# Detectability of nebular emission lines from star-forming galaxies at z>8

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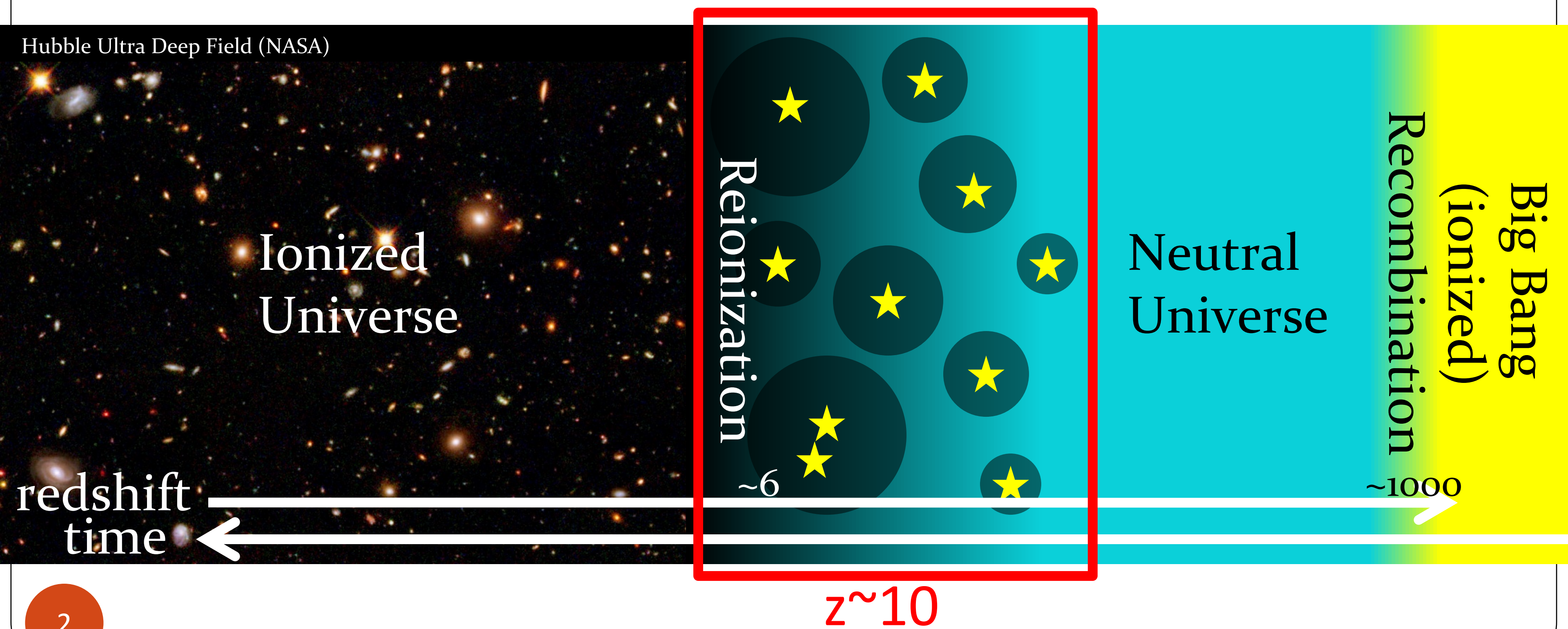
# Motivation

- When and how did the first objects form?
- How did the cosmic reionization proceed?

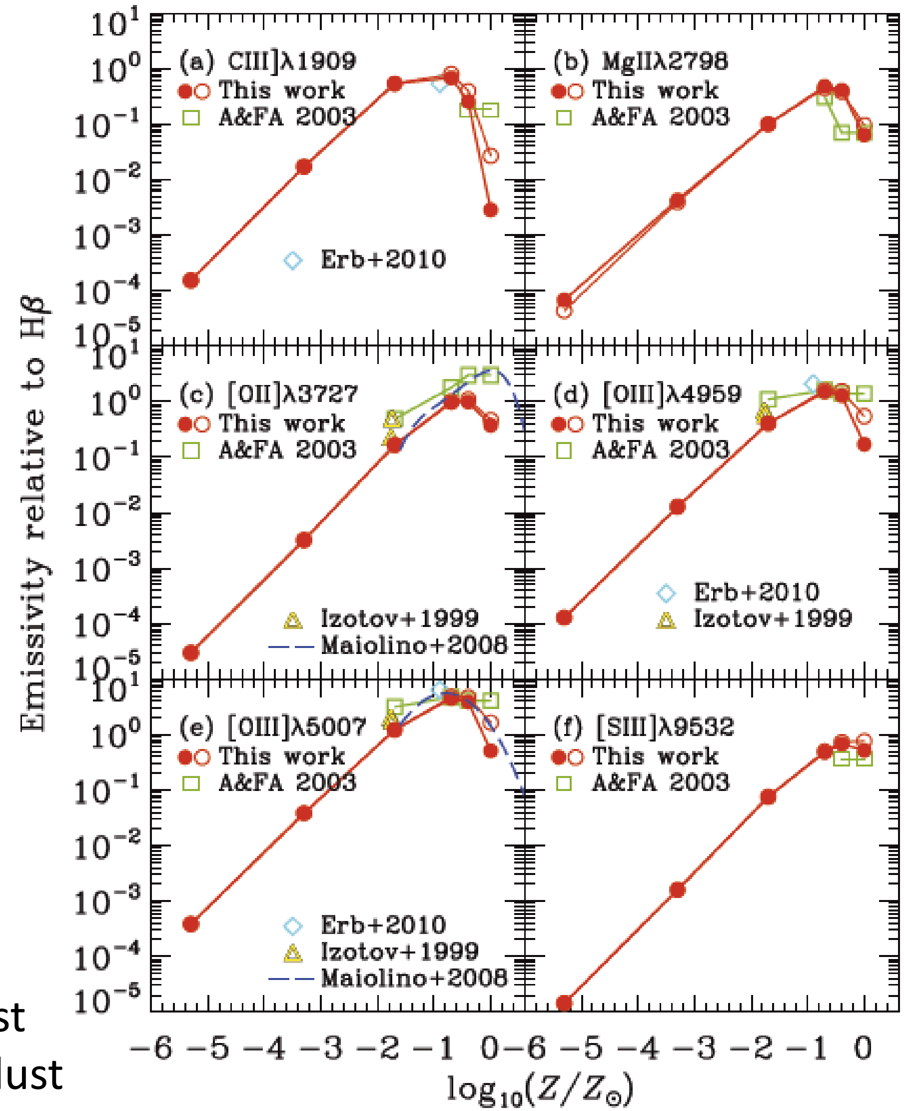
- TMT will be a great spectroscopic machine for high-z galaxies.



# Modelling of emission lines

Inoue (2011)

- Based on Cloudy:
  - UV-optical-IR >100 lines
  - SB99 Padova track
    - Constant SFR, > 10 Myr
  - Stellar and gas metallicities are assumed to be equal
  - Average emissivity over a wide range of nebular parameters
    - logU=-3.0 to -1.0
    - log(nH/cm-3)=0.0 to 2.0

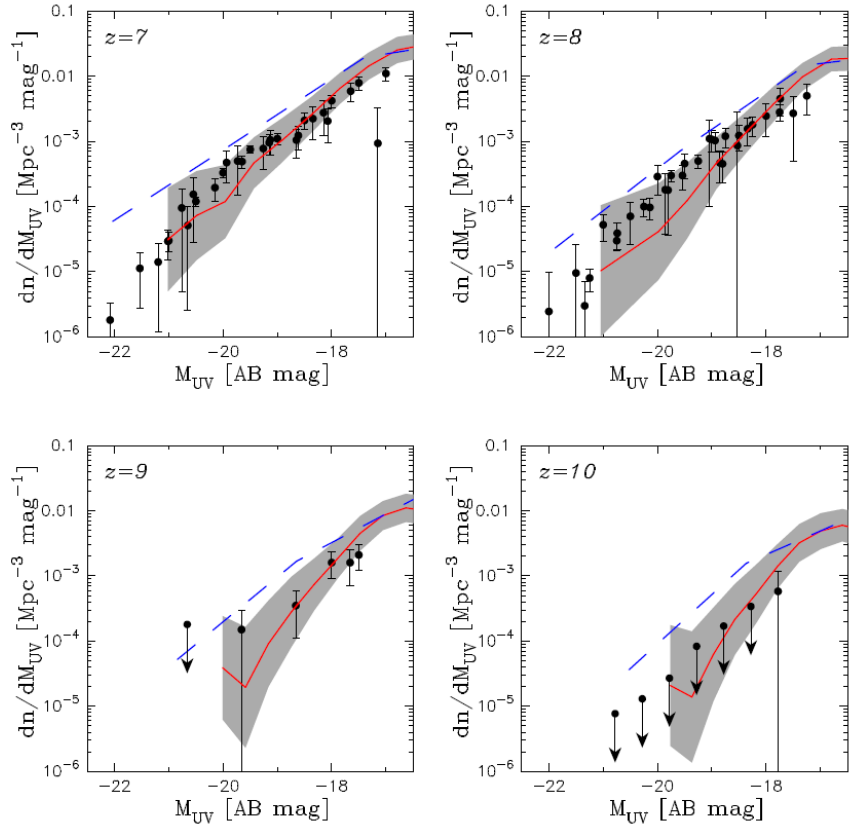


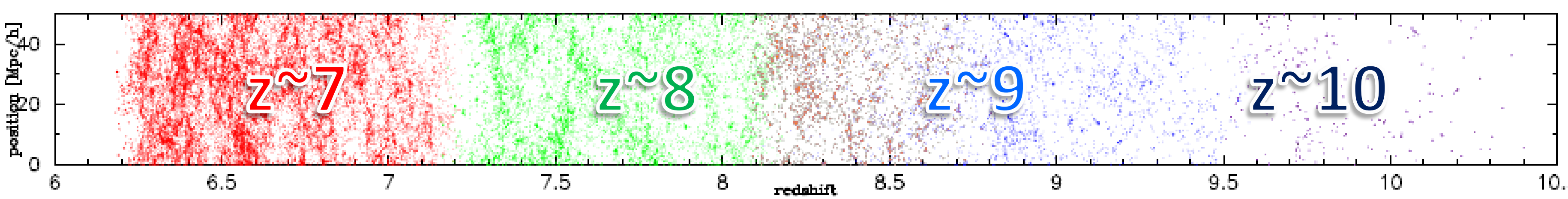

Filled: no dust
Open: with dust

# High-z LBG model

Shimizu, Inoue, et al. (2014)

- A cosmological SPH galaxy formation simulation tailored to the HST/UDF12 survey
  - Mock observation in a light-cone output
  - Exactly same magnitude and color selection criteria as the real survey
  - Stellar mass, DM halo mass, SFR, sSFR, metallicity, dust attenuation, morphology, etc. of the mock UDF12 LBGs



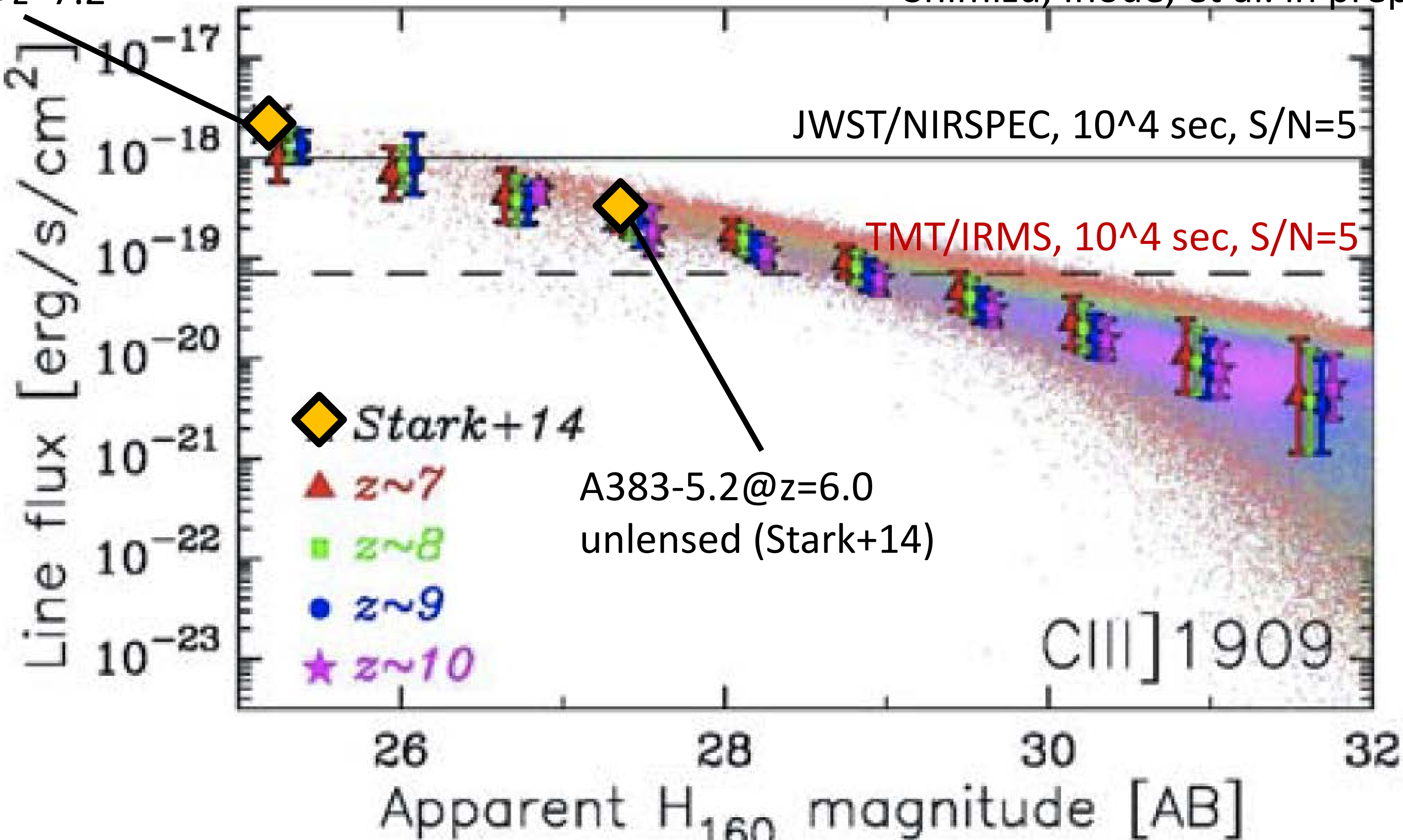
# Emission line flux from high-z LBGs

- Each simulated LBG, we have
  - Redshift (i.e. luminosity distance)
  - SFR
  - Nebular metallicity
    - Z weighted by LyC luminosity of SPH particles
  - Dust attenuation for UV continuum
- From the emission line model, we have
  - L_line/SFR as a function of metallicity
    - [L_line/L_Hβ](Z) * [Q_HI/SFR](Z) * [L_Hβ/Q_HI]
- Combining these information, we have line fluxes from each simulated LBG.
  - Dust attenuation for lines is calculated with the Calzetti law and Es(B-V)=0.44Eg(B-V) i.e. about x2 more line attenuation than continuum

# CIII]1909 → ~2 micron at z=9

GN-108036@z=7.2 (Stark+14)

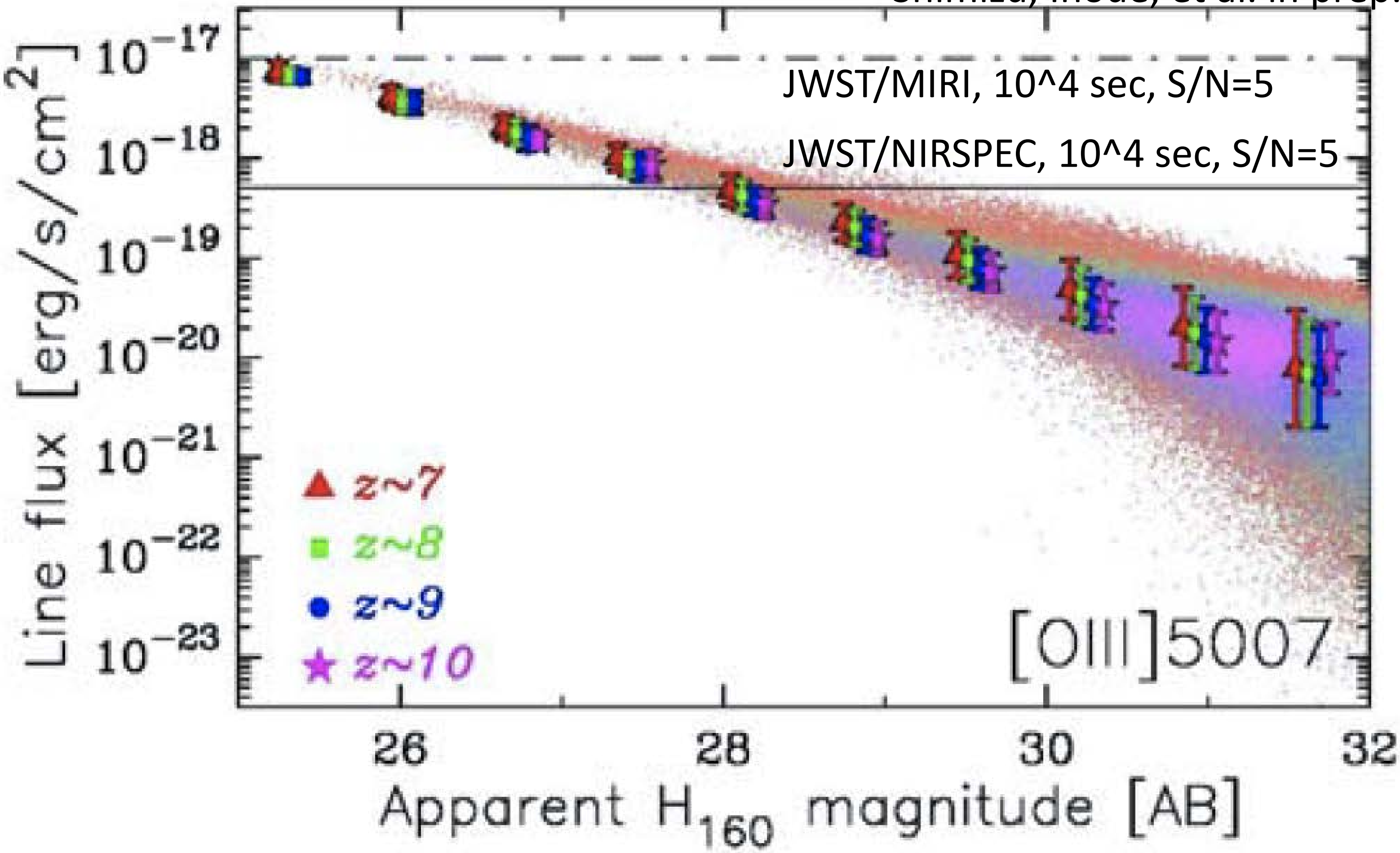
Shimizu, Inoue, et al. in prep.




TMT/IRMS sensitivity is for a <u>point source</u> with R=3270
JWST/NIRSPEC sensitivity is for a <u>point source</u> with R=1000

# [OIII]4959, 5007 → ~5 micron at z=9

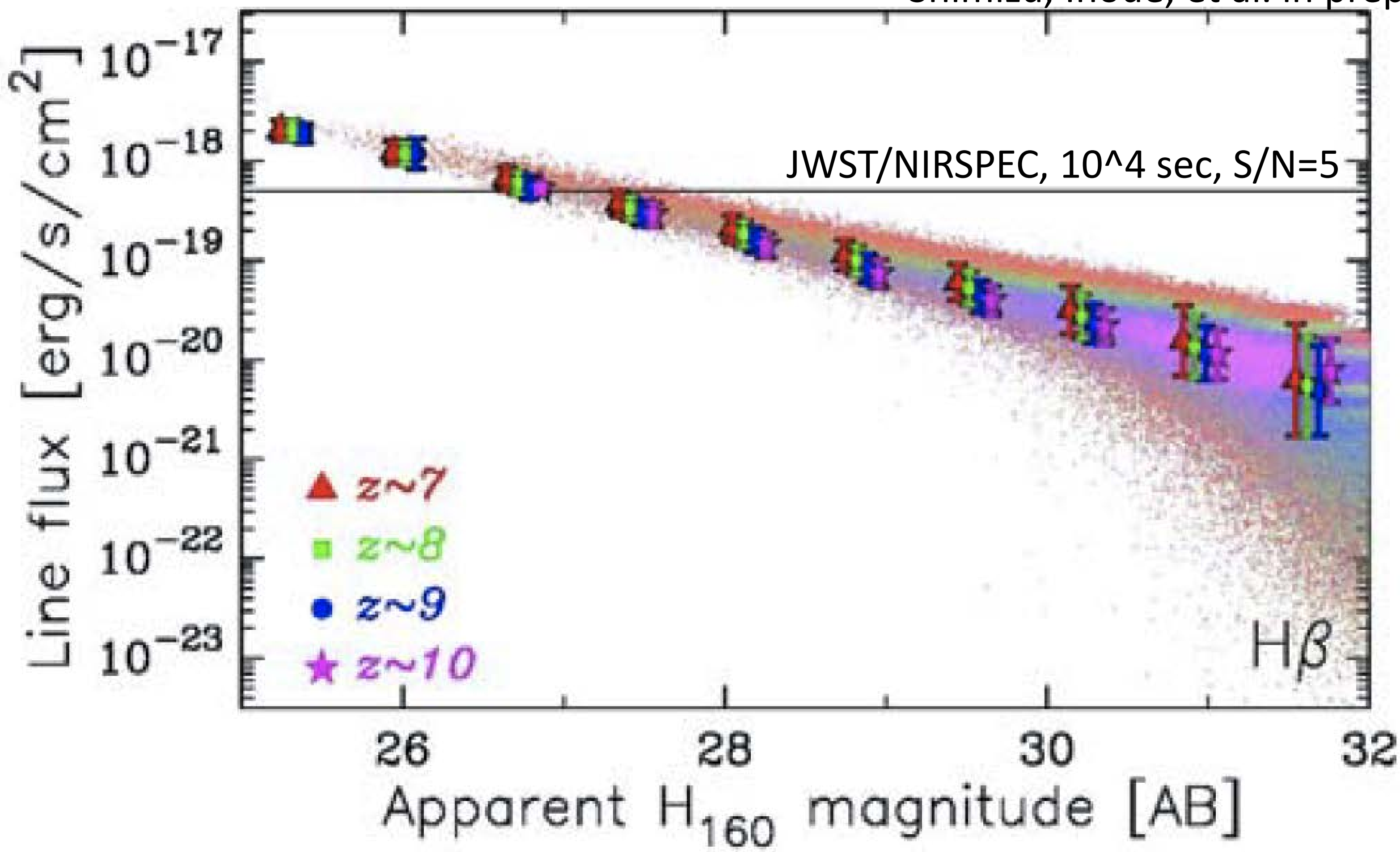
Shimizu, Inoue, et al. in prep.




JWST/NIRSPEC sensitivity is for a <u>point source</u> with R=1000
JWST/MIRI sensitivity is for a <u>point source</u> with R=1000

# Hβ → ~5 micron at z=9

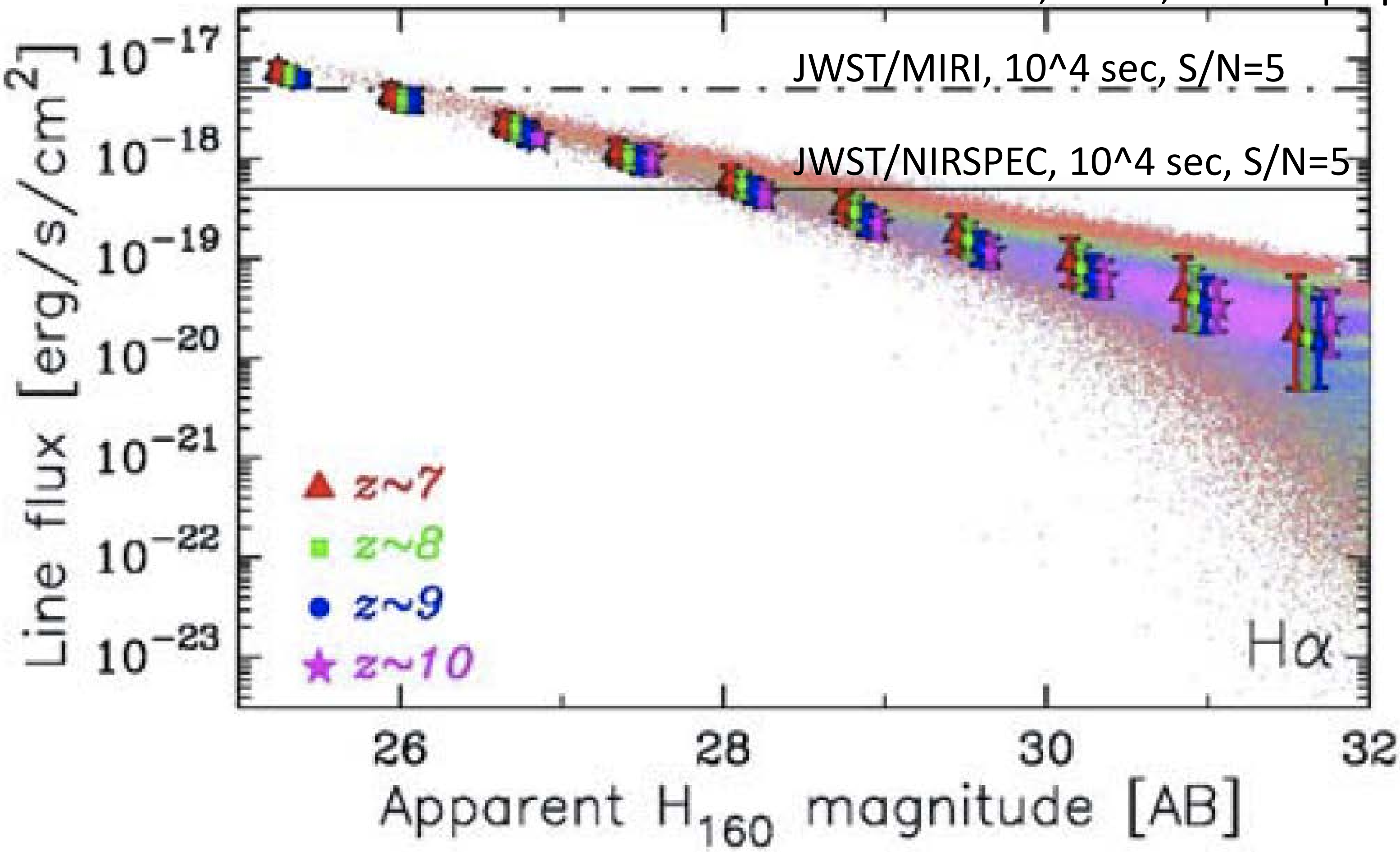
Shimizu, Inoue, et al. in prep.




JWST/NIRSPEC sensitivity is for a <u>point source</u> with R=1000

# Hα → ~7 micron at z=9

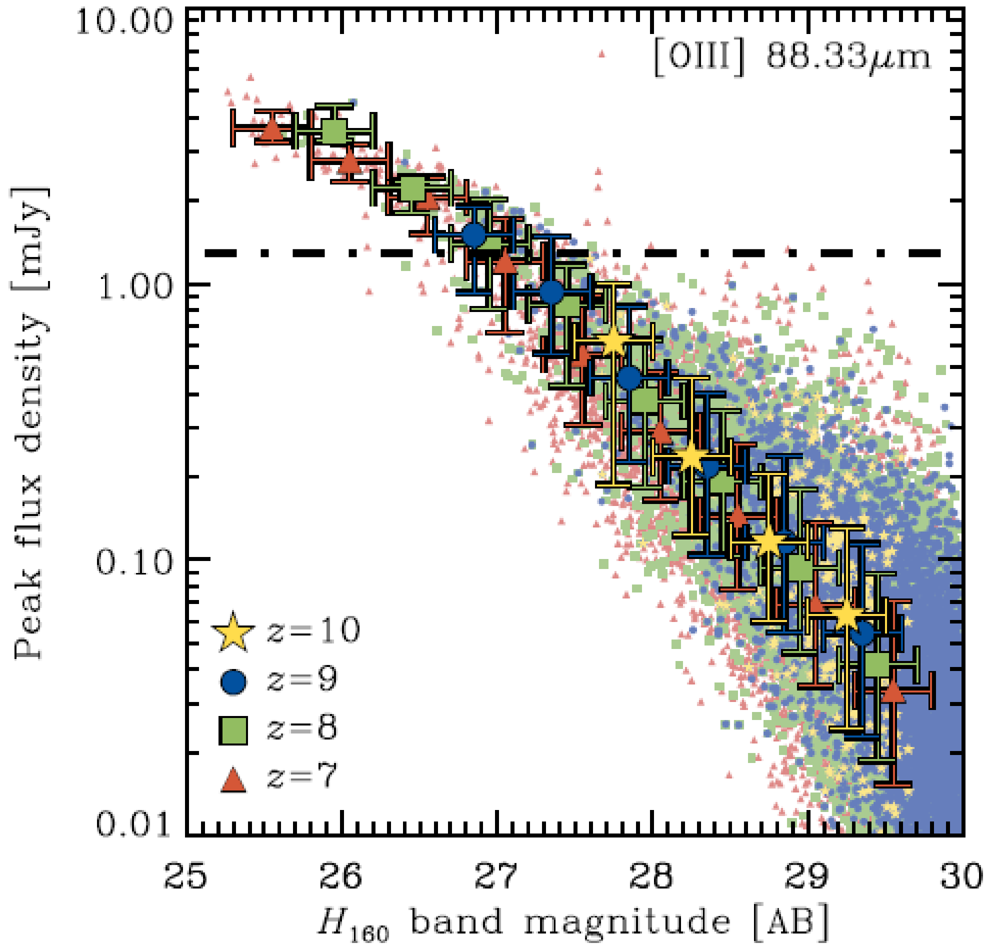
Shimizu, Inoue, et al. in prep.




JWST/MIRI sensitivity is for a point source with R=1000

# [OIII]88 → 340 GHz at z~9

Inoue et al. 2014, MNRAS



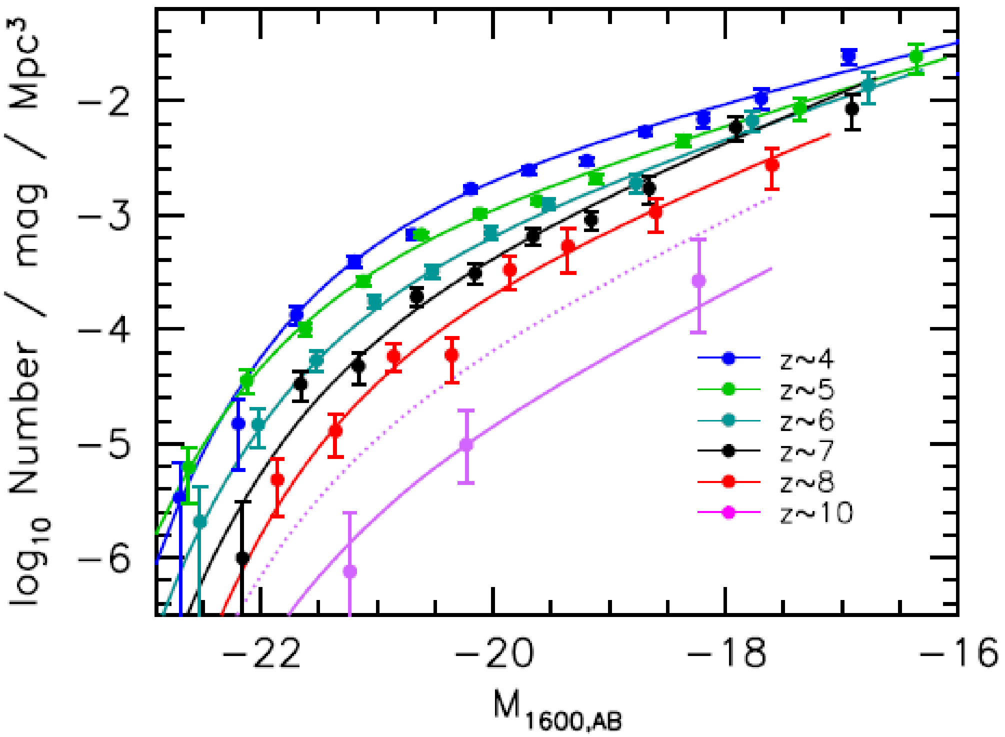

ALMA Band 7 (Cy 2)
1 h, S/N=5, dv=30 km/s
for a point source.

# Summary of emission line modelling

- UV CIII] line of high-z LBGs is a good target for TMT/ELT.
  - However, galaxies will be resolved and the sensitivity for an extended source would not be as good as for a point source.
  - Integral field spectroscopy is a nice option for bright (<27 AB) objects.
- Optical [OIII] and H$\beta$ lines of high-z LBGs are excellent targets for follow-up with JWST/NIRSPEC.
  - ISM physical/chemical conditions
  - [OIII] line can be detectable up to ~29 AB objects.
    - No follow-up method for >30 AB objects.
  - Non-detection of [OIII] probably indicates very low-metallicity, say, <0.01Zsun.
- FIR [OIII] line of brightest LBGs is a good target for ALMA.

# How to find your spectroscopic targets?

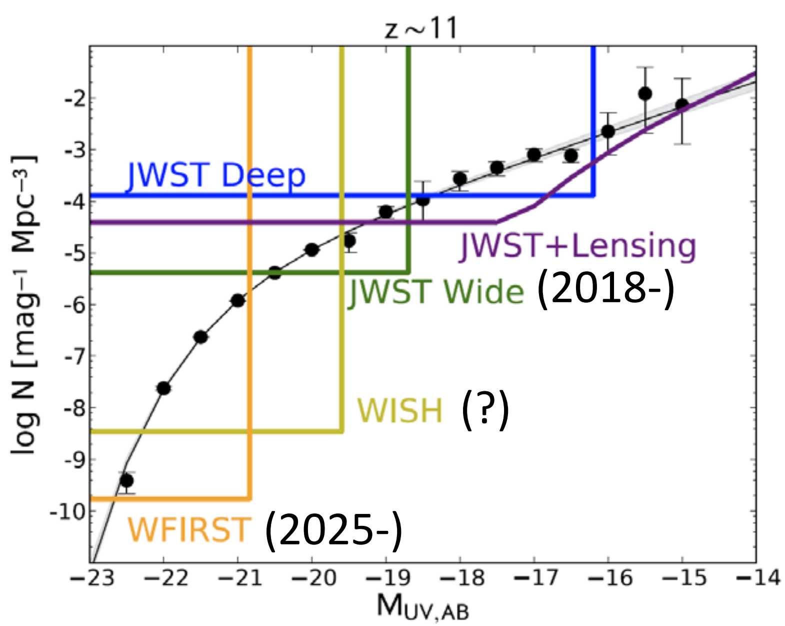
- How rare are galaxies <28 AB at high-z?
  - Bouwens et al. (2014) Table 8
    - z~7 1.7 arcmin-2
    - z~8 1.1 arcmin-2
    - z~10 <0.1 arcmin-2
      - Most of z~10 candidates are ~29AB

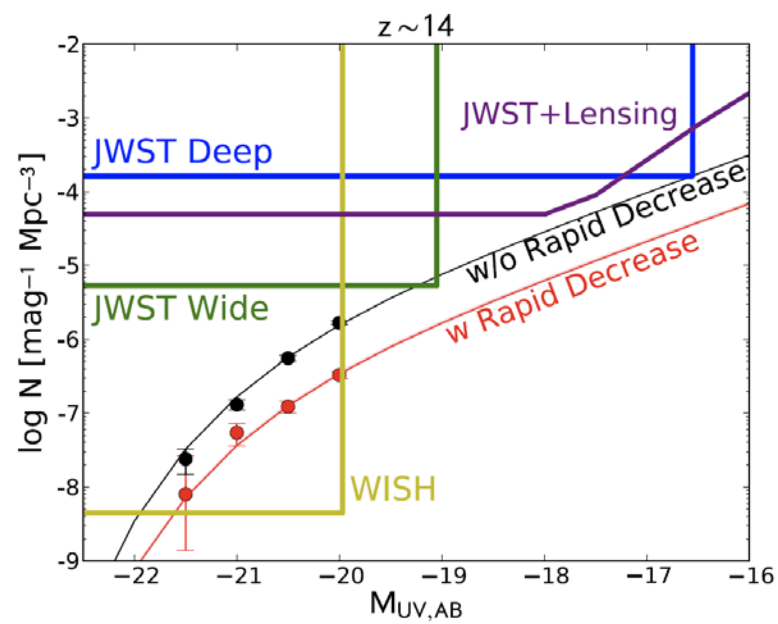


# A wide-field surveyor is needed

- If we have a survey of 100 deg2, 28AB:
  - z~9 LBGs >100,000
  - z~11 LBGs ~10,000
  - z~14 LBGs ~100

JWST may not find good spectroscopic targets at z~14.




Ishigaki (2015, M. Thesis, U. Tokyo)

# Summary

- Based on a state-of-the-art cosmological hydrodynamics simulation with an emission line model, we have identified some useful emission lines and their detectability with current/future telescopes:
  - CIII] 1909, [OIII] 4959/5007, [OIII] 88, as well as Hβ
- Finding a good spectroscopic target is an issue because of the rareness of sufficiently bright galaxies.