GBT CO(1-0) Observations of the Herschel SMGs

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Zpectrometer

Ultra-wideband analog cross-correlator spectrometer for the Green Bank Telescope

Background

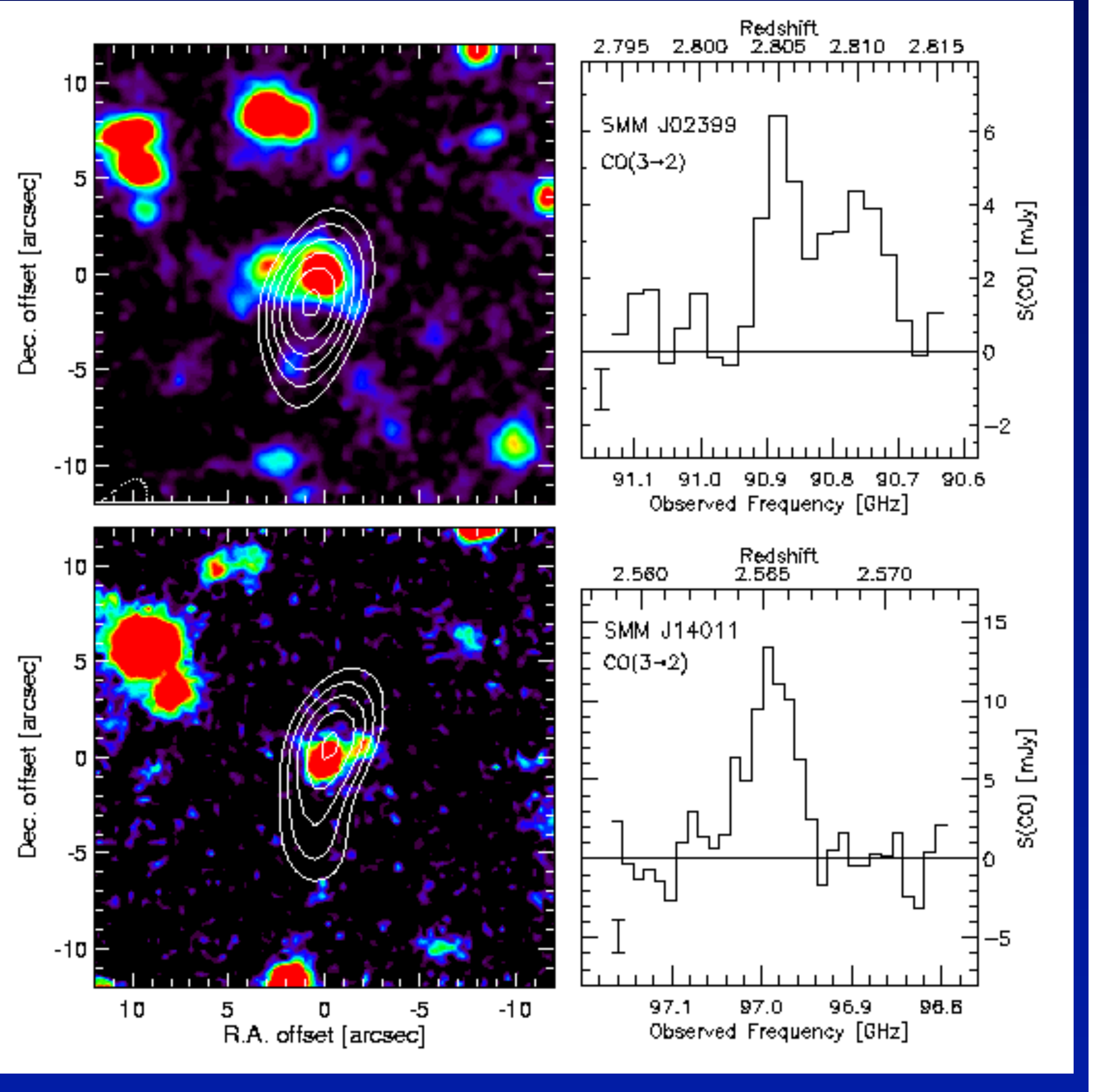
- ULIRG/LIRGs shows good correlation between L(Far-Infrared [FIR]) and L'(CO) (i.e., **FIR {large dust grains} ⇔ CO {cold molecular gas}**)
- CO key tracer for M(H2)
- Sub-mm Galaxies (SMGs) contribute significantly to the total amount of SFR at high-z
- Spitzer 24um (extremely deep in mid-IR) uncovered large samples of LIRGs/ULIRGs at high-redshift
- Herschel is uncovering large numbers of SMGs and enables the accurate measurements of the FIR peak of the SEDs

Personal Motivation -- First SMG CO Detections

SMGs:

•$M(H_2)\sim10^{10-11}$ M(sun) -- enough gas to fuel the star formation implied by $L(FIR)\sim10^{12-13}$ L(sun)

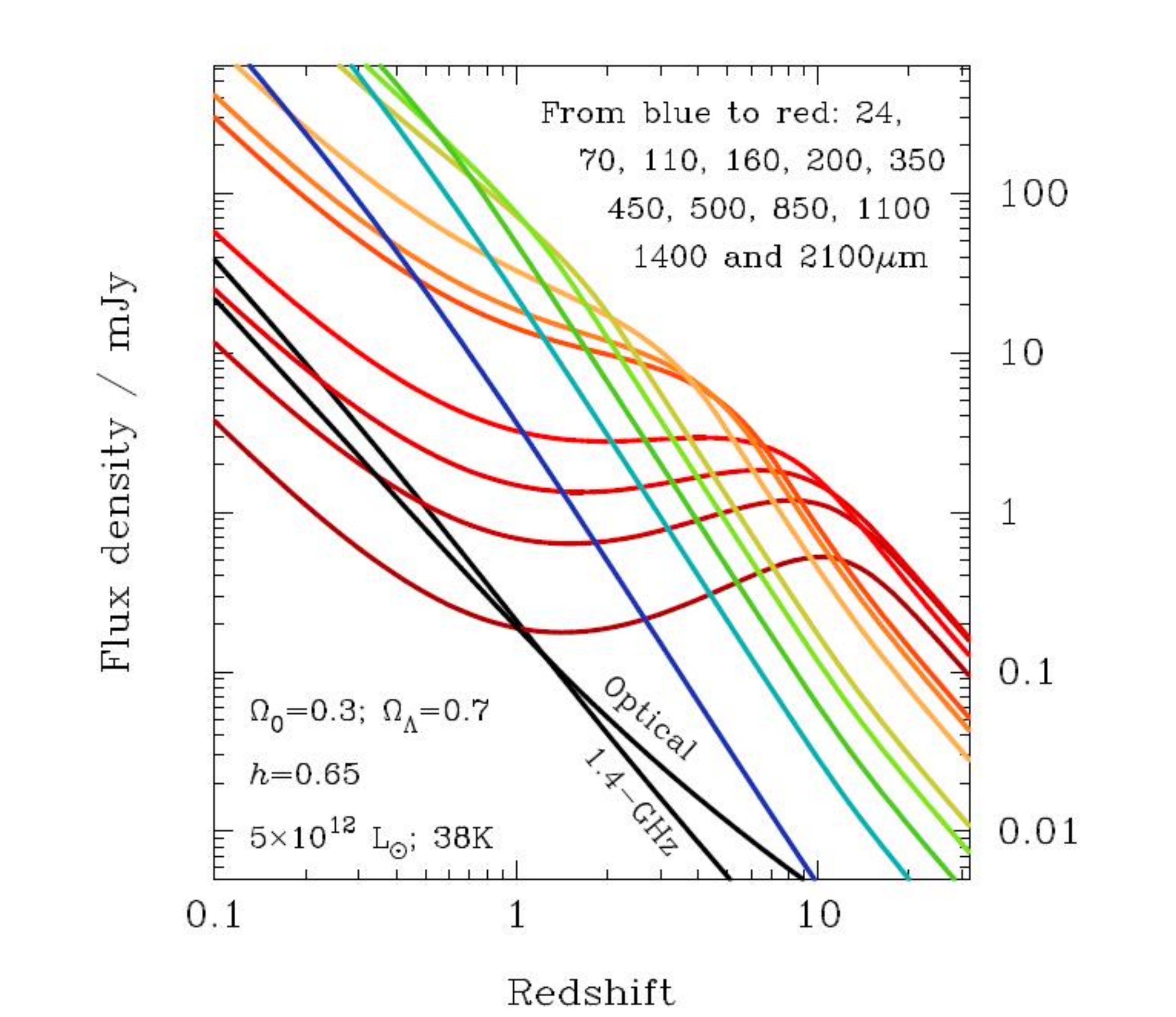
•Similar CO/FIR/radio luminosity ratios as local ULIRGs



(Frayer et al. 1998, 1999 with OVRO)

Observational Motivation ➔K-Corrections

Observed Snu(850) flat from z=1-10

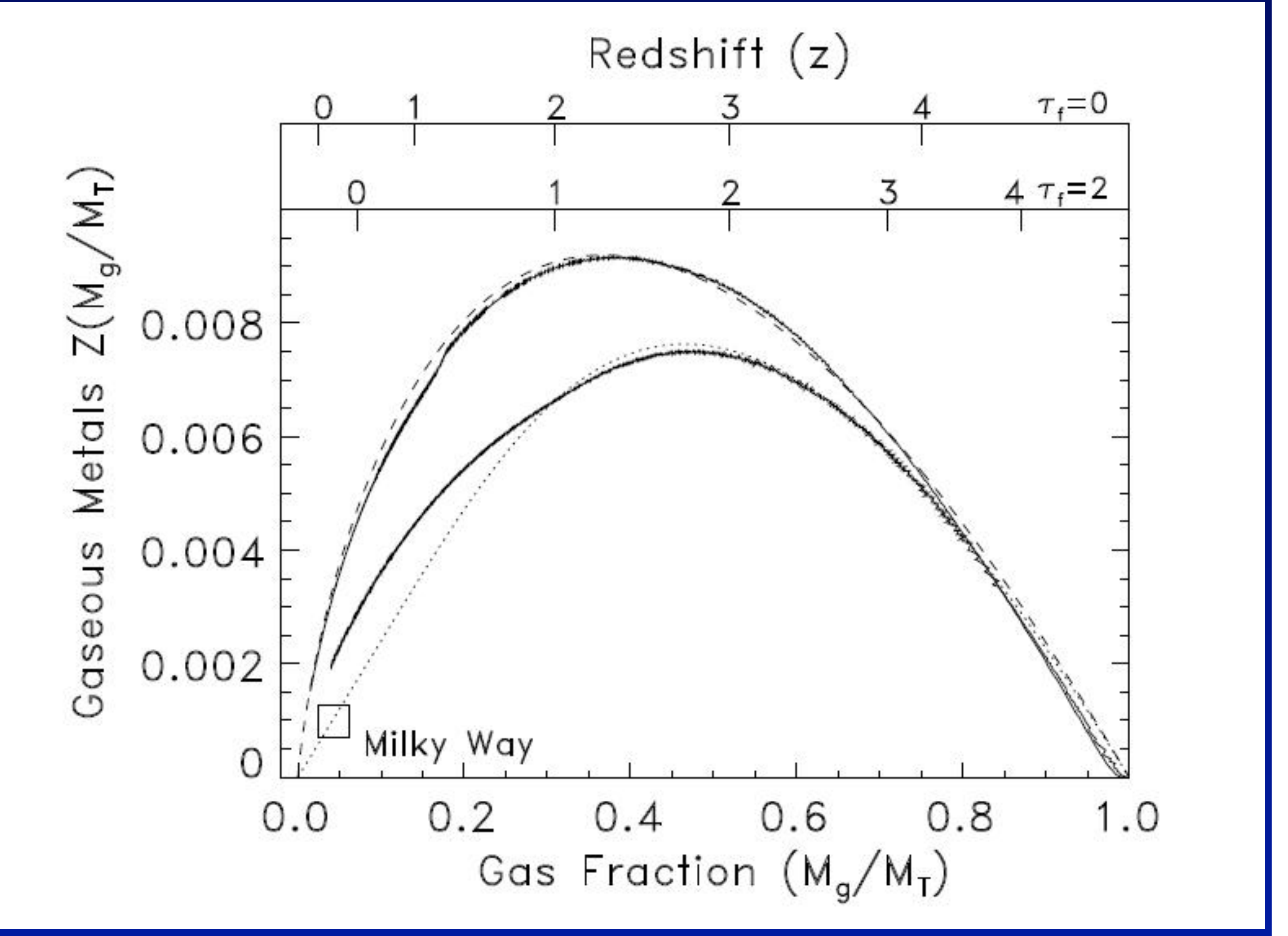


Slide from Blain et al. 2002

Theoretical Motivation

More CO and dust in the past for massive galaxies!!

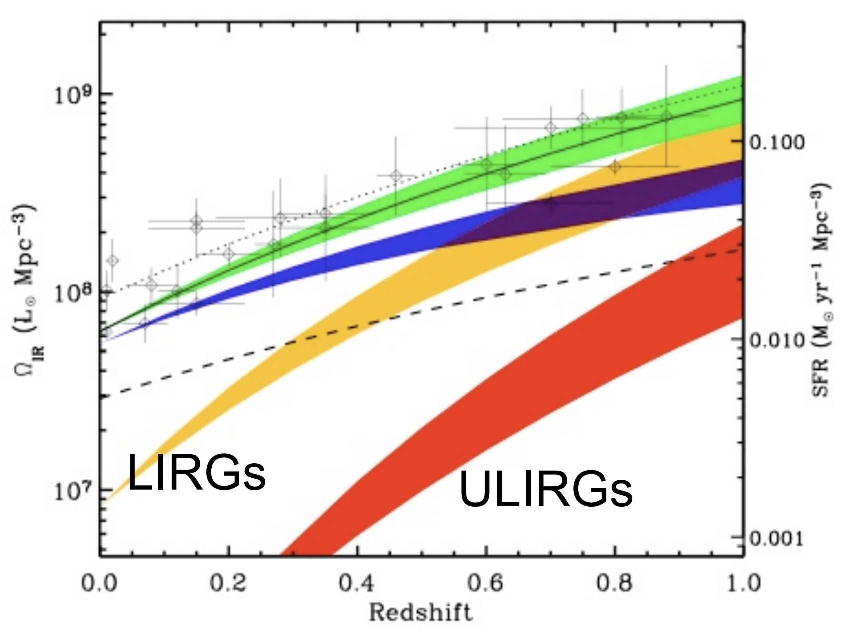
Peak of gaseous metals (Z*Mgas) occurs for gas fractions of 0.3-0.5.



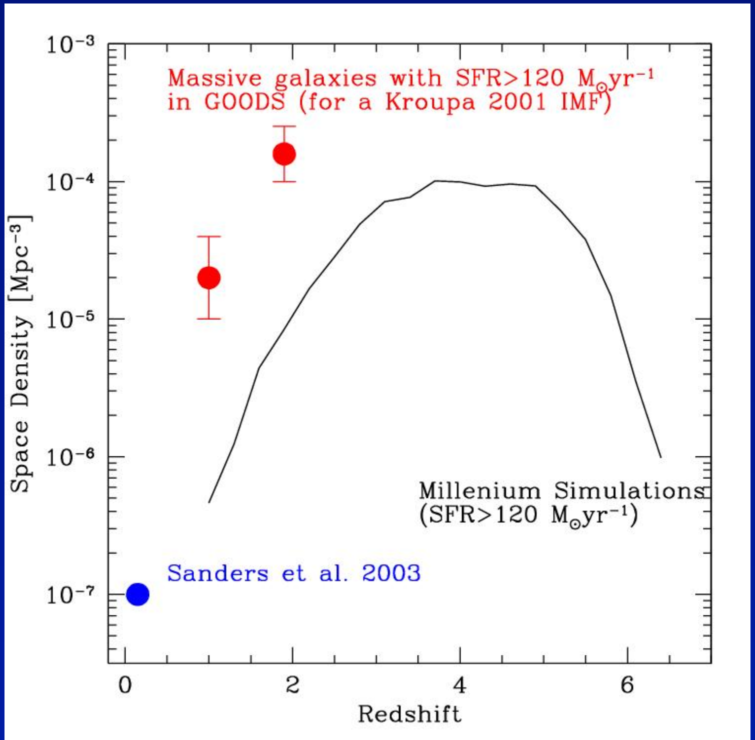
Models from Frayer & Brown 1997

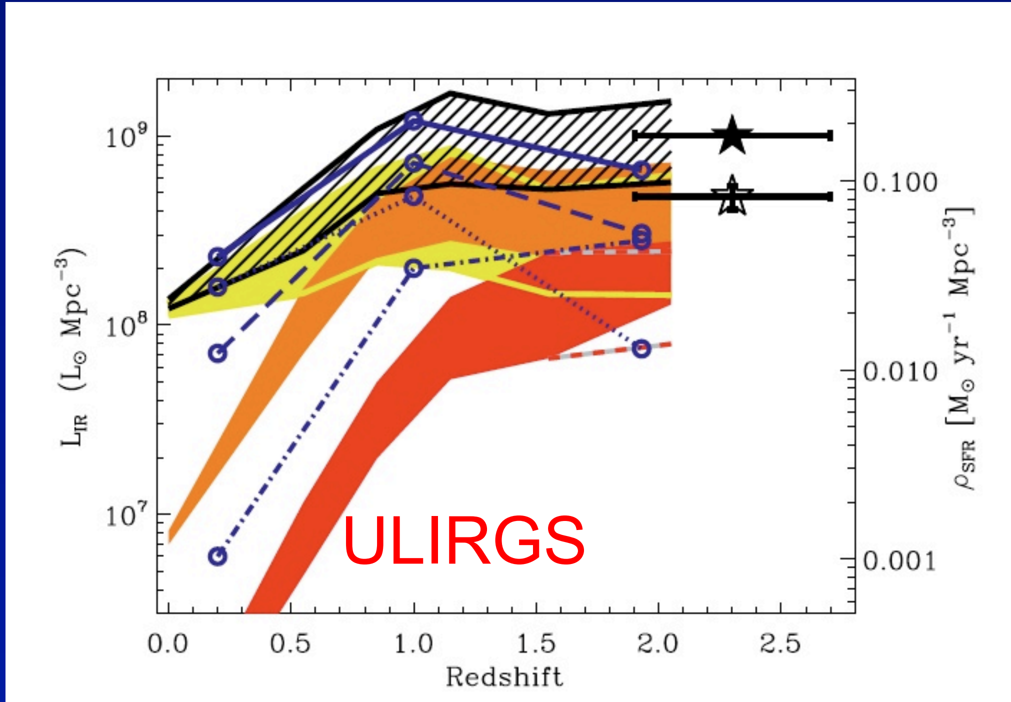
SMGs/ULIRG numbers increase dramatically at z~2

Le'Floch et al. 2005:



Daddi et al. 2007



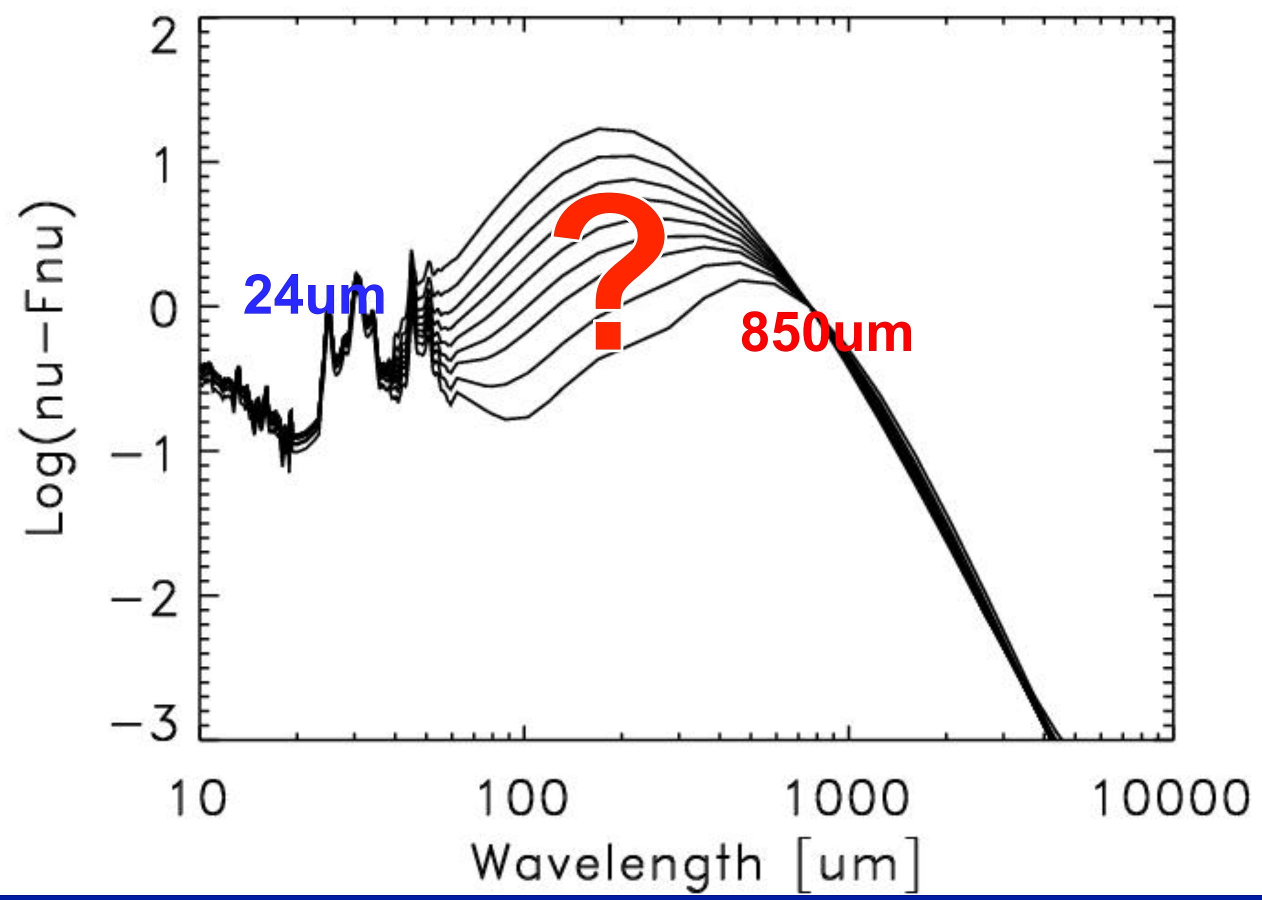


Magnelli, et al. 2009

Need FIR measurements near peak!! → **Herschel**

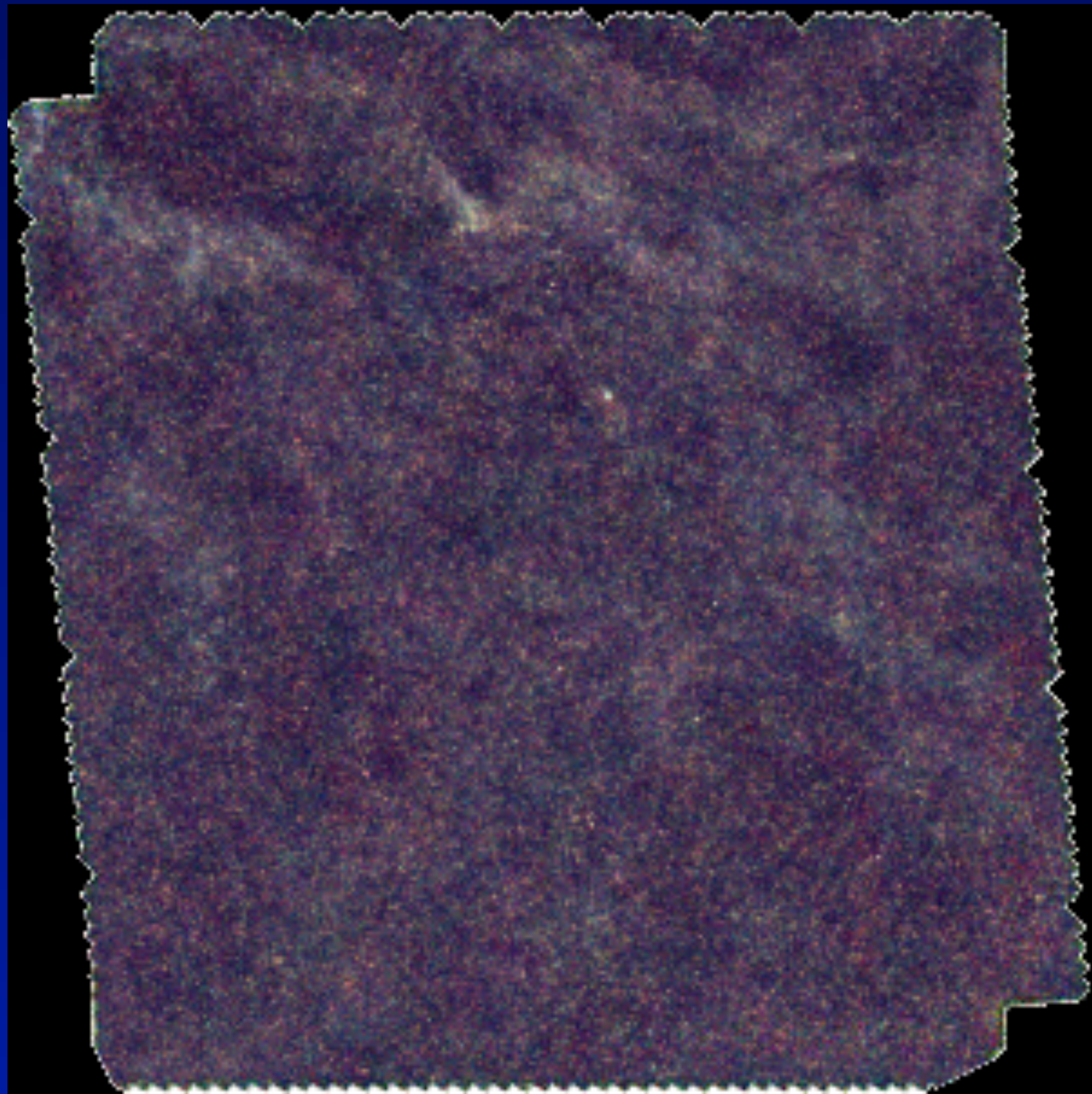
Dale and Helou SEDs at z=3 and normalized at 850um observed-frame.

Pre-Herschel, most high-z based on 850um and Spitzer 24um selection
→Uncertain L(IR).



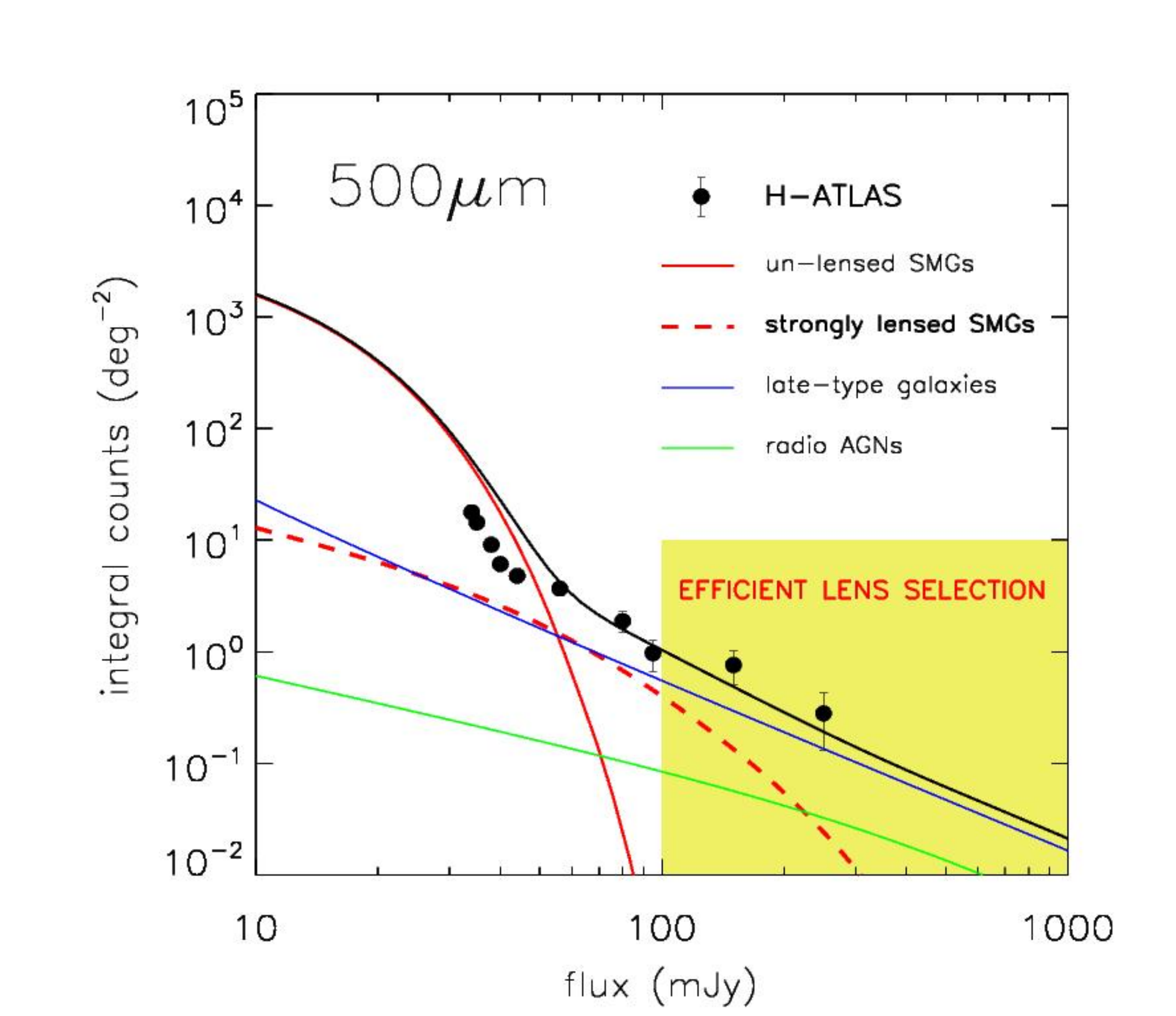
Herschel-ATLAS Survey (Eales et al.)

- Wide-area sub-mm survey: 570 sq-deg (over several fields)
- 100, 160, 250, 350, 500um bands
- rms~10mJy level (confusion limited at longer wavelengths)
- Ancillary optical data
- Right: SDP Gama-9hr field 4deg x 4deg tile (250+350+500um color image)

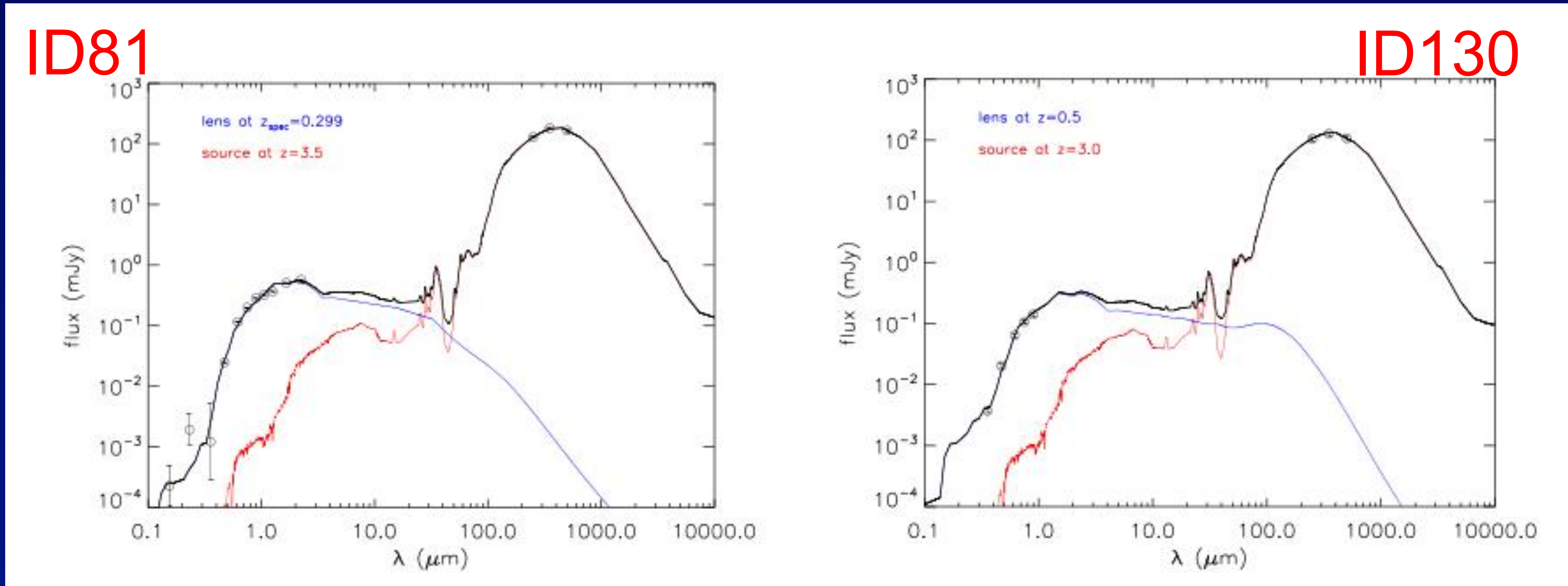


Herschel data shows the upturn in the bright source counts expected from lensed sub-mm sources

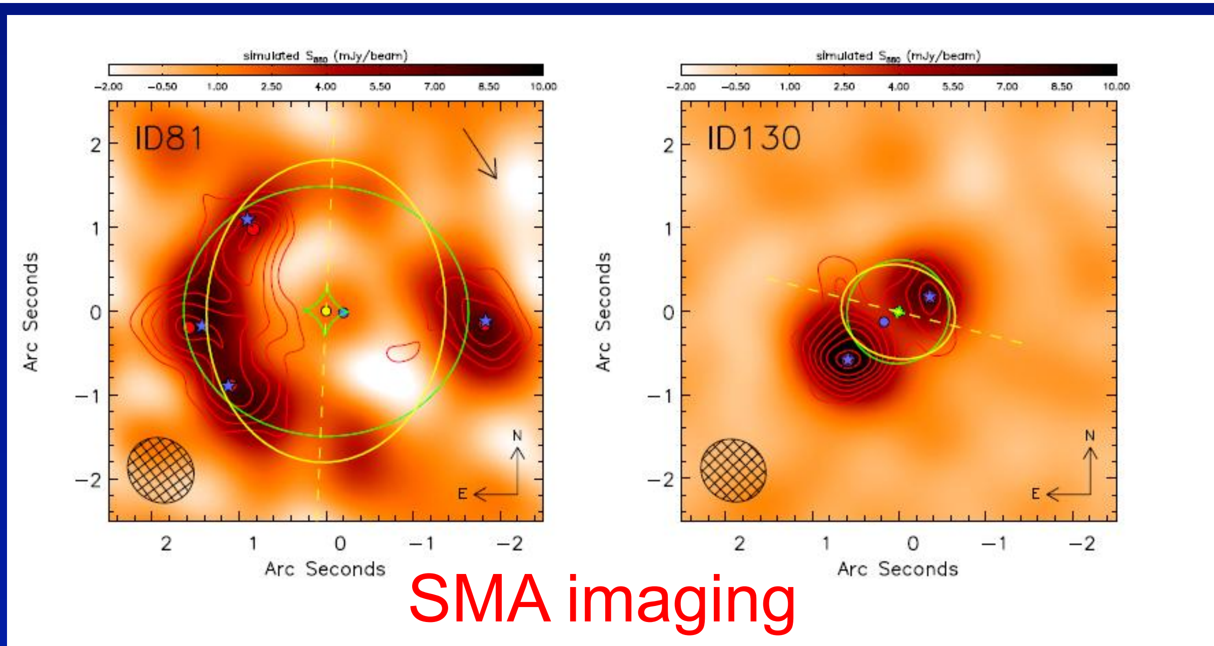
M. Negrello et al. (2010)
H-ATLAS SPIRE results.



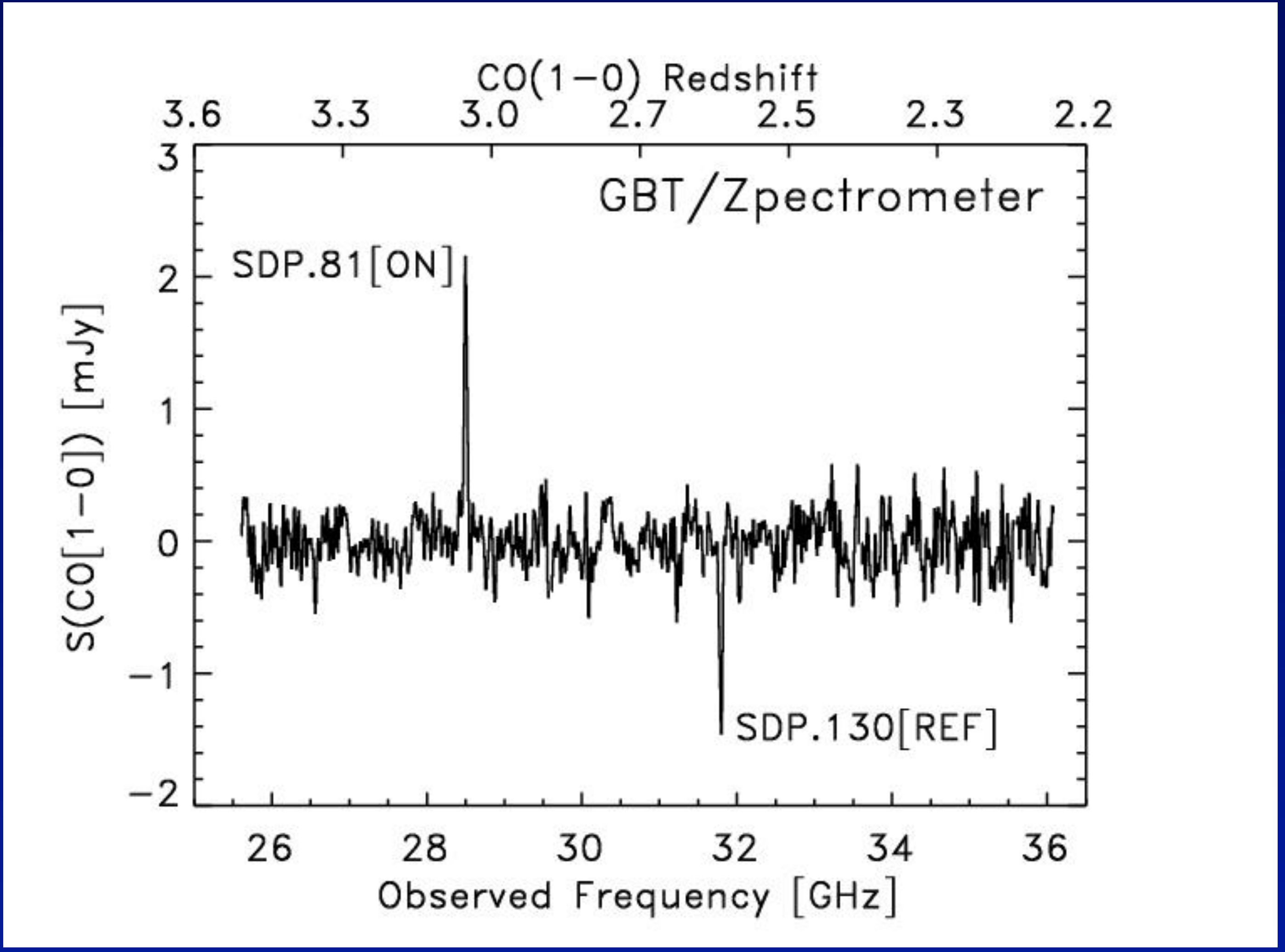
Lensed Candidates: Bright 350um “Peakers”



Strong far-infrared background sources -- Sources that peak at 350um are at z~2-3.5 and are ideal targets for GBT/ Zpectrometer redshift measurements using CO (1-0)



GBT/Zpectrometer (Frayer et al. 2010)

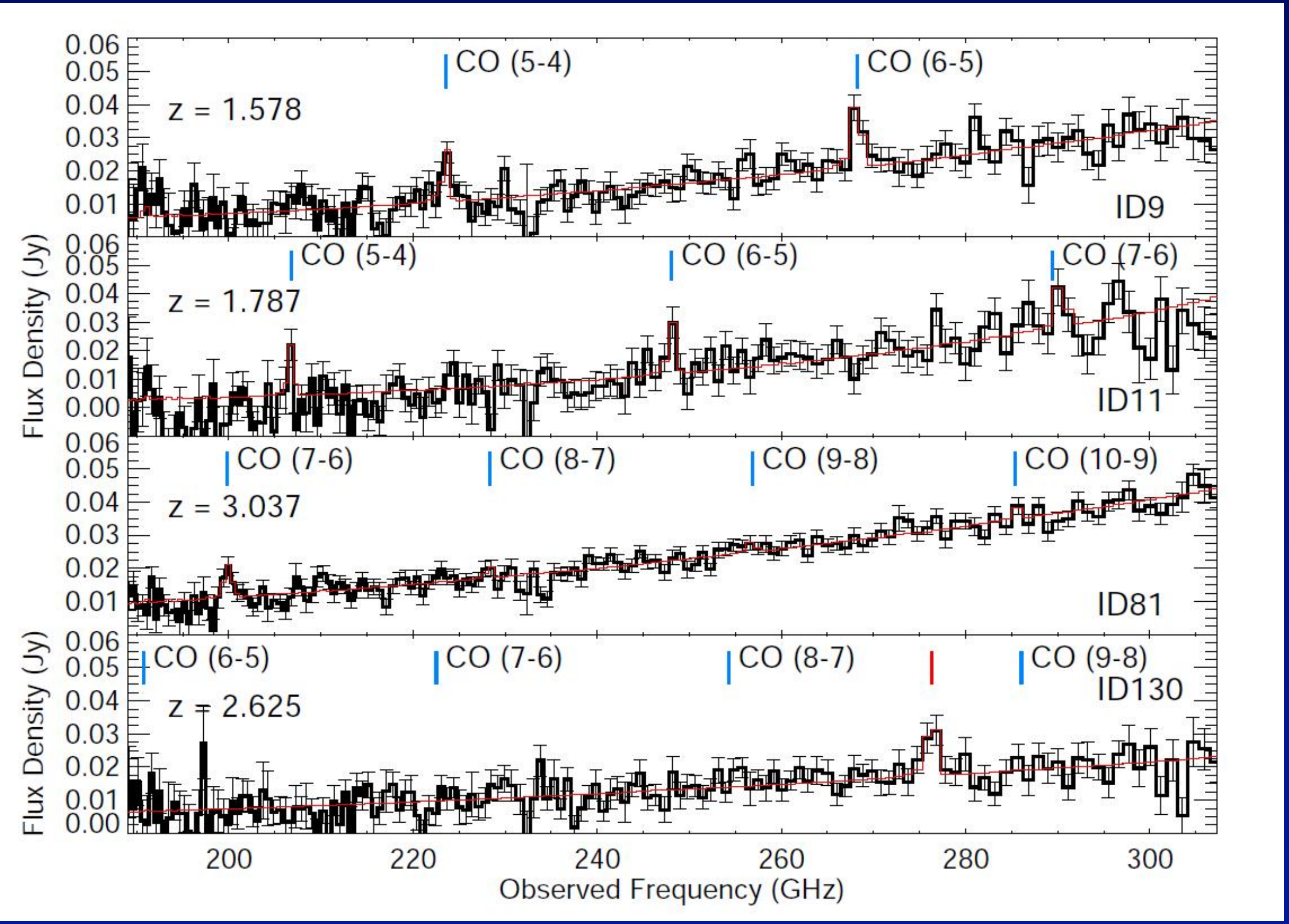


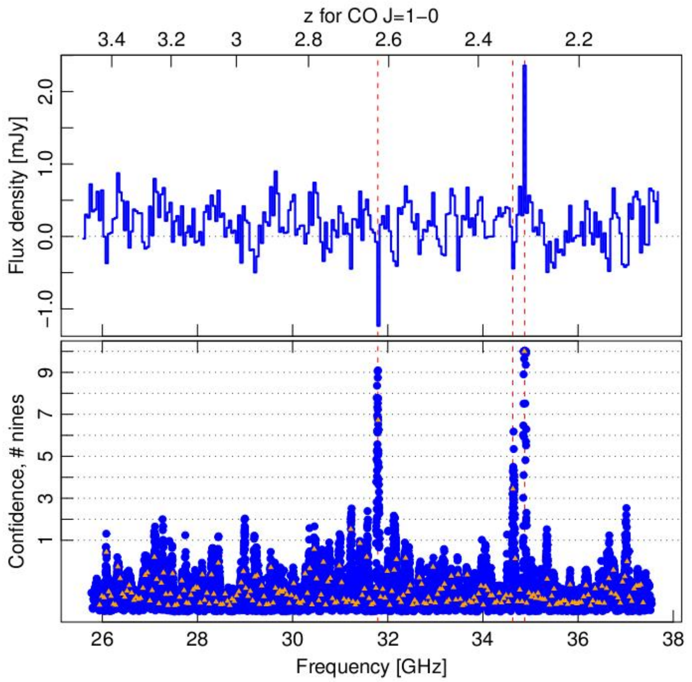
SDP.81(ON)+SDP.130 (REF, negative): CO(1-0) redshifts measured. Confirms sources are background lensed galaxies [only 1.15hr integration time per source]. Both sources confirmed with PdBI CO(3-2) data.

CSO/Z-Spect:

Lupu et al. (2010) searching for redshifts using the high-J CO lines.

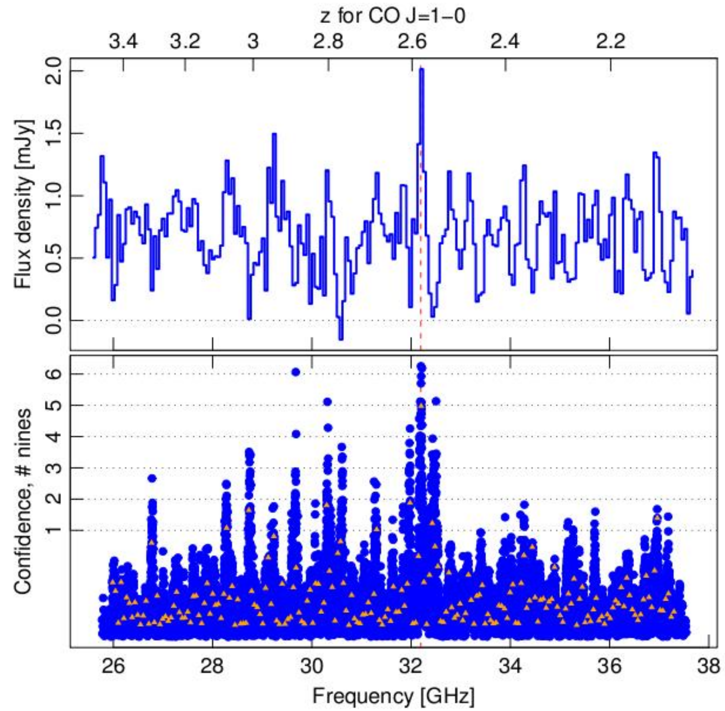
Herschel SMGs ➔ Lots of ongoing GBT, CSO, SMA, PdBI, CARMA, IRAM-30m, and eVLA observations.

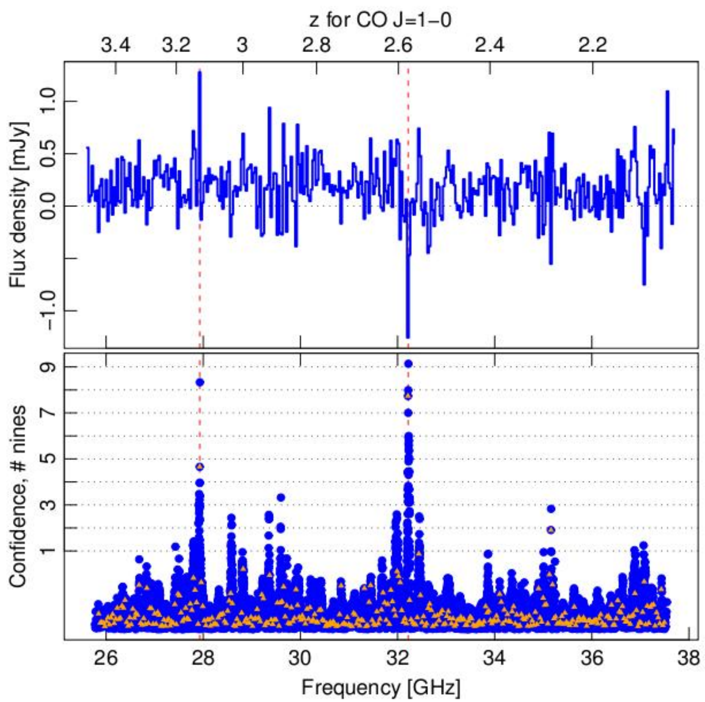


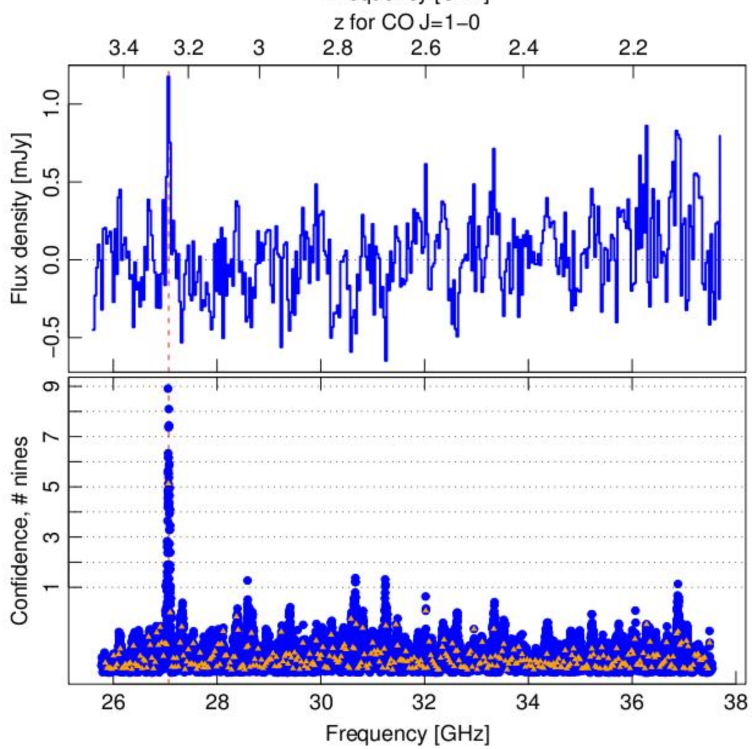


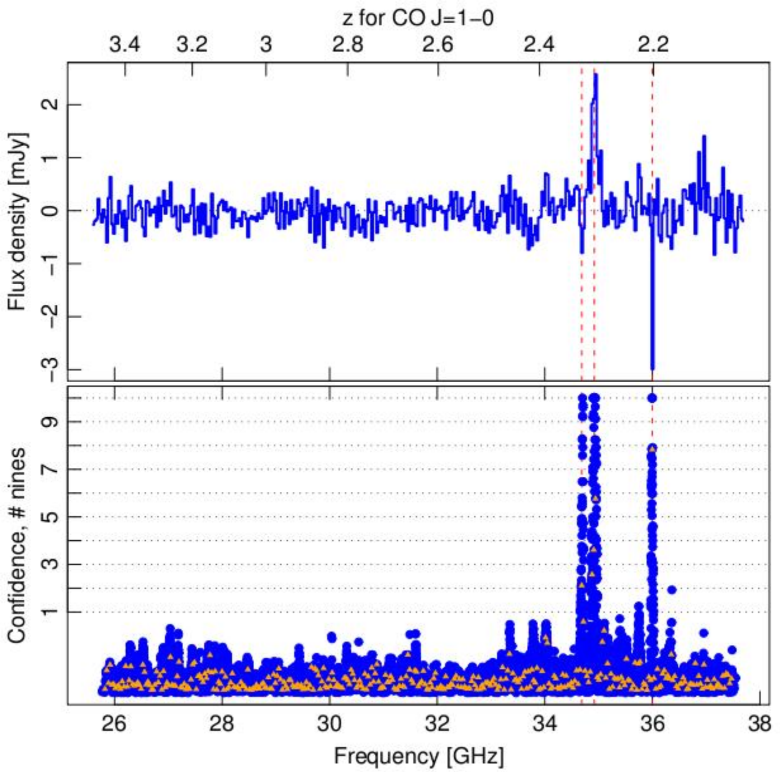
Example GBT CO(1-0) Zpectrometer data:

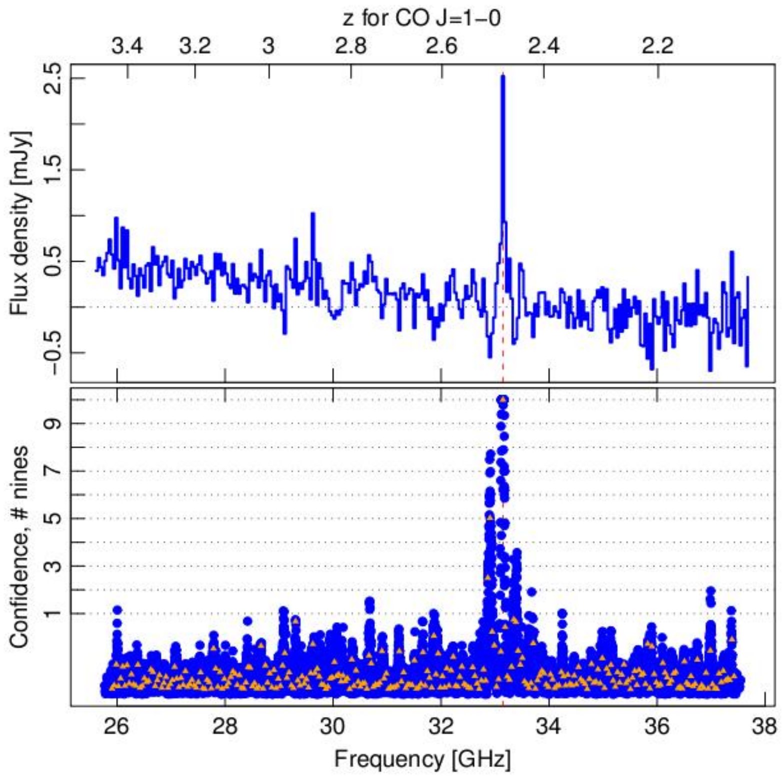
(In 1st season, we have looked at 20-30 sources with 12 detections).



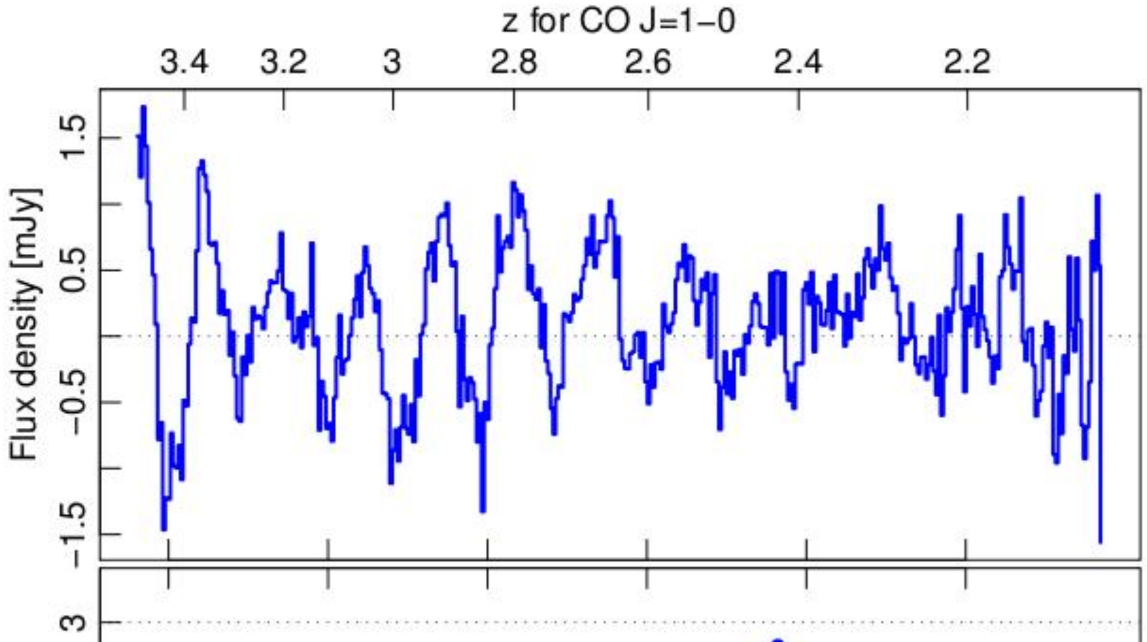








Example bad data:

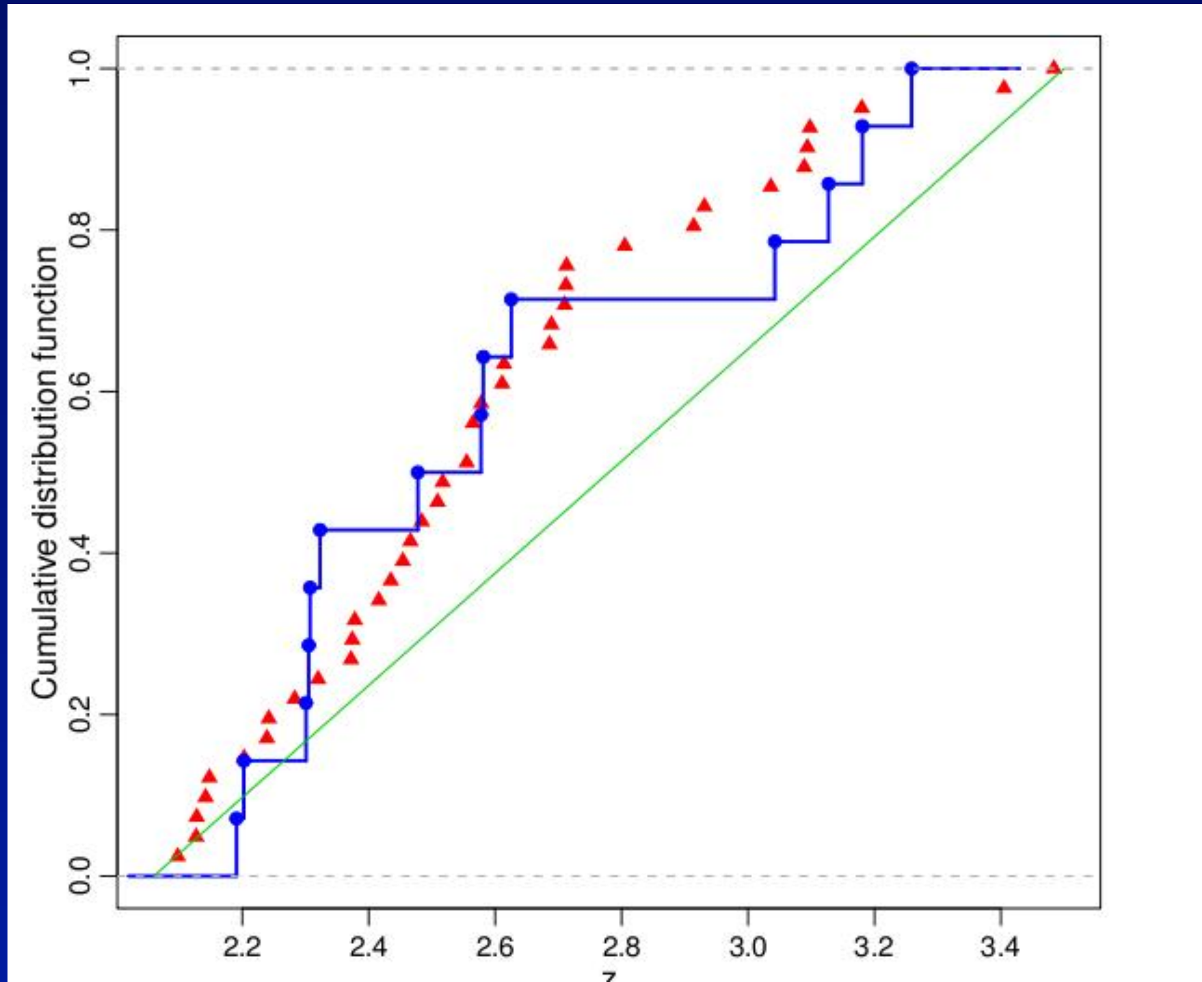


SMGs <z>~2.5

Green Line =uniform distribution of redshifts

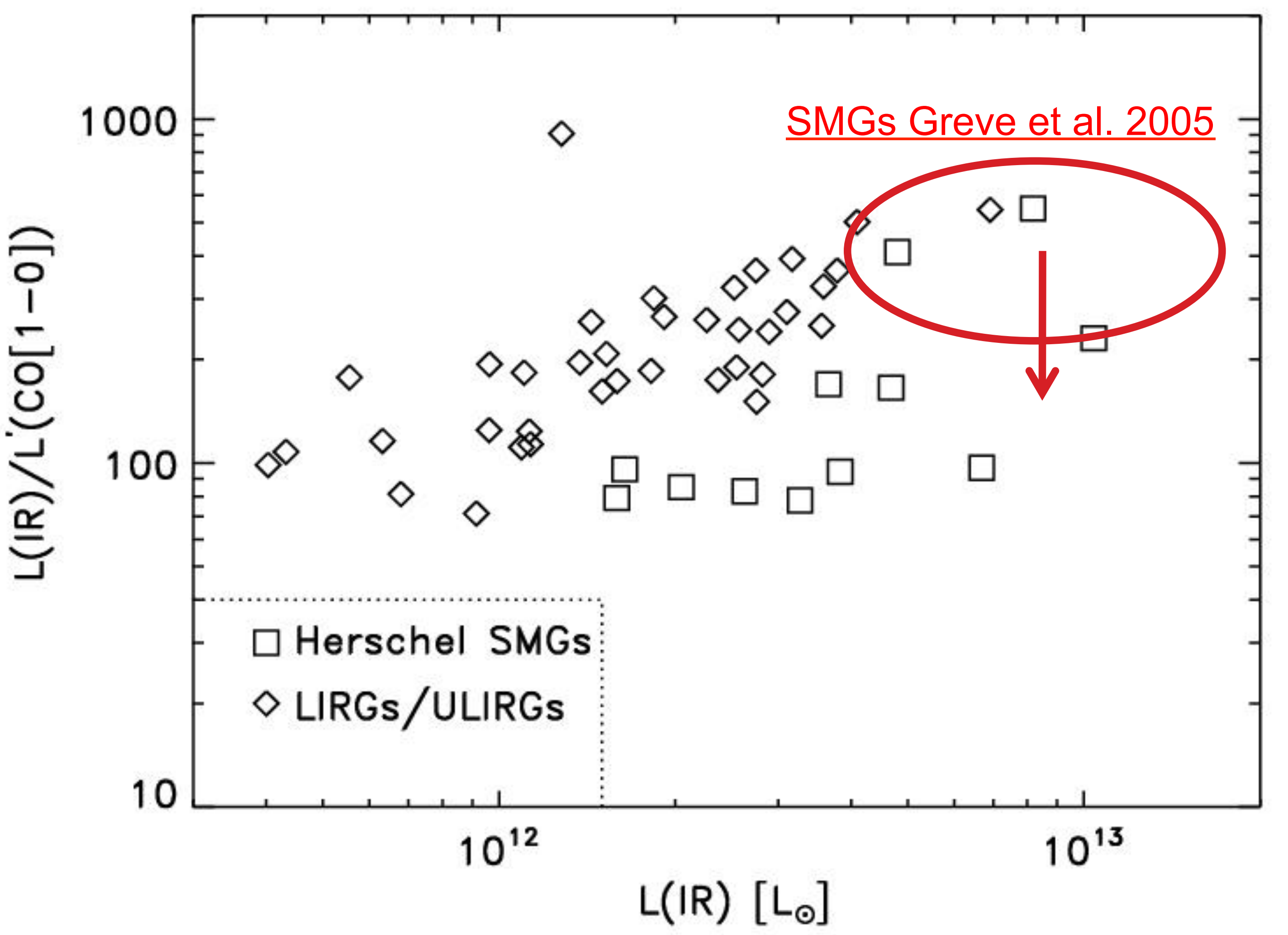
Blue = Observed redshift distribution of H-ATLAS SMGs (based on 12 GBT CO detections)

Red = Observed SMG distribution from Chapman et al. 2005



Slide from Andy Harris

SMGs have slightly lower L(IR)/L'(CO) ratios and similar L'(CO[3-2])/L'(CO[1-0])~0.6 as the local ULIRGs

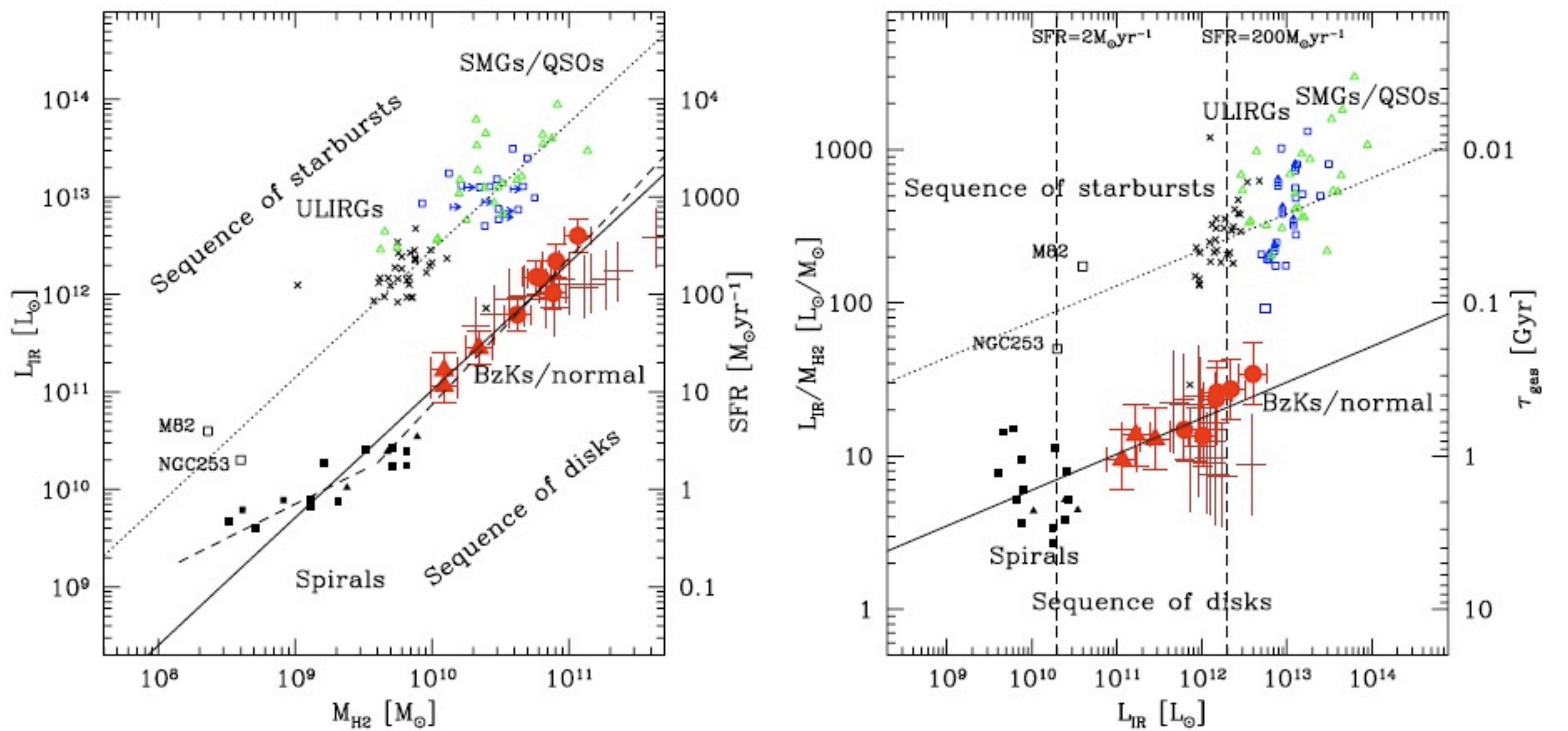


Previous SMG results overestimated Lir by 2x and adopted L'CO(3-2)/L'CO (1-0) = 1 which underestimated L'CO(1-0) by 1.7

Key: Good FIR measurements with CO(1-0)

Note: Assume lensing factor of 10x (x-scale still uncertain for many sources)

Disks vs Merger Starbursts

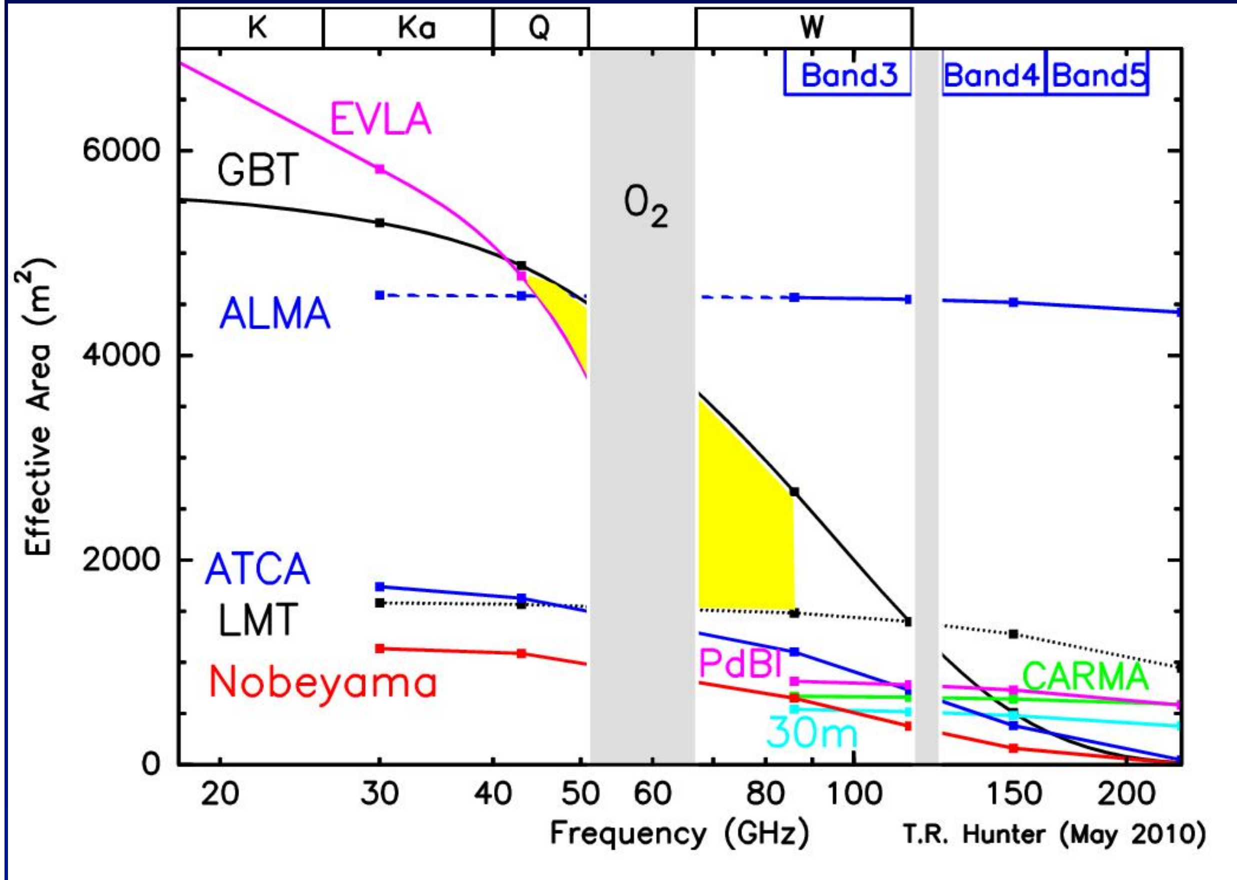


(Daddi et al. 2010) Separation of BzKs from SMGs mostly due to different adopted values of alpha. (Tacconi et al. 2010 disk selected sample show similar Lir/L'co as BzKs)

Results

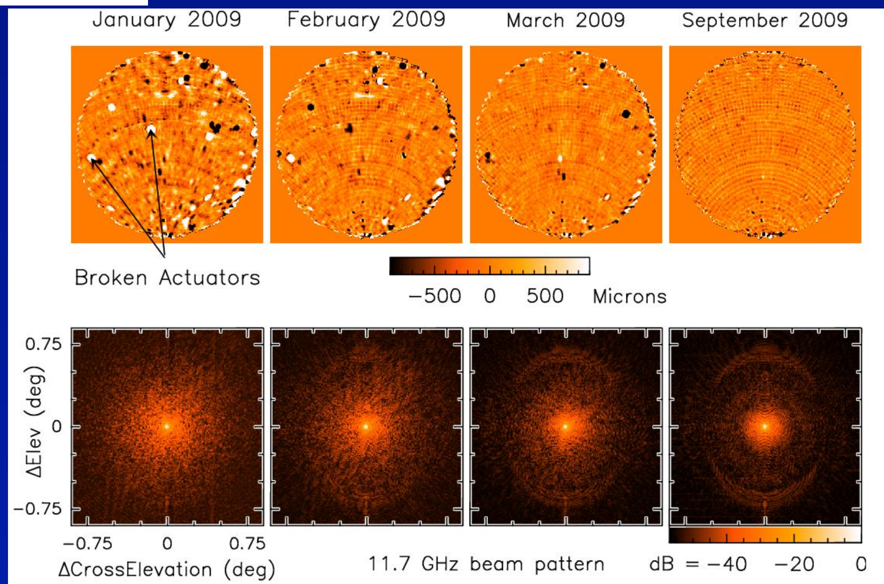
- 12 detections of CO(1-0) for the H-ATLAS SMGs to date (a few more with the GBT for HerMES and other samples)
- Avg/Median Td=36+/-1 K (30--44 K range of Td)

  (~5 K lower than local ULIRGs)
- Median L(IR)/L'(CO) = 100 Lsun (K km/s pc^2)^-1 (~2x lower than local ULIRGs)
- CO(3-2)/CO(1-0) ~0.6 (similar to local ULIRGs)
- Average redshift <z> ~2.5 (similar to SCUBA SMGs)
- ??alpha – CO to H_2 conversion factors??



Robert C. Byrd Green Bank Telescope

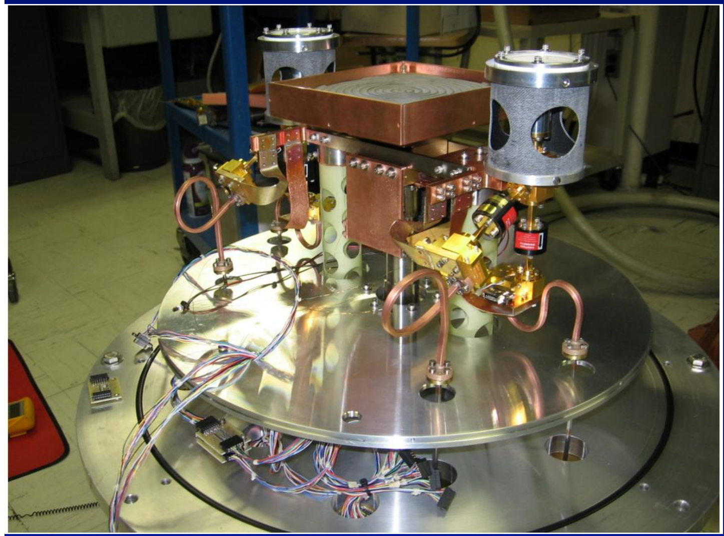
Given recent surface improvements, the GBT has the largest effective area at Q and W-low (ALMA Band2, “4mm Rx”), and there about 1000 hr per year with tau<0.1 and low winds in Green Bank.
(About 6500 hr of scheduled observations and 2000 hr at high-frequency per year)

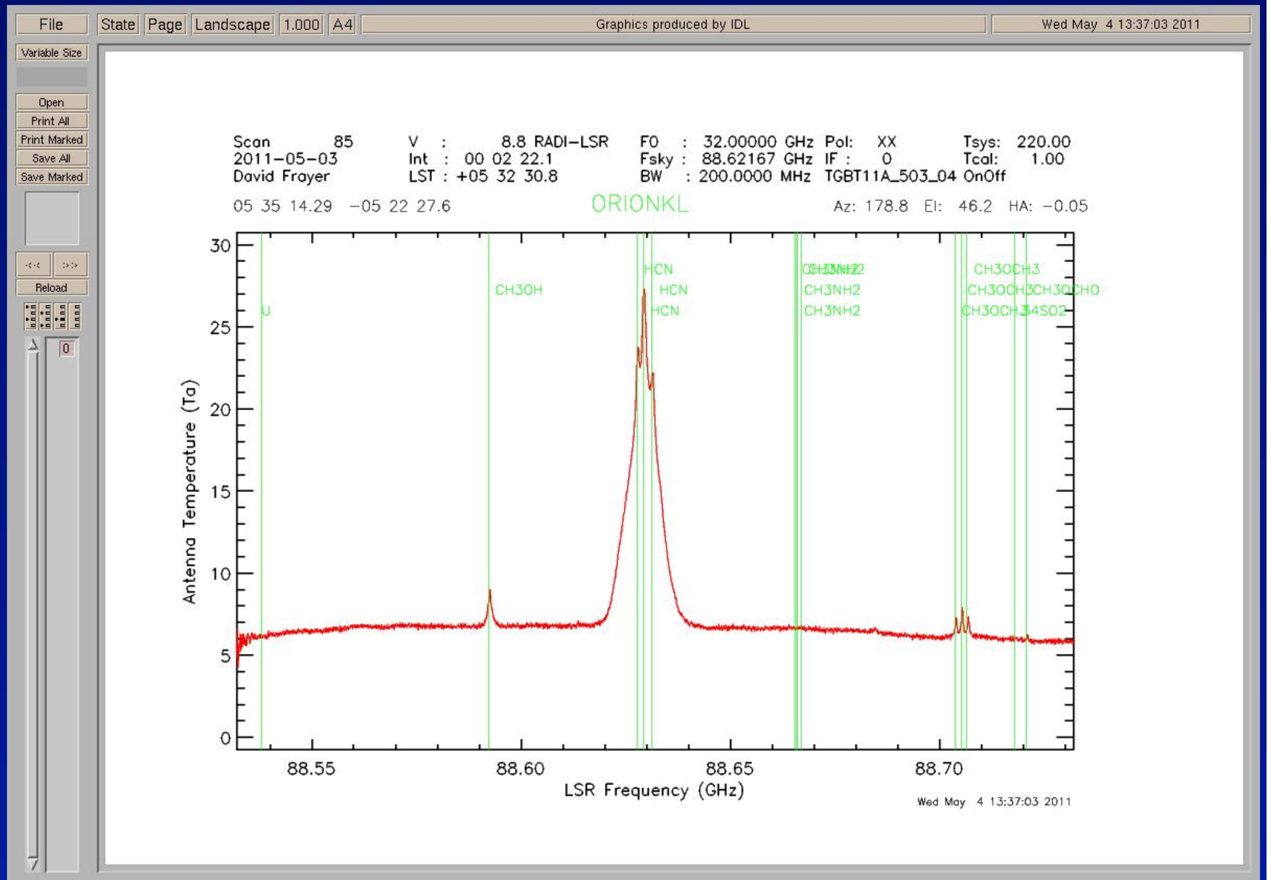


6/07/11

GBT 4mm Receiver (68-92 GHz) First Light, May 2011

NRAO 12A Proposal
Deadline 01 August





See http://www.gb.nrao.edu/4mm for more details.

Concluding Remarks

- **Next decade will greatly advance mm/submm studies of galaxy evolution (ALMA, EVLA, PdBI, GBT, LMT, CCAT -- CO Redshift machines on single dishes and detailed CO, HCN, CI, and C+ imaging with interferometers)**
- **Low-J CO important**
- **Wide-spectrometer backends permit CO/ISM studies at high-z without the need for prior optical/NIR redshifts**

Table 2
Instruments for CO Redshift Searches

Telescope	Instrument	Frequency Range	Bandwidth	Sensitivity (5σ)[a]
GBT	Zpectrometer	25.6–36.1 GHz	34%	0.9 mJy (This work)
CSO	Z-Spec	190–305 GHz	46%	100 mJy (Lupu et al. 2010)
CSO	ZEUS[b]	632–710 GHz	4%	300 mJy (Ferkinhoff et al. 2010)
IRAM 30 m	EMIR[b]	83–117 GHz	8%	9 mJy (IRAM documentation)
PdBI	WideX[b]	80–116 GHz	3.6%	3.7 mJy (Daddi et al. 2009)
CARMA[b,c]		85–116 GHz	8%	13 mJy (Web calculator)
EVLA[c]	WIDAR	12–50 GHz	40%–18%	0.2–0.4 mJy (Project page)
LMT[d]	RSR	74–111 GHz	40%	4 mJy (32 m), 1.5 mJy (50 m)[e]
ALMA[b,d]		84–116 GHz	8%	0.4 mJy (Web calculator)