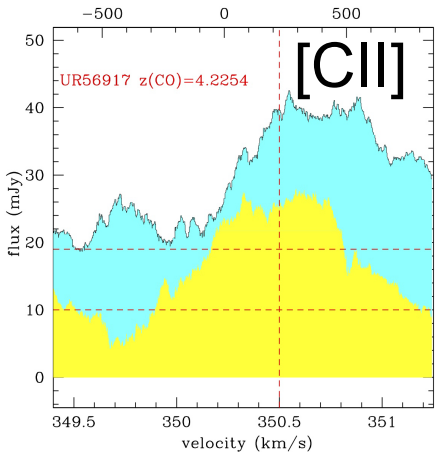
High redshift science with the SMA

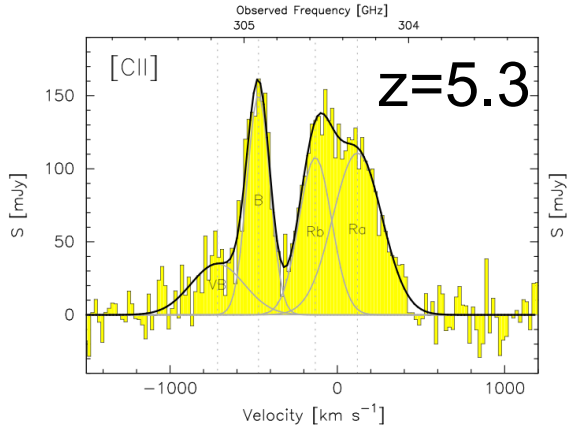


Scott Chapman

Dalhousie University

SMA science in the Next Decade

ASIAA 2016 Oct 27



Outline

Intro to high-z SMGs

SMA IDs

SMA lines

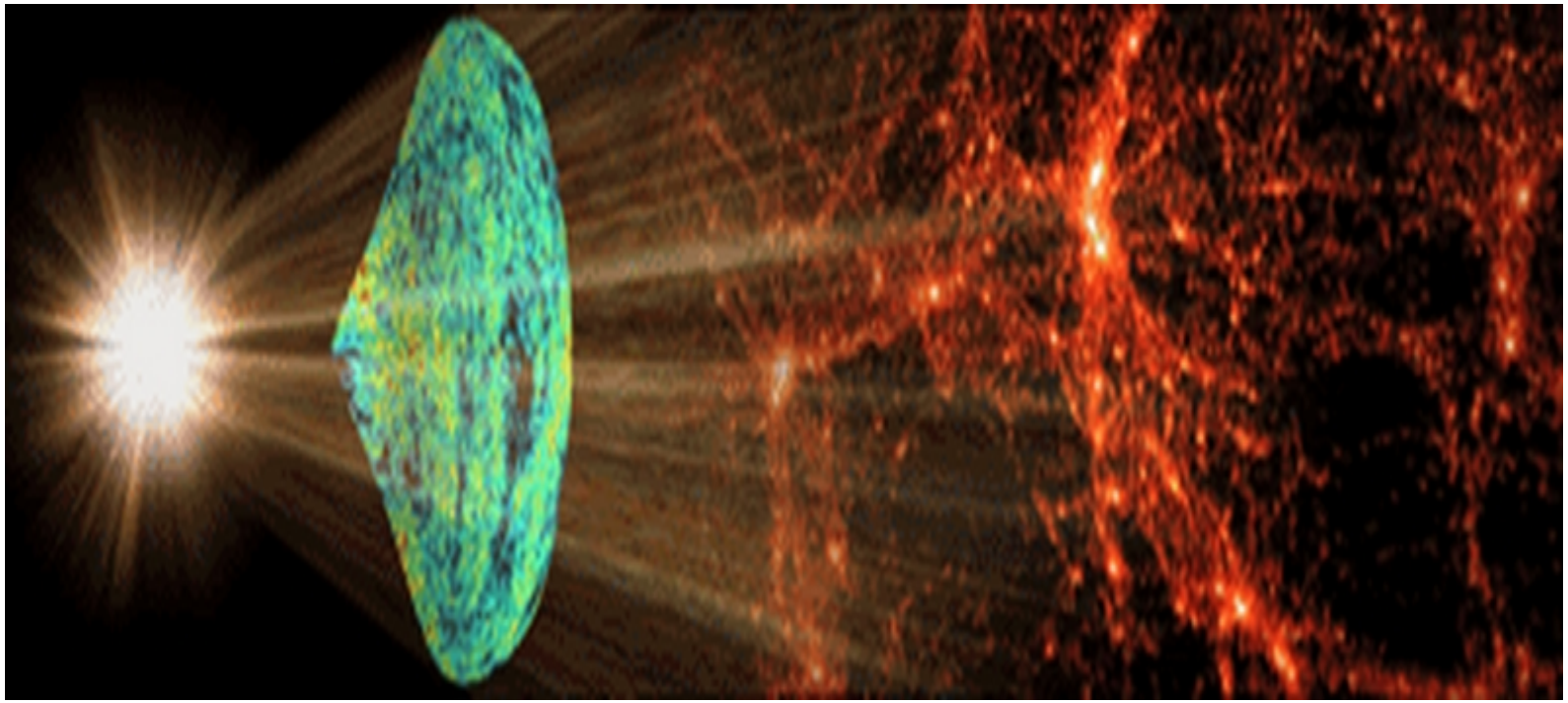
Future IDs

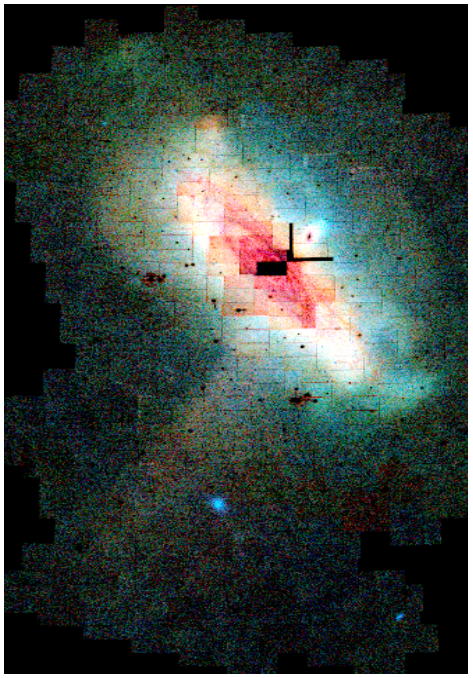
Future line surveys

Conclusion

Context: *Hierarchical Galaxy Formation*

(How/when are the galaxy components assembled?)

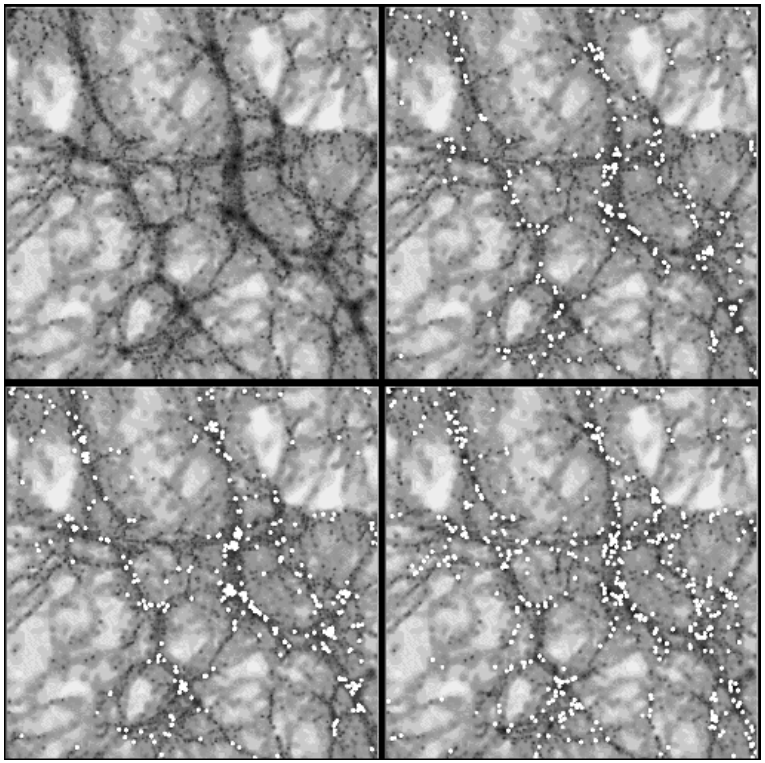




Big Bang … Cosmic Microwave Background …

… Galaxy Formation and Evolution … Fossil Records today!

Submm/Far-IR is a superb probe of forming galaxies

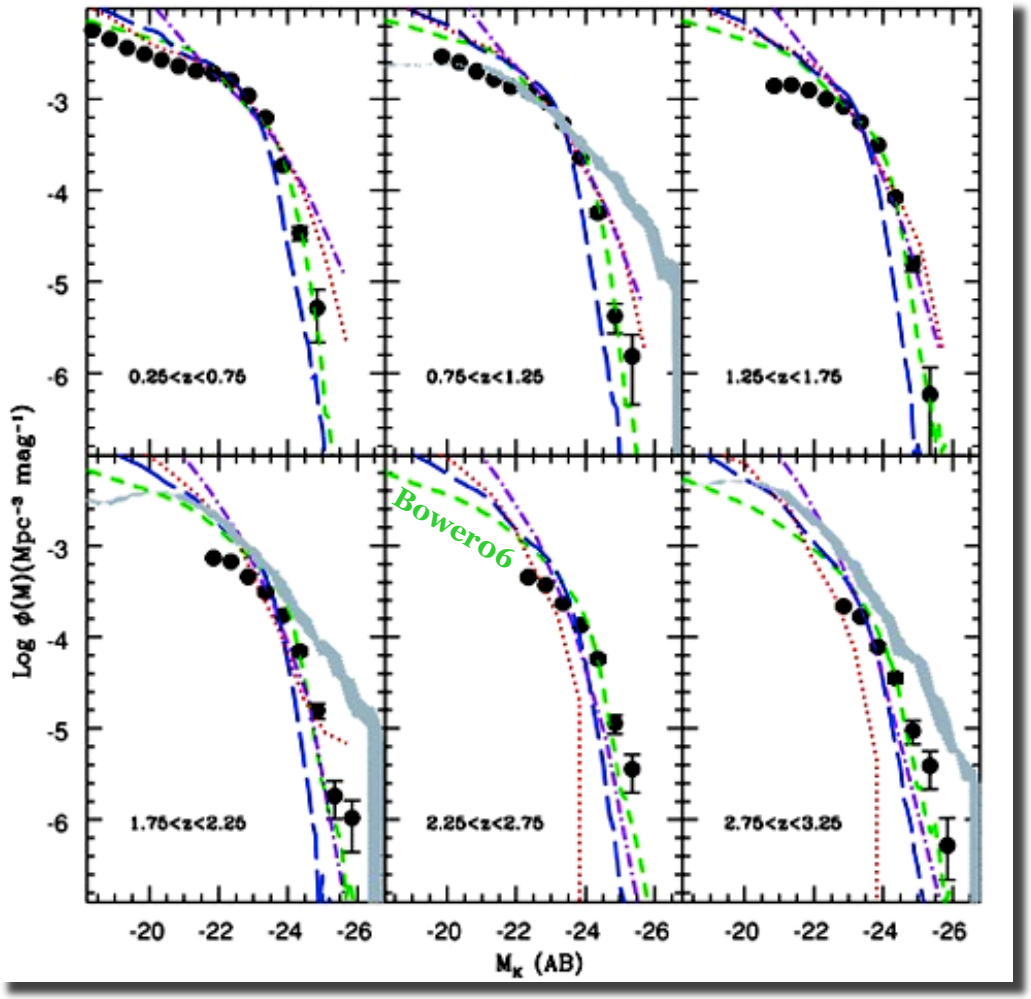


Complex interplay between

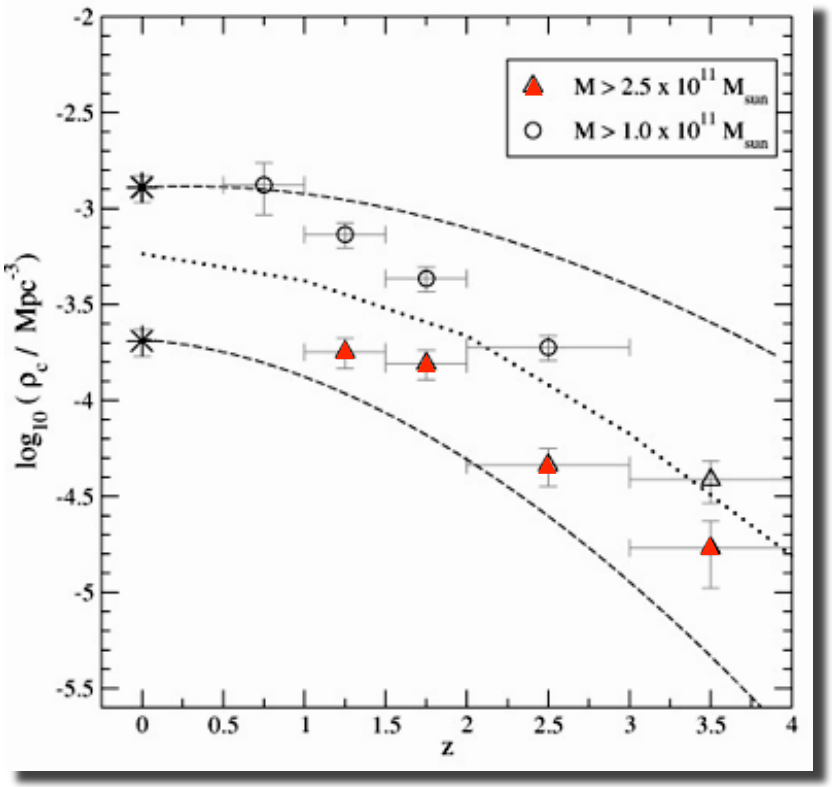
- hierarchical merging of virialized DM halos,
- accretion and cooling of gas onto newly formed galaxies within the halos,
- formation of stars in self-gravitating dense gas clouds in these galaxies,
- metal-enriched gas outflows driven by massive stars, supernovae, and accreting supermassive black holes in nuclei

Things we know: Massive galaxies at high z

Cirasuolo et al. 2010



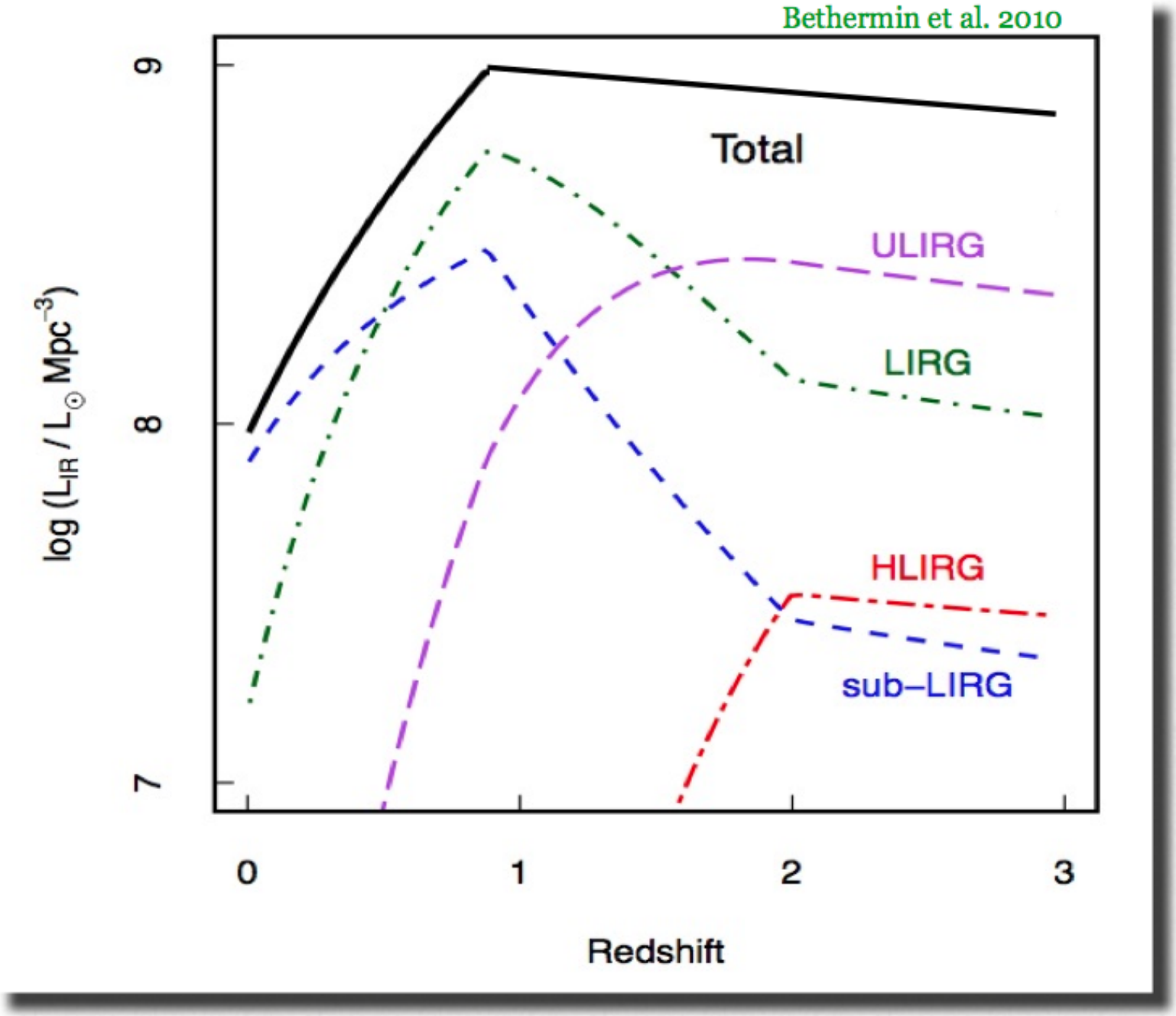
Caputi et al. 2006, 2011



- Evidence from near-/mid-IR surveys of large numbers of bright galaxies at high-z. Many of the most massive appear to be red (passive).
- Suggestion that this pop of massive galaxies builds up rapidly at z>3

Star Formation History

Bethermin et al. 2010

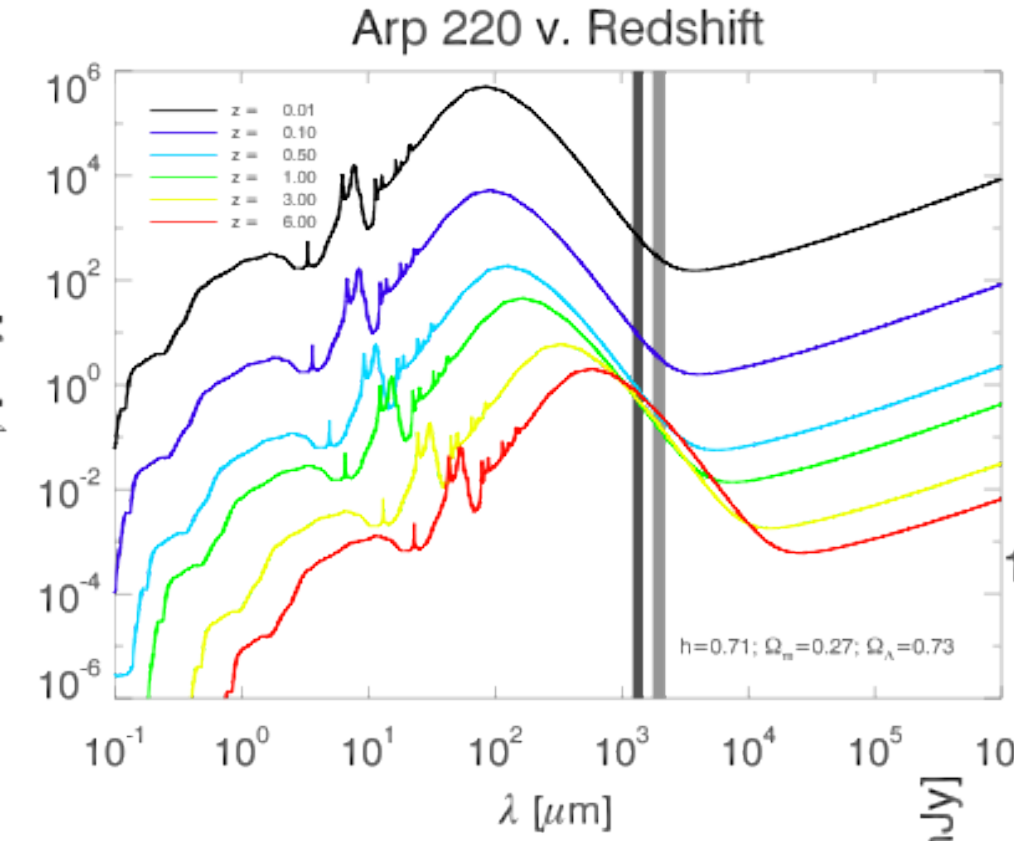


Would like to study these z>3 ULIRGs in detail to see how galaxies are being assembled.

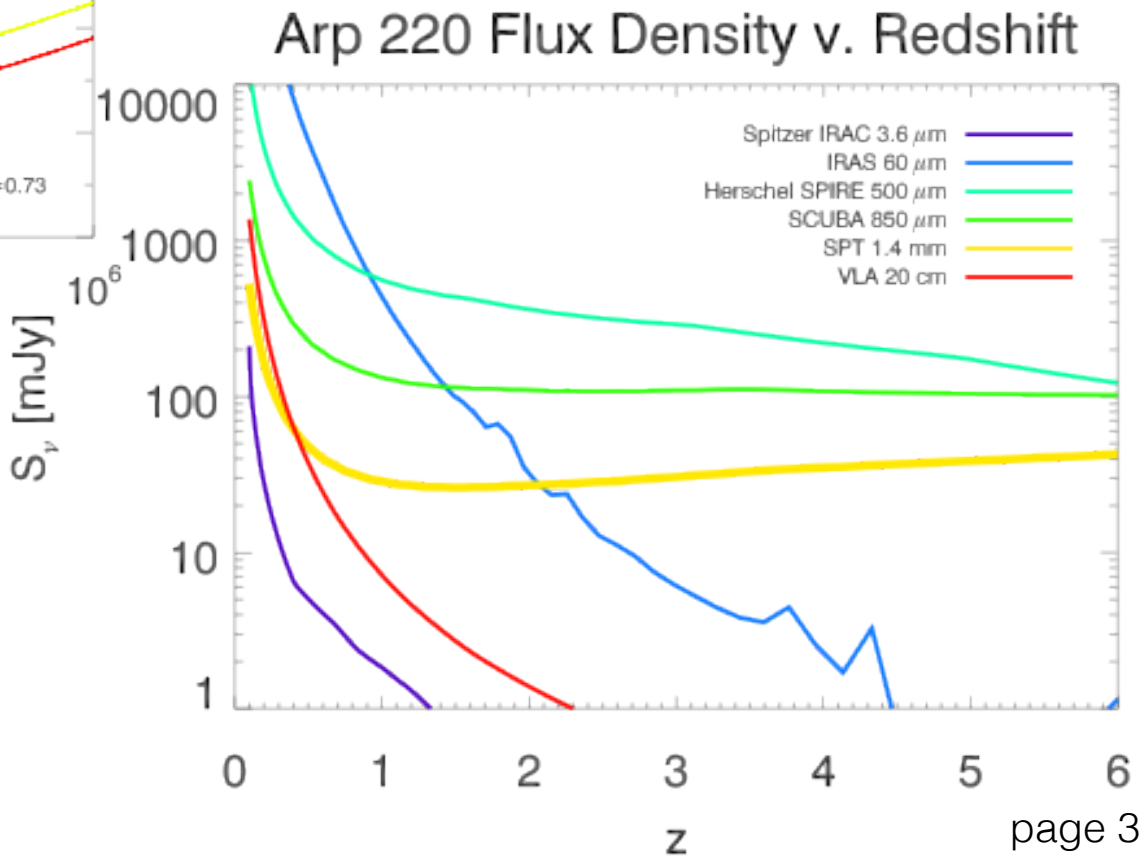
Understand the earliest epochs at z>>3

- ULIRGs (dusty starbursts, SFR>100M_o/yr) produce ~50% stars @ z>1-2
- These are submm galaxies (SMGs) detected in FIR/submm

Submm magic



K-correction allows luminosity limited surveys to z>6



Continuum IDs with SMA

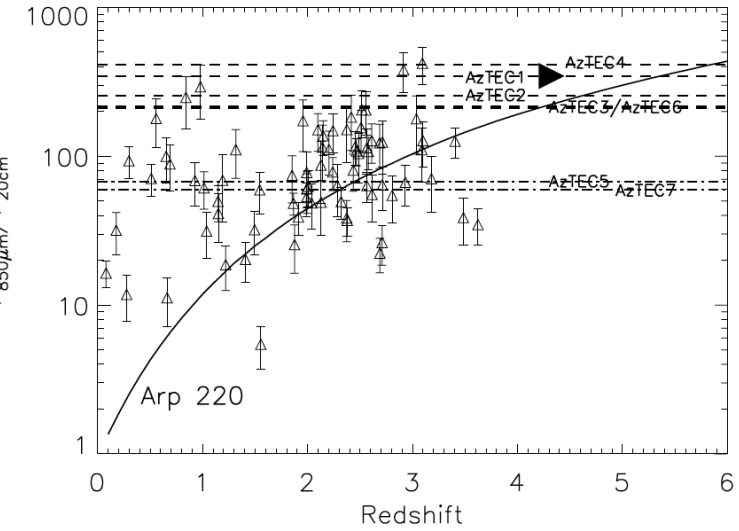
- Theme of readily obtaining IDs or lensing morphologies for SMGs
- Enabling facility which can quickly and reliably get ID, flux, morphology

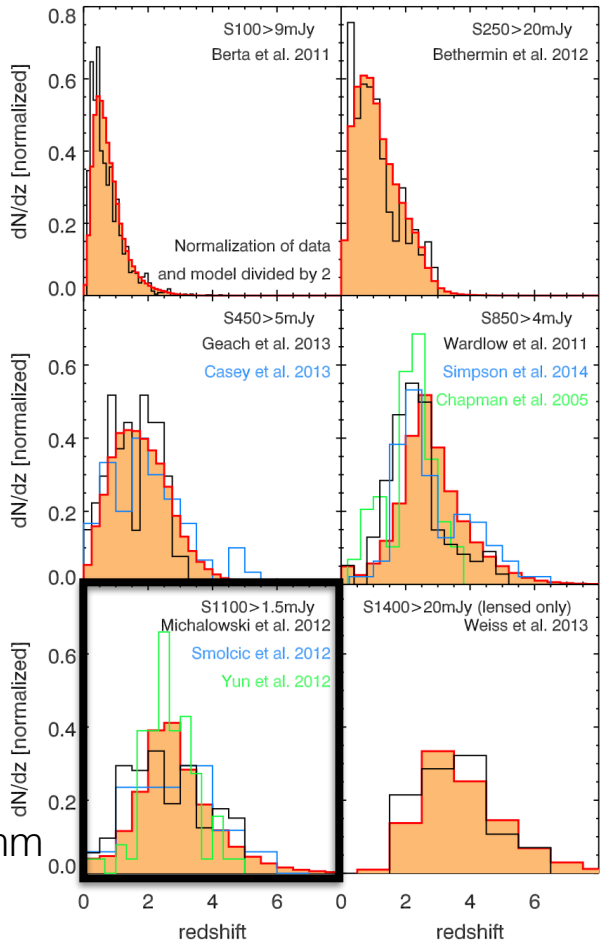
- Discovery phase still of mm/submm surveys
- New sources really do typically go to SMA for first measurements
  - Rather than arduous process of getting time on ALMA (once yearly call; high oversubscription; no flexibility in targets; Very long turnaround on data delivery; impenetrable DDT)

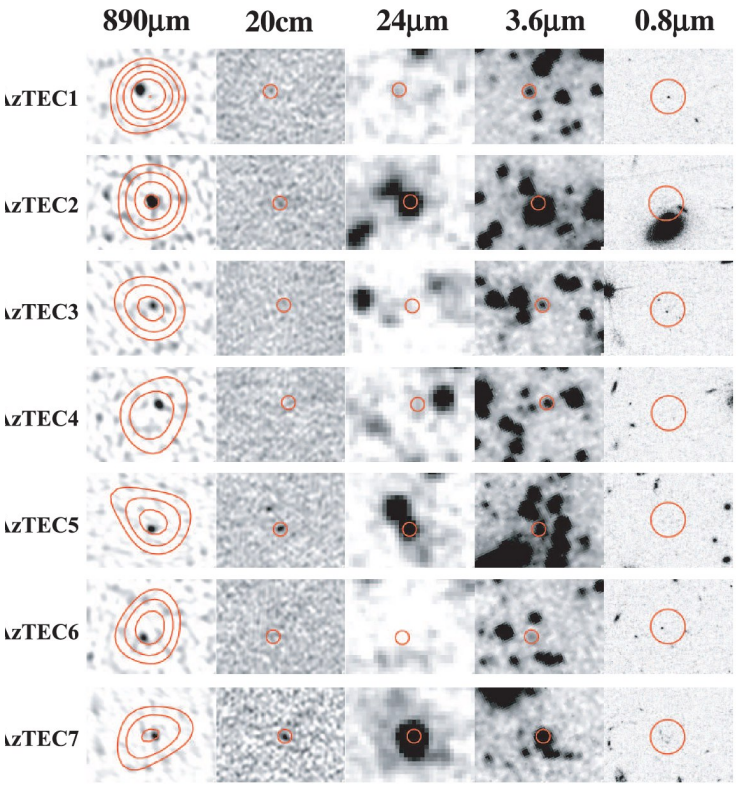
EVIDENCE FOR A POPULATION OF HIGH-REDSHIFT SUBMILLIMETER GALAXIES FROM INTERFEROMETRIC IMAGING

Younger et al.**2007**,2008,2009

- SMA IDs of SMGs pioneered by Younger etal. (bright COSMOS sources)
- Set mindset for ALMA programs! Getting accurate 890um fluxes important
- higher-z prediction for 1.2mm-selected sources turned out to be true!







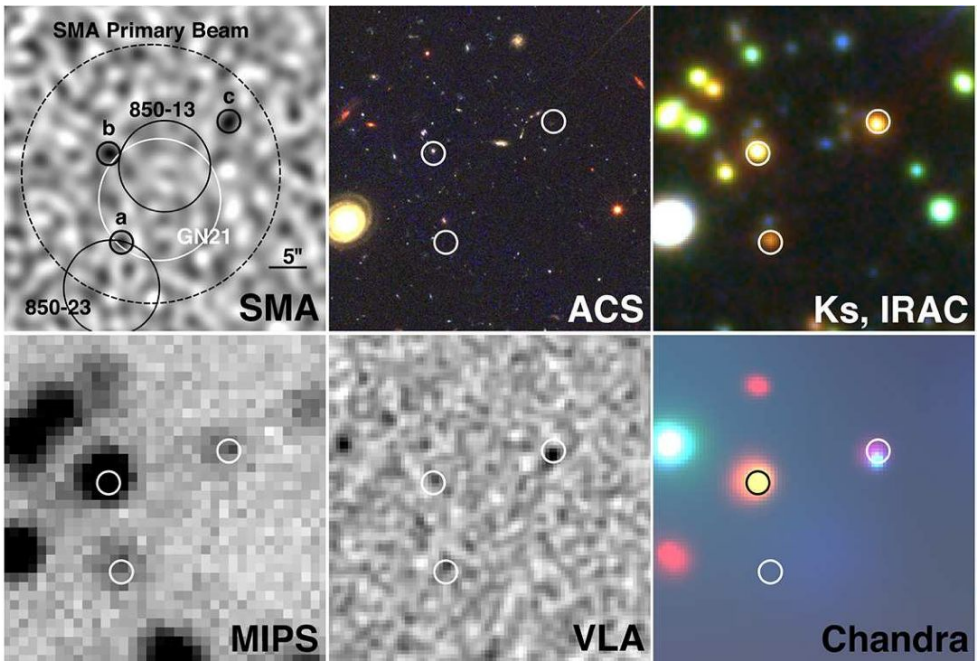
median z=3.1 higher at 1.1mm than at 850um (z=2.5)

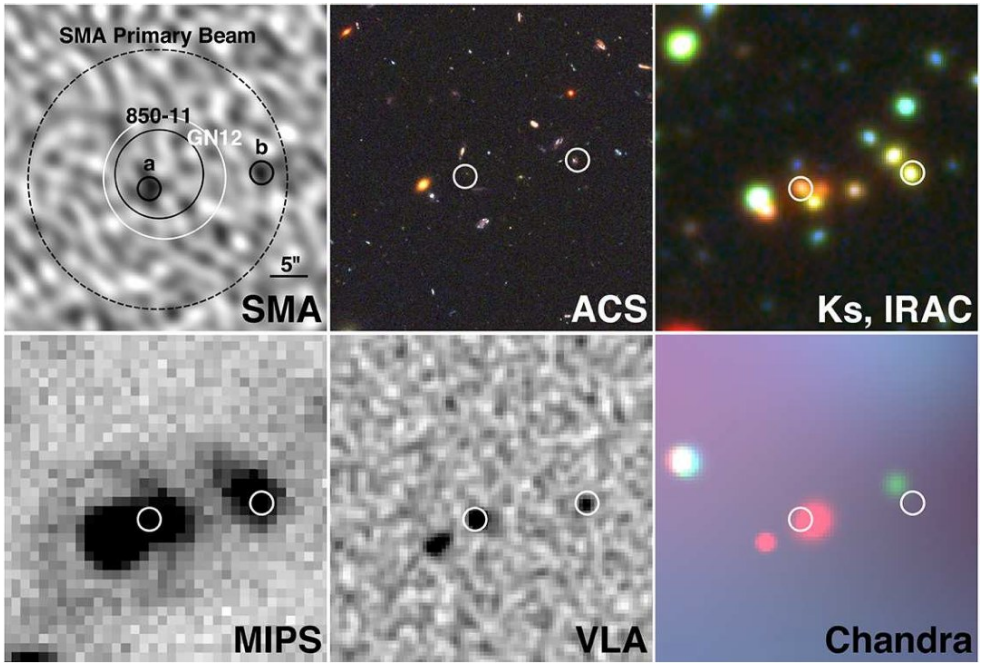
SMA OBSERVATIONS OF GOODS 850-11 AND GOODS 850-13 — FIRST EXAMPLES OF MULTIPLE SUBMILLIMETER SOURCES RESOLVED BY AN INTERFEROMETER

(Wang et al. 2011)

SMA discovery of 860um multiplicity in SMGs

(to which Hodge+13, Karim+13 leveraged to huge fanfare with ALMA — more later)



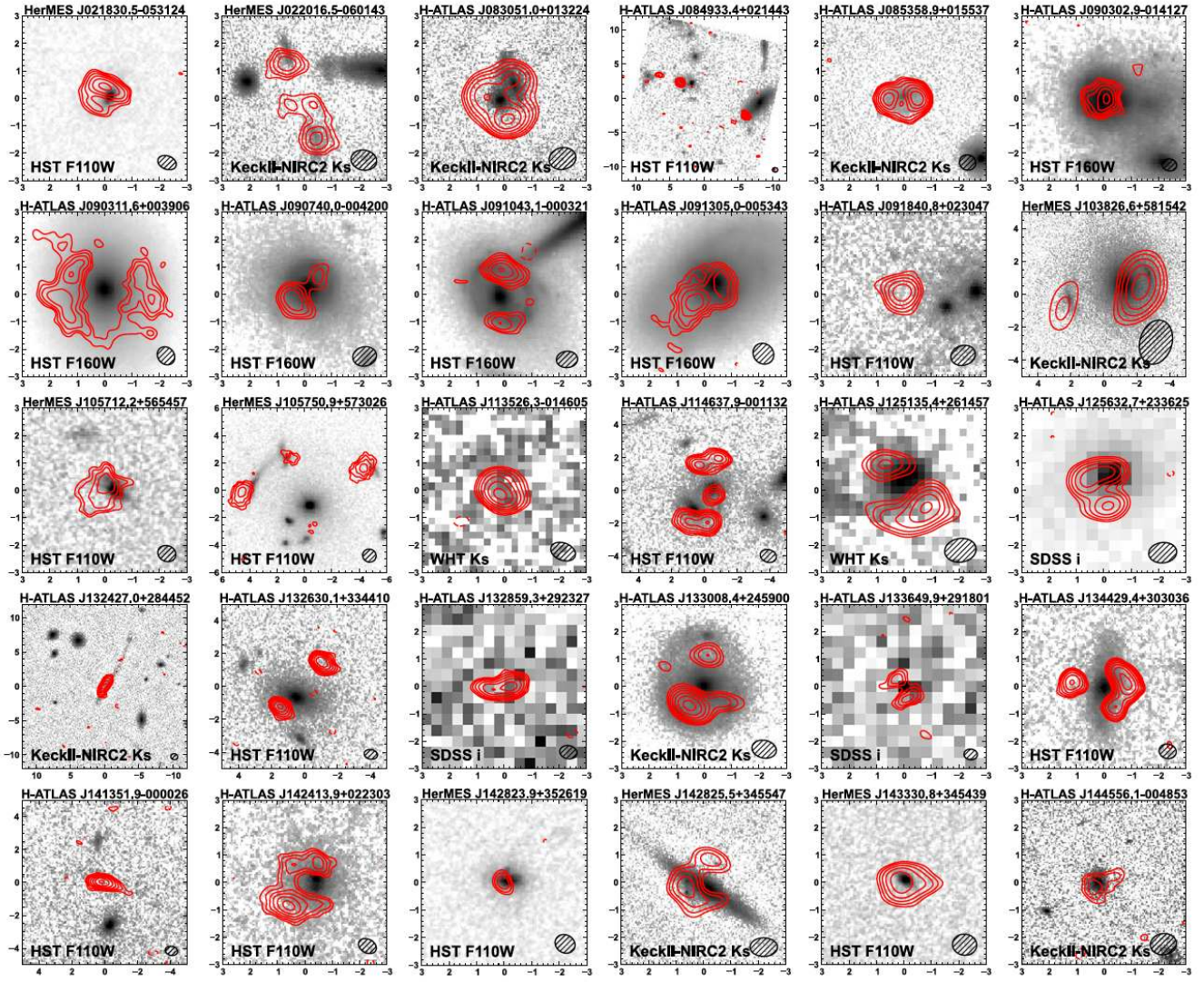


GRAVITATIONAL LENS MODELS BASED ON SUBMILLIMETER ARRAY IMAGING OF HERSCHEL-SELECTED STRONGLY LENSED SUB-MILLIMETER GALAXIES AT $z > 1.5$

(Bussmann et al. 2013)

SMA identification of Herschel-SPIRE lensed SMGs

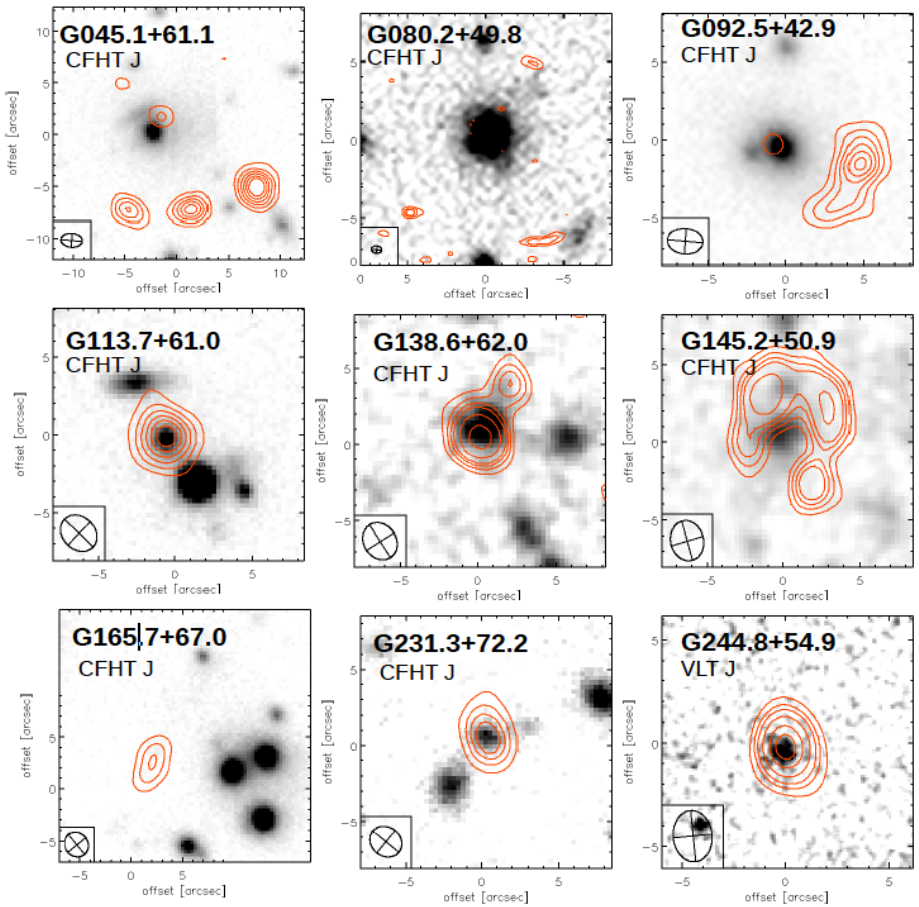
Crucial to model lensing morphology

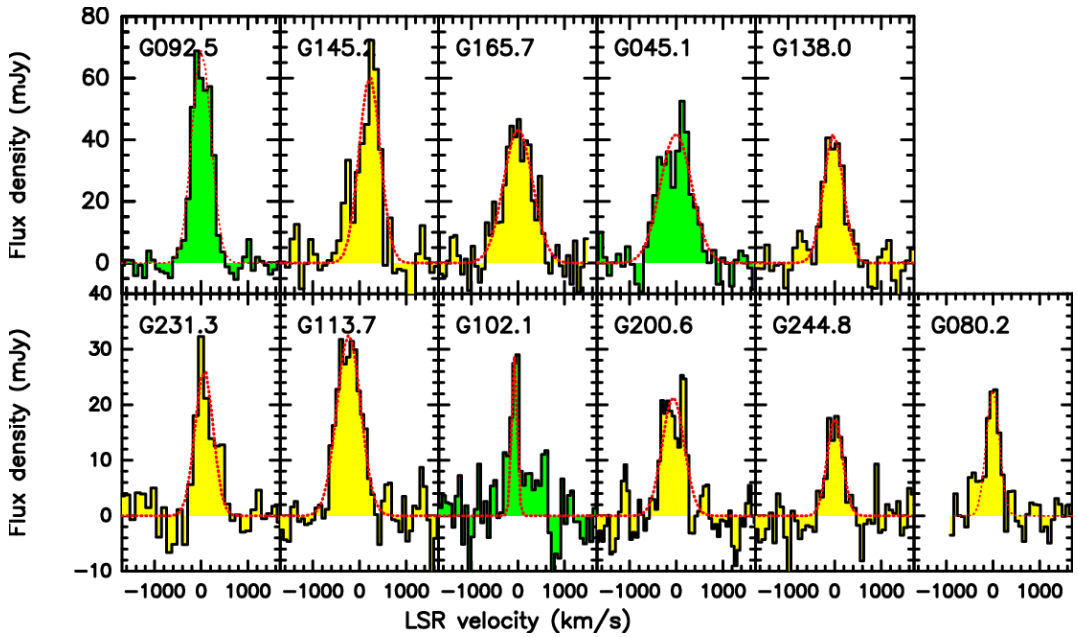


Planck's Dusty GEMS: Gravitationally lensed high-redshift galaxies discovered with the Planck survey

(Canameras et al. 2015)

SMA identification of z~2-3 Planck discovered, lensed SMGs - brightest on the sky!



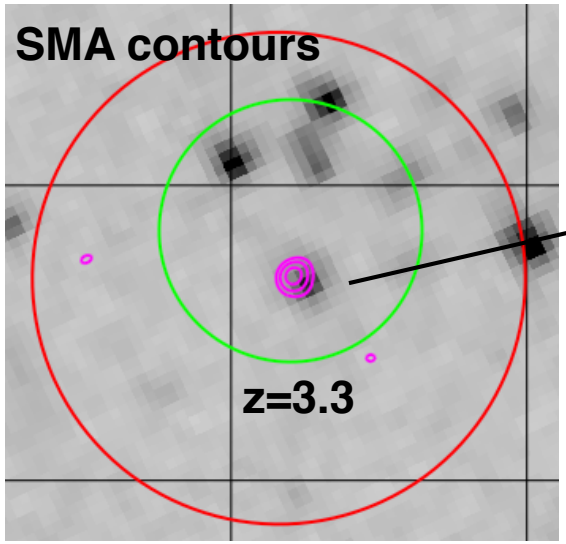


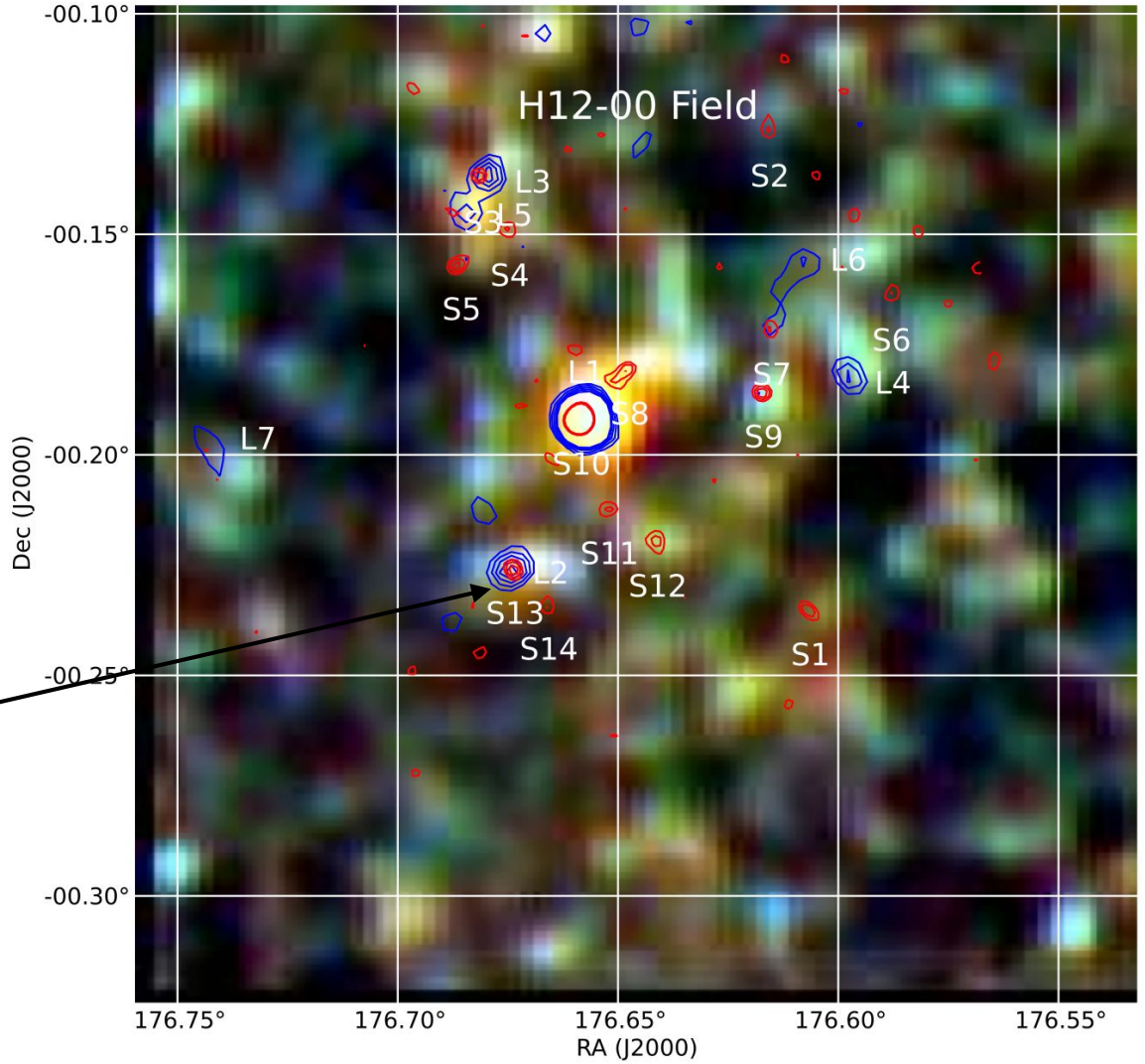
Planck protoclusters at z~2-3

Clements et al. 2013 identified sample of candidate z~2.5 protoclusters through Planck and Herschel-SPIRE

Followup with JCMT SCUBA-2

SMA providing crucial identifications to IRAC galaxies for photo-z / membership
(Clements et al. 2016)

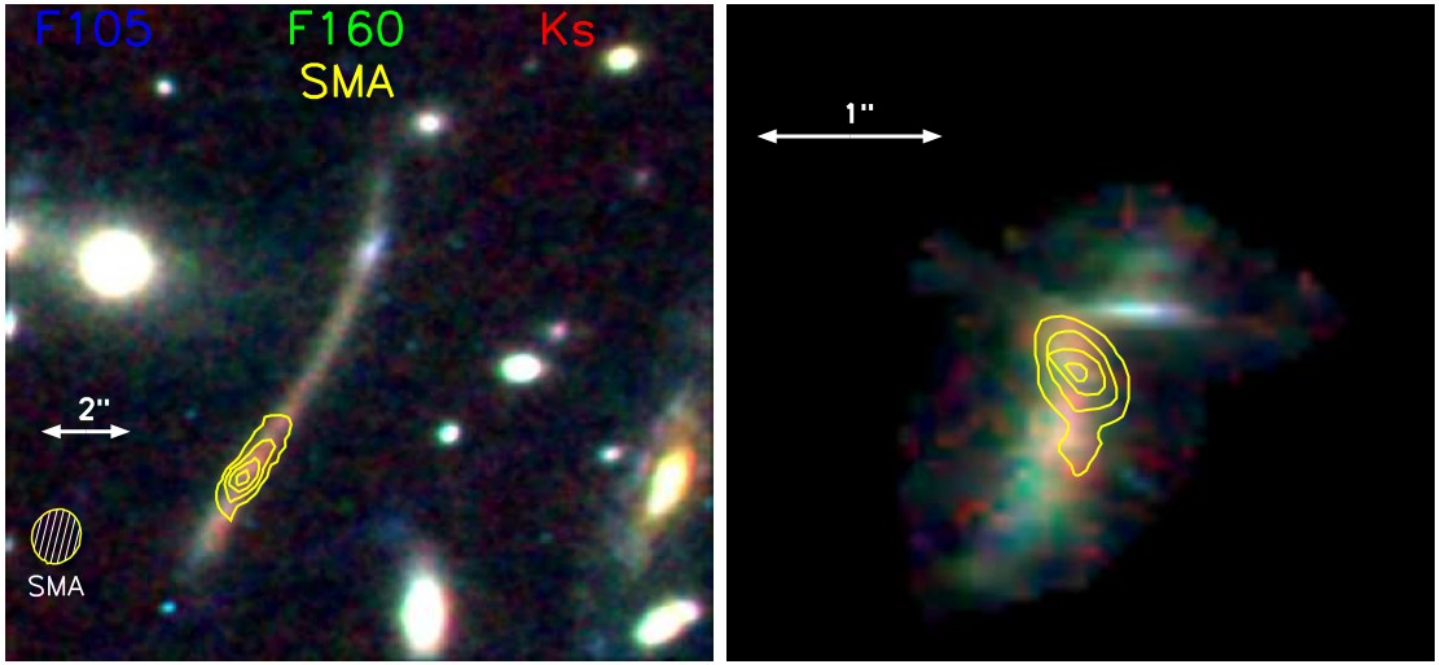




MULTI-WAVELENGTH LENS RECONSTRUCTION OF A PLANCK & HERSCHEL-DETECTED STAR-BURSTING GALAXY

(Timmons, Cooray, et al. 2016)

SMA identification of a Planck lens crucial for identification of the obscured but ultra-luminous burst in the merging system



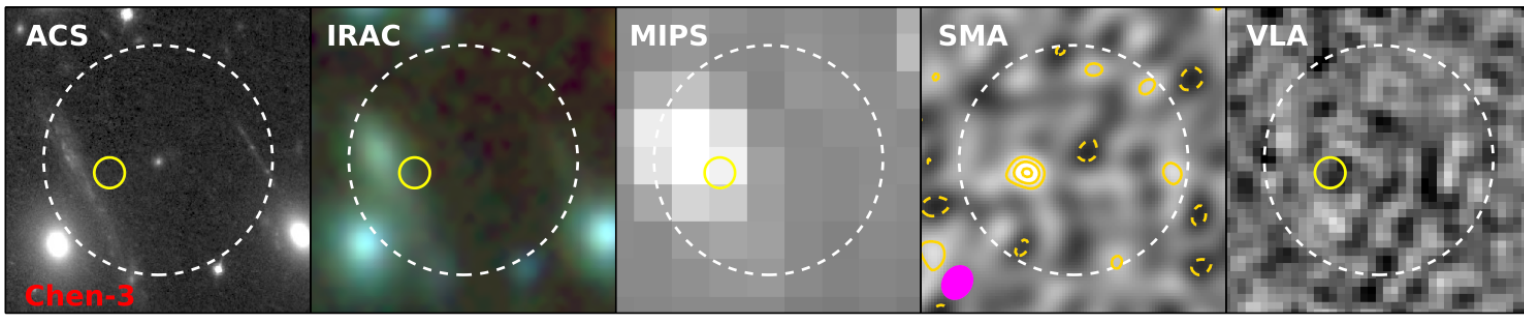
SMA OBSERVATIONS ON FAINT SUBMILLIMETER GALAXIES WITH S850 < 2 MJY: ULTRA DUSTY LOW-LUMINOSITY GALAXIES AT HIGH REDSHIFT

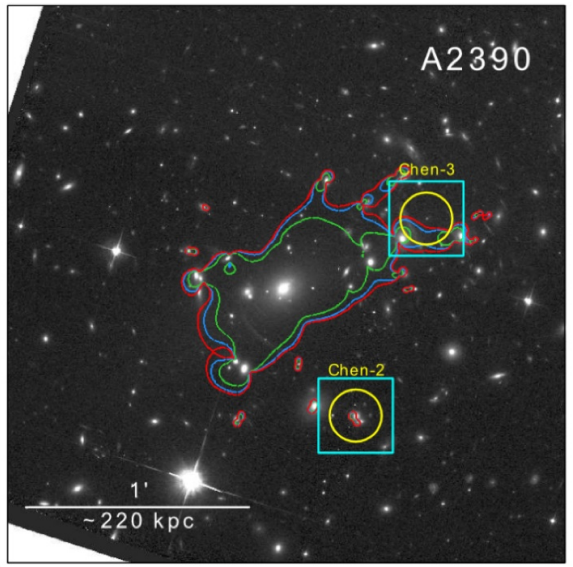
Chen et al. 2014

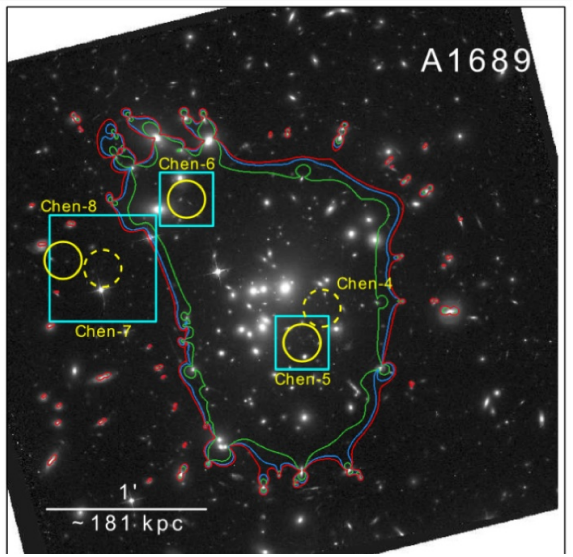
Using massive lensing clusters observed with SCUBA2

… SMA-identified sources

- early results on <1mJy “LIRG” population at 860um
  - 70% of farIR background
  - only 40% detected in opt/IR



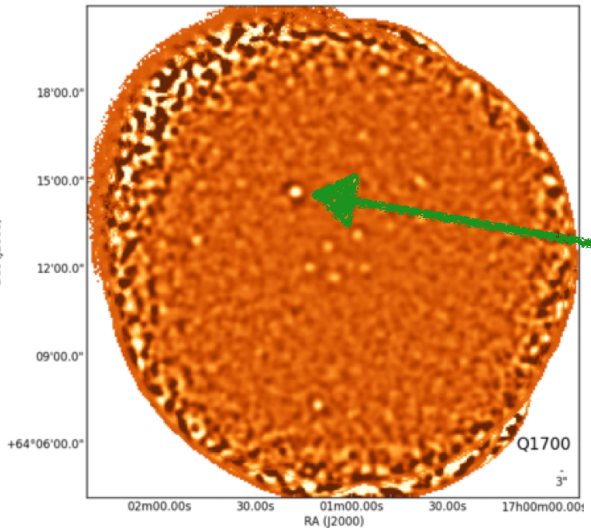




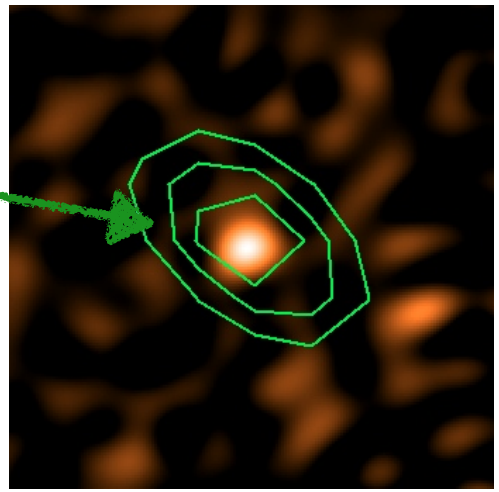
A millimeter-wave redshift search for the unlensed HyLIRG, HS1700.850.1

Chapman et al. 2015

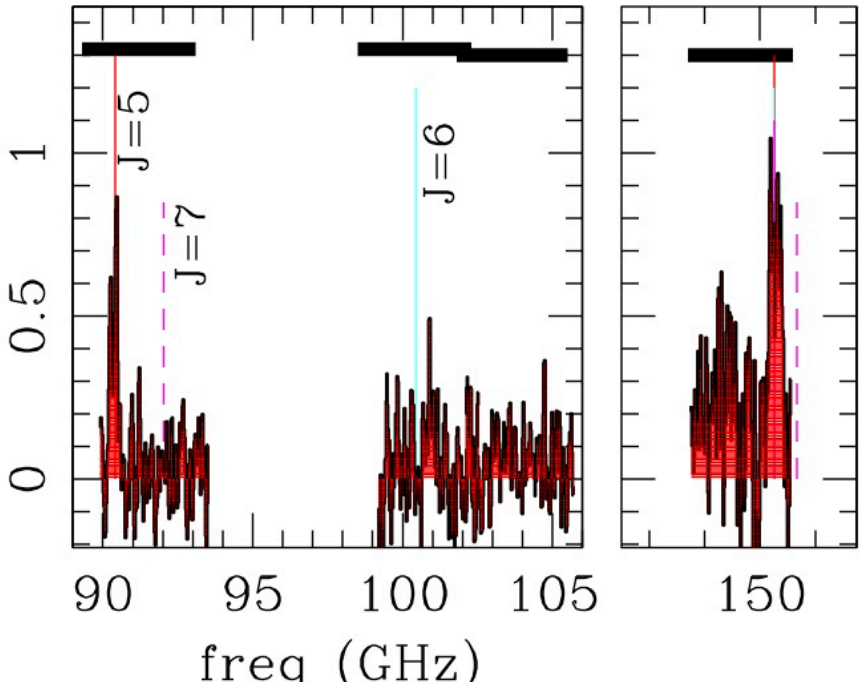
- Brightest source from 0.5deg^2 JCMT S2-Web Large program
- SMA identification enabled photo-z and NOEMA blind redshift search in CO lines

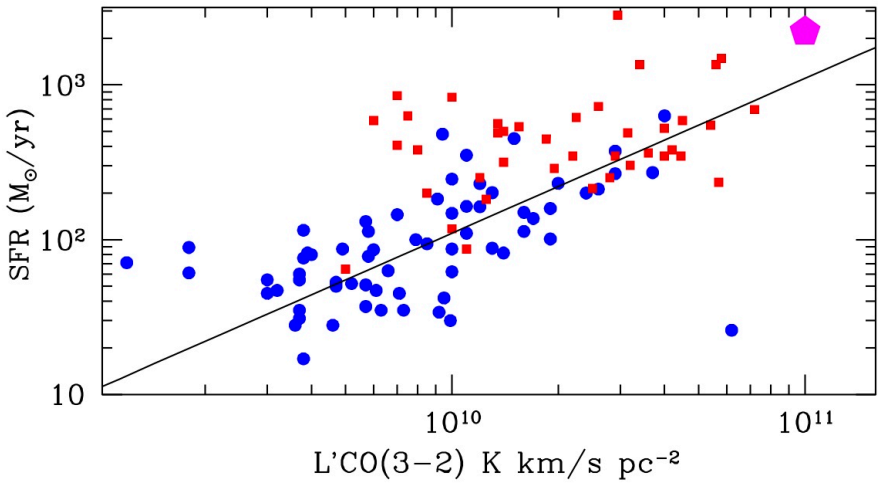


SMA
Confirms 20mJy source 2" beam
But 15mJy in EXT 0.7" beam



z=2.85

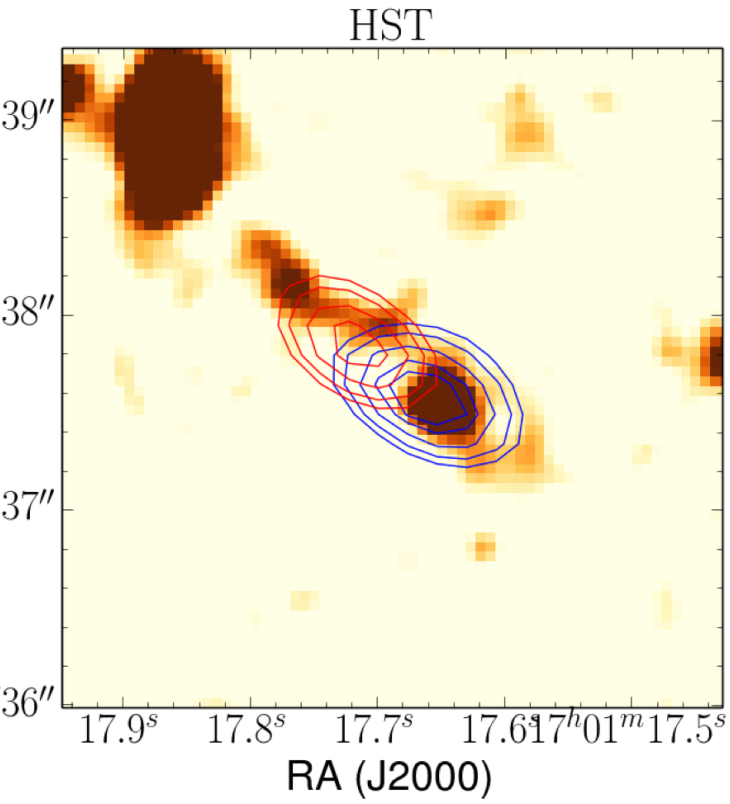


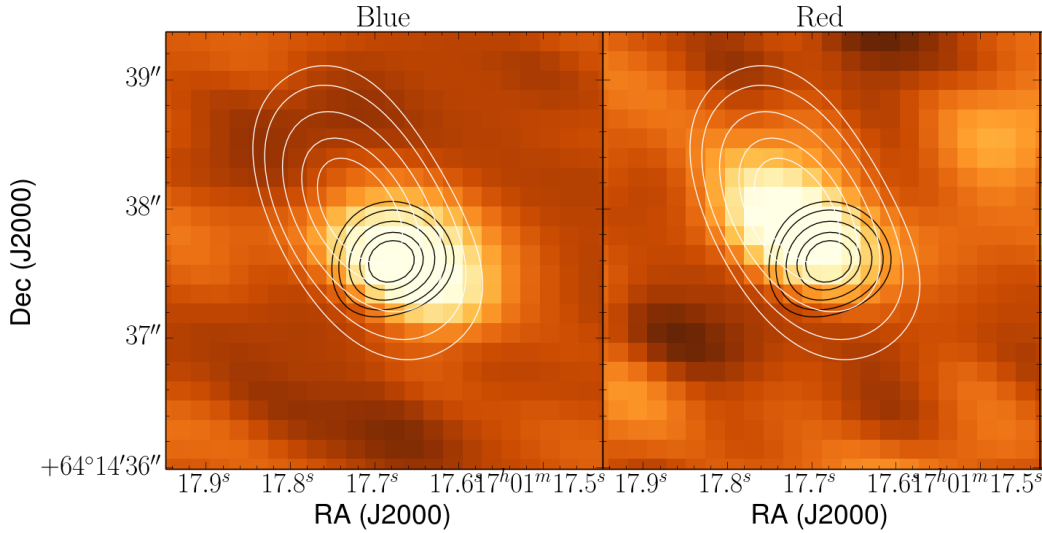


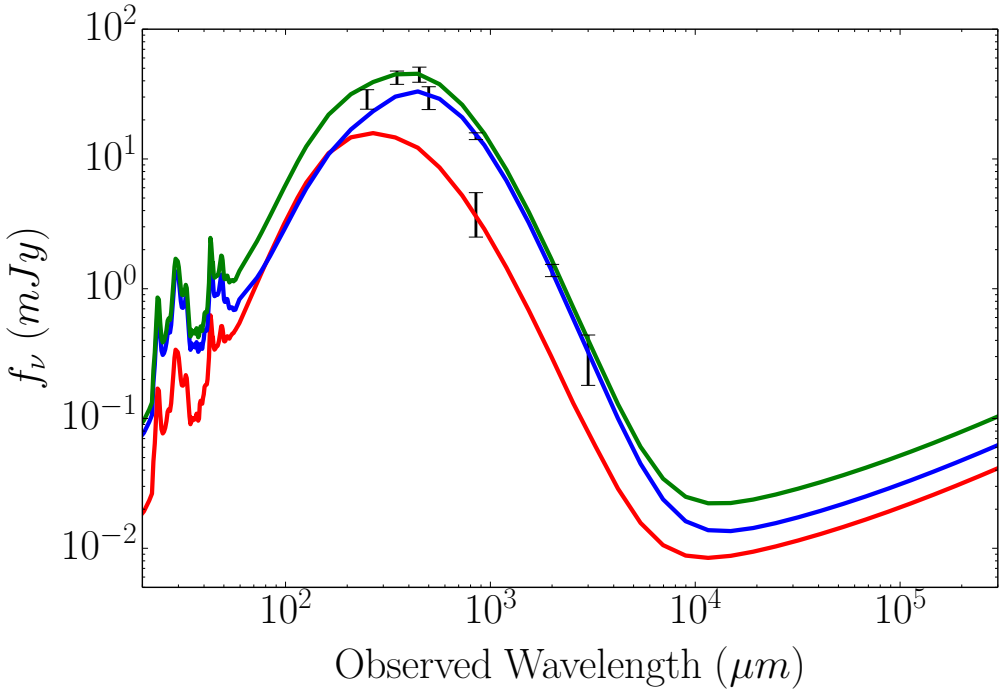
A merging HyLIRG, HS1700.850.1

Perry et al., 2017

SMA EXT-config revealed crucial *hot/cold* SEDs of NOEMA resolved merging CO(5-4).







SMG counts

Karim et al. (2013, MN, in press)

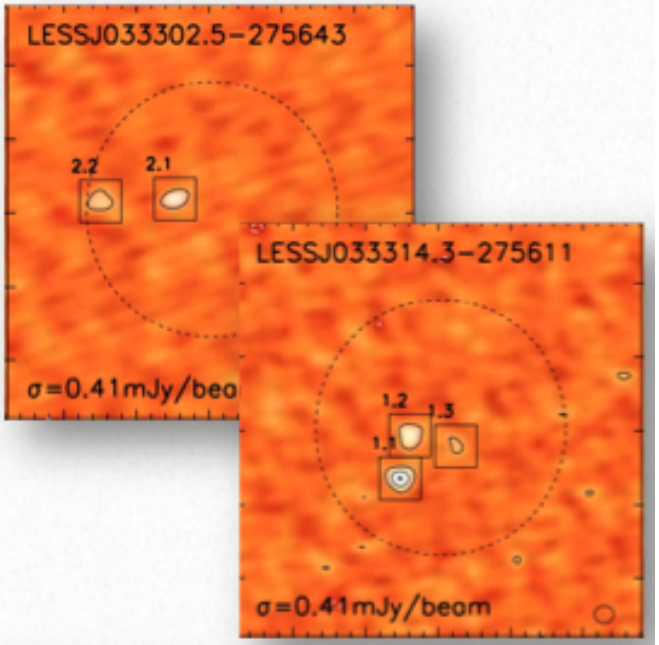
- All >12mJy submm sources are multiples:

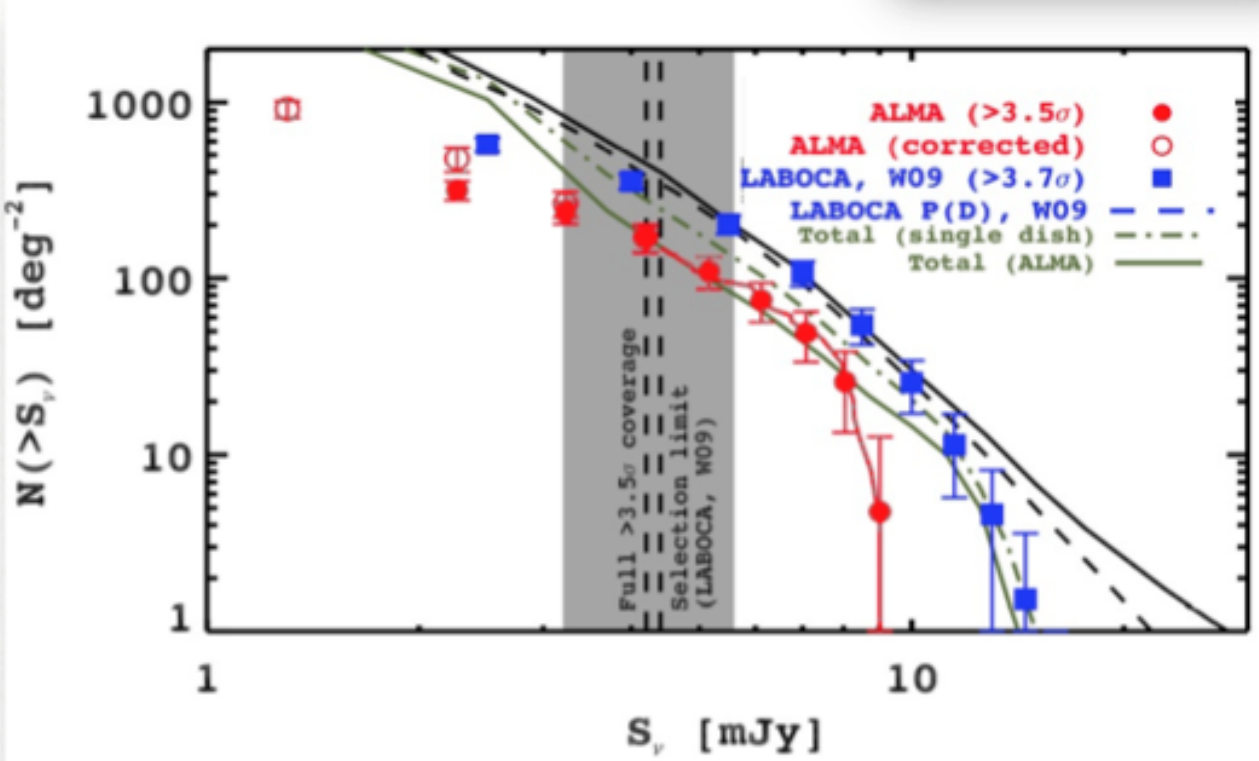
  ***no** single SMG with S_{870um}>9mJy*

- Large fraction of undetected LESS sources may be multiple faint SMGs ($\Sigma > \pm 3\sigma$: $S_{ALMA}/S_{LABOCA}=1$)

- Steepens count slope at bright end and lowers normalisation (but doesn't really improve agreement with theory models)

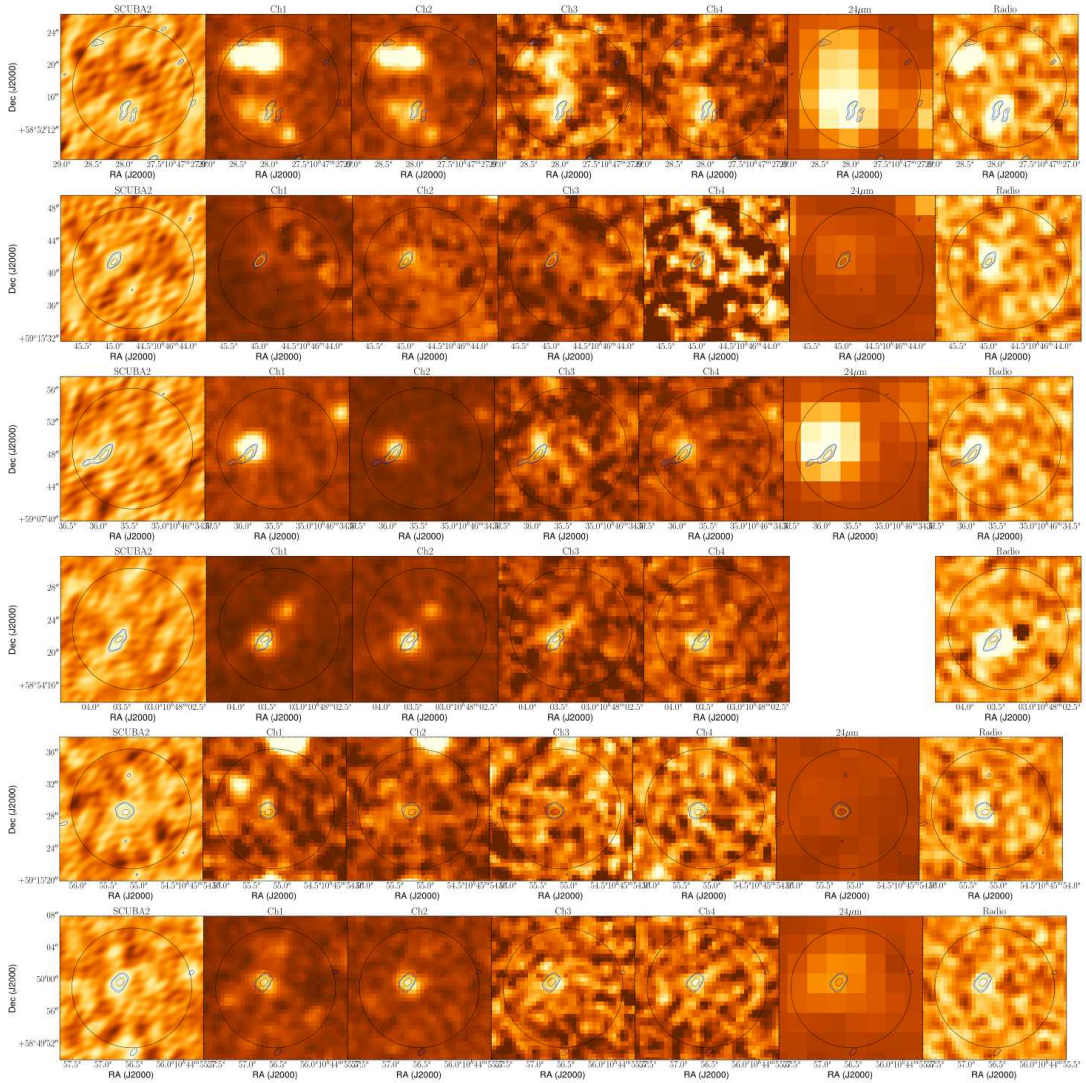
- Implies natural limit to SFR in a single source of $<10^3 M_o/yr$ (few HyLIRGs?)



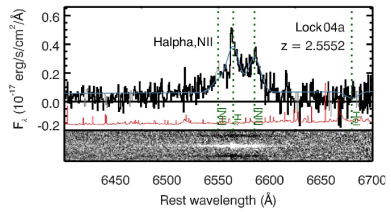


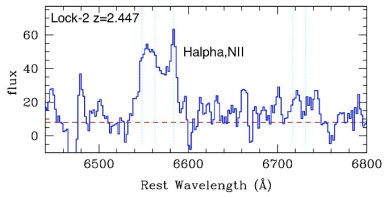
SMA identification of 100 S850>9mJy sources from the S2-CLS 5deg^2 survey

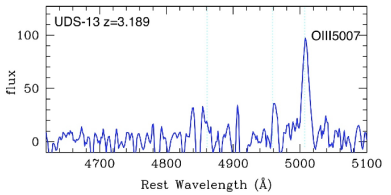
Perry et al., in prep; Chapman et al. in prep

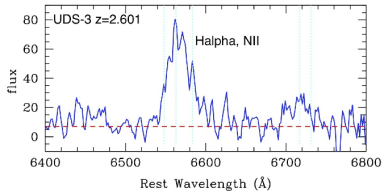


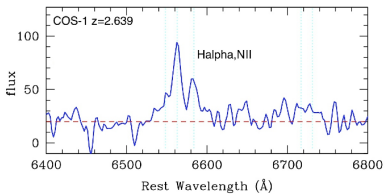
- ~30 tracks, 345GHz
- multi-wave IDs and lensed fraction
- redshifts for brightest 10 SMGs









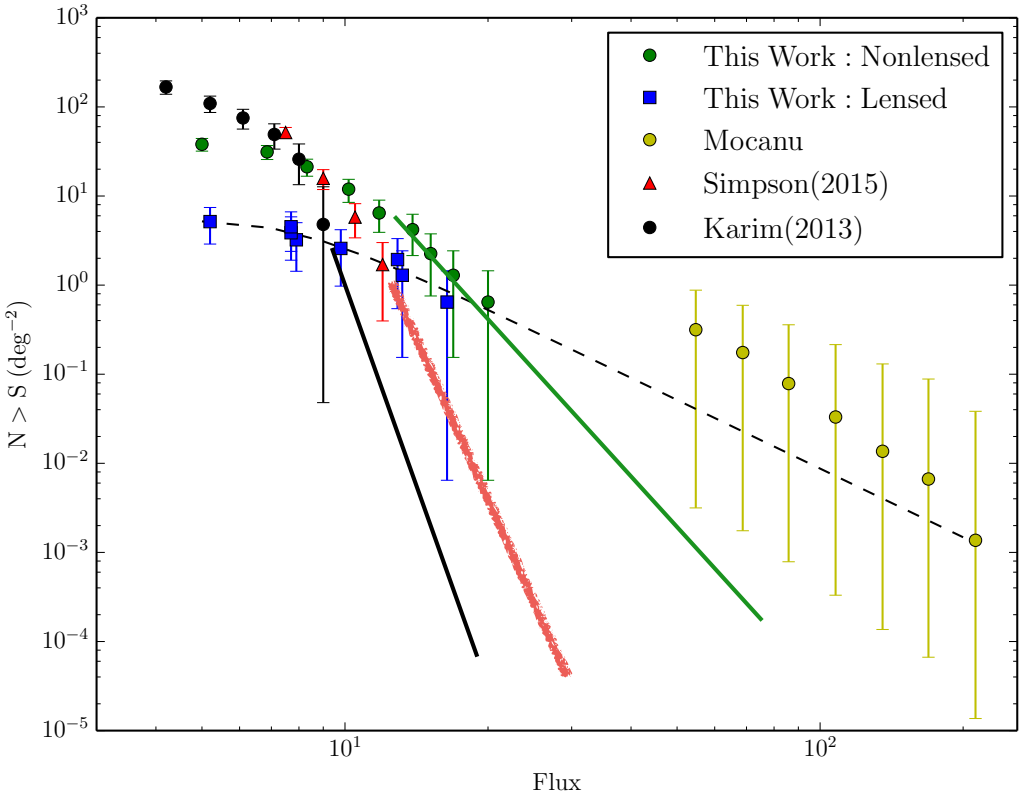


- **THANKS to Glen Petitpas and Mark Gurwell!!!**

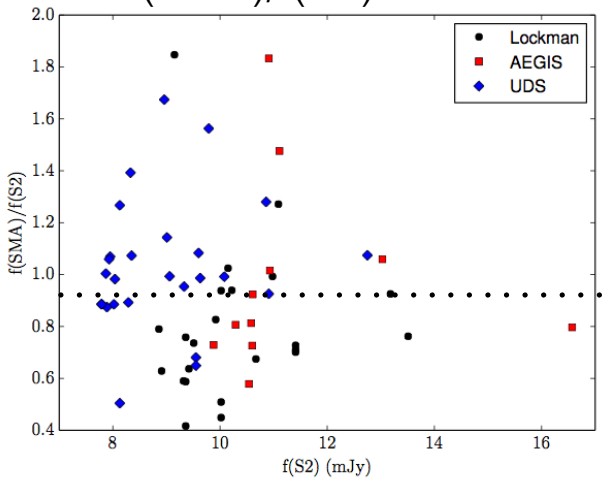
SMA identification of 100 S850>9mJy sources from the S2-CLS 5deg^2 survey

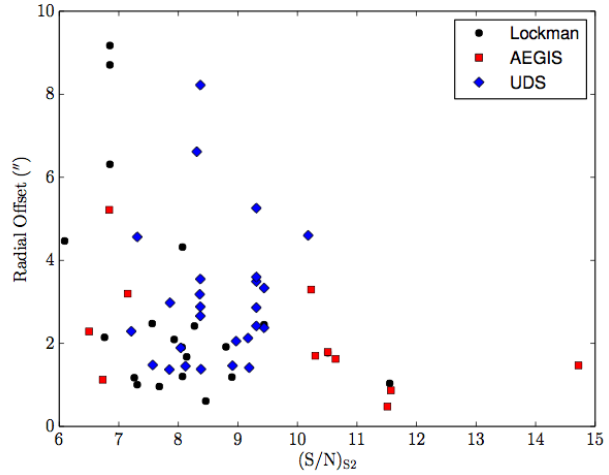
R.Hill,D.Scott, et al. in prep.

- Bright counts slope much shallower than Karim et al. 2013!
- Multiplicity actually of little effect on brightest S_{850um}>10mJy SMGs



f(SMA)/f(S2) ~0.9



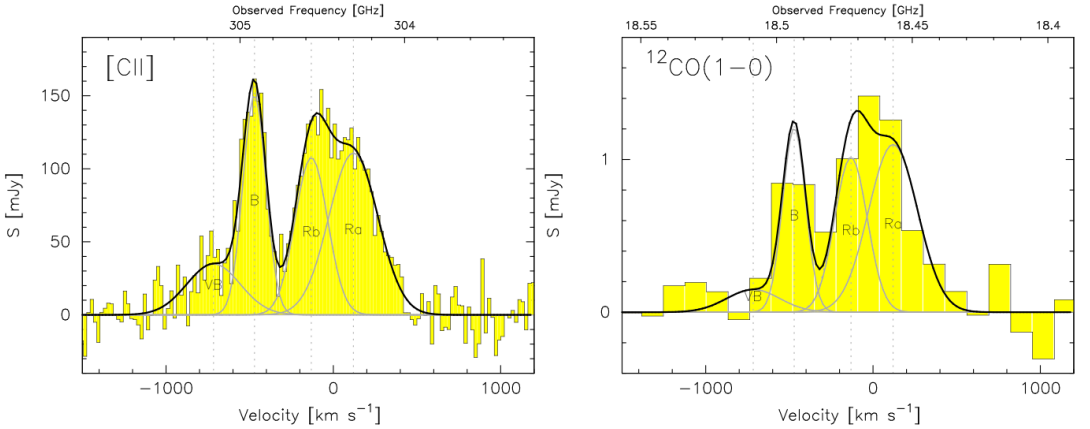


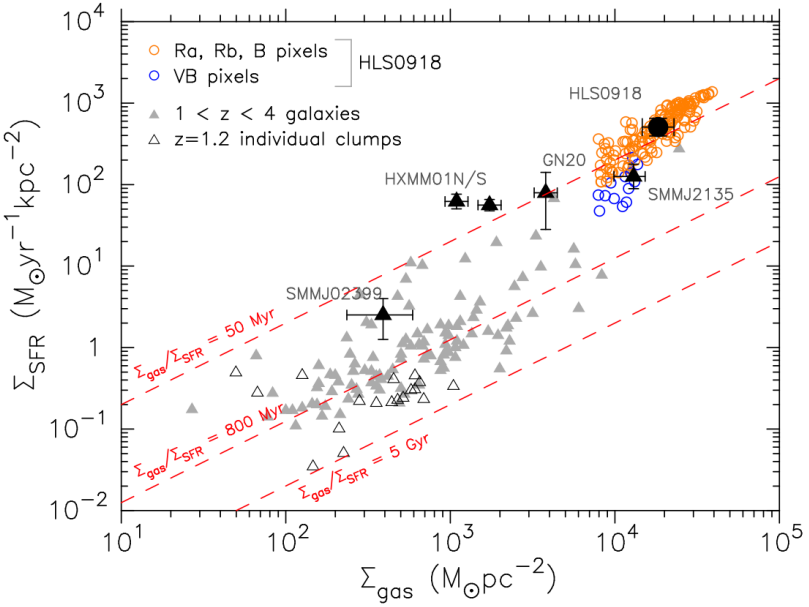
[CII] and 12CO(1–0) Emission Maps in HLSJ091828.6+514223: A Strongly Lensed Interacting System at z = 5.24

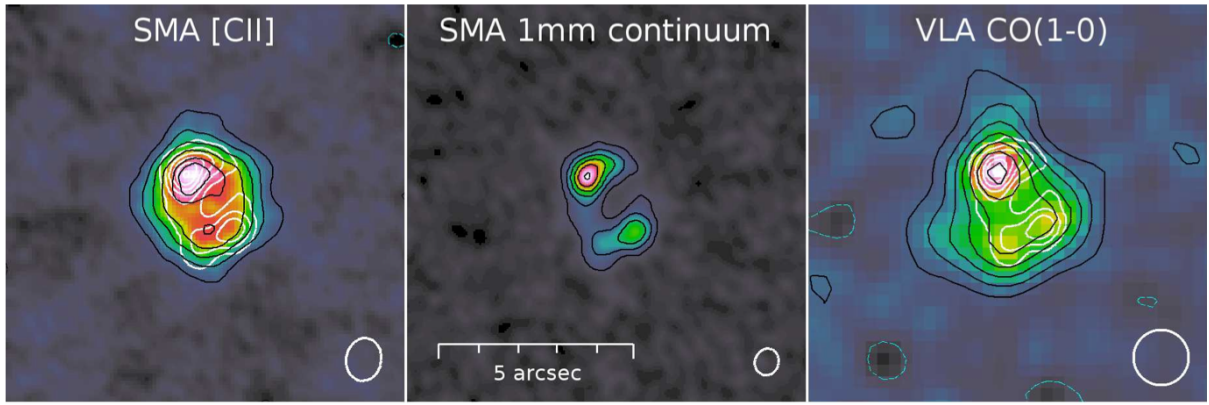
Rawle et al. 2015

SPIRE-identified bright lensed HLIRG

SMA produced spectacular resolved [CII] maps allowing for many of the most constraining ISM diagnostics



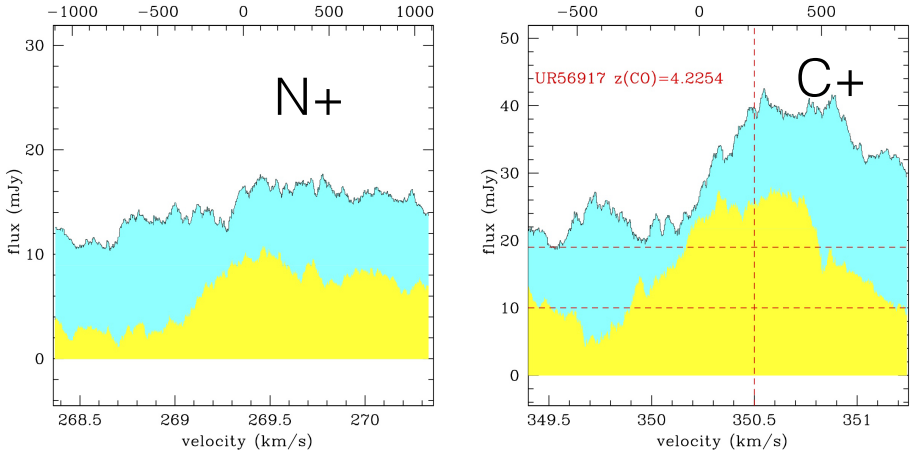


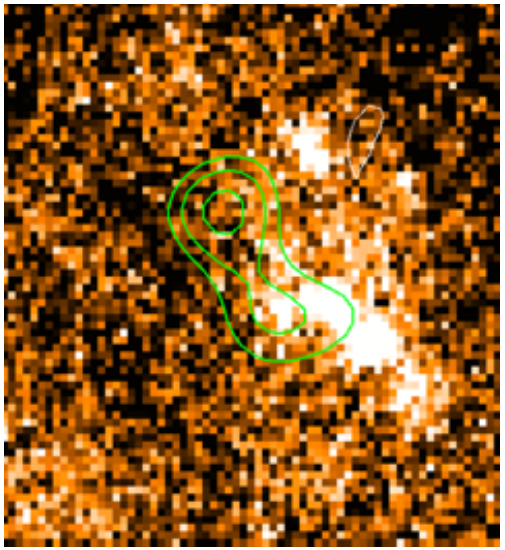


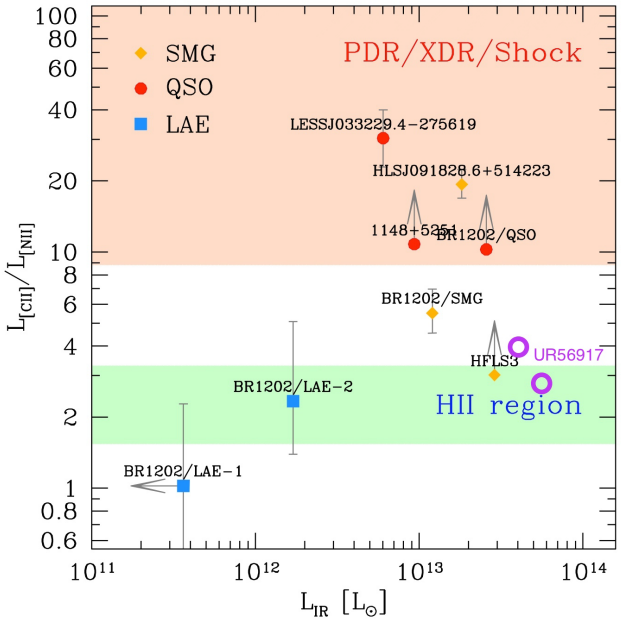
[CII] and [NII] Emission in the most luminous (and unlensed!) starburst known UR56917 at z=4.42

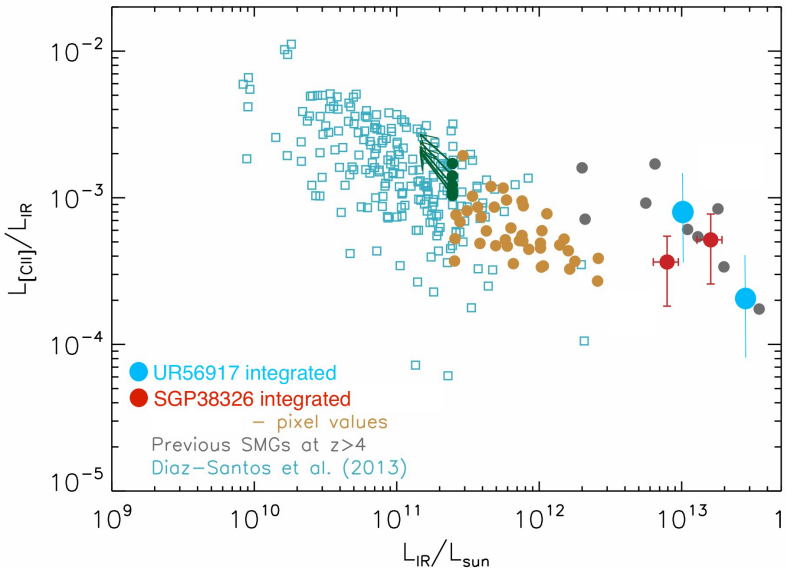
Chapman et al. 2016

- SMA dual receiver: C+ and N+
- Resolves into 2 components.
- Different C+/N+ ratios shows unlensed nature of UR56917 : **most luminous known starburst S860=35mJy**
- Fed A-rated ALMA Cy4 followup!



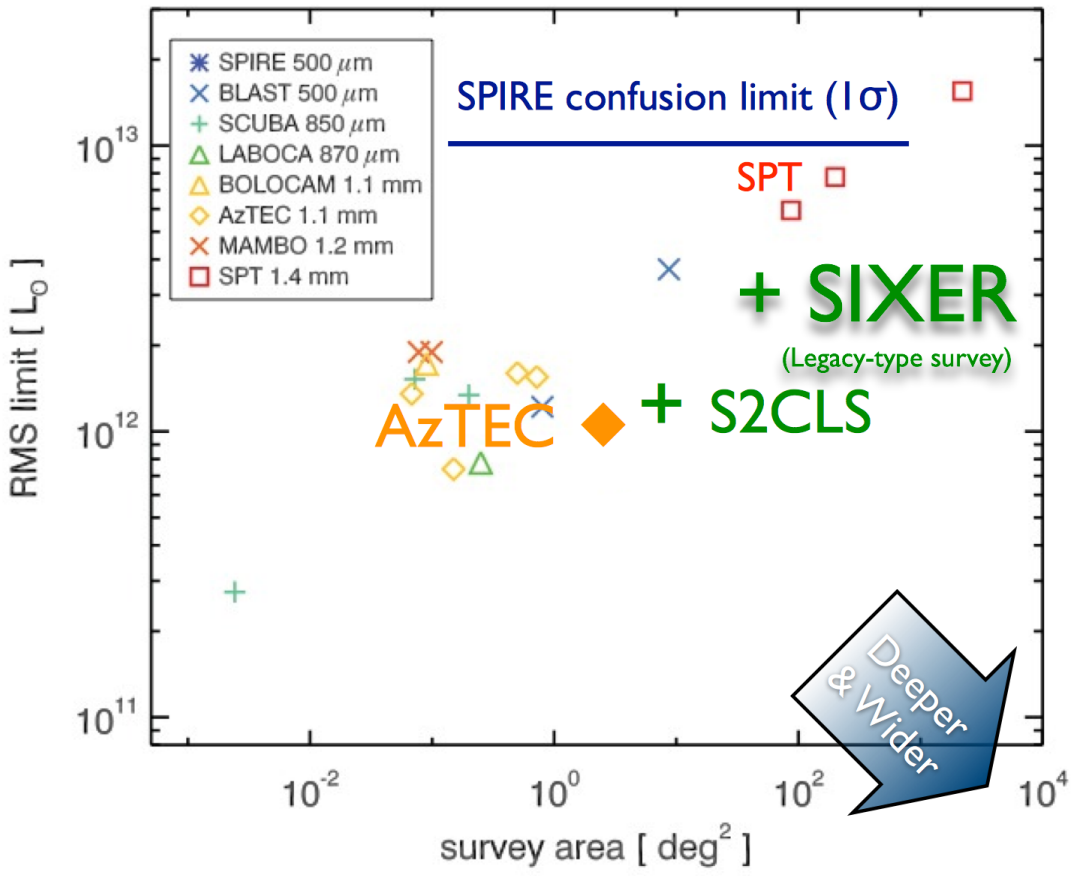






Future work with SMA

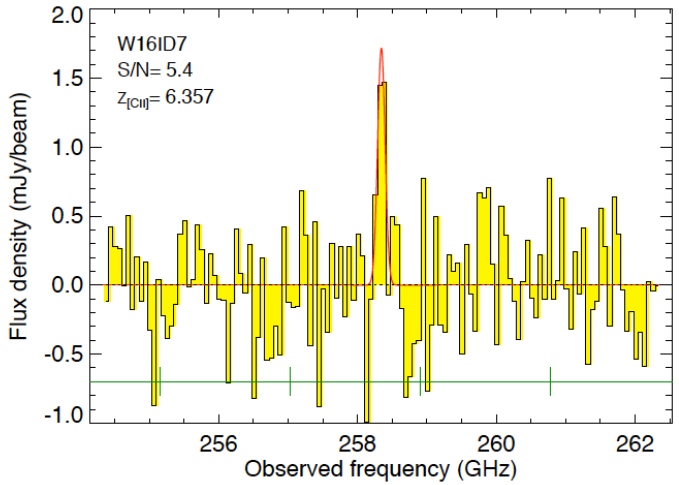
- SMA played crucial role in quickly identifying and studying relatively bright SMGs from **Herschel, LMT, SCUBA2, Planck**
- Next-gen SCUBA2, LMT surveys planned/underway (JCMT 17b Legacy call)
- Planck and Herschel remain treasure troves to mine for sources (in North)
- ***SMA is an agile resource for followup, quickly enabling science from newly discovered sources***

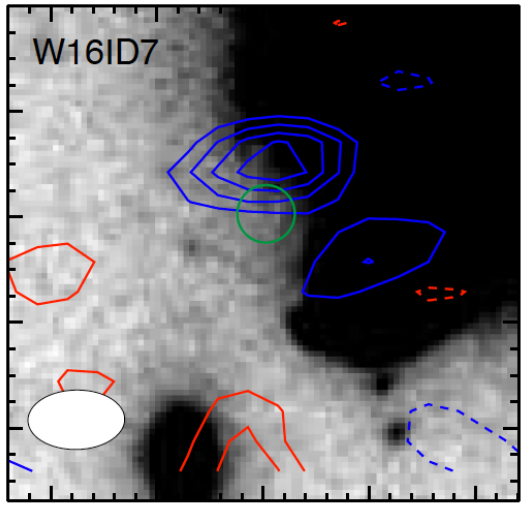


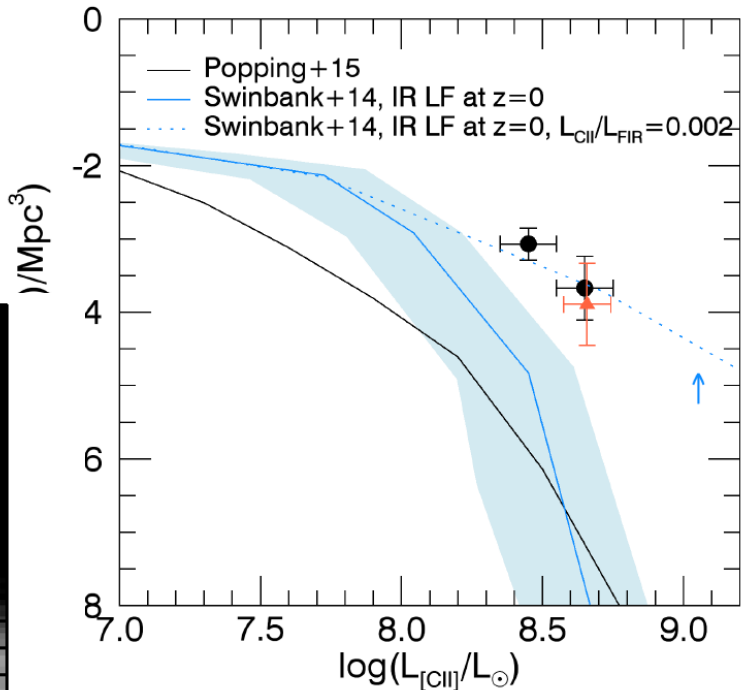
Line searches with 32GHz+ SWARM?

- Huge interest in high-z [CII] (ALMA ASPECS/ Large)
- Intensity mapping experiments (e.g. TIMEpilot - Crites et al. 2015)
- [CII] from z=4-8 in SMA bands
- SWARM [CII] line searches for bright sources photo-z selected z>4 could be interesting niche for an agile SMA
- Proposals in 16B already trying this

Aravena et al. 2016



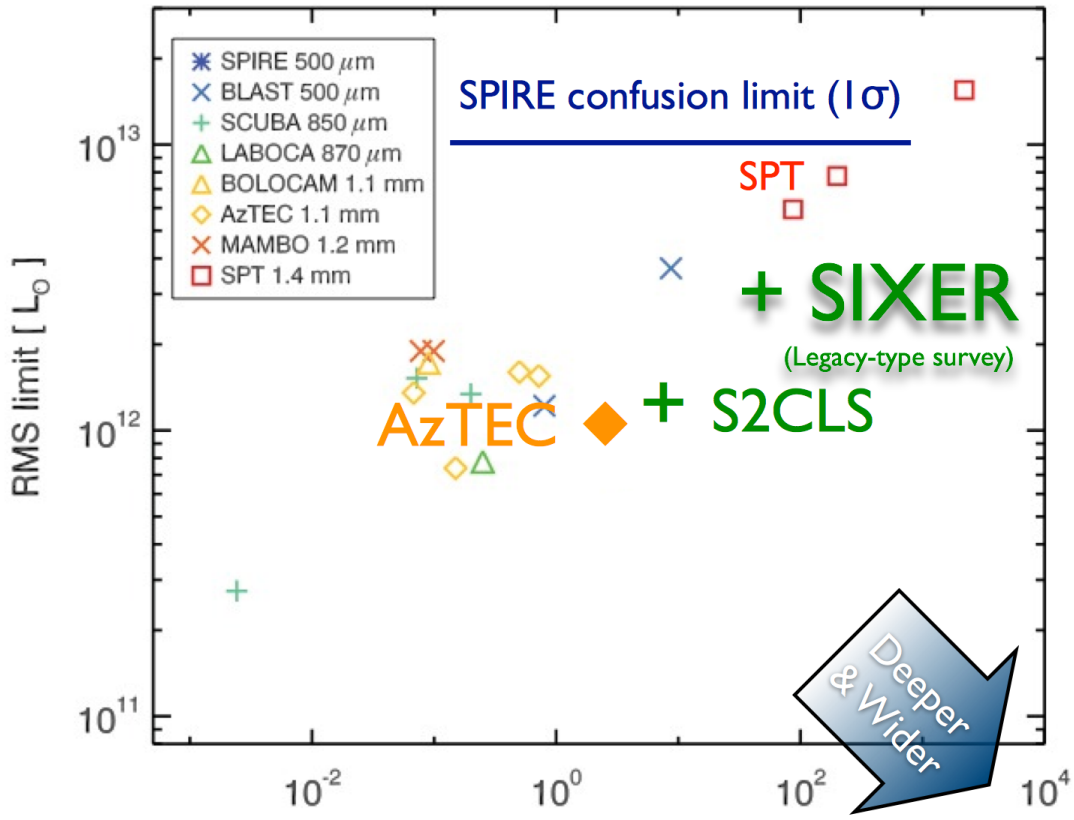


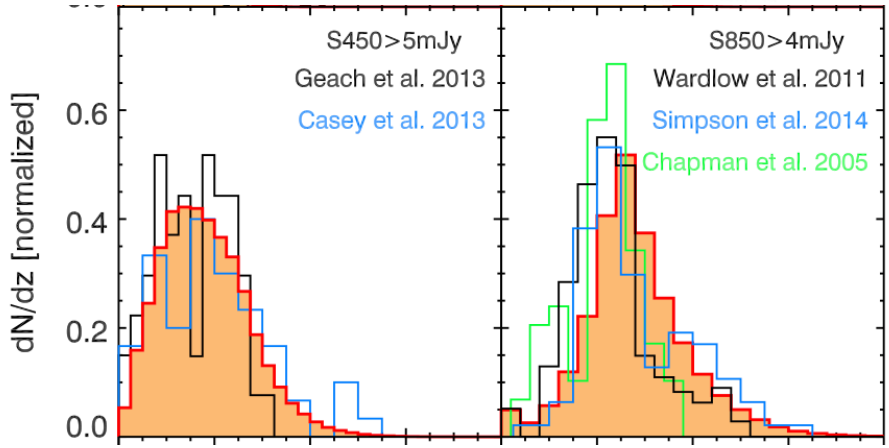


Lots of bright z>4 C+ emitters out there!

Sample survey with eSMA

- **Consider followup program of all S2 Legacy sources with photo-z > 4**
  - ~20% of 850um sources
  - 100 sources S850>5mJy
  - 3 per track; ~33 tracks
- Simultaneously get IDs and for ~40% a C+ detection
- Return to all failed line IDs with 2nd tuning, and increase success to ~80%
- If a `SIXER' type wider S2 survey proceeds, do something similar in ~10 tracks





Conclusions

SMA has been a game changer for identification and characterization of SMGs

SWARM means it can do this much faster and continue to play a big role in ALMA era

Upcoming large 850um, 1.1mm, 2mm surveys, along with Planck mining, ensure many interesting sources to followup

Redshift searches, C+ at z>4, is just starting with SMA, but has huge potential

Much of the power of SMA remains in its agility, being receptive to its user base, and fast turnaround with data!