The Large Millimeter Telescope

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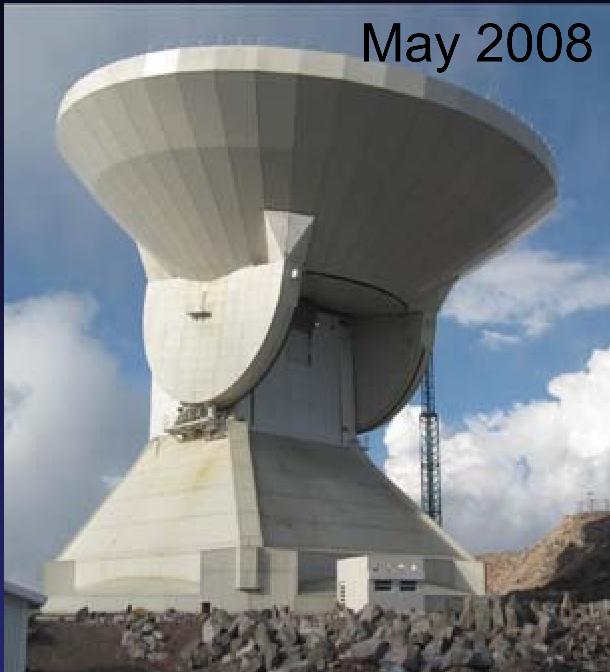


Overview

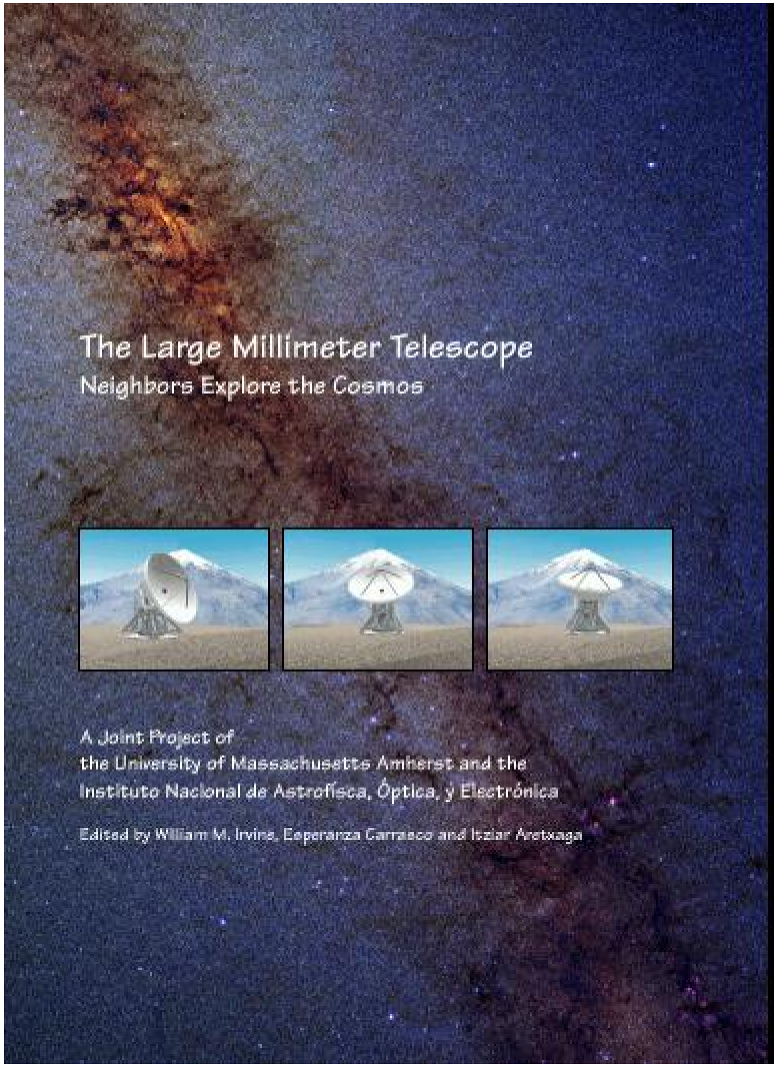
- LMT & specifications
- first-light instrumentation
- LMT cosmology key projects (high-resolution studies of CMB anisotropies and LSS)

www.lmtgtm.org

Funding
Mexico: CONACYT, INAOE
USA: NSF, DARPA, UMASS

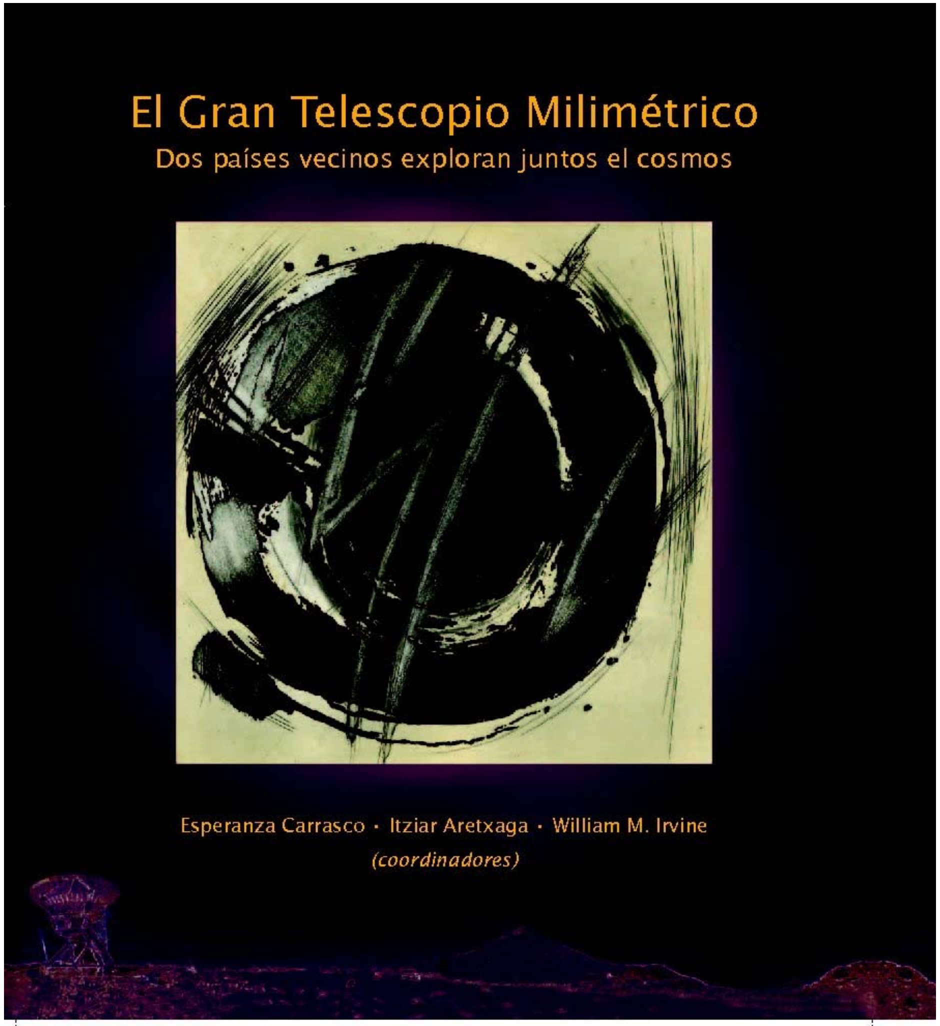
The LMT/GTM project

The LMT book



http://www.lmtgtm.org/book/lmtbook.html

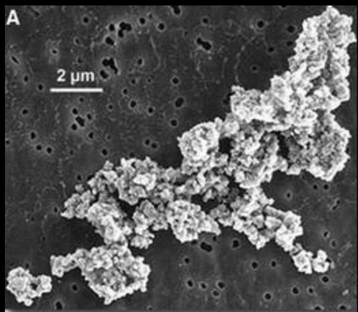
El libro del GTM

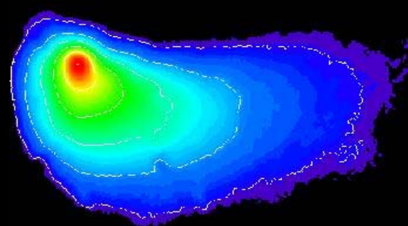


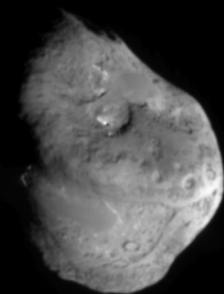
http://www.lmtgtm.org/gtm/book/librogtm.pdf

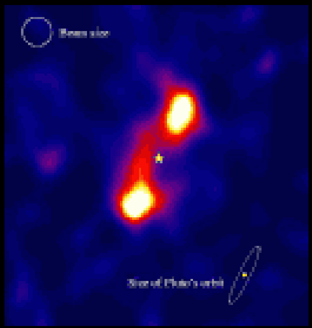
Primary Science with the LMT

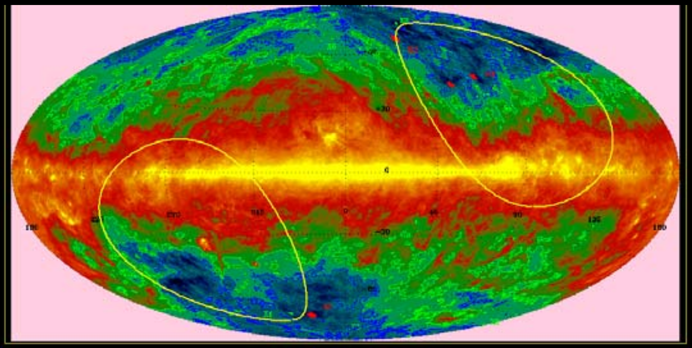
The formation & evolution of structure in the Universe

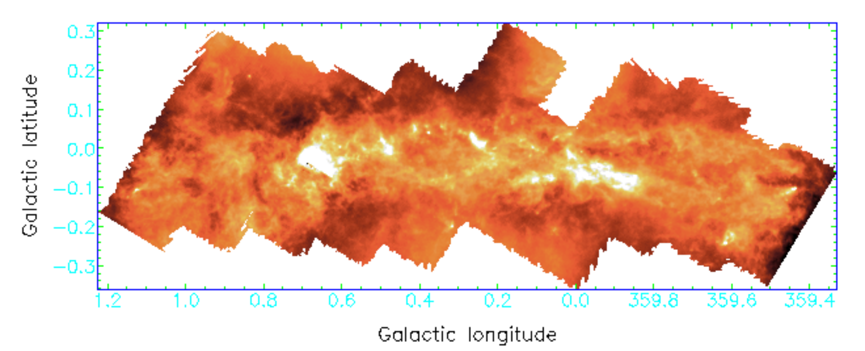


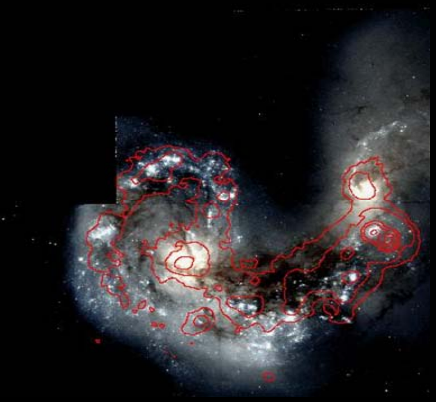


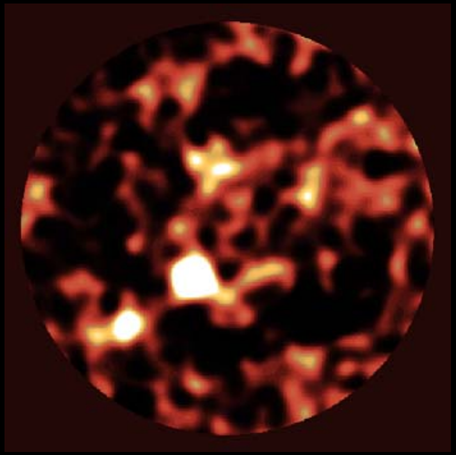


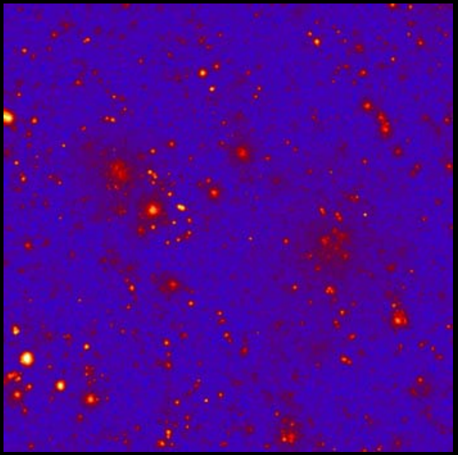


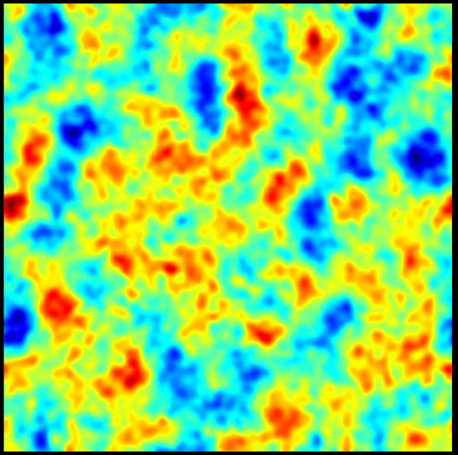












Cosmology at millimeter-wavelengths

- can detect the **earliest evolutionary stages of structure formation** in planet-forming and star-forming regions (cold, dense, optically-thick dust-obscured environments)

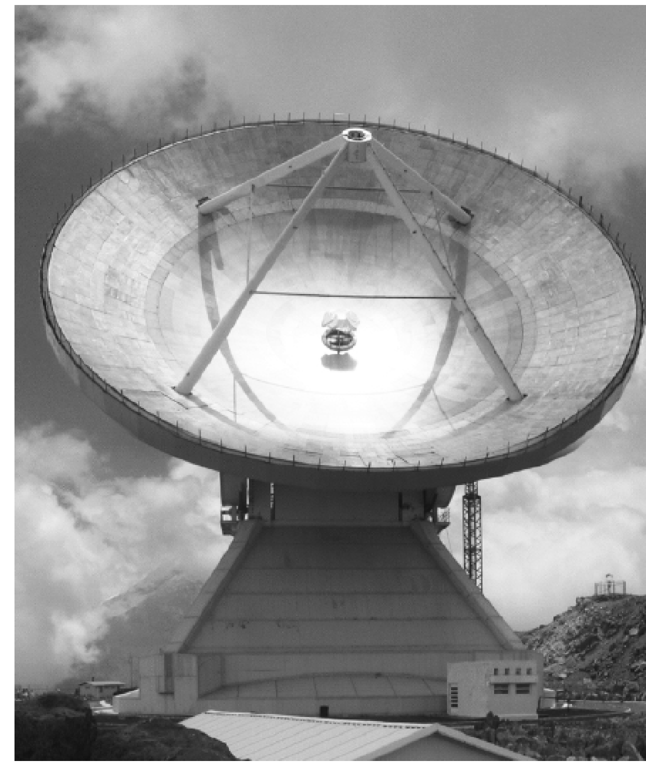
- **independence of flux density on distance** means we can detect starburst galaxies in the high-z Universe (which contribute ~50% of the γ-ray to radio extragalactic background light)

- **rich molecular-line spectrum to understand physical conditions of starformation**, the ISM, gas mass, spectroscopic–z & evolutionary history

- we observe the **CMB** at the peak of its energy distribution. **Sunyaev-Zeldovich effect** is a powerful redshift-independent method to identify clusters in local and high-z Universe

LMT Design Characteristics

- 50-m main reflector (180 panel segments)
  2.5 m secondary mirror



- active surface (compensates gravity & thermal deformations) to achieve surface r.m.s. of ~70 microns

- operational wavelengths 0.85 - 4 mm

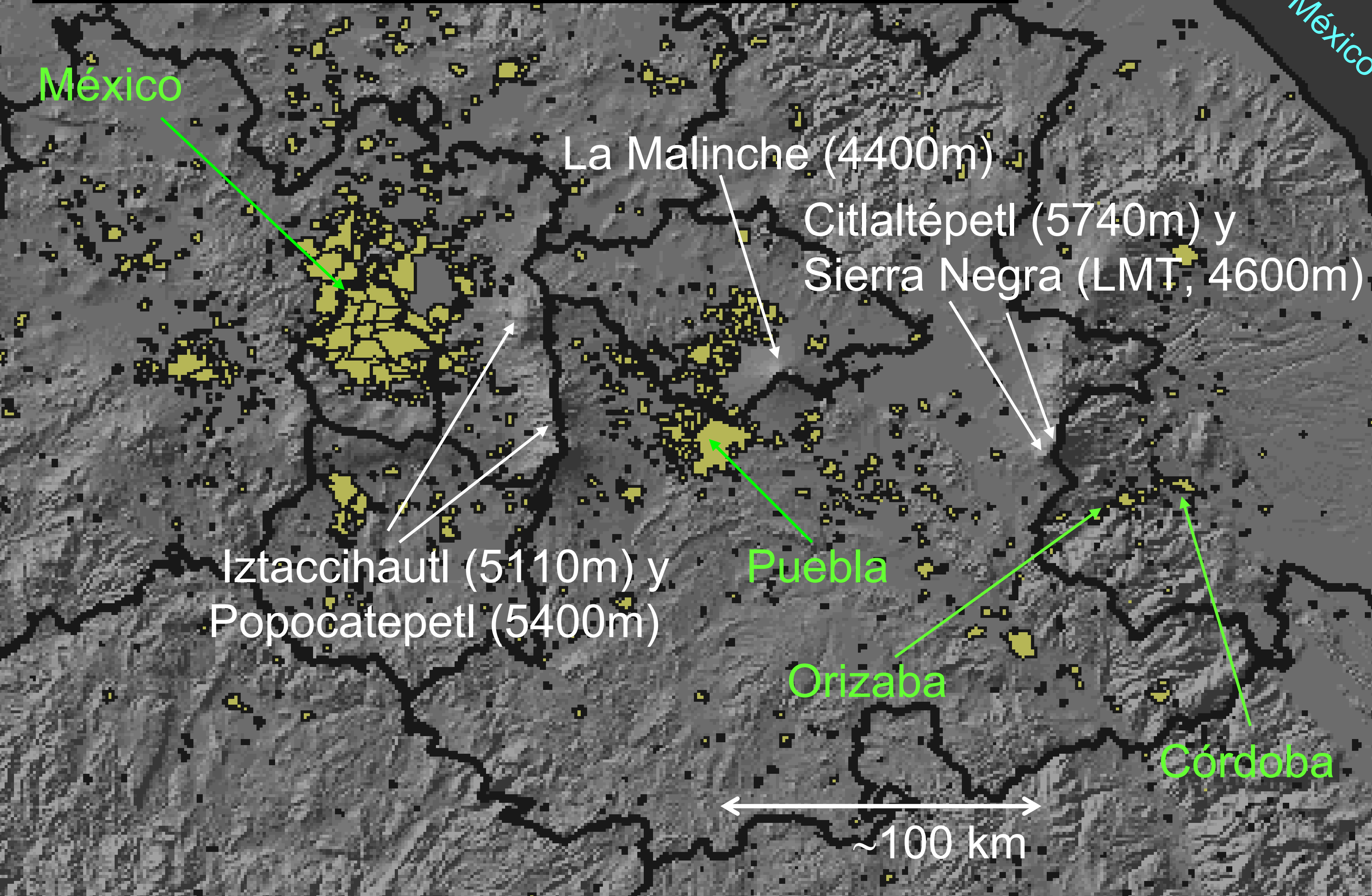
- Beam resolution (FWHM) 5 -18 arcsec

- FOV ~ 4 arcmin diameter

- Sensitivity – 3.0mm 2.0 Jy/K
  1.2mm 3.1 Jy/K

Volcán Sierra La Negra (97° 18’ 53” W, +18° 59’ 06”) altitude 4600m

Location of the Large Millimeter Telescope



- excellent logistical support available (close to major towns/cities)
- only 2 hours travel from INAOE with 110 km of *autopista* and 13 km of access road to summit

LMT Site Characteristics

- Site - Sierra La Negra (97º 18’ 53” W, +18º 59’ 06”)
- altitude 4600m (15100 ft.)

WIND (Q1, **median**, Q2)

- median wind-speed 2.7, **4.5**, 6.7 m/s
- wind speed < 10 m/s (90% time)

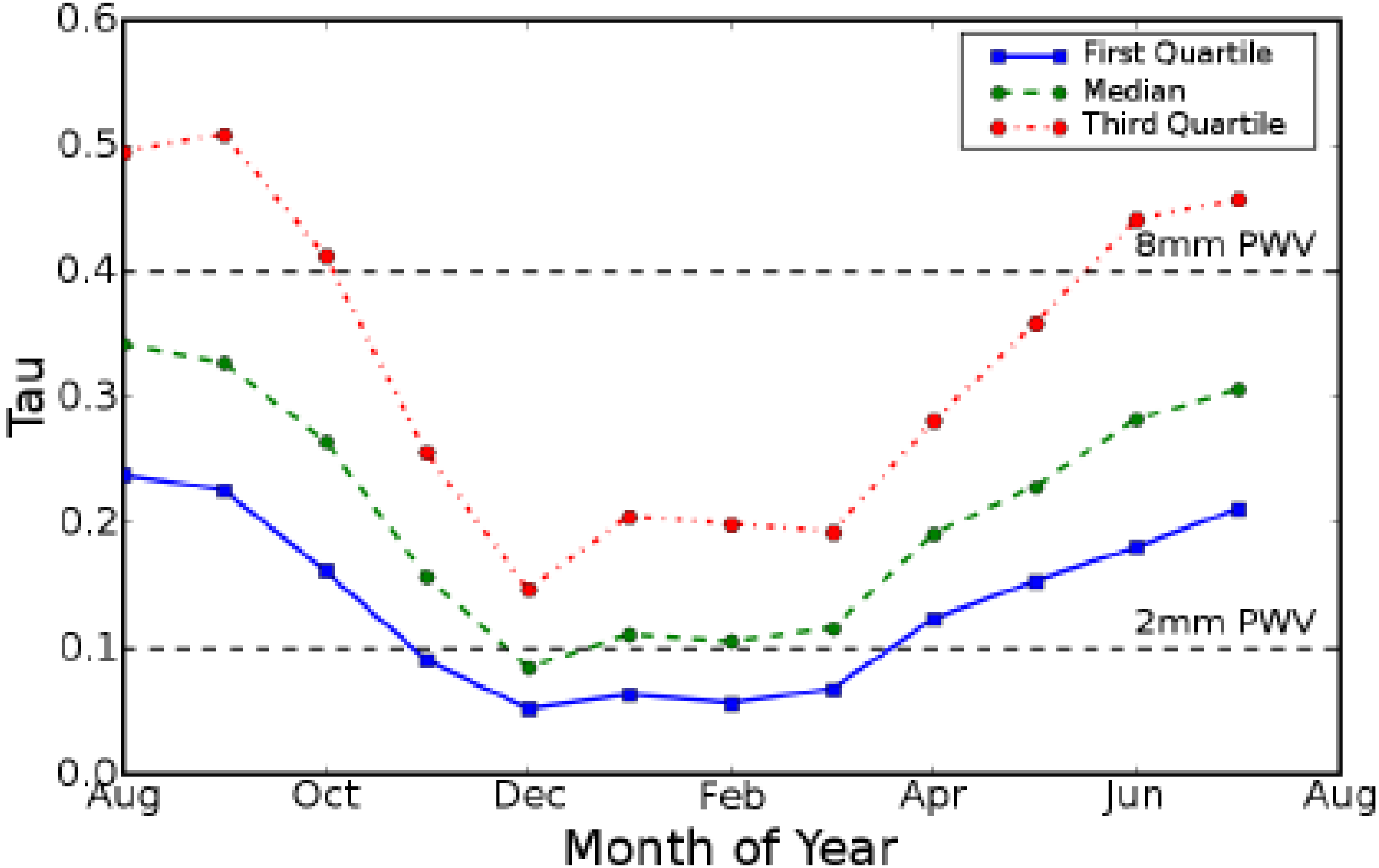
OPACITY

- median opacity T_{225GHz} ~ 0.1 (winter), 0.3 (summer)
  2mm PWV 6 mm PWV

TEMPERATURE (Q1, **median**, Q2)

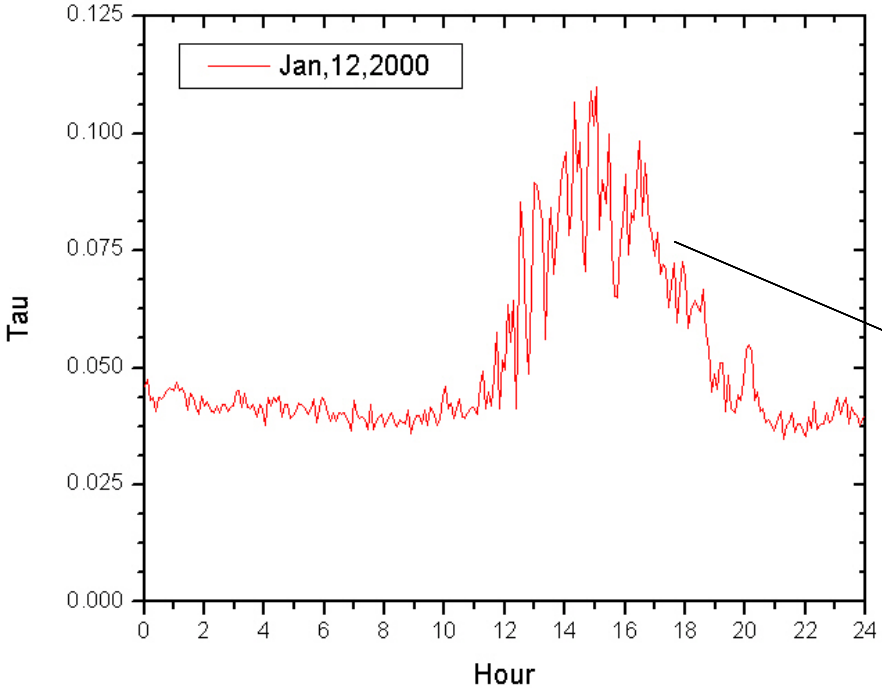
- Day (8am – 6pm) 0.2, **2.0**, 3.4 degrees Celcius
- Night (8pm – 6am) -1.2, **0.3**, 1.4

Monthy-averaged opacity above LMT site

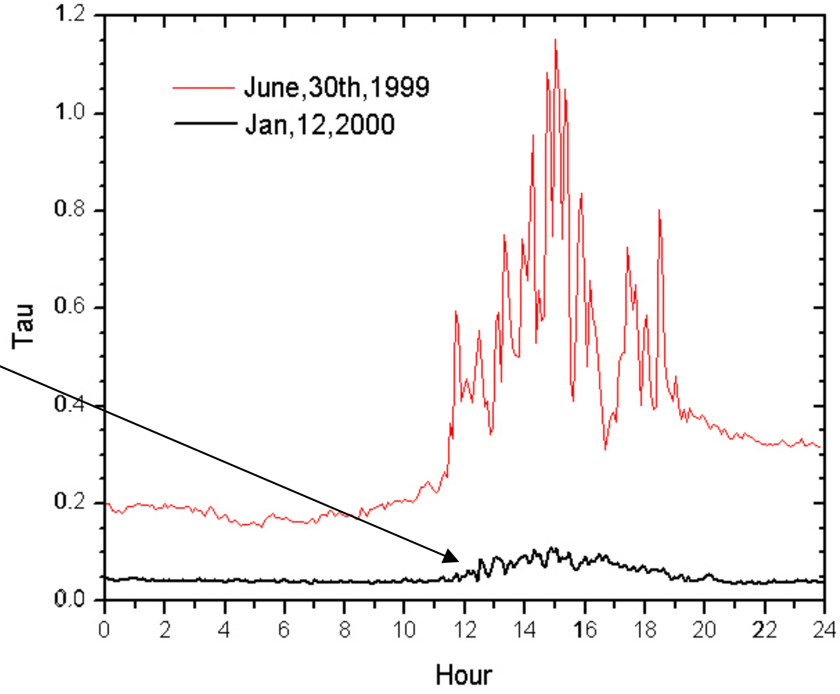


225GHz opacity variations in a 24-hour period

Winter



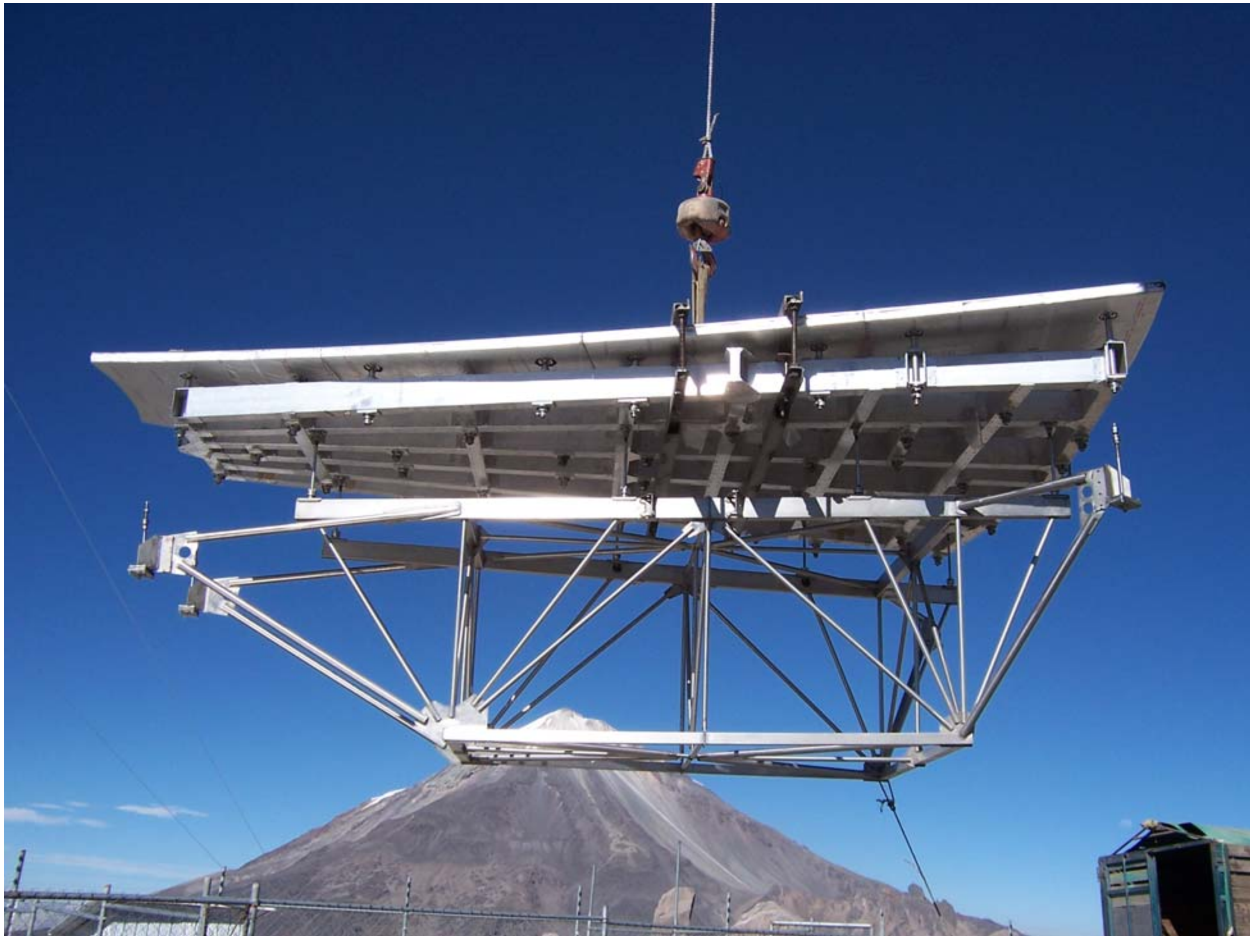
Summer



LMT panel segments

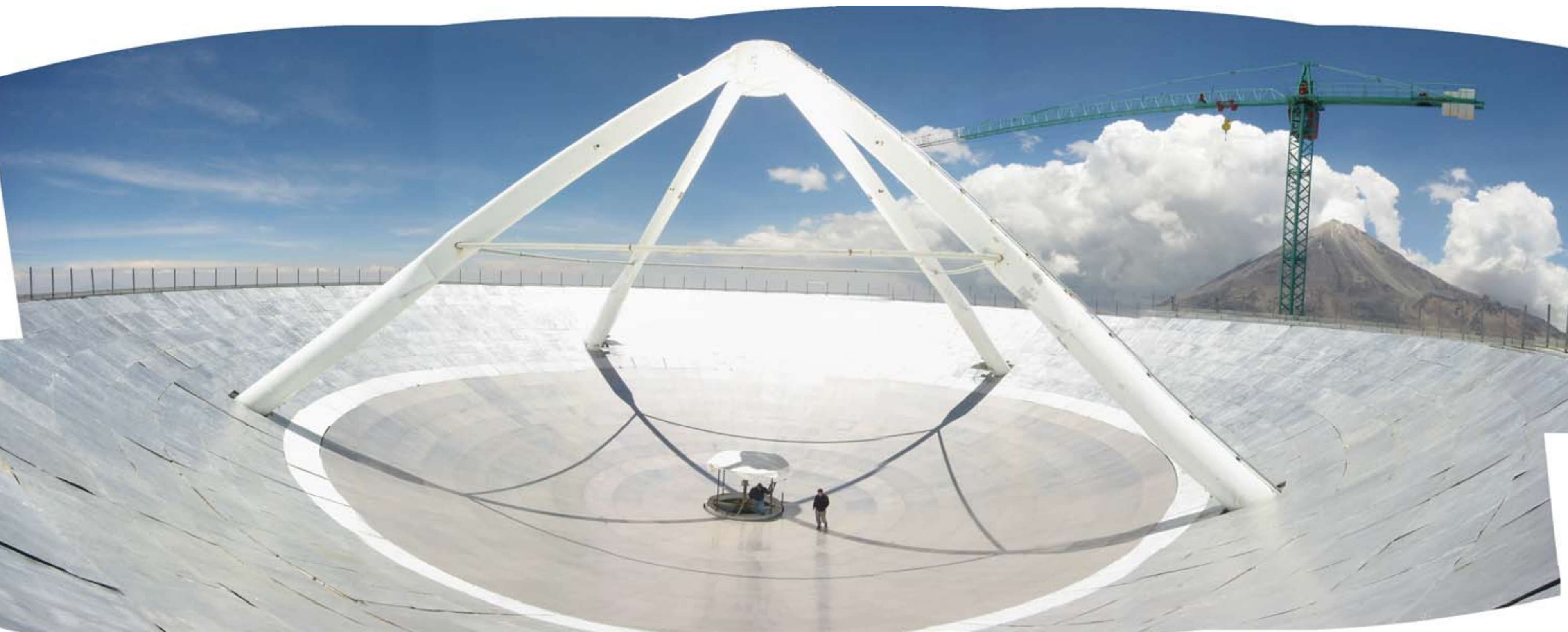
LMT panel segments

- 180 segments (~5 x 3m) in 5 concentric rings
- 8 sub-panels (<7 microns) electro-formed Nickel
- thermal insulation
- adjusters (segments set to 20-30 microns in lab)
- aluminium base plate
- stainless steel sub-frame & axial bars
- actuators

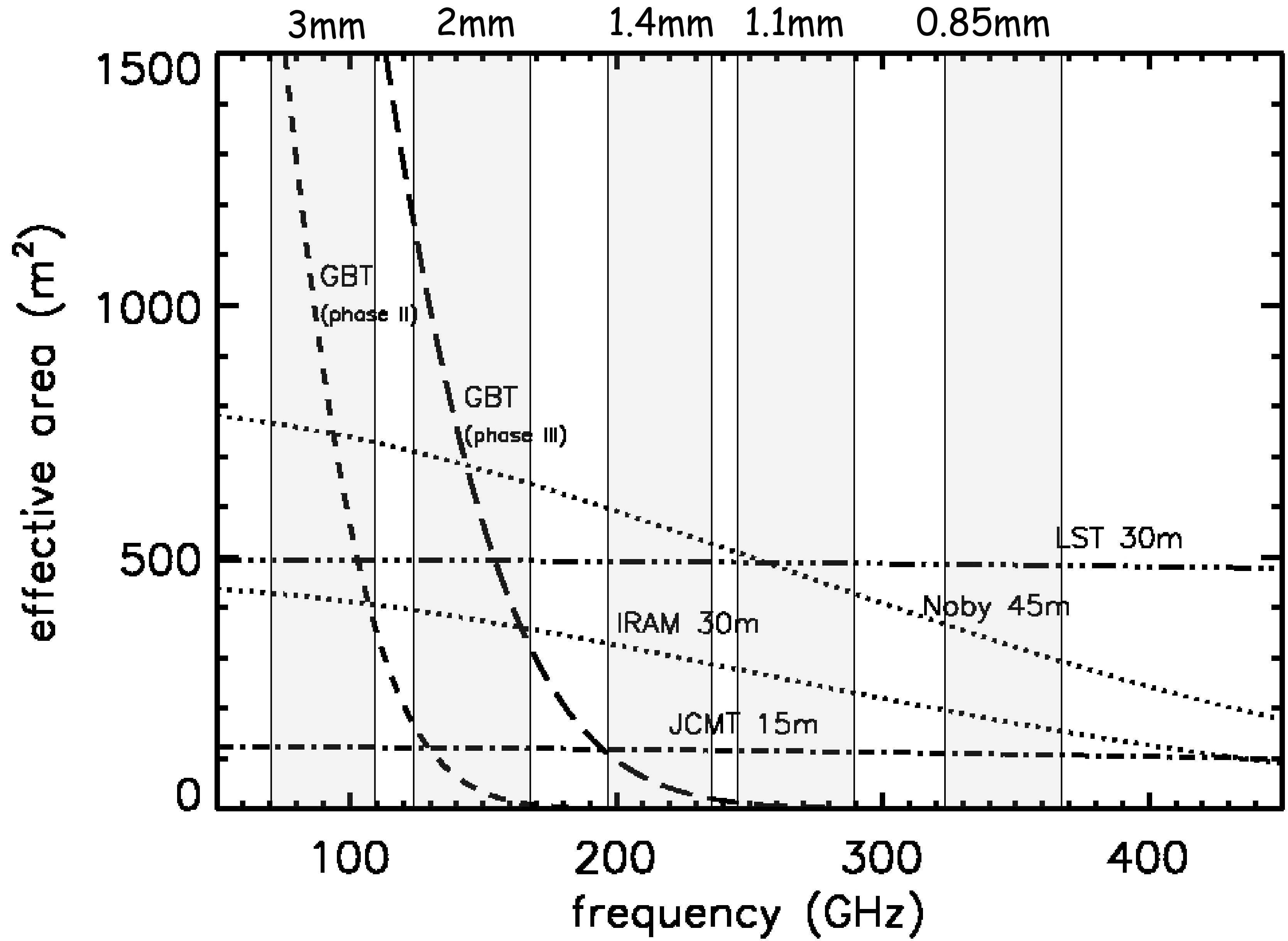


Surface Alignment

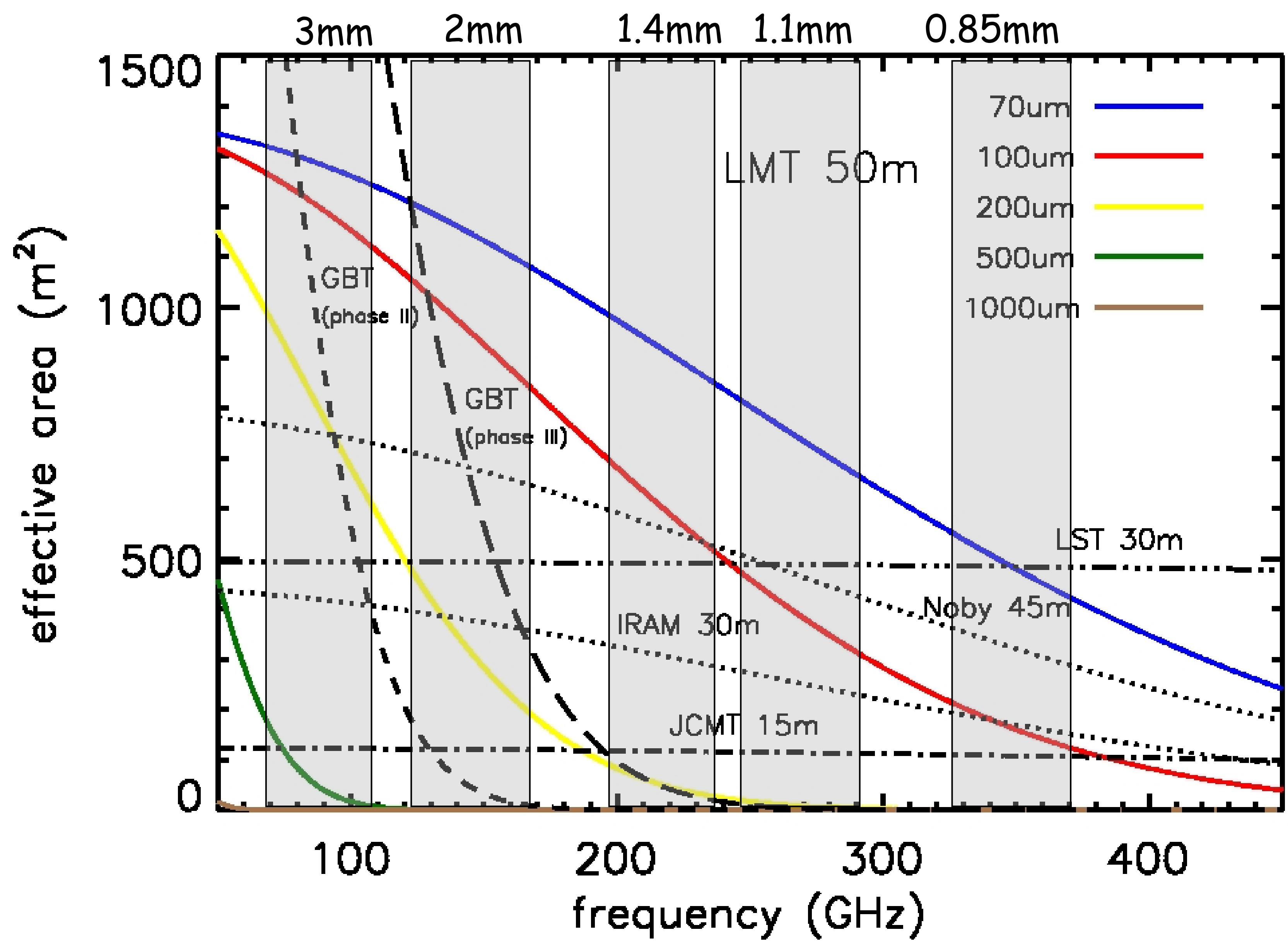
- Inner 32-m installed (inner 3-rings)
- Surface alignment (laser-tracker, holography) to reach <120um before telescope commissioning
- Full telescope sensitivity achieved with 70um r.m.s



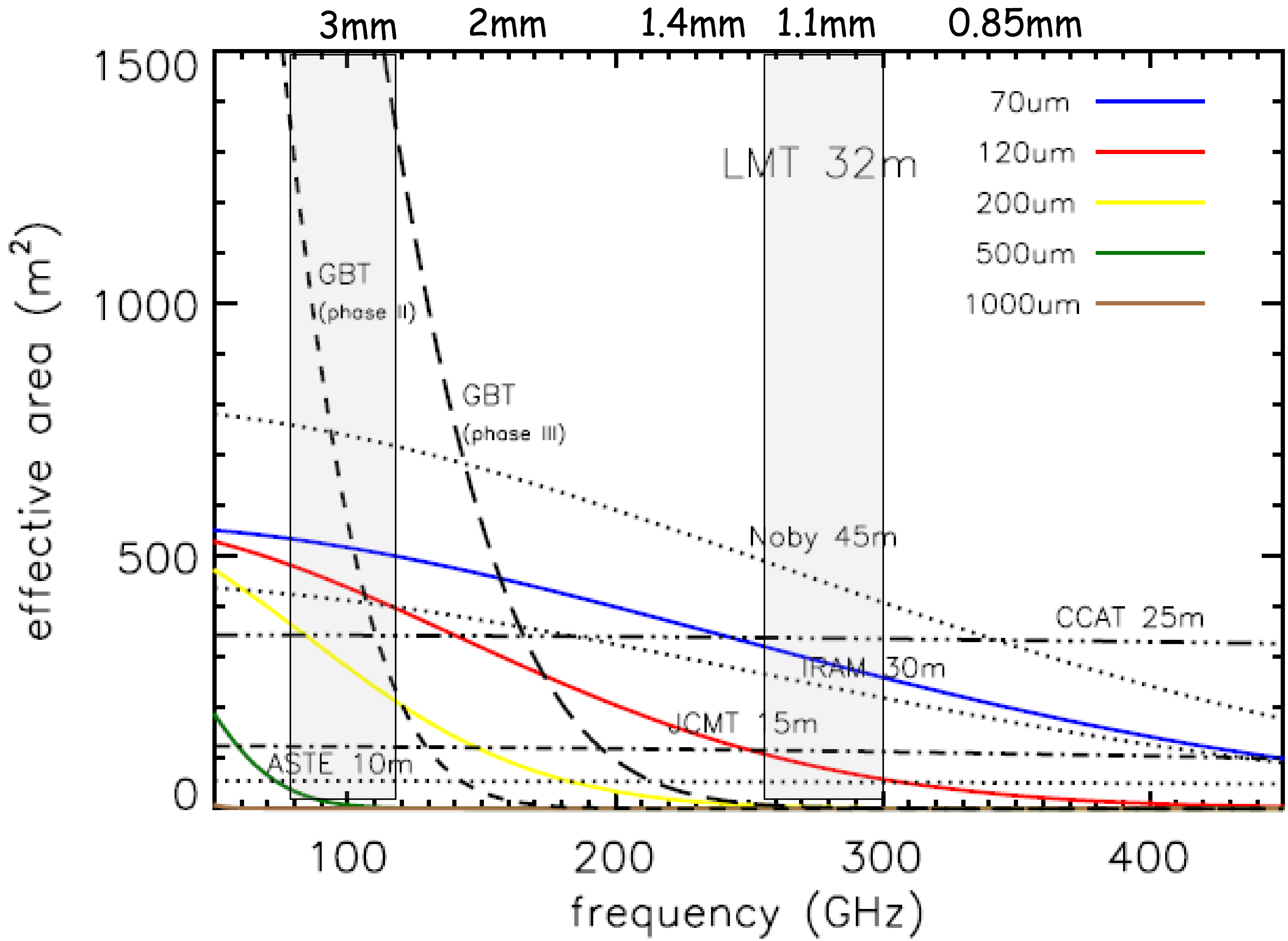
Effective aperture areas of (sub-)mm telescopes



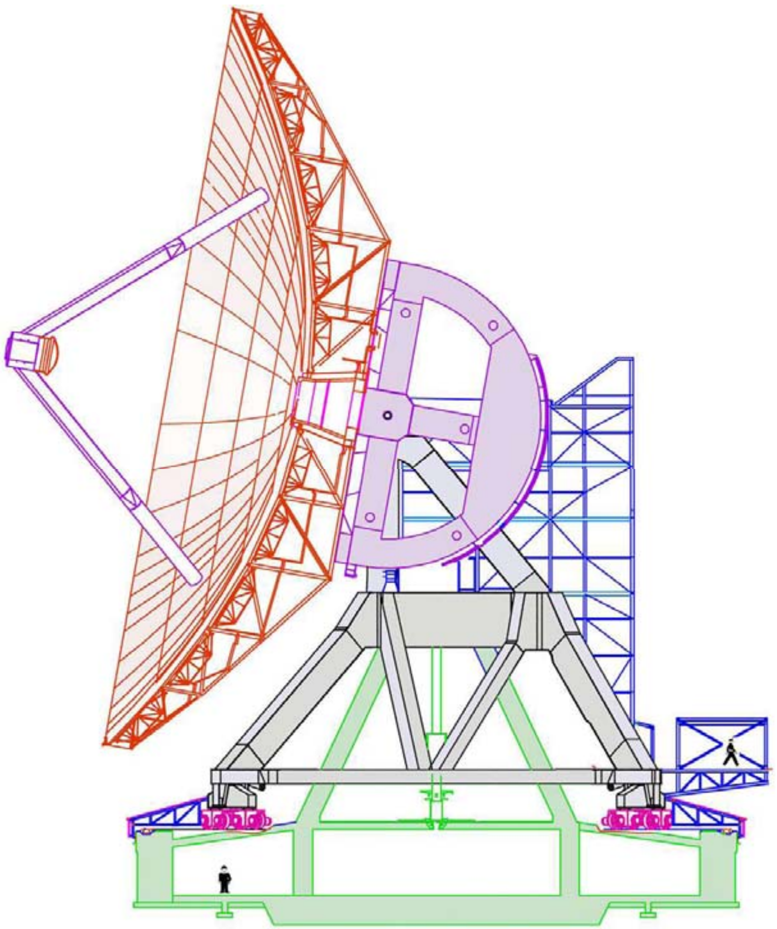
Effective area of (5-ring) 50m LMT



Effective area of (3-ring) 32m LMT

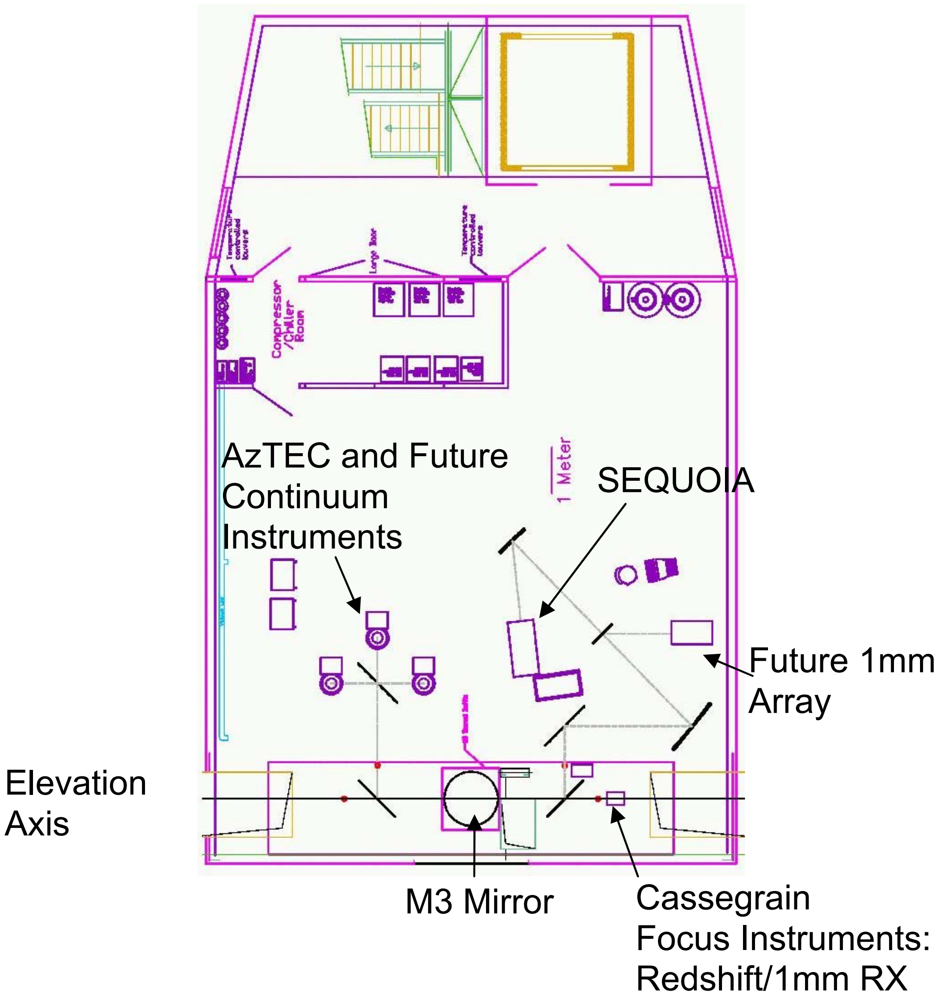


March 2006

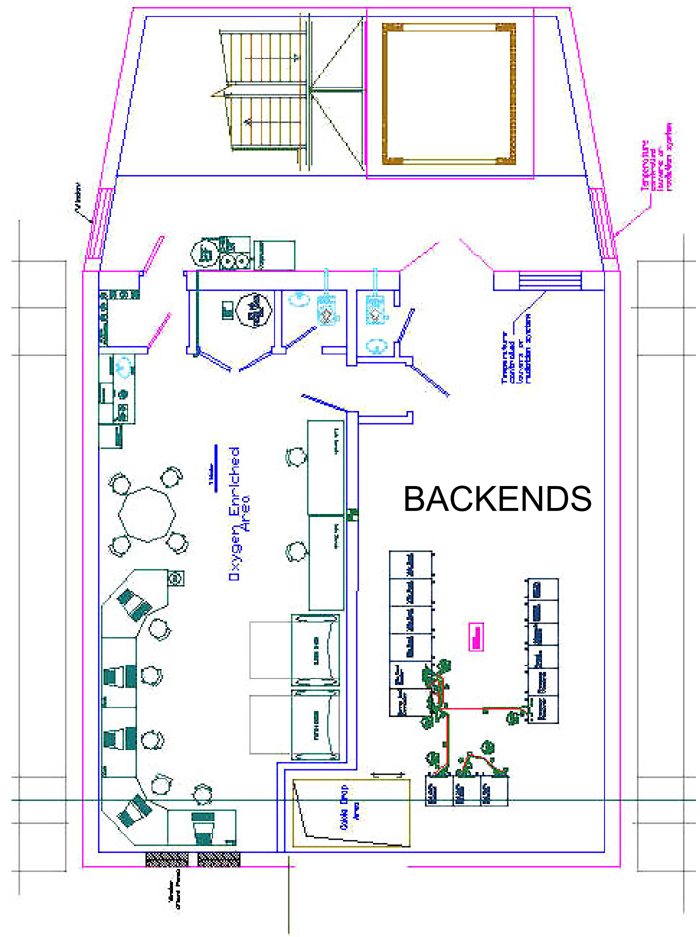


Site Infrastructure

3rd Floor



2nd Floor



First-light Instrumentation Overview

Commissioned

- AzTEC (JCMT 15-m, ASTE 10-m)

  144-pixel 1.1mm (or 2.1mm) continuum camera

- SEQUOIA (FCRAO 14-m)

  32-pixel dual-polarization spectrometer at 85-116 GHz with 15 GHz instantaneous bandwidth

- 90 GHz Redshift Receiver (FCRAO 14-m)

  2 pixel, dual-polarization, ultra-wideband analog autocorrelation spectrometer (instantaneous bandwidth ~35 GHz) at 75-111GHz

First-light Instrumentation Overview

Under development

- SPEED

  4 pixel (FSB) prototype continuum camera. Each pixel operates simultaneously at 0.85, 1.1, 1.4, 2.1 mm

- 1.3mm SIS receiver

  1 pixel dual-polarization spectrometer 210-275 GHz

- LMT wideband spectrometer

  versatile digital autocorrelator -

  e.g. Redshift searches BW > 10000 km/s, dnu~100 km/s

  quiescent Dark Clouds BW ~20km/s, dnu~0.01km/s

Future Instrument Development

- CIX (Cluster Imaging eXperiment)
  256-pixel 4-band multi-frequency camera based on SPEED prototype

- OMAR
  16-pixel receiver (210-275 GHz) based on single-pixel 1.3mm SIS development

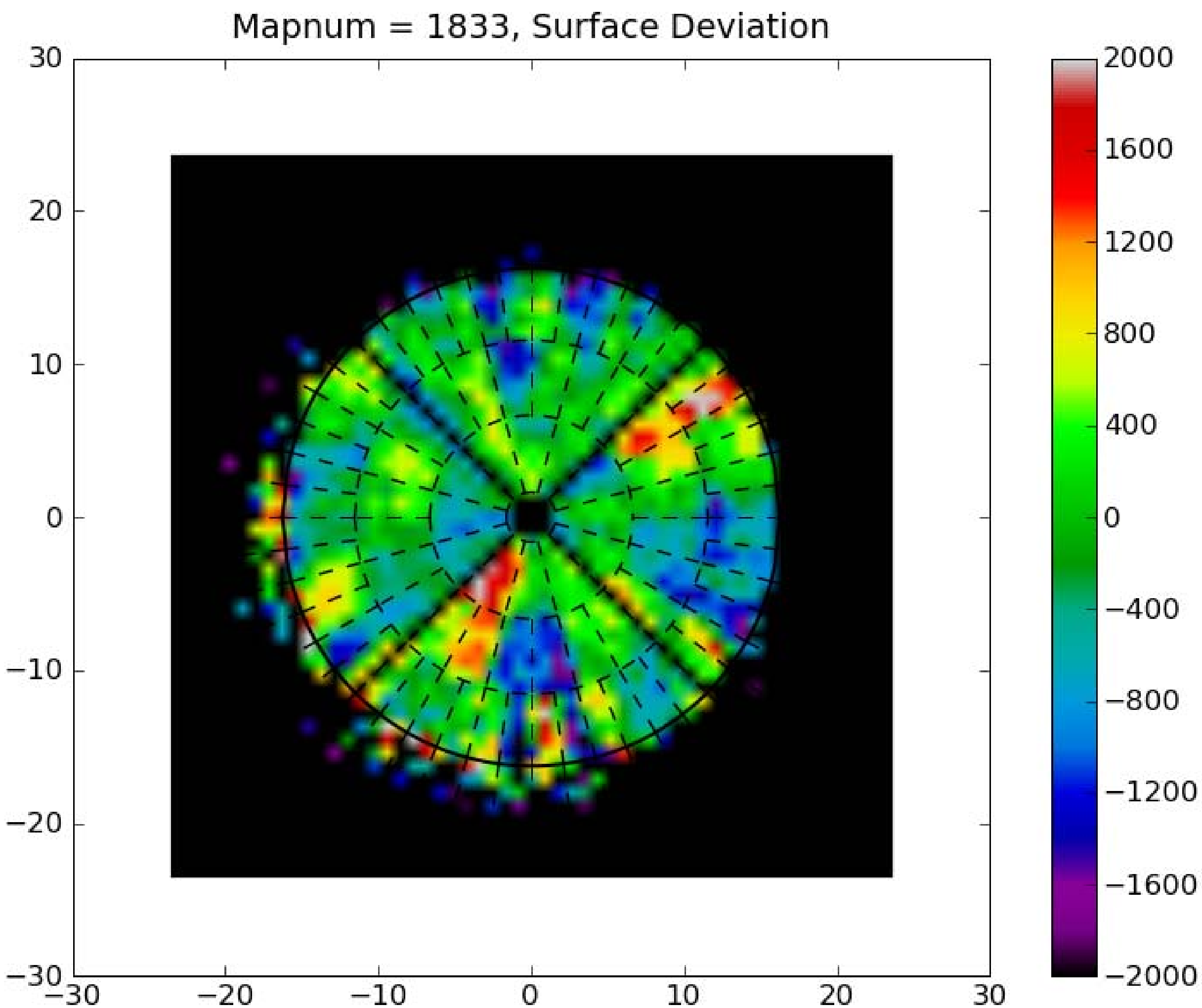
- ToITEC
  Large-format continuum camera (~6400 pixels), full-sampled array filling available FOV based on successful TES development (e.g. SCUBA2, MUSTANG, MBAC, …) or other new technologies

UMass Holography Receiver on the LMT, Installation July 2008

Ref. horn

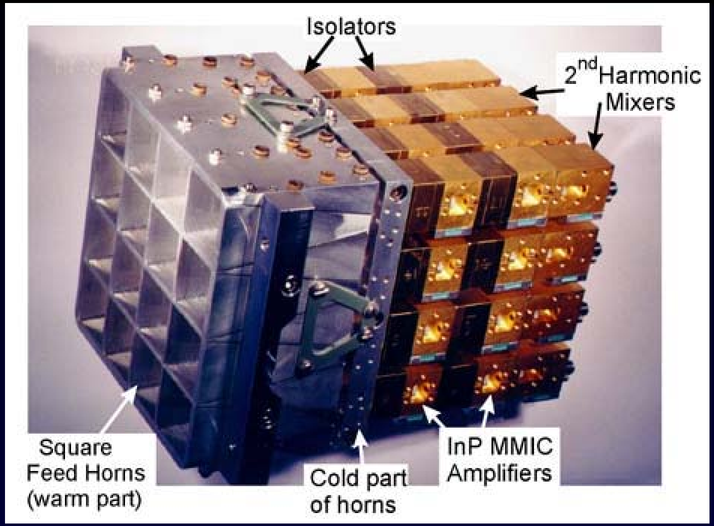
Sig. horn

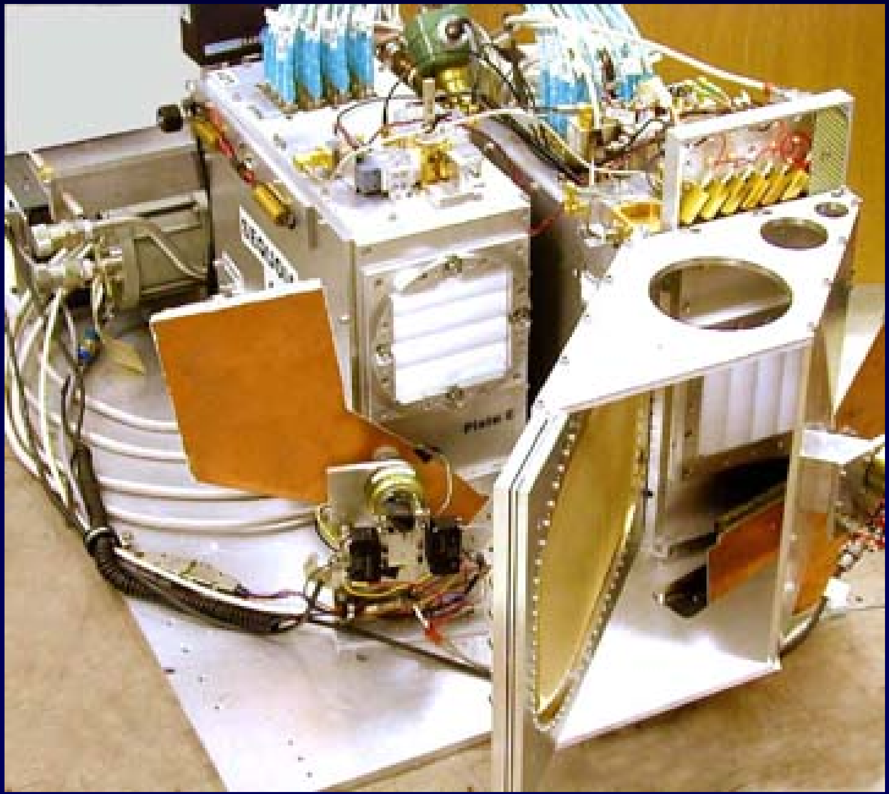
LMT 12GHz holography map (inner 32-m)
0.9 m resolution



SEQUOIA

- A cryogenic focal plane array for the 85-115.6 GHz range
- 32 pixel dual polarization 4 x 4 array
- 50-80 K noise temperature
- No mechanical or electrical tuning
- Single side-band response using just two LOs





Taurus Molecular Cloud Survey (FCRAO 14-m)

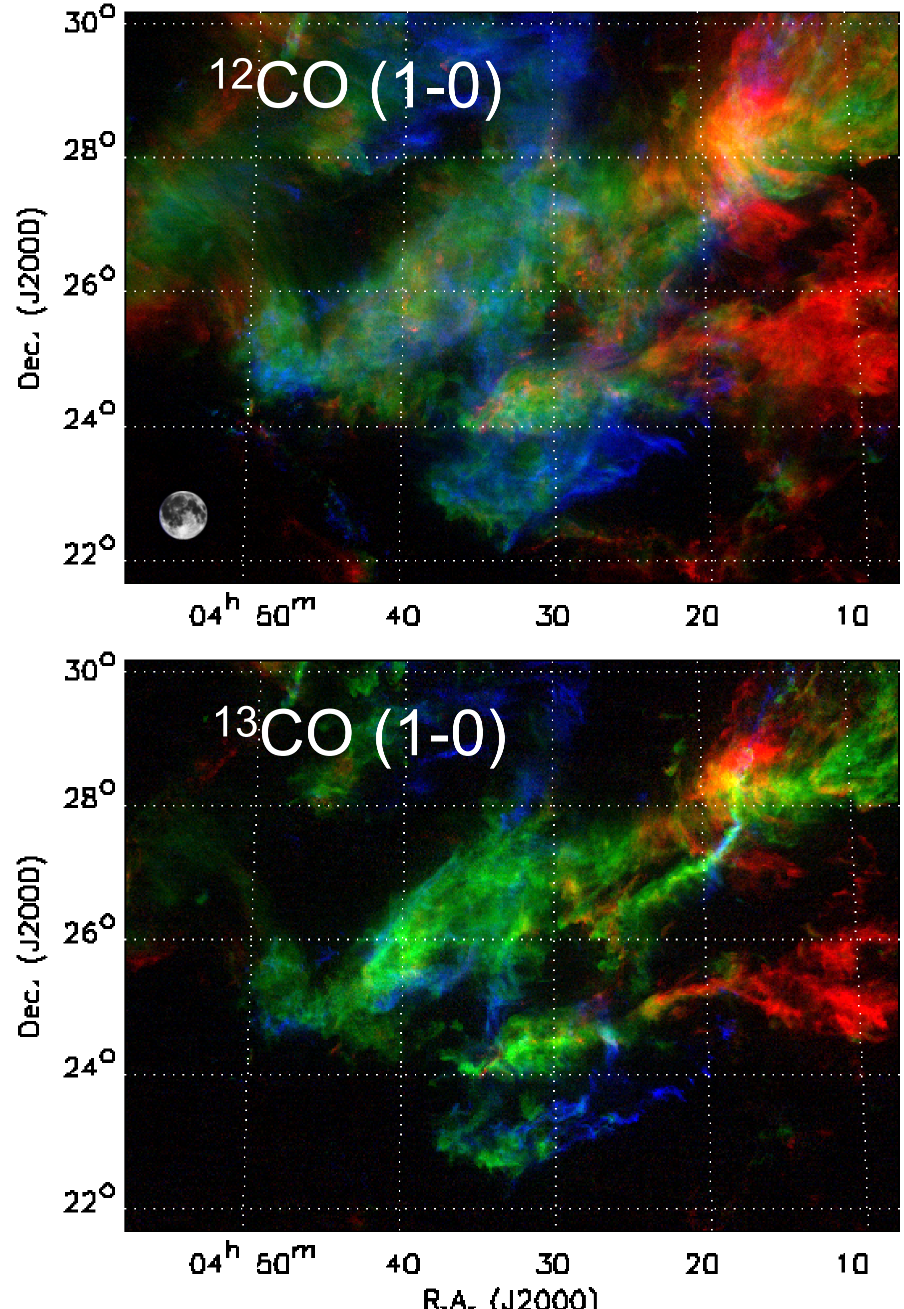
Narayanan et al. 2008 ApJ in press
astroph/08022556

^{12}CO (1-0) -5 < v(kms^{-1}) < 20

^{13}CO (1-0) 3 < v(kms^{-1}) < 9

~45" beam FWHM

0.07 km/s velocity resolution



96 sq degree area and 3.1 million spectra
with 1024 spectral channels - Nov 2003 – May 2005

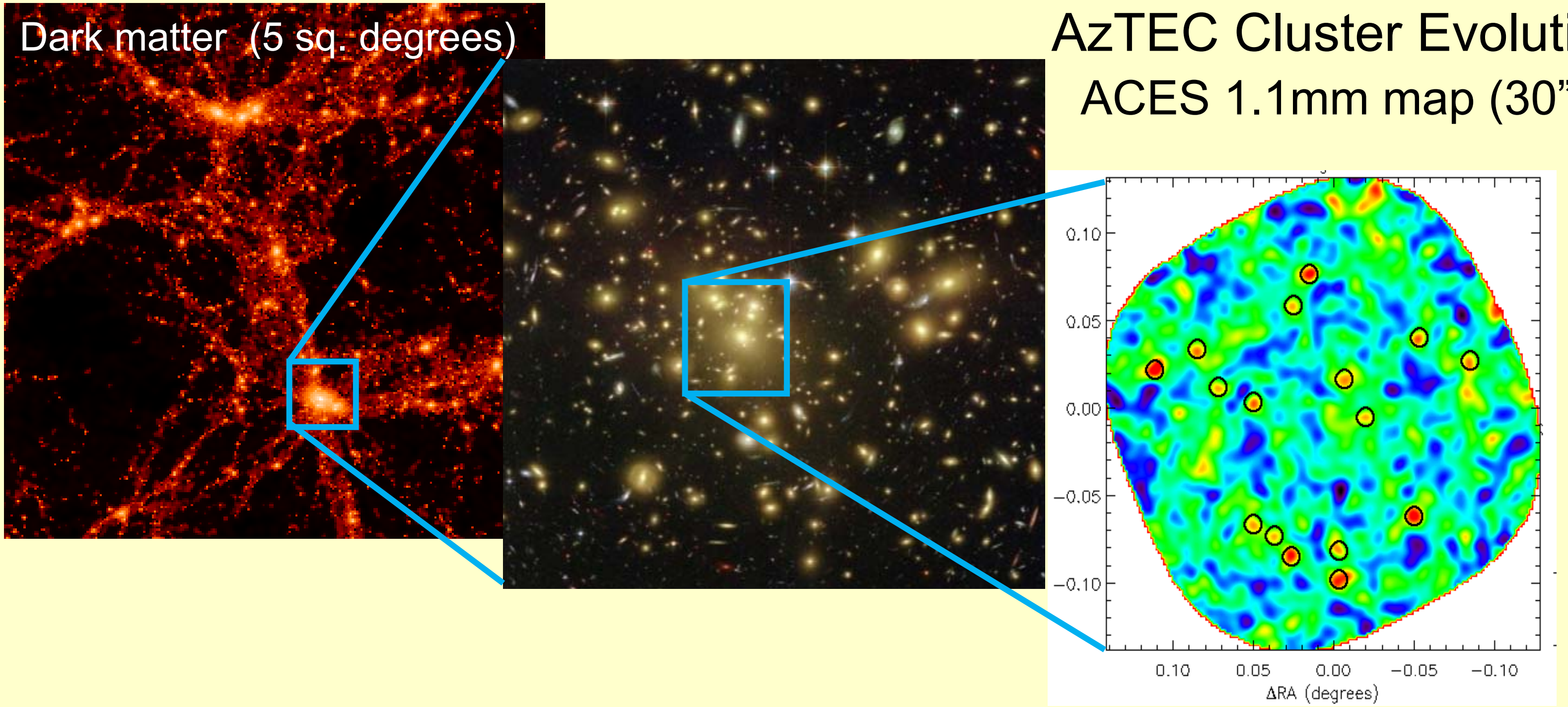
LMT Cosmology Key Projects

High resolution studies of LSS and CMB anisotropies

- take advantage of high pt-source sensitivity, mapping speed and resolution to trace 3-d distribution of LSS down to confusion-limit (resolve ~100% of mm background)
- large single-dish telescopes have all 3 capabilities

D.2. “How do galaxies arise and mature?”

AzTEC Cluster Evolution Survey
ACES 1.1mm map (30” FWHM)



- **we have to search for & find the “first galaxies”**

 - a population of galaxies undergoing an initial massive burst of optically-obscured star formation that generate a significant rest-frame FIR luminosity

D.2. “How do galaxies arise and mature?”

• Statistical properties needed to understand the formation & evolution of galaxies:

- source-counts N(>S)
  + angular distribution ← AzTEC, ToITEC

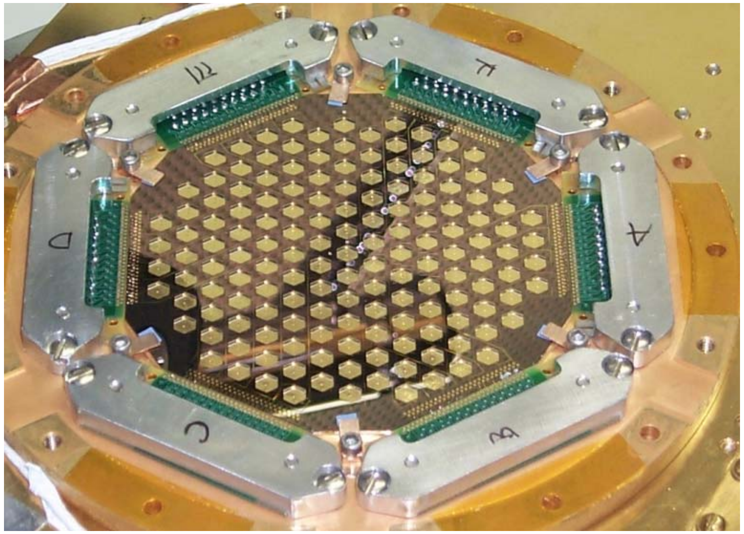
- redshift distribution
  N(> z; S) ← Redshift Search Receiver

- luminosity function Φ(L,z) & spatial clustering

AzTEC

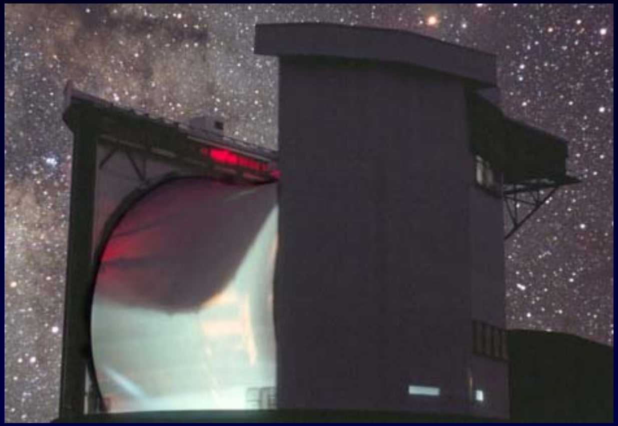
P.I. Grant Wilson (UMASS)

- 144-pixel Si-Ni spiderweb bolometer array
- 6” beam at 1.1mm at LMT
- FOV ~2.4 sq. arcmin
- NEFD < 3 mJy/Hz$^{1/2}$ conservative
- mapping speed > 0.55 deg^2/hr/mJy^2



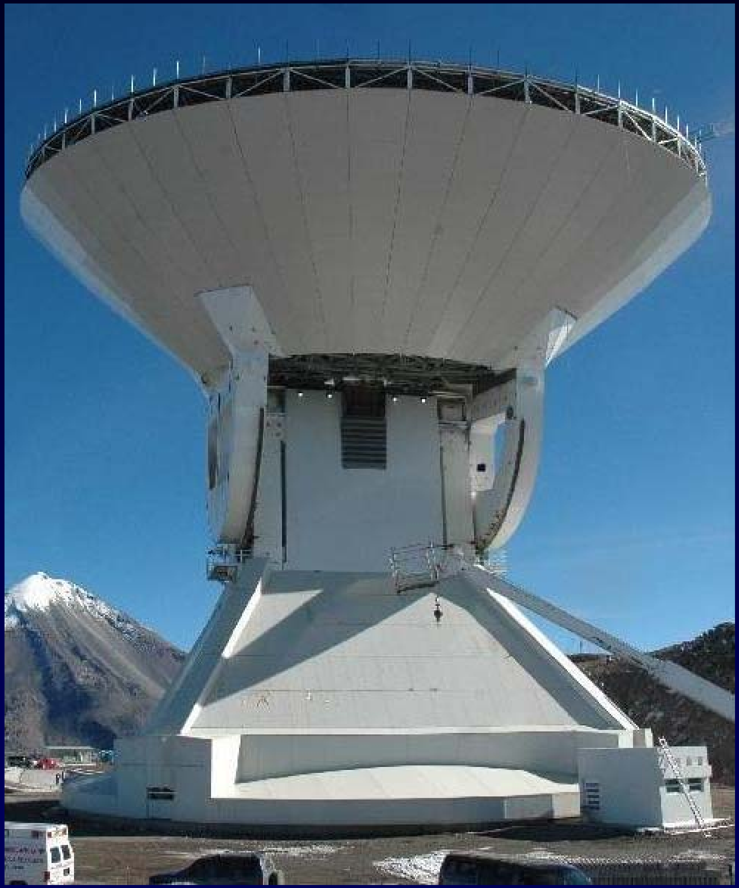
AzTEC commissioning & scientific operation

JCMT – 15m
2005



ASTE – 10m
2007-2008

LMT – 50m
> 2009



3 months continuous operation from JCMT
10 months operation from ASTE (1 week down-time due to cryogen failure)

used by 120+ astronomers from 12 countries

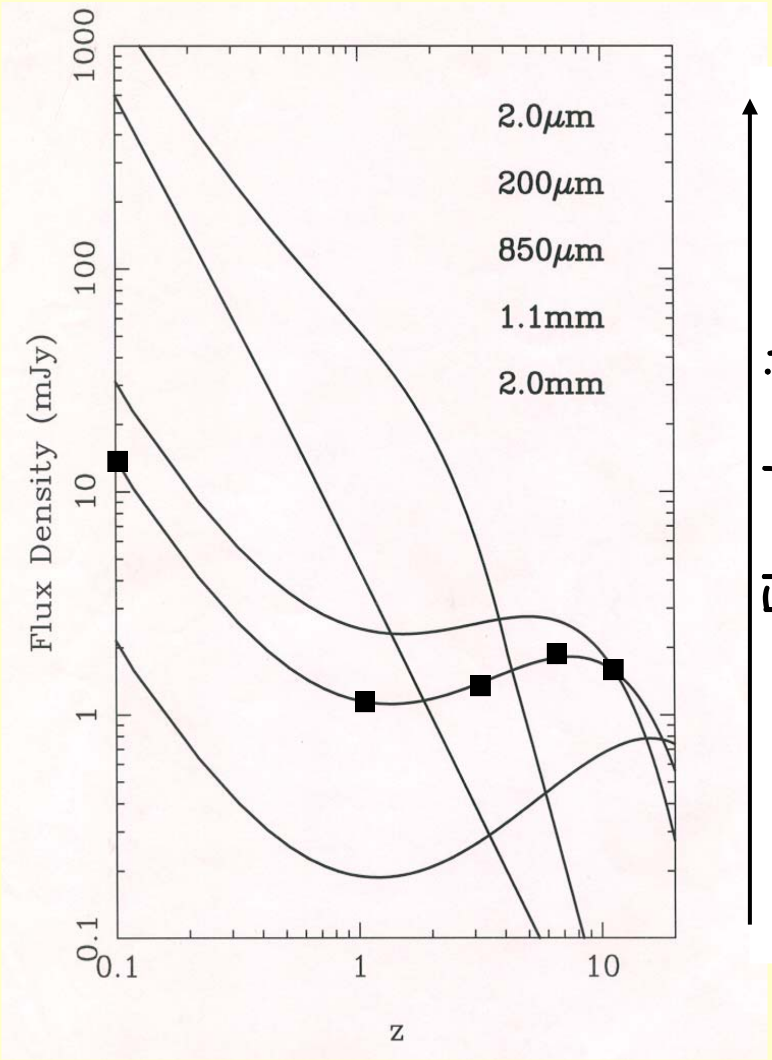
Mapping Speed

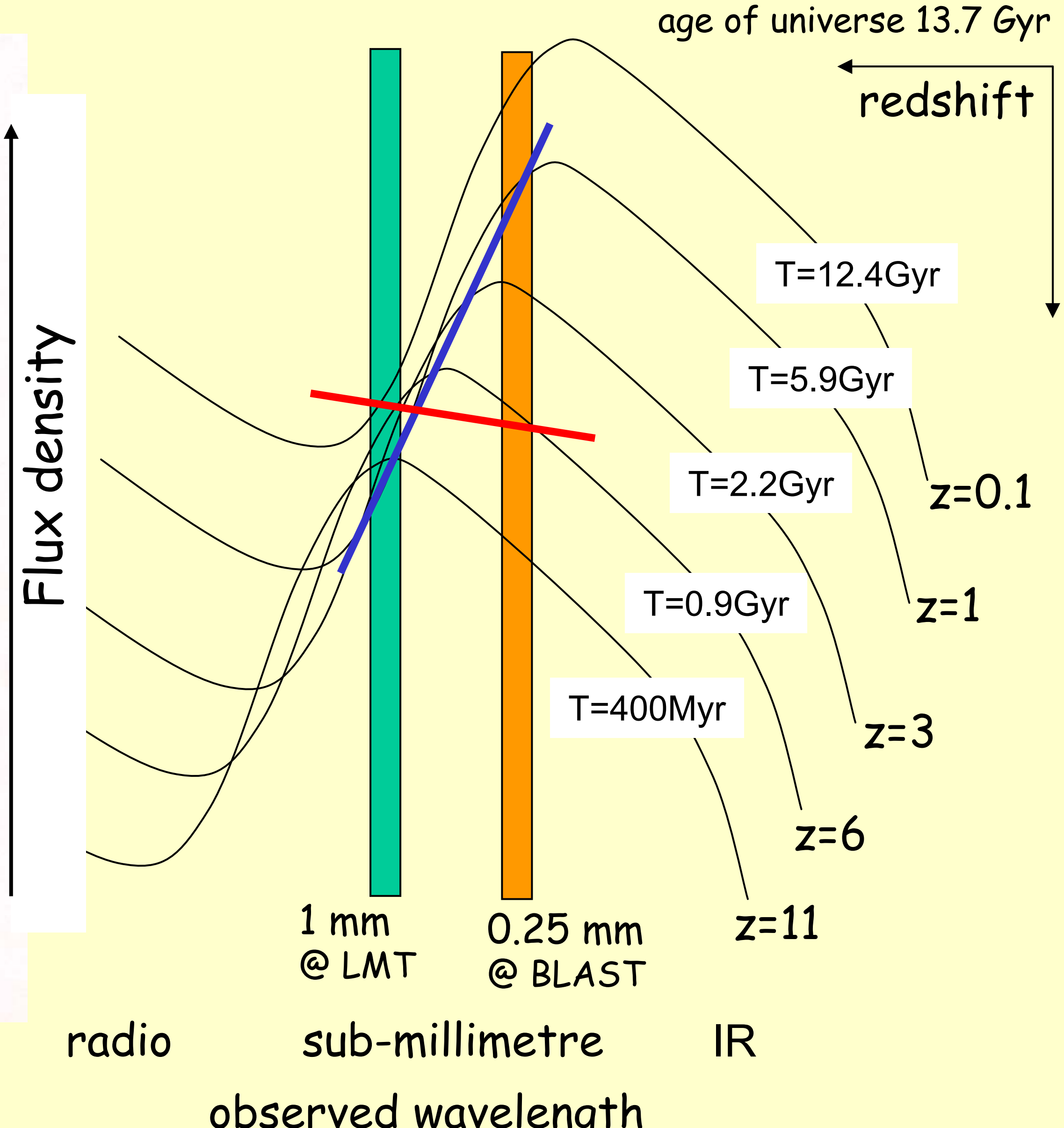
on JCMT: 23-28 $arcmin^2/mJy^2/hr$
on ASTE: 20-30 $arcmin^2/mJy^2/hr$
on LMT (projected): 2000 $arcmin^2/mJy^2/hr$

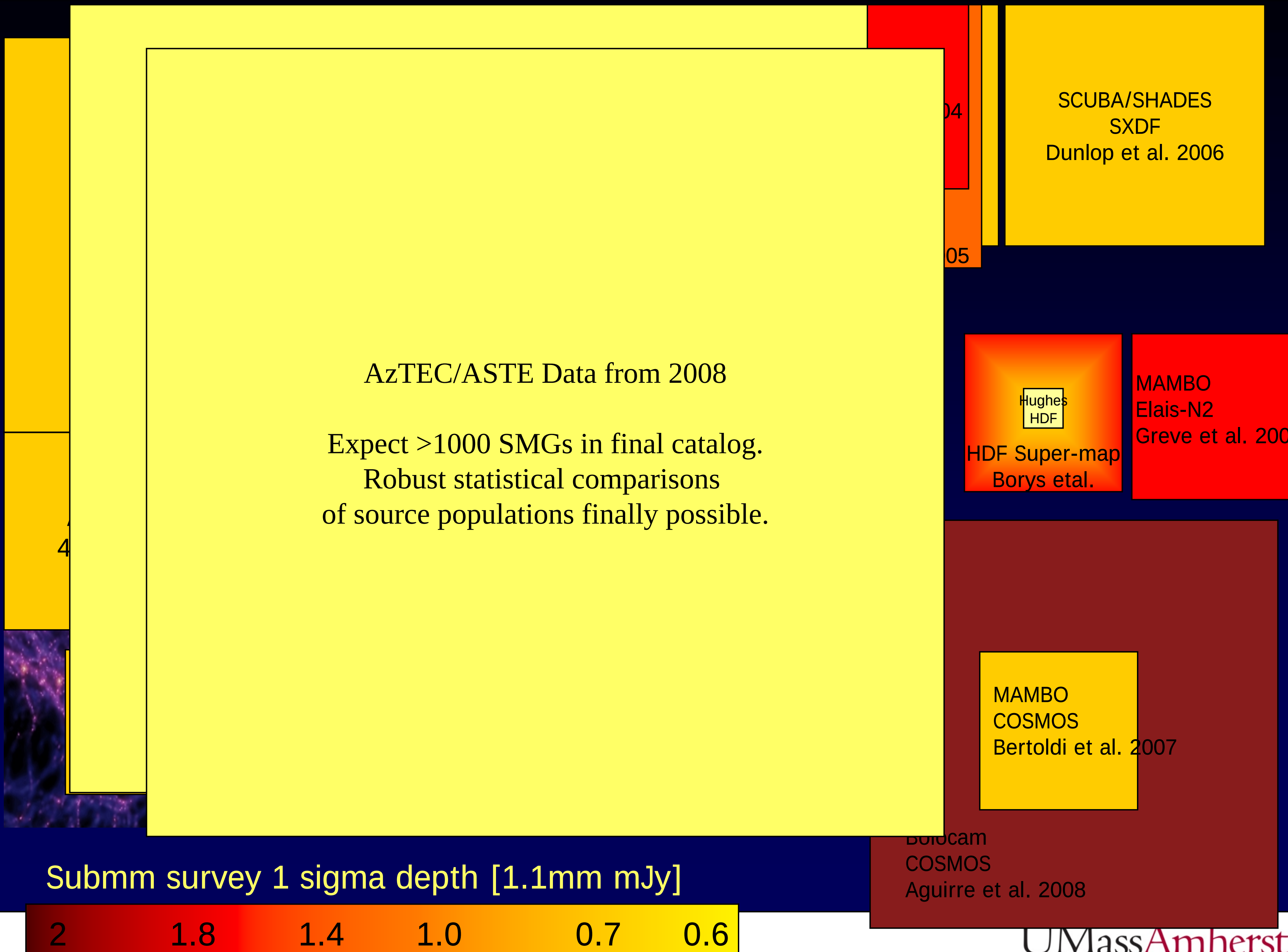
Building galaxies in the early universe

- feasibility of mm surveys

Arp 220 (z=0.018)
$L_{FIR} = 2\times10^{12} L_\odot$

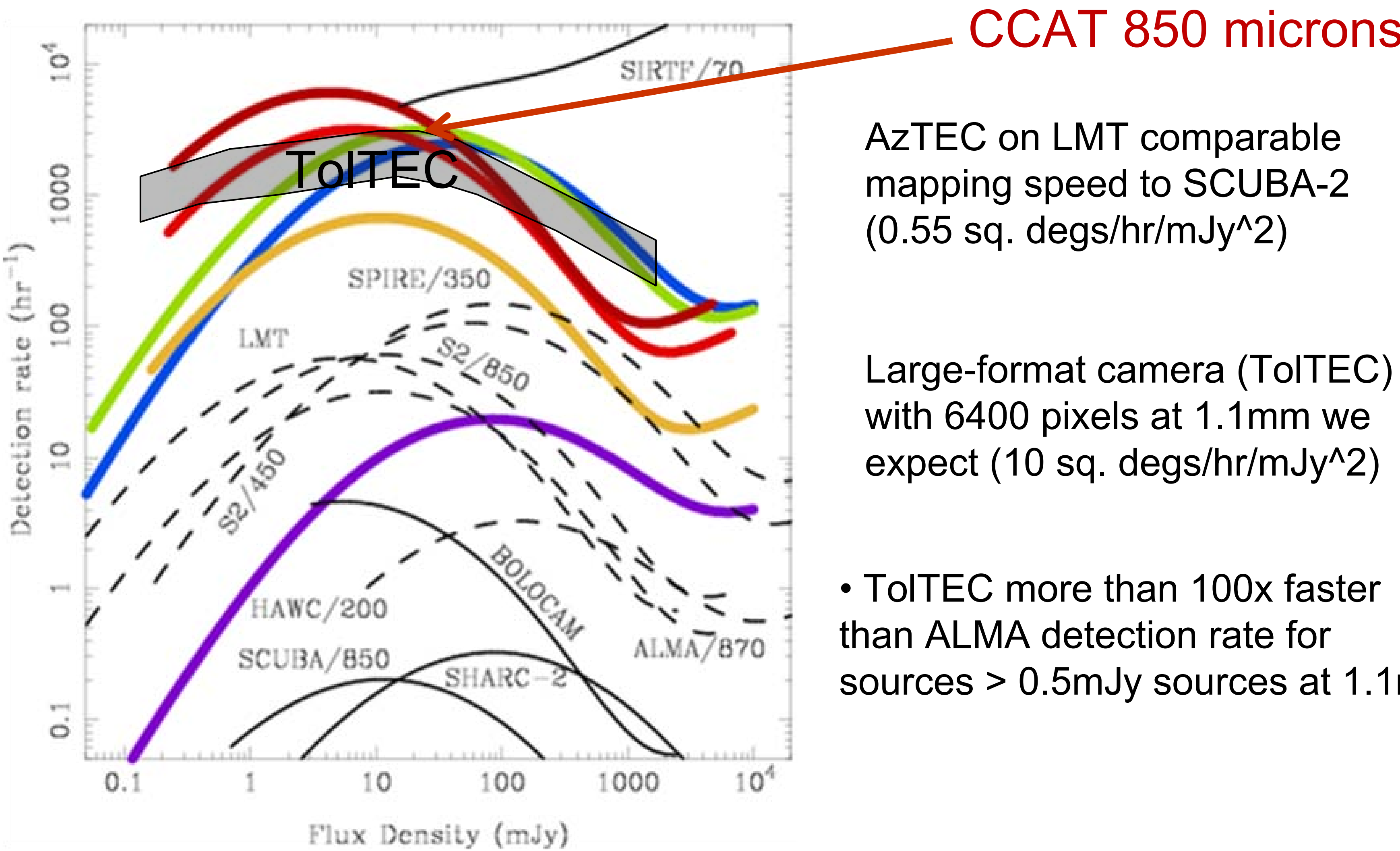






UMassAmherst

Comparison of LMT and other facilities



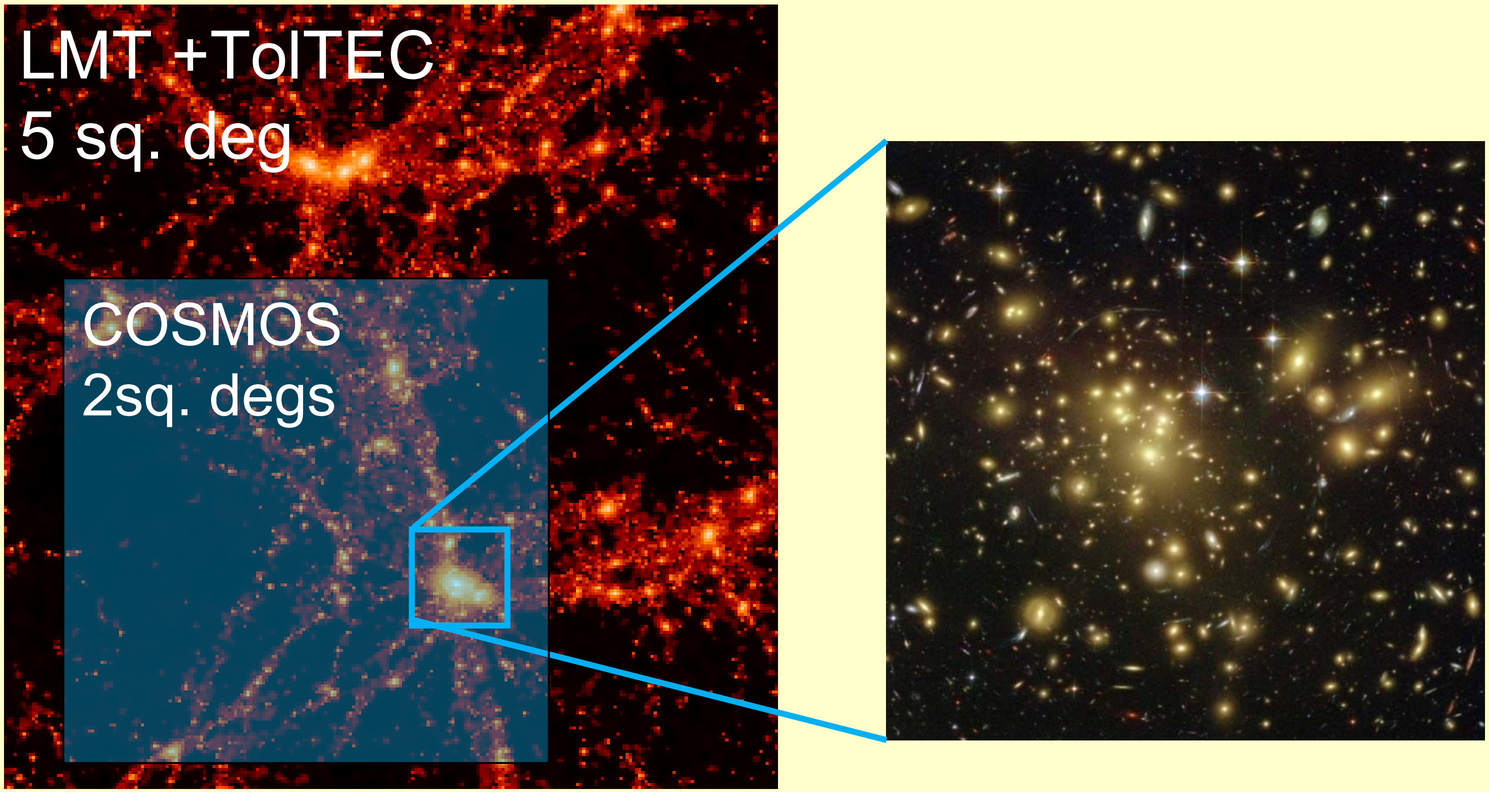
AzTEC on LMT comparable mapping speed to SCUBA-2 (0.55 sq. degs/hr/mJy^2)

Large-format camera (ToITEC) with 6400 pixels at 1.1mm we expect (10 sq. degs/hr/mJy^2)

- ToITEC more than 100x faster than ALMA detection rate for sources > 0.5mJy sources at 1.1mm

adapted from CCAT Feasibility/Concept Study Review

LMT LSS Key Project



- **Key Project:** 5 sq. degs sample - wide variety of LSS environments

- **> 100, 000 galaxies in 100 hr survey** (>0.4mJy; **SFR >40 Msun/yr ;** or resolving 100% of the extragalactic mm-background or 60% of FIR background)

LMT advantage - sensitivity & resolution

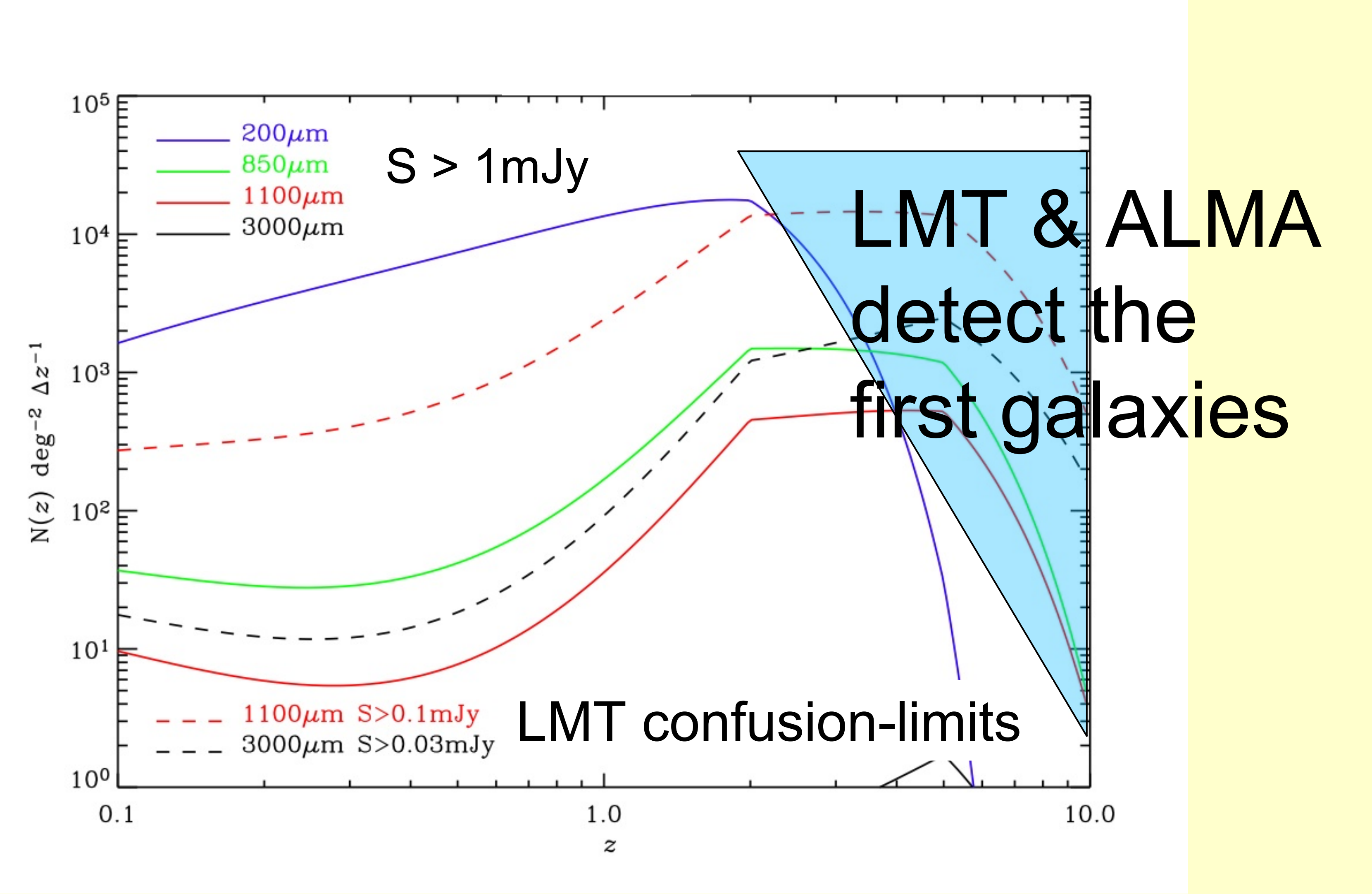
- Resolution of 10-25m diameter telescopes at sub-mm wavelengths imply confusion-limits > 1mJy

  - CSO, HHT, ASTE, APEX, JCMT, CCAT

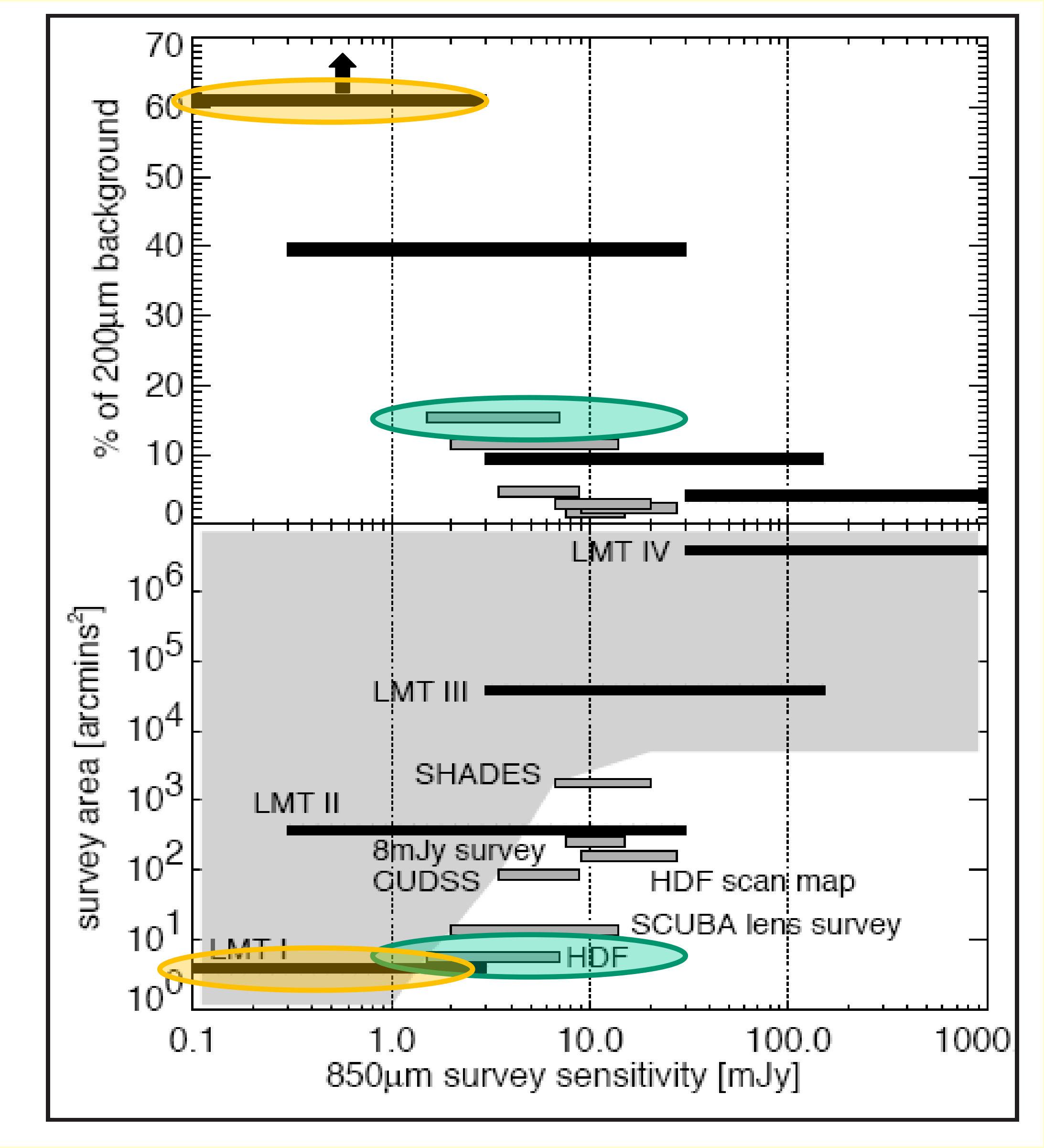
- Confusion-limits and short-submm (<450um) k-correction (flux NOT independent of redshift) of small sub-mm telescopes limits sensitivity to the detectability of the "first" galaxies at z > 6, unless SFR >> 1000 $M_{\odot}$ /yr

- Lower LMT confusion limits (~0.1 mJy) & longer-λ allow more moderate SFRs (few 10's $M_{\odot}$ /yr) to be detected by LMT in the first galaxies at z > 6

LMT advantage - sensitivity & resolution



Resolving the FIR extragalactic background (FIRB)



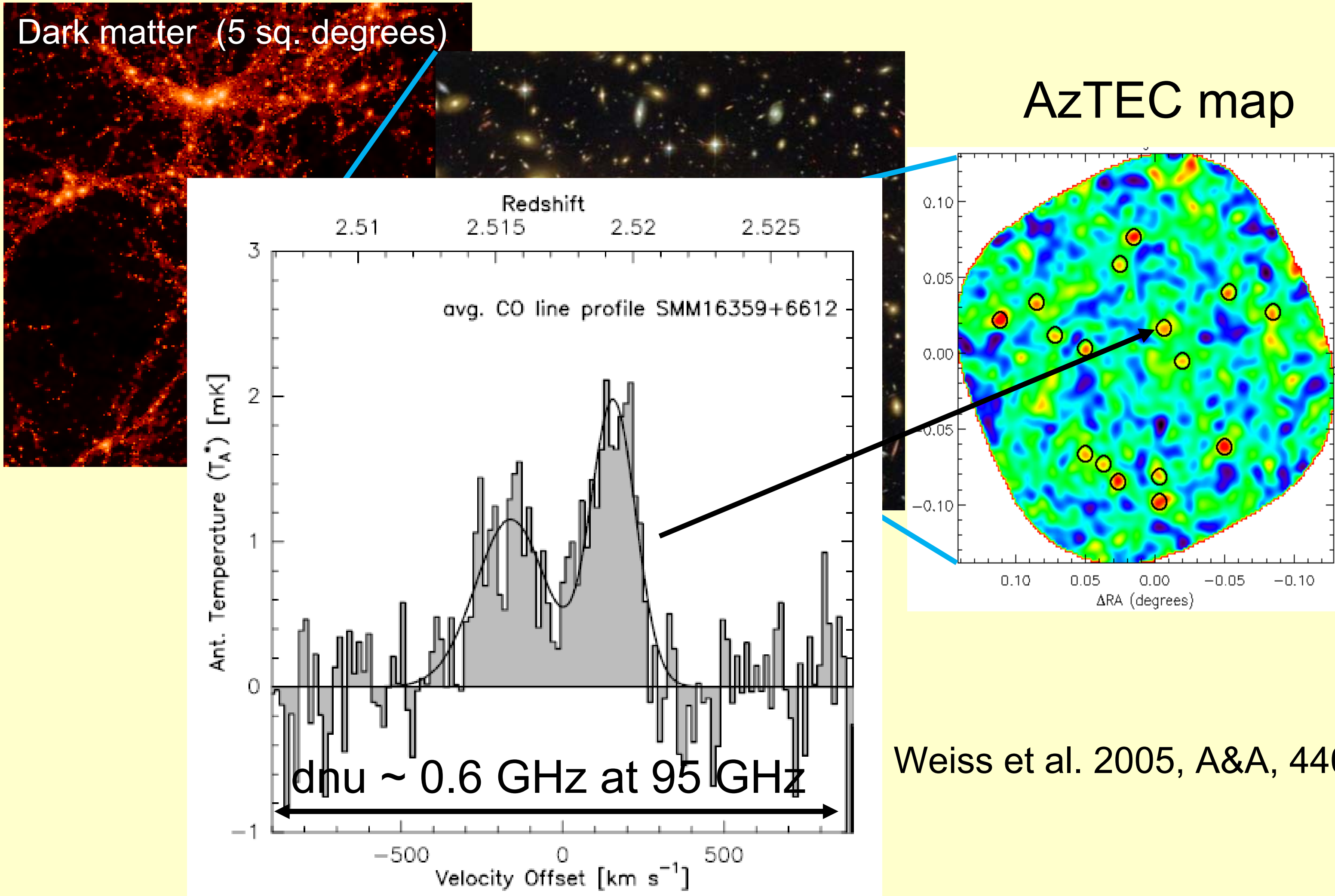
850um SCUBA JCMT

1.1mm AzTEC LMT

Confusion-limited LMT surveys resolve 100% of (sub-)mm background and > 60% of the FIRB at 200um

SCUBA(2) resolves 50% - 80% of 850um background, but ONLY 15% of FIRB.

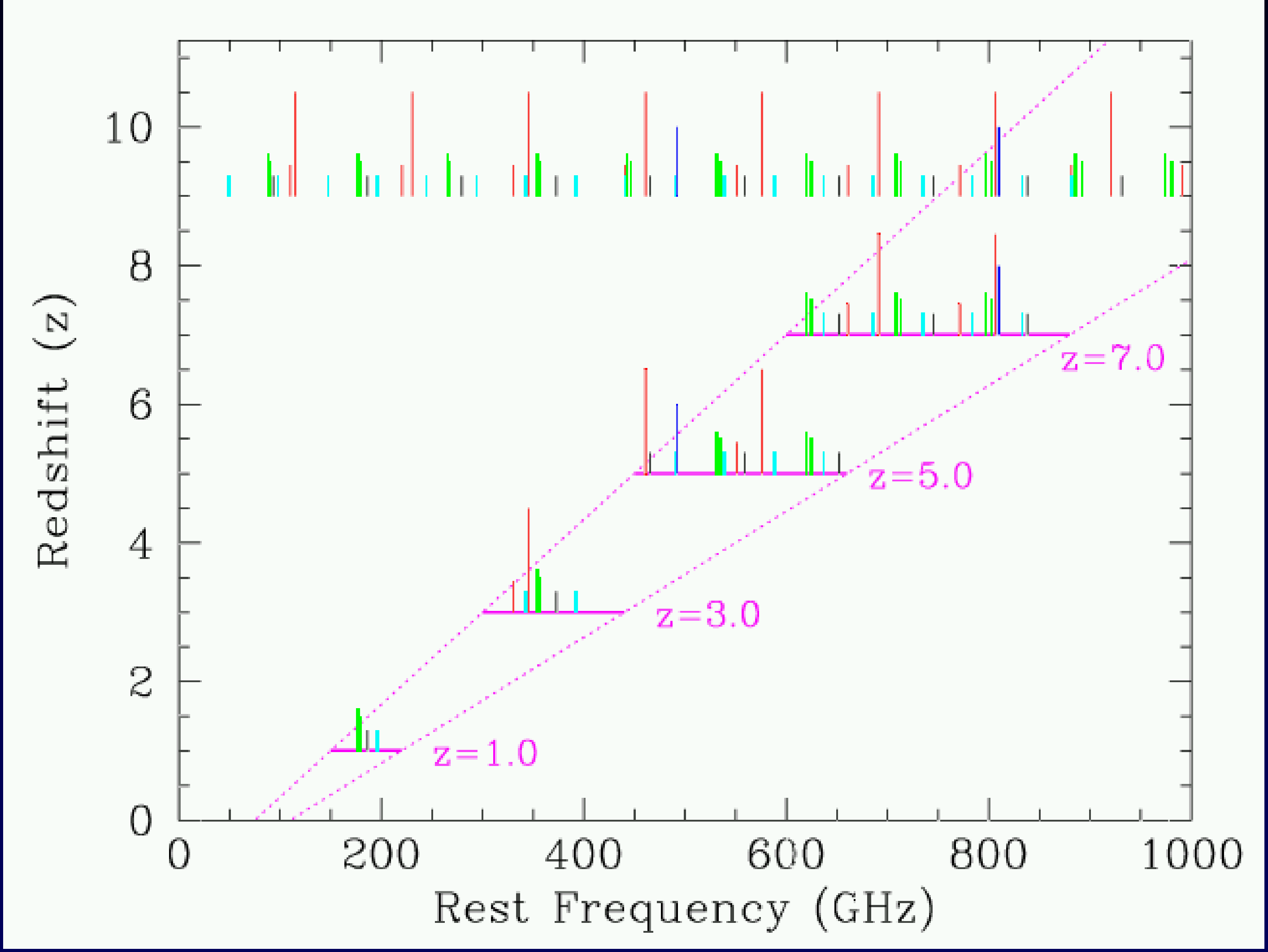
D.2. “How do galaxies arise and mature?”



Weiss et al. 2005, A&A, 440, L45

spectroscopic redshift (CO, CI, HCN, ….) for every(?) source

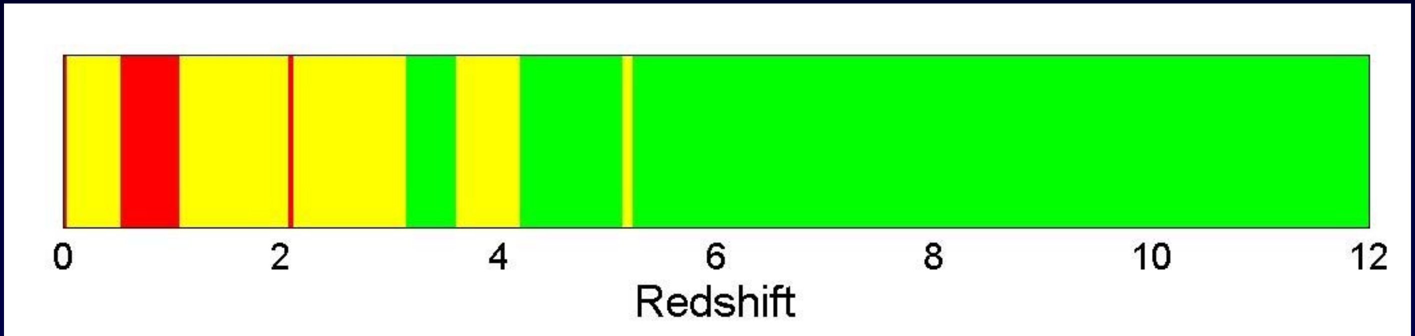
LMT Redshift Search Receiver



bandwidth (z=0) ~ 36 GHz (74-111 GHz)

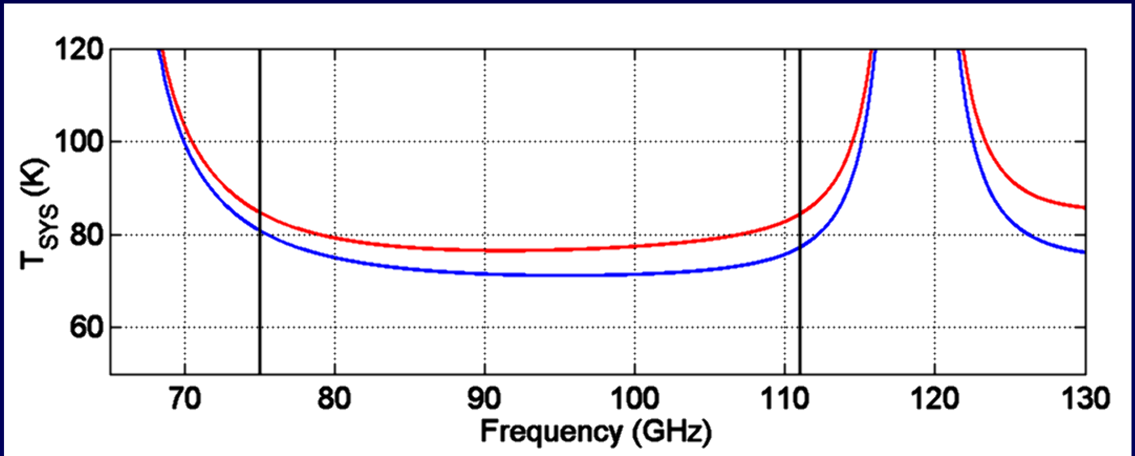
Frequency Range

- Strongest spectral lines from CO and CI (492, 810 GHz). More than one line needed; search the maximum possible bandwidth.
- Lines are expected to be quite weak, search in best 3 mm window.



Redshift coverage in 74-110.5 GHz band,

red no CO line, yellow; one line, green; two lines.



System noise temp with Trec = 60 K and 2 and 5 mm PWV.

Ultra Wideband Redshift Search Receiver

- Science goal is to measure galaxy redshifts where Z is unknown.
- 74-110.5 GHz covered simultaneously with a receiver/spectrometer having 30 MHz resolution.
- Wide bandwidth with very low noise is practical with InP MMIC amps operated at 20 K.
- Full receiver has 4 pixels - two dual polarization feeds with ortho-mode transitions.
- 1 KHz ferrite beam switch on input for very flat baselines.

- Each receiver has 2 IF outputs 1.5-20 GHz x 4 receivers

  $\Rightarrow$ 146 GHz total IF bandwidth!
- A new generation of spectrometer is needed for this problem.

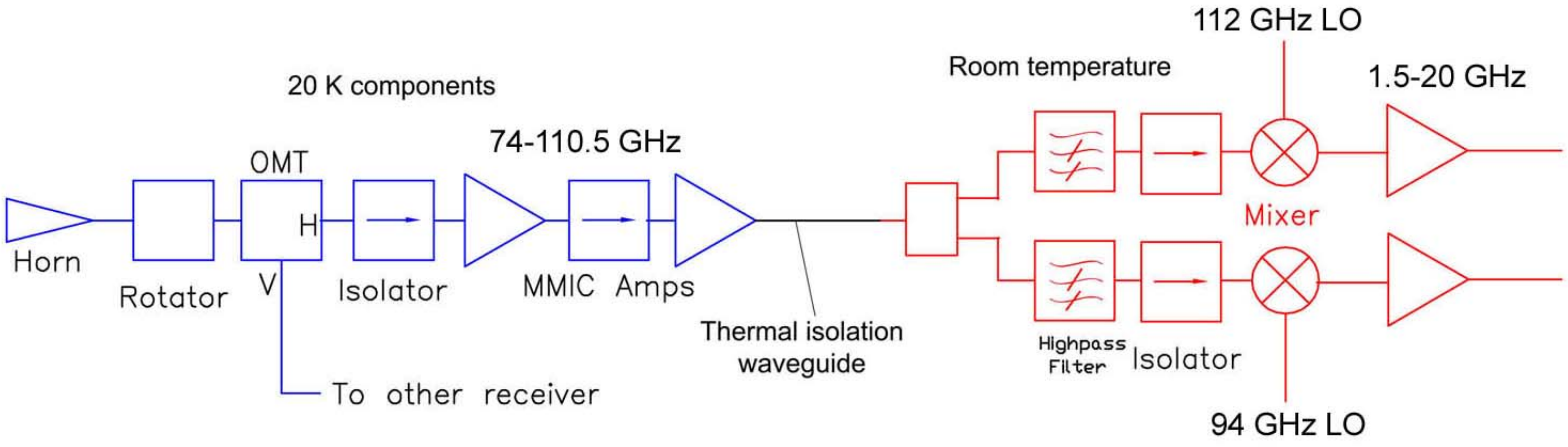
Front end design

•Front end like SEQUOIA, using InP MMIC amps, except that both signal polarizations combined with ortho-mode transition.

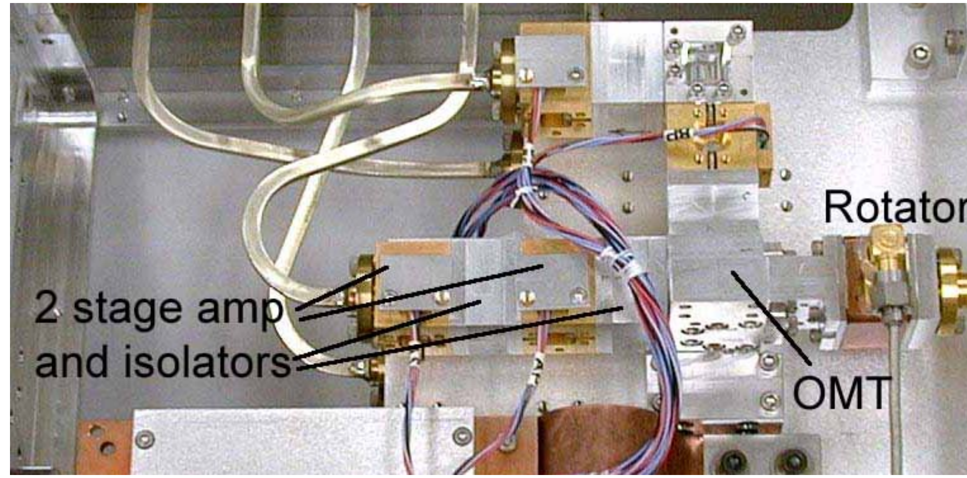
•Entire signal band down-converted at once to two 18.5 GHz wide IF bands.

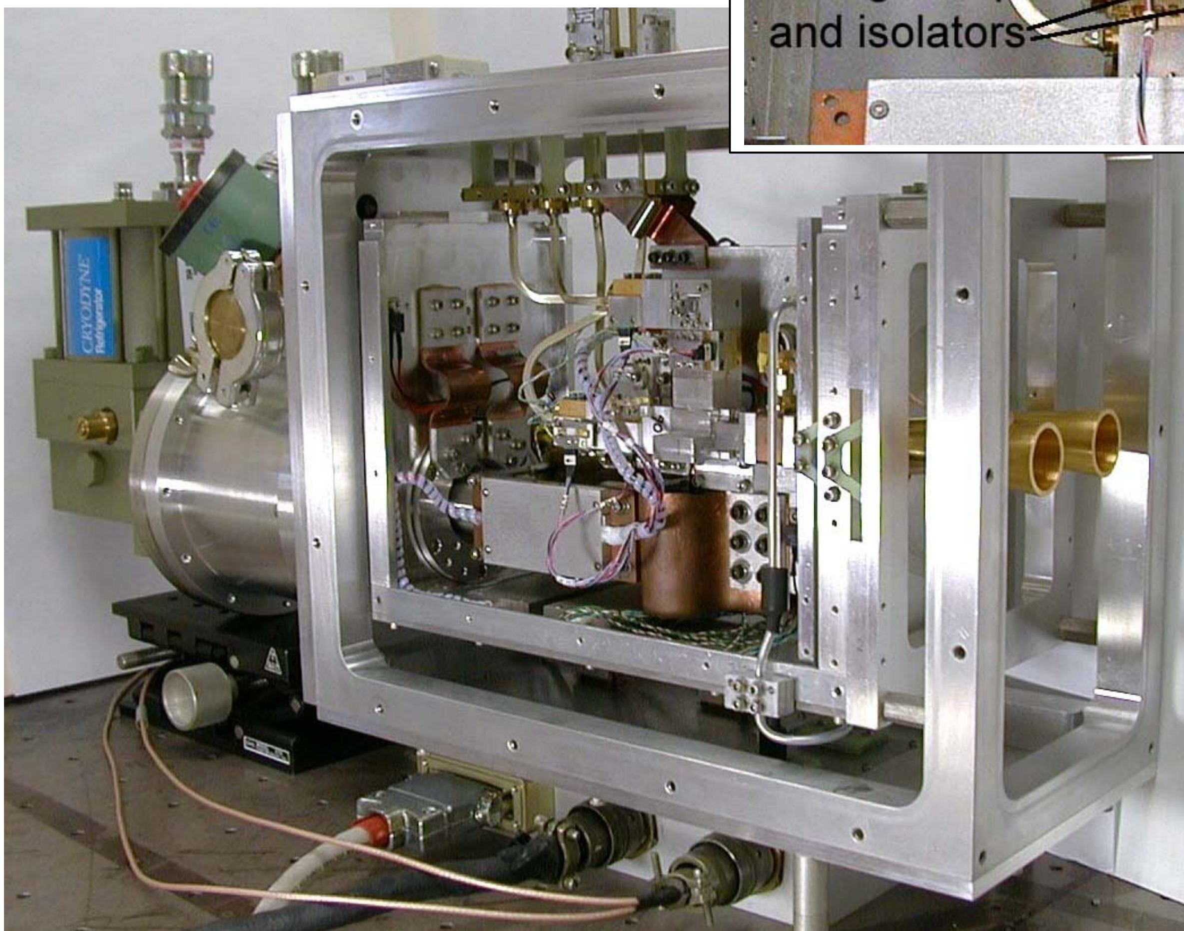
•Four receivers with 8 IF outputs in total.

•1.5-20 GHz IF band split into three overlapping bands of 1.5-8.0 GHz to drive the spectrometer.



Room temp frontend components mount to the outside of the dewar at the waveguide feedthroughs.





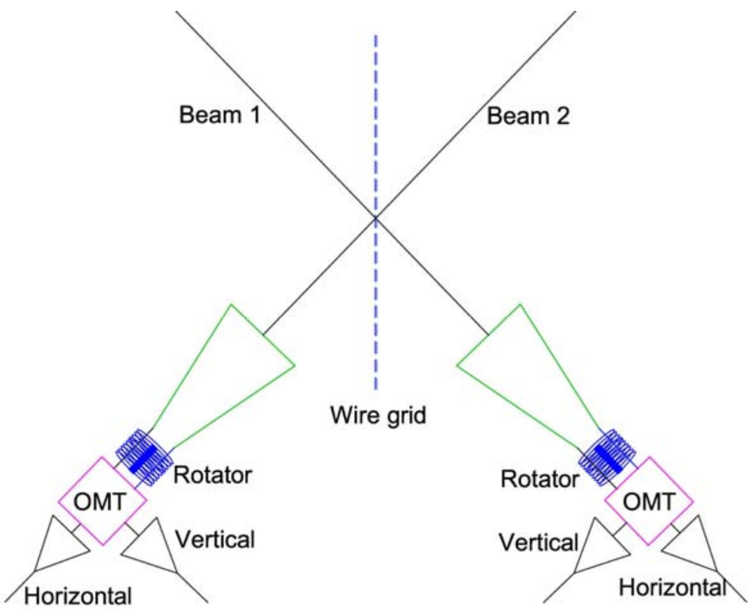
Detail of one dual polarized receiver.

Beamswitch

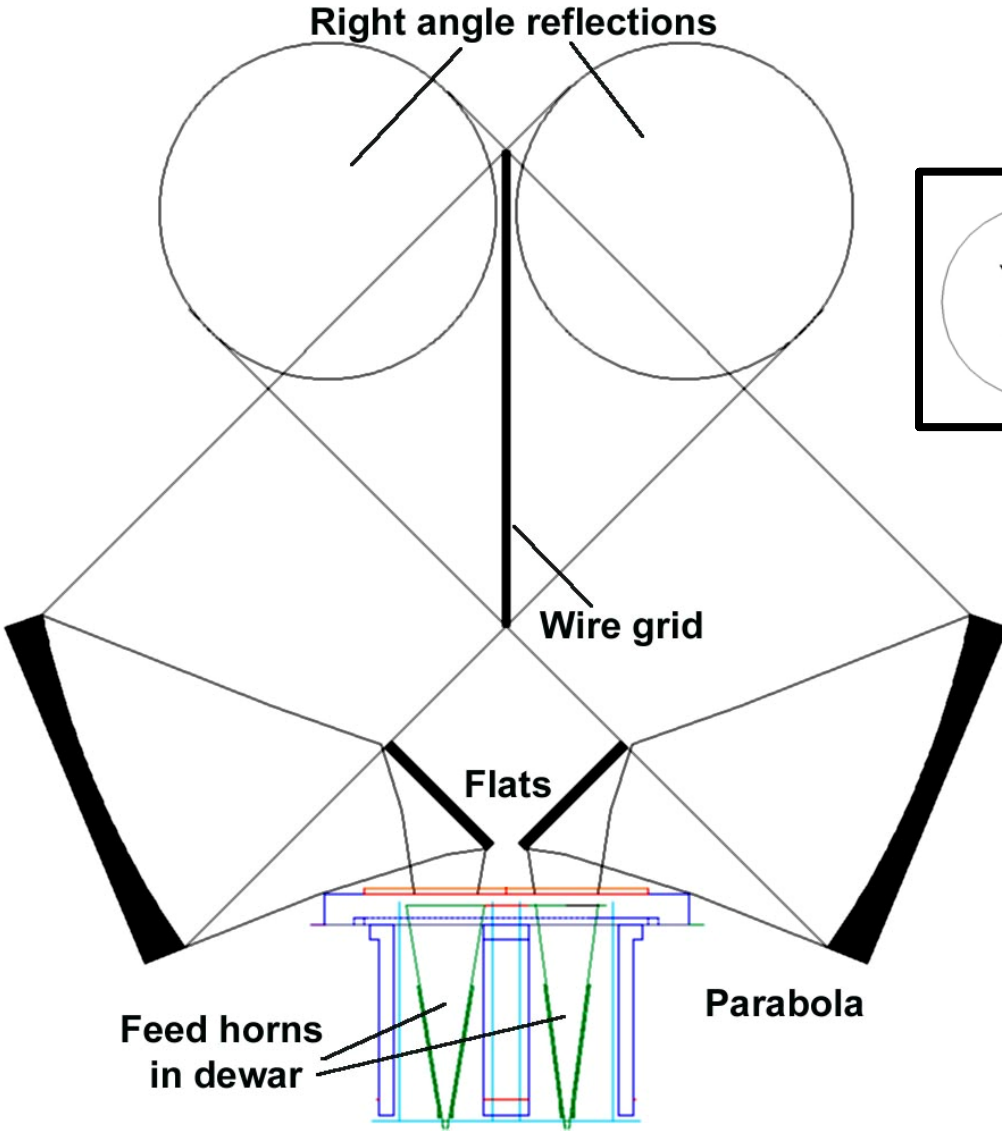
HEMT amplifiers require a fast (~1 KHz) beam switch.

This receiver uses a ferrite rotator to change polarization 0 90 at 1 KHz rate.

Wire grid in front of rotator either passes or reflects beam depending on polarization state.



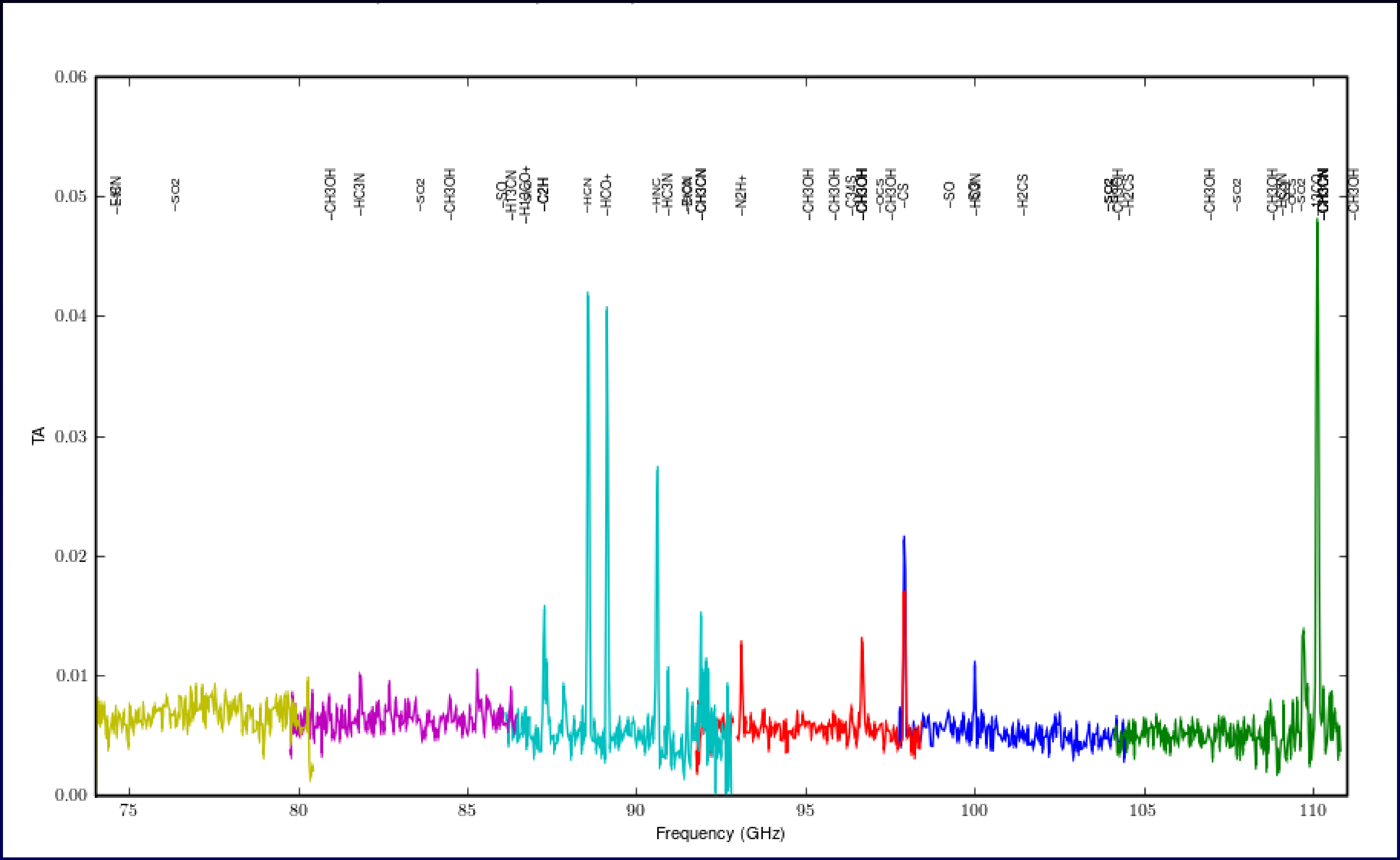
Receiver has two dual polarized beams with a fast beamswitch (flat baselines). One beam always on source.



Beams separated in azimuth with spacing of 3 HPBW.

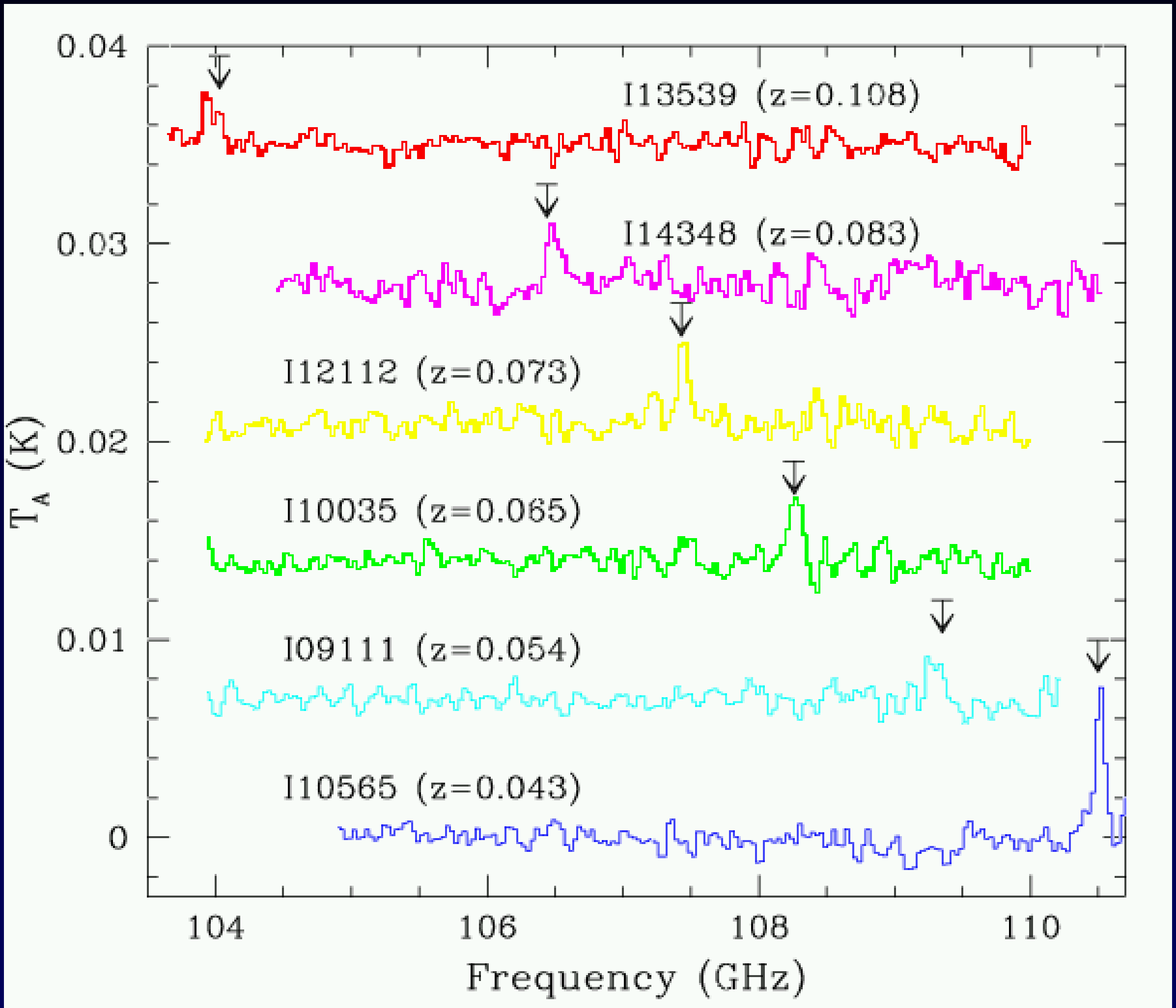
Optical design couples to the 2 horns with 2 beams nearby on the sky, converts f ratio, and has wire grid required as a part of beamswitch.

NGC 253



CO (1-0) Survey of Local ULIRGs

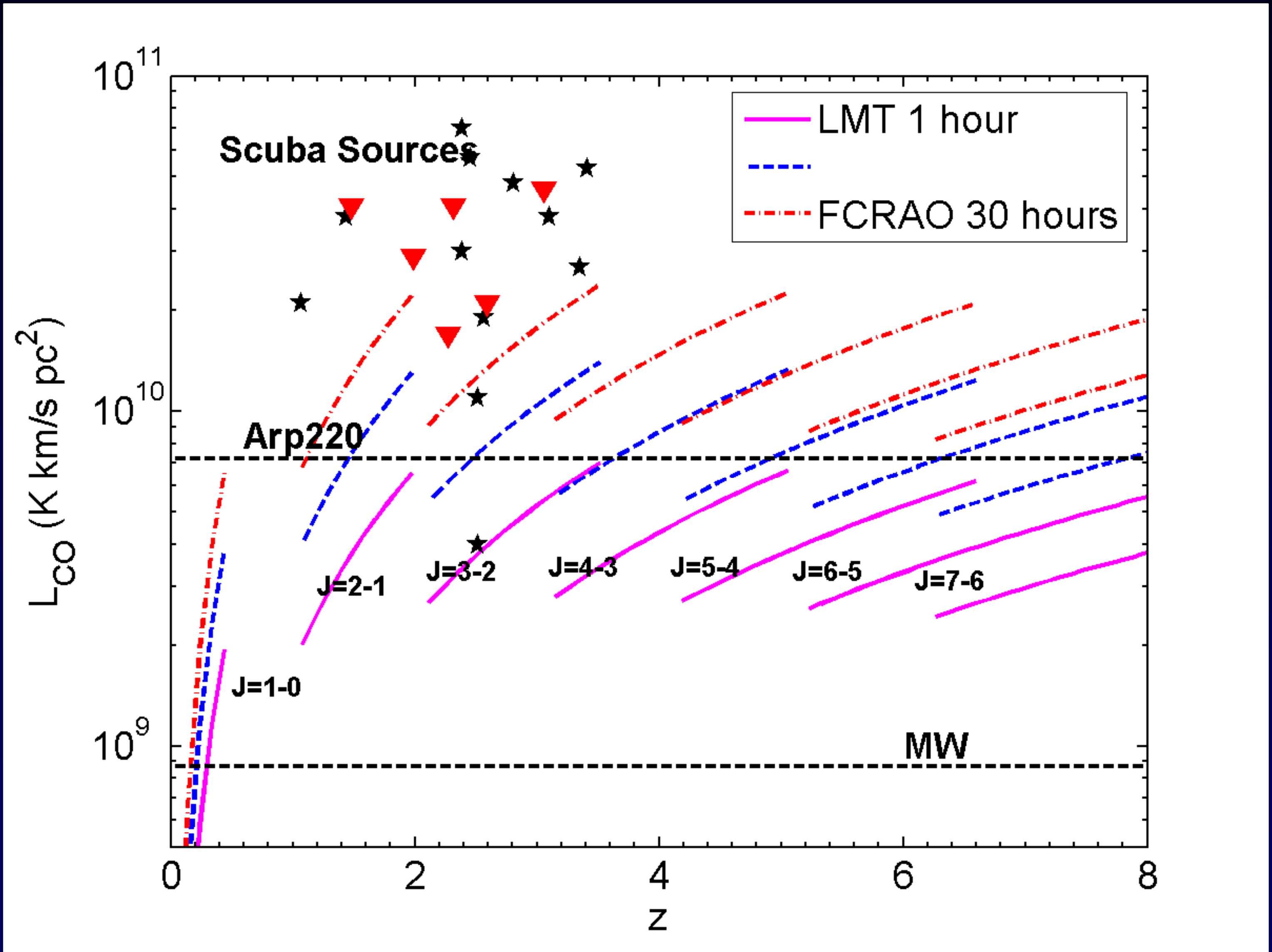
A. Chung et al., in prep.



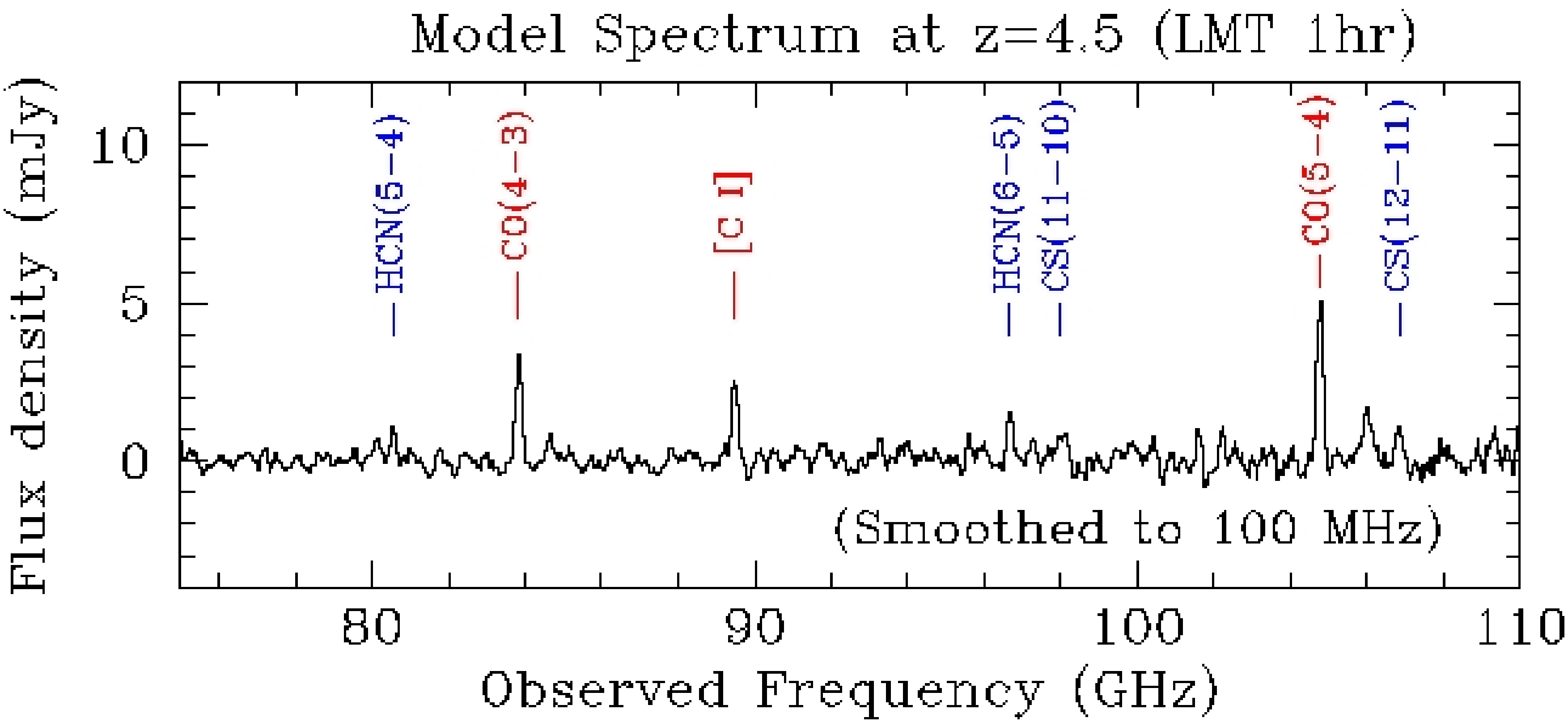
T_{sys}, typically 200-300 K on FCRAO 14-m

T_A^* ~ 1.6mK rms within 1 hr, 0.3 to 0.8 mK with t_{int}~5 to 43 hrs

Redshift Receiver System on the FCRAO and LMT



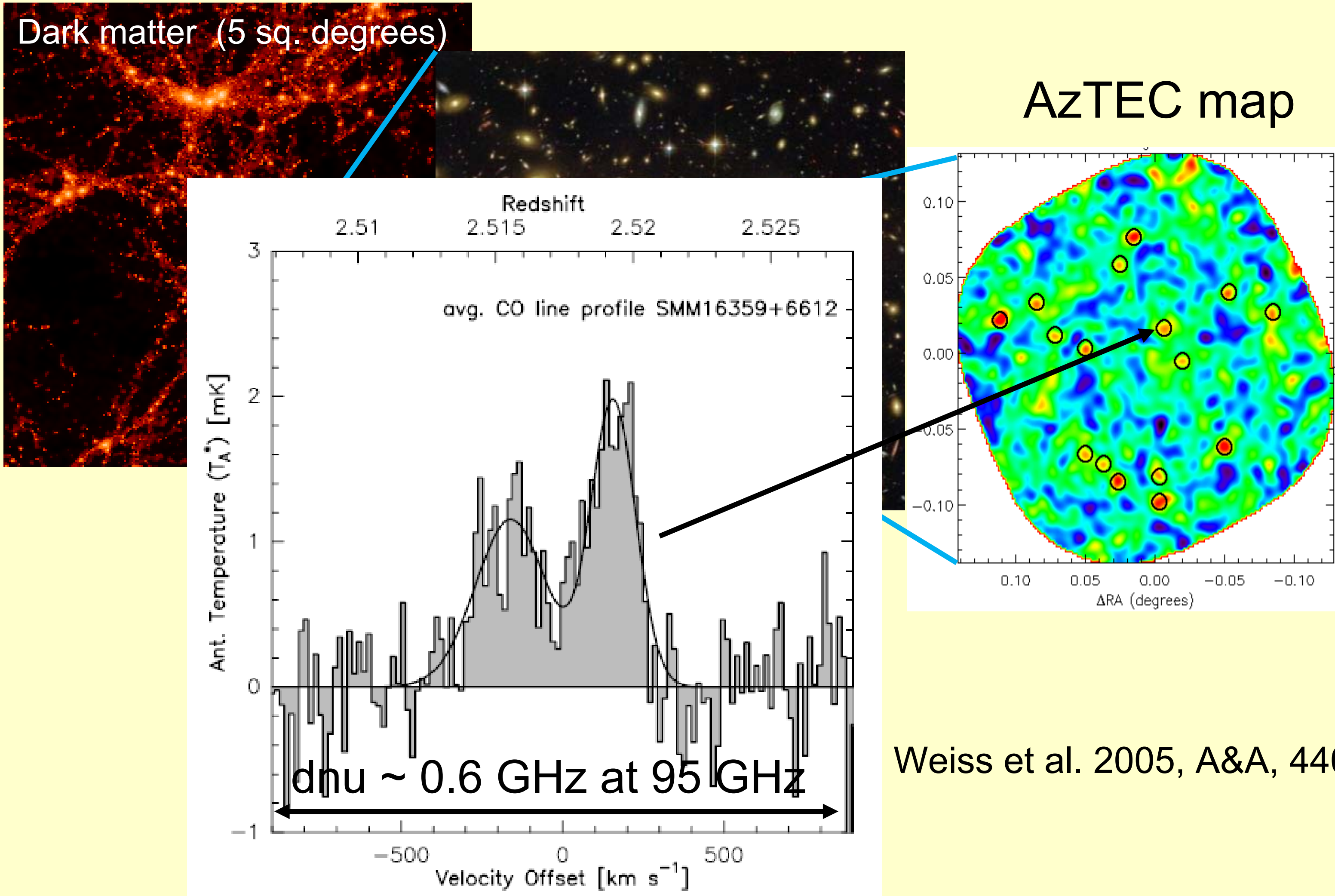
High-redshift molecular-line spectrum and spectroscopic-redshifts with the LMT *"redshift*-receiver"



• perform efficient measurements of CO spectroscopic redshifts without the prior necessity to have accurate X-ray, optical, IR or radio positions.

(simulation by Yun et al. 2006)

D.2. “How do galaxies arise and mature?”

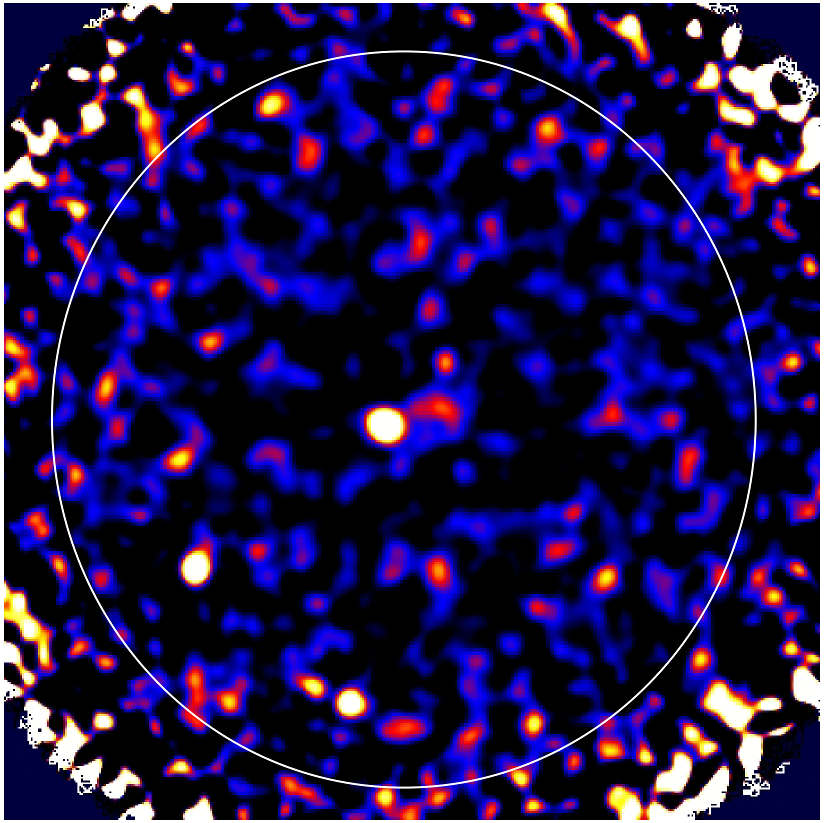


Weiss et al. 2005, A&A, 440, L45

spectroscopic redshift (CO, CI, HCN, ….) for every(?) source

Point-source contamination of the SZE by submillimeter galaxies in arcminute resolution experiments

Bullet Cluster 1E0657-56



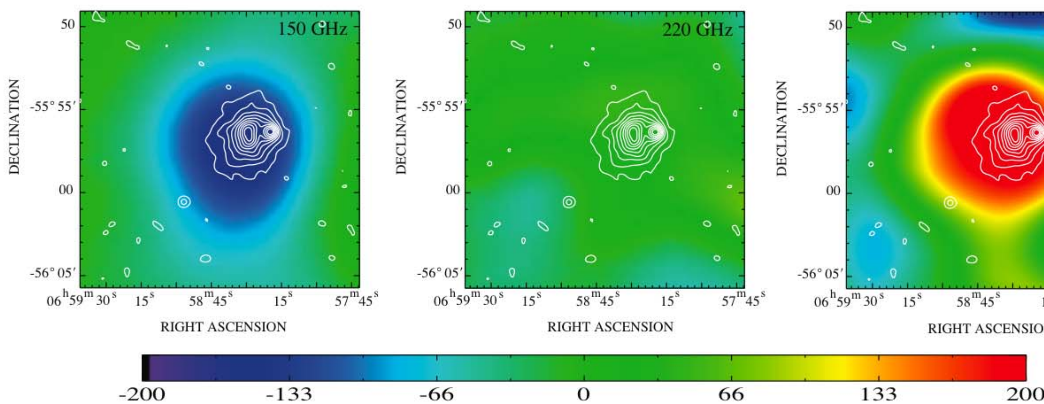
- in ACT -55 deg strip
- 1.1mm AzTEC map
- ~12 x 12 arcmins
- σ<0.6 mJy (25 hours)

Wilson et al. 2008. MNRAS in press arXiv:0803.3462
A bright, dust-obscured, millimeter-selected galaxy beyond the Bullet Cluster

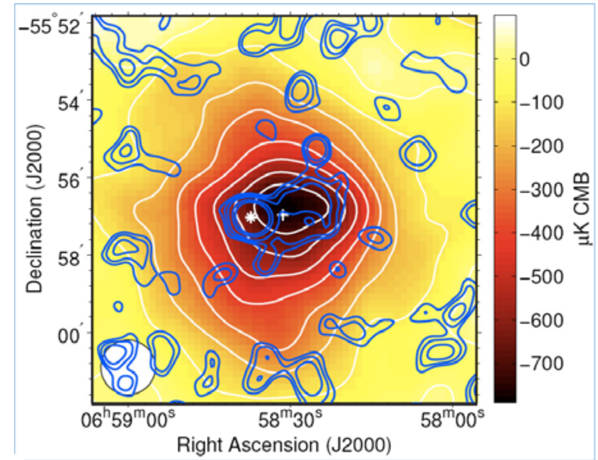
arcmin resolution detections of the Sunyaev-Zeldovich effect

Bullet Cluster - ACBAR map Gomez etal. 2005

beam FWHM ~ 4.5 arcmins



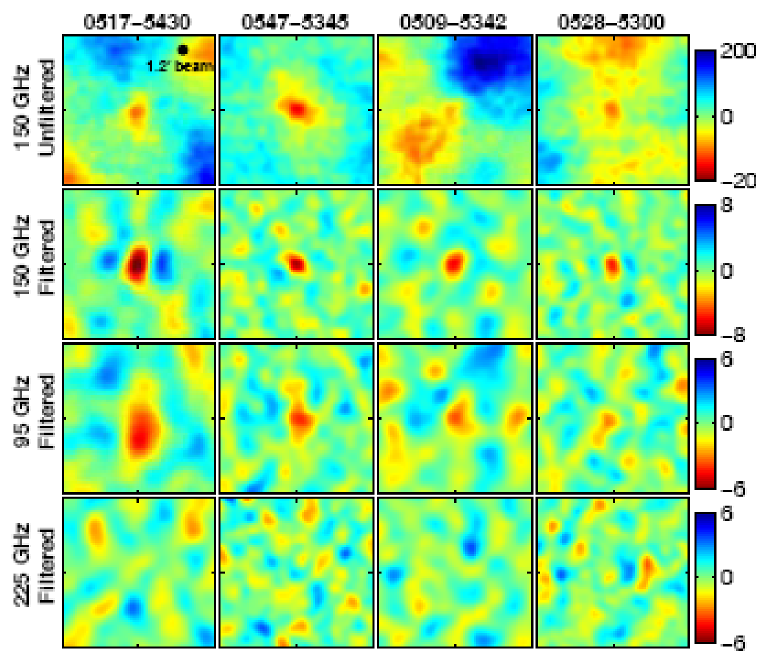
APEX-SZ 2mm map
85 arcsec beam



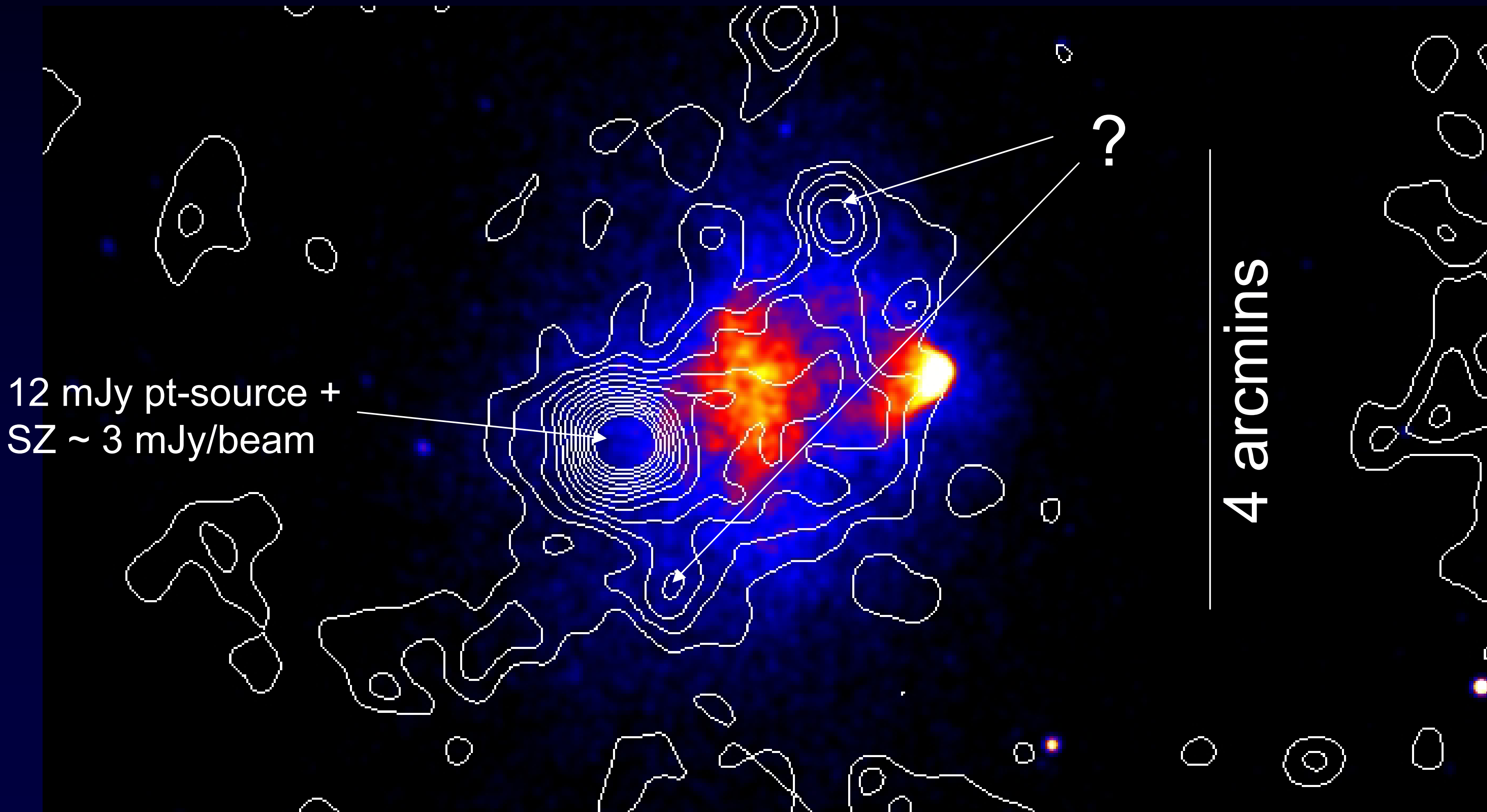
blue contours AzTEC 1.1mm
30 arcsec beam

SPT SZE detections

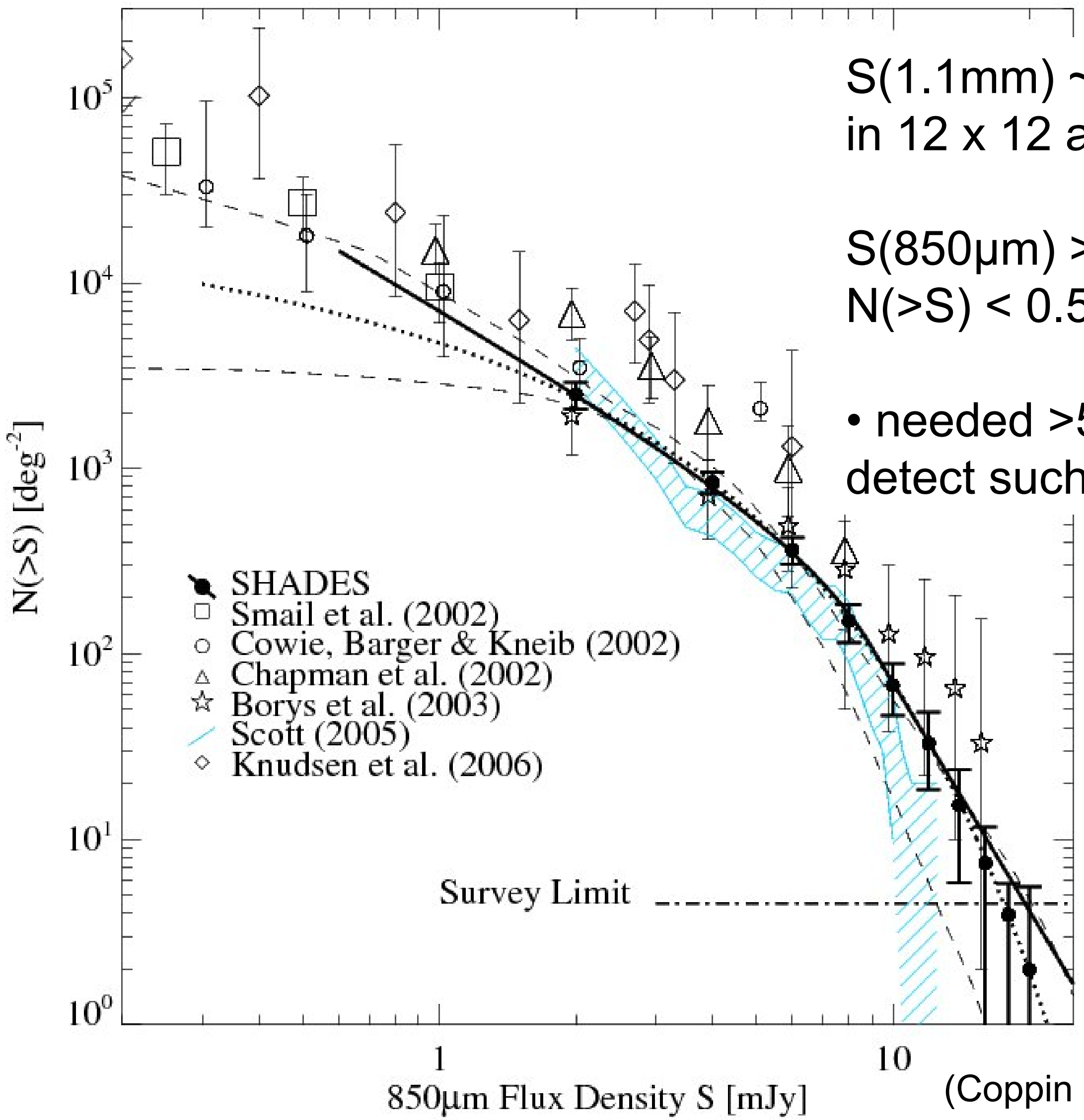
Staniszewski etal. 2008



Bullet Cluster:
AzTEC 1.1mm contours on X-ray emission



• Sub-mm surveys (source-counts) imply a strongly evolving, luminous ($L_{FIR} > 10^{12} L_{\odot}$), optically-obscured, galaxy population in the high-z Universe



S(1.1mm) ~ 16 mJy (pt-source) in 12 x 12 arcmin map.

S(850μm) > 32 mJy
N(>S) < 0.5 /sq deg.

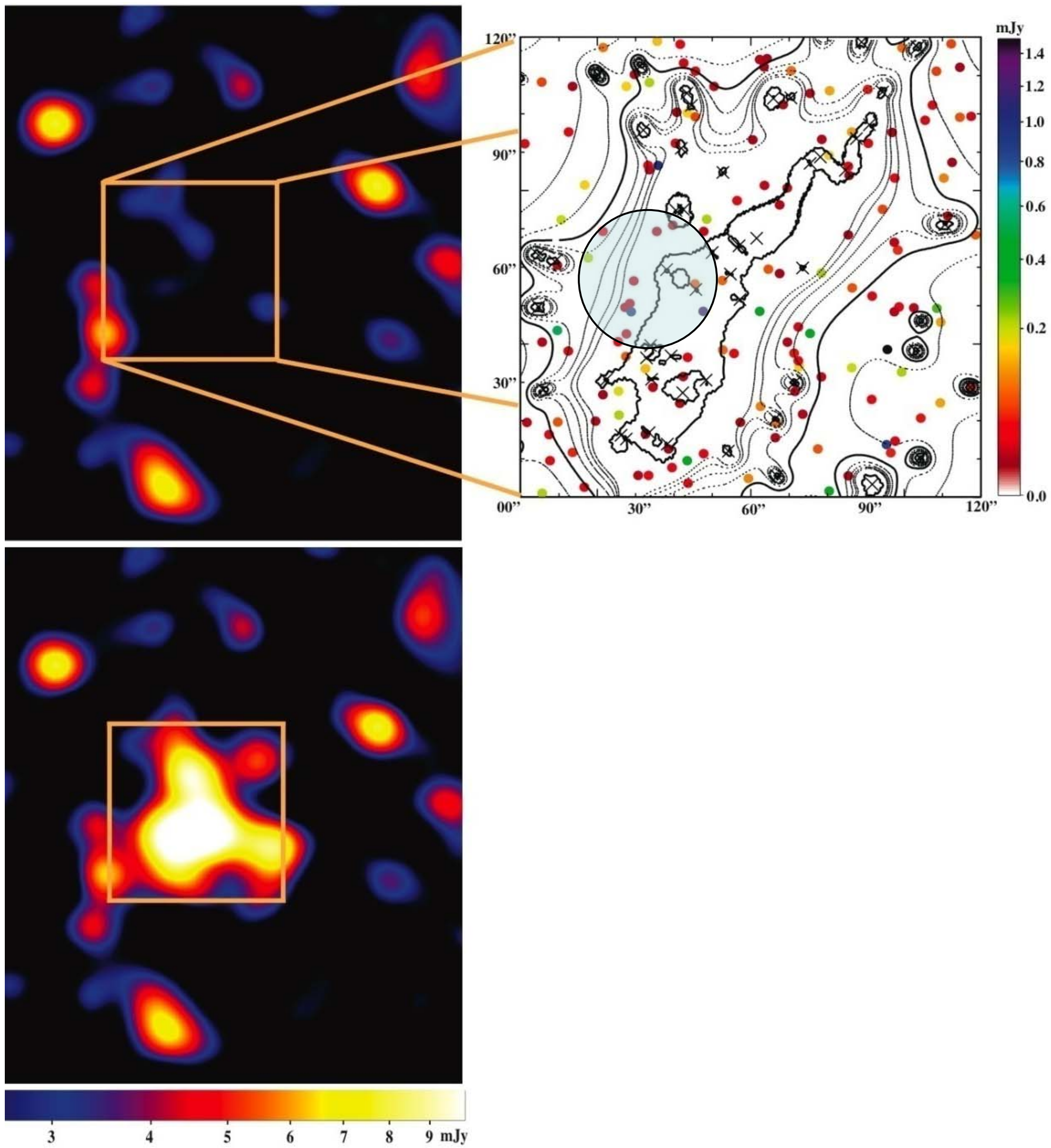
• needed >50 x the map-area to detect such a bright-source

(Coppin et al. 2006)

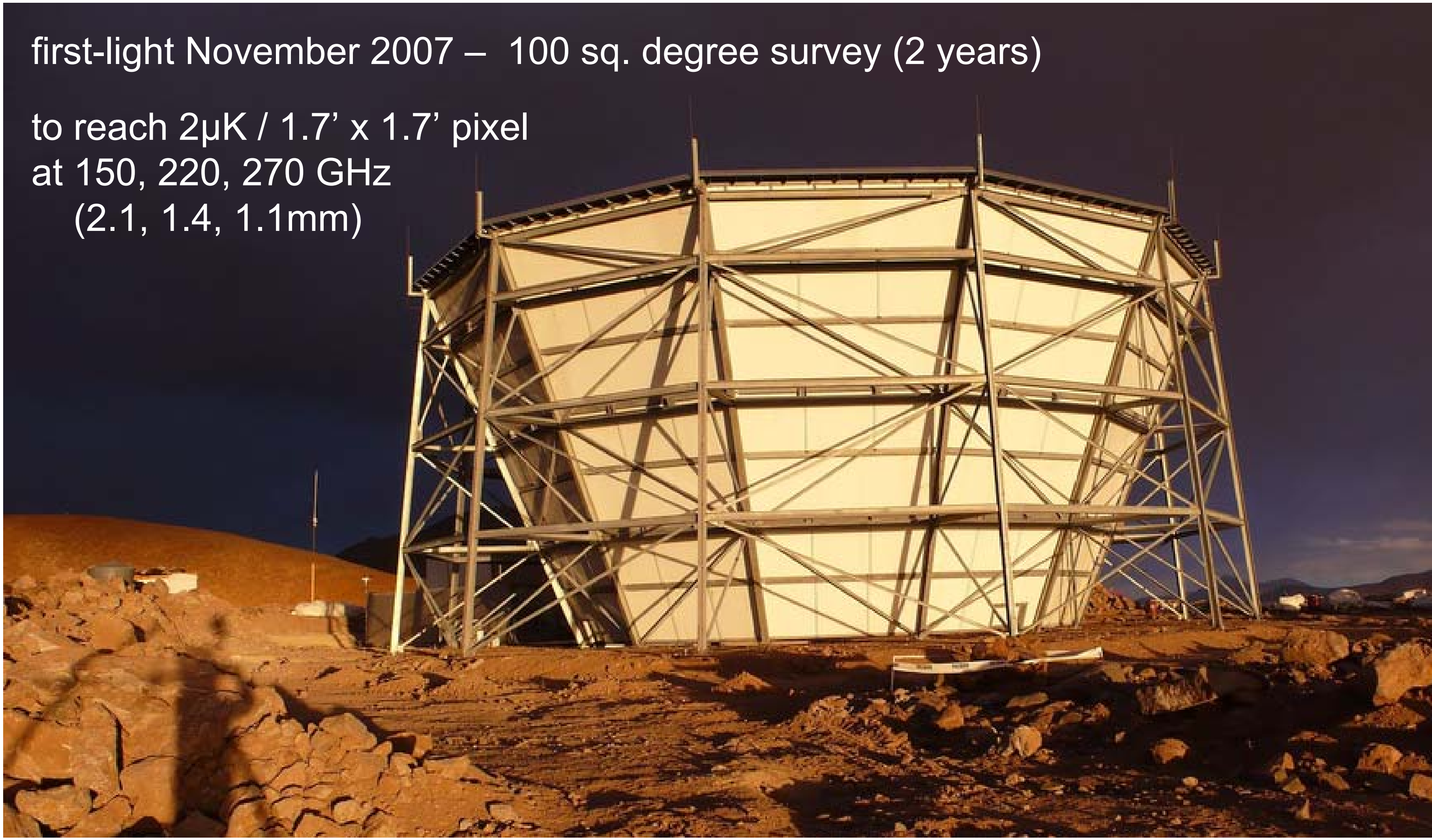
Lensing the millimeter galaxy population

No lensing

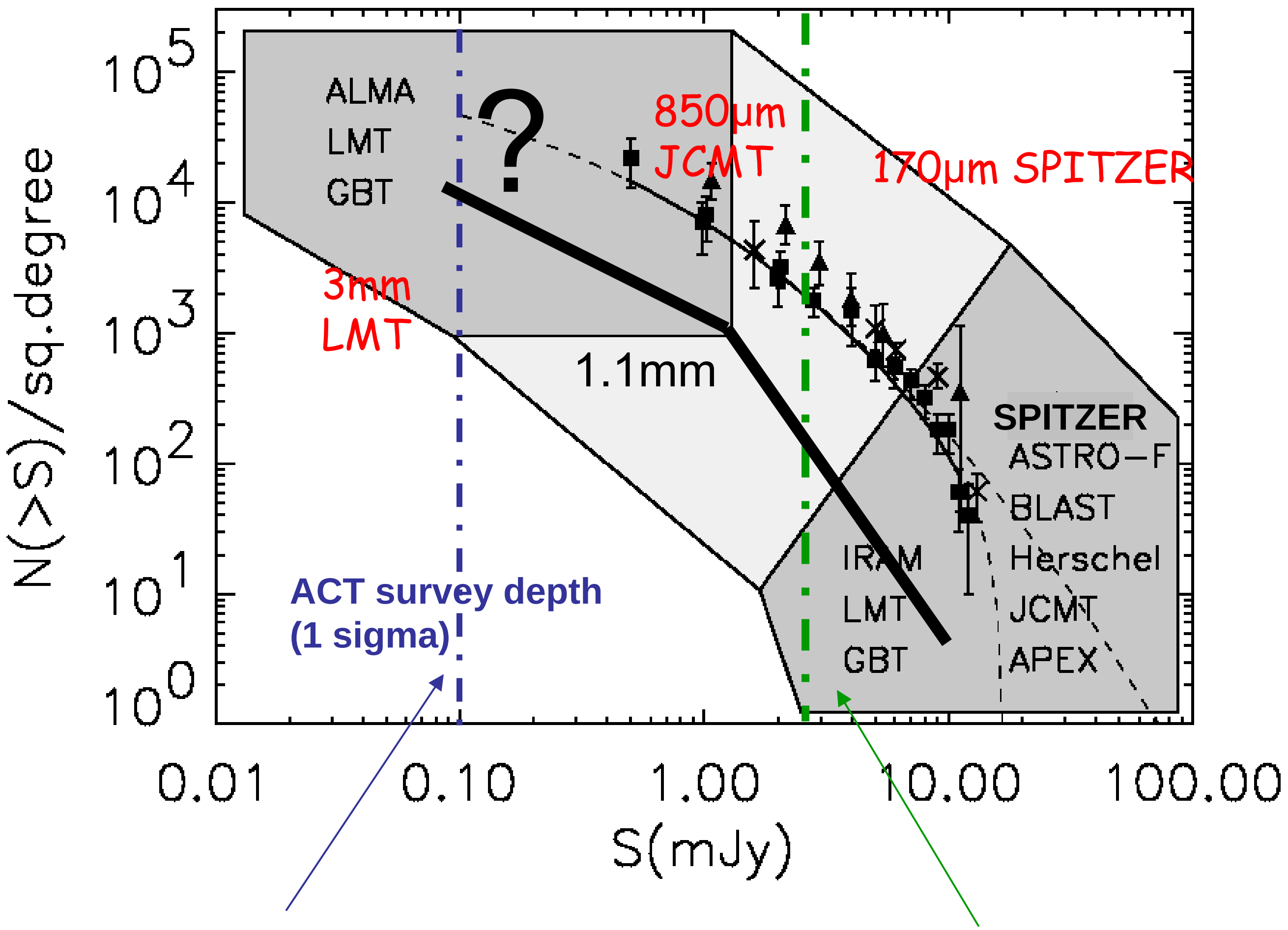
Lensed submm population
by cluster mass 0.7–2e15 Msun.



S-Z effect cluster survey with the Atacama Cosmology Telescope (ACT)



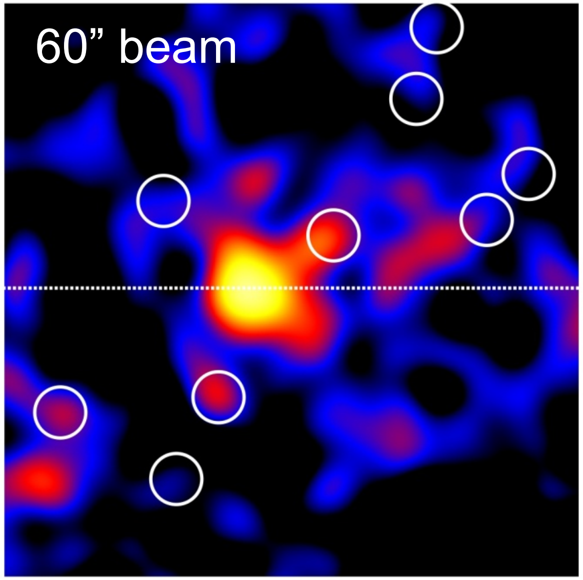
Confusion-limit due to SMG population is ~30x higher than ACT survey depth

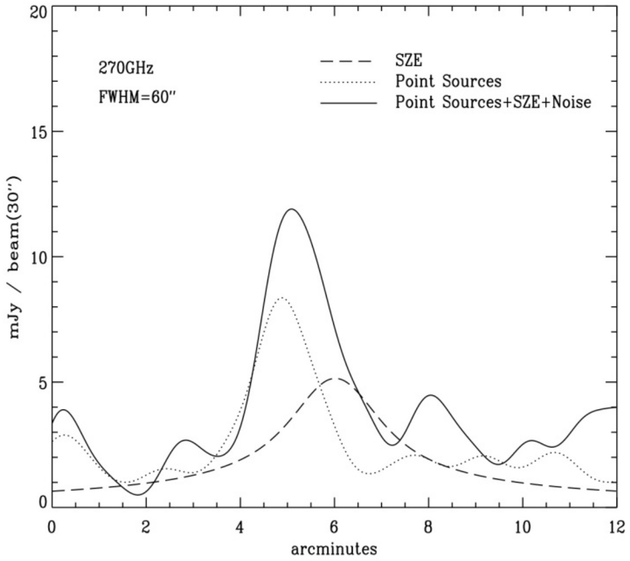


2 microkelvin / 1.7 x 1.7 arcmin pixel
= ~0.1 mJy / ACT beam

SMG confusion-limit
for a 6-m telescope

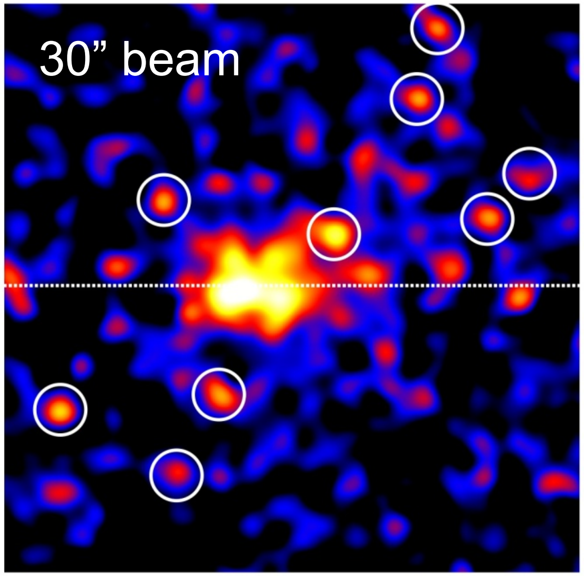
Point-source contamination of SZE (inc. lensing)

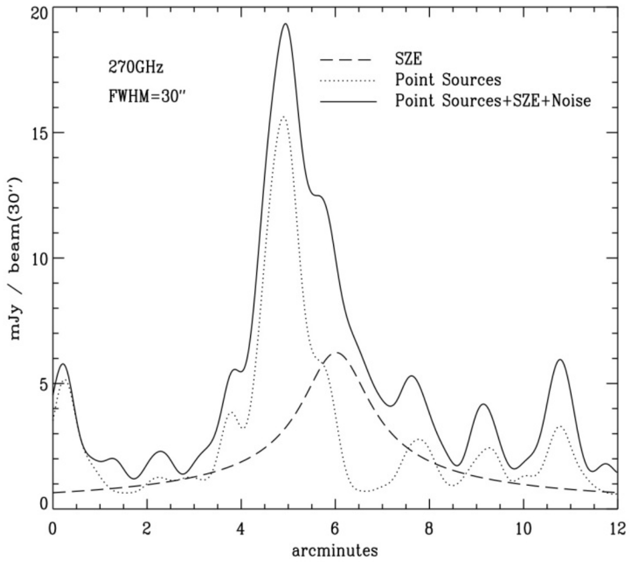




MBAC on ACT simulation

noise ~ 4.2 mJy/beam



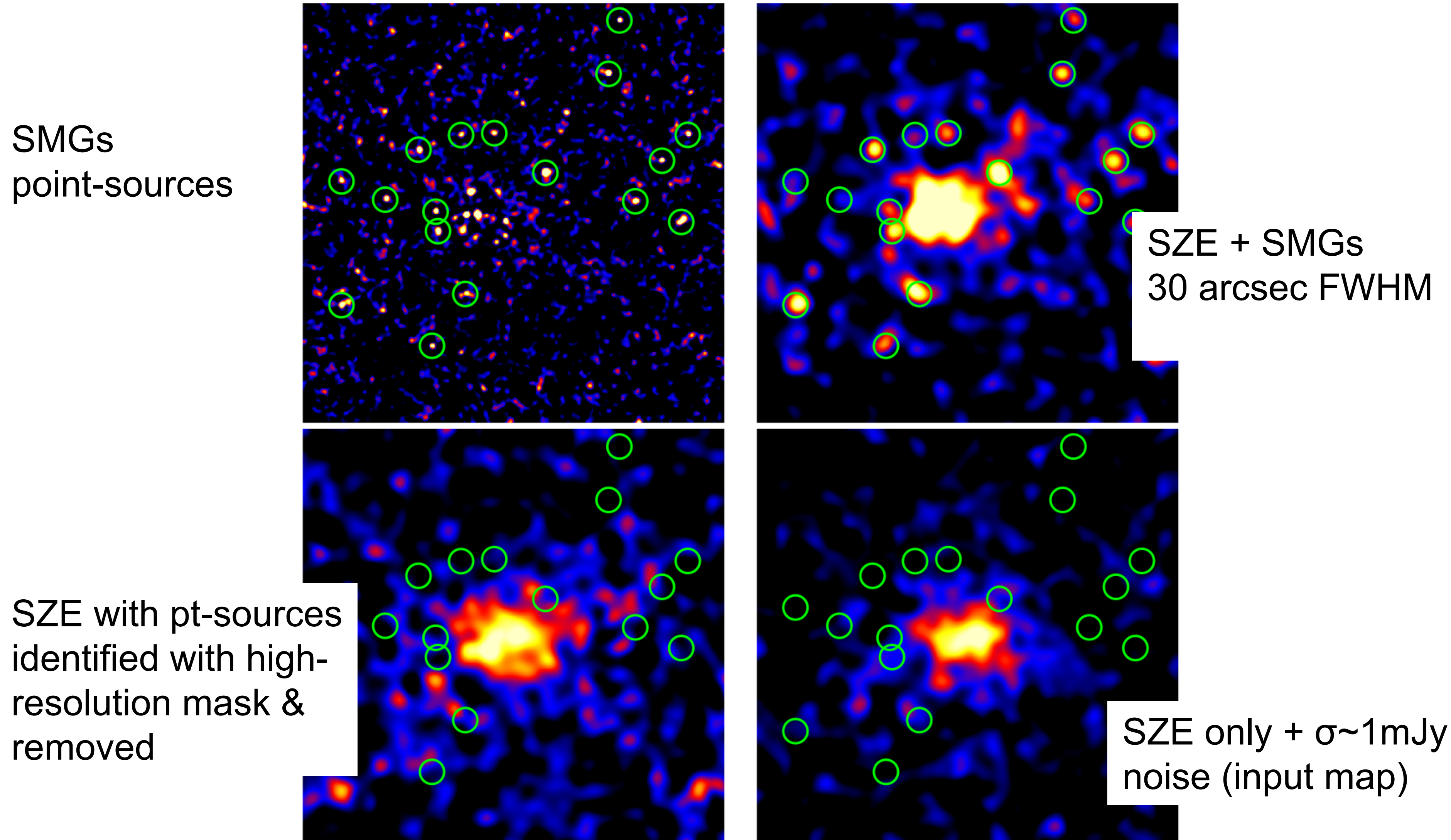


AzTEC on ASTE simulation

noise ~ 1.0 mJy/beam

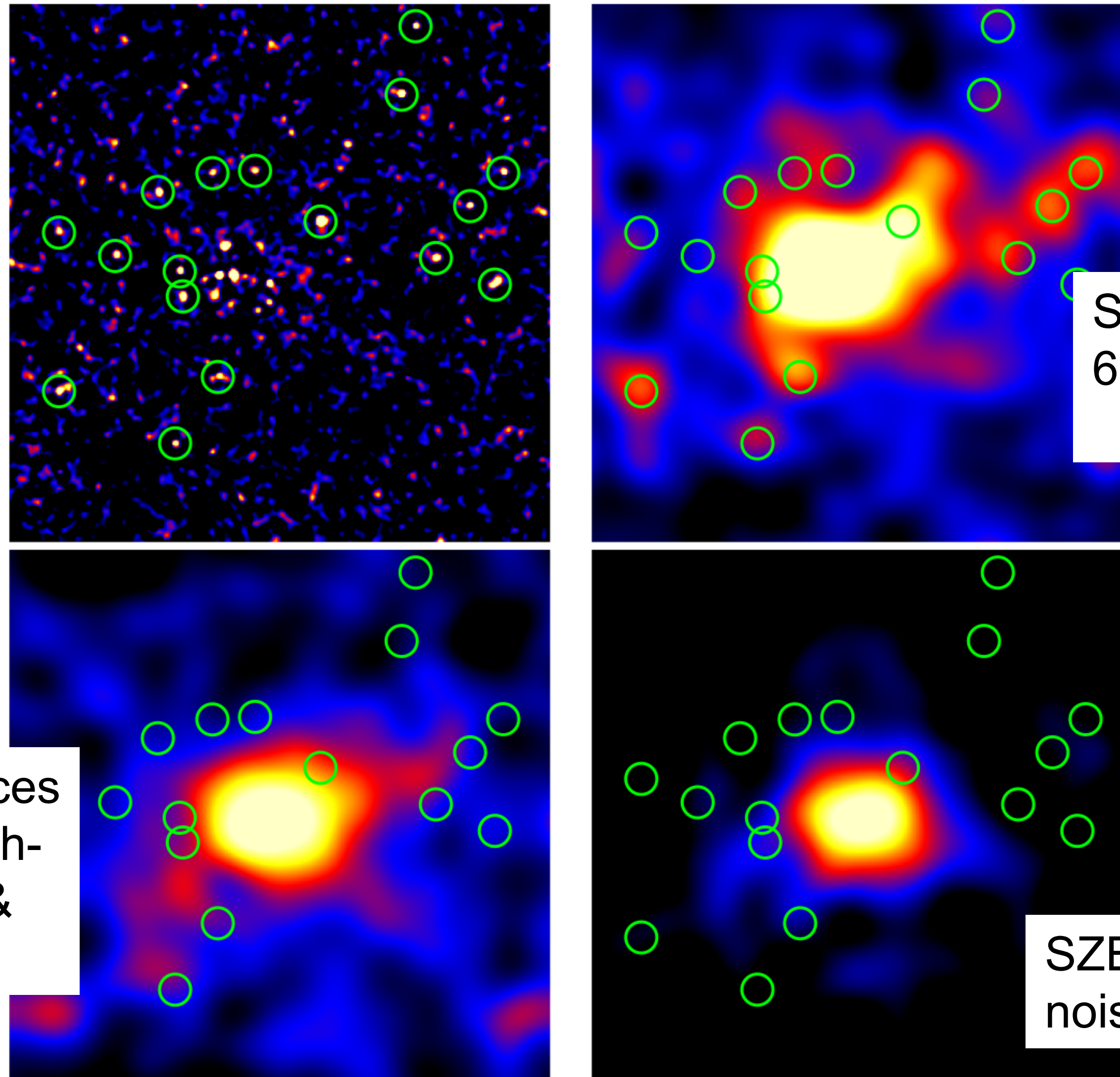
Alfredo Montaña et al. 2008 (in prep)

Advantage of higher-resolution observations: with Large Millimeter Telescope



simulacion por Alfredo Montaña (tesis)

Advantage of higher-resolution observations: with Large Millimeter Telescope



simulacion por Alfredo Montaña (tesis)

Conclusions

- LMT (32-m) is nearing completion of construction phase
- mechanical & drive-control systems working
- installation of M2 & M3 mirrors and M1 surface alignment required before scientific commissioning begins
- first-light & commissioning instrumentation ready (optical camera, holography receiver, Rx-z & AzTEC)
- first-light science in 32-m format expected in early 2010
- funding being sought for completion of 50-m surface

Conclusions

- SEQUOIA, Redshift receiver & AzTEC all commissioned and have operated as scientific instruments on other 10-15m class (sub-)mm telescopes
- AzTEC completed 3 seasons on JCMT and ASTE.
- blank-fields (GOODS-N, COSMOS, CDFS, Lockman Hole, SXDF, SEP, ….)
- biased-fields (ACES survey – 40 HzRG and cluster environments)
- ~3 sq. degrees surveyed at 18-30 arcsec resolution.
  > 2000 SMGs detected (>>10^12 Lsun, SFR >> 100 Msun/yr)

Conclusions

- Increasing likelihood that ACT, SPT, Planck (i.e. low-
- resolution experiments, > 1 arcmin beams) will suffer from
- pt-source contamination from lensed SMG population and
- SMGs intrinsic to high-z clusters

- Need higher-resolution (5- 20 arcsec) observations (e.g.
- LMT) to complement SZE survey experiments and
- maximise the accuracy of cosmological parameters and
- understanding of cluster physics derived from arcminute-
- resolution SZE observations