Stellar to Halo Mass Ratio and Gas Conversion Efficiency of LAEs at z~2

(Kusakabe+17 in prep)

2017/6/8

第4回銀河進化研究会@大阪大学

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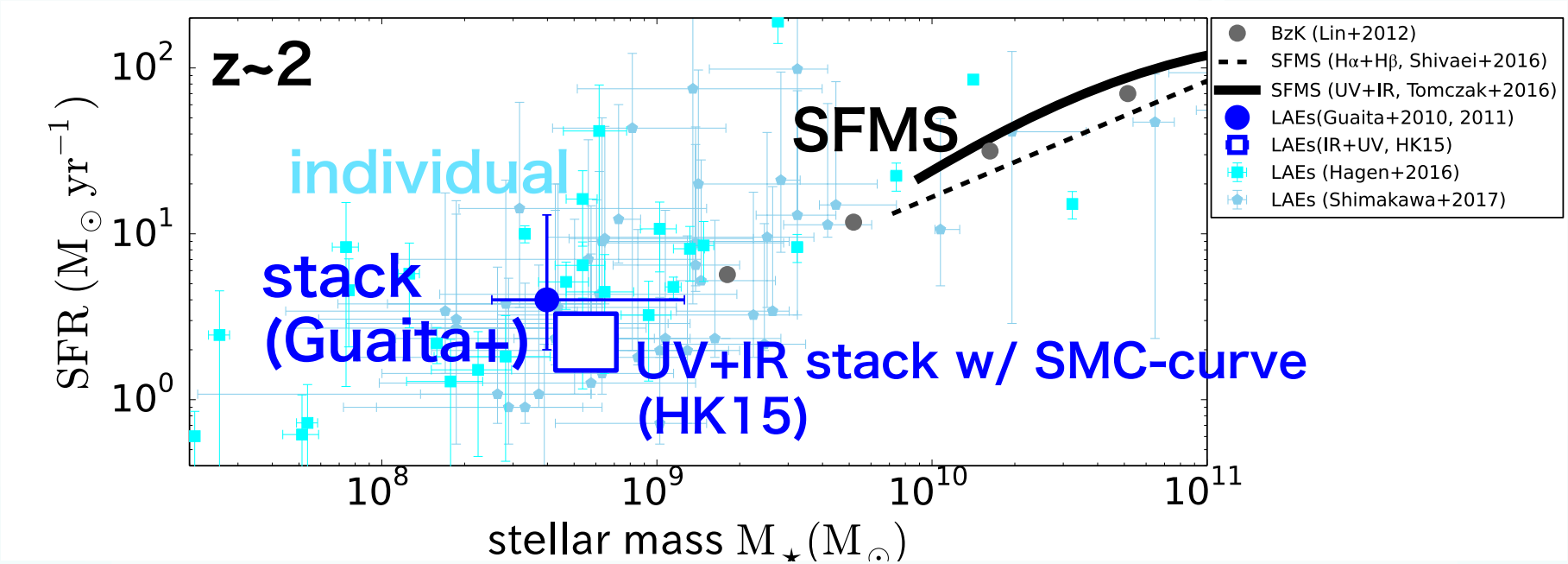
3 Key Properties of SF in galaxies

①star formation mode (SF mode)

②stellar to halo mass ratio (SHMR)

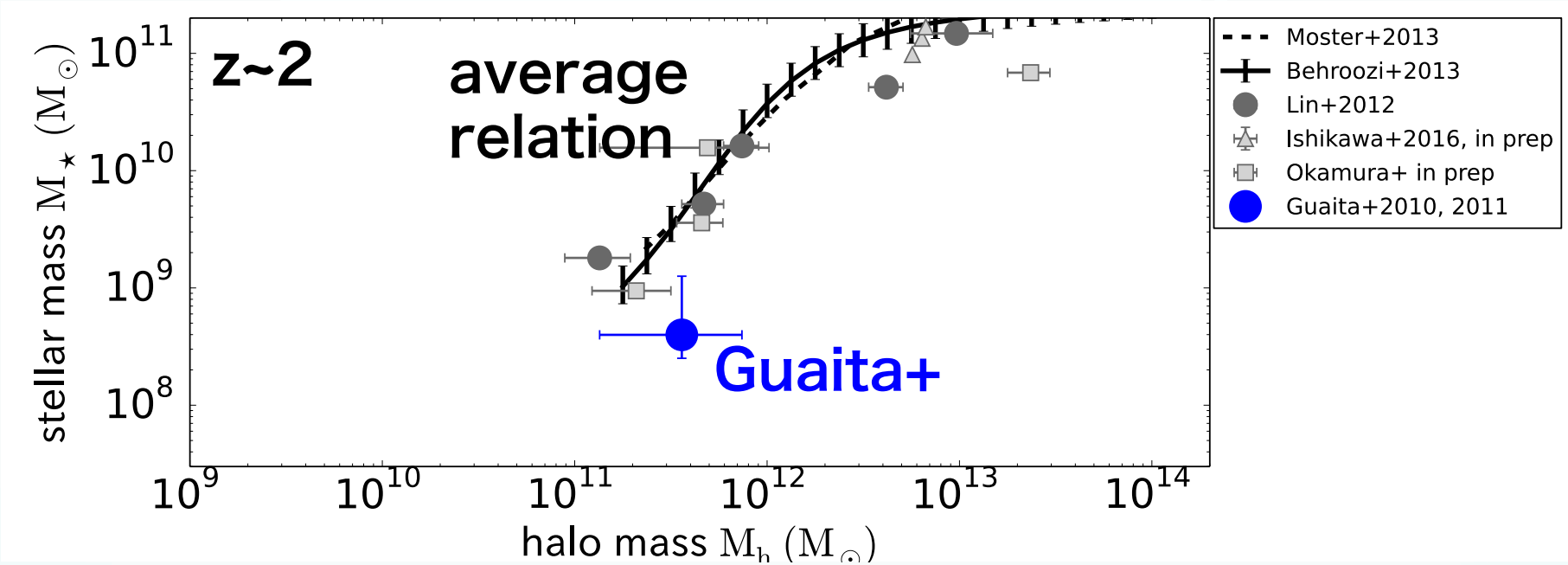
③baryon conversion efficiency (BCE)

①SF Mode (Ms vs SFR)



- SF mode of LAEs: burst or moderate SF?
- ✓ problems:
  - individual → only bright objects
  - individual /stack → no or shallow IRAC photometry
- ✓ UV + FIR stack w/ SMC-curve: moderate SF
  - only one field, no clustering result

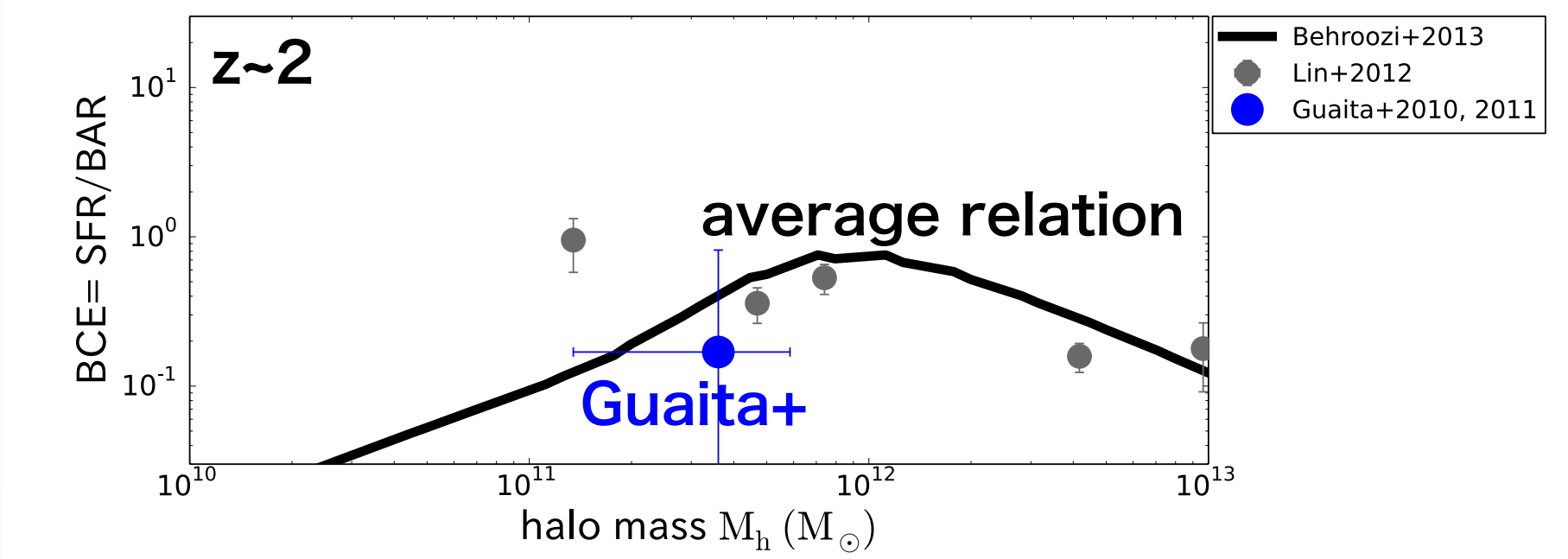
② SHMR (Mh vs Ms)



- lie on or below the average relation?

- problems:
  - small sample size 250→ large statistics error
  - small area 0.3 deg^2→large cosmic variance

③ Mh vs BCE = SFR/BAR



- lie on the average relation? (but with calzetti)

- problems:
  - small sample size 250→ large statistics error
  - small area 0.3 deg^2→cosmic variance

This Study

- SF mode, SHMR, and BCE of z~2 LAEs

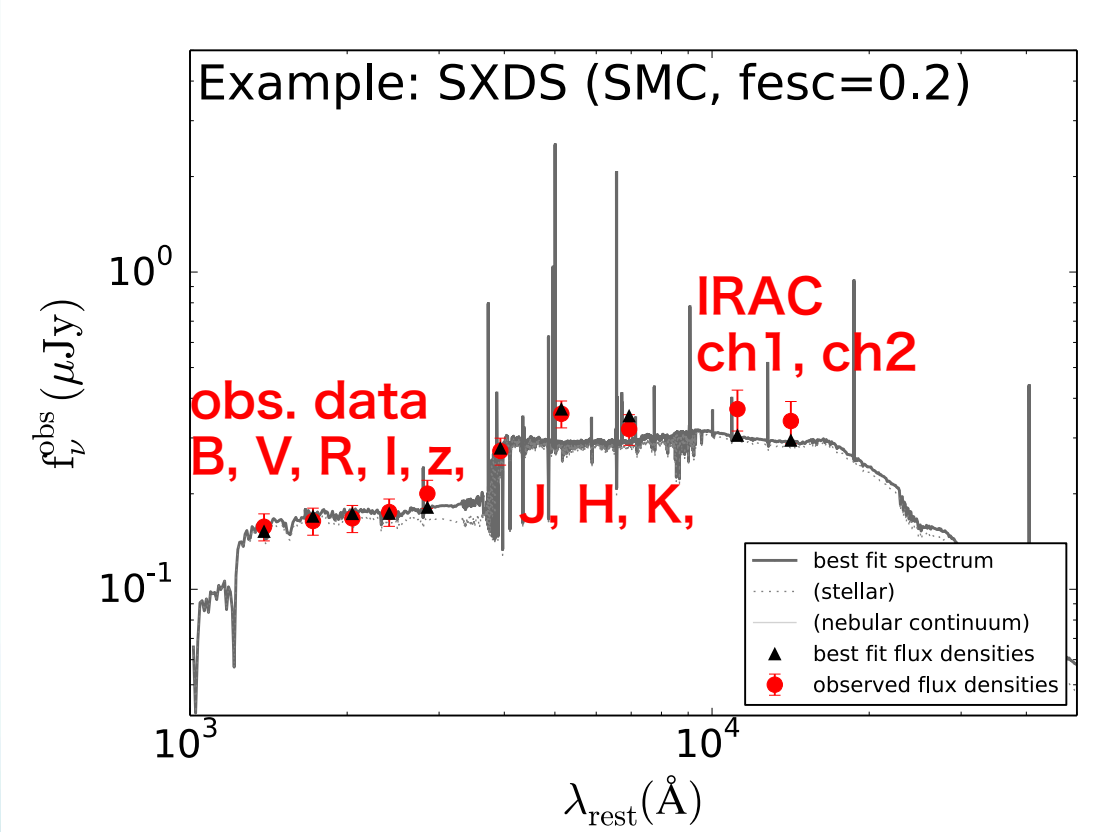
Field	Area (min^2)	NB mag lim (5σ)	Number of objects	
			All	NBtot<=25.5 (sed fit)
SXDS	~1240	25.7	603	**601(93)**
COSMOS	~740	26.1	619	**297(47)**
GOODS-S	~580	26.4	269	**51(4)**
GOODS-N	~780	26.1	950	**299 (56)**
TOTAL	**~1deg^2 ~3×G10**		**~2440**	**~1250 ~5×G10**

Nakajima+2012, 2013; Kusakabe;2015; Konno+2016

- dark matter halo masses: clustering analyses
- stellar properties: SED fitting

Methods

Stacked SED Fit

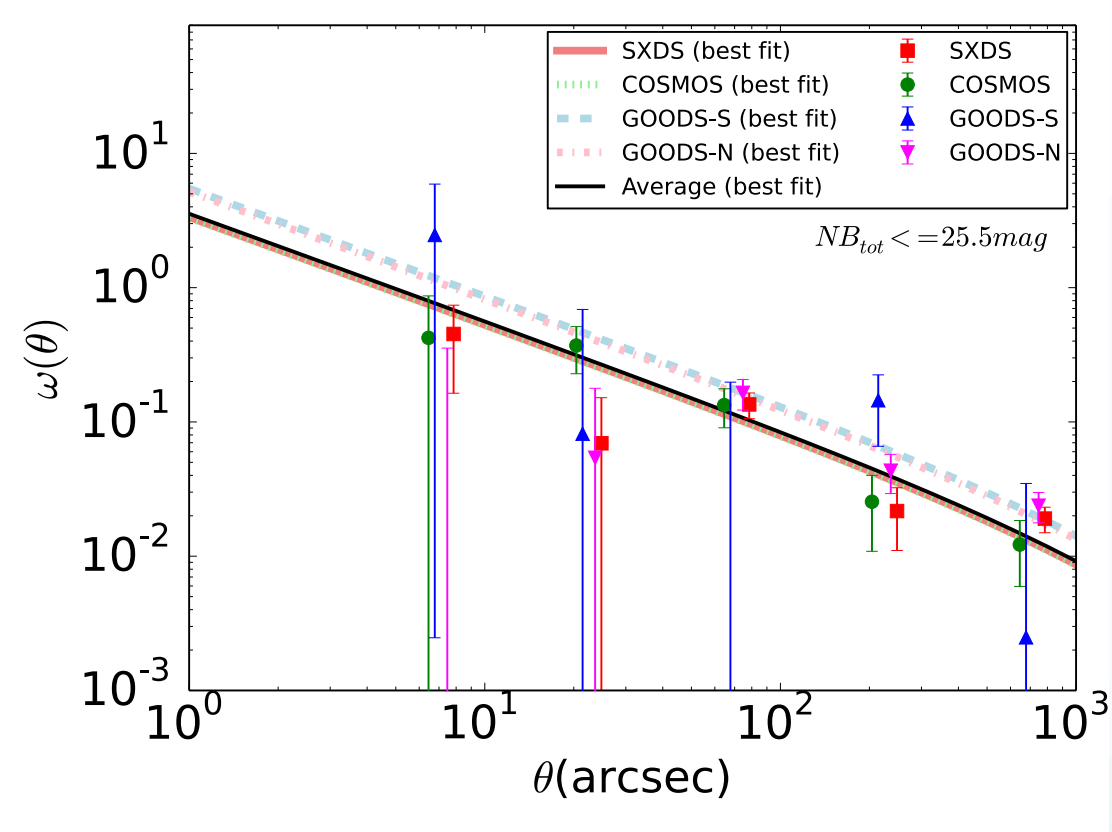


assumed model:

- BC03 with nebular emission (Ono+10)
- constant SFH
- Z=0.2Zsun (Nakajima+12)
- fesc(ion)=0.2 (Nester+09)
- the SMC-like attenuation curve (Kusakabe+15)

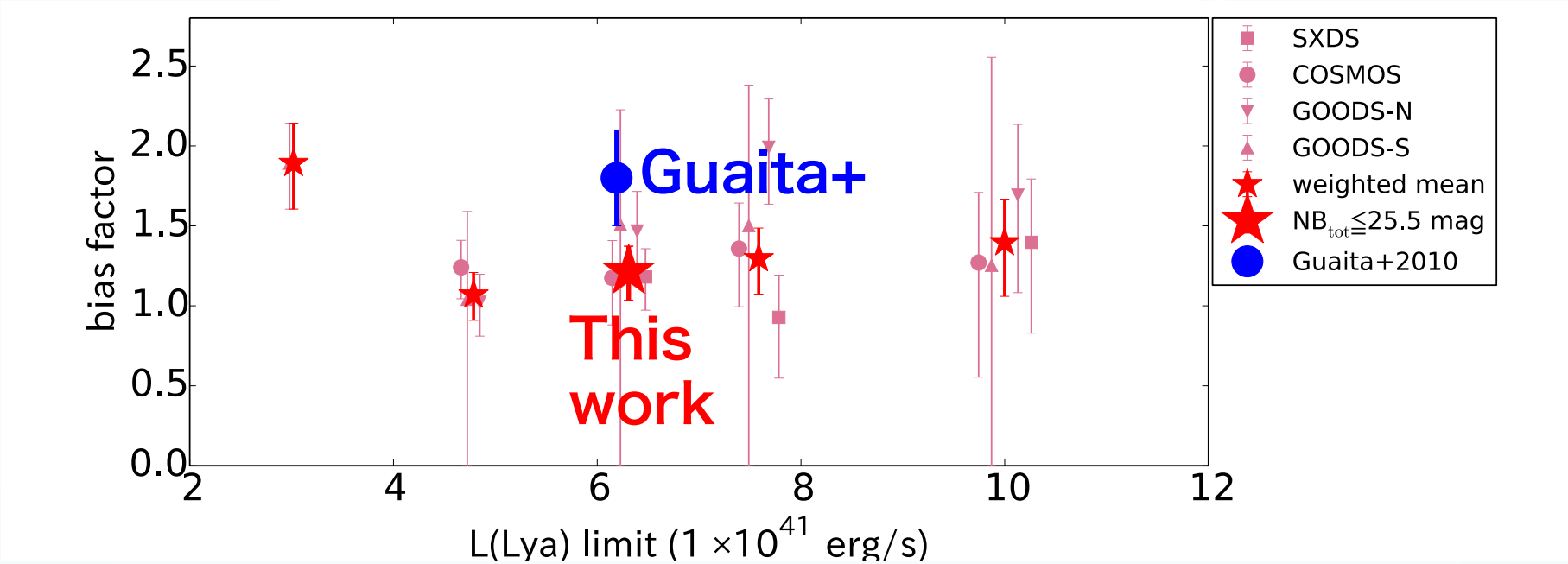
derived parameters: SFR, Ms, age, E(B-V)

Clustering Analysis



- ACF observation: Landy & Szalay+93 error: poisson Khostovan+17
- ACF model: β=0.8, fitting range =40”-1000”
- bias factor-halo mass: Tinker+10

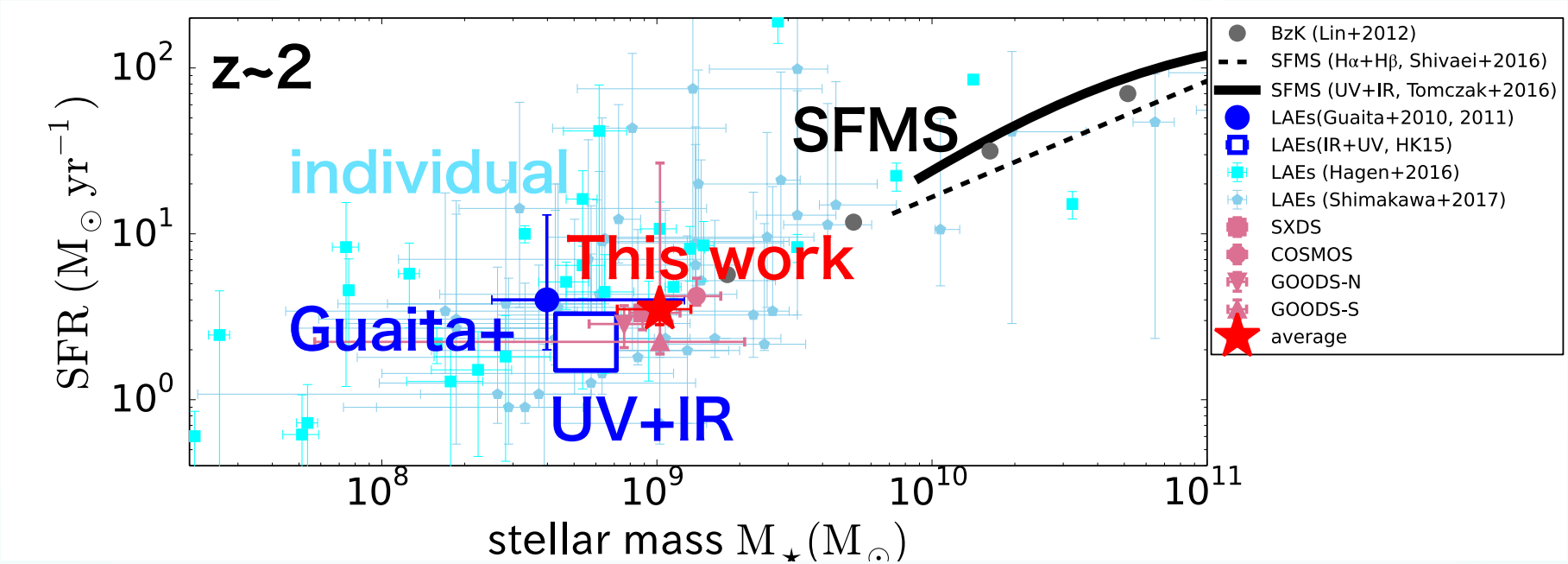
Bias Factor



- No significant dependence on L(Lya) limit
- at NBtot = 25.5 mag
  $b=1.21^{+0.18}_{-0.16}$
  $Mh=2.6^{+6.6}_{-2.4} \times 10^{10} M_{\odot}$

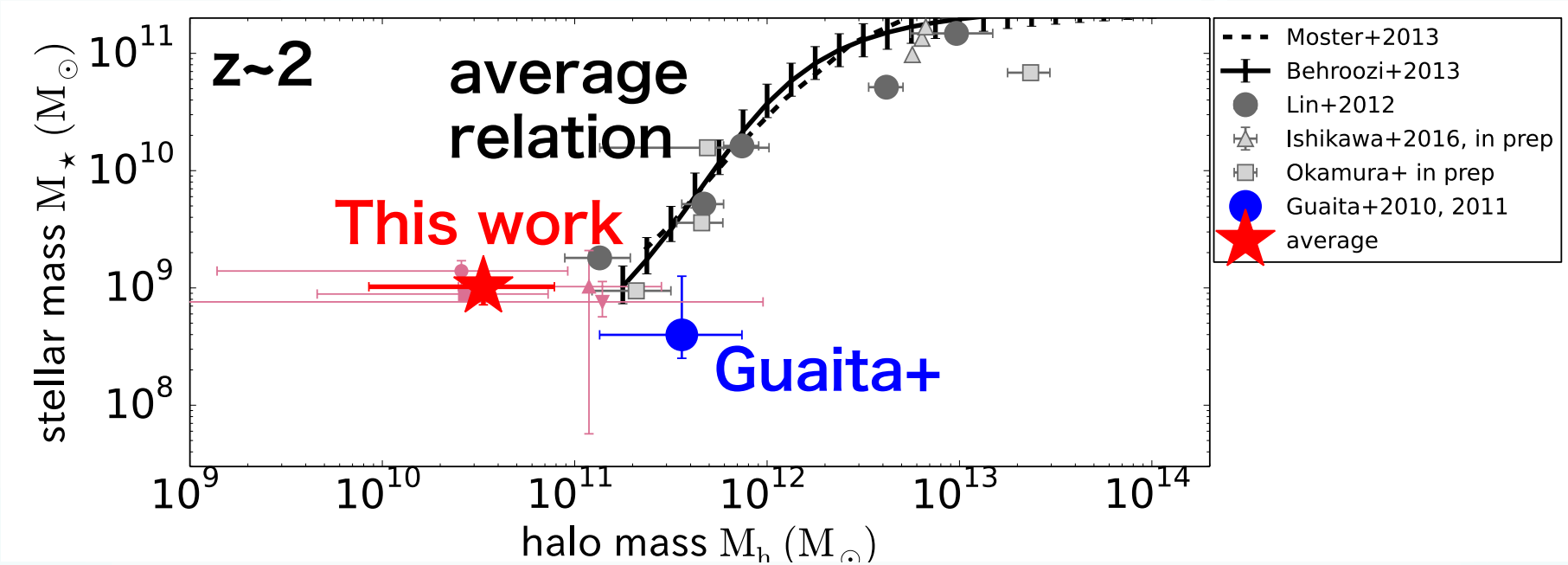
Results

①SF Mode



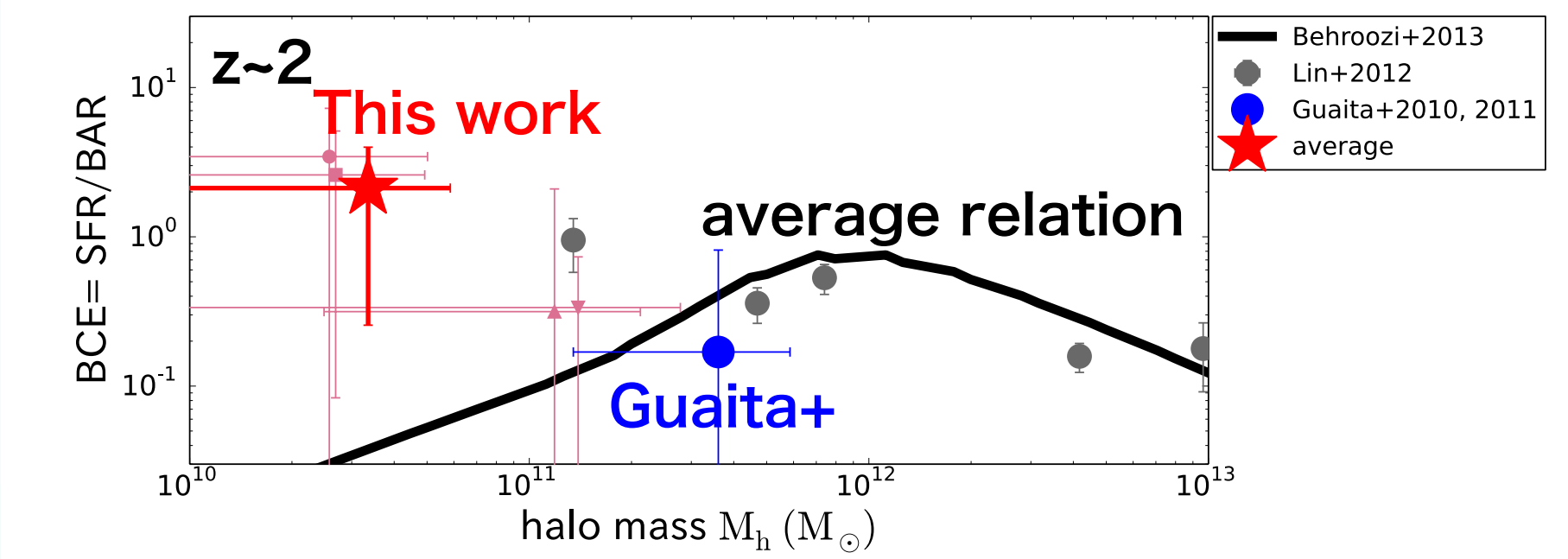
- our LAEs have Ms ~1×10^9 $M_\odot$ & SFR~3 $M_\odot$/yr
- lie on extrapolations of SFMS: **moderate SF**

②Mh vs Ms (SHMR)



- lie slightly above extrapolated average relation
- **possibly high SHMR**~0.01-0.1

③ Mh vs BCE = SFR/BAR



- BCE~2.1±1.9
- **higher than** extrapolated average relation

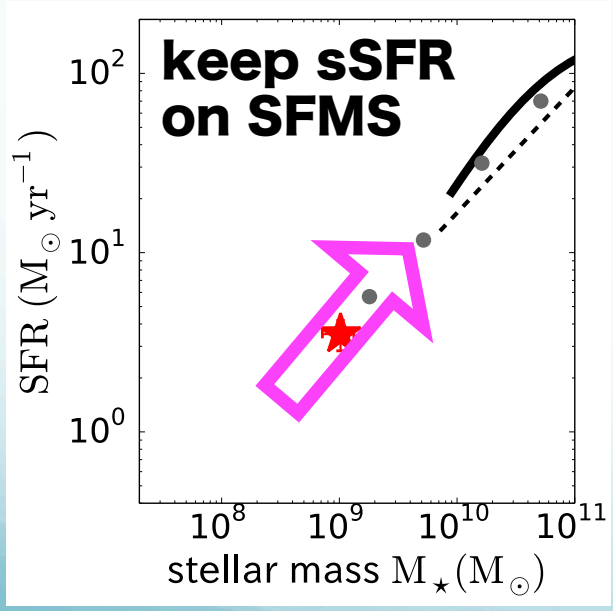
Discussion

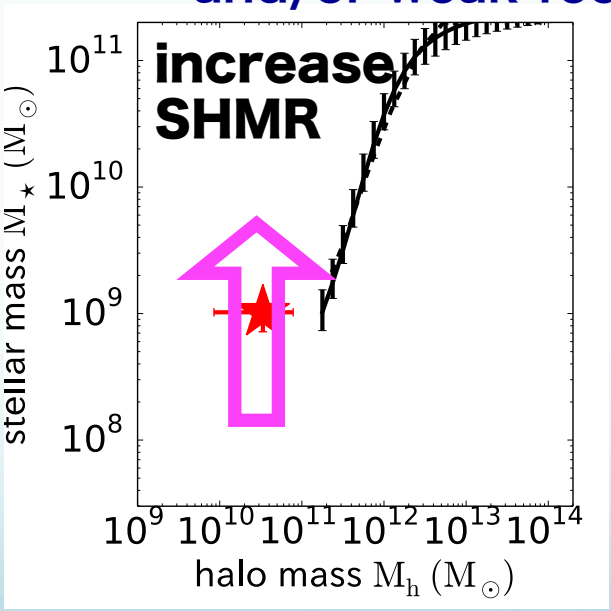
Physical Origin of LAEs

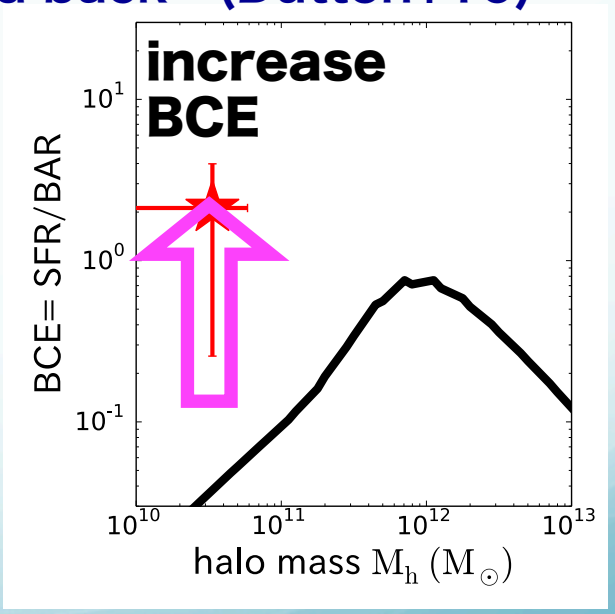
(1) moderate SF **but** possibly high SHMR + high BCE
low Mh → low Mgas? → low M_{HI}? → Lyα can escape

(2) low duty cycle: ~1.6% in Mh=10^{10}-$10^{11}M_\odot$
low LAE fraction: ~14% in Ms=$10^{8.5}$-$10^{9.5}M_\odot$

- How to reproduce (1) & (2)? small spin parameter of DMH and/or weak feed back (Dutton+10)

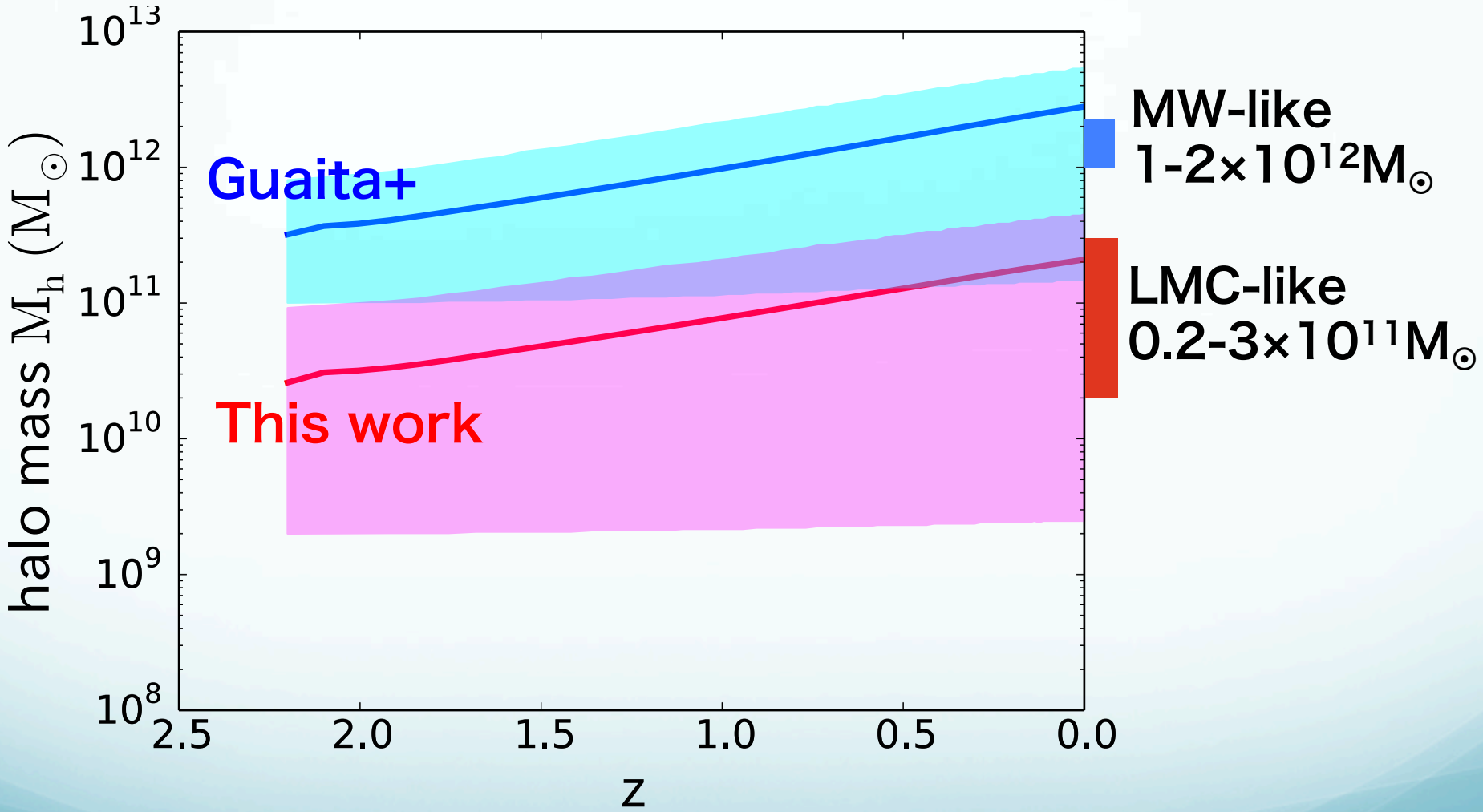






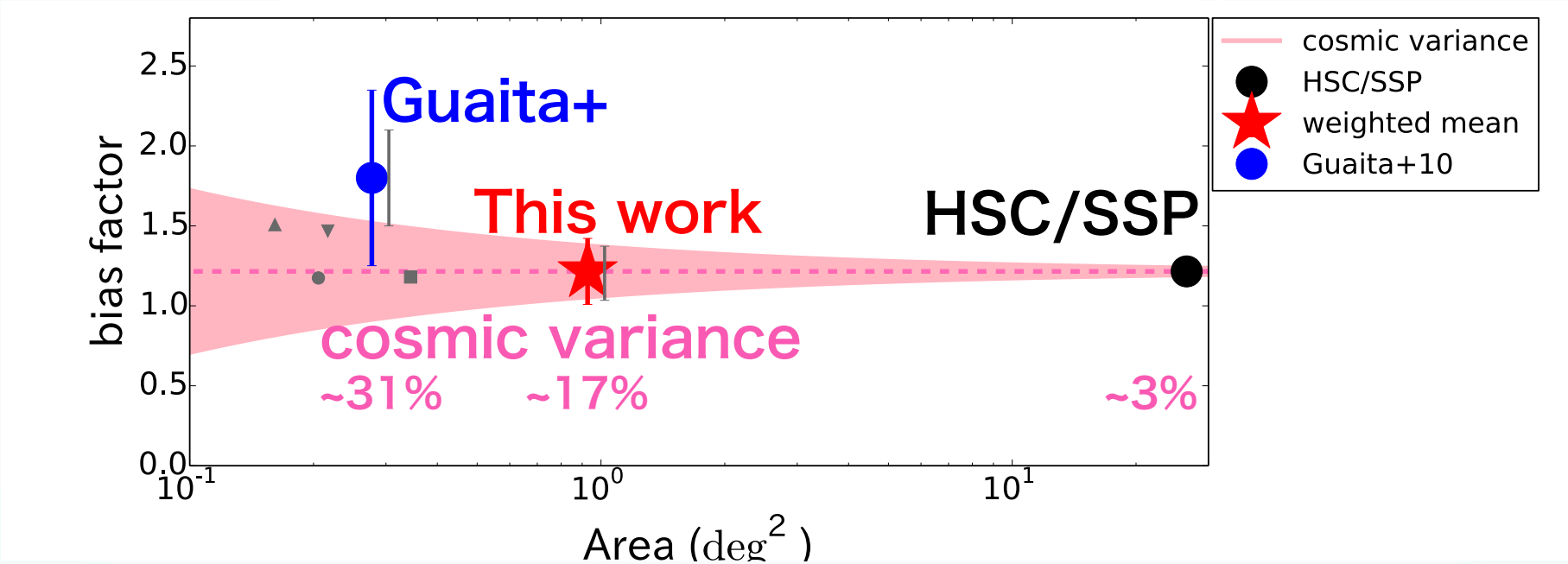
Tomczak+13; Ricciardelli+11; Dutton+10

Future of LAEs



Peñarrubia+15; Wang+15; hamana+04

Cosmic Variance



- first estimation of cosmic variance of bias~$(\omega_{gals}/\omega_{matter})^{0.5}$ assuming that CV comes from fluctuation of ω_{matter}
- HSC SSP: ~ 27 deg^2 →1 σ of cosmic variance ~3%
  << fitting & contami fraction error

Summary

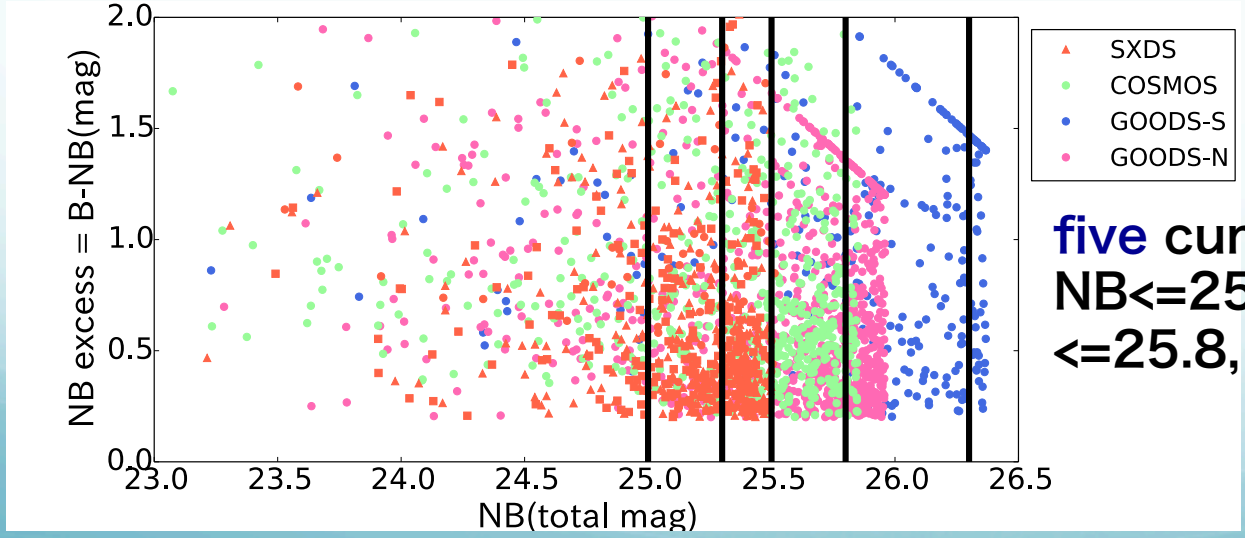
Stellar and halo properties are derived by ~1250 LAEs at z~2 from 1deg^2 field

- average bias = $1.21^{+0.18}_{-0.16}$ with Mh=$4.0^{+8.6}_{-3.0} \times 10^{10} M_\odot$
  - large cosmic variance in each sub sample
  - smaller than Guaita+10 based on 0.3 deg^2 area
- average LAEs form star moderately lying on SFMS
- efficient mass assembly as opposed to their low Mh
  - possibly high SHMR
  - high BCE
- They are progenitors of LMC-like galaxies (not of MW)
- HSC enables us to constrain Mh of LAEs robustly

Appendix

Samples

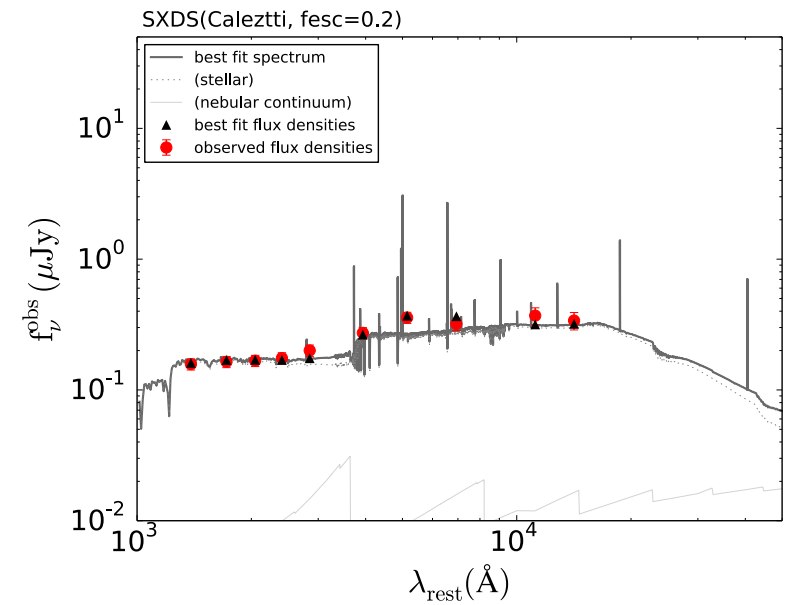
Field	Area (min^2)	NB mag lim (5σ, mag)	Number of samples(#)	# w NBtot<=25.5mag (# for SED fitting)
SXDS	~1240	25.7, 2" ap	603	601(93)
COSMOS	~740	26.1, 2"ap	619	297(47)
GOODS-S	~580	26.4, 2" ap	269	51(4)
GOODS-N	~780	26.1, 3" ap	950	299 (56)
TOTAL	**~1deg^2**		**~2440**	**~1250**

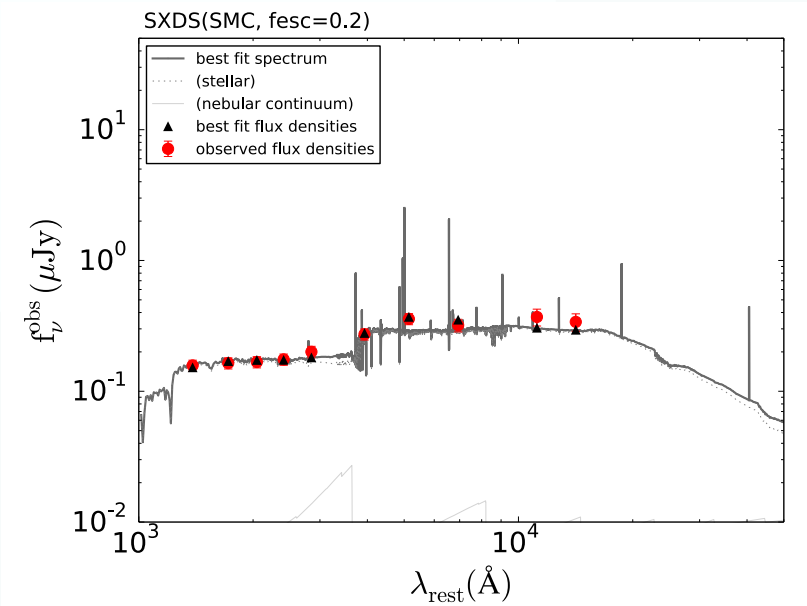


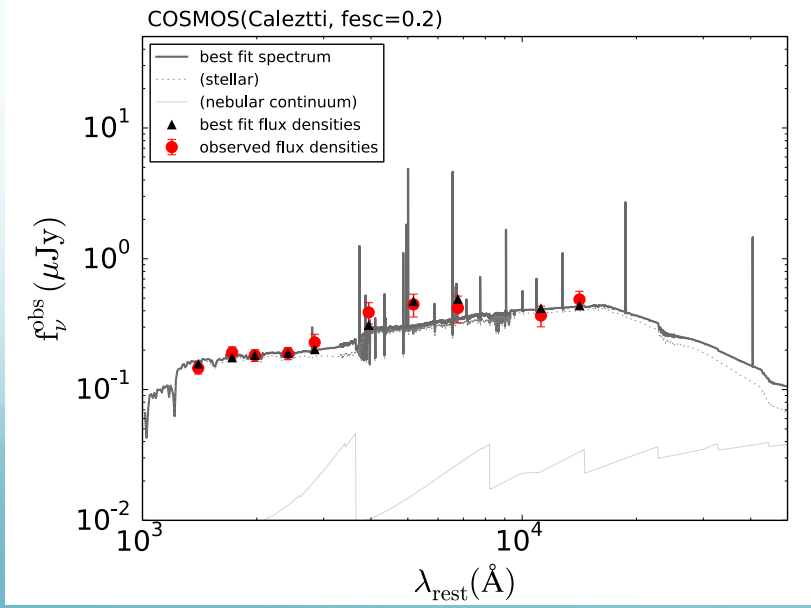
Nakajima+12, 13, Kusakabe+15, Konno+16

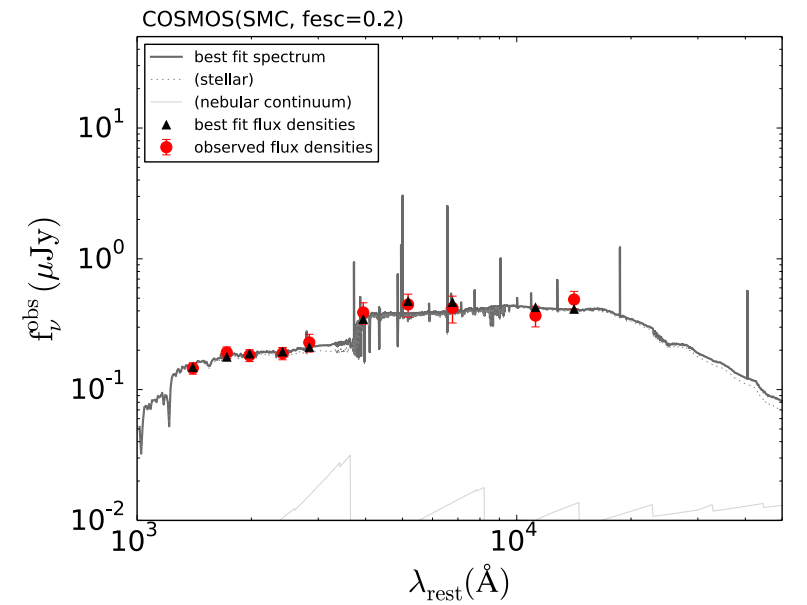
five cumulative samples NB<=25.0, <=25.3, <=25.5, <=25.8, <=26.3

SED fitting(fesc=0.2)

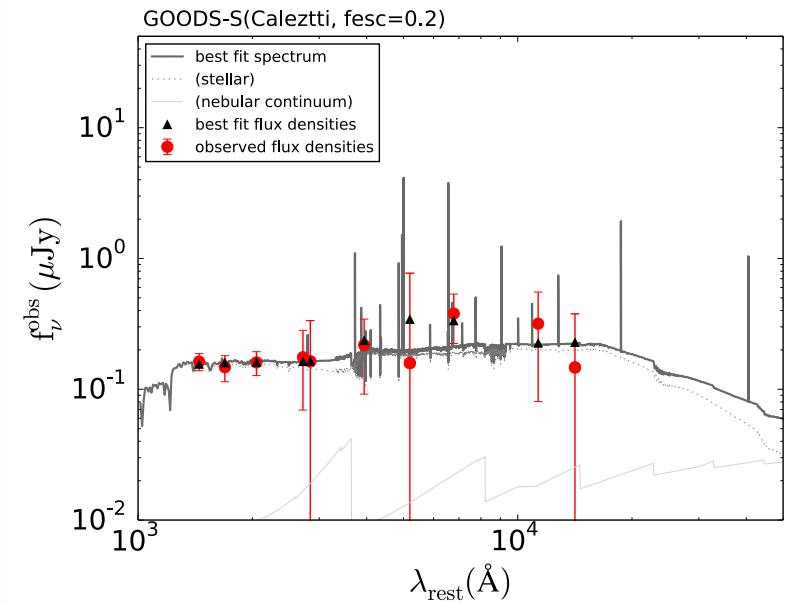


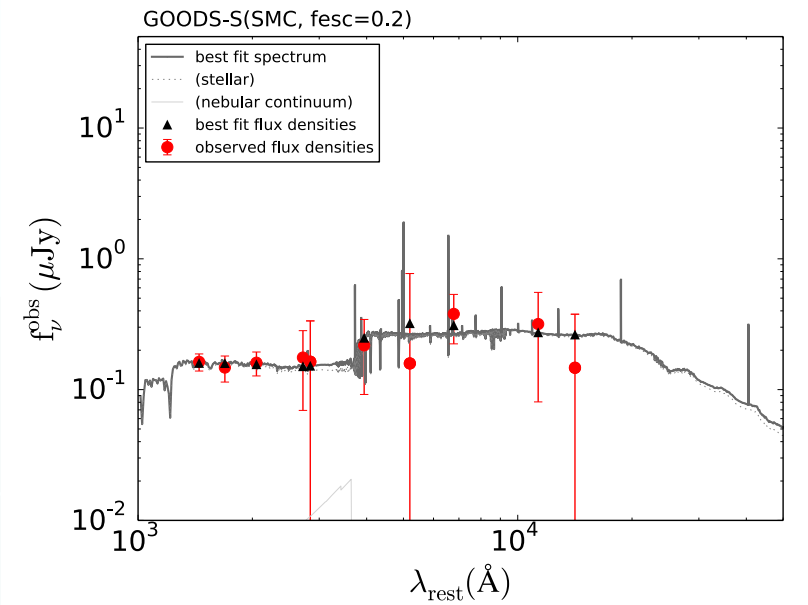


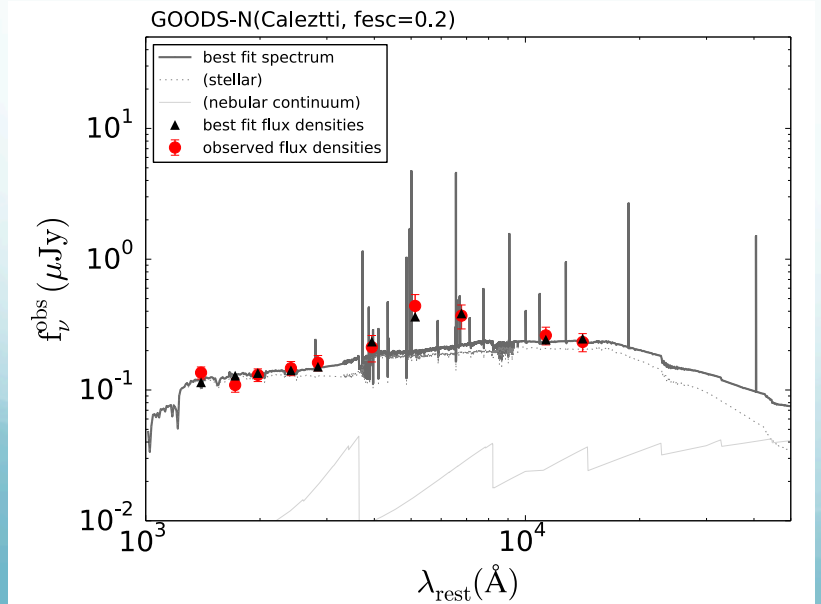


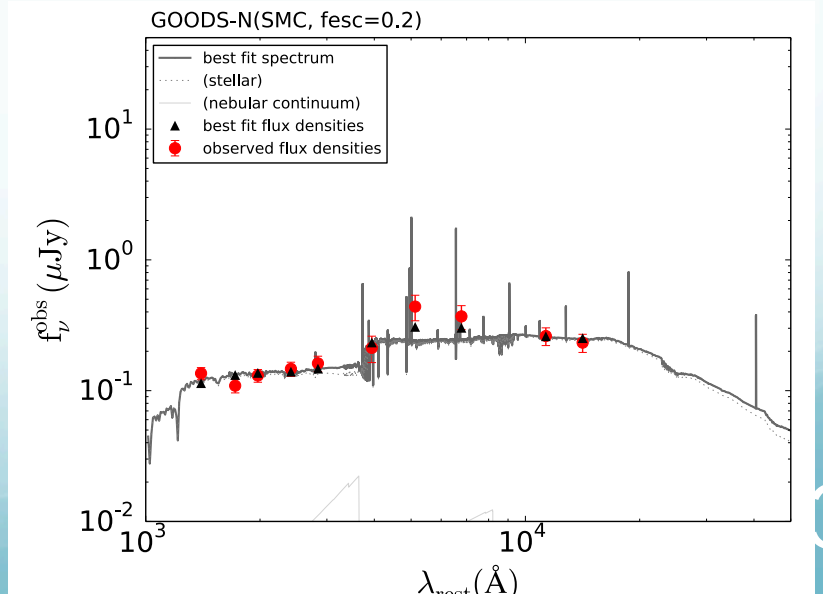


SED fitting(fesc=0.2)







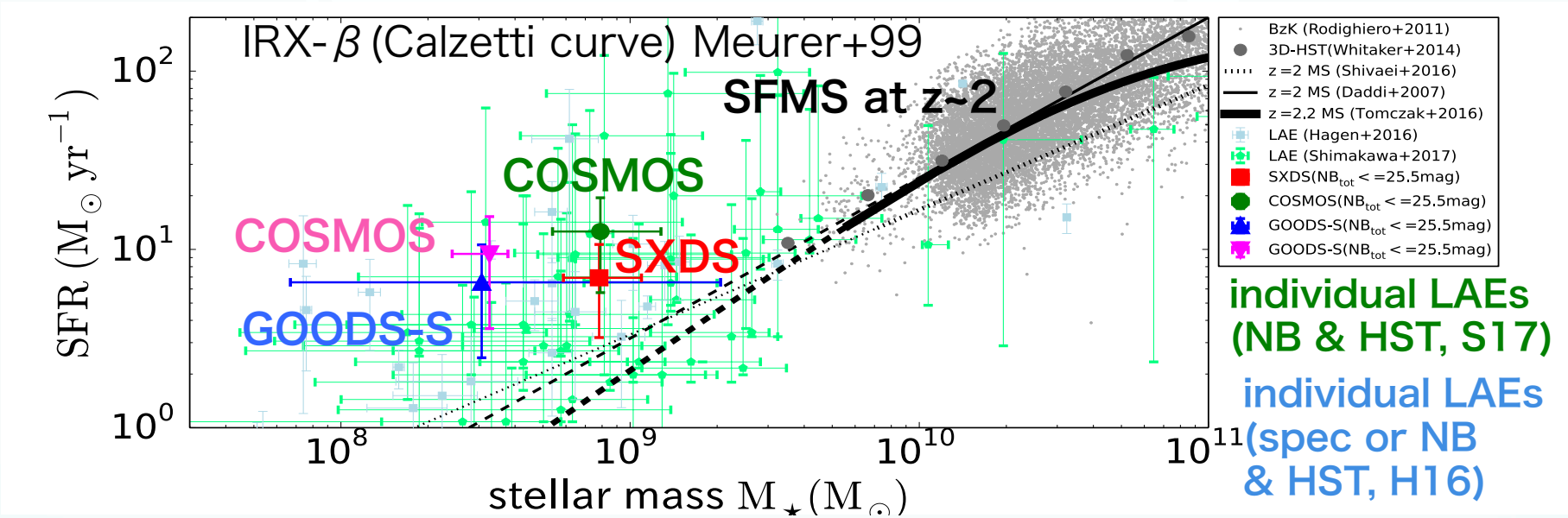


SED fitting(fesc=0.2)

Table 1
Results of SED fitting

attenuation curve	$M_\star$ ($10^8 M_\odot$)	$E(B-V)_\star[A_{1600}]$ (mag)	Age (Myr)	SFR ($M_\odot yr^{-1}$)	f_{esc}^{ion}	χ_r^2
SXDS						
Calzetti	$7.81^{+3.13}_{-1.94}$	$0.11^{+0.02}_{-0.04}[1.1^{+0.2}_{-0.4}]$	$160.90^{+199.31}_{-70.42}$	$5.67^{+1.70}_{-1.98}$	$0.20^{+0.00}_{-0.00}$	0.698
SMC	$8.87^{+3.27}_{-0.91}$	$0.05^{+0.01}_{-0.02}[0.6^{+0.1}_{-0.2}]$	$321.03^{+249.85}_{-66.03}$	$3.34^{+0.39}_{-0.70}$	$0.20^{+0.00}_{-0.00}$	0.628
COSMOS						
Calzetti	$7.89^{+4.89}_{-2.50}$	$0.18^{+0.03}_{-0.04}[1.8^{+0.3}_{-0.4}]$	$71.87^{+130.69}_{-39.87}$	$12.31^{+6.41}_{-4.86}$	$0.20^{+0.00}_{-0.00}$	0.667
SMC	$13.94^{+3.12}_{-3.61}$	$0.07^{+0.02}_{-0.01}[0.8^{+0.2}_{-0.1}]$	$404.16^{+166.73}_{-176.88}$	$4.21^{+1.18}_{-0.50}$	$0.20^{+0.00}_{-0.00}$	0.482
GOODS-N						
Calzetti	$3.26^{+0.52}_{-0.84}$	$0.20^{+0.02}_{-0.03}[2.0^{+0.2}_{-0.3}]$	$26.30^{+16.20}_{-11.85}$	$13.26^{+5.08}_{-3.94}$	$0.20^{+0.00}_{-0.00}$	0.868
SMC	$7.60^{+3.74}_{-1.93}$	$0.06^{+0.02}_{-0.03}[0.7^{+0.2}_{-0.4}]$	$321.03^{+319.51}_{-140.50}$	$2.86^{+0.83}_{-0.80}$	$0.20^{+0.00}_{-0.00}$	1.300
GOODS-S						
Calzetti	$3.07^{+17.49}_{-2.40}$	$0.14^{+0.05}_{-0.13}[1.4^{+0.5}_{-1.3}]$	$37.00^{+1397.00}_{-34.12}$	$9.00^{+23.39}_{-7.14}$	$0.20^{+0.00}_{-0.00}$	0.101
SMC	$10.26^{+10.58}_{-9.69}$	$0.02^{+0.07}_{-0.01}[0.2^{+0.8}_{-0.1}]$	$570.89^{+863.12}_{-568.37}$	$2.23^{+24.48}_{-0.35}$	$0.20^{+0.00}_{-0.00}$	0.120

compared with the previous work

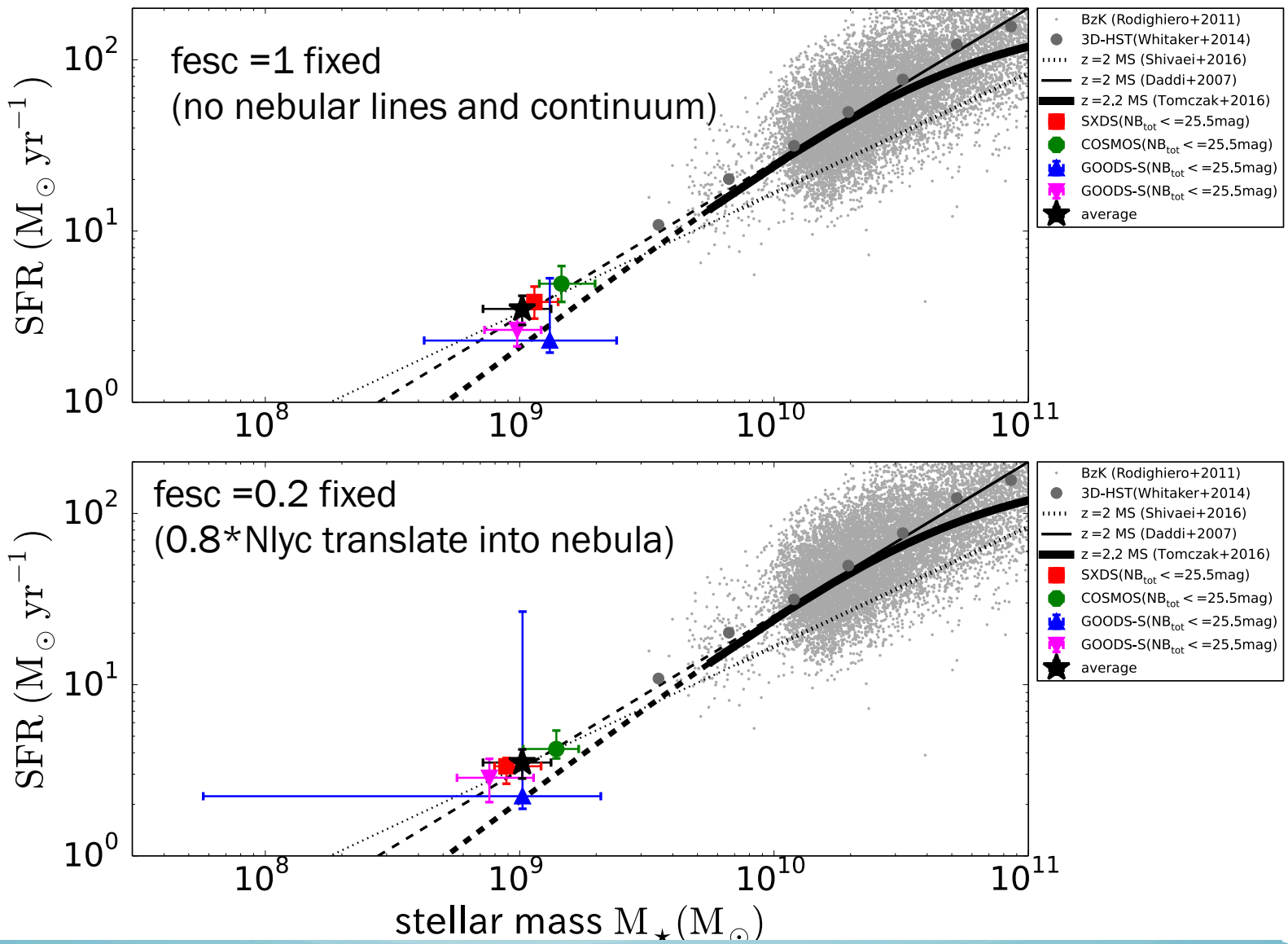


Assuming the Calzetti curve and IRX-β relation

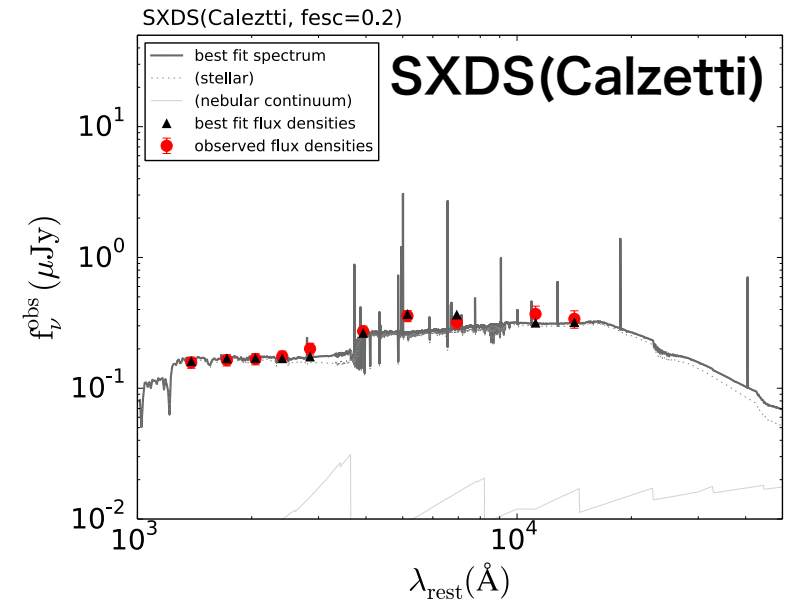
- **Our LAEs lie similary to the previous work**

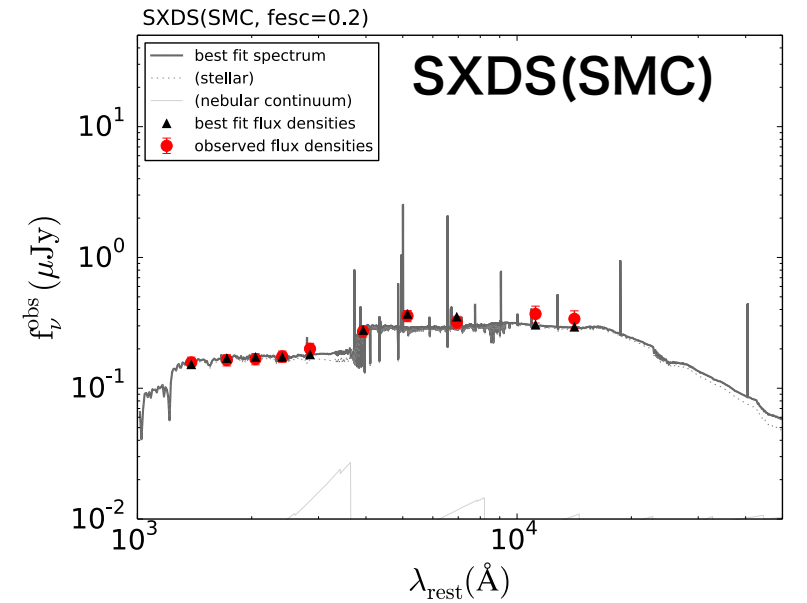
Shivaei+16;Whitaker+14; Rodighiero+11; Daddi+07; Kusakabe+15; Hagen+16; Shimakawa+16

Ms vs SFR (fesc=1)



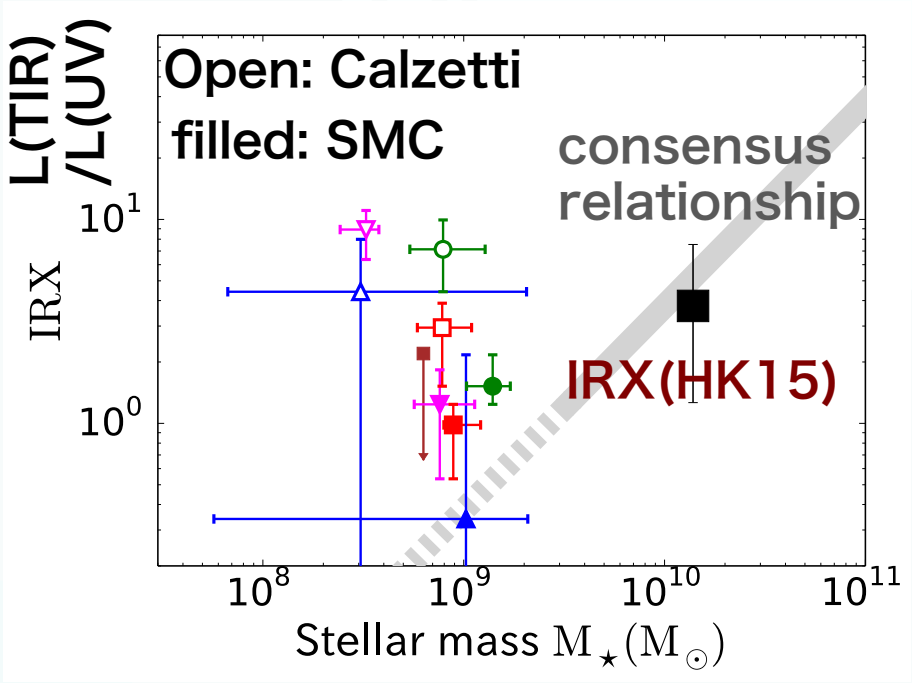
Stacked SED fit

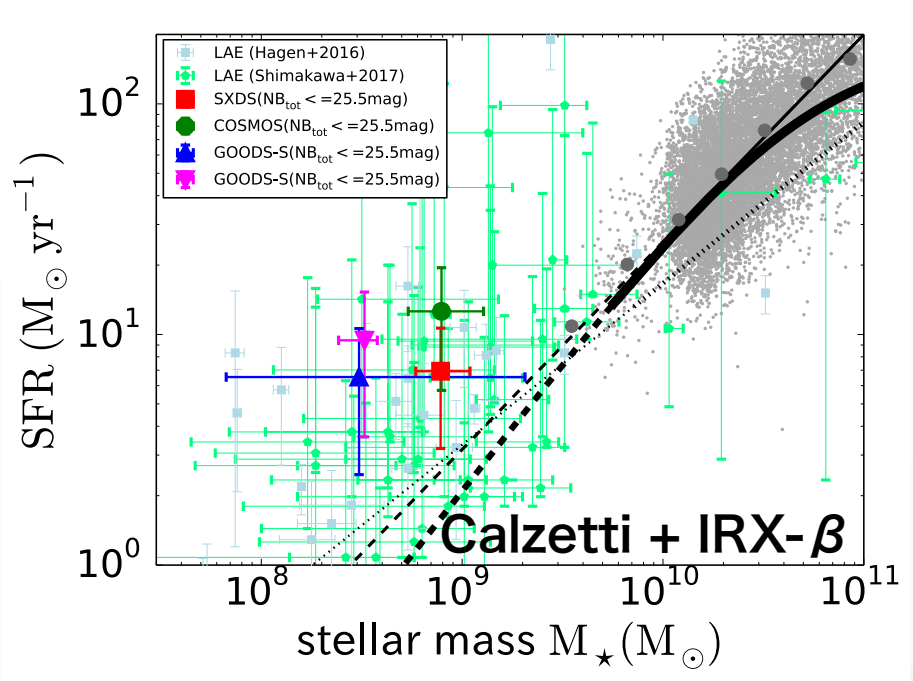




NBtot>=25.5mag

Ms vs IRX: prefer SMC



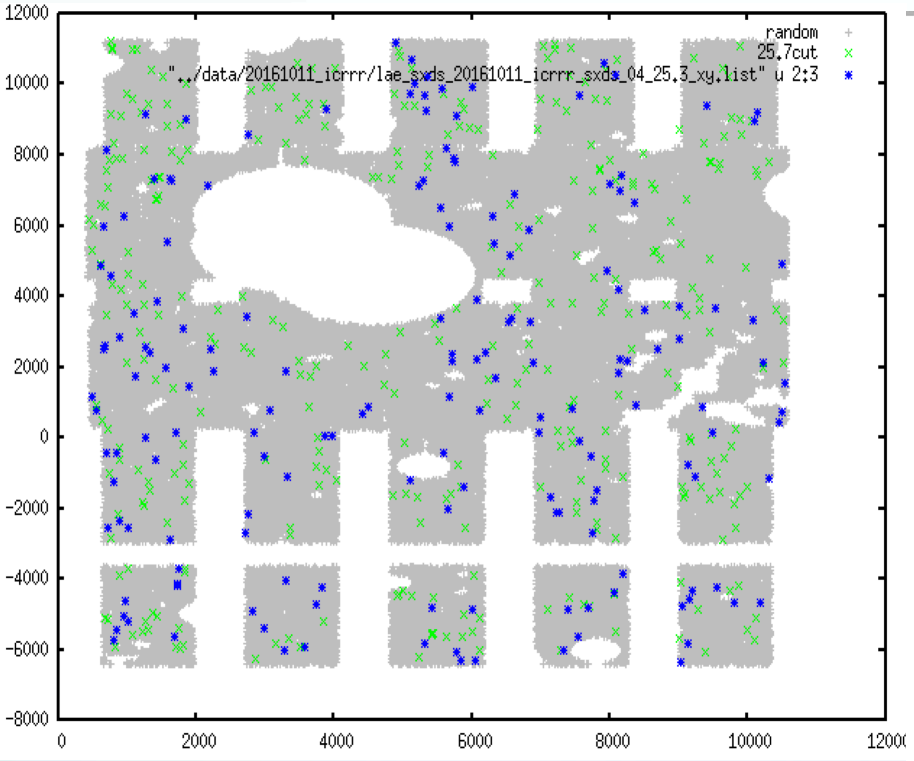


- SMC: our LAEs lie on the consensus relation also consistent with upper limit of IRX < 2.2 (3σ)
- Calzetti: fIVE times higher IRX than those w the SMC curve Ms and SFR of our LAEs are consistent with those of previous studies

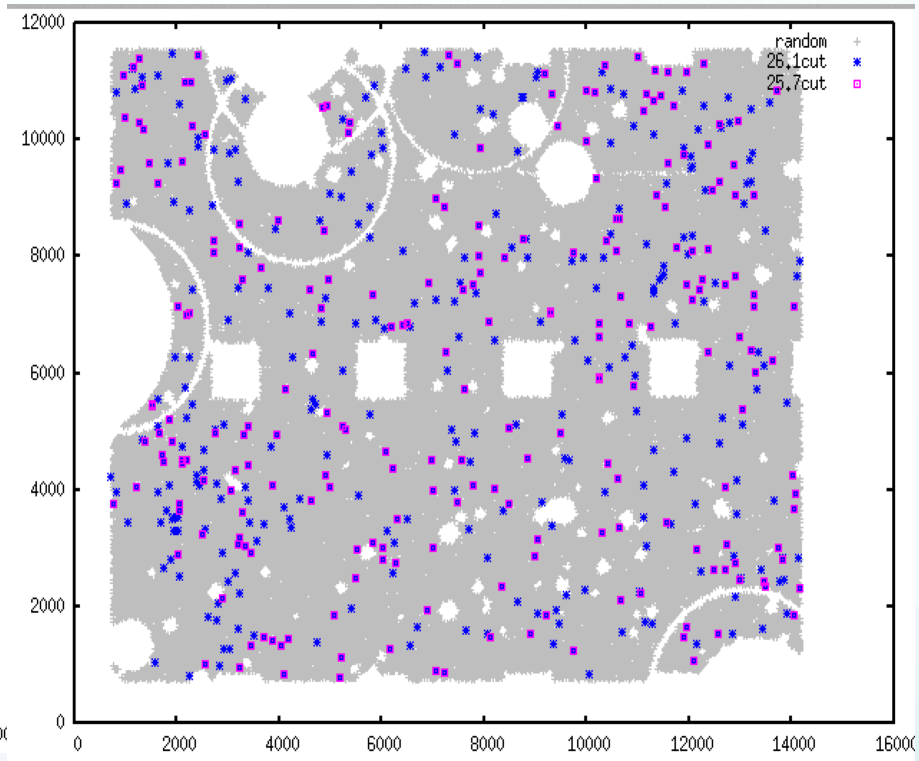
→the SMC curve is adopted

Bowens+16; HK+15; Shivaei+16;Whitaker+14; Rodighiero+11; Daddi+07

Sky distribution

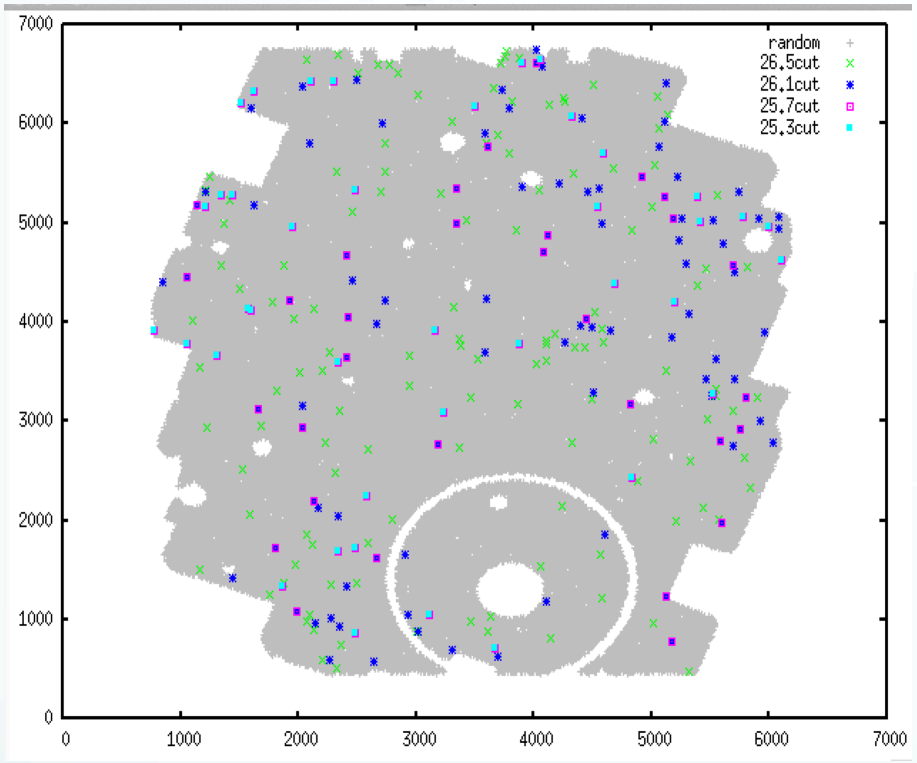


SXDS: 1240arcmin^2, 0.2”/pix

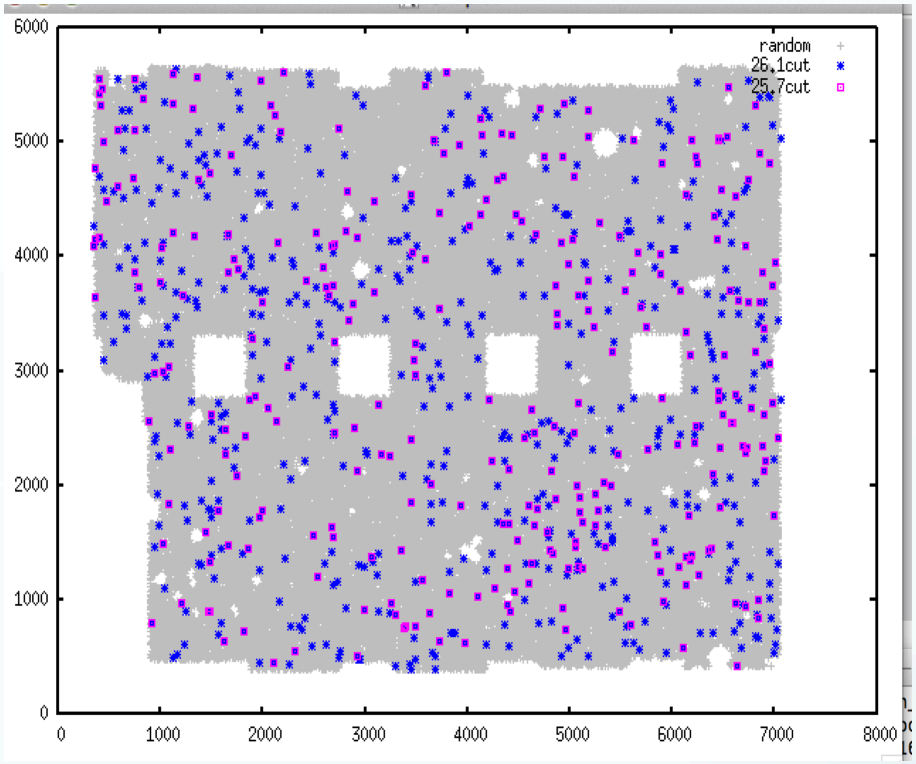


COSMOS: 740arcmin^2, 0.15”/pix

Sky distribution

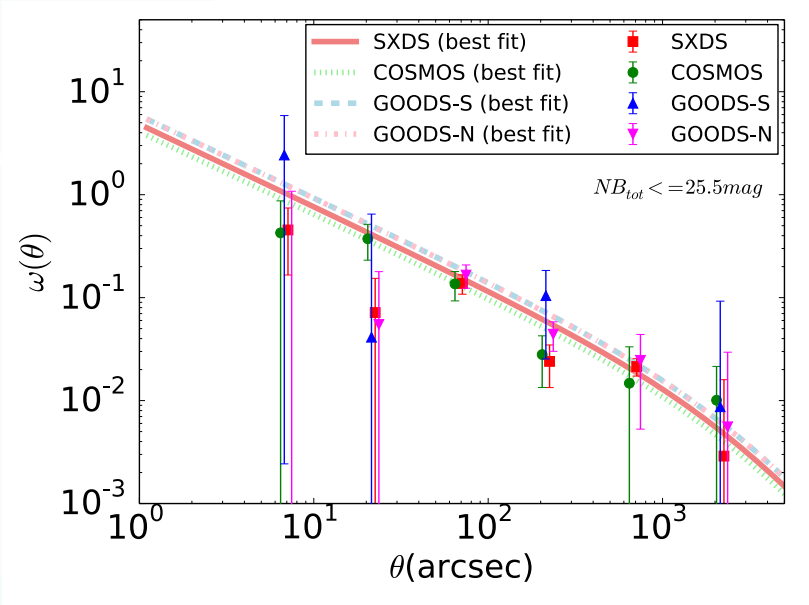


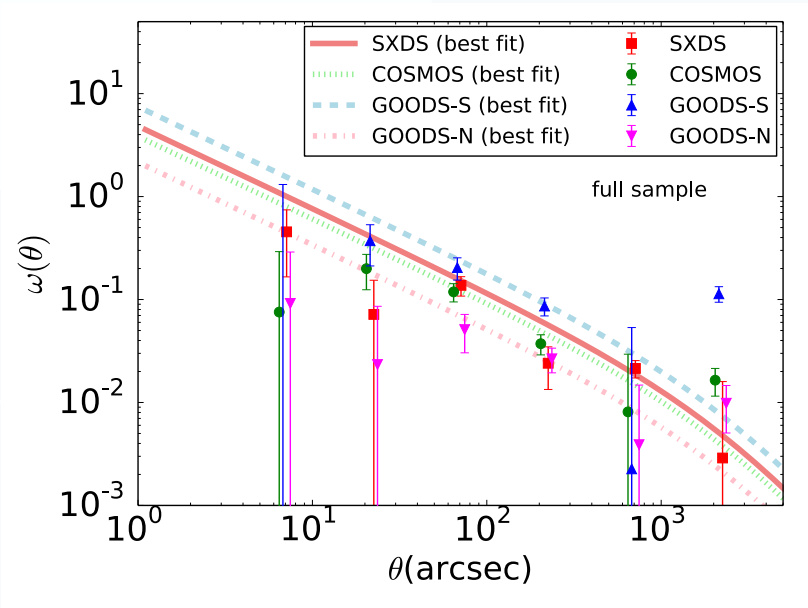
GOODS-S: 580arcmin^2, 0.267”/pix



GOODS-N: 780arcmin^2, 0.3”/pix

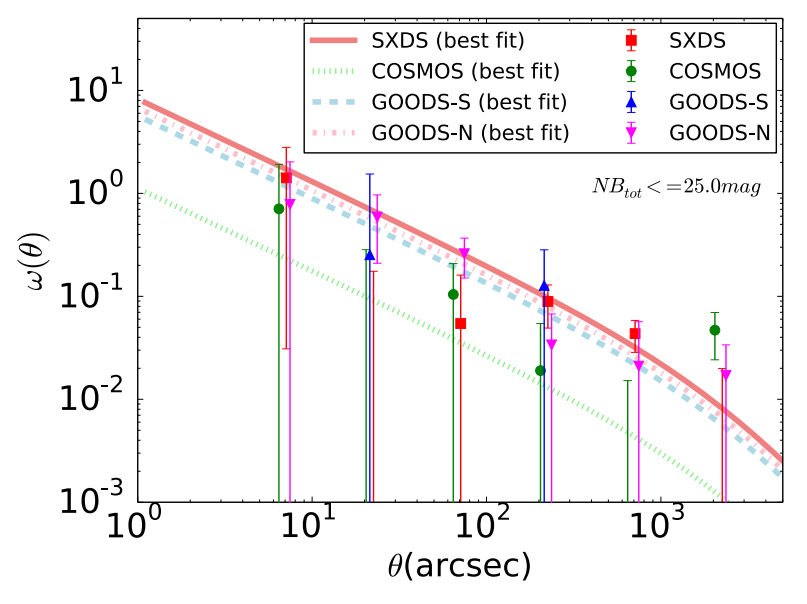
Clustering Analysis

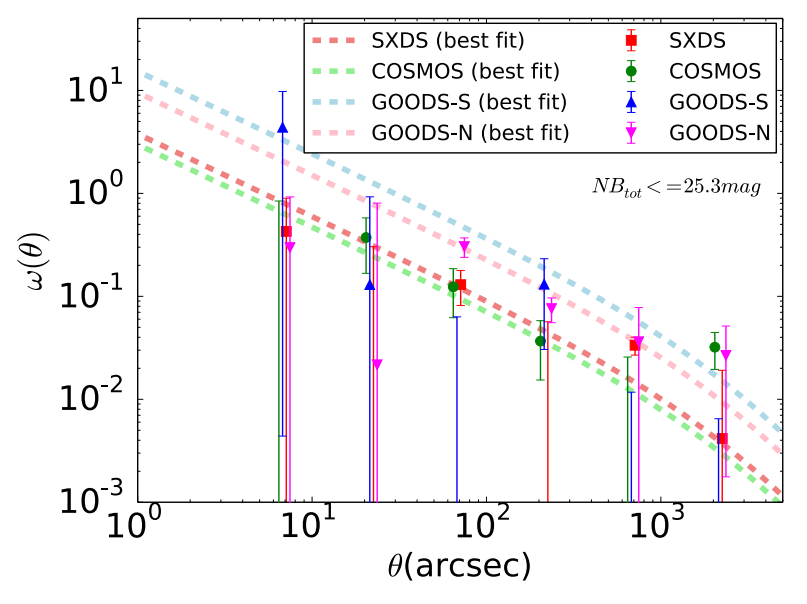


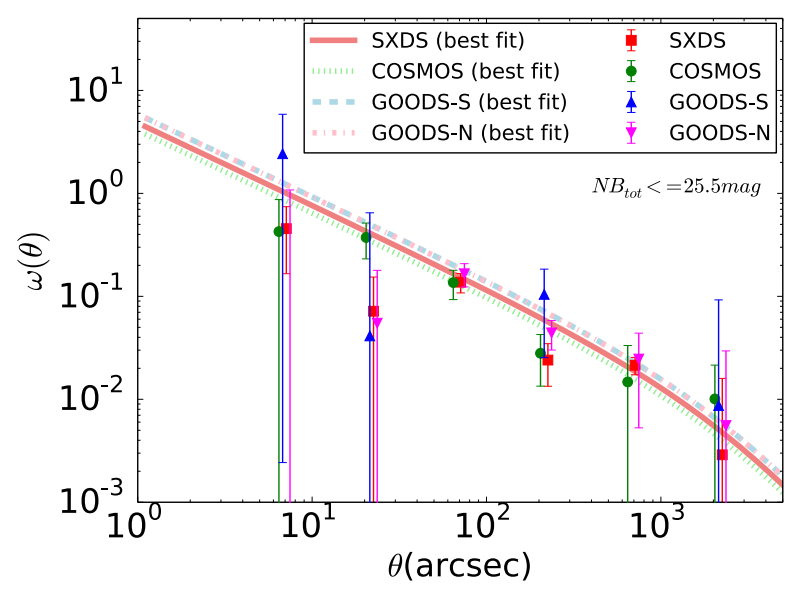


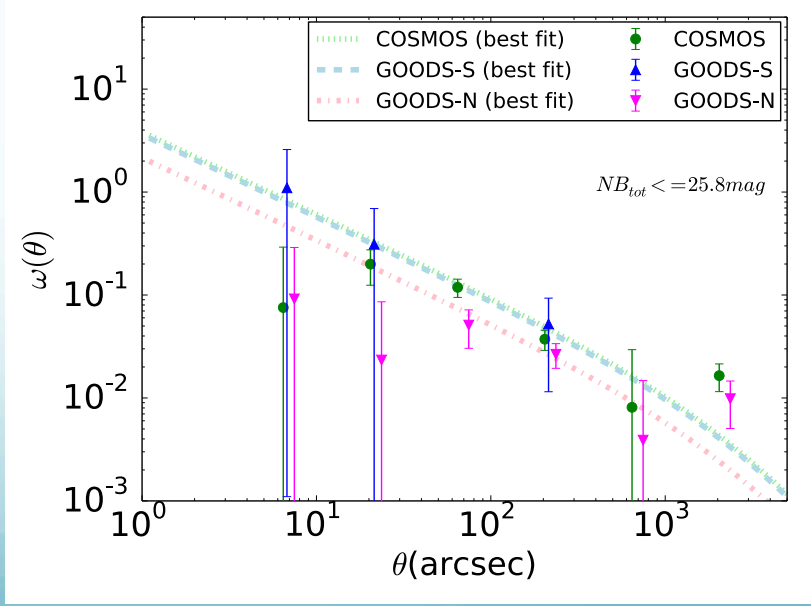
- ACF observation: Landy & Szalay+93 (error: poisson)
- ACF model: β=0.8, fitting range=40”-1000”
- bias factor-halo mass: Tinker+10
- 左だけ、右 文章

ACF

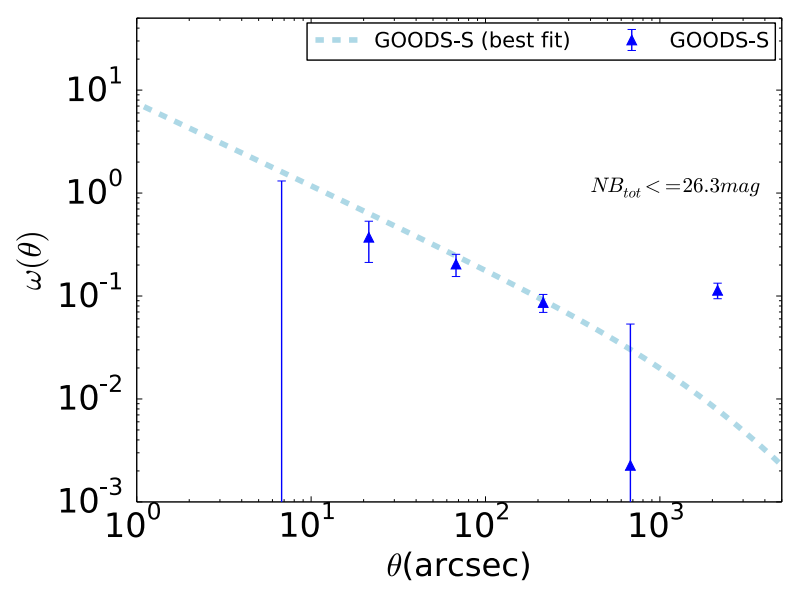

SXDS (best fit)
COSMOS (best fit)
GOODS-S (best fit)
GOODS-N (best fit)
SXDS
COSMOS
GOODS-S
GOODS-N
$NB_{tot} <= 25.0 mag$
$\omega(\theta)$
θ(arcsec)

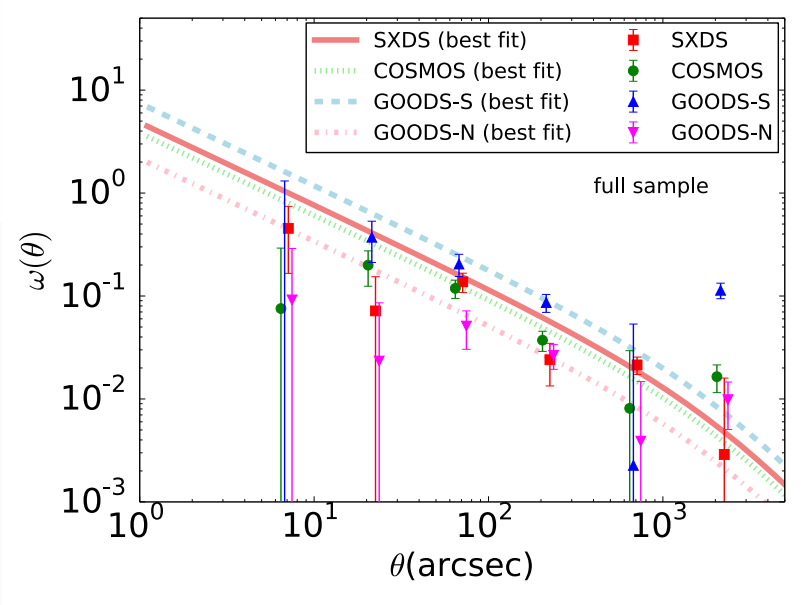

SXDS (best fit)
COSMOS (best fit)
GOODS-S (best fit)
GOODS-N (best fit)
SXDS
COSMOS
GOODS-S
GOODS-N
$NB_{tot} <= 25.3 mag$
$\omega(\theta)$
θ(arcsec)


SXDS (best fit)
COSMOS (best fit)
GOODS-S (best fit)
GOODS-N (best fit)
SXDS
COSMOS
GOODS-S
GOODS-N
$NB_{tot} <= 25.5 mag$
$\omega(\theta)$
θ(arcsec)

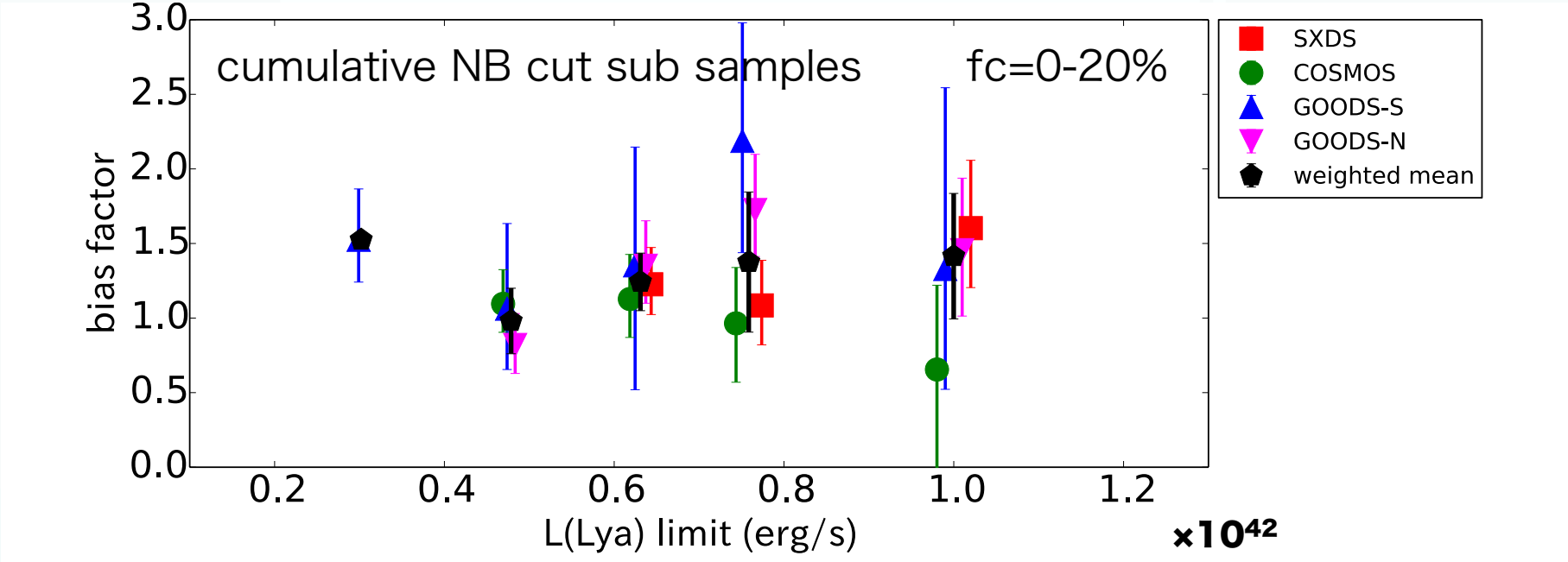

COSMOS (best fit)
GOODS-S (best fit)
GOODS-N (best fit)
COSMOS
GOODS-S
GOODS-N
$NB_{tot} <= 25.8 mag$
$\omega(\theta)$
θ(arcsec)

ACF


GOODS-S (best fit)
GOODS-S
$NB_{tot} <= 26.3 mag$
$\omega(\theta)$
θ(arcsec)

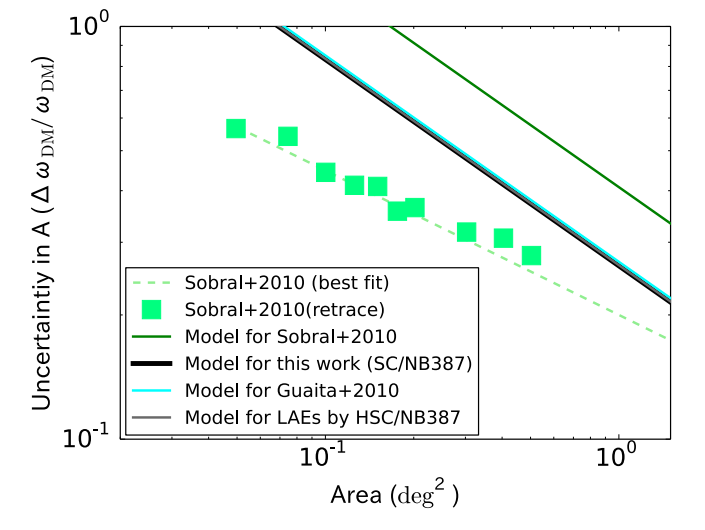

SXDS (best fit)
COSMOS (best fit)
GOODS-S (best fit)
GOODS-N (best fit)
SXDS
COSMOS
GOODS-S
GOODS-N
full sample
$\omega(\theta)$
θ(arcsec)

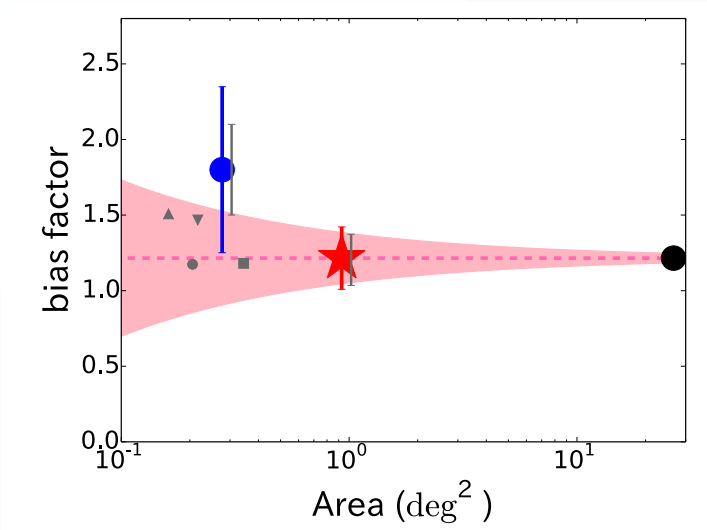
Bias factor



- large cosmic variance > statistics errors ?
- No significant dependence on L(Lya) limit
- No significant dependence on EW (NB excess)

Cosmic Variance





$$b(\text{field}) = \sqrt{\frac{\omega_{\rm DM}(\text{field})}{\langle\omega_{\rm DM}\rangle}\frac{\omega_{\rm gal}(\text{field})}{\omega_{\rm DM}(\text{field})}} = \sqrt{\frac{\omega_{\rm DM}(\text{field})}{\langle\omega_{\rm DM}\rangle}}b_{\rm int}$$

assumption: bint is constant
CV originate from variation of ωDM(field)

$$\sigma^2_{\rm DM}(\theta) \sim \frac{1}{\pi\Omega_{\rm s}}\int {\rm K}\,{\rm dK} J_0^2({\rm K}\theta)\,{\rm P}_2^2({\rm K})$$

k: FT θ
P2(K): FT $\omega(\theta)$ (Kohn 2009)
Ω: area size

$$\frac{\Delta\omega_{\rm DM}}{\omega_{\rm DM}} \propto \Omega^{-0.5}$$

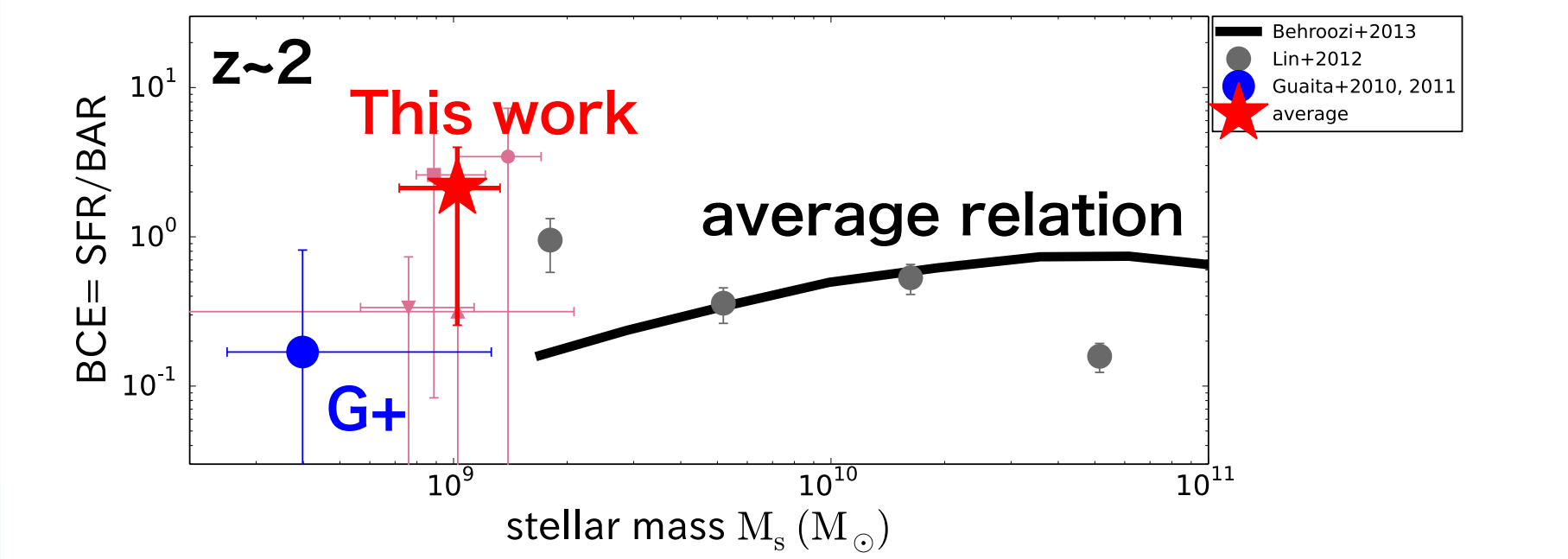
(->Hamana-san's code)

$$\frac{\Delta b_{g,eff}}{b_{g,eff}} = \frac{1}{2}\sqrt{\left(\frac{\Delta A_\omega}{A_\omega}\right)^2 + \left(\frac{\Delta\omega_{\rm DM}}{\omega_{\rm DM}}\right)^2}$$

$$\begin{aligned}\sigma_a^2 &= \overline{(a-\overline{a})^2} \\ &= \frac{1}{(\sum x_i^2)^2}\left(\sum_i x_i^2\overline{(y_i-\overline{y_i})^2} + 2\sum_{i<j} x_i x_j \overline{(y_i-\overline{y_i})(y_j-\overline{y_j})}\right) \\ &= \frac{1}{(\sum x_i^2)^2}\left(\sum_i x_i^2\sigma_i^2 + 2\sum_{i<j} x_i x_j \sigma_{i,j}^2\right)\end{aligned}$$

fitting: y = a * θ^-0.8

③ Ms vs BCE = SFR/BAR



- BCE~2.1±1.9
- higher than that of extrapolated B13 relation