SWIMS Science Workshop 2015
September 17-18, 2015, IoA, Mitaka

ALMA-TAO/SWIMS synergies

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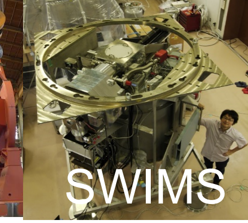
Expected synergies

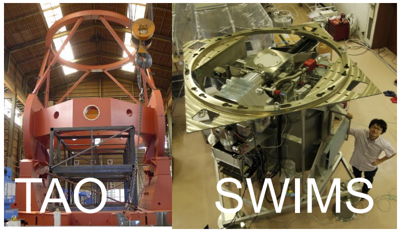


1) Wide area surveys with SWIMS → ALMA follow up of important/intriguing sources

- Subaru/HSC + TAO/SWIMS wide surveys of high-z (z>7.2) quasars → ALMA: M(BH)/M(Bulge), growth of spheroidal, feedback, dust enrichment/metallicity, etc.
- Mstar-limited Hα/[OIII] emitters, etc. (+IFU?) → dust + CO follow up → SFR-Mstar relation vs gas fraction

2) ALMA deep surveys in SWIMS-18 fields

- richness of narrow/medium/broad bands by SWIMS-18 is essential to study the nature of ALMA sources
- Emitter surveys on GOODS-S !?: rich synergies with on-going ALMA deep surveys (including our own cy3)

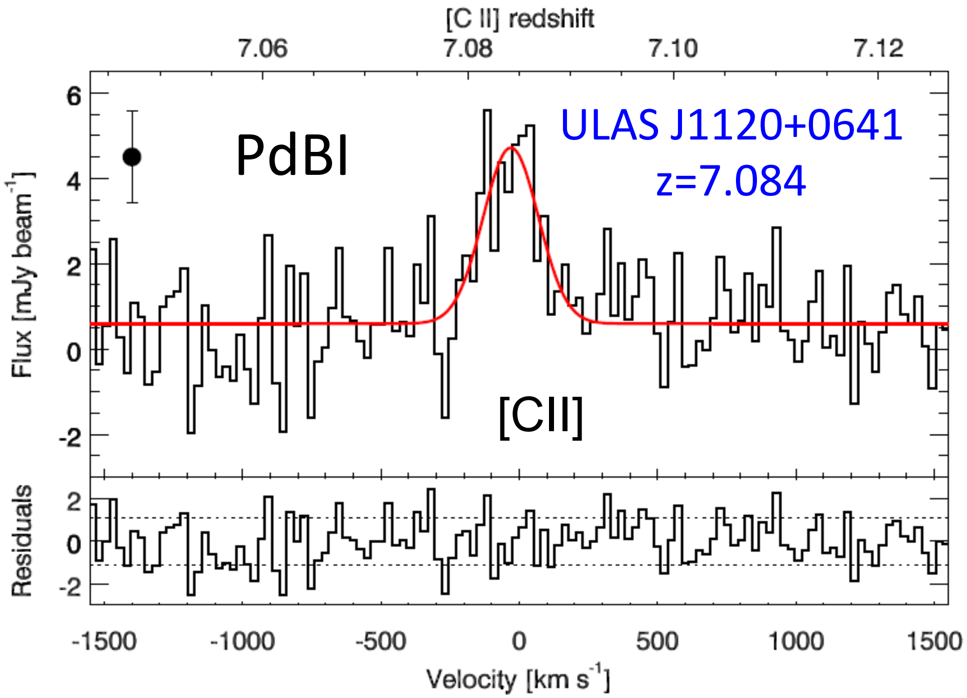


1) Wide area SWIMS surveys
➔ ALMA follow up

Hunting high-z (z>7) quasars ➔ ALMA

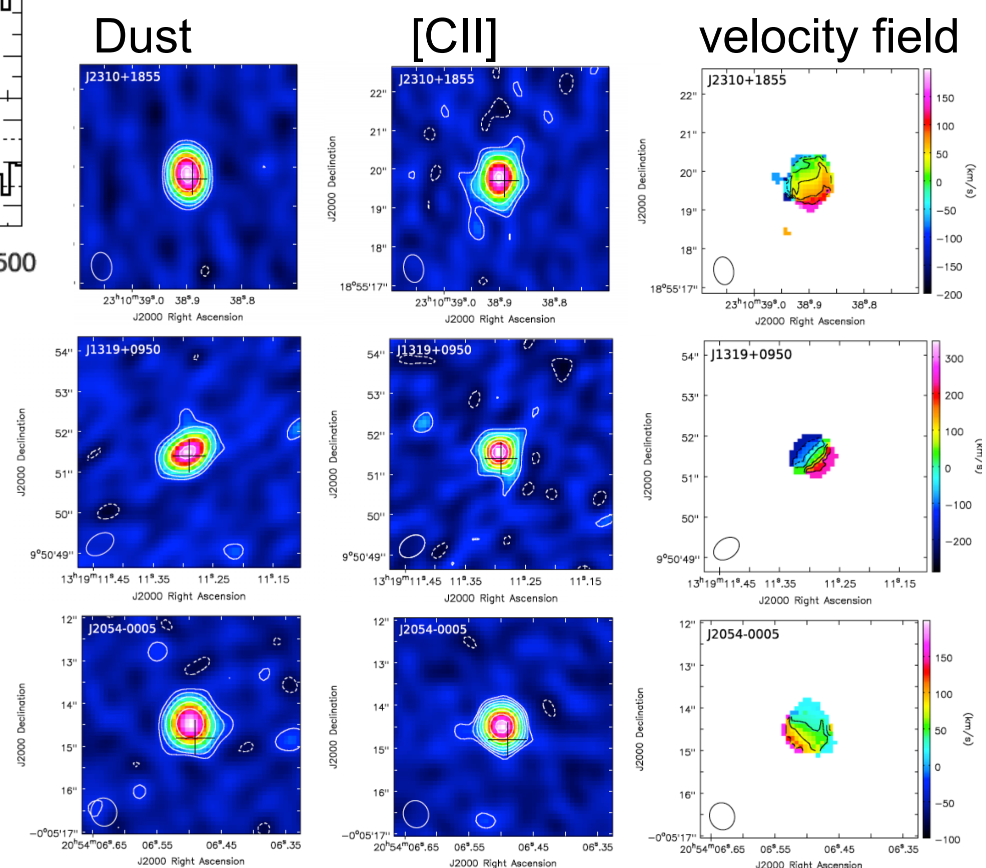
- Matsuoka-san's talk: ~ 1,000 deg^2 SWIMS over HSC-SSP wide field ➔ (0 -) ~20 z > 7.2 quasars
- ALMA [CII] imaging spectroscopy ➔ dynamical mass ~ proxy of bulge mass ➔ constraints on M(BH)/M(bulge) ratio at z>7
- Dust continuum & [CII] ➔ presence of dusty starbursts (= rapid growth of spheroidal) in the z>7 quasar host galaxies: when do they become dust-rich? Differential Maggolian relation
- AGN feedback at z>7: how do they work?
- Fine-structure lines [NIII]57μm, [OIII]88μm, etc. ➔ metallicity of dusty regions (+ calibration)

[CII] & FIR properties of z> 6-7 quasars



ALMA observations of [CII] in 6 quasars (z>6)

Wang et al. 2013, ApJ, 773, 44



$M(BH) = 2 \times 10^9\ M_\odot$

$L(FIR) = (0.6 – 2) \times 10^{12}\ L_\odot$

$SFR = 160 – 440\ M_\odot/yr$

$M(dust) = (0.7 – 6) \times 10^8\ M_\odot$

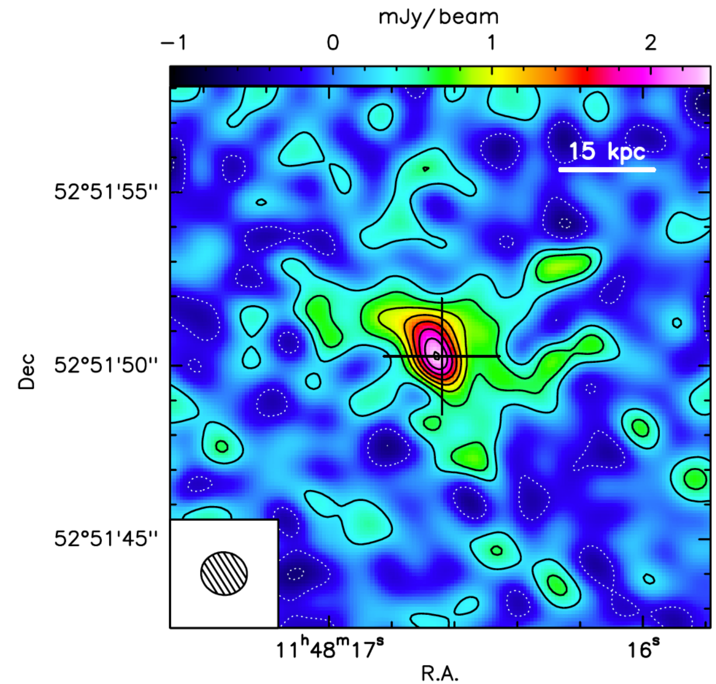
Venemans et al. 2012, ApJ, 751, L25

Page et al. 2014, MNRAS, 440, L91

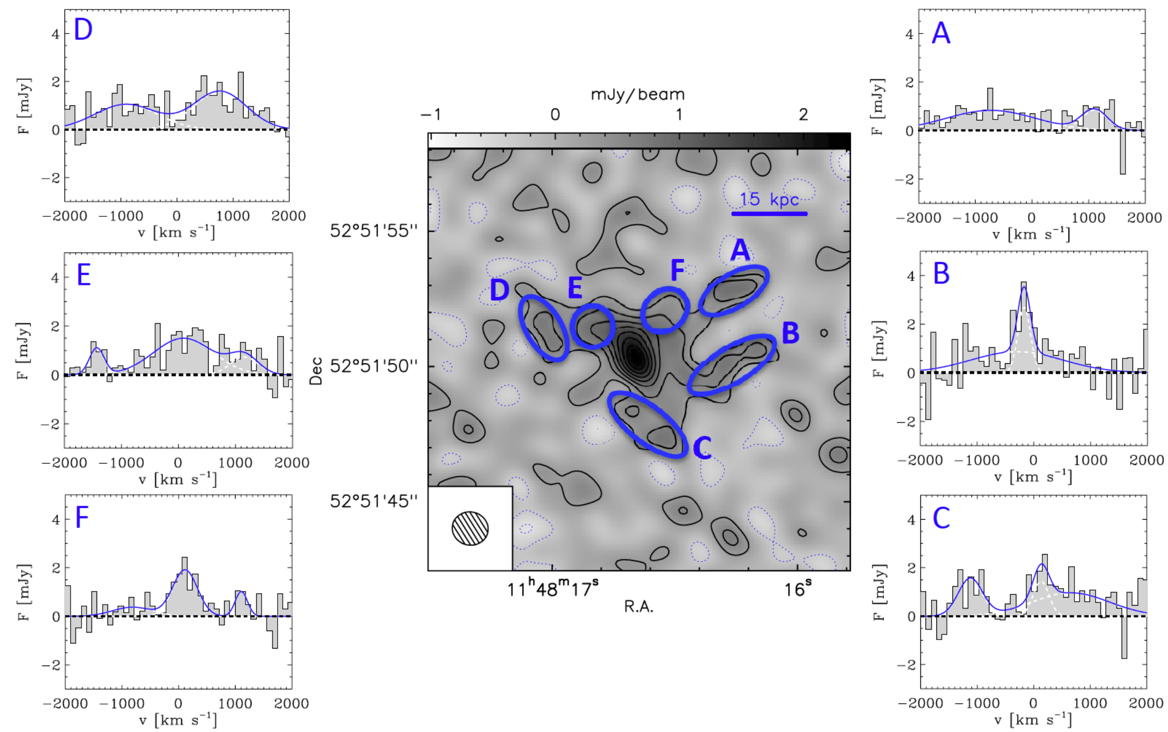
AGN feedback: spatially extended massive [CII] outflows in SDSS J1148+52

- R~30 kpc
- Dynamical timescale ~25 Myr (median)
- Mass loss rate 1400 ± 300 $M_{\odot}$/yr
- Momentum rate $1.0 \pm 0.14\ L_{AGN}/c$
- Kinetic power $(1.6 \pm 0.2) \times 10^{-3}\ L_{AGN}$

z = 6.4

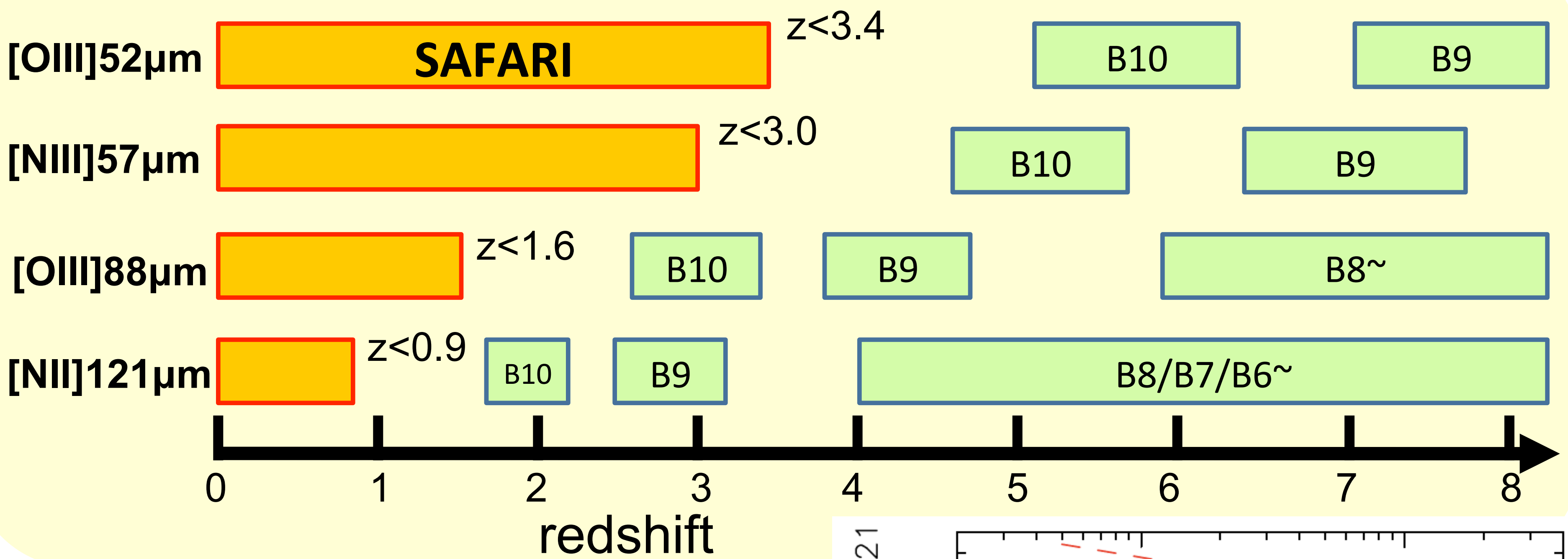


PdBI observation

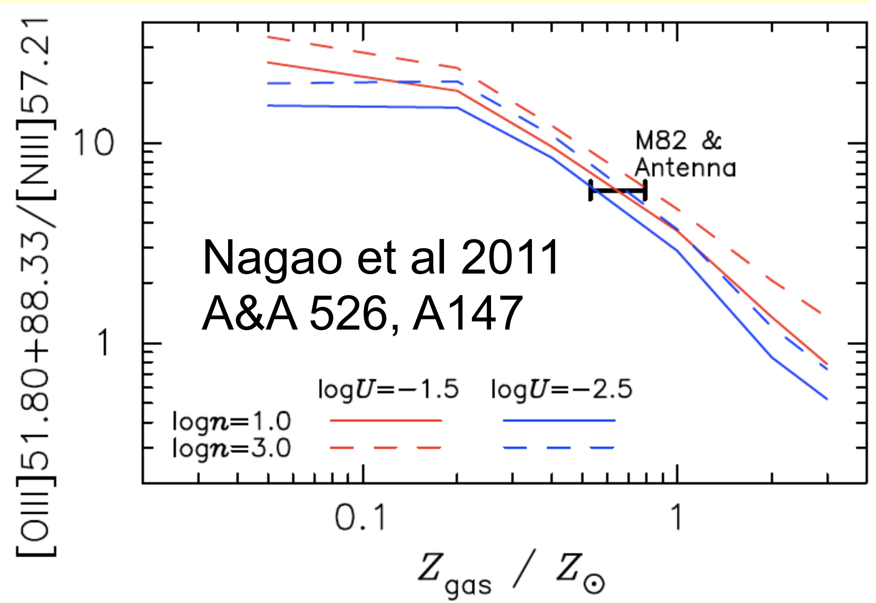


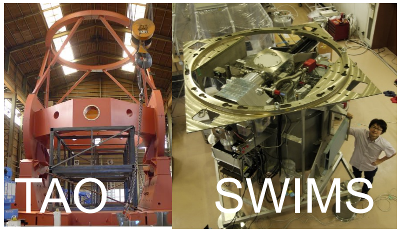
Cicone et al. 2015, A&A, 574, A14

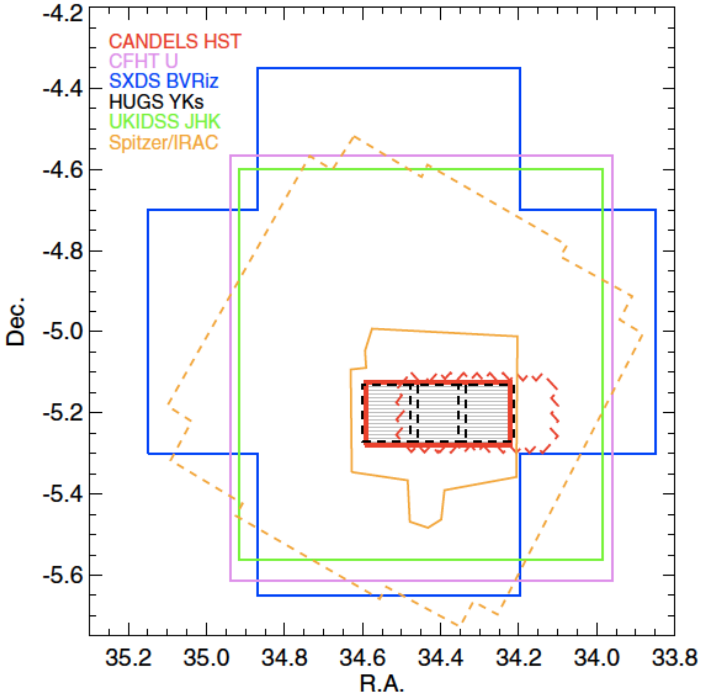
Fine structure lines using ALMA



- Combination of SAFARI/SPICA and ALMA band 10 allows us to calibrate the proposed metallicity indicator ([OIII]52μm/[NIII]57μm ratio) by adding [OIII]88μm line at z~3.
- It also gives a basis for extension of the method to galaxies at z~5 and beyond.







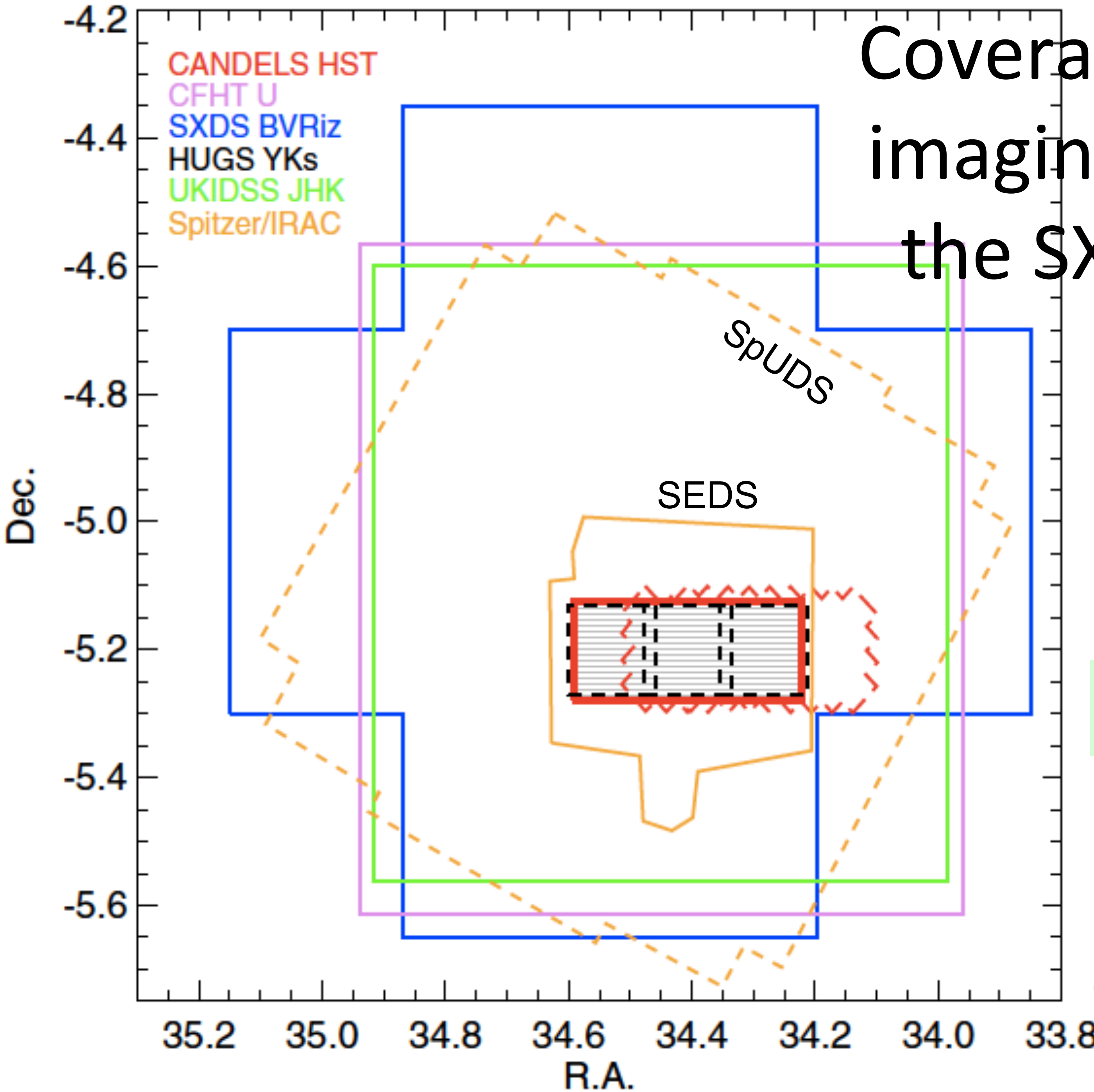
2) ALMA deep surveys in SWIMS-18 fields

(Unbiased) deep surveys using ALMA

- Dust continuum emitting galaxy survey
  - HUDF (cy1, Dunlop et al.), SXDF-CANDELS (cy1, Kohno et al.), SSA22 (cy2, Umehata et al.), HFFs (cy1/cy2), GOODS-S (cy3, two programs, one is led by David Elbaz, the other is by Kotaro Kohno) abstracts available in ALMA science portal
  - Serendipitous faint submm sources (Hatsukade et al. 2013, ApJ, 769, 27; Hatsukade et al. 2015, ApJ, 810, 91)
  - From ALMA archive (Cariniani et al. 2015, Fujimoto et al. 2015, Oteo et al. 2015, all submitted)
- CO, [CII] line emitting galaxy survey
  - Successive reports on [CII] emitter candidates at z>5-6 ?

Richness of multi-wavelength data is a key; adding narrow/medium band data w/ SWIMS-18 to deep fields

Coverage of the imaging data in the SXDS-UDS



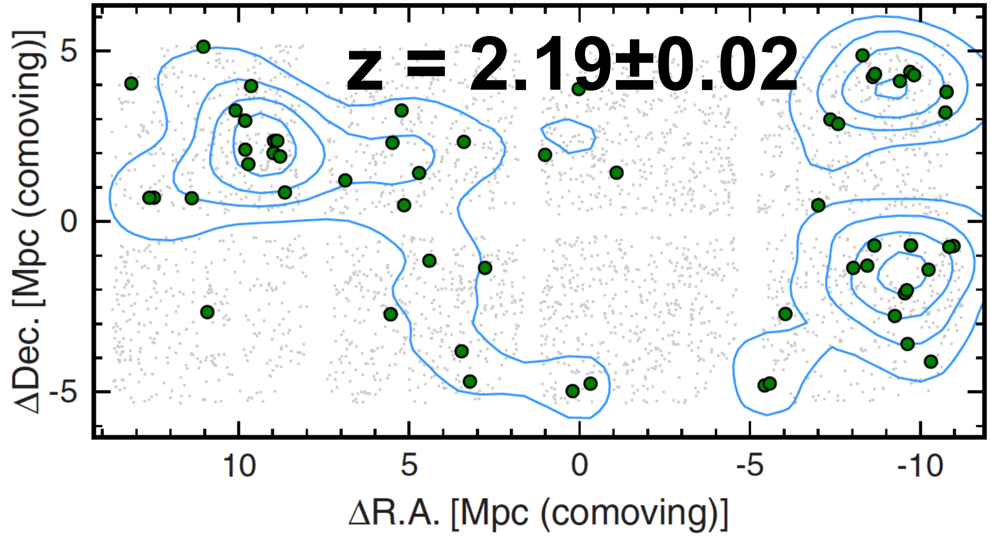
CANDELS-UDS
HUGS

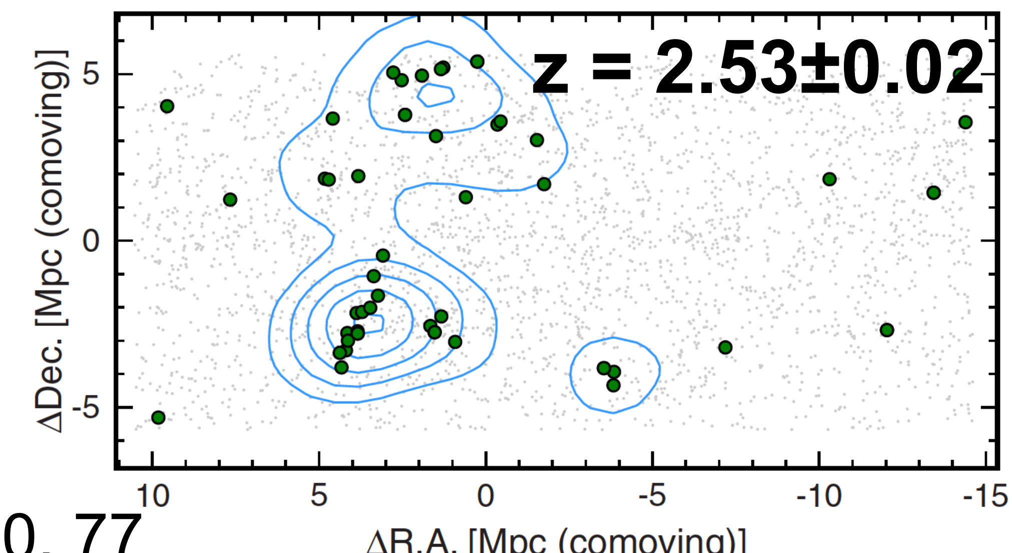
Galametz et al. 2013, ApJS, 206, 10

+ further new data HSC/Subaru, Spitzer, Chandra, ZFOURGE (Lee Spitler's talk)

Hα emitting galaxies (MAHALO/HiZELS)

- Narrow band imaging surveys of Hα emitters (HAEs) using MOIRCS/ Subaru at z=2.2 and 2.5 in the SXDF-UDS-CANDELS field
  - See also HAE surveys and ALMA follow ups:
  - 4C23.56 + ALMA, JVLA (Lee Minju et al.)





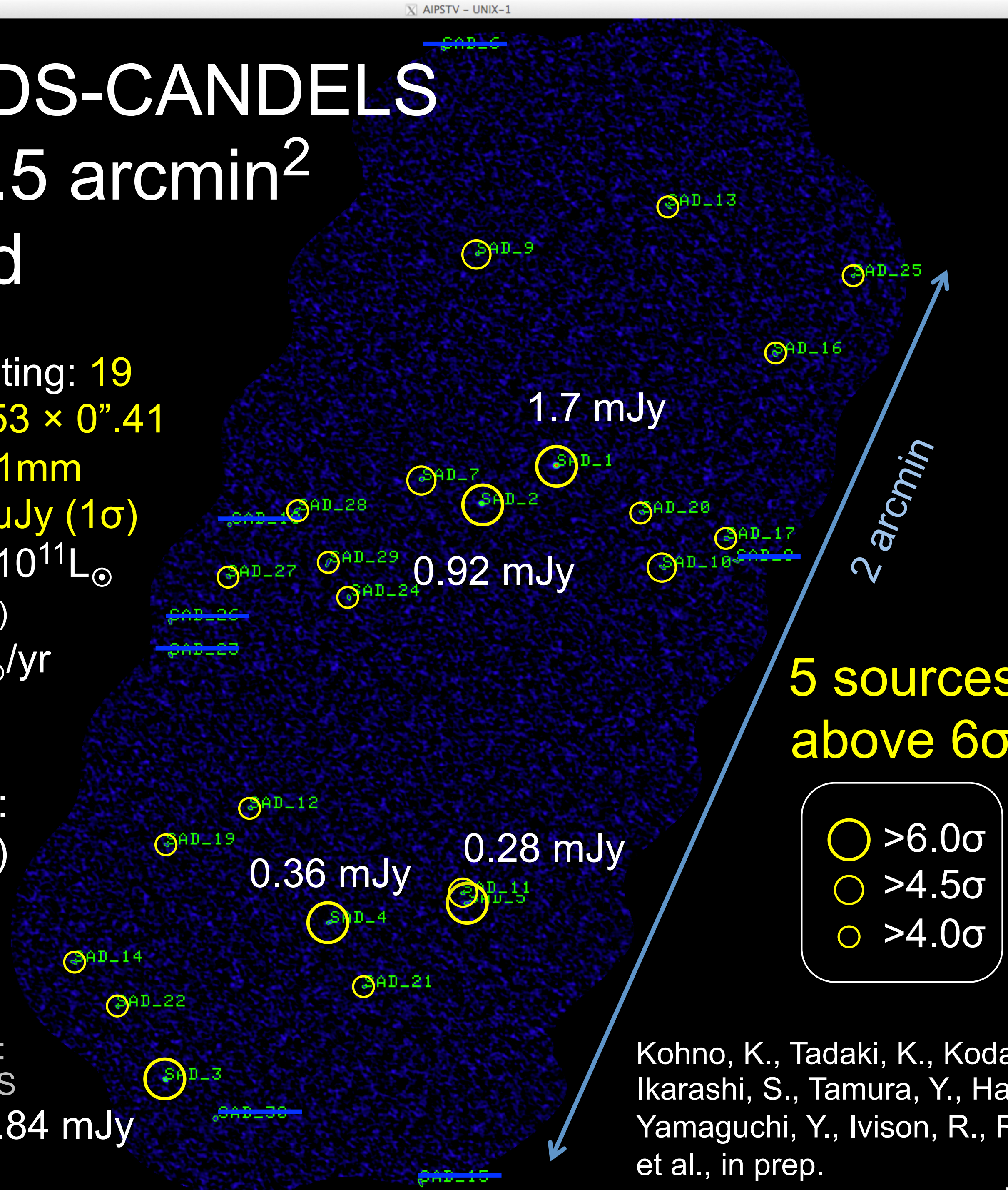
Tadaki et al. 2014, ApJ, 780, 77

SXDF-UDS-CANDELS -ALMA 1.5 arcmin^2 deep field

Number of pointing: 19
Resolution: 0".53 × 0".41
Wavelength: 1.1mm
Noise level: 55μJy (1σ)
⇔ L(IR) ~$1.2\times10^{11} L_\odot$
(if T_{dust} = 40K)
⇔ SFR ~20 $M_\odot$/yr
up to z ~10

Observing time:
3.8 hours (total)

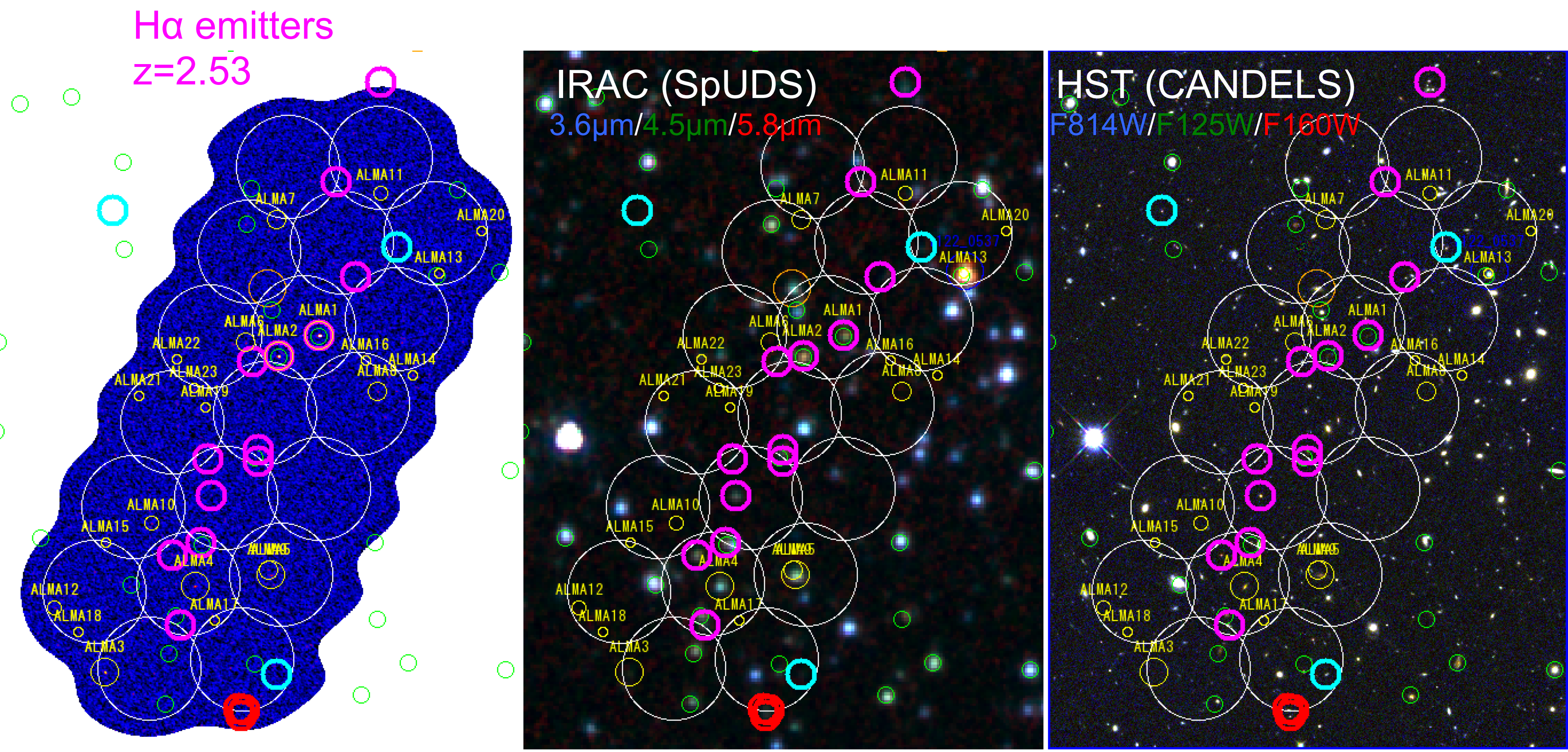
Source extraction:
task "SAD" in AIPS



Lower S/N sources will contain spurious detections

Kohno, K., Tadaki, K., Kodama, T., Ikarashi, S., Tamura, Y., Hatsukade, B., Yamaguchi, Y., Ivison, R., Rujopakarn, W., et al., in prep.

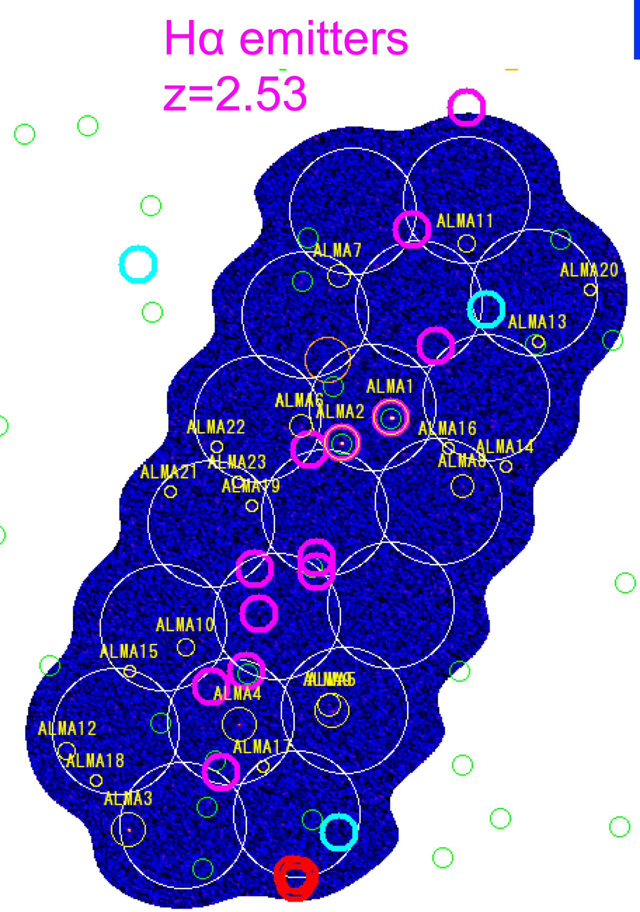
ALMA 1.1mm vs IRAC, ACS/WFC3



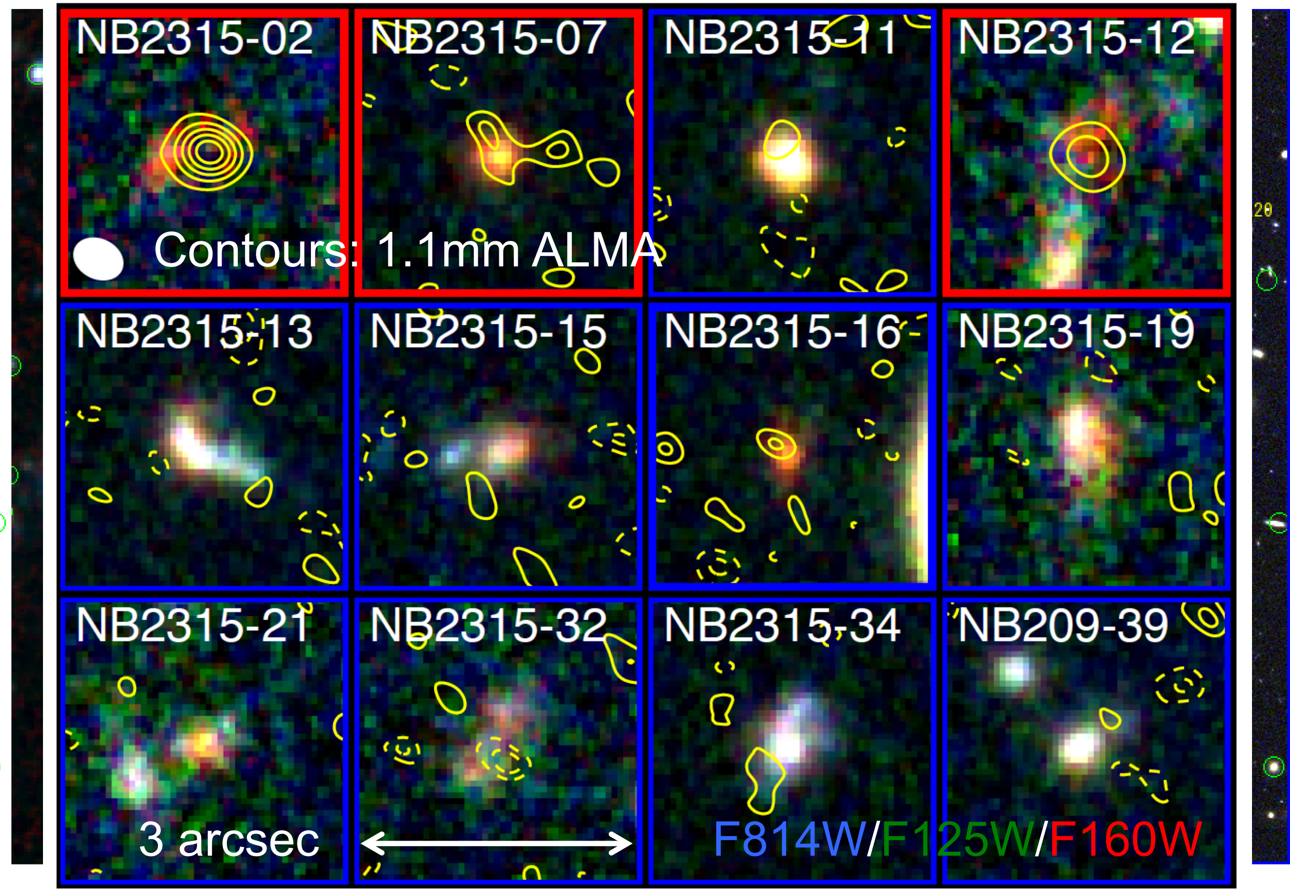
2 Hα emitters: clearly detected in ALMA
Another 1 Hα emitter: marginally detected in ALMA
remaining Hα emitters: no detection in ALMA ➔ bluer color, less massive

Tadaki et al.
2015, ApJ, 811, L3

ALMA 1.1mm vs IRAC, ACS/WFC3



HST(CANDELS) 3 color images of Hα emitters at z=2.53



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Tadaki et al.
2015, ApJ, 811, L3

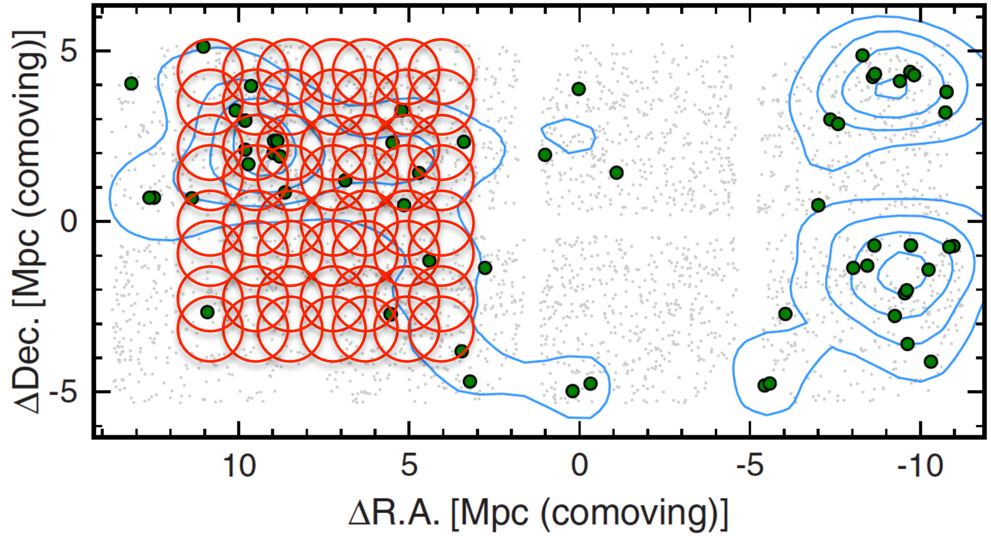
How to harmonize emitters (from Subaru/TAO) and ALMA?

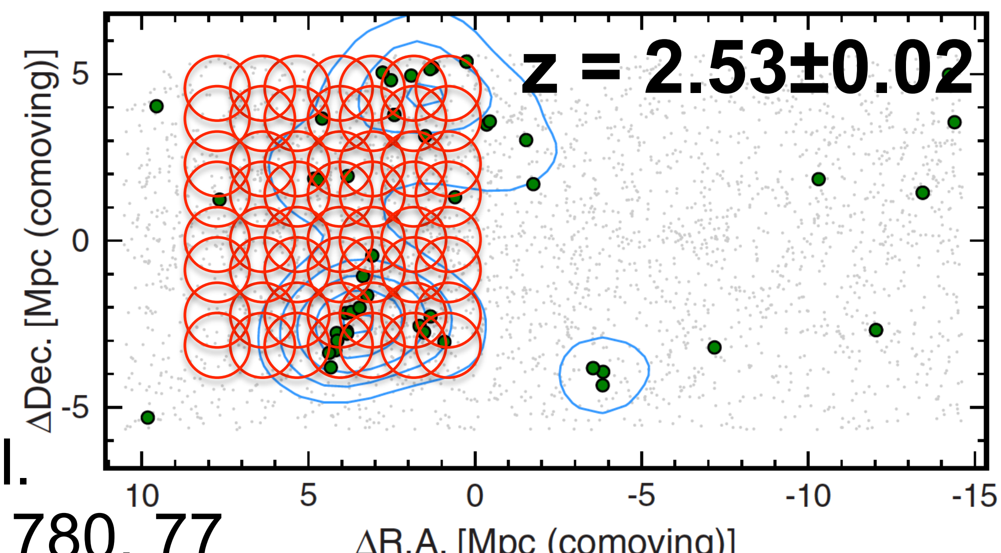
- Individual follow up of Hα (and other) emitters
  - Hα emitters: detection rates of 1.1 mm dust continuum is not very high for our cy 1 pilot surveys (just ~a few min per field) on SXDF-CANDELS (Tadaki et al. 2015, ApJ, 811, L3) and 4C23.56 (Lee Minju et al. in prep.).
  - ➔ Relatively deep integration on individual emitters
    - 870μm individual pointing on Hα emitters (Tadaki-san's talk) and Lyα emitters/brobs (Matsuda et al., in prep.)
- CO(3-2) at z~2.5 ➔ band 3 (~100GHz) observations can be efficient (for biased regions)
  - Multiple sources within FoV ~ 1 arcmin (diameter)

ALMA band3 CO(3-2) contiguous survey toward MAHALO/SWIMS Hα emitters ?

- 1 hour integration per pointing
  ➔ a few × 10^9 $M_\odot$
  - 5σ, α_{CO} = 0.8 $M_\odot$/(K km/s pc^2)
  - (upper limits on) baryonic gas fraction < a few 10 % for the stellar mass limited samples (Mstar = 10^{10} – 10^{11} $M_\odot$)
  - Complete census of both SFR and gas densities (Hα LFs and CO LFs):
    - SFR < a few $M_\odot$/yr
    - M(gas) < a few 10^9 $M_\odot$
  - A few 10 $arcmin^2$ survey with ~ 50 hours or so ➔ using "large program" framework which will be implemented in cycle 4?

z = 2.19±0.02

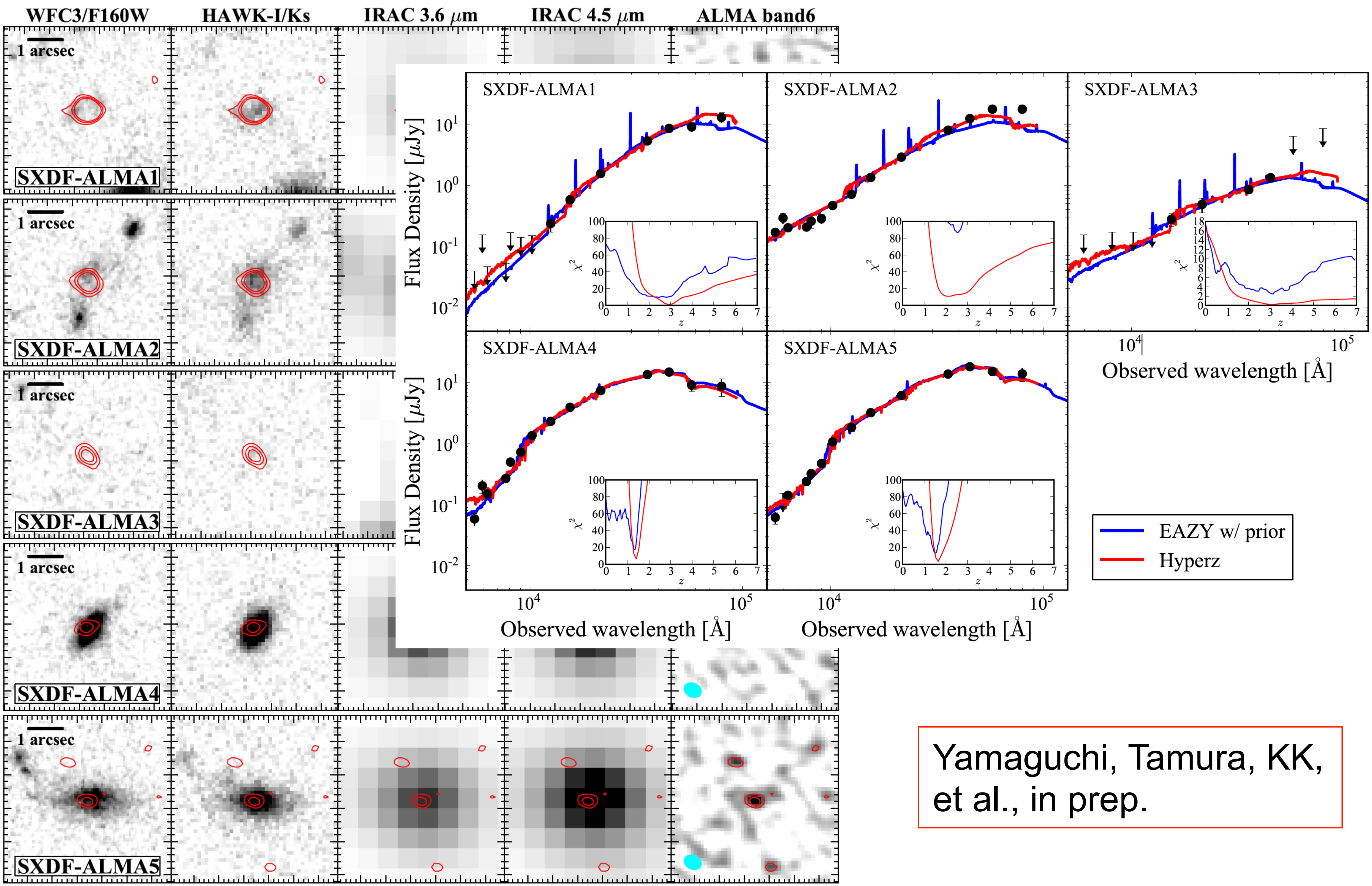




※ 8 GHz ⇔ dz ~ 0.28 @100GHz

Tadaki et al. 2014, ApJ, 780, 77

Characterization of ALMA sources

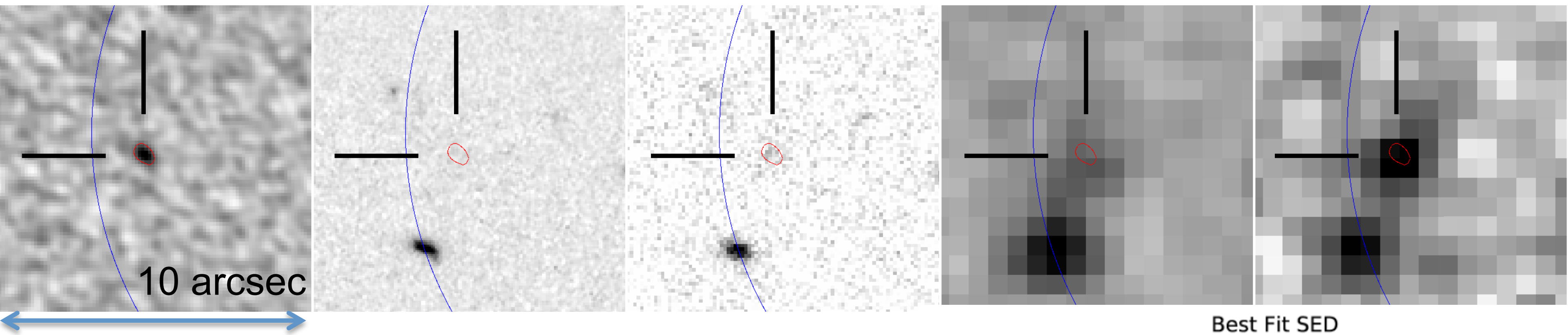


Yamaguchi, Tamura, KK, et al., in prep.

An obscured ULIRG at z >2 uncovered in SXDF-ALMA 1.5 arcmin^2 survey?

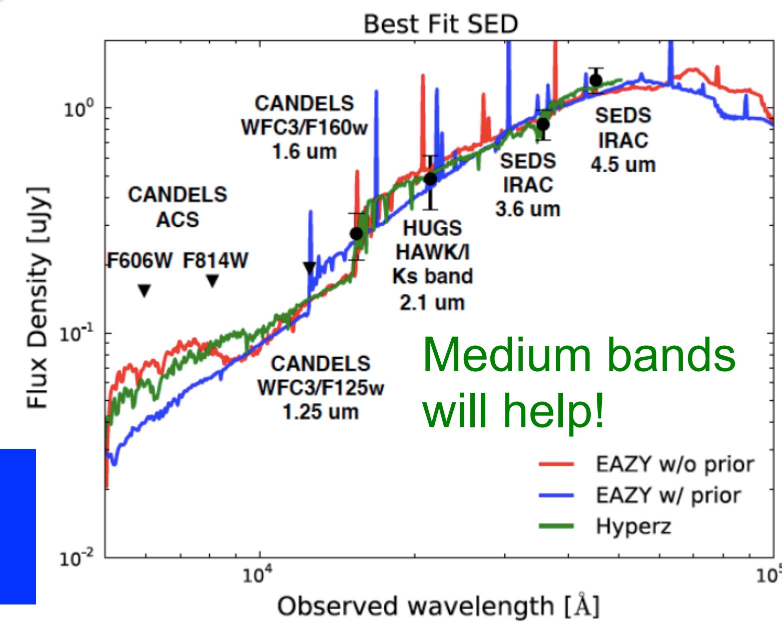
Yamaguchi, Tamura, KK et al. in prep.

ALMA/B6 1.1mm	CANDELS WFC3/F160W 1.6μm	HUGS HAWK-I/Ks-band 2.1μm	SEDS IRAC 3.6μm	SEDS IRAC 4.5μm



- $z_{photo} = 3.1^{+1.8}_{-1.5}$ (Hyper-z),
- $2.4^{>+1.7}_{-1.6}$ (EAZY)
  - One L(IR) = $1\times10^{12} L_\odot$ galaxy in the survey volume (1.5 arcmin^2, z = 3 – 5) ⚠ depends on adopted z-bin
  - ➔ SFRD ~$2\times10^{-2}\ M_\odot$/yr/Mpc^3

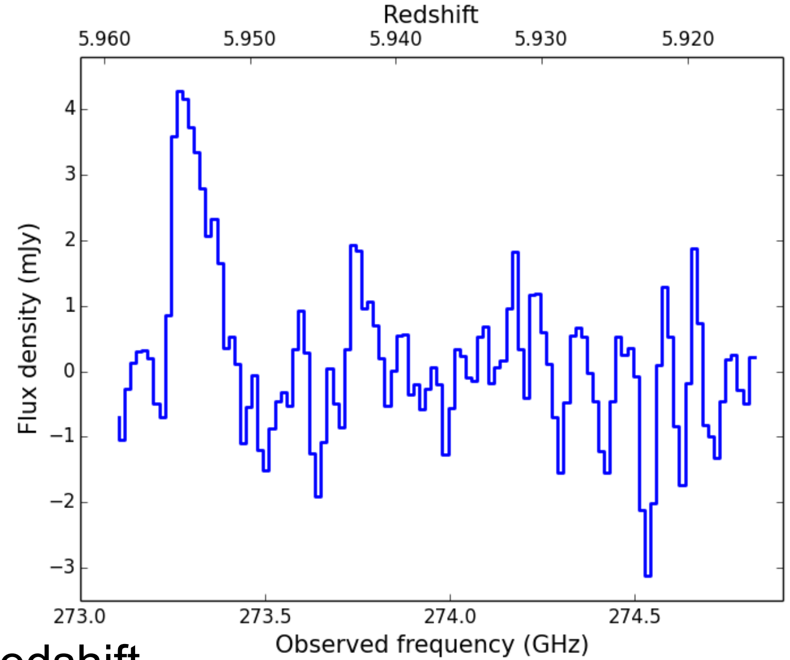
additional contributions to the SF history may come from faint submm galaxies, which do not appear to be fully overlapped with UV/optical-selected galaxies (e.g., Chen et al. 2014, ApJ, 789 12)

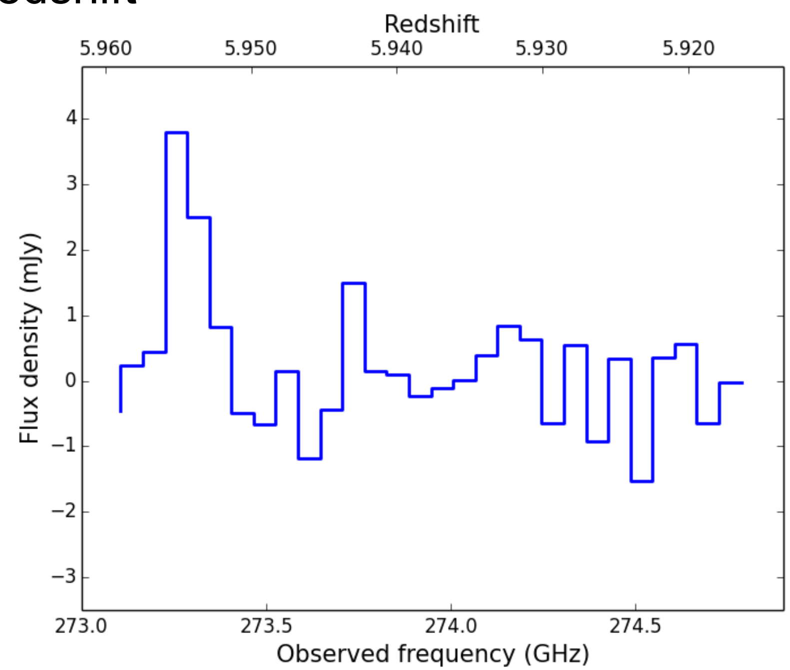


Blind detection of an emission line galaxy?

- Peak flux = 3.8 ± 0.70 mJy (5.4σ)
- S(line) = 0.53 ± 0.079 Jy km/s (6.7σ)
- ➔ L[CII] = $5.1 \times 10^8\ L_{\odot}$
  - (if this is [CII]; faintness of F160W/Ks/IRAC/(and radio) is consistent with z~6 ??)
- Velocity width ~ 100 km/s (FWHM) or 155 km/s (FWZI)

⚠ or a lower redshift CO emitter

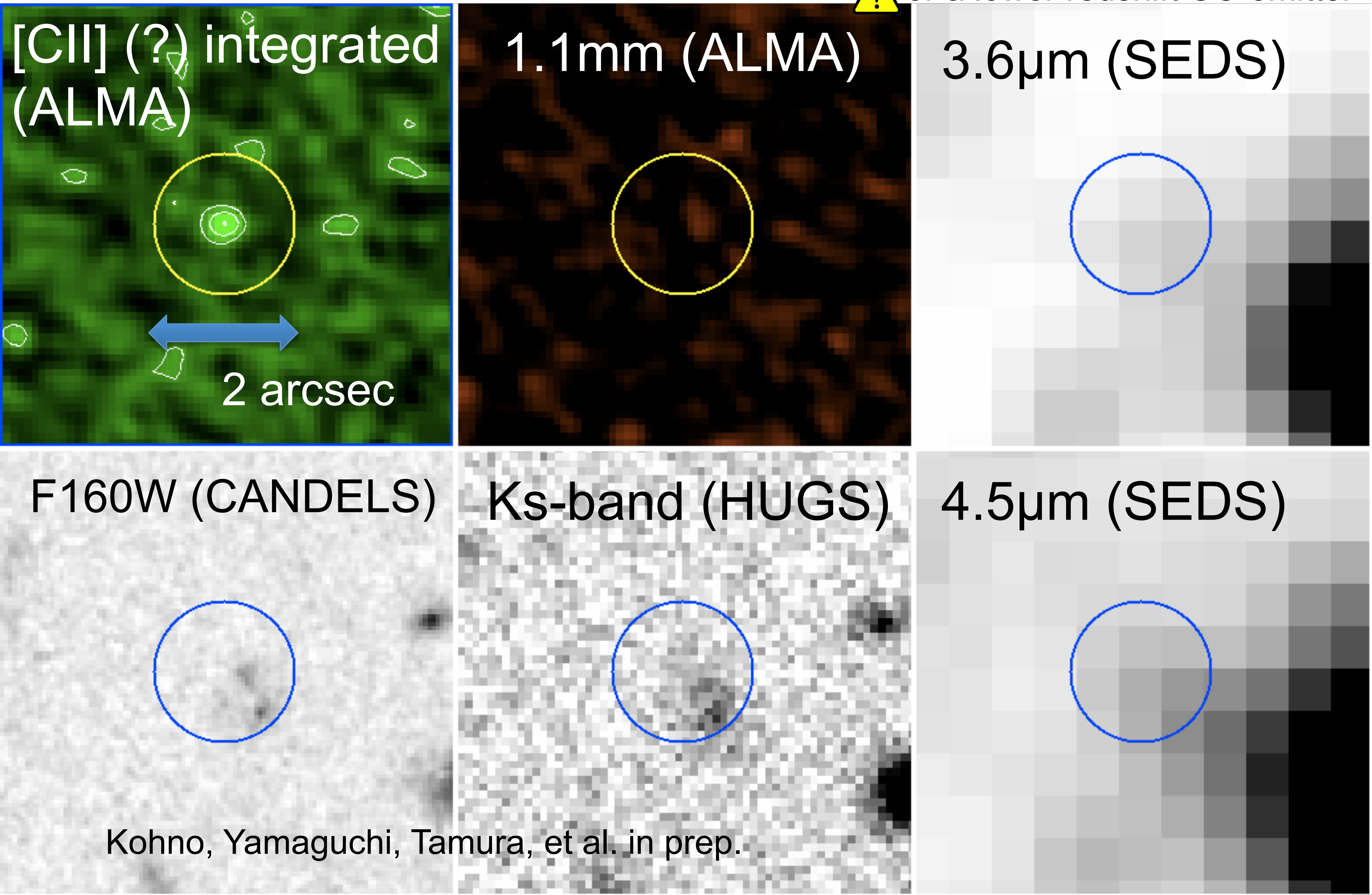




Kohno, Yamaguchi, Tamura, et al. in prep.

A candidate [CII] emitter @z=5.955??

⚠ or a lower redshift CO emitter



Kohno, Yamaguchi, Tamura, et al. in prep.

Serendipitous detection of a mm-line emitting galaxy

- See also a talk by Aravena et al. in IAU-S315 (S315.12.01)
- Let's see how abundant they are

[CII] emitting dark galaxy@z=6.6 ???

ONO ET AL.

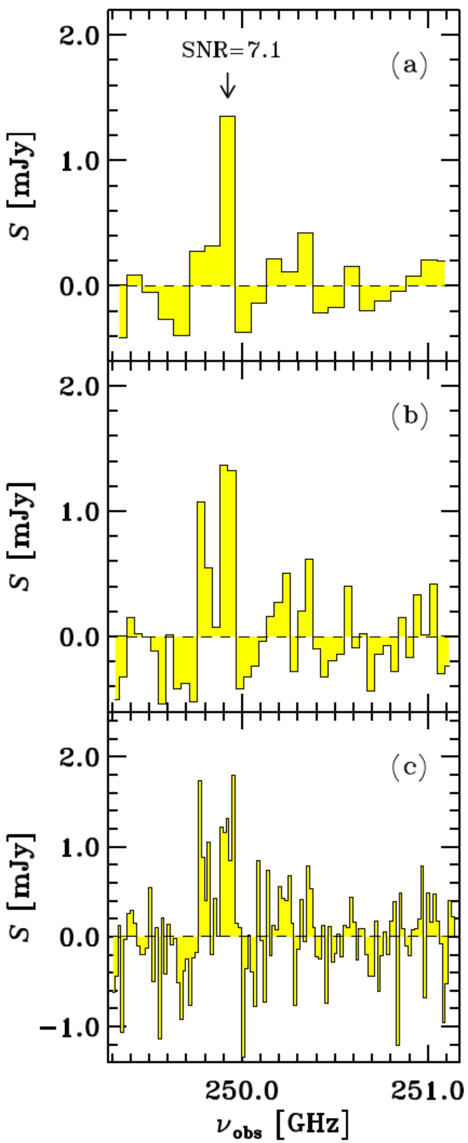


Figure 11. ALMA Band 6 spectra of SLE-1 extracted at the position of the peak emission with frequency binnings of (a) $\Delta v = 100\,\mathrm{km\,s^{-1}}$, (b) $\Delta v = 50\,\mathrm{km\,s^{-1}}$, and (c) $\Delta v = 20\,\mathrm{km\,s^{-1}}$. The flux densities are corrected for the primary beam attenuation. The S/N of the peak flux density in the spectrum of $\Delta v = 100\,\mathrm{km\,s^{-1}}$ is $\simeq 7.1$.

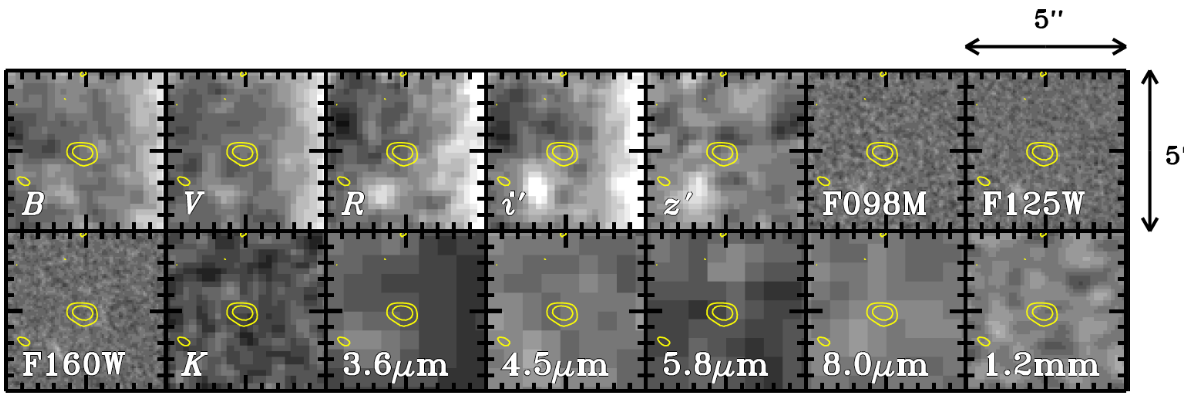
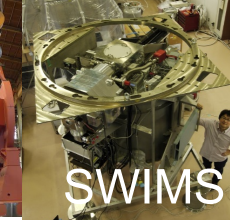


Figure 12. 5″ × 5″ multi-wavelength images of SLE-1. Top panels show the images taken by the Subaru Suprime-Cam (*B*, *V*, *R*, *i*′, *z*′) and the *HST* WFC3 (F098M, F125W). Bottom panels are the images taken by the *HST* WFC3 (F160W), the UKIRT WFCAM (*K*), the *Spitzer* IRAC (3.6 μm, 4.5 μm, 5.8 μm, 8.0 μm) and the ALMA Band 6 (1.2 mm). Contours correspond to the 3σ and 5σ levels of the detected line at 249.9 GHz.

Ono et al. 2014, ApJ, 795, 5

Summary



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