Unveiling the high-z universe with Subaru/PFS

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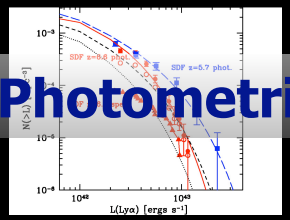
Discovery of the most distant galaxy at z=7 (Iye+06)

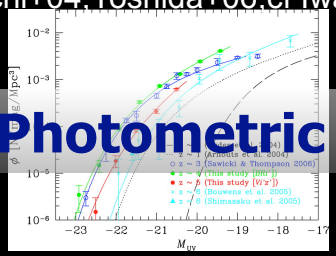
Photometric →Spectroscopic

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



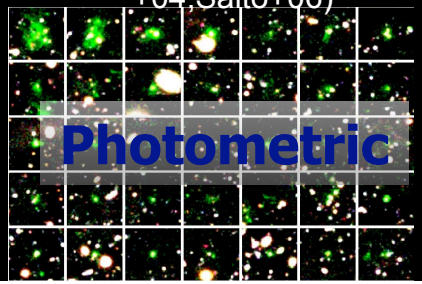
Photometric

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)

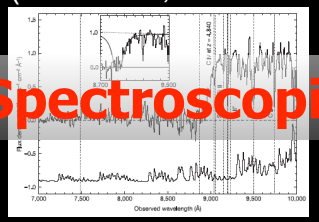
Subaru/FOCAS FoV

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

Imaging results >> Spec. results

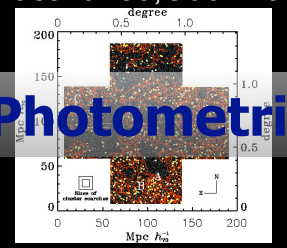
→ Limited analyses(LF,CF), limited physical info.

Spec. identification of GRB050904 near EoR (Kawai+06, Totani+06)



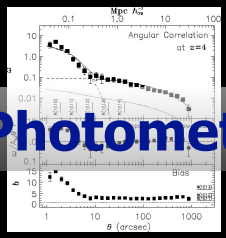
Spectroscopic

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



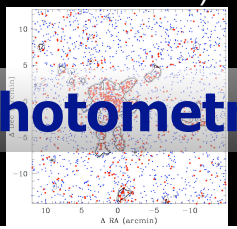
Photometric

Detection of 1&2 halo terms (Ouchi+0 Kashikawa+06,Hamana+06)



Photometric

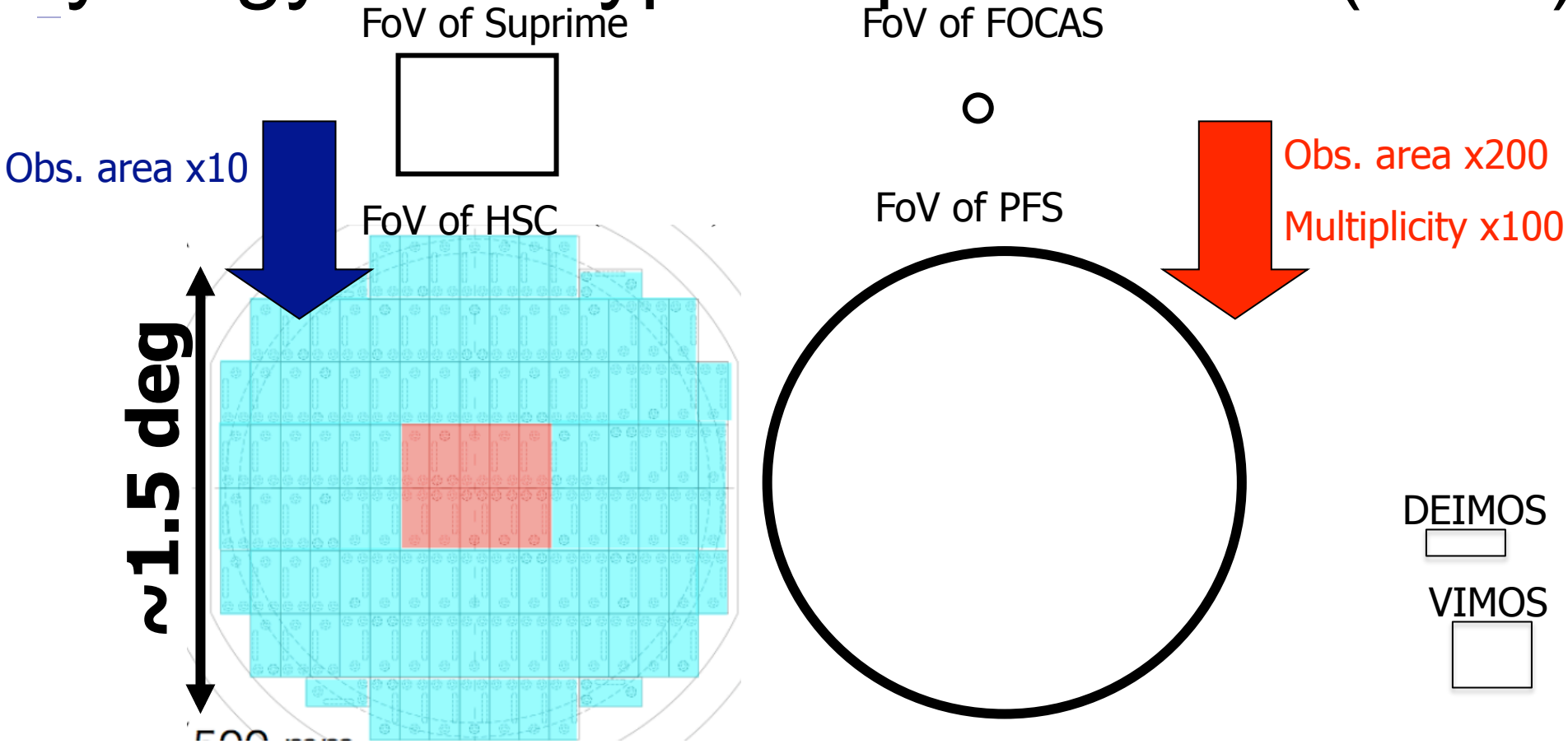
Identification of substructure arou high-z clusters (Kodama+01, Nak +05,Tanaka+06/07)



Photometric

Subaru Deep Field: The Most Distant Galaxy Known
Suprime-Cam (i', z', 921 nm)

Synergy with HyperSuprime-Cam (HSC)

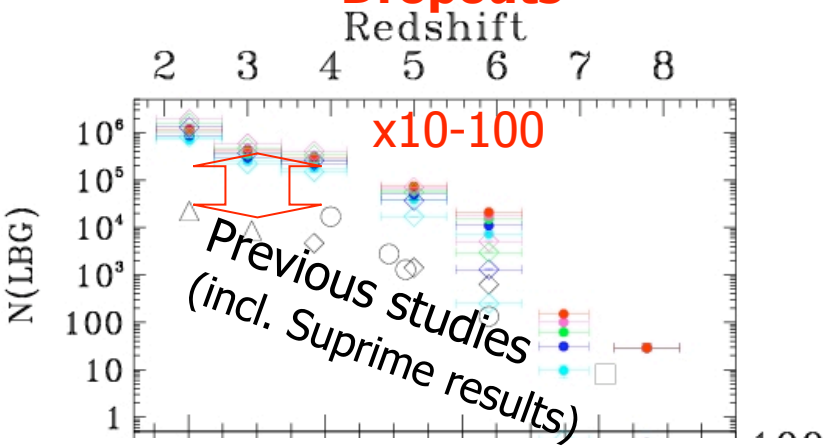


- The size of PFS FoV just fits to that of HSC(~1.5deg-diam) sharing the Subaru top-end hub+PFU.
  - Suprime-Cam→HSC (obs. area x10)
  - FOCAS→PFS (obs. area x200, multiplicity x100)

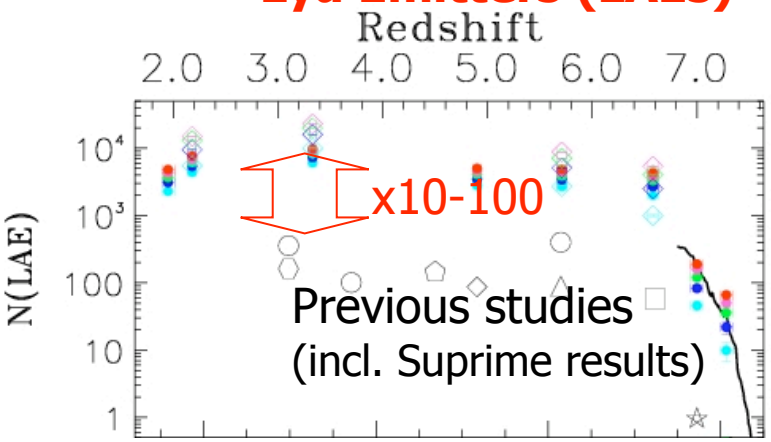
→PFS could revolutionalize spec. studies of highz galaxies!!

Imaging Surveys with HSC (being designed)

Dropouts



Lya Emitters (LAEs)



Expected numbers of high-z galaxies (Ouchi+)

- Very tentative plans
  - Deep survey (i~27mag, NB~25mag) for ~30deg^2
  - Ultra deep survey (i~28mag, NB~26mag) for ~3.5deg^2

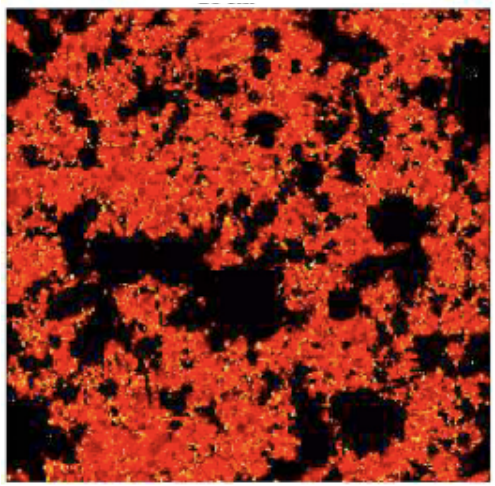
  →10k-1M Dropouts and 1k-10k LAEs at z=2-7. # of galaxy candidates is boosted by 10-100x.
- 10-100 times more spec. targets will be waiting for spectroscopy!!

Science Drivers of PFS (High-z Studies)

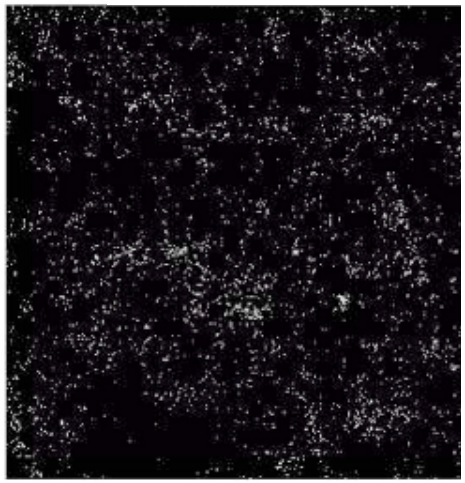
- Cosmic Reionization
  - Physical process (inside-out or outside-in?)
  - Topology (What's 21cmHI-Galaxy relation?)
  - Reionization history (When+What reionized universe?)
- Galaxy+Structure Formation
  - Primordial LSS and Proto-clusters
  - Star-formation duty cycle (intermittent SFH?)
  - Any popIII starbursts at z~2-7?

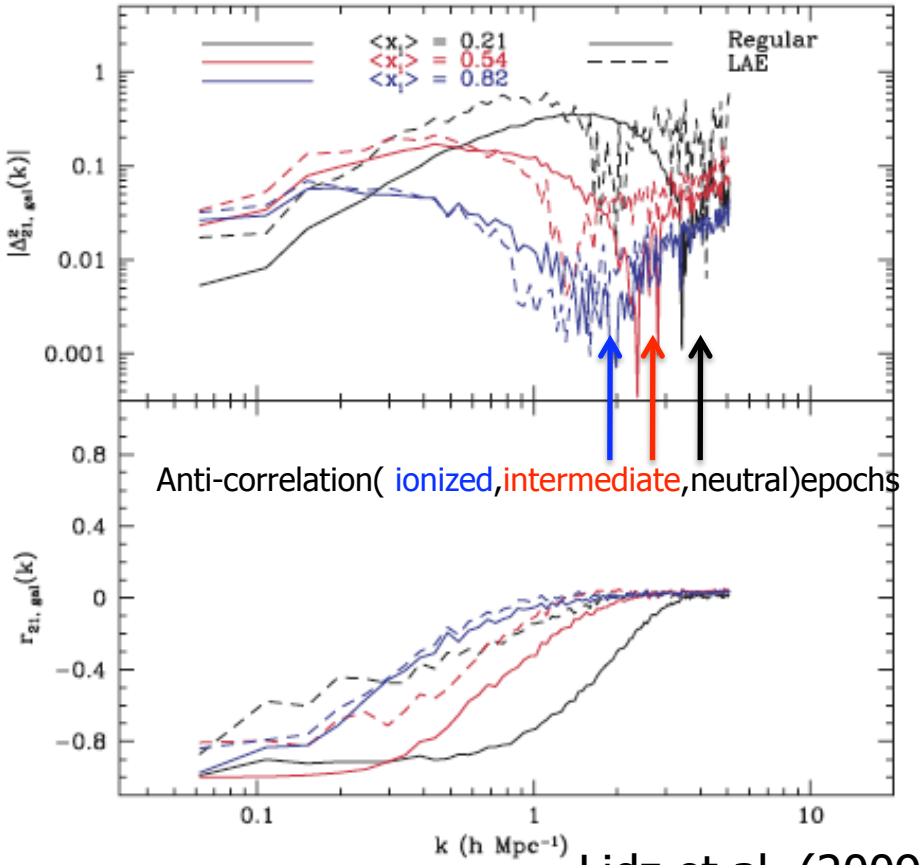
Physical Process of Reionization and Topology

21cm



Galaxies



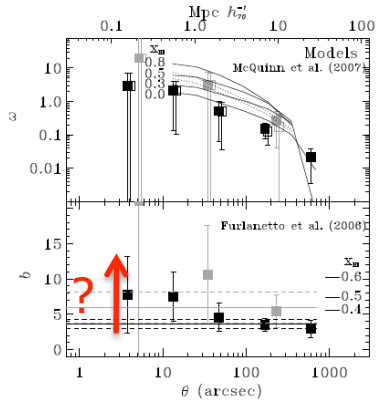


Lidz et al. (2009)

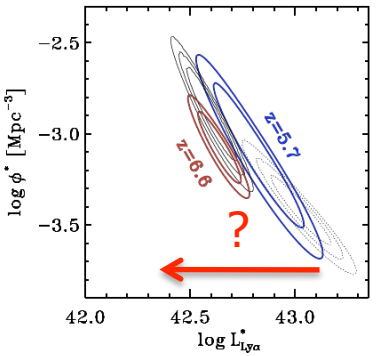
- Ionized bubbles around galaxies→ Distributions of neutral IGM (21cm) and galaxies anti-correlate.
- Distance scales of anti-correlation indicate typical sizes of ionized bubbles at the epoch.
- A signature of reionization and evolution of bubbles can be obtained with 21cm galaxy corss-power spectrum. Eg. LOFAR 21cm+ Subaru/HSC+PFS survey in 3deg^2→~3σ detection of signal (Lidz+09).
- NG 21cm (SKA) and galaxy (Subaru/HSC+PFS) observations would provide reionization+ionizing source relation(z~7-10)

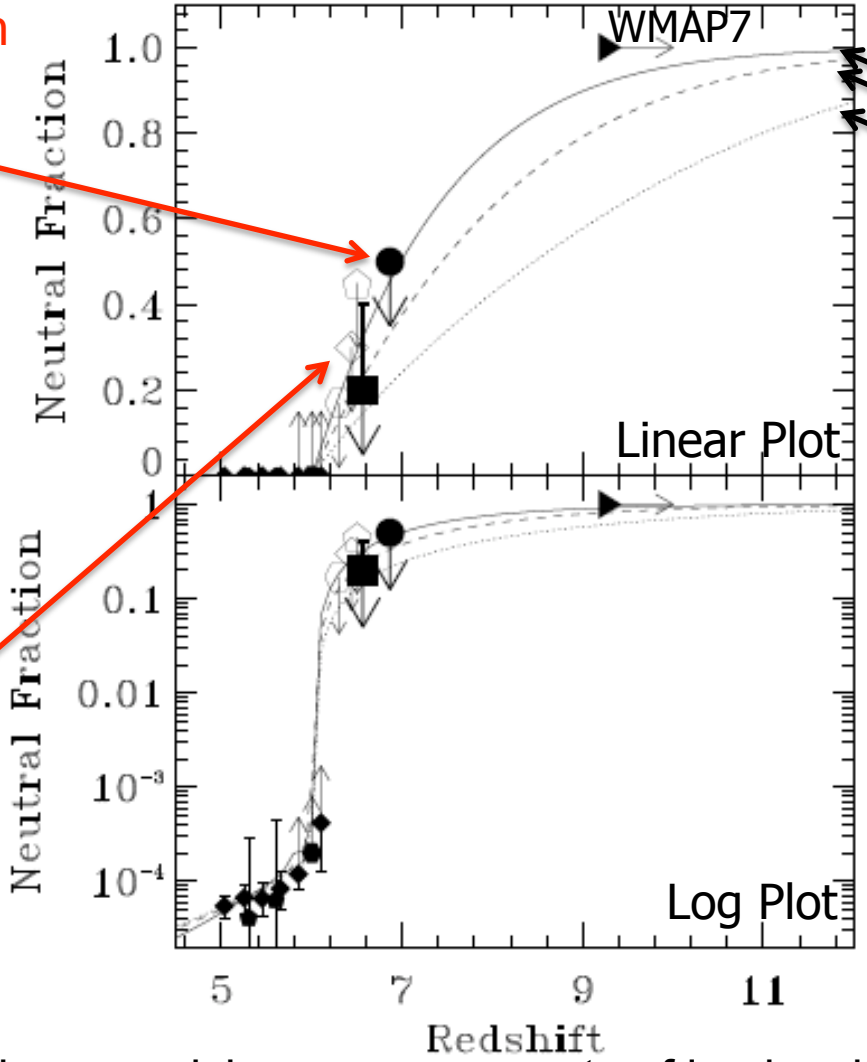
Cosmic Reionization History

Auto-correlation function



Luminosity function

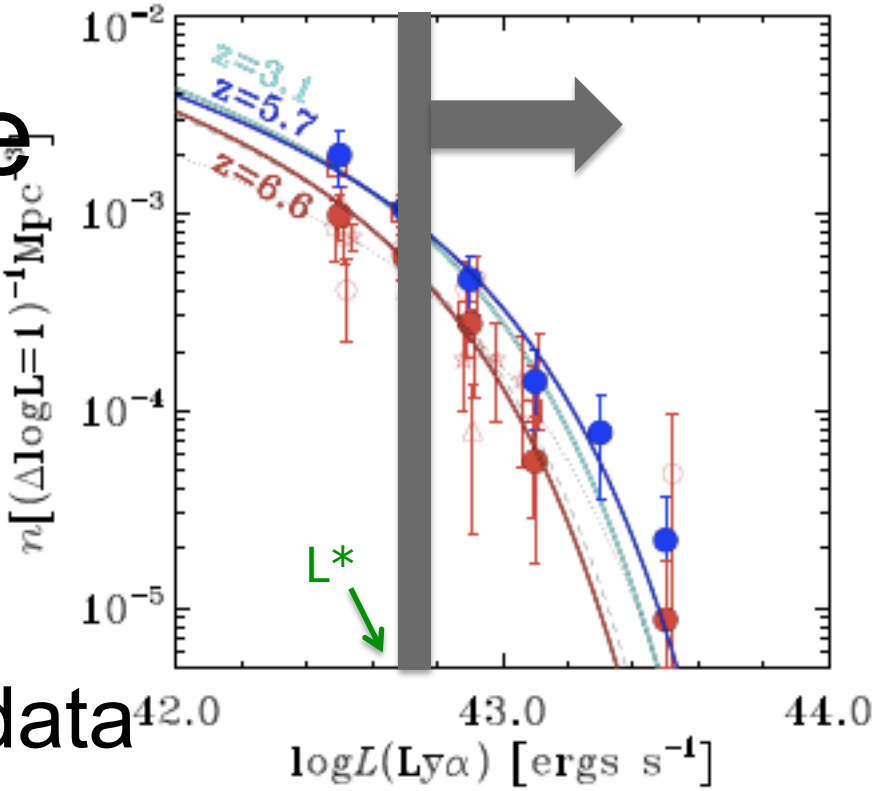




Ouchi et al. (2010)

- Subaru/HSC+PFS sample→ precision measurements of luminosity function and auto-correlation function of LAEs. Significantly improve the present constraints of neutral fraction at z~7.
  - Is the relatively early reionization preferable? Is significant minihalo (Mh~10^6Mo) contribution (Choudhury+08) required?? But suppressed SF in minihalos by background radiation? Other sources of reionization (e.g. dark matter annihilation??)

Observations for the reionization studies

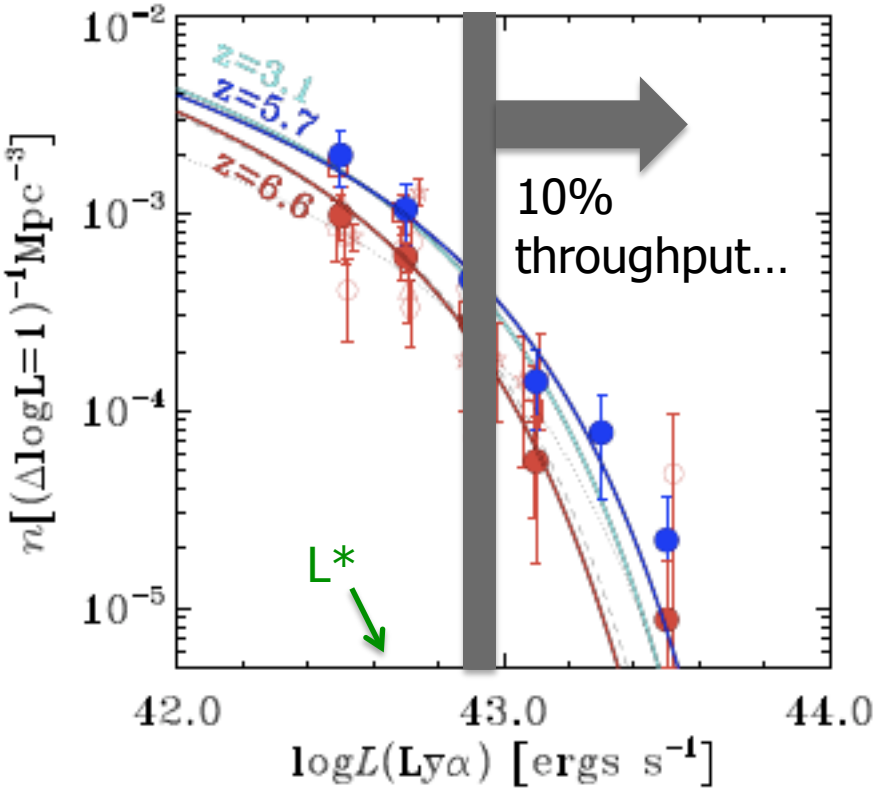


- HSC Deep Survey (DS) data
- PFS 6 hour integration for 30 deg^2
  - Covering HSC DS area (30deg^2): ~30 nights incl. overhead+weather with PFS
  - logL>42.7-42.8 erg/s; 6000 LAEs at z=5.7-6.6

Too large area for JWST/NIRSPEC

cf. ~600 nights with Keck/DEIMOS!!

Required PFS Performance



- Throughput! Most important
- If the throughput is not but 10% (a ~0.9um: similar AAOmega)
  - Only ~300 LAEs at z=6.6 (down to log L=43.0; cf 1000 for 20% throughput) because we target the bright-end of LF.
  - It is not clear if this issue is resolved with twice longer obs time (60nights, 12hr/pt), due to the systematic noise etc.

Fiber diameter is also important. (We assume 1.0” diam. Obs time increase by ~40%, if diam is 1.2”.

Required PFS Performance

- Spectral resolution (R)
- Isolating Lya from a number of [OII] doublets.
- Successful [OII] doublet identification =f(R, S/N, σ_v)

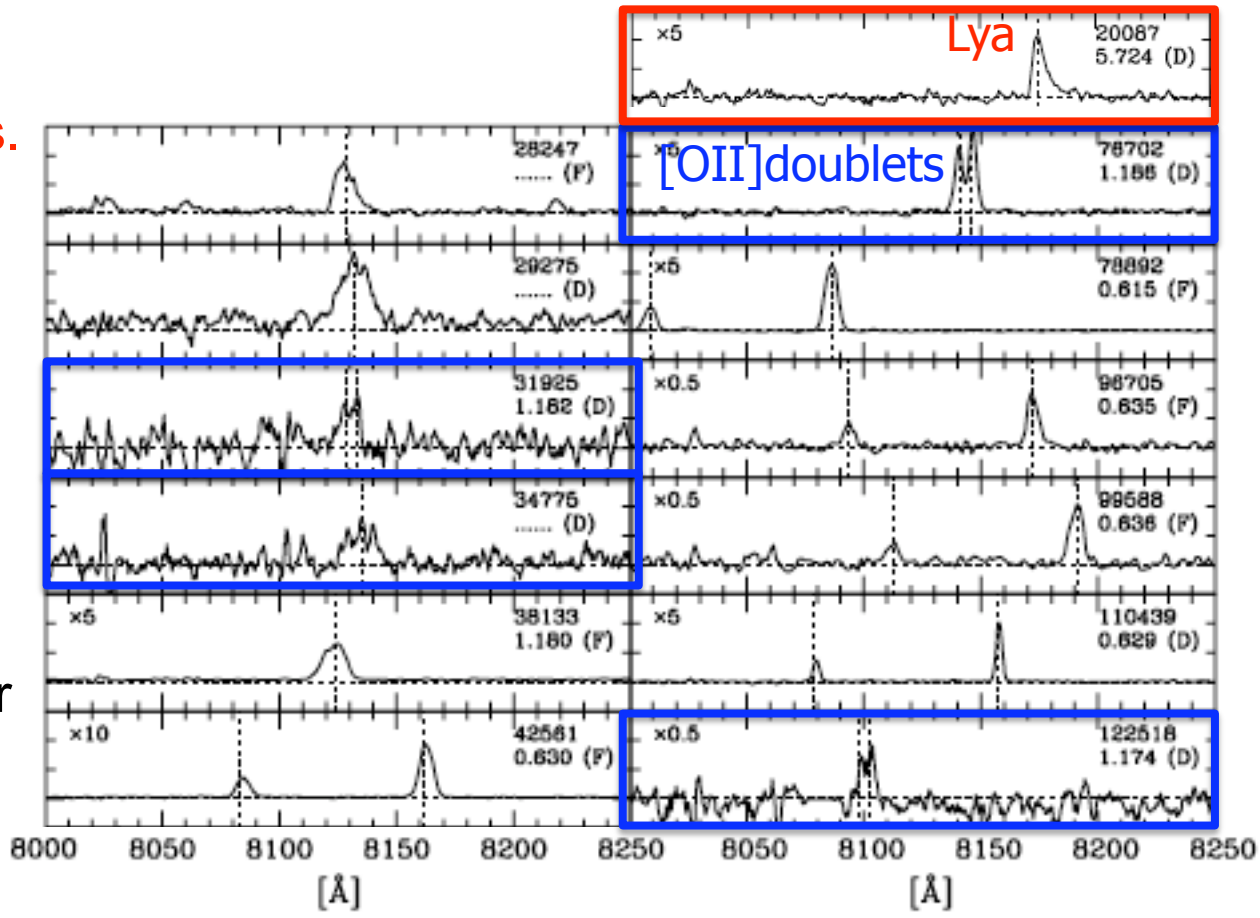
E.g. At 8000A,

R=3200-> 3A reslution
[OII] doublets ->6A sep
σ_v=100km/s->3A

- Lower R gives shallower flux limits for Lya and [OII] identification

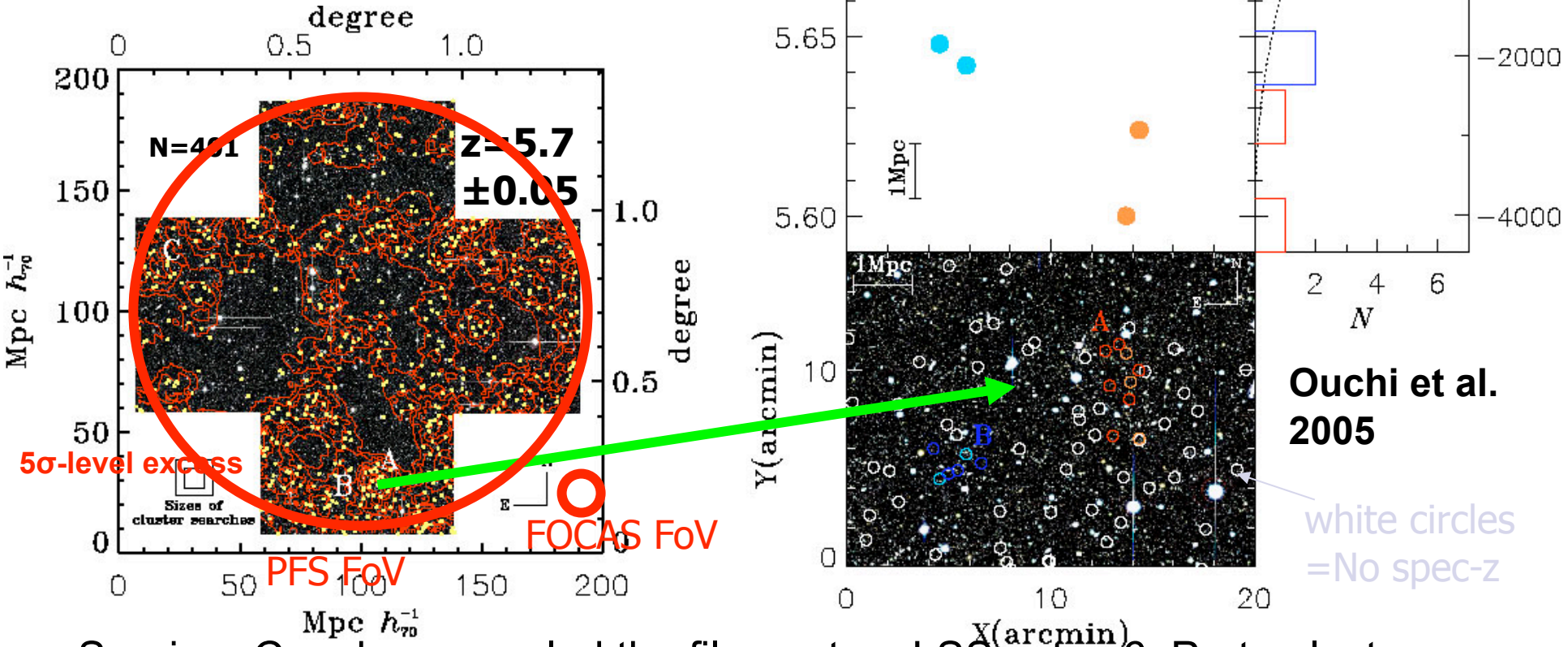
Optimal spectral resolution should be carefully chosen.

Spectral resolution of R=3200



Shimasaku et al. (2006)

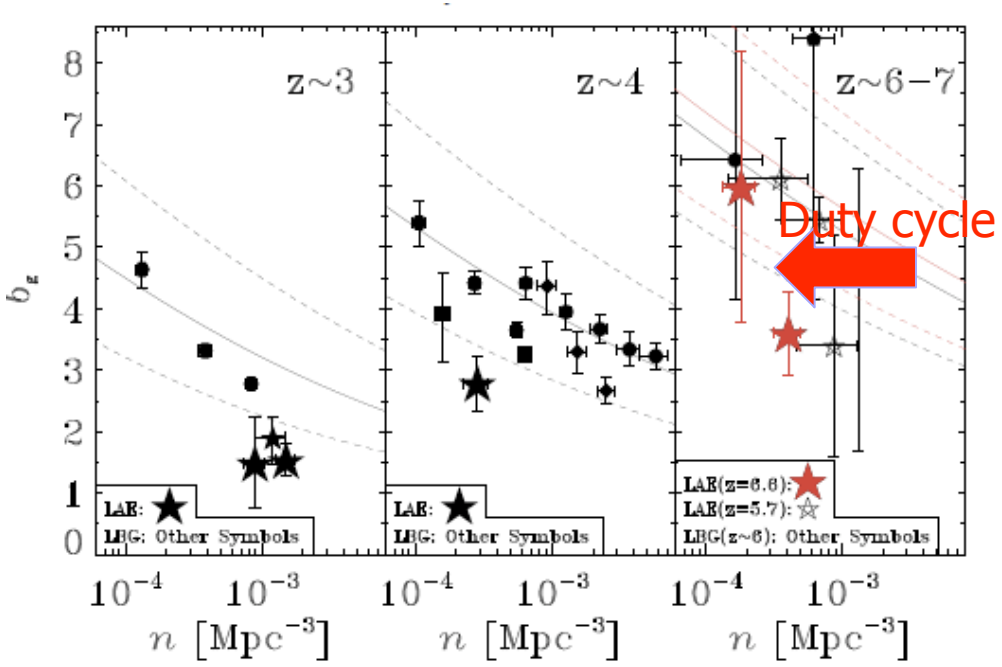
Mapping out high-z Universe for tracing large-scale structures and proto-clusters

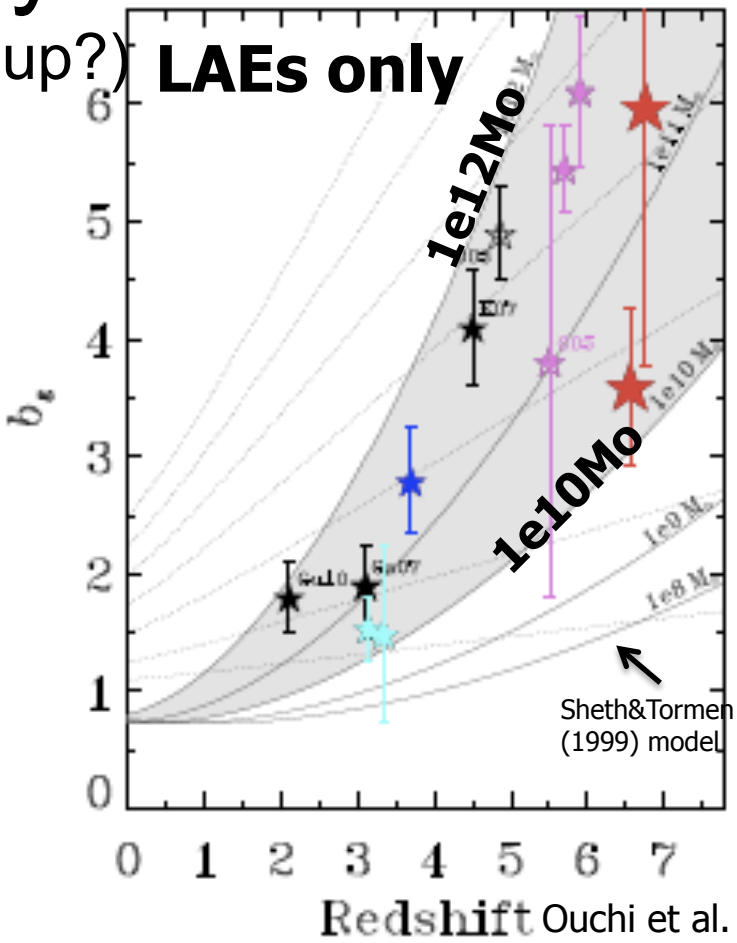


- Suprime-Cam has revealed the filamentary LSSs at z~6. Proto-cluster candidates are identified with FOCAS (Ouchi et al. 2005).
- Only 1/20 of phot. selected LAEs have spec-z.
- PFS will identify not only proto-clusters but 3D view of high-z LSS

Star-Formation Duty Cycle

(intermittent SF history for mass buildup?)

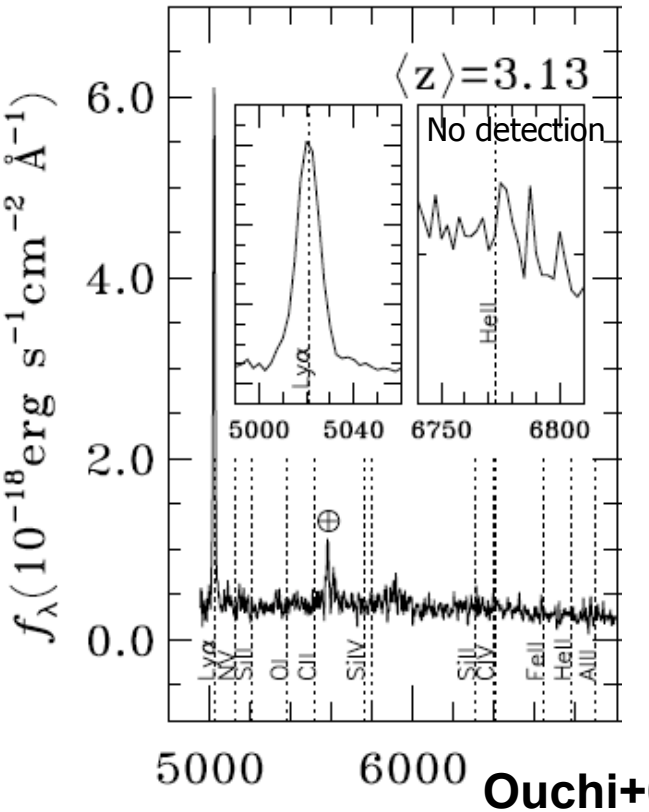




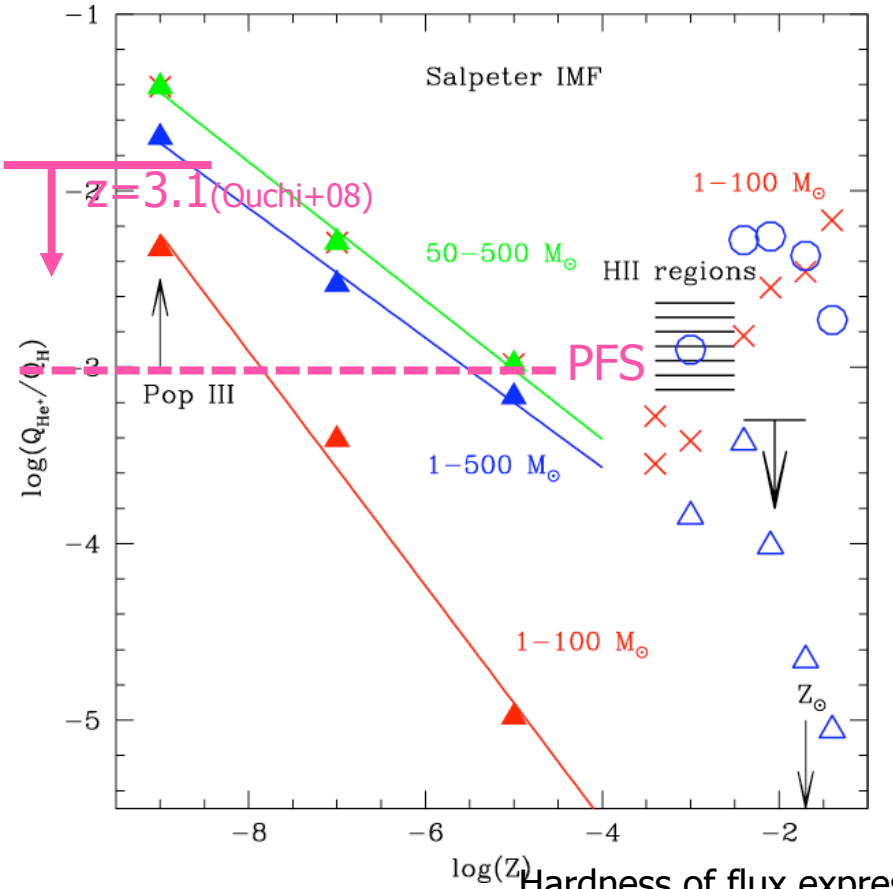
Ouchi et al. (2010)

- Precision measurements of high-z galaxy luminosity function and correlation function.→ hosting halo mass+HOD+duty cycle
- Halo mass determination (just an accuracy of an order)
- Duty cycle of dropout and Lya emitting population is ~10% and ~1%, respectively (just an accuracy of an order). Constraints on SF history and Lya production mechanism.

Do z~2-7 Galaxies include PopIII starbursts?



Ouchi+08

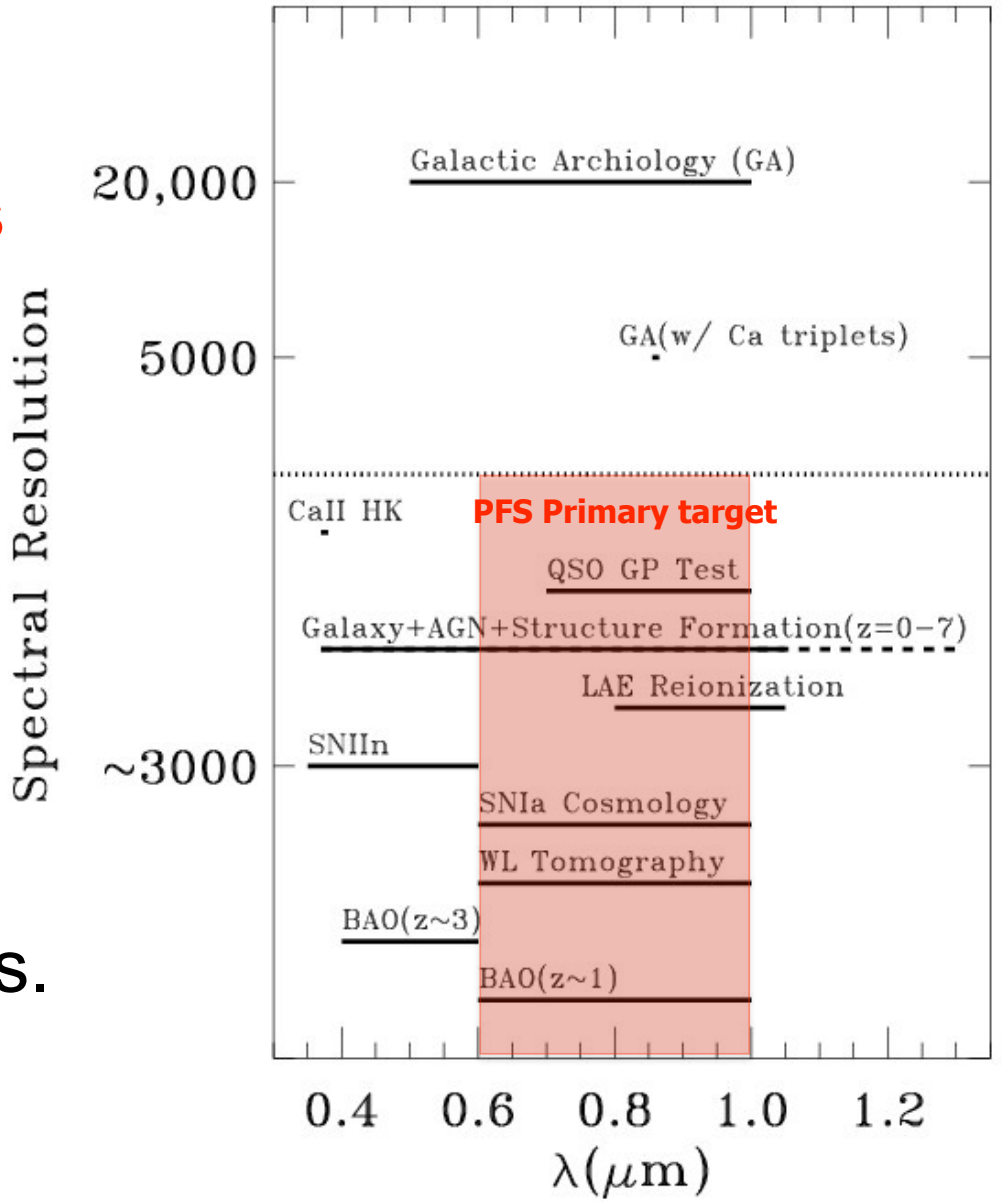


Hardness of flux expressed by the ratio of He+ to H ionising flux (Schaerer 2003)

- HeII is an indicator of forming galaxies.
- Composite spectra→no HeII emission (no signature of popIII/cooling radiation)
  - 3σ upper limits: f(HeII)/f(Lya)< 2% at z=3.13 (Ouchi et al. 2008)
- No signatures of popIII SF.
- PFS observations for 10k high-z galaxies→ identifying popIII SB with a top heavy IMF.

Wavelength Coverage

- PFS basic wavelength coverage (0.6-1.0um)
  - meets the requirements of the LAE Reionization studies.
  - misses z~0-0.5,and 2-4 galaxies+structures
  - AI: How much does the lacking coverage (0.37-0.6um) impact on galaxy+structure studies.
  - If possible, leave the possibility to add a blue arm of PFS.



Summary

- PFS: great synergy with HSC
- Goals of high-z studies with PFS
  - Cosmic Reionization
    - Physical process, Topology, Reionization history
  - Galaxy+structure Formation
    - Primordial LSS and Proto-clusters, SF duty cycle, popIII
  - Requirements to PFS specification
    - Keeping the throughput of ~20%
    - Spectral resolution should be carefully chosen for Lya and [OII] doublet identifications
    - Evaluating an impact by no blue arm of PFS.