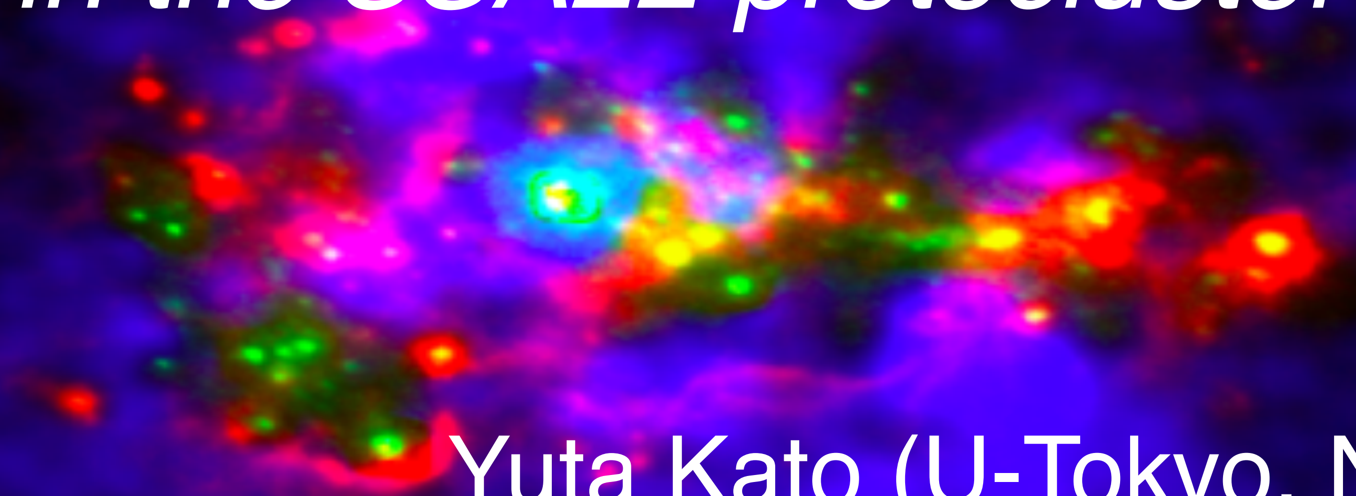
ALMA 860 µm & 3mm & CO J=4-3 Observation for LAB18 in the SSA22 protocluster



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860μm & 3mm & CO J=4-3 Summary

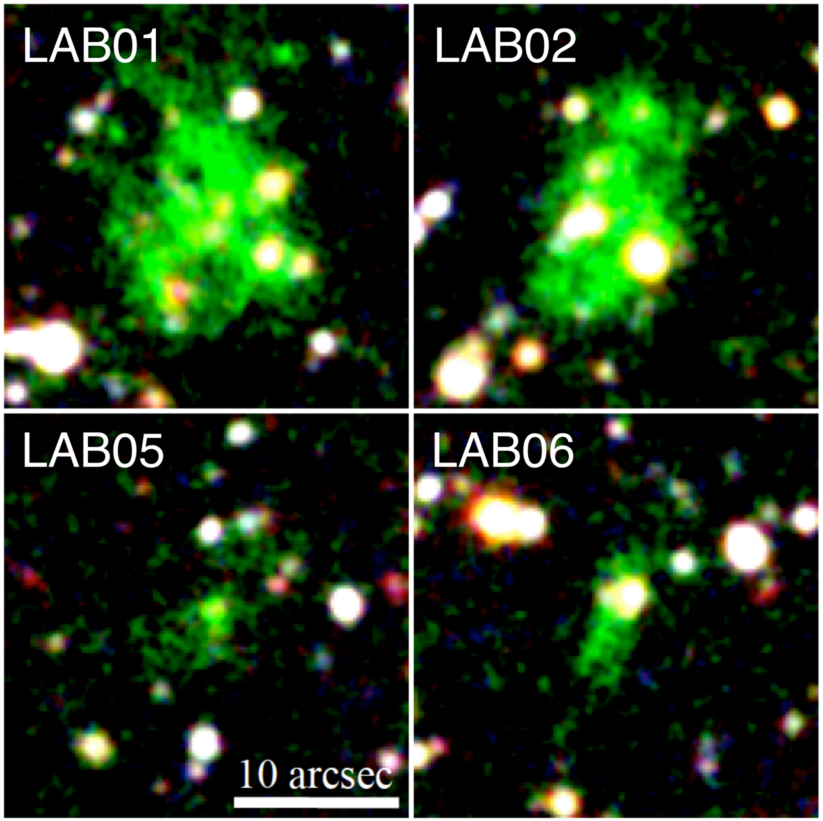
- LABs are ~10-100 kpc Lyα emitting nebula primarily found at protoclusters, thought to relate formation of galaxies. However, the lack of precise spatially and kinematic information with sub-millimeter wavelength prevent us to discuss possible origin.

- Four 860 μm dust continuum sources and one CO J=4-3 line is detected within LAB18 with ALMA. 3 mm dust continuum emissions are also detected from four 860μm sources.

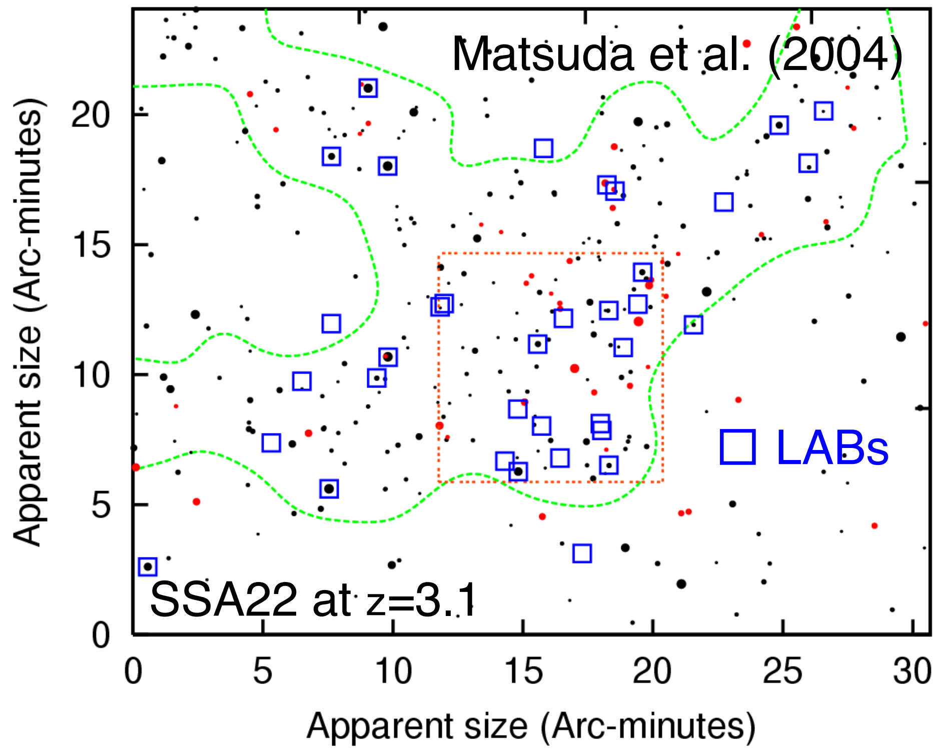
- The discovery of obvious power source suggest photoionization and superwind are possible origins, but the cold accretion is needed if we consider low τ_{dep} and f_{gas} of CO detected source to be evolved z=2 massive main sequence galaxy.

The Lyα Blob (LAB)

- LABs are ~10-100 kpc scale Lyα emitting nebula primarily found at high-z protoclusters (e.g., Steidel et al. 2000, Matsuda et al. 2004)

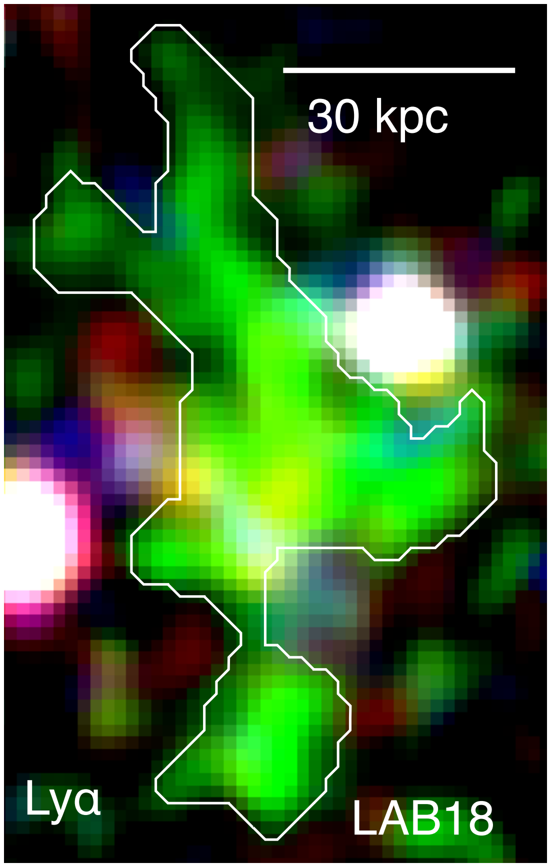


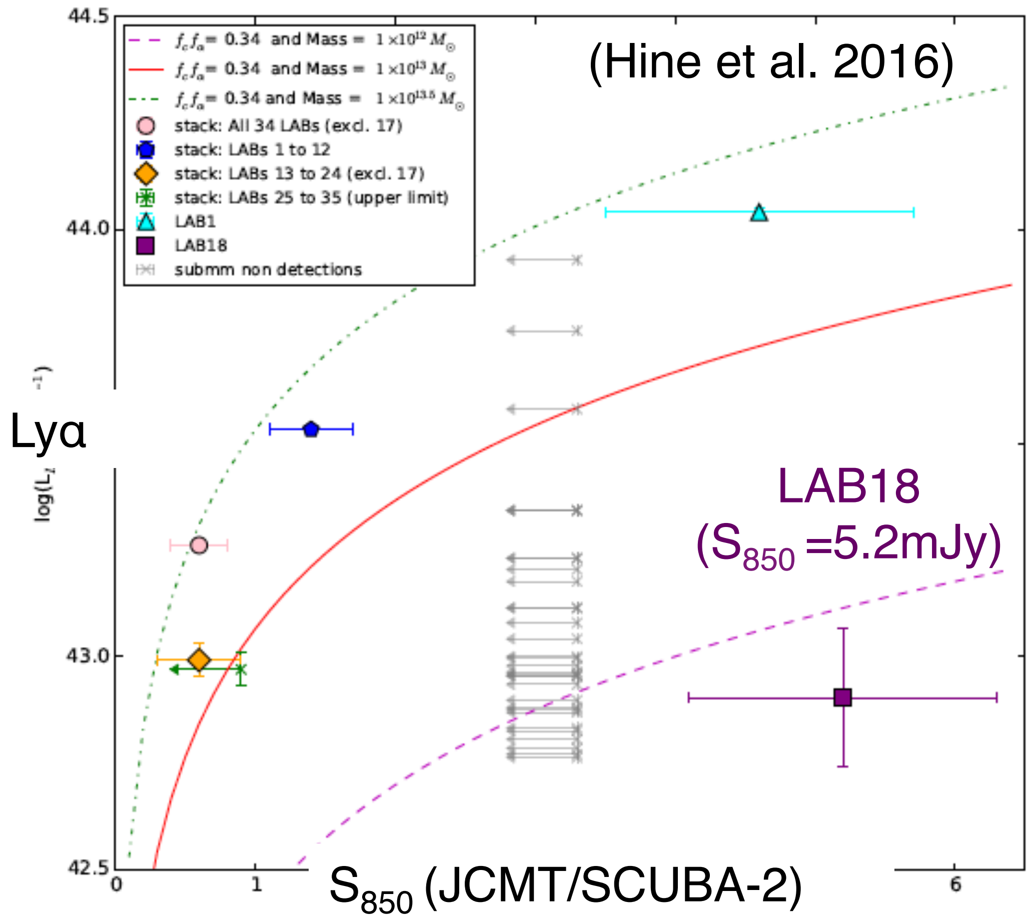
(Matsuda et al. 2011)



- LABs are related to formation of galaxies in protoclusters, and indicate interactions between IGM and galaxies

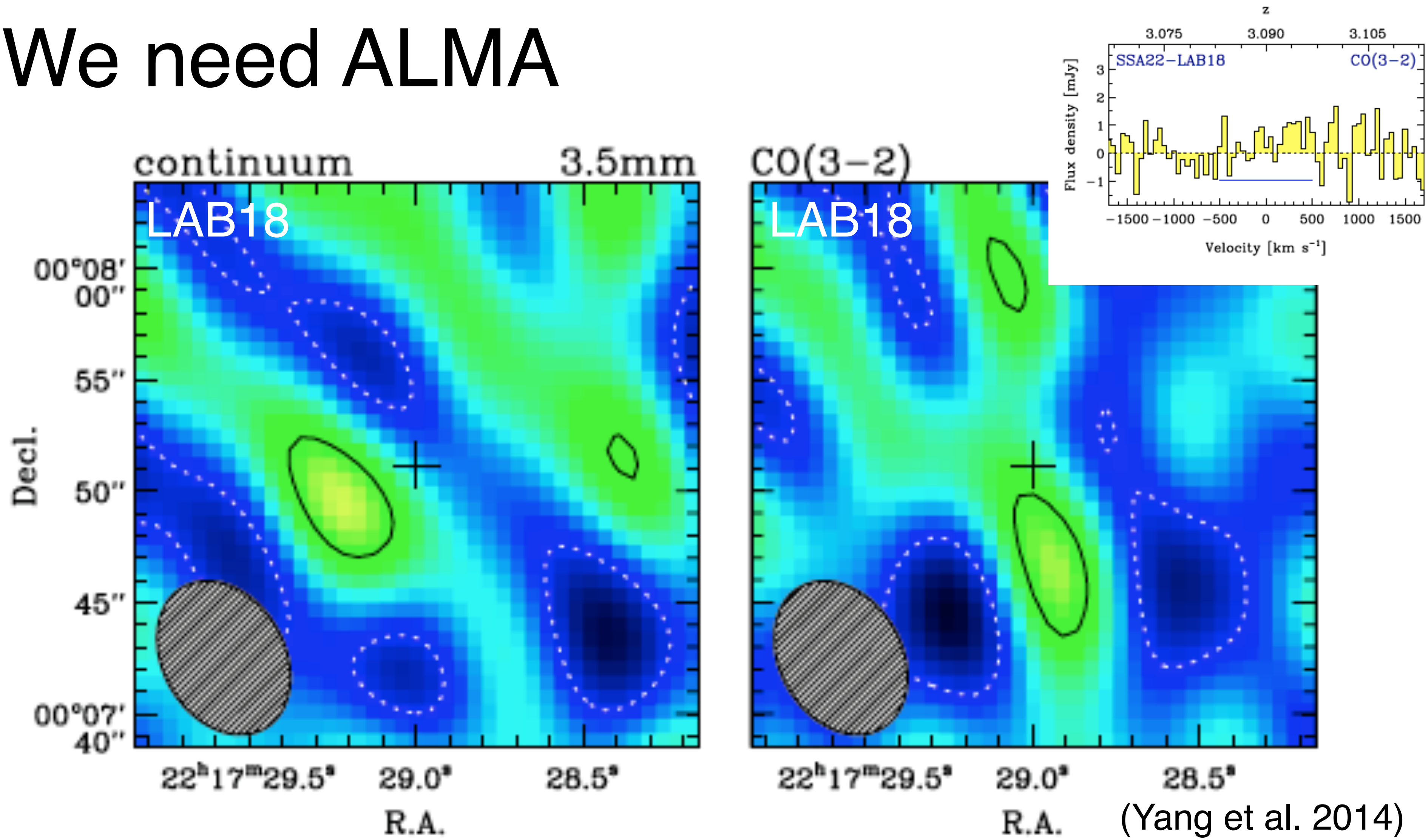
SSA22-LAB18 at z=3.1 (LAB18)





- ➢ LAB18 is 30 x 100 kpc, the most filamentary structure with Lyα (Matsuda et al. 2011) and S_{850} brightest sources (Hine et al. 2016)
- ➢ Its morphology is very similar to the cold stream predicted in the cosmological simulation. What is the possible origins?

We need ALMA



(Yang et al. 2014)

- ➢ The lack of sensitivity, spatially and kinematic information with sub-millimeter observation prevent us to discuss possible origin of LABs and individual properties of companions

ALMA observation for LAB18

"Search for the 860 µm dust continuum sources in 4 LABs"

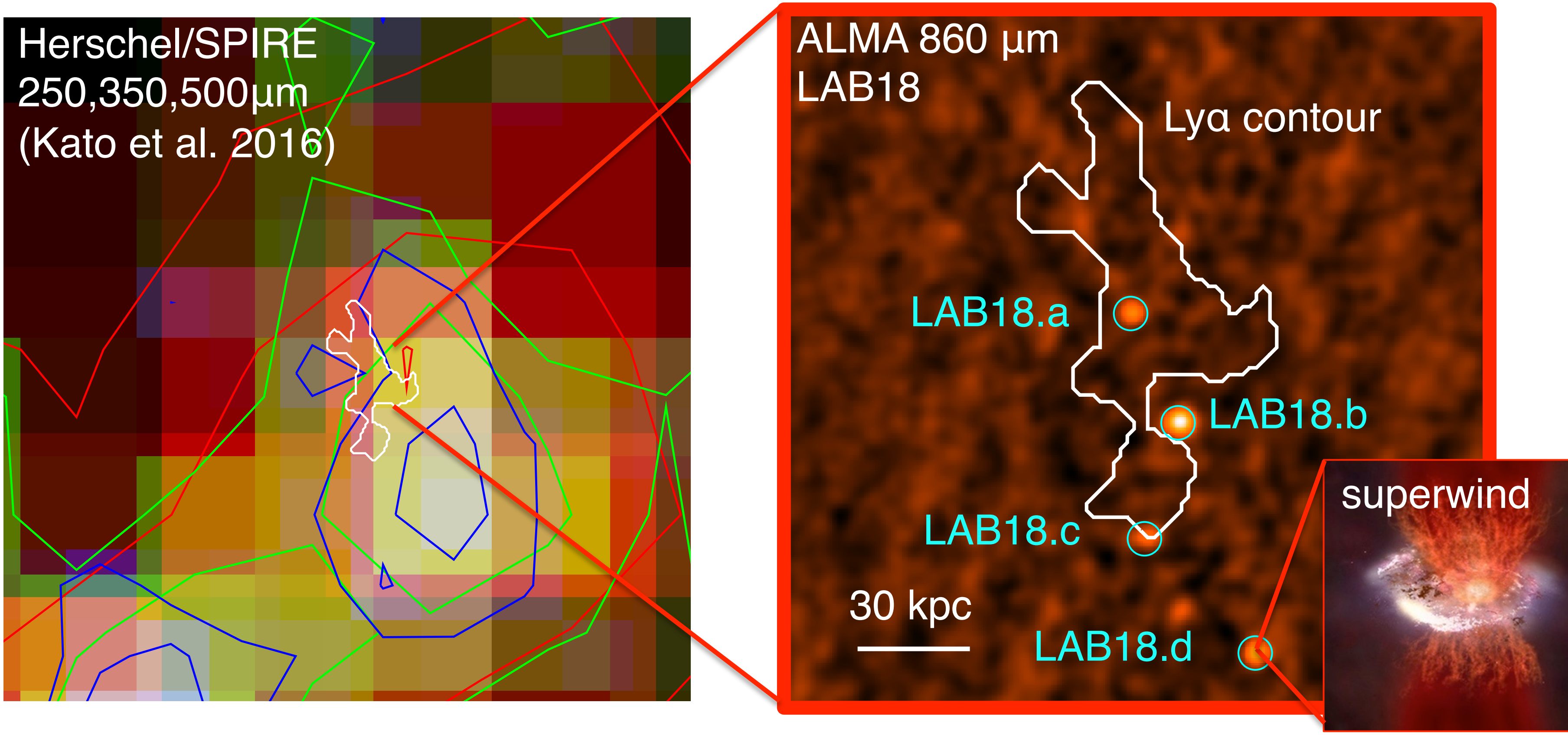
- cycle 2 (PI. Y. Matsuda, Matsuda-san's poster in detail)
- band 7 (~860 µm)
- 10th to 14th June 2015 with 37-41 antennas
- 144 min on-source integration time (36 min per source)
- FWHM 0.35" x 0.33" (~2.7 kpc at z=3.1)
- 1σ = 44 µJy/beam (continuum)

"Investigate gas mass and Kinematics of LAB18"

- cycle 4 (#2016.1.011101.S) PI. Y. Kato
- band 3 (~3 mm, CO J=4-3)
- 12th to 14th November 2016 with 39-41 antennas
- 296.4 min on-source integration time
- FWHM 1.07" x 0.99" (~8 kpc at z=3.1)
- 1σ = 4.9 µJy/beam (continuum)

ALMA 860 µm detection from LAB18

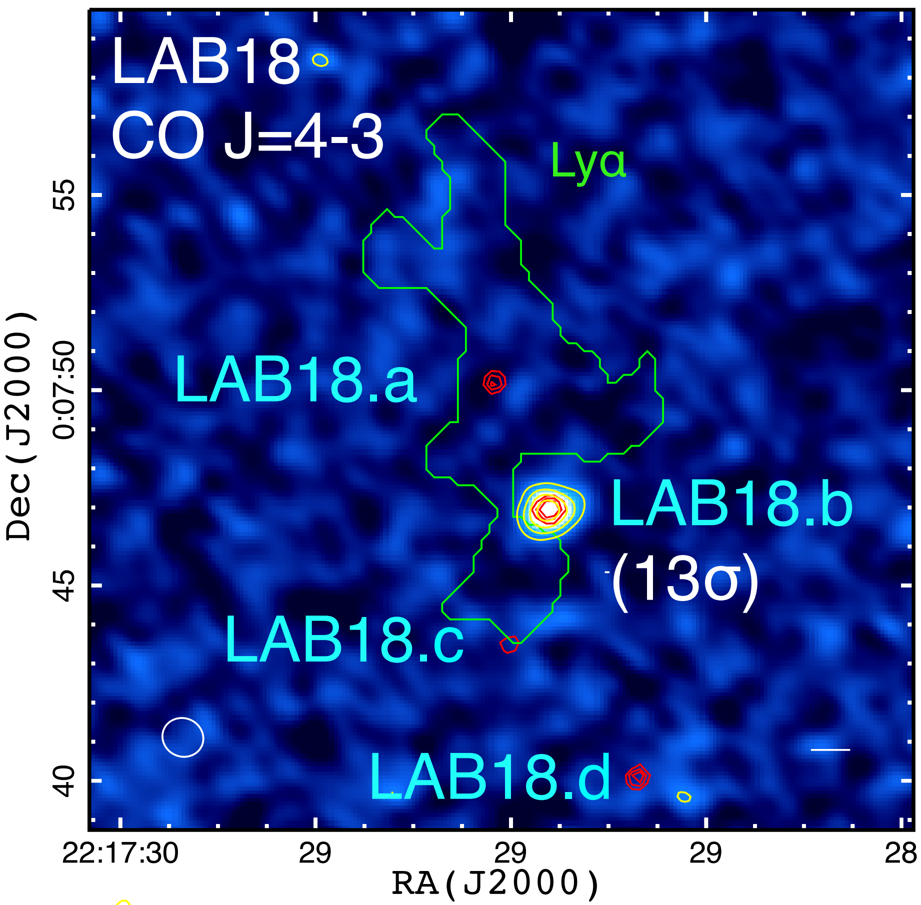
- We detected four >5σ 860 µm sources (SFR = 60-450 M_o yr^{-1})

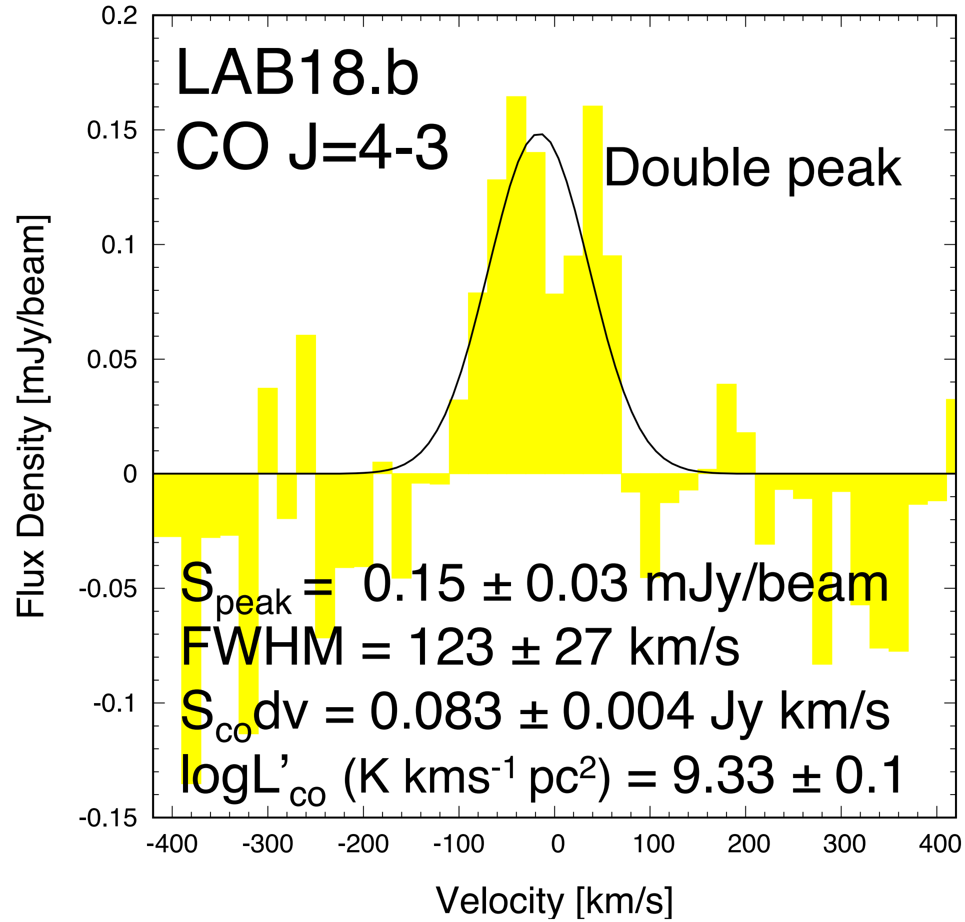


- All can easily induce superwind (ΣSFR = 20-120 M_o yr^{-1} kpc^{-2}) (e.g., ΣSFR >1 M_o yr^{-1} kpc^{-2}, Newman et al. 2012)
- We search for evidence for extended gaseous structure (e.g., outflows/inflows). How about cold stream model?

ALMA CO J=4-3 detection from LAB18

- ^{12}CO(4-3) line is detected at 13σ from LAB18.b

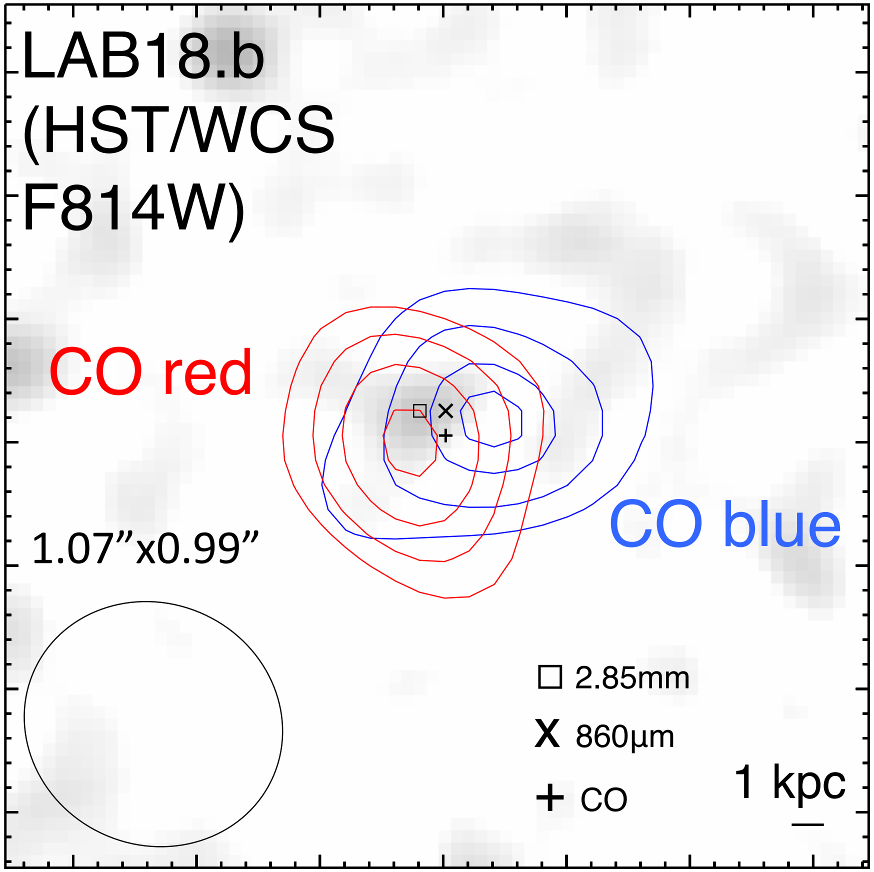


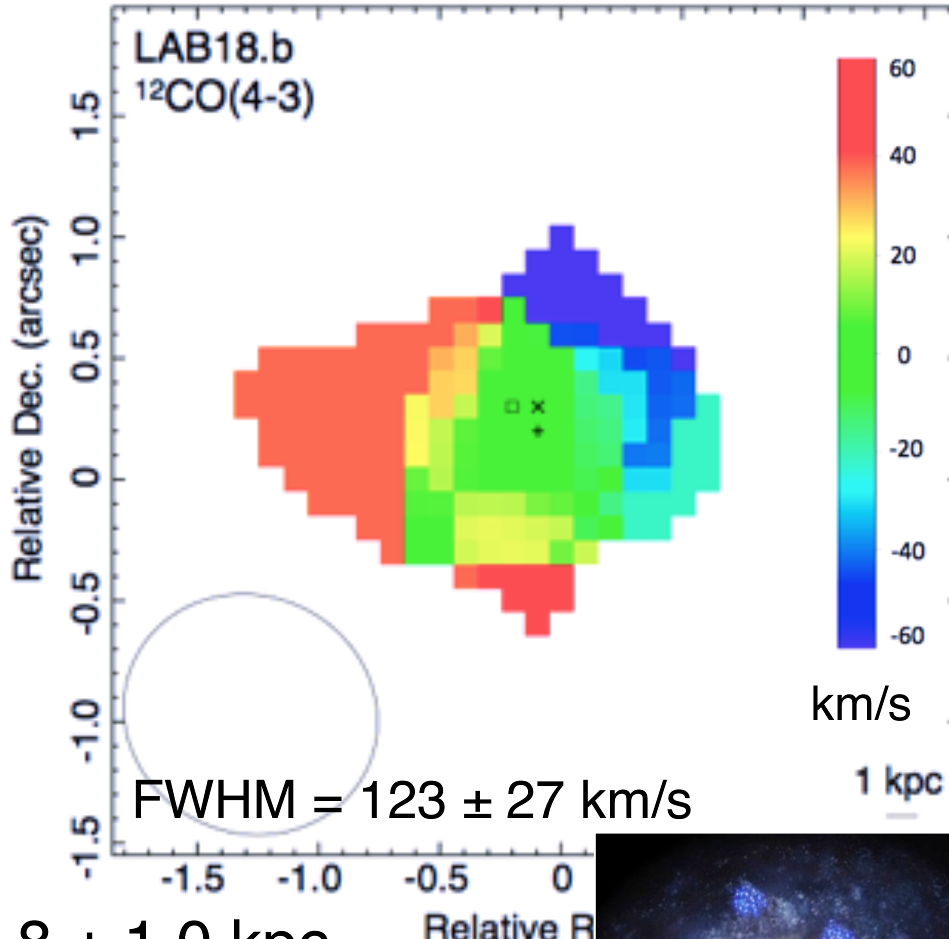


- z(CO) = 3.0936 ± 0.0002, suggesting LAB18.b is really associated with LAB18 at z=3.1. No extended gas structures

CO J=4-3 kinematics for LAB18.b

- ➢ Compact central dusty starburst region & large rotational disk?

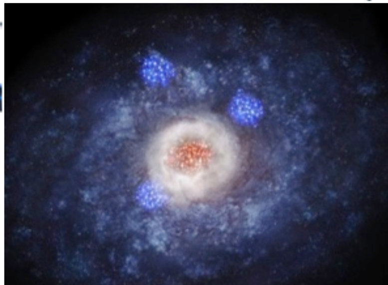




FWHM(CO) 5.6 ± 0.5 kpc, 1.8 ± 1.0 kpc

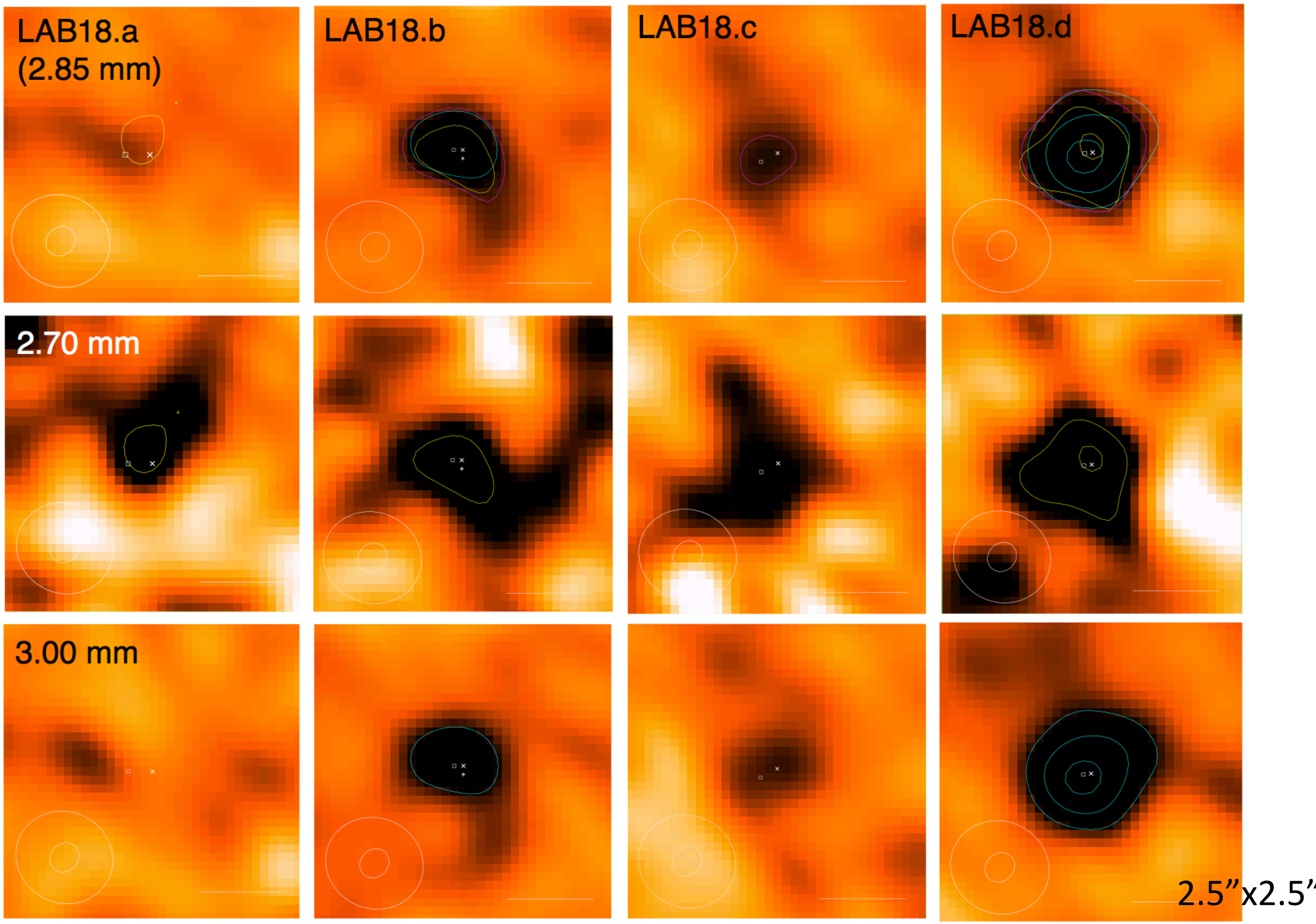
FWHM(860 μm) 2.0 ± 0.1 kpc, 1.1 ± 0.1 kpc

- ➢ Two face-on galaxy (merger / remnants) ?



(Tadaki et al. 2017)

3 mm dust continuum detection



➢ For LAB18.a, we detected 2.70 mm dust continuum

FIR SED fitting for LAB18.b

- From 3 mm & 860 μm detection, Td=24 K & β=2.7 are required
- $\log M_{dust}$ (Td=24K, β=2.7, K_{850}=0.4-1.5 cm^2 g^{-1})=8.04-8.62 (M_o)

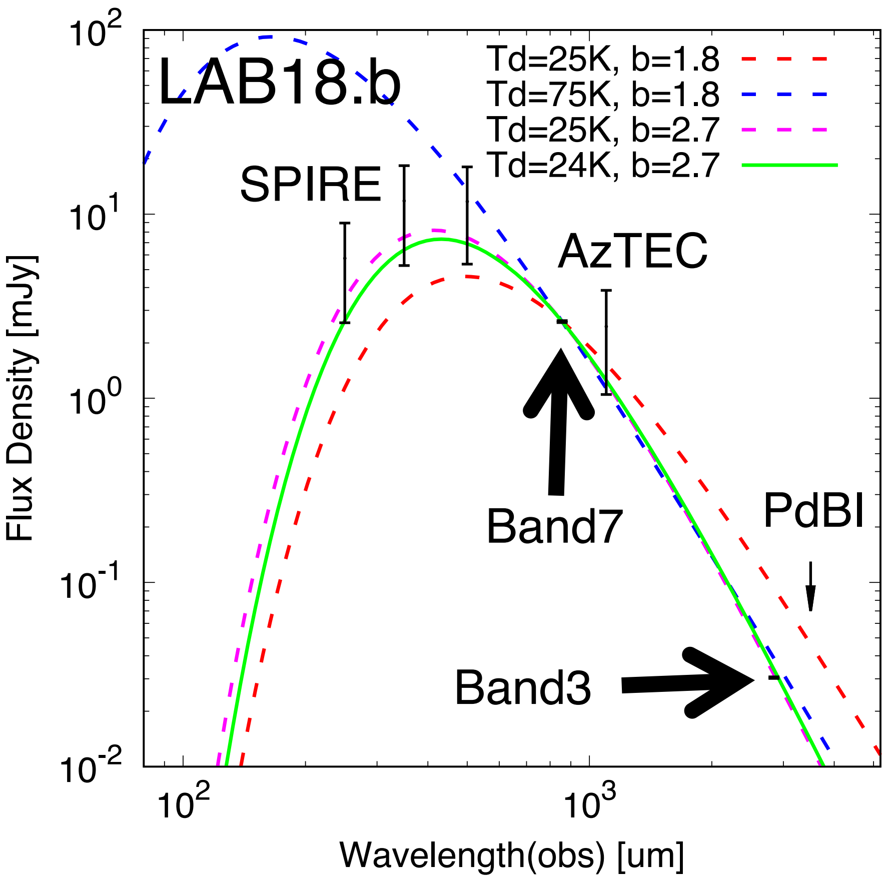
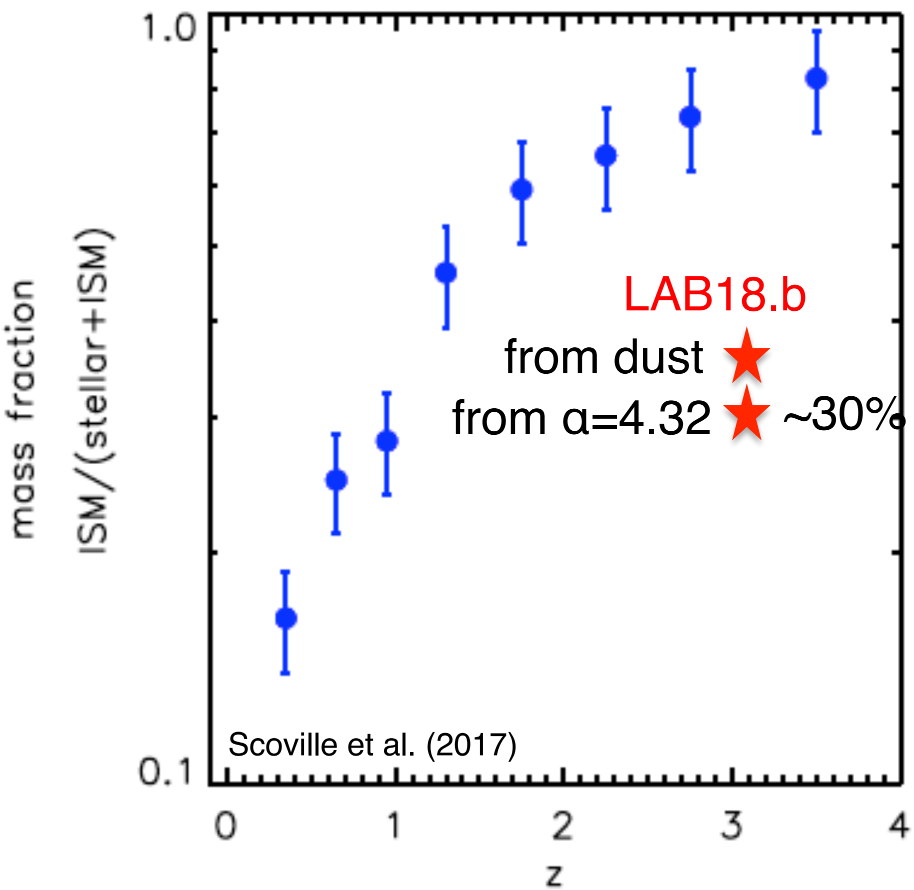


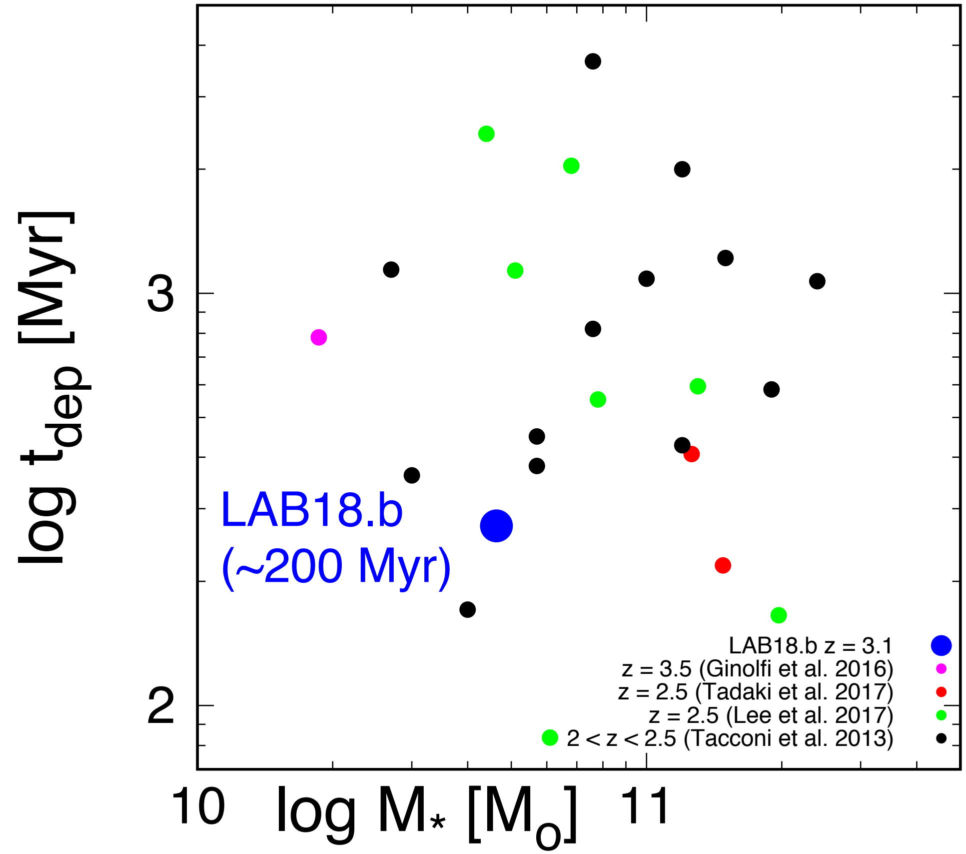
Table 5.3: Summary of derived properties for LAB18.b.

ID		LAB18.b
$S^a_{CO(4-3)}dv$	(Jy km s^{-1})	0.083 ± 0.004
FWHM^b	(km s^{-1})	123 ± 27
$\log L'_{CO(4-3)}$	(K km s^{-1} pc^2)	9.33 ± 0.1
$\log M^c_{gas,CO}(\alpha = 0.8)$	($M_\odot$)	9.62 ± 0.2
$\log M^c_{gas,CO}(\alpha = 4.36)$	($M_\odot$)	10.36 ± 0.2
$\log M^d_{dust}$	($M_\odot$)	8.04–8.62
δ^e_{GDR}	($\alpha = 0.8, 4.36$)	10–38, 55–209
$\log L^e_{FIR}$	($L_\odot$)	12.07 ± 0.01
Major axis (CO)^f	(kpc)	5.57 ± 0.53
Minor axis (CO)^f	(kpc)	1.83 ± 0.99
Position Angle (CO)	($^\circ$)	120 ± 9
Major axis (dust)^f	(kpc)	1.98 ± 0.08
Minor axis (dust)^f	(kpc)	1.14 ± 0.08
Position Angle (dust)	($^\circ$)	98 ± 3
SFR	(M_o/yr)	121 ± 3

- The larger β suggests that dust grain is small (i.e., β=1.7 for the Milky Way). We may see the dust grain size evolution.

Low f_{gas} ($M_{gas}/M_{gas+stellar}$) & τ_{dep} (M_{gas}/SFR)

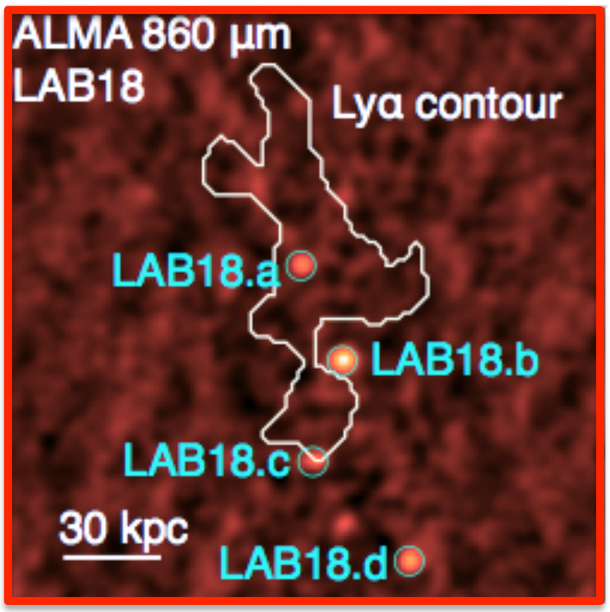




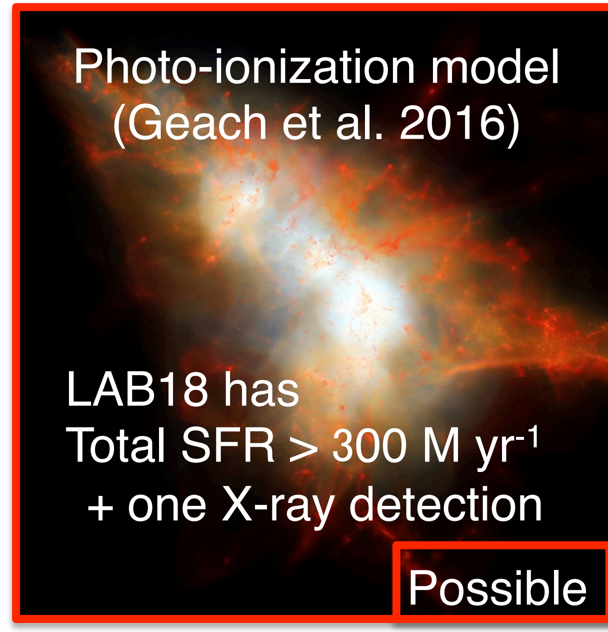
- logM$_{gas}$ (CO) =10.36, f_{gas} = 30%, τ_{dep} = 190 Myr. The derived M_{gas} is small, suggesting that even if the all of the M_{gas} converts to stellar mass, logM$_*$ (M_o)=10.84. Net accretion gas is needed if it evolves main sequence galaxy with logM$_*$ >11 at z=2

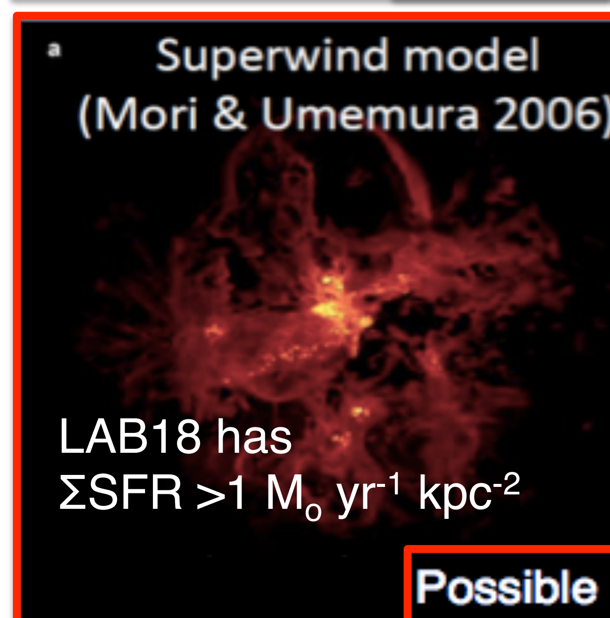
Possible Origin of LAB18 from Dust

ALMA results



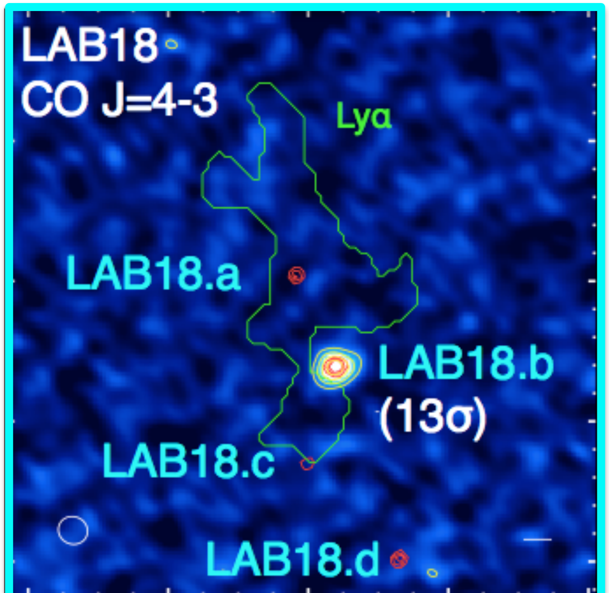
Origins



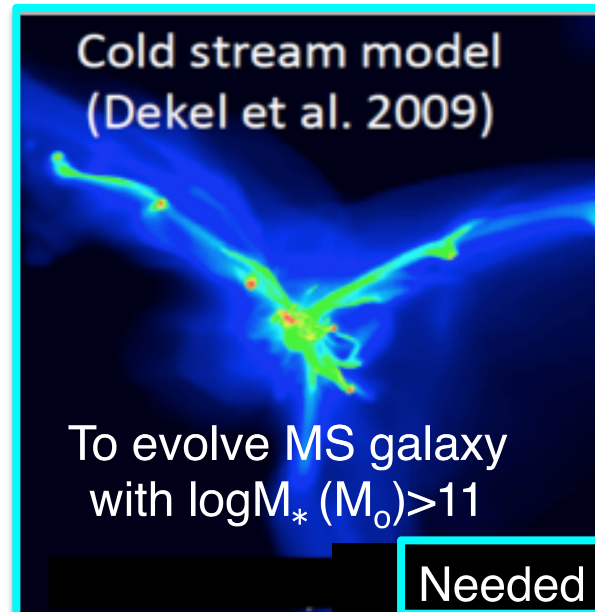


Possible Origin of LAB18 from CO

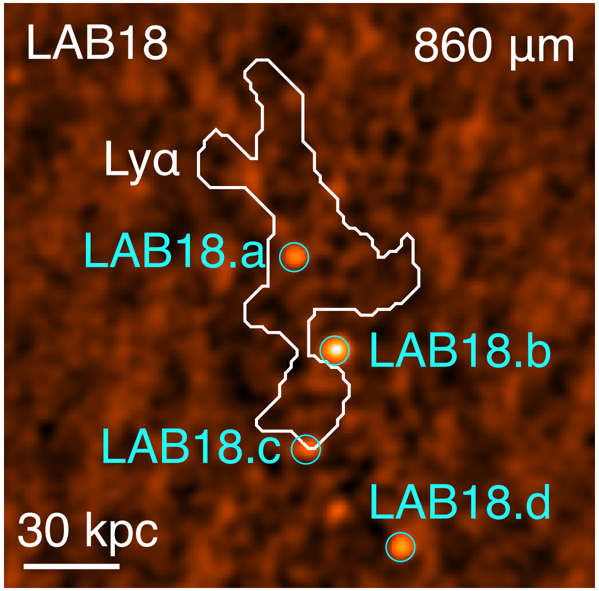
ALMA results

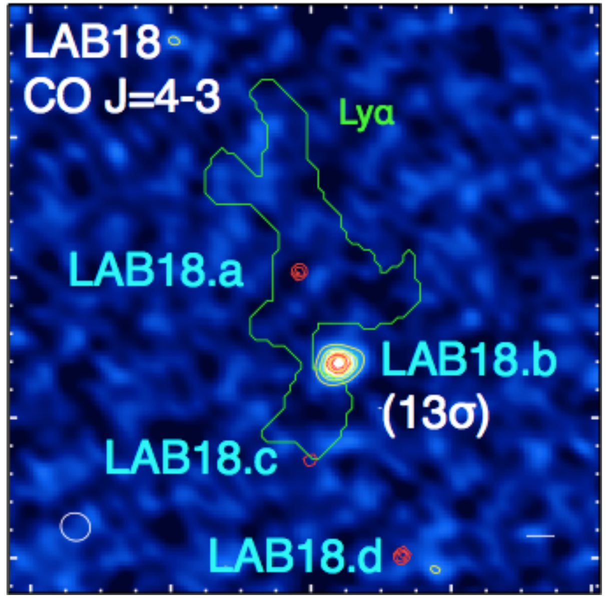


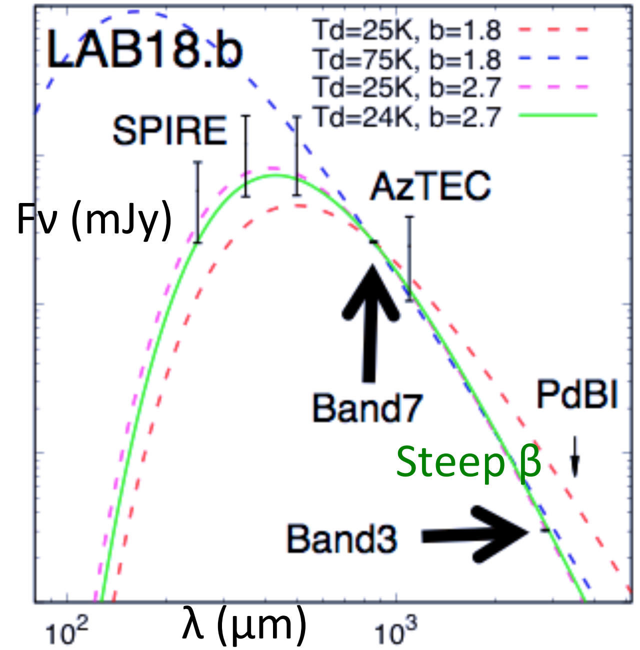
Origins



860µm & 3mm & CO J=4-3 Summary







- We detected four 860µm and 3mm continuum sources within LAB18 and CO J=4-3 line from one source LAB18.b. No signature of outflow/inflow.
- LAB18.b has compact central starburst region and extended rotationally disk or two face on merging/remnants.
- Four dust continuum sources in LAB18 suggest β>2.0, suggesting dust grain is smaller than the Milky Way. We may see the dust grain size evolution.
- Photoionization and Superwind models are possible origins. The cold stream model is needed if LAB18.b evolves galaxy with $\log M_* > 11.0$ along MS