TMT Synergies with Subaru HSC+PFS and Other Facilities

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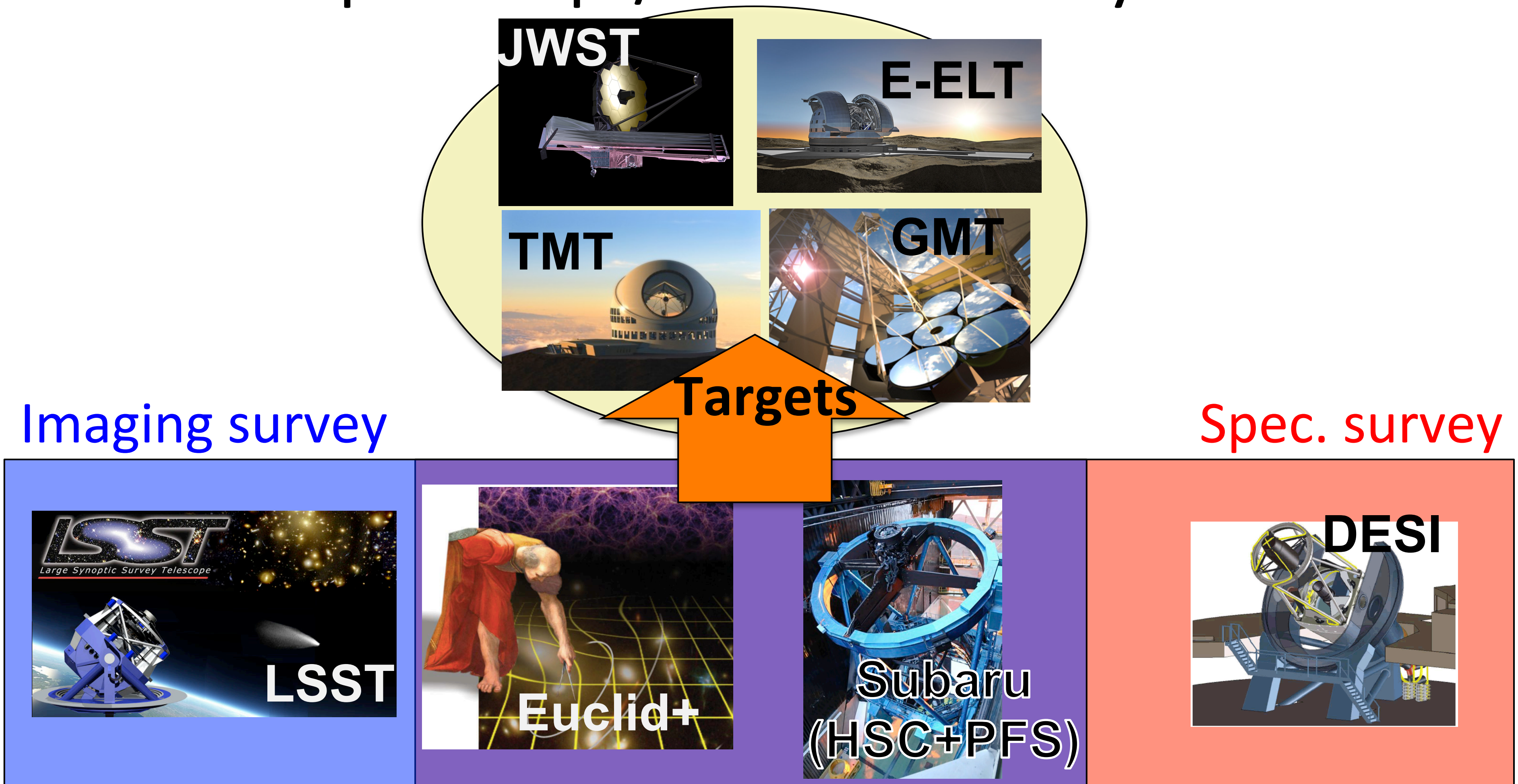
On Behalf of Subaru HSC/PFS Teams

Landscape of Opt/NIR Astronomy in ~2020



More than these!

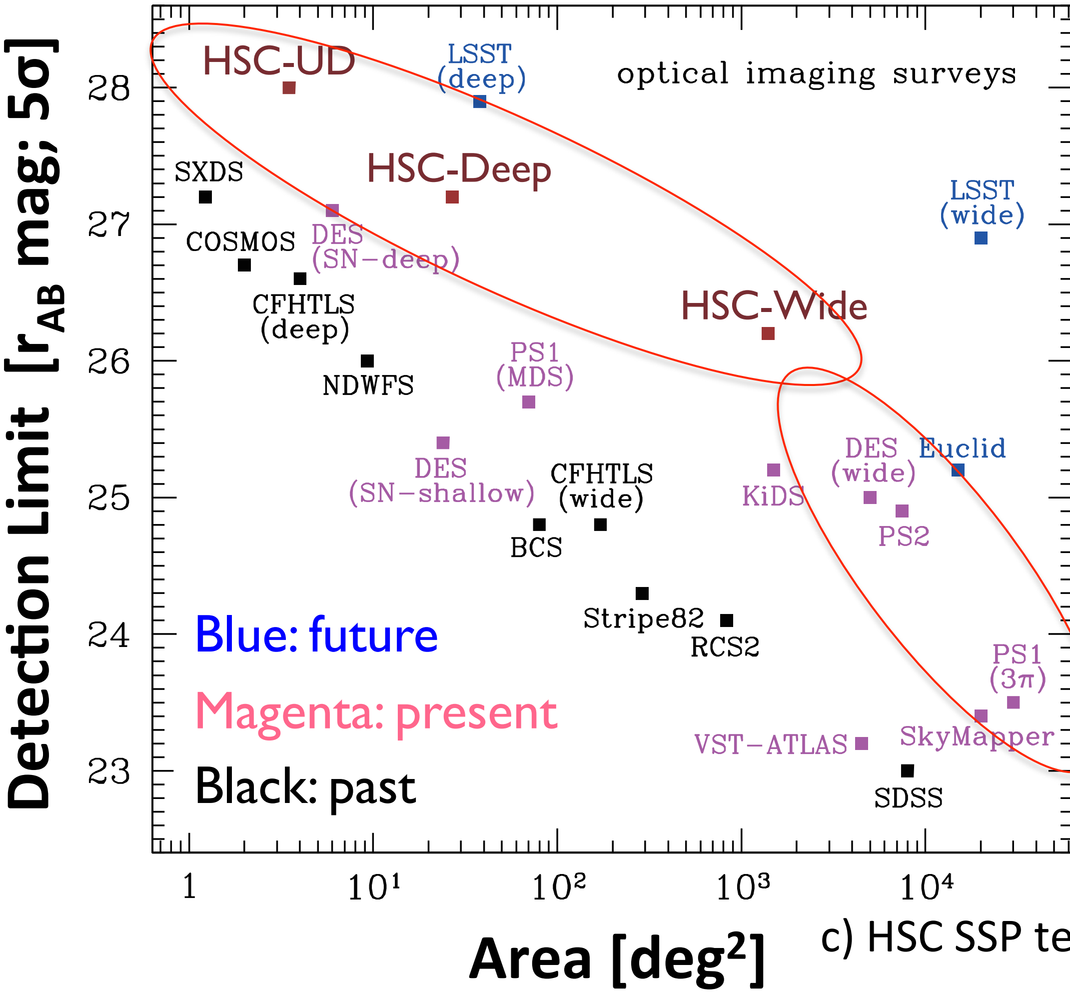
- EL observatories (e.g. TMT). Great sens.+res. Origin of obj.
- Survey telescopes. Imaging/Spec (e.g. LSST, Euclid+AFTA) →Feeding EL observatories

In the past decades, we saw targets from SDSS/CFHT/HST/Subaru -> Keck+ spec

1) Introducing survey telescope projects focusing on Subaru/HSC and PFS proj.

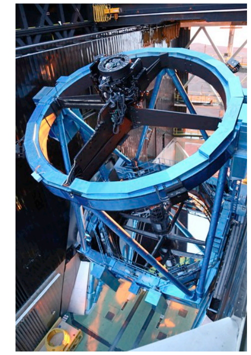
2) TMT Synergies highlighting the past examples

i) Imaging Surveys

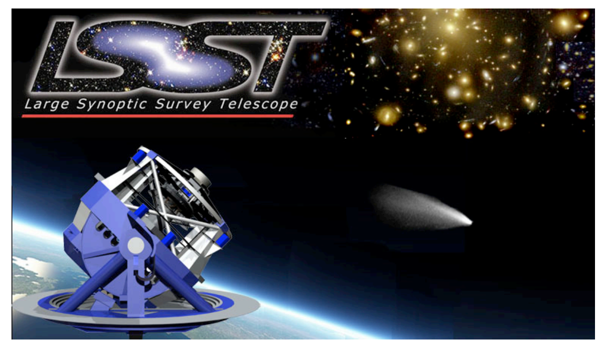


c) HSC SSP team

DARK ENERGY SURVEY

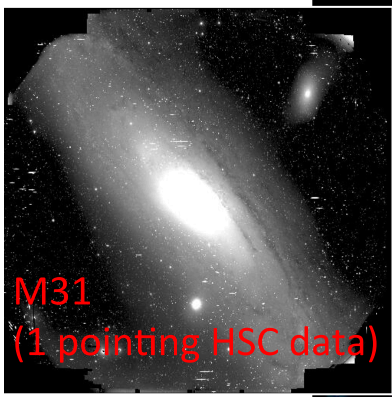


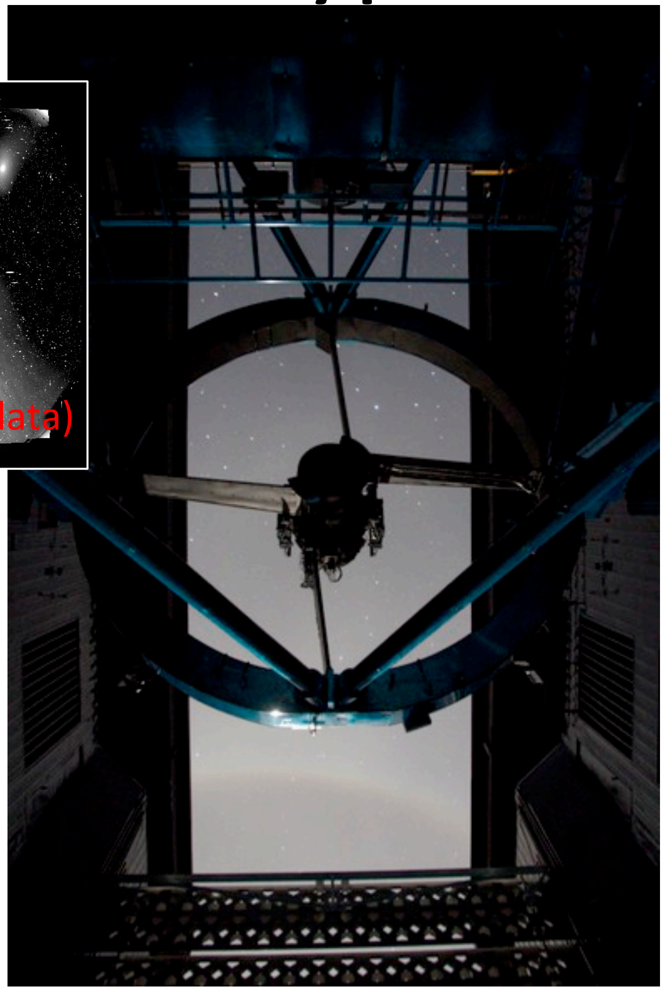
Hyper Suprime-Cam survey (HSC)

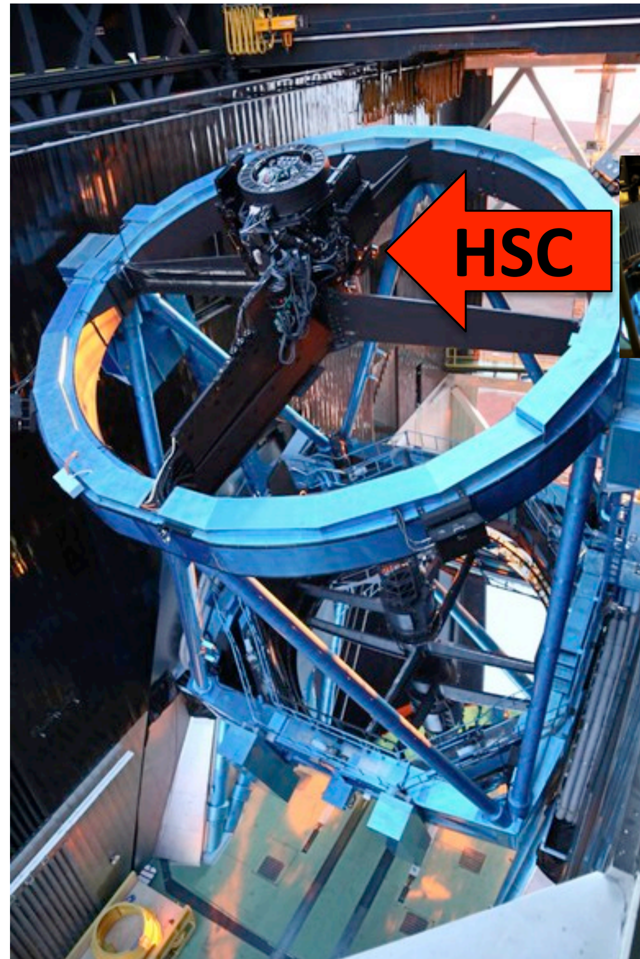


- Pan-STARRS, DES, and HSC followed by LSST, Euclid, and WFIRST-AFTA
  - In future, LSST covers the largest parameter space in depth and area (Willman's talk).
  - In present, Pan-STARRS(Chamber's talk) +DES are covering the largest in area ≳10^3 deg^2.
    HSC is placed at the best among the present surveys in area ≲10^3 deg^2.

Subaru/Hyper Suprime-Cam (HSC)







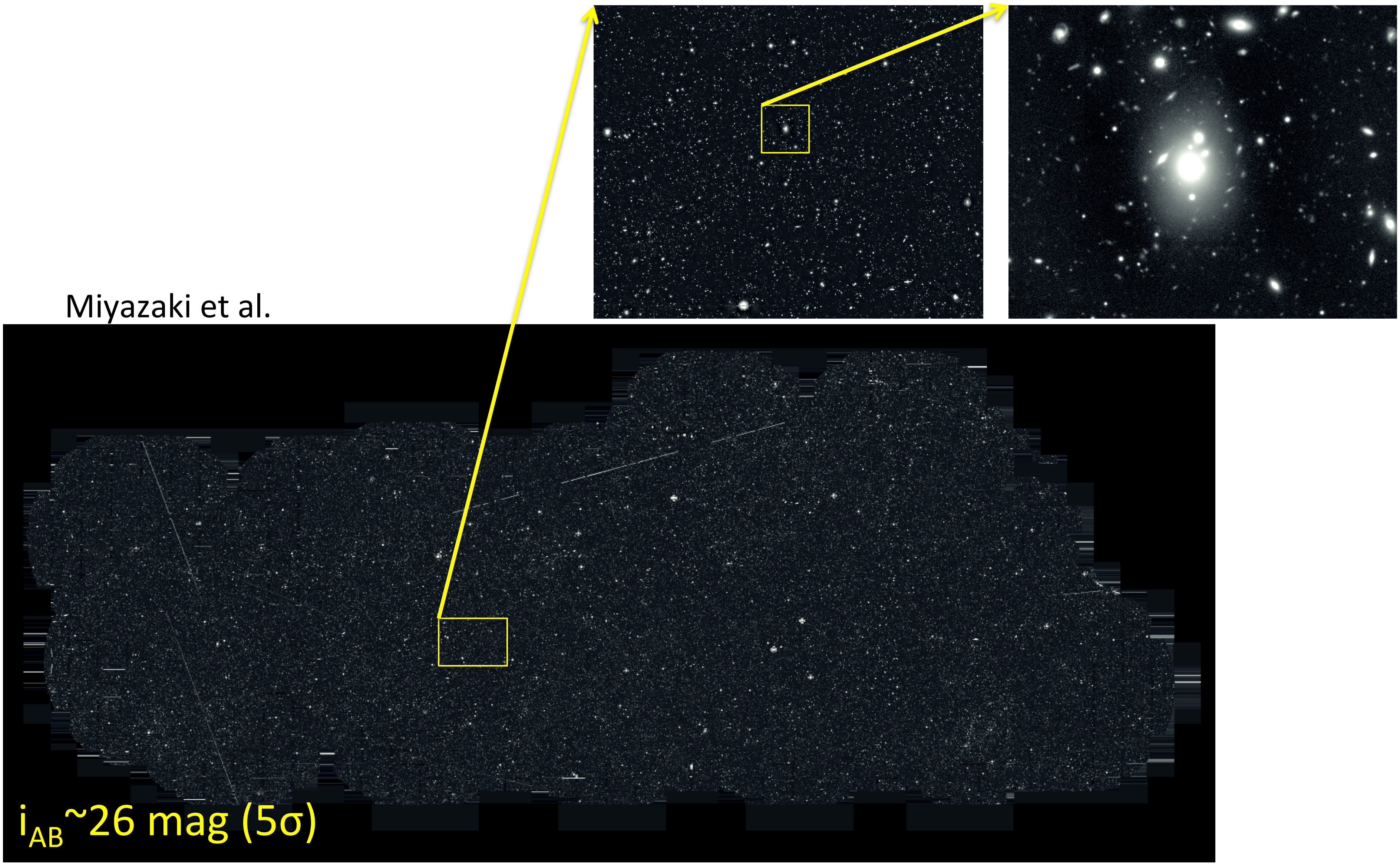
Suprime-Cam

c) HSC Builder's blog

- Subaru optical imager w a 1.5deg-diamger FoV, 7x larger than previous Suprime-Cam.
- Subaru/HSC survey has started since March 24, 2014 under the collaboration of JP/US/TW.
- Spending 300 nights in 5 years
- Slowly started. ~2% of is completed so far.

First HSC Survey Data

Miyazaki et al.



- HSC 20 deg^2 data in GAMA field (one of HSC survey fields).
- It took only ~3 hours! Seeing: 0.4-0.6 arcsec (FWHM).

HSC Survey: 3 Layers

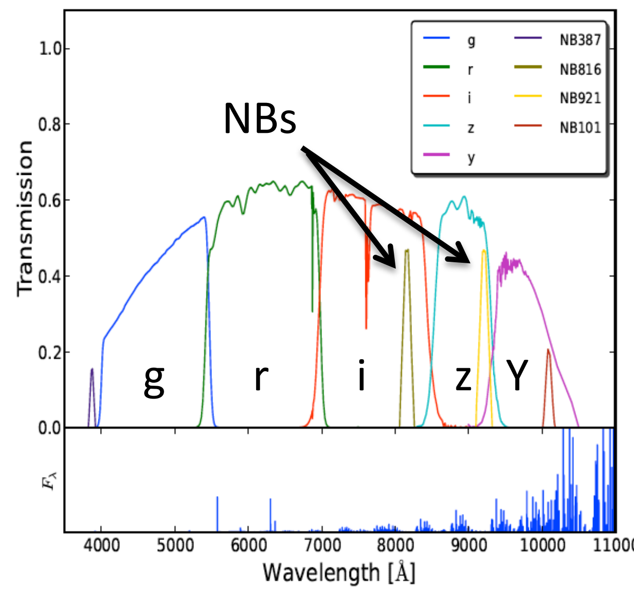
- Major goals: Dark energy and high-z objects/IGM

c) wikipedia

- Wide layer: 1400 deg^2, grizy (i=26)
  - Weak gravitational lensing
  - Galaxy clustering, properties of z~1 L* galaxy
  - Dark Energy, Dark Matter, neutrino mass, the early universe physics (primordial non-Gaussianity, spectral index)

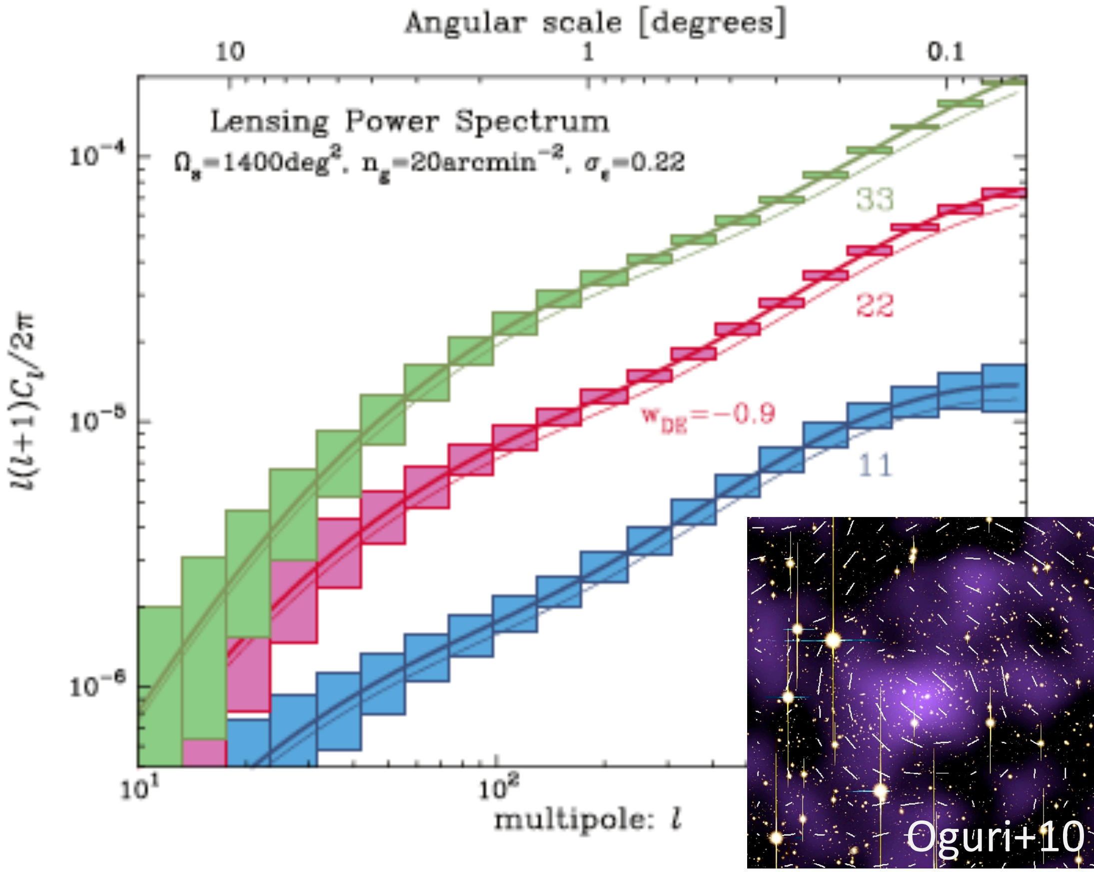
- Deep layer: 28 deg^2, grizy+3NBs (i=27)
  - For calibration of galaxy shapes for HSC-Wide WL
  - Lyman-alpha emitters, Lyman break galaxies, QSO
  - Galaxy evolution up to z~7
  - Cosmic dawn (the physics of cosmic reionization)

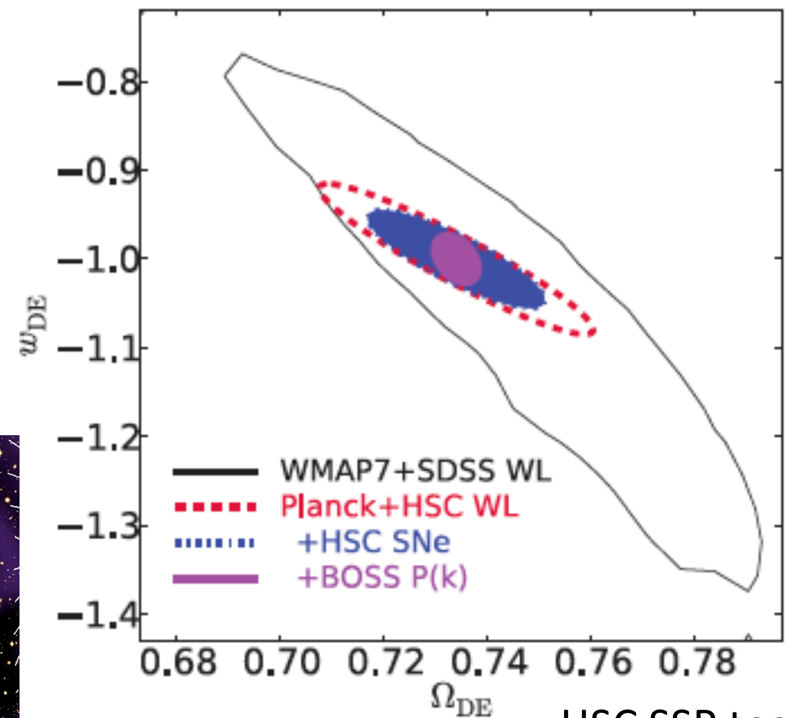
- Ultra-deep layer: 3.5 deg^2, grizy+3NBs (i=28)
  - Type-Ia SNe up to z~1.4
  - LAEs, LBGs at target redshifts
  - Galaxies at faint end
  - Dark Energy, the cosmic reionization



c) HSC SSP team
Updated Takada's slide

HSC Cosmic Shear for Dark Energy





HSC SSP team

- Cosmic shear (very good for HSC). Tomography for 3 redshift bins (z<1.5).
- Lensing power spectrum → Constraints on the dark energy's equation of state, w_{DE}, where $\rho_{DE} \propto a^{-3(1+w_{DE})}$.

- $\sigma(w_{DE})$=0.04 (comparable with the on-going DES projects).

HSC Survey: 3 Layers

- Major go

- Wide laye
  - Weak
  - Galaxy
  - Dark E
    early u
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- Deep laye
  - For ca
  - Lyman-alpha emitte
  - Galaxy evolution up
  - Cosmic dawn (the pl

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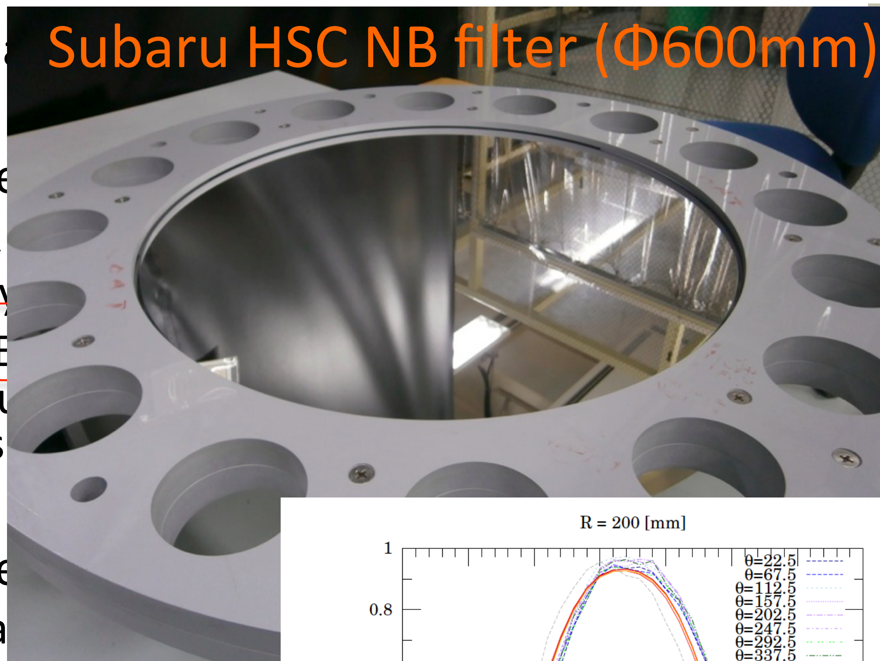
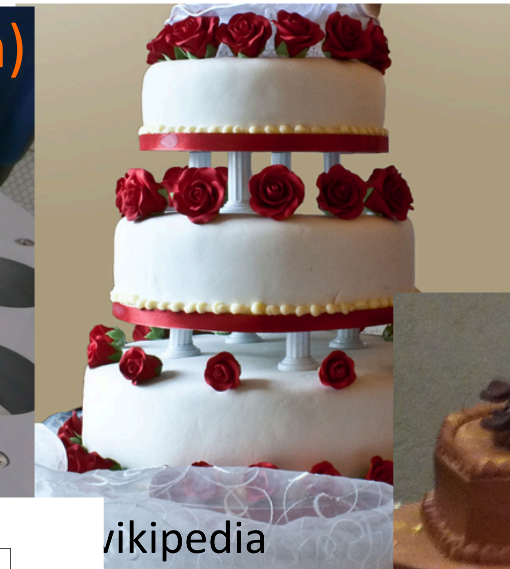
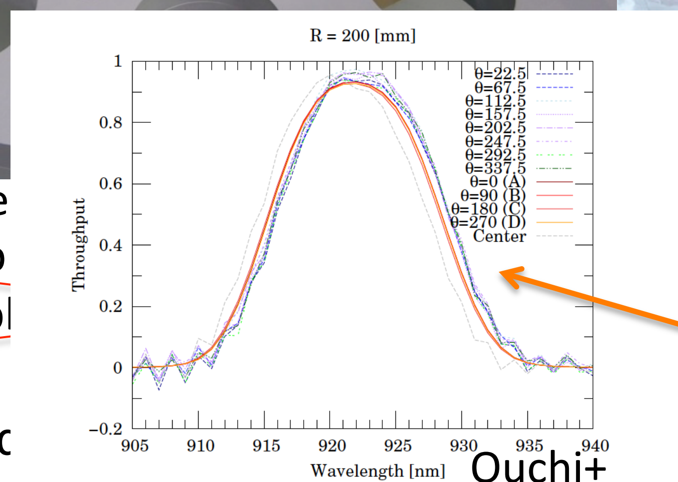
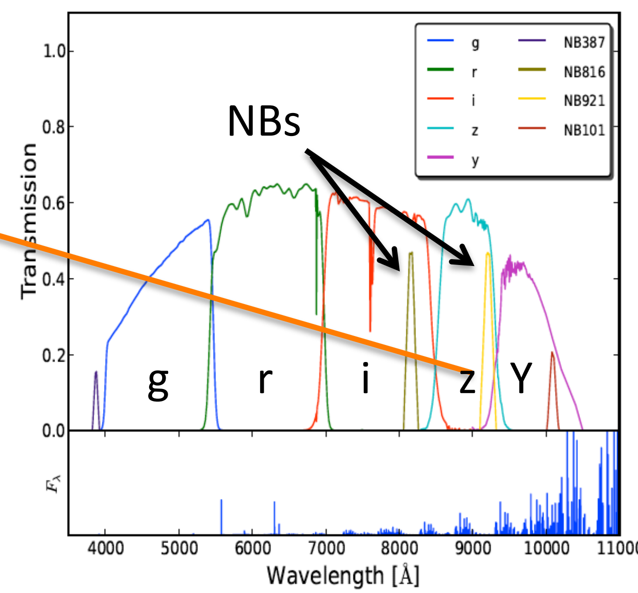
  - LAEs, LBGs at target redshifts
  - Galaxy evolution
  - Dark Energy, the cosmic reionization



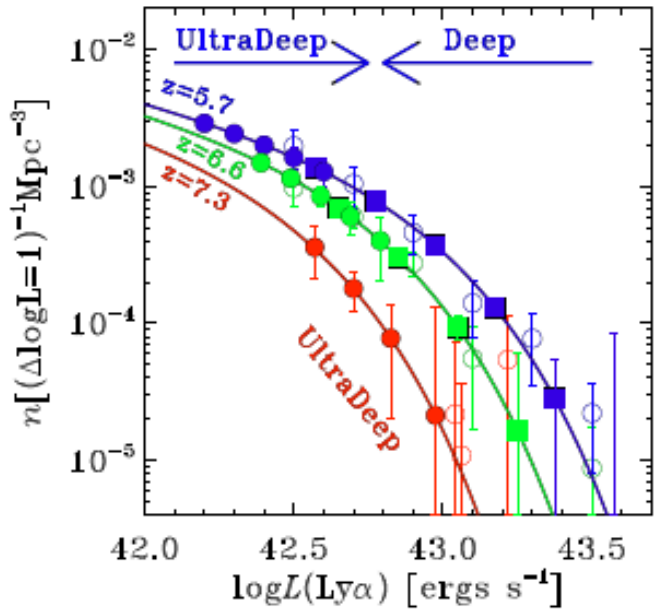




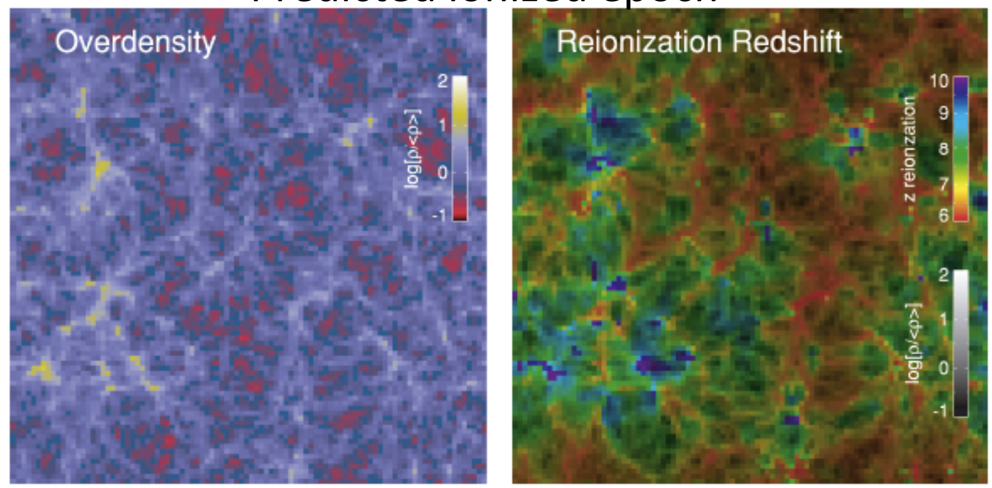


c) HSC SSP team
Updated Takada's slide

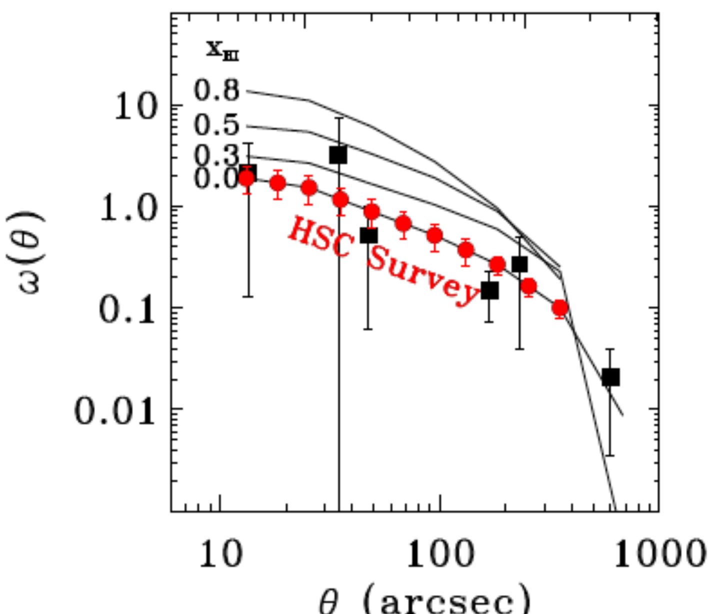
Probing Cosmic Reionization w Early Galaxies



Predicted ionized epoch



Finlator+09



c) HSC SSP team

- HSC survey→ Large sample of ~10,000 Lya emitting galaxies (LAE) at z~6-7, ~x100 larger than present sample. In 1 Gpc x 1 Gpc (comoving) area.
- LAEs are probes of reionization, because Lya is absorbed in neutral IGM at EoR.

- Lya LF (up to z=7.3). Determin. HI fraction w δx_{HI}=0.1.
- LAE clustering. Imprint of ionized bubble of IGM (e.g. McQuinn+07, Ouchi+10). Bubble topology →Physical processes (inside-out, filament-last, etc.)

ii) Spectroscopic Surveys

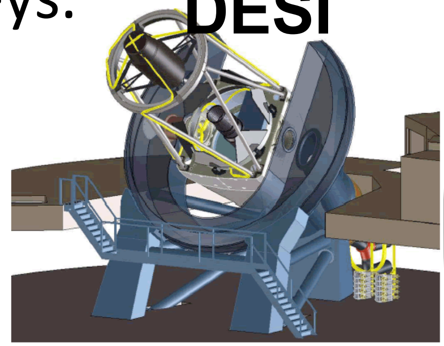
- In the mid 2000s, only LAMOST and WFMOS
- But, new programs are developing rapidly, exploiting the heritage of imaging surveys.

- Ongoing
  - LAMOST

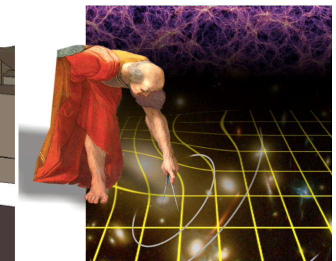
- Planned
  - Subaru/PFS (succeeding WFMOS proj.)
  - KPNO/DESI (Formerly BigBOSS)
  - Euclid (spec. only in NIR)

- Concepts
  - MSE (Formerly ngCFHT)
  - William Herschel/WEAVE
  - 4MOST

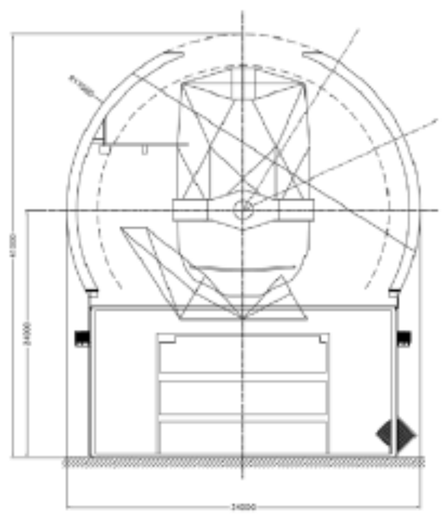
DESI



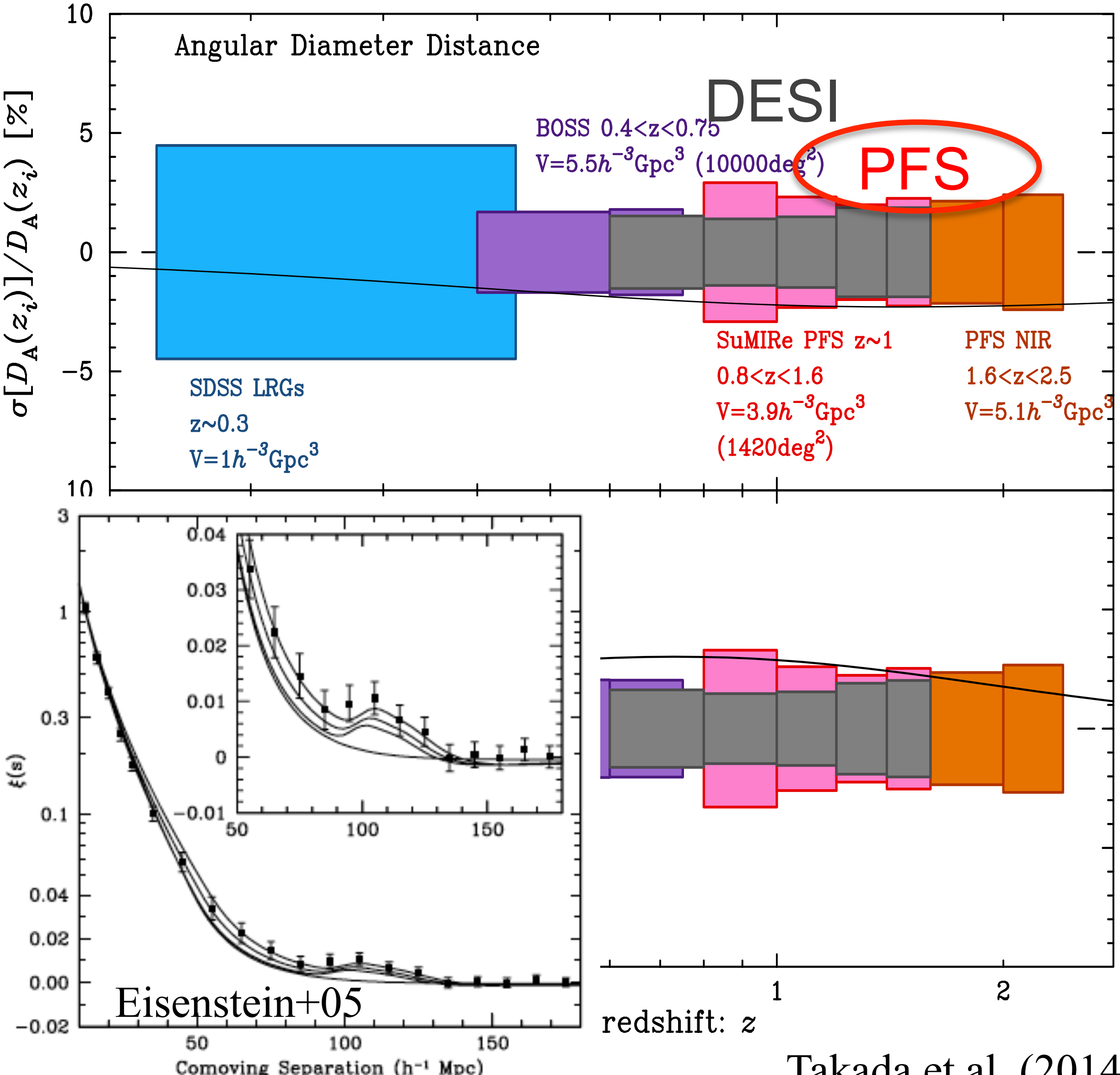
EUCLID



MSE (ngCFHT)



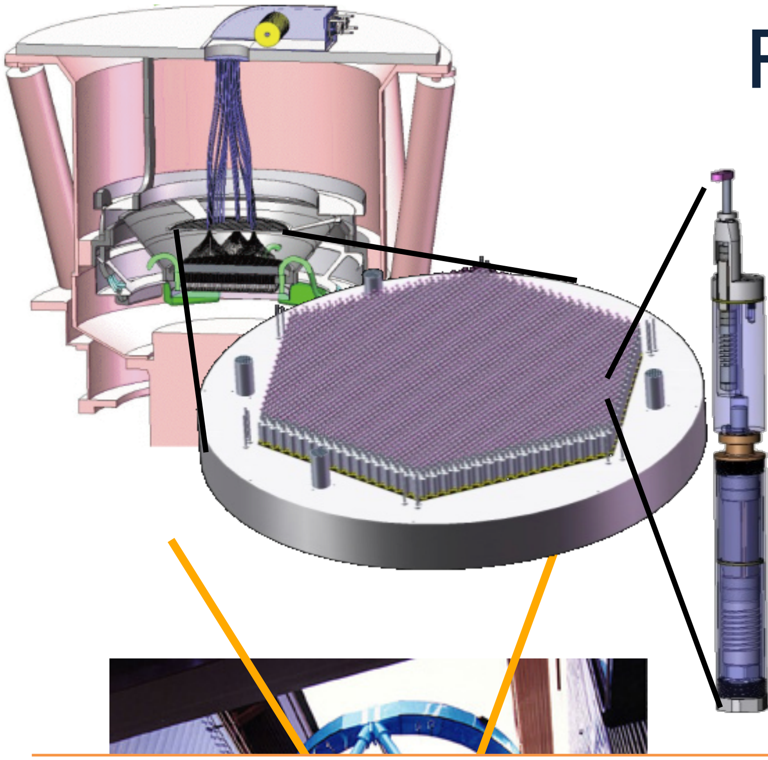
Major goal: Dark Energy



Takada et al. (2014)+

- BAO: imprint of the recomb-epoch acoustic oscillation →standard ruler
- $\sigma(D_A)/D_A$=2-3% for DESI and PFS (PFS reach a redshift of >2.

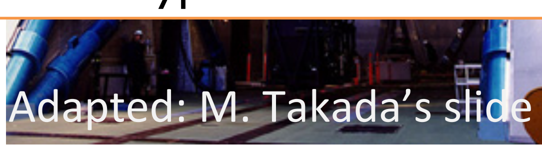
Prime Focus Spectrograph (PFS)



- Multi-object fiber spectrograph for Subaru under the collaboration of Japan, Princeton, JHU, Caltech/JPL, LAM, Brazil, ASIAA. ~2018
- Share WFC with HSC→→

Fiber density: 2200/sq. degs (⇔ ~140 for BOSS; ~570 for DESI)

Number of fibers	2400		
Field of view	1.3 deg^2 (hexagonal-diameter of circumscribed circle)		
Fiber diameter	1.13" diameter at center	1.03" at the edge	
	Blue	Red	NIR
Wavelength range [nm]	380-650	630-970 (706-890)	940-1260
Central resolving power	~2350	~2900 (~5000)	~4200
Detector type	CCD	CCD	HgCdTe



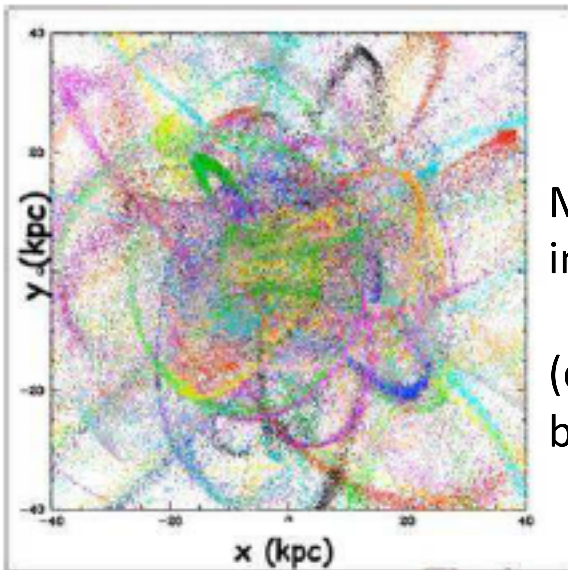
Approved by Preliminary Design Review (2013)

3 Key Sciences of PFS

Massive PFS spectroscopic follow up in the HSC imaging footprints

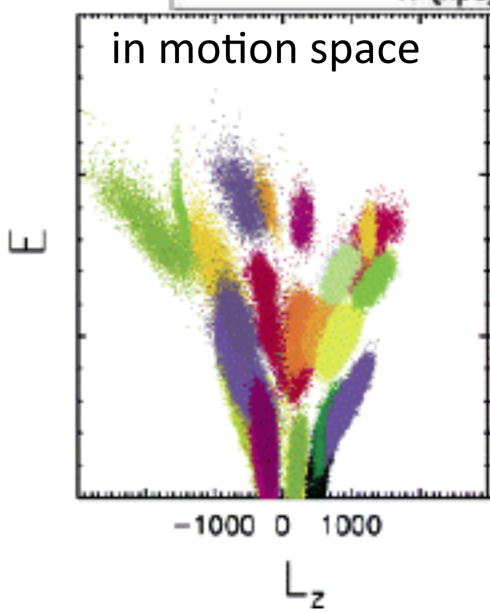
- Cosmology: 3D galaxy clustering
  - Dark Energy, neutrino mass, the primordial fluctuations
- Galactic archeology: studying phase-space structures of stars
  - A stringent test of cold-dark matter structure formation scenario on small scales
- Galaxy evolution history
  - Study physical properties of galaxies from cosmic dawn to the present day

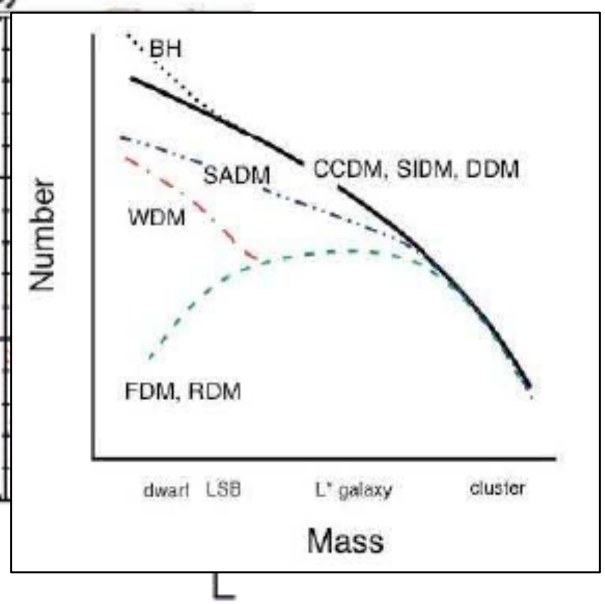
Galactic Archeology with PFS



MW-like galaxy in space

(color→diff. building blocks)





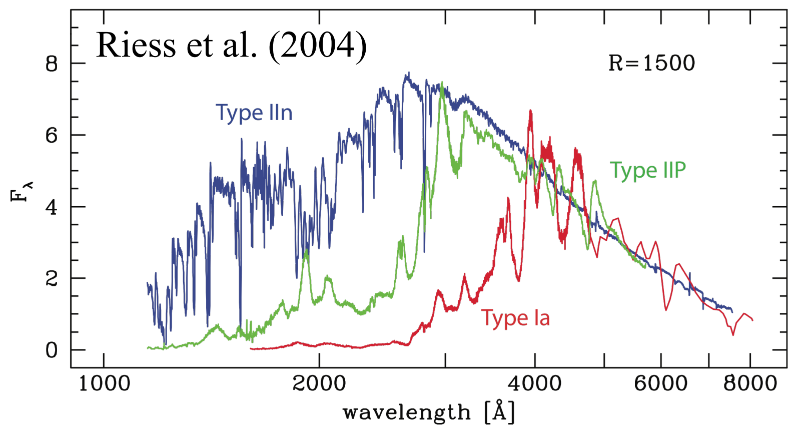
Takada,.., Chiba,..., Cohen et al. (2014)

- PFS deep spectra of a million stars in MilkyWay and M31. → Radial velocities and elemental abundances.
- Chemo-dynamics study.
- Key questions:
  - What is the merging history of MilkyWay?
  - How did the old Galactic components from? (origin of thick disk and stellar halo)
  - How does M31 differ from the Milky Way? (merger/ small-scale structures)

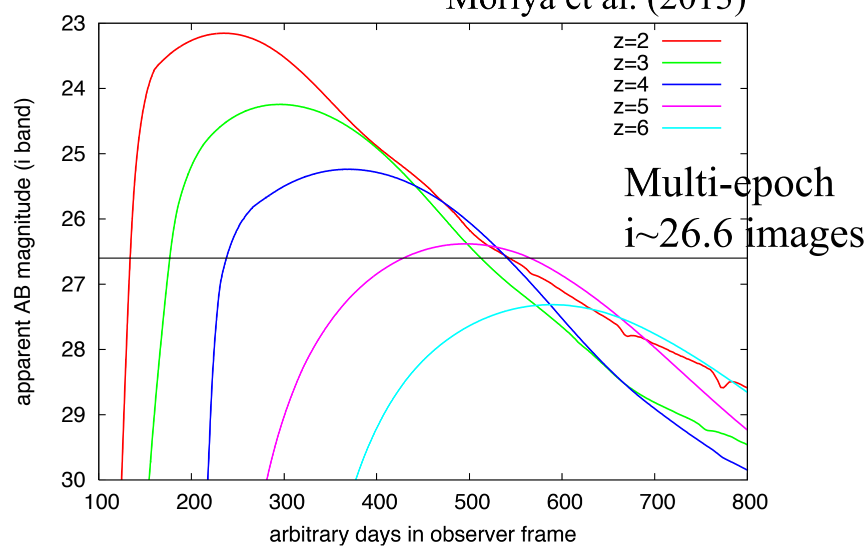
TMT SYNERGY

Large Area Survey: Early Supernovae

- Luminous supernovae, Type IIn SNe up to z~6
  - SNe with narrow emission lines. Bright in UV. (~L* galaxy)
  - Explosions of very massive stars (> ~ 50 Msun)
    - IMF constraints. Top-heavy??
  - HSC etc→TMT/WFOS,IRIS



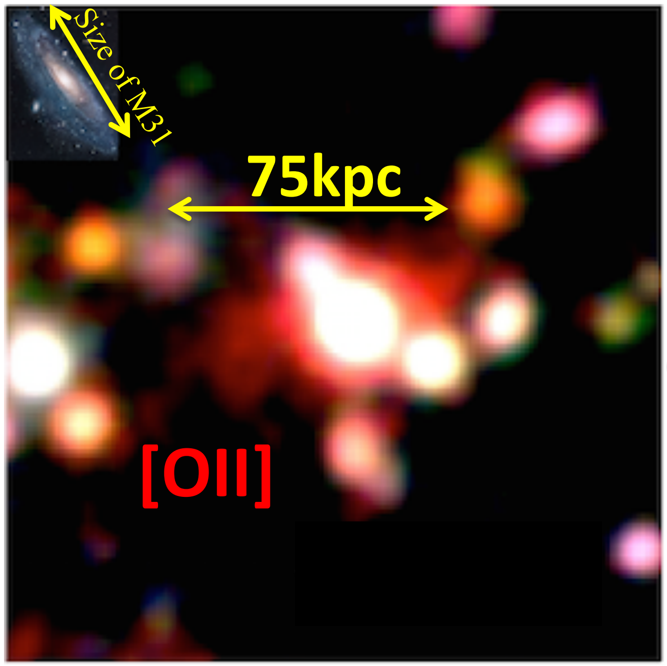
Moriya et al. (2013)

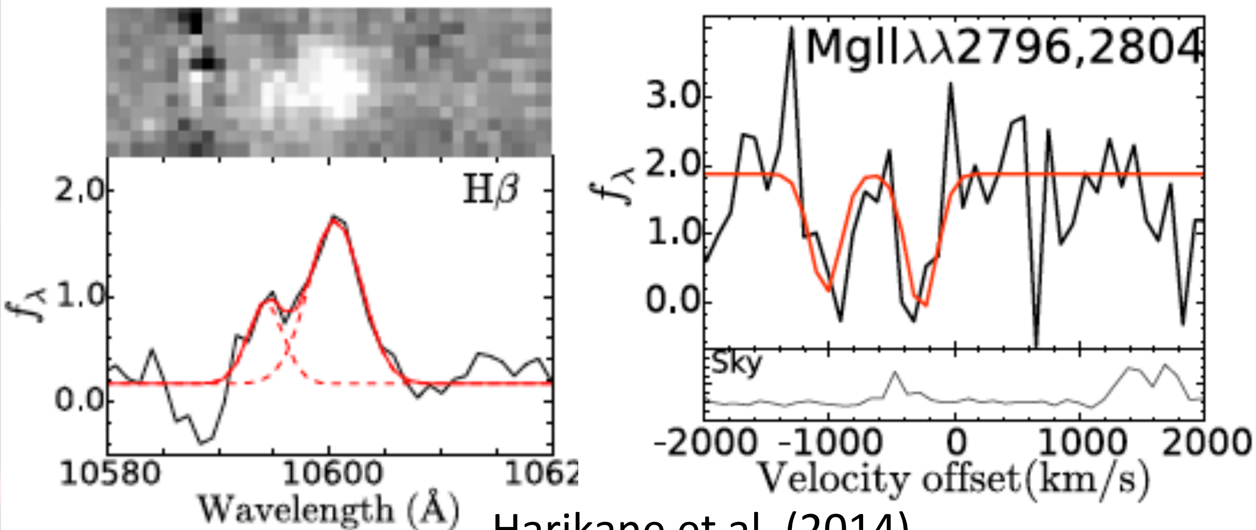


T. Moriya et al. (2013), M. Tanaka et al. (2012)

- Pair-instability SNe really exist? Serendipitous discovery?
  - Still no 'widely-accepted' observations
  - Expected to exist in metal-poor environment: high-z with TMT/WFOS,IRIS.

Large Area Survey
Feedback Process/Galaxy Outflow





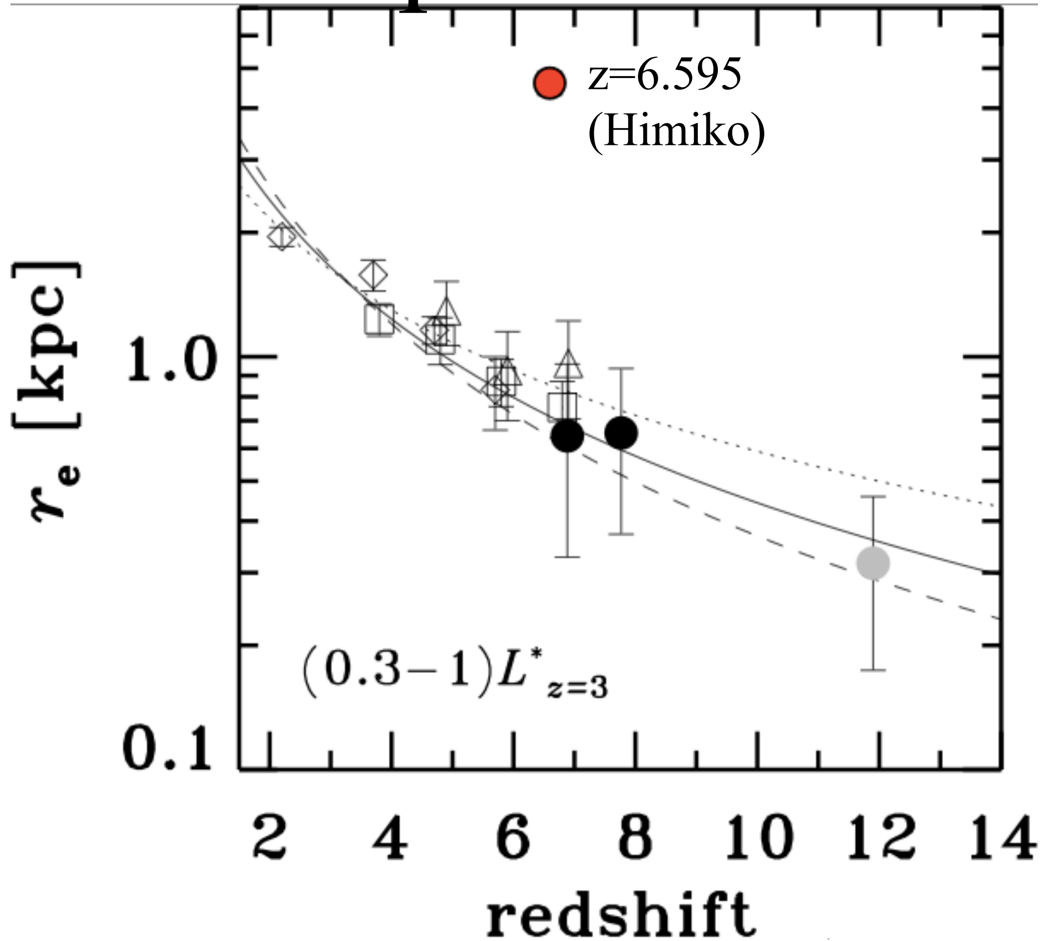
Harikane et al. (2014)

- Subaru large-area NB surveys→ Rare largely extended [OII]3727 nebulae ([OII] blobs) w a > 30 kpc size at z~1 (~10^{-6} Mpc^{-3} ; Yuma, MO+13). AGN + non-AGN.
- Keck/MOSFIRE spectroscopy etc: Emission and absorption lines→ significant gas outflow w 80-260km/s (Harikane, MO+14)

(cf. Escape velocity ~250km/s; assuming a singular isothermal halo potential profile. η>0.8).→ Some fraction of the outflowing gas could escape from the halo of the galaxy, suppressing its star-formation activity.

- Progenitors of elliptical galaxies quenching star-formation by the feedback at z~1??
- HSC/NB→TMT (details e.g. Velocity fields of outflow gas).

Mass Build Up of Galaxies



Ouchi et al. 2009, 2013

- Identified by Subaru wide-field (1deg^2) imaging survey for Lya source redshifted to z~7. Object with a large extended Lya and continuum w/o AGN. The source dubbed Himiko.
  - Keck spectroscopy clearly confirms a redshift of z=6.6 w Lya.
  - HST imaging reveal 3 continuum clumps. Triple merger, instability, or cold stream? Key for M* buildup.
  - Spitzer imaging yeilds M*~10^{10}Mo.
  - ALMA observations the deficit of [CII]158um line.High ionization param, high density, or low metallicity?

Similar sources of major mass build up → TMT spectroscopy for gas dynamics w abs lines.

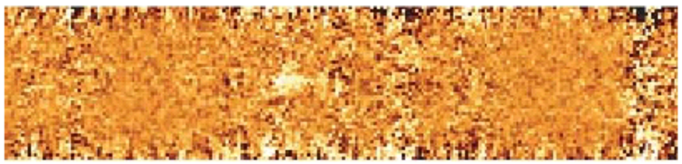
TMT Synergies I

- Rare objects from large imaging/spec surveys. →TMT study.
  - Rare→ minor and unimportant? No.
  - Short time-scale 'key events' that a large fraction of objects experience.
    - Luminous early supernovae
    - AGN (duty cycle). [GRBs by γ-ray monitoring]
    - Large-scale galaxy outflow
    - Galaxy's major mass assembly

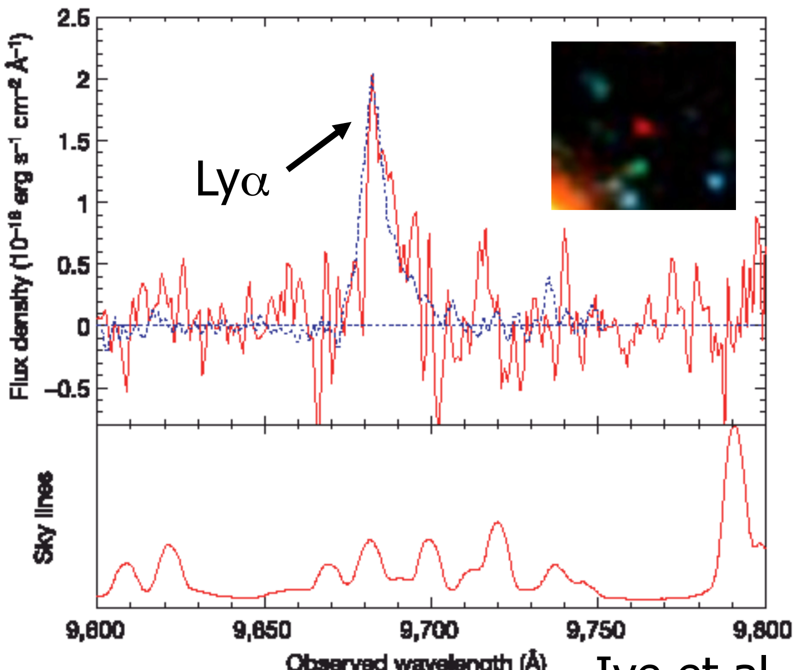
    Duration time: ~1 day to ~ Myr
- Through detailed obs, TMT synergy is to understand the physical origins of such 'key events' first found by the large area surveys such as HSC and LSST.

TMT Synergies II

- One of TMT's major goals: Early light (z>~10)
- Rare apparently bright obj. from large-area surveys
  - – Pushing the redshift frontier

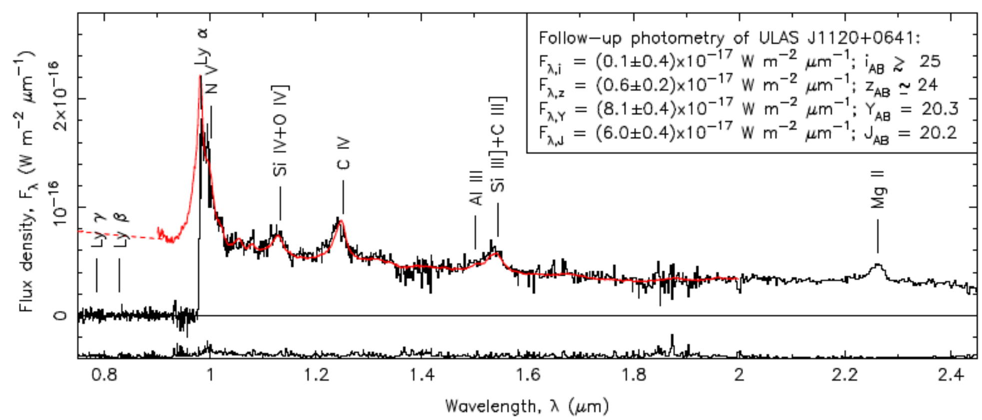


Subaru



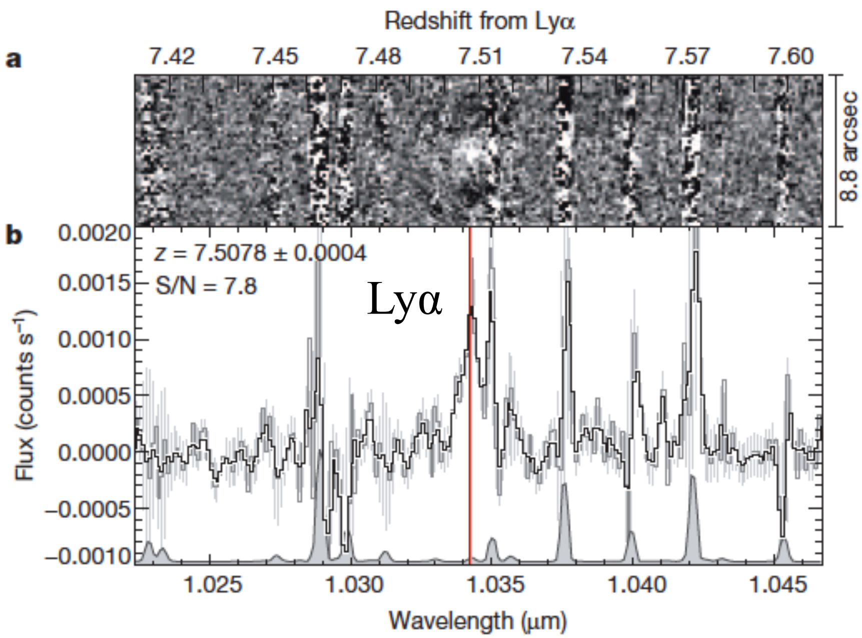
Iye et al. (2006)

UKIRT

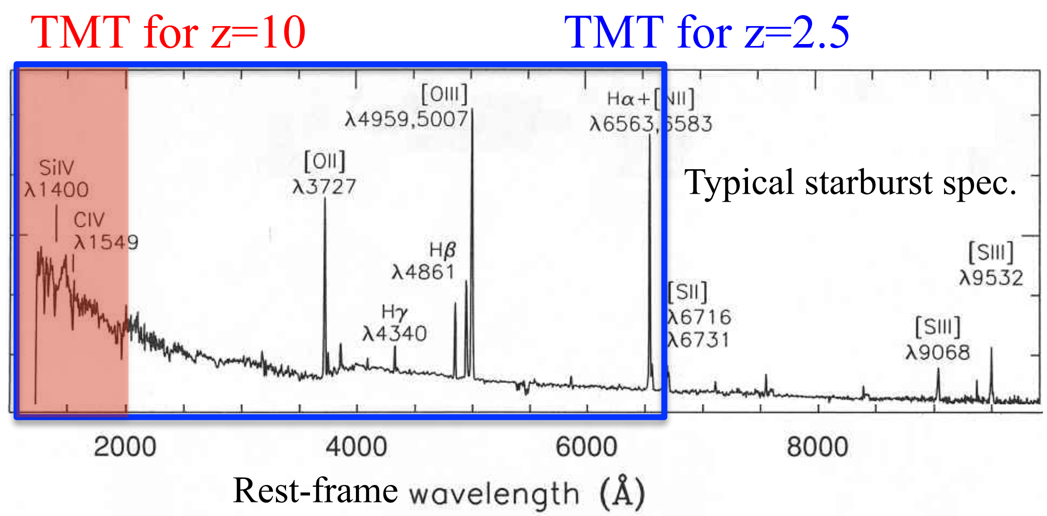


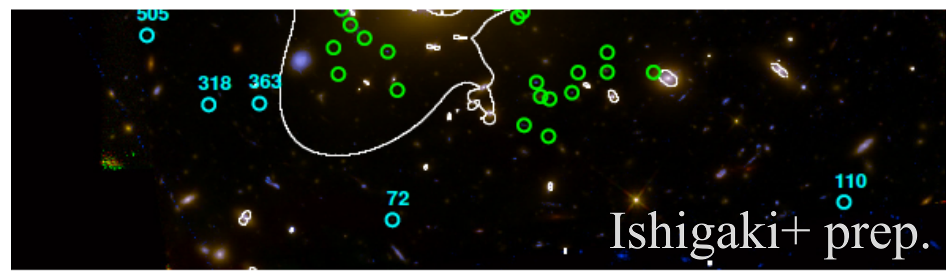
Mortlock et al. (2011)

TMT Synergies II



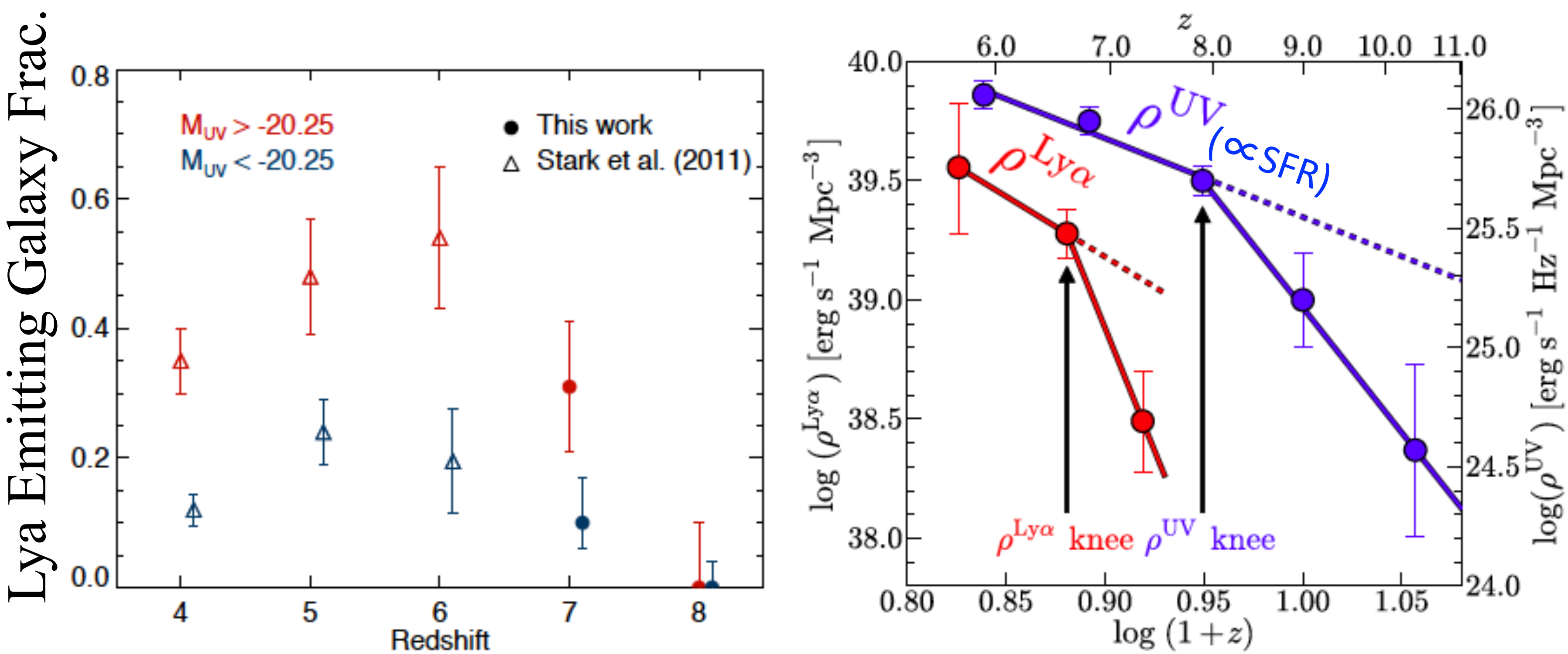
Finkelstein et al. (2013)





- HST large-area imaging survey (CANDELS) →Redshift up to z~7.5 w a Lya line
- Hubble Frontier Fields project: deep Opt/NIR imaging on clusters (PI J. Lotz; Atek+14,Zheng+14,Coe+14…)
- These HST (+upcoming JWST) sources can be targets for probing z frontier.
- Currently, HST sources →Keck spectroscopy for Lya (only detectable line in UV. No continuum).
- For earlier epoch (z~10) by TMT spectroscopy? But, sensitivity/wavelength problems.
  - Faint UV continuum break detectable only up to z~8 w TMT
  - Only Lya is available in the TMT wavelength (up to K band).

Disappearing Lyα at z≳8

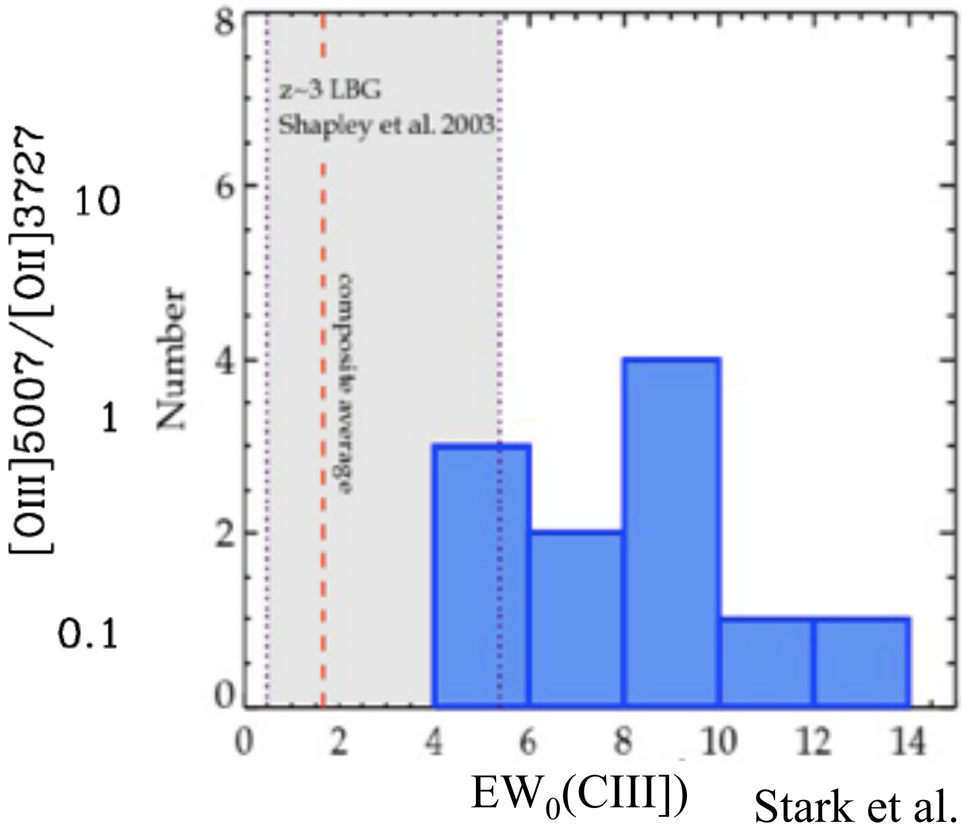


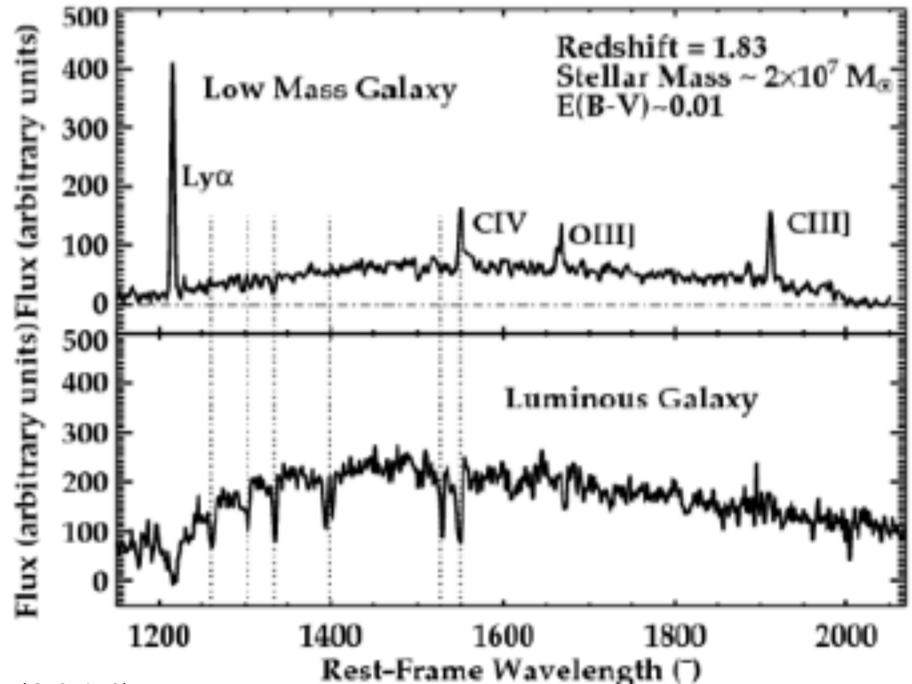
Schenker et al. (2014) Konno et al. (2014)

- Lya emission is absorbed by HI in IGM at the epoch of reionization (z>6).
  - Dropping the fraction of Lya emitting to all galaxies (Stark+11, Ono+12, Pentericci+11,14, Schenker+12,14, Treu+13, Finkelstein+14)
  - Lya drop is even stronger at higher z. Accelerated evolution (e.g Konno+14).

→ No wonder why there are no Lya emission detected at z≳8.

Low Metallicity and High Ionization State





(2014)

Stark et al. in prep.

Siana, Stark, Richard 2014

- f[OIII]/f[OII] ratios of z~2-3 LBGs/LAEs is ~x10-100 higher than those of SDSS galaxies (Nakajima,MO +13,Nakajima&MO+13;See also Kewley+13)
- Average ionization parameter increases towards high-z, more galaxies w low metallicity and young stellar pop.
- High ionization lines in UV continuum is getting strong towards high-z. The EW of CIII]1909 is ≳10A for low mass lensed galaxies (cf. 2A for 10^{10-11}Mo galaxies; Siana, Stark, Richard 2014)
- Keck/MOSFIRE detection of such a high ionization lines in UV continuum from z=6-7 galaxies (Stark et al. in prep.). Dynamics/Metallicity. Not for first-generation galaxies w zero metal, but >2nd generation early galaxies.

Summary

- Landscape of 2020s' opt/NIR astronomy
  - Large-area Imaging surveys
    - Pan-STARRS
    - CTIO/DES
    - Subaru/HSC
    - LSST
    - Euclid, WFIRST-AFTA
  - Next generation spectroscopic surveys
    - LAMOST
    - Subaru/PFS (succeeding WFMOS proj.)
    - KPNO/DESI (Formerly BigBOSS)
    - Euclid (spec. only in NIR)
    - MSE (Formerly ngCFHT)
    - William Herschel/WEAVE
    - 4MOST
- TMT Synergy
    - Rare objects. SN, AGN, merger, outflow. Rare, but short time-scale/important events.
    - Early galaxy identification and characterization. Almost non-detectable Lya lines at z>8, but high-ionization metal lines.