Obtaining Submillimeter Galaxy Redshifts and Probing Large Scale Structure and z ~ 3

James Aguirre

13 November 2010

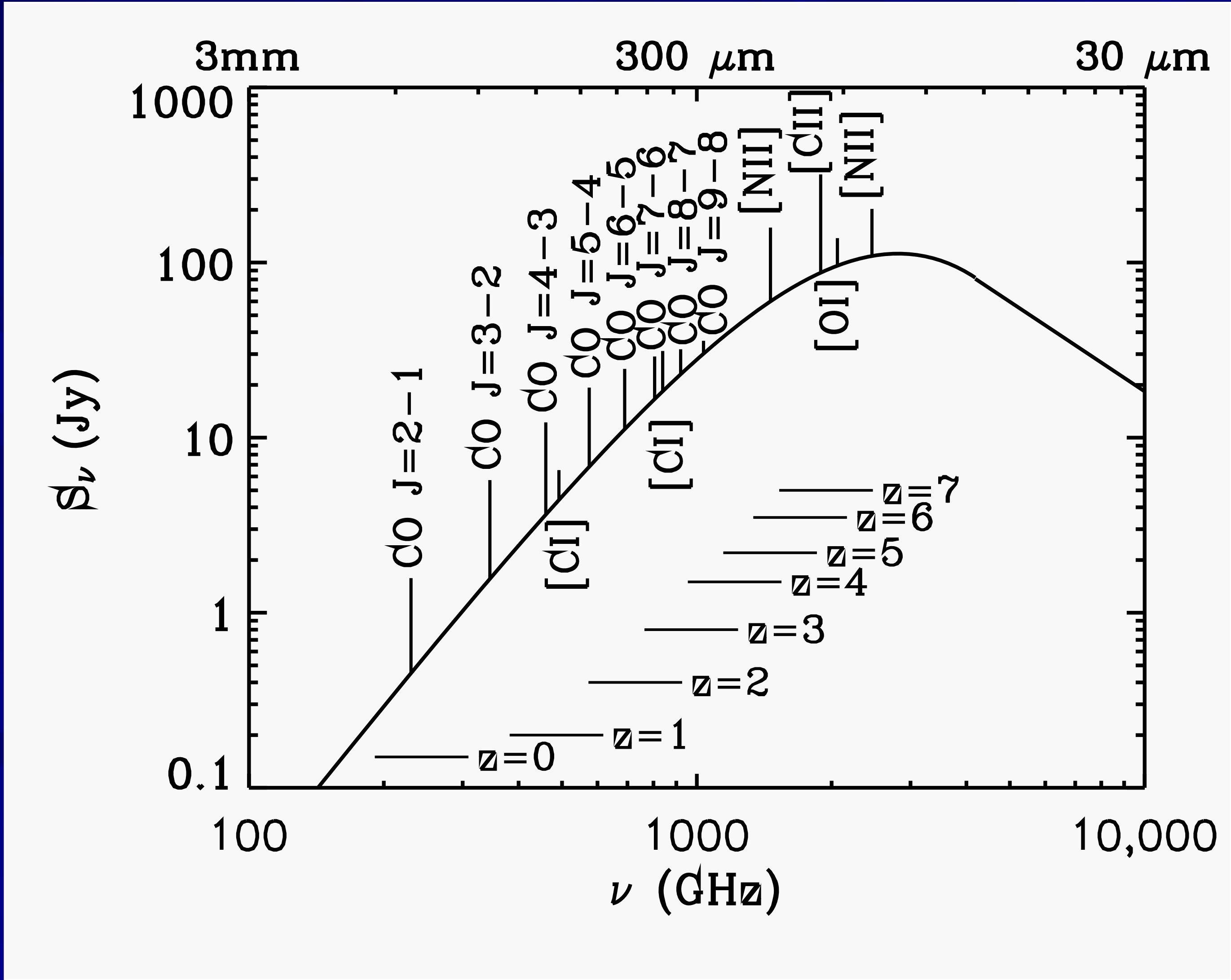
Collaborators

- University of Pennsylvania
  - James Aguirre
  - Roxana Lupu
  - Kim Scott
  - Michael Rosenman
- University of Colorado
  - Jason Glenn
  - Julia Kamenetzky
- ESO
  - Carlos de Breuck
- Chicago
  - Tom Crawford
- Cambridge
  - Scott Chapman
- Caltech
  - Joaquin Vieira
  - Tom Downes
  - Eric Murphy
  - Jonas Zmuidzinas
- JPL
  - Matt Bradford
  - Jamie Bock
  - Hien Nguyen
  - Bret Naylor
- Arizona
  - Dan Marrone
- Denmark
  - Thomas Greve

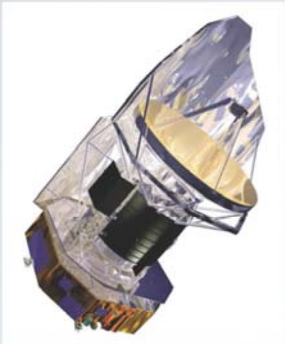
HerMES, H-ATLAS and SPT Collaborations

Z-Spec: A CO Redshift Machine

- Achieve background limited detector performance over the entire 1 mm atmospheric window
- Simultaneously measure 2 CO transitions for all redshifts z > 0.9
- Obtain “blind” redshifts for galaxies with luminosities L > 10^{13} L_{solar}
- Frequency range 185 – 305 GHz,
- R ~ 300 (~1000 km/s)



LARGE AREA SURVEYS



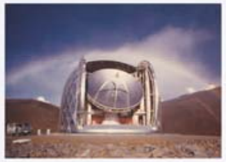
When completed, ~200 lensed sources.

SPT 4000 deg^2
1.4, 2.1, 3.2 mm
SMA, LABOCA
follow-ups

Herschel
H-ATLAS 550 deg^2
HerMES 72 deg^2
250,350,500 μm

Z-Spec

CSO

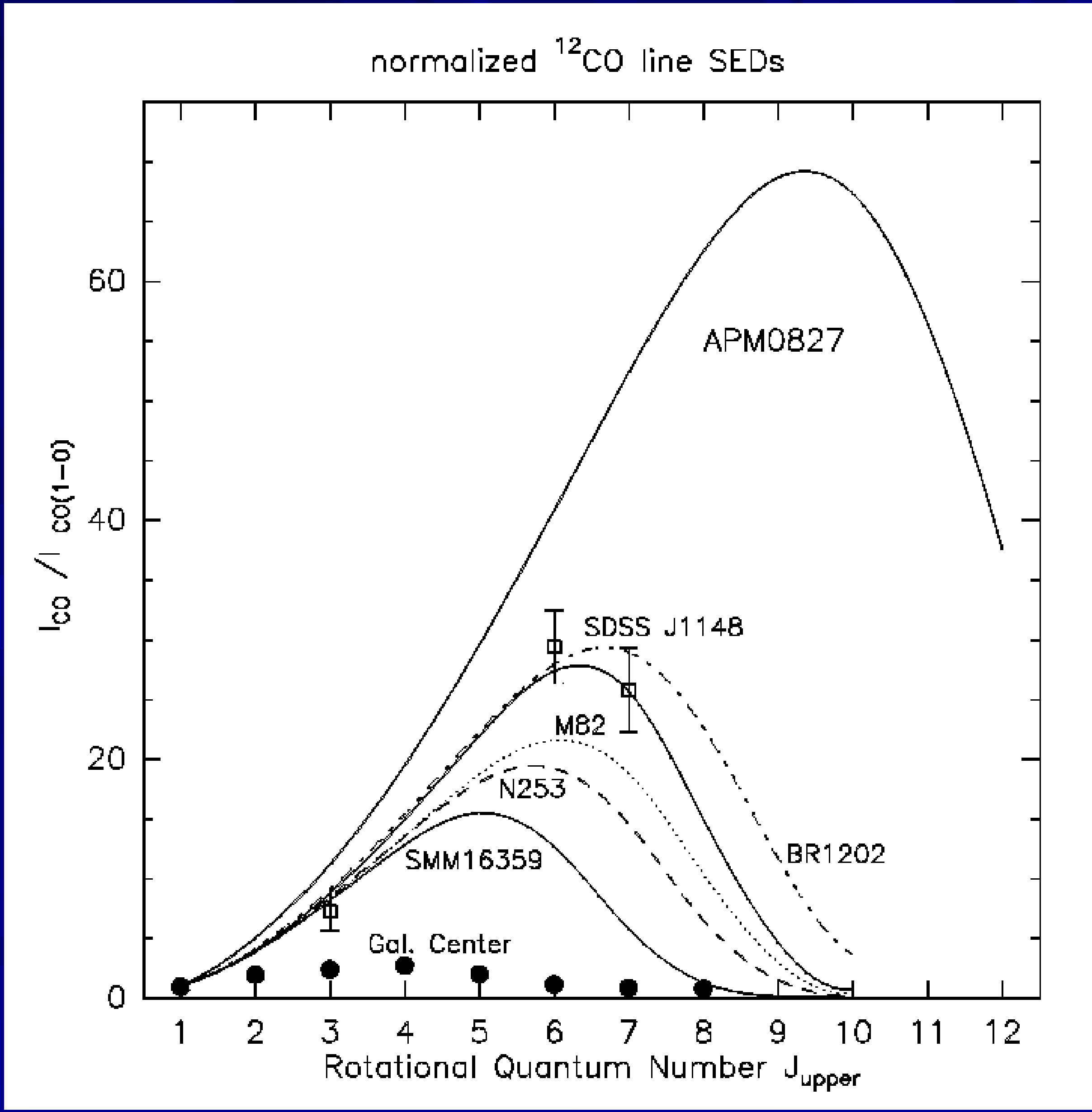


APEX

Redshifts, mid-J CO line strengths

Detailed follow-ups, ALMA

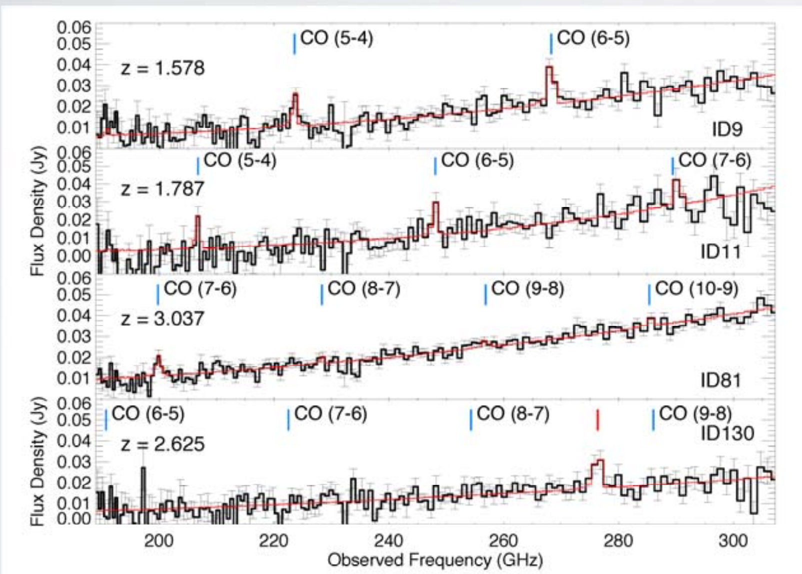
Relative excitation of the various transitions of CO probes the *temperature* and *density* of the molecular gas, and to a lesser extent, the presence of multiple spatial components

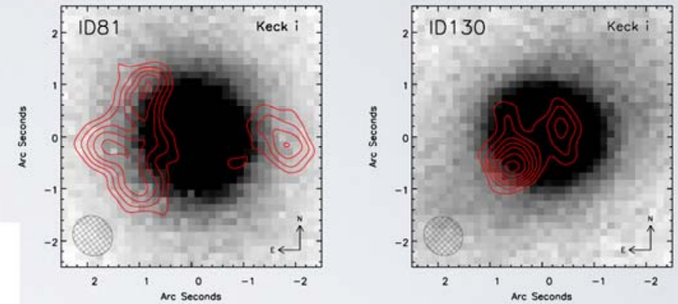


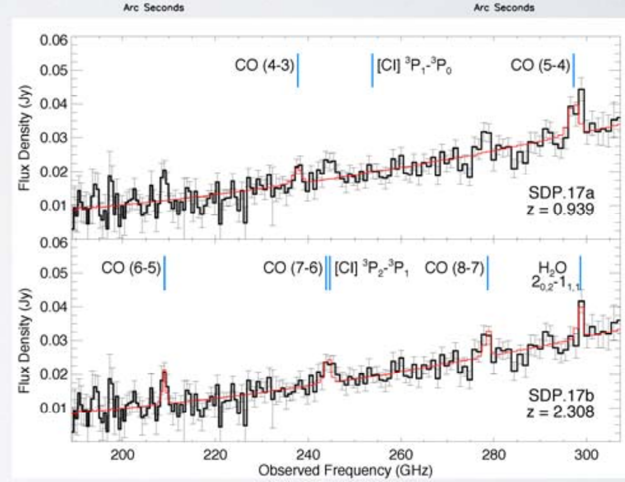
Weiβ et al., astro-ph/0702669

H-ATLAS SDP SOURCES

CSO March-May 2010



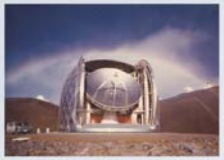




Lupu et al., arXiv1009.5983

Largest number of "blind" CO redshifts: measured the redshifts of 4 out of 5 sources. 3 of them have been confirmed.

HERMES: LOCKMAN-SWIRE 01



CSO March-May 2010

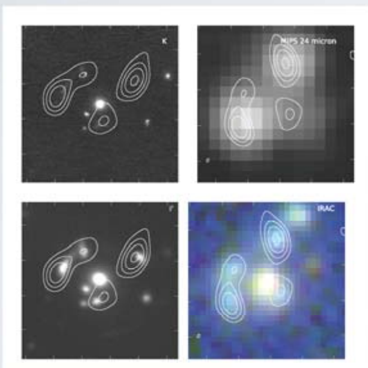
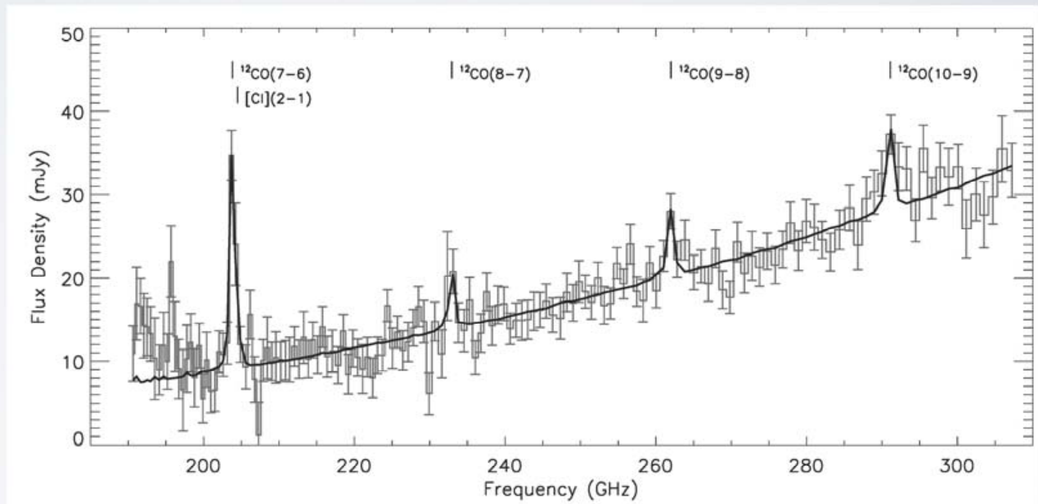


FIG. 2.— A composite of some of the multi-wavelength observations of LockSWIRE01. Clockwise from the upper left: the Keck *K*-band AO image; *Spitzer*/MIPS 24 μm; a false-color composite of *Spitzer*/IRAC data at 4.5, 5.8, and 8 μm; Subaru SuprimeCam *i*. The *Spitzer* images do not share the same orientation as the Subaru and Keck images. In all panels the SMA mm-band observations are overlain as white contours.

Conley et al., in prep.



Scott et al., in prep.

Strongest CO lines recorded from all surveys.

SPT:

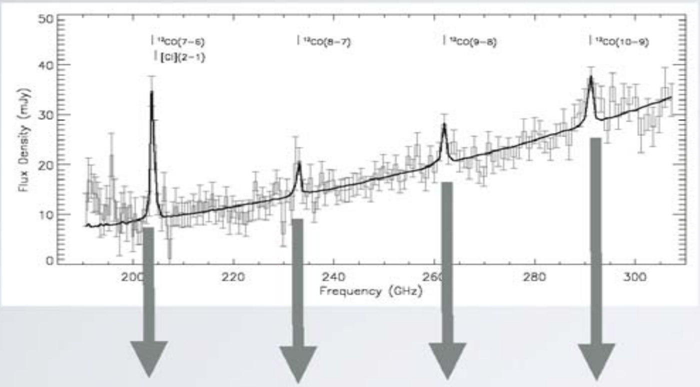
APEX Oct-Nov 2010

1.3 mm SMA detection at 20+ sigma,
K,J band imaging

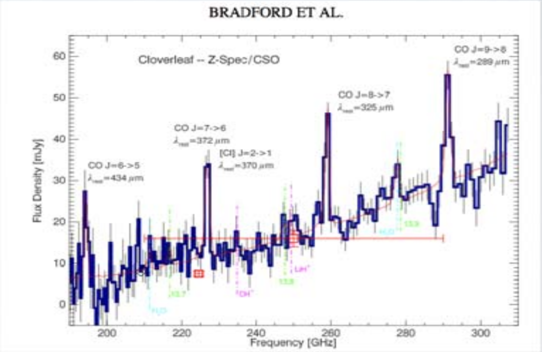
S_{225GHz} = 40 mJy
= x4 Cloverleaf
z>3
Lens is at z=1.1

Highest "blind" redshift obtained by Z-Spec.

REDSHIFT DETERMINATION



Not quite a Cloverleaf spectrum...



Use the S/N in these channels to construct test statistics.

The power of the redshift determination lays in identifying multiple lines.

redshift statistical analysis multiple lines >> significant
more significance plots for the atlas sources

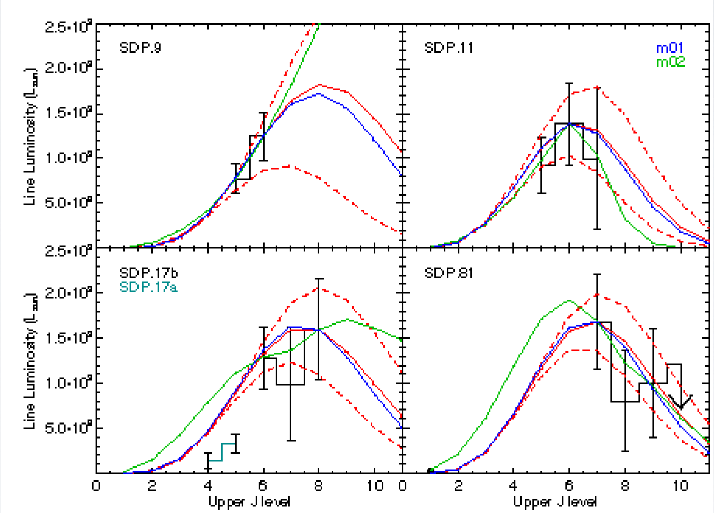
S/N ~ 2 in 2 channels (2 lines)⟶ start to see a redshift.

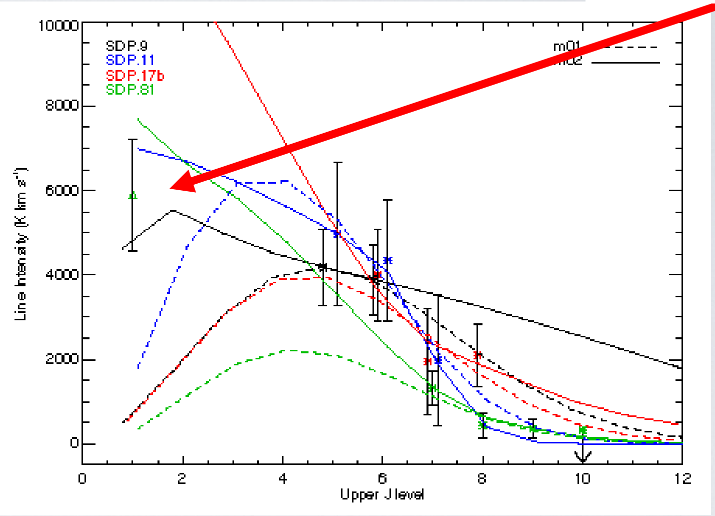
Depends on the strength of the lines and sensitivity...

Using 2 test statistics, the number of false positives is ~3%.

CO SLEDs

Zpectrometer (GBT)





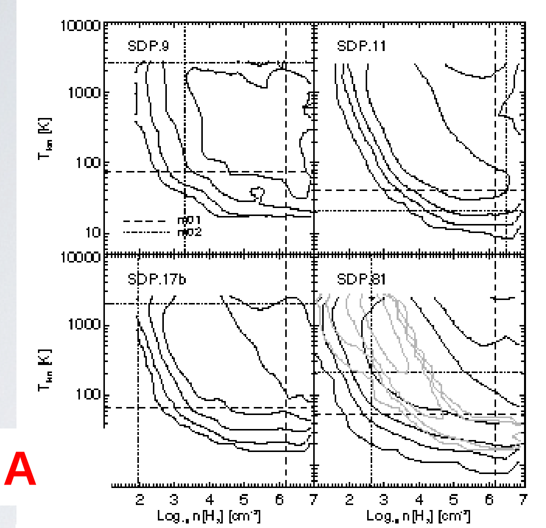
The analysis of based on Z-Spec data is limited.

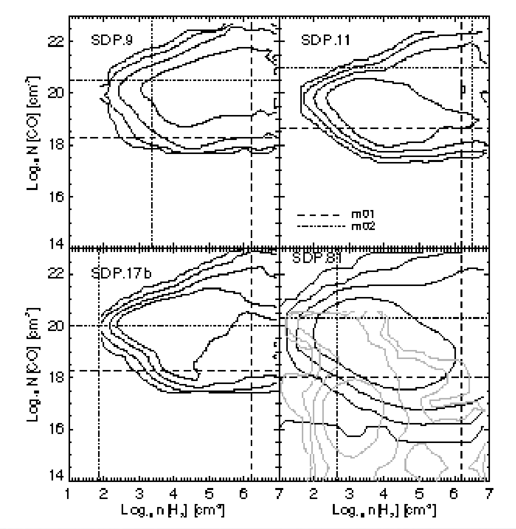
Degeneracies:
CO column density/source size
gas density/kinetic temperature

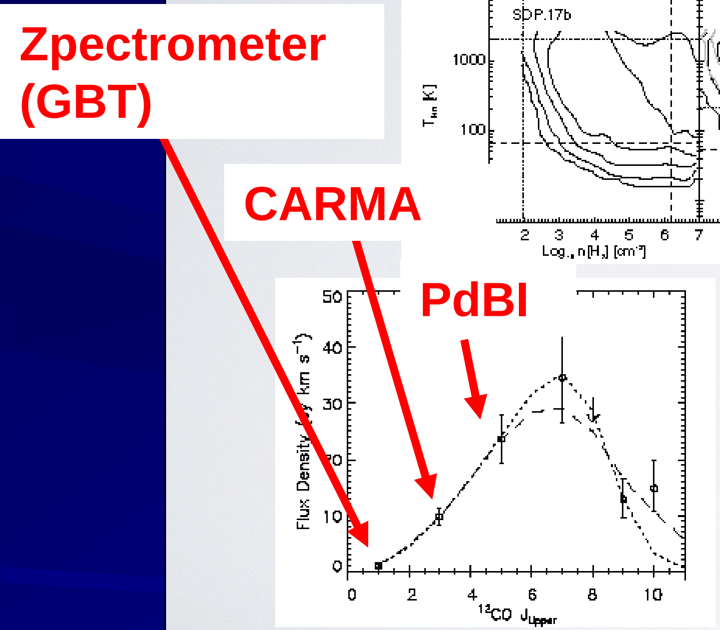
Need additional constraints:
more CO lines, (1-0) in particular.
source sizes.
gas density via dense gas tracers.

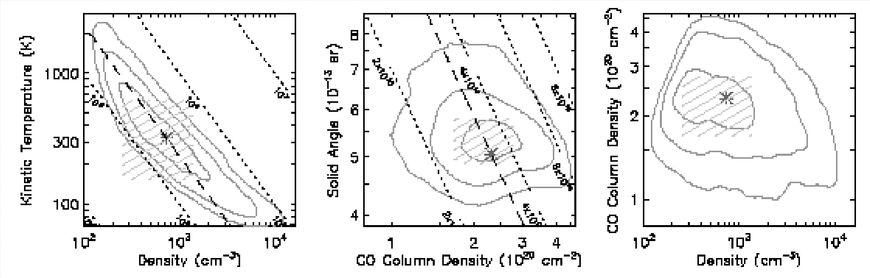
Herschel follow-up proposals approved

LIKELIHOOD ANALYSIS





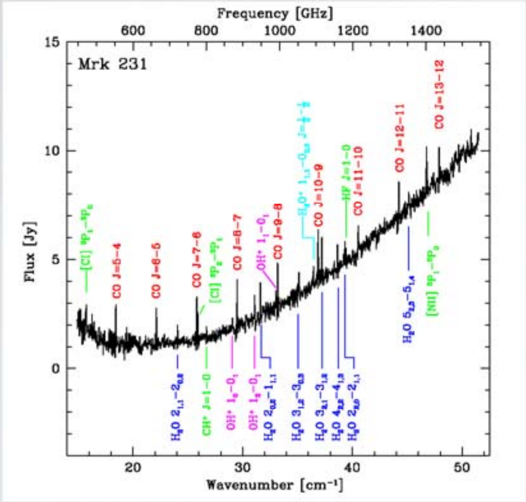


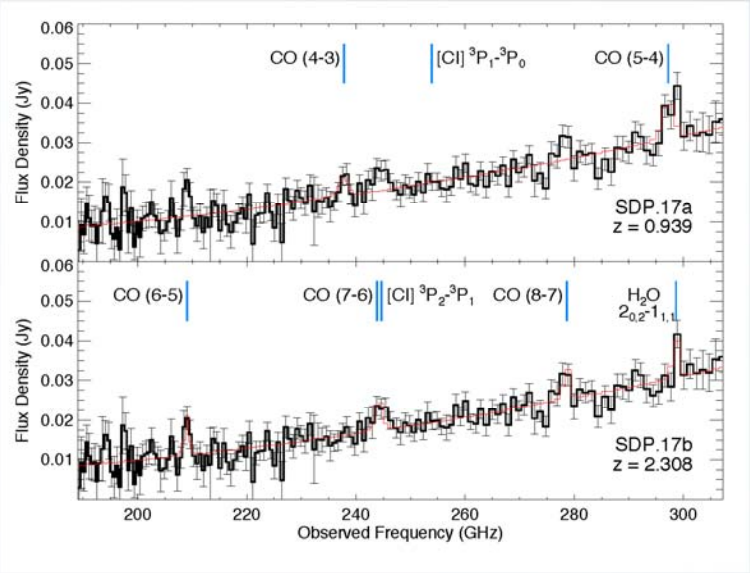


Lockman-SWIRE 01, Scott et al., in prep.

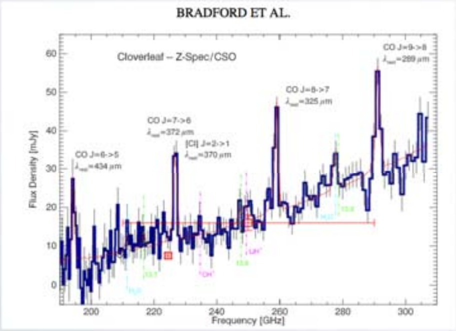
A larger number of measured CO lines improves constraints on parameter space.

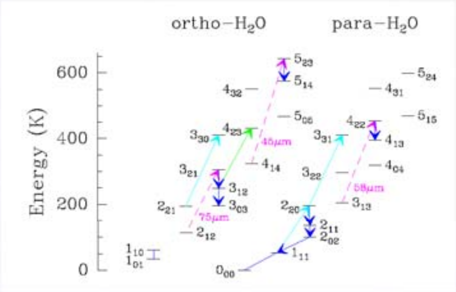
WATER





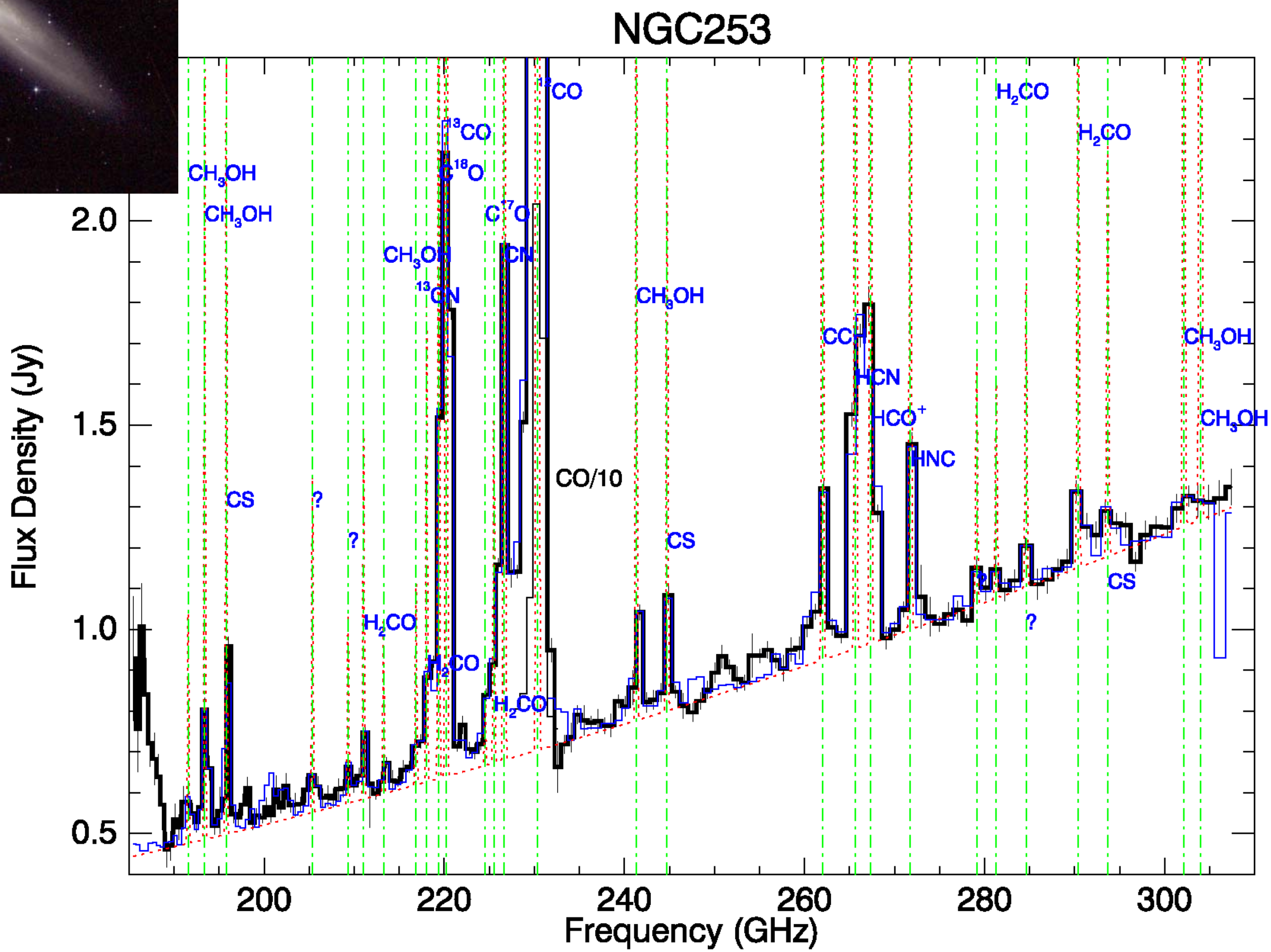
AGN indicator.



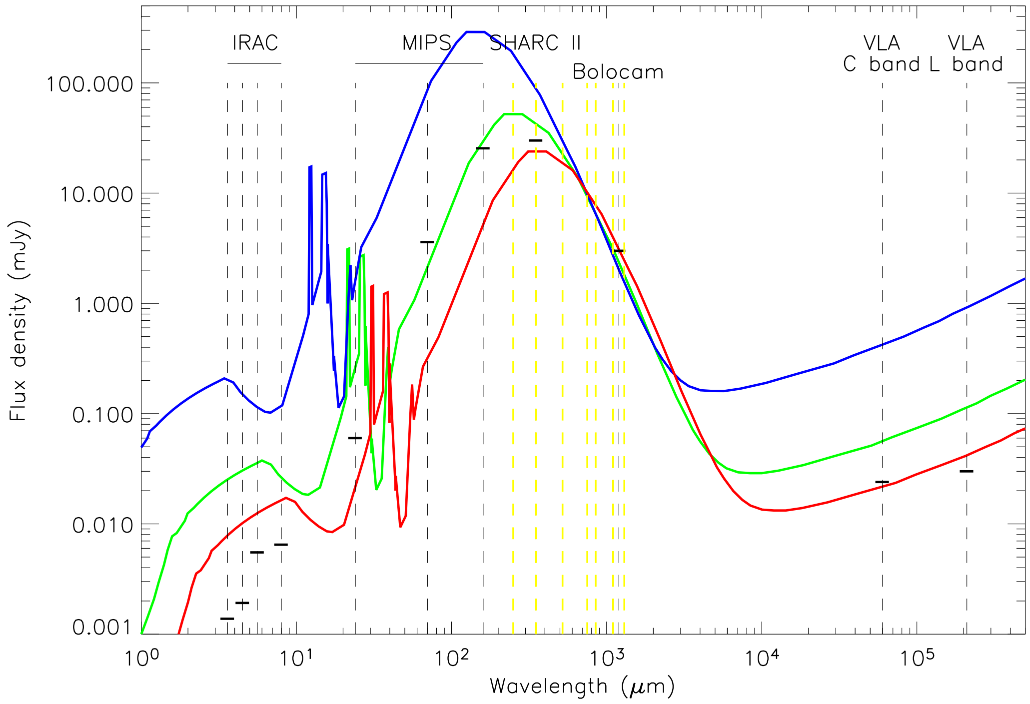


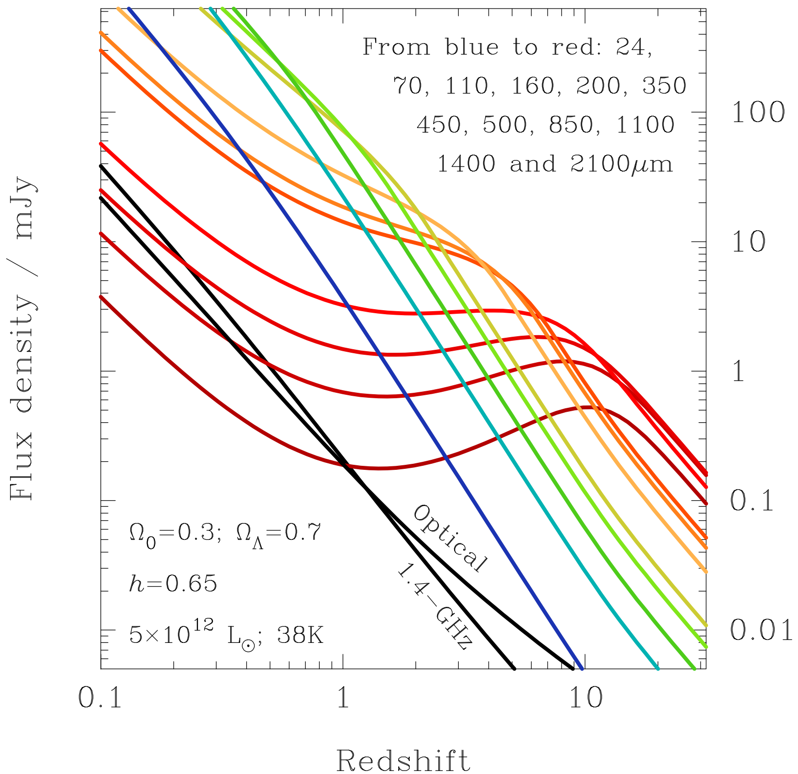
The water lines will fall in ALMA bands 6 and 7.

Dense Gas Tracers



The Power of the Submillimeter Window for High Redshift Searches



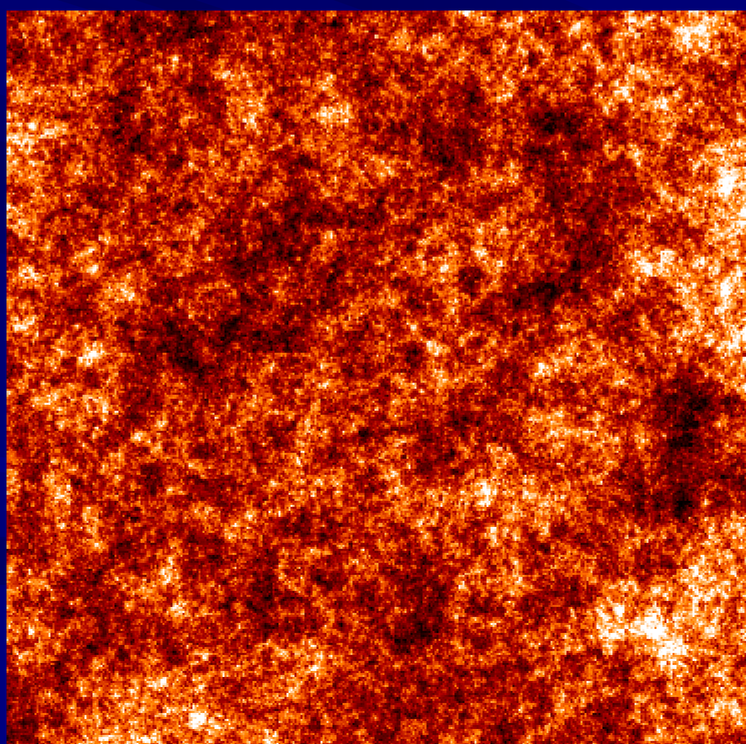


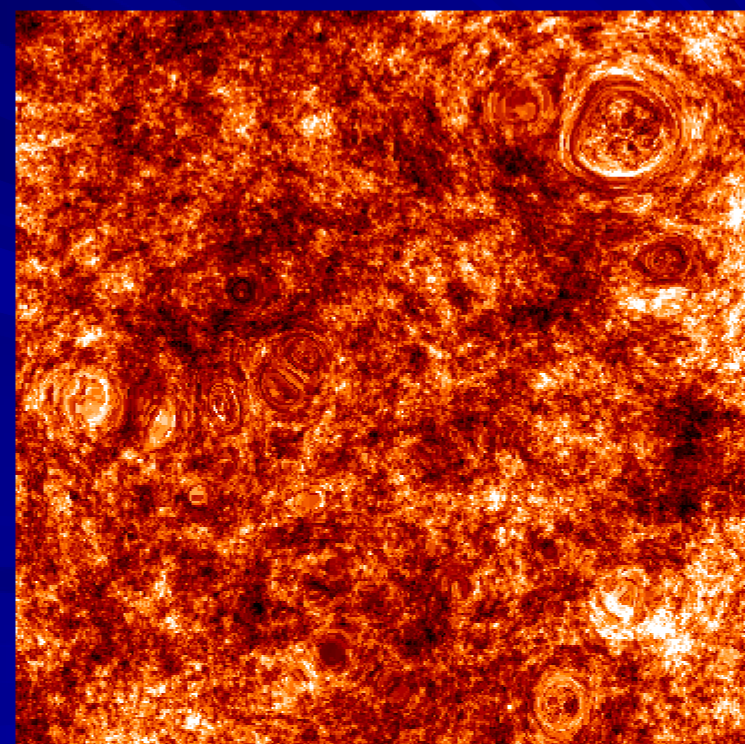
Probing large scale structure at z ~ 3

- Optical surveys are naturally biased toward lower redshifts, and obtaining spectroscopy for a large z=3 sample probably requires next generation telescope
- Submillimeter surveys naturally select high redshift sources
- Even if optical surveys outpace the submm, still interesting to get the bias of the submm population.
- How to get a large (dense?) redshift survey at z=3? Obvious approach is to do a CCAT continuum survey, and then follow up galaxies with ALMA and CCATspec. What about doing the survey simultaneously? Can you also make use of data *below* the individual object detection threshold?

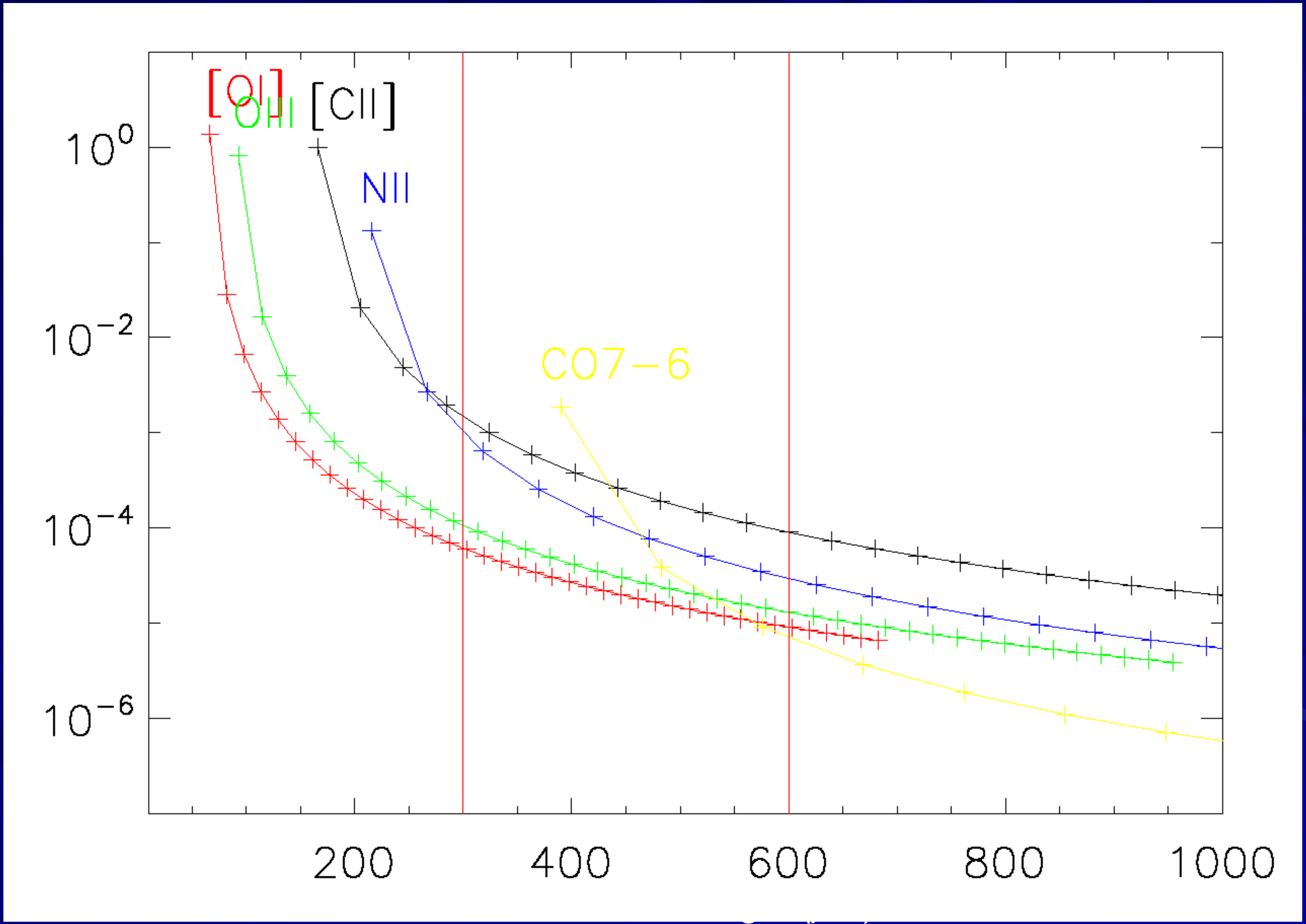
Possible approach: correlation with weak lensing maps created from CMB lensing

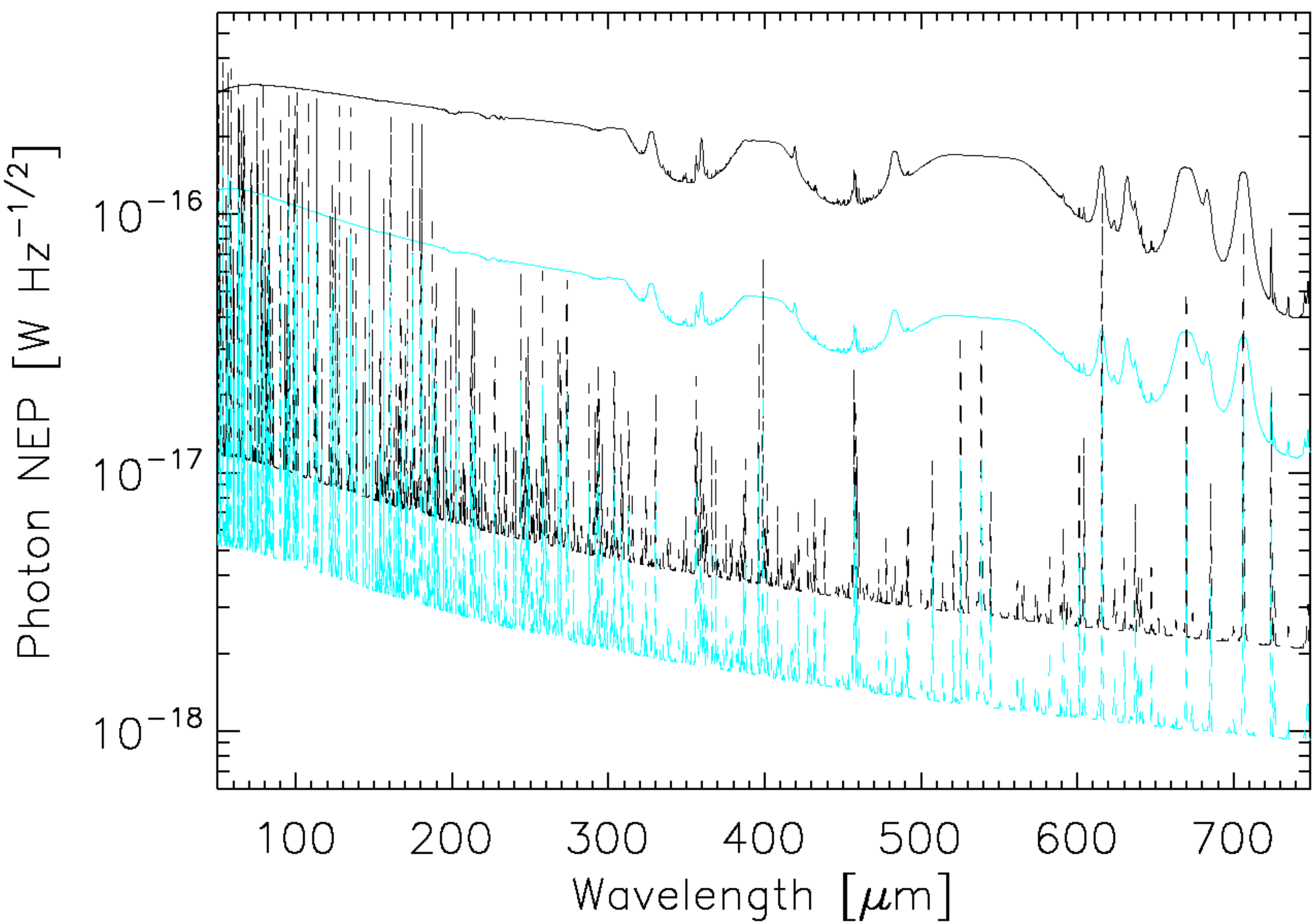
- The bulk of the lensing kernel for the CMB is at $z > 3$
- Cross correlating $z=3$ galaxies and CMB lensing can give bias at that redshift – important for understanding the relation of galaxy formation to structure formation. It can also give $P(k,z=3)$



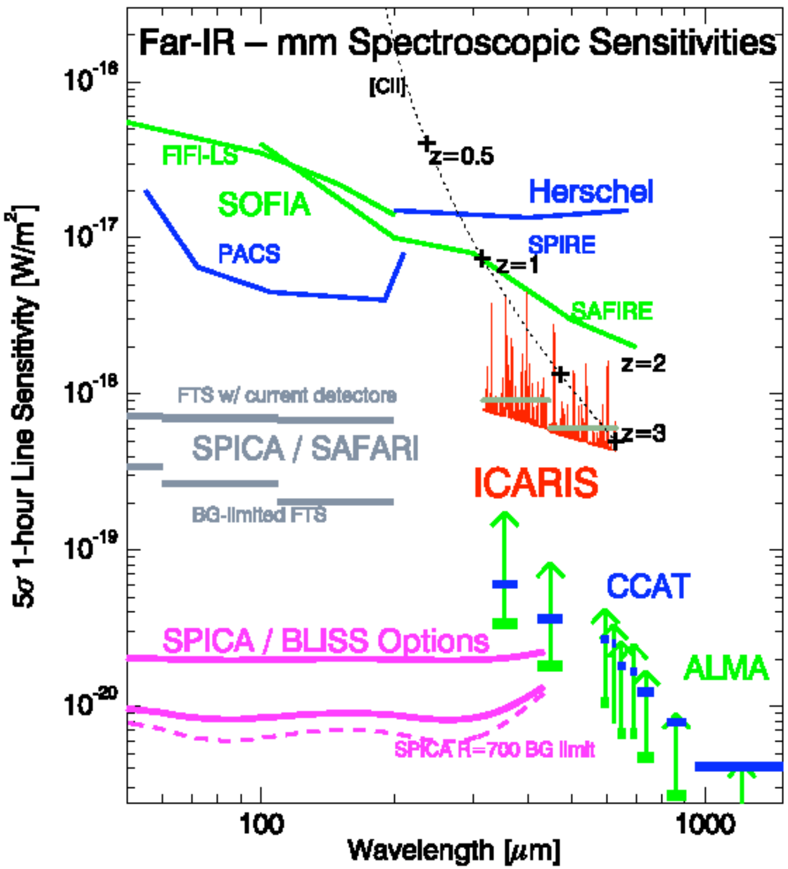


[CII] dominates the far-IR lines

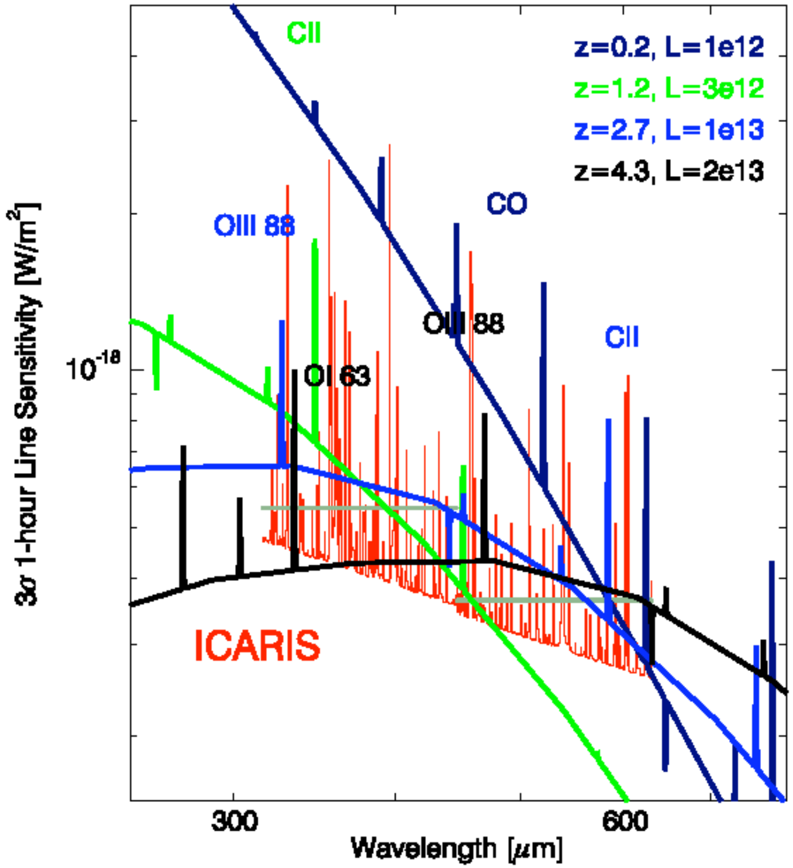




Photon NEP [W Hz$^{-1/2}$]
10^{-16}
10^{-17}
10^{-18}
100
200
300
400
500
600
700
Wavelength [μm]



Far-IR – mm Spectroscopic Sensitivities
[CII]
z=0.5
z=1
z=2
z=3
FIFI-LS
SOFIA
Herschel
PACS
SPIRE
SAFIRE
FTS w/ current detectors
SPICA / SAFARI
BG-limited FTS
ICARIS
CCAT
SPICA / BLISS Options
ALMA
SPICA R=700 BG limit
5σ 1-hour Line Sensitivity [W/m²]
Wavelength [μm]

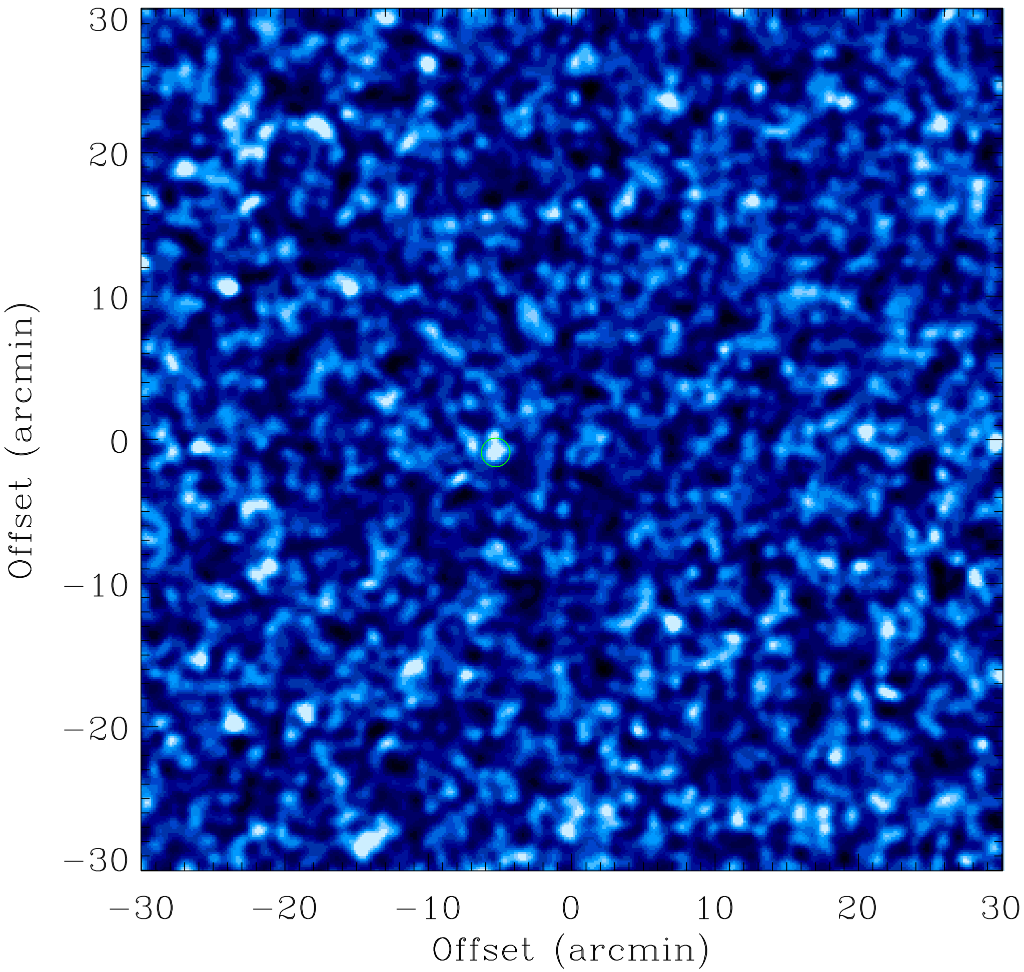


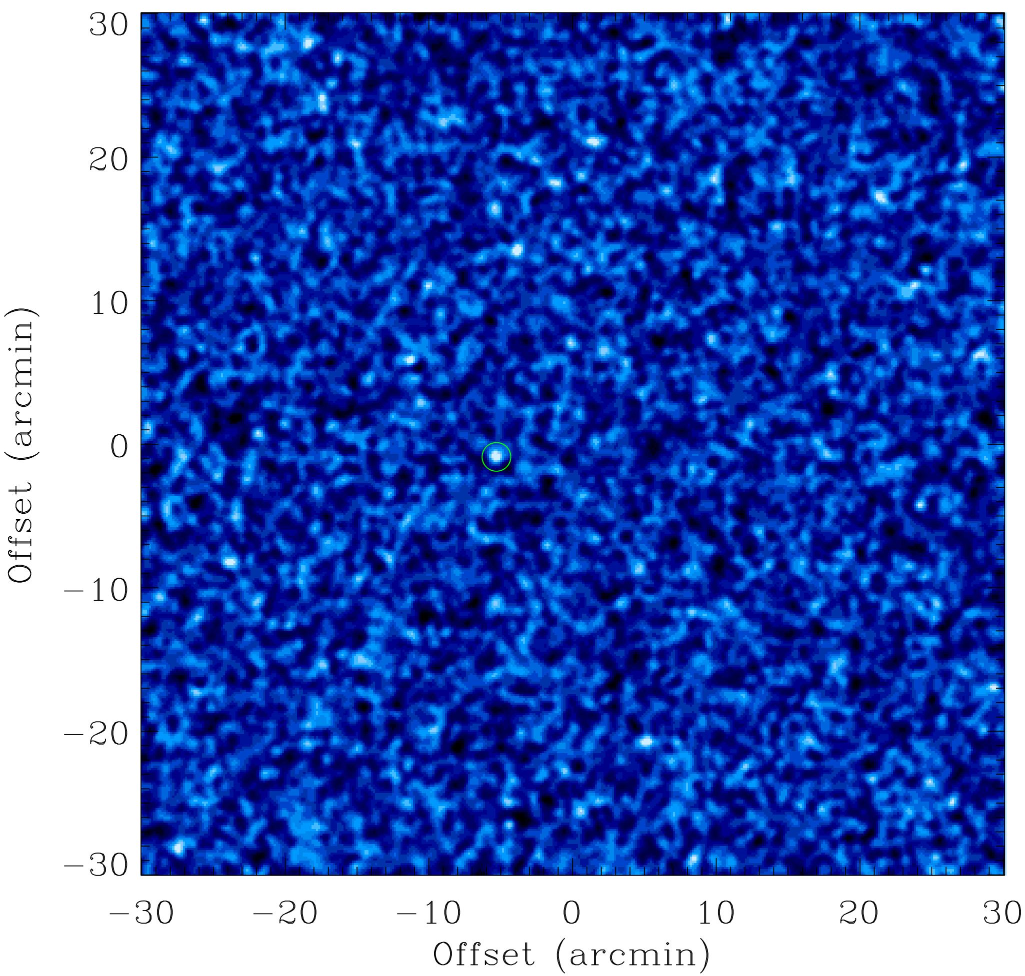
CII
z=0.2, L=1e12
z=1.2, L=3e12
z=2.7, L=1e13
z=4.3, L=2e13
CO
OIII 88
OIII 88
OI 63
CII
ICARIS
3σ 1-hour Line Sensitivity [W/m²]
Wavelength [μm]

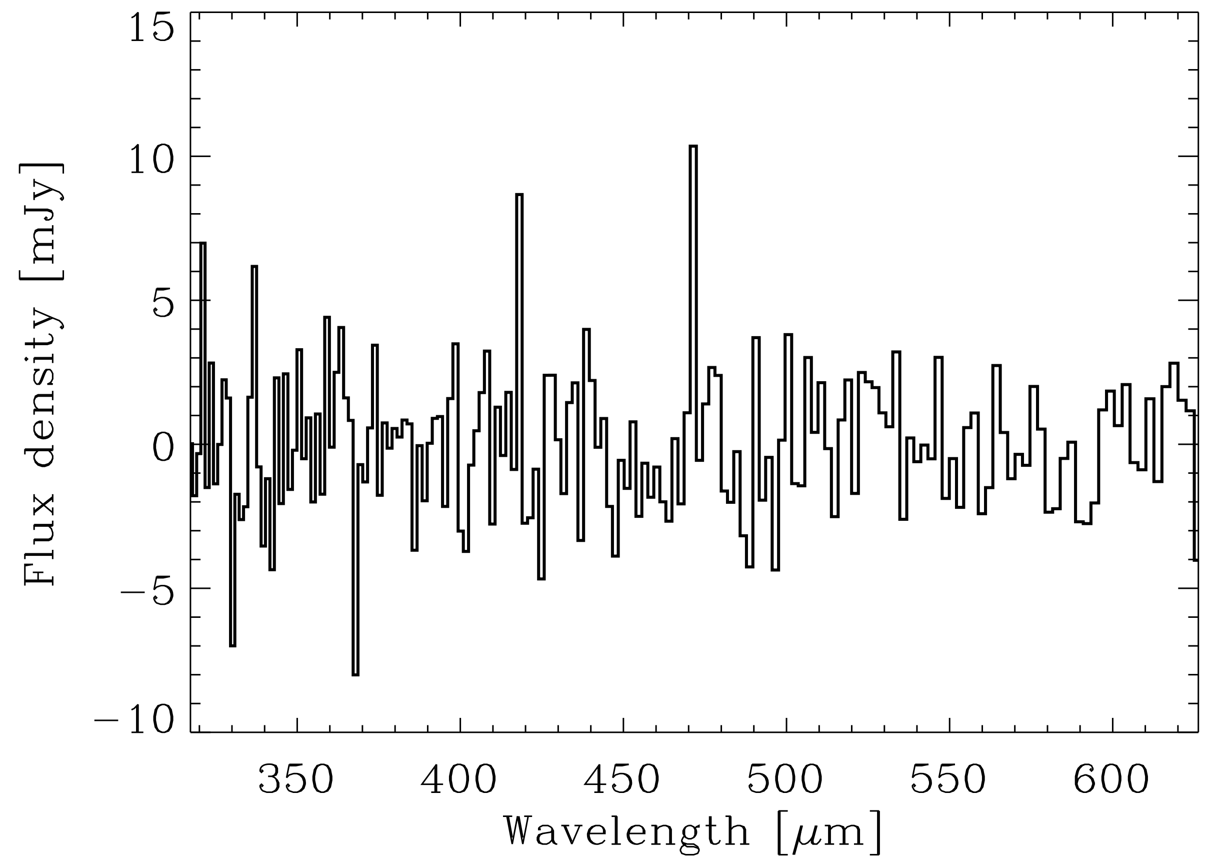
A possible instrument for cosmological redshift surveys

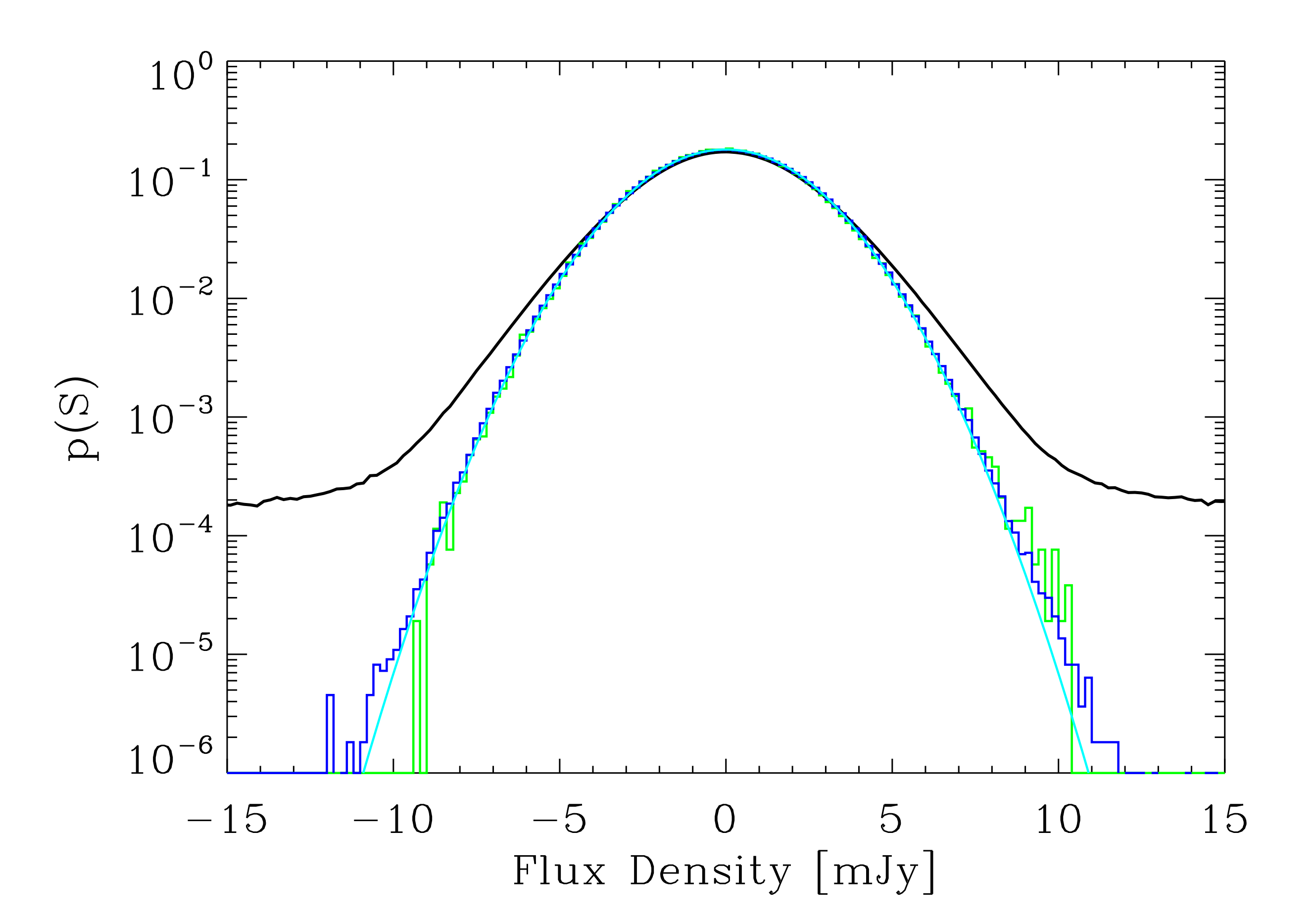
- Long slit spectrometer
- Moderate resolution (R ~ 300)
- Scan a few square degrees
- Build up a data cube. Summing over channels, the map will be confused in the continuum
- Subtract smooth functions at each pixel (along the wavelength direction)

Simulation of ~40,000 sources with $L > 5 \times 10^{11} L_{solar}$




30
20
10
0
−10
−20
−30
Offset (arcmin)
−30
−20
−10
0
10
20
30
Offset (arcmin)


15
10
5
0
−5
−10
Flux density [mJy]
350
400
450
500
550
600
Wavelength [μm]



10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
p(S)
−15
−10
−5
0
5
10
15
Flux Density [mJy]

Conclusions

- Z-Spec is working well as a redshift machine and enabling a lot of science
- More observing planned through period of ALMA early science
- The success of Z-Spec (and ZEUS) indicates that broadband, diffraction grating, direct detection spectrometers on single dishes have a future
- A long slit “data cube” survey might be interesting for cosmology