ALMA 26 arcmin^2 survey of GOODS-S at 1 mm (ASAGAO):

Physical properties of ALMA-selected galaxies

Yamaguchi et al. 2018, submitted to ApJ

Workshop on Galaxy Evolution 2018 @ Ehime Univ.

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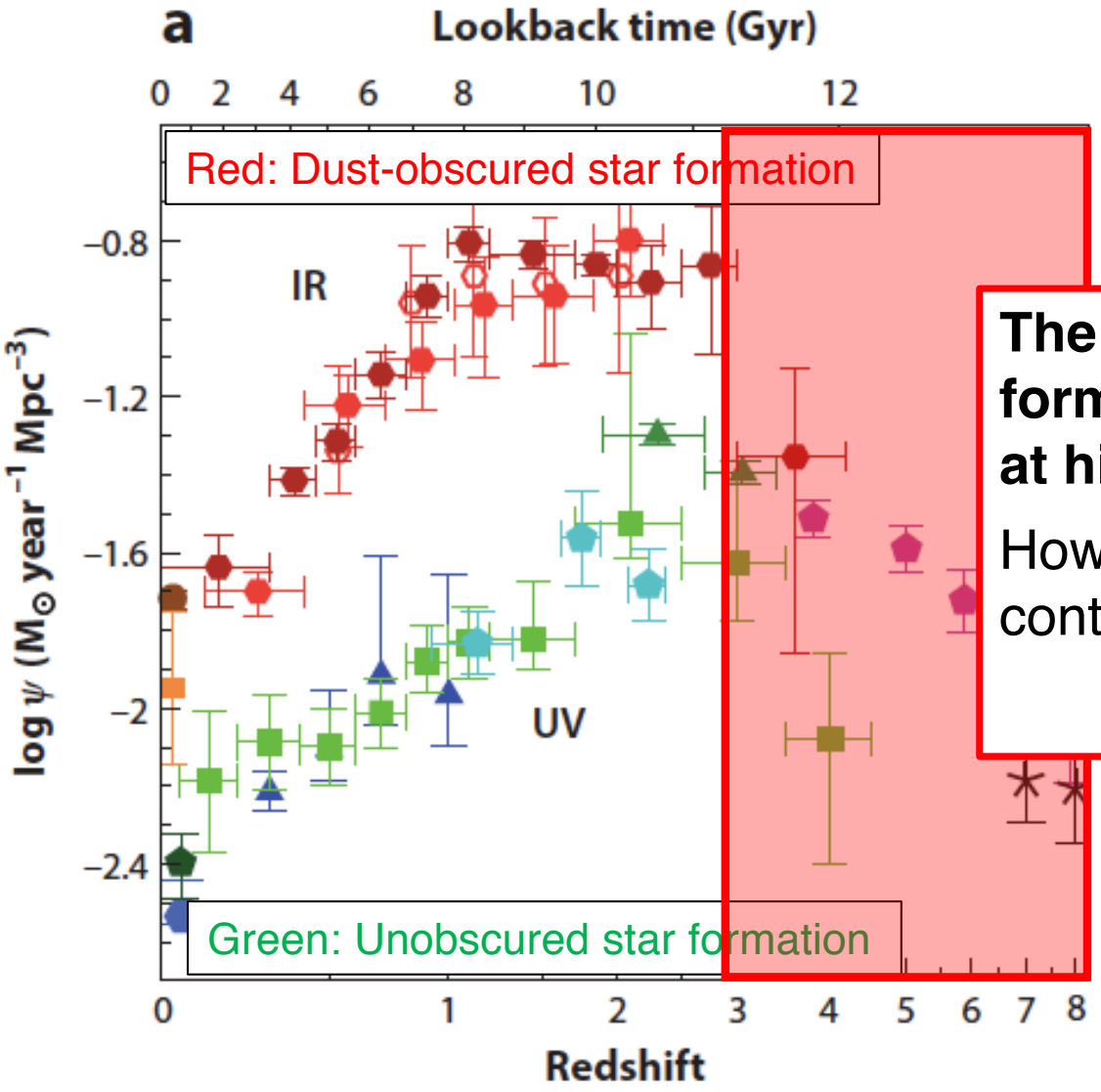
Institute of Astronomy, The University of Tokyo (D3)

Yuki Yamaguchi

Outline

- Introduction
  - The evolution of the cosmic SFRD
    - ✓ The role of deep continuum observations by ALMA
  - Previous studies & this studies
- Multi-wavelength analysis of ASAGAO continuum sources
  - Star formation properties from SED fitting
  - What is the difference between ALMA detected and non-detected sources?
  - K-dropout ASAGAO sources?
- The contributions to the cosmic SFRD
- Summary

Introduction
"The evolution of the cosmic SFRD"

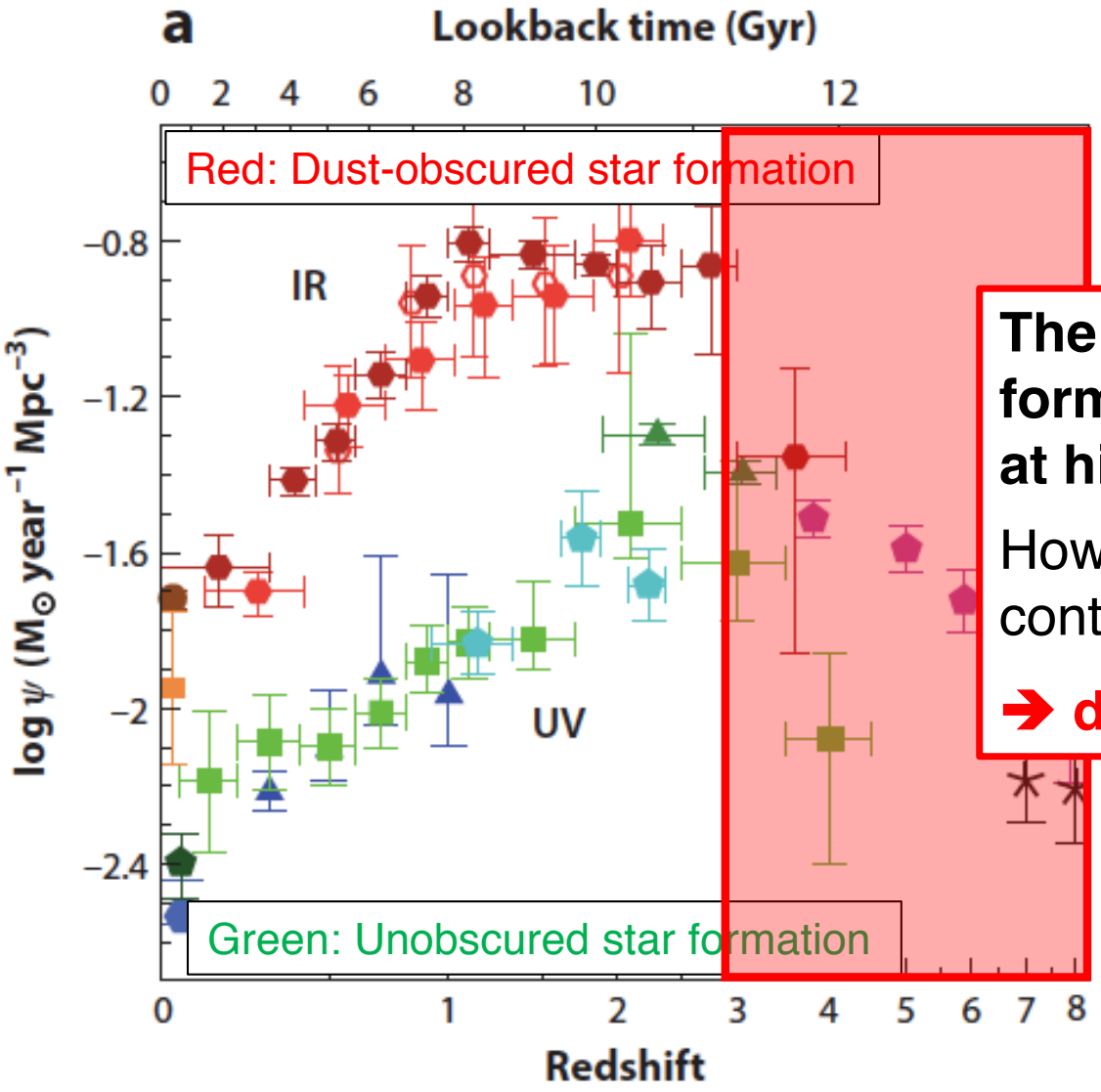


The role of dust-obscured star-formation activities at high-z (z > 3-4)?

How do dusty starburst galaxies contribute to the SFRD at high-z?

Madau & Dickinson 14

Introduction
"The evolution of the cosmic SFRD"



The role of dust-obscured star-formation activities at high-z (z > 3-4)?

How do dusty starburst galaxies contribute to the SFRD at high-z?

➔ **deep survey by using ALMA**

Madau & Dickinson 14

Introduction “Previous studies”

- Deep continuum observations by ALMA
  - ALESS (Hodge+13, da Cunha+15, etc…)
  - SXDF-ALMA 2 arcmin^2 survey (Tadaki+15, Hatsukade+15, Yamaguchi+16, etc…)
  - ASPEC (Aravena+16, Walter+16)
  - ALMA deep observation in the HUDF (Dunlop+17)

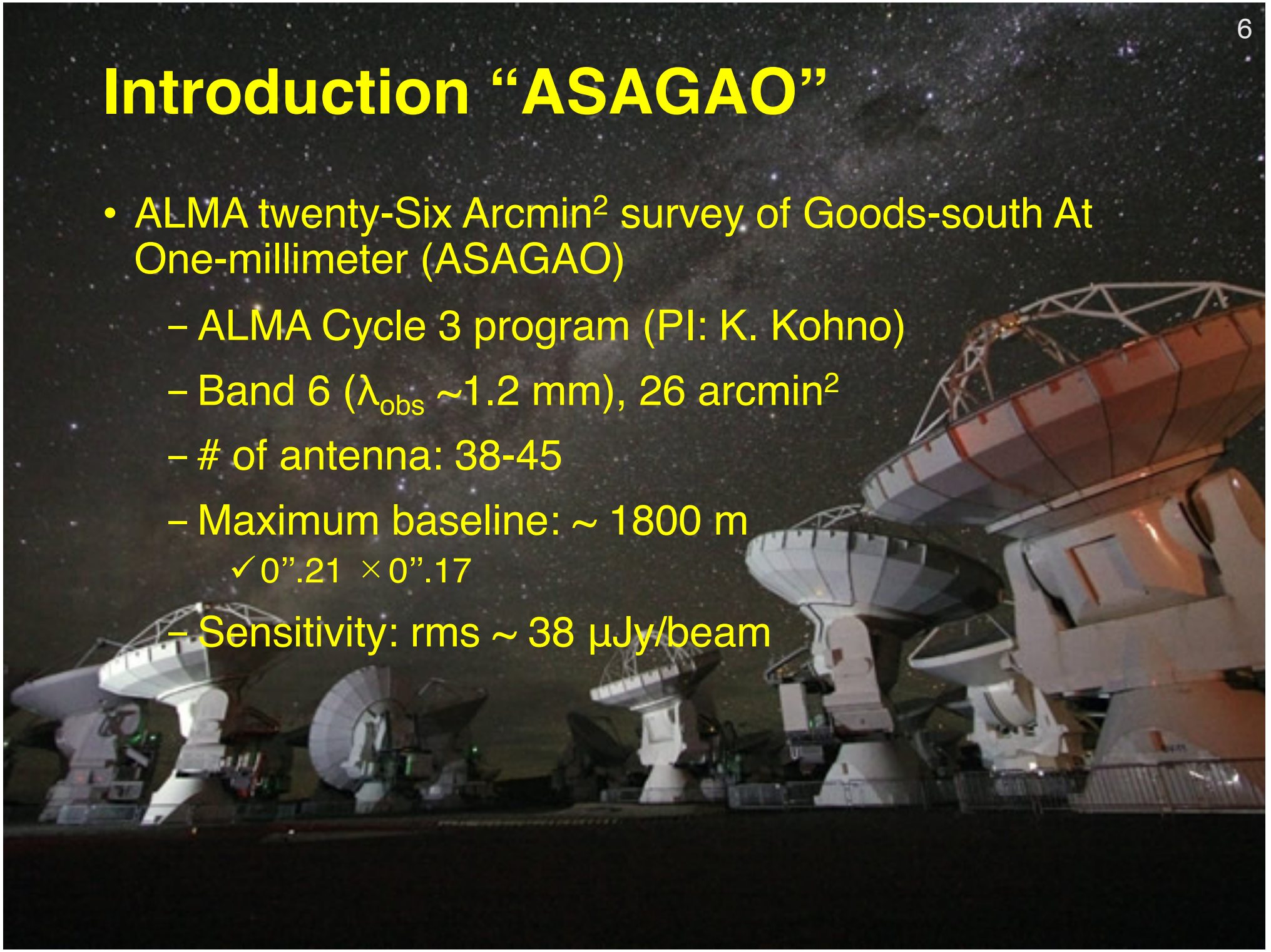
Follow-up observation of single-dish selected sources
or
Small observation area (~ a few arcmin^2)

➔ Large and deep unbiased survey using ALMA!

Introduction "ASAGAO"

- ALMA twenty-Six Arcmin^2 survey of Goods-south At One-millimeter (ASAGAO)
  - ALMA Cycle 3 program (PI: K. Kohno)
  - Band 6 (λ_{obs} ~1.2 mm), 26 arcmin^2
  - # of antenna: 38-45
  - Maximum baseline: ~ 1800 m
    - ✓0".21 ×0".17
  - Sensitivity: rms ~ 38 μJy/beam

Introduction "ASAGAO"



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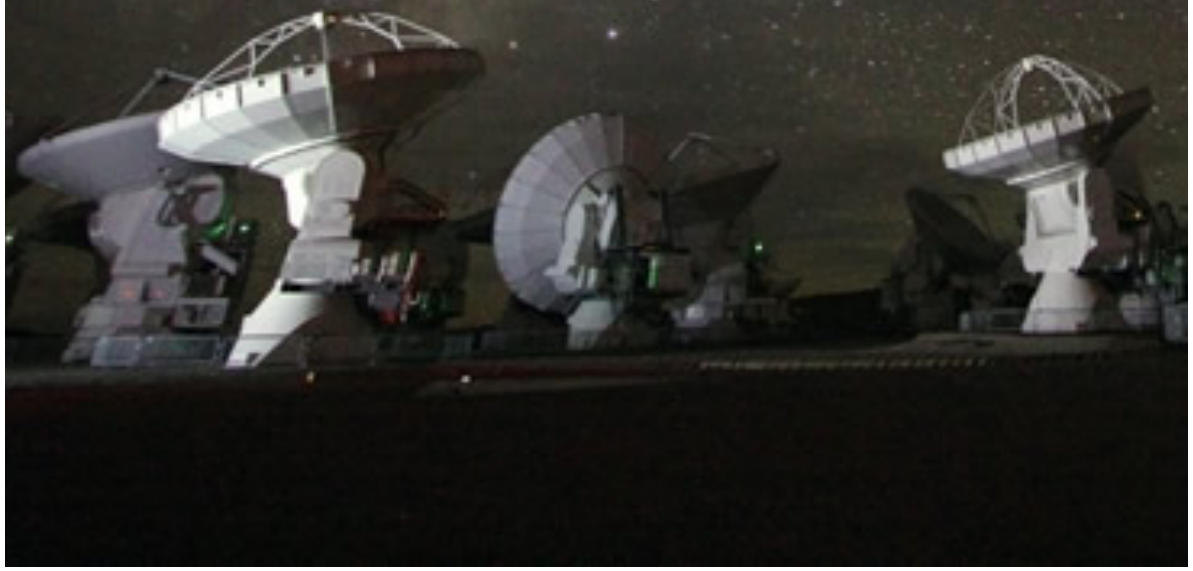
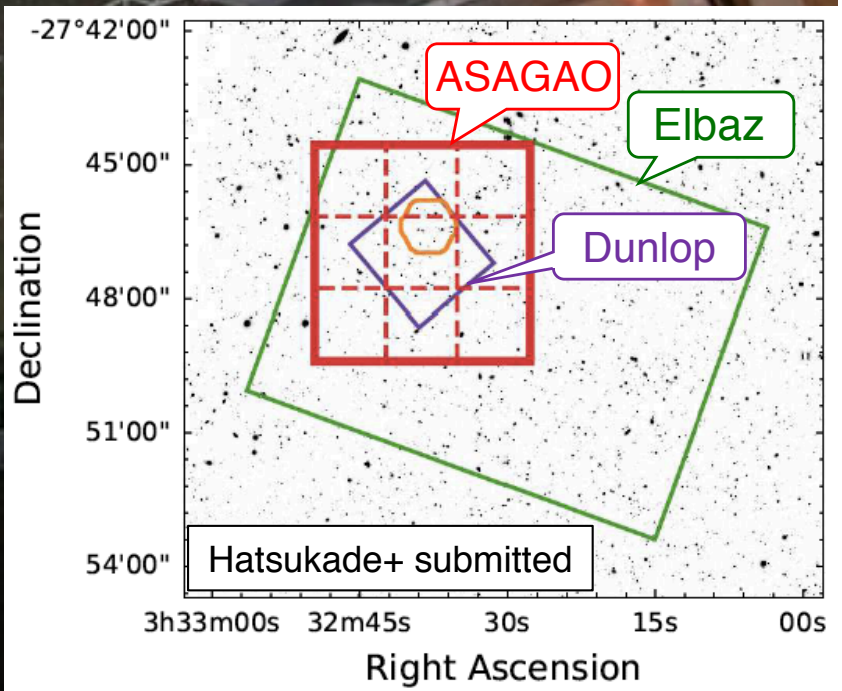
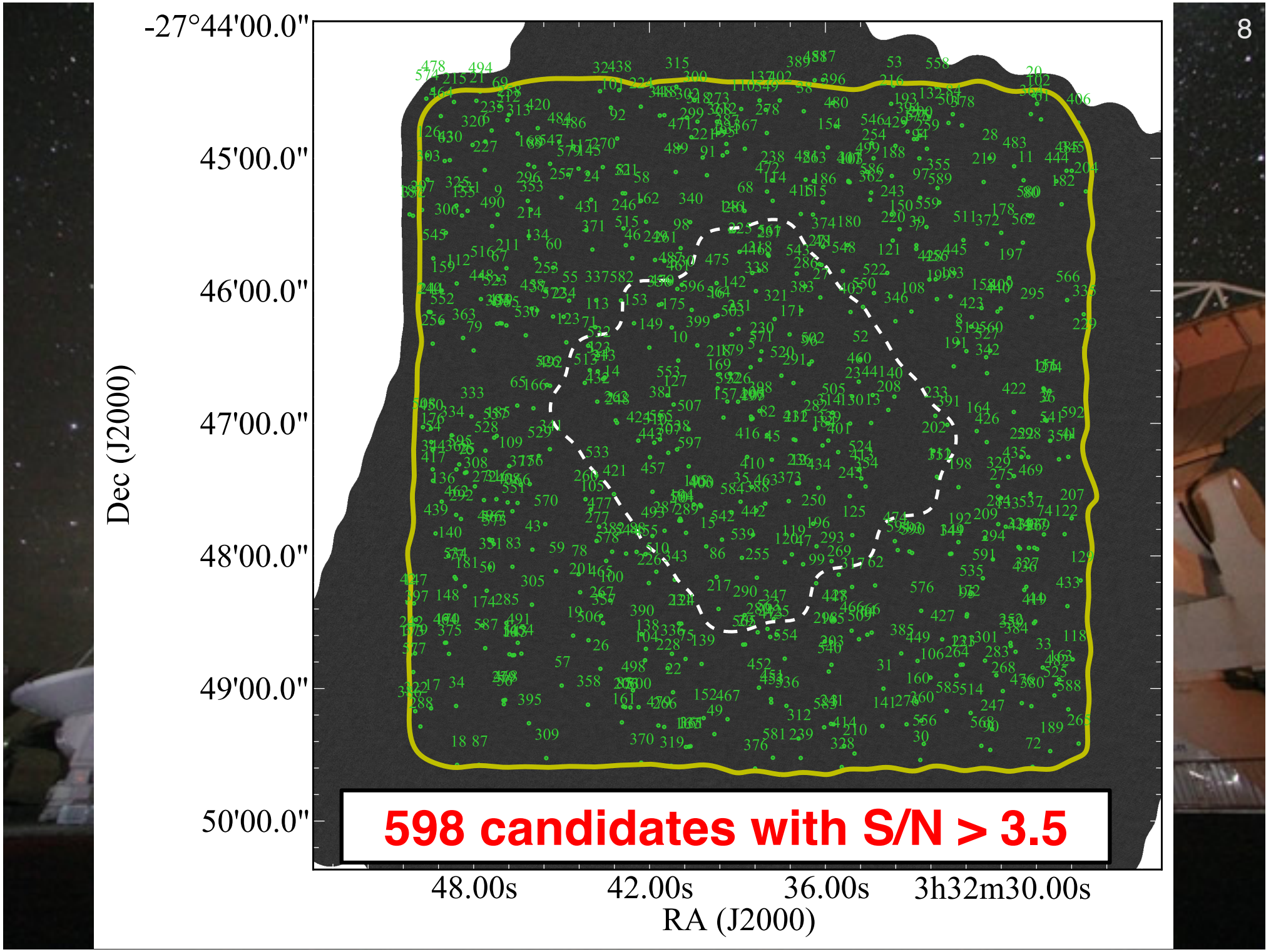
Introduction “ASAGAO”

- ALMA twenty-Six Arcmin^2 survey of Goods-south At One-millimeter (ASAGAO)
  - ASAGAO final map (250 kλ-tapered)
    - ✓ ASAGAO + Dunlop + Elbaz data
    - ✓ Synthesized beam: 0”.59 × 0”.45
    - ✓ Typical noise: ~ 30-70 μJy/beam

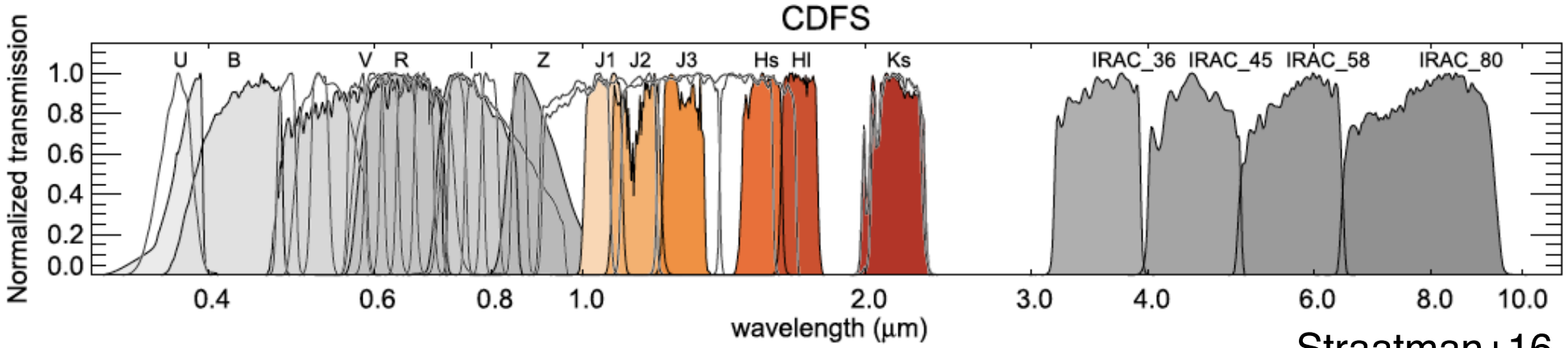





-27°44'00.0"
45'00.0"
46'00.0"
47'00.0"
48'00.0"
49'00.0"
50'00.0"
Dec (J2000)
48.00s
42.00s
36.00s
3h32m30.00s
RA (J2000)
598 candidates with S/N > 3.5

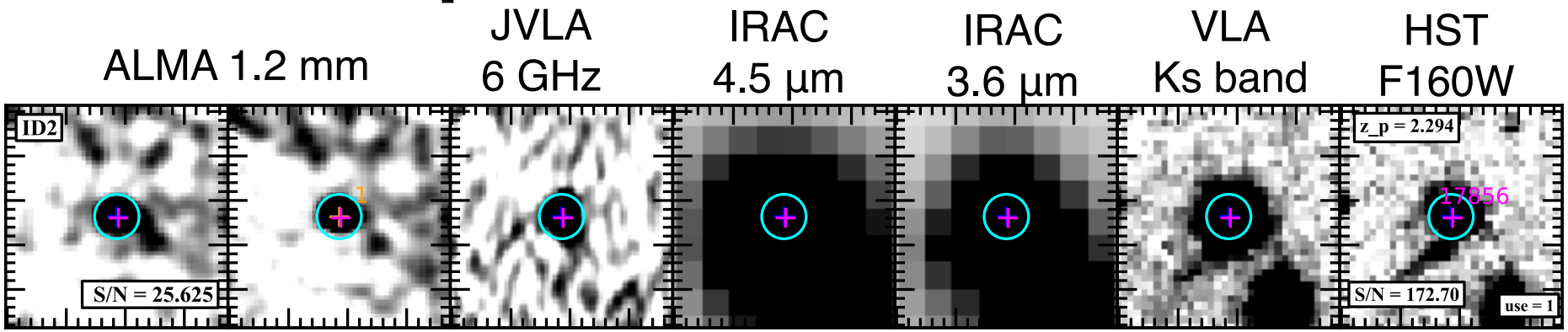
Multi-wavelength analysis "Counterpart identification"

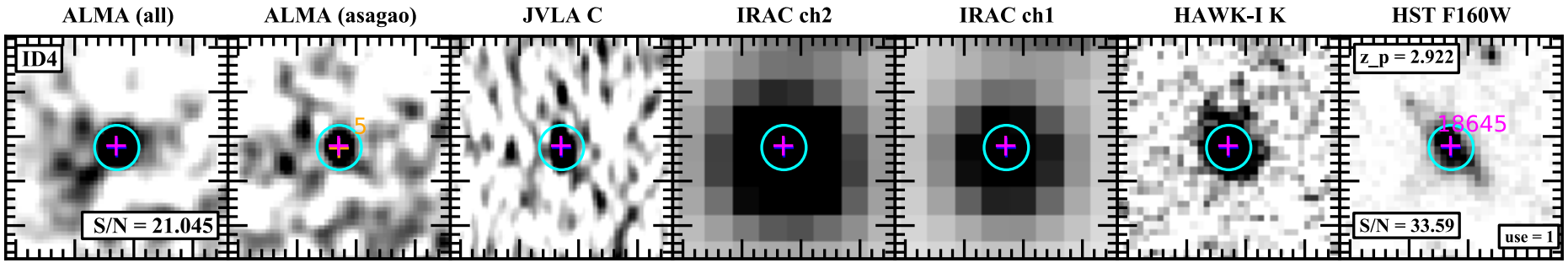
- Multi-wavelength counterpart identification based on ZFOURGE survey
  - K-band selected source catalog (Straatman+16)
    - ✓40 photometry data from U-band to IRAC 8μm
  - Multi-wavelength counterpart with $r_{search} < 0.5$" (p = 0.03)
    - ✓Some extended sources at K-band are included
  - There are 66 sources have K-band counterpart with redshift (photo-z or spec-z)

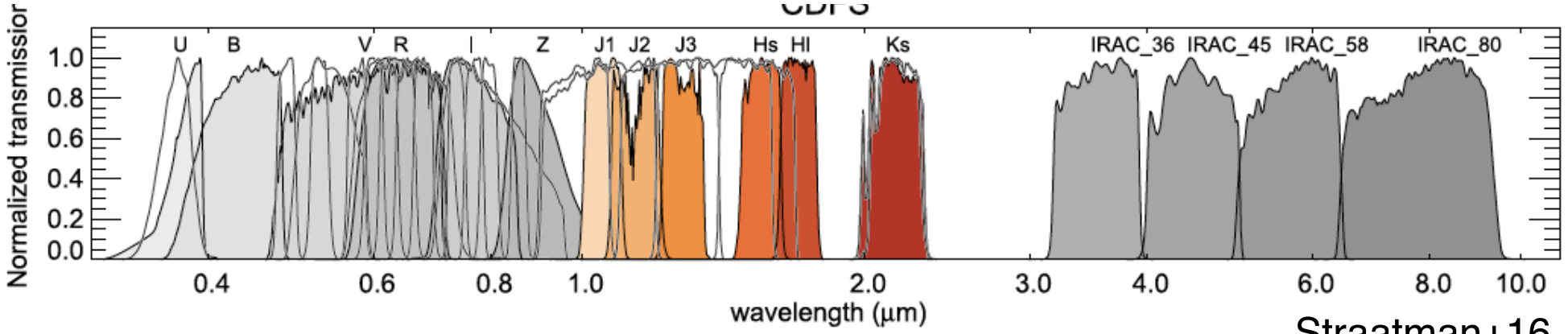


Straatman+16

Multi-wavelength analysis “Counterpart identification”

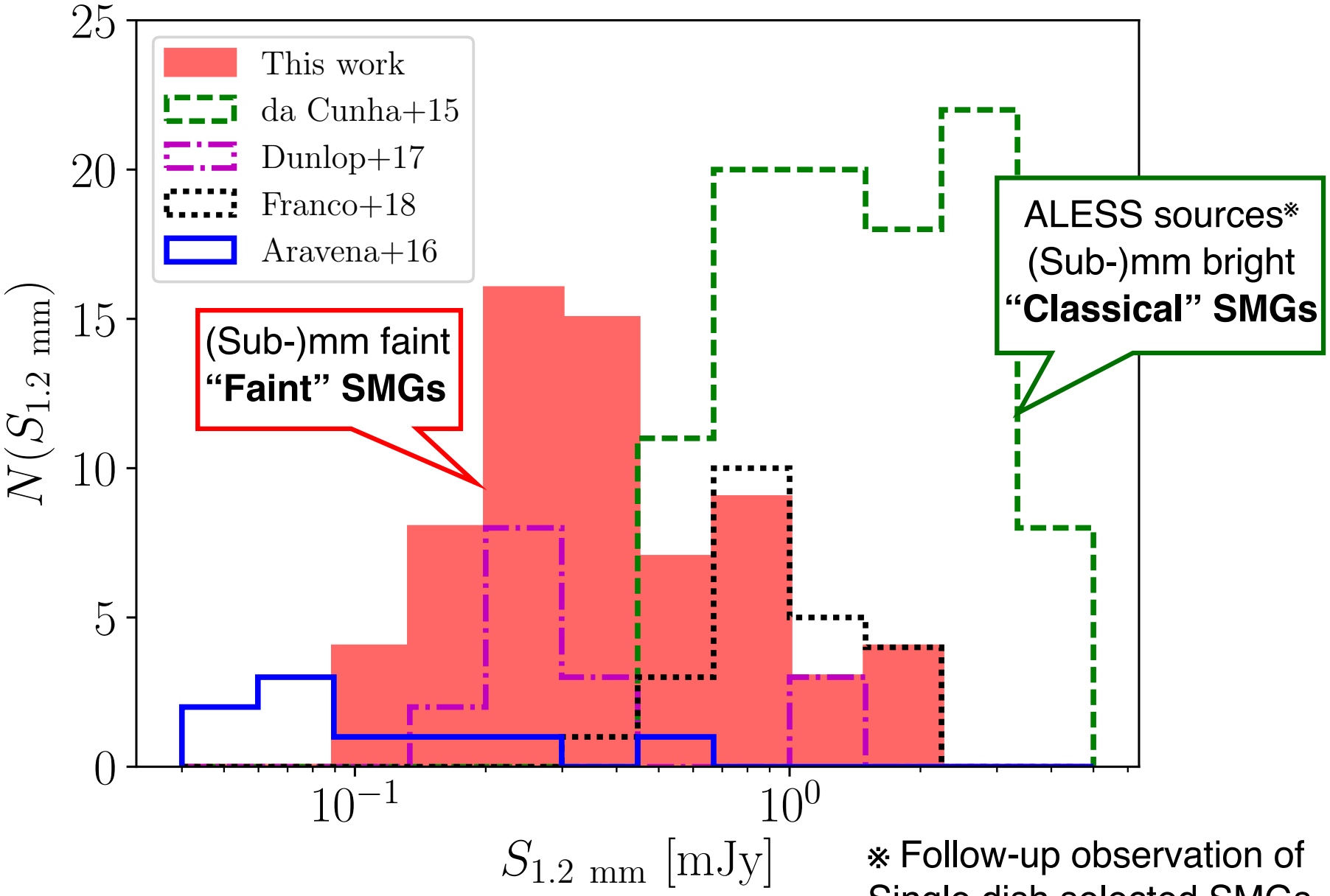






Straatman+16

Multi-wavelength analysis
“Observed flux densities at 1.2 mm”



※ Follow-up observation of Single dish selected SMGs

Multi-wavelength analysis
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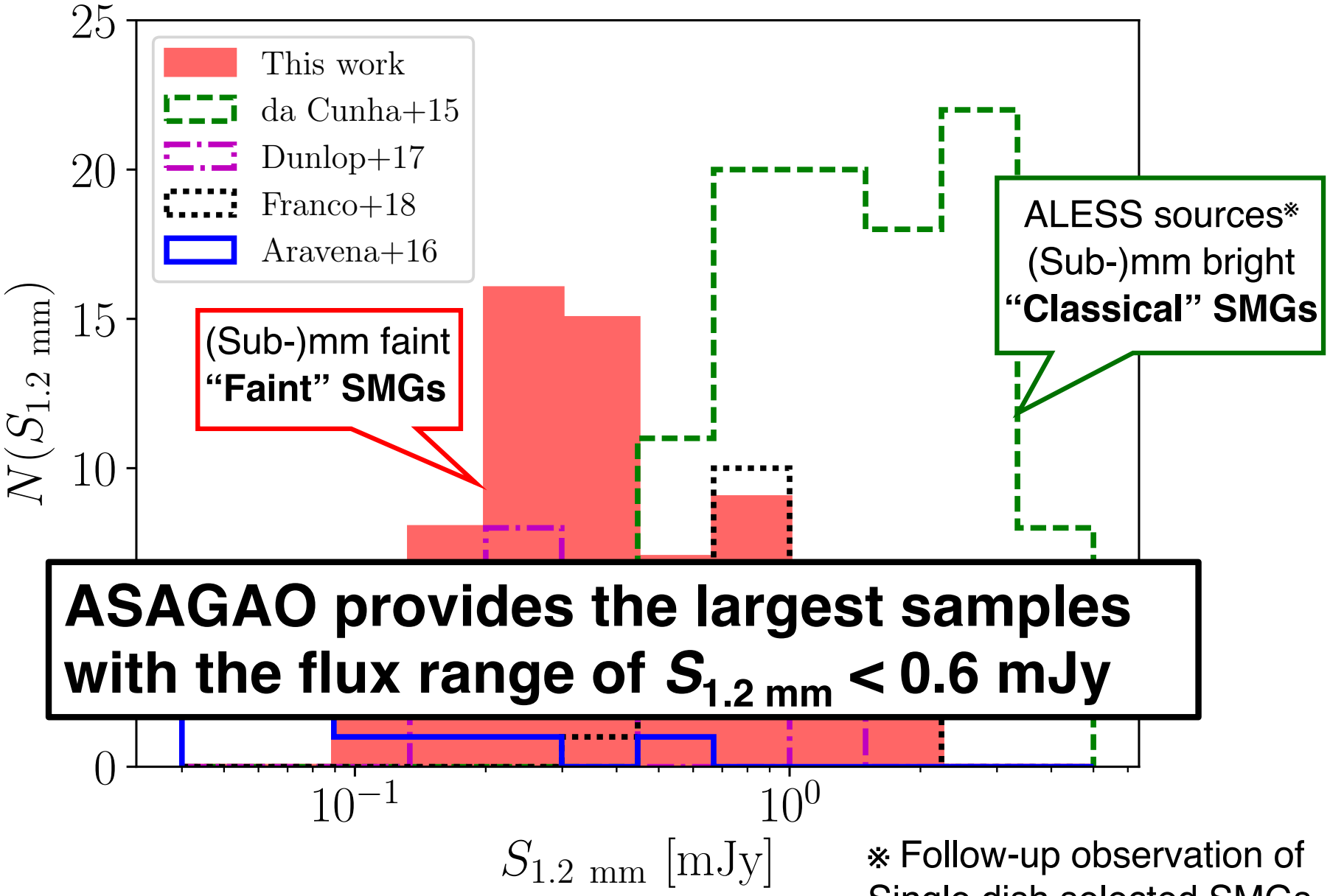

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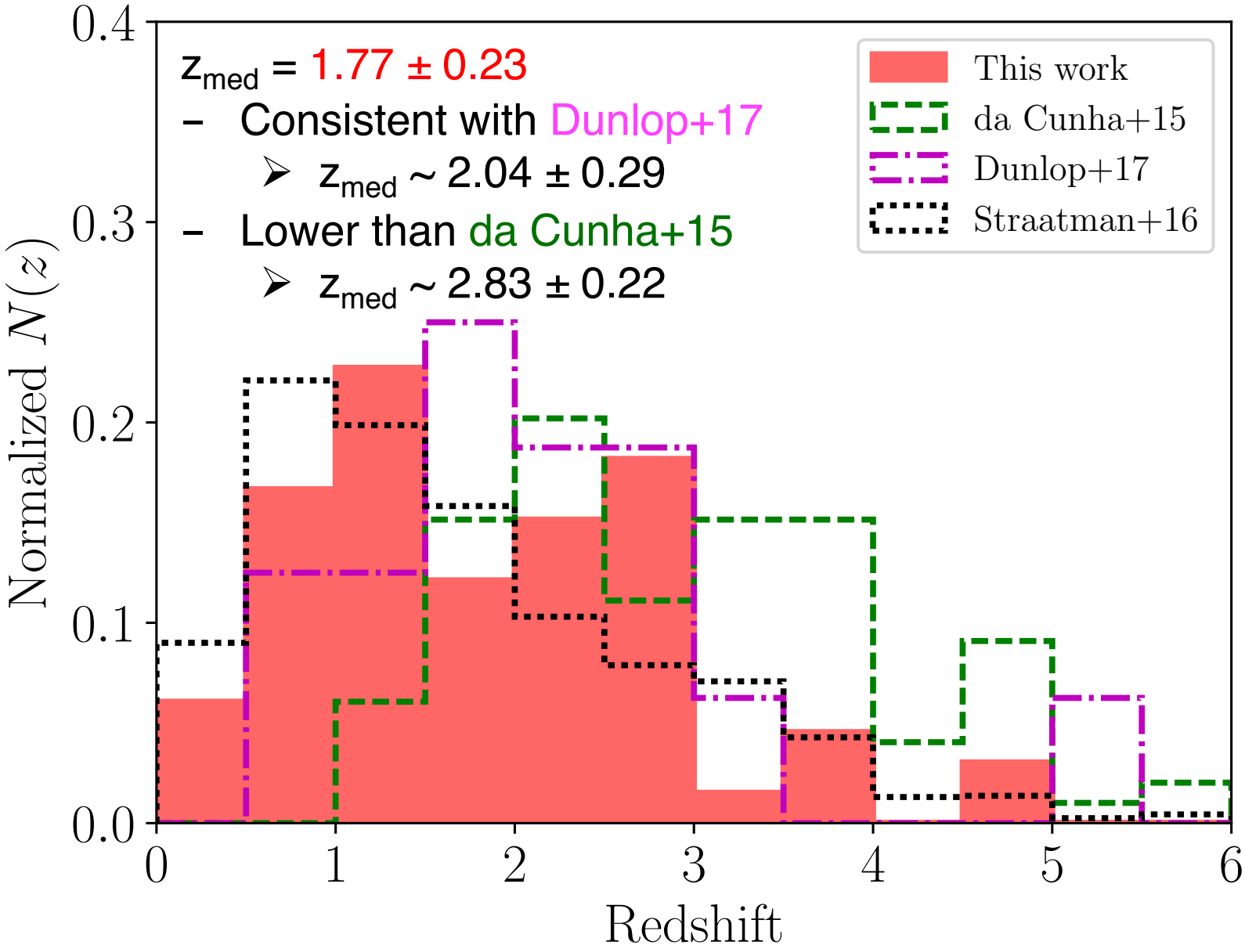
Multi-wavelength analysis
“Redshift distribution”



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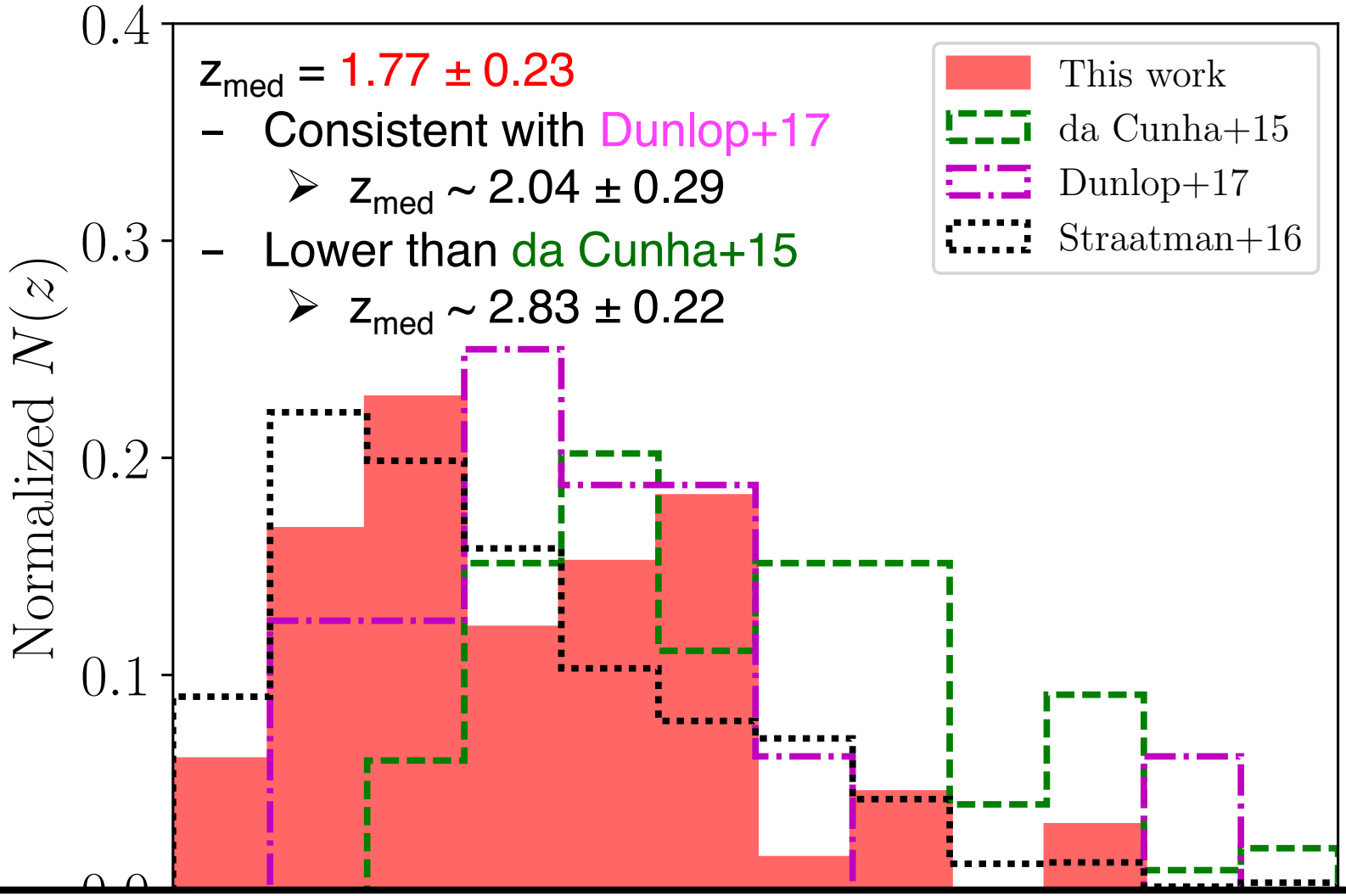
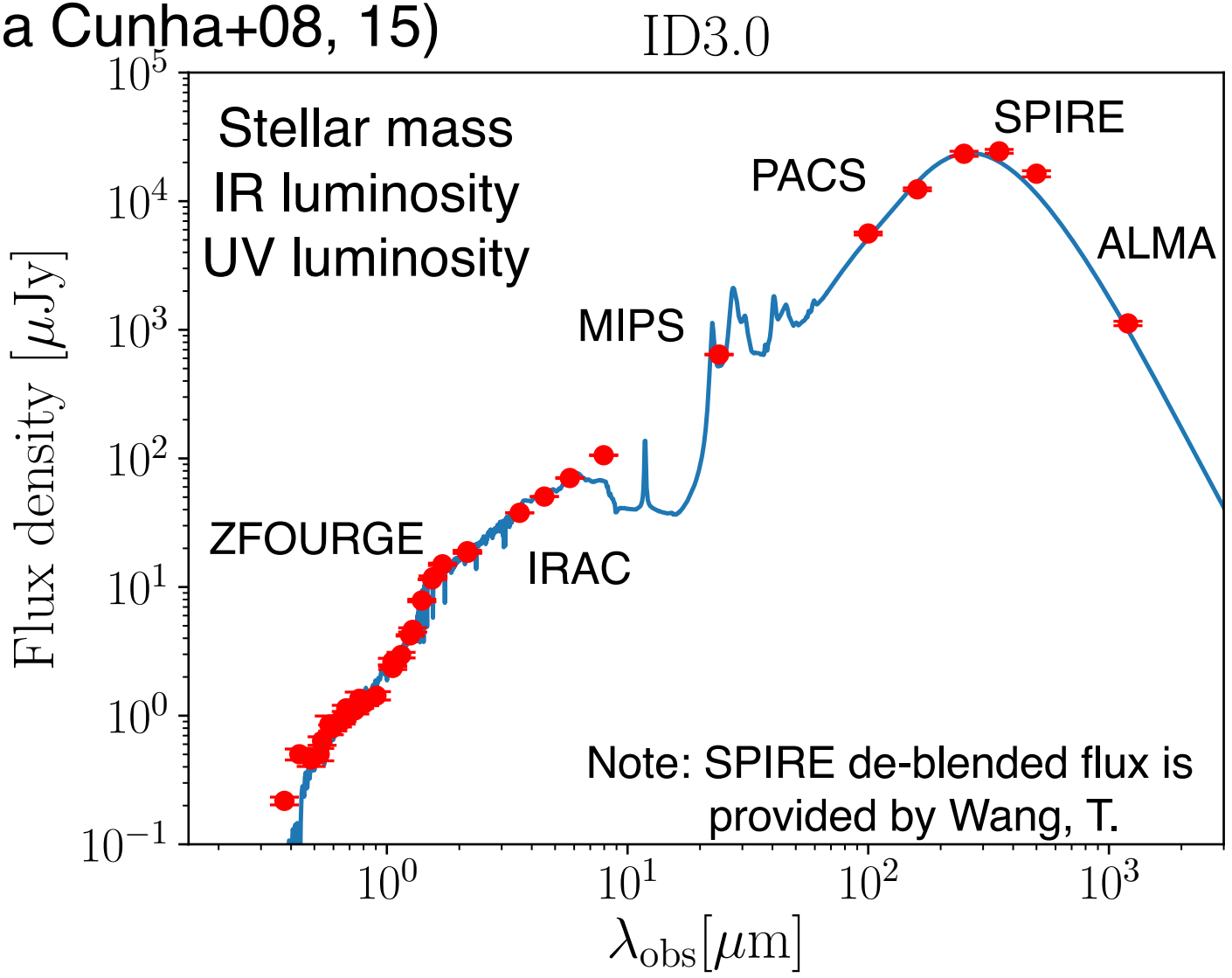


Faint sources tend to have lower redshift than “classical” SMGs

➔The redshift evolution of IR luminosity function (Koprowski+17)

Multi-wavelength analysis “SED fitting using MAGPHYS”

- SED fitting from optical to mm using MAGPHYS (da Cunha+08, 15)



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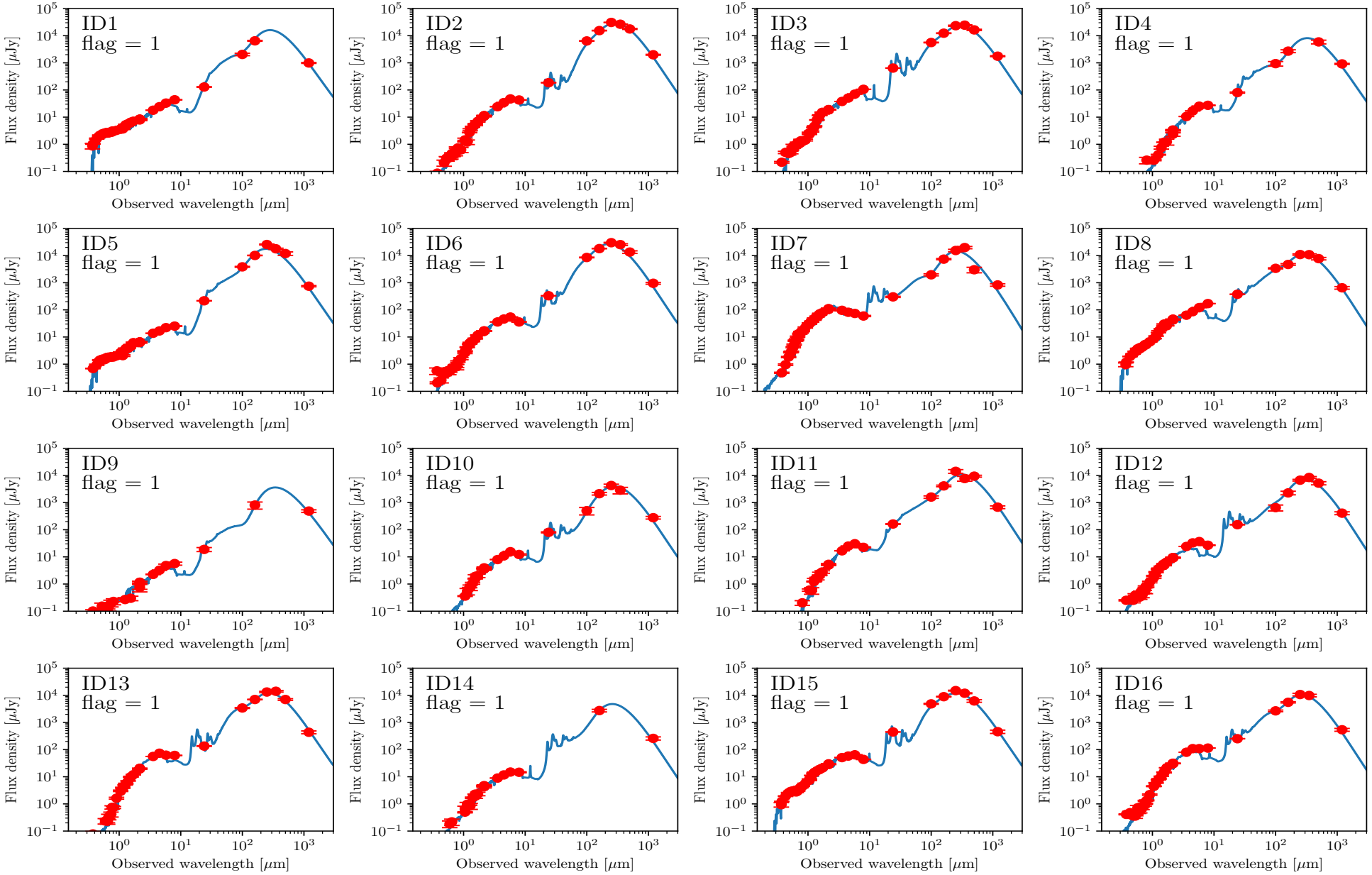

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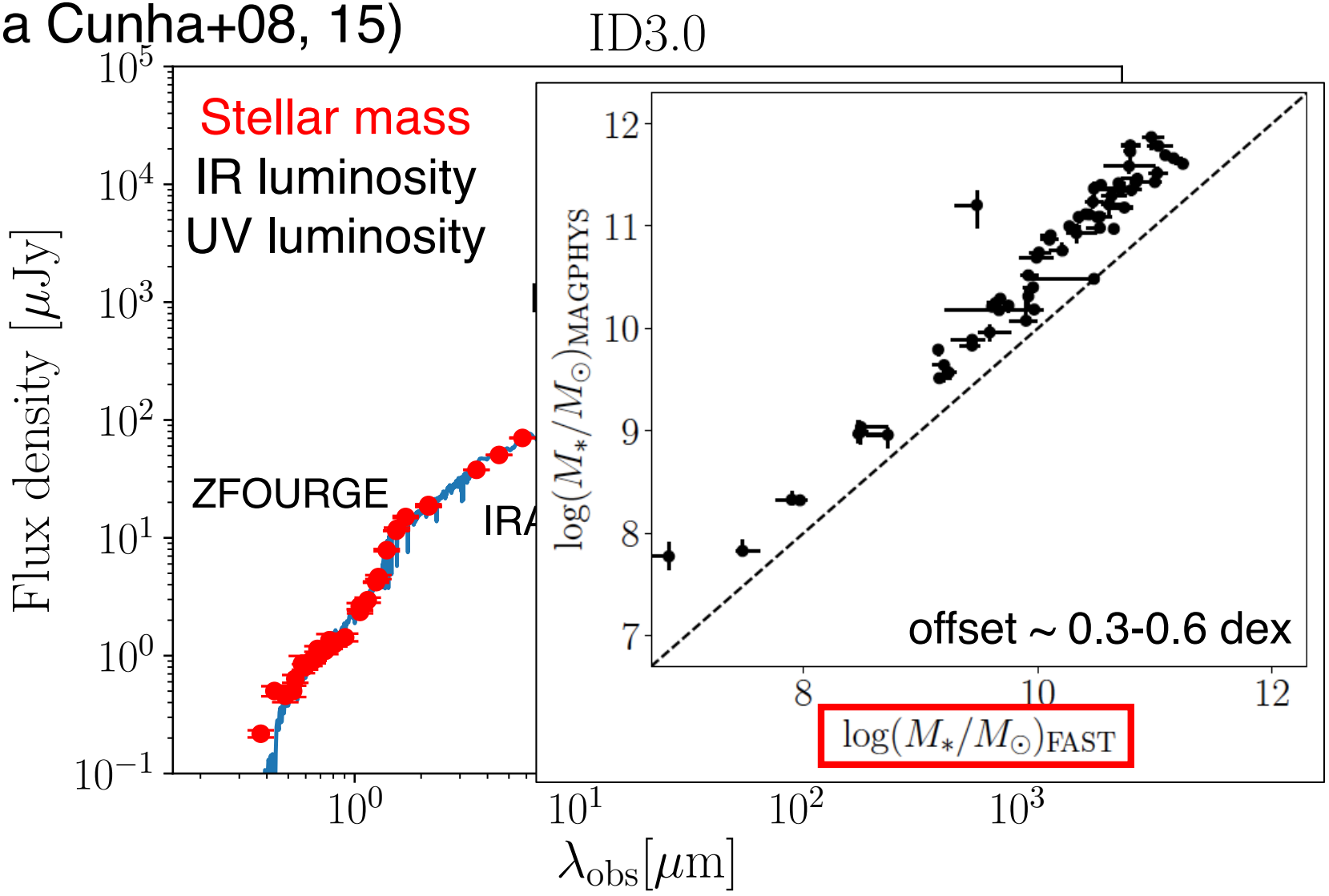
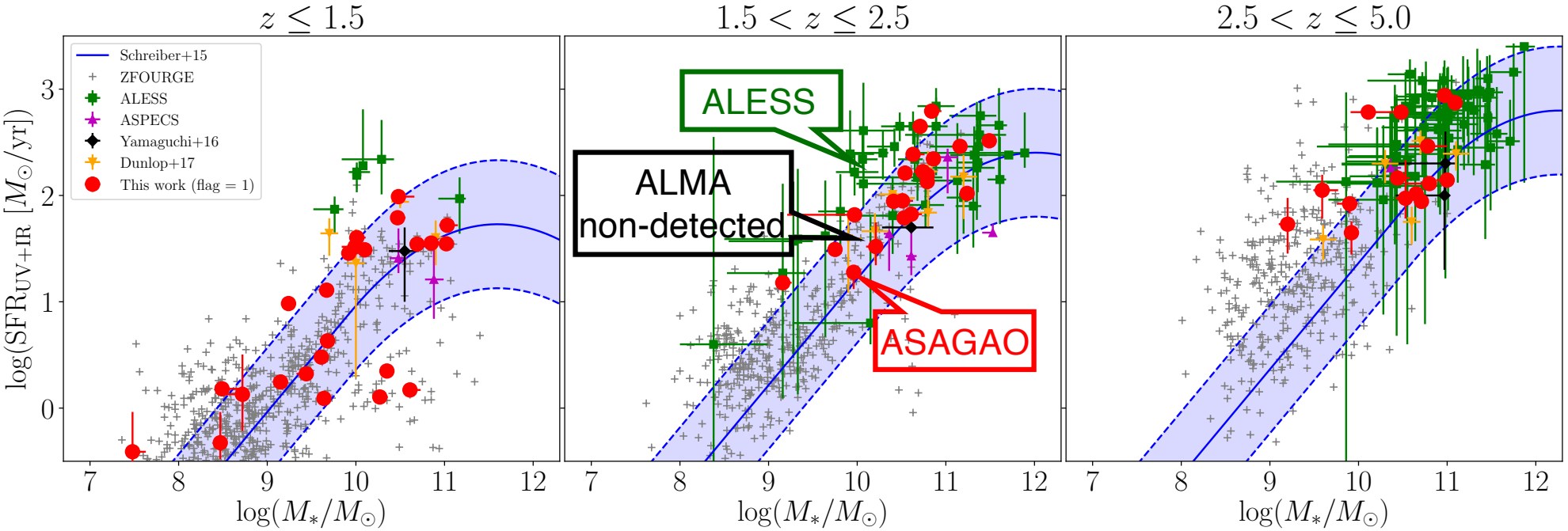
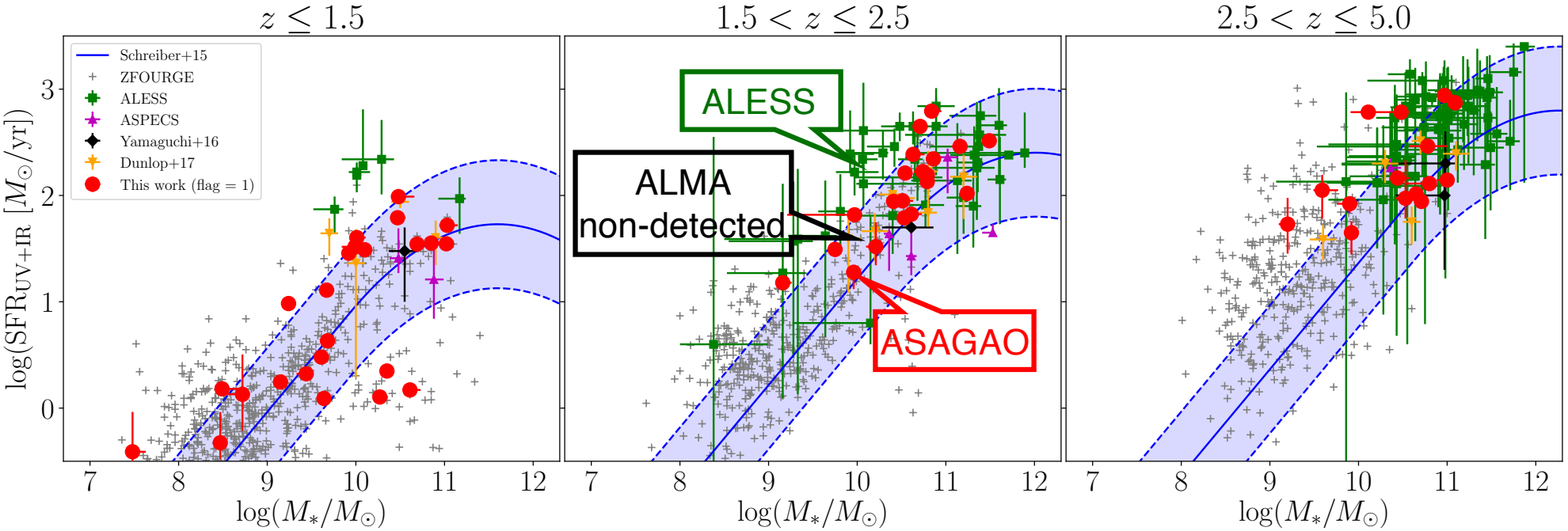


Multi-wavelength analysis "$M_\star$ vs. SFR"



- ASAGAO continuum sources (red symbols)
  - Mainly high-mass end of the main sequence of star formation galaxies
  - Consistent with previous results of faint SMGs (e.g., Dunlop+17)
    - ✓Systematical lower SFRs than "classical" SMGs (ALESS)

Multi-wavelength analysis
"$M_\star$ vs. SFR"



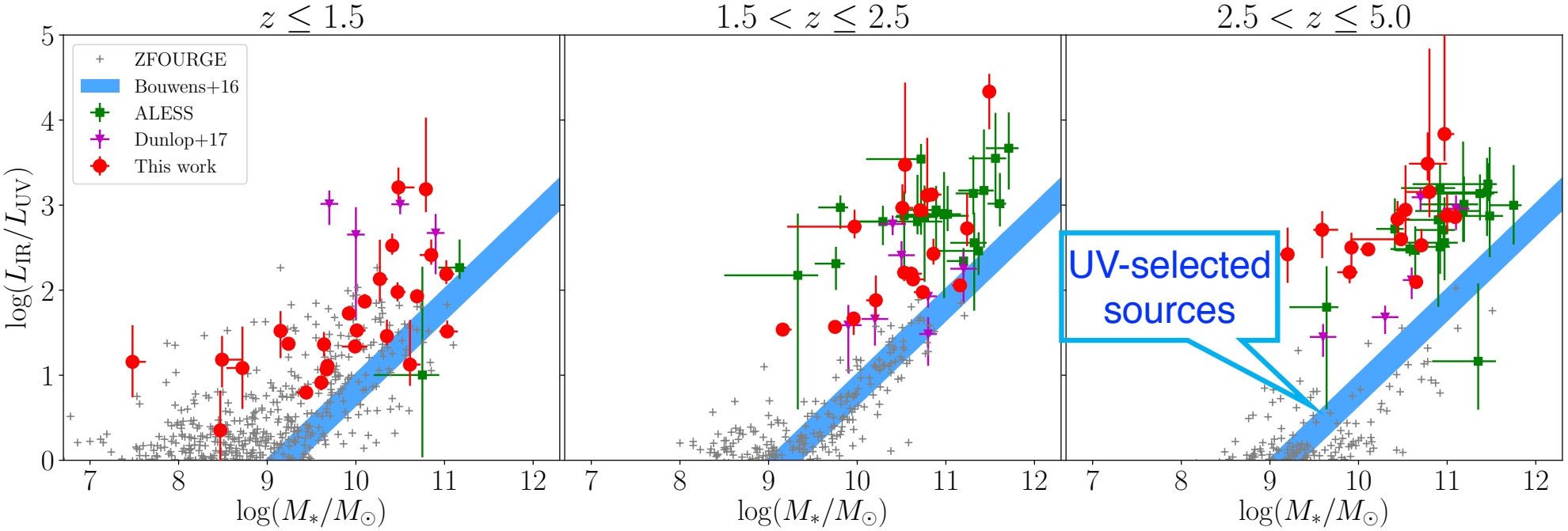
- ASAGAO continuum sources (red symbols)
  - Mainly high-mass end of the main sequence of star

What is the difference between ALMA detected and non-detected sources?

Dunlop+17)

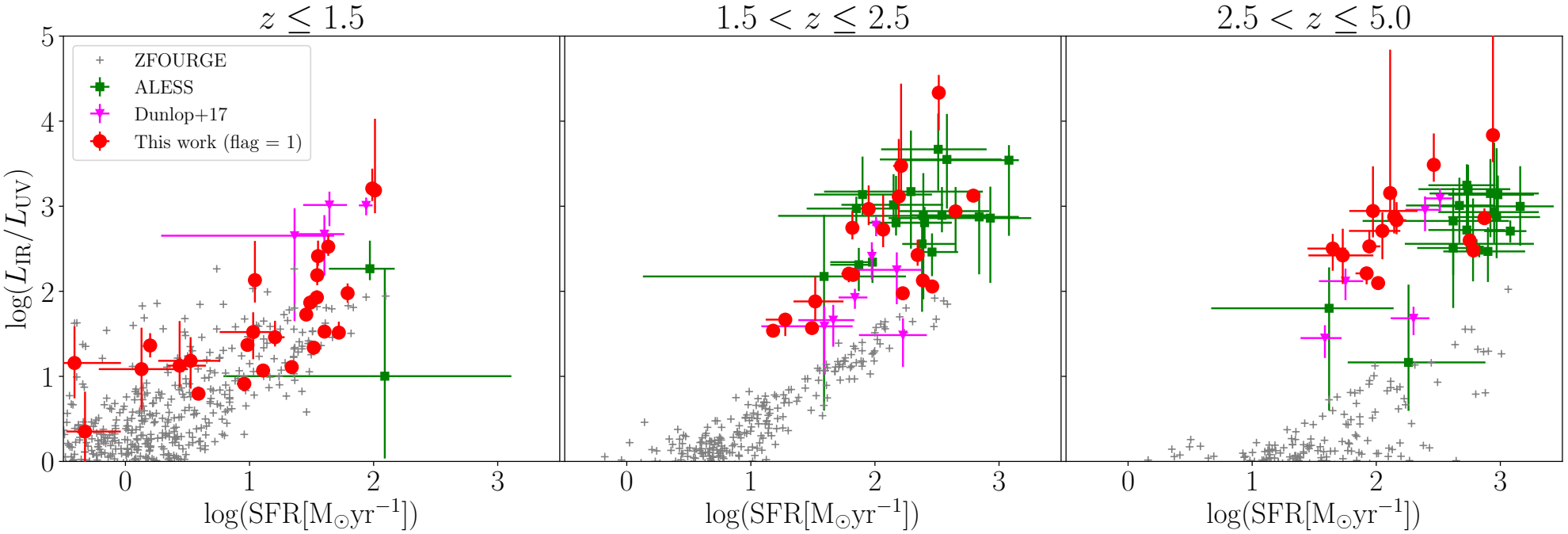
✓Systematical lower SFRs than "classical" SMGs (ALESS)

Multi-wavelength analysis
"What is the difference? (IRX-M★)"



- IRX-M★ relation
  - ALMA detected sources show systematic offset from IRX-M★ relation of UV-selected sources obtained by Bouwens+16 (especially z > 1.5)

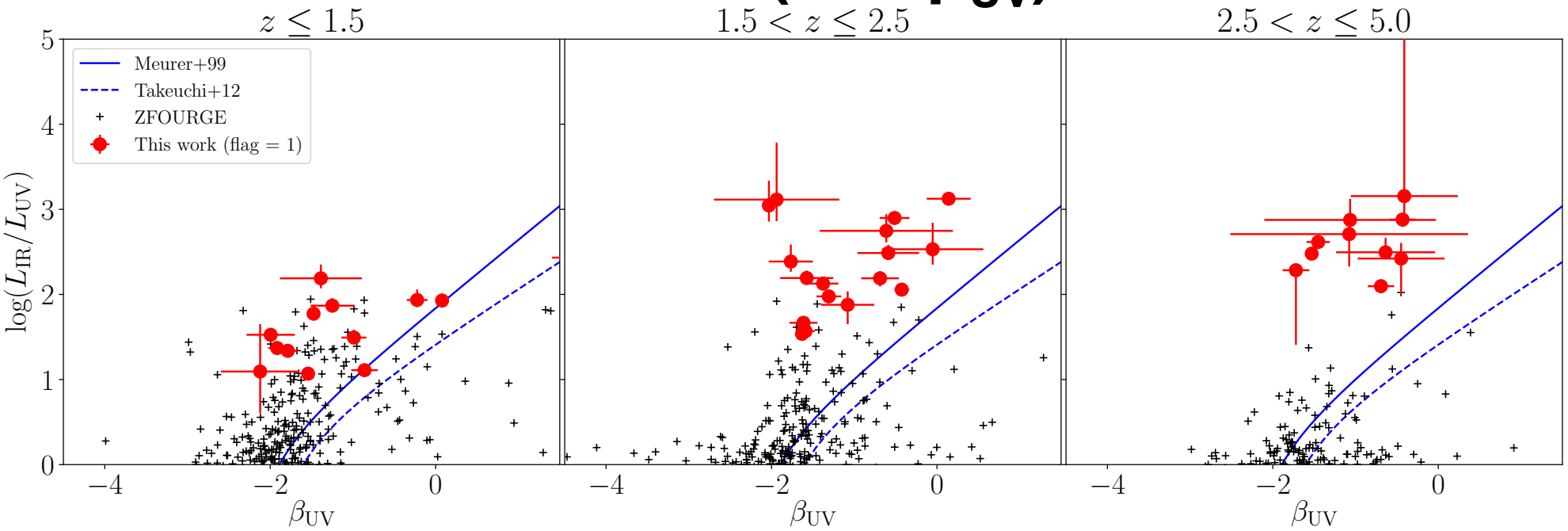
Multi-wavelength analysis
"What is the difference (IRX-SFR)?"



- IRX-SFR relation
  - ALMA detected sources show systematic offset from ZFOURGE sources (especially z > 1.5)

➔IRX seems to be one of the key parameters?

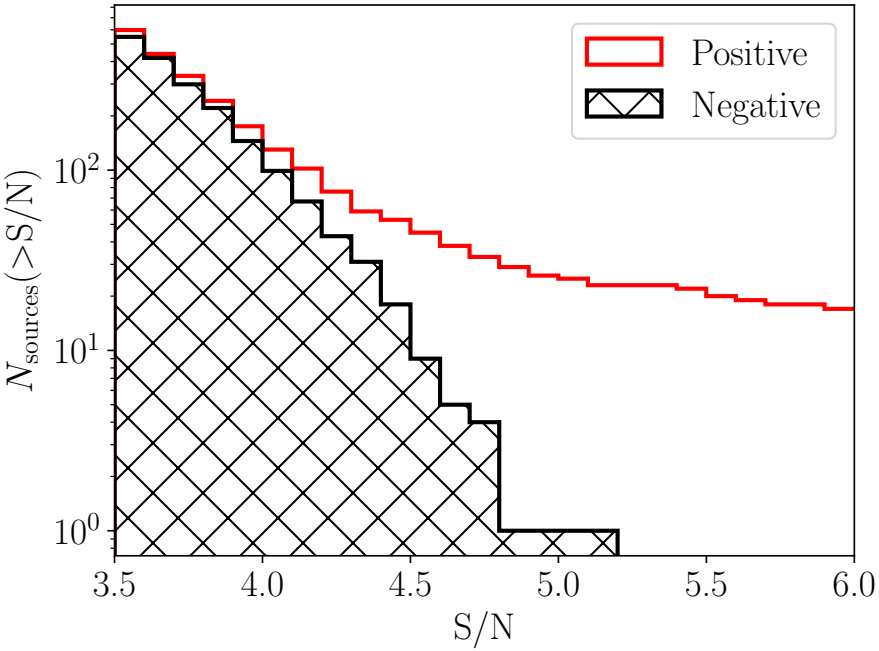
Multi-wavelength analysis
"What is difference (IRX-β_{UV})?"



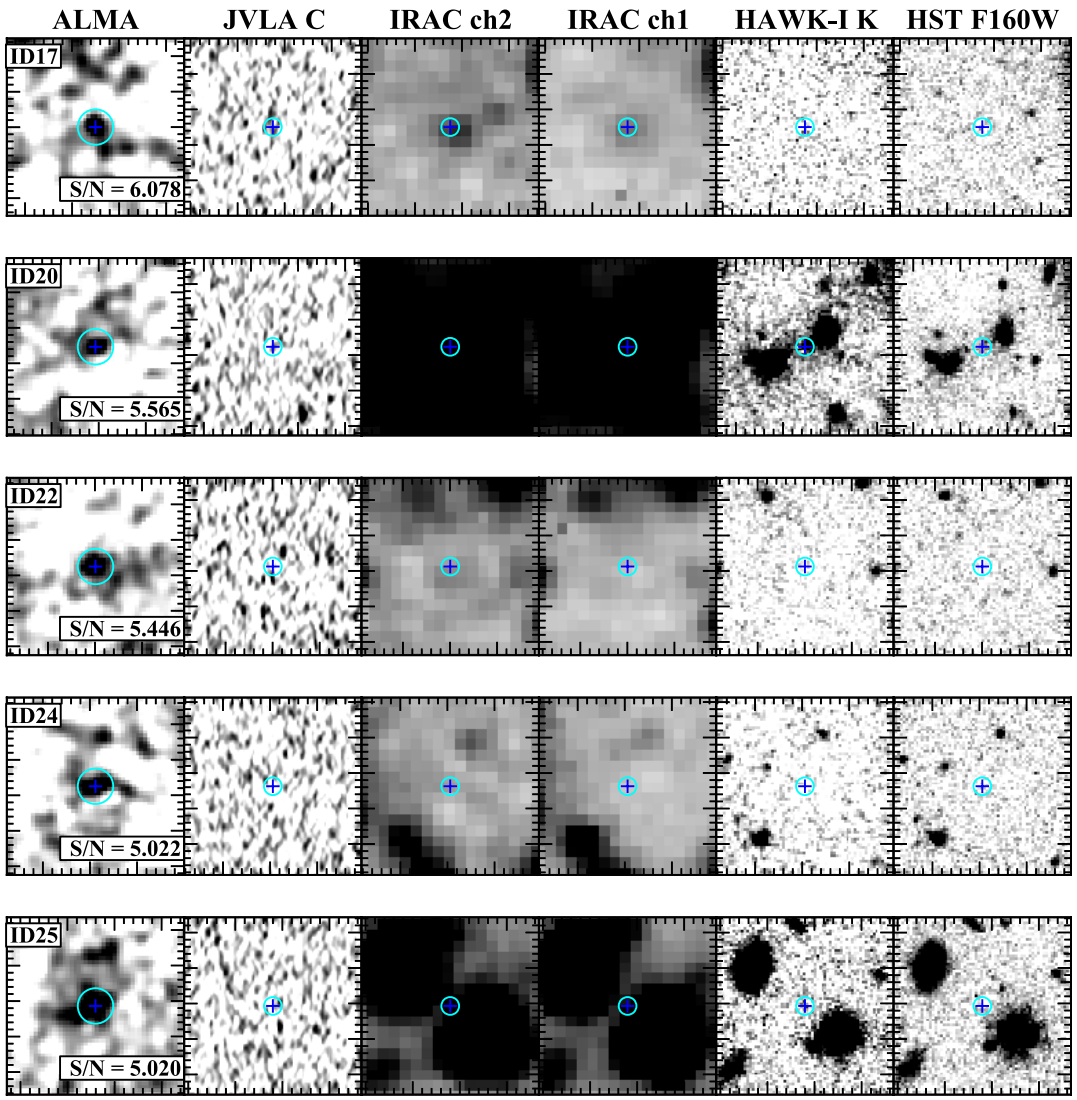
- Offset from the relation of local starburst galaxies
  - Dust compositions, size distribution, or/and spatial distribution are different (Safarzadeh+17)?
- More observation (e.g., higher resolution) is needed!

Multi-wavelength analysis "K-dropout ASAGAO sources"

- We find that 5 ASAGAO sources with S/N > 5 has no K-band counterpart

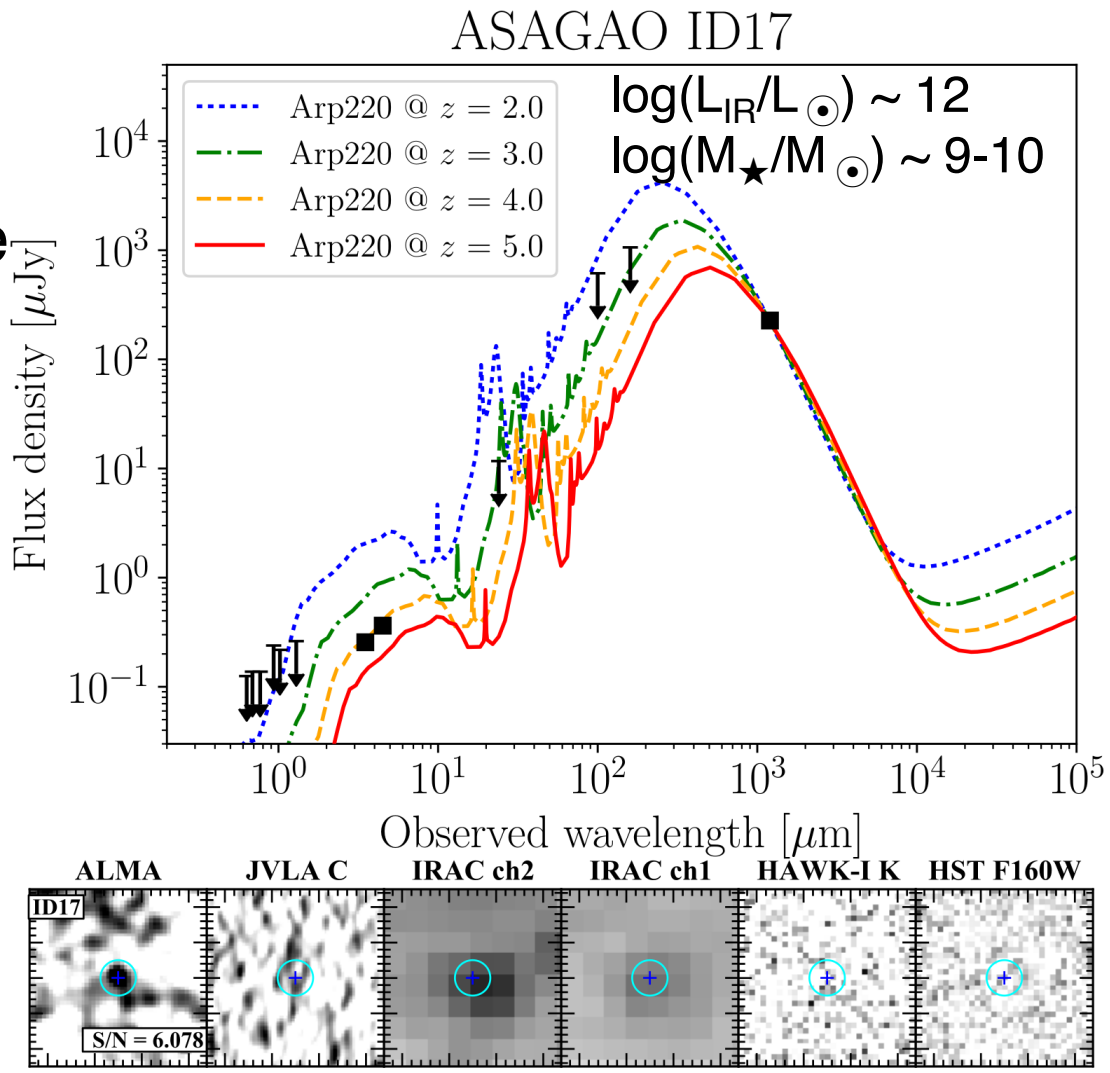


There is only one negative detection with S/N < -5.0.



Multi-wavelength analysis “K-dropout ASAGAO sources”

- High-z dust-obscured galaxies (z > 4-5) ?
  - SFR ~ 100 $M_\odot$ /yr
  - $M_\star \sim 10^{9.5\text{-}11}\ M_\odot$?
- Early phase of massive galaxy formation?
  - e.g., Wang+16
- Explored only by ALMA contiguous survey!



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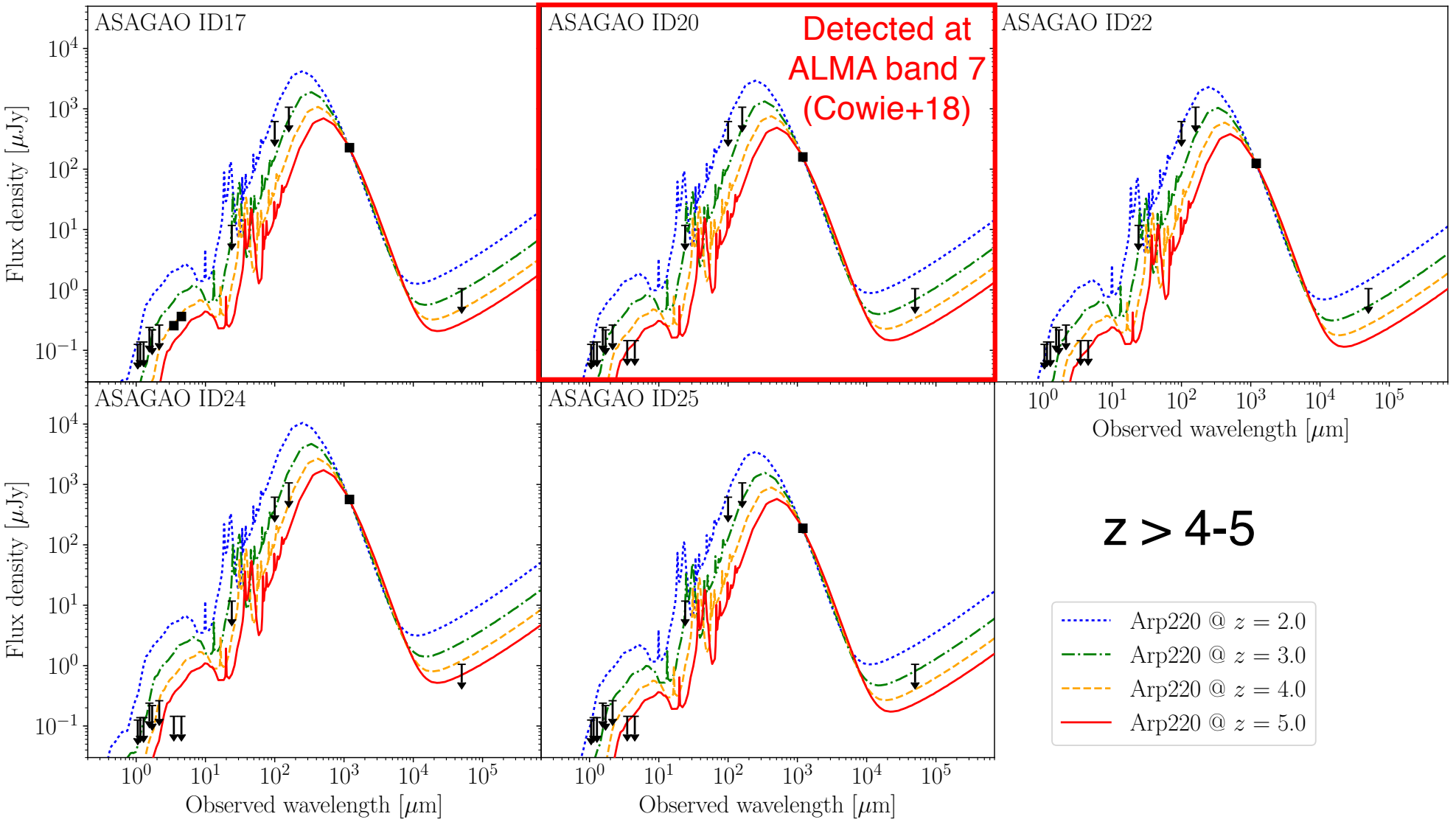

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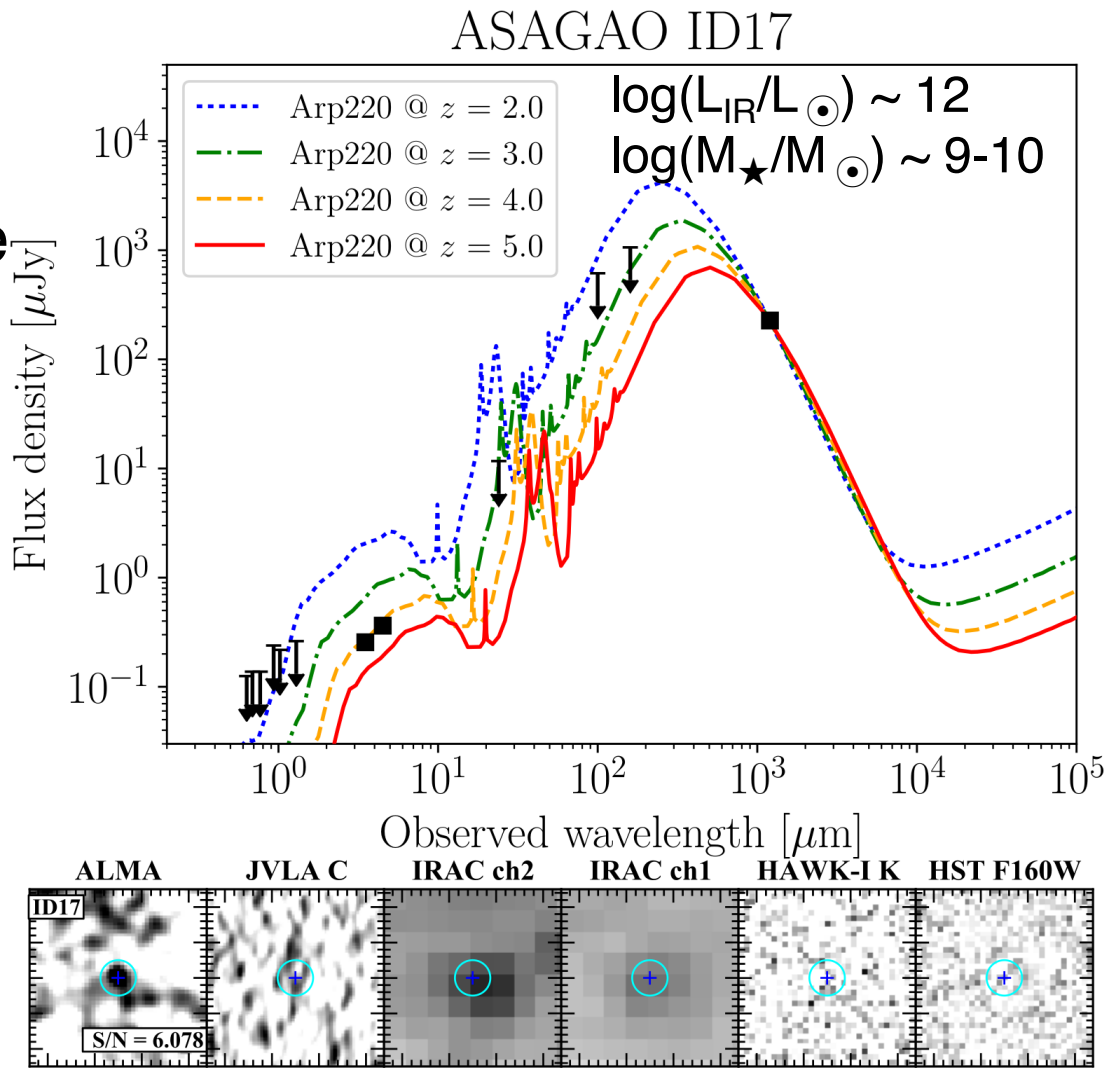
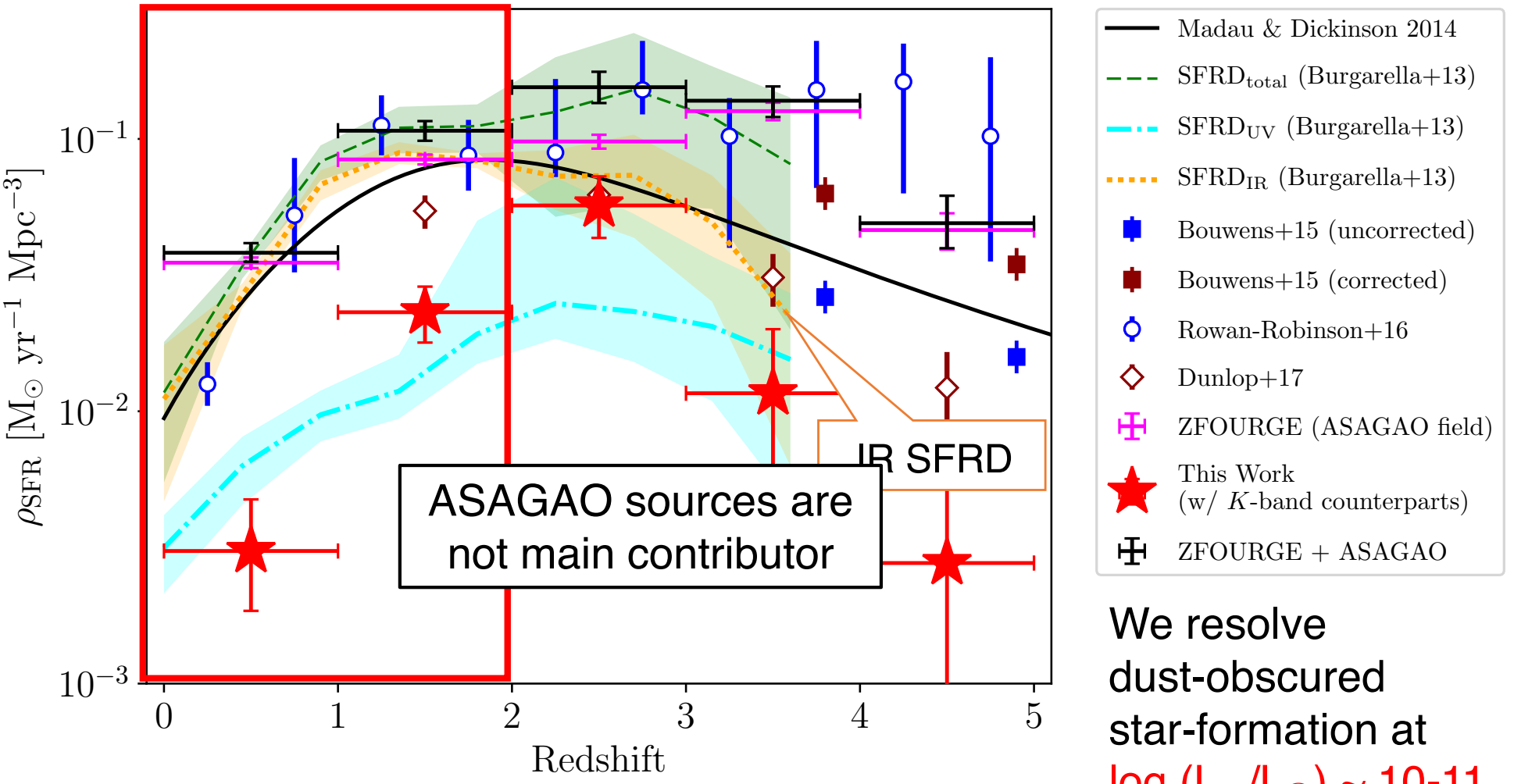


The contributions to the cosmic SFRD

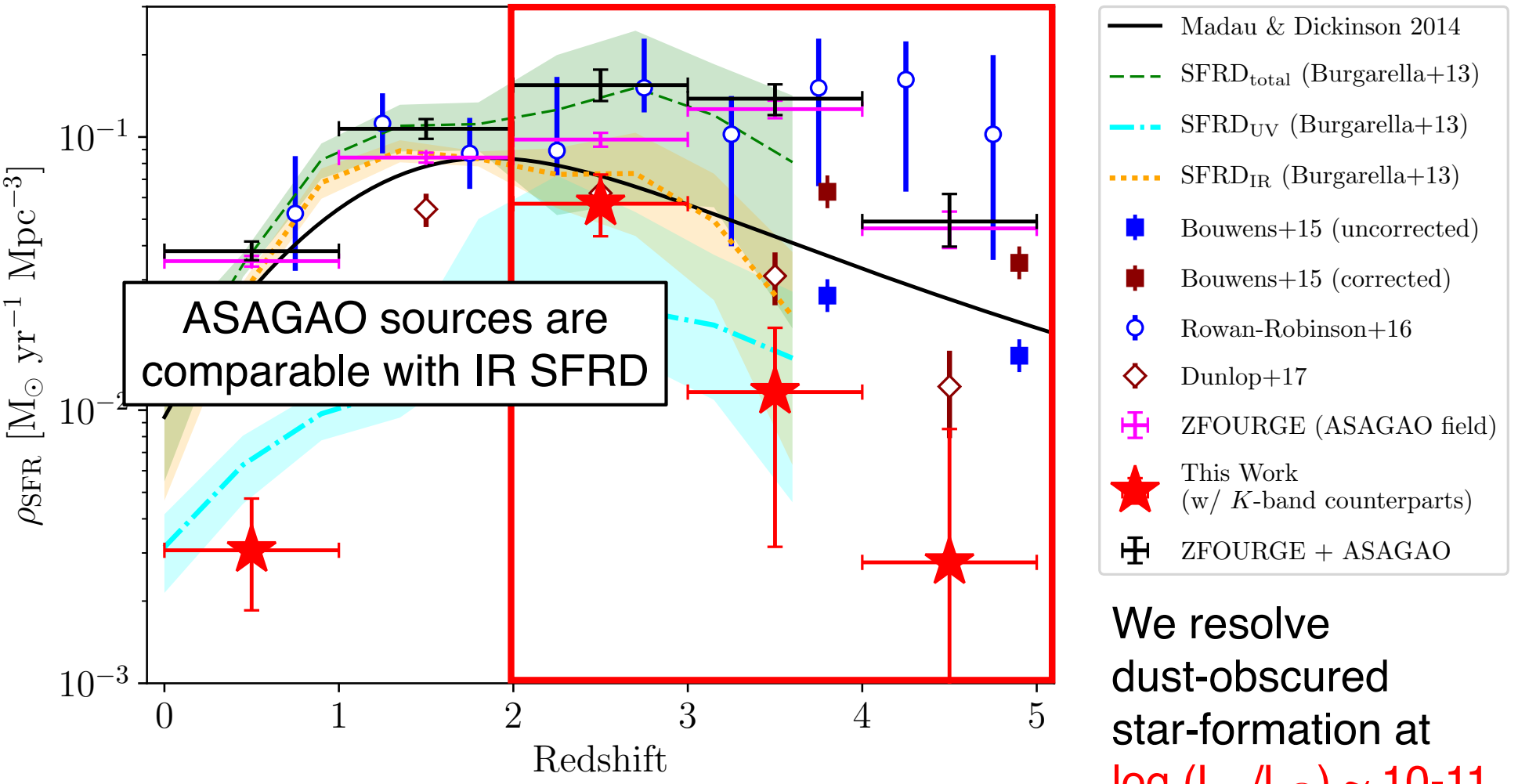
- The contribution of ASAGAO sources with K-band counterparts to the cosmic SFRD



We resolve dust-obscured star-formation at $\log (L_{IR}/L_\odot) \sim 10\text{-}11$

The contributions to the cosmic SFRD

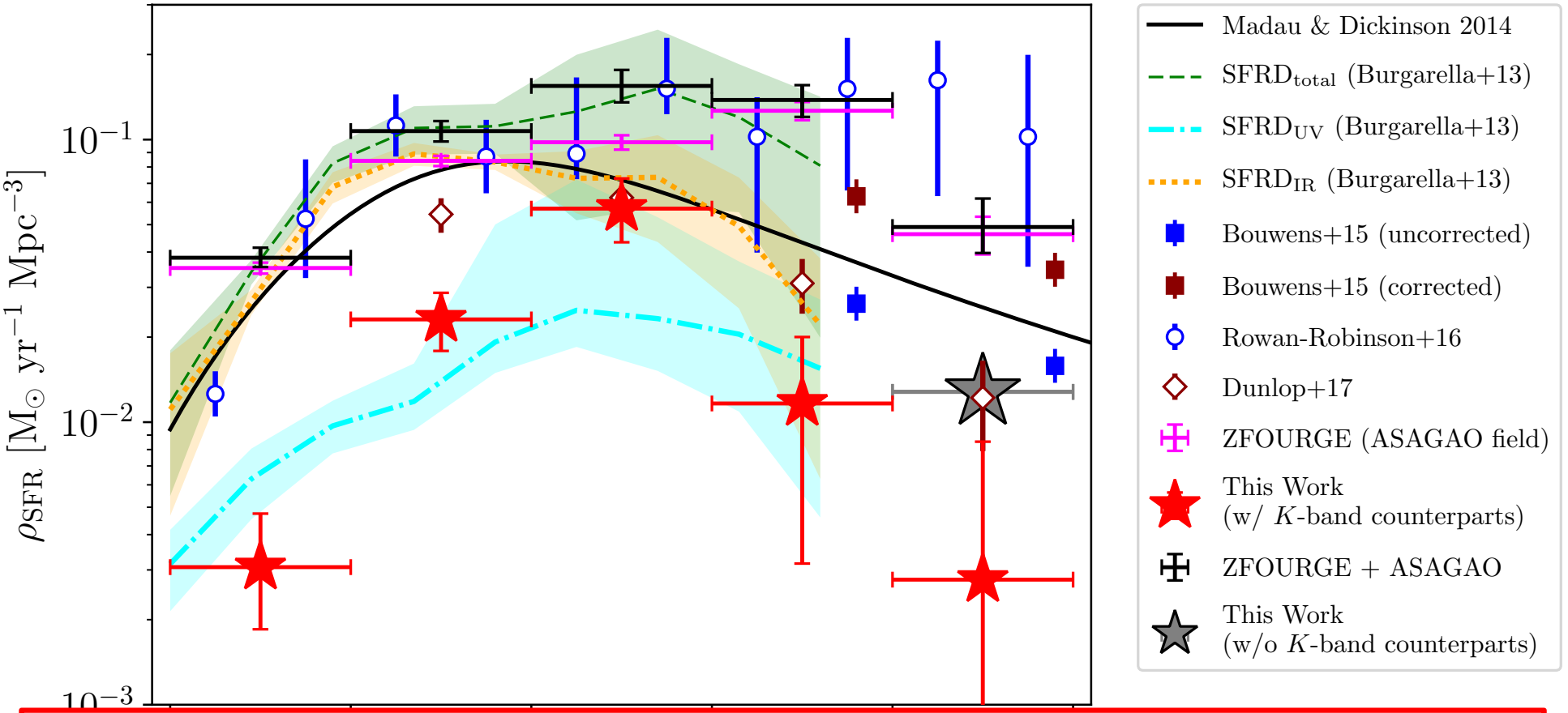
- The contribution of ASAGAO sources *with* K-band counterparts to the cosmic SFRD



We resolve dust-obscured star-formation at log ($L_{IR}/L_\odot$) ~ 10-11

The contributions to the cosmic SFRD

- The contribution of ASAGAO sources *without* K-band counterparts to the cosmic SFRD



Their contributions are consistent with UV-selected galaxies?

Multi-wavelength analysis "Summary"

- Multi-wavelength counterparts of ASAGAO sources
  - 66 sources with K-band-selected counterparts (z_{med} = 1.77)
  - Mainly high-mass end of the main sequence of star formation galaxy
  - ALMA detected sources have larger IRX than ALMA non-detected sources
    - ✓ Dust composition, size distribution or/and spatial distribution is different?
- ASAGAO sources are main contributors to the cosmic SFRD at z > 2.
- Five K-dropout ASAGAO sources (S/N > 5)
  - Important contributors to the cosmic SFRD