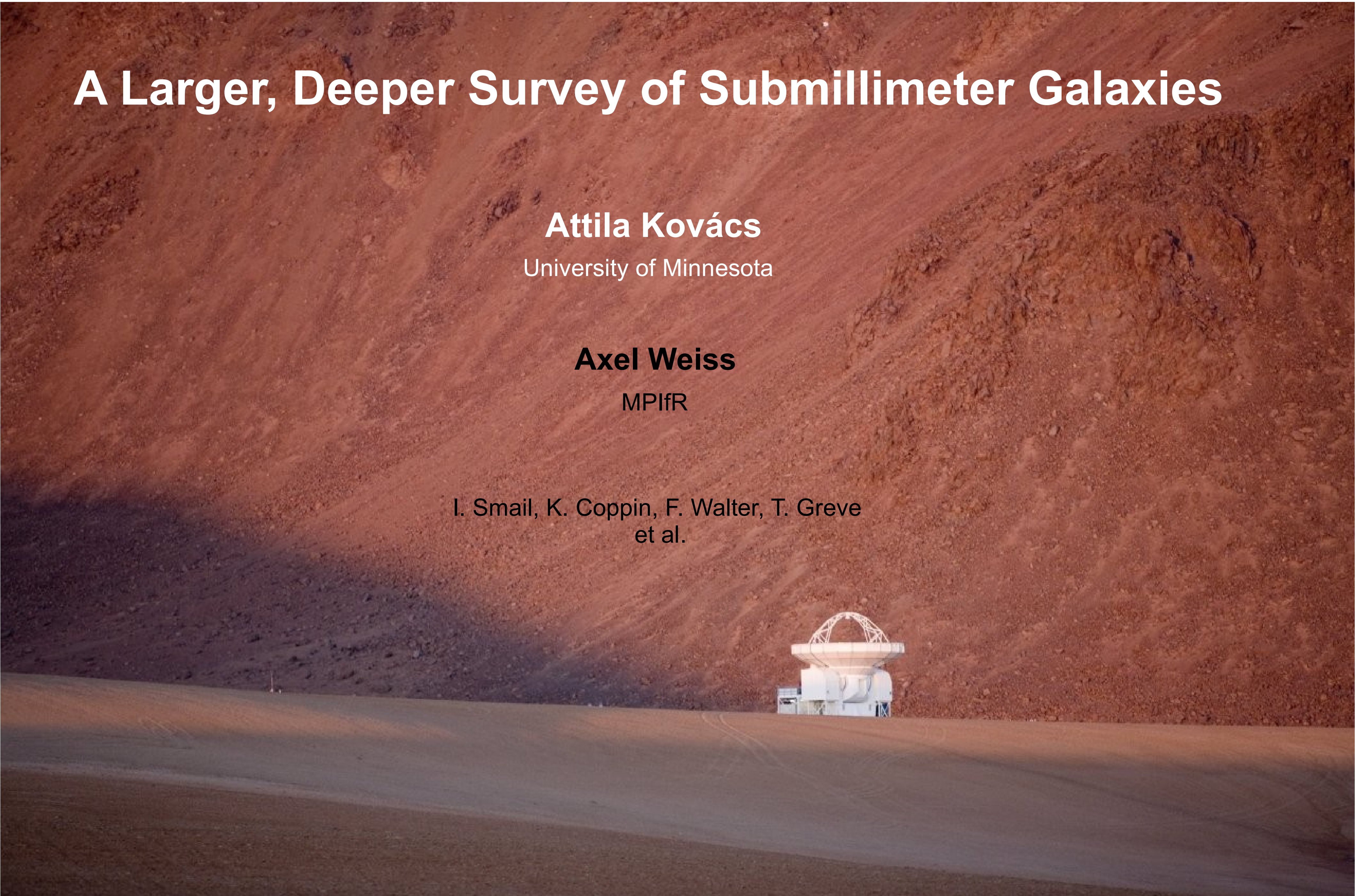


A Larger, Deeper Survey of Submillimeter Galaxies

Attila Kovács

University of Minnesota

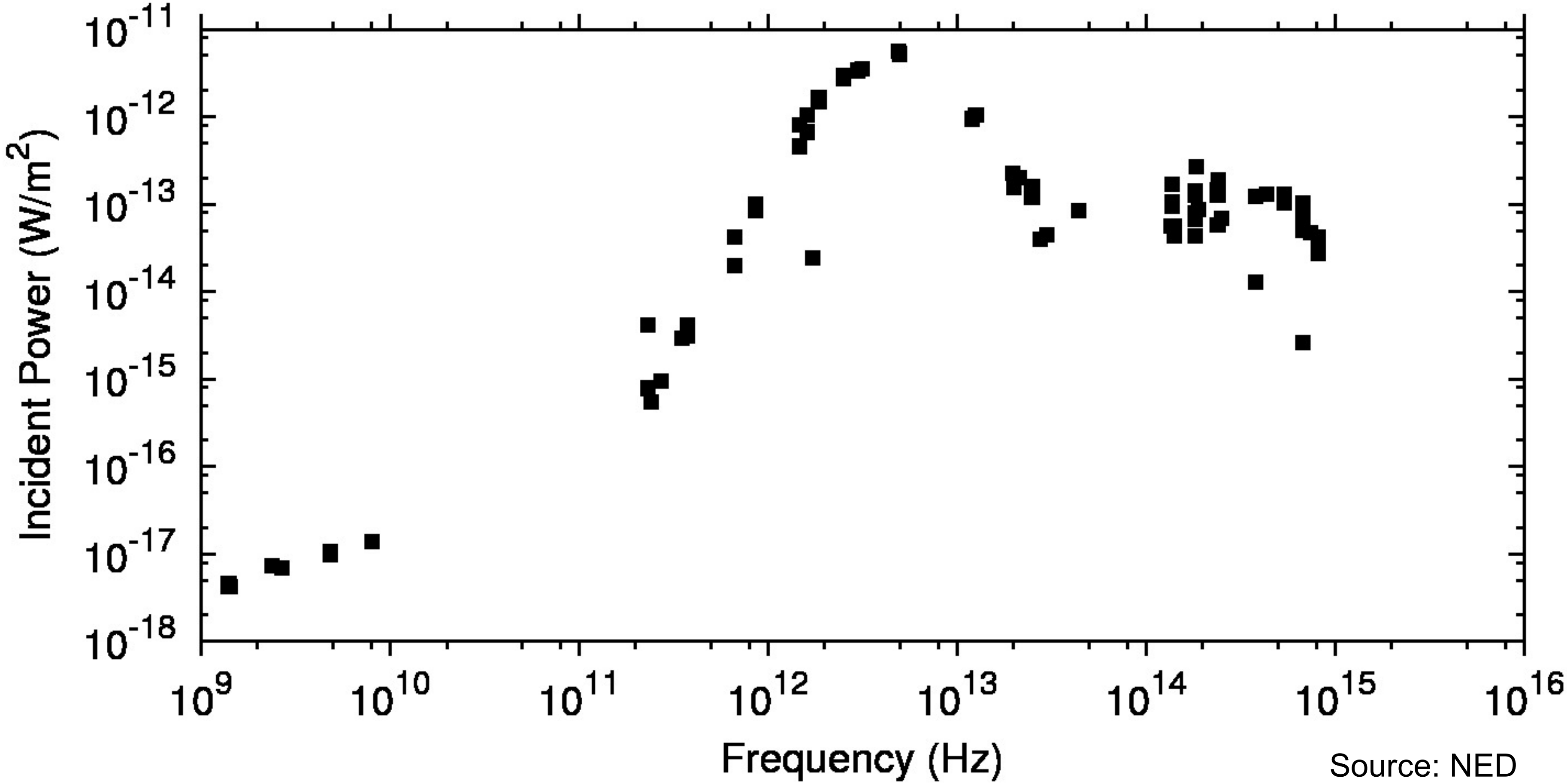
Axel Weiss

MPIfR

I. Smail, K. Coppin, F. Walter, T. Greve
et al.

Arp 220

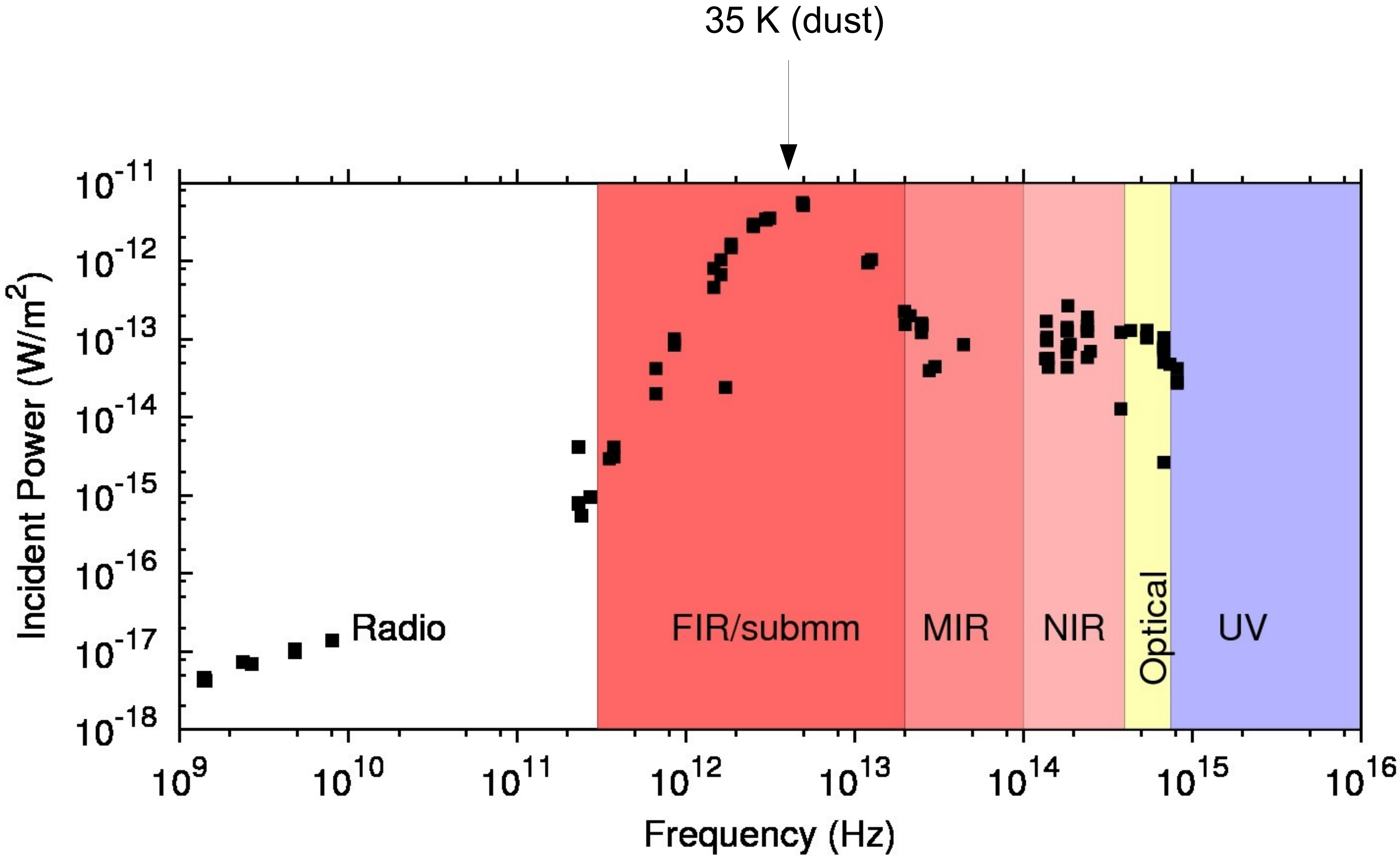
The Energy Spectrum of a Luminous Galaxy



Source: NED

Arp 220

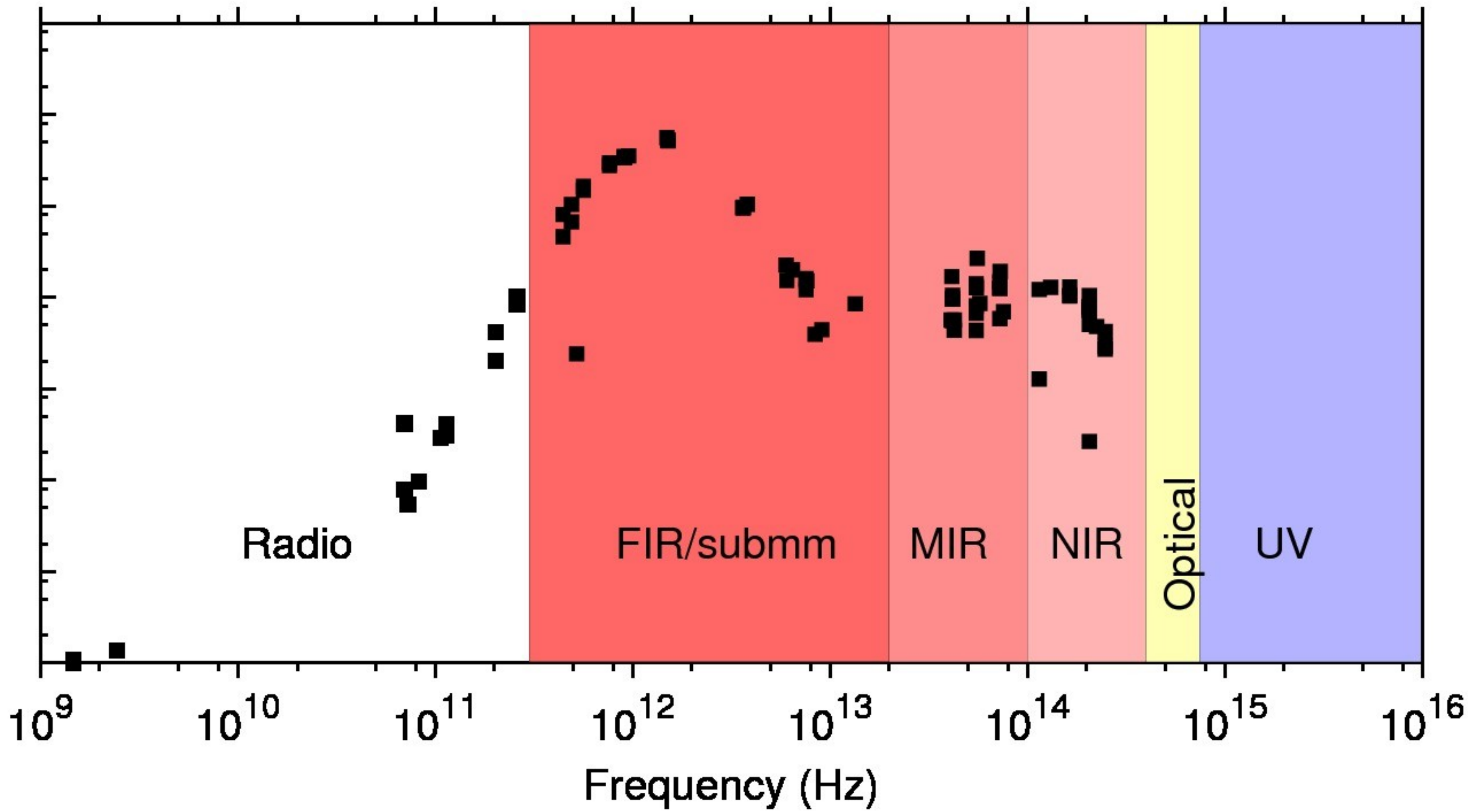
The Energy Spectrum of a Luminous Galaxy



Milky Way FIR fraction is about 50%, T~16K

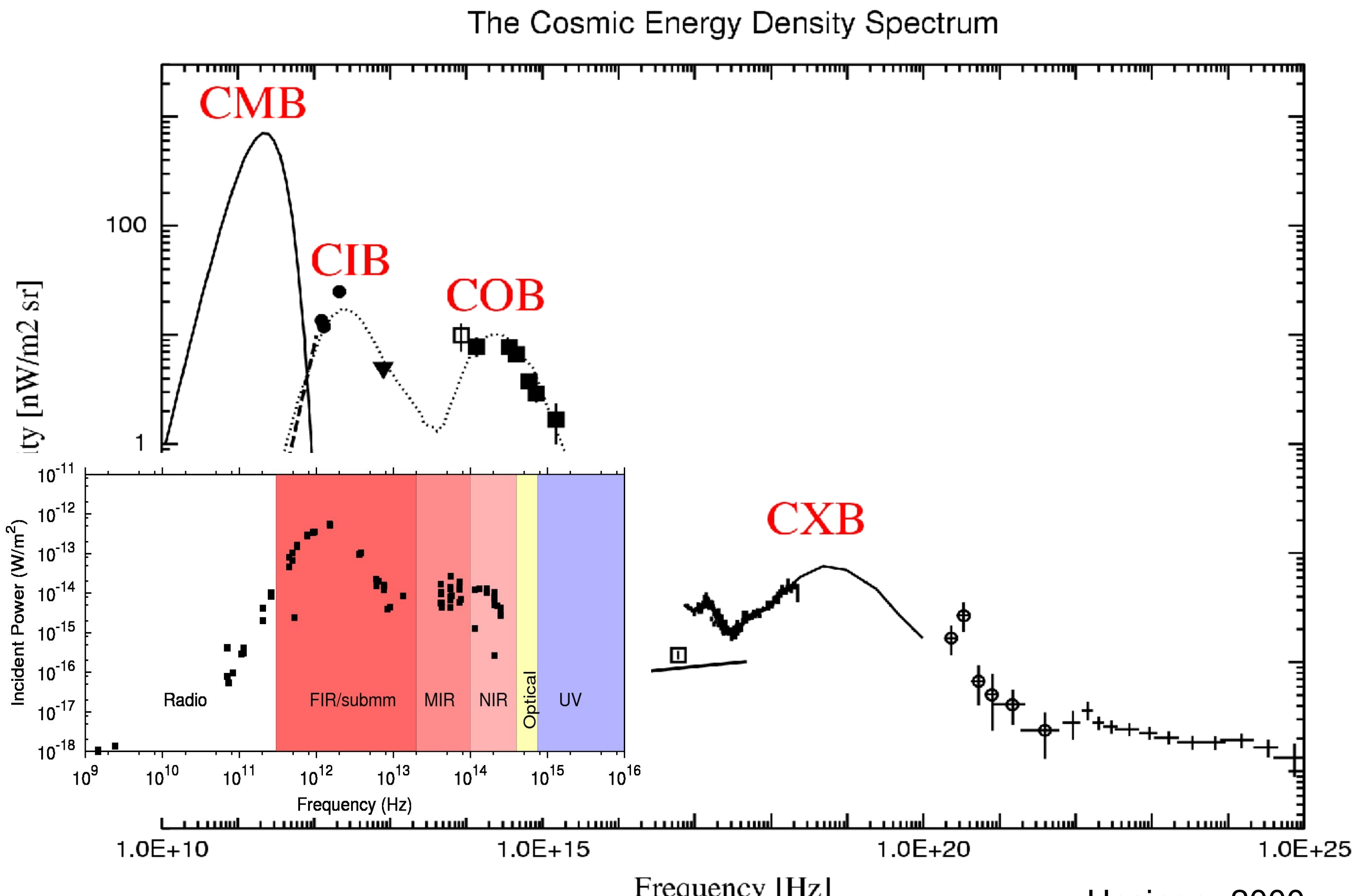
Arp 220 at z=2.3

The Energy Spectrum of a Distant Luminous Galaxy?



FIR is also good for studying distant populations?

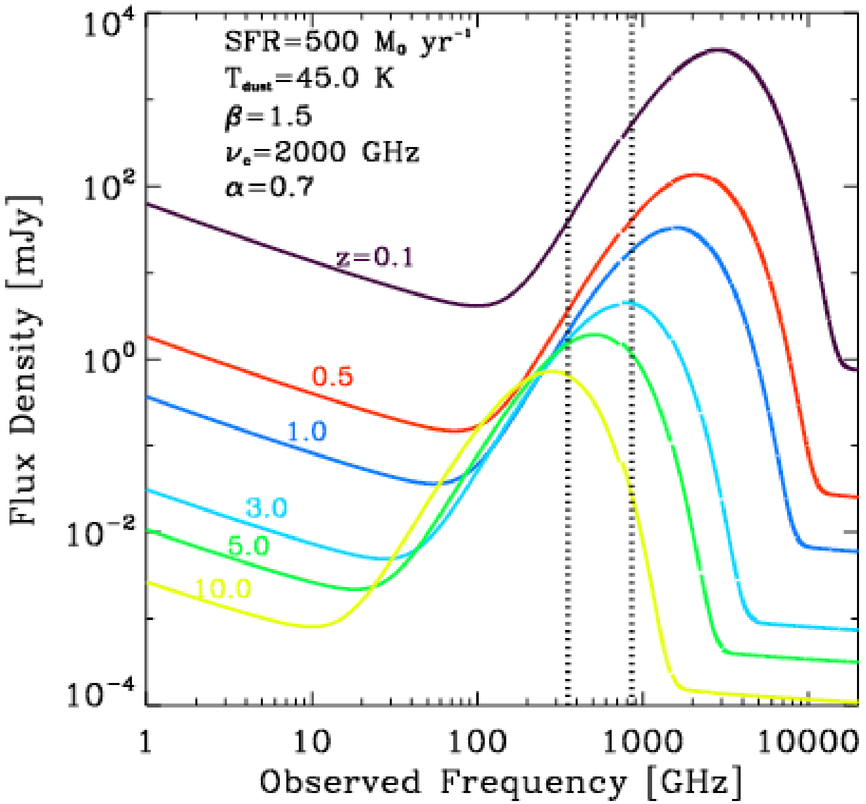
The Cosmic Background

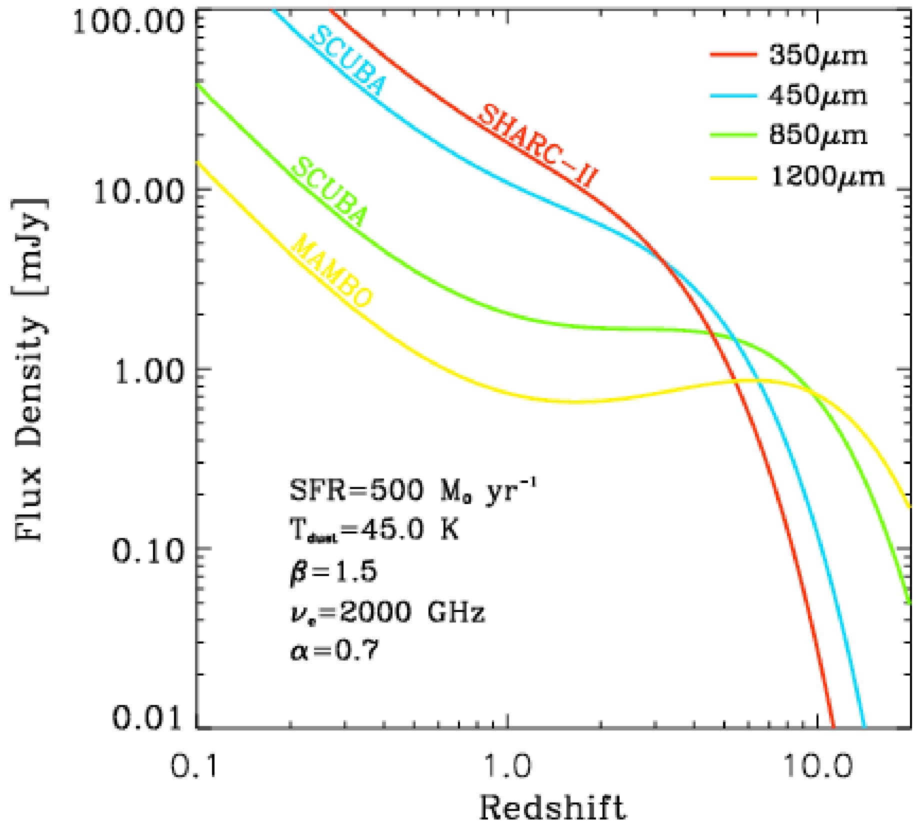


Hasinger 2000

Infrared (and optical?) background may be due to such galaxies....

K-Correction Benefits...



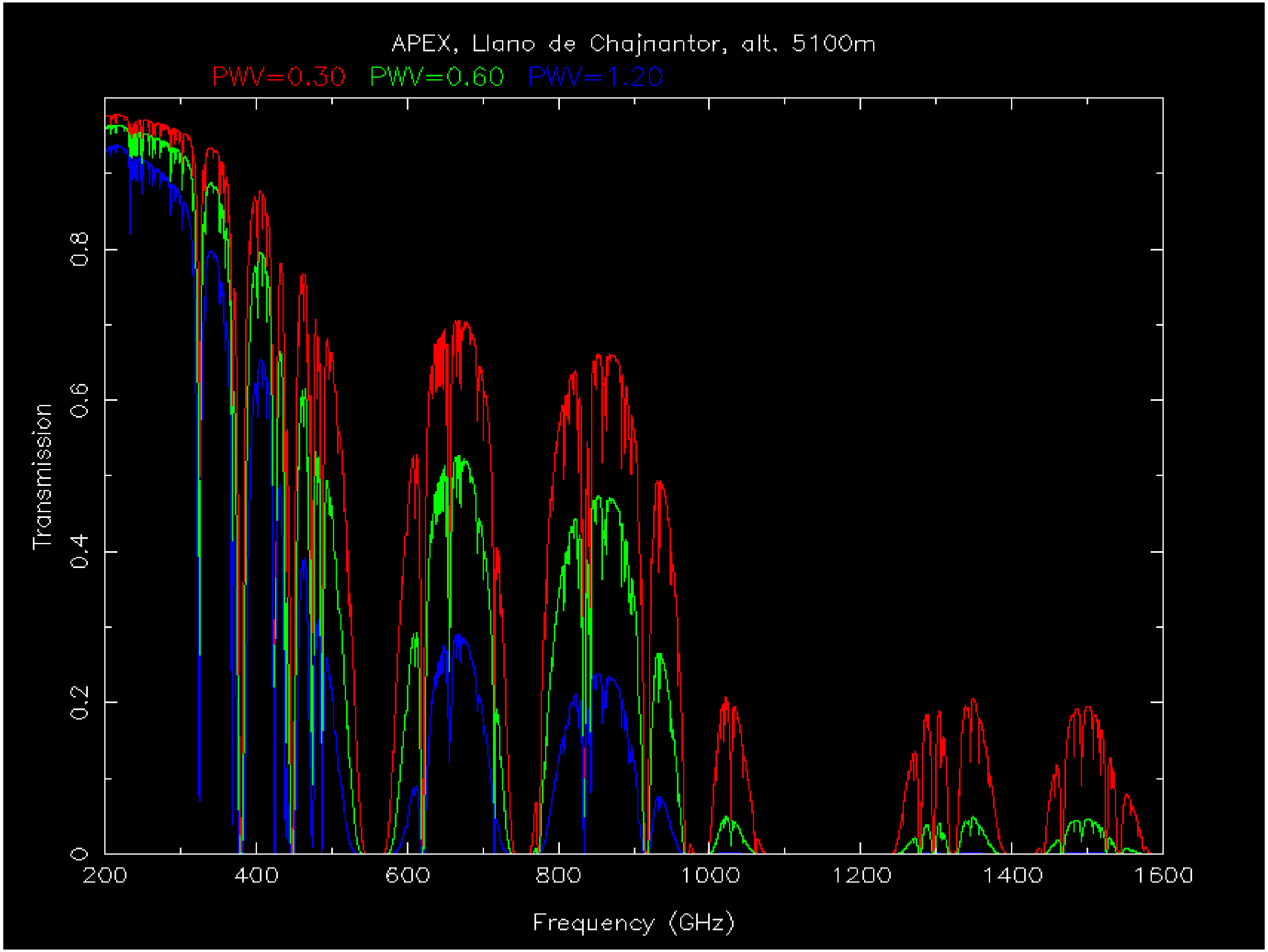


T. Greve

850 micron is equally sensitive to the *same* galaxy at z ~ 1-8...

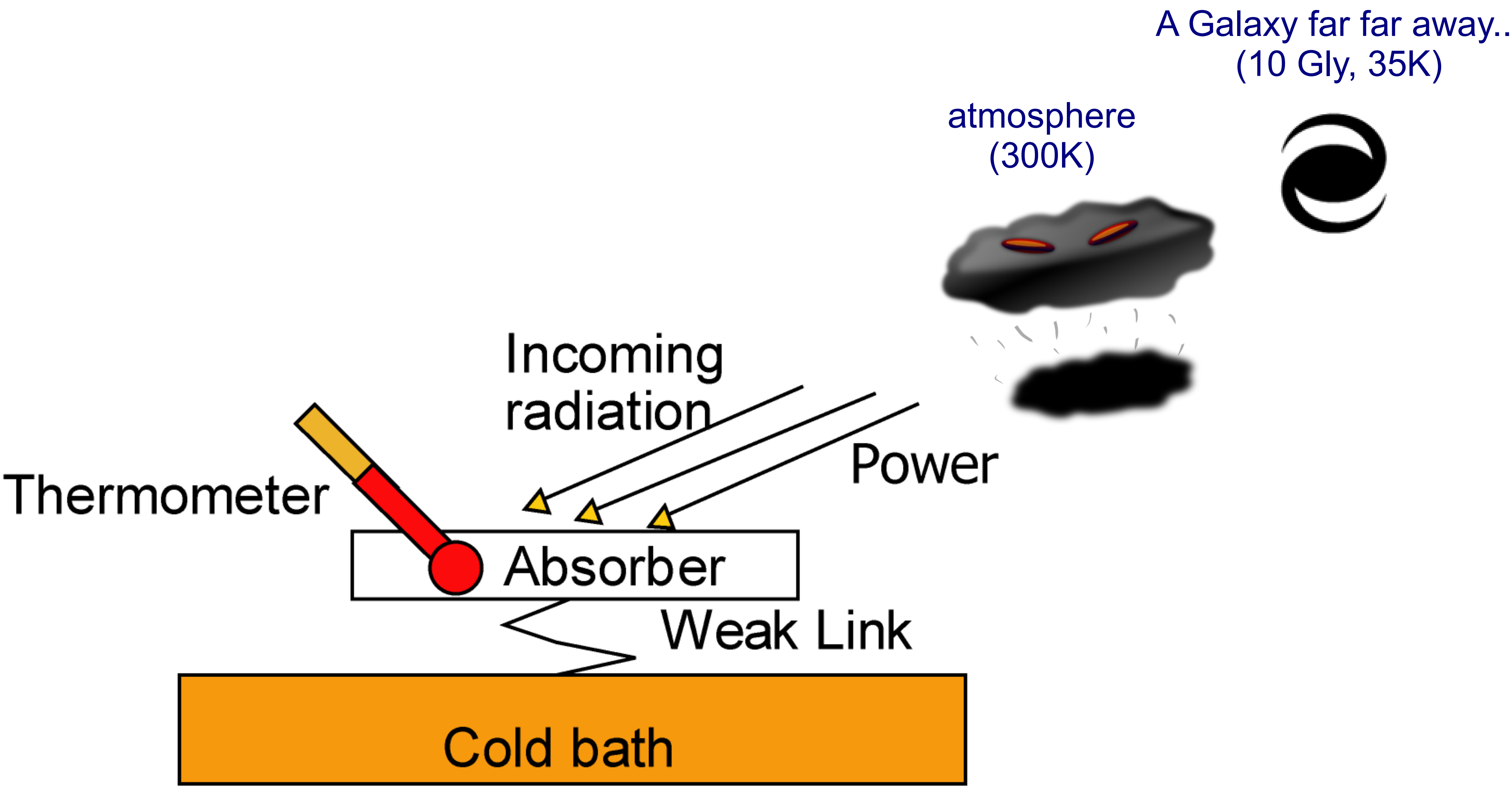
Sky is Bright

Analogy: Imaging a 17 mag star on a bright summer day



Atmospheric Transmission at APEX

Bolometers

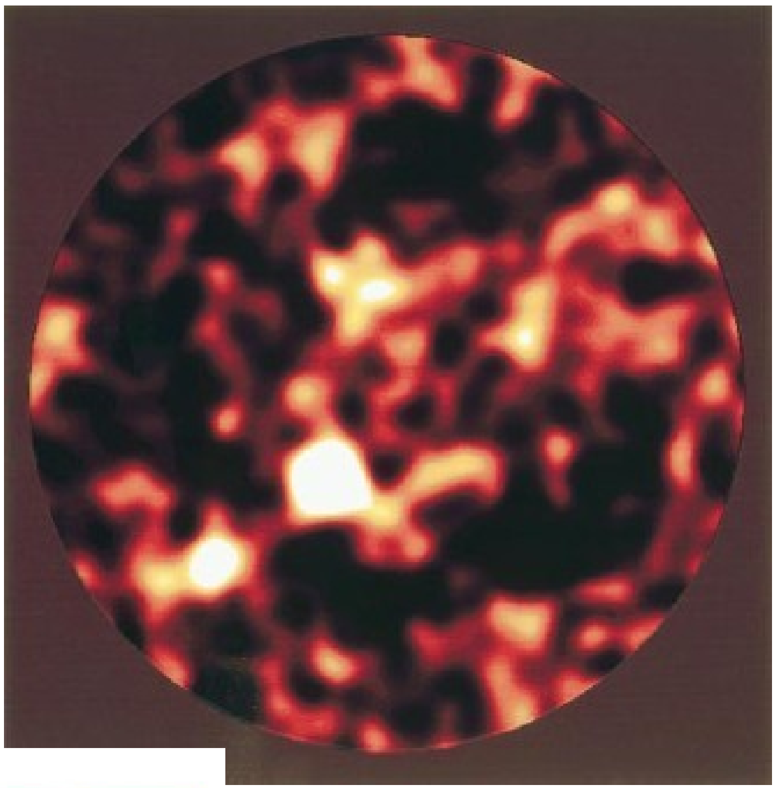


Bolometers are just thermometers doing the impossible...


1998

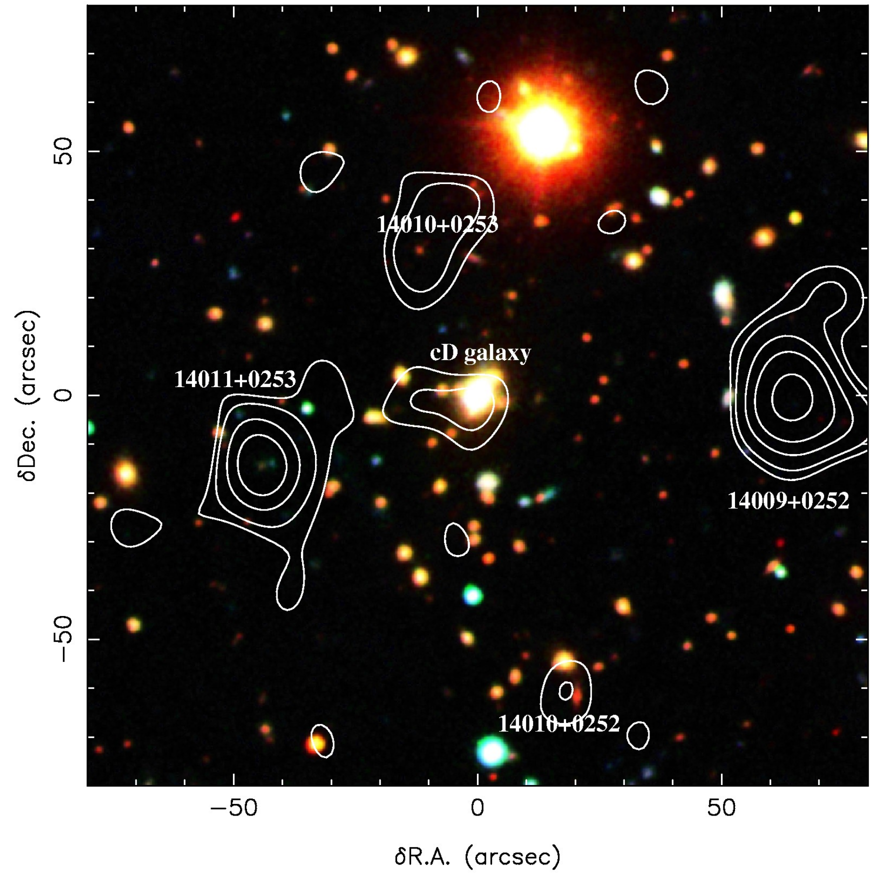
Submillimeter Galaxies (SMGs)

The First Detections

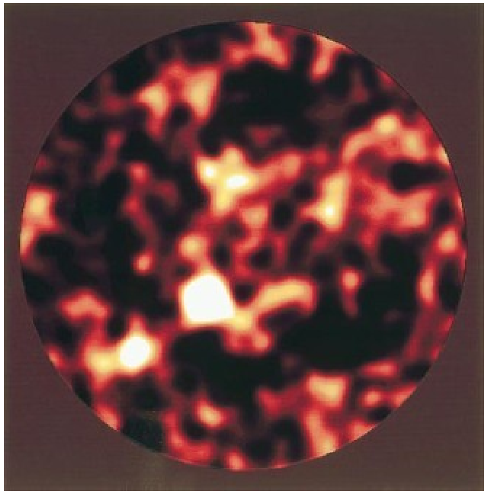


Hughes et al. 1998

SCUBA



Too many optical counterparts
Or none at al...

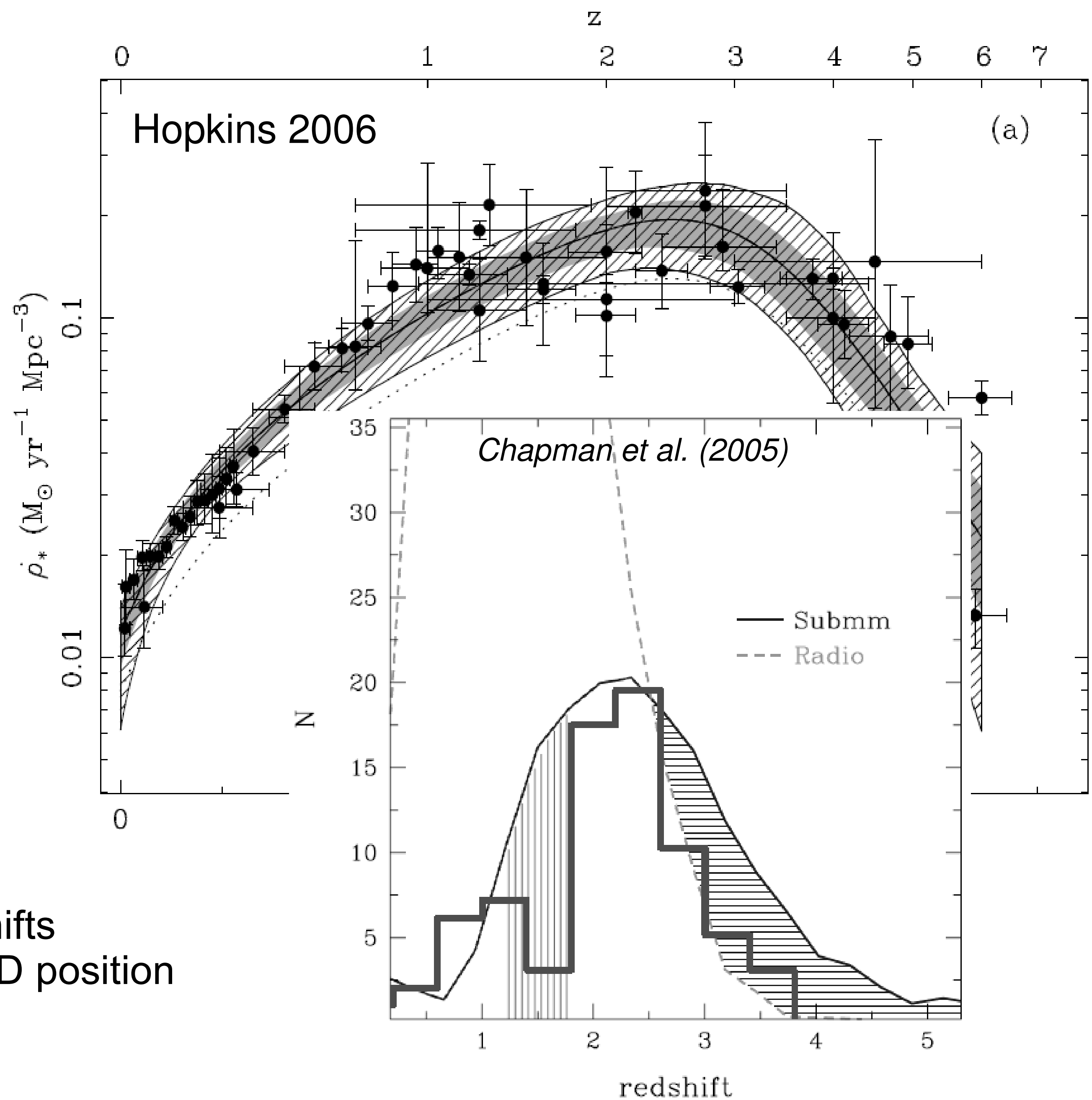


Hughes et al. 1998

1998 **2003**

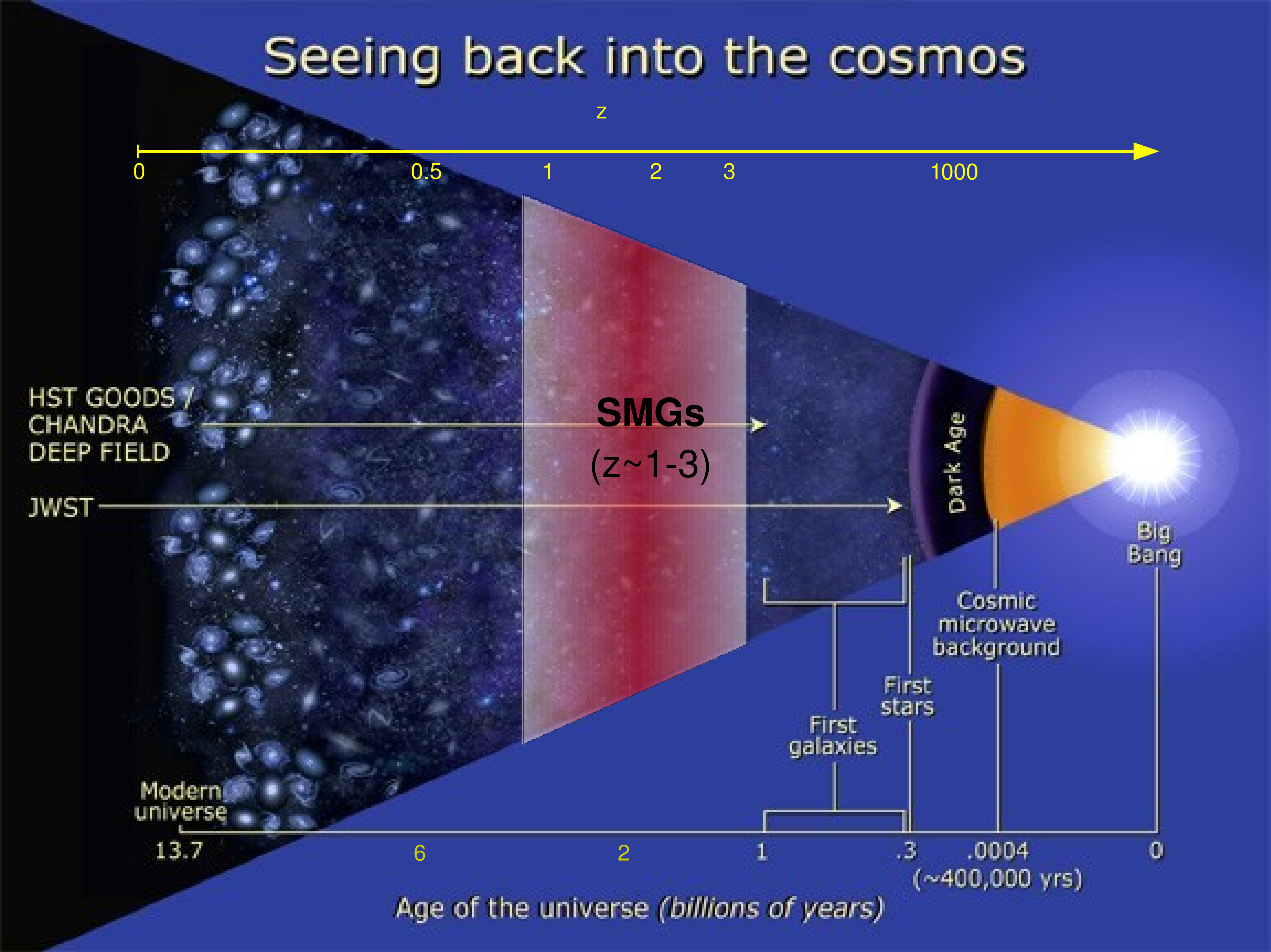
Redshift Distribution of SMGs

Chapman et al 2003, 2005

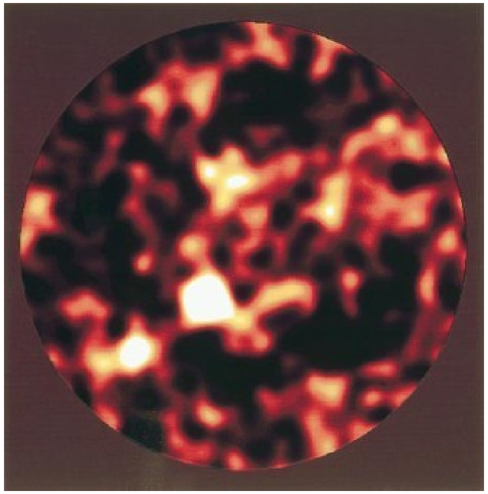


z ~ 2.3

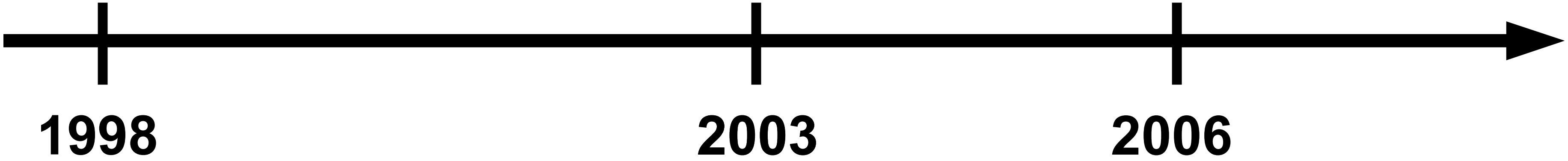
Optical redshifts
At the radio ID position

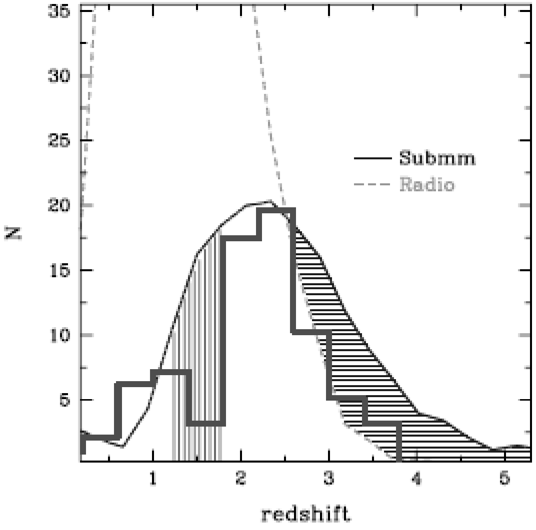


Seeing back into the cosmos
z
0
0.5
1
2
3
1000
HST GOODS / CHANDRA DEEP FIELD
SMGs
(z~1-3)
JWST
Dark Age
Big Bang
Cosmic microwave background
First stars
First galaxies
Modern universe
13.7
6
2
1
.3
.0004
(~400,000 yrs)
0
Age of the universe (billions of years)



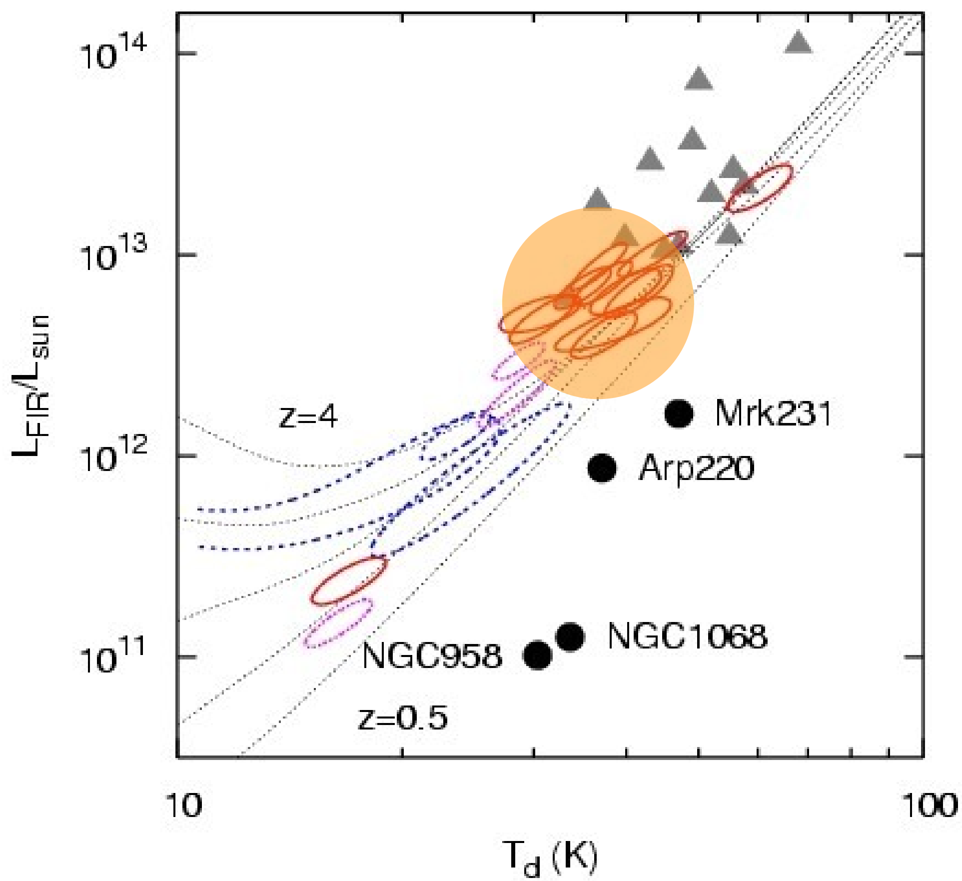
Hughes et al. 1998





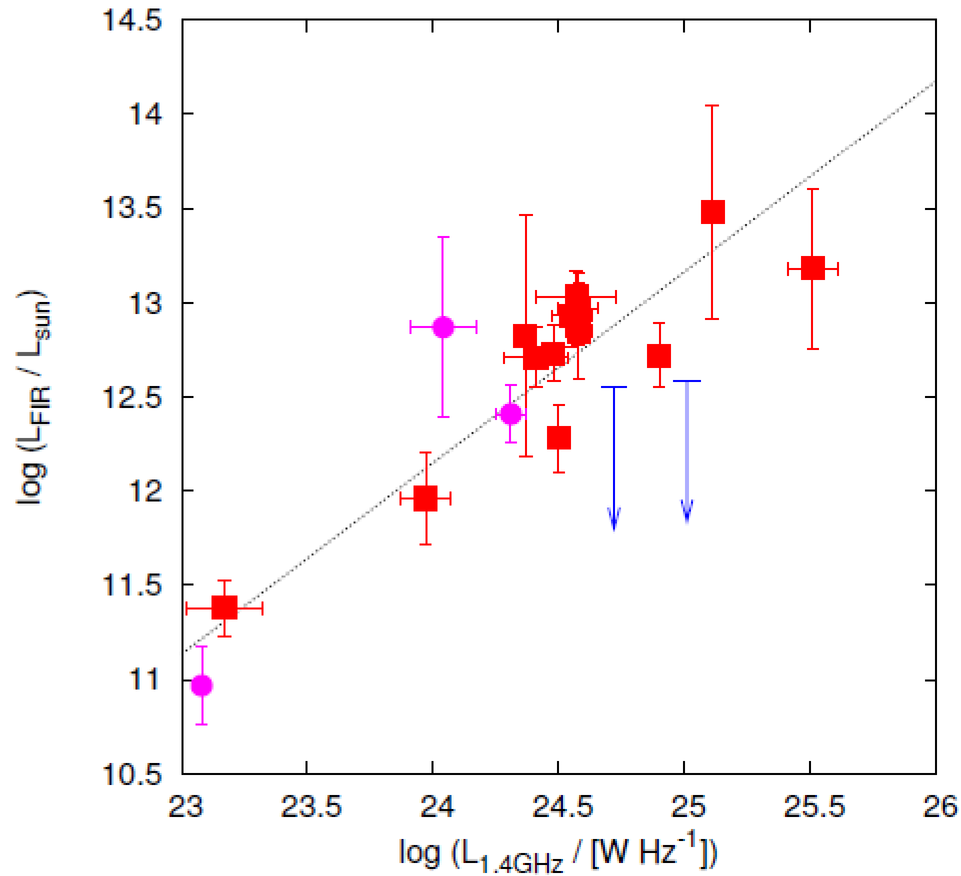
Chapman et al. 2003 & 2005

Kovács et al. 2006



Temperatures & Luminosities

T ~ 35K, L ~ 10^{13} L_{sun}



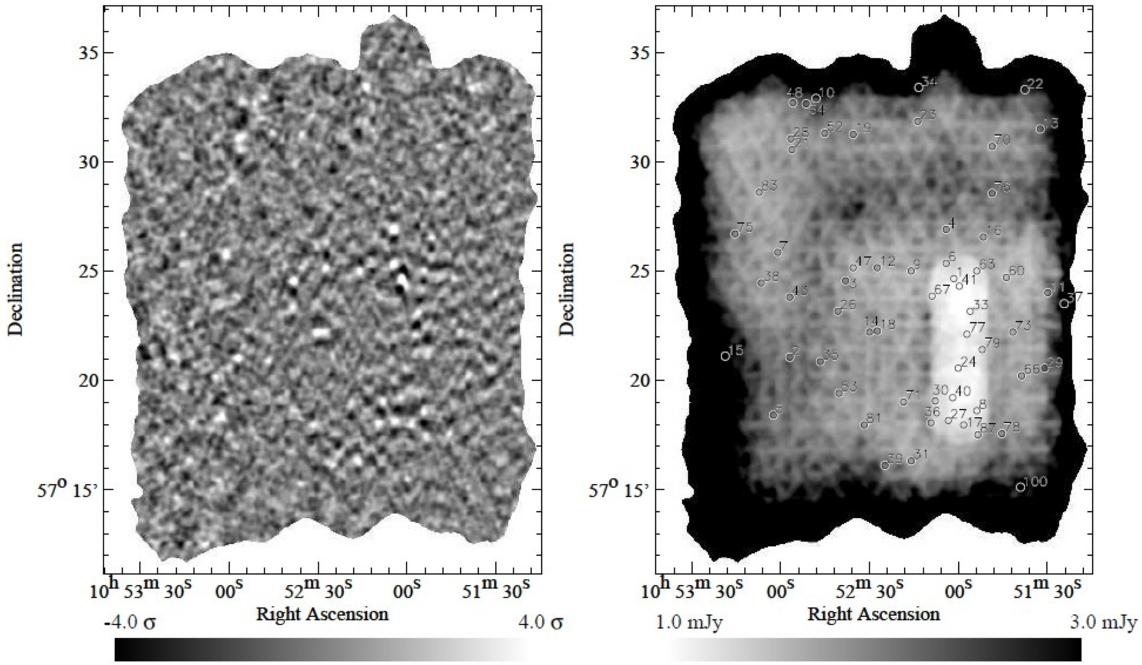
Radio-FIR Correlation

Luminosities fueled by star-formation

SHADES

Coppin et al 2006

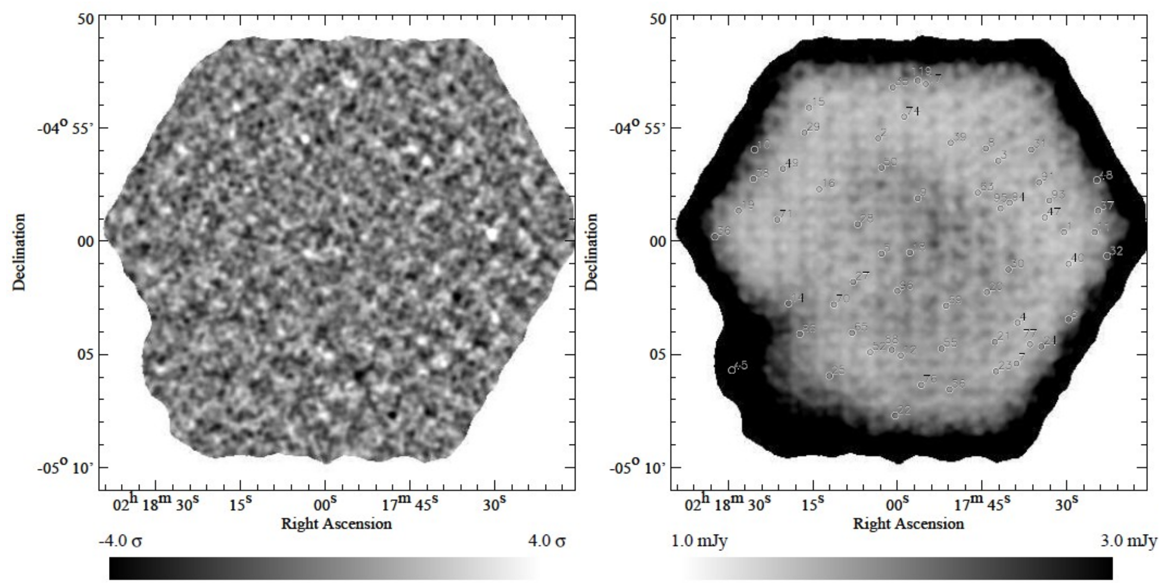
SCUBA **Ha**lf **De**gree **S**quared survey



SCUBA

37 pixels

Lockman Hole
(*485 arcmin*^{2})



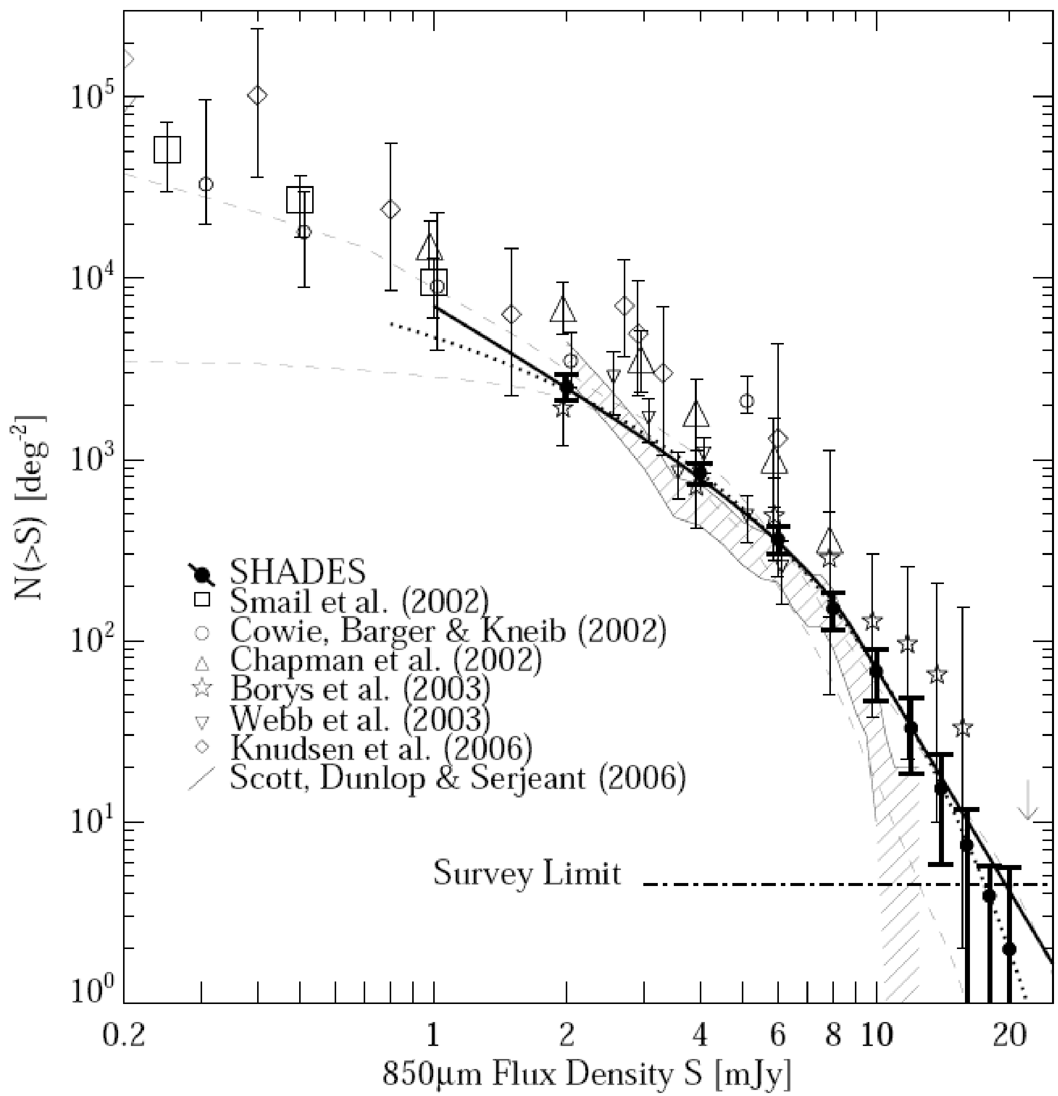
SXDF
(*406 arcmin*^{2})

SHADES: Source Counts
(brightness distribution)

Formation

Evolution

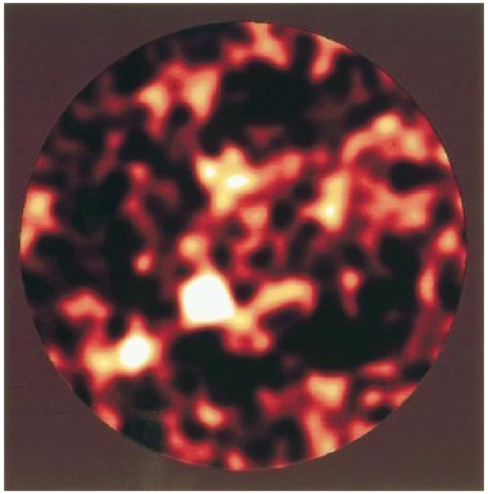
(z-Distribution)



Stellar Analogy:

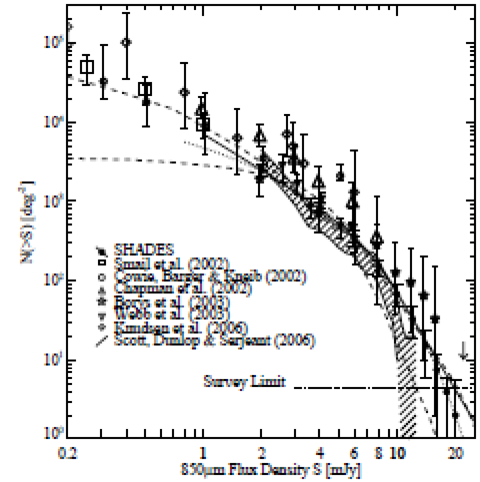
IMF

Coppin et al. 2006



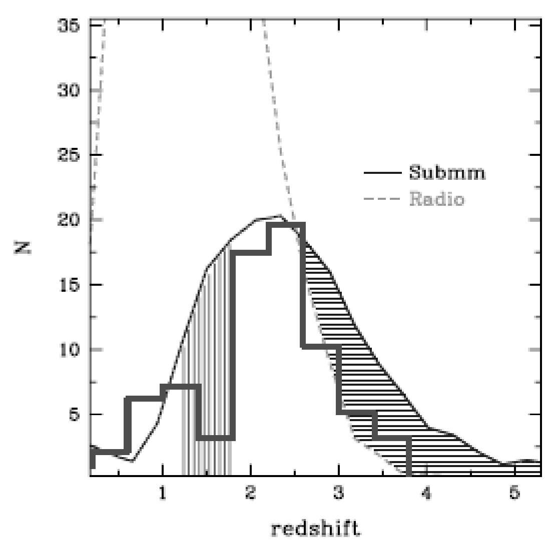
Hughes et al. 1998

SHADES

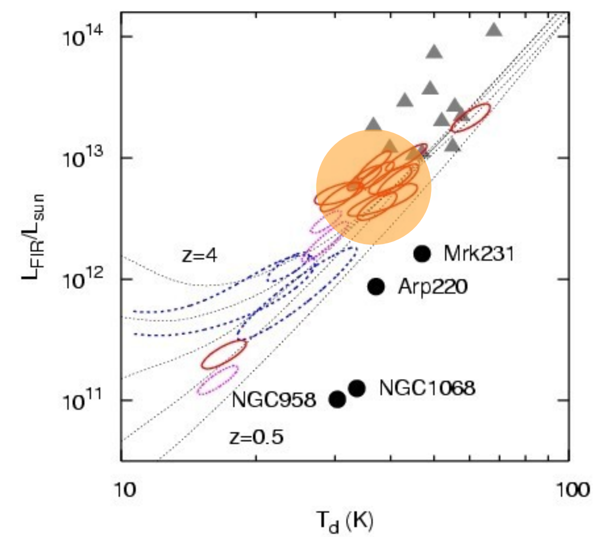


Coppin et al. 2006

1998 **2003** **2006** **2007**



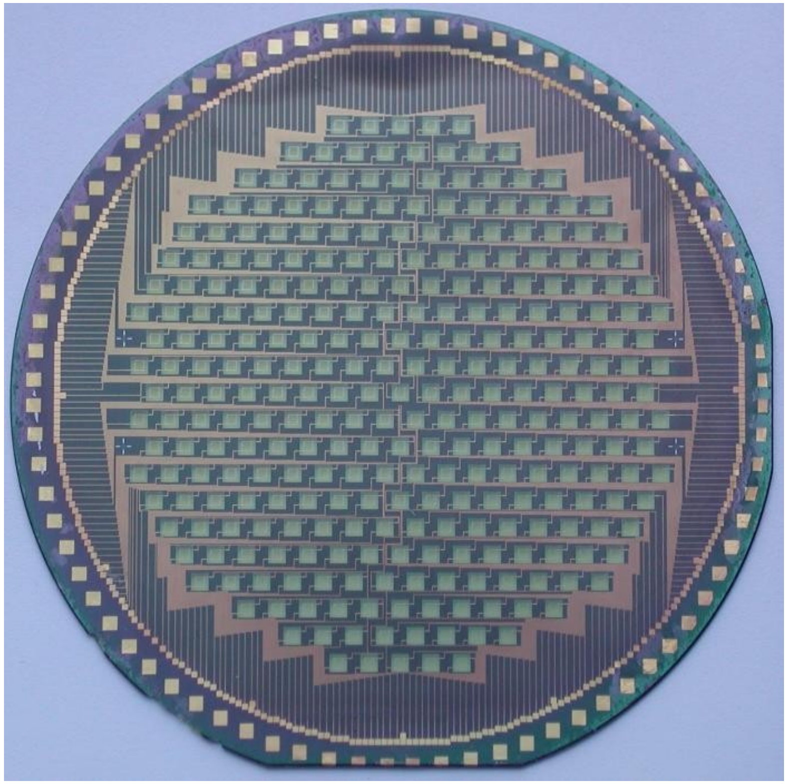
Chapman et al. 2003 & 2005



Kovács et al. 2006


TMZ-50/30

LABOCA
(Large Bolometer Camera)



Siringo et al. 2009

295 pixels

Max-Planck-Institut
für
Radioastronomie

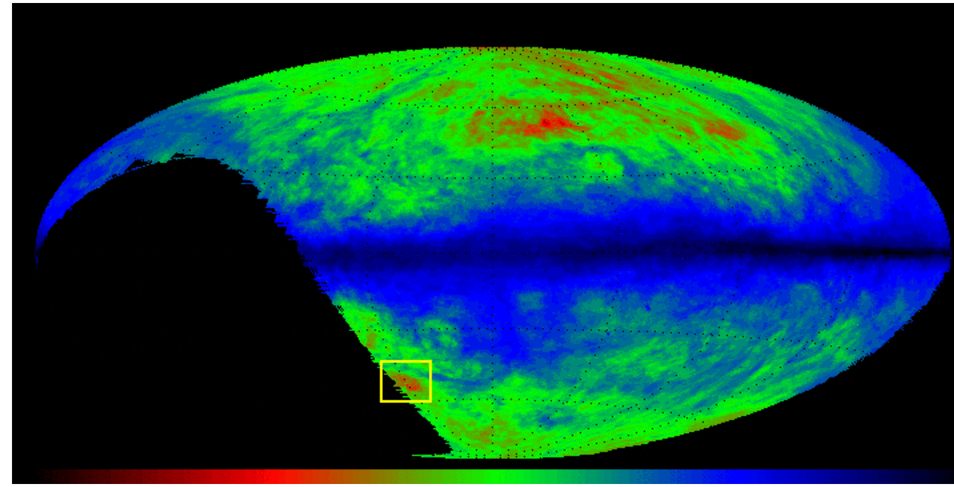
MPE

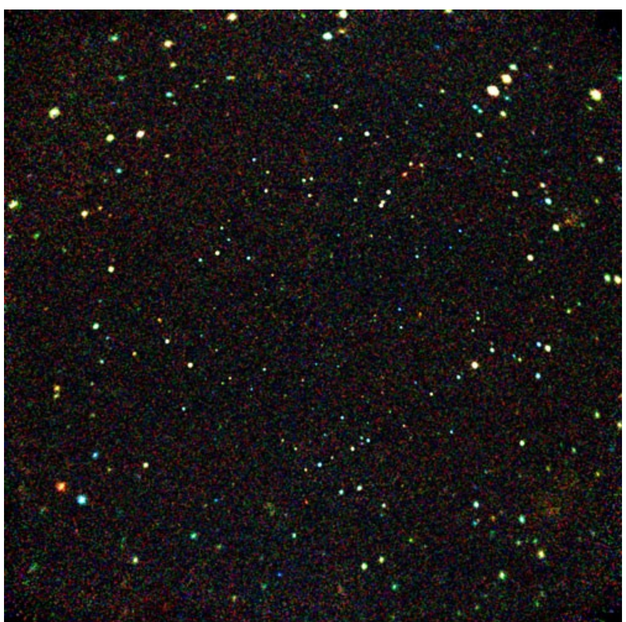
Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg

ESO

The *Extended* Chandra Deep Field South (CDFS)

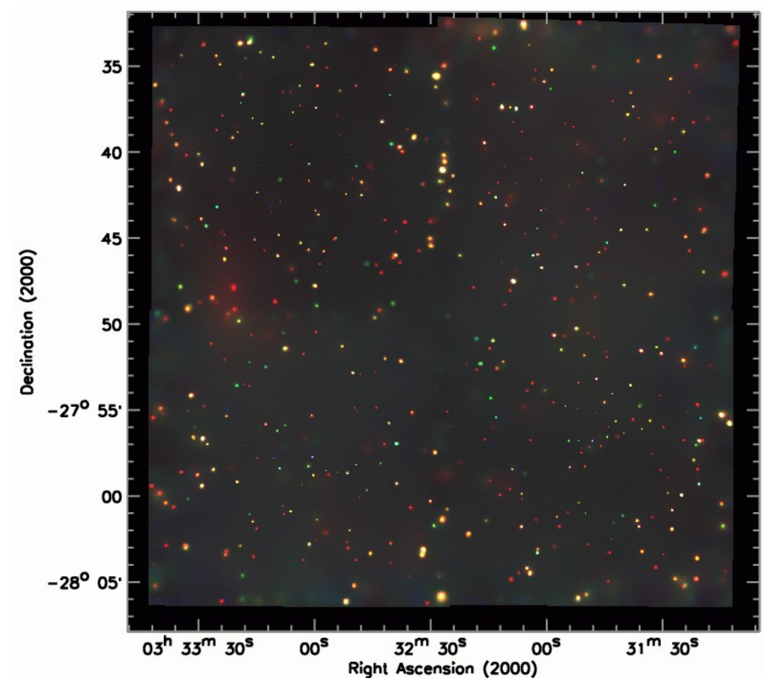
X-ray *Chandra*, *XMM*
UV *GALEX*
Opt *HST* GEMS/GOODS, COMBO-17
IR *Spitzer* IRAC/MIPS
Radio *VLA* 1.4GHz





CHANDRA

30'



Optical

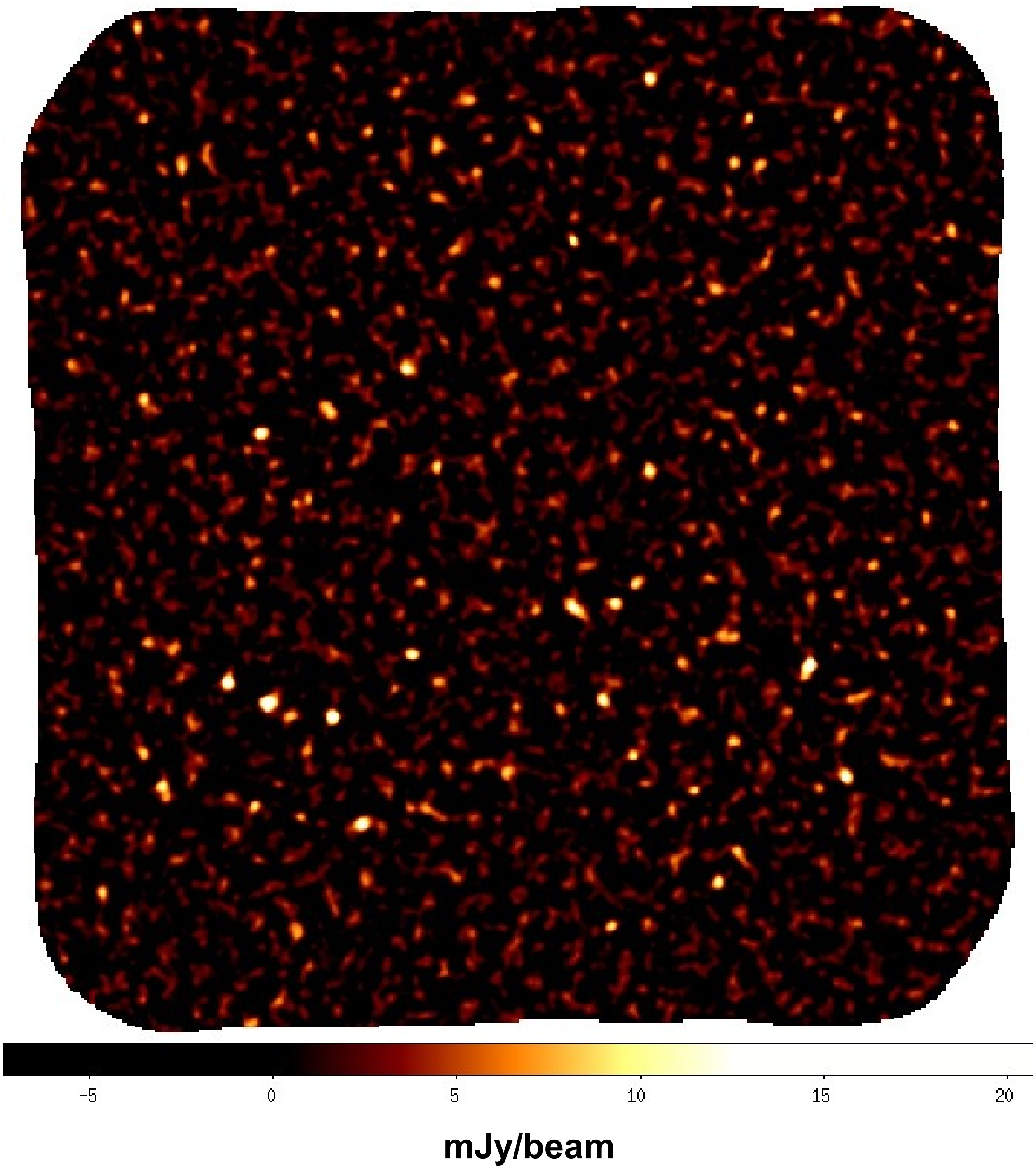
The CDFS at 870 microns

300 hours

19” beam
(27” smoothed)

1.2 mJy/beam

125 sources
(5 false)



The CDFS at 870 microns

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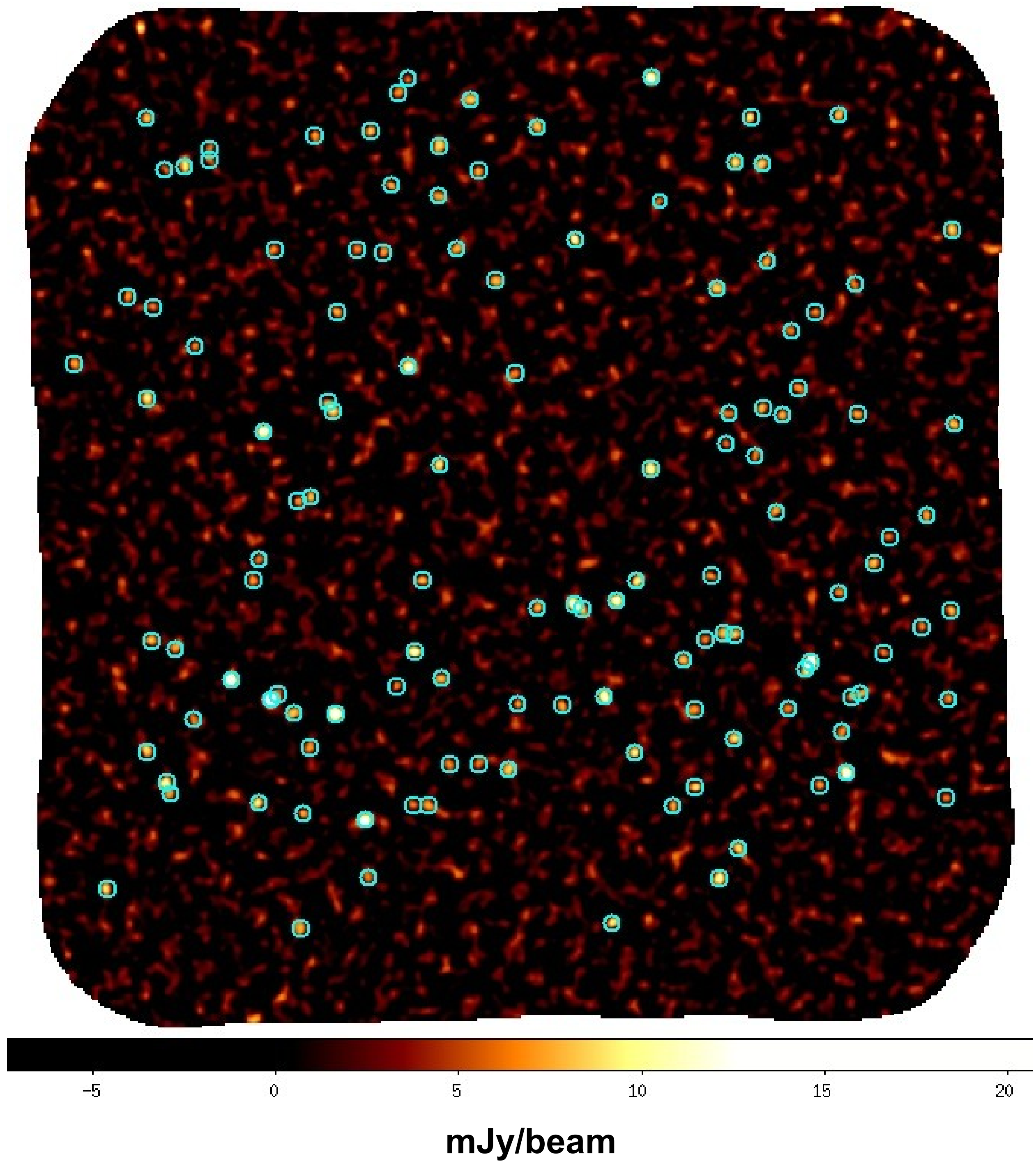
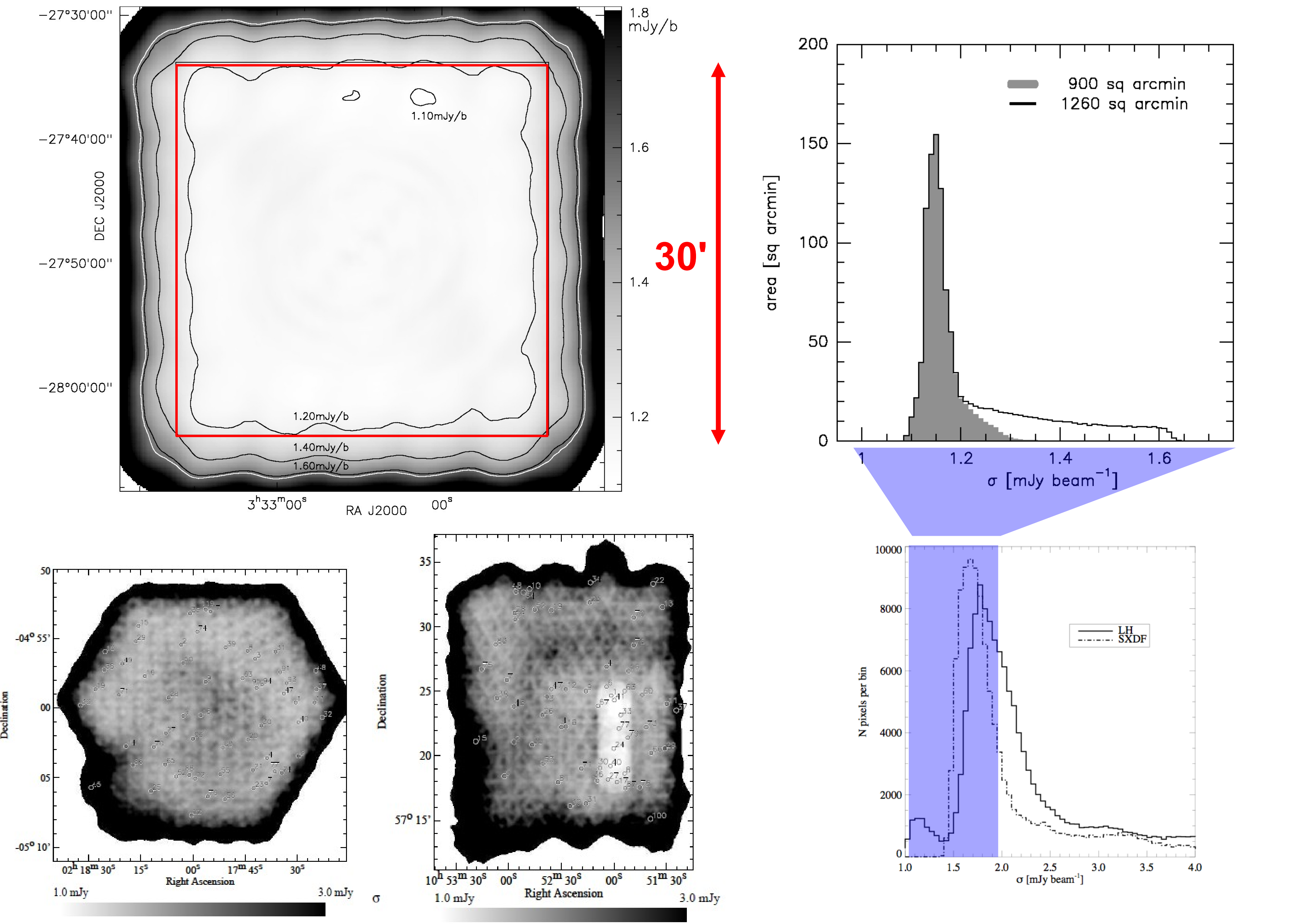


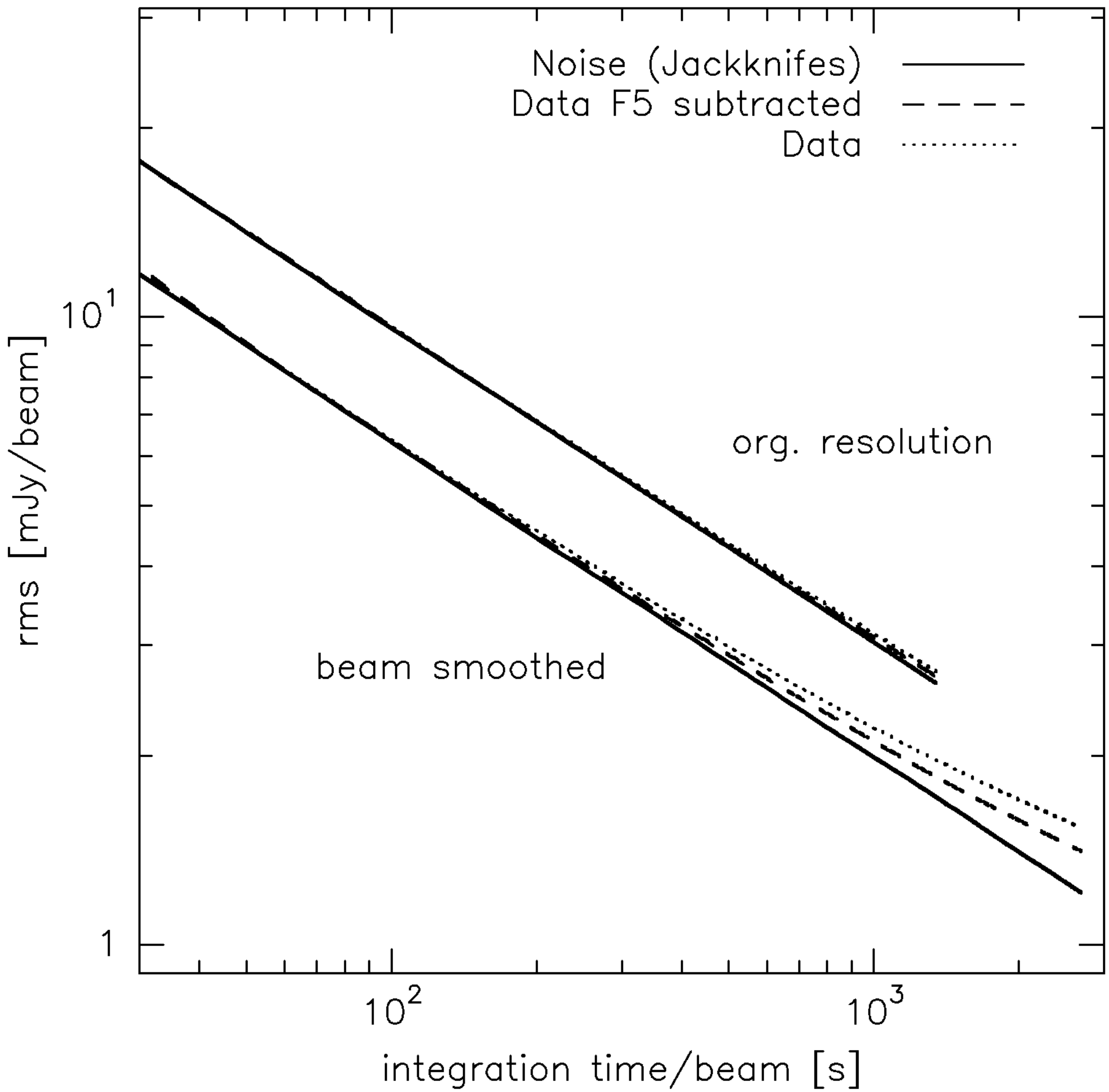


−27°30'00"
−27°40'00"
−27°50'00"
−28°00'00"
DEC J2000
3h33m00s
00s
RA J2000
1.8 mJy/b
1.6
1.4
1.2
1.10mJy/b
1.20mJy/b
1.40mJy/b
1.60mJy/b
30'
200
150
100
50
0
area [sq arcmin]
900 sq arcmin
1260 sq arcmin
1
1.2
1.4
1.6
σ [mJy beam−1]
Declination
−04° 55'
00
05
−05° 10'
02h 18m 30s
15s
00s
17m 45s
30s
Right Ascension
1.0 mJy
3.0 mJy
σ
35
30
25
20
57° 15'
10h 53m 30s
00s
52m 30s
00s
51m 30s
Right Ascension
1.0 mJy
3.0 mJy
10000
8000
6000
4000
2000
0
N pixels per bin
LH
SXDF
1.0
1.5
2.0
2.5
3.0
3.5
4.0
σ [mJy beam−1]

Confusion Noise

Rule of Thumb

When the number of sources per beam exceeds 1, sources start to look like a noisy background....



$\sigma^2_{obs} = \sigma^2_m + \sigma^2_c$

$\sigma_c \sim 0.7$ mJy/beam

Observed noise is the combination of measurement noise and confusion noise

How to Get Source Counts...

The “Direct” Method...

SHADES Recipe

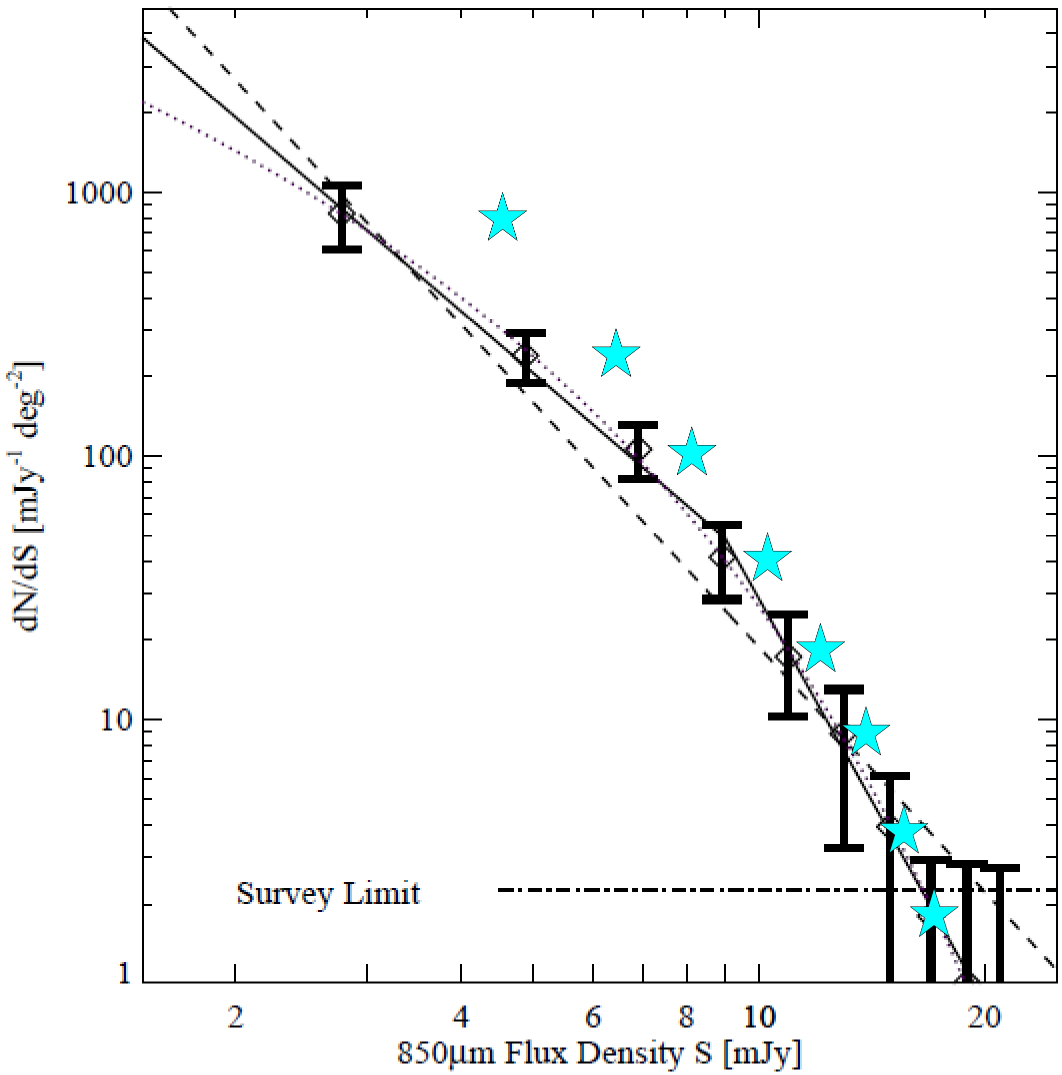
1. Bin your sources

2. Assume dN/dS

3. Deboost with

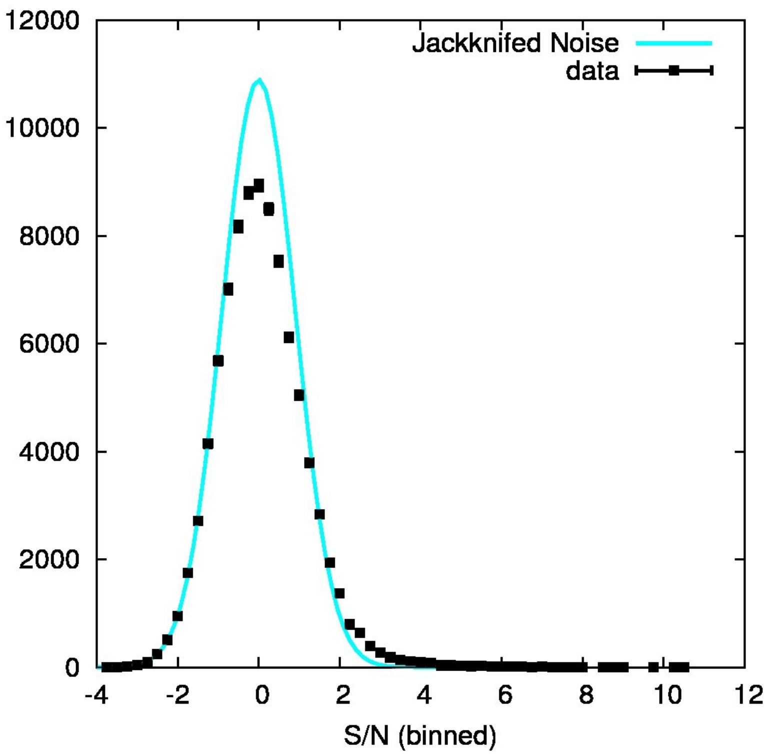
$$p(S) = \frac{\partial N}{\partial S}$$

4. get dN/dS

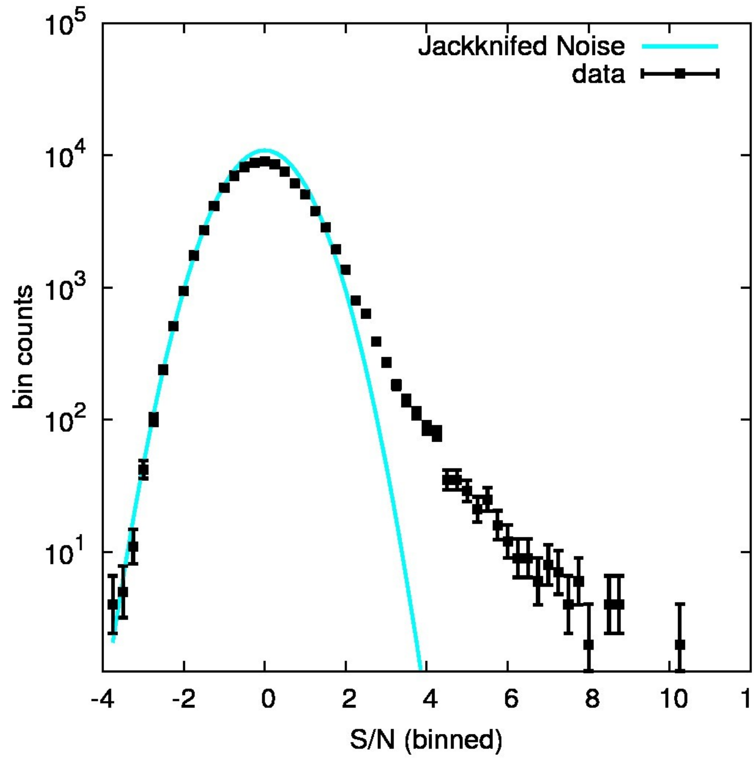


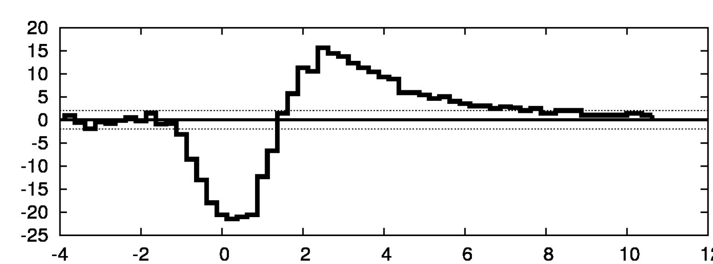
$P(D)$ Analysis

Many faint sources
Widen distribution
(confusion)



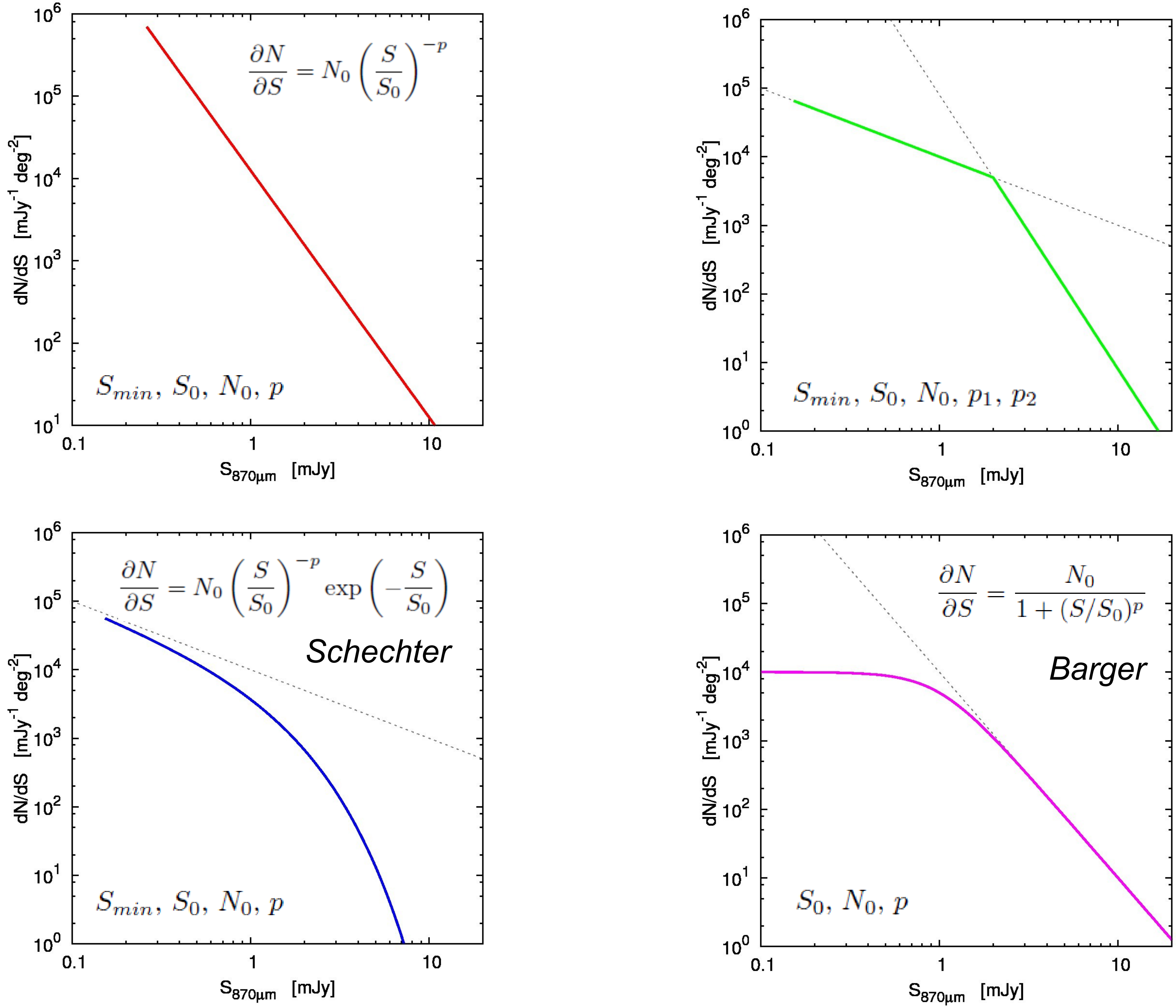
Bright sources
Produce tail





$P(D)$ analysis

Observed distribution is a product of the source distribution and the underlying noise...



$$\frac{\partial N}{\partial S} = N_0 \left(\frac{S}{S_0}\right)^{-p}$$
$S_{min},\ S_0,\ N_0,\ p$
$S_{min},\ S_0,\ N_0,\ p_1,\ p_2$
$$\frac{\partial N}{\partial S} = N_0 \left(\frac{S}{S_0}\right)^{-p} \exp\left(-\frac{S}{S_0}\right)$$
Schechter
$S_{min},\ S_0,\ N_0,\ p$
$$\frac{\partial N}{\partial S} = \frac{N_0}{1+(S/S_0)^p}$$
Barger
$S_0,\ N_0,\ p$
dN/dS [mJy^{-1} deg^{-2}]
$S_{870\mu m}$ [mJy]

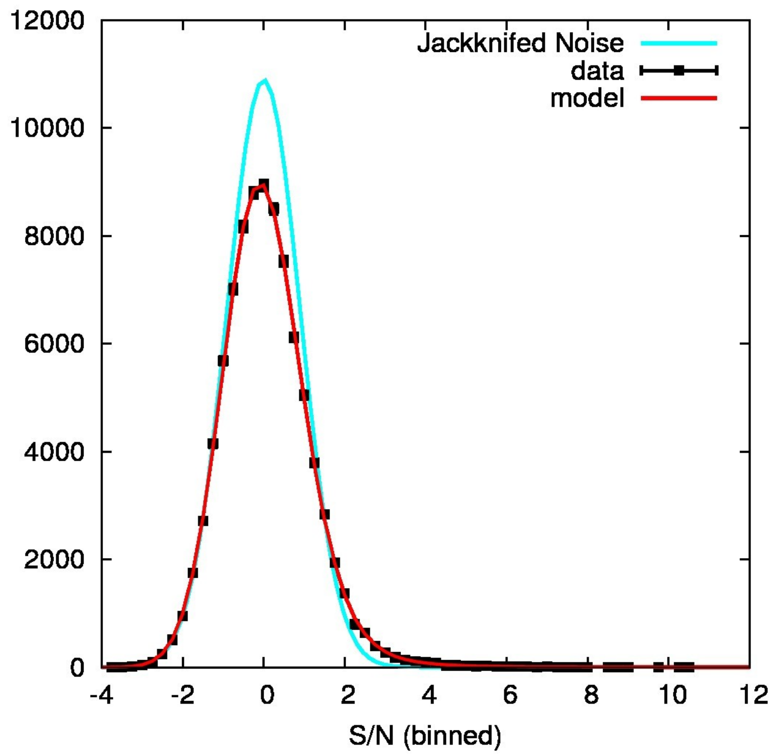
P(*D*) Results

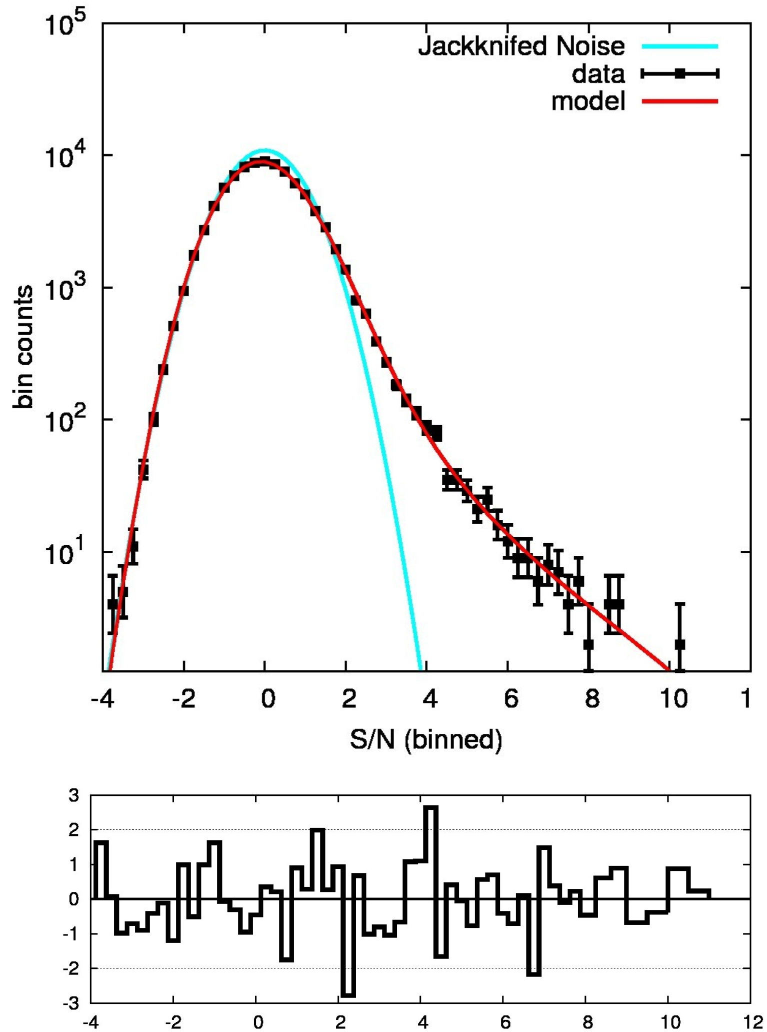
Power Law

S_{min} = 0.5 mJy

N_0 = 92.7 mJy^{-1} deg^{-2}

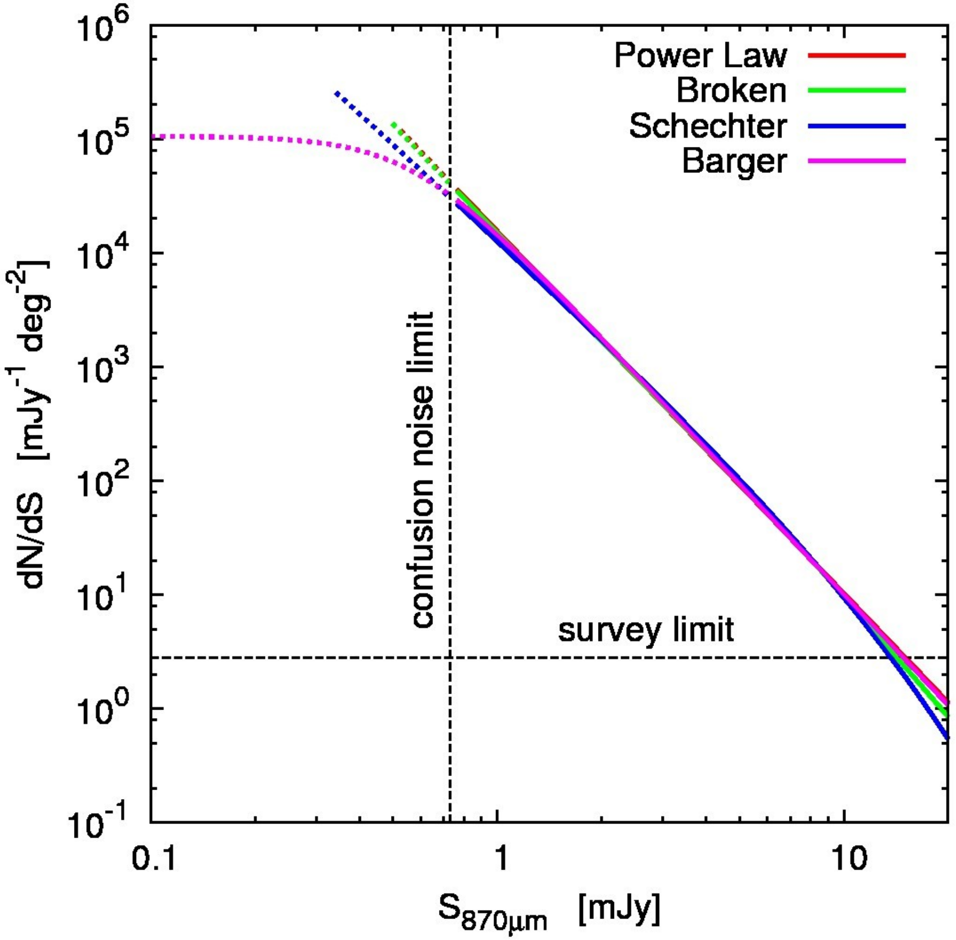
p = 3.178



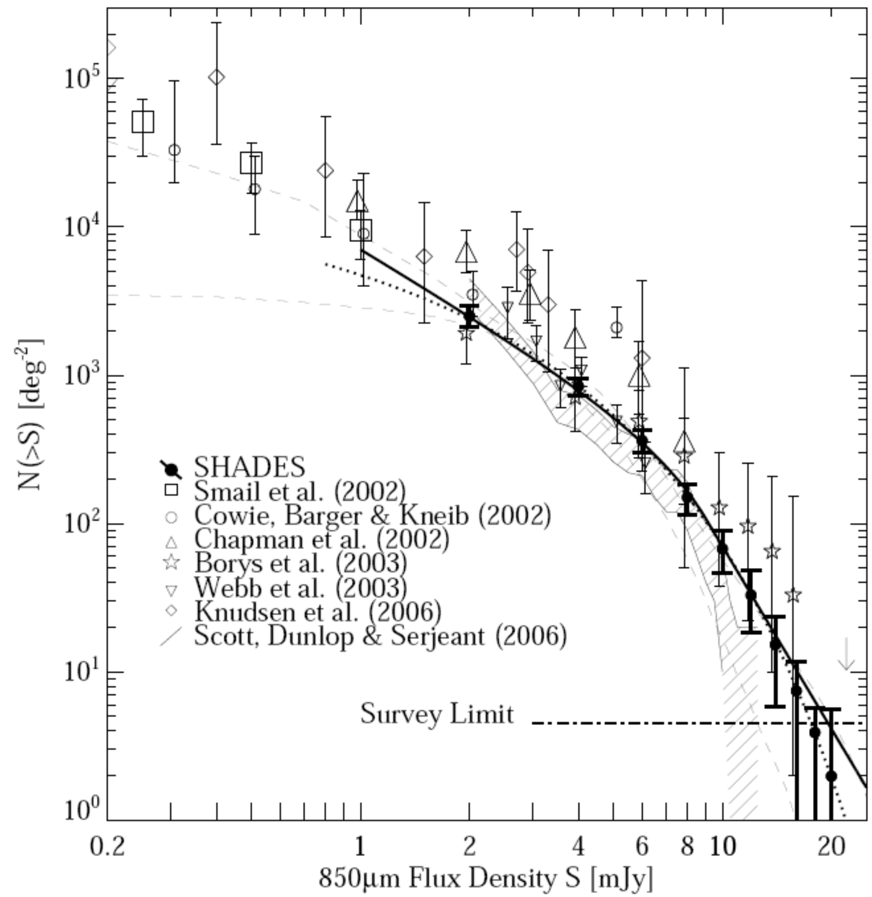


Source Counts from the CDFS

CDFS



SHADES

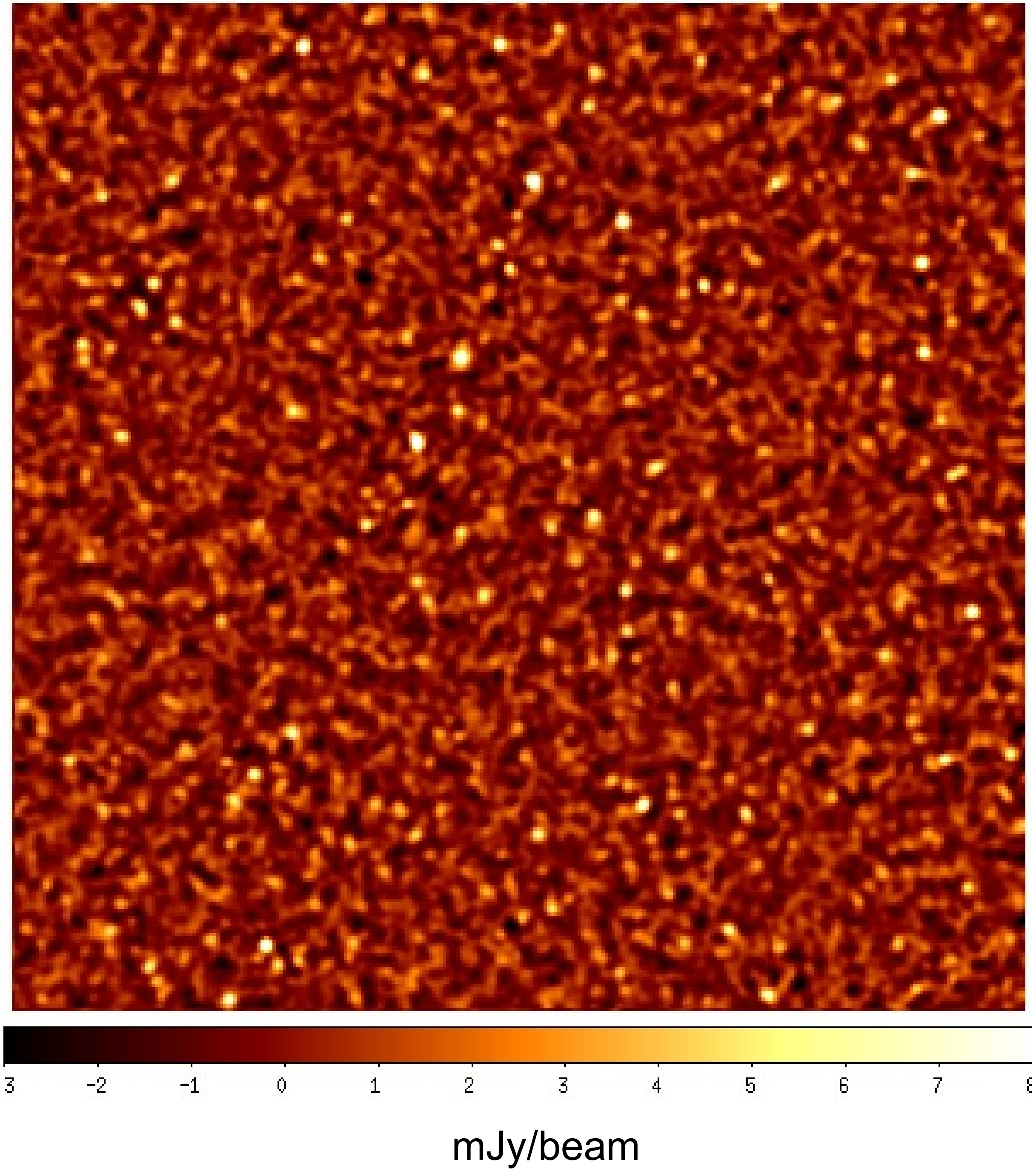


Integrated 870um Background: 29-33 Jy/deg^2

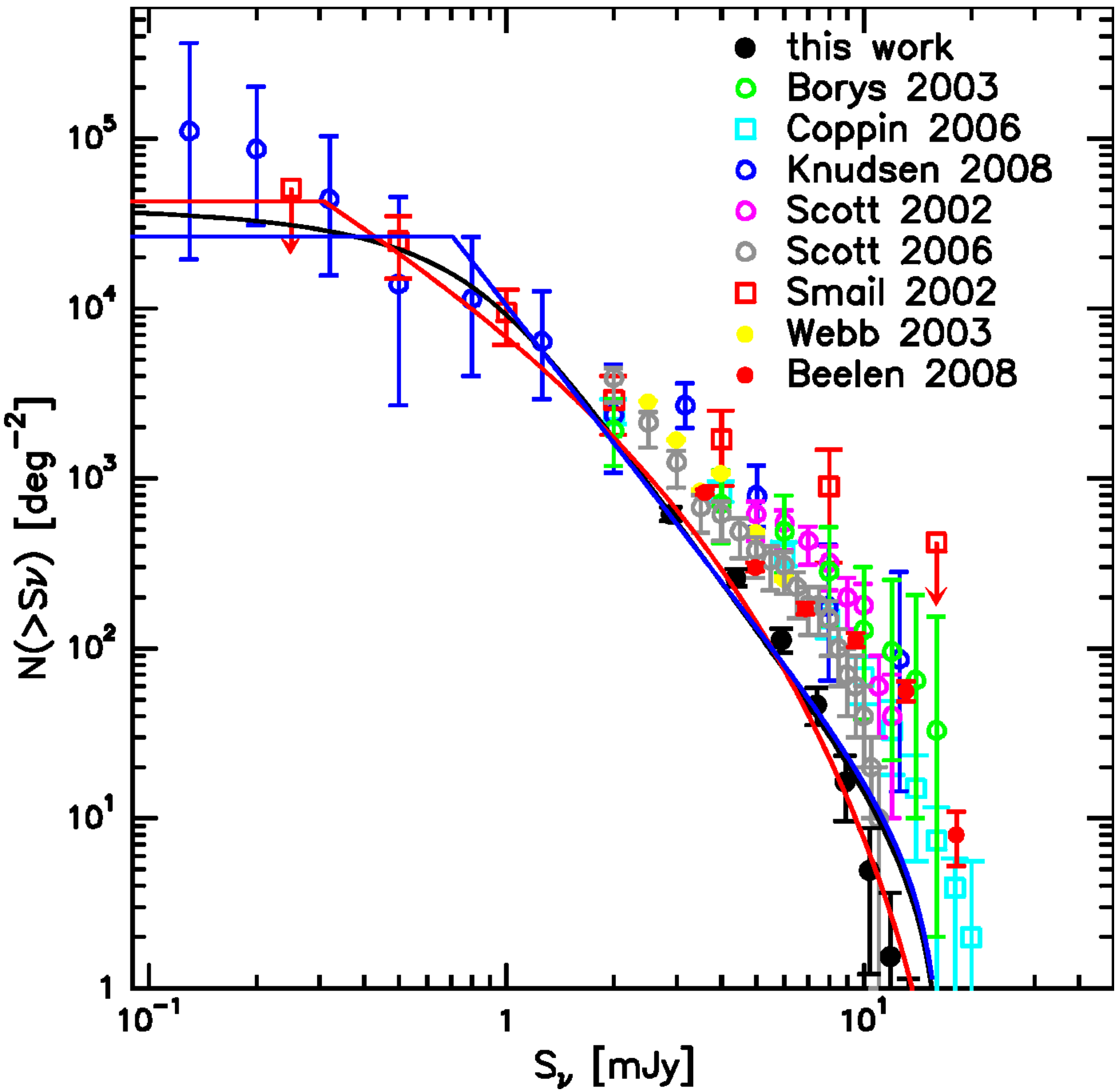
COBE: 45 +- 5

The Perfect View

Over
12,000
sources



Cosmic Variance?



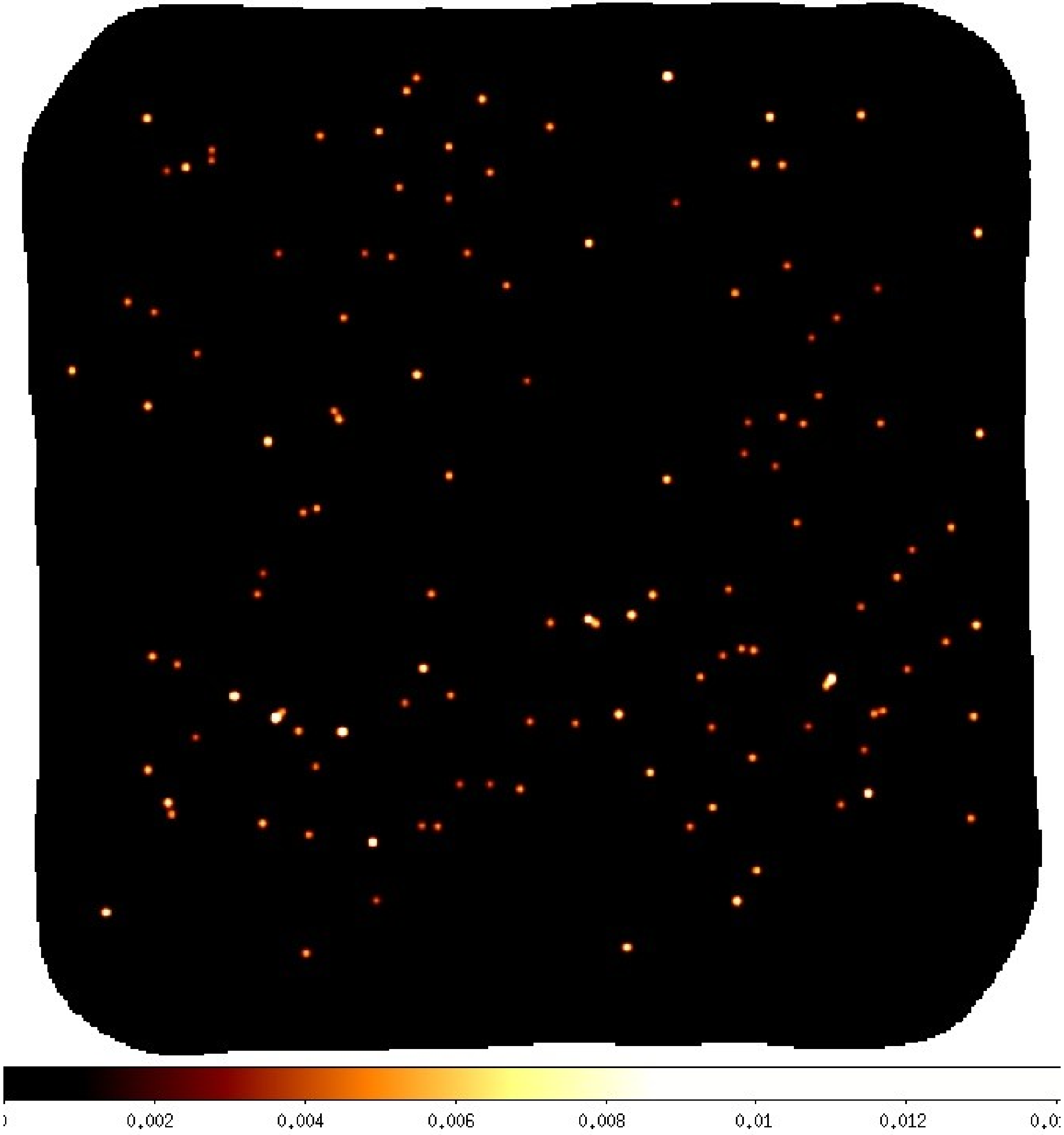
Underdensities In the CDFS:

Z > 2 K-band selected galaxies are under-abundant by ~60%. (Dokkum et al. 2006)

Z > 2.5 DRGs (Marchesini et al. 2006)

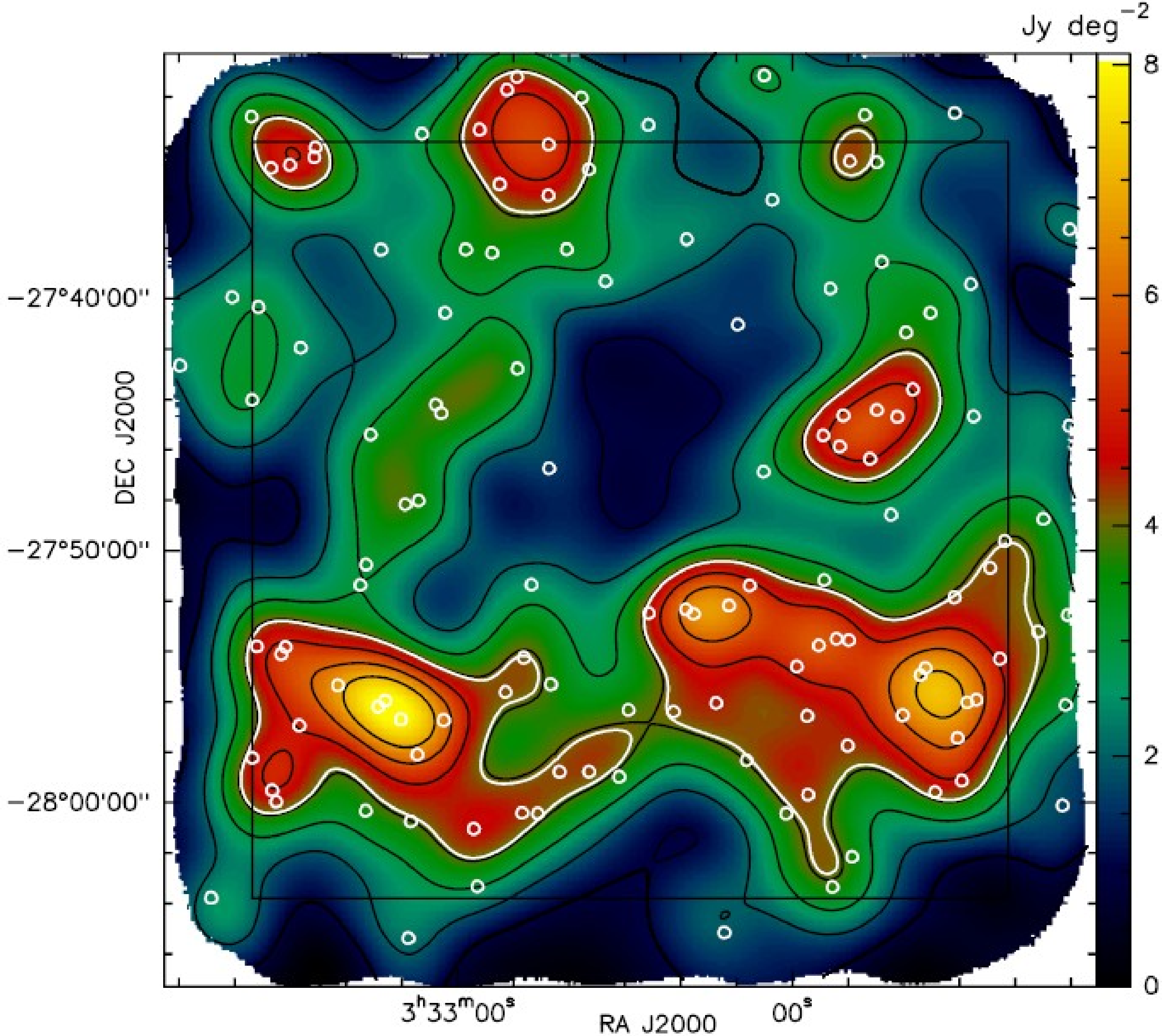
High-z optically bright AGNs (Dwelly & Page 2006)

Spatial Source (Flux) Distribution



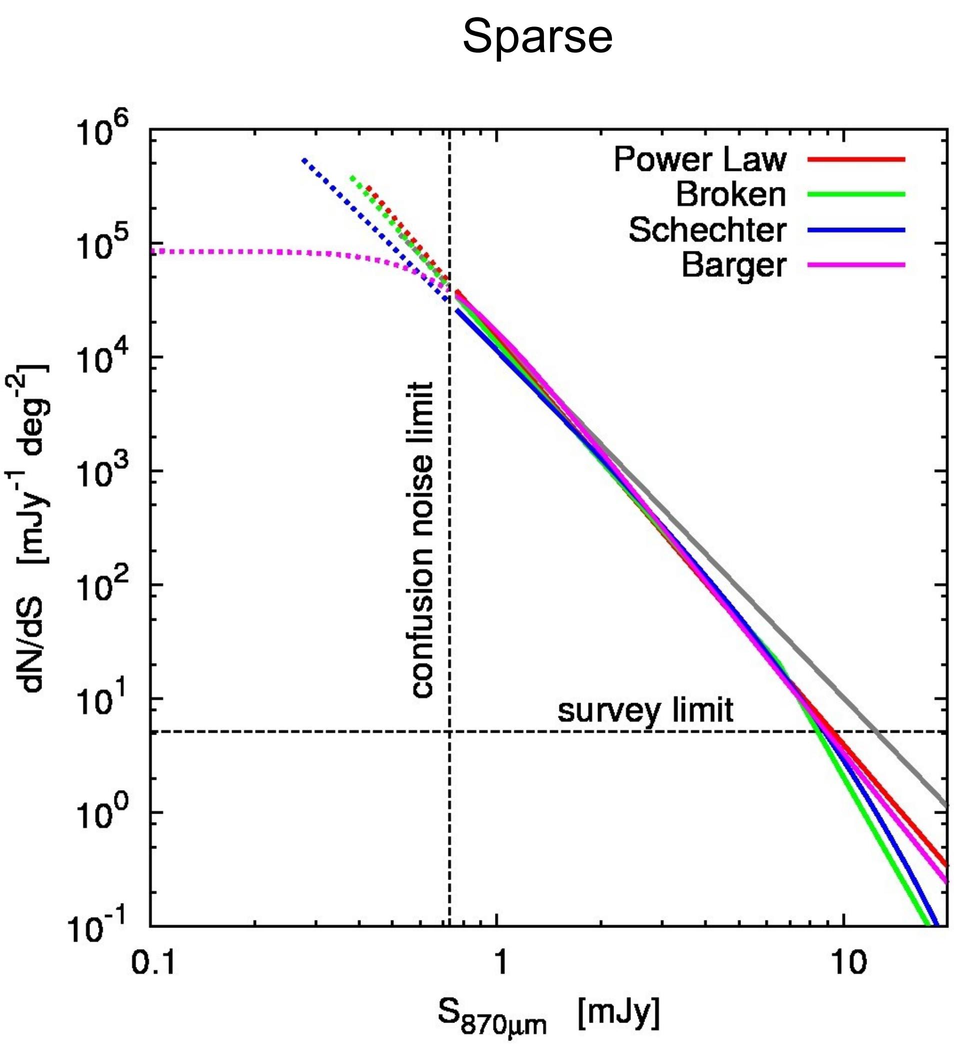
mJy/beam

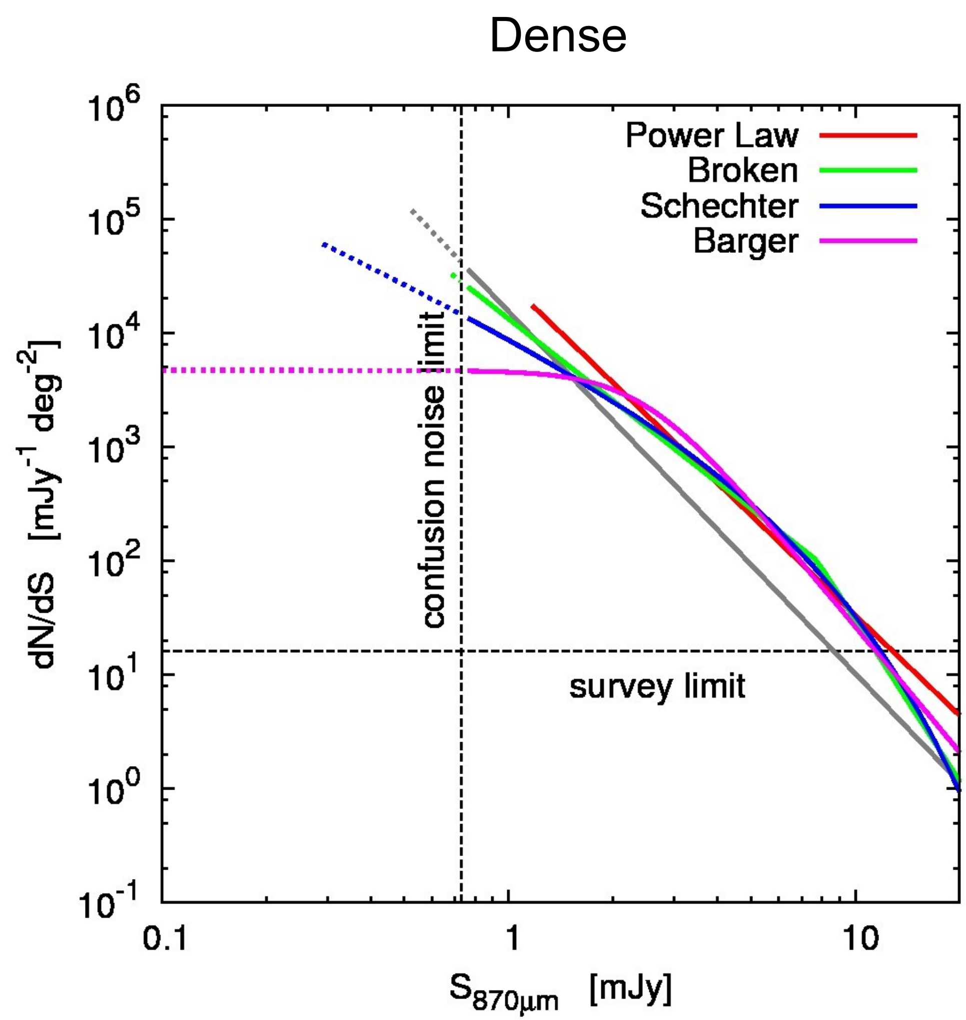
Bright Source Flux Distribution



Smoothed to 5' resolution

Cosmic Variance?

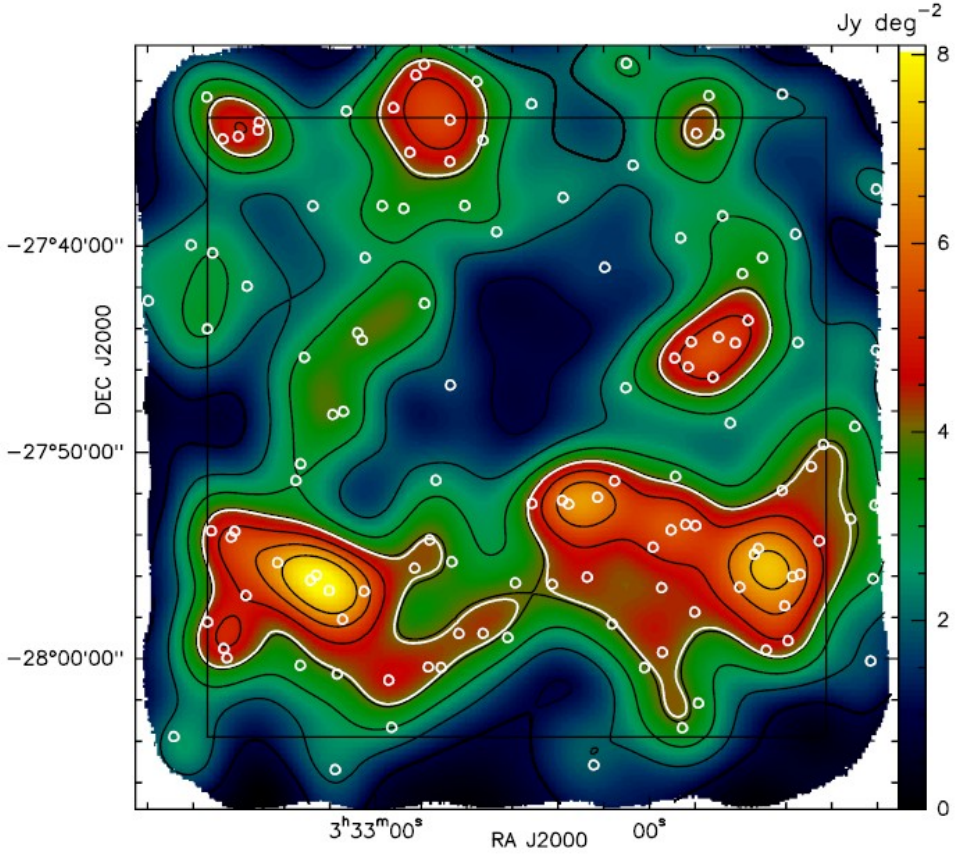


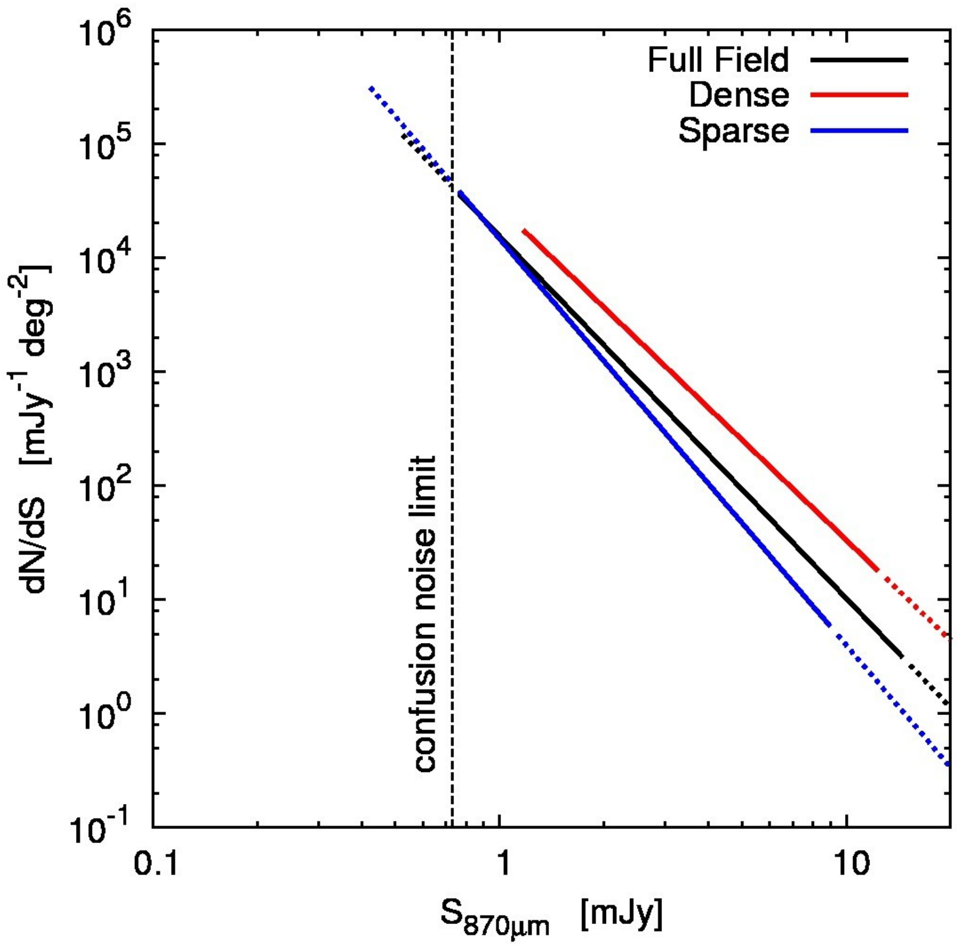


30-38 Jy/deg^2

22-28 Jy/deg^2

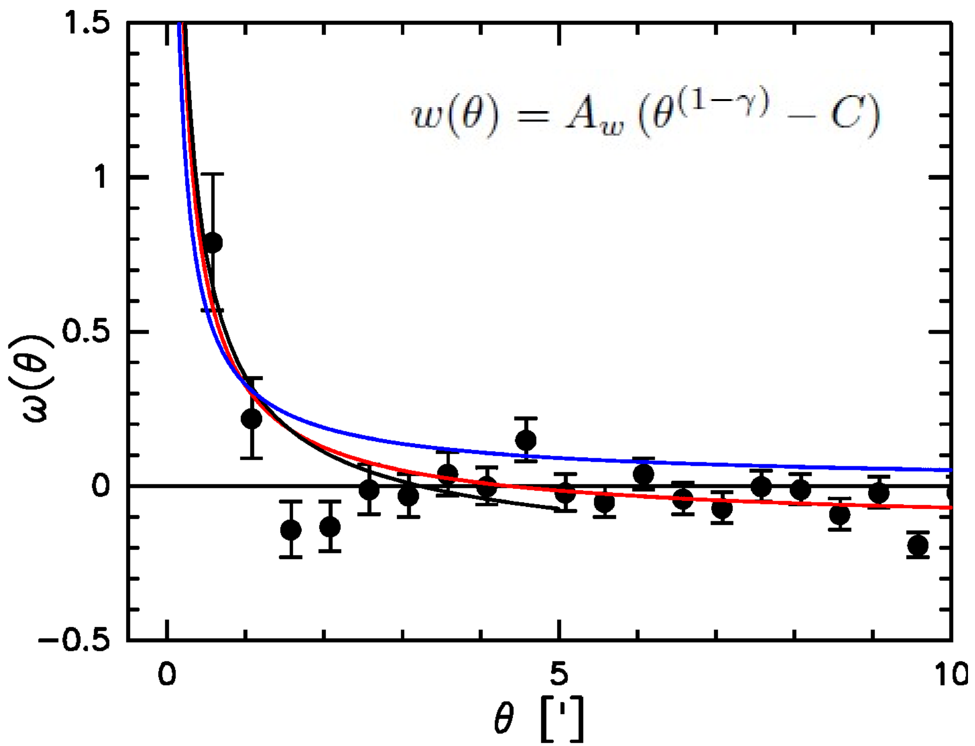
Cosmic Variance?





Seems more a variation in steepness rather than density

The Perfect View



$\gamma = 1.8$ (assumed)

$A_w = 0.011 \pm 0.0046$

$\theta_0 = 14'' \pm 7''$

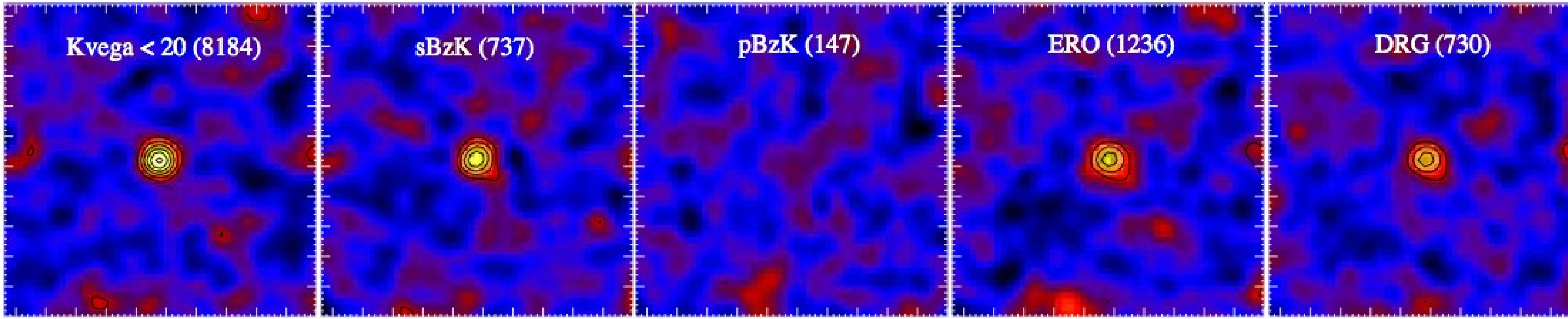
$r_0 = 13 \pm 6\,h^{-1}\,\mathrm{Mpc}$

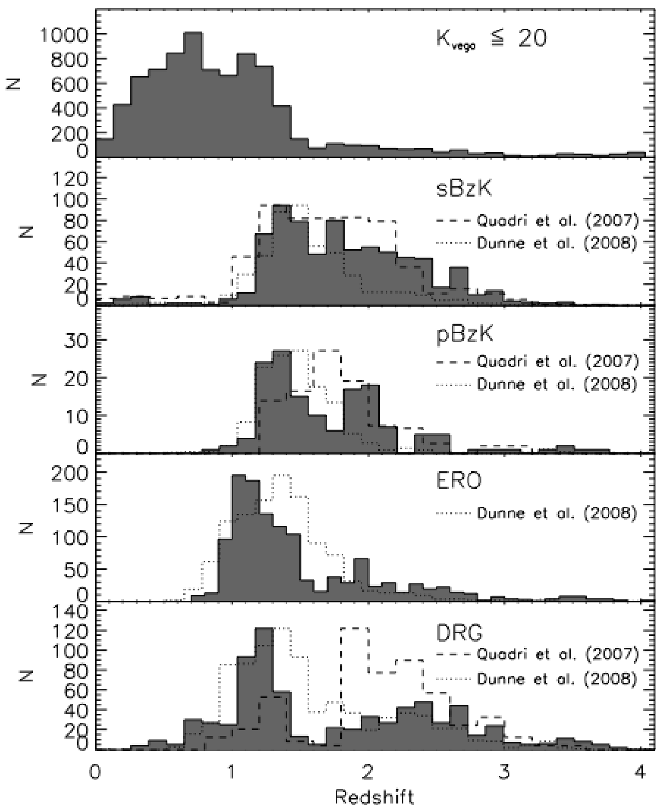
Clustering of SMGs consistent with other high-z populations

Corresponds to present epoch galaxy clusters

Associated with more massive DM halos

Other high-z Populations





Greve et al. 2009

Summary (so far...)

Largest, deepest, cleanest to date

125 Galaxies

A Better way of Analyzing Data

Robust Source Counts

Cosmic Variance?

Need Redshifts...

PHOTOMETRIC

e.g. from *Spitzer* IRAC/MIPS

↓

Problem:

Ambiguous MIR Ids
Within search radius

NEED BETTER POSITIONS
For securing ID

SPECTROSCOPIC

Based on radio Positions
From VLA 1.4 GHz

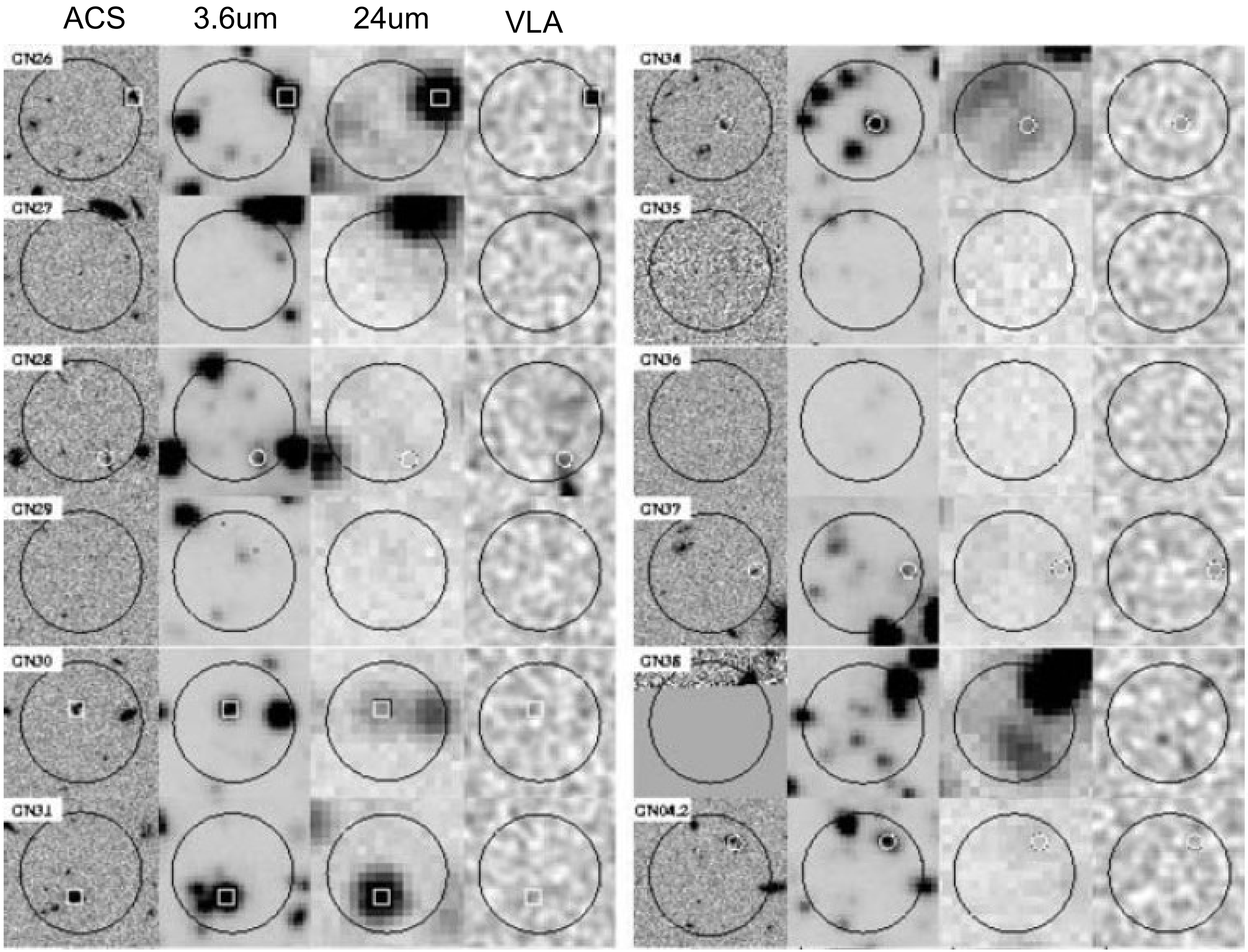
↓

Problem:

Deep radio surveys have
Known redshift cutoff
at z~3

NEED BETTER POSITIONS
For optical followup

Troublesome IDs



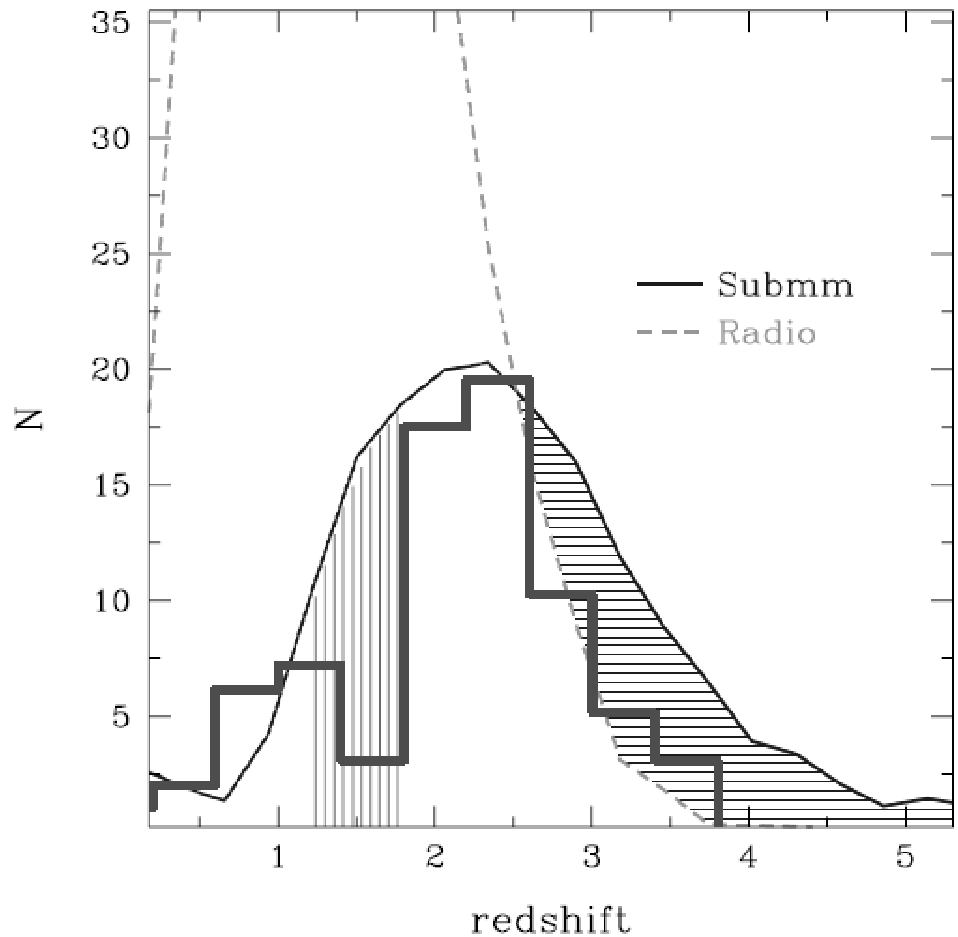
Pope et al. 2006

My Big Question...

(What about the other half of SMGs?)

FIR emission is not fueled by star-formation...

AGNs?



More SMGs at z>3 than we think

Looking for New Ways...

Combined **MIR/NIR**
analysis for isolating potential candidates
(Wilson et al. 2004)

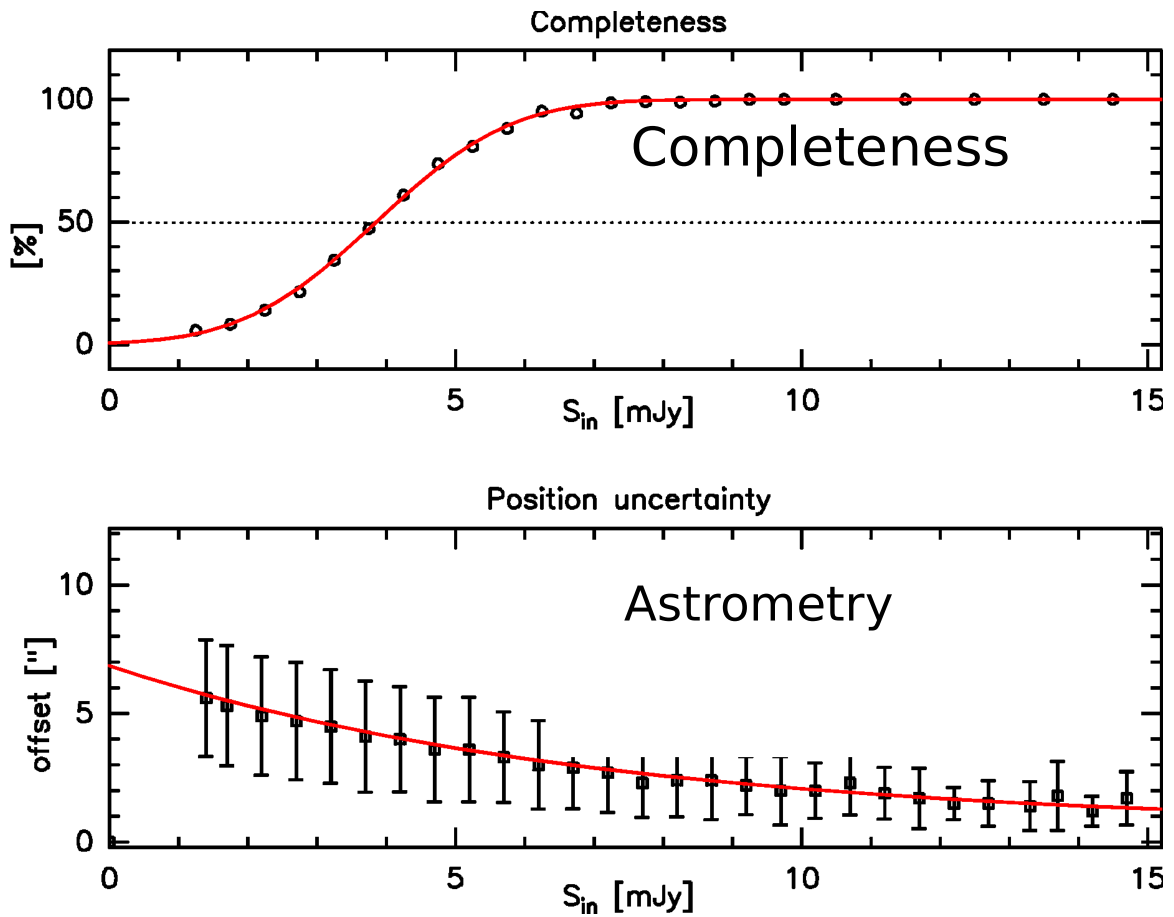
E-VLA followup
positions from thermal continuum, possibly
redshift from CO(1-0)

Wide band submm grating spectrometers
For CO or CI transitions (e.g. z-SPEC)

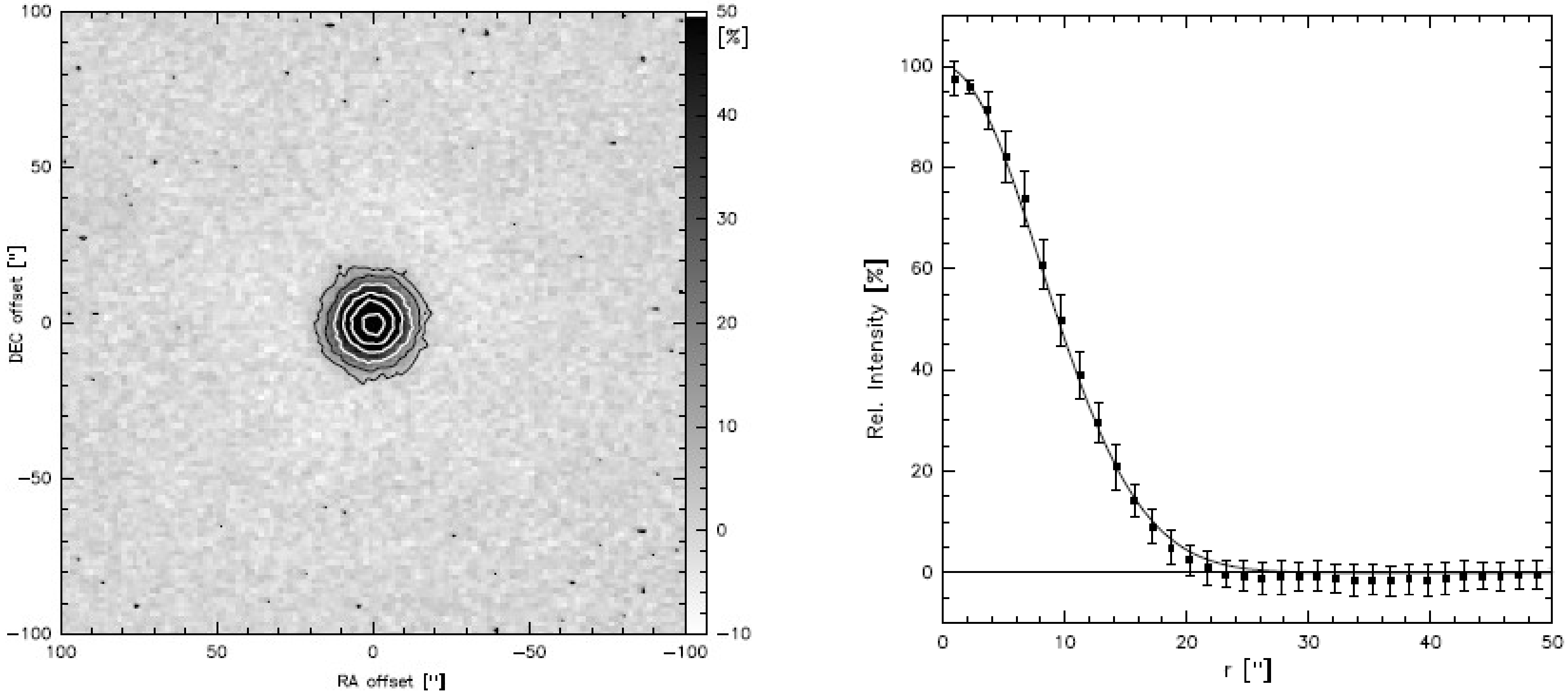
Herschel (esp. 200um)

ALMA...

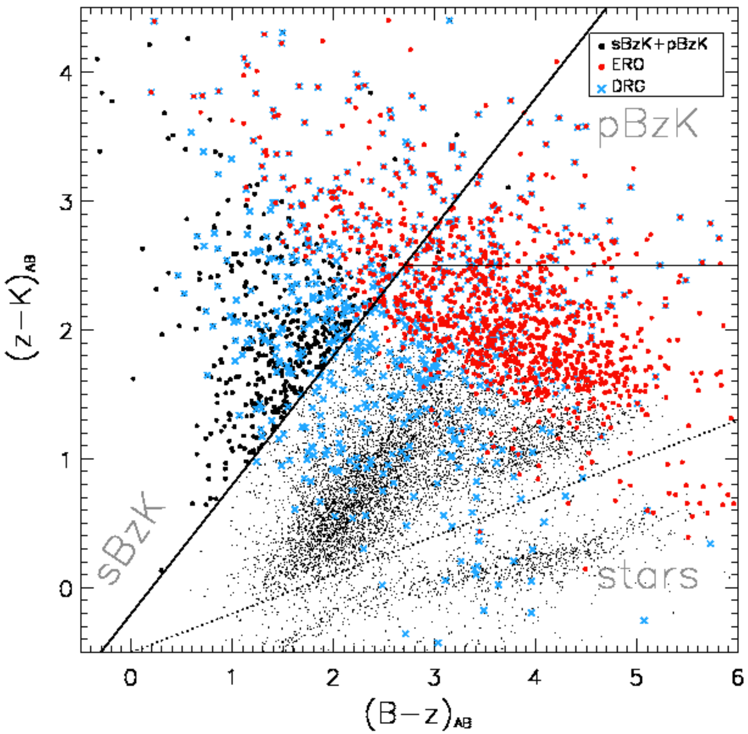
Interested?

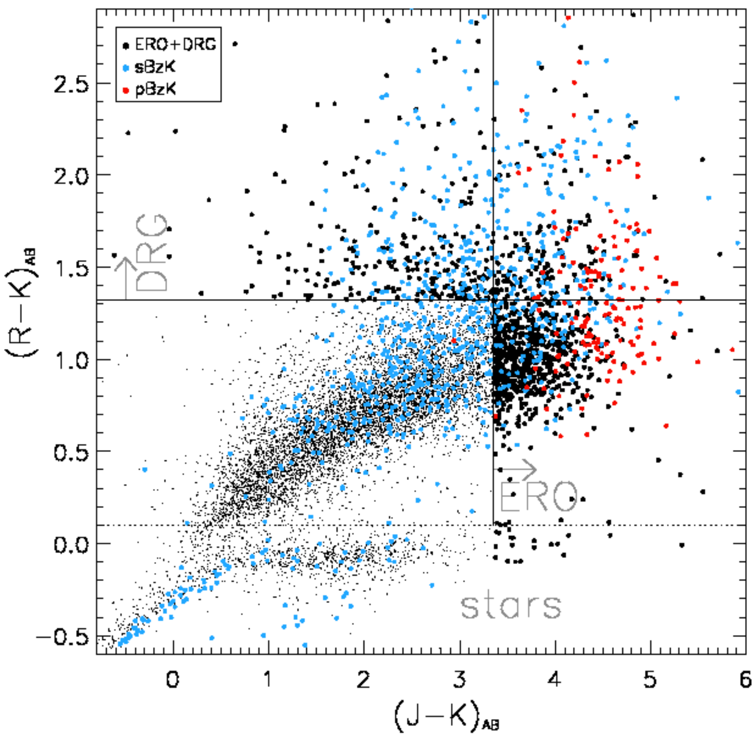

Completeness
Completeness
100
50
0
[%]
0
5
10
15
S_{in} [mJy]
Position uncertainty
Astrometry
10
5
0
offset ["]
0
5
10
15
S_{in} [mJy]

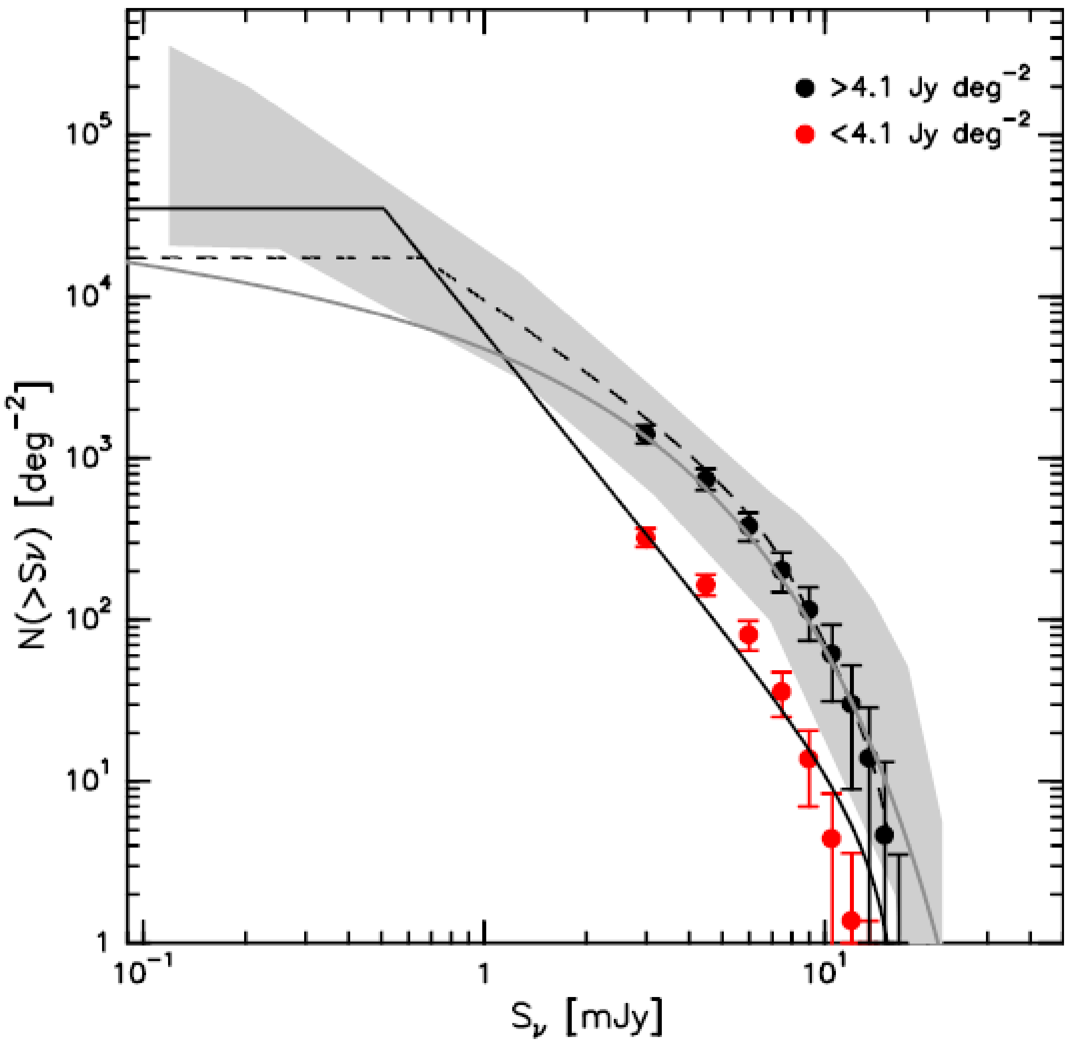
LABOCA Beam Shape



BzK Selection



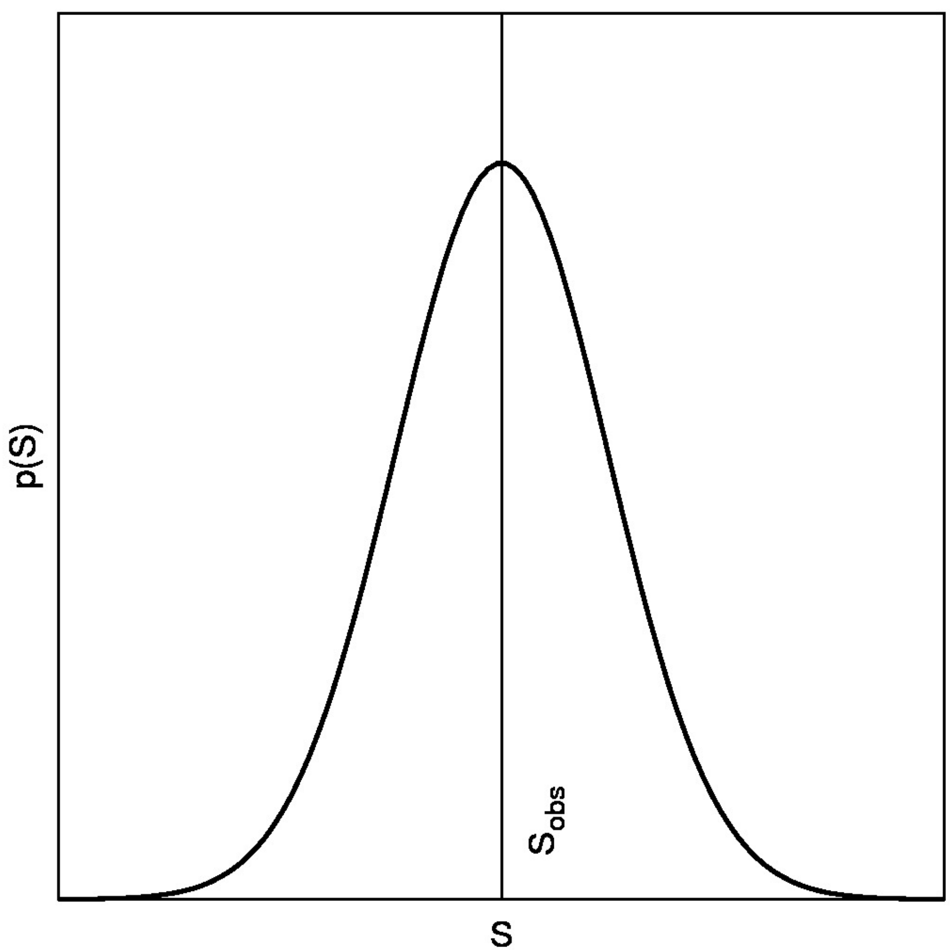




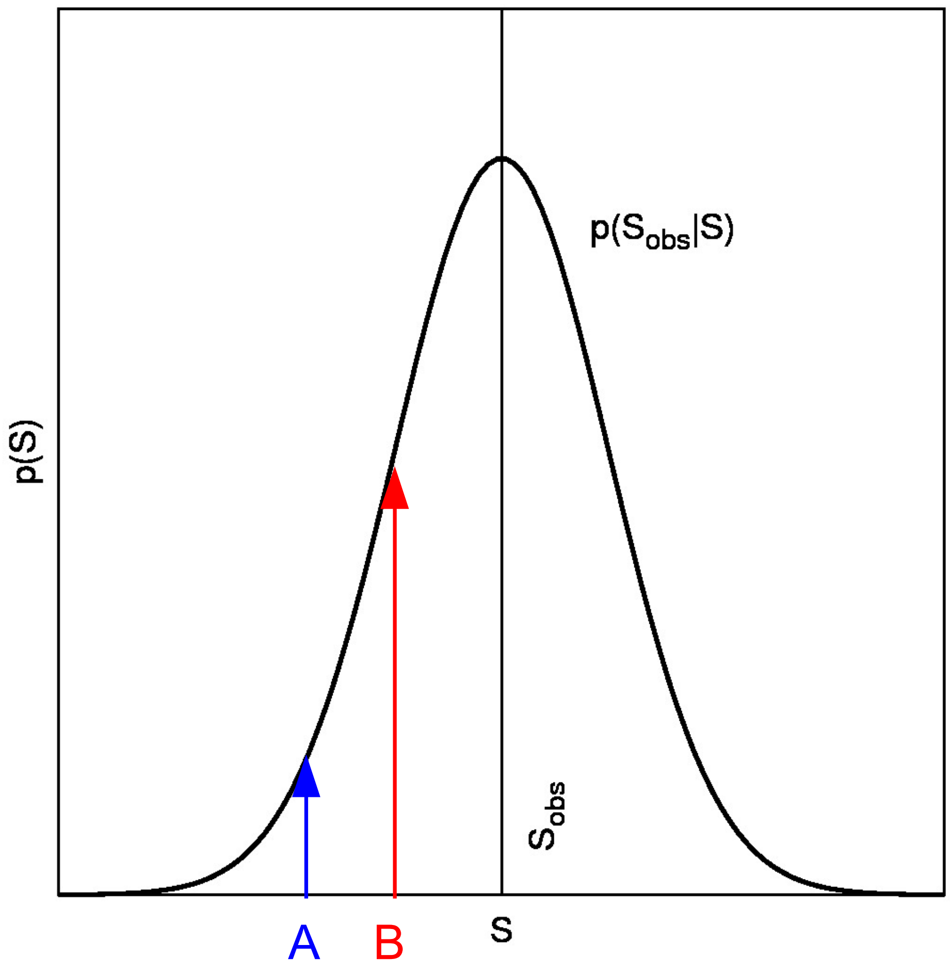
>4.1 Jy deg^{-2}
<4.1 Jy deg^{-2}
N(>Sν) [deg^{-2}]
S$_\nu$ [mJy]
10^5
10^4
10^3
10^2
10^1
1
10^{-1}
1
10^1

Measured a Flux S_{obs} with some uncertainty

What was the underlying flux producing the signal?



Measured a Flux S_{obs} with some uncertainty
What was the underlying flux producing the signal?

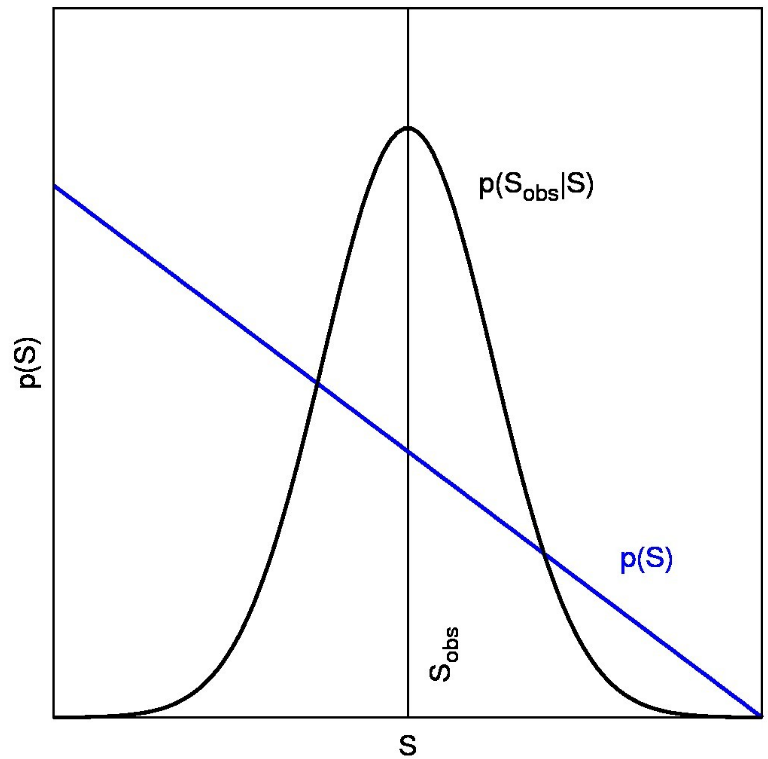


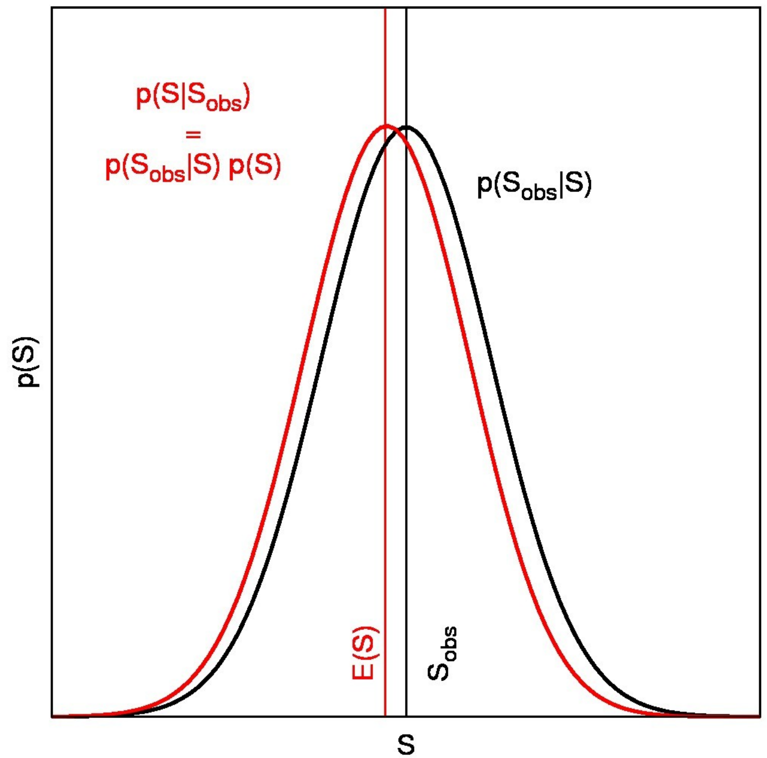
Meaning: Probability of measuring value of S_{obs}, **<u>if</u>** the true value is S

$$p(S|S_{obs}) \propto p(S_{obs}|S) \cdot p(S)$$

Deboosting

When the underlying flux distribution p(S) is skewed....





$$\mathbf{E}(S) \neq S_{\text{obs}}$$

A More pathological Case of deboosting...

$$p(S) \sim S^{-p}$$