Color Selection of High-z ULIRGs

Haojing Yan　严皞璟

(1)CAS - South America Center for Astronomy (CASSACA) / NAOC

(2)University of Missouri-Columbia

EAO Sub-mm Future

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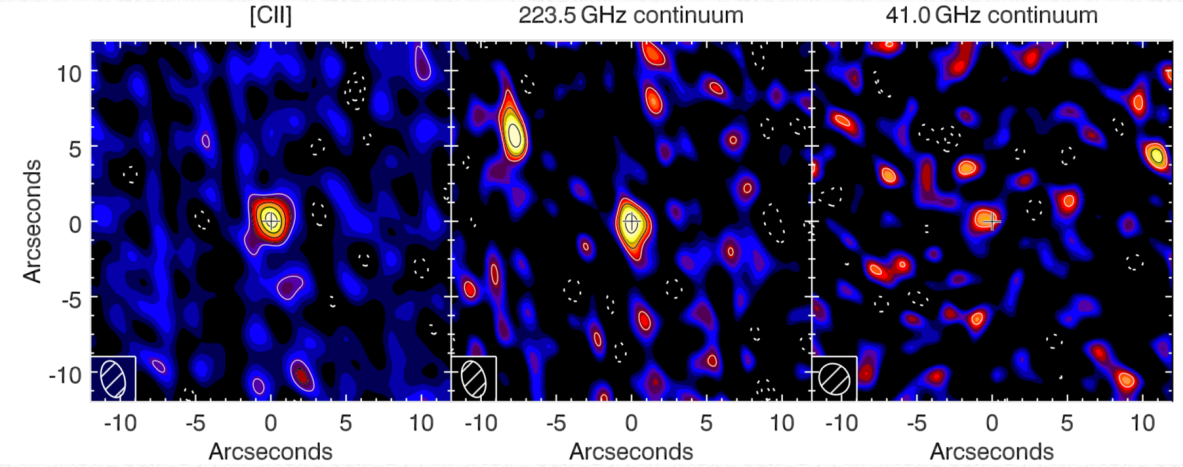
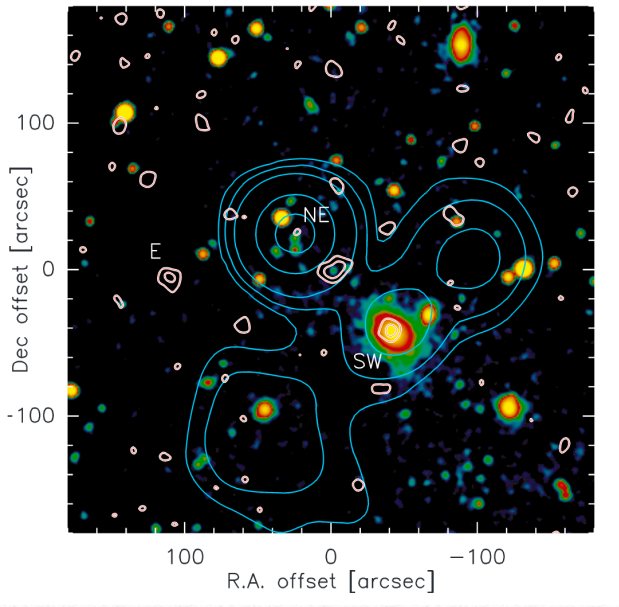
Dusty Starbursts at High Redshifts

- Dusty starbursts have been found **into the epoch of reionization** (EoR; z>6.3)
- Some are found as quasars hosts/companions (e.g., Bertoldi et al. 2003; Decarli et al. 2017)



Venemans et al. (2017)
ULAS J1320+0928; **z=7.54** (Banados et al. 2018)
[CII] detected @ NOEMA; scaling from continuum =>
$L_{IR}=1.4x10^{12}L_{sun}$

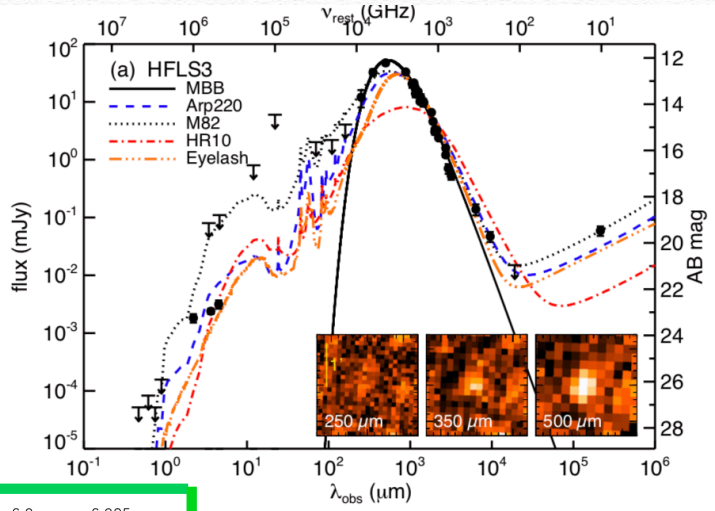


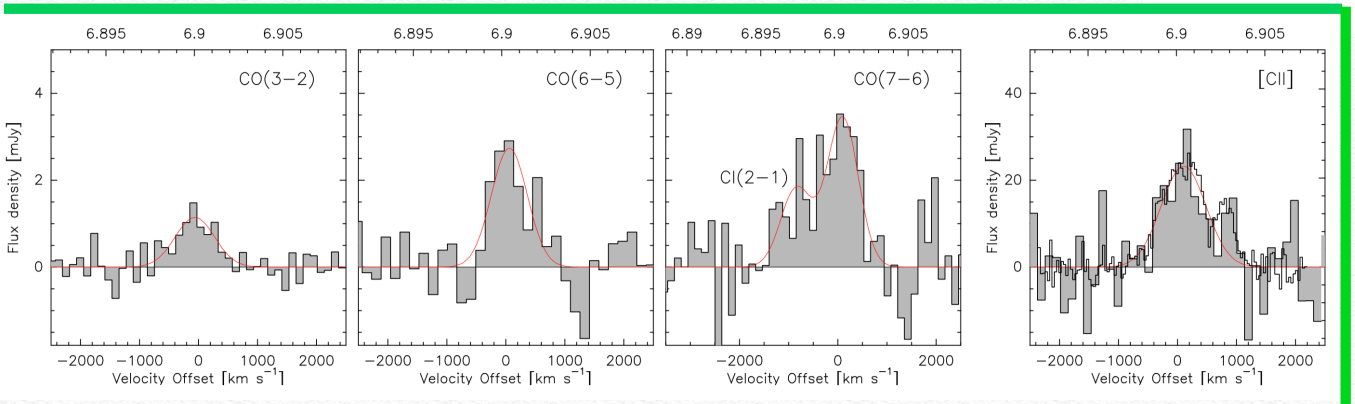
Bertoldi et al. (2003)
SDSS J1148+5251; **z=6.42**
(Fan et al. 2003)
IRAM 30m/MAMBO @ 1.2mm
=> $L_{IR}=1.2x10^{13}L_{sun}$

BK - SDSS
Blue - VLA NVSS 1.4GHz
White - 1.2mm

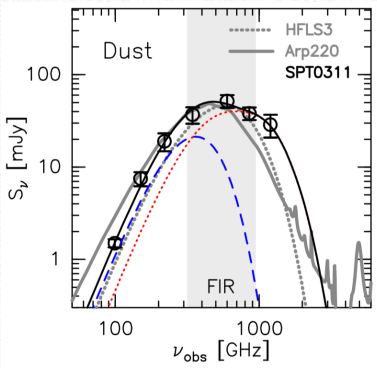
Dusty Starbursts at High Redshifts

- Others are found in blind submm/mm surveys (e.g., Riechers et al. 2013; Strandet et al. 2017)
- In terms of IR luminosities, they are all ULIRGs/HyLIRGs => SFR>100-1000 M_{sun}/yr





[Riechers et al. (2013)](#)
HFLS3
CARMA 3mm & PdBI 2mm
& JVLA 19-6mm
& CSO 1mm
=> **z=6.34**
$L_{IR}=2.86x10^{13}L_{sun}$



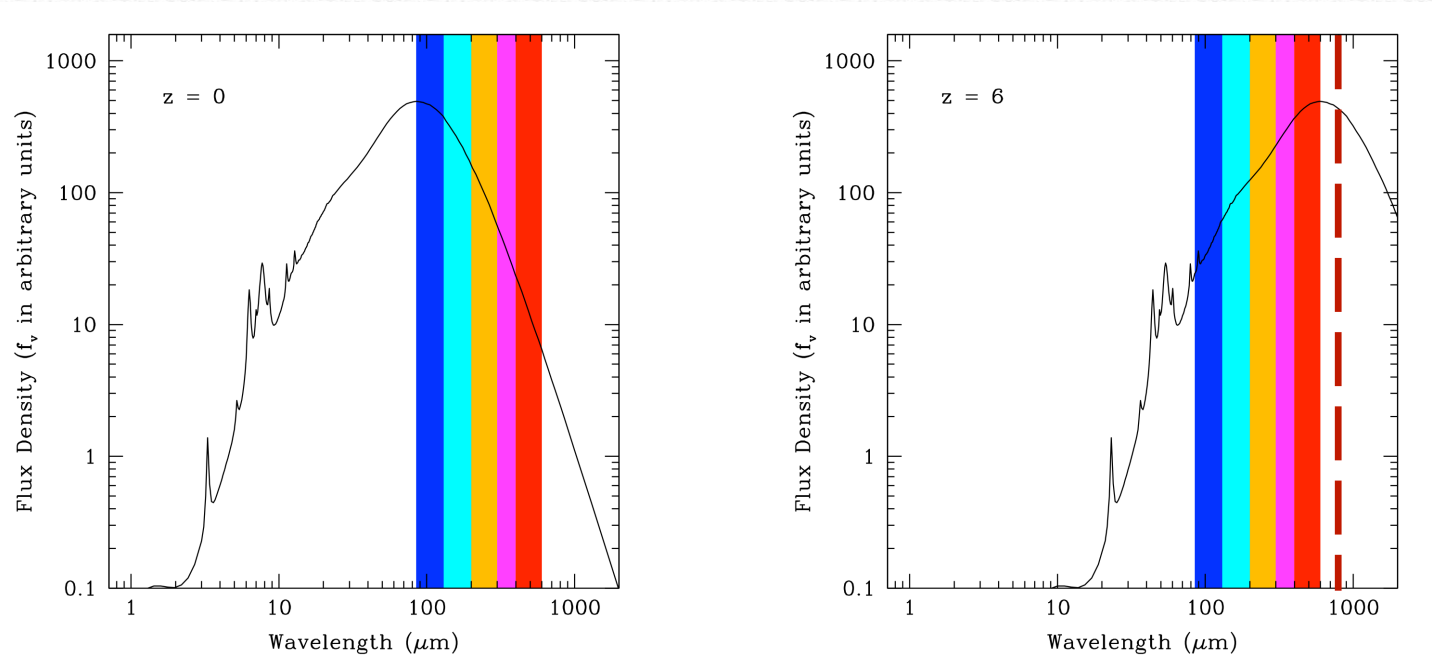
[Strandet et al. (2017)](#)
SPT 0311-58; μ=1.9
ALMA 3mm + APEX 1.2mm =>
z=6.90
$L_{FIR}=4.1x10^{13}L_{sun}$ /μ

The Big Picture

- Dust-embedded SF plays an important role at z ~ 6-7; extinction-corrected GSFRD based on LBGs might be severely underestimated
- Dust already prevails at z ~ 6-7 => there must be very active SF at even earlier epochs - but this seems to contradict the paucity of LBGs found at z > 7
- Large samples of high-z ULIRGs selected in a systematic manner are needed
- The most promising method to systematically select high-z ULIRGs is through the use of FIR/submm colors

FIR/submm Color Selection

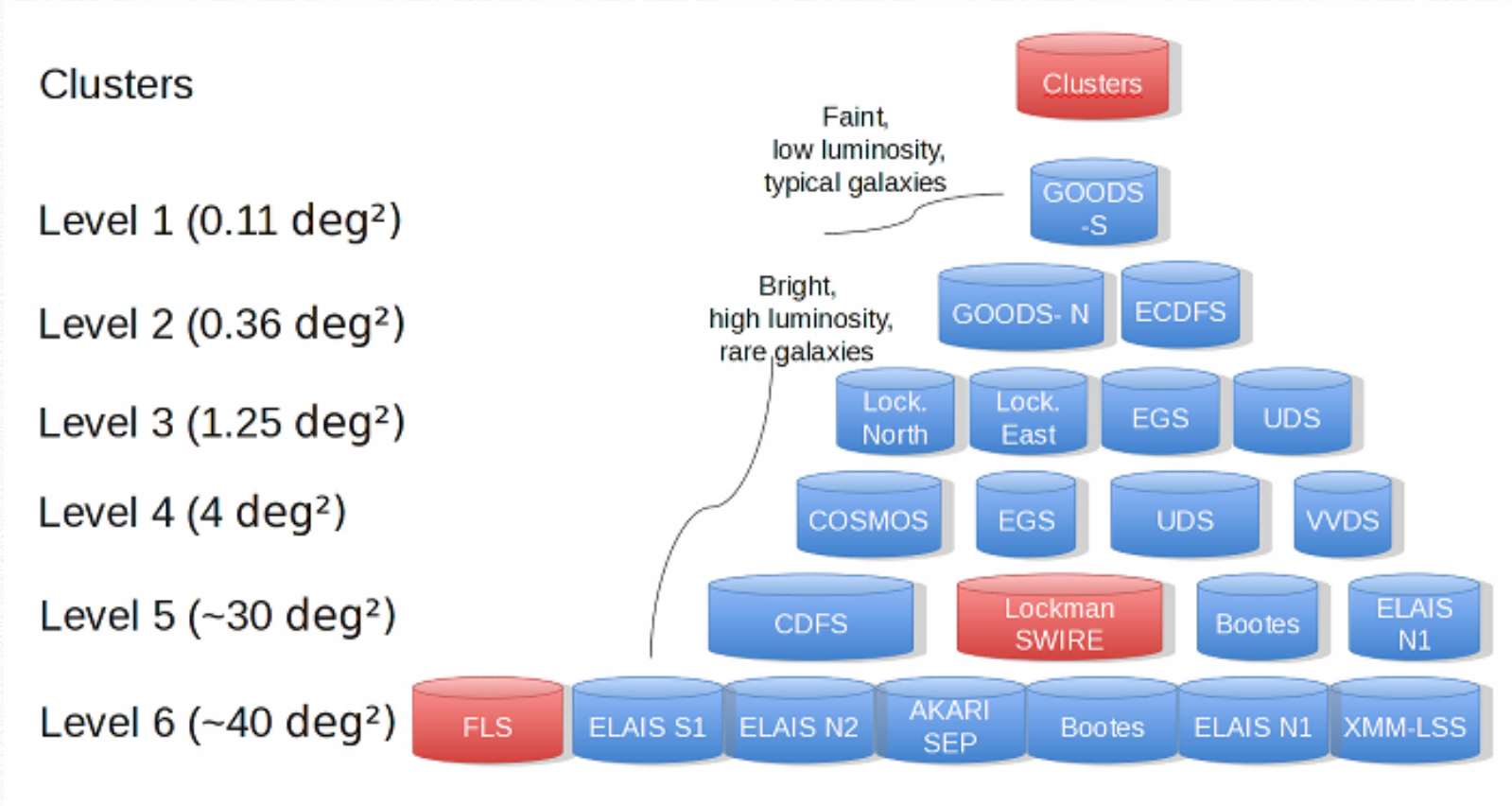
- "500μm peaker" or "500μm riser" technique, tailored for the BLAST and the Herschel/SPIRE bands (Pope & Chary 2010; Roseboom et al. 2012) - suitable up to z~6
- With a passband redder than the SPIRE 500μm, e.g., 850μm/870μm, one can select objects at higher redshifts: "850μm/870μm riser"
- Catch: the T_d - z degeneracy



Our search of high-z ULIRGs

- A paper soon to be finished (Haojing Yan, Zhiyuan Ma, Jiasheng Huang, & Lulu Fan 2019)
- A systematic search of 500μm risers and 850μm risers in the HerMES fields, using the DR4 data
- 500μm risers: 12 HerMES fields (including embedded fields), totaling ~110 deg^2 (all significantly deeper than the HeLMS field used by Asboth et al. (2016))
- 850μm risers: within the overlapping regions of the SCUBA2 Cosmological Legacy Survey (S2CLS), about 3.85 deg^2 - these are currently the only fields where a systematic search can be carried out

500μm Risers in the HerMES fields

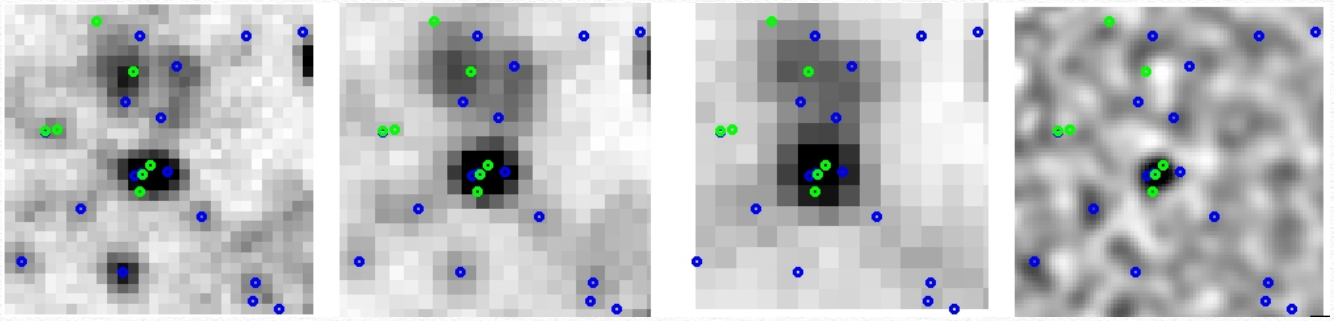


- Criteria: $SNR_{500\mu m} >= 5$ && $S_{500\mu m} > S_{350\mu m}$ && $S_{350\mu m} > S_{250\mu m}$
- About 900 highly-secure 500μm risers selected

Example: 500μm-risers

- The sample is soon to be finalized; a small fraction of the objects have accurate positions from the existing interferometry data, and their optical/NIR counterparts are identified

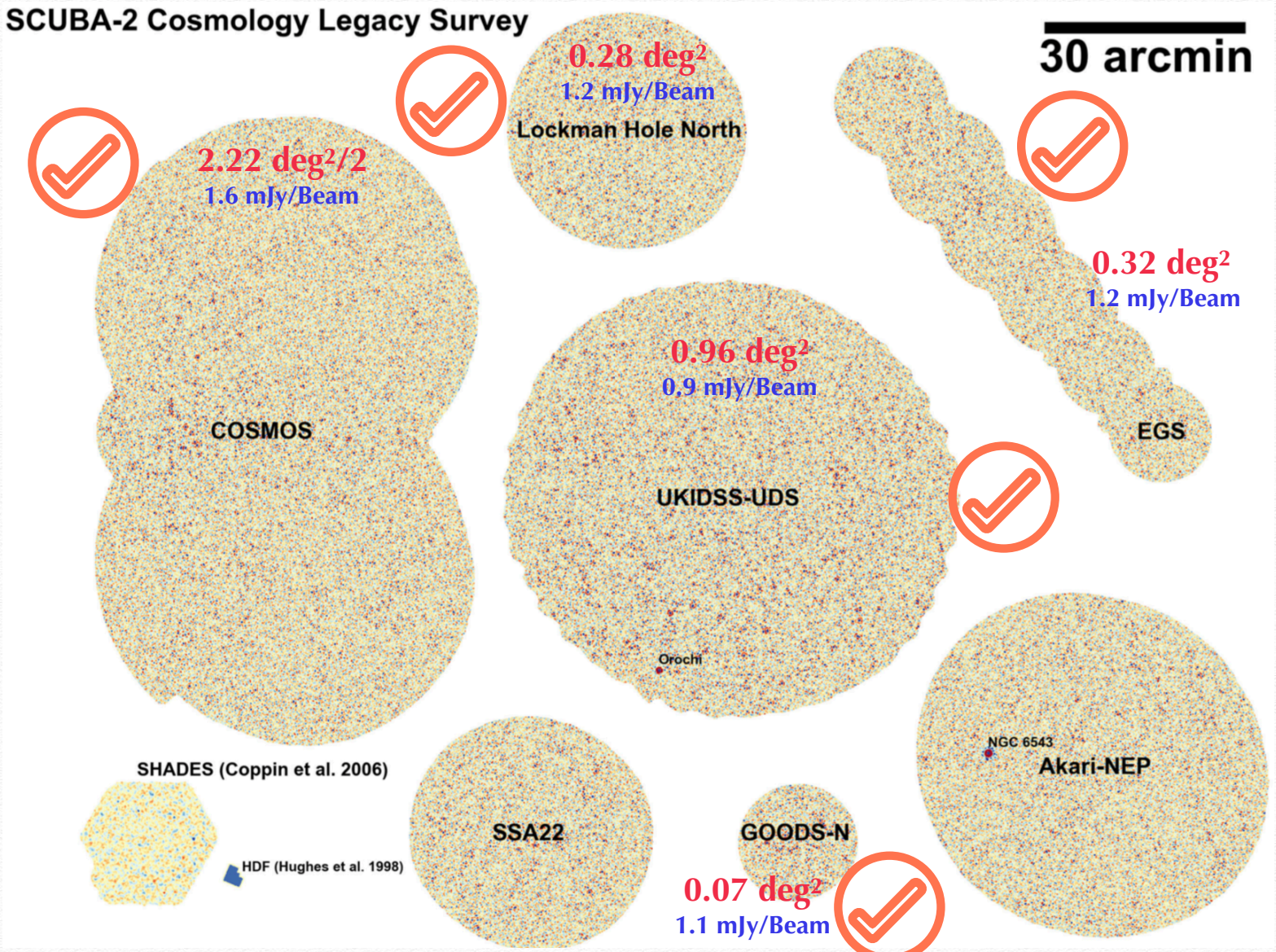
Example: a peculiar source in COSMOS



250μm 350μm 500μm **850μm**

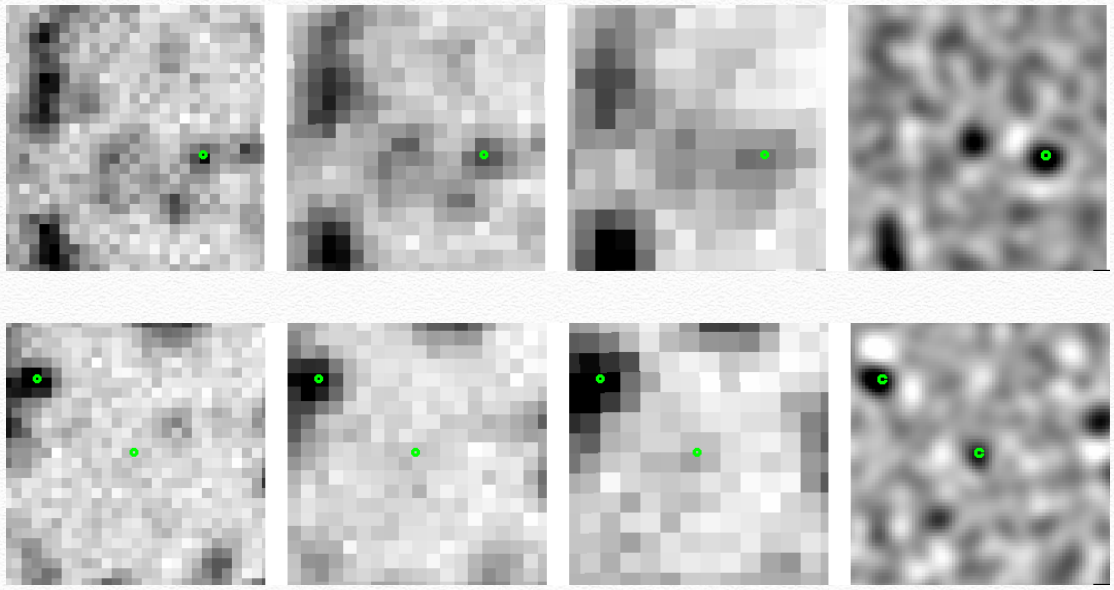
Blue: 3.0GHz (Smolcic et al.)
Green: 1.4GHz (Schinnerer et al.)

Selection of 850μm-risers in the S2CLS Fields



Geach et al. (2017)

Examples of SPIRE-dropouts



(In UDS - Reported non-detection in HerMES; w/ and w/o radio position)

- Interestingly, none of the 500μm risers within the 3.85 deg^2 S2CLS footprints (about 30 of them) qualify as 850μm risers
- About 170 "SPIRE-dropouts" (S/N>5 in S2CLS but S/N<2 in HerMES 250μm) found; however we cannot decide if they are 850μm risers due to the bright limit of HerMES (2σ limit ~ 10-12 mJy in 500μm)
- 850μm risers, if they exist in the S2CLS fields, must be among these SPIRE dropouts

Relate to the EAO Sub-mm Future

- In the new decade, very-wide-field (over a few x 100 deg^2) 850μm continuum survey(s) at JCMT will be a unique contribution to the FIR/submm/mm study of galaxy formation & evolution

- These should be done in the *Herschel* wide-field survey regions - **HerMES** (including HeLMS + HerS) and **H-ATLAS** - to take advantage of the existing 250-500μm coverage (cannot be reproduced at such depths anywhere else any time soon)

- JCMT 15m (North) vs. CCAT-prime (South) - 6m; CSO (moving to Chile; South) - 10.4m; APEX (South) - 12m

FIR vs. Submm

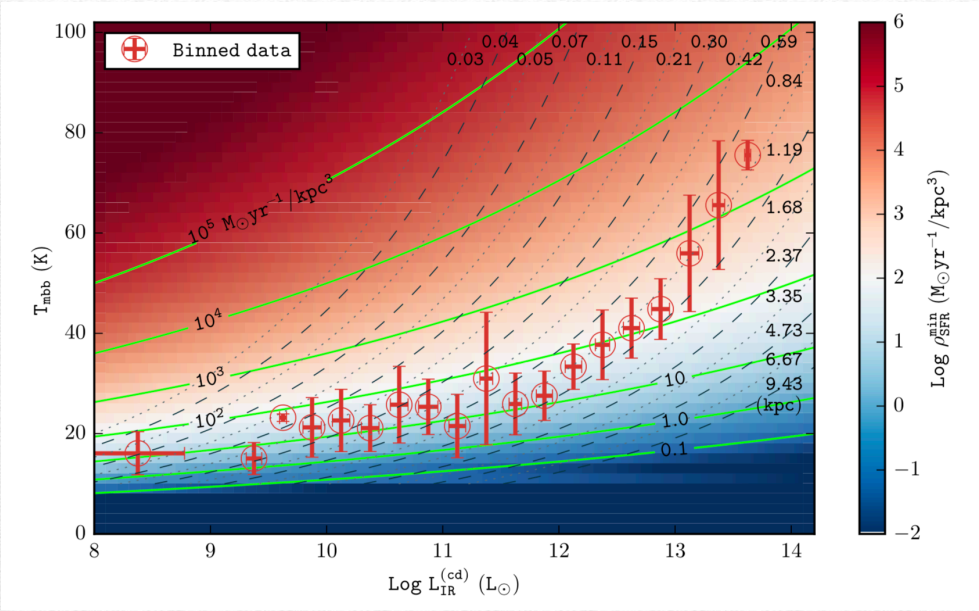
- The vast majority of *Herschel* sources do not have 850μm counterparts (e.g., only ~14% of the S/N>5 HerMES 250μm sources in the S2CLS COSMOS field are detected in 850μm)
- Presumably this is due to the fact that FIR and sub-mm are sampling ULIRGs at different redshift ranges (mostly z<2 for *Herschel* SPIRE bands and mostly z~ 2-3 for S2CLS)
- A small fraction of the S2CLS 850μm sources (4-12%) are NOT detected in HerMES (S/N<2) - these are among the most interesting objects awaiting further study, some of which could be at z~6 and beyond
- 850μm survey will complement the Herschel surveys very well

Survey Depth

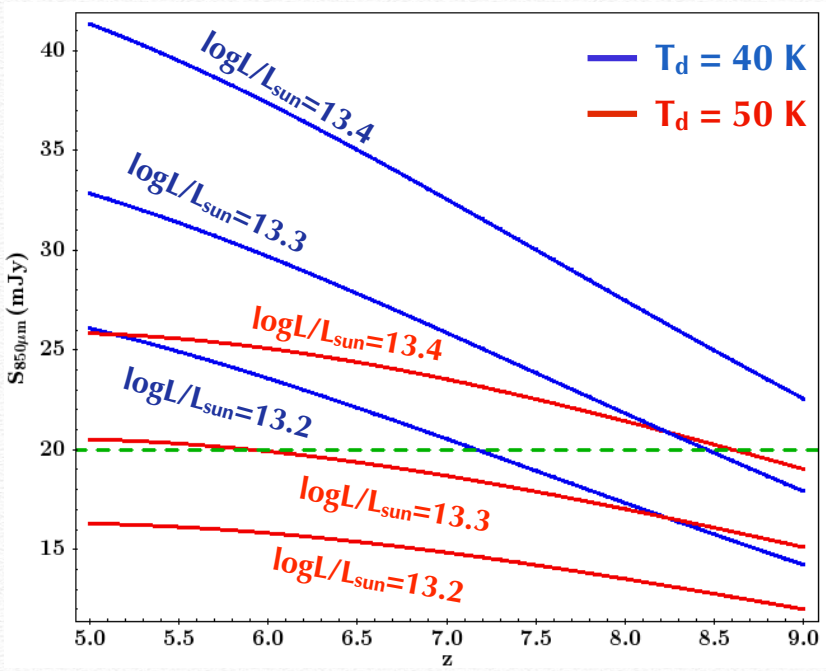
- Searching for "850μm risers" should be one of the key goals of such very-wide-field 850μm surveys
- Lesson learned from the S2CLS data within the HerMES fields:
  - Some of the "SPIRE dropouts" could be 850μm risers (i.e., z>6 candidates), but we do not know which ones are (due to the lack of SPIRE photometry)
  - The most obvious targets should be those known 500μm risers because, by definition, 850μm risers should be 500μm risers
  - As the minimum, the depth of very-wide-field 850μm surveys should be sufficient to select 850μm risers among the known 500μm risers
- $S_{500\mu m}$ ~ 20 mJy for the known 500μm risers at the faint-end => requires $S_{850\mu m}$ ~ 20 mJy at S/N~5 => rms of 4 mJy/beam (would need ~ 100 hrs of SCUBA2 time to cover 2 deg^2)

What to expect

T_d - L_{IR} relation



(Yan & Ma 2016)



- Such surveys will be selecting high-z HyLIRGs of T_d ~ 40-50 K, L_{IR} > $10^{13.2\text{-}13.3}$ L_{sun}