The LMT science-case & synergy(?) with SASIR

Scientific priorities in astronomy in future decades

- The LMT & current status
- LMT Key Projects and Legacy Surveys
- Requirements from next-generation IR telescopes

David Hughes

LMT Project Scientist (Mexico)
Instituto Nacional de Astrof_sica, Optica y Electrónica (INAOE)

The Decadal Report (2000)

In Astronomy & Astrophysics in the New Millennium, or the "Decadal Report", five fundamental questions for the field of astronomy and astrophysics were identified:

D1. How did the universe begin, how did it evolve from a primoridal soup of elementary particles into the complex structure seen today, and what is its destiny?

D2. How do galaxies first arise and mature?

D3. How are stars born and how do they live and die?

D4. How do planets form and change as they age?

D5. Does life exist elsewhere in the Universe?

The Decadal Report (2000)

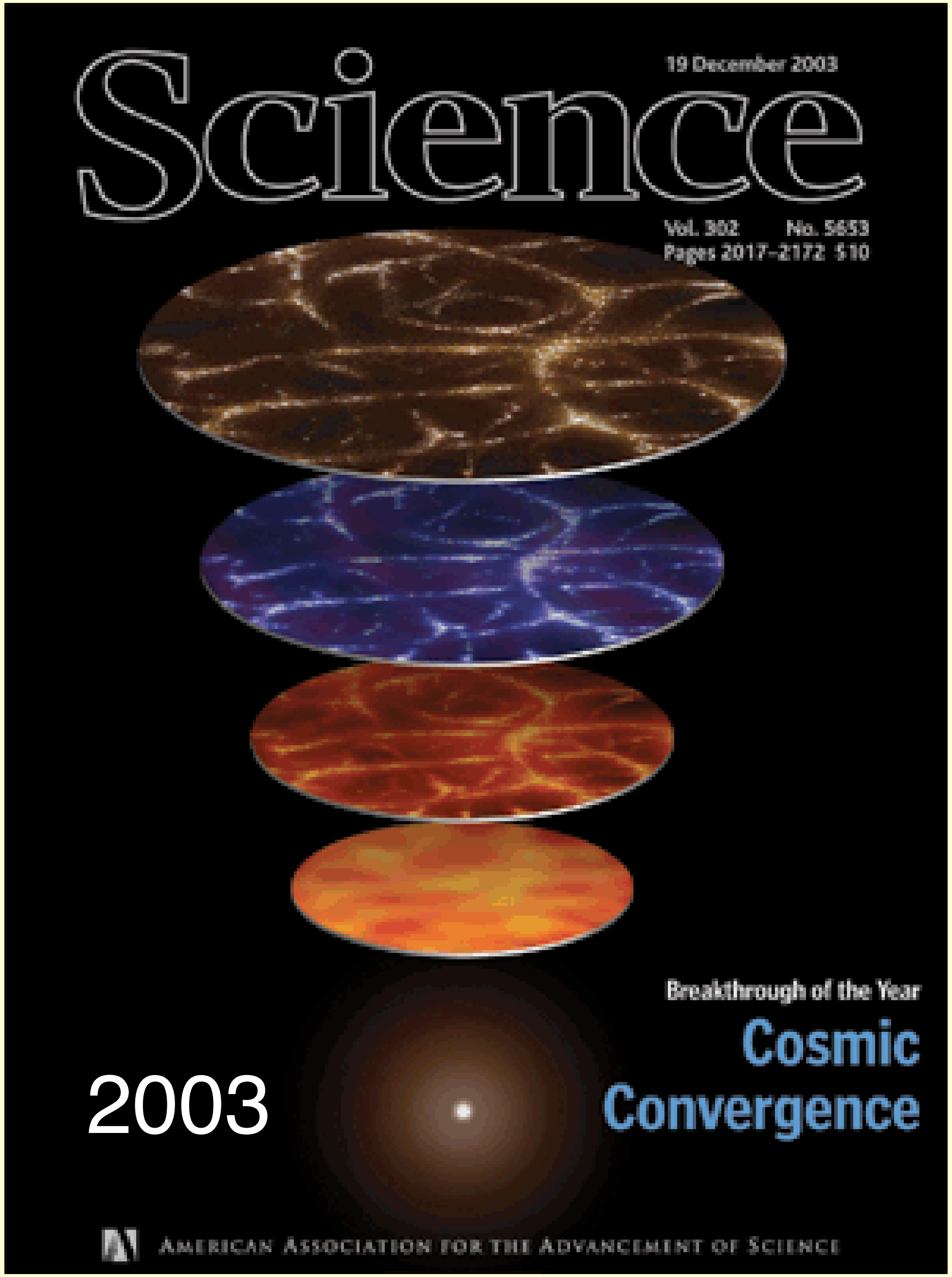
In Astronomy & Astrophysics in the New Millennium, or the "Decadal Report", five fundamental questions for the field of astronomy and astrophysics were identified:

D1. How did the universe begin, how did it evolve from a primordial soup of elementary particles into the complex structure seen today, and what is its destiny?

D2. How do galaxies first arise and mature?

Millimeter astronomy & LMT in particular can address all these identified priorities with high sensitivity, resolution & mapping-speed

Science - “Breakthrough of the Year”



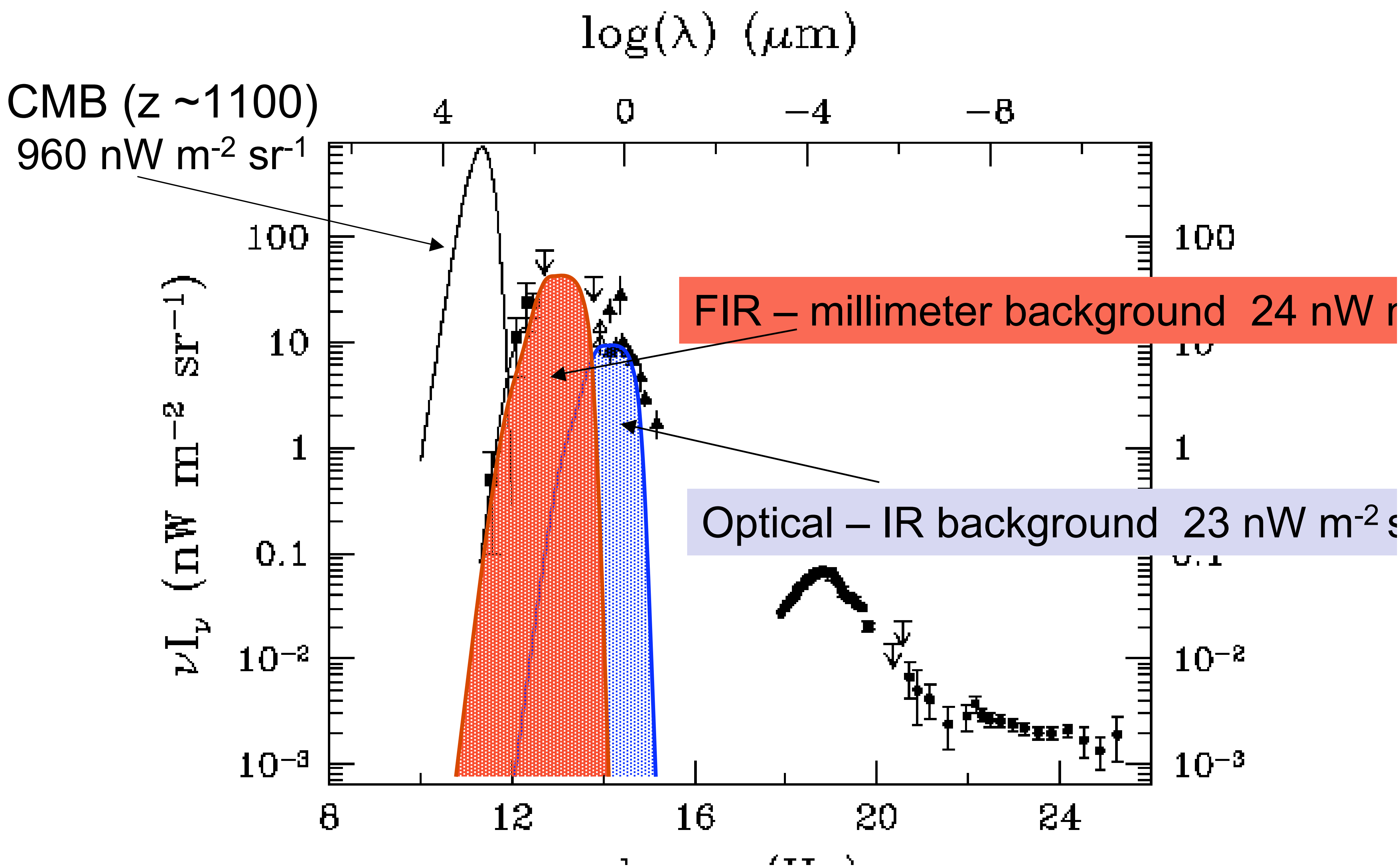
The nature of the Dark Energy is one of the outstanding unsolved problems of fundamental physics.

Progress requires more precise probes (e.g. higher resolution & sensitivity of CMB anisotropies) of Dark Energy

Nature of Dark Energy now a key area for funding in astronomy (DES, ACT, SPT, SNAP, ….)

LMT surveys & follow-up will also contribute to DES

-ray to radio extragalactic background emission



Why millimeter-wavelength astronomy ?

- 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 _-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

El Gran Telescopio Milimétrico

The Large Millimeter Telescope

- 50-m main reflector, 2.5-m secondary
- primary surface: 180 panels, <75 _m rms
- active surface (gravity, wind & temp)

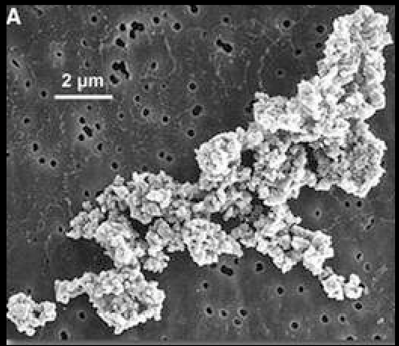
- operating wavelengths 0.85 - 3.4 mm
- FOV ~ 4′, with 8′ field available
- 5 -18 arcsec resolution, < 1.0″ pointing

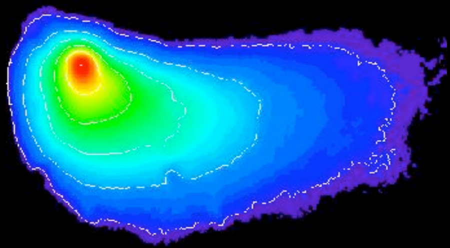
- altitude 4600m (15100 ft.)
- average wind speed < 10 m/s (90% time), 4.5 m/s or 10 mph (median)
- median opacity _225GHz ~ 0.12 (winter)

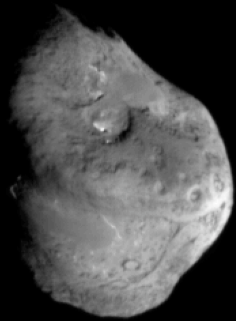
www.lmtgtm.org

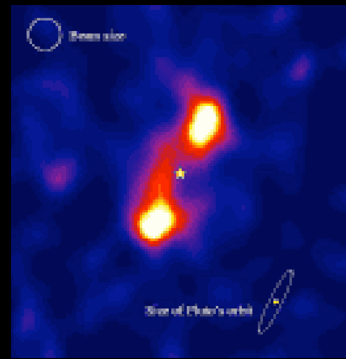
Primary Science with the LMT

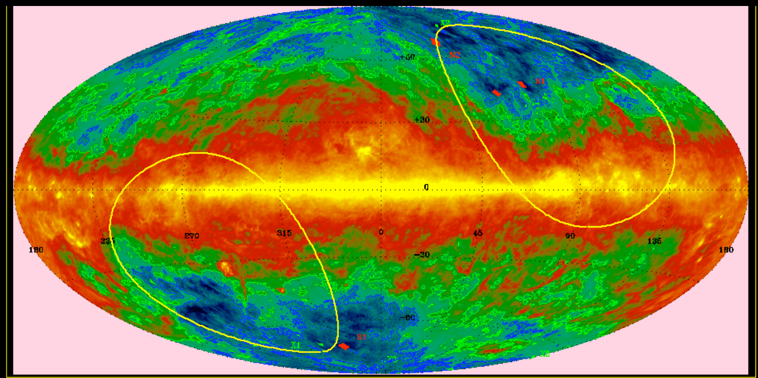
The formation & evolution of structure in the Universe

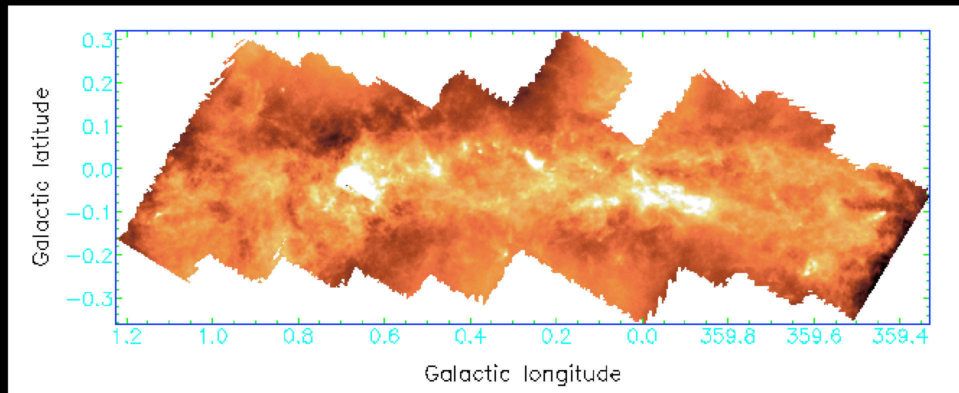


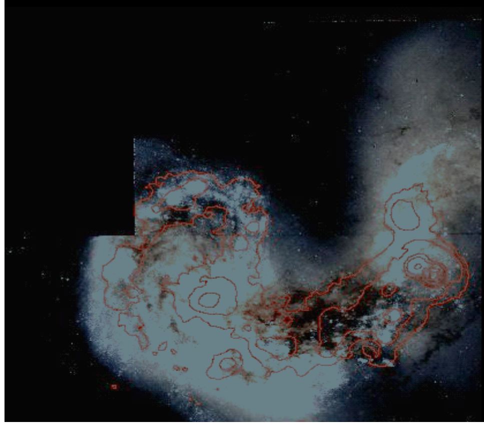


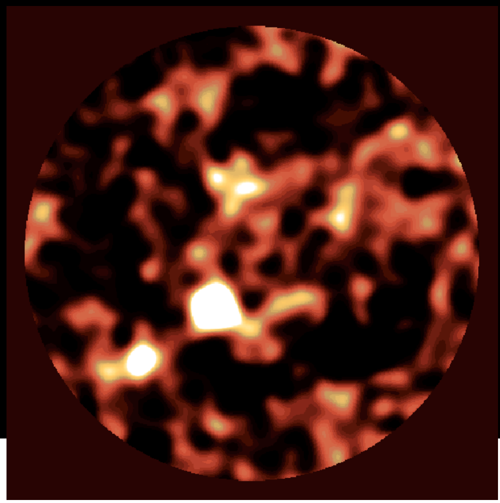


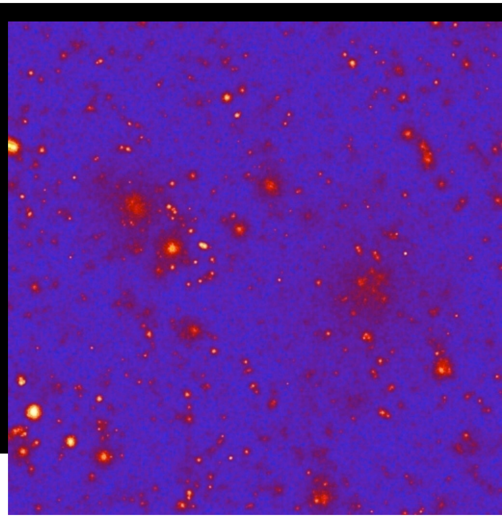


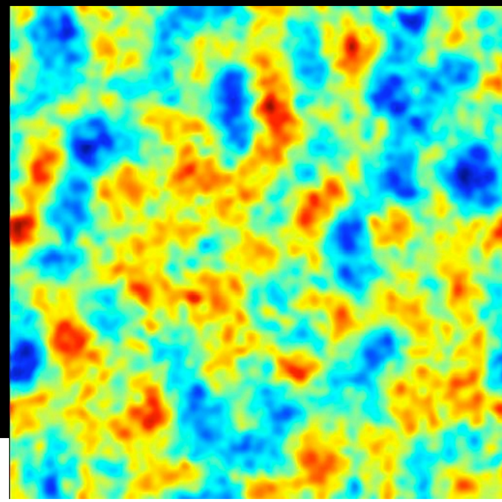












First-light Instrumentation Overview

Commissioned

- AzTEC

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

- SEQUOIA

  16-pixel (upgrade to 32-pixel), dual-polarization, spectrometer at 85-116 GHz with 15 GHz instantaneous bandwidth

- 90 GHz Redshift Receiver

  2 pixel, dual-polarization, ultra-wideband 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 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 multi-frequency camera based on SPEED prototype

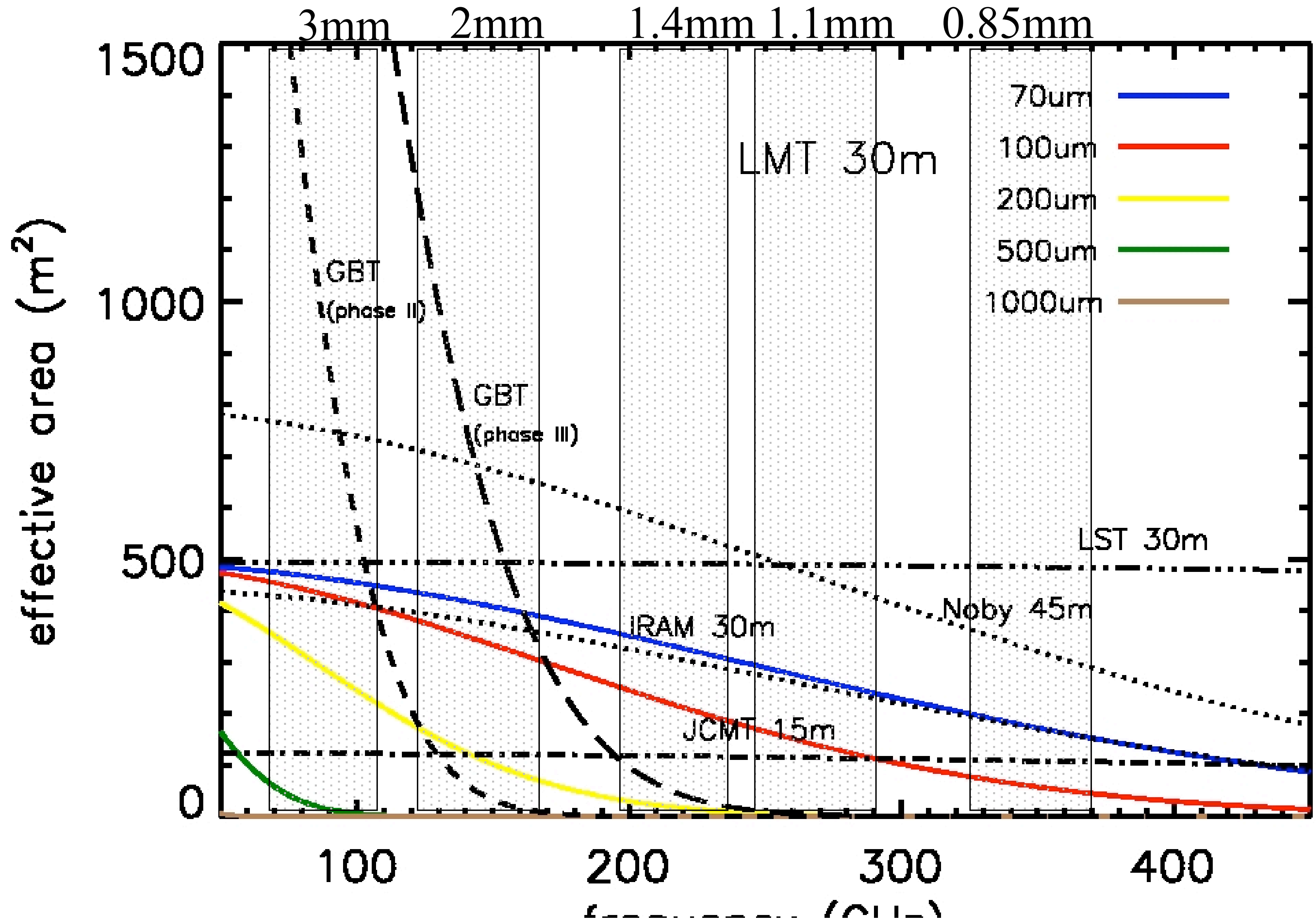
- OMAR

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

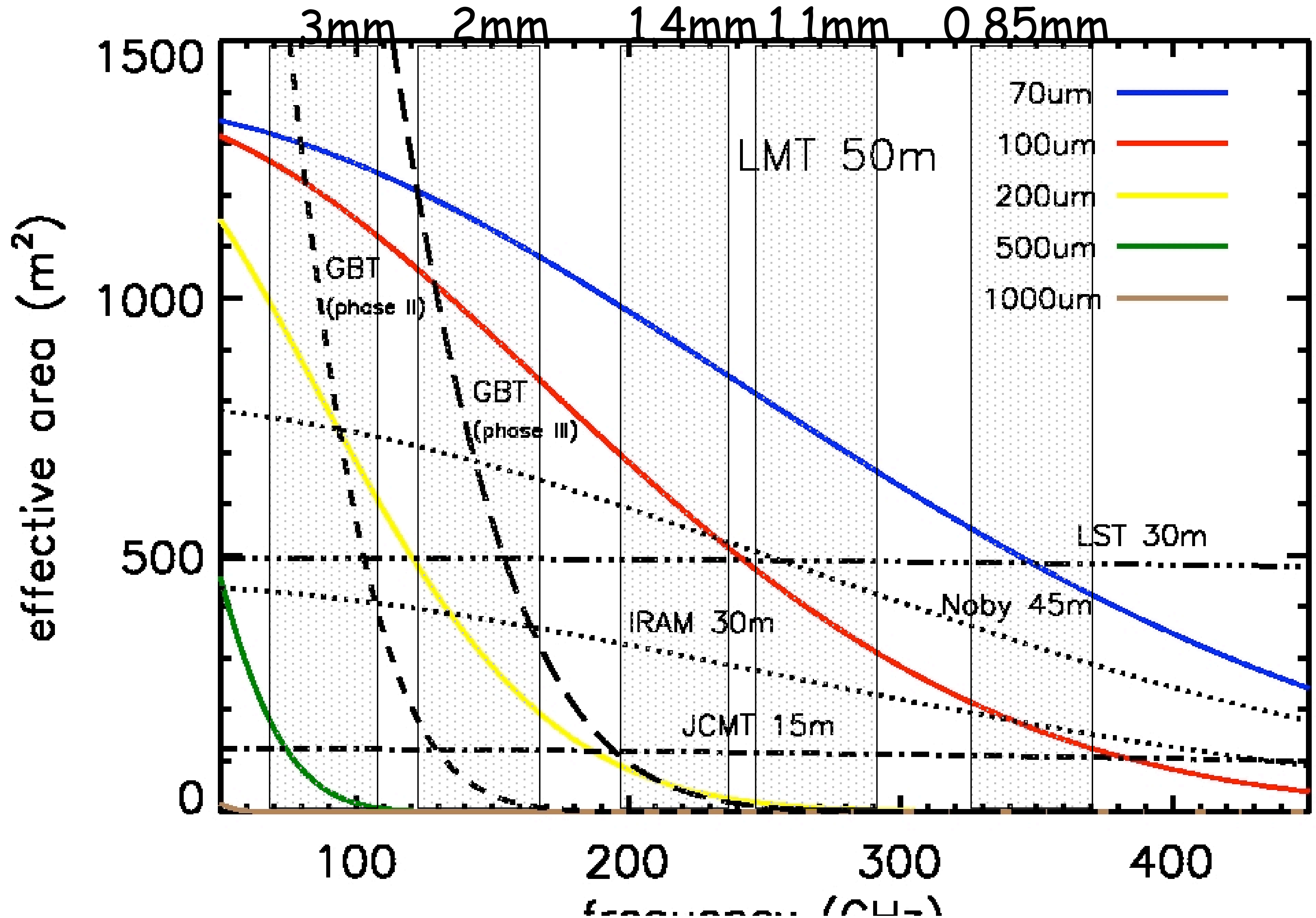
- ToITEC

  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 technology

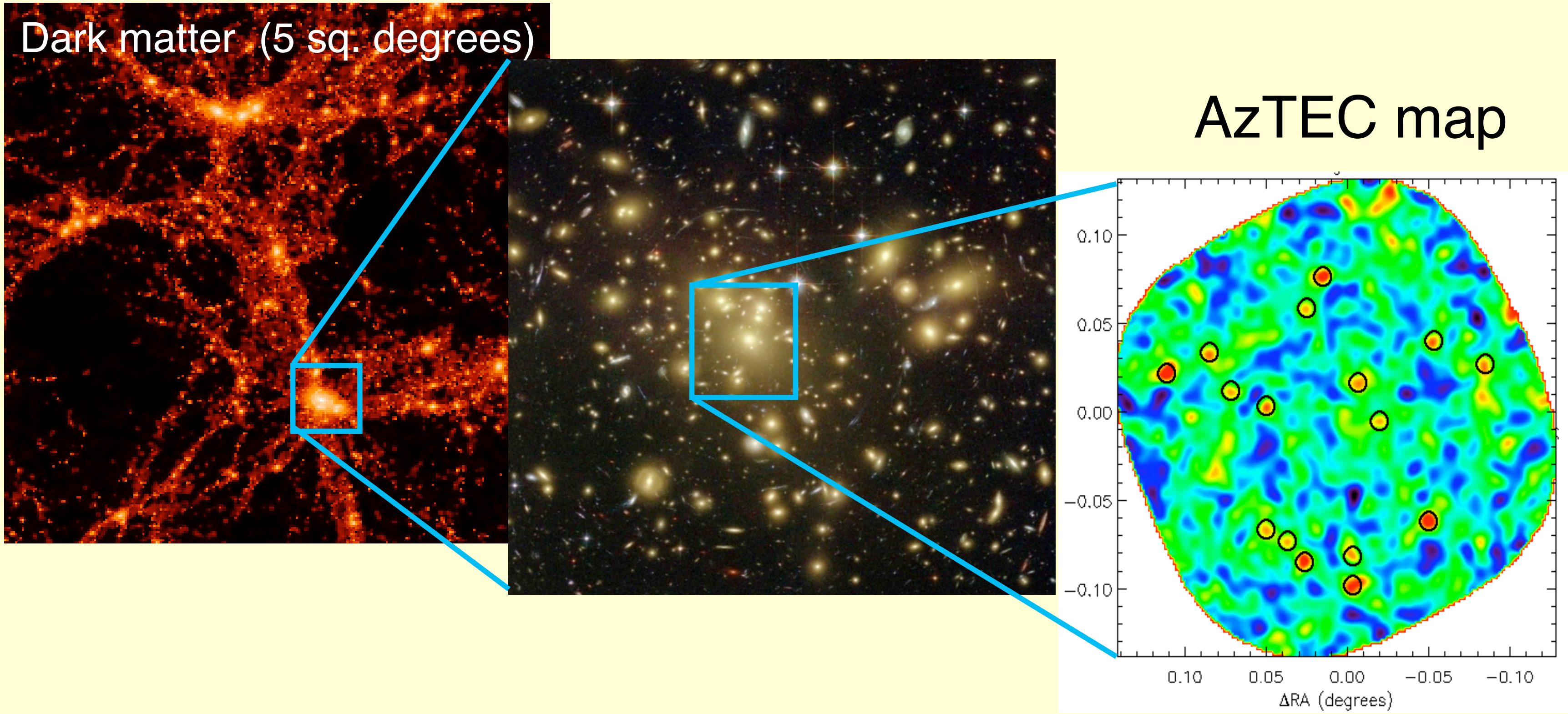
Effective area of (3-ring) 30-LMT



Effective area of (5-ring) 50-LMT



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



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?”

mm-wavelength surveys of the first galaxies require:

_ High point-source sensitivity AND

_ high-mapping speed (≥ 1 sq. deg./hr/mJy^2) AND

_ low confusion-limit (<< 1mJy)

_ **ONLY large single-dish telescopes can provide all these capabilities**

_ (small) interferometers – CARMA, SMA, IRAM PdB do not have sufficient sensitivity and mapping-speed

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

- Statistical properties 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 _ (L, z) & spatial clustering
- morphology, stellar pop./age, mass, AGN fraction

Why the LMT? – sensitivity & mapping-speed

Continuum cameras	Mapping Speed	equivalence
AzTEC (1st light)	0.3 sq. degs/hr/mJy^2	3 x ALMA at 850um, ~SCUBA-2/JCMT
ToITEC (2nd generation)	10 sq. degs/hr/mJy^2	100 x ALMA

- LMT can provide large mm-selected samples (>10^5 – 10^7 galaxies)
  - confusion-limited, pencil-beam surveys (0.1 - 1 deg^2)
  - shallow, wide-area surveys (1 - 1000 deg^2)
  - multi-wavelength data (SPEED) & redshifts (RSR)

Why the LMT? - sensitivity & resolution

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

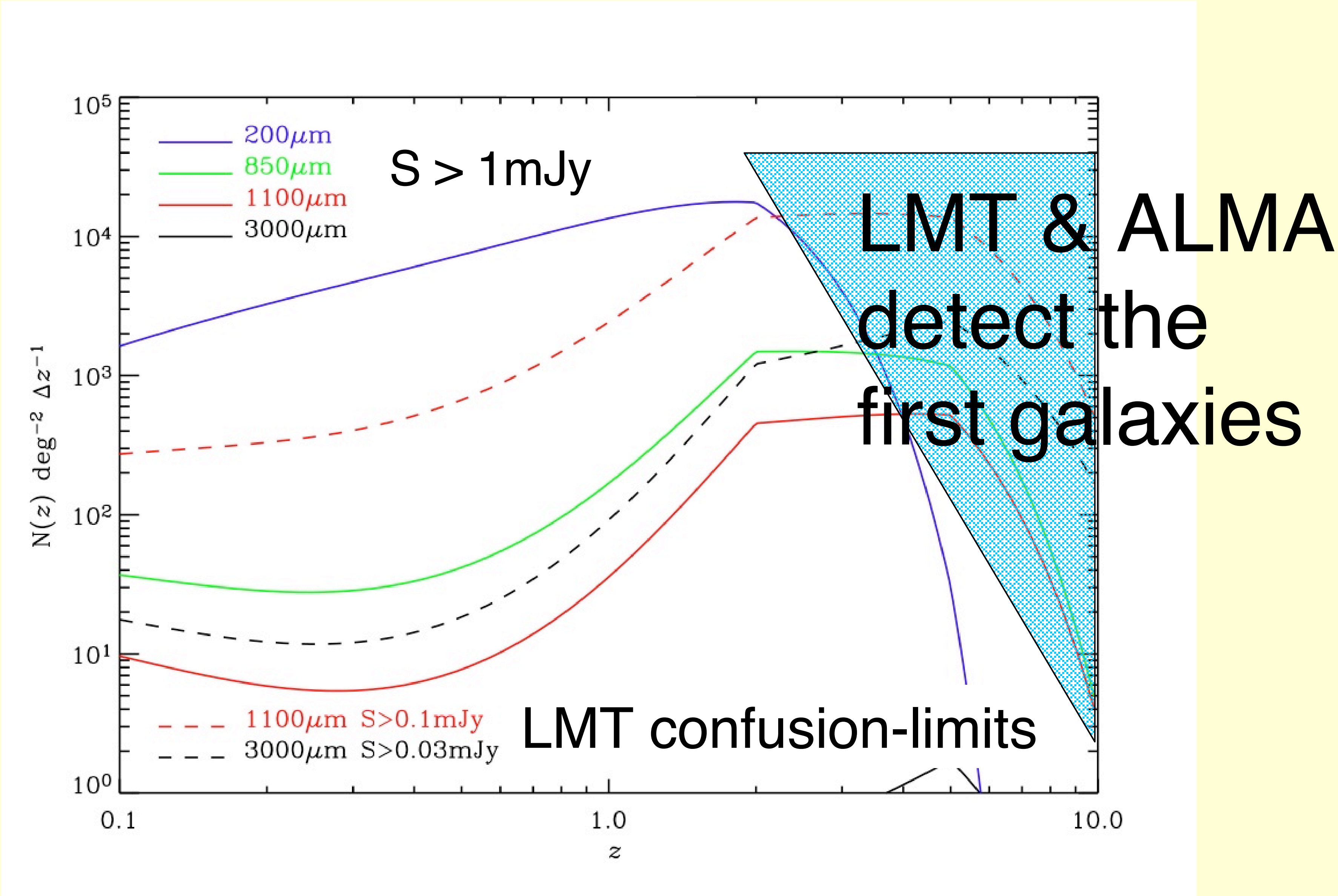
    - CSO, HHT, ASTE, APEX, JCMT, CCAT

- 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_ /yr

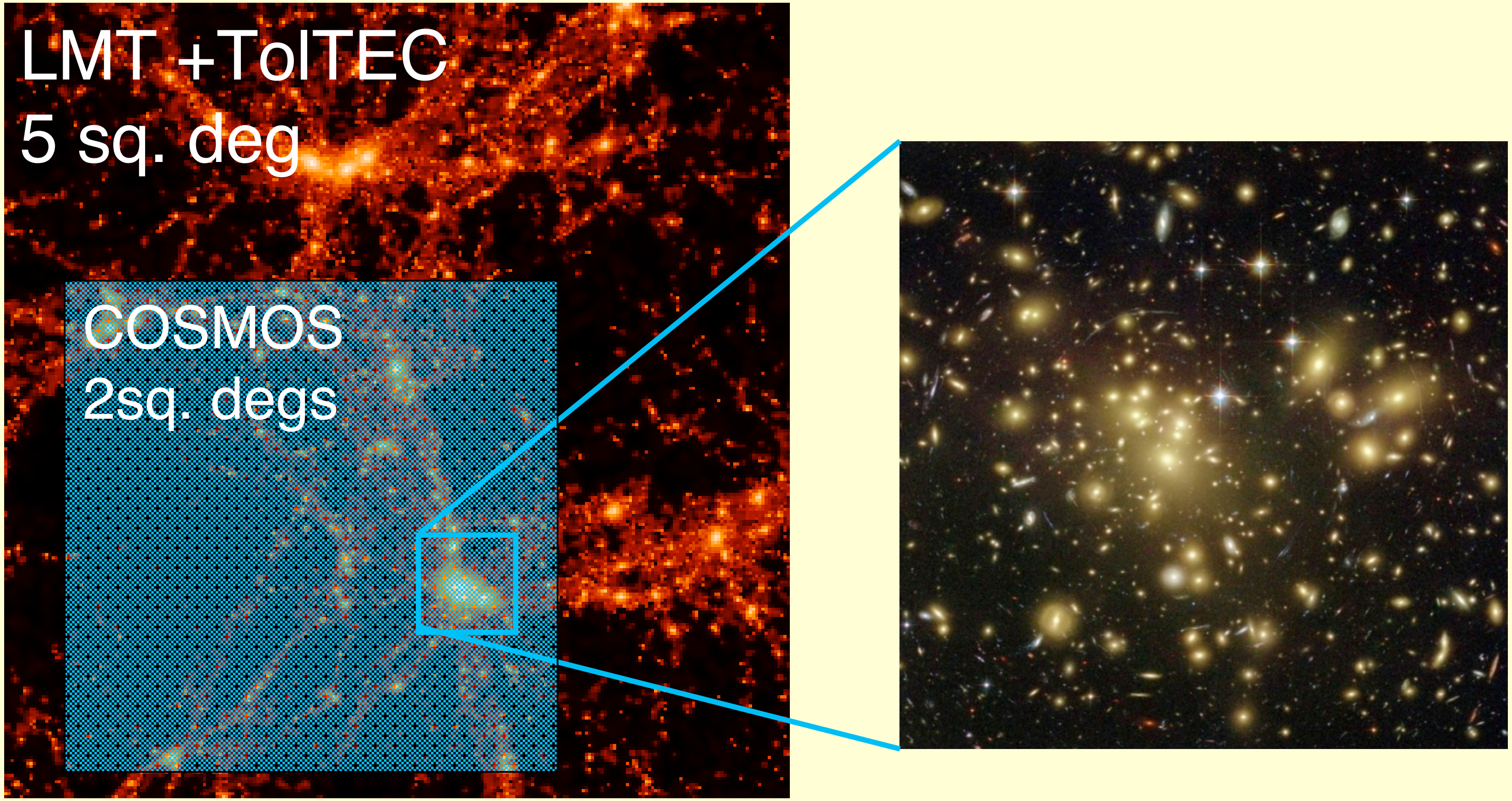
- Lower LMT confusion limits (~0.1 mJy) & longer-_ allow more moderate SFRs (few 10's M_ /yr) to be detected by LMT in the first galaxies at z > 6

  - LMT catalogs ready for ALMA @ higher-resolution

Why the LMT? - sensitivity & resolution



An LMT 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)

Multiple CO lines in SMM J16359+6612 – further evidence for a merger

A. Weiß[1,4], D. Downes[2], F. Walter[3], and C. Henkel[4]

2005, A&A, 440, L45

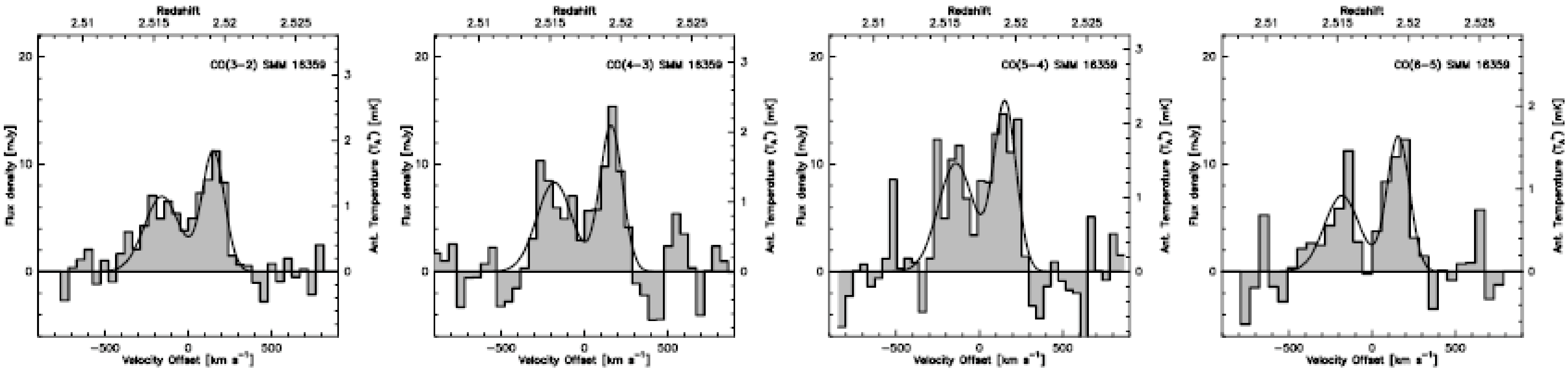


Fig. 1. Spectra of the CO(3–2), CO(4–3), CO(5–4) and CO(6–5) lines towards SMM J16359+6612 B, with Gaussian fit profiles superposed. The velocity scale is relative to a CO redshift of $z = 2.5174$. The velocity resolution is 50 km s^{-1} (3–2, 4–3, 5–4) and 55 km s^{-1}(6–5). All spectra are shown with the same flux scale.

CO 3-2 line detected without optical identification by LMT redshift receiver in 75-110 GHz band

CO 7-6 line detected by LMT 1.3mm SIS receiver with high spectral resolution using tuning based on CO(3-2) redshift.

LMT redshift search receiver - "redshift machine"

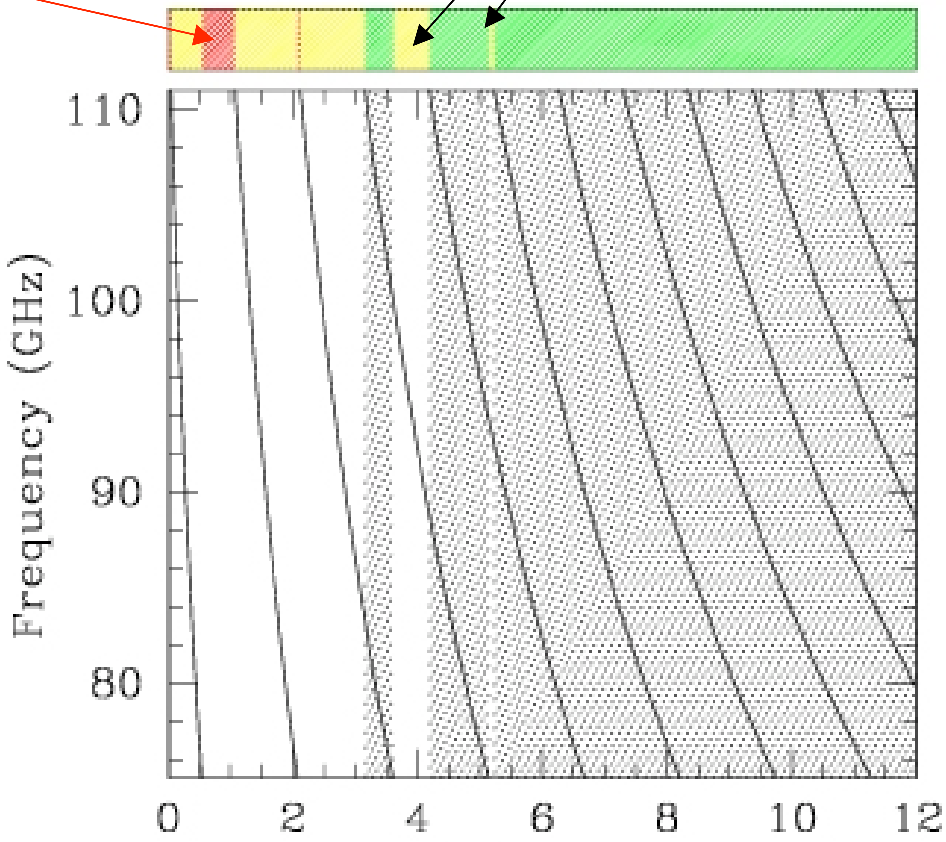
redshift search strategy on LMT requires maximum possible bandwidth

- 75-111 GHz bandwidth gives high probability of at least one CO line from galaxies

CI (492 GHz) provides 2^{nd} line for $3.5 < z < 5.6$

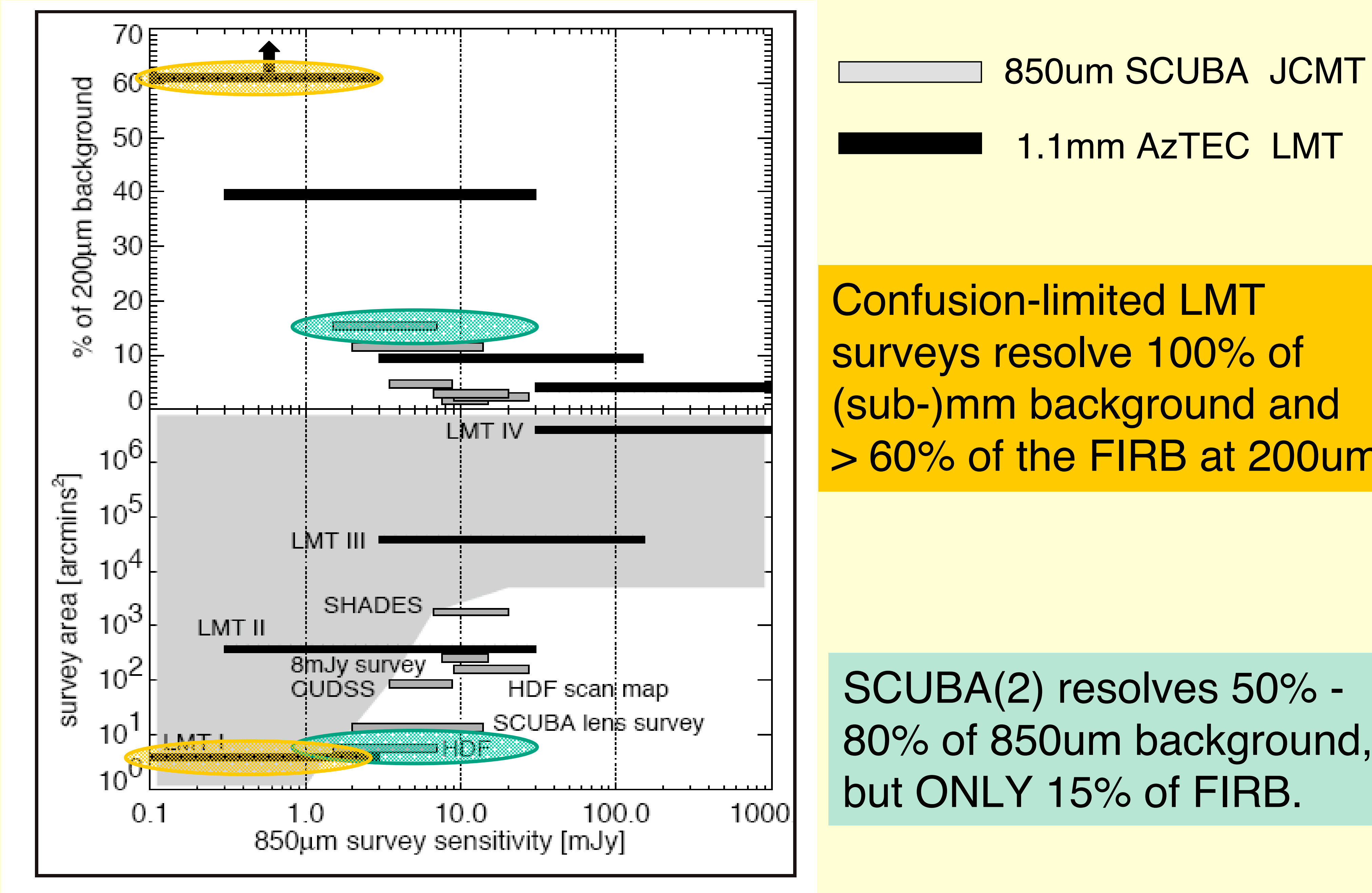
only gap at $z = 0.537 - 1.077$

Red – no line
Yellow – one CO line
Green – two CO lines



CO line separation ~ 115/(1+z)

Resolving the FIR extragalactic background (FIRB)



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.

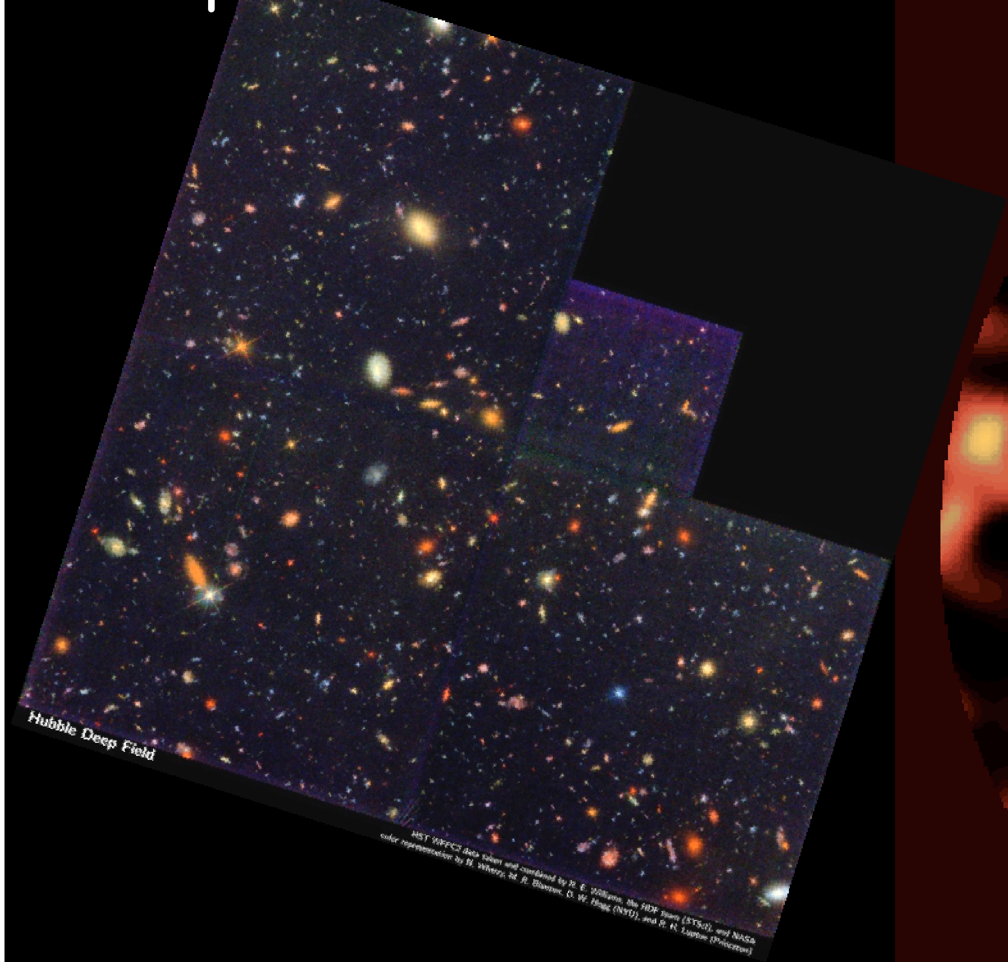
LMT requirements of IR surveys

- IR imaging leads to identification of galaxy counterparts of SMGs, providing

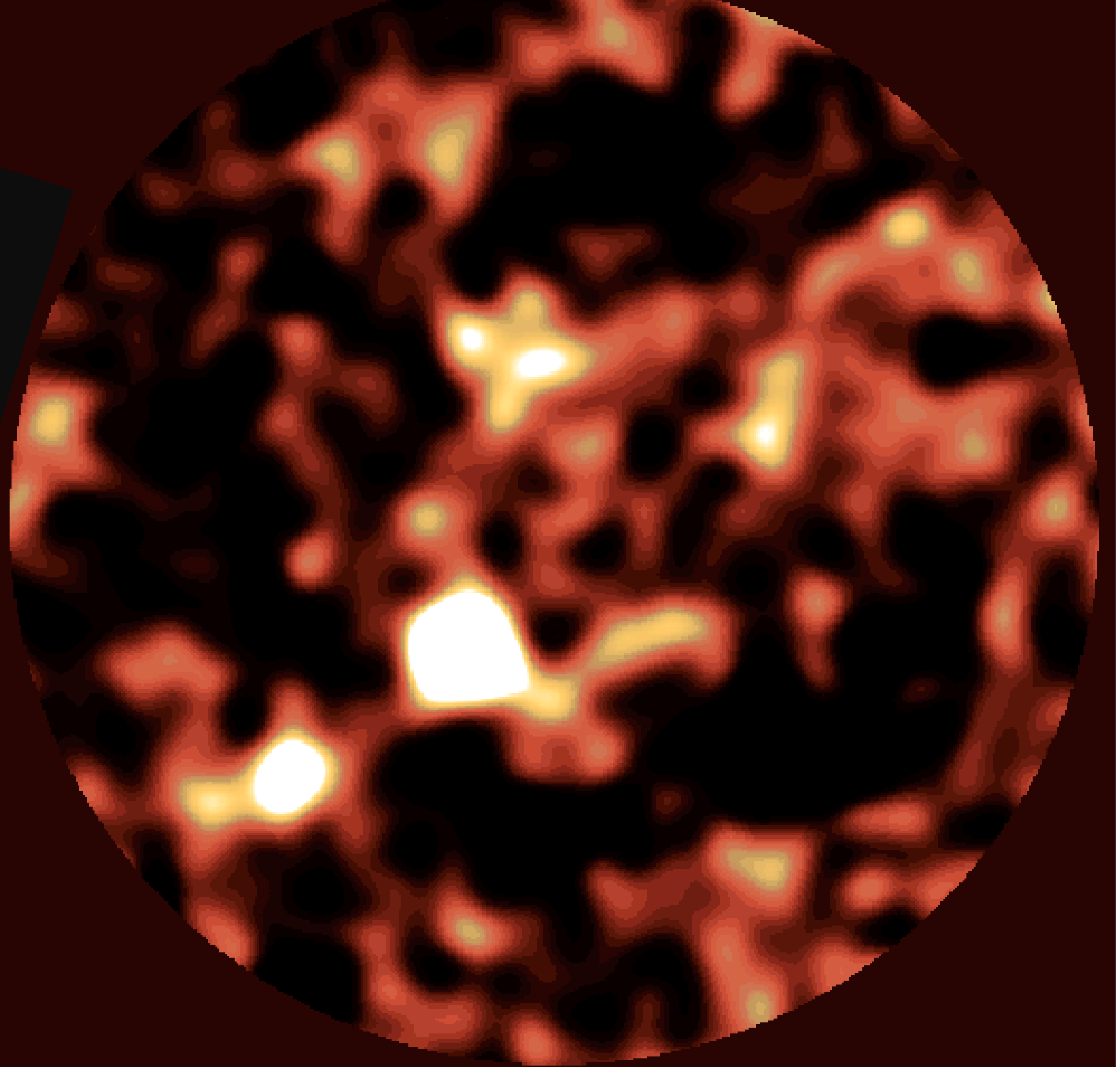
  - Spectroscopic (photometric) redshifts
  - morphology & dynamics
  - stellar population / age
  - AGN fraction
  - ……

HST vs. SCUBA maps of Hubble Deep Field

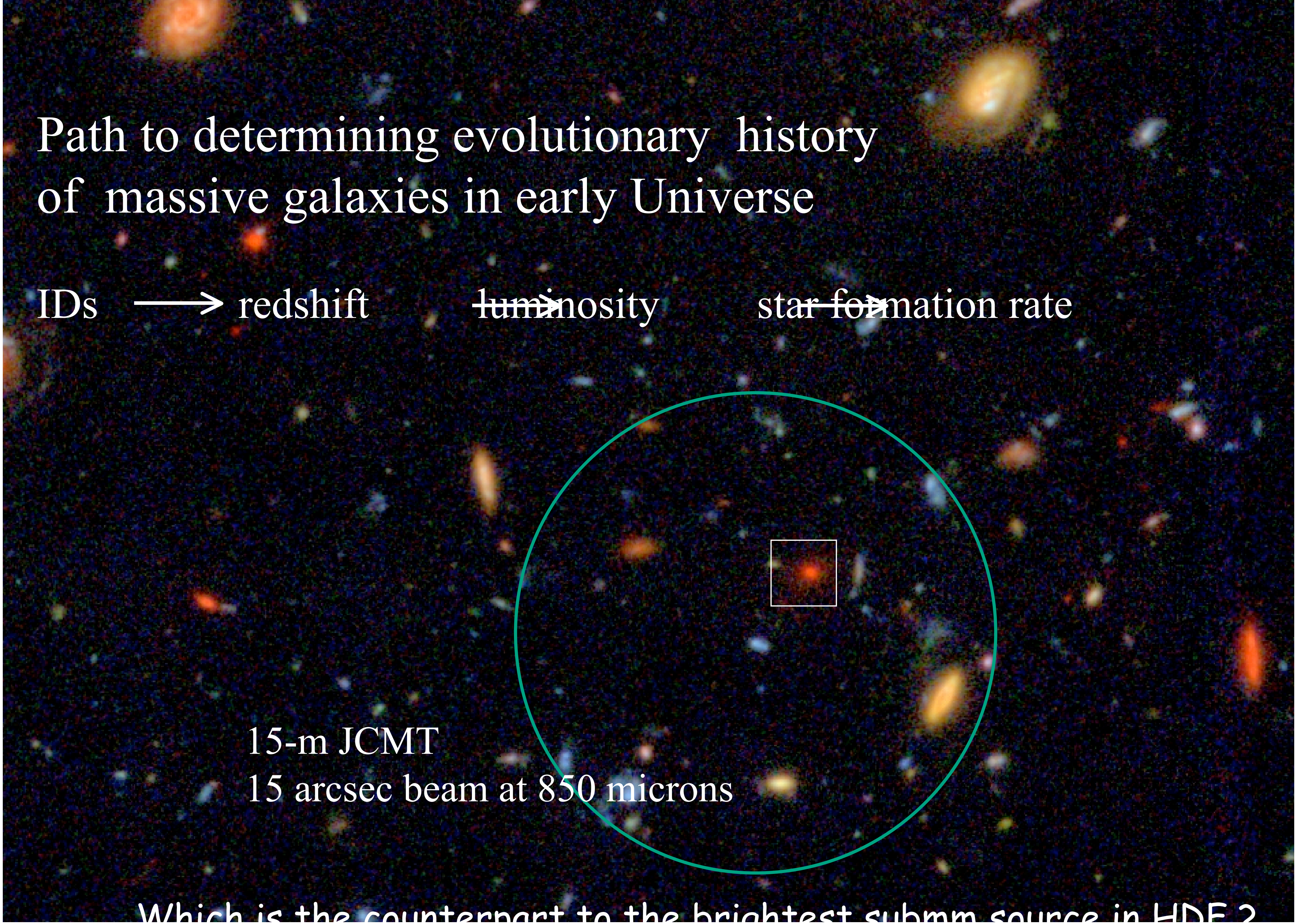
optical



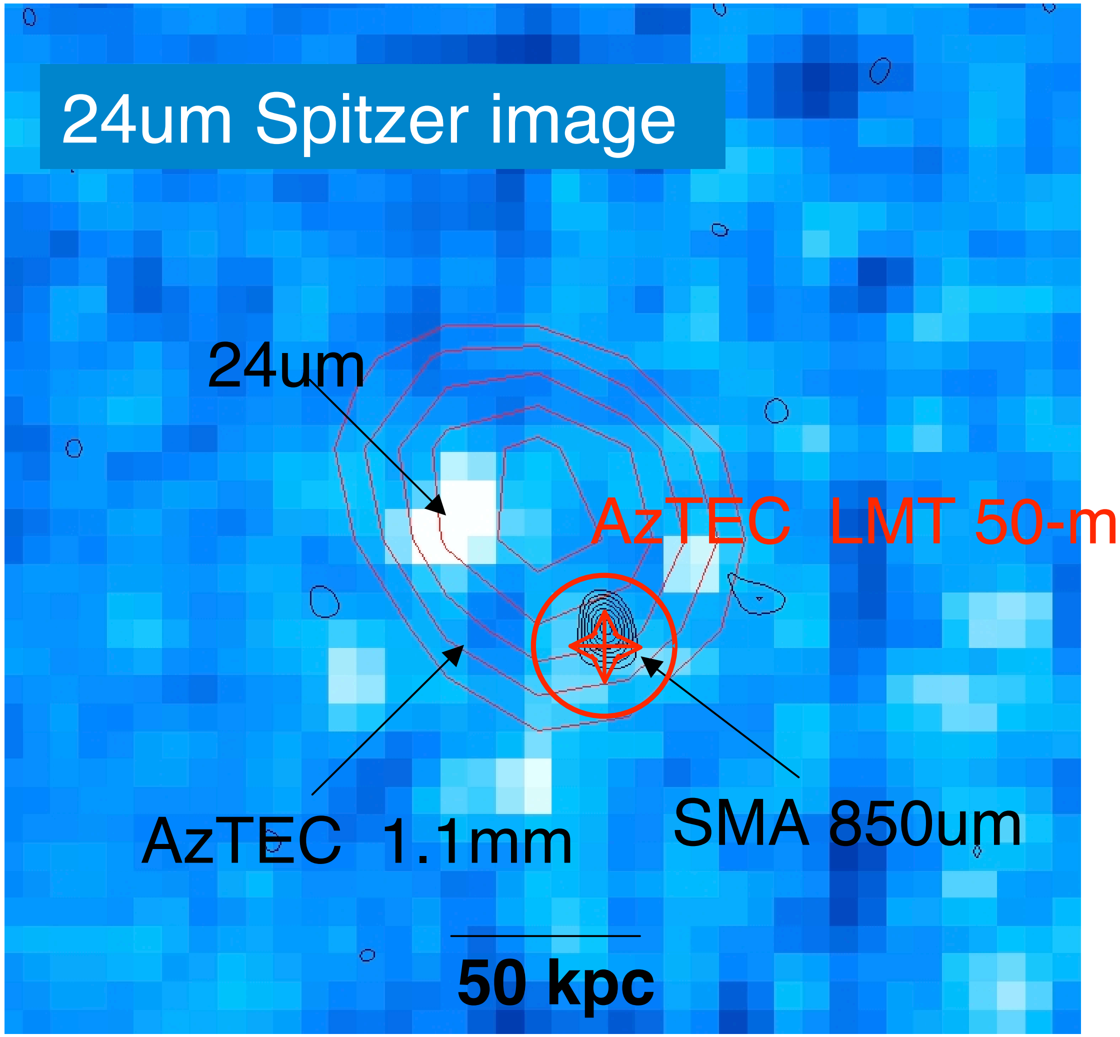
sub-millimeter



Hubble Space Telescope


Path to determining evolutionary history
of massive galaxies in early Universe
IDs → redshift → luminosity → star formation rate
15-m JCMT
15 arcsec beam at 850 microns
Which is the counterpart to the brightest submm source in HDF ?

How secure are Spitzer 24um counterparts to SMGs, redshifts and spectral energy distributions?



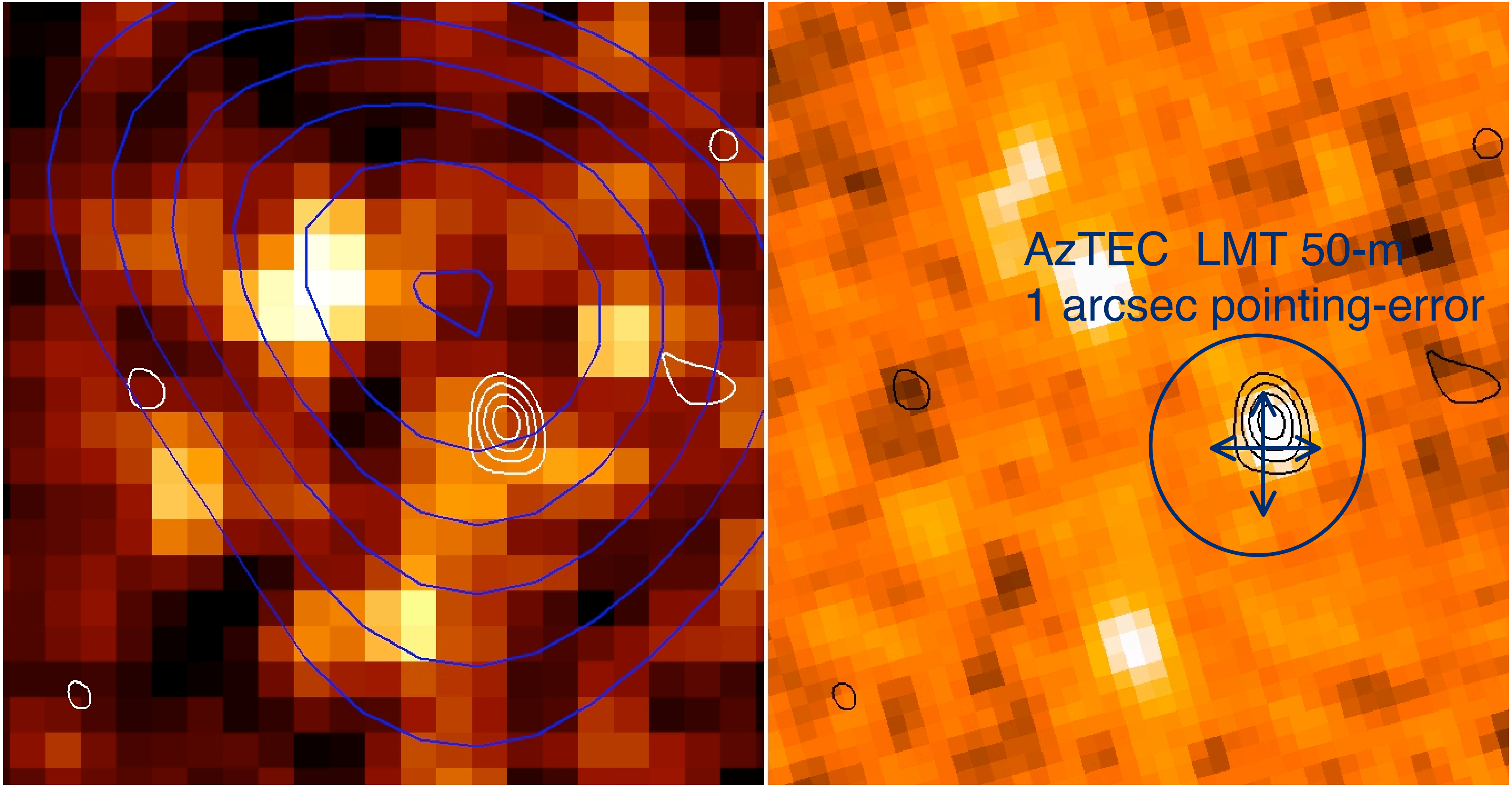
- AzTEC 1.1mm observations on 15-JCMT: beamsize FWHM ~ 18 arcsec (outer red contour)

- no optical counterpart to SMGs,

- need secure ID's to attempt blind spectroscopy in optical with subarcsec pointing accuracy

Hence need for SMA, CARMA, IRAM PdB follow-up (6-8 hr tracks)

•



24 microns AzTEC

8 microns SMA

Clarifying the nature of the brightest submillimetre sources via SMA interferometry

J. D. Younger,[1⋆] J. S. Dunlop,[2,3] A. B. Peck,[1,4] R. J. Ivison,[2,5] A. D. Biggs,[5] E. L. Chapin,[3] D. L. Clements,[6] S. Dye,[7] T. R. Greve,[8] D. H. Hughes,[9] D. Iono,[10] I. Smail,[11] M. Krips,[1] G. R. Petitpas,[1] D. Wilner,[1] A. M. Schael,[2] and C. D. Wilson[12]

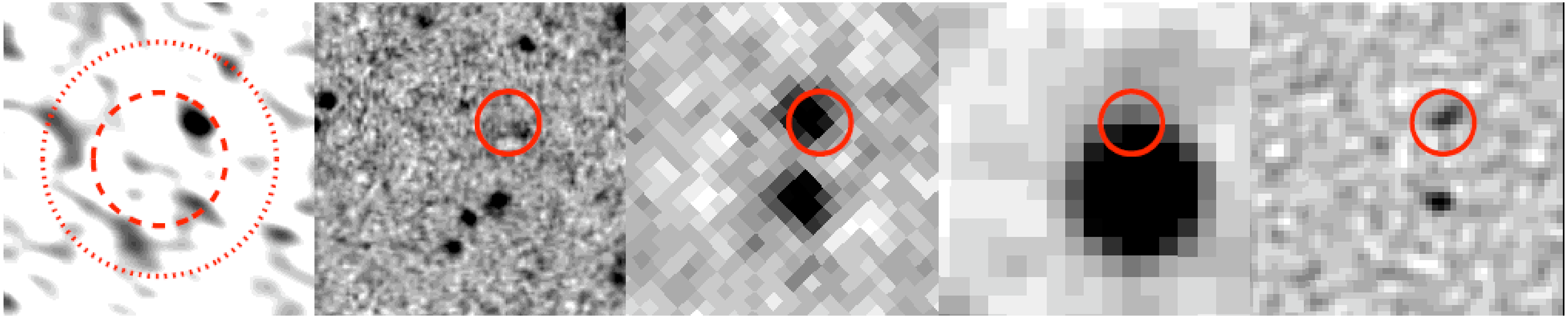
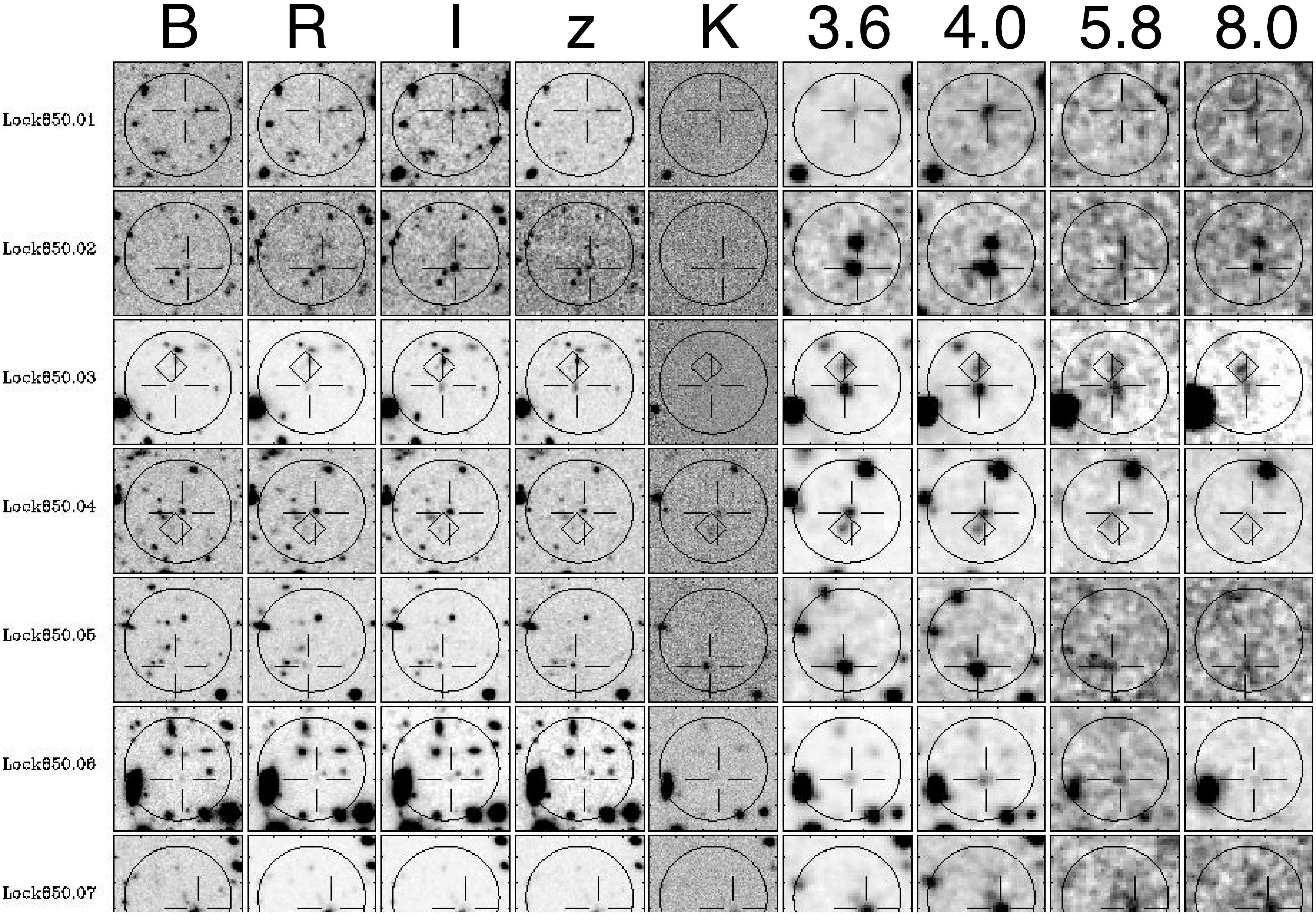


Figure 3. Postage stamp images, centred on the SMA phase center position of LH 850.02, which is the original SCUBA centroid from Coppin et al. (2006). From left to right: SMA 890μm, Subaru R-band, IRAC 3.6-μm, MIPS 24-μm and VLA 1.4-GHz imaging. The red dotted line indicates the FWHM of the SCUBA beam, and the red dashed line indicates the 2σ positional uncertainty (Ivison et al. 2007). The synthesized beam size is 2.3 arcsec × 1.3 arcsec with a position angle of 60°. The red circle is 4-arcsec in diameter, roughly twice the SMA beam size, and the stamps are 20 arcsec on a side. The SMA clearly identifies one compact point source as the origin of the submm emission.

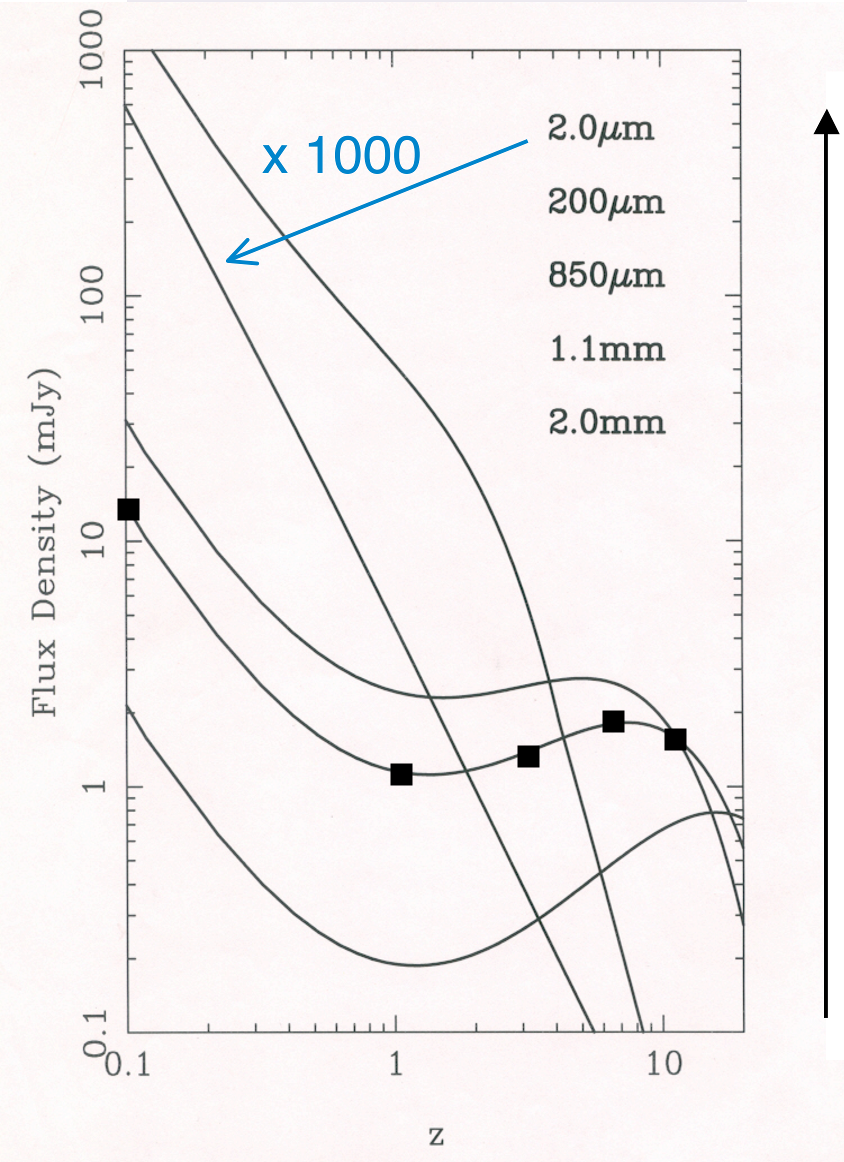
astro-ph/08012764

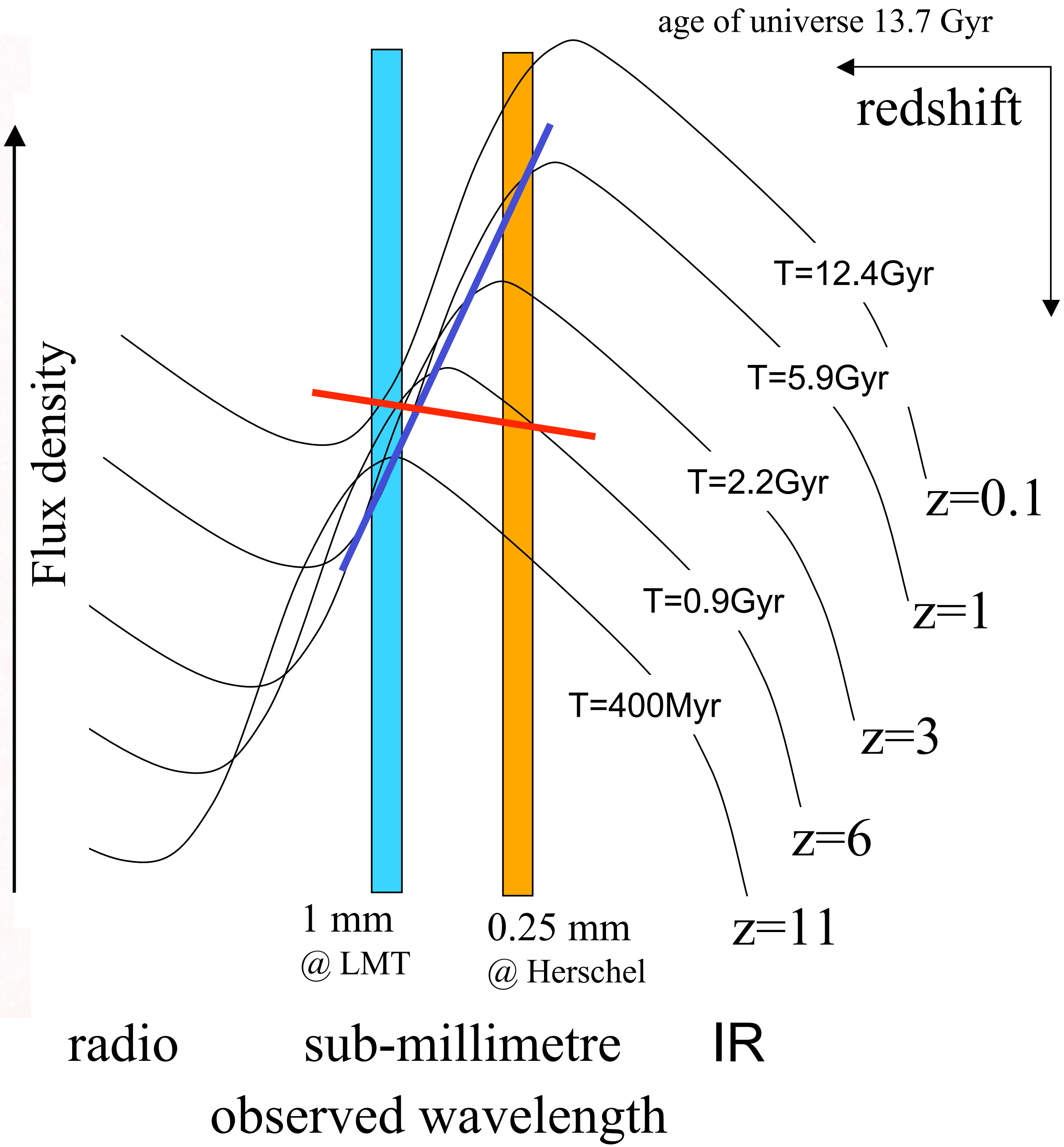

B
R
I
z
K
3.6
4.0
5.8
8.0
Lock850.01
Lock850.02
Lock850.03
Lock850.04
Lock850.05
Lock850.06
Lock850.07

Building galaxies in the early universe

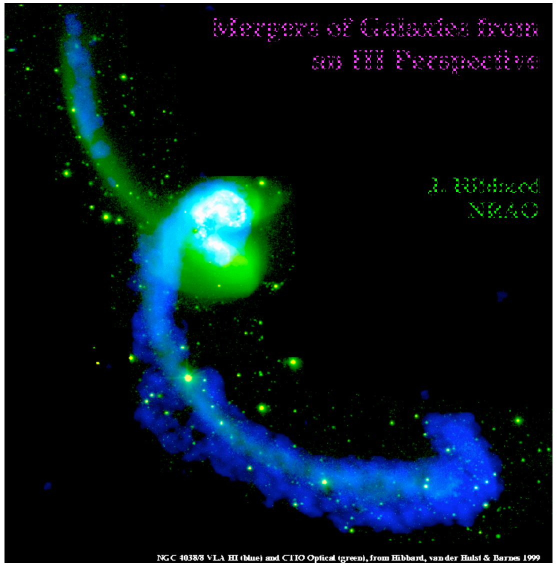
- feasibility of mm surveys

Arp 220 (z=0.018)
$L_{FIR} = 2x10^{12}\ L_\odot$





IRAS FIR (60um) luminosity function



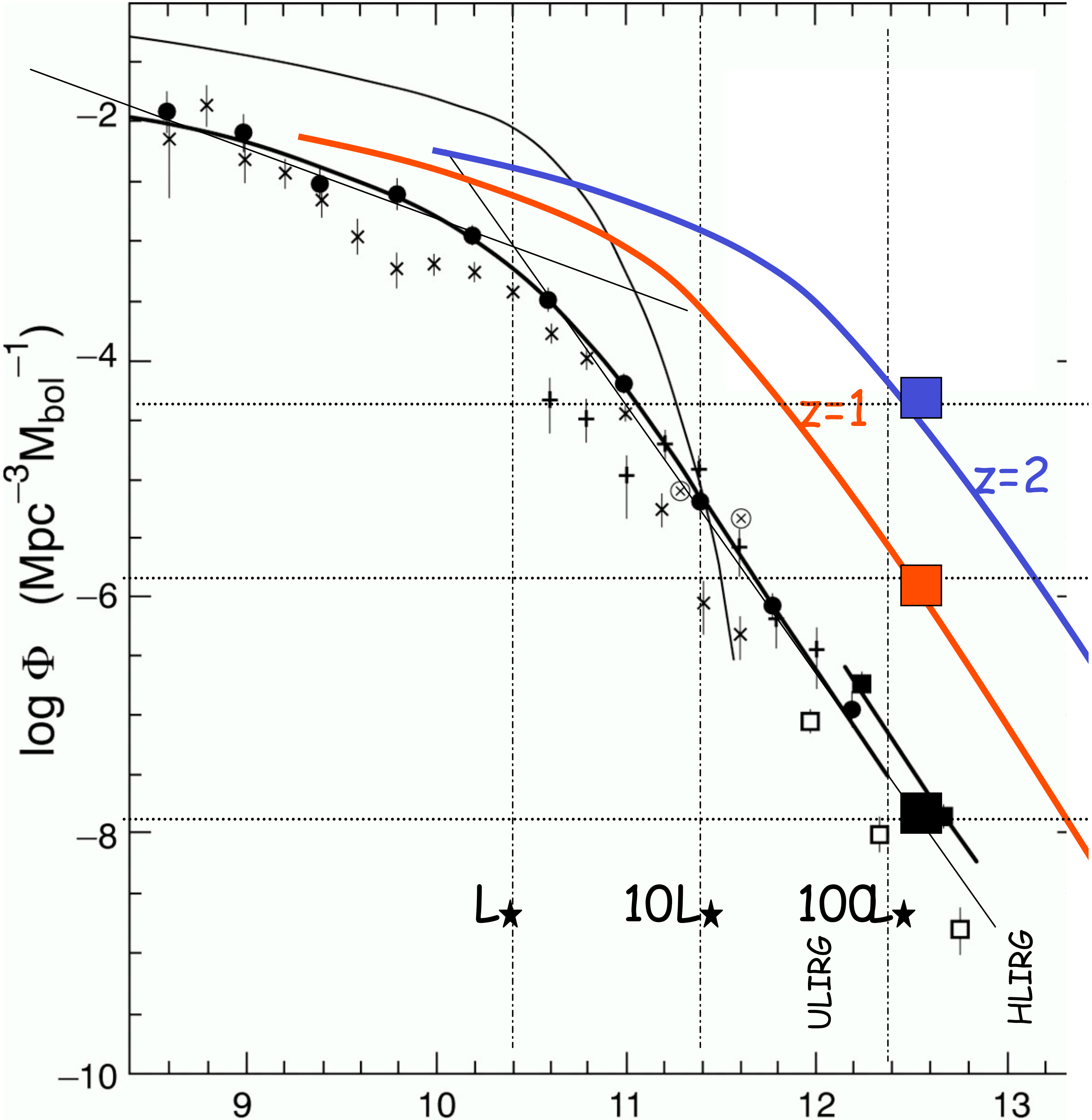
$L(z) = L_{\star}(1+z)^3$

at z=1, L(z) = 8 L★

at z=2, L(z) = 27 L★

Saunders etal. 1990
MNRAS, 242, 318

Soifer etal. 1986,
ApJ Lett. 303, L41



K-band sensitivity & mapping requirements from SASIR

- <50% of bright SMGs (>3mJy at 1.1mm), at z > 2, have IR counterparts K < 23

- LMT confusion-limit ~ 0.1 mJy at 1.1mm

if K-band scales with mm flux (or given k-correction at 2 microns), then the LMT needs SASIR (+ KECK + TMT) to provide sensitivities that reach K~27 over >1 sq. deg

LMT Scientific Potential

• As LMT 50-m exploits its full potential (>2015) it requires larger multi-wavelength facilities to complement the ability to conduct confusion-limited surveys

> 2009 GTC & SALT
Herschel & Planck
CARMA
Atacama Cosmology Telescope & South Pole Telescope
E-VLA & LOFAR

>2015 eROSITA,
JWST, TMT
CCAT (?)
ALMA-50

> 2020 Constellation-X
30-50m Extremely Large Telescope (optical)
SPICA (8-m cryo-cooled FIR satellite)
SKA

LMT Scientific Legacy

- Galaxy evolution in the high-redshift Universe
- Formation & evolution of large-scale structure (including anisotropies of the CMB – e.g. clusters)
- the nature and influence of Dark Energy on the growth of structure in the early Universe
- Proto-planetary (gas & dust) disks around young stars; physics of planet-formation
- The origin of the stellar Initial Mass Function; the physics of star-formation