神戸高専

Please see Ogura et al. (2020), ApJ, 895, 9

Emission line galaxy model with a semi-analytic galaxy evolution model, "New Numerical Galaxy Catalog (ν^2GC)"

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The New Numerical Galaxy Catalog (ν^2GC)

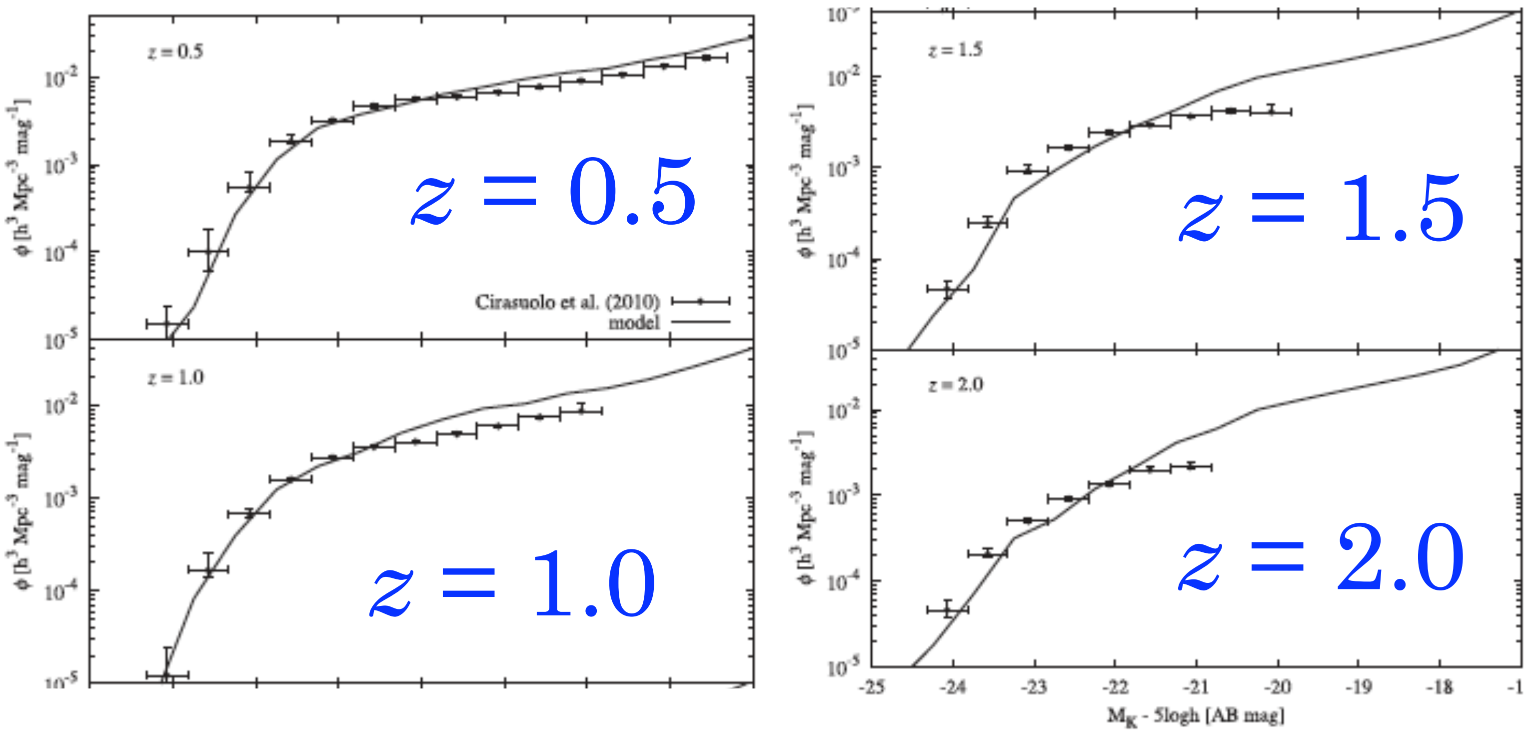
ν^2GC: State-of-art N-body simulation + phenomenological baryonic evolution model
(N-body; Ishiyama+15,21, Model; Makiya+16, Shirakata+19, Oogi+22)

- large comoving volume (up to ~4.5 Gpc^3)
- successful to reproduce various statistical properties of galaxies
  - HI mass function, luminosity function (FL), cosmic star-formation history...

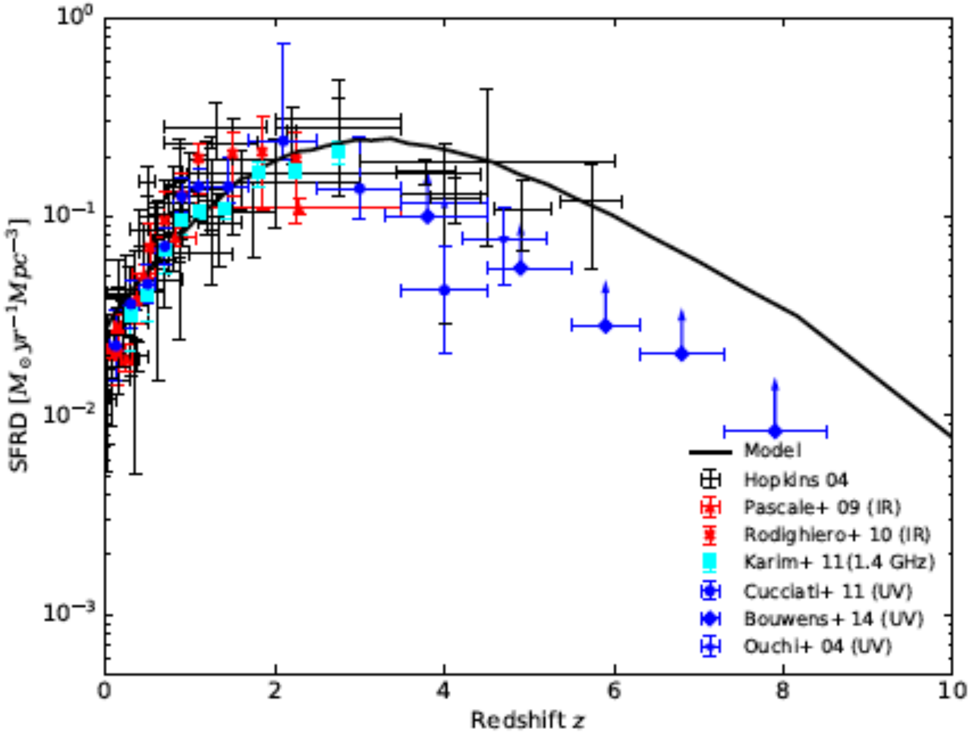
The New Numerical Galaxy Catalog (ν^2GC)

- The ν^2GC is successful to reproduce various statistical properties of galaxies

K-band luminosity function (LF) (Makiya+16)



SFR density (Shirakata+19)



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"Uchuu (宇宙)" means "cosmos" in Japanese

- **ν^2GC has been updated to "Uchuu-ν^2GC"** by utilizing *state-of-art N*-body simulation (Ishiyama et al. 2021, Oogi et al. 2022)

＊The work introduced in this talk is based on the previous version of the ν^2GC

The New Numerical Galaxy Catalog (ν^2GC)

ν^2GC simulations
(Ishiyama et al. 2015)

Name	N	L (h^{-1} Mpc)	m (h^{-1} $M_\odot$)
ν^2GC–L	8192^3	1120.0	2.20×10^8
ν^2GC–M	4096^3	560.0	2.20×10^8
ν^2GC–S	2048^3	280.0	2.20×10^8
ν^2GC–SS	512^3	70.0	2.20×10^8
ν^2GC–H1	2048^3	140.0	2.75×10^7
ν^2GC–H2	2048^3	70.0	3.44×10^6
ν^2GC–H3	4096^3	140.0	3.44×10^6

Uchuu-ν^2GC simulations
(Ishiyama et al. 2021)

Name	N	L (h^{-1}Mpc)	m_p (h^{-1}M$_\odot$)
Uchuu	12800^3	2000.0	3.27×10^8
mini-Uchuu	2560^3	400.0	3.27×10^8
micro-Uchuu	640^3	100.0	3.27×10^8
Shin-Uchuu	6400^3	140.0	8.97×10^5
Phi-4096	4096^3	16.0	5.13×10^3
GLAM	2000^3	2000.0	8.60×10^{10}

N: number of particles
L: box size (comoving)
m: mass resolution

The New Numerical Galaxy Catalog (ν^2GC)

ν^2GC simulations

hiyama et al. 2015)

550 billion particles

		$L\,(h^{-1}$ Mpc)	$m\ (h^{-1}\ M_\odot)$
ν^2GC–L	8192^3	1120.0	2.20×10^8
ν^2GC–M	4096^3	560.[illegible]	2.20×10^8
ν^2GC–S	2048^3	[illegible]	[illegible]20×10^8
ν^2GC–SS	512^3	[illegible]	[illegible]20×10^8
ν^2GC–H1	2048^3	[illegible]	[illegible]75×10^7
ν^2GC–H2	2048^3	70.0	3.44×10^6
ν^2GC–H3	4096^3	140.0	3.44×10^6

~4.5 Gpc^3 volume

Uchuu-ν^2GC simulations

(Ishiyama et al. 2021)

2.1 trillion particles

	N	L (h^{-1}Mpc)	m_p ($h^{-1}\mathrm{M}_\odot$)
Uchuu	12800^3	2000.0	3.27×10^8
mini-Uchuu	2560^3	400[illegible]	3.27×10^8
micro-Uchuu	640^3	[illegible]	[illegible]$.27 \times 10^8$
Shin-Uchuu	6400[illegible]	[illegible]	[illegible]$.97 \times 10^5$
Phi-4096	4096[illegible]	[illegible]	[illegible]$.13 \times 10^3$
GLAM	2000^3	2000.0	8.60×10^{10}

~25.7 Gpc^3 volume

N: number of particles
L: box size (comoving)
m: mass resolution

The galaxy formation model of the ν^2GC

・DM halo is filled with the **hot gas** with virial temperature

radiation cooling

・form a **cold gas disk**

・star-formation in the disk: $SFR = \frac{M_{\mathrm{cold}}}{\tau_{\mathrm{star}}}$

SN feedback

reheat the cold gas

$$\tau_{\mathrm{reheat}} = \frac{\tau_{\mathrm{star}}}{\beta(V_{\mathrm{d}})}$$

(Type-Ia SNe are neglected)

See Makiya+16 and Shirakata+19 for more details

Major/minor merger

→ Starburst & gas accretion onto SMBH

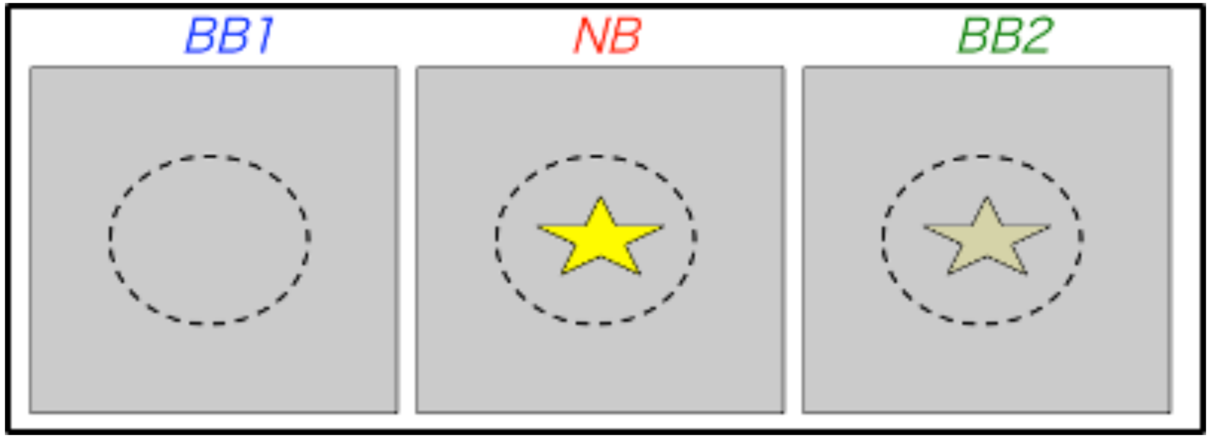
$$\Delta M_{\mathrm{star,burst}} = \frac{\alpha}{\alpha + \beta(V_{\mathrm{d}}) + f_{\mathrm{BH}}} M_{\mathrm{cold}}^{0}$$

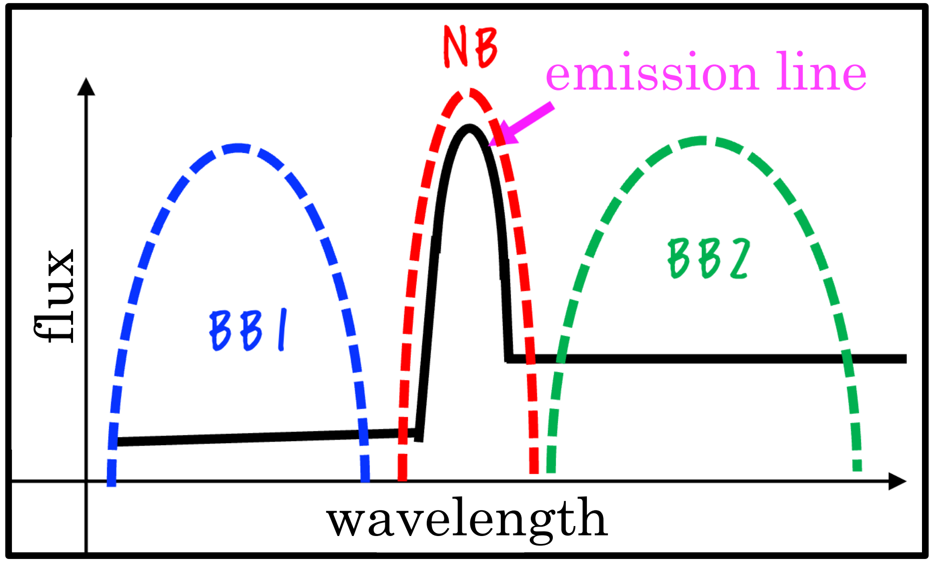
AGN feedback

→ gas cooling is quenched

Emission-line galaxies (ELGs)

- galaxies with strong emission lines (Lyα, [O II], [O III], Hβ, Hα)
- can be observed over a significantly wide area by narrow-band (NB) filters + wide field cameras





- brighter in NB than in BB

	$z = 0$	1	2	3	4	5	6	7
Lyα (λ1216)					Optical			
[O II] (λ3727)	Optical			NIR				
Hβ (λ4861)	Optical		NIR					
[O III] (λλ4959,5007)	Optical		NIR					
Hα λ (6563)		NIR						

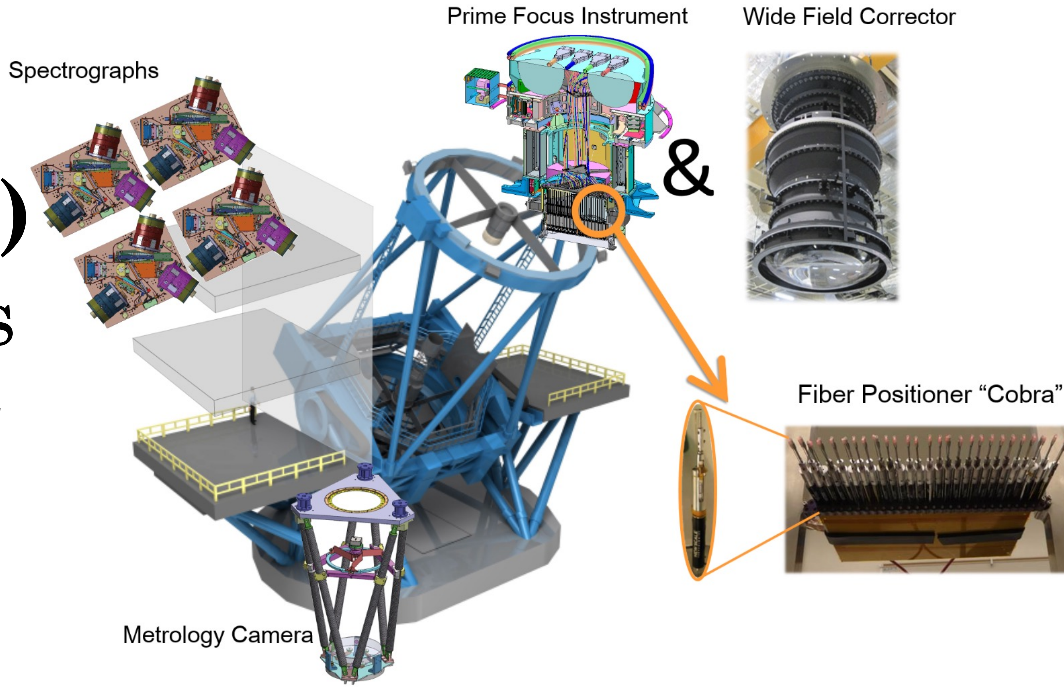
Wide field survey with the Subaru

Hyper Suprime-Cam (HSC)

- wide-field imaging camera on the prime focus of the 8.2 m Subaru telescope
- FoV: ~1.8 deg^2 (~1.5° in diameter)

Prime Focus Spectrograph (PFS)

- a wide-field spectrograph
- FoV: ~1.25 deg^2 (w/ 2386 fibers)

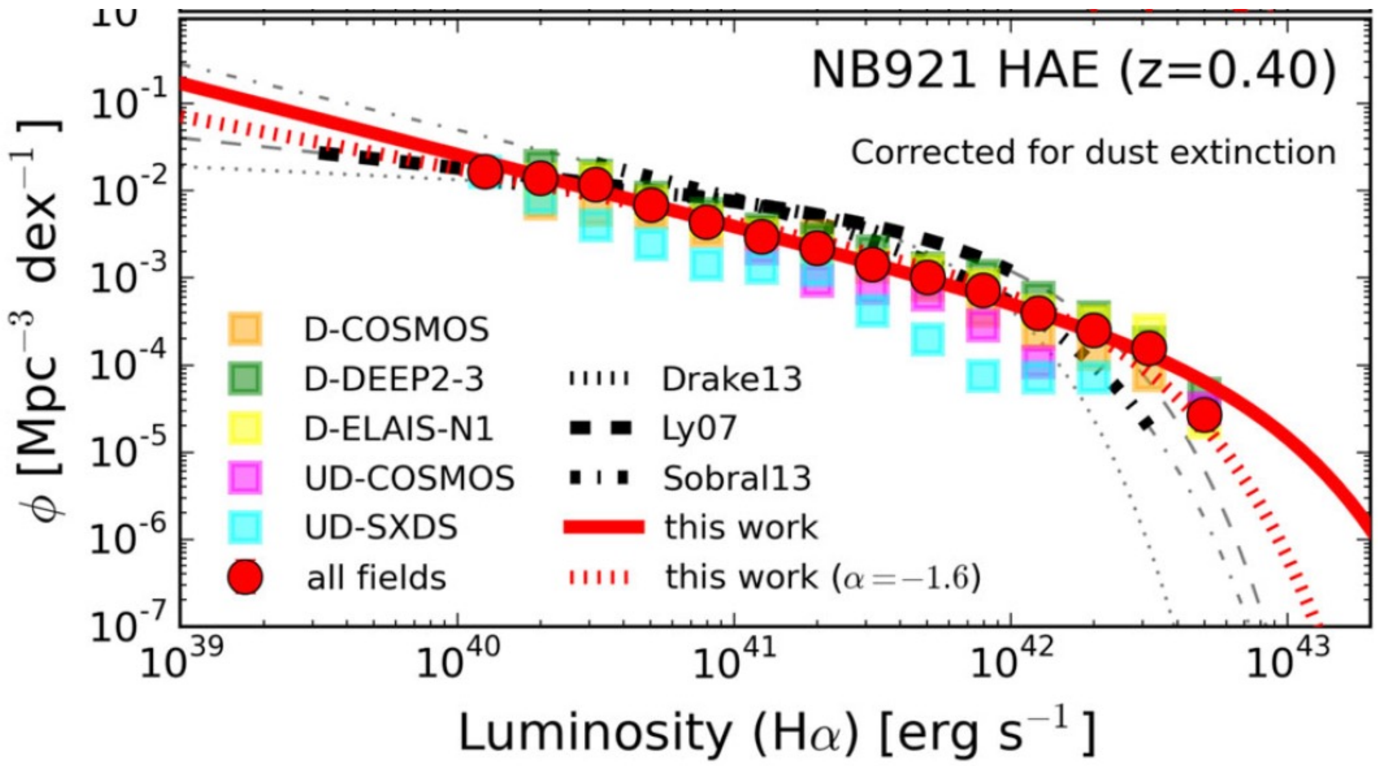


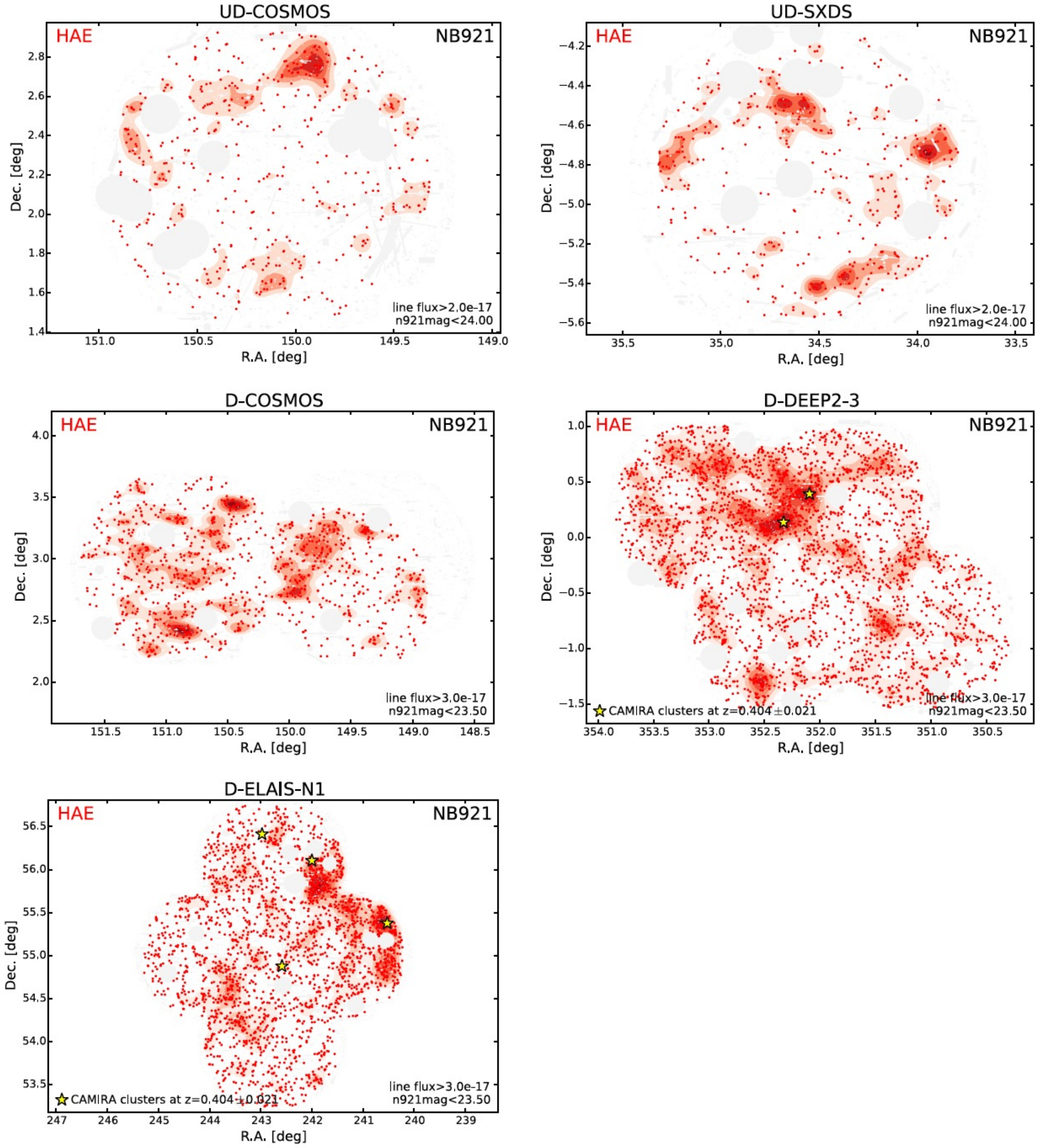
Subaru Strategic Program (SSP)

- HSC-SSP: completed, ~330 nights between 2018 – 2023, ~1200 deg^2
- PFS-SSP: ongoing,~360 nights between 2025 – 2030, ~1100 deg^2

HSC-SSP ELG survey

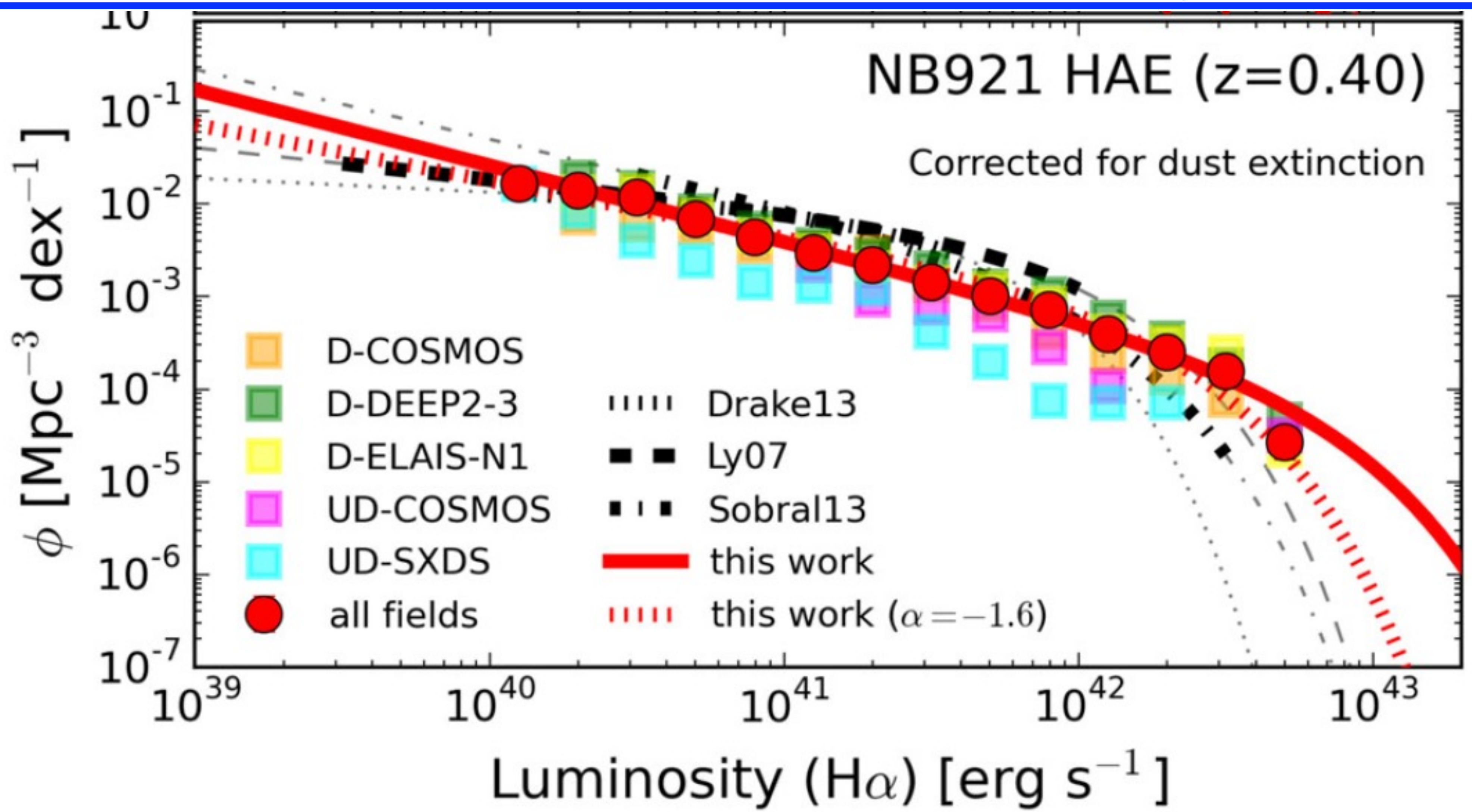
★Hα luminosity function (LF) at $z = 0.4$ by HSC-SSP





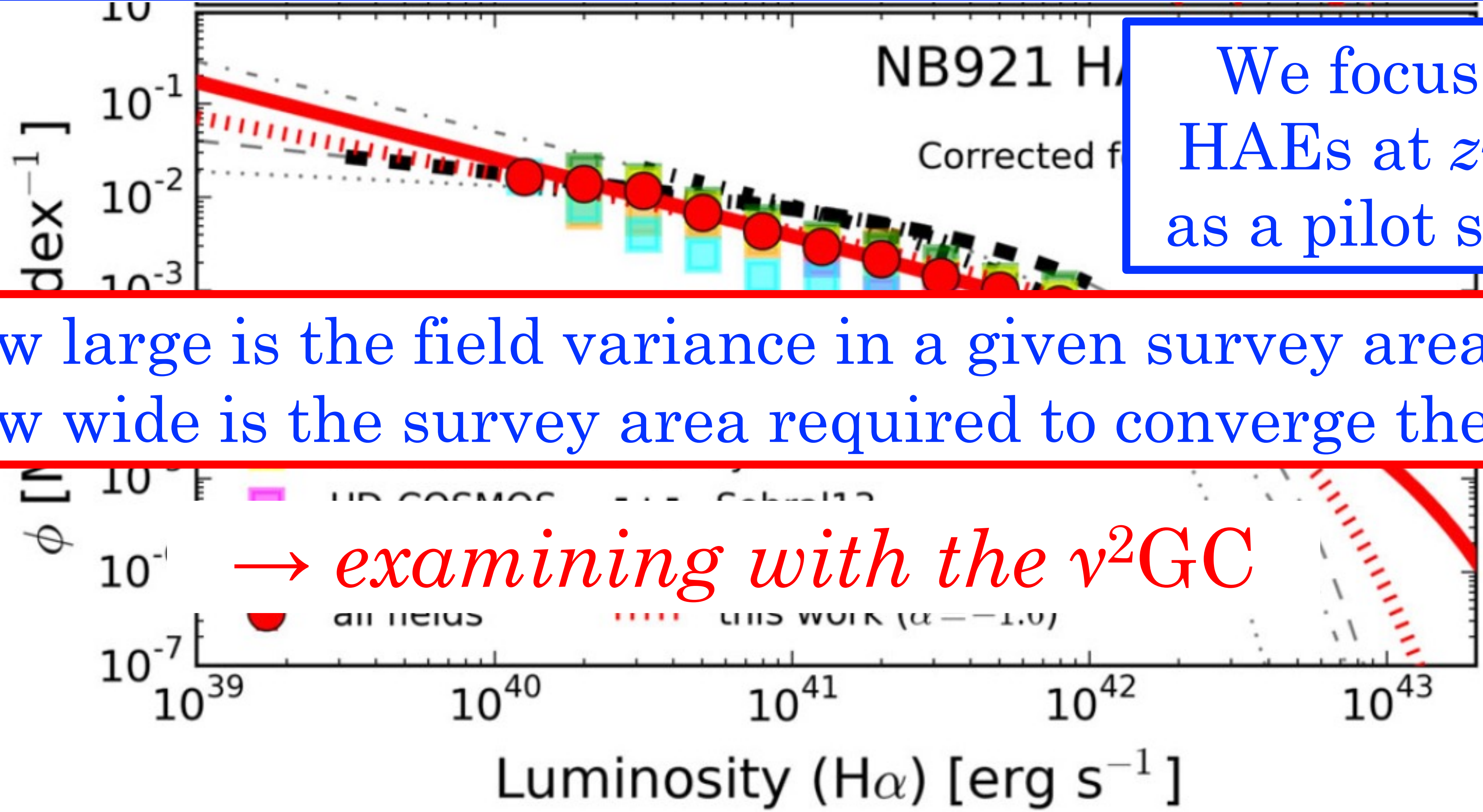
Field variance (cosmic variance") is a serious problem.

”field variance” on the HAE surveys



- Hα LFs show the variance up to ~1dex
- Hα LFs with different selection criteria show good agreement

”field variance” on the HAE surveys



We focus on HAEs at z~0.4 as a pilot study

How large is the field variance in a given survey area?
How wide is the survey area required to converge the LF?

→ *examining with the ν²GC*

- Hα LFs show the variance up to ~1dex
- Hα LFs with different selection criteria show good agreement

HAE model with ν^2GC

- $L_{\mathrm{H}\alpha}$ is simply calculated from the SFR adopting the Kennicutt (1998) relation (corrected for the Chabrier IMF)

$$L_{\mathrm{H}\alpha}^{\mathrm{int}}\,[\mathrm{erg\,s^{-1}}] = \frac{SFR\,[M_\odot\,\mathrm{yr}^{-1}]}{4.4\times10^{-42}}$$

<u>Dust extinction</u> (for continuum)

- dust-to-gas ratio ∝ gas metallicity
- optical depth ∝ column density
- dust geometry: slab dust
- extinction curve: Calzetti (2000) law

$$f_{\mathrm{neb}} \equiv \frac{E(B-V)_{\mathrm{star}}}{E(B-V)_{\mathrm{line}}}$$

We employ a fixed value: $f_{\mathrm{neb}} = 0.5$

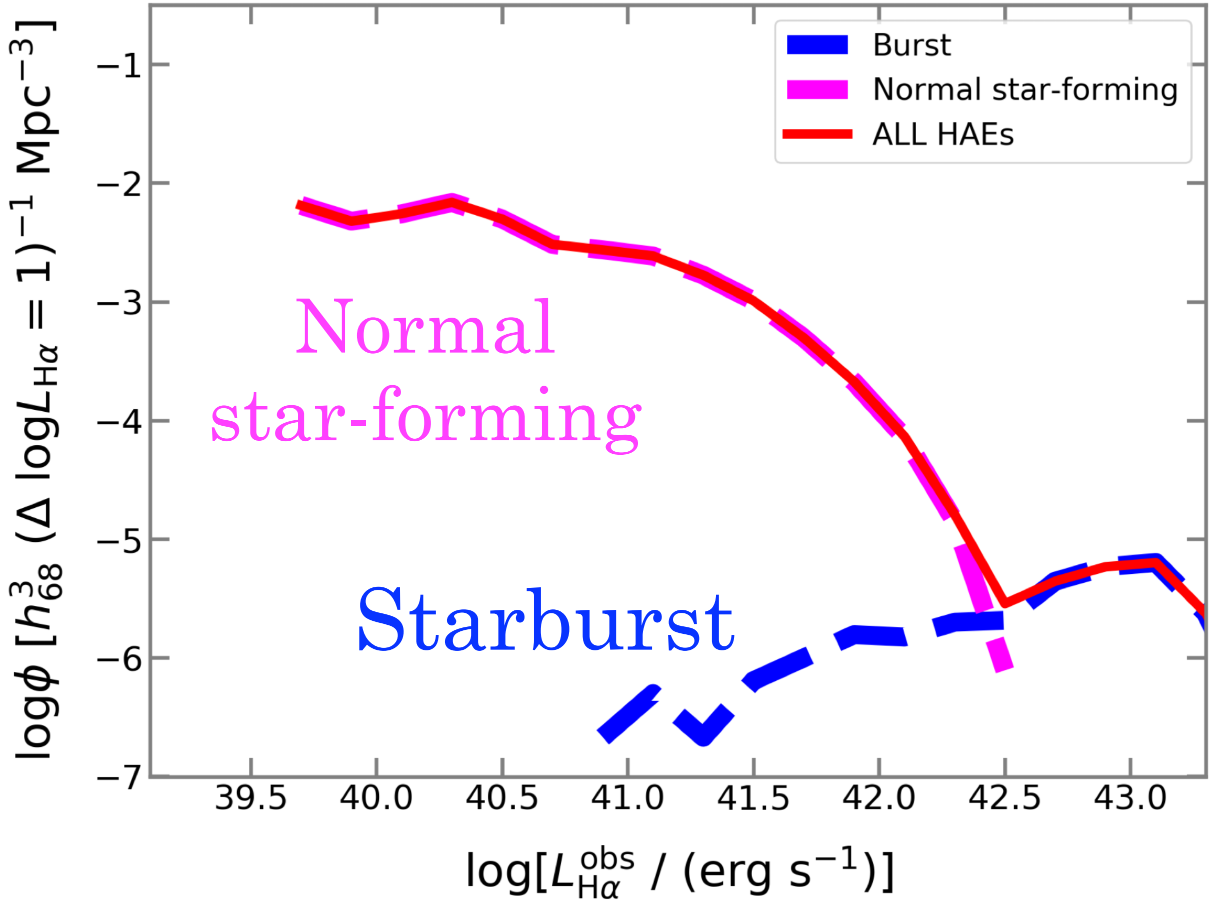
observed value @$z < 1$: $f_{\mathrm{neb}} = 0.44 - 0.6$

- Cut by cold gas fraction <u>(only for starbursts)</u>

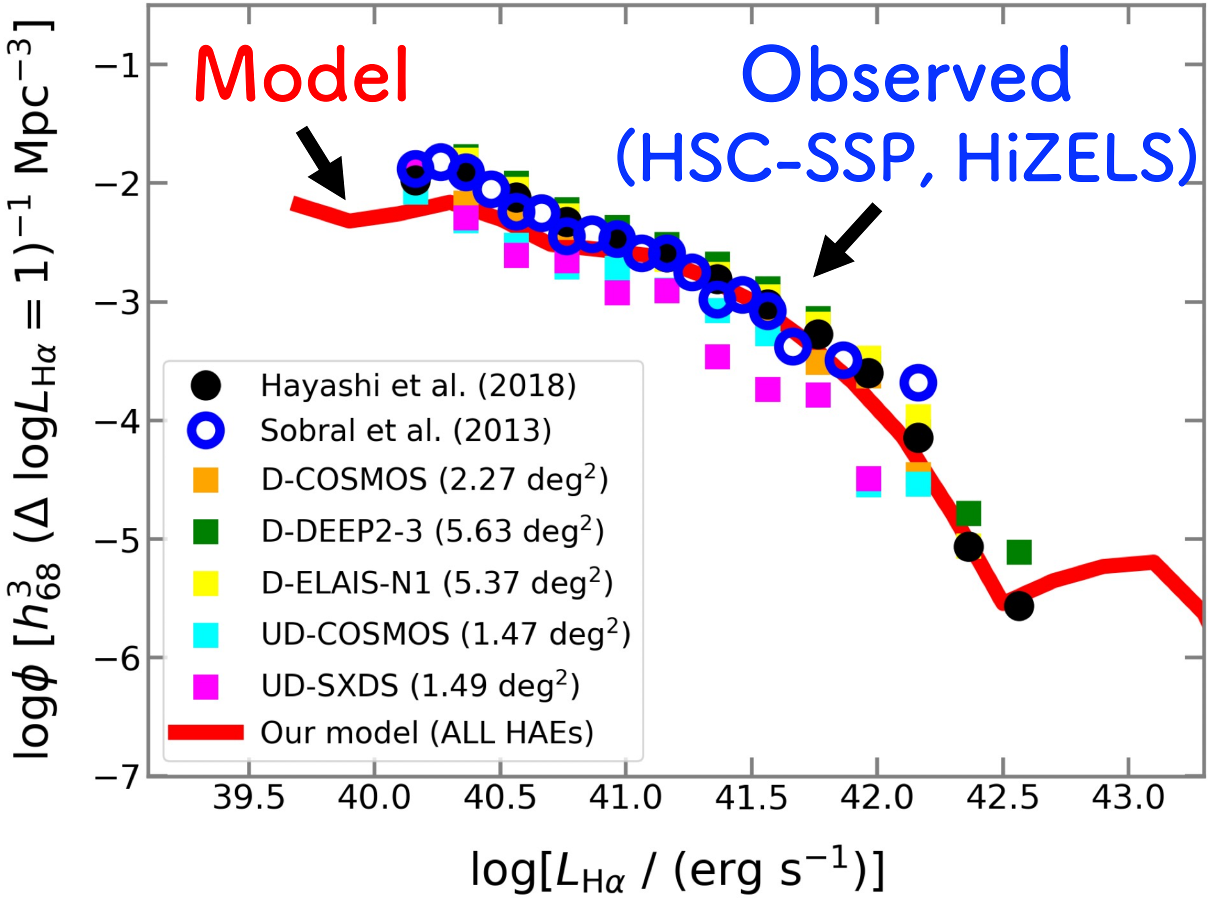
$$f_{\mathrm{gas}} \equiv \frac{M_{gas}}{M_{\mathrm{star}} + M_{\mathrm{gas}}} \geq 0.1$$

Hα luminosity function (@ $z = 0.4$)

Model LF

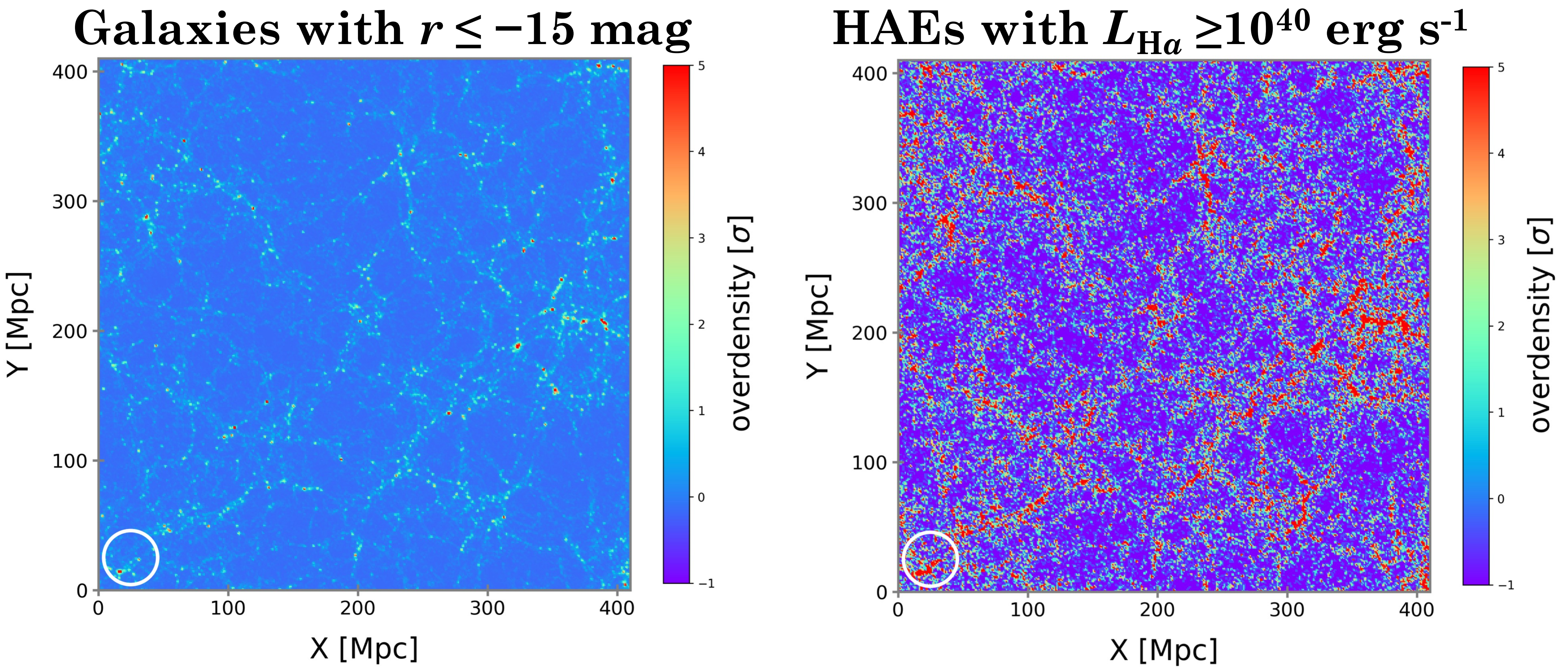


Comparison with observed LFs



- Our model well reproduces the observed Hα LFs

The overdensity (δ) map



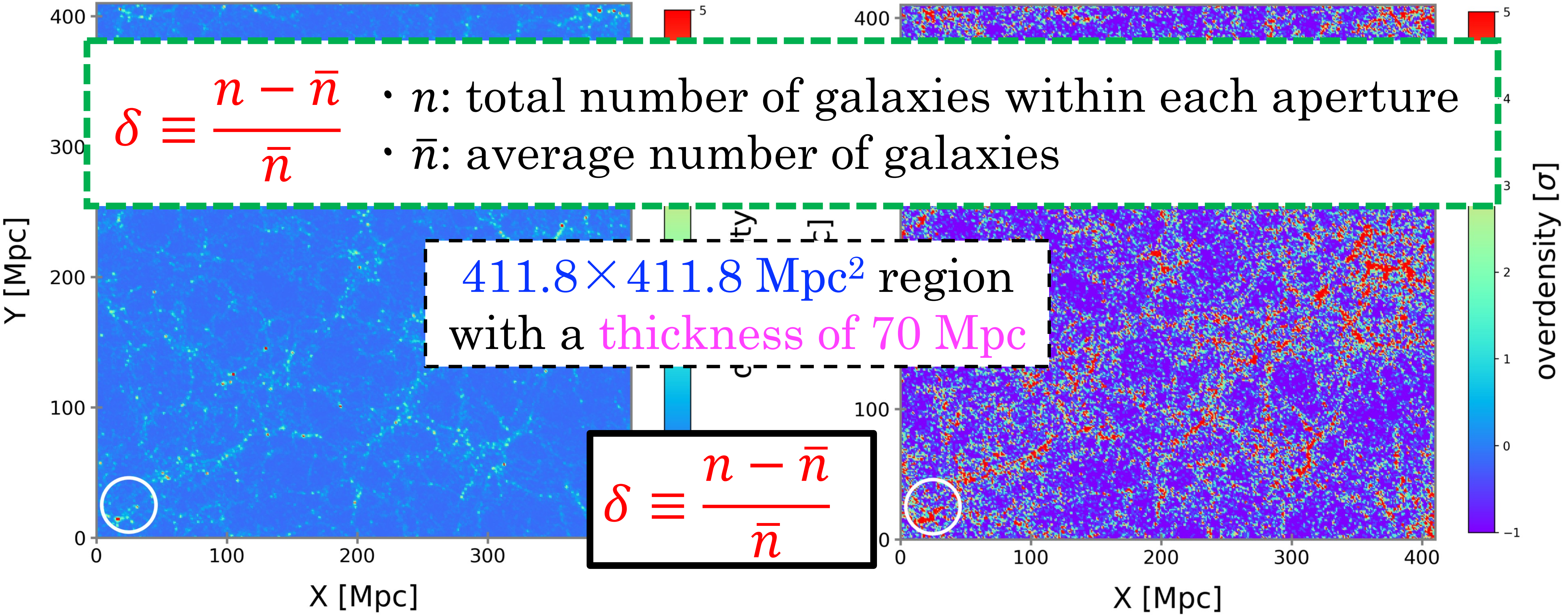
・HAEs show higher overdensity in clusters and filaments compared to all galaxies ($r \leq -15$ mag)

The overdensity (δ) map

Galaxies with $r \leq -15$ mag | **HAEs with $L_{\mathrm{H\alpha}} \geq 10^{40}$ erg s^{-1}**

$$\delta \equiv \frac{n - \bar{n}}{\bar{n}}$$

- n: total number of galaxies within each aperture
- $\bar{n}$: average number of galaxies

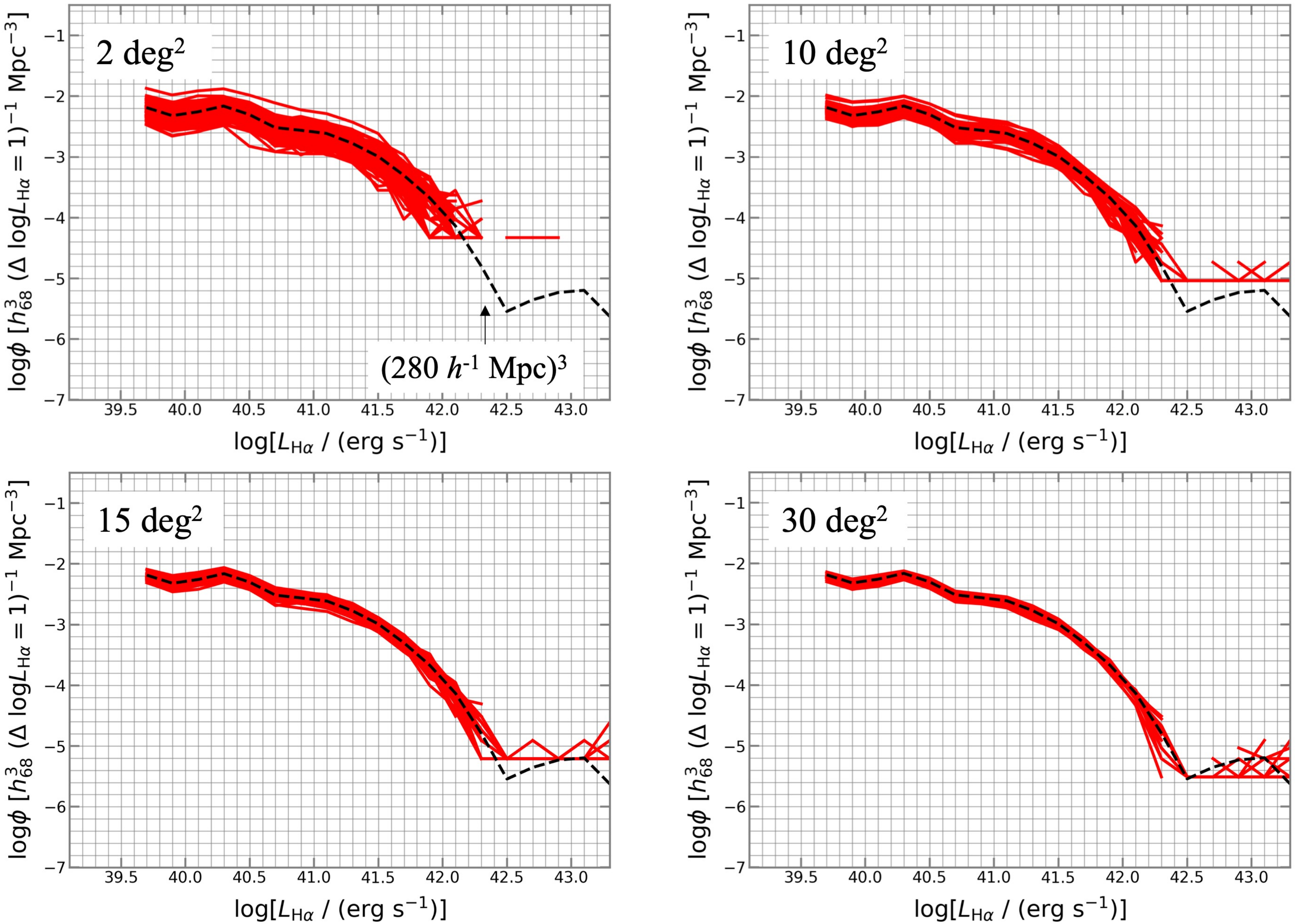


411.8×411.8 Mpc² region
with a thickness of 70 Mpc

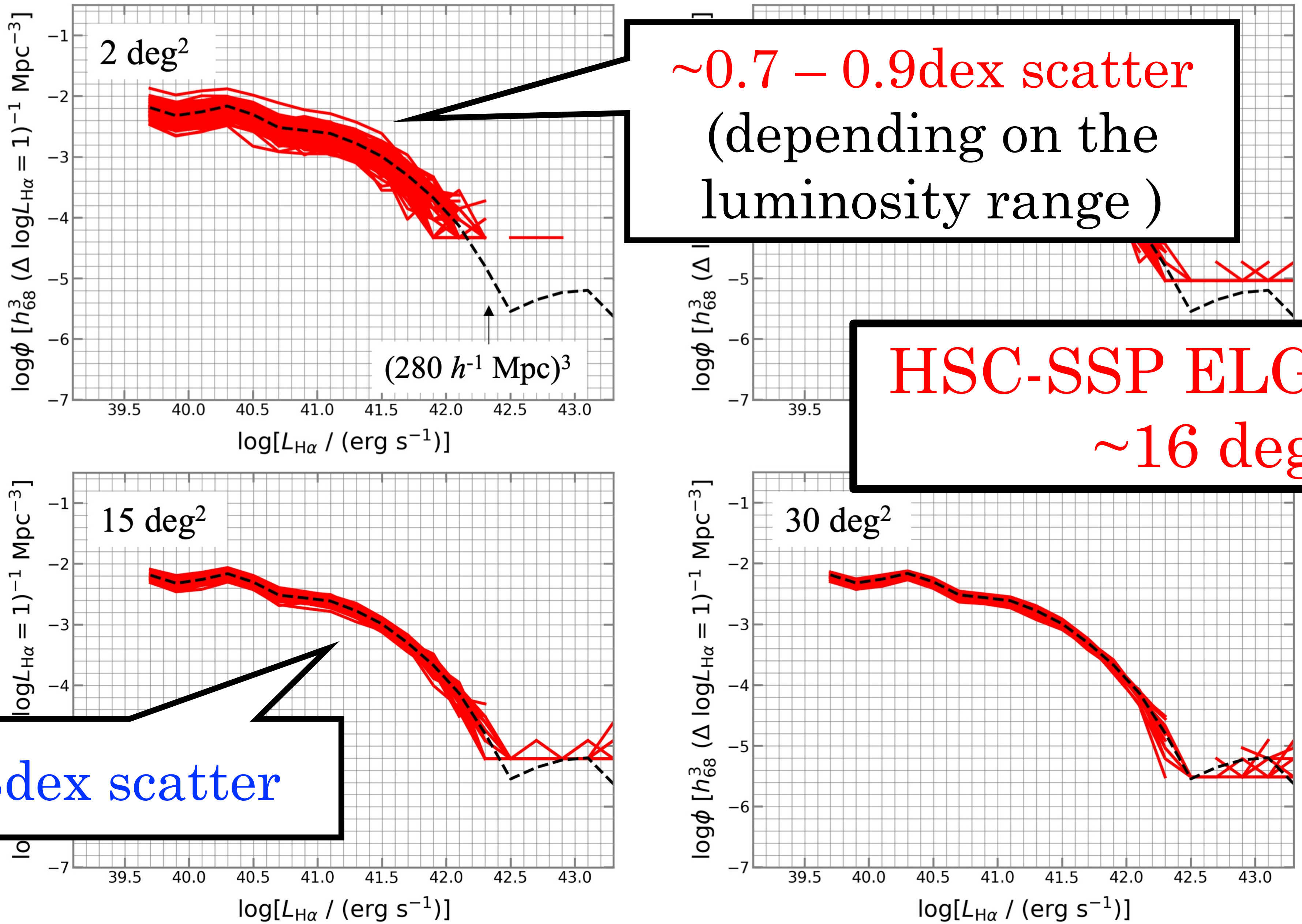
$$\delta \equiv \frac{n - \bar{n}}{\bar{n}}$$

- HAEs show higher overdensity in clusters and filaments compared to all galaxies ($r \leq -15$ mag)

The field variance on the Hα LF



The field variance on the Hα LF

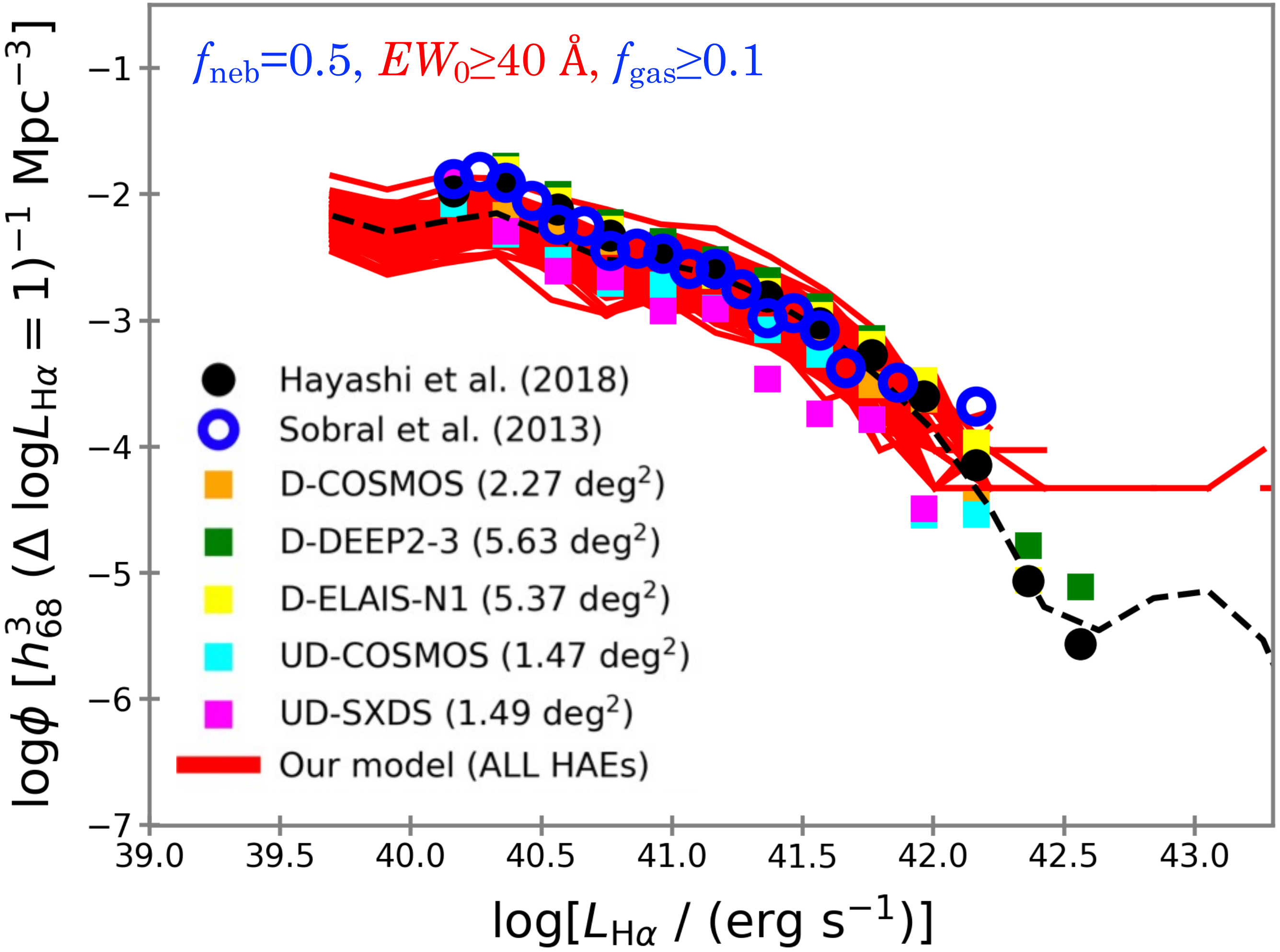


~0.7 – 0.9dex scatter (depending on the luminosity range)

HSC-SSP ELG survey: ~16 deg²

~0.3dex scatter

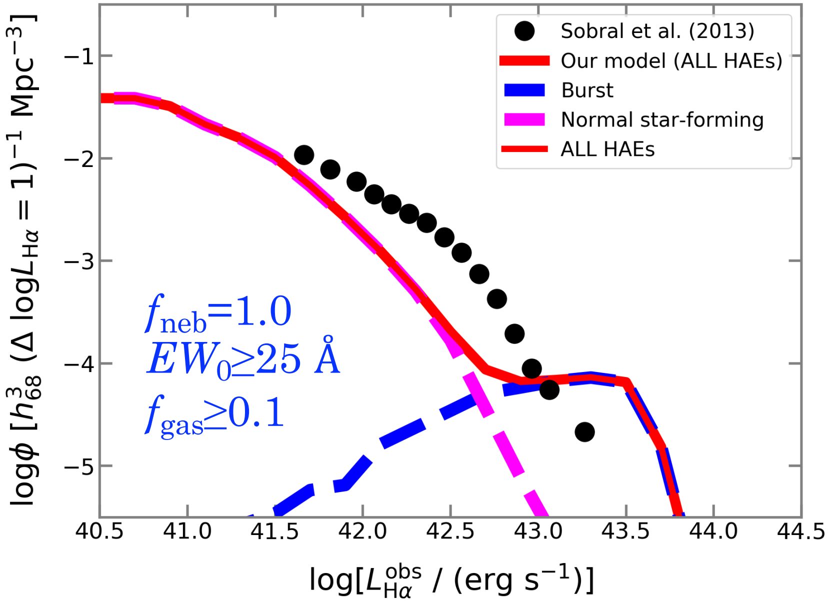
The field variance on the Hα LF

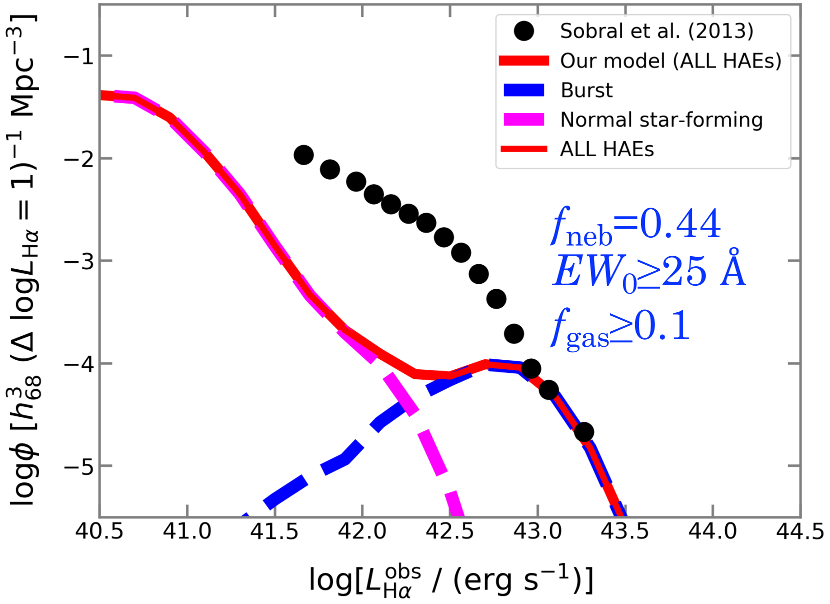


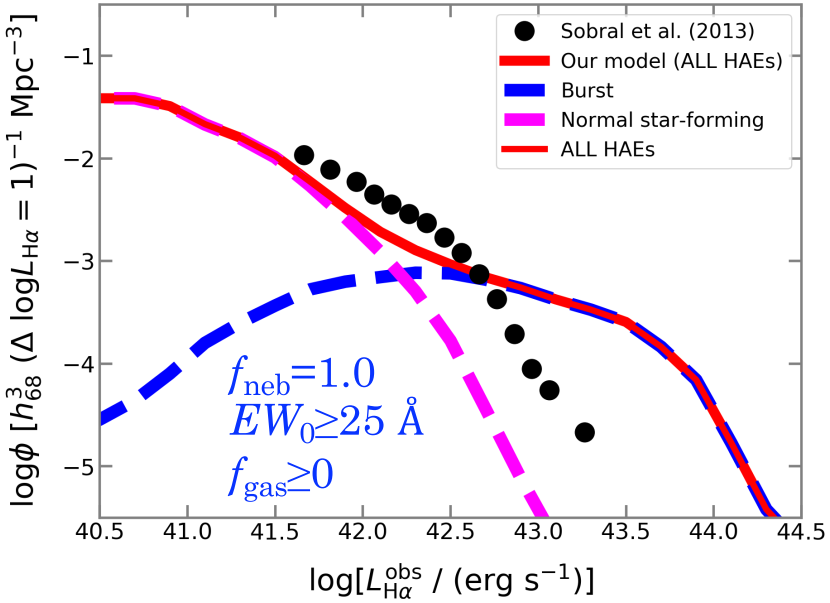
・Differences of the Hα LFs in HSC-SSP fields can be explained by the field variance

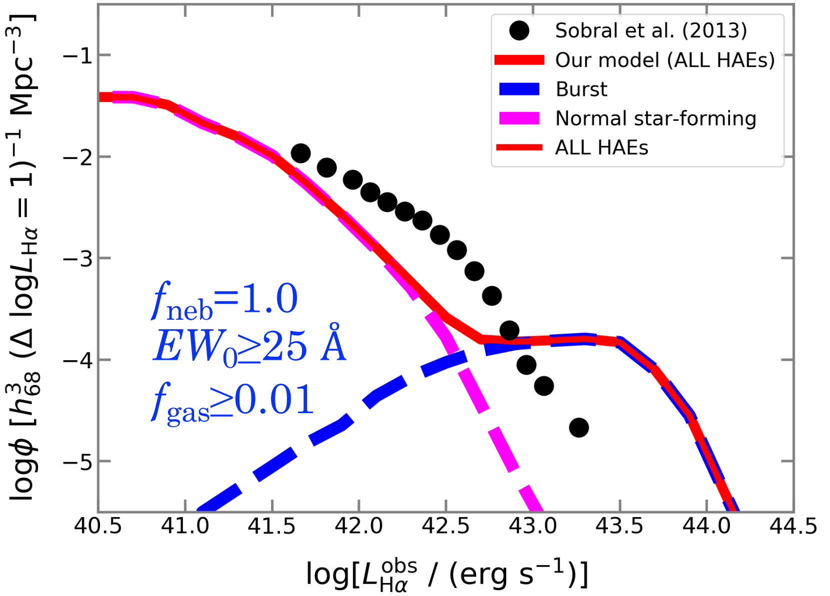
Future work: HAE model at $z \sim 2$

★currently, our model cannot reproduce the observational results...









Future work: HAE model at $z \sim 2$

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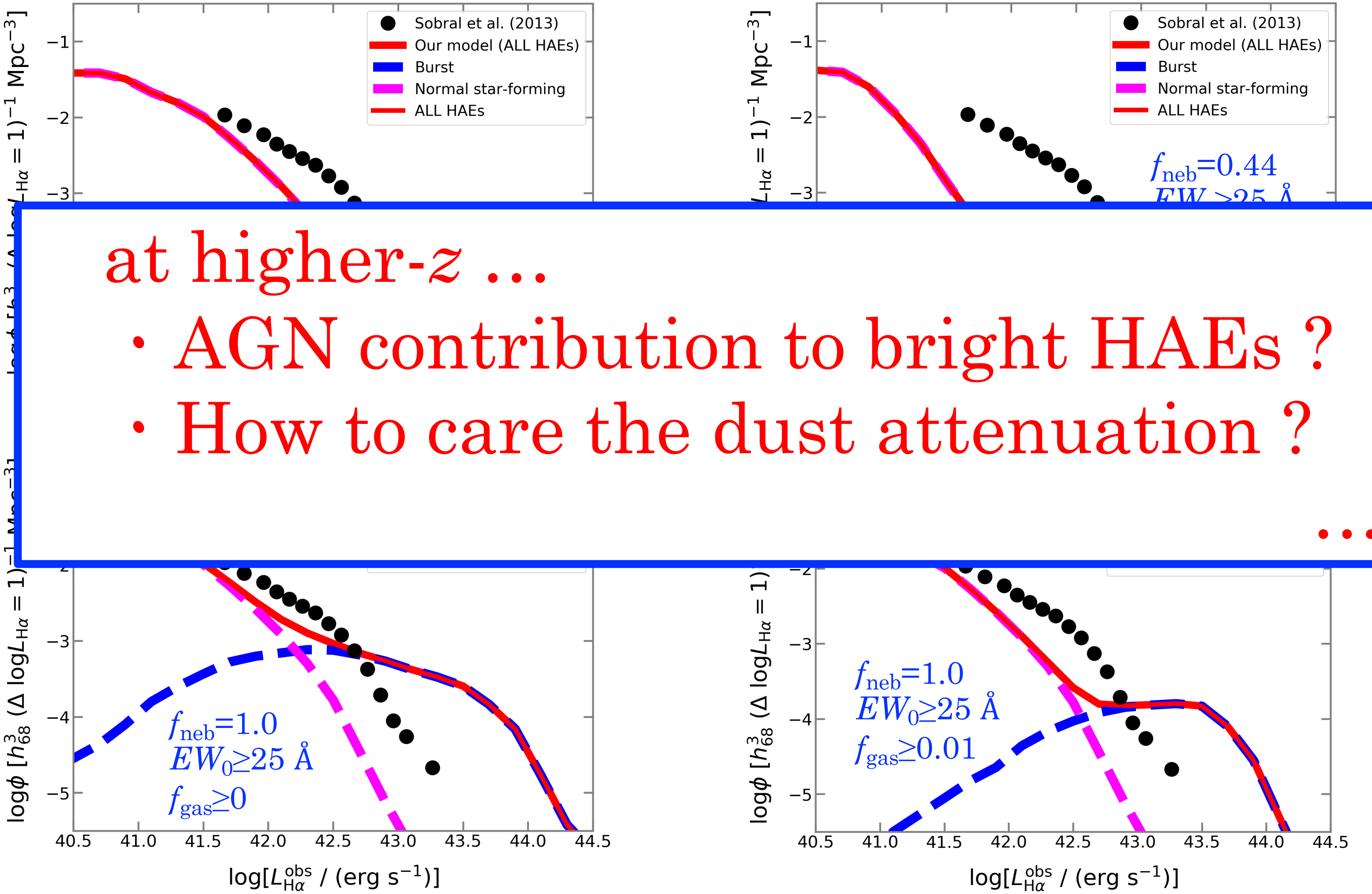

at higher-z …

- AGN contribution to bright HAEs ?
- How to care the dust attenuation ?

…

Summary

Danke schön !

HAE model at z ~ 0.4

- Our model well reproduces observed properties of HAEs
  e.g., the Hα LF, SFR vs. $M_{\rm star}$
- ~2 deg^2 surveys could suffer from the field variance
  up to ~1 dex
- the scatter of LFs is ~0.3 dex in ~15 deg^2 survey

Future works

- Detailed properties of z = 0.4 HAEs: clustering, EW distribution, MS...)
- utilizing Uchuu-ν^2GC
- Higher-z HAE models
- Models of other emission line galaxies: LAE, O2E, O3E
- How do we include the contributions of AGNs?