Galaxy formation & evolution: The sub-mm view

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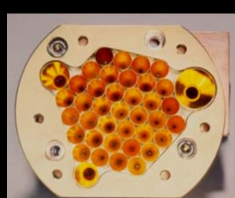
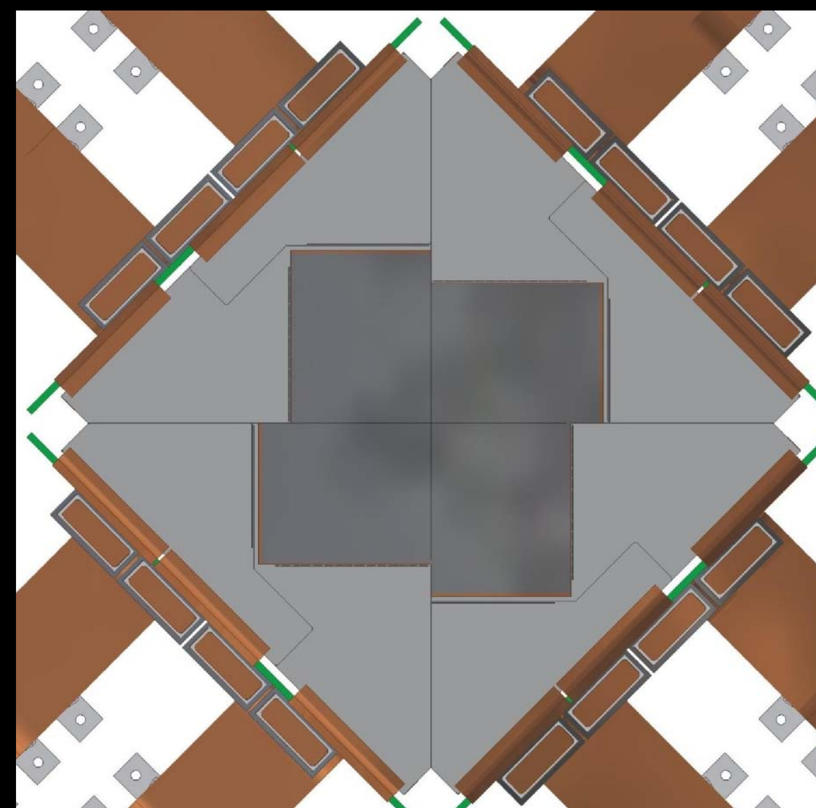
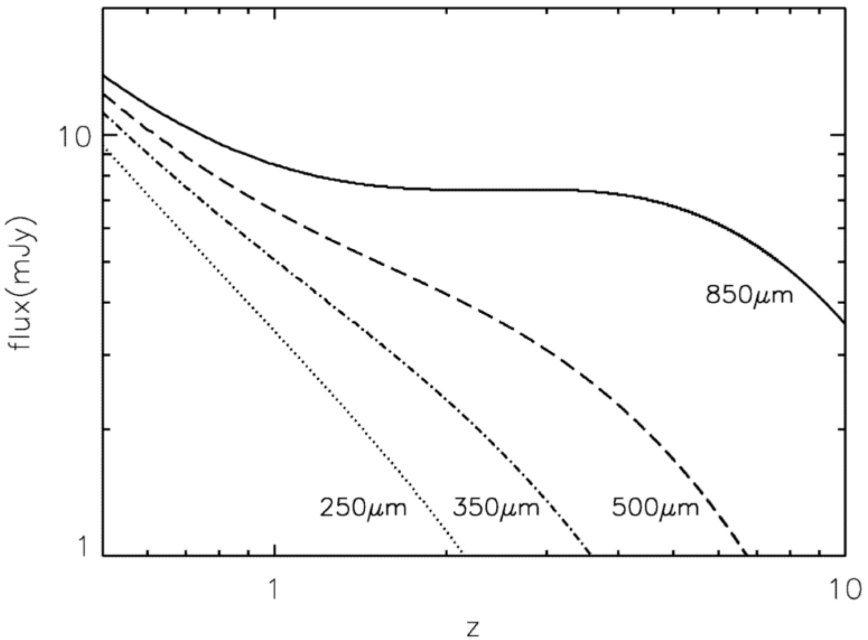


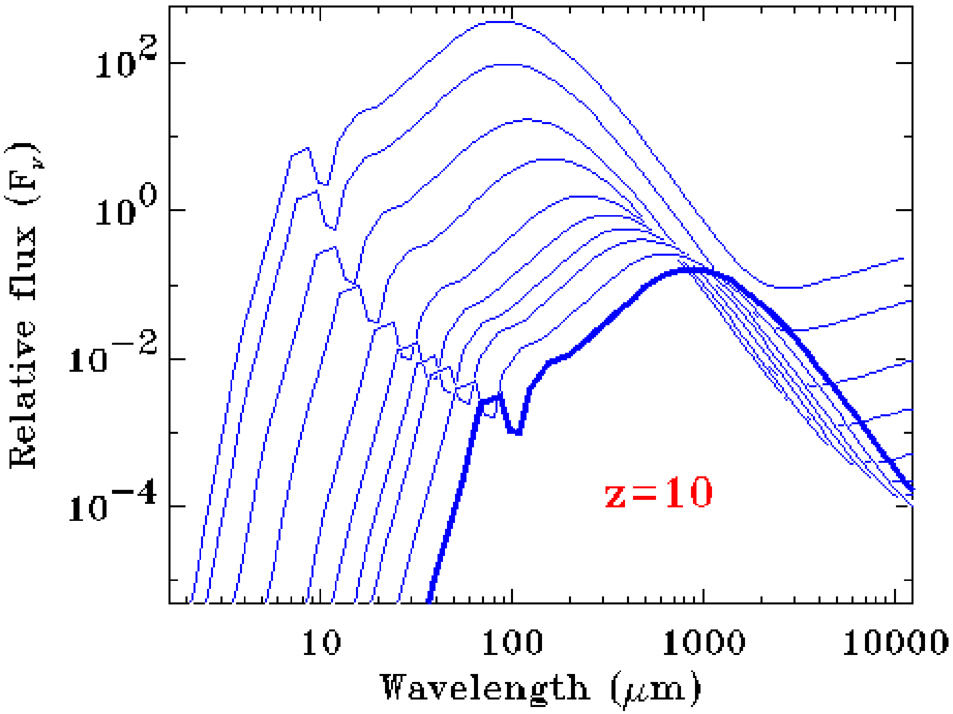


Talk presented by Eelco van Kampen (ESO)

A clear view from z = 1 to z = 8



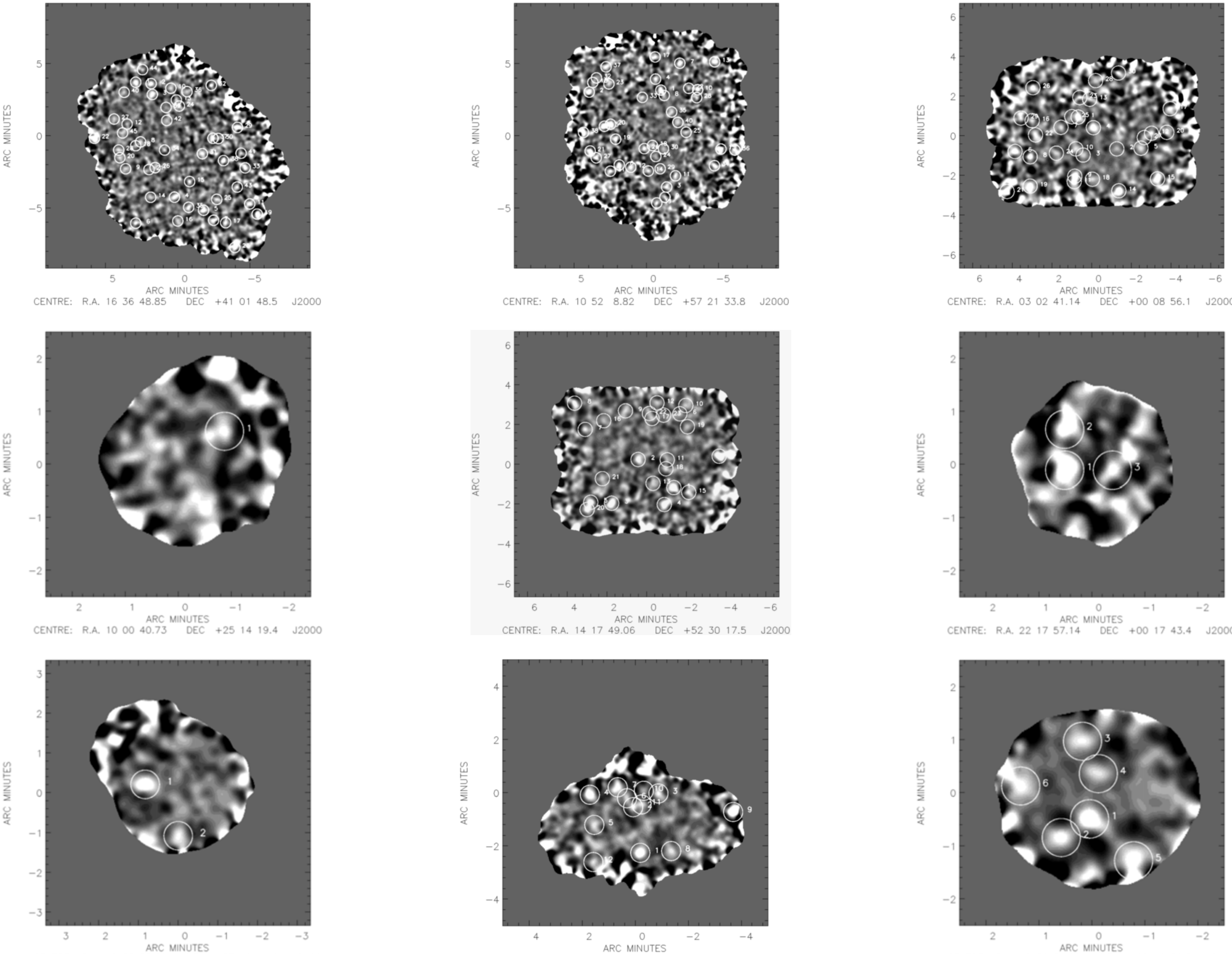
Galaxy spectrum at progressively higher redshifts



Early sub-mm / mm surveys

- Clusters – Smail et al. (1997)
- HDF – Hughes et al. (1998)
- Canada-UK Deep Submm Survey (CUDSS) – Eales et al. (2000)
- Hawaii Flanking Fields survey – Barger et al. (1998)
- 8-mJy survey – Scott et al. (2002)
- 8-mJy IRAM Mambo follow-up – Greve et al. (2004)

Combined reanalysis of the blank-field SCUBA surveys published in Scott, Dunlop & Serjeant et al. (2006)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SHADES

An attempt to put extragalactic sub-mm astronomy on a solid footing.

The first complete, unbiased, large area, sub-mm survey

Aim to determine number counts, redshift distribution, clustering, and other basic properties of the bright (~8 mJy) sub-mm population

RATIONALE

Available dynamic range with JCMT is limited

So stay bright – 8 mJy
unconfused
maximum chance of effective follow-up
massive starbursts = big challenge to theory

SHADES www.roe.ac.uk/ifa/shades

Dunlop 2005, astro-ph/0501419

van Kampen et al. 2005, MNRAS, 359, 469

Mortier et al. 2005, MNRAS, 363, 563

Coppin et al. 2006, MNRAS, 372, 1621

Aretxaga et al. 2007, MNRAS, 379, 1571

Ivison et al. 2007, MNRAS, 380, 199

Takagi et al. 2007, MNRAS, 381, 1154

Coppin et al. 2007, MNRAS, 384, 1597

Dye et al. 2008, MNRAS, 386, 1107

Serjeant et al. 2008, MNRAS, 386, 1907

Clements et al. 2008, MNRAS, 387, 247

Younger et al. 2008, MNRAS, 387, 707

van Kampen et al. 2009, in prep

Schael et al. 2009, in prep

Dunlop et al. 2009, in prep

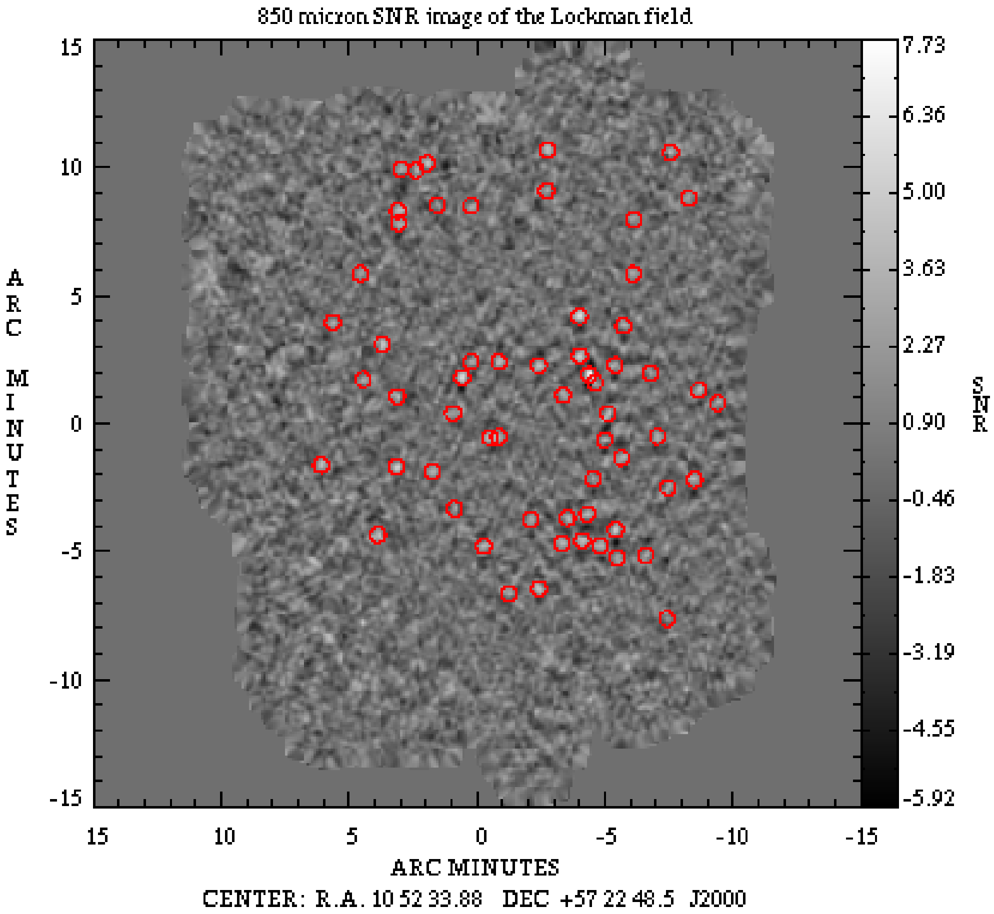
+ AzTEC papers to follow...

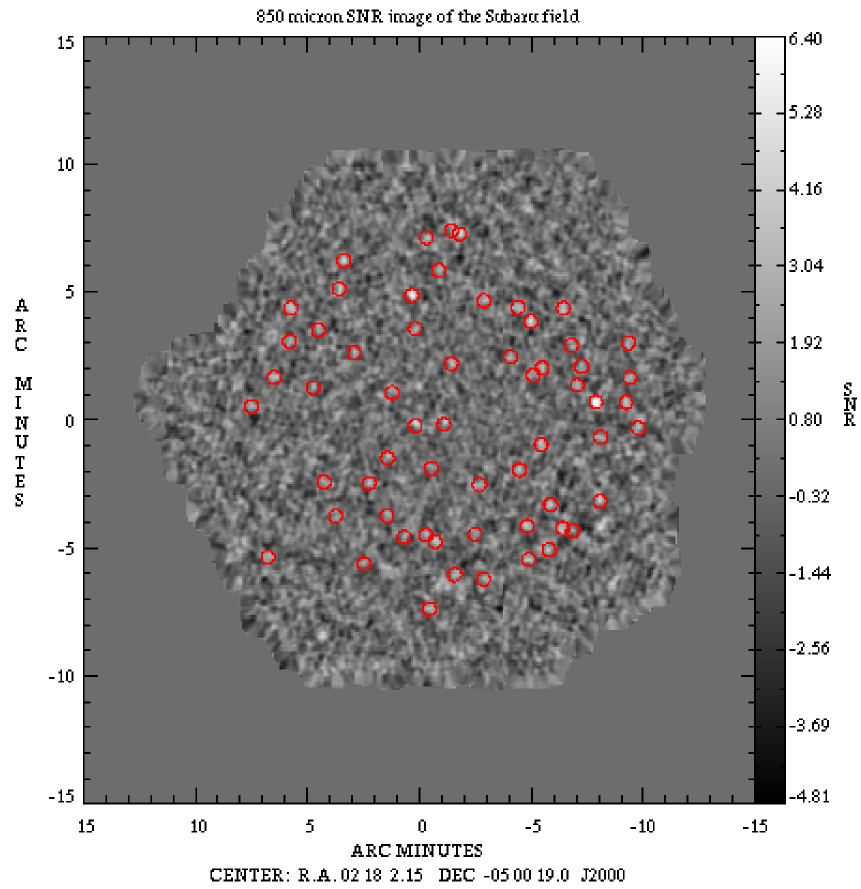
SHADES SCUBA 850-micron maps

2 fields – Lockman Hole & SXDF/UDS

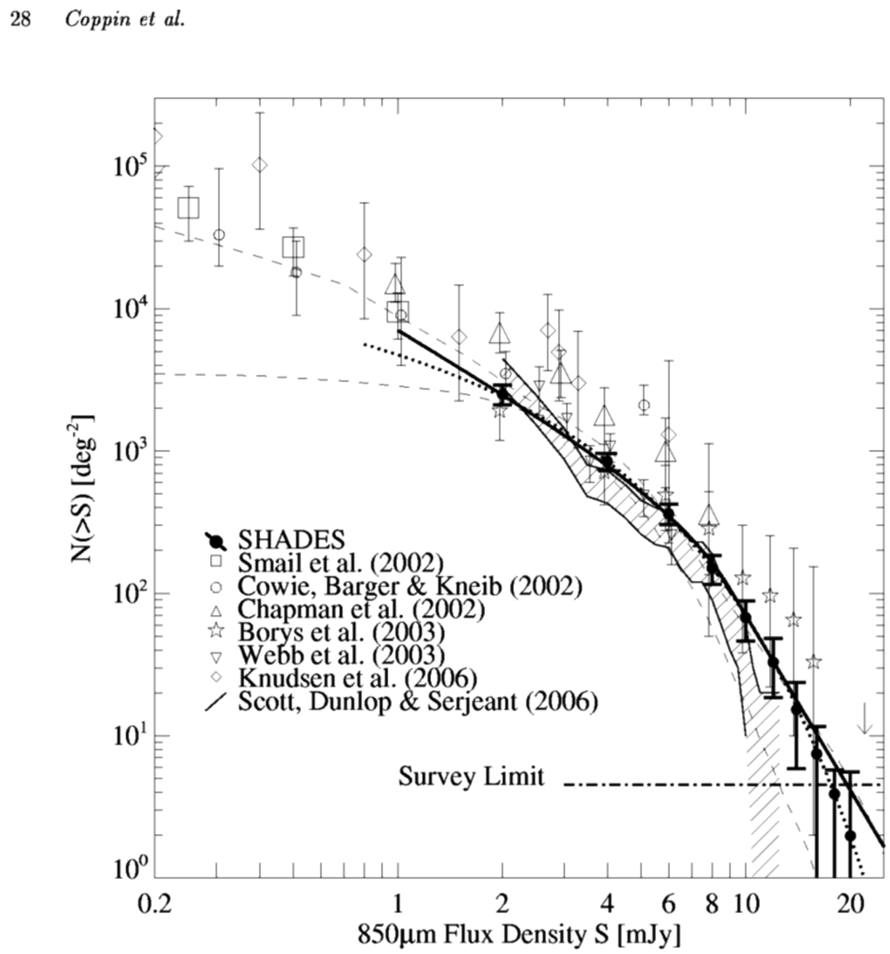
4 independent reductions combined to produce one SHADES catalogue

120 sources with unbiased (deboosted) flux densities





Number counts

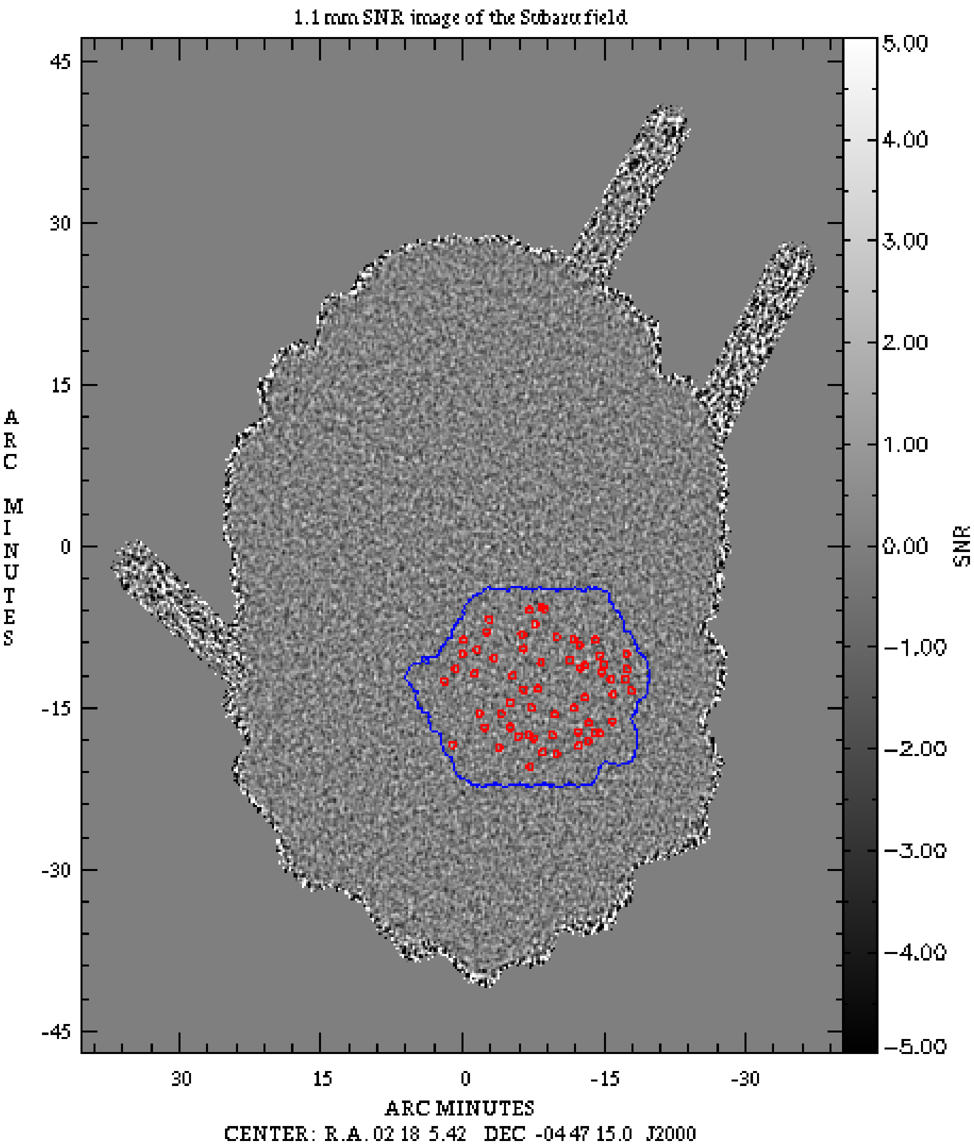


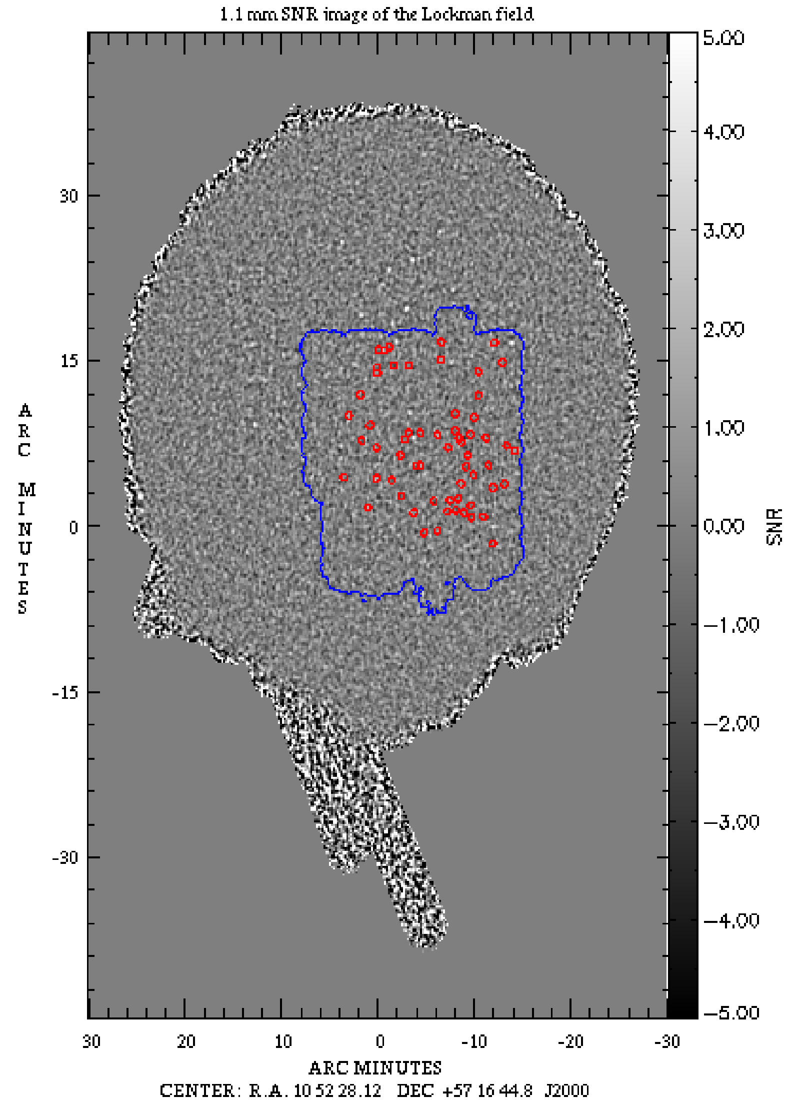
Coppin et al. 2006

Estimated background of sources >2mJy is ~9700 mJy/deg^2
>20-30% of FIRB resolved

New SHADES AzTEC 1.1mm maps

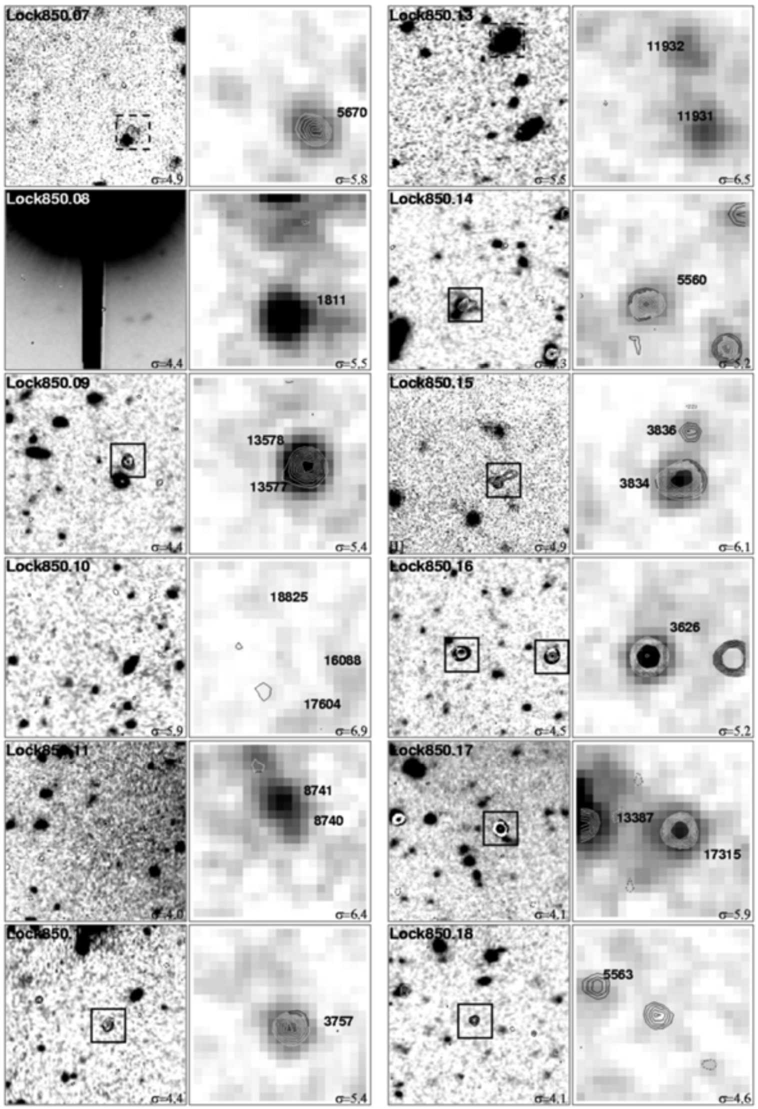
(SNR maps shown here produced by Jason Austerman)





IDs: Radio and mid-infrared

10 *Ivison et al.*



Ivison et al., 2007

25 x 25 arcsec stamps

VLA radio contours on

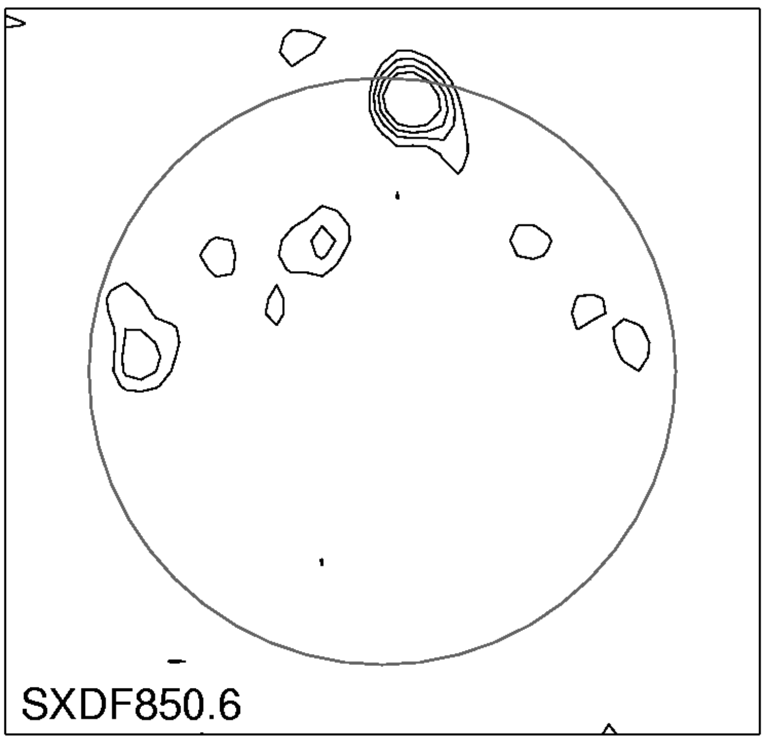
R-band Subaru image, and

Spitzer 24-micron image

85-90% of the 120 sources identified via VLA and/or Spitzer

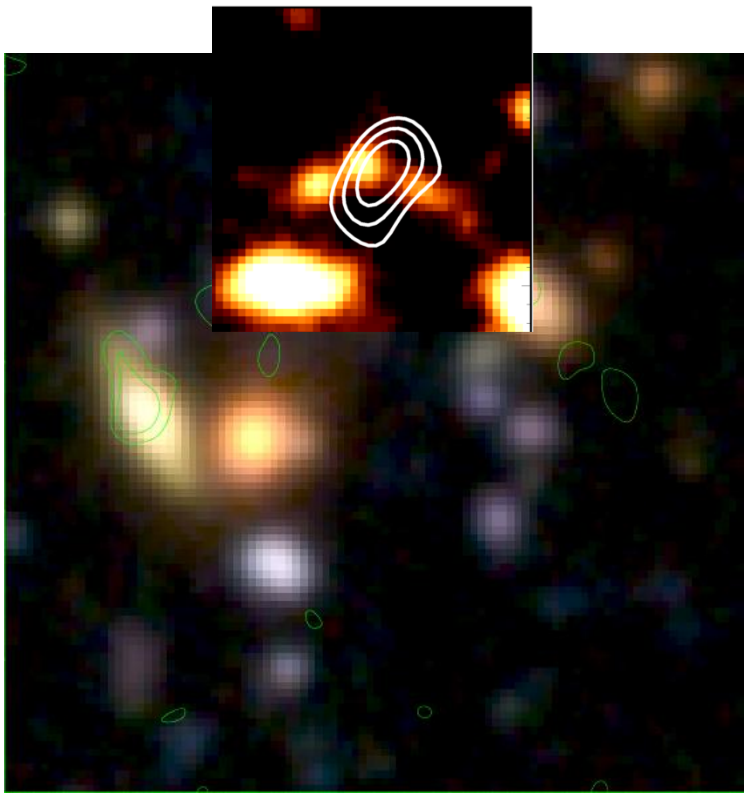
Sometimes identification can be tricky

e.g. SMA follow-up of SXDF850.6 Iono et al. (2009)



VLA 1.4 GHz

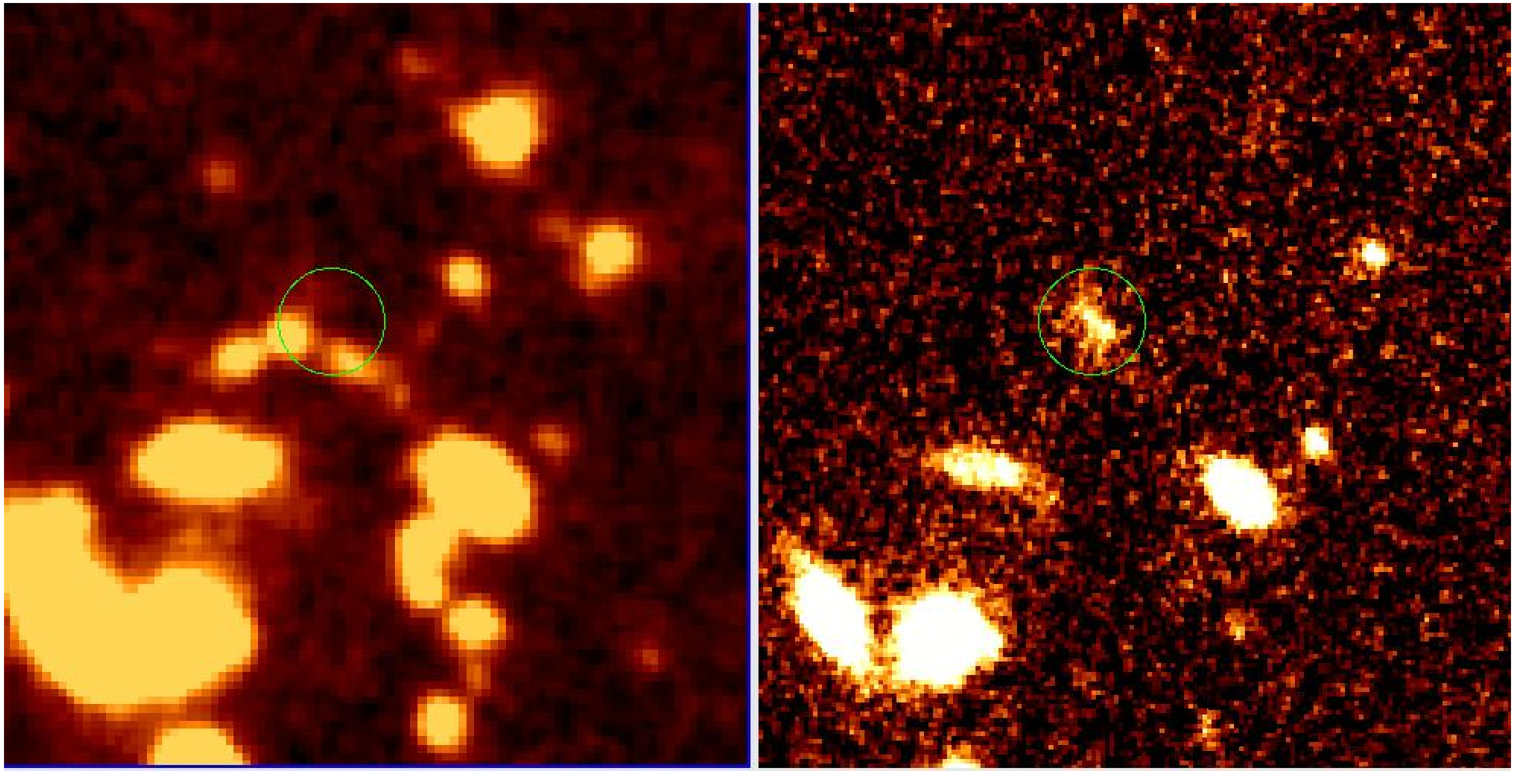
SMA



Optical - Subaru

Finally …….unambiguous K-band ID

SMA on optical SMA on K-band



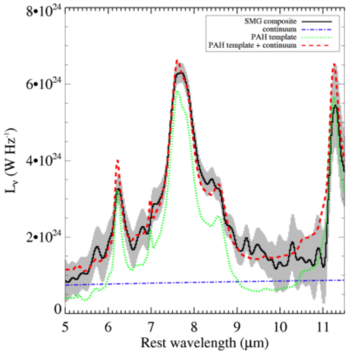
Demonstrates

1. power of sub-mm interferometry
2. importance of near-IR data identification & study of host galaxy

Redshifts

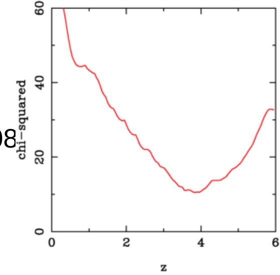
4 different forms of redshift information:

- Spectroscopic – Chapman et al., Stevens et al.
- Far-infrared to radio – Carilli & Yun, Aretxaga et al.
- Optical – near-infrared – Dye et al., Clements et al.
- Spitzer – Pope et al.



In SHADES only ~16 sources (i.e. 12%) currently have an <u>unambiguous</u> spectroscopic z

GN20 –
Iono et al. 2006
Younger et al. 2008

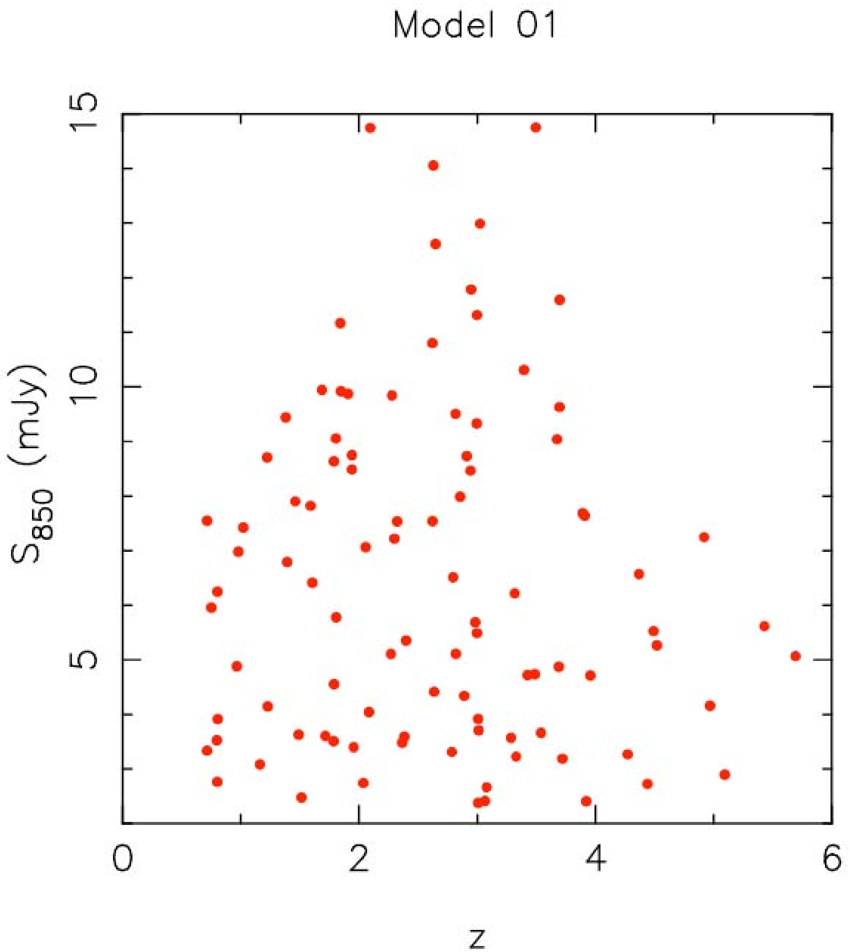


)SMOS AzTEC 1 –
unger et al. 2007

)ODS 850.5 –
ıng et al. 2008

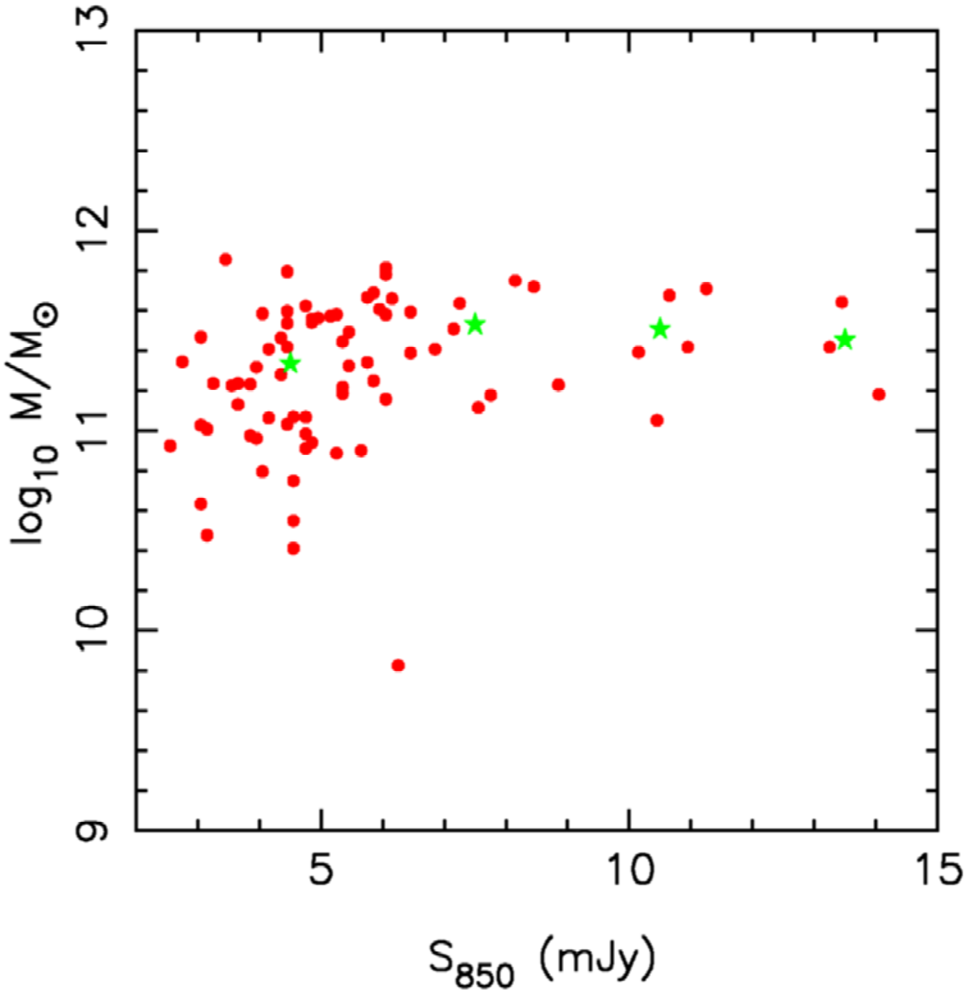
SFR > 2000 M_{sun} yr $^{-1}$

SFR > 1000 M_{sun} yr $^{-1}$



Stellar masses – Schael et al. 2009; Dunlop et al. 2009

Sub-mm sources are already massive: > 10^{11} solar masses



CO dynamical masses suggest

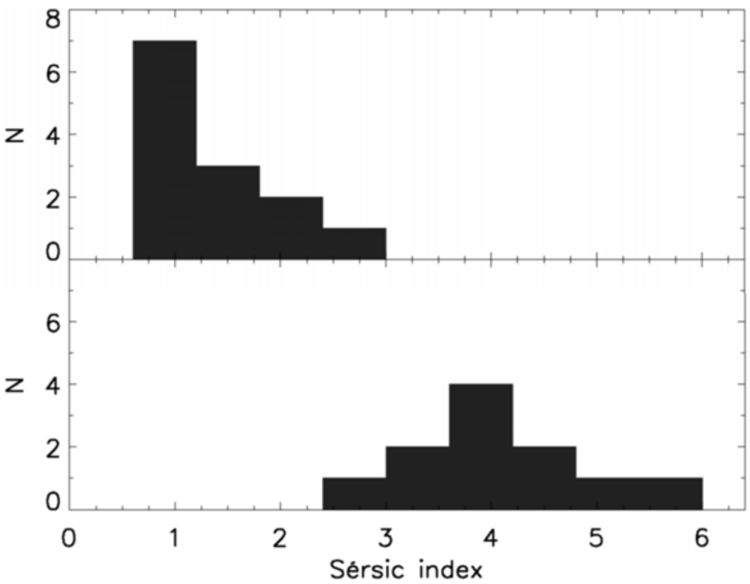
$\sim 10^{11}\ M_{sun}$ within r ~ 2 kpc (Tacconi et al. 2006)

We find typical stellar masses

$\sim 3 \times 10^{11}\ M_{sun}$ and typical $r_{0.5}$ = 2-3 kpc

Galaxy formation models typically predict
$\sim 10^{11}\ M_{sun}$ for the stellar mass component

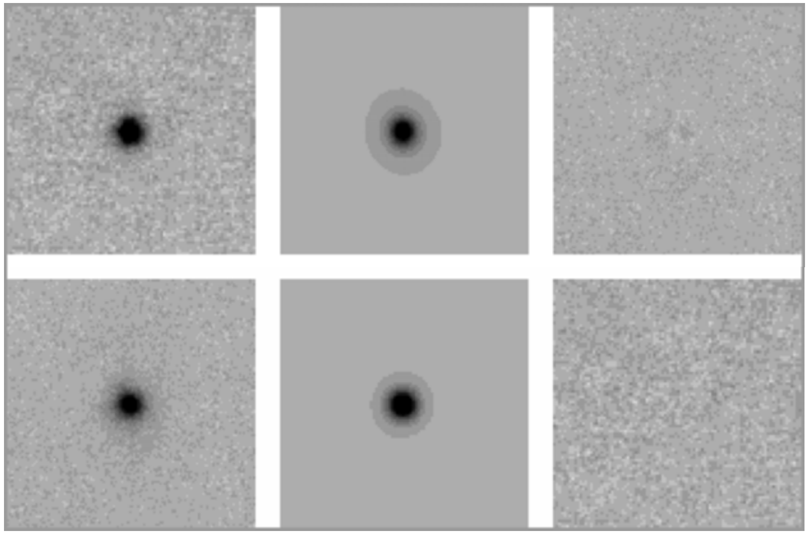
Morphologies – Targett et al. 2009



Sub-mm galaxies are mainly discs

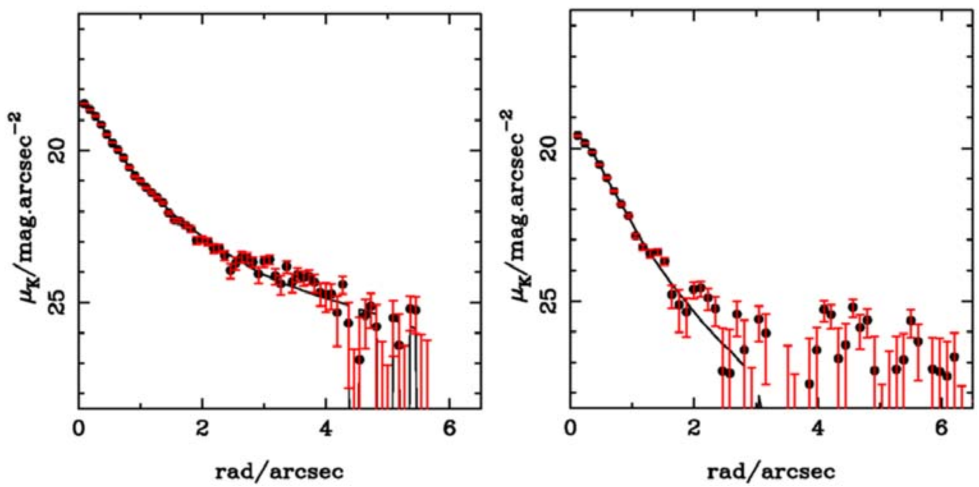
Radio galaxies are $r^{1/4}$ spheroids

Image Stack



~50 hr UKIRT image of
z = 2 radio galaxy

~20 hr Gemini image of
z = 2 sub-mm galaxy



K-band,
0.4” seeing

Future prospects

Larger, deeper samples with complete SEDs

- BLAST, SCUBA2, Herschel, LMT, CCAT

Complete IR identifications, redshifts, masses

- UKIDSS, Ultra-VISTA, Spitzer, FMOS, KMOS

Detailed high-resolution imaging, spectroscopy

- ALMA, ELTs, JWST

Cosmology Legacy Survey

Jim Dunlop
+ Ian Smail (Durham), Mark Halpern (UBC), Paul van der Werf (Leiden)