

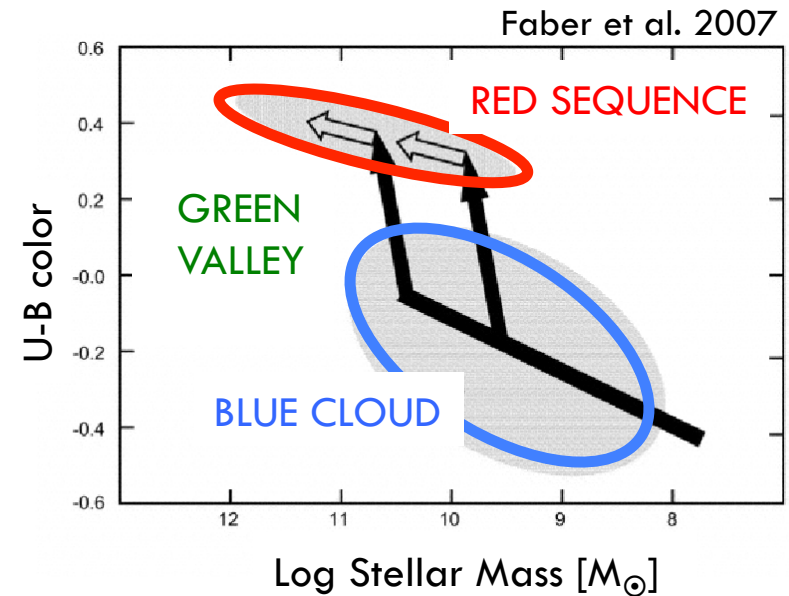
## Searching for high-redshift submillimeter galaxies in the COSMOS field

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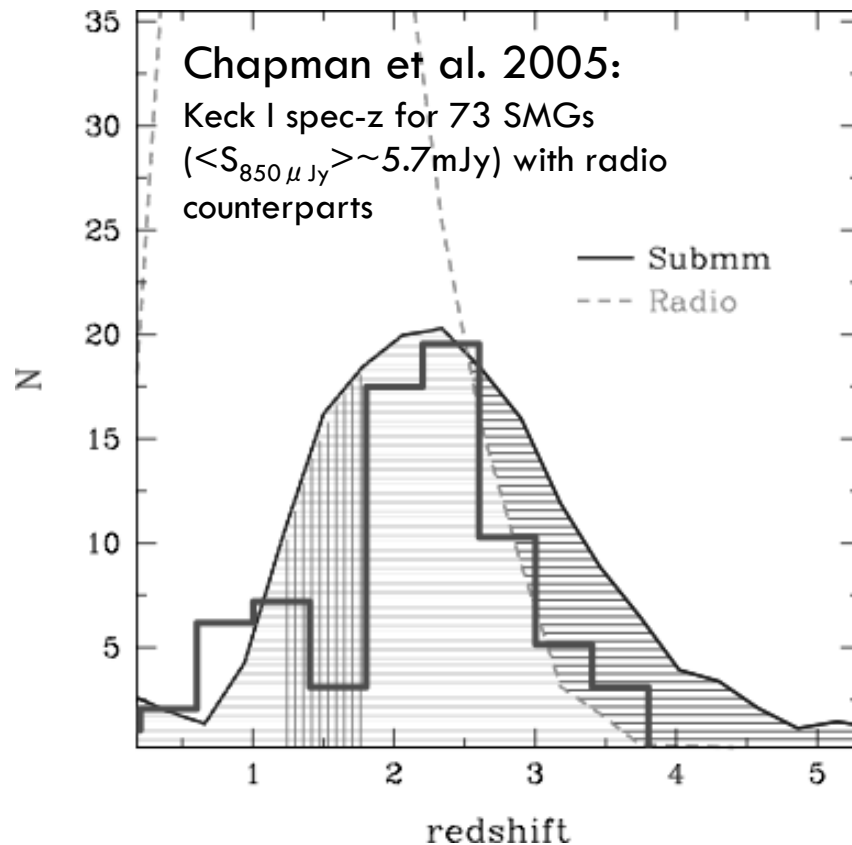
P. Capak, O. Ilbert, M. Aravena & COSMOS team

# Massive galaxy formation

- **Blue-to-red galaxy formation** (Sanders & Mirabel 1996, Bell et al. 2004, Borch et al. 2006, Faber et al. 2007, Hopkins et al. 2007 & many others)
- **Bulk of stellar body in red galaxies formed in intense burst at  $z \gg 2$**  (Naab et al. 2007; Cimatti et al. 2008; Daddi et al. 2009) → **submillimeter galaxies at  $z > 4$  good candidates**

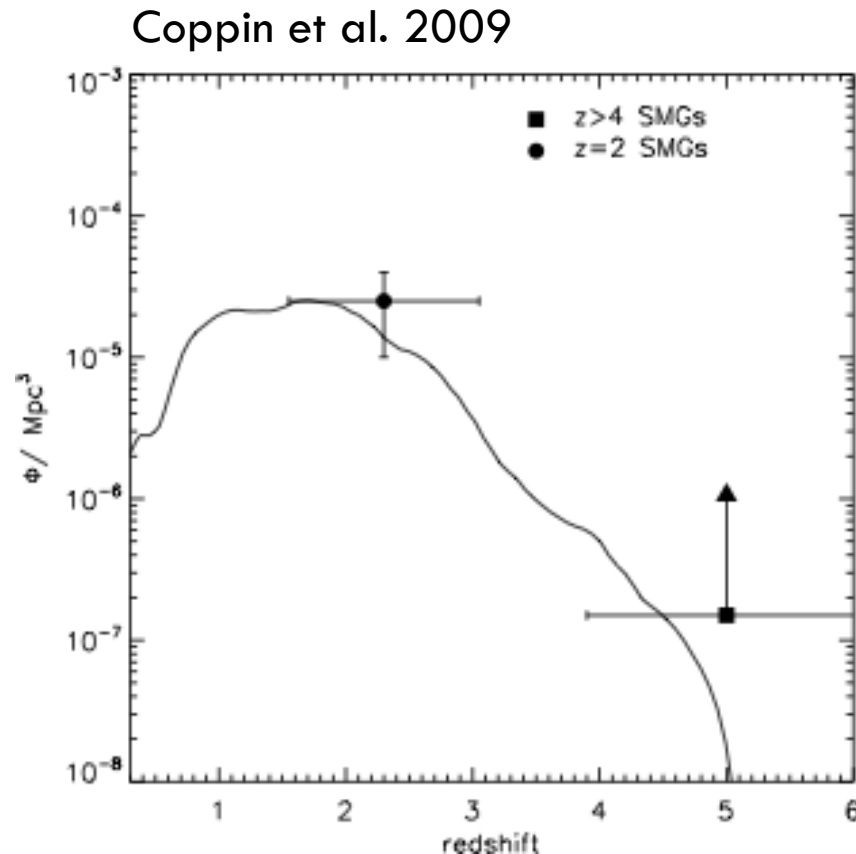


# Submillimeter galaxies (SMGs)



- $S_{850 \mu\text{Jy}} > 5 \text{ mJy}$
- $\text{SFR} \sim 100\text{-}1000 M_{\odot}/\text{yr}$
- $\langle z \rangle \sim 2.2$
- $z > 4$  SMGs start emerging:
  - 4 in GOODS-N (Daddi+2009a,b; Carilli et al. 2011)
  - 3 in COSMOS (Capak+08, Schinnerer +08, Riechers+10, Capak+11, Smolcic+11)
  - 1 in ECDFS (Coppin+2009,2010)
  - 1 in Abell 2218 (Knudsen+2010)

# $z > 4$ SMGs



- Number density of detected  $z > 4$  SMGs in ongoing surveys is (marginally) consistent with that predicted in cosmological models

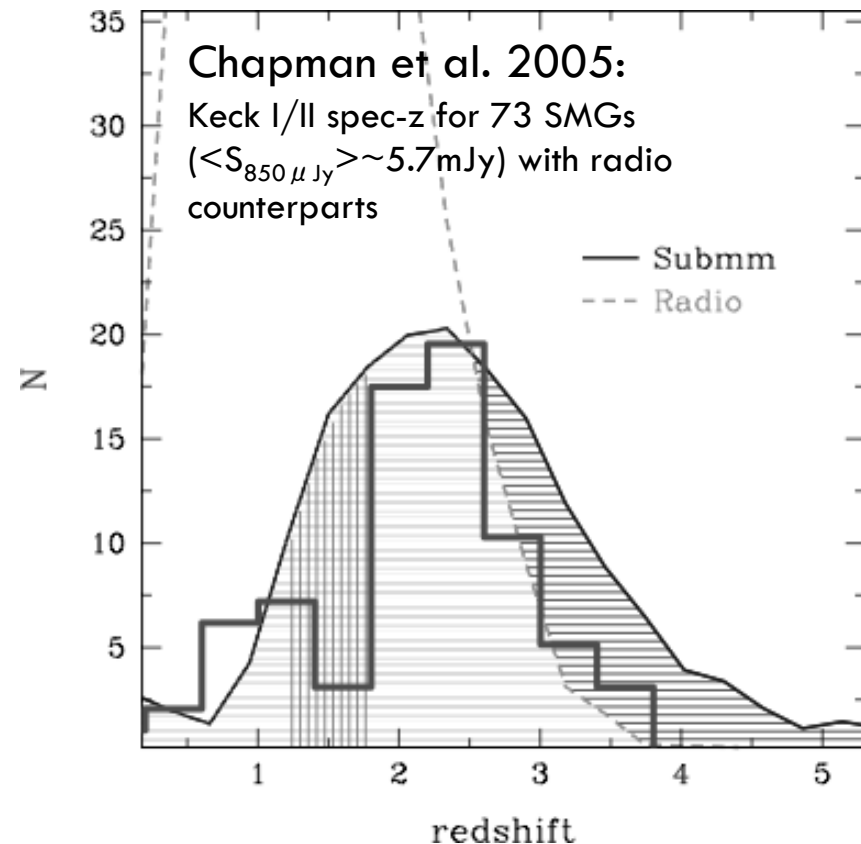
(Baugh et al. 2005, Coppin et al. 2009, 2010)

- High- $z$  & low- $z$  SMGs: Different populations?

(Wall et al. 2008)

# Redshift distribution of SMGs

- 73/150 SCUBA/JCMT sources drawn from various fields
- Counterparts associated via faint radio emission
- Spectroscopic redshifts obtained with Keck
- $\langle z \rangle = 2.2$  (interquartile range 1.7–2.8)

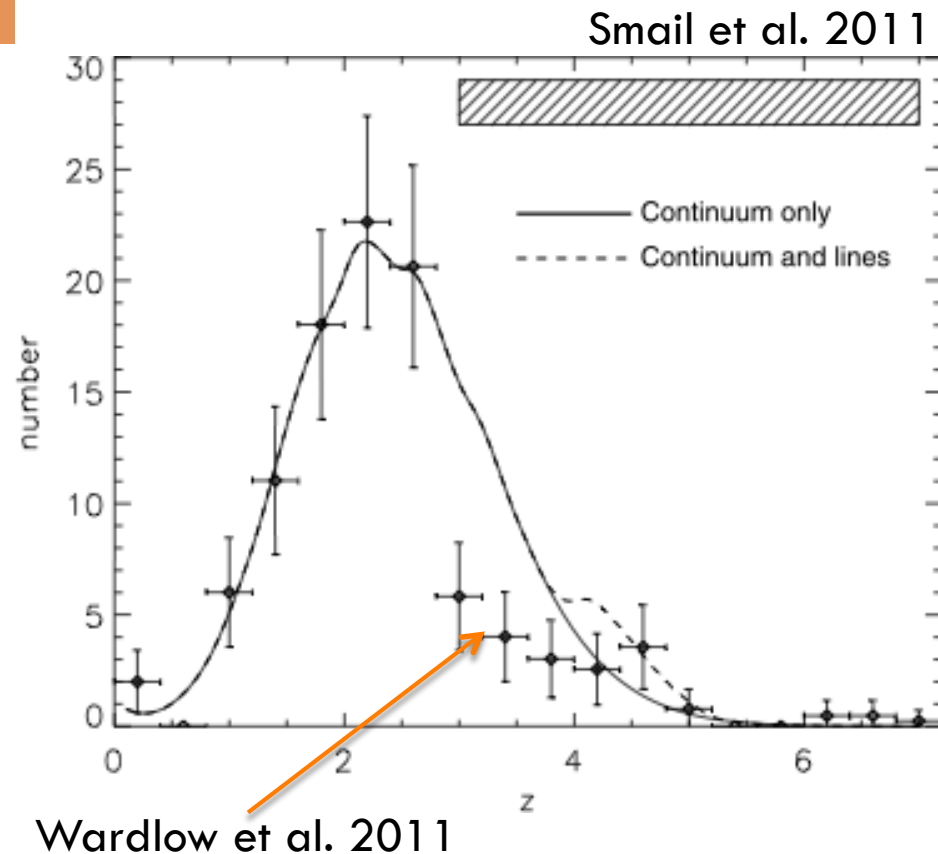


# Redshift distribution of SMGs

Biggs et al. 2010; Wardlow et al. 2011

- LESS: LABOCA ( $870 \mu\text{m}$ ) + ECDFS
- Photo-z,  $\sigma_z = 0.05(1+z)$ , for
  - ▣ 68 radio/ $24 \mu\text{m}$ /IRAC identified counterparts
  - ▣ 55 unidentified and statistically taken into account; ;  $21 \pm 19$  may be at  $z > 3$  (hatched area)
- $\sim 30\%$  ( $< 45\%$ ) of all SMGs at  $z > 3$
- $\langle z \rangle = 2.5 \pm 0.6$

High-z: ???



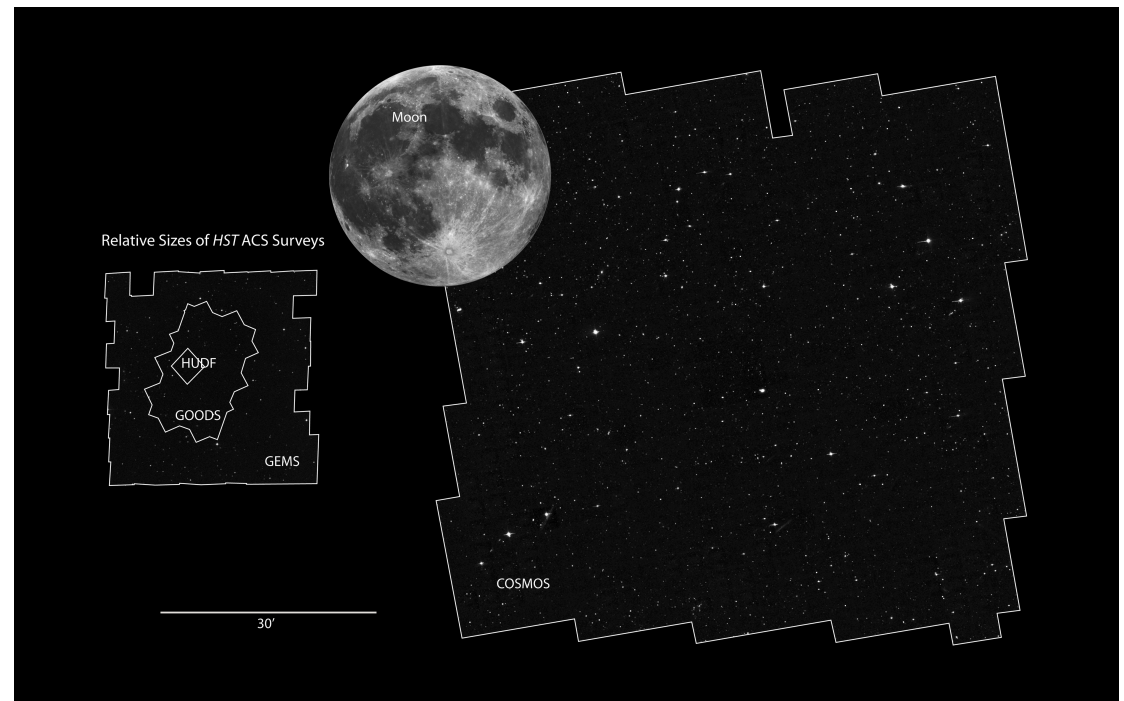
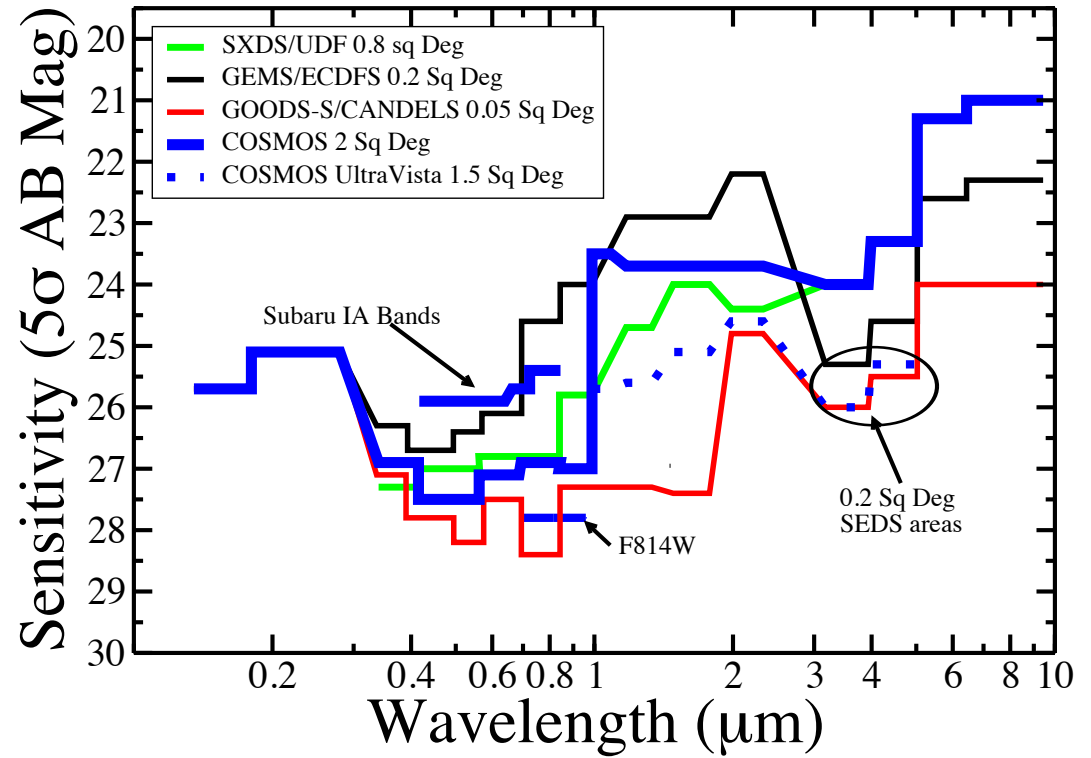


# Quest for $z > 4$ SMGs in COSMOS

# The COSMOS survey

COSMOS overview (Scoville et al. 2007)

- 2  $\square^{\circ}$  equatorial field
- X-ray to radio imaging (>30 bands)
  - galaxy photo-z accuracy, 0.7% (Ilbert et al 2009)
  - quasar photo-z accuracy, 1.5% (Salvato et al. 2009)
- spectroscopy (VLT-VIMOS + Magellan-IMACS)





# mm-COSMOS → awaiting for ALMA

## □ Bolometer (~10-30" resolution)

□ MAMBO (0.11°; Bertoldi et al. 2007)

□ AzTEC (0.3°; Scott et al. 2008;  
0.72°; Aretxaga et al. 2011)

□ BOLOCAM (0.27°, Aguirre et al, in prep)

□ LABOCA (1°, Albrecht et al., in prep)

## □ Follow-up: counterparts & redshifts

□ Interferometry (1-3"; SMA, CARMA, PdBI) to pin-point multi-  
 $\lambda$  counterparts (Younger et al. 2007, 2009, Aravena et al. 2010, Smolčić et al., subm.)

□ Spectroscopy with Keck, VLT, PdBI, IRAM-30m

(Capak et al. 2008, 2011; Schinnerer et al. 2008, Riechers et al. 2010, Smolčić et al. 2011)

# Interferometric sample of SMGs in COSMOS

## □ SMA

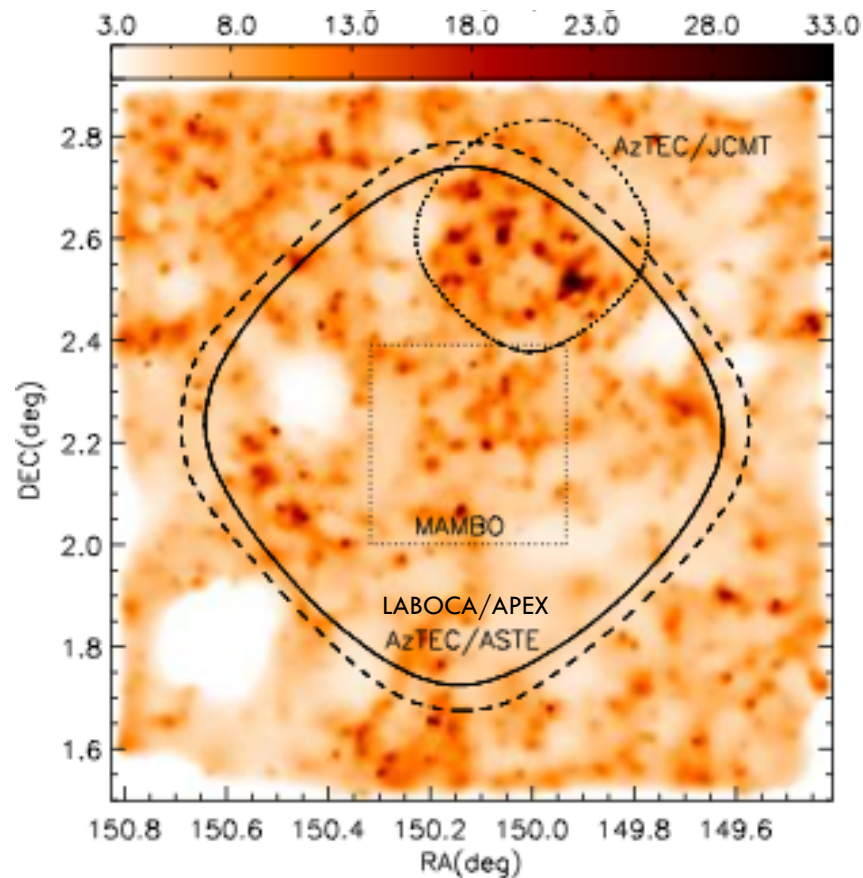
- Younger et al. 2007, 2009, Aravena et al. 2010
- 2" resolution
- 15 AzTEC/JCMT sources
- 2 COSBO sources

## □ CARMA

- Smolcic et al., subm., Sheth et al., in prep
- ~3" resolution
- 3 AzTEC(JCMT+)ASTE + 2 COSBO sources

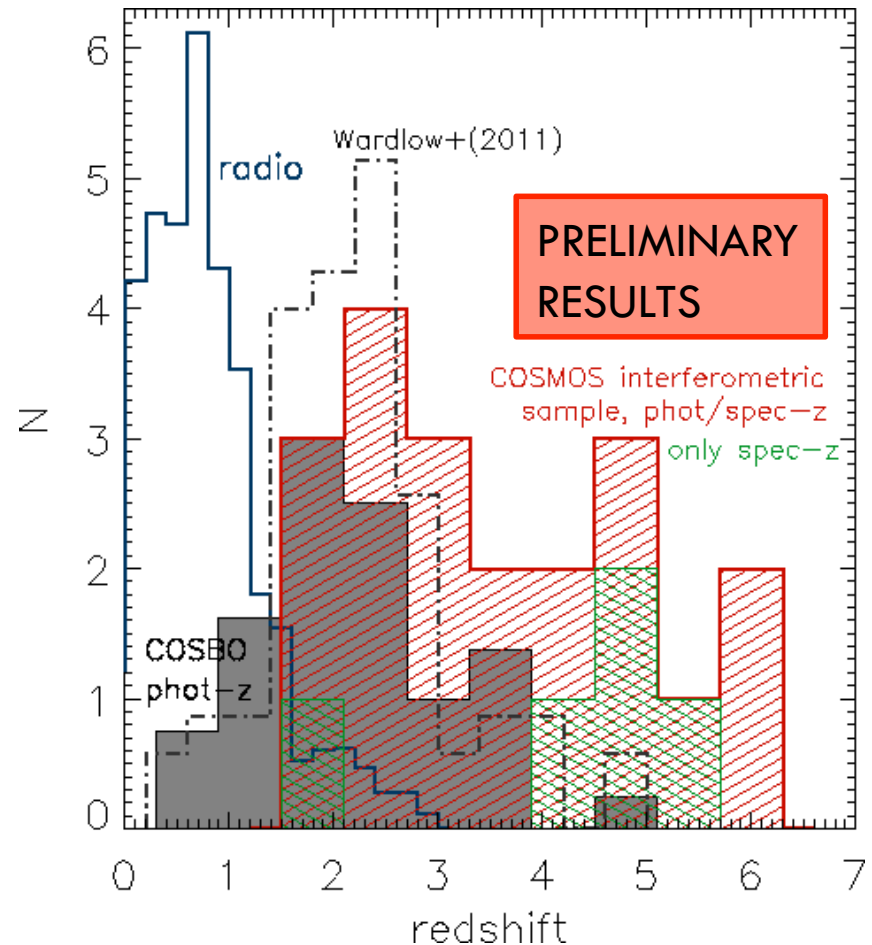
## □ $S_{\text{mm}} > 4 \text{ mJy}$

## □ Counterparts & spec/photo-z



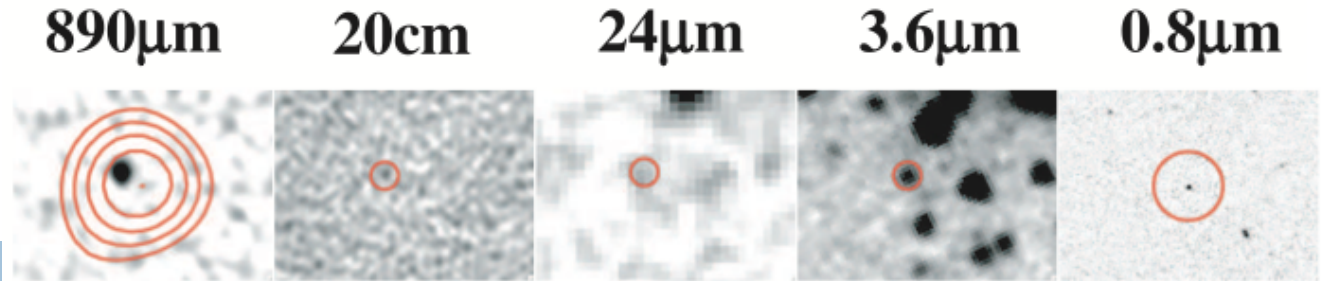
# Redshift distribution of COSMOS SMGs

- Interferometric sample heterogeneous (AzTEC, MAMBO areas)
  - ▣ most sources selected from  $0.3 \square^\circ$  overdense field
  - ▣ Not complete
- Photo-z for SMGs:  
 $\sigma_z = 0.06(1+z)$
- 5 spec-z (Capak et al. 2008, 2010, Riechers et al. 2010, Smolcic et al. 2011, Karim et al. in prep, Sheth et al., in prep)



# AzTEC/COSMOS 1: a starburst at $z=4.6$

# AzTEC-1

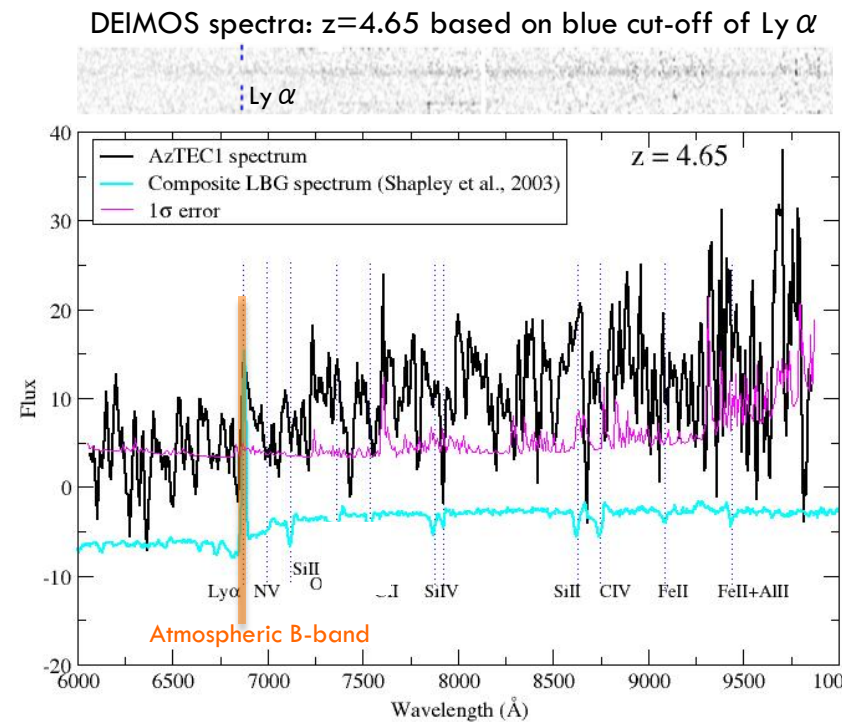


Younger et al. 2007

- Initially detected in AzTEC/JCMT survey (Scott et al. 2008)
- SMA follow-up pin-pointed opt/IR/radio counterpart: B-band drop-out ( $z \sim 4$ ) & unresolved at  $0.3''$  resolution (Younger et al. 2007, 2008)
- Keck-II/DEIMOS follow-up: 4 hrs integration
- PdBI/CARMA 3mm follow-up

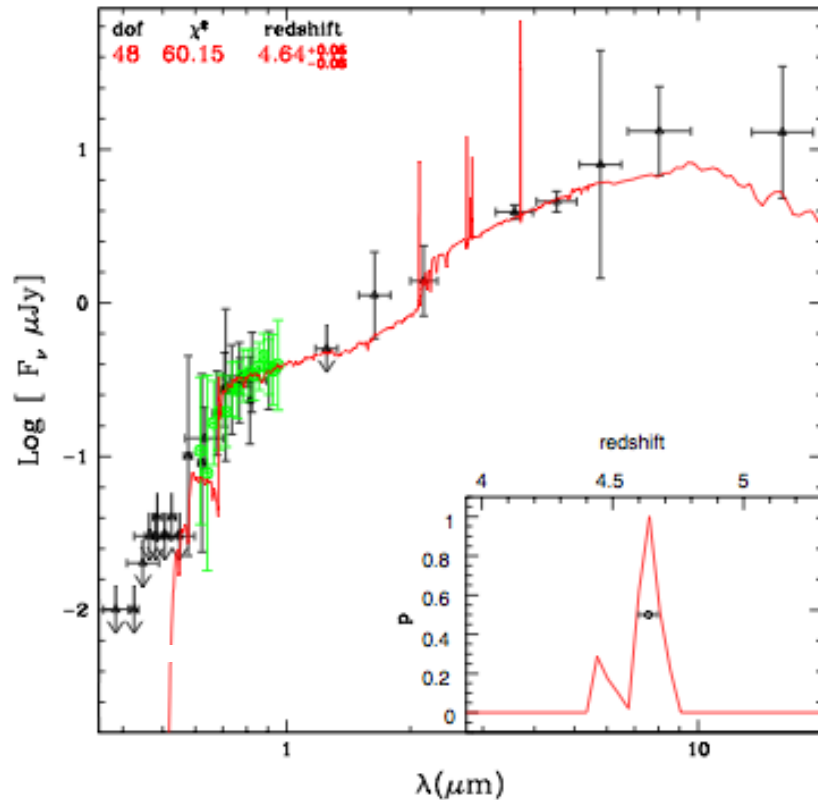
$$S_{1.1\text{mm}} = 9.3 \pm 1.3 \text{ mJy}$$

$$S_{20\text{cm}} = 42 \pm 10 \mu\text{Jy}$$

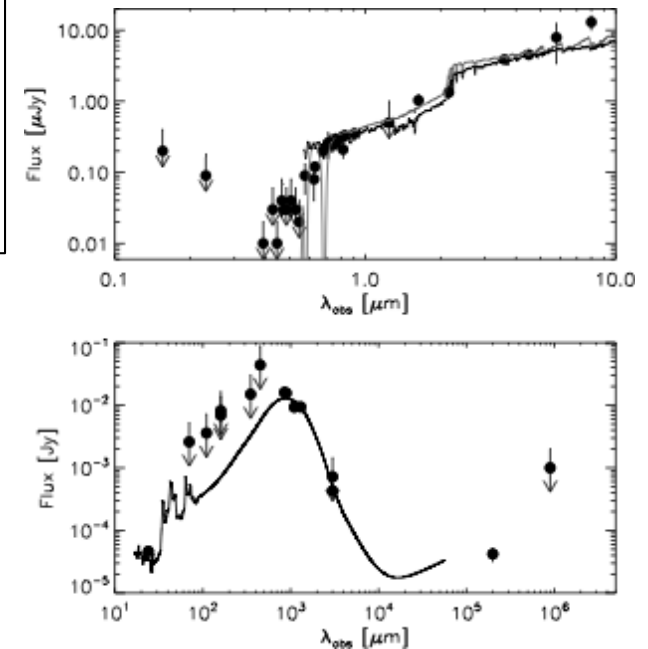


Smolcic et al. 2011

# AzTEC/COSMOS 1: a starburst at $z=4.6$



$z=4.64^{+0.06}_{-0.08}$  based on binned DEIMOS spectrum and >30 band photometry



Smolcic et al. 2011

- PdBI, CARMA follow-up ( $4.56 < z < 4.76$ ;  $4.94 < z < 5.02$ )
- ➔ no CO(5-4) detection:  $M_{\text{gas}} < 10^{10} M_{\odot}$ 
    - redshift outside the covered range
    - low CO(5-4) excitation (as in case of  $z=4.05$  SMG GN20; Carilli et al. 2010)
    - AGN?

UV-NIR SED analysis yields AzTEC-1 is a very compact ( $\leq 2 \text{ kpc}$ ), young ( $< 50 \text{ Myr}$ ), already massive ( $M_* \sim 10^{11} M_{\odot}$ ) galaxy forming stars at a rate of  $\sim 1300 M_{\odot}/\text{yr}$  at  $z=4.6$  ➔ possible progenitor of  $z \sim 2$  compact red galaxies (e.g. van Dokkum et al. 2008)

# Summary / conclusions / outlook

- Interferometric follow-up of complete samples of SMGs optimal and now possible for complete samples
  - ▣ Sample of  $\sim 20$  SMGs at  $2''$  resolution at mm- $\lambda$  in COSMOS
  - ▣ Ongoing (continuum/spec) follow-up
- Photo-z + spec-z + further follow-up
  - ▣ Fraction of  $z > 4$  SMGs
  - ▣ Physical properties of  $z > 4$  SMGs
  - ▣ Role of  $z > 4$  SMGs in galaxy evolution and formation
- AzTEC/COSMOS 1: compact, massive starburst at  $z = 4.6 \rightarrow$  progenitor of compact red galaxies at  $z \sim 2$ ?