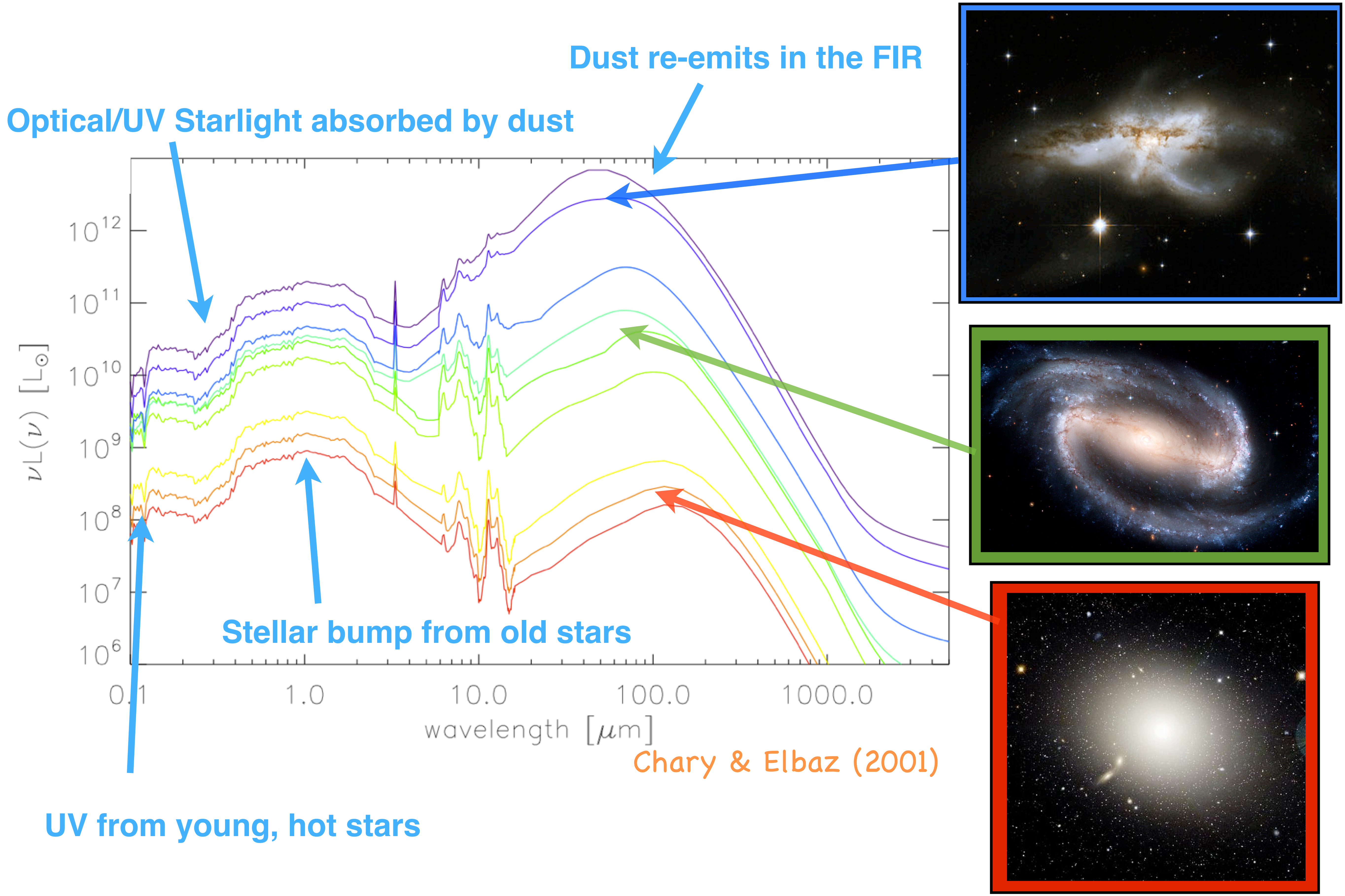
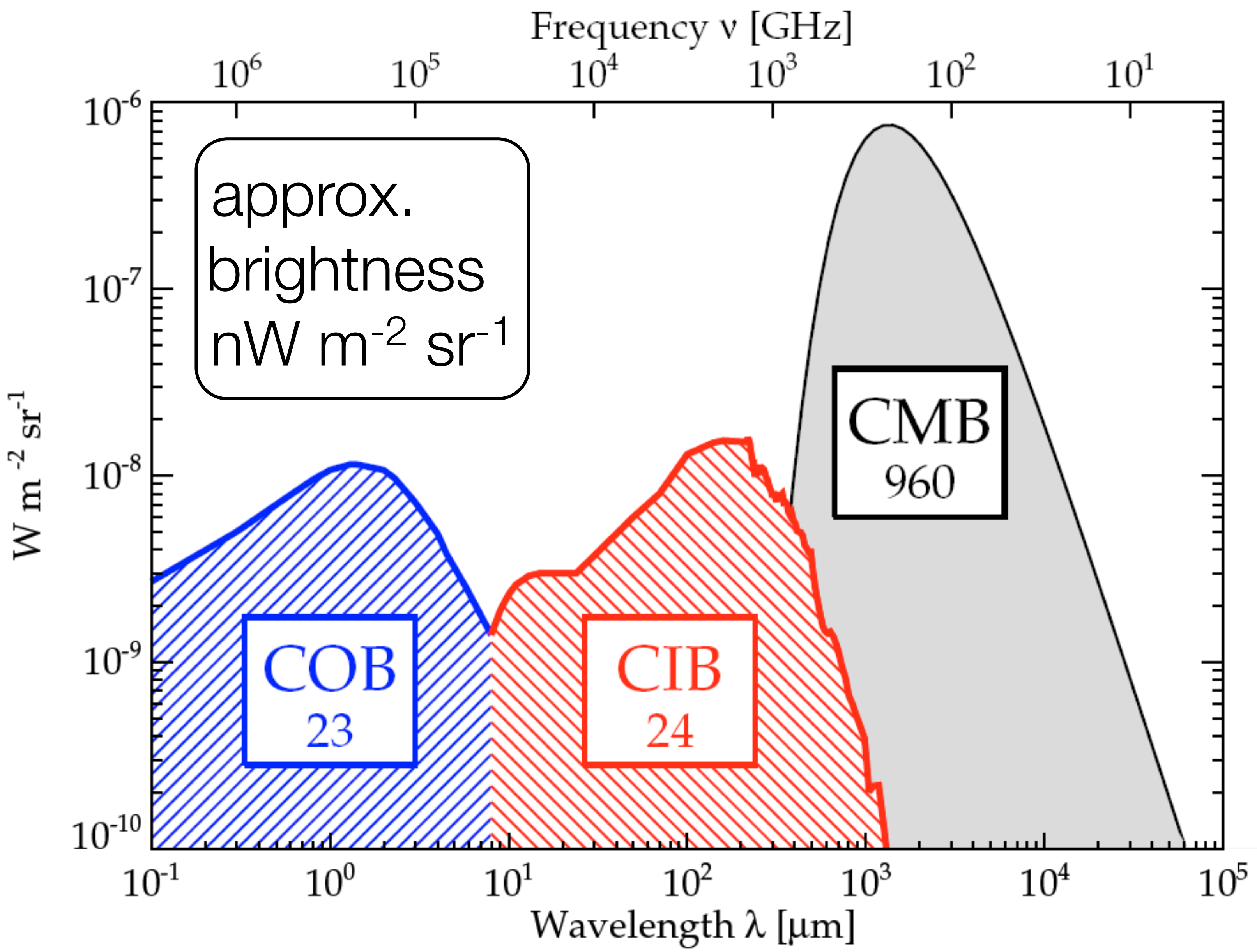
Dusty Galaxies

Berkeley CMB Lensing Workshop - April 2011

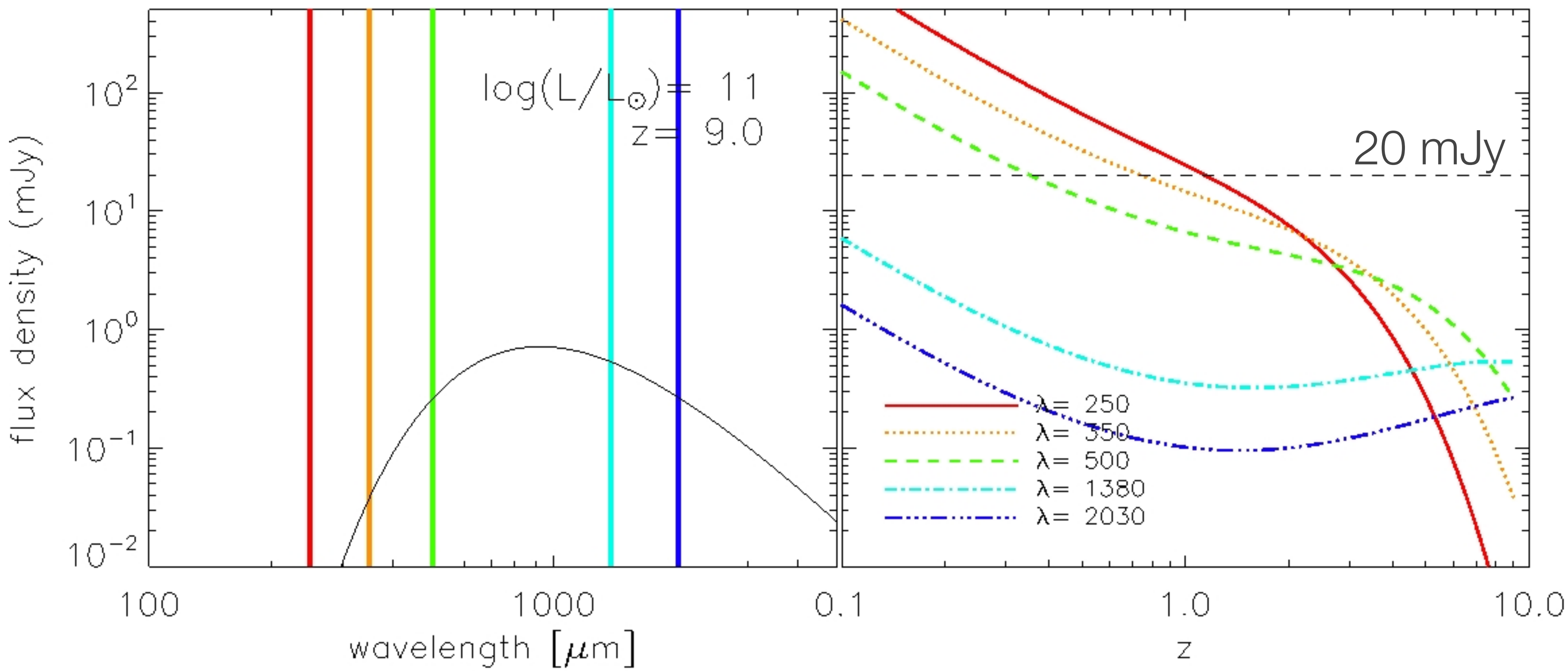
marco viero


Dust re-emits in the FIR
Optical/UV Starlight absorbed by dust
Stellar bump from old stars
UV from young, hot stars
Chary & Elbaz (2001)
$\nu L(\nu)\ [L_\odot]$
wavelength $[\mu m]$
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
0.1
1.0
10.0
100.0
1000.0



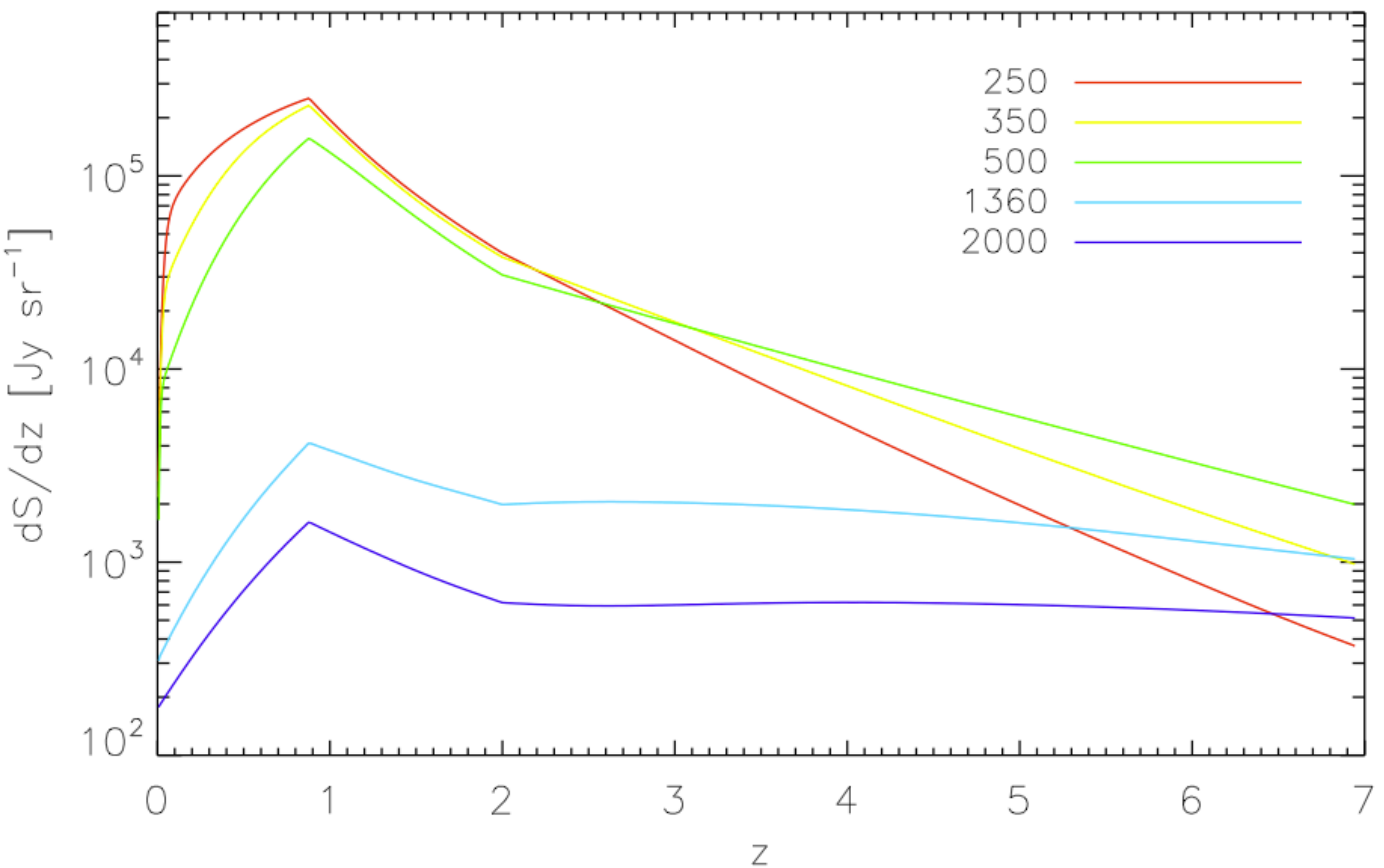
Dole et al. 2006

Extragalactic Background Light (EBL)



Negative K-correction

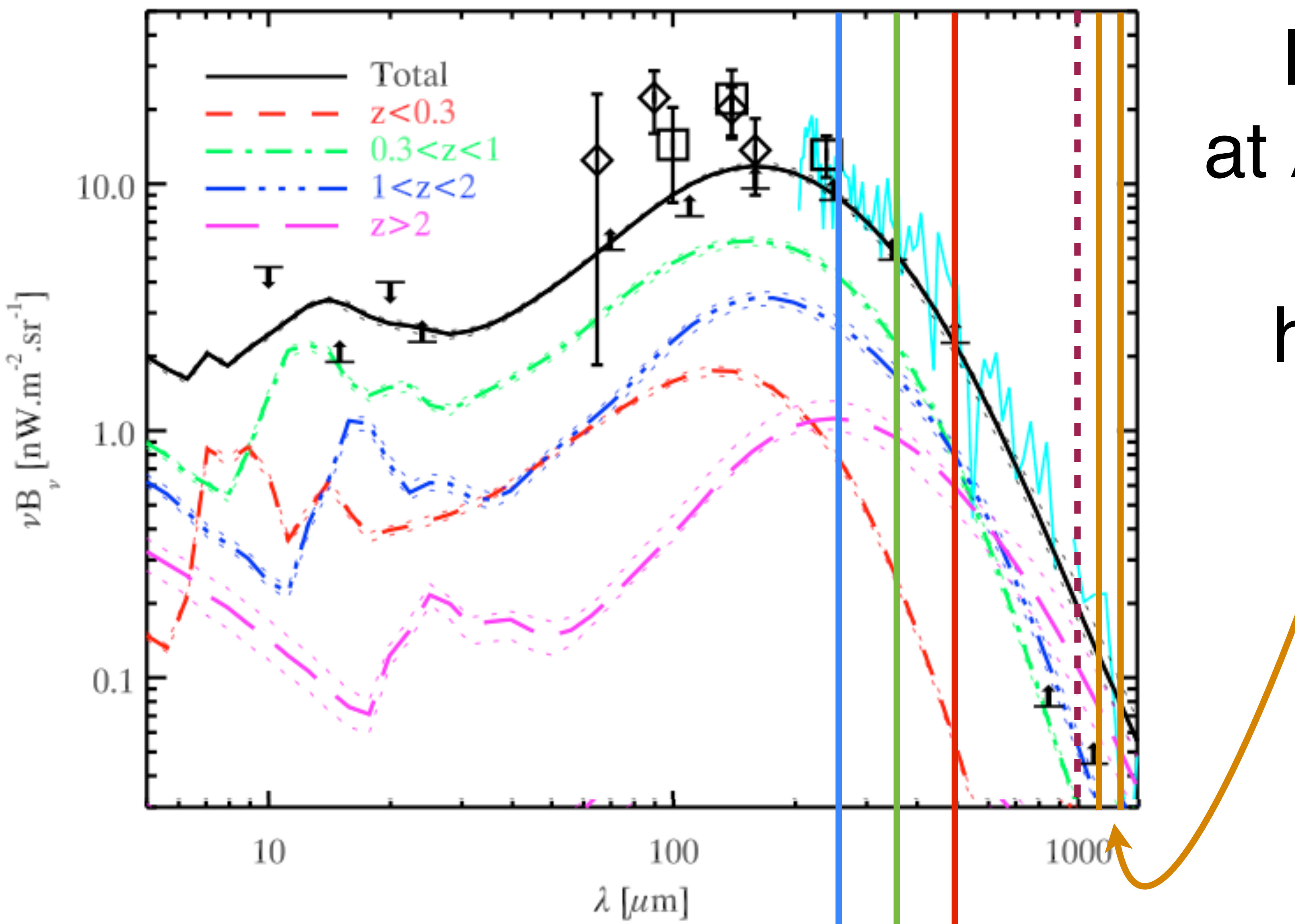
get this data @ http://www.ias.u-psud.fr/irgalaxies/model.php#Counts



Béthermin et al. (2011)
arXiv:1010.1150

Redshift Distribution

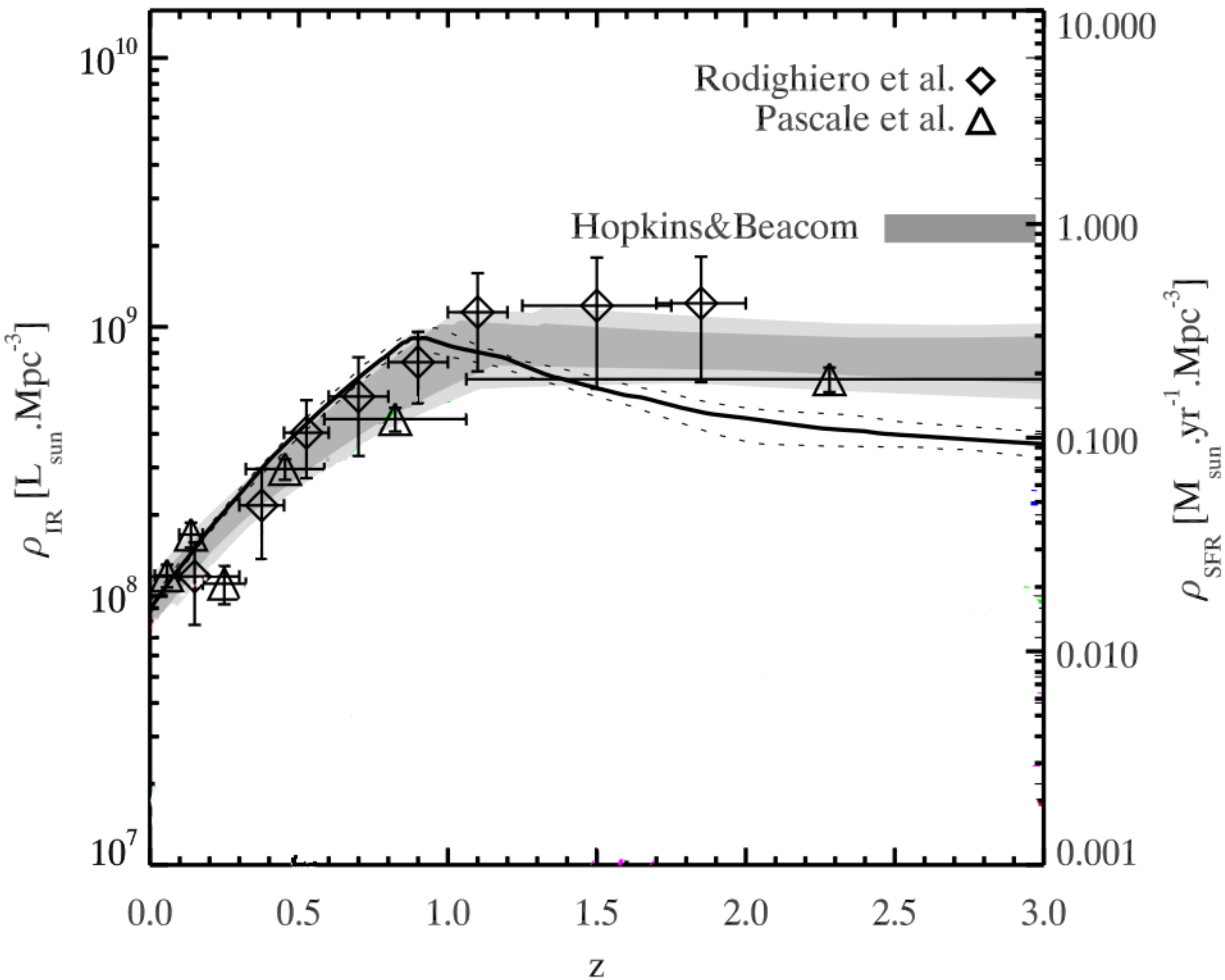
Total Infrared Background



Béthermin et al. (2011)
arXiv:1010.1150

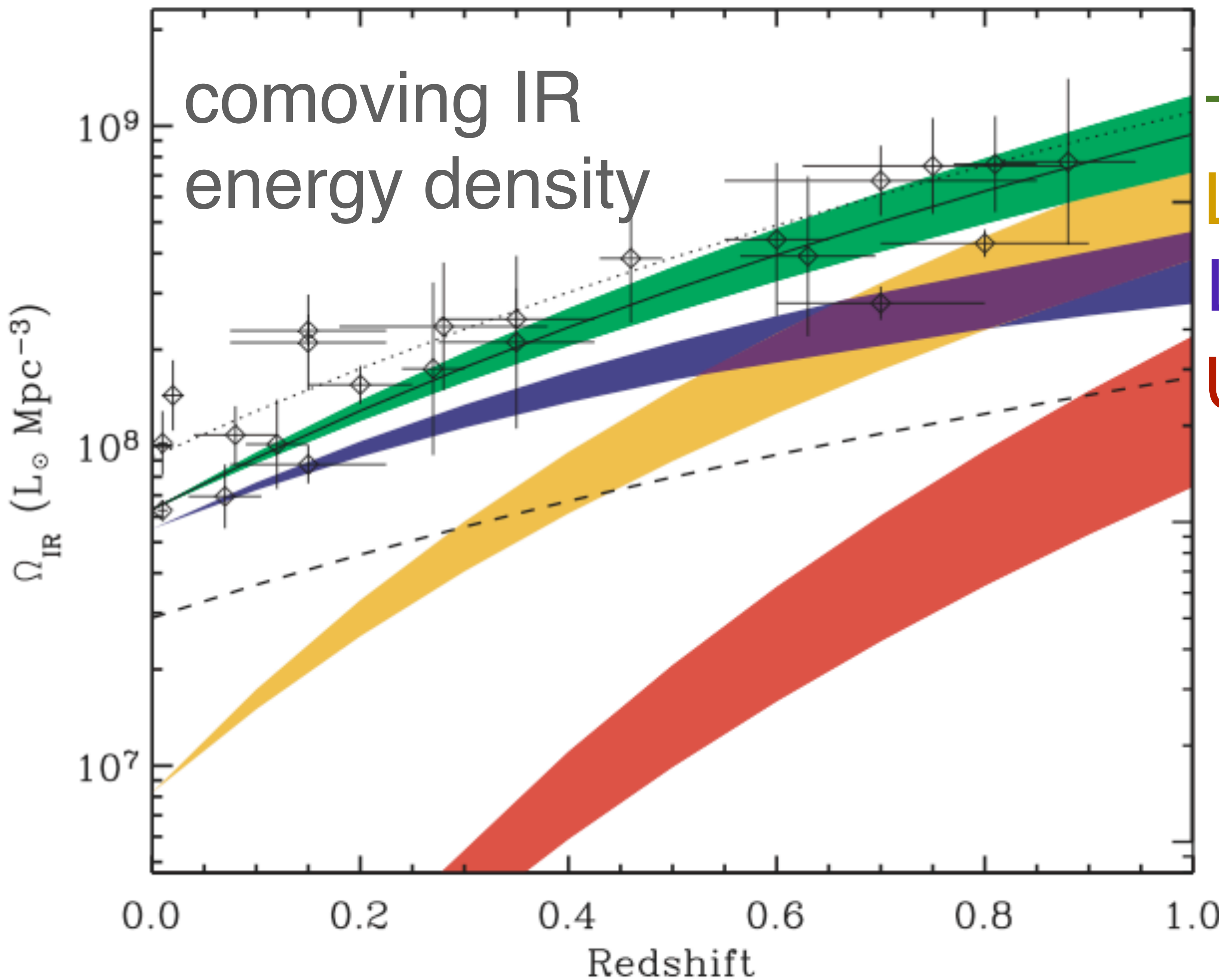
Infrared Background
at λ > 1 mm (< 300 GHz)
dominated by
high-redshift sources

CMB bands at
220 GHz (1.4 mm)
148 GHz (2 mm)



Béthermin et al. (2011)
arXiv:1010.1150

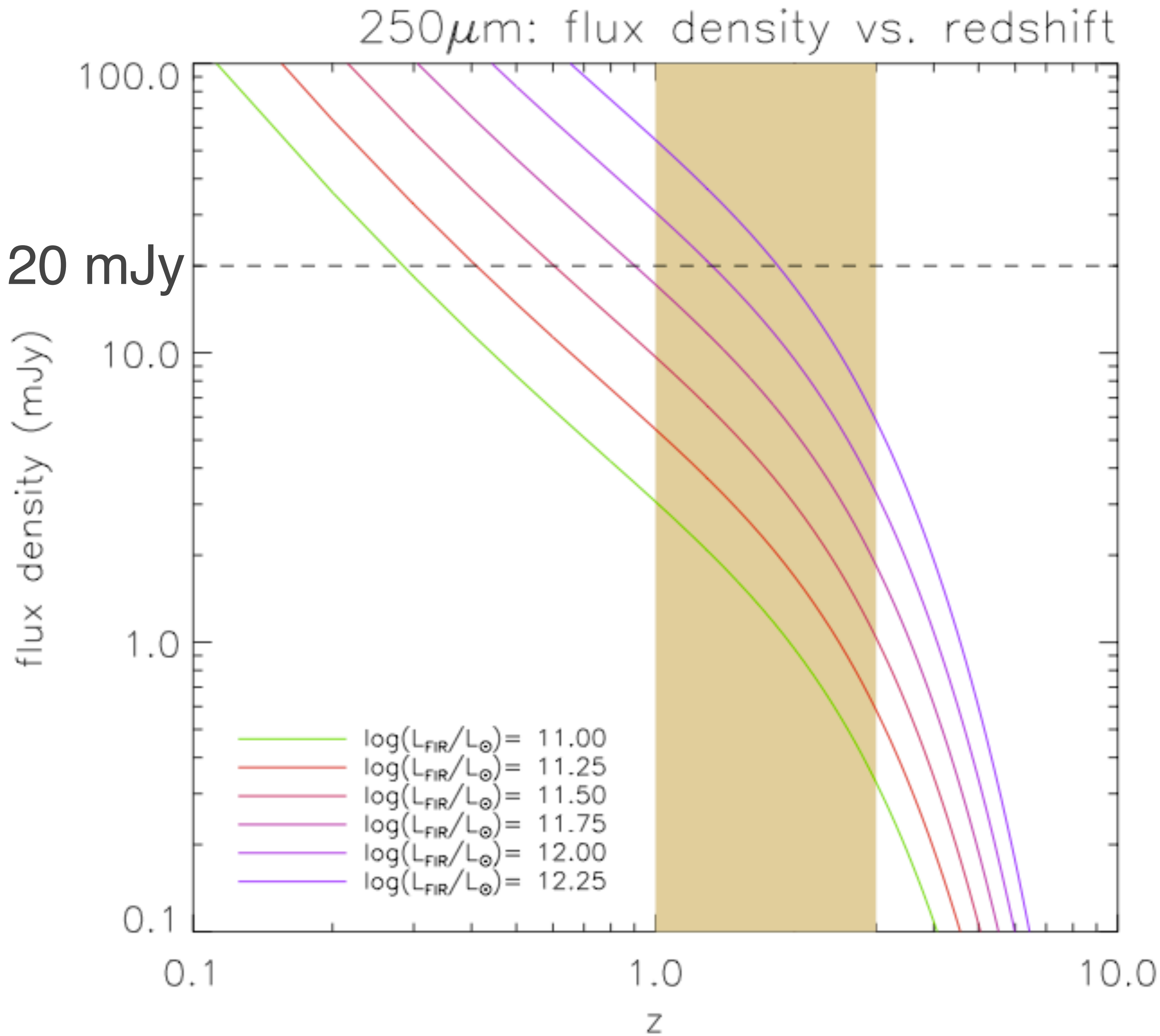
Star Formation History



Le Floc'h et al. (2005)

Most of that Star Formation occurs in LIRGS, i.e.: $L_{FIR}=10^{11}$-10^{12} M_{sun}

What are they?



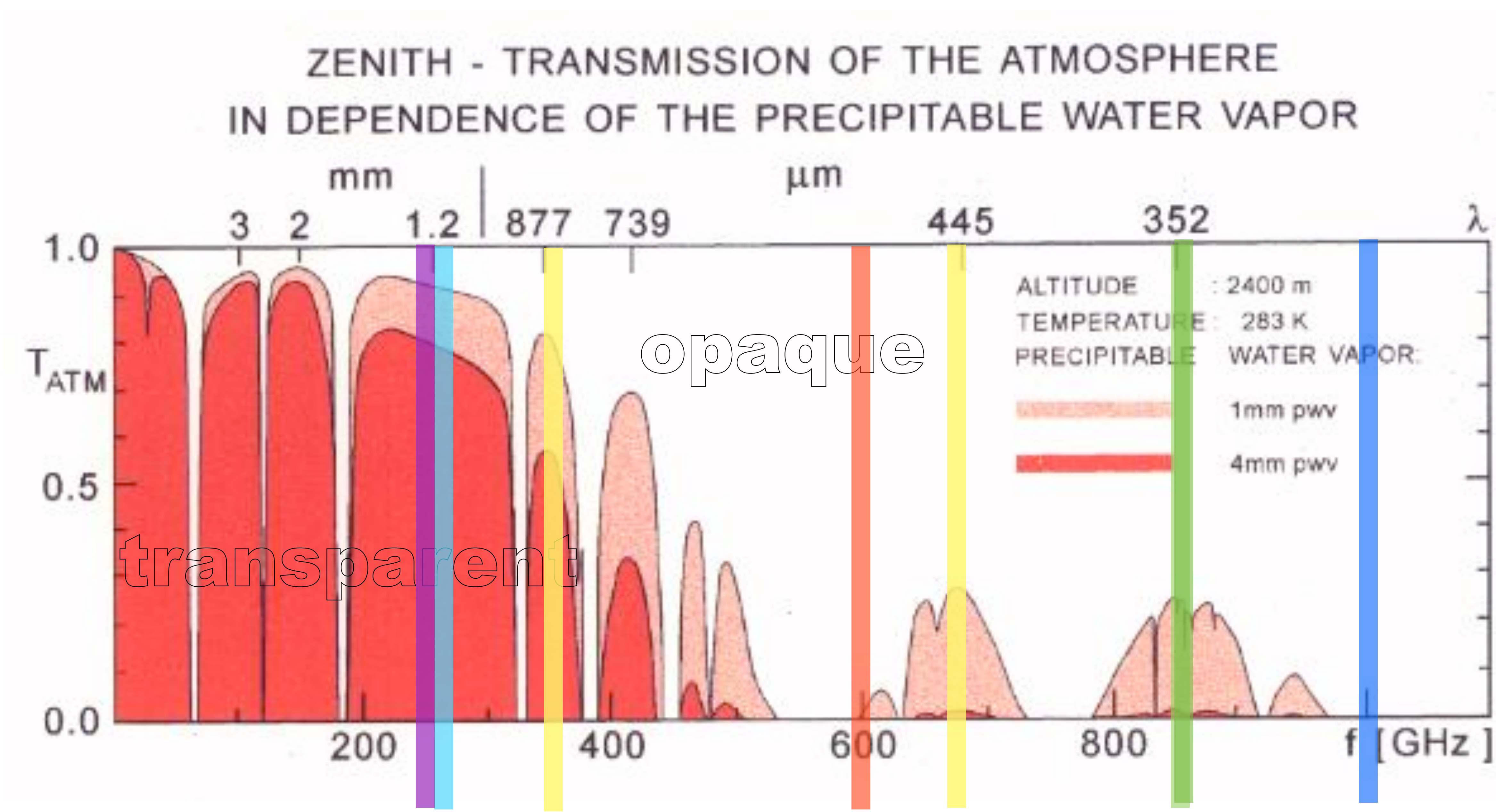
Typical LIRGS at z~1-3 have flux densities S_{250} ~ 1-10 mJy

What are they?

BIG QUESTIONS

1. How many are there?
2. Where are they?

Observing in the submillimeter

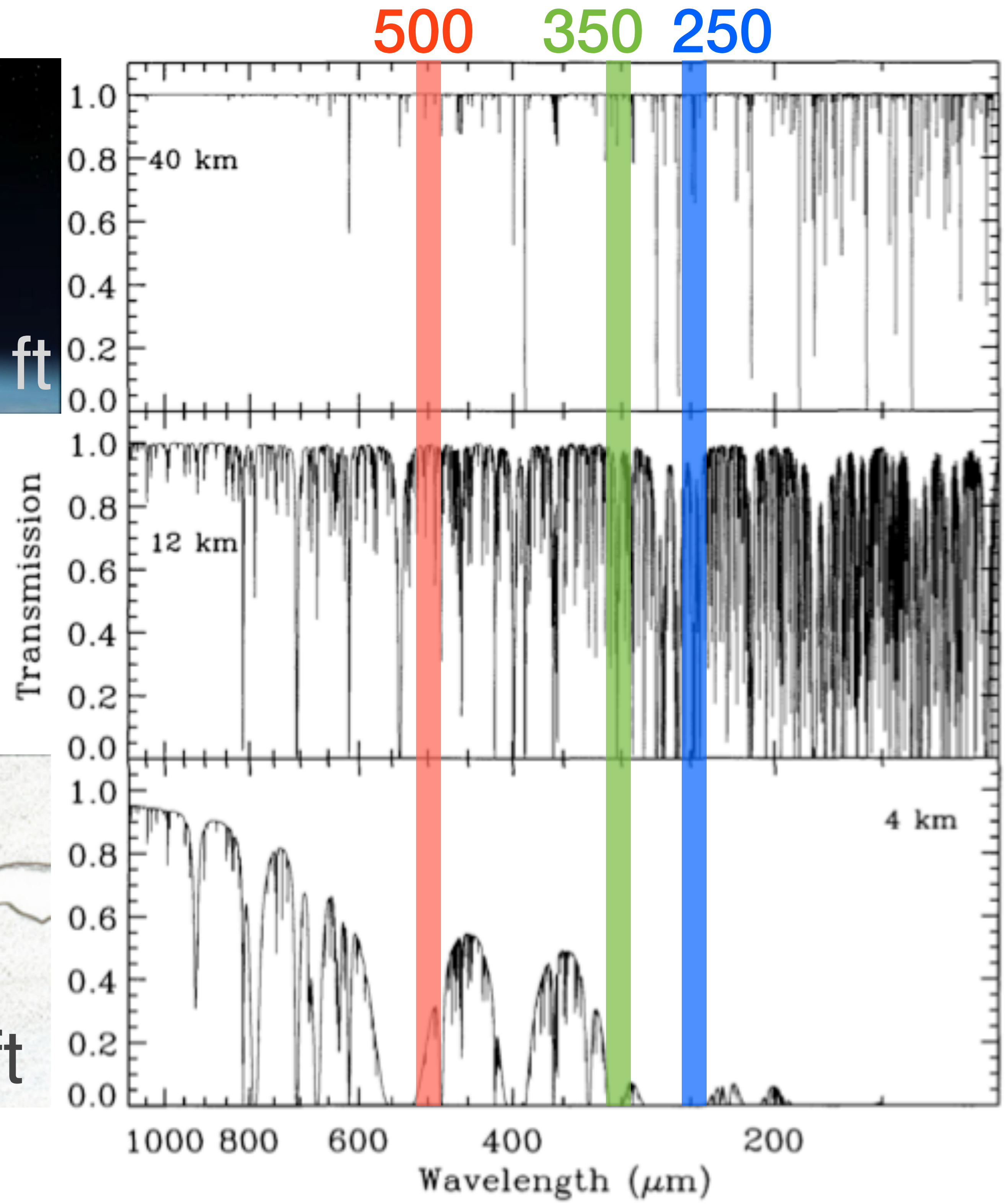


MAMBO
AzTEC
SCUBA
500
SHARC
350
250

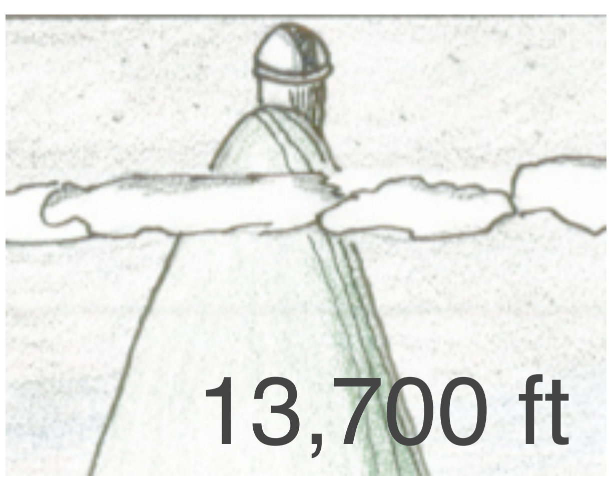
Submm Observations

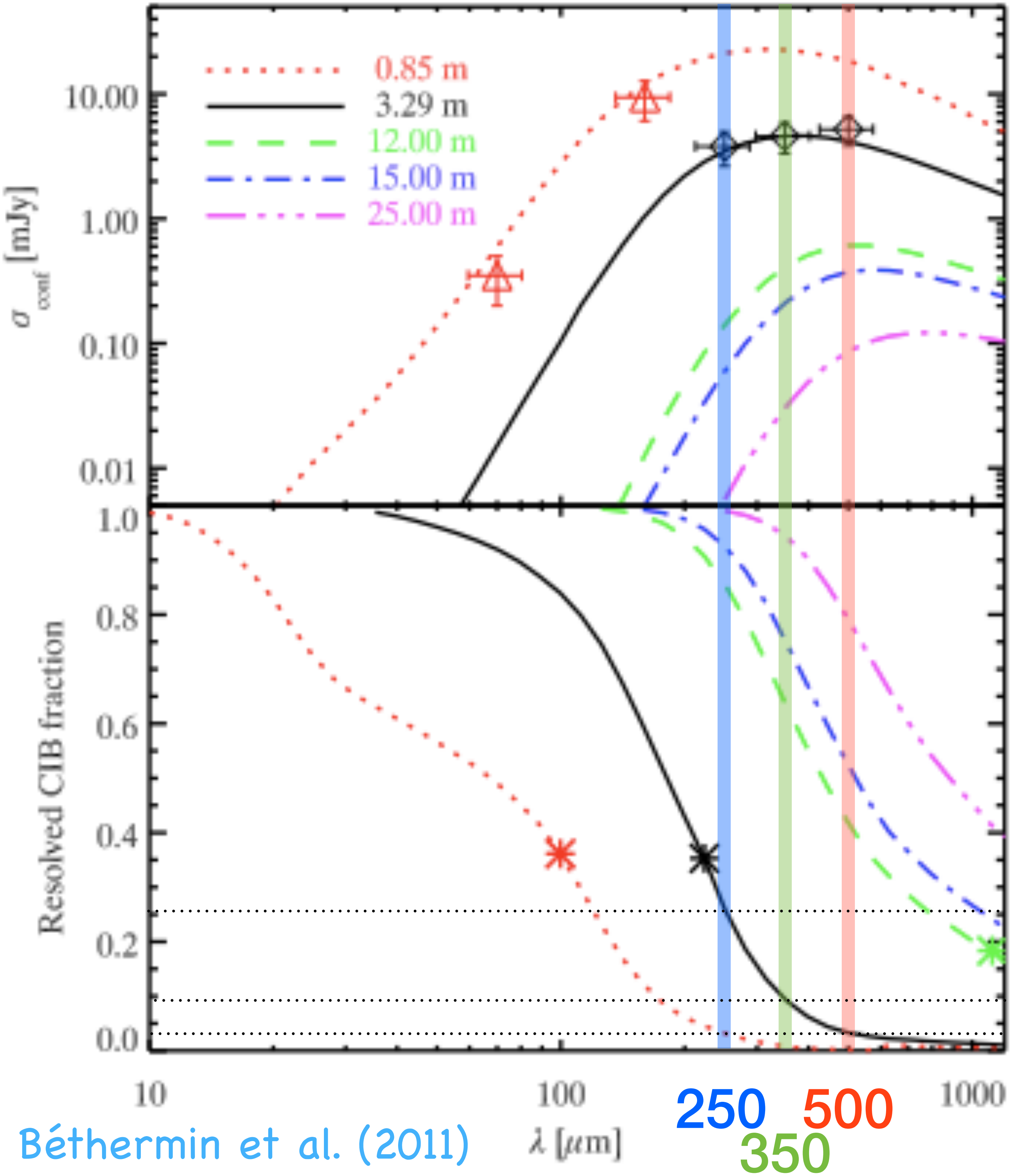

137,000 ft


HERSCHEL


500
350
250
Transmission
1.0
0.8
0.6
0.4
0.2
0.0
40 km
12 km
4 km
1000 800 600 400 200
Wavelength (μm)


41,000 ft

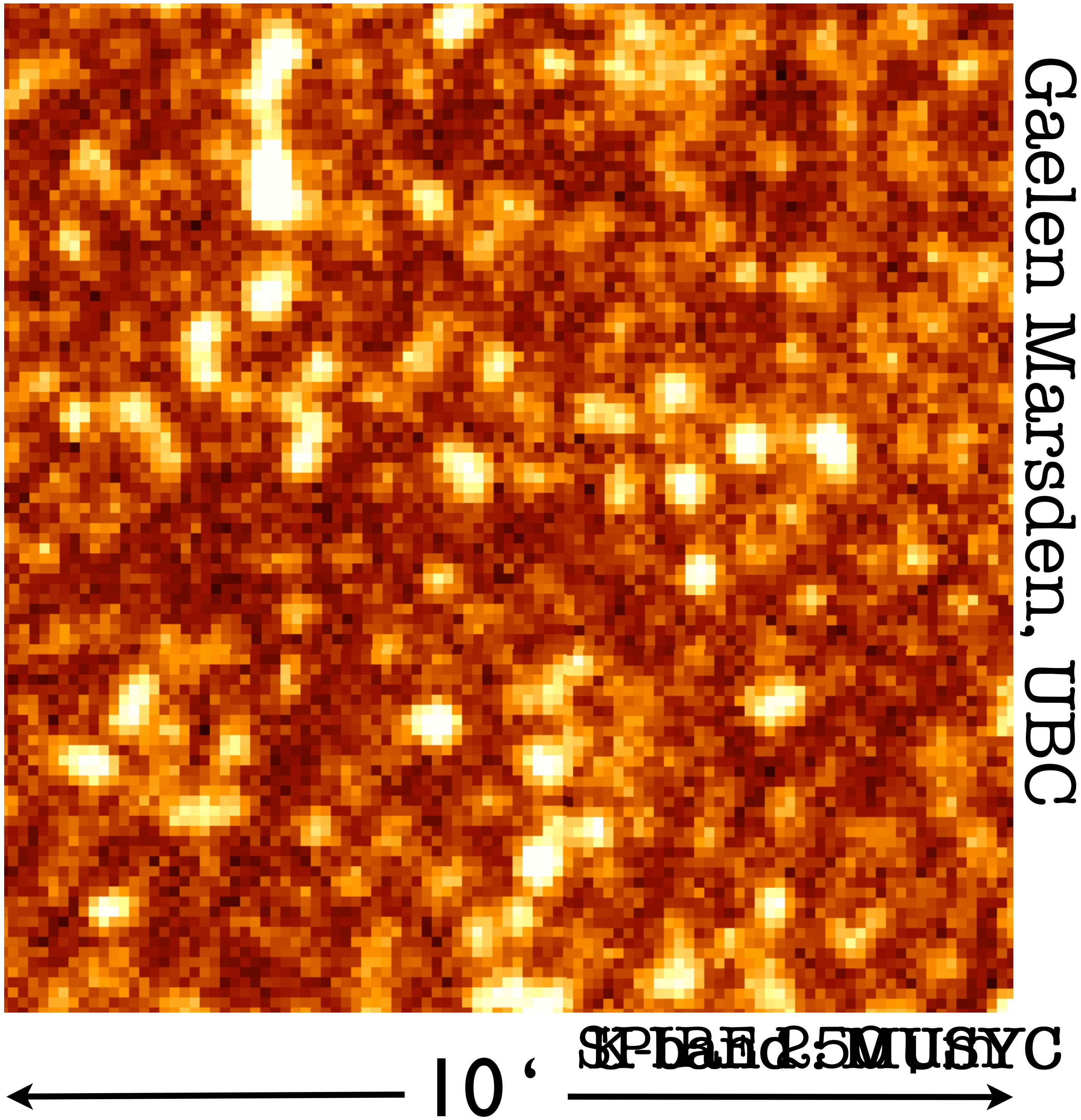

13,700 ft



Spitzer (Frayer 2009)
Herschel (Nguyen 2010)
APEX
CSO
CCAT

Béthermin et al. (2011)
arXiv:1010.1150

Confusion



U-band

~ 60 sources/arcmin²

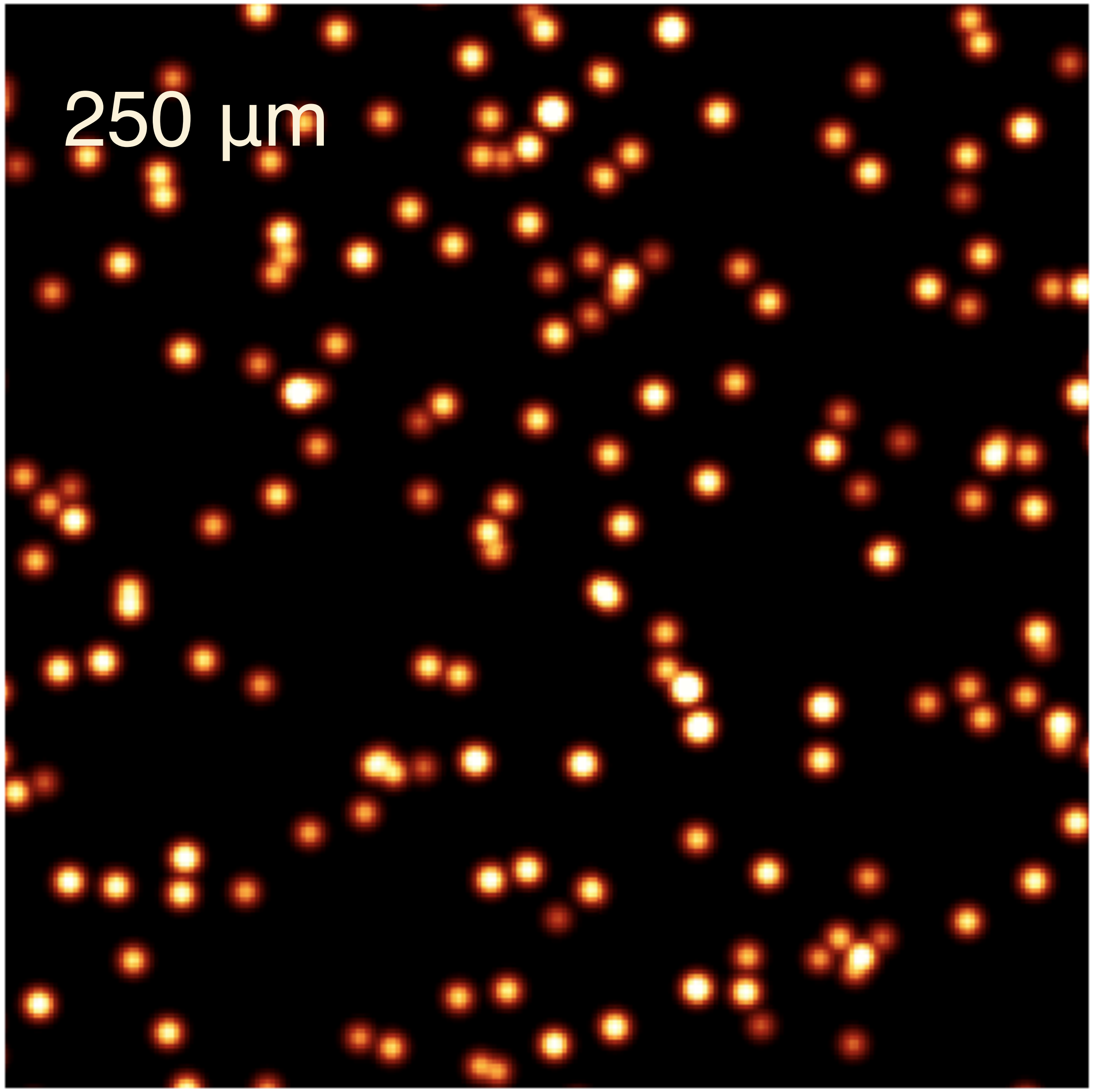
K-band

~ 45 sources/arcmin²

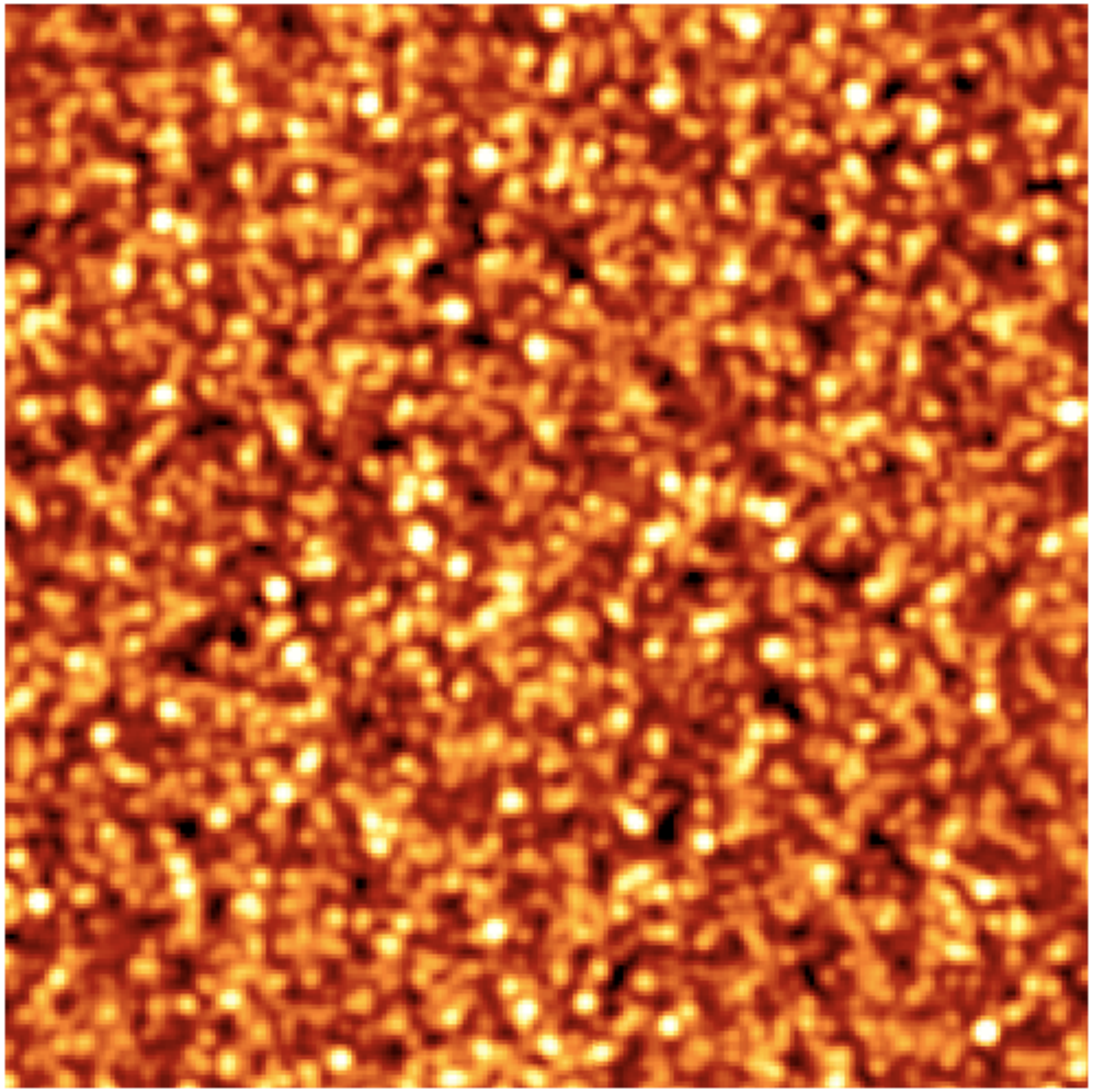
SPIRE

~ 0.5 sources/arcmin²

Confusion

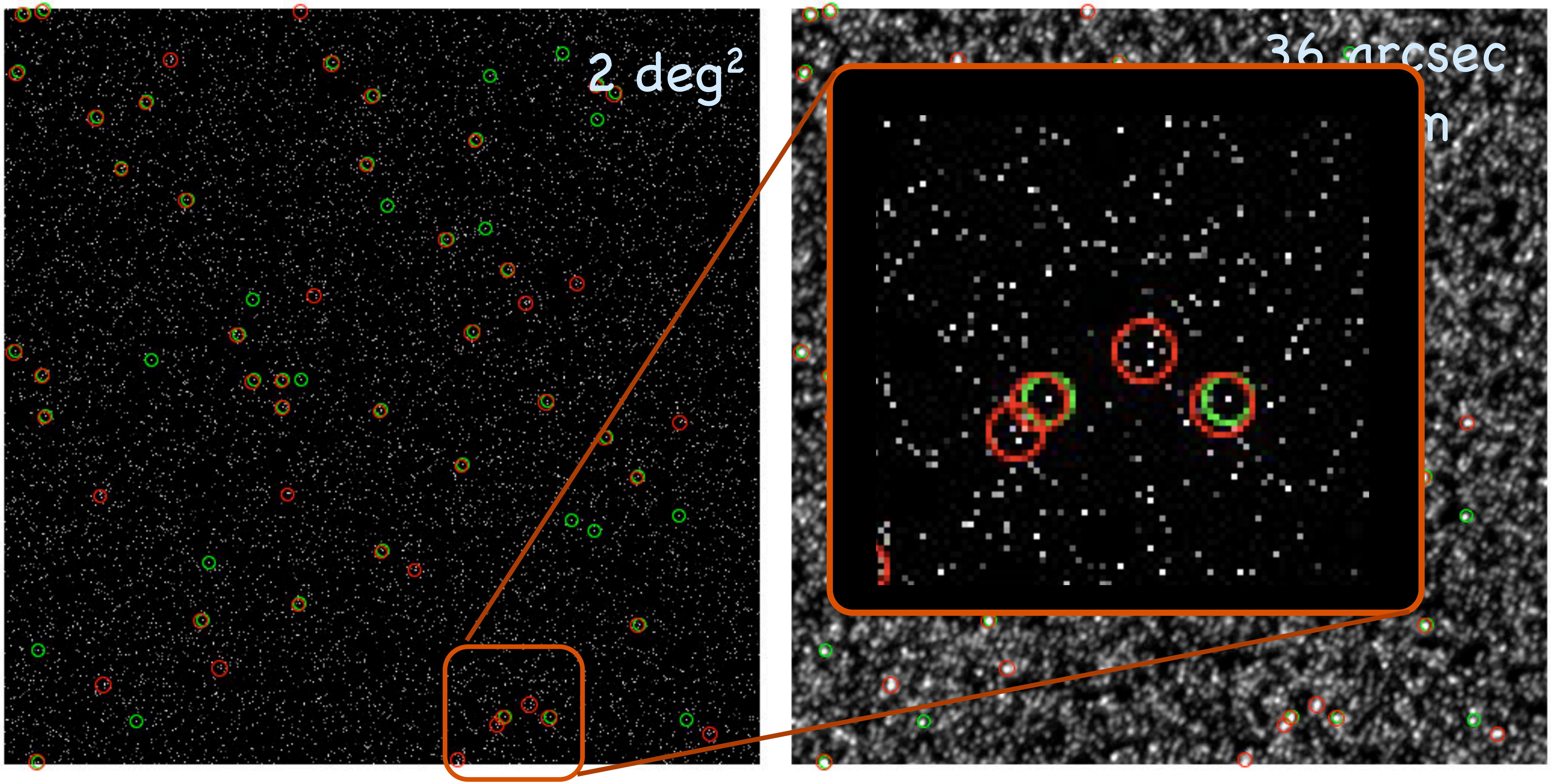


S > 20 mJy : 1,200/deg^2



S < 20 mJy : 480,000/deg^2

Confusion



50 brightest (top 0.5%)

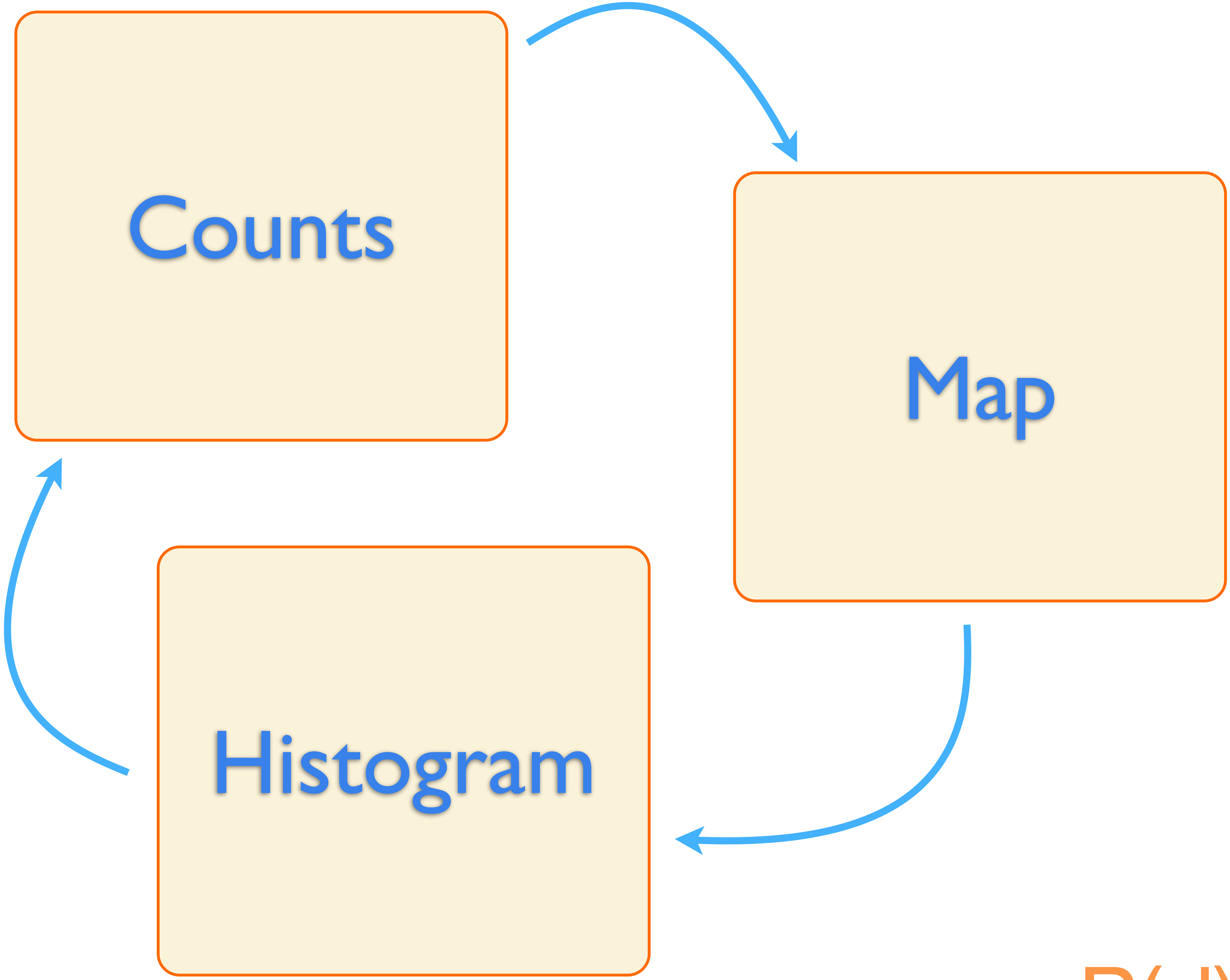
70% of top 0.5% recovered

50 brightest recovered

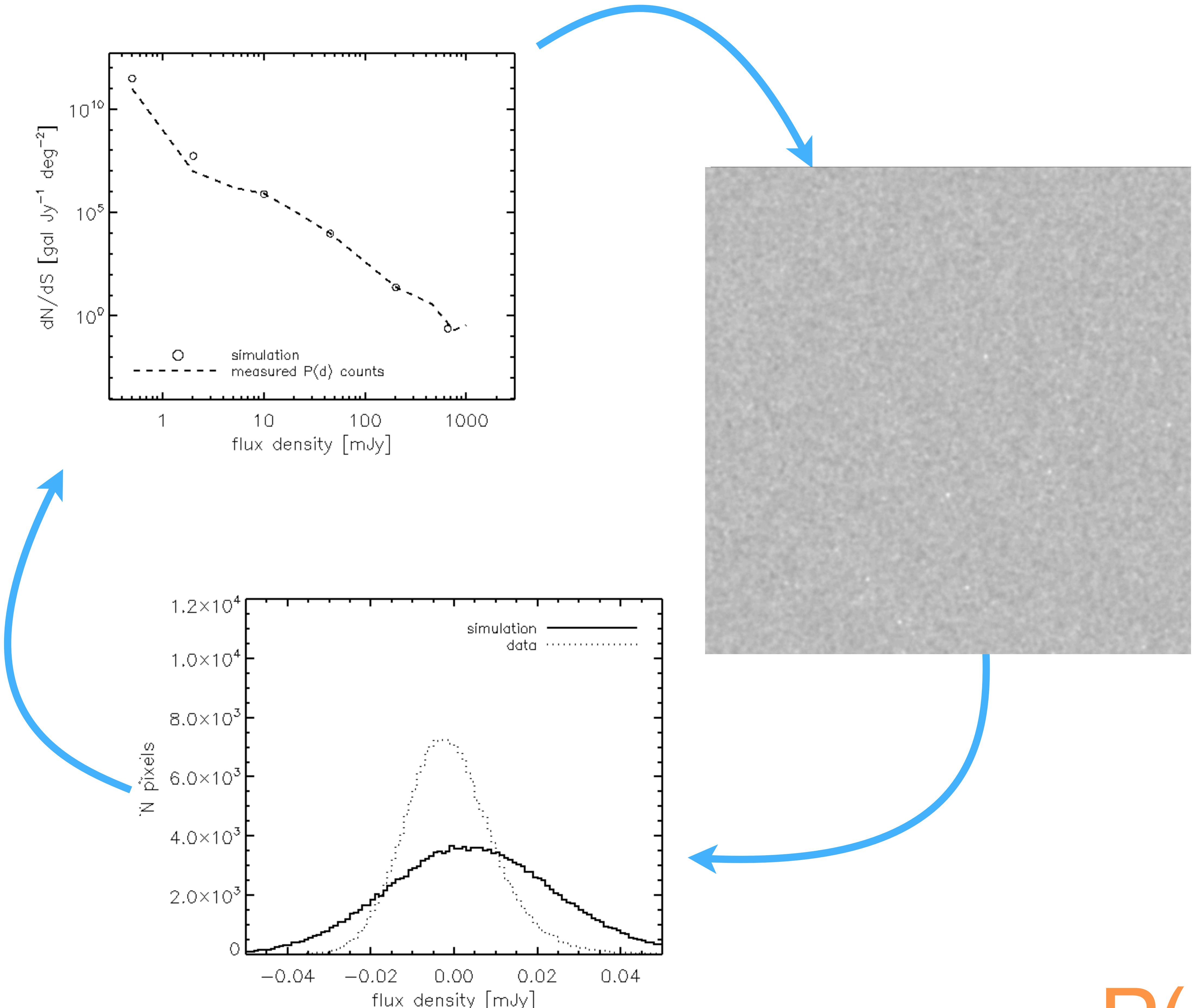
Confusion

1. How many are there?

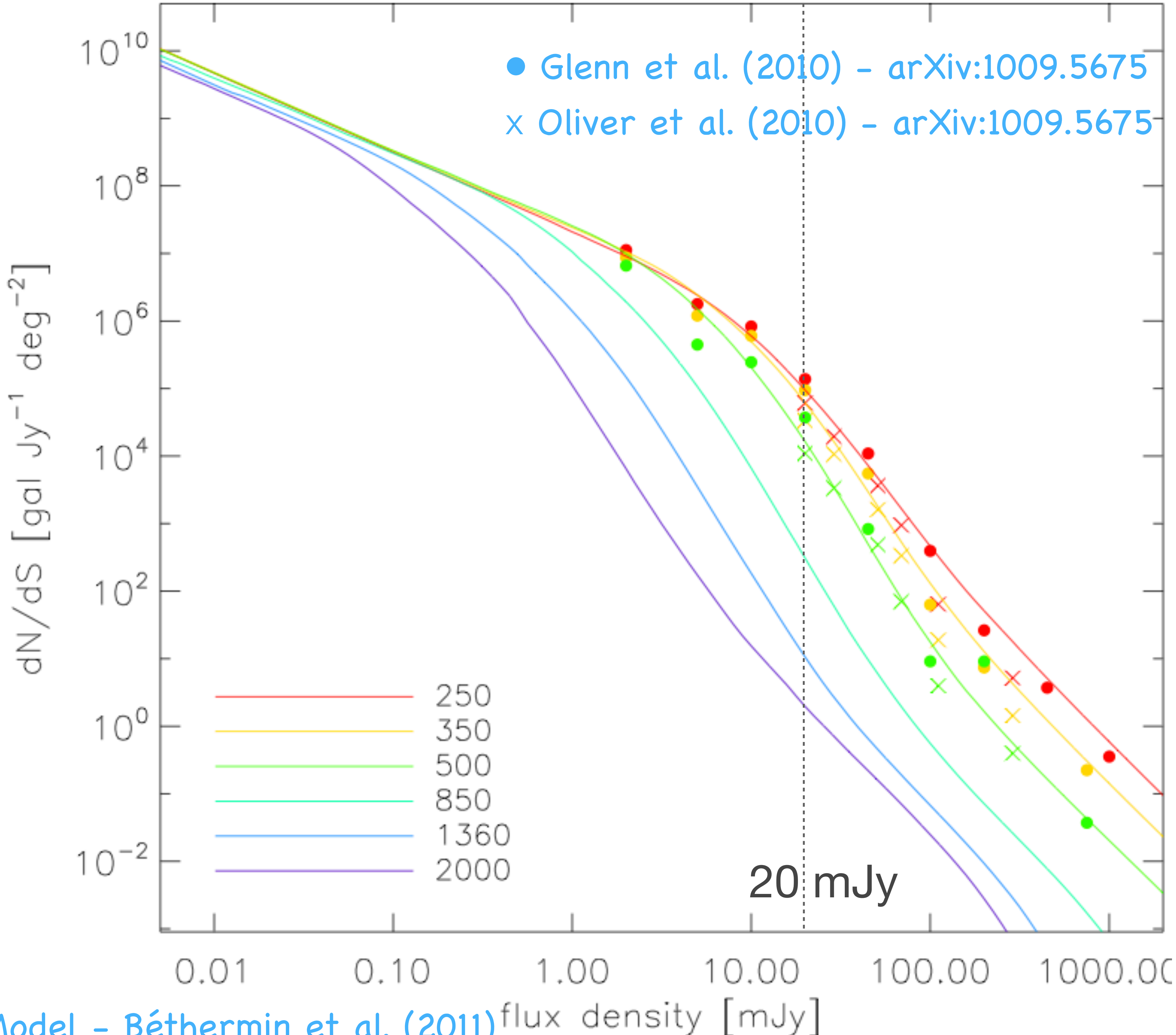
How do you count sources without sources to count?



P(d)

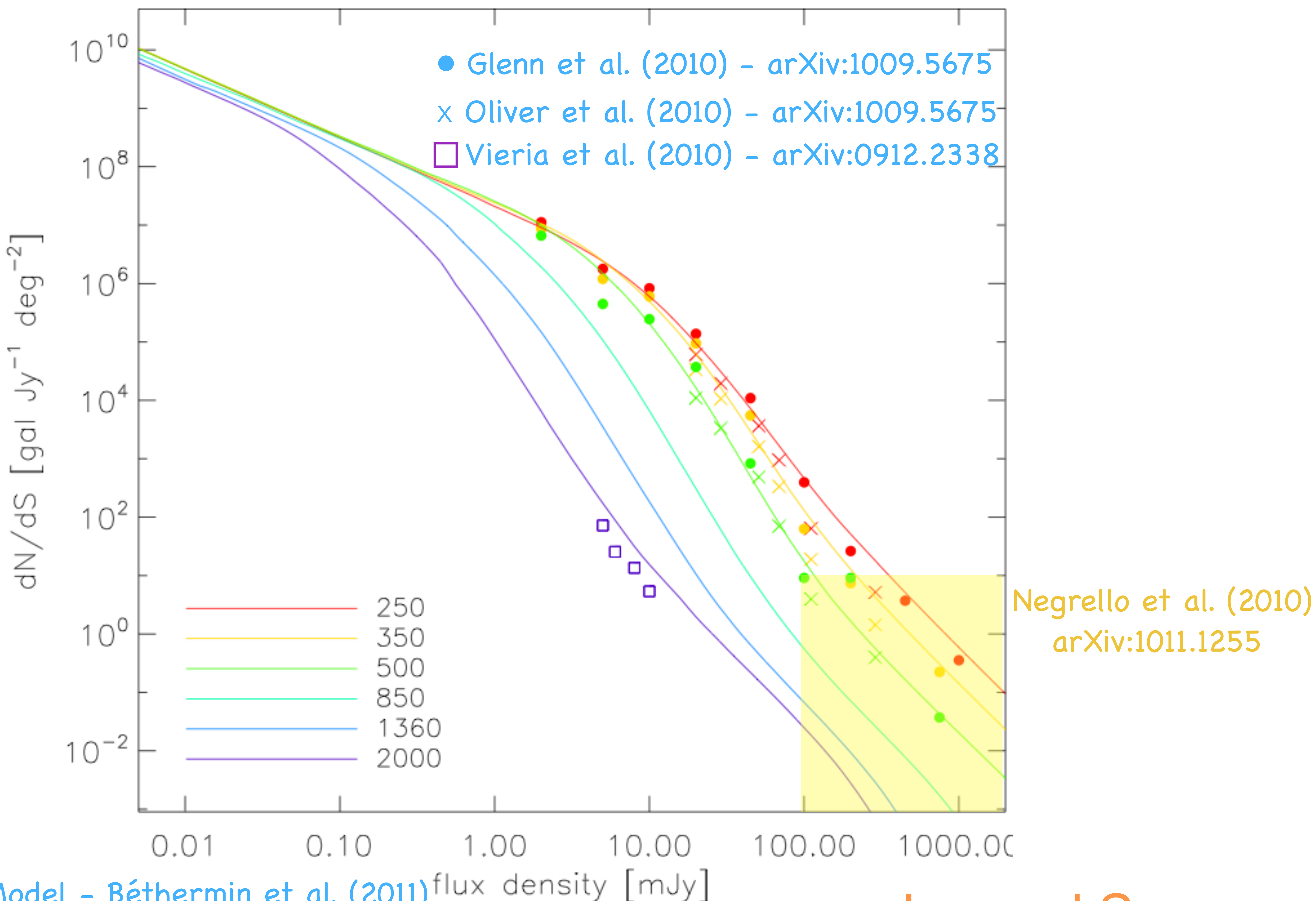

dN/dS [gal Jy^{-1} deg^{-2}]
10^{10}
10^{5}
10^{0}
simulation
measured P(d) counts
1
10
100
1000
flux density [mJy]
1.2×10^{4}
1.0×10^{4}
8.0×10^{3}
6.0×10^{3}
4.0×10^{3}
2.0×10^{3}
0
N pixels
simulation
data
−0.04
−0.02
0.00
0.02
0.04
flux density [mJy]

P(d)



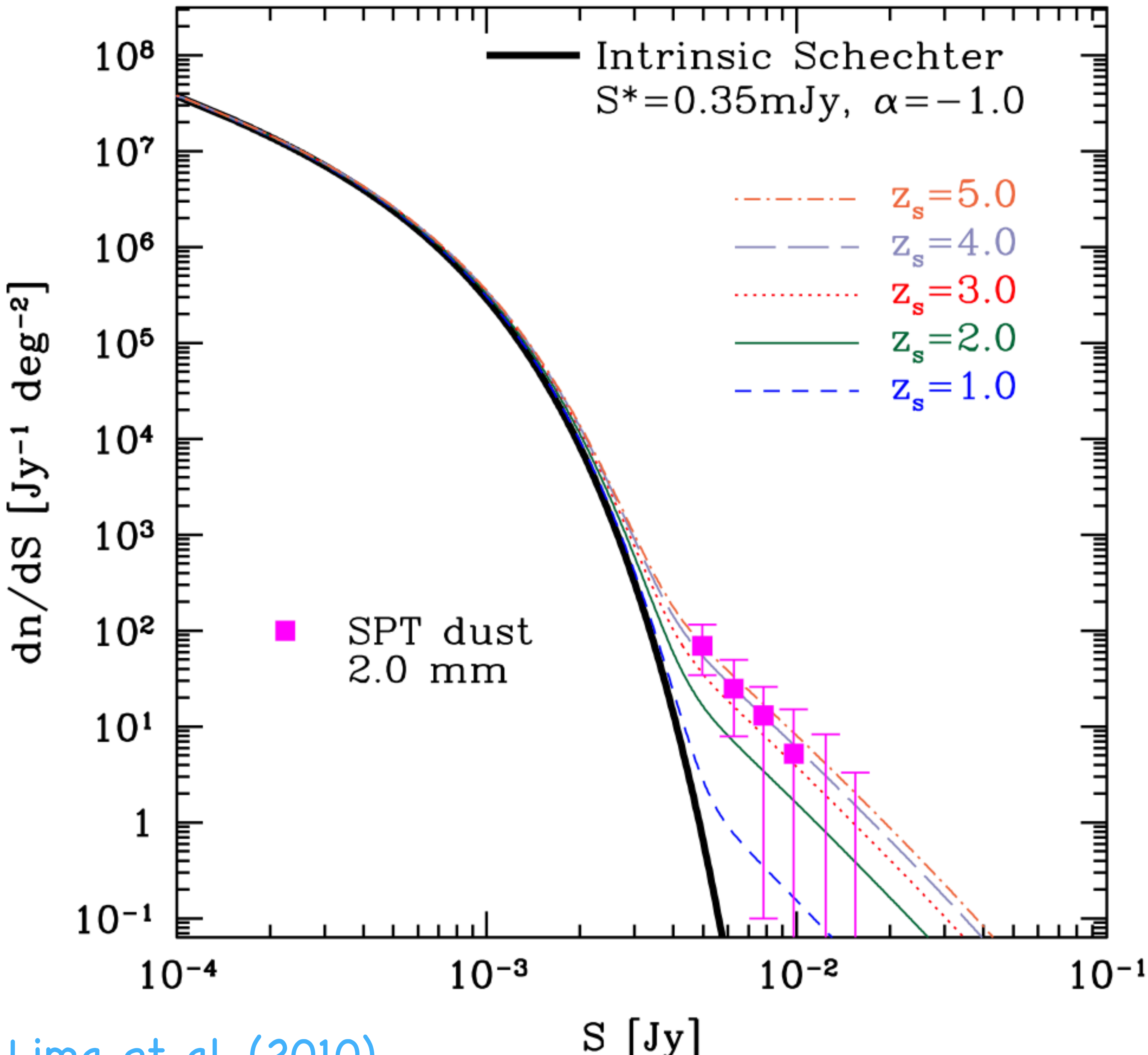
Model - Béthermin et al. (2011)
arXiv:1010.1150

Measured Number Counts



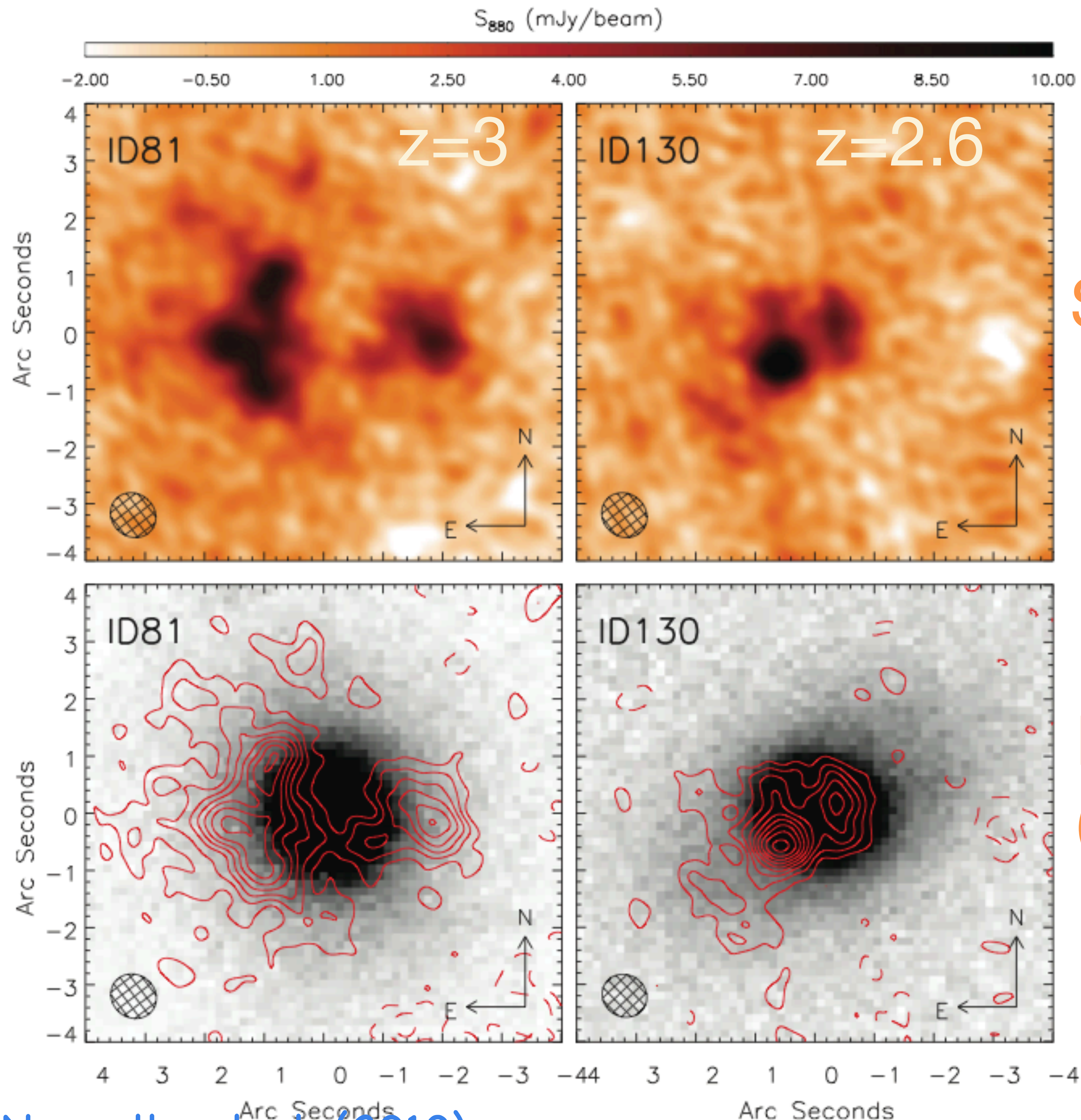
Model - Béthermin et al. (2011)
arXiv:1010.1150

Lensed Sources



Lima et al. (2010)
arXiv: 1004.4889

Lensed Sources

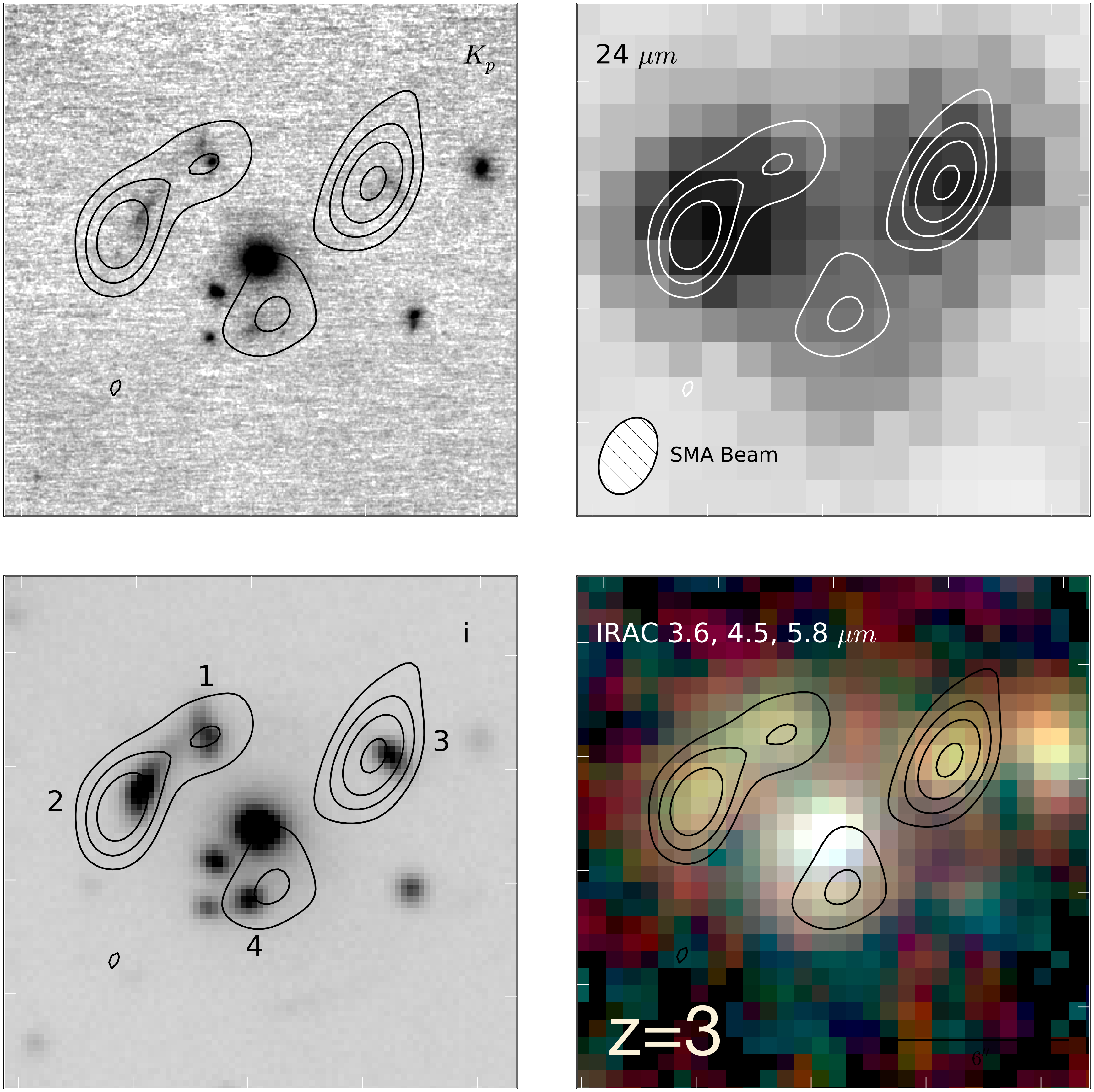


SMA

Keck i-band
(SMA contours)

Negrello et al. (2010)
arXiv:1011.1255

Lensed Sources



Strong Detections:

PdBI: CO(J=5→4)

CARMA: CO(J=3→2)

GBT: CO(J=1→0)

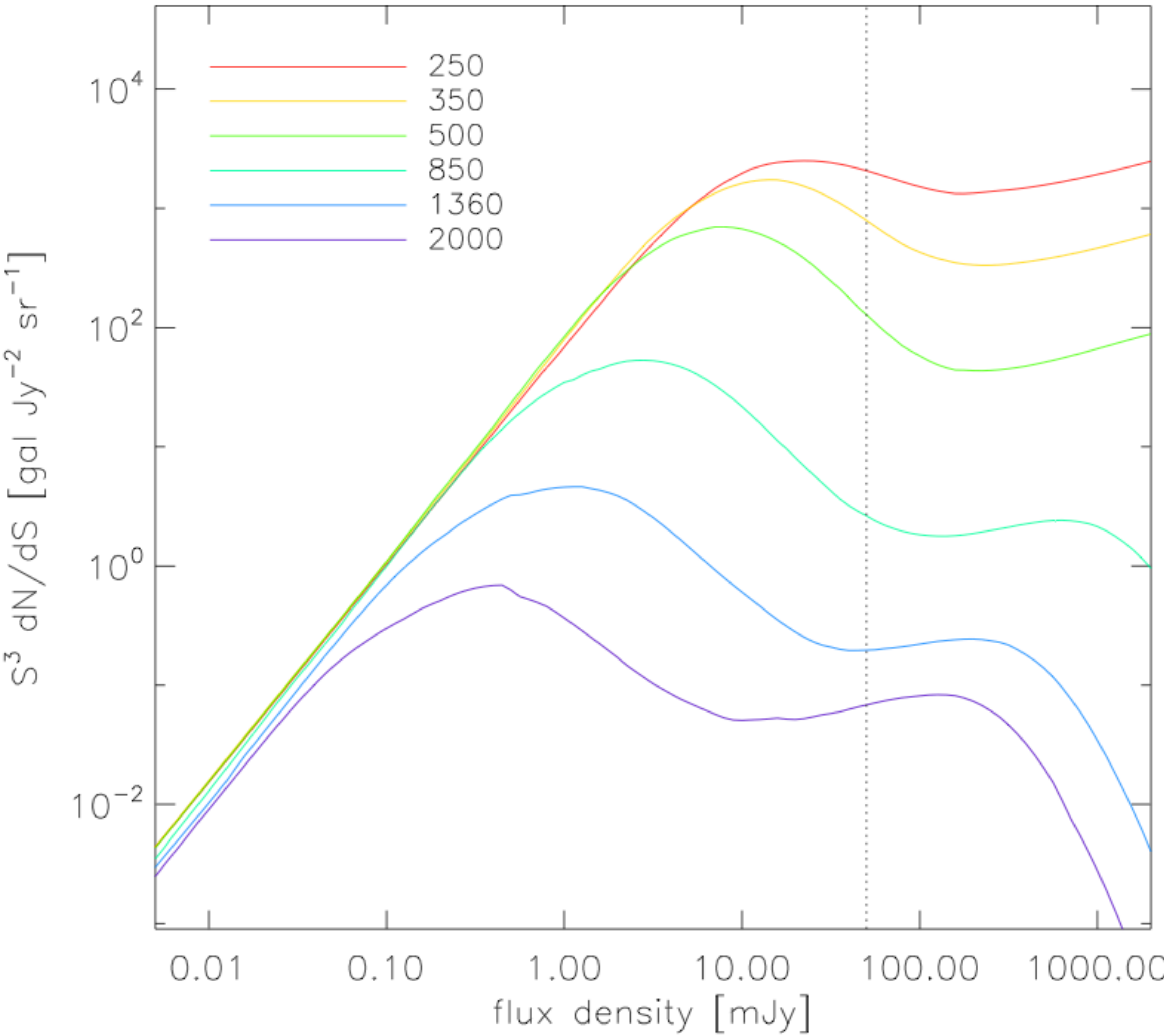
Riechers et al. (2011)
arXiv: 1104.4116

Lensed Sources

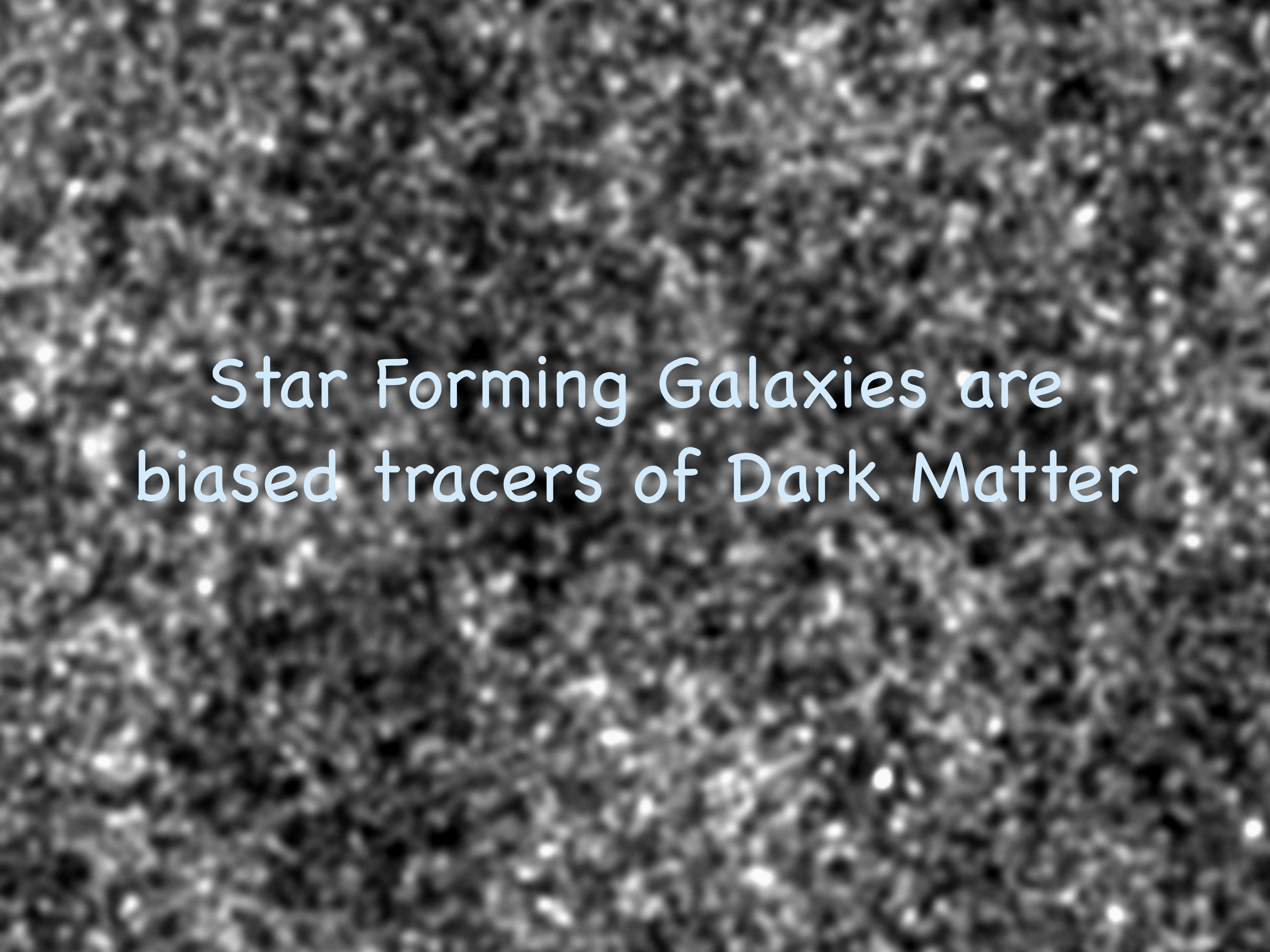
3. Where are they?

How do you measure clustering when most of what you see are fluctuations?

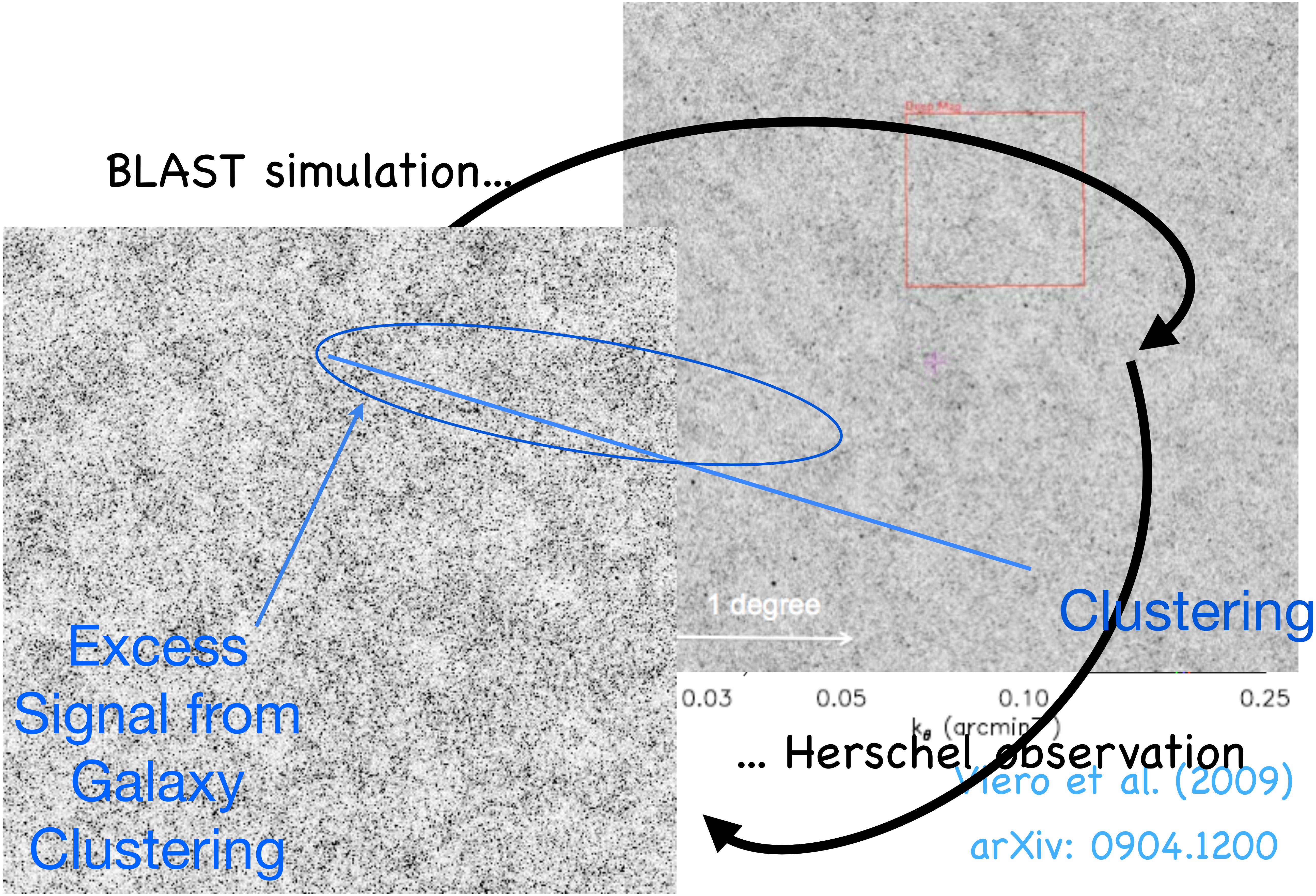
$$P_{shot}=S^2 dN/dS$$



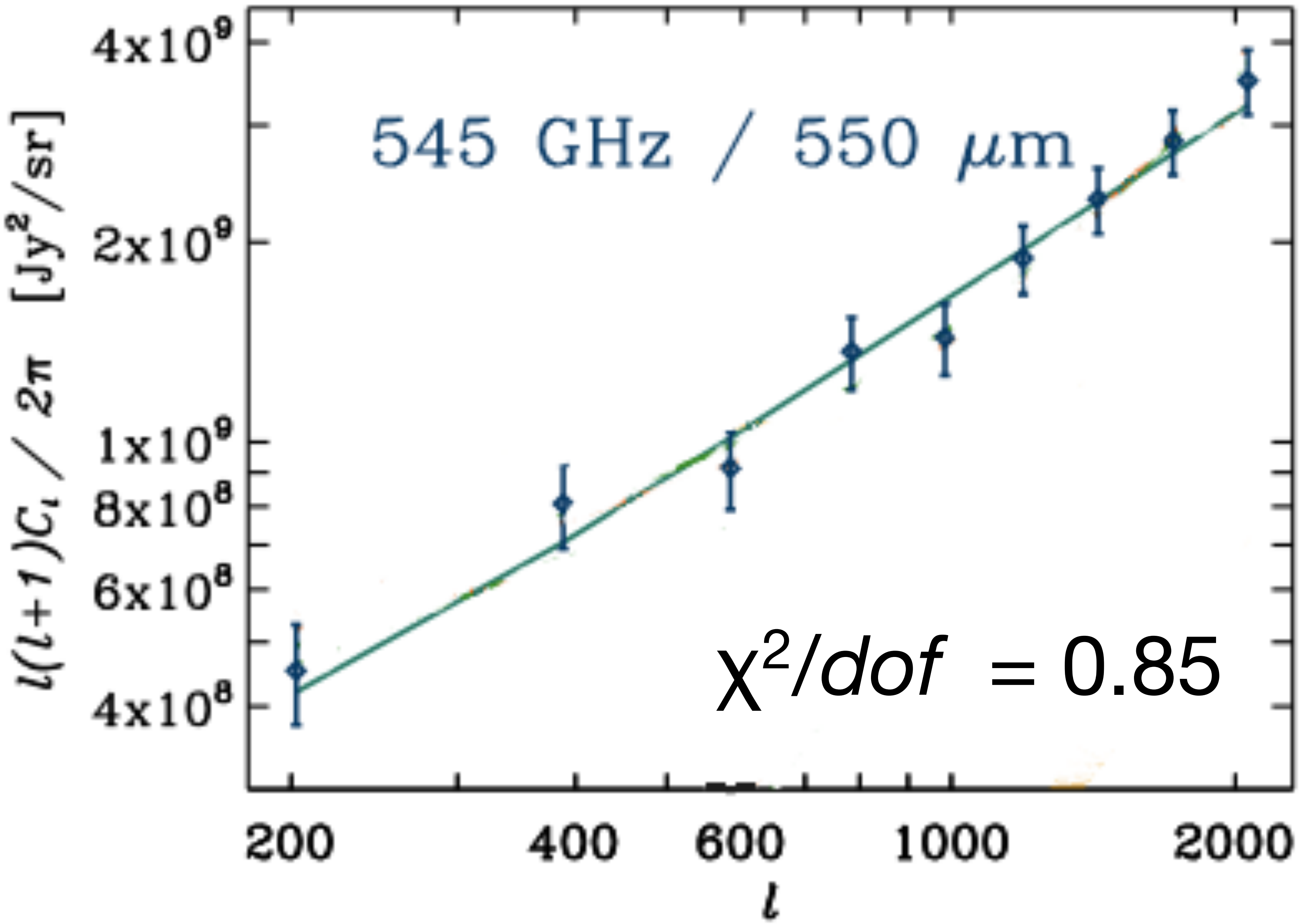
Poisson (shot) Noise



Star Forming Galaxies are
biased tracers of Dark Matter



BLAST Power Spectrum

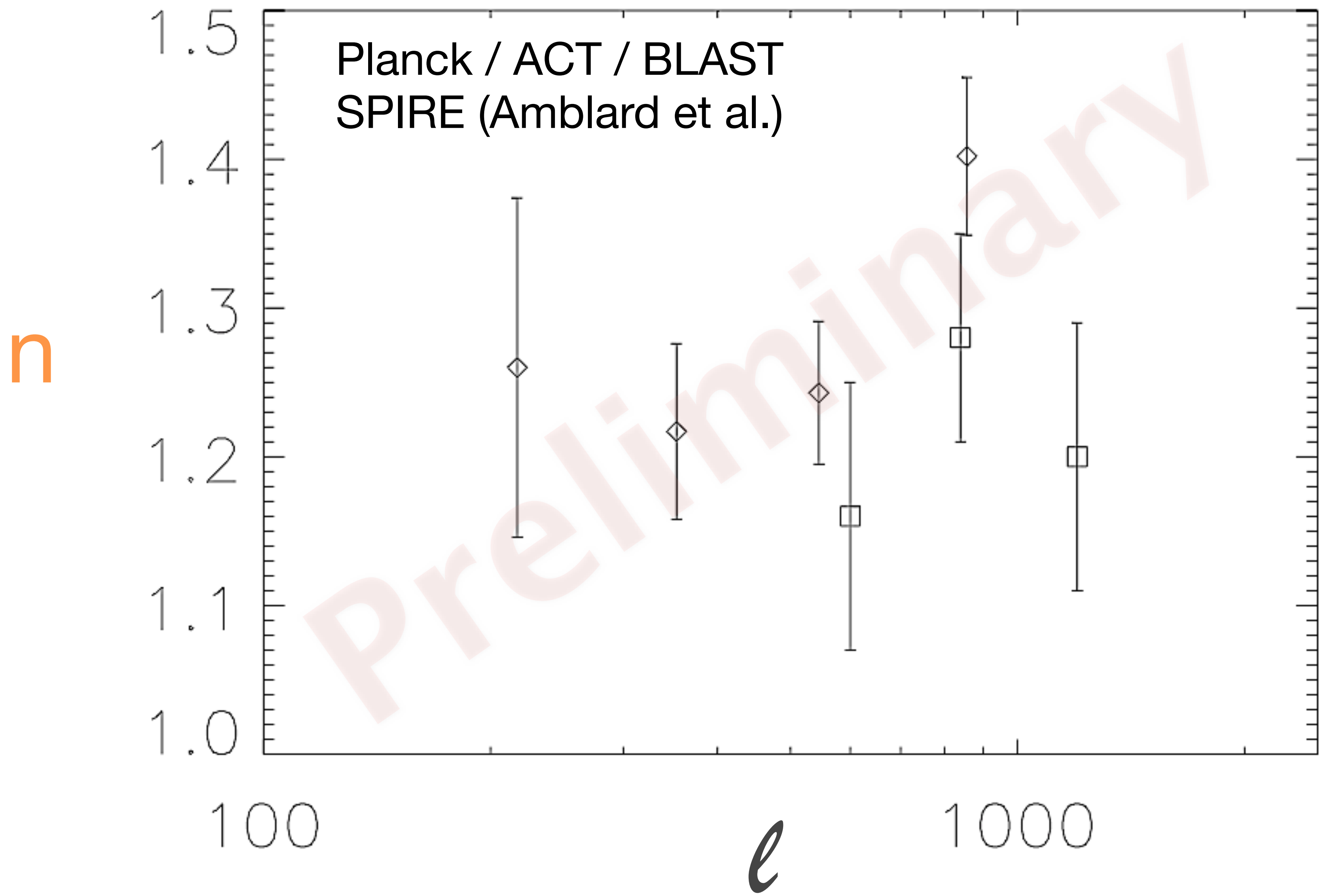


Planck Collaboration et al. (2011)

arXiv: 1101.2028

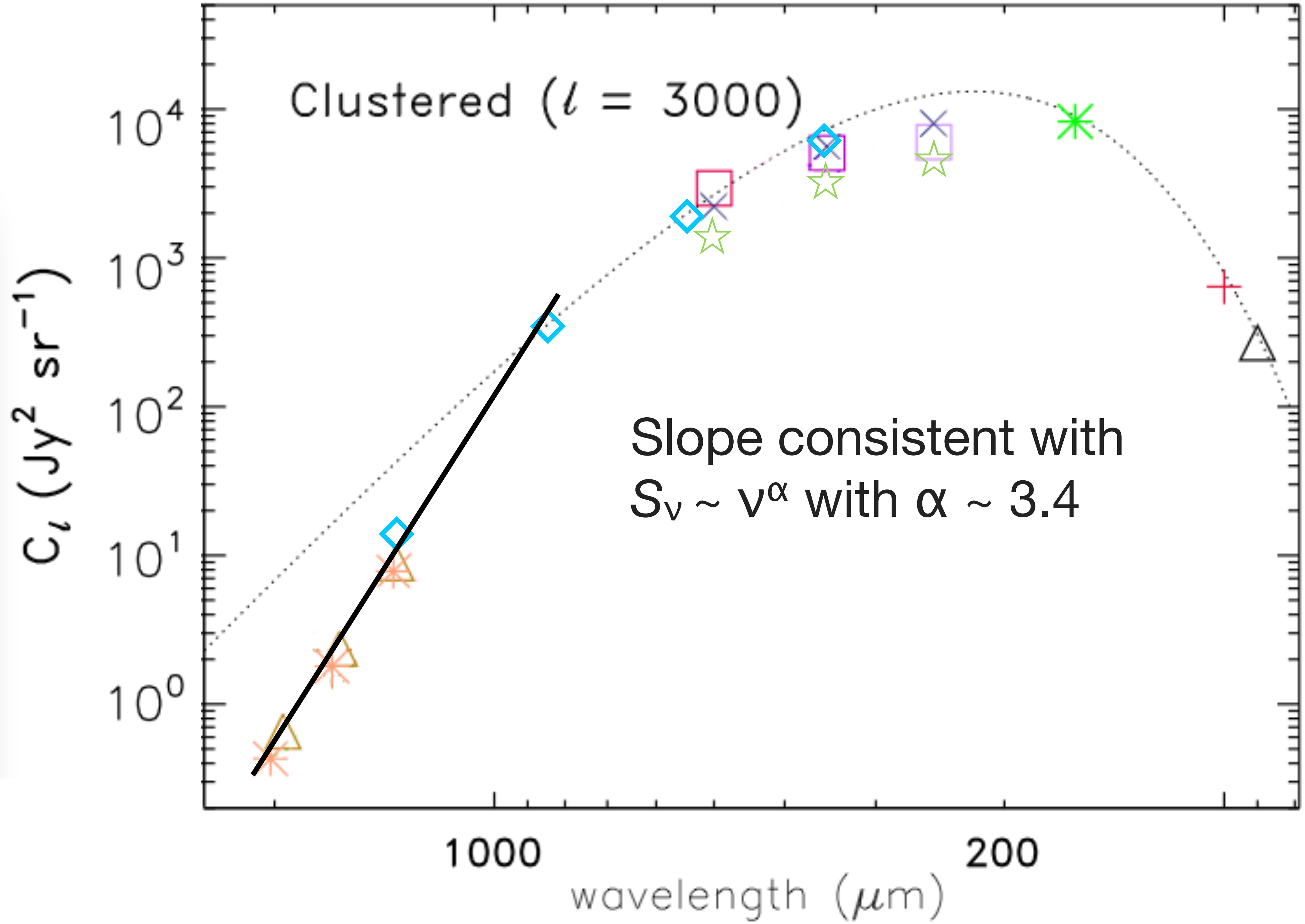
Planck Power Law

$$P(\ell) = P_{shot} + A\,(\ell/1000)^{-n}$$



Addison et al. (in prep.)

Frequency-dependence of Power-law

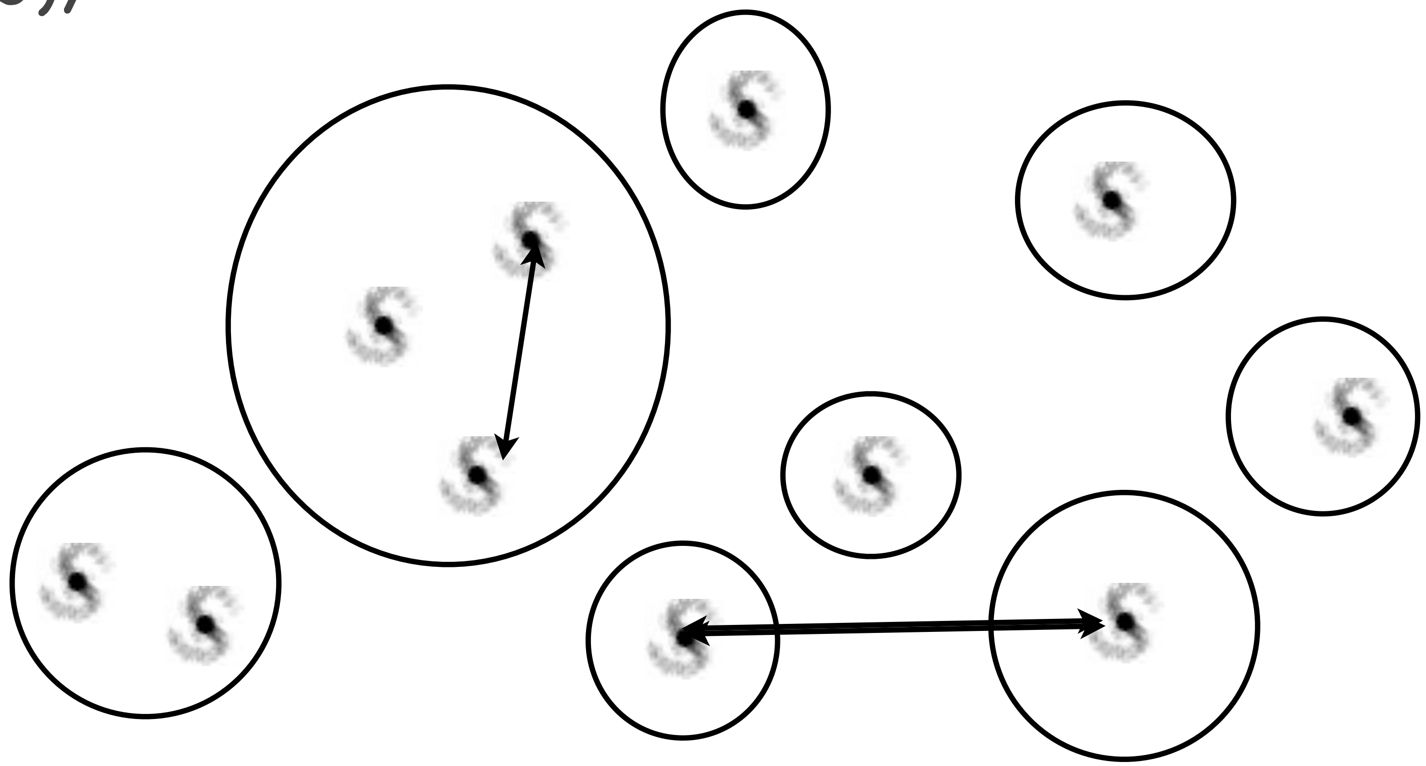


see also Shirokoff et al. (2010) - arXiv: 1012.4788

Millea et al. (2011) - arXiv: 1102.5195

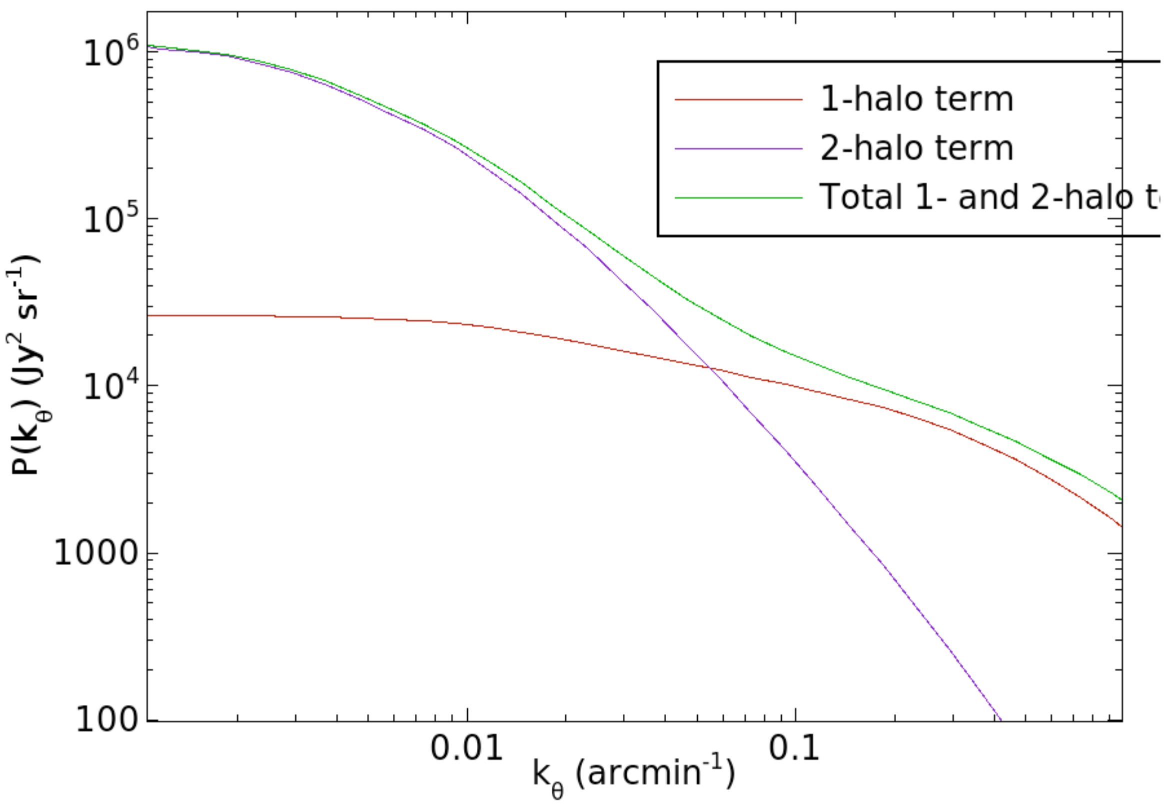
Latest Power Spectra

see e.g., Cooray & Sheth (2000), Zehavi et al. (2005, 2008)



- Clustering Signal made up of two regimes
  - 2-halo: Linear Regime (large scales)
  - 1-halo: Non-Linear Regime

(small scales)



BLAST Halo Model

What are you *actually* fitting?

$$P_{1h}(k,z) = \int_{\mathcal{M}} n_{\rm halo}(M,z)\big[2N_{\rm cen}(M)N_{\rm sat}(M)u_{\rm DM}(k,z|M) + N_{\rm sat}^2(M)u_{\rm DM}^2(k,z|M)\big]dM \big/ n_{\rm gal}^2(z),$$

$$P_{2h}(k,z) = P_{\rm DM}(k,z)\left[\int_{\mathcal{M}} n_{\rm halo}(M,z)N_{\rm gal}(M,z) \times b(M,z)u_{\rm DM}(k,z|M)dM\right]^2 \Big/ n_{\rm gal}^2(z).$$

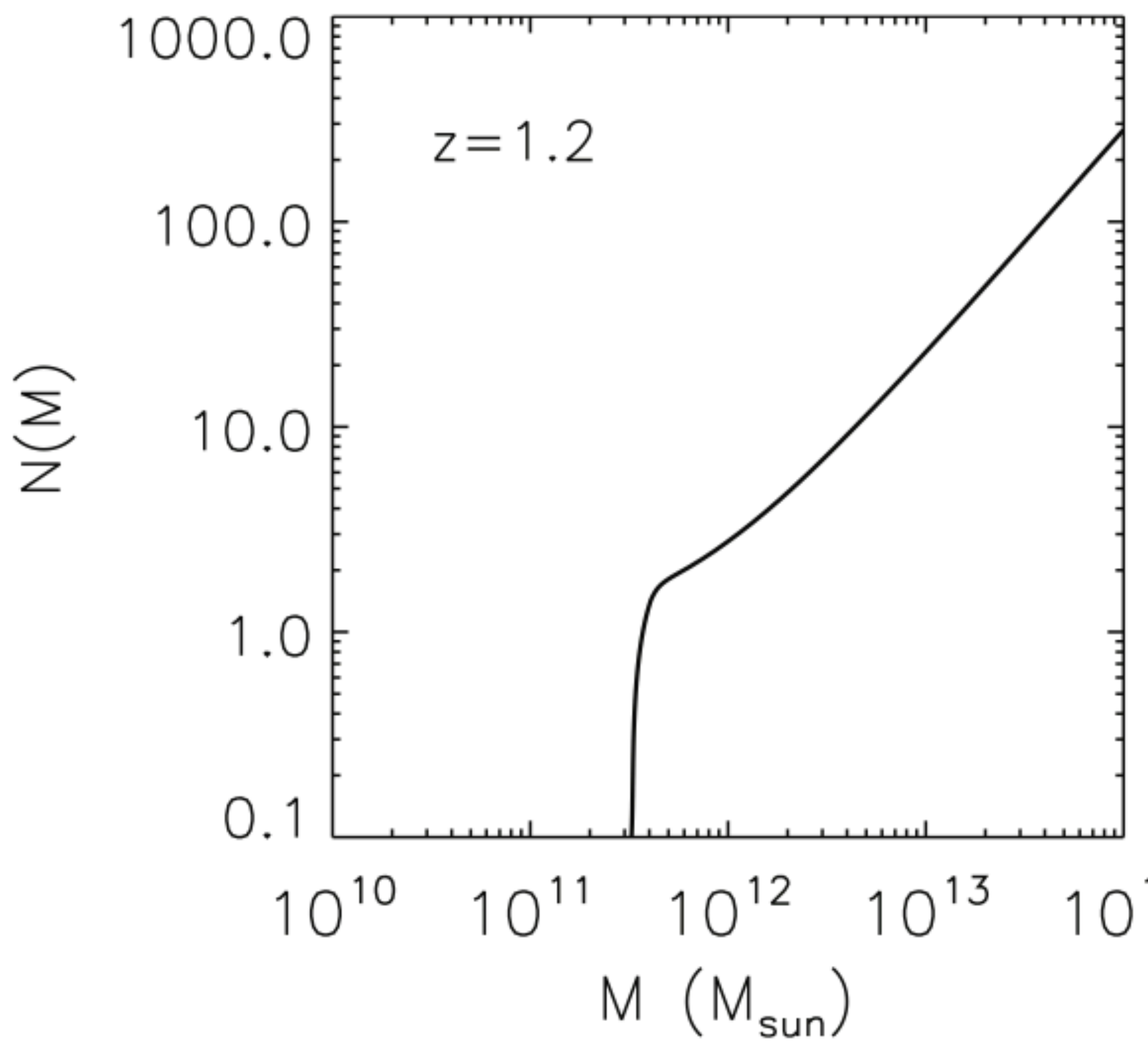
$$n_{\rm gal}(z) = \int_{\mathcal{M}} n_{\rm halo}(M,z)\left[1 + \left(\frac{M}{M_1}\right)^{\alpha}\right]dM$$

and for each M_{min}-α pair, M_1 fixed to agree to source model by requiring:

$$\int_0^{\infty} \frac{dN}{dS\,dz}(S,z)\,dS = n_{\rm gal}(z)\,dV_c(z)$$

$M_{min} \approx 3\times10^{11}\ M_{sun}$

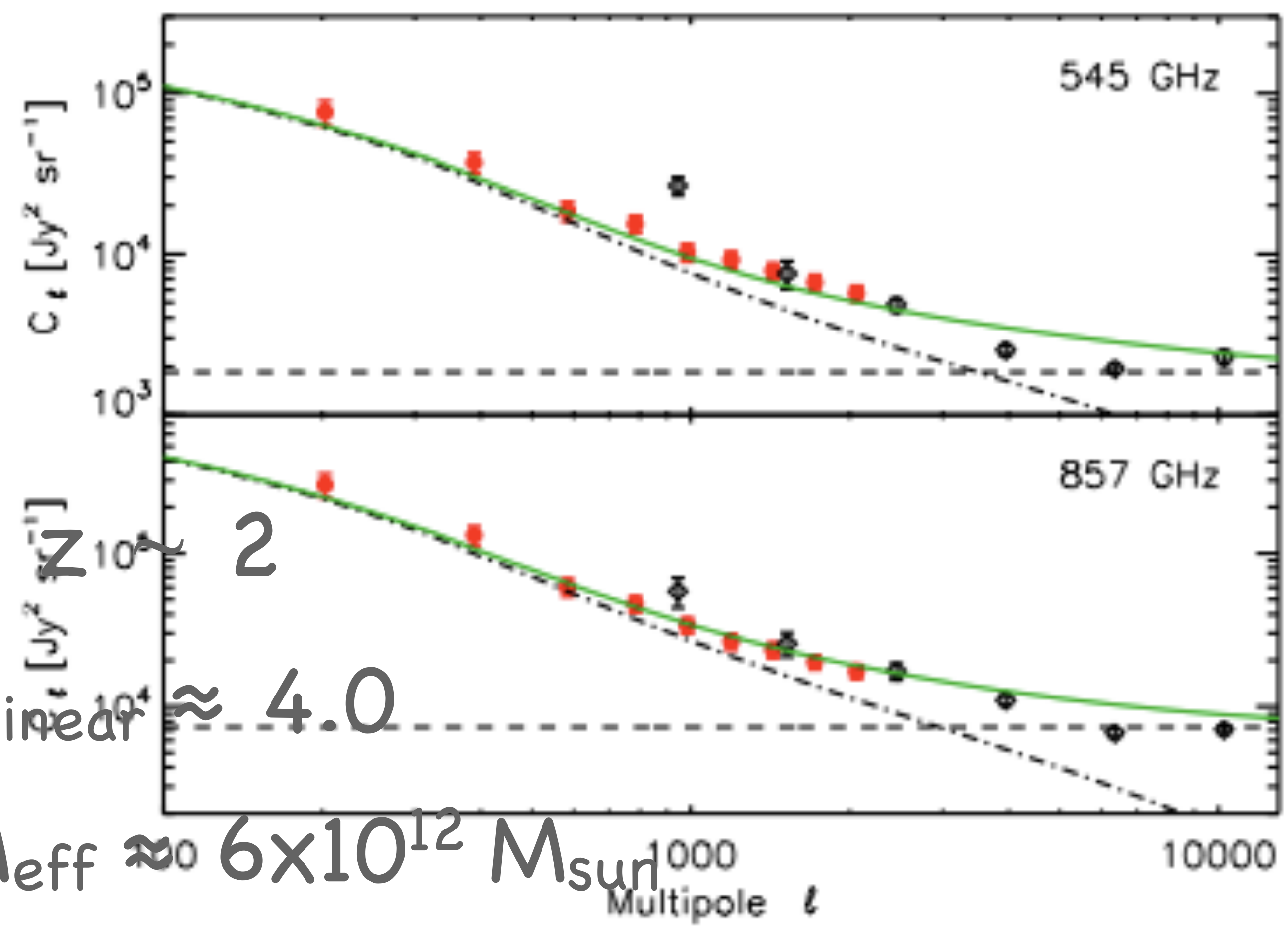
$\alpha \approx 1.1$



Viero et al. (2009)

BLAST Halo Model

BLAST Halo Model



At z ~ 2

- $b_{linear} \approx 4.0$
- $M_{eff} \approx 6\times10^{12}\ M_{sun}$
- $M_{min} \approx 3\times10^{11}\ M_{sun}$
- $b_{eff} \approx 2.4$

Confirmed by Planck!

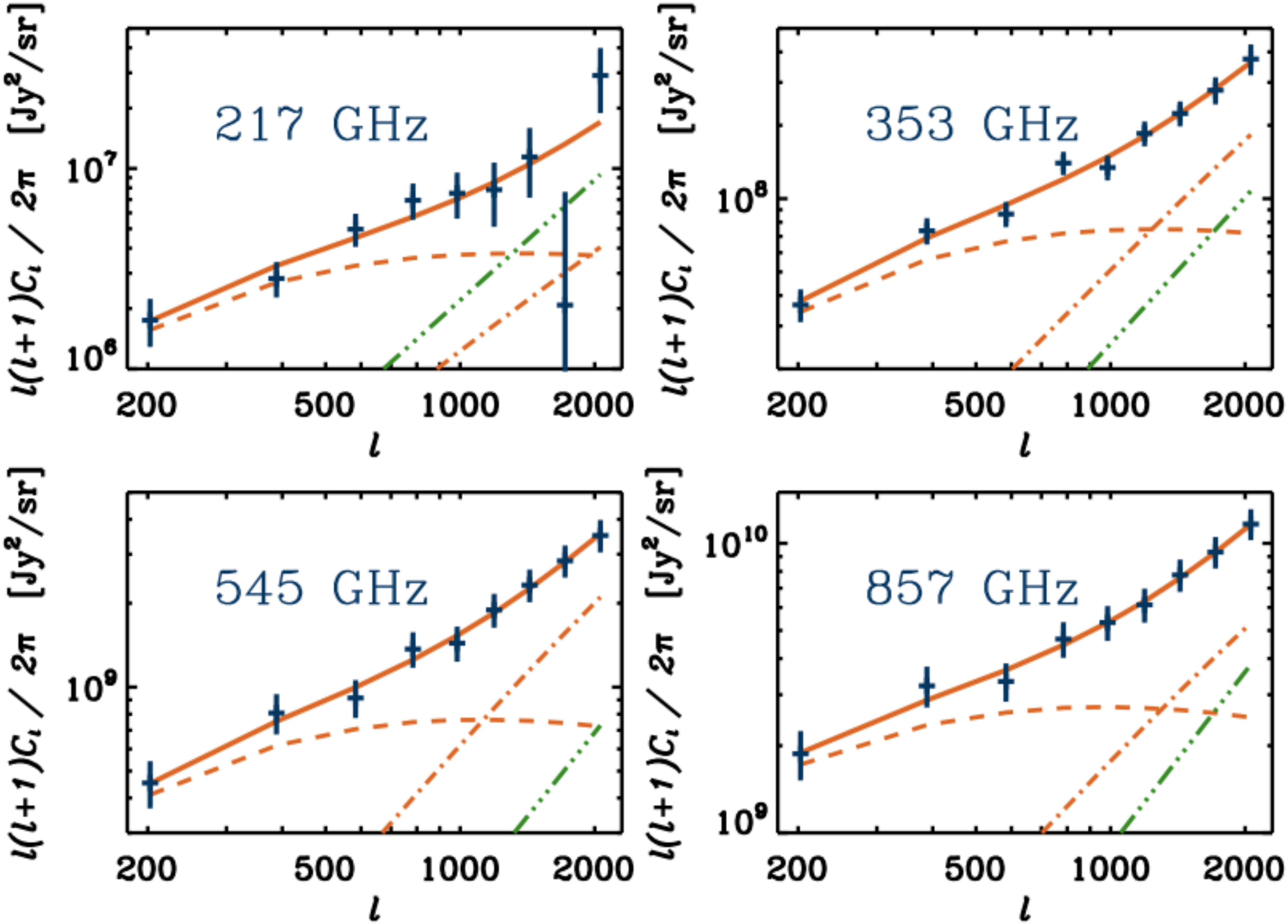
Confirmed by Herschel!

...xies reside in dark matter halos with ...n 3×10^{11} $M_\odot$

...a[1], B. Altieri[3], V. Arumugam[4], H. Aussel[5], A. Blain[2], J. Bock[2,6],
...odríguez[8,9], A. Cava[8,9], P. Chanial[10], E. Chapin[11], D.L. Clements[10],
...owell[2,6], E. Dwek[13], S. Eales[14], D. Elbaz[5], D. Farrah[15], A. Franceschini
...n[14], M. Halpern[11], E. Hatziminaoglou[17], E. Ibar[18], K. Isaak[14],
...G. Lagache[19], L. Levenson[2,6], N. Lu[2,20], S. Madden[5], B. Maffei[21],
...Marsden[11], K. Mitchell-Wynne[1], H.T. Nguyen[6,2], B. O'Halloran[10],
...ge[23], P. Panuzzo[5], A. Papageorgiou[14], C.P. Pearson[23,24], I. Pérez-
...gwala[12], I.G. Roseboom[15], M. Rowan-Robinson[10], M. Sánchez

Using the halo model fits, we estimate the mininum dark matter mass scale for dusty star-forming galaxies at the peak of the star formation history of the universe to be $\log_{10} M_{\rm min}/{\rm M}_\odot = 11.5^{+0.7}_{-0.2}$ at 350 μm with a bias factor for the galaxies of $2.4^{+1.0}_{-0.2}$. The minimum halo masses $\log_{10} M_{\rm min}/{\rm M}_\odot$ at 250 and 500 μm are $11.1^{+1.0}_{-0.6}$ and $11.8^{+0.4}_{-0.3}$, respectively. The corresponding bias factors for the galaxies are $2.0^{+0.9}_{-0.1}$ and $2.8^{+0.4}_{-0.5}$ at 250 and 500 μm, respectively. The differences in the minimum halo masses and the bias factors between the three wavelengths are likely due a combination of effects including overall calibration uncertainties, the fact that at longer wave-

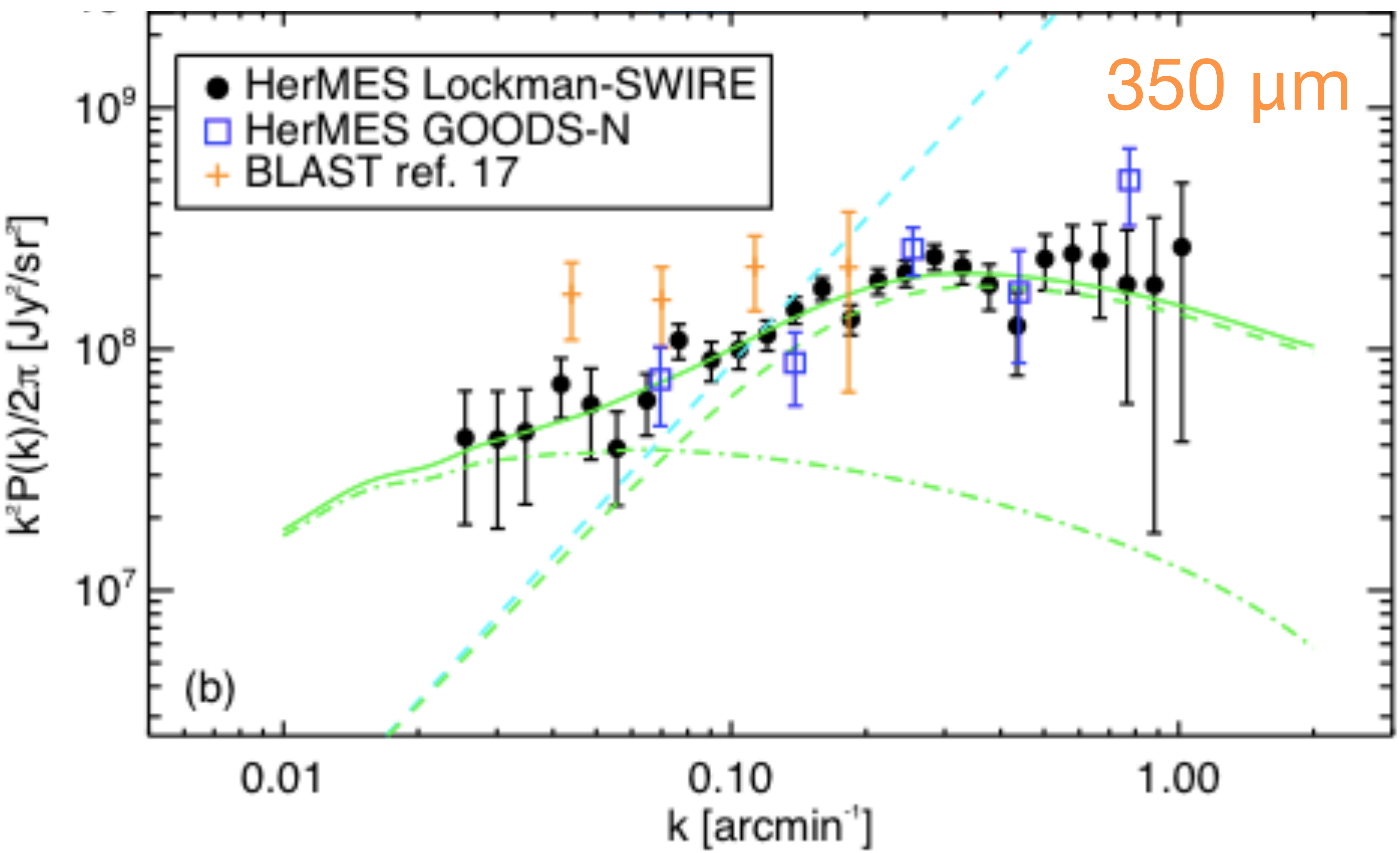
arXiv: 0904.1200



Planck Collaboration et al. (2011)

arXiv: 1101.2028

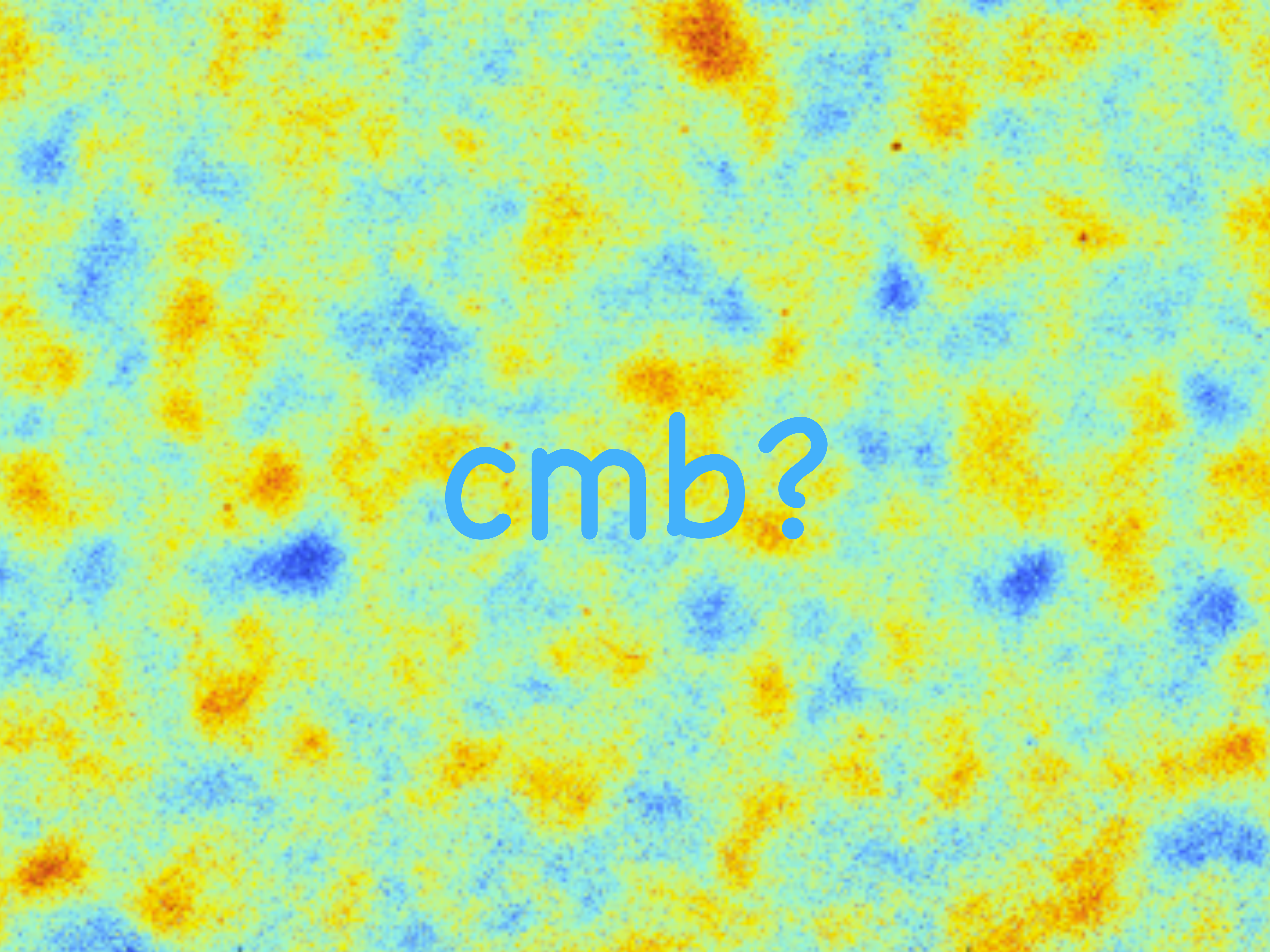
Planck Halo Model



Amblard et al. (2011)

arXiv: 1101.1080

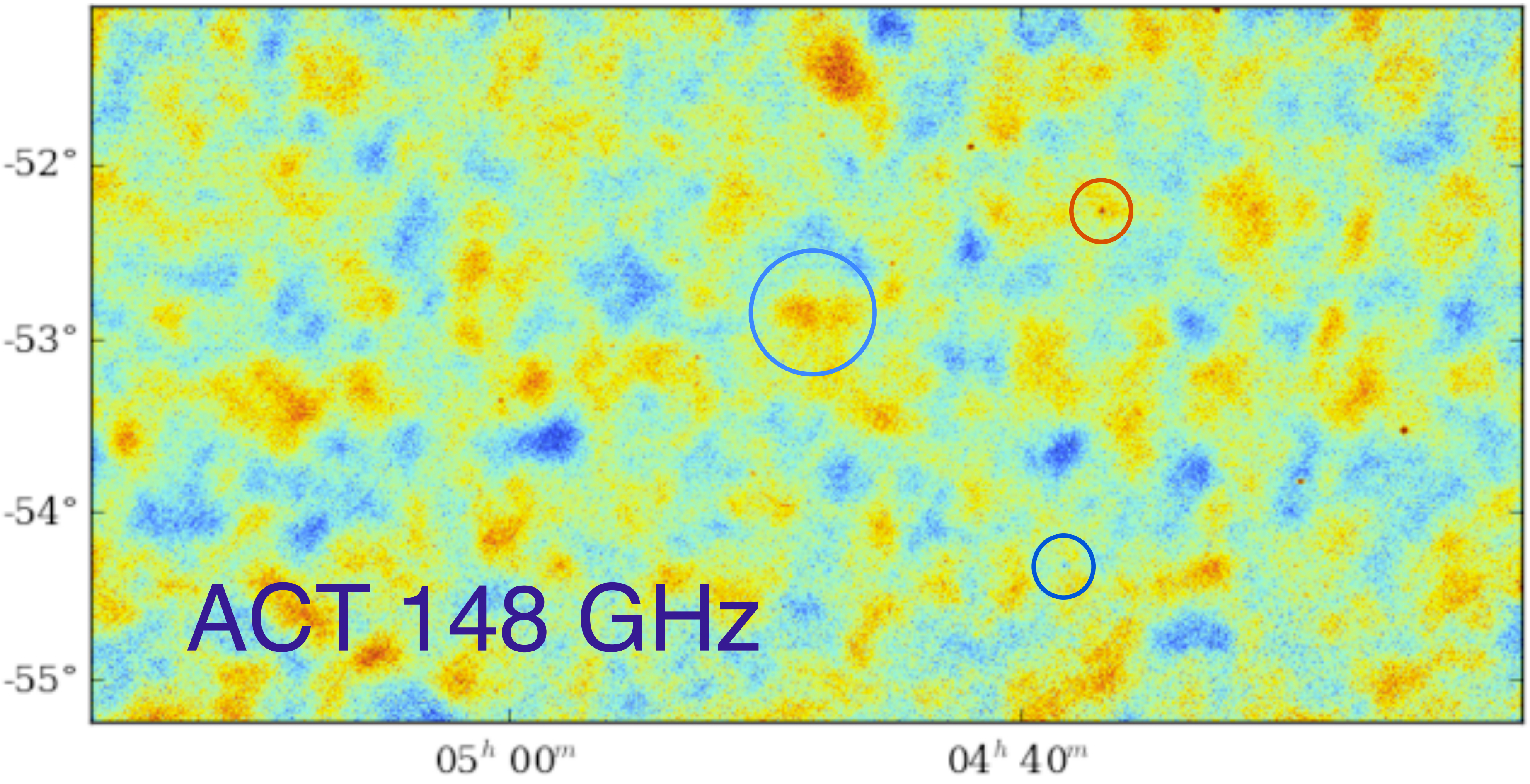
Herschel Halo Model


cmb?

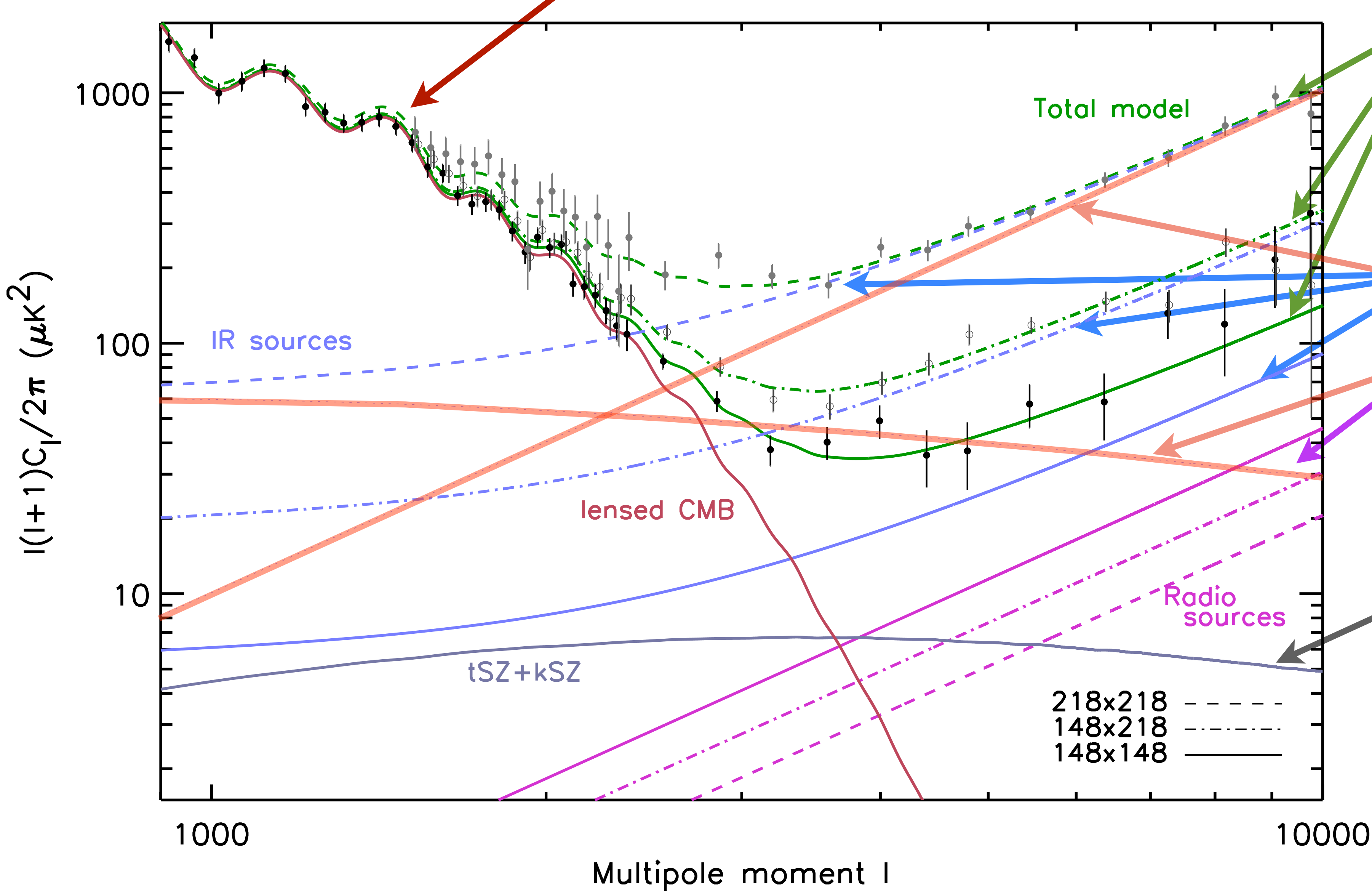
CMB

Galaxies

SZ Clusters



The high-ℓ CMB sky



Primary CMB

Total Signal

Galaxies:

Dusty

Radio

Clustered

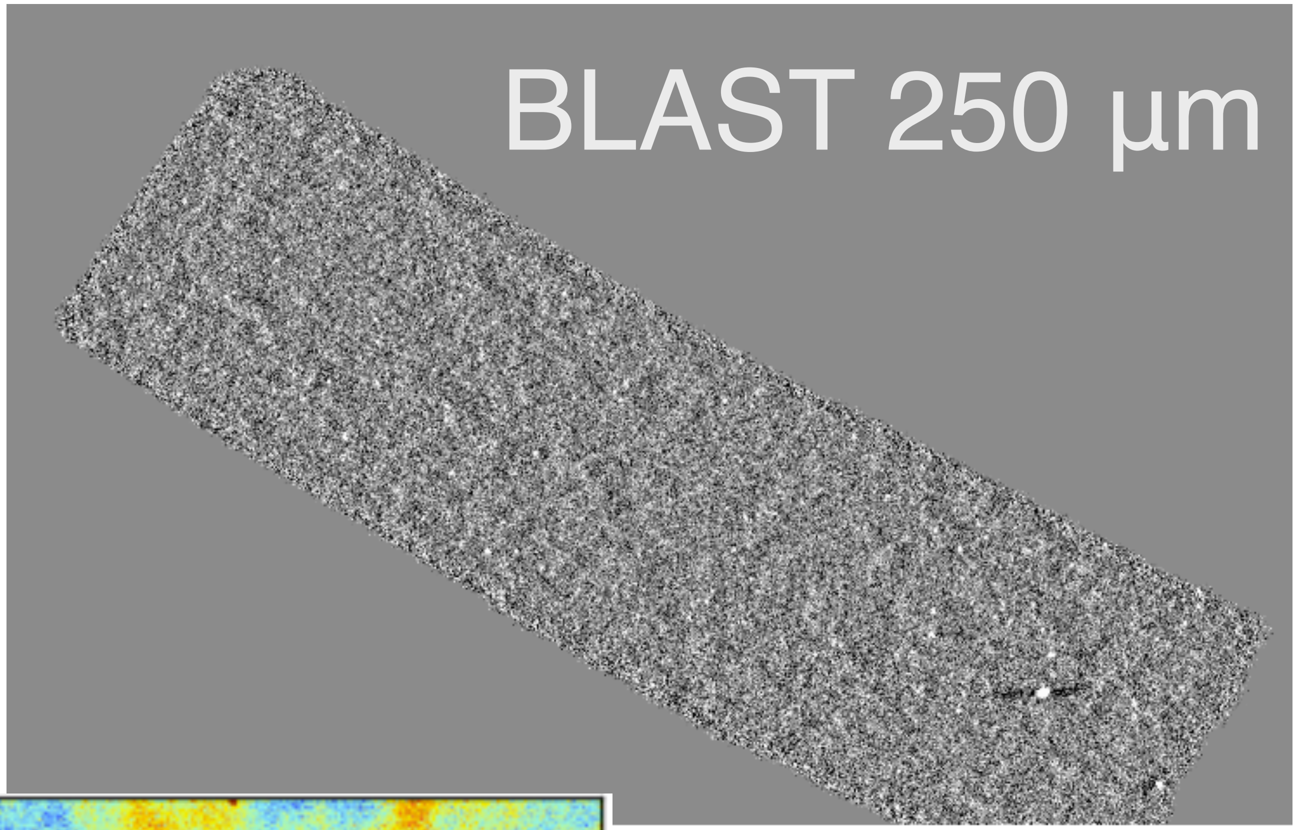
Secondary CMB:

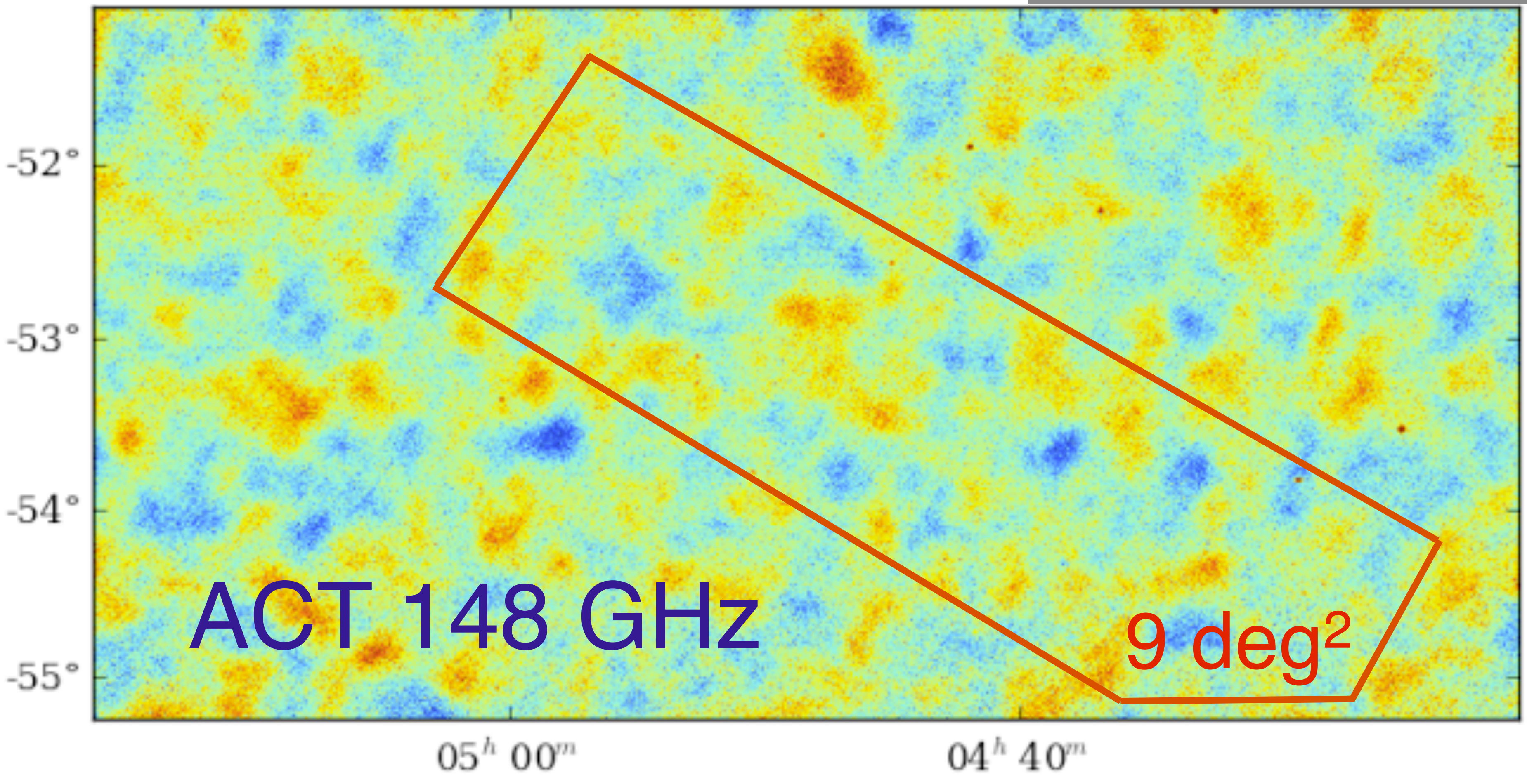
Sunyaev-Zel'dovich (SZ)

Dunkley et al. 1009.0866

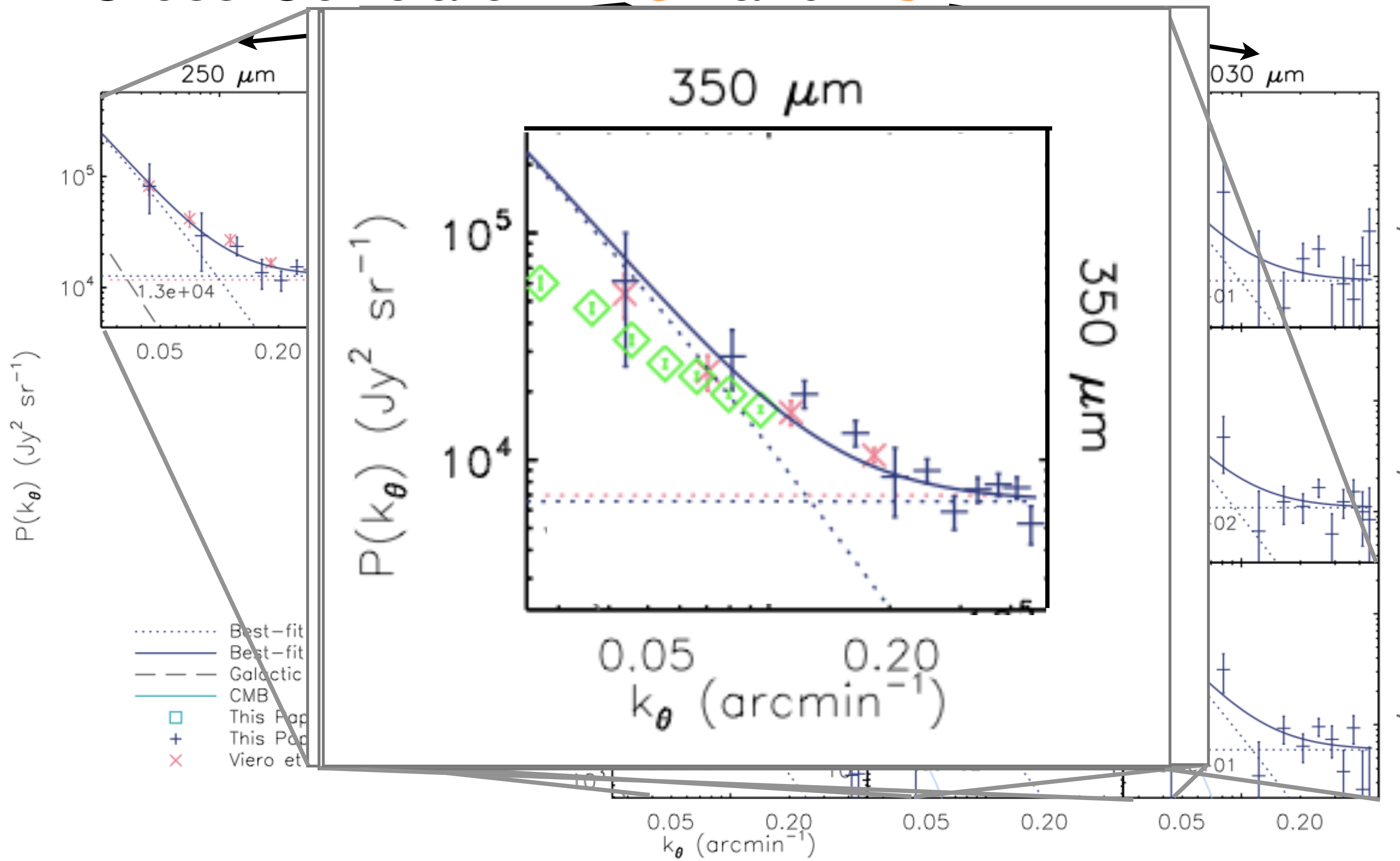
CMB Foregrounds

Cross-Correlations Isolate Dusty Galaxies from the Rest



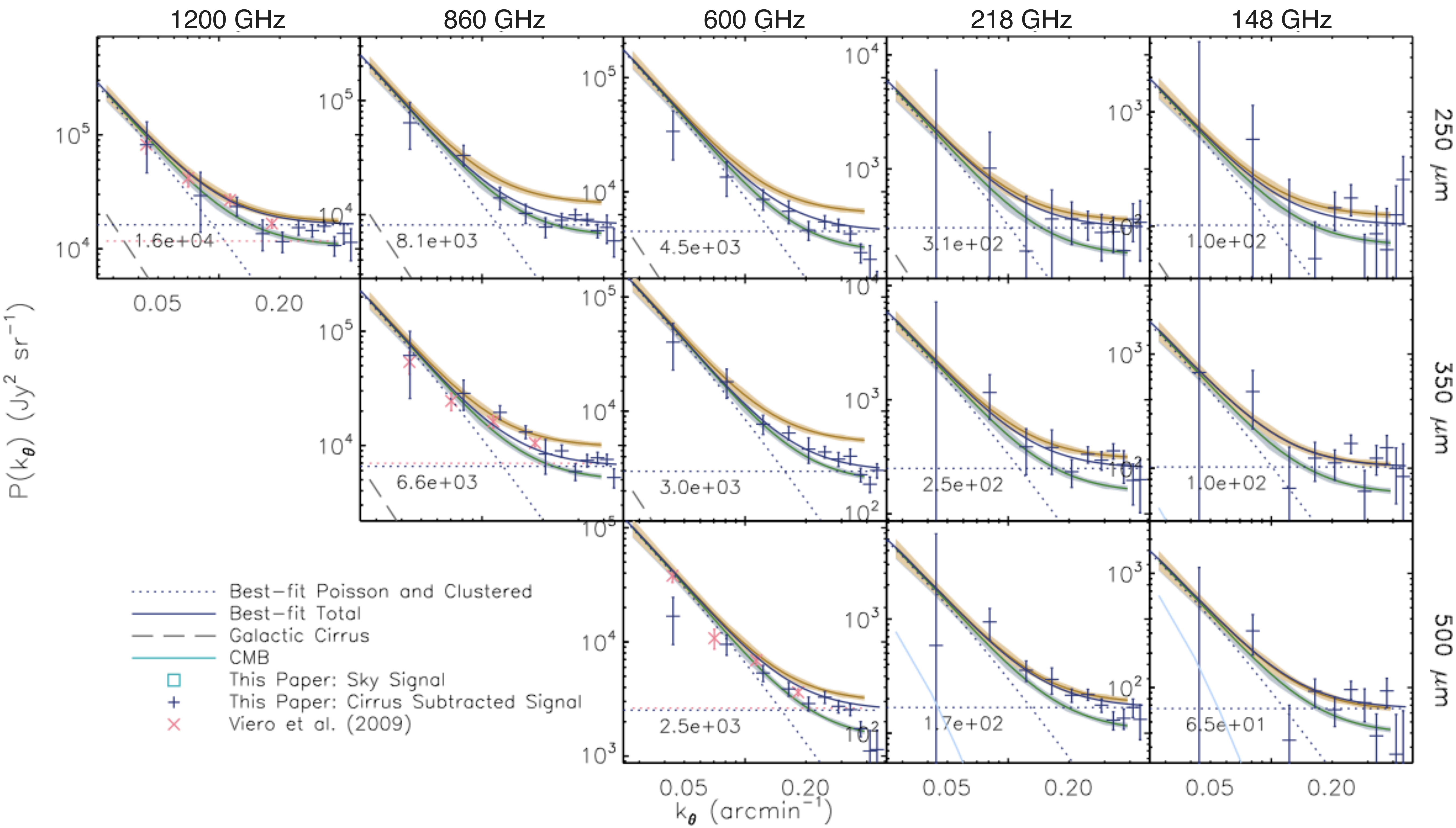


Cross-Correlate BLAST and ACT



Hajian & Viero et al.

arXiv:1101.1517

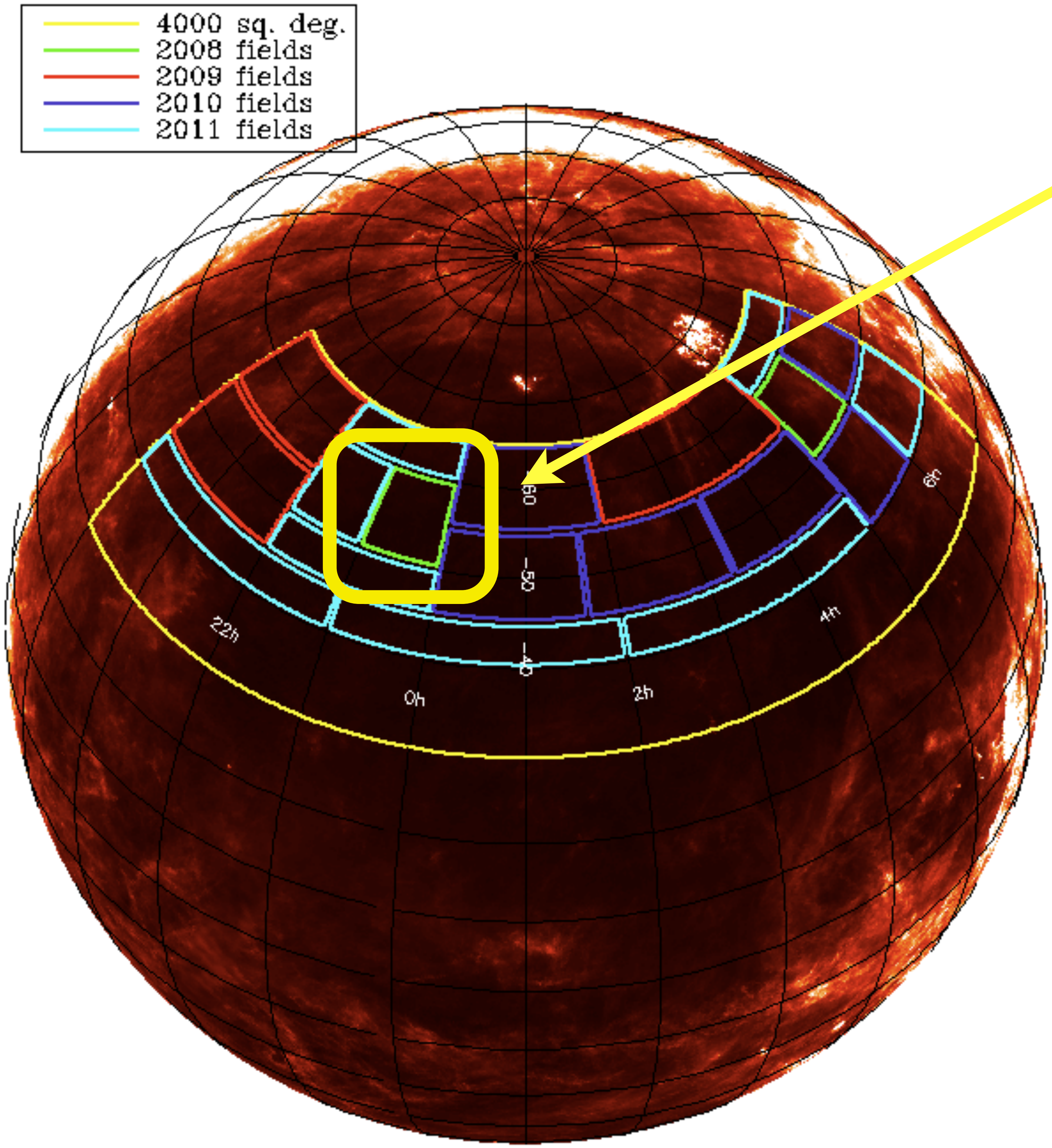


Model: Marsden et al. 1010.1176

Model: Béthermin et al. 1010.1150

future surveys

image: Joaquin Vieira



SPT 100 deg^2 deep field is the deepest mm map in existence and will remain so for the next decade.

Given 79 hours to map a 100 deg^2 with SPIRE

Will use this field for cross-correlations in hopes of measuring the kSZ power spectrum

SPT X SPIRE


end