Submm / mm Survey Spectroscopy

Intro & source densities for spectroscopy

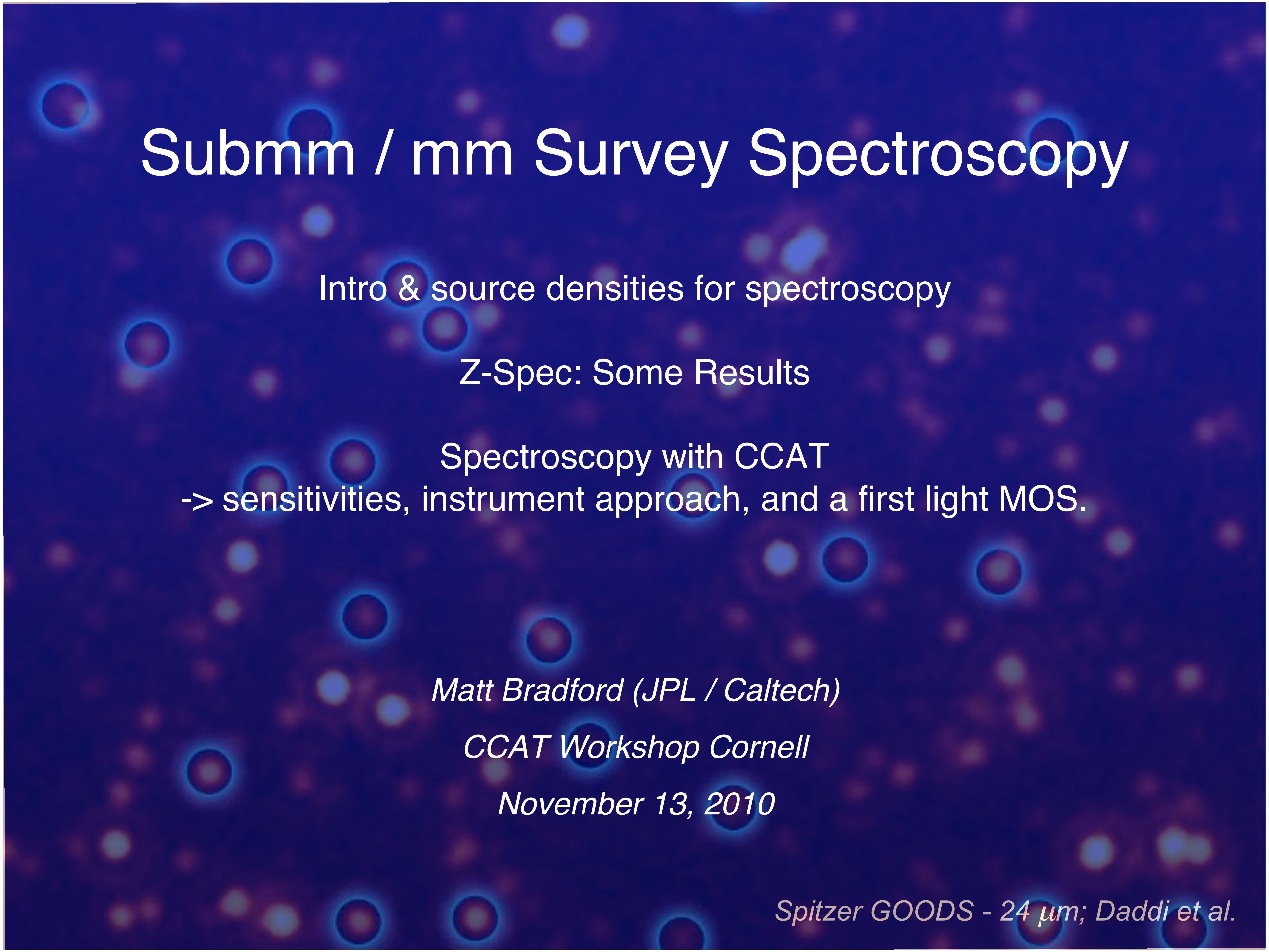
Z-Spec: Some Results

Spectroscopy with CCAT
-> sensitivities, instrument approach, and a first light MOS.

Matt Bradford (JPL / Caltech)

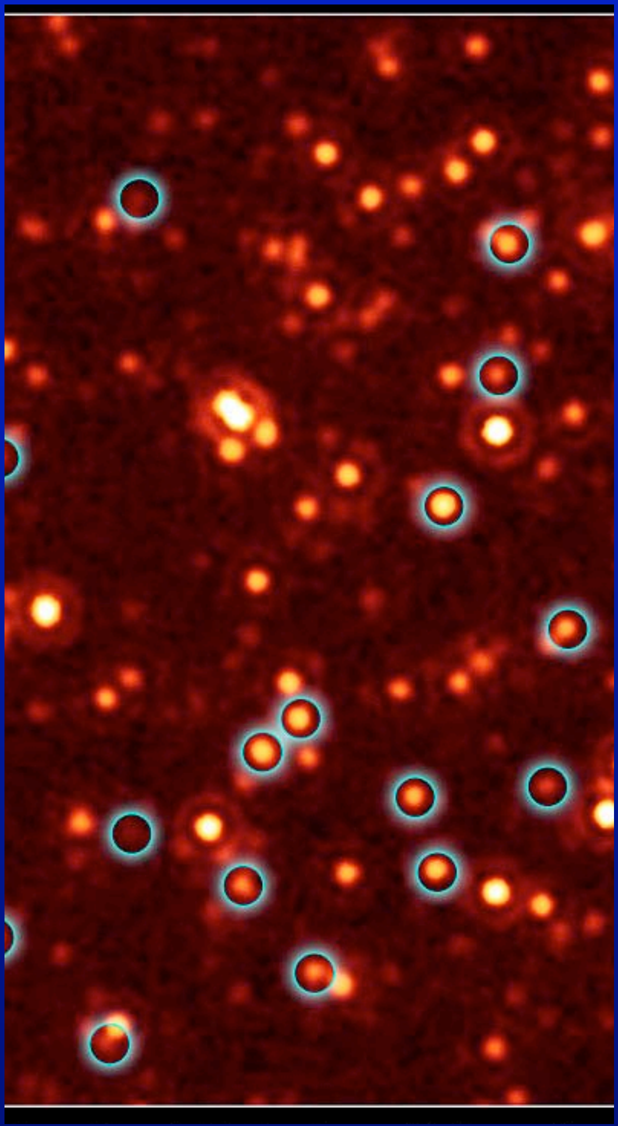
CCAT Workshop Cornell

November 13, 2010

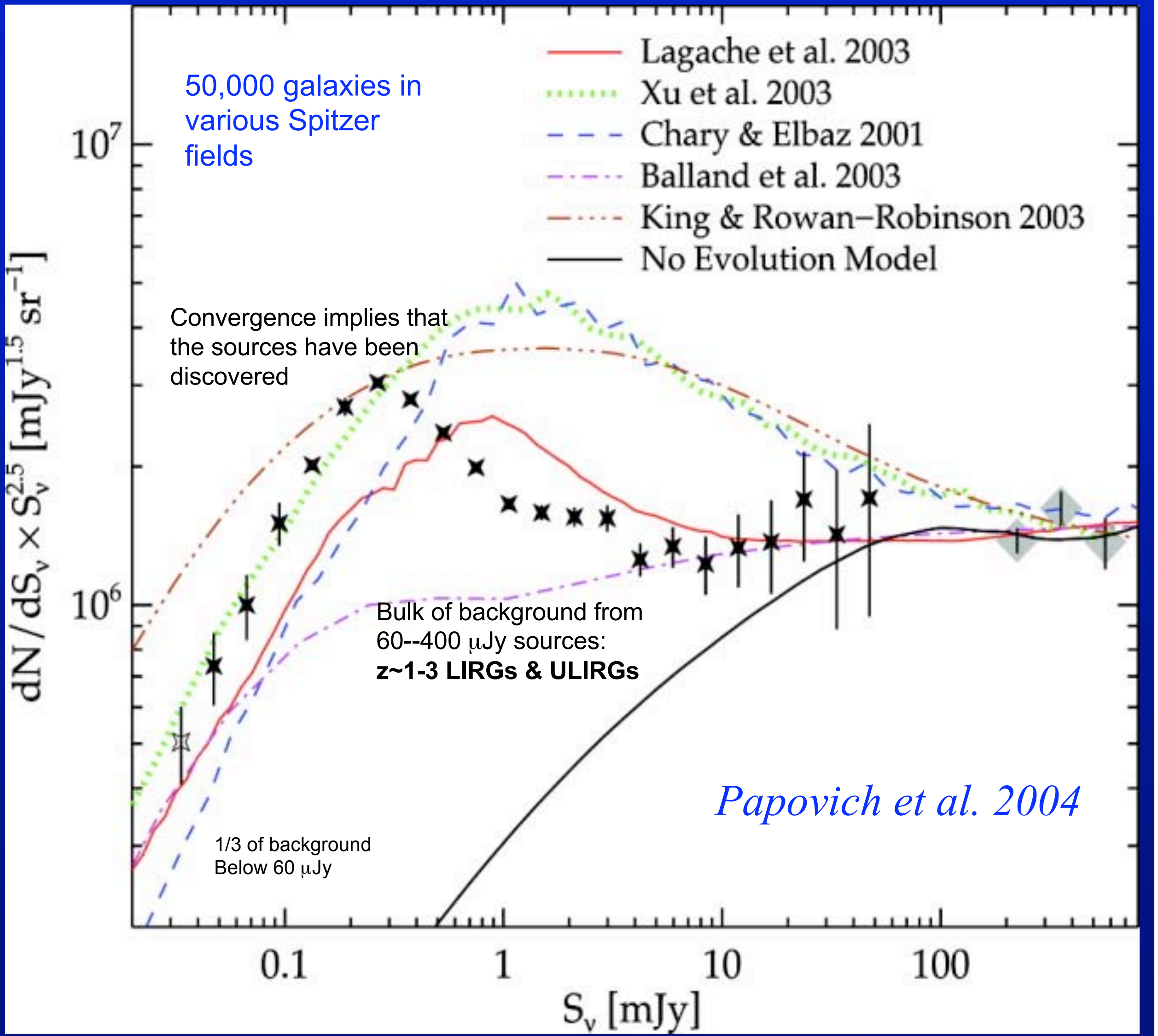


Spitzer GOODS - 24 μm; Daddi et al.

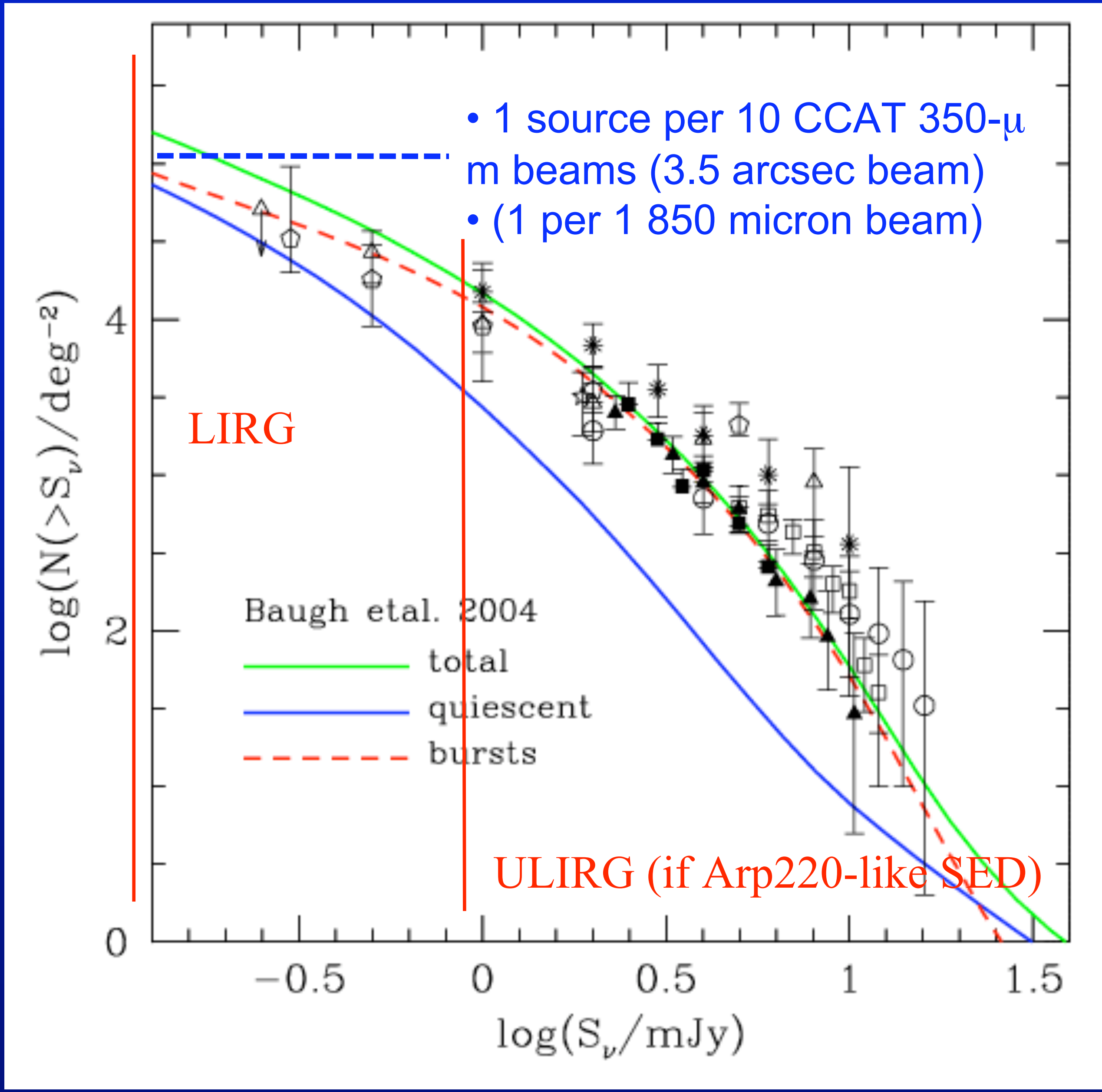
Detecting all the light at 24 microns with Spitzer MIPS



GOODS Daddi et al



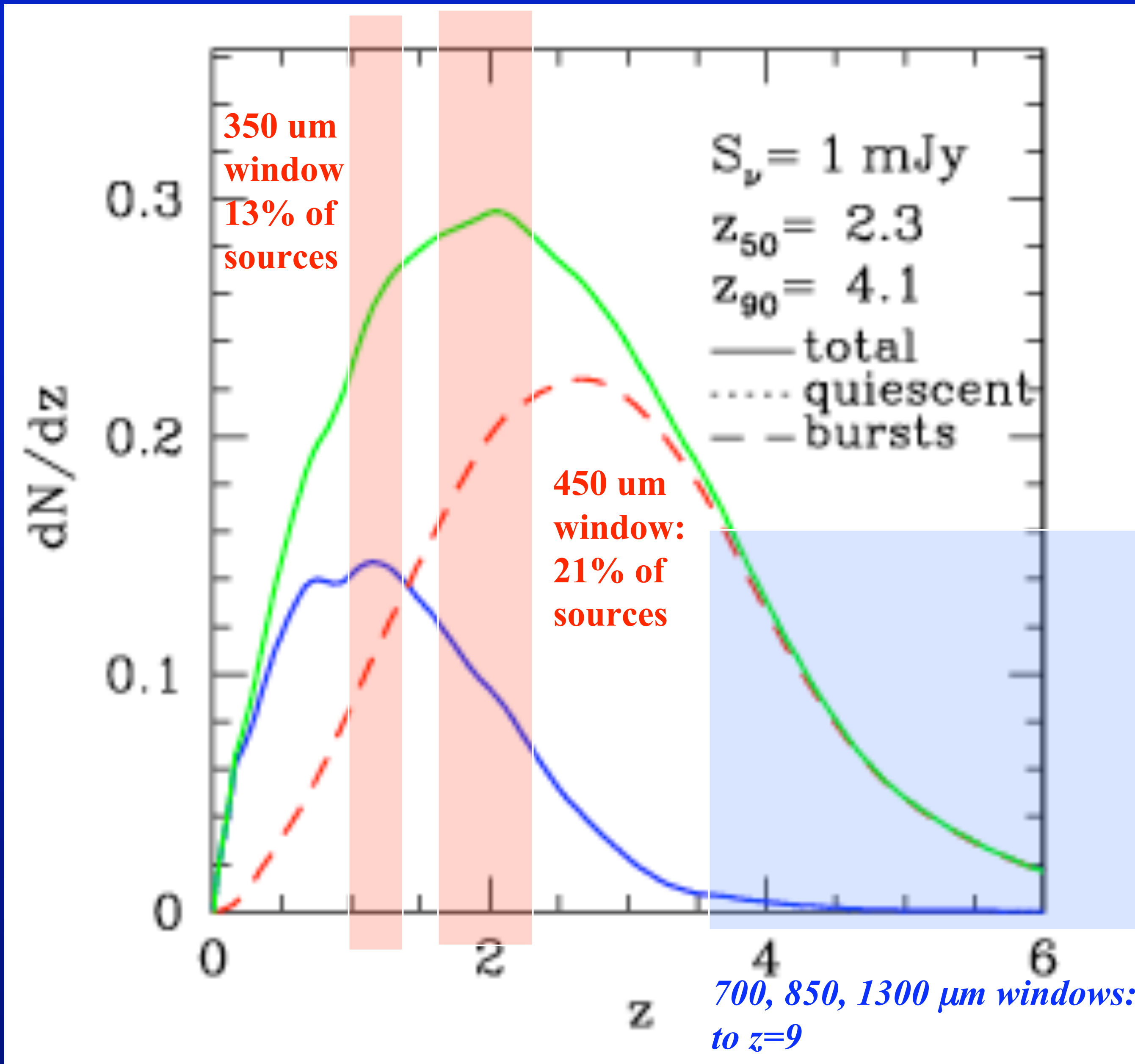
850 micron N(S) is to first order a luminosity function



Models from A. Benson et al. (Galform group)

modified IMF and star formation timescale included to reproduce 850 micron counts

Models provide approach to CCAT population z distribution: Apply to C+

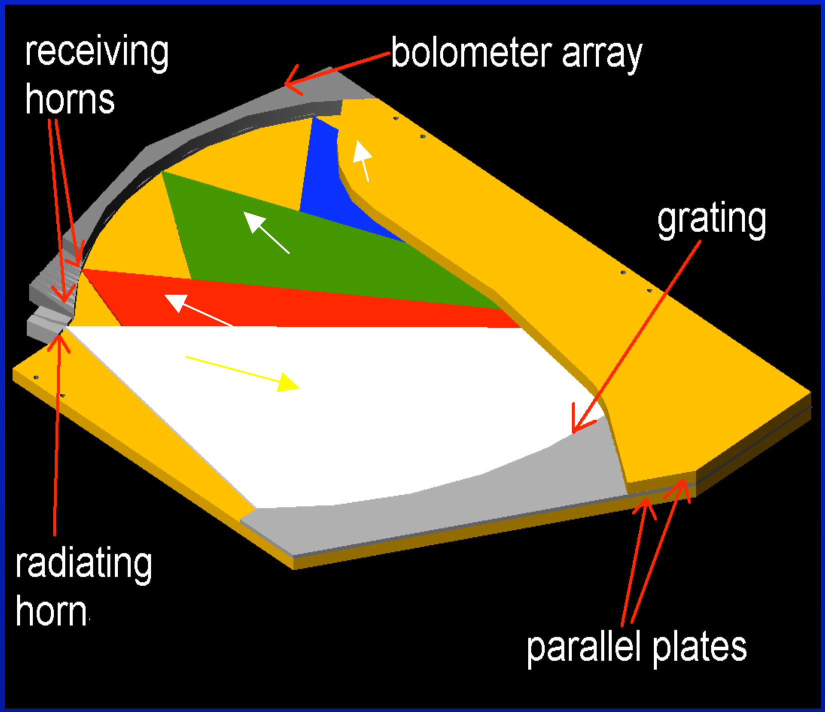


350 & 450 microns window are likely to access 31% of the 850 micron population in C+

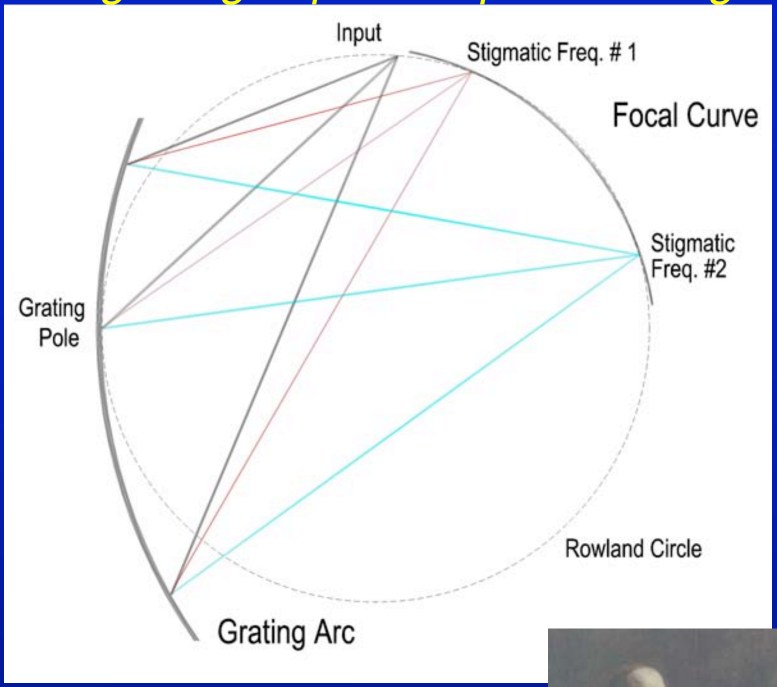
High-z sources can be probed in the long submm and mm windows.

Redshift Distribution from GALFORM model -- similar to Chapman

Ultra-compact approach: WaFIRS spectrometer



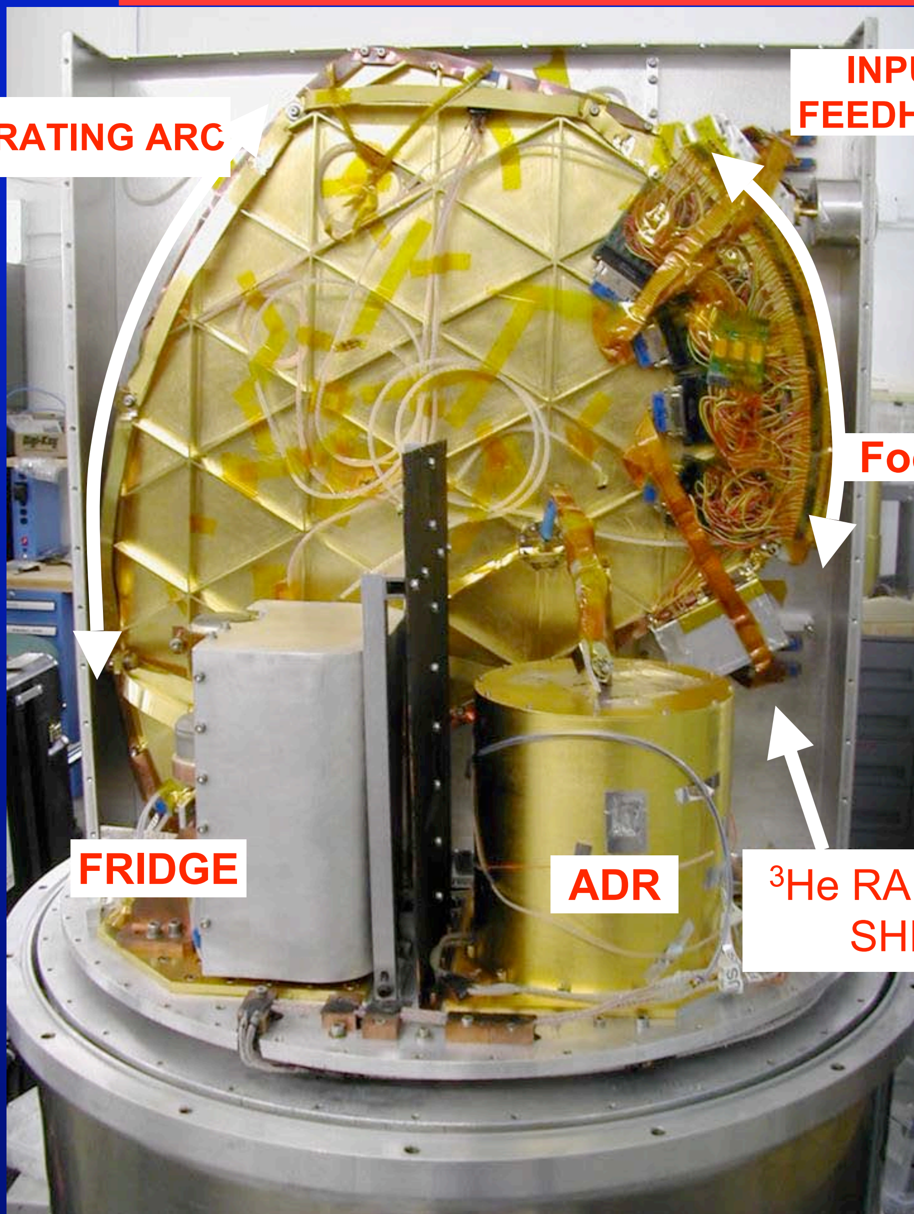
curved grating in parallel plate waveguide

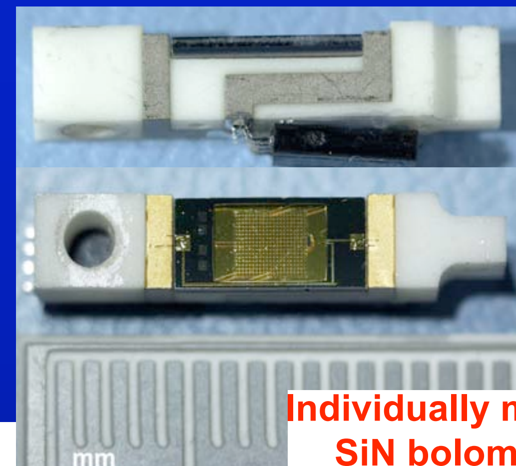


- Propagation confined in parallel-plate waveguide
  - 2-D Geometry
  - Stray light eliminated
- Curved grating diffracts and focuses
  - Efficient use of space
  - No additional optical elements
- Custom "stigmatic" grating design possible at long wavelengths

H.A. Rowland, 1883, Phil. Mag 16
K.A. McGreer, 1996, IEEE Phot. Tech. 8

True broadband spectroscopy in the submillimeter: Z-Spec, a 1st order grating covering 190-305 GHz.





Z-Spec Team

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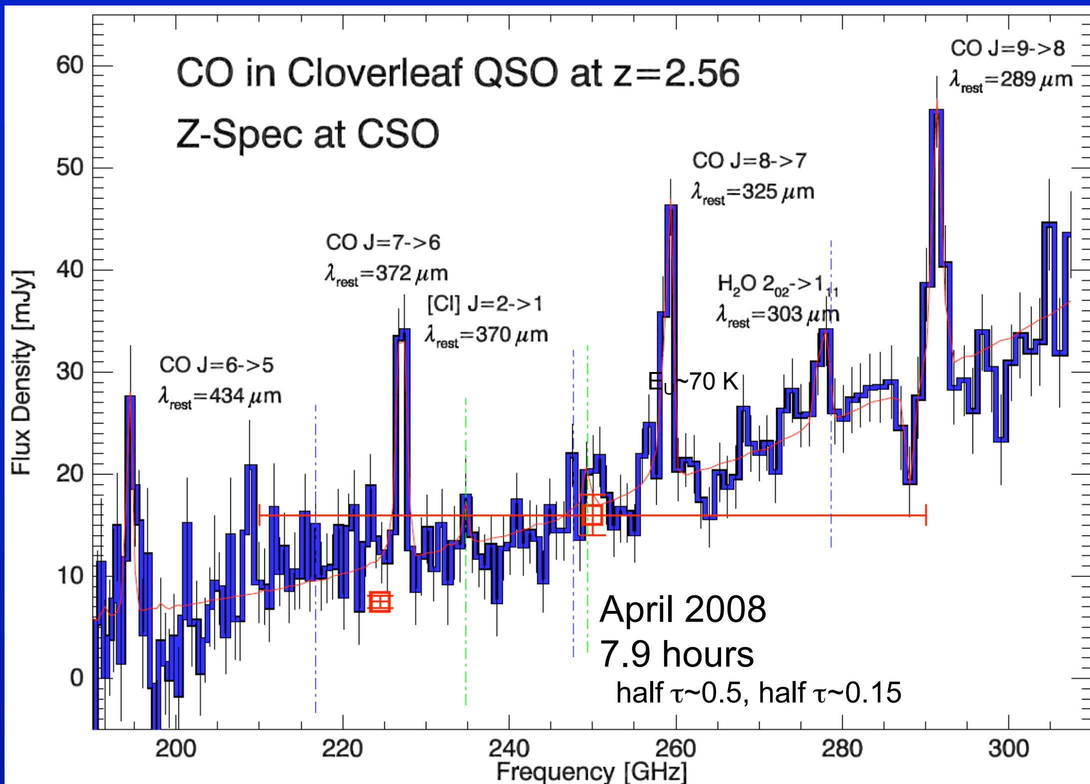
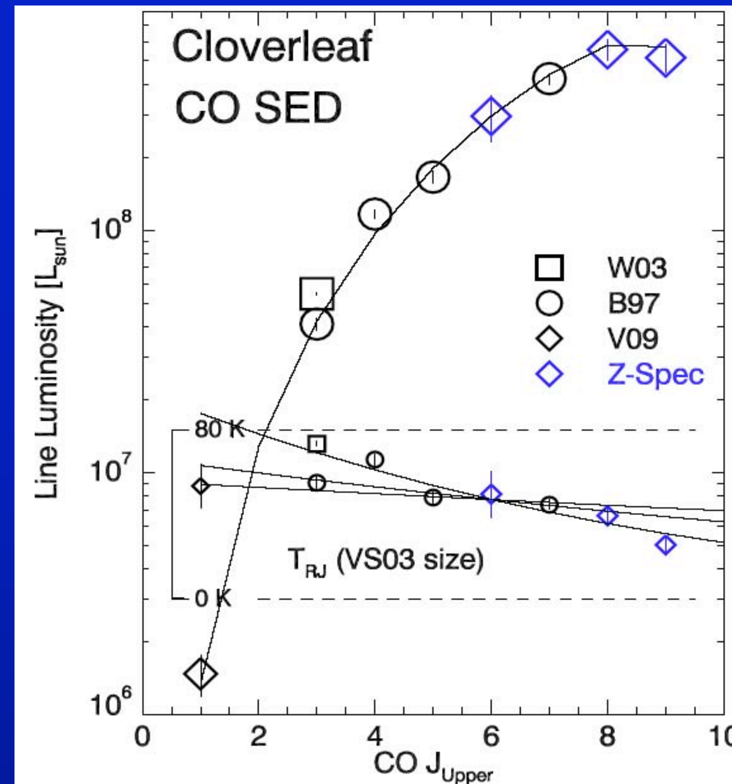
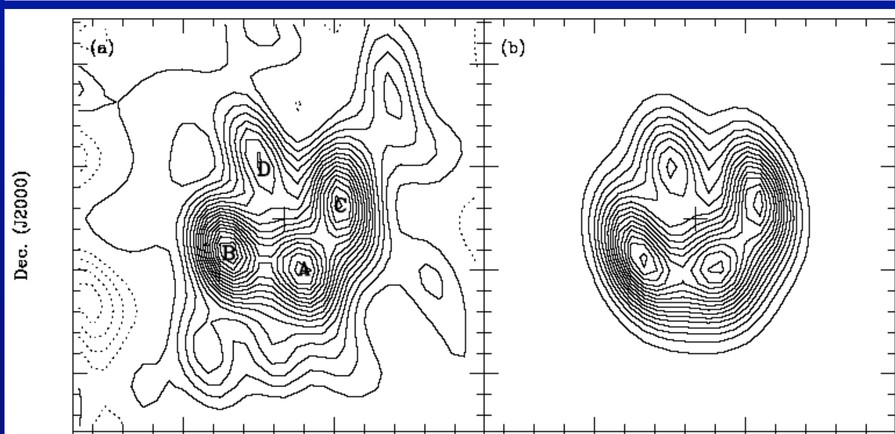
Glenn, L. Earle, P. Maloney *(CASA, University of Colorado)*
Aguirre, Scott, Lupu *(U.. Penn)*
Matsuhara (*ISAS / JAXA*)





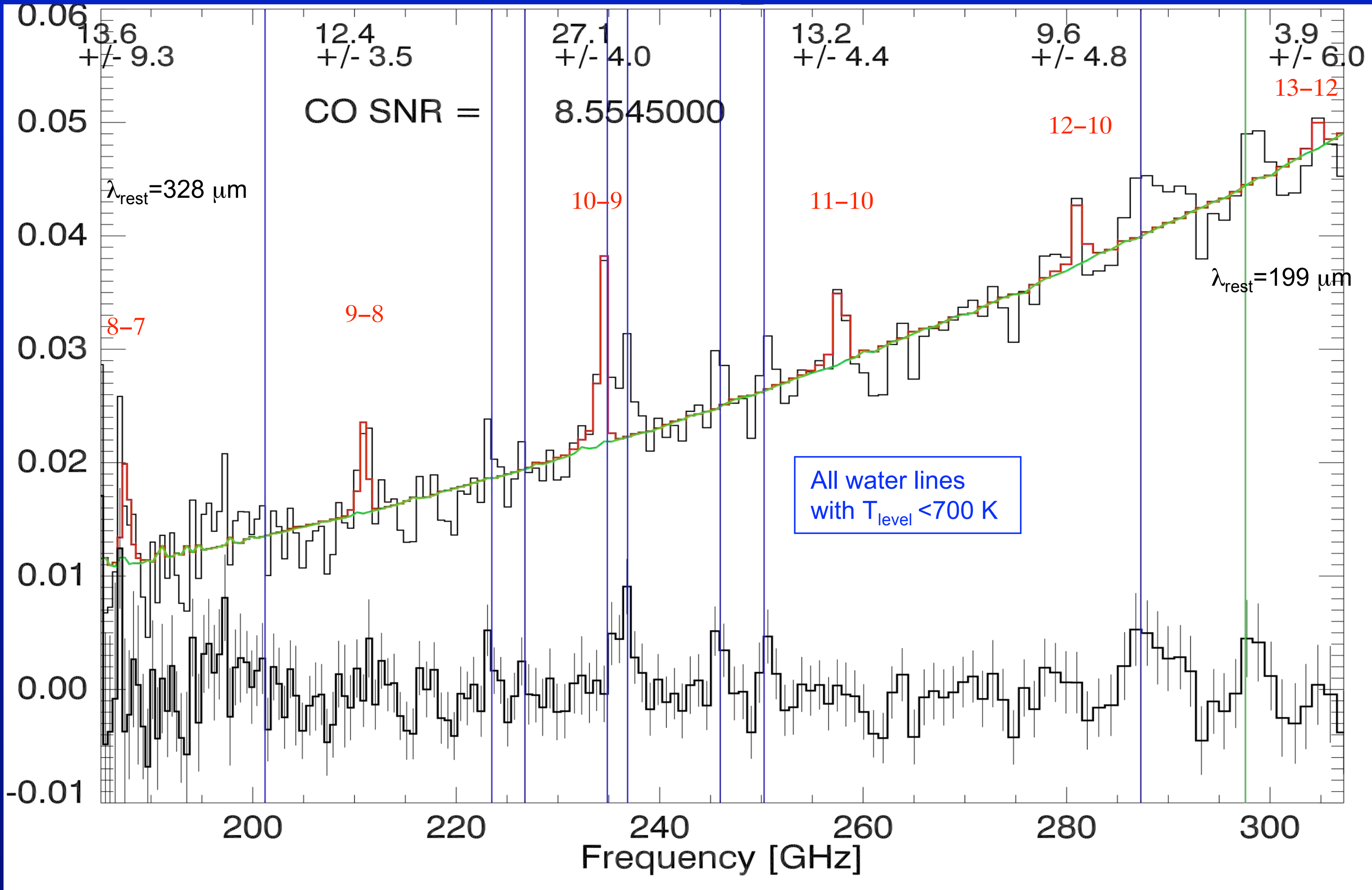


Venturini and Solomon, 2003, using PdB data
Intrinsic source is 650 by 560 pc disk, m=11

- Source size breaks T / n degeneracy, requires T>50 K
- CO cooling / far-IR exceeds local starbursts & ULIRGS by 2-5.
- X-rays may be heating the gas.
- Plenty of energy, easy to get high gas line / dust luminosity with X-rays (e.g. Maloney et al.)
- Bulk heating like X-rays (or cosmic rays) increases minimum temp to which gas cools, thus increases the stellar IMF.

APM 08279+5255, z=3.91

~16 hours, 0.7-1 Jy sqrt(sec)



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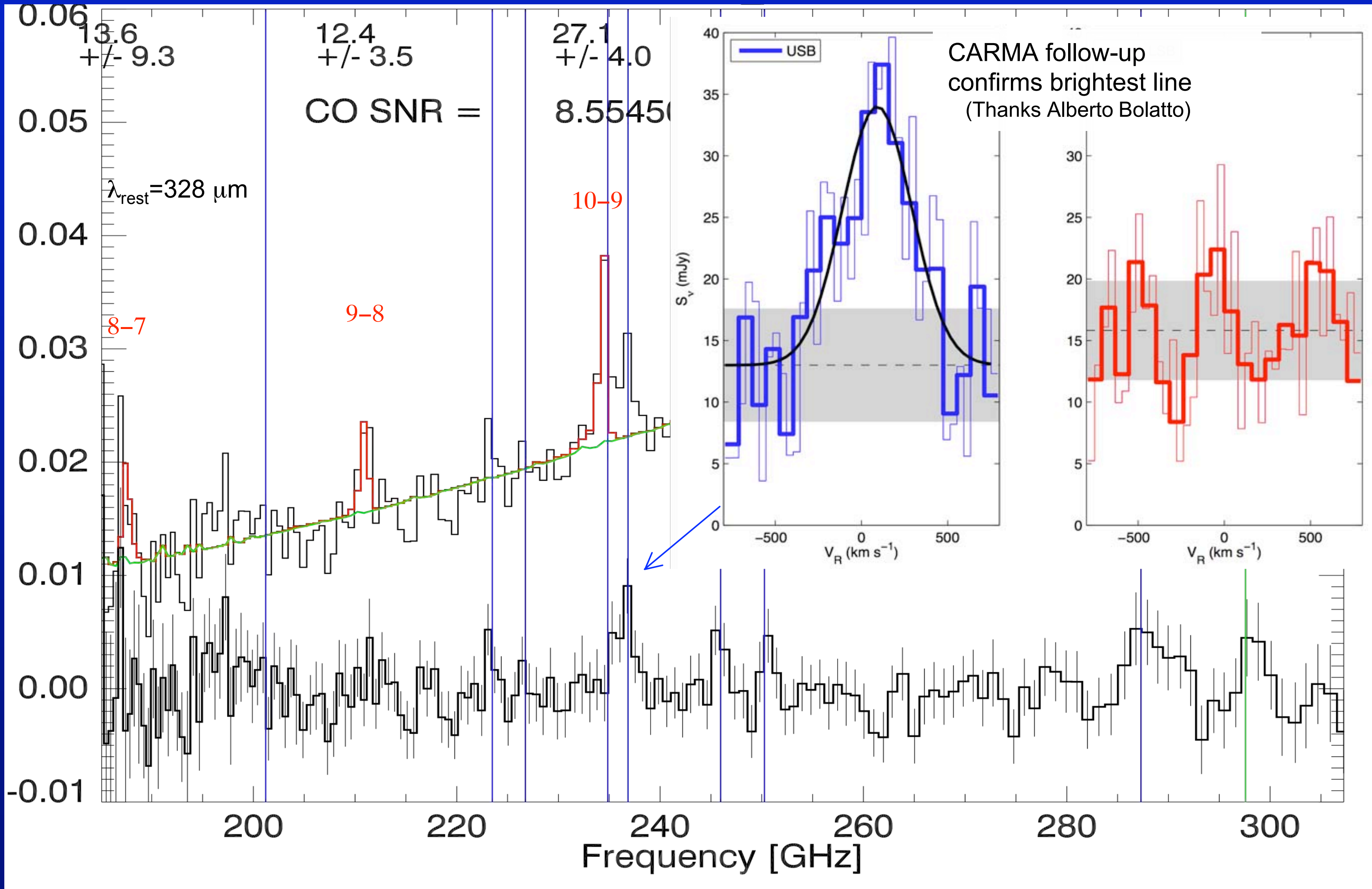
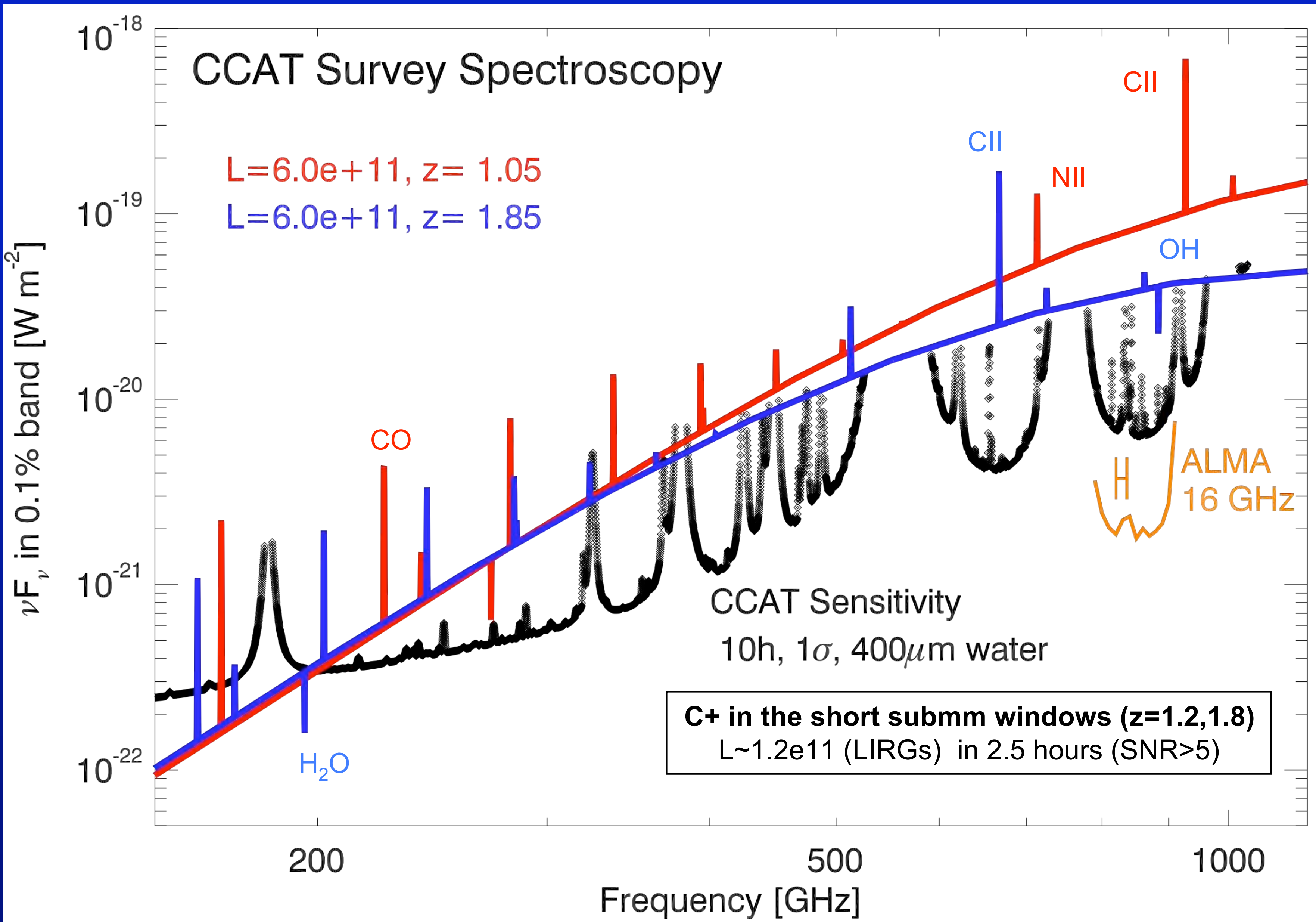
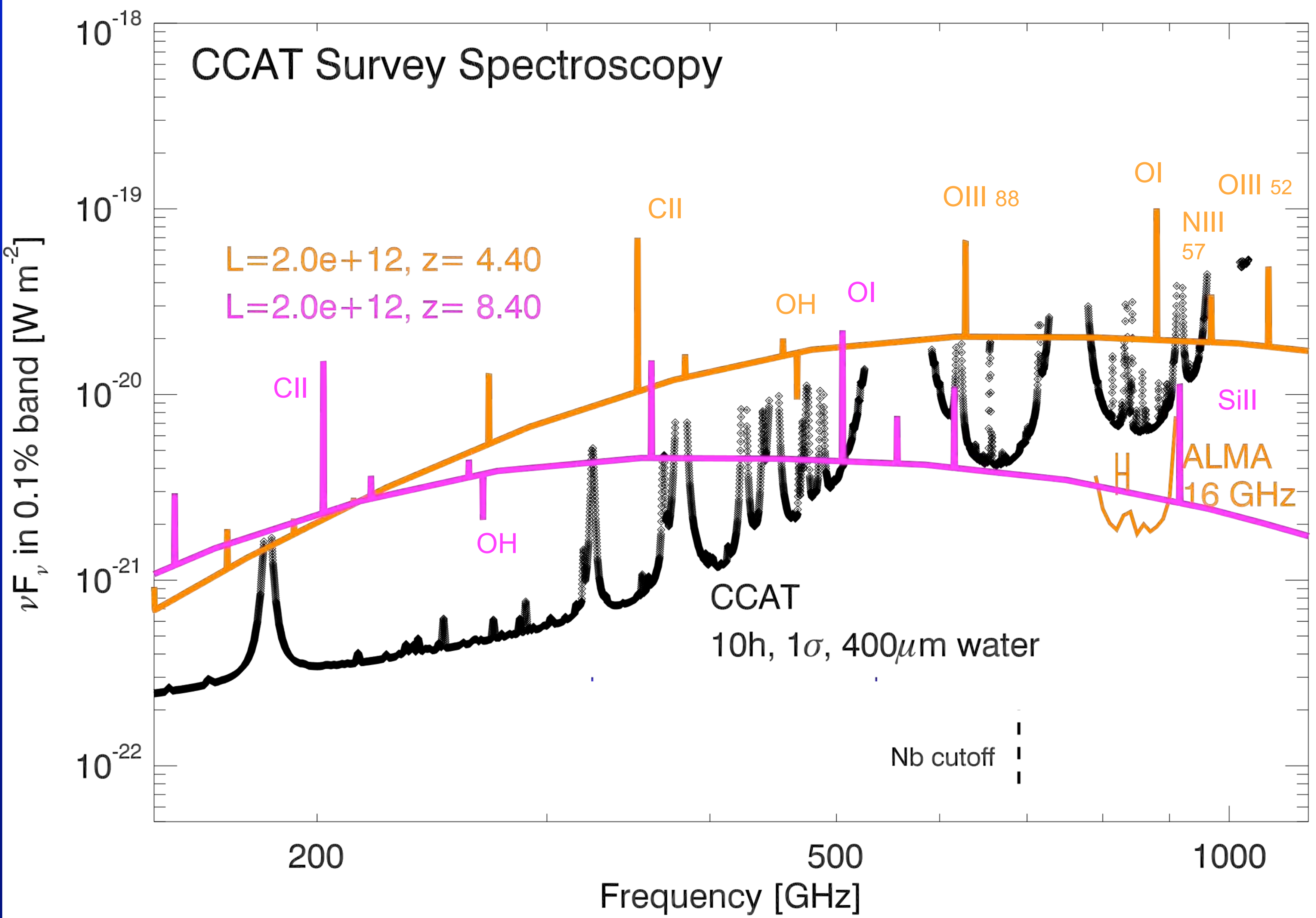




CCAT Survey Spectroscopy
L=6.0e+11, z= 1.05
L=6.0e+11, z= 1.85
CII
CII
NII
OH
CO
H2O
ALMA
16 GHz
CCAT Sensitivity
10h, 1σ, 400μm water
C+ in the short submm windows (z=1.2,1.8)
L~1.2e11 (LIRGs) in 2.5 hours (SNR>5)
νFν in 0.1% band [W m-2]
10-18
10-19
10-20
10-21
10-22
200
500
1000
Frequency [GHz]



CCAT Survey Spectroscopy
L=2.0e+12, z= 4.40
L=2.0e+12, z= 8.40
CII
OH
OI
OIII 88
OI
OIII 52
NIII
57
CII
OH
OI
SiII
ALMA
16 GHz
CCAT
10h, 1σ, 400μm water
Nb cutoff
10-18
10-19
10-20
10-21
10-22
νFν in 0.1% band [W m-2]
200
500
1000
Frequency [GHz]

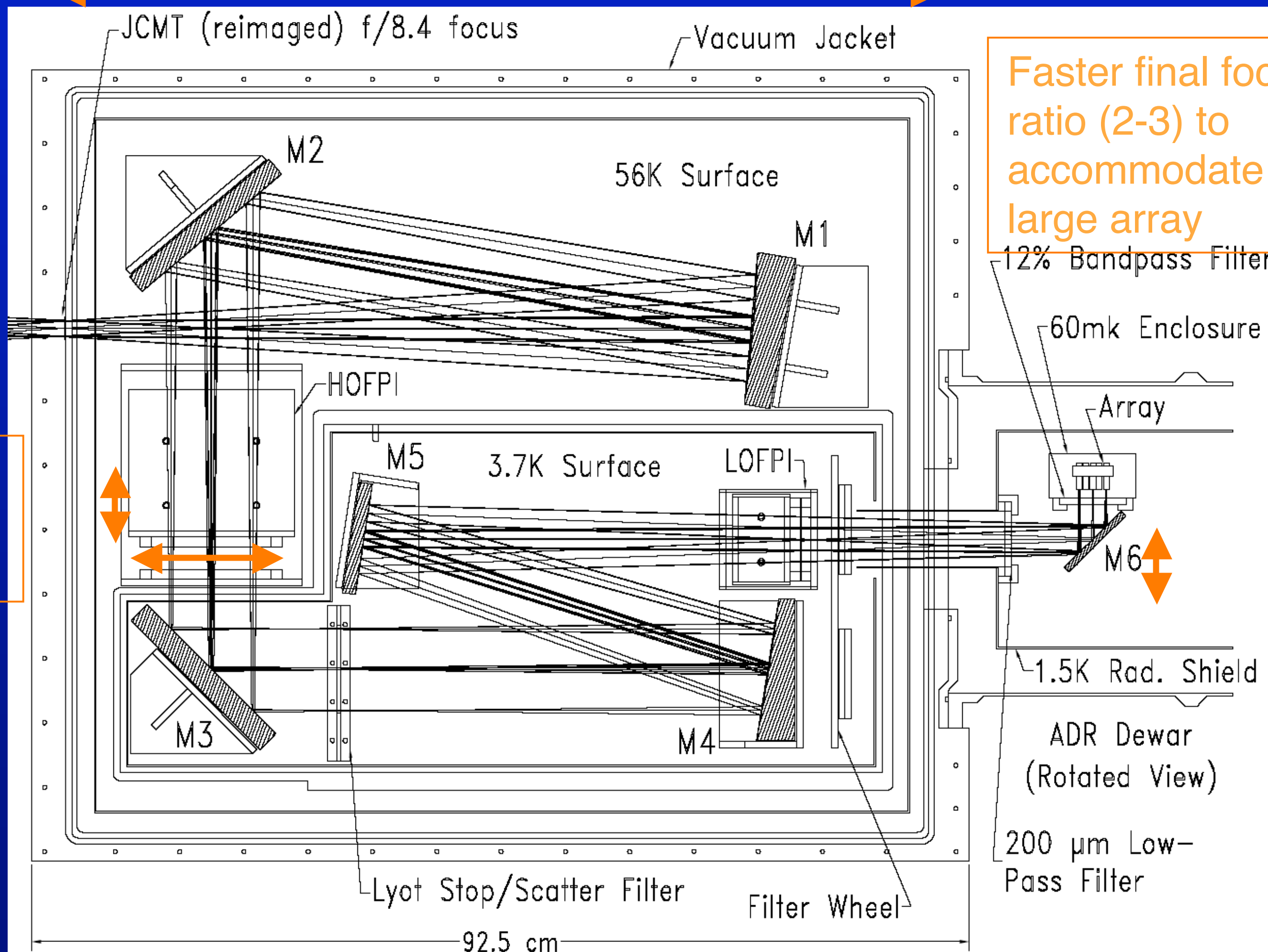
CCAT IFPI will be much larger than SPIFI due to the huge throughput

8 x 20 cm = 160 cm collimator focus

Full field at f/8: 20 cm window!

Etalon spacing is modest: few cm even for 650 μm

Collimated beam + overheads: 25 cm dia (and etalon must be near pupil)

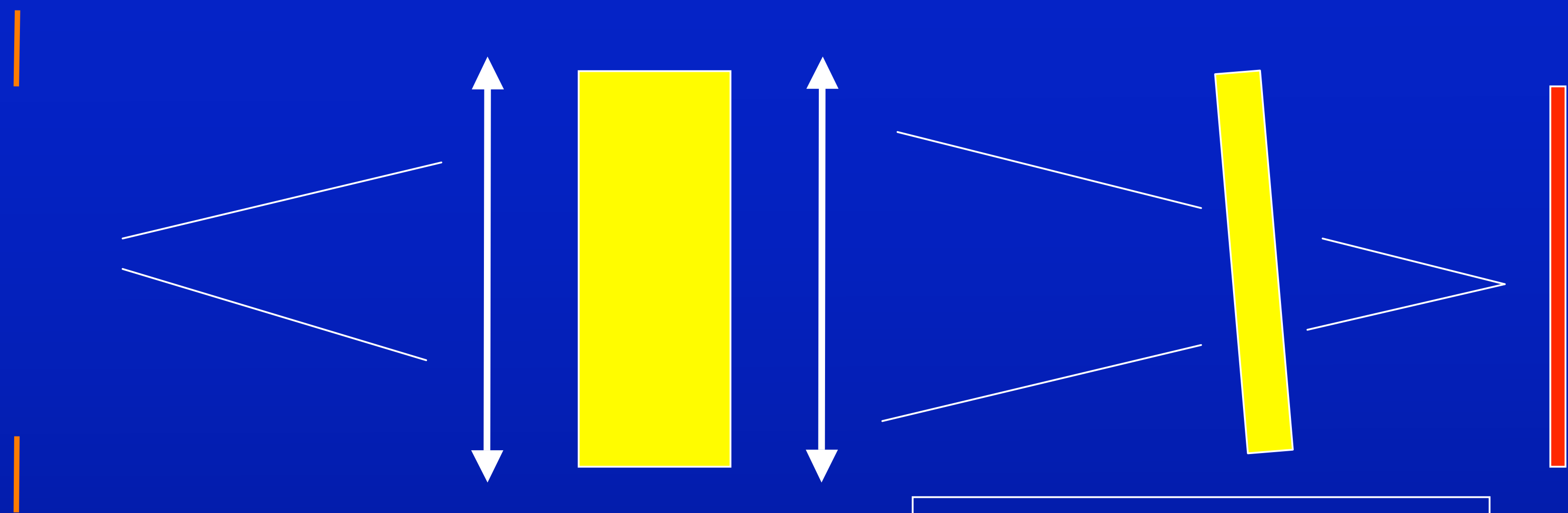


Faster final focal ratio (2-3) to accommodate large array

Array is as large as 10 cm

Factor of two in all dimensions of the optical train

Refractive Fabry Perot: e.g. 850 microns 10,000 spatial beams



Order sorting etalon or filter, also scanning, also ~40 cm

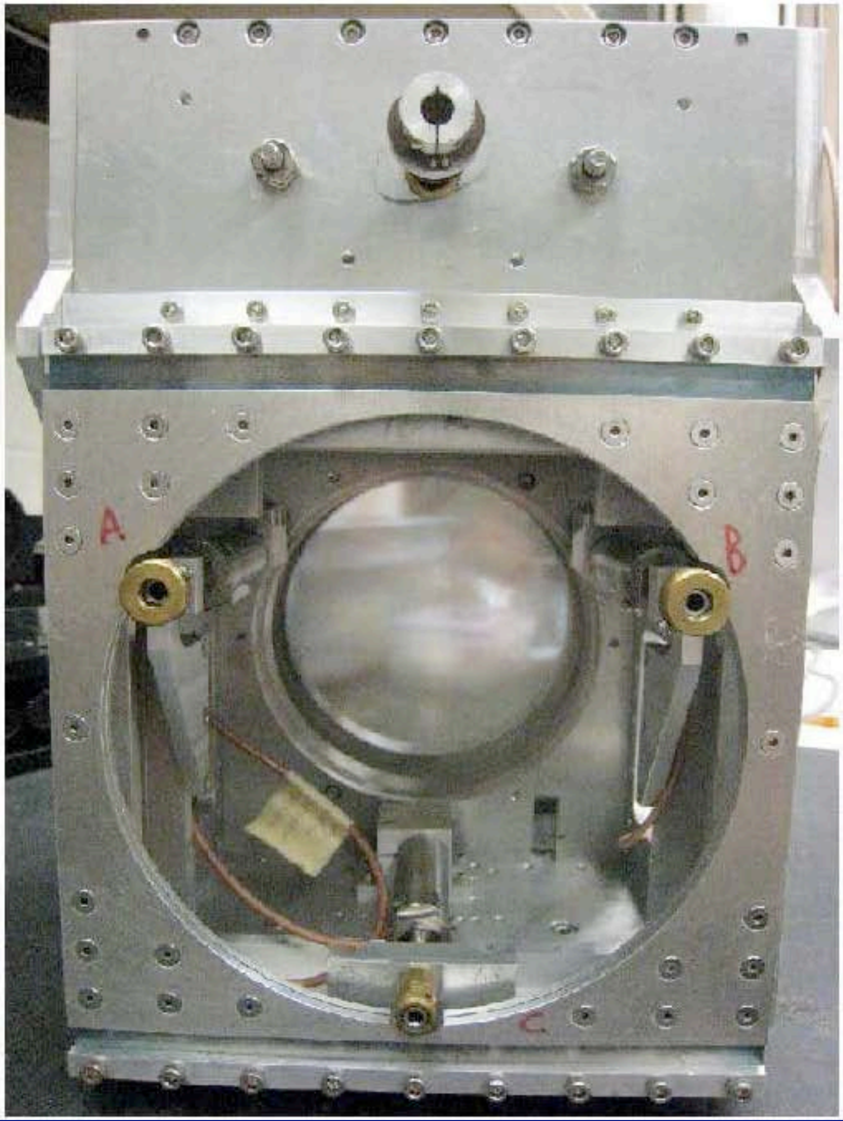
12 arcmin field requires ~42 cm entrance window.

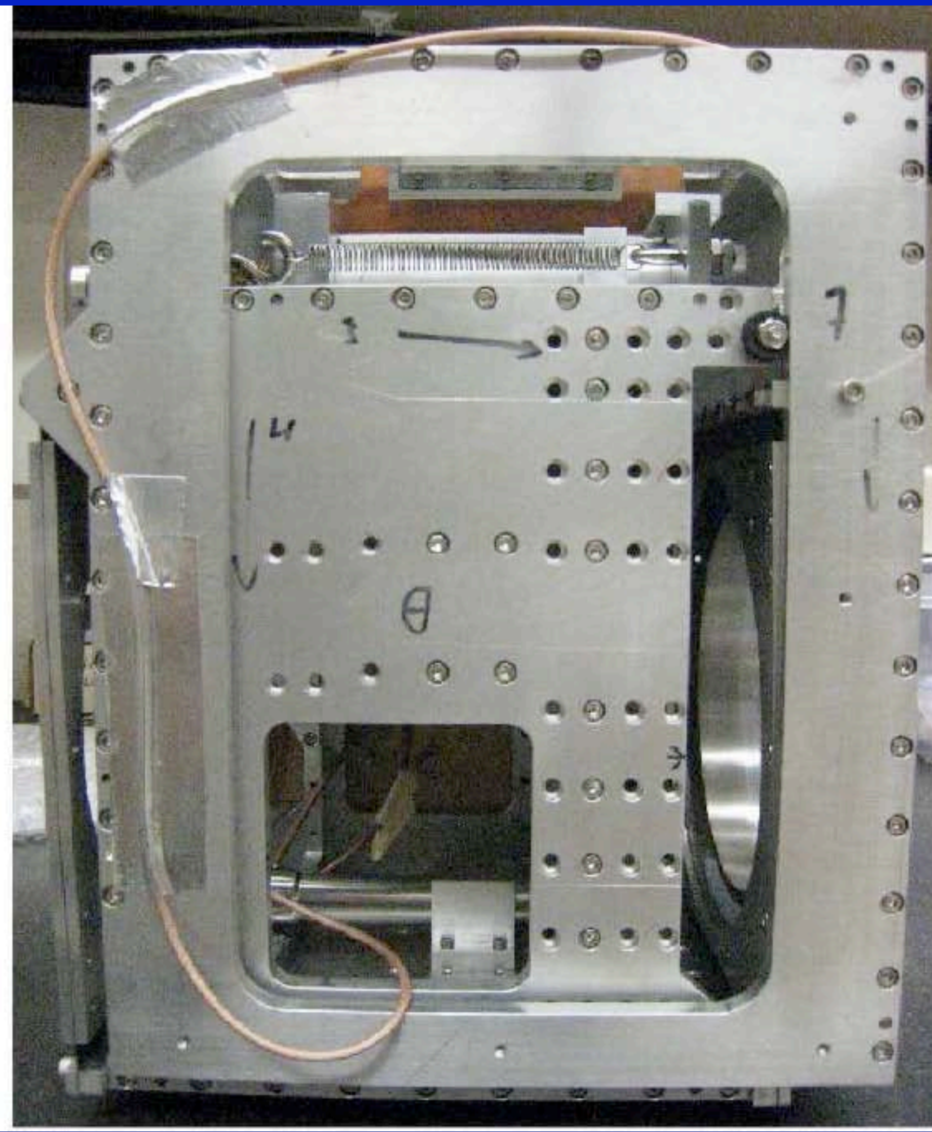
Collimating and decollimating lenses: e.g. high purity silicon with AR grooves or coat.

Detector array, 100 x 100 w/ ~1-2e-18 NEP
Will be spectral shift across array

Main scanning etalon 38 cm diameter, metal mesh
e.g. F=25, m=40
Matched filter for CO?
(e.g. m=40 J=5, m=48 J=6, m=56 J=7)
Might work in the 1 mm window. Could scan a fraction of the window, e.g. z=2-2.2

Cryogenic Scanning Etalons





SPIFI HOFPI -> Oberst dissertation (Cornell)

C+ Detection Rate: Comparison Between F-P & Grating

Could a Fabry-Perot serve to select sources at specific redshift from a field ?
Yes, but in the short submillimeter, the source densities are low enough that detection rate in the field will be low. Broadband grating is faster if you can couple even a couple sources.

Fabry-Perot at 350

Source detection rate =

$dN / dz \times \Omega$

dN / dz = 36 -- 62 per square deg, per res el.

Ω = 1.7e-2 sq deg (200x200 array)

Rate = 0.6-0.7

Same number of spatial modes gives a higher rate in the 850 / 1 mm bands, could be interesting for highest-z C+

Most optimistic R=1000 FP at 350 microns: 200 x 200 = 4e4 beams or 1.7e-2 sq deg

Take 10 resolution element scan: Gives 1.7e-2 x 36 x 10 = 6 LIRG+ sources

In 10 hours observation. Doesn't look good, not enough volume due to finite z

Grating

Source detection rate =

z_fraction x N_mos

z_fraction = 0.3 (including 350 & 450)

N_mos = ? (10-100)

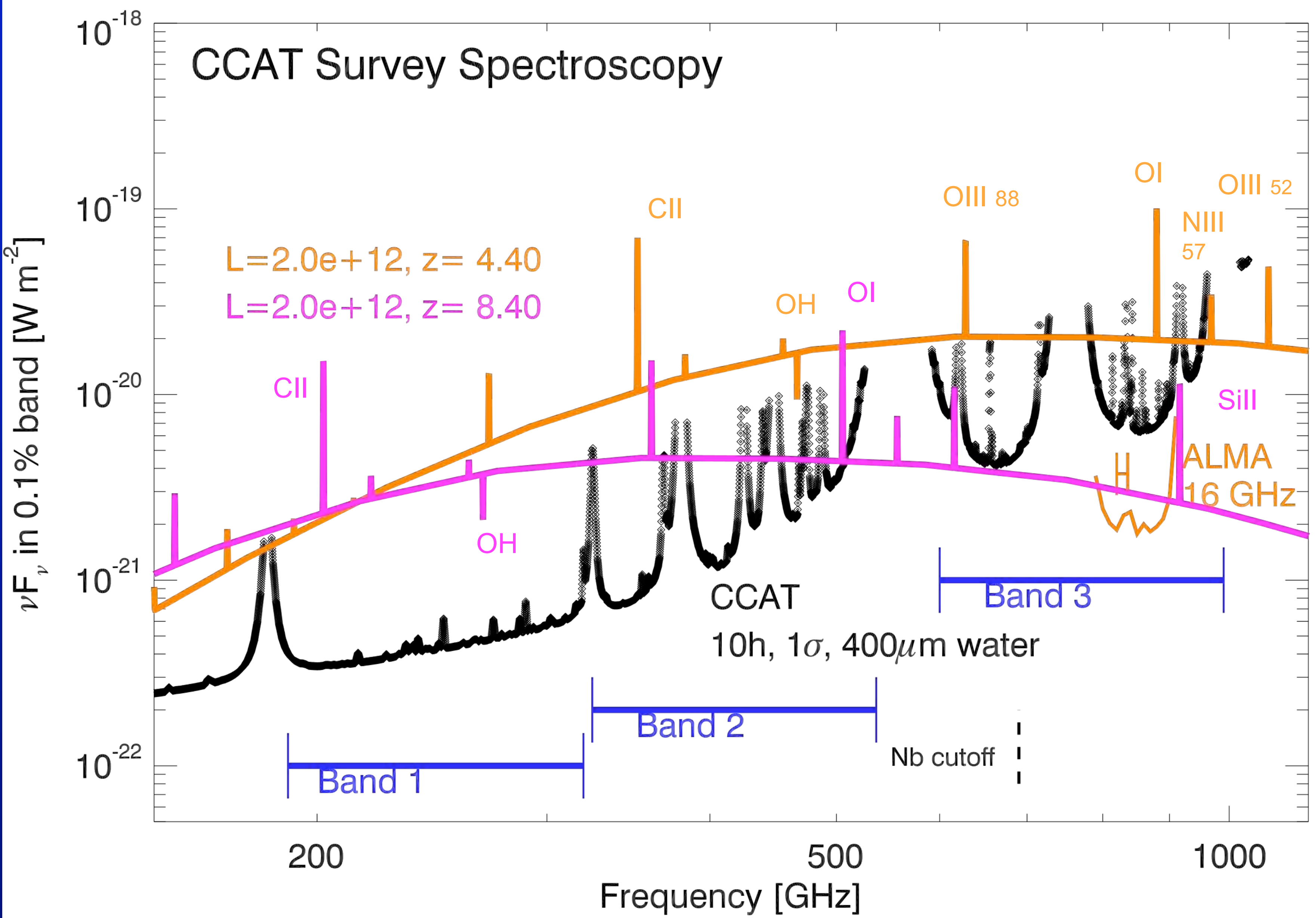
Rate = 0.3 x 10-100 = 3-30

FTS

BG noise penalty compensated by instantanous bandwidth

BUT spectrum is encoded with time need stability over the interferogram – how to do this with the mapping?

Also lose half the light in the interferogram + encoding loss -> sqrt(8) penalty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10h, 1σ, 400μm water
Band 1
Band 2
Band 3
Nb cutoff
νFν in 0.1% band [W m-2]
Frequency [GHz]
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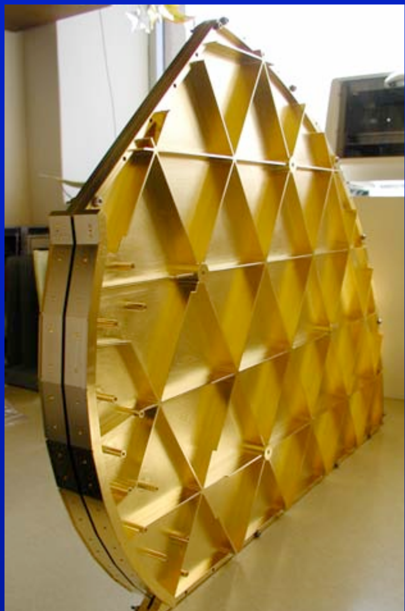
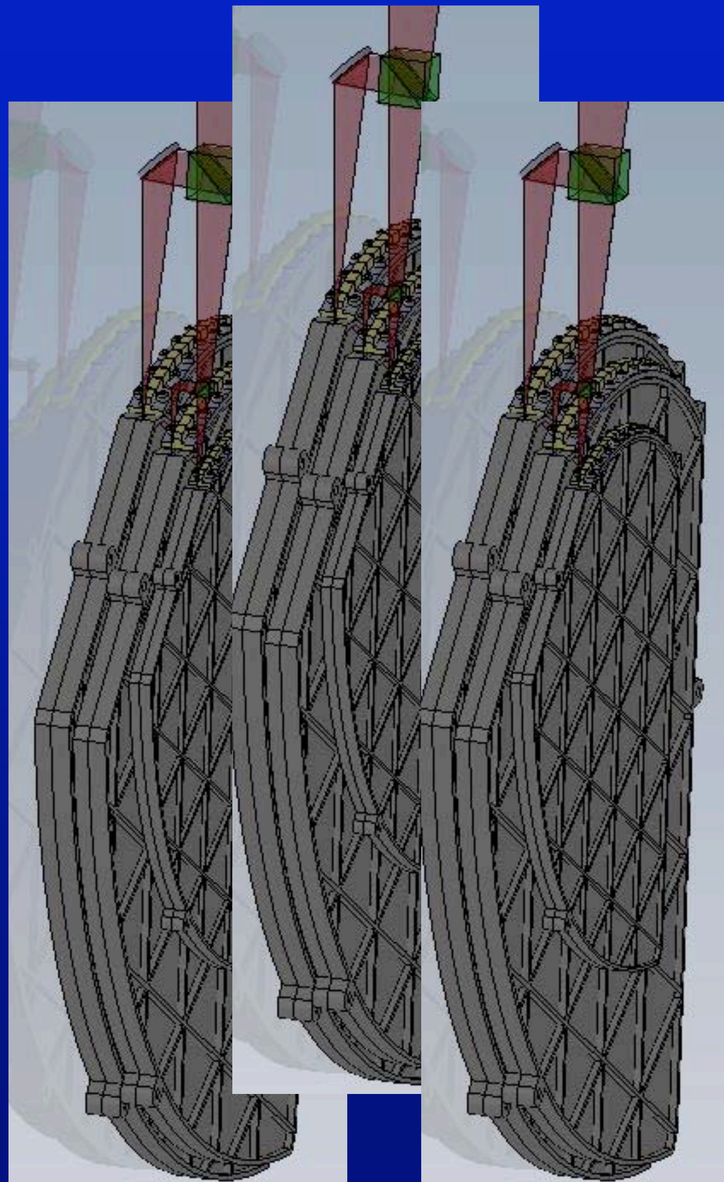
500
1000
10-18
10-19
10-20
10-21
10-22

A first-light 3-band multi-object CCAT spectrograph



Silicon WaFIRS development.



- 3 Bands per beam, each a WaFIRS module with matched horns & detectors.
- All couple instantaneously to a single point source -> use polarizer and dichroic filters.
- Cooled to 100 mK, detector NEP ranging from 2e-18 to 3e-17.
- ~1000 detectors per 3-band unit.
- R=700-1000,
- except 1 mm band: R=400-500 due to size limitation, can use second polarization with staggered channel spacing.
- Silicon devices coming!
- Size: 75 cm by 60 cm.
- Width ~5 cm, can stack 12-15.
- Array in ~2-D in the ~1m cryostat cryostat.
- Front end is set of warm quasioptical, elbowed-arm feed Seiffert / Goldsmith.

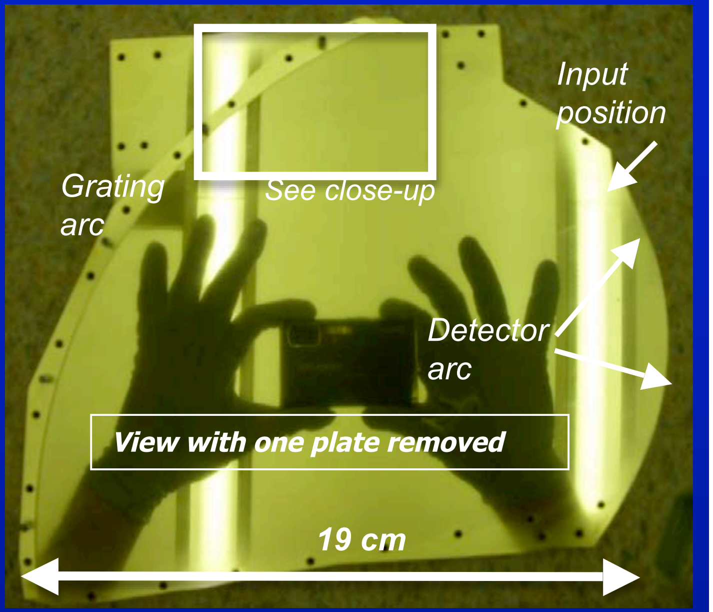
Prototyping CCAT Spectrometer Modules

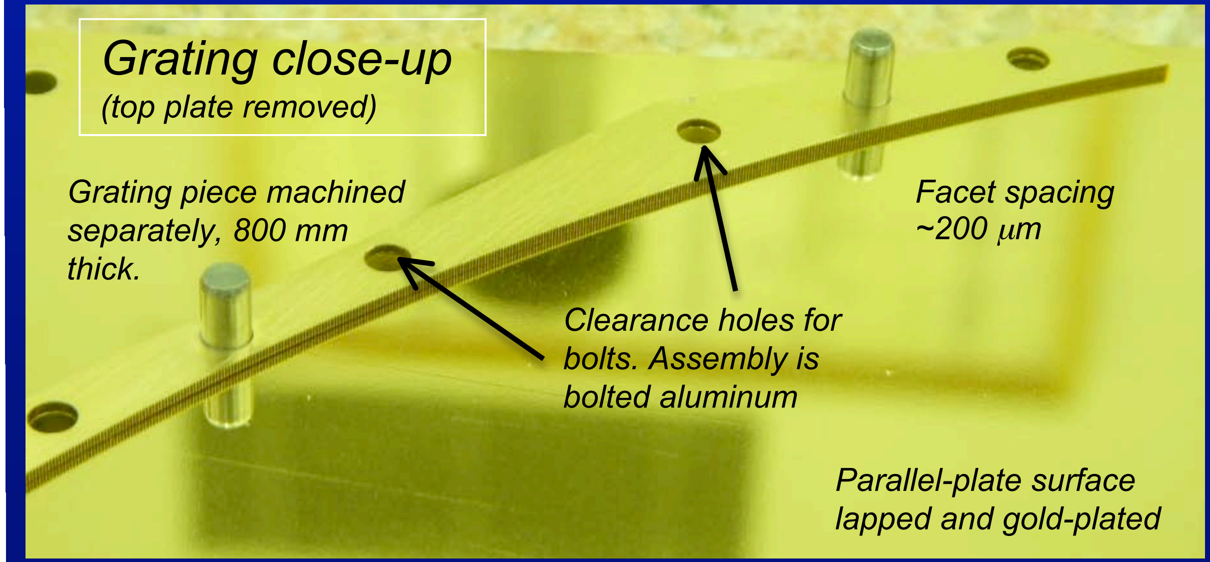
WaFIRS module for 180-300 μm designed for R=700.

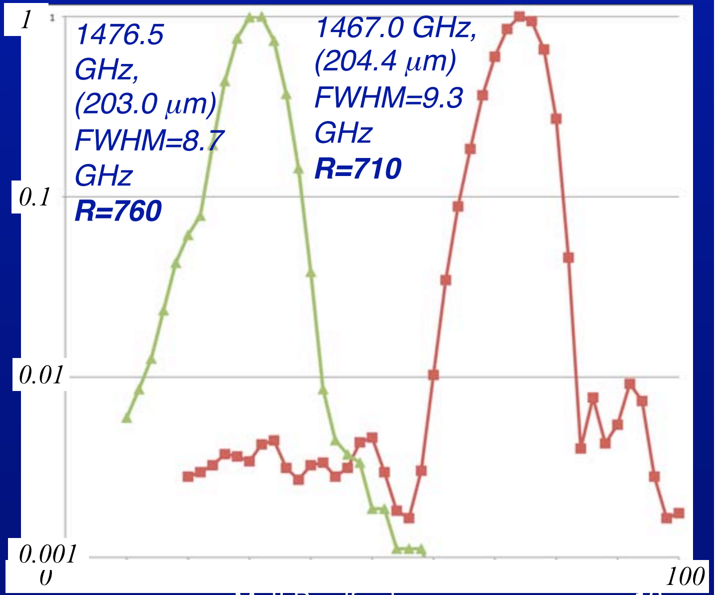
- *980 grating facets.*
- *Plate spacing 800 μm.*
- *19 cm in size.*

Demonstrates design resolving power! *(below right).*

Warm efficiency measurements show > 60-70% warm!

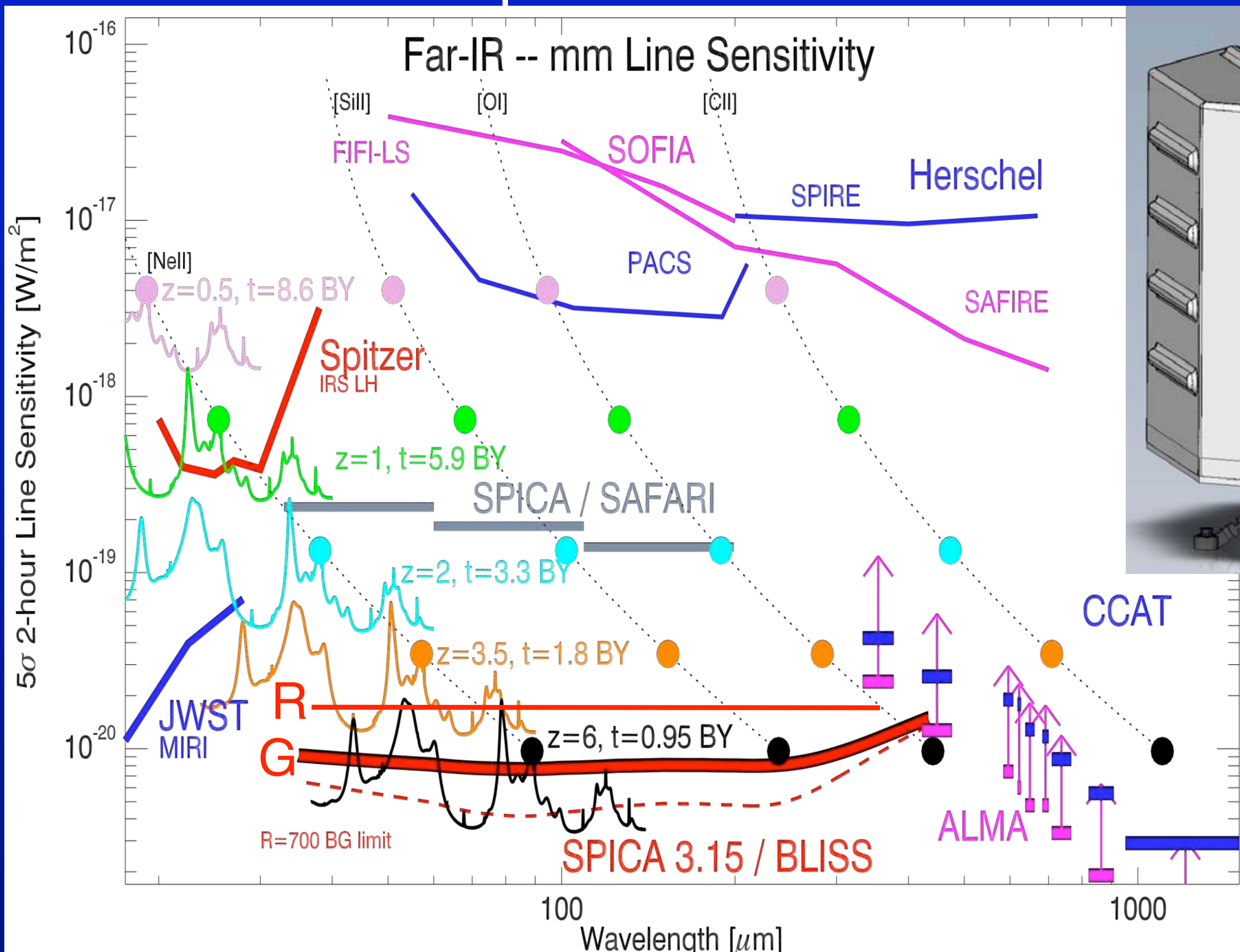


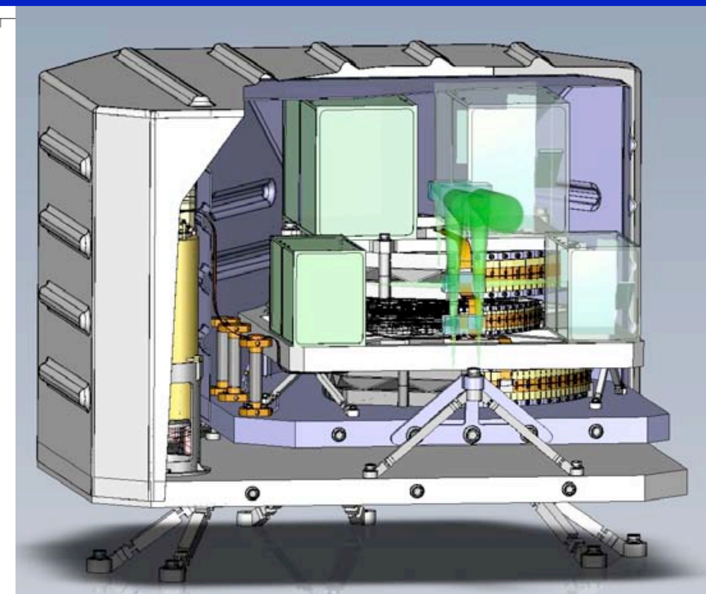




SPICA and BLISS:

The complement to CCAT for the next decade.





- Sensitive wideband grating spectrometer.
- 5 or 6 bands to cover 35-433 μm at R~700.
- Baseline 4224 TES bolometers at 50 mK with time-domain SQUID MUX.

- Detector NEP: Requirement: 1e-19 W Hz$^{-1/2}$, Goal: 3e-20 W Hz$^{-1/2}$
- Gives sensitivity of 2e-20 W m^{-2} (3σ, 1h) for Requirement and 1e-20 W m^{-2} for Goal under conservative assumptions (photons contributing equally at goal sensitivity).

Thank you!