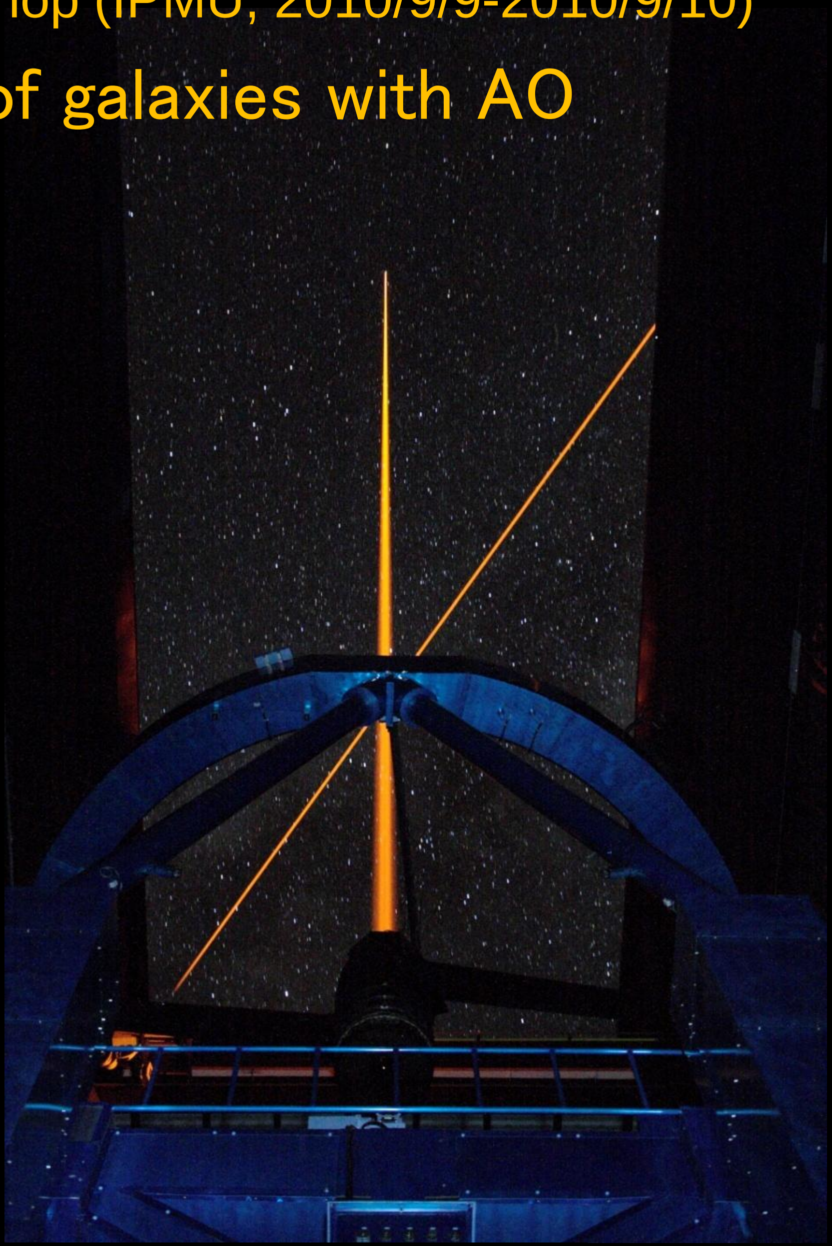
Subaru Future Instrumentation Workshop (IPMU, 2010/9/9-2010/9/10)

Resolving the build-up of galaxies with AO



Tadayuki Kodama (Subaru Telescope)

The 1st Subaru Conference (Dec. 2007, Hayama)

Panoramic Views of Galaxy Formation and Evolution

The X-th Subaru Conference:

"Narrow" *Views of Galaxy Formation and Evolution with results from Adaptive Optics ??*

Venue…

Accommodation…

The *X-th* Subaru Conference:
"Clear" Views of Galaxy Formation and Evolution with results from Adaptive Optics !?

The Mt. Fuji (3776m) on the Fuji river viewed from Shinkan-sen

Resolving power of AO on Subaru

Diffraction Limit: 0.06”@2μm ⇔ ~0.4-0.5kpc @z>1

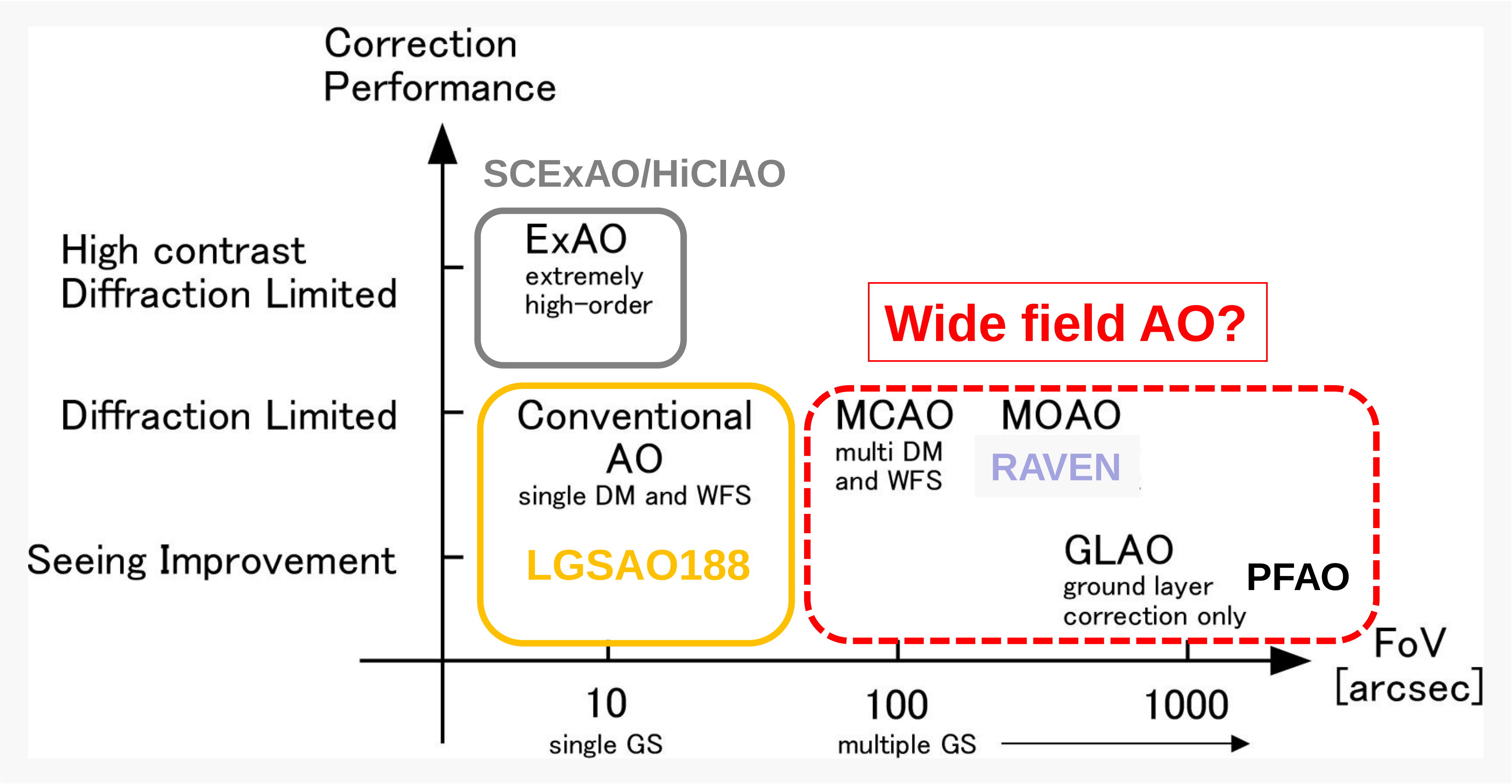
Ground Layer AO: 0.3”@opt-nir ⇔ ~2.0-2.5kpc @z>1

Subaru+AO can resolve stars and gas within galaxies.
In the case of DL, resolving power is comparable to ALMA.

- Imaging
  galaxy morphologies (Hubble types, mergers, size)
- Spectroscopy:
  internal kinematics (rotation/random, inflow/outflow)

Caution: Field of view is (has been) the limiting factor!

Adaptive Optics



Wide-Field AOs

Which combination of FoV and fwhm is the best?

- PFAO: Prime-Focus AO
  - FoV: 30’, fwhm: ~0.4” (2.5~3kpc)
  - Tip-tilt using bright stars, movable CCDs or charge transfer
- GLAO: Ground-Layer AO
  - FoV: 10’, fwhm: ~0.3” (2~2.5kpc)
  - Ground layer correction only, Deformable secondary mirror
- MOAO: Multi-Object AO
  - FoR: 3’, FoV : 0.2-0.3”, fwhm: <0.1” (diffraction-limited)
  - Multiple deformable mirrors, Target observations only
- MCAO: Multi-Conjugate AO
  - FoV: 2’, fwhm: <0.1” (diffraction-limited)
  - Multiple layers corrections, Survey observations possible

"Resolved", "sharp" views of galaxy formation and evolution

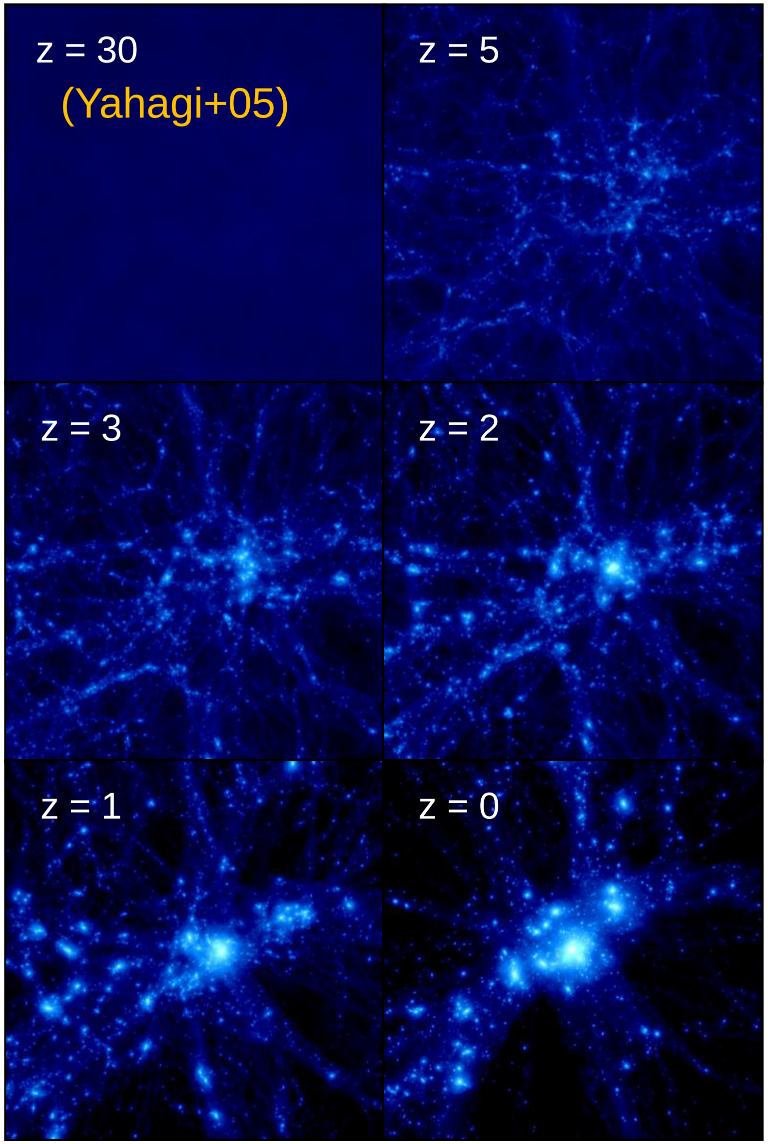
1. Origin of the cosmological division of habitats
   merger/interaction, morphologies, starbursts (AGN)
   versus environment and time

2. Origin of the Hubble sequence of galaxies
   shapes, size, and kinematics of distant galaxies

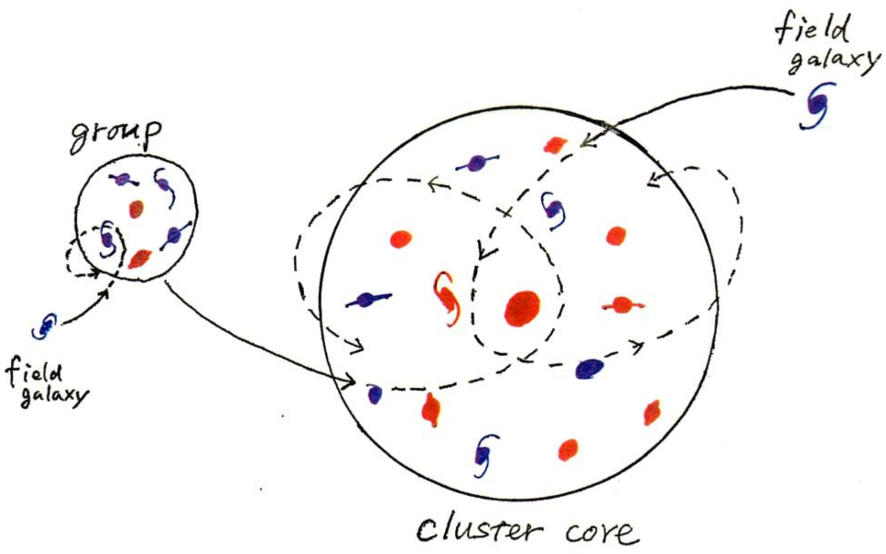
3. Internal structures of forming galaxies
   Inflow/outflow (feedback), rotation/random motions, and stellar population gradient

Origin of the Environmental Dependence

N-body simulation of a massive cluster



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



Nature? (intrinsic)

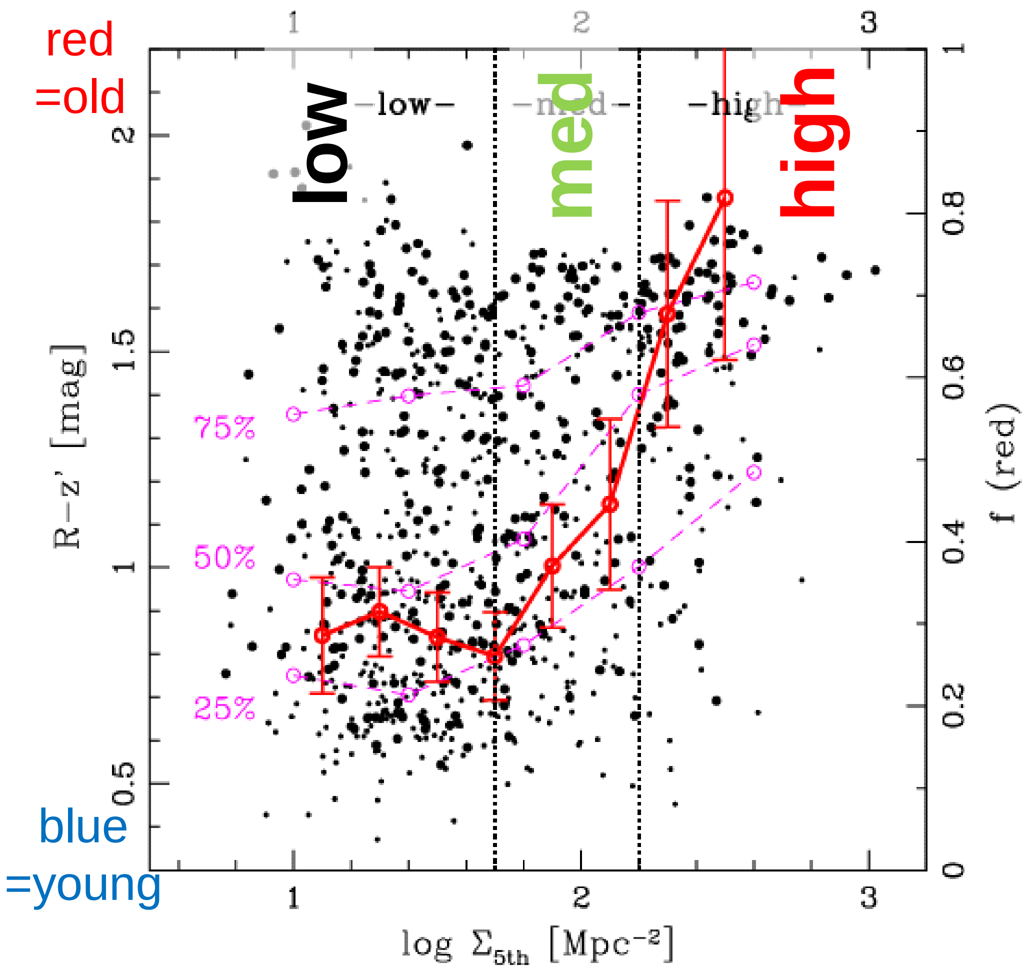
earlier galaxy formation and evolution in high density regions

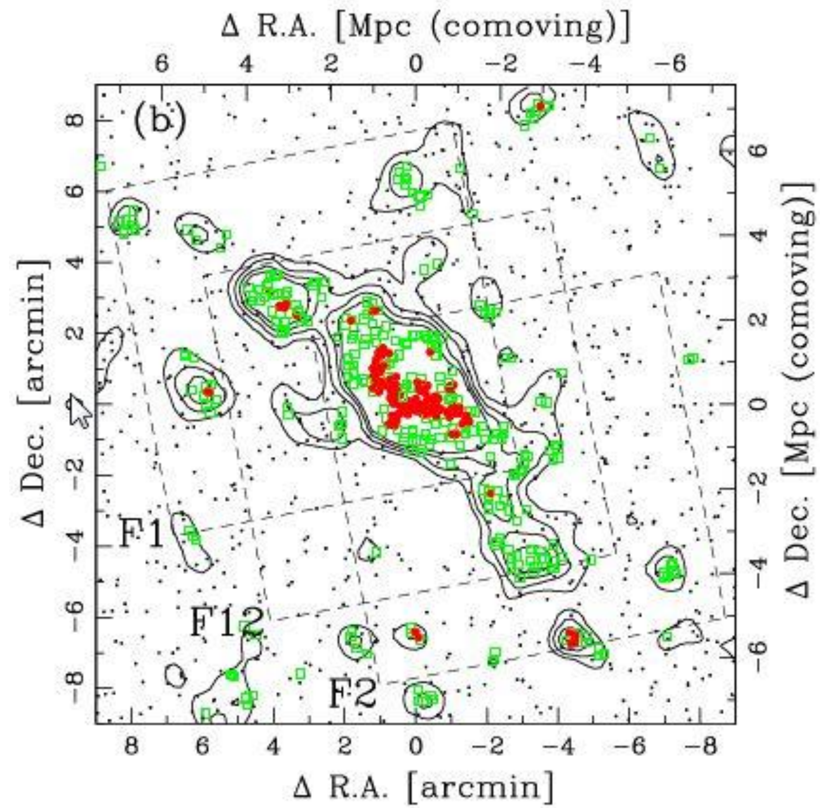
Nurture? (external)

galaxy-galaxy interaction/mergers, gas-stripping

Sharp colour transition in groups/outskirts

RXJ1716 cluster (z=0.81)





high ∼ cluster core

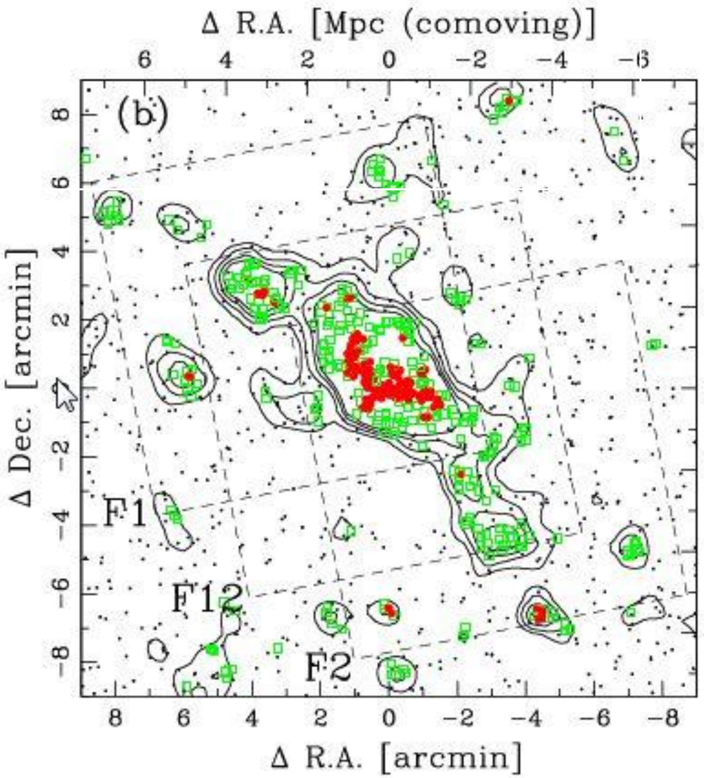
med ∼ group / filament

low ∼ field

Koyama et al. (2008). see also Kodama et al. (2001), Tanaka et al. (2005)…

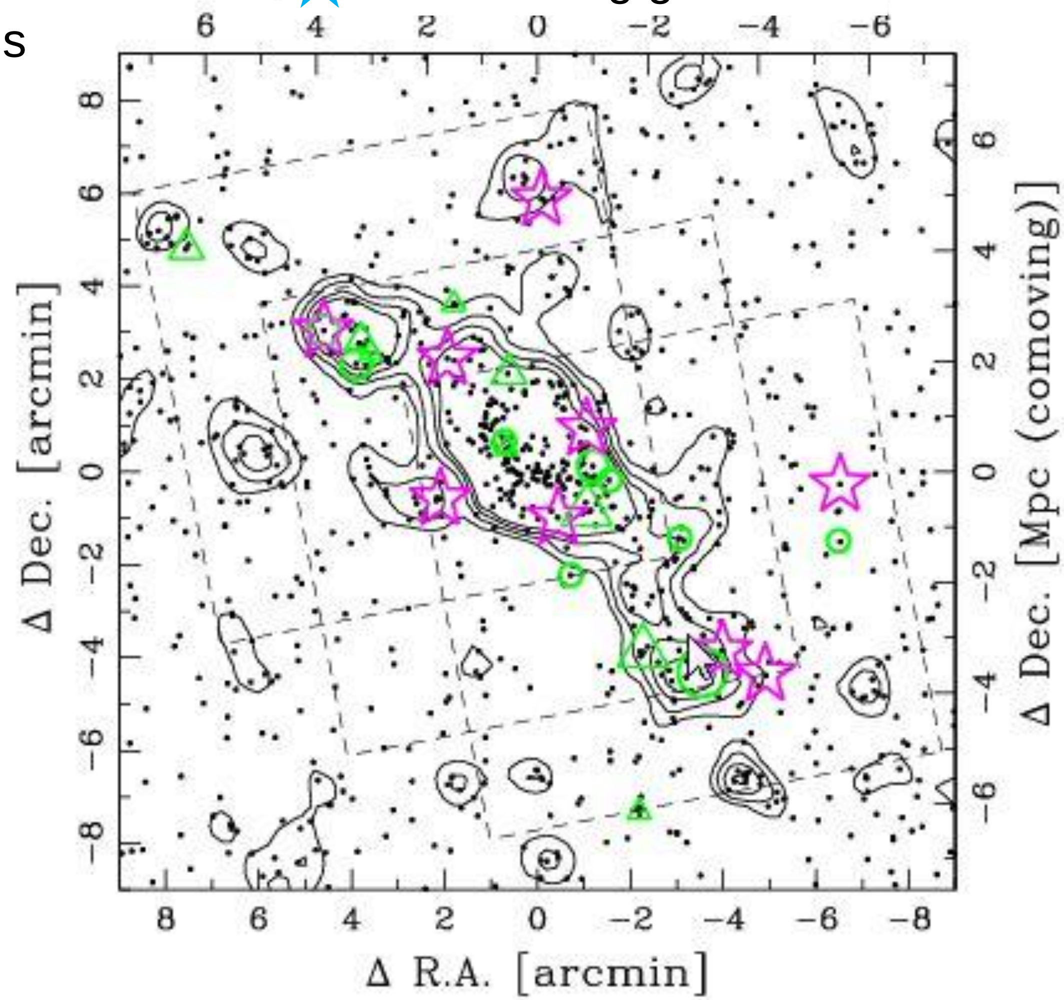
Star-bursts in groups/outskirts

- Galaxies in med. density regions



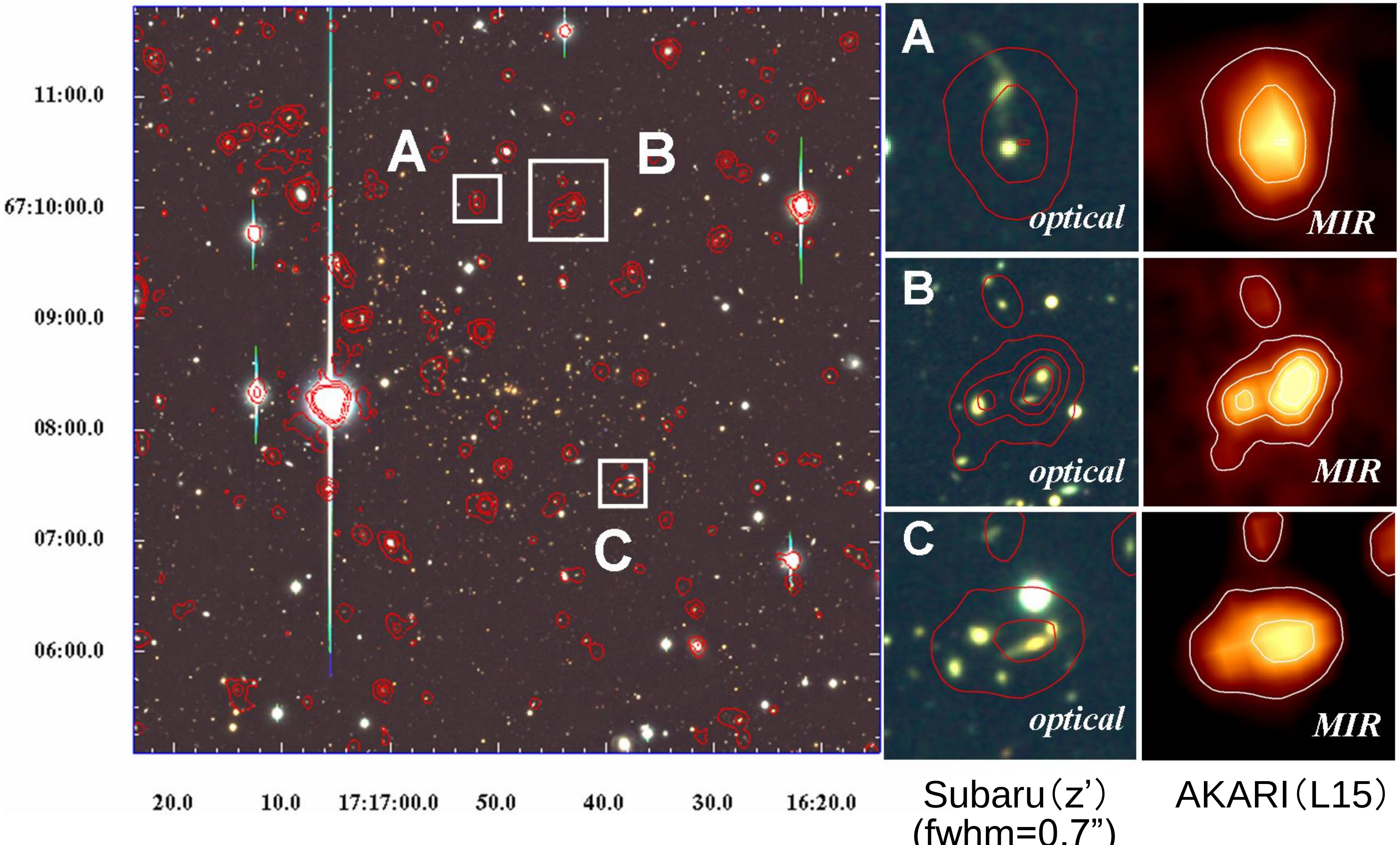
Koyama et al. (2008)

star-bursting galaxies



Starbursts are likely to be triggered in groups/outskirts by external environmental effects before they merge into the central cluster.

Mergers in star-bursting galaxies

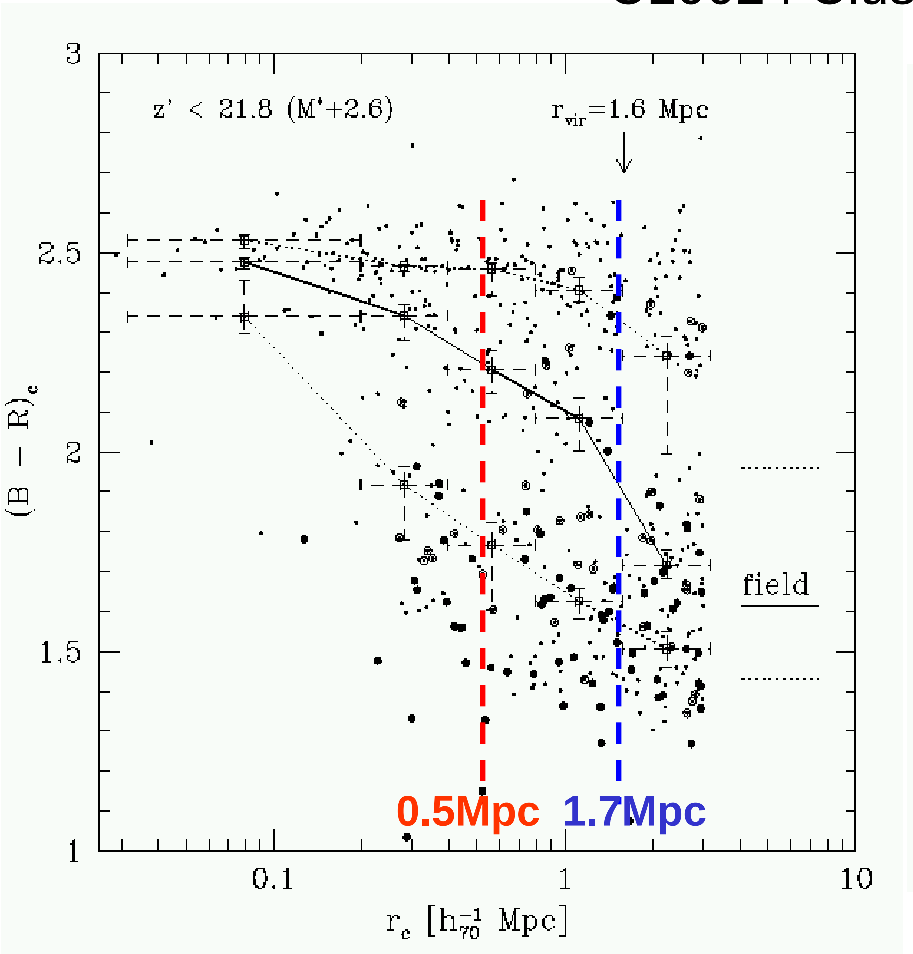


Clear signatures of galaxy-galaxy interactions are seen in some star-bursting AKARI sources.

Koyama, TK, et al. (2008)

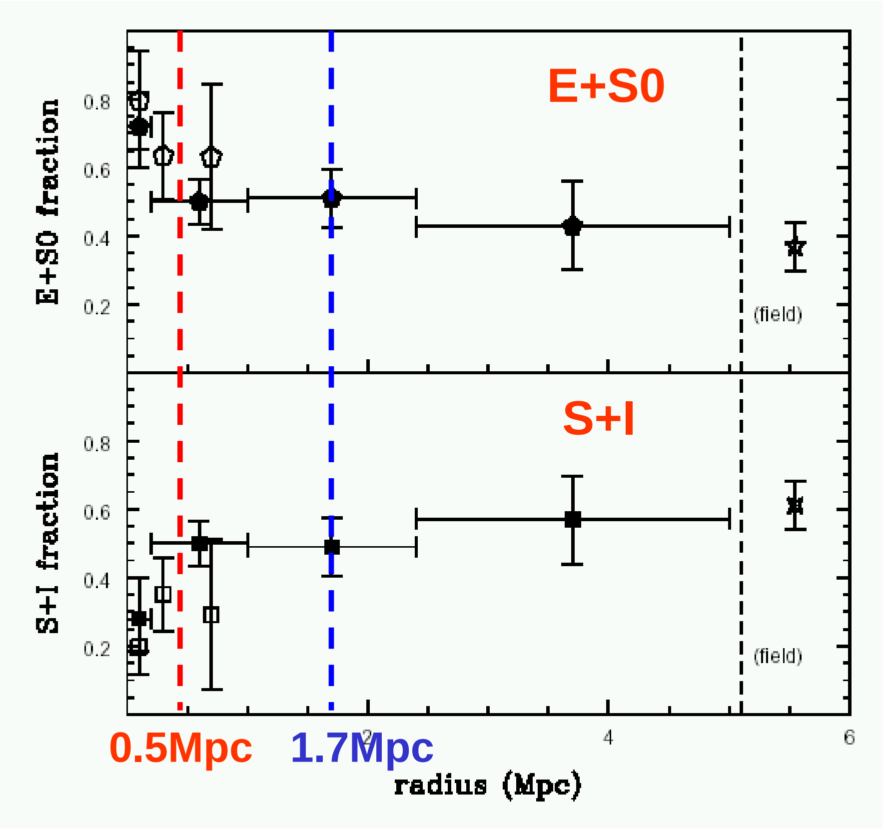
Star Formation vs. Morphology

CL0024 Cluster (z=0.4)



Kodama, Balogh, et al. (2004)

Subaru/Suprime-Cam



Treu et al. (2003)

39 HST/WFPC2 pointings

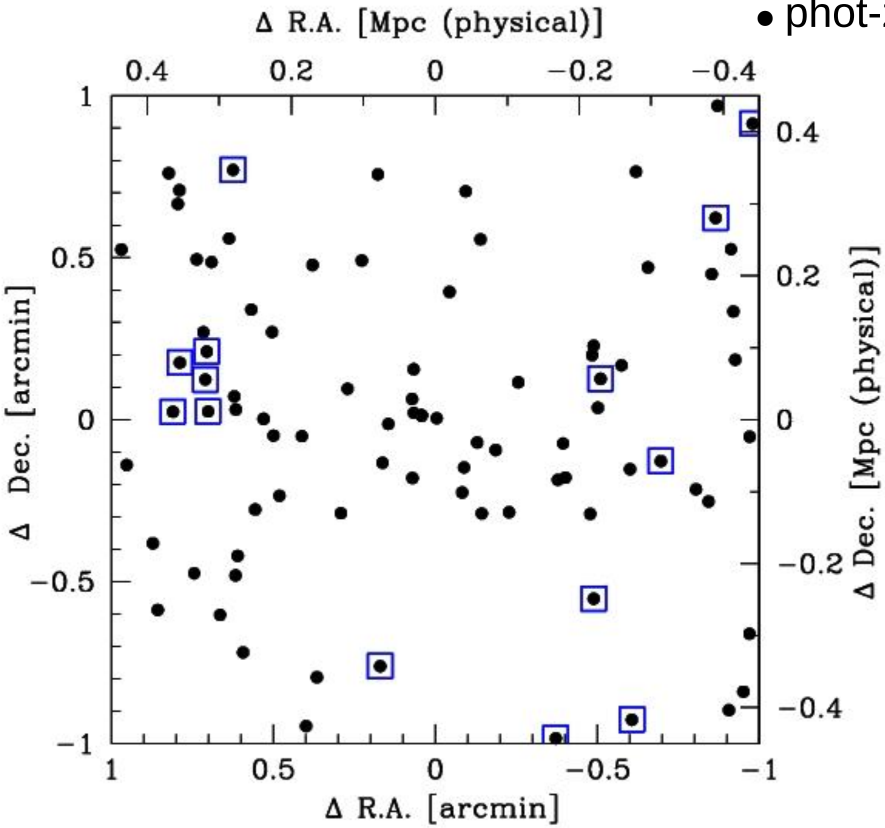
Morphologies seem to react later (or at inner region) than SF.

Star forming activity in the cluster cores

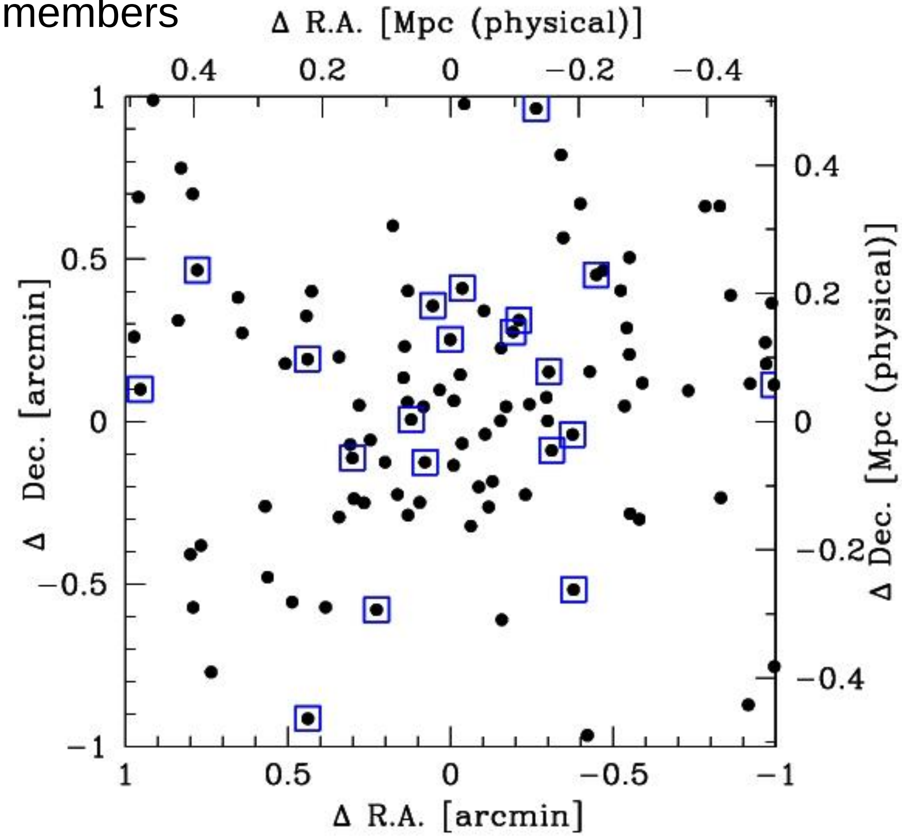
□ Hα emitters at z=0.81 (RXJ1716)
$L_X = 2.7 \times 10^{44}$ erg/s

□ [OII] emitters at z=1.46 (XCS2215)
$L_X = 4.4 \times 10^{44}$ erg/s

• phot-z members



Koyama, et al. (2009)



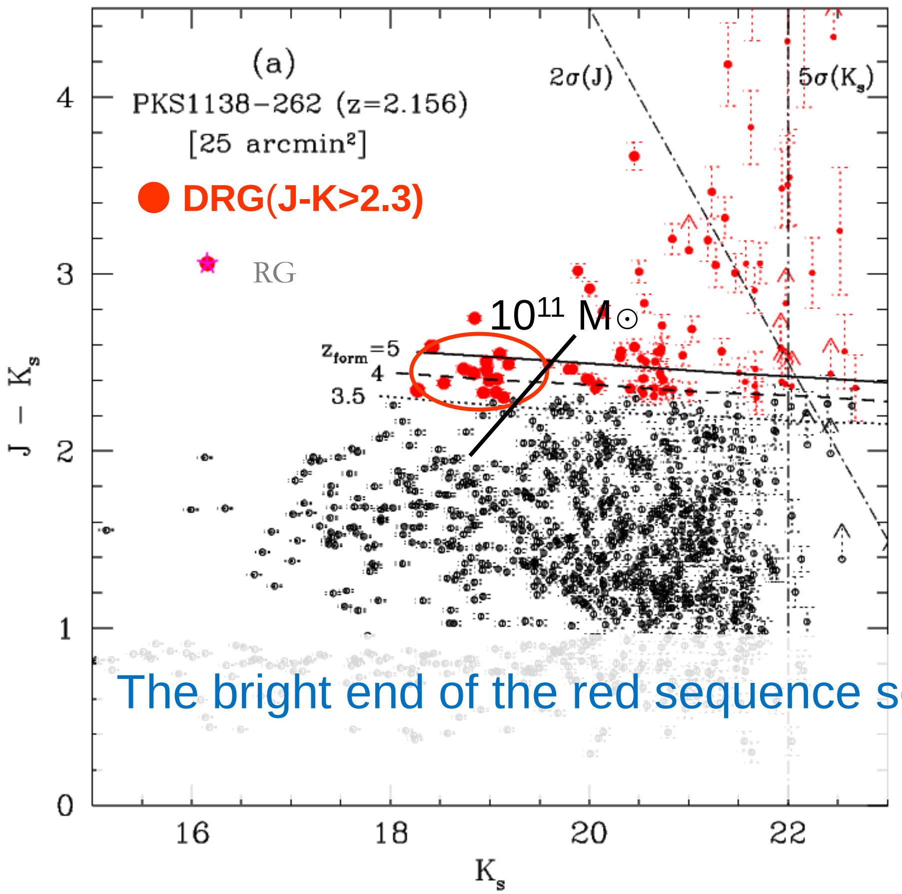
Hayashi, et al. (2010)

Star forming activity in the core is much higher in the higher redshift cluster, suggesting the inside-out truncation of star formation activity in clusters!

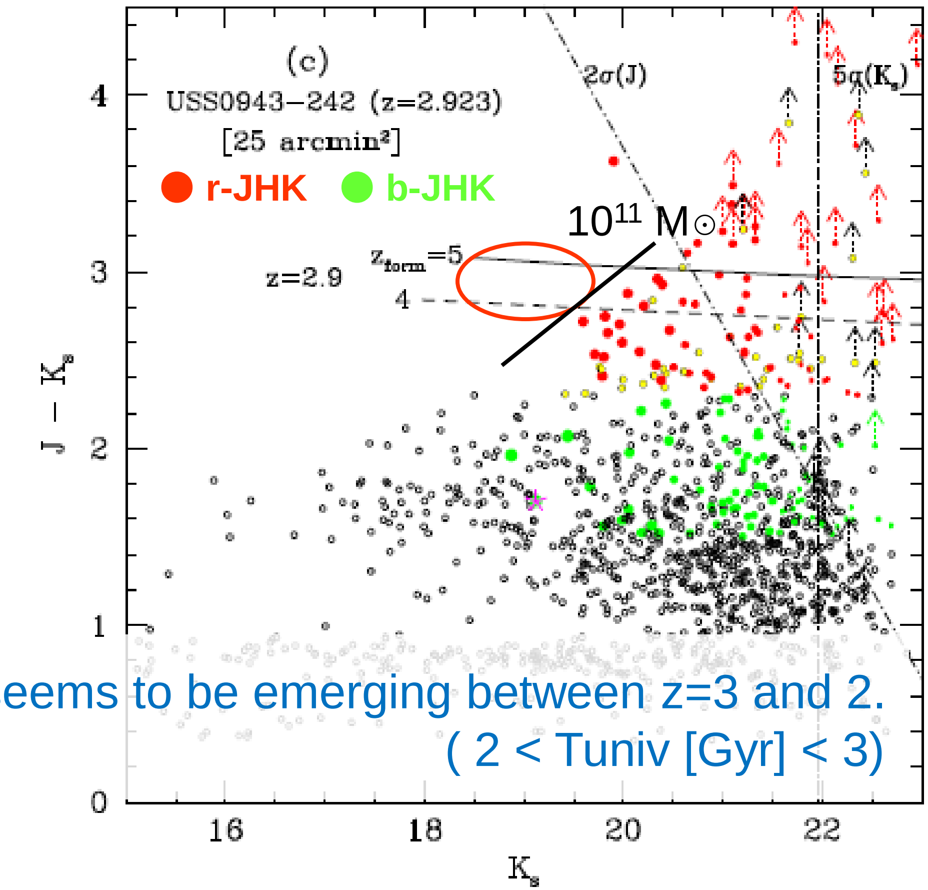
Emergence of the red-sequence at z~2 in proto-clusters?

Spectroscopically confirmed proto-clusters in terms of Lyα emitters associated to RGs.

PKS1138 (z=2.16)



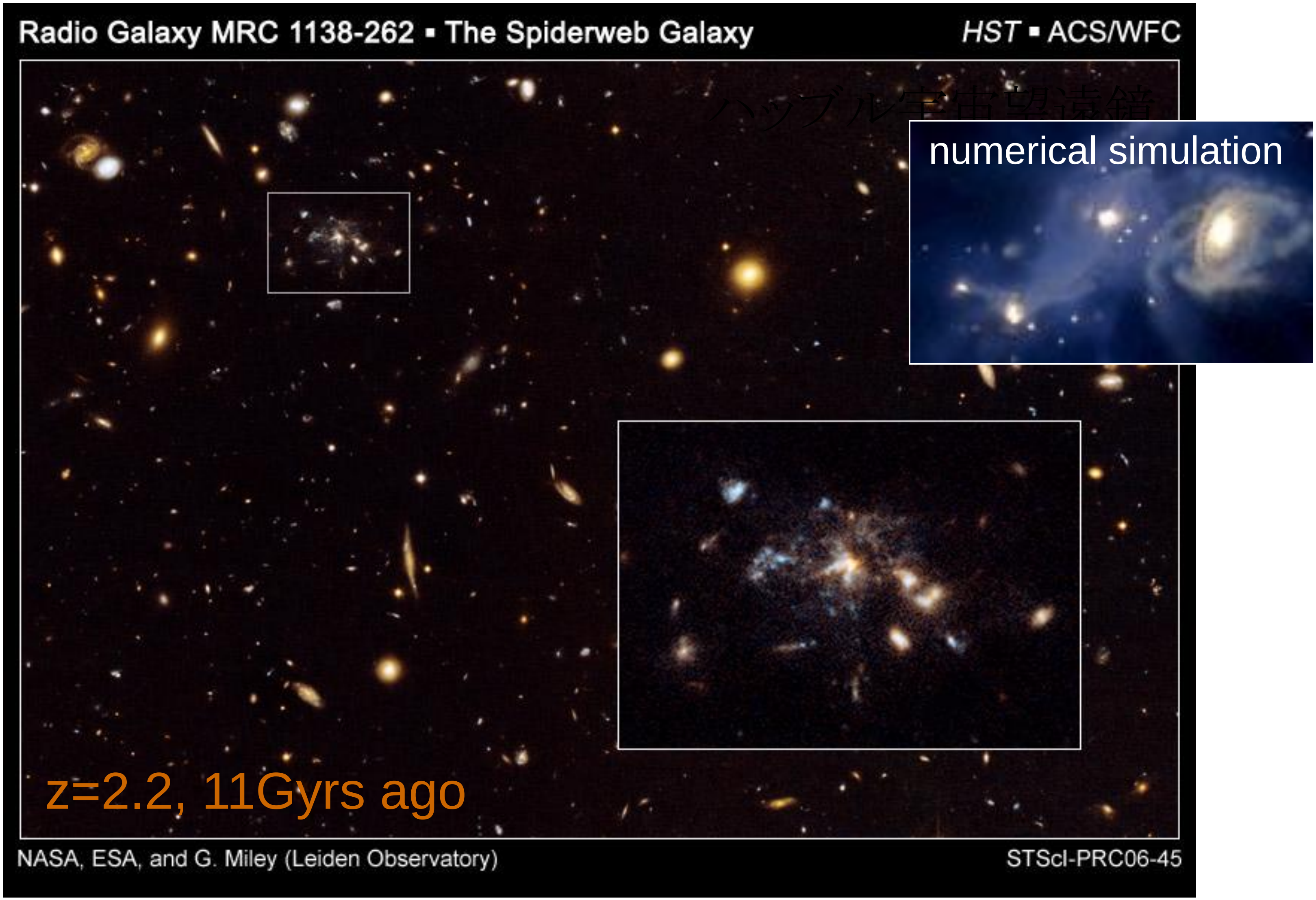
USS0943 (z=2.93)



The bright end of the red sequence seems to be emerging between z=3 and 2.
(2 < Tuniv [Gyr] < 3)

How do we build-up massive galaxies since z~3 by z~2? (~1Gyr).
star formation (starbursts) or mass assembly (mergers) ?

A spider-web galaxy at z=2.2 (witnessing a hierarchical assembly?)

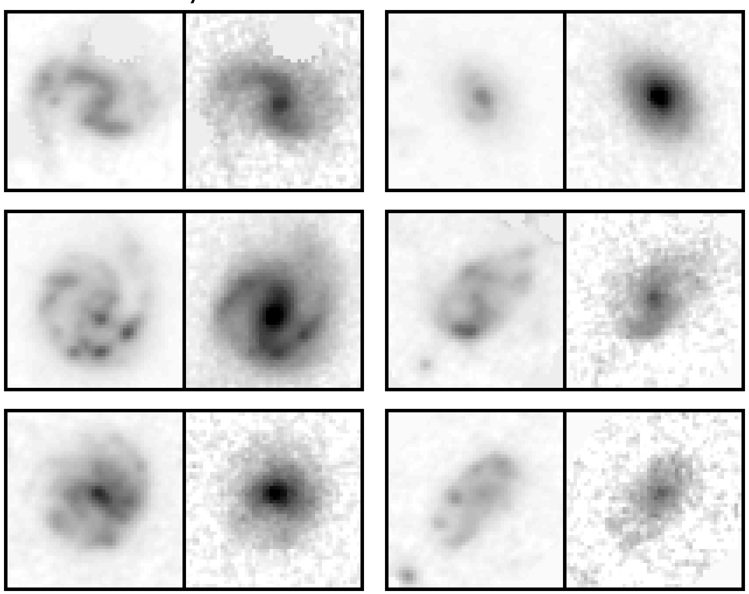


Miley et al. (2006)   Hubble Space Telescope

Emergence of the Hubble sequence between z=1 and 2?

z~1 (8 Gyrs ago)

λrest=3000 Å , 6500 Å

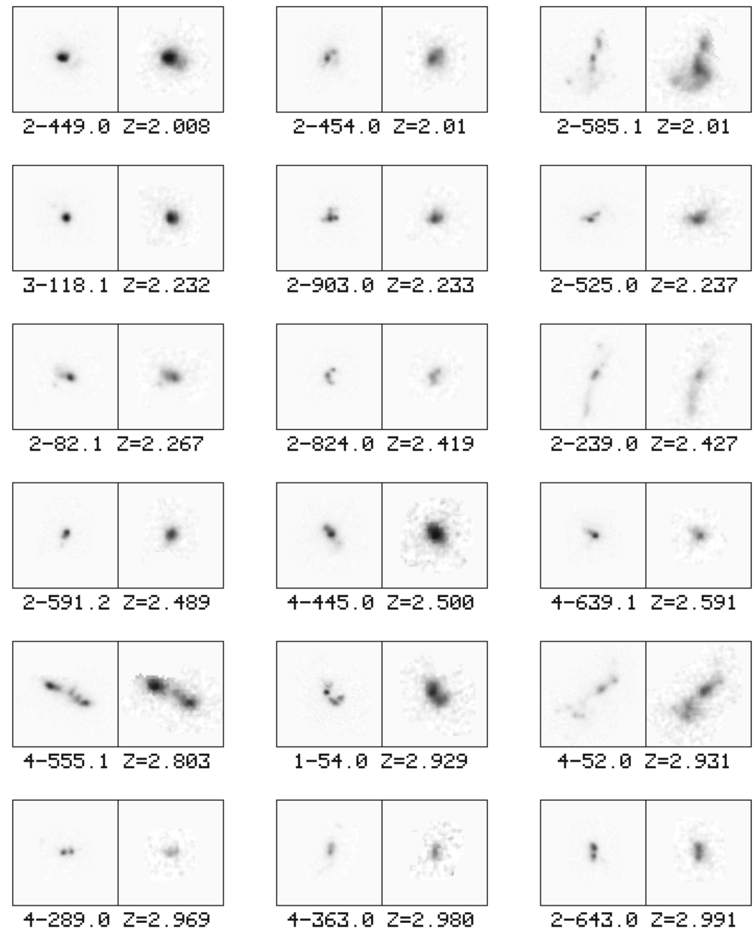


4 x4 arcsec^2 squares

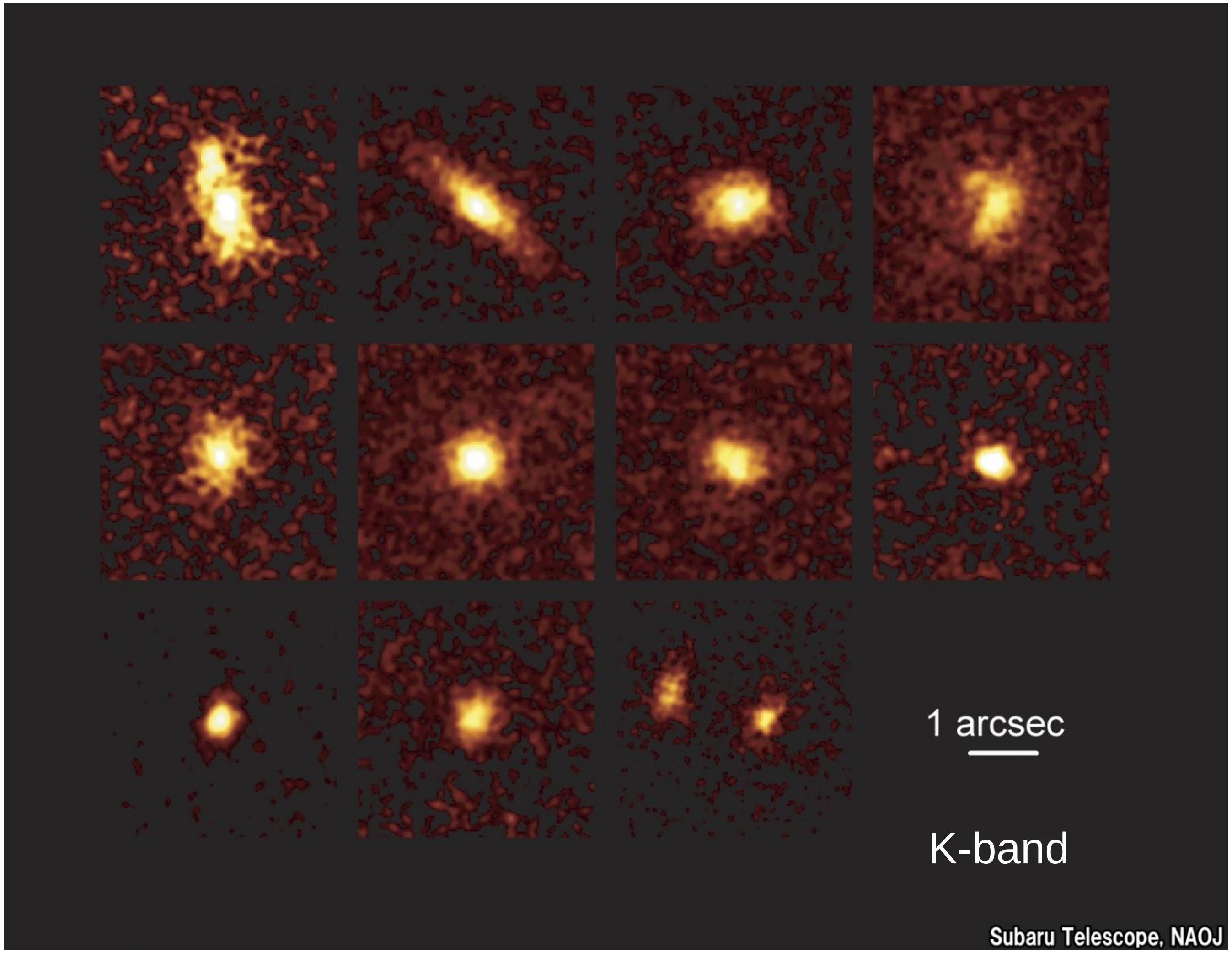
Dickinson (2000), HDF-N
Hubble Space Telescope

z~2-3 (10-11 Gyrs ago)

λrest=1700 Å , 4300 Å LBGs



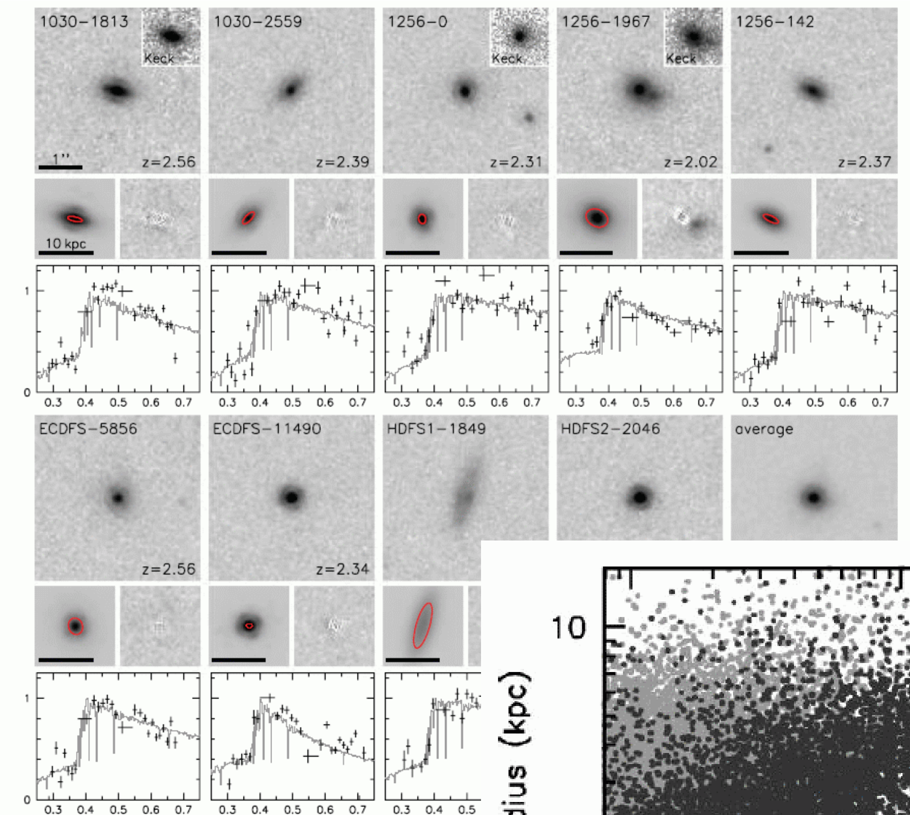
Subaru+AO views of galaxies at z~3 (11Gyrs ago)



A much higher fraction of disk-type galaxies is seen, indicating the morphological transition from ellipticals to disk galaxies since z~3?

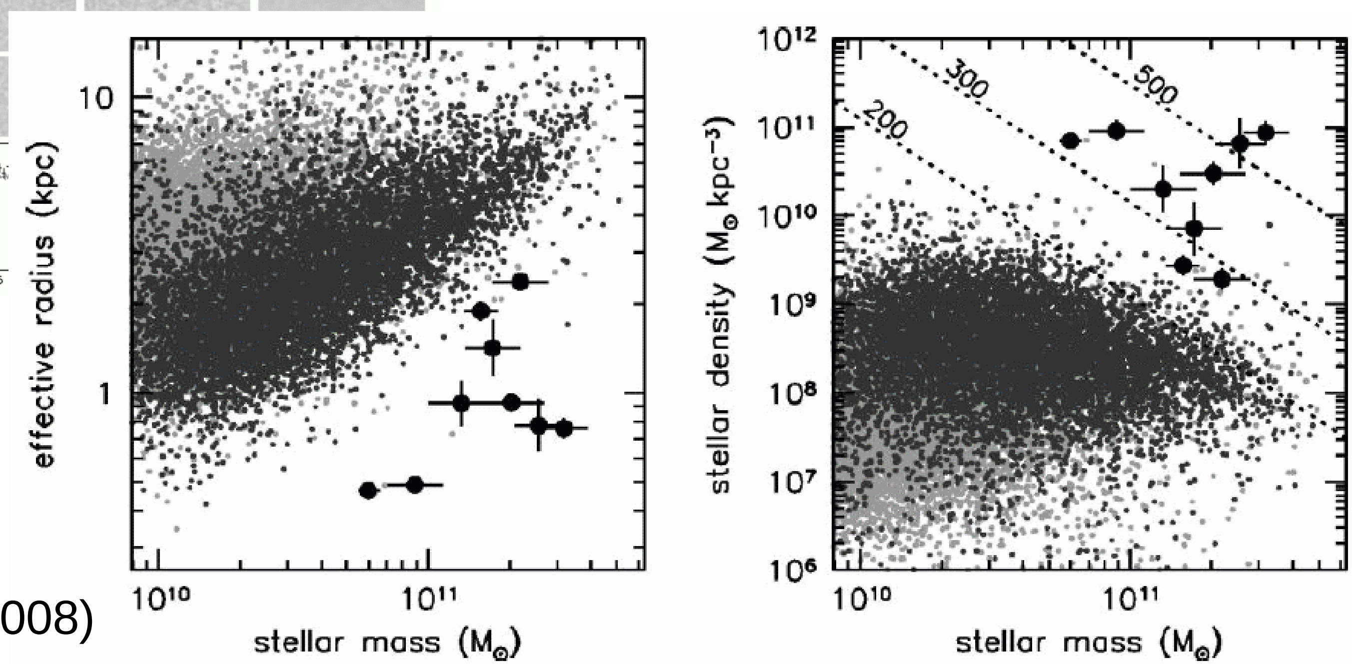
Akiyama et al. (2007)

Massive, compact, sheroidal galaxies at z>2



Median stellar mass: $1.7 \times 10^{11} M_{\odot}$
Median effective radius: 0.9 kpc

Sizes are x5 smaller, and densities are 2 orders higher than nearby ellipticals!

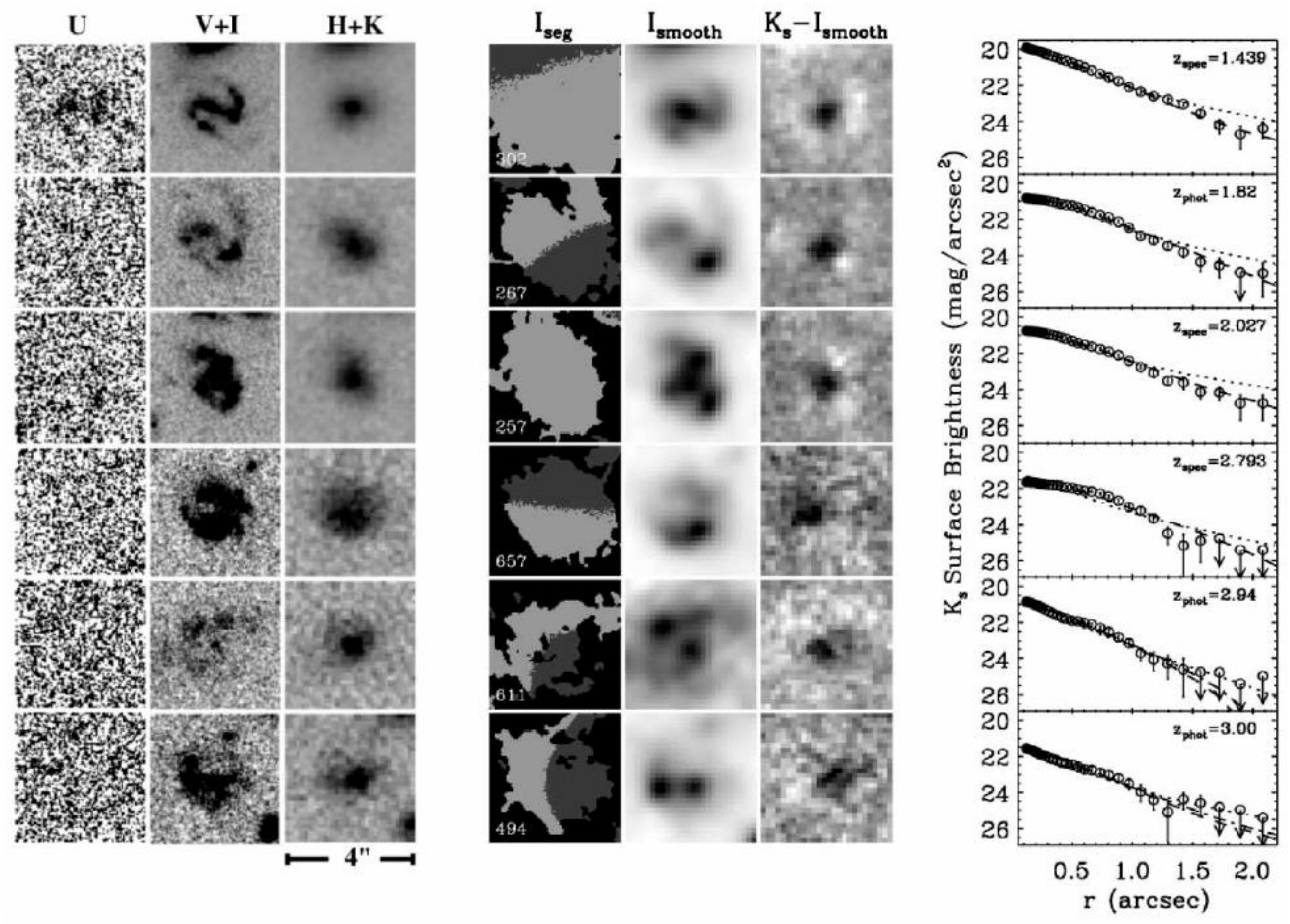


HST/NIC2
Keck/LGS-AO

van Dokkum et al. (2008)

Large disk galaxies (1.4<z<3)

WFPC2(HST) + ISAAC (VLT)   102hr JHK imaging in HDFS



Re = 5～7.5 kpc !

Labbe et al. (2003)

Remaining issues on environmental effects to be studied with AO

- Merger rates as functions of environment and time? (PFAO or GLAO)
- Co-incidence of truncation of star formation and transformation of morphology? (PFAO or GLAO)
- Nucleated starbursts (blue core) or wide spread star formation and truncation (disk) in the transition objects? (PFAO, GLAO, MOAO, MCAO)
- Mass assembly or star formation to build-up massive galaxies in proto-clusters? (MOAO,MCAO)
- Size evolution in elliptical galaxies, and its environmental dependence? (MOAO, MCAO)

“Resolved”, “sharp” views of galaxy formation and evolution

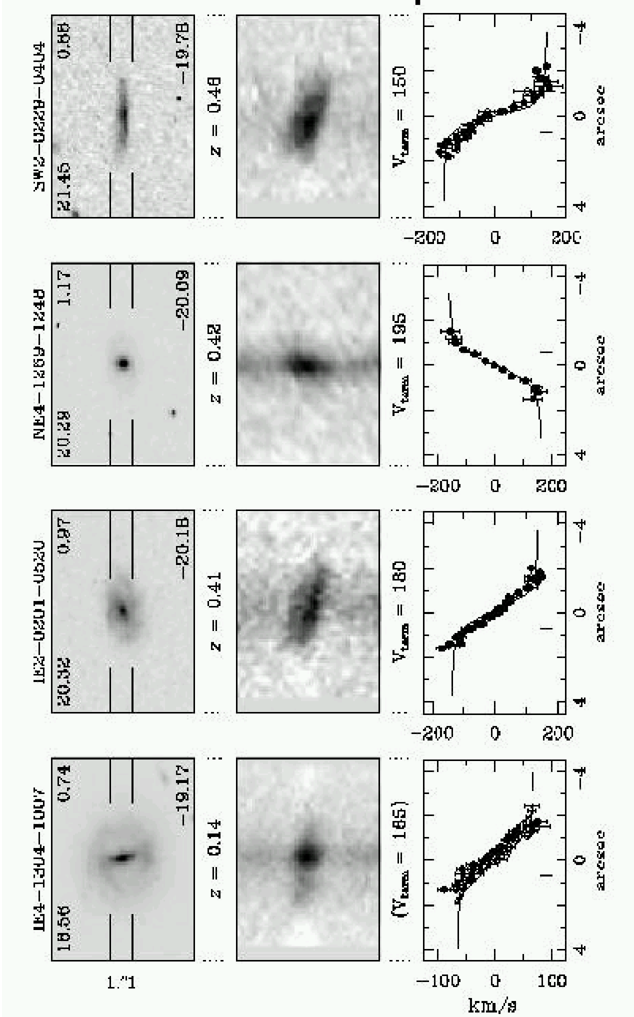
1. Origin of the cosmological division of habitats
   merger/interaction, morphological mix, starbursts (AGN) *versus* environment and time

2. Origin of the Hubble sequence of galaxies
   shapes, size, and kinematics of distant galaxies

3. Internal structures of forming galaxies
   Inflow/outflow (feedback), rotation/random motions, and stellar population gradient

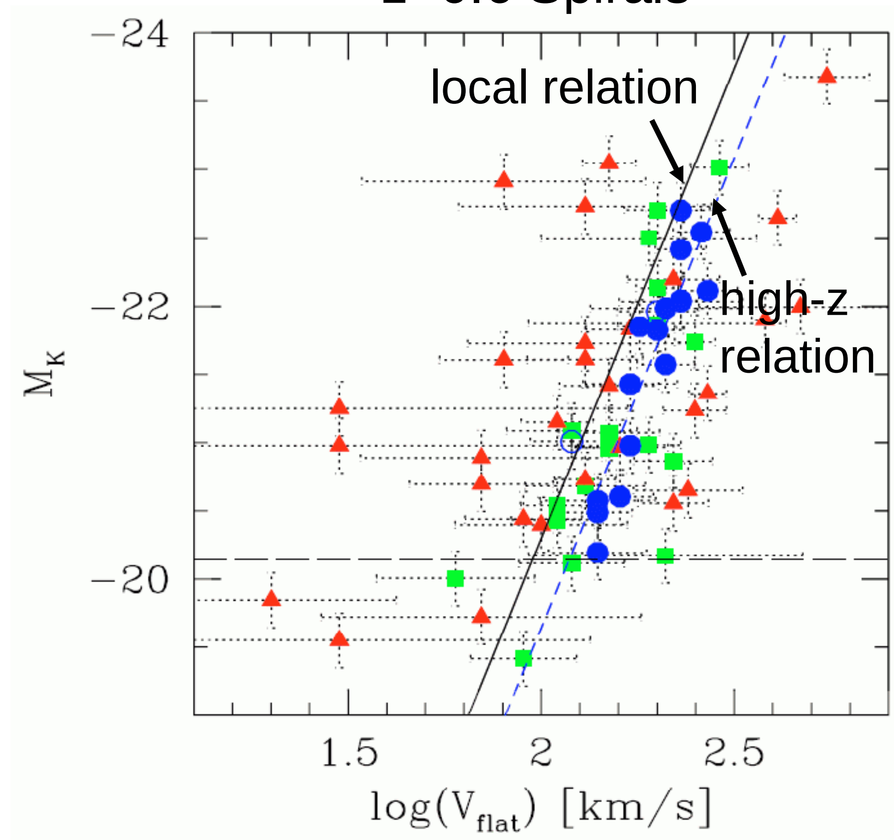
Evolution of the Tully-Fisher Relation

0.15<z<0.75 Spirals



Keck telescope, Vogt et al. (1997)

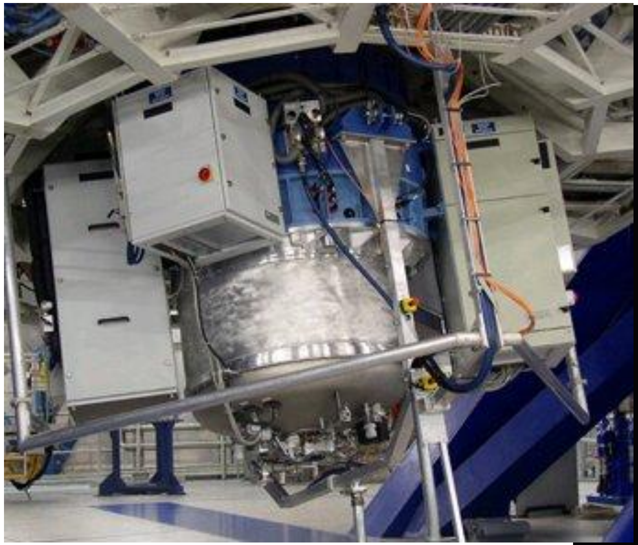
z~0.6 Spirals



The offset can be explained by mass growth by a factor of 2.

Puech et al. (2008)

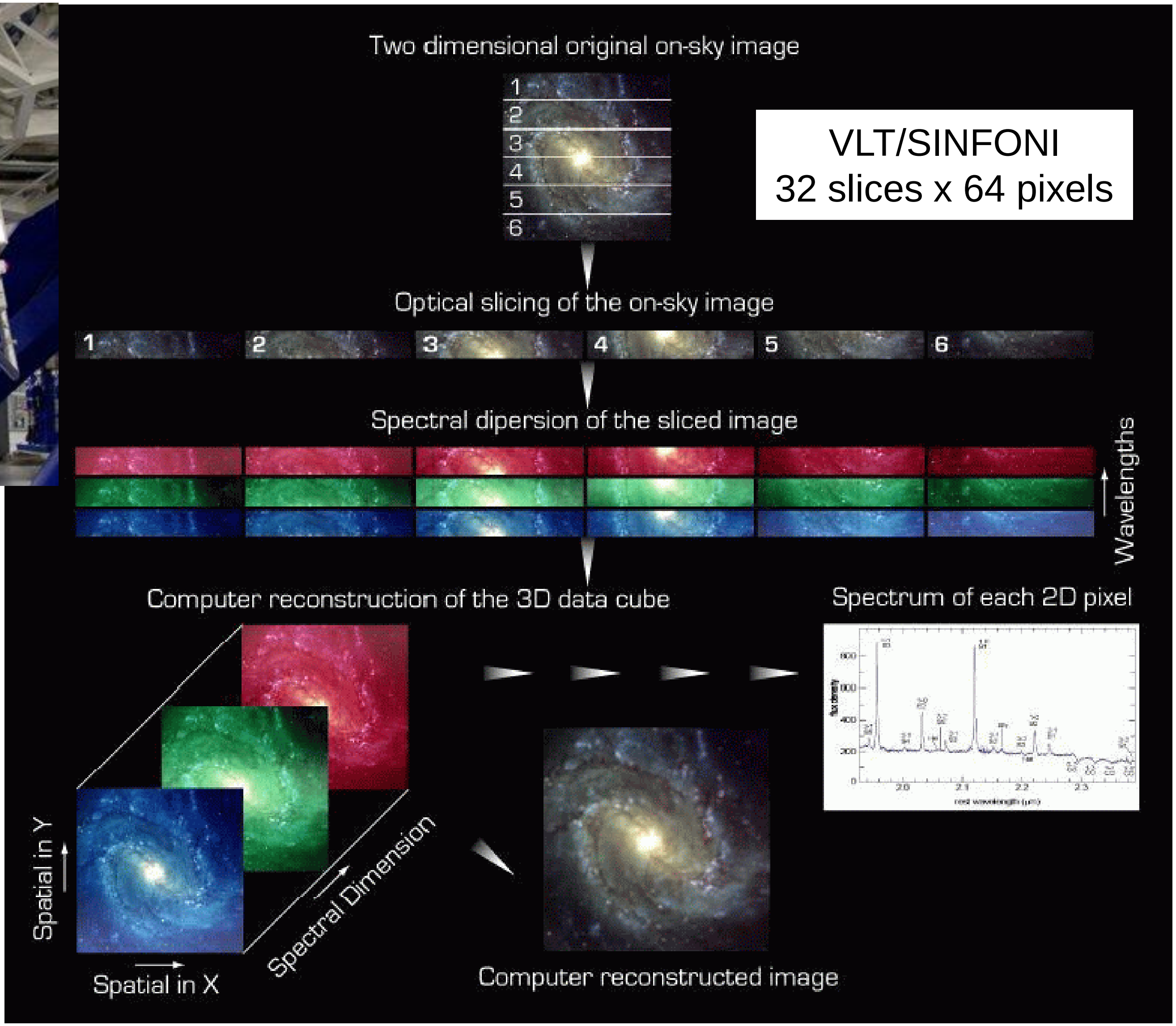
3-D spectroscopy (Integral Field Unit)



VLT(UT4) / SINFONI

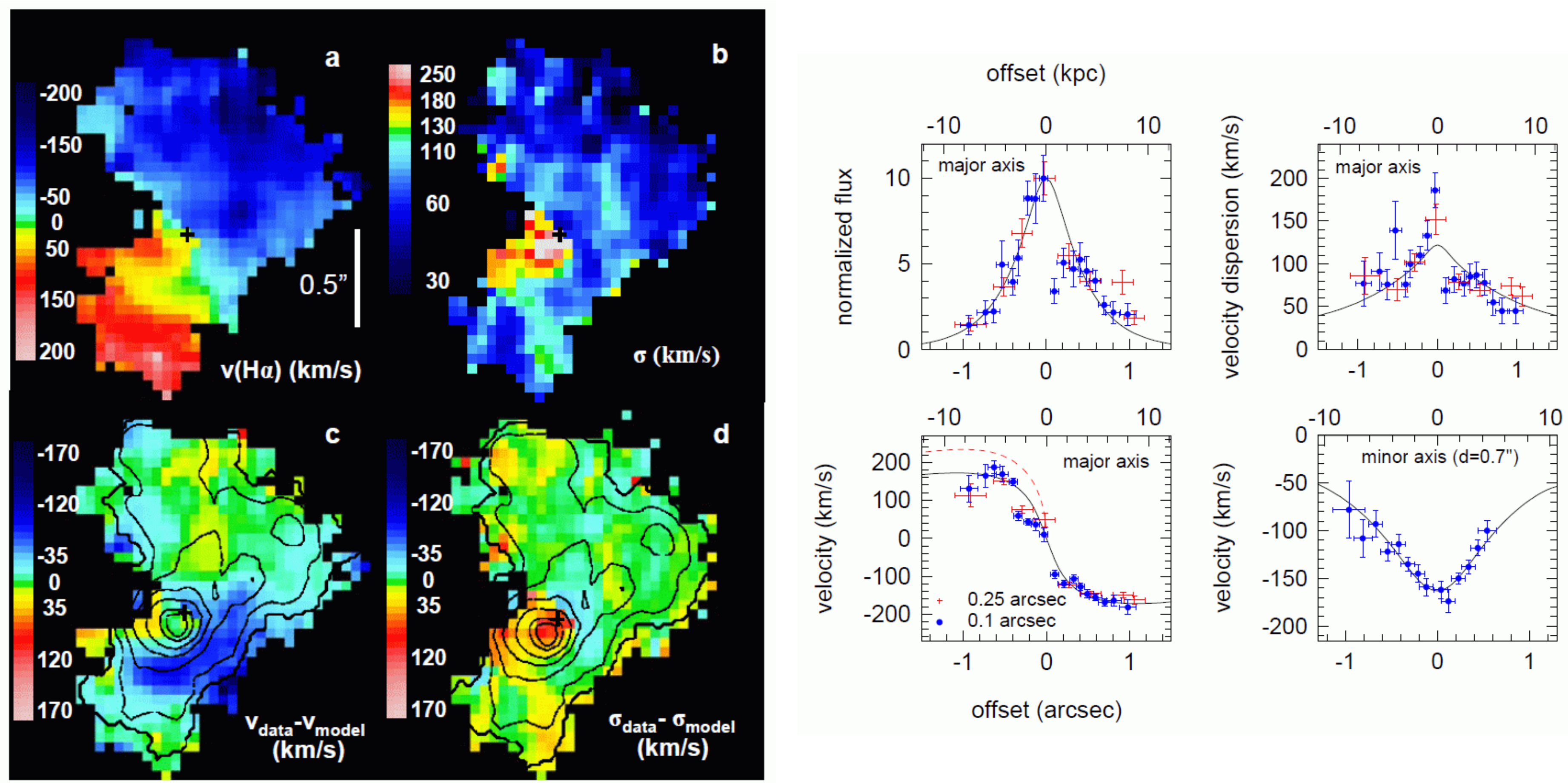
Keck/OSIRIS
Gemini/NIFS

Subaru is lacking this type of instruments…



Rotation of distant star forming galaxies

VLT/SINFONI(IFU) + AO → 0.15” resolution (~1.2kpc@z=2.38)

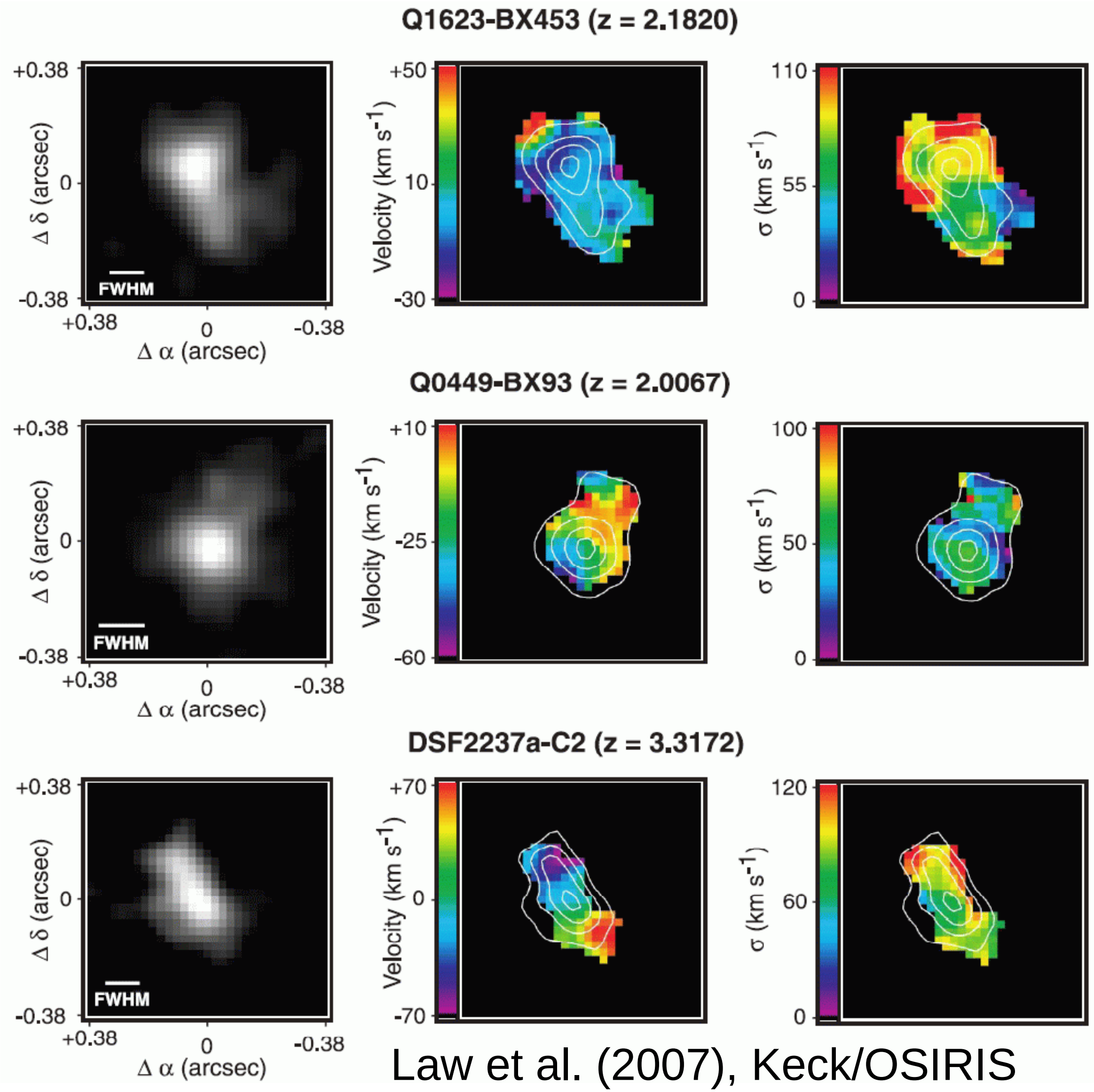


z=2.38, Ks=19.2, M_{dyn}=1.13 × $10^{11}M_{\odot}$ (Vc=230km/s),
M_{stars}=7.7 × $10^{11}M_{\odot}$, Re=4.5kpc , M_{gas}(Hα)=4.3 × $10^{10}M_{\odot}$

Genzel et al. (2006, Nature) Foerster-Schreiber et al. (2009)

High-z galaxies tend to be random motion dominated

Keck/OSIRIS(IFU) + AO → 0.11～0.15” resolution (~1kpc@z=2～3)



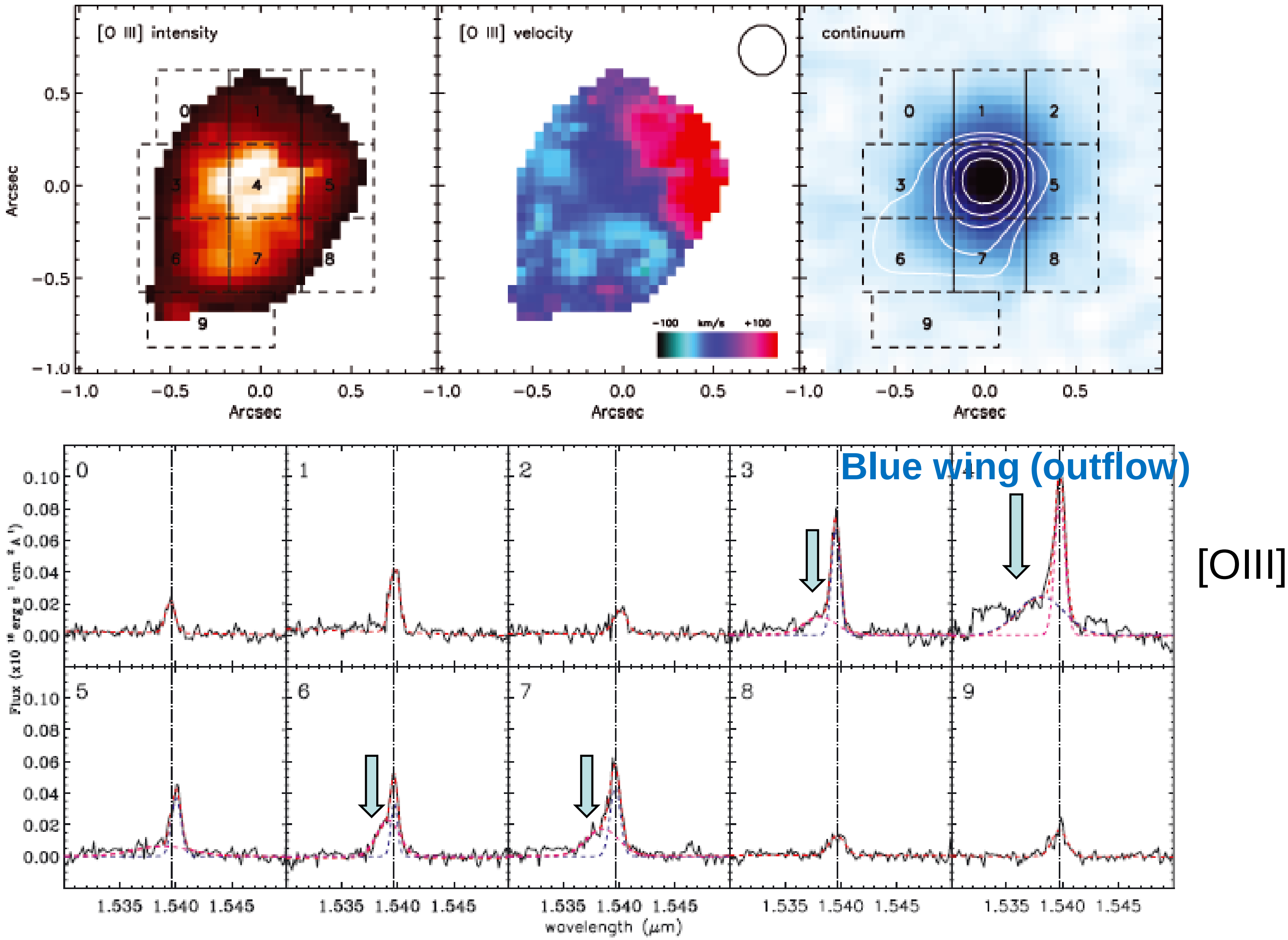
random motion dominated

random motion dominated

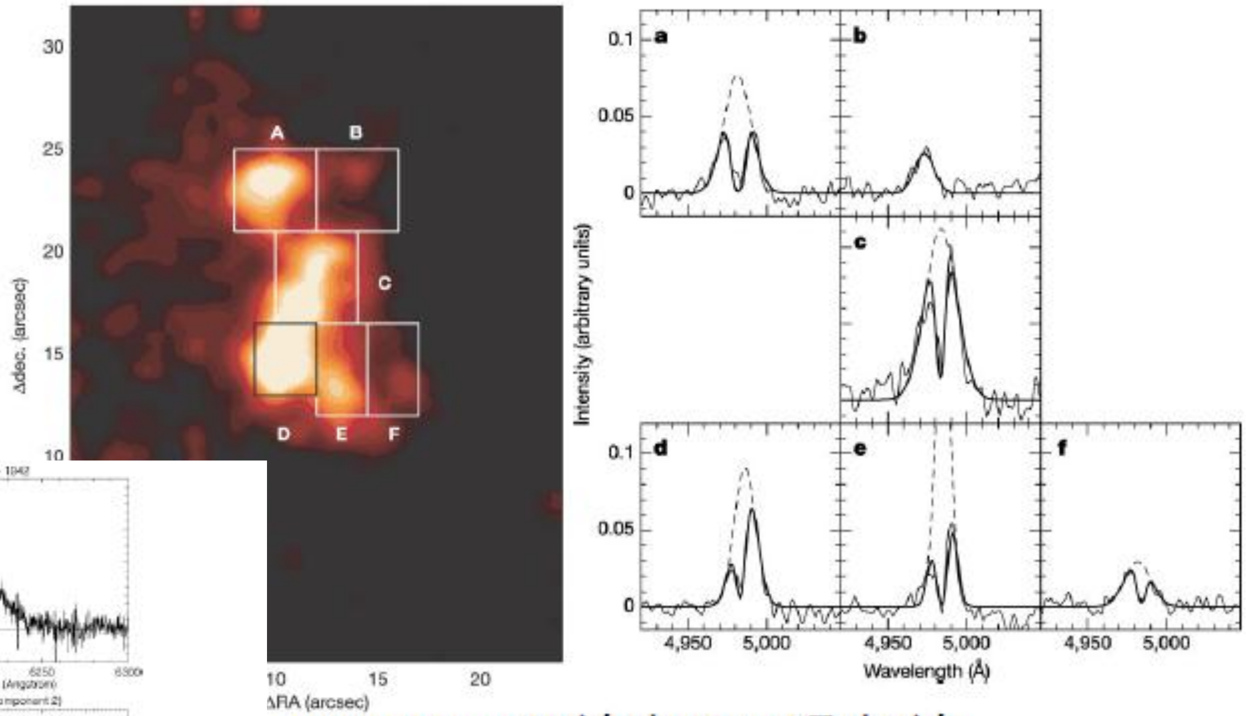
rotation + random

Law et al. (2007), Keck/OSIRIS

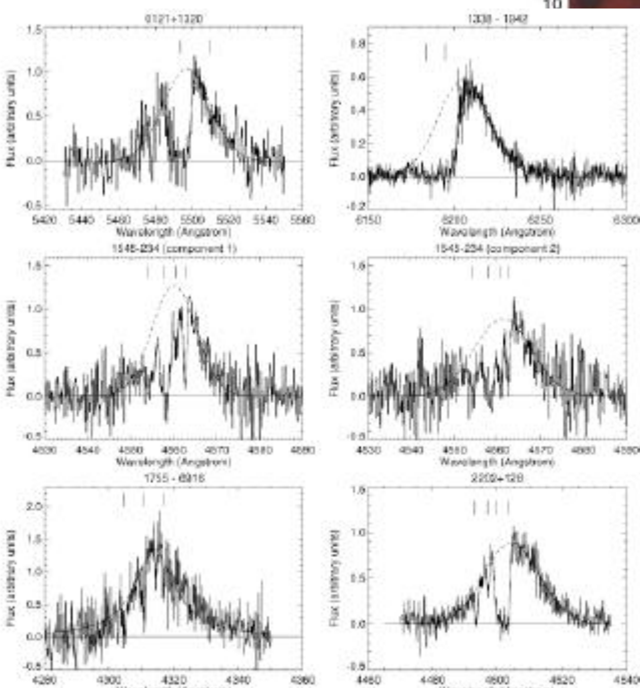
Kinematical structure of ionized gas in SMG (with AGN) at z~2.1



Gemini + NIFS Alexander et al. (2010)



LABのLya輝線中のHI吸収線
（Wilman+05, R~1000）



電波銀河のLya輝線中のHI吸収線
（Wilman+04, R>10,000）

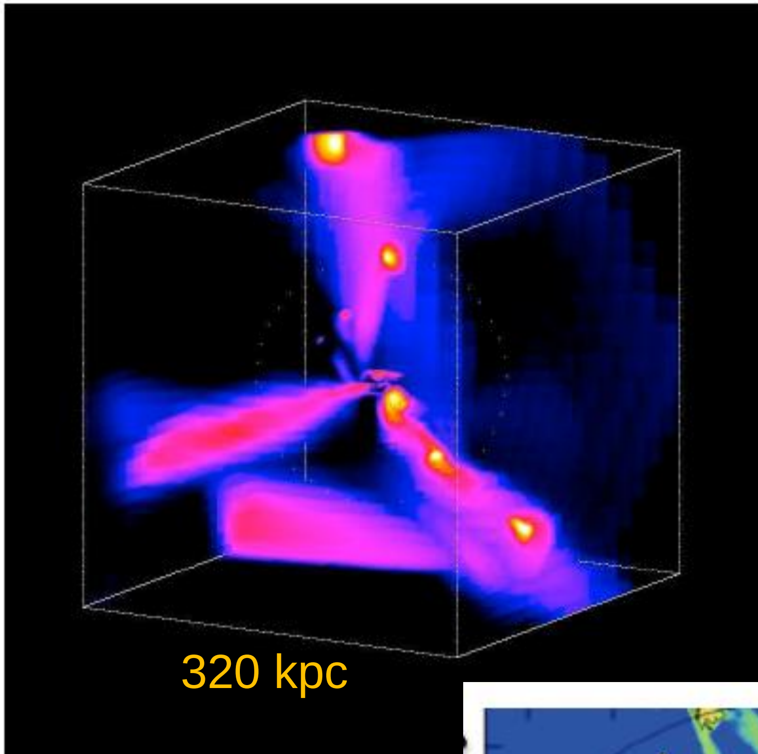
Outflow gasが中性なら、Lyα輝線中の
青い側に吸収として見える。

“Cold Streams” along filaments (Inflow)

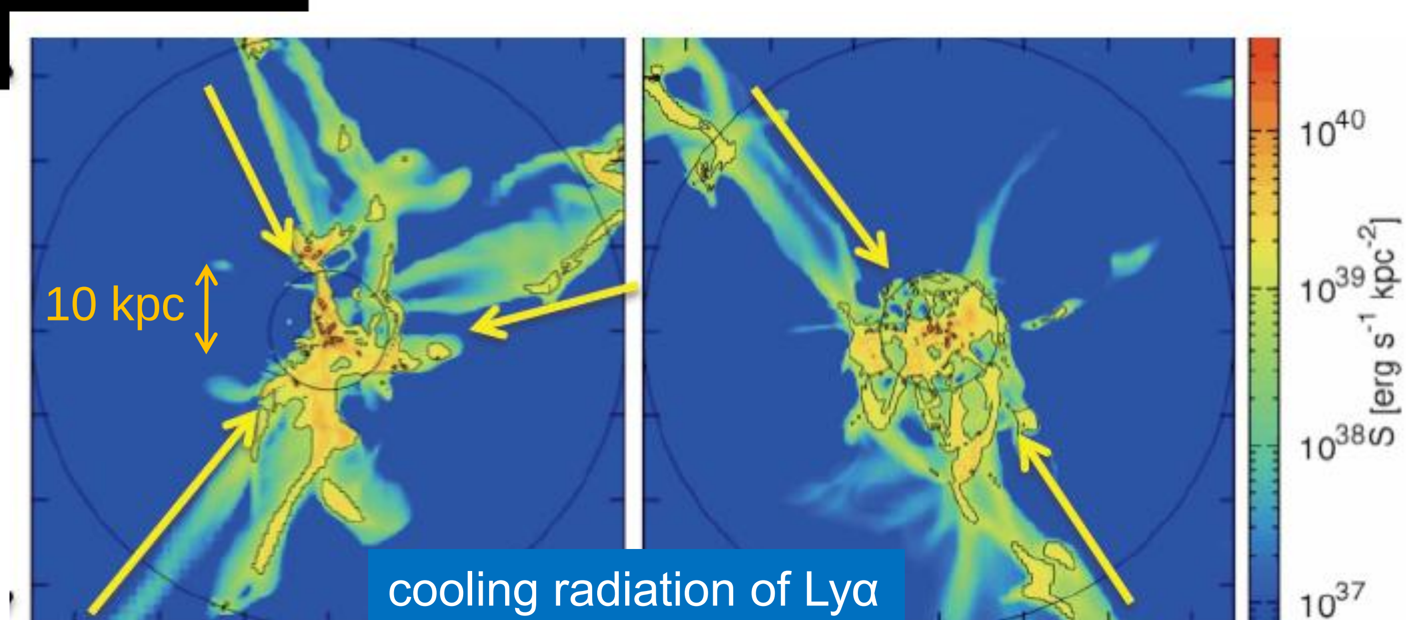
efficient gas supply to form a massive galaxy on a short time scale at high-z

Should be observable as “un-isotropic” inflow of gas either by cooling radiation or by redshifted abs. line?

When does the gas motion turn to “outflow” due to feedback (SNe and AGN)?



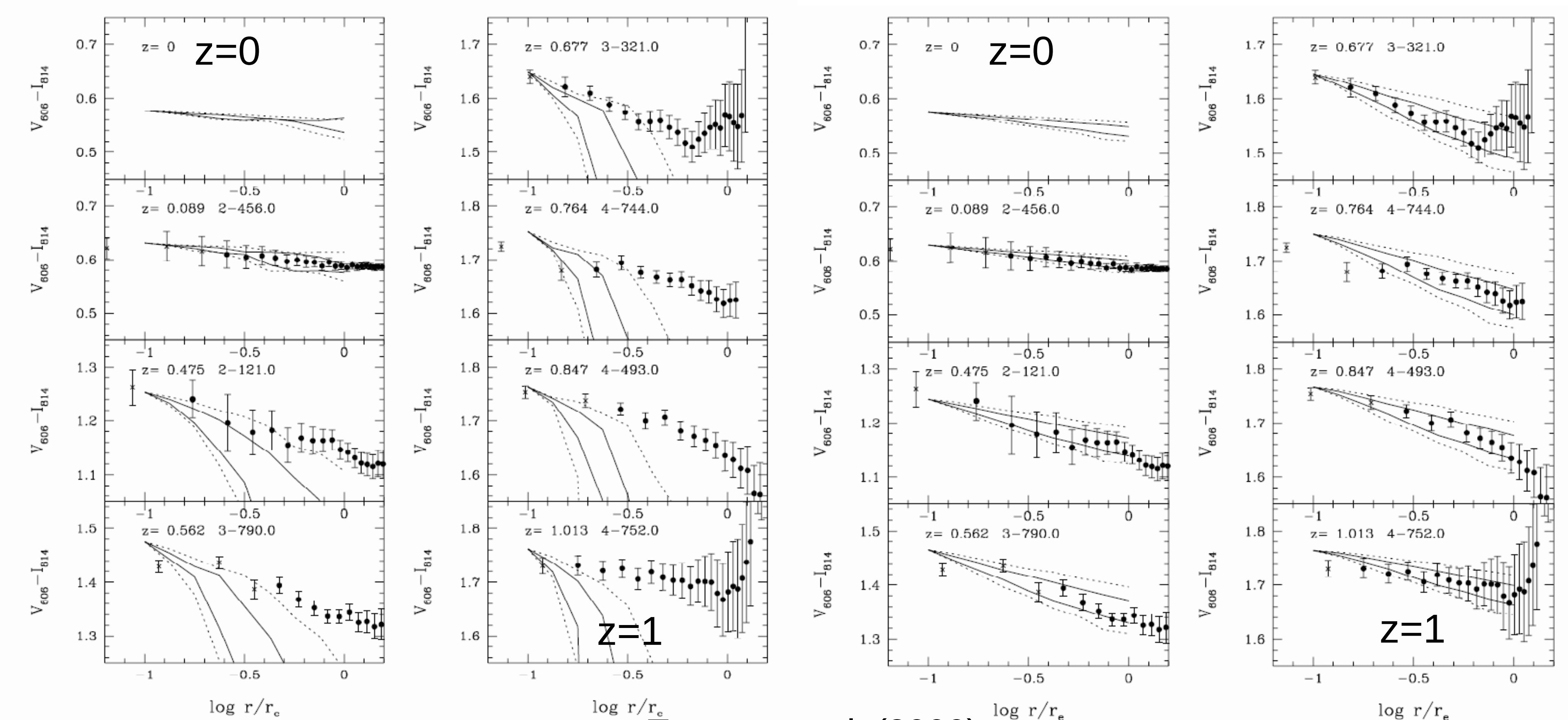
Dekel et al. (2009, Nature)



Goerdt et al. (2010)

Colour gradient in elliptical galaxies

Age seq. model (outside is younger)   [M/H] seq. model (outside is metal poorer)



Tamura, et al. (2000)

Gaseous metallicity gradient (R23, N2) can be also investigated for spiral galaxies.

Propagation of star formation within galaxies: “inside-out” or “outside-in”?

Summary-1

MCAO/MOAO (diff.lim.) + IFU

FoV=2-3 arcmin, 0.06”@2μm ⇔ ~0.4-0.5kpc @z>1

→ Detailed inspection of individual galaxies

- Internal gas dynamics
  - rotation/random motions (kinematical Hubble seq.)
  - cold streams (inflow)
  - SNe/AGN feedback (outflow)
- Stellar population gradient
  - propagation of SF (inside-out or outside-in?）

Summary-2

GLAO/PFAO (wide-field) + imaging

FoV=10-30 arcmin,   0.3”@opt-nir ⇔ ~2.0-2.5kpc @z>1

→ Statistical sample of galaxies in general
→ Environmental effects in/around clusters

Beat the Space Telescope (JWST) by Areal Coverage!

- Galaxy morphology (radial profile/light concentration)
- Merger rate as functions of environment and time
- Localized star formation (blue core or disk)

Some thoughts…

1. MOAO/MCAOなどの準狭視野型はTMTの時代には厳しい。
それまでの10年（開発を含めて）でどれほど成果を出せるか？
他の望遠鏡との競争もシビア。すばるは出遅れている。

2. GLAO/PFAOなどの広視野型はTMTの時代にも相補的。
広視野はすばるのお家芸（PFAOはユニーク）。FWHMが0.3-0.4”程度で何ができるか？宇宙望遠鏡との競争は厳しいが、広視野で勝負（サンプル＆環境）。GLAOはVLT（南天）が先行。

3. すばるは次世代AOはとりあえず先送りにして、他のユニークな装置を目指す？しかし日本のAO技術が廃れてしまう？何もかもできないのも事実。