Introduction to Kodama Labo

Revealing the History of Galaxy and Cluster Formation and Evolution with Observations by Modern Telescopes (e.g., Subaru and ALMA) and Phenomenological Models

Taddy Kodama

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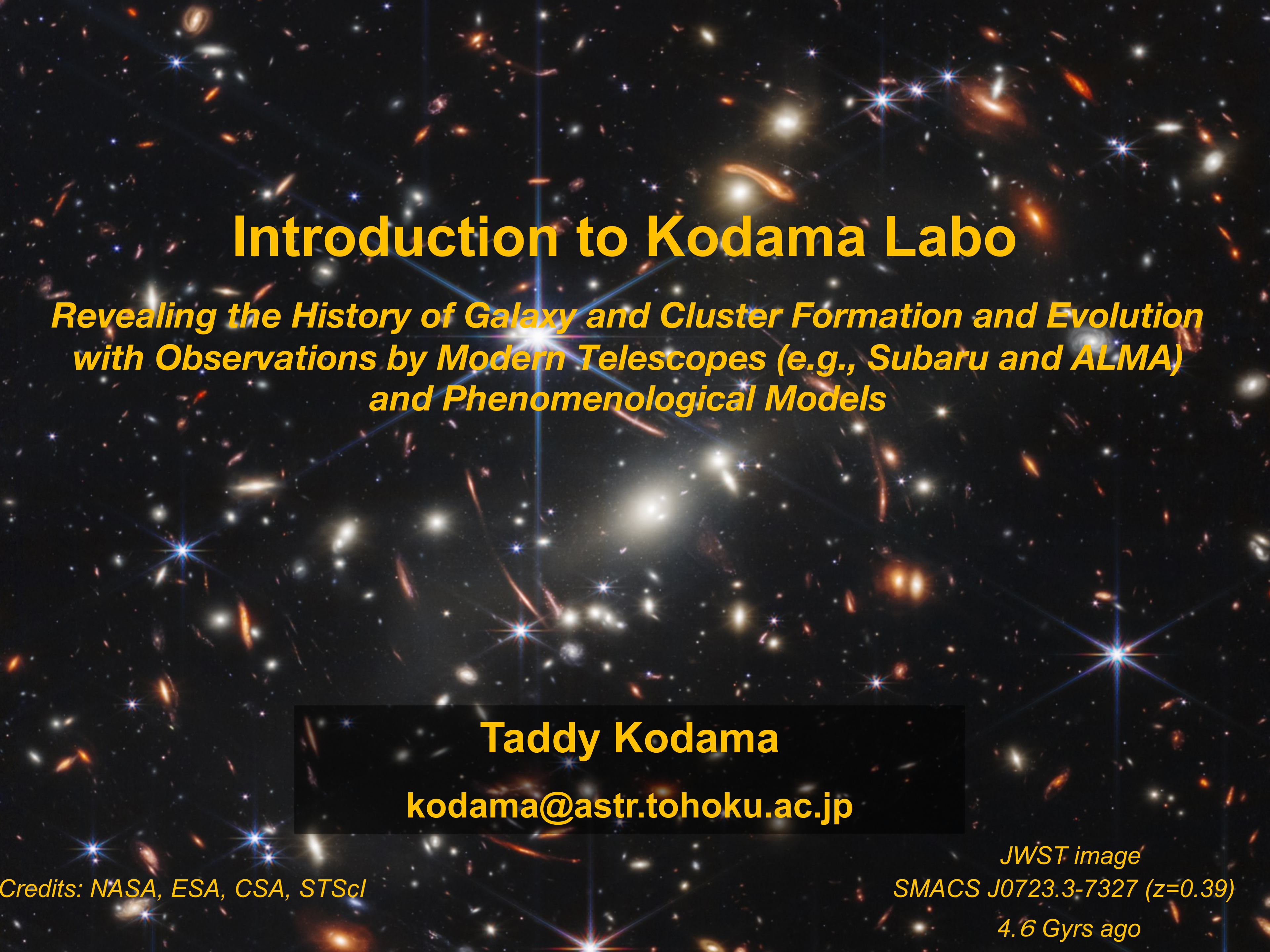

Credits: NASA, ESA, CSA, STScI

JWST image
SMACS J0723.3-7327 (z=0.39)
4.6 Gyrs ago

Labo members

児玉　忠恭
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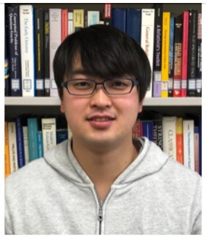
Professor

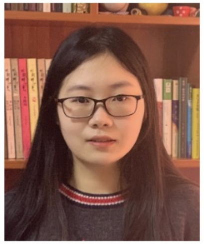
久保　真理子
Mariko Kubo
Assistant Professor

山本　直明
Naoaki Yamamoto
D3 student

Ronaldo Laishram
D3 student



大工原　一貴
Kazuki Daikuhara
D2 student



刘　兆然
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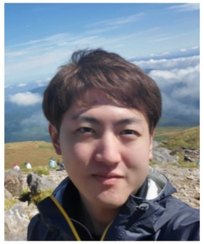
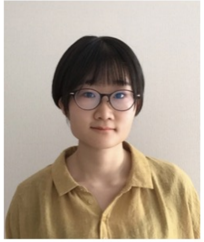
Riho Okazaki
M2 student

田村　真大
Masaharu Tamura
M2 student

石田　光
Ko Ishida
M1 student



高橋　宏典
Kosuke Takahashi
M1 student



舩木　美空
Miku Funaki
B4 student

D3: 2
D2: 2
D1: 0
M2: 3
M1: 2
B4: 1
計：10

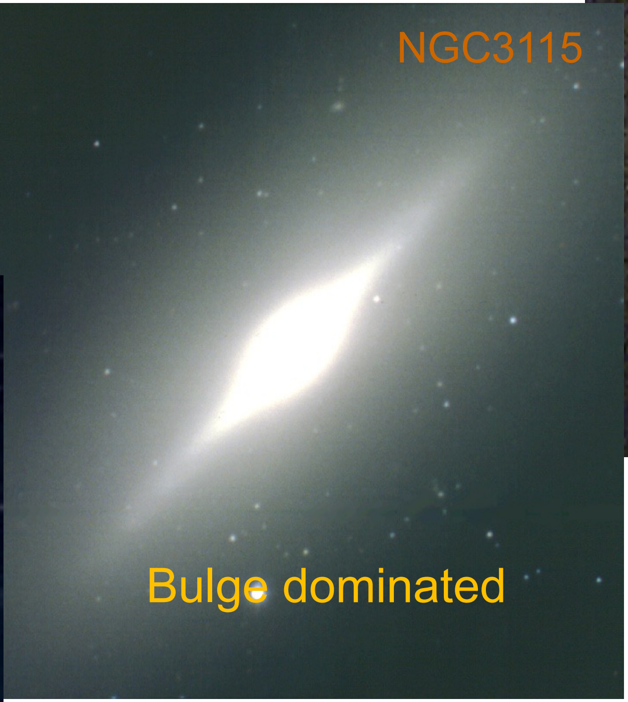
Labo Homepage
http://mahalo.galaxy.bindcloud.jp

Various types of galaxies

"Hubble sequence" of galaxies

Blue = Young
(star forming)

Spiral (disk) galaxy



Lenticular (S0) galaxy

Green = Intermediate

Elliptical galaxy

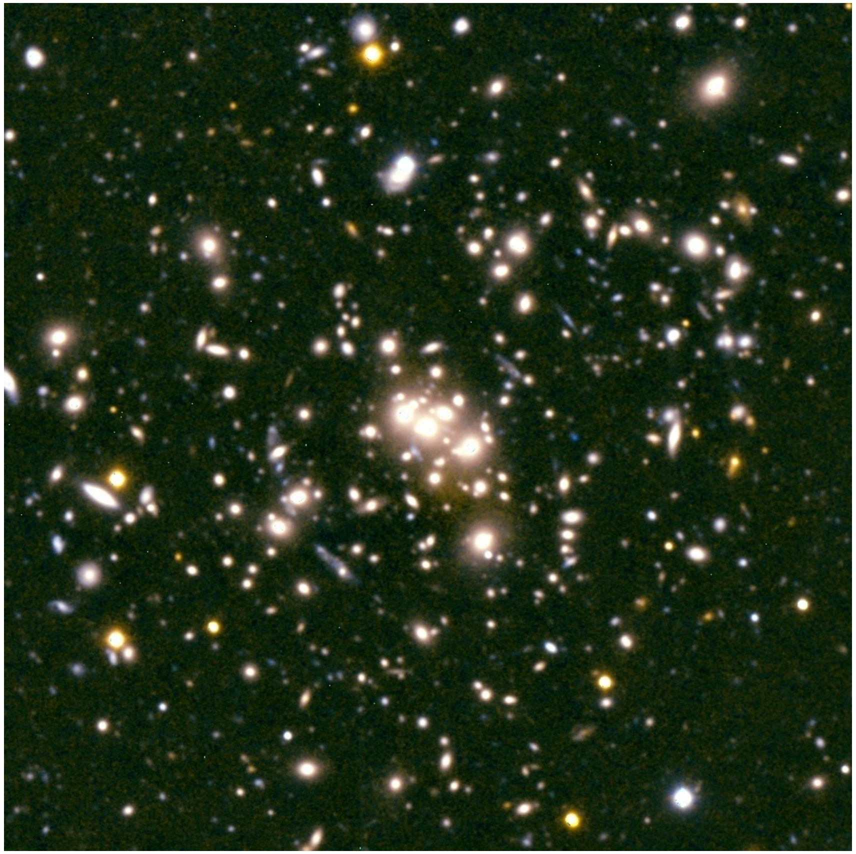
Red = Old
(no more star formation)

Our MW Galaxy is classified as a spiral galaxy!

There are ~100 billion galaxies in the Universe.

Clusters of Galaxies

A cluster of galaxies consists of 100s -1000s of galaxies.



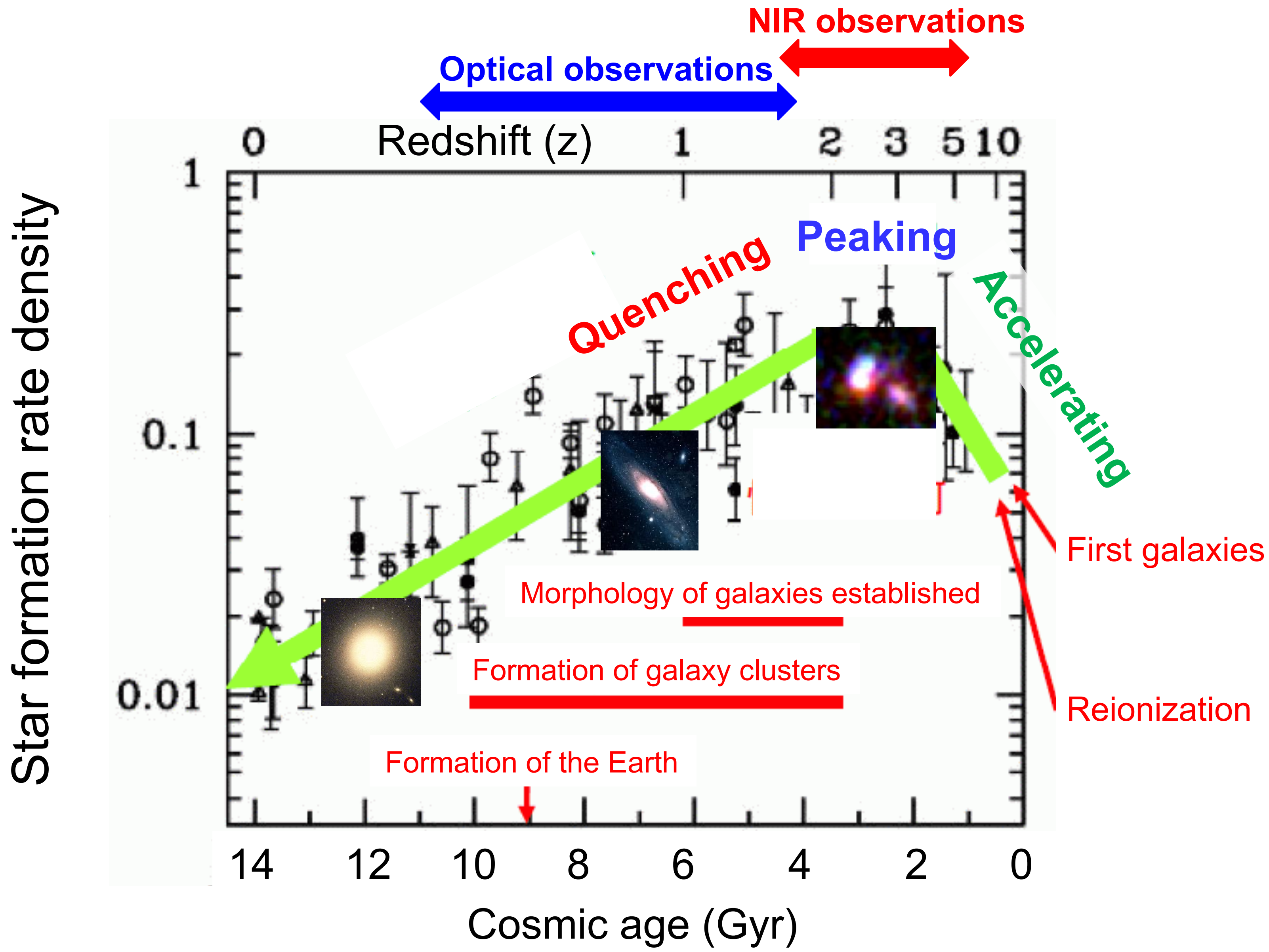
CL0024 cluster (4.2 Gyr) ©Subaru Telescope

Abell1689 cluster (2.2Gyr)
©Hubble Space Telescope

radius ~ 1Mpc Mass ~ $10^{14\text{-}15}\ M_\odot$

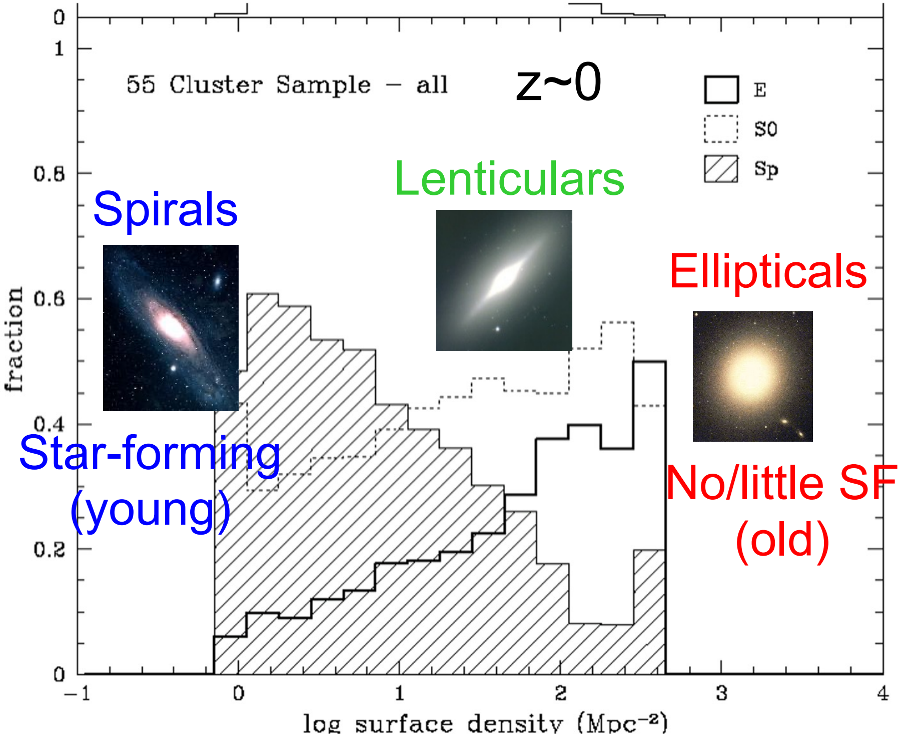
85%: dark matter, 13%: gas, 2%: stars

Cosmic Star Formation History

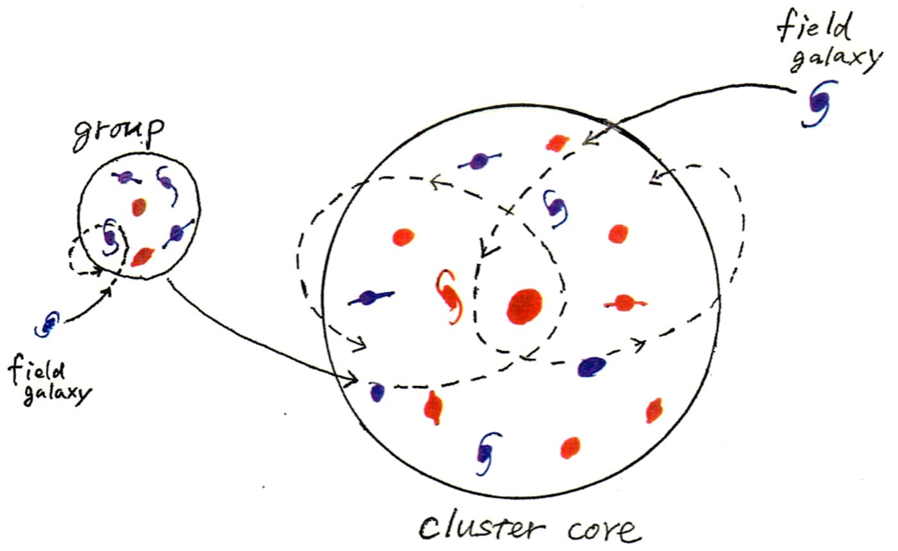


Cosmic habitat segregation

Morphology- (SFR-) density relation
(Dressler 1980)



log surface density (Mpc^{-2})



Nature? (intrinsic)

earlier galaxy formation and evolution in high density regions

Nurture? (external)

galaxy-galaxy interaction/mergers, gas-stripping

Internal effects on galaxy formation and evolution

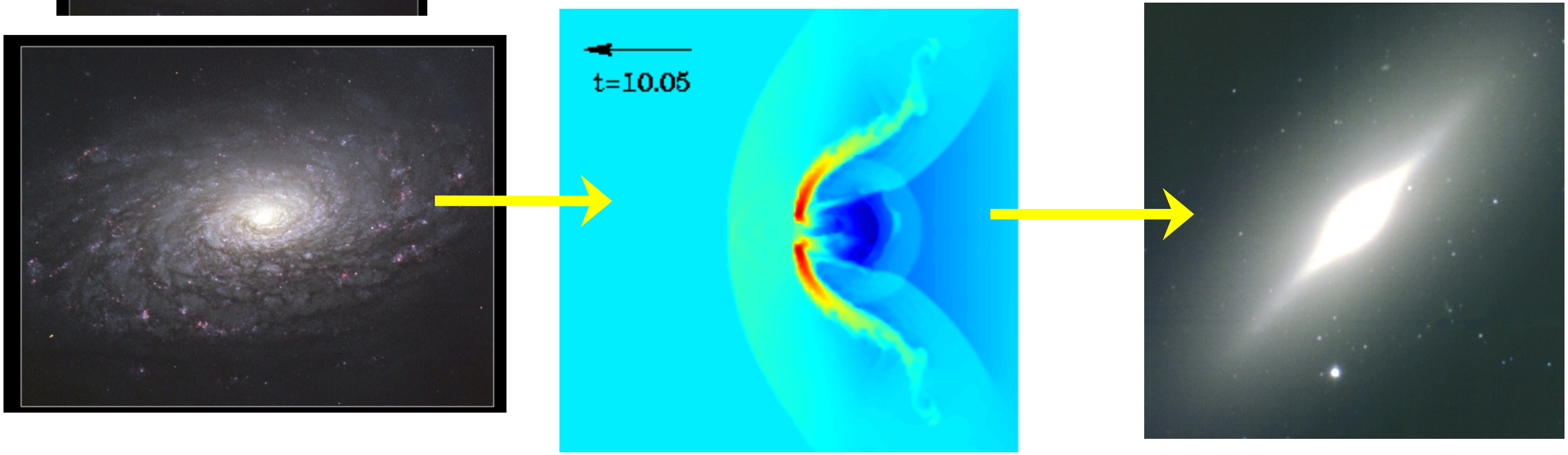
galaxy merger → loss of angular momentum of gas → gas infall to galaxy center → central starburst → gas infall further to central black-hole → boost of AGN activity → bipolar jet → removal of gas → quenching of star formation

http://www.mpifr-bonn.mpg.de/bonn04/

Co-evolution of galaxies and BHs.

External effects on galaxy formation and evolution

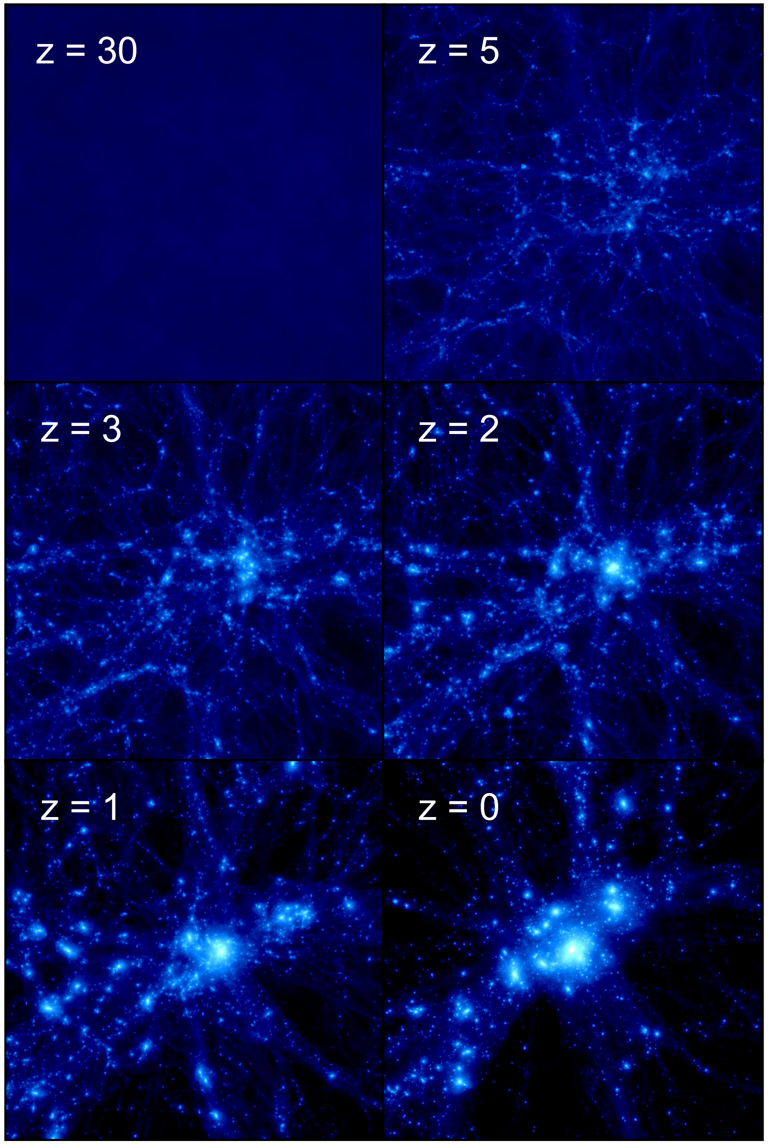
Mergers induce starburst first, but then lose or use up the gas, and star formation is truncated sharply.



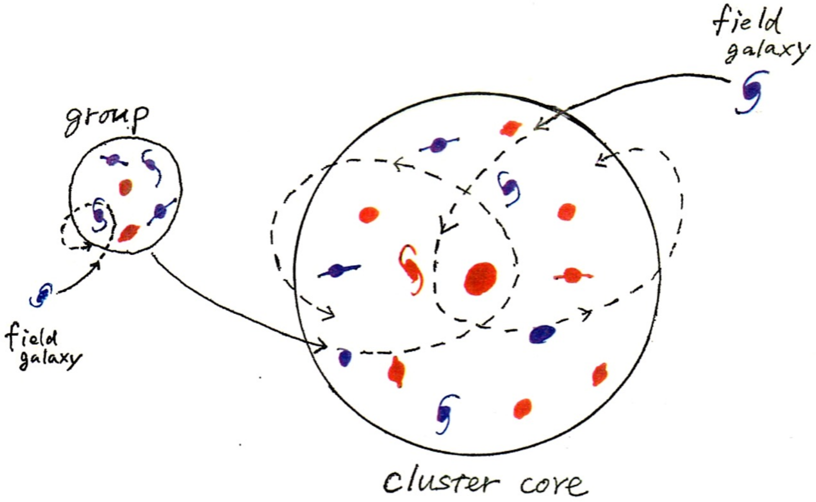
Ram-pressure strips gas from the system and terminates SF.

Environment matters in acceleration of galaxy formation and its quenching!

N-body cosmological simulation (Yahagi+05)



M=6 × 10^{14} $M_\odot$ 20 × 20Mpc^2 (co-moving)



Nature? (internal)

earlier (biased) galaxy formation and evolution in high density regions

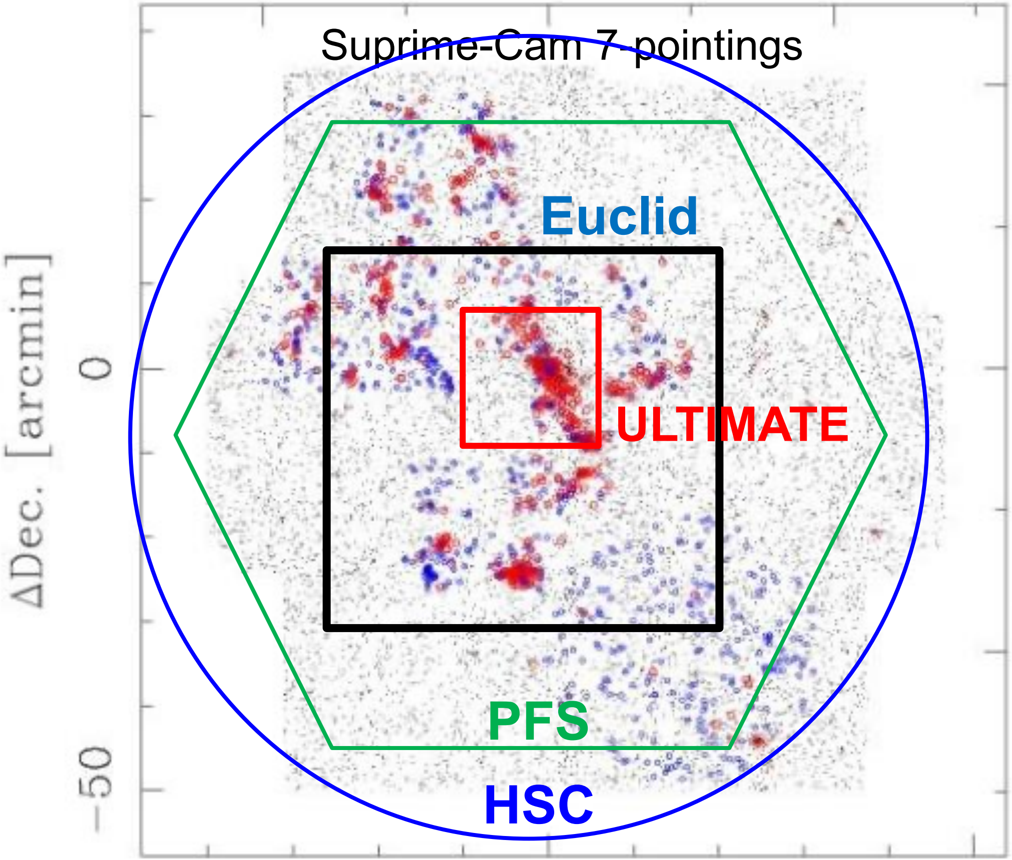
Nurture? (external)

galaxy-galaxy interaction/mergers, gas-stripping

Subaru/HSC&PFS and Euclid are extremely powerful to probe LSSs

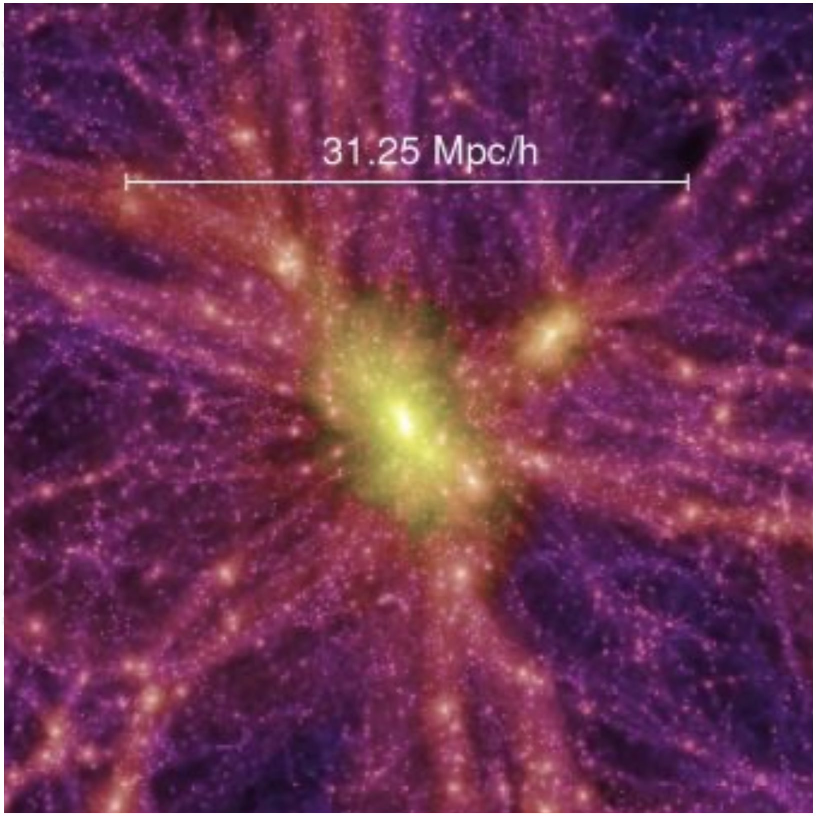
1.3° = 75 Mpc (z=1), 100 Mpc (z=1.5), 118 Mpc (z=2) in co-moving

CL0016 cluster (z=0.55)
(Tanaka, M. et al. 2009)



LSS around the richest cluster at z=0.55
~1,200 redshifts from spectroscopy
red are cluster members, while blue are non-members

Millenium Simulation
(Springel et al. 2005)



Key questions on galaxy clusters

1. How much are (proto-)clusters ***biased (earlier/faster) in*** (massive) ***galaxy assembly and quenching?***
2. Are the ***SF/AGN activities ever boosted in situ in cluster cores, or pre-processed in the outskirts and then accreted?*** How do the ***SF/AGN activities and quenching propagate*** within cluster galaxies?
3. How much of SF in clusters is ***hidden by dust?***
   Is there an ***environmental effect in dust extinction?***
4. When and how does the ***gas accretion*** to clusters become ***efficient*** and then ***inefficient?***
5. Where and how do the ***gas outflow or stripping*** affect the galaxies in clusters?

1. How much are proto-clusters biased (earlier/faster) in (massive) galaxy assembly and quenching?

JWST seems to be finding (too) many candidates for massive monsters at 7<z<11 !

7 with log $(M/M_\odot)$ >10, including 2 with log $(M/M_\odot)$ ~11

log$(M/M_\odot)$ =10.93 at z=9.92

log$(M/M_\odot)$ =11.16 at z=7.56

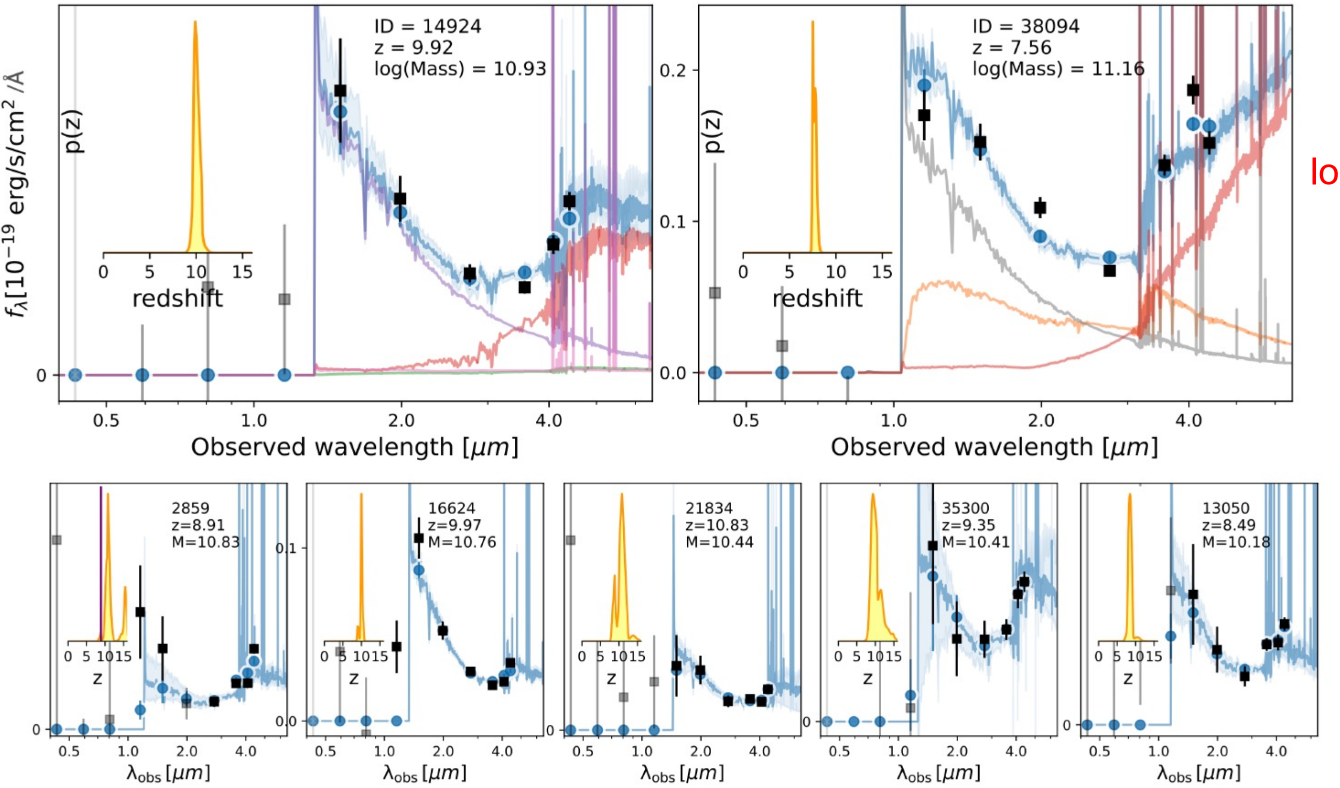


Figure 3: Spectral energy distributions (SEDs) and photometric redshift probability distributions $P(z)$ of the 7 galaxies with $\log(M_*/M_\odot) > 10.0$. The flux density units are in $F\lambda$ versus wavelength in μm. All galaxies show a characteristic V-shaped SEDs, with a clear upturn at $3-4\,\mu$m and a double break. The redshifts are well-constrained owing to the presence of two breaks. The two most massive galaxies are highlighted on the top row. Shown are the contribution of each template in the fit, where the fit produces a prominent contribution of an older stellar population (left) or dusty stellar population (right) shown in red. Emission lines contribute clearly to the F356W and F444W bands, with the narrower F410M band providing a powerful diagnostic, improving both the redshift and the SED fit.

Labbe et al. 2022, arXiv:2207.12446

Flux calibration issue?

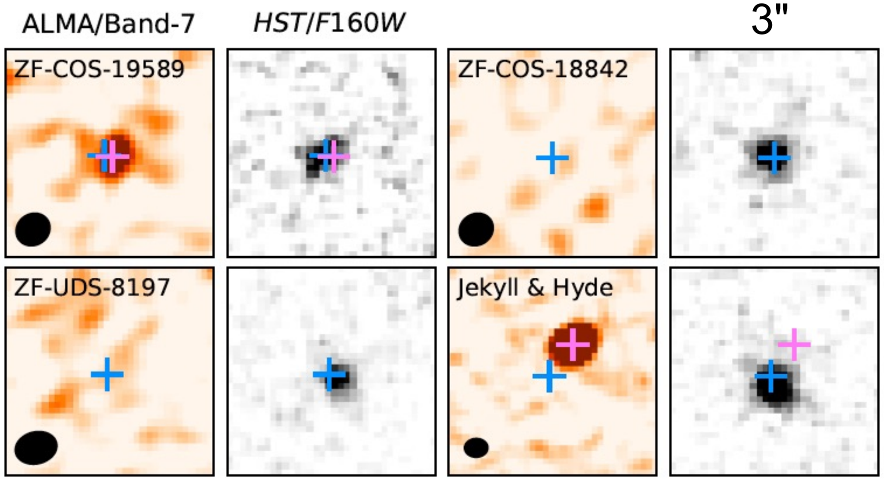
What causes the quenching of star formation in high-z massive monsters (z~4)?

Whether f_{gas} is low, or t_{dep} is long (*SFE* is low) ?

→ ALMA observations of $[\mathrm{C\ I}](^3\mathrm{P}_1 - ^3\mathrm{P}_0)$ line and dust@870μm

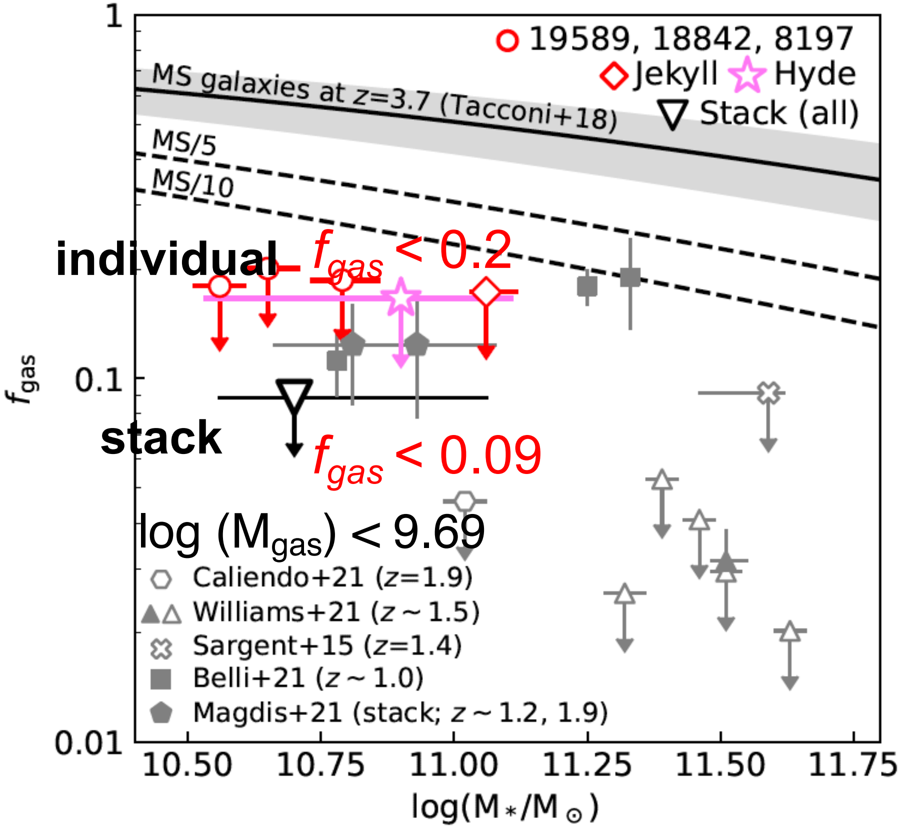
4(+1) massive (log $M/M_\odot$~11)
galaxies at z=3.5~4 (ZFOURGE)

Glazebrook et al. 2017; Schreiber et al. 2018b



Non detection for ¾ with ALMA
(Band-7: 870μm, Band-3: [CI])

Already gas poor ! $f_{gas} < 0.1$-0.2



individual $f_{gas} < 0.2$

stack $f_{gas} < 0.09$

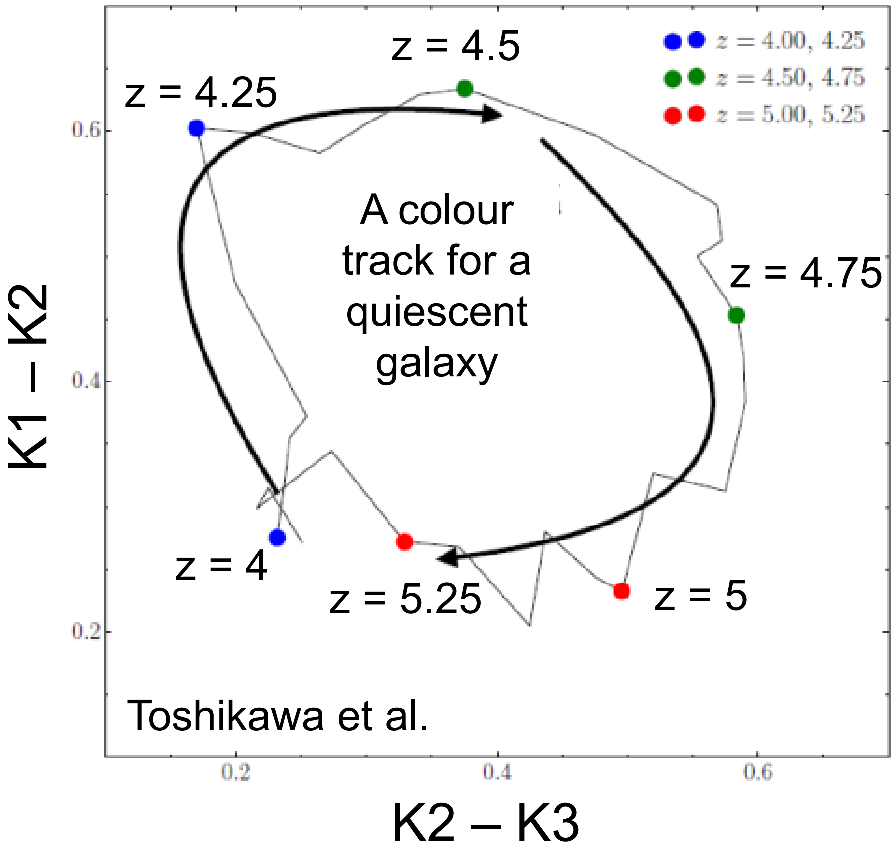
log $(M_{gas}) < 9.69$

Suzuki et al. (2022)

> 3-6 times lower than the MS !

MBFs (K1-K4) can neatly capture the Balmer break out to z=5.4

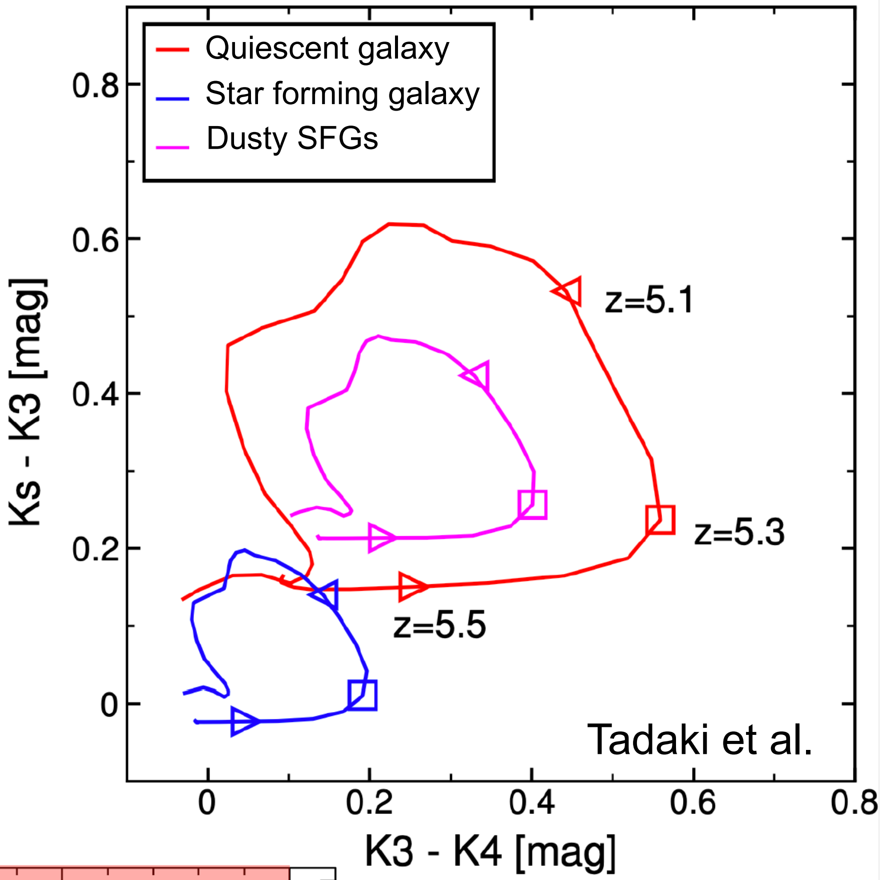
K1−K2 vs K2−K3



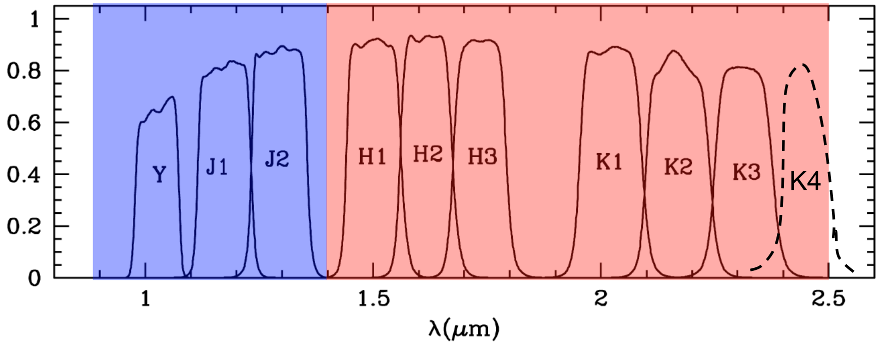
A colour track for a quiescent galaxy

Toshikawa et al.

Ks−K3 vs K3−K3



Tadaki et al.



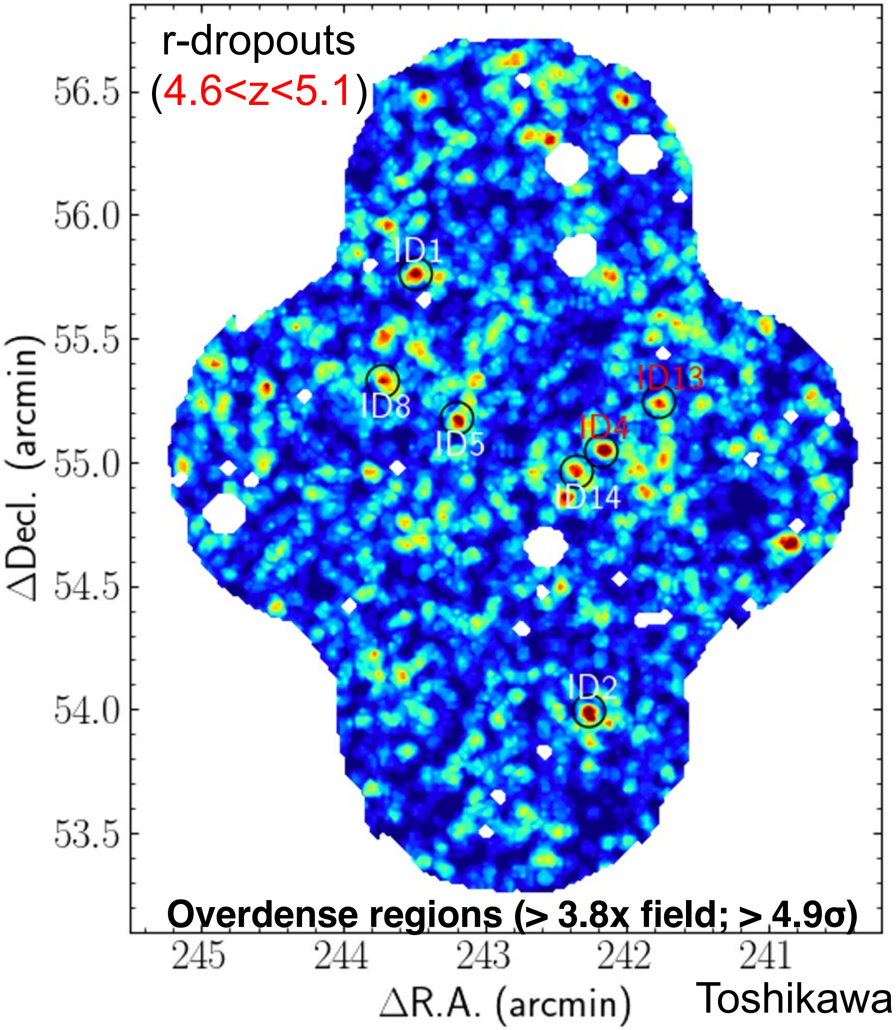
MBFs on SWIMS (Y~K3) and MOIRCS (K4)

Hunting ultra-massive galaxies in the early Universe

GOLD-RUSH

LBG-selected protoclusters (Subaru/HSC)

UD-ELAIS-N1



Toshikawa et al.

RUBY-RUSH

(PI: Kodama)

Red Ultra-massive
Billion-YeaR-Universe SHiners

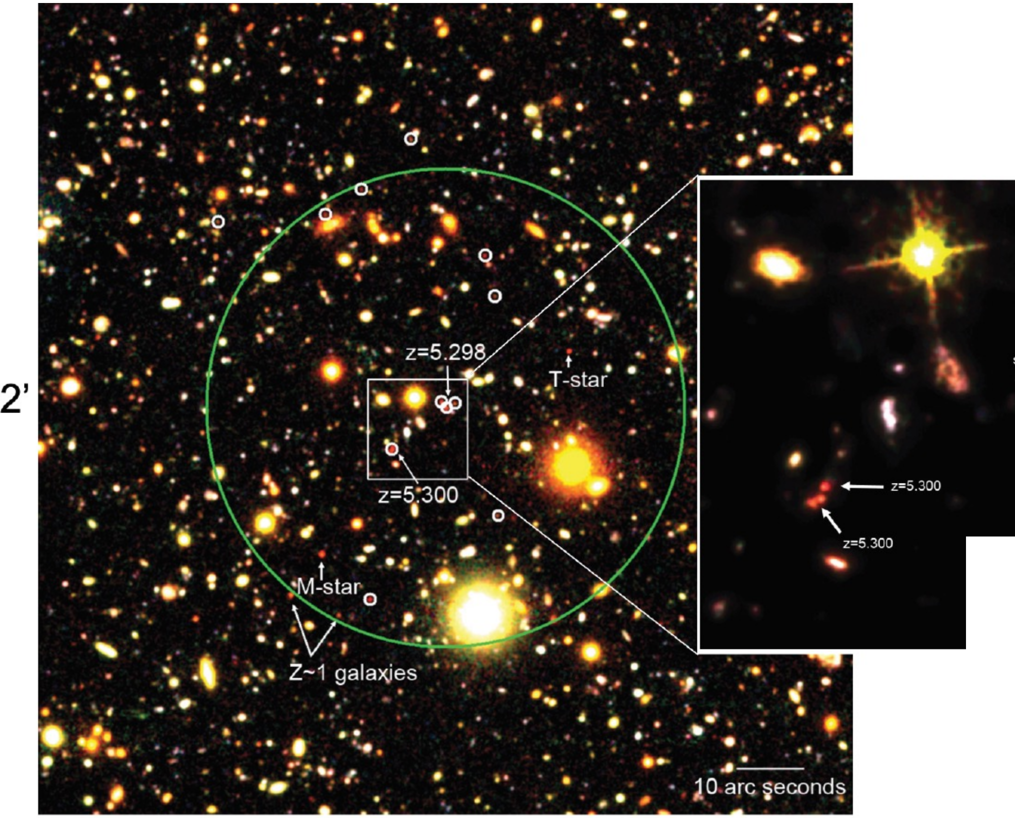
Hunting ultra-massive jewels at z~5 in the Gold-Rush mines (LBG-selected protoclusters).

The existence of such massive quiescent galaxies at high-z will put strong constraints on the timescale of massive galaxy formation and their quenching processes.

Un-biased survey will also be conducted to quantify the massive galaxy formation bias (acceleration) in protoclusters (dense regions at high-z).

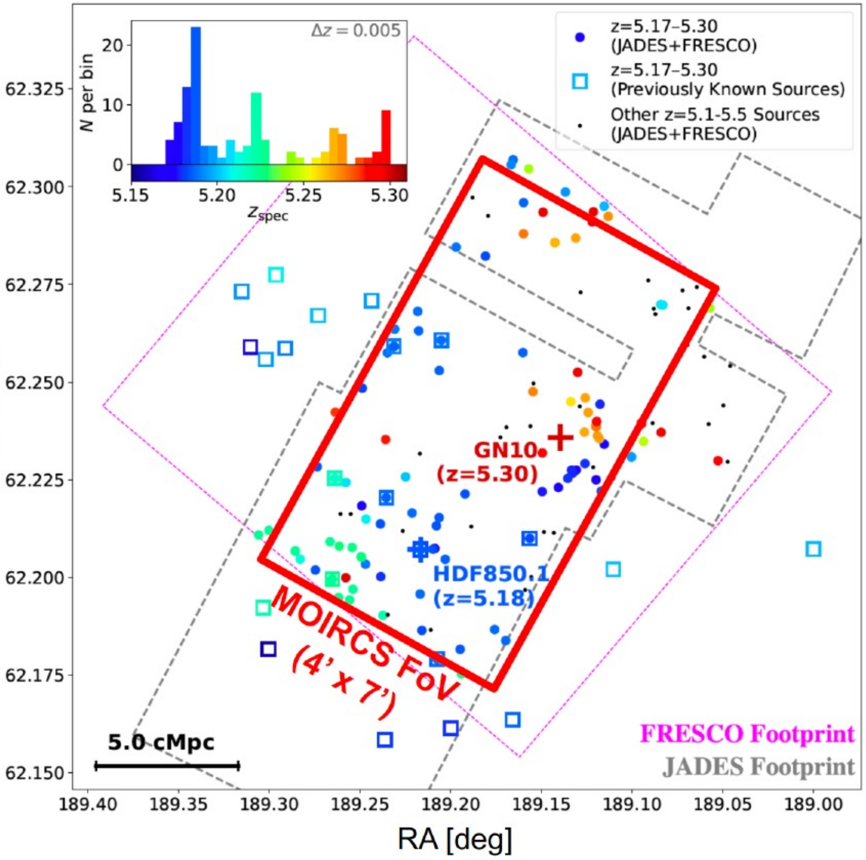
RUBY-RUSH

extention to z=5.3



COSMOS–AzTEC3 cluster (z=5.3)

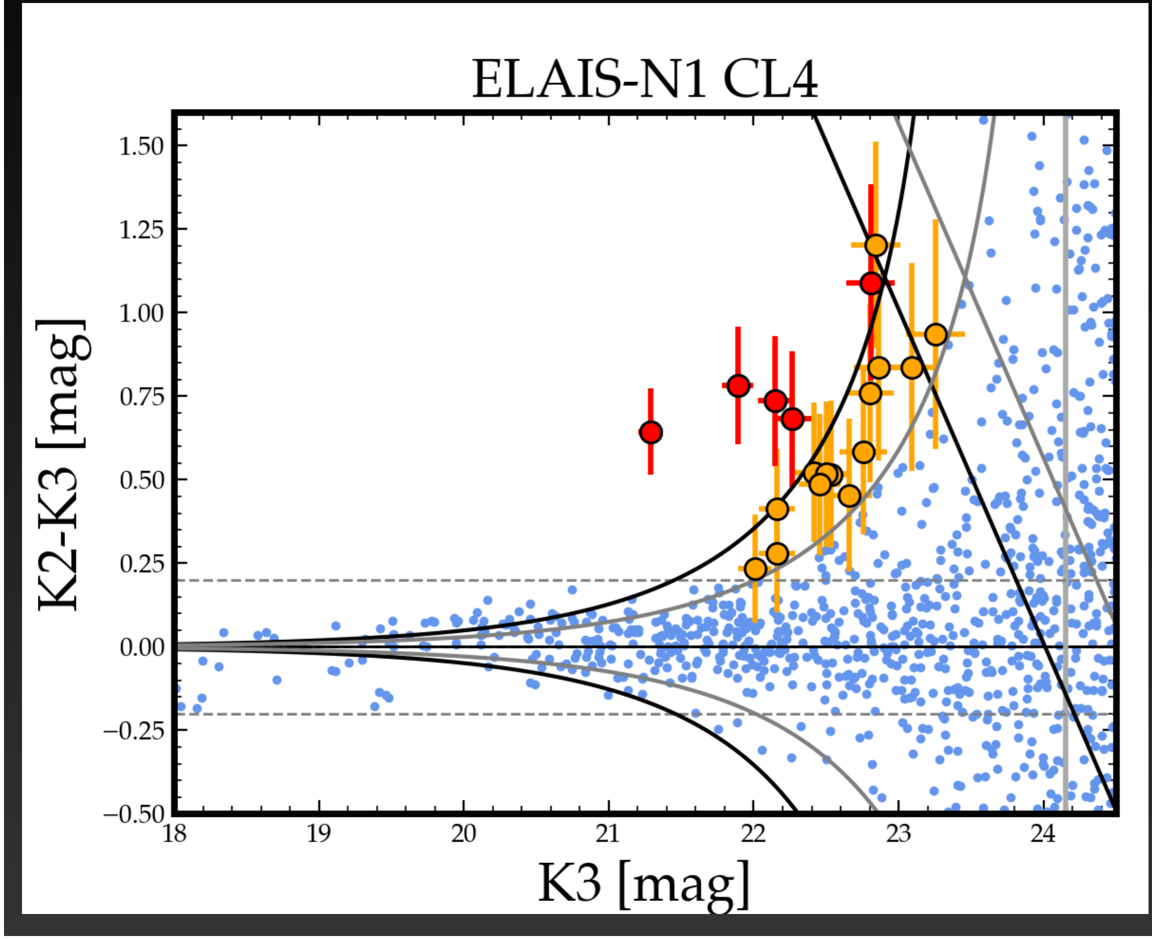
GN10/HSD850.1 structure at z=5.2-5.3



Subaru/MOIRCS K3 and K4 filters

MB filter	λ_c (μm)	FWHM (μm)	z(Bal.break) 3645Å
K_3	2.31	0.14	5.14
K_4	2.41	0.12	5.45

Selection of Balmer break galaxy candidates



● >5σ detection
5 sources

● >3σ detection
14 sources

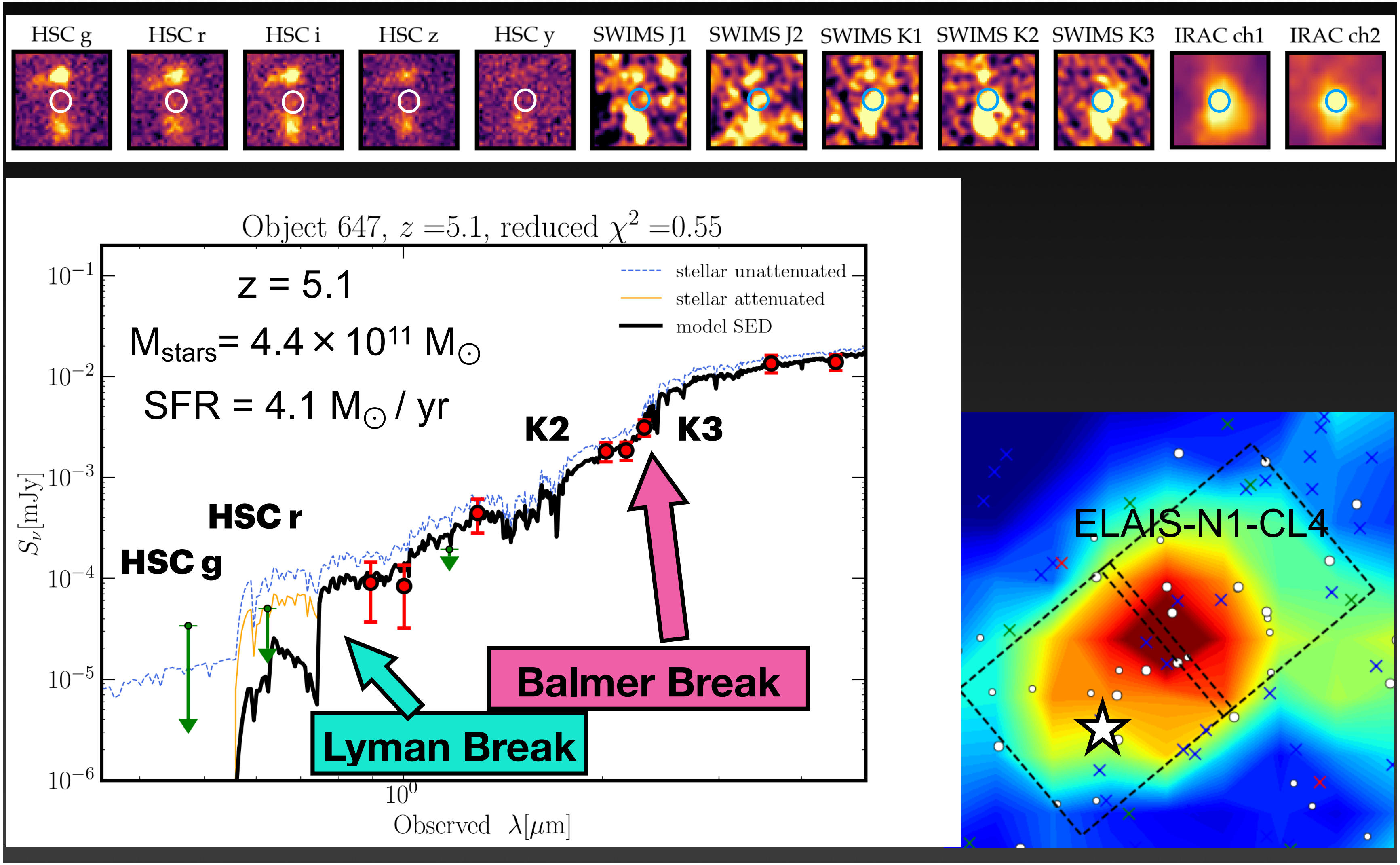
● Other detected sources by SExtractor

Clustering of massive quiescent galaxies in a proto-cluster??

→ Many of them turn out to be lower redshift objects due to detections at g, r-bands.

RUBY-RUSH

Candidate massive quiescent galaxies at z~5



z = 5.1

M_{stars}= 4.4 × 10^{11} $M_\odot$

SFR = 4.1 $M_\odot$ / yr

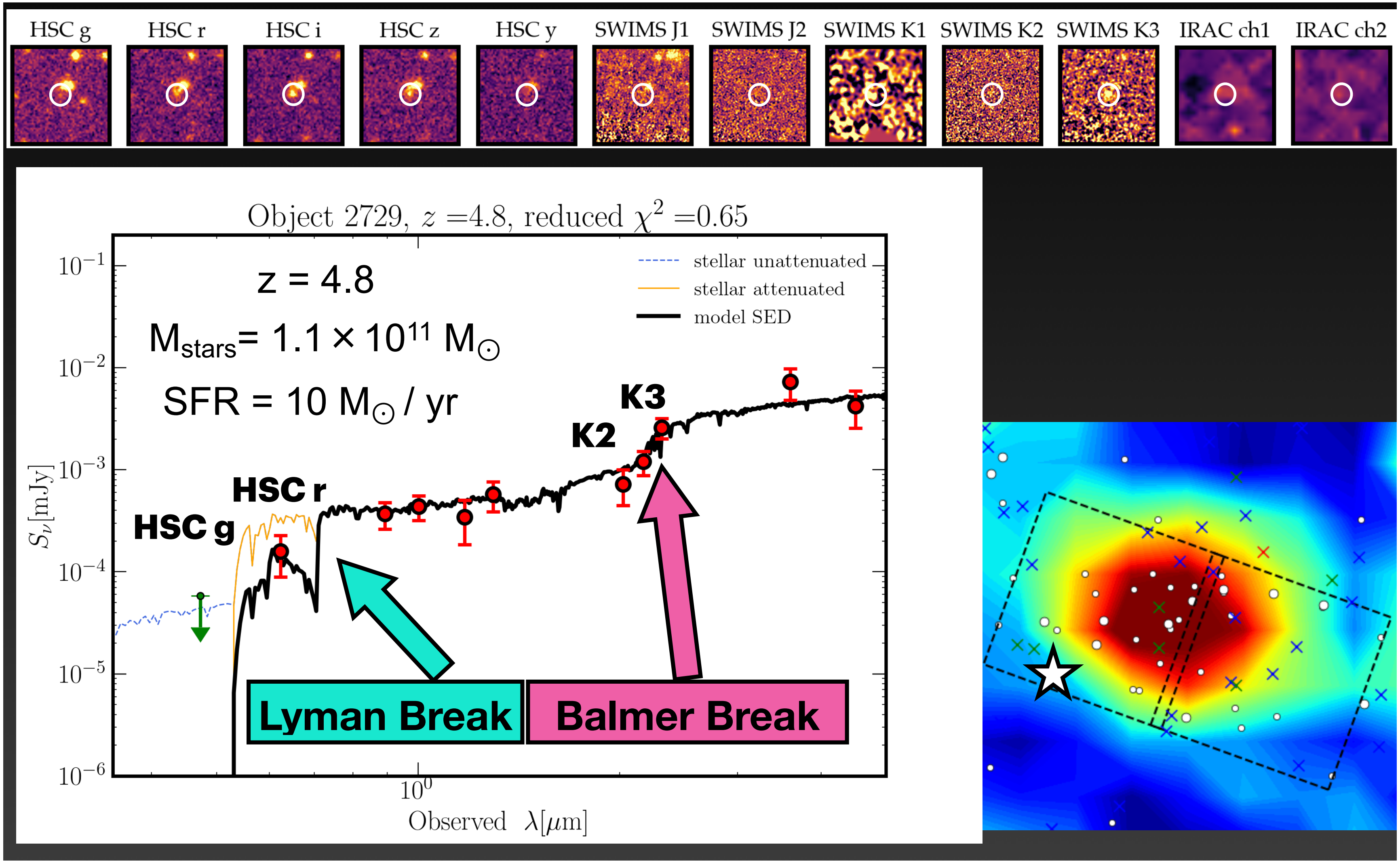
Balmer Break

Lyman Break

Takahashi et al. 2023, in prep.

RUBY-RUSH

Candidate massive quiescent galaxies at z~5



z = 4.8

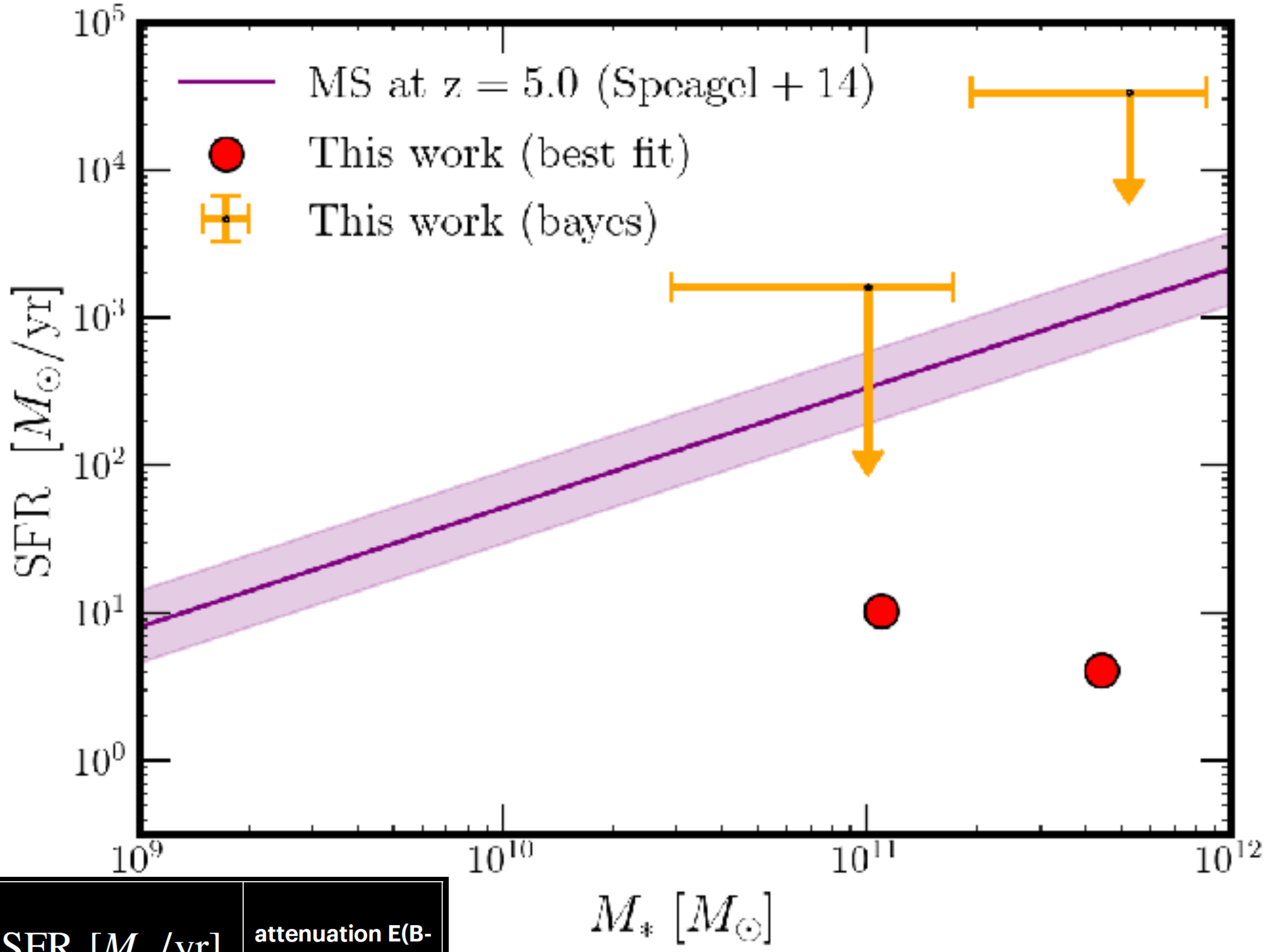
$M_{\mathrm{stars}} = 1.1 \times 10^{11}\ M_\odot$

SFR = 10 $M_\odot$ / yr

Lyman Break

Balmer Break

Takahashi et al. 2023, in prep.



OBJECT name	z_{phot}	$M_* \ [M_\odot]$	SFR $[M_\odot/\mathrm{yr}]$	attenuation E(B-V) lines
C1 - 647	5.1	4.4×10^{11}	4.1	0.05
C4 - 2729	4.8	1.1×10^{11}	10	0

Milky Way $M_* \sim 6 \times 10^{10} M_\odot$

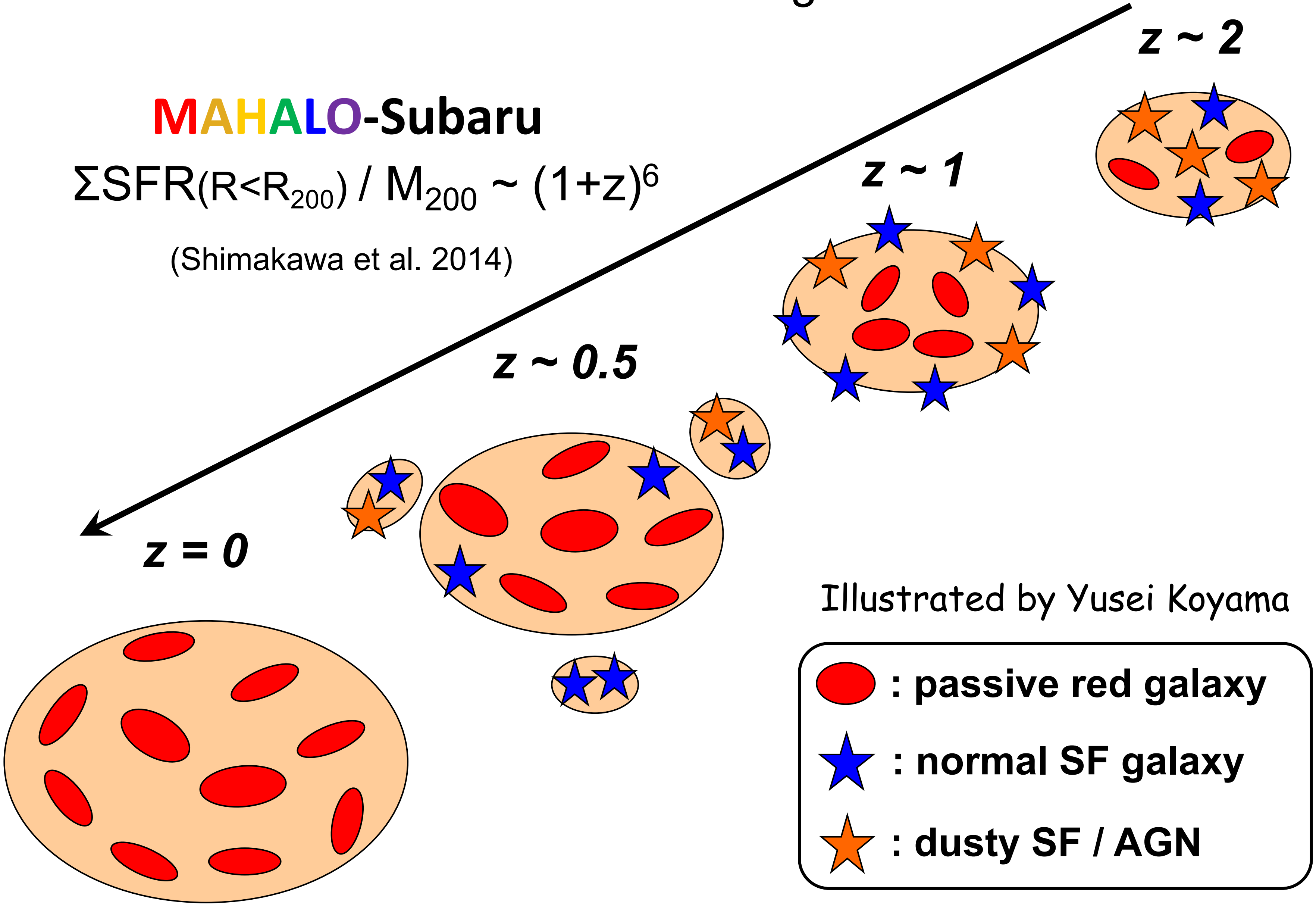
Timothy+ 15

2. How do the *star formation* and its *quenching propagate* in and around clusters and within galaxies?

MAHALO-Subaru

$\Sigma \mathrm{SFR}(R<R_{200}) / M_{200} \sim (1+z)^6$

(Shimakawa et al. 2014)



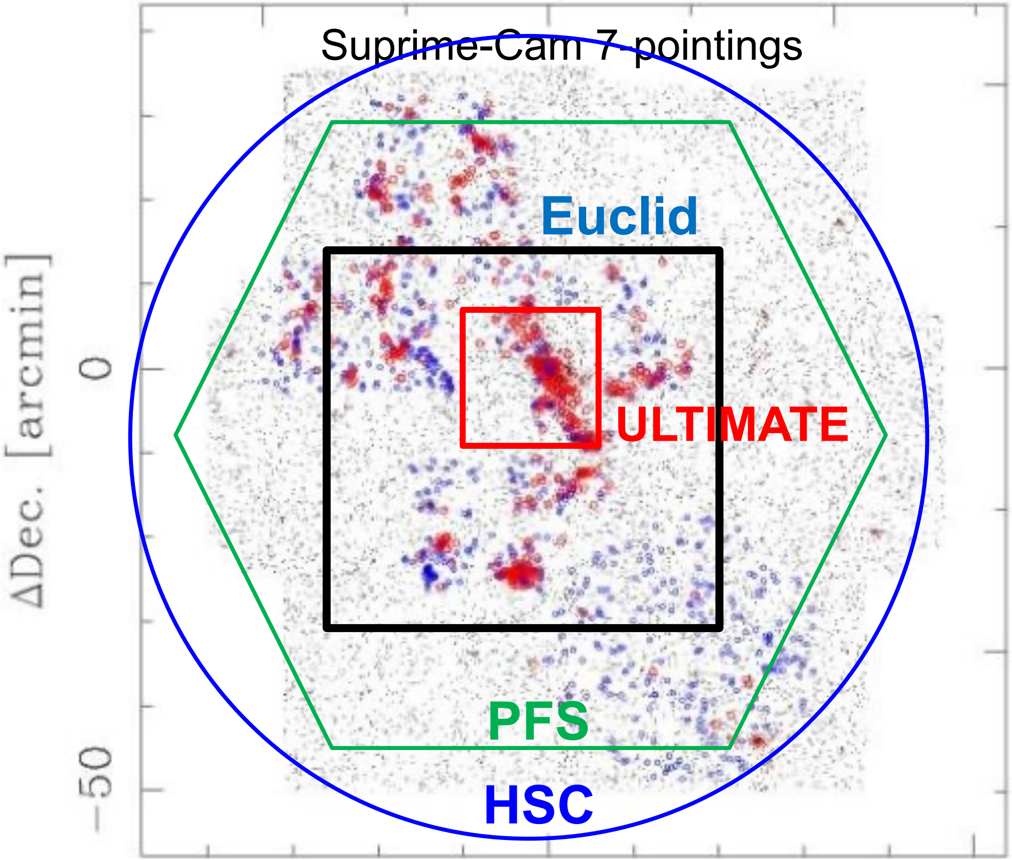
Illustrated by Yusei Koyama

Subaru/HSC&PFS and Euclid are extremely powerful to probe LSSs

1.3° = 75 Mpc (z=1), 100 Mpc (z=1.5), 118 Mpc (z=2) in co-moving

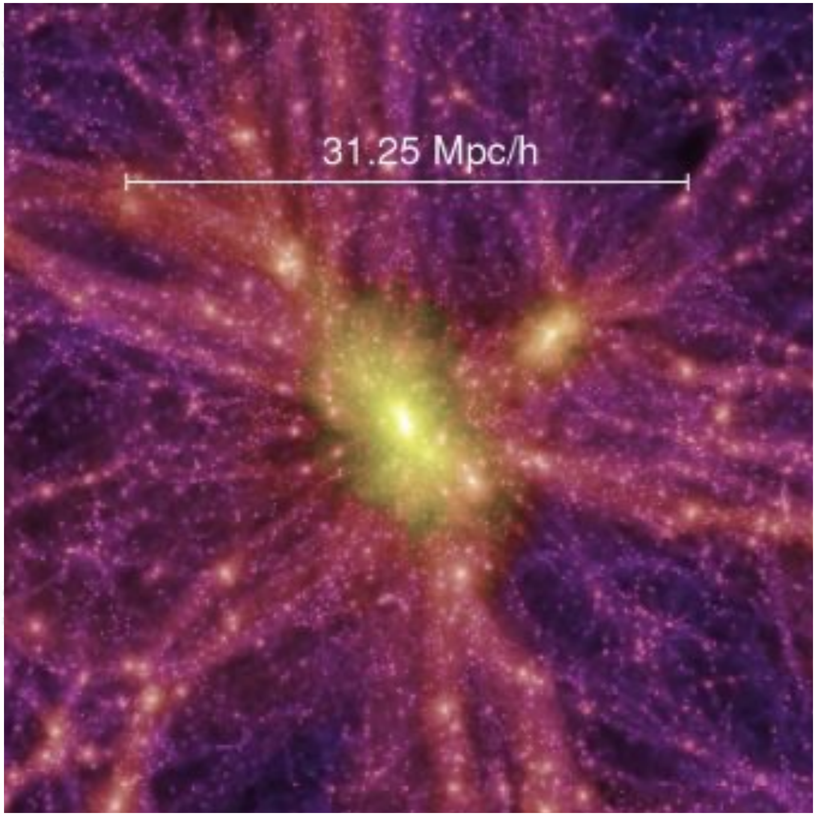
PISCES

CL0016 cluster (z=0.55)
(Tanaka, M. et al. 2009)

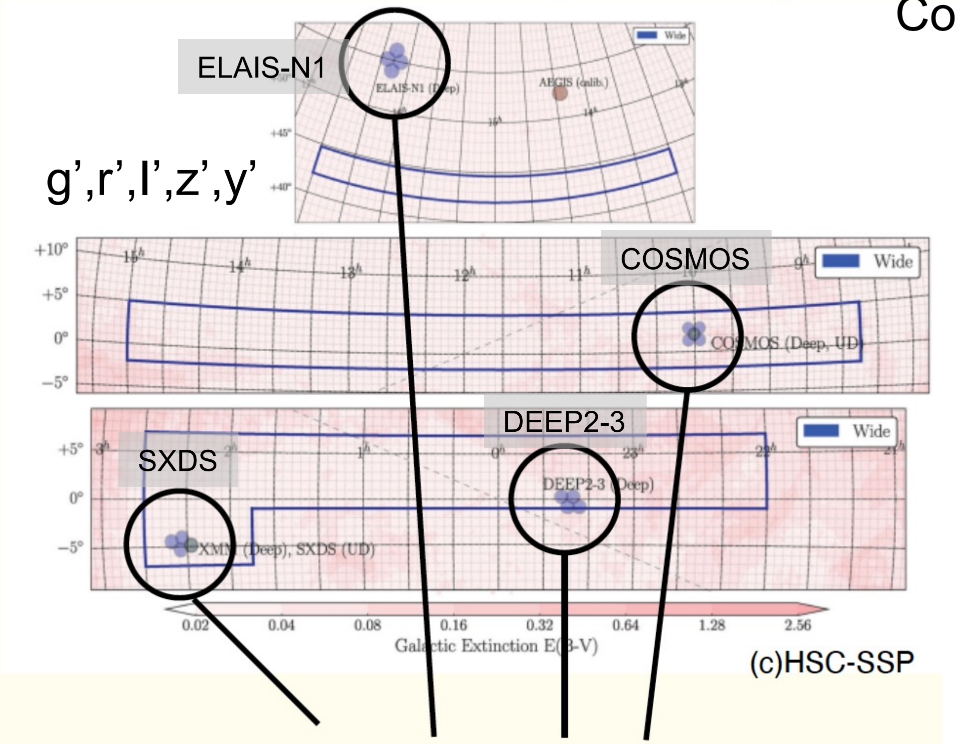


LSS around the richest cluster at z=0.55
~1,200 redshifts from spectroscopy
red are cluster members, while blue are non-members

Millenium Simulation
(Springel et al. 2005)



HSC-SSP Deep Survey



g’,r’,I’,z’,y’

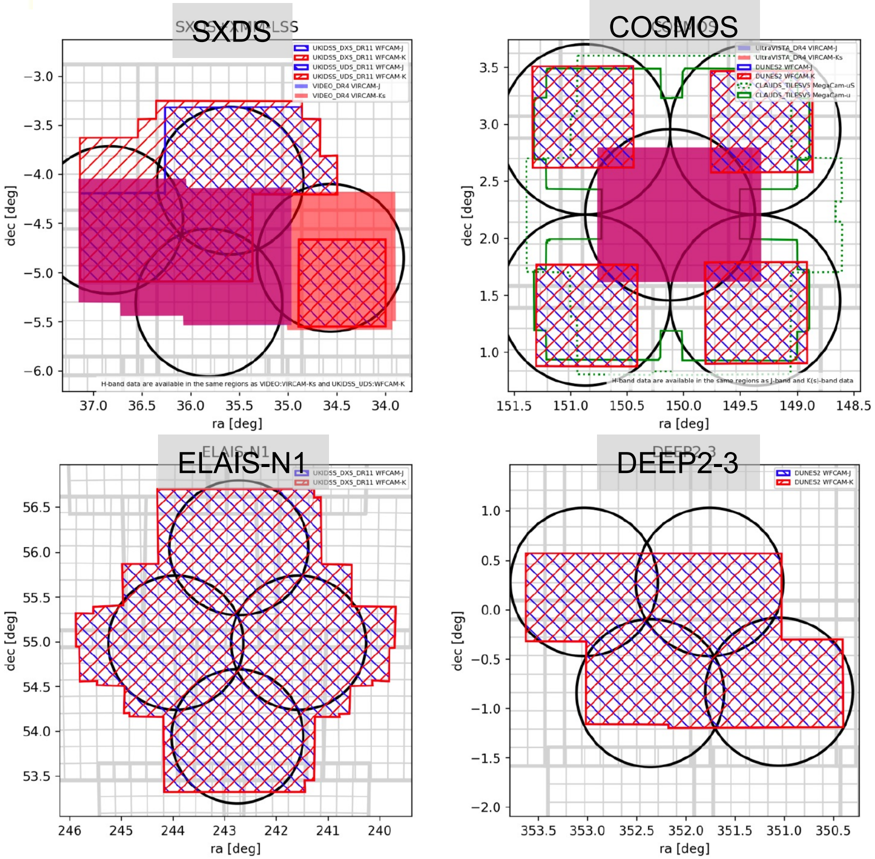
(c)HSC-SSP

4 Deep Regions

$\sim 26deg^2$

Coordinated NIR imaging (UKIRT, VISTA)

- DUNES^2 (UKIRT/WFCAM)
- UKIDSS-UDS DR11 (UKIRT/WFCAM)
- UKIDSS-DXS DR11 (UKIRT/WFCAM)
- VIDEO DR4 (VISTA/VIRCAM)
- UltraVISTA DR4 (VISTA/VIRCAM)



NB imaging

Filter	CW [Å]	FWHM [Å]	$z(\mathrm{Ly}\alpha)$	$z([\mathrm{OII}])$	$z(\mathrm{H}\beta)$	$z([\mathrm{OIII}])$	$z(\mathrm{H}\alpha)$
NB816	8160	120	5.711±0.049	1.189±0.016	0.679±0.012	0.630±0.012	0.243±0.009
NB921	9210	131	6.574±0.054	1.471±0.018	0.895±0.013	0.839±0.013	0.403±0.010
NB973	9730	138	7.002±0.057	1.611±0.019	1.002±0.014	0.943±0.014	0.483±0.011
NB101	10095	143	7.302±0.059	1.709±0.019	1.077±0.015	1.016±0.014	0.538±0.011

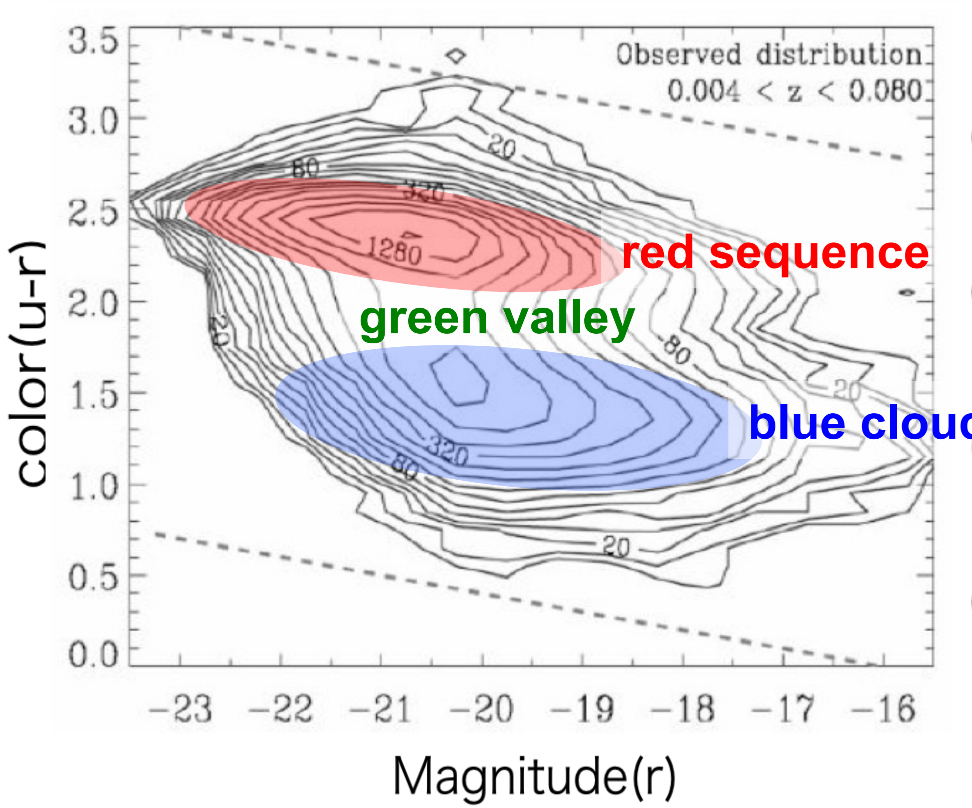
+ CHORUS (more NBFs for COSMOS)

HSC^2

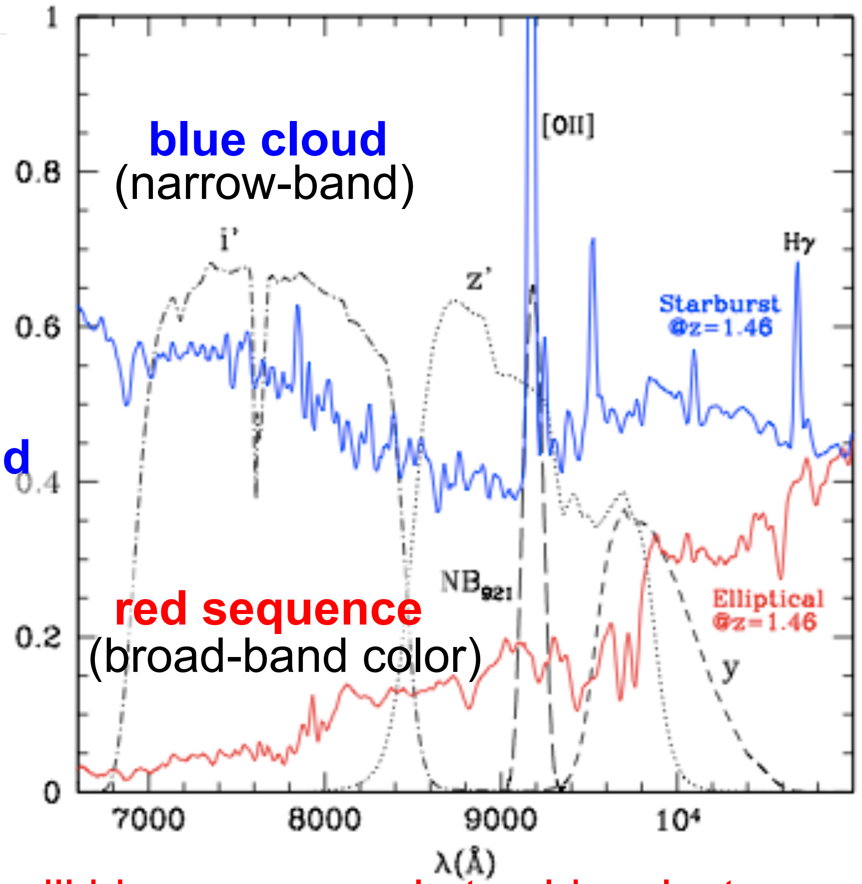
Hybrid Search for Clusters with HSC 0.4<z<1.7

HSC-SSP (Deep and Ultra-Deep layers; 27 deg^2)

Two galaxy populations



Hybrid cluster finder

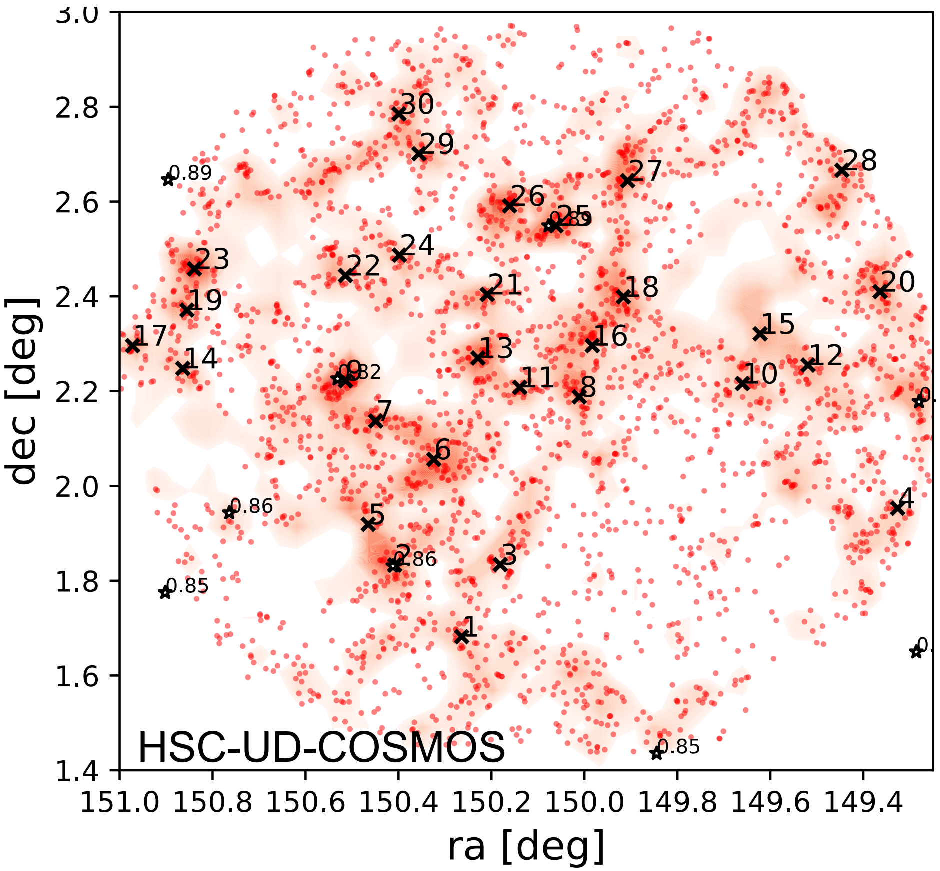


The conventional red seq. technique alone will bias your sample to older clusters.

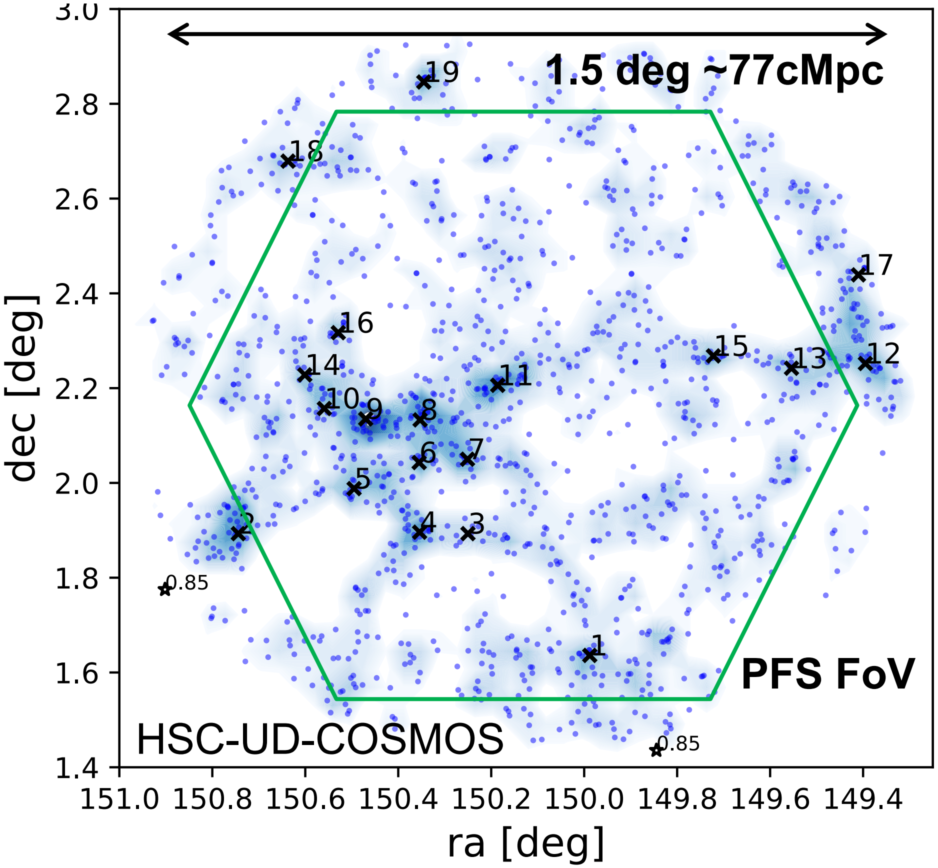
HSC^2 is a large, systematic cluster survey with little selection bias to z~1.7

Hybrid Search for Clusters with HSC (**HSC^2**)

Red sequence galaxies at 0.8<z<0.9



[OIII] line emitters at 0.82<z<0.86



We have ~100s of cluster candidates, and systematic and intensive spectroscopic confirmation with PFS is critical (cluster mass function can also compare with cosmological models).

Panoramic Follow-up Spectroscopy with PFS

HSC² : Hybrid Search for Clusters with HSC @0.4<z<1.6

Dual (red + blue) cluster

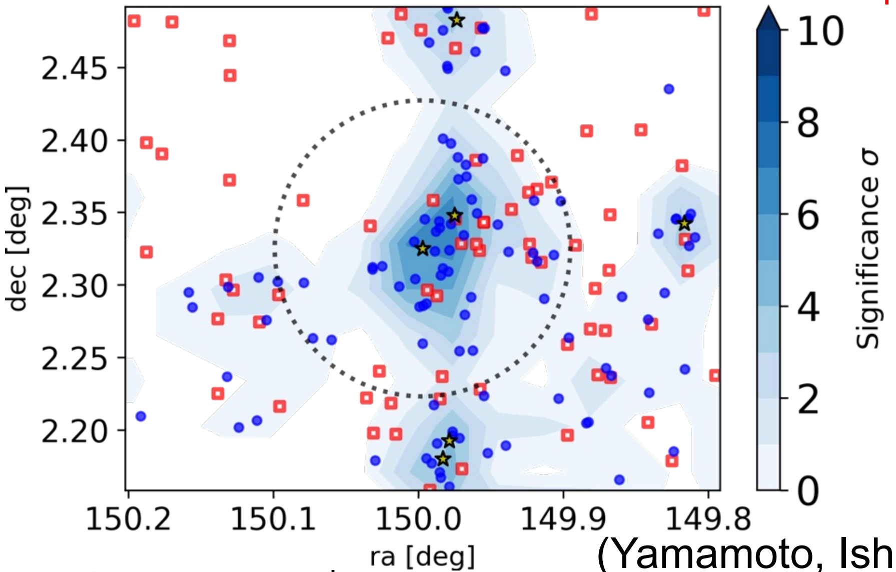
CL1 @ z=1.47

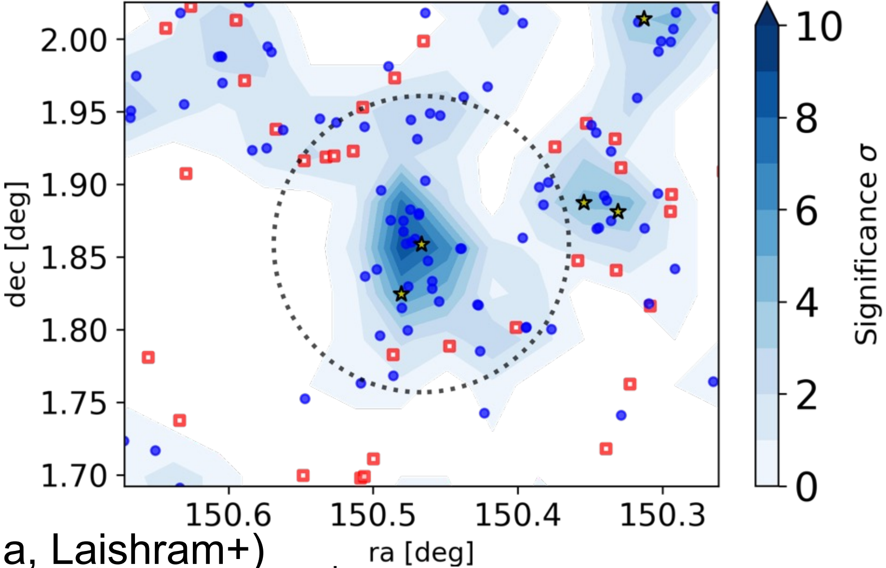
Blue dominated cluster/group

CL2 @ z=1.61

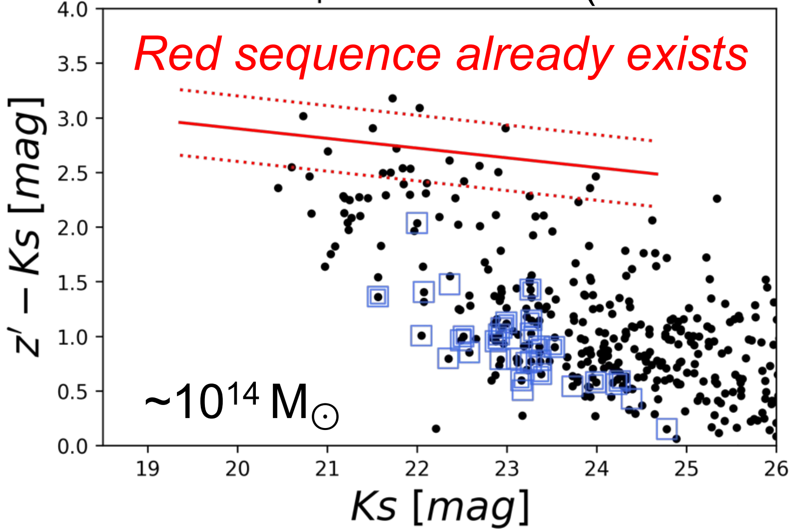
● NB [OIII] emitters

☐ red seq. galaxies



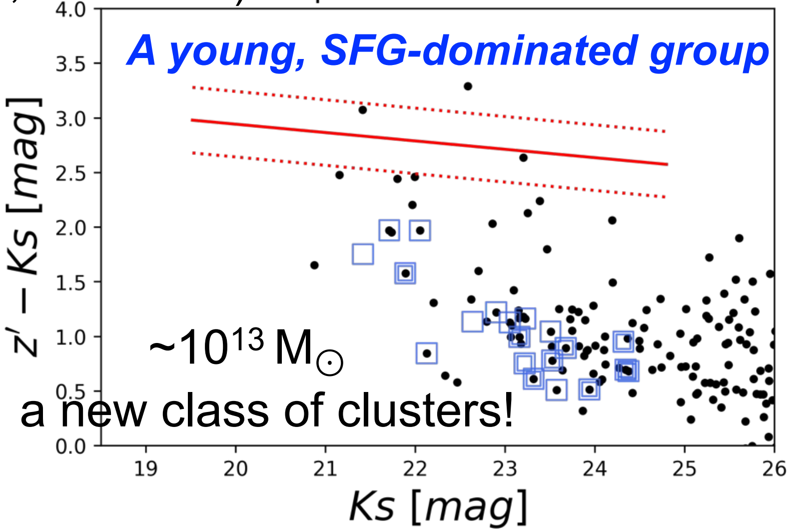


(Yamamoto, Ishida, Laishram+)



Red sequence already exists

~10^{14} M$_\odot$



A young, SFG-dominated group

~10^{13} M$_\odot$

a new class of clusters!

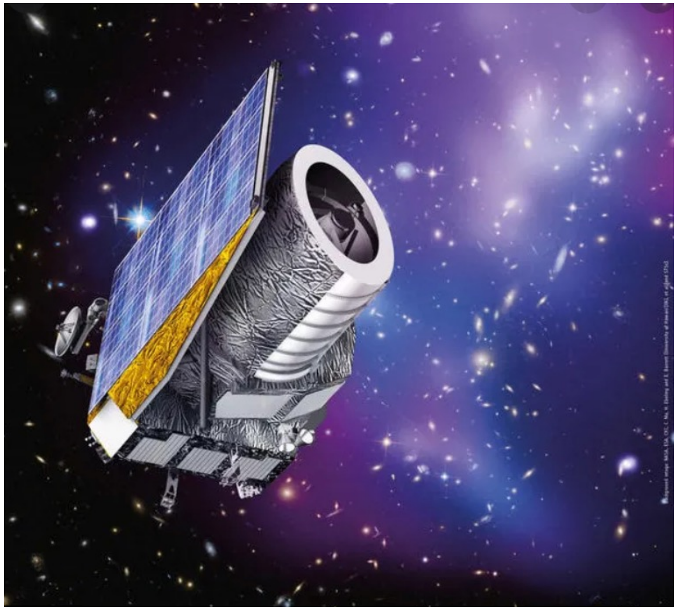
Euclid

1.2m telescope to be launched in Jul 2023

Japanese Euclid Consortium (JEC)

Japan is participating Euclid through the Subaru intensive program by Oguri et al.:
z-band imaging follow-up of the Euclid fields.
Wide Imaging with Subaru HSC of the Euclid Sky (WISHES)

T.Kodama is a member of JEC and the Euclid Consortium
Will do distant cluster search (1<z<3)

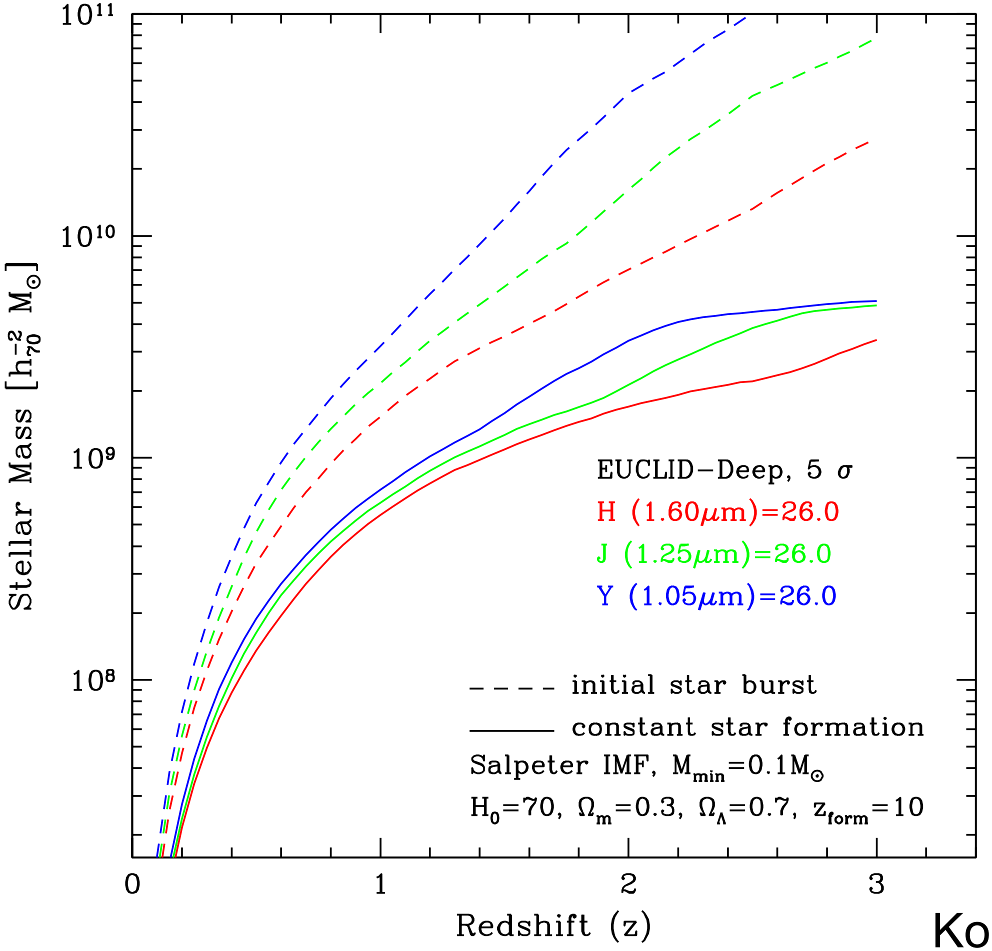


Space X Falcon 9
Cape Canaveral, Florida, USA
17:12 CEST, 1 July 2023

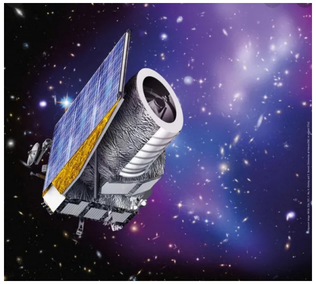
EUCLID Deep Survey

M_{stars} = (5 -20) × 10^8 $M_\odot$ (z=1) ~ (2-8) × 10^9 $M_\odot$ (z=2)

H=26 ←→ M*+5 (z=1) and M*+3.5 (z=2)



Based on
Kodama et al.'s (1999) model



HySPEC-Euclid:
Hybrid Search for Proto Evolving Clusters with Euclid

Kodama, Koyama, Shimakawa, Kubo, Ishida, et al.,

Red sequence survey + **Grism emitter survey** (Euclid-Deep over ~50 deg^2)

Similar to our HSC^2 concept (tracing both QGs and SFGs), but not limited to NB redshift slices!

- **VIS, z (Subaru), Y, J, H** can capture **4000Å/Balmer break** back to **z=3**

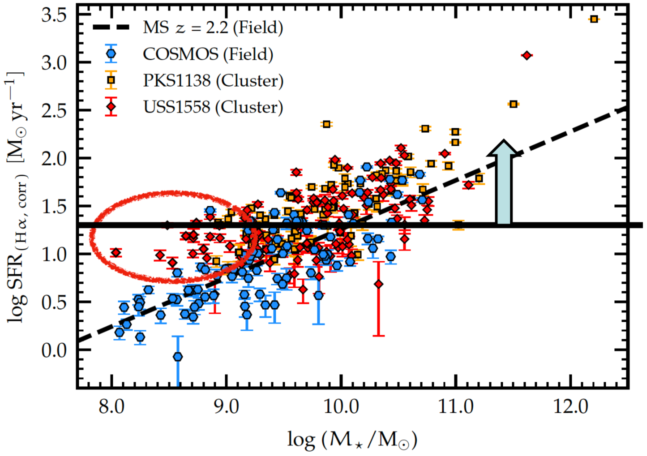
H=26 (5σ) ↔ $3\times10^9\ M_\odot$ @z~2

(CH1=24.8 (5σ) ↔ $6\times10^9\ M_\odot$ @z~2)

- **Grism** (R=260) can capture **Hα** to **z=1.8**, **[OIII]** to **z=2.6**

5×10^{-17} cgs (3.5σ) ↔ 22 $M_\odot$/yr @ z~1.8
5.2 $M_\odot$/yr @ z~1

($A_{H\alpha}$=1mag is assumed)



Future spectroscopic confirmation/characterization campaign is planned with Subaru/PFS and VLT/MOONS.

Immediate science goals of HySPEC (only with imaging)

1. Finding galaxy clusters and the surrounding structures back to z~3

   Selection bias will be minimized by tracing both red sequence galaxies and star forming galaxies.

2. Mapping star formation activities in and around clusters and within galaxies

   Propagation of star formation along the large-scale structures and also within individual galaxies.

3. Quantifying starburst, normal star-forming, and quenched fraction

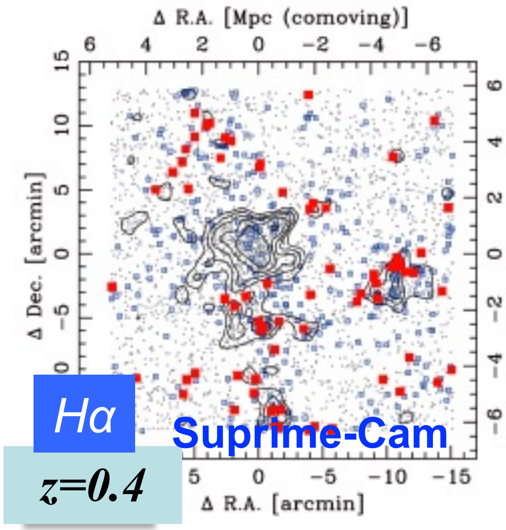
   We will quantify its redshift, environment (overdensity, cluster mass), and galaxy stellar mass dependence to characterize star formation boosting and quenching histories of galaxies.

4. Intrinsic scatter in galaxy cluster formation and evolution

   We will address the intrinsic scatter in the evolutionary stages of galaxy clusters, and its origin.

Panoramic narrow-band imaging by MAHALO-Subaru

MApping HAlpha and Lines of Oxygen with Subaru

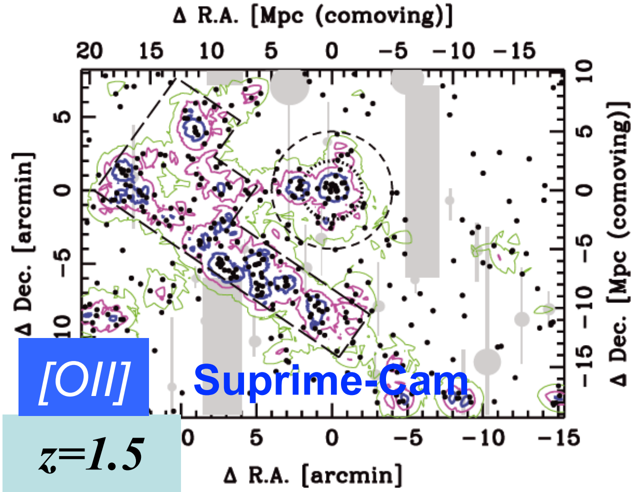


Hα Suprime-Cam

z=0.4

CL0939 *(Koyama+11)*

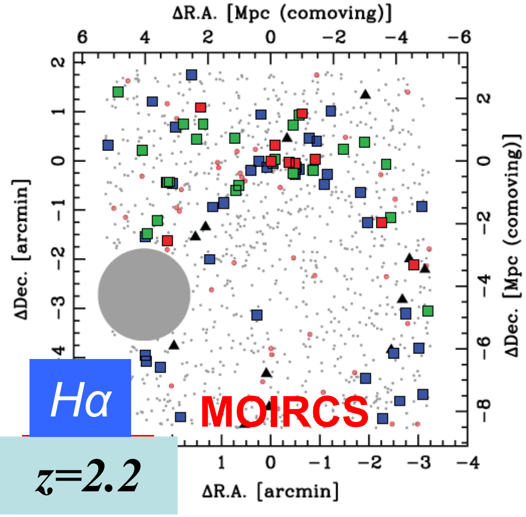
(Hayashi+10, 11)



[OII] Suprime-Cam

z=1.5

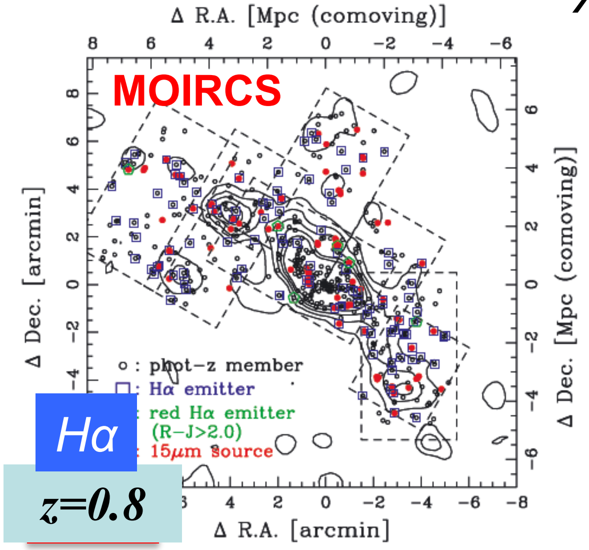
XCSJ2215



Hα MOIRCS

z=2.2

PKS1138 *(Koyama+13)*



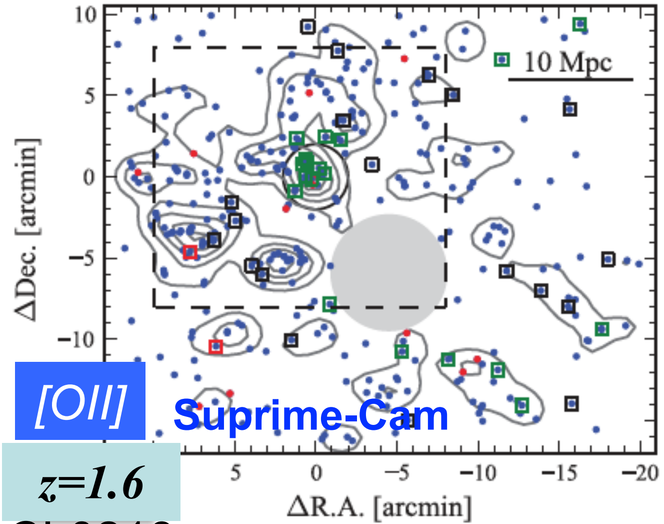
MOIRCS

Hα

z=0.8

RXJ1716 *(Koyama+10)*

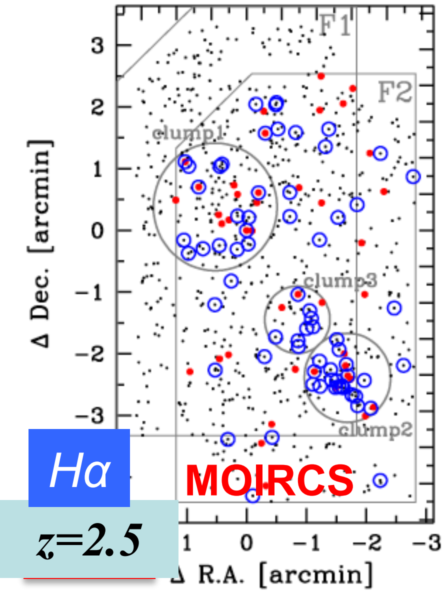
(Tadaki+12)



[OII] Suprime-Cam

z=1.6

CL0218



Hα MOIRCS

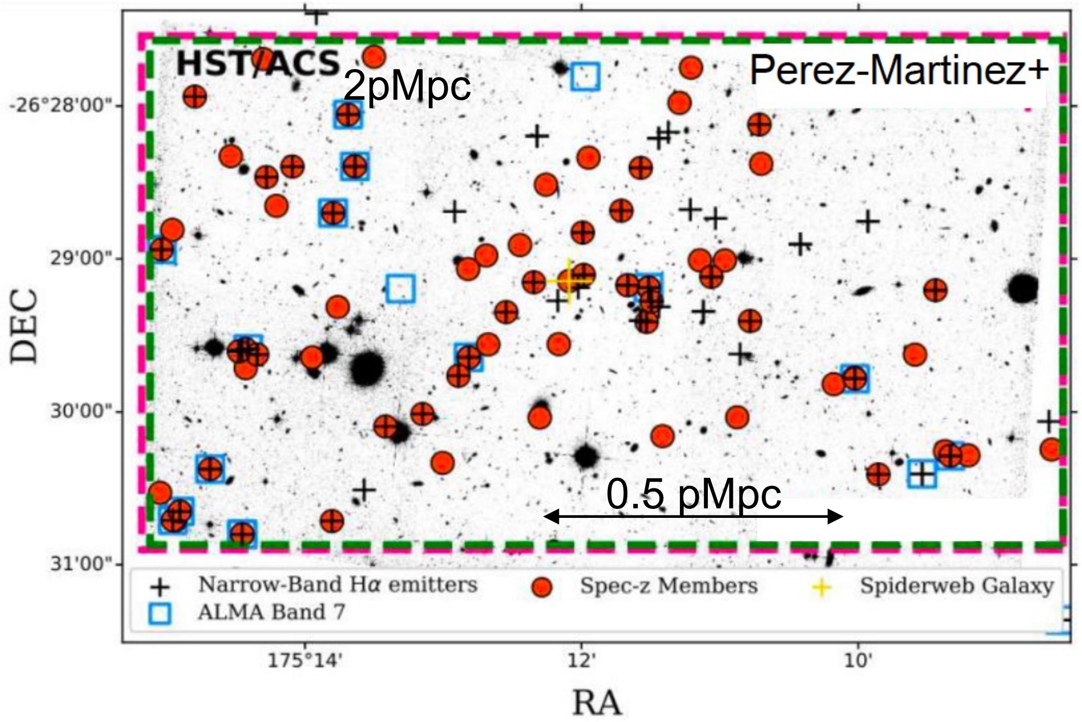
z=2.5

USS1558 *(Hayashi+12)*

MApping HAlpha and Lines of Oxygen with Subaru

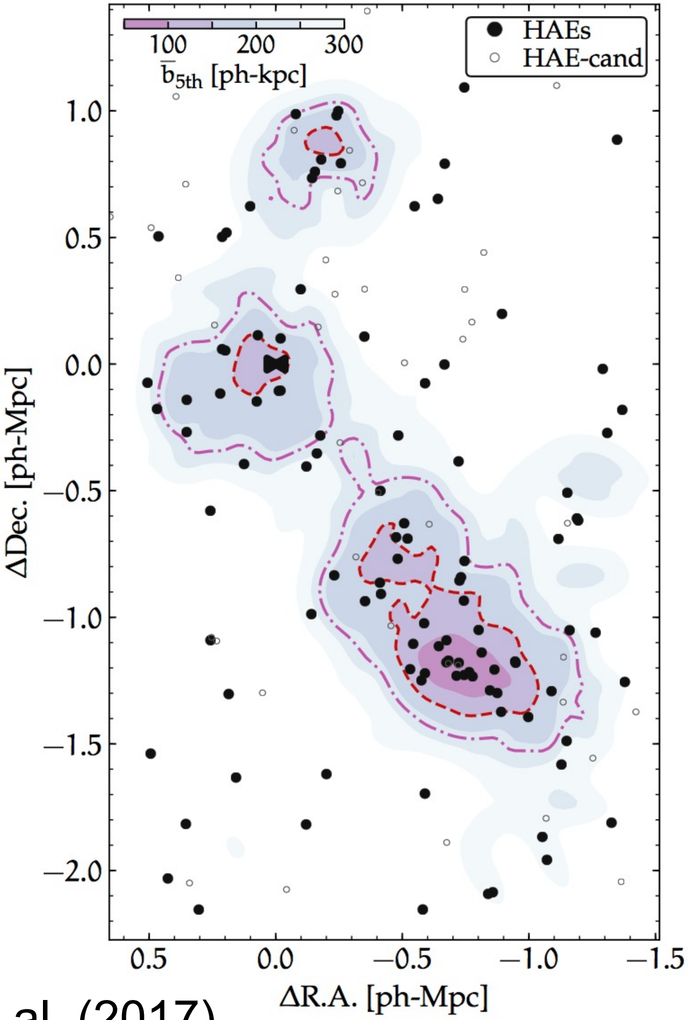
NB imaging of proto-clusters at $1.5<z<2.5$

PKS1138 at $z=2.16$
A rich protocluster with a giant cD progenitor
$M_{dyn} \sim 2 \times 10^{14}\, M_{\odot}$



Shimakawa et al. (2014; 2015)

USS1558 at $z=2.53$
A younger clumpy protocluster
$M_{dyn} \sim 1 \times 10^{14}\, M_{\odot}$



Shimakawa et al. (2017)

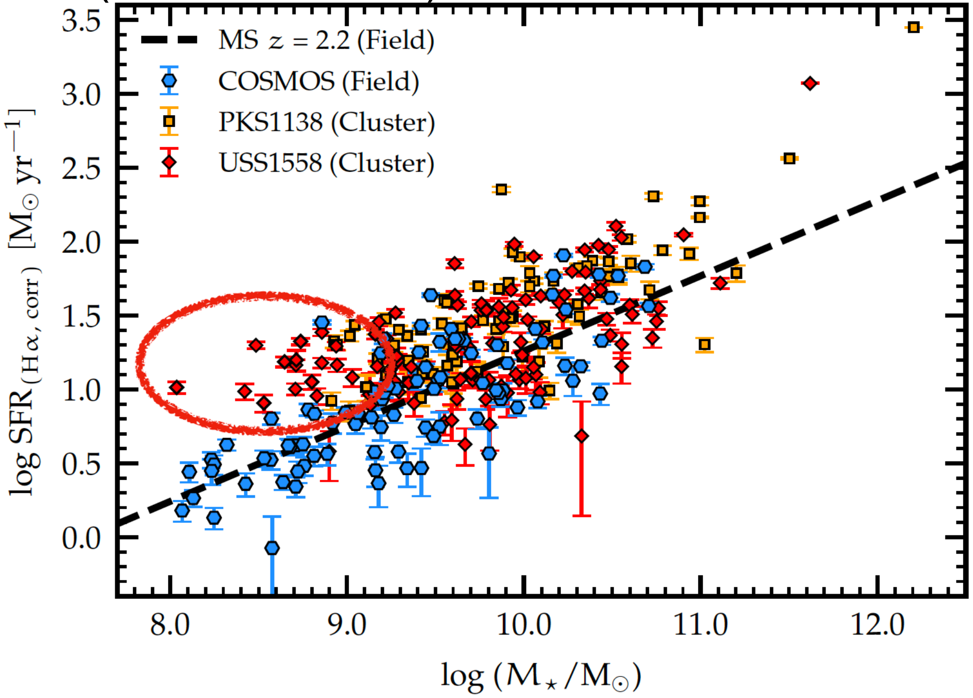
2. Is the star formation ever boosted in-situ in cluster cores?

"Boosted star formation" and "lower metallicity"
in low-mass galaxies in the young protocluster USS1558 (z~2.5)

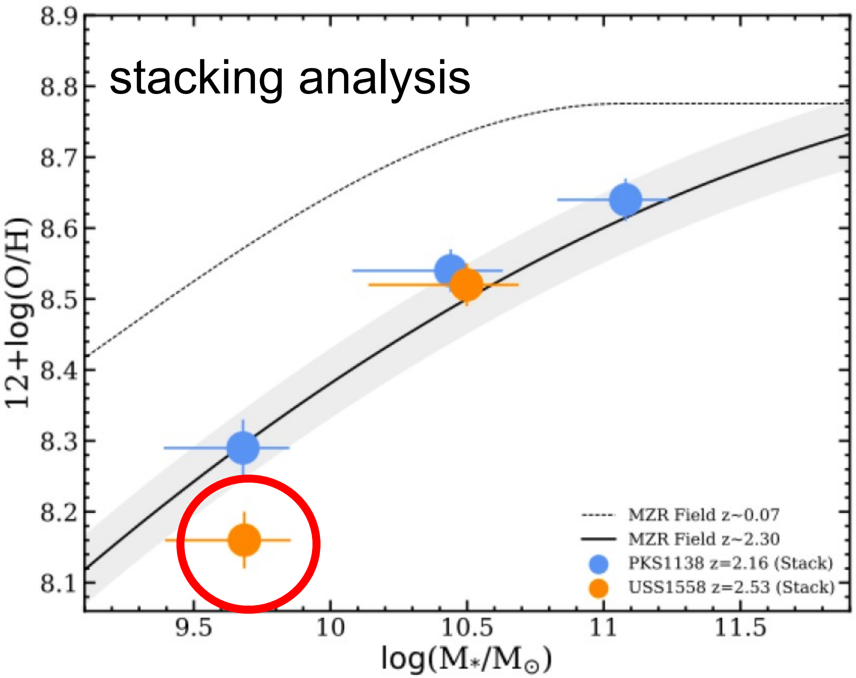
Main sequence diagram

Mass-metallicity relation

SFR(Hα + dust corr.)



Daikuhara et al., in prep.



Perez-Martinez (2023)

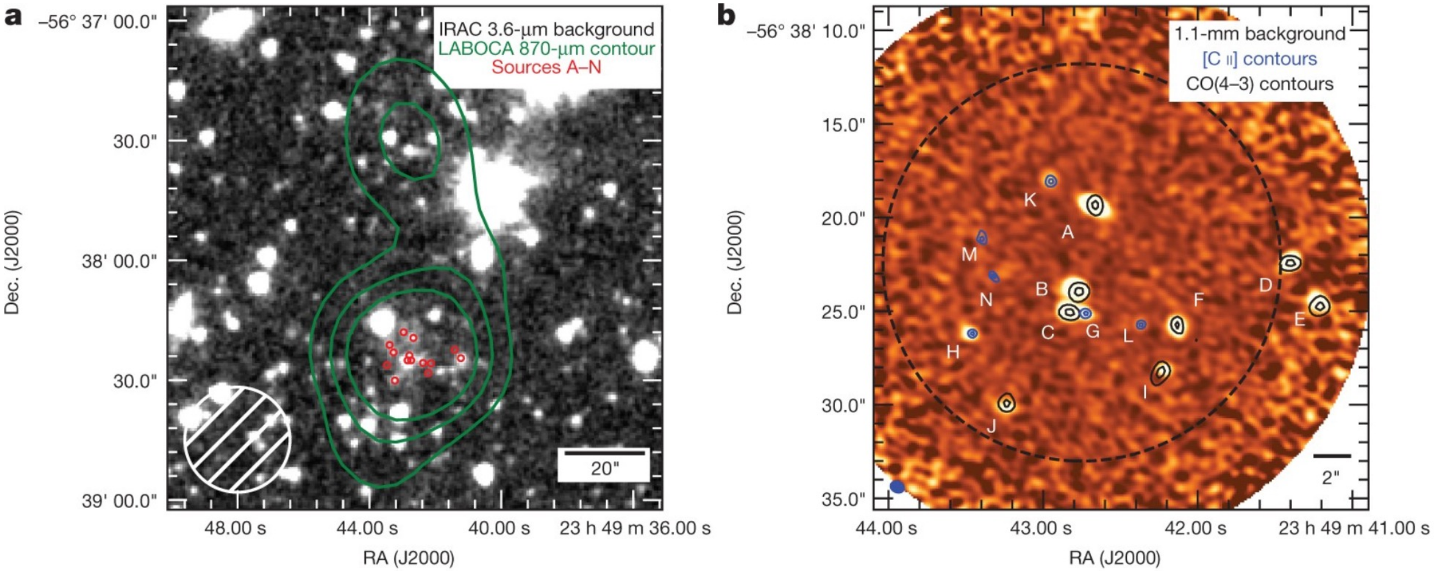
Enhanced star formation and dilution of metals in young protoclusters
due to efficient accretion of cold gas along filaments?

3. How much of star formation is hidden by dust?

Submm selected proto-clusters

SPT (South Pole Telescope) millimeter-wave survey (S1.4mm=23.3mJy)
+ ALMA follow-up (CO43, [CII], dust)

SPT2349-56 at z=4.3 Miller et al. (2018), Nature



14 SMGs within 130kpc ! $M_{cl} = 9 \times 10^{12}\ M_\odot$

Total SFR > 10,000 $M_\odot$ /yr, Total SFR density ~ 40,000 $M_\odot$ /yr/Mpc^3 !?

No current simulations can reproduce such high SFR density!

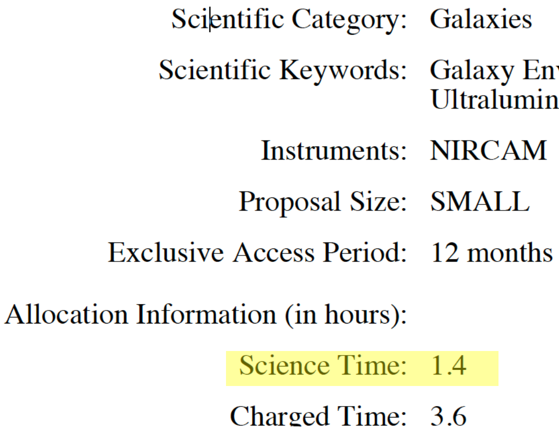
We may be still missing ***a lot*** of SFR by dust??

Unveiling the propagation of “intrinsic” SF activities across the proto-cluster and within individual galaxies

JWST cycle-1 GO program (Dannerbauer, Koyama, et al.)

Resolving and penetrating into the dusty Spiderweb and its surrounding protocluster with Pa-beta imaging

Dust-free SF tracer down to SFR=3.5 $M_\odot$ /yr
(rest-frame 1.28µm)



Scientific Category: Galaxies

Scientific Keywords: Galaxy Environments, High-Redshift Galaxies, Starburst Galaxies, Ultraluminous Infrared Galaxies

Instruments: NIRCAM

Proposal Size: SMALL

Exclusive Access Period: 12 months

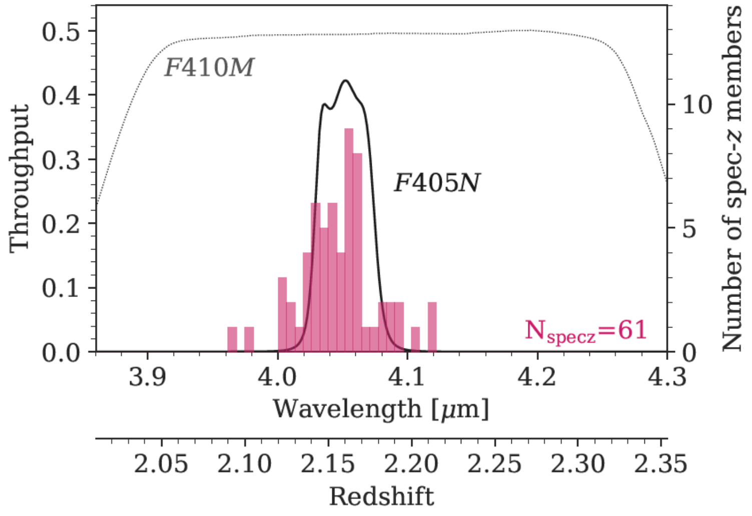
Allocation Information (in hours):

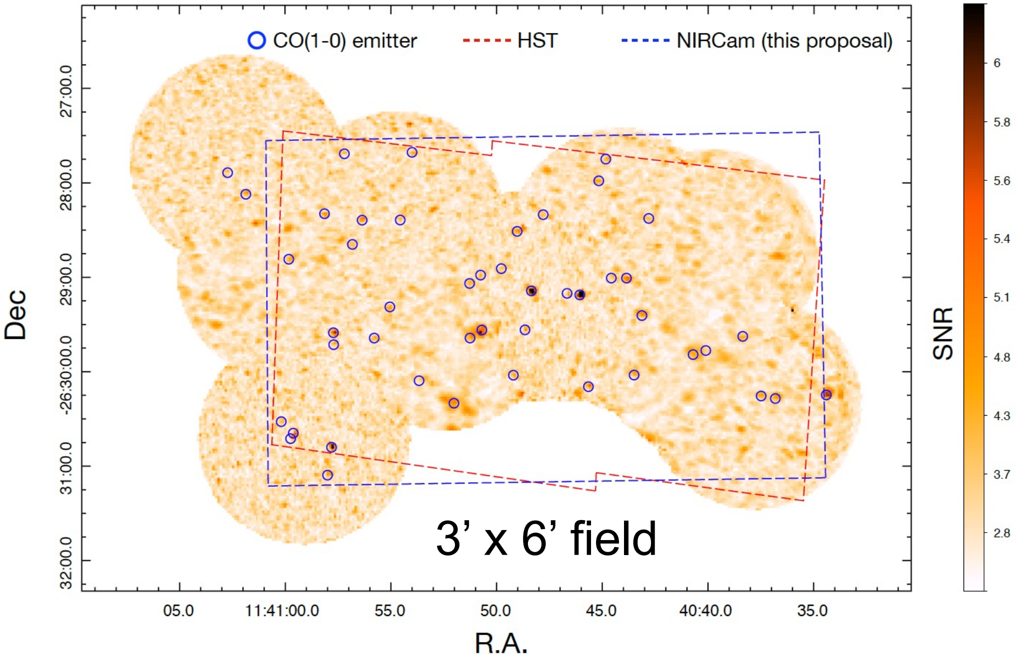
Science Time: 1.4

Charged Time: 3.6

Data will be delivered in May-Jun 2023.

The spiderweb protocluster PKS1138 @z=2.16





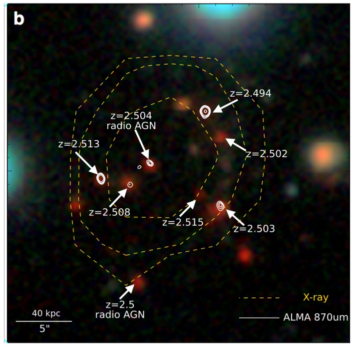
3’ x 6’ field

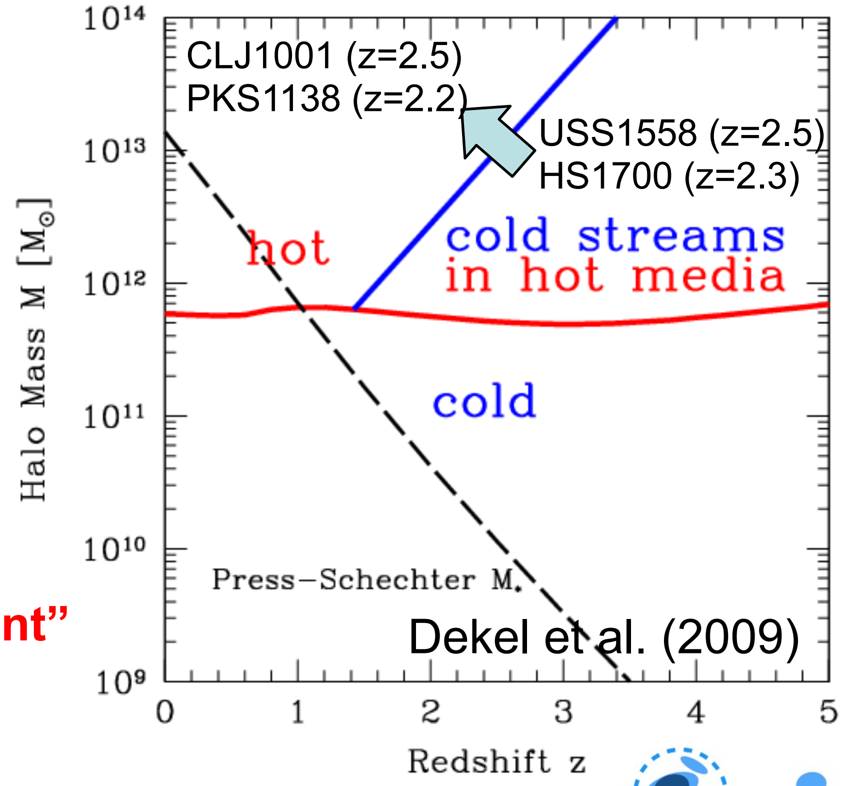
We can capture Paβ line (rest 1.28µm) from the cluster members with F405N narrow-band filter.

4. When and how does *gas accretion* to proto-clusters become *inefficient?*

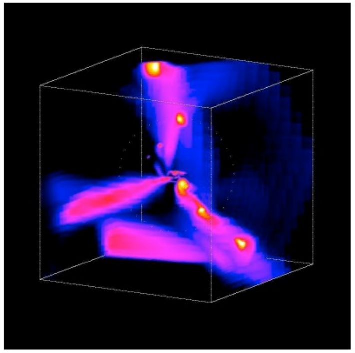
Transition of gas accretion mode in proto-clusters?

c.f., Valentino et al. (2015)





Dekel et al. (2009)

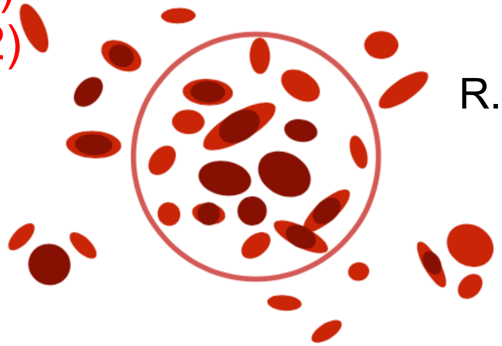


accretion "inefficient" phase

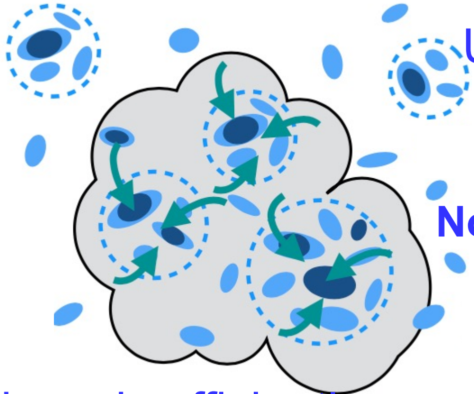
accretion "dominated" phase

CLJ1001 (z=2.5)
PKS1138 (z=2.2)

X-ray clusters



Credit:
R. Shimakawa



USS1558 (z=2.5)
HS1700 (z=2.3)

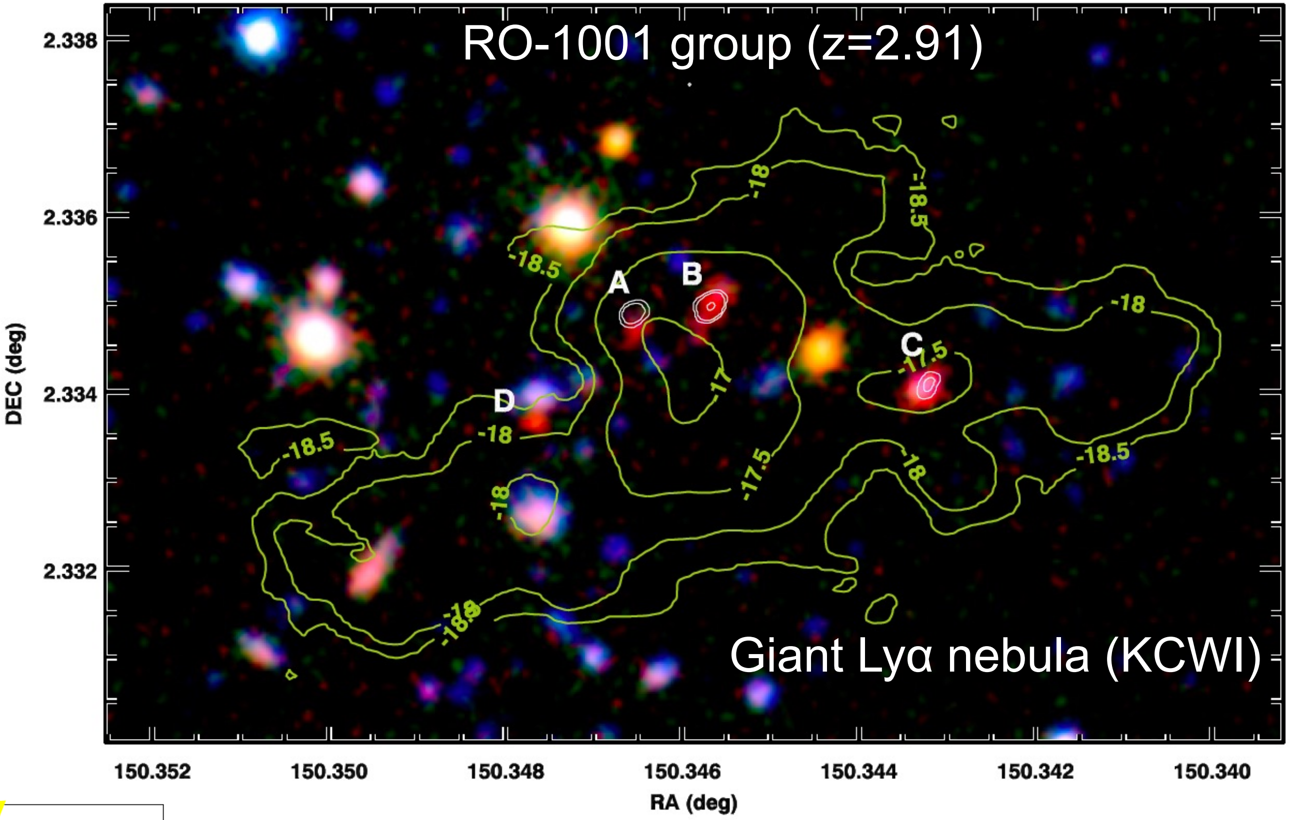
Non-X-ray clusters

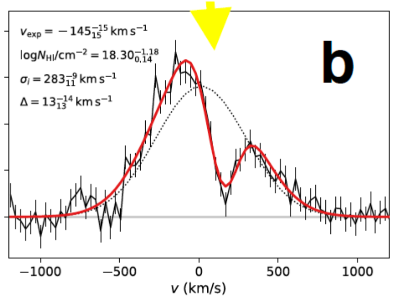
As cluster halos grow massive/dense, gas is heated up to high T, and X-ray is emitted.

Cold gas is efficiently supplied to proto-clusters with cold streams along filaments.

A 300 kpc-wide giant Lyα nebula centered on the massive galaxy group at z~3

$4 \times 10^{13}\ M_\odot$ dark matter halo, hosting 1,200 $M_\odot\ \mathrm{yr}^{-1}$ of star formation





Daddi et al. (2021), see also Daddi+22

Red shifted Lyα absorption → inflow

Direct evidence for cold streams

But diffuse Lyα emission is hard to observe due to cosmological dimming of $\mathrm{SB} = (1+z)^{-4}$

Evidence for the transition of cold-stream to hot mode accretion as traced by Lyα emission from 9 groups/clusters at 2<z<3.3

Lyα nebula efficiency vs. cold stream mass fraction

Protoclusters crossing the cold-hot boundary

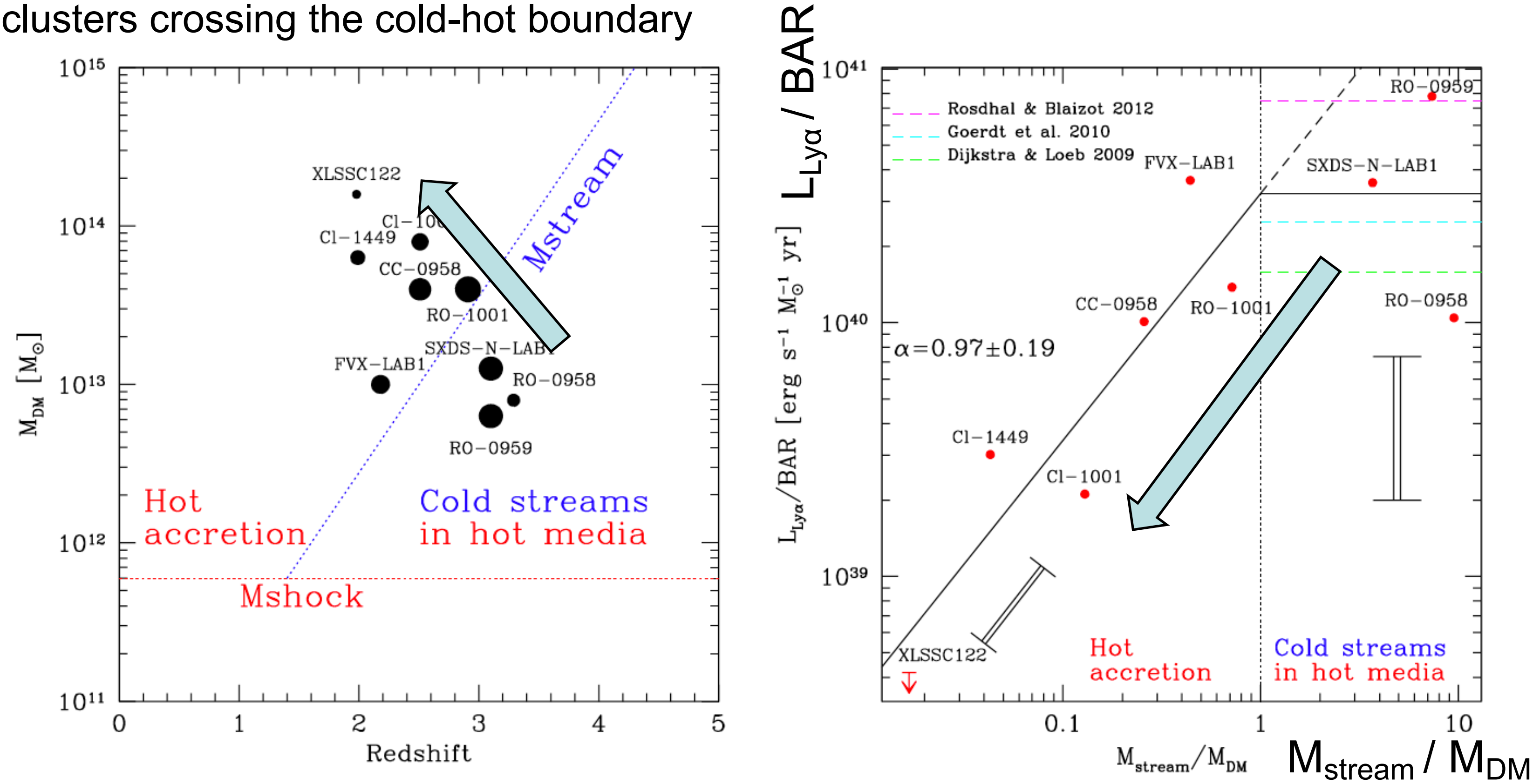
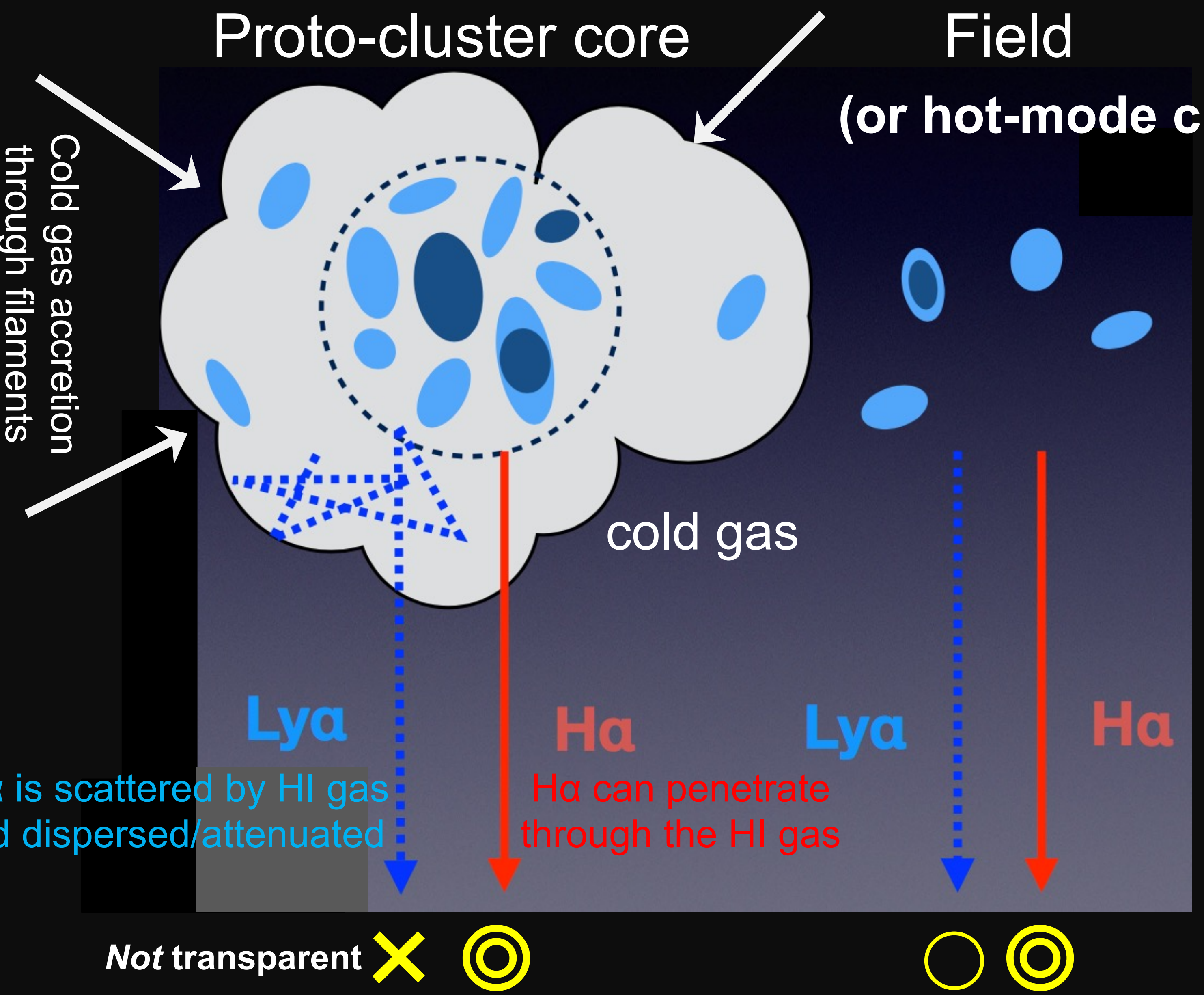


FIG. 2.— (Left:) Our sample in the DB06 diagram. Symbol sizes are proportional to $L_{Ly\alpha}$ (Tab. 1). The blue diagonal line defines M_{stream} (Eq. 2). Right: the ratio of extended Lyα luminosity in the structures is plotted versus the M_{stream} to halo-mass ratio. The relation in Eq. 4 is fitted (solid black line). Typical uncertainties are shown: 0.2 dex along the slope above M_{stream}, 0.3 dex along the y-axis below M_{stream}. Predictions for $M_{DM} < M_{stream}$ (cold-stream regime) are shown (colored dashed lines).

Daddi et al. (2022)

But Lyα diffuse emission is hard to observe due to cosmological dimming of SB=$(1+z)^{-4}$…



Not transparent ✕ ◎ ○ ◎

Lyα is scattered by HI gas and dispersed/attenuated

Hα can penetrate through the HI gas

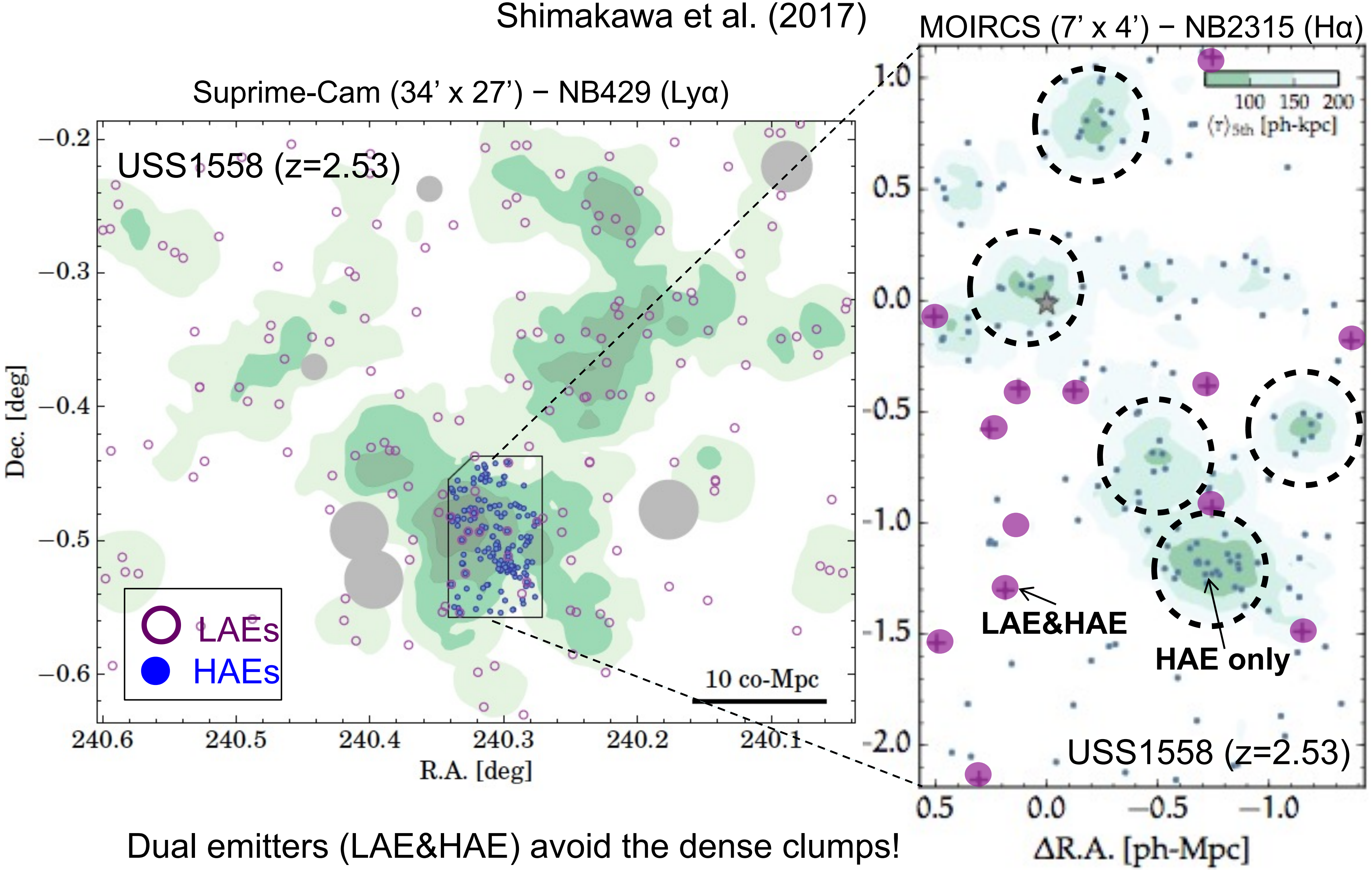
Shimakawa et al. (2017)

Dual NB Survey (Lyα + Hα)

Lyα/Hα ratio within a certain aperture can trace the associated HI gas.

Dual NB emitter survey (Lyα, Hα) of USS1558 at z=2.53

Shimakawa et al. (2017)



Dual emitters (LAE&HAE) avoid the dense clumps!

→ Dense cores are enshrouded by HI gas fed by cold streams?

Triple NB imaging (Lyα+Hα+[OIII]) of HS1700+64 protocluster (z=2.30)

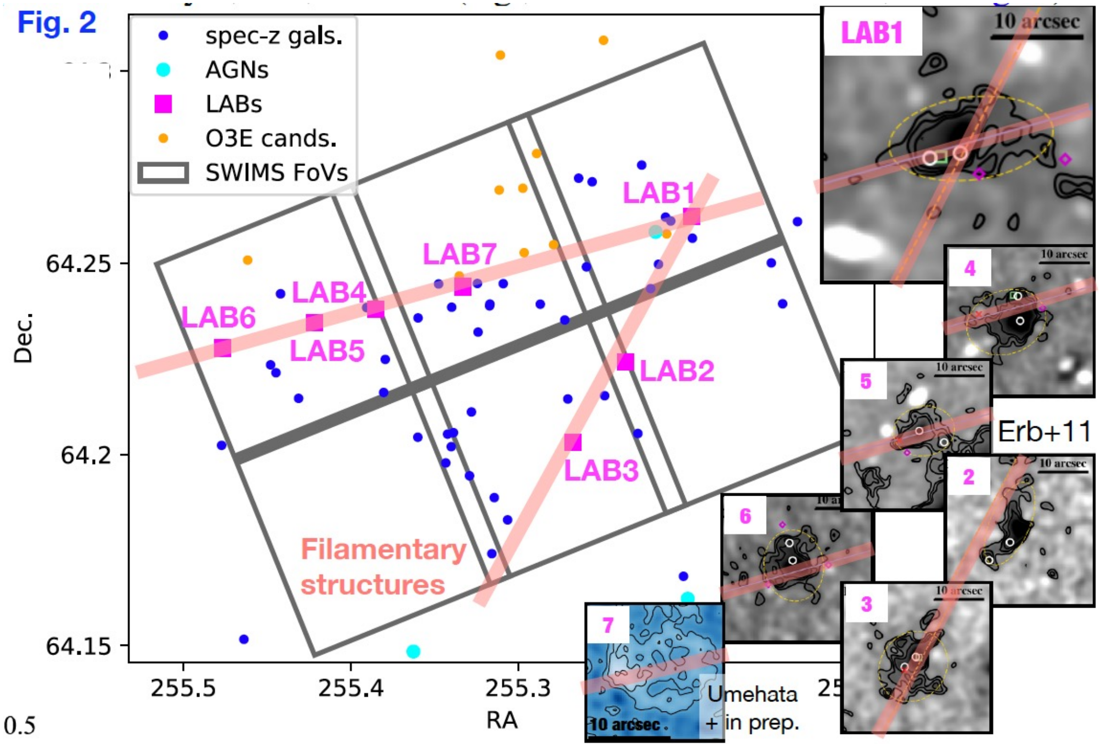
Just observed in S22A with SWIMS on Subaru (Kusakabe et al.)

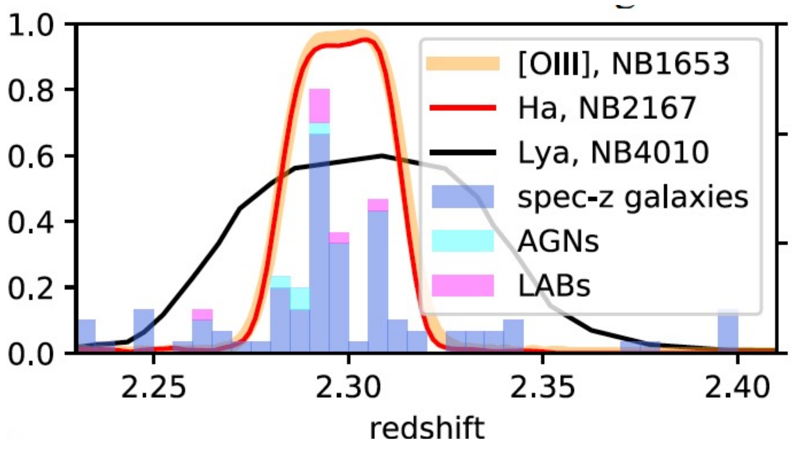
Lyα / Hα ratio → HI gas (resonant scattering) + dust attenuation

Do we see lower ratios towards the filaments?

[OIII] / Hα ratio → AGN

Is AGN fraction higher in protoclusters?





SWIMS

NB1653: [OIII] emitters

NB2167: Hα emitters

Palomer/LFC

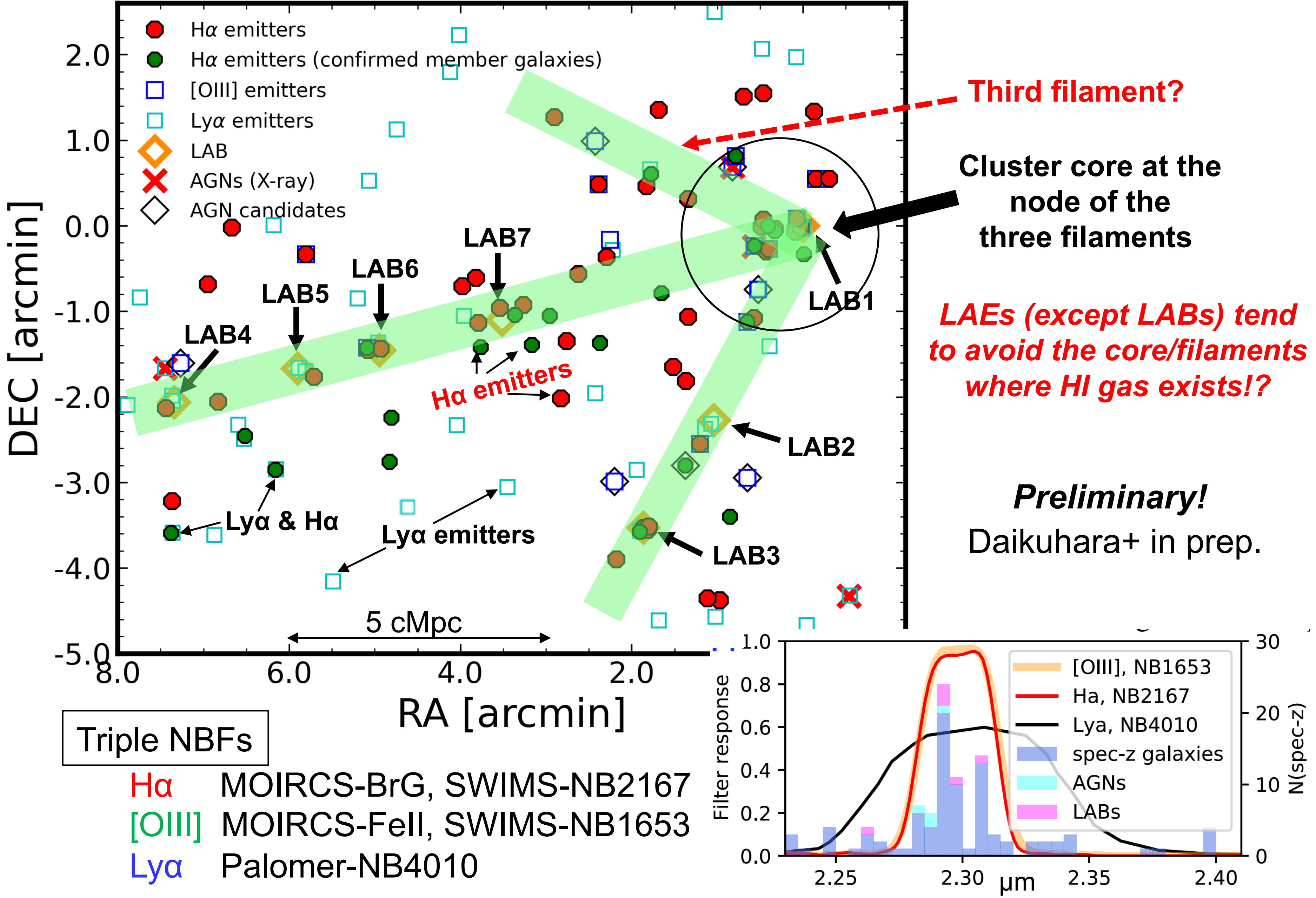
NB4010: Lyα emitters

7 Lyα blobs are aligned in 2 filaments!

Steidel (2005), Erb et al. (2011), Umehata et al. (2021), Bogosavljevic (2010)

HS1700+64 (z=2.30)

A young protocluster with linear Lyα blob (LAB) filaments (Steidel, Erb…)



Third filament?

Cluster core at the node of the three filaments

LAEs (except LABs) tend to avoid the core/filaments where HI gas exists!?

Preliminary!

Daikuhara+ in prep.

Triple NBFs

Hα	MOIRCS-BrG, SWIMS-NB2167
[OIII]	MOIRCS-FeII, SWIMS-NB1653
Lyα	Palomer-NB4010

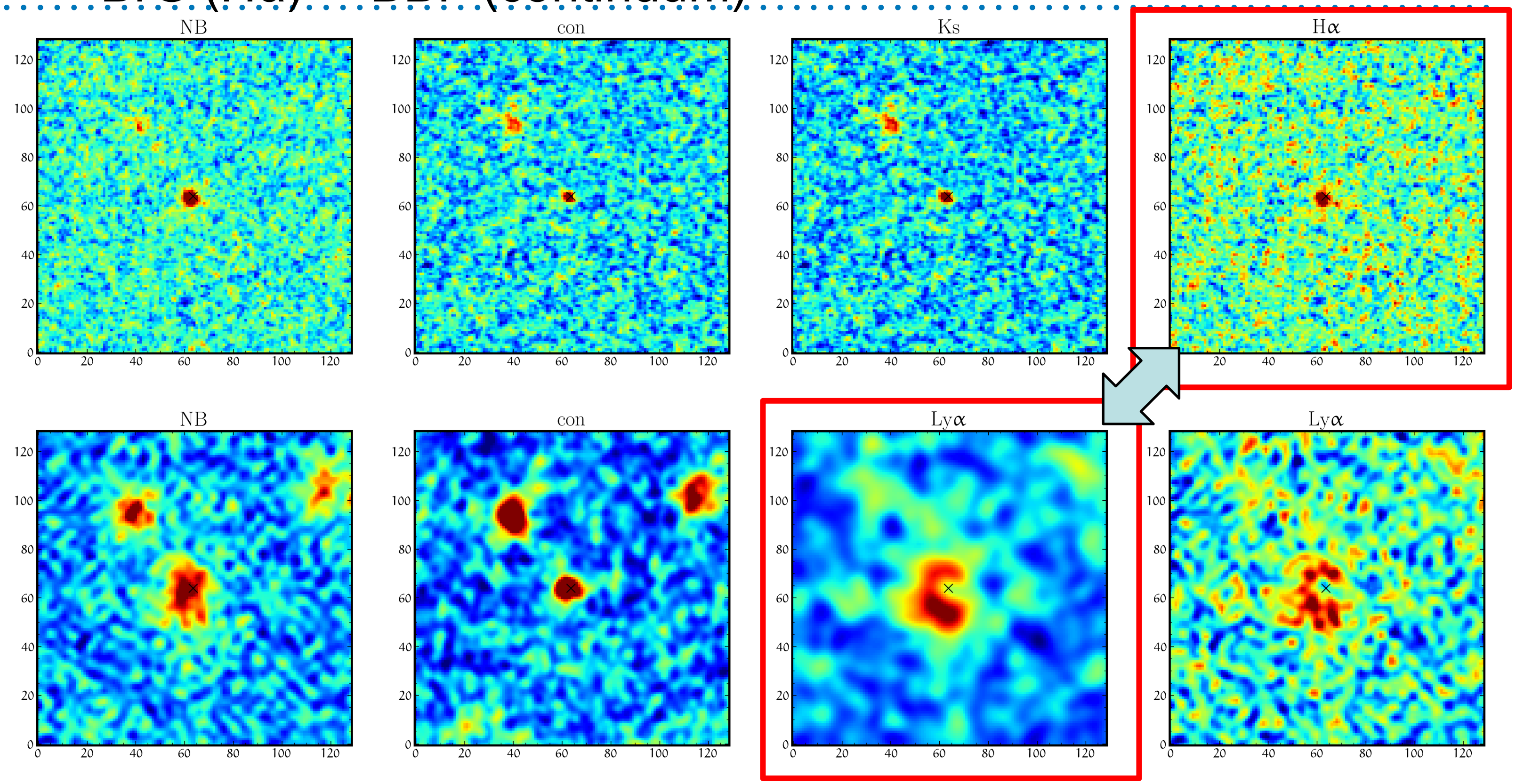
An example of extended Lyα emitters

Lyα size ≫ Hα or continuum sizes

→ resonant scattering of Lyα

BrG (Hα) BBF (continuum)

Hα (NB-BB)



NB4010
(Lyα)

BBF
(continuum)

Lyα (NB-BB)

central dent?

Preliminary!

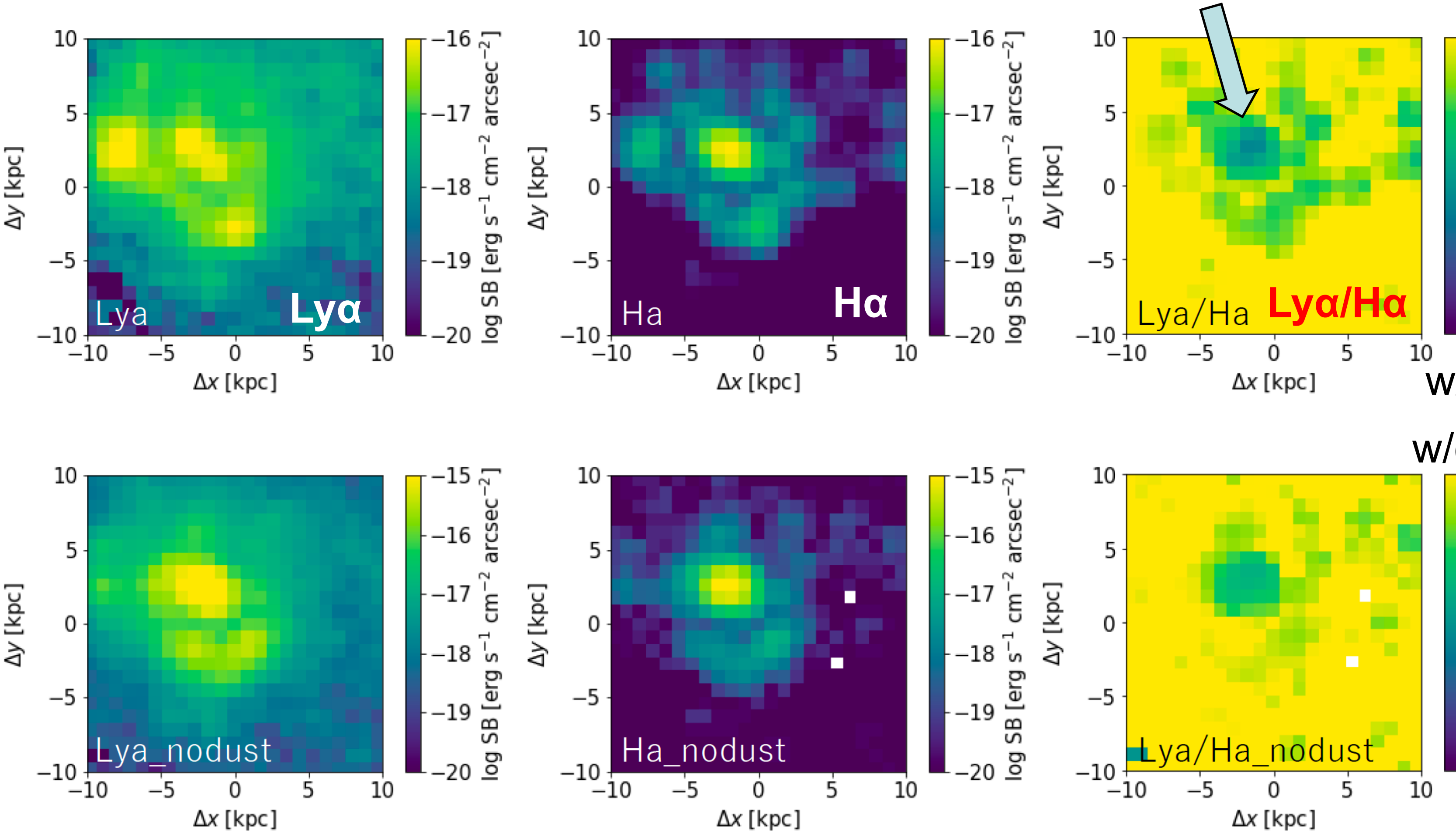
Daikuhara+ in prep.

Lyα versus Hα in the simulation

Osaka zoom-in hydrodynamical-simulation with radiative transfer (post process)

A central dent in Lyα/Hα ratio is predicted due to Lyα resonant scattering (+dust)

More prominent in protoclusters due to more associated HI gas.



w/ dust

w/o dust

a simulated SFG at z~2

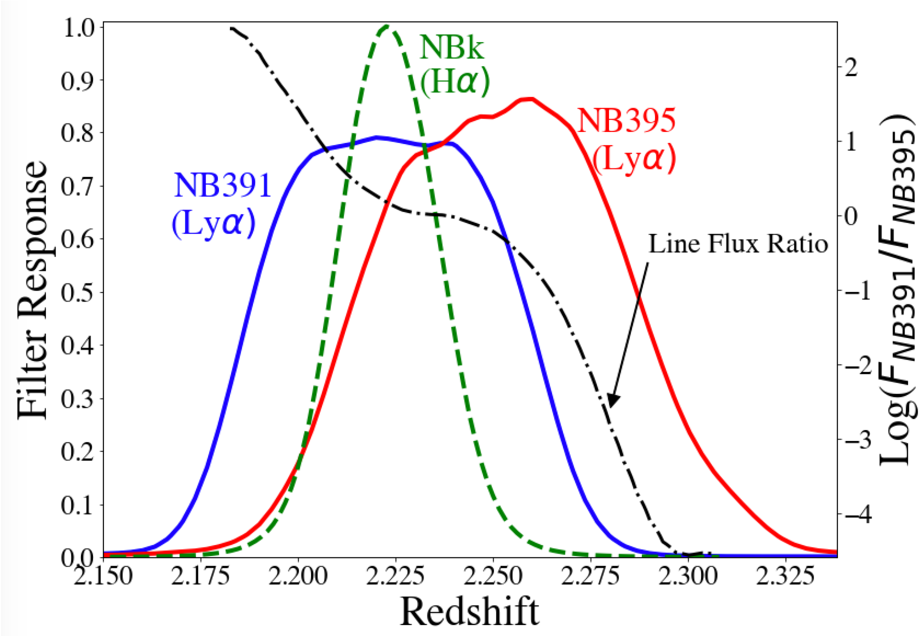
Nagamine et al., private communication

Mapping HI gas with pair narrow-band filters at z=2~2.5

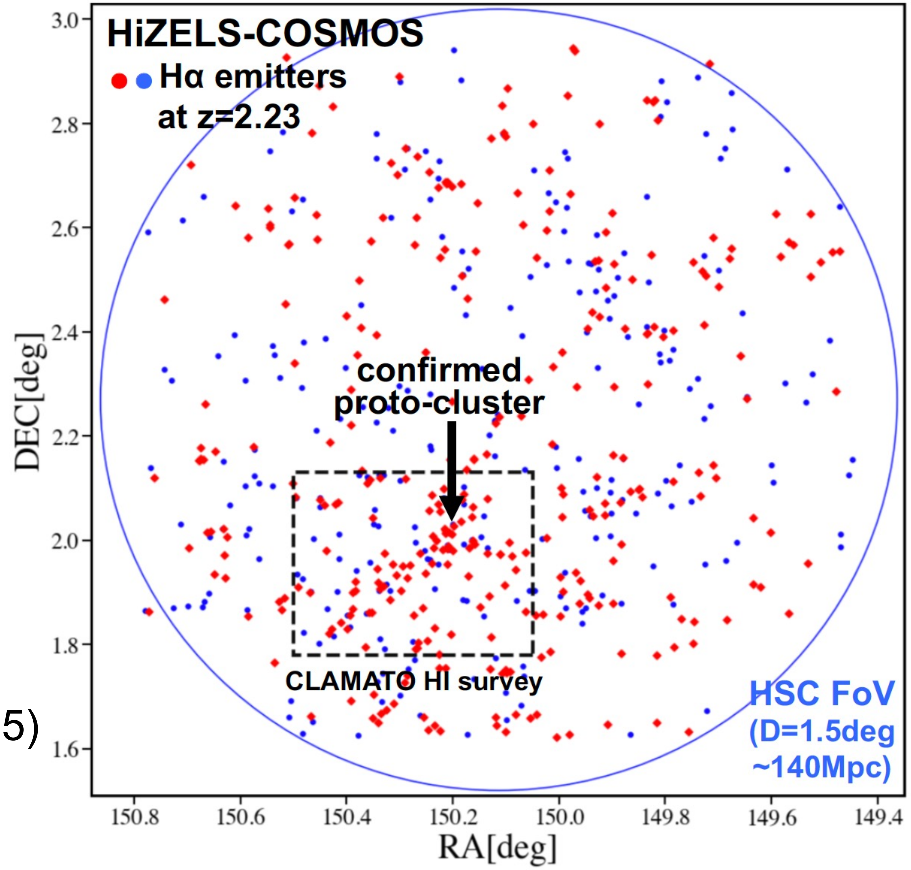
Lyα / Hα ratio → HI gas (resonant scattering) + dust attenuation

Do we see lower ratios (in a certain aperture) towards the protocluster and filaments?

Lyα: HSC NB filters, Hα: NIR NB filters



Partially overlapping NB filters (eg. NB391 & NB395) can also trace 3D structures (at z=2.23).

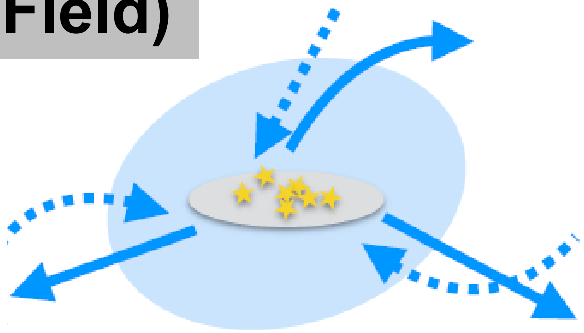


NB387 (z=2.18) and NB428 (z=2.53) are also available on HSC where we plan to make matching Hα filters on SWIMS.

Approve in S22B (Kodama+), and will be observed in Jan 2023

4. Where and how do the *gas outflow or stripping* affect galaxies in clusters?

Isolated galaxies (Field)



(Inflow)

Stochastic, rapid, cold gas accretion through filaments

(Outflow)

Gas removal due to feedback (SN, AGN)

→ Selective ejection of metal rich gas

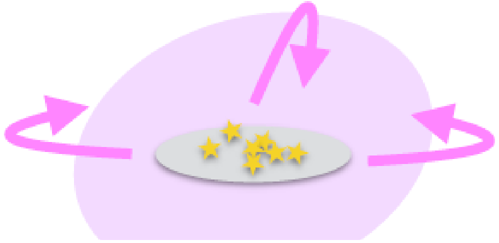
→ Metal dilution by accreting pristine gas

(Proto-)Cluster galaxies

(Inflow)

A common halo is formed and gas is shock heated to its virial temperature.

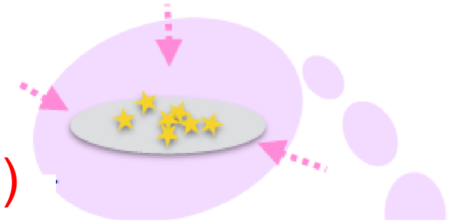
→ inefficient gas accretion compared to isolated galaxies.



(Outflow)

Fall back of gas due to deeper potential wells and surrounding gas pressure (Dave+11, Klus+13)

→ Recycling of gas (further enrichment)

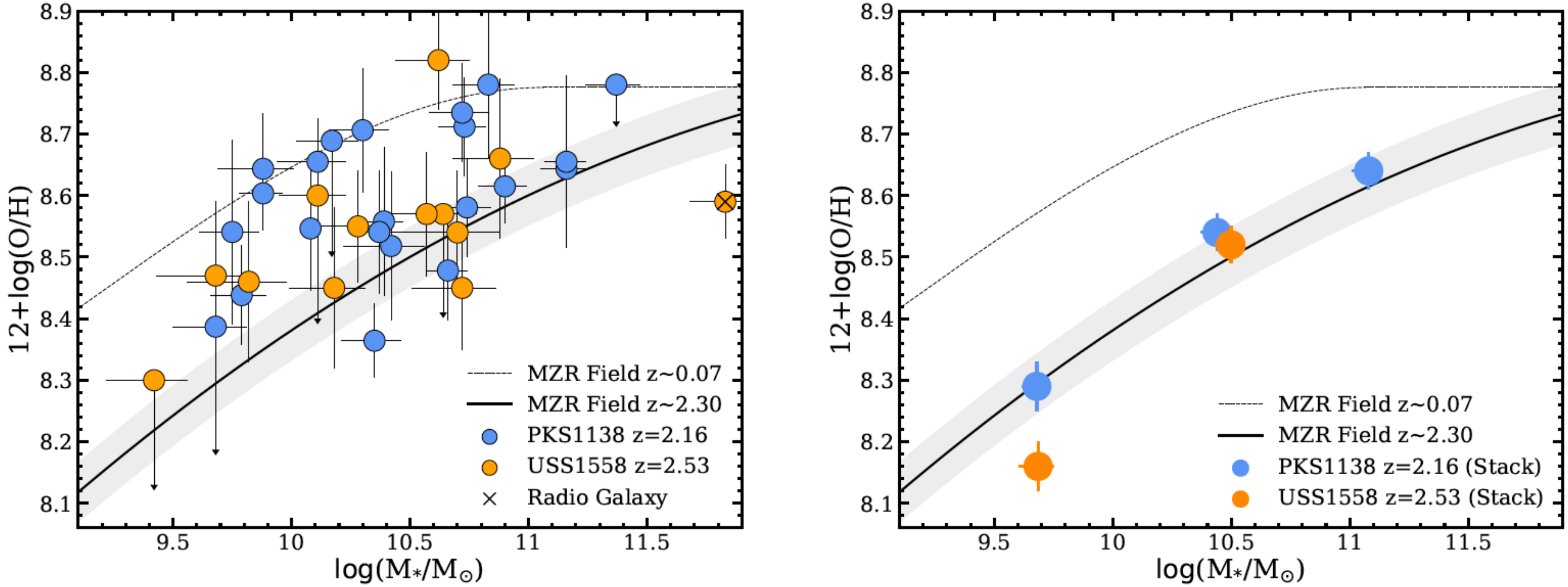


(Stripping)

Gas stripping (tidal or ram-pressure)

→ Removal of outer metal poor gas

Mass-Metallicity Relation of Galaxies in Proto-Clusters



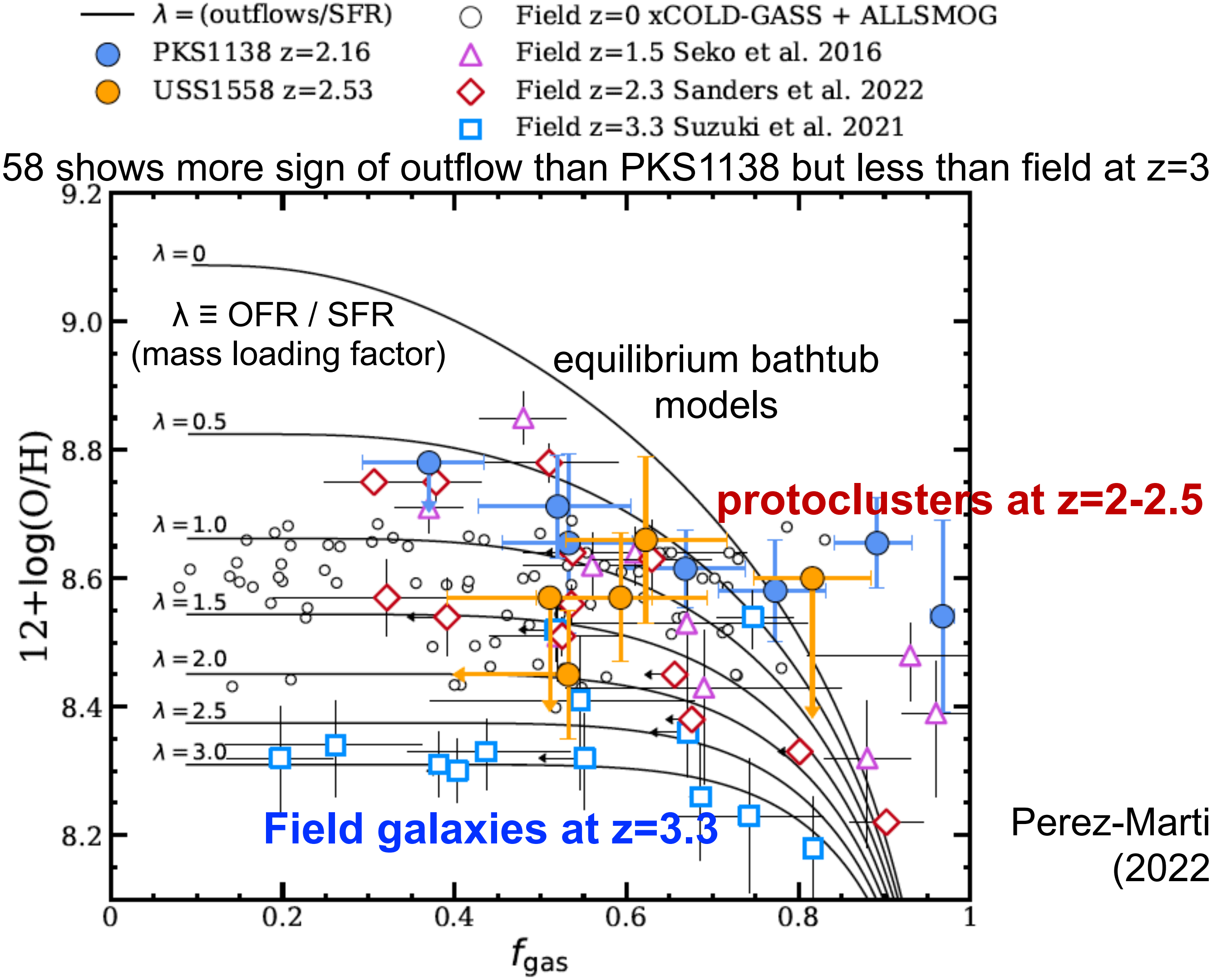
Perez-Martinez et al. (2022a,b)

USS1558@z=2.5 shows slightly lower gaseous metallicity compared to the field or richer protocluster PKS1138@z=2.2

Efficient cold gas accretion to USS1558 which elevates SF and also dilutes metals.

Gas Outflows constrained by Chemical Evolution

Gaseous metallicity (Z_{gas}) versus gas fraction (f_{gas}) diagram can constrain outflows (mass loading factor).



USS1558 shows more sign of outflow than PKS1138 but less than field at z=3.3

Perez-Martinez et al. (2022a,b)

Gas is more confined in galaxies in protoclusters due to deeper potential wells and surrounding gas pressure?

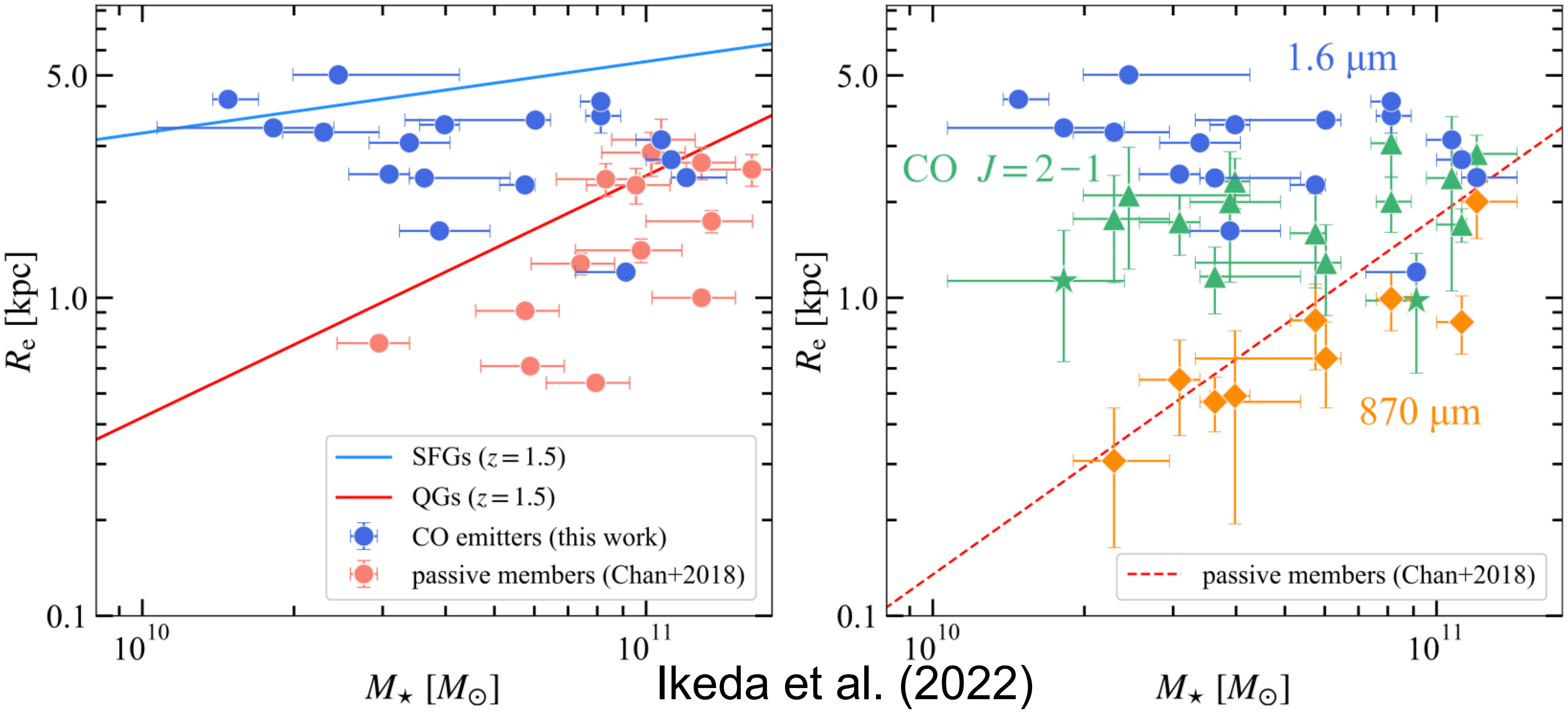
Size comparison of various galaxy components

dust continuum < molecular gas < stars

→ Formation of bulges with higher SFE in galaxy centers?

XCS2215 cluster (z~1.47)

ALMA high-R observations of CO(2-1) line and dust continuum (870μm)



Ikeda et al. (2022)

Figure 7. Stellar mass–size distribution of the galaxies in XCS J2215. Left: HST/1.6 μm sizes are shown for 17 CO emitters (blue circles) and 14 spectroscopically confirmed passive members (red circles; Chan et al. 2018). The solid lines correspond to the best-fit mass–size relation of star-forming (blue) and passive (red) galaxies at $z = 1.5$ (van der Wel et al. 2014). Right: comparison of the sizes of the CO emitters measured from different tracers. The blue circles, green triangles or stars, and orange diamonds indicate the effective radii of the HST/1.6 μm, CO $J = 2$–1 line, and 870 μm continuum, respectively. Two AGNs (ALMA.11 and ALMA.14) are shown with green stars for the CO size. The red dashed line is the best-fit mass–size relation of the passive members of XCS J2215 at 1.6 μm, as presented in the left panel.

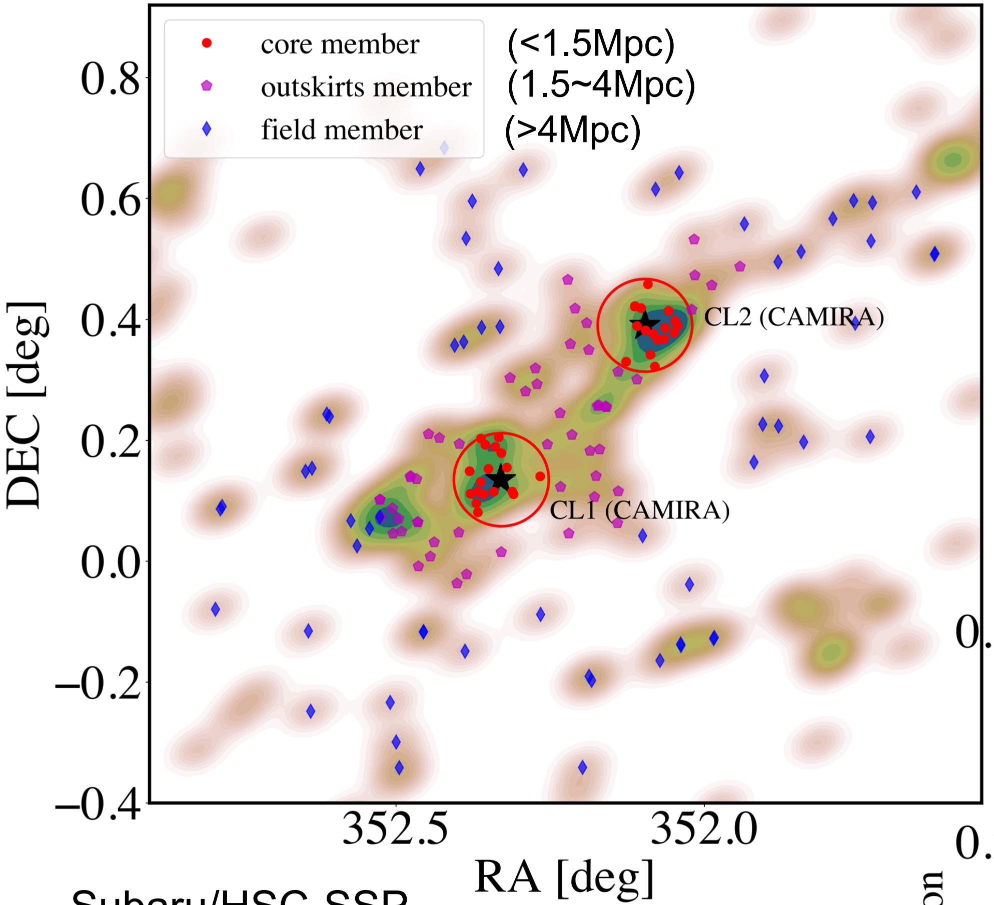
We also see this trend for field galaxies at z~2 (Tadaki et al. 2017).

Any environmental dependence? → Need more data.

Sizes of NB selected Hα emitters in the z=0.4 supercluster

(Deep2-3 field)

Laishram, R., et al. in prep.



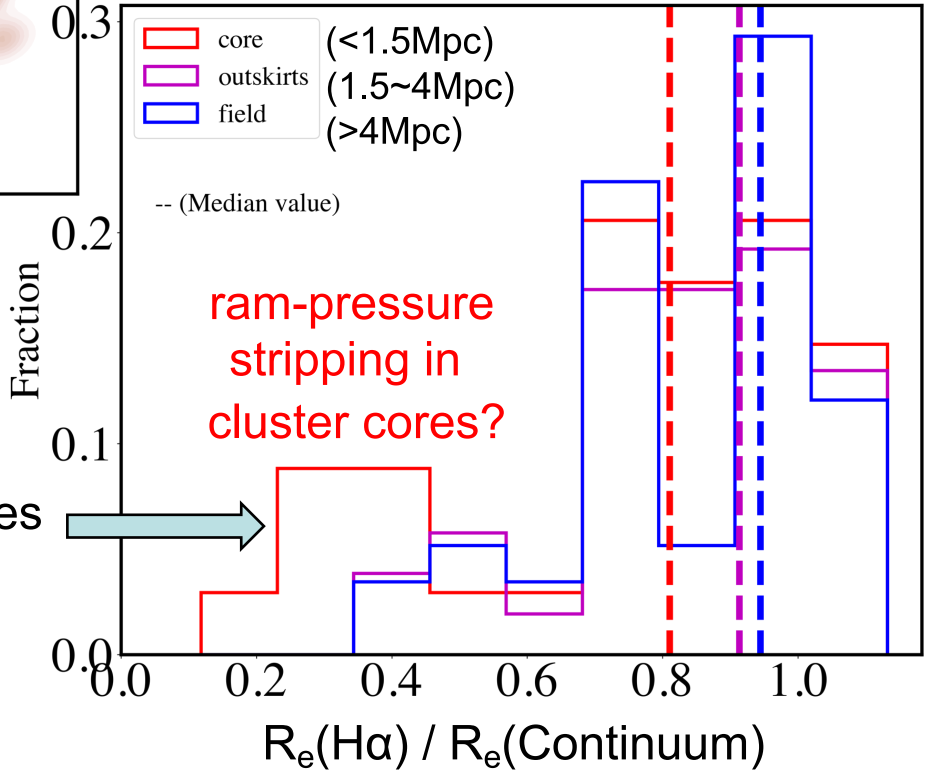
Subaru/HSC-SSP

Hayashi et al. (2020)

Smaller Hα sizes in cluster cores!

$R_e(H\alpha) / R_e(\mathrm{Continuum})$

$\sim R_e(\mathrm{SFR}) / R_e(M_*)$



ram-pressure stripping in cluster cores?

Hα size is smaller in cluster cores w.r.t. continuum (stellar) size

ULTIMATE-Subaru

2028-

Ultra-wide Laser Tomographic Imager and MOS with AO for Transcendent Exploration

Ground Layer AO with Adaptive Secondary Mirror (4 LGSs)

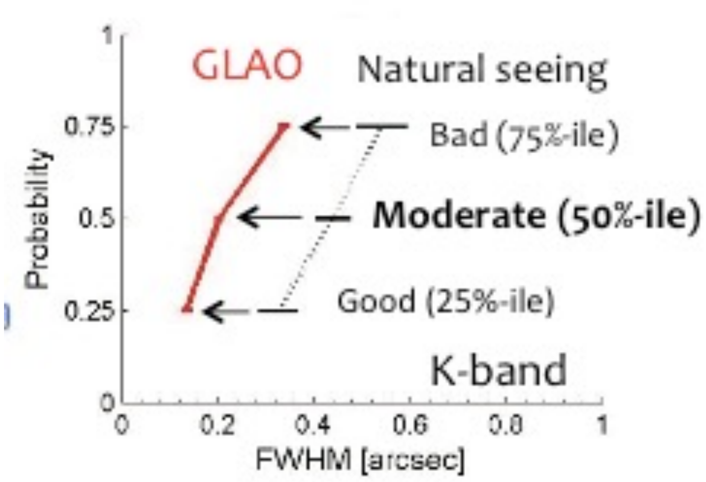
+

Wide-field (14’) Near-IR Imager (WFI)

Seeing improvement

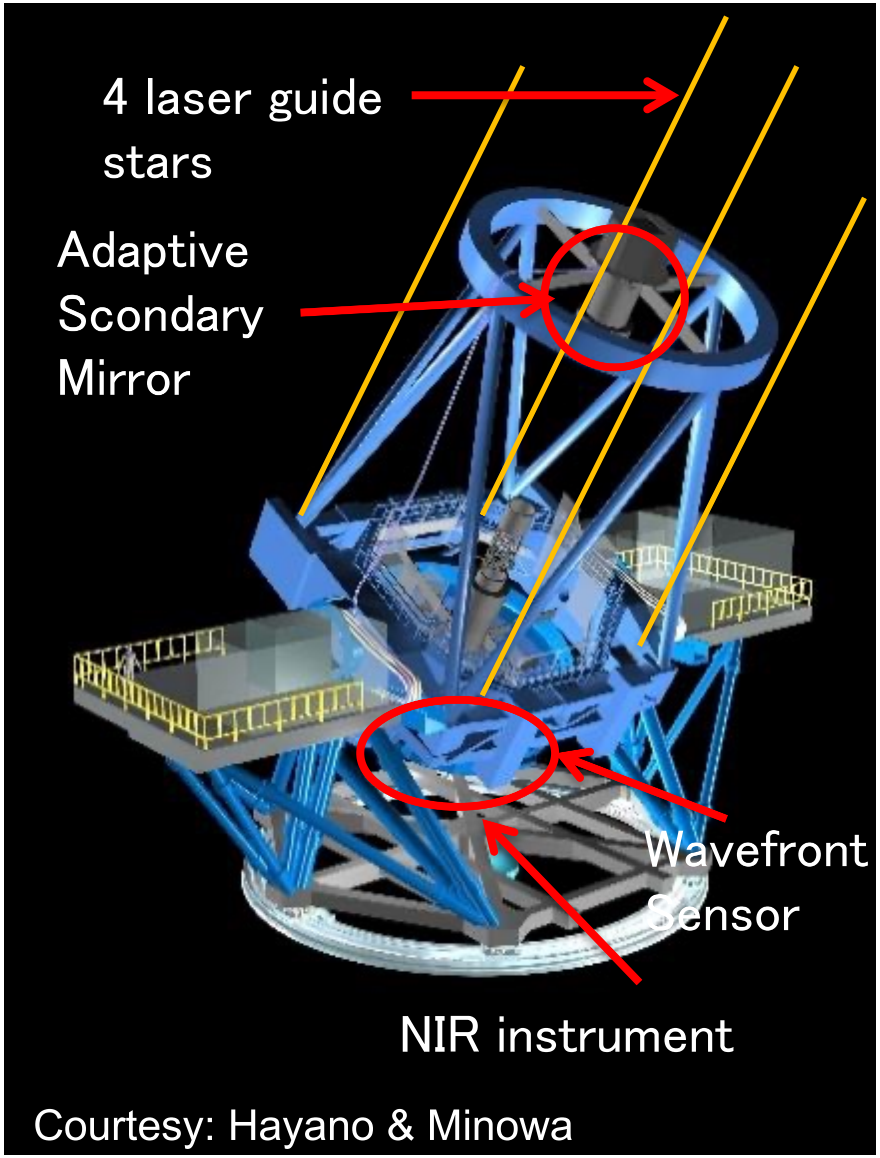
(FWHM 0.4”→ 0.2” in K) over 14’ FOV

(cf. ~0.4” over 7.5’ with VLT/GRAAL)



→ 0.2” resolution for extended sources

1.5~2x higher sensitivity for point sources



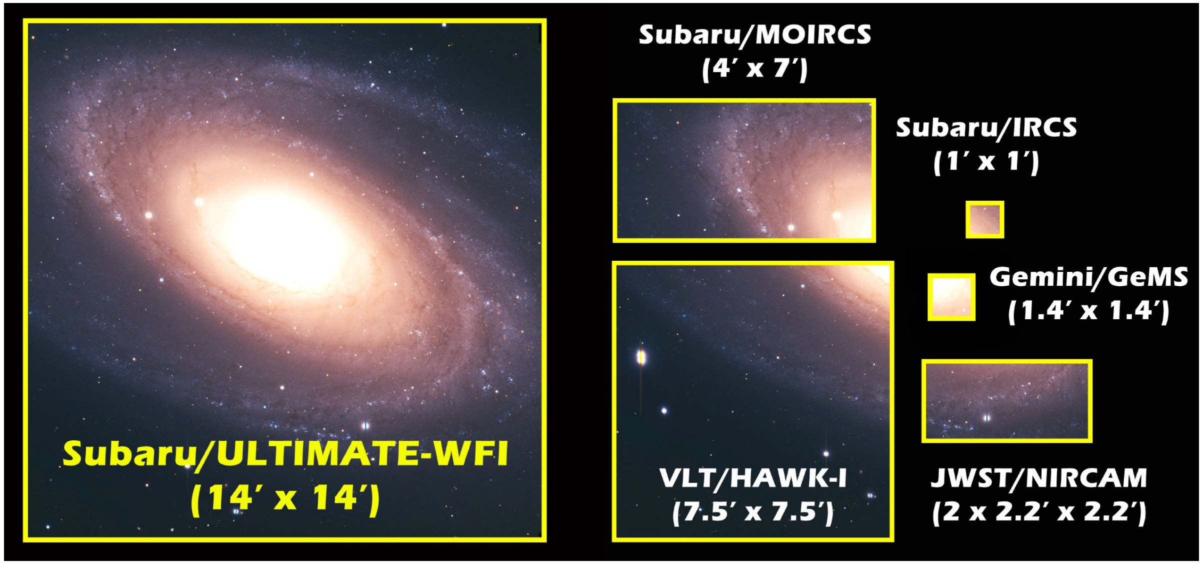
Courtesy: Hayano & Minowa

ULTIMATE–Subaru 2028-

Ultra-wide Laser Tomographic Imager and MOS with AO for Transcendent Exploration

Ground Layer AO (GLAO) + Wide-field Near-IR Instruments w/ MB/NB filters

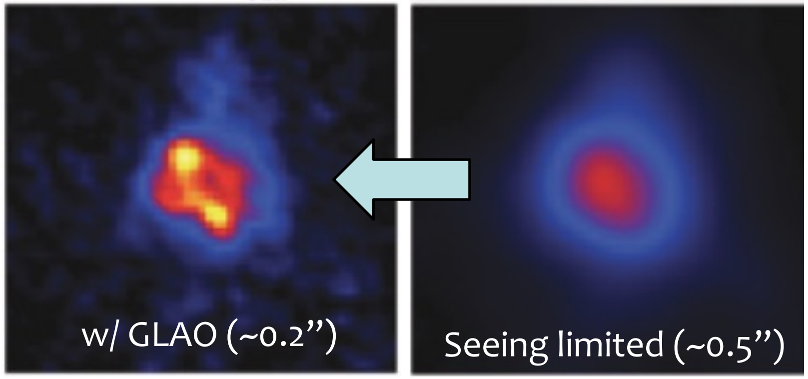
largest FoV (**14’ × 14’**) and a **0.2”** resolution (FWHM) in K-band



International partners are welcome!

Roman will have a Ks filter, although the priority of its large survey is likely to be low.

A clumpy star-forming galaxy at z~2



0.2” ⇔ 1.5kpc at $1<z<3$
(1/3~1/2 R_e for SFGs)

Spatially resolve extended SFGs and gain sensitivity *(1.5-2x) for* compact QGs.

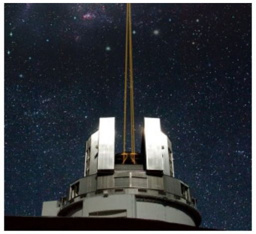
Courtesy: Y. Koyama

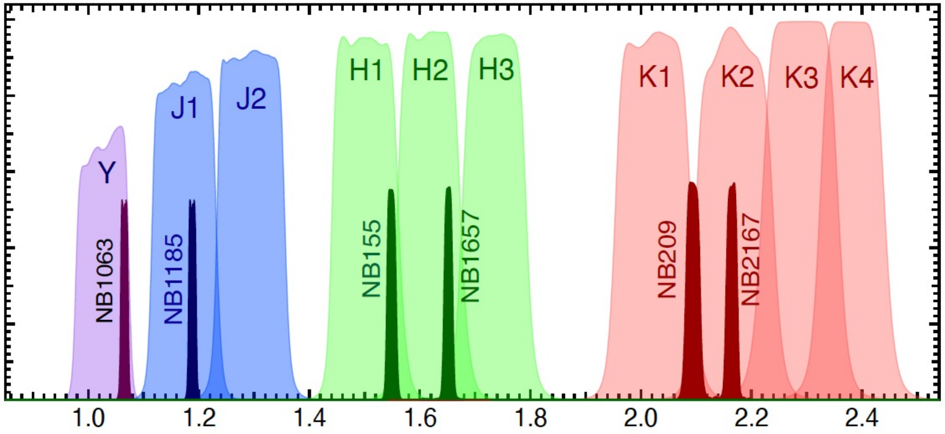
A powerful tool for future protocluster studies.

Space (Euclid/Roman) BBF + Ground (ULTIMATE) MBF

ULTIMATE WFI (Subaru)

2028~

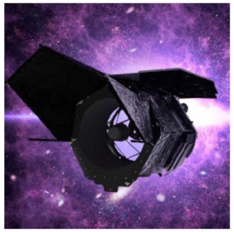


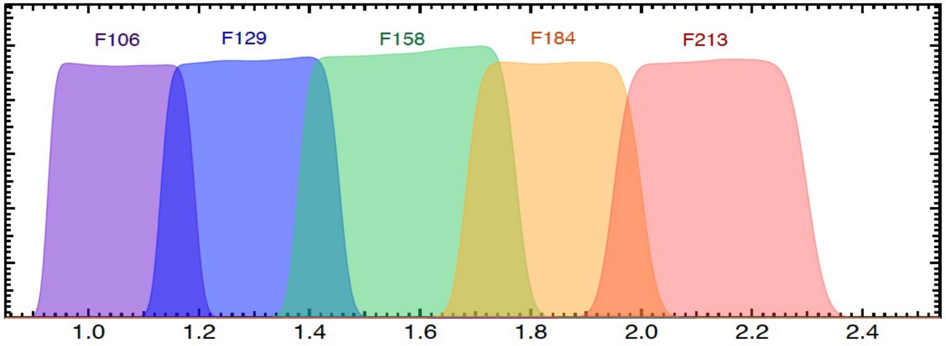


- 10 MBFs
- Hα-[OIII] NBF pair ($z=2.3$)
- Hα-Hβ-[OII] NBF set ($z=2.2$)
- Lyα NBFs ($z=7.7, 8.7$)

Unique and complementary!

Roman

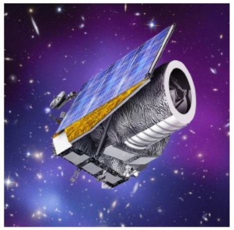


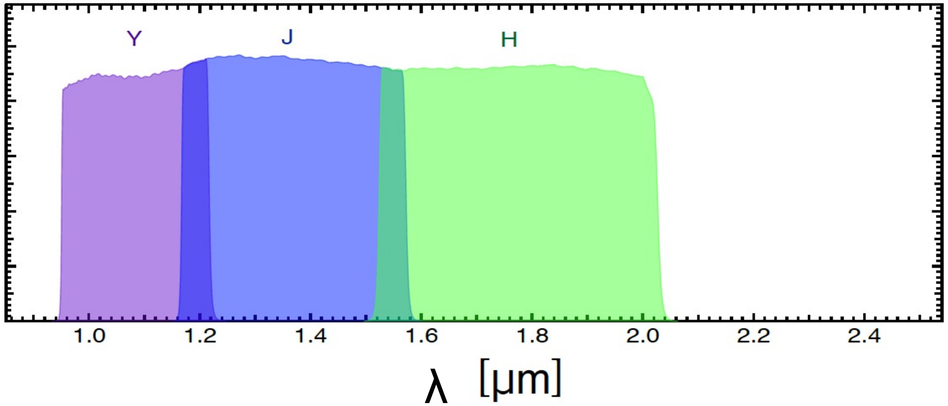


2026~

2,000 deg^2

Euclid





2023~

Wide: 15,000 deg^2
Deep: 50 deg^2

Summary

Revealing the History of Galaxy and Cluster Formation and Evolution with Observations by Modern Telescopes (e.g., Subaru and ALMA) and Phenomenological Models

Formation of galaxies and their clusters was most active around 100-120 Gyrs ago. We aim to see the galactic Universe across this peak epoch and obtain global and statistical views of galaxy formation and evolution (macroscopic approach) and at the same time spatially resolve the internal structures and kinematics within individual galaxies to understand the physical processes directly (microscopic approach). With the observational data obtained through modern telescopes and the phenomenological models to interpret them, we are revealing how the galaxies and clusters form and grow.