TAO近赤外線装置ワークショップ (IoA, Univ of Tokyo, 11/09/2009)

TAO近赤外装置による原始銀河団研究

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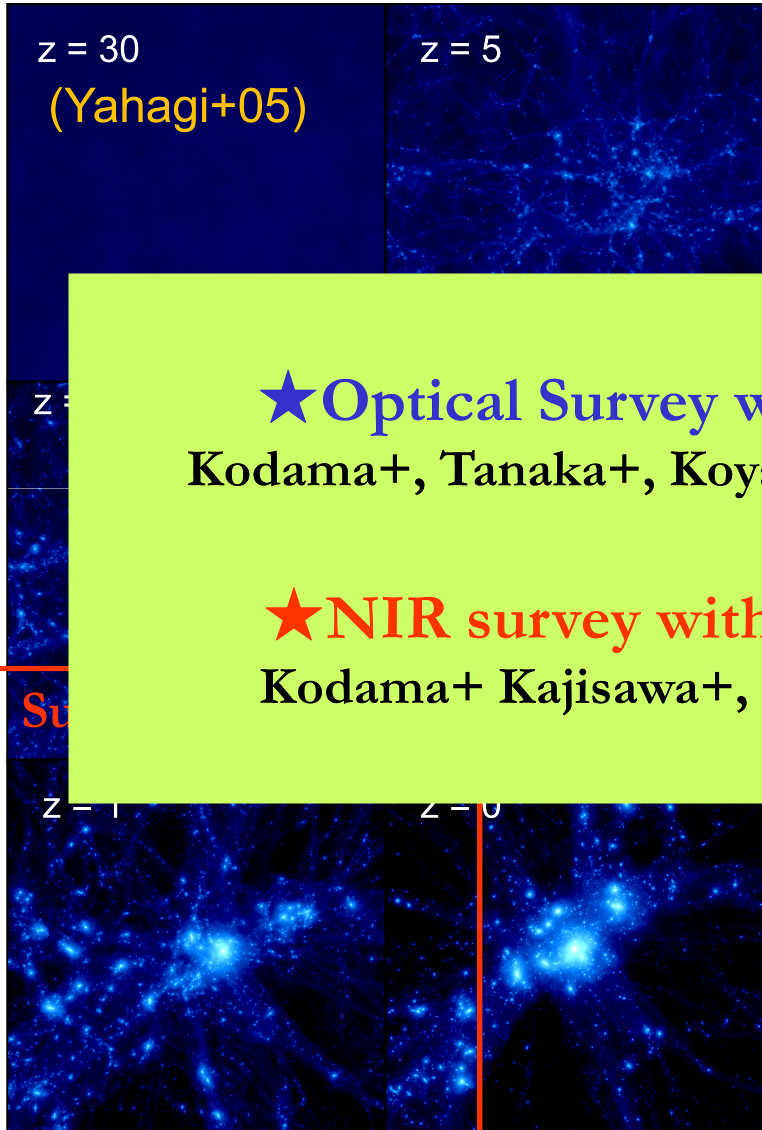
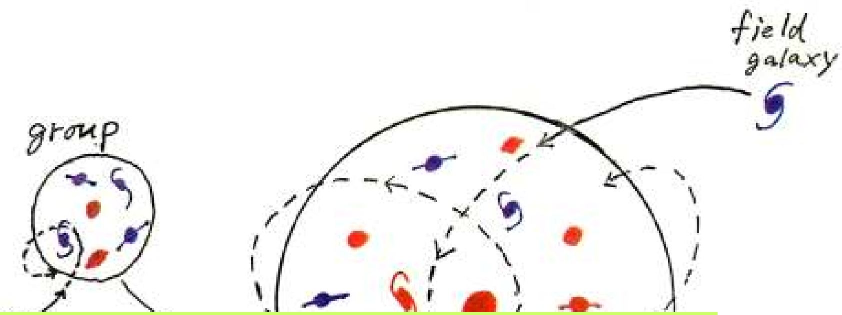
Kenichi Tadaki (U.Tokyo), Ichi Tanaka (Subaru), et al.

Origin of Environmental Dependence

N-body simulation of a massive cluster



$M=6\times10^{14}\ M_{\odot}\ 20\times20 Mpc^2$ (co-moving)



★Optical Survey with S-Cam (0.4<z<1.5):

Kodama+, Tanaka+, Koyama+ Hayashi+, PISCES team

★NIR survey with MOIRCS (1.5<z<5.2):

Kodama+ Kajisawa+, HzRG team (Subaru+ESO)

Su

s it becomes more important at high-z.

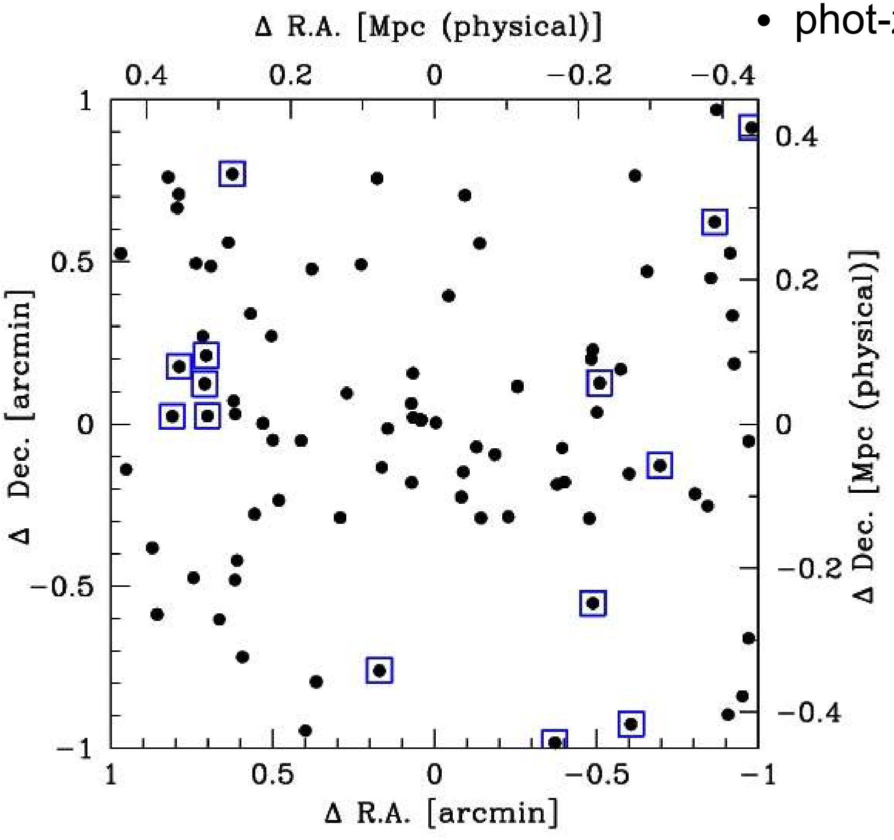
Nurture? (external)

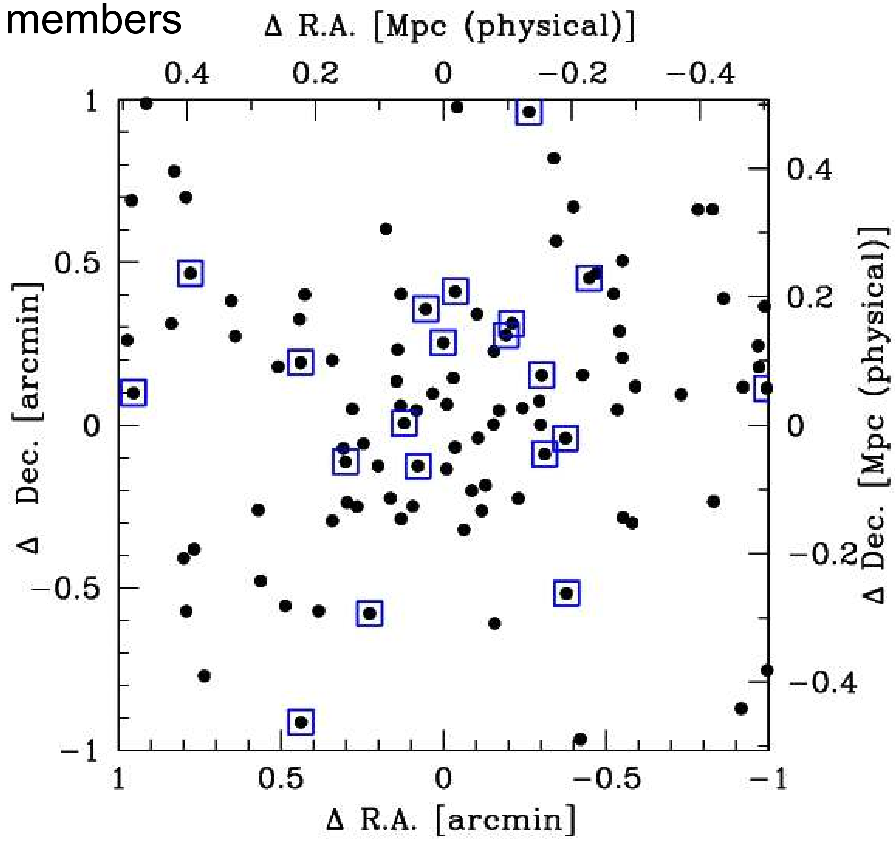
Need to go outer infall regions to see directly what's happening there.

Star forming activity in the cluster cores

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

• phot-z members





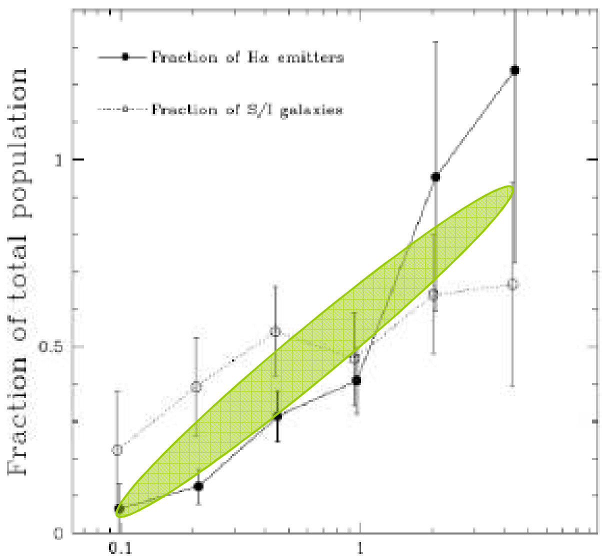
Koyama, TK, et al. (2009) Hayashi, TK, et al. (2009)

Inside-out propagation of star forming activity in cluster cores !?

中心から外側へ星形成活動･減衰が移行する？

Galaxy formation bias & External environmental effects (mergers?)

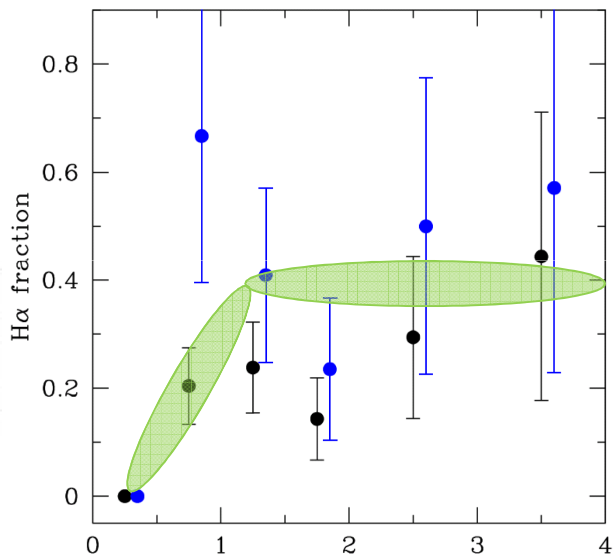
Hα @ z=0.4



Radius [Mpc]

(Kodama+ 04)

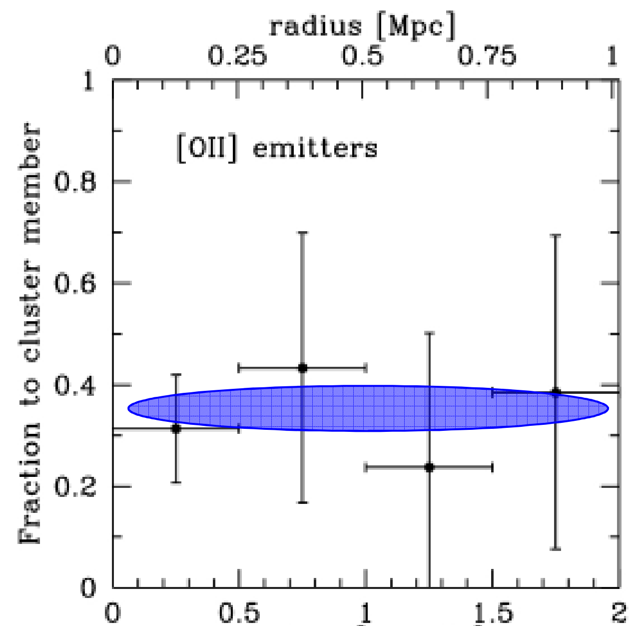
Hα @ z=0.8



Radius [arcmin]

(Koyama+ 09)

[OII] @ z=1.5



Radius [arcmin]

(Hayashi+ 09)

より遠方の原始銀河団で、星形成中の活動的銀河と星形成を終えた受動的銀河の両方をとらえて、それら空間分布の比較とその進化を調べることが重要！

High redshift(z) Radio Galaxies [HzRG] with Subaru, VLT, and Spitzer

7 confirmed proto-clusters at 2 < z < 5.2 associated to radio galaxies

Overdense regions in Lyman-α emitters by a factor of 3—5.

Name	redshift	NIR	Spitzer	Lya	spectra	others
PKS 1138-262	2.16	JHKs	3.6--8.0	16	NIR/Opt	Ha, VLA, Chandra, SCUBA
4C 23.56	2.48	JHKs	3.6--8.0		NIR	Ha
USS 1558-003	2.53	JHKs	3.6--8.0			
USS 0943-242	2.92	JHKs	3.6--24.0	29	Opt	
MRC 0316-257	3.13	JHKs	3.6--8.0	32	NIR	
TNJ 1338-1942	4.11	JHKs	3.6--8.0	37		Suprime-Cam, VLA, MAMBO
TNJ 0924-2201	5.19	JHKs	3.6--24.0	6		Suprime-Cam/ACS (LBGs)

using MOIRCS/Subaru and Hawk-I/VLT

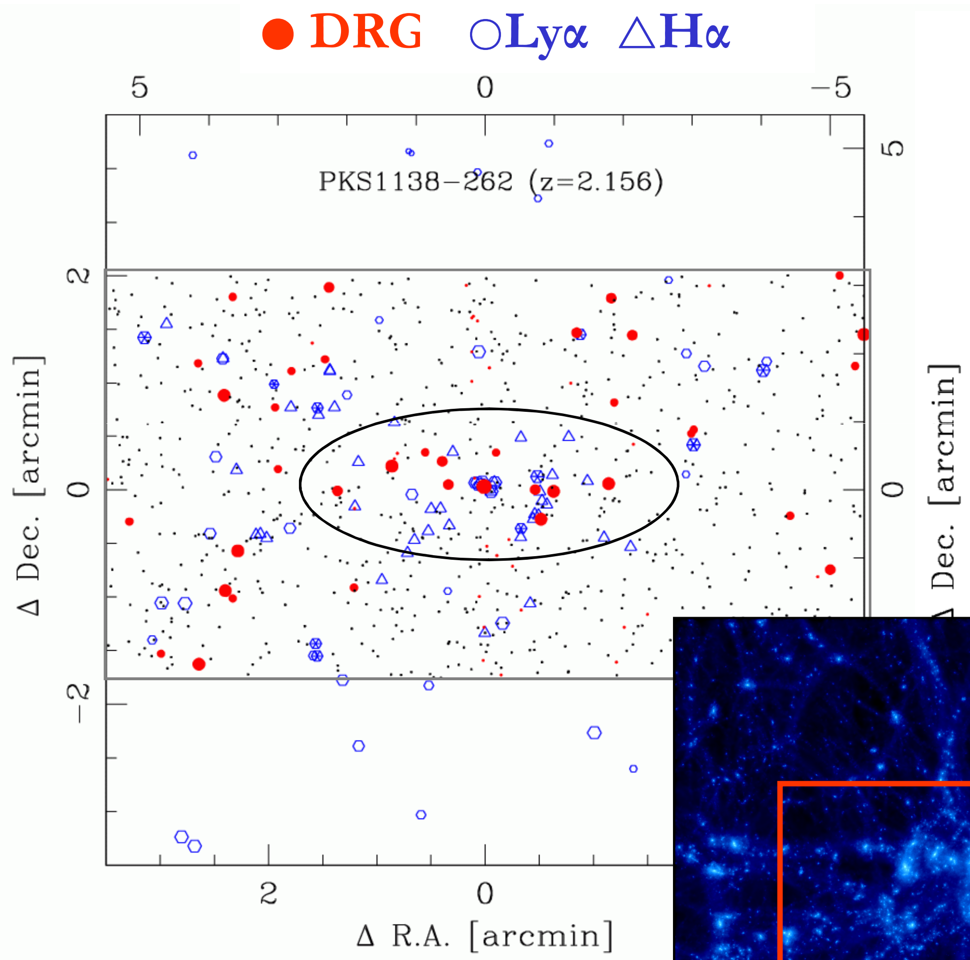
Kodama et al. (2007), De Breuck et al. (Spitzer HzRGs)

今後VISTAサーベイによって、大量の原始銀河団候補（100−1000）が見つかってくる。
すばるでもそう簡単でない深さ（J～24,H～23,K～22）で、系統的な観測はなかなか大変。

Structures in proto-clusters

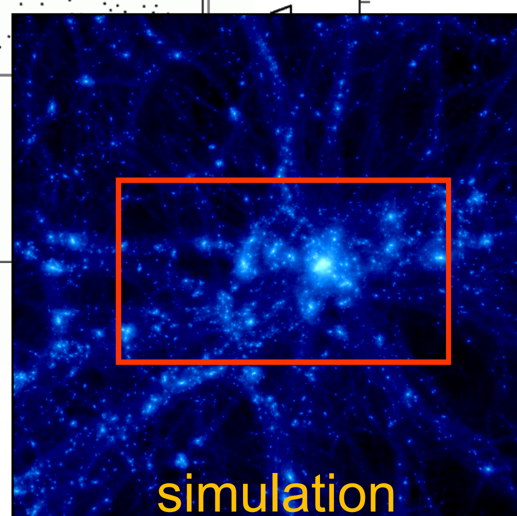
Spatial distribution of NIR-selected member candidates and emitters

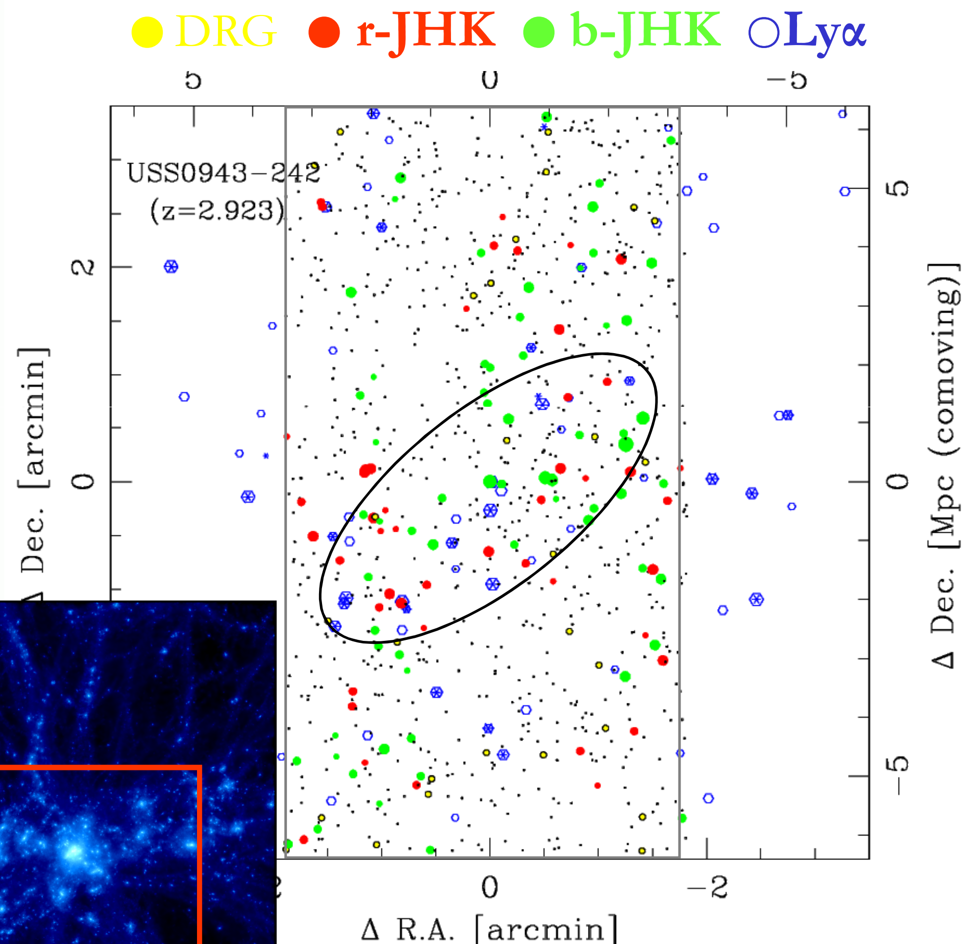
Kodama, et al. (2007)



PKS 1138-262

(z~2, 10.5Gyr ago)



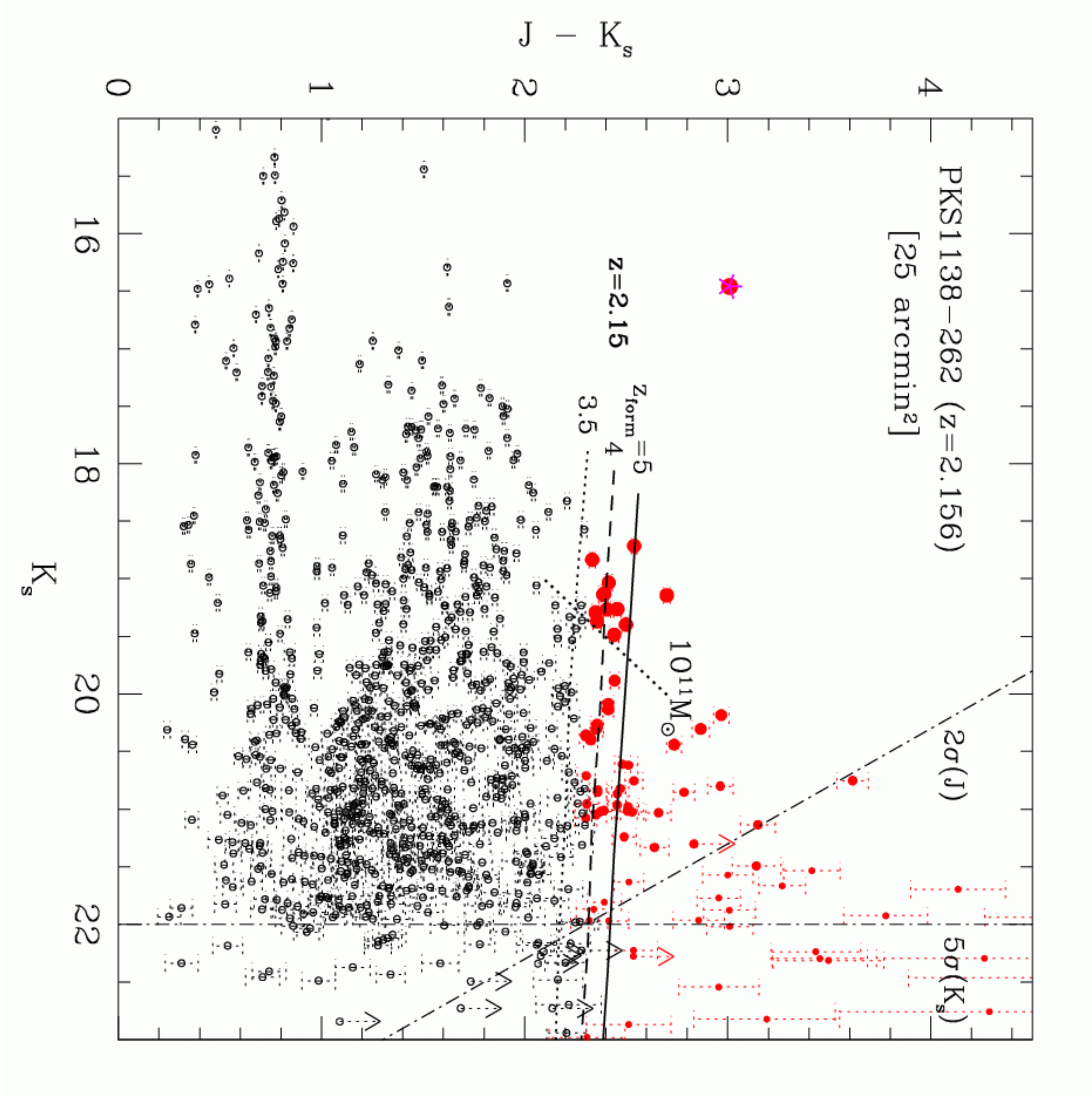


USS 0943-242

(z~3, 11.5Gyr ago)

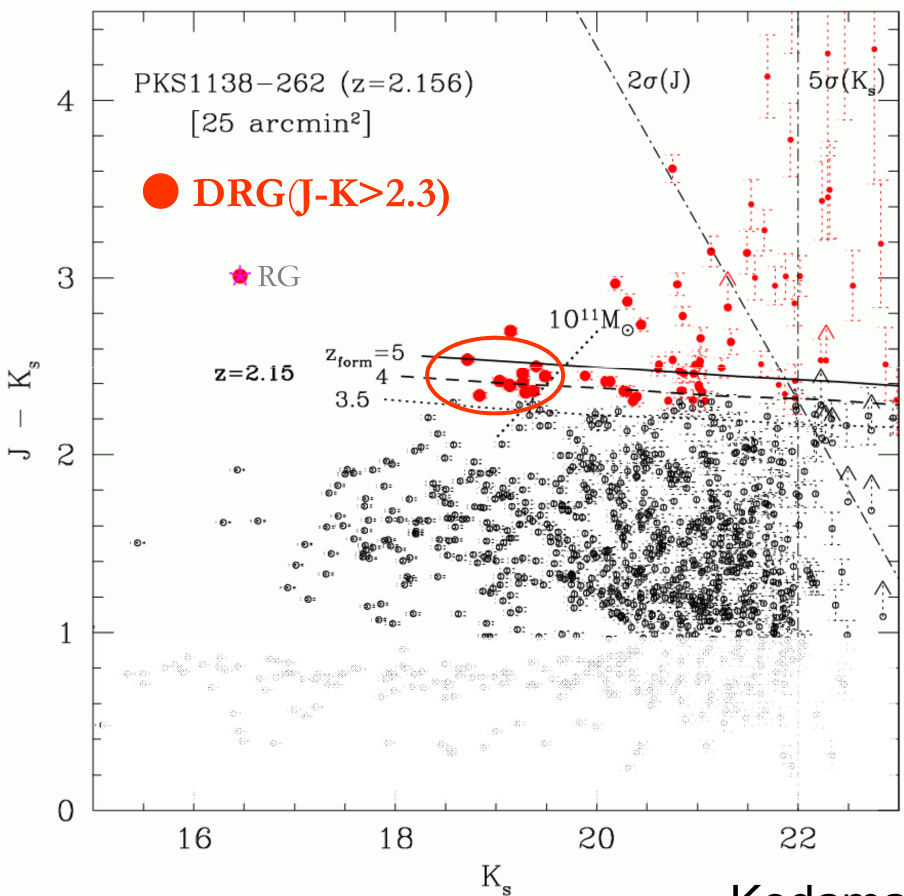
赤い銀河

“Red Sequence” of galaxies

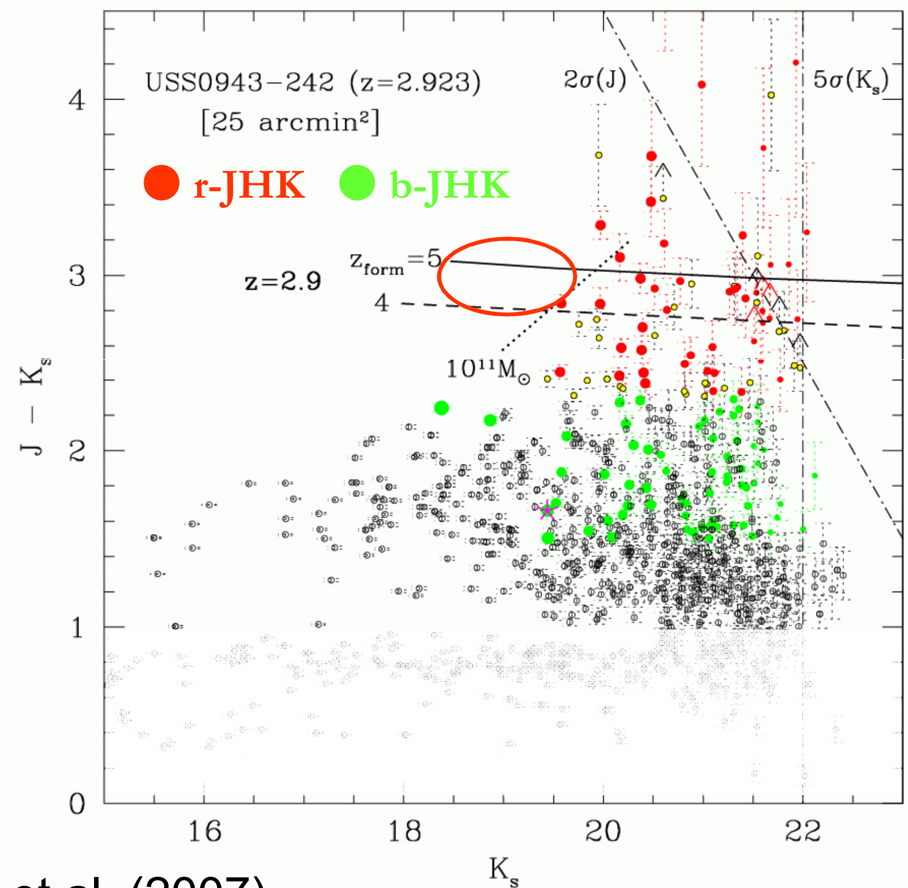


Emergence of the red-sequence at z~2 in proto-clusters?

z~2 (PKS1138)



z~3 (USS0943)



Kodama et al. (2007)

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

Spectroscopic follow-up *"still"* in progress…

Incredibly unlucky with weather so far!
(10 out of 13 Subaru nights were clouded out !)
Nevertheless…

- **Subaru/MOIRCS (NIR, ~30 slits over 7'×4', R=1300, 5 hrs)**

  3 Hα emitters (members) are detected around 4C23.56 ($z=2.483$)
  2 Hα emitters (members) are detected around PKS1138 ($z=2.156$)

- **Subaru/FOCAS (optical, ~30 slits over 6'φ, R=1000, 5 hrs)**

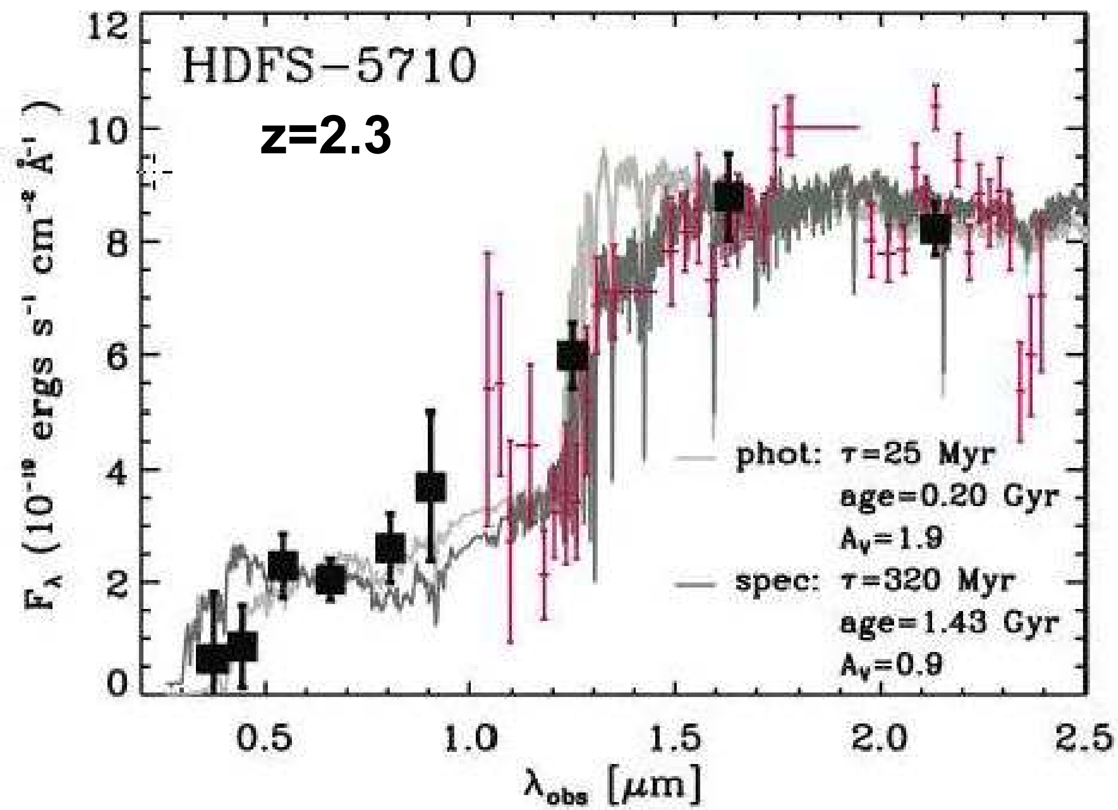
  6 redshifts (Lyα+) are measured for USS0943 ($z=2.923$), of which 2 are members (LAE, b-JHK), while the others are still within $2.4<z<3.1$, consistent with our b-JHK selection.

- **VLT/FORS2 (optical, ~30 slits over 7'×7', R=1000, 5 hrs)**

  11 redshifts (Lya+) are measured for USS0943 ($z=2.923$), of which 2 are members, while 4 out of 9 others are still within $2.4<z<3.1$, consistent with our JHK selection.

We don't see many strong emissions... Need to search for continuum break and/or absorption lines.

Ultra-Deep Continuum Spectrum of a DRG



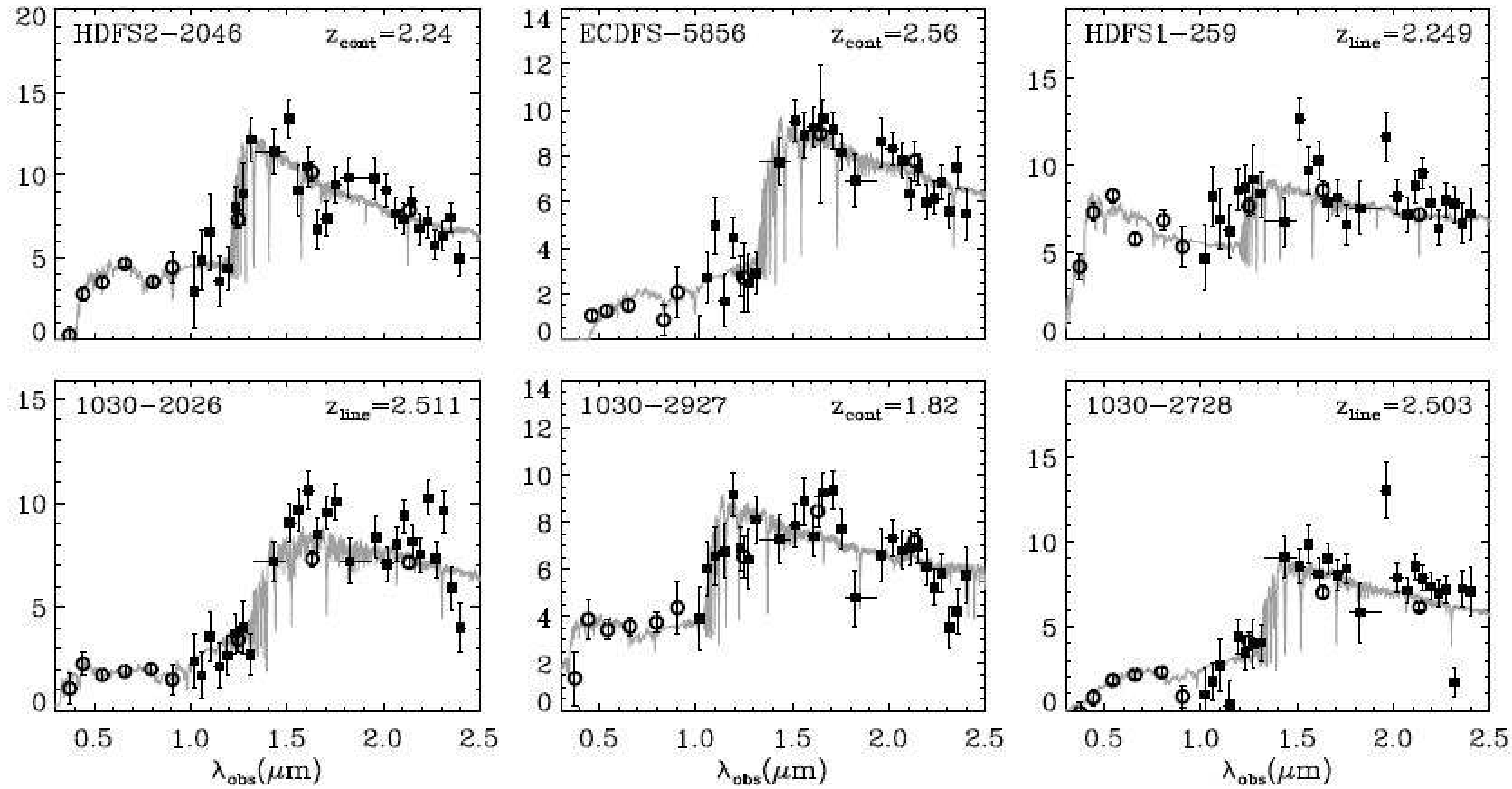
Kriek et al. (2008)

GNIRS on Gemini-S, R=1000, 20-30hrs?

これが限度！

Continuum (Balmer/4000Åbreak) redshifts for DRG

Kriek et al. (2008)



MUSYC survey, K<19.7　GNIRS on Gemini-S, R=1000, 2-3hrs each

R=1000のデータをR=40-50になまらしてSEDを得、ブレイクの位置からzを決める。
遠方(z>1.5)の赤い銀河のzを決めるのに有効な方法。$\Delta z/(1+z) < 0.019$ (~6000km/s)

NEWFIRM Medium-Band Survey (Kitt Peak 4m, 27.6’ × 27.6’)

van Dokkum et al. (2009), arXiv:0901.0551

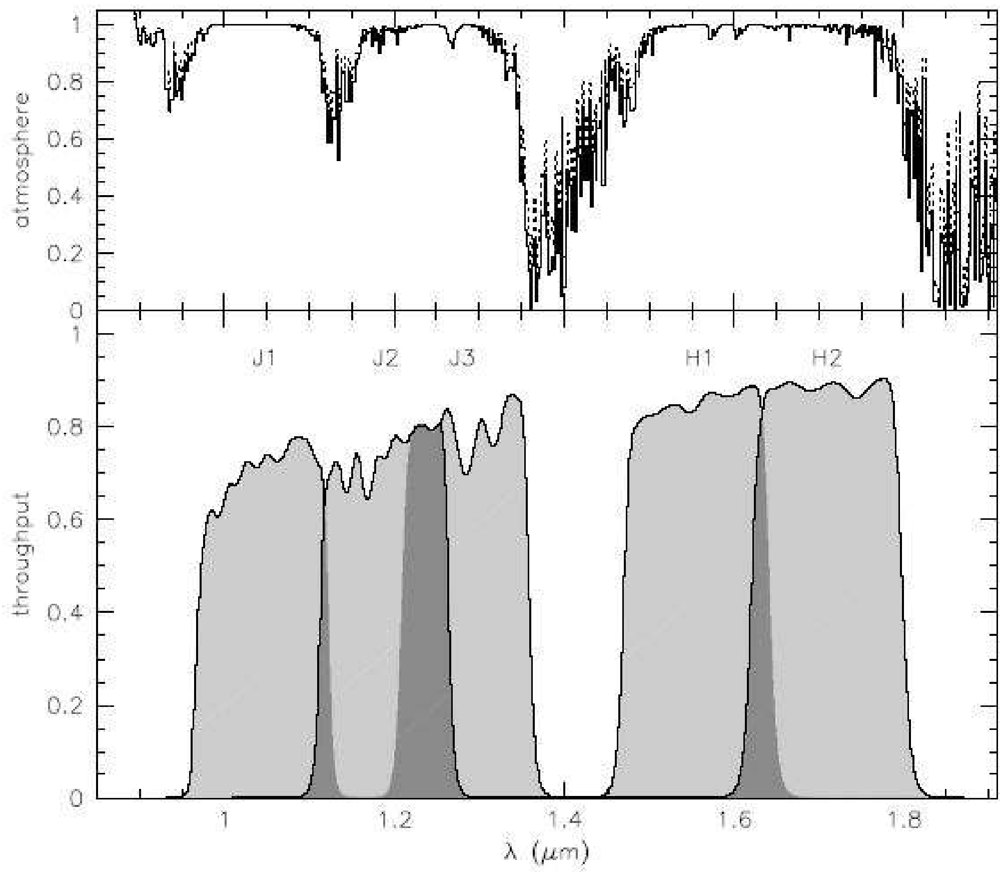


Fig. 1.— Medium-bandwidth filters designed for NEWFIRM and used in the NMBS. The throughput of the filters ranges from ≈ 70 % for J_1 to ≈ 90 % for H_2 (excluding effects of the atmosphere). The top panel shows the atmospheric transmission spectrum, for two different water columns: the broken line is for a column of 1.6 mm and the solid line is for 3.0 mm.

Medium-band redshifts

● NEWFIRM medium-band data

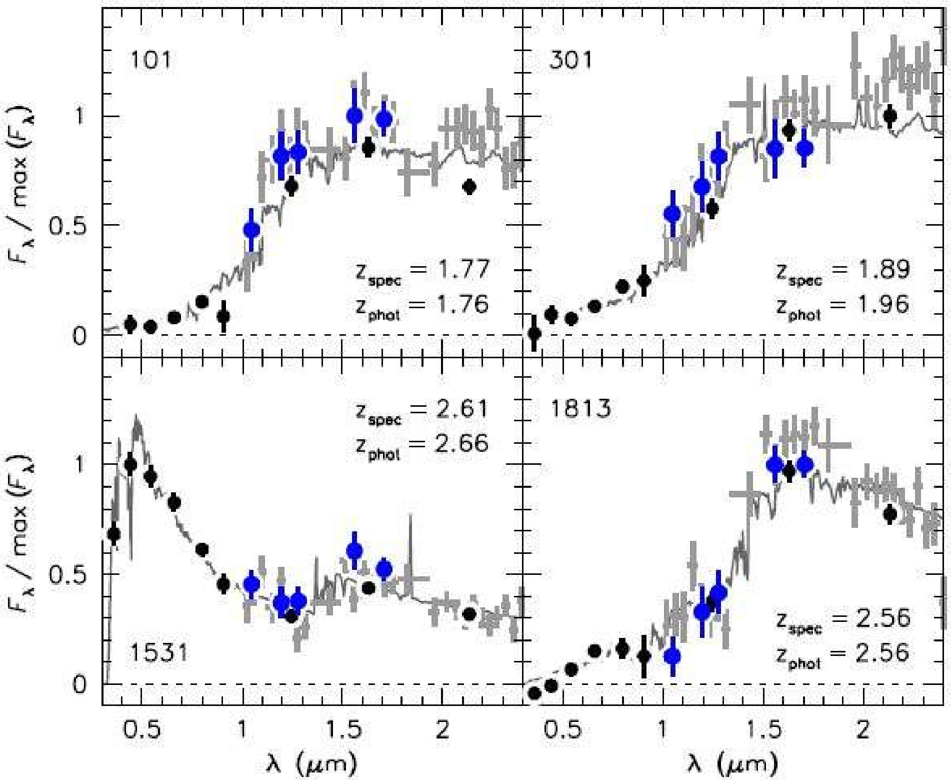


Fig. 2.— Spectral energy distributions from 0.3 – 2.4 μm of the four galaxies in the SDSS 1030 Kriek et al. (2008) sar
the highest S/N ratio. Black points are broad band photometric data, blue points are the new medium band data. The med
data are able to pinpoint the location of rest-frame optical breaks in the spectra. Dark grey spectra are the best-fit EAZ
SEDs. Light grey points are binned near-IR spectra obtained with GNIRS on Gemini, from Kriek et al. The best-fit model
the (independent!) GNIRS spectra very well.

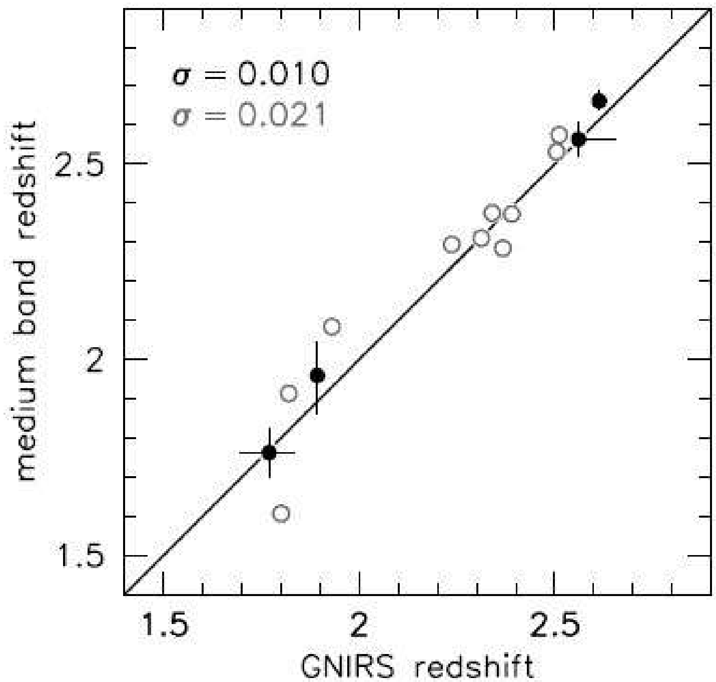
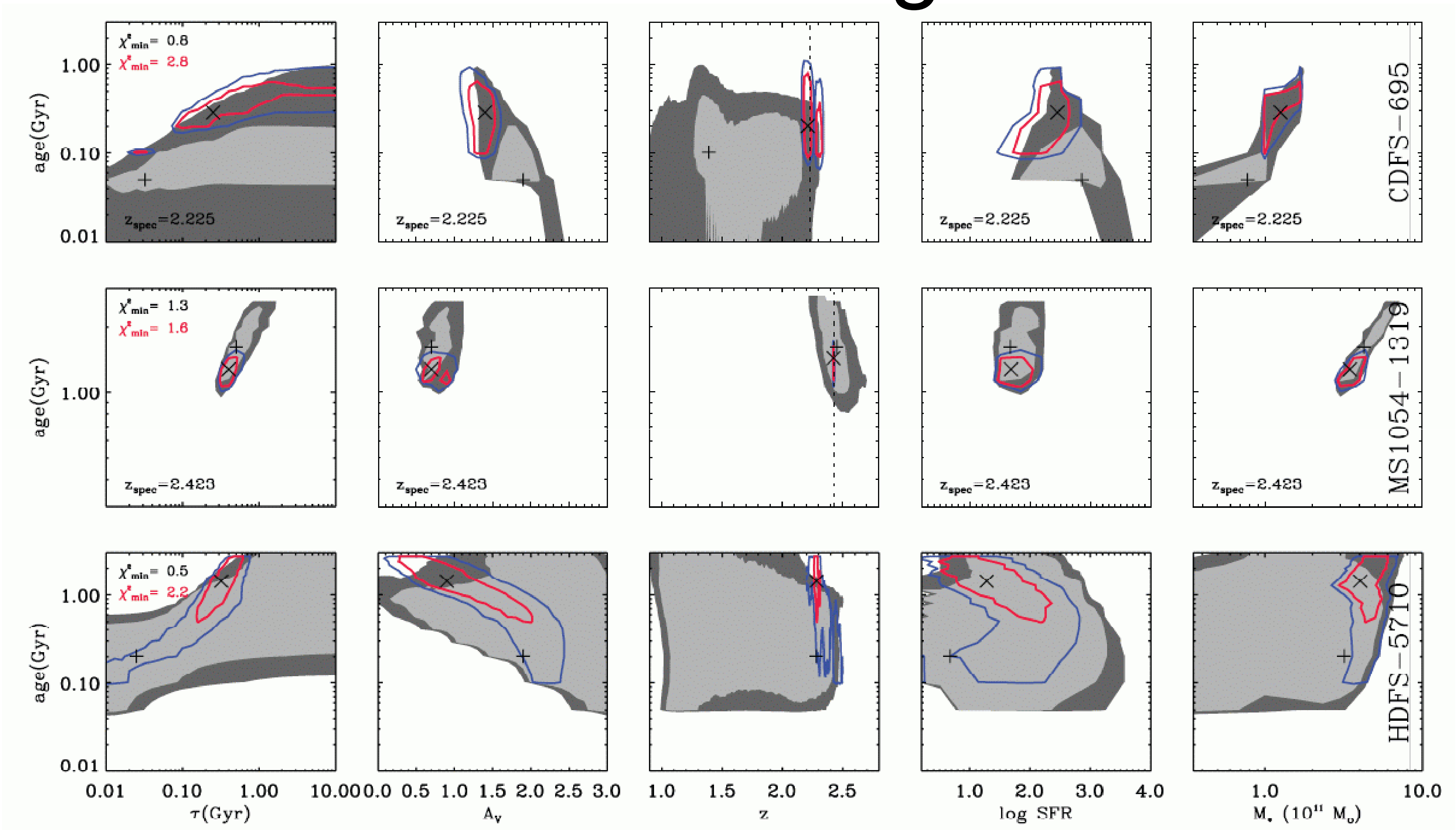


Fig. 3.— Comparison of photometric redshifts derived from medium band photometry to spectroscopic redshifts measured with the GNIRS near-IR spectrograph on Gemini for the four galaxies shown in Fig. 2 (solid symbols). There is very good agreement, with scatter 0.01 – 0.02 in $\Delta z/(1+z)$. Open symbols show the remaining 10 objects from the Kriek et al. (2008) sample. The scatter is small even for these galaxies, even though the S/N of their medium band photometry is lower than our survey criterion.

⊿z/(1+z) ~ 0.06 を達成

van Dokkum et al. (2009), arXiv:0901.0551

SED fitting

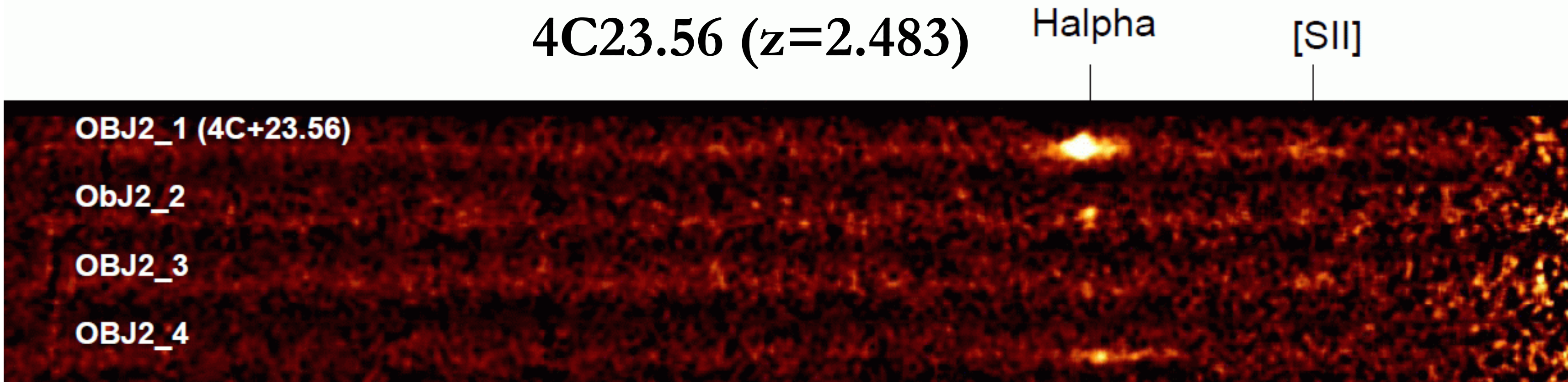


Balmer/4000ÅブレイクやMg_2フィーチャーの強さから星の平均年齢が推定できる。

Kriek et al. (2006)

青い銀河

4C23.56 (z=2.483)

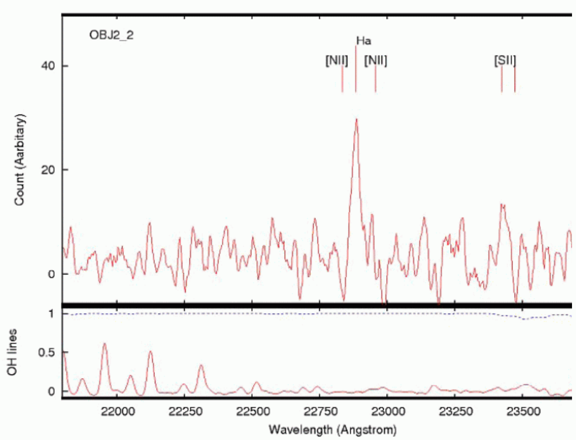


K-band spectra with Subaru/MOIRCS (4.7 hours, R=1300, 4'x7')

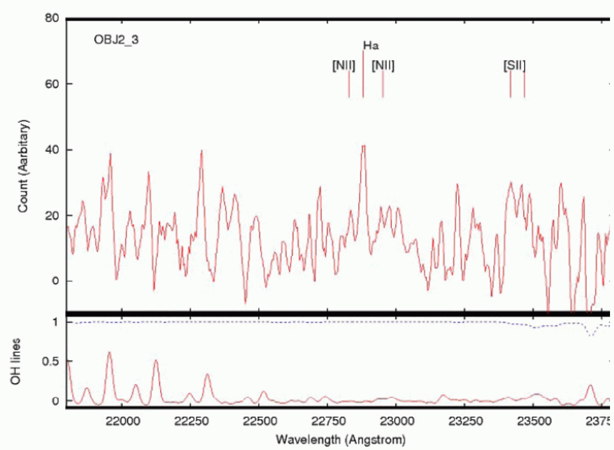
4 Hα emitters including the RG.

I. Tanaka et al., in preparation

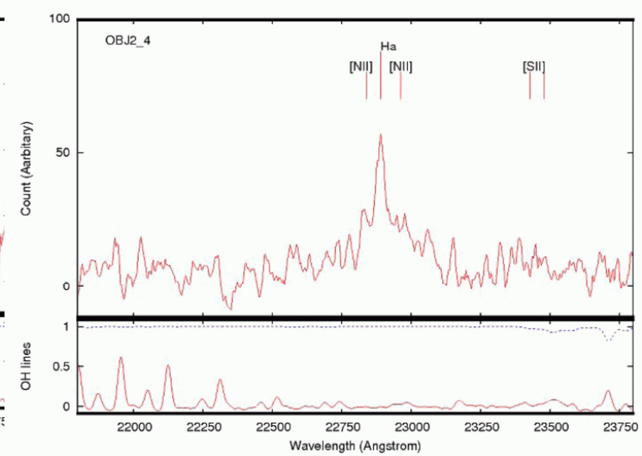
Obj2_2
z=2.4872



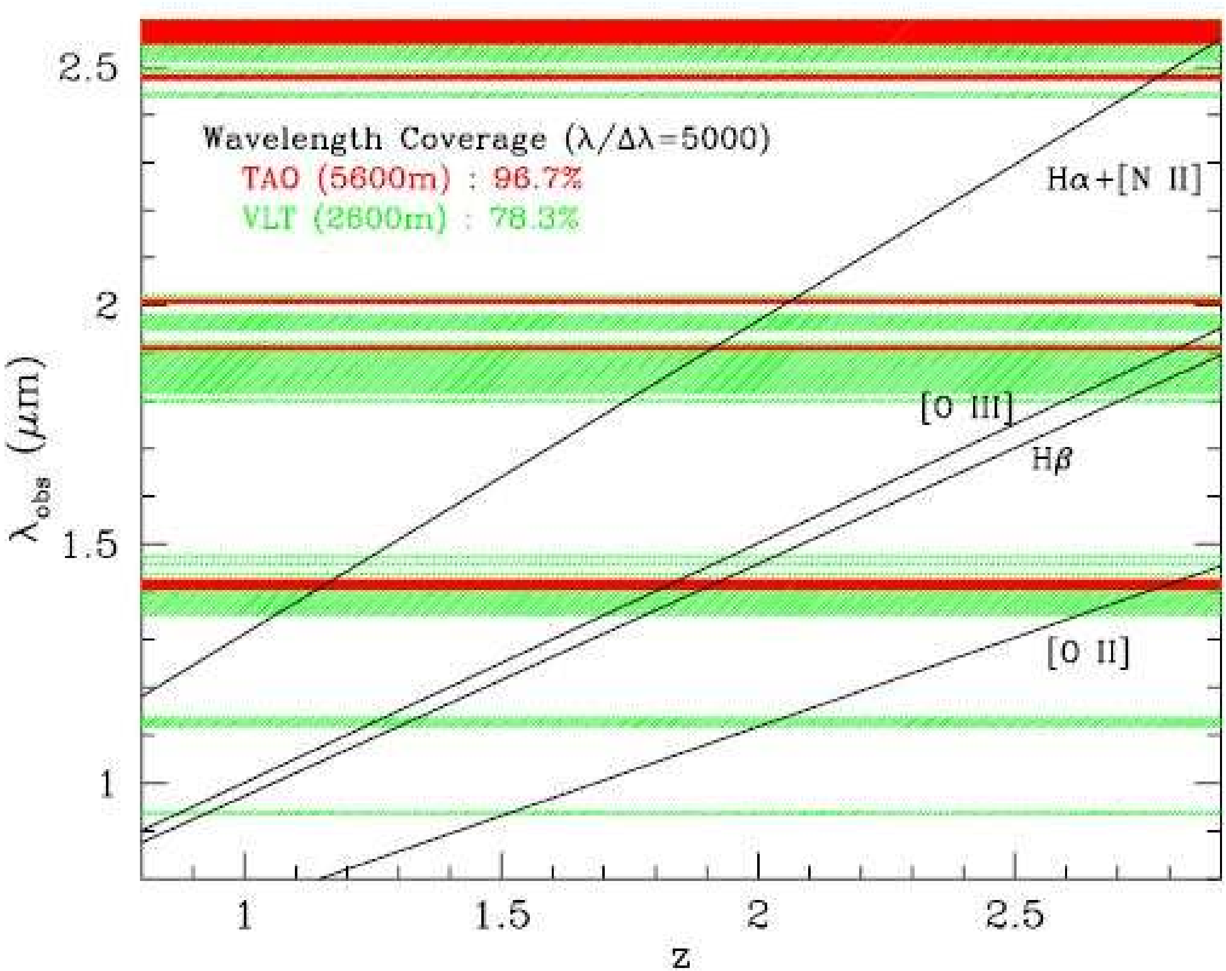
Obj2_3
z=2.4865



Obj2_4
z=2.4879



TAO Window（0.85＜λ[μm]＜2.4）



0.30 < z(Hα) < 2.65

0.75 < z(Hβ) < 3.94

1.28 < z(OII) < 5.44

バンドギャップが小さいことも大きな魅力！

0.4＜z＜4 銀河の星形成史/重元素量/力学質量とその環境依存性

8’ = 8Mpc (z=1), 10Mpc (z=1.5), 12Mpc (z=2), 14Mpc (z=2.5)

Science with Line Emitters

- ＊ 3-D large scale structures with spec-z
- ＊ Environmental dependence of SFH

  Star formation rate (Hα, [OII] emission lines)

  Dust extinction (Hα/Hβ)

  Gas metallicity (R23, O32, [NII]/Hα)

  AGN separation ([OIII]/Hβ vs. [NII]/Hα)

  Dynamical mass (line width)

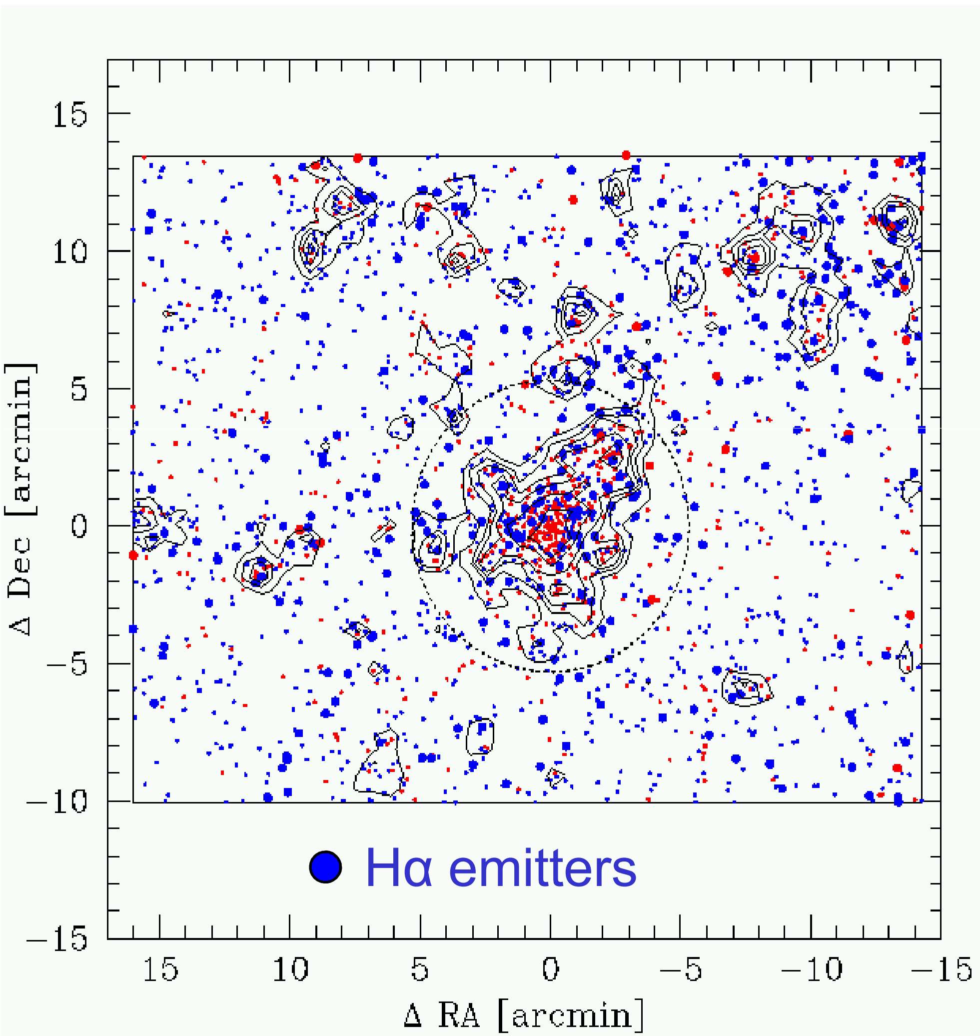
  Post-starburst (composite Balmer absorption)

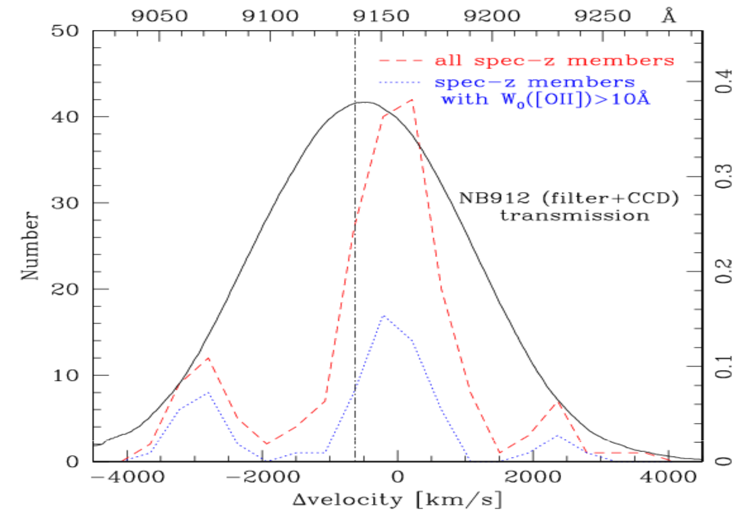
"When and Where do we see (post-)starbursts and truncation?"

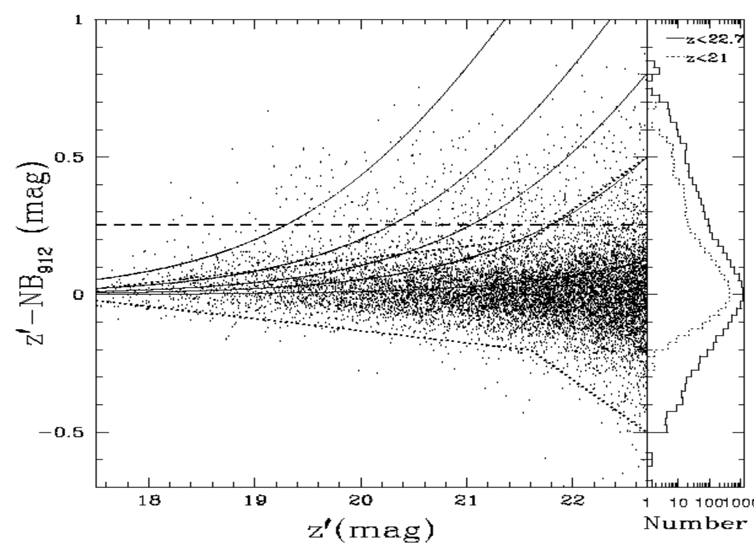
"How much star formation is hidden in the optical (rest-UV) surveys?"

Hα Mapping of CL0024 Cluster (z=0.4)

Suprime-Cam + BRz' and NB912 (FWHM=134Å=4000km/s)



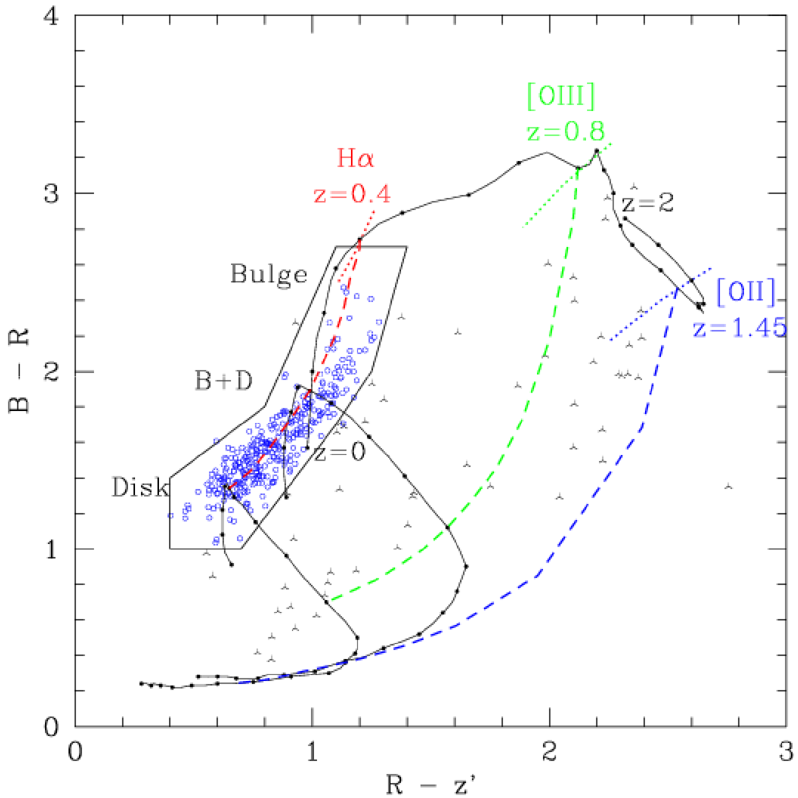




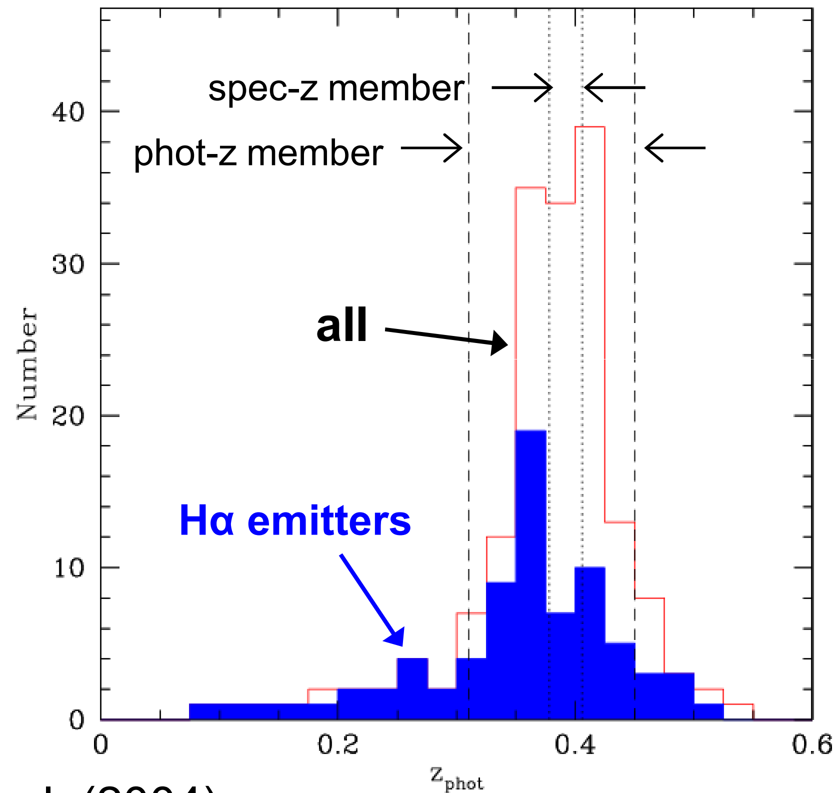
Kodama, et al. (2004)

NB輝線銀河探査の重要性

Colour selection of Hα emitters



Phot-z of the Hα emitters



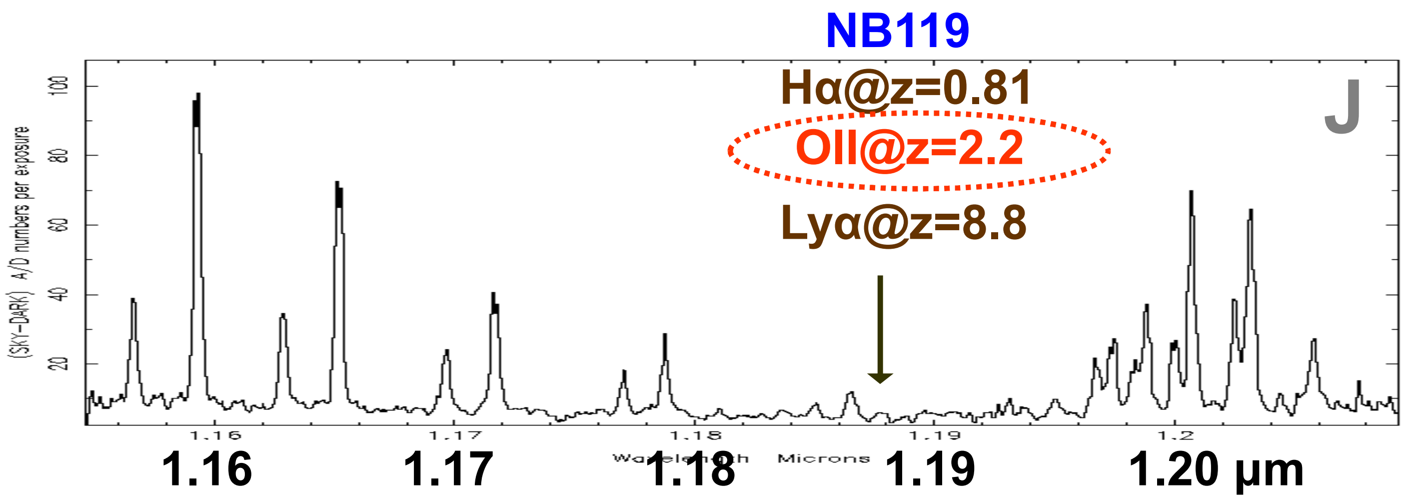
Kodama, et al. (2004)

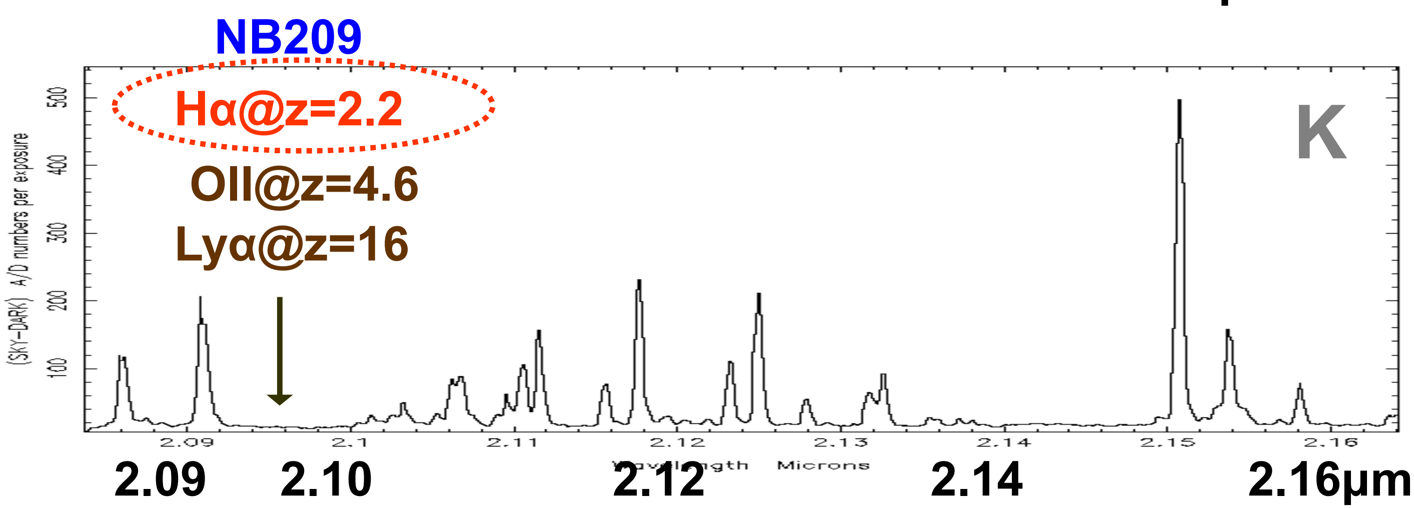
広・中帯域撮像(passive galaxies)と狭帯域撮像(active galaxies)を組み合わせることによって、あるredshift（銀河団）にある赤く古い銀河と青い星形成銀河の両方をカバーした優れたサンプルを得ることができる！

Narrow-band emitter surveys (Hα, Hβ, [OII]) with Suprime-Cam/MOIRCS on Subaru

Targets	Redshift (z)	Filter	Instr.	CW (μm)	FWHM (μm)	Line	SFR (M/yr, 5σ)	Status
(Clusters: PISCES)								
CL0024+1652	0.395	NB912	S-Cam	0.9139	0.0134	Hα	0.1	Kodama+04
CL0939+4713	0.407	NB921	S-Cam	0.9196	0.0132	Hα	0.1	Nakata+
RXJ1716.4+6708	0.813	NB119	MCS	1.1885	0.0141	Hα	1.7	Koyama+09
		NA671	S-Cam	0.6714	0.0130	[OII]		Koyama+09
XCS2215.9-1738	1.457	NB912	S-Cam	0.9139	0.0134	[OII]	4.3	Hayashi+09
(Proto-clusters: HzRG)								
Q1126+101	1.517	NB1657	MCS	1.657	0.020	Hα		planned
Q0835+580	1.536	NB1657	MCS	1.657	0.020	Hα		planned
PKS 1138-262	2.156	NB2071	MCS	2.069	0.027	Hα	5.4	proposed
4C 23.56	2.483	CO	MCS	2.288	0.023	Hα		I.Tanaka+09
USS 1558-003	2.527	NB2315	MCS	2.313	0.027	Hα	12.4	proposed
(Blank fields)								
GOODS-N	2.19	NB209	MCS	2.091	0.027	Hα	10	Tadaki+09
		NB155	MCS	1.545	0.017	Hβ		Tadaki+09
		NB119	MCS	1.189	0.014	[OII]	10	Tadaki+09
SXDF/UDS	2.19	NB209/NB155/NB119	MCS					planned

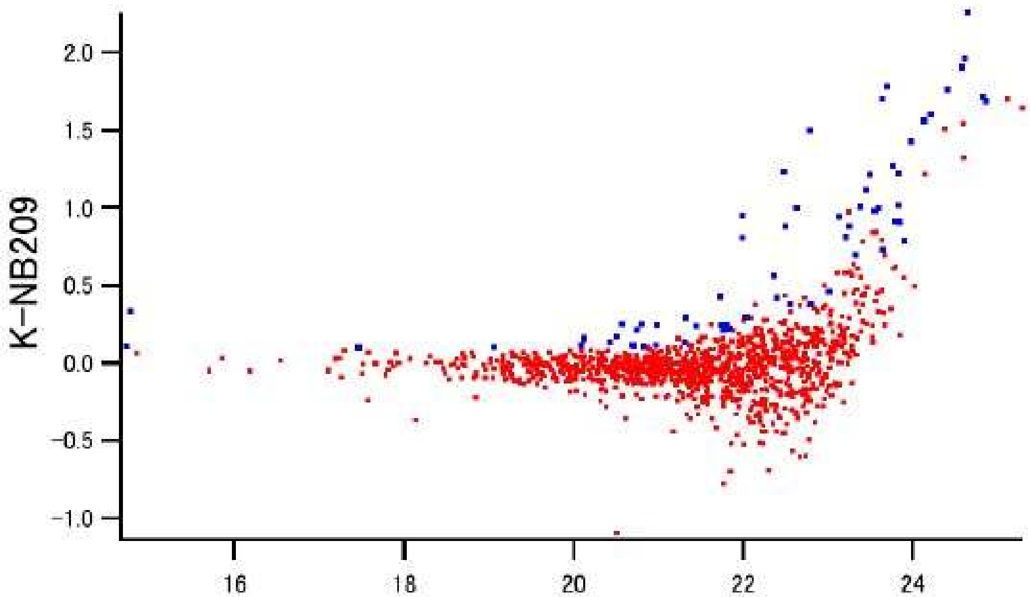
MOIRCSのペアNB撮像によるz=2.2輝線銀河の探査
(一般フィールド領域：GOODS-N, SXDF…)

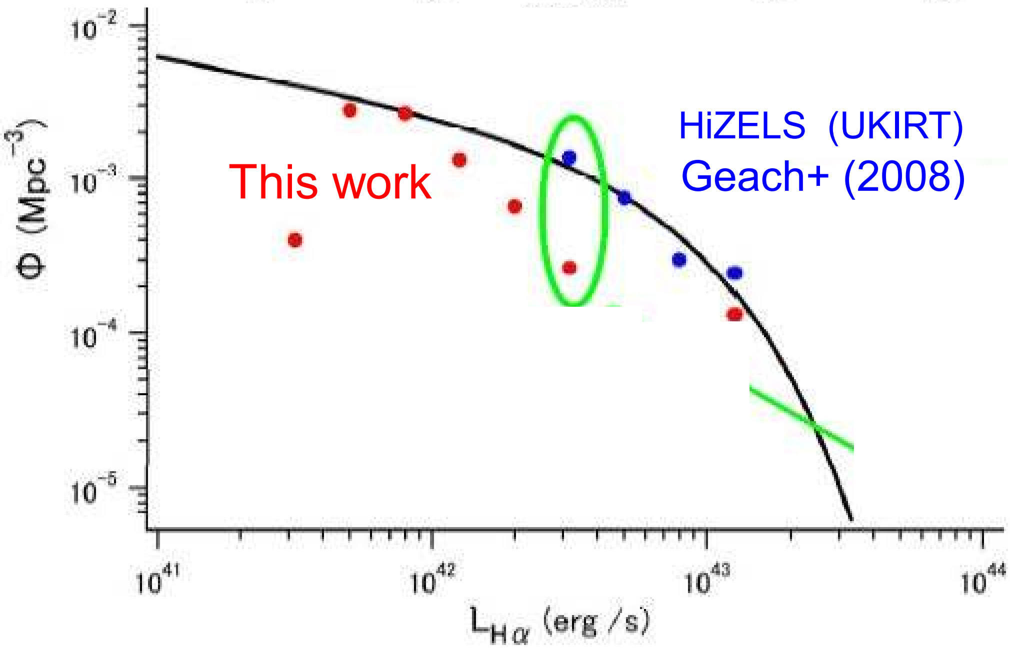


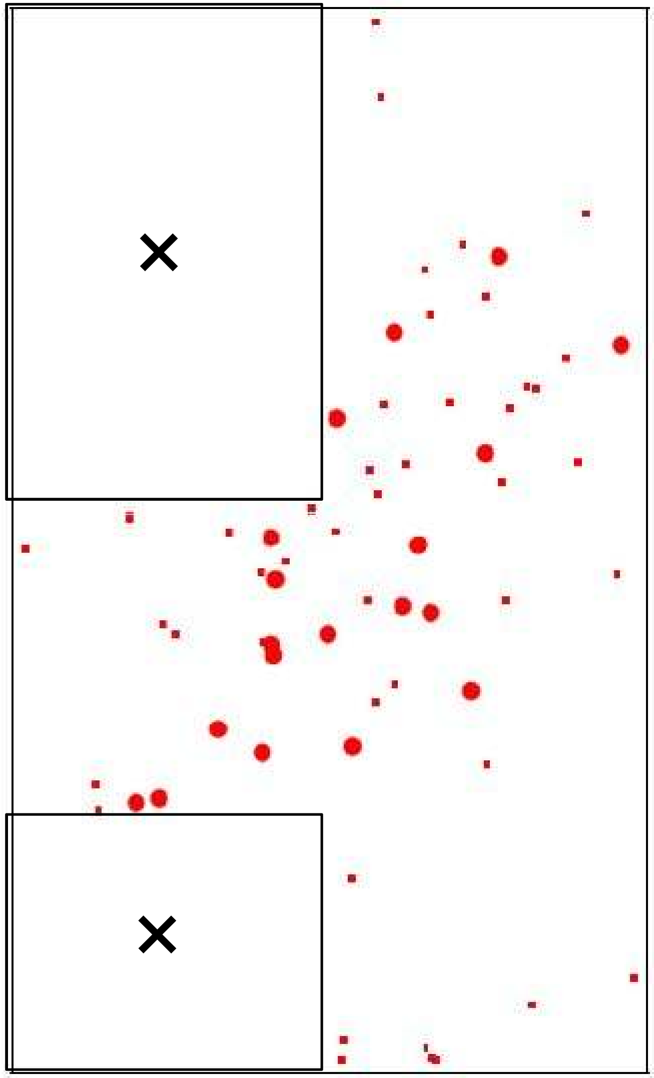


[OII] と Hα とを両方捉えることができる。したがってredshiftが決まる。

z=2.2 Hα輝線銀河 in GOODS−N







Tadaki et al. (2009)

ALMAとの連携観測（近赤外～電波）

TAO/Subaru (Near infrared)

- L(NIR)+SED → Stellar Mass (M_{star})
- Hα/Hβ/[OII] survey → HII region (SFR)

ALMA (Submm--Radio)

- Submm conti. (850μm) → Dust (SFR)
- CO(3→2) (~100GHz@z~2) → Mol. Gas (M_{gas})

$$a = \frac{M_{star}}{M_{gas}}$$ ：ガス消費率

$$b = \frac{SFR}{M_{star}}$$ ：星形成タイムスケール

TAO-NIRによる原始銀河団（およびフィールド）の研究

銀河形成・進化のピーク期（1.5<z<3）の系環境を網羅した系統的探査

2～3バンド同時撮像＆広視野＆小バンドギャップ＆長時間投入
などの特長を活かして、ユニークな深撮像サーベイを！
GLAOが効けば尚よい（銀河間相互作用を分離できる）！

- Medium-band break survey (J1,J2,J3,H1,H2,K1,K2)

  赤い受動的銀河のメンバー同定とSED年齢

  (D4000/Balmer break)

- Narrow-band emitter survey (10~100 filters or TFs)

  青い活動的銀河の星形成率と重元素量、AGN

  (Hα、Hβ、[OII]、[OIII]、[NII])

分光サーベイでは事前ターゲット選択によるバイアスがかかるのに対し、
撮像サーベイでは“コンプリートサンプル”を構築できる（但し分光確認も必要）。