Lya EW distribution at z~4.5 and Beyond

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Outline

- Why Lya EW distribution
- Lya EW Measurements
- Simulation on the Completeness of Narrowband Selection at z~4.5
- Band-Ratio Distribution Fitting
- Evolution of Lya EW Distribution

Why we study Lya EW Distribution

EW(Lya) = F(Lya) / f_UV

- Statistically analyze the resonant scattering properties of Lya photons in LAE galaxies
- Connect to the galaxy structure
  - ➡ Dust, Outflow, Clumpy structure ?
- Connect to the galaxy evolution
  - ➡ SFG/AGN ?
- Probe the different epoch of our Universe
  - ➡ IGM, Re-ionization ??

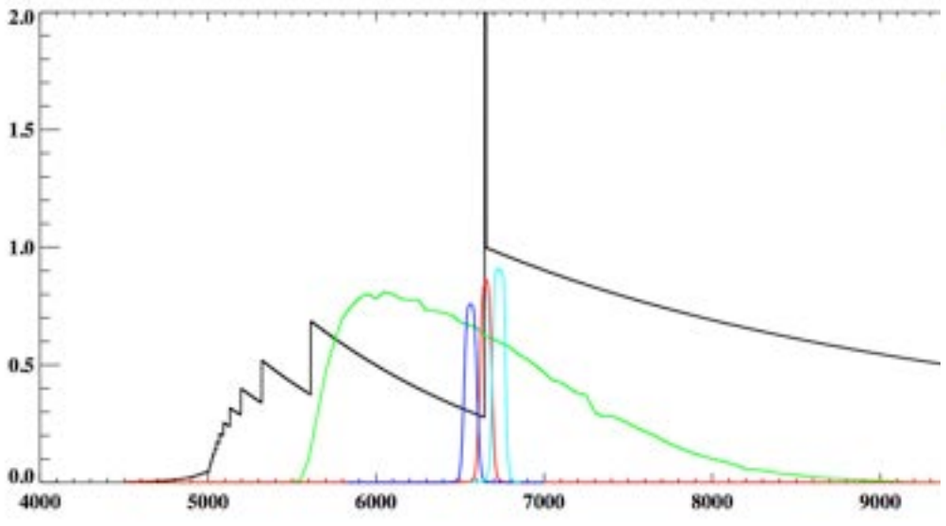
Measurements

- Photometric:

  ✓ Broadband + Narrowband $\Longrightarrow$ Lya-line + UV-Cont.

  $\Longrightarrow$ Lya EW

  ✓ Following Exponential distribution N∝exp(-EW/EW_0)



$$\frac{N}{W_N} = f_\mu(NB) \times \frac{c}{\lambda_R^2} = \int T_{NB,\lambda}\,(f_\lambda(line) + f_\lambda(Cont.))\,d\lambda \quad (1)$$

$$= a_N \times \frac{F_{Ly\alpha}}{W_N} + b_N \times \frac{F_{Ly\alpha}/\varkappa}{EW_{rest} \times (1+z)},$$

$$\frac{R}{W_R} = f_\mu(R) \times \frac{c}{\lambda_R^2} = \int T_{R,\lambda}\,(f_\lambda(line) + f_\lambda(Cont.))\,d\lambda \quad (2)$$

$$= a_R \times \frac{F_{Ly\alpha}}{W_R} + b_R \times \frac{F_{Ly\alpha}/\varkappa}{EW_{rest} \times (1+z)},$$

- EW equation with IGM correction on continuum but not on Lya line:

$$EW_{rest}^{no_IGM_corr} = \varkappa \times EW_{rest}^{IGM_corr}$$

$$= \frac{b_R \times N \times W_R - b_N \times R \times W_N}{a_N \times R - a_R \times N} \times \frac{1}{1+z},$$

Correction factor from filter shape, here x = NB or BB, Tx is the filter transmission curve.

$$a_x = \frac{\int f_\lambda(line) T_x d\lambda}{max(T_x) \times \int f_\lambda(line) d\lambda},$$

$$b_x = \frac{\int \frac{f_\lambda(Cont.)}{f_{1215.67\text{Å}}(Cont.)} T_x d\lambda}{\int T_x d\lambda},$$

Monte-Carlo Simulation on EW distribution

1) Input: L* (Lya LF) and EW_0 (scale factor, e.g., N=N0 exp(-EW/EW_0)),

2) Monte-Carlo simulation to generate individual [L, EW] which meet the distribution of input,

3) [L, EW] → [NB, BB]_intrinsic → add gaussian errors from observational limits → simulated NB and BB for individual sources,

4) Check Selection Criteria

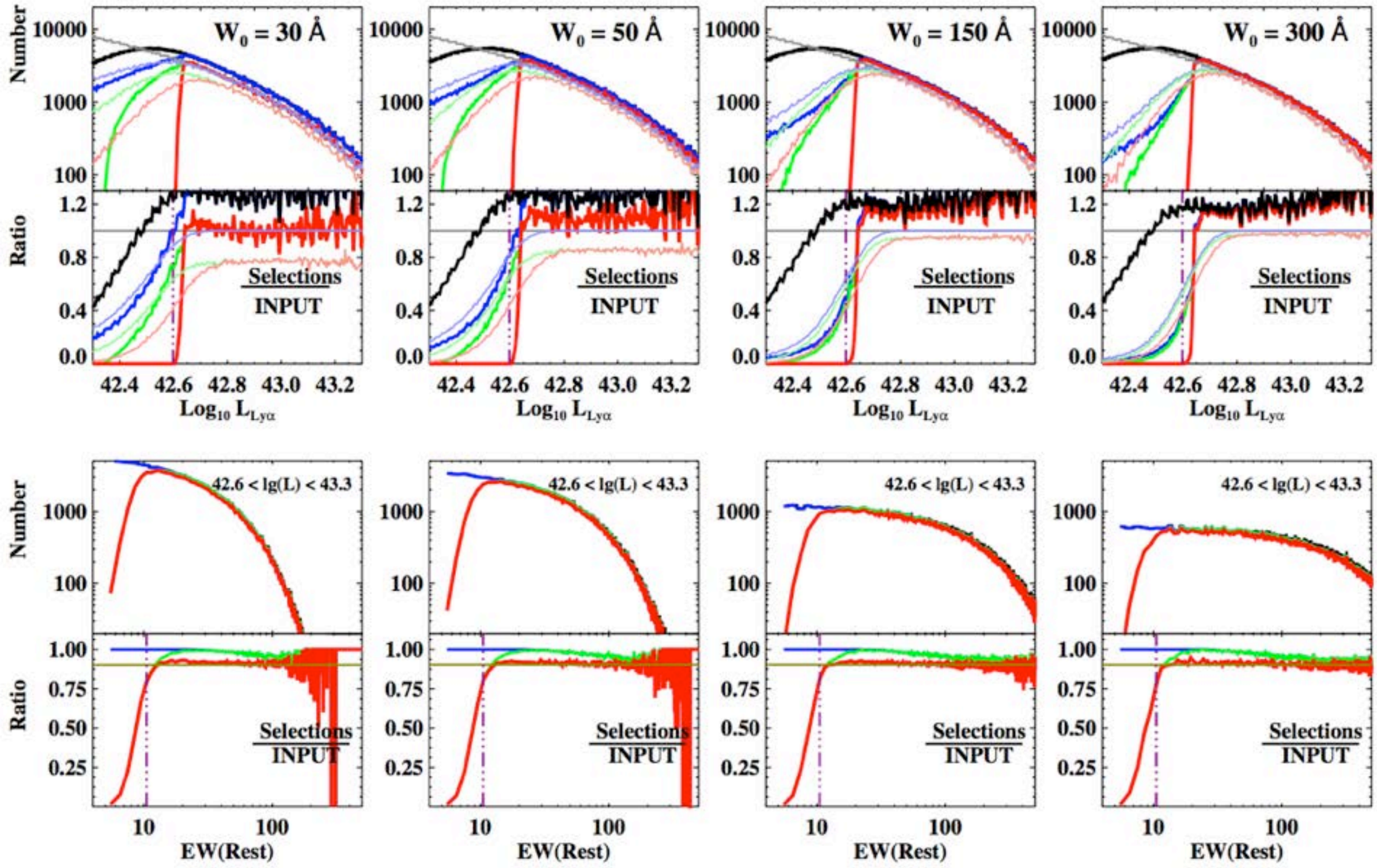
5) Compare with real data to get statistic fitting on EW_0

Simulation with EW Exponential Distribution

Selection Criteria: CR1 : NB ≥ $5\sigma_{NB}$; CR2 : R/NB ≤ 1/2; CR3 : NB − R ≥ $4 \times (\sigma_{NB}^2+\sigma_R^2)^{1/2}$

Selections: INPUT CR1 CR1+CR2 CR1+CR2+CR3

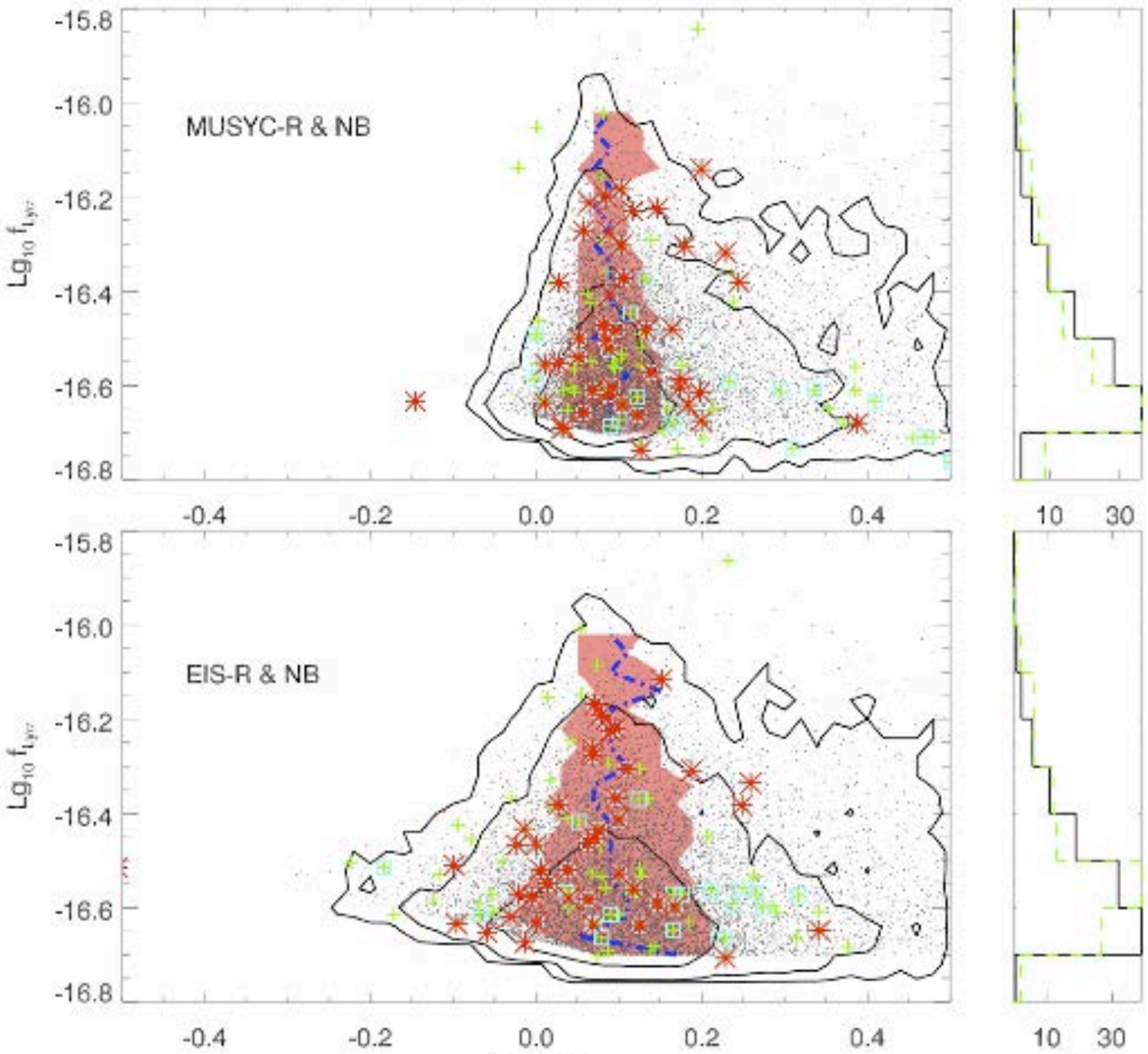
$L_{Ly\alpha}$ distribution



EW distribution

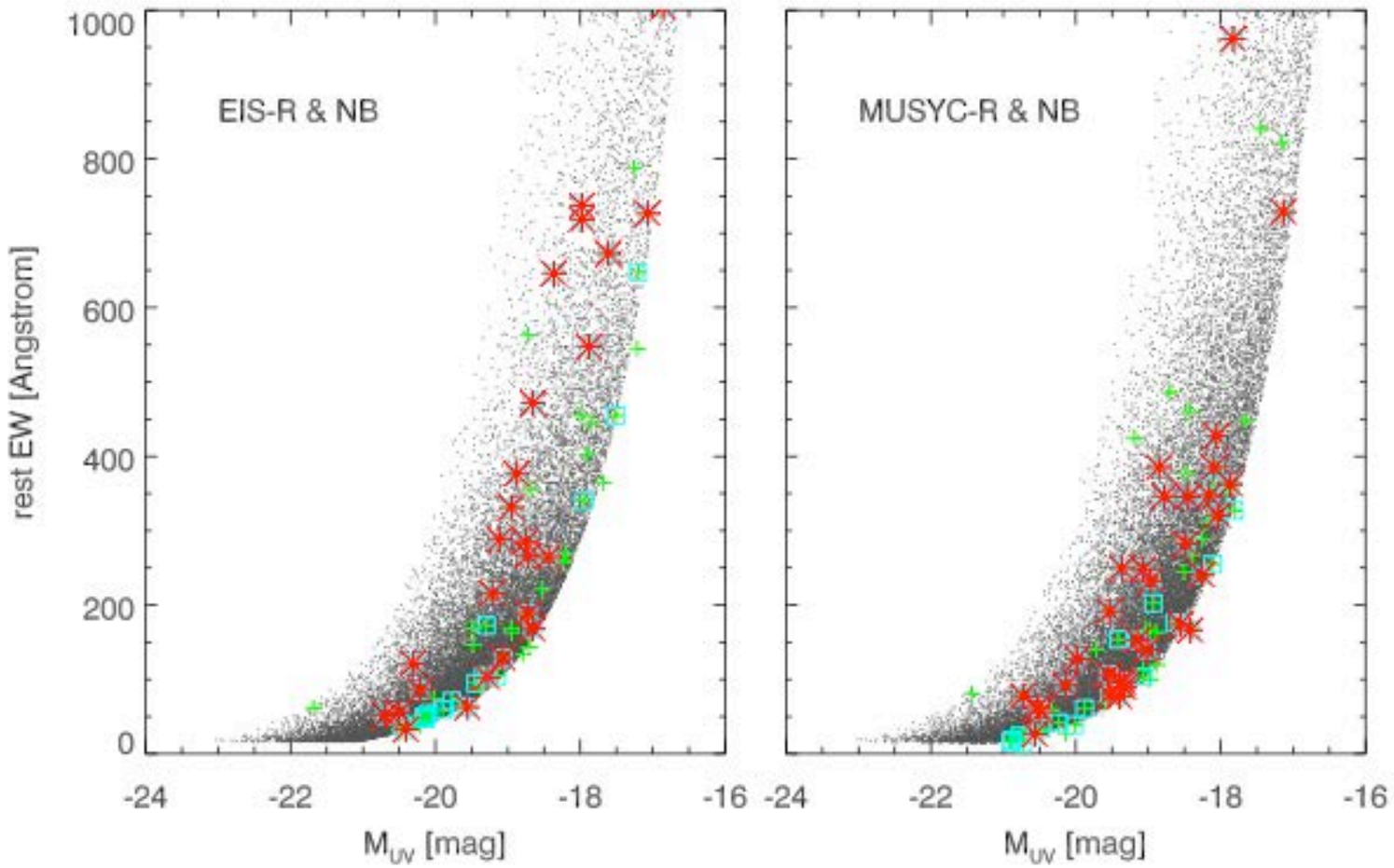
Simulation results:

1. EW distribution independent with Flux



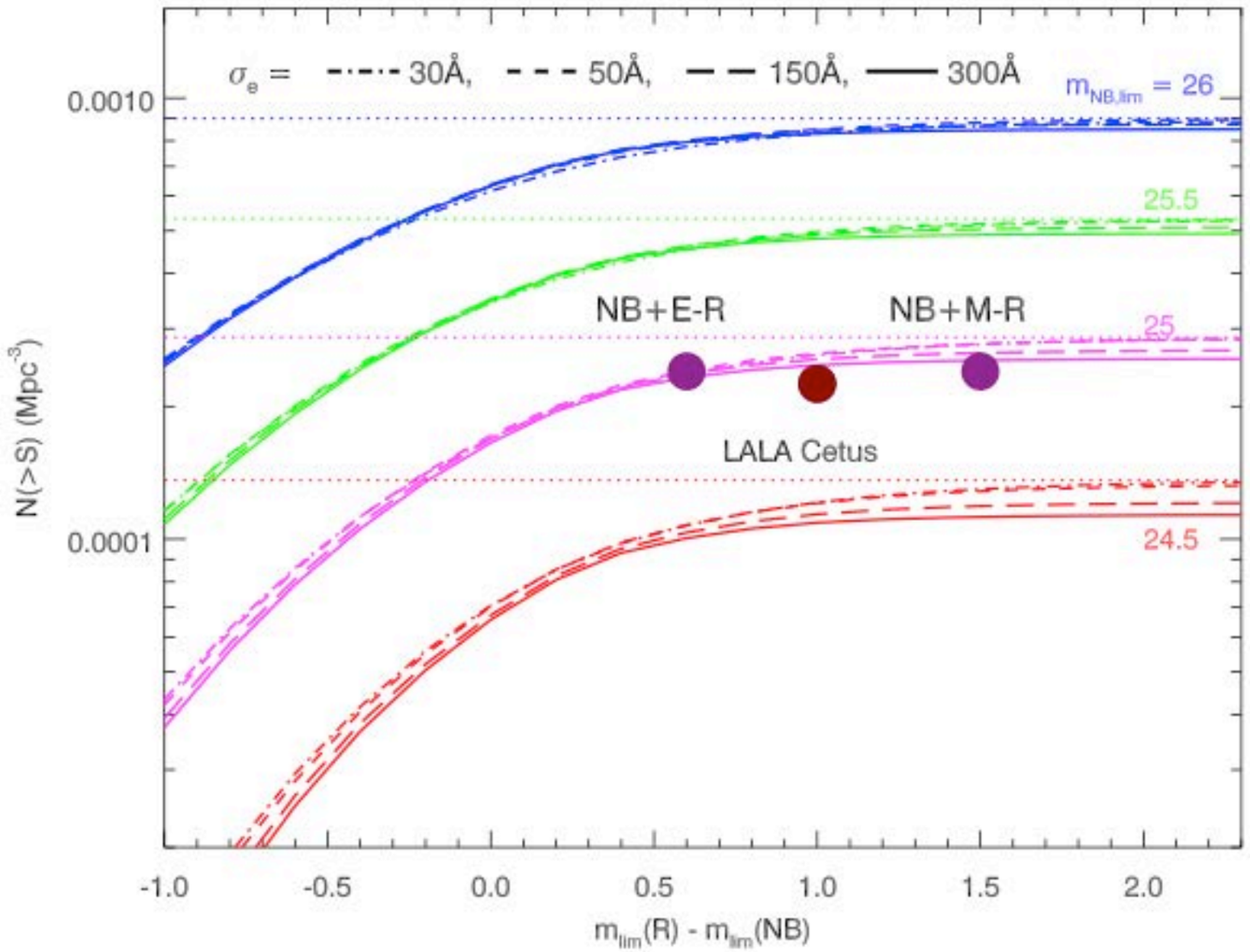
Simulation results:

1. EW distribution independent with Flux
2. Automatically generate Ando effect

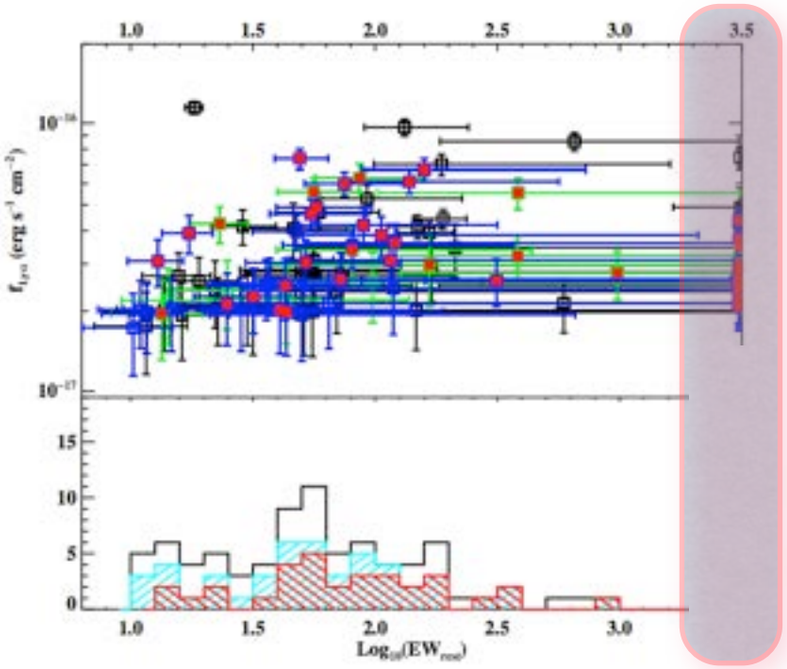


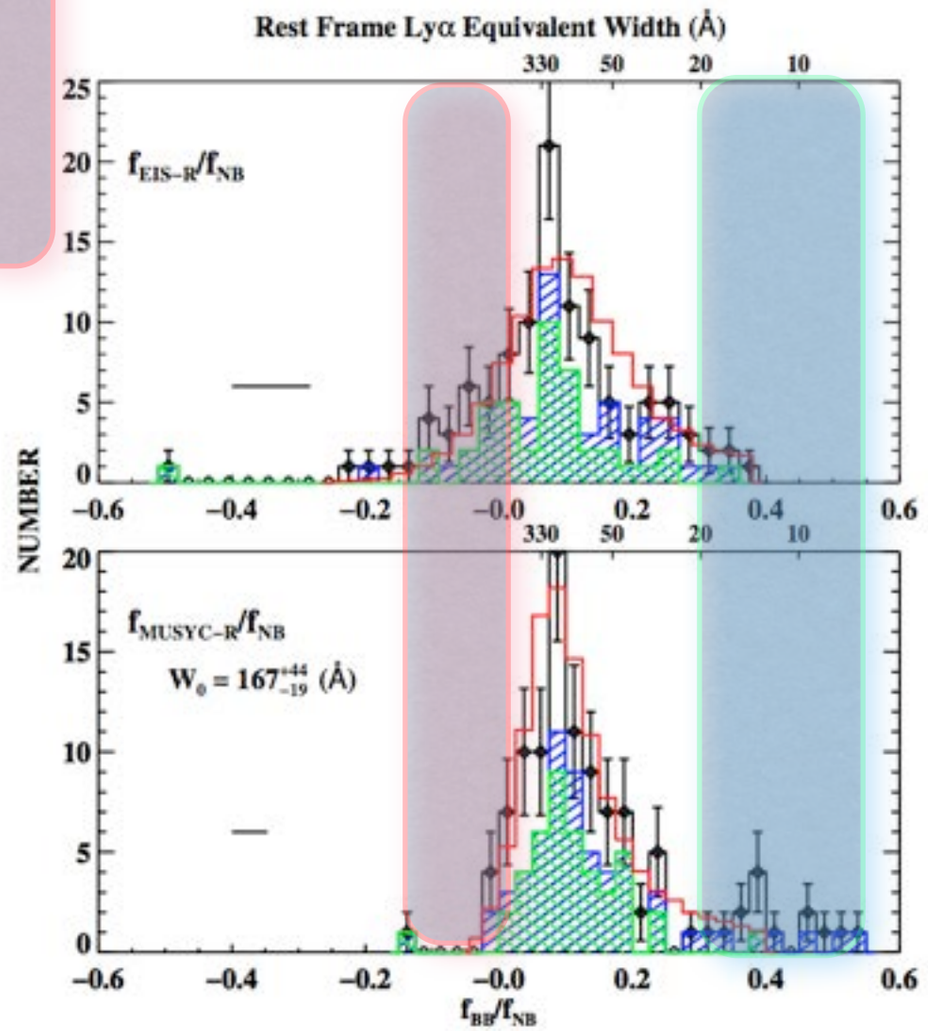
Simulation results:

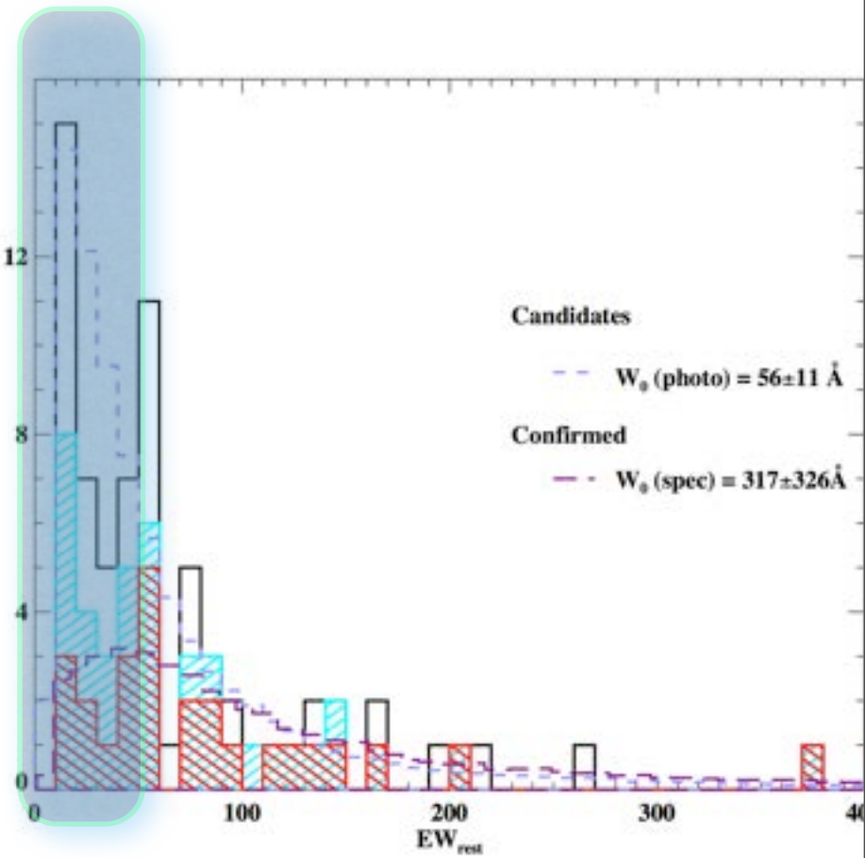
1. EW distribution independent with Flux
2. Automatically generate Ando effect
3. BB - NB >= 0.5--1.0 needed for NB surveys (NB located in BB)



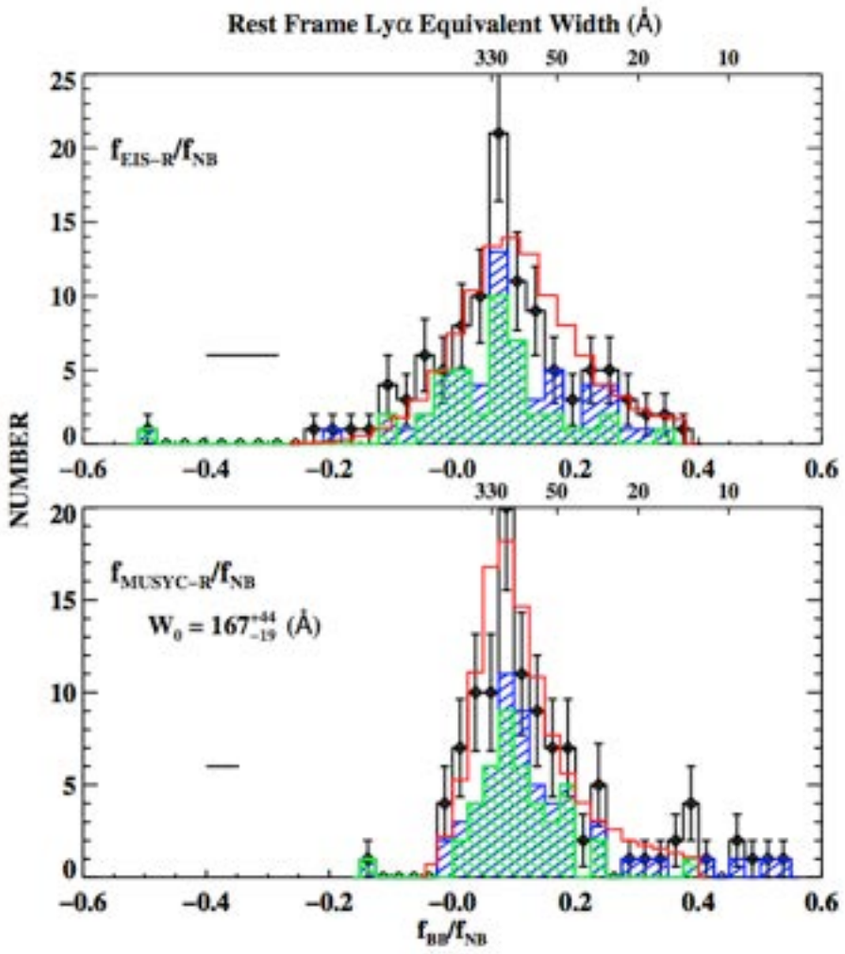
Why fitting on band-ratio distribution







Fitting results on scale EW_0



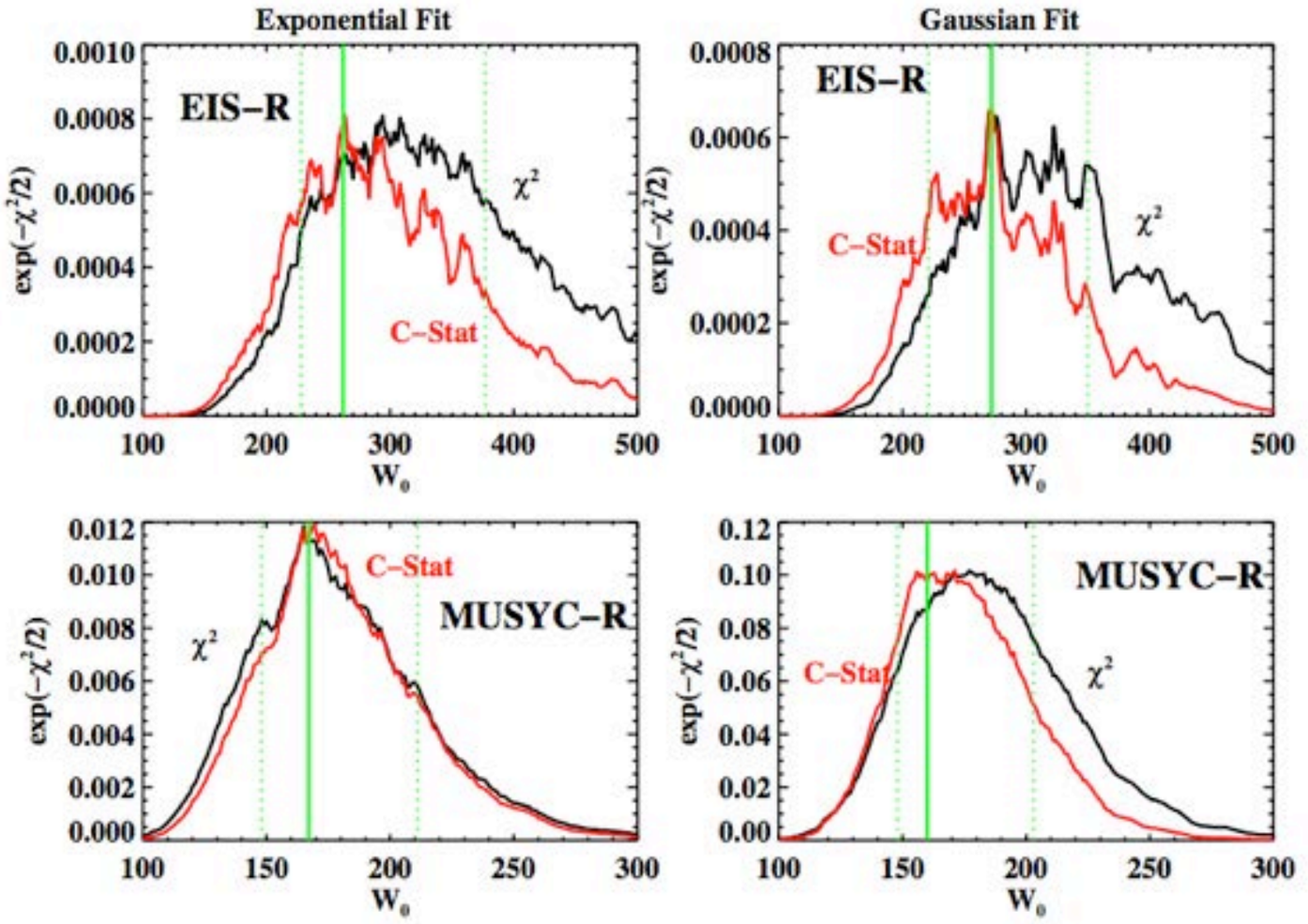


Figure 6. Statistical probability ($P \propto \exp(-\chi^2/2)$ for fitting band-ratio dis-

EW distribution at other redshifts

- Direct fitting EW dist.:
  - z~0.3 (Cowie+10,11), z=3.1 (Ciardullo+12), z=5.7 and 6.5 (Kashikawa+11)
- Monte-Carlo simu. on band-ratio dist.:
  - z~4.5 (this work), z=5.7 and 6.5 (Hu+10)

z~0.3 LAEs

- Finkelstein+09: AGN fraction as high as 20%-40% at z~0.3

GALEX EGS sample only (Cowie+10,11)

Filled hist.: AGNs (N =9), two EW peaks

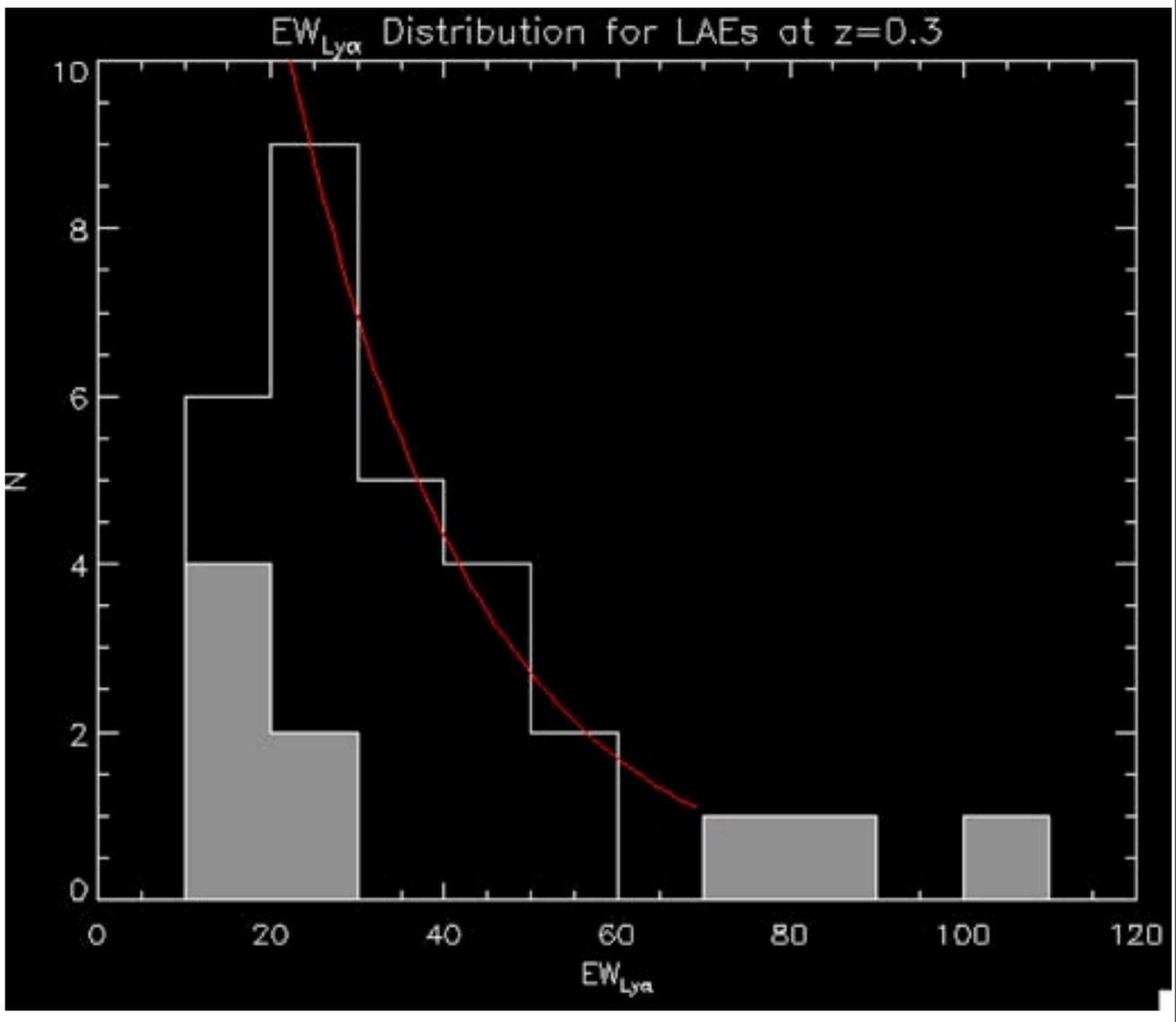
Empty hist.: SFG (N = 26), EW_0 = 22+/-9

EW(Lya) > 60: 3 AGNs

Seyfert 1.5 (EW(Ha)~12 && EW(Lya)~ 70)

Seyfert 1.8 (EW(Ha)~ 7 && EW(Lya)~ 80)

AGN Type ?? (EW(Ha)~1390 && EW(Lya)~100)



z~3.1 LAEs

- Z~3.1 LAEs in CDFS (Ciardullo+12)

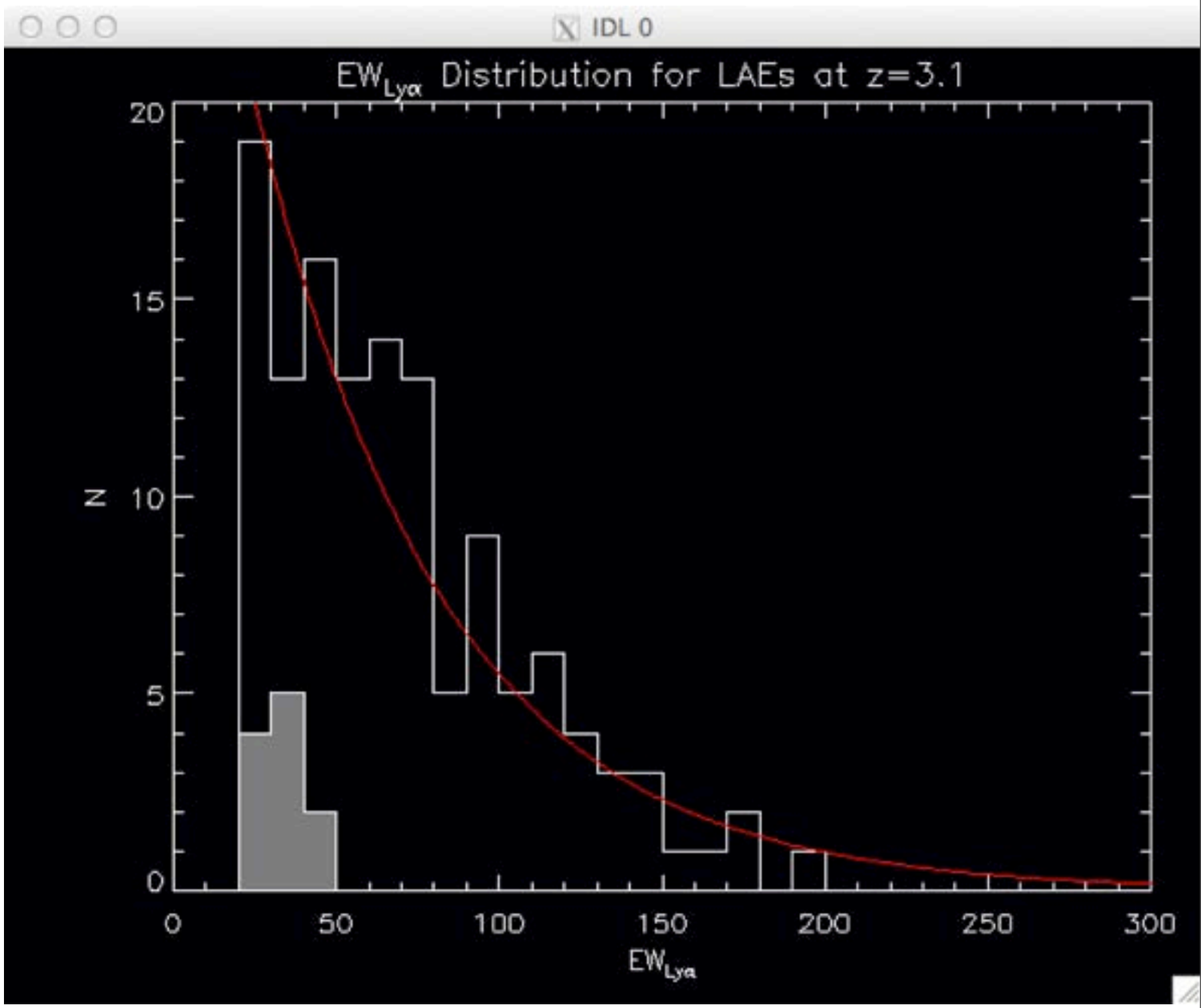
Filled hist.:

- X-ray||GALEX||low-z: all with EW<50A

Empty hist.:

- SFG, EW_0 = 58+/-7

EW(Lya) > 194.7, #=3/141



z~5.7 LAEs

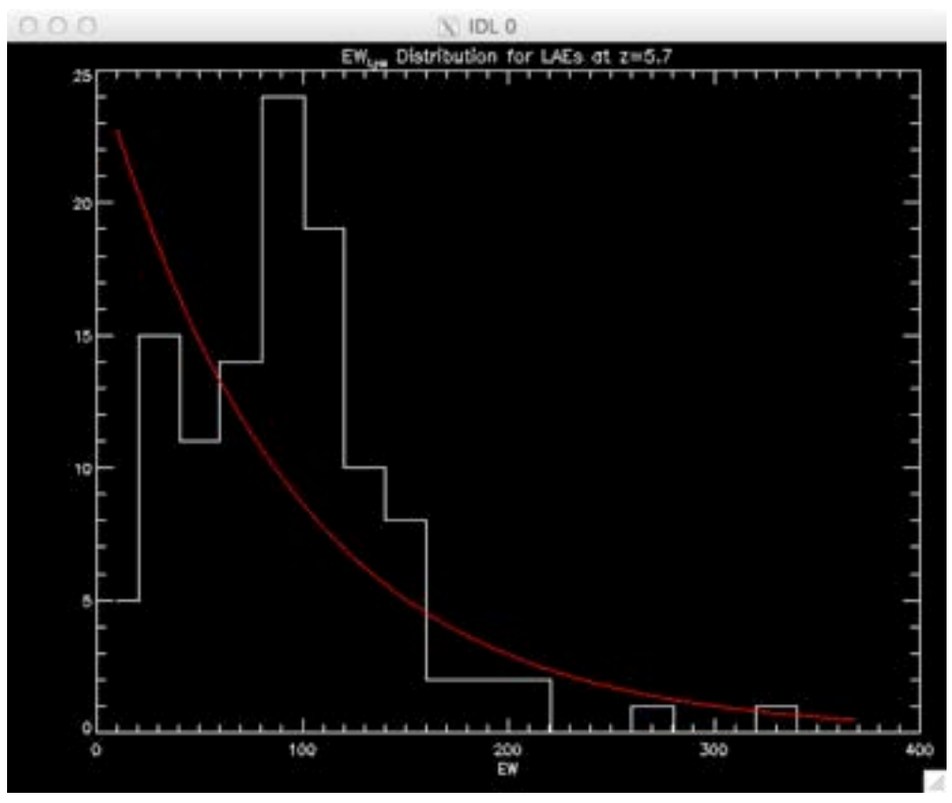
- Kashikawa+11

Z~5.7 LAEs in COSMOS

Empty hist.:

EW_0 = 108+/-20

EW(Lya) > 129 Number = 23/89



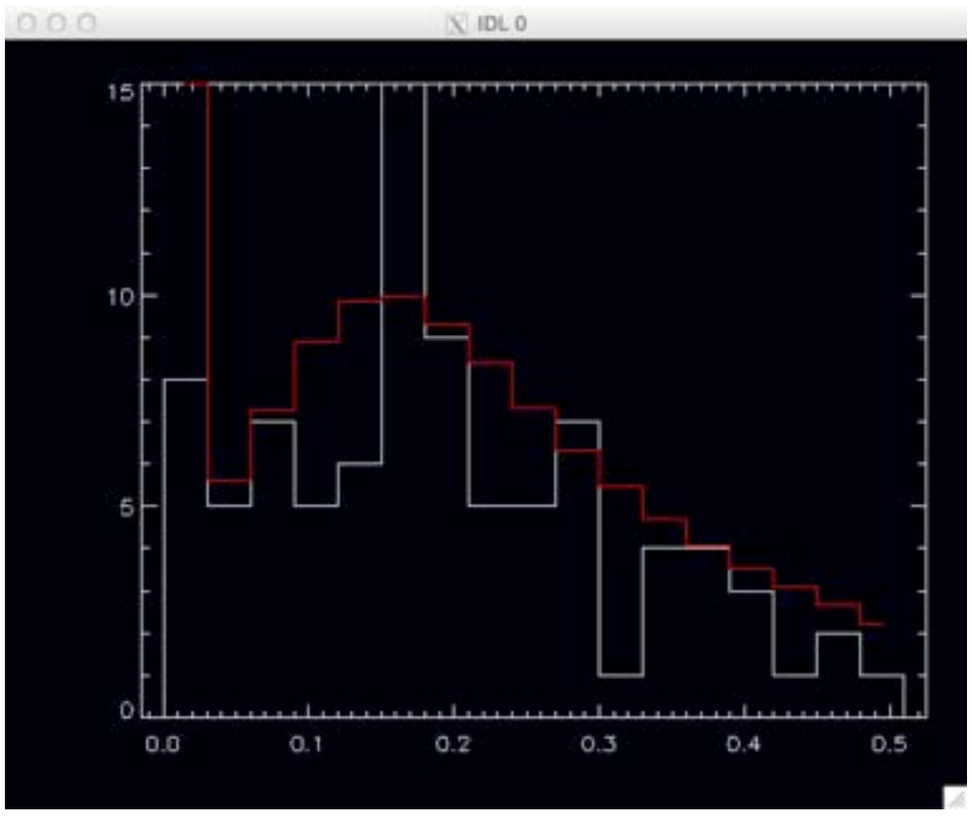
- Hu+10

Z~5.7 LAEs

Empty hist.:

EW_0 = 123+61-23

EW(Lya) > 129, # = 28/88



z~6.5 LAEs

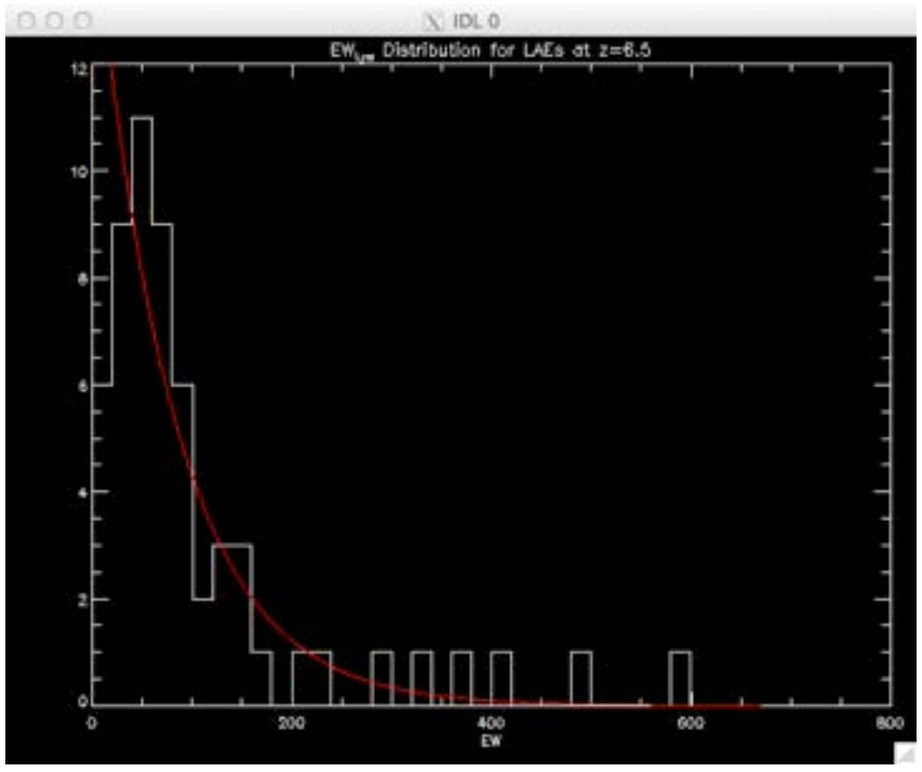
- Kashikawa+11

Z~6.5 LAEs in COSMOS

Empty hist.:

EW_0 = 79+/-19

EW(Lya) > 122 Number = 15/58



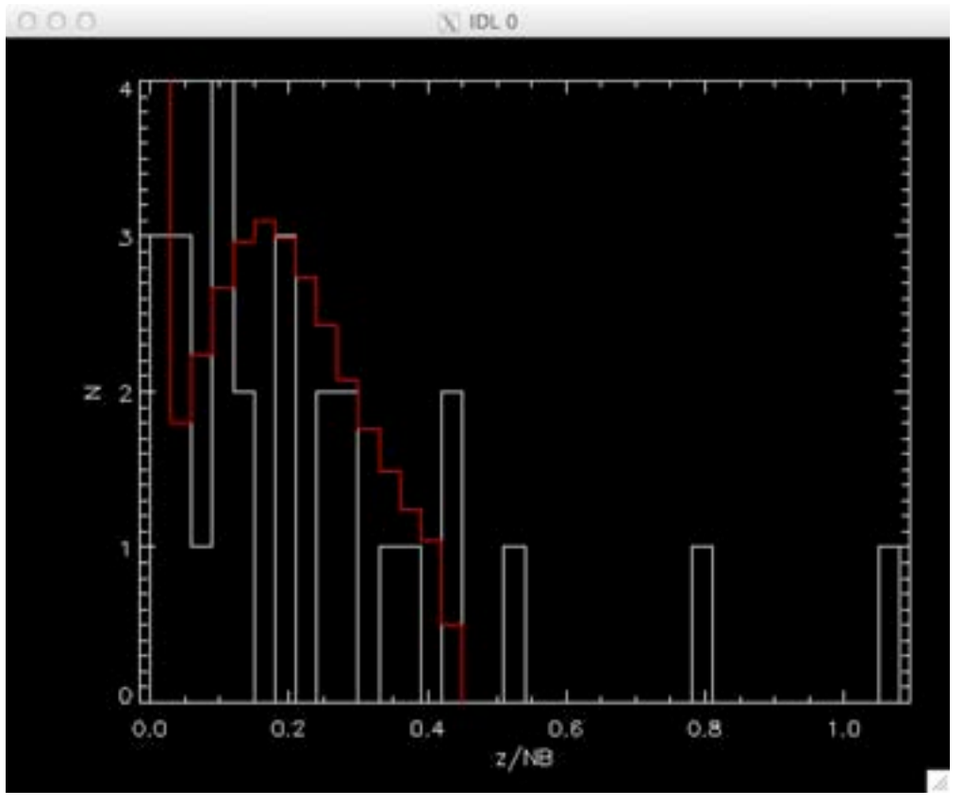
- Hu+10

Z~6.5 LAEs

Empty hist.:

EW_0 = 178+433-26

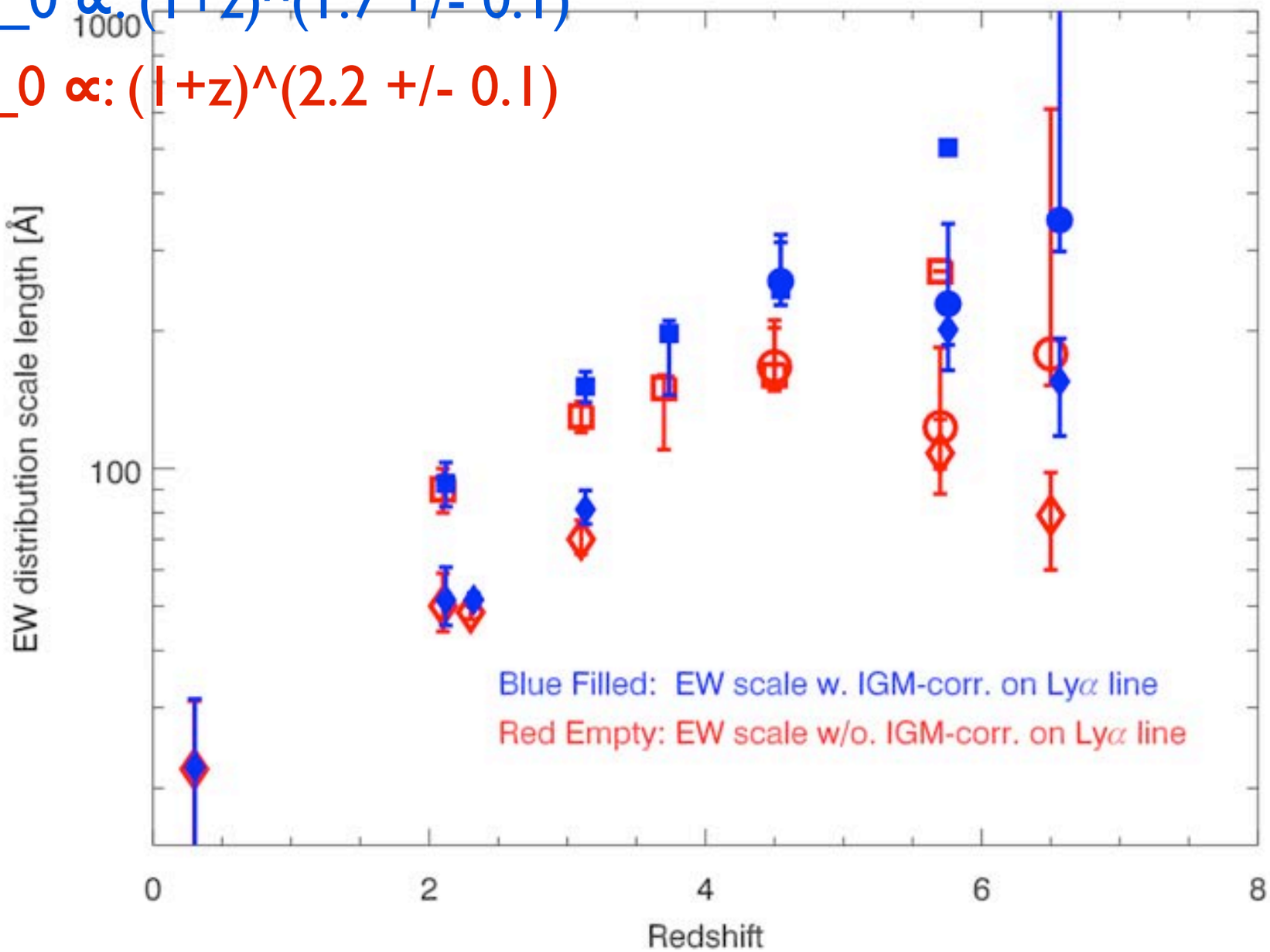
EW(Lya) > 122, # = 13/27



Lya EW distribution over redshift 0.3-6.5

blue: W_0 ∝: (1+z)^(1.7 +/- 0.1)

red: W_0 ∝: (1+z)^(2.2 +/- 0.1)



Strong Evolution over redshift

Summary

- We update the equations used to calculate Lya EW when NB located in BB with the consideration of filter shape.
- We use Monte-carlo simulation to check our NB selection and find weak bias. EW and L can be independent, and automatically generate “ando” effect. Simulations help us to optimize LAE surveys.
- We find band-ratio distribution is better than direct fitting EW distribution as it minimize the effect of interlopers and large EW errors.
- We find a strong evolution trend of Lya EW distribution over the redshift range of 0.3—6.5.

compare with dust and f_esc

blue: W_0 ∝: (1+z)^(1.7 +/- 0.1)

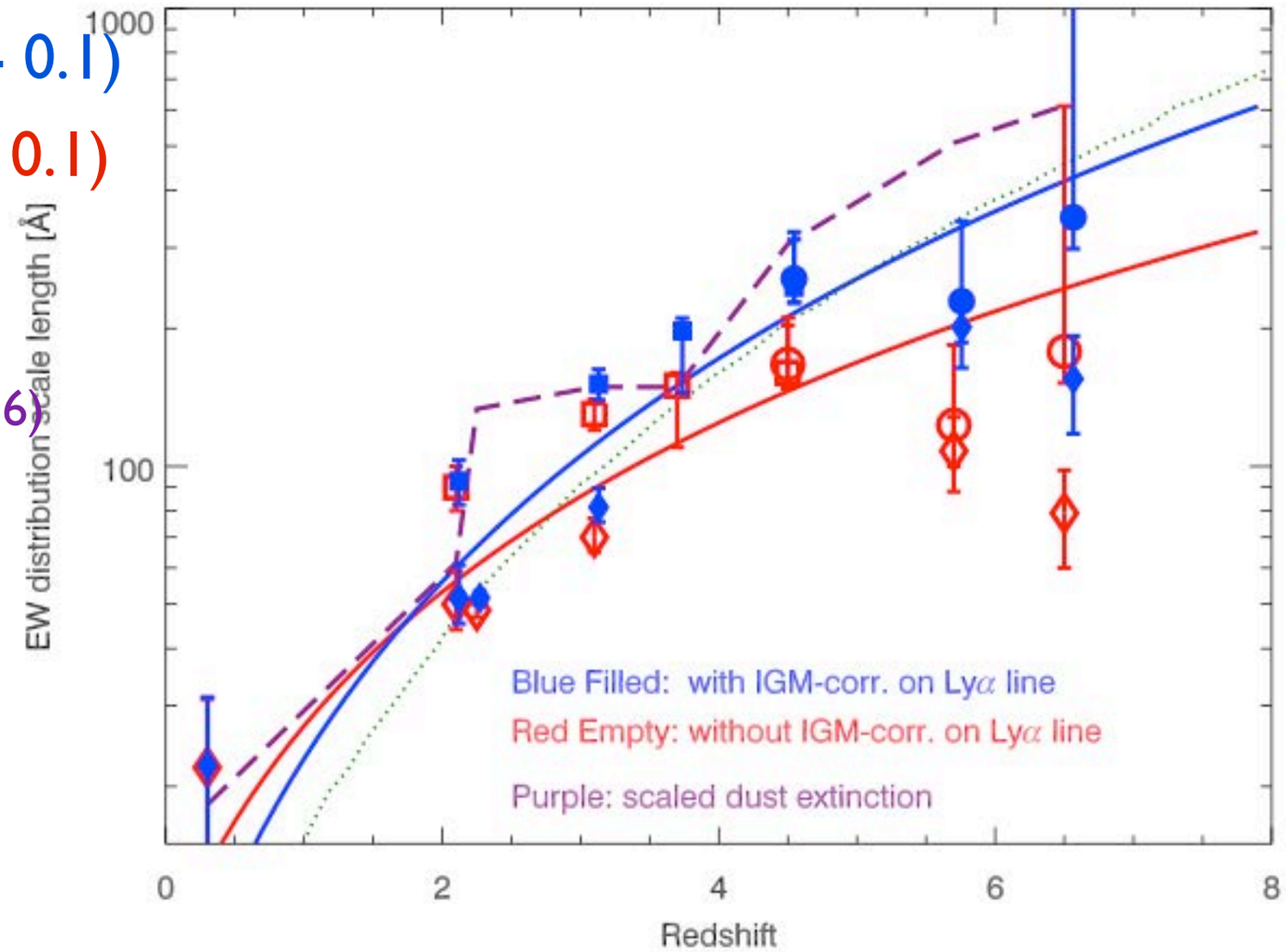
red: W_0 ∝: (1+z)^(2.2 +/- 0.1)

purple: dust ∝: 10^(-0.4E(B-V)k_1216)

k_1216=12 from Calzetti+00

green: f_esc ∝: (1+z)^(2.6 +/- 0.2)

from table 1 of Hayes+11



Conclusion: Connection with Dust/ISM Evolution