Unveiling the high-z universe with Subaru/PFS

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

Decrease of UV luminosity function (Ouchi+04, Yoshida+06, cf. Iwata+03/07)

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

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

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

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

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)

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

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

Subaru Deep Field: The Most Distant Galaxy Known
Suprime-Cam ($i'$, $z'$, 921 pm)
Synergy with HyperSuprime-Cam (HSC)

- The size of PFS FoV just fits to that of HSC (∼1.5 deg-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)

- 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?
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 cross-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)
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?)

Cosmic Reionization History

Ouchi et al. (2010)
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
  - log$L$ > 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 8000Å,
R=3200 -> 3Å resolution [OII] doublets -> 6Å separation
σ_v = 100 km/s -> 3Å

- 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 $z \sim 6$. 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?)

- 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 $z \sim 2$-7 Galaxies include PopIII starbursts?

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

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

**PFS basic wavelength coverage (0.6-1.0μm)**

- 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 (0.37-0.6μm) 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.