Extremely Faint Millimeter Sources Identified by Multi-Field Deep ALMA Survey and Subaru Follow-up Spectroscopy

Fujimoto et al. 2016 (ApJS, 222, 1)
Fujimoto et al. in prep.

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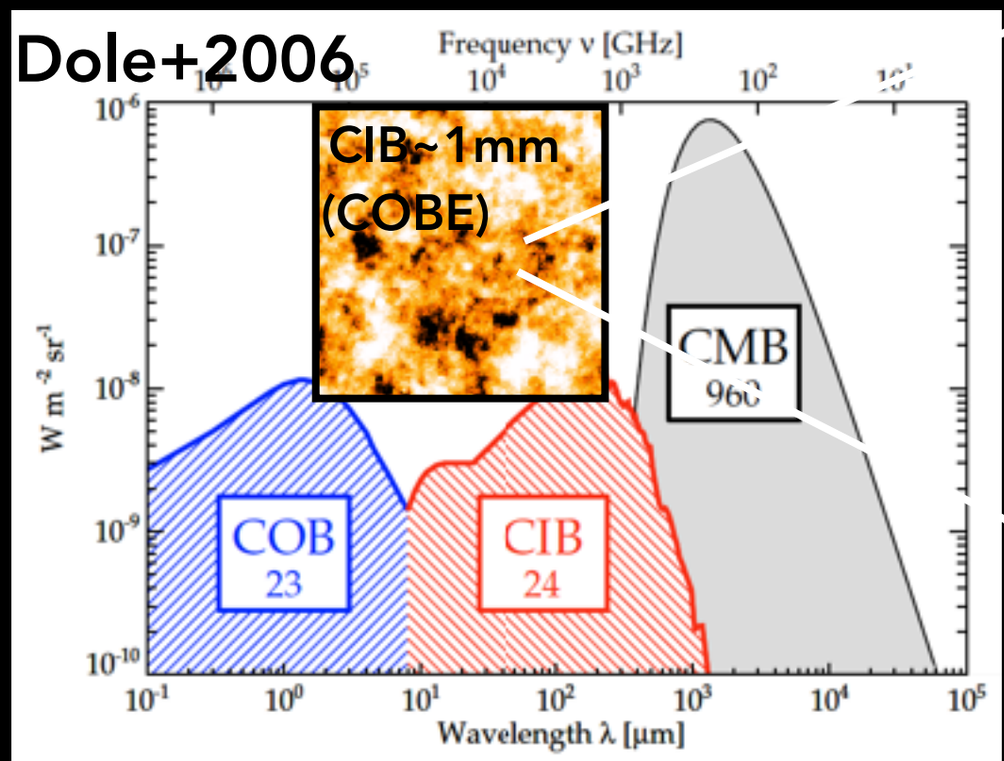
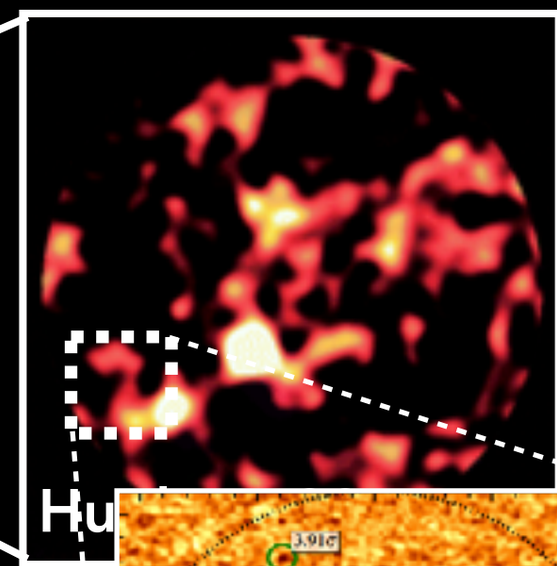
OUTLINE

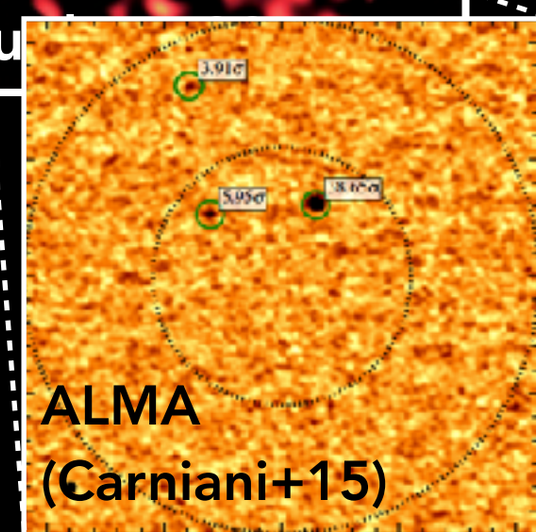
- Resolve the Cosmic Infrared Backgournd light (CIB)

- Origin of the Faint mm Source

Cosmic Infrared Background-light (CIB)







Before ALMA

Submm galaxies (SMGs)

~1.0 – 10mJy

~10% (e.g., Scott+12)

ALMA Sources

~0.1 – 1.0 mJy

~60% (Hatsukade+13, Ono+14, Carniani+15)

CIB has not been fully resolved…

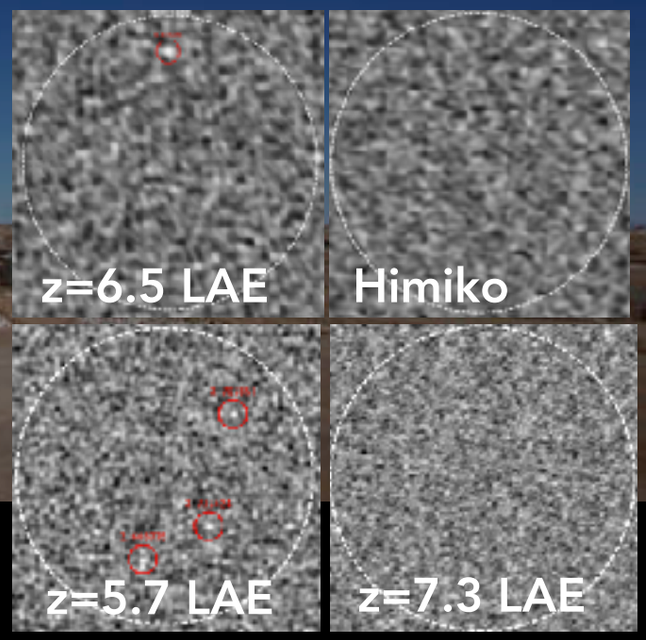
This work:

Largest dataset of multi-field deep ALMA

-> Resolve CIB / Physical origins

Sample Selection

Our Deep ALMA Maps



DATA: ALMA Band 6 & 7 (~submm/mm)

- Our quite deep 4 ALMA data(Ouchi+13, etc)
- ALL ALMA data so far archived (2012/12-2015/7)

Criteria:

- Noise level < 0.1 mJy
- No too Bright/Extended Sources

Total: 67 deep maps

Obs. hrs ~100 hrs (cf. typical obs. hrs ~4 hrs)

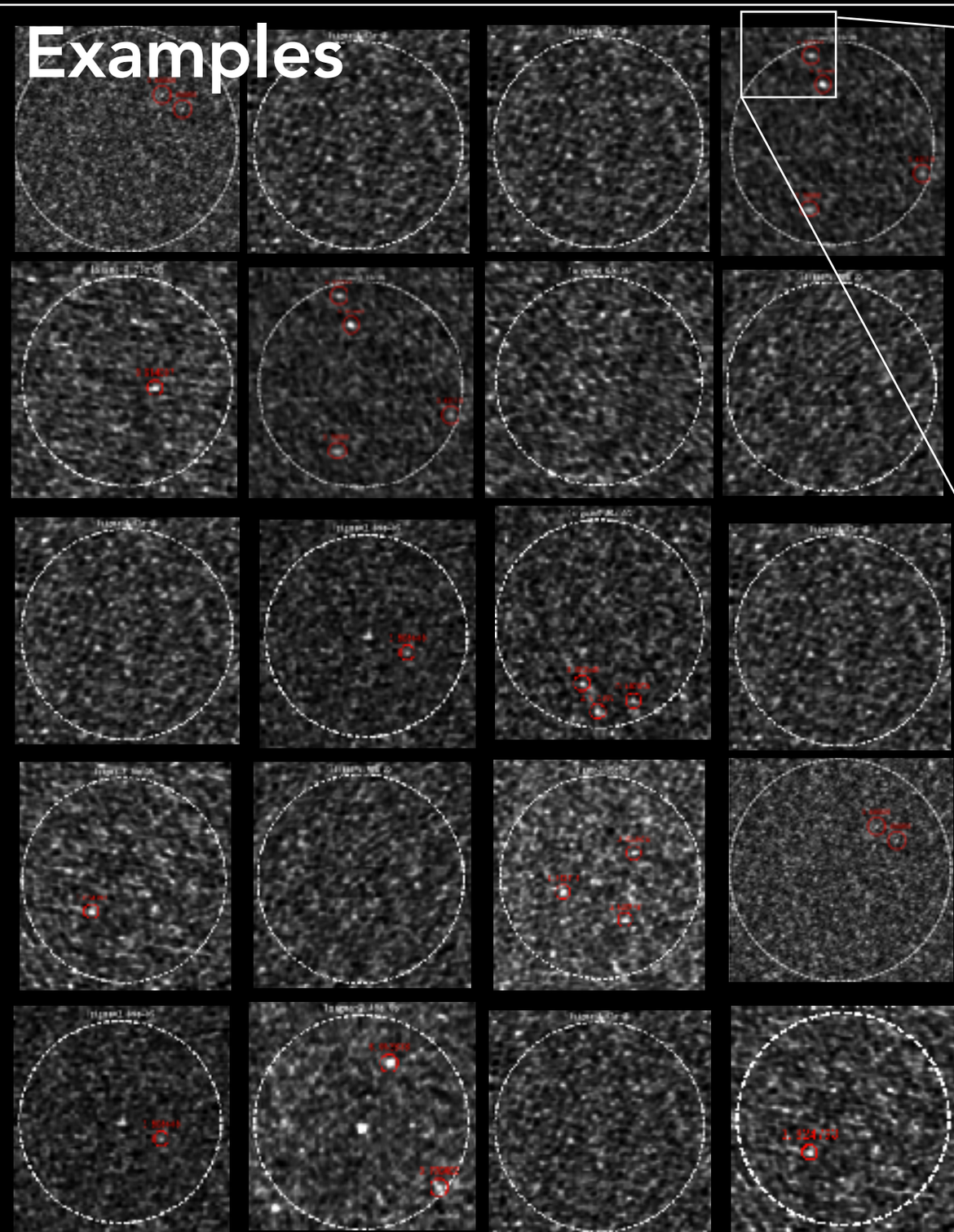
Cluster Data (1 map)

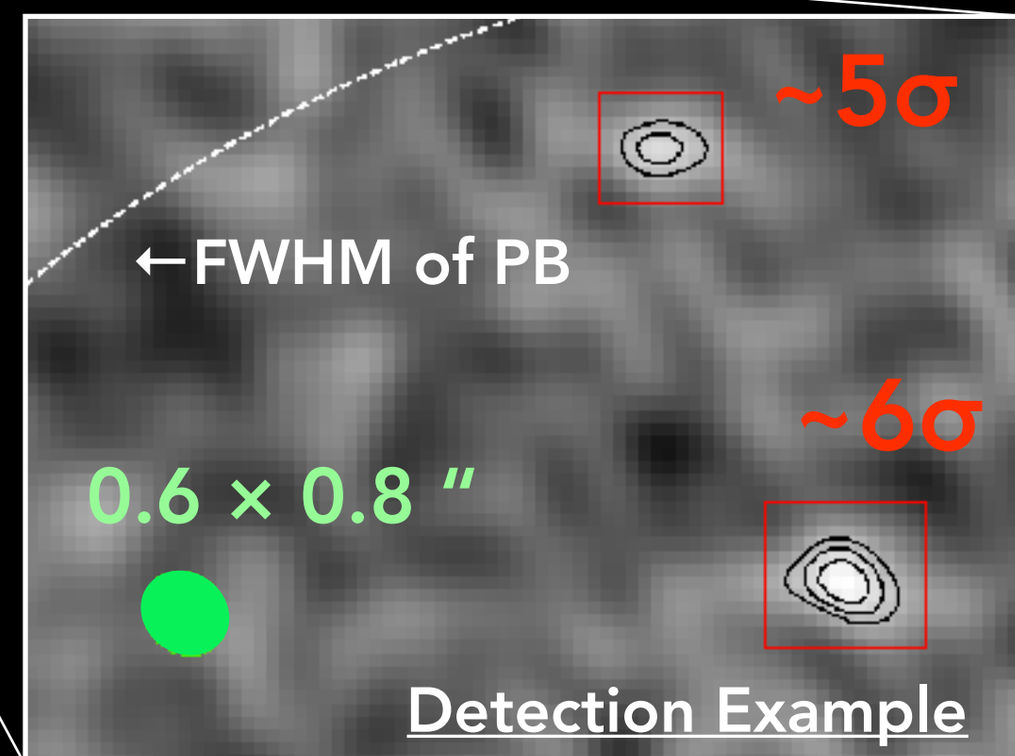
- Multiple image: Diego+14
- Optical Catalog: Diego+14, Coe+10
- Software: GLAFIC (Oguri 10)

(e.g., Ishigaki+15)

Critical Line

Field Data (66 maps)





* Original Target Sources Removed

Total Sources : 133

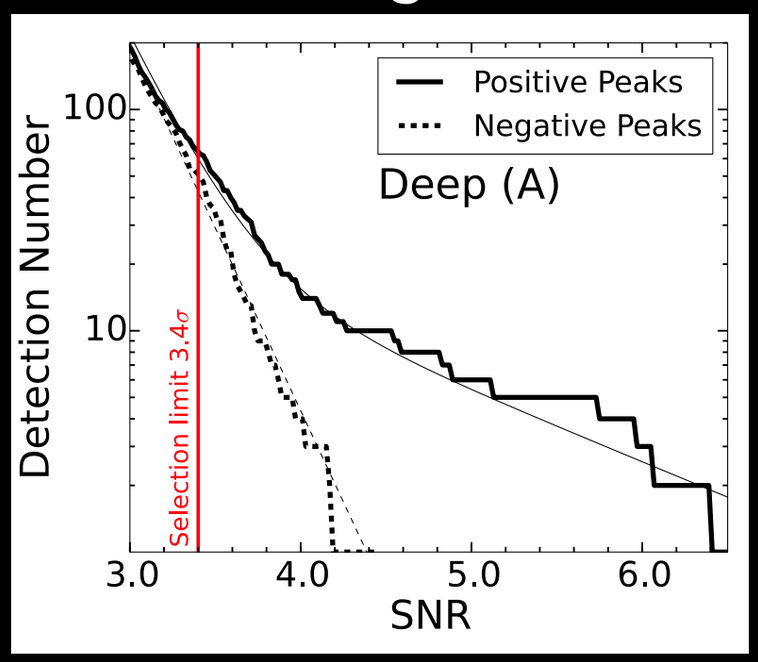
Data Analysis

Resolve CIB -> Derive Number Counts

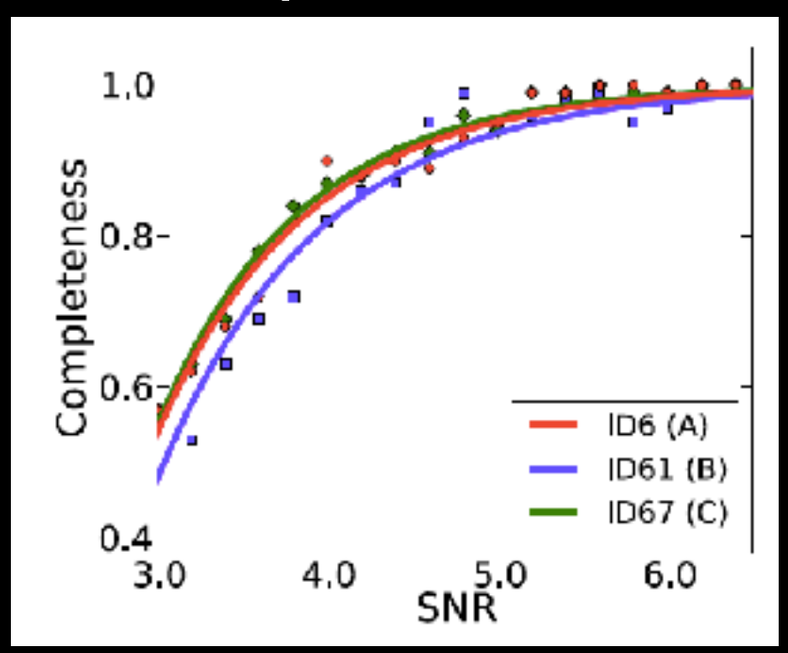
$$N_{eff} = \frac{1 - R_S(S/N)}{C(S/N)}$$

N_{eff}: Effective Number
Rs (S/N): Spurious Source Rate
C (S/N): Completeness

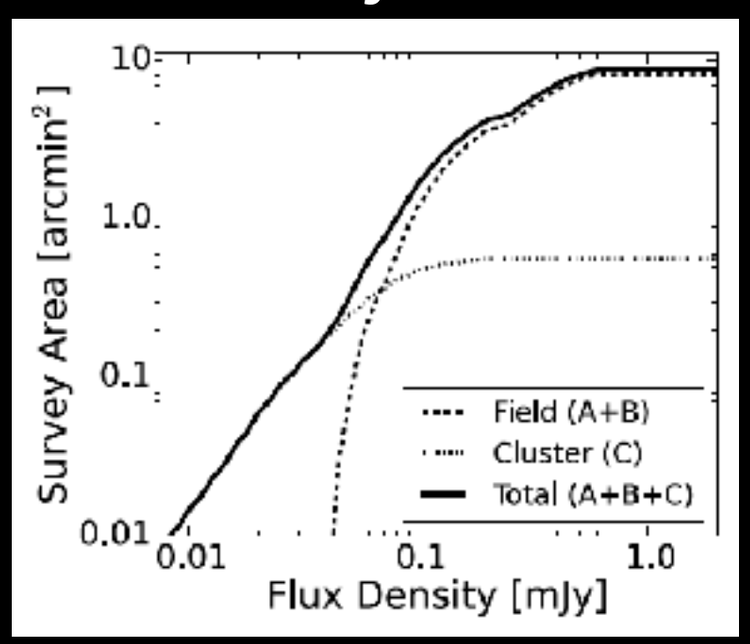
Positive & Negative Peaks



Completeness

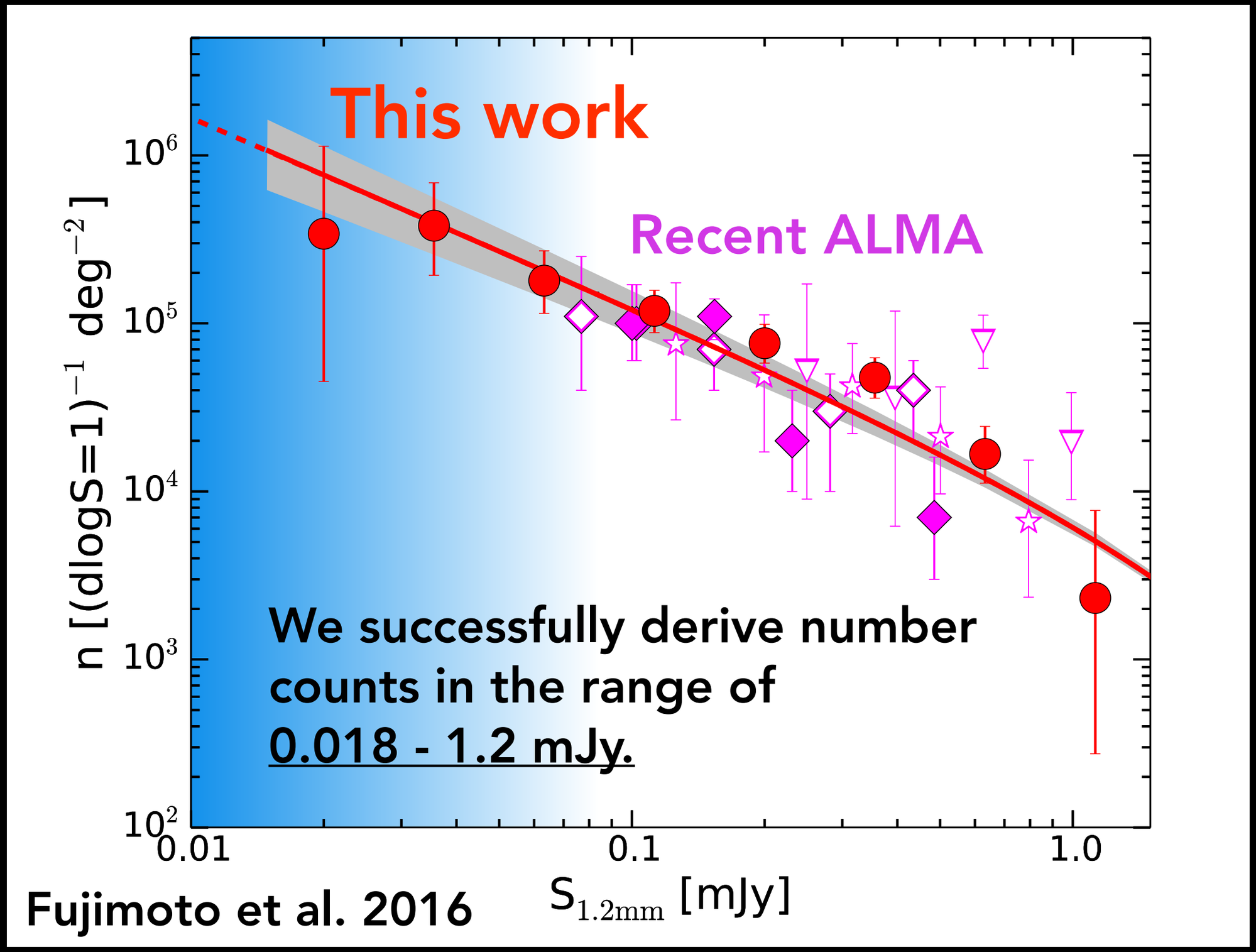


Survey Area



(e.g., Hatsukade+13, Ono+14, Carniani+15)

Number Counts at 1.2 mm

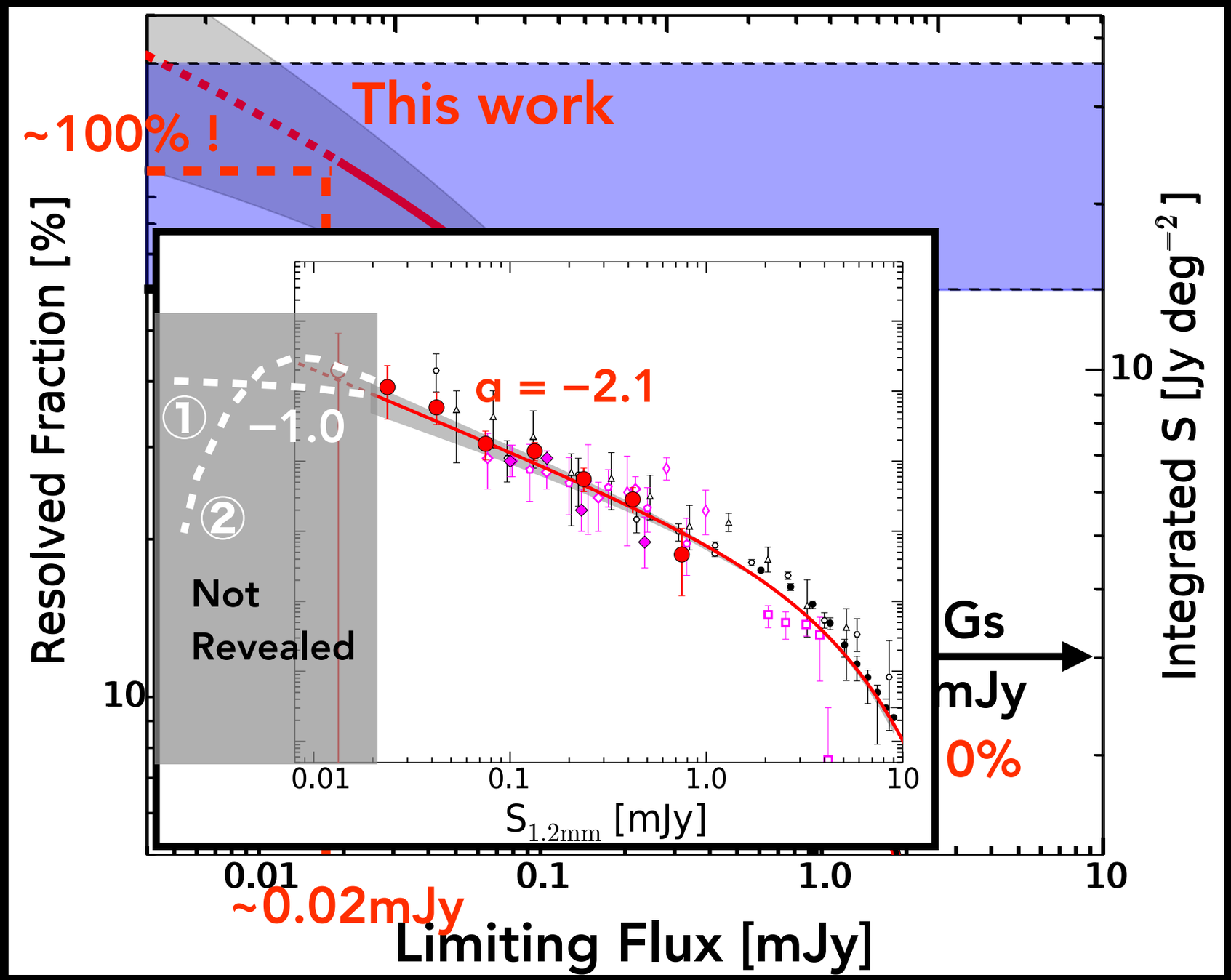


Fujimoto et al. 2016

Resolve the CIB

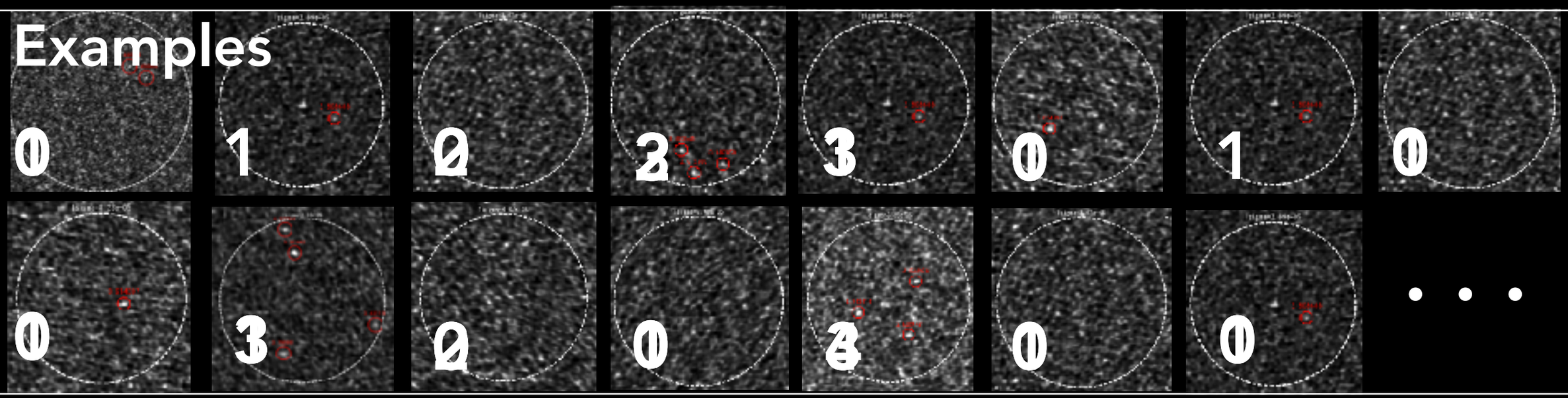
- Almost fully (104±30%) resolve the CIB
- < 0.02 mJy sources would be negligible

-> 1) Flattening
2) Truncation
below 0.02 mJy



What are the faint ALMA sources ?

1. Statistical Approach: Cluster Analysis



Field-to-Field Scatter = Poisson Error + Galaxy Bias

Counts-in-Cells

$$b_g^2 \approx \frac{\sigma_N^2 - \bar{N}}{\bar{N}^2 \sigma_V^2(z)}$$

(e.g., Robertson+10)

b_g: galaxy bias σ_V: matter variance

σ_N: dispersion of source counts

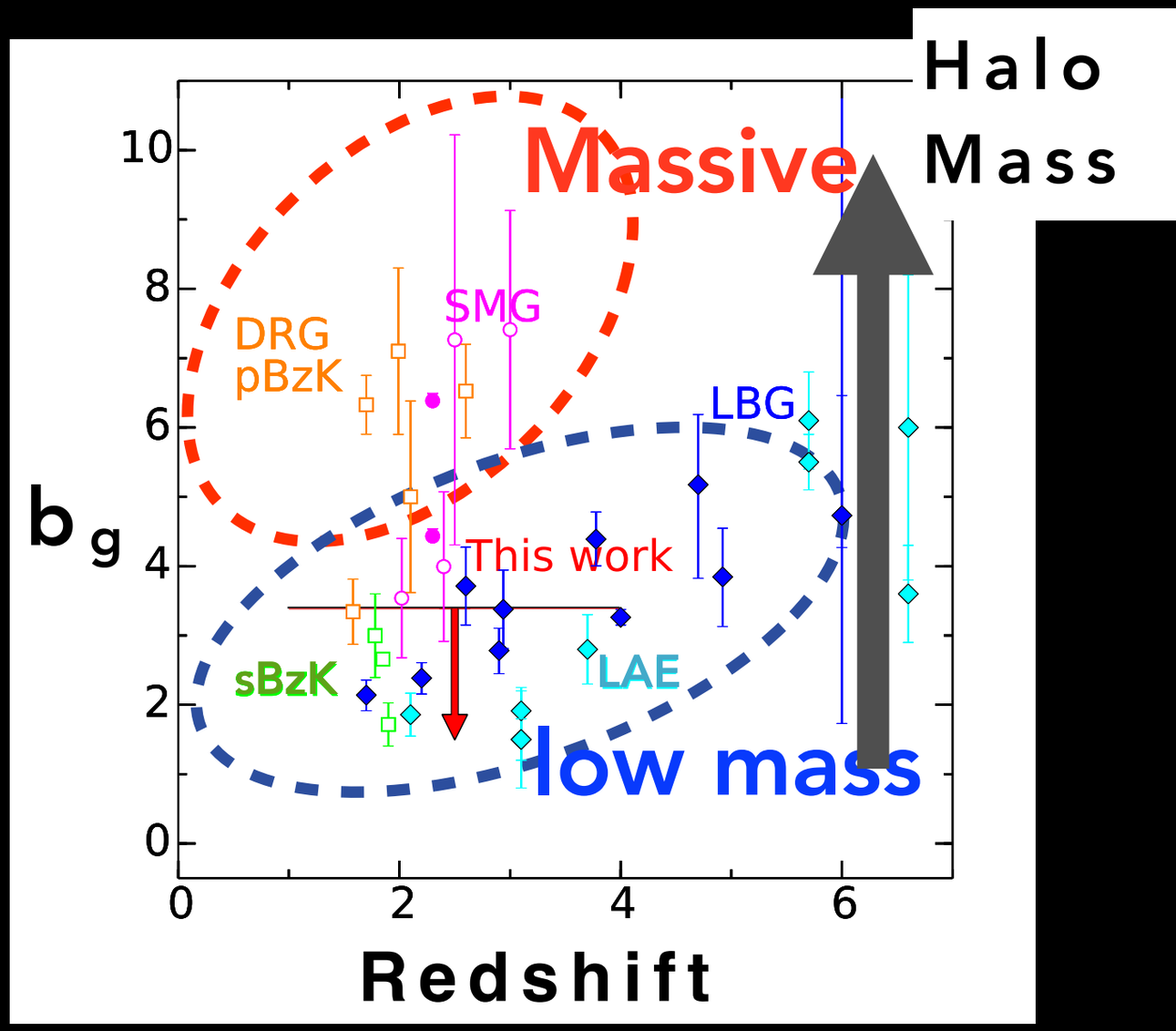
N: mean source counts

Faint ALMA Sources

$b_g < 3.5$

(ΛCDM->) $M_{DH} < 5 \times 10^{12}\ M_{sun}$

1. Statistical Approach: Cluster Analysis



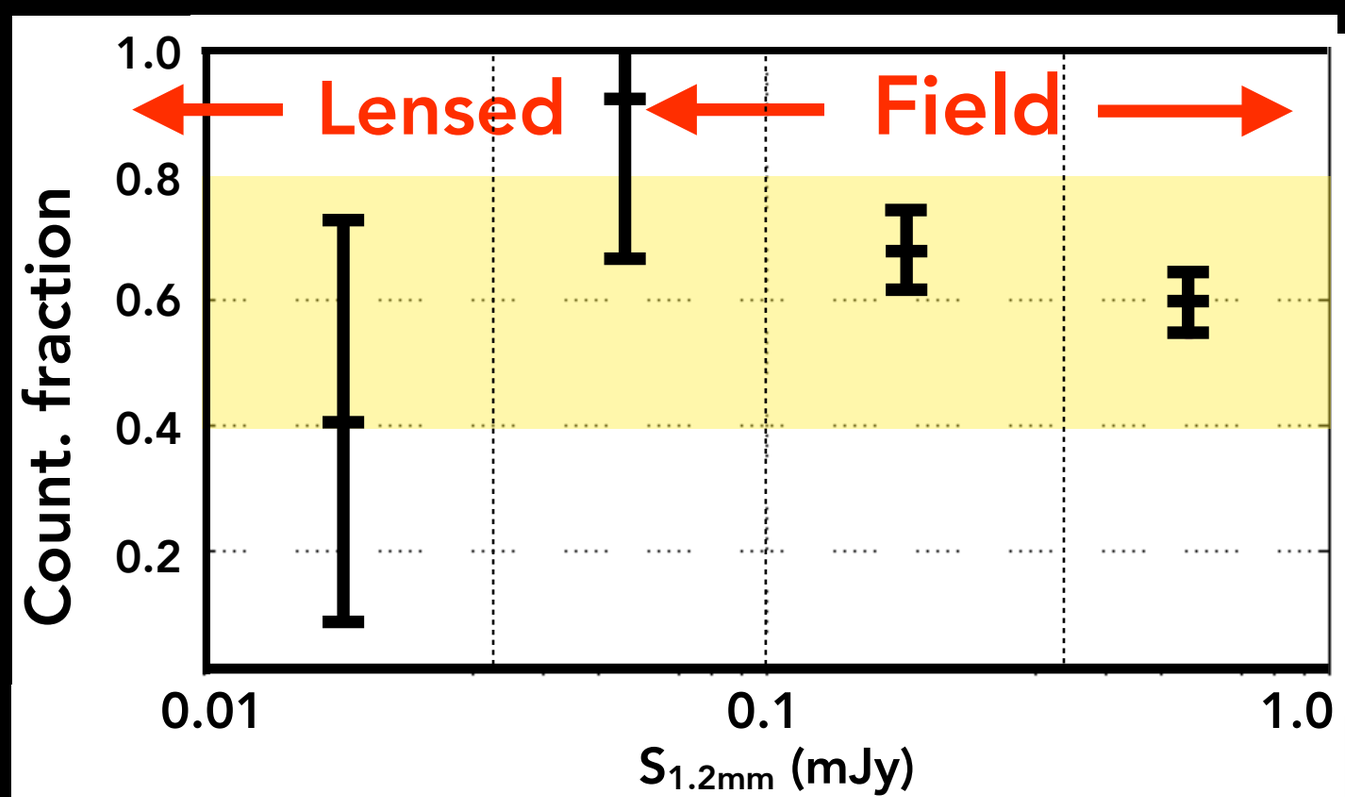
- <u>Faint ALMA Sources</u>
  $b_g < 3.5$
- <u>SMGs / DRGs / pBzK</u>
  $b_g \sim 5 - 7$
- <u>sBzK / LBGs / LAEs</u>
  $b_g \sim 2 - 3$

Faint ALMA Sources = sBzK, LBGs, LAEs?

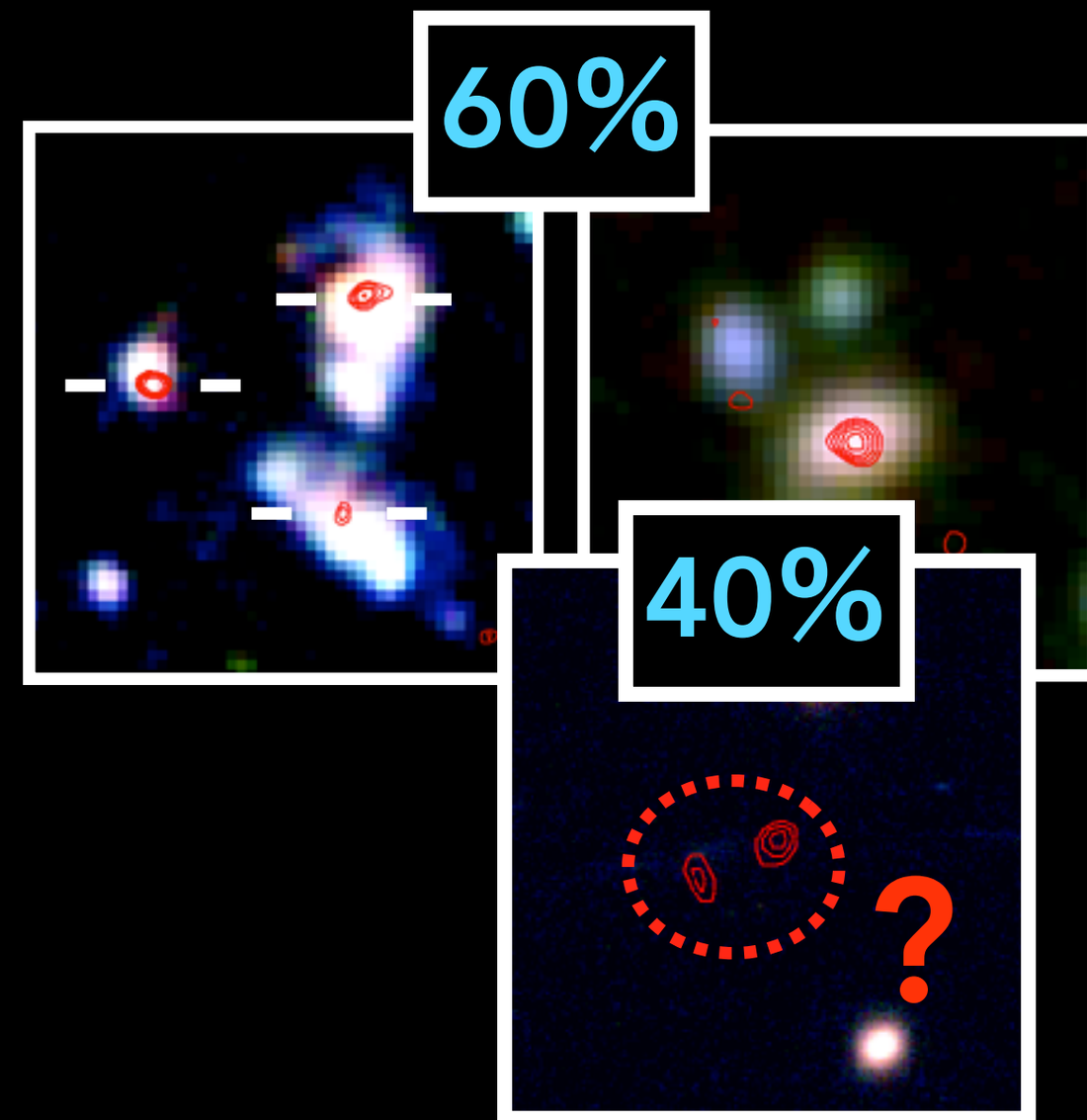
2. Individual: Opt.-NIR Counterparts

- Multi-wavelength data(X-ray, Optical, IR, radio)
- Opt.-NIR Counterparts

-> ~60±20%

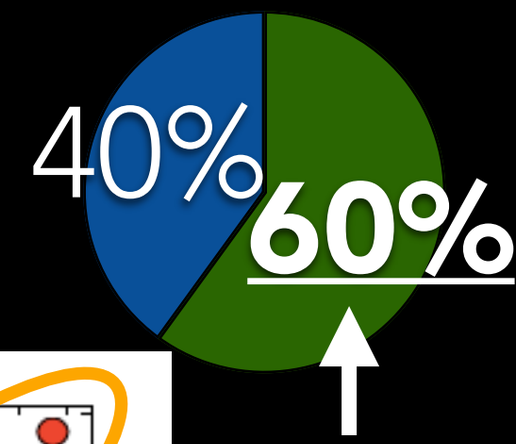


Source Flux vs Count. fraction

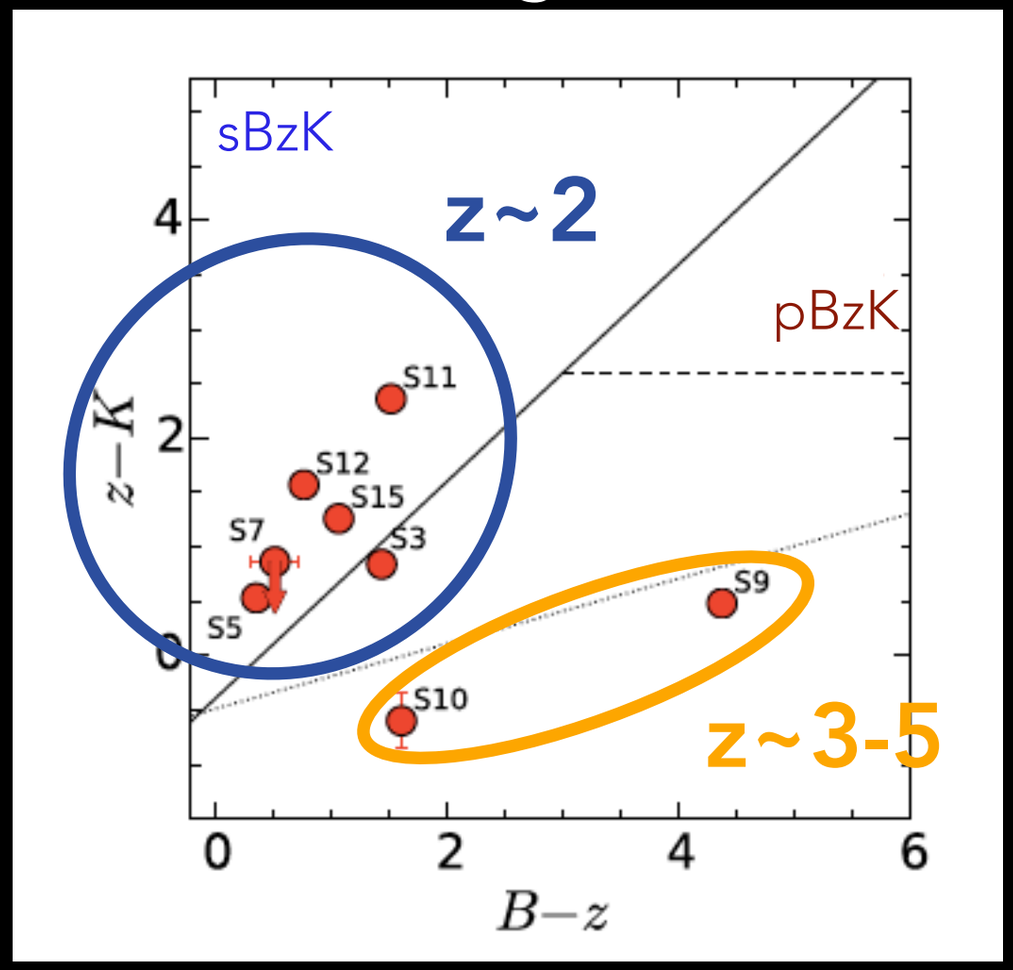


Faint ALMA Sources (red contour) w(/o) opt. counterparts (B,r,z)

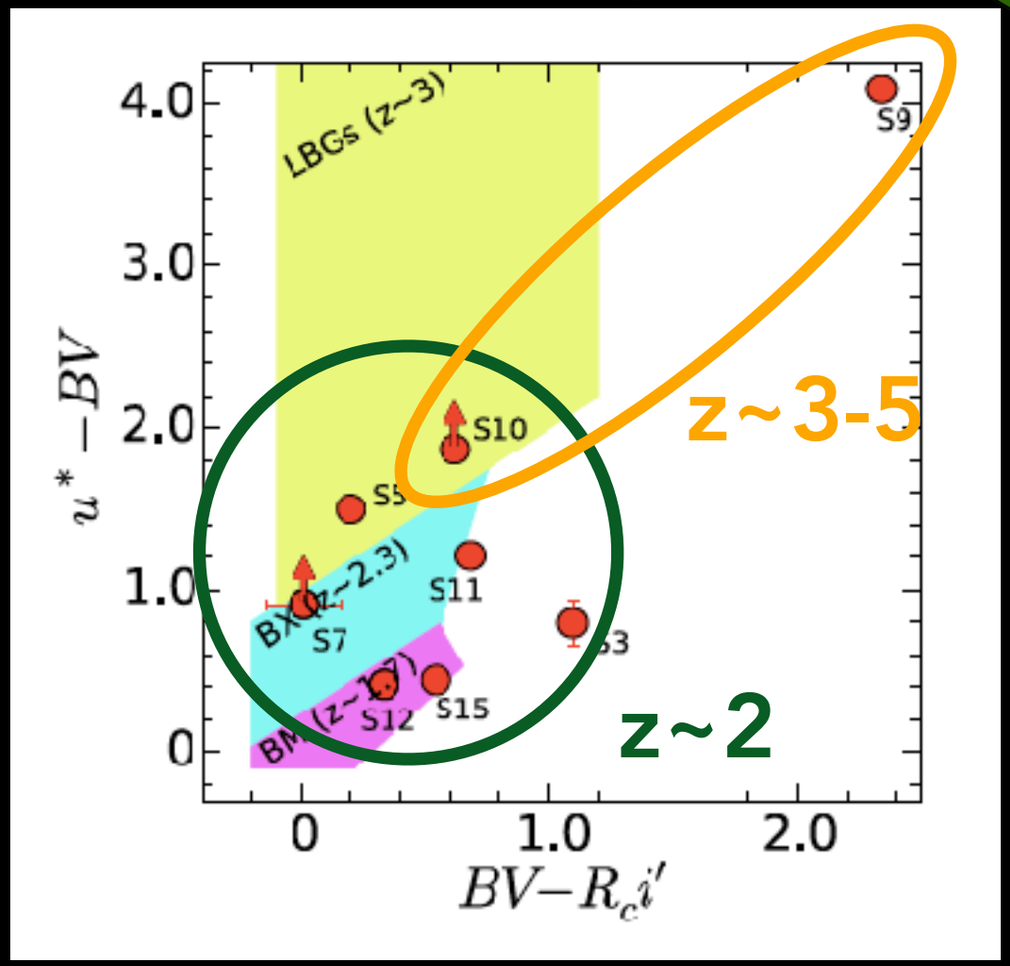
Photometric Properties ①



BzK Color Diagram



BX/BM Color Diagram

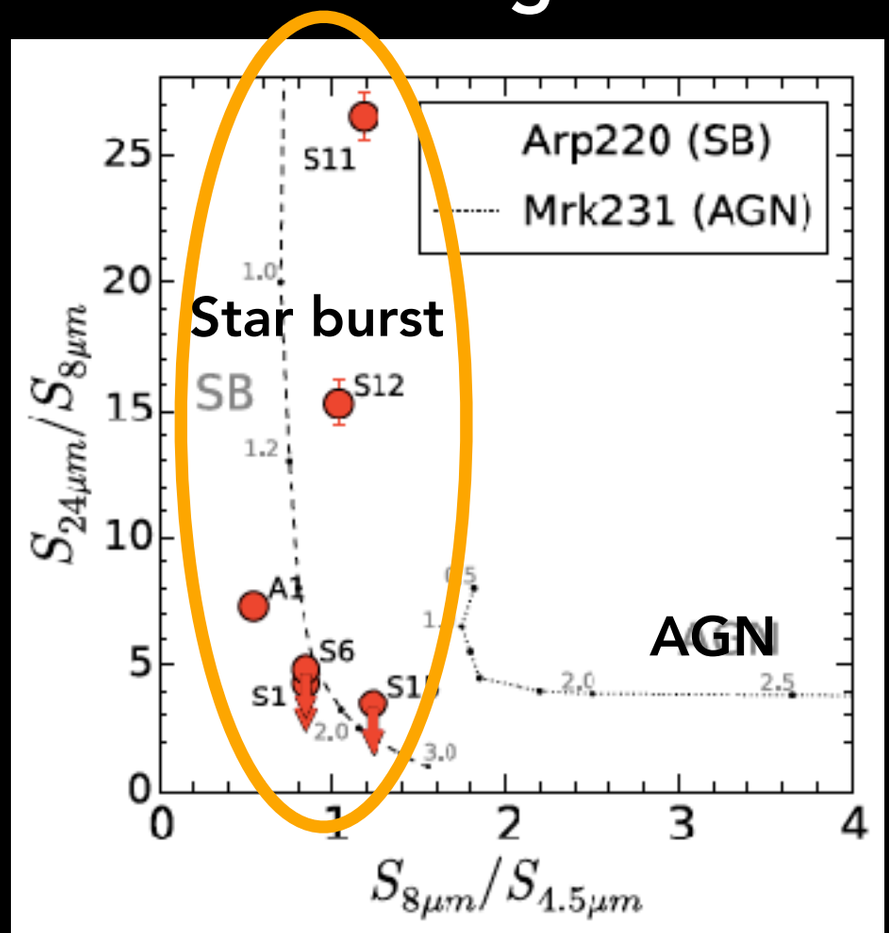


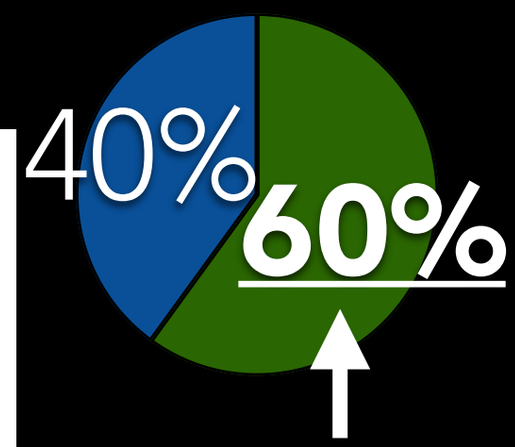
Majority of Faint ALMA Sources

-> sBzK / LBG(BX/BM)

Photometric Properties ②

AGN diagram





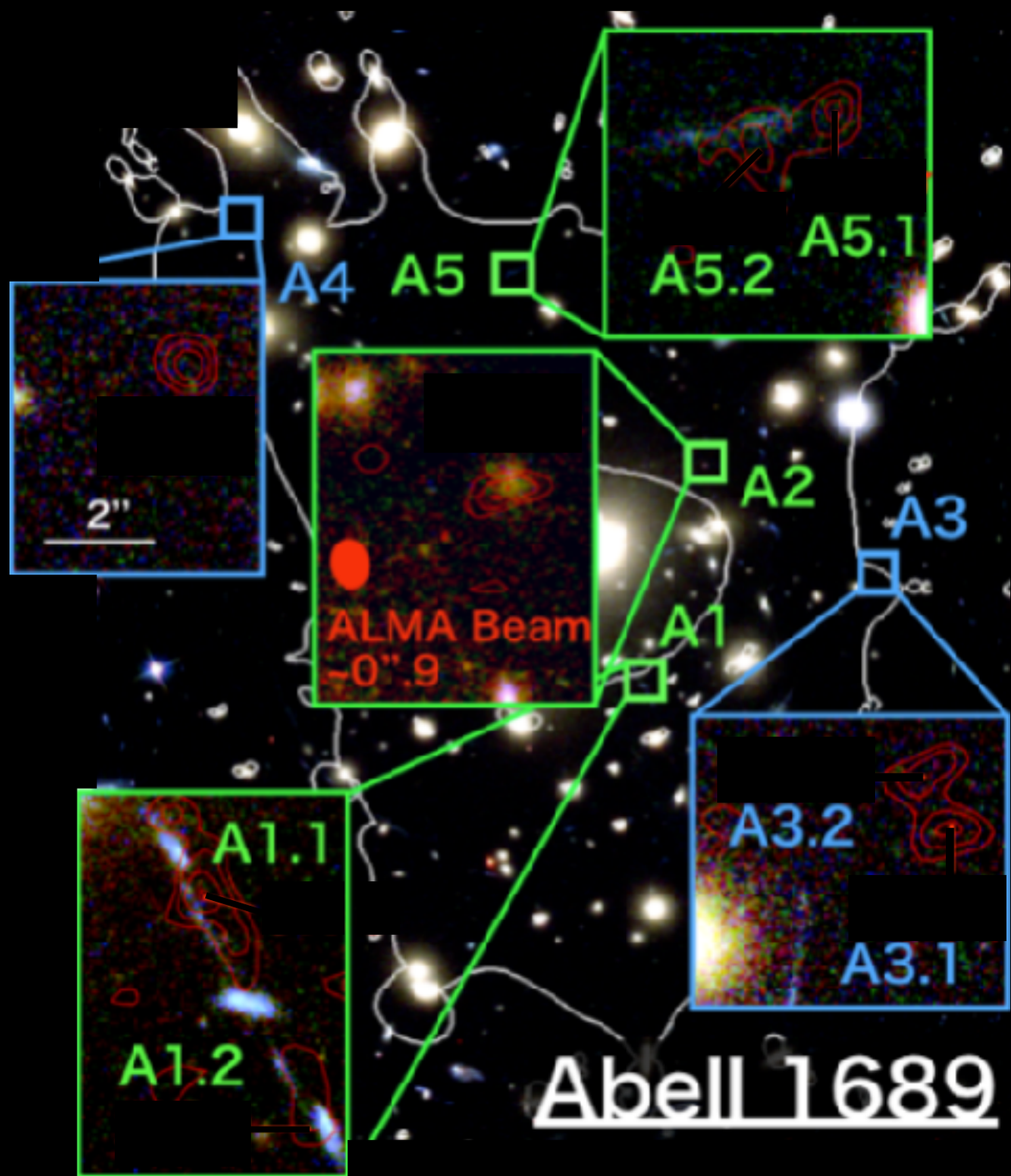
① Clustering
(Statistical)
② Opt. Counterparts
(Individual)

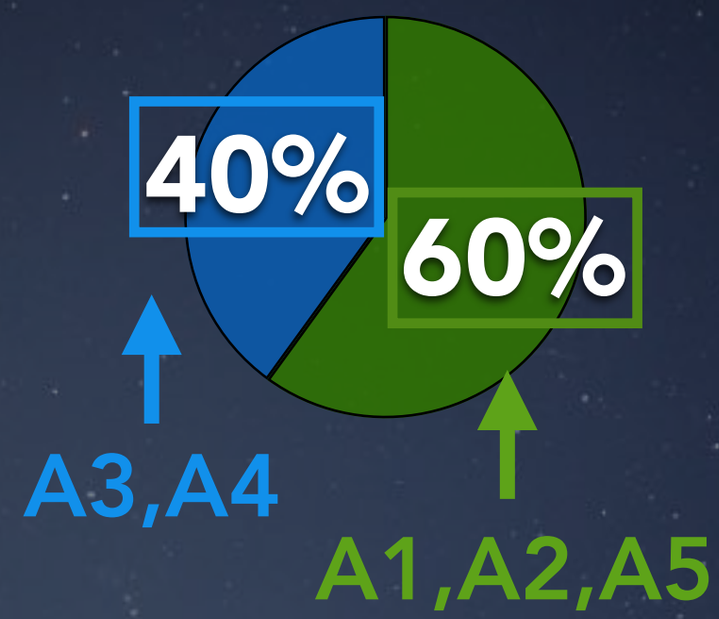
Faint ALMA Sources

-> x AGN
o Optically selected SFG

Faint ALMA Sources
(60%)
↓
Optically Selected
SFGs

Subaru NIR Spectroscopy

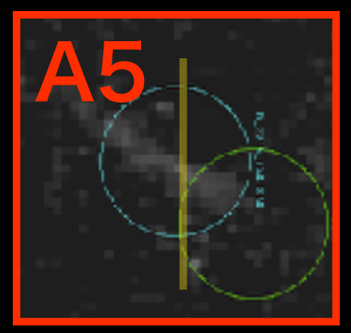


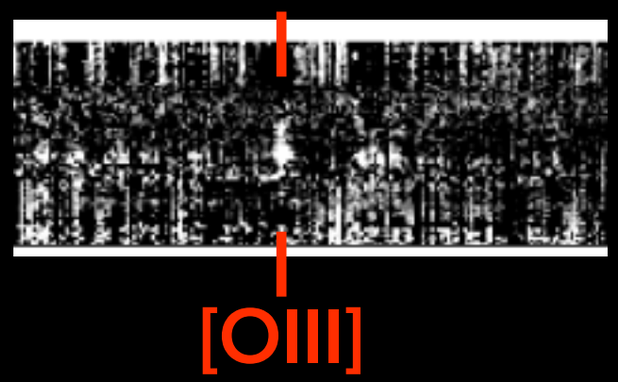


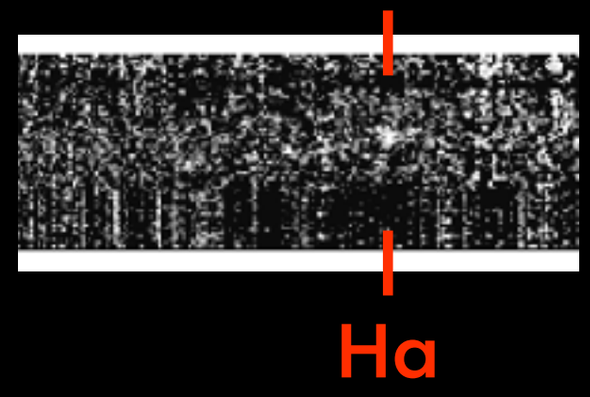
Date: 6/19-6/21/2016
Mode: MORICS/HK500

- Five faint ALMA sources
- To determine redshift, Z

Subaru NIR Spectroscopy

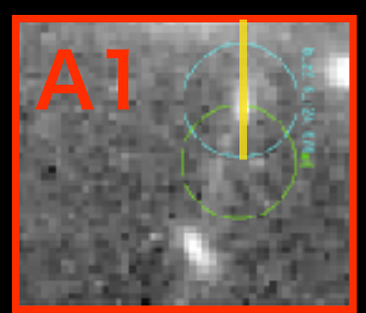


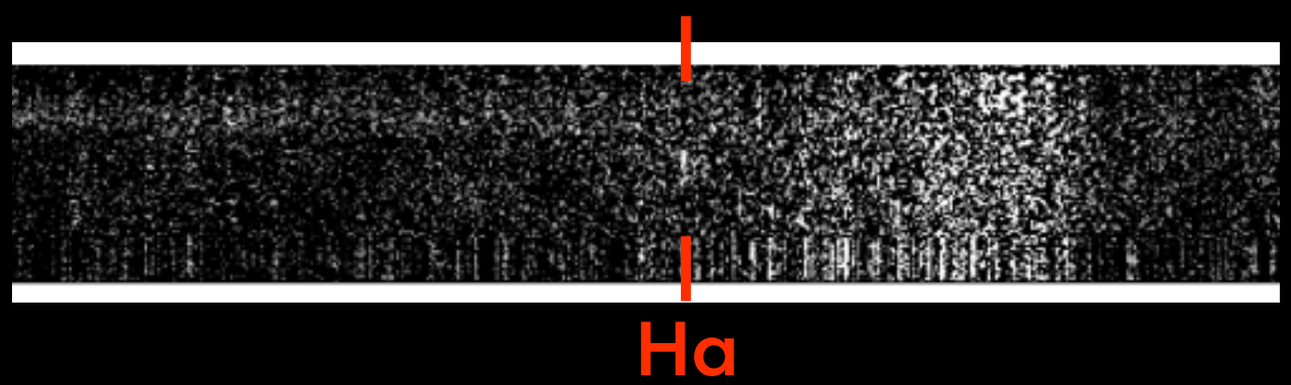




z=2.50

12+log(O/H) $\lesssim$ 8.2

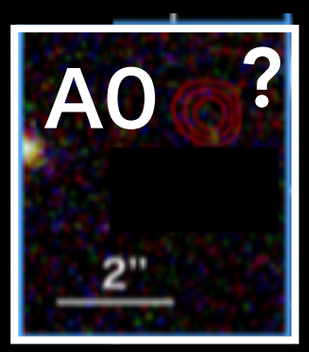


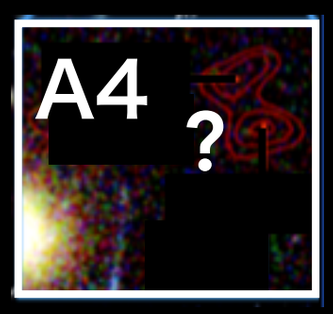


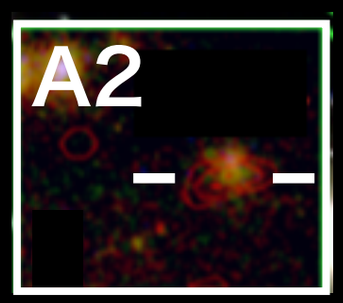
z=2.63

(Jullo+10)

12+log(O/H) $\lesssim$ 8.2







Other 3 faint ALMA sources …

- No lines are detected

Summary

Largest ALMA Dataset (133 down to 0.02 mJy)

- Resolve the CIB ~100%
- Statistical / Individual
  - galaxy bias: $b_g < 3.5$
  - Opt.-NIR counterparts:

    (60%) Opt. SF galaxies z~2-3

    (40%) unknown