Submm Imaging of High-z Galaxies: SMA´s Achievement

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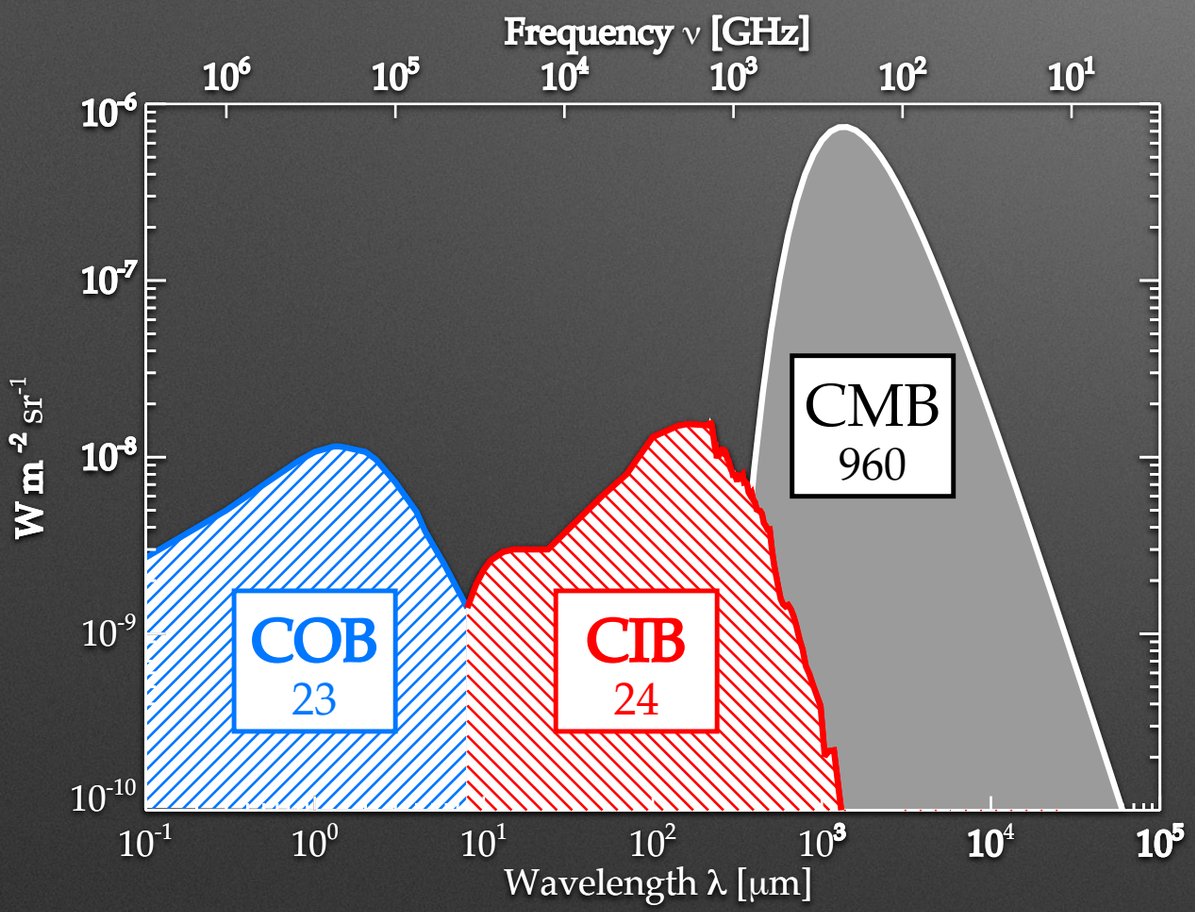
Outline

- Why submm?
- Identification of submm galaxies (SMGs)
  - radio bias and the high-z tail of SMGs
  - groups, pairs, clustering
- High resolution imaging of SMGs
  - structure of SMGs
  - strongly lensed SMGs
- Future Prospect

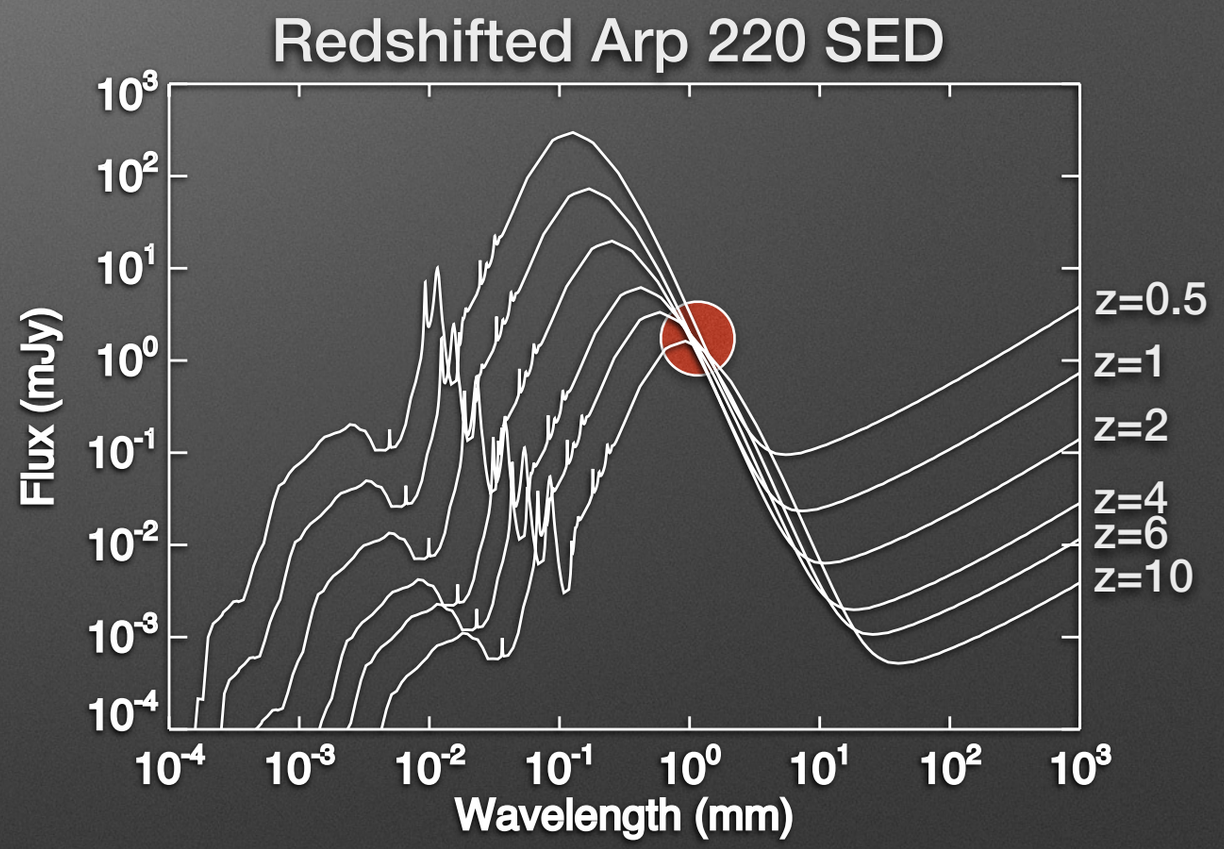
Why is submm important?

Extragalactic Background Light

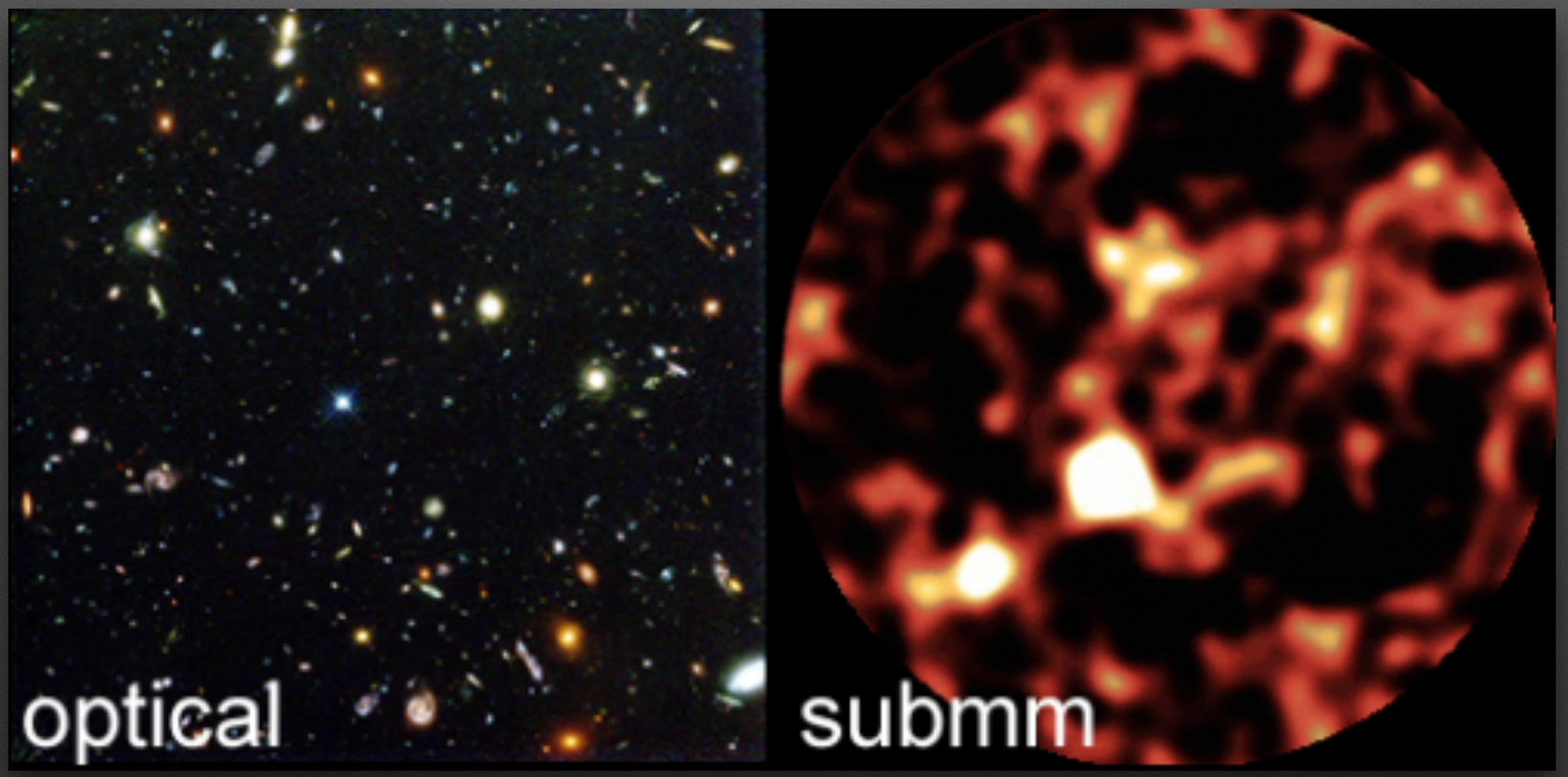


Dole et al. (2006)

Negative *K*-correction



- The submm window can provide the dust-hidden half of the story.
- Submm observations are sensitive to high-z sources.

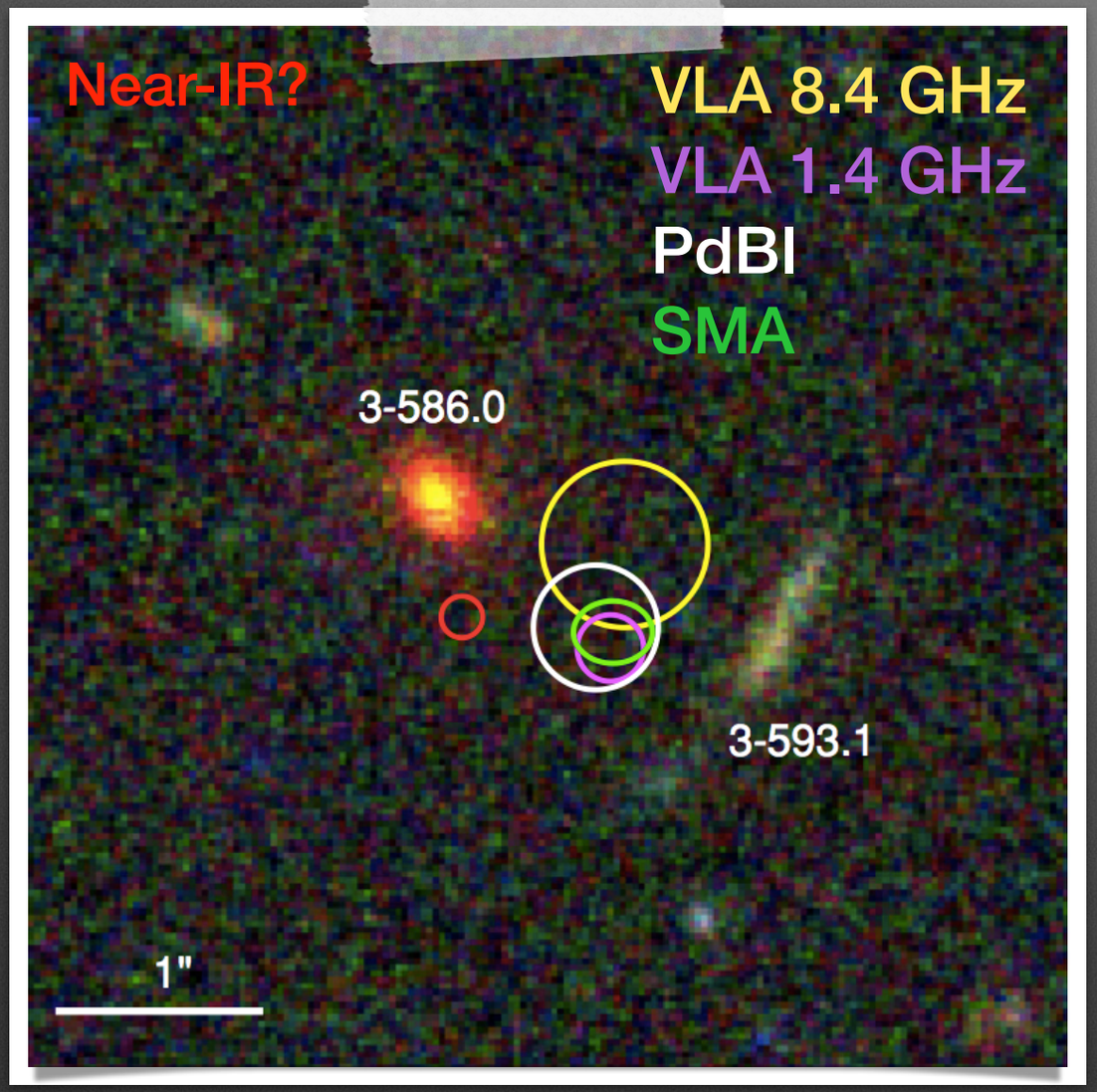


Hughes et al. (1998)

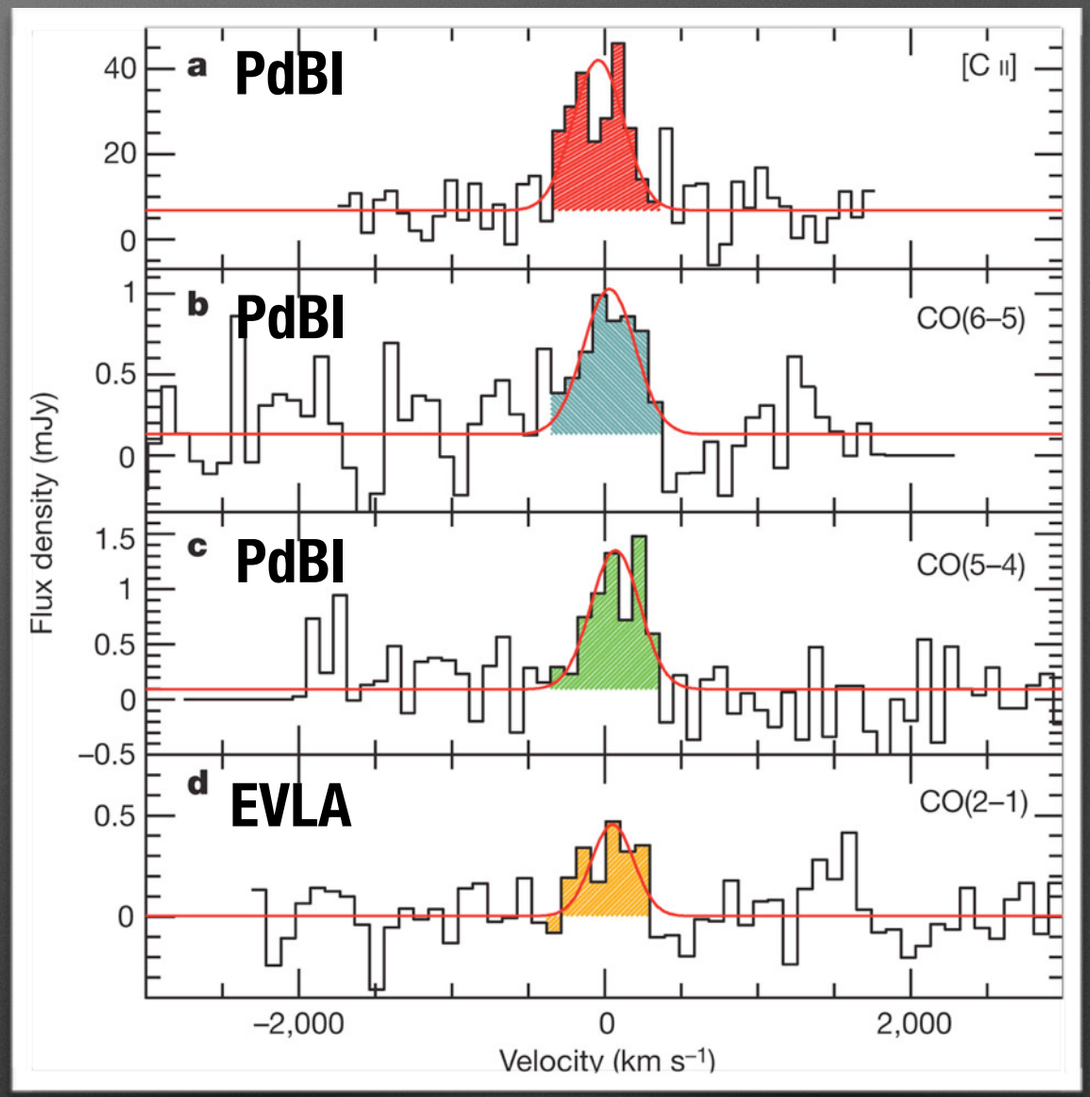
Identification of Submm Sources

HDF 850.1

z = 5.183



Cowie et al. (2009)

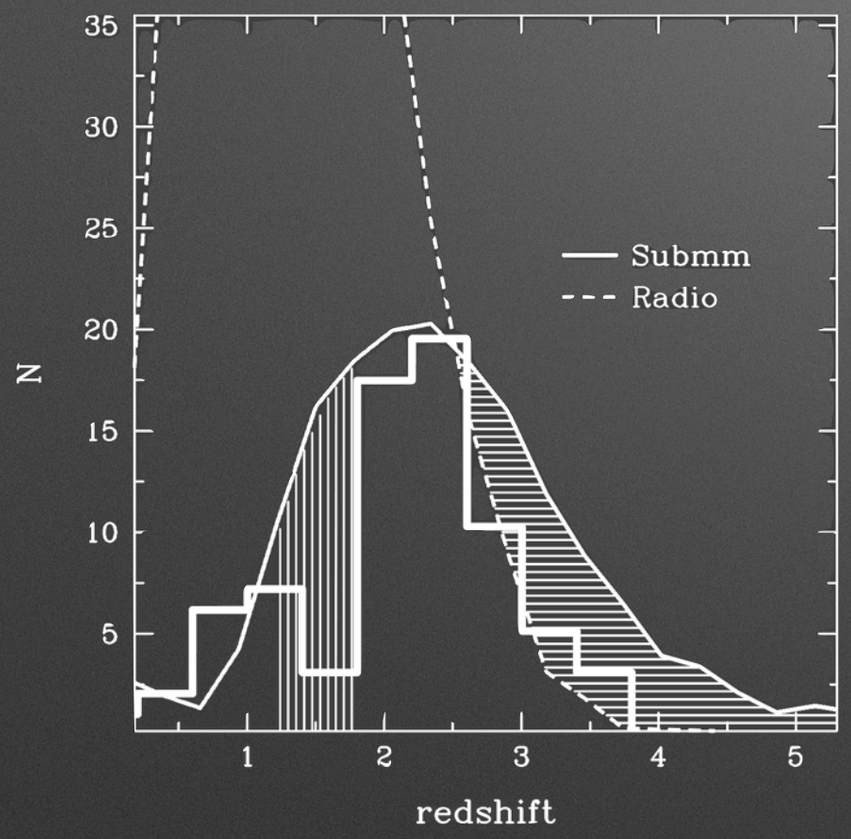


Walter et al. (2012)

- Position pinned down 11 years after its discovery.

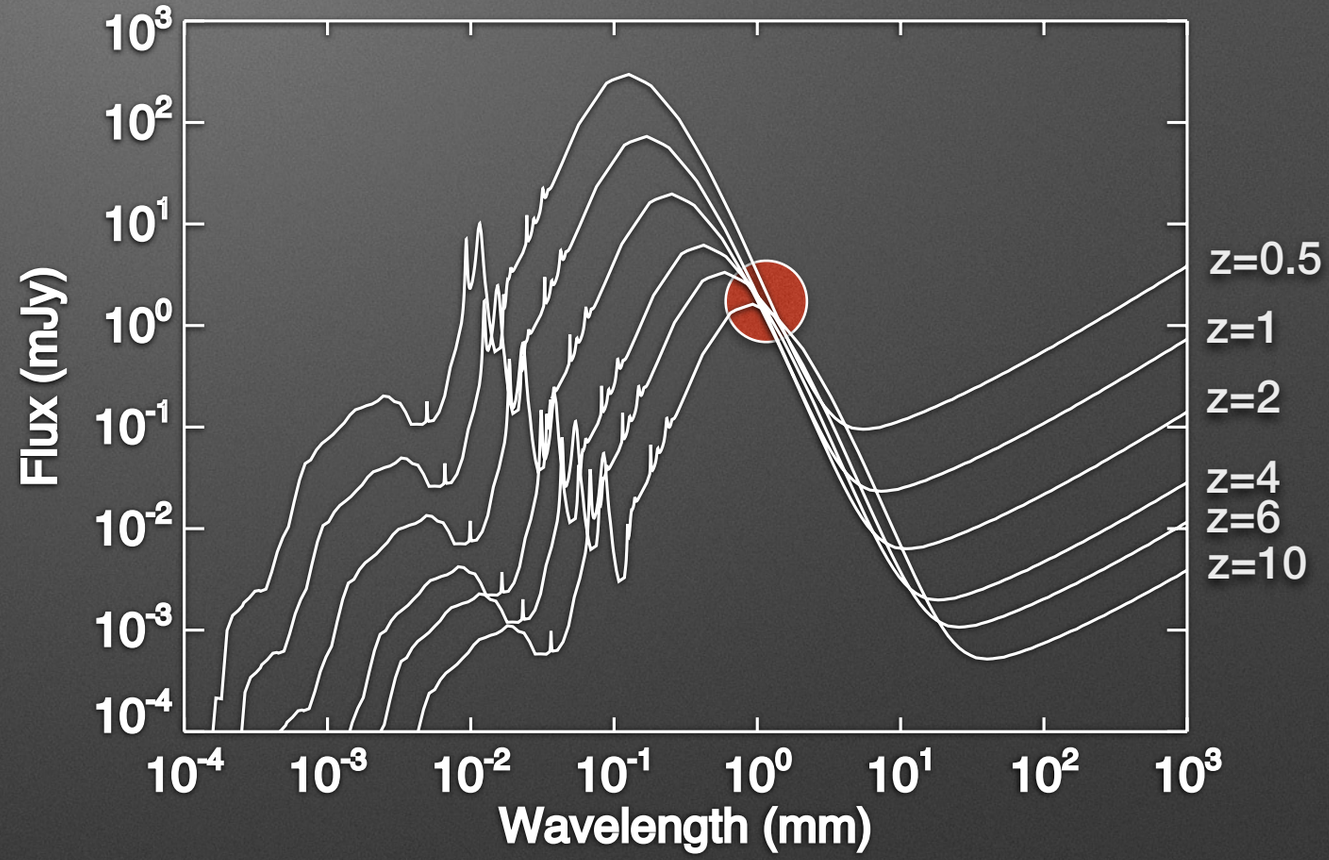
Radio Identification and Bias

Radio-Selected SCUBA Sources



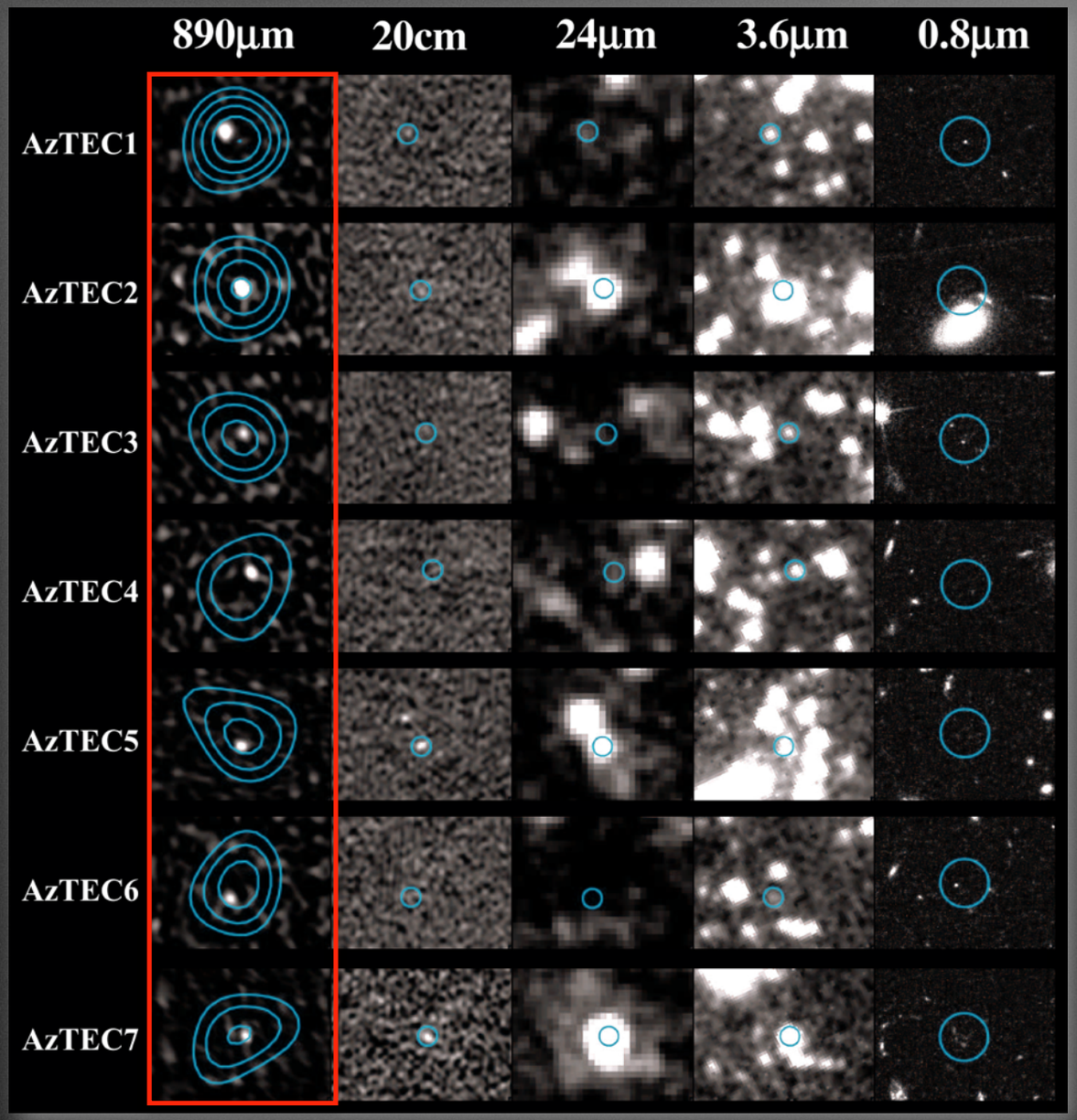
Chapman et al. (2005)

Redshifted Arp 220 SED

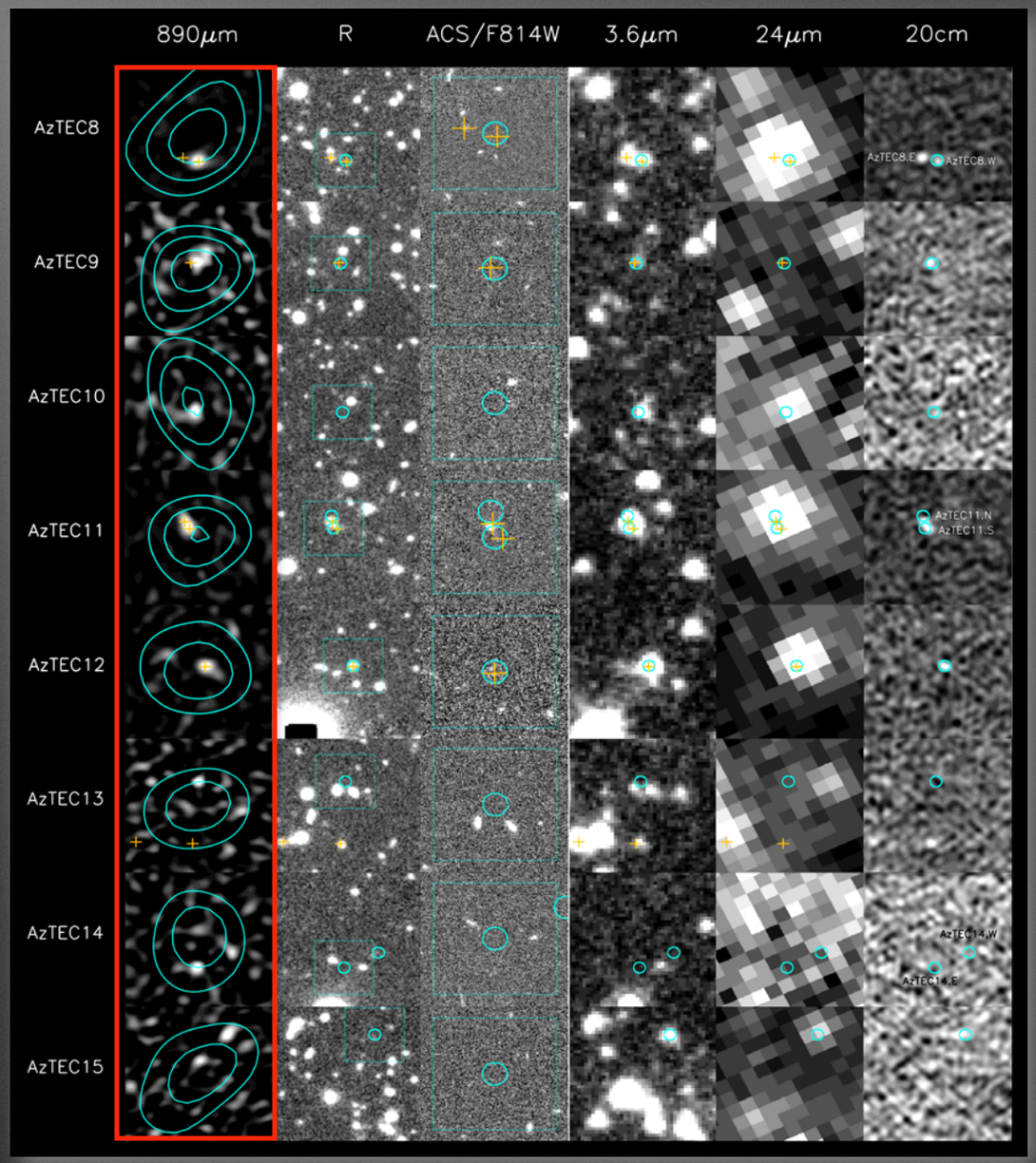


- Radio is less sensitive to SMGs at z > 3.

Submm-Bright, Radio-Faint Sources



SMA Younger et al. (2007)



SMA Younger et al. (2009)

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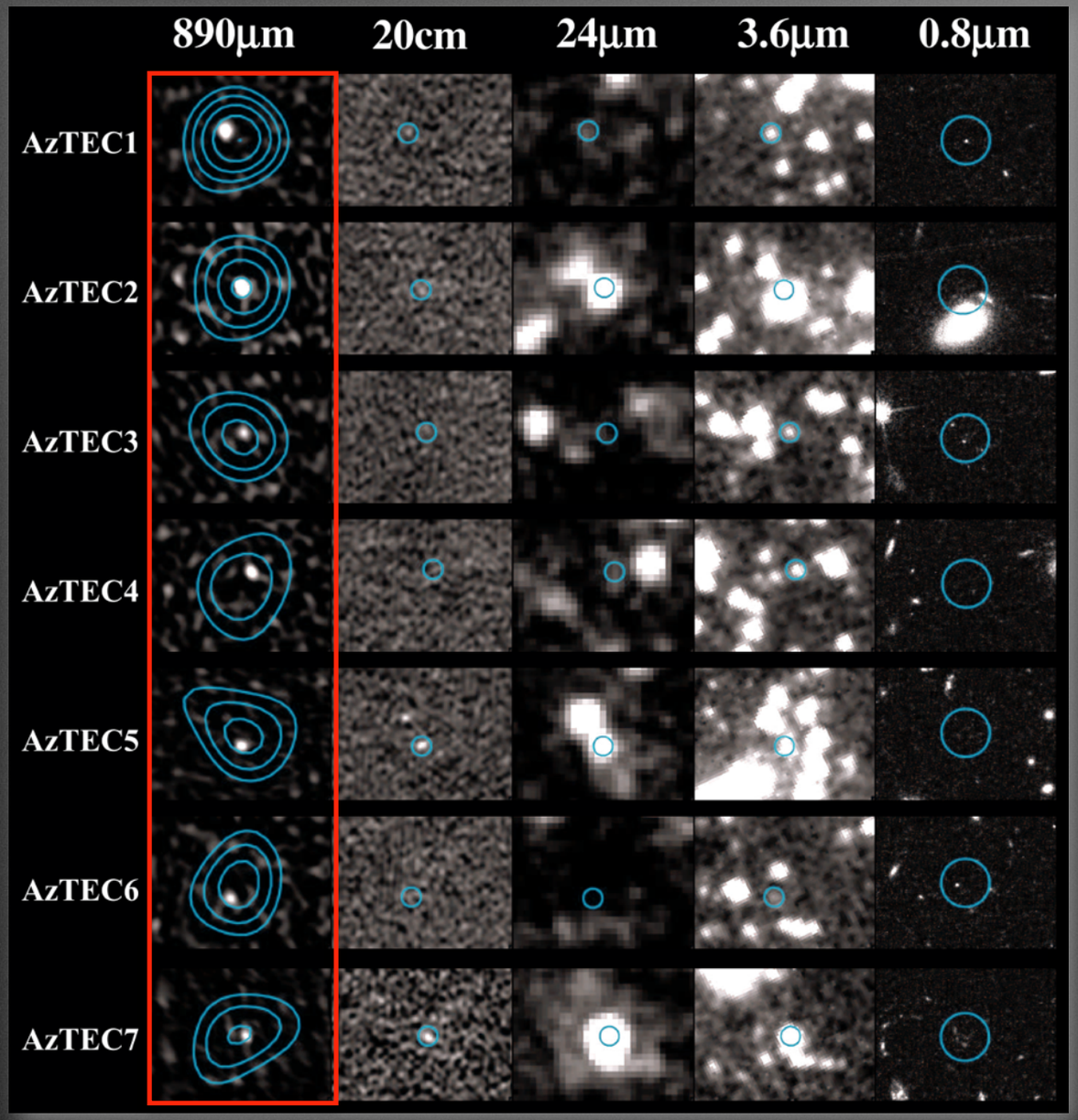
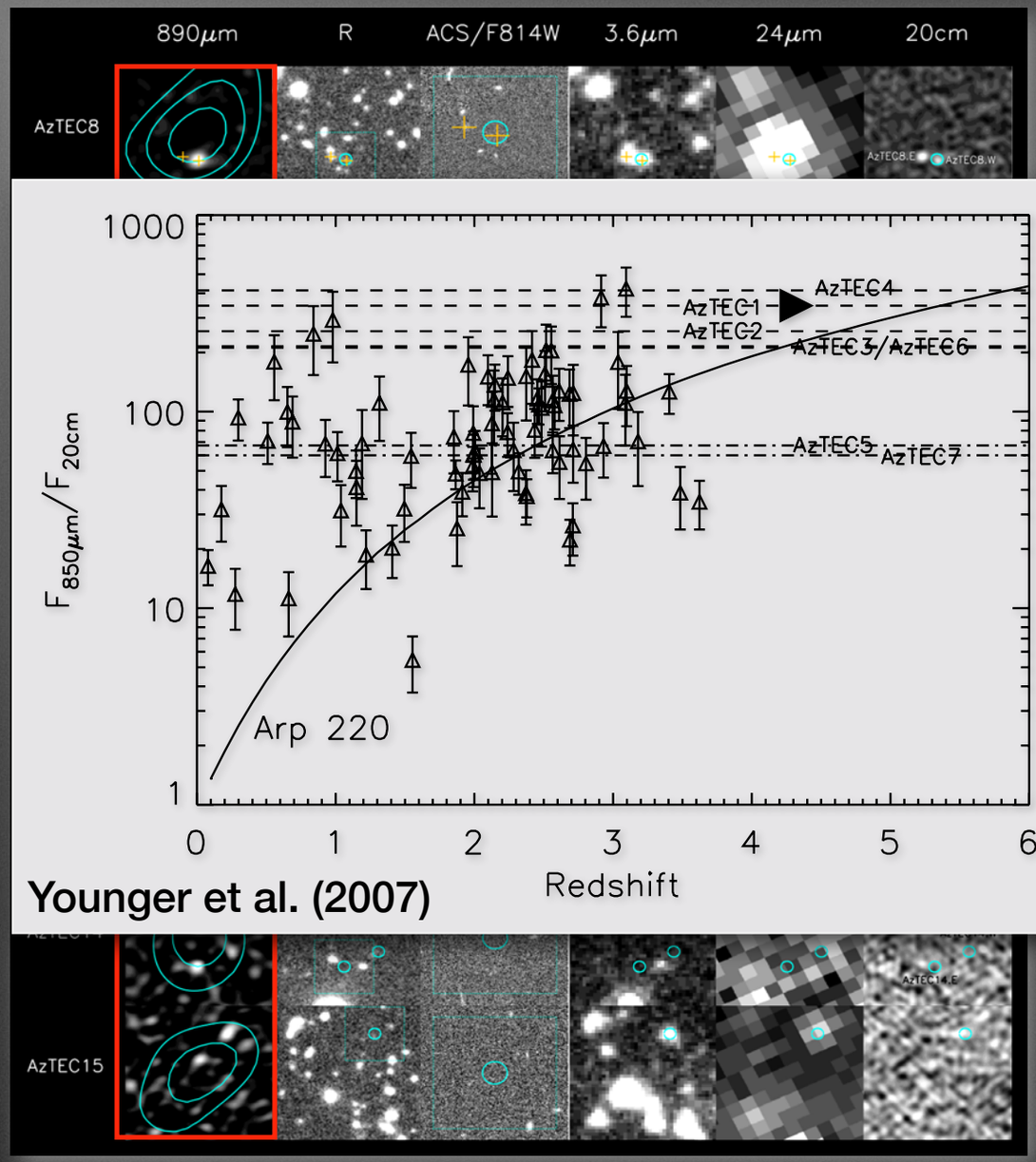
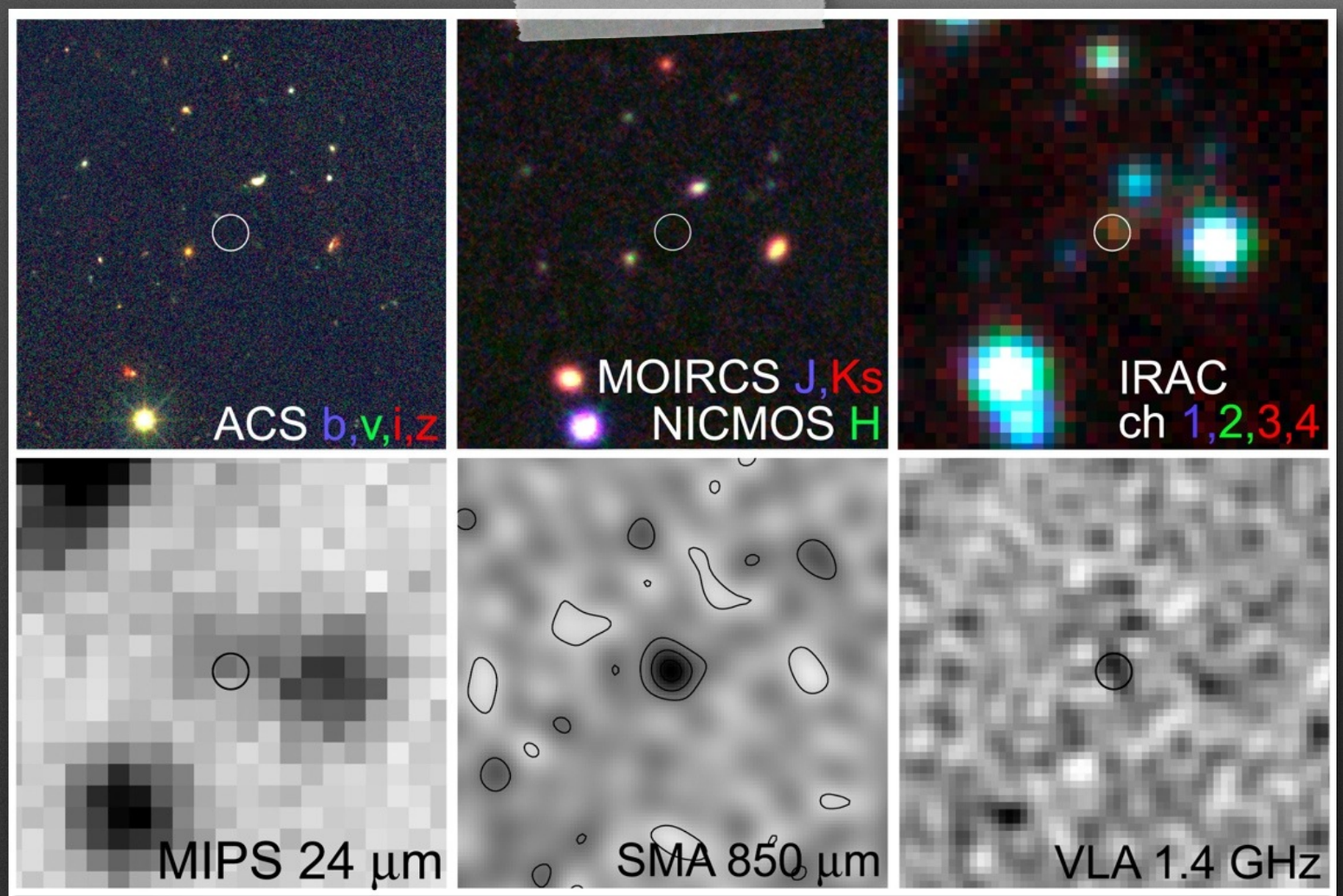


SMA Younger et al. (2007)



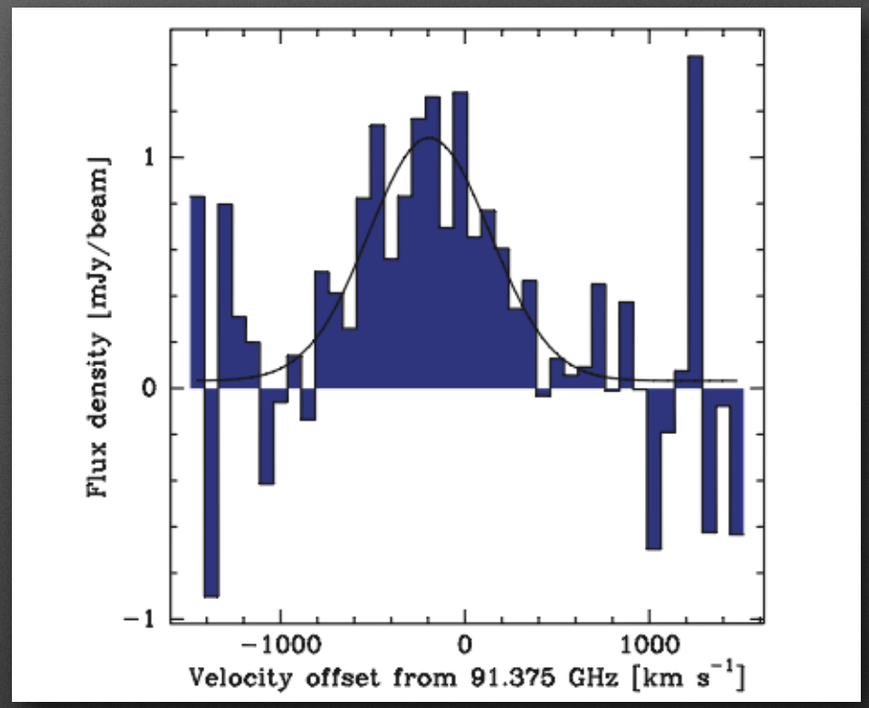
SMA Younger et al. (2009)

Submm-Bright, Radio-Faint Sources



Wang et al. (2007, 2009)

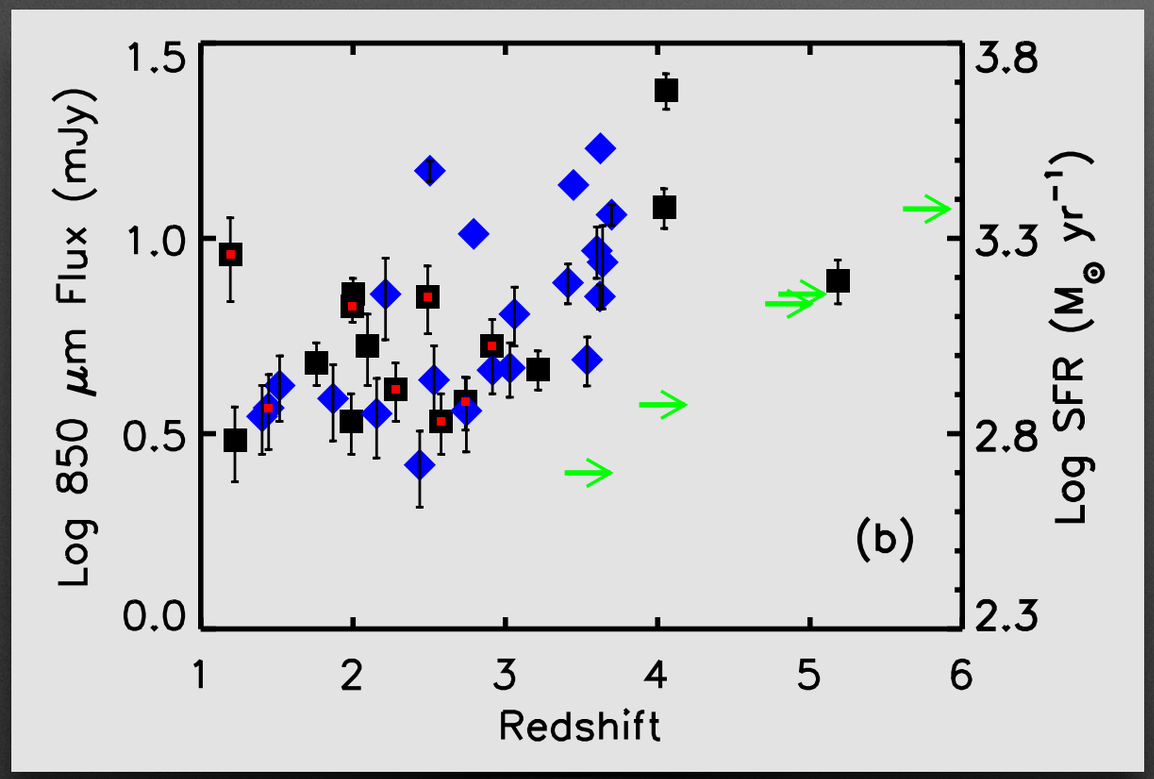
PdBI Detection of CO(4–3):
z = 4.042

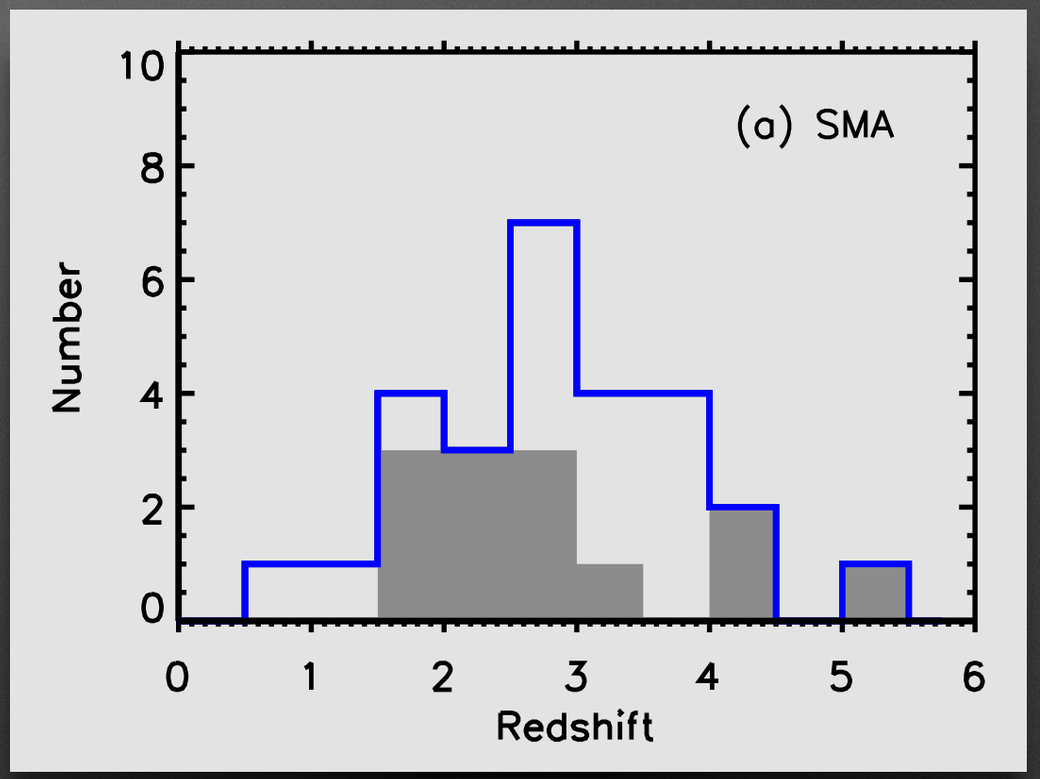


Daddi et al. (2009)

When SMA Meets SCUBA-2

- 49 SCUBA-2 sources in the GOODS-N
  24 SMA identifications, 18 unambiguous radio identifications



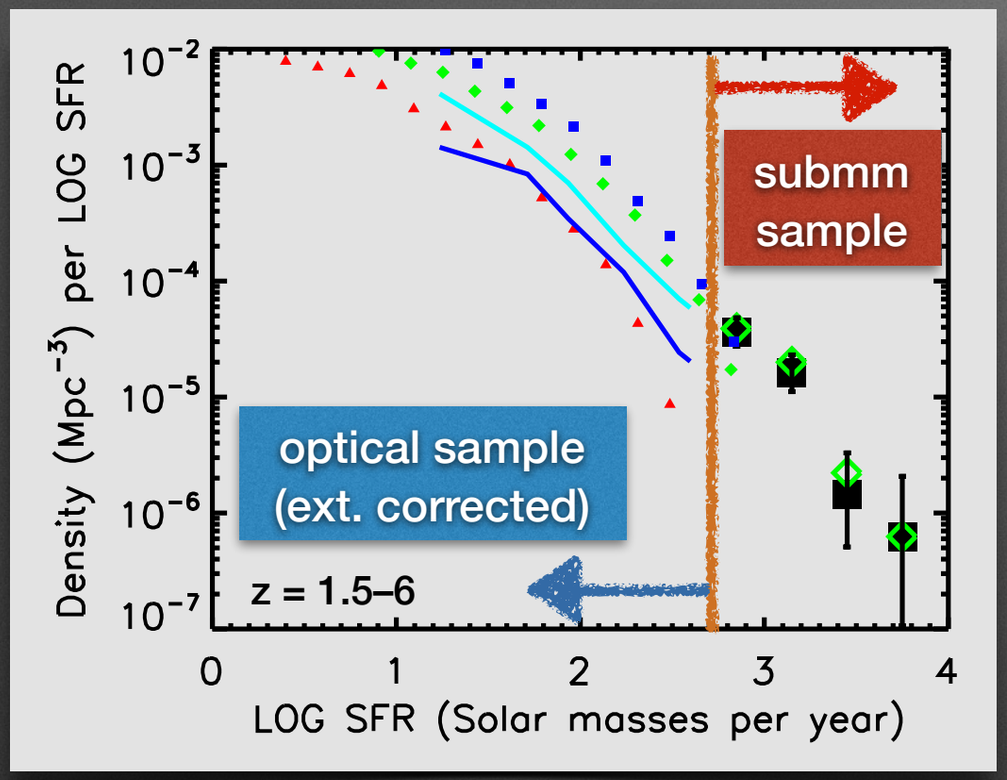


Barger et al. (2014)

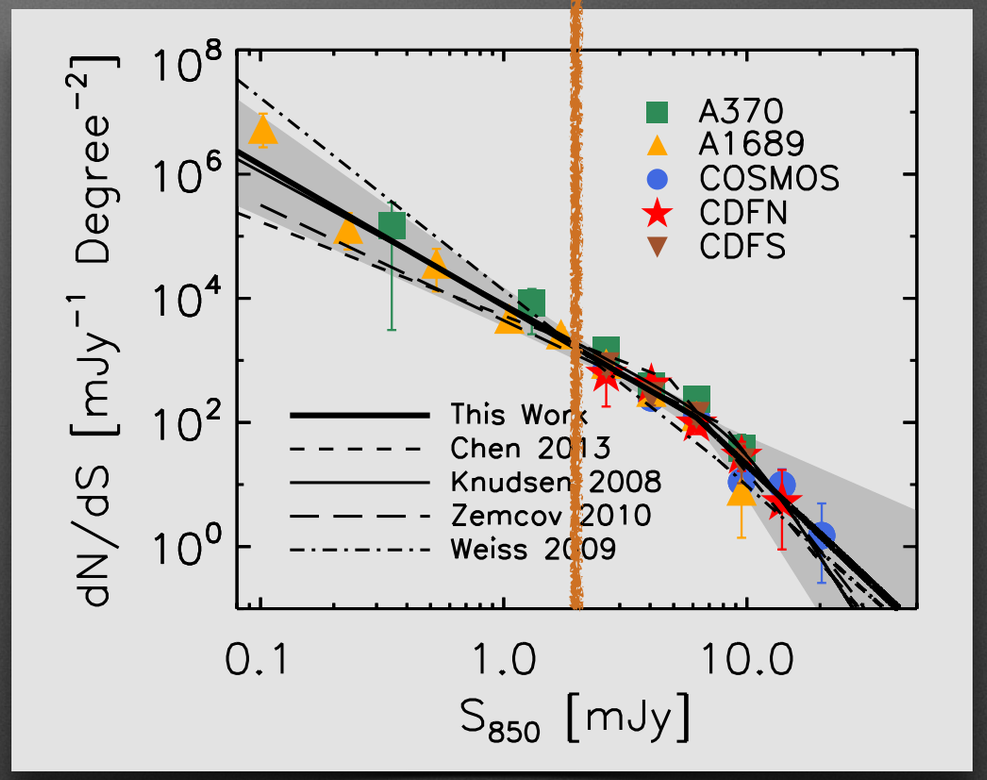
When SMA Meets SCUBA-2

cluster lensed
faint submm sources

blank-fleld
submm sources



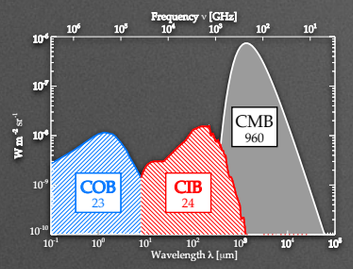
Barger et al. (2014)



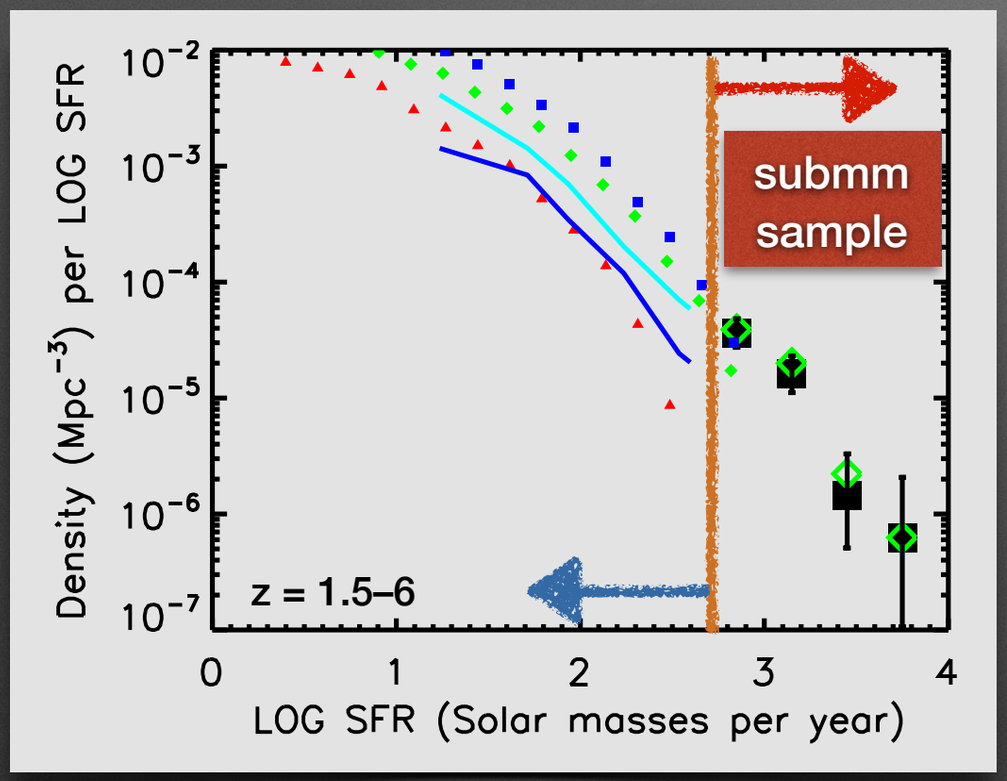
Chen et al. (2013)

- rest-frame UV selected galaxies max out at ~400 $M_\odot$/yr (even after extinction correction)
- 400 $M_\odot$/yr is also the confusion limit of single-dish surveys.
- Are the < 400 $M_\odot$/yr optically selected galaxies also the faint submm sources in the lensed sample?

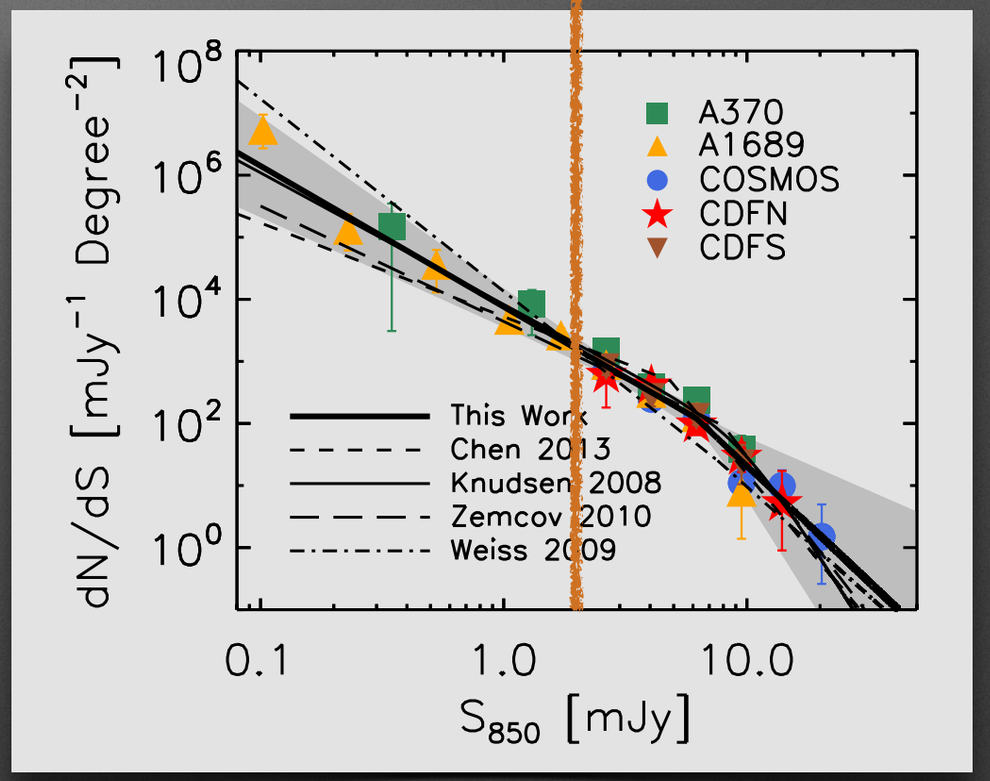
When SMA Meets SCUBA-2



optical sample (ext. corrected) = ? cluster lensed faint submm sources ↔ blank-fleld submm sources



Barger et al. (2014)



Chen et al. (2013)

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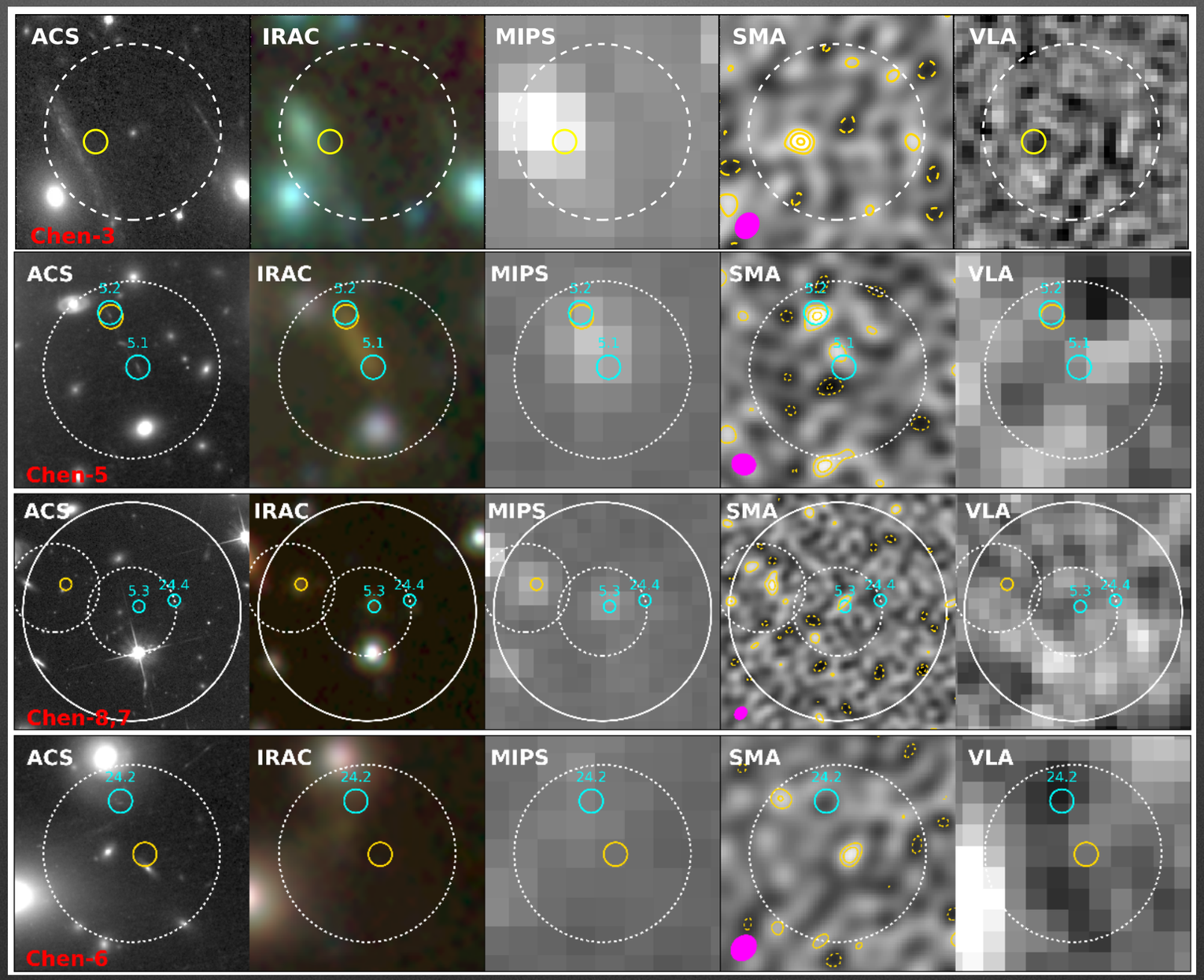
SMA Imaging of Cluster-Lensed SCUBA-2 Sources



Chen et al. (2014)

SMA Imaging of Cluster-Lensed SCUBA-2 Sources

optically faint

ACS detected

optically faint

optically faint

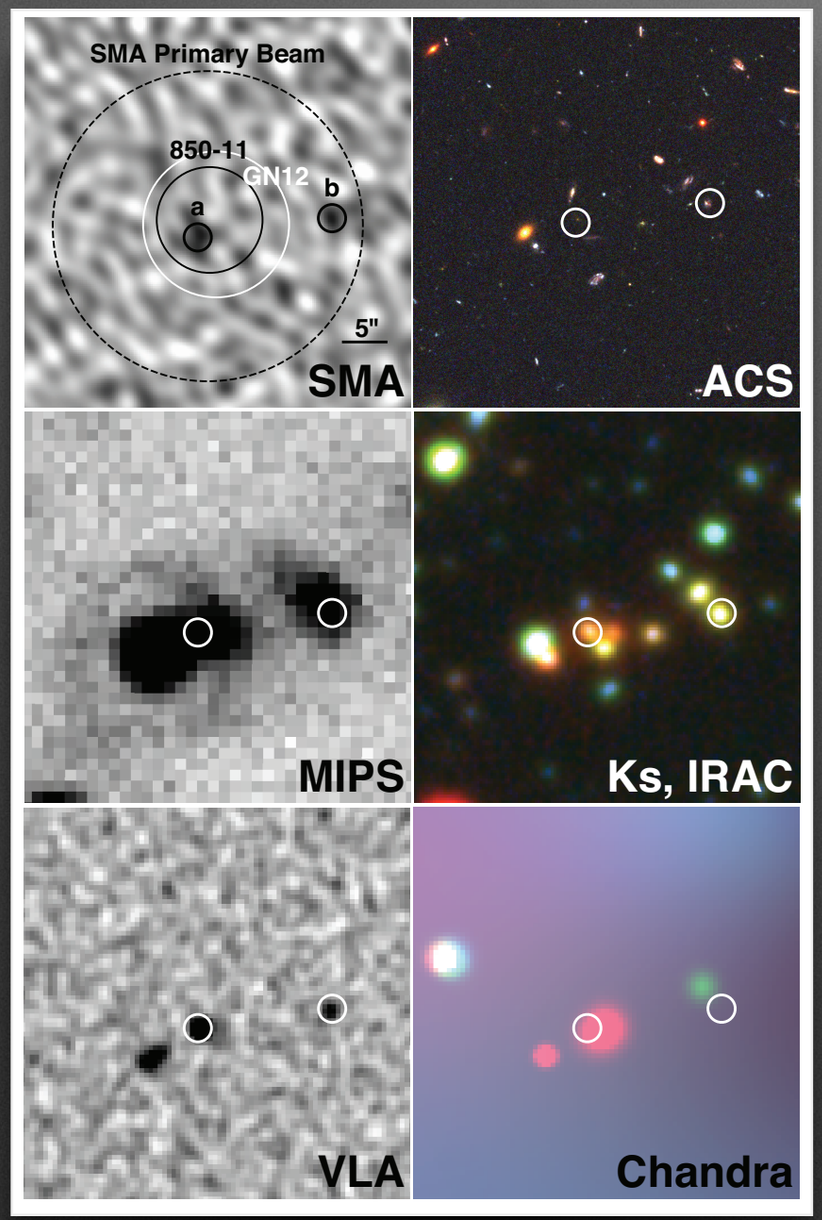
Small sample

Chen et al. (2014)

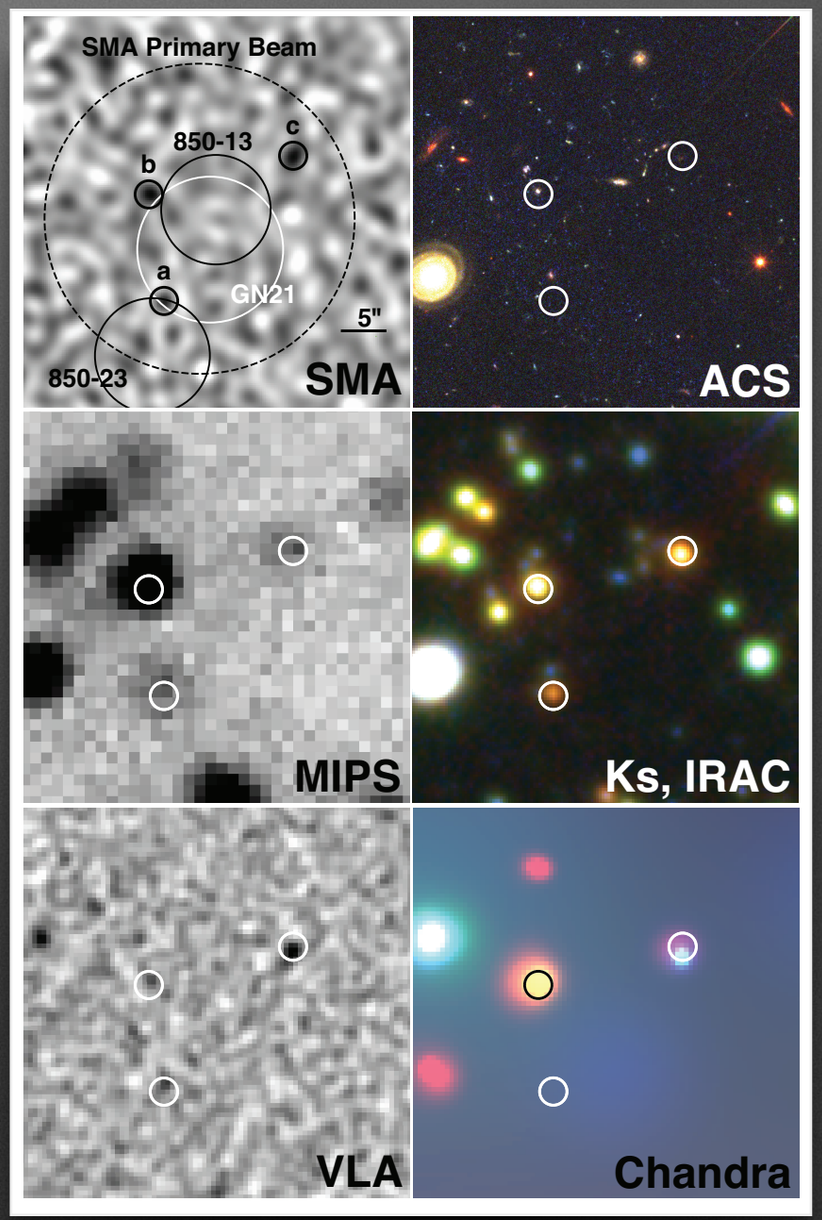
New Capability Brings Surprise

After the bandwidth doubling in 2010…..

GOODS 850-11



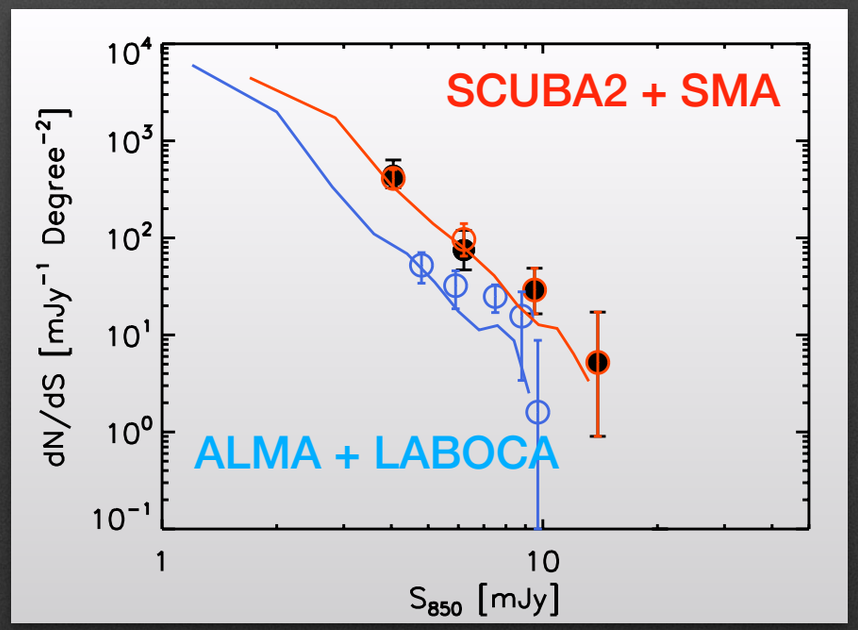
GOODS 850-13



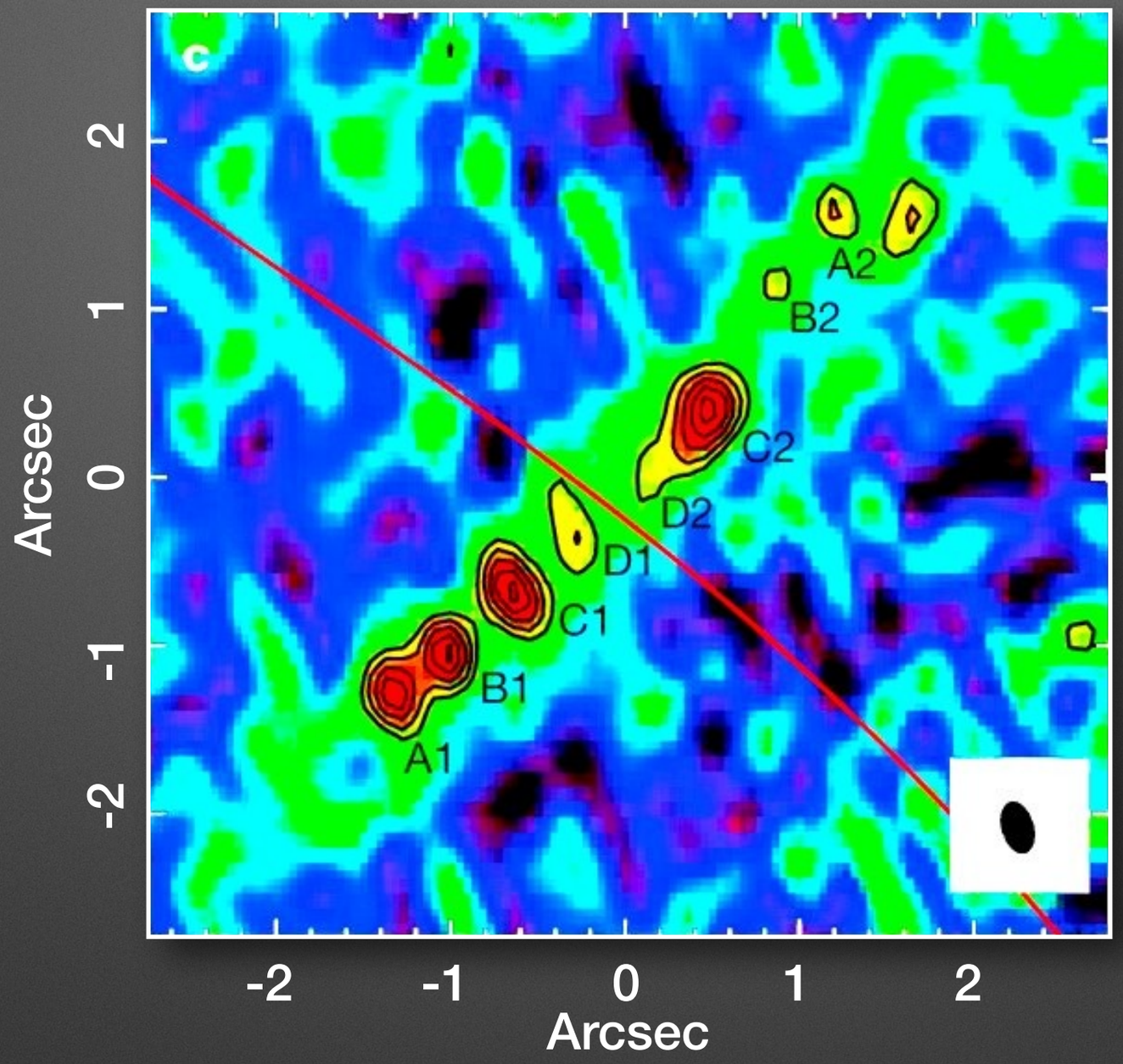
Wang et al. (2011)

Many New Issues

- Fraction of multiple sources, as functions of
  - submm flux
  - single-dish beam size (SCUBA vs. LABOCA vs AzTEC, etc)
  - sensitivity of interferometer (SMA vs. PdBI vs. ALMA)
  - primary beam size of interferometer
- Nature of the multiple sources
  - unassociated galaxies
  - close pairs/groups
- True shape of the source counts



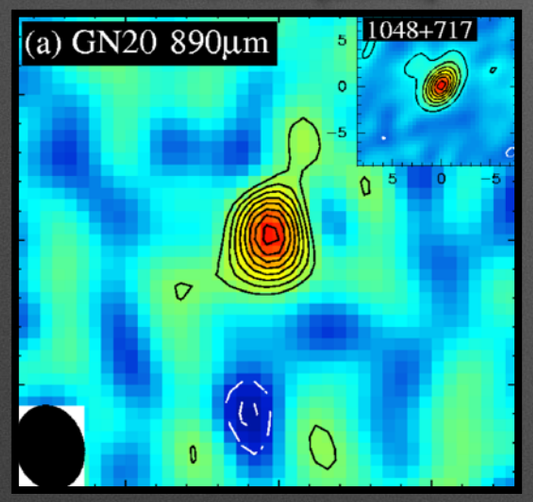
Chen et al. (2013)



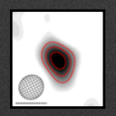
High Resolution Imaging of Submm Sources

Structure of Submm Galaxies

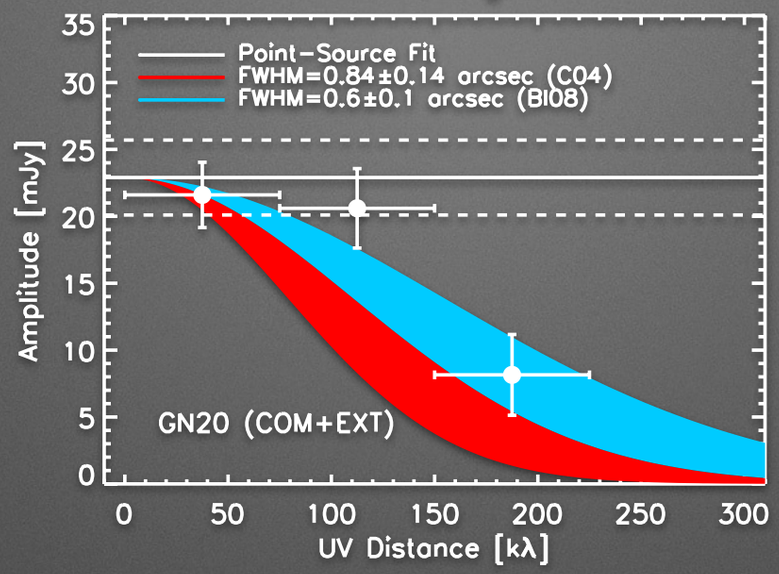
GN20
Iono et al. (2006)



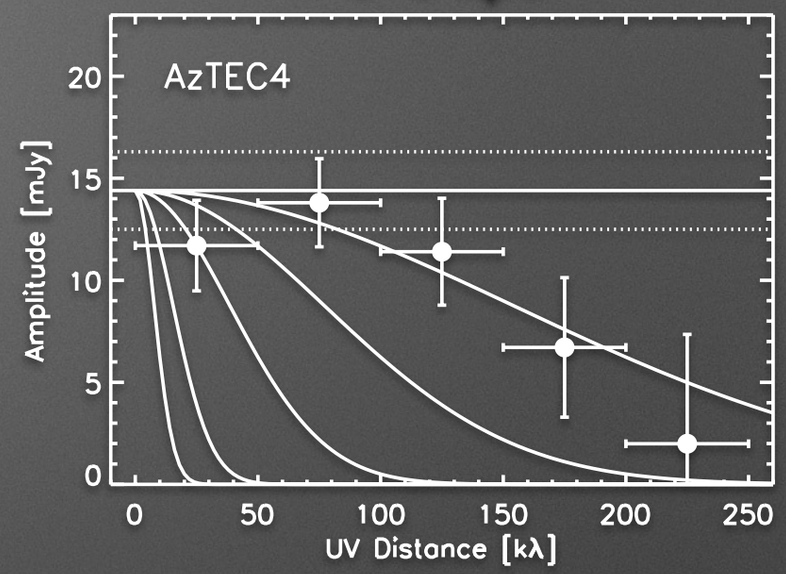
GN20
Younger et al. (2008)



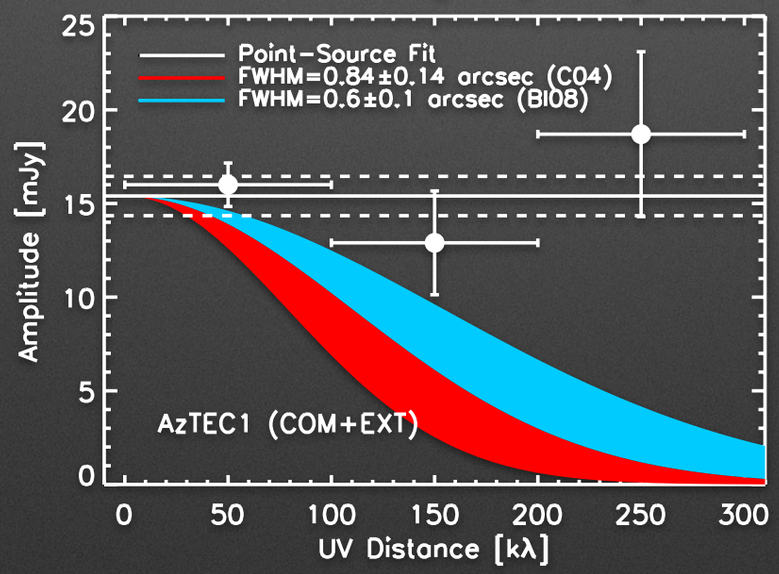
4–8 kpc



5–8 kpc

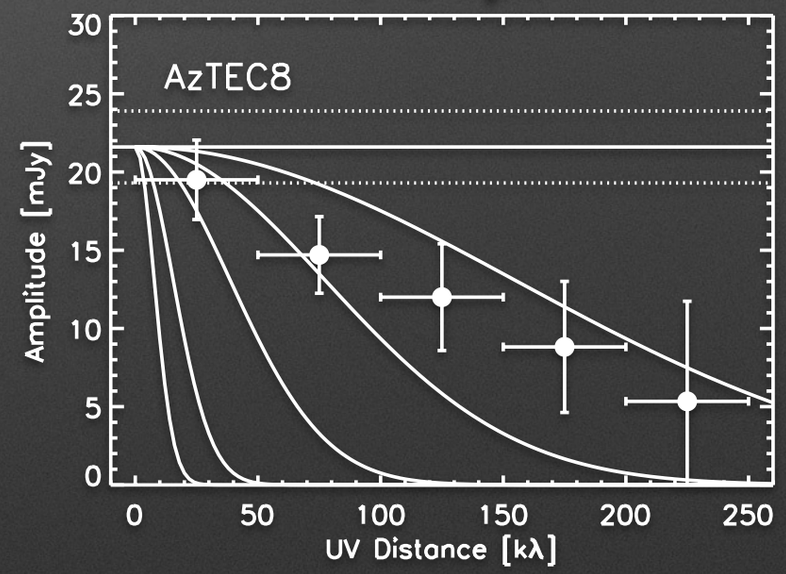


1.5–3 kpc (VEX)



Younger et al. (2008)

5–8 kpc



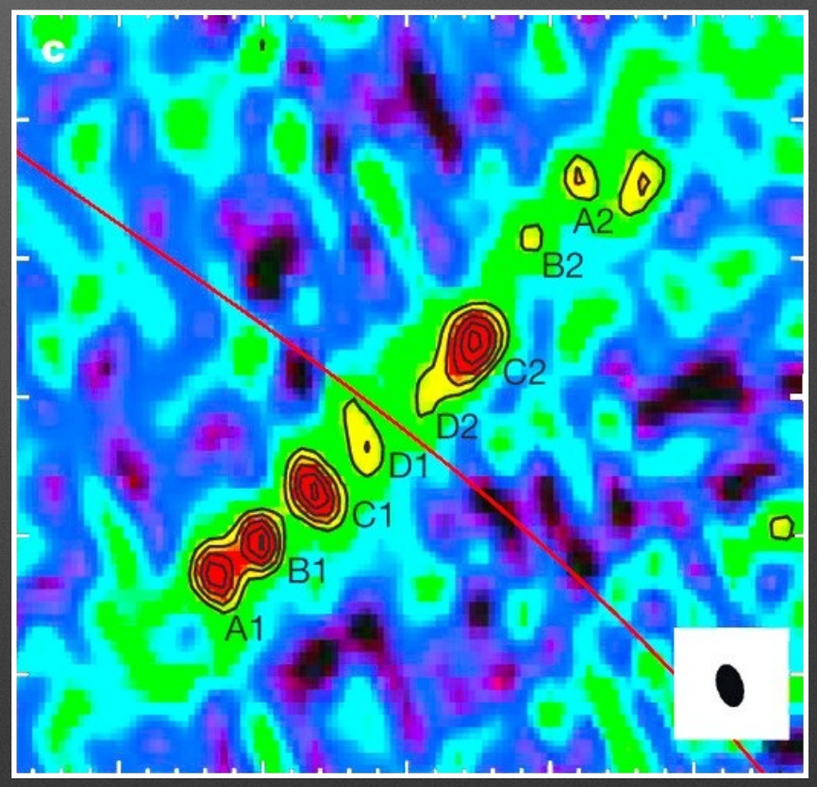
Younger et al. (2010)

- larger than AGN cores, but probably smaller than disks: merger driven?

Cluster-Lensed Submm Source

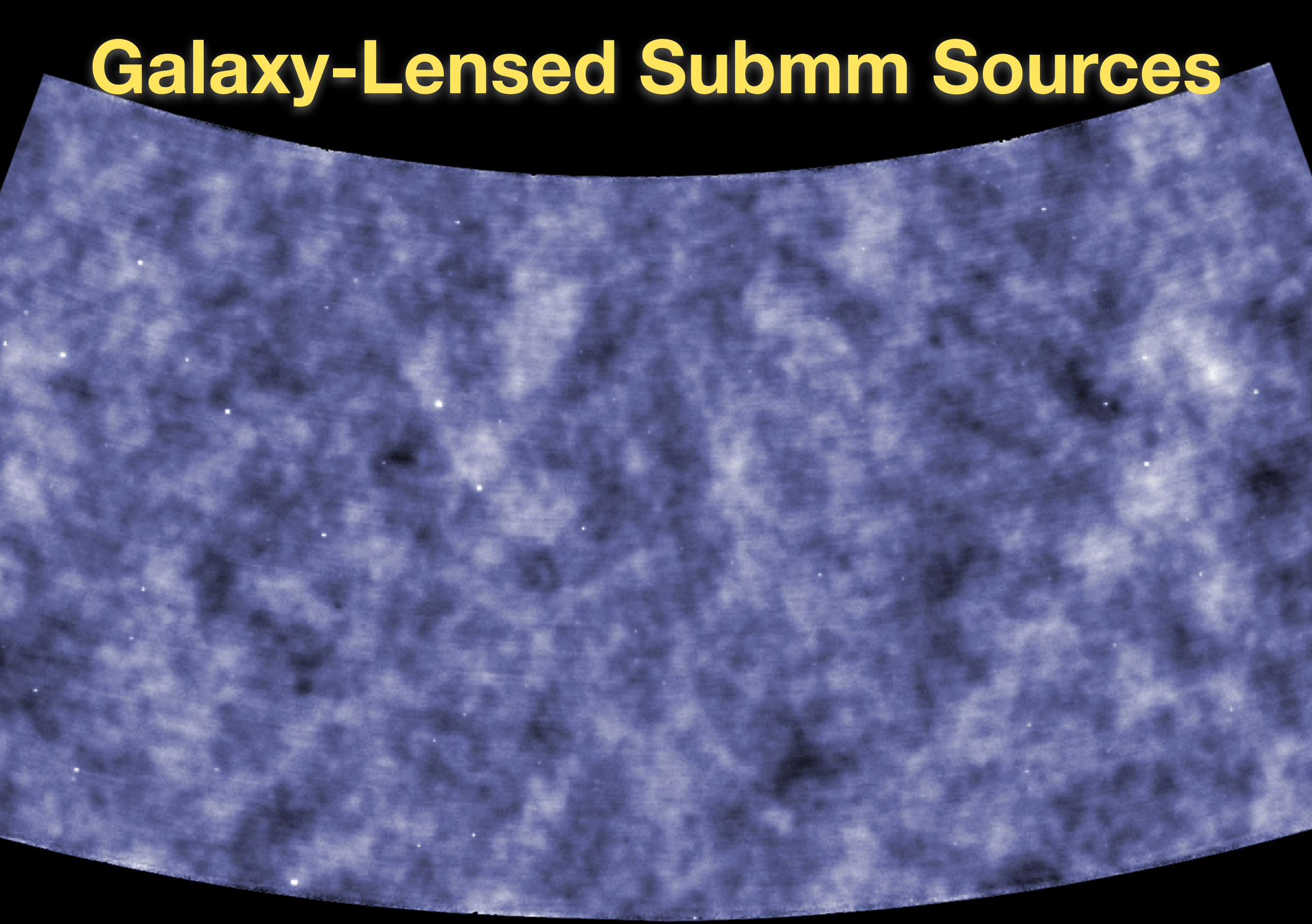
- z = 2.326
- strongly lensed by a z = 0.325 cluster, with μ = 32.5.
- $S_{345,int}$ = 3.0 mJy, SFR = 210 $M_\odot$/yr. (not a typical high-z galaxy, still in the ultraluminous class)
- 1.5 kpc total extent. 100–400 pc for the size of star-forming regions.
- follows the same luminosity density—size relation as in Arp 220

SMA 345 GHz
beam = 0.2″ (90 pc)



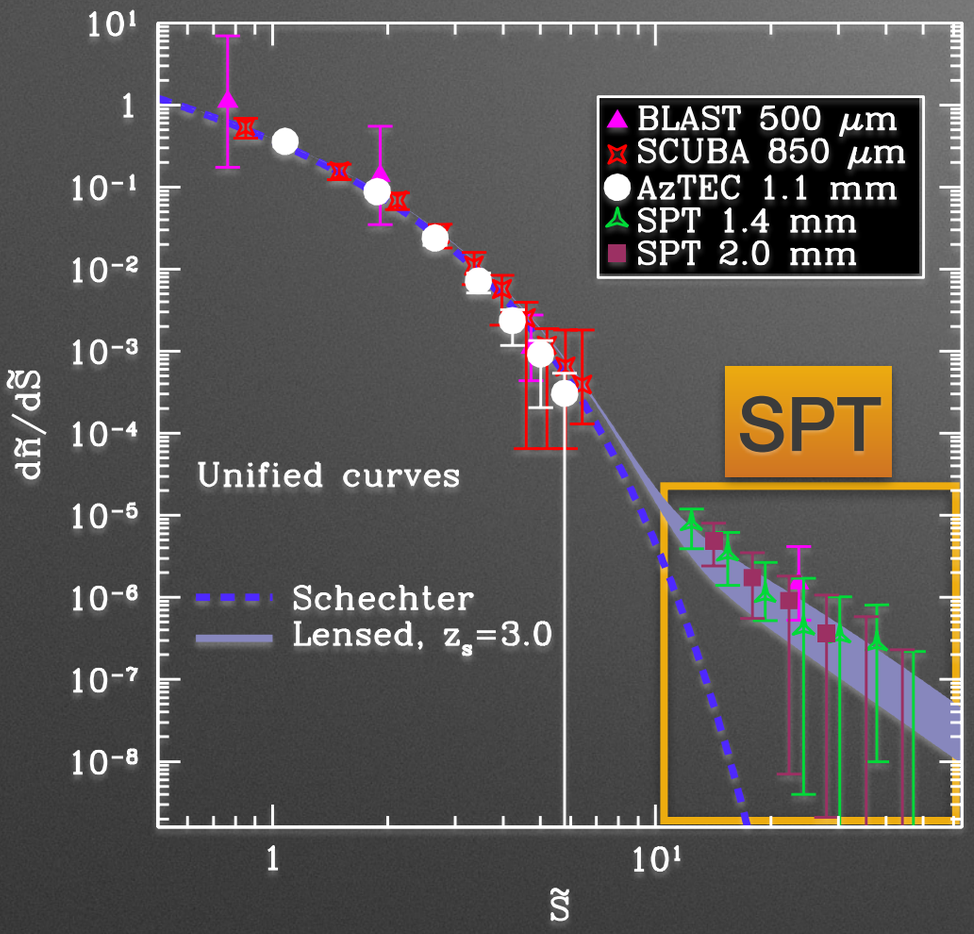
Swinbank et al. (2010)

Galaxy-Lensed Submm Sources



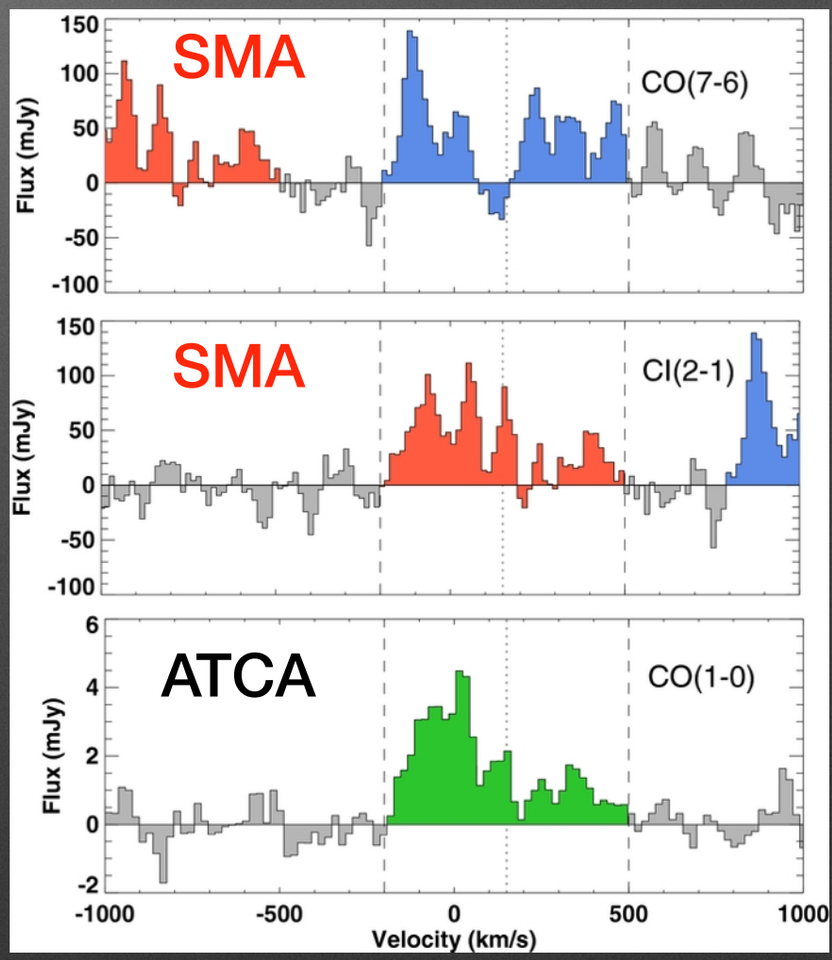
South Pole Telescope

Bright SPT Lensed Sources



Lima et al. (2010)

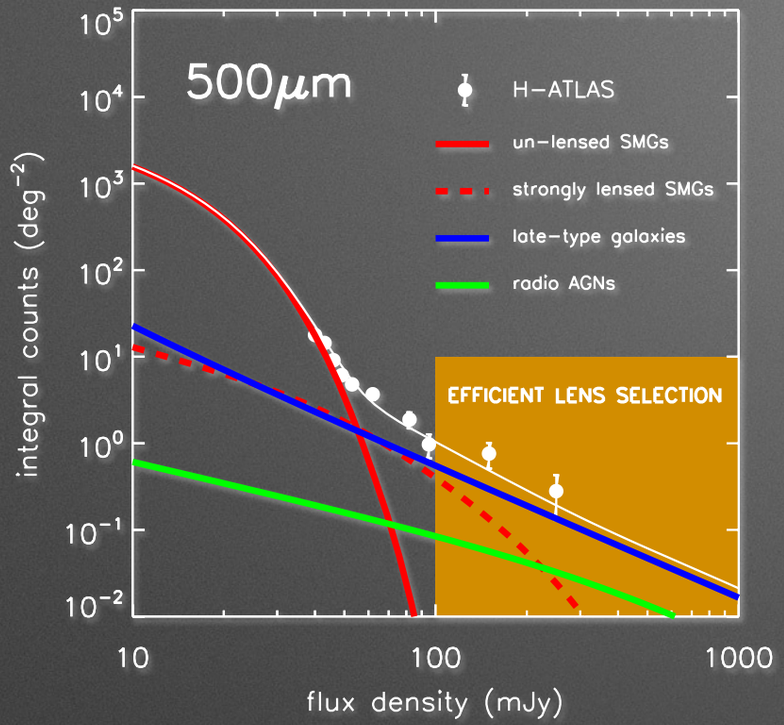
SPT 0538-050
z = 2.782

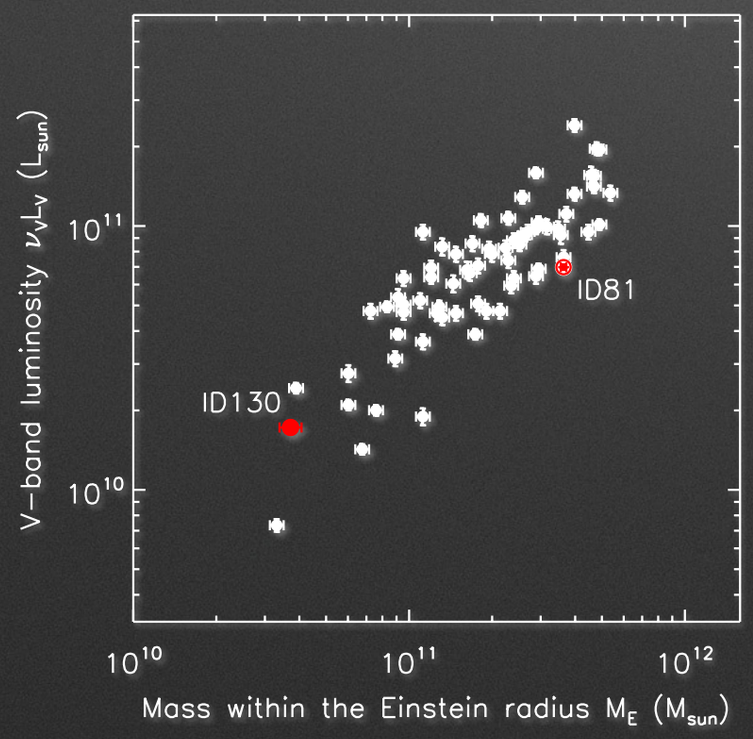


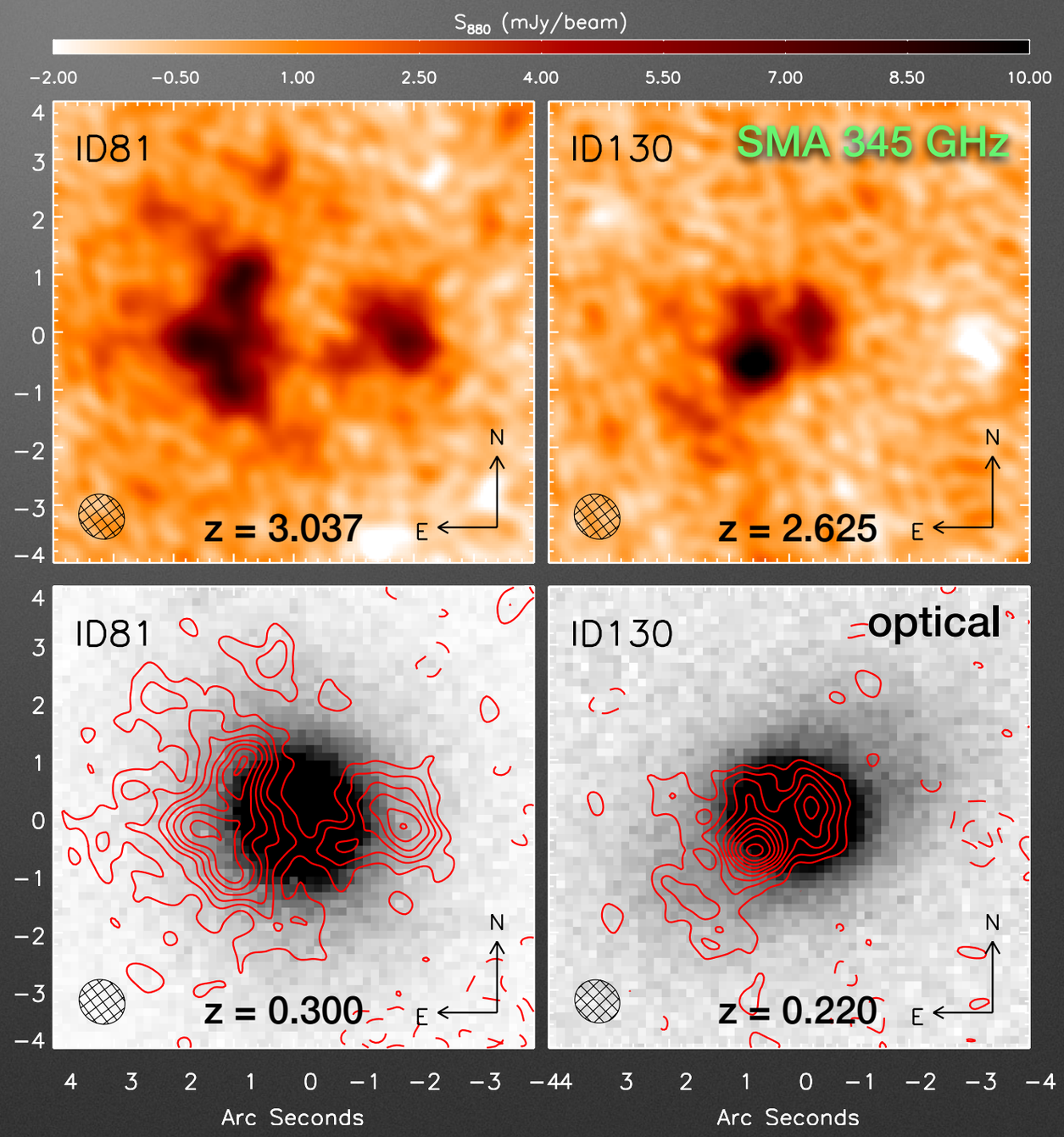
Bothwell et al. (2013)

- **SMA**: many are compact sources sitting on/next to (foreground) massive galaxies.
- Recently better imaged by ALMA.
  (too far south for SMA to make decent images)

Bright Herschel Sources

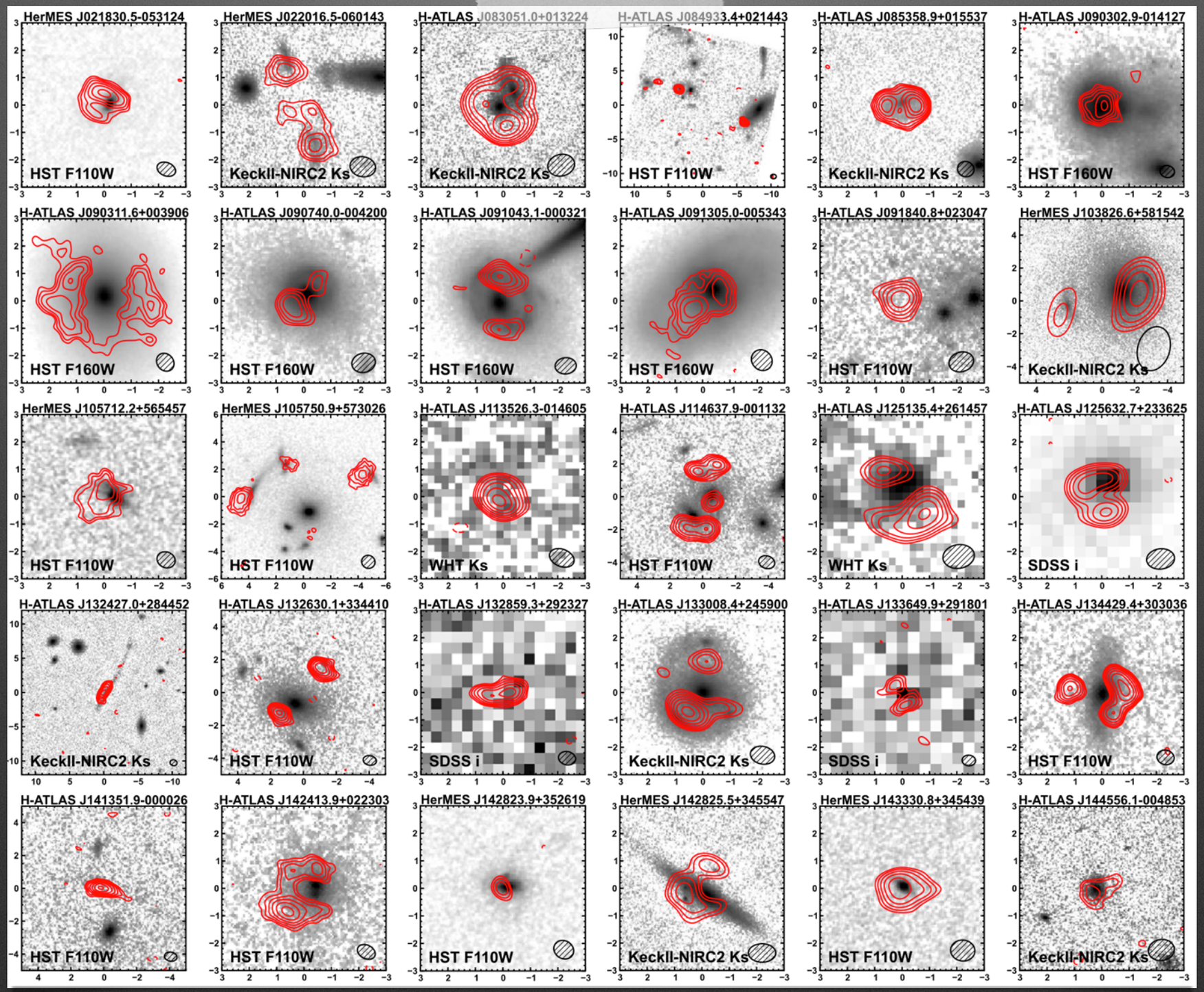






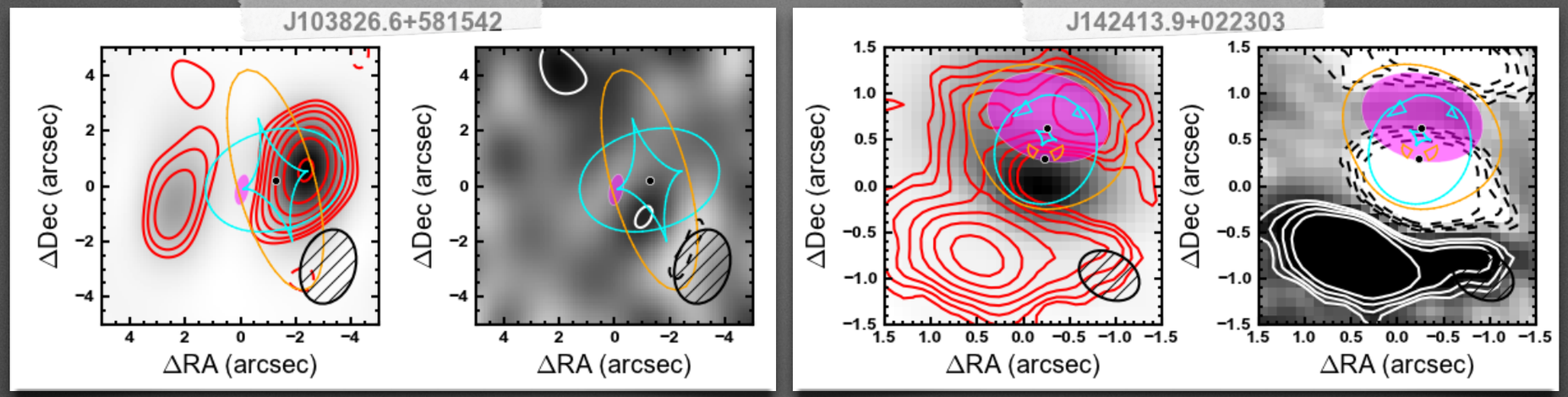
Negrello et al. (2010)

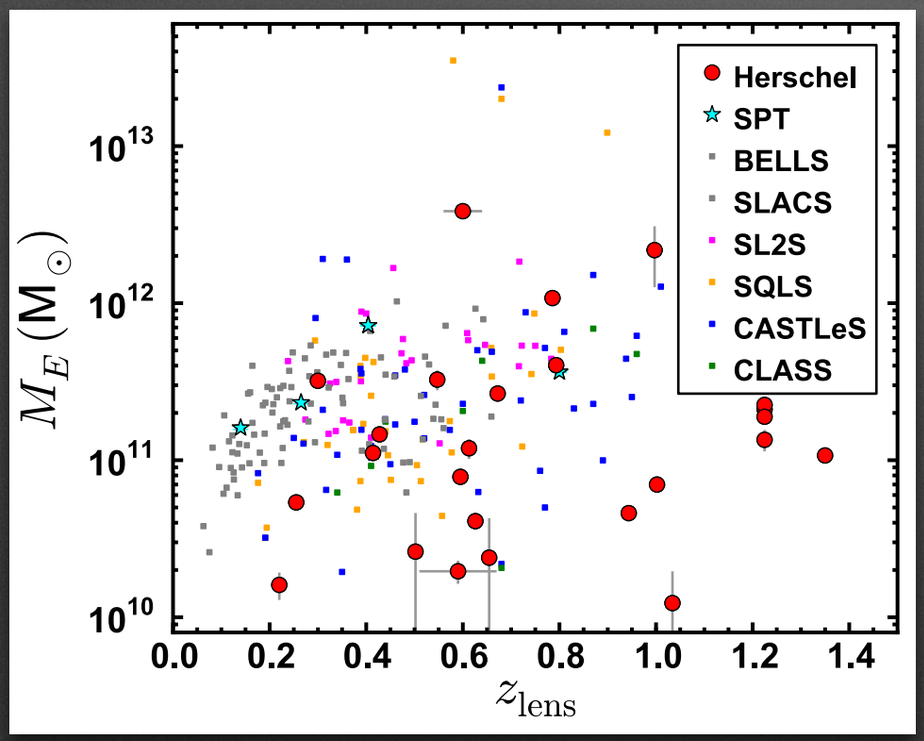
Bright Herschel Sources

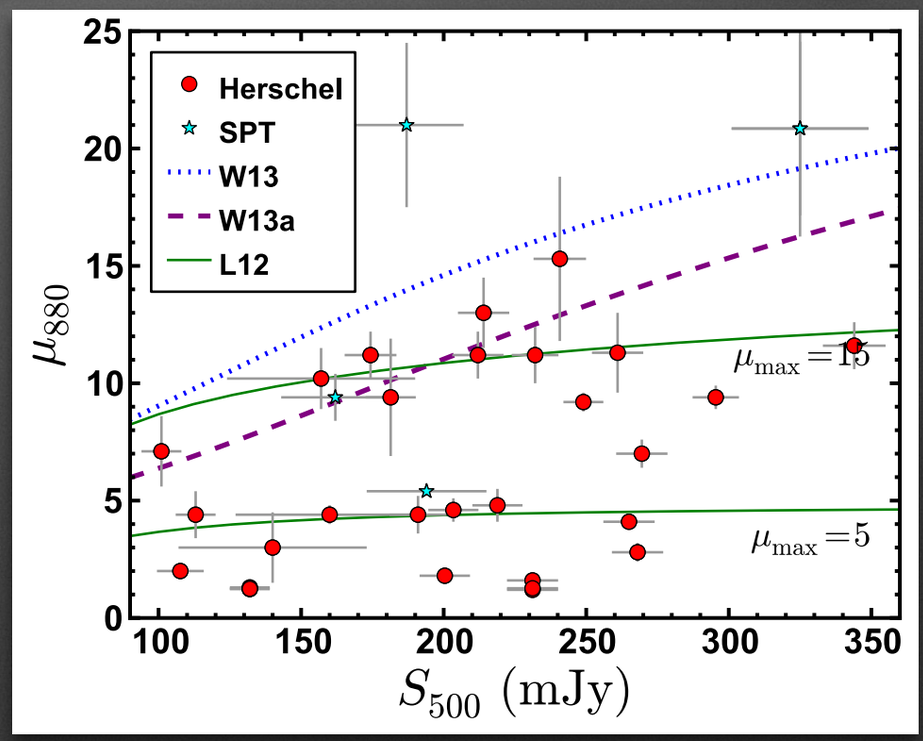


Bussmann et al. (2013)

Bright Herschel Sources

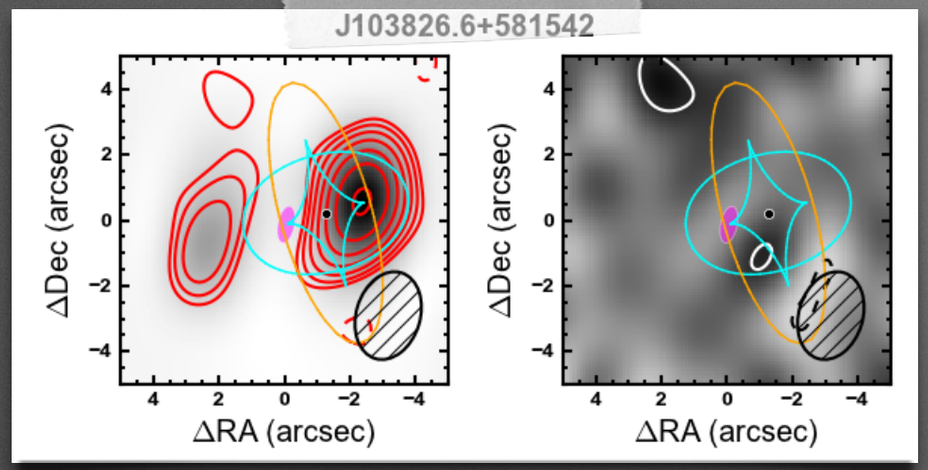


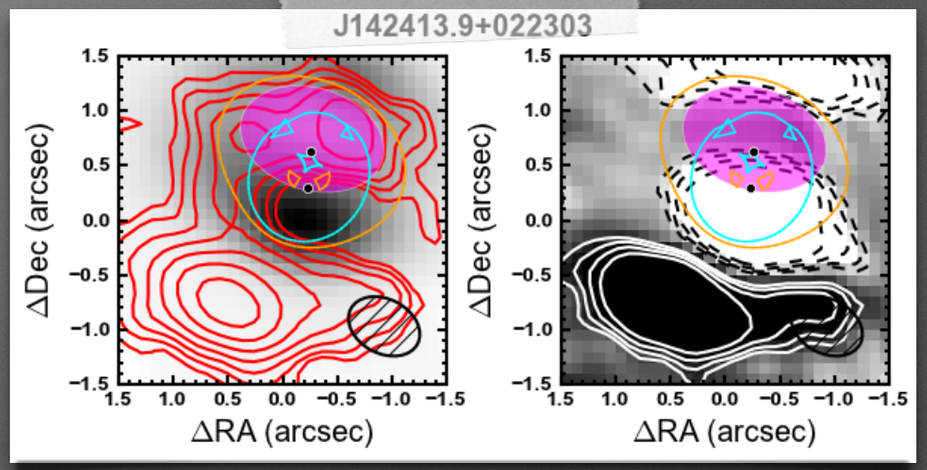


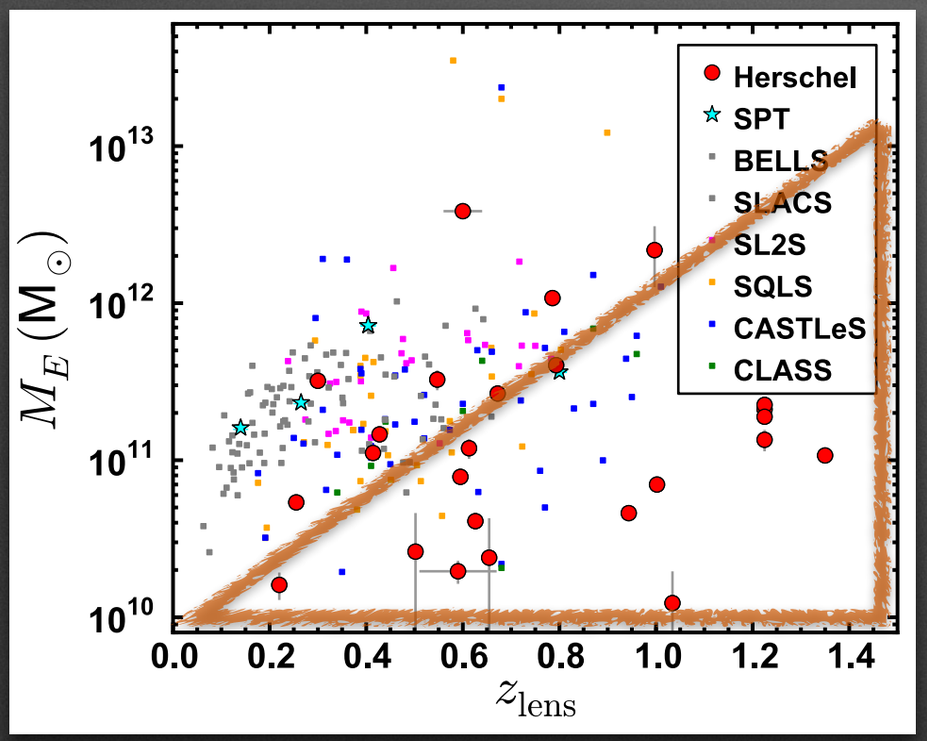


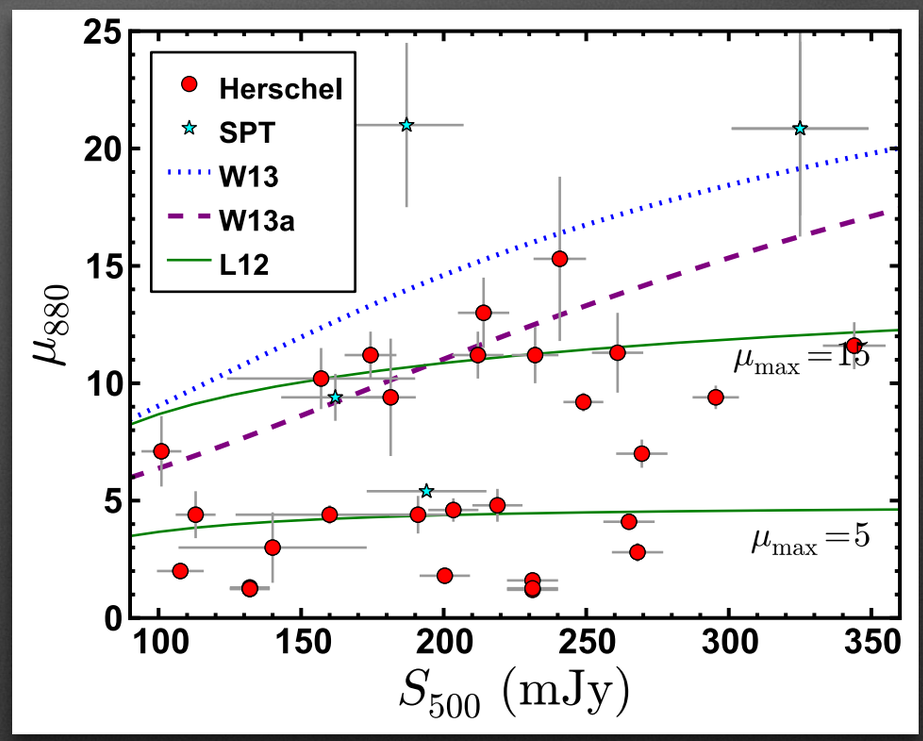
Bussmann et al. (2013)

Bright Herschel Sources





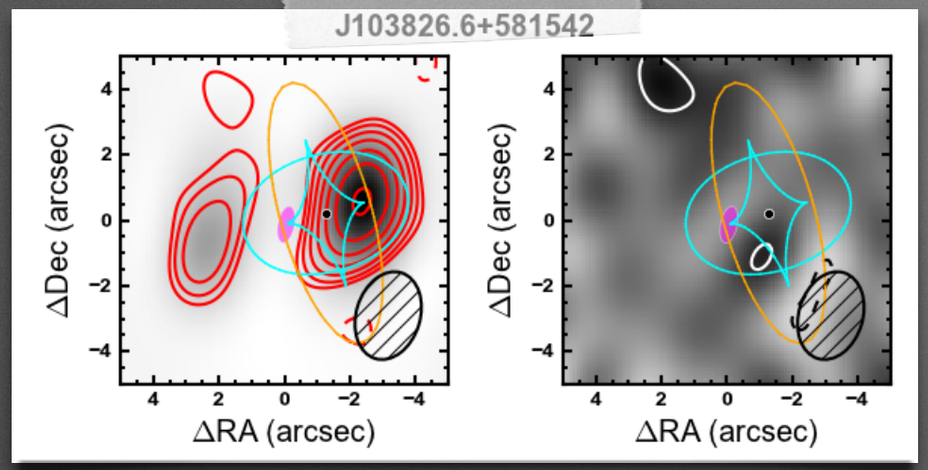


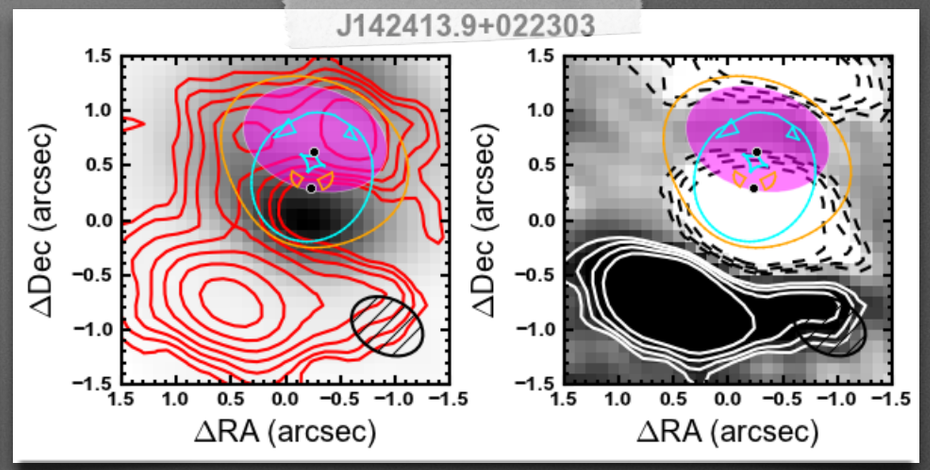


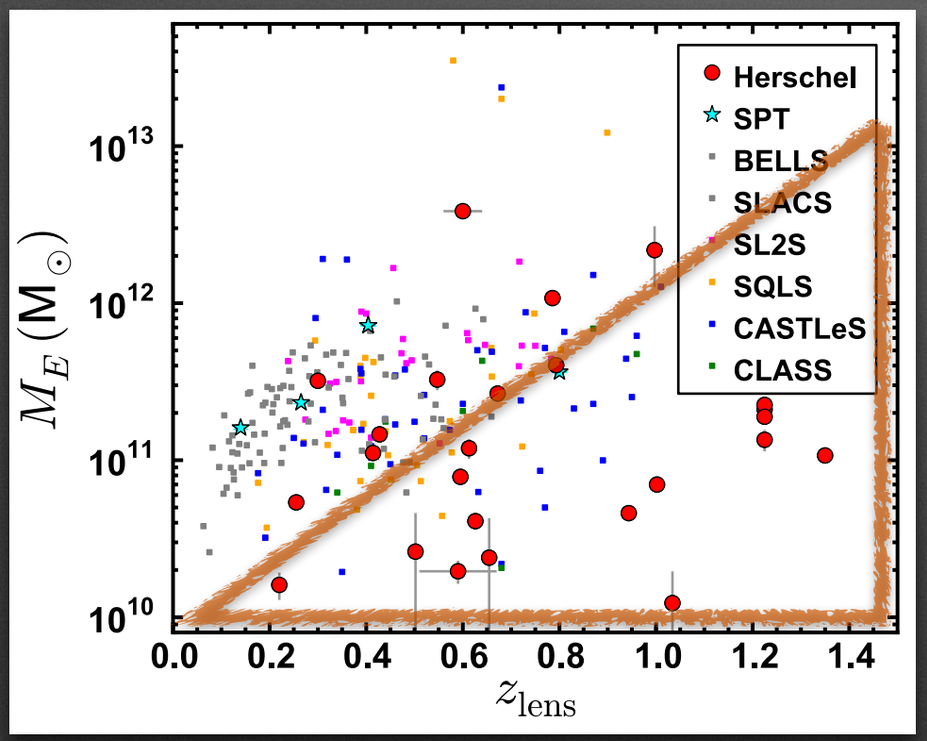
new parameter space
opened up by Herschel+SMA
dark matter models, IMF, etc

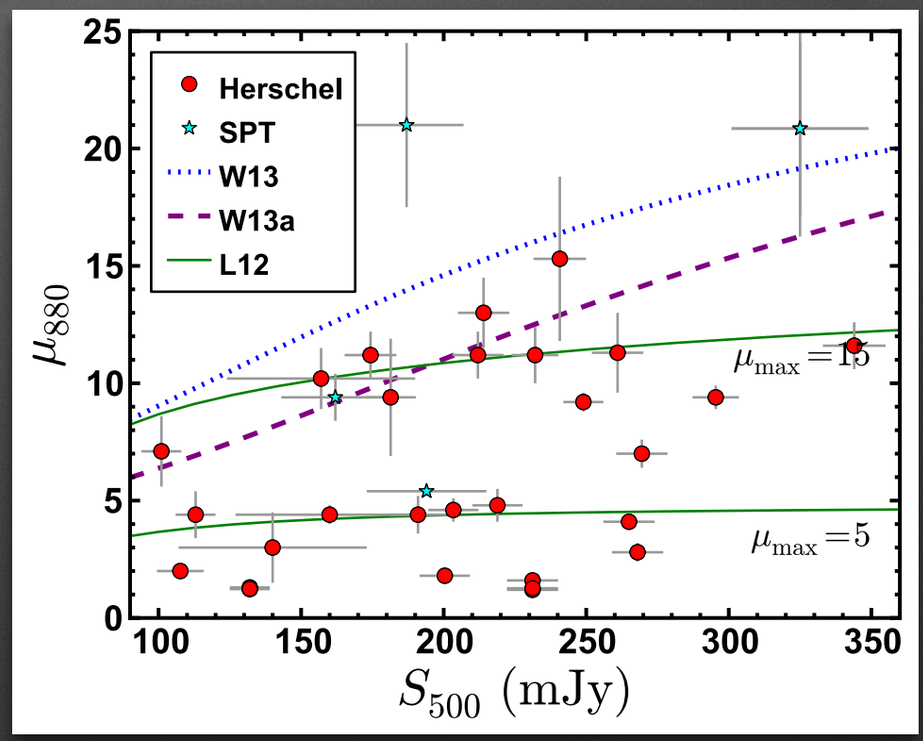
Bussmann et al. (2013)

Bright Herschel Sources









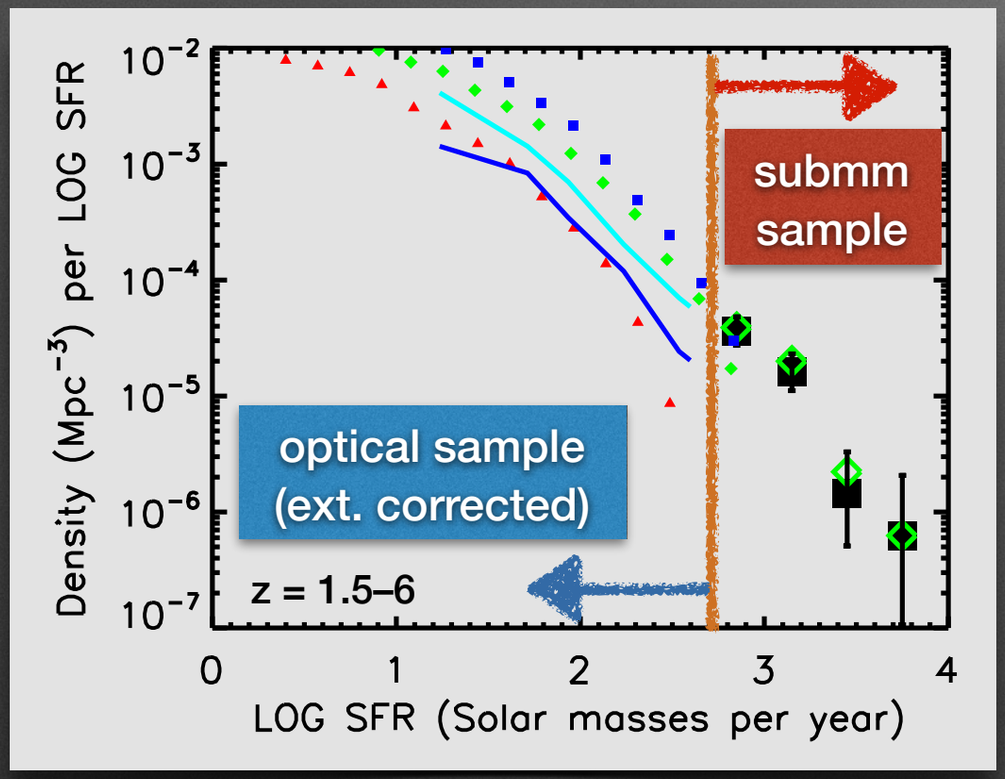
new parameter space
opened up by Herschel+SMA
dark matter models, IMF, etc

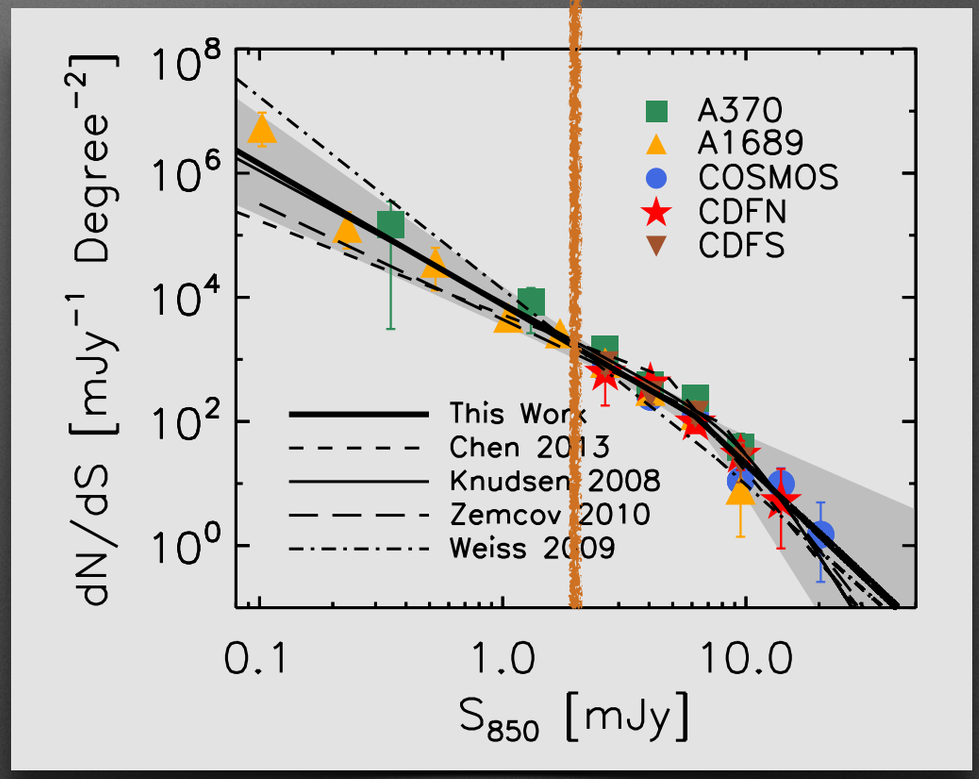
- Typical lensing factor = 2 to 20
- They are still intrinsically ultraluminous.

Bussmann et al. (2013)

Galaxy vs. Cluster Lensing

optical sample (ext. corrected) ? = cluster lensed faint submm sources → blank-fleld submm sources

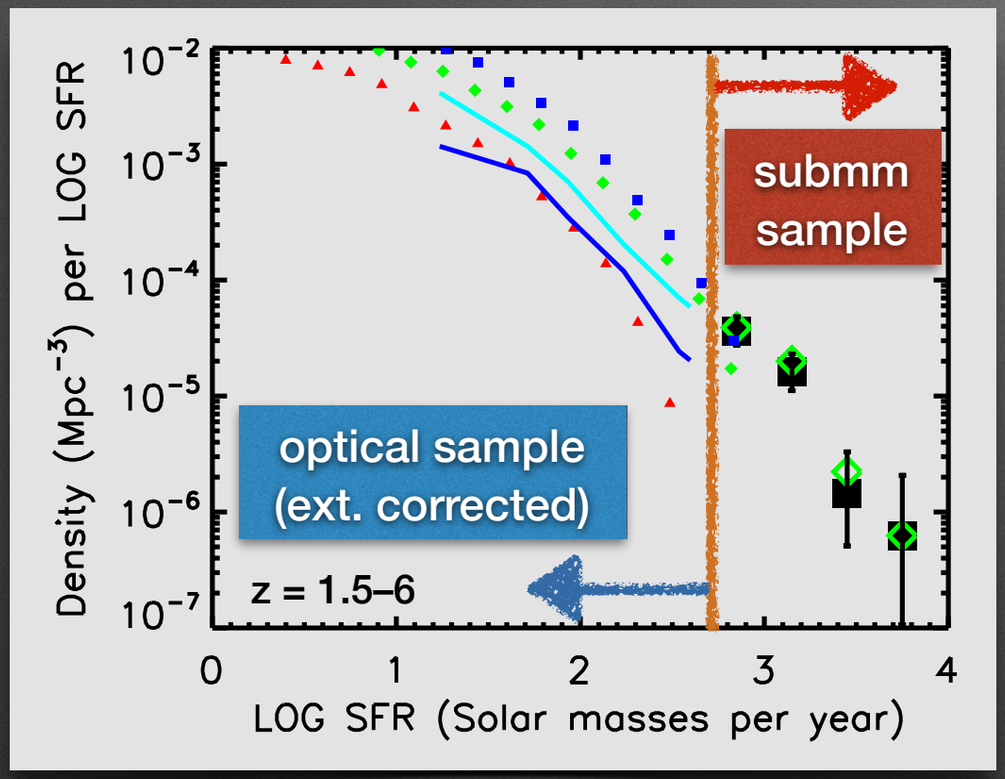


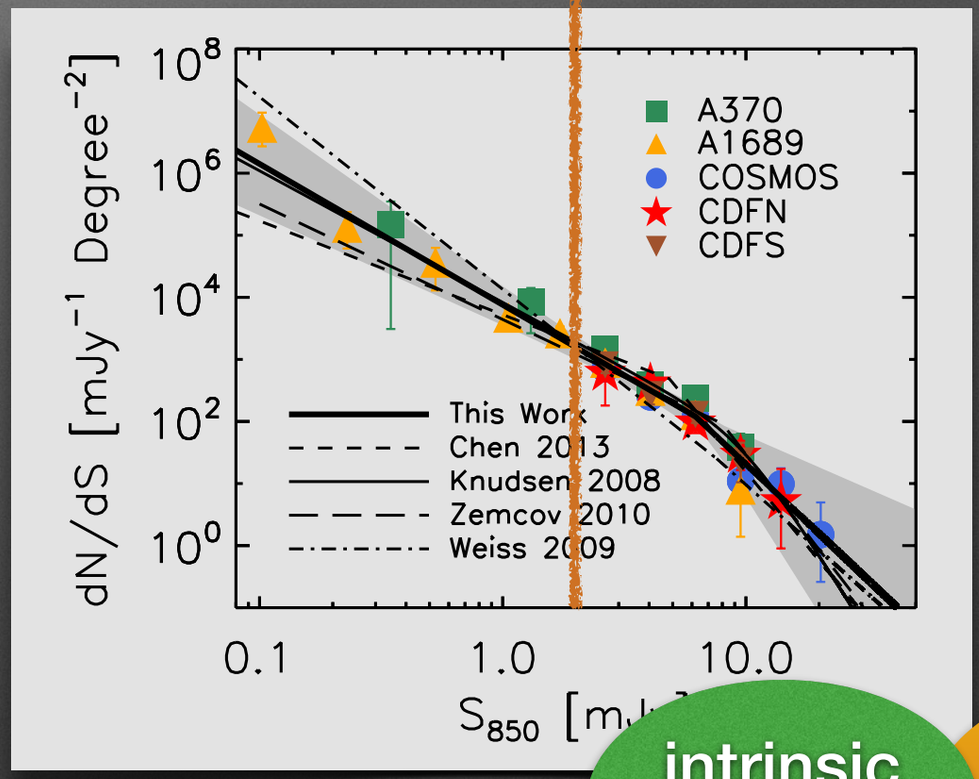


Galaxy vs. Cluster Lensing

optical sample (ext. corrected) ? = cluster lensed faint submm sources

blank-fleld submm sources





intrinsic flux

observed flux

Herschel Bright Sources

- Bright, galaxy-lensed submm samples do not probe the < 100 400 $M_{\odot}$/yr regime.
- We still need faint, cluster-lensed samples.

Summary

- SMA has played a critical role in the following topics:
  - more complete redshift distribution of submm galaxies
  - true shape of the submm counts and multiplicity
  - structure of submm galaxies
  - high-z galaxy masses measured with lensing
  - nature of faint submm sources and optically selected galaxies?
- SAO, ASIAA, UH, and external users all have produced major results.

Future Prospect

- The SWARM correlator will soon further double SMA's bandwidth. New surprises?
- Even broader bandwidth in the future?
  Good for continuum and line (CO, [CII]?) survey can enable new studies.
- SMA remains the only submm interferometer in the north (HDF, Lockman Hole…).