(WISH science workshop @Mitaka, 2012/7/19-20)

Histories of mass assembly and star formation in galaxies and clusters

Tadayuki Kodama (Subaru) and Mahalo-Subaru Team

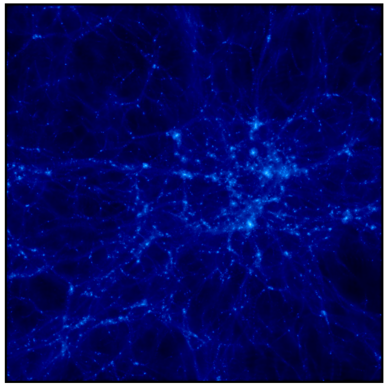
A galaxy cluster RXJ0152 at z=0.83 (Subaru/Suprime-Cam)

階層的な銀河・銀河団の形成（理論モデル）

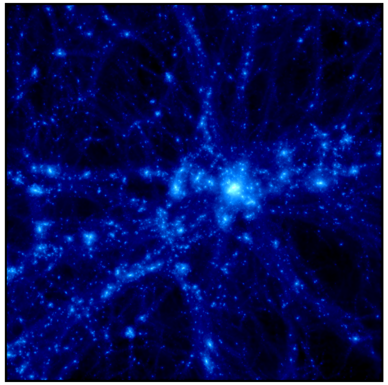
http://4d2u.nao.ac.jp/

銀河団形成

125億年前

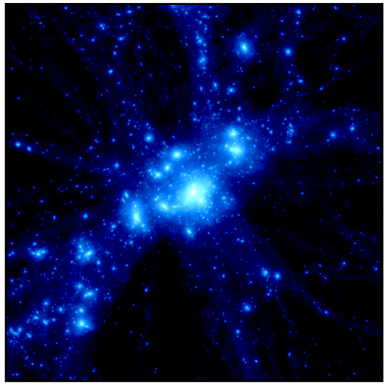


100億年前



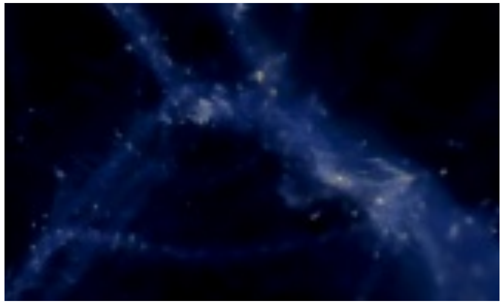
movie

現在

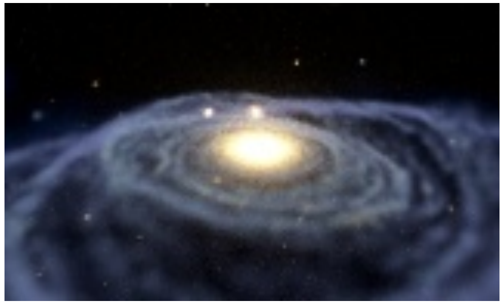


矢作氏ほか

銀河形成



movie



斎藤氏ほか

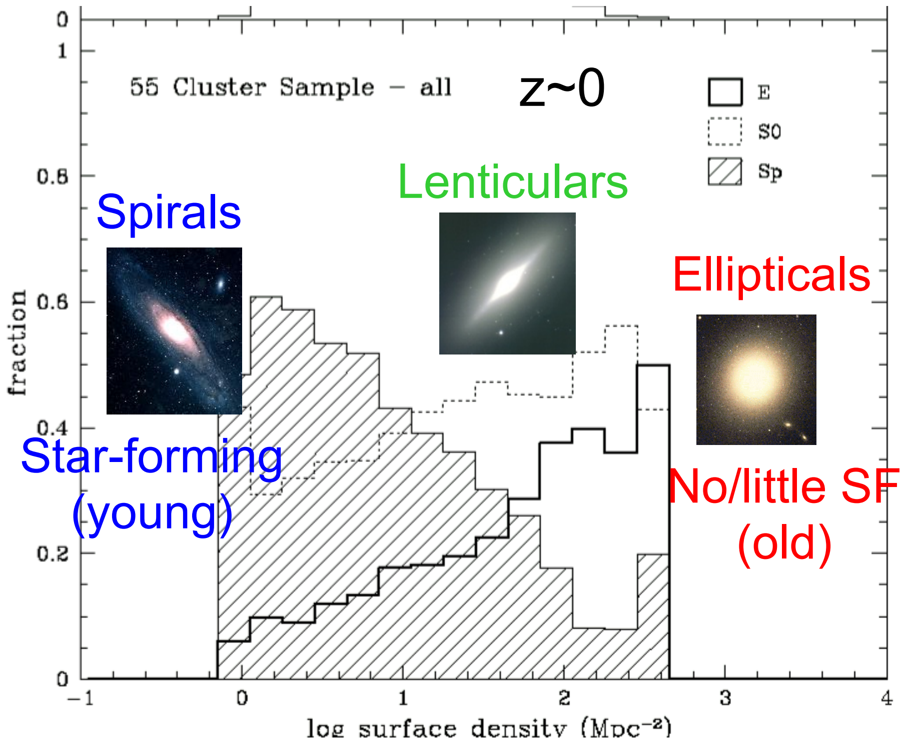
初めに小さな天体がたくさん生まれ、それらが重力で引き合って集まり、
合体を繰り返しながら、より大きな天体へと成長してゆく。

What's the origin of the environmental dependence?

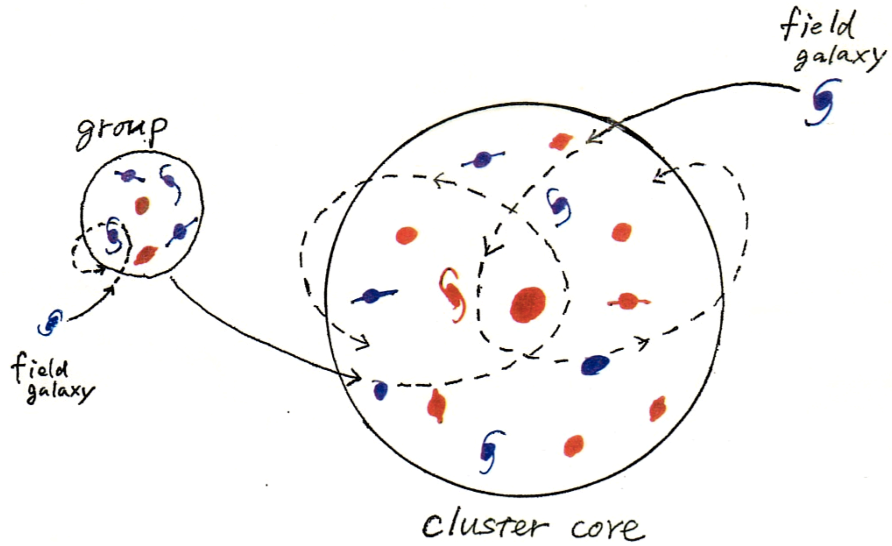
Morpgology(SFH) - Mhalo relation

morphology - density relation

(Dressler 1980)



log surface density (Mpc^{-2})



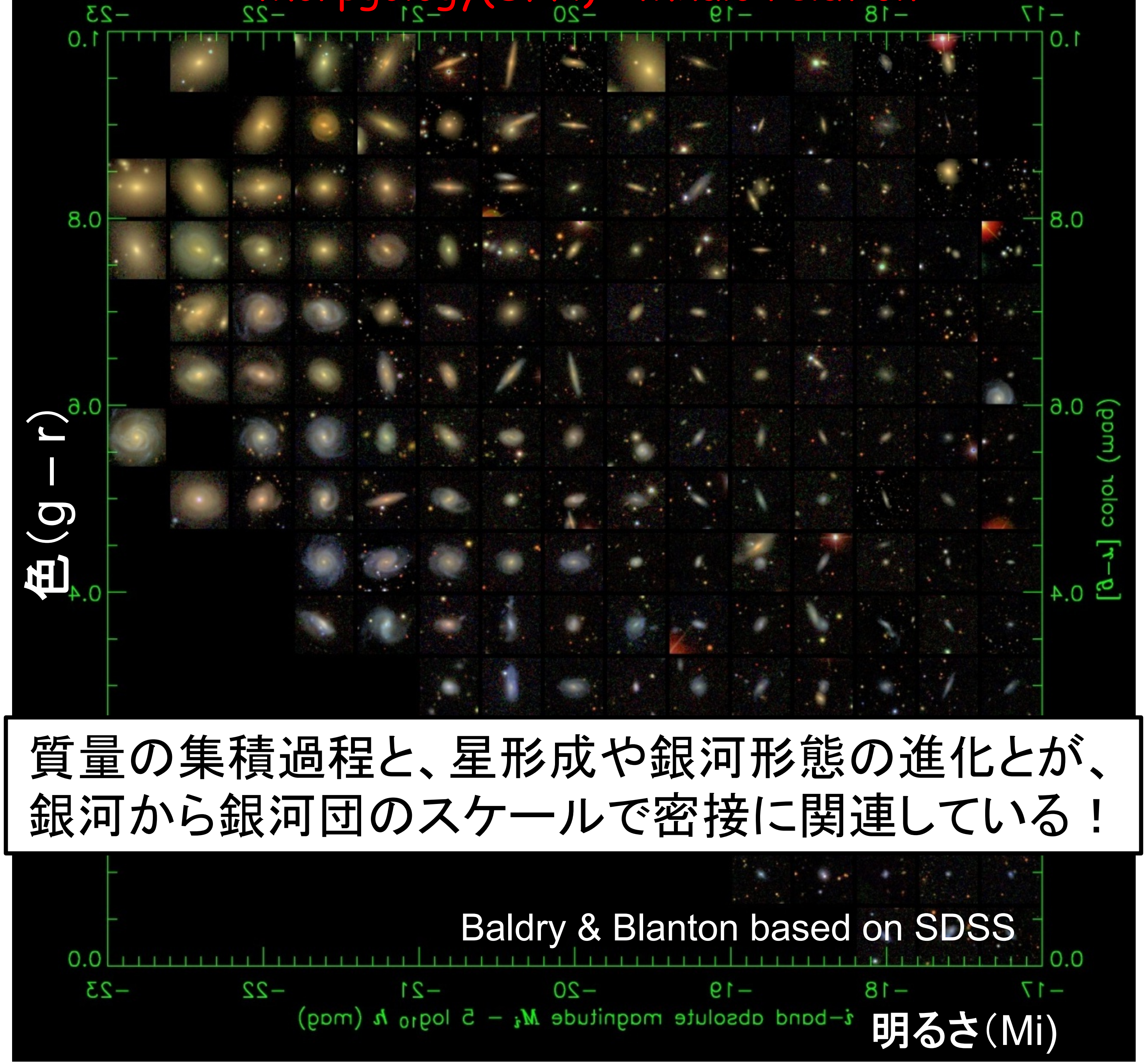
Nature? (intrinsic)

Need to go higher redshifts when it becomes more evident.

Nurture? (external)

Need to go outer infall regions to see directly what's happening there.

Morpgology(SFH) - Mhalo relation

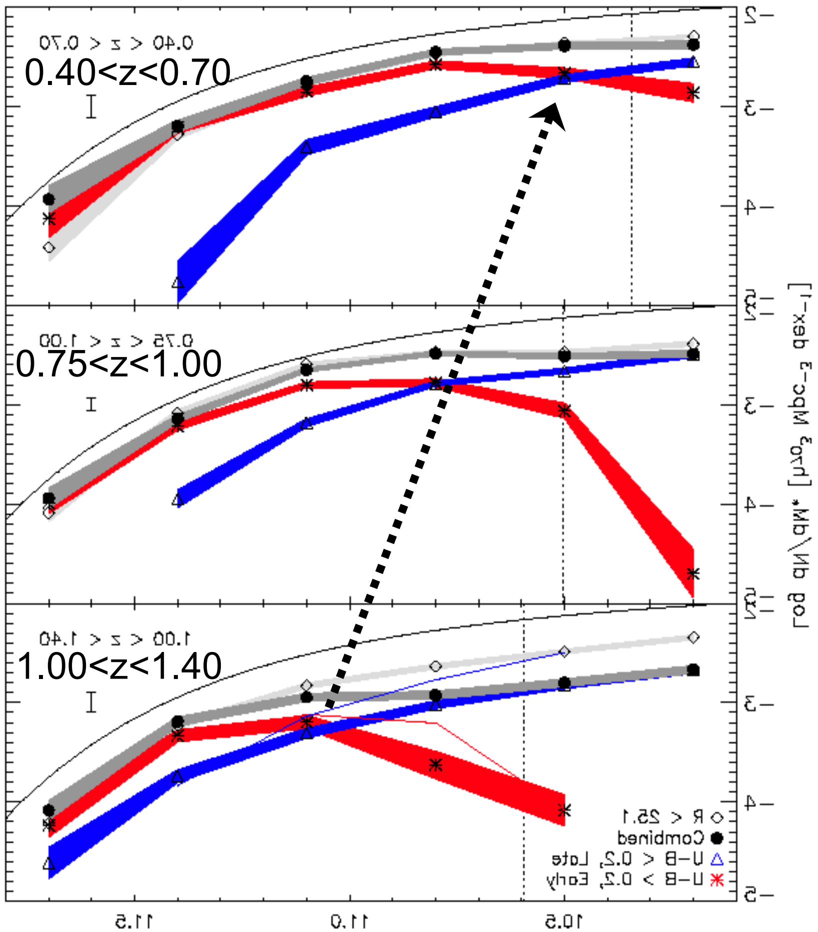


質量の集積過程と、星形成や銀河形態の進化とが、
銀河から銀河団のスケールで密接に関連している！

明るい銀河
赤い銀河ほど
早期型銀河の
割合が高い。

ダウンサイジング

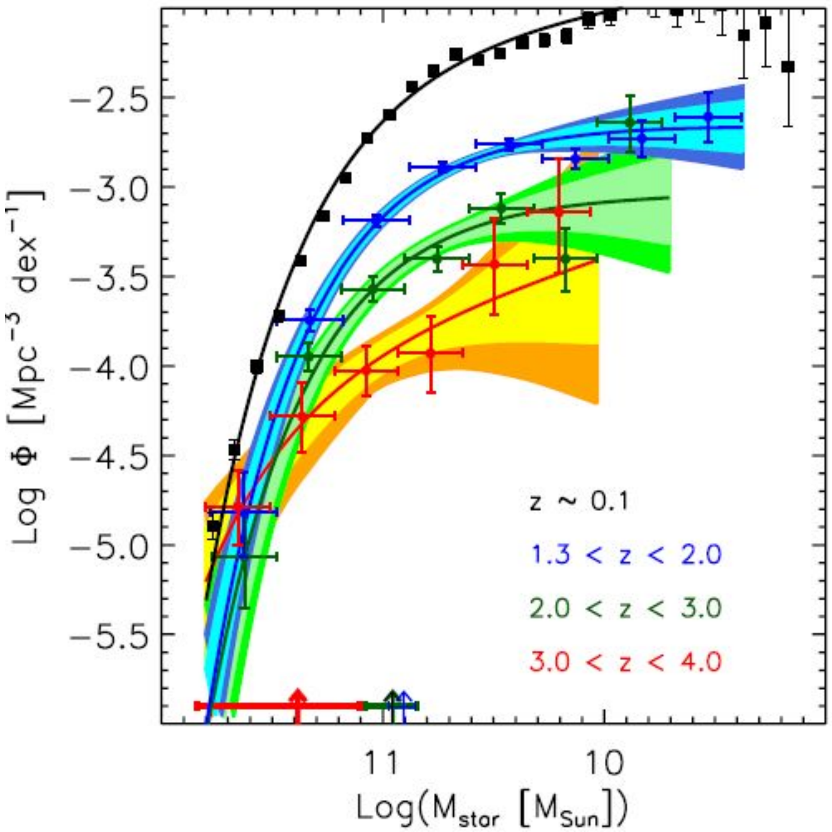
星形成



log Mstar

Bundy et al. (2006)

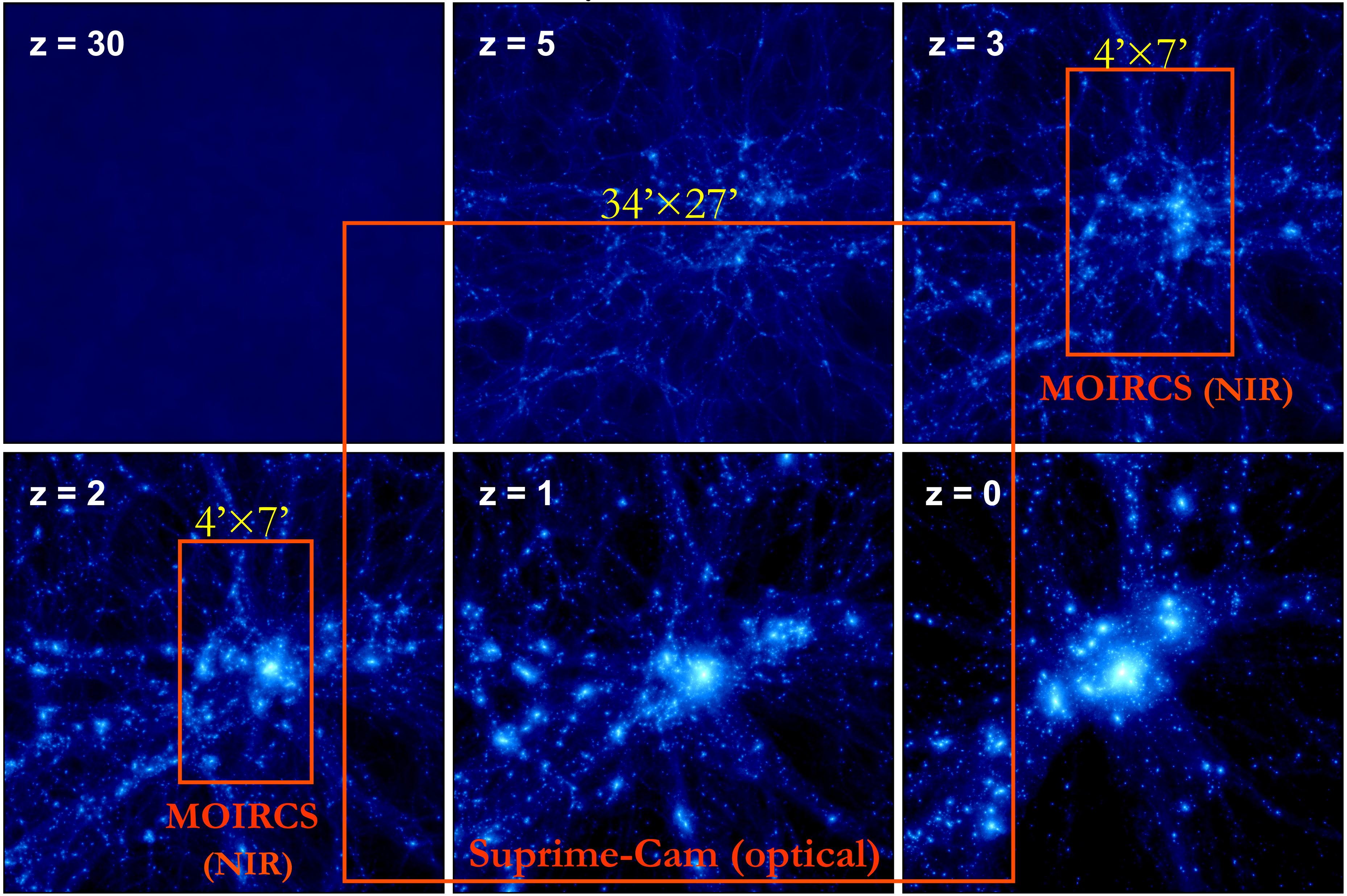
質量集積



Yale-Chile, GOODS-CDFS
Marchesini et al. (2009)

大きい銀河ほど形成が早く、小さい銀河ほど遅れて形成される → “Down-sizing”？

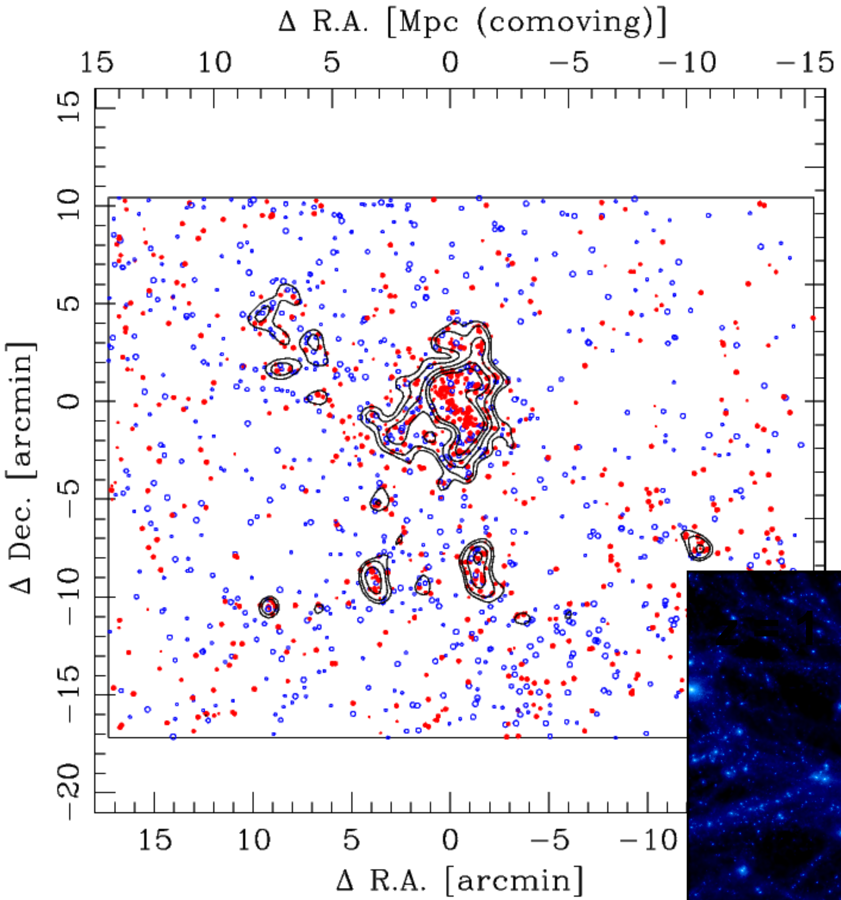
Why Subaru?



Final cluster with $M=6\times10^{14}\ M_{\odot}$, $20\times20Mpc^2$ (co-moving) (Yahagi et al. 2005; ν GC)

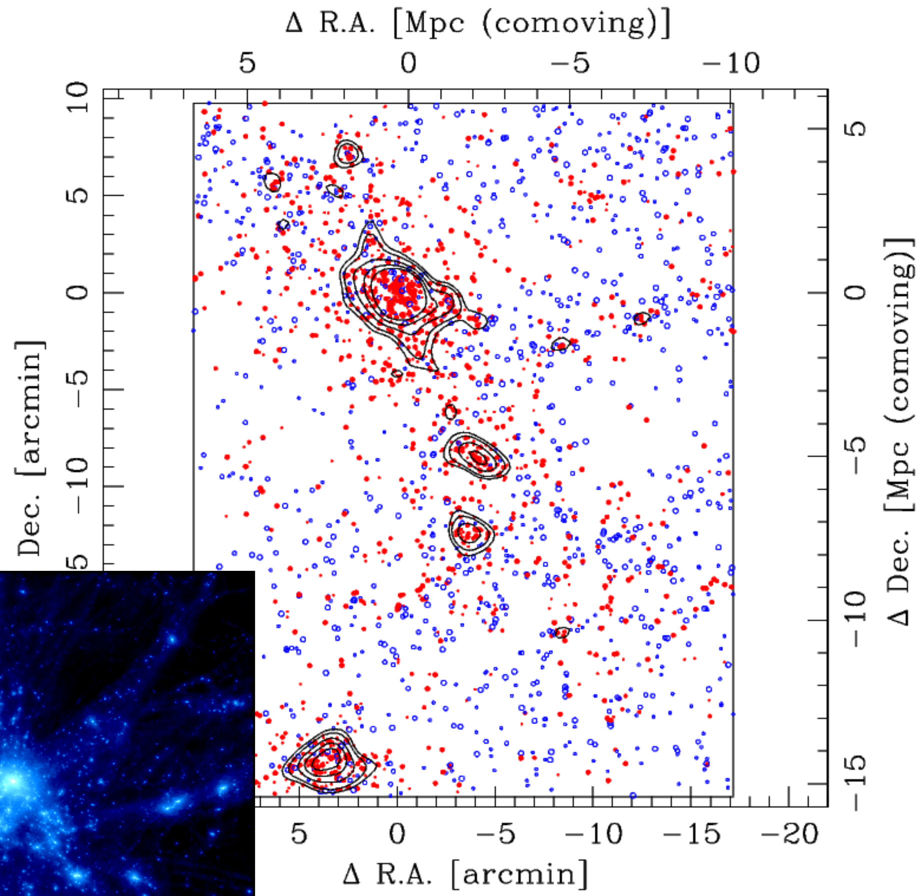
銀河団集積過程のパノラマ

RXJ 0152.7-1357 (VRIz')

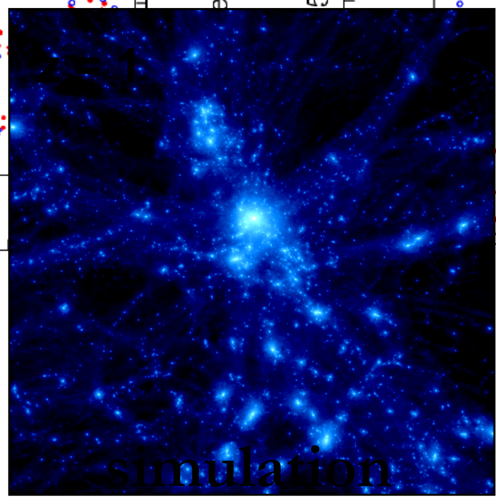


z=0.83（70億年前）

CL 0016+16 (BVRi'z')



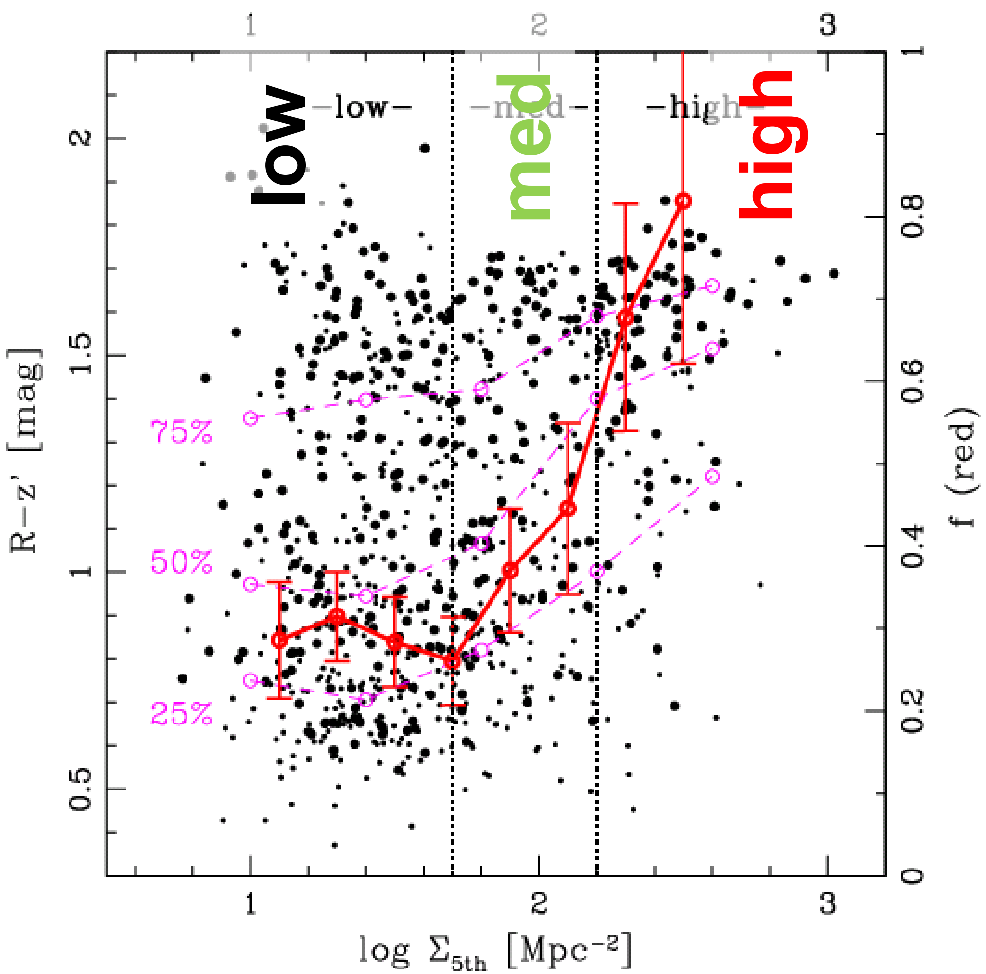
z=0.55（54億年前）

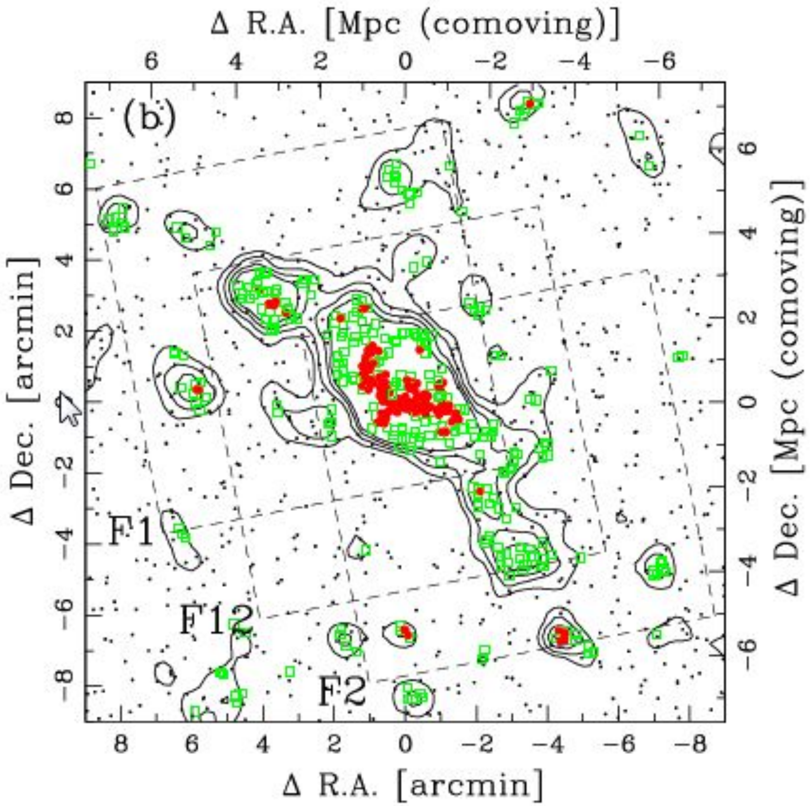


Kodama, et al. (2005)

銀河群・フィラメントにおける急激な色の変化

RXJ1716 Cluster（z=0.81）





high ～ 銀河団コア

med ～ 銀河群 / フィラメント

low　～ フィールド

Koyama, TK, et al. (2008)

"MAHALO-Subaru"

MApping HAlpha and Lines of Oxygen with Subaru

NB mapping of star forming galaxies at the peak epoch of galaxy formation

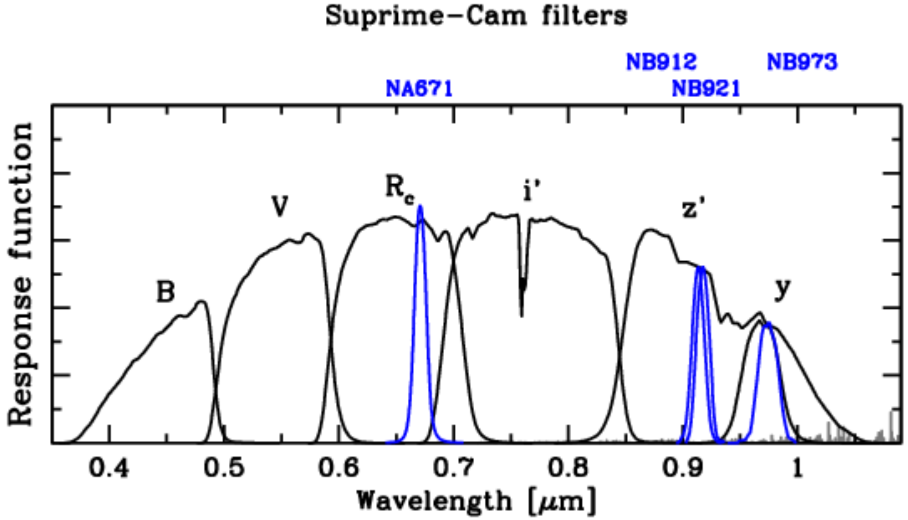
Pilot obs (5 nights) + Intensive (10 nights @S10B-11A) + Normal (3 nights @S11B)

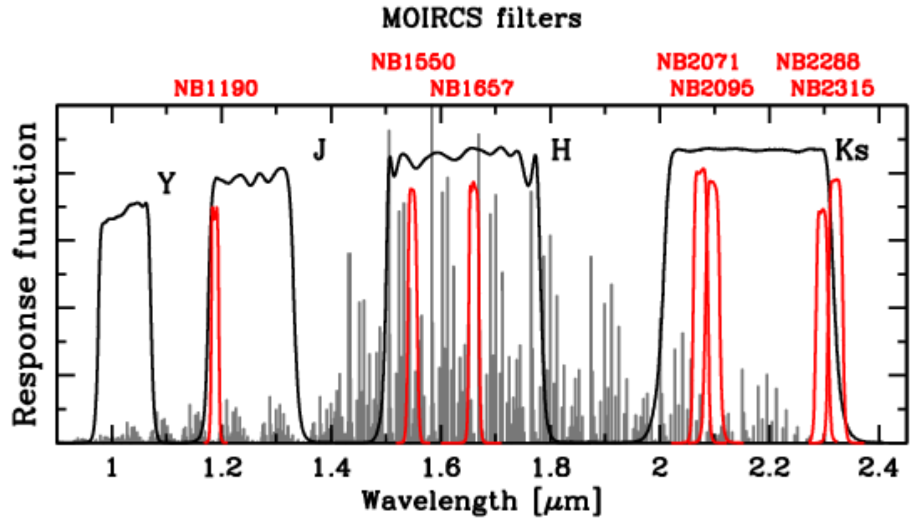
environment	target	z	line	λ (μm)	camera	NB-filter	continuum	status (as of Apr 2012)
Low-z cluster	CL0024+1652	0.395	Hα	0.916	Suprime-Cam	NB912	z'	Kodama+'04
	CL0939+4713	0.407	Hα	0.923	Suprime-Cam	NB921	z'	Koyama+'11
	RXJ1716+6708	0.813	Hα	1.190	MOIRCS	NB1190	J	Koyama+'10
			[O II]	0.676	Suprime-Cam	NA671	R	observed
High-z cluster	XCSJ2215–1738	1.457	[O II]	0.916	Suprime-Cam	NB912, NB921	z'	Hayashi+'10,'11
	4C65.22	1.516	Hα	1.651	MOIRCS	NB1657	H	observed
	Q0835+580	1.534	Hα	1.664	MOIRCS	NB1657	H	observed
	CL0332–2742	1.61	[O II]	0.973	Suprime-Cam	NB973	y	Hayashi+ in prep.
	CIGJ0218.3–0510	1.62	[O II]	0.977	Suprime-Cam	NB973	y	Tadaki+'11b
Proto-cluster	PKS1138–262	2.156	Hα	2.071	MOIRCS	NB2071	K_s	Koyama+ in prep.
	4C23.56	2.483	Hα	2.286	MOIRCS	NB2288	K_s	Tanaka+'11
	USS1558–003	2.527	Hα	2.315	MOIRCS	NB2315	K_s	Hayashi+ '12
General field	GOODS-N	2.19	Hα	2.094	MOIRCS	NB2095	K_s	Tadaki+'11a
	(62 arcmin^2)		Hβ	1.551	MOIRCS	NB1550	H	not yet
			[O II]	1.189	MOIRCS	NB1190	J	observed
	SXDF	2.19	Hα	2.094	MOIRCS	NB2095	K	Tadaki+ in prep.
	(110 arcmin^2)		Hβ	1.551	MOIRCS	NB1550	H	not yet
			[O II]	1.189	MOIRCS	NB1190	J	not yet
		2.53	Hα	2.313	MOIRCS	NB2315	K_s	Tadaki+ in prep.

Kodama, T. (PI), Hayashi, M., Koyama, Y., Tadaki, K., Tanaka, I., et al.

Unique sets of Narrow-Band Filters on Suprime-Cam and MOIRCS

The existing Suprime-Cam NB-filters capture emission lines from known good targets.
The MOIRCS NB-filters were specifically designed for good targets at frontier redshifts.





4 narrow-band filters

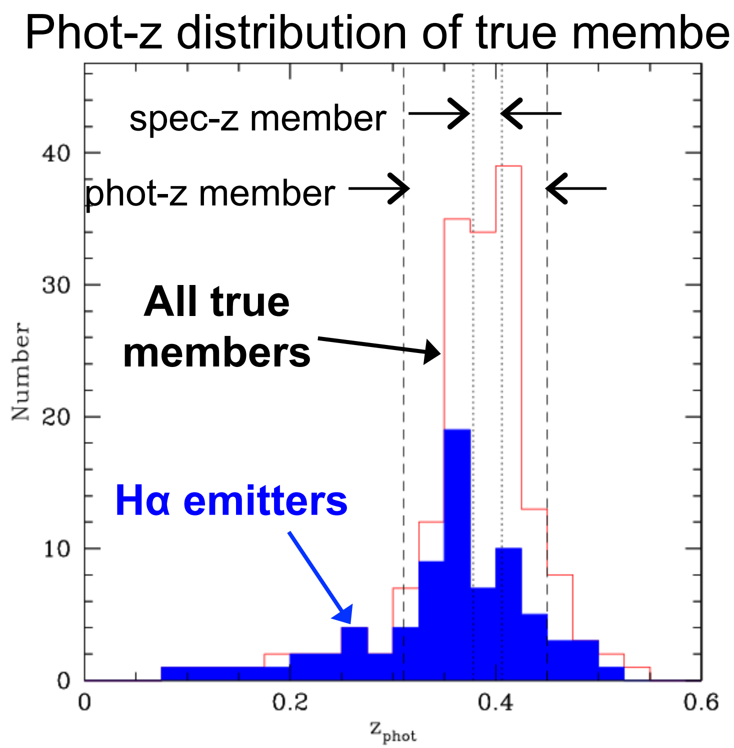
Camera	Filter	λ_c	FWHM
MOIRCS	NB1190	1.189μm	0.014μm
	NB1550	1.550μm	0.018μm
	NB1657	1.656μm	0.019μm
	NB2071	2.068μm	0.027μm
	NB2095	2.095μm	0.025μm
	NB2288	2.288μm	0.023μm
	NB2315	2.313μm	0.027μm
Suprime-Cam	NA671	0.6714μm	0.0130μm
	NB912	0.9139μm	0.0134μm
	NB921	0.9173μm	0.0132μm
	NB973	0.9755μm	0.020μm
	y	0.9860μm	0.059μm

7 narrow-band filters

FWHMs correspond to ±1000-3000km/s

NB（+BB）サーベイの利点

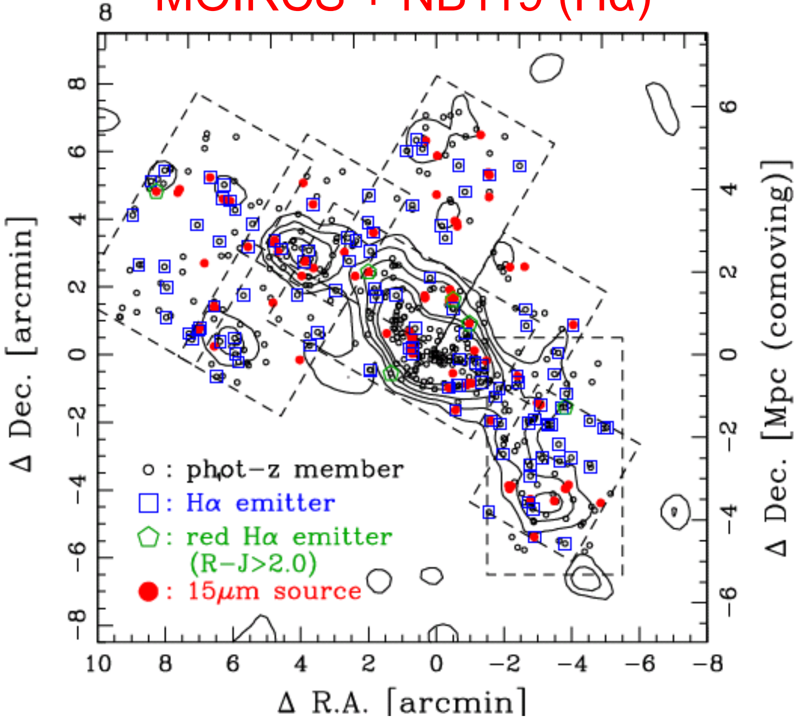
（１）ほぼ星形成率リミットの星形成銀河をコンプリートに選択。
（２）UV選択やIR選択のように星形成モードに依存しない。
（３）赤方偏移がほぼ確実でかつ揃っている。銀河団では特に有力。
（４）BB選択(phot-z)の受動的銀河と、NB選択の星形成銀河を組み合わせて、よりコンプリートな銀河種族を選択できる！

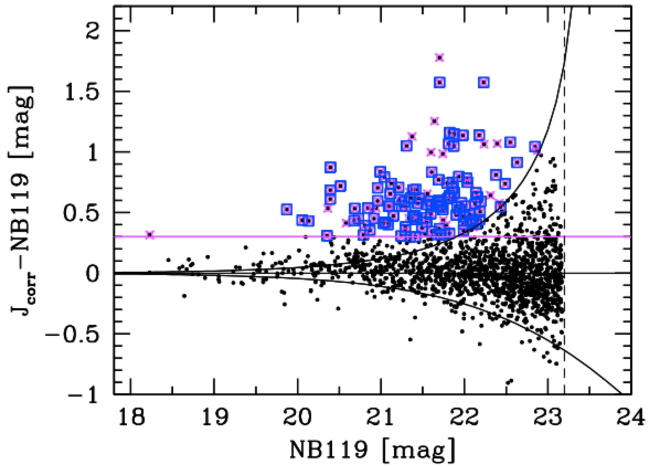


CL0024 cluster (z=0.4)
NB912 + Suprime-Cam
Kodama et al. (2004)

RX J1716.6+6708 (z=0.81)

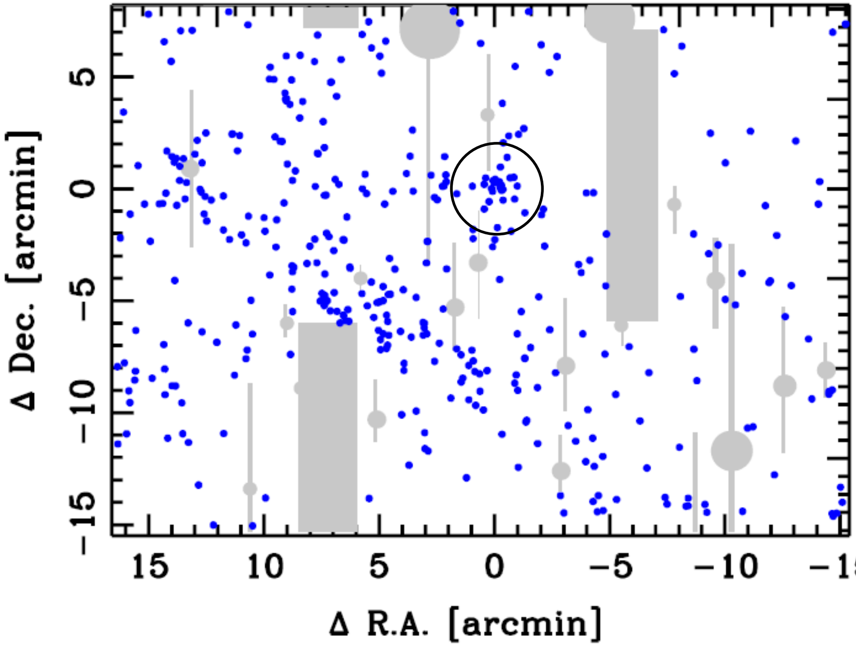
MOIRCS + NB119 (Hα)

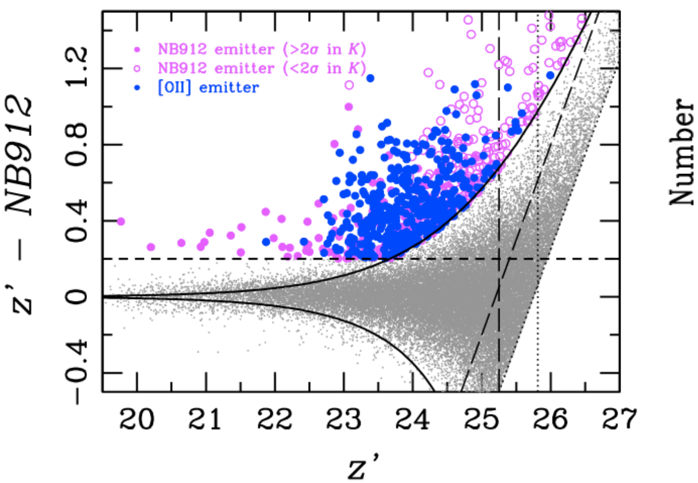




XCS J2215.9-1738 (z=1.46)

Suprime-Cam + NB912 ([OII])



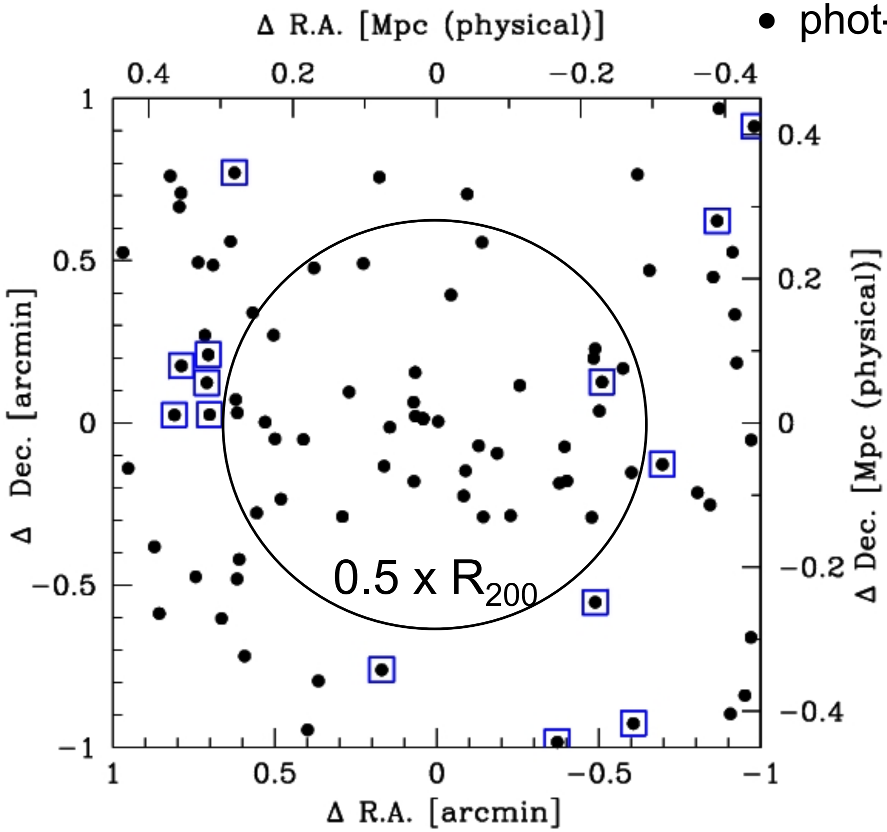


Broad-band colours (phot-z) are used to identify which emission line is in the NB filter.

Inside-out formation and evolution of galaxy clusters

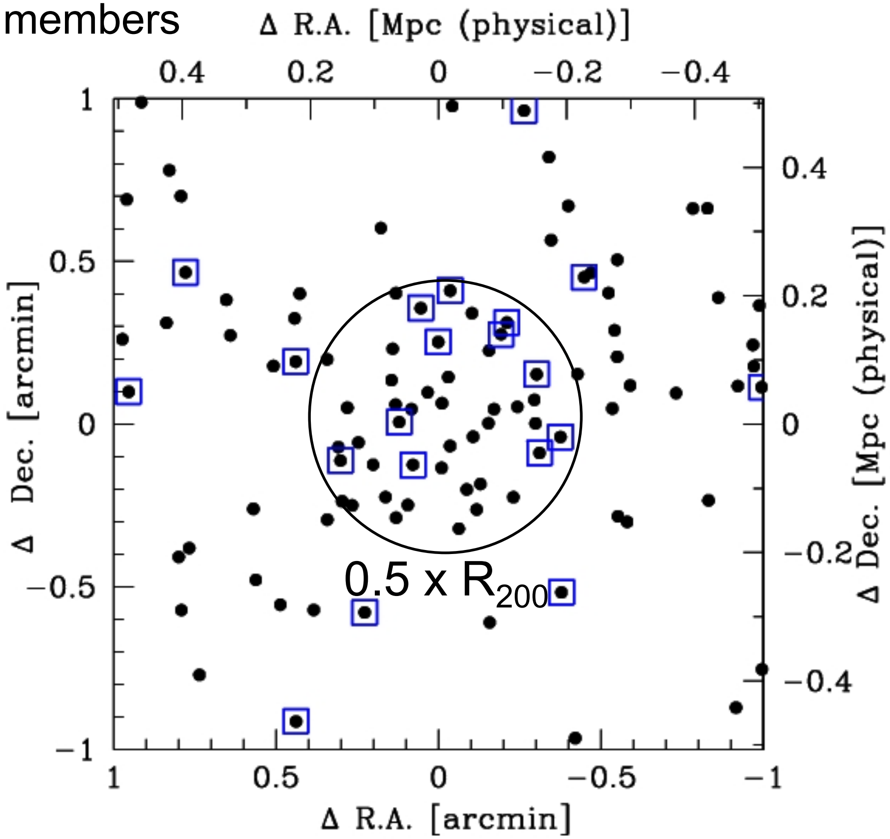
□ Hα emitters at z=0.81 (RXJ1716)   □ [OII] emitters at z=1.46 (XCS2215)

• phot-z members



Lx=2.7×10^44 erg/s

Koyama, et al. (2011)

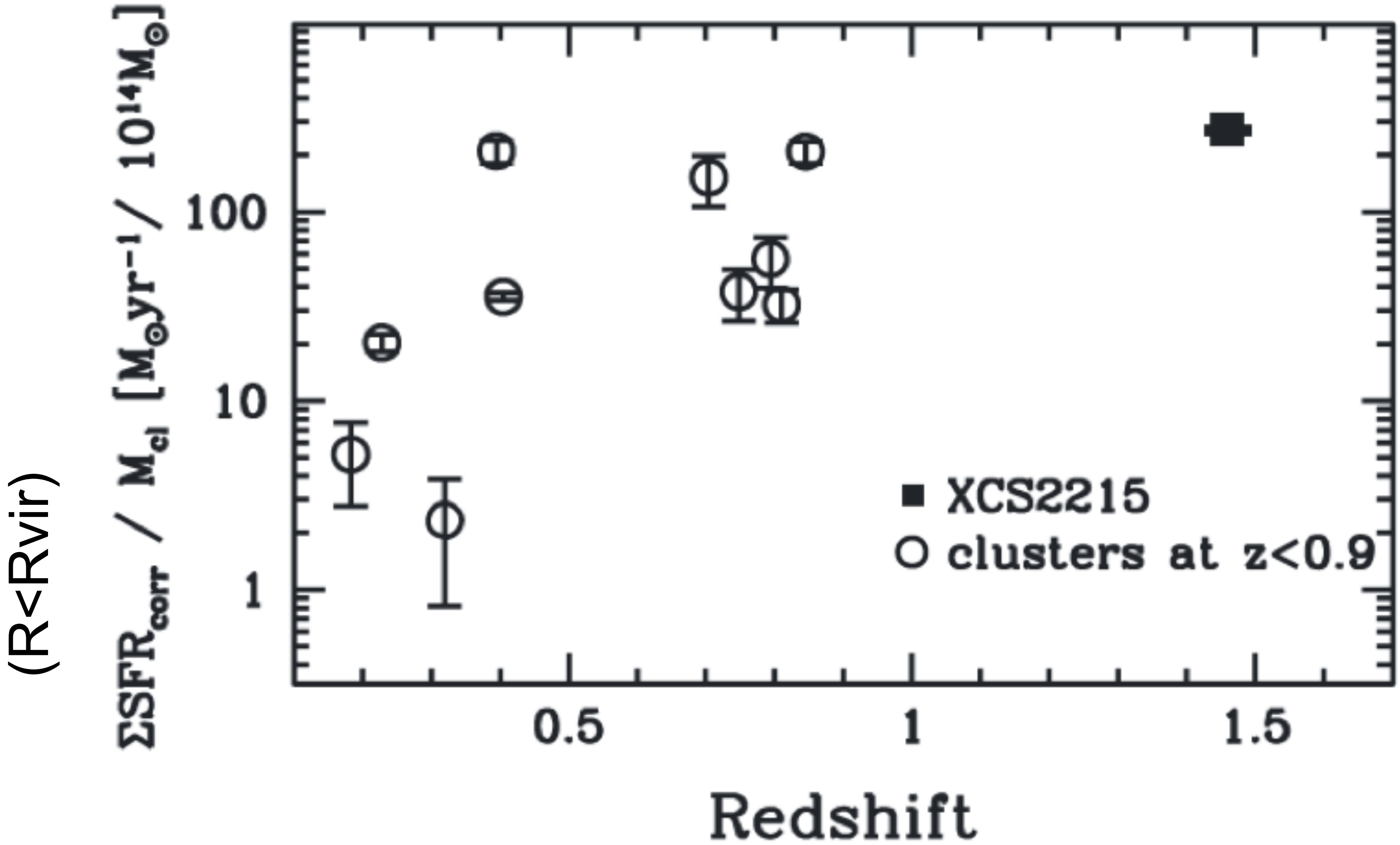


Lx=4.4×10^44 erg/s

Hayashi, et al. (2010)

Clusters Grow Inside-Out !

ΣSFR/M_{cl} vs. Redshift (z)

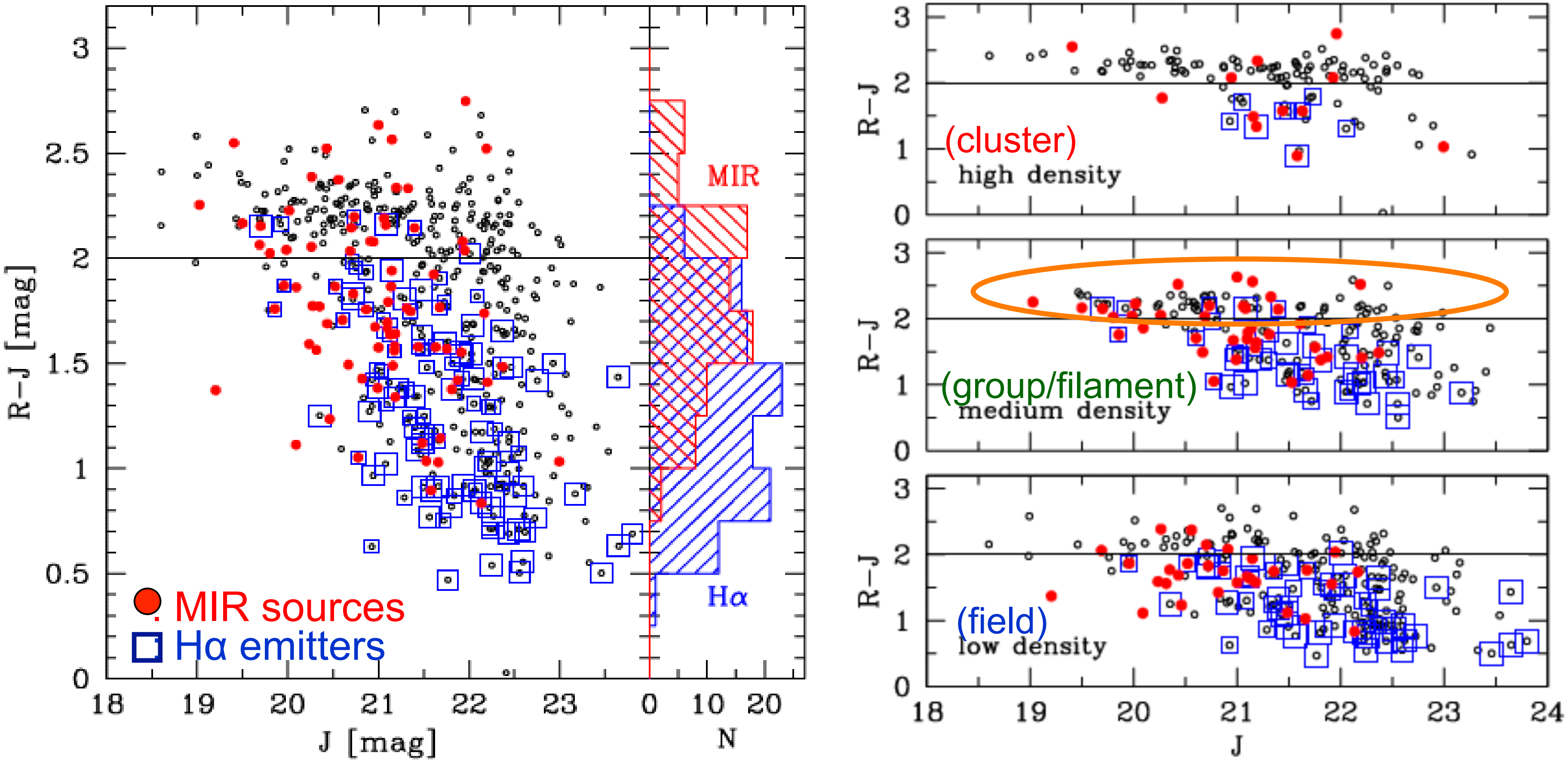


Decline of SF activity by two orders of magnitudes since z~1.5!

Hayashi et al. (2010)

Hidden star formation in the red sequence?

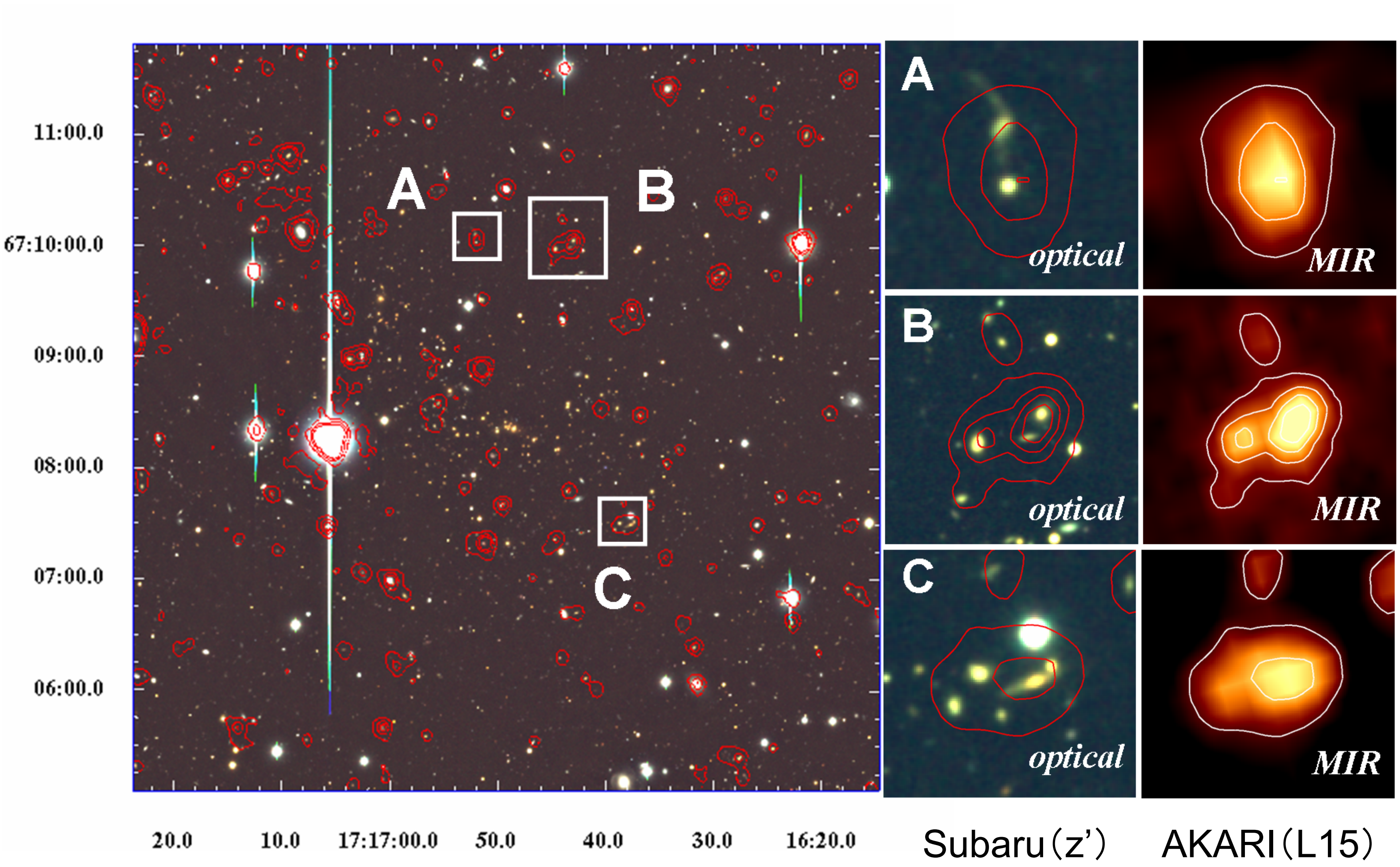
Hα emitters and 15μm sources on the red sequence!



Lots of star formation is likely to be hidden in the optical (rest UV) surveys!

Koyama, TK, et al. (2009)

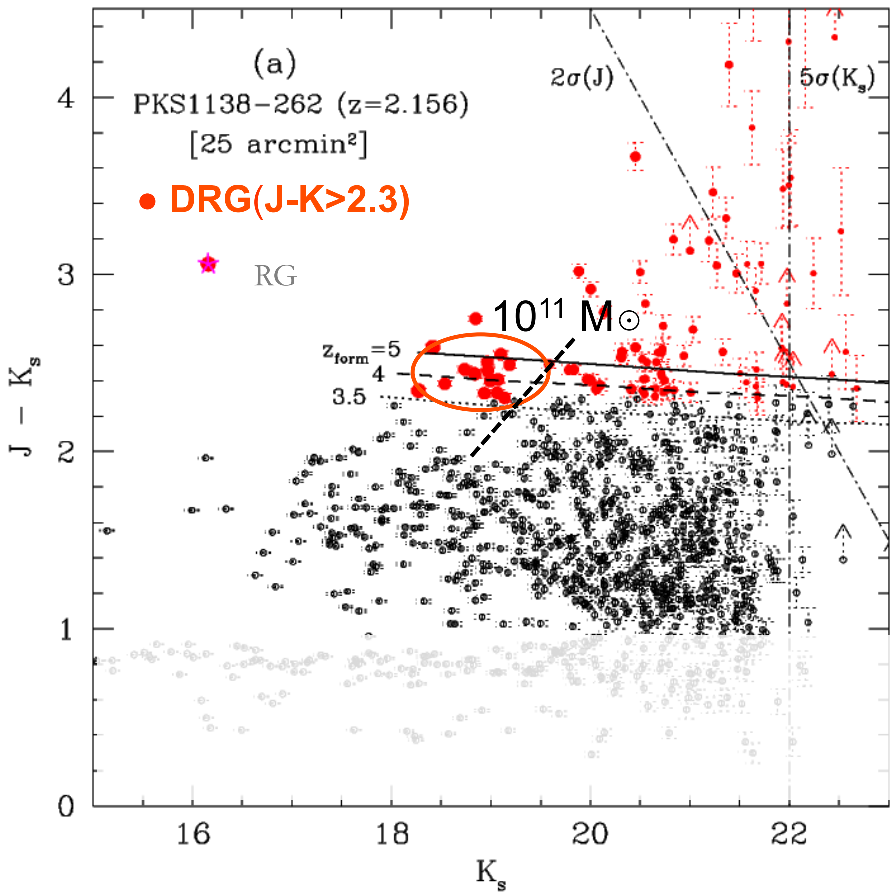
あかり（15μm）で受かった相互作用銀河



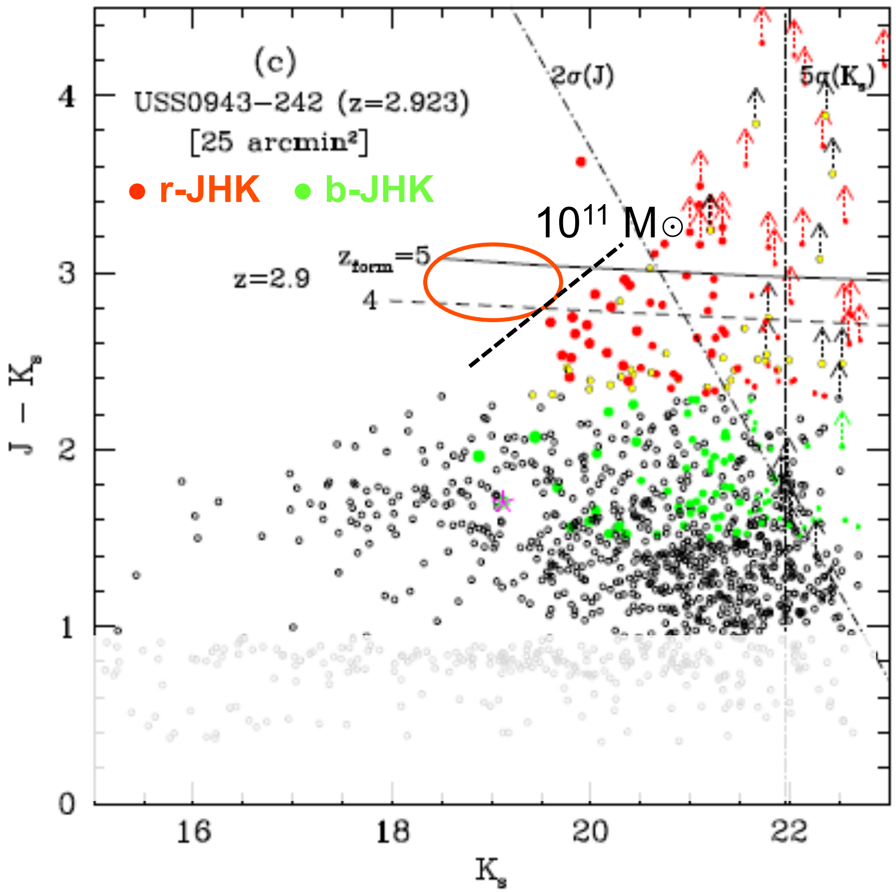
Koyama, TK, et al. (2008)

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

PKS1138 (z=2.16)



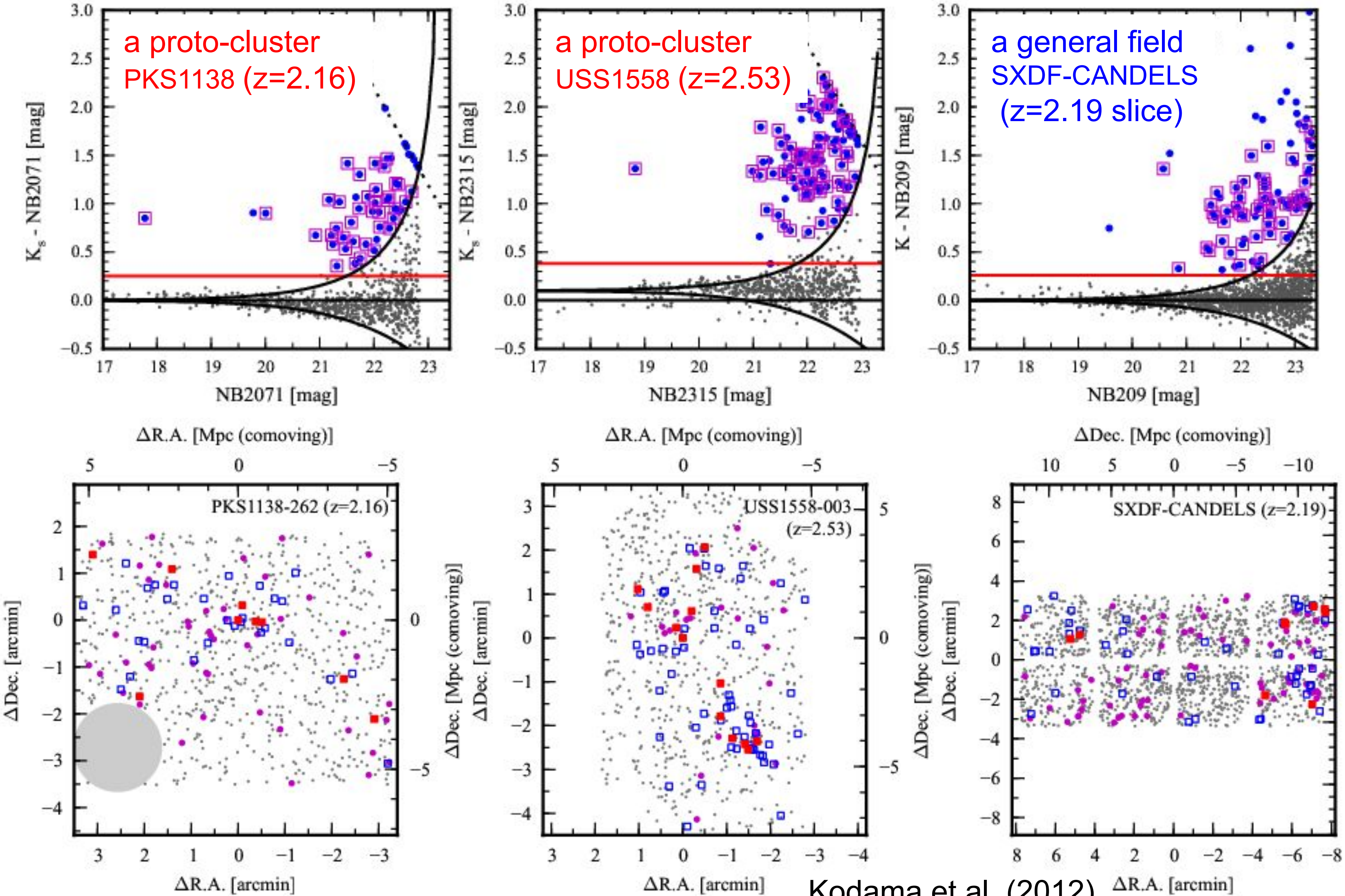
USS0943 (z=2.93)



The red sequence seems to be emerging between z=3 and 2 (2 < Tuniv[Gyr] < 3) !

e.g., 100 $M_\odot$/yr× 1 Gyr = 10^{11} $M_\odot$

Hα emitters in proto-clusters at z>2, and in the field



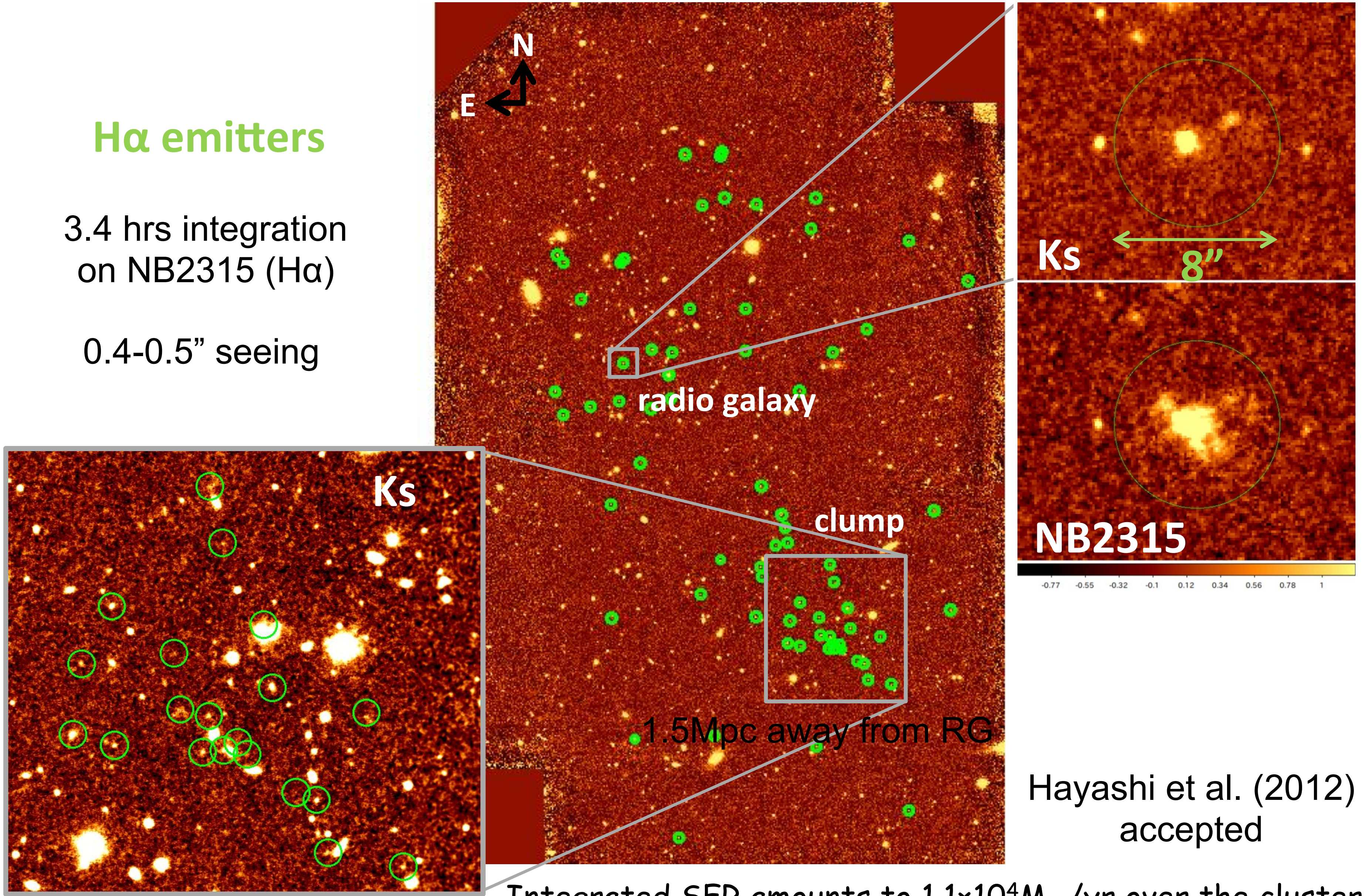
Kodama et al. (2012)

USS1558-003 proto-cluster at z=2.53

Hα emitters

3.4 hrs integration on NB2315 (Hα)

0.4-0.5” seeing



x 24 denser than field

Integrated SFR amounts to $1.1\times10^4 M_\odot$/yr over the cluster

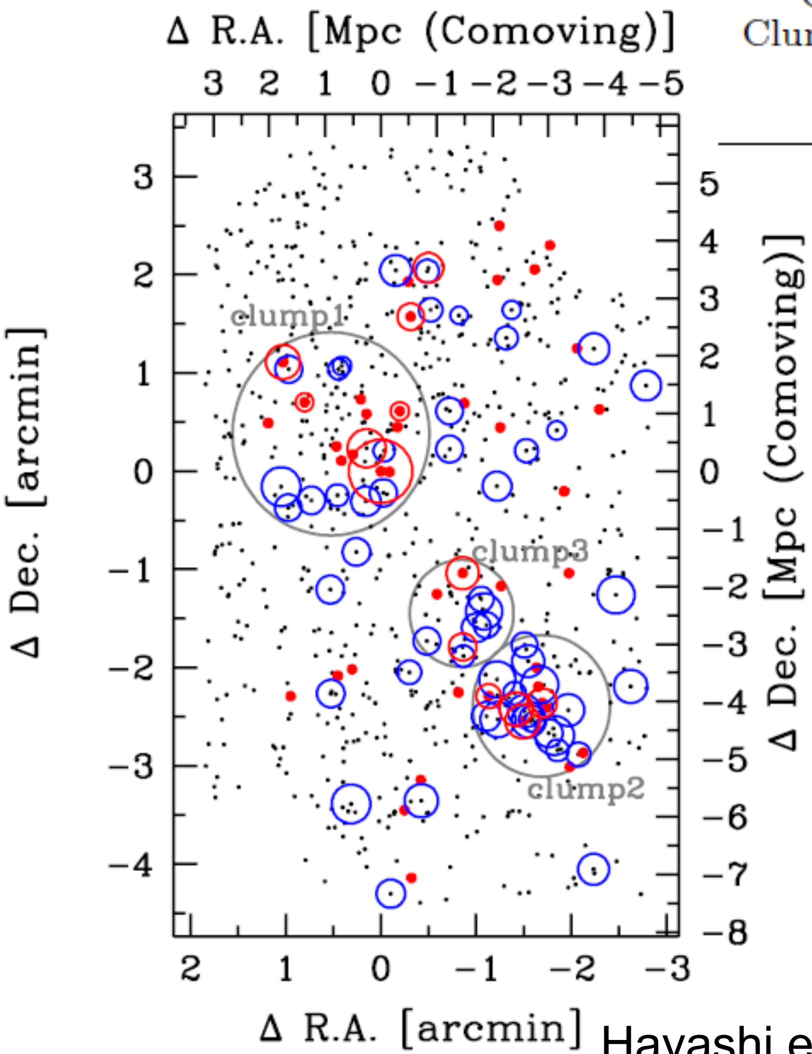
Hayashi et al. (2012) accepted

USS1558-003 (z=2.53)

○ blue HAE

○ red HAE

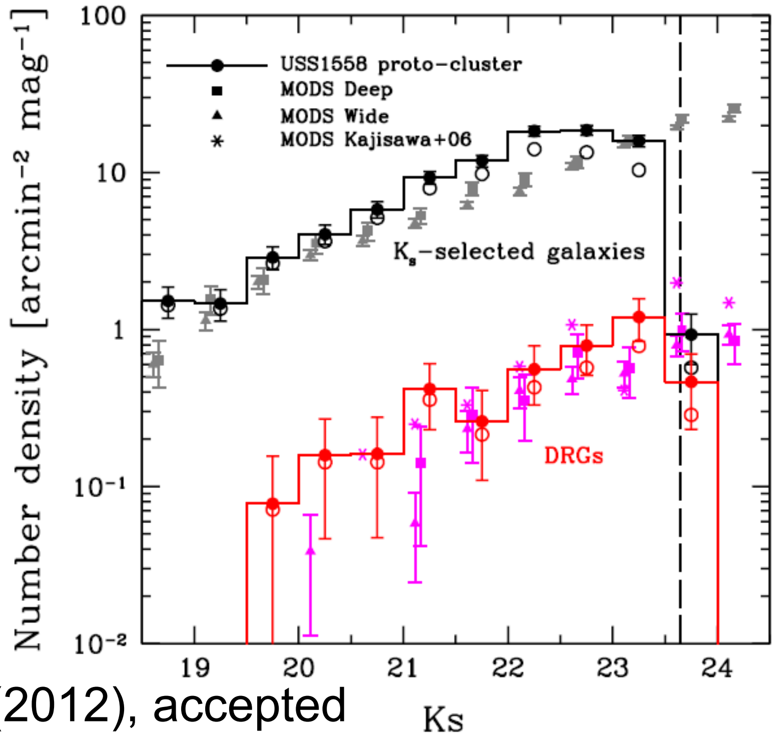
● DRG



Region	Area (arcmin^2)	Number HAE	Number DRG	Density (arcmin^{-2}) HAE	Density (arcmin^{-2}) DRG
Clump 1	3.36	15	12	4.46	3.57
Clump 2	1.64	20	8	12.20	4.88
Clump 3	0.94	8	3	8.51	3.19
Clumps 1+2+3	5.94	43	23	7.24	3.87
Others	21.16	25	19	1.18	0.90
All	27.10	68	42	2.51	1.55
SXDF	110.0			0.5	

Excess of HAEs is huge! (x24 in clump2 and x5 in All)

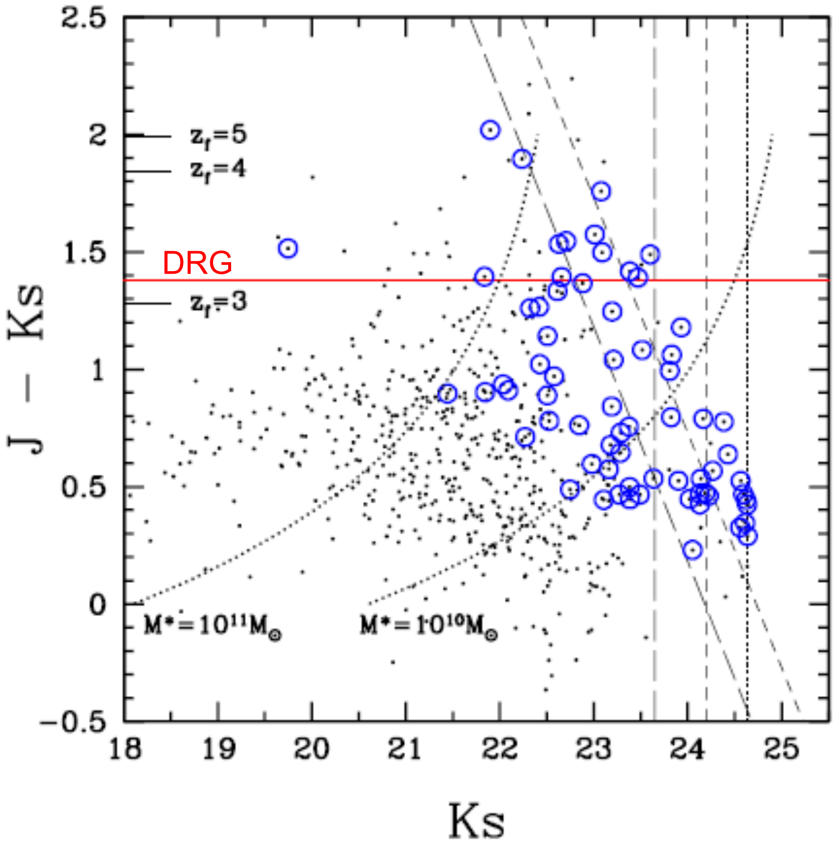
Excess of DRGs is also significant at K<22.

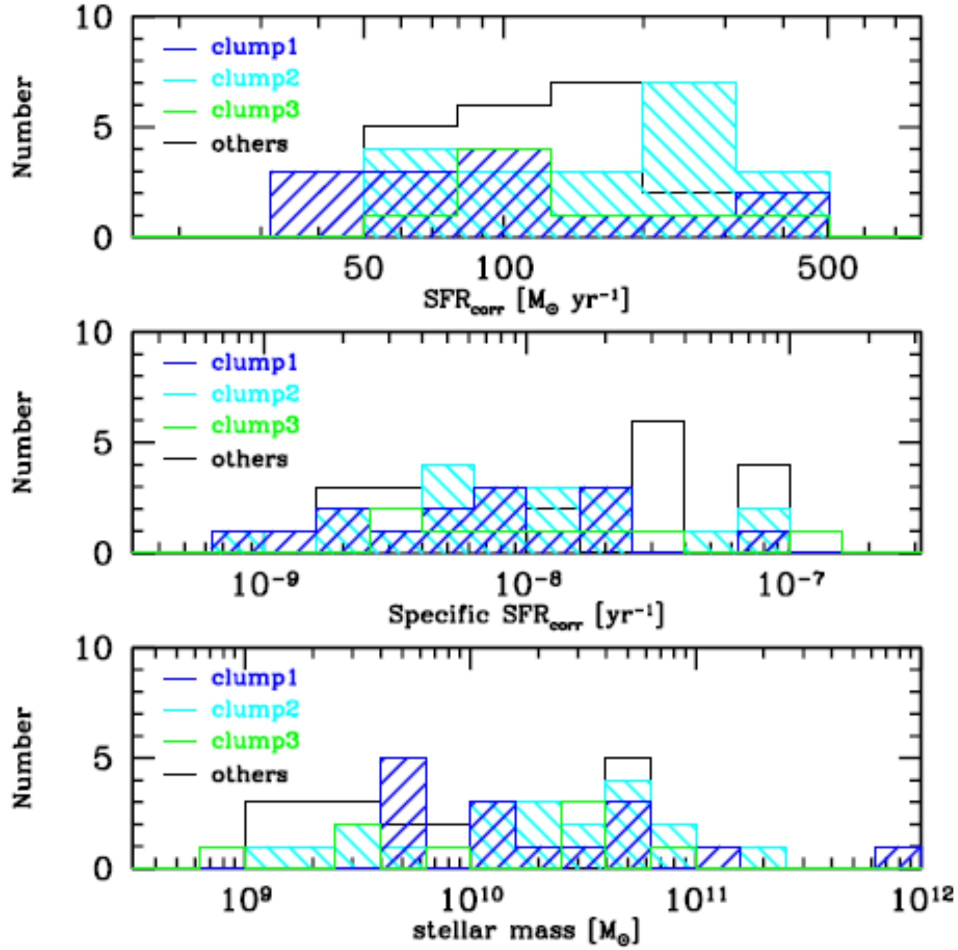


Hayashi et al. (2012), accepted

Properties of Hα emitters in the proto-cluster

USS1558-003 (z=2.53)
Hayashi et al. (2012) accepted



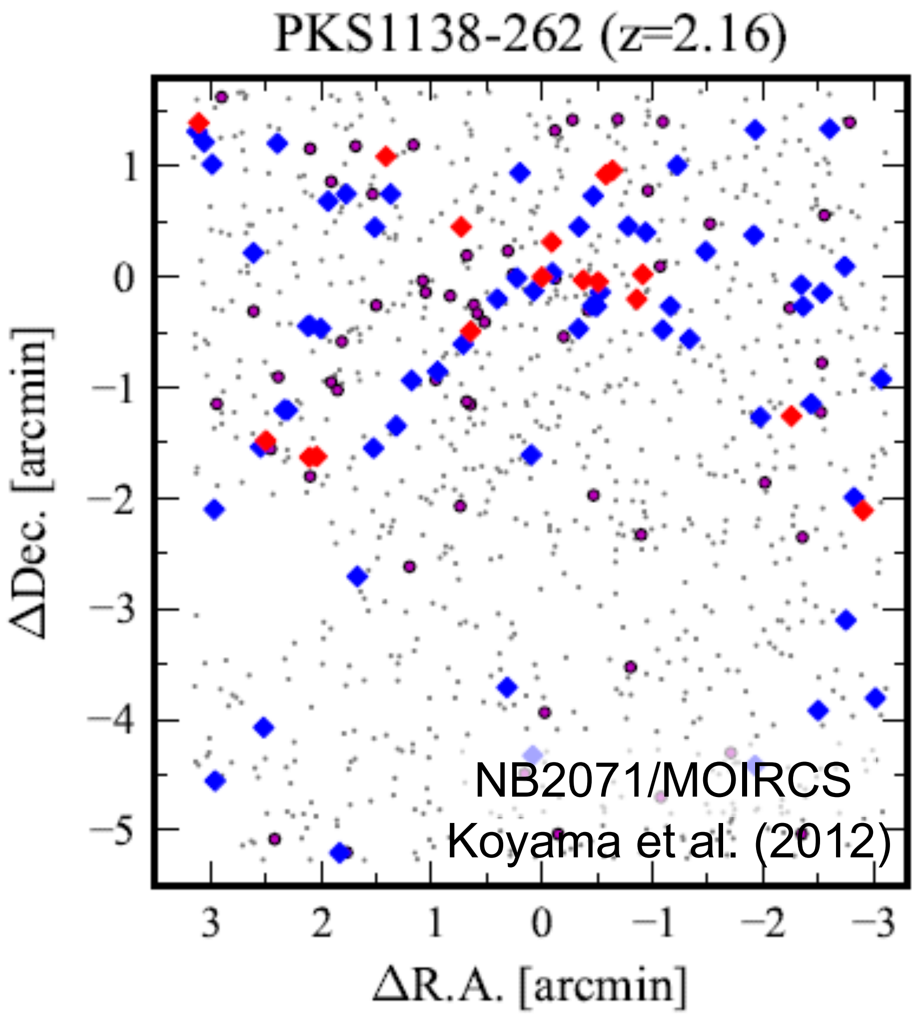


Most emitters are less massive (< 10^{11} $M_\odot$).
Significant fraction of red emitters.

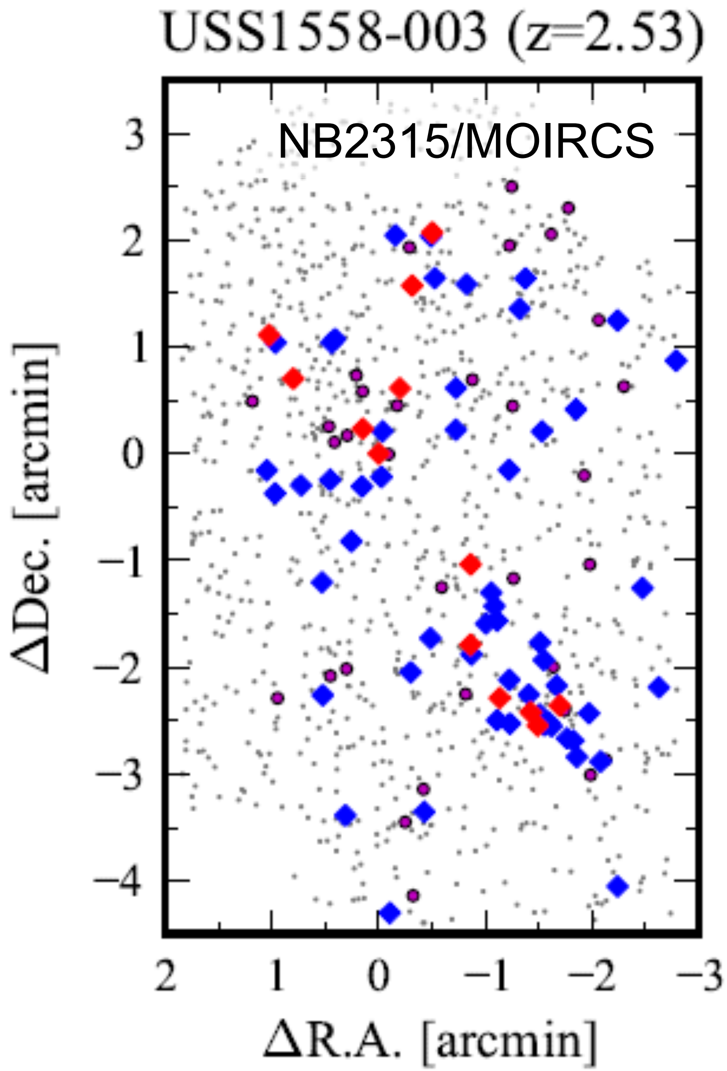
SFRs are generally very high!
Integrated SFR amounts to $1.1\times10^4 M_\odot$/yr
Clump-2 may have higher SFR (at 2σ)

dust extinction is corrected using the Garn's calibration between A(Hα) and L(Hα).

Red Ha emitters tend to favor higher density regions!

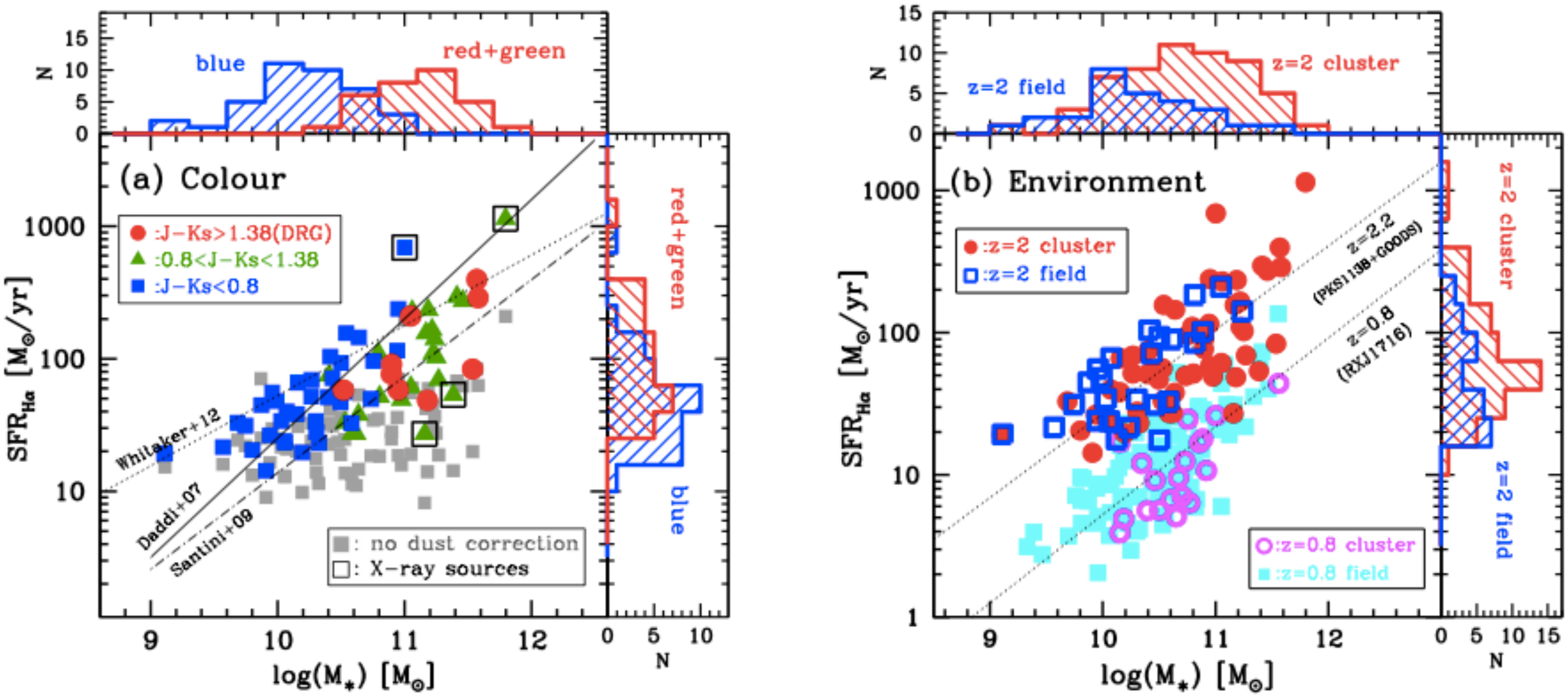


Such "red" Ha emitters are found in groups (medium density regions) at z~0.5-0.8.



Hayashi et al. (2012)

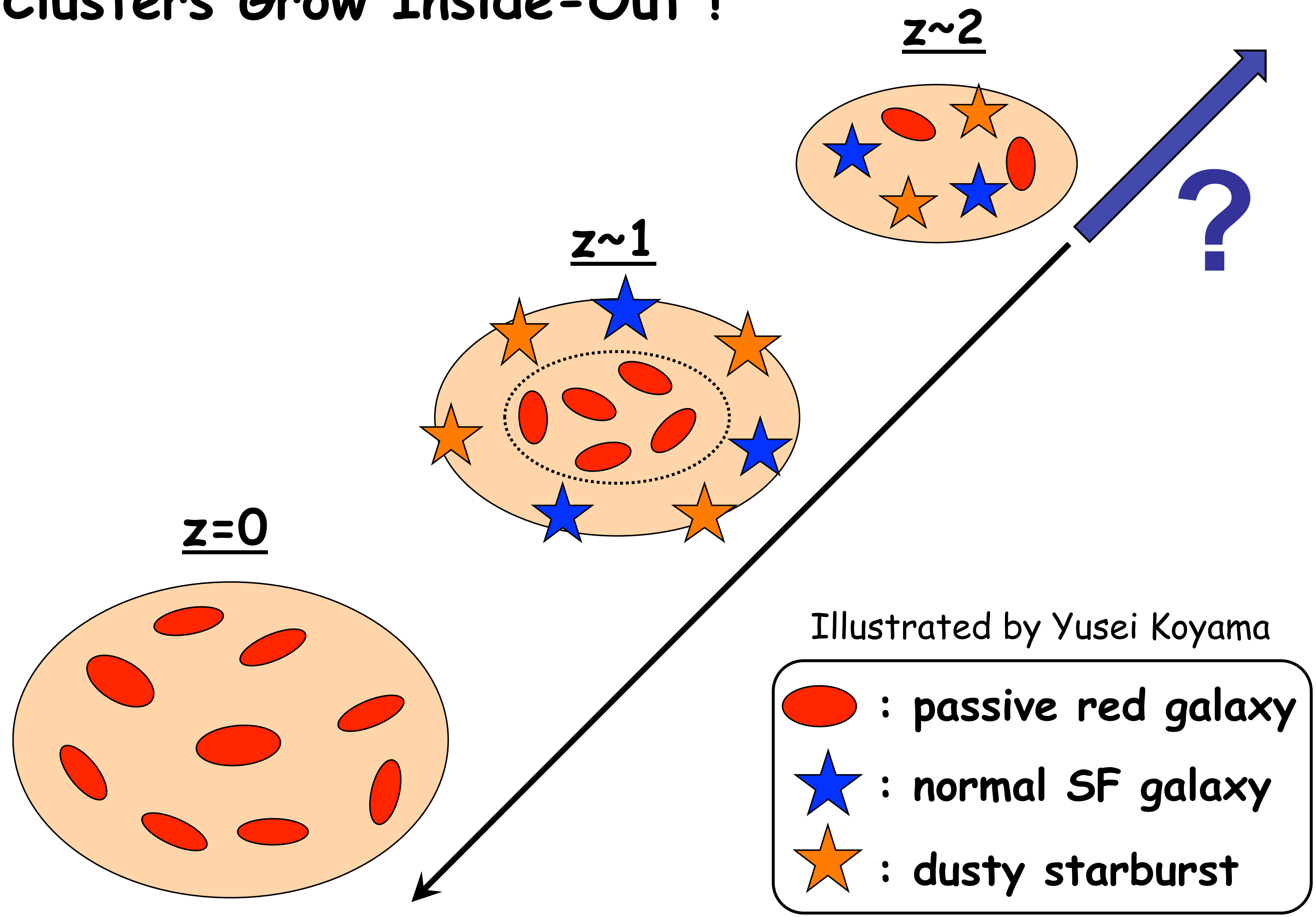
赤いHαエミッターは、星質量が重く、星形成率も高い



高密度領域では、重くて活発な銀河が、早く成長する！

Koyama, et al. (2012), submitted

Clusters Grow Inside-Out !



"Mahalo-Subaru"

MApping HAlpha and Lines of Oxygen with Subaru

"Gracias-ALMA"

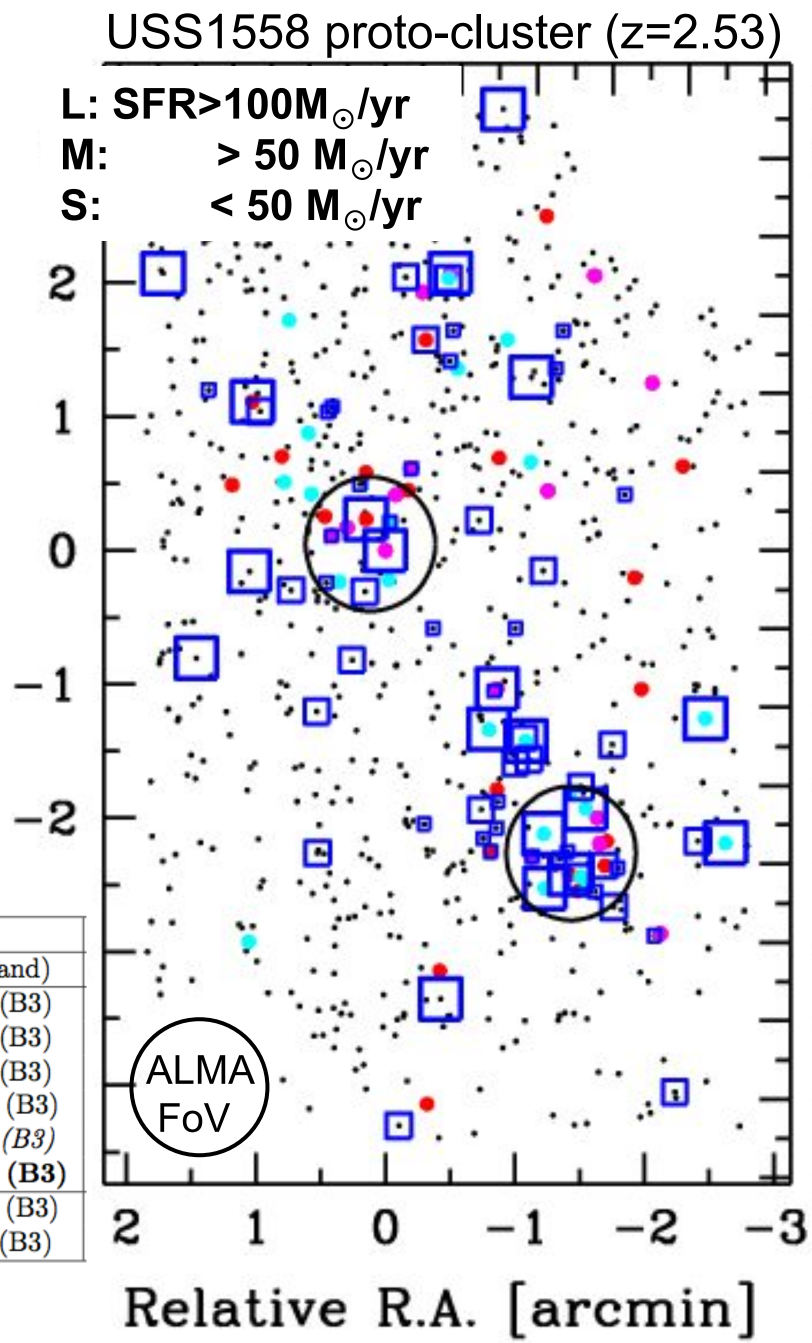
GRAphing CO Intensity And Submm with ALMA

CO(3→2) @ z~2.5 @100GHz → M_{gas}

Dust conti. @450 μm–1.1 mm → Dusty SFR

		Mahalo-Subaru				Gracias-ALMA	
target	z	line	μm	NB-filter	Camera	Continuum	Line@GHz(band)
2215–1738	*1.46*	[OII]	0.916	NB912	S-Cam	*B7,9*	CO(2-1)@94 (B3)
0332–2742	1.61	[OII]	0.973	NB973	S-Cam	B7,9	CO(2-1)@89 (B3)
0218.3–0510	1.62	[OII]	0.977	NB973	S-Cam	B7,9	CO(2-1)@88 (B3)
1138–262	*2.16*	Hα	2.071	NB2071	MOIRCS	*B7,6,9*	CO(3-2)@110 (B3)
4C23.56	*2.48*	Hα	2.286	NB2288	MOIRCS	*B6,7,9*	*CO(3-2)@99 (B3)*
1558–003	**2.53**	Hα	2.315	NB2315	MOIRCS	**B7,6,9**	**CO(3-2)@98 (B3)**
SXDF	*2.19*	Hα	2.094	NB2095	MOIRCS	*B7,6,9*	CO(3-2)@108 (B3)
-CANDELS	*2.53*	Hα	2.315	NB2315	MOIRCS	*B7,6,9*	CO(3-2)@98 (B3)

upon a first galaxy....



ここまでのまとめ

- PISCES is mapping out LSS in and around distant clusters
- Mahalo-Subaru is mapping out star formation activities across time and environment at the peak epoch of galaxy formation and evolution.
- Inside-out propagation of SF in clusters.
- Accelerated formation of massive & high-SFR galaxies in proto-clusters at $z\sim2$.
- Clumpy nature of HAEs at $z>2$.

WISH

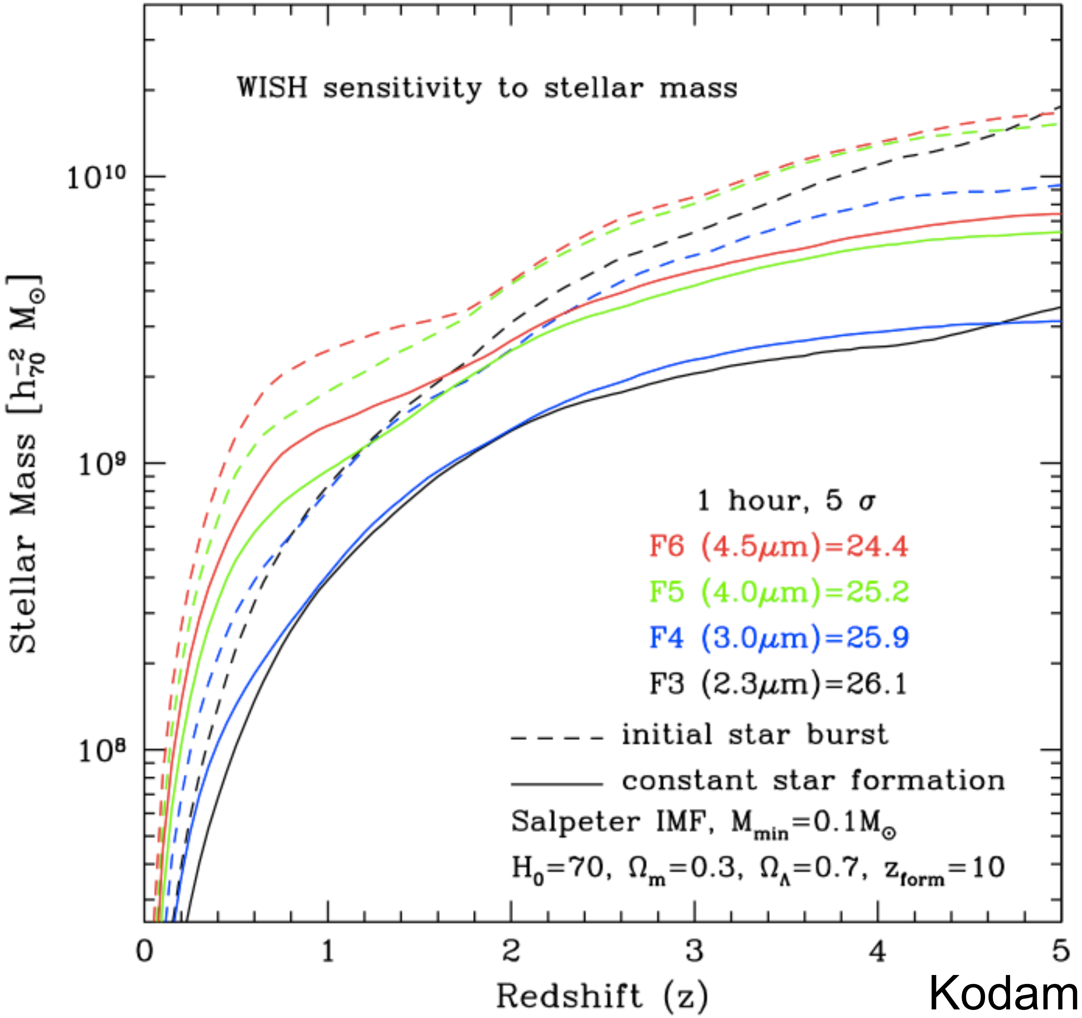
- Broad-band (1-5μm) ＋ HSC (<1μm) の phot-zによる、1.5<z<8における、星質量リミットサンプル（受動的銀河を含む）の構築と研究。

- Narrow-band (2-5μm) のHα輝線探査による、2.5<z<6.6における、星形成率リミットサンプルの構築と研究。

→ これにより、銀河・銀河団の「質量集積」と「星形成」の歴史を、これまでのz＝３から、z＝５-１０まで遡る！

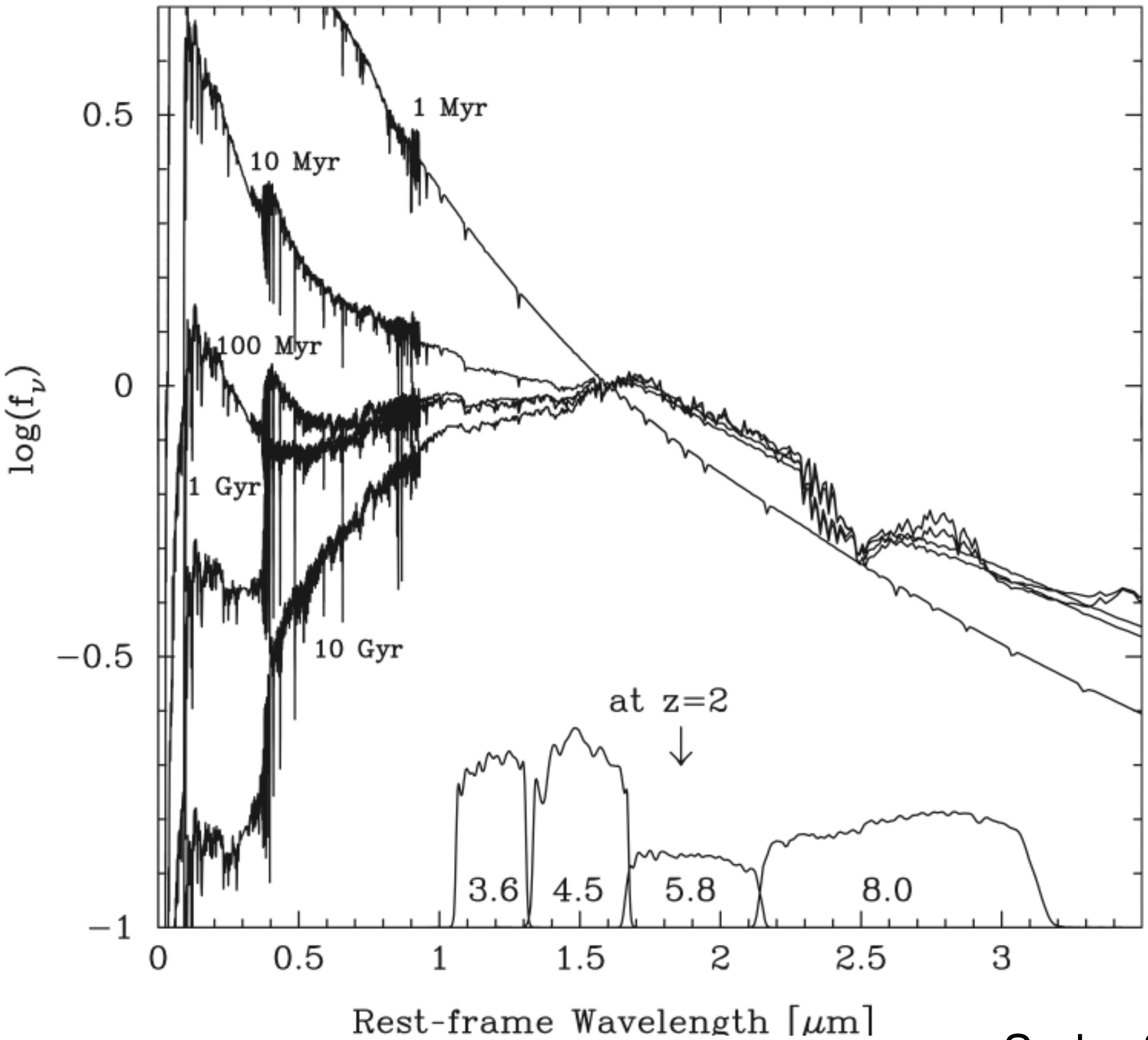
Broad-Band Filters

1時間積分(5σ) ←→ M_{stars} = (3-10)×10^8 $M_\odot$ (z=1) ~
(3-10)×10^9 $M_\odot$ (z=5)



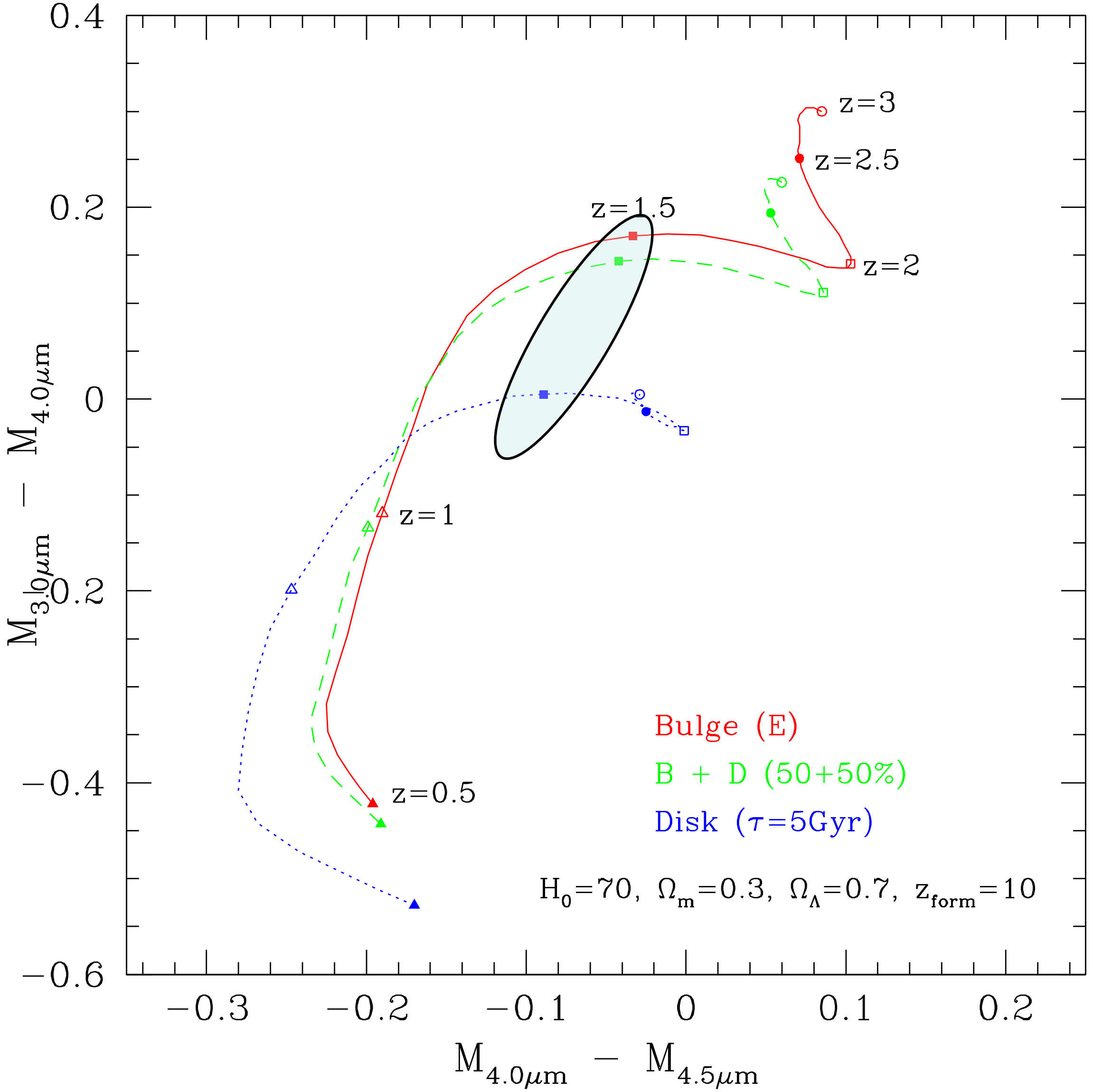
Based on
Kodama et al.'s (1999) model

1.6μm bump



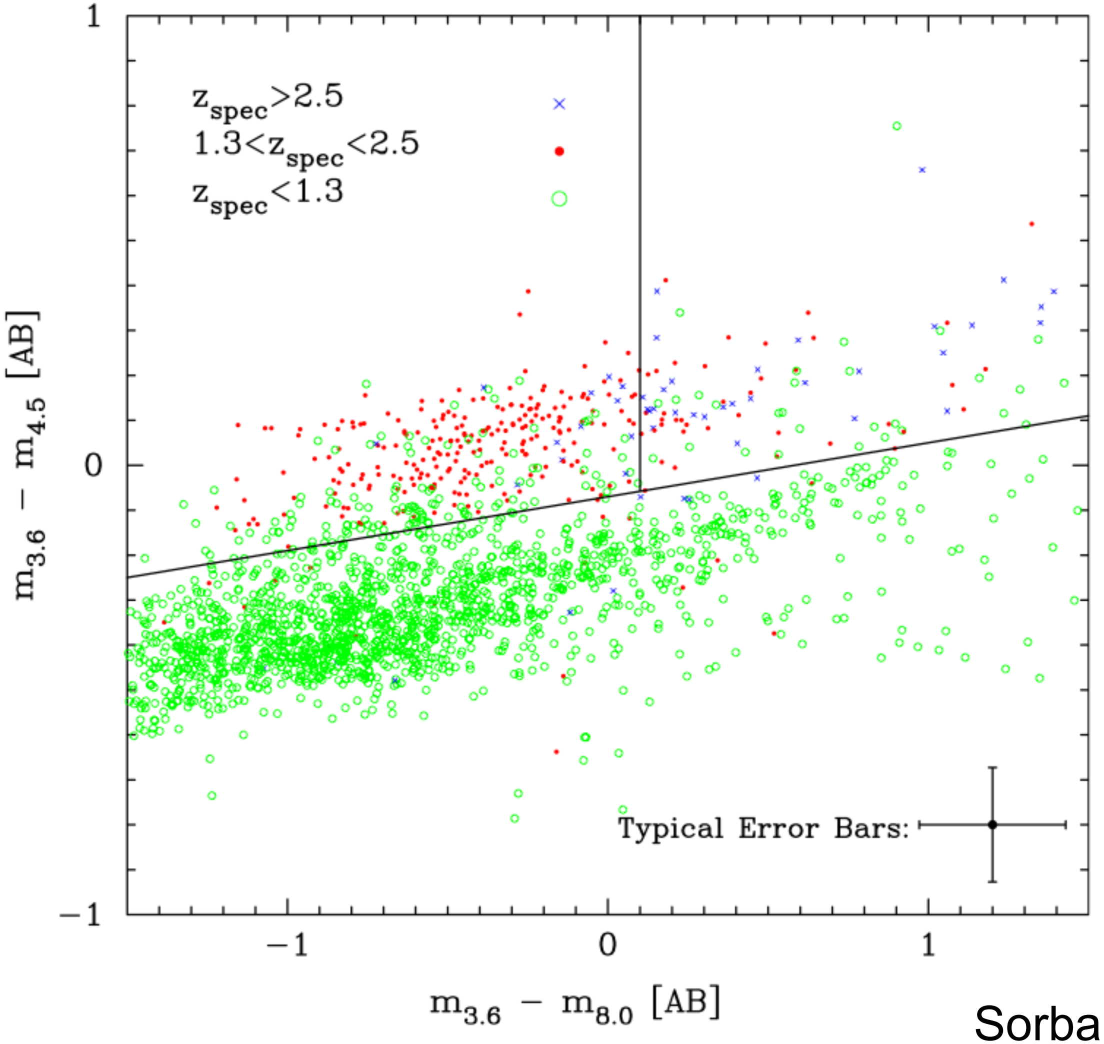
Sorba & Sawicki (2010)

z~1.5銀河に最適（HSCサーベイとのシナジー）



Redshift Confirmation

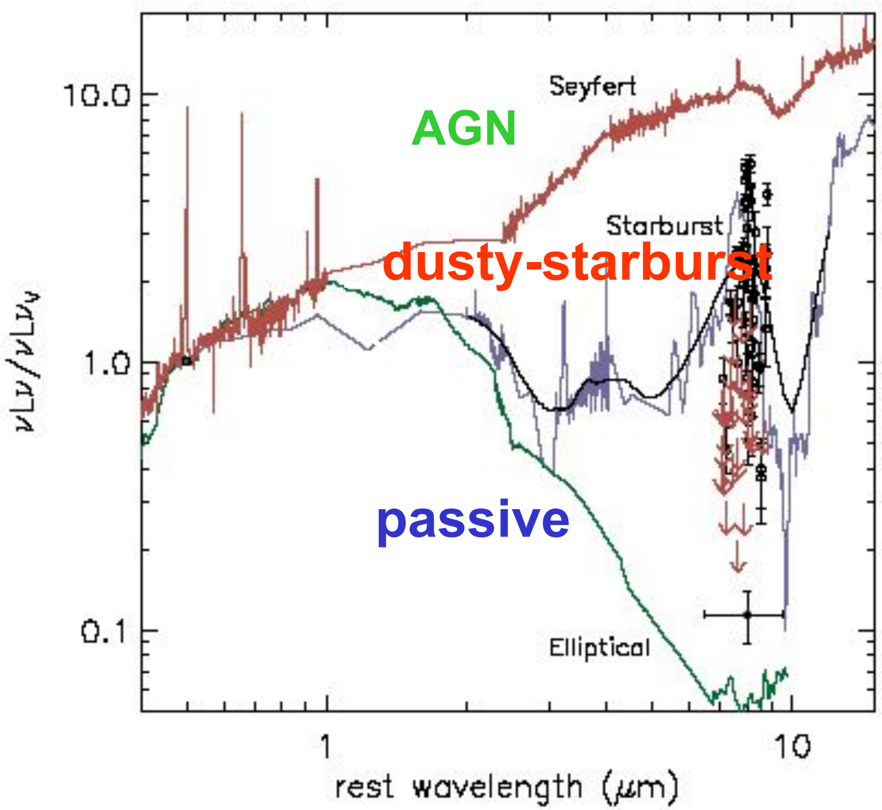
Completeness is high, but lower-z contamination is significant.



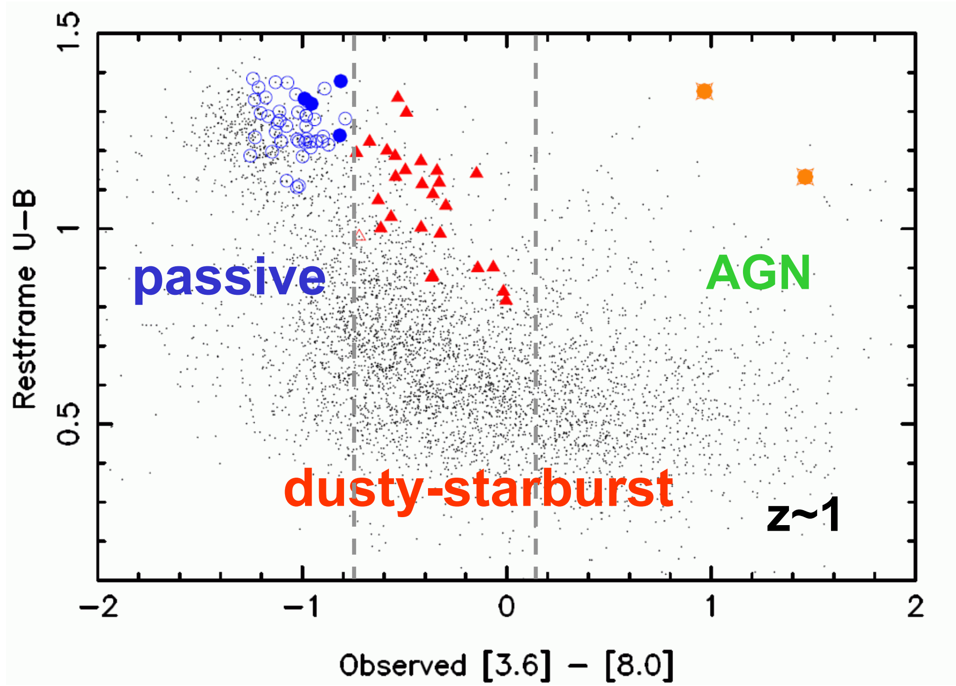
Sorba & Sawicki (2010)

AGN/Starburst/Passive separation

Webb et al. (2006)



Wilson et al. (2006)



SED slope at 1~5μm (rest-frame) can discriminate AGN / SB / E.

Narrow-Band Filters

6時間積分(5σ)
1等吸収補正

NB Filter	Wavelength (μm)	Redshift (Hα)	SFR (Msun/yr)	Number / FoV
NB01-04	2.19	2.33 3.5 (Hβ)	7 50	~1500 (~10)
	2.69	3.1	~15	
	2.95	3.5	~20	~200
	3.25	3.96 5.7 (Hβ)	~30 ~210	~150
NB01-05	4.41	5.7	87	~20
NB01-06	4.97	6.6	252	??

Narrow-Band Filters

6時間積分（5σ）
1等吸収補正

NB Filter	Wavelength (μm)	Redshift (Hα)	SFR (Msun/yr)	Number / FoV
NB01-04	2.19	2.33 3.37 ([OIII])	7 50	~1500 (~10)
	2.69	3.1	~15	
	2.86	3.37	~20	~200
	3.35	4.11 5.7 ([OIII])	~30 ~210	~150
NB01-05	4.41	5.7	87	~20
NB01-06	4.97	6.6	252	??

WISH-7 Survey

- 「**7**」平方度

  ~7×10^7 Mpc^3 / (Δz=1)

  NB: 3.5-7×10^6 Mpc^3 / (Δz=0.05-0.1)

  30 WISH pointings (0.24平方度 / FoV)

- 所要時間

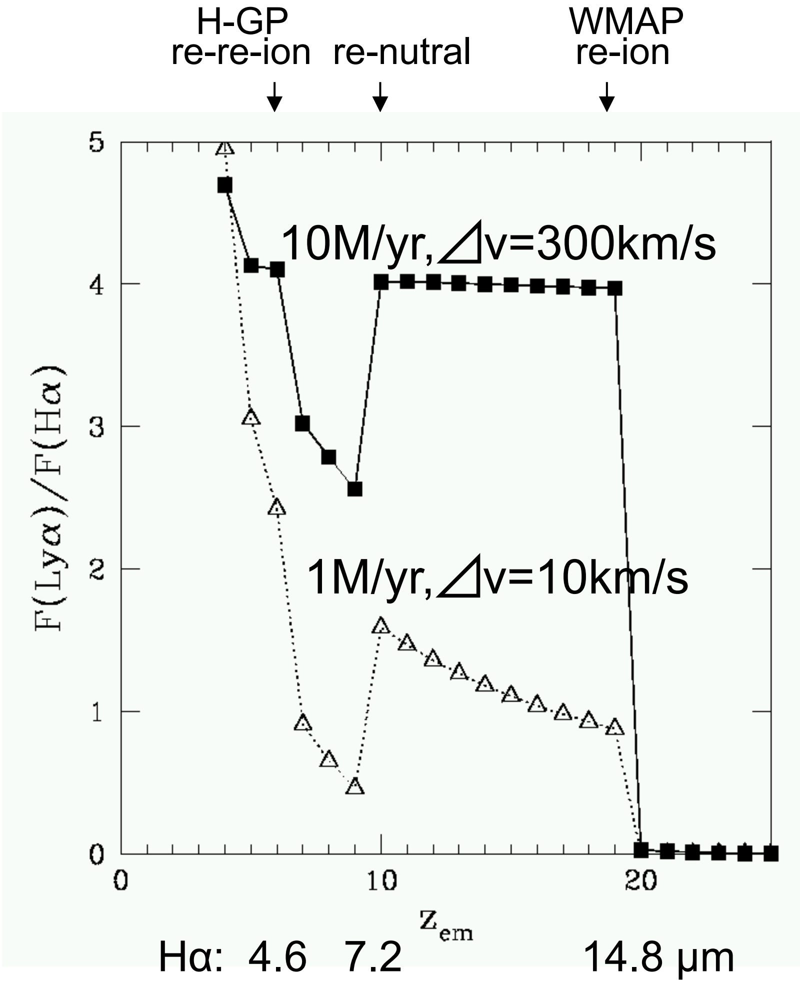
  BB: 1 hrs × 6 filters x 30 p = 180 hrs

  NB: 6 hrs × 4 filters x 30 p = 720 hrs

  計 900 hrs (1200 hrs including overheads)

First Light and Re-ionization

Reionization History



Susa et al.

The End

WISH

upon a first galaxy....