WFMOS Studies of Galaxy Formation and Reionization

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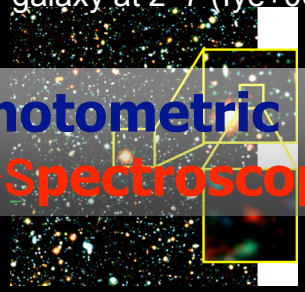
Outline

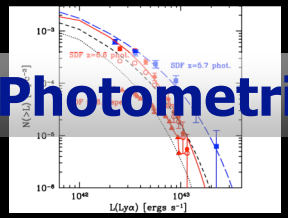
- Introduction
- HyperSuprime-Cam (HSC) surveys
- Science drivers+possible plans of WFMOS spectroscopy in the HSC survey fields
- Comments on the WFMOS project
- Summary

Discovery of the most distant galaxy at z=7 (Iye+06)



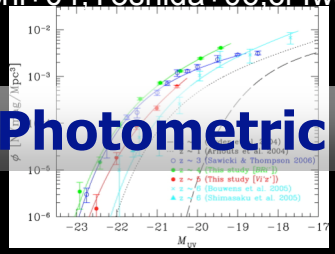
Photometric →Spectroscopic

Signature of Cosmic Reionization (kashikawa+06,Shimasaku+06)



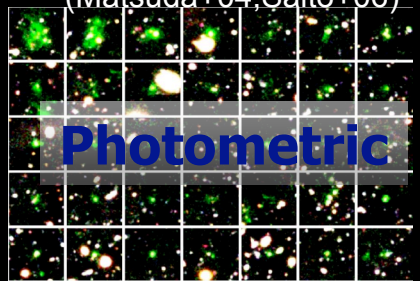
Photometric

Decrease of UV luminosity function (Ouchi+04,Yoshida+06,cf Iwata+03/7)



Photometric

First Census of Lya Blobs (Matsuda+04,Saito+06)



Photometric

Suprime-Cam Image
(1 pointing: 918 arcmin^2)

Subaru/FOCAS FoV

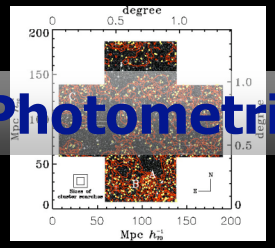
FOCAS is much less efficient than Suprime,
FoV(Suprime)~30 FoV(FOCAS)

Imaging results >> Spec. results

→ Limited analyses(LF,CF), limited physical info.

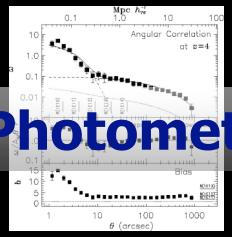
~2011年HyperSuprimeの登場で悲劇は繰り返されようとしている。

Discovery of Large-Scale Struc.& Proto-clusters (Shimasaku+03,Ouchi+05)



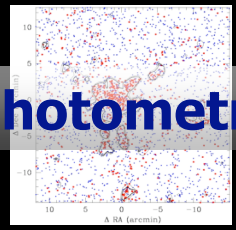
Photometric

Detection of 1&2 halo terms (Ouchi+05 Kashikawa+06,Hamana+06)



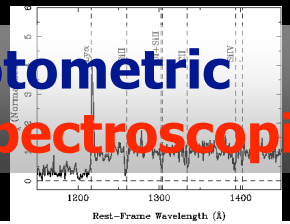
Photometric

Identification of substructure arou high-z clusters (Kodama+01, Nakata+05,Tanaka+06/07)



Photometric

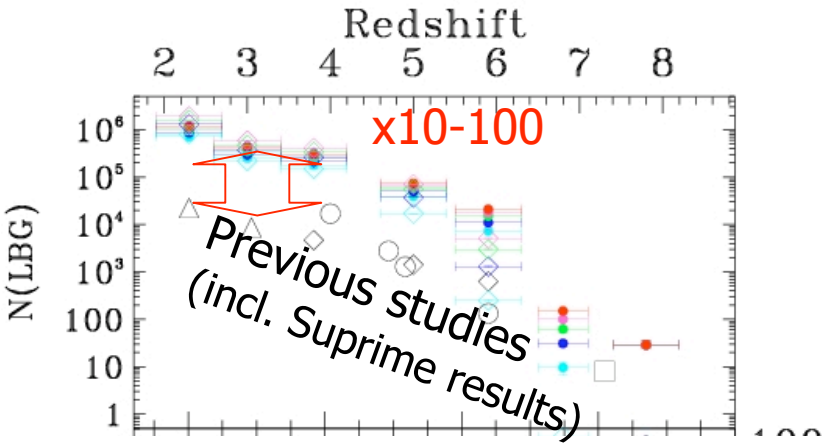
UV bright population for deep Spec. (Ando+04/06/07,Nagao+04/05)



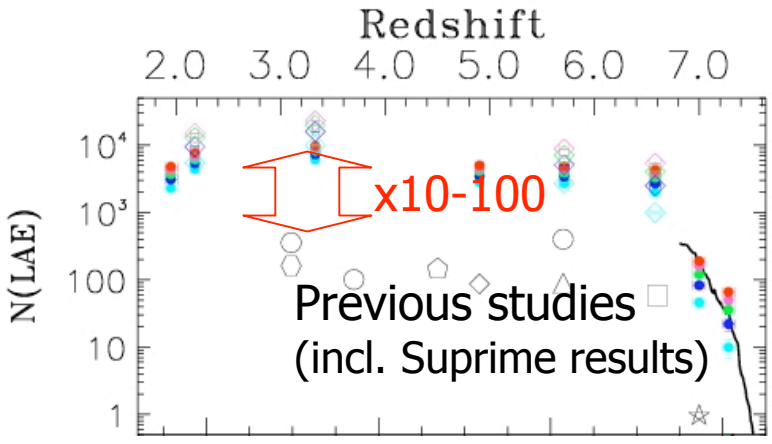
Photometric →Spectroscopic

Hyper Suprime-Cam Surveys (being designed)

Dropouts



LAEs



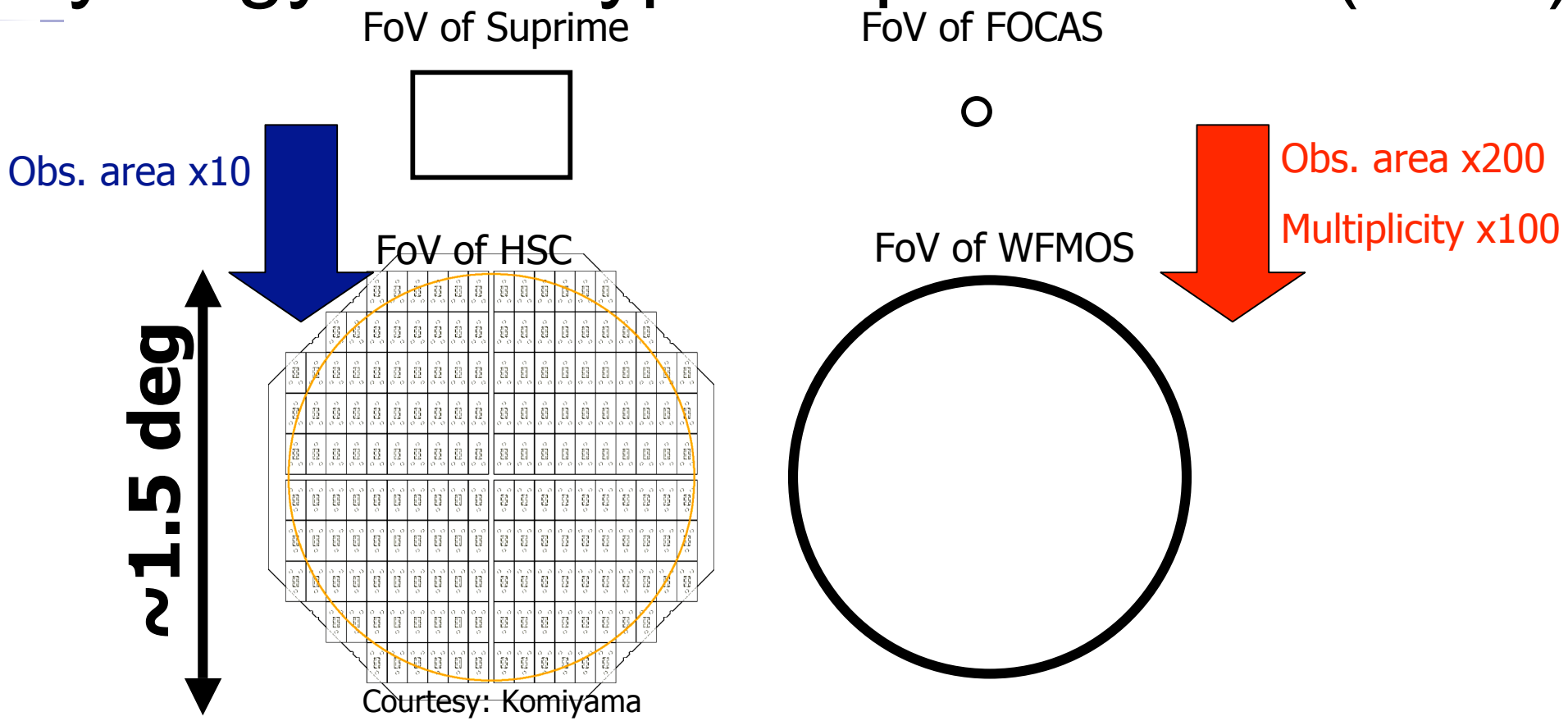
Expected numbers of high-z galaxies (Ouchi+)

- Very tentative plans (suggested by Japan-Taiwan team. Cf. princeton proposal)
  - Deep survey (i~27mag, NB~25mag) for ~40deg^2
  - Ultra deep survey (i~28mag, NB~26mag) for ~4deg^2

  →10k-1M Dropouts and 1k-10k LAEs (Of course, not all for spec. targets)

  →Number of z=2-7 galaxy candidates is boosted by 10-100 times mostly by wider-area coverage of HSC.
- 10-100 times more (bright) spec. targets will be waiting for spectroscopy (after 2011-) !!

Synergy with HyperSuprime-Cam (HSC)



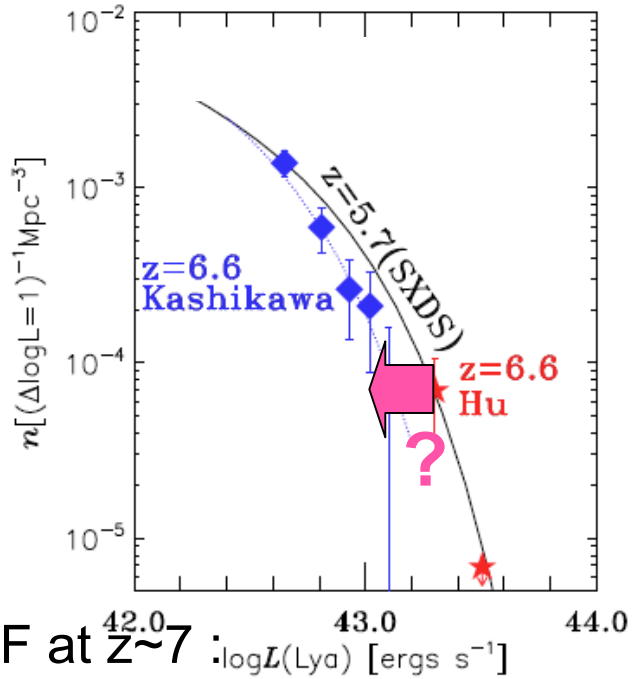
- The size of WFMOS FoV just fits to that of HSC(~1.5deg-diam) sharing the Subaru top-end hub+PFU.
  - Suprime-Cam→HSC (obs. area x10)
  - FOCAS→WFMOS (obs. area x200, multiplicity x100)
    - Example (at z=5.7): ~3 LAE/FoV(FOCAS)→ ~700 LAEs/FoV (WFMOS)

→WFMOS may revolutionalize spec. studies of highz galaxies!!

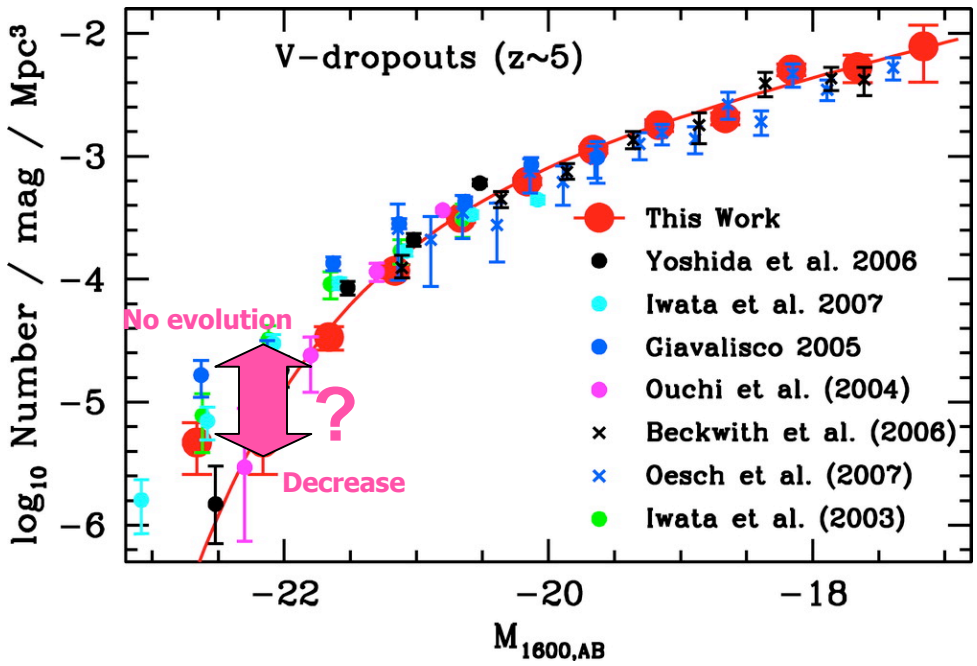
Science Drivers of WFMOS spectroscopy in the HSC fields

1) Determination of Luminosity Function at z<7.5 Critical for cosmic reionization and galaxy formation

Lya LF of Lya emitters at z=6.6



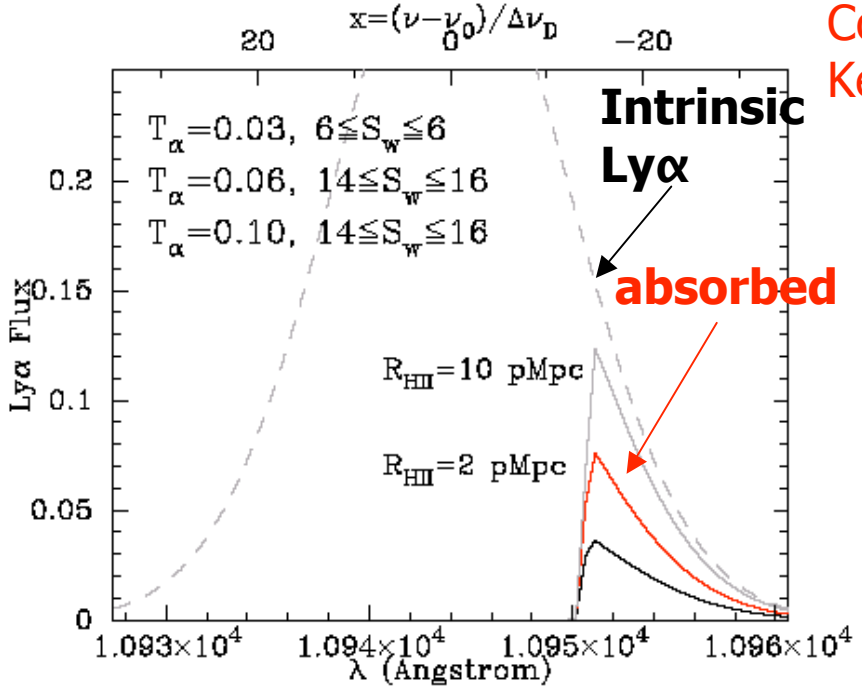
UV LF of dropout galaxies at z=5



- Lya LF at z~7 :
  - Evolved? → signature of reionization (Kashikawa+06)
  - No evolution? → no signature of reioinzation (Malhotra+04) Field variance? (Hu+06)
- UV LF at z~5 at the bright end
  - Evolution → signature of hierarchical structure formation (e.g. Ouchi+04, Bouwens+07)
  - No evolution → UV-bright galaxies following down-sizing (Iwata+03,07, Giavalisco+05)
- Uncertainties of field variance, redshift dist., completeness/contamination in photometric samples. (e.g. z~3 LBG LF claimed by spec. redshift survey of VVDS by Le Fevre+05. Paltani+06).

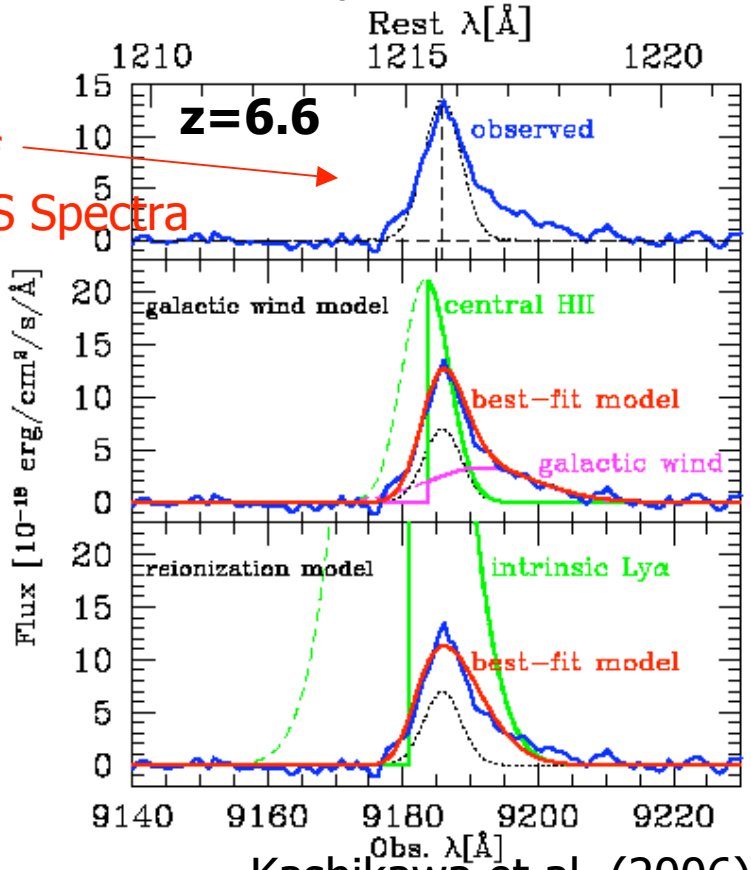
2) Constraining Neutral Fraction with Lya Profiles

Lyα line profiles of galaxies at z=8 (Model prediction)



Dijkstra et al. (2007)

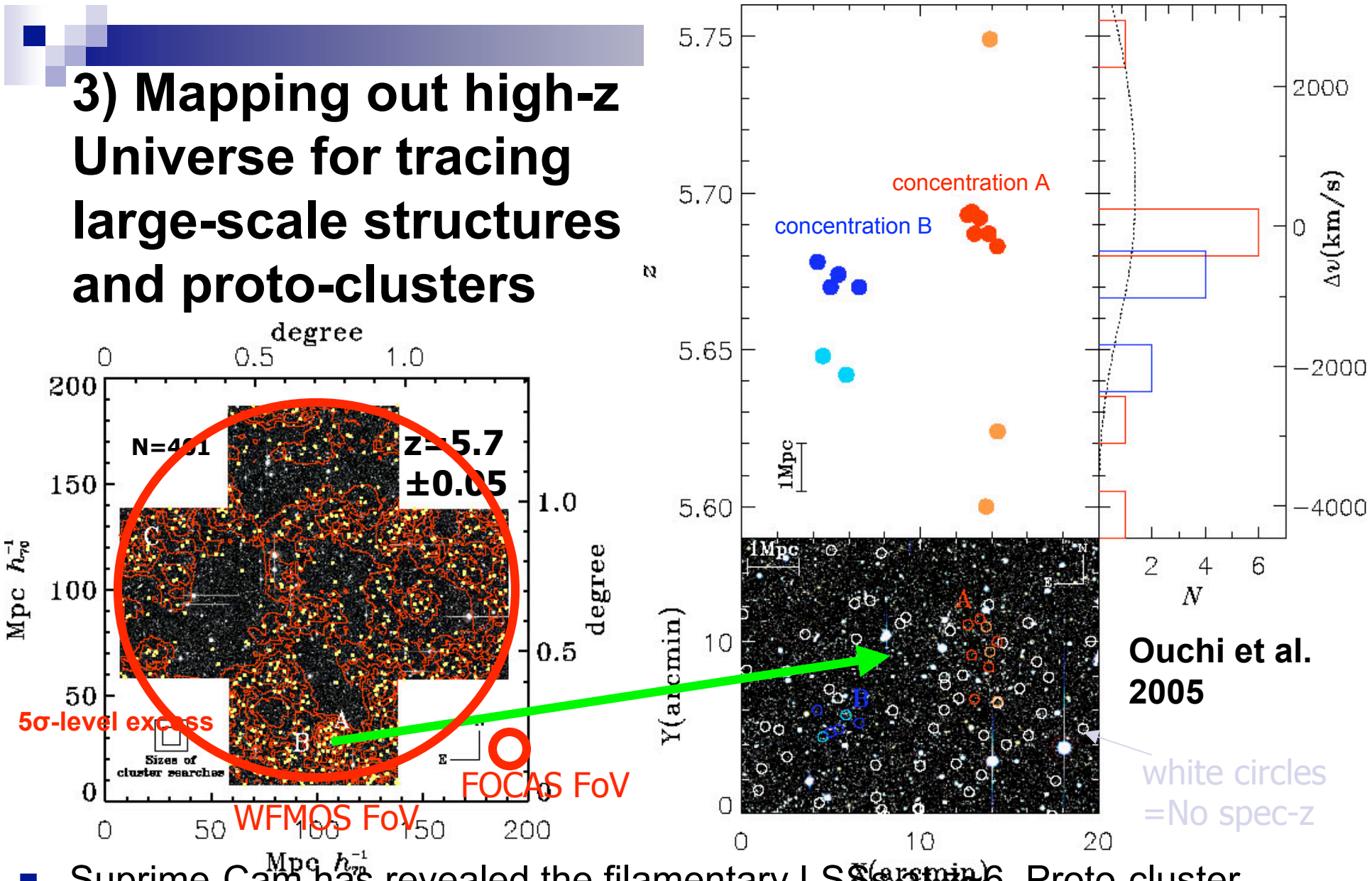
Composite of Keck/DEIMOS Spectra



Kashikawa et al. (2006)

- Lya profiles give constraints on neural fraction of IGM at the epoch of reionization.
- Suprime-Cam+DEIMOS studies: Based on a composite of ~10 spectra of Lya emitters at z=6.5 Lyα profile is well explained by a galactic wind model. No significant feature of neutral IGM is found in a Lyα emission line... → No constraints on reionization (Kashikawa +06).
- Higher S/N spectra (i.e. more objects for stacking analysis) with medium-high spectral resolution (R~3000-4000) are needed.

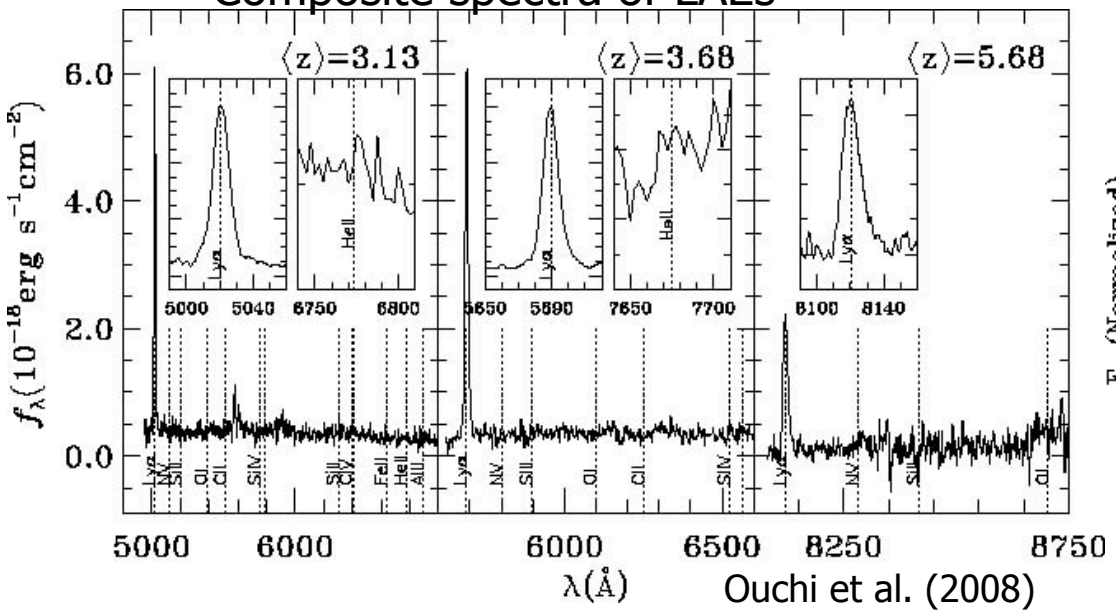
3) Mapping out high-z Universe for tracing large-scale structures and proto-clusters



- Suprime-Cam has revealed the filamentary LSSs at z~6. Proto-cluster candidates are identified with FOCAS (Ouchi et al. 2005).
- Only 1/20 of phot. selected LAEs have spec-z.
- WFMOS will identify not only proto-clusters but 3D view of high-z LSS

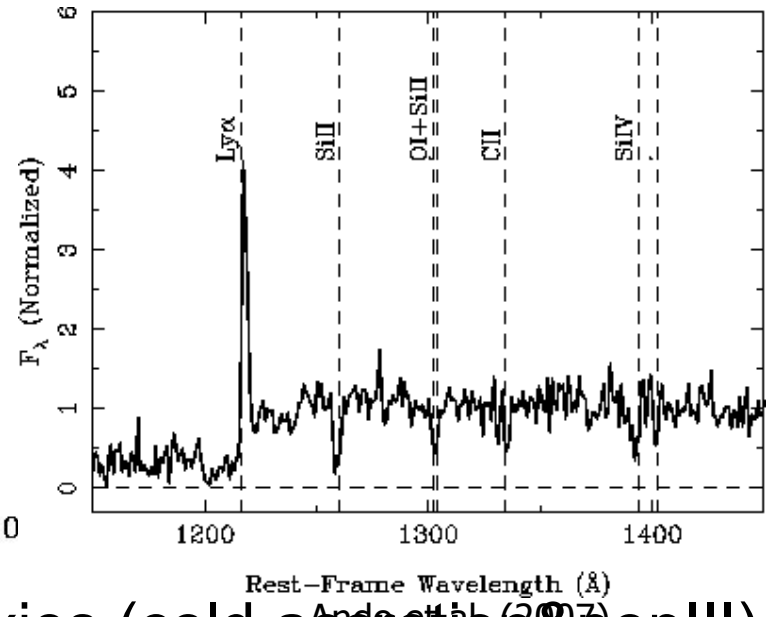
4) Statistics of faint emission/absorption lines in high-z galaxies

Composite spectra of LAEs



Ouchi et al. (2008)

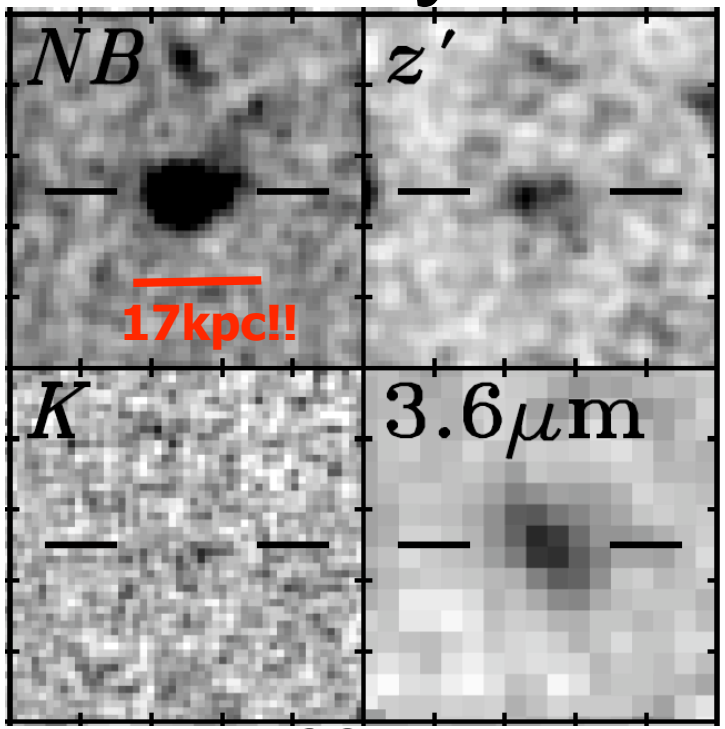
Composite spectrum of LBGs



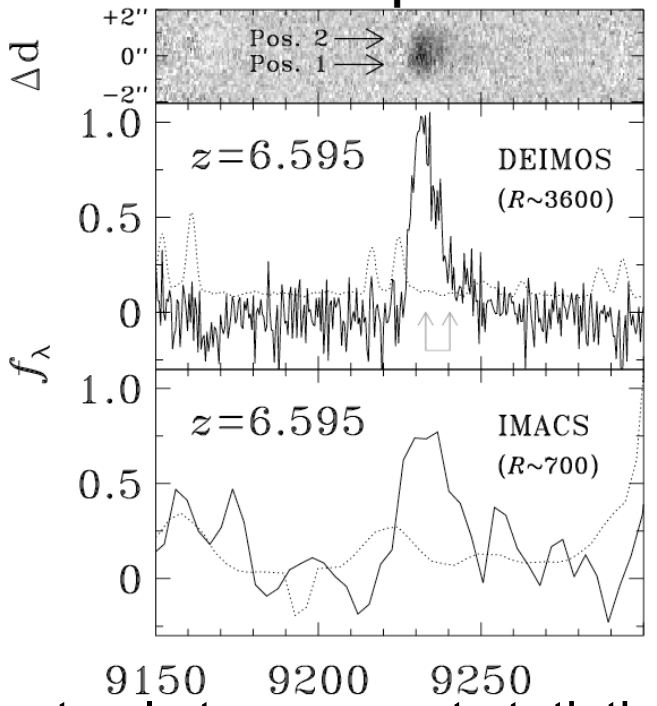
Ando et al. (2007)

- HeII emission line for primeval galaxies (cold accretion&popIII)
  - No HeII lines from premeval population are detected in spec.(+composite spec.) Current best 3σ limit f(HeII)/f(Lya)<2% at z~3 (Ouchi+08) Theory PopIII f(HeII)/f(Lya)~0.1-10% Shaerer+08→˜12,000LAE spec.→40deg^2
  - Perfect for HSC data + WFMOS follow-up!
- UV absorption lines to constrain metallicity. Composite spectra of 8 LBGs at z~5 (Ando+07, see+Shapley+03).→ More spectra to give strong constraints on the history of metal enrichment.

5) Identifying a rare population: Extended Lyα sources at z<7.5



Ouchi et al. ApJ submitted



- Large area WFMOS spectroscopy will allow us not only to carry out statistical studies, but also to identify rare interesting objects (a few/1deg^2) at high-z.
- HSC+WFMOS surveys will provide a number of extended Lya sources (Lya blobs).
- Up to z~7. An example of z=6.595. ~3” (=17kpc) spatial extension in a narrow band with very bright Lya emission (L[Lya]=4x10^{43} erg/s) + Spitzer detection. → massive galaxy formation with outflow? Key for understanding massive galaxy formation.

Strategies of WFMOS spectroscopy in the HSC fields

Case 1. z~5-7 galaxies (=very faint)

pre-selected with HSC multi-band data

- LAEs (BB-NB>0.5+No BV flux)

Sample	N(1FoV)	Exp/pt(hr)	Exp/FoV(hr)
NB921<~25.5	500	3	3

- z~5-7 dropouts (No B flux)

z<~25.0	1400	15	15

- for (z=6.6 LAEs + z=5-6 dropouts) x 9FoV(WFMOS=HSC) = 27 nights
  - ~3000 spec. confirmed z=4.5-6.5 dropouts
  - ~500 spec. confirmed z=6.6 LAEs

x30-100 larger high-z galaxy sample !!

Bright sources (<~25mag) only:

Faint sources→TMT/WFOS

Case 2. z<5 galaxies by redshift survey in HSC field

Obvious and straight forward strategy for z<5 gal.

mag	N(1FoV)	Exp/pos(hr)	Exp(total;hr)
m< 23.0	76000	0.4	10
m=23.0-23.5	32000	1.0	11
m=23.5-24.0	45000	2.5	42
m=24.0-24.5	64000	6.0	128
total			191(hr)

For 1 FoV(WFMOS=HSC) ~ 30nights

Redshift survey in multiple(~3) WFMOS FoV is realistic.

~500,000 redshifts (comparable to SDSS!!) at z~0-5

コメント:
WFMOSに寄せて

「すばるはWFMOSをやるのかやらないか？」という表現は正確ではない。

「貴重なすばる時間とWFMOS装置＋サイエンスとのトレードをGeminiコミュニティーと行うかどうか？」というのが命題。

トレード→損得を伴う

すばる時間とWFMOSのトレードを行うか？

- すばるコミュニティーにどのような利点と欠点があるか？思い込みや感情論抜きに文書化して整理した上で方針案を練ってはどうですか？例えば、
  - 利点 1)国際協力で、地上分光BAOでDEへの制限の決定版が得られる
    - この他、GAやSN、GEなどにサイエンスメリットがある

    2)HyperSuprime並みの視野をもつ可視分光器へのアクセスが得られる

    3) 等々…
  - 欠点 i) 年間すばるの>100晩??、BAO,GAサーベイの為に占有
    - 宇宙論以外の研究へ多大なインパクト。機動的な小規模プログラムへのしわ寄せ。

    ii) 視野は大きくてもFiber分光なので限界等級はFOCASほど深くいかない。(＋空間情報も無い可能性。)サイエンスは制限されている

    iii) 等々…
  - 方針案 a)日本側の利点が費用(すばる時間)に見合わず。WFMOS不参加

    b) Geminiとの時間交換は2対1の時間比で行う。それ以下の時間比なら日本はWFMOSに参加しない、という条件を付ける。等々..
- これまでのすばるSAC/すばるUMでの議論をまとめる＋具体的数値(予想夜数、感度等)を明示＋方針案を策定。(分野横断的な特命委員からなるWFMOSプロジェクト委員会およびサイエンス委員会を早急に立ち上げ？)5月までに文書をgopiraを通じて配布→コミュニティーからのfeedback。→台長判断

Summary

- Hyper Suprime-Cam (HSC) Surveys
  - WFMOS spectroscopy is quite suitable for objects found by HSC surveys
- Science drivers of WFMOS spectroscopy in the HSC fields
  1. Determination of UV+Lya luminosity functions at $z<7.5$
  2. Lya profile for consraining cosmic reionization
  3. Mapping the high-z Universe for understanding strucure formation
  4. Statistics of high-z UV spectra for primeval gal. and dynamics/metal abundance
  5. Spc. identification of rare objects such as extended LAEs.
- Strategies of WFMOS spectroscopy in the HSC fields
  - Reasonable nights of WFMOS will provide 1-2 orders of mag larger samples in a very wide field.
  - Redshift survey may provide spec. sample as large as that of SDSS, but deeper for z=0-5 galaxies
- Comments on the WFMOS project