PFS-SSP GALAXY SURVEY WORKSHOP 2015
at Kashiwa (from Munich)
November 13, 2015

Submillimeter Galaxies and PFS

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Outlines

§ Introduction

- Target: submillimeter galaxies (SMGs)
- Recent large surveys with ALMA

§ The possible science cases w/ PFS (+ALMA)

- The role of SMGs across cosmic time; SFR, Stellar mass, etc
- The connection between SMGs and large-scale structures

§ Strategy for PFS

- Previous optical surveys of SMGs
- Suggetion for PFS-SSP

§ Summary

SMG Studies in the ALMA Era

- Brief introduction of SMGs

- Large ALMA surveys in terms of possible PFS targets

1. ALMA Deep Field
2. ALMA (continuum) Follow-up of SMGs

SMGs: Submillimeter-selected Galaxies

§ What're SMGs?

- First Discovery: < 20 years ago

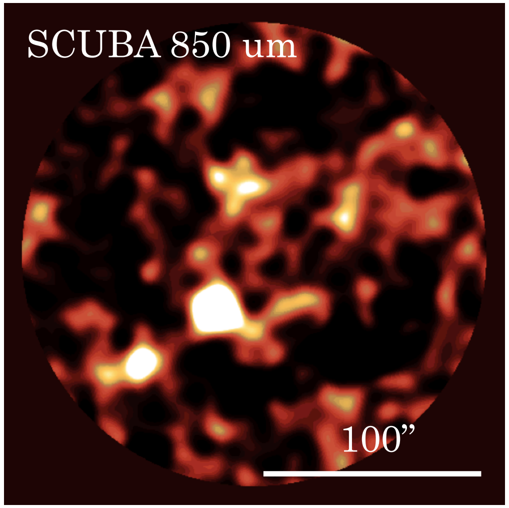
  (e.g., Smail+1997, Hughes+1998)

- Properties:
  - Luminous in rest-frame FIR bands ($10^{12\text{-}13}$ Lsun)
  - High SFR (a few 100 – 1000 Msun/yr)
  - Large gas reservoir ($10^{10\text{-}11}$ Msun)
  - Large stellar mass ($10^{10\text{-}11}$ Msun)
  - AGN-host (a few x 10 %?)
  - high-z population (<z> =2.5~3.0 ?)

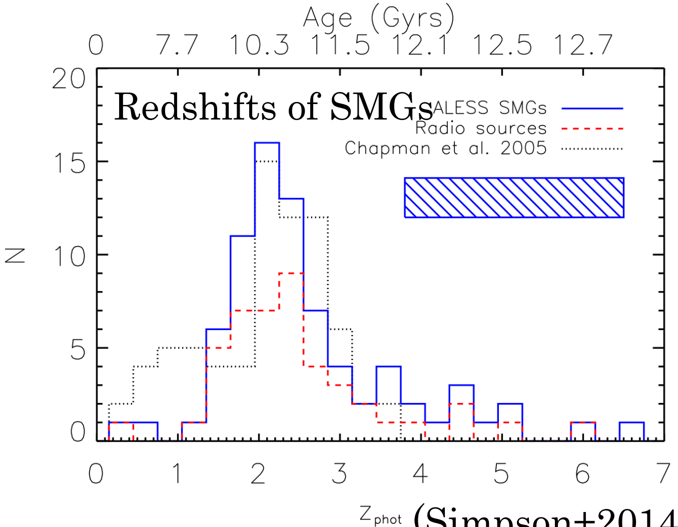
(For review; e.g., Casey+2014)

⇒ Massive Dusty Starbursts in the early universe.

"The First SMG"



(Hughes+1998)

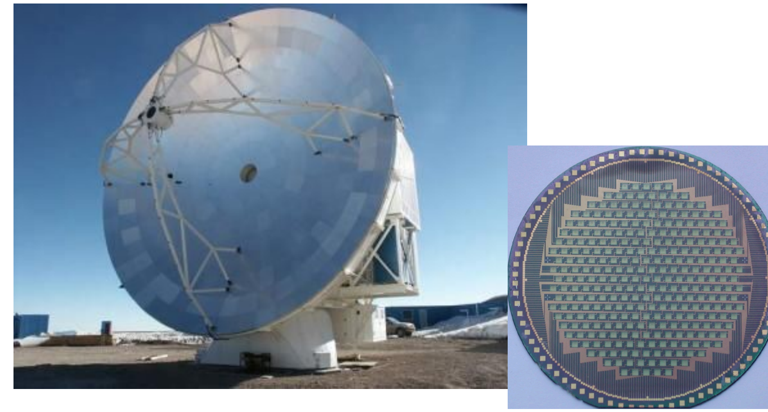


(Simpson+2014)

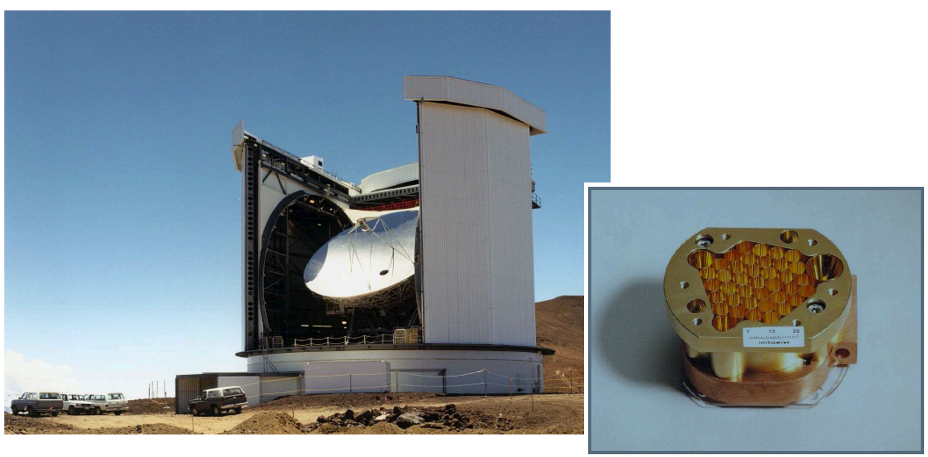
Wide Surveys w/Single Dish Telescopes

§ Example of sub(mm) surveys

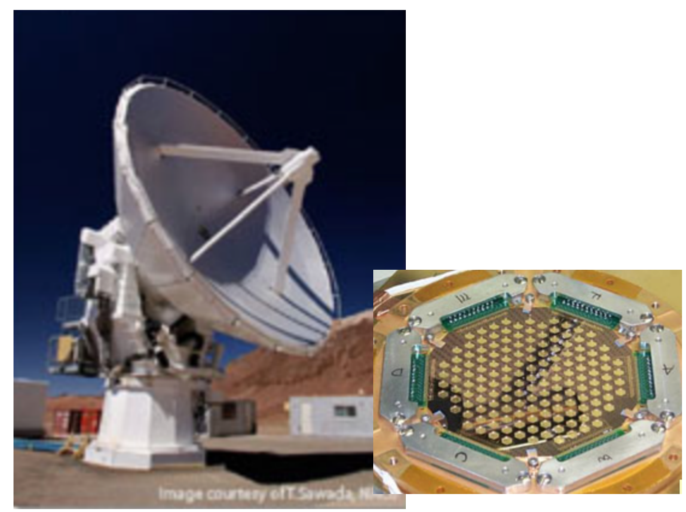
- Wavelength: 850 ~ 2000 mm
- Large-format bolometer camera
  + 10-15m telescope
- Angular reslution: ~15-30”
- ex) SCUBA(2), LABOCA,
  AzTEC, MAMBO, GISMO…
- Next generations come soon (e.g., TESCAM)



LABOCA on APEX



SCUBA, SCUBA2 on JCMT



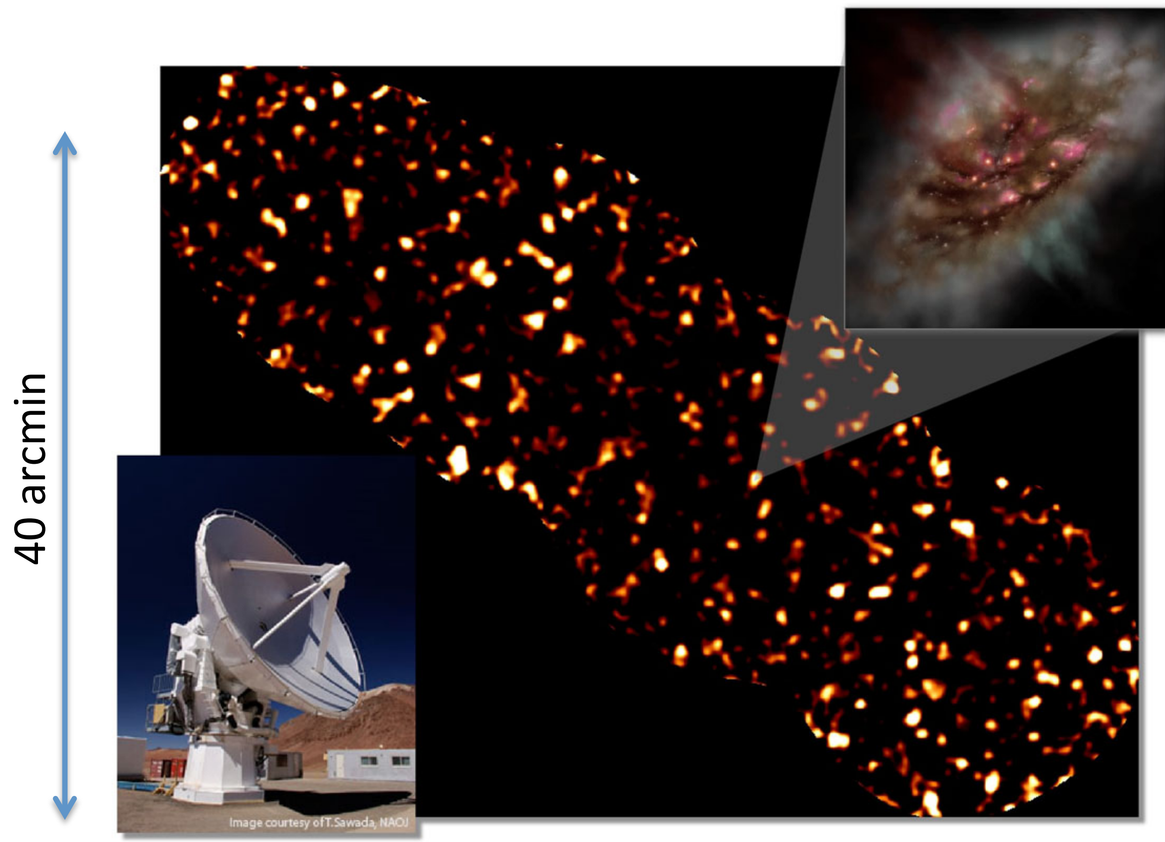
AzTEC/ASTE

Wide Surveys w/Single Dish Telescopes

§ AzTEC/ASTE 1.1mm Surveys

- Angular resolution: 30”
- rms noise revel: ~1 mJy/beam (SFR_IR ≧ several 100 Msun/yr)
- 100-200 sources across ~40arcmin area

  e.g., 198 sources in 900 arcmin^2 (ADF-S, Hatsukade et al. 2011)



AzTEC 1.1mm Map in ADF-S
(Hatsukade et al. 2011)

Large ALMA Surveys

§ **ALMA Deep Fields**

- Cy1 : ~2-4 arcmin^2 (e.g., SXDF:Kohno et al, HUDF:Dunlop et al.)
- Cy2 : ~6 arcmin^2 (e.g., SSA22:Umehata et al.)
- Cy3 : ~20 arcmin^2 (GOODS-S;Kohno et al, Elbaz et al)
- Cy4 : ??? (2016 April deadline?)

§ **ALMA follow-up of submm sources** (e.g., LABOCA, AzTEC, SCUBA2)

- Cy0: #126 ECDF-S (Smail et al.)
- Cy1: #45 SSA22(Umehata et al.) #30 SXDF(Ikarashi et al.)
- Cy2: #333 SXDF, SSA22, ADF-S (Hatsukade et al.)
  #125 COSMOS (Aravena et al),
- Cy3: #533 UKIDSS-UDS (Smail et al.)
- Cy4: ??? (2016 April deadline?)

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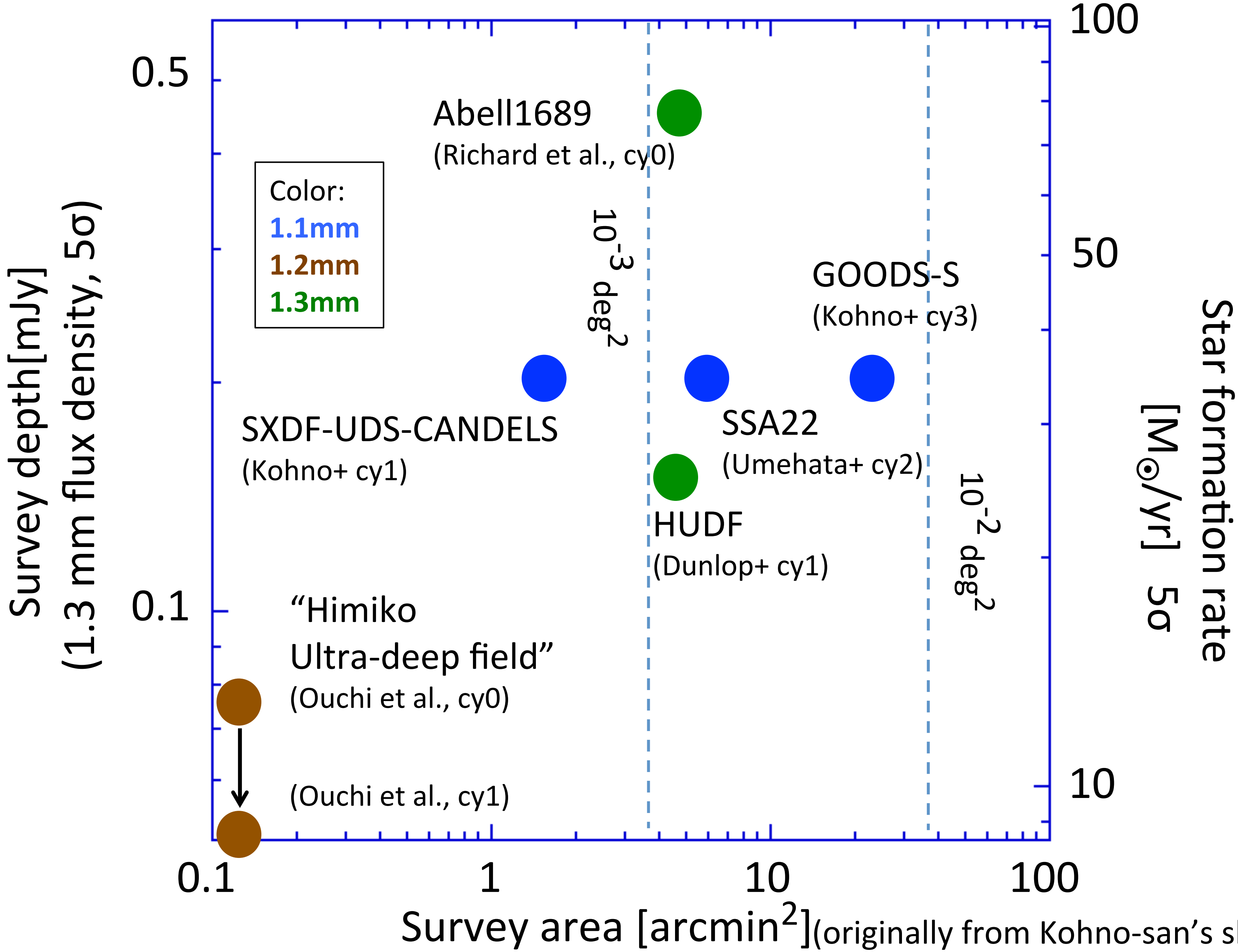
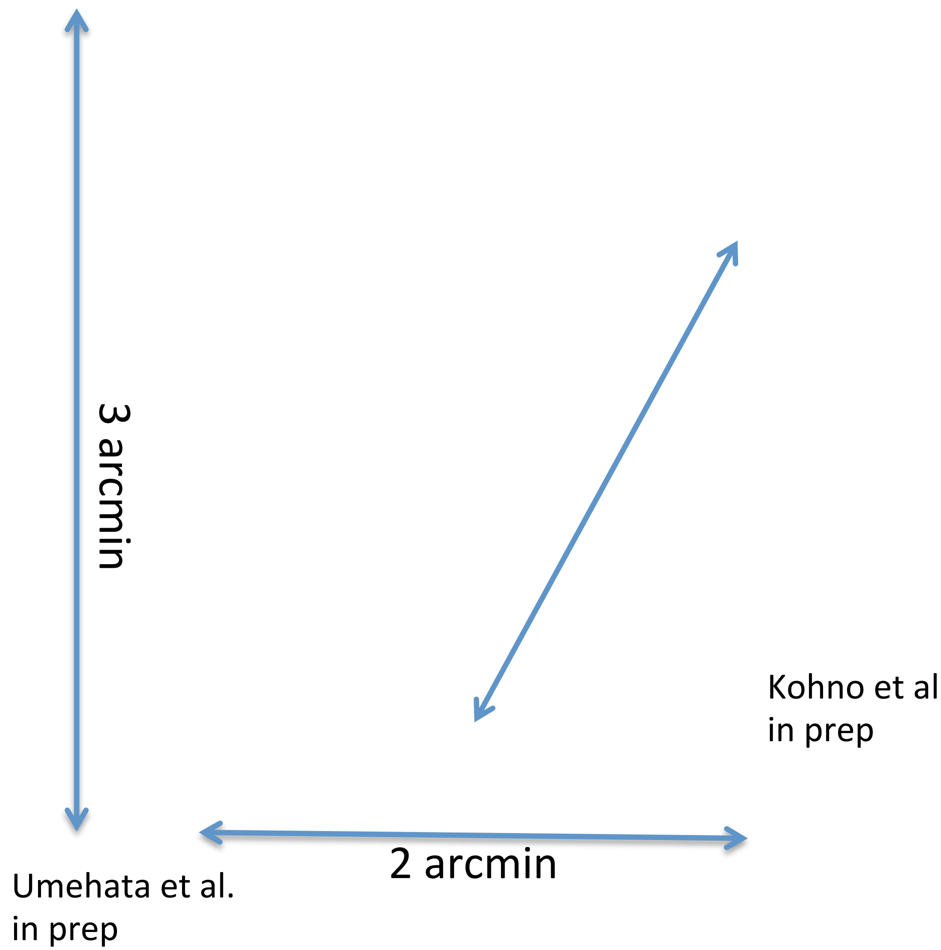
ALMA Deep Imaging at ~1mm



(originally from Kohno-san's slide)

Example of ALMA Deep Fields



- There are a number of sources w/o spec-z and PFS can be helpful.
- However, the survey area is still small compared to that of PFS.

Large ALMA Surveys

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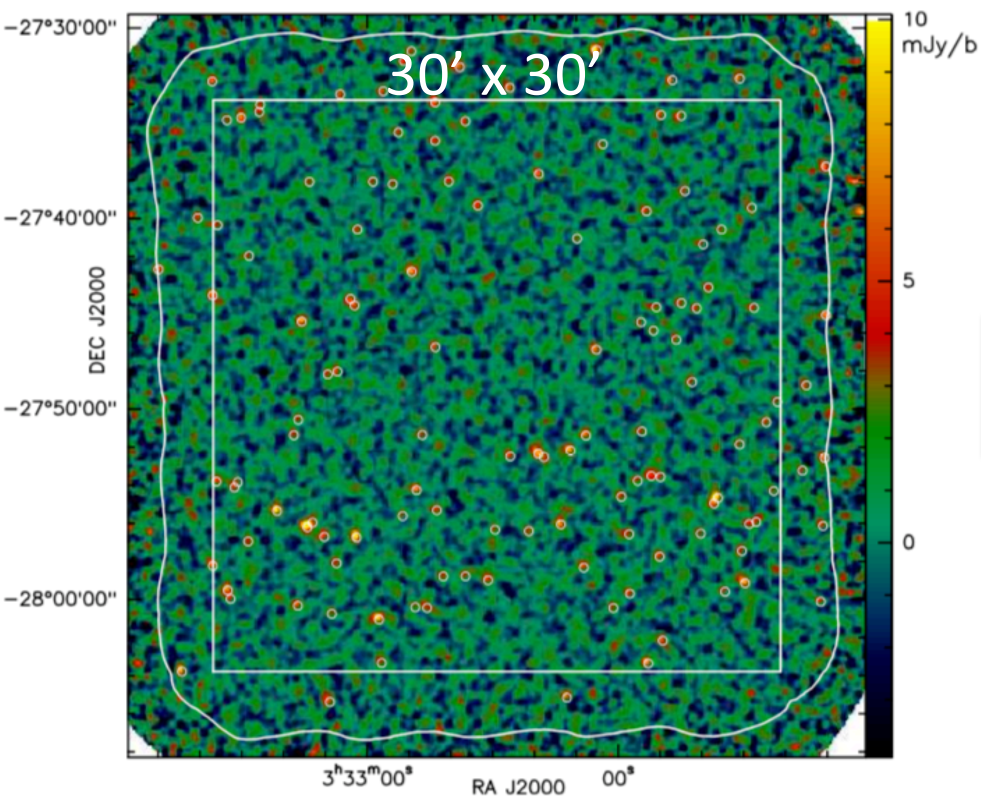
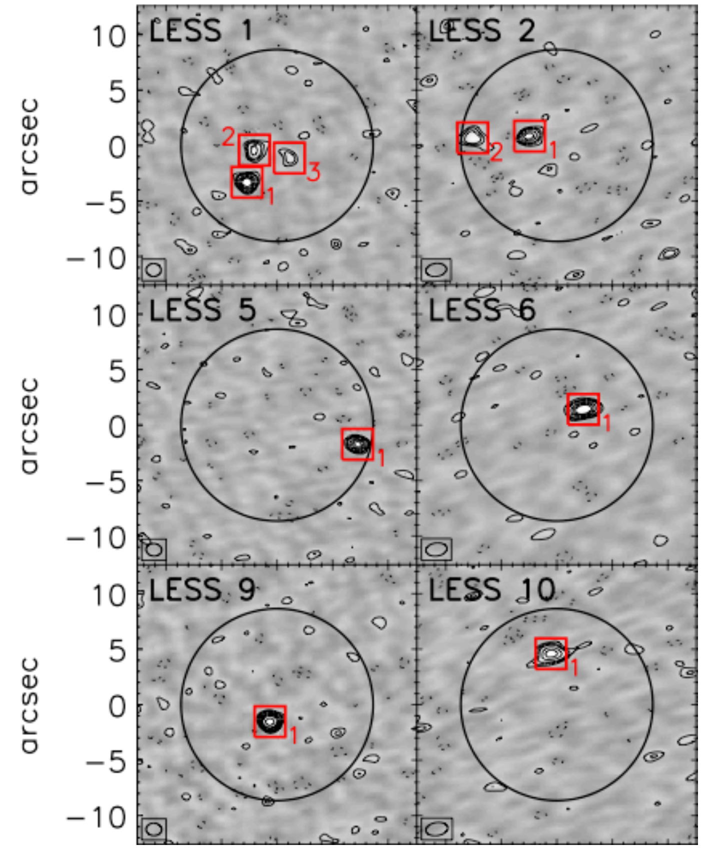
Example of ALMA SMG Follow-up

§ ALMA Follow up in Cy0

- ‘good quality’ ALMA map for 88/125 LABOCA sources
- Angular resolution: ~1.5”



Weiss et al. 2009



Hodge et al. 2013

- Many targets across wider area => Good PFS candidates.

The Targets of PFS

- Wide surveys taken with Single-dish telescopes (e.g., AzTEC/SCUBA2) can provide large number of samples, though the angular resolution is insufficient.

- "ALMA Deep Field" is also worthwhile considering.
  - SXDF and SSA22 are being investigated.
  - A lot of 'faint SMGs' (S_1.1mm <1mJy) has been found.

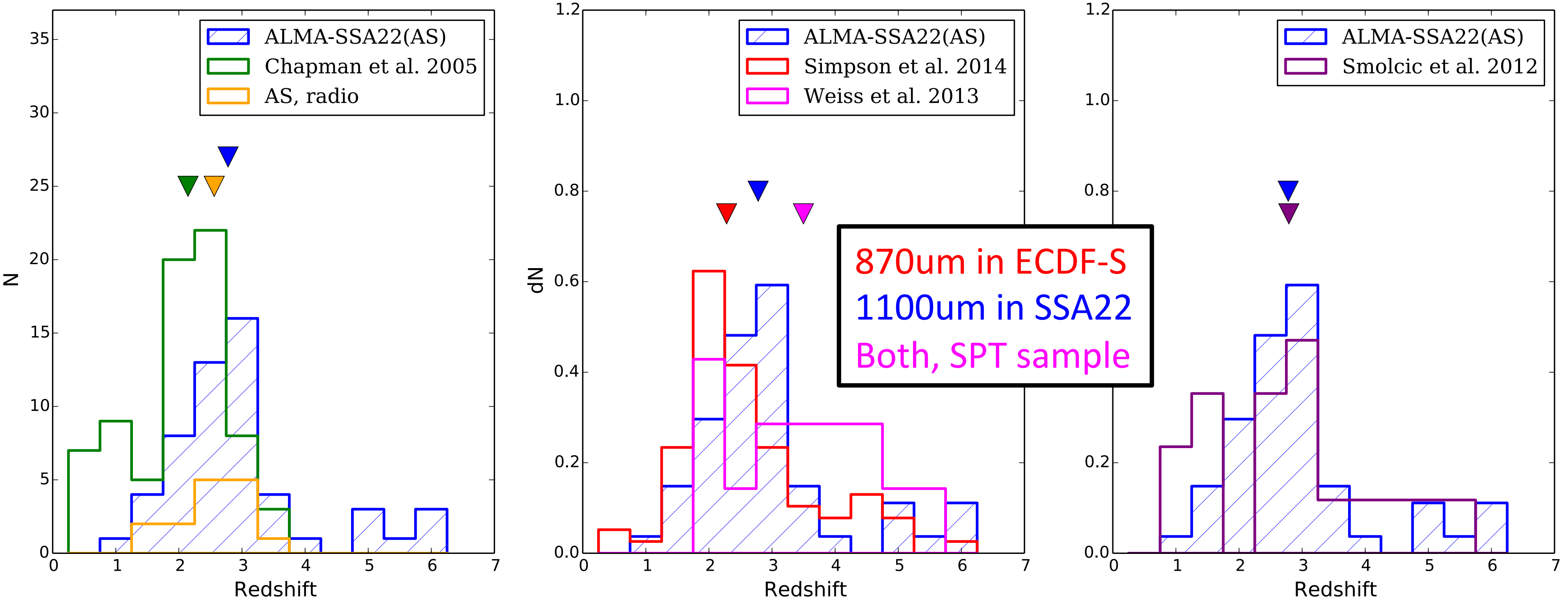
- ALMA-identified SMGs can be the best targets.
  - Our team is constructing catalogs in SXDF and SSA22.
  - NA/Chile team has COSMOS samples.

Possible Science Case w/ PFS

- Panoramic spec-z survey of SMGs

1. To assess the role of SMGs across the cosmic time.
2. To unveil environmental dependence on SMG formation.

Redshift Distribution of SMGs



Umehata 2015 (PhD Thesis)

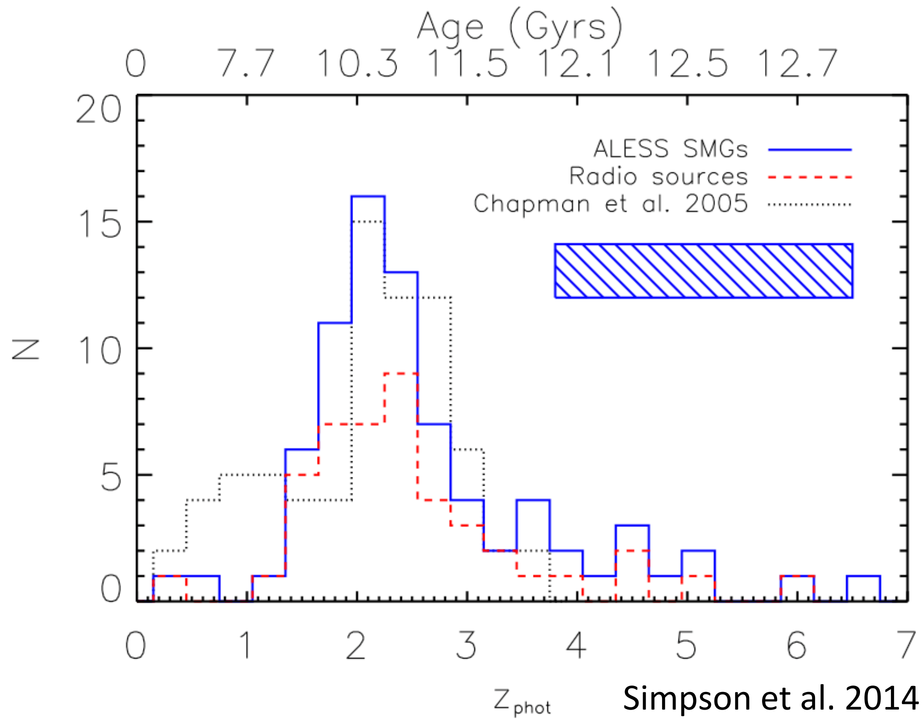
§ The redshift distribution is still unclear.

- 1.1mm / 870 um selected SMGs might have different distributions.
- 'high-z' tail (z>3) is yet mystery.

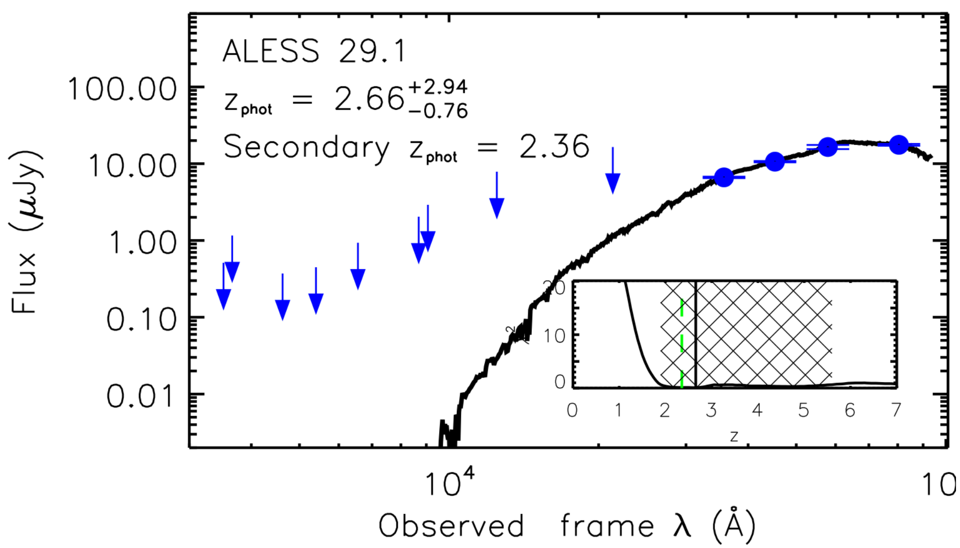
Redshift Distribution of SMGs

§ Example : ALESS Survey (ALMA SMGs in ECDF-S)

- Only 10 / 96 have spec-z.
- Photo-zs are not well-restricted for many cases.



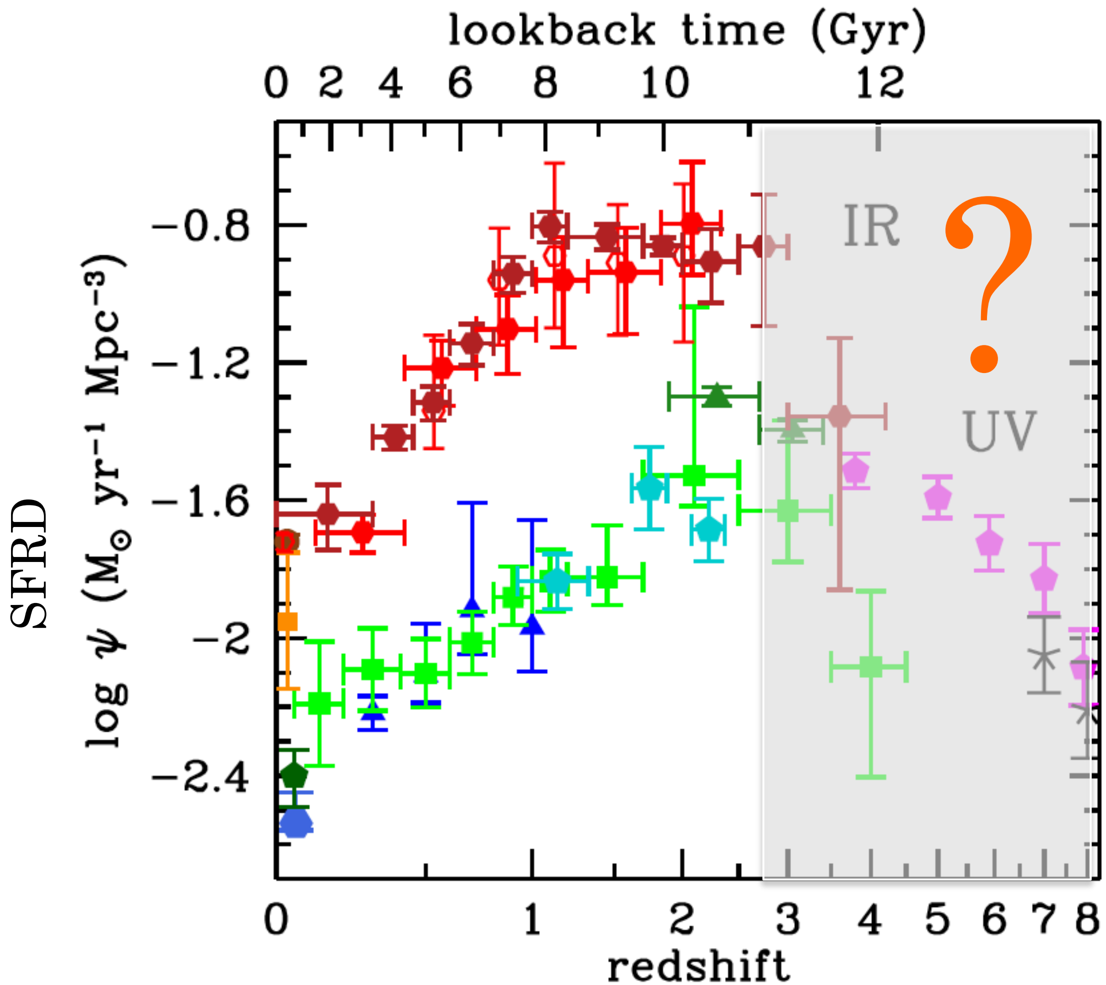
Simpson et al. 2014



Simpson et al. 2014

- Comprehensive spec-z surveys are strongly required.
- PFS is expected to be useful.

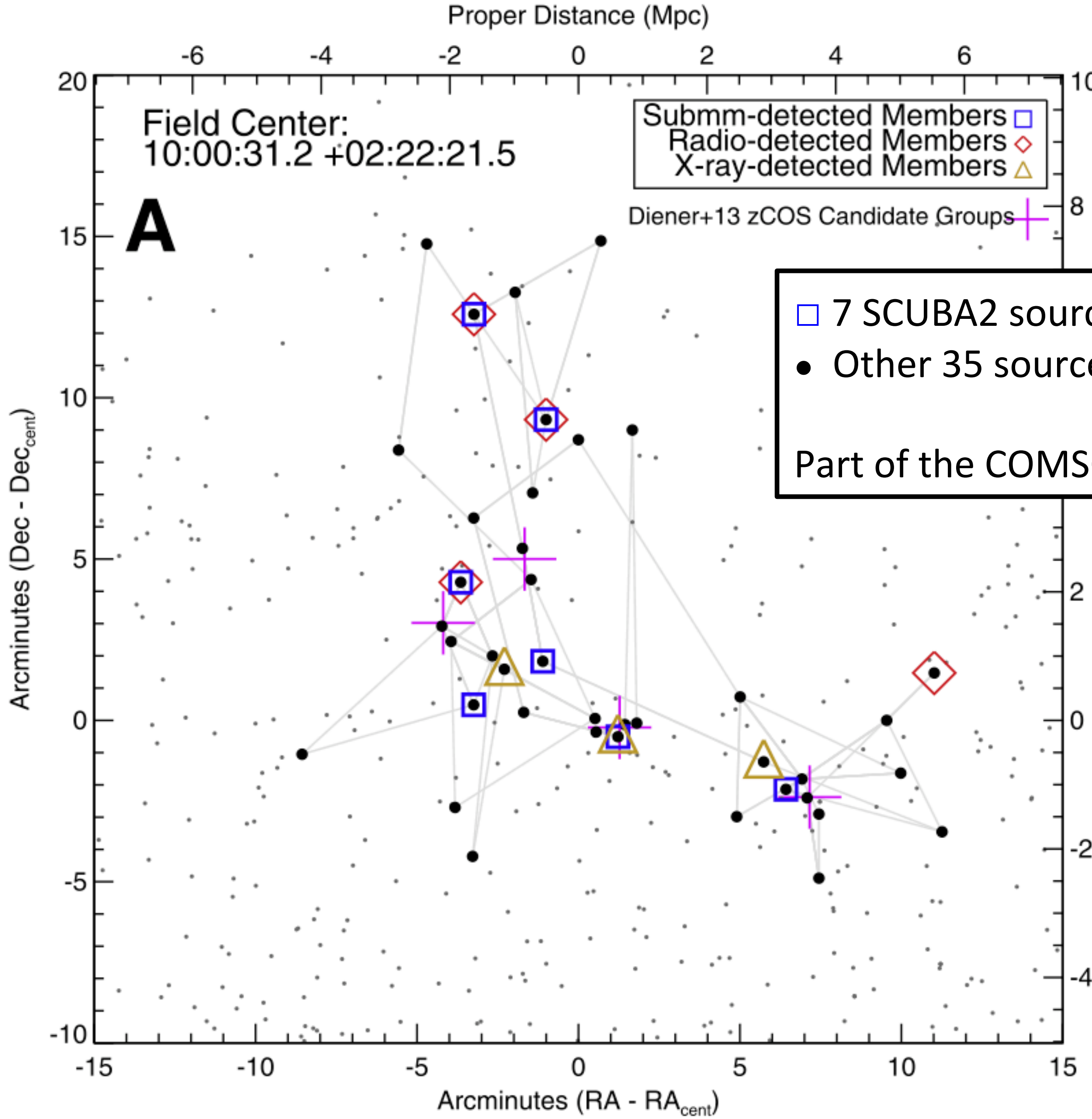
Dusty part of Cosmic SFRD



Madau & Dickinson 2014

- Dust obscured galaxies play a main role in the early universe.
- What amount of SFRD are contributed by SMGs?

SMGs and Cosmic Structures: COSMOS



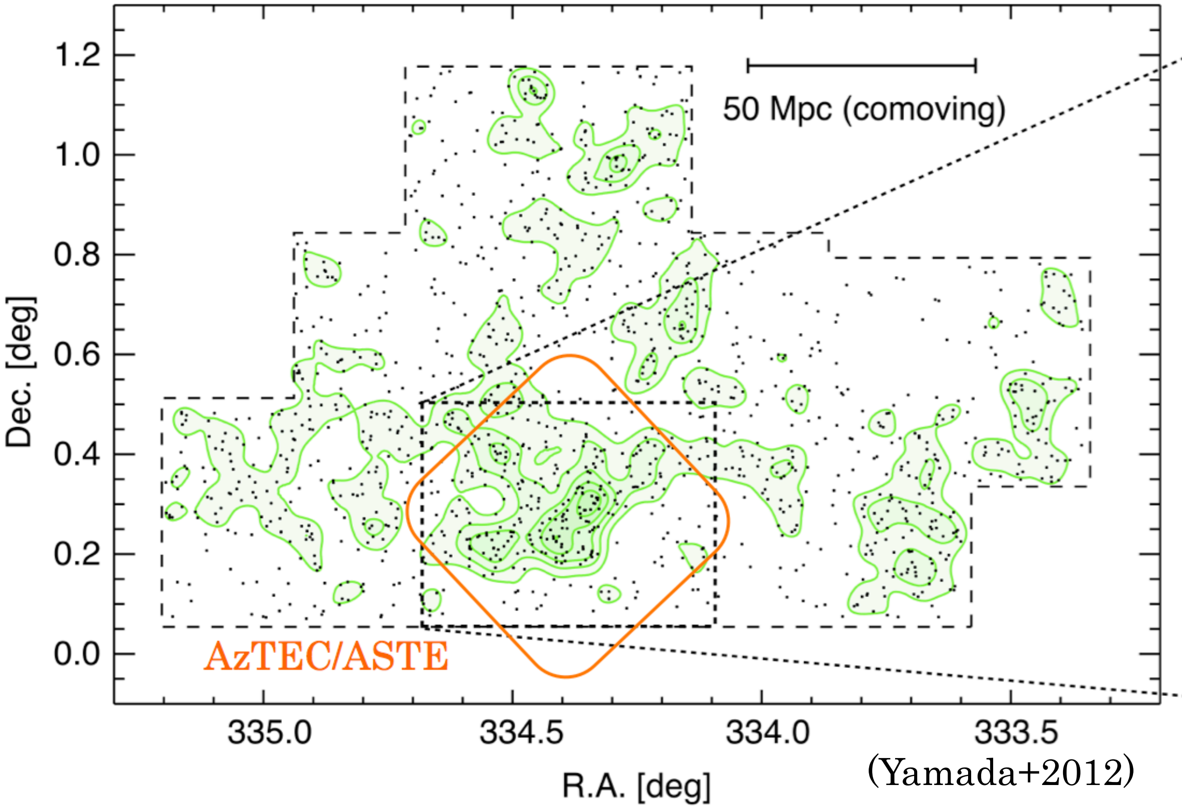
7 SCUBA2 sources at z=2.47

• Other 35 sources at z=2.47

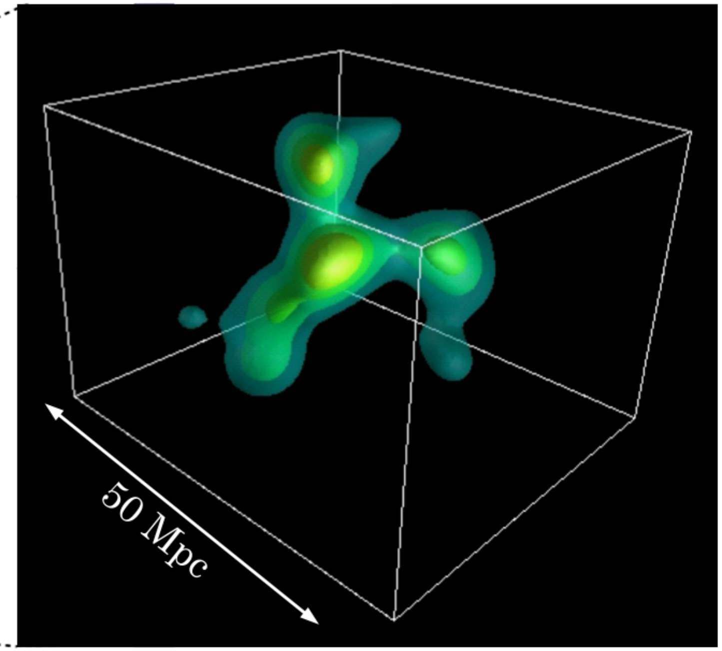
Part of the COMSOS field

Casey et al. 2015

SMGs and Cosmic Structures: SSA22



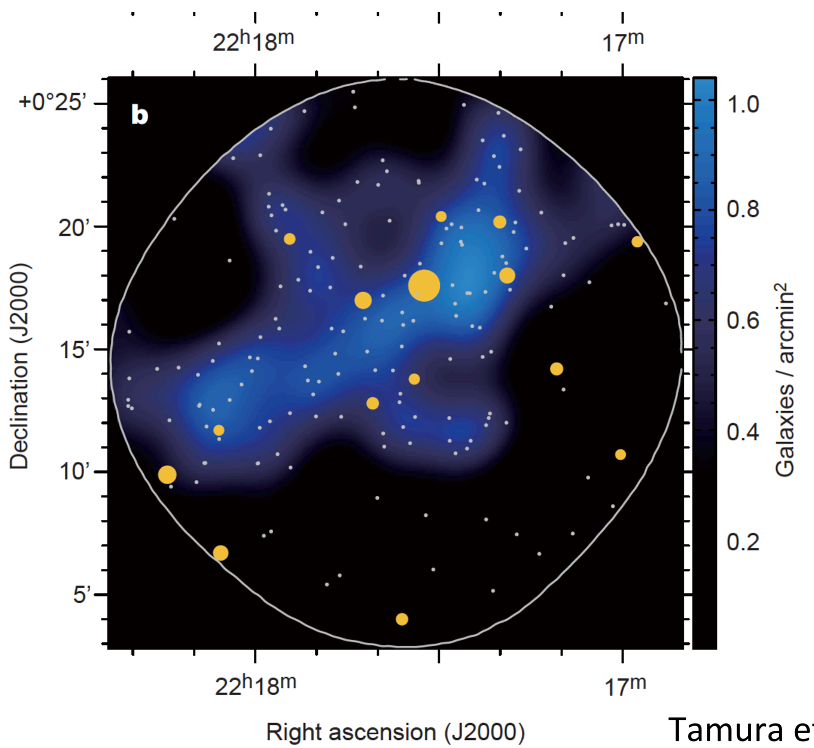
(Yamada+2012)



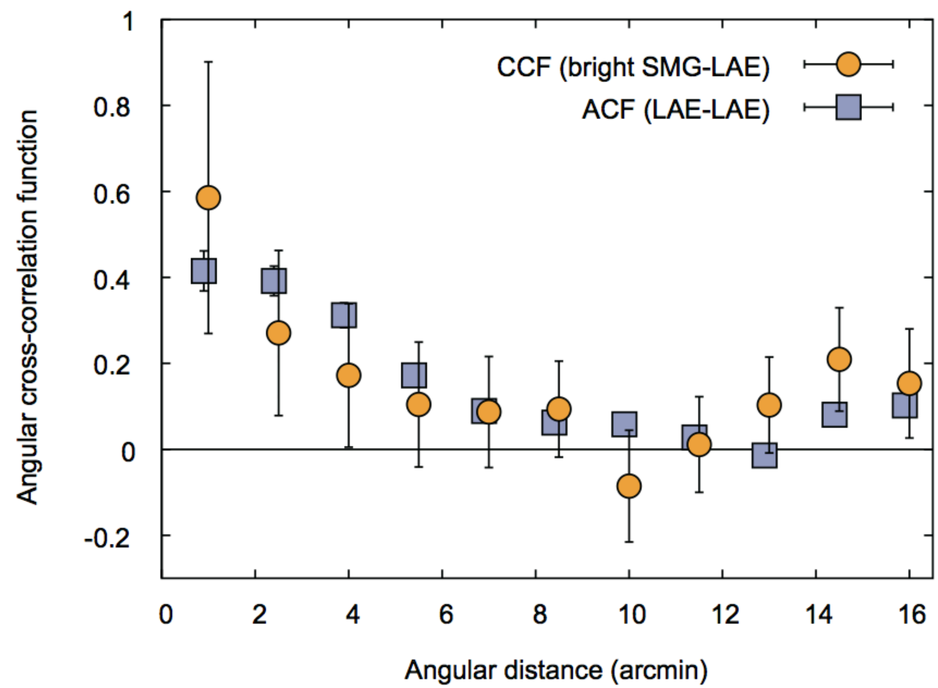
(Matsuda+2005)

- Large-scale Structure traced by LAEs (~1deg)
- 8-10sigma overdensity for central 100 Mpc^2 (comoving)
- Enhancement of LBGs, LABs, DRGs, X-ray sources, K-selected galaxies, etc are found around the density peak.

SMGs and Cosmic Structures: SSA22



Tamura et al. 2009

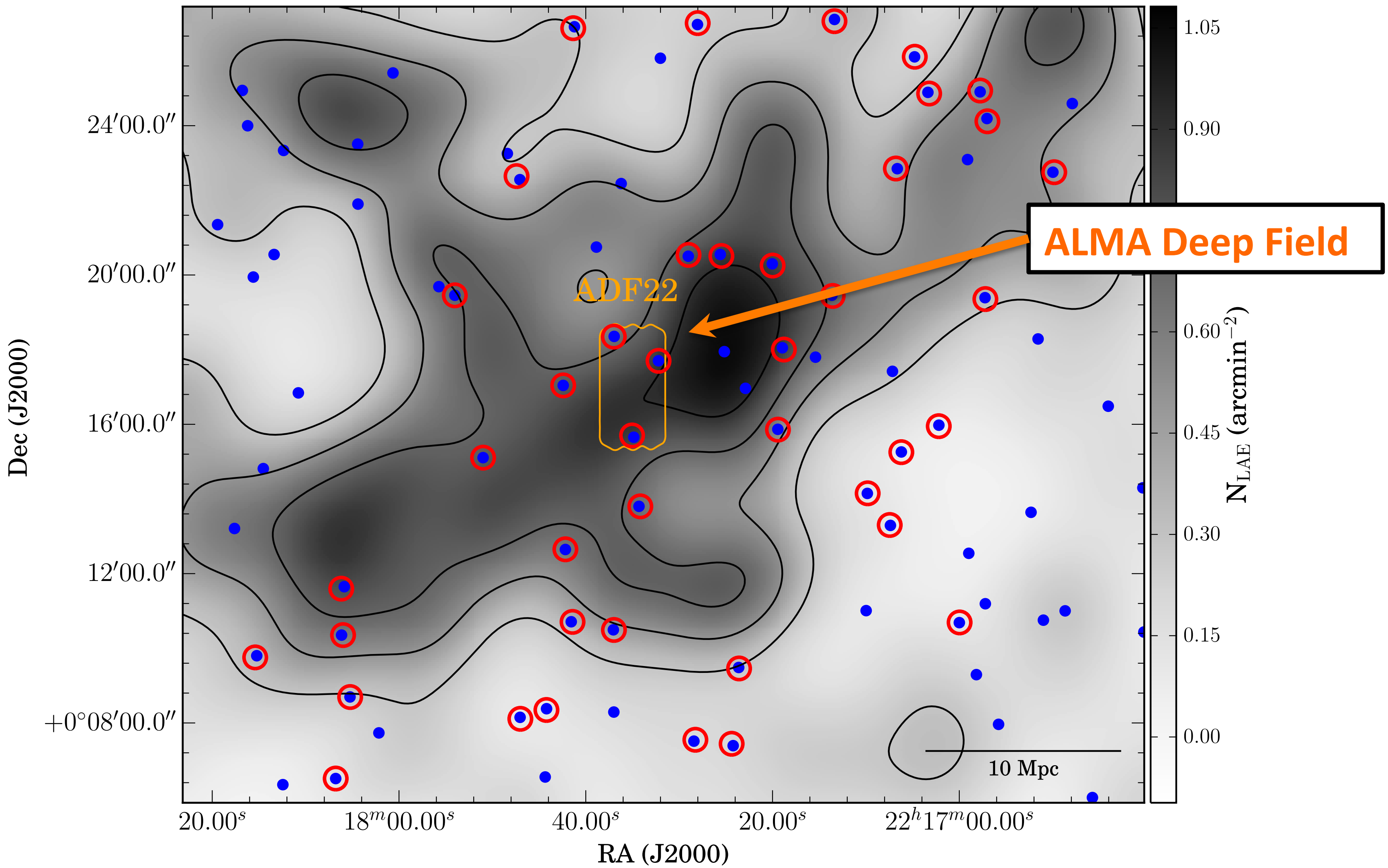


Tamura et al. 2009

- Using two-point angular cross-correlation function, Tamura et al. (2009) found that bright SMGs are likely to be correlated with LAEs.

- But there were no redshift information.

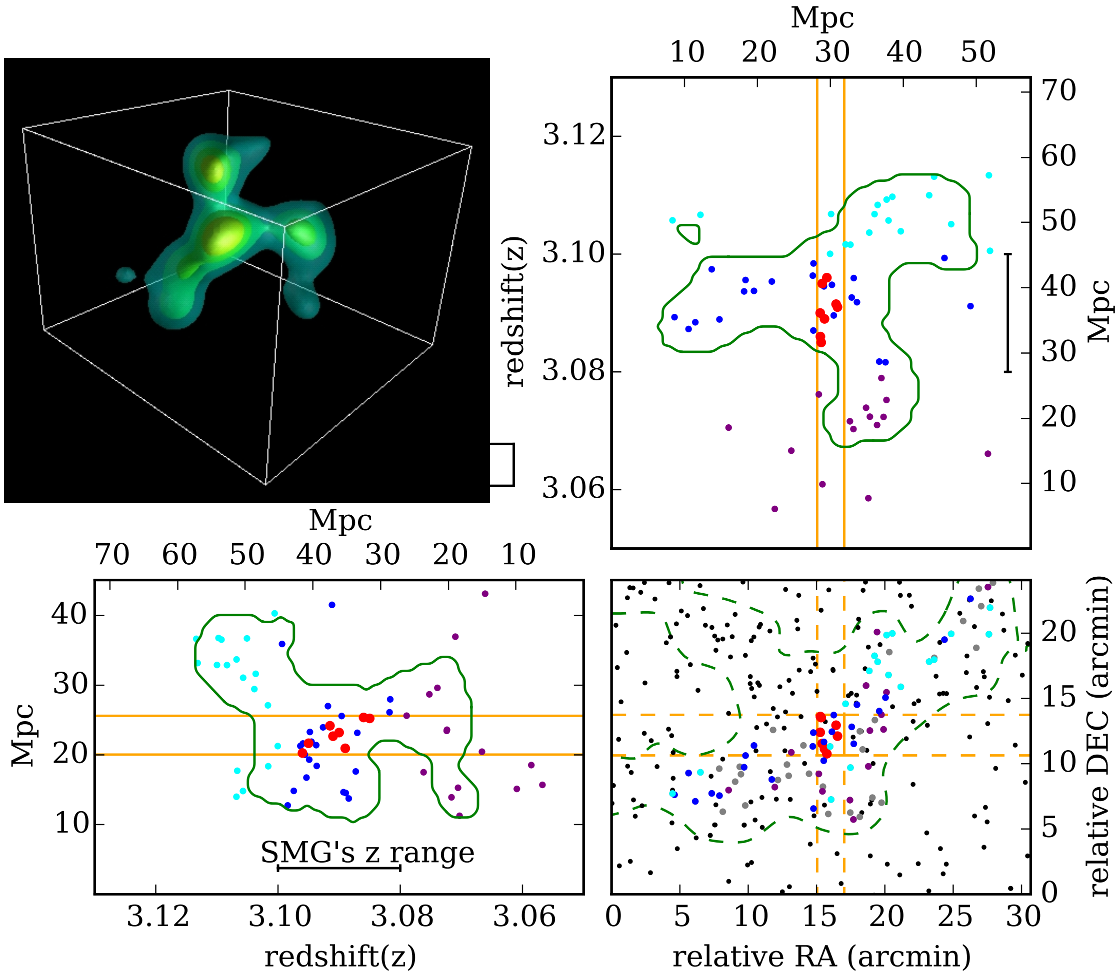
SMGs and Cosmic Structures: SSA22



● AzTEC SMGs ○ ALMA FoVs

Background: LAE surface number densities (Hayashino et al. 2004)

SMGs and Cosmic Structures: SSA22



Umehata et al. 2015

- Extremely rich SMG Cluster in the node of a cosmic web.
- PFS can expand the number of examples and trace the evolution.

Feasibility of PFS Spectroscopy for SMGs

- Optical spectroscopic surveys of SCUBA/Herschel-selected SMGs

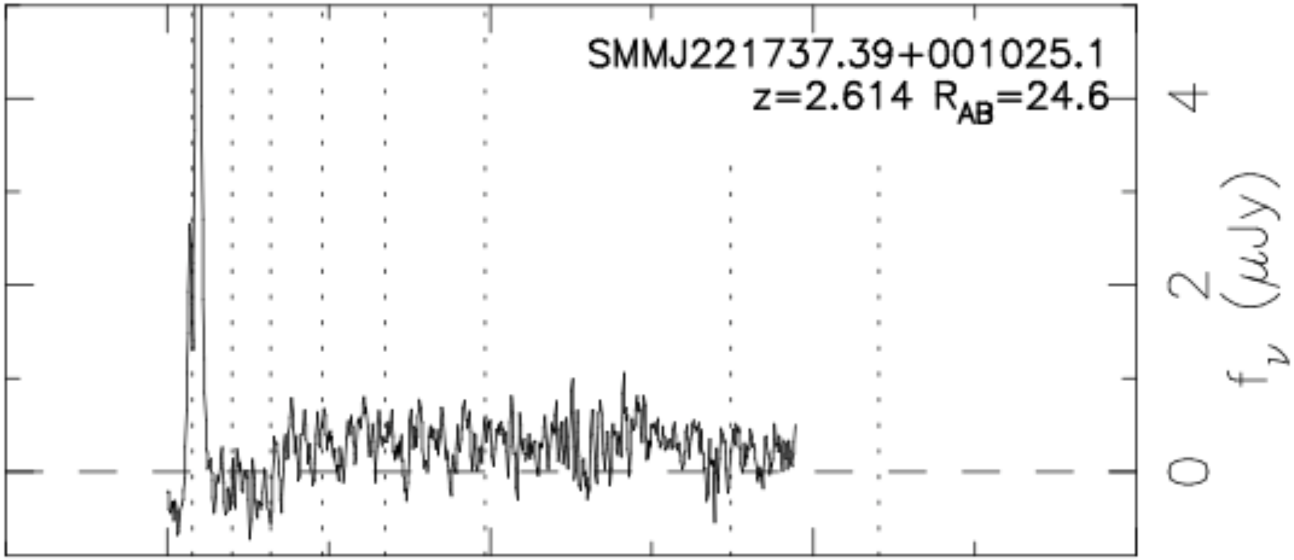
- VIMOS Observations of ALMA SMGs as a pilot survey

Chapman+2005: SCUBA sources

§ Observations

- Targets:
  - 98 radio (1.4 GHz) sources within SCUBA beam (~14")
  - Various fields: Lockman/HDF/SSA13/SSA22, etc
- Instrument: LRIS on Keck-I
- Integration time: 1.5-6.0 hrs
- Seeing: 0.7"-1.1"
- Wavelength range:
  3100 – 8000 A

Example Spectra, Chapman et al. 2005



§ Results

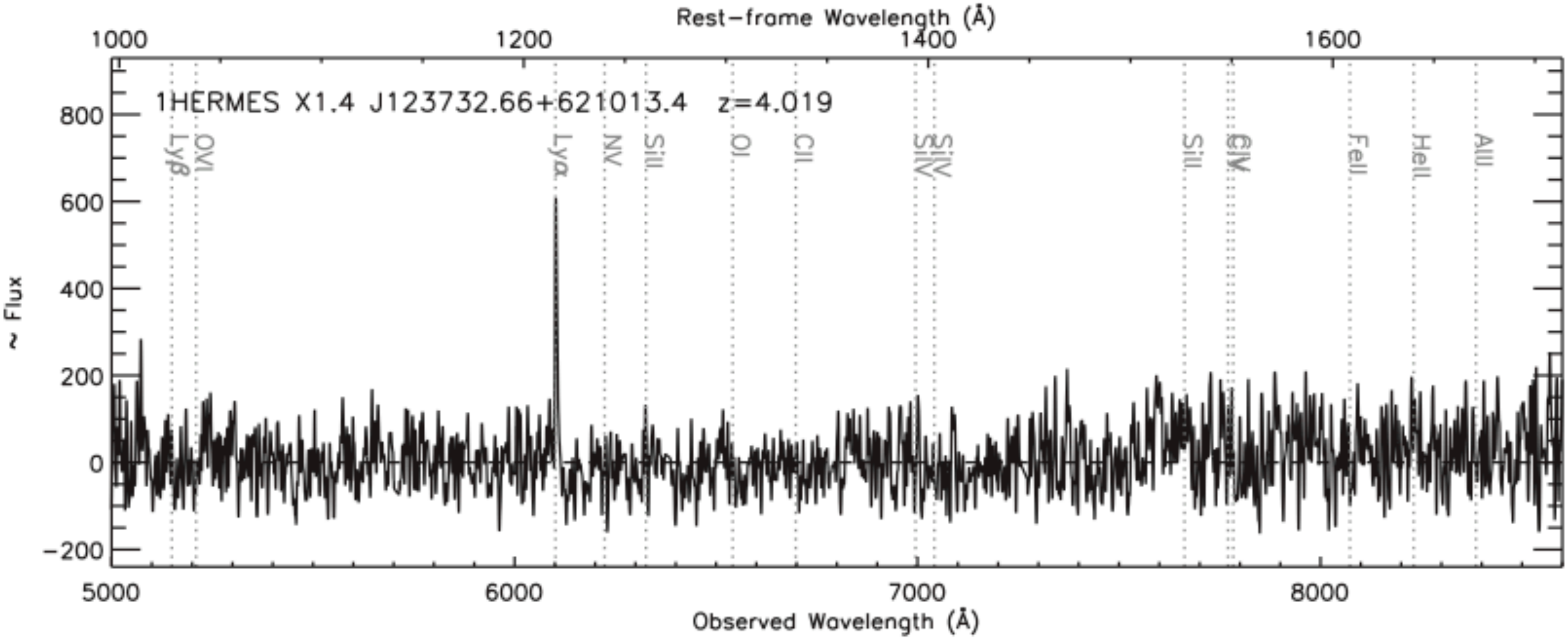
- 73/98 have spec-z
- LyA detection rate: 38/98 (39%) for z=1.408-3.623
- [OII] detection rate: 14/98 (14%) for z=0.176-1.190

Casey+2012: Herschel Sources

§ Observations

- Targets:
  - 36 radio 1.4 GHz and/or MIPS 24 um sources within SPIRE beam (18” at 250um)
  - Various fields observed as a part of HERMES
- Instrument: LRIS on Keck-I, DEIMOS on Keck-II
- Integration time: 0.75-1.5 hrs
- Seeing: unknown
- Wavelength range:
  3000 – 10000 A (LRIS), 4500 – 9500 A (DEIMOS)

Casey+2012: Herschel Sources



Example Spectra, Casey et al. 2012

§ Results

- Among >1000 targets including not SMGs, they found 36 target with spec-z=2-5.
- 28/36 have LyA ● Lyman-break, CIV etc were also utilized.

Caveat: Difficulty of ID

§ Traditionally ID method

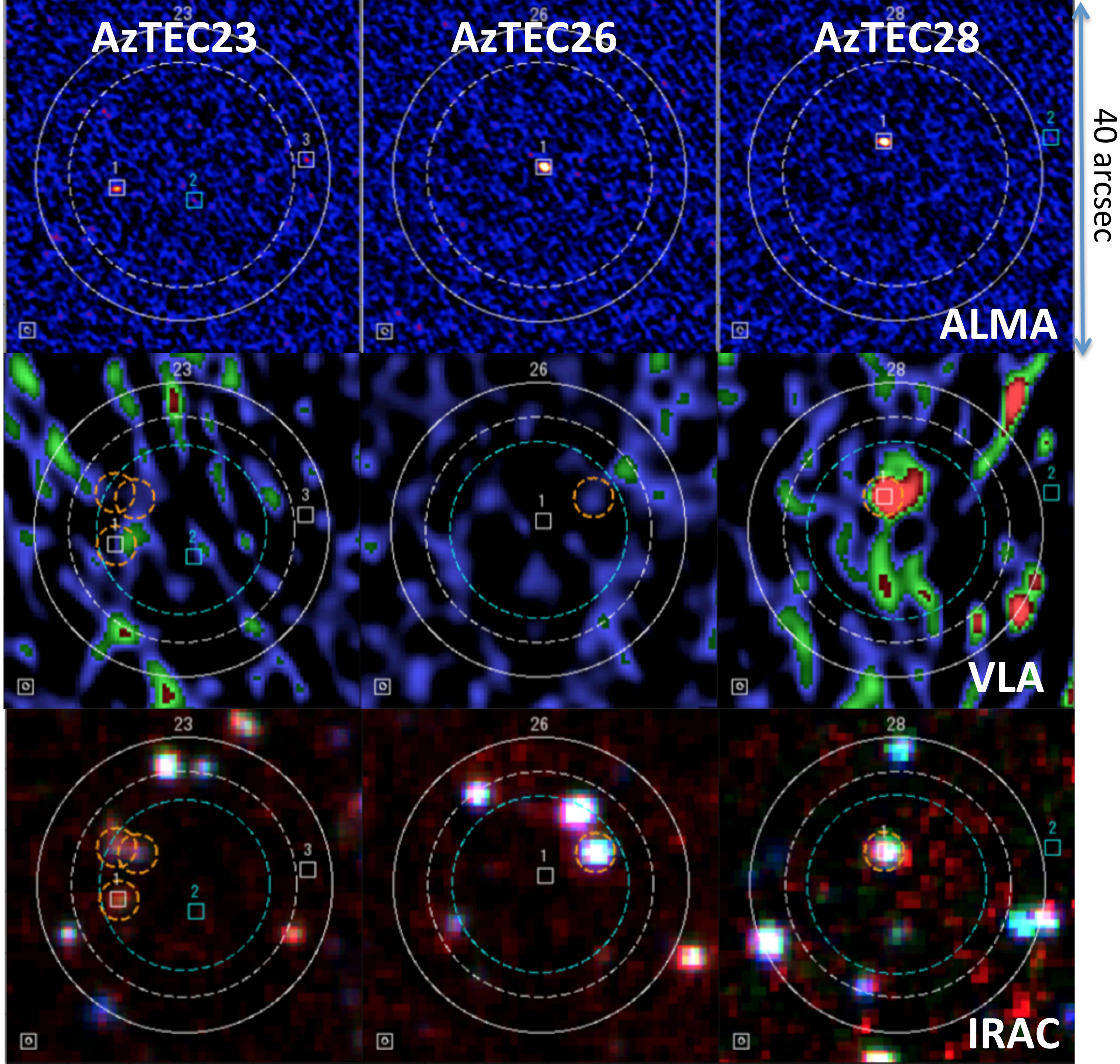
- VLA 1.4 GHz (e.g., Ivison et al. 2007)
- MIPS 24um (e.g., Yun et al. 2012)
- Red IRAC sources (e.g., Yun et al. 2008)

=> They are useful, but we need to keep our mind the possibility of error.

§ Example: 45 AzTEC source follow up in SSA22
(Umehata et al. 2014, Umehata 2015 PhD)

- the accuracy rate (the fraction of ALMA sources among candidates)
  - VLA 1.4 GHz : 79%
  - IRAC Color : 52%
  - MIPS 24um : 33%

=> Previous spec-z surveys of SMGs should be contaminated.
(see also Hodge et al. 2013)


AzTEC23
AzTEC26
AzTEC28
40 arcsec
ALMA
VLA
IRAC

VIMOS Survey of ALMA sources

§ Observations (PI. Umehata)

- Targets:
  - 21 radio/IRAC counterparts of AzTEC sources
  - 13/21 counterparts has been confirmed by ALMA
  - Field: SSA22
- Instrument: VIMOS on VLT
- Integration time: 3-4 hrs
- Seeing: 0.7—2.0”
- Wavelength range:
  3700 – 6700 A

VIMOS Survey of ALMA sources

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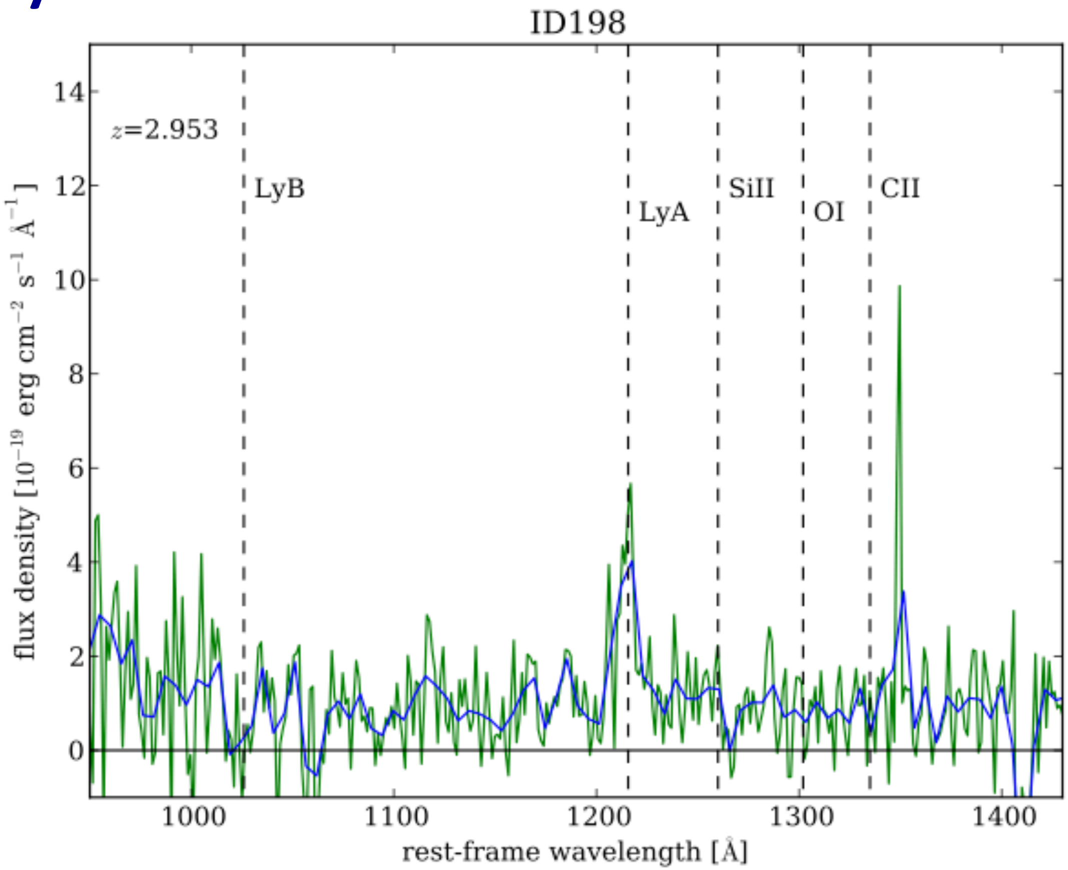
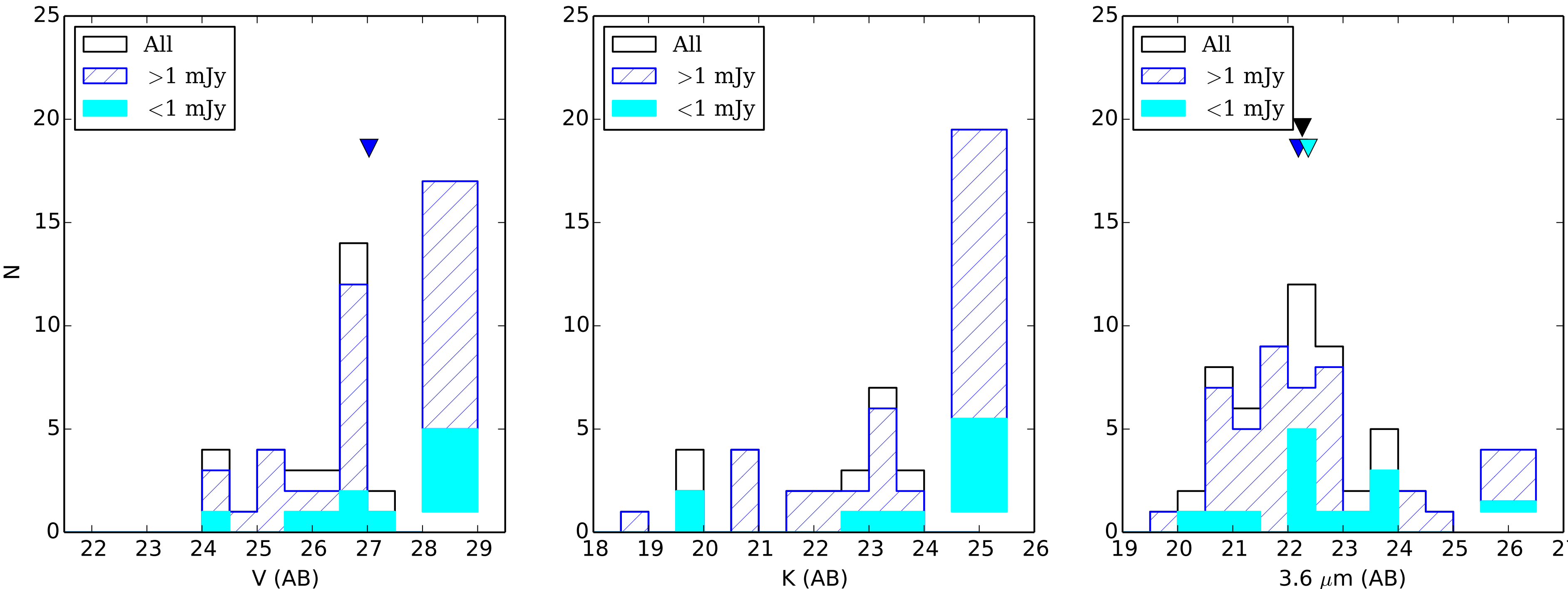


Example Spectra, Umehata 2015 PhD

§ Results

- 5σ detection limit: ~5 x 10 ^-18 erg cm^-2 s^-1 **<= ~ 4hrs PFS Obs**
- Spec-z was obtained for 3/13 (2 LyA, 1 Lyman-break)
- z=2.633, 2.953, 3.225 (not z=3.1 proto-cluster members)
- If we exclude 4 z_phot≦2.2 sources, the success rate is ~ 30%

Caveat: Faintness of SMGs



V=25.3AB / 26.6AB for the two ALMA SMGs w/ LyA

Umehata 2015 PhD

- SMGs are very faint at optical to near-IR wavelength.
- We need to prioritize 'optically bright' SMGs in using PFS.

Suggestion for PFS Surveys

- Dusty star-forming galaxies are important targets to achieve (some of) PFS goals.

- PFS + ALMA collaboration can be powerful.
  - As far as possible, ALMA ID is preferable.
  - If we need to observe SMGs without ALMA ID, radio counterparts can be the second best.

- Selecting target is important.
  - '(relatively) optically bright' sample should improve a success rate.

- As deep as possible!
  - 4 hrs integration time is much better than 1 or 2 hrs.
  - 'moderate' success rate is expected.