

将来計画 JWST, TMT, WISHに向けた 様々な輝線検出の可能性

今日の話は $z \sim 7$ 以上の HII region 起源の輝線のみ

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Detectability of Line emission at Very High-z

● Ly α 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]158 μ m line

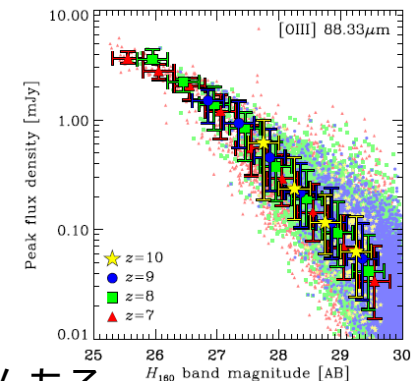
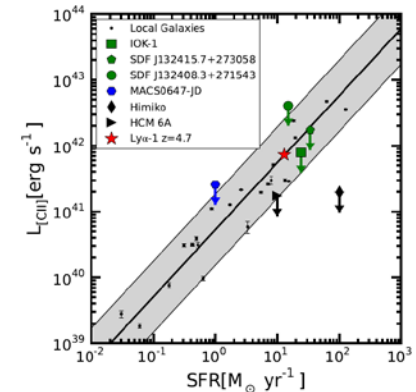
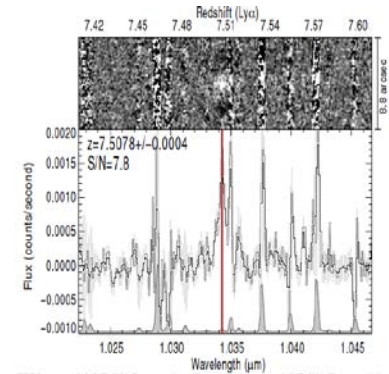
- ✓ ALMA の良いターゲット
- ✓ 多くの high-z LAEs で [CII] 輝線が受かっていない
- ✓ High-z に行くほど LAE like な天体が増えてくる
- ✓ 主に PDR 起源の輝線のため放射機構が複雑

● [OIII]88 μ m line

- ✓ Metal ($Z > 0.01Z_{\text{sun}}$) 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
- ✓ [CII]1909 は実際観測されている (Stark et al. 2014)
- ✓ [OII]3727, [OIII]4959, 5007 等明るい輝線がたくさんある



Cosmological Hydrodynamic Simulation

- Cosmology (Planck 1st year)

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

- Simulation code :Gadeg3

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)

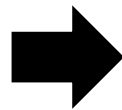
- Simulation setup

Boxsize : 50Mpc/h

Number of particles : 2×1280^3

M_{dm} : $4.4 \times 10^6 M_{\text{sun}}$

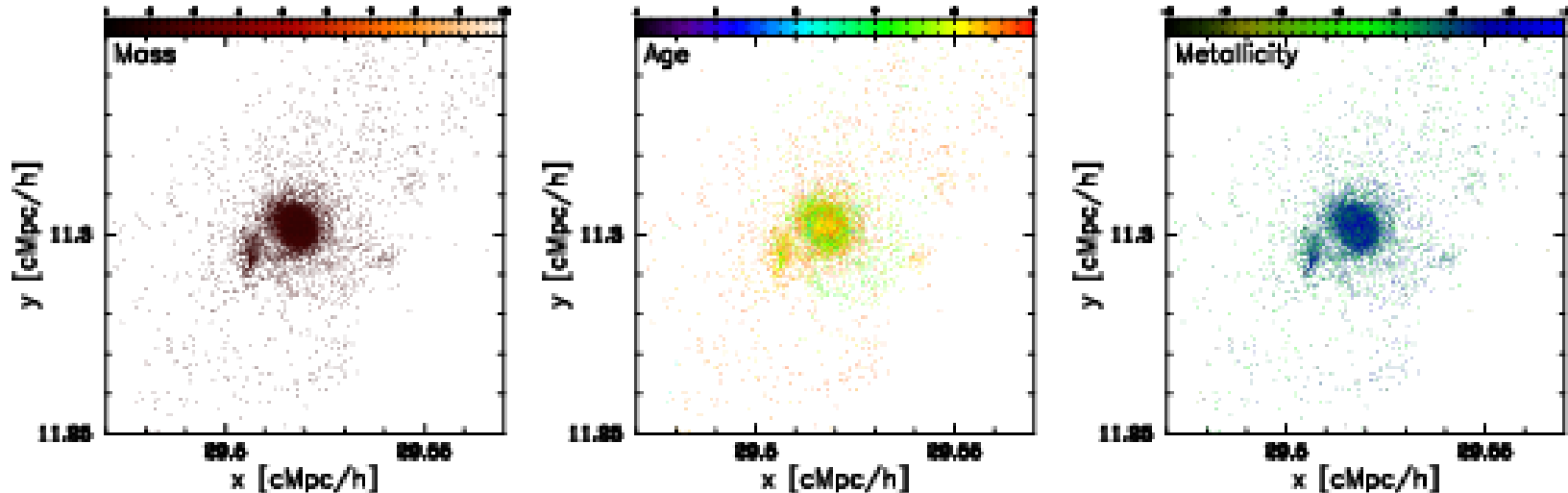
M_{gas} : $8.1 \times 10^5 M_{\text{sun}}$



Minimum halo mass: $\sim 10^8 M_{\text{sun}}$

Minimum stellar mass: $\sim 10^6 M_{\text{sun}}$

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)

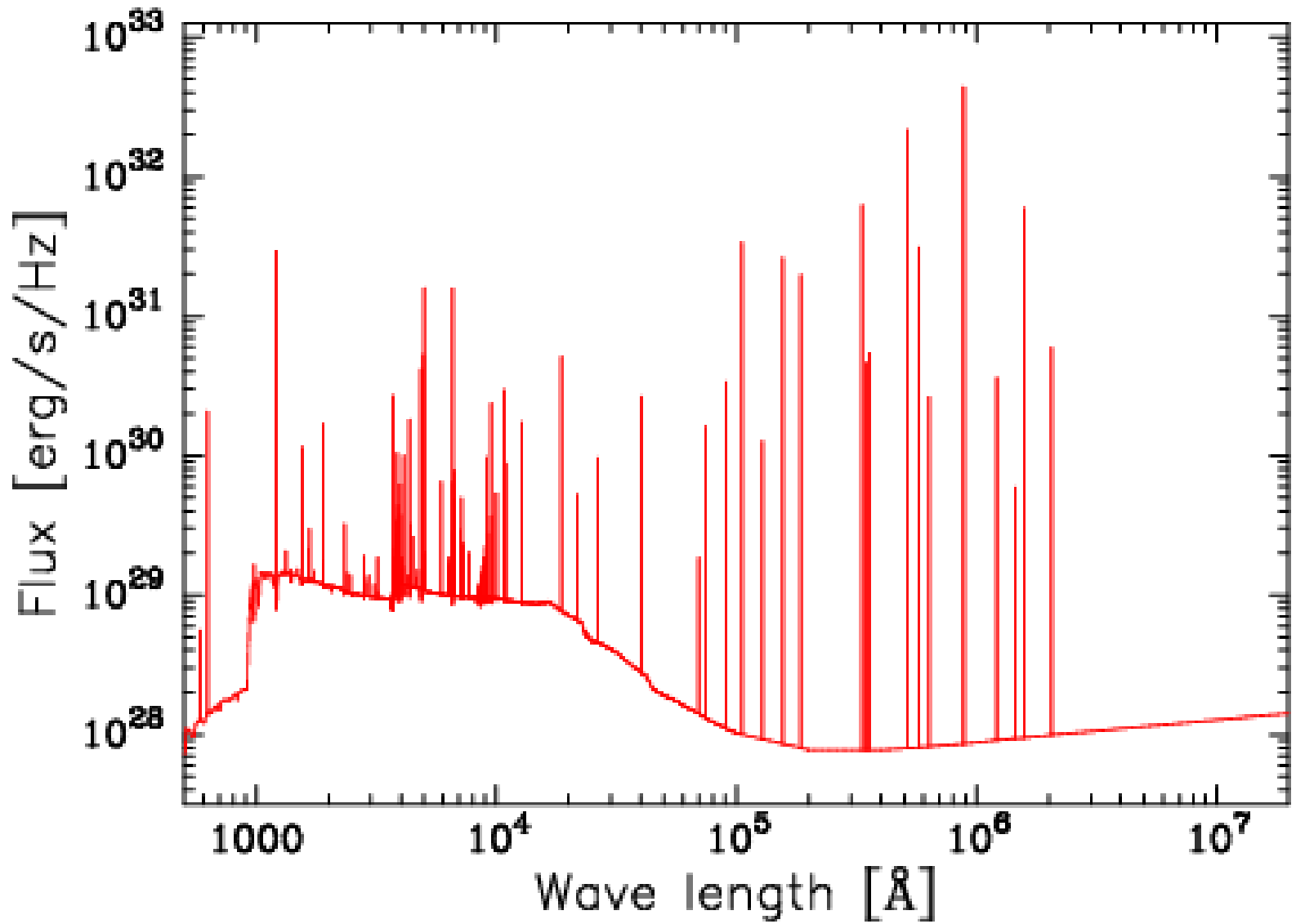
- IMF (Chabrier IMF)
- Current Mass (SN で mass loss するため)
- Age
- Metallicity

Calculation of intrinsic SED of galaxy

- PEGASE2 であらかじめ作っておいた、SED data を各 star cluster にアサイン
- 各 star cluster の SED を足し合わせる
- Nebular continuum も PEGASE2 で計算
- 水素の輝線は case B でその他の輝線は Inoue 2011 を使う ($L_{\text{line}} = aL_{\text{H}\beta}$)
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 (= 1500Å)

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

$$\tau_d = \frac{3\Sigma_d}{4as} \leftarrow \Sigma_d = e_{\tau} \frac{M_{\text{metal}}}{\pi r_{\text{half}}^2} \rightarrow \text{simulation から求める}$$

a:dust grain size (0.05 μm), s:dust grain density (2.5 g/cm³)

UV luminosity function を再現するように、パラメータ 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., $E(B - V)_* = 0.44E(B - V)_{\text{gas}}$

Calculation of IGM absorption ($\lambda < 1216\text{Å}$)

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

Calculation of Galaxy SED

Calculation of dust emission (e.g., Hirashita & Ferrara. 2002)

- ✓ 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

$$T_d = \alpha \left(\frac{L_d}{M_d} \right)^{\frac{1}{1+\beta}}$$

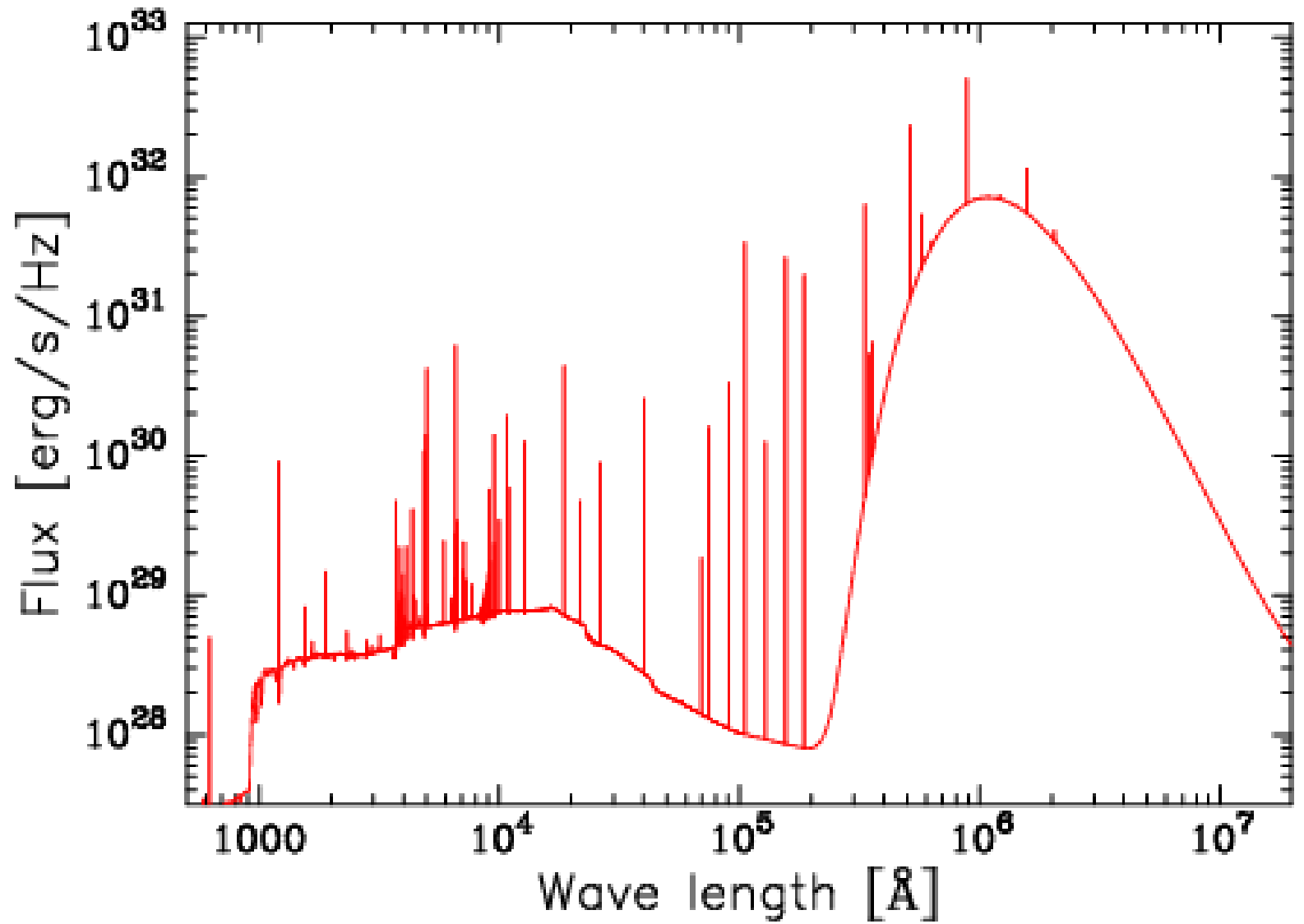
$$\left\{ \begin{array}{l} L_\nu = 4\pi M_d \kappa_\nu B_\nu(T_d) \\ \kappa_\nu = \kappa_0 \left(\frac{\nu}{\nu_0} \right)^\beta \\ L_d = \int [L_\nu^{\text{int}} - L_\nu^{\text{ad}}] d\nu = \int L_\nu d\nu \end{array} \right.$$

- Dust emission

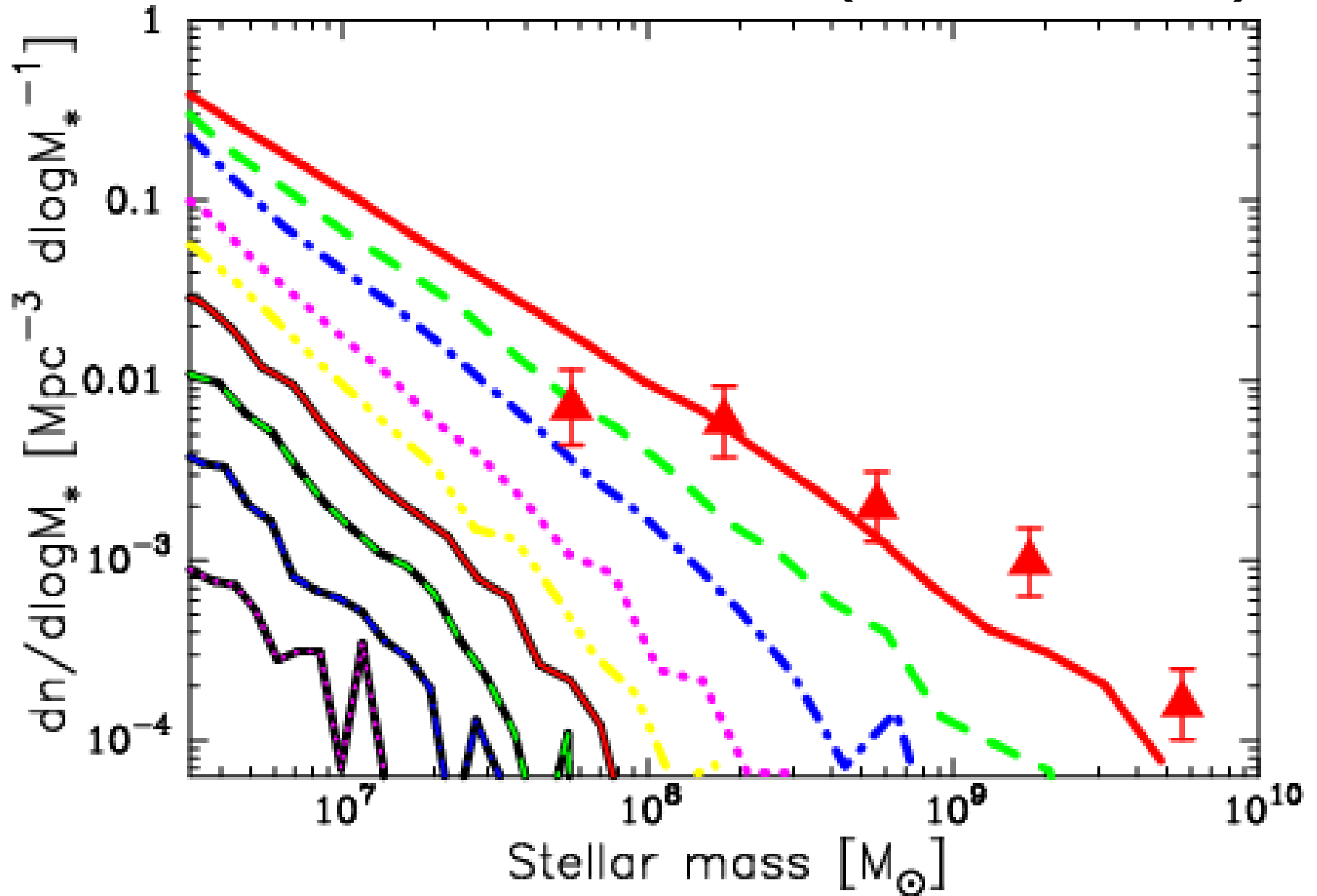
$$f_\nu = \frac{(1+z)L_\nu(1+z)}{4\pi d_L^2}$$

Example of High-z Galaxy SED

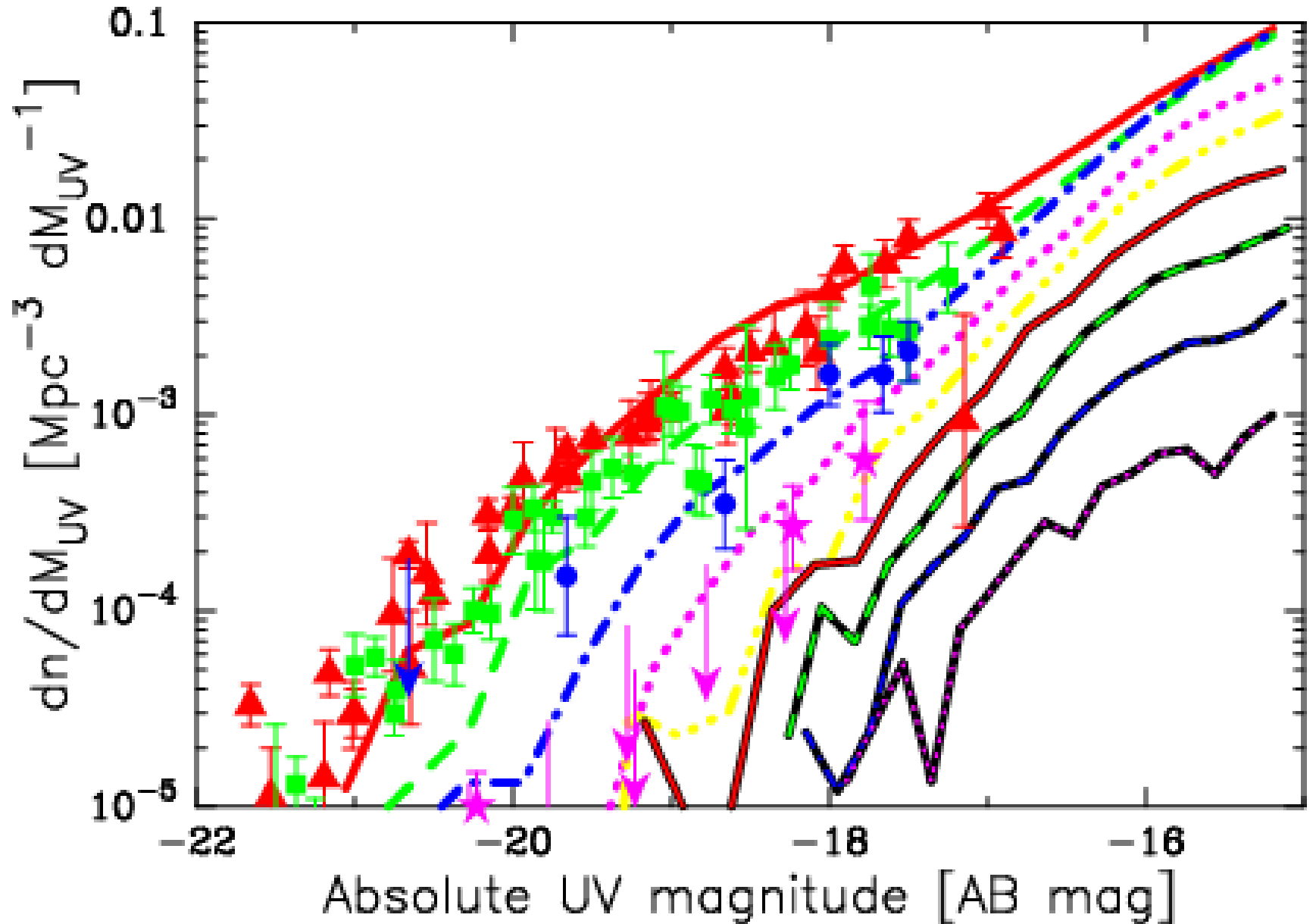
Stellar continuum + nebular continuum & line + dust emission



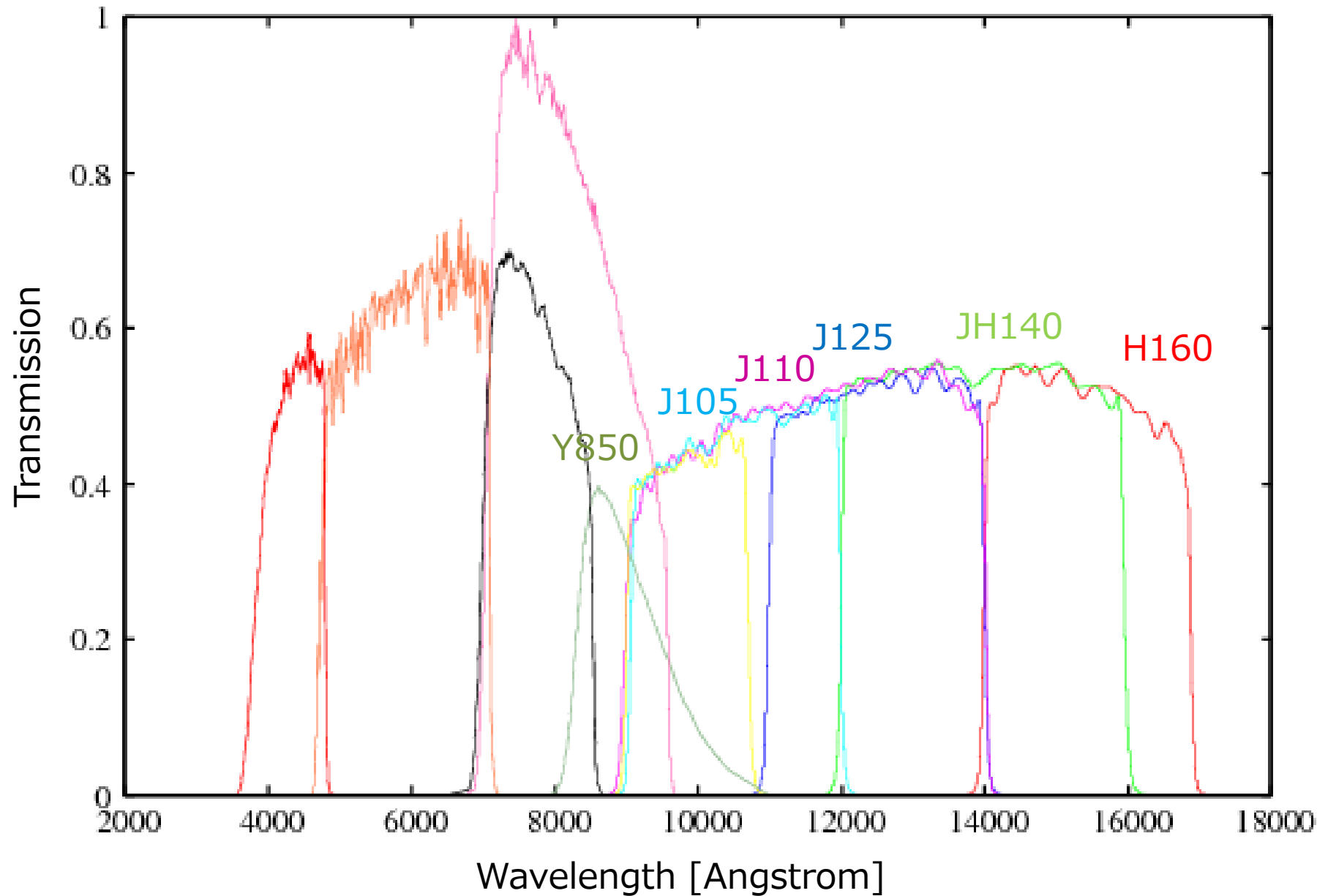
Stellar Mass Functions ($7 < z < 15$)



UV Luminosity Functions ($7 < z < 15$)



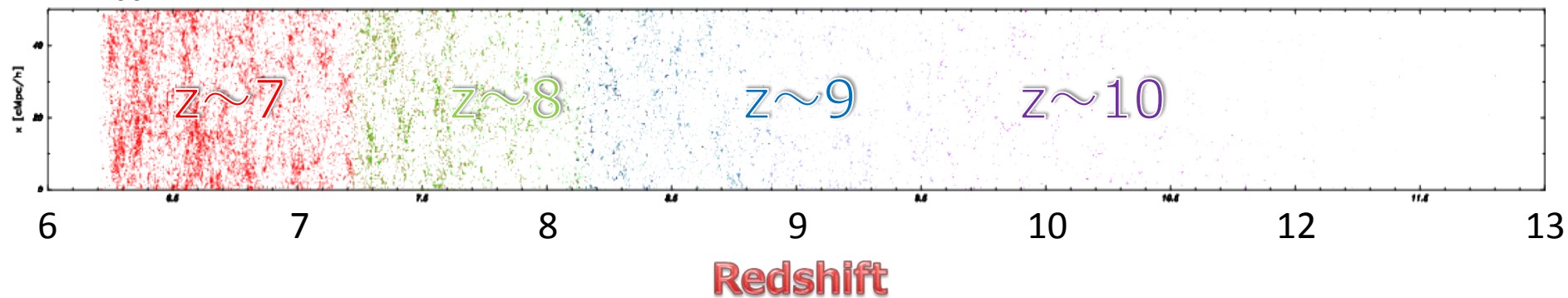
Hubble Broad Band Filters



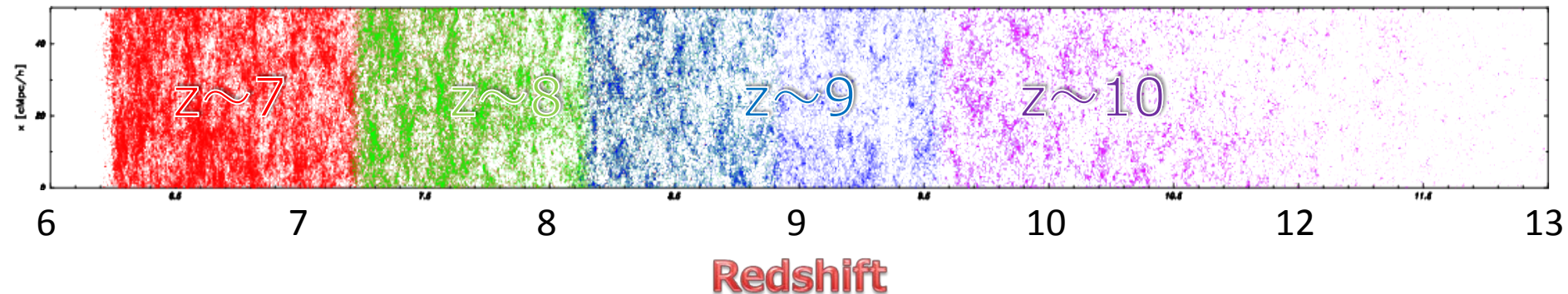
Color Selected Galaxies in Light-Cone

- 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)

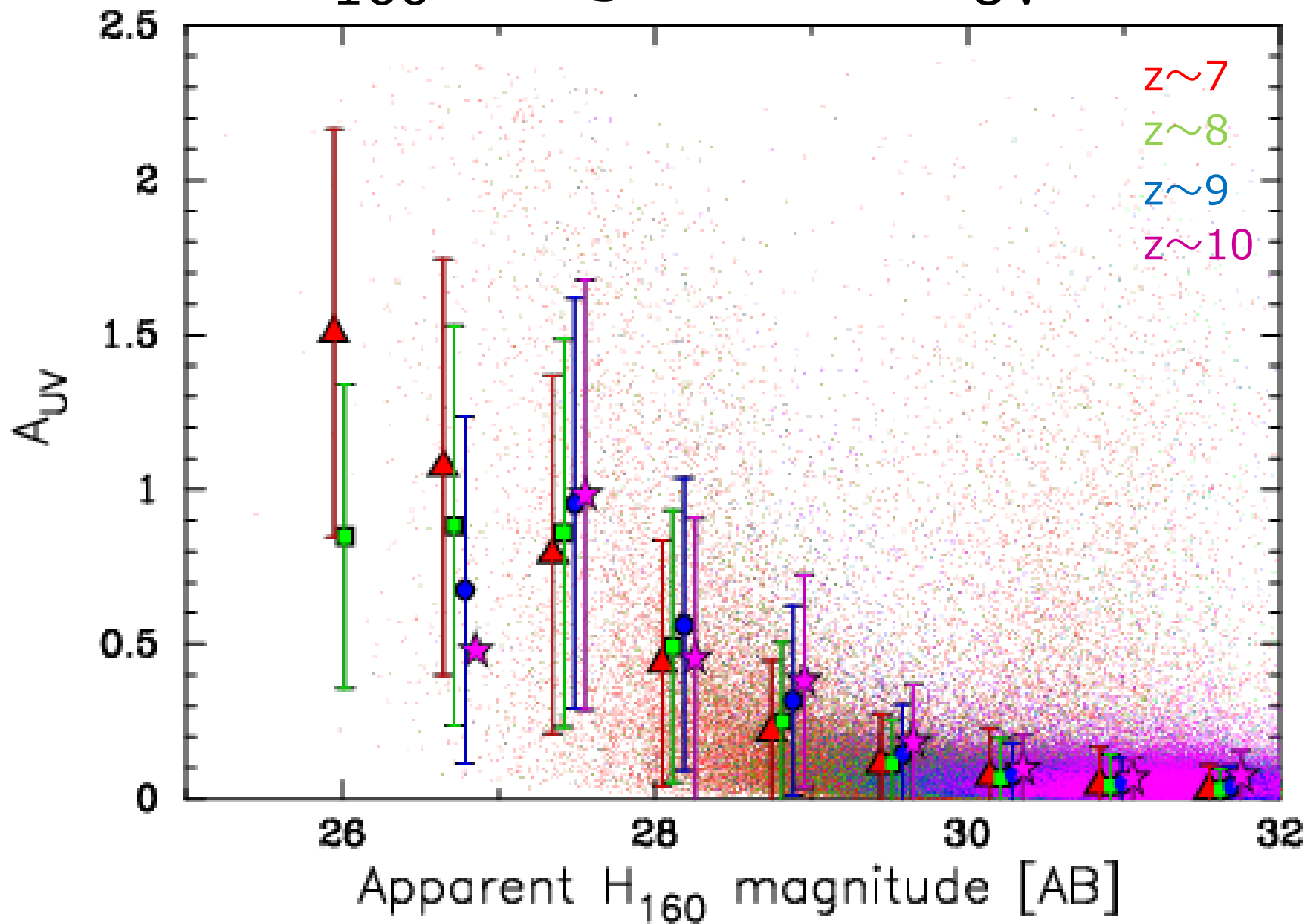


FOV $\sim 0.1 \text{ deg}^2$

HST + JWST & TMT

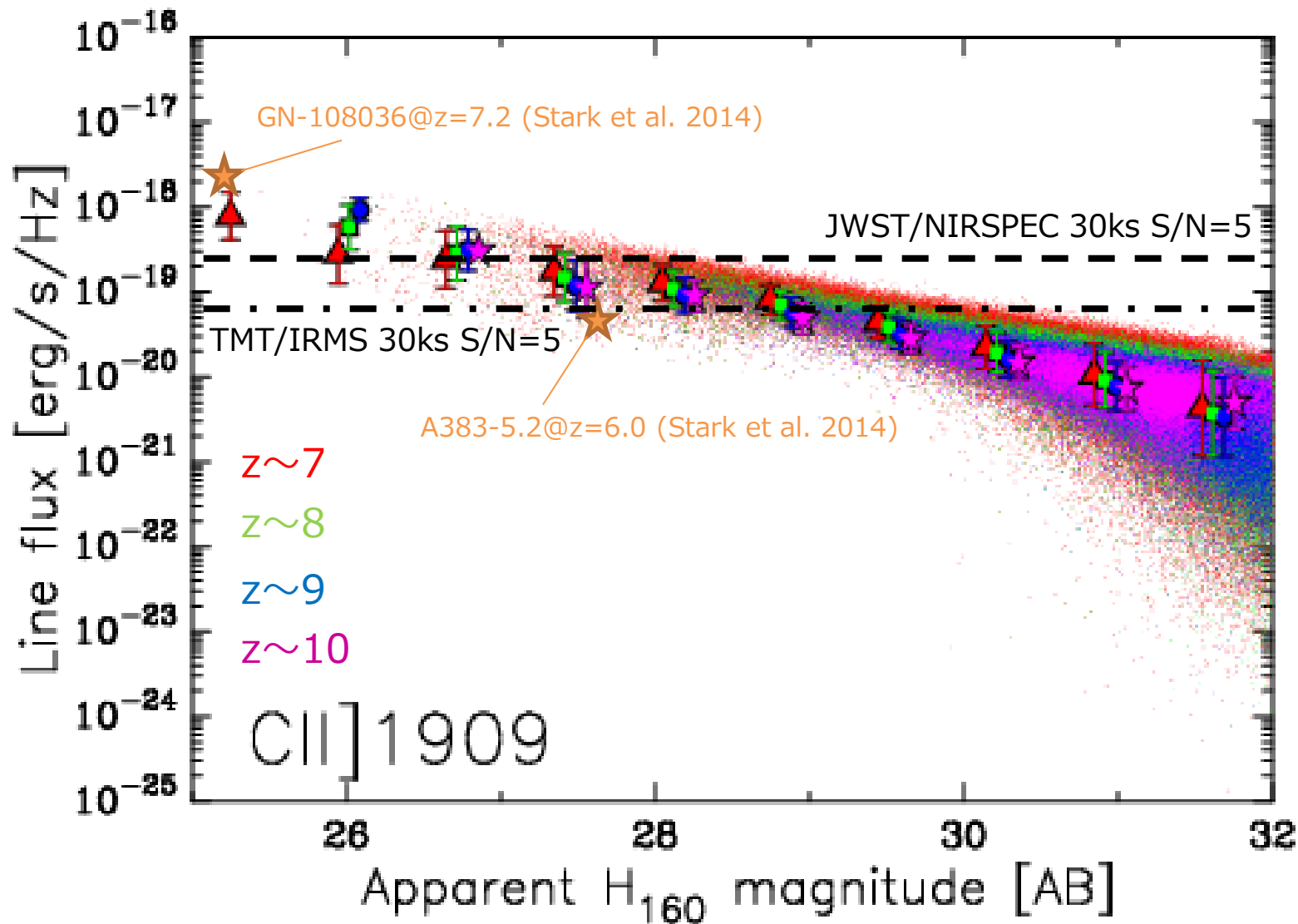
JWST/NIRSPEC	0.6 ~ 5 μm
TMT/IRMS	0.8 ~ 2.5 μm

H_{160} magnitude- A_{UV}



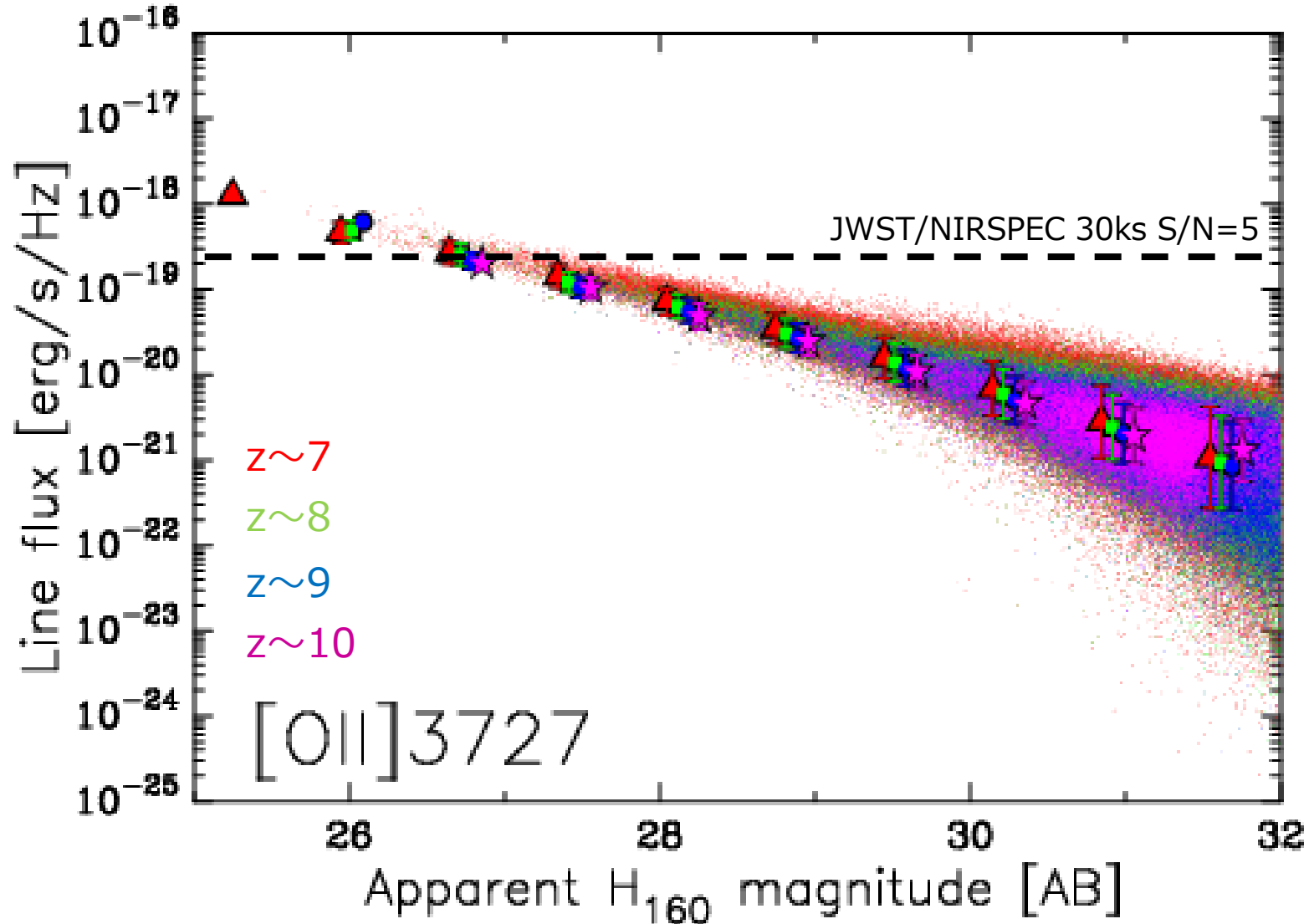
CII]1909

CII]1909 \rightarrow \sim 2 micron for $z \sim 9$



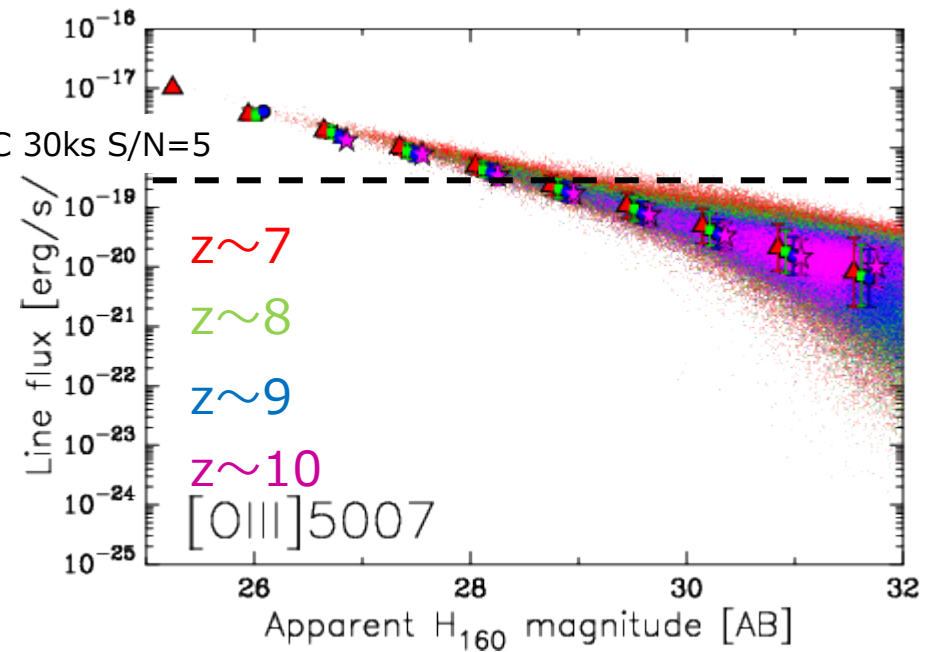
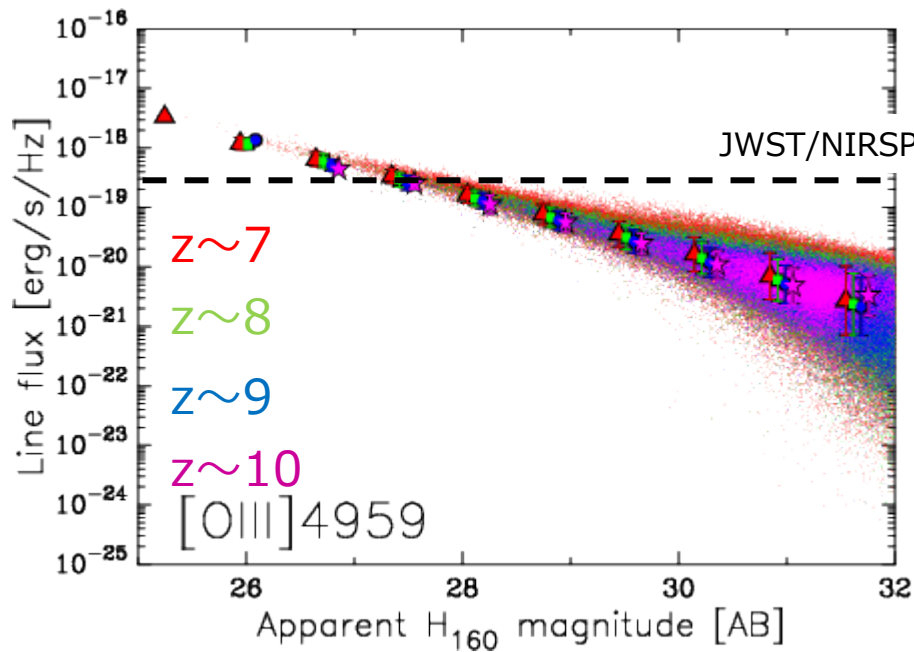
[OII]3727

[OII]3727 \rightarrow \sim 4 micron for $z \sim 9$



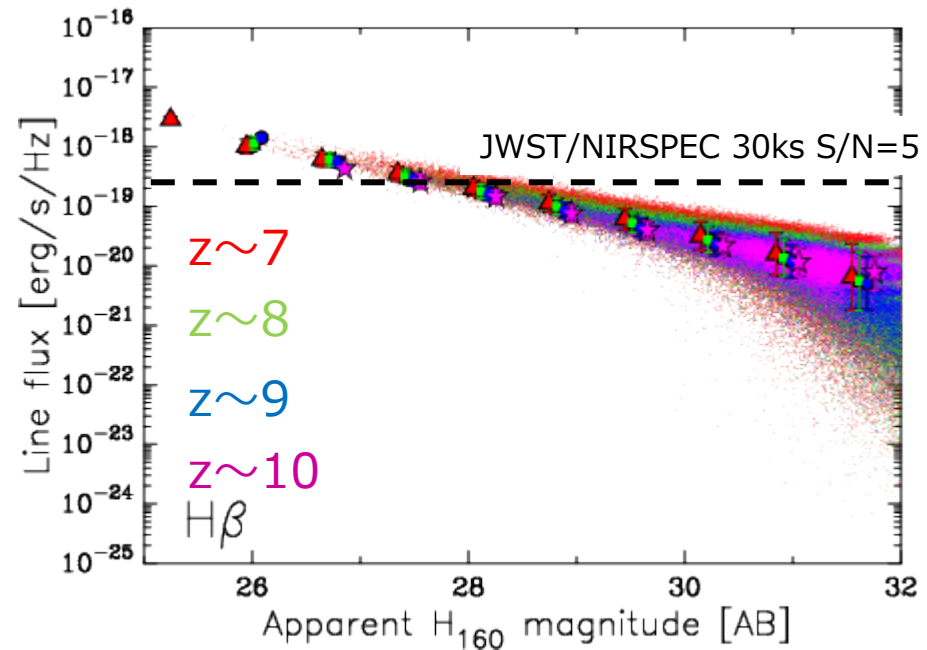
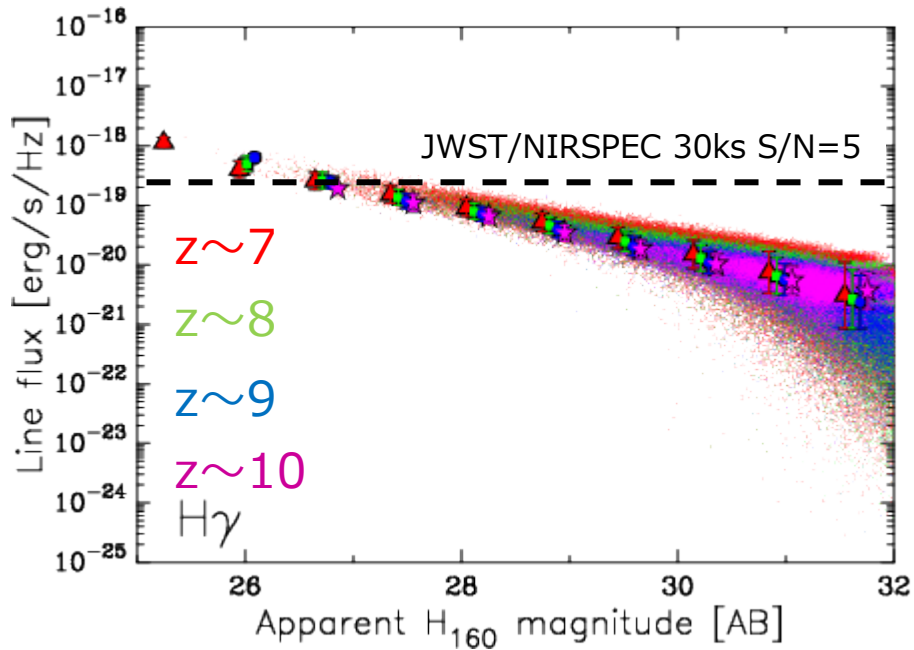
[OIII]4959 & [OIII]5007

[OIII]4959, [OIII]5007 \rightarrow \sim 5 micron for $z \sim 9$



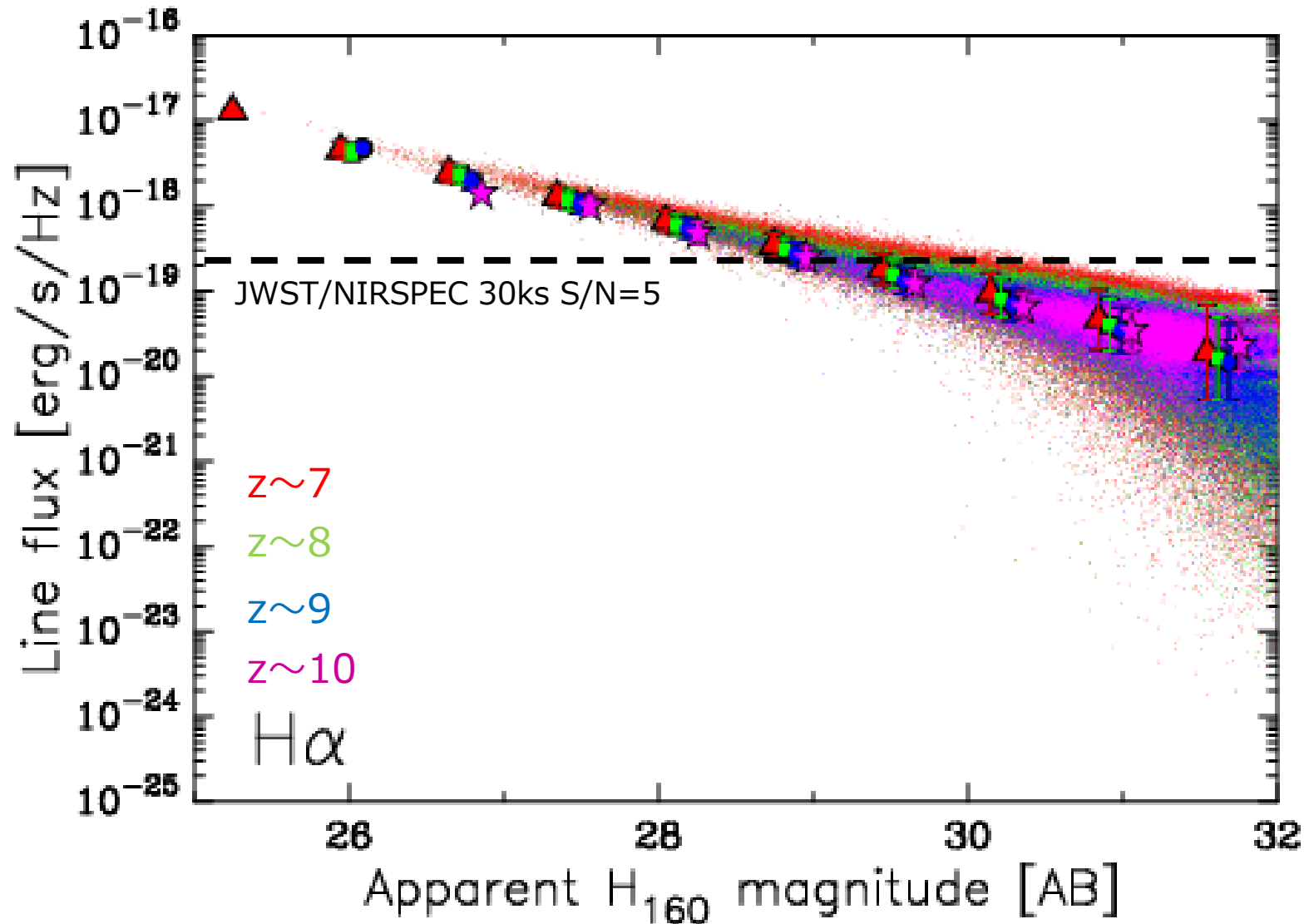
H γ & H β

H γ , H β \rightarrow \sim 4 - 5 micron for $z \sim 9$



H α

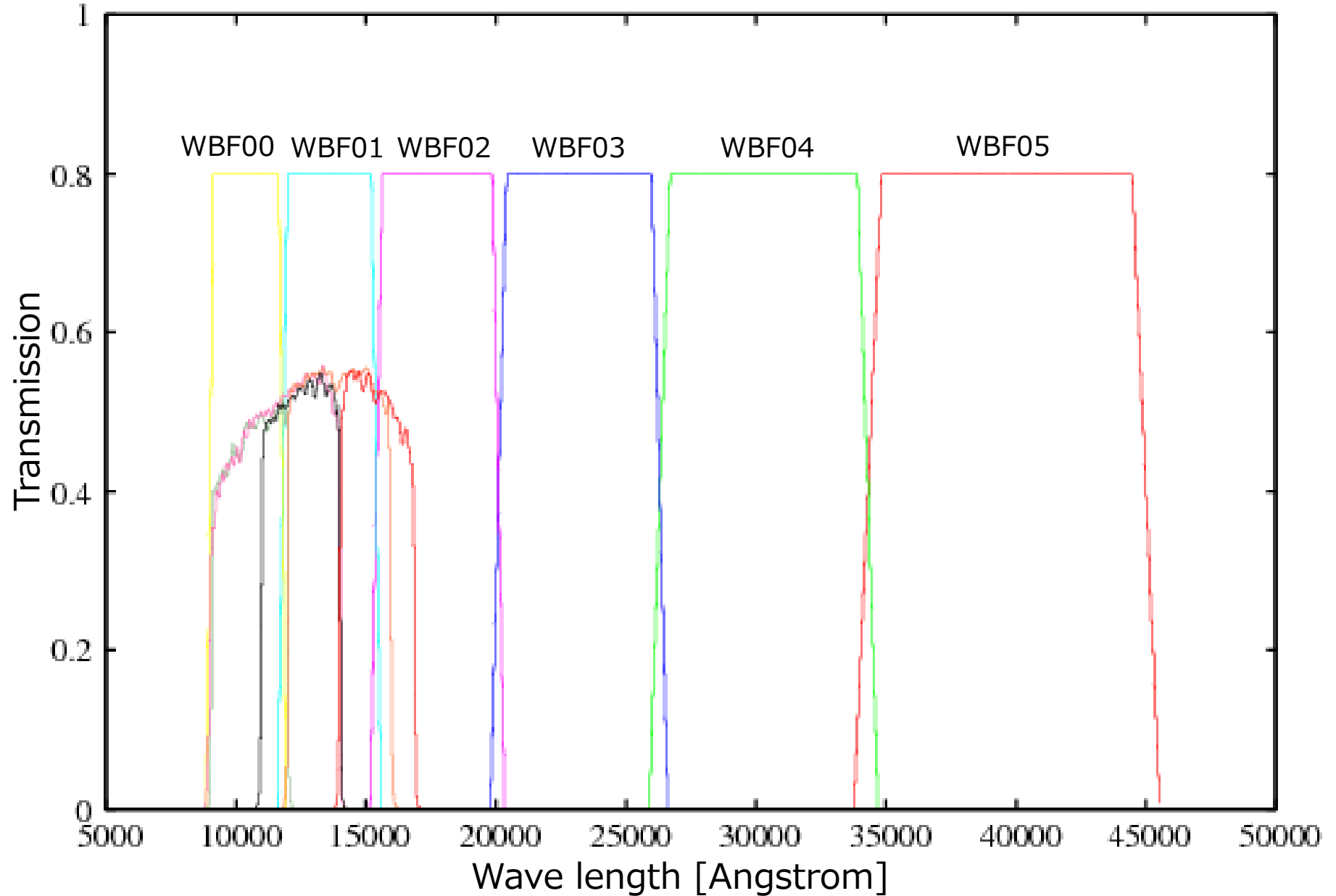
H α \rightarrow \sim 7 micron for $z \sim 9$



WISH + JWST & TMT

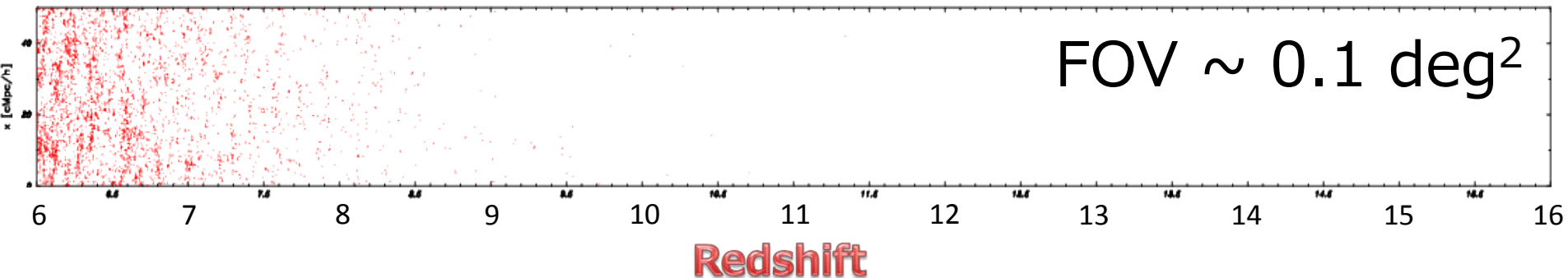
JWST/NIRSPEC	0.6 ~ 5 μm
TMT/IRMS	0.8 ~ 2.5 μm

WISH Broad Band Filters

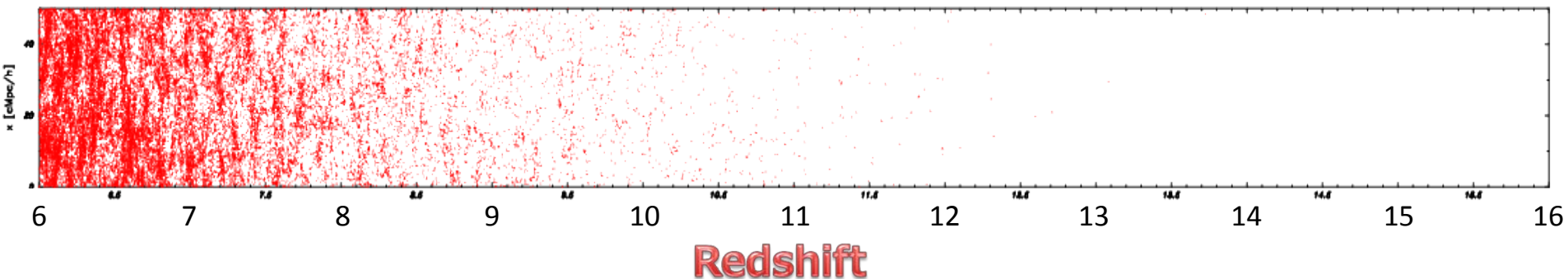


Simulated Galaxies in Light-Cone

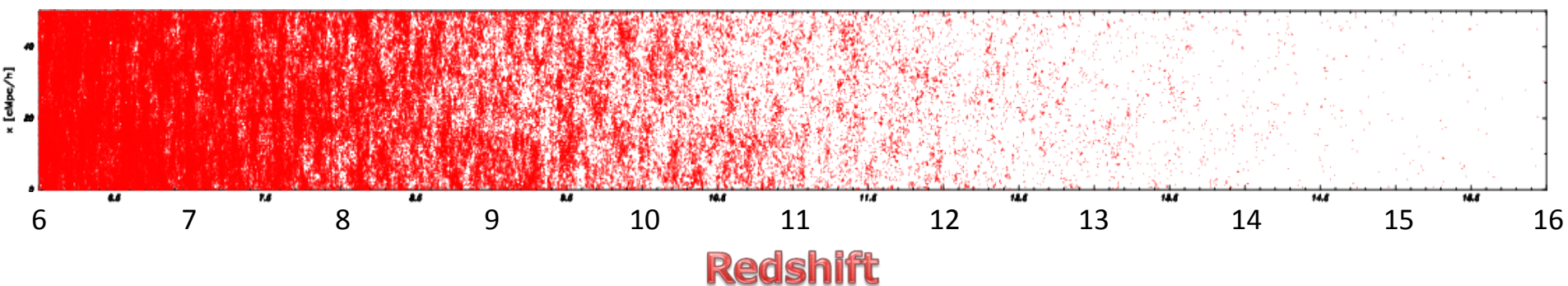
WBF05 < 28



WBF05 < 30

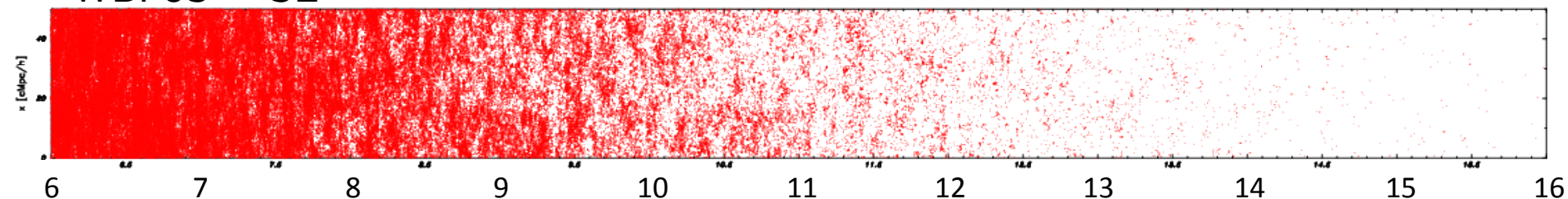


WBF05 < 32



Spatial Distribution of Simulated Galaxies

WBF05 < 32

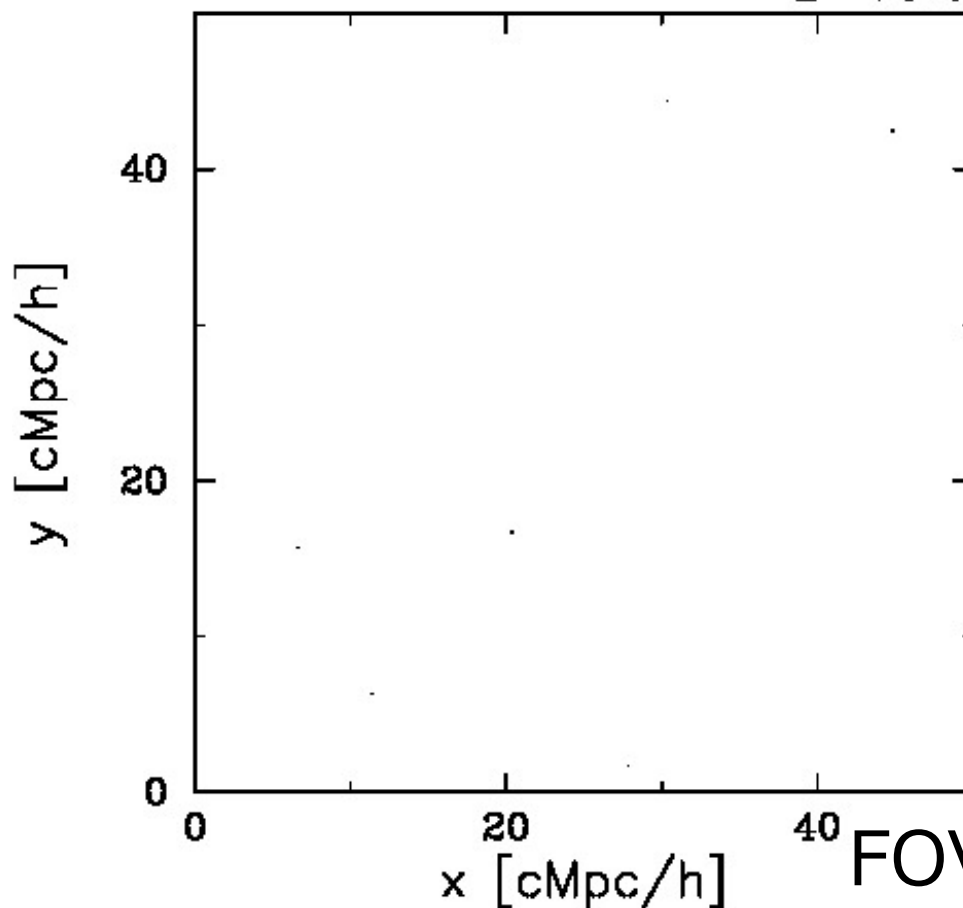


Point size = band magnitude

Redshift

$z=15.9$

$dz = 0.2$

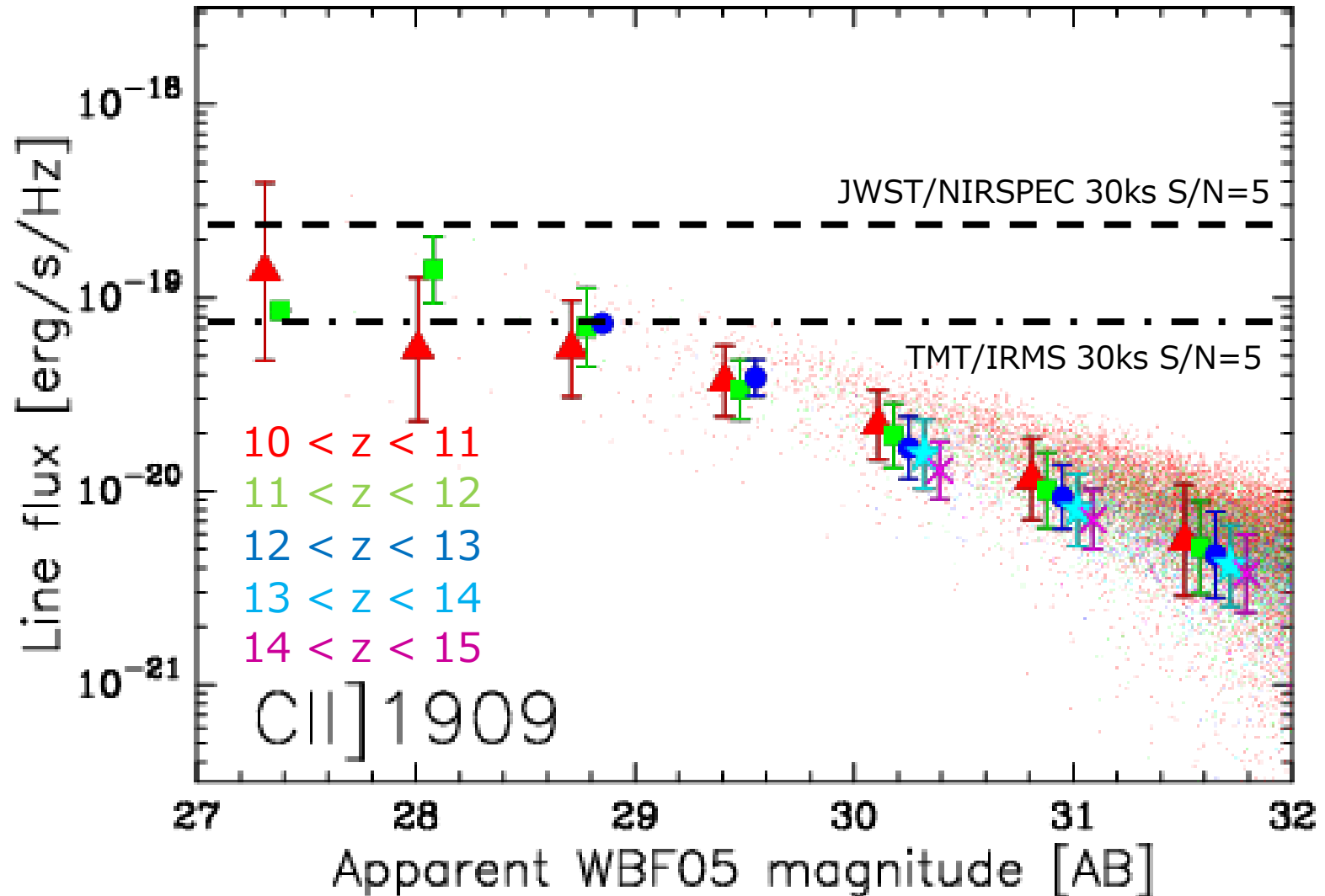


FOV $\sim 0.1 \text{ deg}^2$

[CII]1909

CII]1909 \rightarrow 2 \sim 3 micron

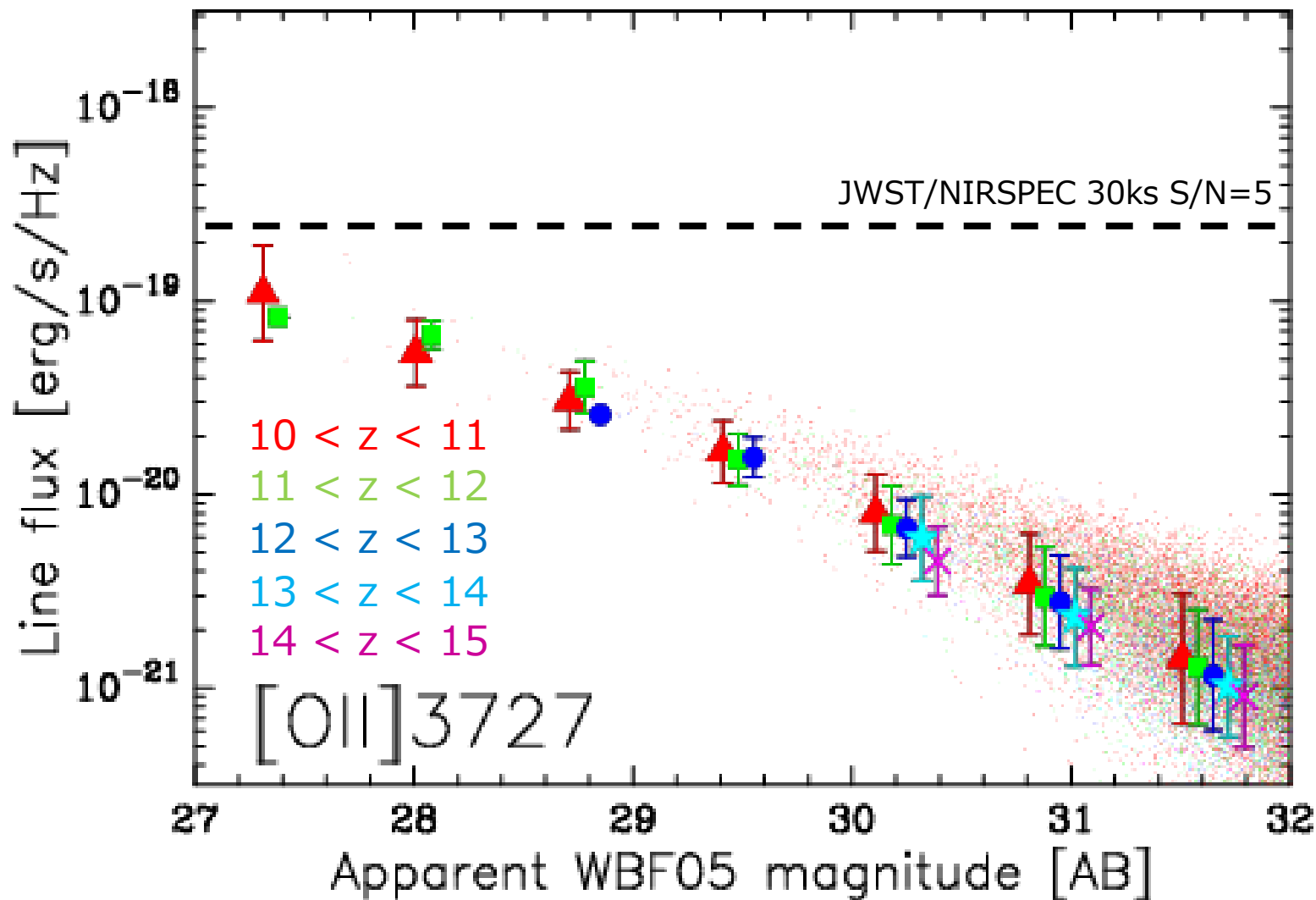
WBF05 < 32



[OII]3727

[OII]3727 \rightarrow 4 \sim 6 micron

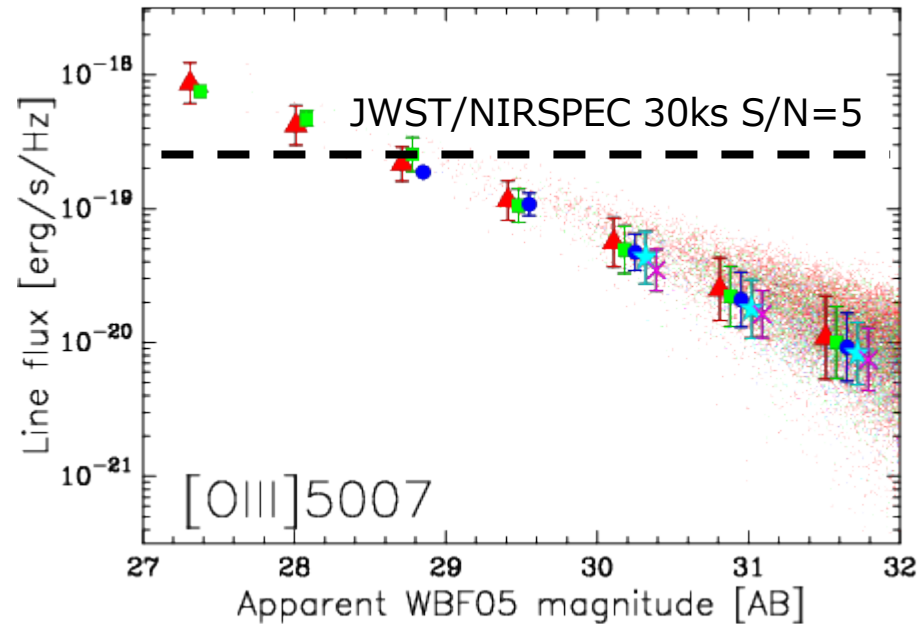
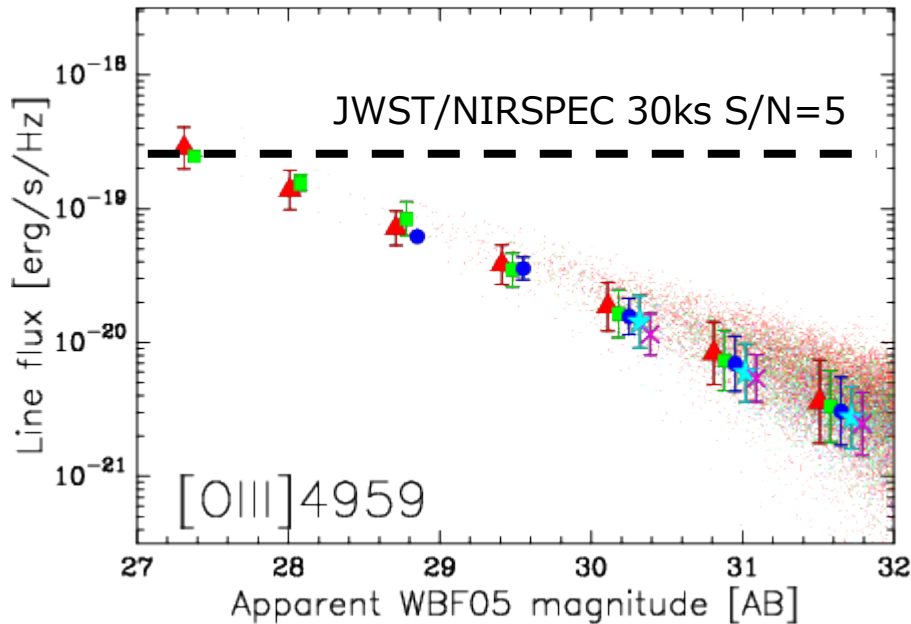
WBF05 < 32



[OIII]4959 & [OIII]5007

[OIII]4959, [OIII]5007 \rightarrow 5 ~ 8 micron

WBF05 < 32

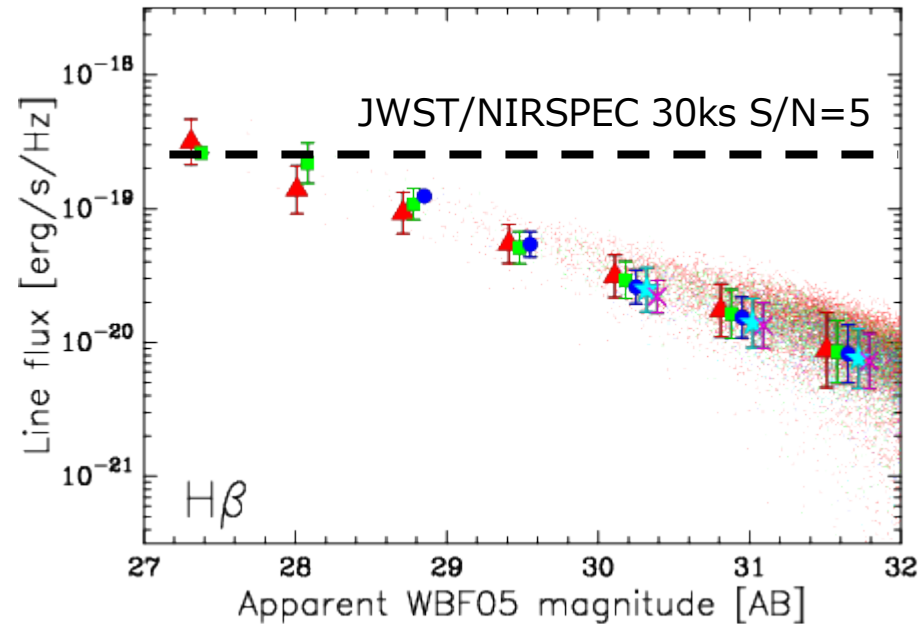
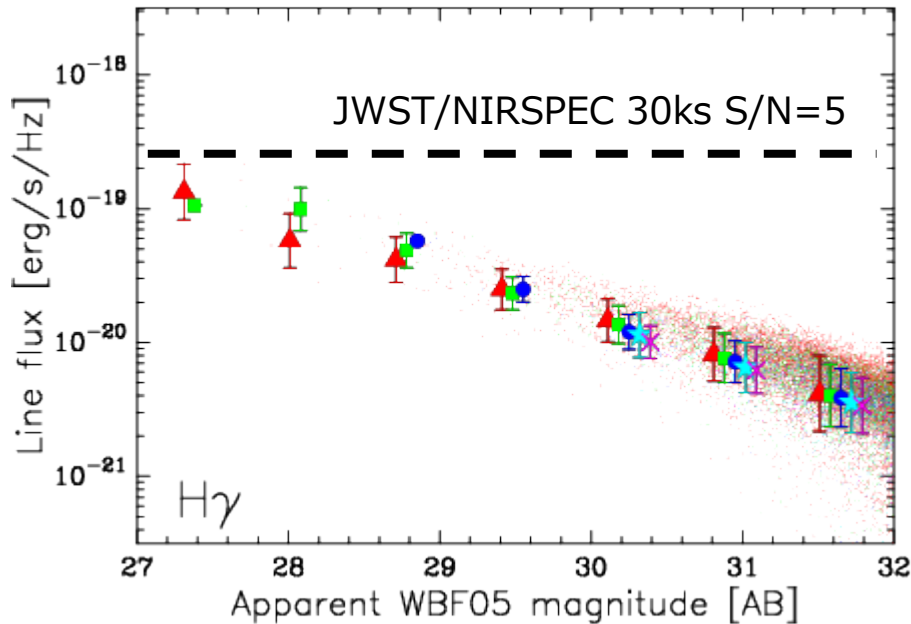


10 < z < 11
11 < z < 12
12 < z < 13
13 < z < 14
14 < z < 15

H γ & H β

H γ , H β \rightarrow $\sim 5 \sim 8$ micron

WBF05 < 32



10 < z < 11

11 < z < 12

12 < z < 13

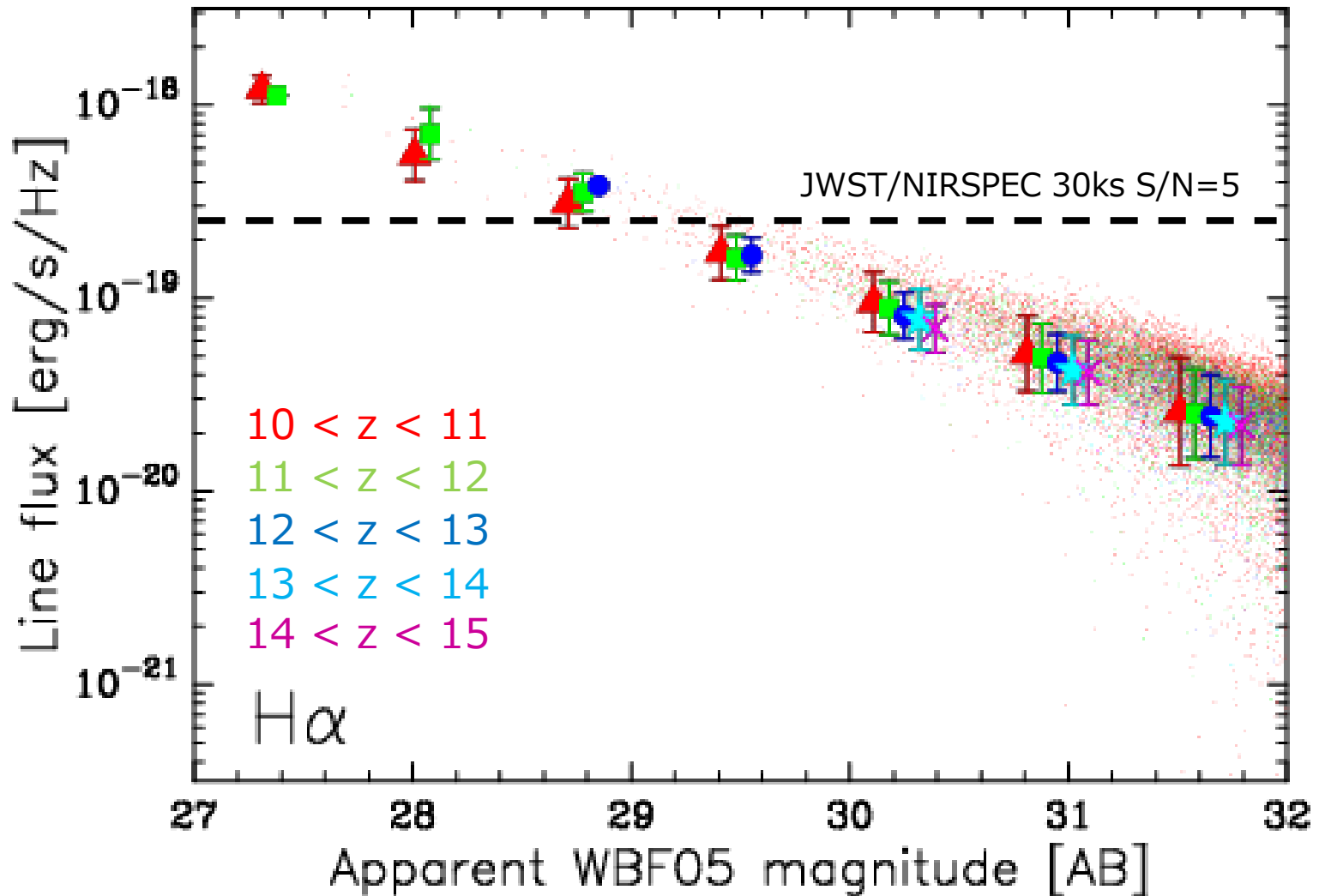
13 < z < 14

14 < z < 15

H α

H α \rightarrow 7 \sim 10 micron

WBF05 < 32



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 $z \sim 10$ でも余裕で ALMA で観測可能
- [CII]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], H α , H β は JWST の良いターゲット
 - ✓ ISM physics や chemical condition
 - ✓ [OIII]5007 line は $H < 29$ 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
 - ✓ [CII], H α , H β , [OIII]5007 が良い輝線ターゲットか？