Ultimate Subaru, NAOJ, June 16th

EARLY EMISSION LINE GALAXIES IN A COSMOLOGICAL SIMULATION

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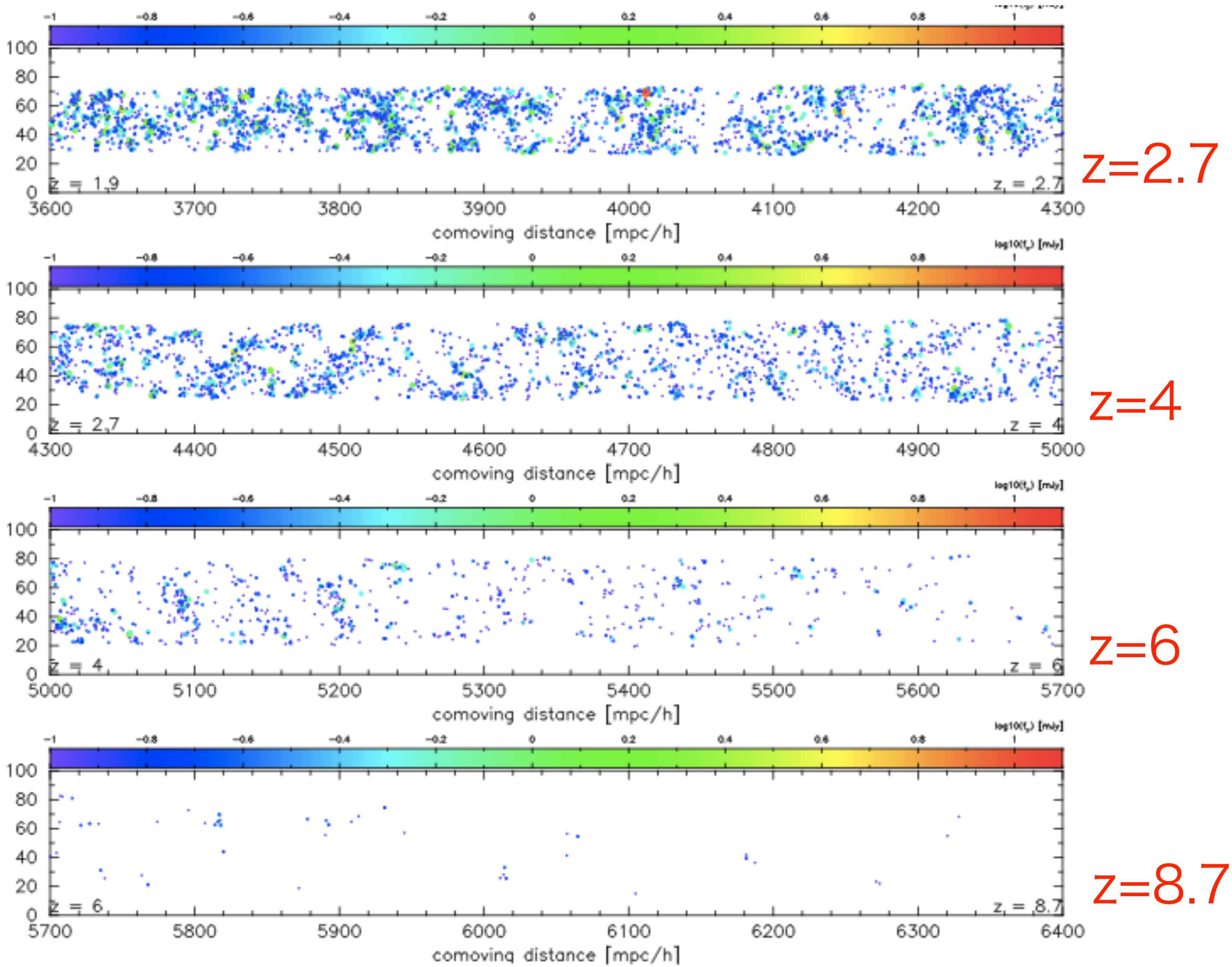
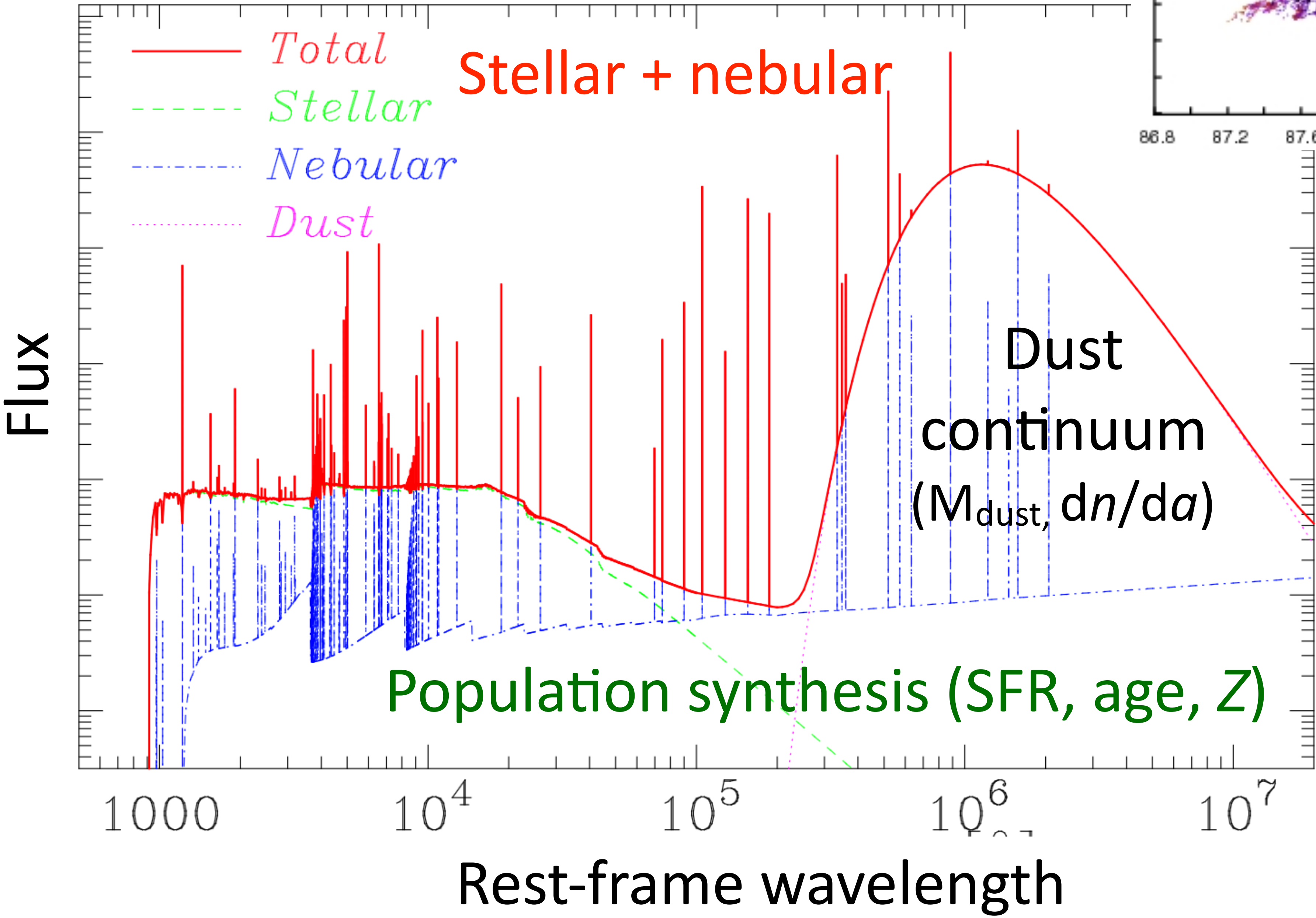
References
Okamoto, Shimizu, NY, 2014, PASJ
Shimizu, Inoue, Okamoto, NY, 2014, ApJ
Inoue et al. 2016, Science
Shimizu, Inoue, Okamoto, NY, 2016, MN

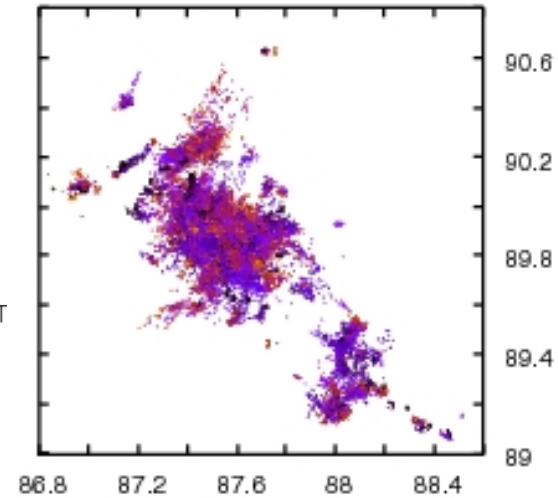
Star-forming galaxies



Galaxy SED



Total
Stellar
Nebular
Dust
Stellar + nebular
Dust continuum
(M_{dust}, d*n*/d*a*)
Population synthesis (SFR, age, *Z*)
Flux
1000
10^4
10^5
10^6
10^7
Rest-frame wavelength



90.6
90.2
89.8
89.4
89
86.8
87.2
87.6
88
88.4

THE ASTROPHYSICAL JOURNAL LETTERS, 780:L18 (5pp), 2014 January 10 doi:10.1088/2041-8205/780/2/L18

ALMA WILL DETERMINE THE SPECTROSCOPIC REDSHIFT $z > 8$ WITH FIR [O III] EMISSION LINES

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ABSTRACT

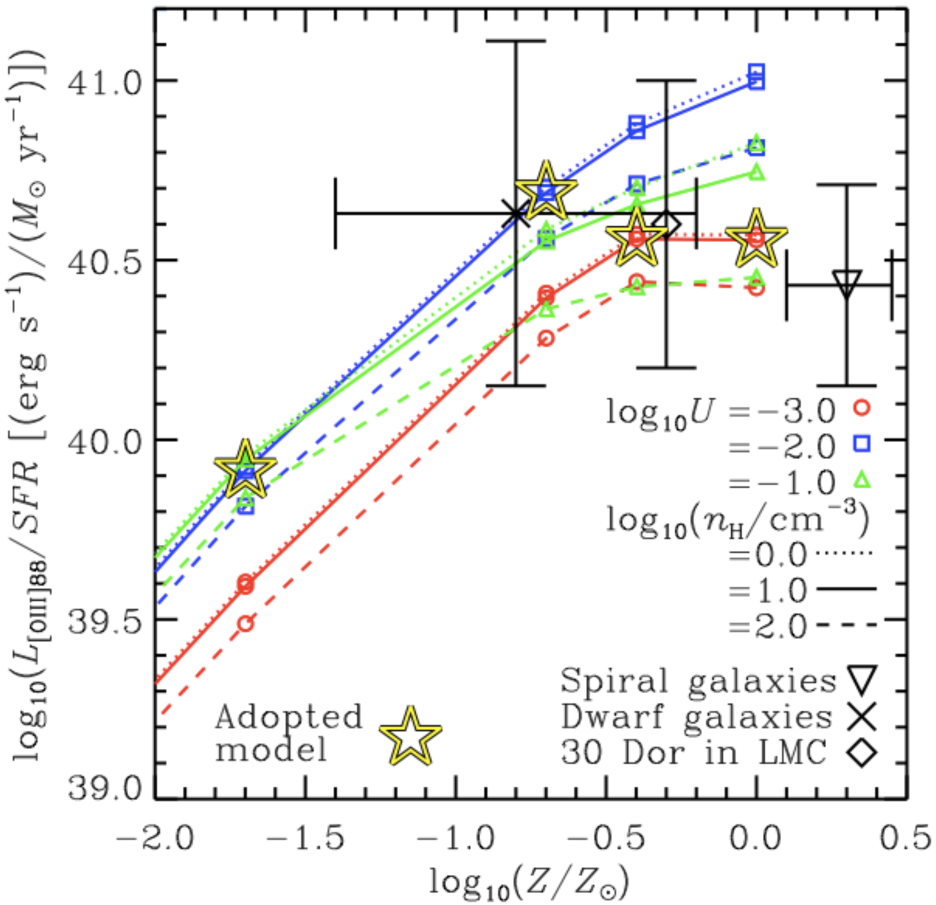
We investigate the potential use of nebular emission lines in the rest-frame far-infrared (FIR) for determining spectroscopic redshift of $z > 8$ galaxies with the Atacama Large Millimeter/submillimeter Array (ALMA). After making a line emissivity model as a function of metallicity, especially for the [O III] 88 μm line which is likely to be the strongest FIR line from H II regions, we predict the line fluxes from high-z galaxies based on a cosmological hydrodynamics simulation of galaxy formation. Since the metallicity of galaxies reaches at $\sim 0.2\,Z_\odot$ even at $z > 8$ in our simulation, we expect the [O III] 88 μm line as strong as 1.3 mJy for 27 AB objects, which is detectable at a high significance by <1 hr integration with ALMA. Therefore, the [O III] 88 μm line would be the best tool to confirm the spectroscopic redshifts beyond $z = 8$.

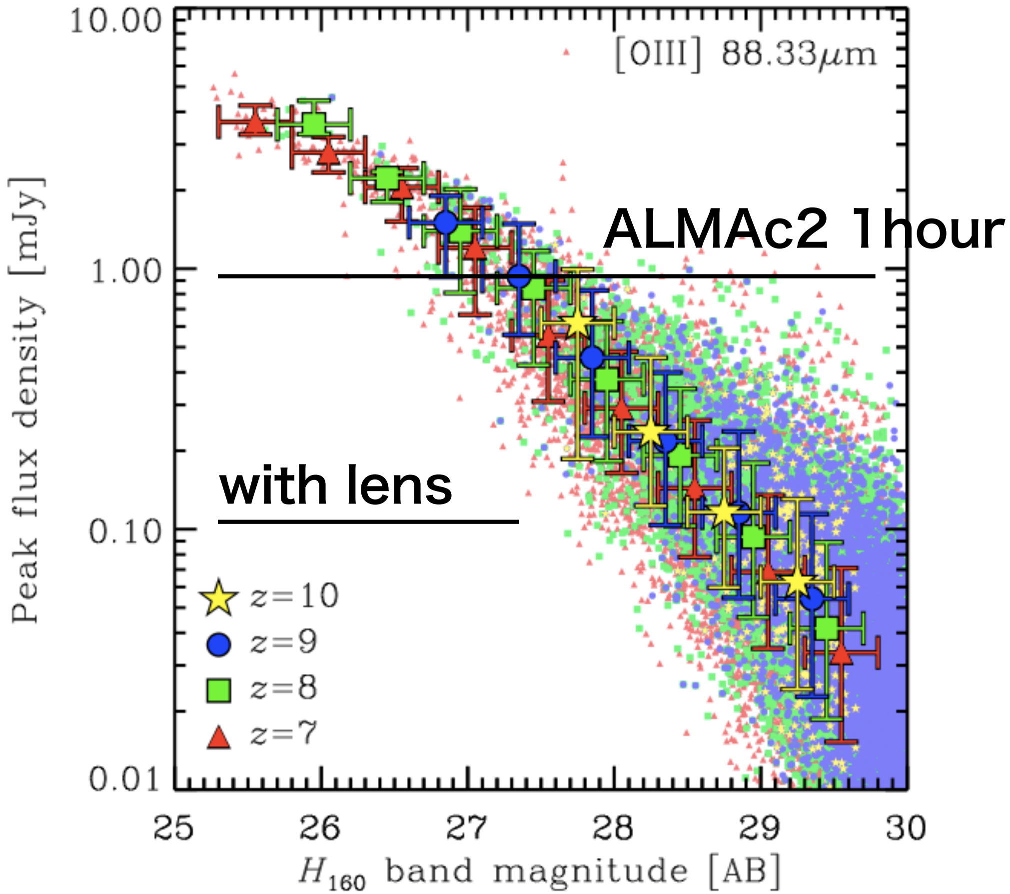
Key words: cosmology: observations – galaxies: evolution – galaxies: high-redshift

Online-only material: color figures

OIII emitters

Cosmo. simulation (Inoue, Shimizu et al. 2014, ApJL)





ALMA cycle 2, 37 antennae, 2 hours

Inoue et al. 2016, Science (TONIGHT!)

5 σ detection of [OIII]!!!

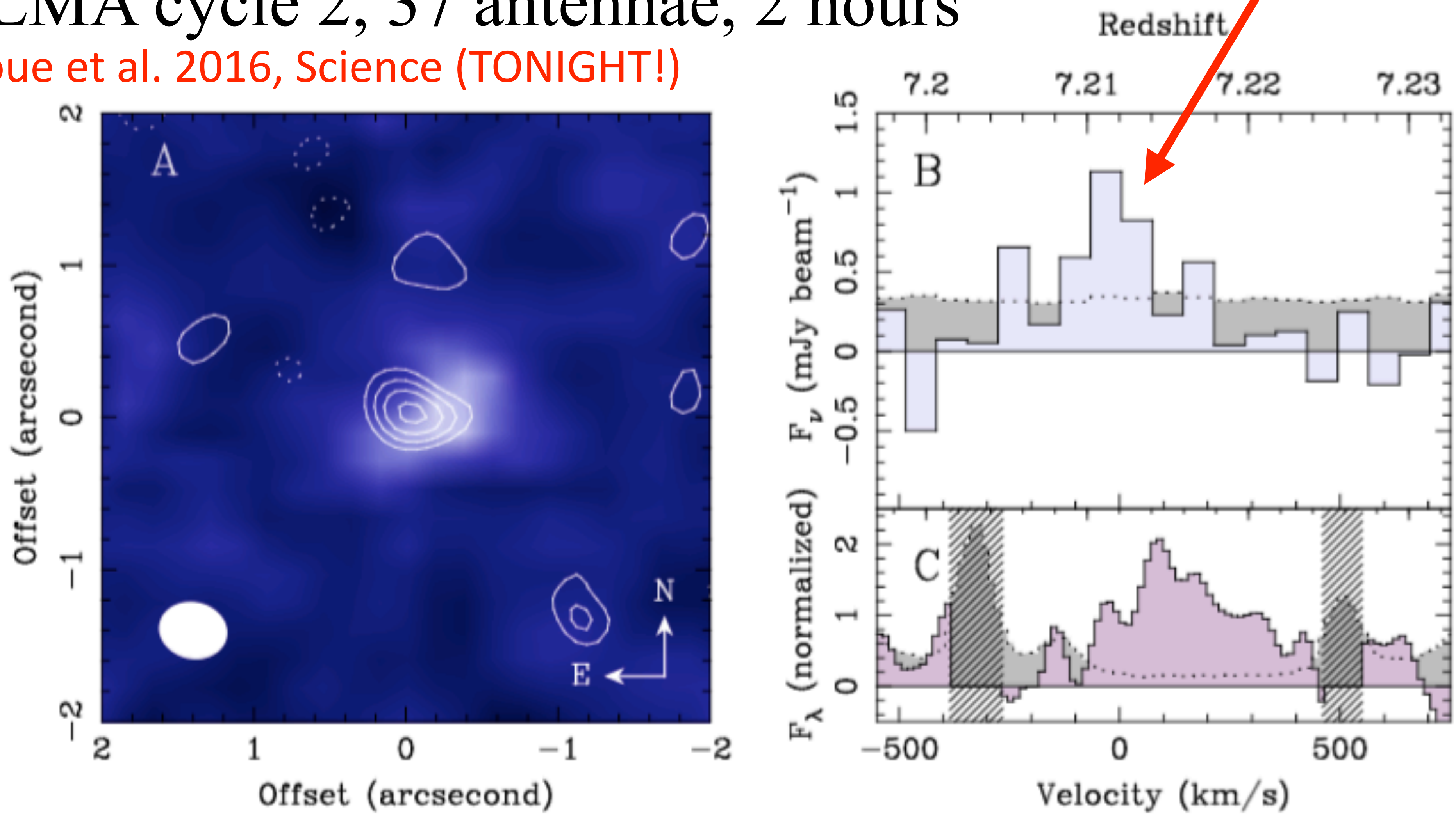
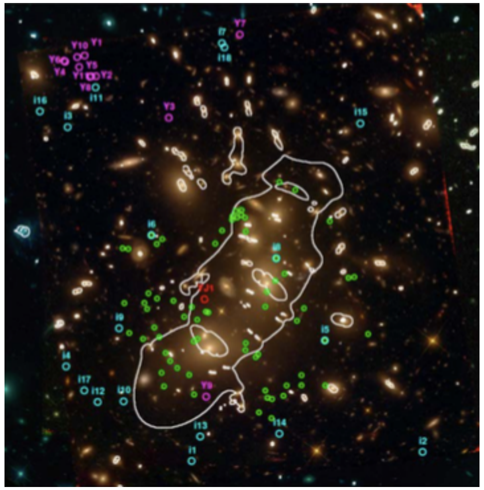


Figure 1: The [O III] 88 μm and Lyα emission images and spectra of SXDF-NB1006-2. (A) ALMA [O III] 88 μm image (contours) is overlaid on Subaru narrow-band Lyα image. Contours are drawn at (−2, 2, 3, 4, 5)×σ, where σ = 0.0636 Jy beam^{-1} km s^{-1}. The negative contours are shown in dotted line. Ellipse at the bottom-left corner represents the synthesized beam size of ALMA. (B) ALMA [O III] 88 μm spectrum with a 70 km $^{-1}$ resolution is shown against the relative velocity with respect to z = 7.212. The r.m.s. noise level is shown as

Emission lines

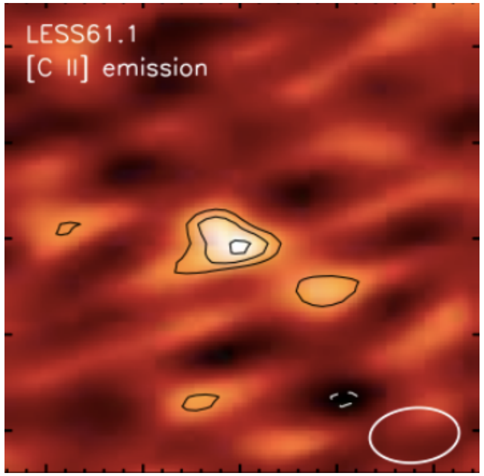


Hydrogen Ly-α

Hard to detect at z > 8 (IGM abs.)

UV/optical line

Target of JWST/TMT. Bright lines such as [OII]3727, [OIII]4959,5007. Recent success of CIII]1909@z>6



[CII] 158μm

ALMA detection@high-z. From PDR.

[OIII] 88μm

Success. From HII regions, simple emission process.

Cosmological Hydrodynamic Simulation

- Cosmology (Plank 1st year)

  $$(\Omega_m \Omega_\lambda, \Omega_b, h, \sigma_8) = (0.3175, 0.6825, 0.049, 0.6711, 0.8344)$$

- Simulation code :Gadeget3

  radiative cooling/heating, star formation, SN & galactic wind feedback, radiation pressure, AGN like feedback (Okamoto et al.2008, 2009, 2014)

This code can reproduce many observational results from low-z to high-z.

✓ Stellar mass function ($0 < z < 7$)
✓ Star formation history
✓ Mass-metallicity relation
✓ Downsizing
✓ Star formation efficiency (M_*/M_{halo}: Moster plot)

- Post process

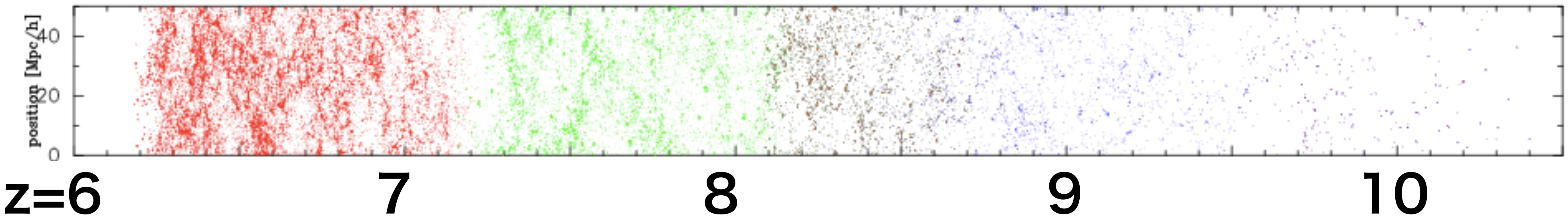
✓ Intrinsic SED (Stellar continuum+ nebular continuum & line)
✓ Dust attenuation + Dust emission

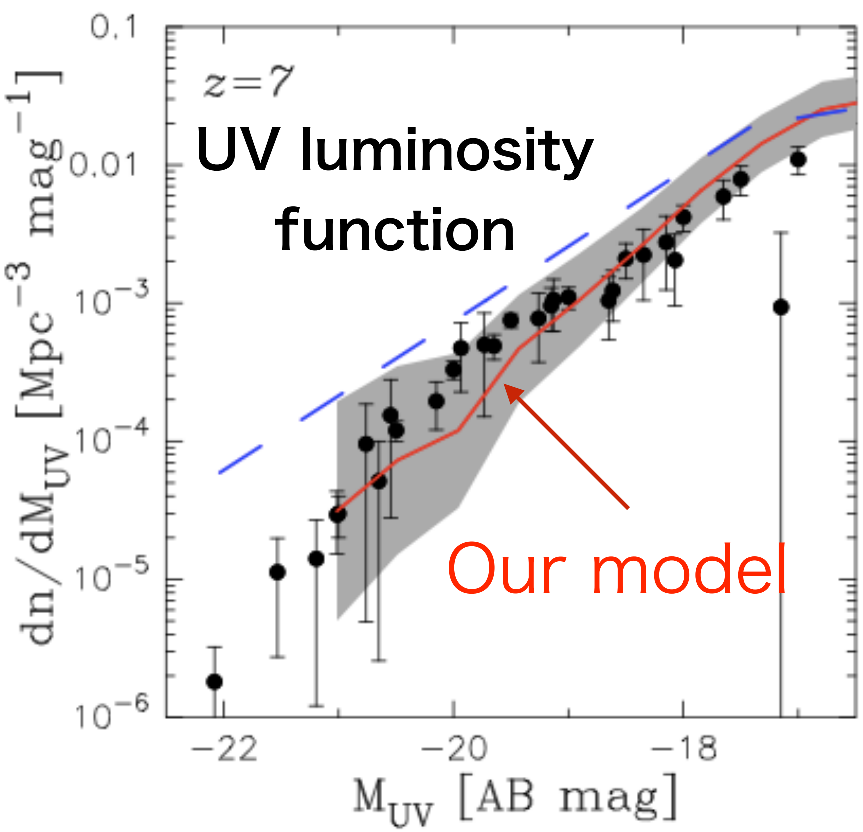
- Simulation setup

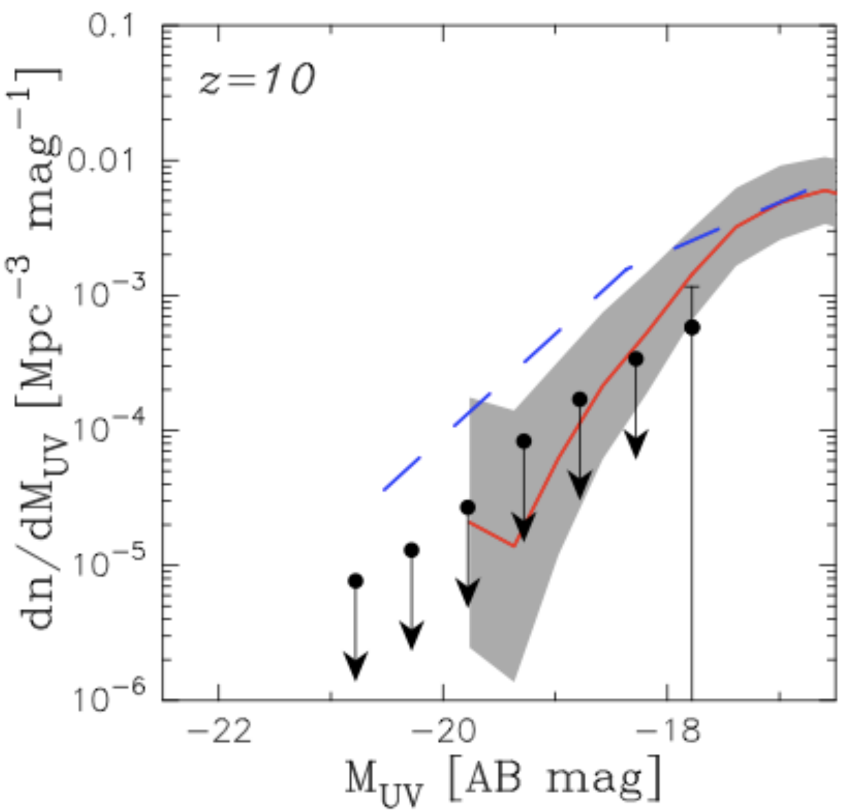
Boxsize :	$50 Mpc^3/h^3$
Number of particles :	2×1280^3
M_{dm} :	$4.4 \times 10^6 M_{sun}$
M_{gas} :	$8.1 \times 10^5 M_{sun}$

→ Minimum halo mass: $\sim 10^8 M_{sun}$
Minimum stellar mass: $\sim 10^6 M_{sun}$
Spatial resolution: 2 ckpc

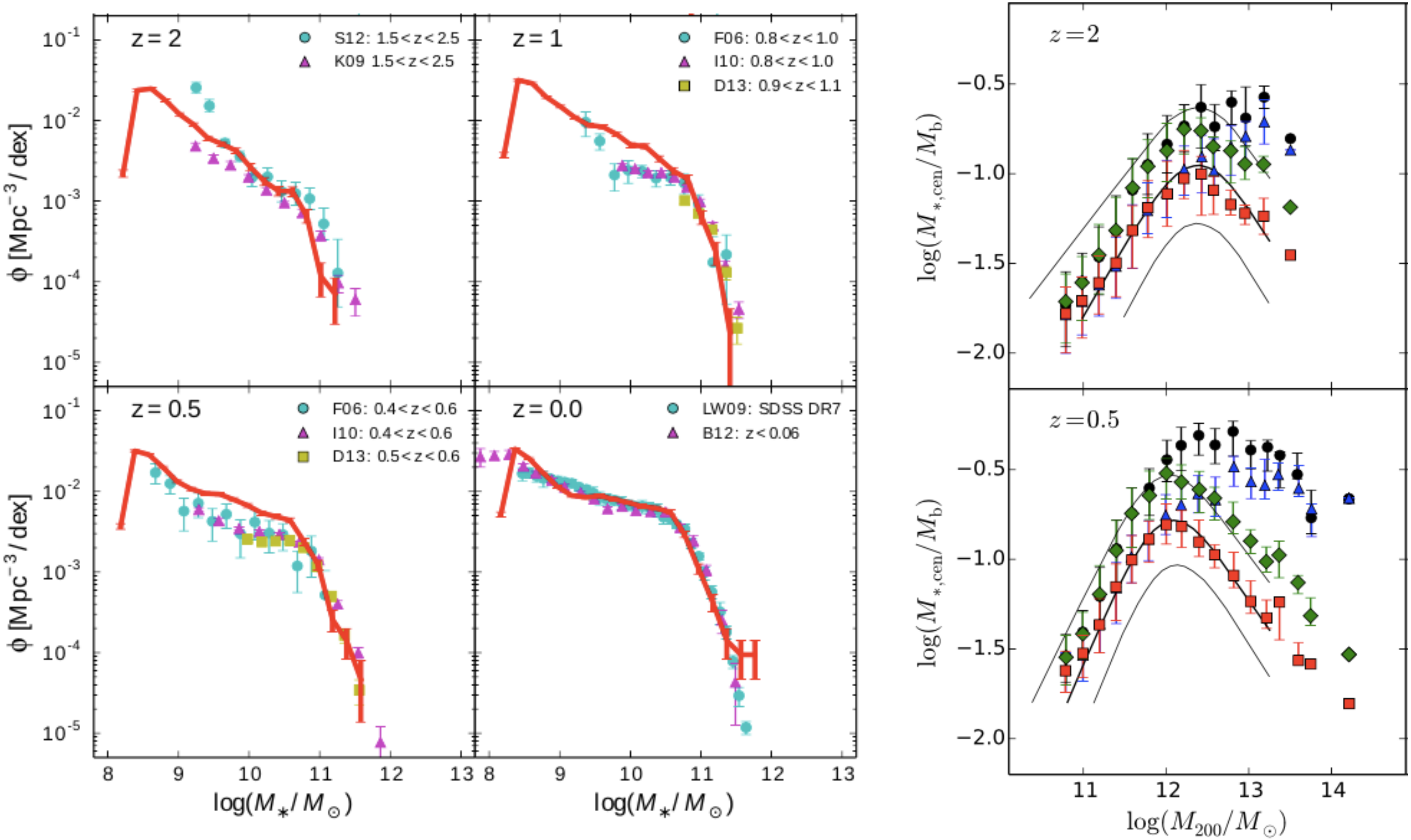
Color selection on the lightcone





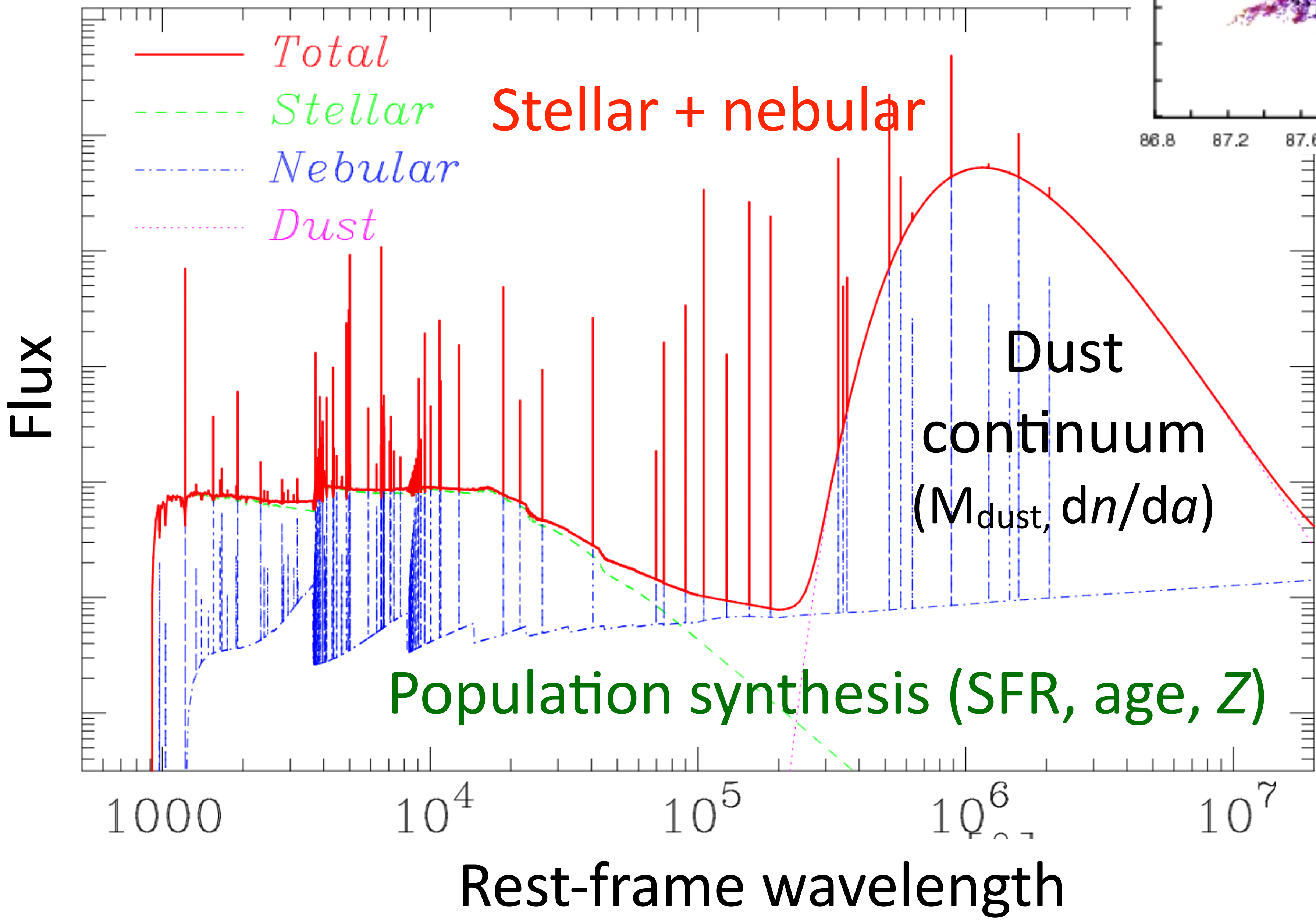


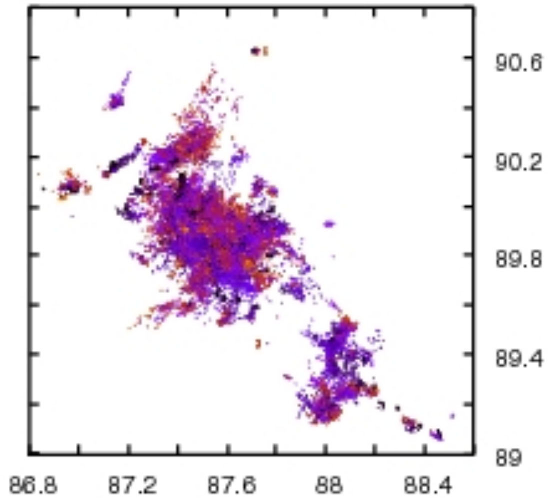
SMF at z < 4 reproduced



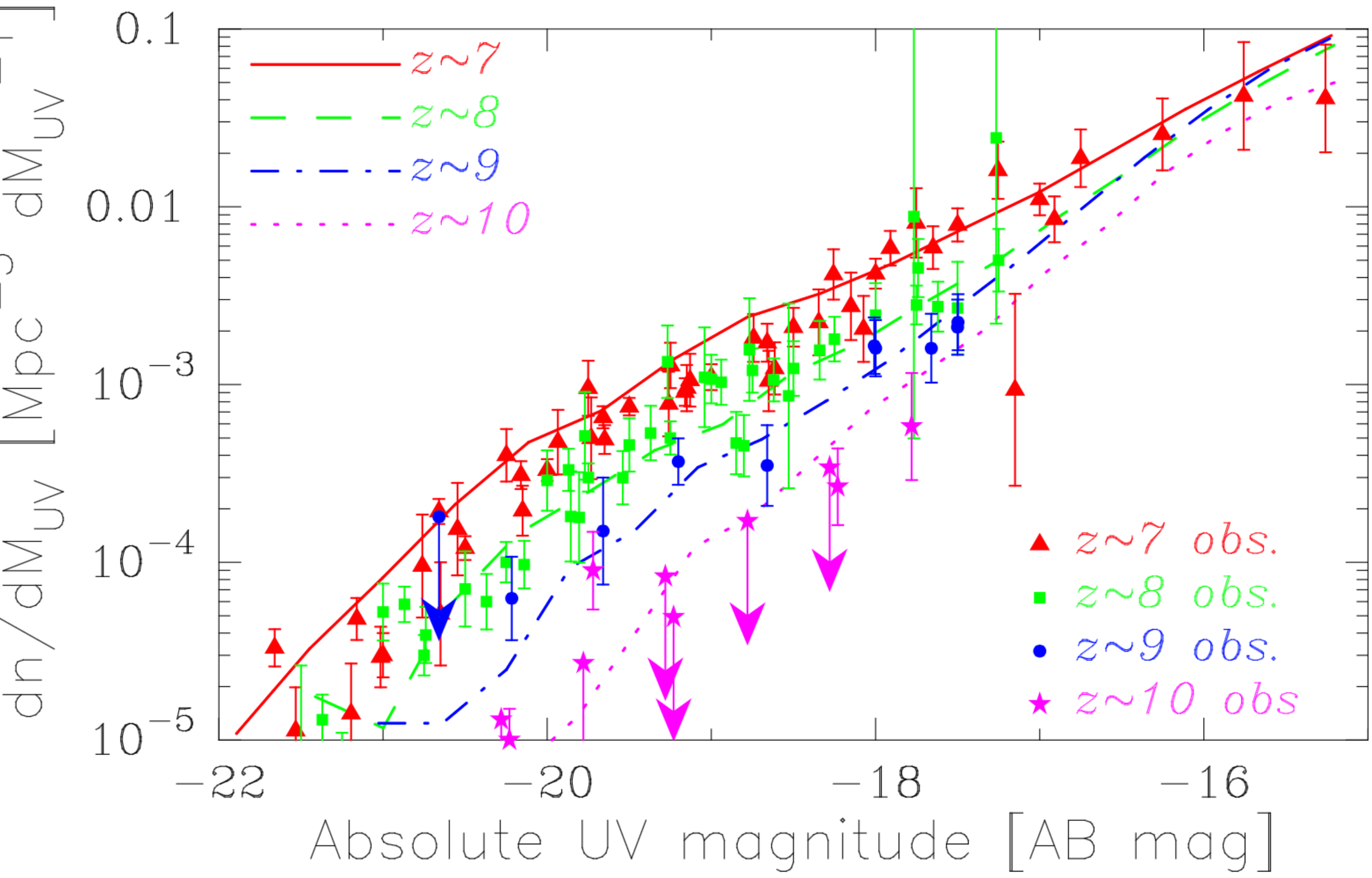
Okamoto, Shimizu, NY, 2014

Galaxy SED


Total
Stellar
Nebular
Dust
Stellar + nebular
Dust continuum (M_{dust}, dn/da)
Population synthesis (SFR, age, Z)
Flux
1000
10^4
10^5
10^6
10^7
Rest-frame wavelength

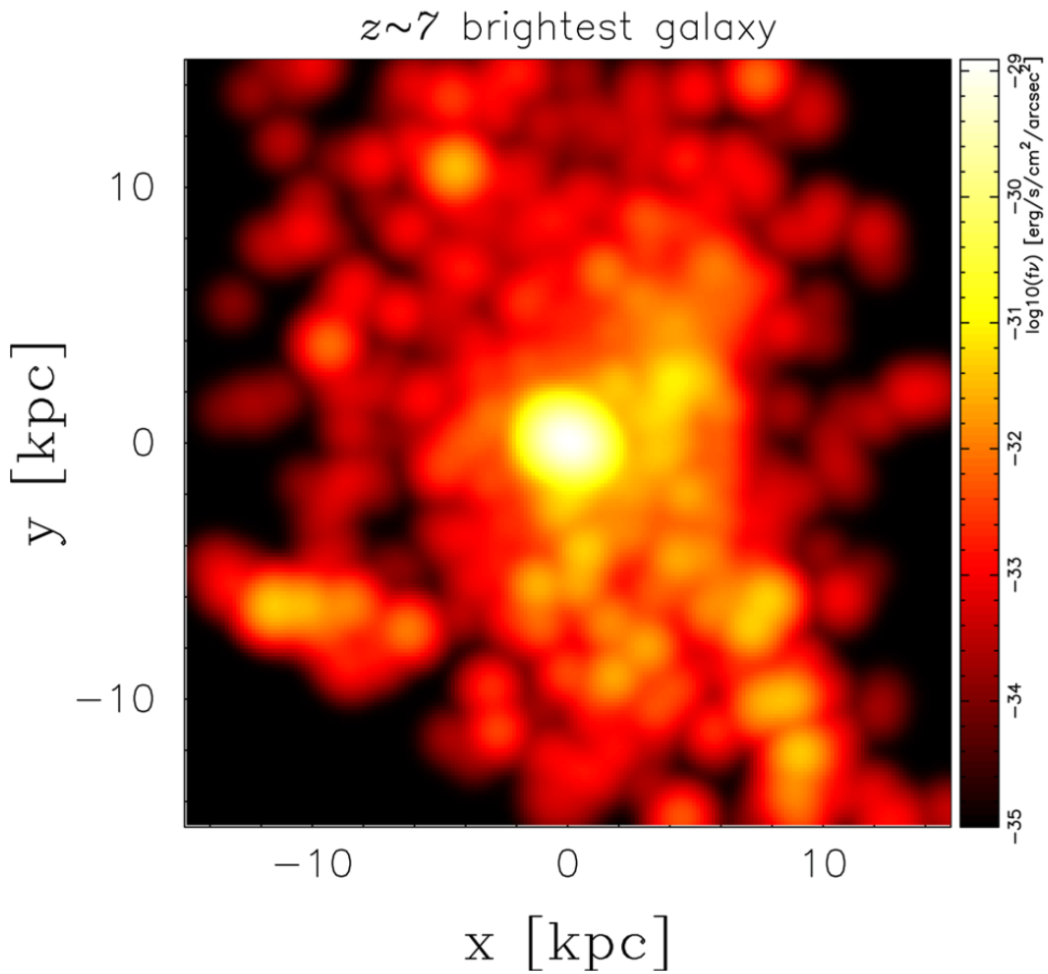

90.6
90.2
89.8
89.4
89
86.8
87.2
87.6
88
88.4

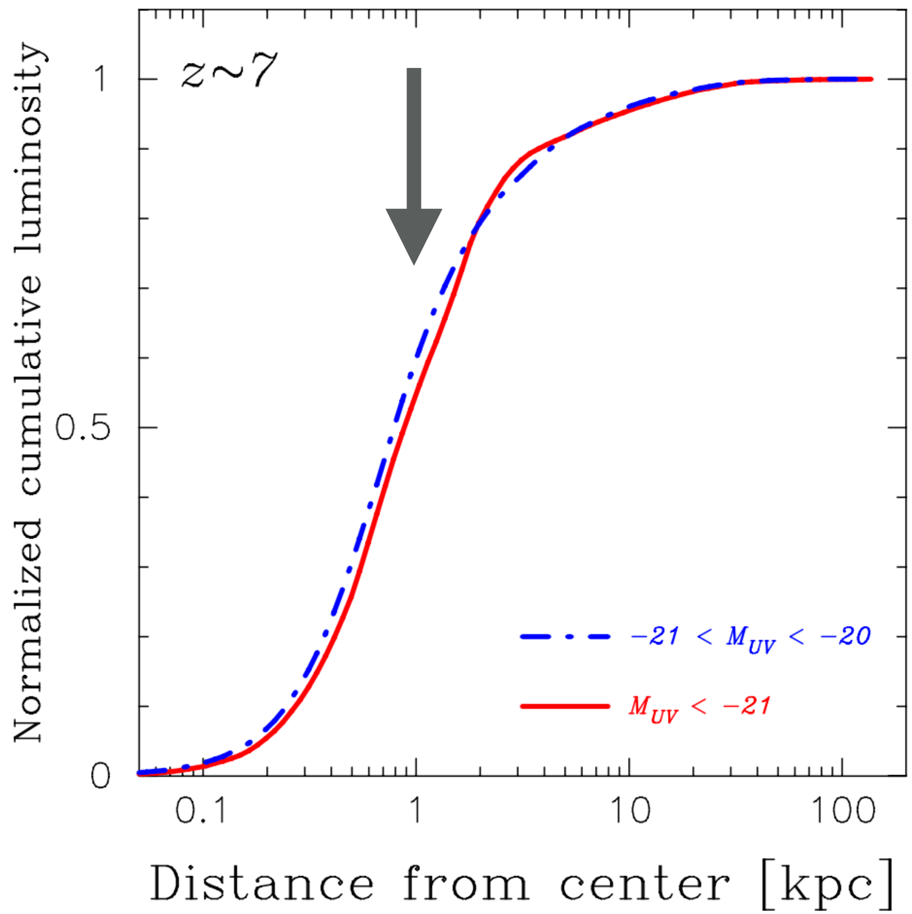
UV luminosity function



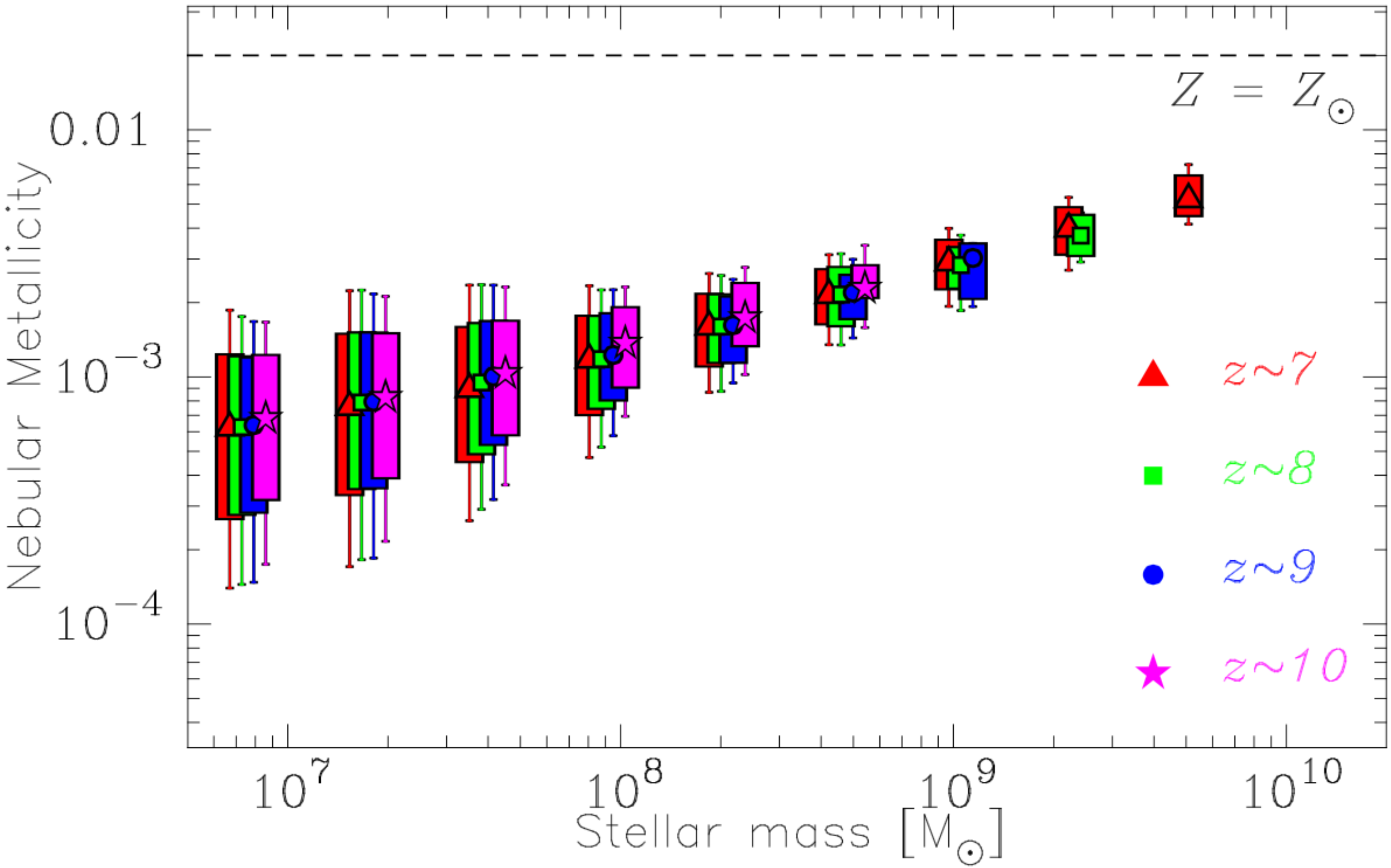
Galaxy size

With 0.1 arcsec smoothing





Nebular metallicity



UV slope β

$\beta = 4.39 \times (J_{125} - H_{160}) - 2.0,$

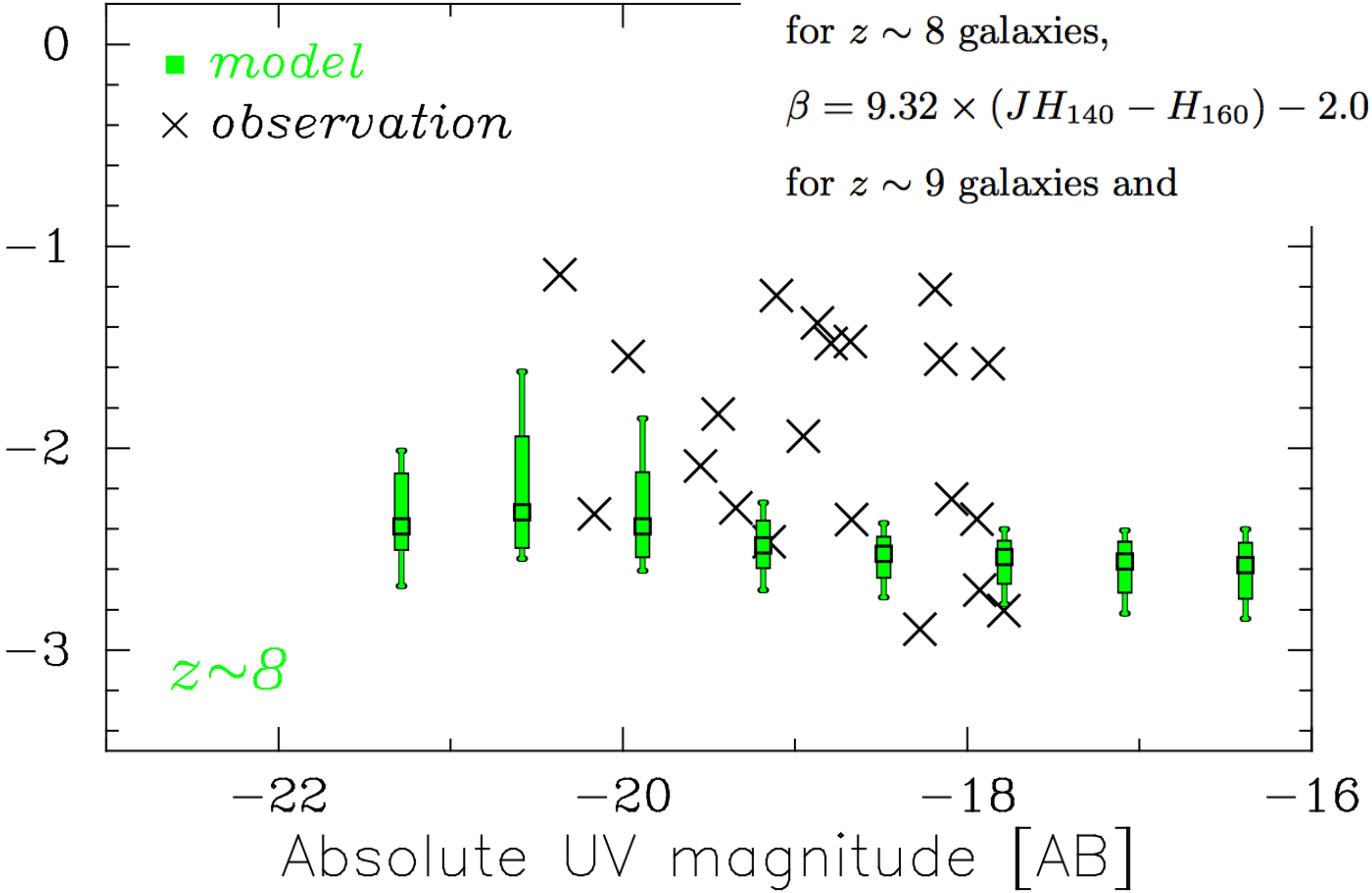
for $z \sim 7$ galaxies,

$\beta = 8.98 \times (JH_{140} - H_{160}) - 2.0,$

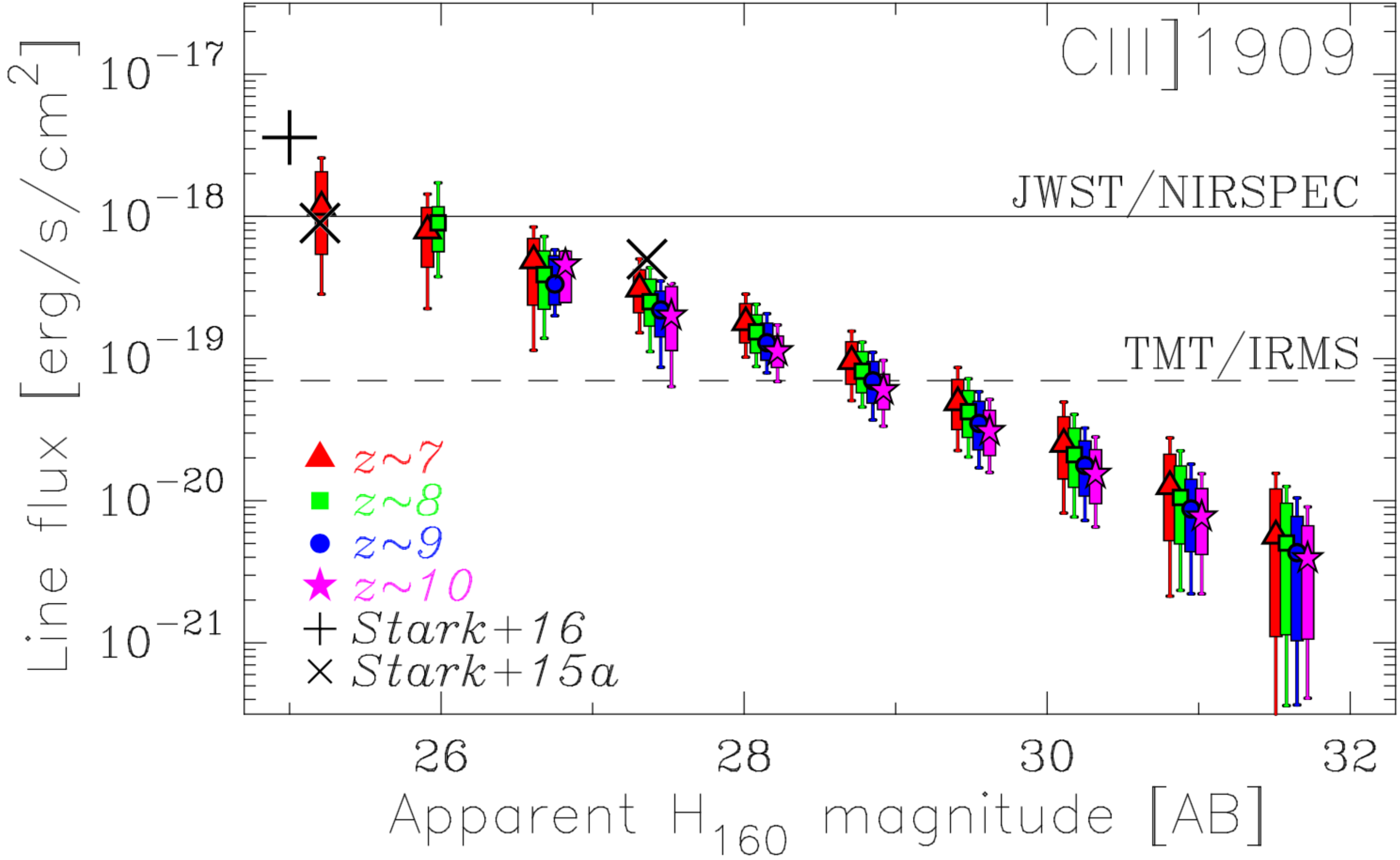
for $z \sim 8$ galaxies,

$\beta = 9.32 \times (JH_{140} - H_{160}) - 2.0,$

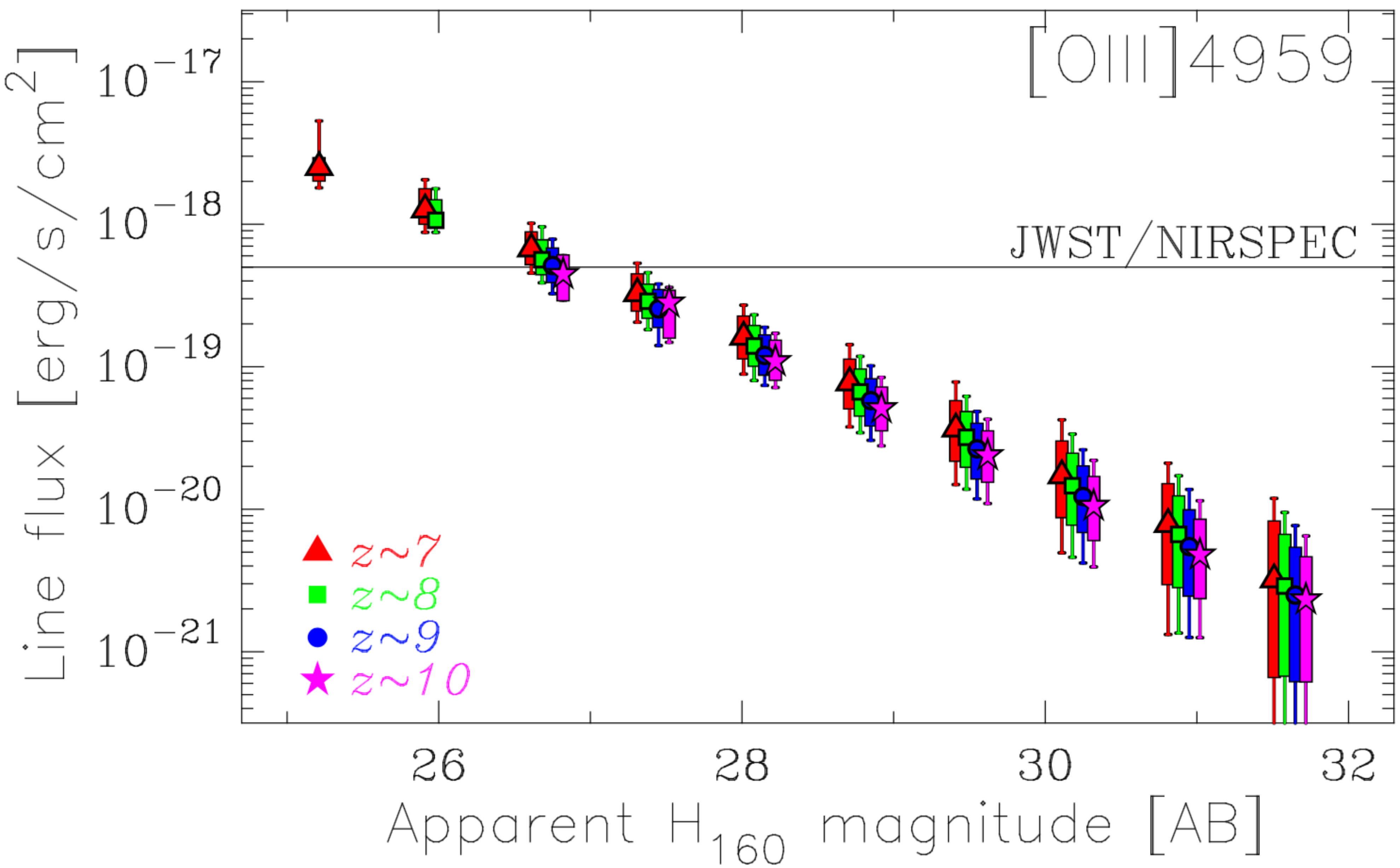
for $z \sim 9$ galaxies and



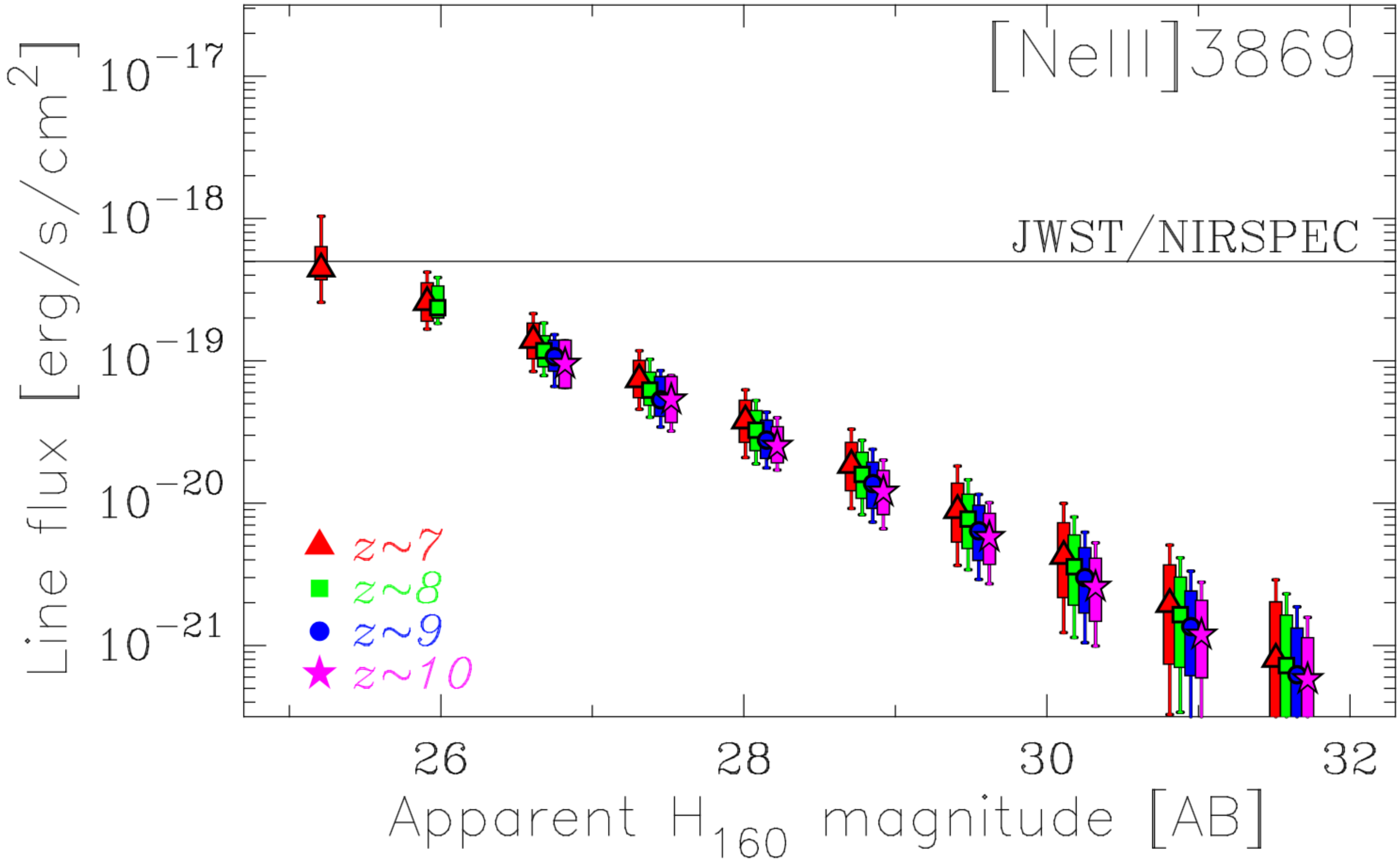
Line flux: Ciii]



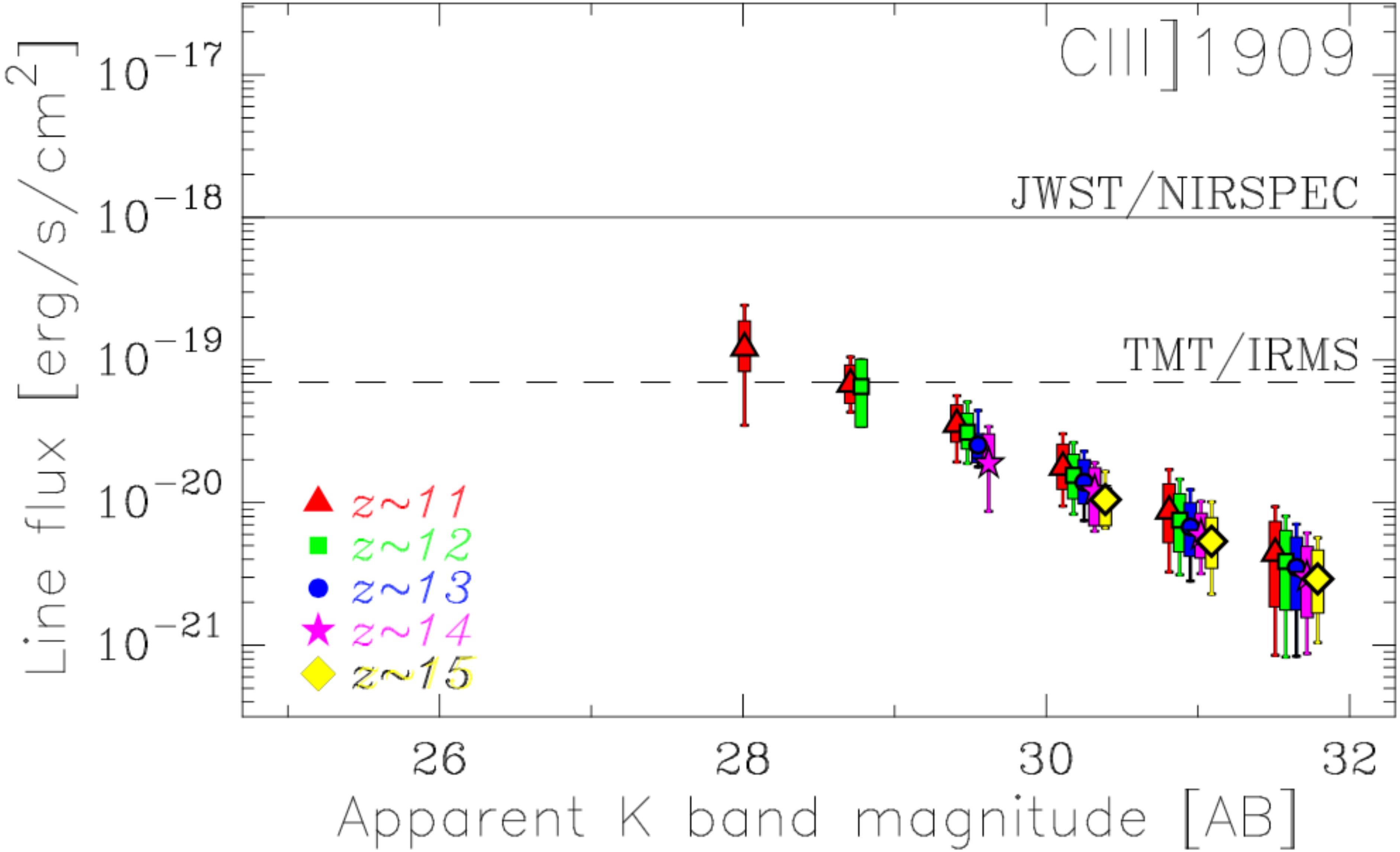
Line flux: [OIII]



Line flux: Neiii



z > 10 galaxies



Cosmological galaxy formation simulations
are able to predict early galaxy SEDs.

There are several promising lines (C, O, Ne)
that can be detected by TMT etc.

Absence of bright sources partly due to
the small box size.

Real galaxies may contain less amount of dust
(Inoue et al. 2016)

Combination of rest-UV and FIR lines
(ULTIMATE ALMA)

Answers

A1. Locating high-z galaxies (candidates) for spec. follow up

A2. WFC

A3. Spectroscopy of brightest and spatially resolvable galaxies at $z>5$ maybe with lensing

A4. Oriented to time domain survey.