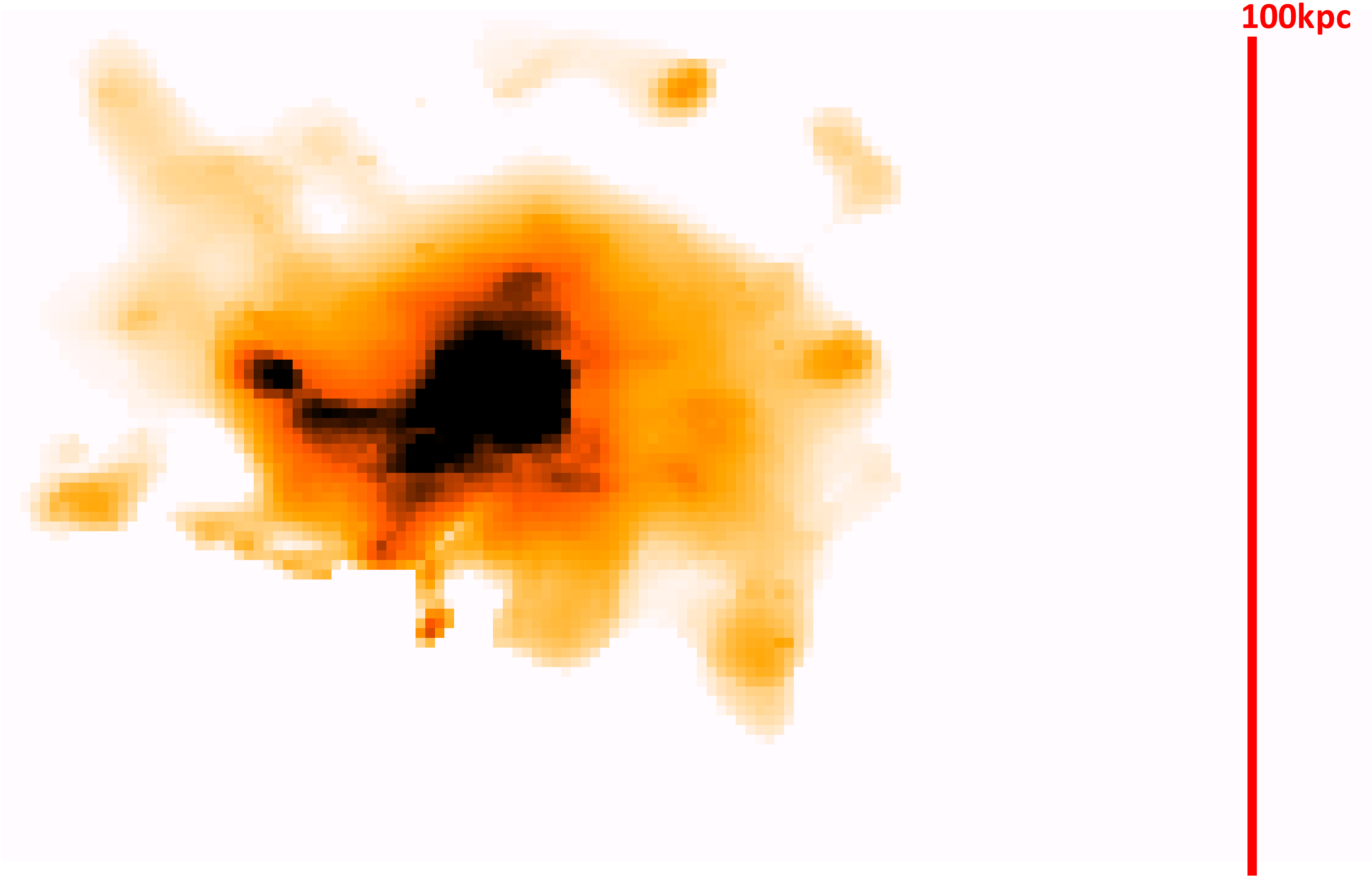
Figure 2: **Left:** The most distant X-ray detected cluster known so far at z = 2.506 (Wang+2016). White and red arrows mark spectroscopic and photometric members, respectively. **Right:** A very strong concentration of red, strongly star-forming galaxies (total SFR≈3400 $M_{\odot}yr^{-1}$) is evident in the central 80 kpc. White and yellow lines mark the ALMA 870 µm and *Chandra* X-ray contours.

Wang et al 2016 z=2.51 cluster



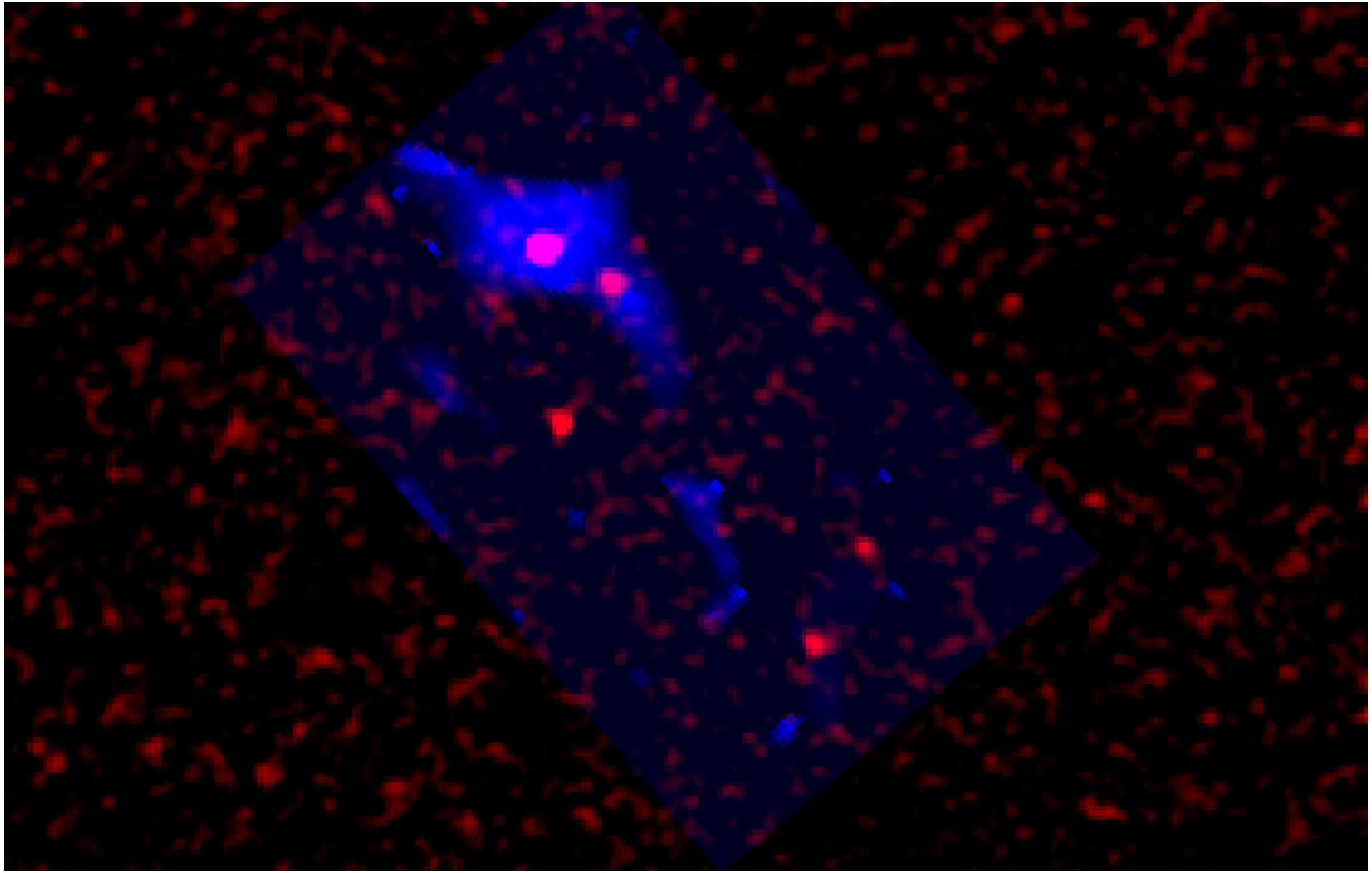
Lya image from Keck KCWI observations

A radio selected cluster z=3.1



Lya image from Keck KCWI observations

R0958 Red=radio ALMA galaxy 600 Msun/yr SF z=3.046 Ly Alpha 10x weaker. Lower mass halo?



Future Work

- ALMA observations just completed
- HST time in WFC3/IR allocated
- KCRM or MUSE to detect CIV, CII, He lines
- Gemini IFU under consideration

Conclusions

- LAN detected in 6/7 cases; more processing will probably find all
- Associated with radio overdensities and in some cases, no AGN so source of photoionization not known.
- Note that these are distinct from the LANs detected in QSO with z>3 as there is usually no QSO responsible for photoionization.
- Often structures exceed 300 p kpc and associated filaments extend beyond the field of view. Structures appear complex and extended mosaics needed
- The halo masses and redshifts are consistent with predictions of cosmological cold flows (Dekel+2009)
- Publications soon

- This project exists in part because of the superb dataset that the COSMOS collaboration has built over the years. Thank you to you all, and sorry I could not be with you in NY. And thank you Nick Scoville and all, for your vision in envisioning COSMOS... it's just the beginning.
- Thanks also to Chris Martin and the KCWI instrument team, and Keck Observatory