Gas kinematics of star forming galaxies during early cluster formation epoch

Minju Lee
(The University of Tokyo)

Lee et al. 2018 (in prep.)

In collaboration with

Ichi Tanaka (Subaru/NAOJ), Ryohei Kawabe (NAOJ/UT), Kotaro Kohno (UT), Tadayuki Kodama (NAOJ), Masaru Kajisawa (Ehime U.), Min S. Yun (UMass), Daisuke Iono (NAOJ), Yoichi Tamura (Nagoya U.), Kouichiro Nakanishi (NAOJ), Bunyo Hatsukade (UT), Hideki Umehata (Open University), Kenichi Tadaki (NAOJ), Izumi Takuma (NAOJ), Toshiki Saito (MPIA), Soh Ikarashi (Kapteyn), Davie Huges (INAOE), Grant Wilson (UMass) and Rob Ivison (ESO)

Outline

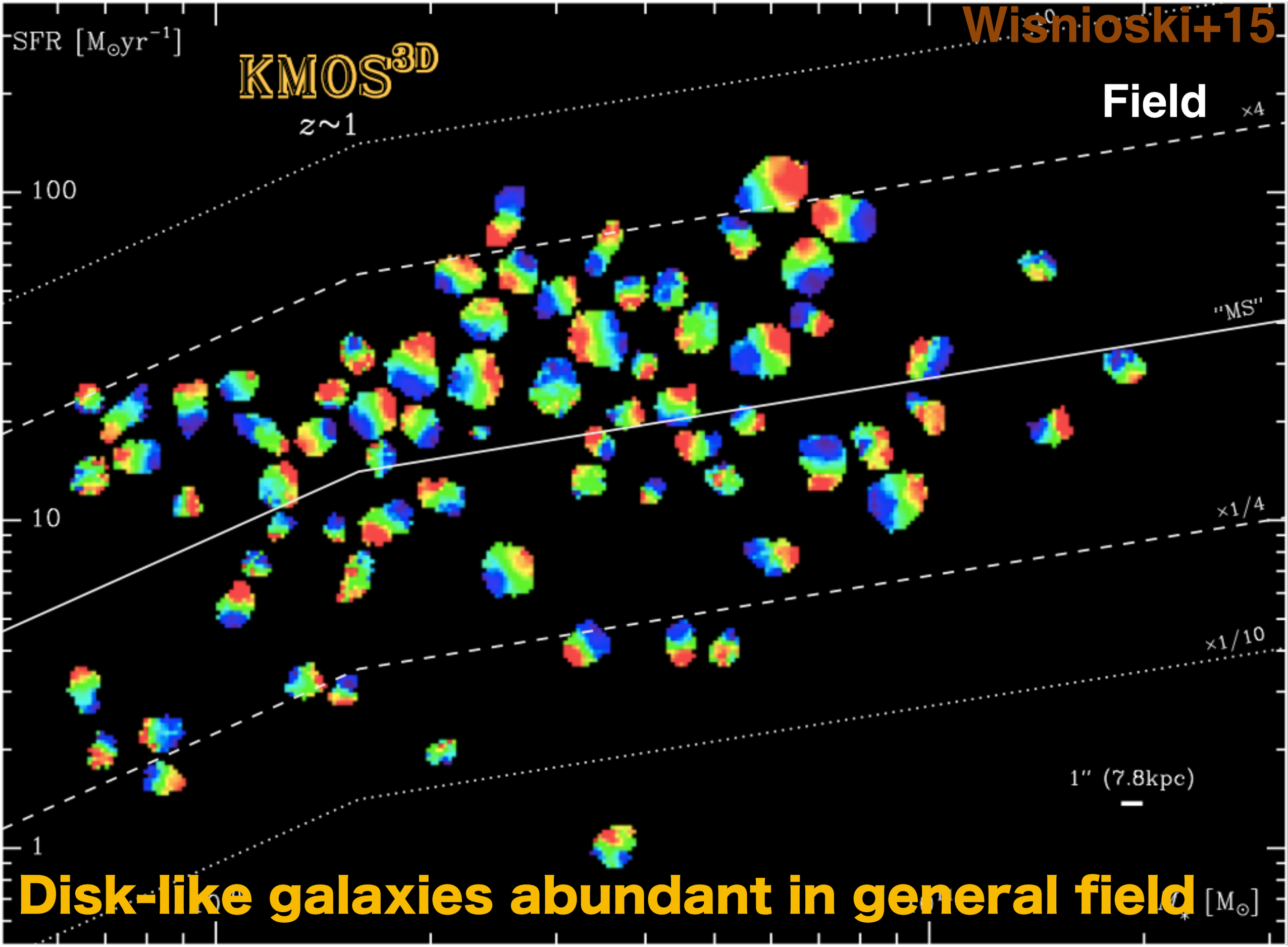
* Current understanding of gas kinematics toward high-z galaxies

* Protocluster as a tool for probing galaxy evolution in clusters

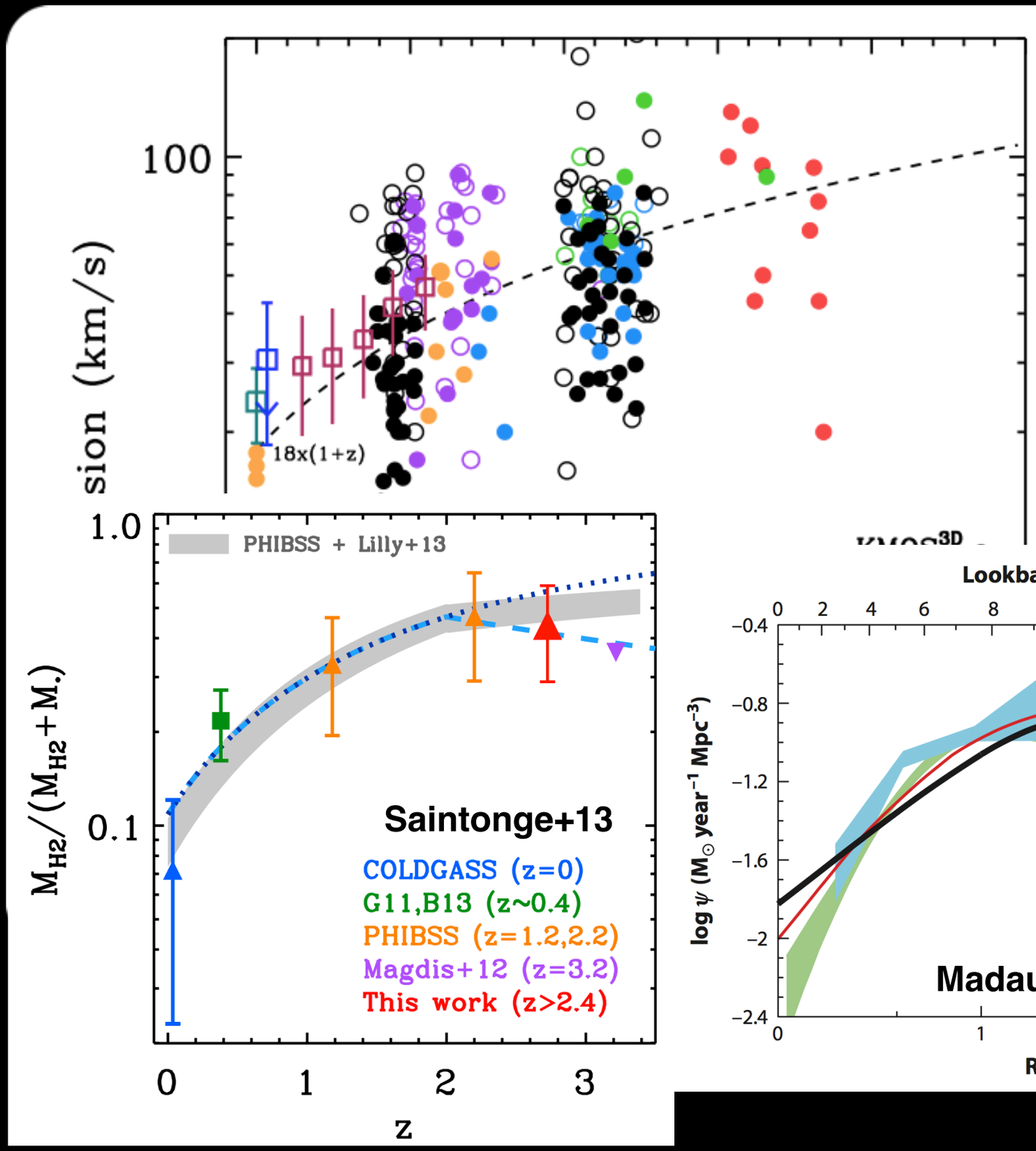
* Our ALMA cycle 3 observations using CO(4-3)

* Results : disk and mergers

* Summary of the talk and future prospects


Wisnioski+15
Field
KMOS3D
z~1
SFR [M⊙yr−1]
100
10
1
×4
×1/4
×1/10
"MS"
1" (7.8kpc)
Disk-like galaxies abundant in general field
[M⊙]

Velocity dispersion over cosmic time

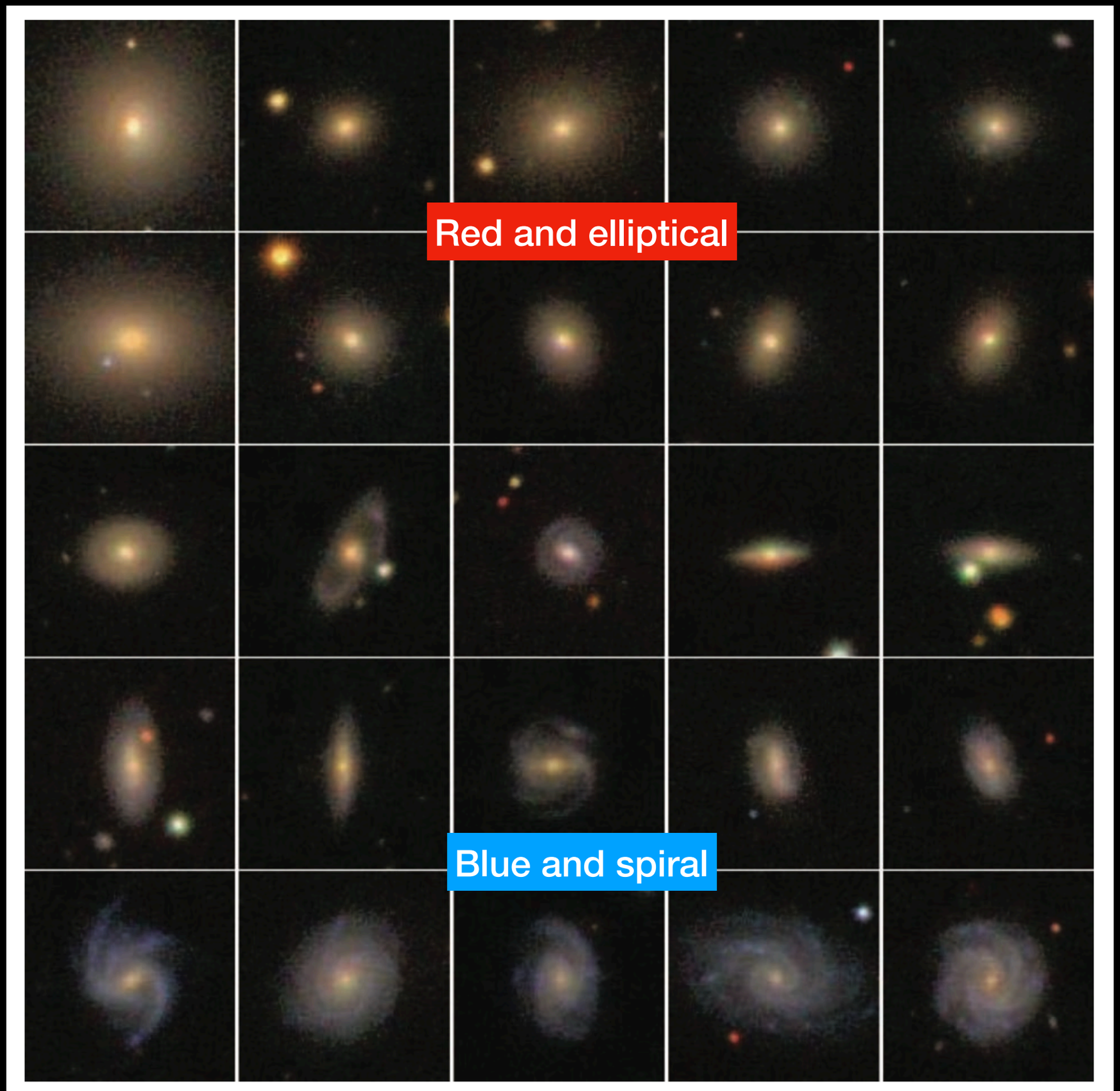


$$\sigma_0(z) = \frac{1}{\sqrt{2}} v_{\rm rot} f_{\rm gas}(z)$$

- for galaxies Mstar > 1e10.1 Msun

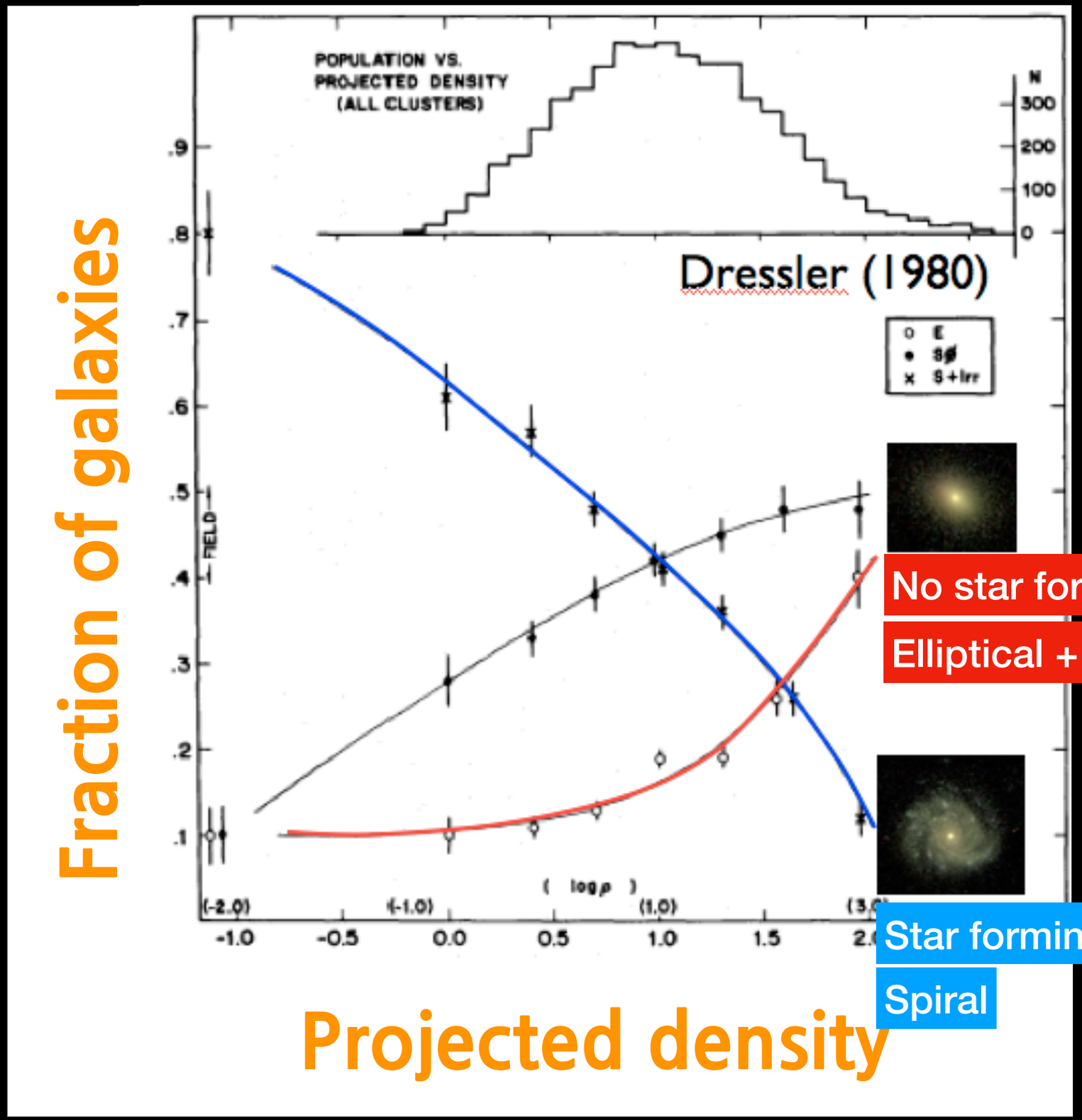
ion dominated
s at high-z
s due to high
tion)
s evolution will
rent in high-z
lusters?

Galaxy quenching may accompany morphological (or kinematical) transformation



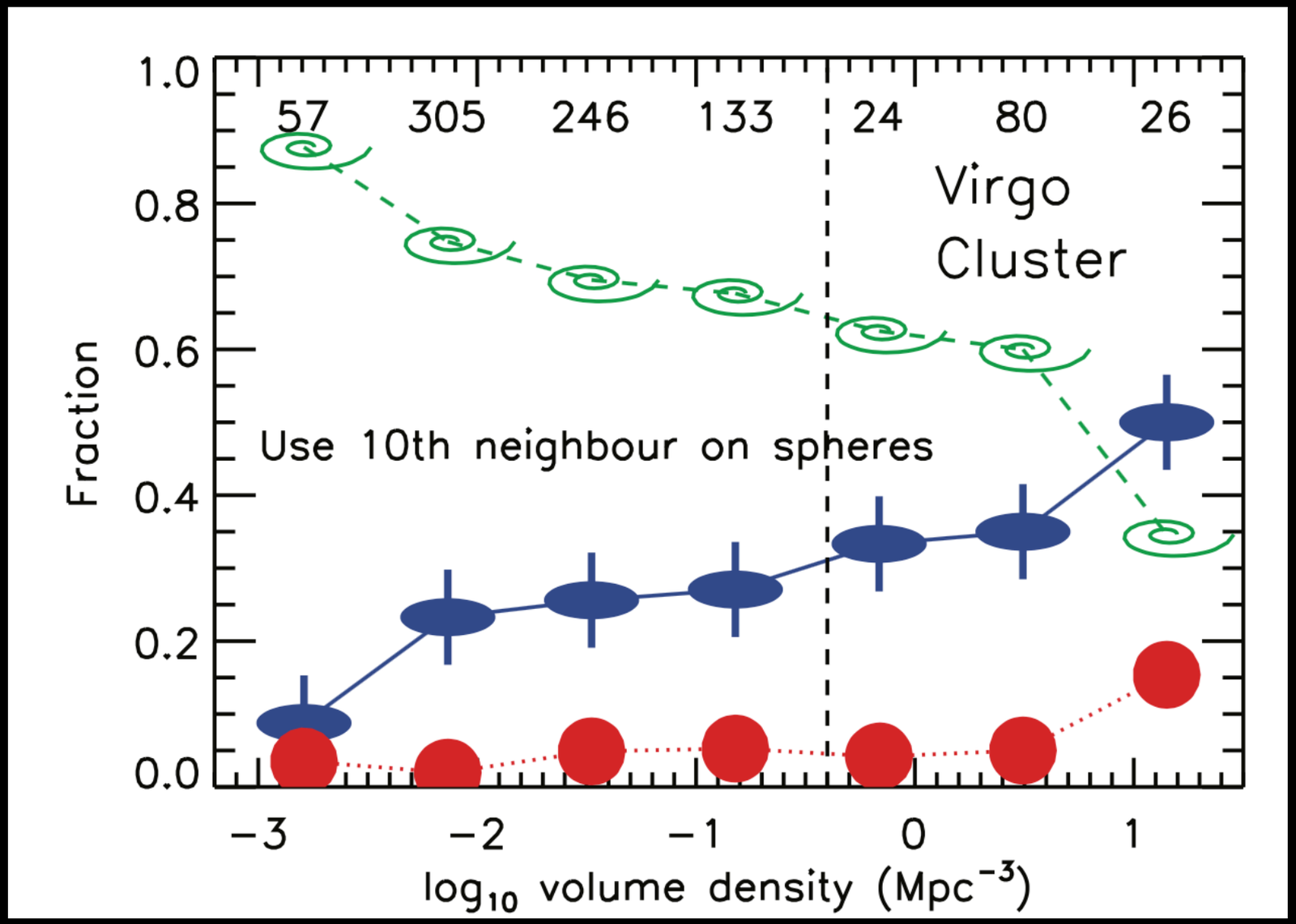
Ball+08

Galaxy quenching may be related to environment : morphology-density



Galaxy quenching may be related to environment : kinematic parameter-density

slow rotators concentrated in cluster center
fast rotators distributed widely and increase gradually



Both its appearance and the SF activity should be changed

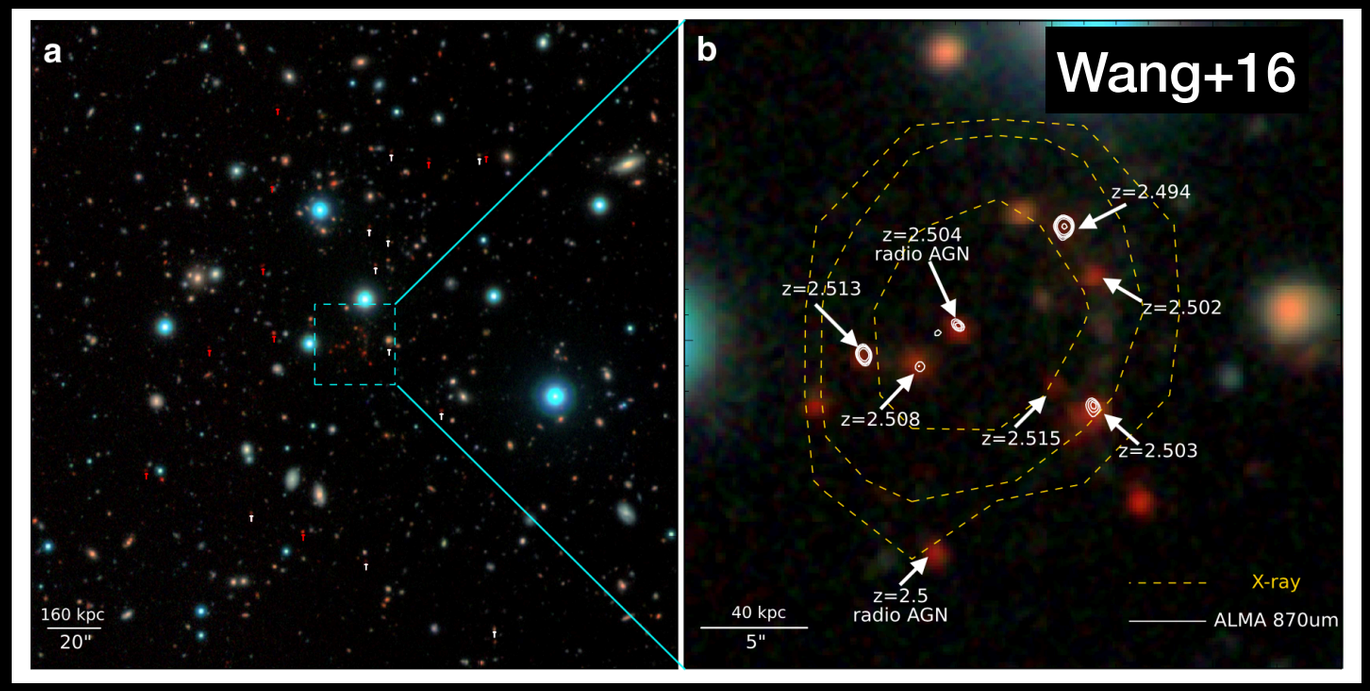
Protocluster

A key to probe early build-up of red and dead populations

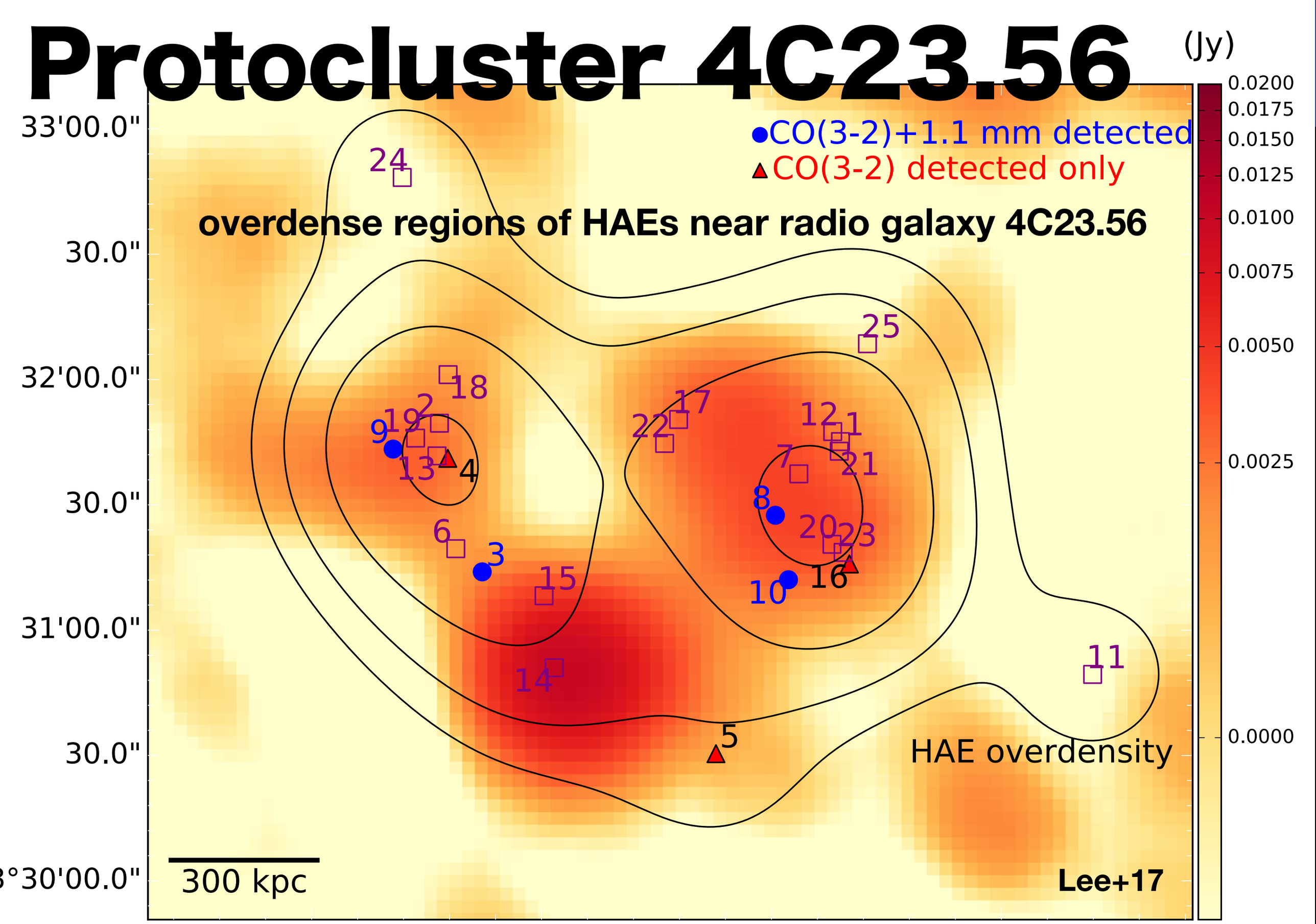
- Current somewhat ambiguous definition : **`overdense' regions** of galaxy population **that may be evolved into present-day clusters**
  - e.g., overdenstity of H-alpha emitters (HAEs), Lyman alpha emitters (LAEs), Dusty Star-forming galaxies (DSFGs), Lyman break galaxies (LBGs)…
- c.f., **High-z virialized clusters** (and detected by X-ray emission from ICM) found **up to z~2.5**

Theoretical background : the protocluster may evolve into z=0 cluster given sufficient overdensity (e.g., Chiang+13)

With increasing number of candidate protoclusters, it is time for *investigating* currently identified protoclusters



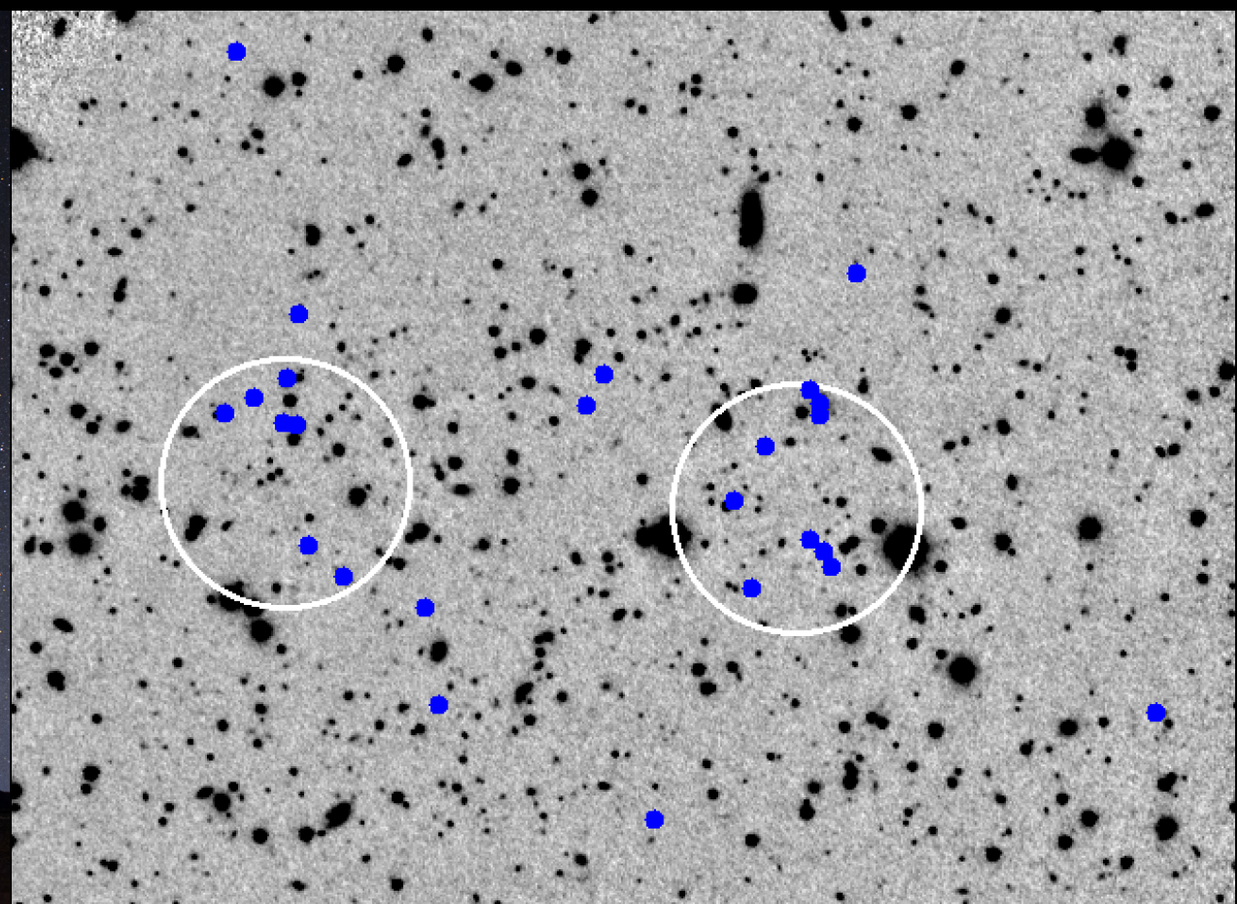
Protocluster 4C23.56



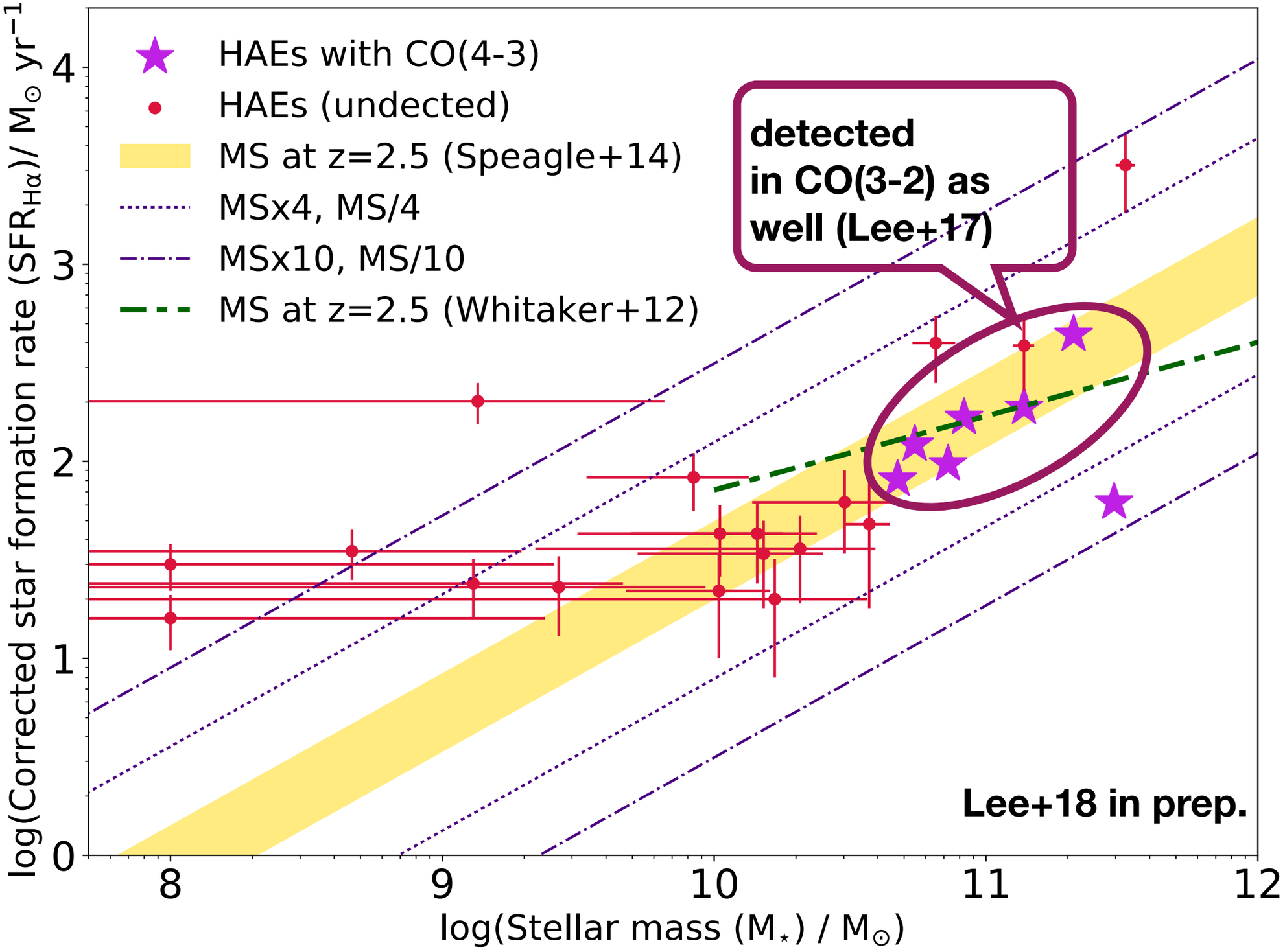
HAEs
MS at z=2.5 (Speagle+14)
MSx4, MS/4
MSx10, MS/10
MS at z=2.5 (Whitaker+12)
Massive-end mostly on the main sequence
log(Corrected star formation rate ($SFR_{H\alpha}$)/ $M_\odot$ yr^{-1})
log(Stellar mass ($M_\star$) / $M_\odot$)
0
1
2
3
4
8
9
10
11
12

ALMA observations

- ALMA cycle 3 (PI : Minju Lee)
  - Band 4 targeting CO(4-3) (and [CI])
  - 2-point covering 16 HAEs
  - ~1.3 hrs of on-source per pointing
    - continuum sensitivity = 13 uJy/beam
    - line sensitivity = 0.16 mJy/beam (at 80km/s)
  - Resolution : 0″.3x0″.5 (x2 higher from previous cycle observations)

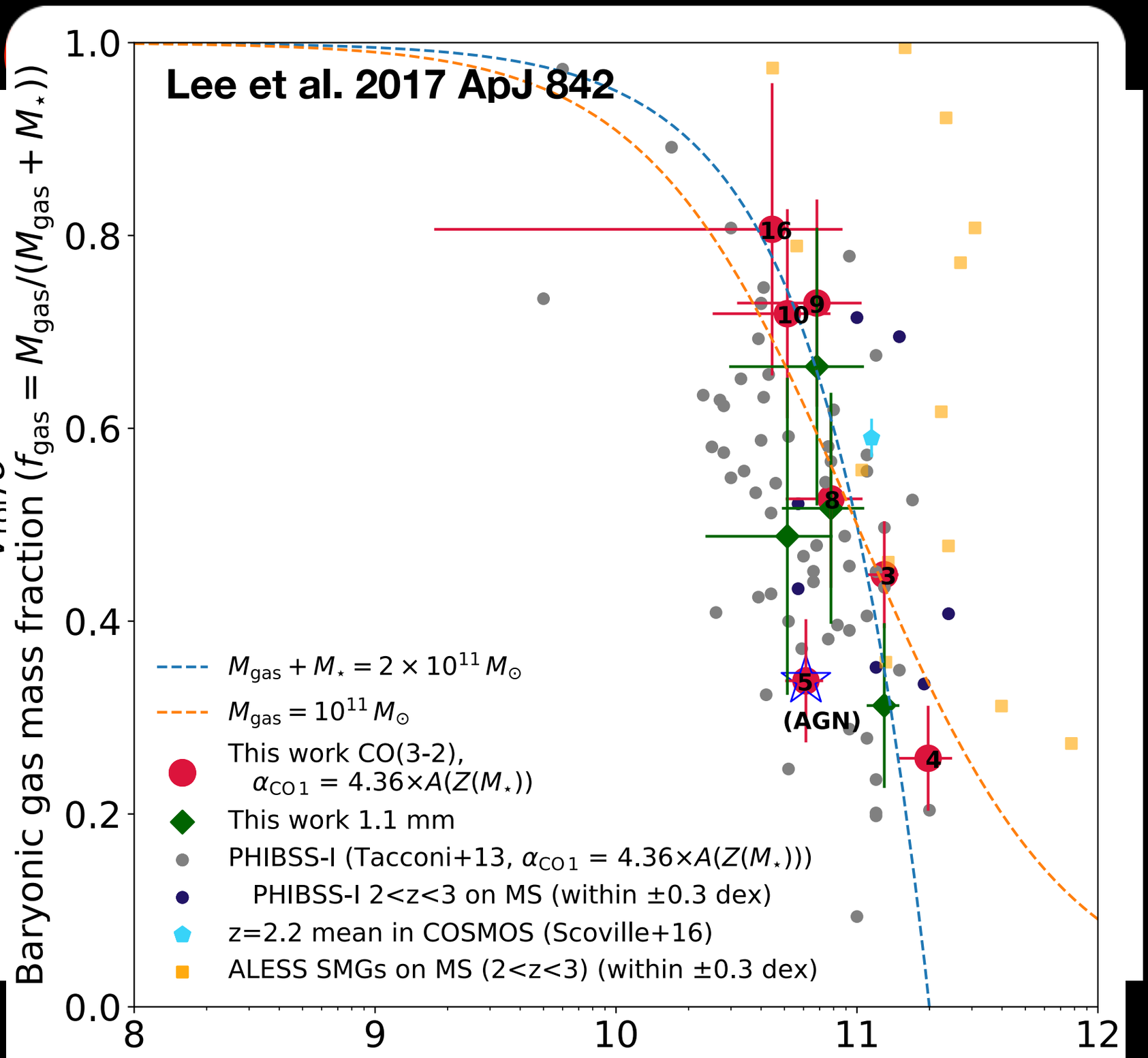


Massive HAEs mostly on the main-sequence



Large scatter of v_{rot}/σ

2/7 HAEs are disk-like



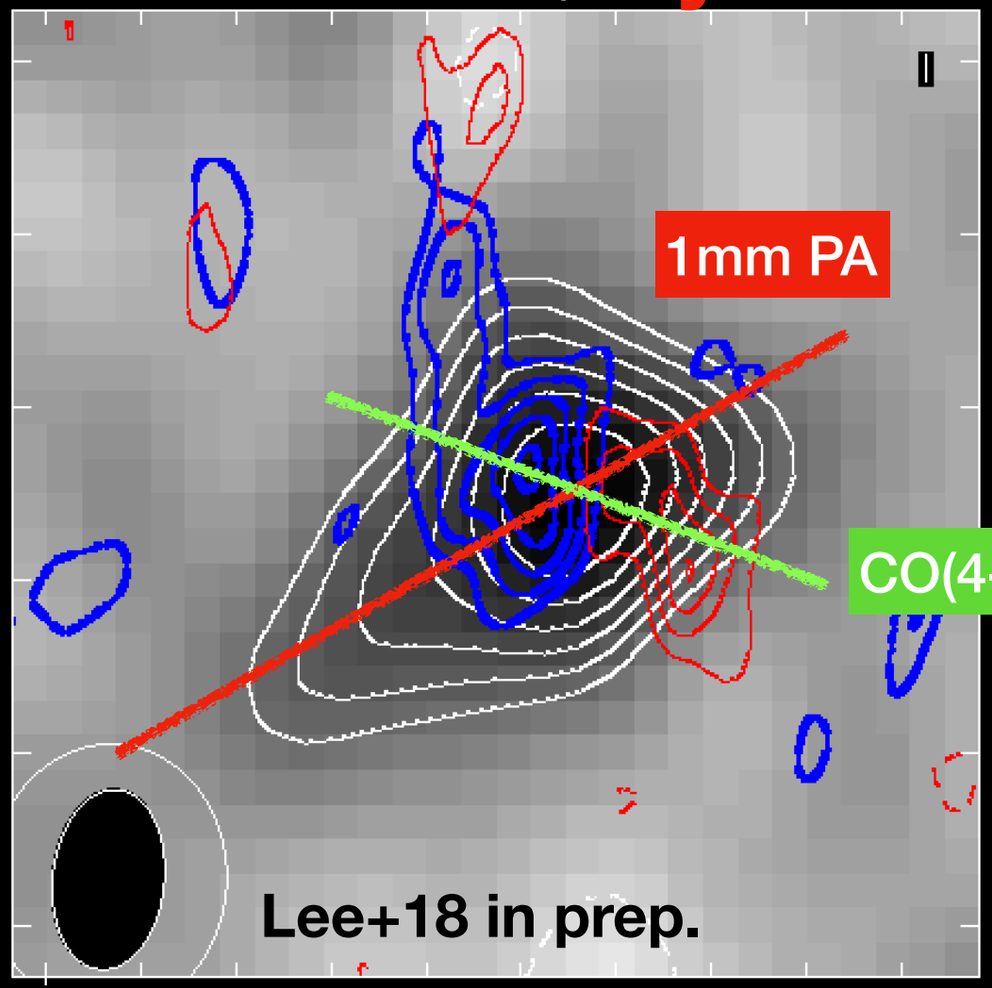
A hint for evolution of elliptical galaxies (in clusters)?

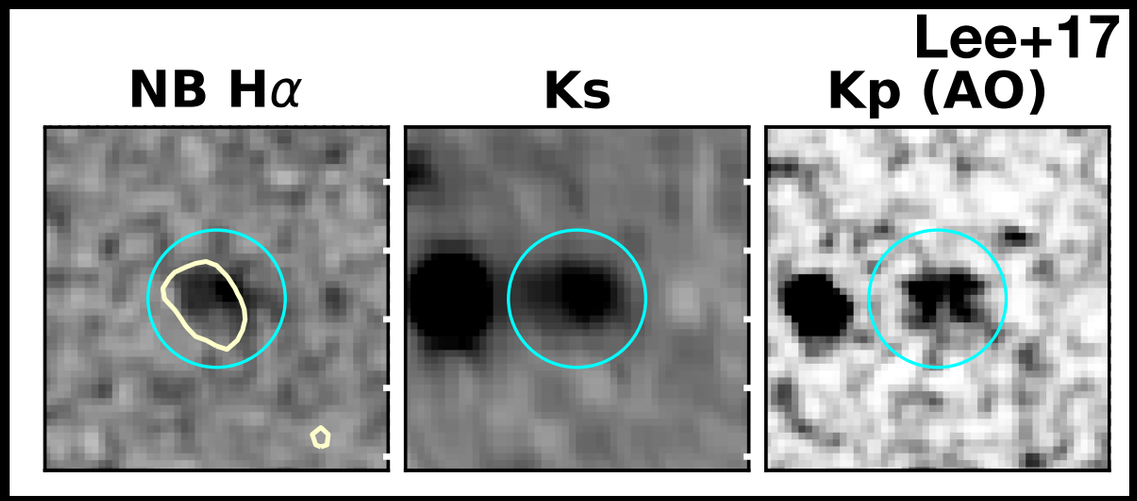
lines : expected vrot/σ at given fgas and Q
field galaxies consistent with marginally stable disk

$$\frac{v_{\rm rot}}{\sigma_0} = \frac{a}{f_{\rm gas}(z) Q_{\rm crit}},$$

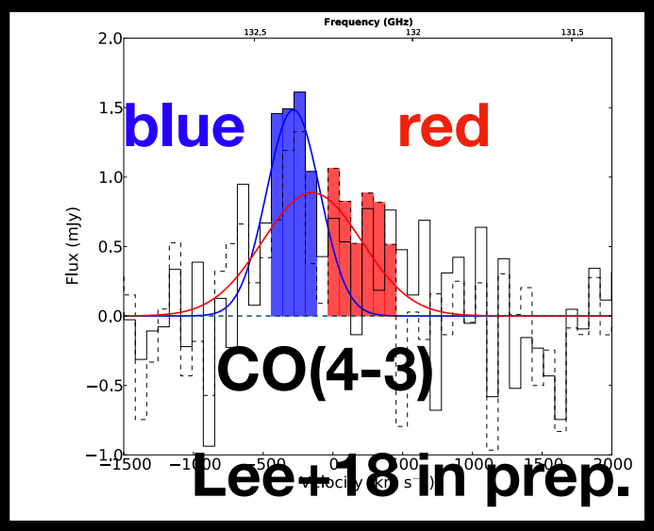
Not all galaxies are disks : mergers

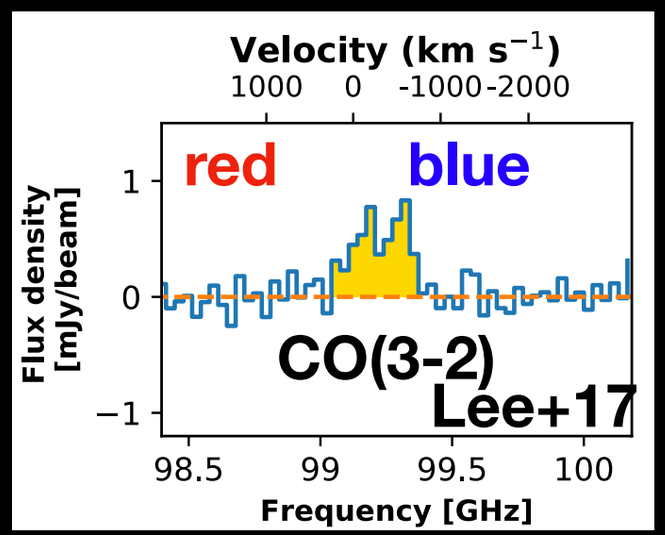
2/7 HAEs are likely associated to mergers





- White contour : 1 mm continuum (low-res, but high S/N than 2 mm)
  - morphological PA and kinematical PA is different (from uvmodelfit)





- blue and red component : spectroscopically/spatially distinctive “sub-structure”, or *a <u>merger</u>*
- Galaxy with high fgas ~0.7

Summary

- **Kinematical diversity of star forming galaxies** seen in the high-z protocluster
  - **Kinematics** :
    - kinematically “evolved” disk
    - some galaxies appear to have a counterpart to be merged

- Good quality of larger samples, in different environment necessary **(>> expectation to Subaru/HSC SSP + future ALMA surveys)**