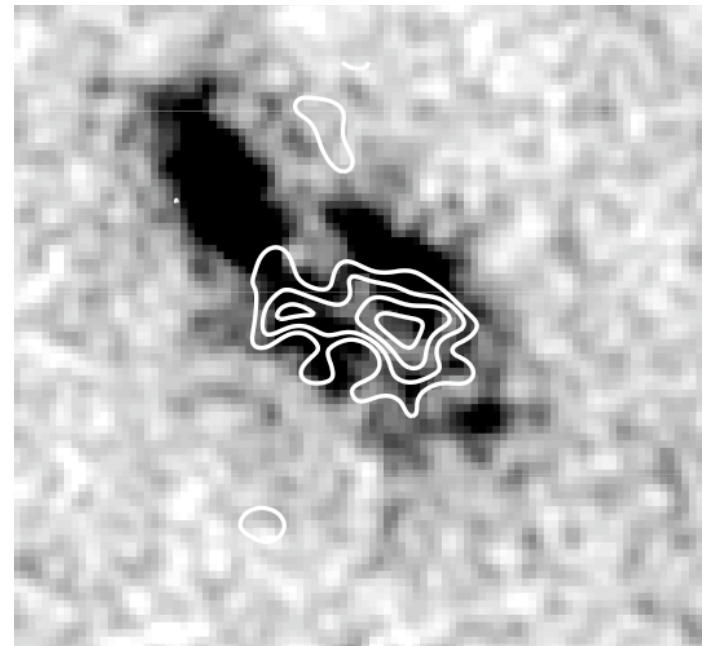
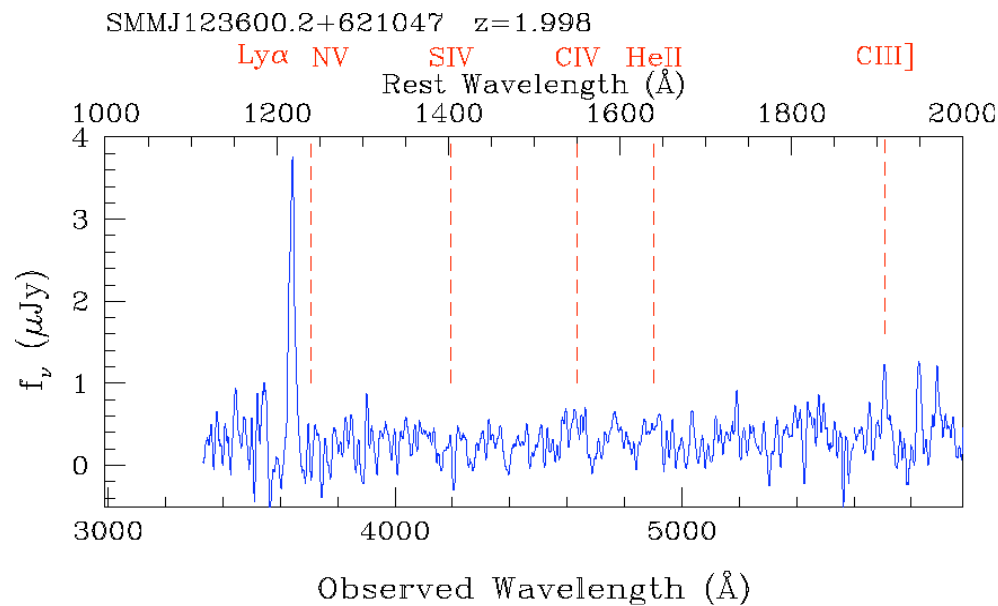
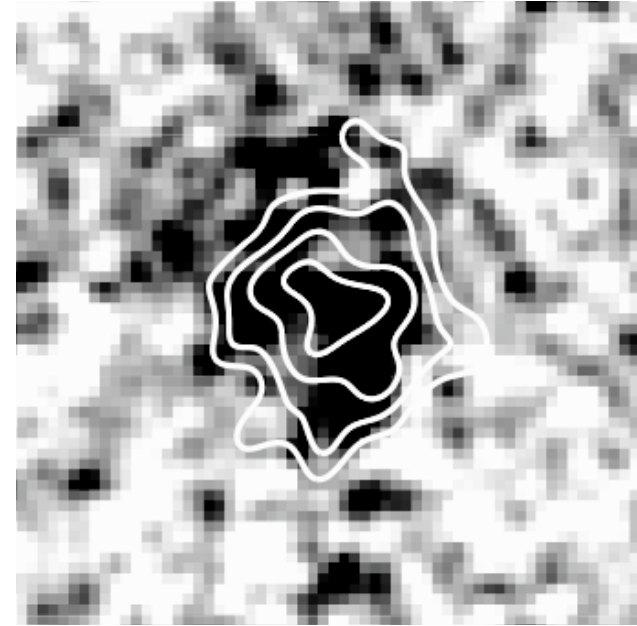
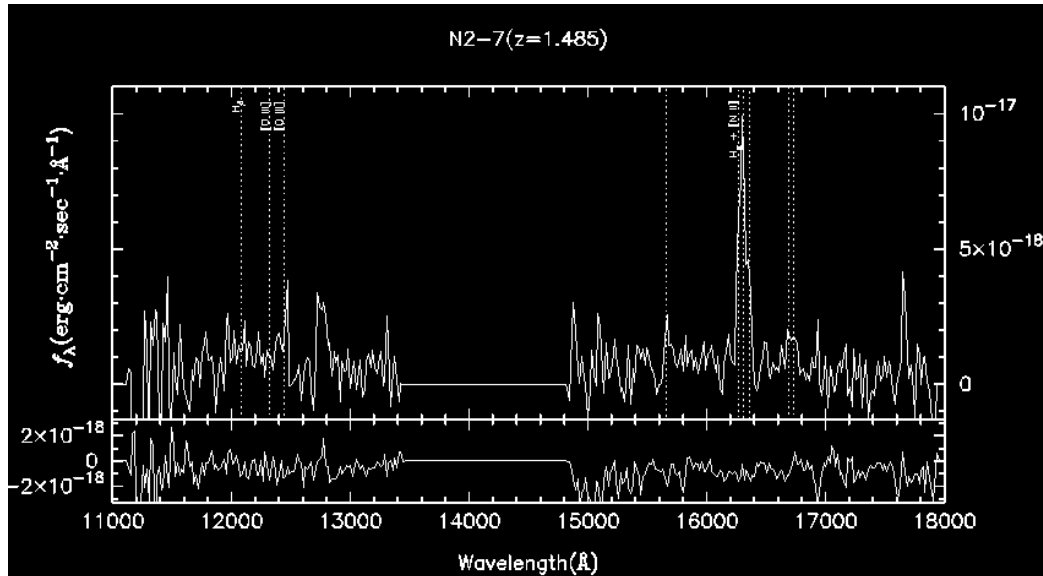


# UV/optical spectroscopy of Submillimeter Galaxies

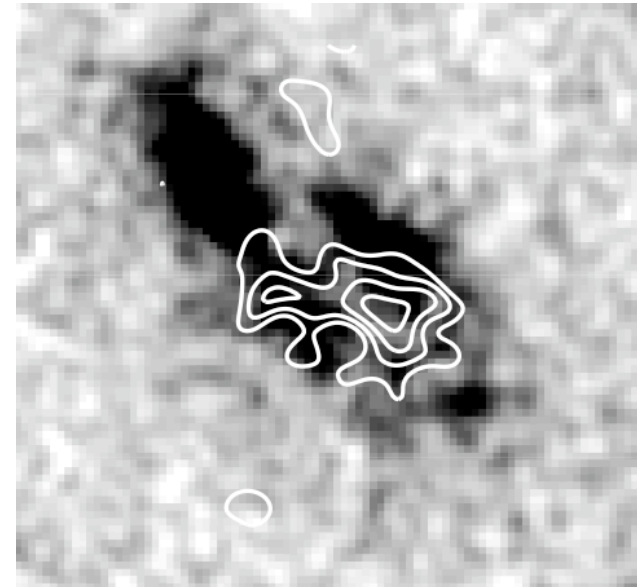
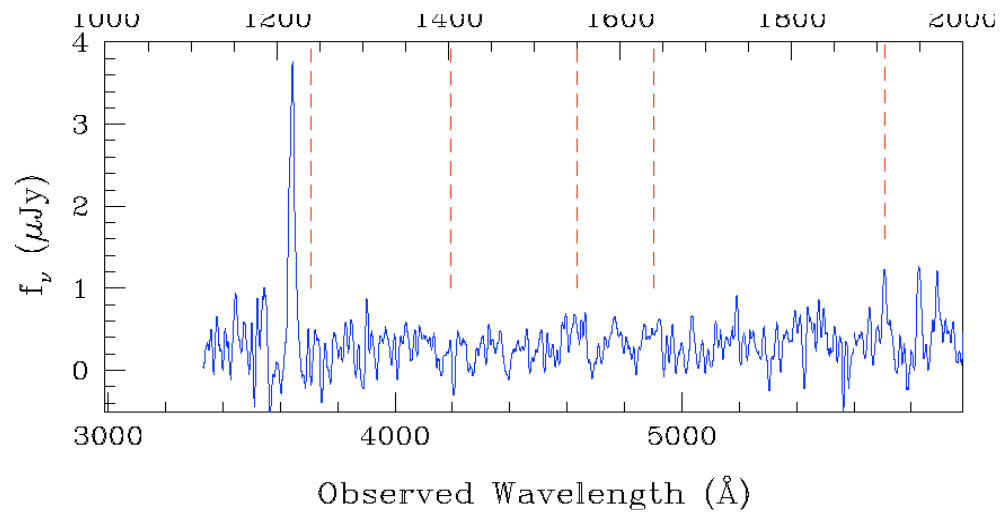
Scott C. Chapman (Caltech),  
A. Blain (Caltech),  
I. Smail (Durham), M. Swinbank (Durham)  
R. Ivison (Edinburgh)



$$\text{SFR}_{\text{H}\alpha} = \text{SFR}_{\text{FIR}}$$



$$\text{SFR}_{\text{H}\alpha} = 1/10 \text{ SFR}_{\text{FIR}}$$



# Outline:

## 1) spatial/kinematic properties of SMGs

- radio vs HST: bolometric locus and UV measures of  $L_{\text{bol}}$
- Nebular line measures of  $L_{\text{bol}}$  (H $\alpha$ , OIII, H $\beta$ )
- IFU observations of H $\alpha$  suggest mergers and lots of star formation in the vicinity
- UV/optical spectroscopy: astrophysical diagnostics, not obtainable in any other way
- Rest-UV easier than rest-optical ....
- stacked spectra: properties of the ISM and winds, understanding of AGN properties

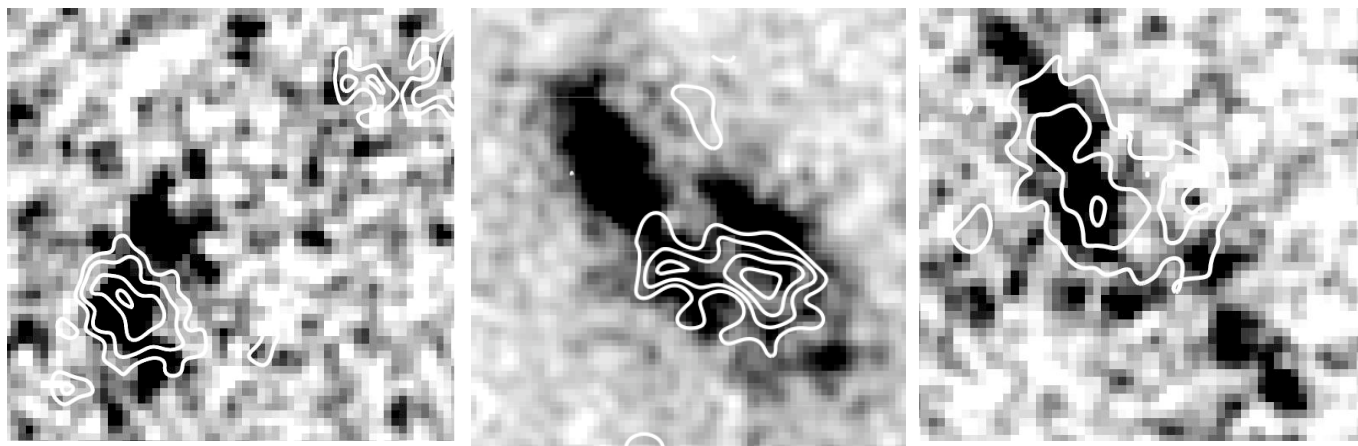
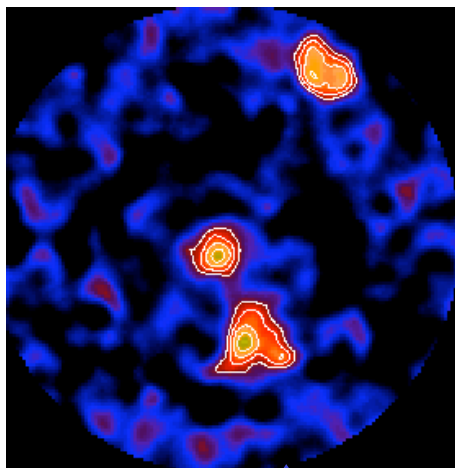
## 2) implications for the UV/optical spectral followup of next generation SMG surveys





# SCUBA galaxies (SMGs)

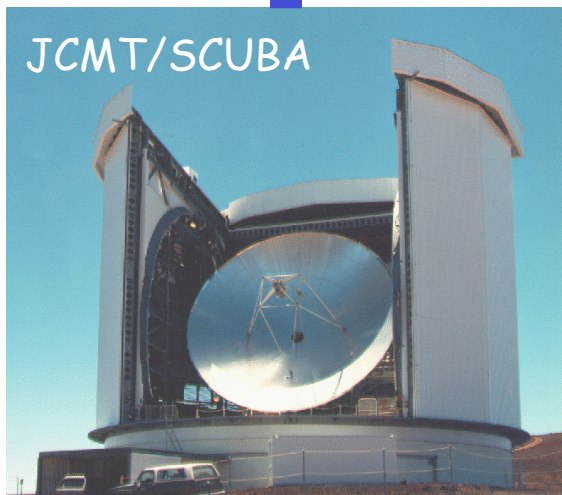
High resolution RADIO gives precise positions,  
together with HST reveal **large, merging** galaxies.



Chapman et al. (2003, 2004)

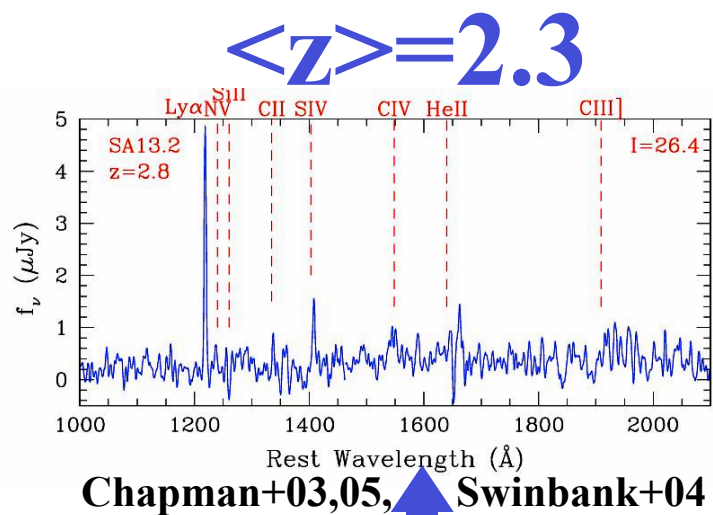
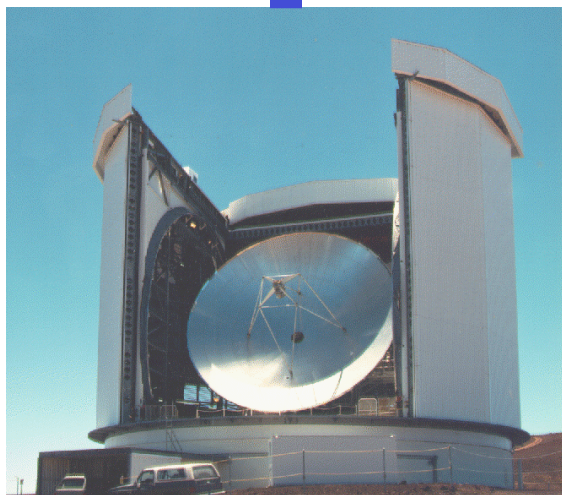
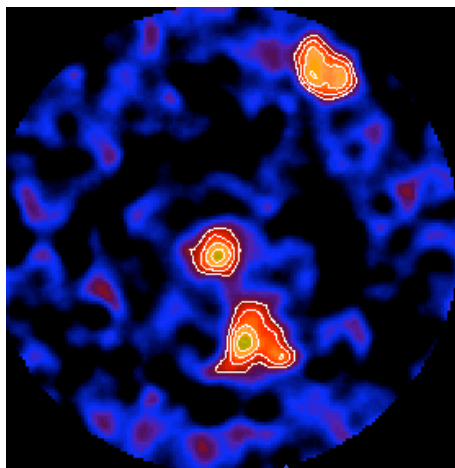
contours

greyscale

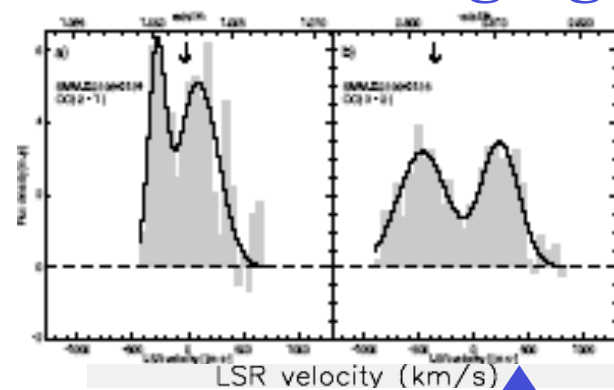


# SCUBA galaxies (SMGs)

Redshift surveys have given us tremendous insight into a hyper-luminous population of cool dust SB-dominated galaxies.

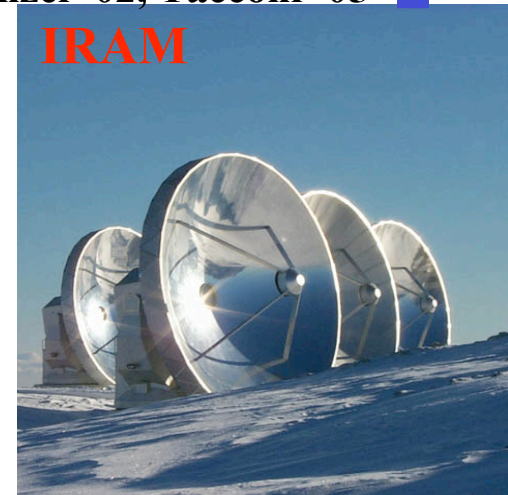


## Massive/merging



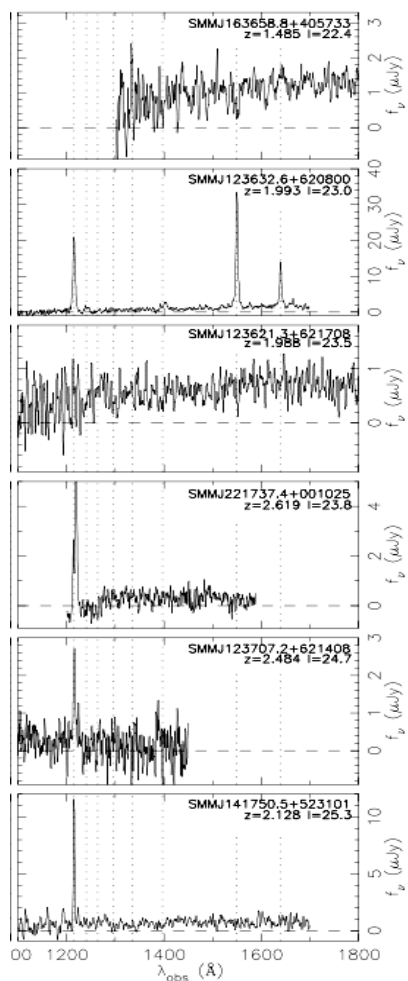
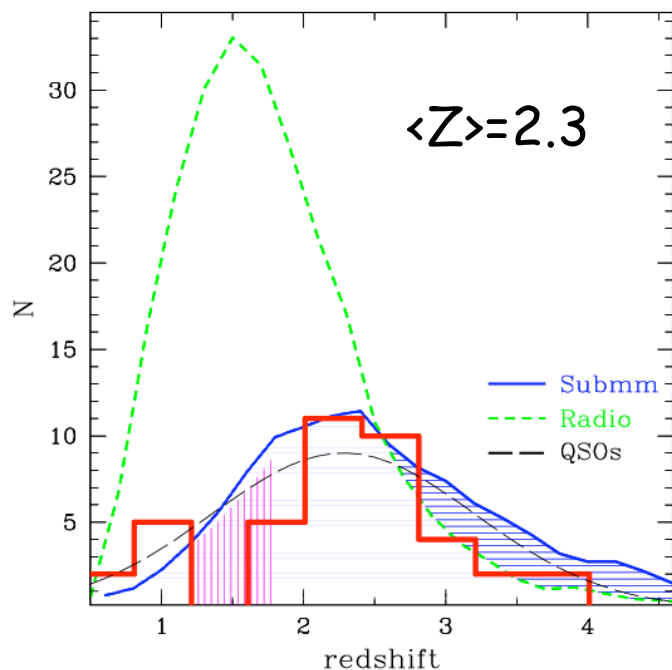
Neri+03, Greve+05

Genzel+02, Tacconi+05



# Redshifts for SMGs

- Radio-detected sample
- Easier than expected ... strong emission lines (50%) (especially Ly $\alpha$ )
- ~70% spectroscopic completeness  
(Chapman et al. 2003, 2005)

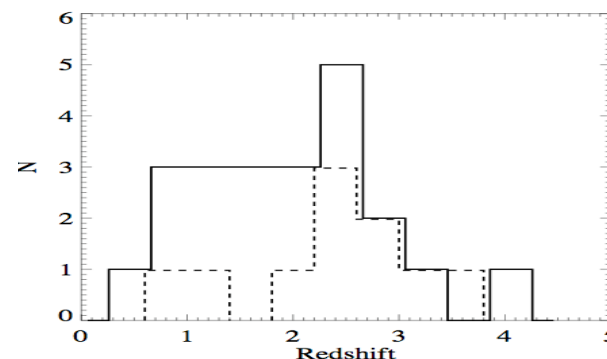


# Photo-z's for SMGs

Pope et al. (2005,2006):

UV/opt phot-z's

Find similar N(z) for "complete" SMG sample.



# SHADES

Keck/DEIMOS red-optimized spectroscopy finds sources in z-desert  
(Blain et al. 2006)

~25% of sources at z=1-1.5 with OII3727

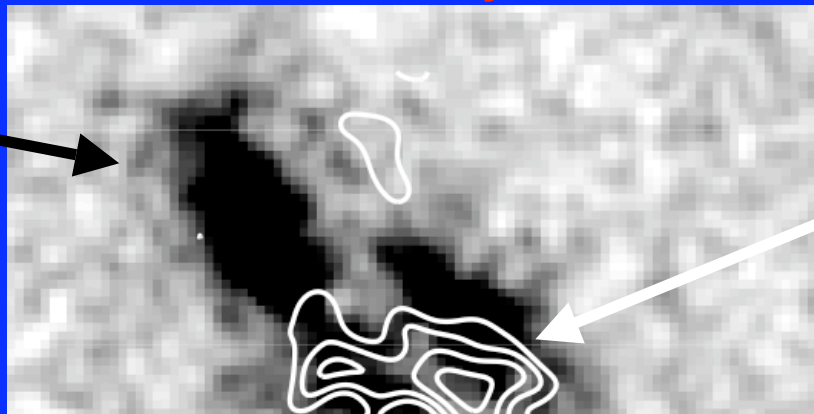


# Submm/Radio Morphologies (dust+gas)

Bolometric locus not always where UV source is

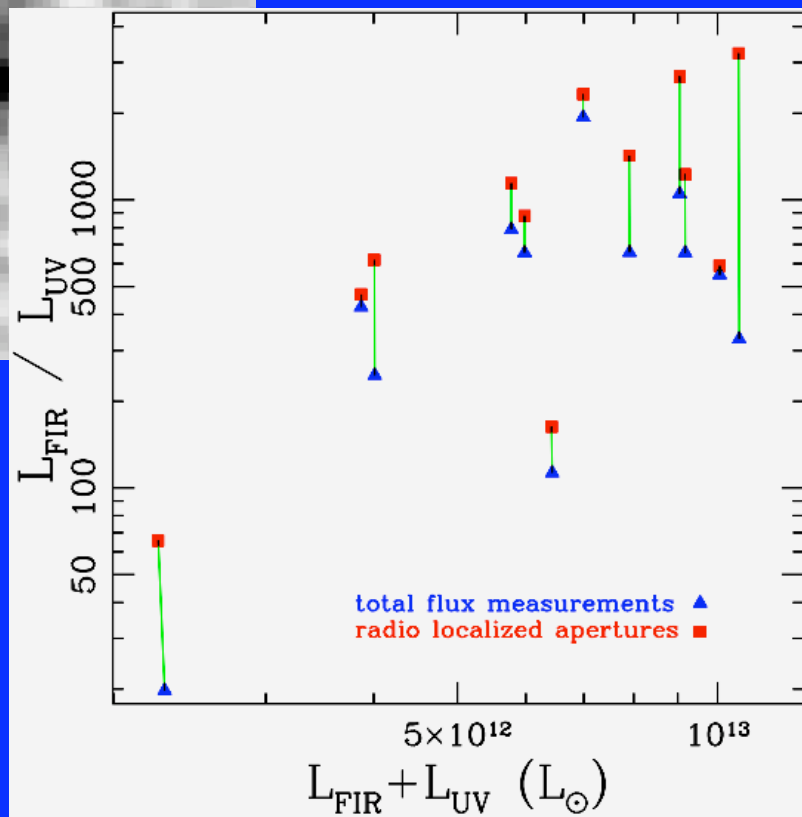
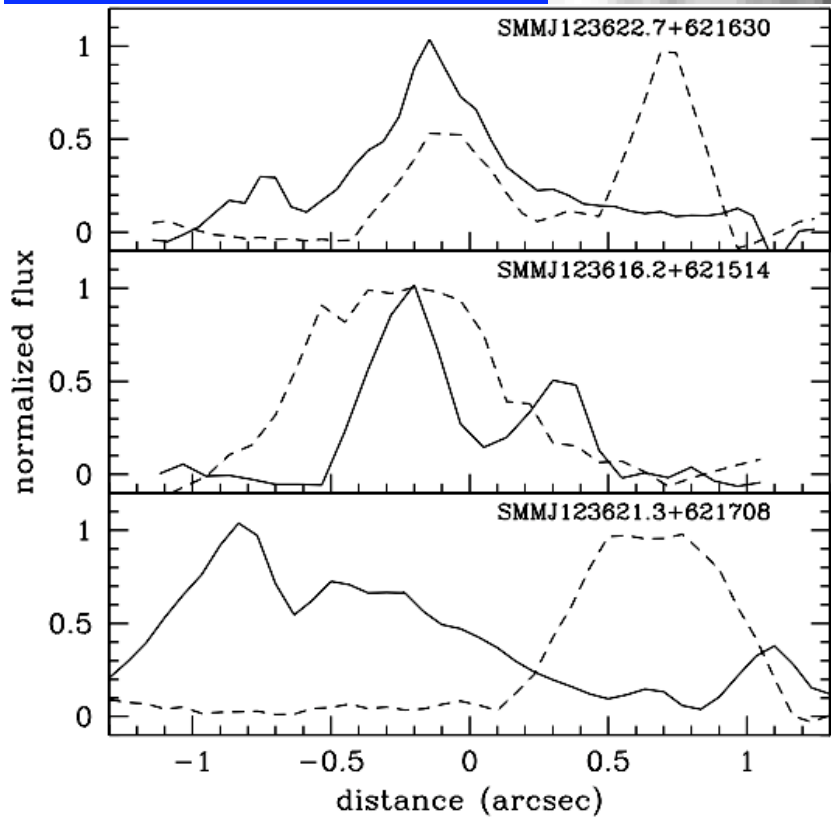
HST-uv  
(3orbits)

slices



VLA/MERLIN-radio  
(100hr HDF)

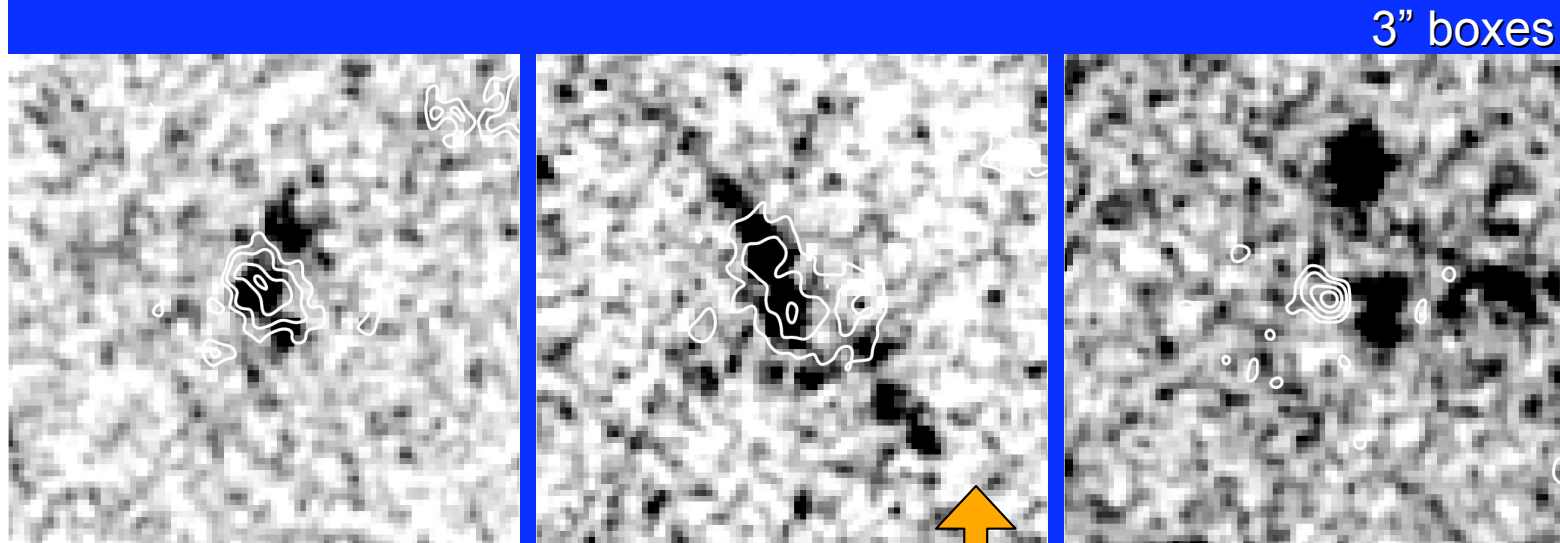
obscuration



# Submm/Radio Morphologies -- DIVERSITY

(Chapman, Smail, Windhorst, Muxlow, Ivison 2004)

Giant Extended (10kpc) starbursts ... RADIO tracing UV?

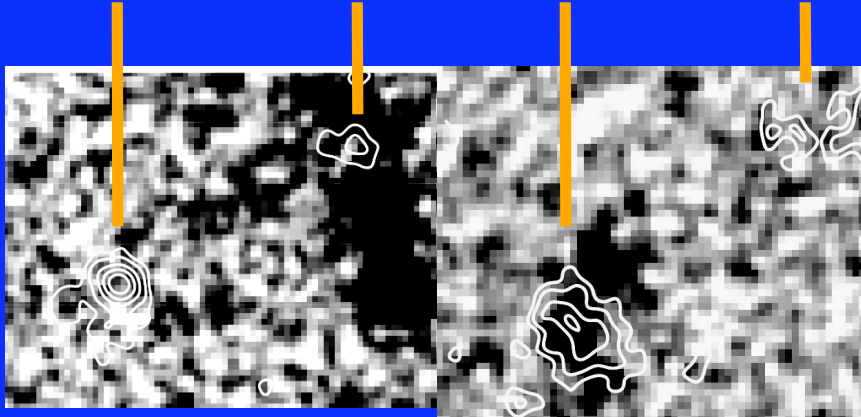


- MERLIN  $\sim 0.3$  arcsec radio beam:
- **EXTENDED on  $\sim 1$  arcsec scales.**
- 2/3 appear to trace *some of* the optical structure
- 1/3 suggest a single compact component
- $\sim 0.4$  arcsec RMS accuracy in radio/optical alignment
- Internal obscuration maps ...

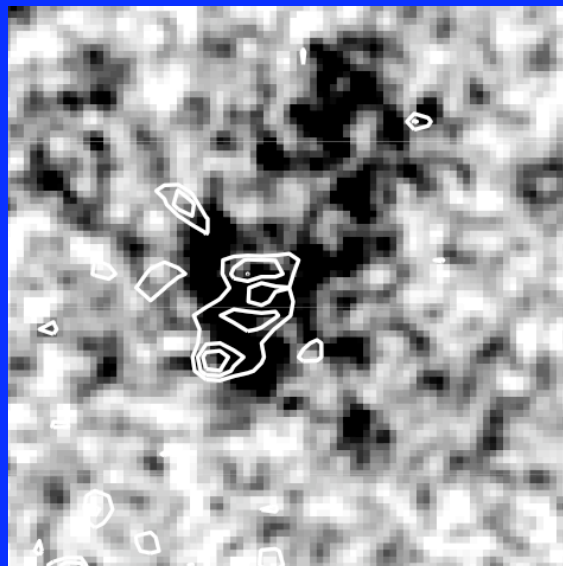
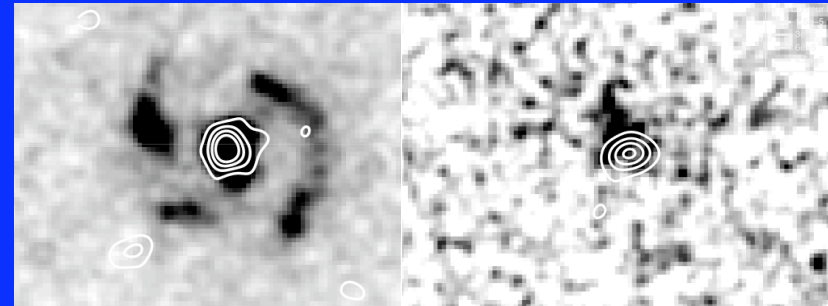
# Double radio/submm sources

(Consistent with findings in CO and Xray)

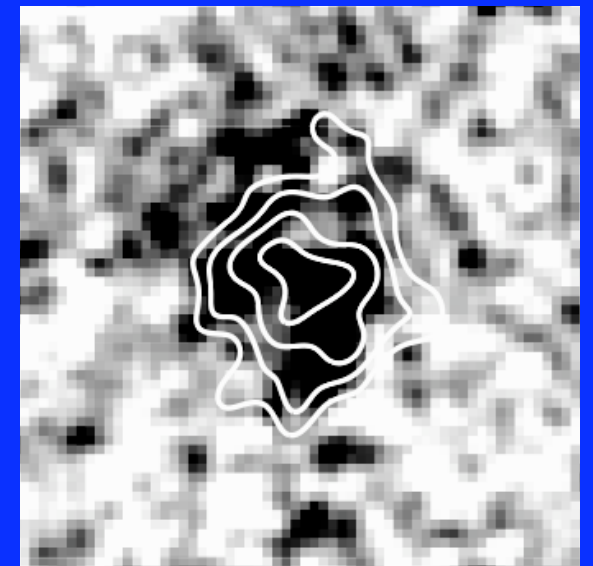
Double radio sources 15% of cases



Compact MERLIN-radio sources (30%)



Resolve multiple components to see which optical sources are participating in the burst.



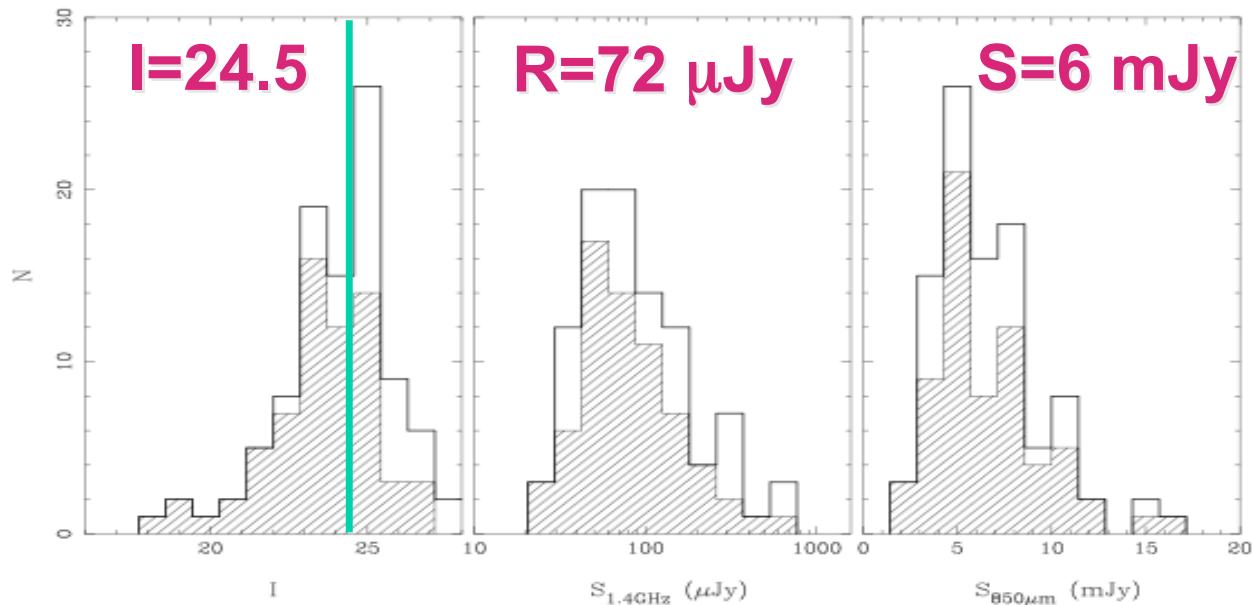
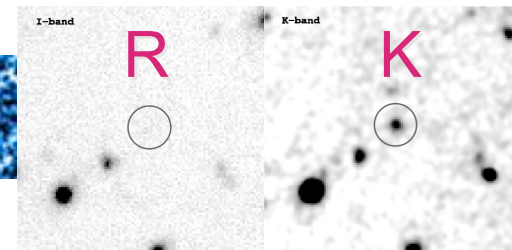
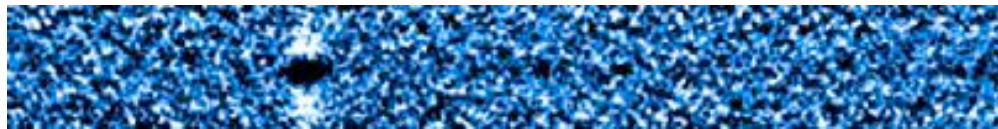
Small part of merger is actively SF

Most of UV galaxy actively SF



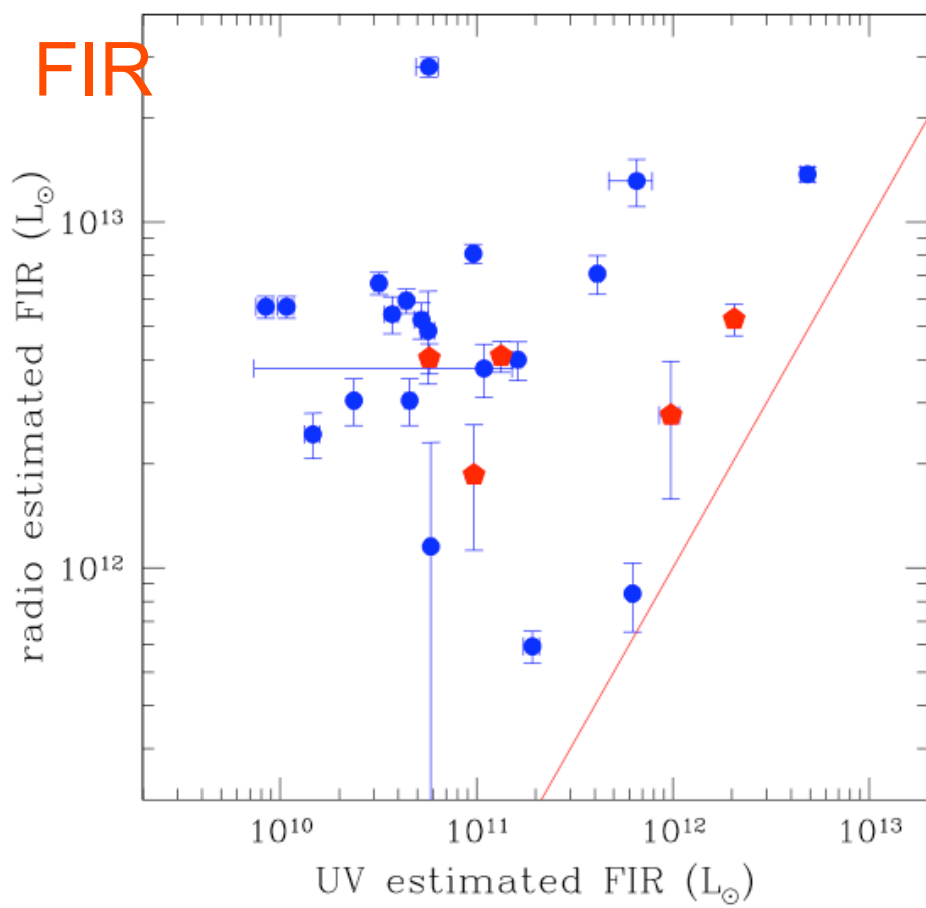
100 spectroscopic redshifts for radio-SMGs, requires:

- 1) assembling the requisite data (ultra-deep radio  $\sim 50$ hr VLA, optical and submm); detecting and identifying the SMGs
- 2) Sensitivity  $< 4000\text{\AA}$  = Keck/LRIS-B (many at  $z \sim 2$ )
- 3) Faith in radio position!
- 4) Cooperation of  $10^{13}$  Lsun objects (Ly-alpha, merging pieces)
- 5) Confirmation: Keck/NIRSPEC H $\alpha$ , NB-imaging, **CO**



# CAUTION: UV clearly not representing $L_{bol}$ on average!

submm/radio versus U,B,R



-detect 'many SMGs at  $U, B, R, I, J, K$  - bands

-but ... FIR luminosities severely under predicted

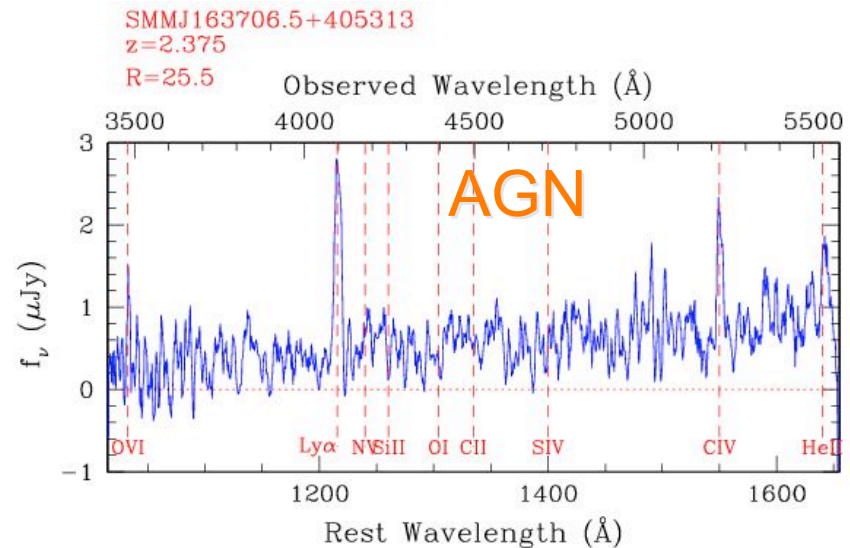
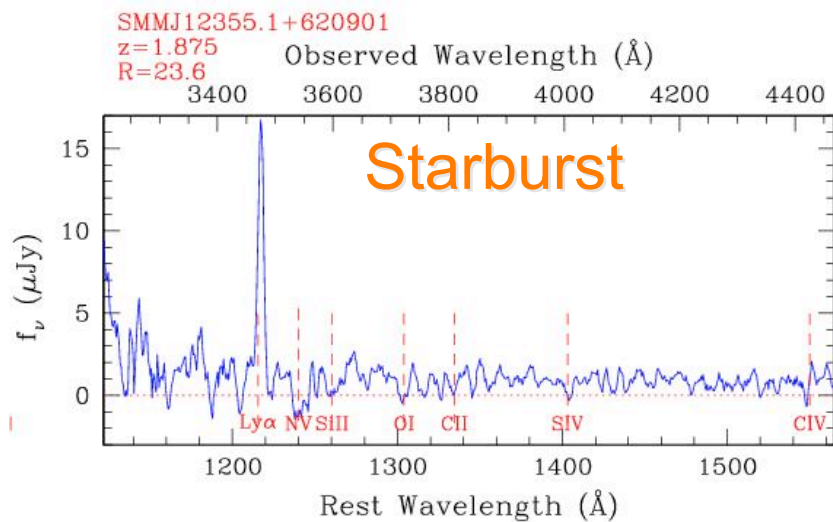


Dust-corrected UV

# Spectral classes: SMG demographics

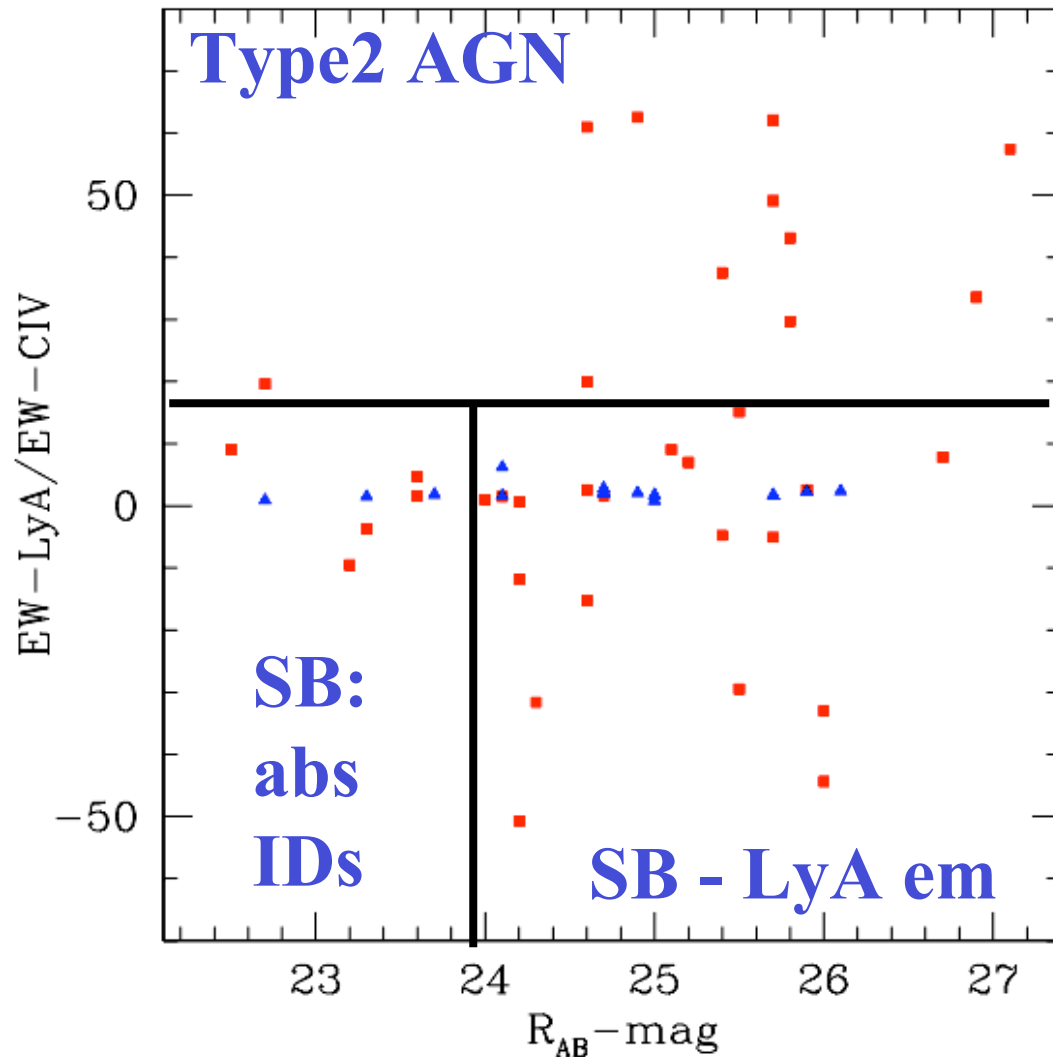
## SAMPLE: radio-ID'd SMGs

- Overlap significantly with  $R < 25$  UV-selected surveys  $\sim 50\%$
- 25% show clear Starburst features
- 25% show AGN emission lines (3% BL AGN)
- 50% too faint to classify (SB??? Ly $\alpha$  only, or no ID)
  - Of which  $\sim 1/2$  we fail to get redshifts for



# UV-Types of SCUBA galaxies

Stacks of Keck/LRIS rest-UV spectra  
(Chapman et al. in prep)



# UV-Types of SCUBA galaxies

Stacks of Keck/LRIS rest-UV spectra  
(Chapman et al. in prep)

**SB - LyA emitters  
(UV faint)**

**no evidence for AGN**



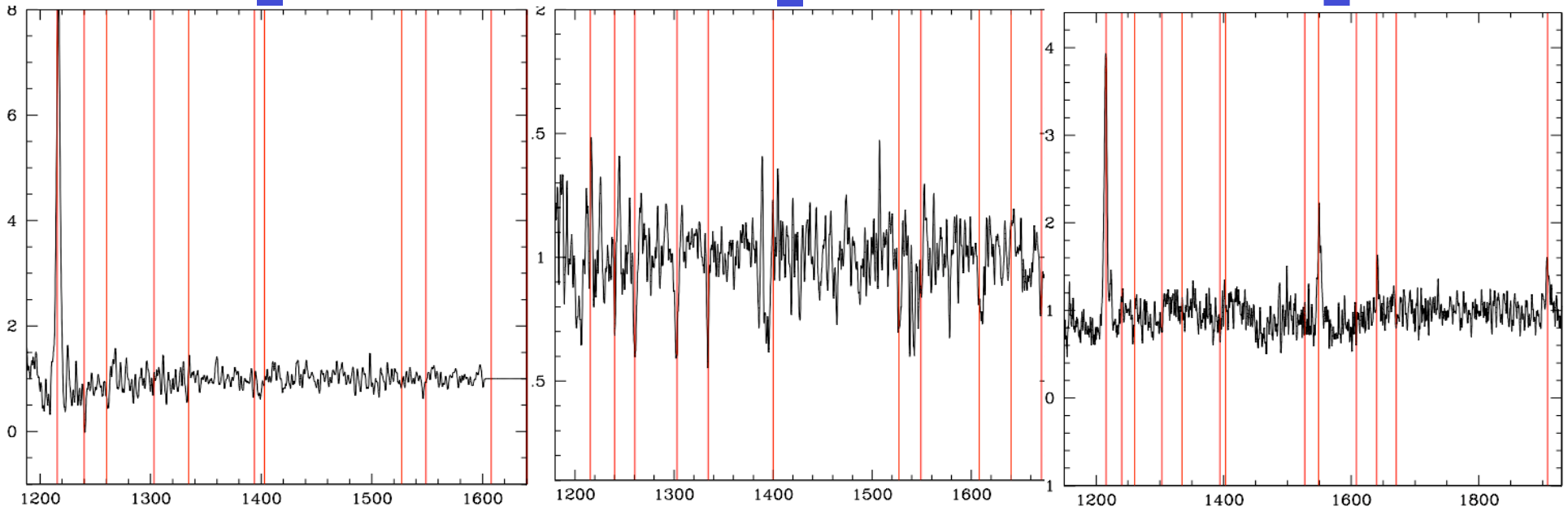
**SB - absorption IDs  
(UV bright)**

**Study IGM lines  
and metallicities**



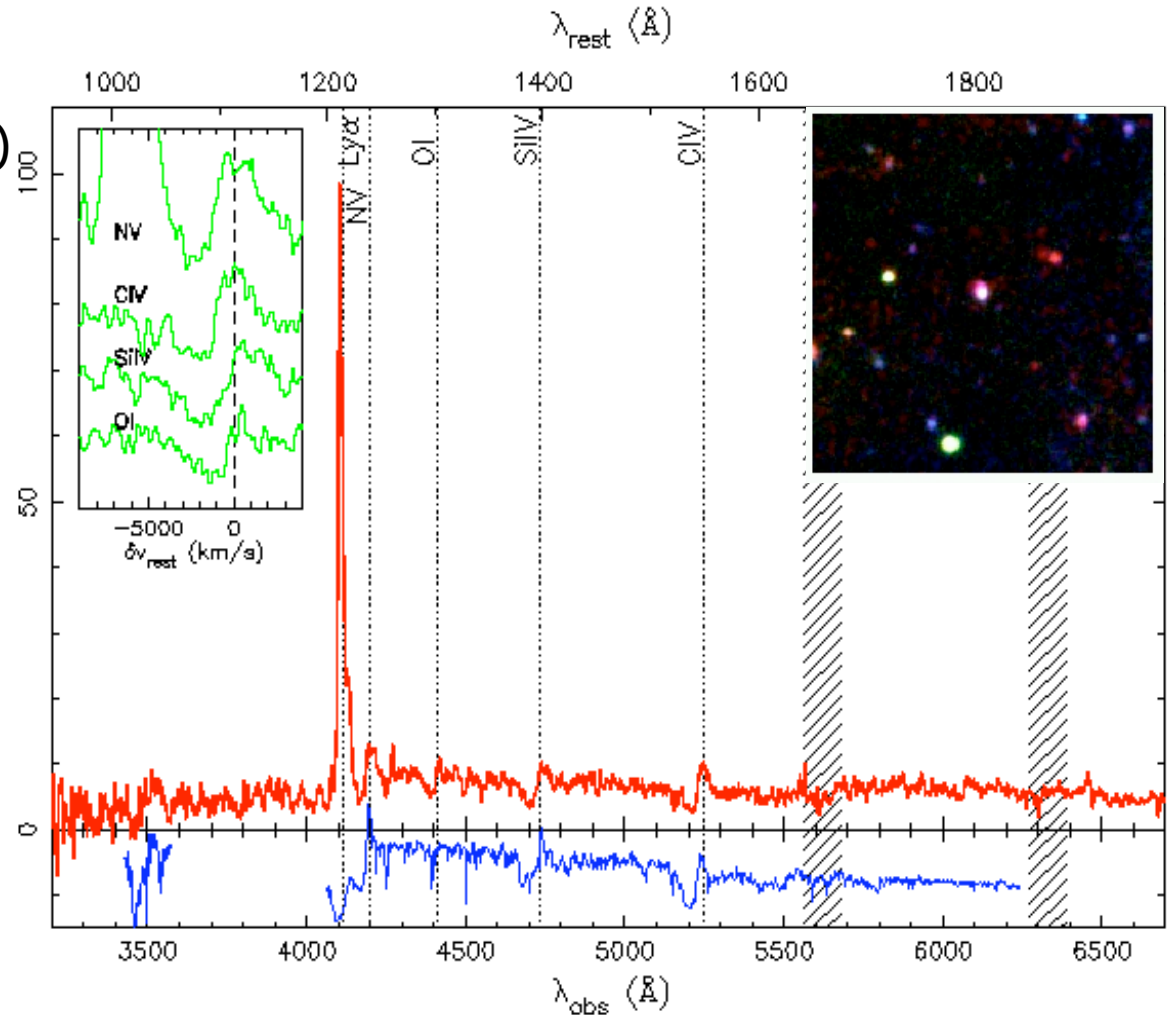
**Type2 AGN  
(all mags)**

**Compare to other  
AGN pops**



# Spectral Properties of SCUBA galaxies

- Elais N2.4 (Smail et al. 03)
- Starburst modeling suggests young (<10Myr old) burst.
- Line offsets suggest strong >500km/s starburst outflows

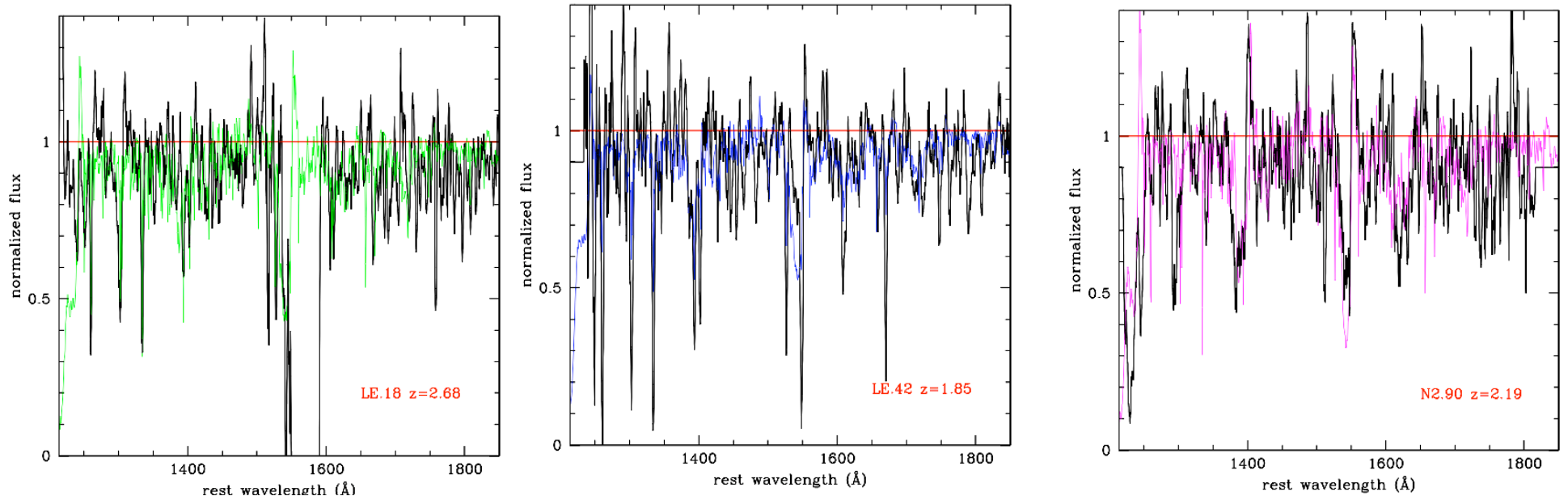




# Spectral Properties of SCUBA galaxies

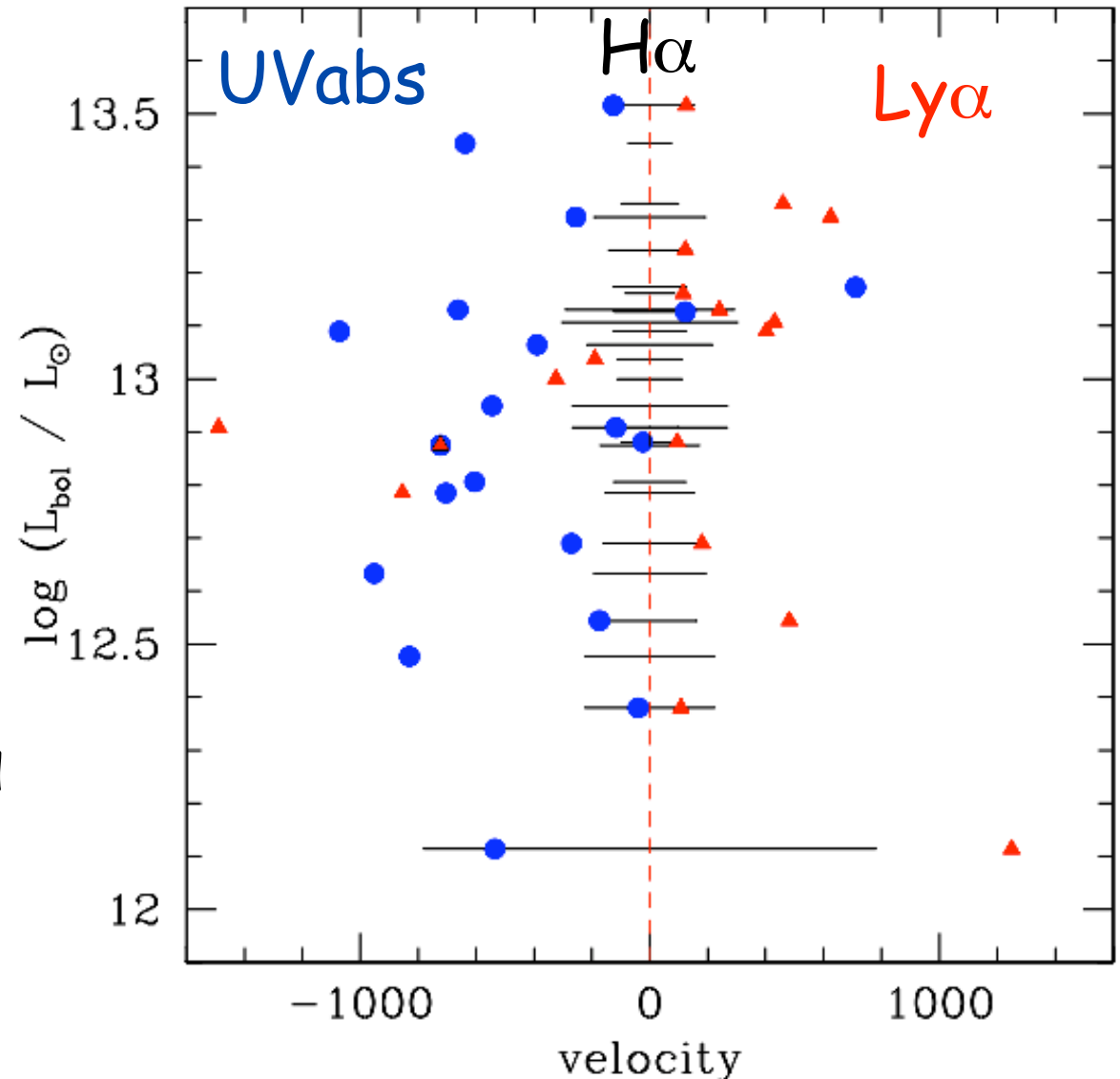
- More UV-bright starburst dominated SMGs
- <10% amenable to individual study.
- Starburst99 model compare
- Wind offsets
- Young Starbursts <20Myr
- Relatively high metallicities (relative to UV-selected: mass-metal relation?)

(Chapman+06)



# Spectral Properties of SCUBA galaxies

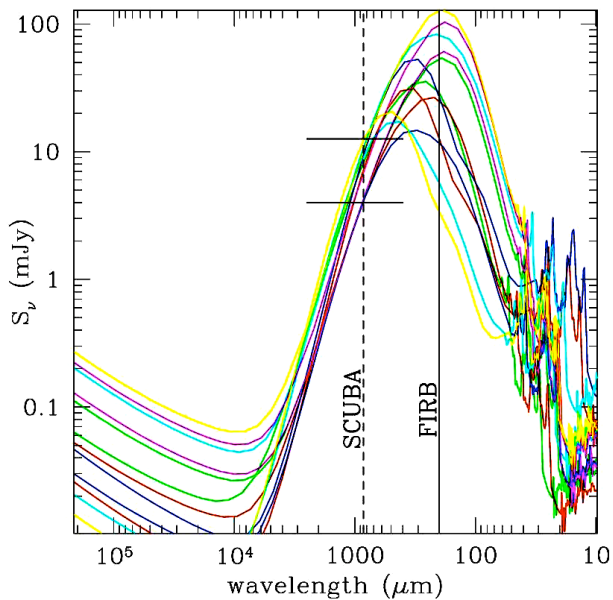
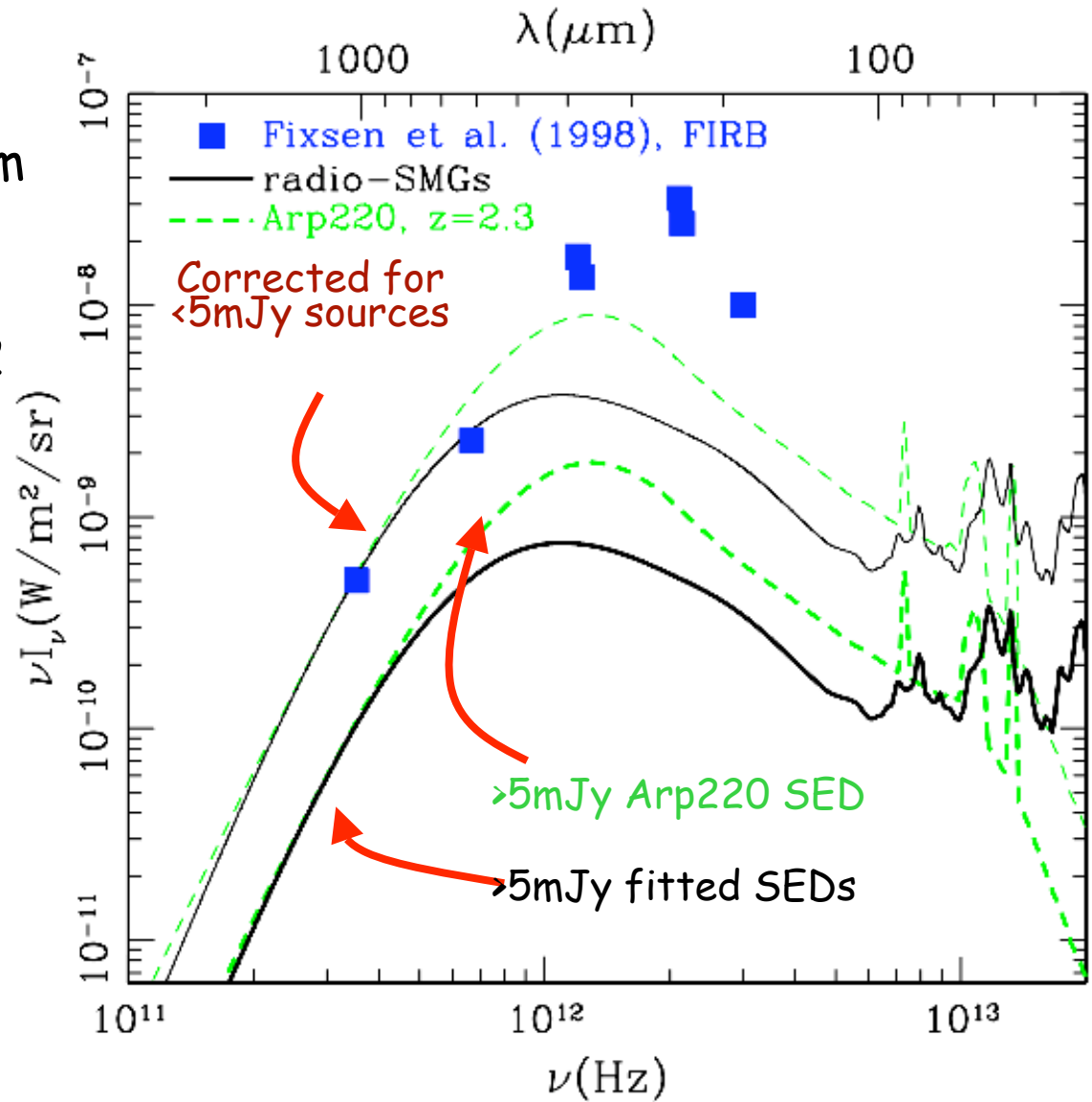
- Wind offsets:
- Treat  $H\alpha$  as systemic:  
IGM absorption lines blue-shifted on average ...  
similar to BX/LBG  
situation.
- Lyalpha mostly redshifted



# Fits to 20cm, 850um, 350um, 24um...

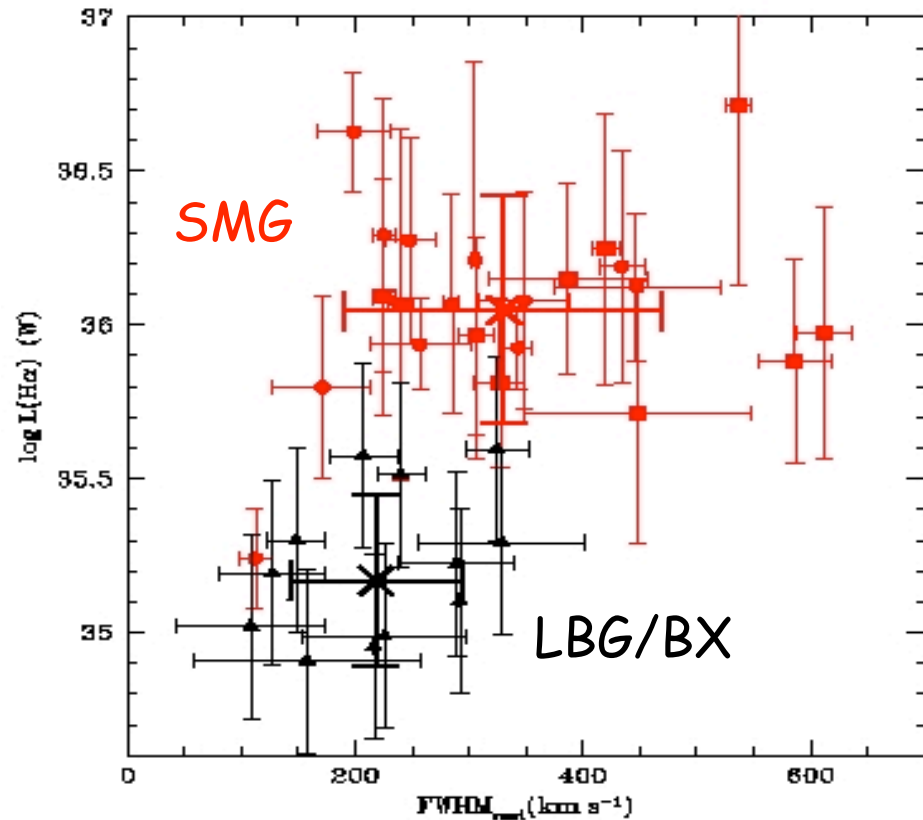
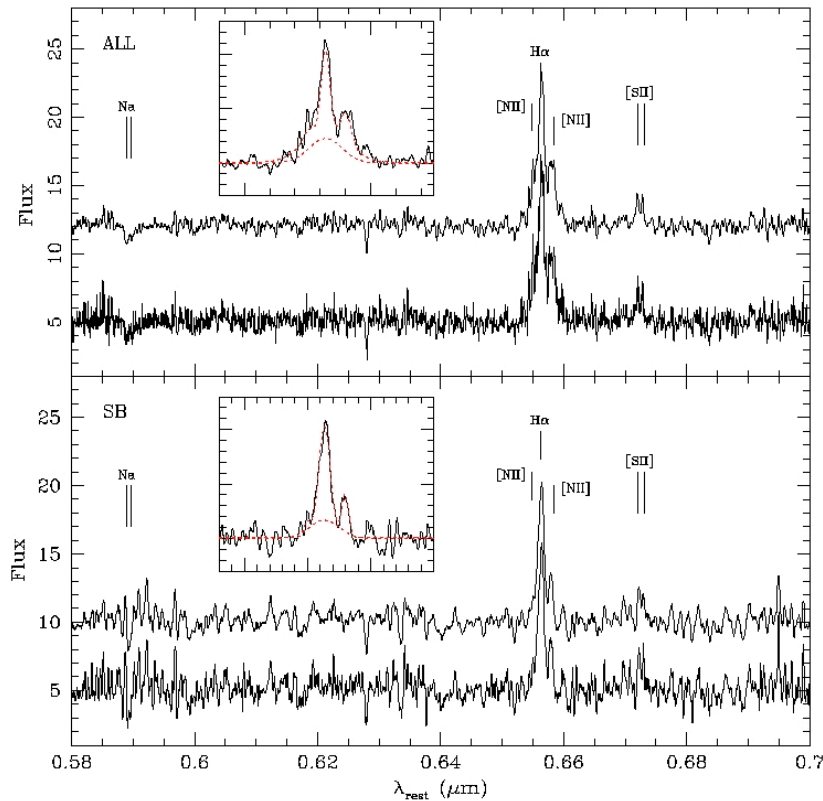
## redshifts allow SMG contribution to submm/FIRB

- $>0.5\text{mJy}$  SMGs ( $>10^{12} L_{\odot}$ ) produces 80-100% of 850um background
- Conclude that the SCUBA population will produce  $\sim 1/2$  of the  $>400\text{um}$  FIRB



(Kovacs et al. 2005; Chapman et al. 2005)

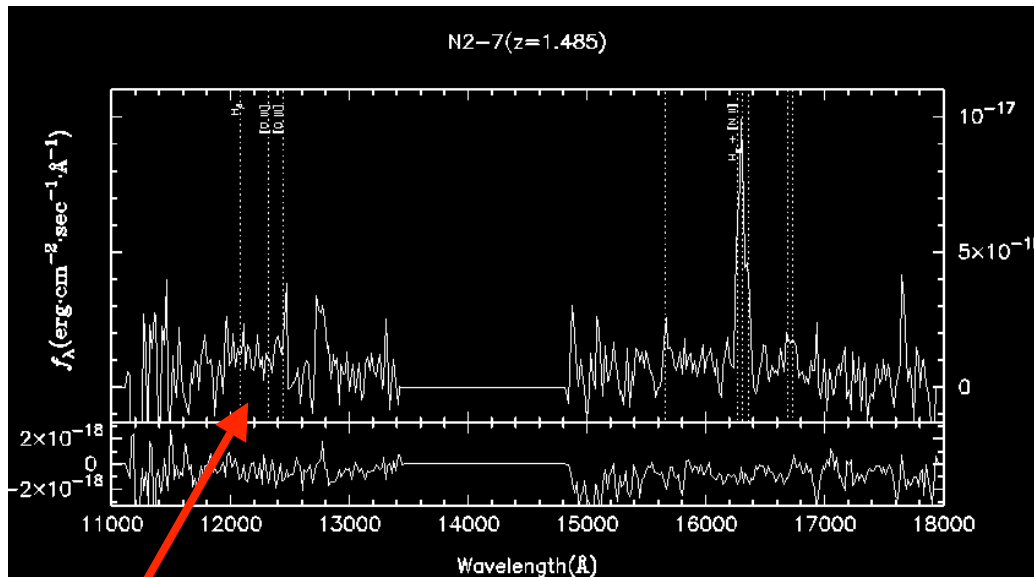
# H $\alpha$ Dynamics (Swinbank et al. 2004)



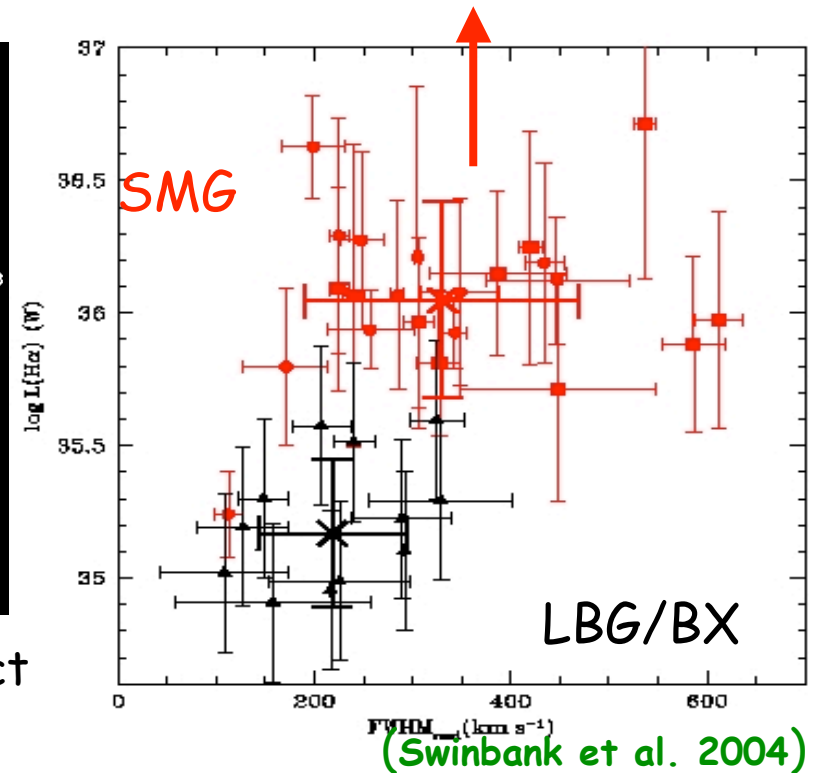
- SFRs  $\sim 100 M/\text{yr}$  (not extinction corrected)
- Line widths (330km/s, 1.5x) and typical sizes (0.5", 2x) suggest SMGs  $1.5 \times 10^{11} M_{\odot}$  -  $\sim 5x$  more massive than LBGs
- Supported by CO line width measurements

# OIII, H $\beta$ , OII

(Takata, Sekiguchi, Chapman, Geach, Smail, Blain, Ivison 2006)

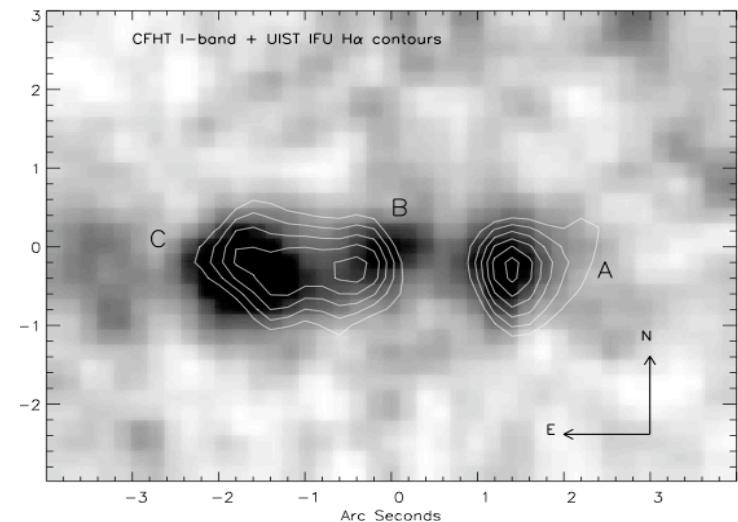
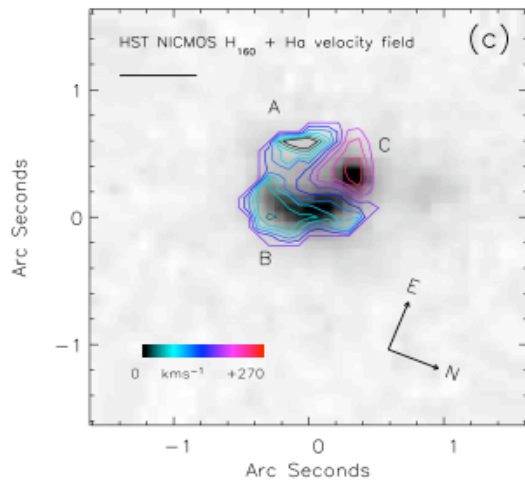
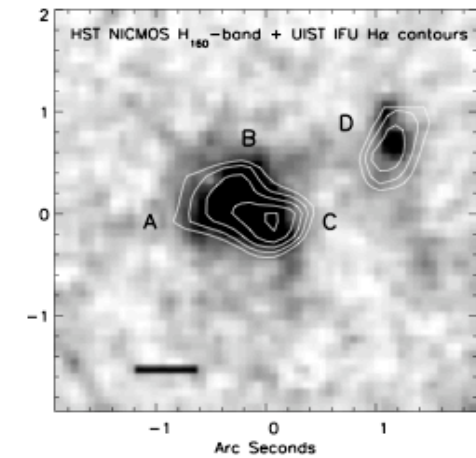
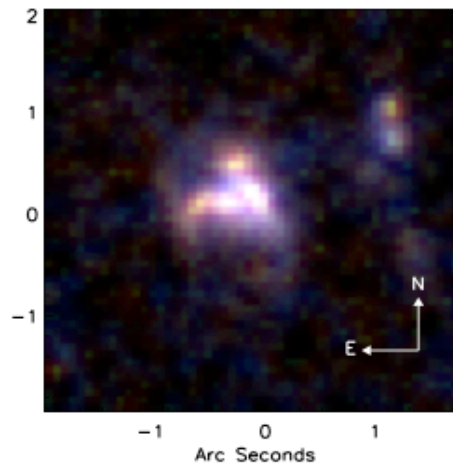
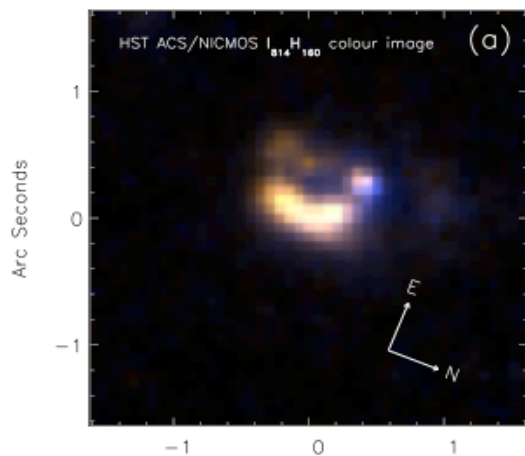


Starburst SMG: OIII/H $\beta$  hard to detect



- $H\alpha/H\beta \sim 0.05\text{--}0.1 \Rightarrow$  factor  $\sim 3\text{--}30$  correction to SFRs.
- extinction corrected  $H\alpha$  SFRs close to FIR derived
- O3N2 metallicities ... consistent with N2 and "1425"UV.

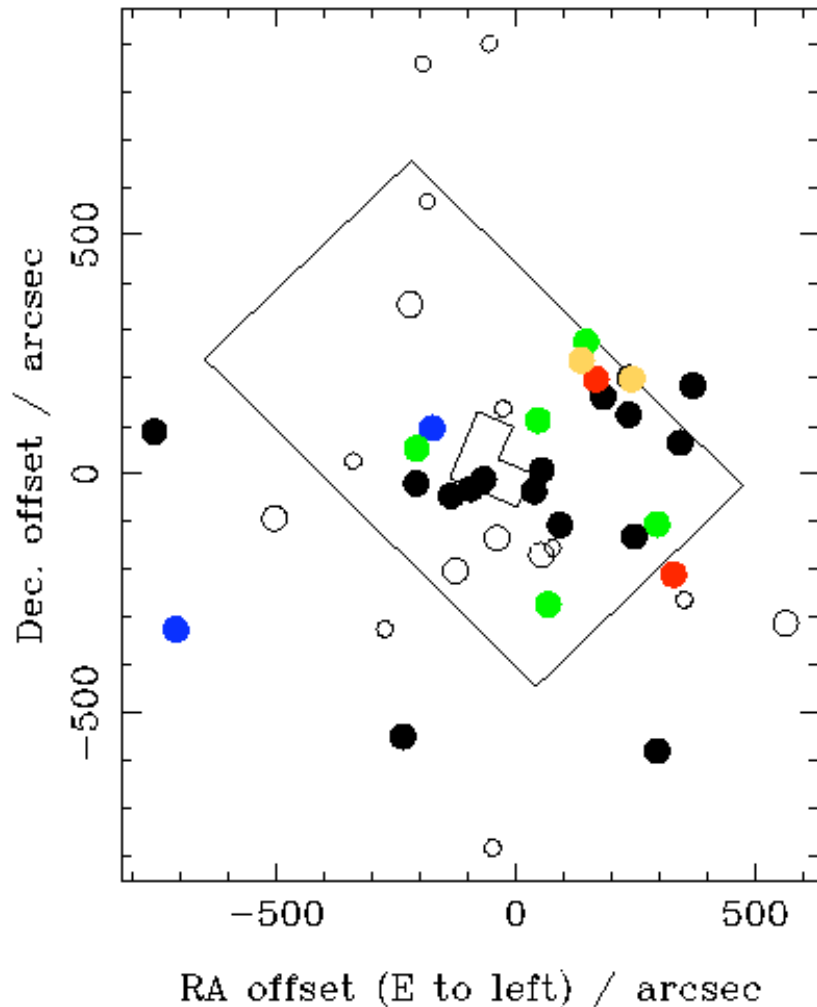
# IFU H $\alpha$ spectroscopy: UKIRT4m / UIST (Swinbank+04,05,06) “group” dynamics / masses ; extra SF





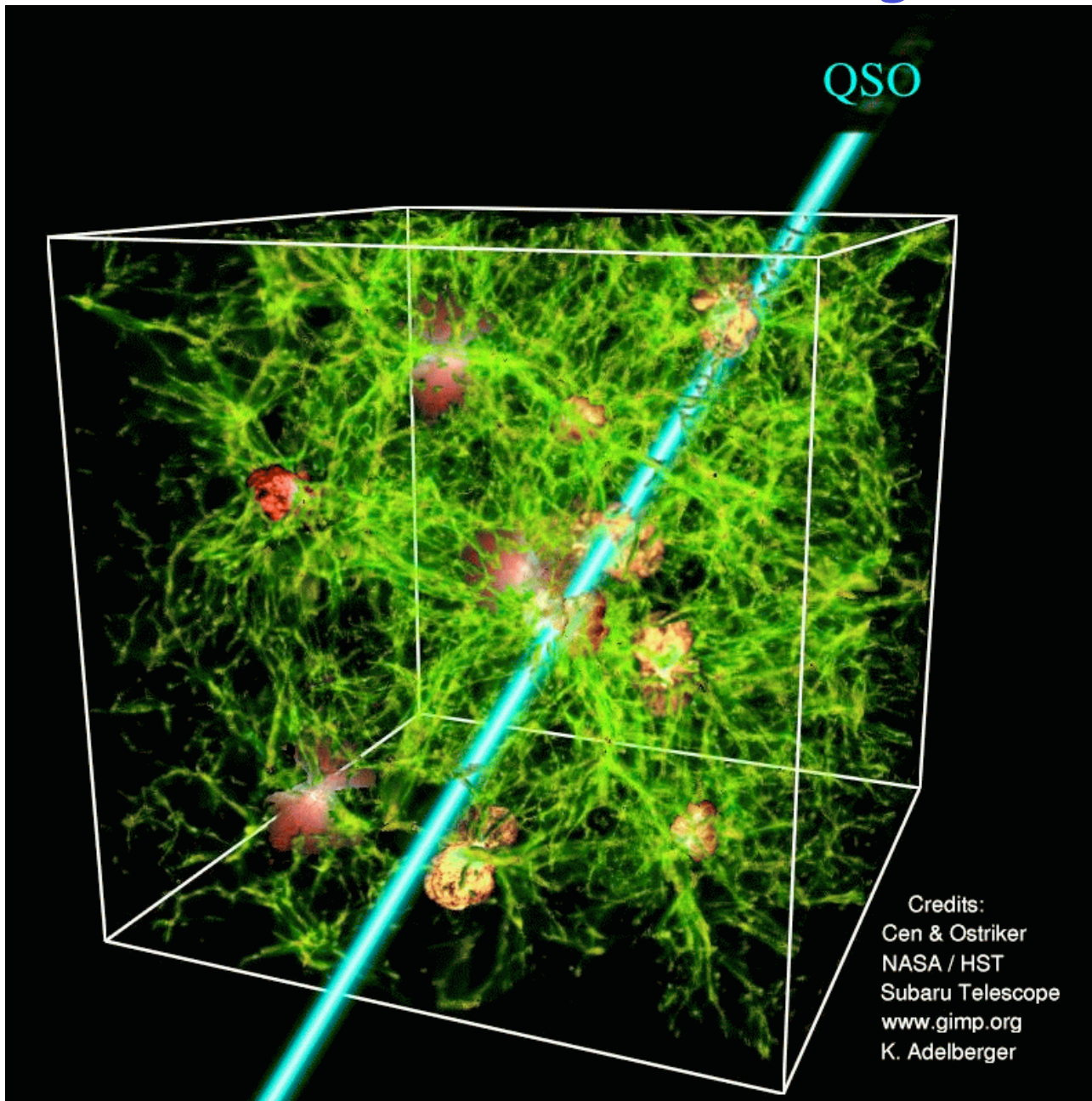
# Clustering of SCUBA Galaxies (Blain et al. 2004)

## link distribution of dark matter to visible galaxy populations



- If SMGs are massive then should be strongly clustered...
- Sample field: GOODS-N (HDF)
  - Found Quintuple and 3 SMG pairs within  $<1200\text{km/s}$  in sample of 27
  - $< 0.1\%$  likelihood of random chance
  - $R_0 \sim 8 h^{-1} \text{ Mpc}$
- Implies VERY strongly clustered (given wide SCUBA selection function)
- More clustered (massive) than UV-selected galaxies

# IGM and Luminous galaxies ( $\sim 10^{13}$ Lsun)



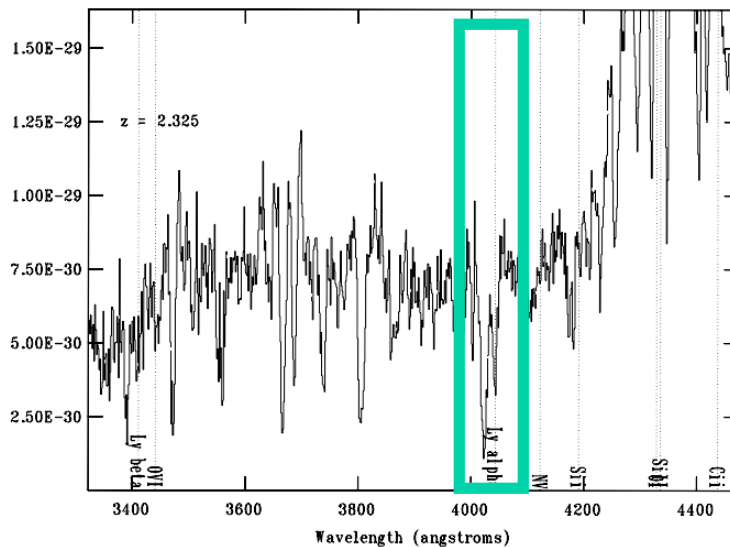
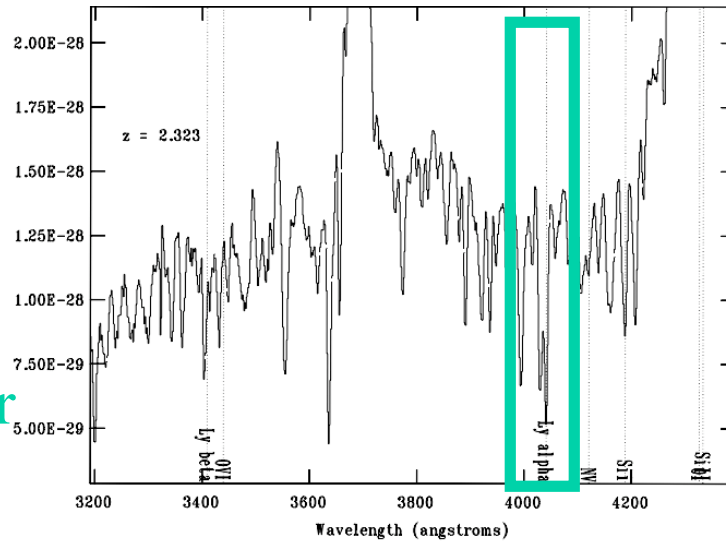
- 5 SMG fields with background AGN and/or QSOs
- Find relative distributions of SMGs & neutral HI
- After Adelberger+03 expect strong correlation

# Strong correlations with neutral H

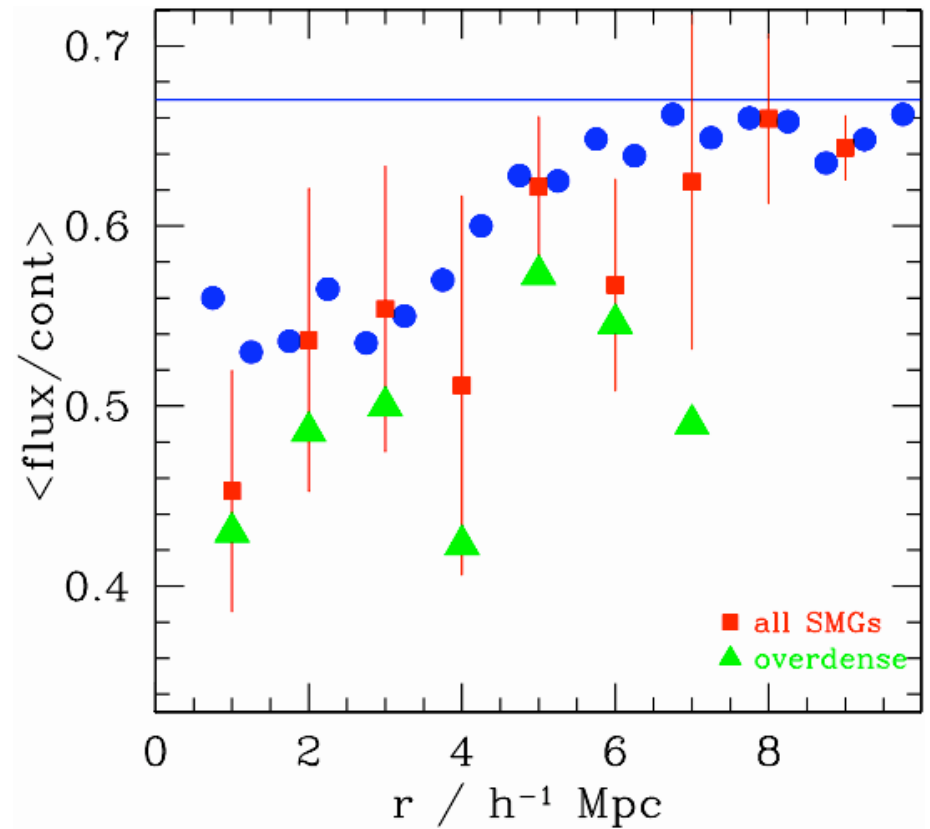
$z=2.32$   
SMG pair

...

$z=2.32$   
Ly $\alpha$  abs  
in 2 qsos



- Correlate as strong or stronger than **LBGs**

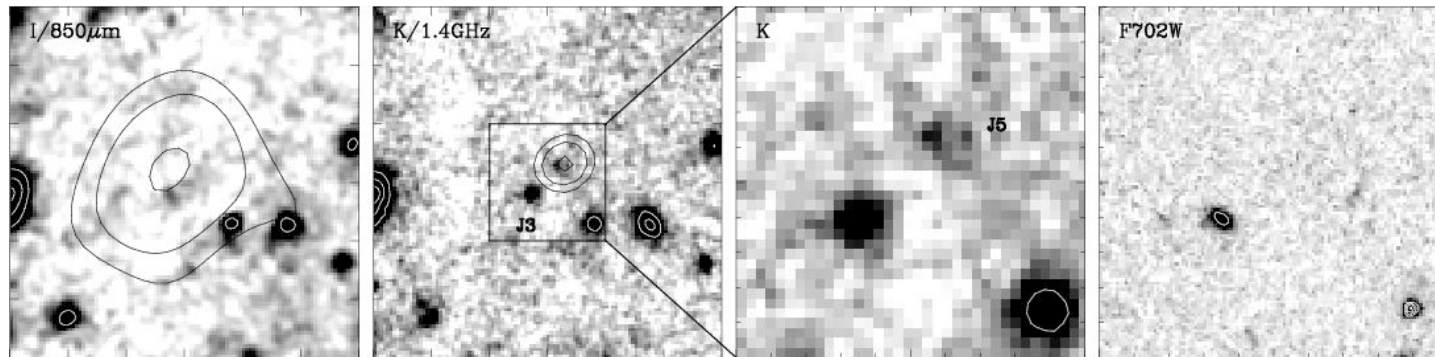


Chapman et al. 2006

## PART 2: implications for next-gen submm surveys:

Difficulty identifying SCUBA Galaxies...  
(the requirement for UV/optical spectroscopy)

The typical submm galaxy: 15" beam ... FAINT ( $I > 24$ )



too faint for positional coincidence ID given large 15" SCUBA beam

Currently need VLA-radio/Spitzer to ID sources

(Iverson+98, Smail+00, Barger+00, Chapman+01,02,03, Iverson+02,04,  
Egami+04, Frayer+04, Pope+05,06)

## PART 2: implications for next-gen submm surveys:

Do we require UV/optical spectroscopy of wide-field SCUBA2 surveys?

PRO:

- Interesting and complementary astrophysical diagnostics (IGM wind lines, masses and kinematics)
- Precise redshifts essential for many studies (IGM, redshift clustering, dust SED modeling, stacked Xray spectroscopy)

CON:

- Relatively expensive in telescope time (source density)
- Feasibility? (expensive to obtain complete IDs with radio/Spitzer)
- QUESTION: is UVspec valuable in ALMA era?

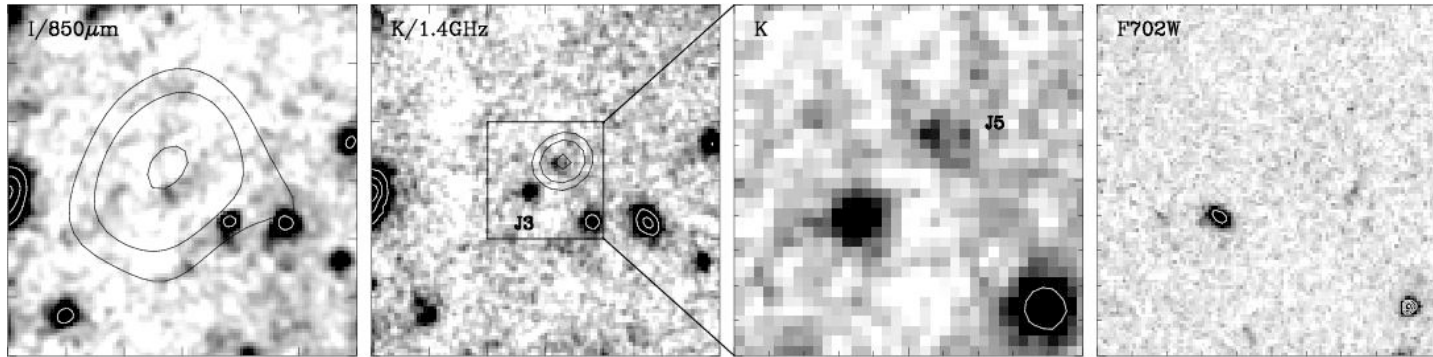
direct gas dynamics, dust morphologies, etc for MW @  $z < 5$



## PART 2: implications for next-gen submm surveys:

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(Iverson+98, Smail+00, Barger+00, Chapman+01,02,03, Iverson+02,04,  
Egami+04, Frayer+04, Pope+05,06)



# Conclusions

- SCUBA galaxies have **many** of the expected properties of proto-E's ... many derived from the UV/opt spectroscopy
- Danger of inferences drawn from UV (spatially offset)
- **Many** Unknowns as well - Astrophysics of SMM region!
- UV spectroscopy of Future large SMM surveys?
  - YES: valuable astrophysical information
  - CAUTION: expensive ... careful with justification!
  - QUES: still valuable in ALMA era?
    - - direct gas dynamics, dust morphologies, etc for MW @  $z < 5$