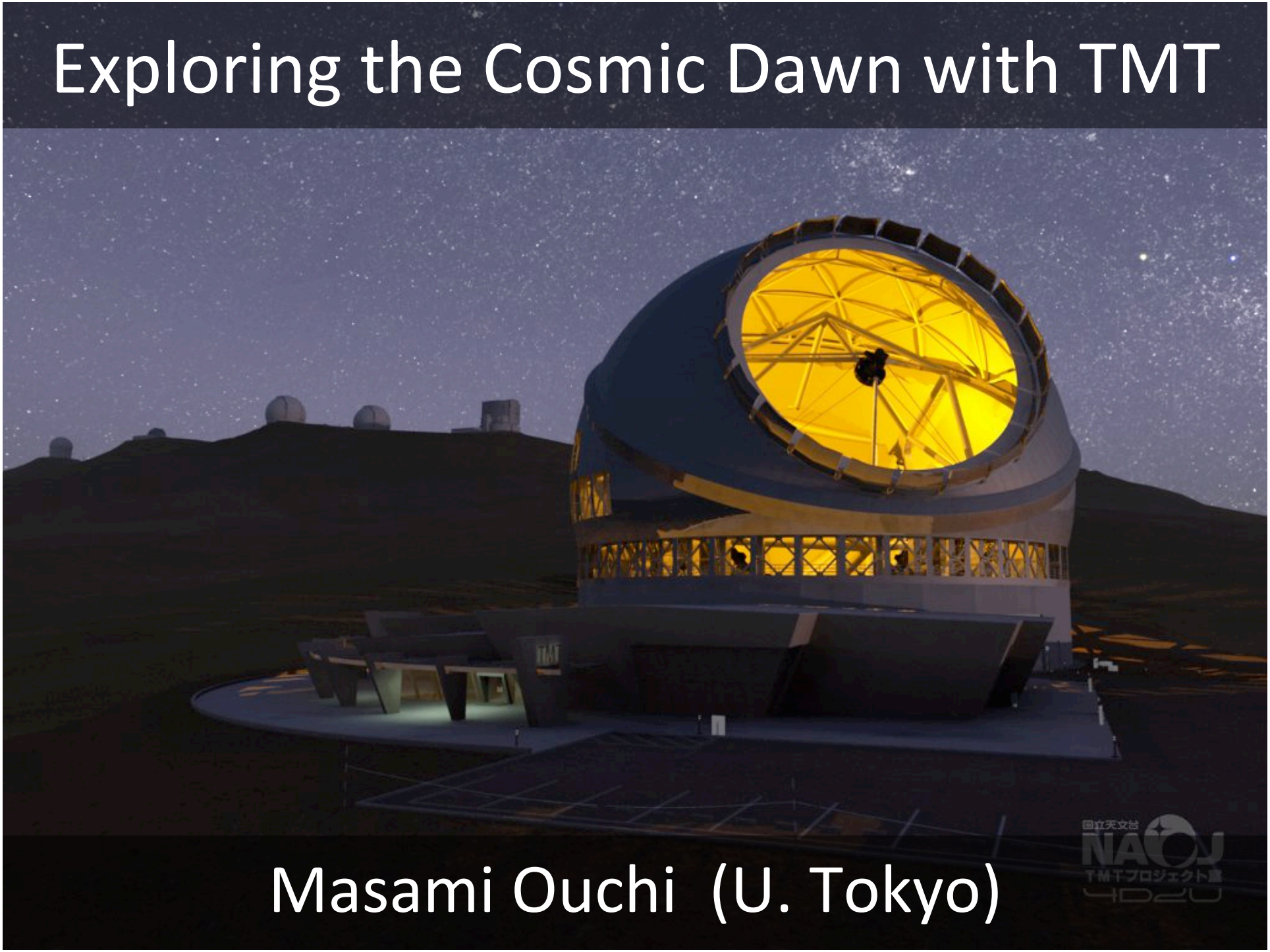
Exploring the Cosmic Dawn with TMT

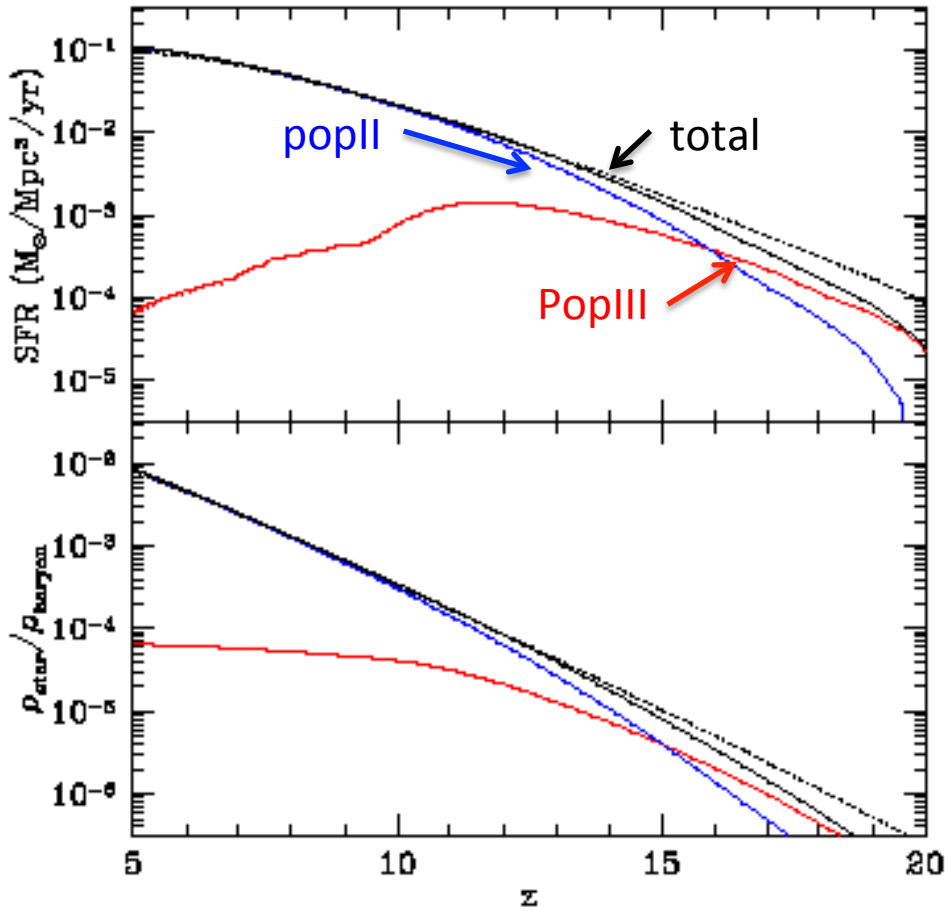


Masami Ouchi (U. Tokyo)

Outline

- Open questions addressed with TMT
- TMT feasibility studies for early galaxies ($z \gtrsim 10$)
  - IRIS and IRMS imaging and spectroscopy
  - Two difficulties for the identification of early galaxies
- TMT/WFOS & synergistic Subaru/HSC wide-area obs

Missing Link of Galaxy Formation: 1st Generation Stars/Galaxies



Trac & Cen06

So far, galaxy observations have reached z~10, no identifications of 1st generation stars/ galaxies. Galaxies at higher redshifts (z≳15) as suggested by theoretical models. → TMT for z≳15 gals. Goals of TMT obs. are answering

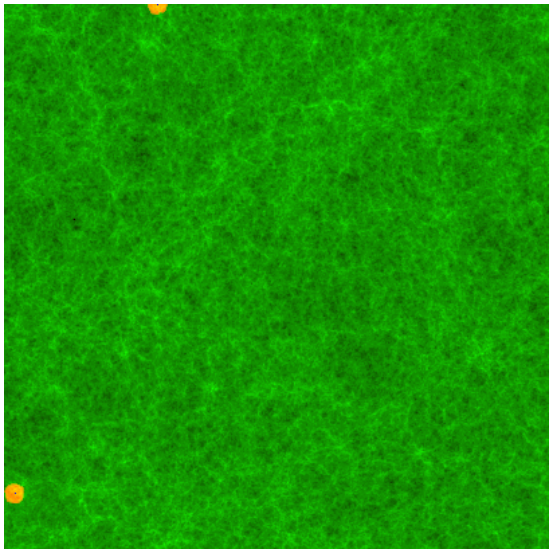
-when the first generation galaxies formed, what the dominant epoch of the formation is ?

-how stars formed? (tiny proto-stars first, subsequently massive stars ??)

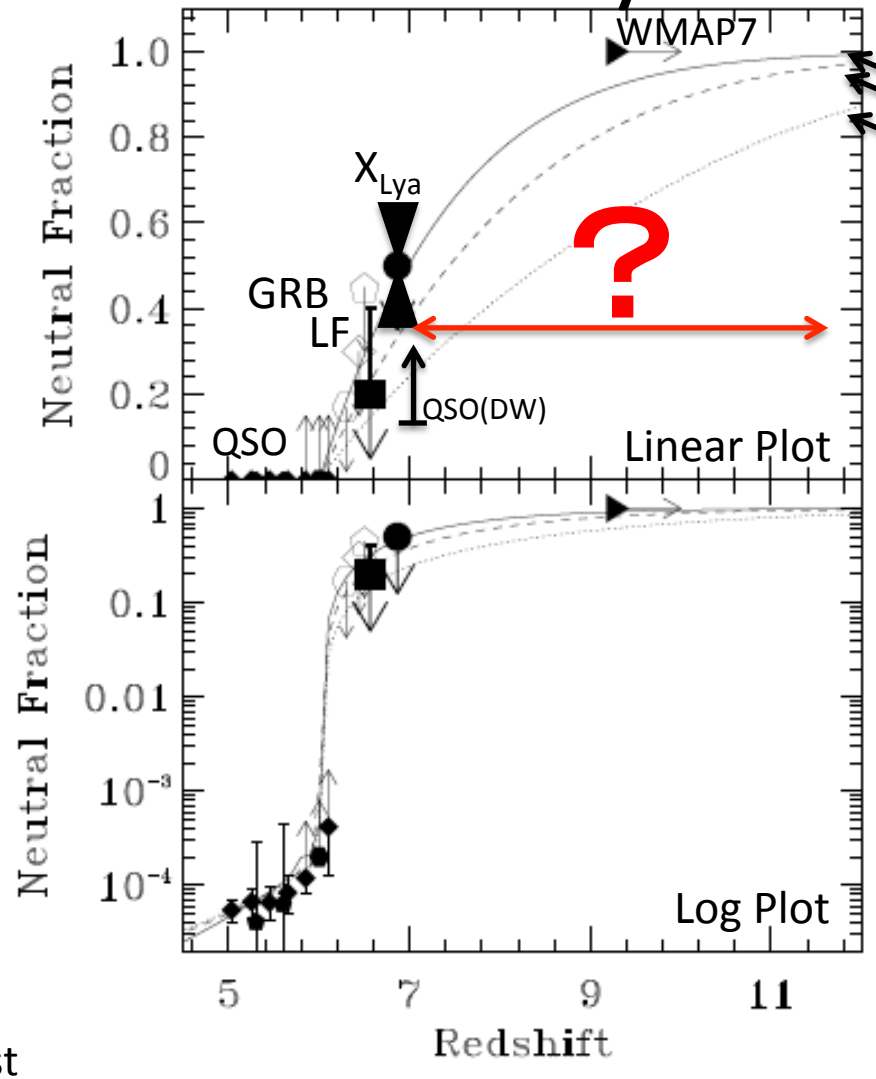
how these 1st generation gals. grow/merge to form present-day galaxies, such as Milky Way?

Cosmic Reionization History and Sources

Reionization predicted by the RT model (Iliev+06)



Galaxies (blue dots) and ionized bubbles (orange)



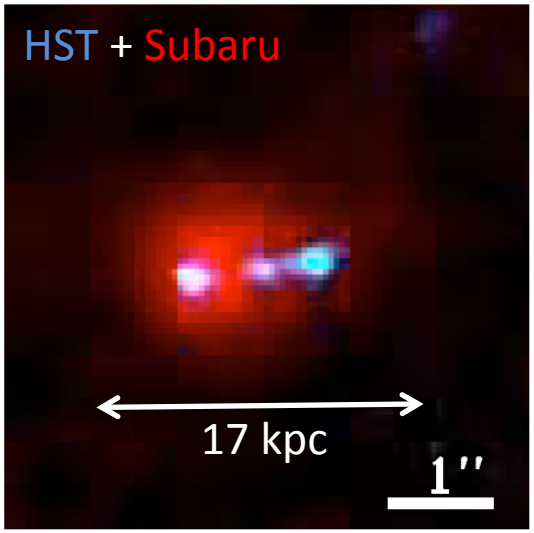
Ouchi et al. (2010) +latest results

- z~6: QSO Gunn-Peterson test
- z~11: CMB Thomson scattering optical depth

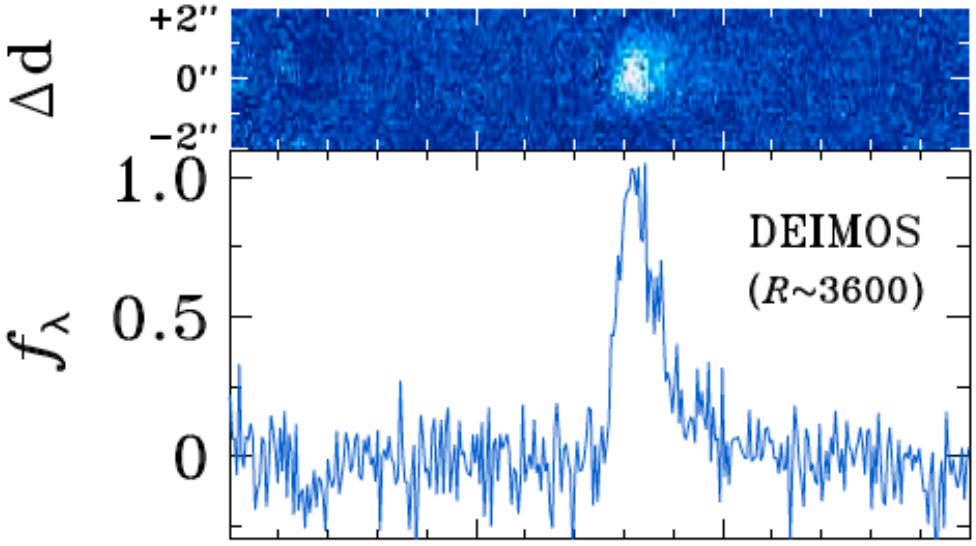
Sharp reionization (e.g. Fukugita+94) or extended reionization (Dunkley+09)?

Probing early galaxies (+QSOs and GRBs) at z~7-11 (at heart of EoR) by deep spec. to constrain reionization models.→Difficult for 10m-class telescopes→ TMT is needed!

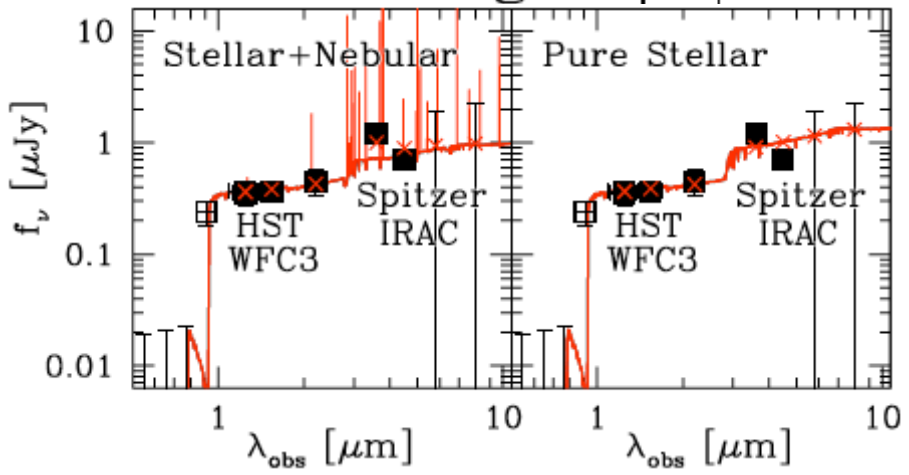
Advantages of TMT



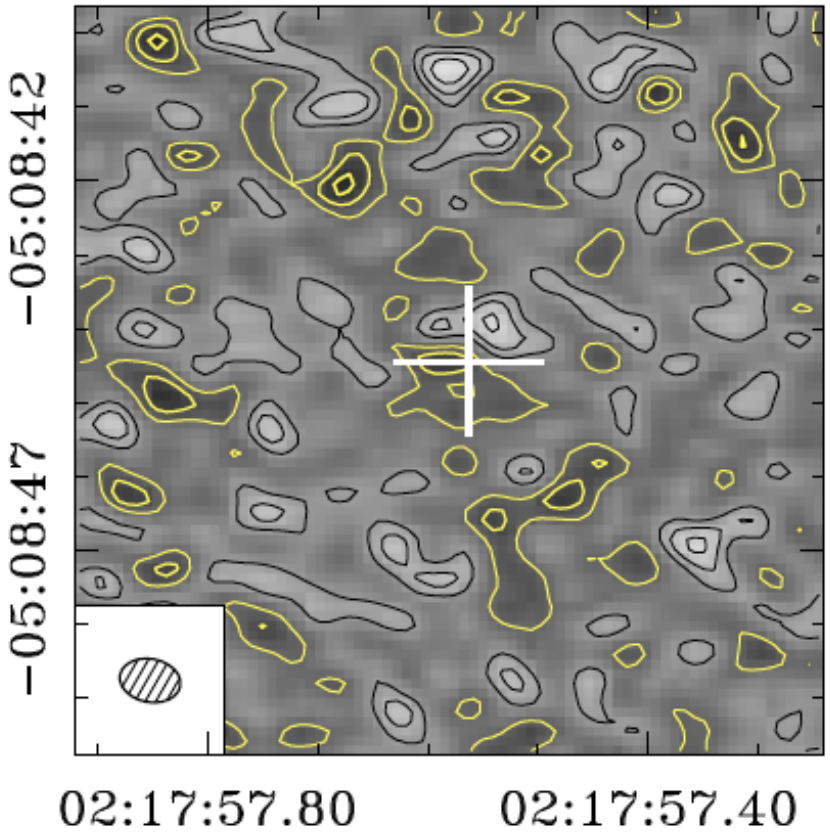
Ouchi et al. (2013)

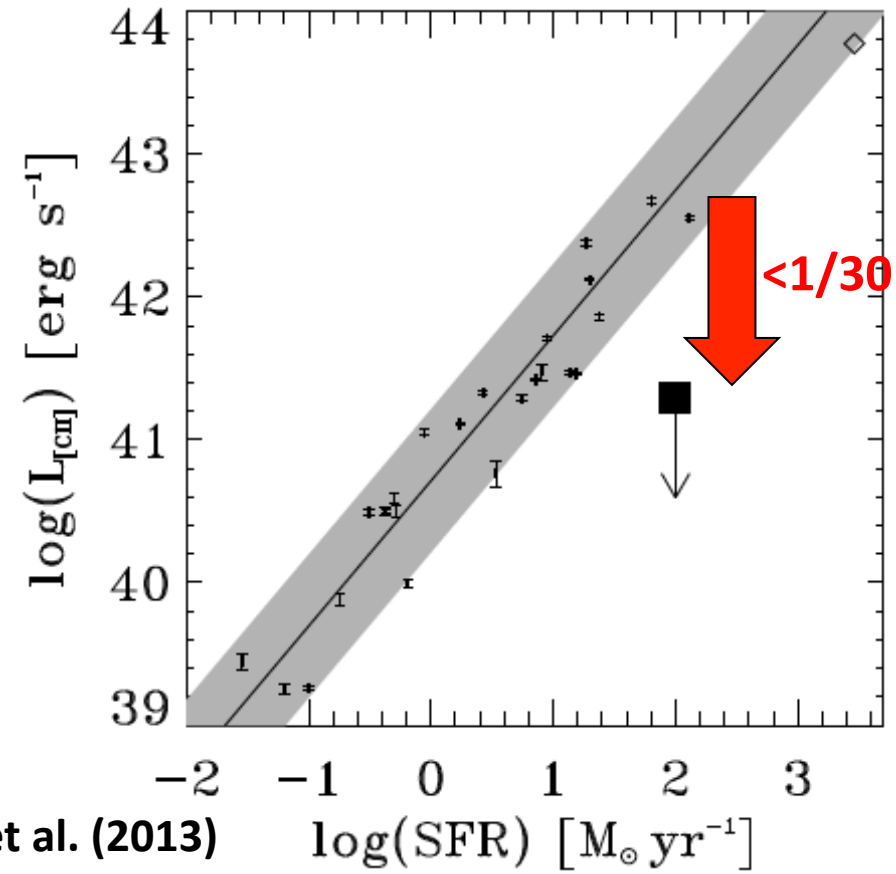


- Identified by Subaru imaging an Keck spectroscopy confirming z=6.595. The source is dubbed 'Himiko' (Ouchi+09)
- Made of 3 L* clumps (~26.5mag). Muv = 25.0mag in total
- Triple merger system with SFR=100 Mo/yr, M*=2x10^{10}Mo and a >17 kpc-large Lya halo.



Advantages of TMT

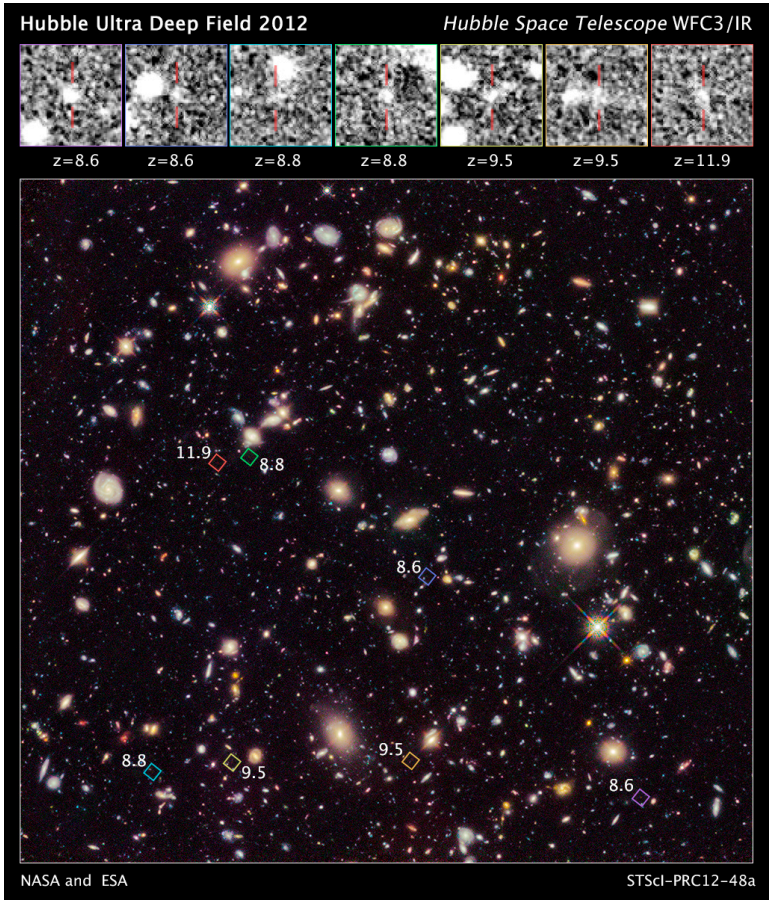


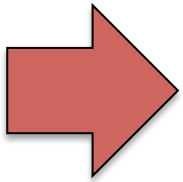


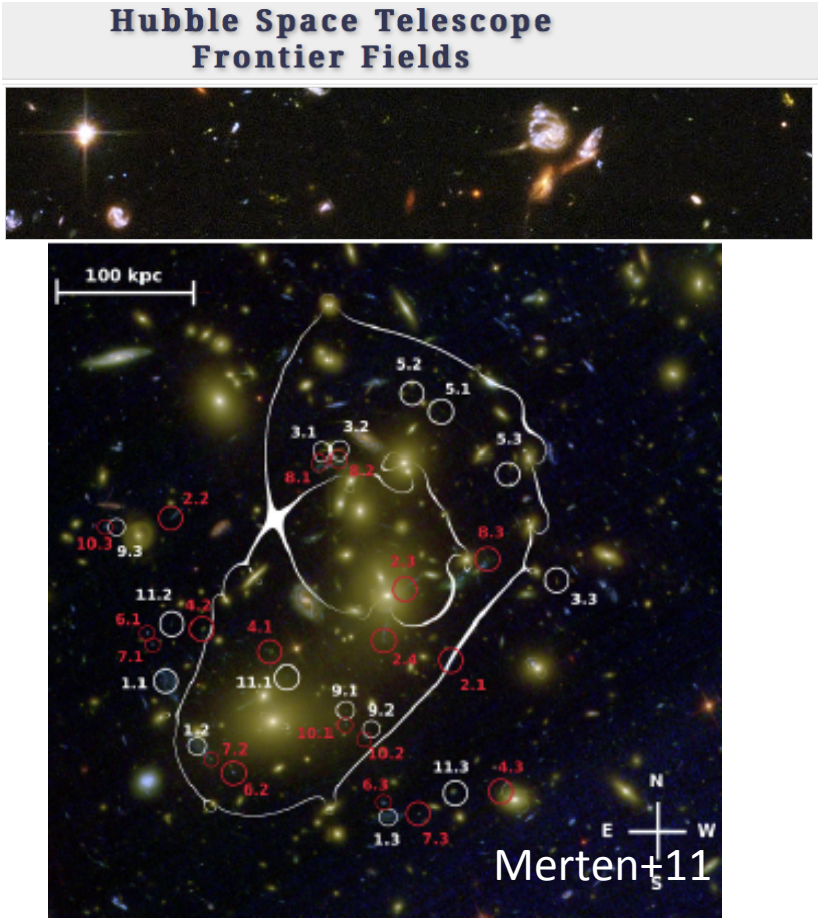
Ouchi et al. (2013)

- ALMA Cycle 0 observations (rms) down to 17μJy! : but no detection of dust continuum and [CII] even for 100 Mo/yr. Lying off from the local L(CII)-SFR scaling relation by x1/30 or less.
- The brightest z~7 galaxy has a very low dust content and perhaps a near primordial IS gas (see Vallini+13)?
- Early galaxies are metal+dust poor.
- TMT is observing strong emission from young massive stars + H/He gas, common features of early galaxies. Deep NIR observations with TMT are key for early galaxy studies.

Galaxies at z>8
2012 Hubble UDF (UDF12) & Hubble Frontier Fields





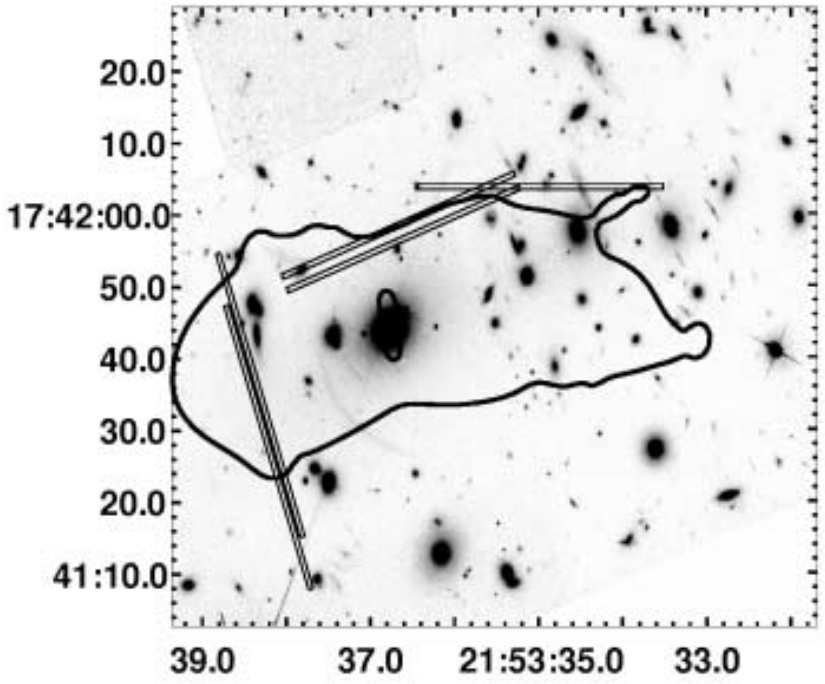


- UDF12(Ellis et al. 2012; Caltech, Edinburgh, Arizona, Tokyo, STScI, UCLA,IAP) , follow. UDF09 prog.
→5 sigma limits: YJH~29.5-30 AB mag for 7 z~8.5-10 galaxy candidate identification

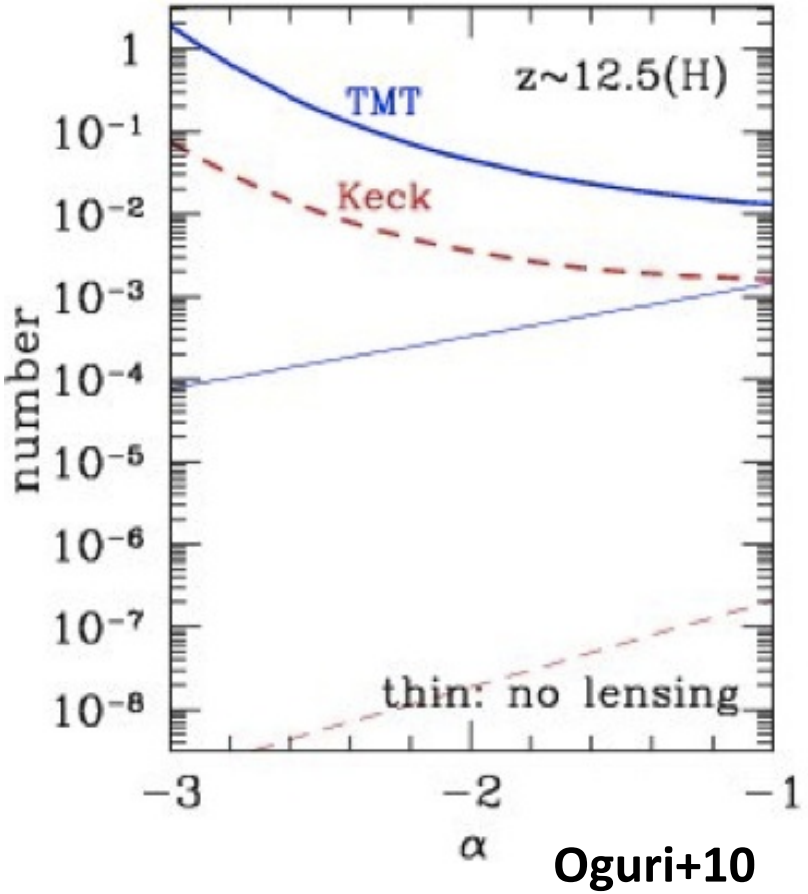
Hubble Frontier Fields program: six strong lensing galaxy clusters in parallel with "blank fields".

- 10-50 times fainter than known galaxies up to z~10 + high-z galaxies magnified enough for spectroscopy

TMT+Gravitational-Lensing Telescope



Stark+07



Oguri+10

- IRMS blind spectroscopy on critical lines of very massive clusters found by Subaru/HSC → constraining faint-end luminosity function and slope up to z~13 to test whether faint galaxies can be major reionization sources.
- 1.5hr/2arcmin long-slit (width=1") x 60 nights
- → 5 faint galaxies α=-2 (or 10-100 gals for α=-3; no LF evolution), [~5-10x10^{41}erg/s]

Narrowband Survey for z>7 LAEs w IRMS

・Why TMT? Why not JWST?

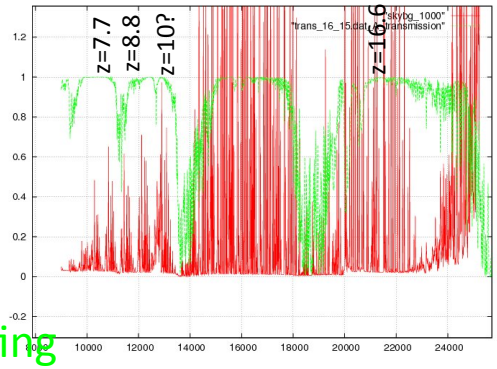
•JWST TFI won't be installed to JWST

- •Faster survey speed than JWST/NIRCam (4arcmin2,R~100,25.5ABmag in 10,000sec)
  - •Targeting OH windows (low backgr.)
  - •Larger primary
  - •Moderate AO
  - •Smaller readout noise effects

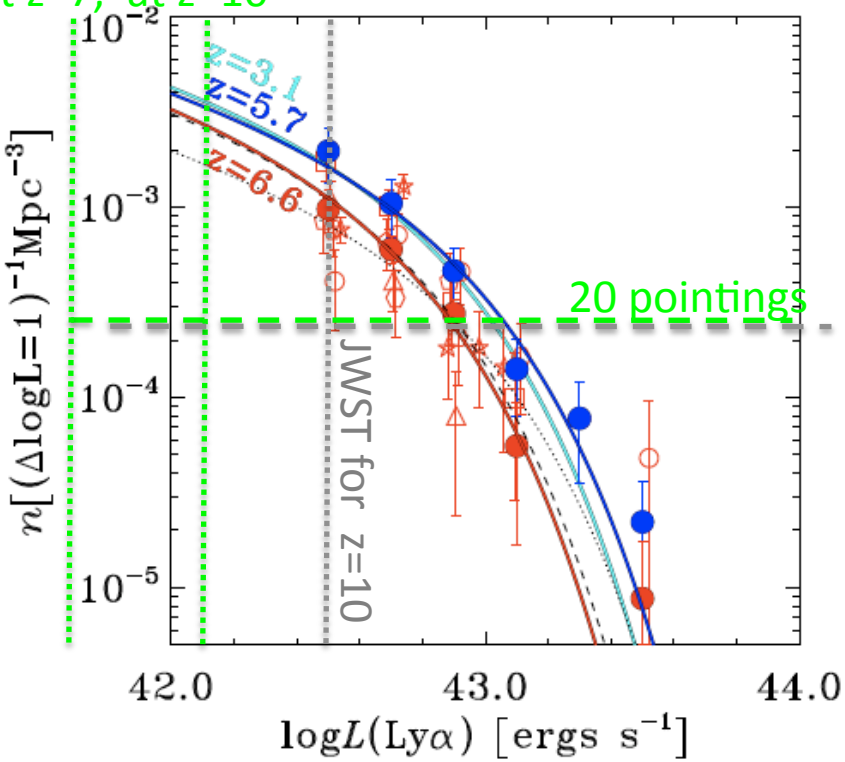
→26-27 ABmag in narrowbands (cf. E-ELT/MICADO,OPTIMOS, GMT/ NIRMOS)

•Feasibility: NB imaging with IRMS: 3hr/ pointings for 0.1deg^2, 100-1000 LAEs at z=8-12 (based on semi-analytic model of Kobayashi+).

→50 TMT nights



30 hr/pointing at z=7, at z=10



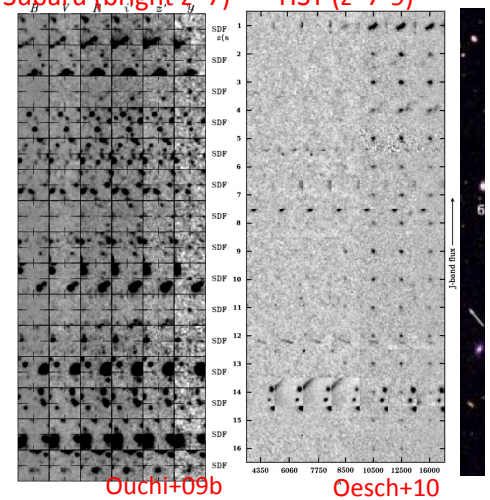
Ouchi et al. (2010)

Spectroscopic Confirmation of the 1st Generation Galaxies w IRMS/IRIS?

Goal : Spectroscopic conf. of 1st generation

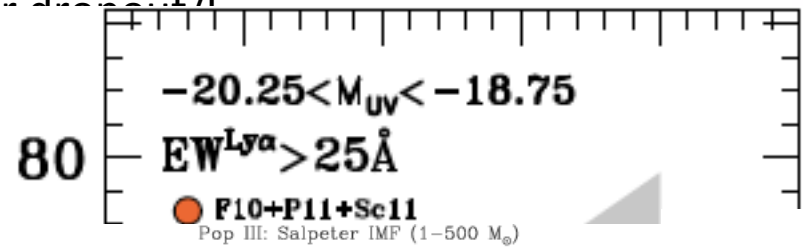
Method: Deep spectrosc… for dropout/L…

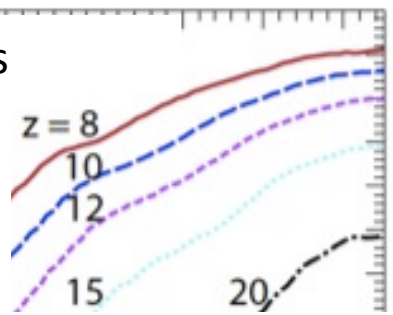
Subaru (bright z~7) HST (z~7-9)

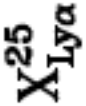


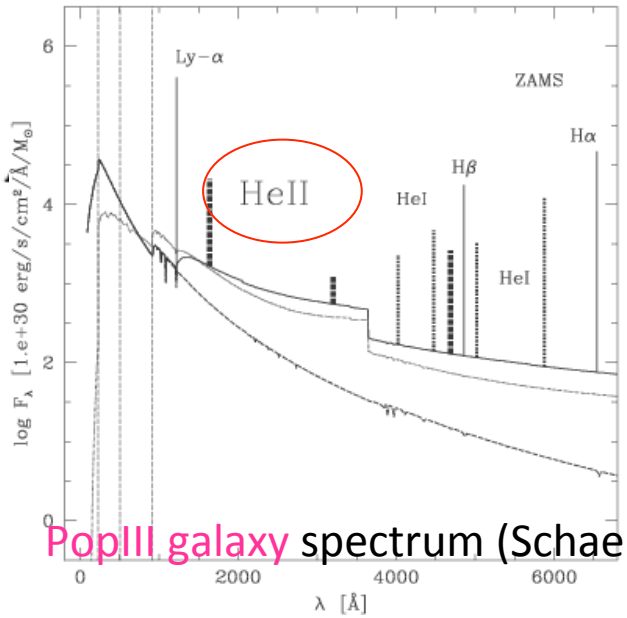
Ouchi+09b Oesch+10

Ono, MO et al. (2012)









PopIII galaxy spectrum (Schaerer+03)

- Sample (>1000 in total)
  - Suprime,HSC z~7 c…
  - HST/UDF12+HFFs-…
  - IRMS narrowband
  - JWST deep field z^…
- Feasibility:z~7-10 UV continuum+abs; z~7-20 Lya
- Issue 1. Can strong Lya lines escape from neutral universe?
- Issue 2. How can 1st generation gals be identified? Too weak HIIλ1640. No metal line?? UV slope (β~-3)?

Subaru HSC Survey for High-z Galaxies

Hyper Suprime-Cam(HSC) PFU

- Hyper Suprime-Cam (HSC)

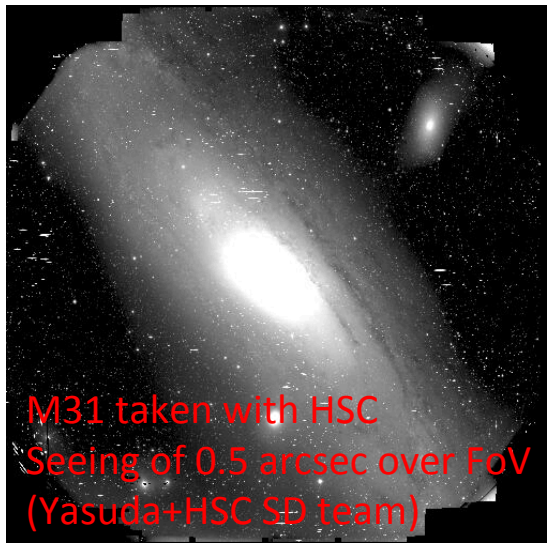
=Subaru Next generation WF optical camera

- Starting from early 2014.

  300 nights in 5 years (PI: Miyazaki)

- HSC high-z galaxy studies will identify
  - 20 million galaxies at z~2-4 in 1400deg^2
  - 10k galaxies at z~6-7 in 30deg^2

distributed in the cosmological scale of ≳1 comoving Gpc→ Bubble topology of cosmic reionization from Lya emitter clustering (see Ouchi+10)

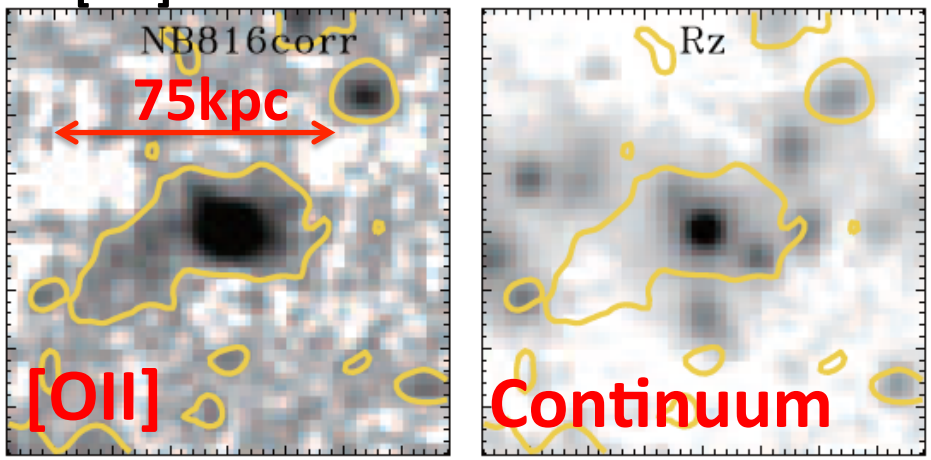

M31 taken with HSC
Seeing of 0.5 arcsec over FoV
(Yasuda+HSC SD team)

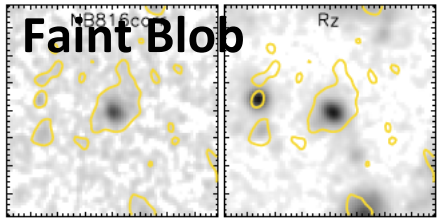
Providing very massive clusters for GL+TMT studies and z~7 bright galaxies for detailed IRMS & IRIS spectroscopy

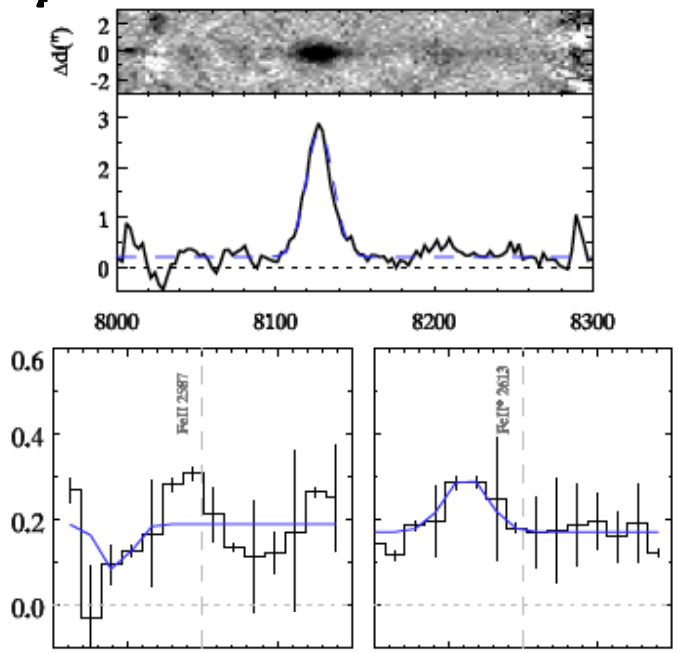
+Various synergistic studies, using TMT/WFOS.

One Example: Probing AGN/SF Feedback with [OII] Blobs found by Subaru Obs.

[OII] Blob 1







Yuma, MO et al. 2013

- Subaru NB images→ 13 largely extended [OII] nebulae ([OII] blobs) w a > 30 kpc size at z=1.2 (Yuma, MO et al. 2013).
- The brightest one has a 75 kpc size! VLT spectroscopy → type2 AGN w outflow at z=1.18
- Metal line absorption/emission→ significant outflow that would quench star-formation. Important for elliptical galaxy formation.
- The rest of 12 faint [OII] blobs would be powered by SF, i.e. SN heating. But too faint (~25mag) to identify the outflow from continuum absorption lines by 8m-class spectroscopy → Deep TMT/WFOS and IRIS spectroscopy to confirm outflow.

Summary

- Open questions addressed in TMT era
  - Formation of 1st generation galaxy
  - Cosmic reionization history and ionizing sources

- TMT Studies targeting very early galaxies (z>~10)
  - Gravitational lensing survey w IRMS and Subaru/HSC
  - Narrowband survey w IRMS. Comparisons w JWST imaging and spectroscopy.
  - IRMS/IRIS spectroscopy for 1st generation galaxy identification. Two Difficulties for the identification of early galaxies
    - Weaker Lya lines from neutral universe
    - Missing indicators of 1st generation galaxies

- TMT/WFOS and synergistic Subaru/HSC wide-area obs.
  - One example, spectroscopy for [OII] blobs found by HSC survey.