Observations of High-z Galaxies

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SMA Follow-Up of AzTEC/COSMOS Sources

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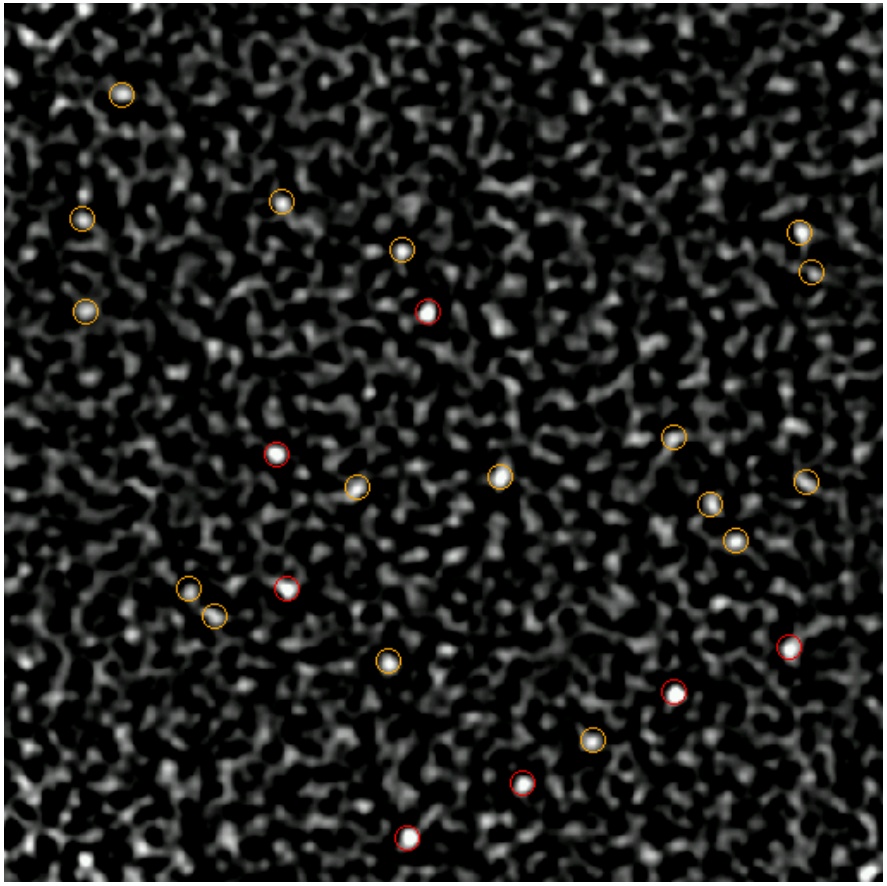
OBSERVATIONS

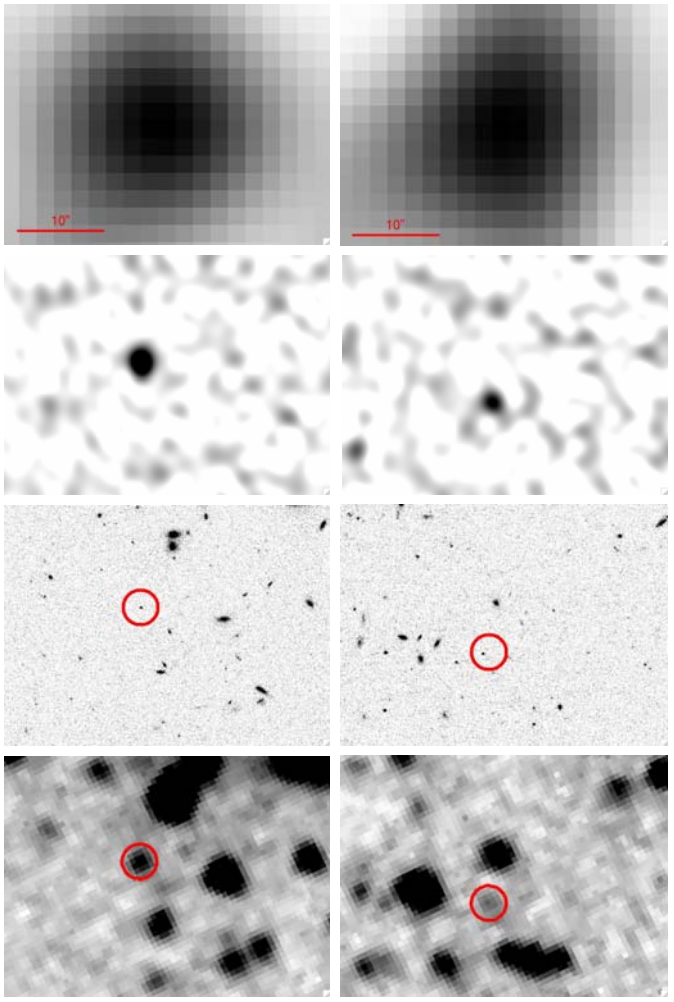
- AzTEC camera observations (1.1 mm wavelength; 18 arcsec resolution) on the JCMT of the COSMOS field (0.15 deg^2) detected 44 submm galaxies (SMGs) above 3.5σ.
- SMA interferometric observations (890 μm wavelength; 2 arcsec resolution) of the seven brightest AzTEC sources detected all seven SMGs and pinpointed their location to 0.2 arcsec.
- Follow-up observations by HST (ACS), SPITZER (IRAC and MIPS), and Very Large Array (VLA) revealed the detailed properties of these sources.

The AzTEC/COSMOS Survey
(Scott et al. 2007)

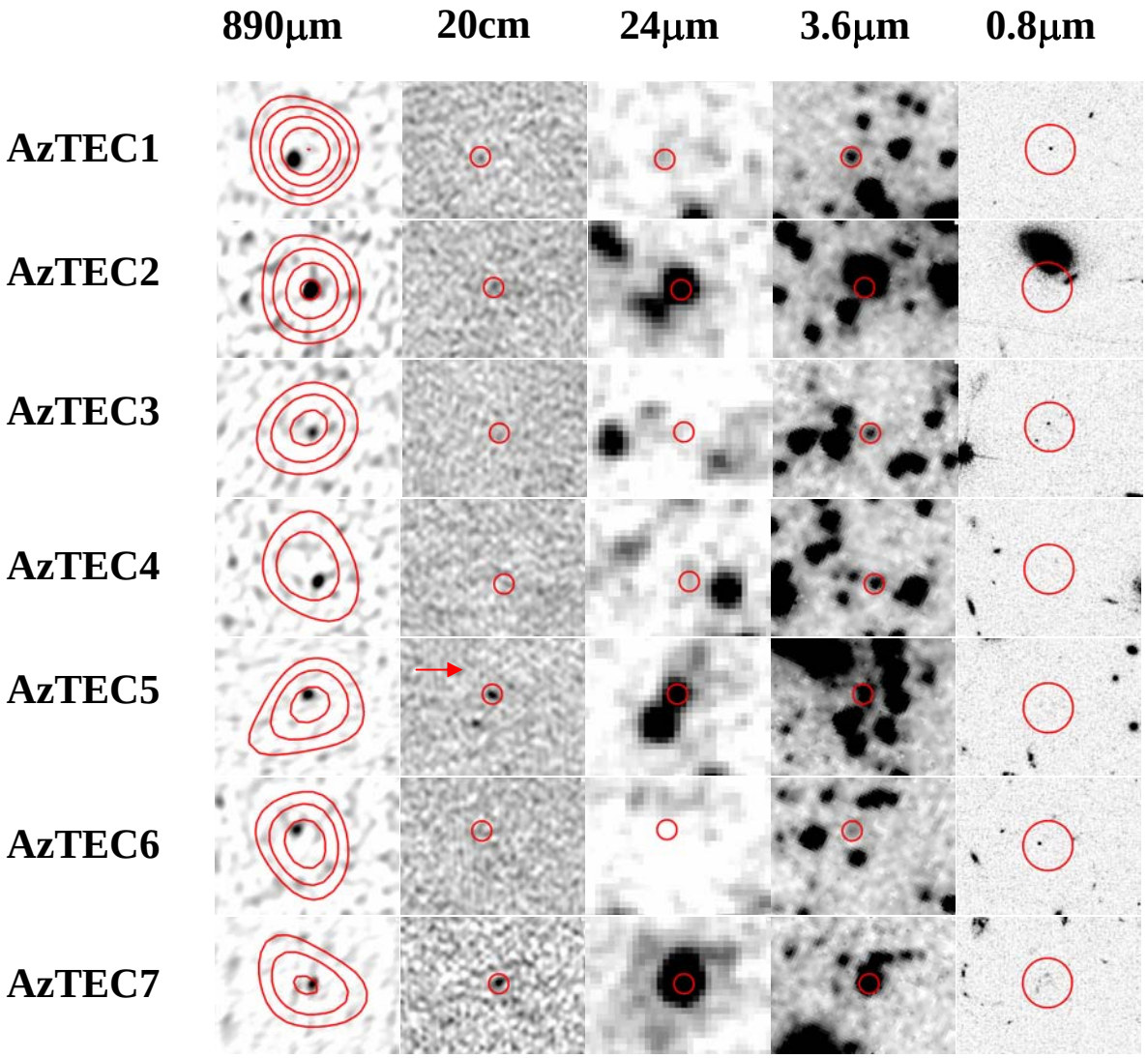


Extreme Starbursts in the Early Universe: SMA/AzTEC Observations of Submillimeter Galaxies

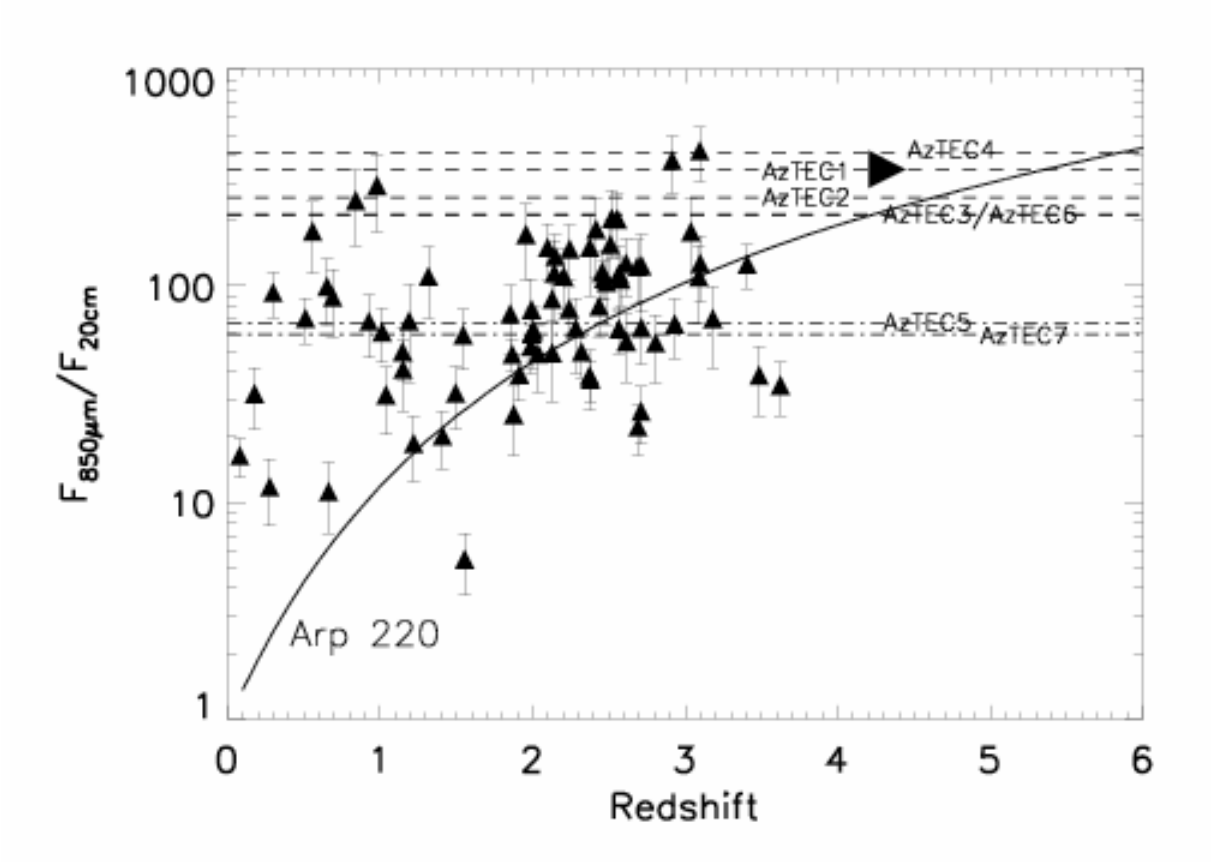
- Of the seven SMGs detected, five are radio-quiet.
- For the five radio-quiet sources (< 60 μJy), the submm, infrared and optical properties of these counterparts suggest high redshift.
  - High submm/radio fluxes
  - Submm sizes < 1.2 arcsec
  - Very low IRAC fluxes
  - Lack of optical flux
  - No MIPS detection at 24 μm
- These results are evidence for a population of extreme starburst galaxies when the universe was less than 16% of its current age (z > 3).



Multiwavelength Images

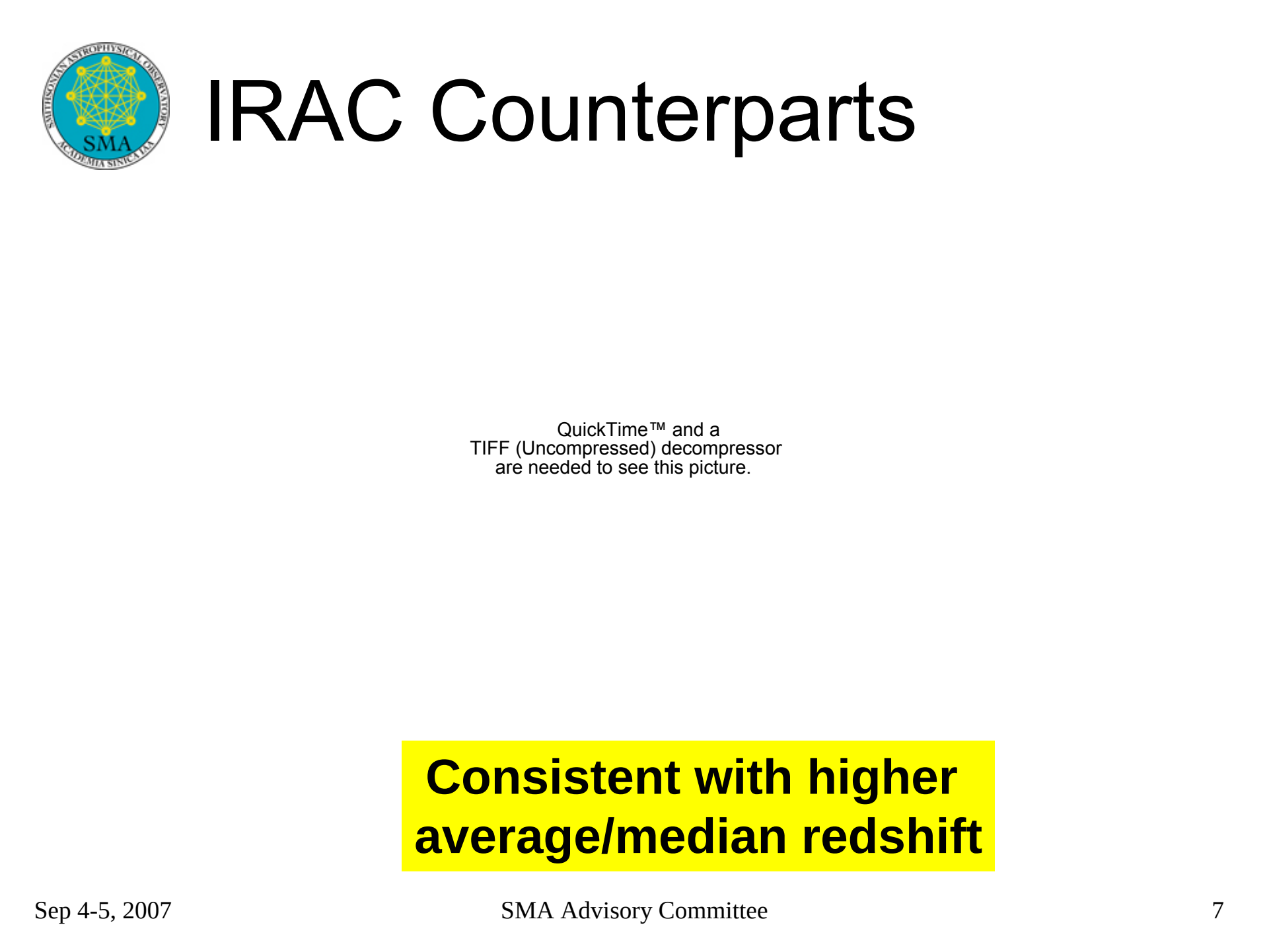


Radio/Submm Flux Ratios



Consistent with higher average/median redshift

IRAC Counterparts



Consistent with higher average/median redshift

CONCLUSIONS

- Detected a complete, flux limited sample of SMGs at high angular resolution
- Radio-quiet sources appear to be at higher redshift ($z > 3$) than radio-loud sources
  - Chapman redshift distribution is a lower-limit on z
- Brightest SMGs are compact; size scales analogous to local ULIRGs; $L > 5 - 10 \times 10^{12}$ L(sun).
- Population of higher redshift SMGs that contribute significantly to observed number counts
  - Constraints on galaxy formation models; have to have massive starbursts at early times
  - Constraints on dust formation models; how to make enough dust given short age of the system
- The brightest SMGs may be at the highest z.

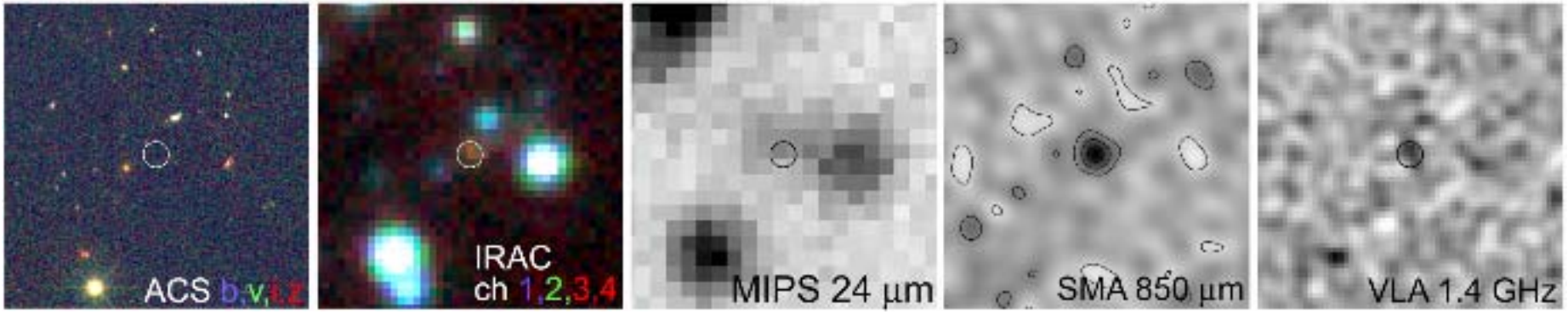
SMA 890 μm Images of High-z Galaxies

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

- GN20
  - GOODS-N; S(850 μm) ~ 20 mJy
  - High z: very weak radio; B-band dropout
  - Position: 0.1 to 0.2 arcsec; size < 1.2 arcsec
  - Optical galaxy offset by 0.8 arcsec

D. Iono et al. 2006 ApJ, 640, L1

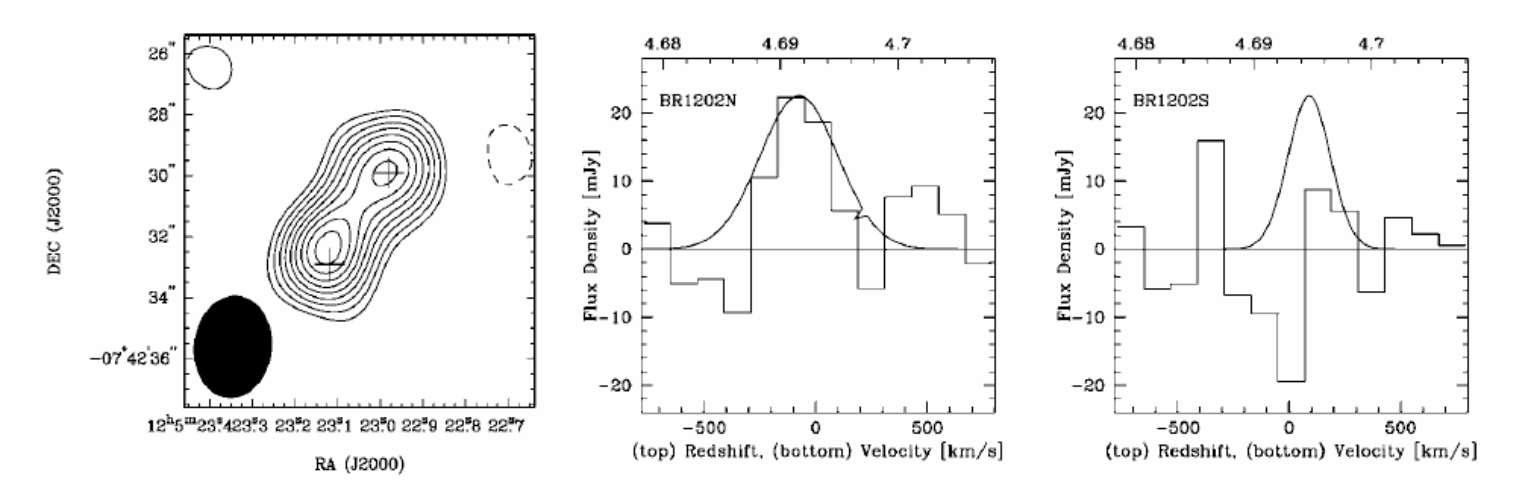
SMA Observations of GOODS 80-5 (z > 4)



- Submm: 12 mJy source at 850 mm
- Radio: < 20 μJy at 1.4 GHz, indicating high z
- Spitzer: 1 - 5 μJy at 3.6 - 8 μm; 46 mJy at 24 μm
- May be the first z > 4 source identified in the submm

W-H. Wang et al., submitted to ApJL

[CII] Line Emission in a z = 4.7 Quasar



- SMA imaging (~ 3 arcsec) of quasar QSO BR 1202-0725 at z = 4.7 yields two components
- [CII] detection with SMA from northern source [4.5 x 10^9 $L_{(sun)}$]
- [CII]/FIR luminosity = 0.04%
- X-ray emission: Pair of interacting galaxies (both AGN)

D. Iono et al., 2006 ApJ, 645, L97

A Biased mm-Wavelength AzTEC Survey Towards 4C41.17 at z~3.8

Tracing accelerated galaxy formation in a high-z (proto-)cluster

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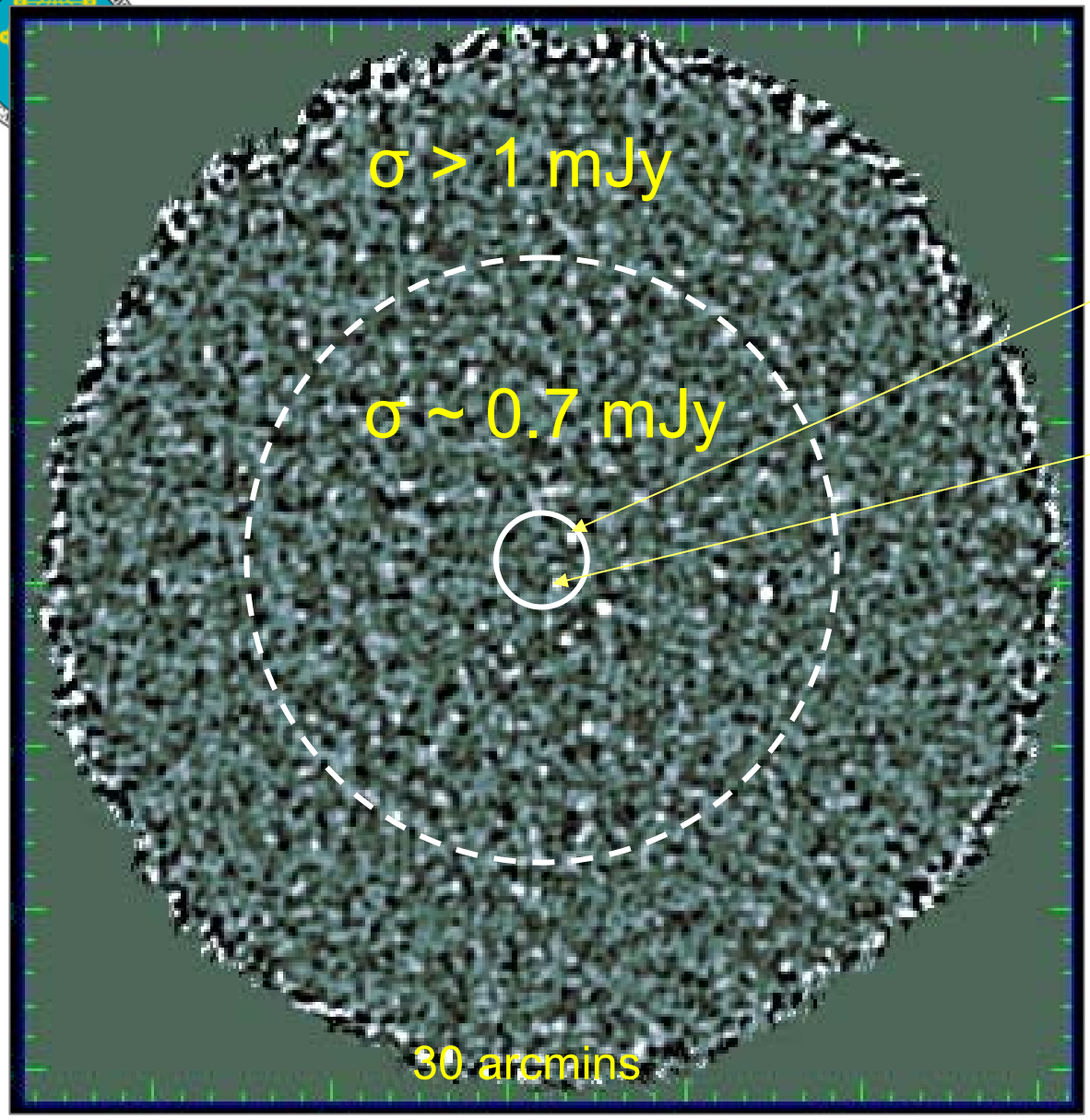
G. Wilson, M. Yun, J. Lowenthal, J. Austerman, T. Perera, K. Scott (Umass)
J. Dunlop (ROE, UK)
K. Kohno (NAOJ)

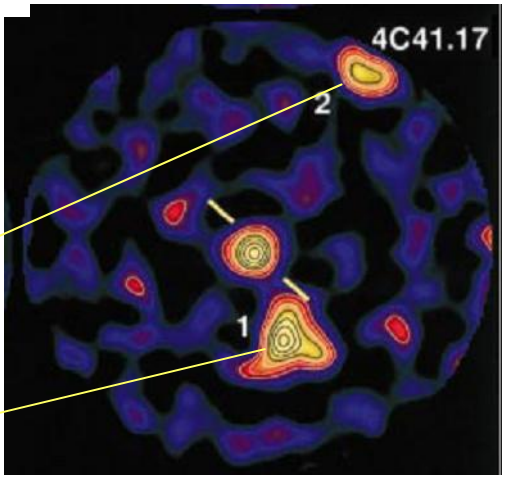
Survey Goals

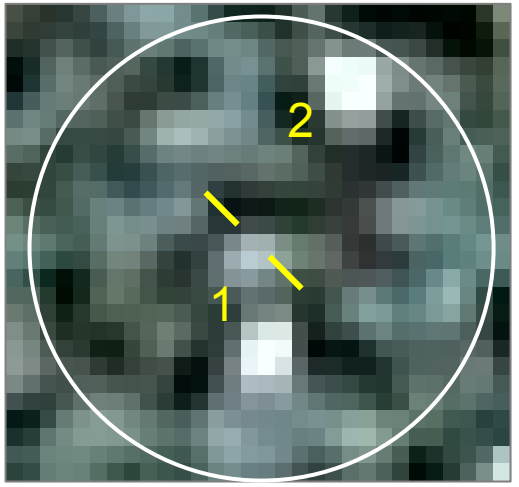
- Is the AzTEC source over-density associated with the environment of 4C41.37?
- Determine the multiplicity of AzTEC sources.
- Is star formation or AGN activity powering the FIR luminosity?

AzTEC 1.1mm survey (50 hours on JCMT)

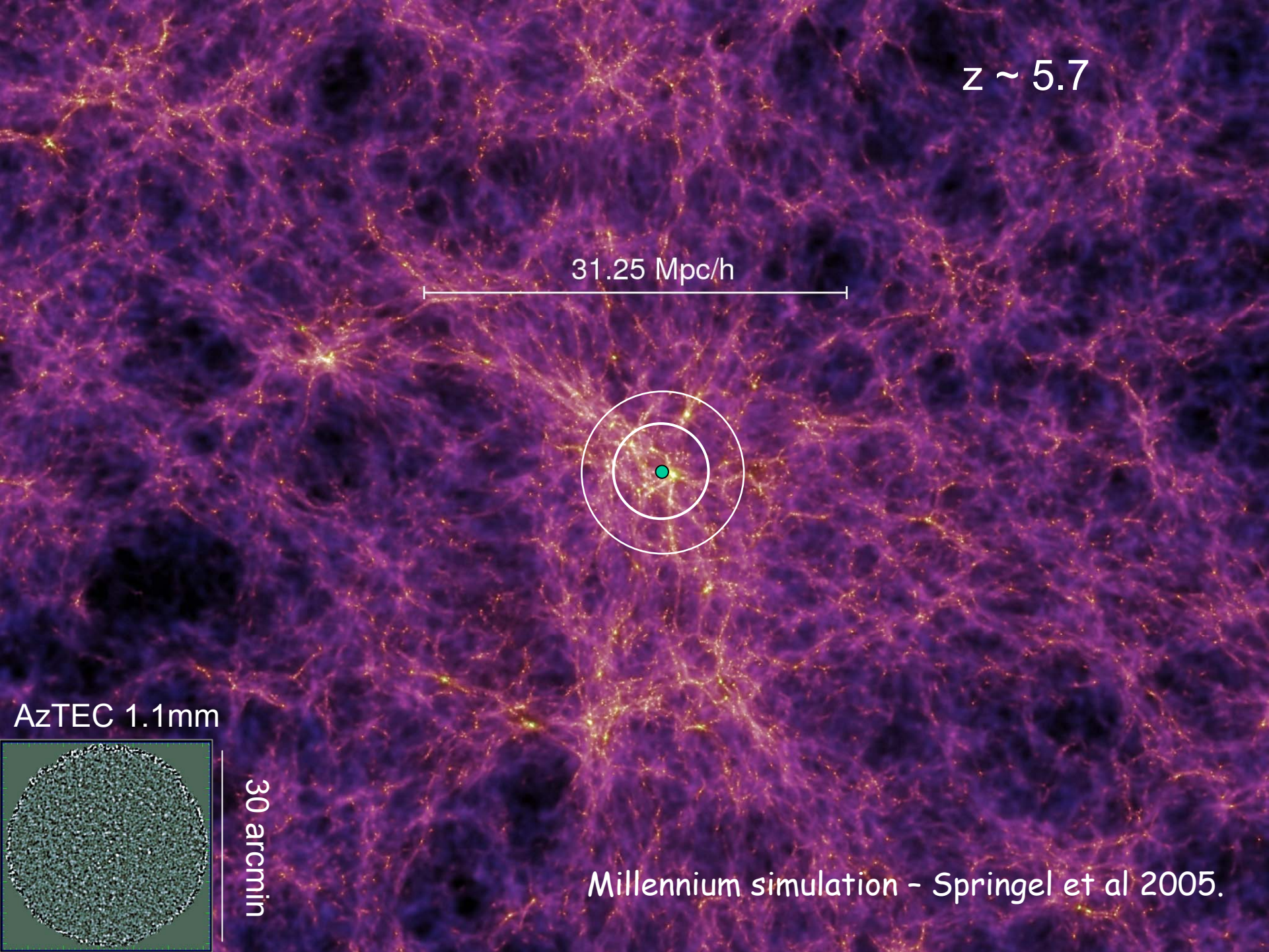


SCUBA/JCMT 850um
Stevens et al. 2003

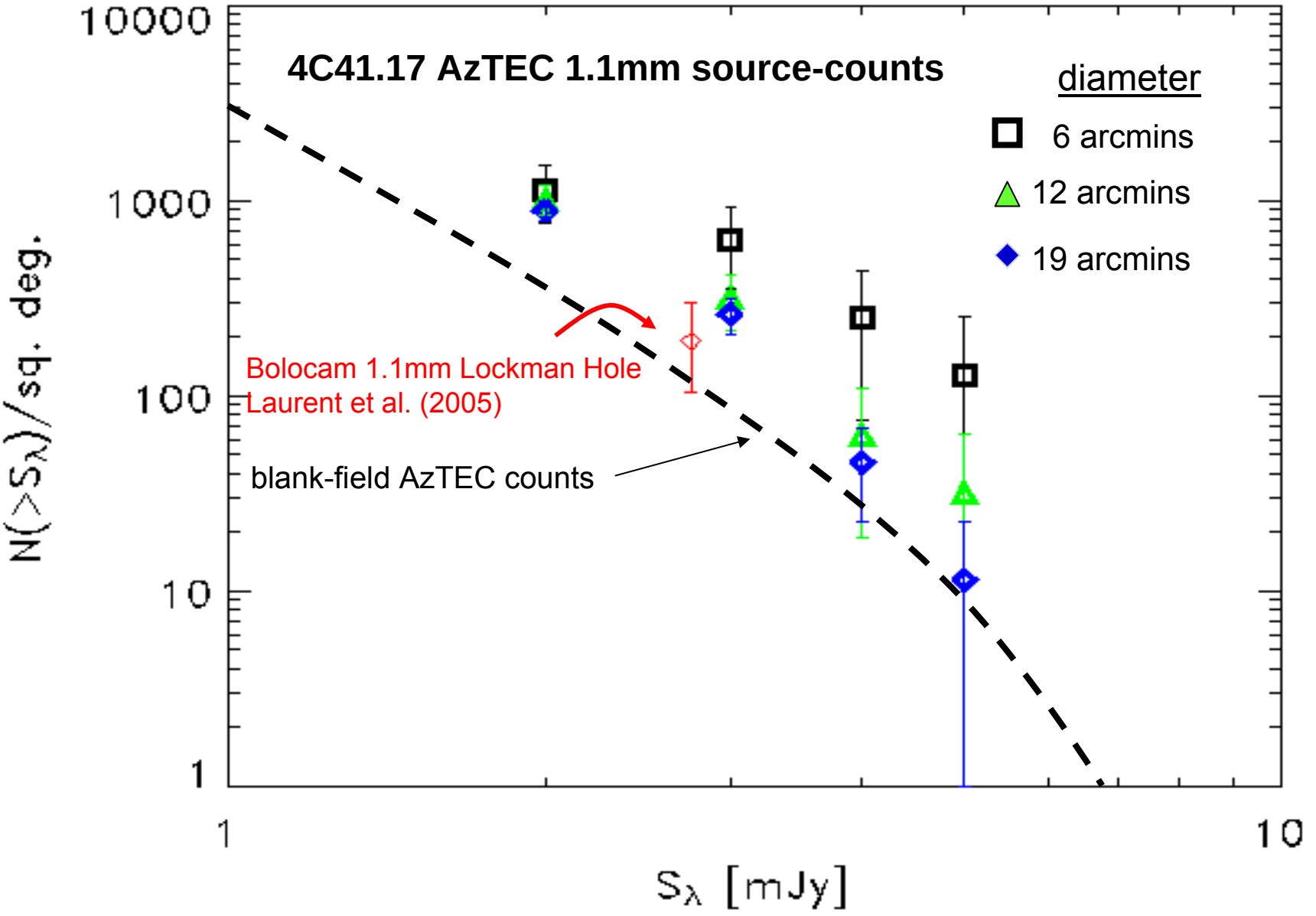




AzTEC 1.1mm

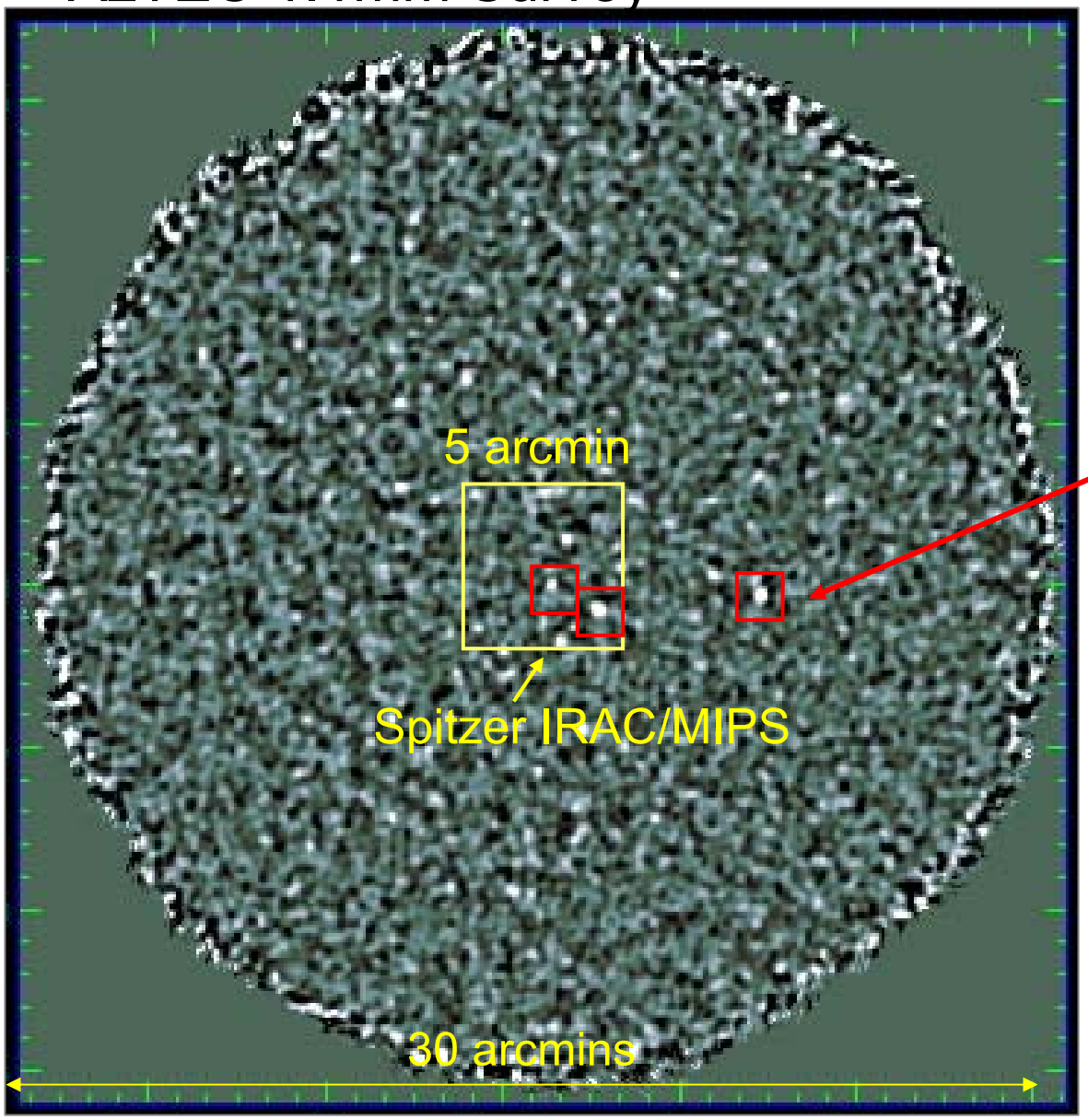

z ~ 5.7
31.25 Mpc/h
AzTEC 1.1mm
30 arcmin
Millennium simulation - Springel et al 2005.

Radially-increasing (factor x 5-10) over-density in N(>S) towards 4C41.17 compared to luminous SMGs in unbiased blank-fields

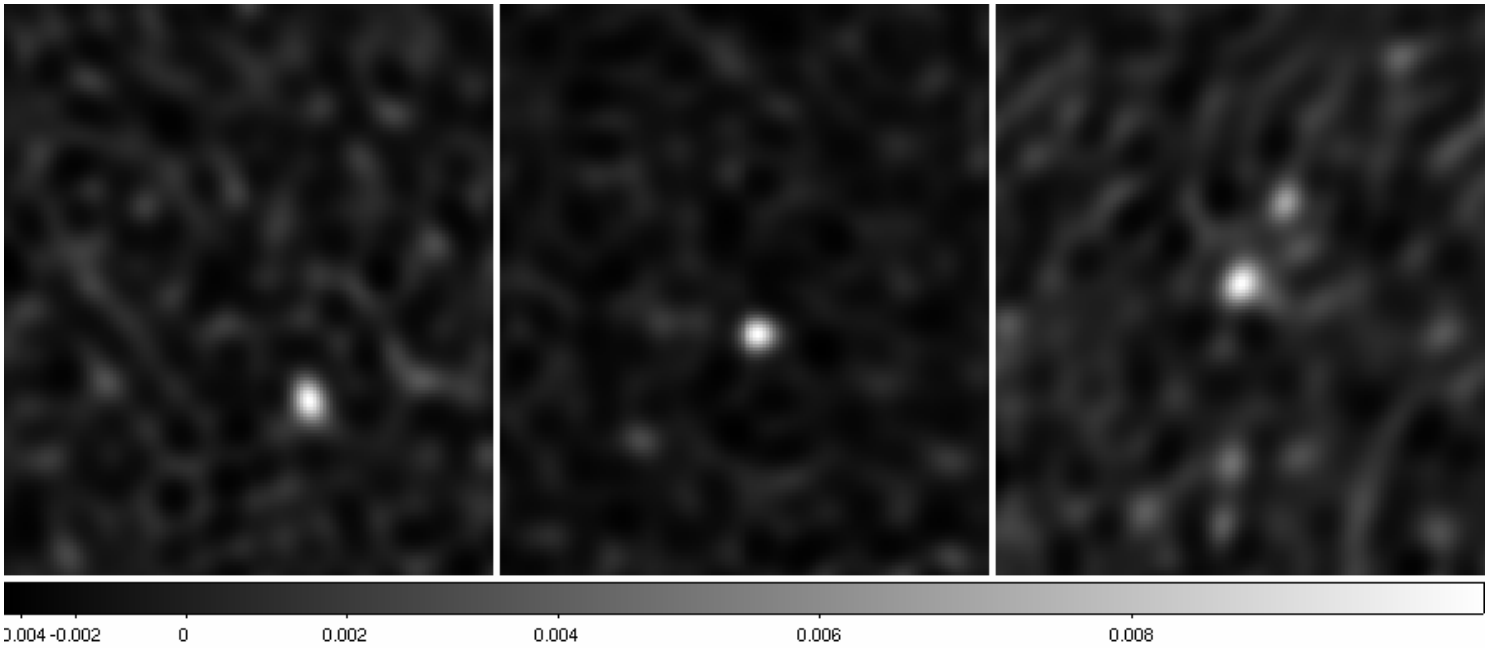


Se

AzTEC 1.1mm Survey

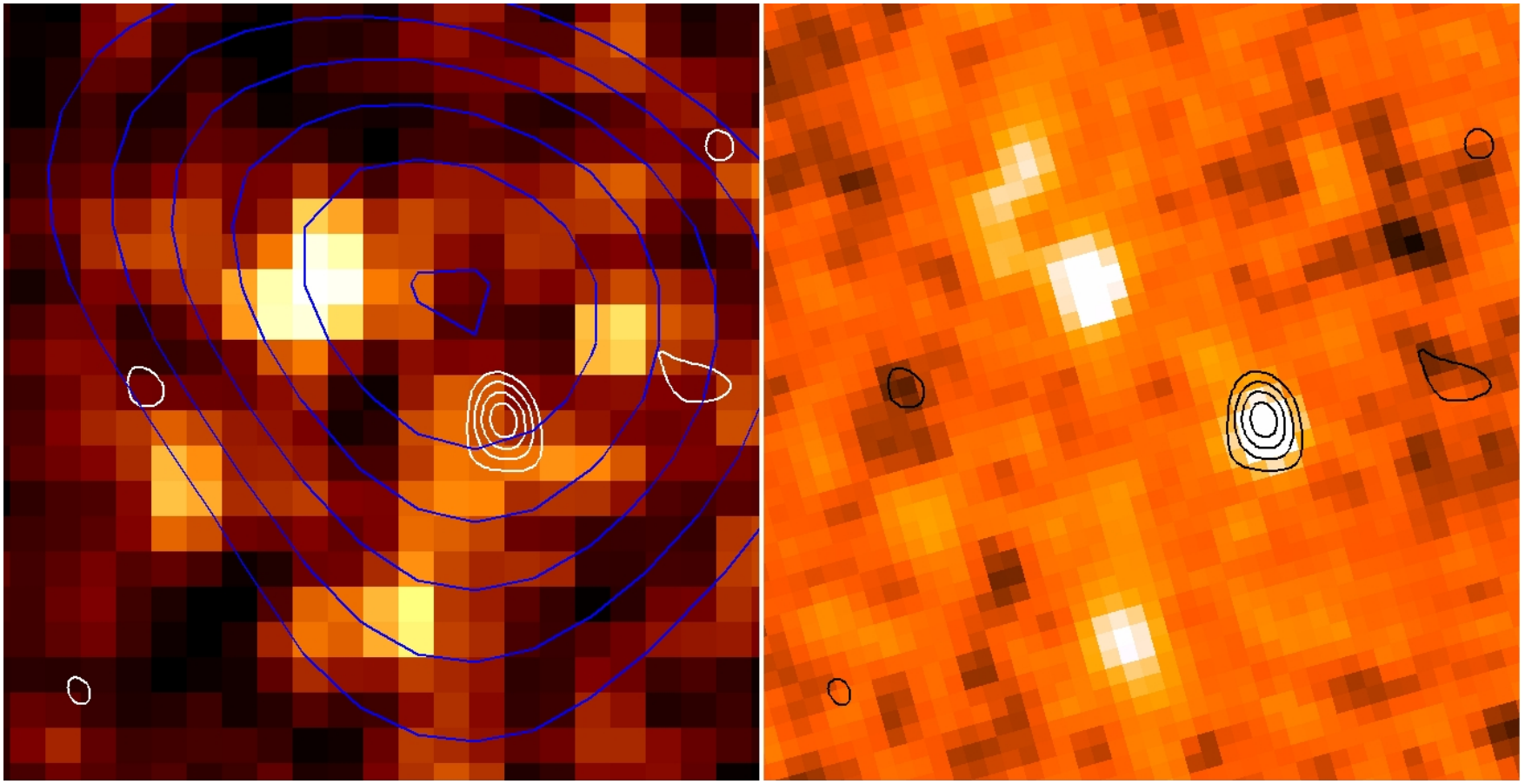


SMA follow-up of bright AzTEC sources in 4C41.17



- SMA target selection: AzTEC > 4 mJy at 1.1mm (equivalent to > 10 mJy at 850um)
- SMA requires 4-8 hours for 6-12 sigma detections
- Easily detected all 3 AzTEC sources

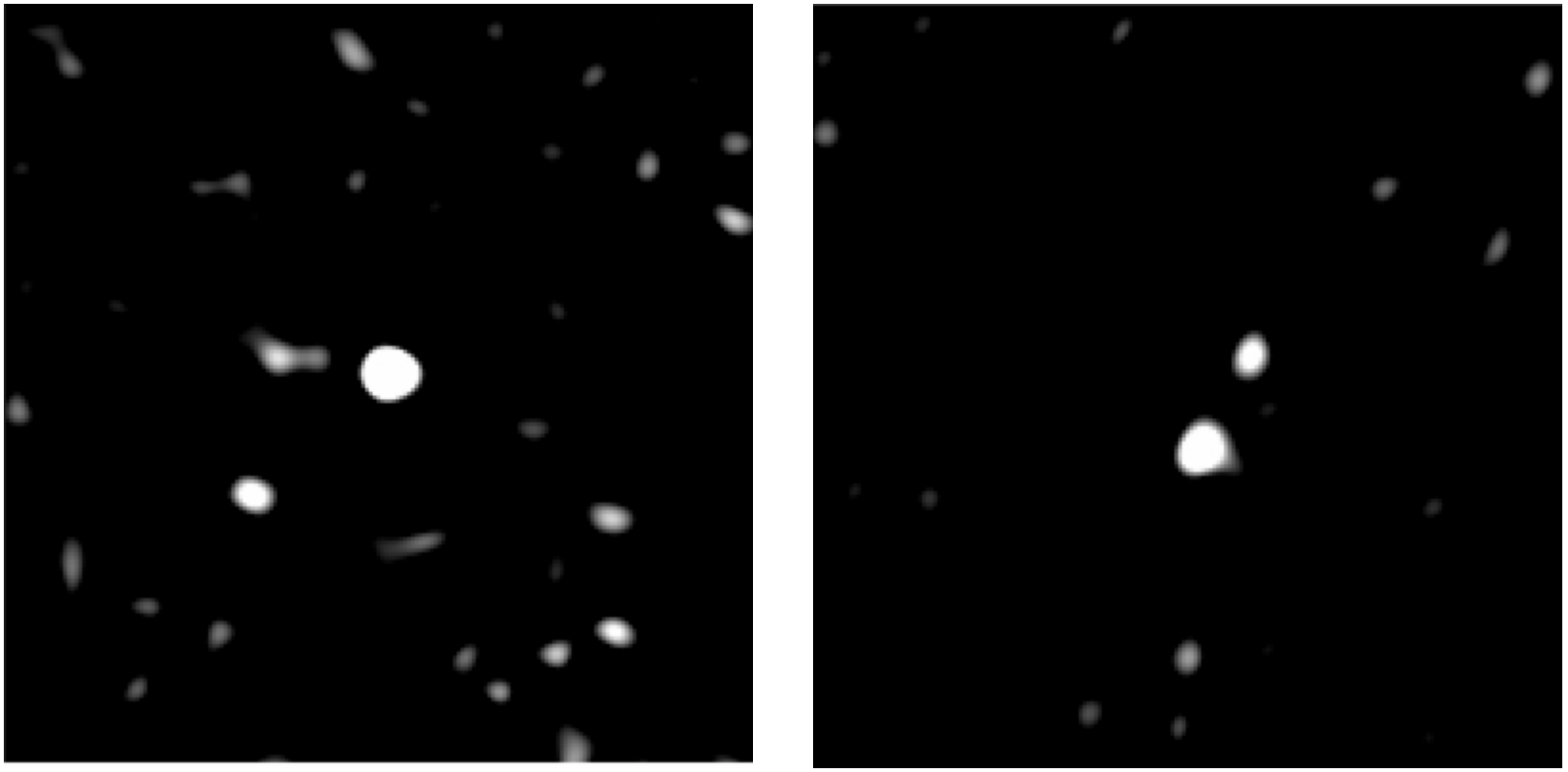
SMA/AzTEC/ Spitzer Observations



24 microns AzTEC SMA

8 microns SMA

Multiplicity of sub-mm galaxies?



SMA observations of two bright > 4mJy AzTEC sources toward 4C41.17

Summary

- Significant improvements in the sensitivity and stability of the SMA now permit the observation at 890 microns of galaxies at z > 3.

- The SMA is essential in locating the precise position of these high-z galaxies, measuring their size and multiplicity; when combined with multiwavelength observations permits the determination of SEDs/photo-z.

- Brightest submm galaxies detected by SMA may be at high redshift (z > 3); important for determining SFR in early Universe.

Future Work

- Very deep Spitzer follow-up (approved)
  - Proposal accepted to image detected radio-quiet sources with IRAC, MIPS, and IRS to get better handle on the redshift
- Ground-based observations with Keck to get redshifts
- Expand the high-z SMG sample
  - Program accepted to do SMA follow-up of AzTEC sources in MS0451; Are SMGs in the field like SMGs in a biased environment?
  - SMA follow-up of next 21 AzTEC/COSMOS bright sources (11 of these sources are radio quiet)
  - SMA follow-up of 10 brightest LABOCA/APEX sources in the ECDFS (with Ian Smail, Fabian Walter and Axel Weiss)
- Resolve SMGs with large SMA baselines
  - Get a better constraint on size scales
  - Compare to merger models
- Theoretical numerical simulations of the formation of SMGs at high z (with Lars Hernquist).