将来計画JWST, TMT, WISHに向けた様々な高赤方偏移銀河の輝線検出可能性

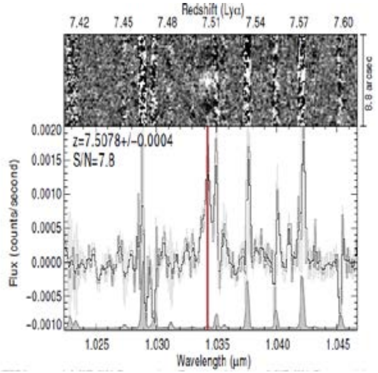
今日の話は z ~ 7 以上の HII region 起源の輝線のみ

清水 一紘 （東京大学）

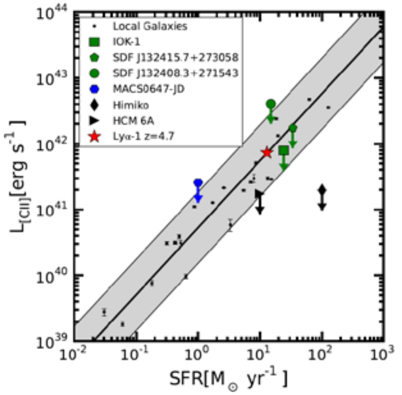
Detectability of Line emission at Very High-z

- Lyα line
  - ✓ z > 8 を超える観測例はなし
  - ✓ IGM 吸収が強く効くため？

  Brammer et al. 2013., Treu et al. 2013., Finkelstein et al. 2013

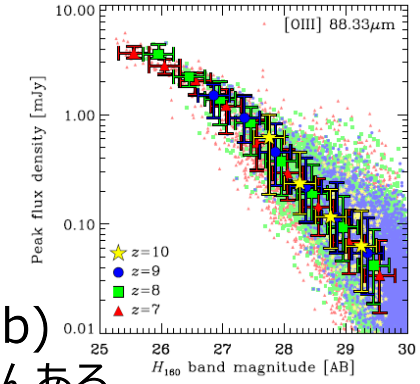


- [CII]158μm line
  - ✓ ALMA の良いターゲット
  - ✓ 多くの high-z LAEs で [CII] 輝線が受かっていない
  - ✓ High-z に行くほど LAE like な天体が増えてくる
  - ✓ 主に PDR 起源の輝線のため放射機構が複雑



- [OIII]88μm line
  - ✓ Metal ($Z > 0.01Z_{sun}$) と HII region があれば出てくる
  - ✓ HII region 起源の輝線のため放射機構が簡単
  - ✓ ALMA の良いターゲット (Inoue, IS, et al. 2014)

- UV to optical line
  - ✓ JWST, TMT の良い分光ターゲットになりうる
  - ✓ WISH 等によって広域探査でターゲットを見つけられる
  - ✓ CIII]1909 は実際観測されている (Stark et al. 2014b)
  - ✓ [OII]3727, [OIII]4959, 5007 等明るい輝線がたくさんある



Cosmological Hydrodynamic Simulation

- Cosmology (Plank 1st year)

$$(\Omega_{\mathrm{m}}, \Omega_{\Lambda}, \Omega_{\mathrm{b}}, h, \sigma_8) = (0.3175, 0.6825, 0.049, 0.6711, 0.8344)$$

- Simulation code :Gadeget3

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

high-z から low-z における様々な観測を再現するモデル

- ✓ Stellar mass function ($0 < z < 7$)
- ✓ Star formation history
- ✓ Mass-metallicity relation
- ✓ Downsizing
- ✓ Star formation efficiency (Moster plot)

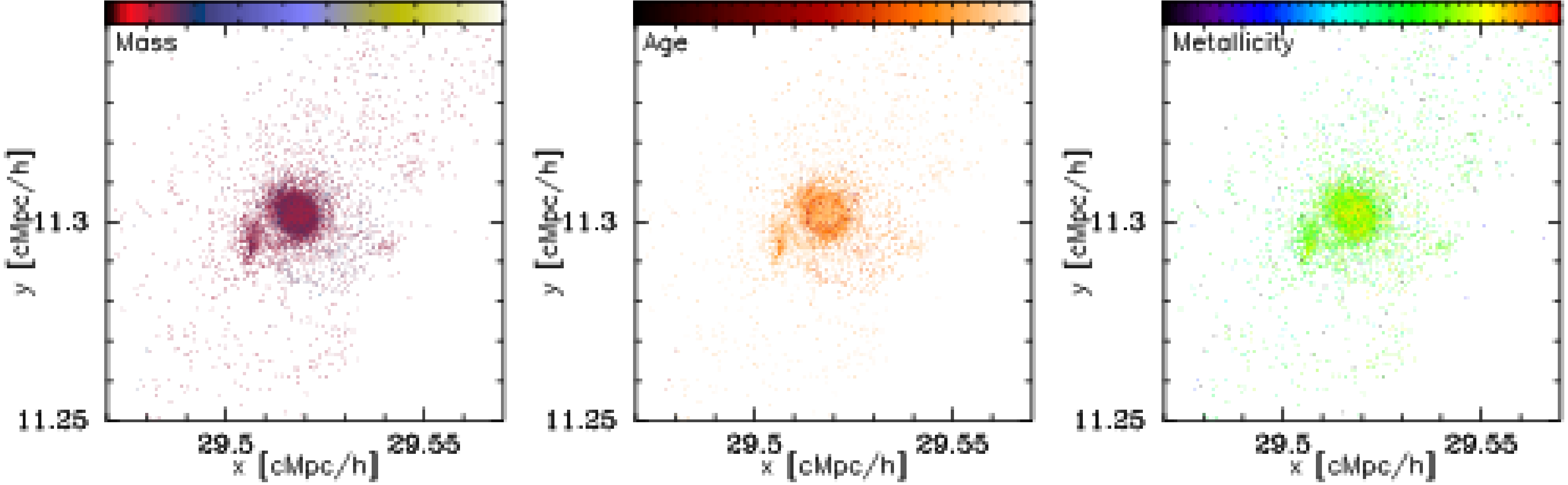
- Simulation setup

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

→

Minimum halo mass: $\sim 10^8\ M_{\mathrm{sun}}$
Minimum stellar mass: $\sim 10^6\ M_{\mathrm{sun}}$

Calculation of Galaxy SED



Simulation で出来た銀河内の各 star cluster data (星自体は分解できない)

- ●IMF (Chabrier IMF)
- ●Current Mass (SN で mass loss するため)
- ●Age
- ●Metallicity

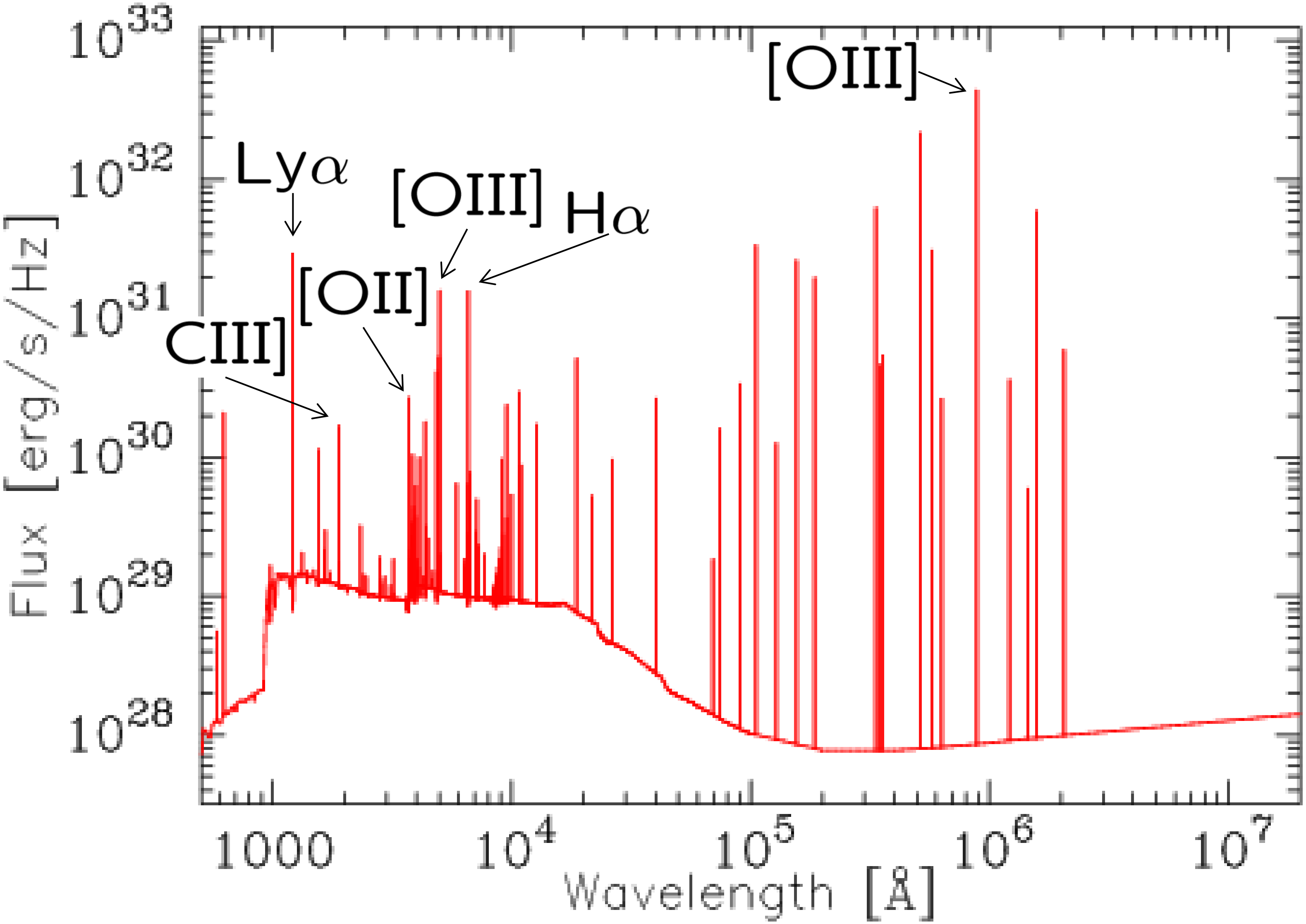
Calculation of intrinsic SED of galaxy

A) PEGASE2 であらかじめ作っておいた、SED data を各 star cluster にアサイン
B) 各 star cluster の SED を足し合わせる
C) Nebular continuum も PEGASE2 で計算
D) 水素の輝線は case B でその他の輝線は Inoue 2011 を使う ($L_{line} = \alpha L_{H\beta}$)

Intrinsic SED = stellar continuum + nebular continuum & line

Example of High-z Galaxy SED

Stellar continuum+ nebular continuum & line



Calculation of Galaxy SED

Calculation of dust attenuation at UV (= 1500A)

$$f_{\rm UV} = \frac{1-\delta}{2}(1 + e^{\tau_{\rm d}}) + \frac{\delta}{\tau_{\rm d}}(1 - e^{\tau_{\rm d}})$$

$$\tau_{\rm d} = \frac{3\Sigma_{\rm d}}{4as} \Longleftarrow \Sigma_{\rm d} = e_\tau \frac{\boxed{M_{\rm metal}}}{\pi \boxed{r^2_{\rm half}}}$$

simulation から求める

δ:slab fraction,(0~1) , a:dust grain size (0.05 μm), s:dust grain density (2.5 g/cm^3)

UV luminosity function を再現するように、パラメータ δ, e_τ を調整

Calculation of dust attenuation at the other wavelength

- Calzetti law (Calzetti et al. 2000) ⇒ さまざまな Extinction law 対応可能

Calculation of dust attenuation for line

- Calzetti law, e.g., $E(B - V)_* = 0.44E(B - V)_{\rm gas}$

Calculation of IGM absorption (λ < 1216A)

- Madau 1994 ⇒ Inoue, IS et al. 2014 に変える予定

Calculation of Galaxy SED

Calculation of dust emission (e.g., Shimizu et al. 2012)

- ✓ Dust mass は、metal mass の 50%
- ✓ Dust に吸収された、光子は FIR ですべて再放出

- Dust temperature

$$T_{\mathrm{d}} = \alpha \left(\frac{L_{\mathrm{d}}}{M_{\mathrm{d}}} \right)^{\frac{1}{1+\beta}}$$

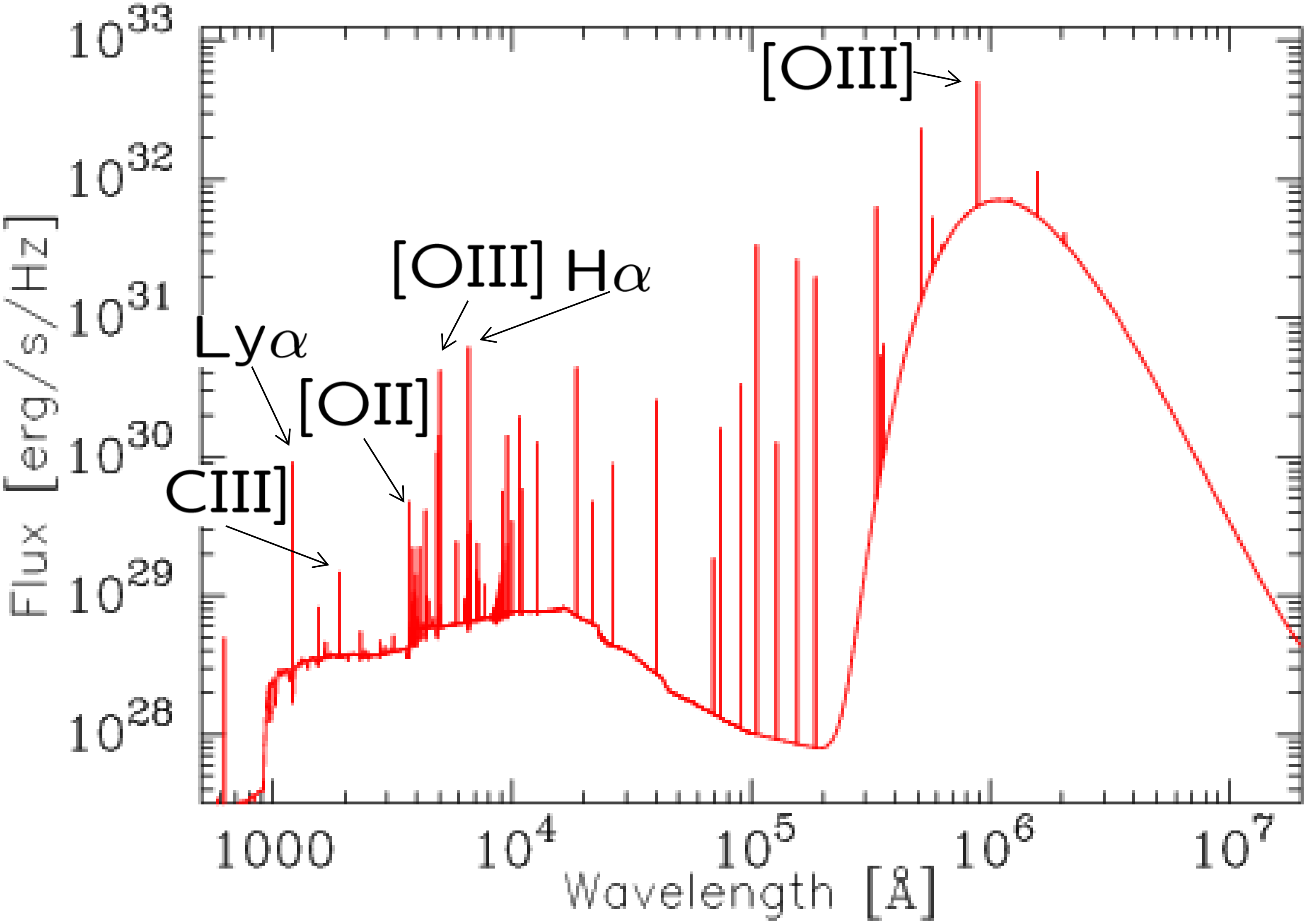
$$\begin{cases} L_\nu = 4\pi M_{\mathrm{d}} \kappa_\nu B_\nu(T_{\mathrm{d}}) \\ \kappa_\nu = \kappa_0 \left(\frac{\nu}{\nu_0} \right)^\beta \\ L_{\mathrm{d}} = \int [L_\nu^{\mathrm{int}} - L_\nu^{\mathrm{ad}}] d\nu = \int L_\nu d\nu \end{cases}$$

- Dust emission

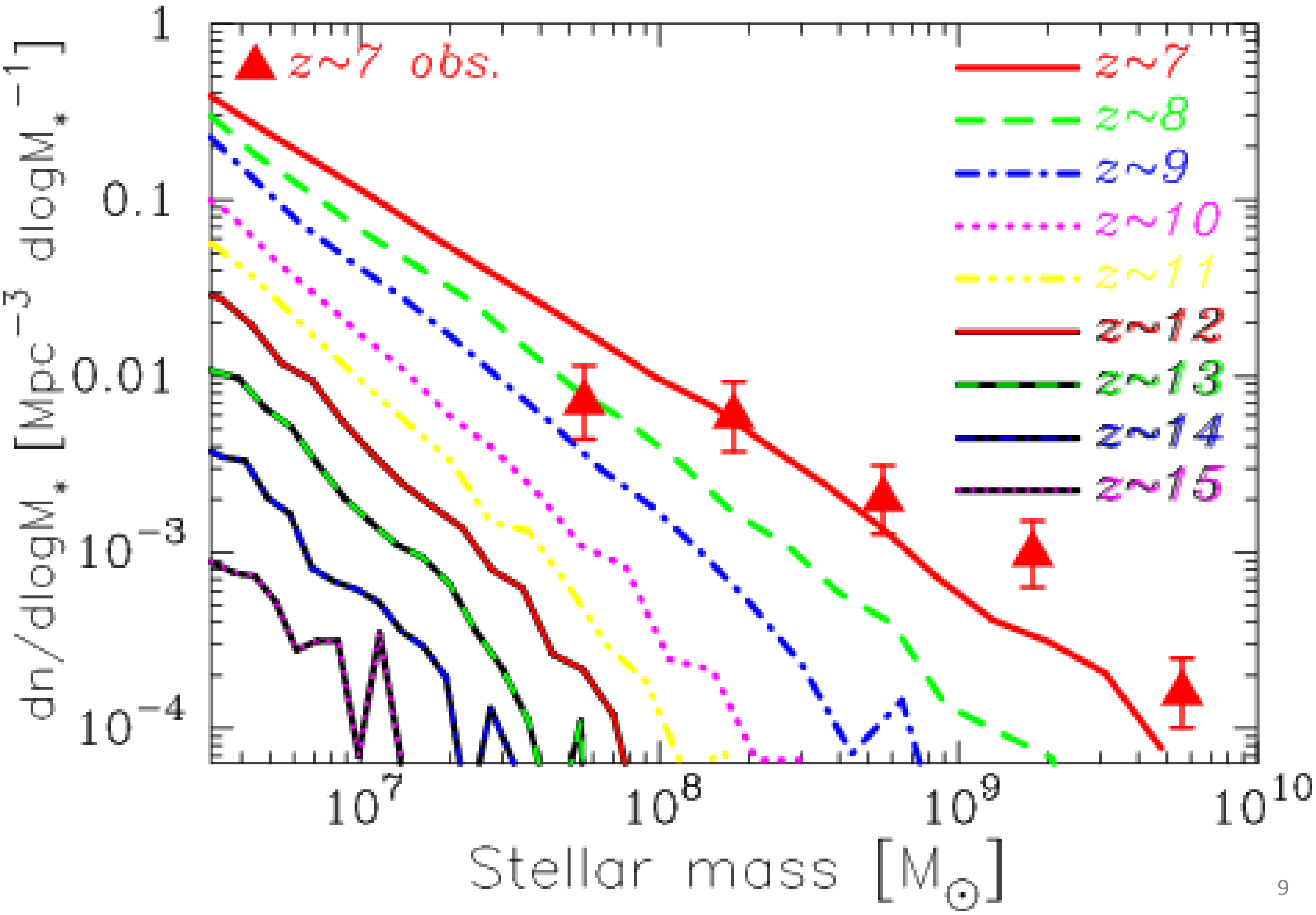
$$f_\nu = \frac{(1+z) L_{\nu(1+z)}}{4\pi d_{\mathrm{L}}^2}$$

Example of High-z Galaxy SED

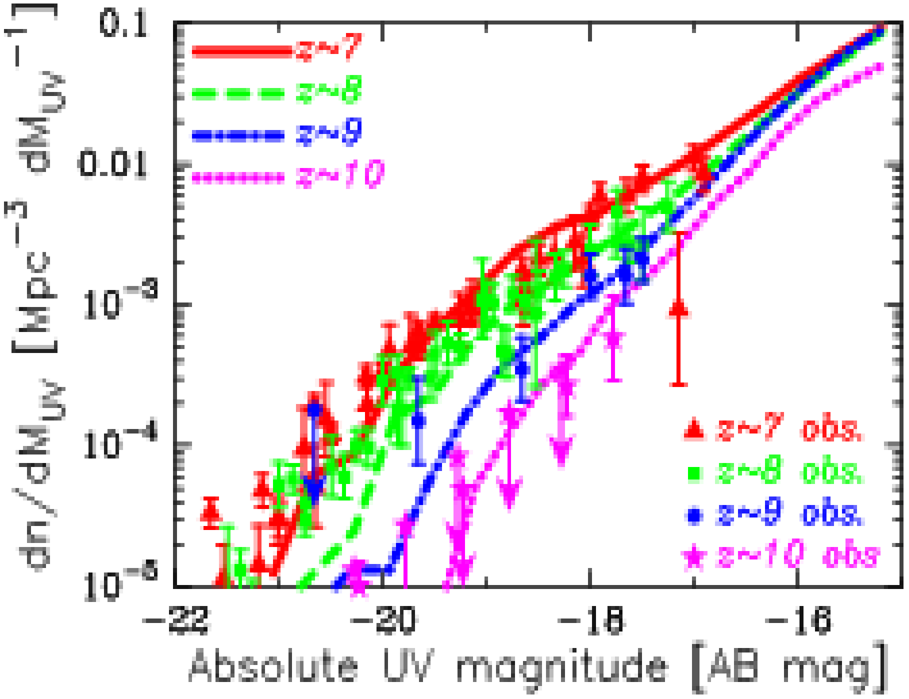
Stellar continuum+ nebular continuum & line + dust emission

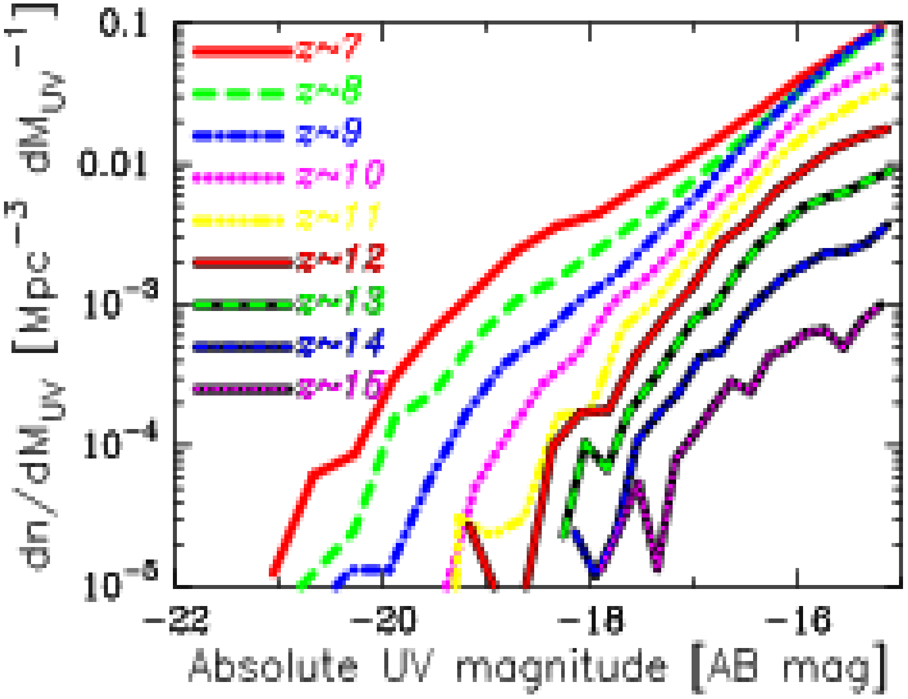


Stellar Mass Functions (7 < z < 15)

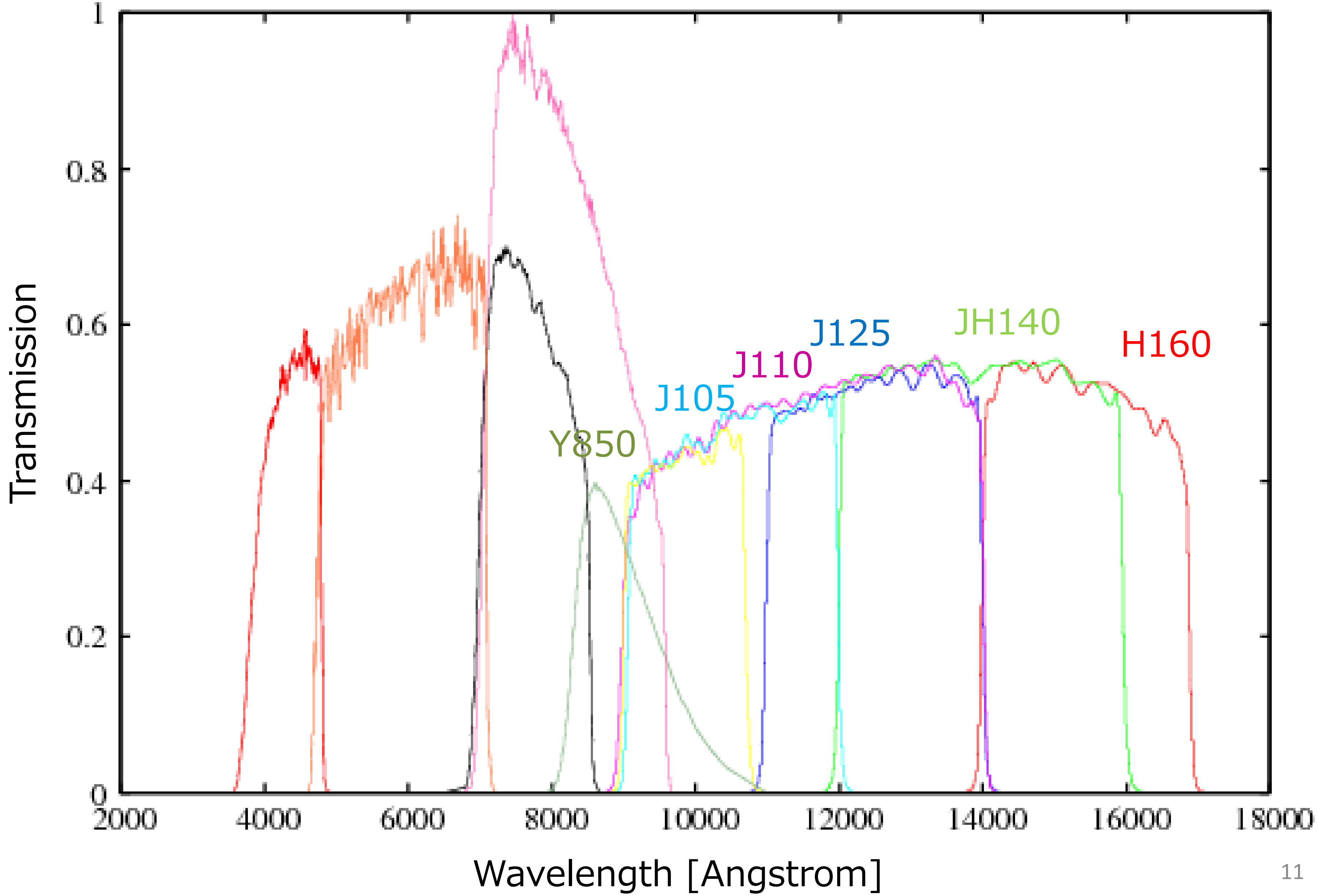


UV Luminosity Functions (7 < z < 15)





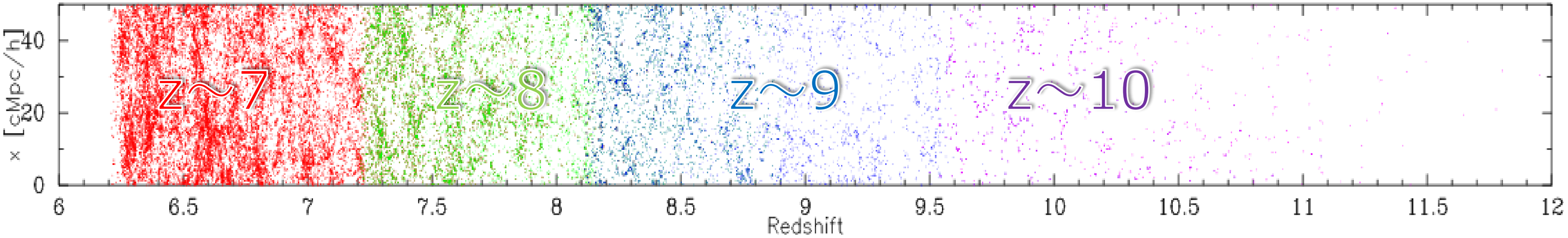
Hubble Broad Band Filters



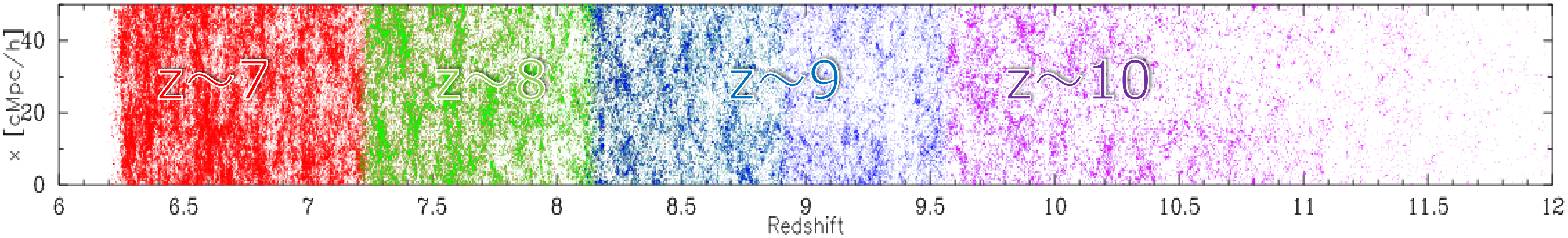
Color Selected Galaxies in Light-Cone

- 観測と同じ color selection で各赤方偏移の銀河を同定
  (z=7, 8, 10:Bouwens et al. 14, z=9:Oesch et al. 13)

$H_{160} < 30$ (for Hubble)

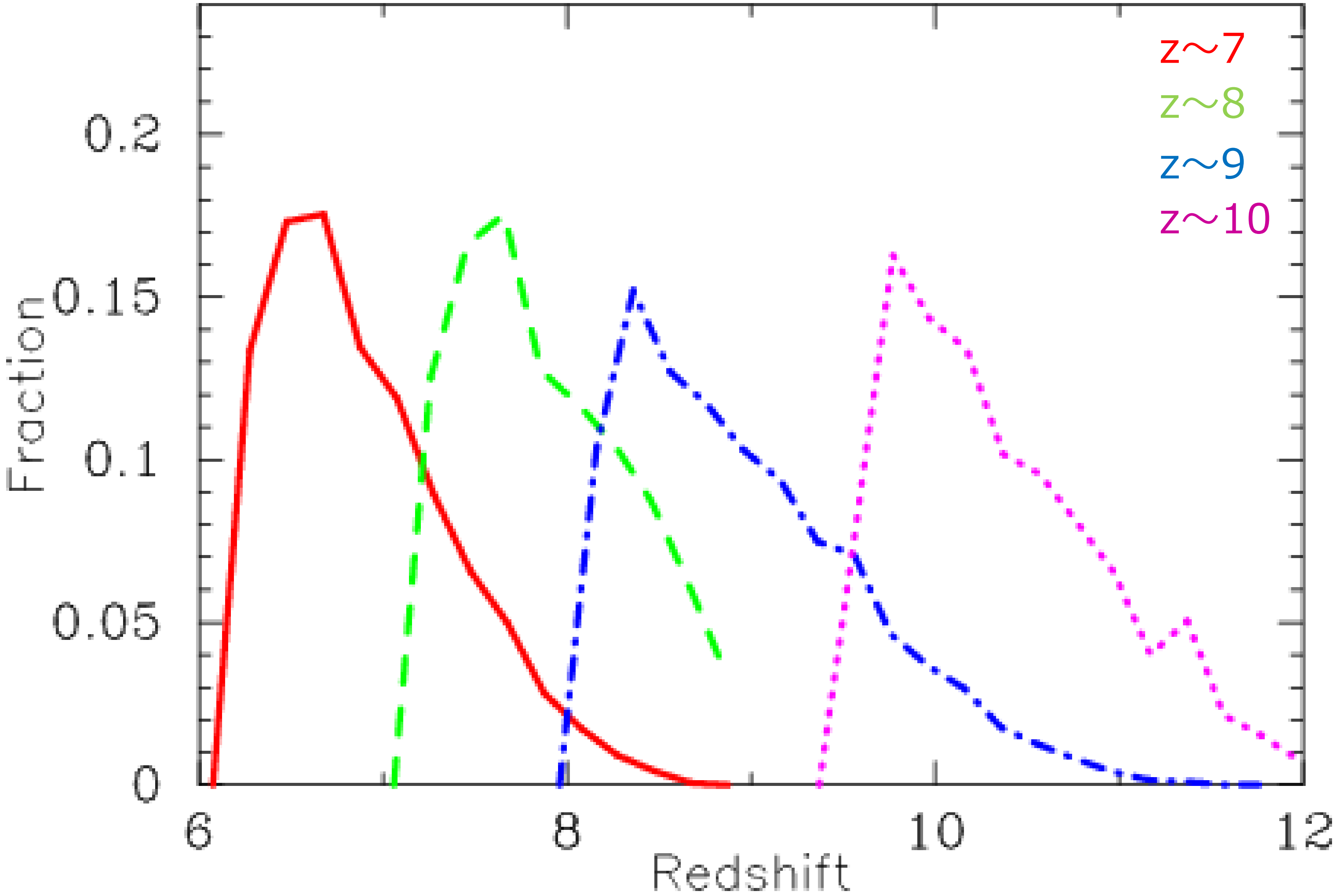


$H_{160} < 32$ (for JWST)



FOV ~ 0.16 deg^2

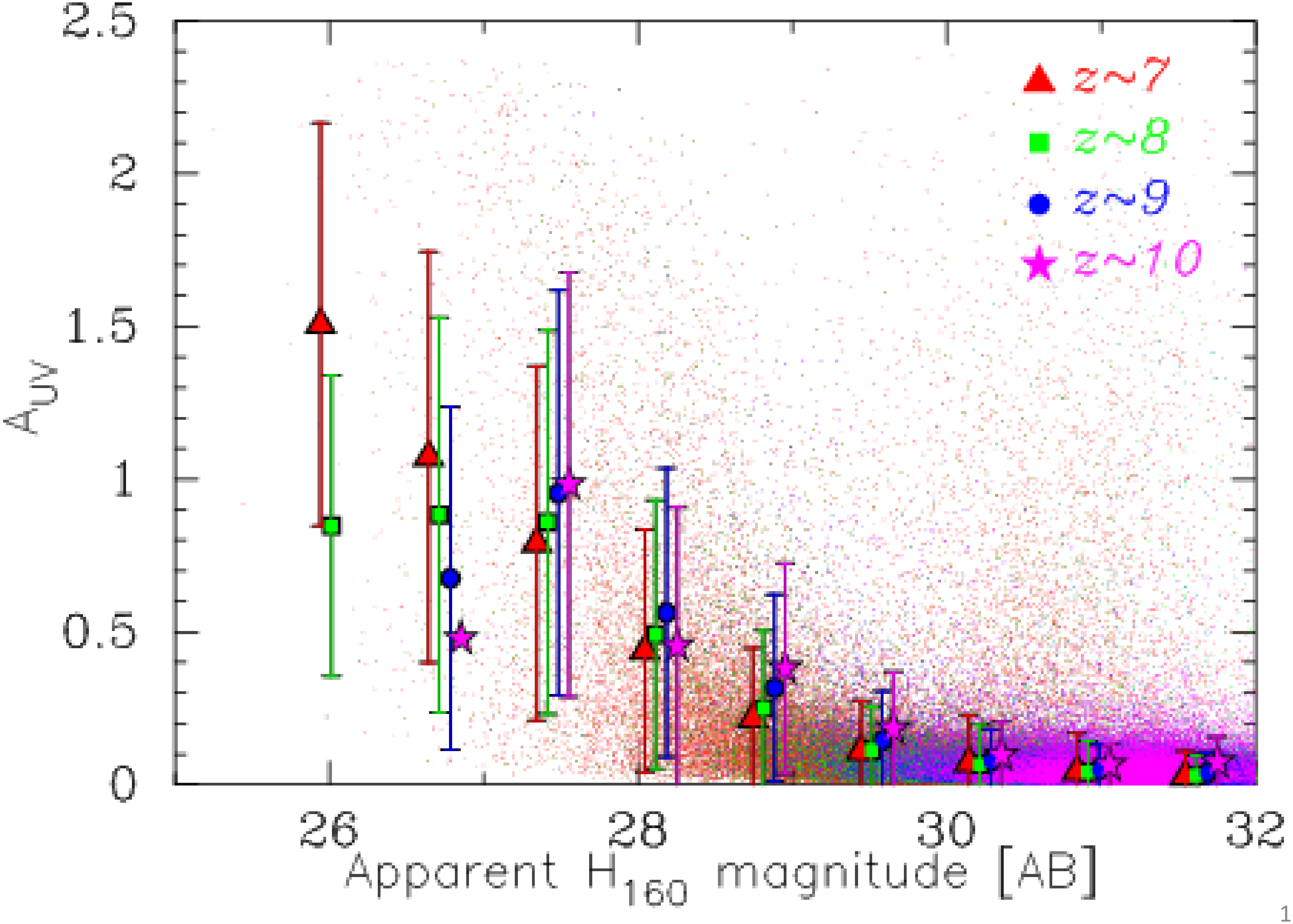
Color Selection Efficiency



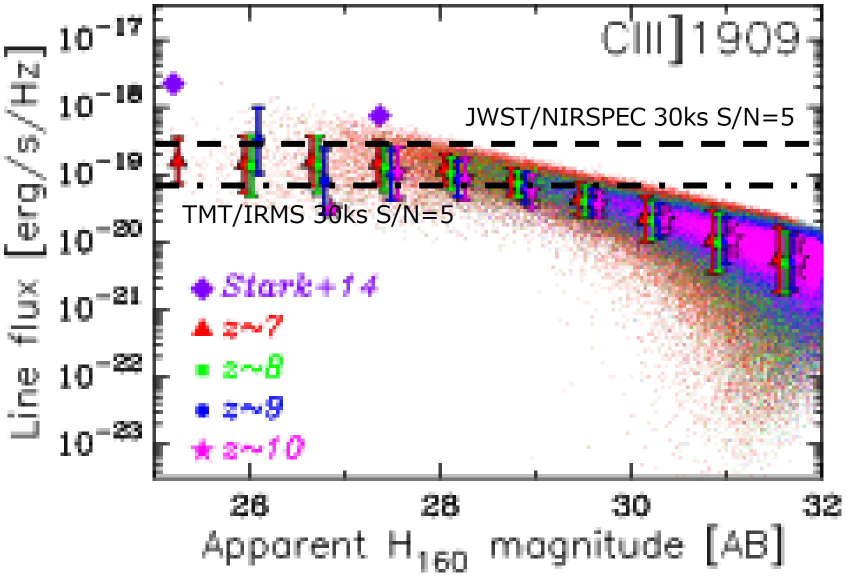
HST+ JWST & TMT

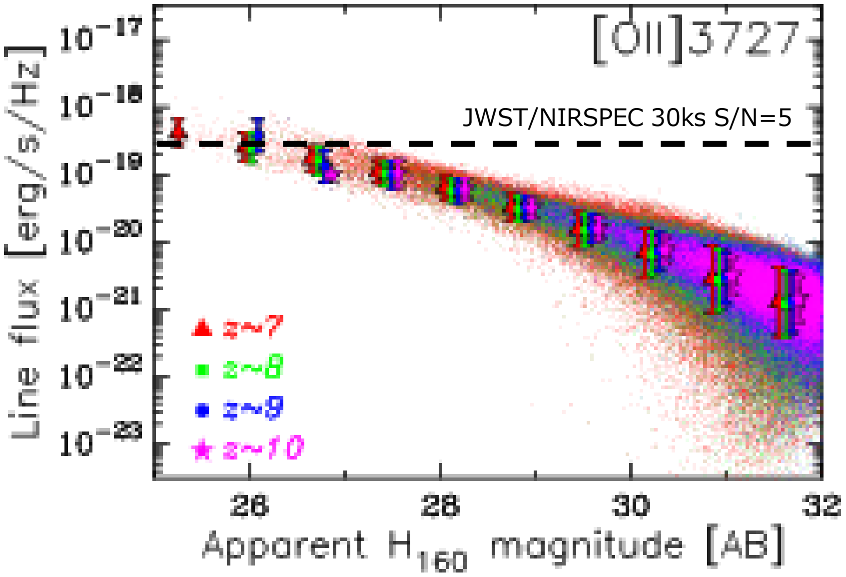
JWST/NIRSPEC	0.6 ～ 5 μm
TMT/IRMS	0.8 ～ 2.5 μm

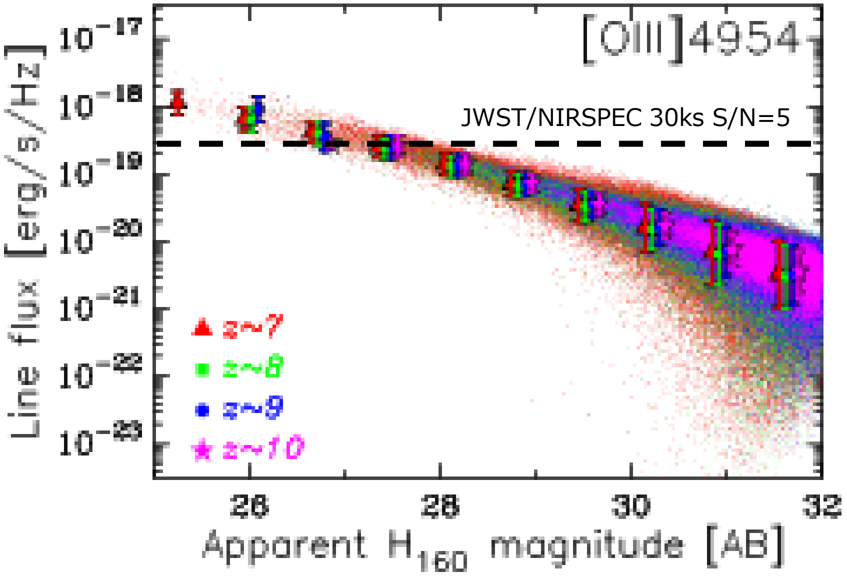
H_{160} Magnitude-A_{UV}

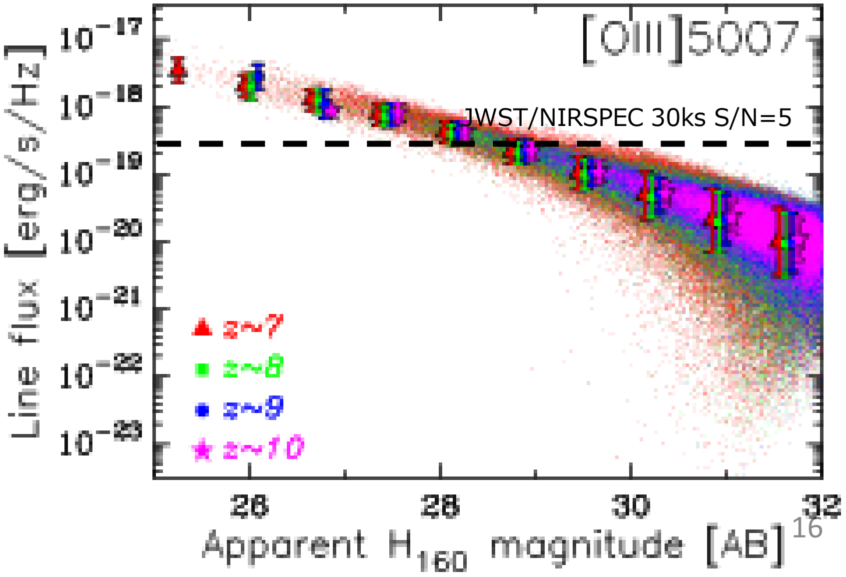


Metal Lines

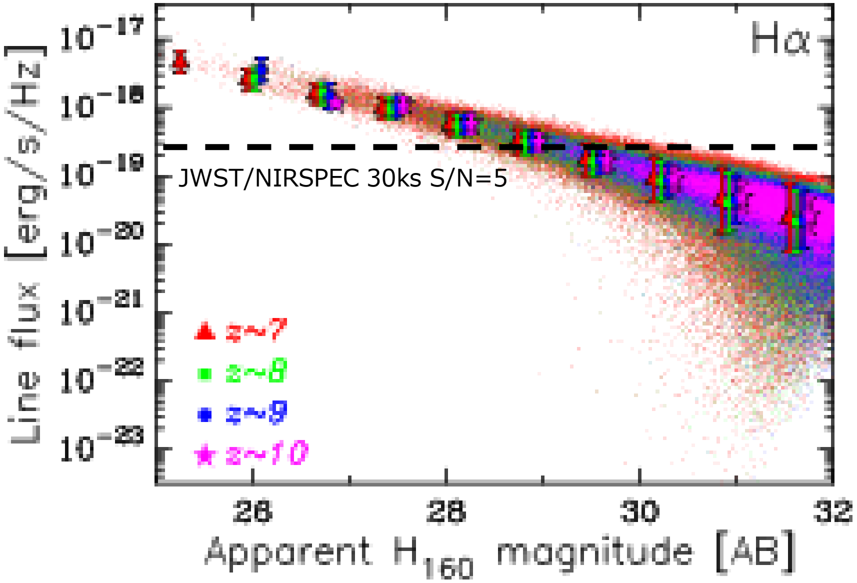

CIII]1909
JWST/NIRSPEC 30ks S/N=5
TMT/IRMS 30ks S/N=5
Stark+14
z~7
z~8
z~9
z~10
Line flux [erg/s/s/Hz]
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
26
28
30
32
Apparent H_{160} magnitude [AB]


[OII]3727
JWST/NIRSPEC 30ks S/N=5
z~7
z~8
z~9
z~10
Line flux [erg/s/s/Hz]
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
26
28
30
32
Apparent H_{160} magnitude [AB]

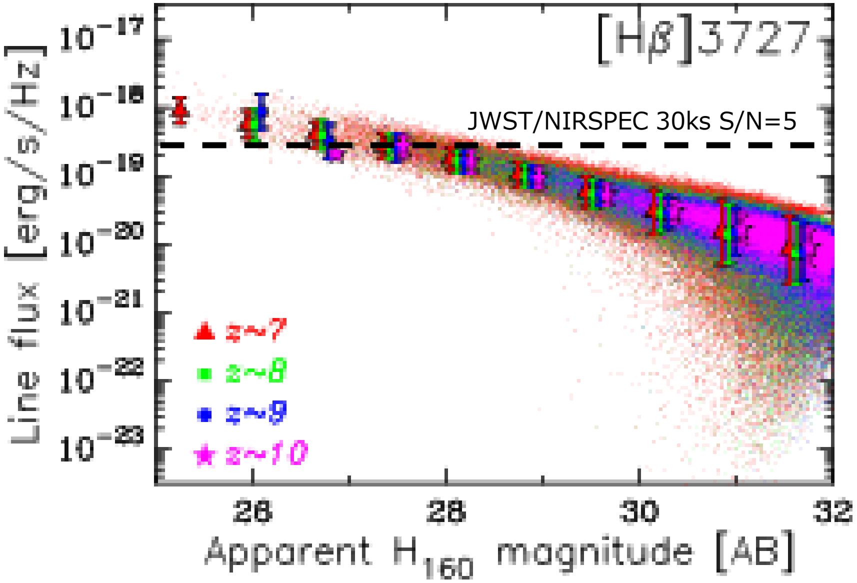

[OIII]4954
JWST/NIRSPEC 30ks S/N=5
z~7
z~8
z~9
z~10
Line flux [erg/s/s/Hz]
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
26
28
30
32
Apparent H_{160} magnitude [AB]


[OIII]5007
JWST/NIRSPEC 30ks S/N=5
z~7
z~8
z~9
z~10
Line flux [erg/s/s/Hz]
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
26
28
30
32
Apparent H_{160} magnitude [AB]

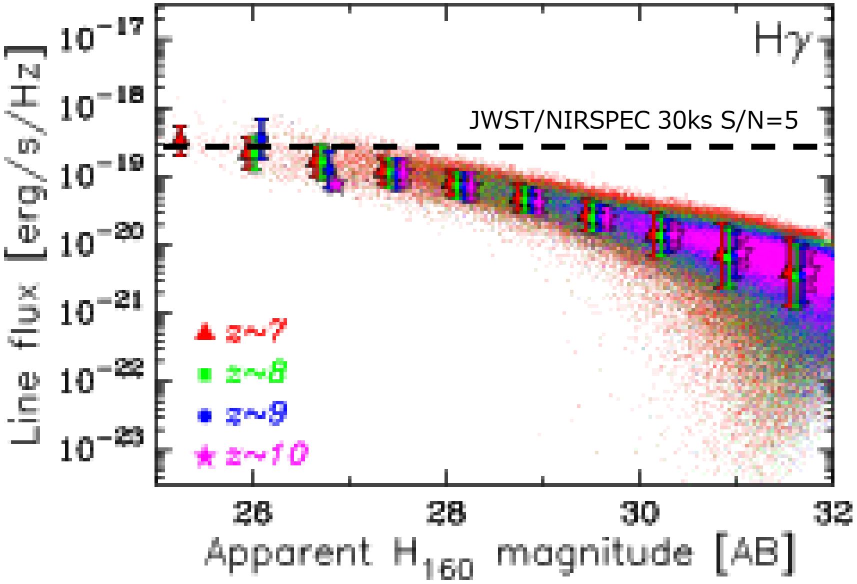
Hydrogen recombination lines



JWST/NIRSPEC 30ks S/N=5



JWST/NIRSPEC 30ks S/N=5

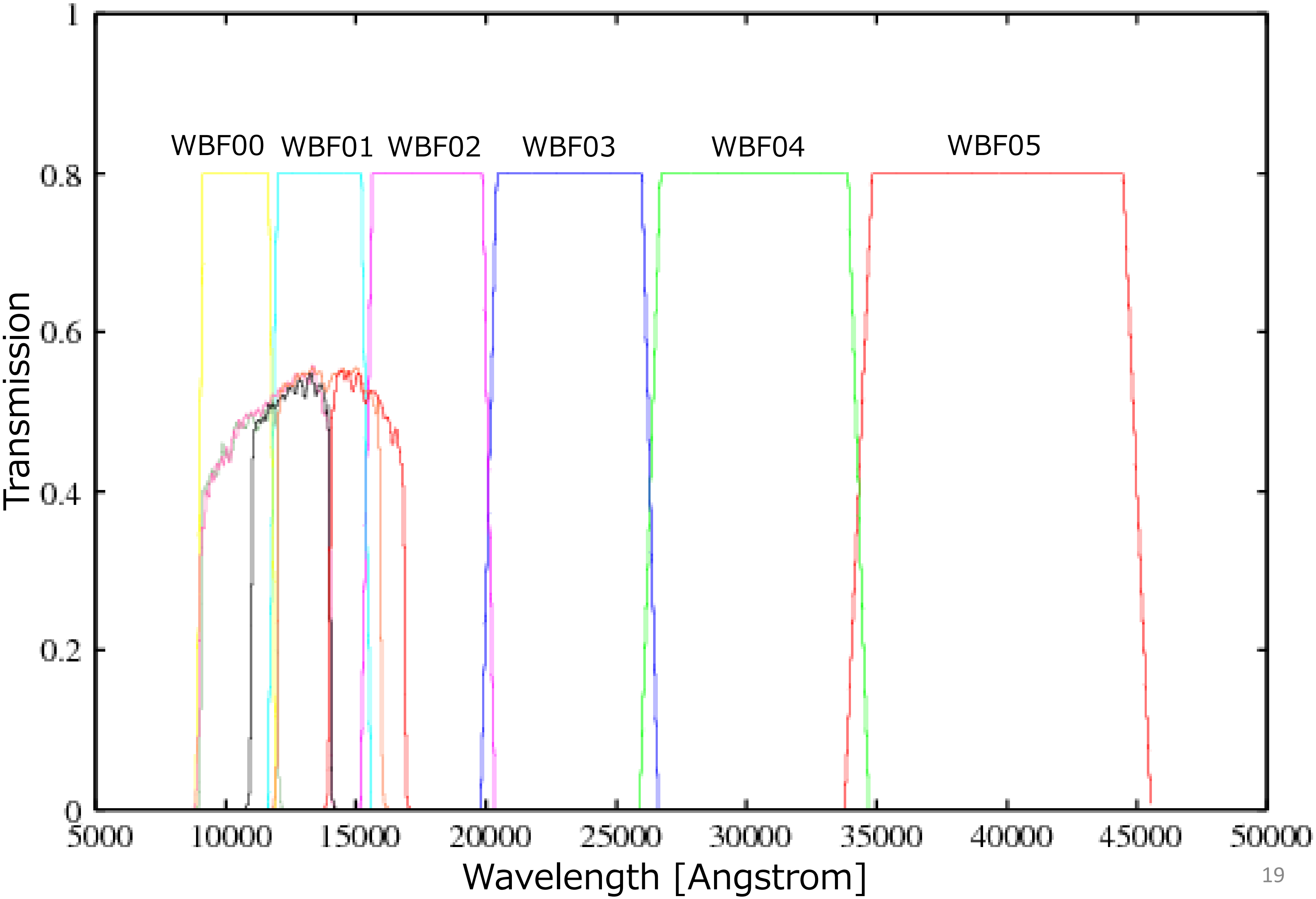


JWST/NIRSPEC 30ks S/N=5

WISH + JWST & TMT

JWST/NIRSPEC	0.6 ～ 5 μm
TMT/IRMS	0.8 ～ 2.5 μm

WISH Broad Band Filters

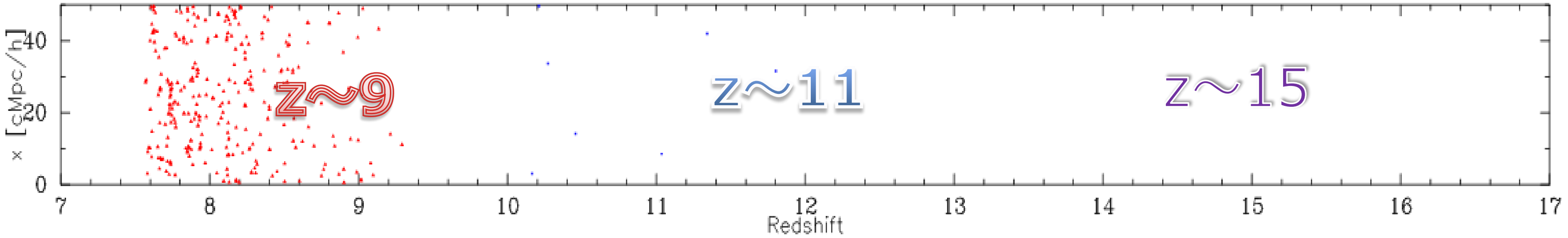


Simulated Galaxies in Light-Cone

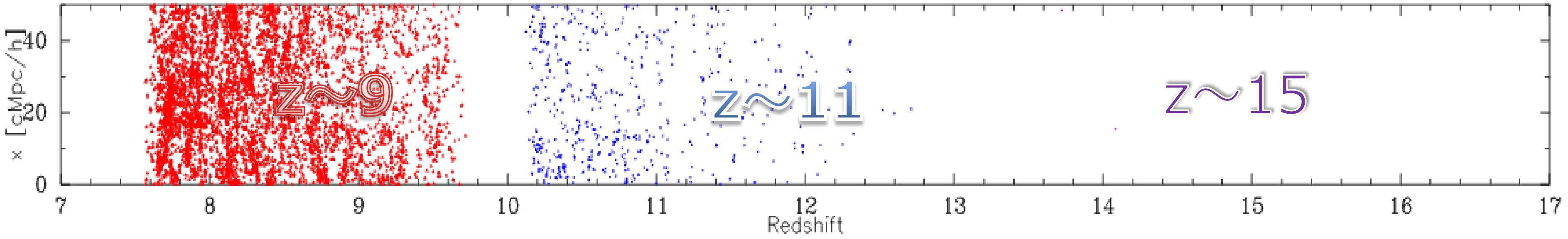
- WISH color selections for z~9, 11, 15

FOV ~ 0.14 deg^2

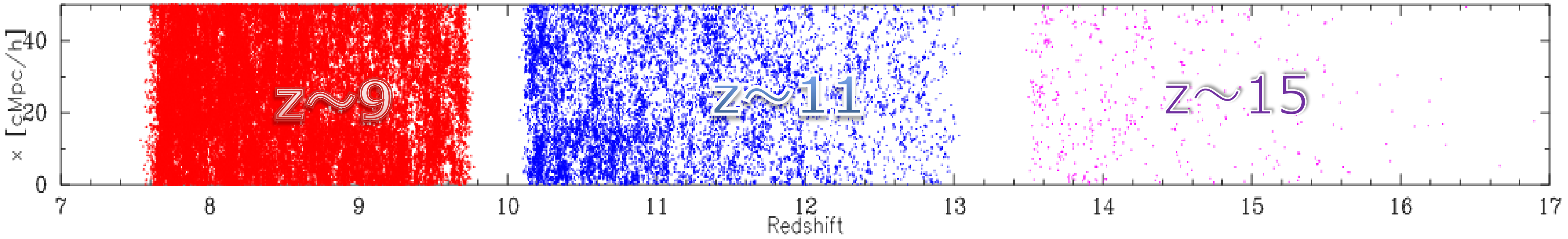
Detection limit < 28 mag (for wish)



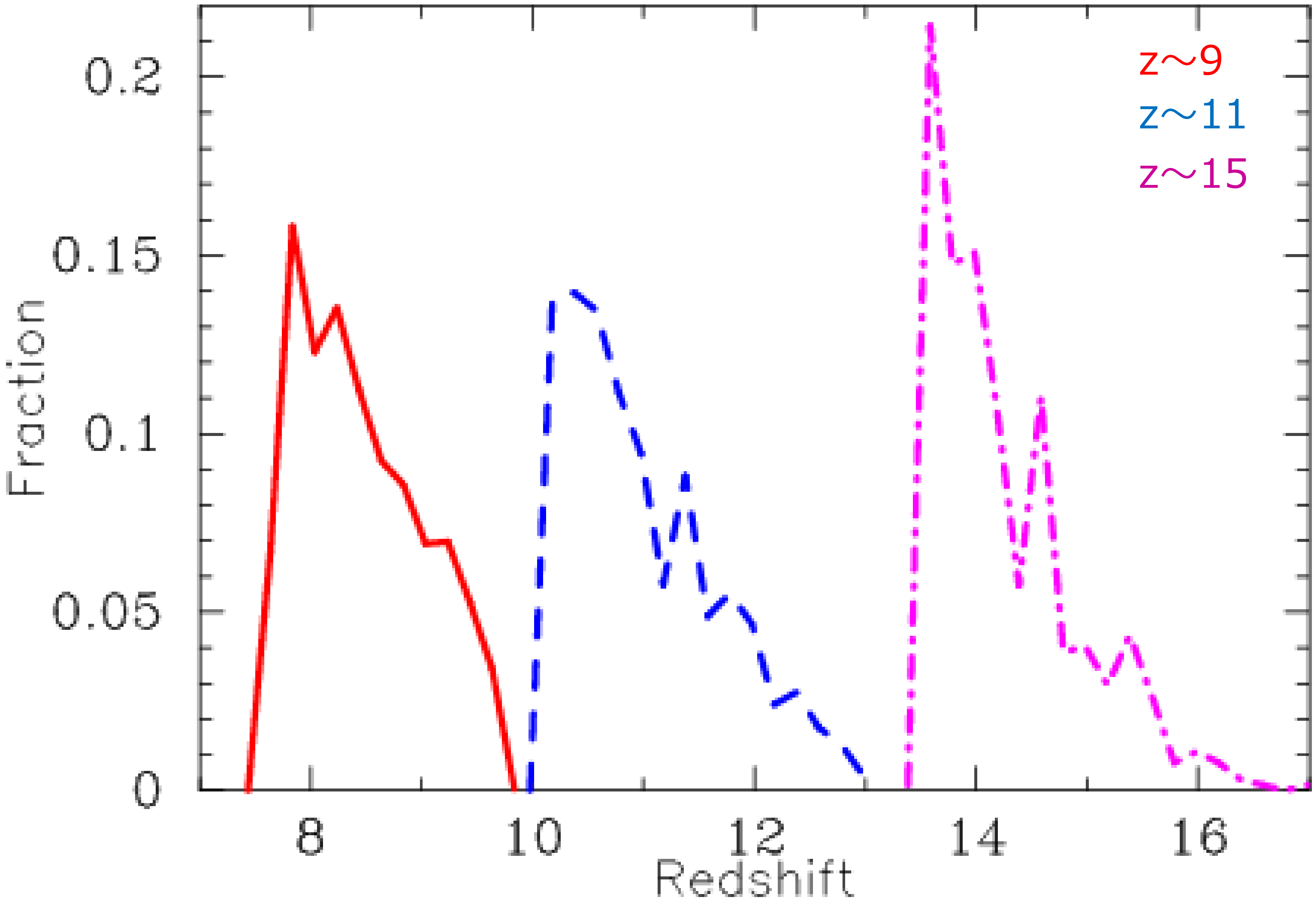
Detection limit < 30 mag (for wish)



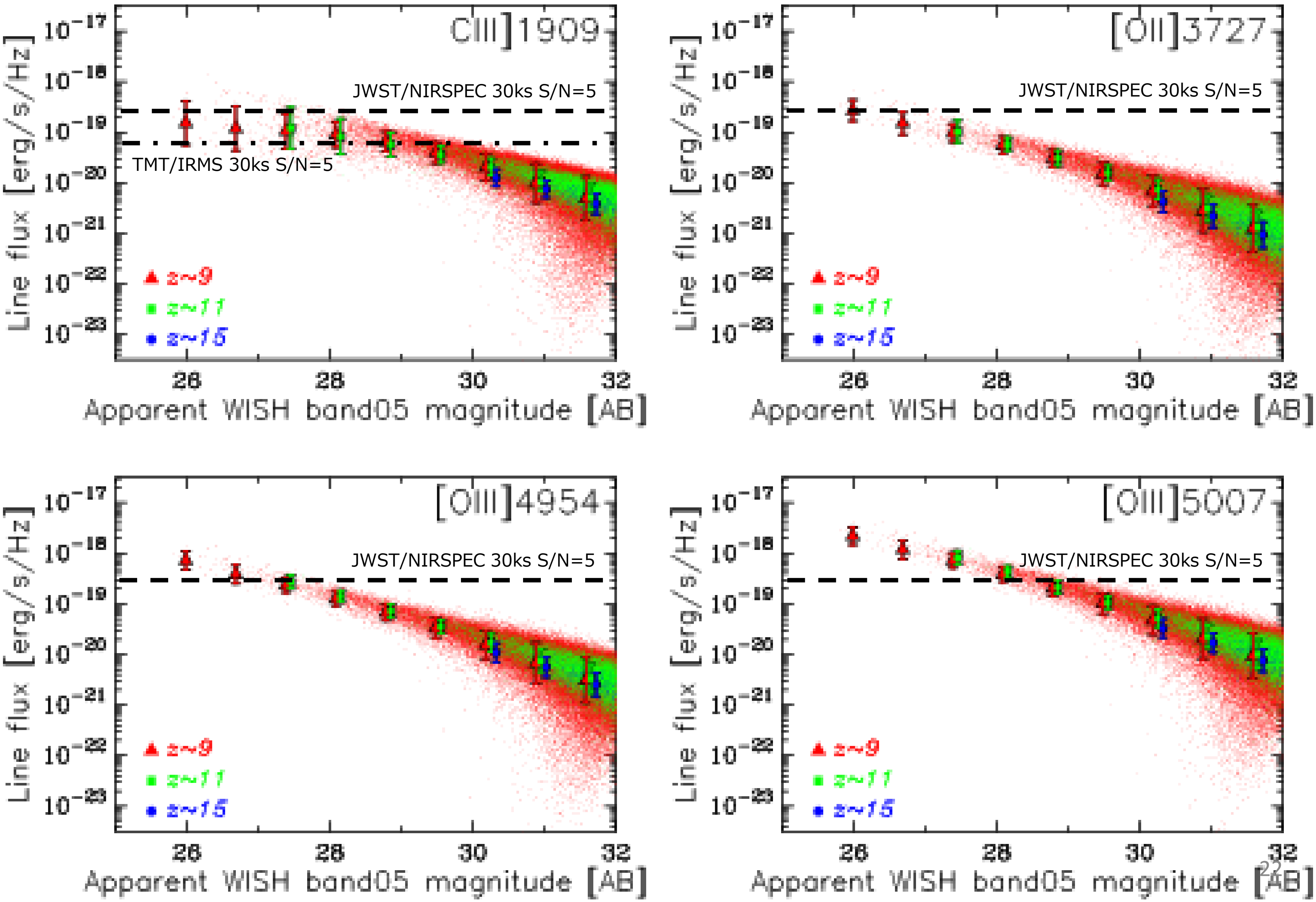
Detection limit < 32 mag (for JWST)



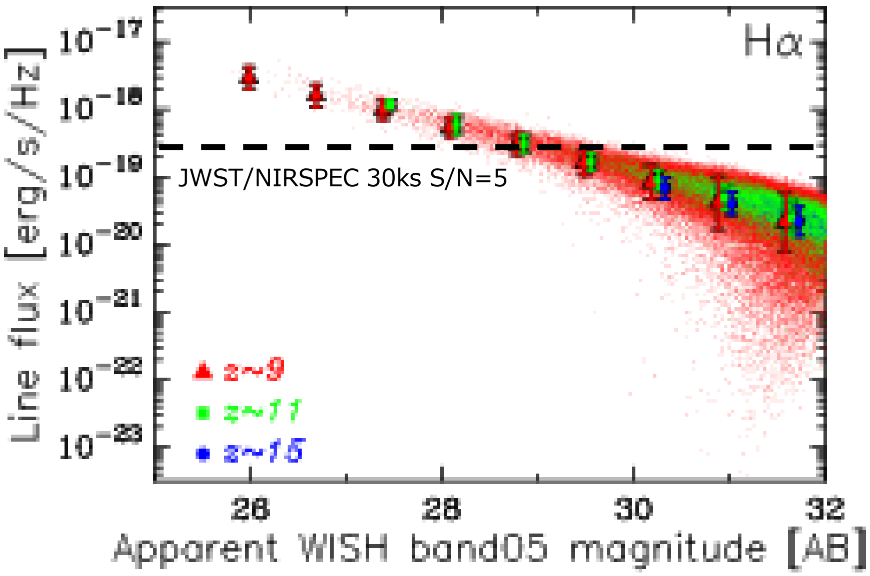
Color Selection Efficiency

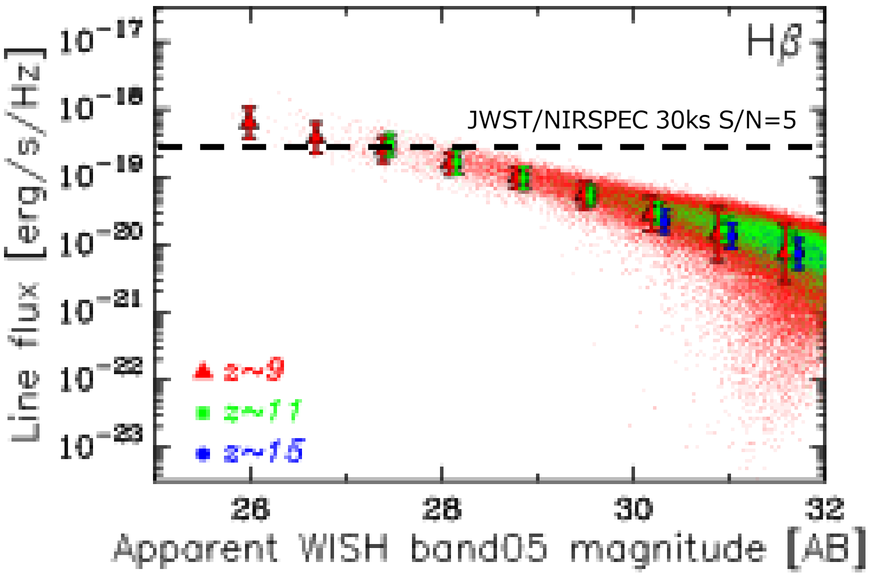


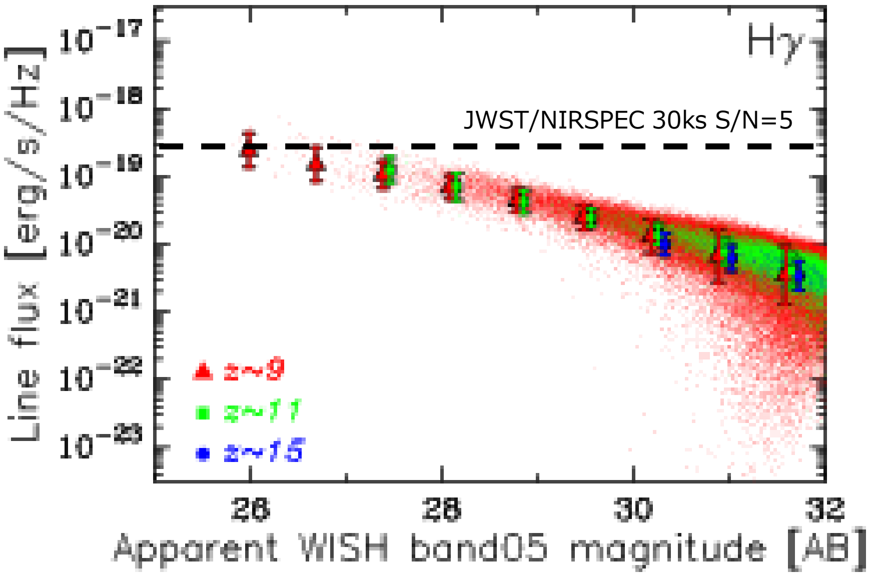
Metal Lines


CIII]1909
JWST/NIRSPEC 30ks S/N=5
TMT/IRMS 30ks S/N=5
[OII]3727
JWST/NIRSPEC 30ks S/N=5
[OIII]4954
JWST/NIRSPEC 30ks S/N=5
[OIII]5007
JWST/NIRSPEC 30ks S/N=5
▲ z~9
■ z~11
● z~15
Line flux [erg/s/Hz]
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
26
28
30
32
Apparent WISH band05 magnitude [AB]

Hydrogen recombination lines


JWST/NIRSPEC 30ks S/N=5


JWST/NIRSPEC 30ks S/N=5


JWST/NIRSPEC 30ks S/N=5

Summary

- [OIII] 88 micron は ALMA の良いターゲット
  - ✓WISH 等で観測ターゲットは今後増えていくはず
  - ✓H < 28 で z～10 でも余裕で ALMA で観測可能
- CIII]1909 は TMT/ELT の良いターゲット
  - ✓銀河内構造を分解してしまうと、観測できない可能性も
- Optical [OIII], Hα, Hβ は JWST の良いターゲット
  - ✓ISM physics や chemical condition
  - ✓[OIII]5007 line は WB05 < 29 であれば観測可能
- WISH で今後 10 < z < 13 の銀河が多く発見されるはず
  - ✓JWST や TMT/ELT などでフォローアップが必要不可欠
  - ✓CIII], Hα, Hβ, [OIII]5007 が良い輝線ターゲットか？