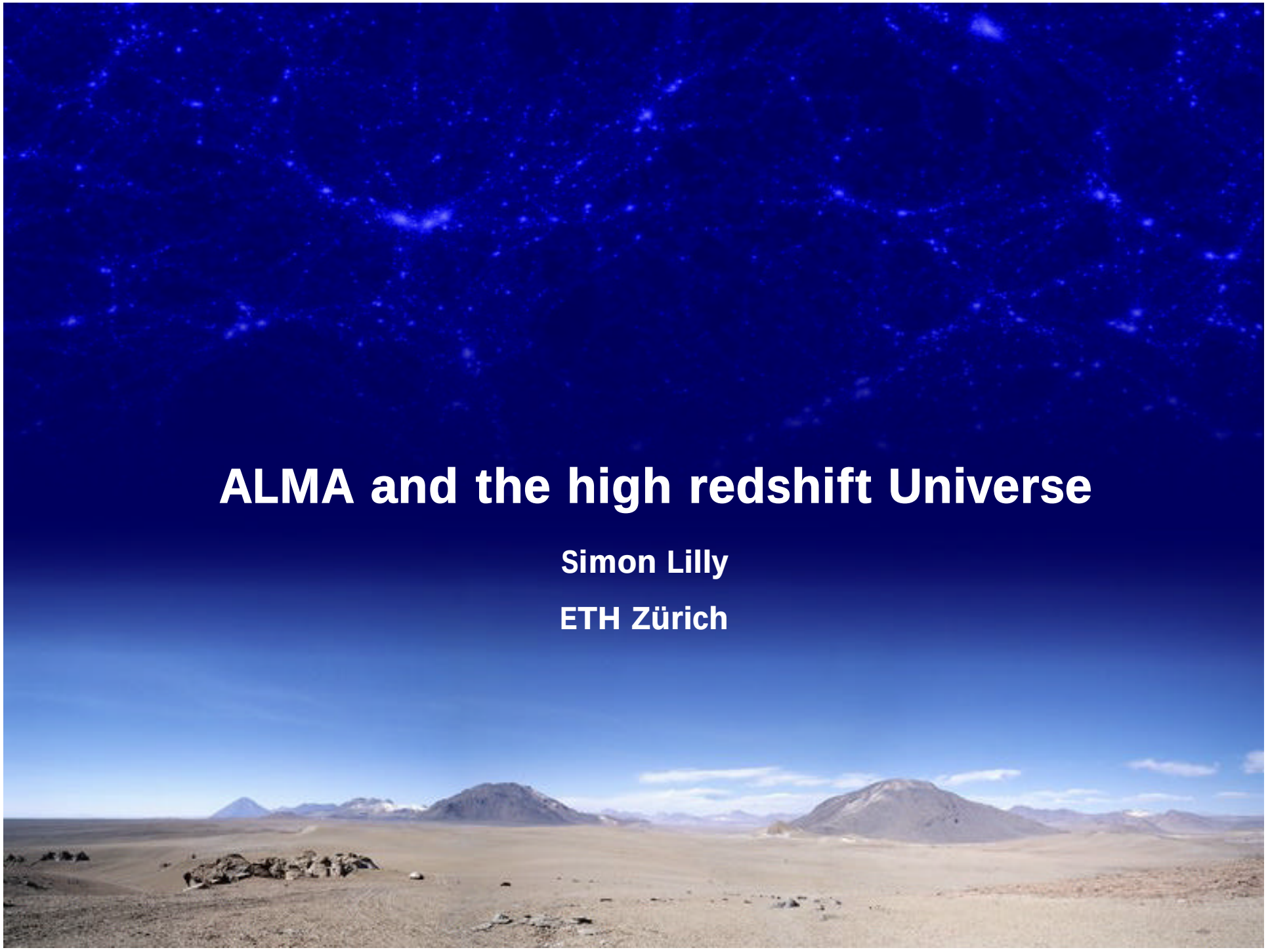
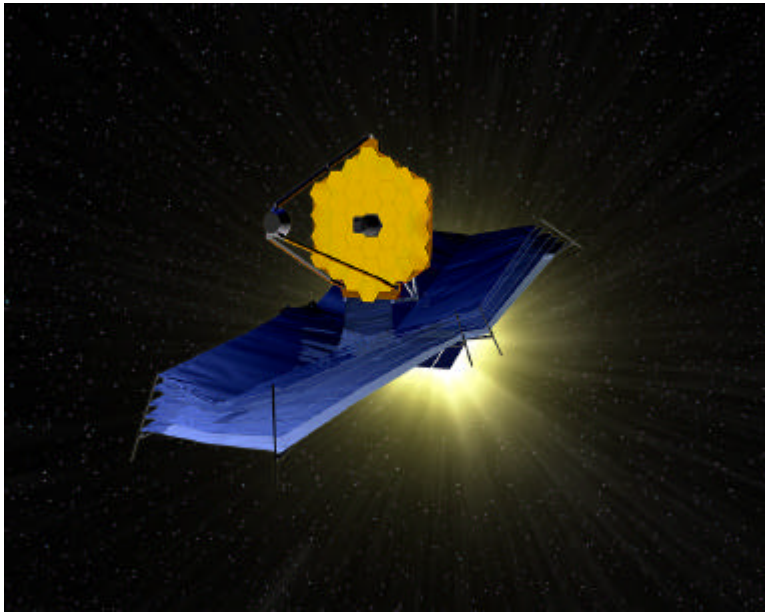


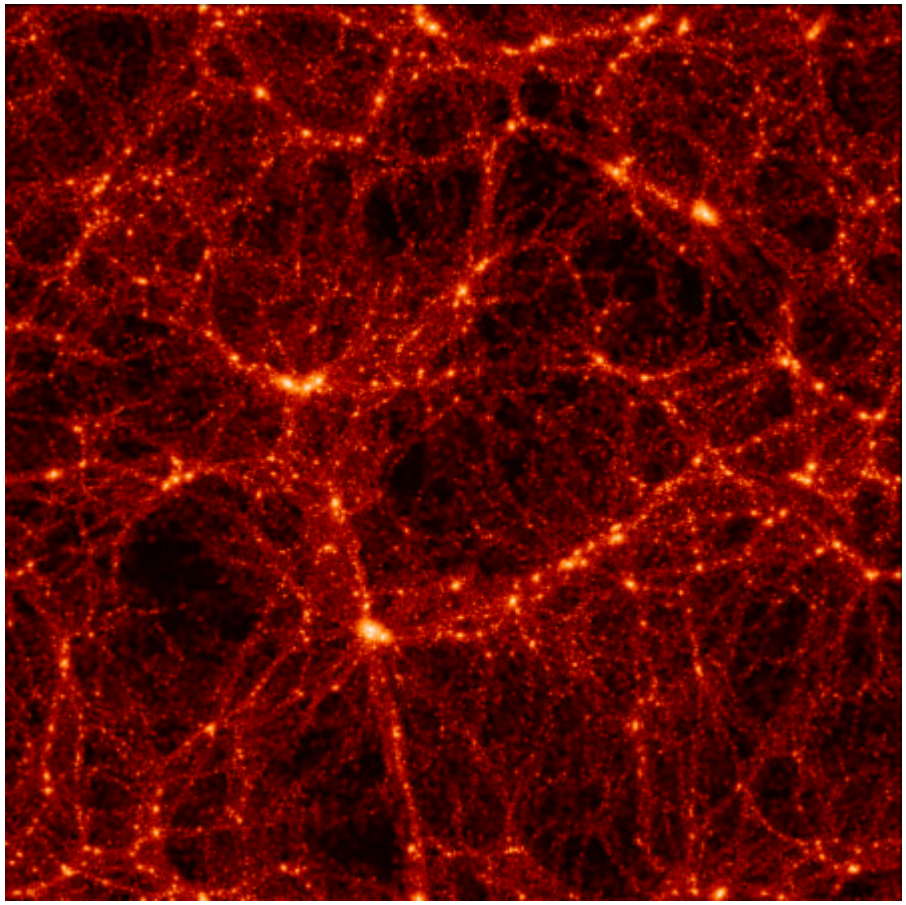
ALMA and the high redshift Universe

Simon Lilly

ETH Zürich

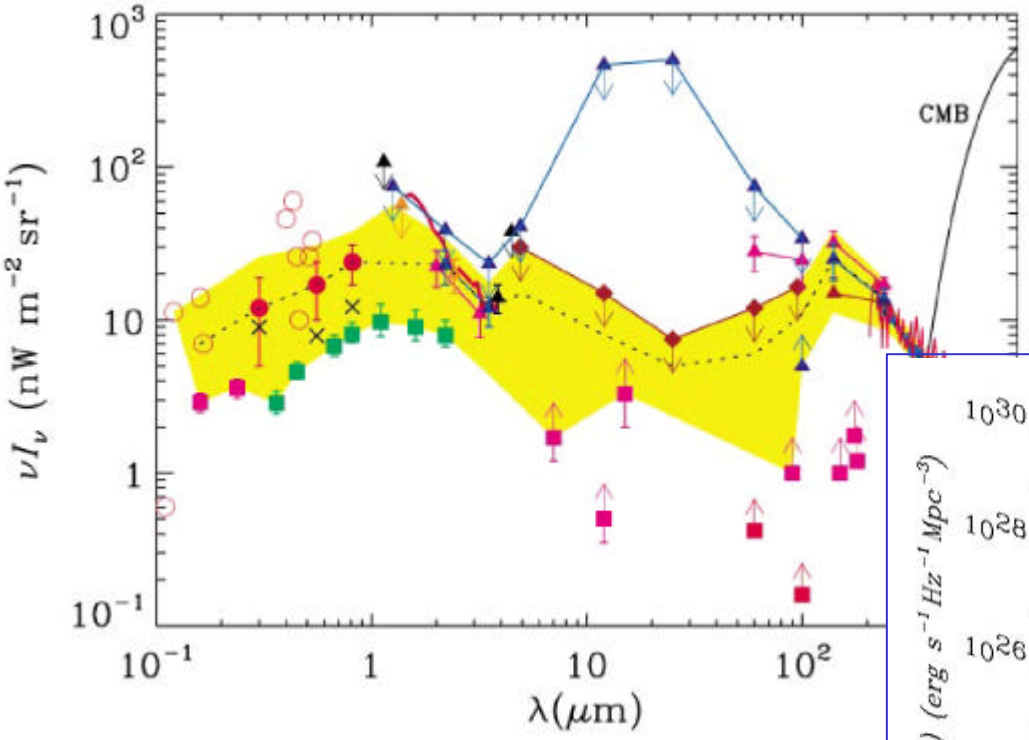
2012 will be an exciting year



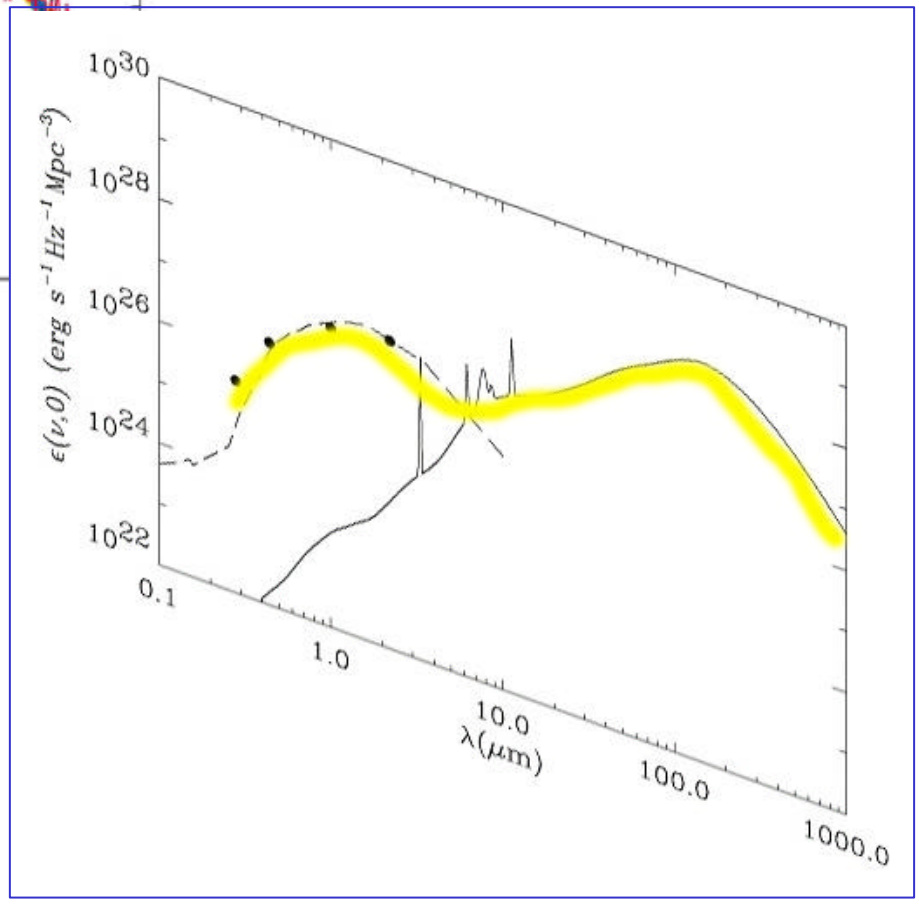


?

Cool material is central to this process



(Hauser and Dwek ARAA 2001)



Extragalactic background light: far-IR major component of energy production

c.f. local luminosity density

Dwek et al (1999)

A: "First Light" up to reionization

1. DETECTION OF FIRST LUMINOUS OBJECTS AT VERY HIGH REDSHIFTS z ~ 15-20:

   What is nature of first luminous objects

   How is formation of zero-metal objects different (cooling etc)

   Feed-back mechanisms

2. ESTABLISHING WHEN REIONIZATION OCCURRED

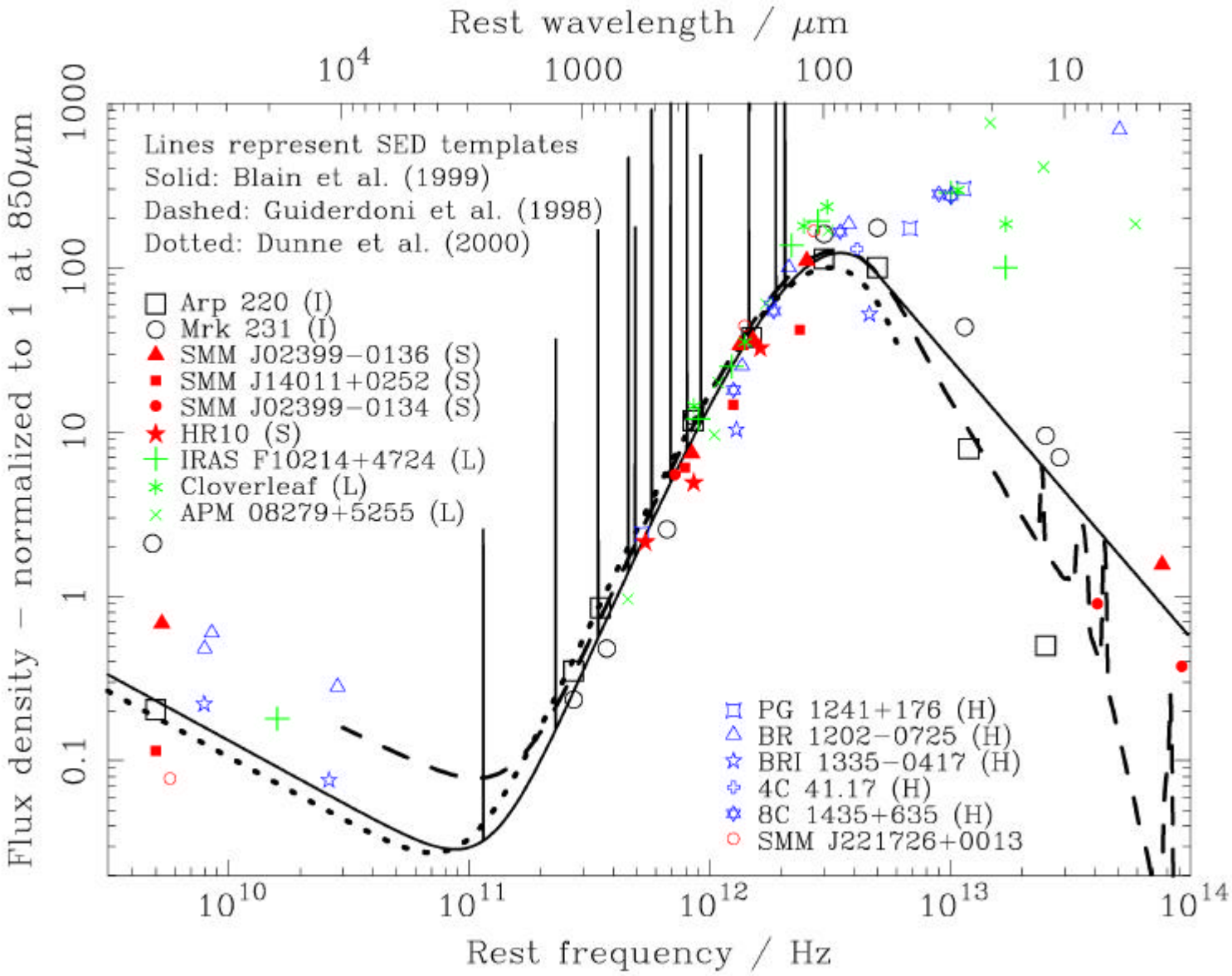
   Once? Or more than once?

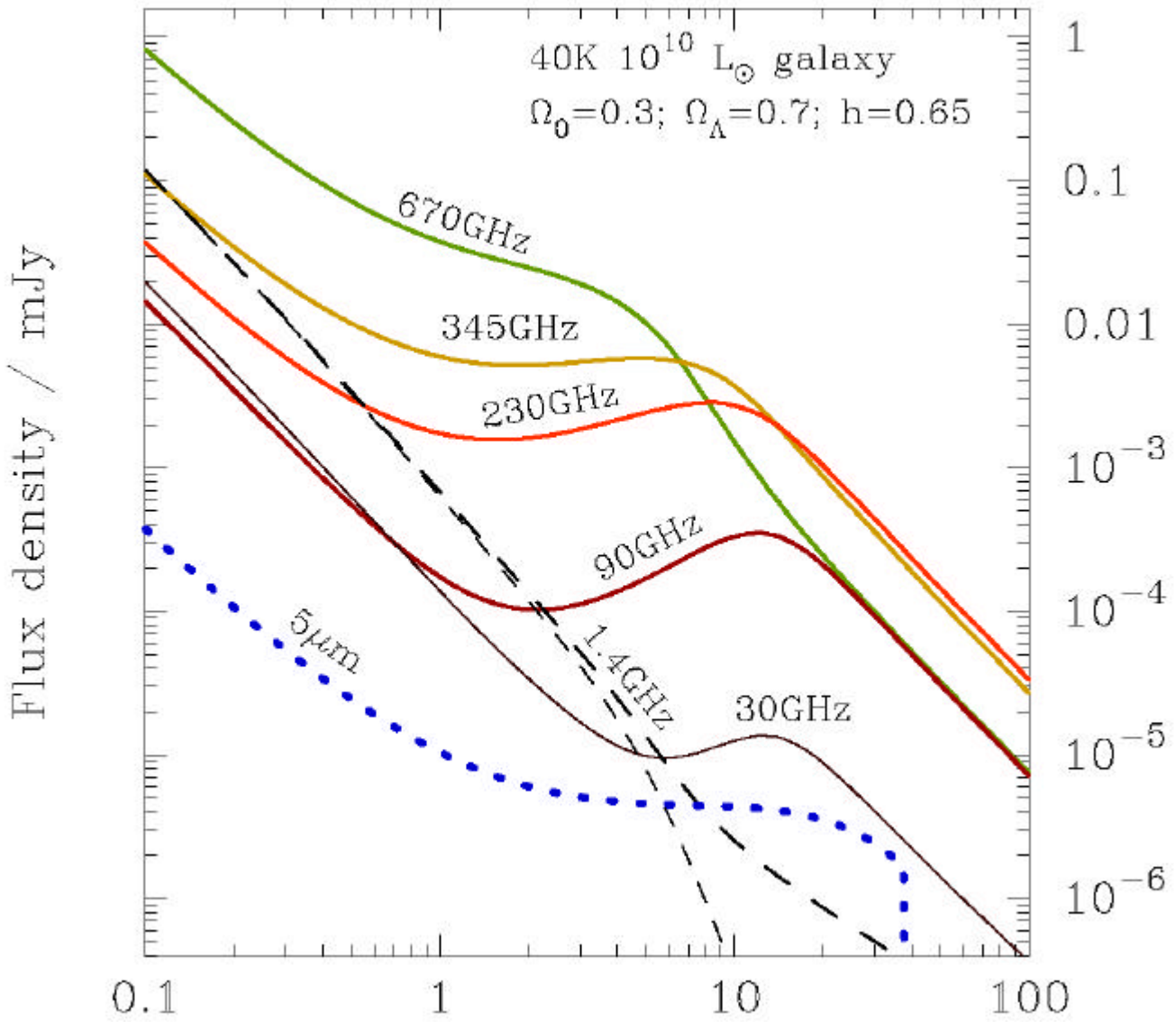
3. IDENTIFYING THE REIONIZERS

   Which end of the LF did it and how were they spatially distributed

B: "Assembly of galaxies after reionization"

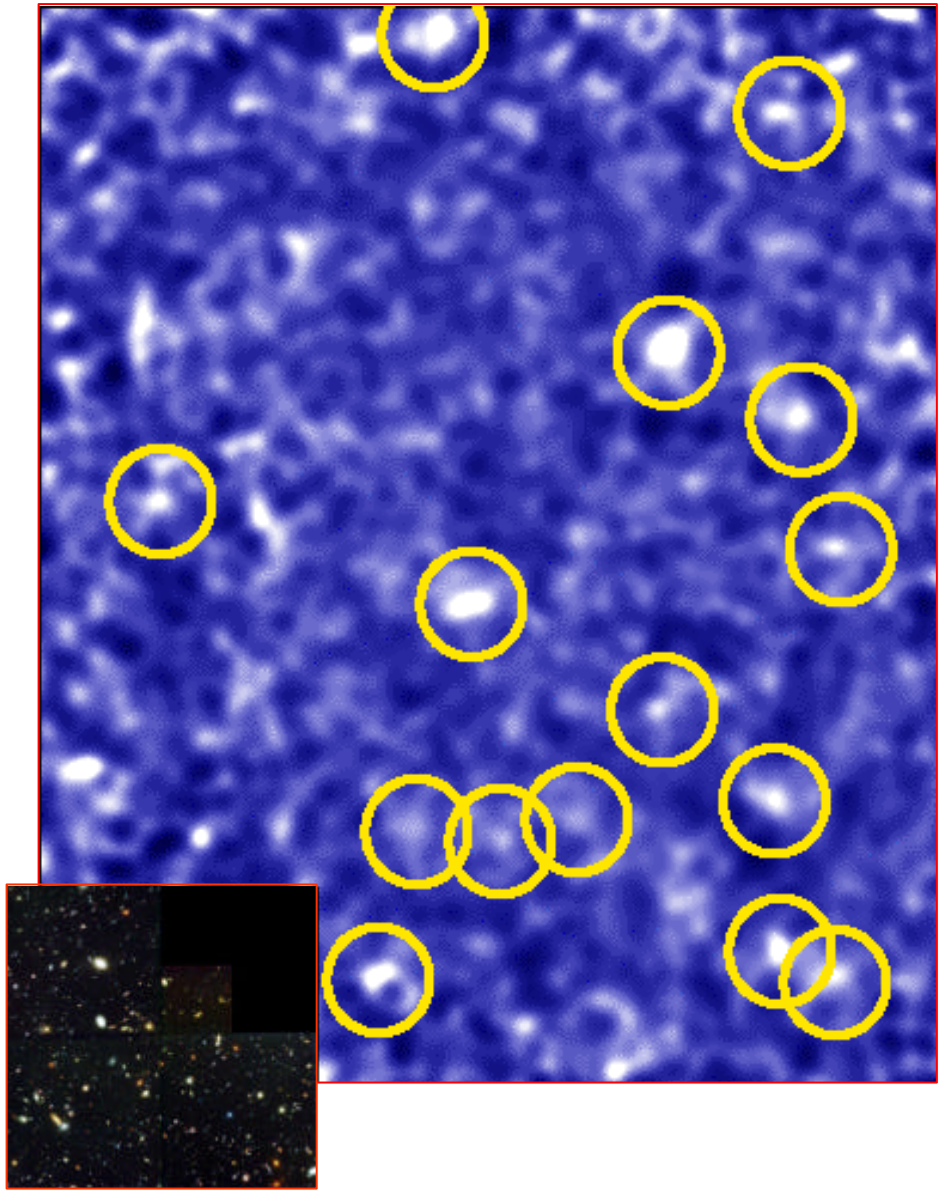
4. WHERE WERE THE STARS IN TODAY'S HUBBLE SEQUENCE FORMED
   For different morphological components (esp. spheroids) were stars formed in situ or brought-in by merging, or formed in merging-induced star-bursts?
   Was spheroid star-formation different from present-day disk star-formation?
   When did recognizable disk structures first appear and why?
   When did quiescent galaxies first appear and why?
5. CAN WE PROPERLY TEST HIERARCHICAL ASSEMBLY OF DARK MATTER HALOES?
   Group dynamics and Cluster assembly
   Lensing of galaxy haloes, cluster cores etc.
6. HOW DOES THE METALLICITY OF THE UNIVERSE BUILD UP WITH TIME
   Is there global consistency with metal production?
   How do galaxies exchange enriched material with the IGM in proto-clusters and the field?
7. WHAT IS THE ROLE OF DUST IN OBSCURING MAJOR PHASES OF GALACTIC EVOLUTION?
8. WHAT ARE THE CONNECTIONS BETWEEN CENTRAL BLACK-HOLES, AGN EVOLUTION AND GALAXY EVOLUTION AT R > 100 pc.


Rest wavelength / μm
10^4
1000
100
10
Flux density – normalized to 1 at 850μm
1000
100
10
1
0.1
Lines represent SED templates
Solid: Blain et al. (1999)
Dashed: Guiderdoni et al. (1998)
Dotted: Dunne et al. (2000)
Arp 220 (I)
Mrk 231 (I)
SMM J02399−0136 (S)
SMM J14011+0252 (S)
SMM J02399−0134 (S)
HR10 (S)
IRAS F10214+4724 (L)
Cloverleaf (L)
APM 08279+5255 (L)
PG 1241+176 (H)
BR 1202−0725 (H)
BRI 1335−0417 (H)
4C 41.17 (H)
8C 1435+635 (H)
SMM J221726+0013
10^10
10^11
10^12
10^13
10^14
Rest frequency / Hz



Sub-mm flux density relations

ALMA and the high redshift Universe



SCUBA Surveys (2002)

- 8 mJy survey (UK: Scott et al, +)
- CUDSS (Cardiff-Toronto: Eales et al +)

JCMT/SCUBA-1:

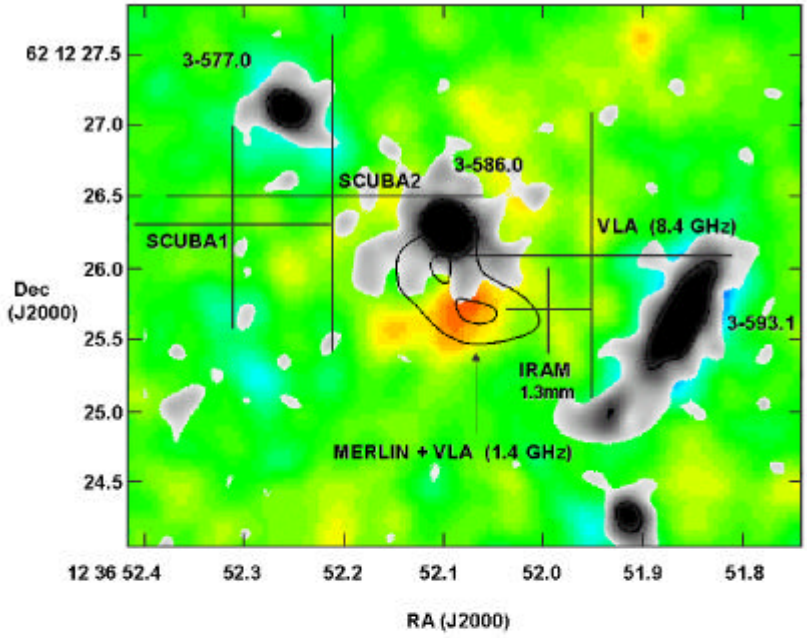
S_{850} > 3mJy/8 hr

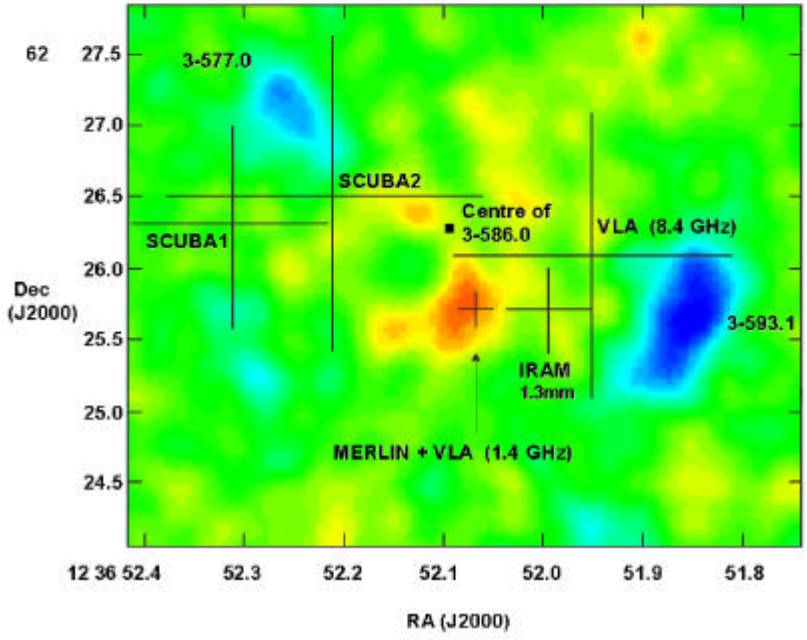
15 arcsec beam

ALMA:

S_{850} > 0.015mJy/8 hr ?200

~ 0.15 arcsec beam ?100

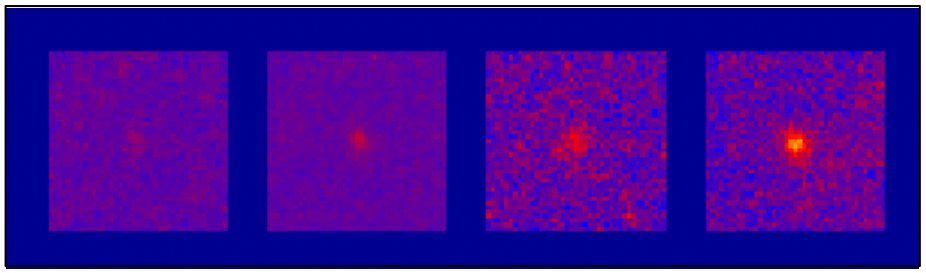




Identifications are extremely faint (or impossible)

Identification of HDF 8501.1 (Dunlop et al 2002)

$K_{AB} \sim 25.5 \quad z_{est} \sim 4$



CUDSS-14A

z_{est} = 2

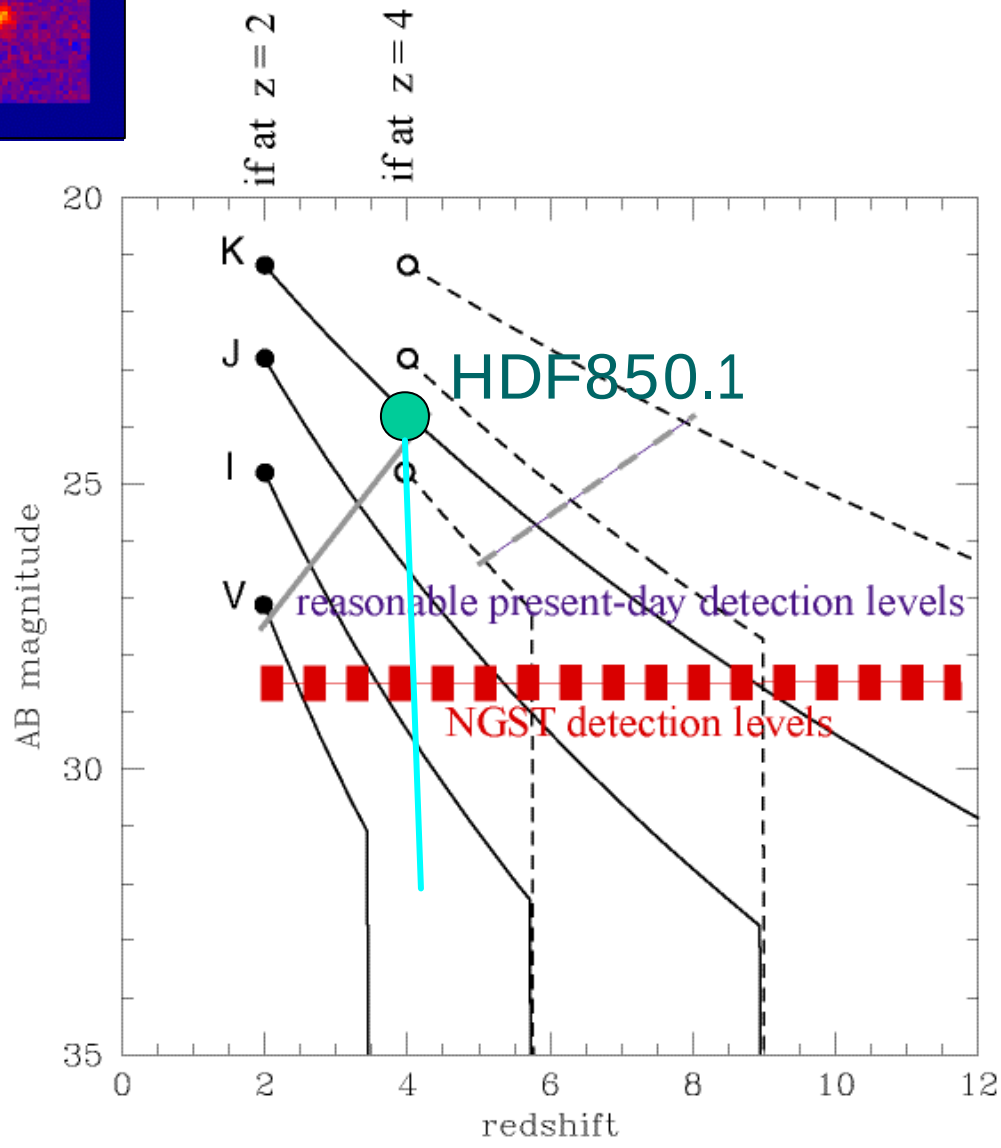
V = 27.01 ? 0.33

I_{AB} = 25.02 ? 0.13

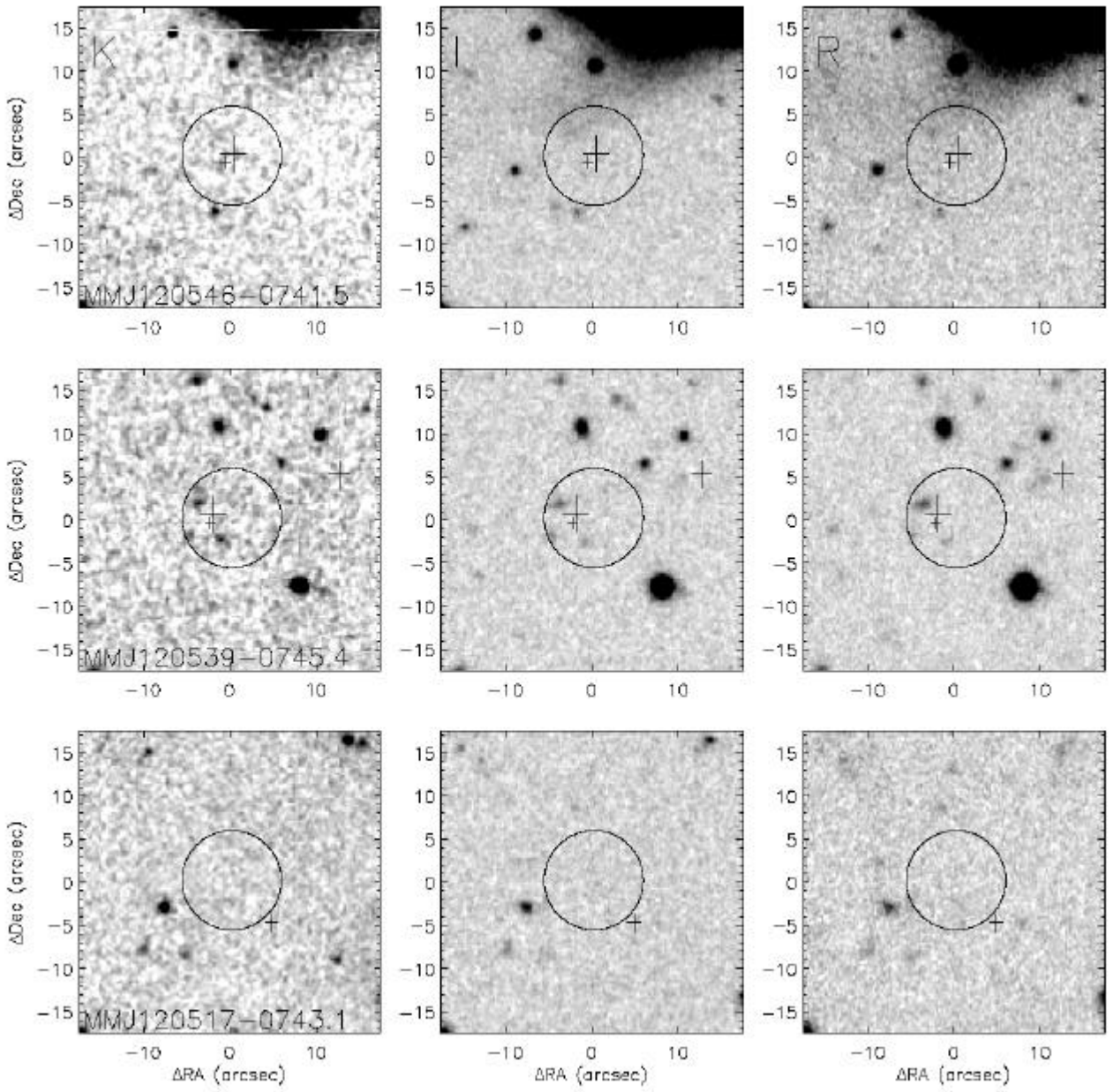
J_{AB} = 22.87 ? 0.12

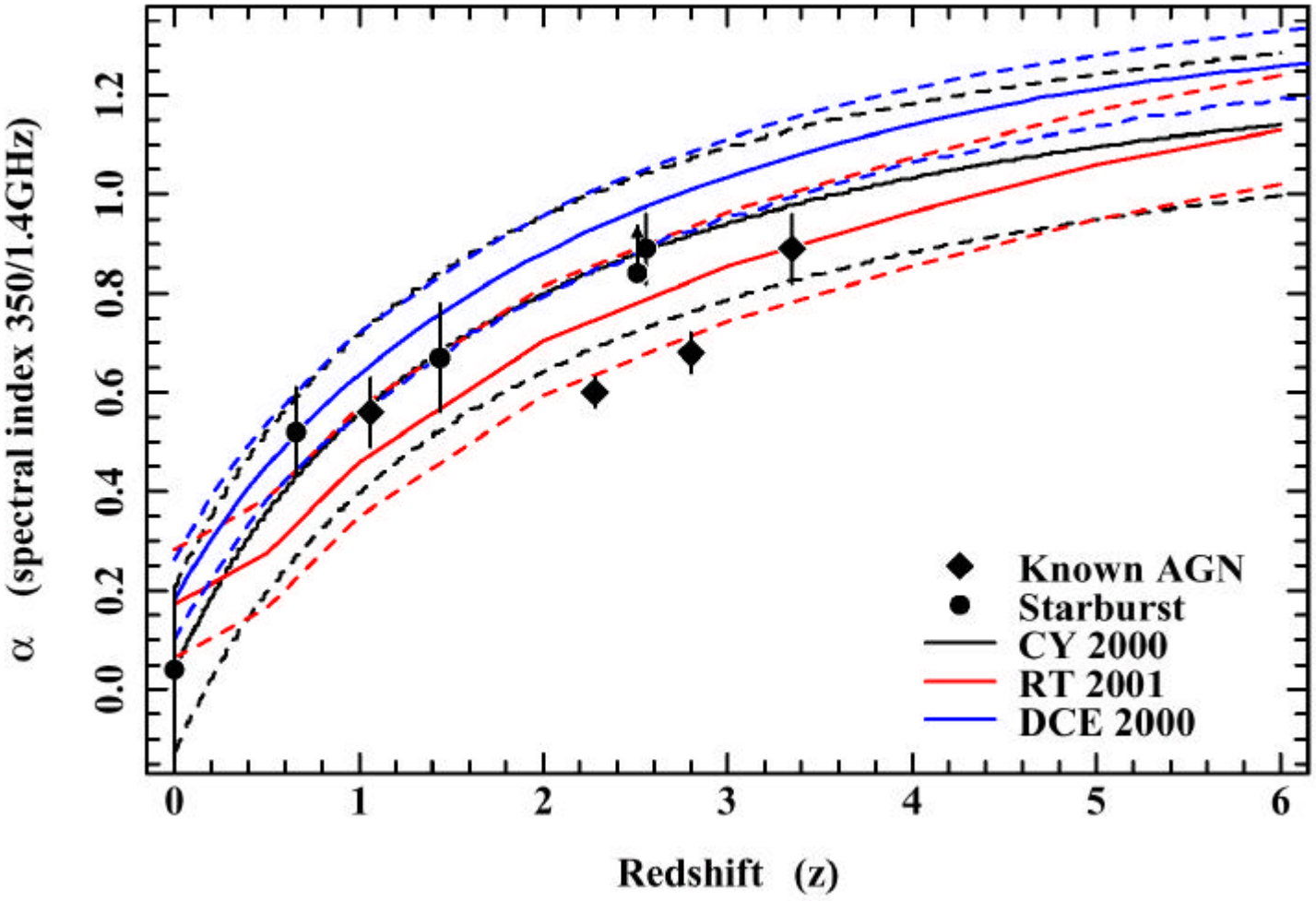
K_{AB} = 21.19 ? 0.07

$(V-K)_{AB}$ ~ 6

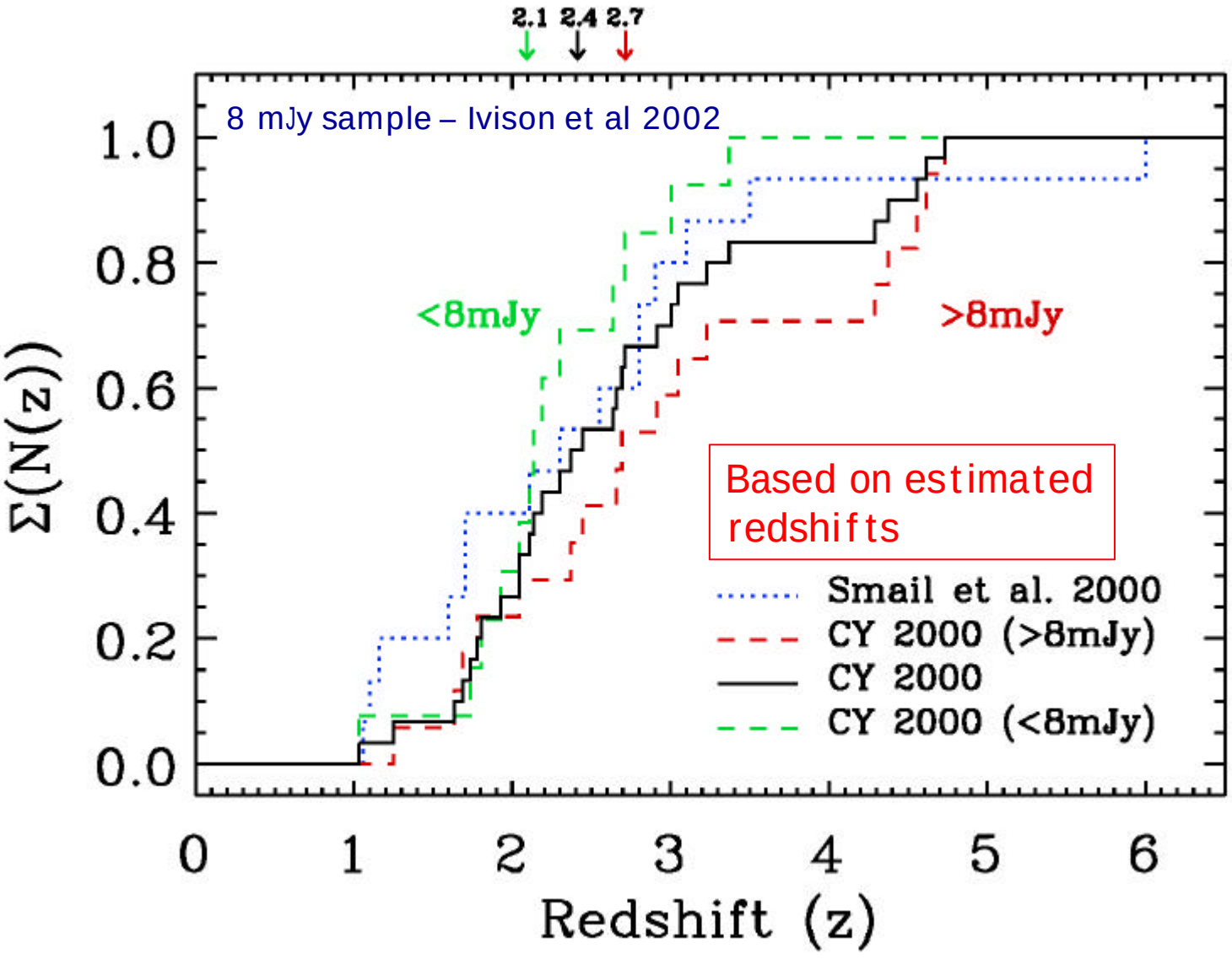


Dannerbauer et al 2002: IR empty fields of galaxies with mm-interferometric positions, $K_{AB} > 24$

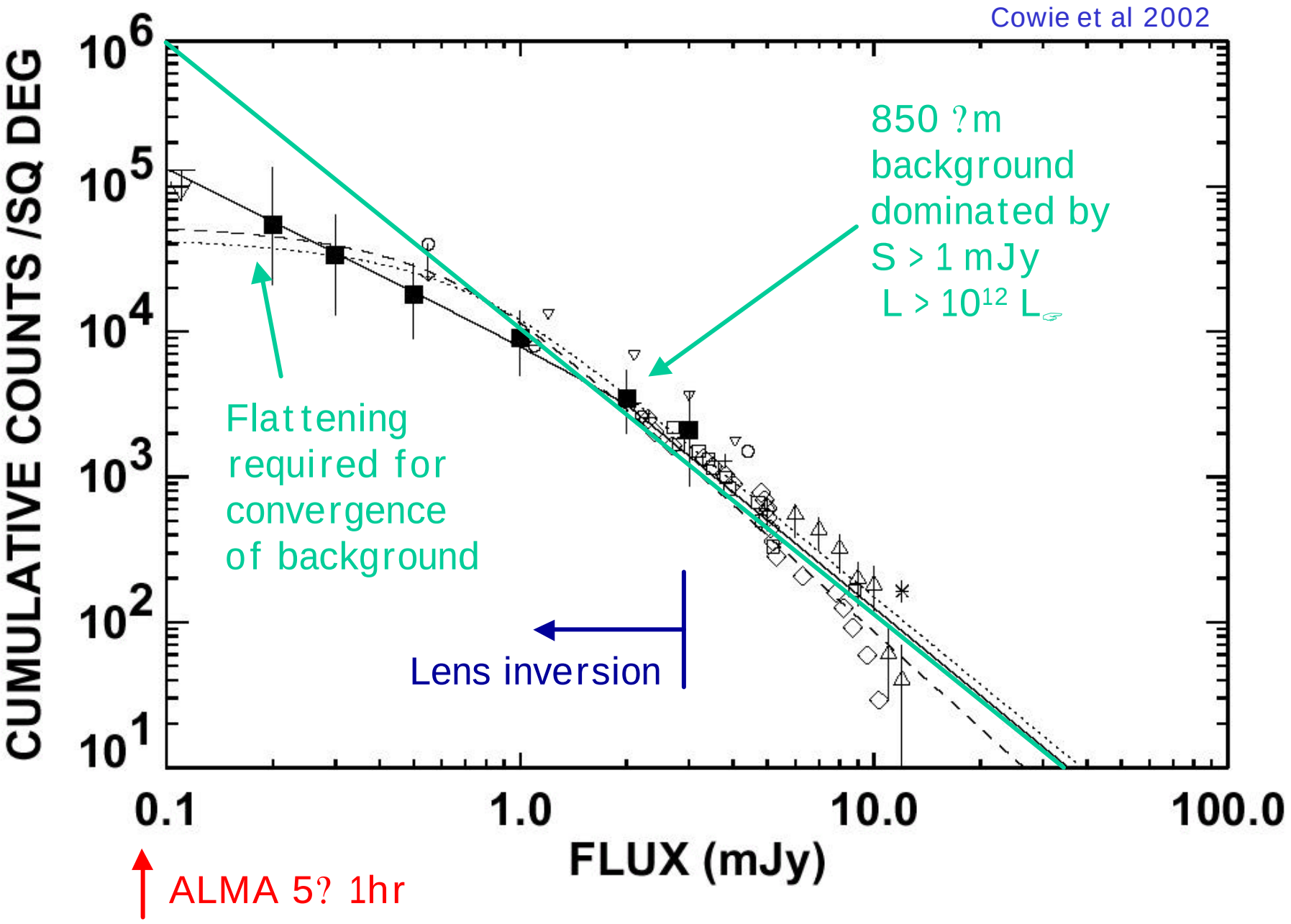


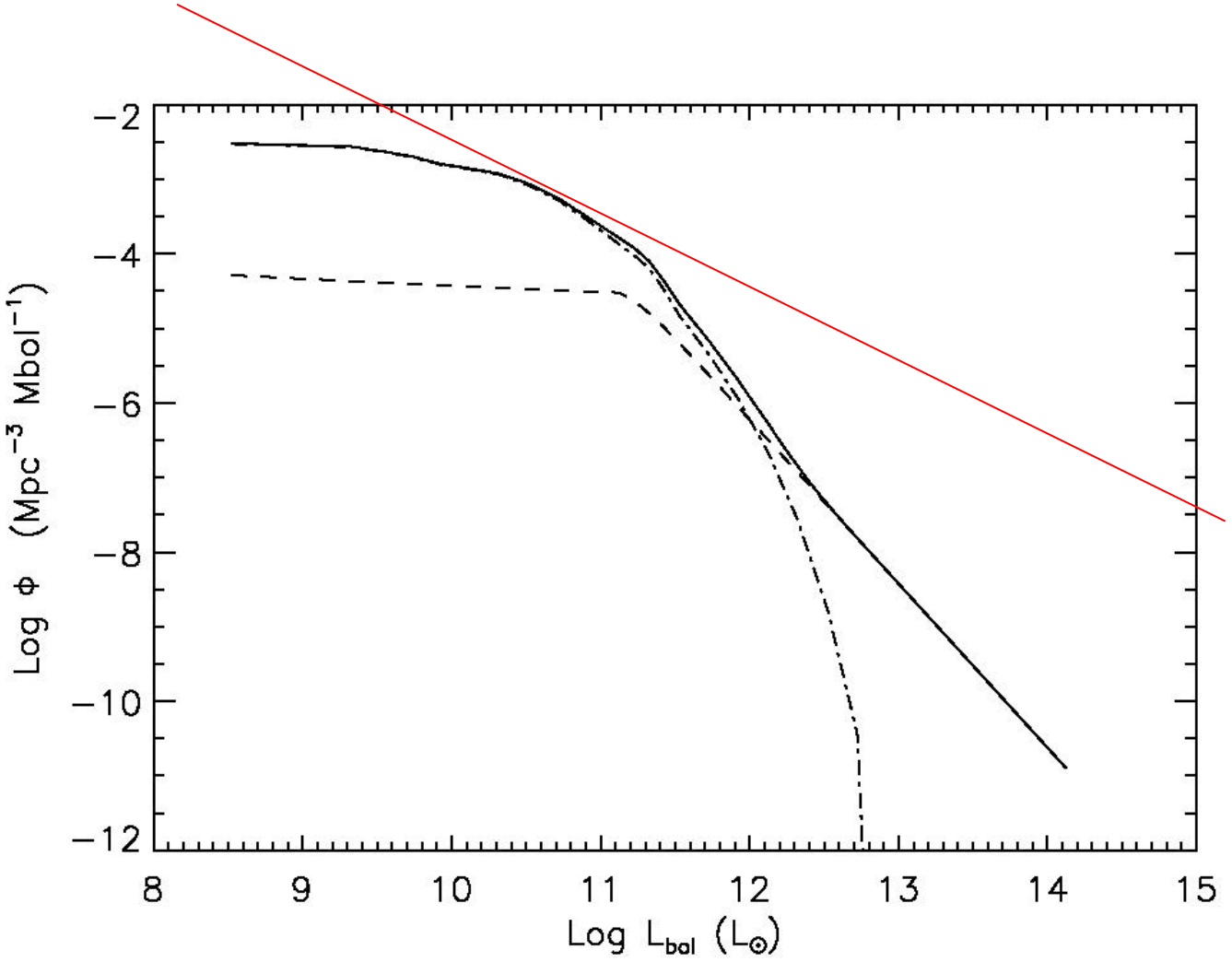


Radio-submm redshift estimation



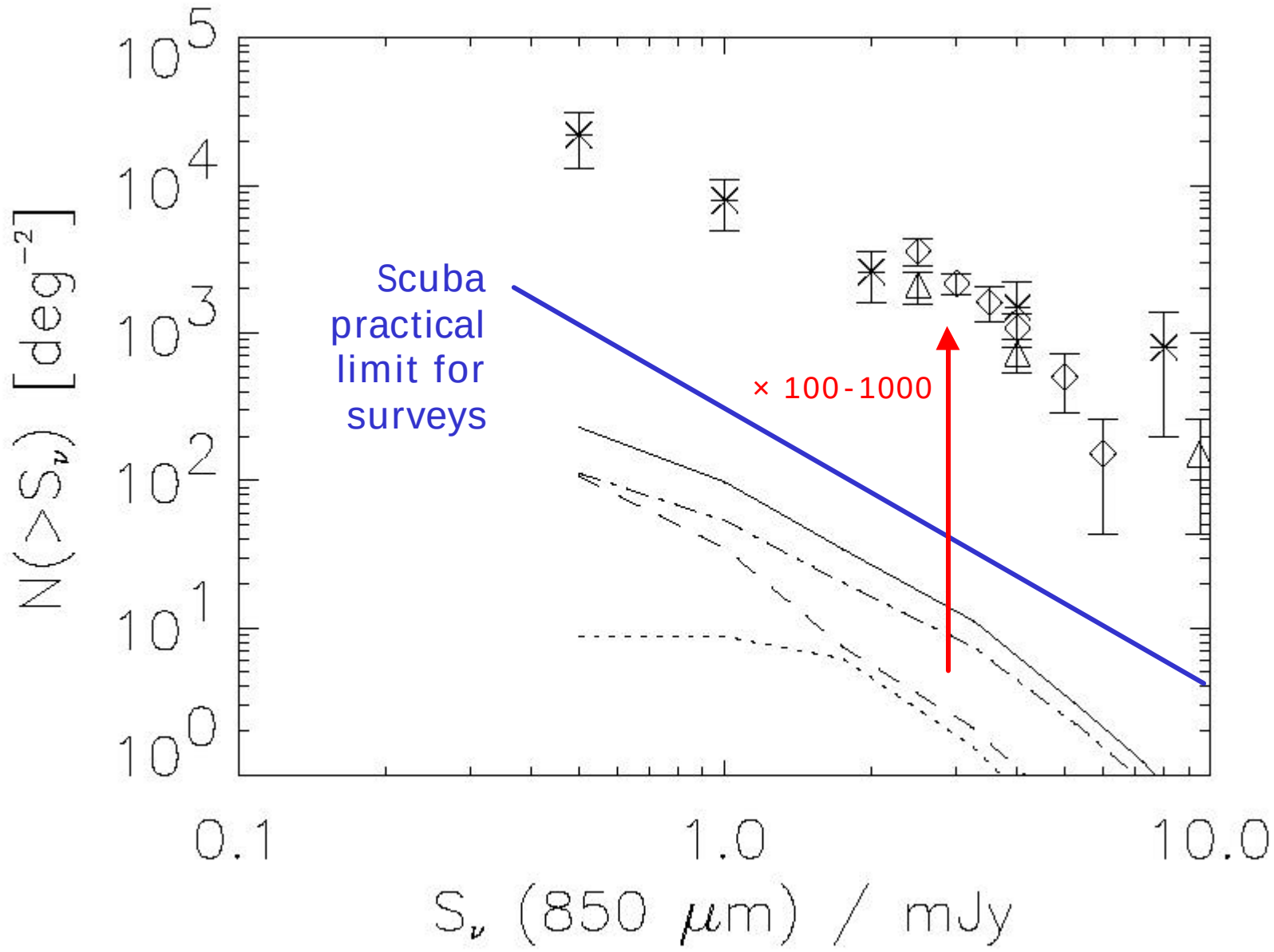
CO redshifts may be only way for many


Cowie et al 2002
CUMULATIVE COUNTS /SQ DEG
10^6
10^5
10^4
10^3
10^2
10^1
0.1
1.0
10.0
100.0
FLUX (mJy)
850 ?m background dominated by S > 1 mJy
L > 10^{12} L☞
Flattening required for convergence of background
Lens inversion
ALMA 5? 1hr

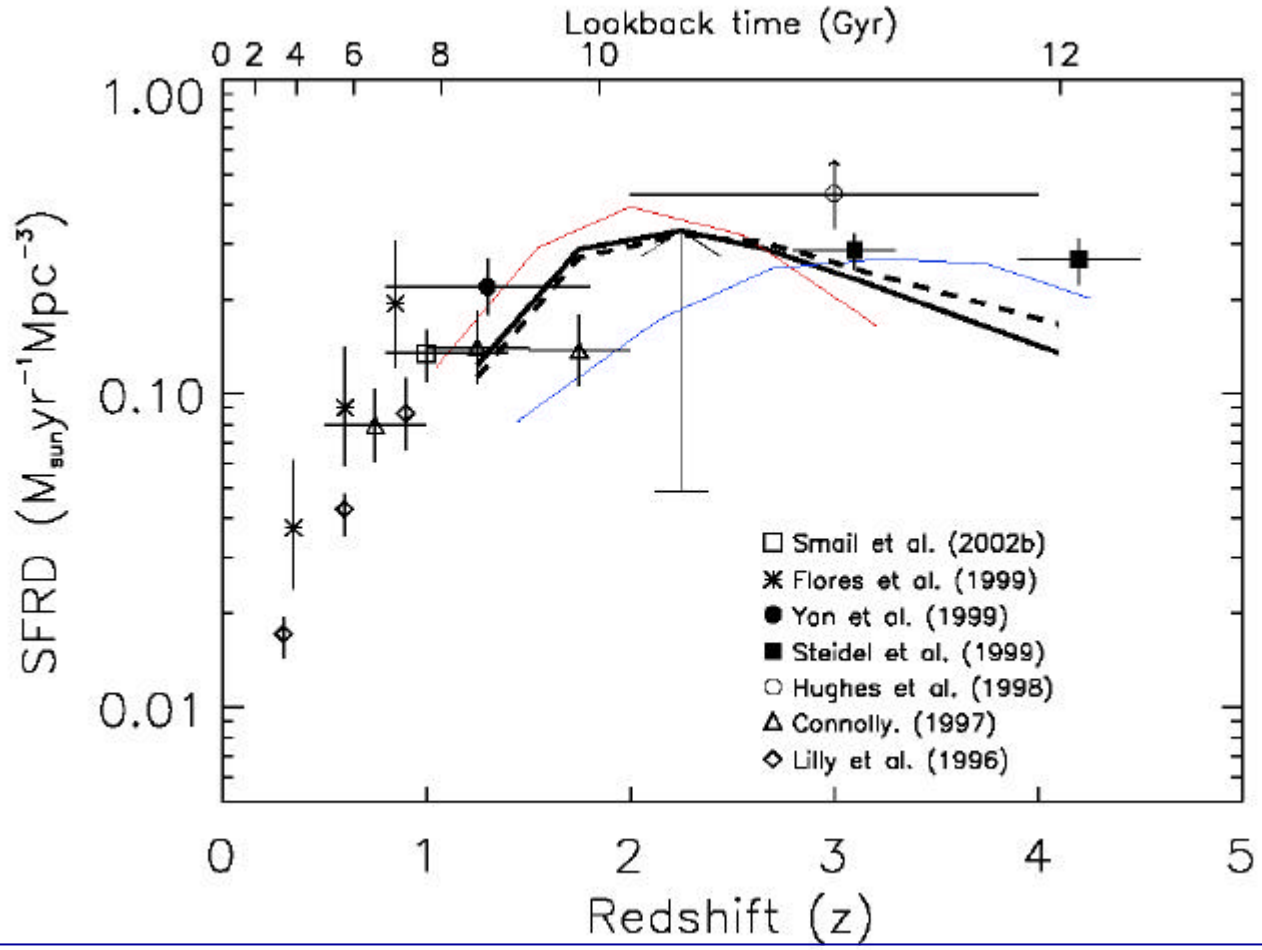


c.f. locally....

From Lagache et al 2002



SCUBA was “lucky”



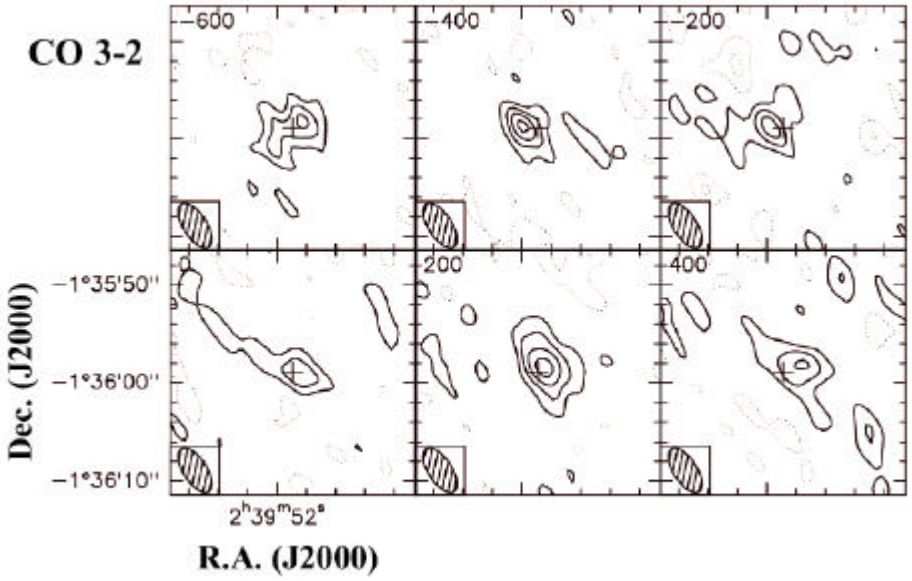
High z ULIRGs are playing a major role in galaxy formation/evolution at $1 < z < 4$.

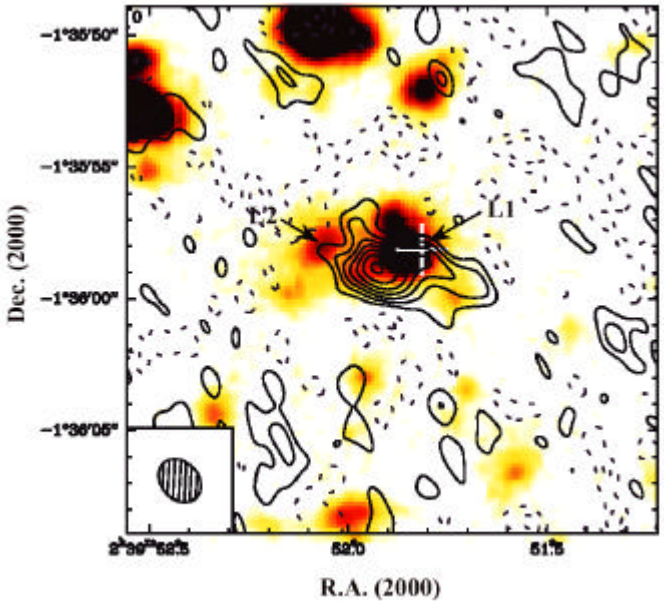
ALMA has immediate role in identifications and redshifts..... also in physical understanding

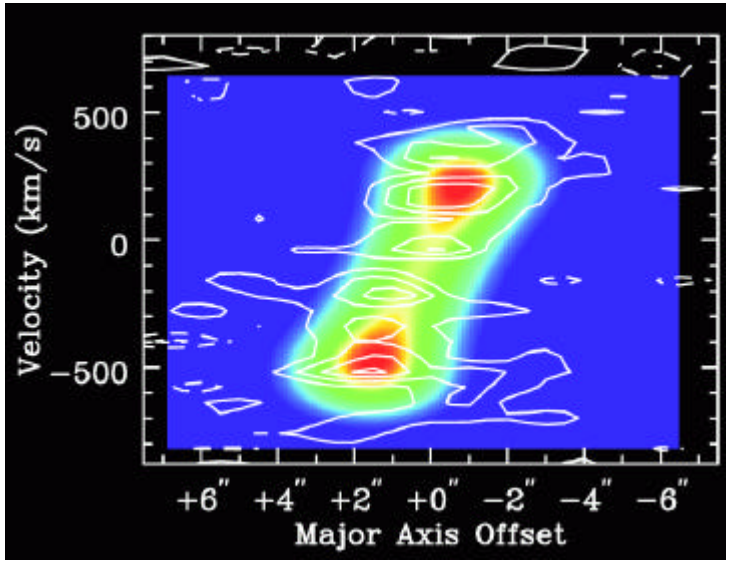
SMM J020399-0136 (Genzel et al 2002) z=2.80

Rotation > 420 kms-1

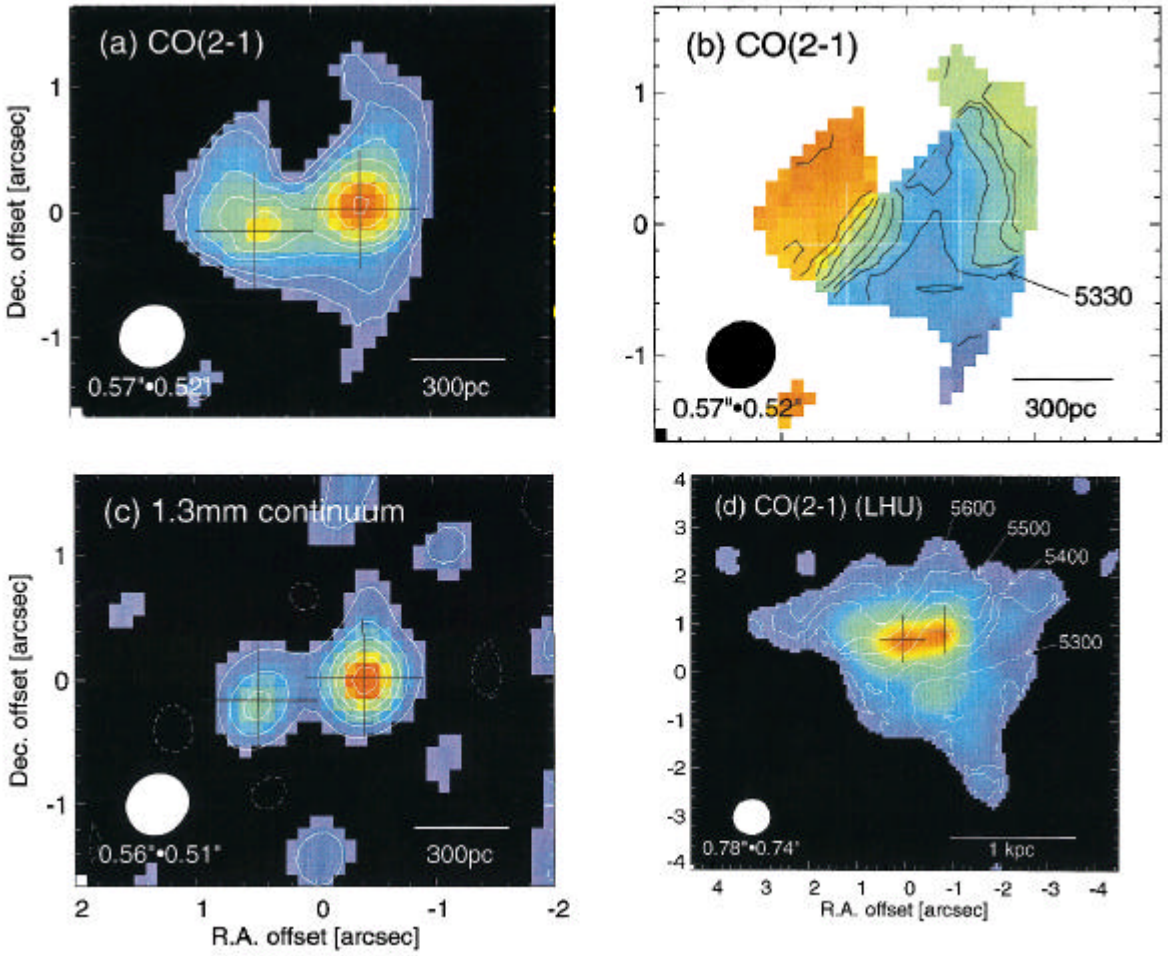
M > 3 x 10^{11} $M_{\odot}$ within 8 kpc?







Starting to study them



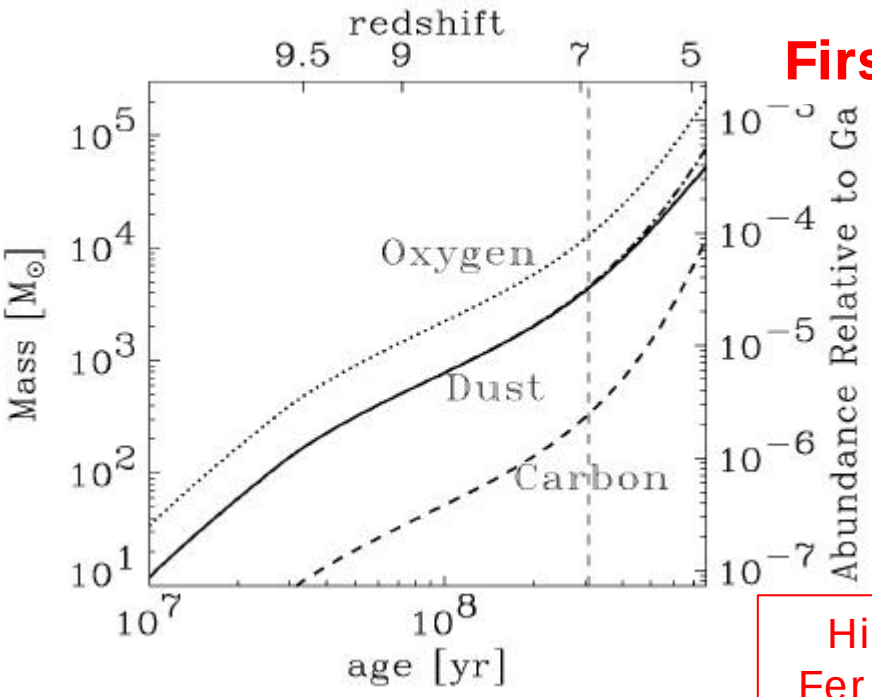
Arp 220 - Sakamoto et al (1999)

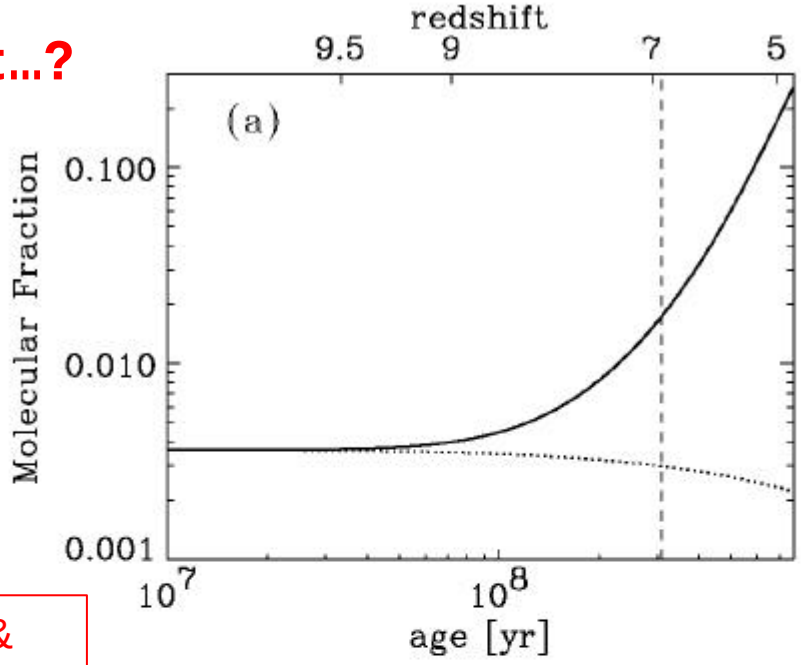
Arp 220 (z = 0.02) ? z = 2

0.5” beam CO 2-1 at 2-8 mJy beam^{-1}(30 kms^{-1} channel)

0.02” beam CO 5-4 at 0.4-1.6 ?Jy beam^{-1} (“)

First light...?

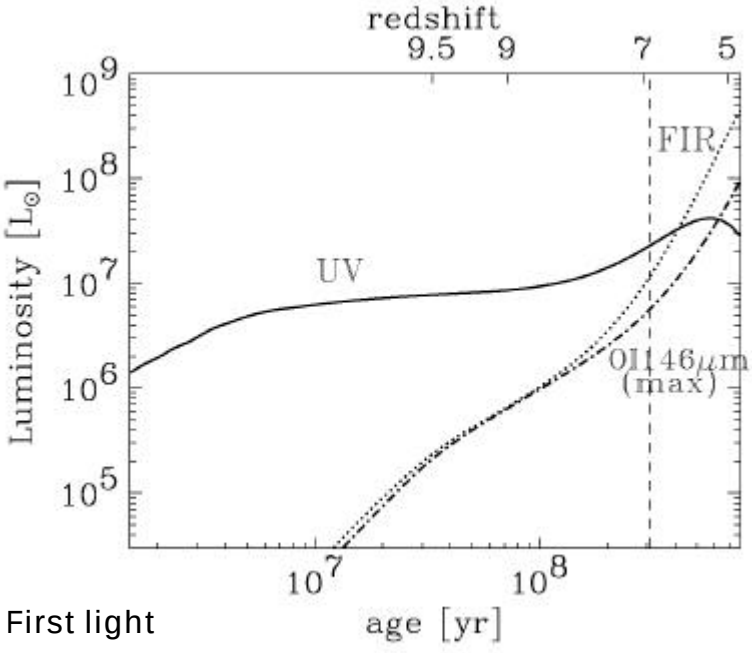


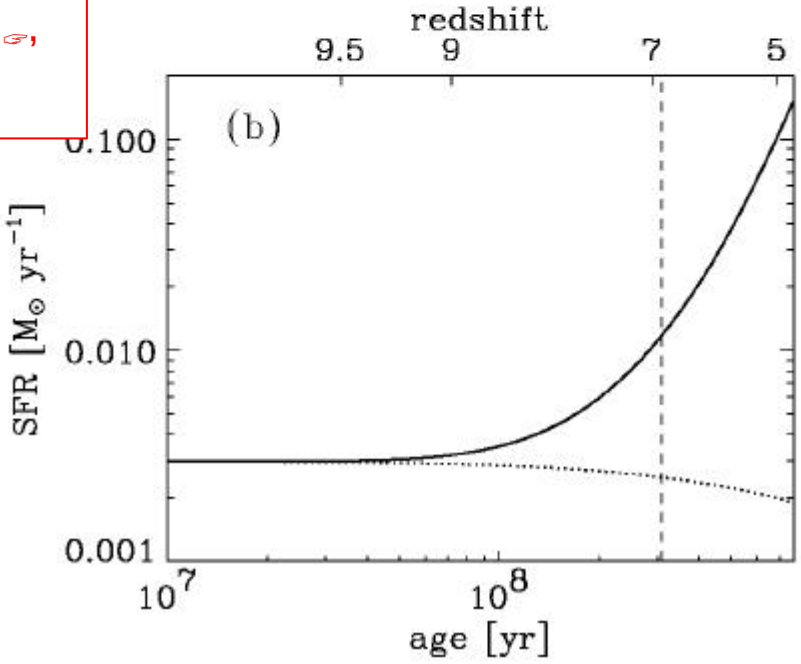


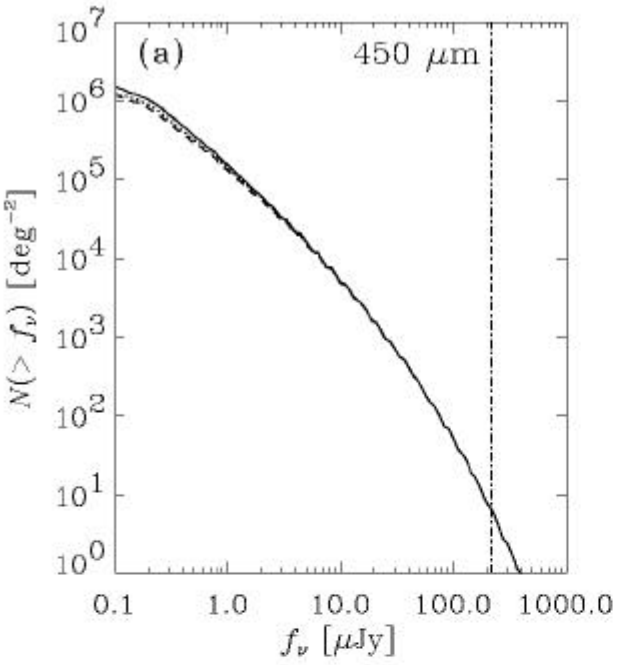
Hirashita & Ferrara 2002:

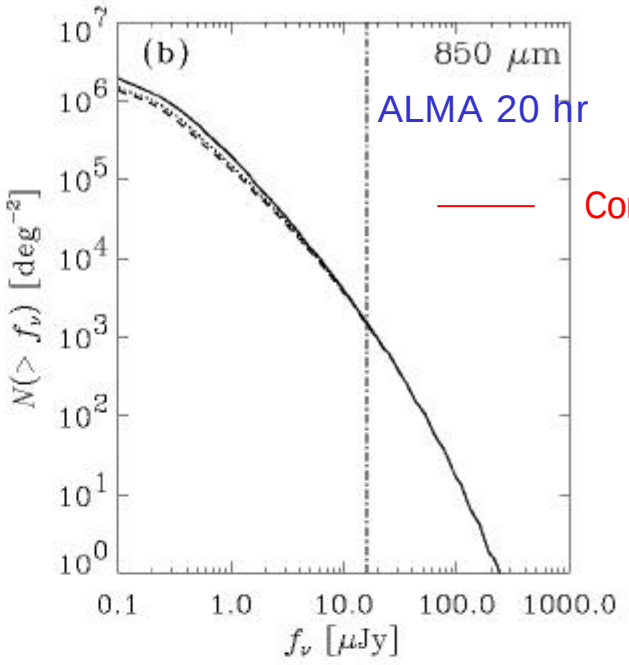
Mvir = $10^9 M_\odot$,

z_{vir} = 10



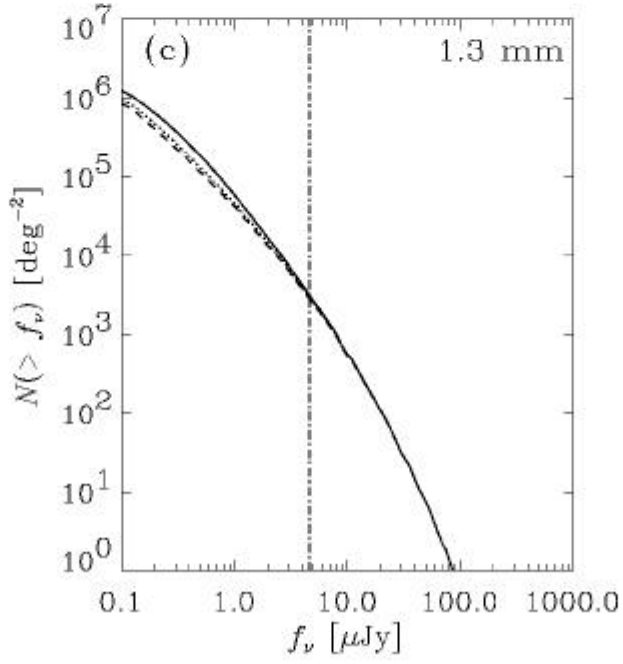






ALMA 20 hr

Converging counts



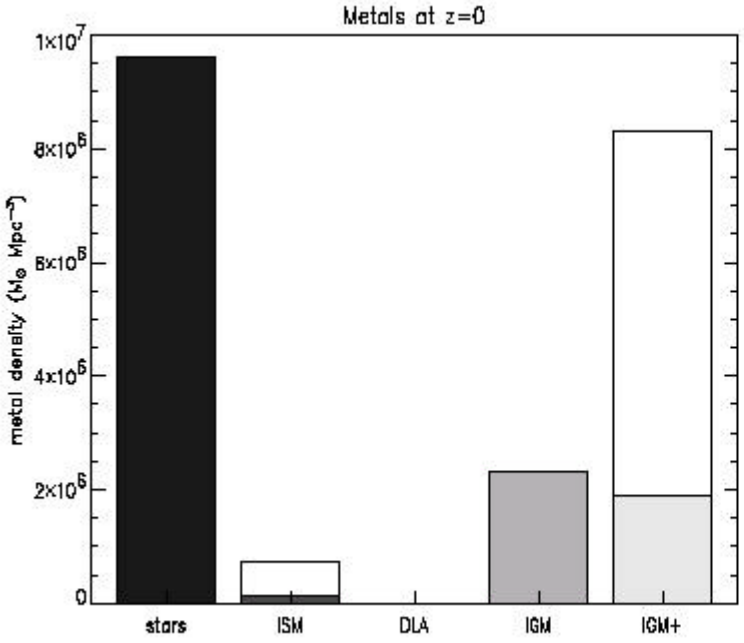
Hirashita & Ferrara 2002:

5 < z < 20

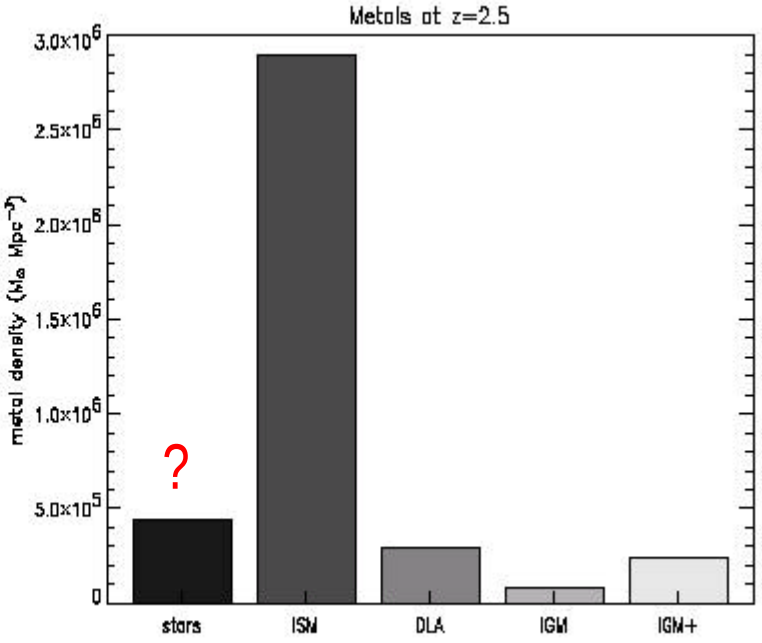
Metals…

Dunne et al (2002)… where are the metals at high z ?

z = 0



z = 2.5



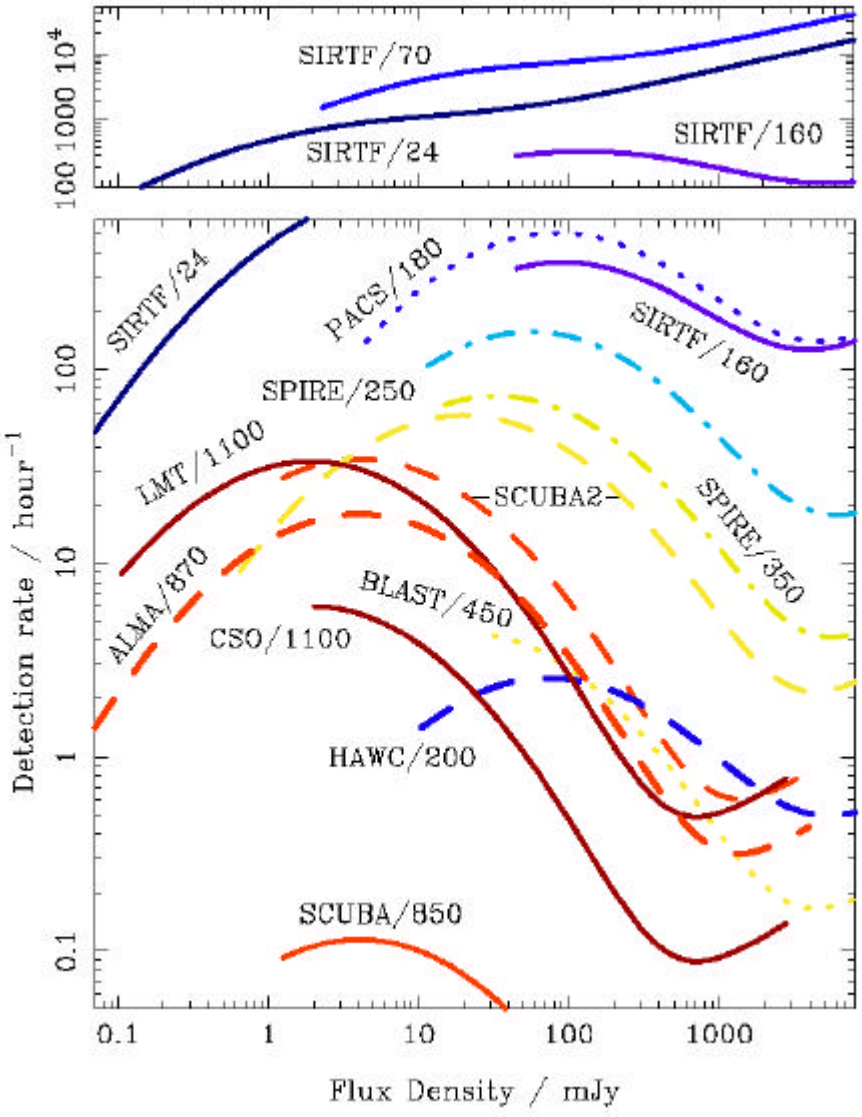
Dust dominates "known" metals at high z

Dark mass…

Gravitational Lenses: “amplification” has played major role in the story….

But see Blain (2002) MNRAS **330** 219 for the ALMA era

- Deamplification in presence of flat counts boosts numbers of objects
- Deamplified lines of sight through core, coupled with magnified images near caustics ？ mass profile near core, inaccessible with optical



ALMA Deep Surveys

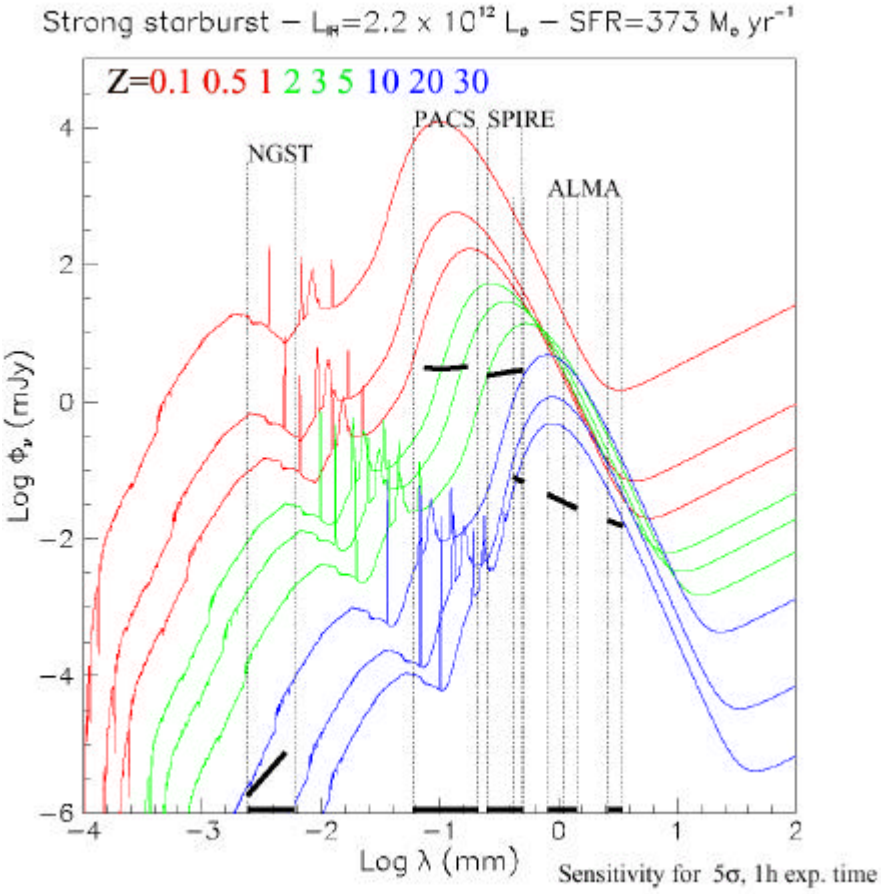
Continuum and CO redshifts (always get CO in 3mm window at $z > 1$)

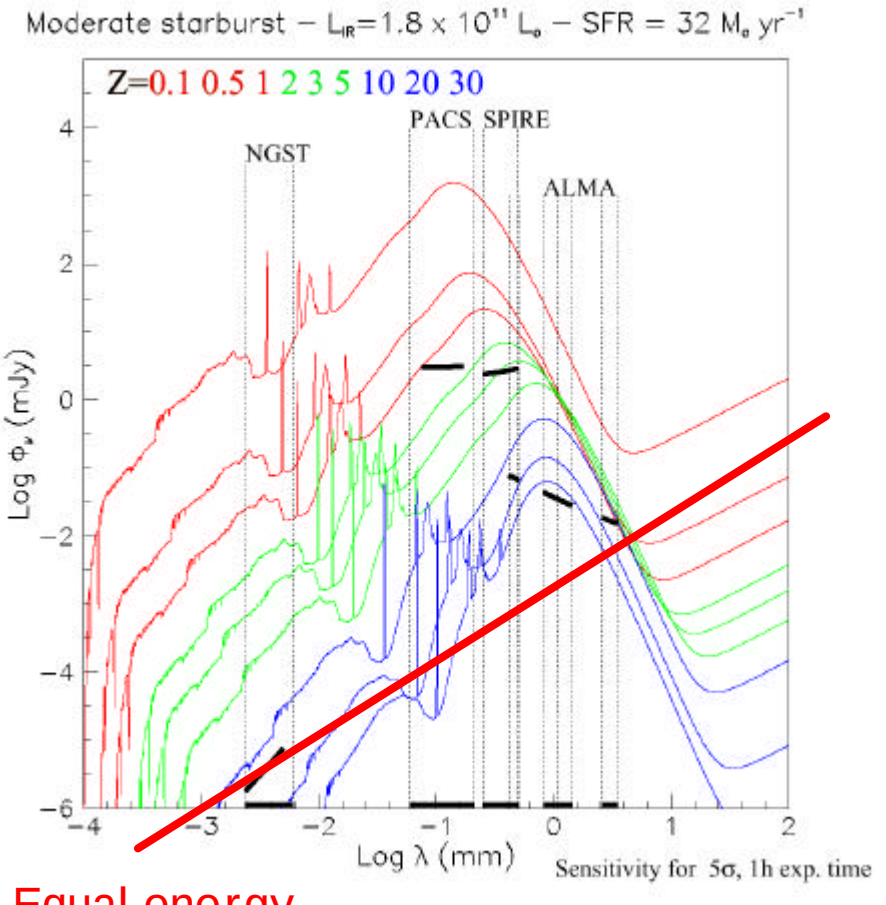
10 days 4'?4' 5? to 0.1 mJy at 3 mm:

80-300 sources, all with CO redshifts

(Guilloteau 1999)

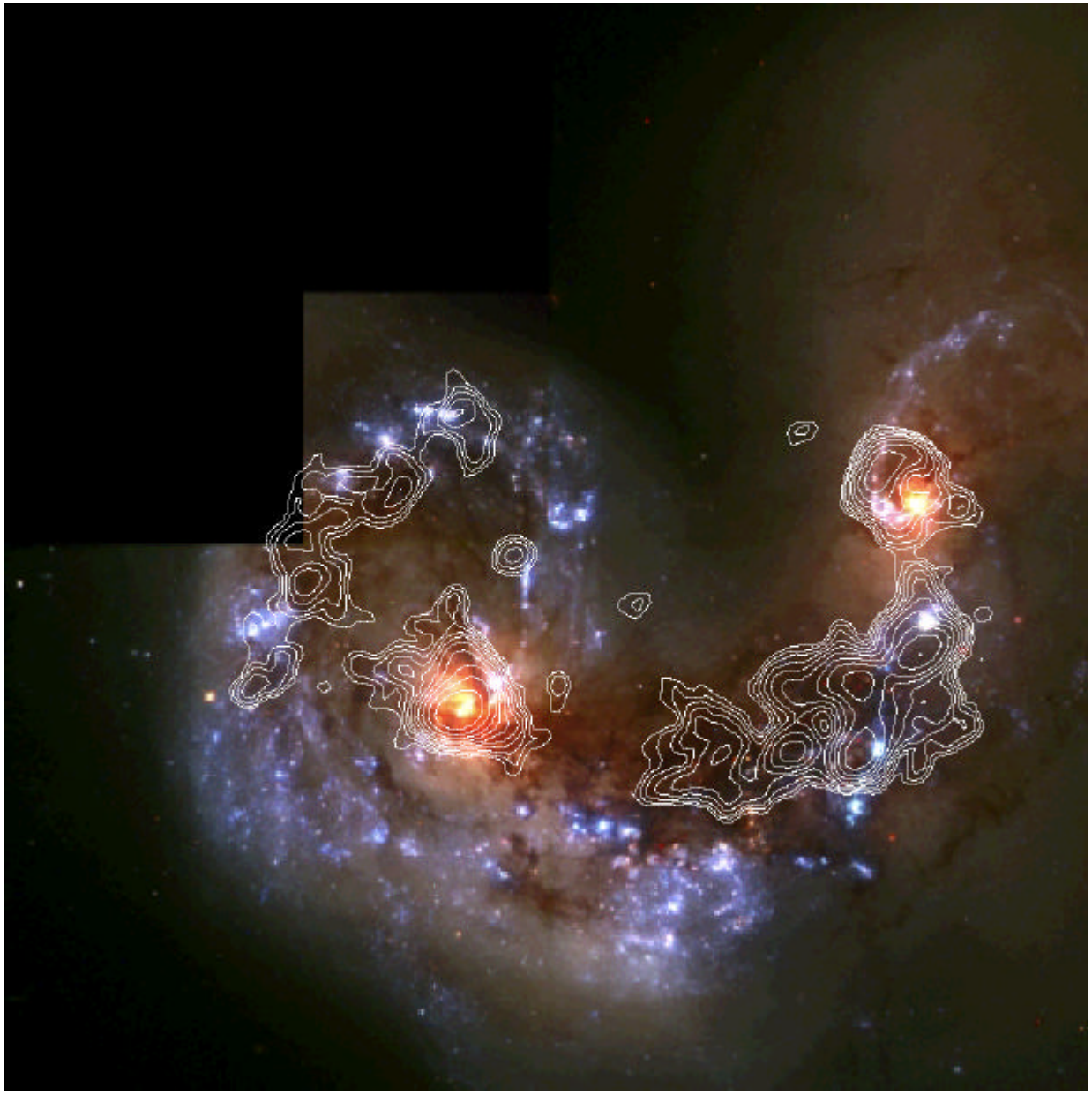
Serendipitous discoveries





Equal energy

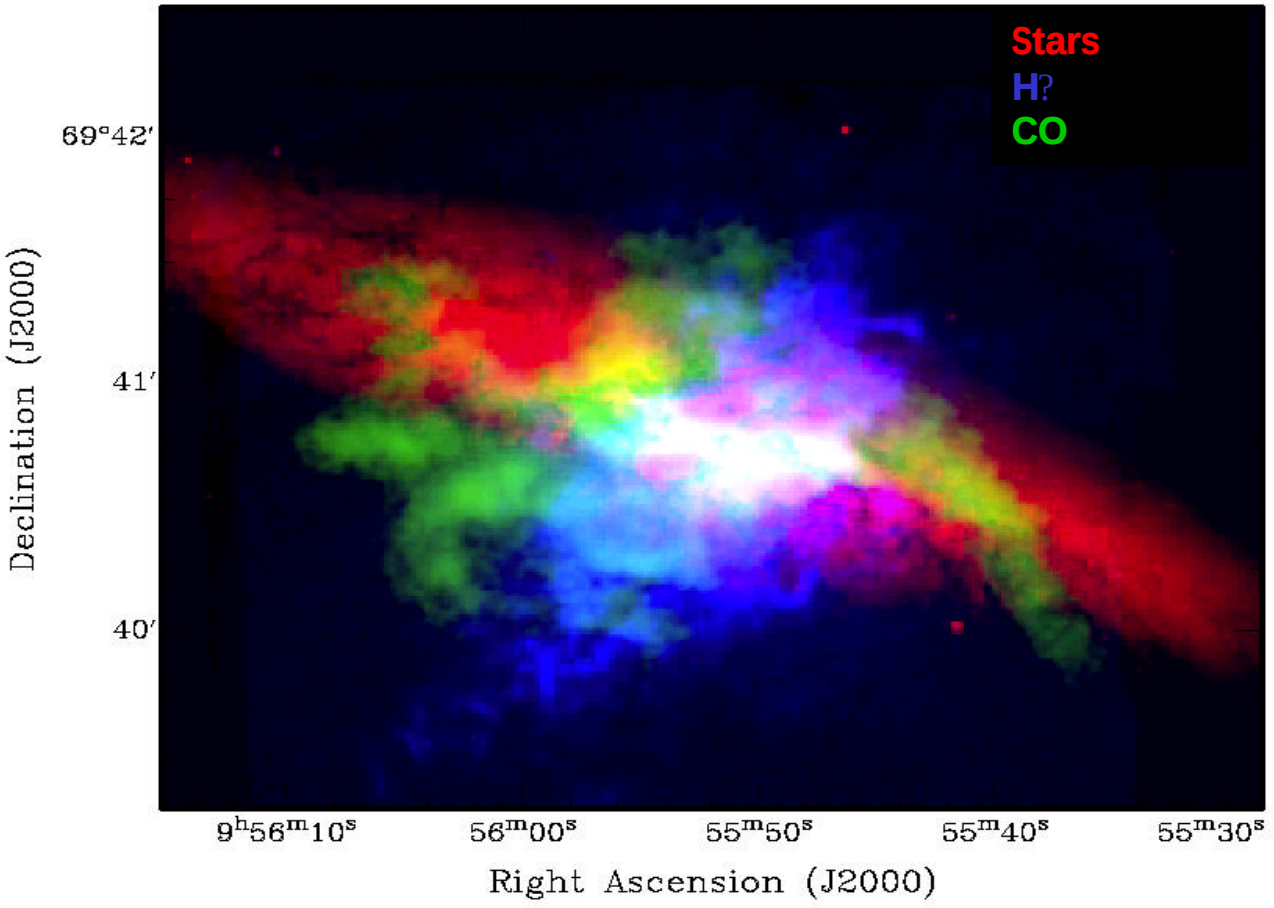
NGST and ALMA – fundamentally complementary



Understanding galactic physics locally

Antennae: Wilson et al 1999

Mass motions of cool molecular material in M82



AN ALMA HIGH z SCORE CARD

1. DETECTION OF FIRST LUMINOUS OBJECTS AT VERY HIGH REDSHIFTS z ~ 15-20: ☞
2. ESTABLISHING WHEN REIONIZATION OCCURRED
3. IDENTIFYING THE REIONIZERS
4. WHERE WERE THE STARS IN TODAY'S HUBBLE SEQUENCE FORMED ☞☞☞
5. WHEN DID LUMINOUS QUIESCENT GALAXIES EMERGE AND WHY?
6. CAN WE PROPERLY TEST HIERARCHICAL ASSEMBLY OF DARK MATTER HALOES? ☞
7. HOW DOES THE METALLICITY OF THE UNIVERSE BUILD UP WITH TIME ☞☞
8. WHAT ARE THE REDSHIFTS AND POWER SOURCES IN HIGH Z ULIRGS? ☞☞☞
9. WHAT ARE THE CONNECTIONS BETWEEN CENTRAL BLACK-HOLES, AGN EVOLUTION AND GALAXY EVOLUTION AT R > 100 pc. ☞

Thoughts on operations

.... make ALMA accessible to non-experts

A knowledge center

Excellent software

Usable archive (images?)

.... balance of major projects vs. others