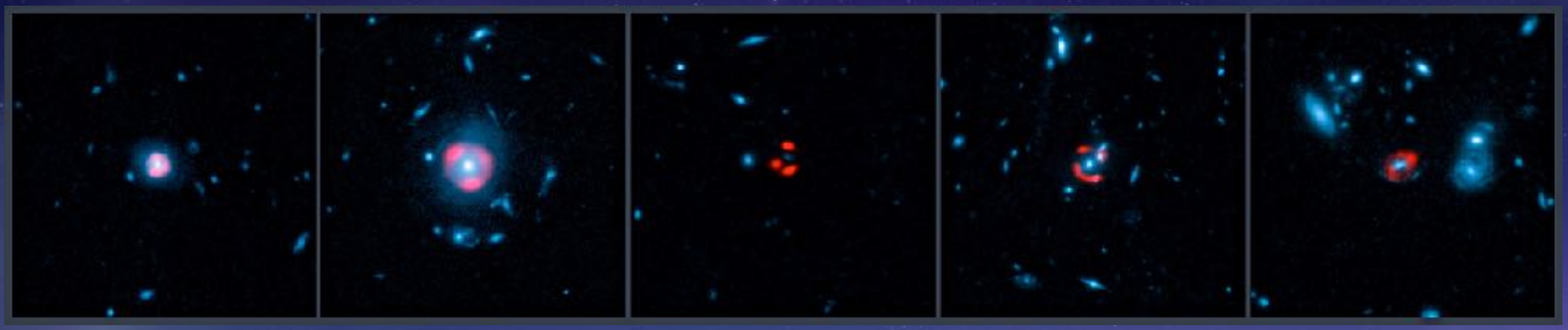
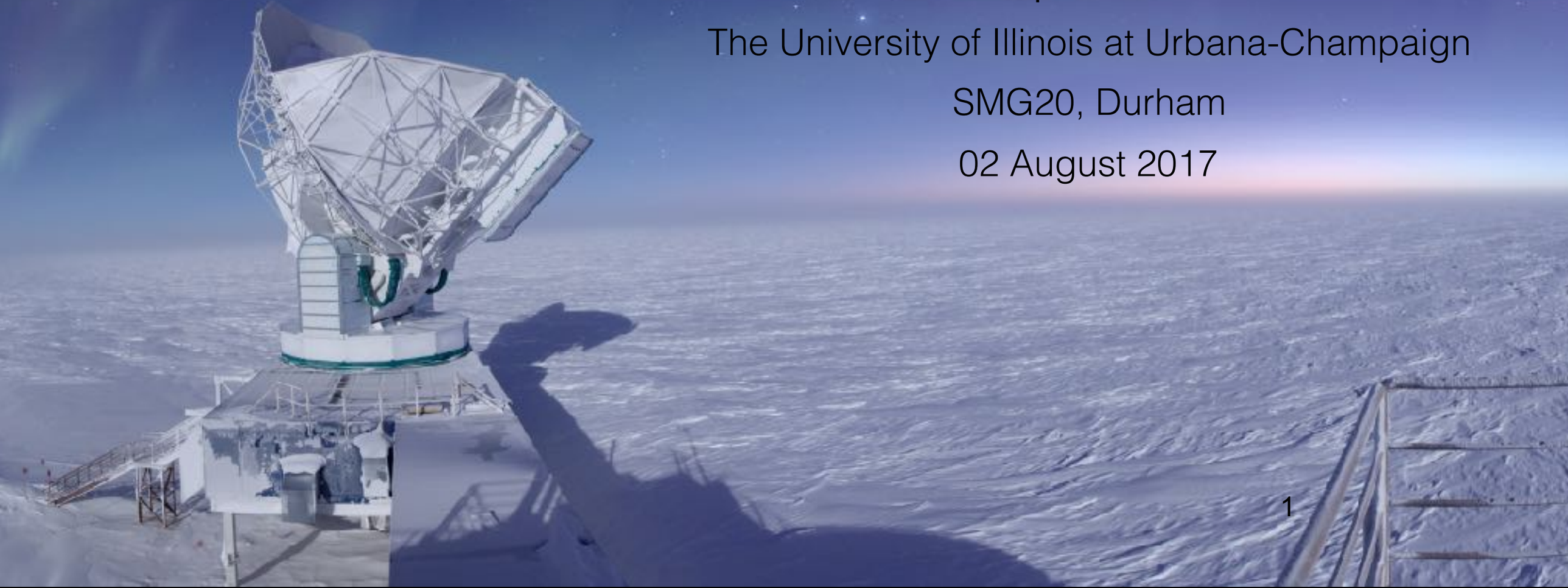
SPT SMGs: High-redshift star formation under the cosmic microscope

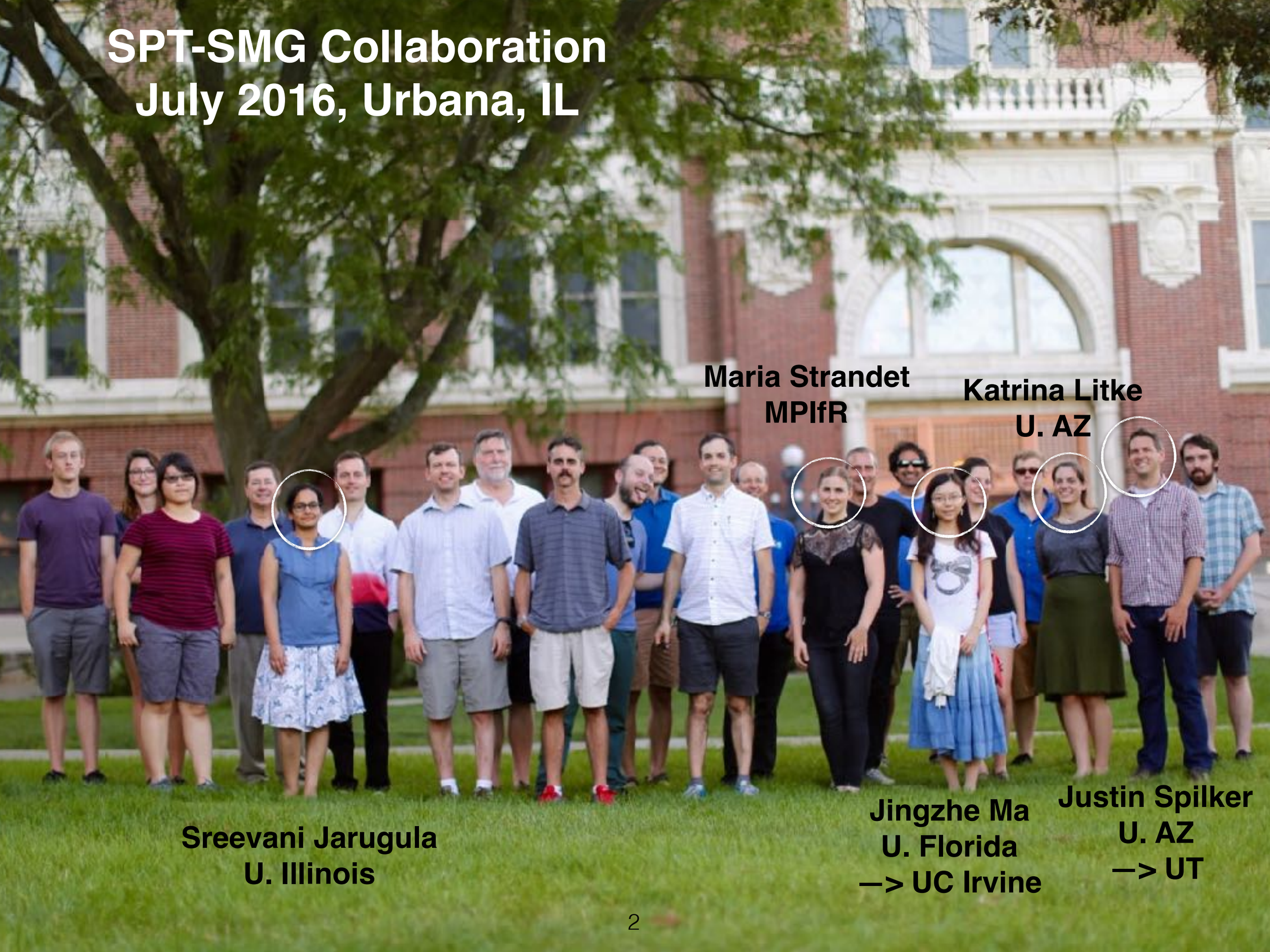


Joaquin Vieira
The University of Illinois at Urbana-Champaign

SMG20, Durham

02 August 2017




SPT-SMG Collaboration
July 2016, Urbana, IL
Maria Strandet
MPIfR
Katrina Litke
U. AZ
Sreevani Jarugula
U. Illinois
Jingzhe Ma
U. Florida
—> UC Irvine
Justin Spilker
U. AZ
—> UT


SPT-SMG Collaboration
July 2016, Urbana, IL
Axel
Desika
Chris
+ Matt Bothwell
+ Bitten Gullberg

SPT

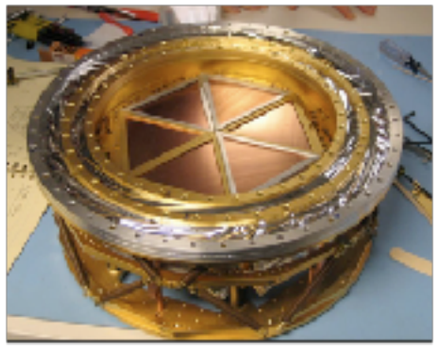
The South Pole Telescope

Telescope

- 10 meter off-axis sub/mm telescope
- located at the geographic south pole
- 1 deg^2 field of view
- ~1' beams
- optimized for fine scale anisotropy measurements

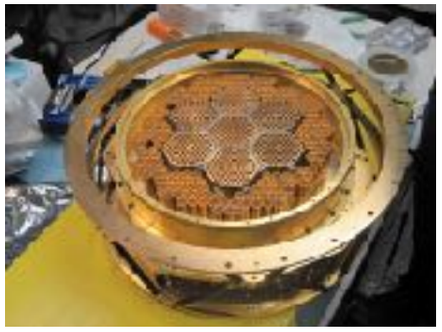
SPT-SZ Camera (1st Generation):

- 2007 – 2011
- 960 pixel mm camera, 1 deg^2 FOV
- 1.4, 2.0, and 3.0 mm
- completed 2500 deg^2
- 18 μK-arcmin depth, ~1 mJy



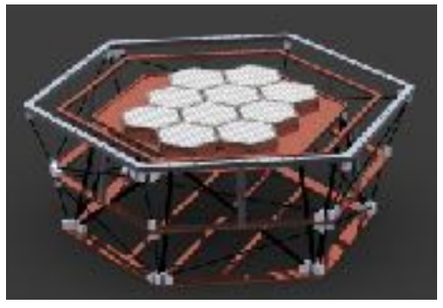
SPT-pol Camera (2nd Generation):

- 2012 – 2016
- 1600 detector mm camera, 1 deg^2 FOV
- 2 and 3 mm + polarization
- currently surveying 500 deg^2
- 4.5 μK-arcmin depth

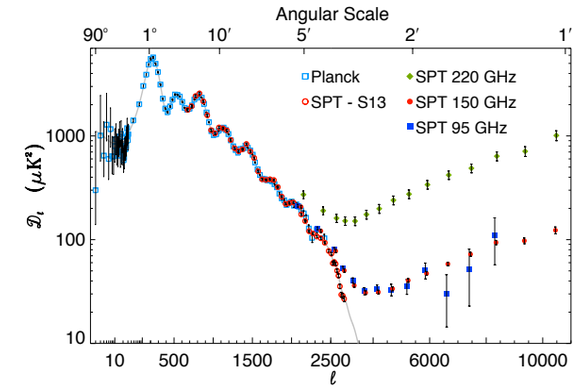


SPT-3G Camera (3rd Generation):

- 2017 – 2020
- 15k detector mm camera, 2.4 deg^2 FOV
- 1.4, 2, 3 mm + polarization
- planned 2500 deg^2 x5 deeper
- 2.5 μK-arcmin depth

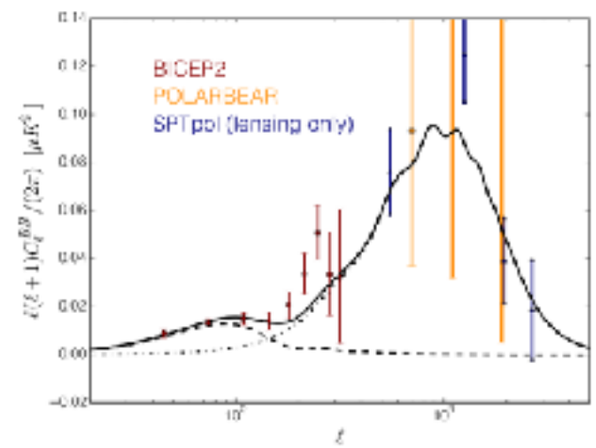


SPT Science



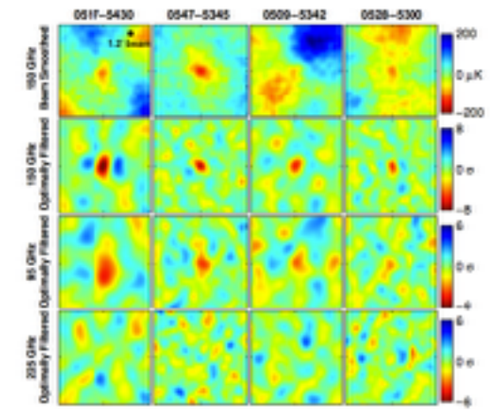
Cosmic Microwave Background:

- CMB power spectrum: Story *et al.* 2013 ApJ, George *et al.* 2014
- CMB Lensing: van Engelen *et al.* 2012 ApJ; Holder *et al.* 2013 ApJ
- Epoch of Reionization: Zahn *et al.* 2012 ApJ
- CMB Polarization: Hanson *et al.* 2013 PRL



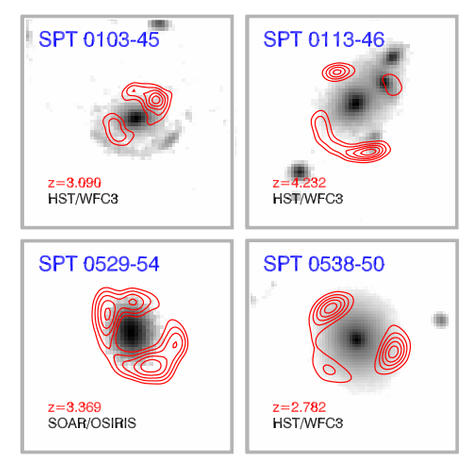
Galaxy Clusters:

- SZ cluster catalog: Reichardt *et al.* 2013 ApJ
- Cluster Cosmology: Benson *et al.* 2013 ApJ
- Cluster Astrophysics: McDonald *et al.* 2013 ApJ



Galaxy Evolution:

- Catalog of mm sources: Mocanu *et al.* 2013 ApJ
- High-z strongly-lensed starforming galaxies: Vieira *et al.* 2013 Nature



South Pole Telescope
2 mm data

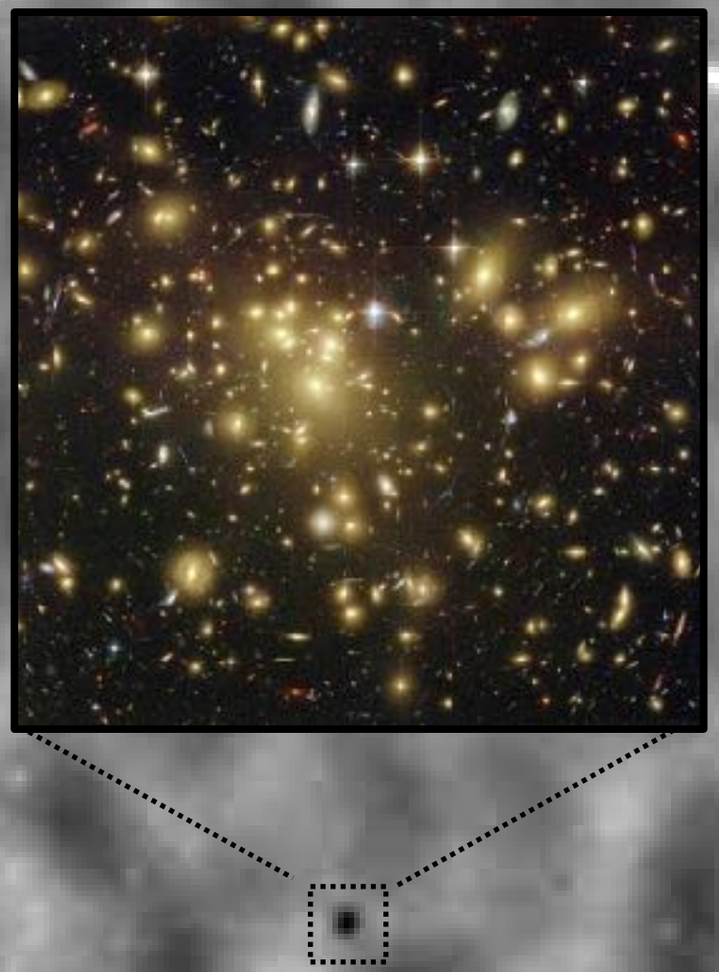
South Pole Telescope
2 mm data

Galaxy Clusters detected with the Sunyaev-Zeldovich effect

“Shadows” in the cosmic microwave background from inverse compton scattering

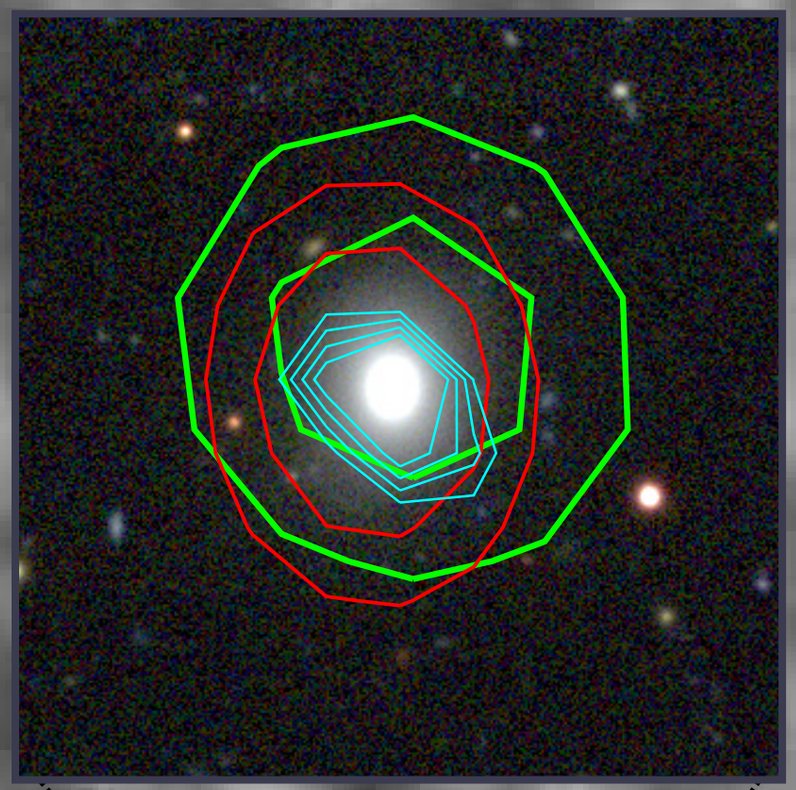
Use ‘em to measure Dark Energy

Probes the 2nd half of the history of the universe



South Pole Telescope
2 mm data

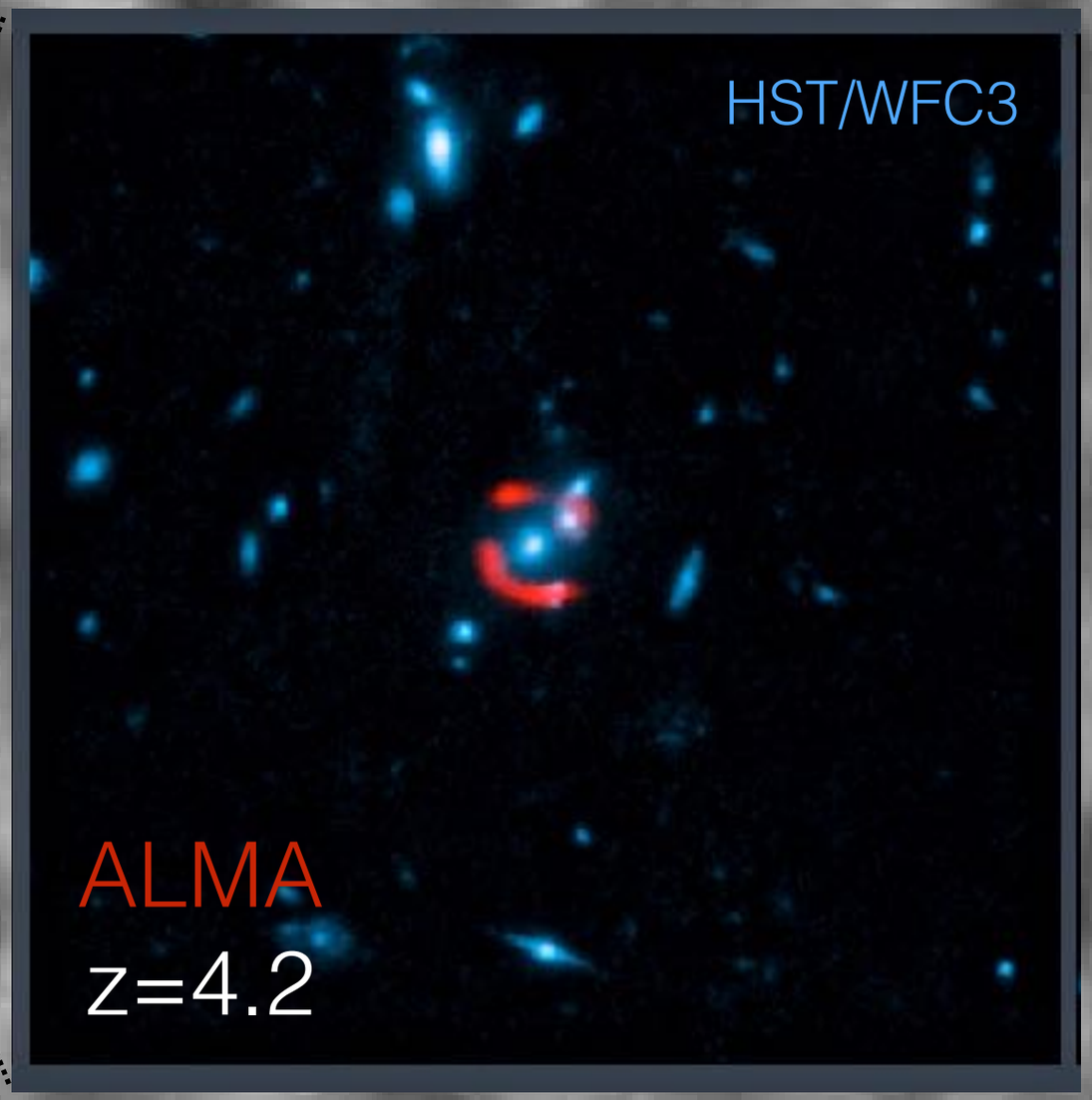
Majority of the SPT sources are high redshift AGN with the jets pointed at us. They have radio, x-ray, and sometimes gamma-ray counterparts.



South Pole Telescope
2 mm data

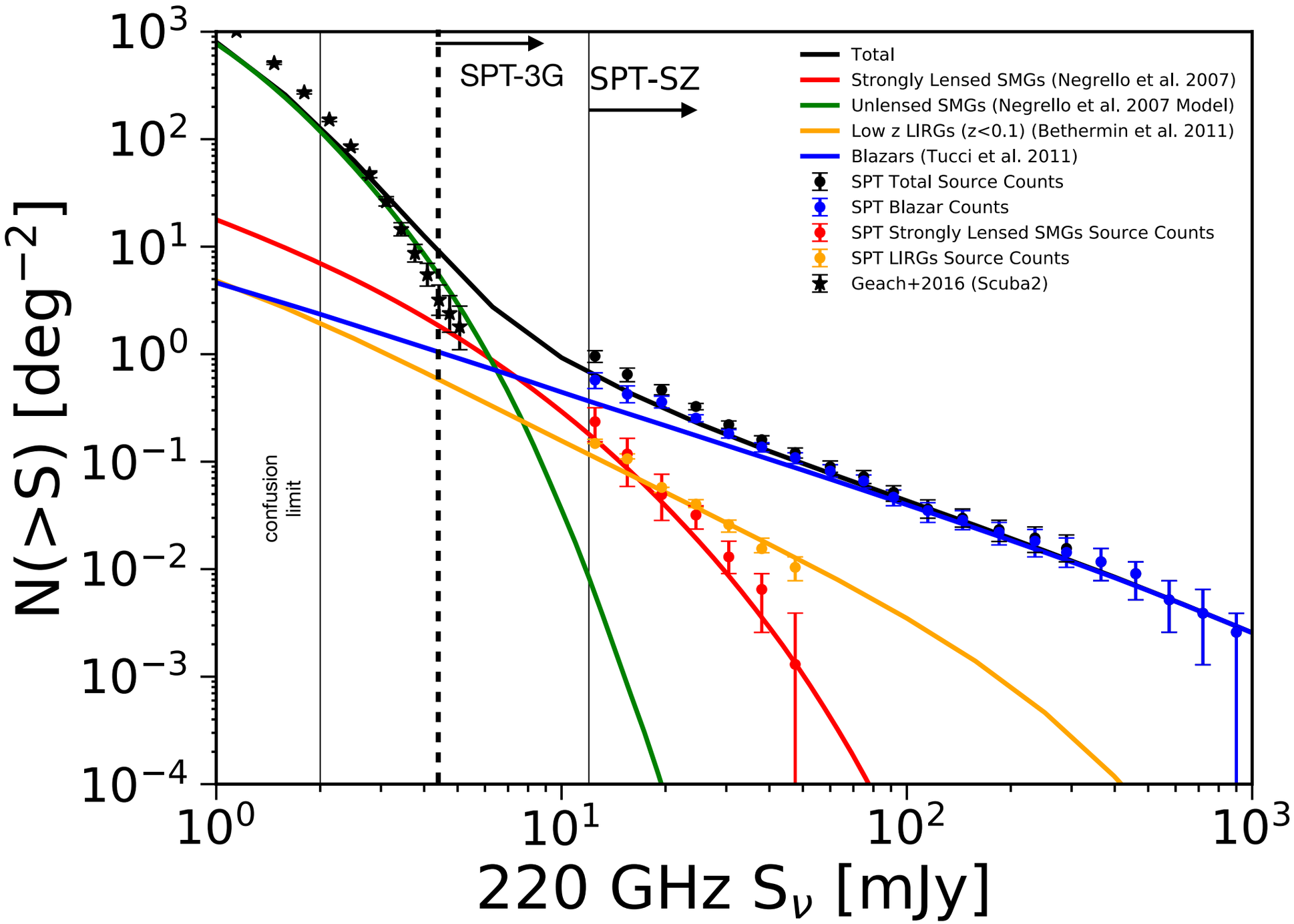
high redshift
strongly lensed
dusty starforming
galaxies

Use gravitational lensing as a cosmic telescope to study the first galaxies and directly image dark matter



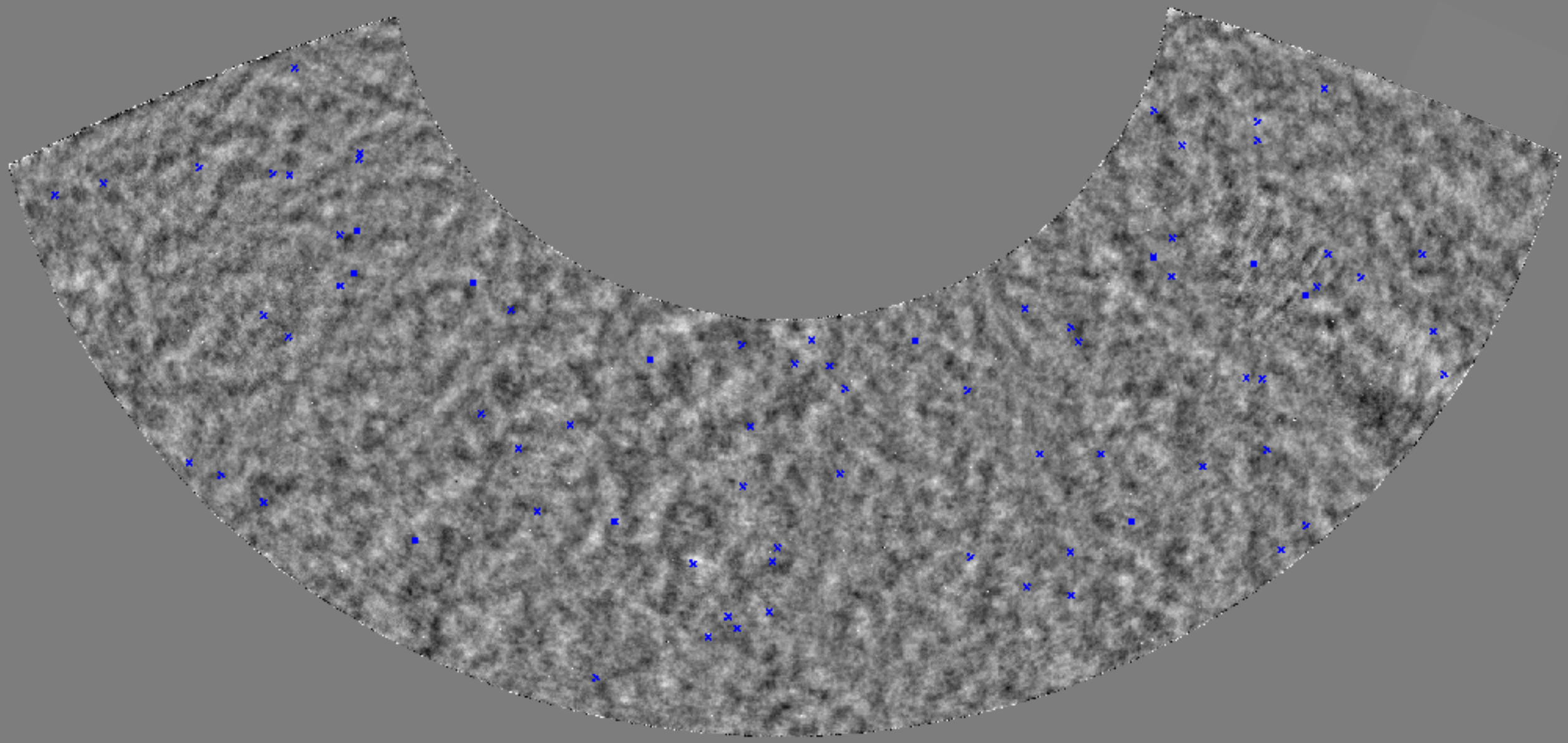
mm-wave source counts

Vieira et al 2010
Mocanu et al 2013
Everett et al in prep

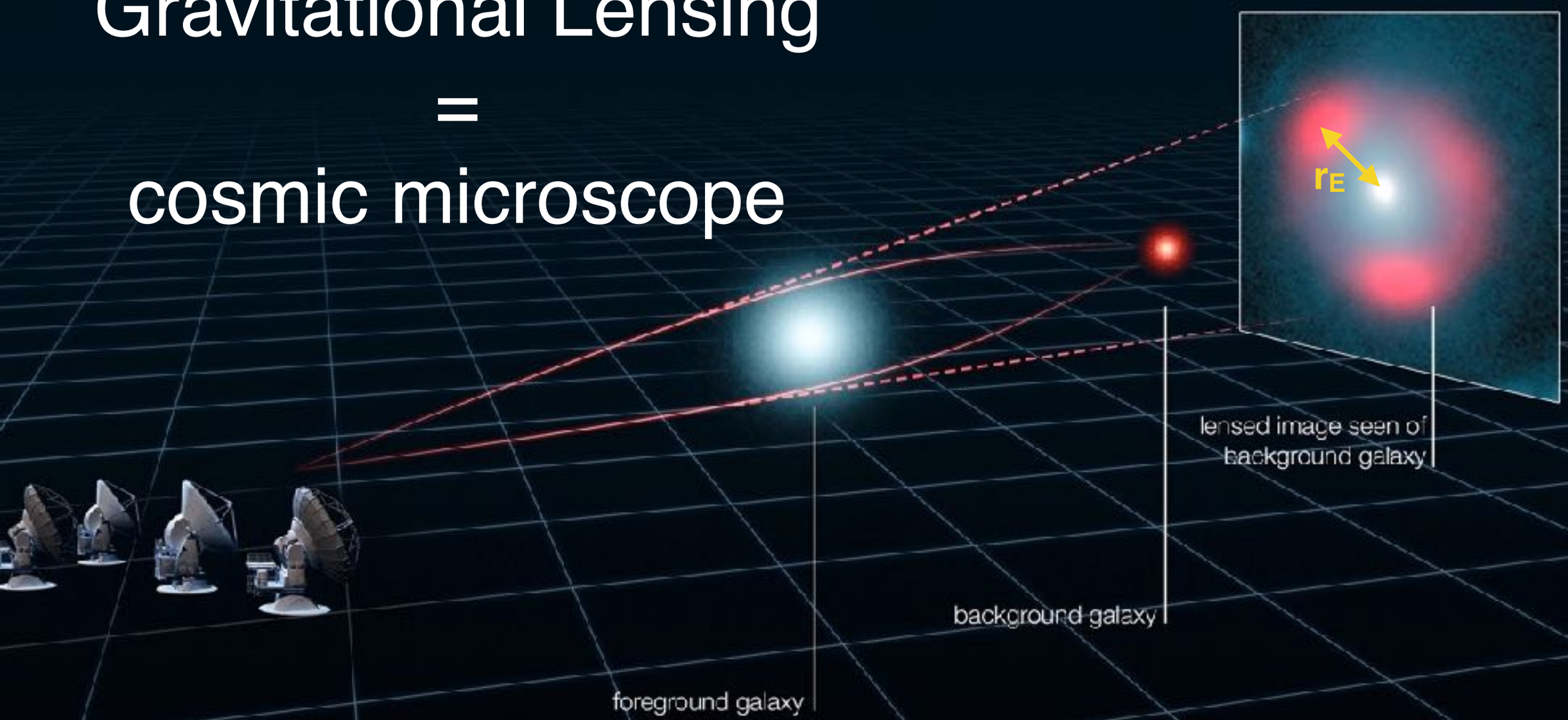


2500 deg² SPT survey

81 strongly lensed SMGs at S_{870um} > 25 mJy



Gravitational Lensing
=
cosmic microscope

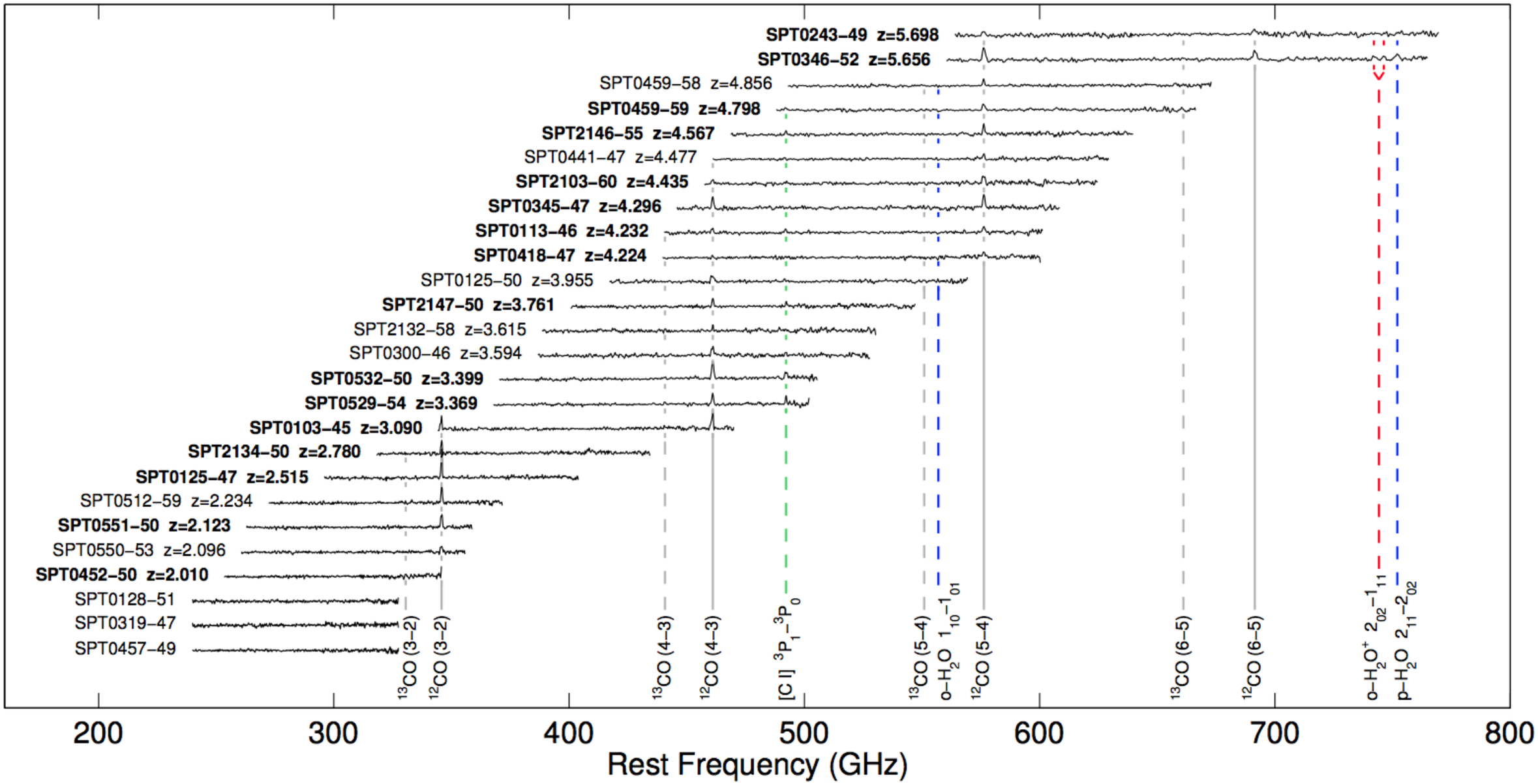


- **The SPT sources are rare and bright (~1/30 deg^2)**
- **The SPT selection is independent of lensing configuration (e.g. r_E, z_{lens}, z_{source})**
- **Majority are galaxy-galaxy lenses with r_E ~ 0.5" and magnification μ ~ 8**
- **4 cluster lenses (~5%)**
- **4 unlensed sources (~5%)**

- **When the system is unresolved, we save μ^2 time on the telescope —> great for line surveys. (20 min instead of 20 hours)**
- **When we resolve the system we gain in angular resolution by sqrt(μ) —> we can resolve kpc scales.**
- **Excellent complement to deep submm surveys.**

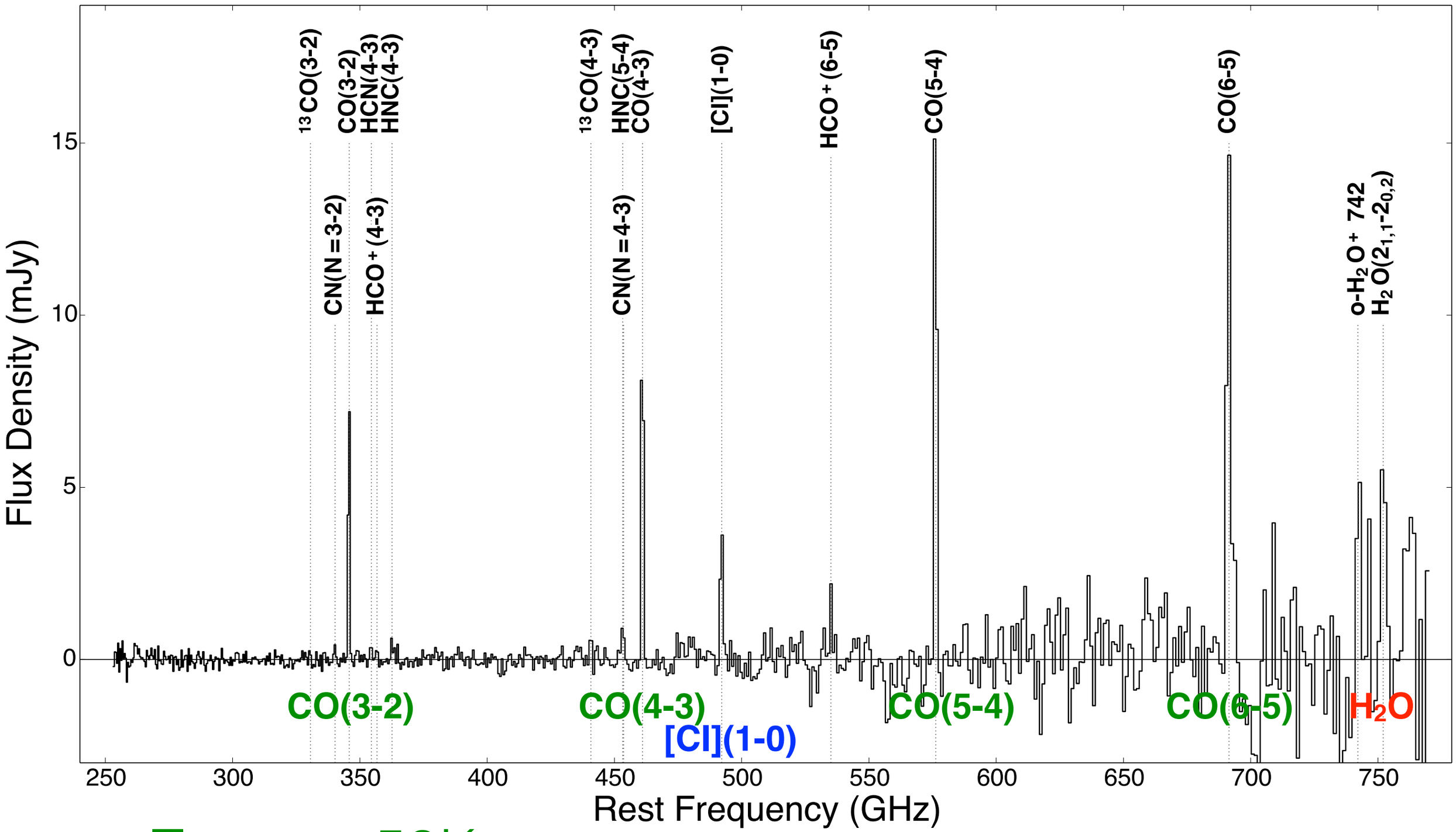
Spectroscopic redshift survey with ALMA

ALMA Cycle 0 Band 3
100 GHz compact configuration
26 sources
5 tunings in the 3 mm band
~20 minutes per source



Vieira *et al.* 2013 Nature

Composite CO spectrum

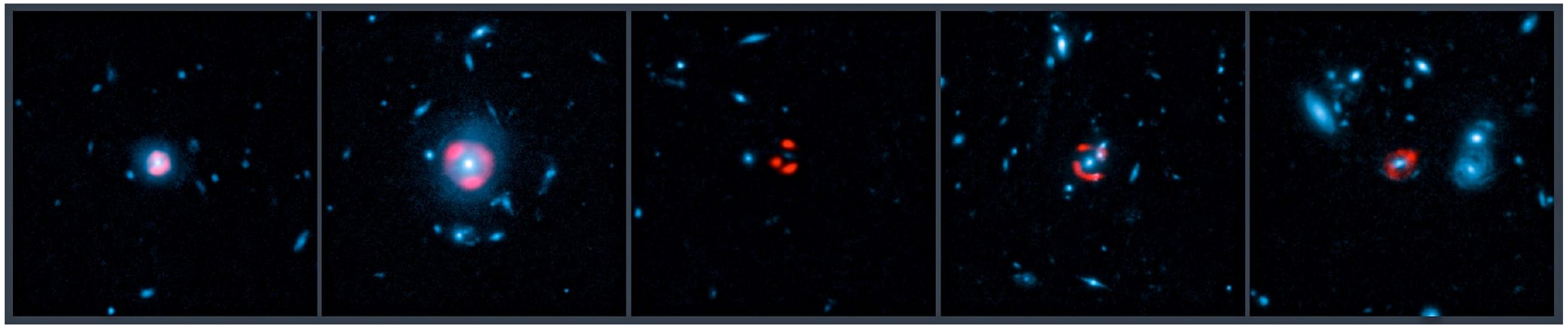


$T_{EX,CO} < 50K$

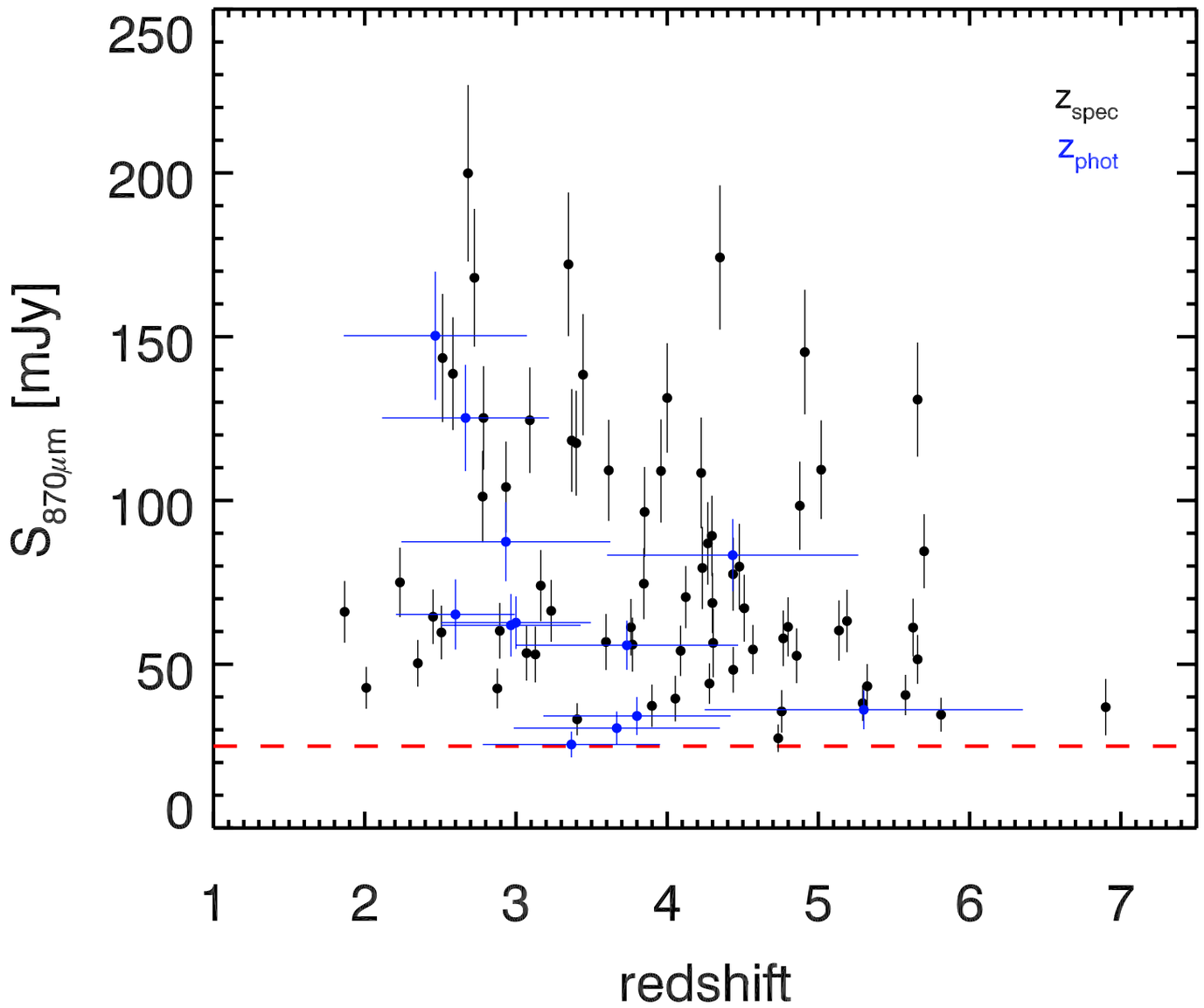
$1 < \tau_{CO(1\text{-}0)} < 10$

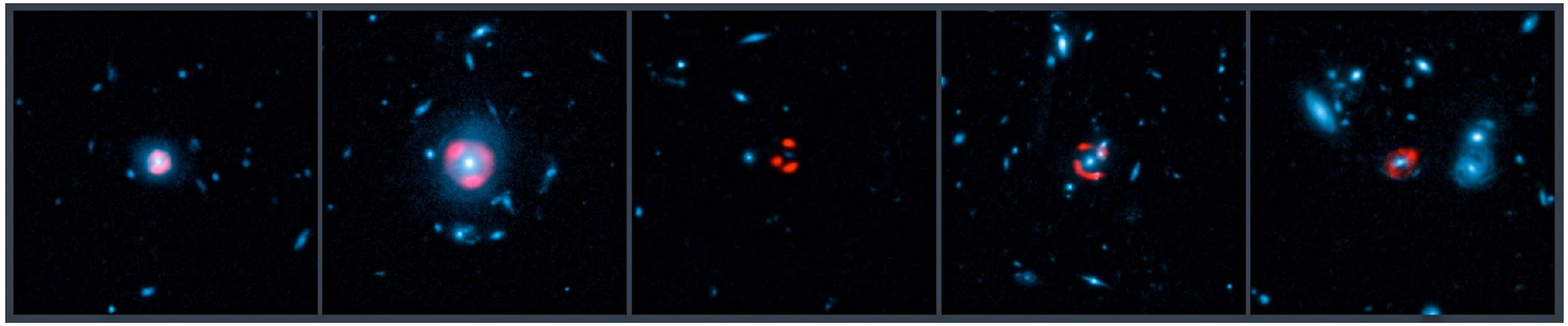
Spilker *et al.* ApJ 2014

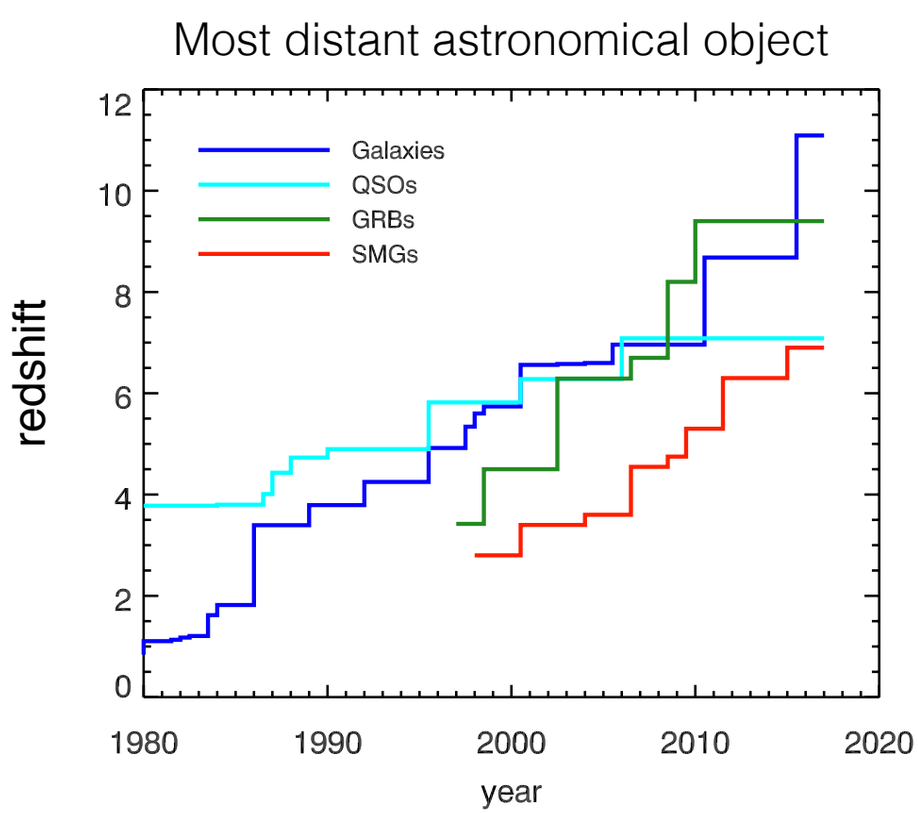
stats

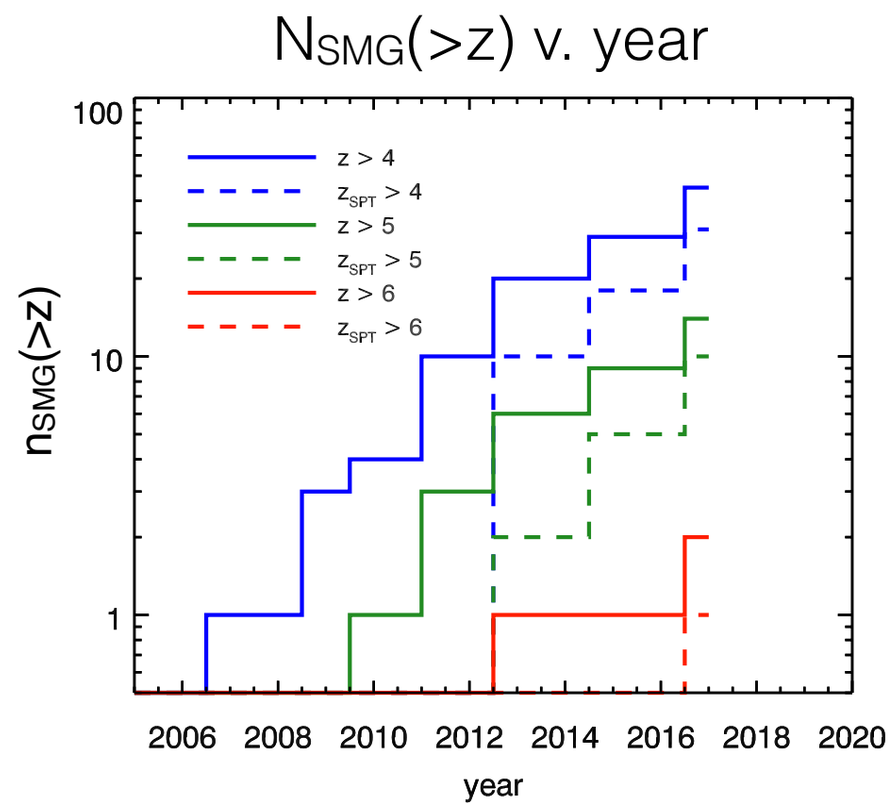


- 100+ sources total from 2500 deg^2 SPT-SZ survey
- **81** with S_{870um}>25 mJy —> this is our sample
- ALL have ALMA 3mm spectra
- 69 with confirmed spectroscopic redshifts (>85% complete so far)
- 1.9<z<6.9; median < z > = 4.1; 36 at z>4, 12 at z>5
- of these, 42 have ALMA imaging. (call it half)



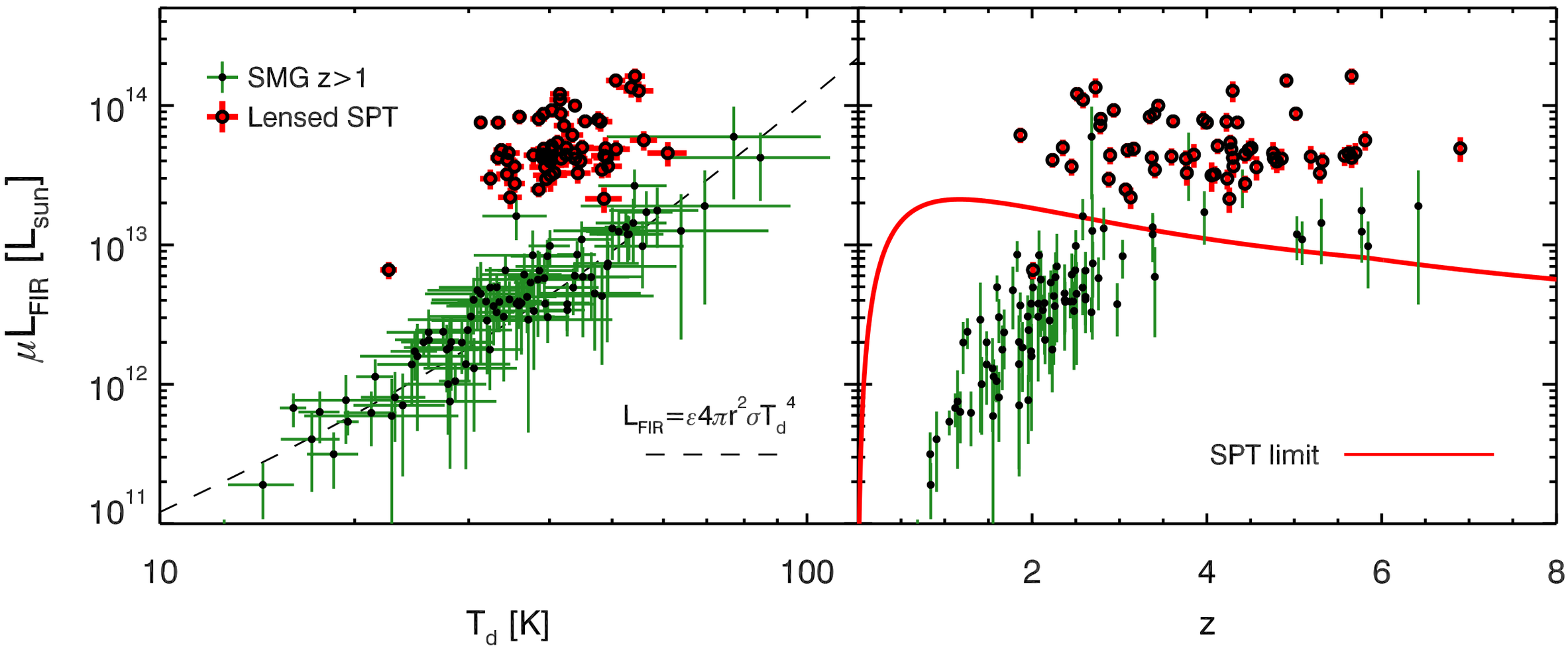




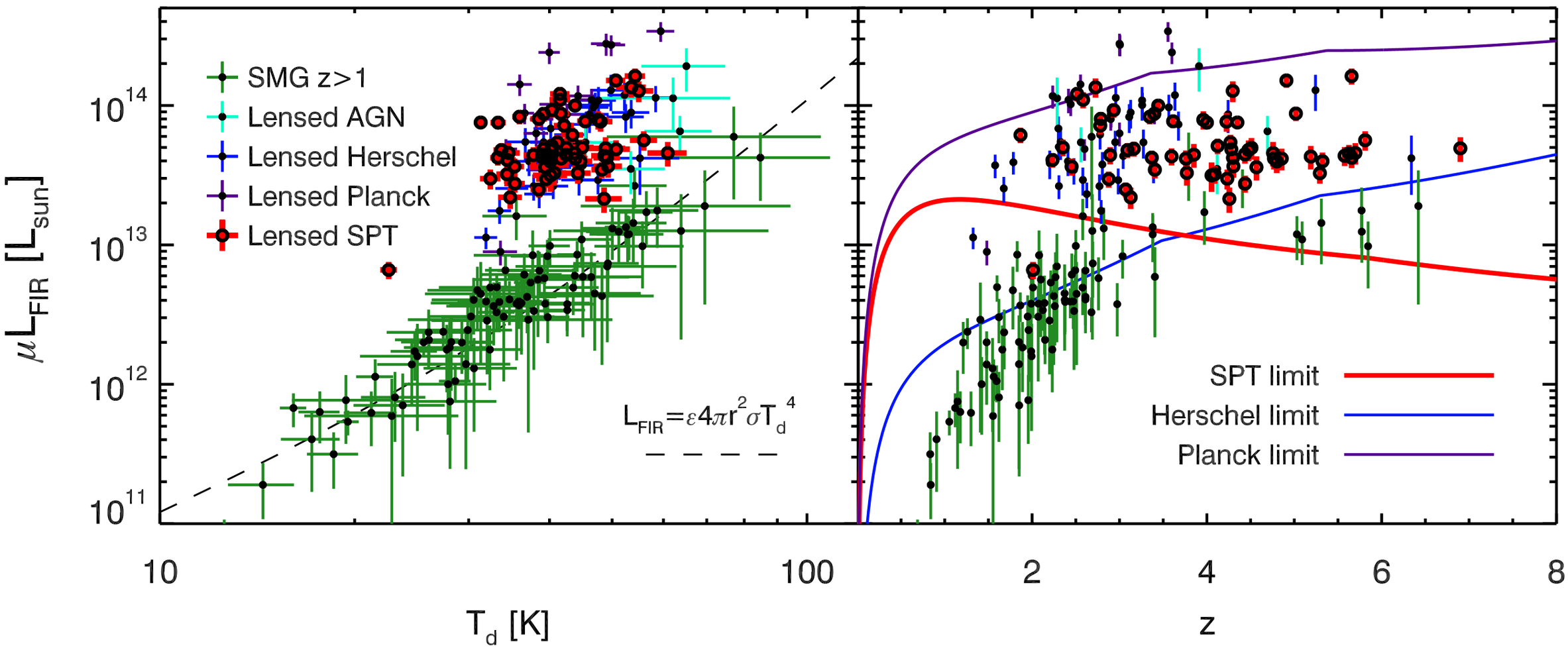


- 82 with S_{870um}>25 mJy from 2500 deg^2 SPT-SZ survey —> All have ALMA 3mm spectra. This is among the largest samples of lensed galaxies in the literature.
- 69 with confirmed and unambiguous spectroscopic redshifts (>85% complete so far). This is among the highest spectroscopic completeness of any sample of high redshift galaxies
- 1.9<z<6.9; median < z > = 4.1; 36 at z>4, 12 at z>5
- Of these, 42 have ALMA imaging. (call it half)
- SPT has discovered 70% of dusty star forming galaxies at z>4

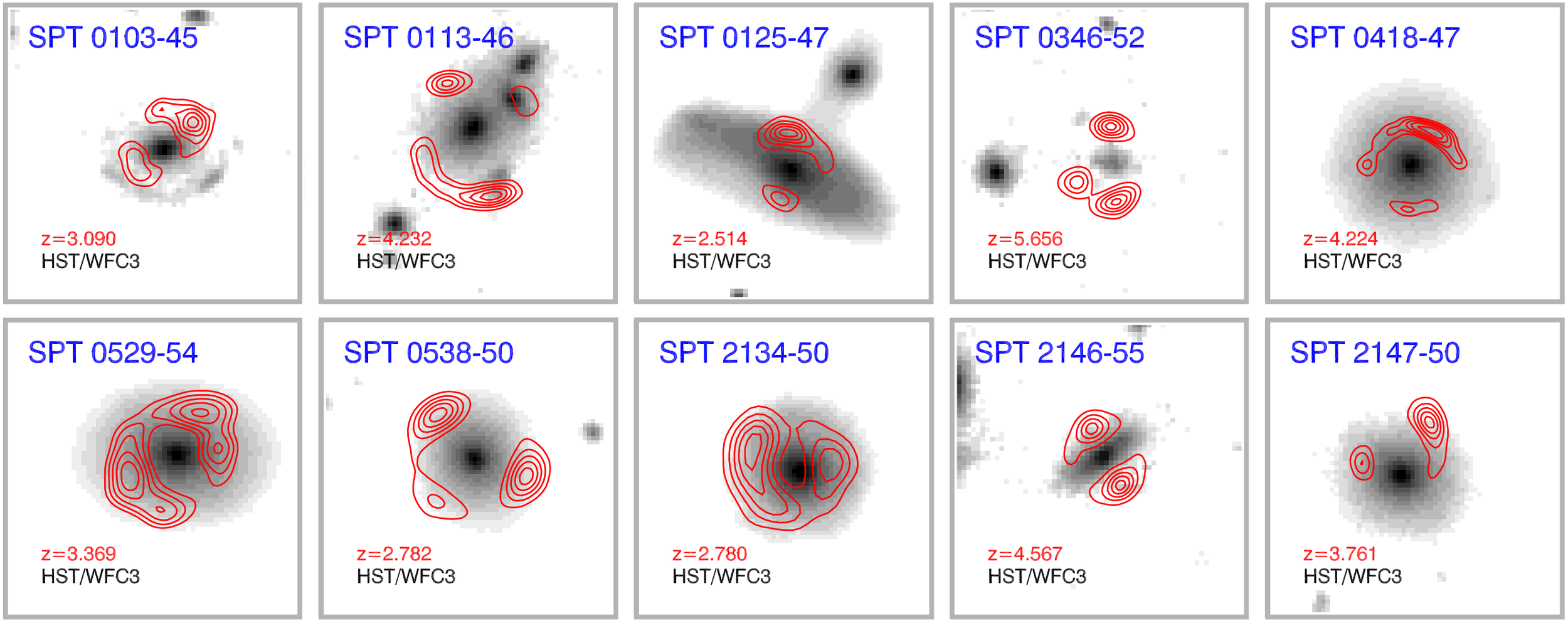
submm-selection



submm-selection



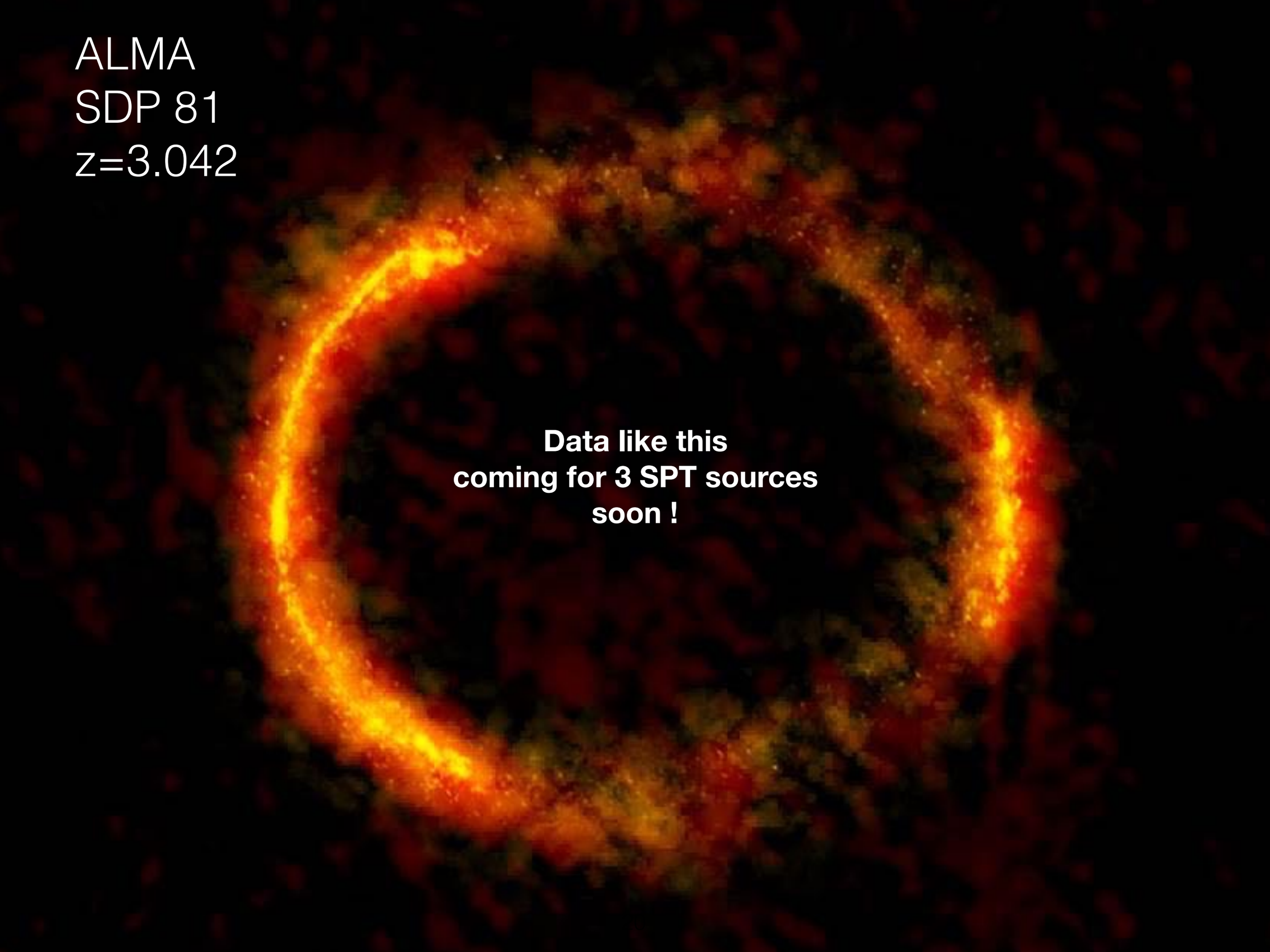
ALMA Cycle 0 Band 7 350 GHz
2 minute snapshots with 16 antennas



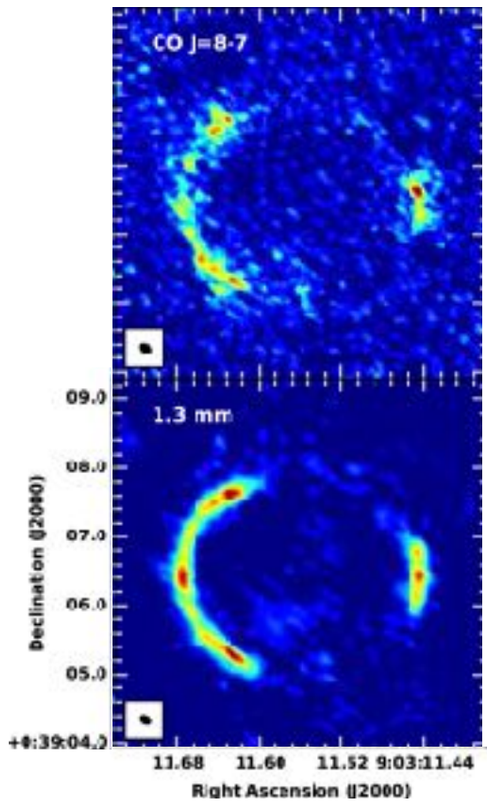
8" x 8" boxes

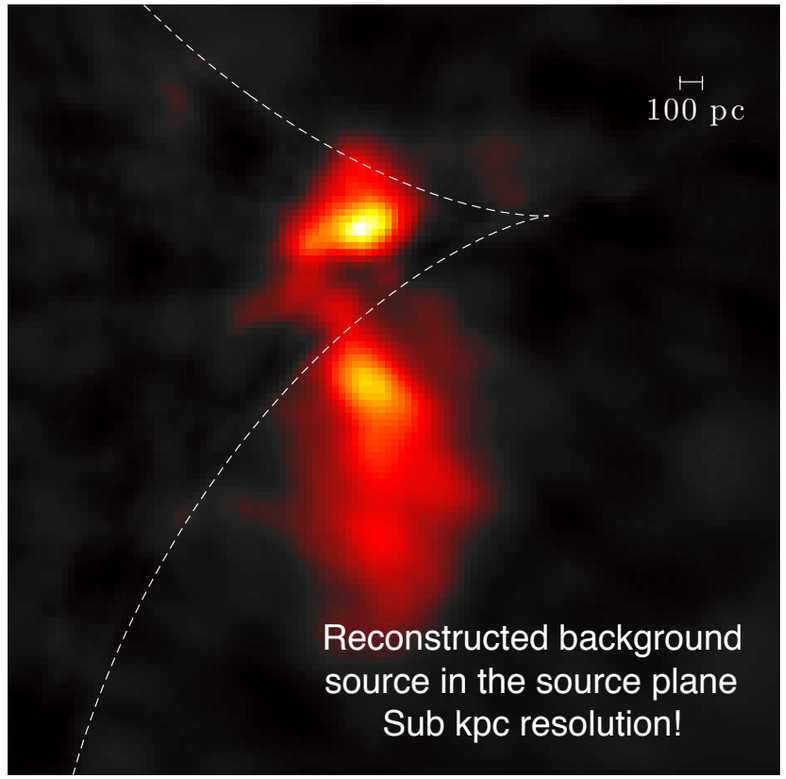
= 1 orbit HST/WFC3 imaging

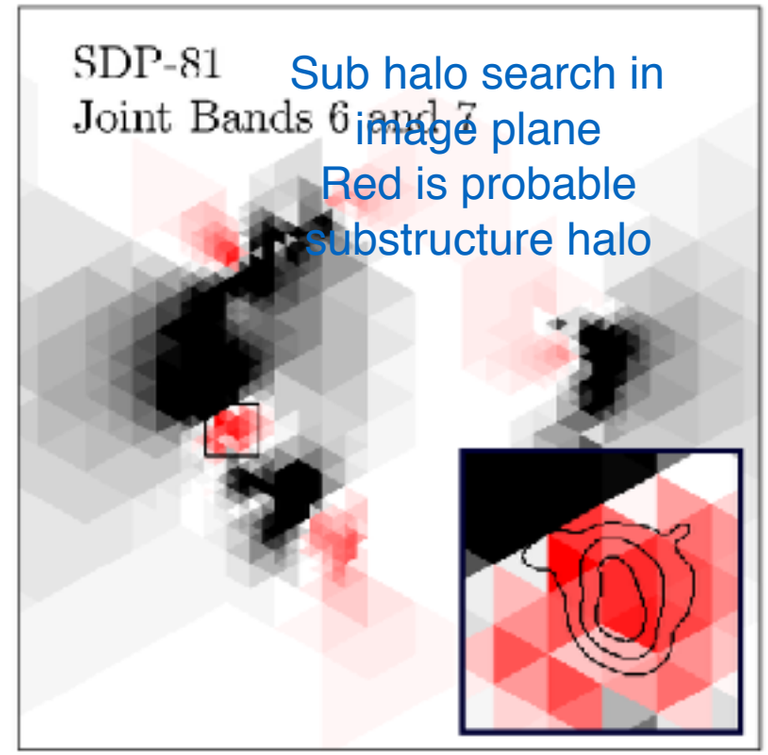
= 2 minute ALMA 350 GHz snapshot


ALMA
SDP 81
z=3.042
Data like this
coming for 3 SPT sources
soon !

Dark Matter Sub-Structure detection with ALMA

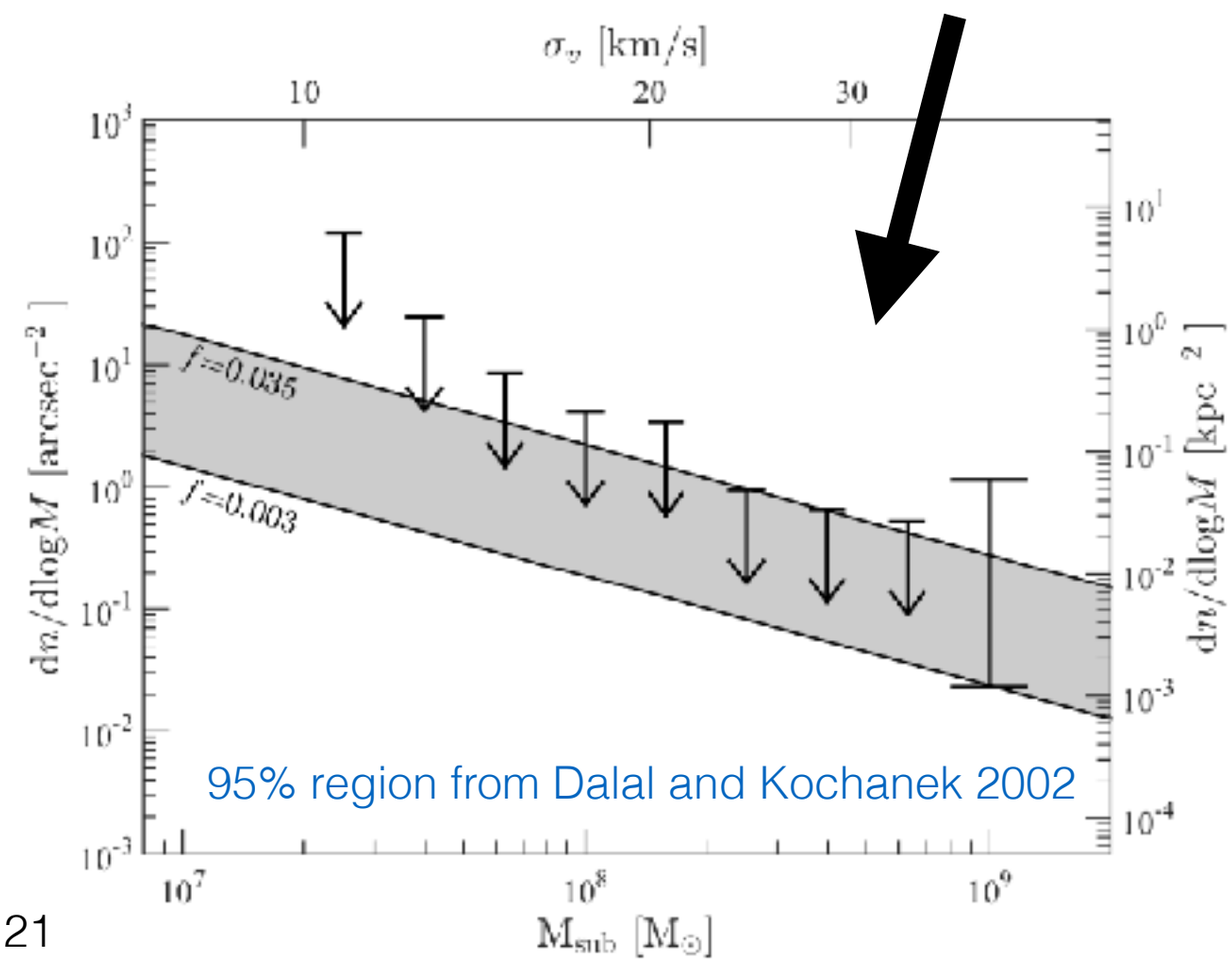






- We can use these background sources as backlights to image the foreground lensing halo.
- Dark matter substructure is an interesting and powerful probe of LCDM on small scales
- ALMA SDP81- like data for 3 SPT sources was completed in Cy4

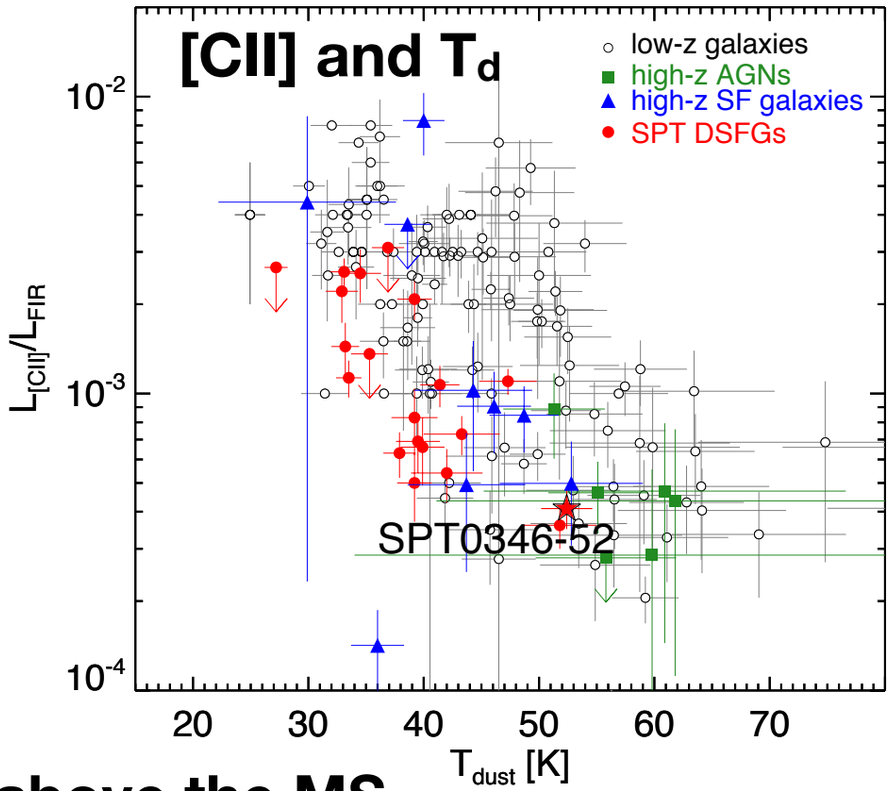
Hezaveh, Dalal, Marrone *et al.* 2016, ApJ



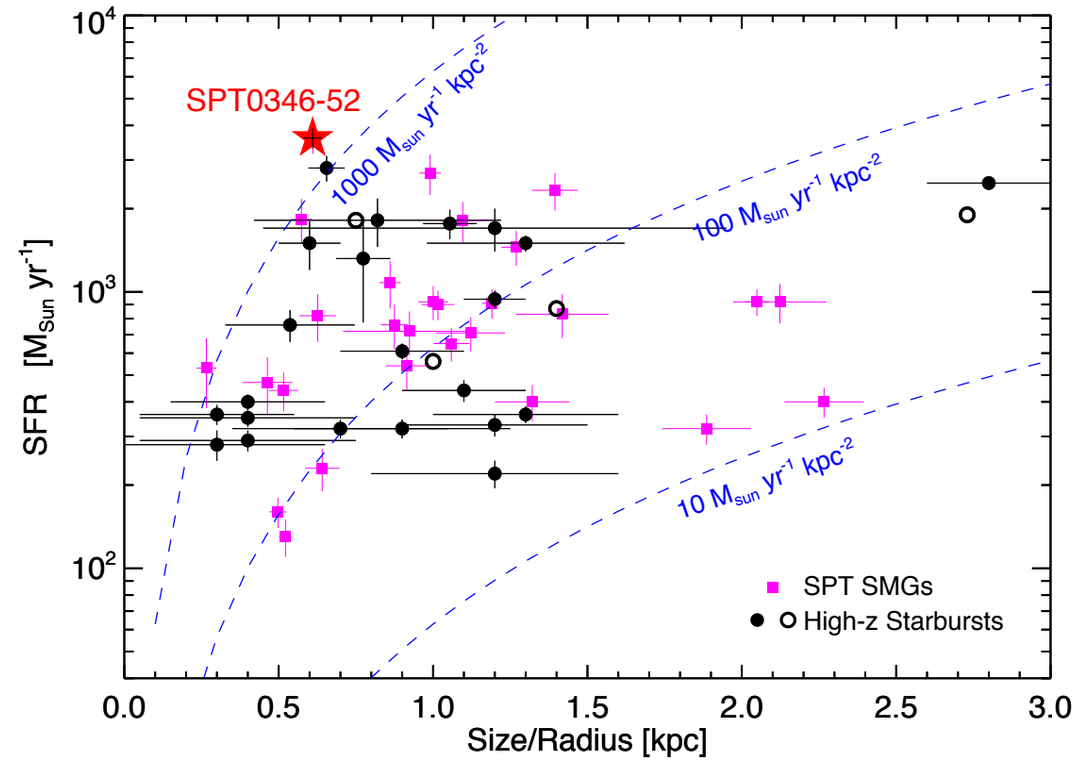
SPT0346-52 at z=5.7

The most intensely star forming galaxy

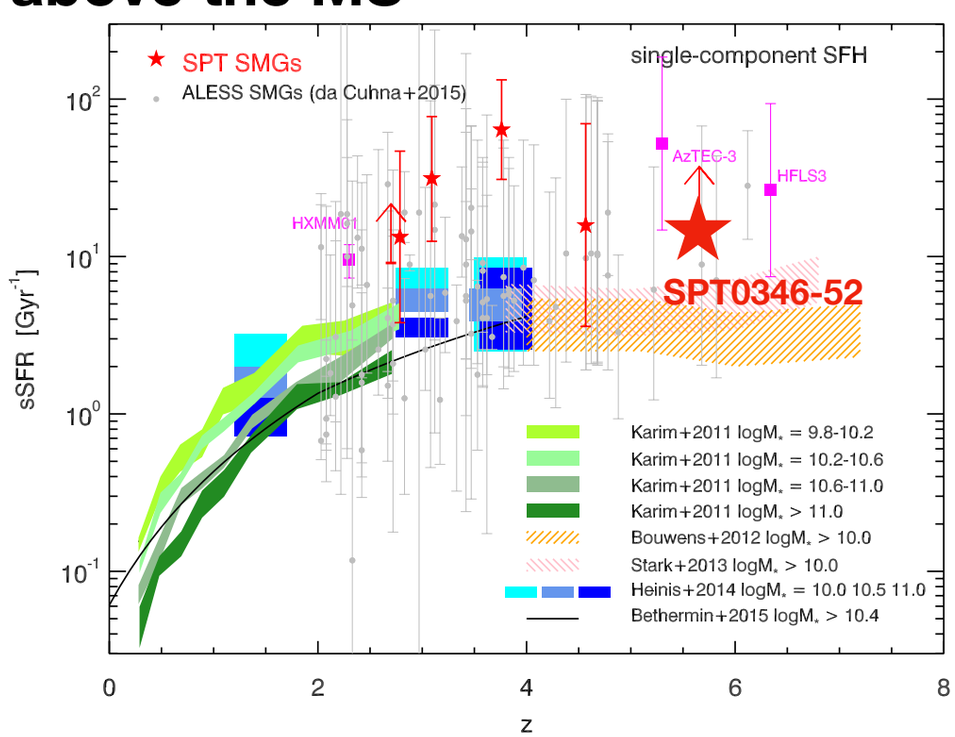
Ma *et al.* 2016
Ma *et al.* 2015



Σ_{SFR}

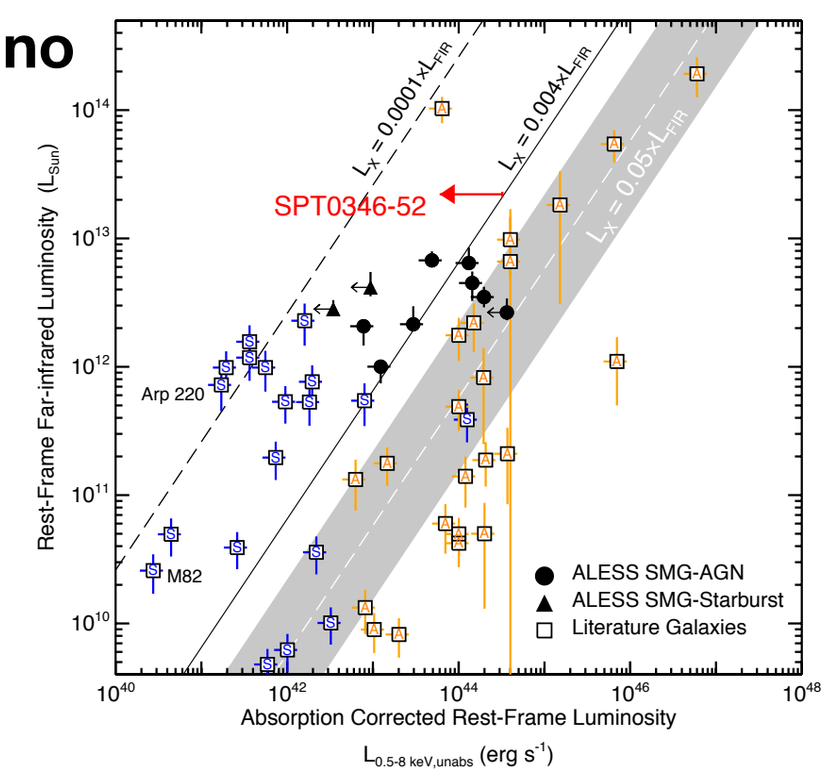


well above the MS



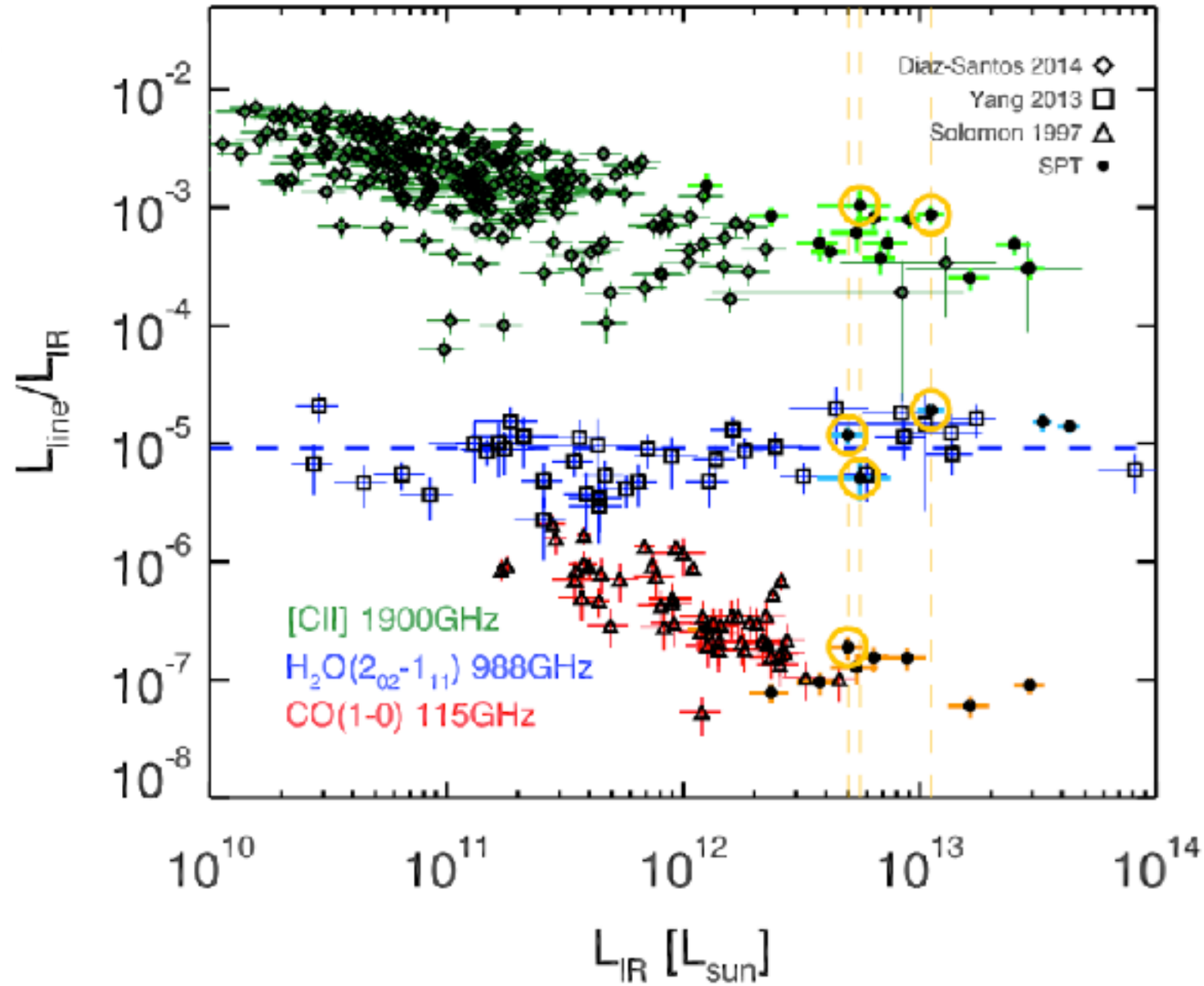
50ks with Chandra

AGN = no

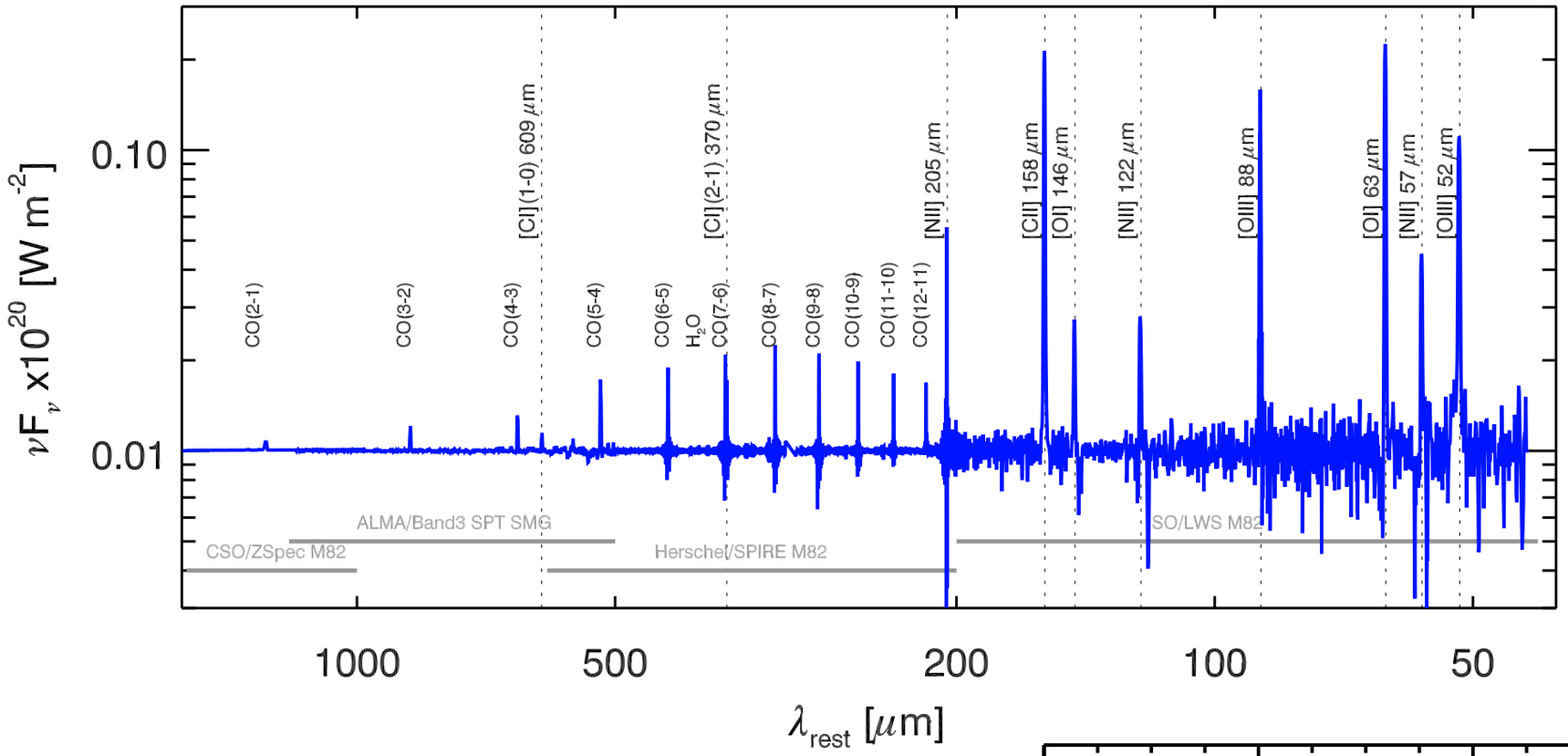


H_2O as a resolved SFR indicator

- H_2O is bright !
- Best tracer of L_{IR}
- We want to calibrate this line as a resolved SFR indicator
- We have three sources with 10-20σ resolved detections of H_2O 988 GHz
- B9 continuum coming in cycle 5

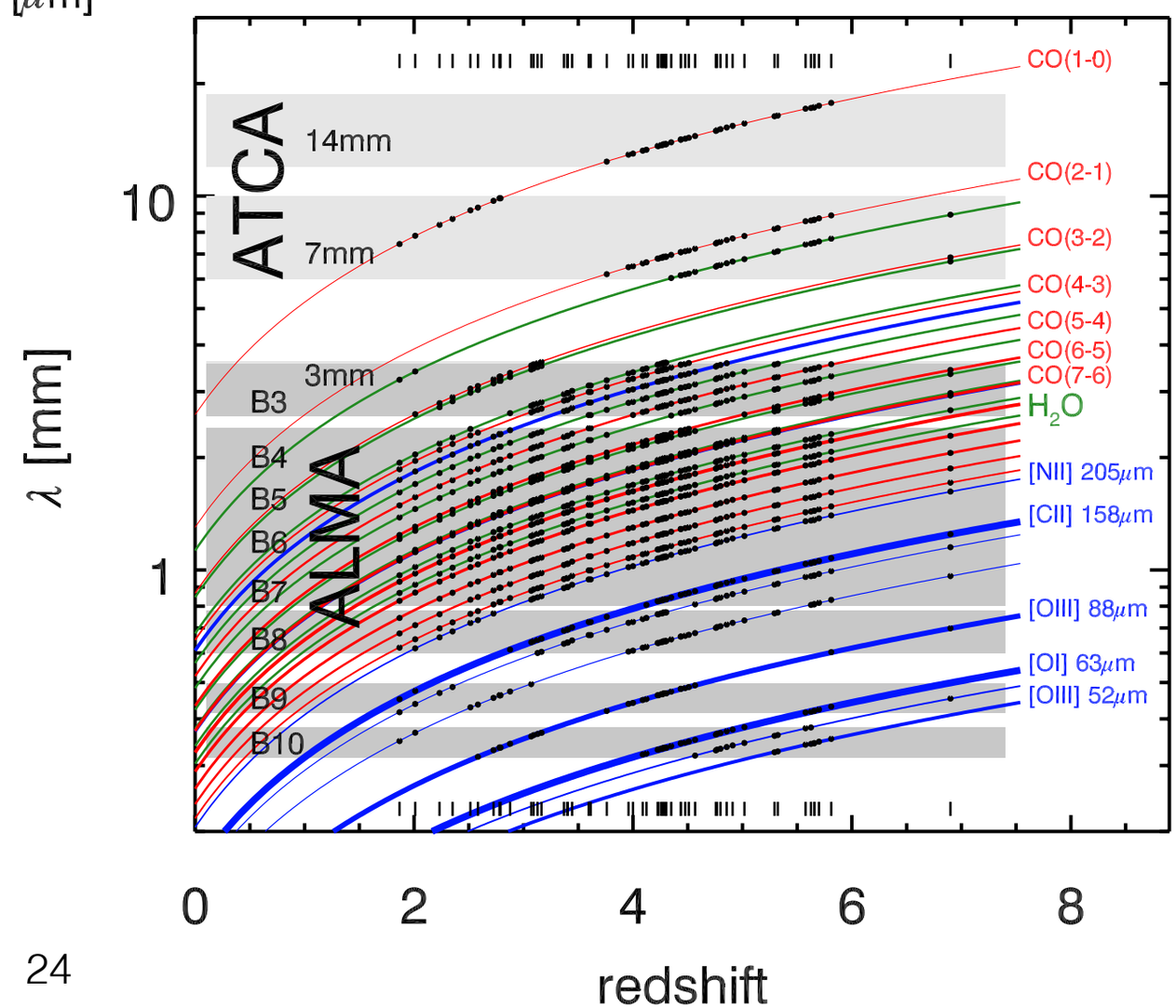


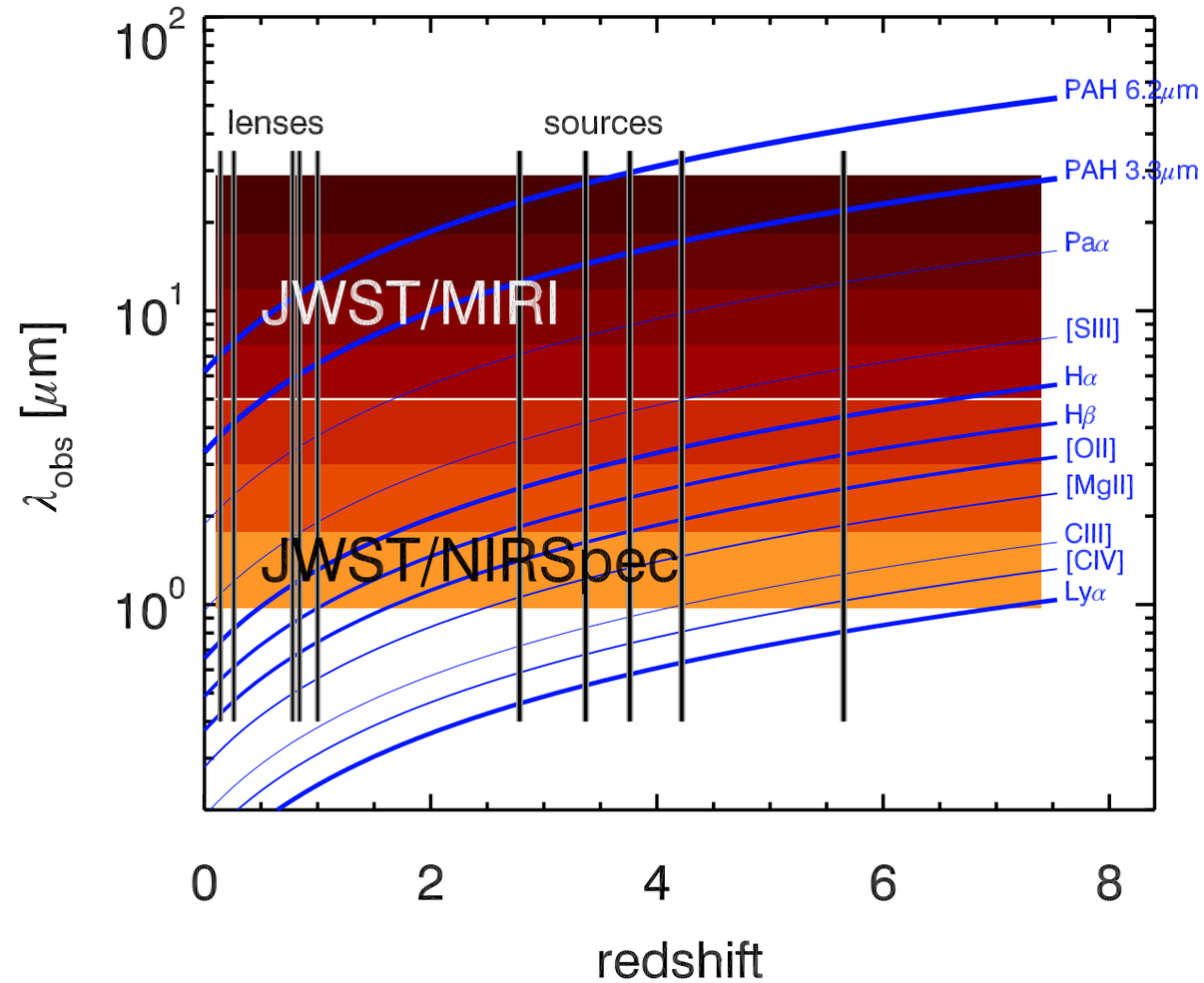
source	z	magnification μ	$r_{Einstein}$ [arcsec]	*intrinsic* L_{IR} $[10^{12}L_\odot]$	$T_{\rm dust}$ [K]	*measured* L_{H_2O} $[10^8 L_\odot]$	*measured* $L_{H_2O/L_{IR}}$ $[10^{-5}]$
SPT0529-54	3.369	13.2 ± 0.85	1.536	3.9 ± 0.7	33.3 ± 0.9	3.8 ± 0.3	0.5 ± 0.2
SPT0532-50	3.399	10.0 ± 0.57	0.55	9.0 ± 1.8	39.2 ± 1.0	21.7 ± 0.4	1.9 ± 0.2
SPT0538-50	2.782	20.0 ± 1.8	1.987	3.8 ± 0.9	38.5 ± 1.1	11.9 ± 0.7	1.2 ± 0.2



Future line line studies:

- This high redshift sample opens up a new window onto the ISM
- z > 4 brings [CII]158μm from B10 to B7 —> high resolution spatially resolved spectroscopy
- redshift makes FSL [OI]63μm and [OIII]52μm possible
- now: CO, H_2O, HCN, OH, …
- Fute: HD: CH … ?

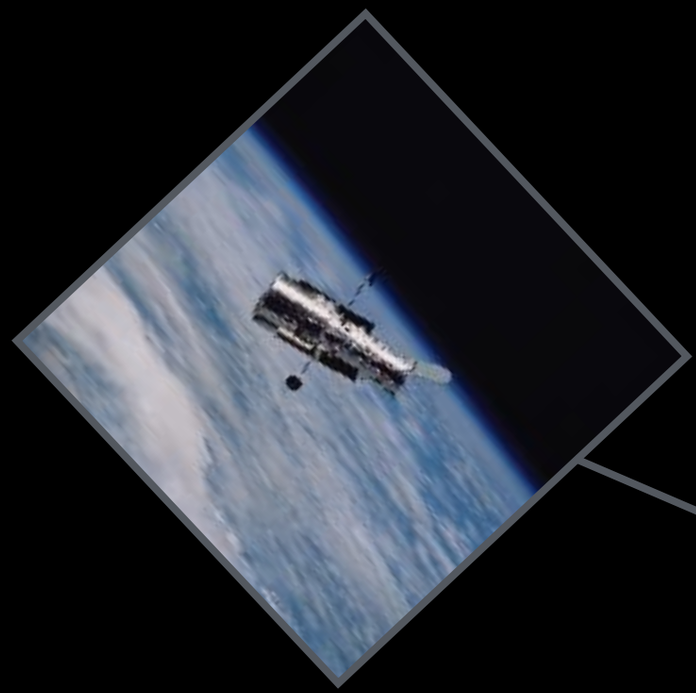




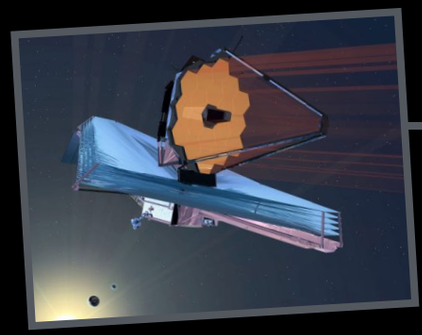
We will finally be able to do good, old-fashioned optical astronomy with the SPT sources:

- **stellar masses**
- **calibrating obscured+unobscured SFR indicators**
- **Resolved Hα, Pα**
- **metallicities**
- **AGN diagnostics**
- **3.3 um PAH line**
- **etc**

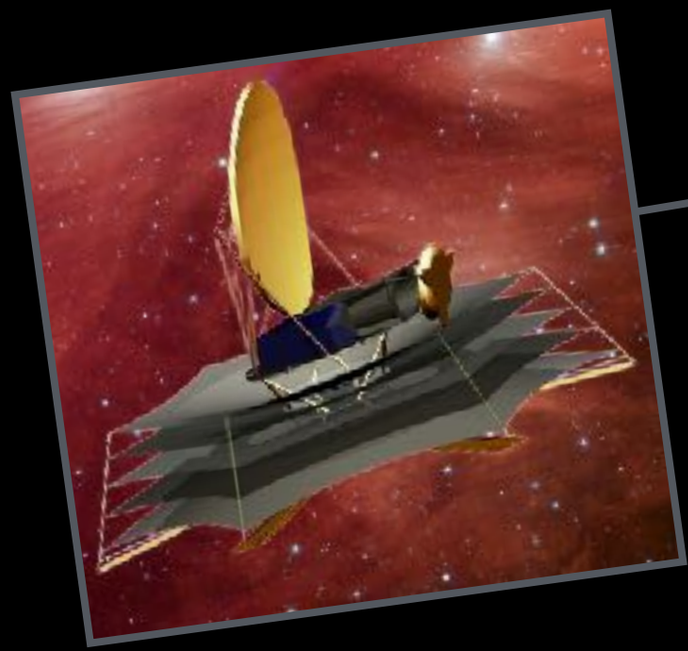
Hubble Space Telescope
1990—2018
2.4 meter
0.1—2.4 µm
260 K

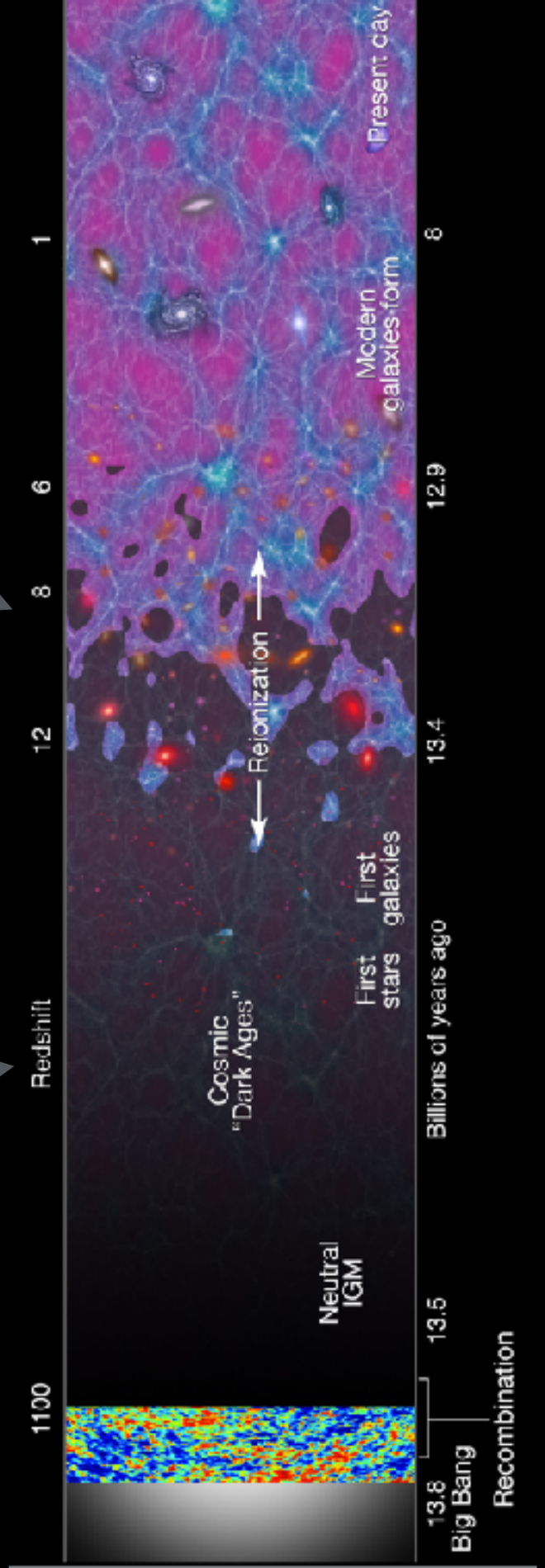


James Webb Space Telescope
2018—2028
6.5 meter
0.6—27 µm
50 K



Origins Space Telescope
2030—2040
9 meter
7—300 µm
4 K

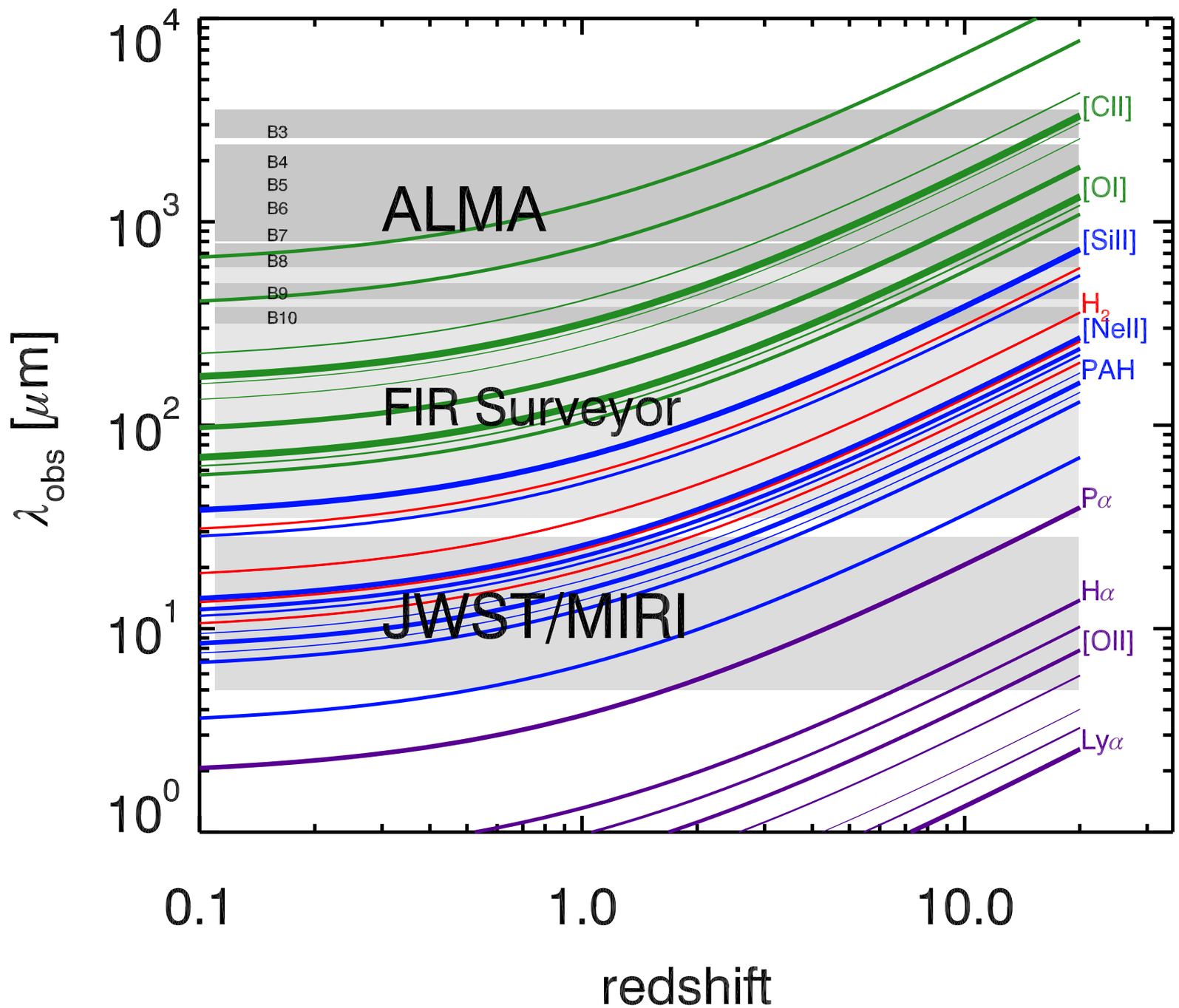




ORIGINS Space Telescope

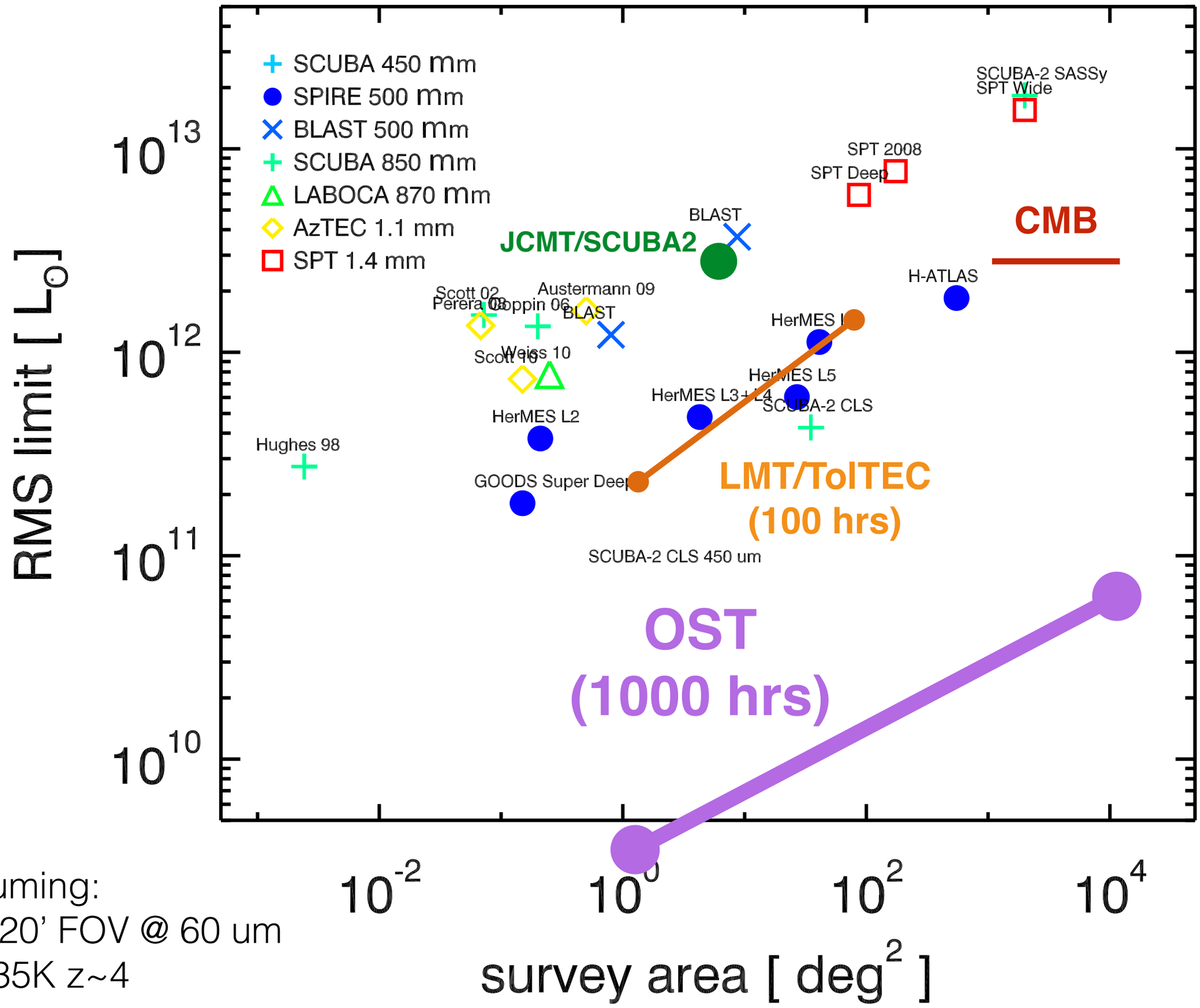
OST provides the crucial link in wavelength coverage between JWST and ALMA to complete our view of the evolution of the universe.

https://asd.gsfc.nasa.gov/firs/



ORIGINS Space Telescope

discovery space

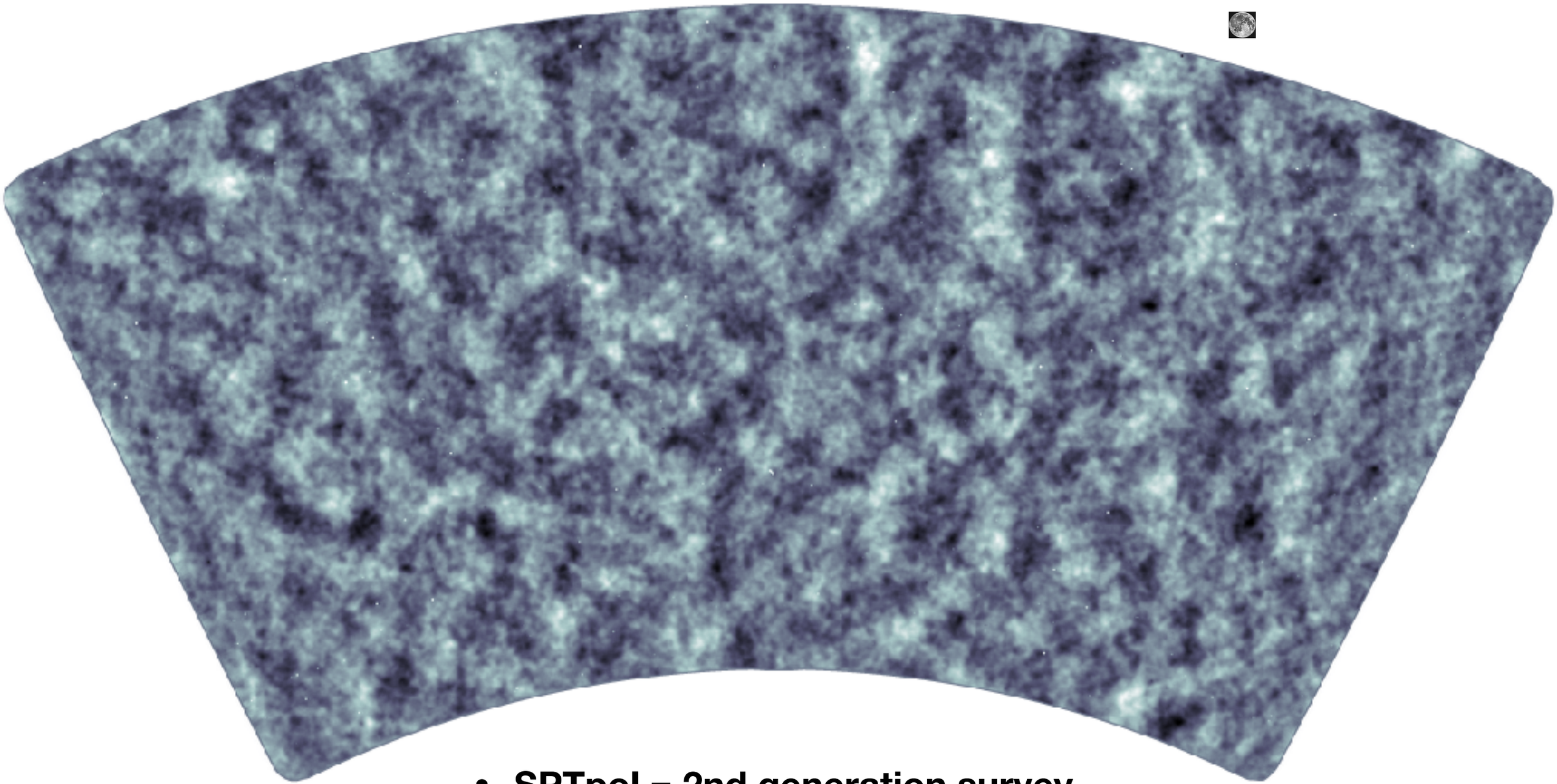


assuming:
20'x20' FOV @ 60 um
T_d~35K z~4

SPTpol

500 deg^2 survey at 150 GHz with arcminute resolution

full moon for scale



- **SPTpol = 2nd generation survey**
- **x2 as deep as SPT-SZ**
- **SPT-3G has deployed**

Open Questions:

- When was the first dust formed?
- When were the first massive galaxies formed?
- How are these extreme galaxies forming? Inside-out ? Outside-in ?
- What regulates and shuts down the most intense SF?
- Can we develop FIR lines as a robust metallicity indicator for dusty galaxies?
- What are the roles of BHs and accretion in this evolution?
- Does the structure in the subahol structure of the foreground lenses jive with LCDM ?

Conclusions:

- CMB experiments have made huge impacts in the fields of cosmology and astrophysics and will continue to do so into the next decade.
- SPT has constructed one of the most unique samples of high redshift galaxies and possibly the best sample for molecular studies.
- SPT+ALMA redshift survey is complete
- This is THE sample for detailed high-redshift studies of SMGs
- SPT-3G has deployed and is in commissioning.
- Many exciting years ahead with ALMA and JWST.