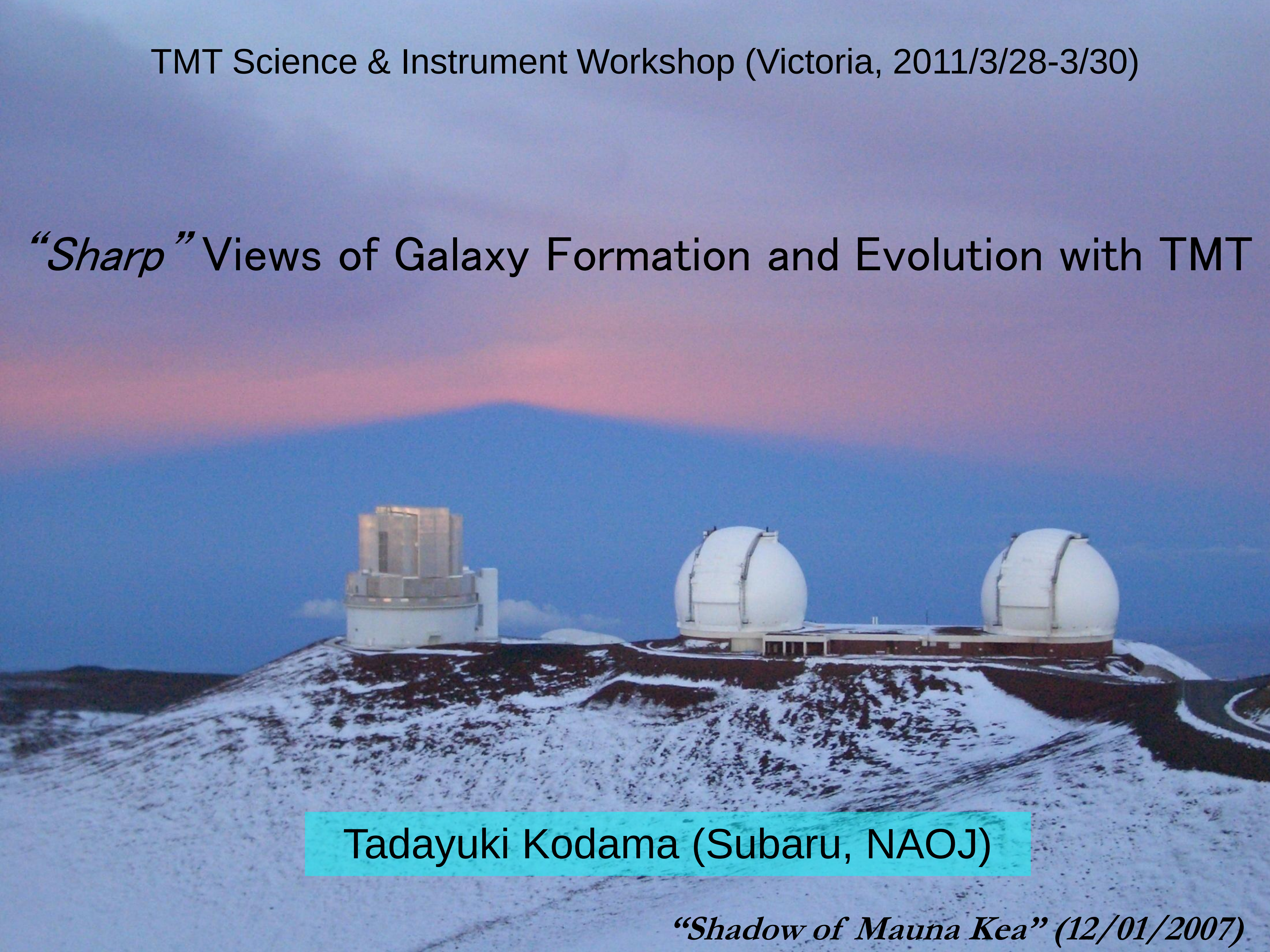
TMT Science & Instrument Workshop (Victoria, 2011/3/28-3/30)

"*Sharp*" Views of Galaxy Formation and Evolution with TMT

Tadayuki Kodama (Subaru, NAOJ)



"Shadow of Mauna Kea" (12/01/2007)

Japanese Science Report for TMT has just been issued!

(392 pages! written in Japanese, but all the abstracts have English translations.)

TMT science working group in Japan
consists of 51 members,
and the report is written by 73 people.

ー**Chiefs and Speakers in this WS**ー

+**Cosmology and Early Universe:**
N. Yoshida (IPMU, Tokyo)
→ **M. Ouchi** (ICRR, Tokyo)

+**Galaxy**: K. Motohara (IoA, Tokyo)
→ **T. Kodama** (Subaru)

+**AGN**:
T. Nagao (Ehime) → **M. Akiyama** (Tohoku)

+**Stars/Local group**:
W. Aoki (NAOJ) → **K. Kawabata** (Hiroshima)

+**SF/Planets/Solar systems**: **N. Narita** (NAOJ)

Key Performances of TMT (30m)

Huge light collecting power (13 × Subaru), and
High spatial resolution (0.015"@2μm with AO)

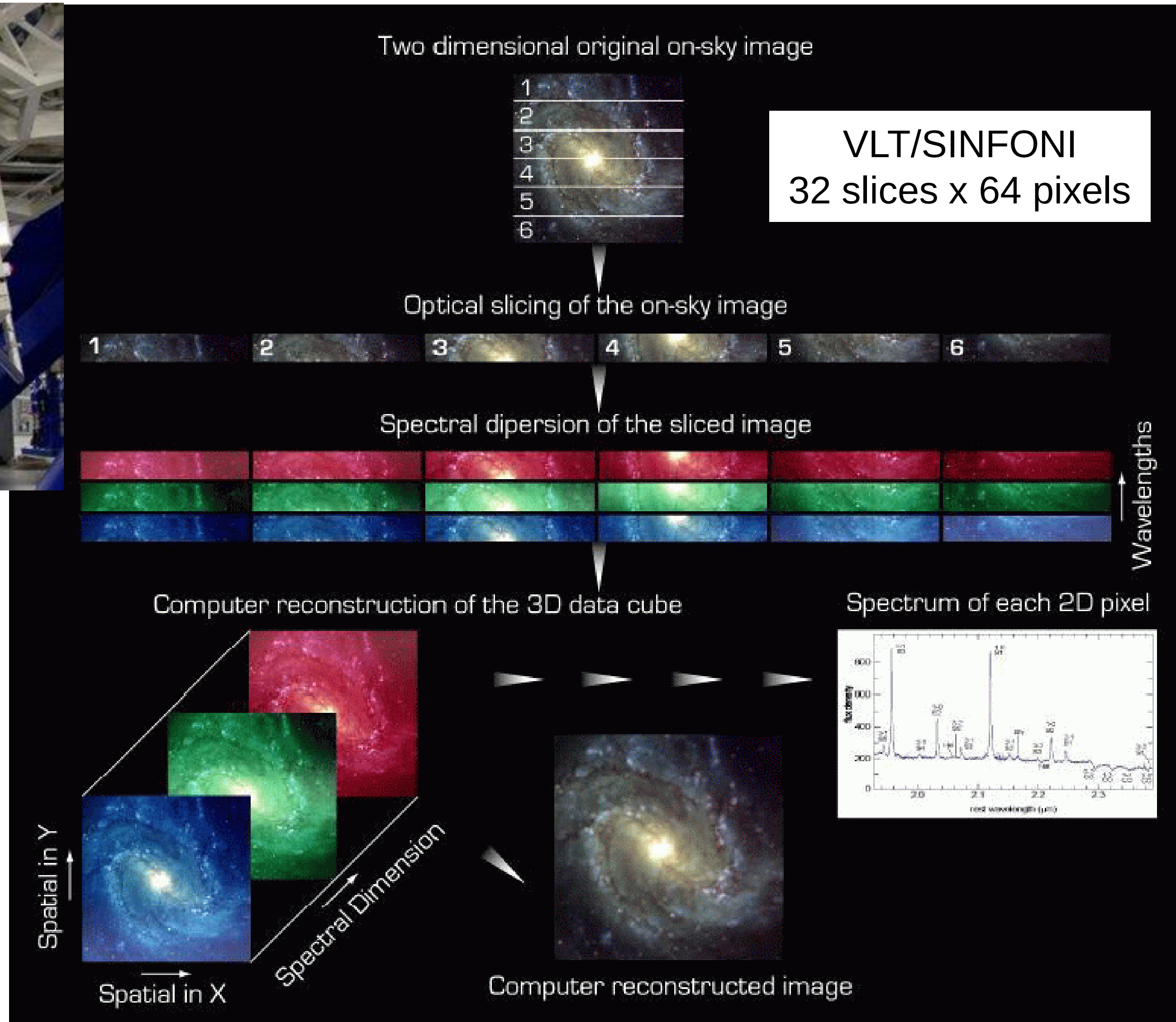
~3 mag deeper (x 15) for point sources and
~1.5 mag deeper (x 4) for extended sources
compared to Subaru (8.2m diameter)

0.015"@2μm ⇔ ~0.1kpc @z>1

TMT can resolve stars and ionized gas with this resolution
which is comparable to ALMA (molecular gas and dust)!

AO assisted IFU is the key instrument at the TMT era, which resolves the internal kinematical structures of high-z galaxies

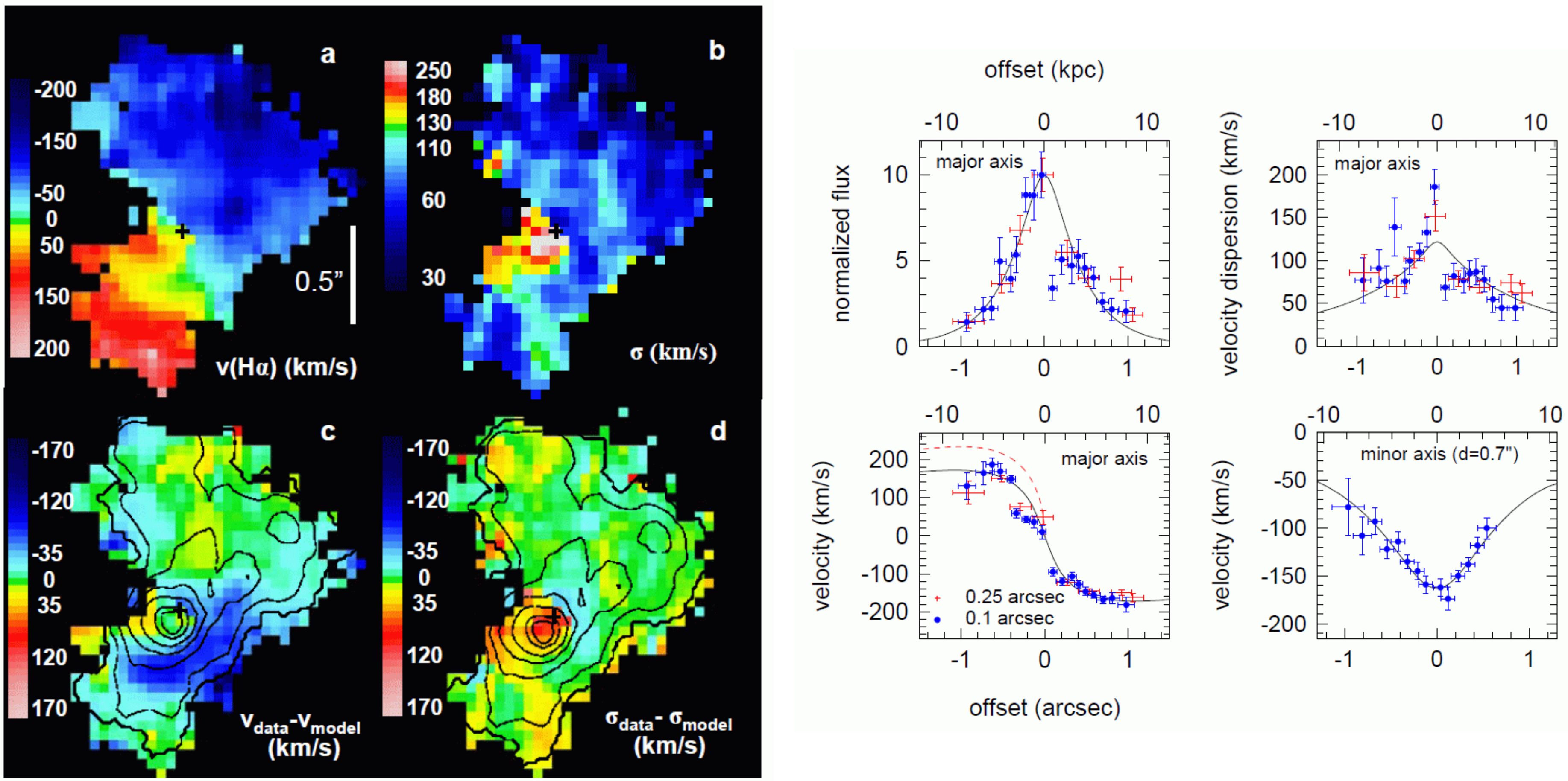
VLT(UT4) / SINFONI



TMT will have IRIS as an early-light-instrument and IRMOS (multi-IFU) is planned as a first-generation-instrument

Rotation of a star-forming galaxy at z=2.4

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

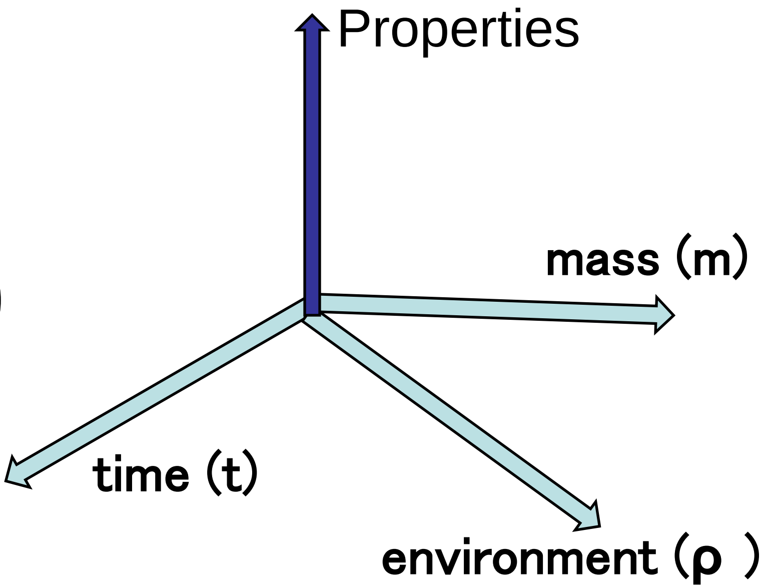


z=2.38, Ks=19.2, $M_{dyn}=1.13\times10^{11}M_\odot$ (Vc=230km/s), $M_{stars}=7.7\times10^{11}M_\odot$, Re=4.5kpc , M_{gas}(Hα)$=4.3\times10^{10}M_\odot$

V_c/σ~2-4

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

Key Scientific Goals
(Galaxy working group)



"Sharp Views of Galaxy Formation and Evolution"

- SF and MA histories as a function of environment and mass

  Relative contributions of SF and MA? How is AGN activity related?

- Emergence/establishment of galaxy morphologies/types

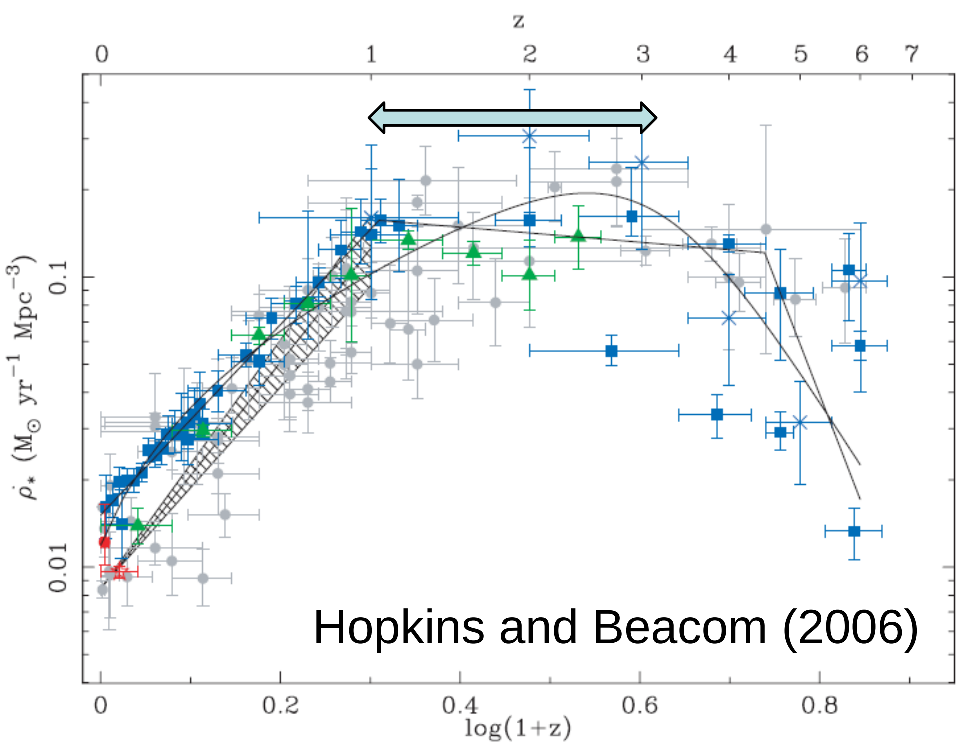
  Visual shapes, Internal kinematics of stars and gas (V/σ), Mergers

- Internal structures and kinematics of forming galaxies

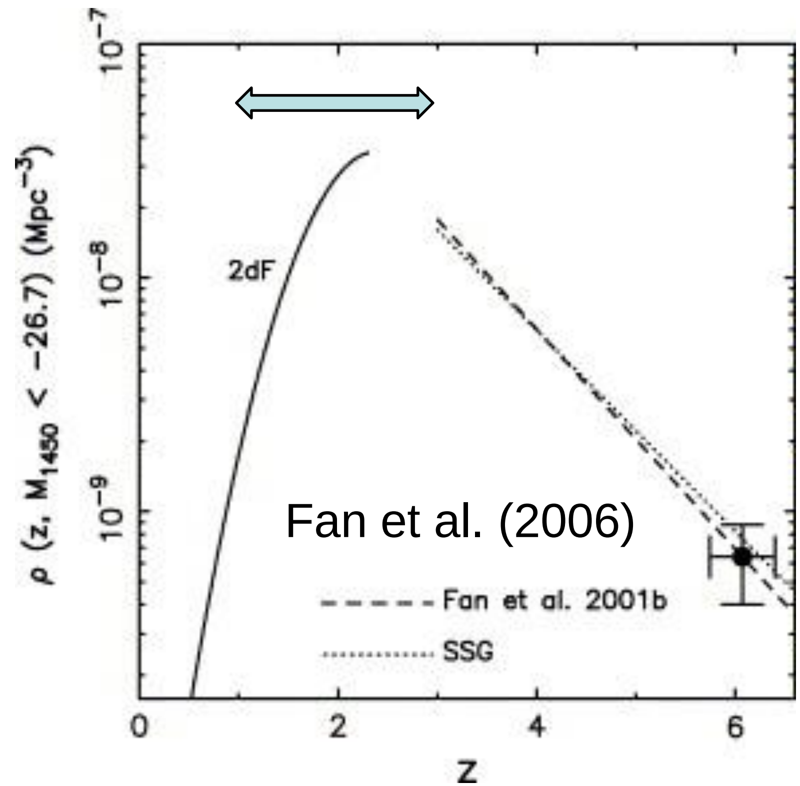
  Population/chemical structure (inside-out), Gas dynamics (inflow/outflow)

The peak epoch of the Universe: 1<z<3 $(6>T_{cos(Gyr)}>2)$

Star formation



AGN (QSO)



※ Hα ([OII]) can be observed from the ground (<2.5μm) up to z=2.8 (5.7),
Lyα can be observed from the ground (>0.35μm) from z=2.

“MAHALO-Subaru”

MApping HAlpha and Lines of Oxygen with Subaru

Narrow-band survey of line emitters (Hα, [OII]) at 0.4<z<2.5 (primarily z>1.5)

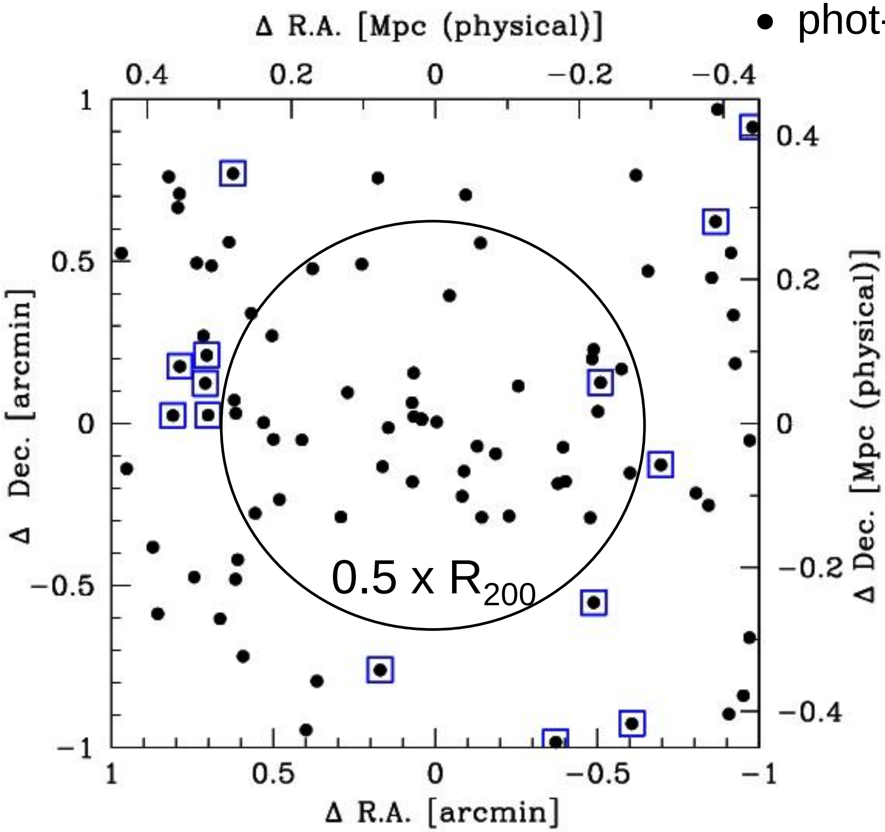
down to 2 $M_\odot$/yr at z=1.5, and 10 $M_\odot$yr at z=2.5

environ-	target	z	line	λ (μm)	camera	NB-filter	conti-nuum	ALMA visibility	status
clusters	CL0024+1652	0.395	Hα	0.916	S-Cam	NB912	z'	Yes	Kodama+ '04
	CL0939+4713	0.407	Hα	0.923	S-Cam	NB921	z'	No	Koyama+ '11
	RXJ1716+6708	0.813	Hα	1.190	MOIRCS	NB1190	z', J	No	Koyama+ '10
	XCSJ2215–1738	1.457	[OII]	0.916	S-Cam	NB912	z'	Yes	Hayashi+ '10
	4C65.22	**1.516**	Hα	1.651	MOIRCS	NB1657	H	No	not yet
	Q1126+101	**1.517**	Hα	1.652	MOIRCS	NB1657	H	Yes	not yet
	Q0835+580	**1.534**	Hα	1.664	MOIRCS	NB1657	H	No	observed
	CL0332–2742	**1.61**	[OII]	0.973	S-Cam	NB973	z, y	Yes	observed/analysed
	CIGJ0218.3–0510	**1.62**	[OII]	0.977	S-Cam	NB973	z', y	Yes	observed/analysed
	PKS1138–262	**2.156**	Hα	2.071	MOIRCS	NB2071	K_s	Yes	scheduled in S11A
	4C23.56	**2.483**	Hα	2.286	MOIRCS	NB2288	K_s, K_{cont}	Yes	Tanaka+ '11
	USS1558–003	**2.527**	Hα	2.315	MOIRCS	NB2315	K_s, K_{cont}	Yes	scheduled in S11A
Fields	GOODS-N	2.19	Hα	2.094	MOIRCS	NB2095	K_s	No	Tadaki+ '11
	(2.5 pointings)		[OII]	1.189	MOIRCS	NB1190	z', J	No	Tadaki+ '11
	SXDF	**2.19**	Hα	2.094	MOIRCS	NB2095	K	Yes	observed
	(3 pointings)		Hβ	1.551	MOIRCS	NB1550	H	Yes	not yet
			[OII]	1.189	MOIRCS	NB1190	z', J	Yes	not yet

Inside-out propagation/truncation of star formation activities in clusters

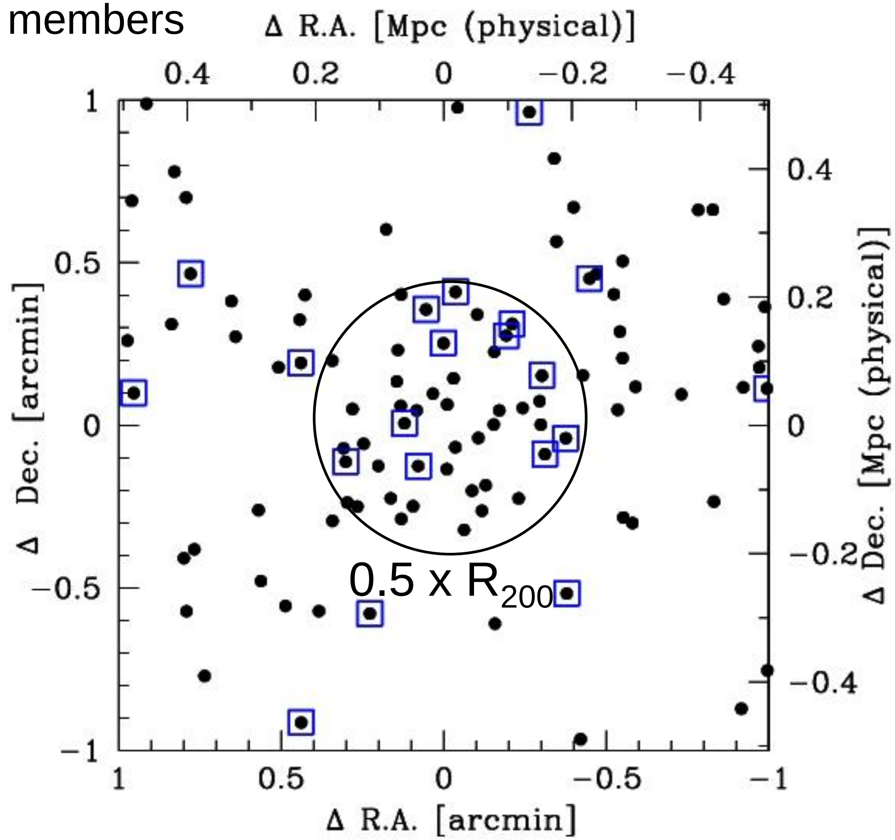
□ Hα emitters at z=0.81 (RXJ1716) □ [OII] emitters at z=1.46 (XCS2215)

• phot-z members



$Lx=2.7\times10^{44}$ erg/s

Koyama, et al. (2010)

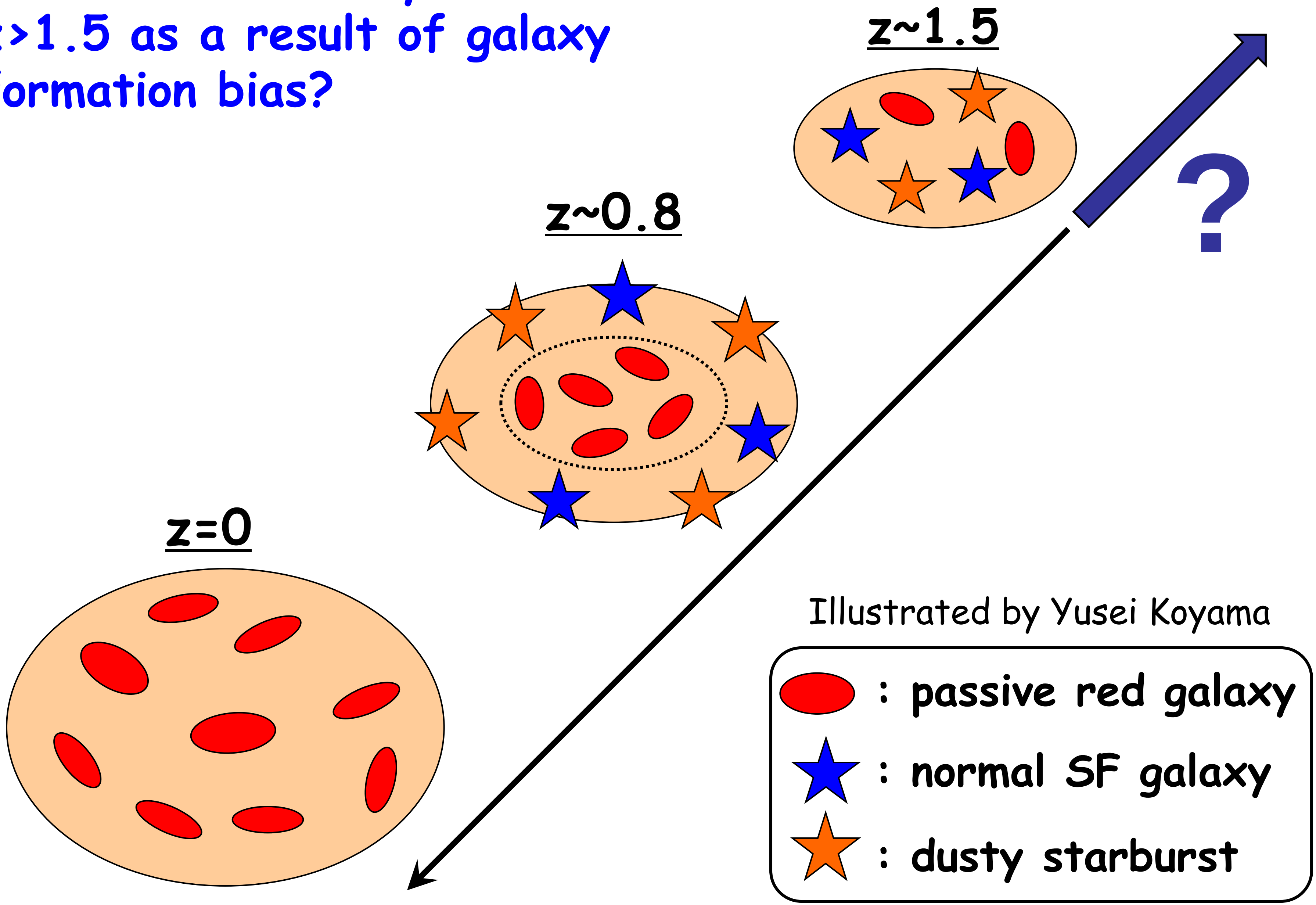


$Lx=4.4\times10^{44}$ erg/s

Hayashi, et al. (2010)

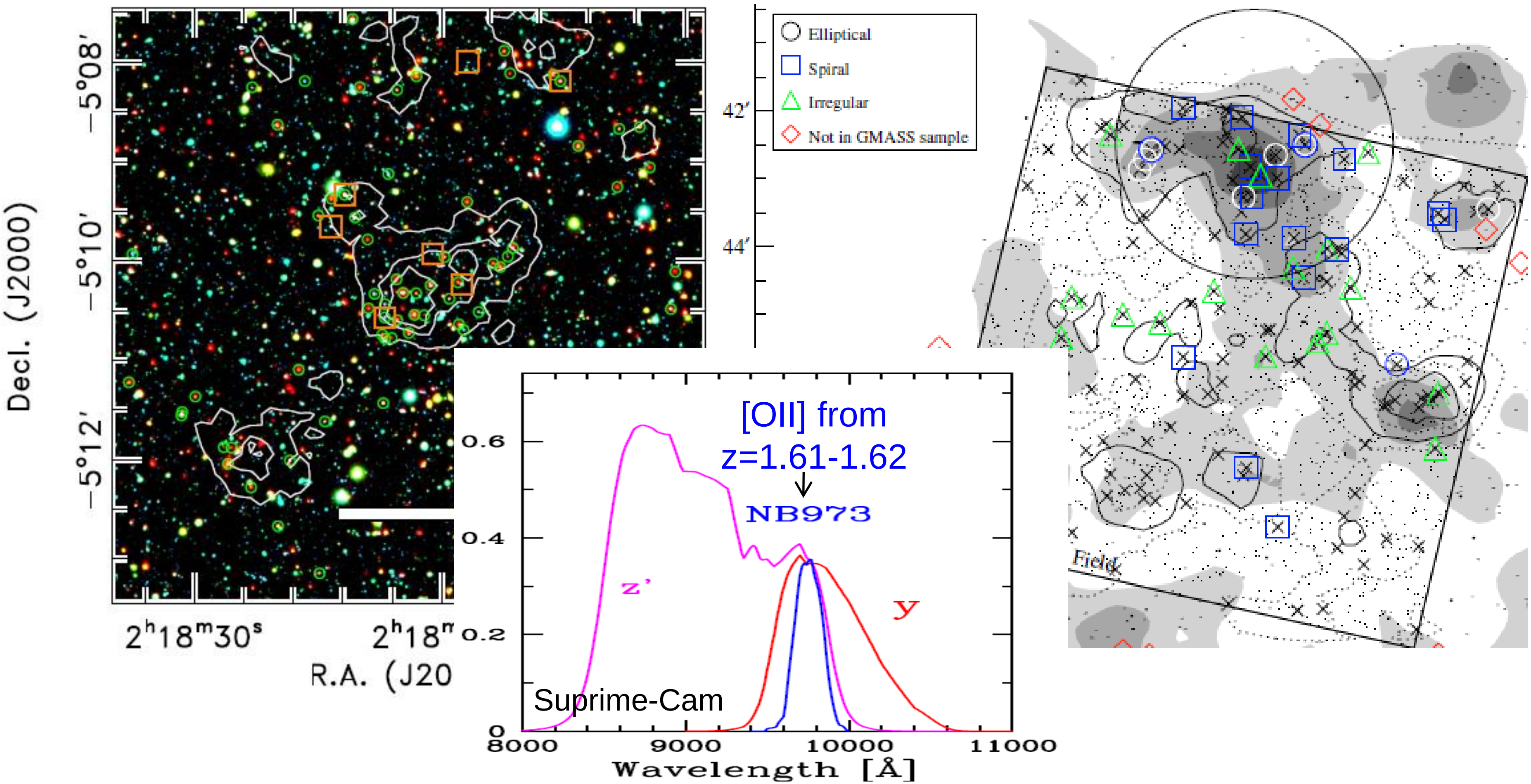
Star forming activity in the core is much higher in the higher redshift cluster!

Do we eventually see the reversal of the SFR-density relation at z>1.5 as a result of galaxy formation bias?



Two recently found, confirmed clusters at z~1.6

ClG J0218.3-0510 (z=1.62) in SXDF CL0332-2742 (z=1.61) in GOODS-S

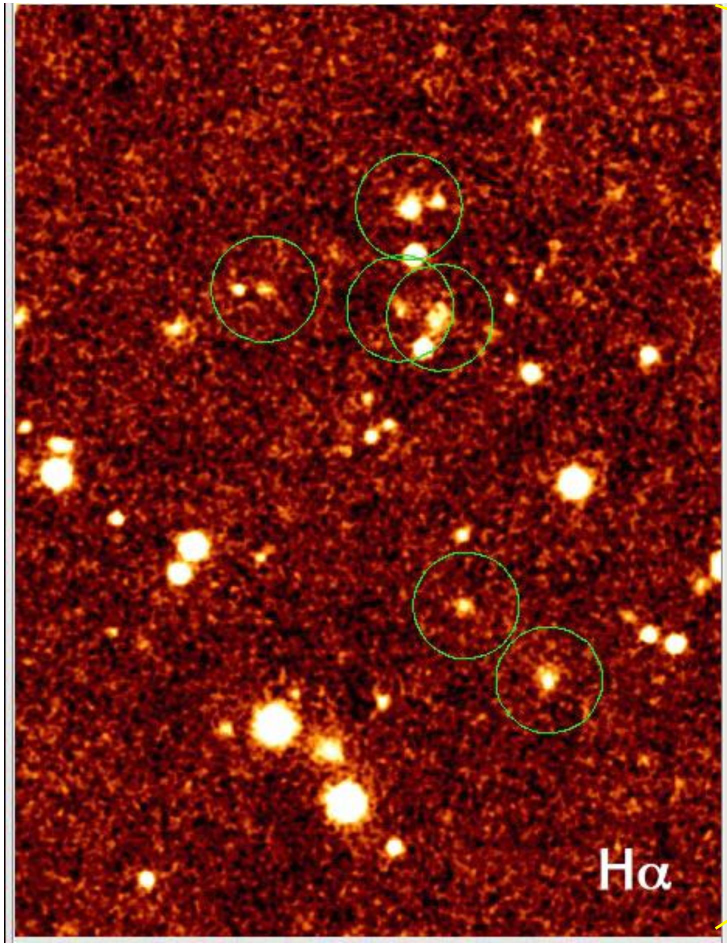


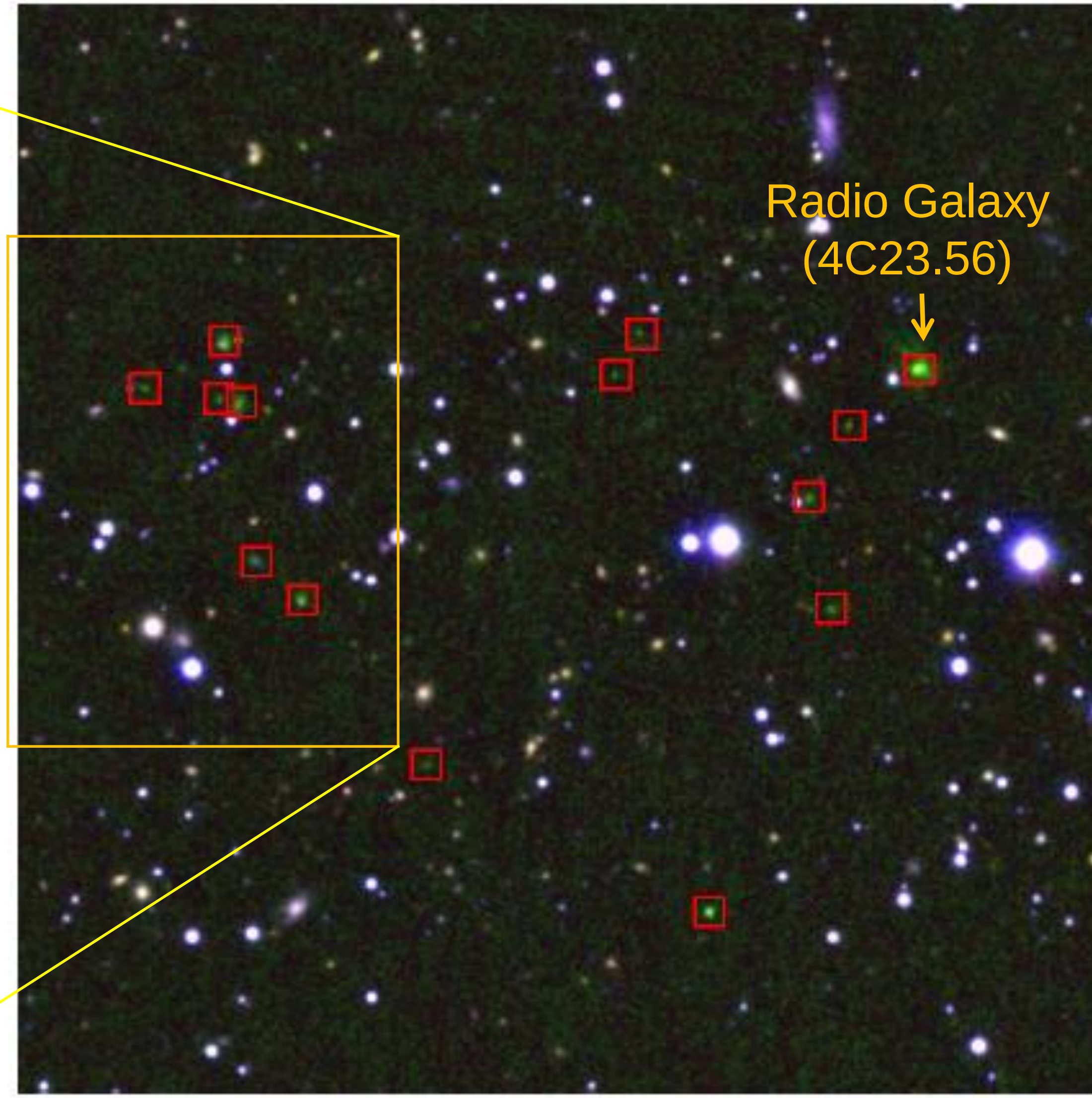
9 spec-z members, σ=540km/s
X-ray detection (4.5σ)
(Papovich et al. 2010; Tanaka et al. 2010)

42 spec-z members, σ=500km/s
Kurk et al. (2009)

Hα Emitters in a Proto-Cluster 4C23.56 at z=2.48

Subaru/MOIRCS
NB2288(Hα) / Ks





Spatially extended (Hα Blobs!)
Offset?

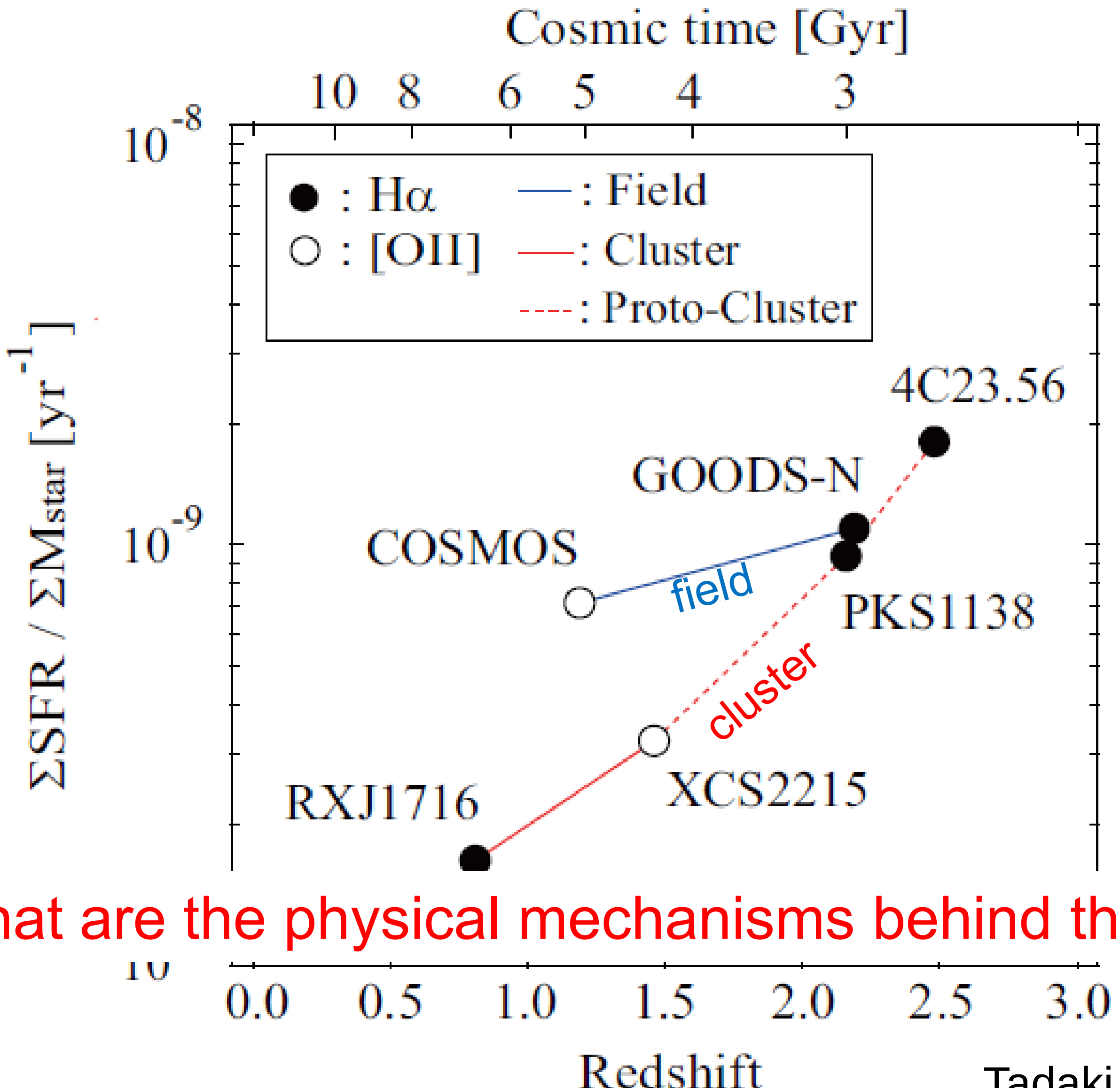
3arcmin = 1.3Mpc

SFR=100~1000 $M_\odot$/yr !

Tanaka, I., et al. (2011)

"Mahalo-plot" (in analogy to "Madau-plot")

〈SSFR〉 vs. z and environment for emitters



Emitters Only!

Highly uncertain yet !

incompleteness
cosmic variance
…

"What are the physical mechanisms behind this diagram?"

Tadaki et al. (2011), in press

IRIS (IFU: imaging spectroscopy)

FoV=2” (IFU), 0.015”@2μm ⇔ ~0.1kpc @z>1

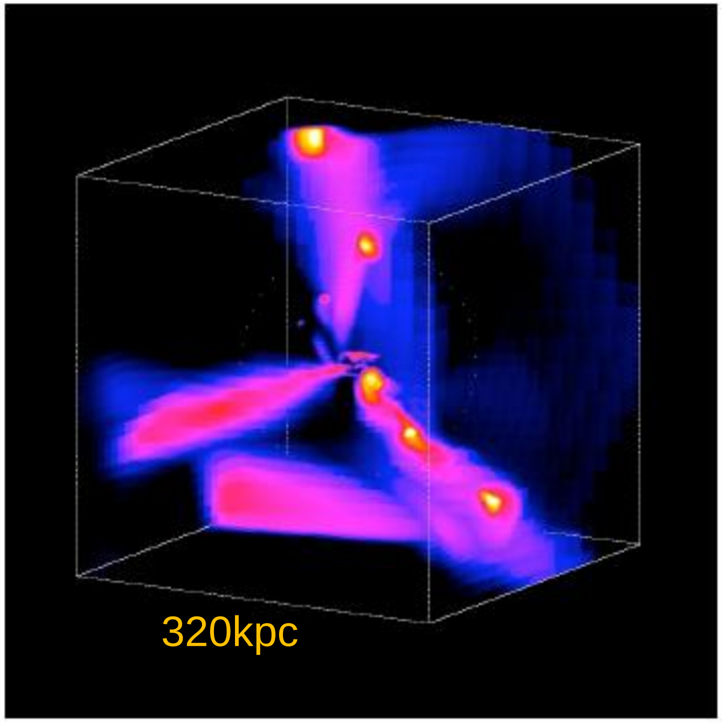
- Spatially resolved star formation (Hα) and chemical evolution ([NII]/Hα, R23)
  - Nucleated starburst (merger-driven)?
    or wide-spread star formation over disk (secular evolution)?
  - Propagation of star formation/chemical evolution (inside-out)?

- Internal gas kinematics (Hα, [OII], Lyα…)
  - Establishment of kinematical morphology?
    (rotation or random motion or disordered merger?)
  - Inflow (cold streams) and Outflow (feedback)?

- AGN activity (BPT diagram at galactic center)
  - AGN contribution at center? Is it accompanied by starbursts?

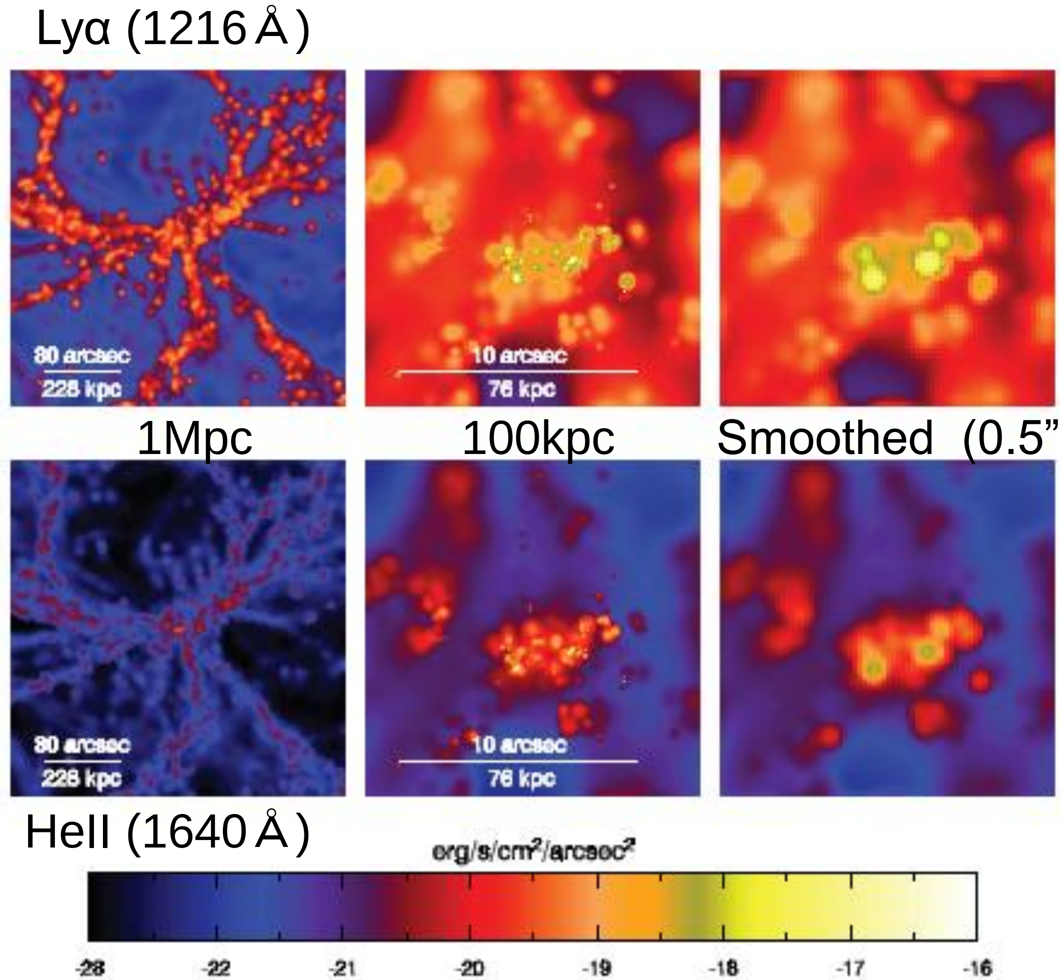
IRMOS (Multi-IFU) will be efficient especially for high density regions.

Can we see cold streams in forming galaxies?



Dekel et al. (2009)

"Cold Streams"



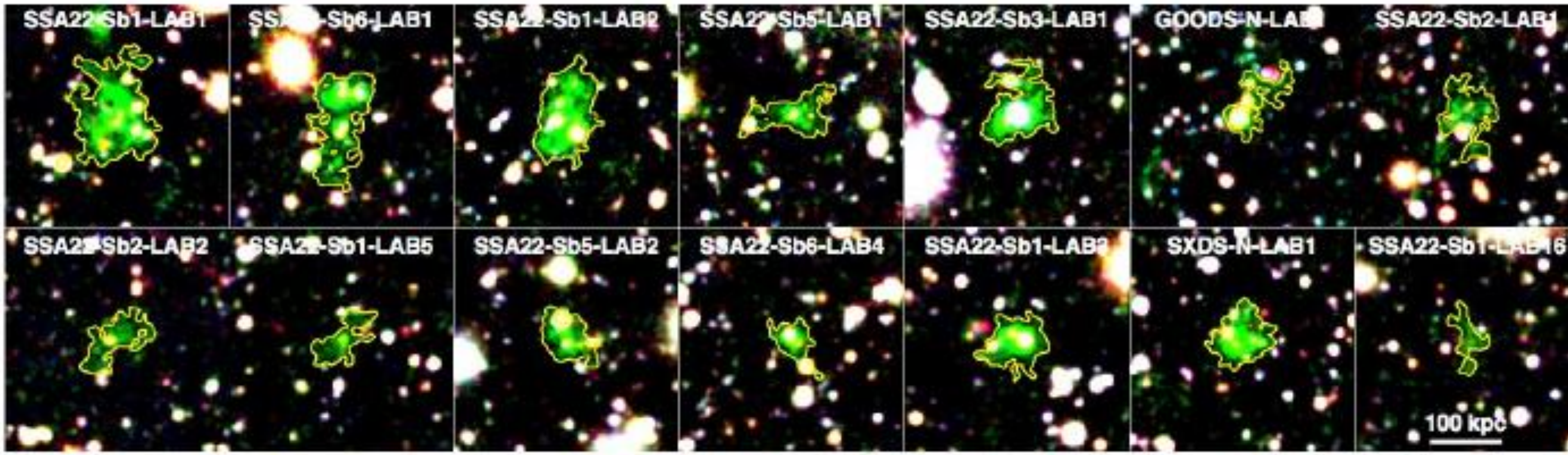
A model for z=3 Yang et al. (2006)

An excellent mechanism of efficient gas supply along filaments to form massive galaxies at high-z.

Lyα Blobs in a high density region SSA22 at z=3.1

Progenitors of massive galaxies in their early formation phase?

Lyα emission is extended due to photo ionization and/or resonant scattering of the surrounding gas trapped in a massive halo.

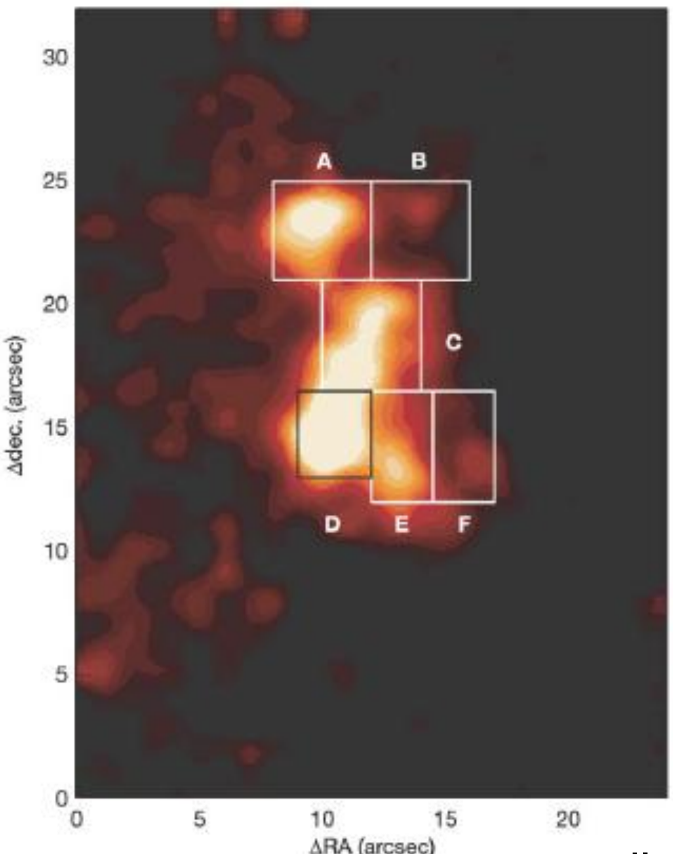


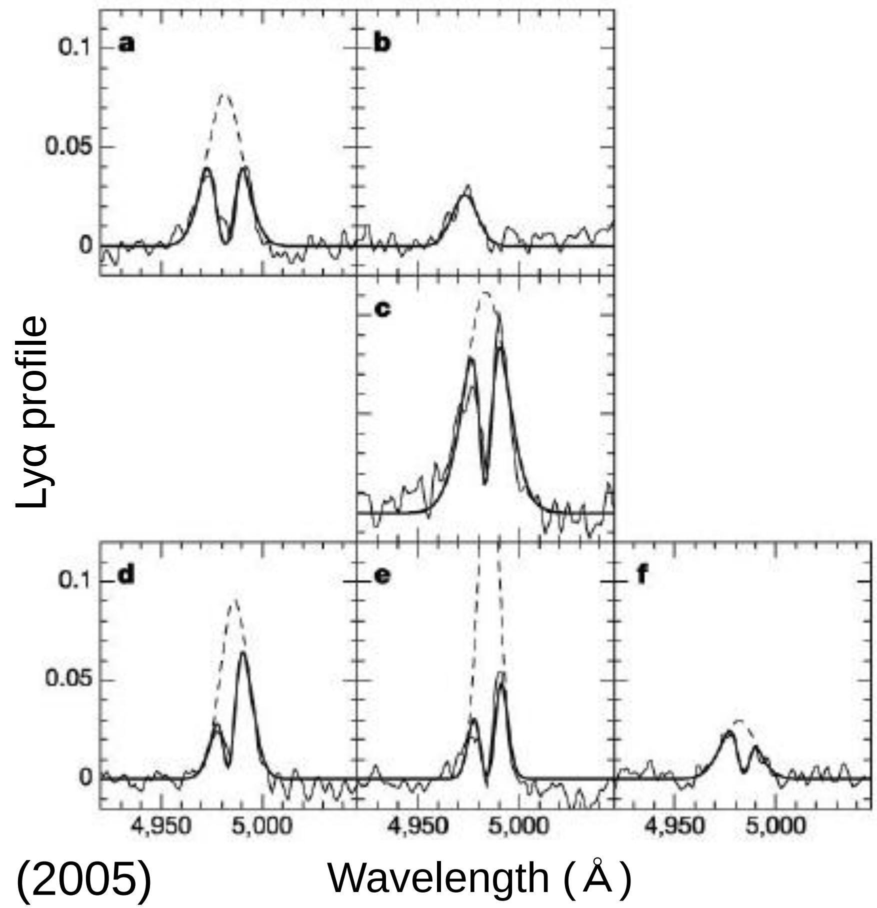
40 arcsec
= 300kpc

Can we see cold streams (as Lyα filaments) if we go much deeper with TMT?

Matsuda et al. (2011)

Velocity structure of neutral gas in Lyα blob at z=3



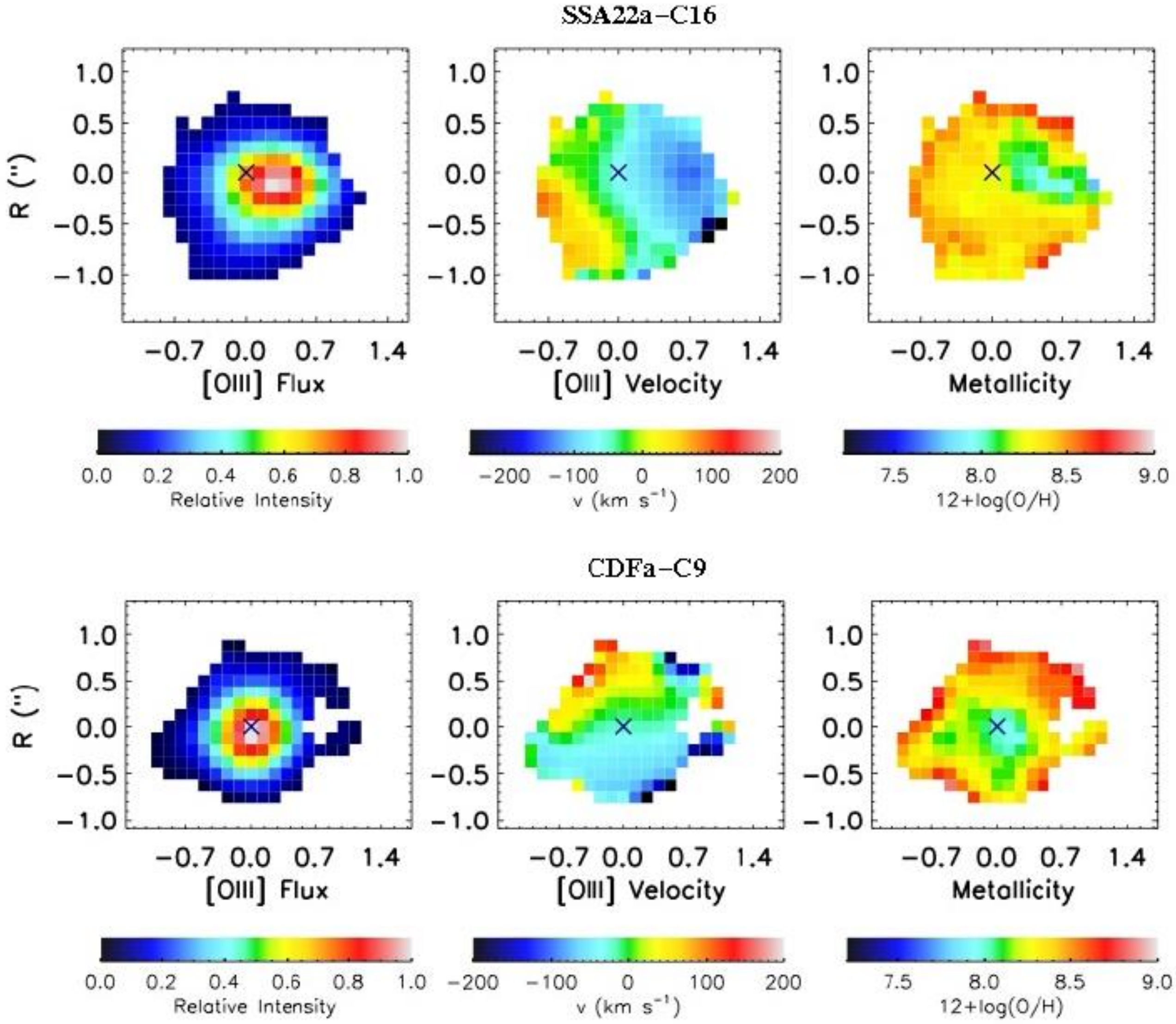


Wilman et al. (2005)

absorbers = associated HI gas along the line of sight

→ line-of-sight velocity as a function of location → gas inflow/outflow?

Resolved Gas-Phase Chemical Evolution



2D map of line ratios (metallicity indicators) such as [OIII]/Hβ and [NII]/Hα

VLT/SINFONI

Cresci et al. (2010)

see also
Jones et al (2010)
With Keck2/OSIRIS

Lower metallicity at the center → Dilution by (almost) metal-free cold streams?

IRIS (IFU: imaging spectroscopy)

FoV=2” (IFU), 0.015”@2μm ⇔ ~0.1kpc @z>1

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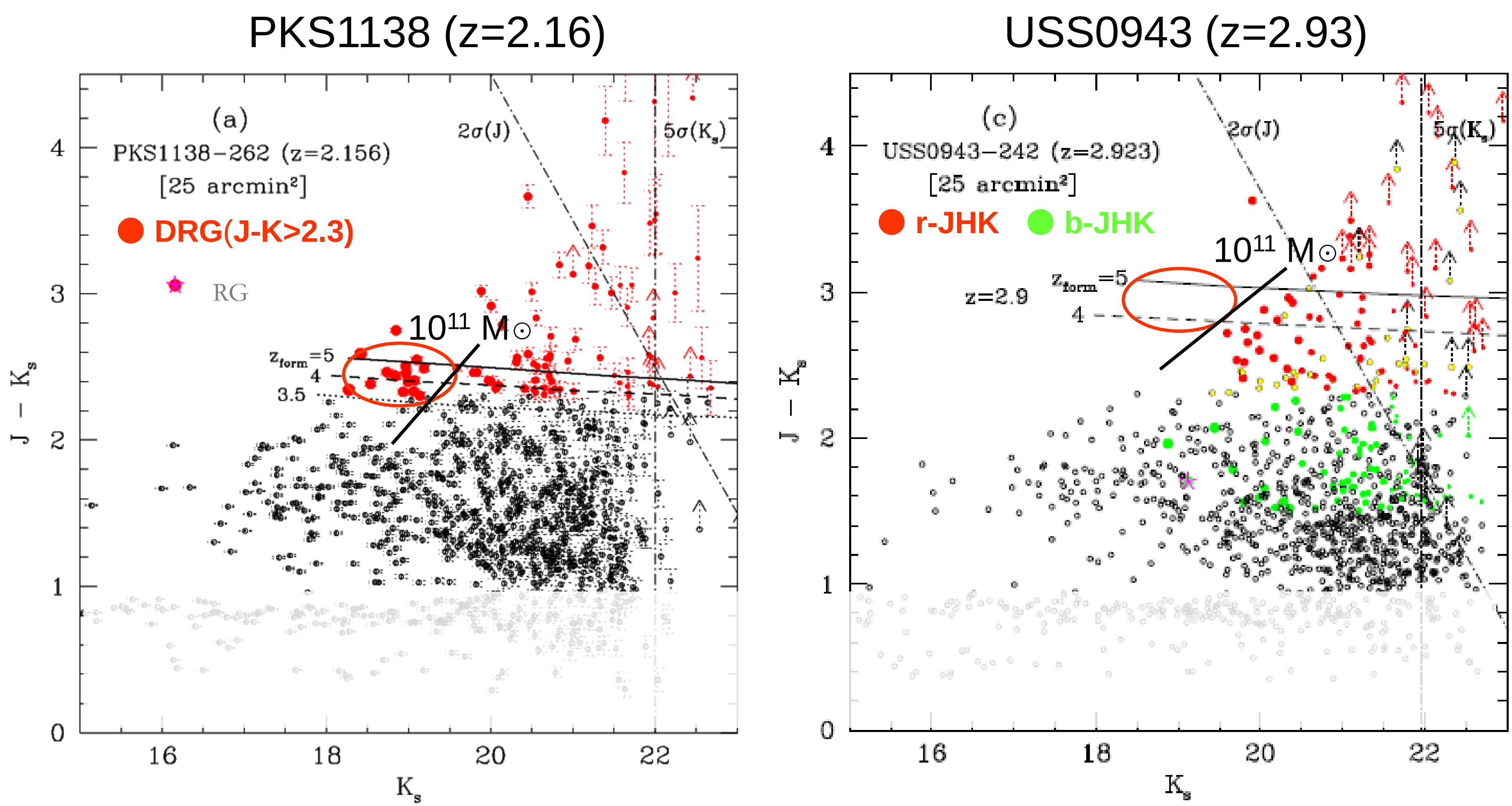
IRMOS (Multi-IFU) will be efficient especially for high density regions.

Emergence of the red sequence (massive-end) at 2<z<3

Confirmed proto-clusters (in terms of associated Lyα emitters) around radio galaxies

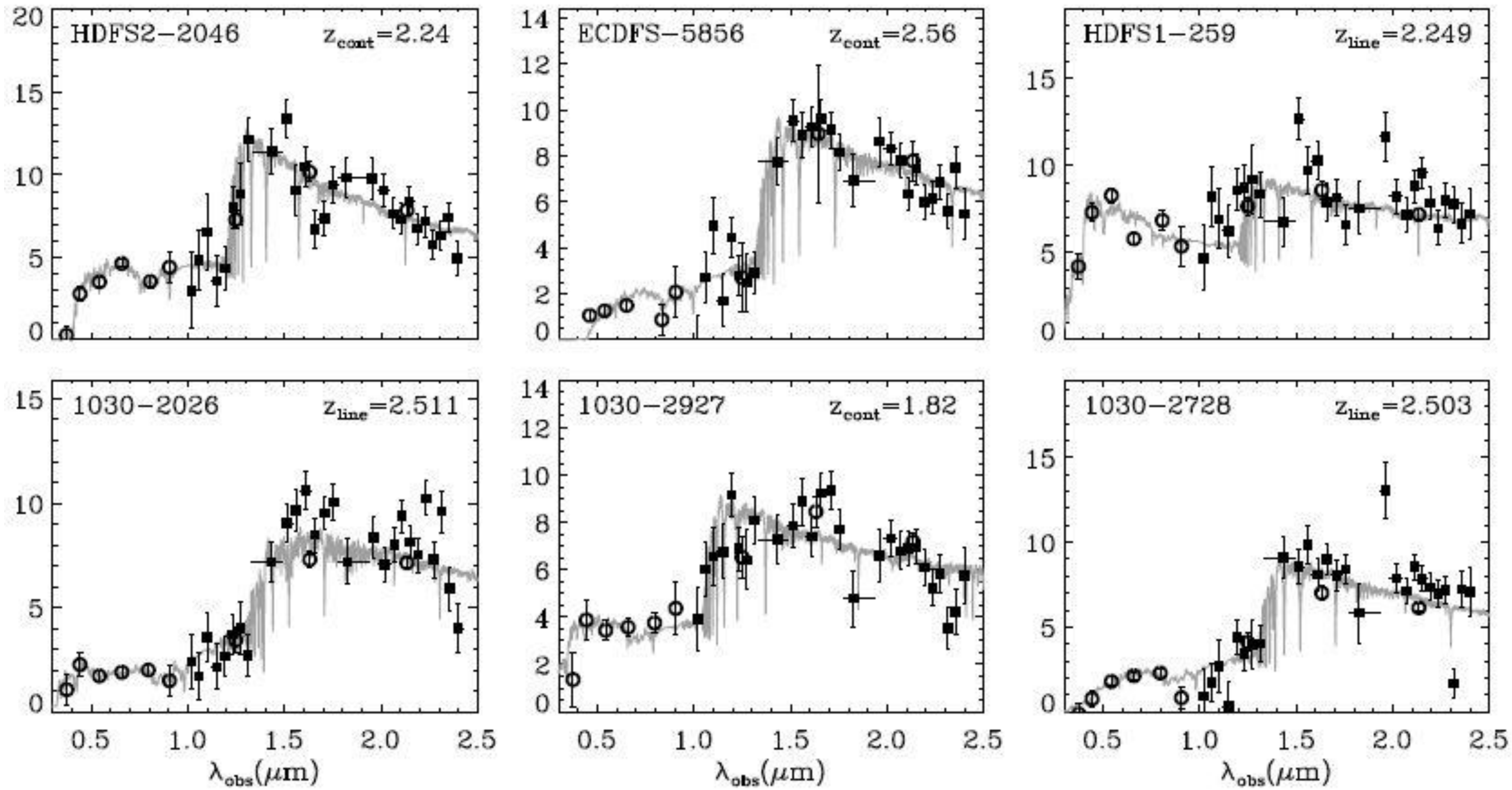


Ancestors of massive galaxies in clusters are just vigorously forming between 2<z<3.

Subaru/MOIRCS, Kodama et al. (2007)

Continuum (Balmer/4000 Å break) redshifts for DRG

Kriek et al. (2008)



MUSYC survey, K<19.7(~M*−0.5)

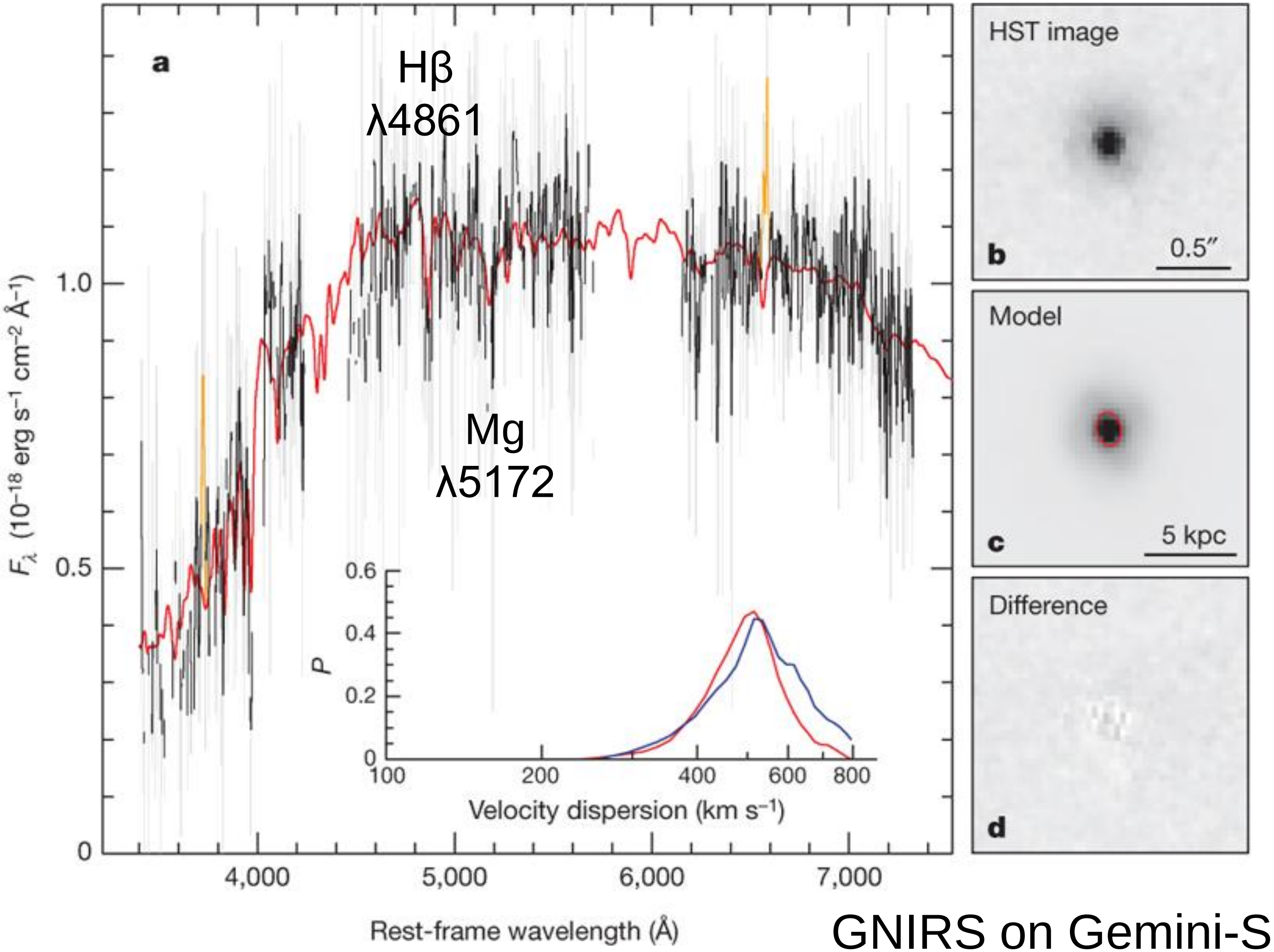
→ K~21.5 (Vega, M*-1) with TMT

GNIRS on Gemini-S, R=1000, 2-3hrs each

R=1000 → SED: R=40-50 (smoothing)

$\Delta z/(1+z) < 0.019$ (~6000km/s)

Ultra-Deep Continuum Spectrum of a DRG at z=2.2



GNIRS on Gemini-S, 29 hrs

Spectrum and HST images of 1255-0 at *z* = 2.186.
van Dokkum *et al*. *Nature* **460**, 717-719 (2009)

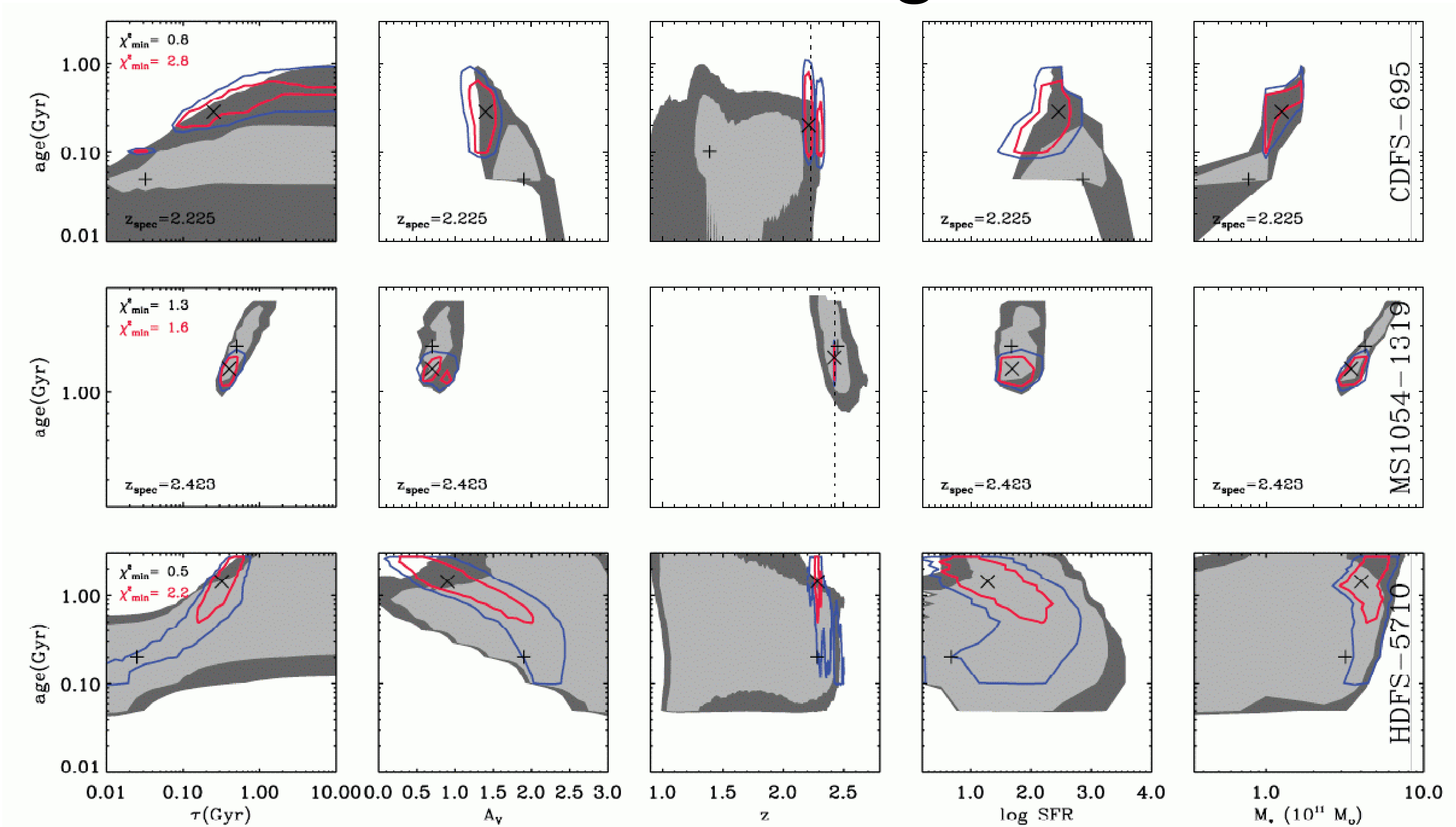
K=19.26 (Vega)

$M^{*}=2\times10^{11}M_{\odot}$

→ 2hrs exposure with TMT !

SED fitting

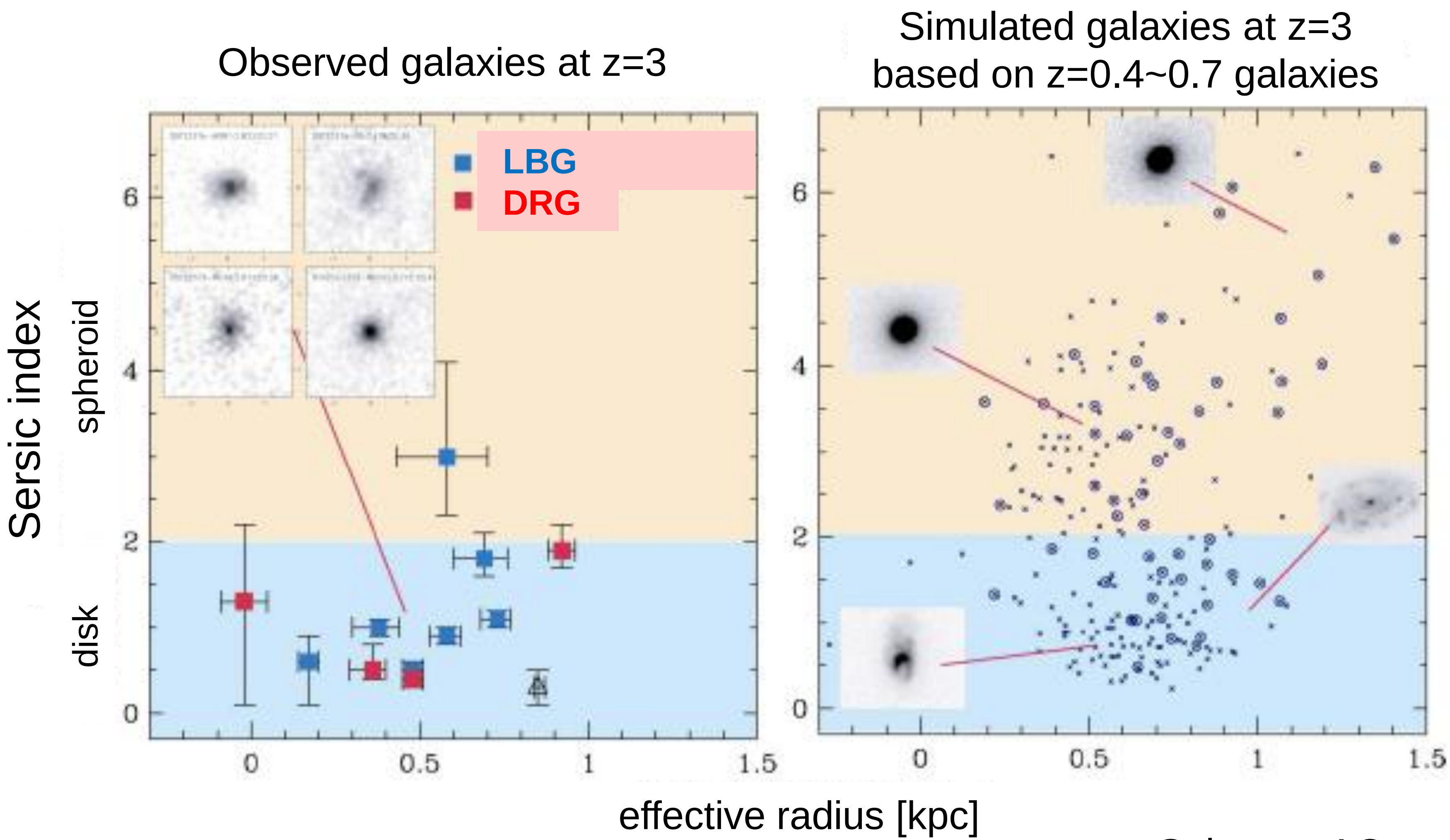
see colored contours



Balmer/4000 Å break, Mg2 feature → luminosity weighted age, Av, SFR…

Kriek et al. (2006)

Establishment of Hubble types at 1<z<3?

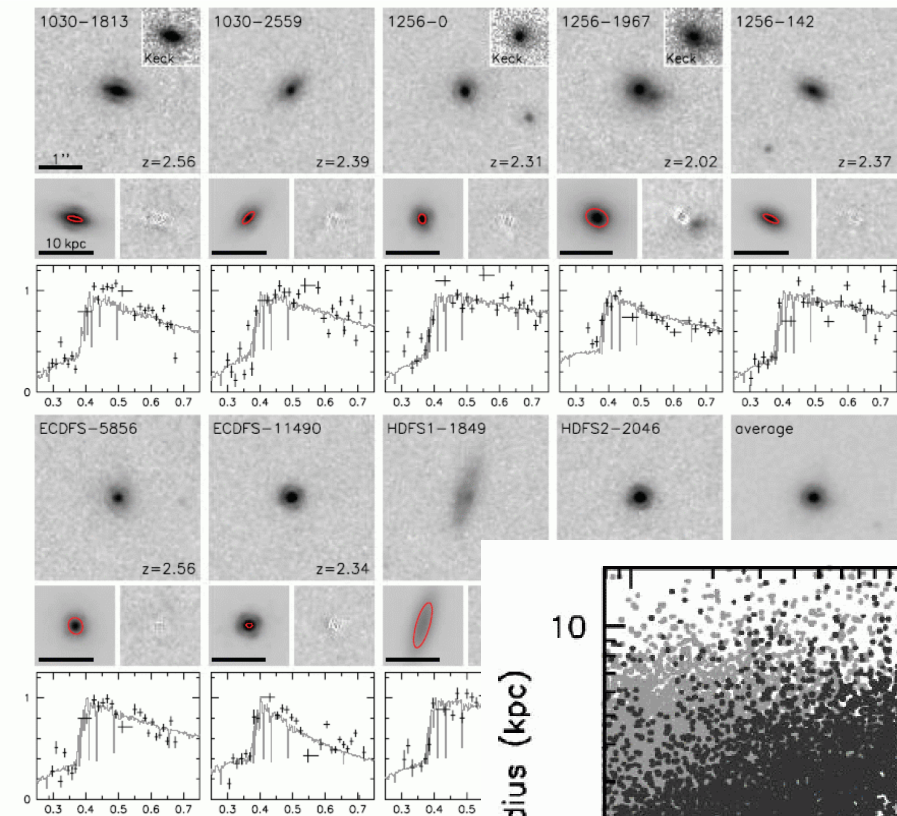


Subaru + AO

Spheroidal galaxies are much scarcer at high-z (~3).

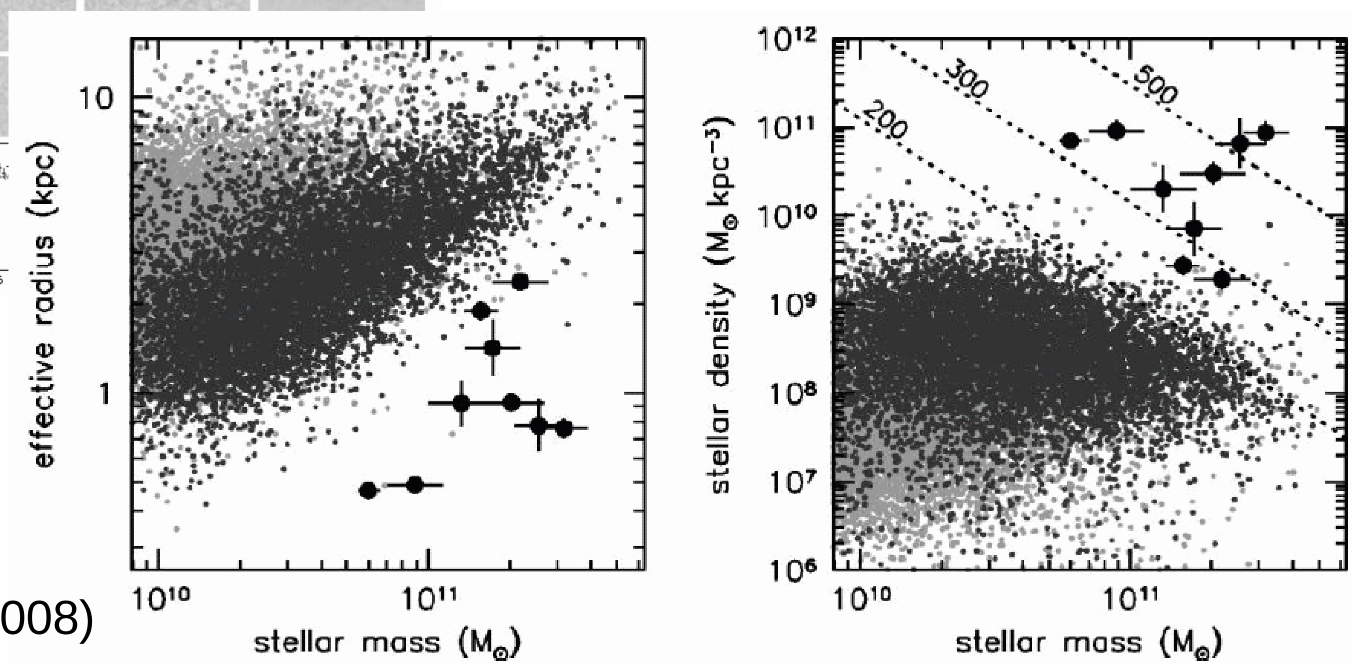
Akiyama et al. (2008)

Massive, compact, spheroidal 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!



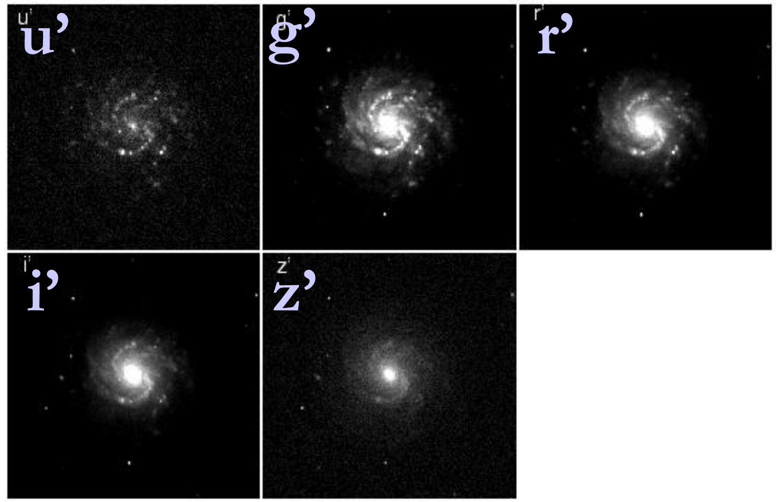
HST/NIC2
Keck/LGS-AO

van Dokkum et al. (2008)

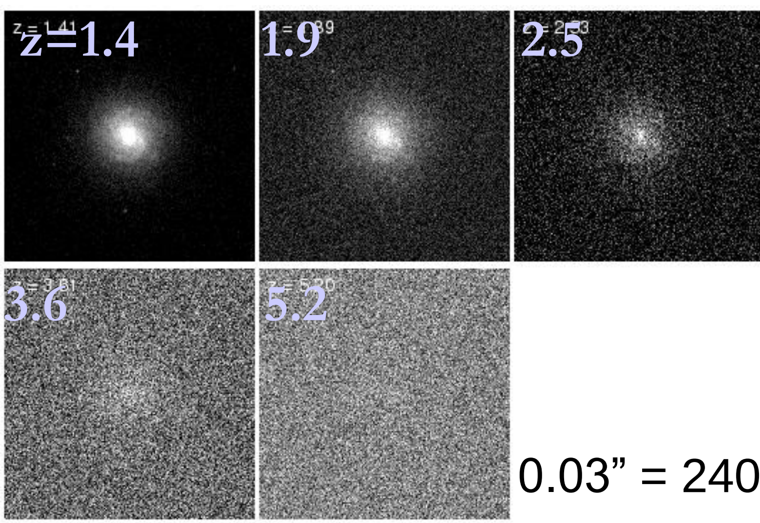
How well can we determine galaxy morphology at high-z?

Sa galaxy at z~0 (SDSS)

Minowa et al. (2004)

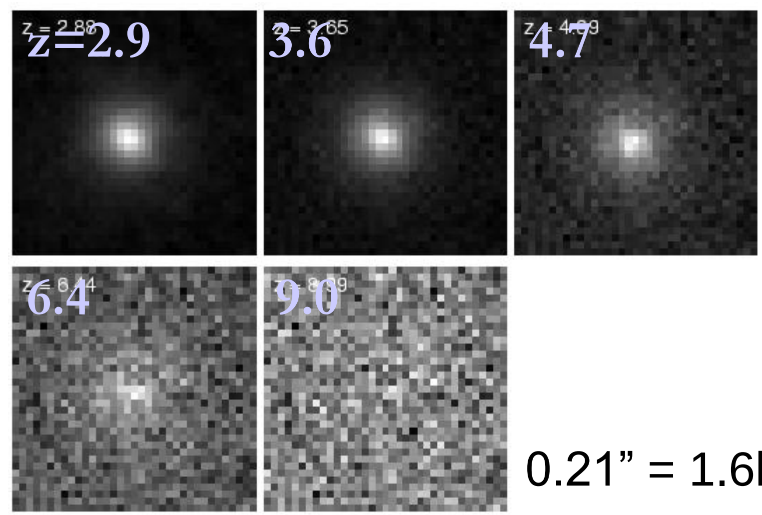


Conclusions
z<3: ground 20m
z>3: space 3.5m



0.03” = 240pc

Ground-based 20m + AO (K-band)



0.21” = 1.6kpc

Space 3.5m (L-band)

IRMS (multi-slit spectroscopy)

Imaging: 2’ × 2’ Spectroscopy: 2’ × 0.6’, 46 slits

- **Morphology and Size Evolution**

  AO imaging (~0.1kpc) of less massive galaxies ($M^* < 10^{11} M_\odot$)
  → merger rate, bulge/disk ratio, size evolution

- **Resolving Star Formation History in Finer Time Scale**

  Hα + Balmer absorption + SED + dust correction
  10^7 yr 10^{8-9} yr $>10^9$ yr (Hα/Hβ)
  Starburst? Truncation timescale? → Physical mechanisms

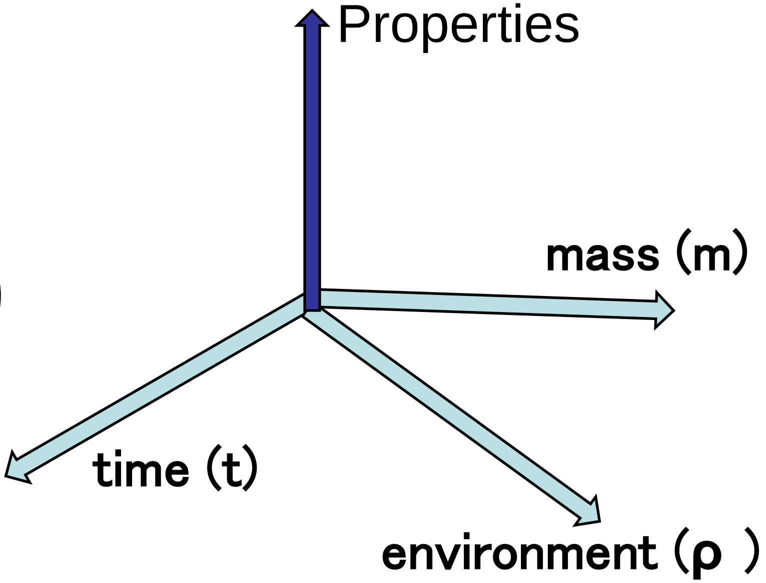
- **Chemical Evolution of Interstellar Gas**

  [NII]/Hα and ([OII]+[OIII])/Hβ → Metallicity in HII regions

- **Co-appearance of AGN with Active Galaxies**

  BPT diagram → Conditions for AGN (environment and time)

Key Scientific Goals
(Galaxy working group)



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