SPICA mid-infrared observations of high-redshift galaxies

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Our Previous Studies

■ Cosmic Reionization

- The Lya-emitting galaxy fraction at z=7
  - … **optical spectra (Keck)**
- The escape fraction of ionizing photons from galaxies at z=6-7
  - … **optical-to-NIR images (Subaru, Spitzer)**

■ Galaxy Formation and Evolution

- The UV luminosity function of galaxies at z=4-7
  - … **optical images (Subaru)**
- Size evolution of galaxies in the rest-frame UV at z>7
  - … **NIR images (Hubble)**
- Stellar population of Lya-emitting galaxies at z=3-7
  - … **optical-to-NIR images (Subaru, Spitzer)**

arXiv.org > astro-ph > arXiv:1710.02353

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Astrophysics > Astrophysics of Galaxies

Tracing the evolution of dust obscured star-formation and accretion back to the reionisation epoch with SPICA

C. Gruppioni, L. Ciesla, E. Hatziminaoglou, F. Pozzi, G. Rodighiero, P. Santini, L. Armus, M. Baes, J. Braine, V. Charmandaris, D.L. Clements, N. Christopher, H. Dannerbauer, A. Efstathiou, E. Egami, J.A. Fernandez-Ontiveros, F. Fontanot, A. Franceschini, E. Gonzalez-Alfonso, M. Griffin, H. Kaneda, L. Marchetti, P. Monaco, T. Nakagawa, T. Onaka, A. Papadopoulos, C. Pearson, I. Perez-Fournon, P. Perez-Gonzalez, P. Roelfsema, D. Scott, S. Serjeant, L. Spinoglio, M. Vaccari, F. van der Tak, C. Vignali, L. Wang, T. Wada

(Submitted on 6 Oct 2017)

Our current knowledge of star formation and accretion luminosity at high-redshift (z>3-4), as well as the possible connections between them, relies mostly on observations in the rest-frame ultraviolet (UV), which are strongly affected by dust obscuration. Due to the lack of sensitivity of past and current infrared (IR) instrumentation, so far it has not been possible to get a glimpse into the early phases of the dust-obscured Universe. Among the next generation of IR observatories, SPICA, observing in the 12-350 micron range, will be the only facility that can enable us to make the required leap forward in understanding the obscured star-

Comments: This paper belongs to the SPICA Special Issue on PASA

potential of both deep and shallow photometric surveys performed with the SPICA mid-IR instrument (SMI), enabled by the very low level of impact of dust obscuration in a band centred at 34 micron. These unique unbiased photometric surveys that SPICA will perform will be followed up by observations both with the SPICA spectrometers and with other facilities at shorter and longer wavelengths, with the aim to fully characterise the evolution of AGNs and star-forming galaxies after re-ionisation.

Comments: This paper belongs to the SPICA Special Issue on PASA
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- NASA ADS

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See also Kaneda et al. (2017)
Spinoglio et al. (2017)
Fernandez-Ontiveros et al. (2017)

One of the Strengths of SPICA

= SMI's wide field of view (12' x 10') with good sensitivity

- JWST MIRI: FoV = 1.25'x1.88' (about 2 $arcmin^2$).
  100 $arcmin^2$ survey at 21 μm down to 16 μJy → 160 hours

- SPICA SMI: FoV = about 120 $arcmin^2$.
  a similar survey at 34 μm → 1 hour

(Spinoglio et al. 2017)

3. **Shallow survey (SS)**: 600 deg^2 (to study the bright-end of the LF) to 5σ about 0.2 mJy. The estimated time need without instrument overhead is about 78 hours (21600 pointings to cover the whole area). A wide-area multi-wavelength surveyed region of the sky to be covered by the SS, could be part of the GAMA *Herschel*-ATLAS survey (Eales et al. 2010), or the Euclid Deep Survey fields.

(Gruppioni et al. 2017)


HSC
Hyper Suprime-Cam Subaru Strategic Program
(HSC SSP)
・300 nights of Subaru time over 5 years from 2014
・will cover more than 1000 deg² down to 26 mag in gri and 24-25 mag in zy.
… may give us a hint of good possible projects with SPICA
http://www.ipmu.jp/ja/20170228-HSC_datarelease

Data

■ Data: S16A internal release of the HSC SSP (Aihara et al. 2017)
- Ultradeep (UD)
- Deep (D)
- Wide (W)

■ Total Effective area for our study = **102.7 deg^2**

■ Limiting magnitude (5-sigma ABmag)
- UD: g∼27, r∼27, i∼26.5, z∼26, y∼25
- D: g∼26.5, r∼26, i∼26, z∼25, y∼24.5
- W: g∼26, r∼26, i∼26, z∼25, y∼24

⇩

select Lyman break galaxies (LBGs).

LBG Sample

z~4

z~5

z~6

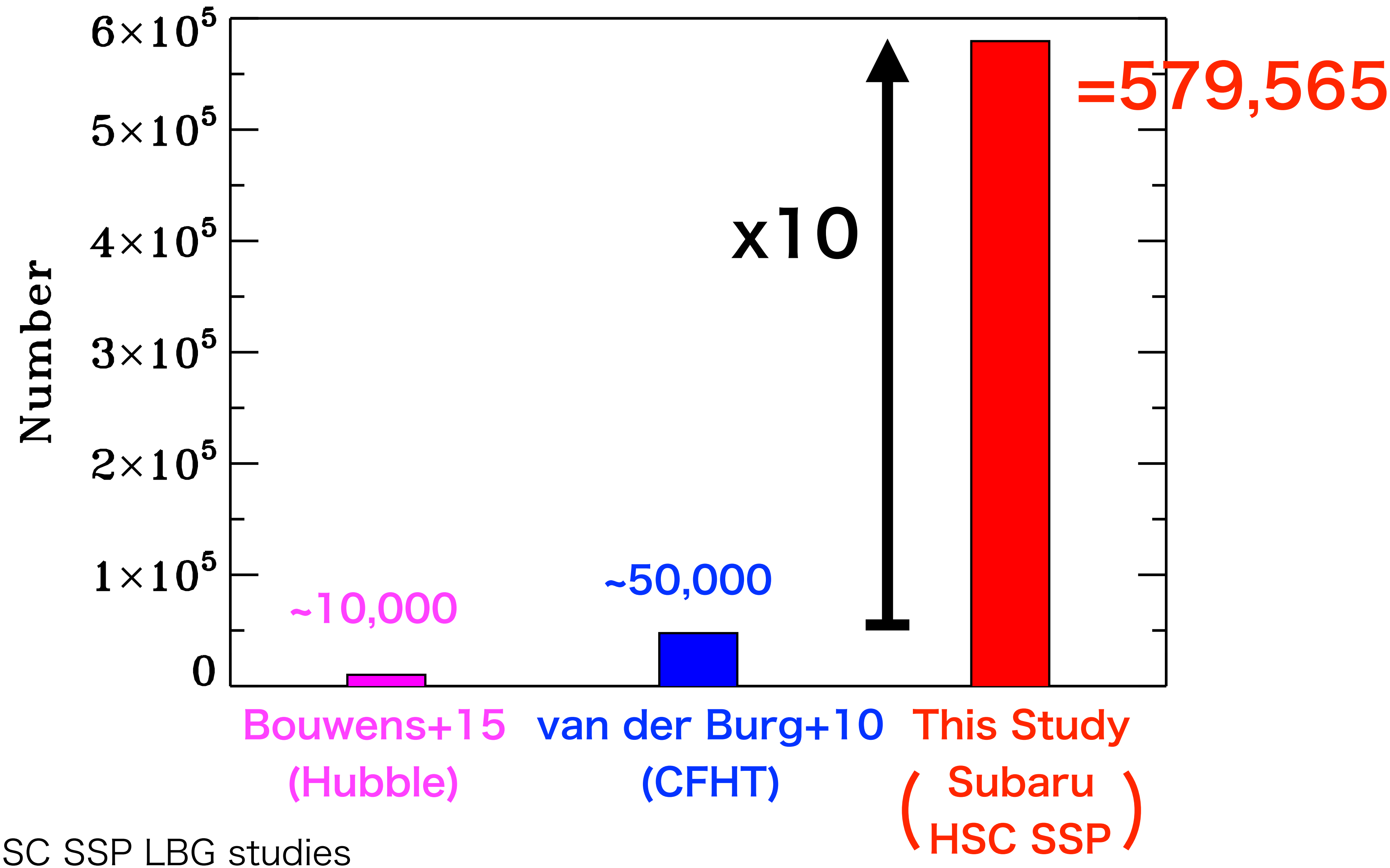
z~7

Field	# of g-drops	# of r-drops	# of i-drops	# of z-drops
UD-SXDS	9916	1209	36	—
UD-COSMOS	10644	1990	50	—
D-XMM-LSS	6730	711	6	0
D-COSMOS	45767	6282	64	4
D-ELAIS-N1	19631	612	15	1
D-DEEP2-3	35963	1498	47	5
W-XMM	113582	6371	81	7
W-GAMA09H	44670	5989	98	16
W-WIDE12H	94544	5243	36	8
W-GAMA15H	104224	6457	73	14
W-HECTOMAP	30663	1082	11	7
W-VVDS	23677	1500	20	11
Total	540011	38944	537	73

 # in total

579,565

LBG Sample



■ HSC SSP LBG studies

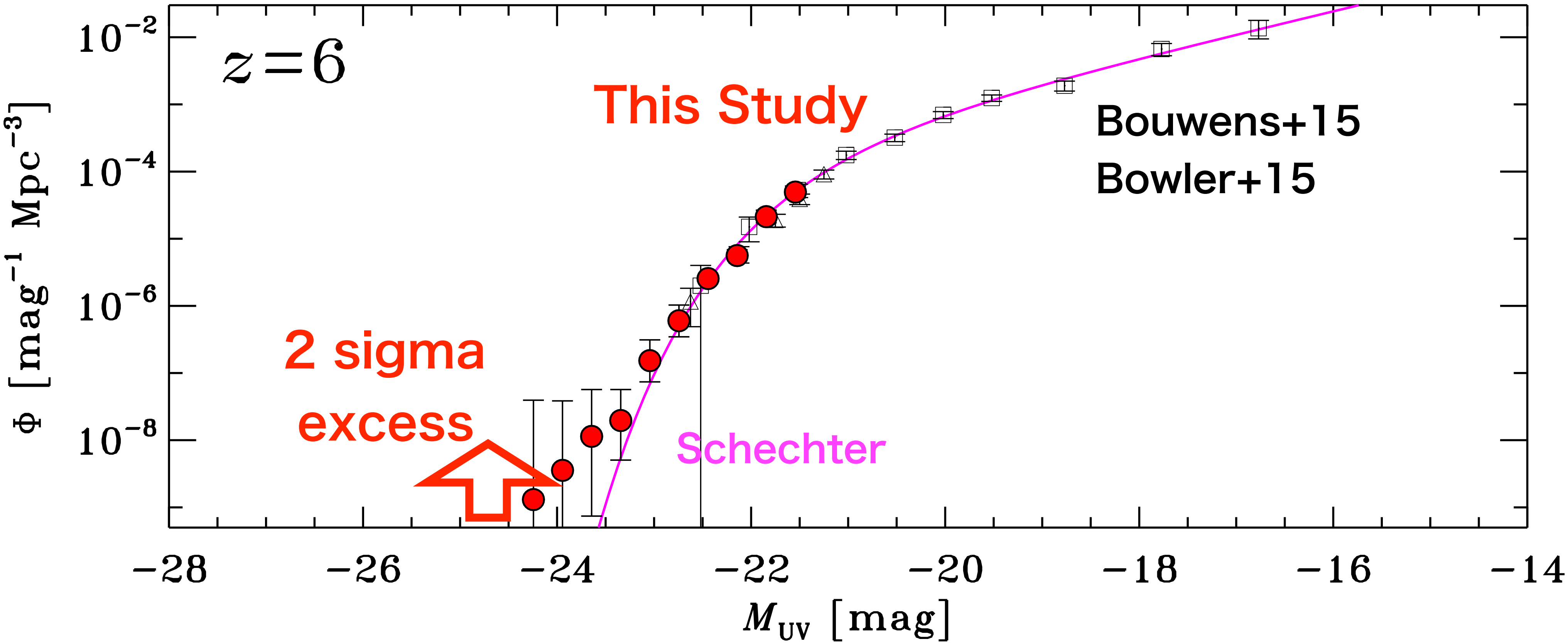
・UV luminosity function: **Ono et al. (2017)**

・clustering analysis: **Harikane et al. (2017)**

・protocluster search: **Toshikawa et al. (2017)**

and others …

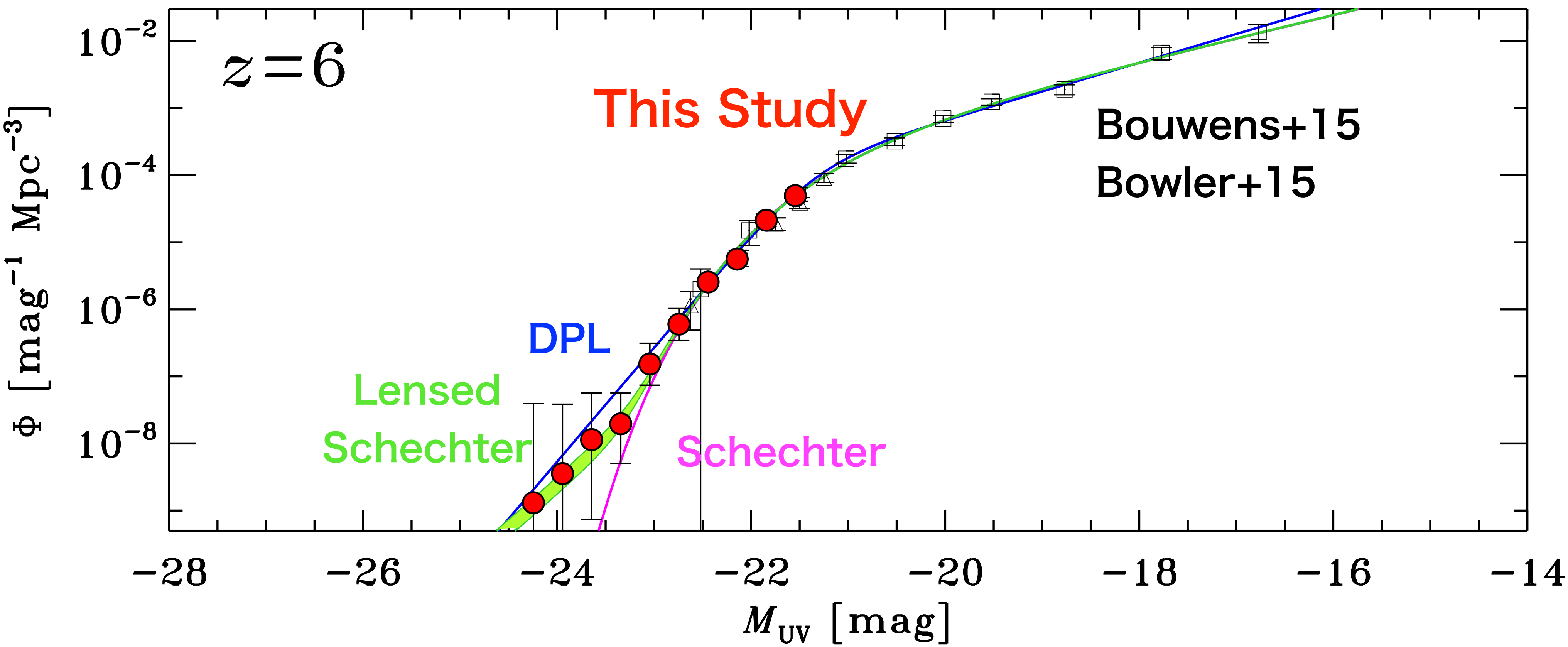
Galaxy UV Luminosity Function at z=6



(Ono et al. 2017)

- Red circles: our results of the galaxy UV LFs derived by subtracting the AGN contributions based on the galaxy fraction.
- The bright end shape cannot be explained by the Schechter function.

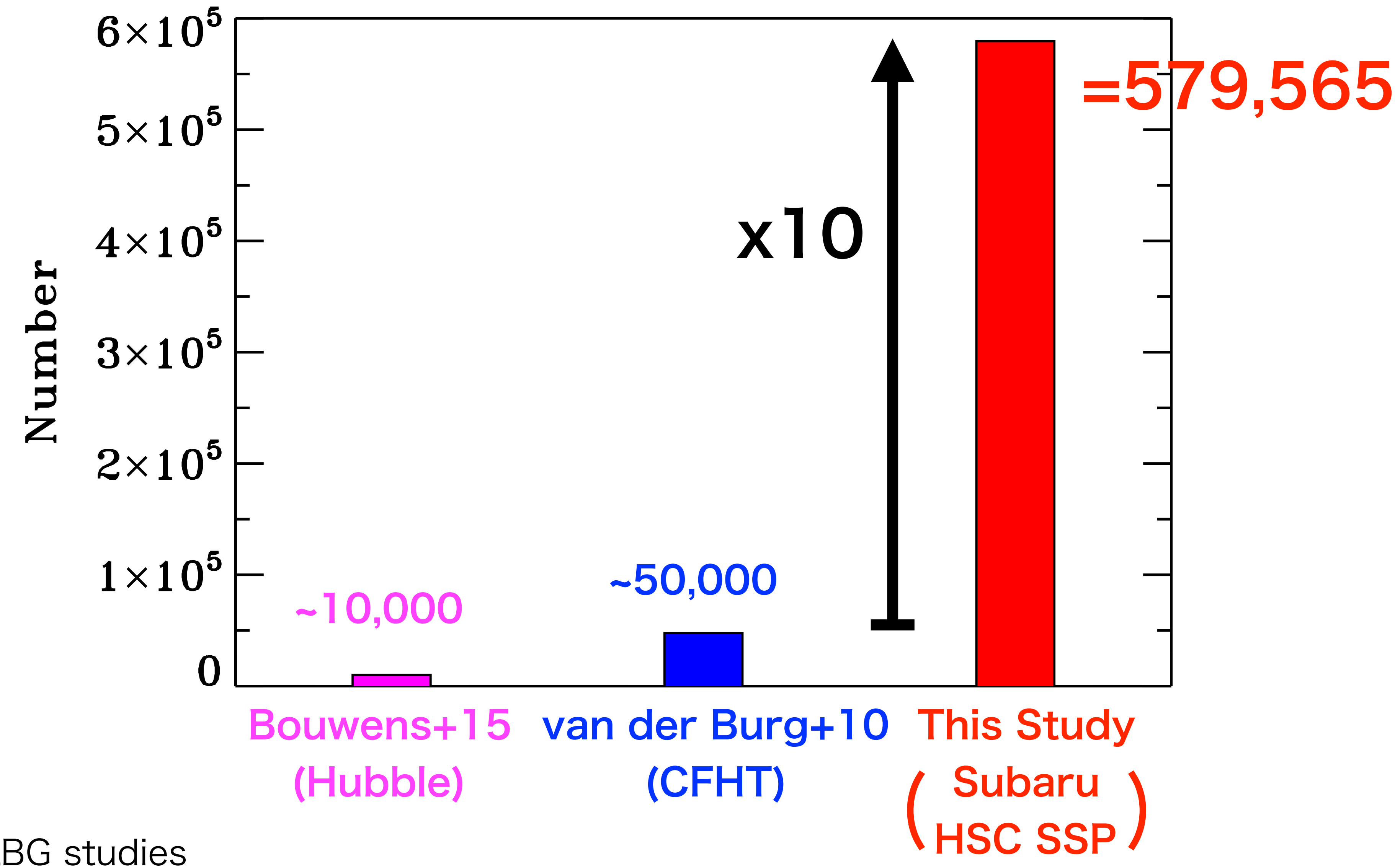
Galaxy UV Luminosity Function at z=6



(Ono et al. 2017)

- Red circles: our results of the galaxy UV LFs derived by subtracting the AGN contributions based on the galaxy fraction.
- The bright end shape cannot be explained by the Schechter function.
- DPL and lensed Schechter provide better fits.

LBG Sample



■ LBG studies

- UV luminosity function: **Ono et al. (2017)**
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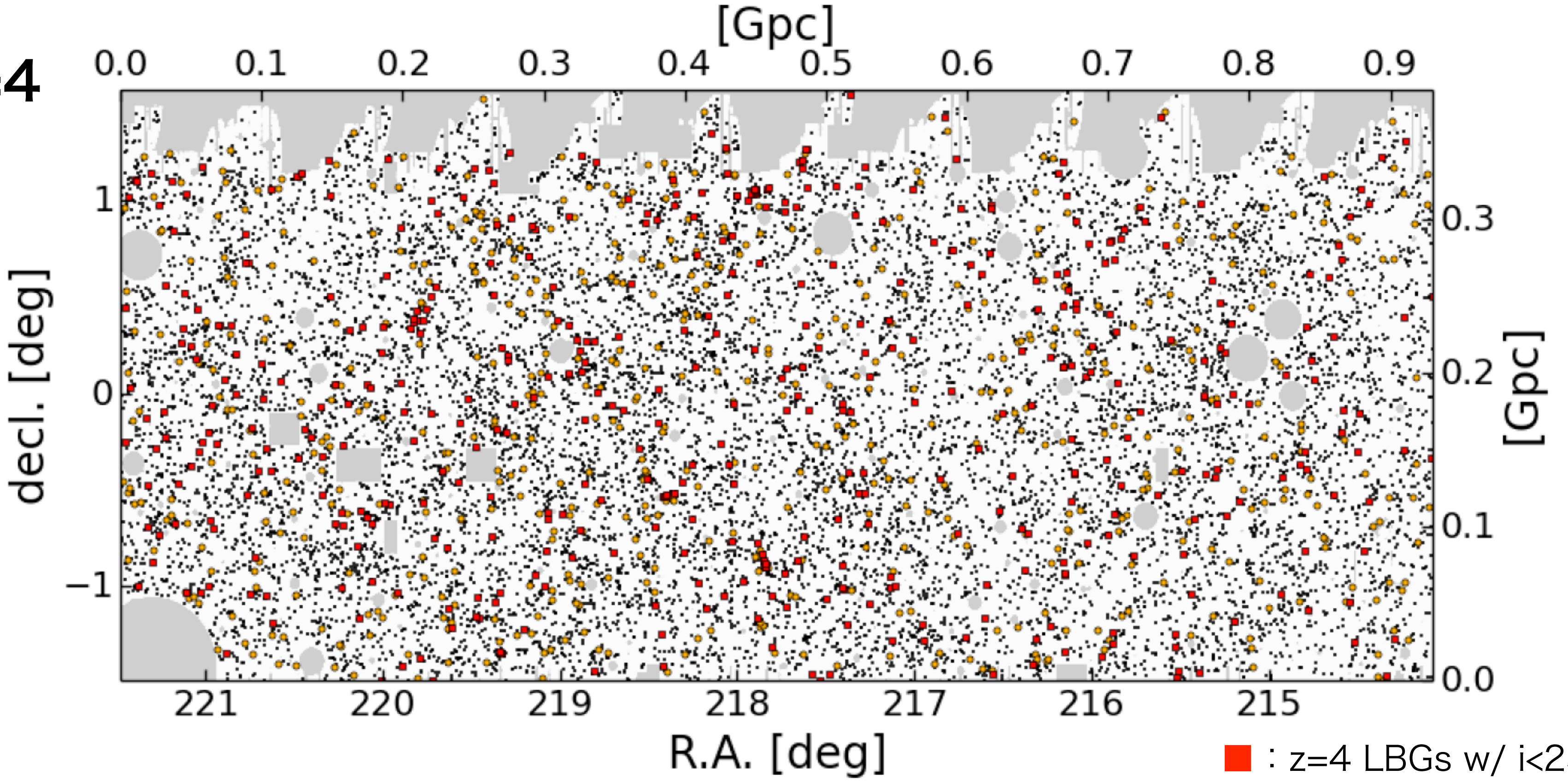
- galaxy overdense region search: **Toshikawa et al. (2017)**

and others …

Galaxy Overdense Region Search

z=4



: z=4 LBGs w/ i<23.0

: z=4 LBGs w/ i=23.0-23.5

: z=4 LBGs w/ i=23.5-25.0

(Harikane et al. 2017)

■ Importance of overdense regions

・They would be progenitors of today's galaxy clusters, whose formation history is still an open question.

■ Local surface number density of galaxies

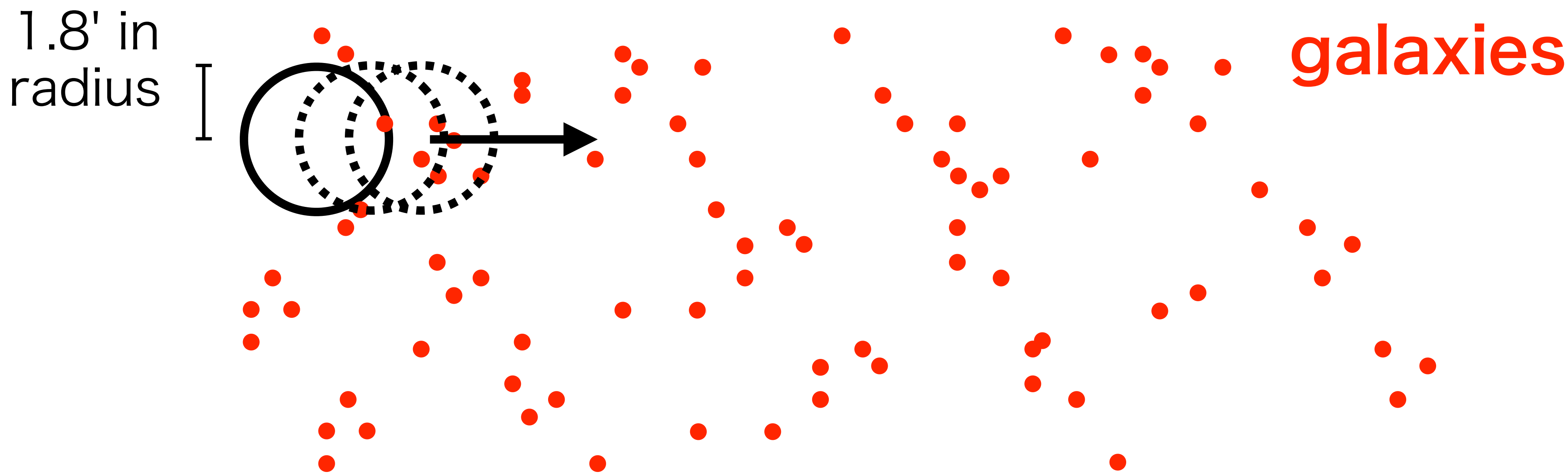
・use LBGs down to i=25.0 mag

・count LBGs within an aperture of 1.8' in radius (0.75 physical Mpc)

・calculate galaxy overdensity = $(N-N_{ave})/\sigma$

Galaxy Overdense Region Search

fixed aperture method



(Toshikawa et al. 2017)

- Importance of overdense regions
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- Local surface number density of galaxies
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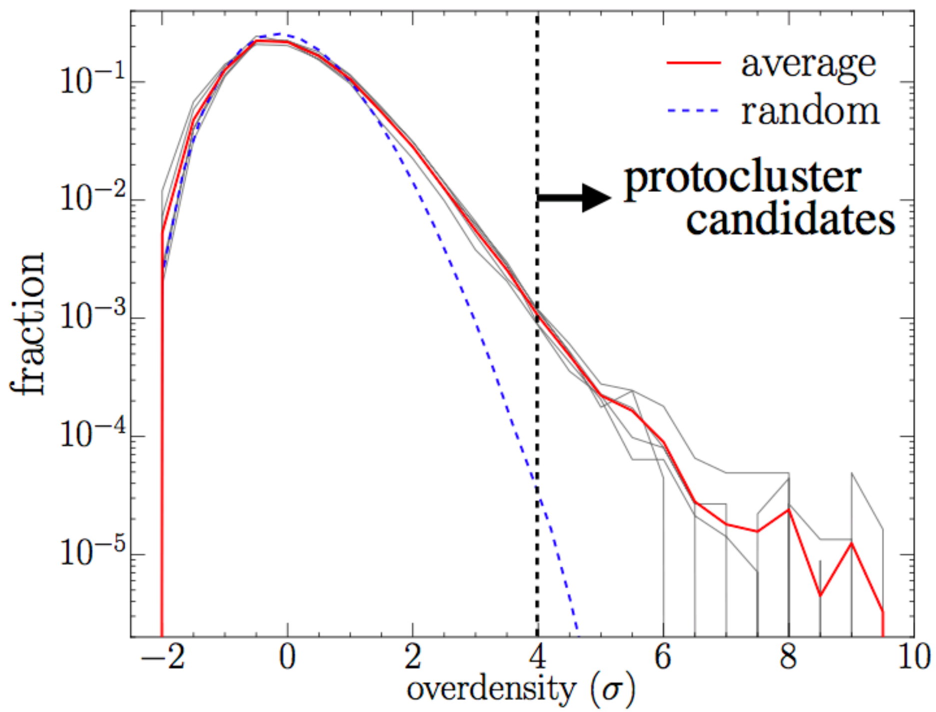
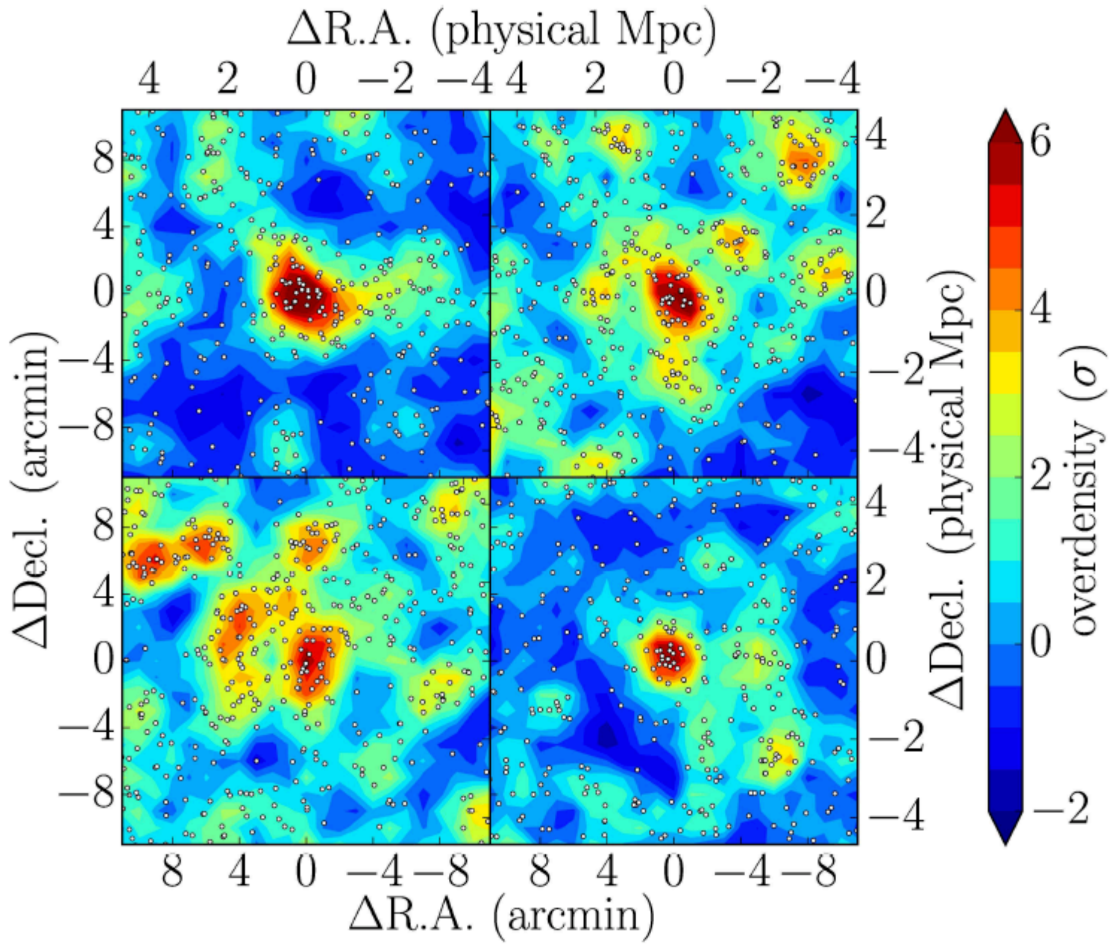
Galaxy Overdense Region Search

z=4



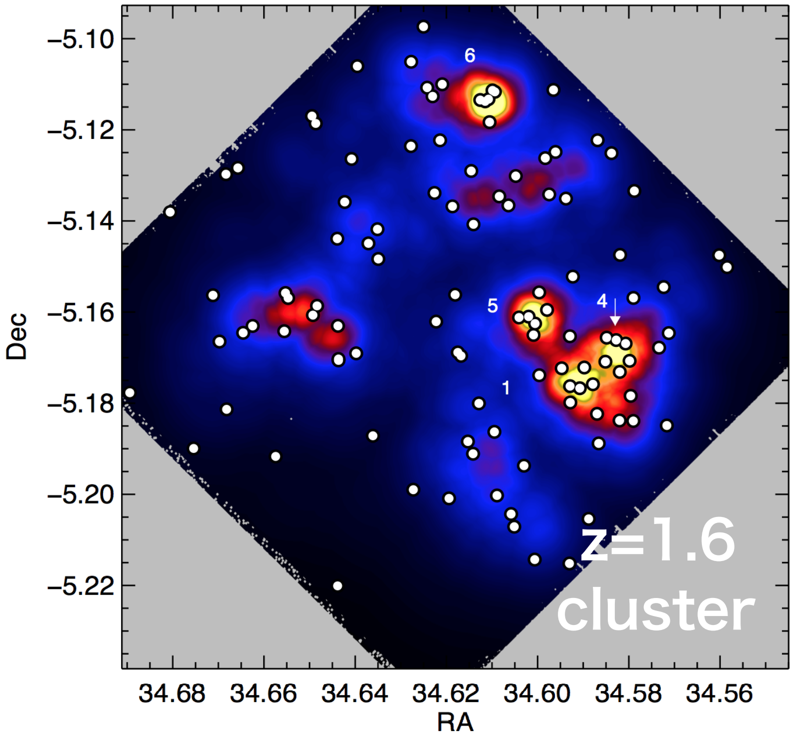


(Toshikawa et al. 2017)

- Identify galaxy overdense regions at z=4
  - ・protocluster candidates := >4σ overdensities of galaxies
    >70% are expected to evolve into galaxy clusters (>$10^{14}M_{sun}$) at z=0 based on the semi-analytic galaxy model (Chiang et al. 2013)
  - → 216 protocluster candidates are selected.
    We are going to search for z=2-3 and z=5-6 protoclusters as well.

Importance of IR Observations

Star-forming Galaxies

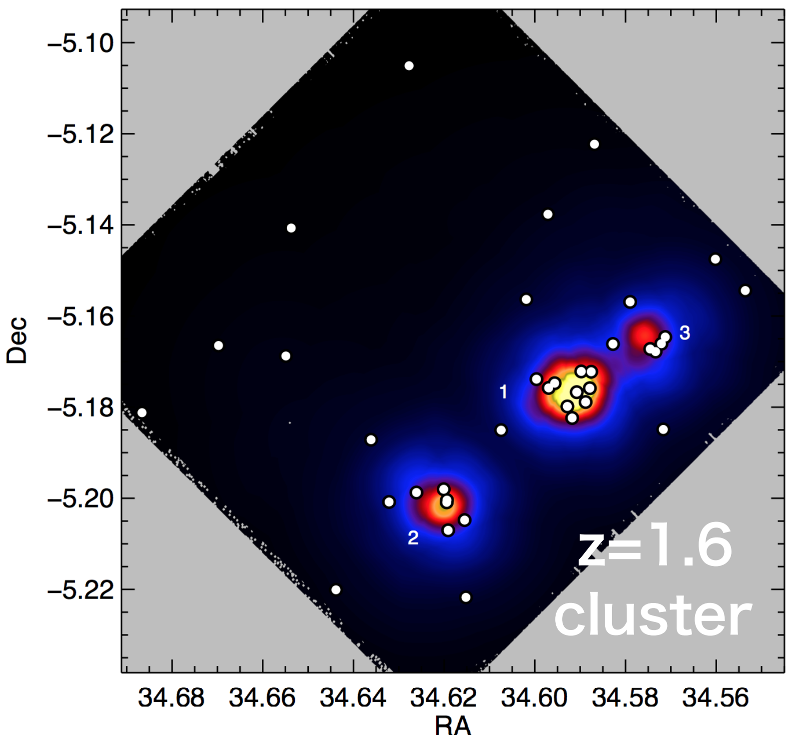


(Hatch et al. 2016)

- The current protocluster study may bias our view of protoclusters.

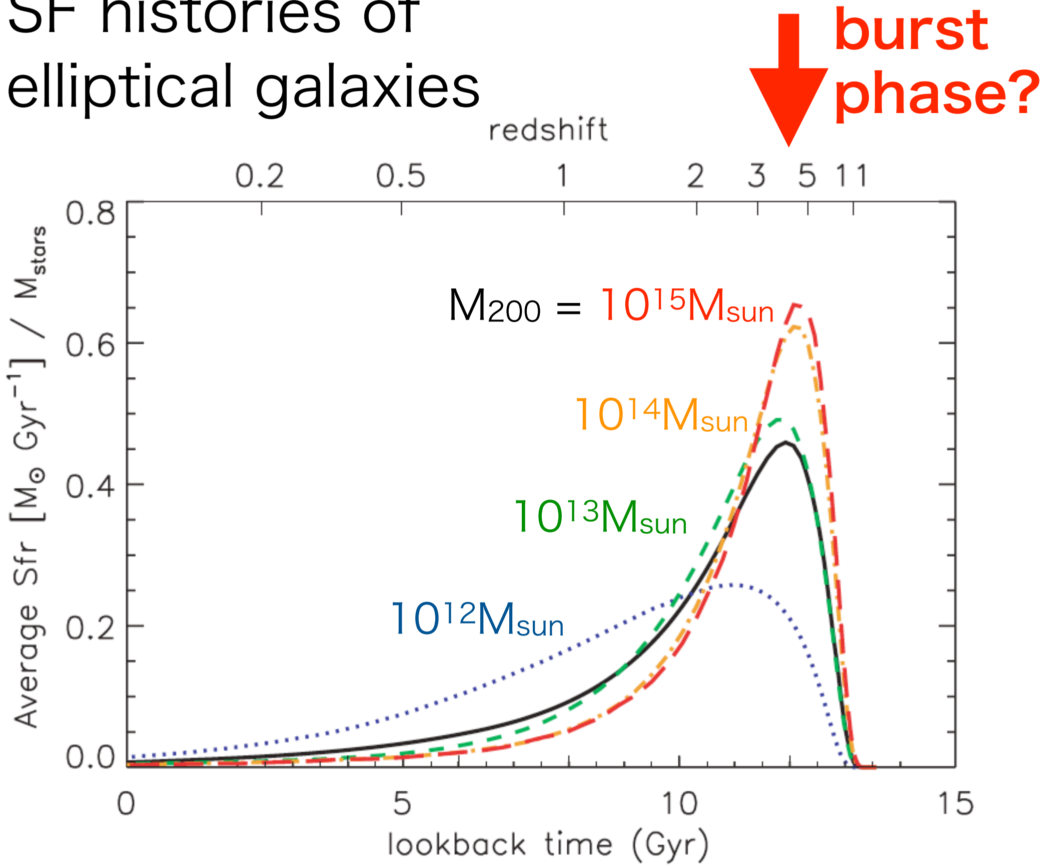
Importance of IR Observations

Red Galaxies



(Hatch et al. 2016)

SF histories of elliptical galaxies



(De Lucia et al. 2006)

- The current protocluster study may bias our view of protoclusters. It is important to observe them with multi-wavelength data.
- Some theoretical study have predicted a burst-like star-formation of massive galaxies in clusters at high redshift, which may be missed w/o IR obs.

Follow-up Sub-mm Imaging

z=4

Preliminary

(J. Toshikawa et al. in prep.)

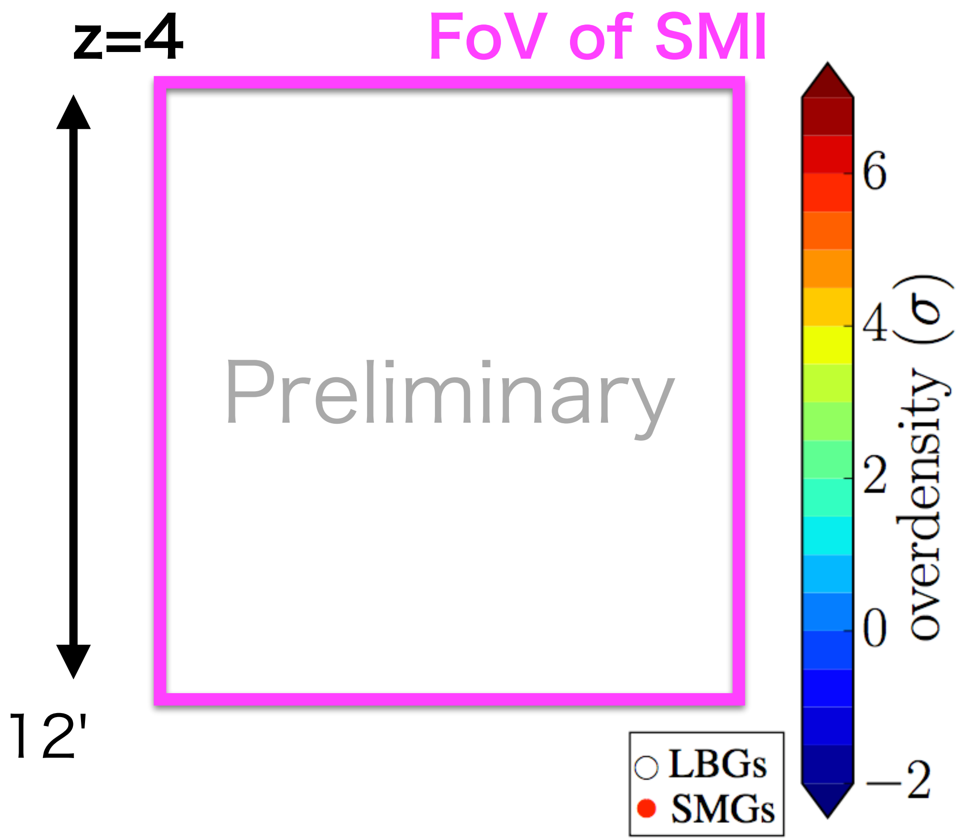
■ JCMT/SCUBA-2 850μm observations have been carried out (PI: Y. Matsuda)

- 6 overdense regions have been observed. 4σ = 4.4 mJy = **$6 \times 10^{12} L_{sun}$.**
- Some SMGs appear to be located near the peak of the galaxy overdensity contour.
- ALMA follow-up proposal for these SMGs has been accepted, but it is difficult to investigate the distributions of less luminous IR sources in these regions.

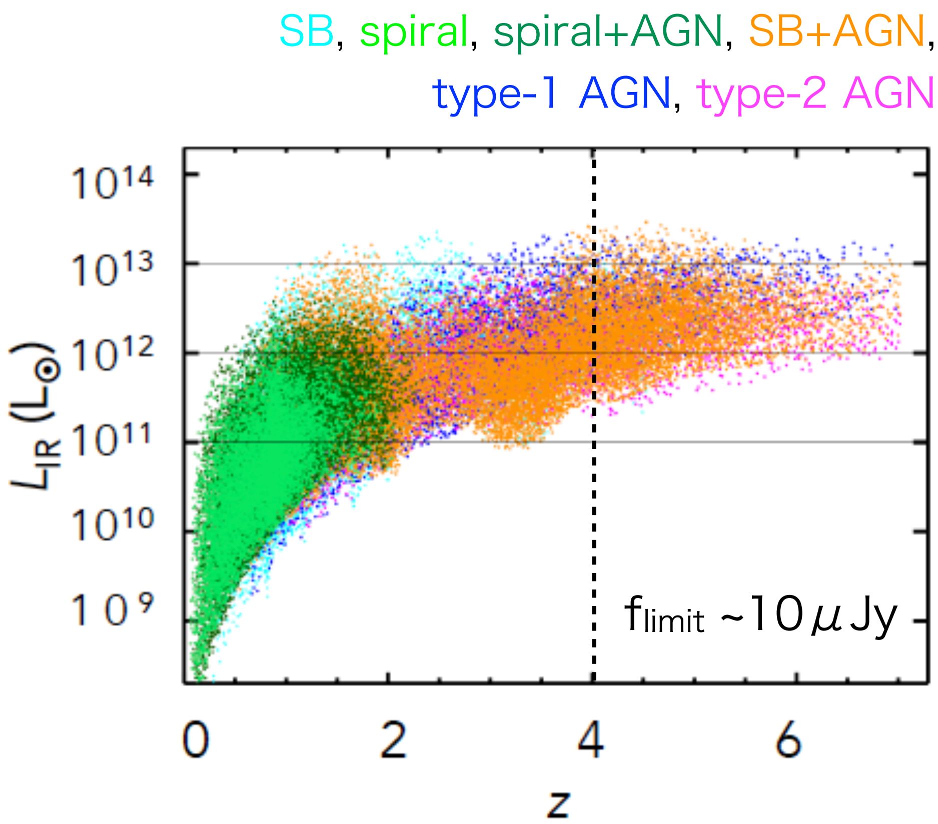
Possible Projects with SPICA

1. Investigating the infrared properties of high-z galaxy overdense regions

SPICA SMI Follow-up



(J. Toshikawa et al. in prep.)



(Gruppioni et al. 2017)

■ SPICA can easily reveal the distribution of mid-IR sources in protocluster regions.

- 1 hour integration can reach 5σ ~ 10 μJy over the FoV 10'x12' at 34μm.
- Starbursts and AGNs with **L_{IR} > $10^{11.5}$ L_{sun}** in z=4 protoclusters can be identified with relatively short integartion time with SPICA.
- JWST/MIRI needs more than 100 hours to obtain similar data due to its small FoV (Spinoglio et al. 2017).

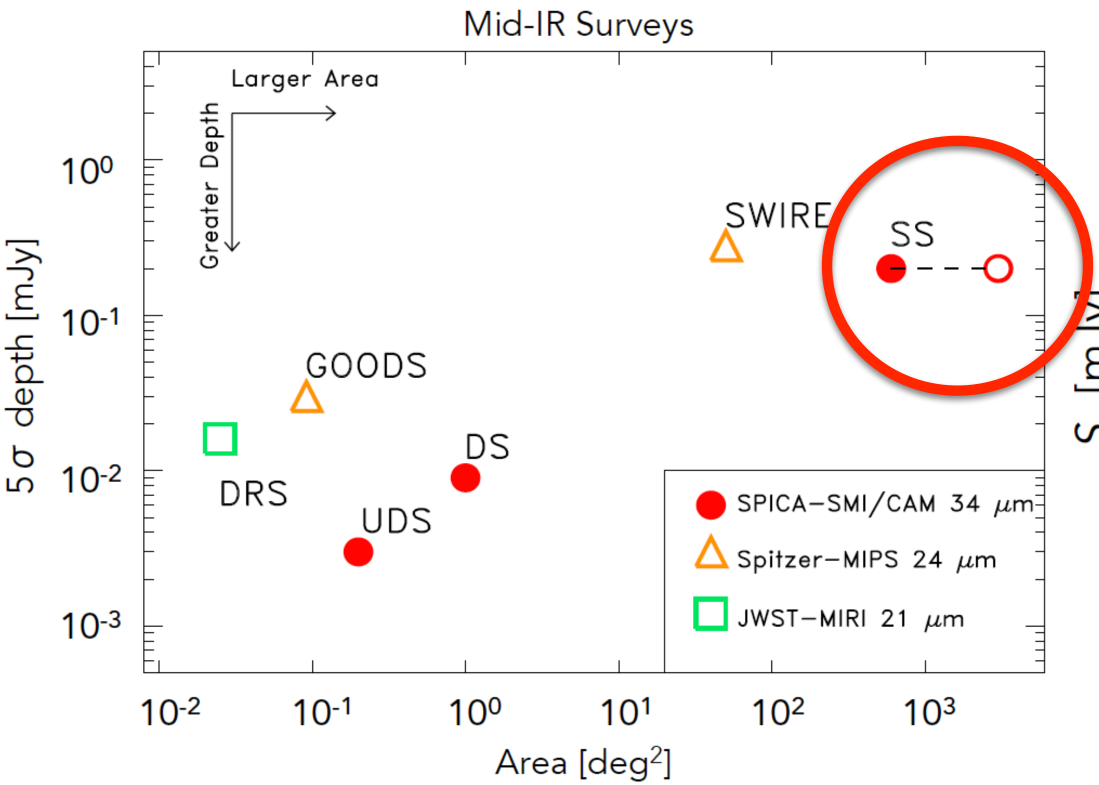
Possible Projects with SPICA

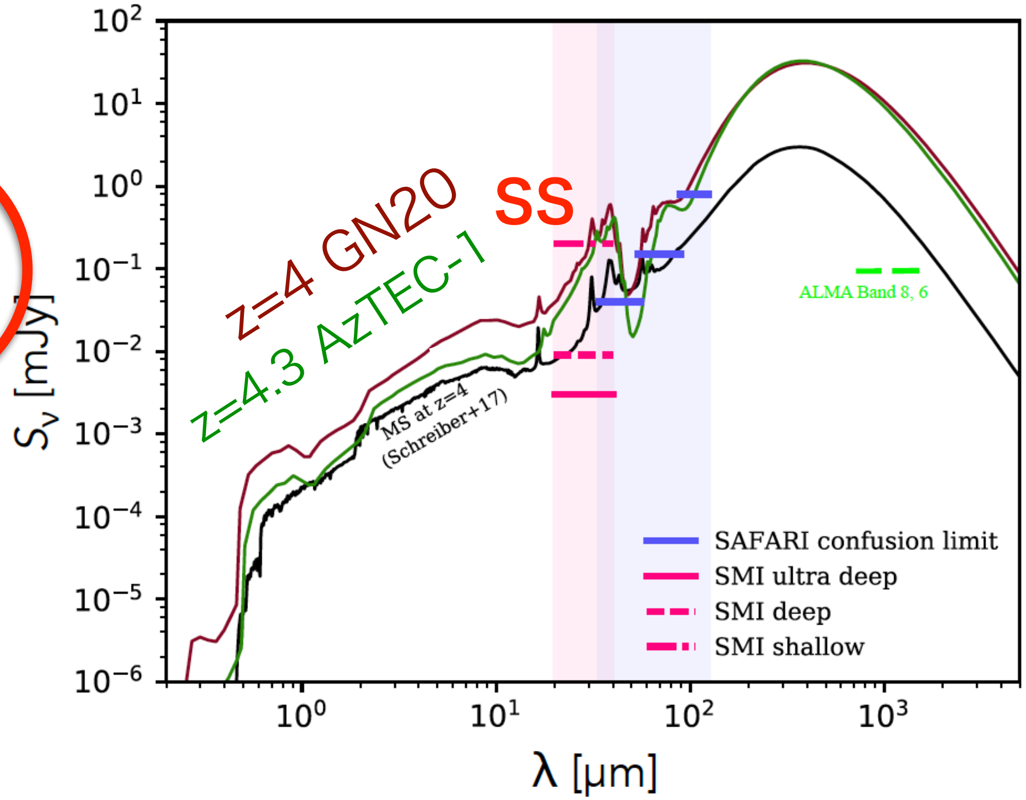
1. Investigating the infrared properties of high-z galaxy overdense regions

2. A wide area search for very rare interesting infrared sources

← Gruppioni et al. (2017)

SPICA SMI/CAM Survey

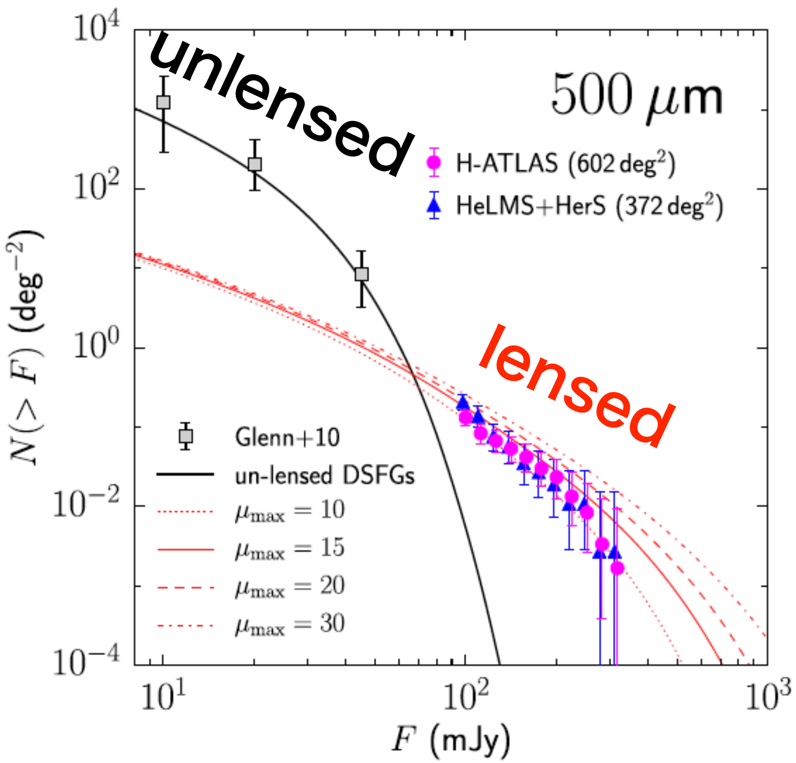


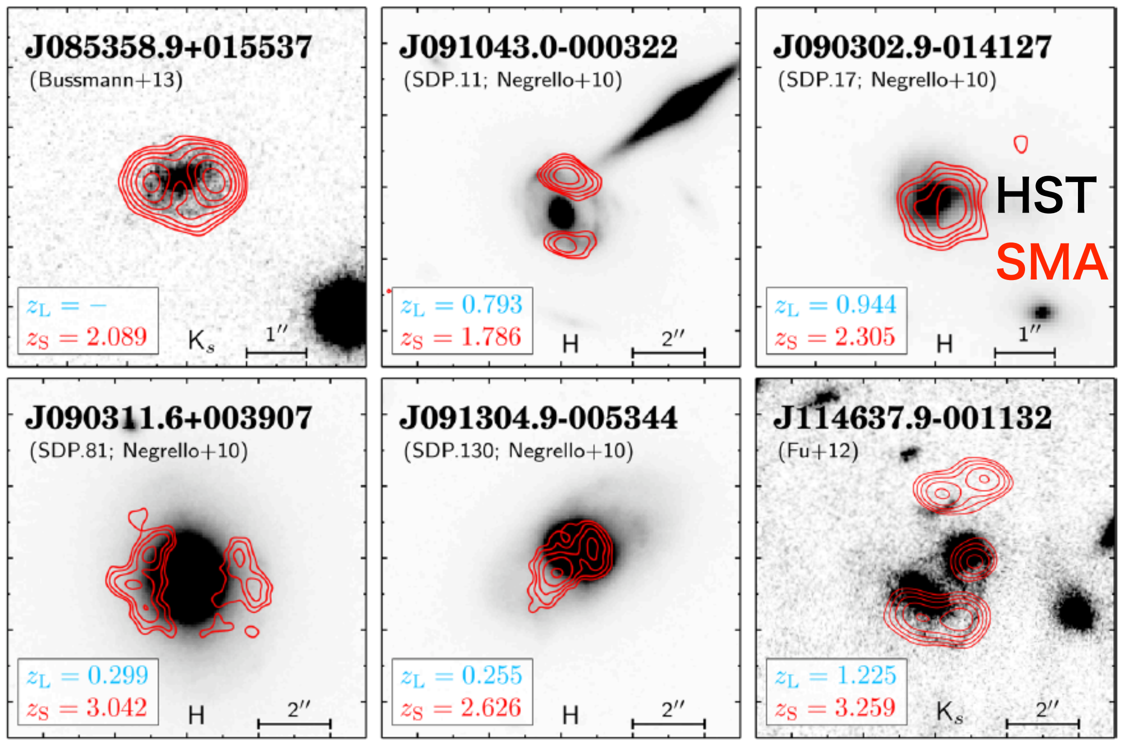


(Gruppioni et al. 2017)

- ■ a wedding-cake strategy
  - ・Ultra-deep survey (UDS): 5σ = 3μJy, 0.2 deg^2.
  - ・Deep survey (DS): 5σ = 9μJy, 1 deg^2.
  - ・Shallow survey (SS): 5σ = 0.2mJy, 600 deg^2.
- ■ SS can detect z=4 dusty galaxies such as GN20 and AzTEC-1.
  - ・The wide area may enable us to find a sample of interesting very rare sources.

Example 1: Lensed Sources

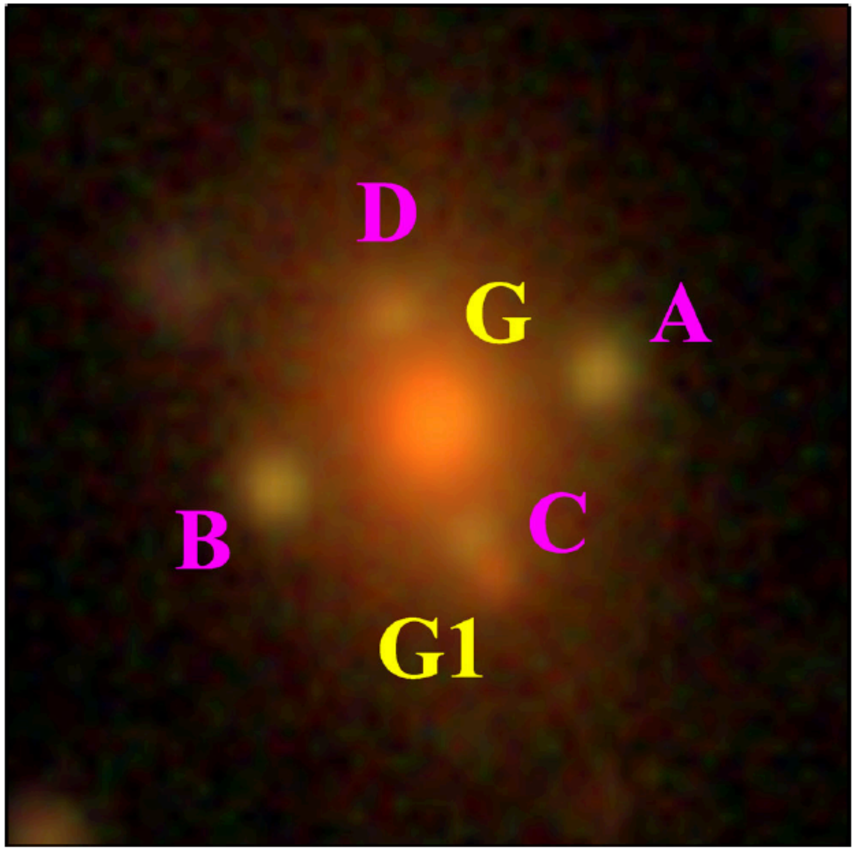


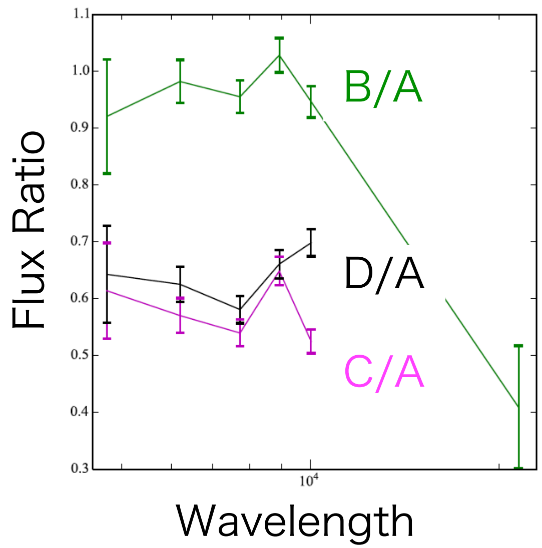


(Negrello et al. 2017)

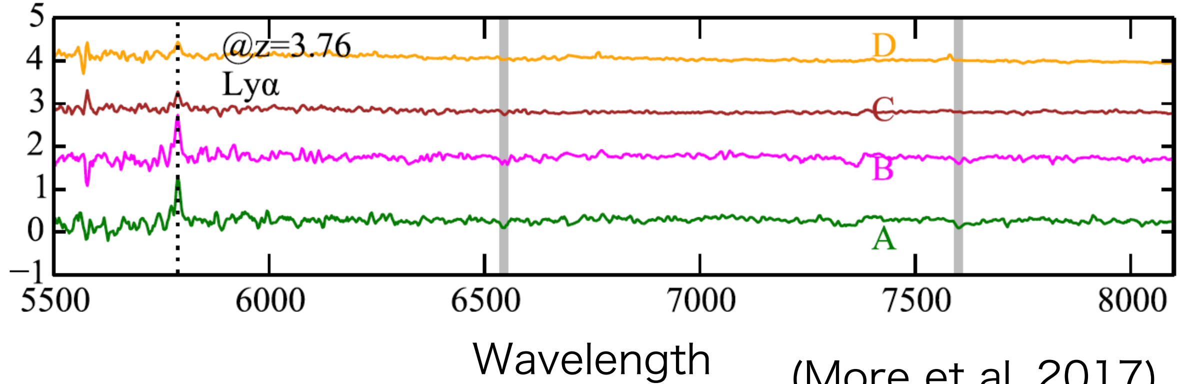
- lensed dusty sources
  - found from the 600 deg^2 Herschel ATLAS data with flux density >100 mJy whose number densities are excessed from the extrapolation of the fainter range.
  - low-z interlopers (local galaxies, radio sources, blazers, dusty stars) identified in the literature are removed
    → 80 lensed candidates.
    → 20 sources: strongly lensed; only one object: not lensed (a binary of HyLIRGs).

Example 1: Lensed Sources





← Their SEDs are simiar



(More et al. 2017)

- quadruply lensed source
  - found around a massive red galaxy from the HSC SSP data
  - their SEDs are similar → multiple images of a background source
  - relatively broad Lya emission, very compact size (0.20 physical kpc) → likely an AGN
  - If so, this is the highest reshift quadruply imaged AGN known to date (z_{spec}=3.76).

Example 1: Lensed Sources

Preliminary

Preliminary

Preliminary

(M. Oguri et al. in prep.)

■ lensed i-dropout

- found in a galaxy cluster field from the HSC SSP data
- spectroscopically confirmed by our follow-up with Magellan LDSS3
- one of the brightest lensed galaxies at z~6-7

  → easier to follow-up for detailed studies than unlensed ones

Example 2: Strong Emission-Line Sources

Preliminary

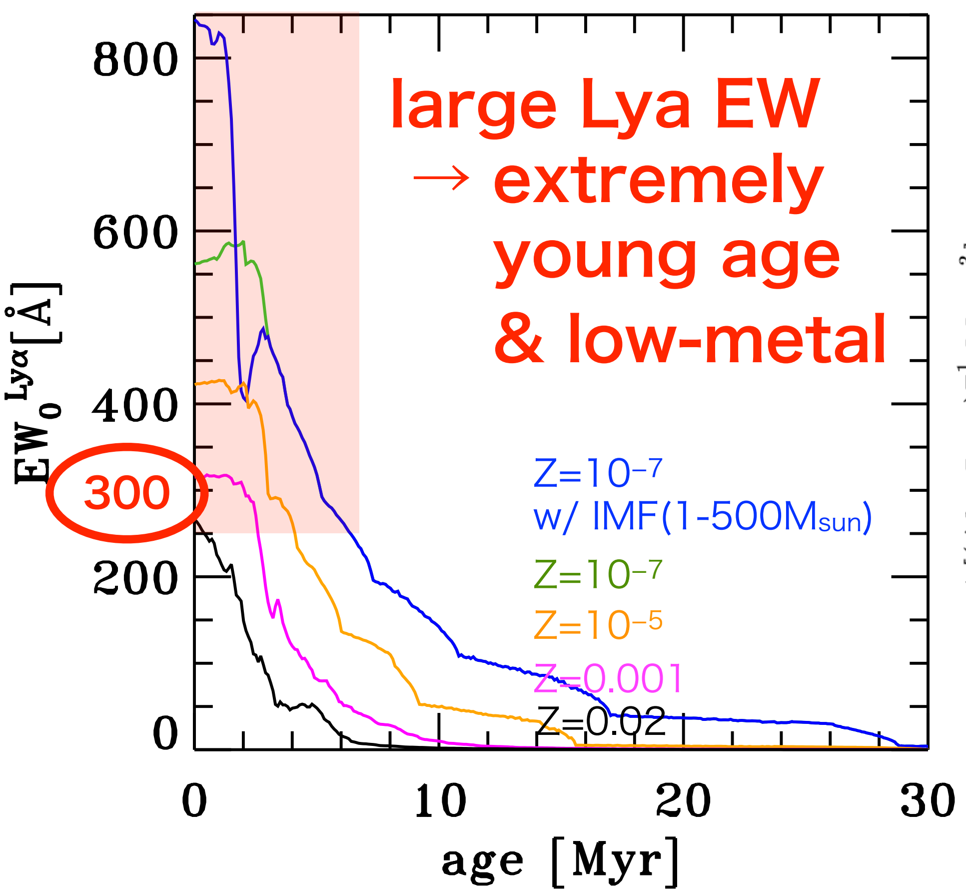
Preliminary

gri

(Y. Ono et al. in prep.)

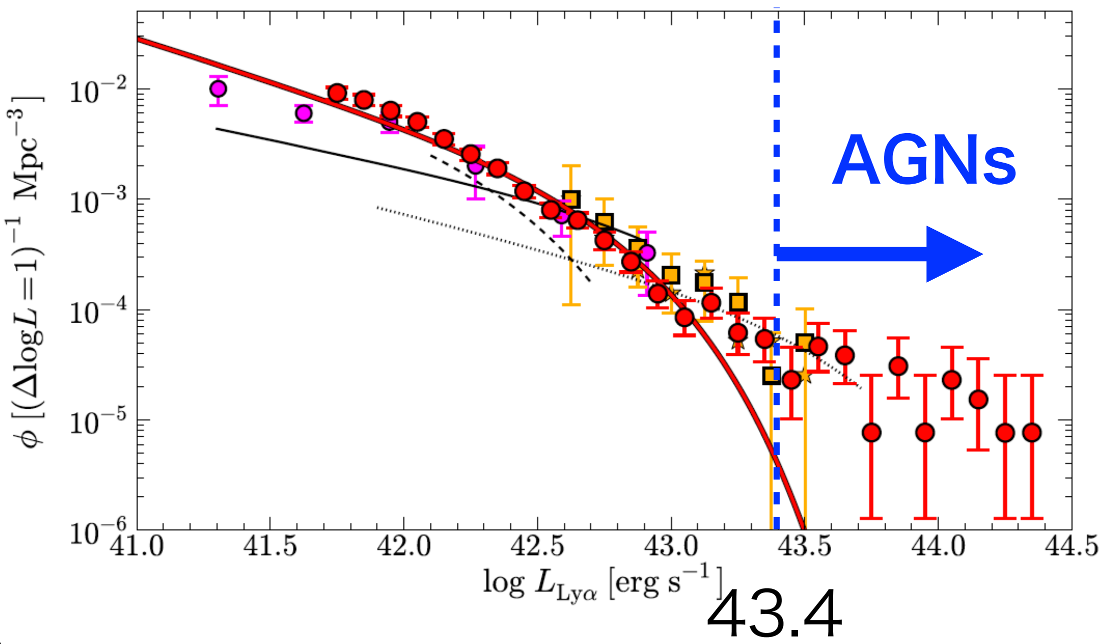
- r-band excess g-dropouts are good candidates of large Lya EW galaxies (LLEGs)
- four candidates at z=4 and five candidates at z=5 are selected from the 100 deg^2 HSC SSP data.
- Lya EW_0 ~ 250-600Å.

Example 2: Strong Emission-Line Sources



(Schaerer et al. 2003; Y. Ono et al. in prep.)

z=2.2 Lya luminosity function



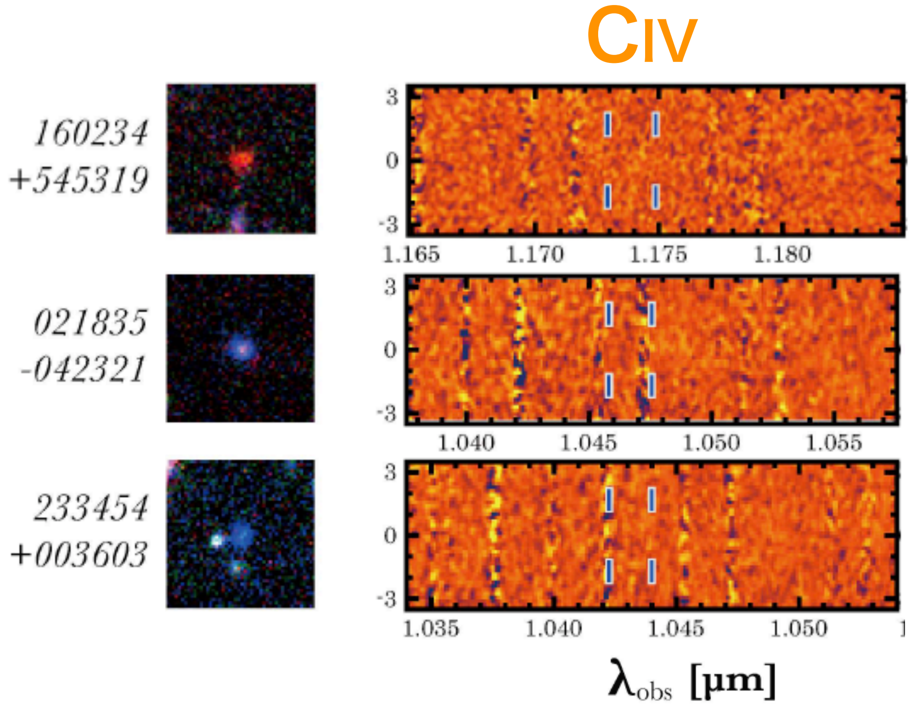
(Konno et al. 2016)

・LLEGs are candidates of very young galaxies with low metallicity and AGNs.

Example 2: Strong Emission-Line Sources

Preliminary

z~6 bright LAEs



(Y. Ono et al. in prep.)

(Shibuya et al. 2017)

- LLEGs are candidates of very young galaxies with low metallicity and AGNs.
  → Follow-up spectroscopy for four candidates

Summary

Possible Projects with SPICA:

1. Investigating the infrared properties of high-z galaxy overdense regions

2. A wide area search for very rare interesting infrared sources
   i) lensed sources?
   ii) strong emission line sources?