Correlations in the (Sub)millimeter Background from ACT x BLAST

marco viero / california institute of technology

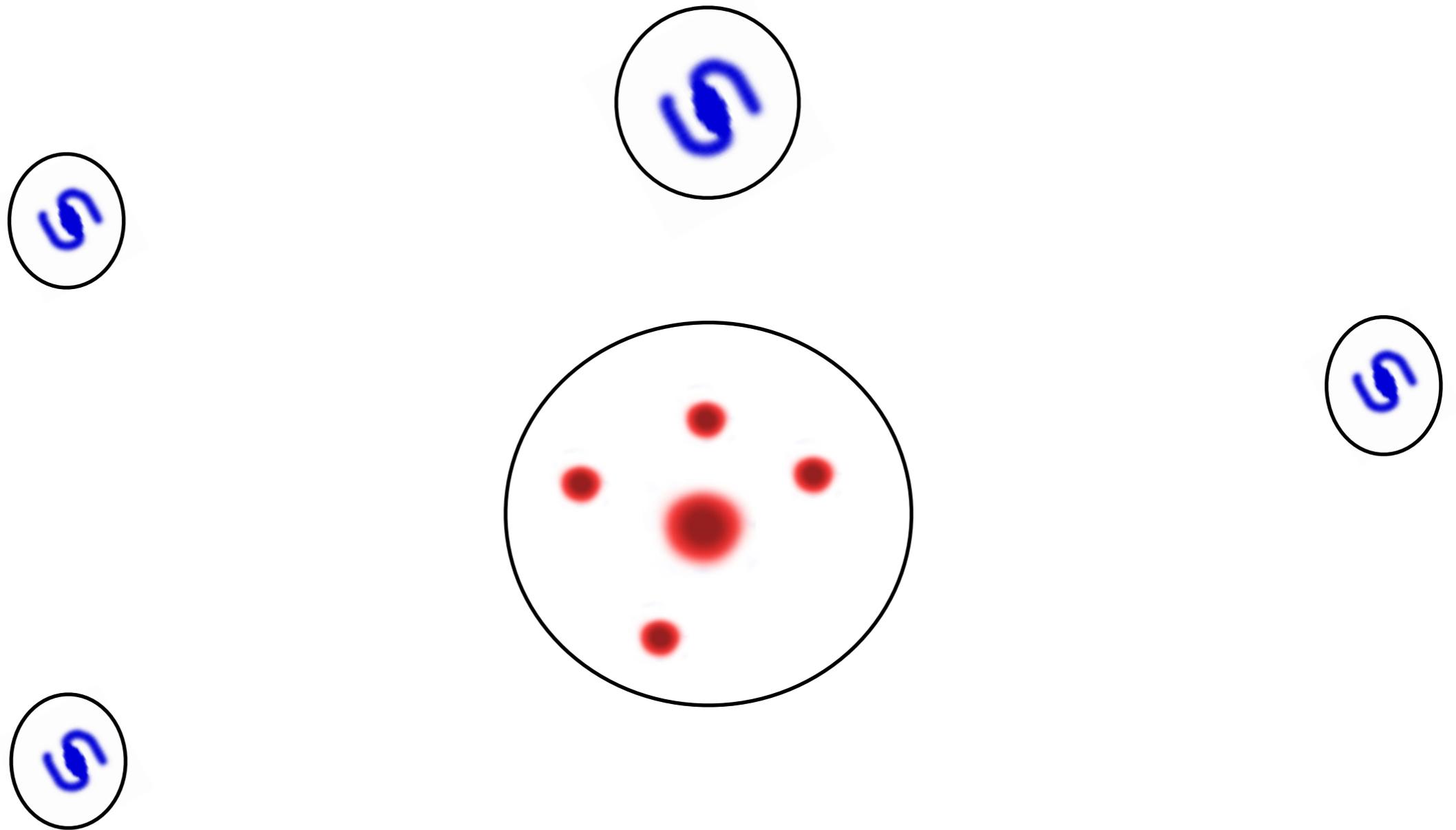# Galaxy Formation is Not Independent of Environment

Blue
Star-Forming
Galaxy

Red
Quiescent
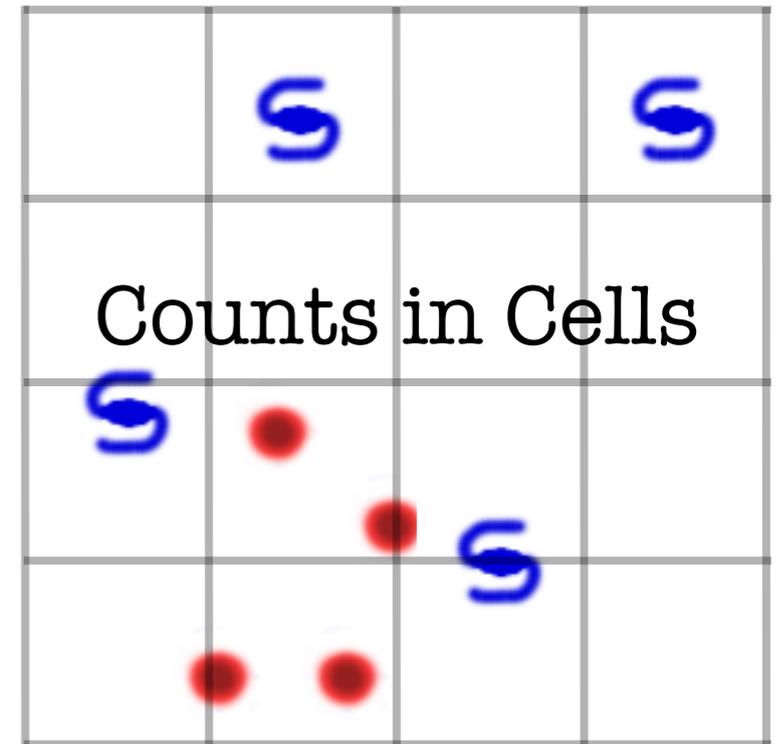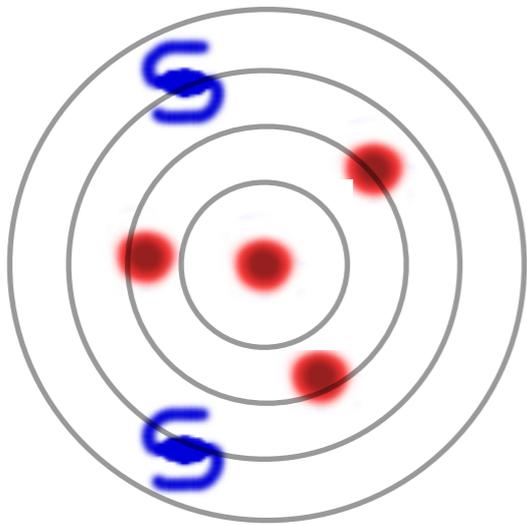Galaxy

Galaxy Formation is Not Independent of Environment

Clustering Relates Galaxies to Their Environment
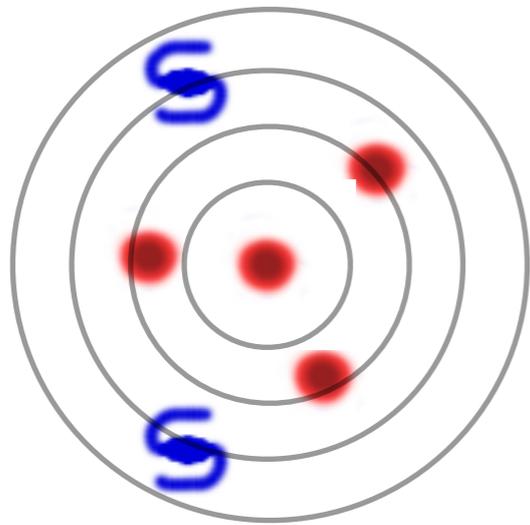
2-Point Correlation Function

Counts in Cells
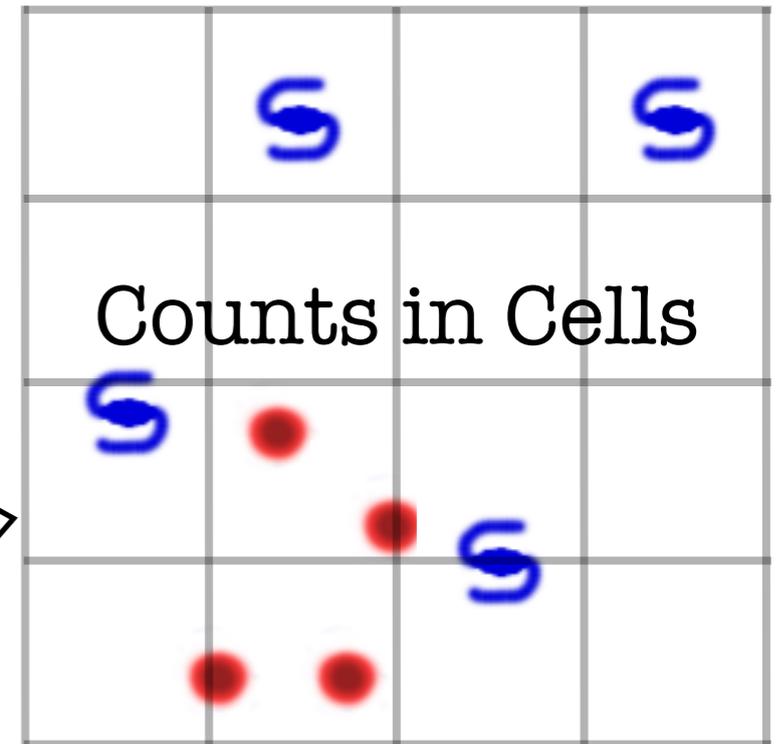
Nearest Neighbor

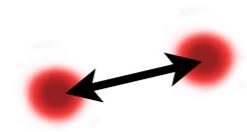# Clustering Relates
Galaxies to Their Environment

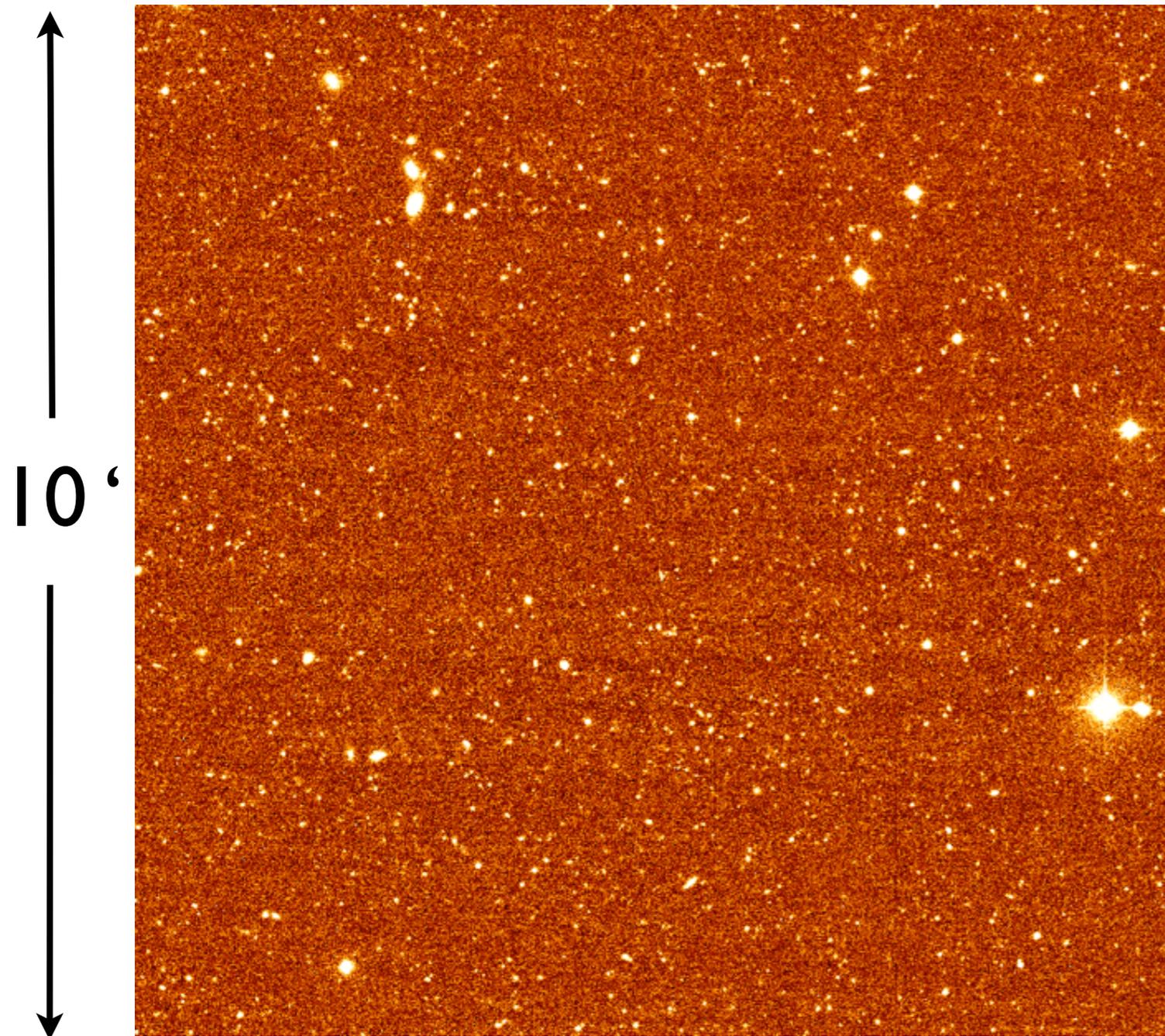2-Point
Correlation Function

Counts in Cells

Catalog

Nearest Neighbor

Submm Maps/Catalogs are NOT
Like Those at Shorter - Wavelengths

U-band : MUSYC

10'

U-band

~ 60 sources/ arcmin²

Submm Maps/Catalogs are NOT Like Those at Shorter - Wavelengths

10'

K-band : MUSYC

U-band
~ 60 sources/ arcmin^2

K-band
~ 45 sources/ arcmin^2

Submm Maps/Catalogs are NOT Like Those at Shorter - Wavelengths

10'

Gaelen Marsden, UBC

SPIRE 250 μm
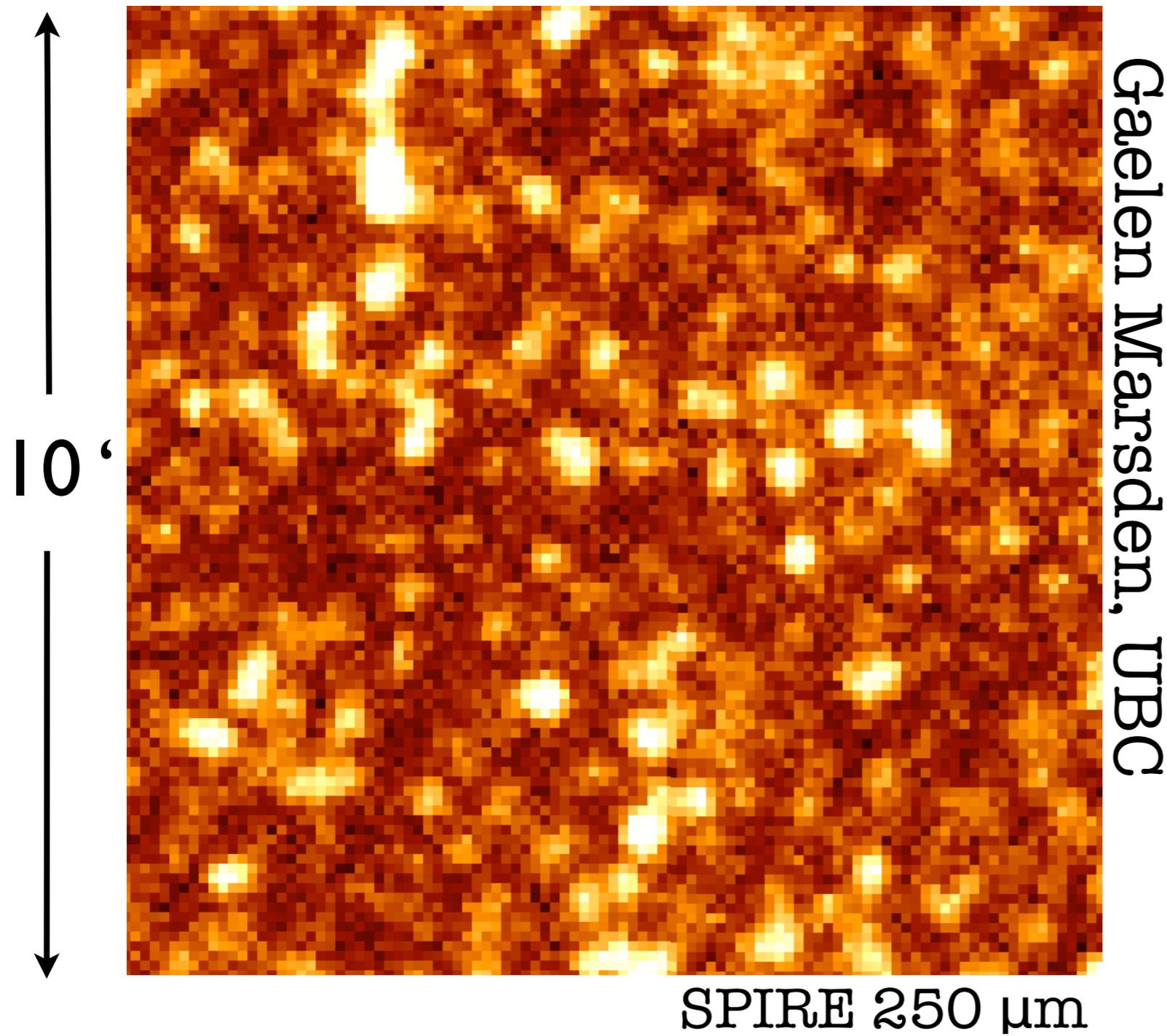
U-band
~ 60 sources/ arcmin²

K-band
~ 45 sources/ arcmin²

SPIRE
~ 0.5 sources/ arcmin²

marco viero 4

Submm Maps/Catalogs are NOT
Like Those at Shorter - Wavelengths

2.5 '
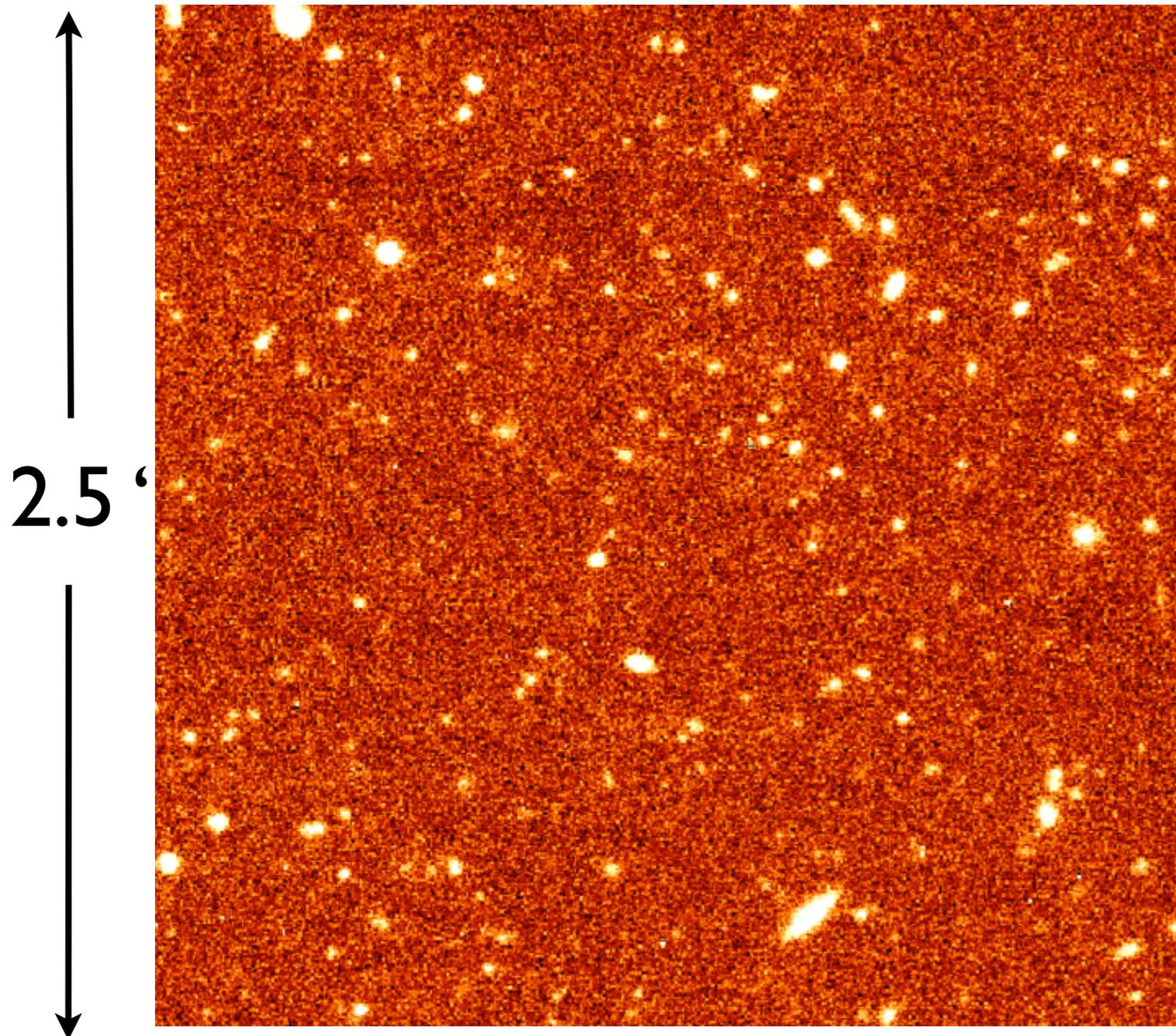
U-band : MUSYC

Submm Maps/Catalogs are NOT
Like Those at Shorter - Wavelengths

2.5 '

Gaelen Marsden, UBC

SPIRE 250

Submm Maps/Catalogs are NOT Like Those at Shorter - Wavelengths

2.5 '

Gaelen Marsden, UBC

SPIRE 250
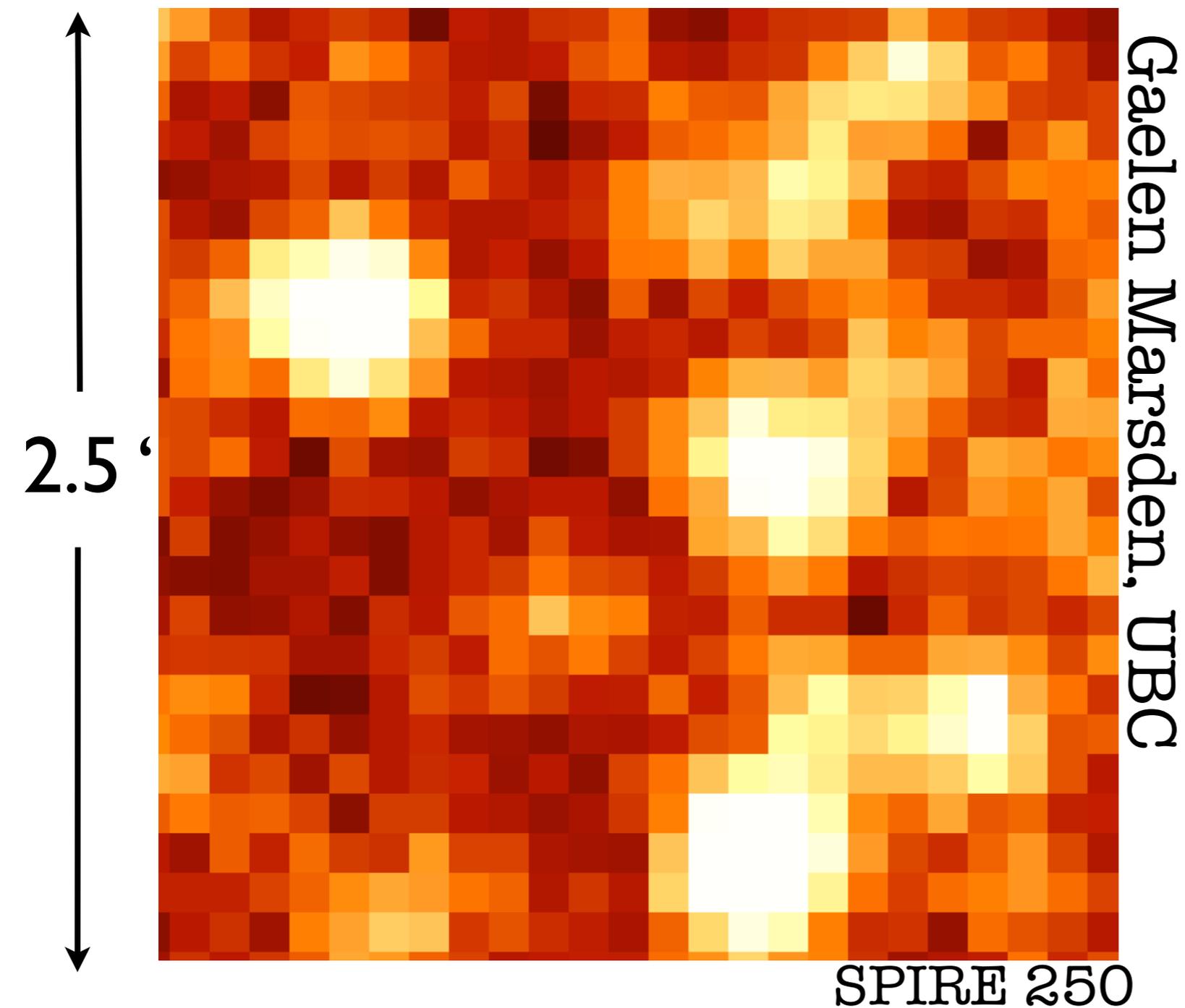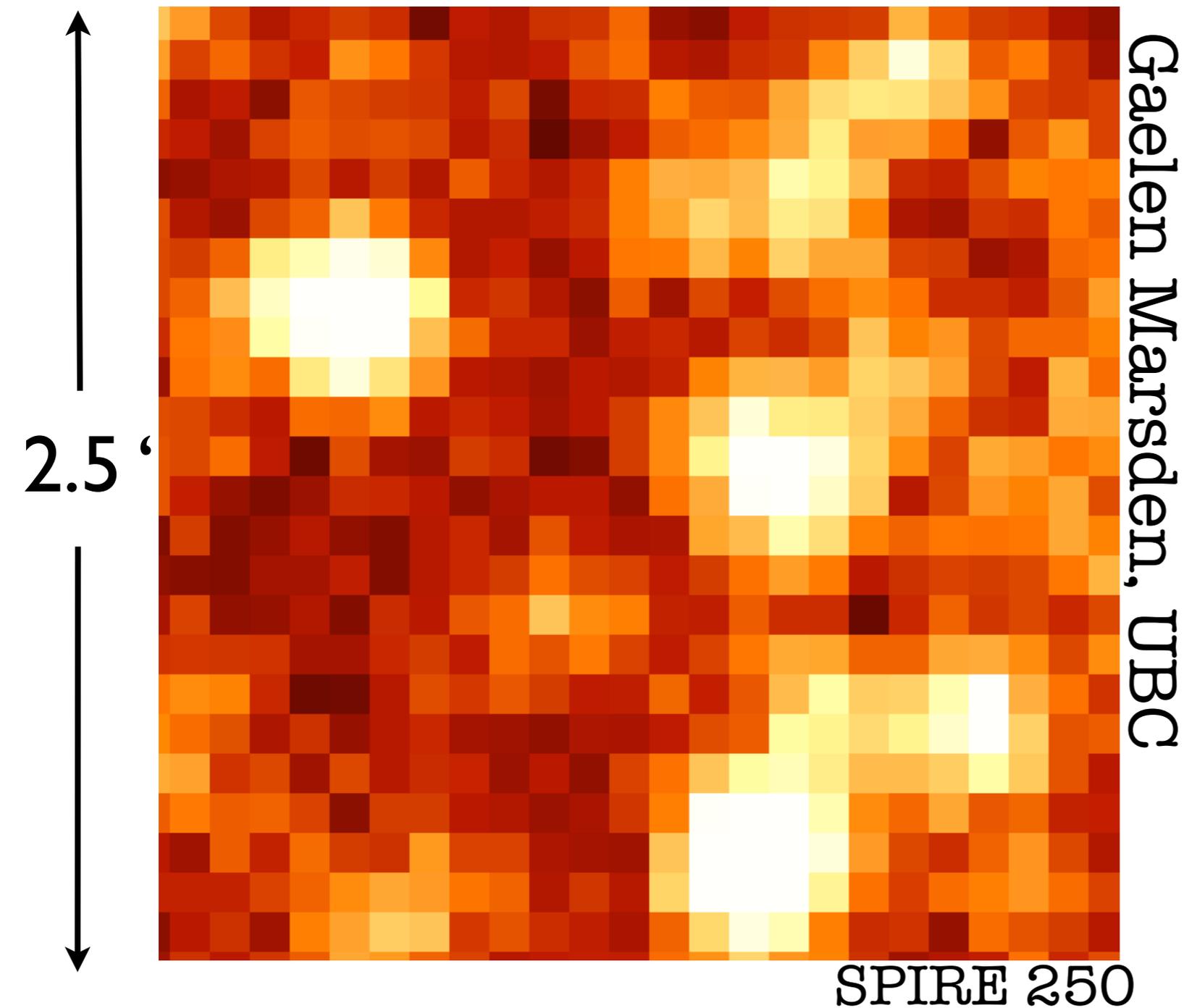
~ 85% of Sources in the Map Appear as Fluctuations

Why care about the ~ 85% of Flux that is unresolved?

250 μm

S > 20 mJy : 1,200/deg²

S < 20 mJy : 480,000/deg²

Why care about the ~ 85% of Flux that is unresolved?
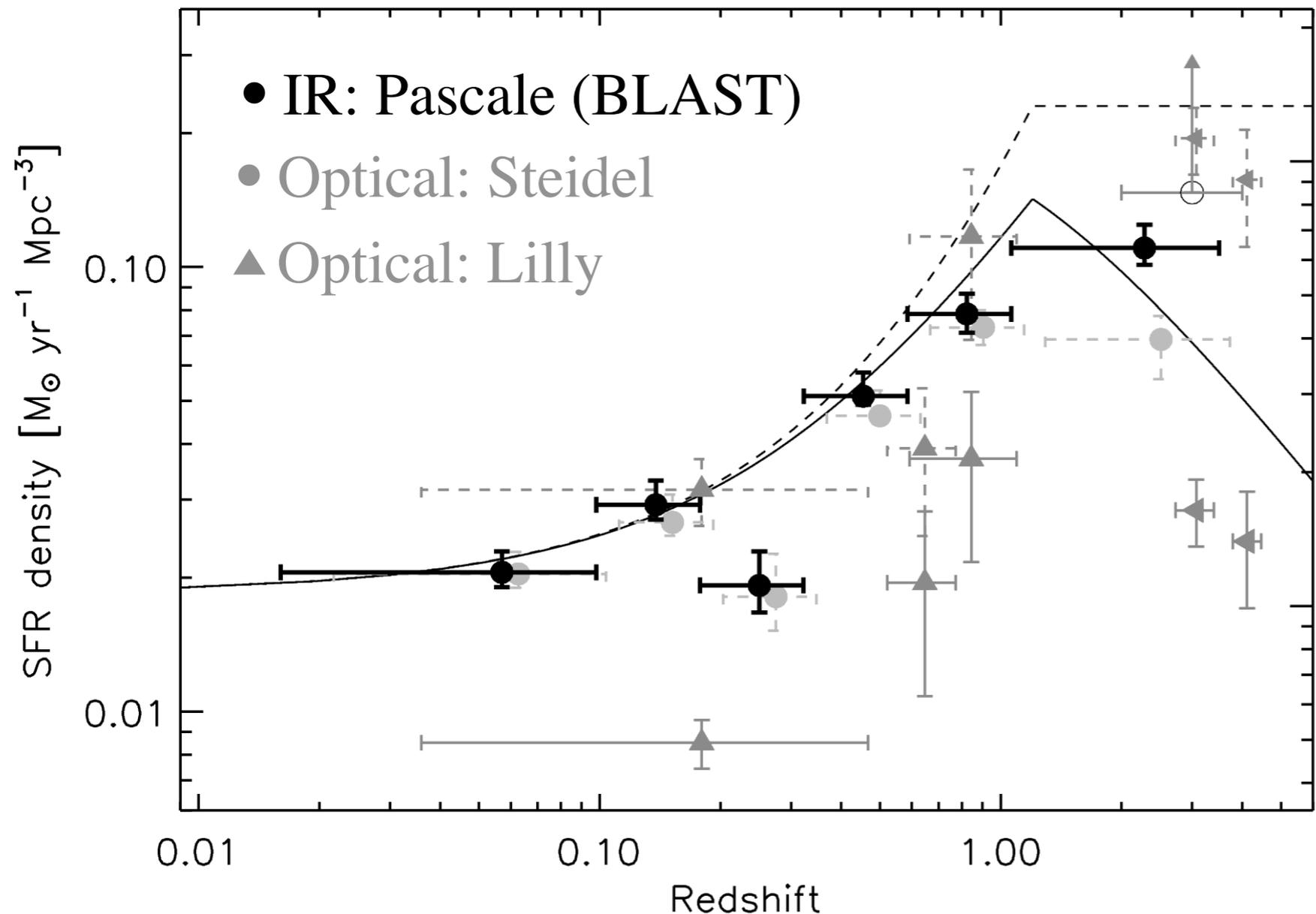
Pascale et al. (2009) - 0904.1206

Peak Epoch of Star Formation

z ~ 1-3

Why care about the ~ 85% of Flux that is unresolved?
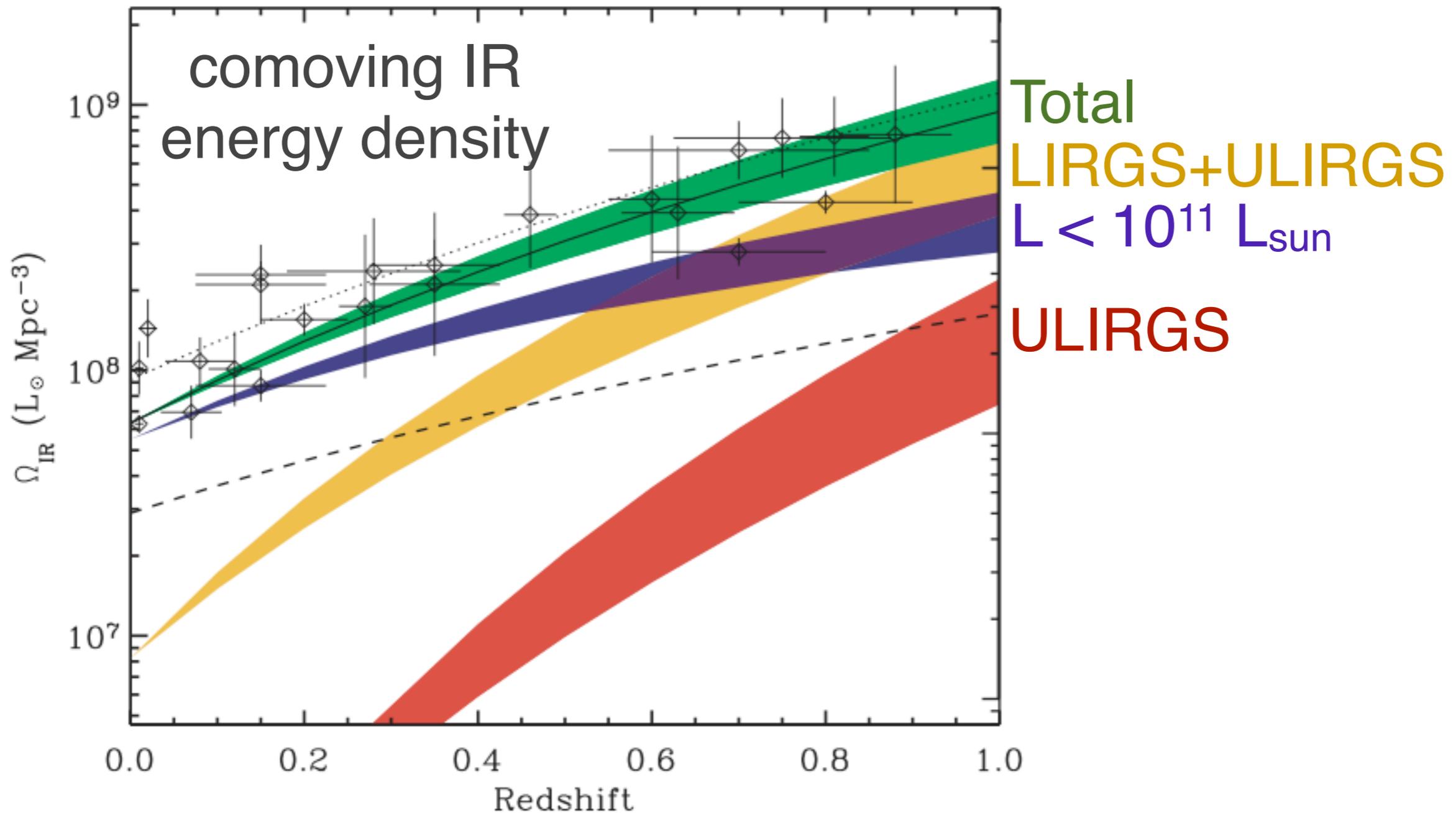
comoving IR energy density

Total

LIRGS+ULIRGS

$L < 10^{11} L_{sun}$

ULIRGS

Le Floc'h et al. (2005)

Why care about the ~ 85% of Flux that is unresolved?

comoving IR energy density

Total
LIRGS+ULIRGS
$L < 10^{11} L_{sun}$

ULIRGS

Most of that Star Formation occurs in LIRGS (i.e., $L_{FIR} \sim 10^{11} M_{sun}$)

Le Floc'h et al. (2005)

Why care about the ~ 85% of Flux that is unresolved?

250μm: flux density vs. redshift

flux density (mJy) vs. z

20 mJy

log($L_{FIR}/L_\odot$)= 11.00
log($L_{FIR}/L_\odot$)= 11.25
log($L_{FIR}/L_\odot$)= 11.50
log($L_{FIR}/L_\odot$)= 11.75
log($L_{FIR}/L_\odot$)= 12.00
log($L_{FIR}/L_\odot$)= 12.25

Why care about the ~ 85% of Flux that is unresolved?

250μm: flux density vs. redshift
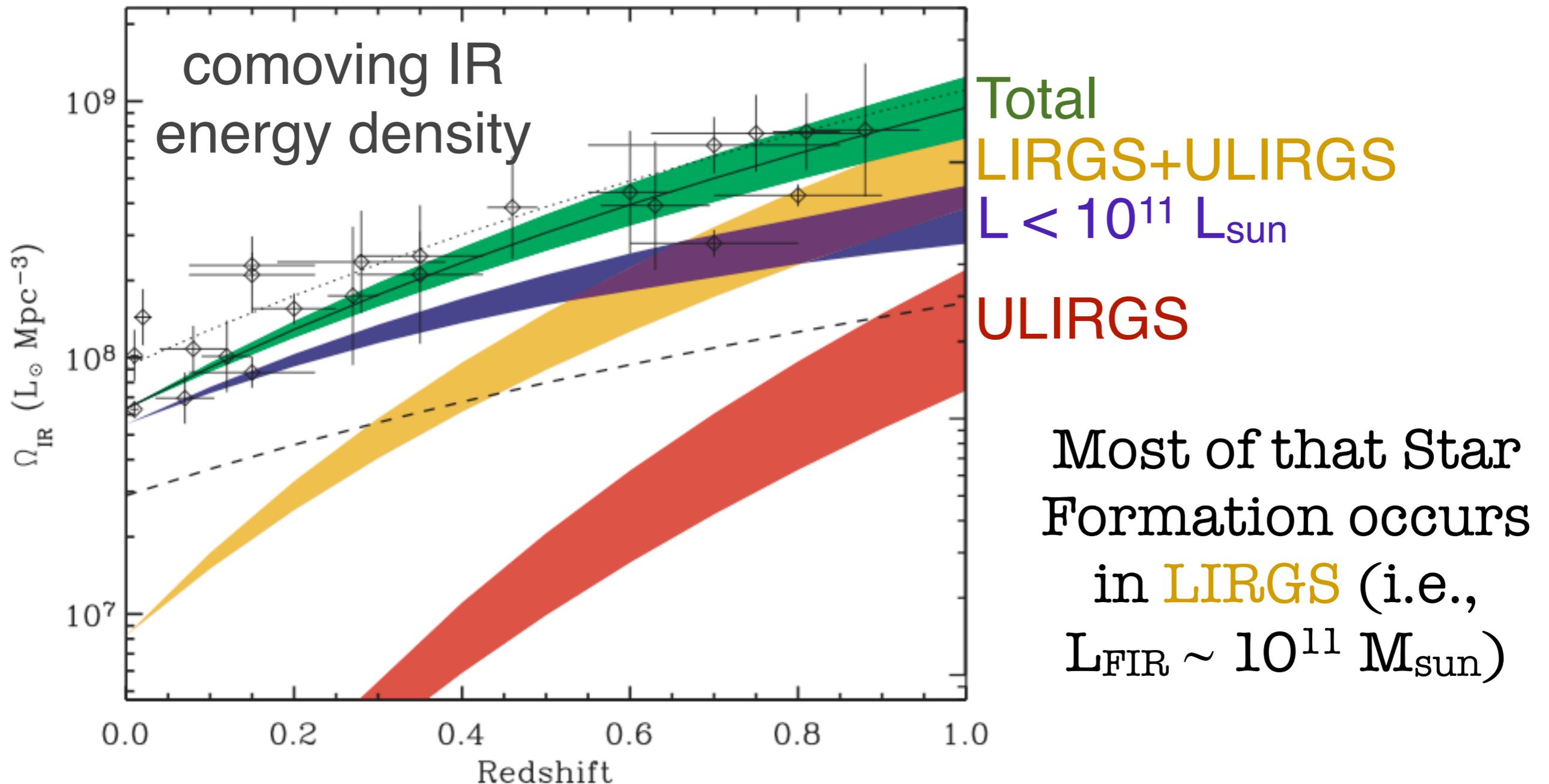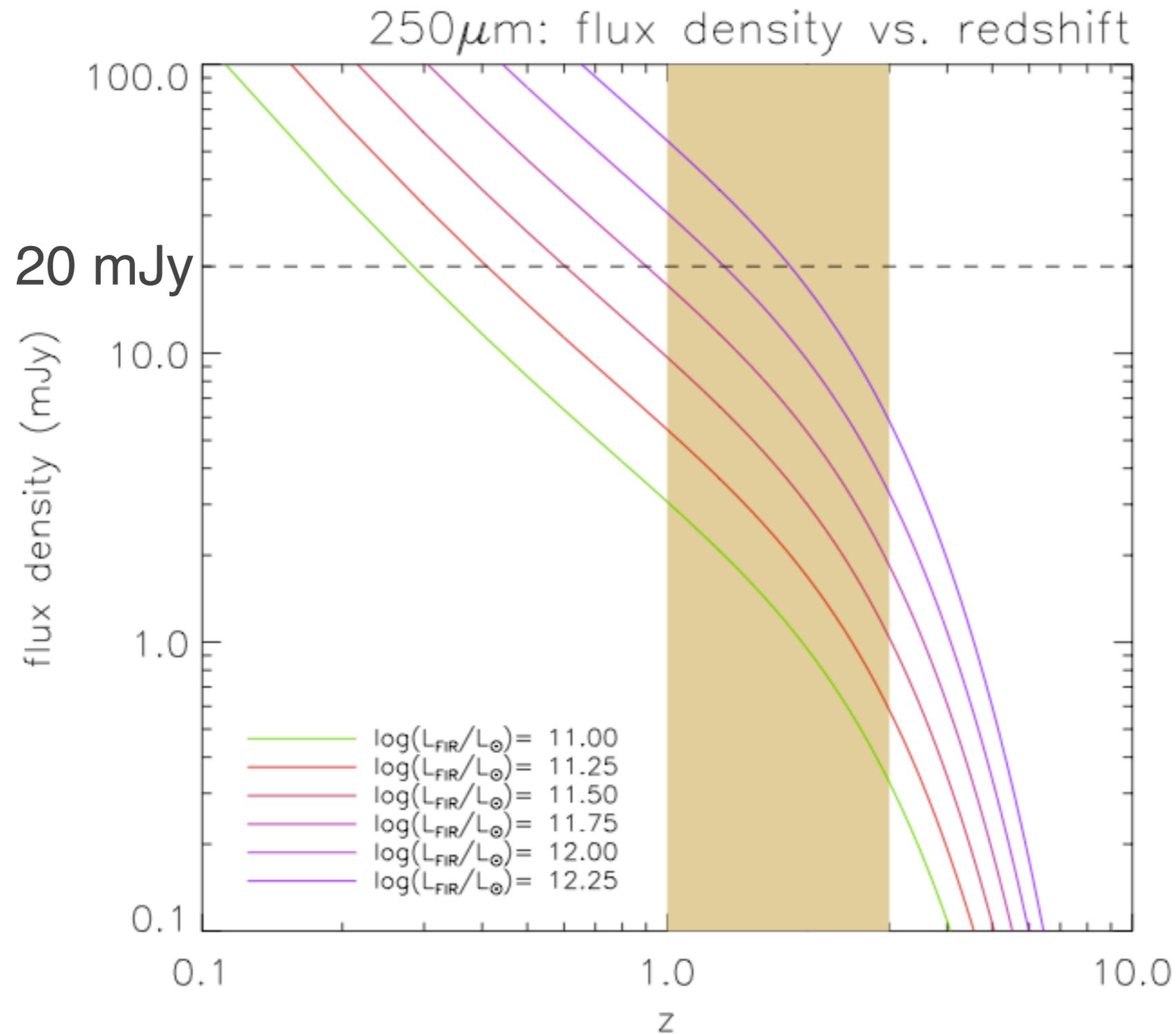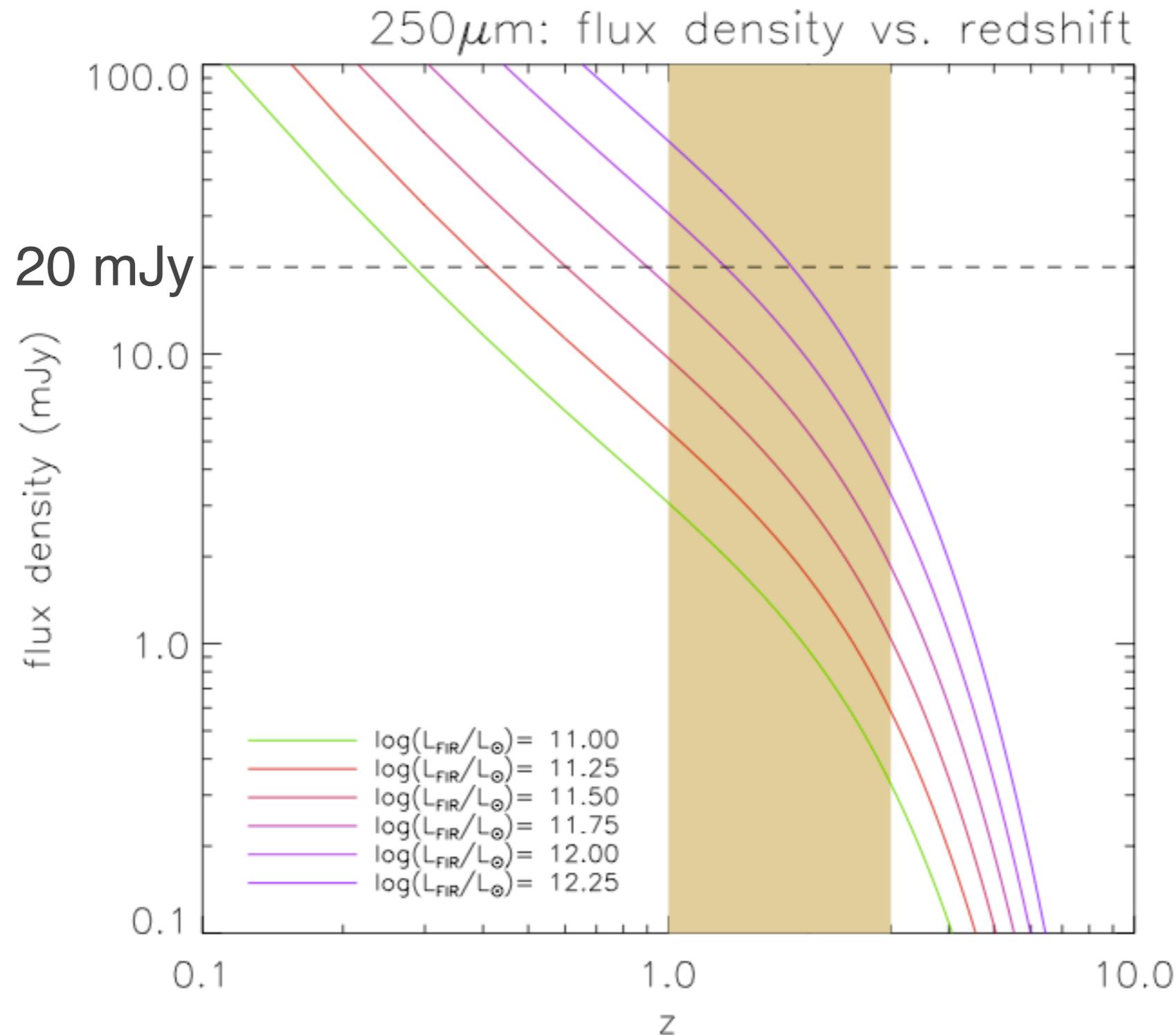
Typical LIRGS at z ~ 1-3 have flux densities S_{ave} ~ 1-10 mJy (at 250 μm)

the galaxies which form the bulk of the stellar mass are those which make up the unresolved background!

Measure Clustering Directly from Correlations in the Fluctuations!
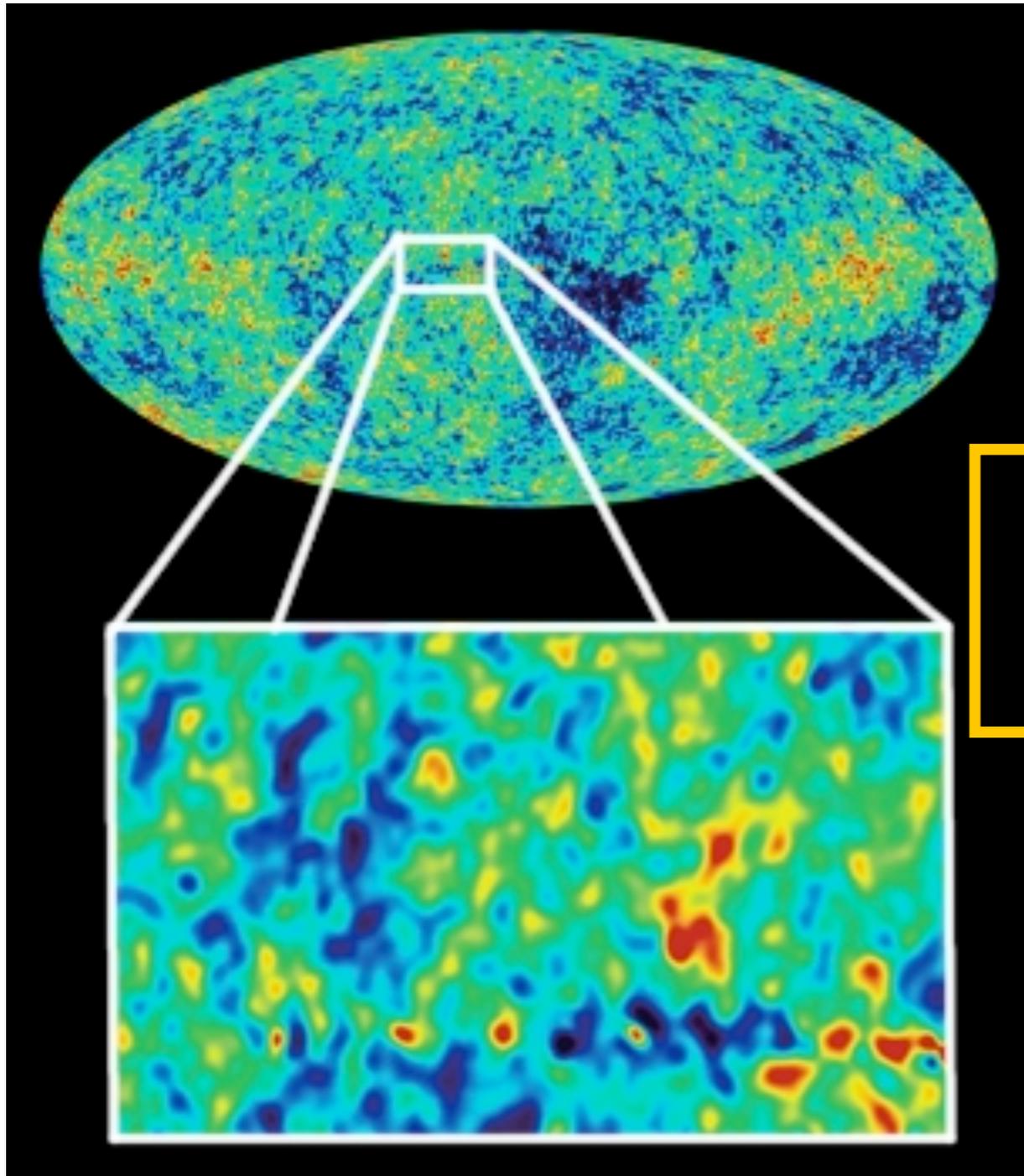
WMAP

Measure Clustering Directly from Correlations in the Fluctuations!
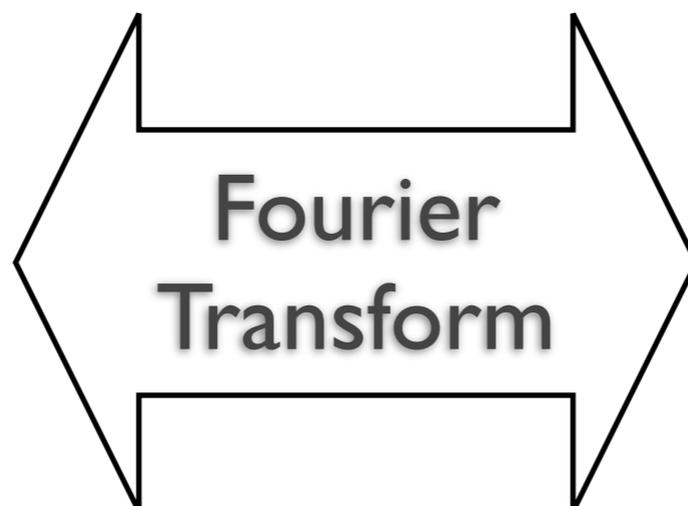
Power Spectrum ⟸ Fourier Transform ⟹ **2-Point Correlation Function**
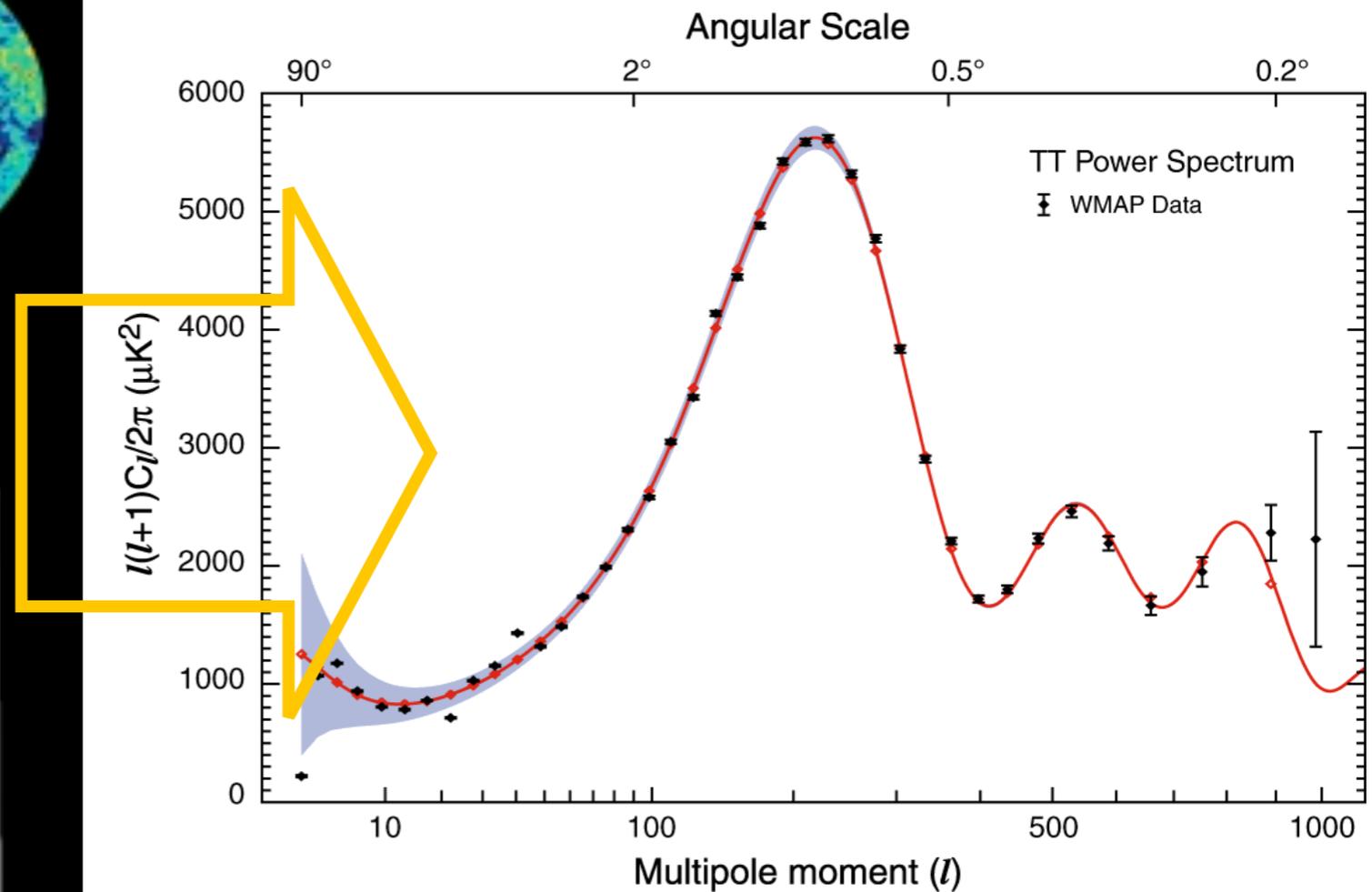
BLAST

UBC
Ed Chapin
Mark Halpern
Gaelen Marsden
Douglas Scott
Don Wiebe

U of T
Peter Martin
Barth Netterfield

Brown University
Greg Tucker

UPenn
Mark Devlin
Jeff Klein
Chris Semisch
Matt Truch

U of Miami
Josh Gundersen
Nick Thomas

INAOE (Mexico)
David Hughes
Itziar Aretxaga

Cardiff University
Peter Ade
Matt Griffin
Peter Hargrave
Phil Mauskopf
Carole Tucker
Enzo Pascale
Lorenzo Moncelsi

Open University
Mattia Negrello

U. Arizona
Marie Rex

JPL
Jamie Bock

CDF (France)
Guillaume Patanchon

Caltech
Marco Viero

Saskatoon

Archeops

MIT balloon

White Mountain

BAM

Toco

QMAP

BOOMERanG

WMAP

Cobra

QMAT

MINT

MAX

White Dish

ACT

UBC
Ed Chapin
Mark Halpern
Gaelen Marsden
Douglas Scott
Don Wiebe

U of T
Peter Martin
Barth Netterfield

Brown University
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Lorenzo Moncelsi

Open University
Mattia Negrello

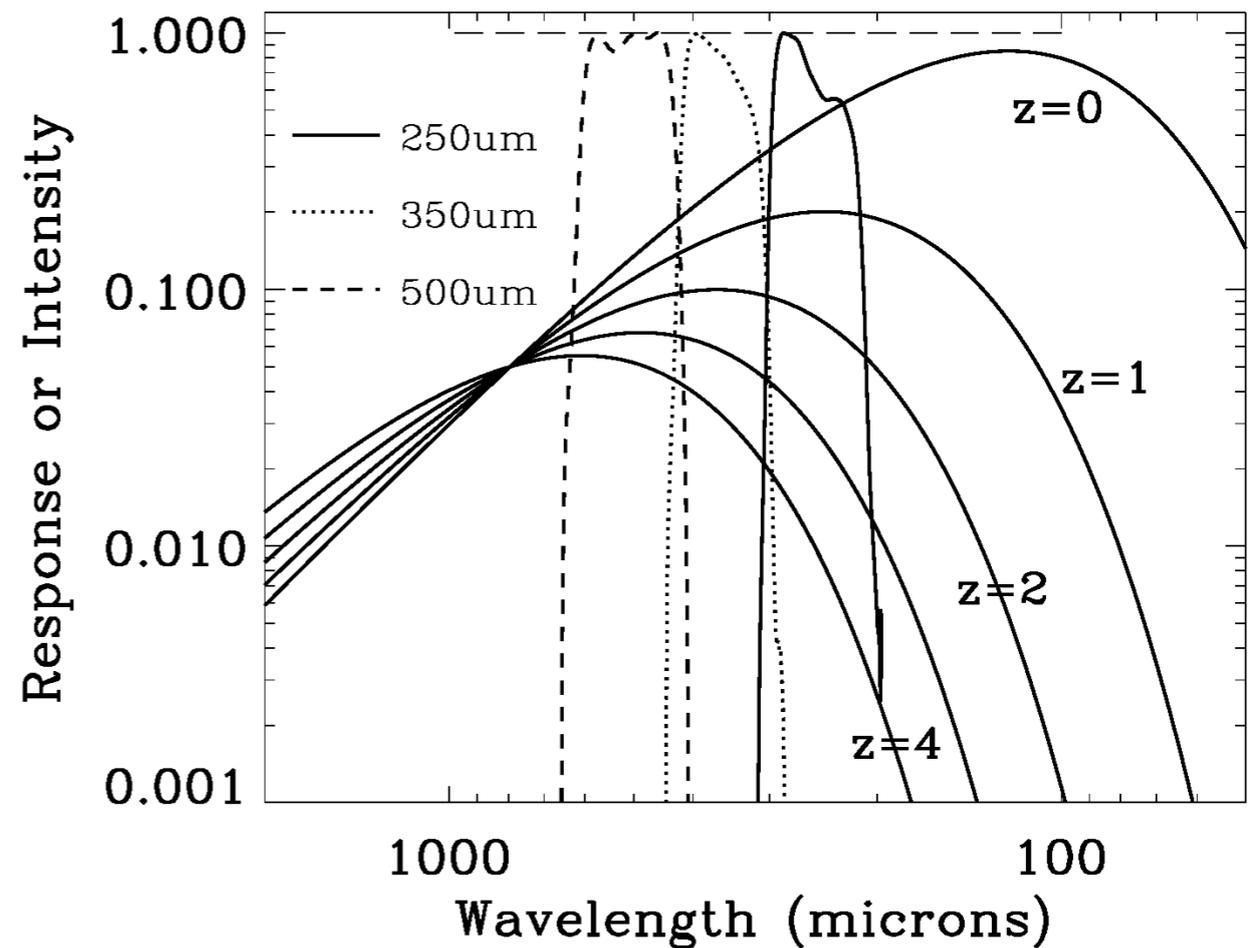**U. Arizona**
Marie Rex

JPL
Jamie Bock

CDF (France)
Guillaume Patanchon

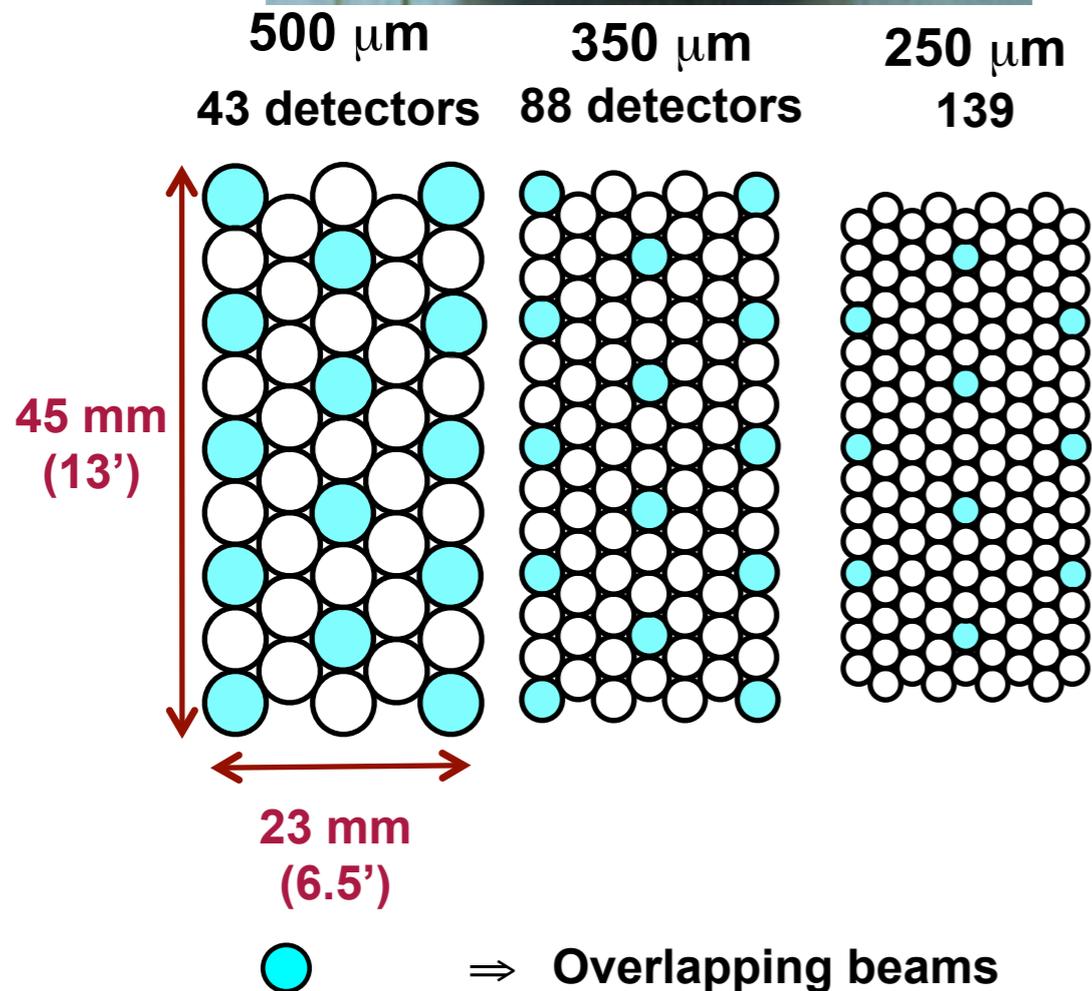**Caltech**
Marco Viero

BLAST

designed to bracket the redshifted peak

Balloon-borne Large Aperture Submillimeter Telescope (BLAST)

SPIRE-like
spider-web bolometer
detector arrays...

500 μm
43 detectors

350 μm
88 detectors

250 μm
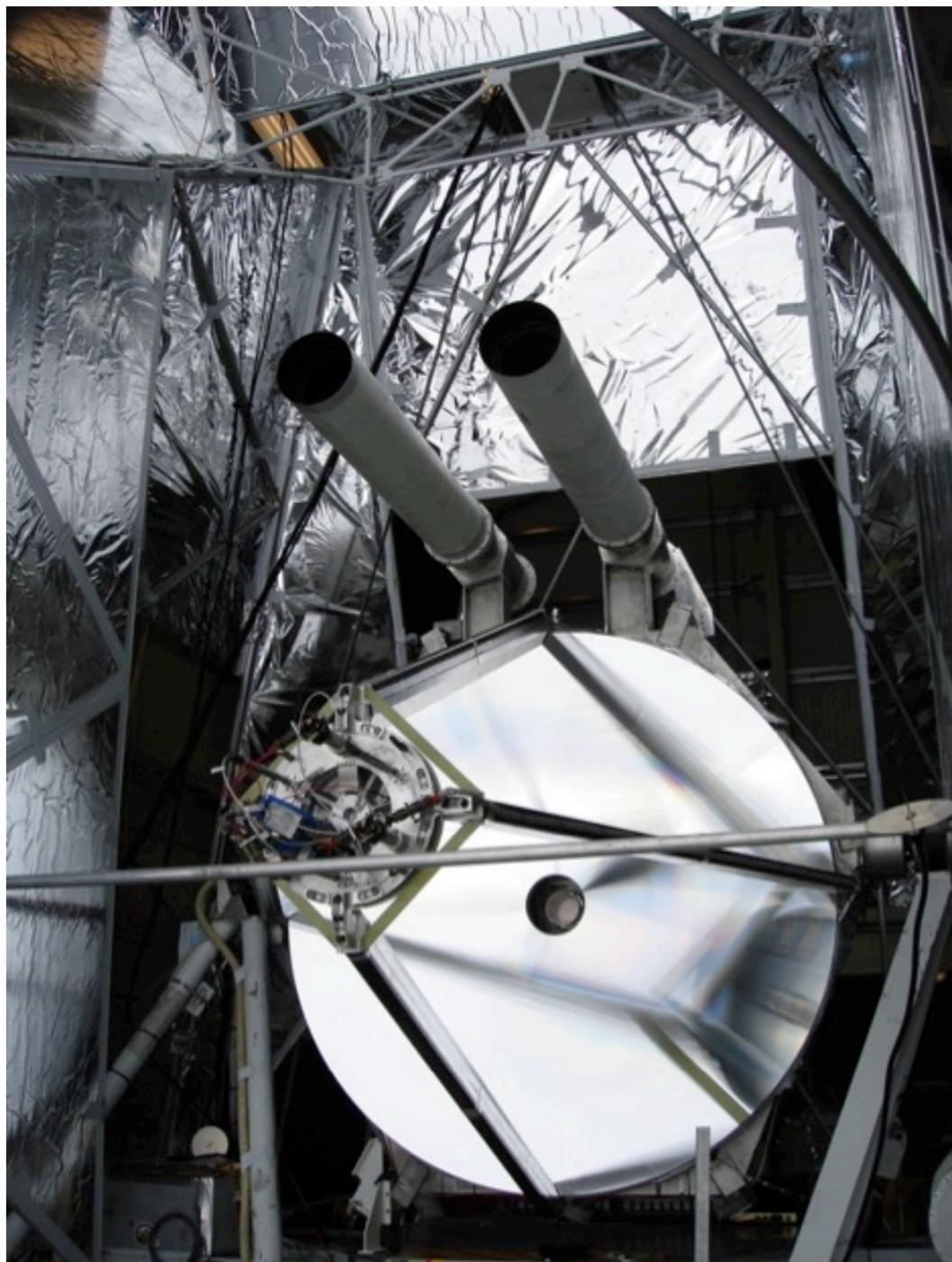**139**

45 mm
(13')

23 mm
(6.5')

⇒ **Overlapping beams**

Balloon-borne Large Aperture Submillimeter Telescope (BLAST)

SPIRE-like
spider-web bolometer
detector arrays...

... but a 1.8 m primary
resulting in beams:
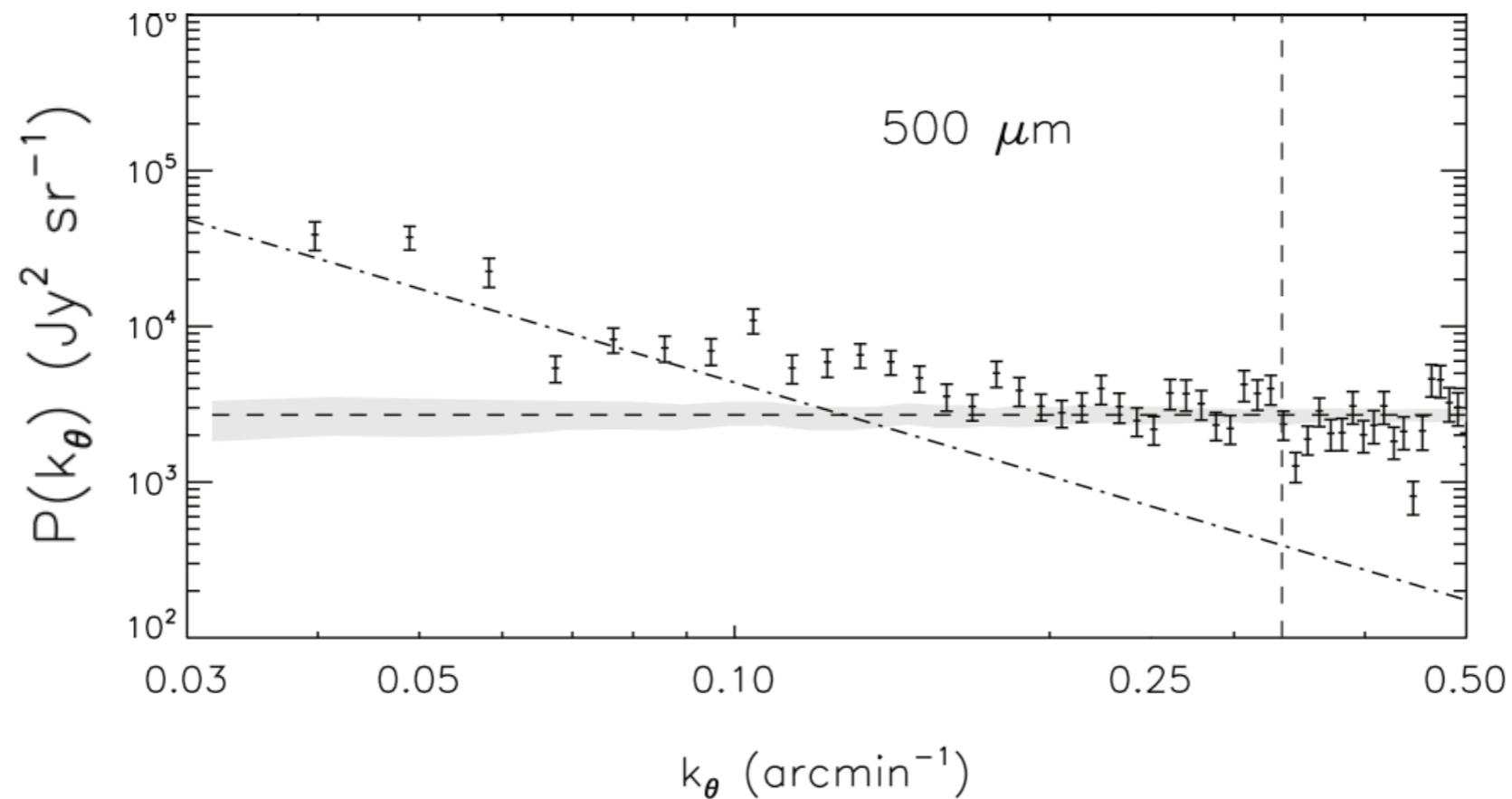36" - 250 µm
45" - 350 µm
60" - 500 µm
i.e., twice the size of SPIRE's
beams

BLAST Measured Clustering from Fluctuations

BLAST Measured Clustering from Fluctuations

500 μm
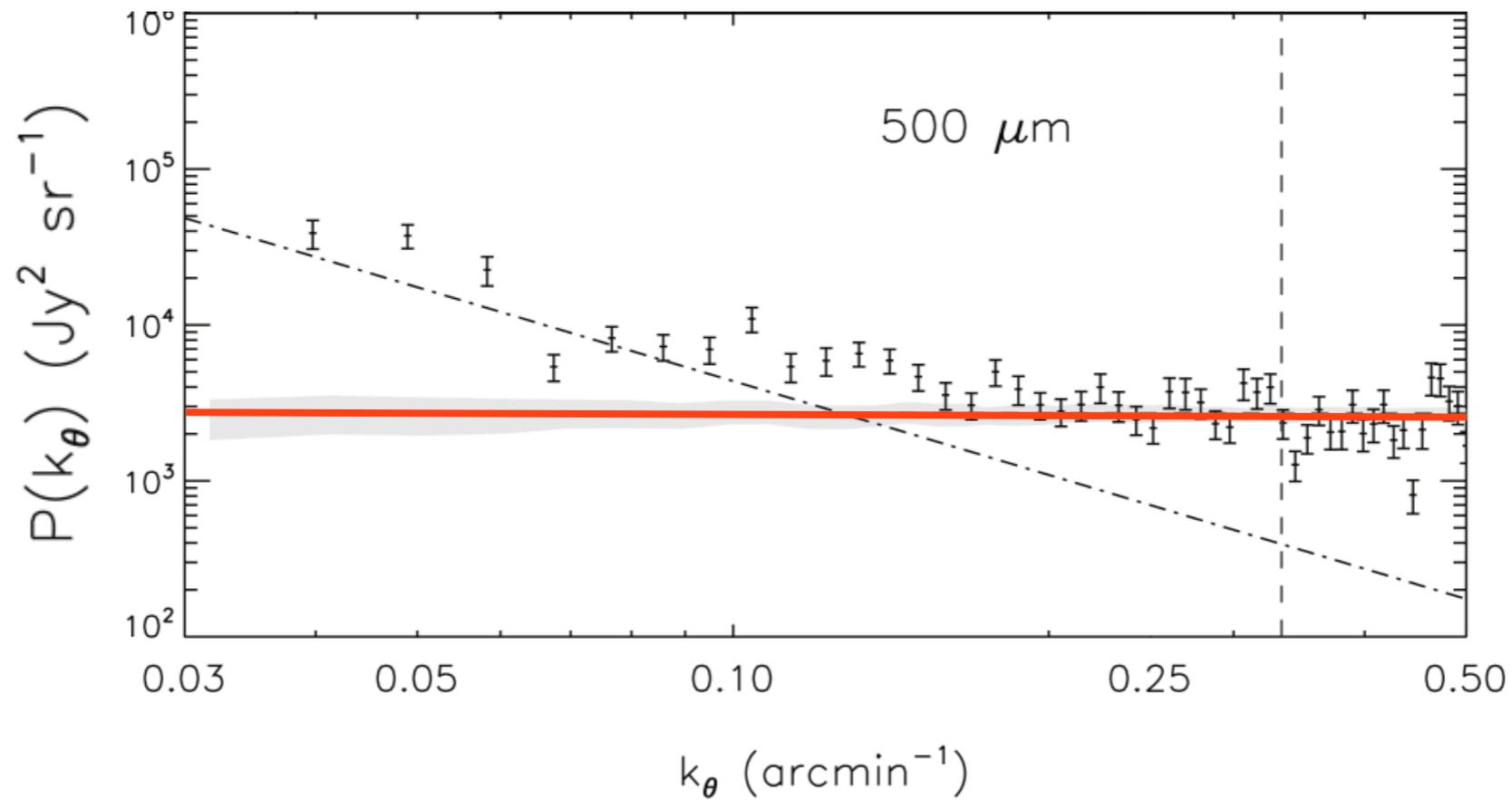
Viero et al. 0904.1200

BLAST Measured Clustering from Fluctuations

Shot Noise

Viero et al. 0904.1200

BLAST Measured Clustering from Fluctuations

Shot Noise

Clustering

Viero et al. 0904.1200

BLAST Measured Clustering from Fluctuations

Excess Signal from Galaxy Clustering

500 μm

Shot Noise

Clustering

Viero et al. 0904.1200

BLAST Measured Clustering from Fluctuations

Clustering Signal After Removal of Shot Noise
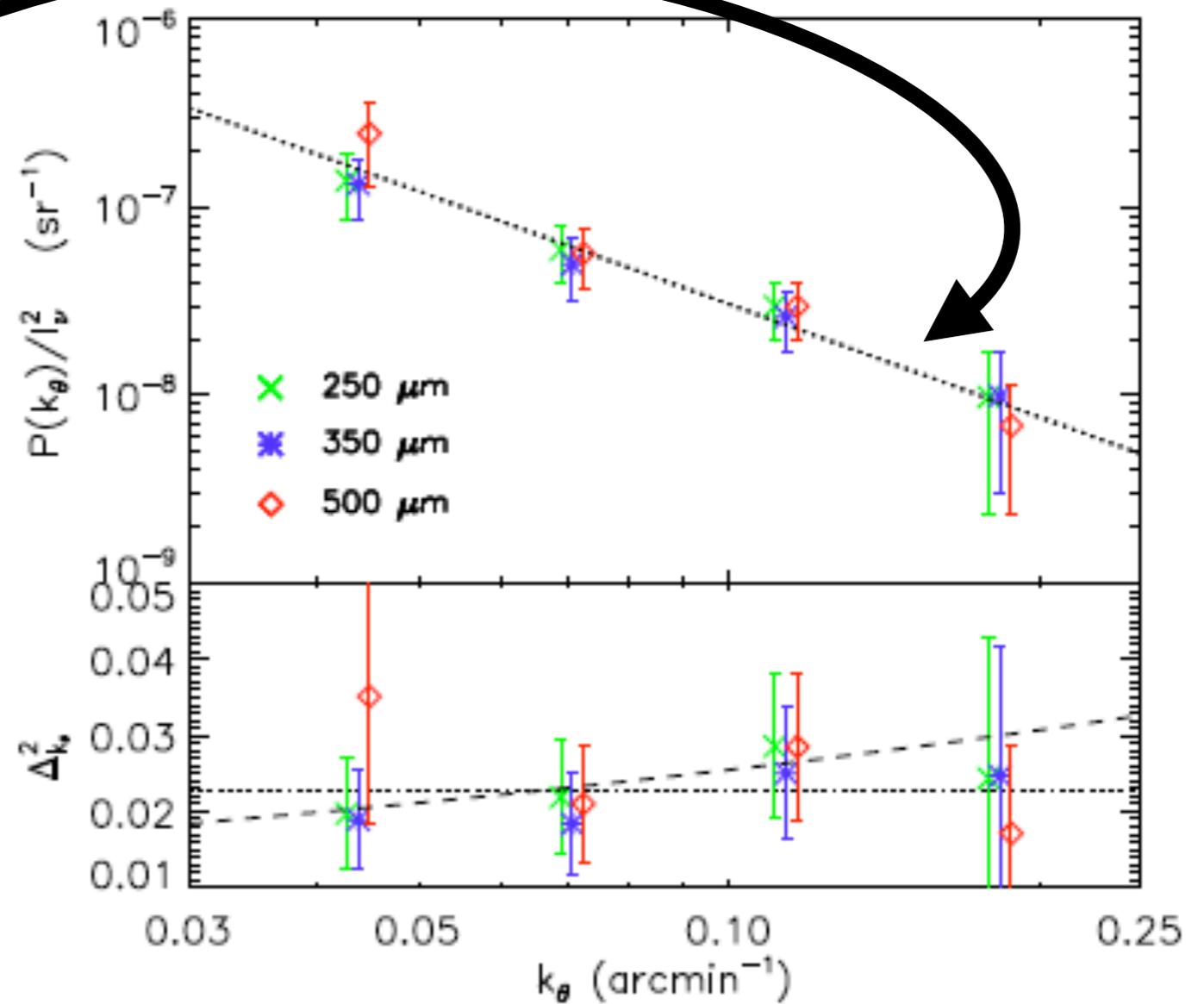
Viero et al. 0904.1200

BLAST Measured Clustering from Fluctuations
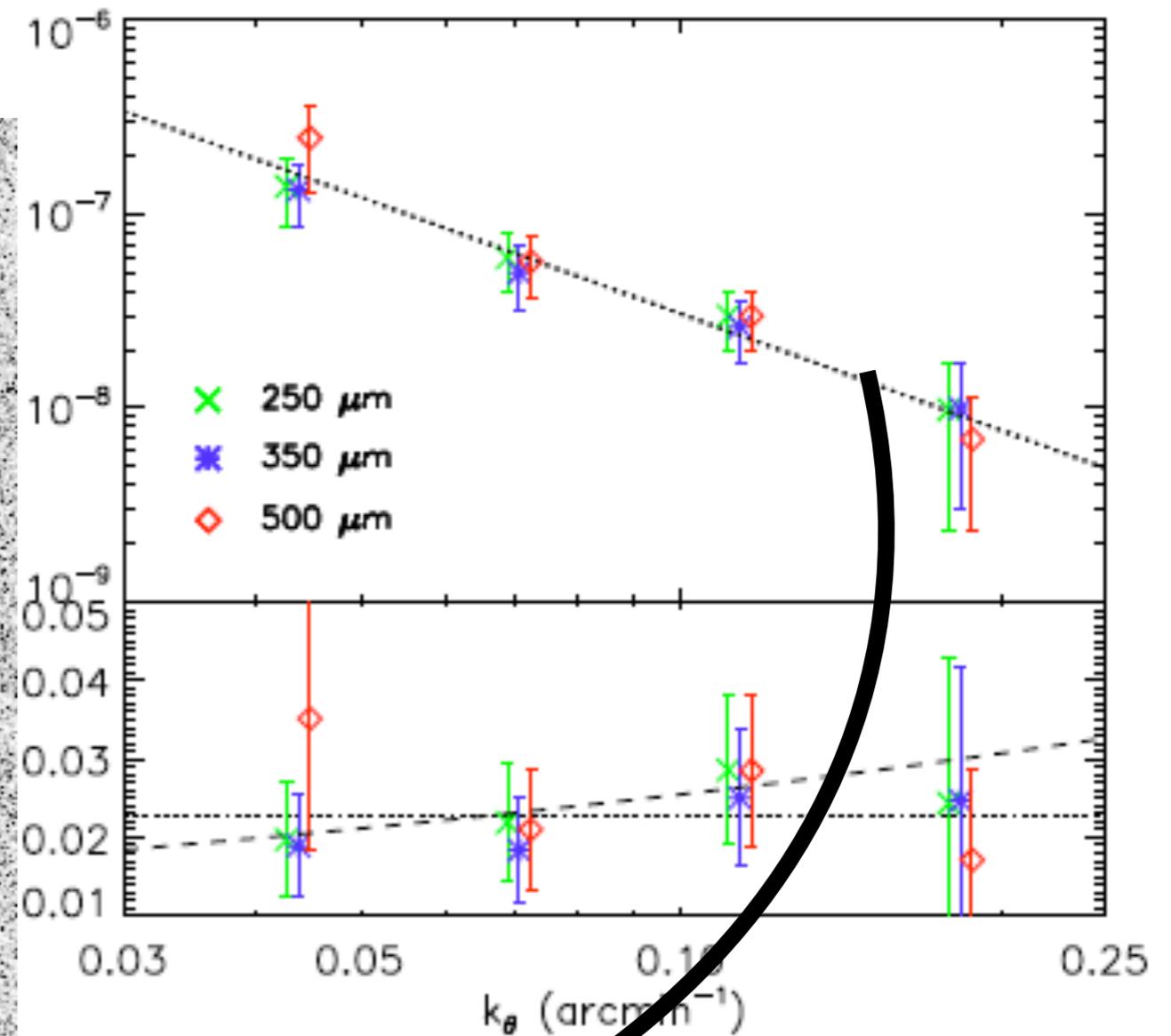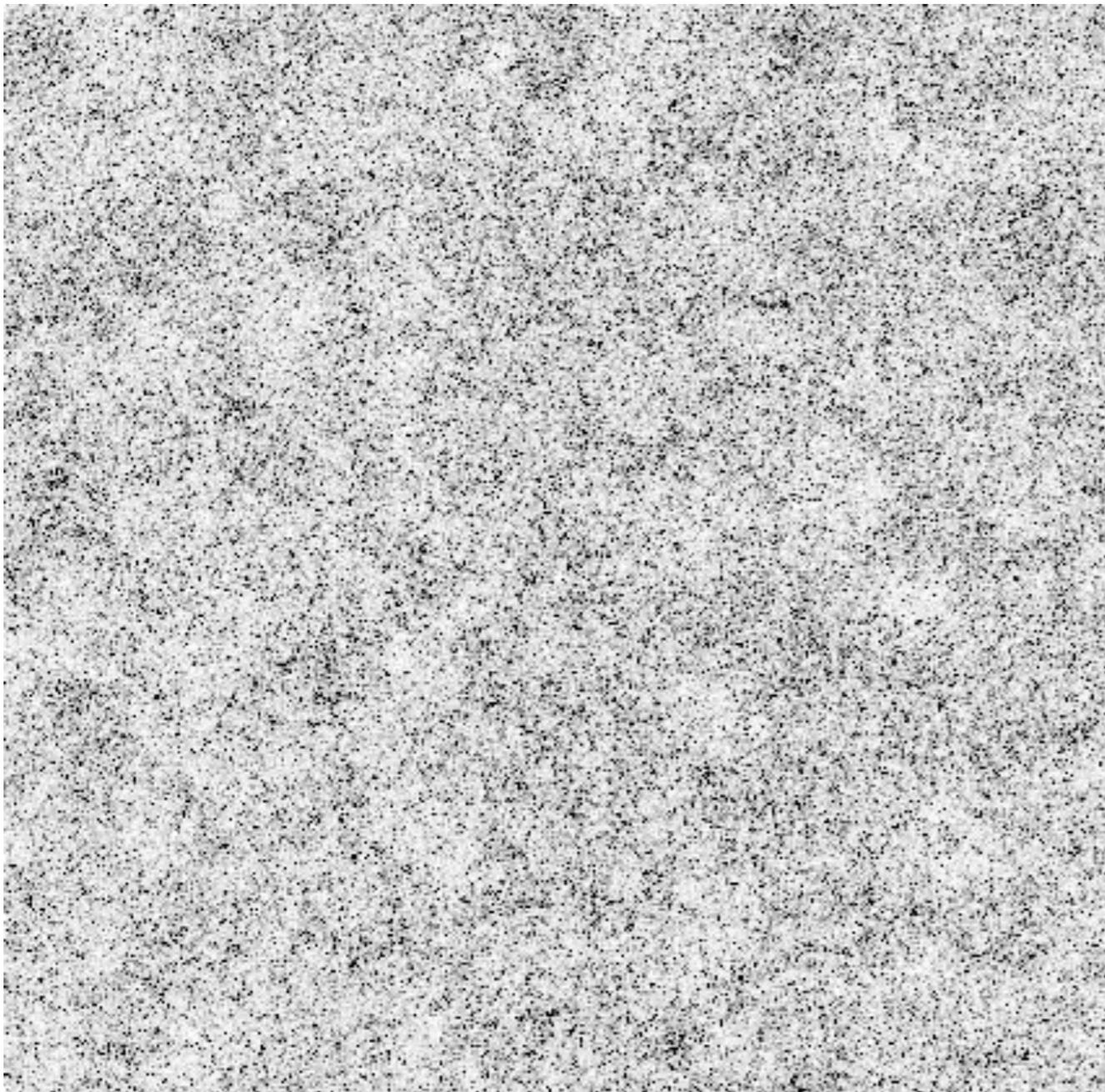
BLAST prediction...

BLAST Measured Clustering from Fluctuations

BLAST prediction...
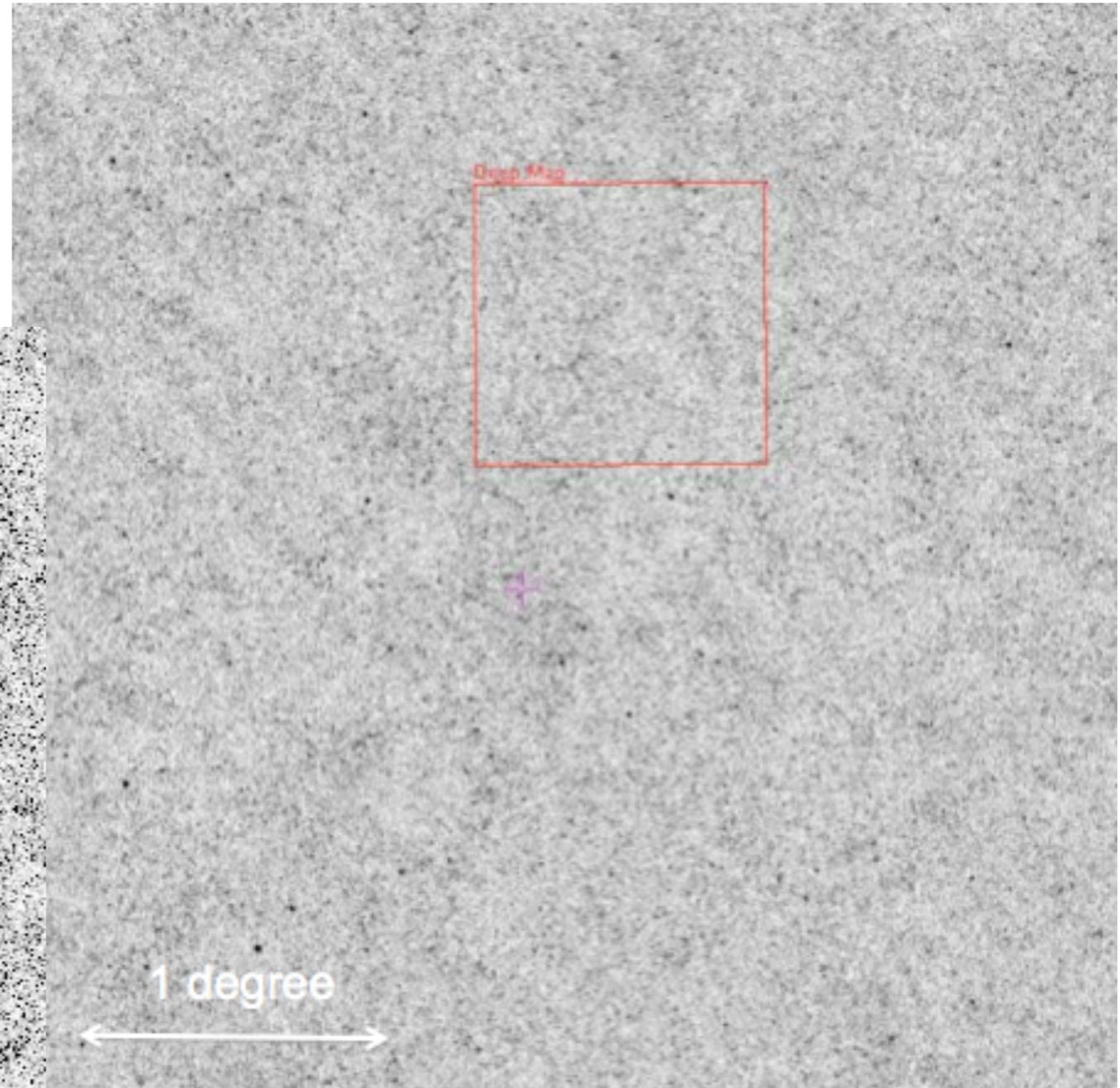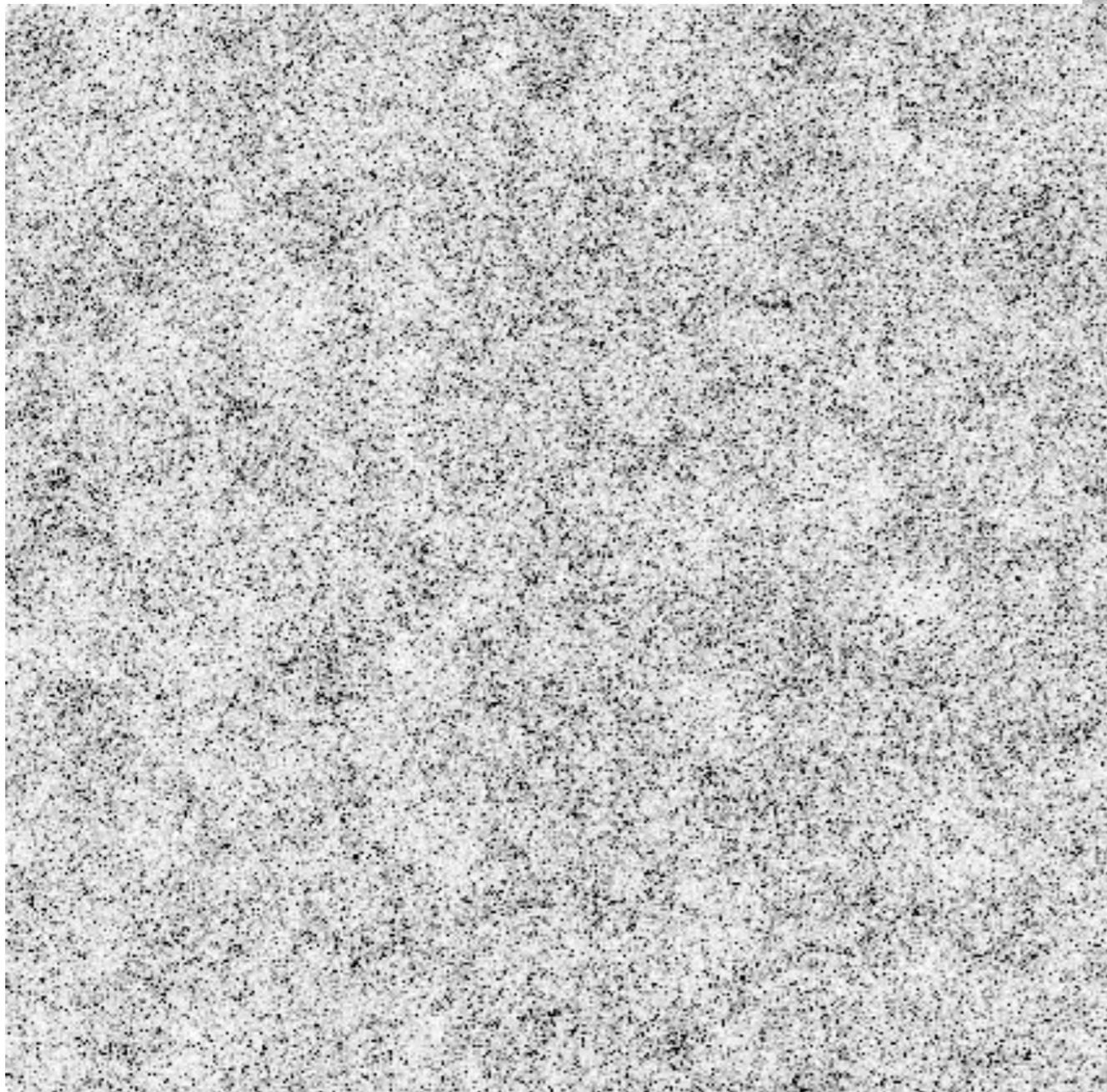
... Herschel observation

1 degree

Estimated Host Halo Mass with Halo-Model

Estimated Host Halo Mass with Halo-Model
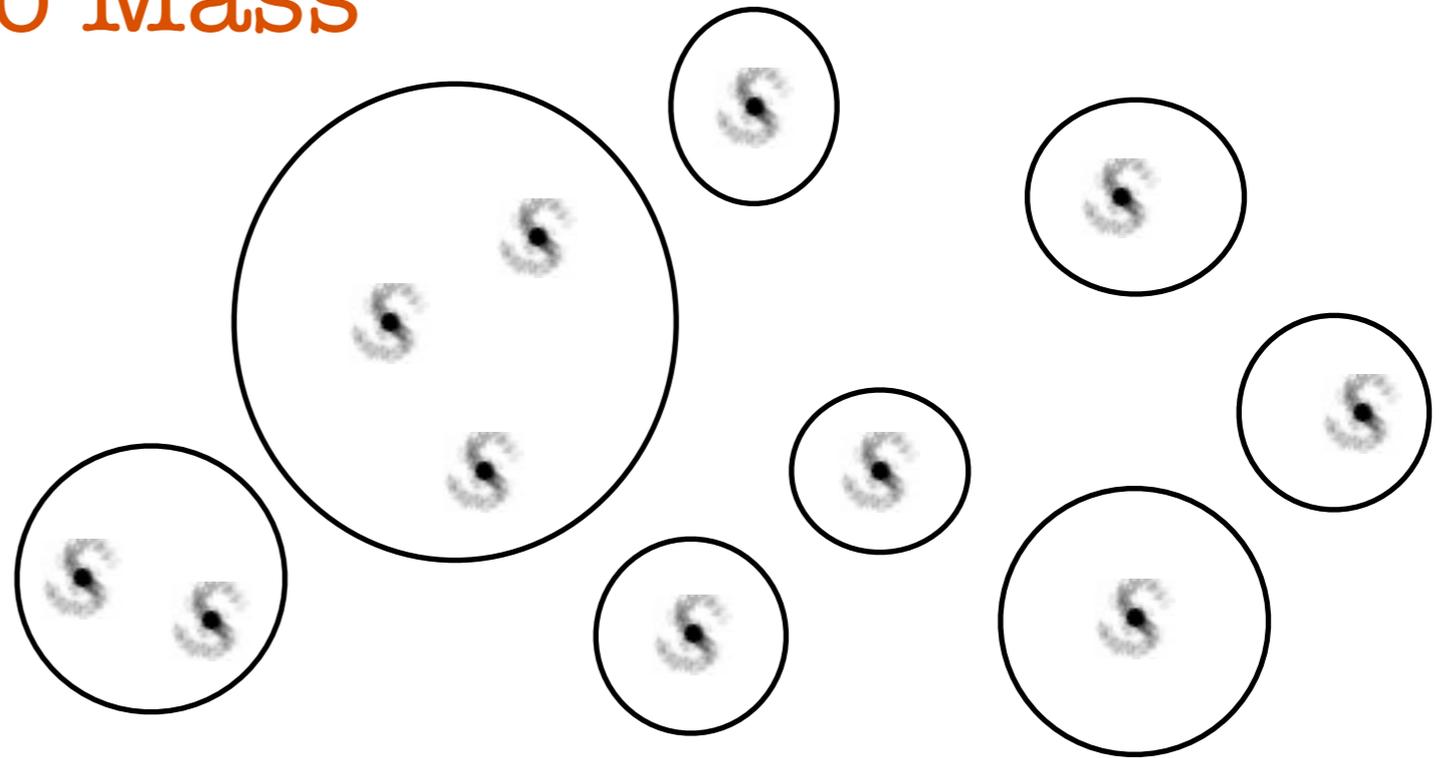
- Clustering Signal made up of two regimes

Estimated Host Halo Mass with Halo-Model

- Clustering Signal made up of two regimes

  - 2-halo: Linear Regime (large scales)

Estimated Host Halo Mass with Halo-Model

- Clustering Signal made up of two regimes

  - 2-halo: Linear Regime (large scales)

  - 1-halo: Non-Linear Regime (small scales)

Estimated Host Halo Mass with Halo-Model

- Clustering Signal made up of two regimes

  - 2-halo: Linear Regime (large scales)

  - 1-halo: Non-Linear Regime (small scales)

Estimated Host Halo Mass
with Halo-Model

Halo Model of Mattia Negrello &
Source Model of Lagache 2004

Viero et al. 0904.1200

marco viero   17
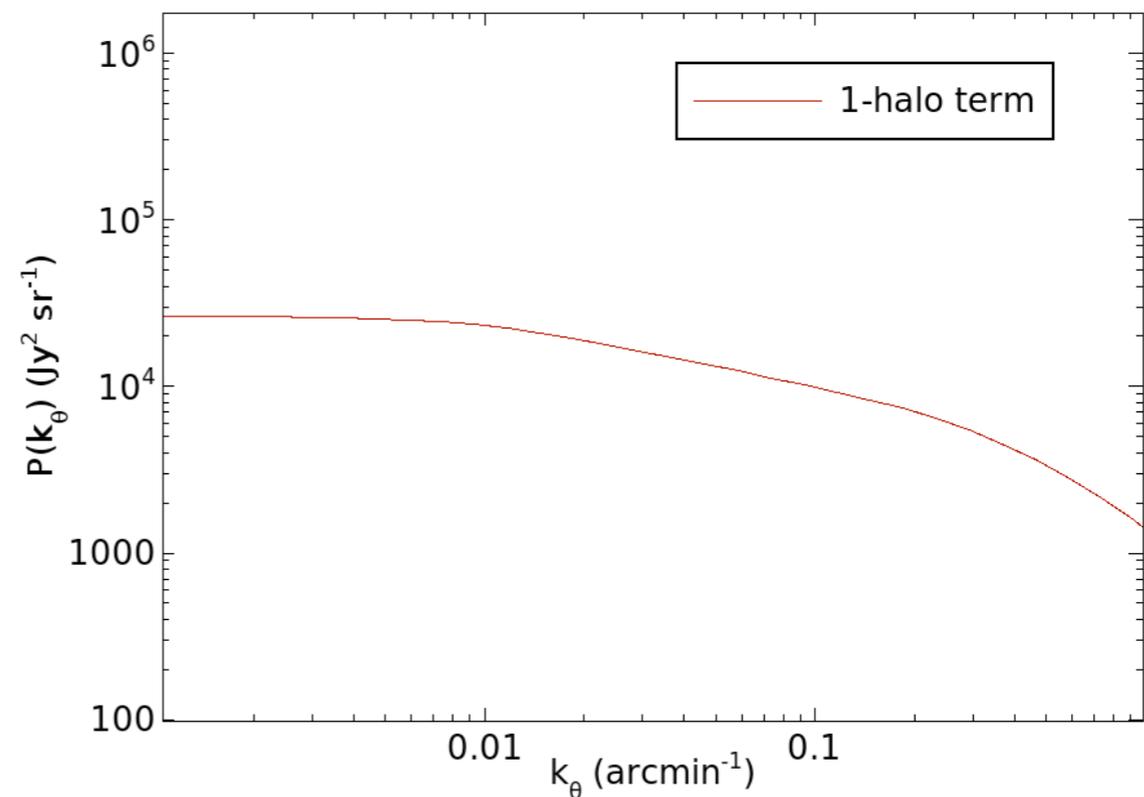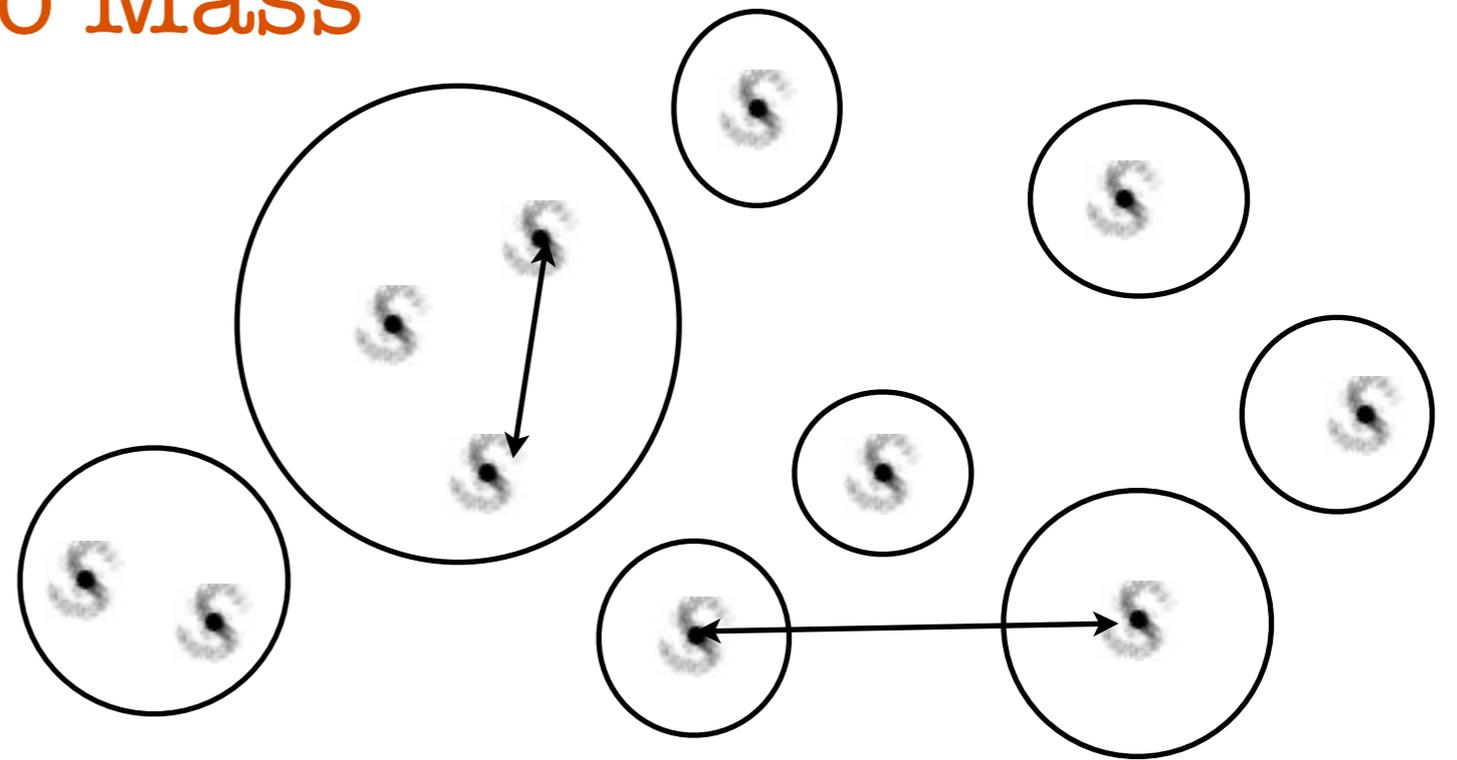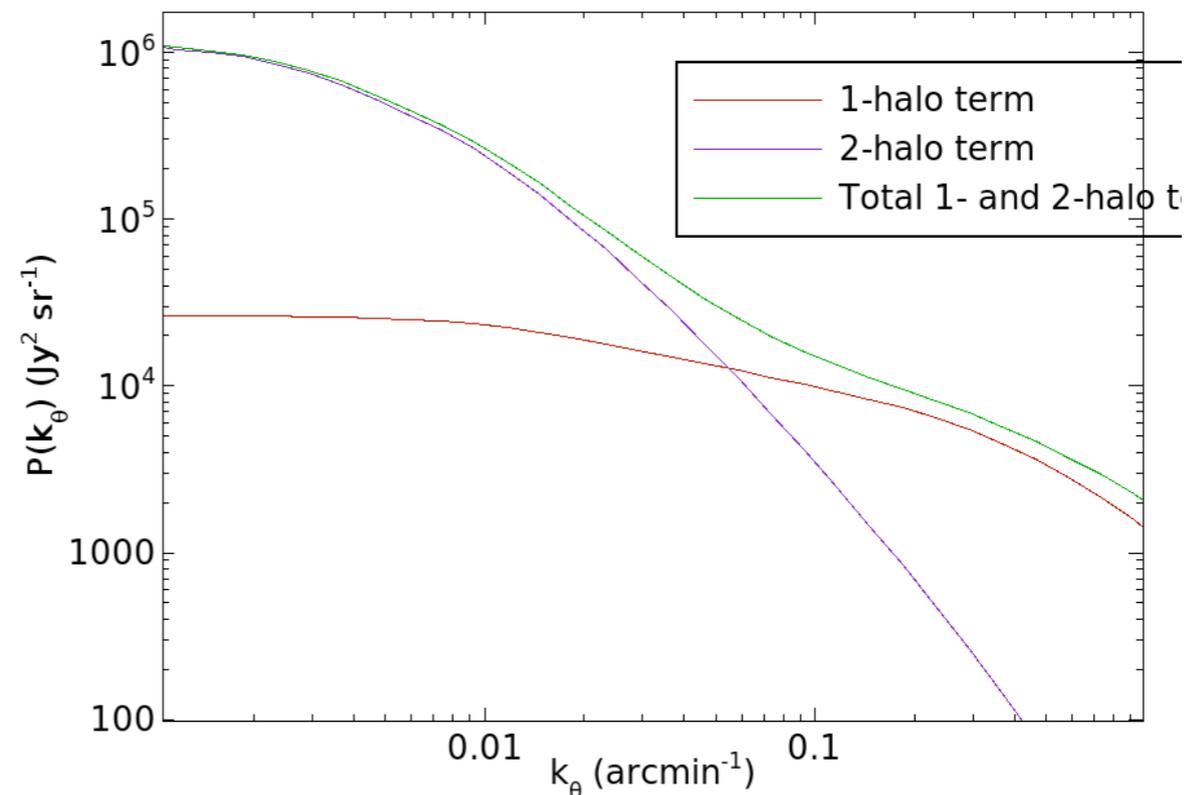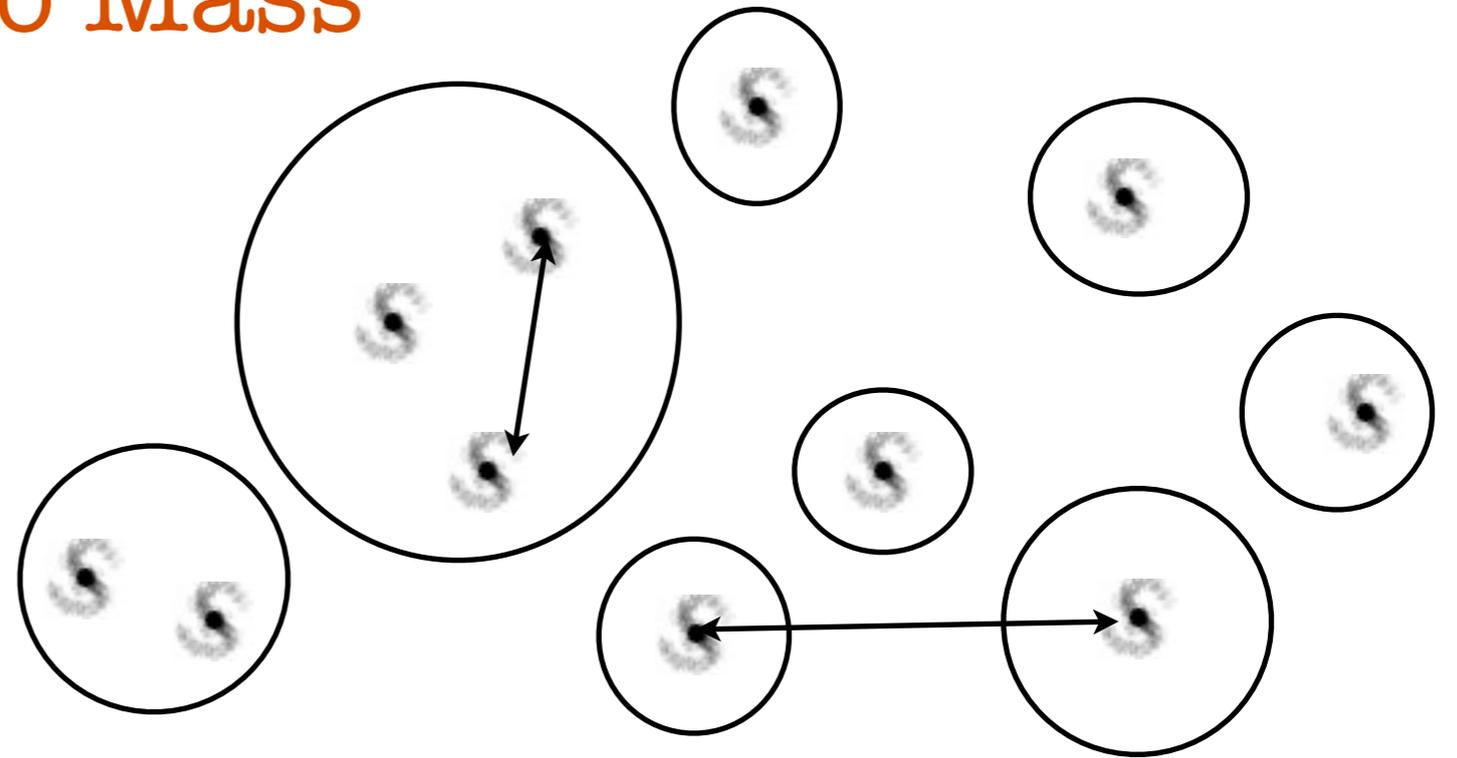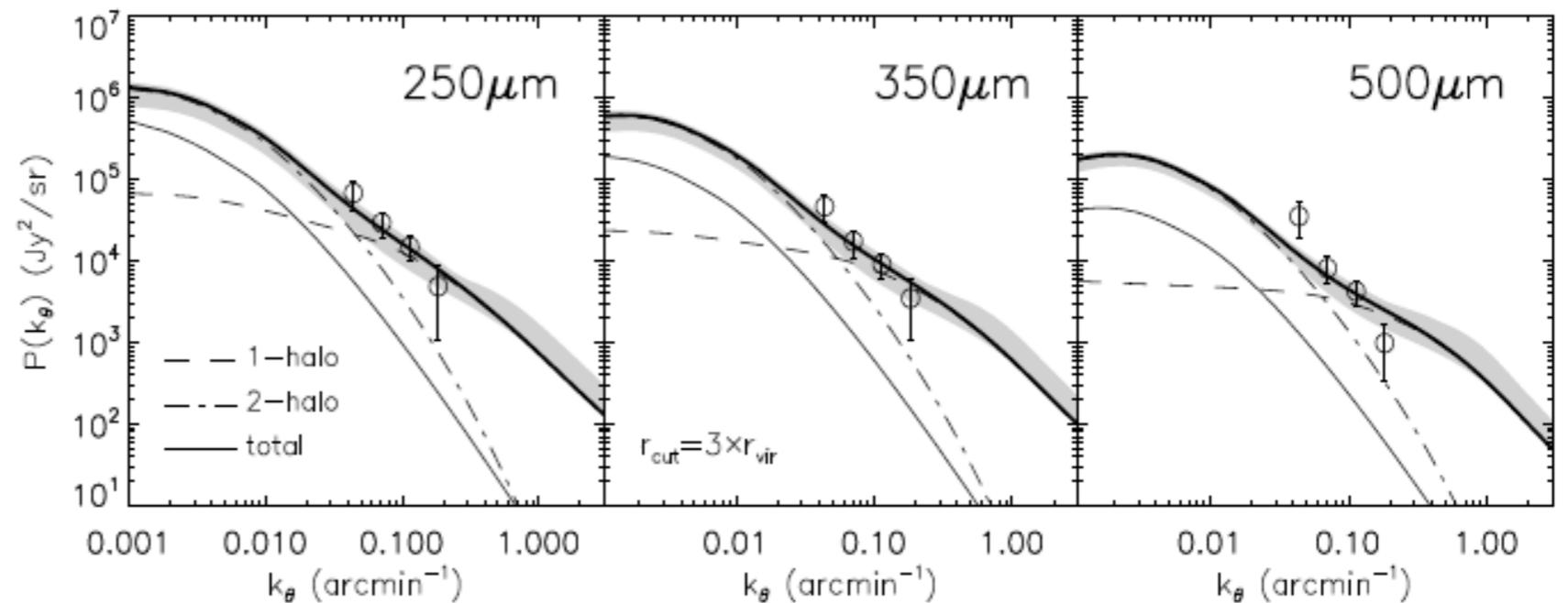
Estimated Host Halo Mass with Halo-Model

Confirmed Today by Planck!

Halo Model of Mattia Negrello & Source Model of Lagache 2004

Viero et al. 0904.1200

Estimated Host Halo Mass with Halo-Model

Halo Model of Mattia Negrello & Source Model of Lagache 2004

At z ~ 2

- $b_{linear} \approx 4.0$
- $M_{eff} \approx 6 \times 10^{12} \, M_{sun}$
- $M_{min} \approx 3 \times 10^{11} \, M_{sun}$
- $b_{eff} \approx 2.4$

Viero et al. 0904.1200

Estimated Host Halo Mass with Halo-Model

At z ~ 2

- $b_{linear} \approx 4.0$
- $M_{eff} \approx 6 \times 10^{12} \, M_{sun}$
- $M_{min} \approx 3 \times 10^{11} \, M_{sun}$
- $b_{eff} \approx 2.4$
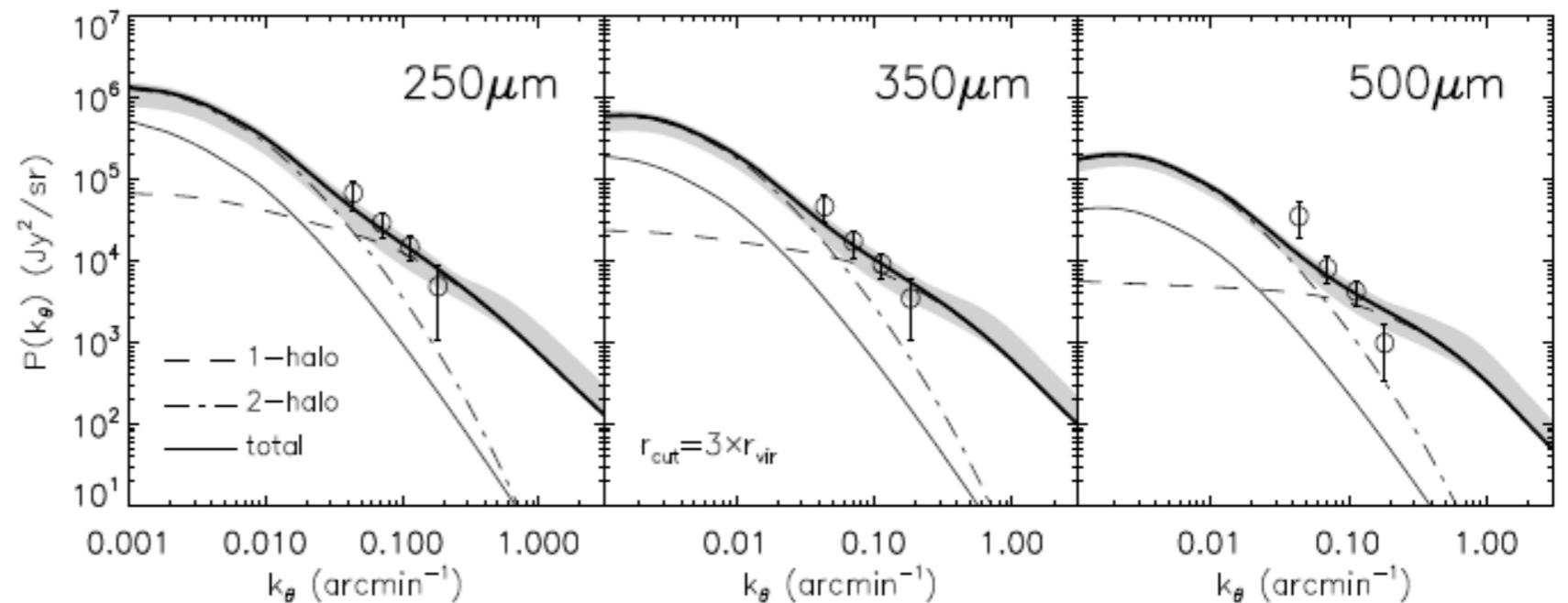
Confirmed 5 days ago by Herschel!

Sub-millimetre galaxies reside in dark matter halos with masses greater than 3×10^{11} M$_\odot$

A. Amblard[1], A. Cooray[1,2], P. Serra[1], B. Altieri[3], V. Arumugam[4], H. Aussel[5], A. Blain[2], J. Bock[2,6], A. Boselli[7], V. Buat[7], N. Castro-Rodríguez[8,9], A. Cava[8,9], P. Chanial[10], E. Chapin[11], D.L. Clements[10], A. Conley[12], L. Conversi[3], C.D. Dowell[2,6], E. Dwek[13], S. Eales[14], D. Elbaz[5], D. Farrah[15], A. Franceschini, W. Gear[14], J. Glenn[12], M. Griffin[14], M. Halpern[11], E. Hatziminaoglou[17], E. Ibar[18], K. Isaak[14], R.J. Ivison[18,4], A.A. Khostovan[1], G. Lagache[19], L. Levenson[2,6], N. Lu[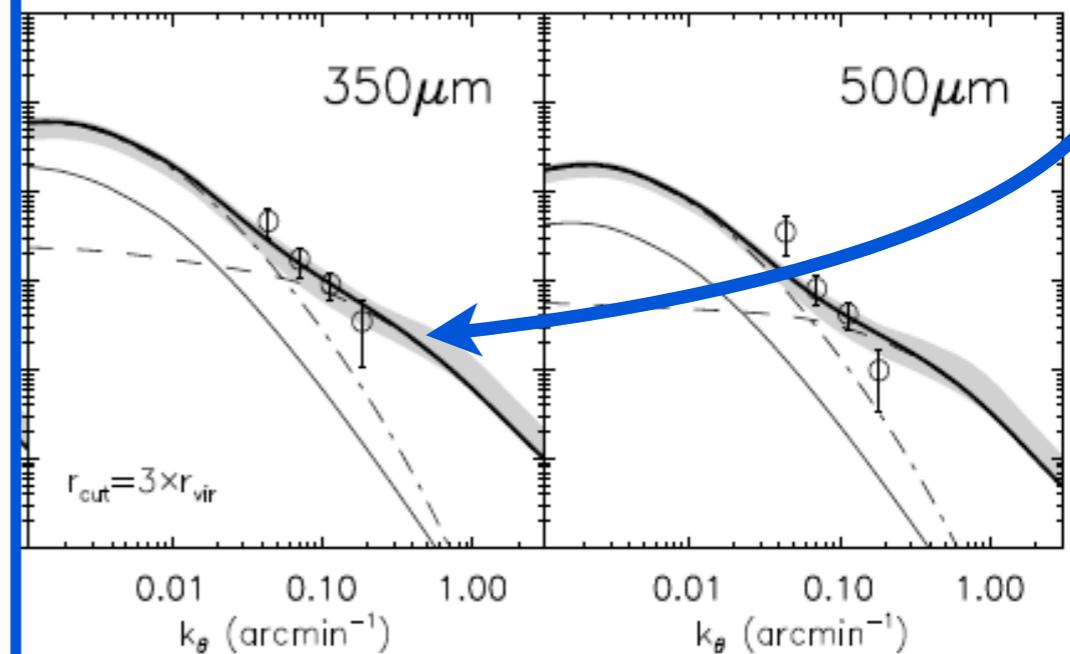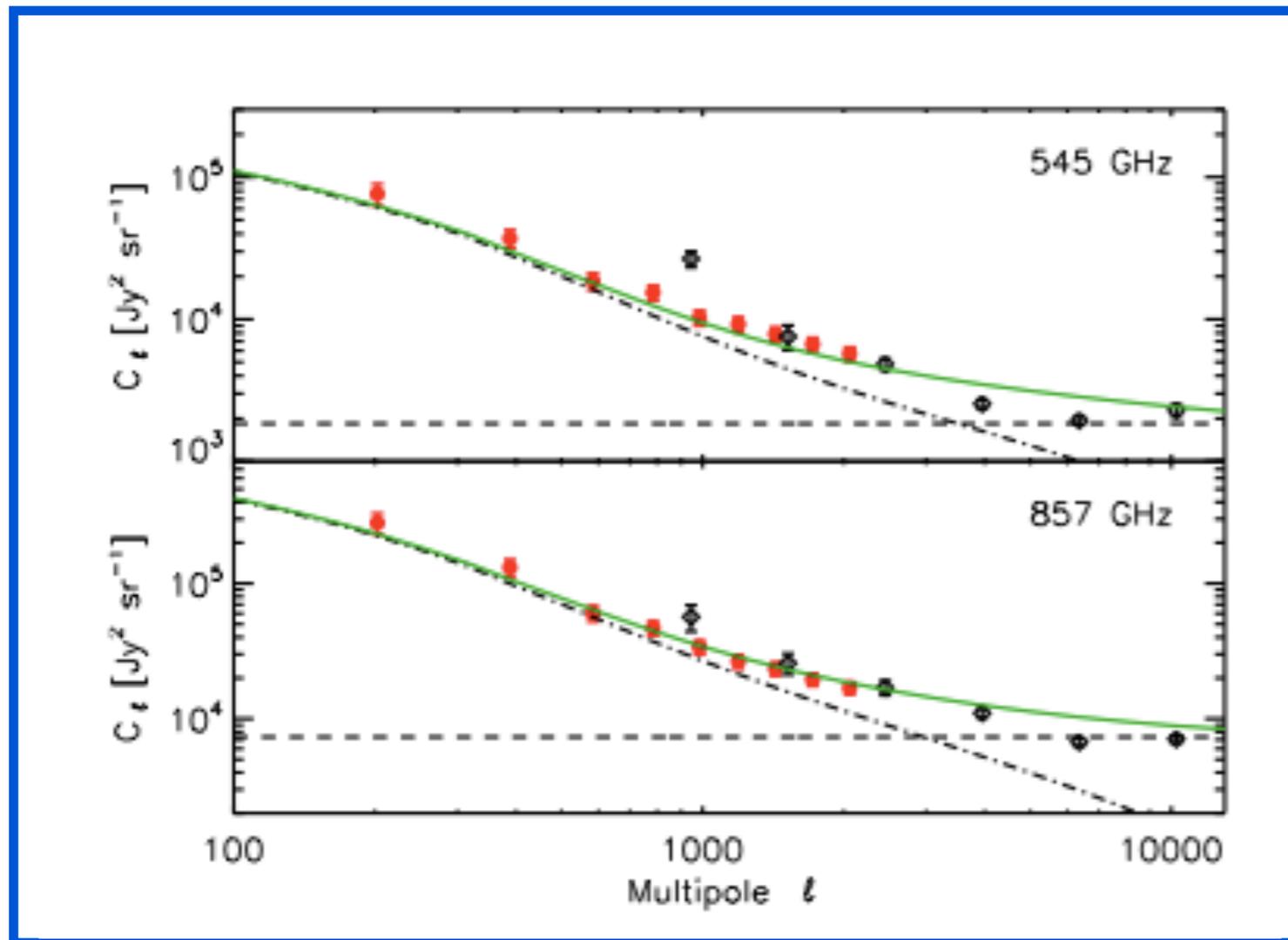2,20], S. Madden[5], B. Maffei[21], G. Mainetti[16], L. Marchetti[16], G. Marsden[11], K. Mitchell-Wynne[1], H.T. Nguyen[6,2], B. O'Halloran[10], S.J. Oliver[15], A. Omont[22], M.J. Page[23], P. Panuzzo[5], A. Papageorgiou[14], C.P. Pearson[23,24], I. Pérez-Fournon[8,9], M. Pohlen[14], N. Rangwala[12], I.G. Roseboom[15], M. Rowan-Robinson[10], M. Sánchez Portal, M. Sy, L. Vig

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 $\log_{10} M_{min}/M_\odot = 11.5^{+0.7}_{-0.2}$ at 350 μm with a bias factor for the galaxies of $2.4^{+1.0}_{-0.2}$. The minimum halo masses $\log_{10} M_{min}/M_\odot$ 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-

"I do CMB, so I don't care"

Galaxies Dominate the CMB at $\ell \geq 3000$
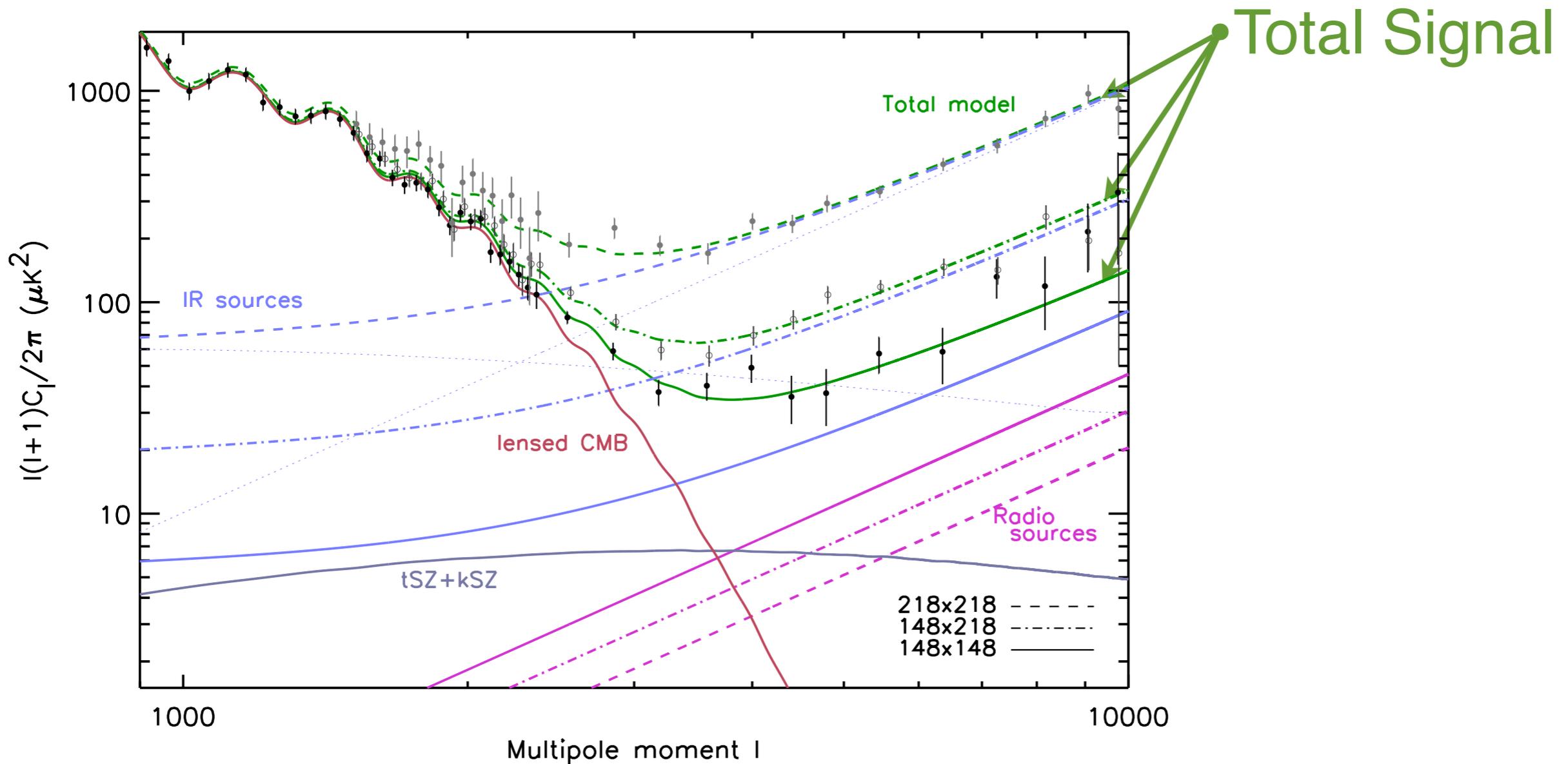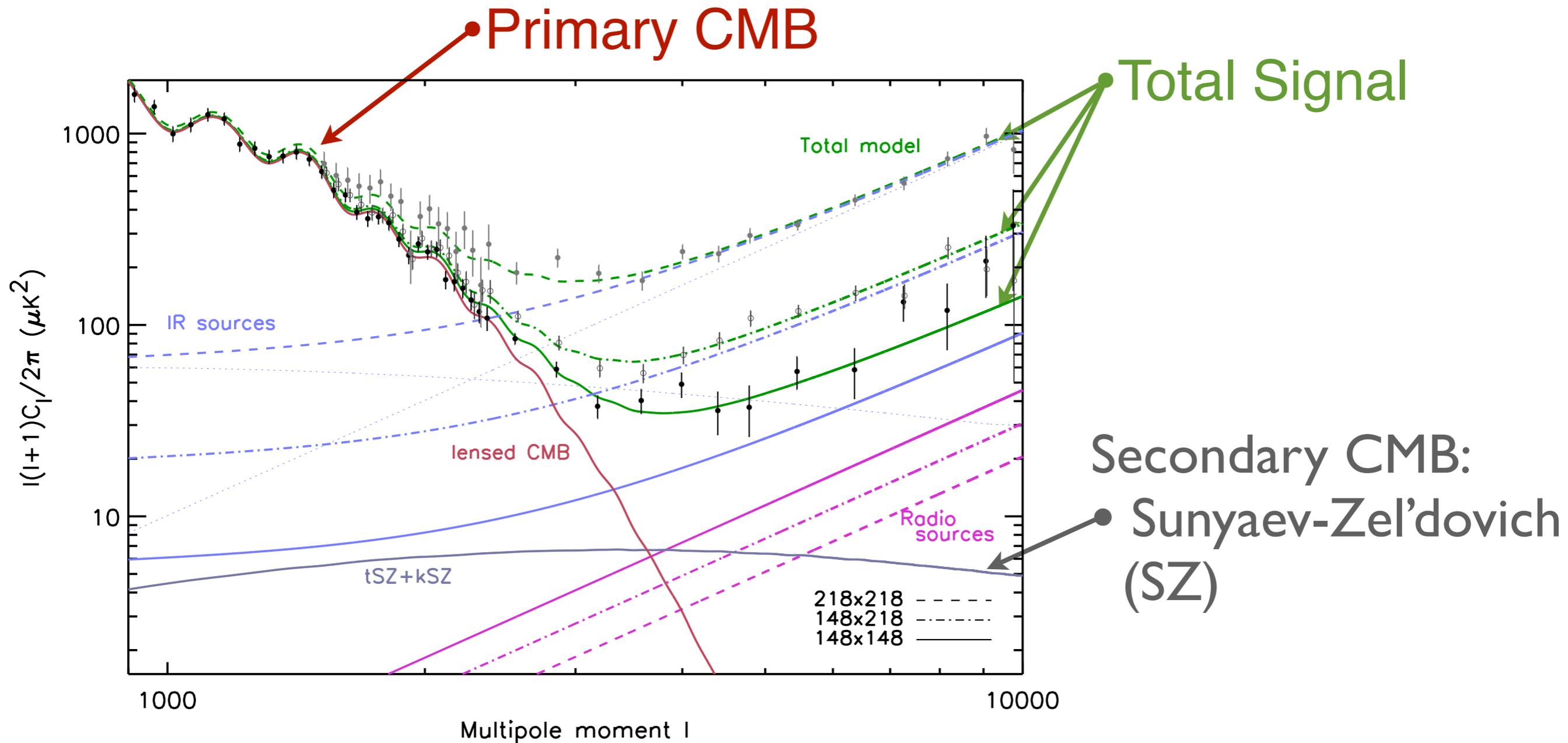
Dunkley et al. 1009.0866

Galaxies Dominate the CMB at $\ell \geq 3000$

Dunkley et al. 1009.0866

Galaxies Dominate the CMB at $\ell \geq 3000$

Primary CMB

Total Signal

Galaxies:
Dusty

Total model

IR sources

lensed CMB

tSZ+kSZ

Radio sources

Secondary CMB:
Sunyaev-Zel'dovich (SZ)

218x218 -----
148x218 -----
148x148 -----

$l(l+1)C_l/2\pi$ (μK^2)

Multipole moment l

Dunkley et al. 1009.0866

Galaxies Dominate the CMB at $\ell \geq 3000$

Primary CMB

Total Signal

Galaxies:

Dusty

Radio

Secondary CMB:
Sunyaev-Zel'dovich (SZ)

Total model

IR sources

lensed CMB

tSZ+kSZ

Radio sources

218×218
148×218
148×148

$l(l+1)C_l/2\pi$ (μK^2)

Multipole moment l
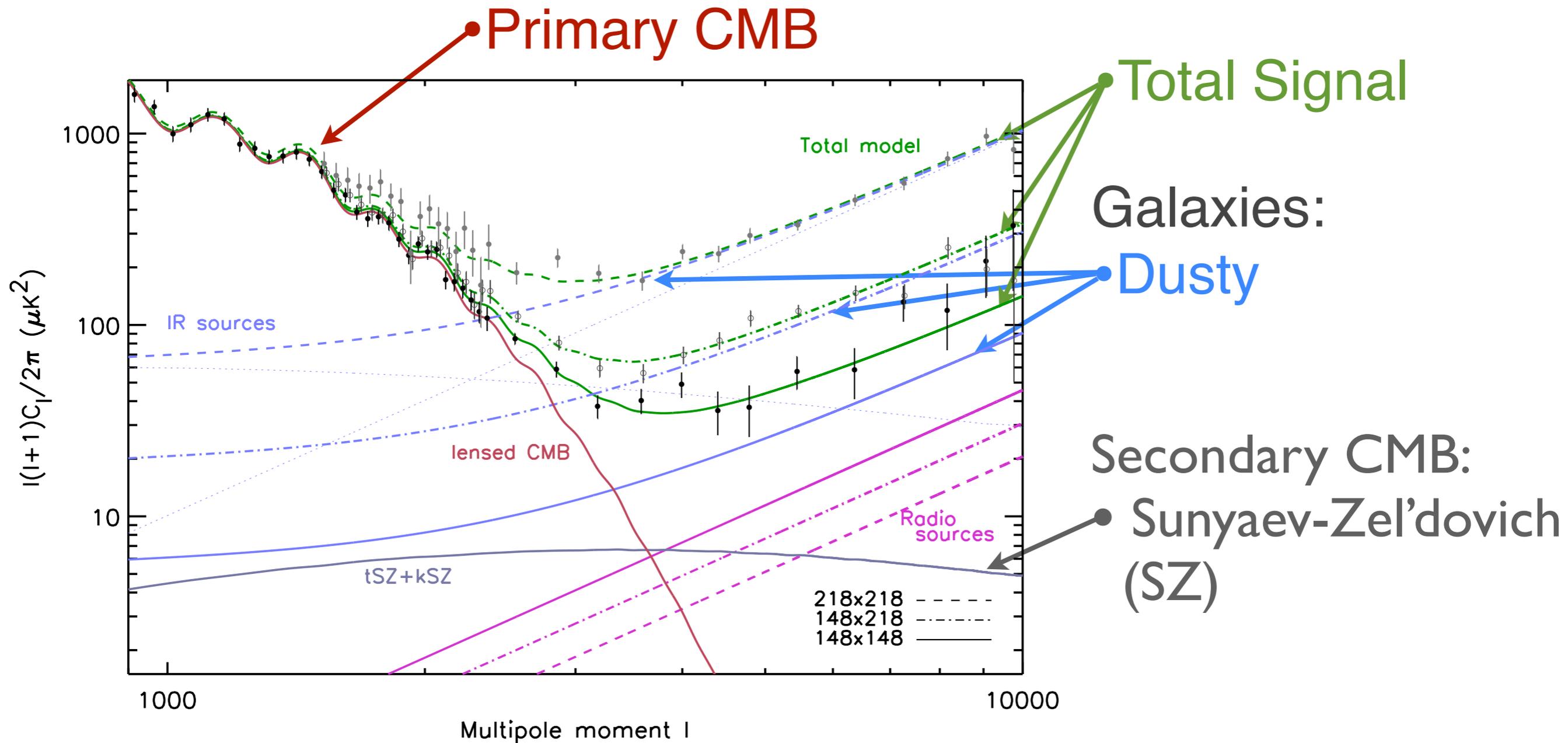
Dunkley et al. 1009.0866
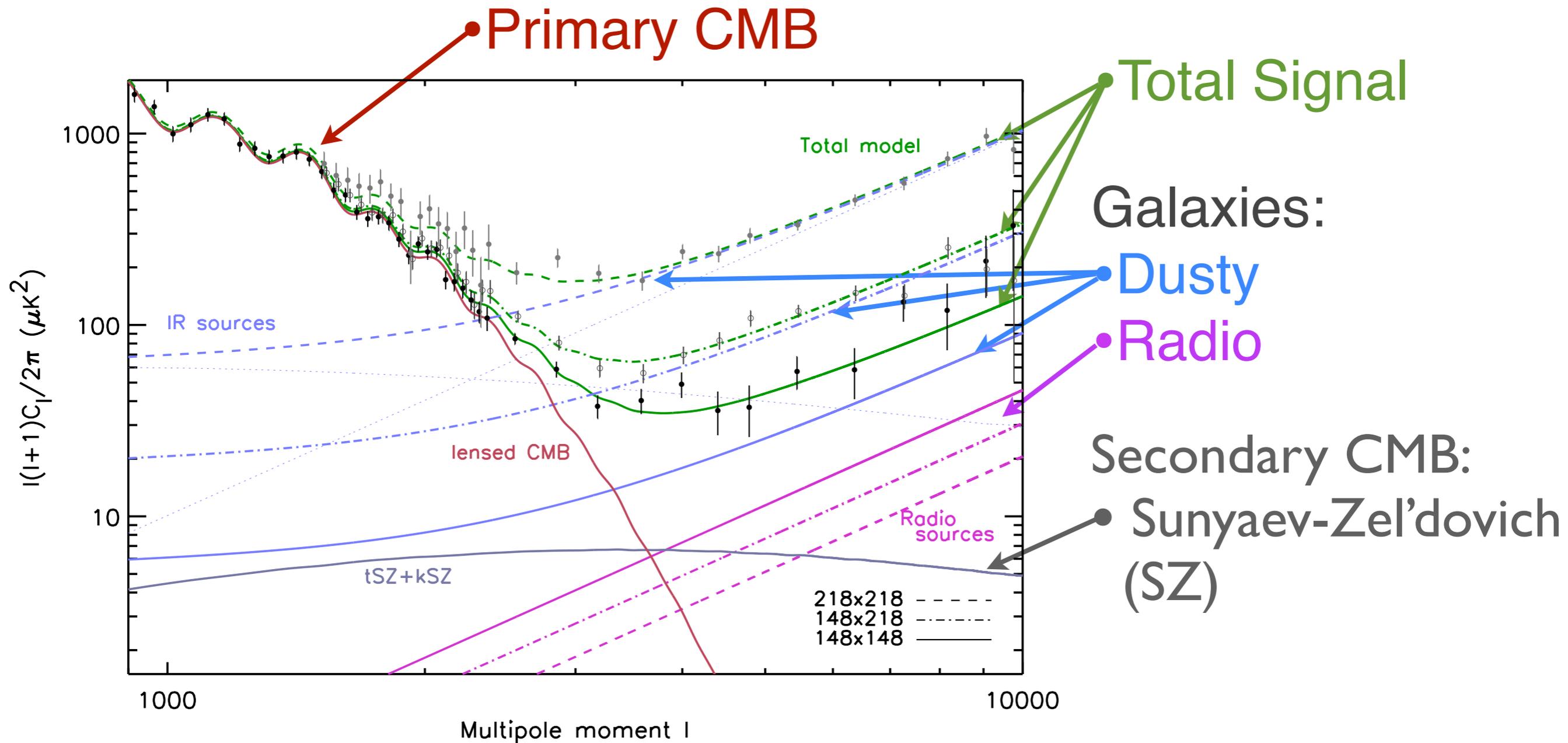
Galaxies Dominate the CMB at $\ell \geq 3000$

Galaxies:
- Shot
- Clustered
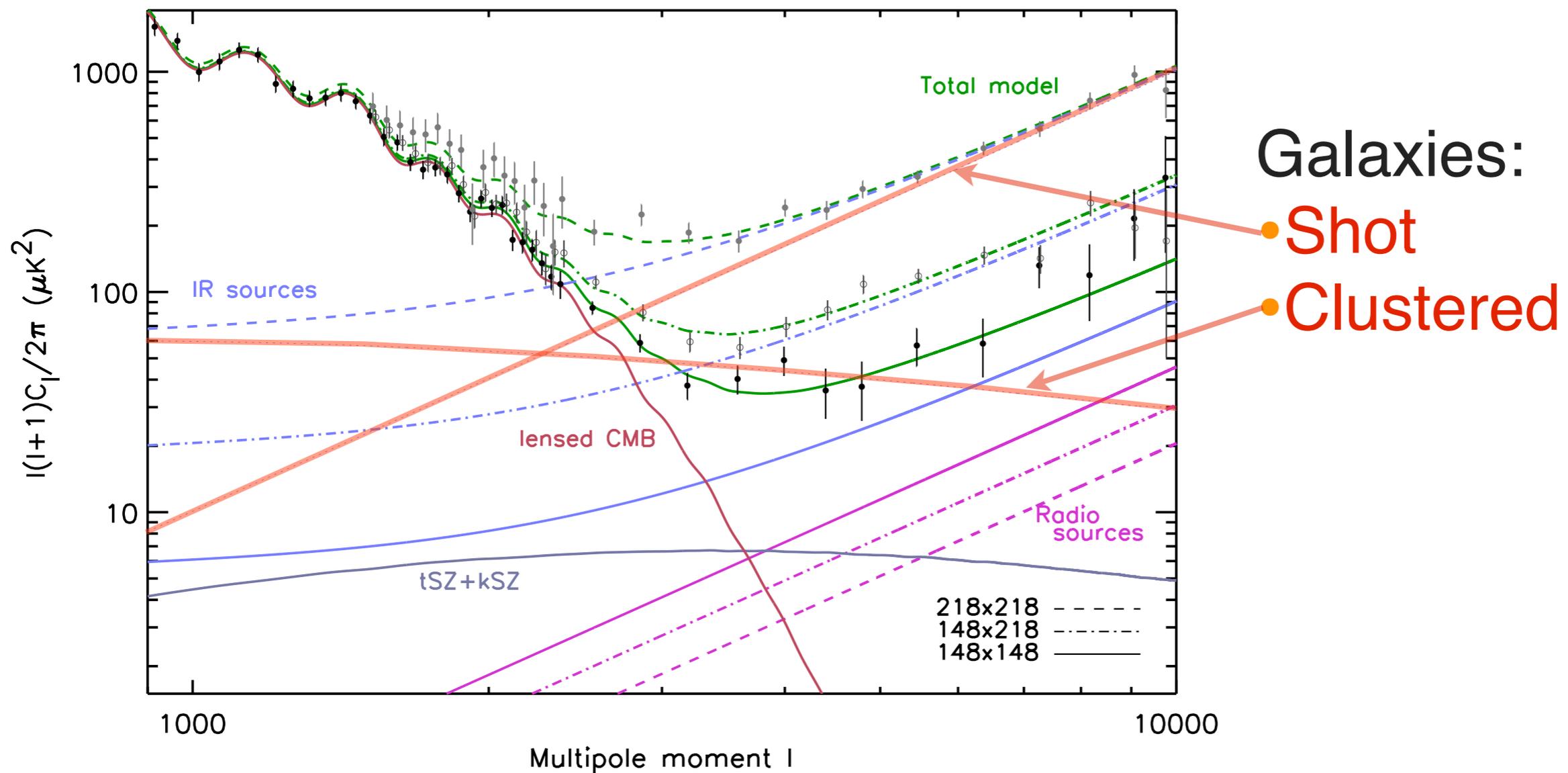
Dunkley et al. 1009.0866

Negative K-correction

Typical ULIRG (L = 10^{12} L$_{sun}$)

flux density (mJy)

100.00

10.00

1.00

0.10

0.01

λ = 250
λ = 350
λ = 500
λ = 1380
λ = 2030

0.1   1.0   10.0

z
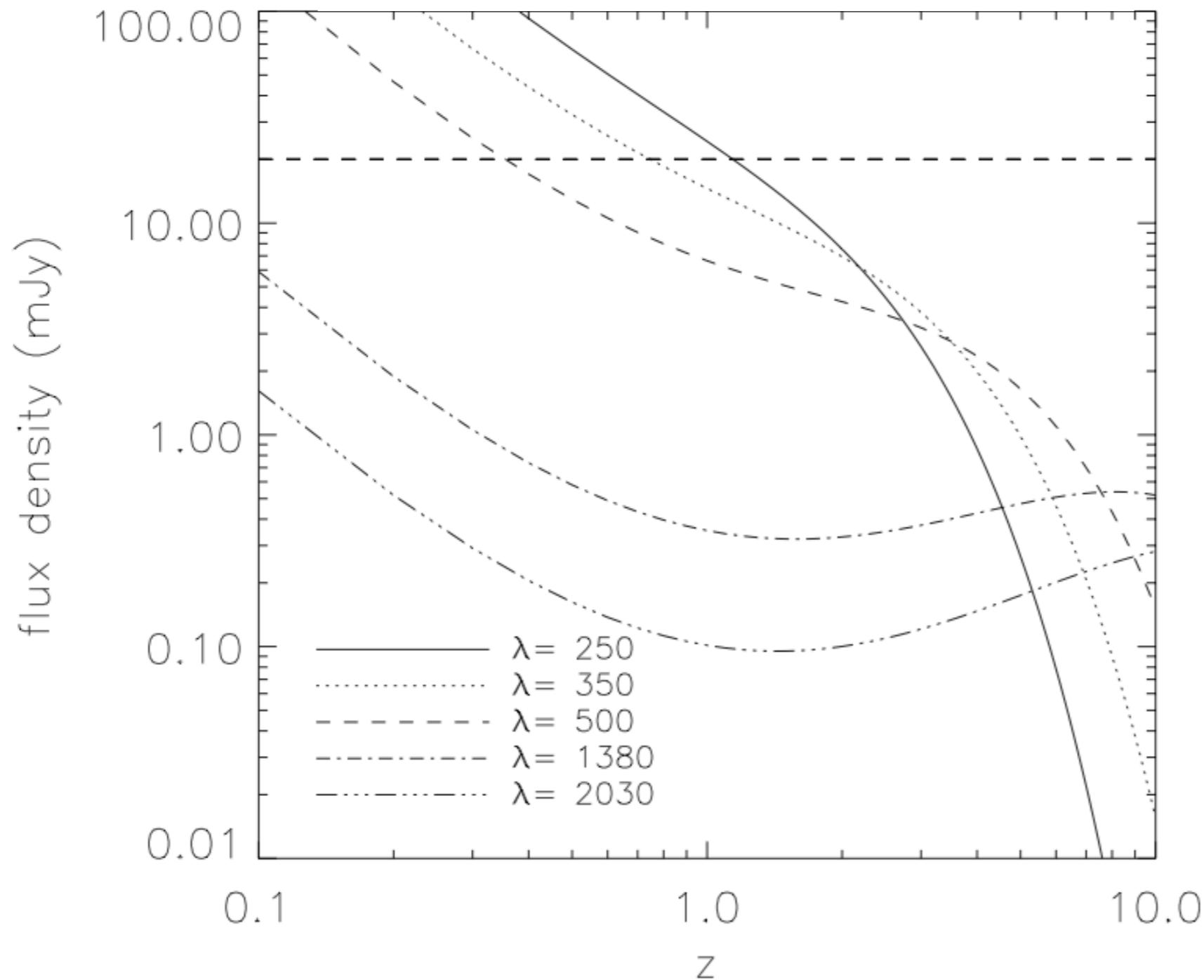
Negative K-correction

Typical ULIRG (L = 10^{12} L_{sun})
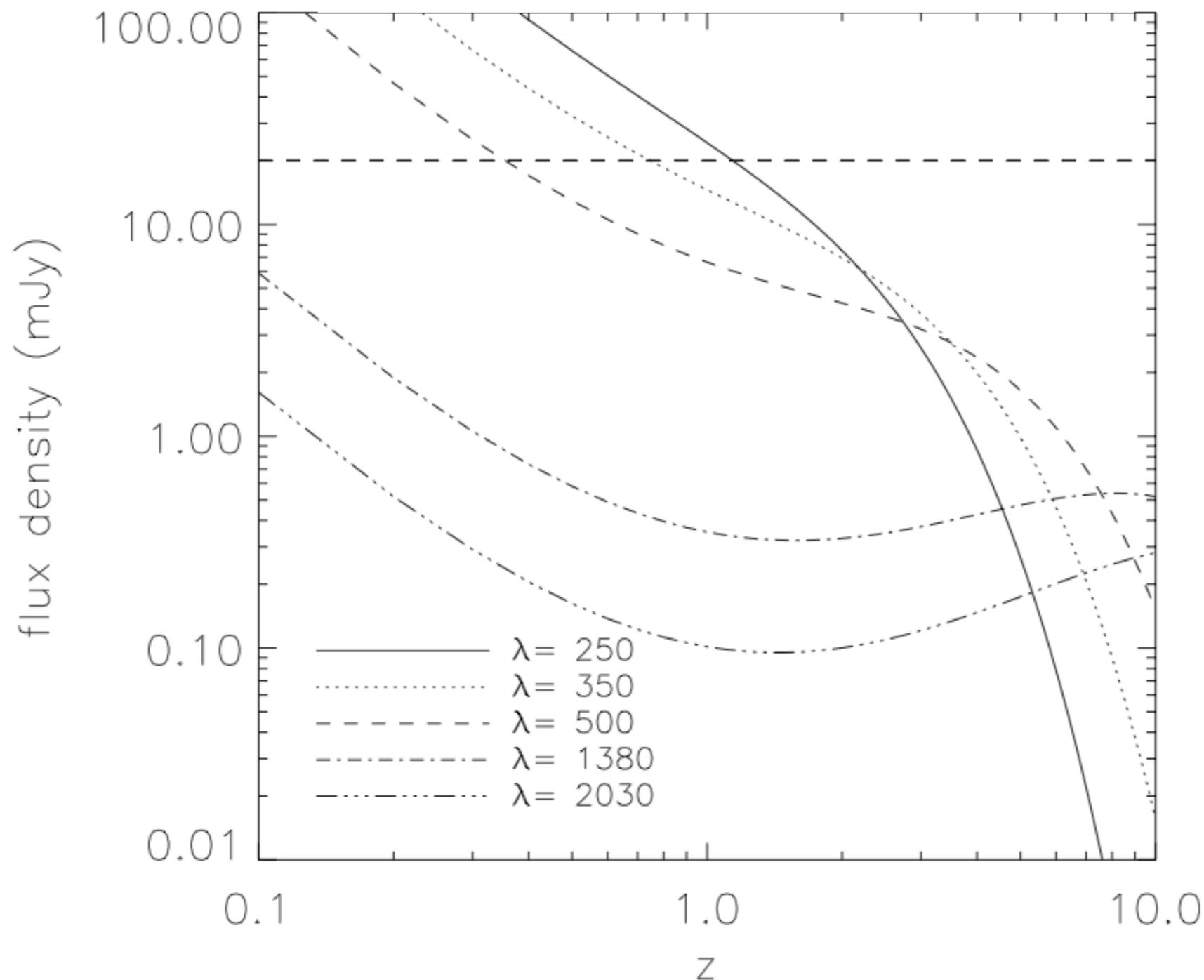
- Different Wavelengths sensitive to unique redshift ranges

- Longer wavelengths more sensitive to higher redshifts

Multi-Wavelength Data
Contains Redshift Information
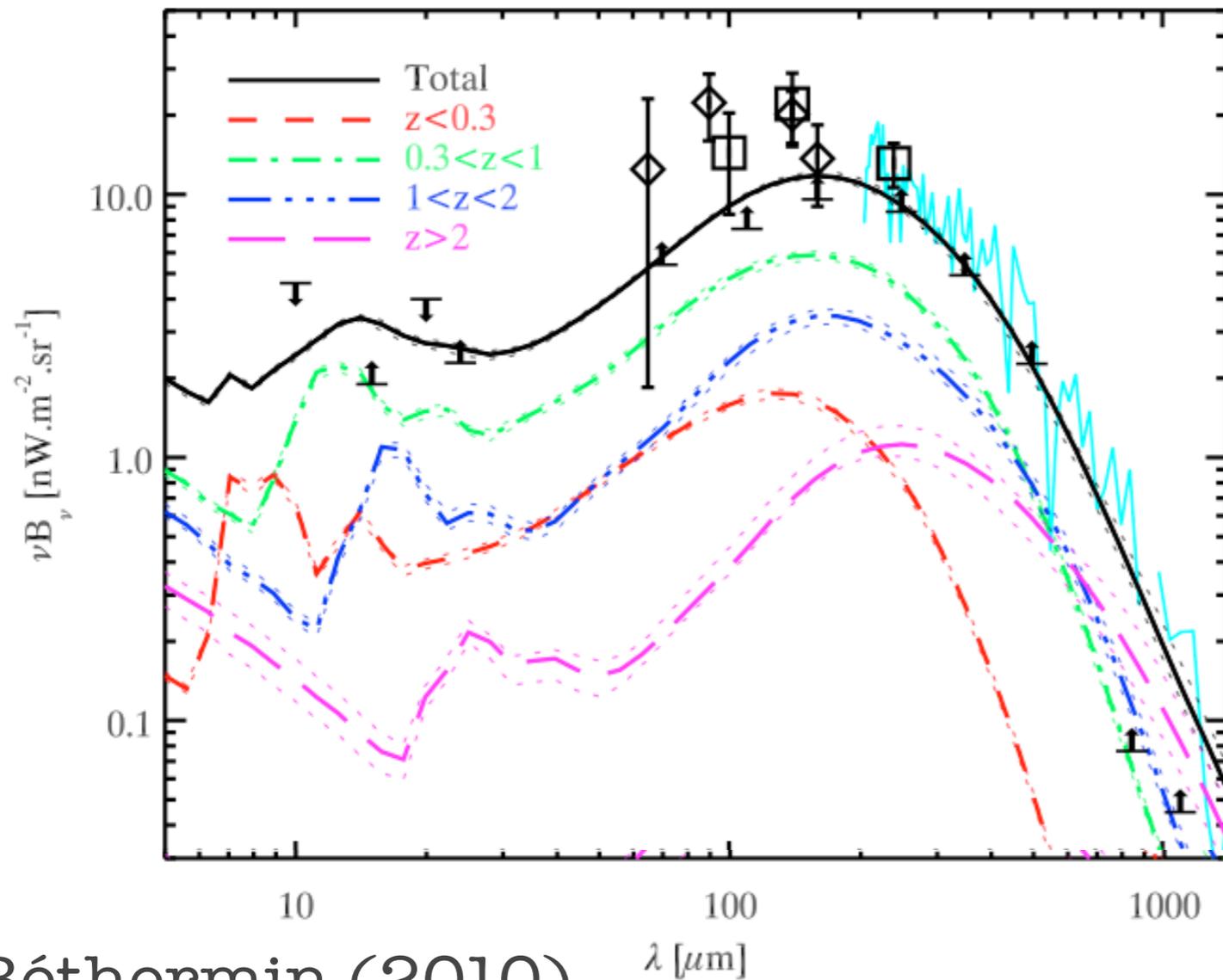
Total Infrared Background

Béthermin (2010)

arXiv: 1010.1150

Multi-Wavelength Data
Contains Redshift Information

Total Infrared Background

Béthermin (2010)

arXiv: 1010.1150

Multi-Wavelength Data
Contains Redshift Information

Total Infrared Background
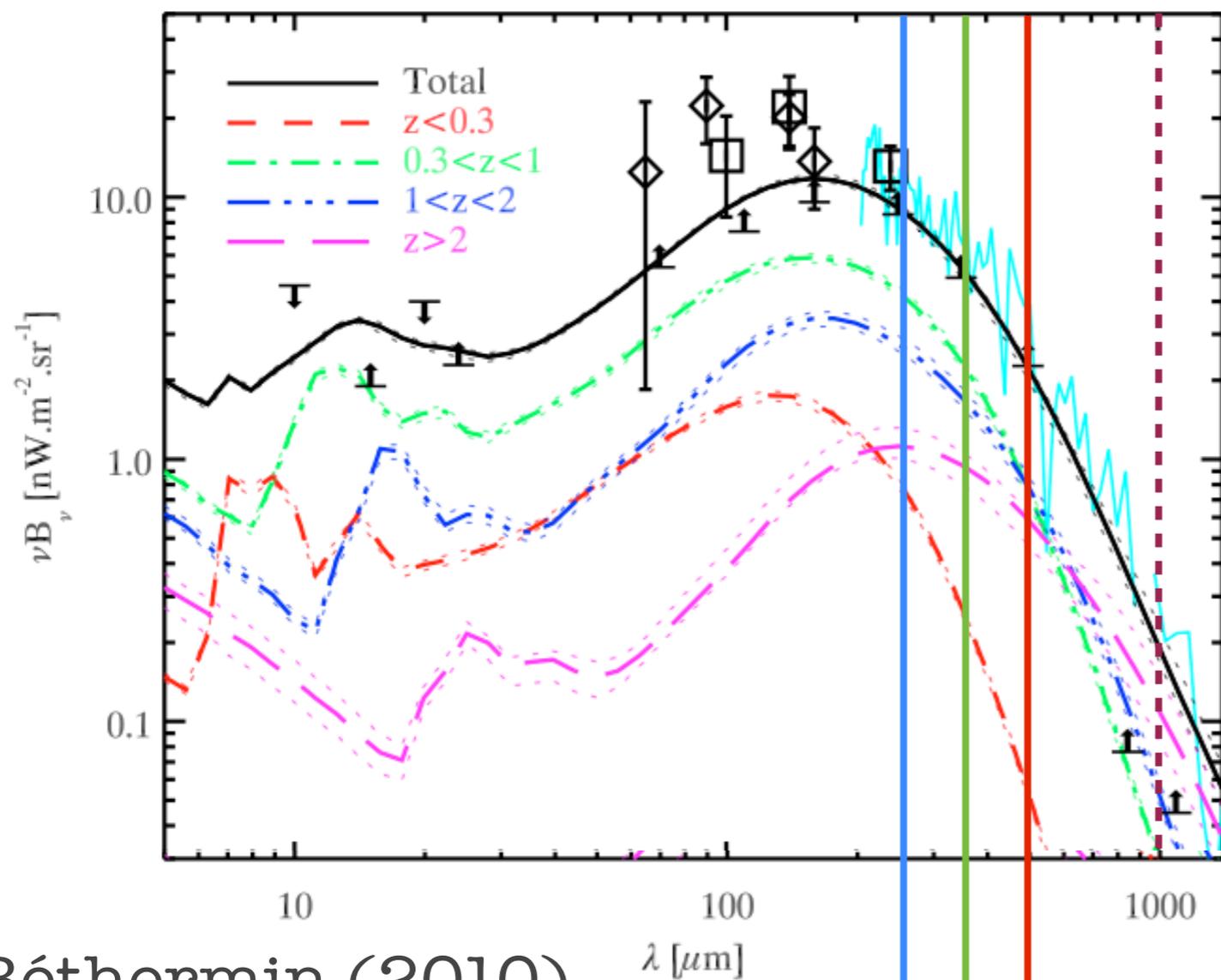
Béthermin (2010)

arXiv: 1010.1150

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

Multi-Wavelength Data Contains Redshift Information

Total Infrared Background

Béthermin (2010)
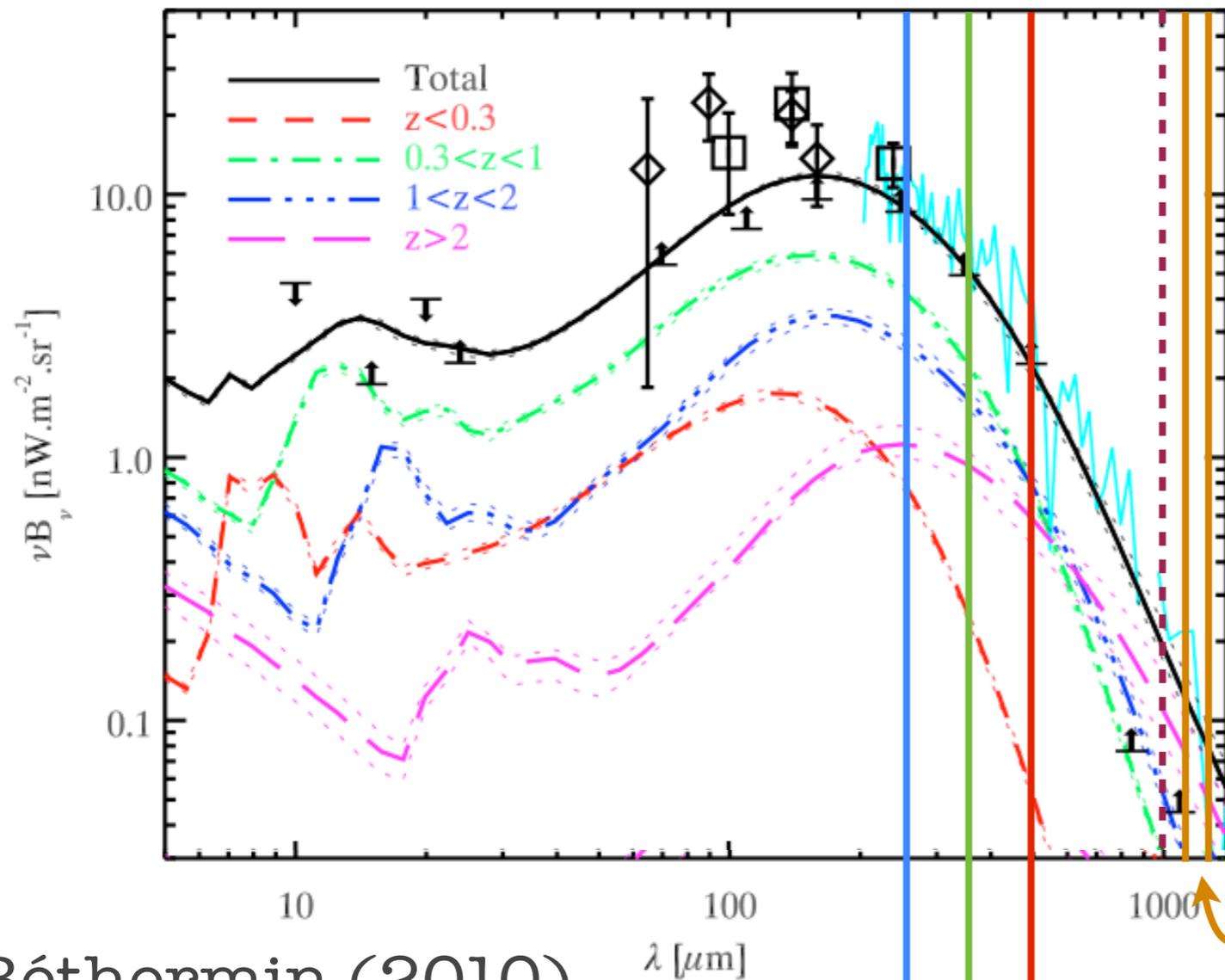
arXiv: 1010.1150

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

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

Atacama Cosmology Telescope (ACT)

ACT Southern Field

Hajian et al (2010)

ACT

WMAP
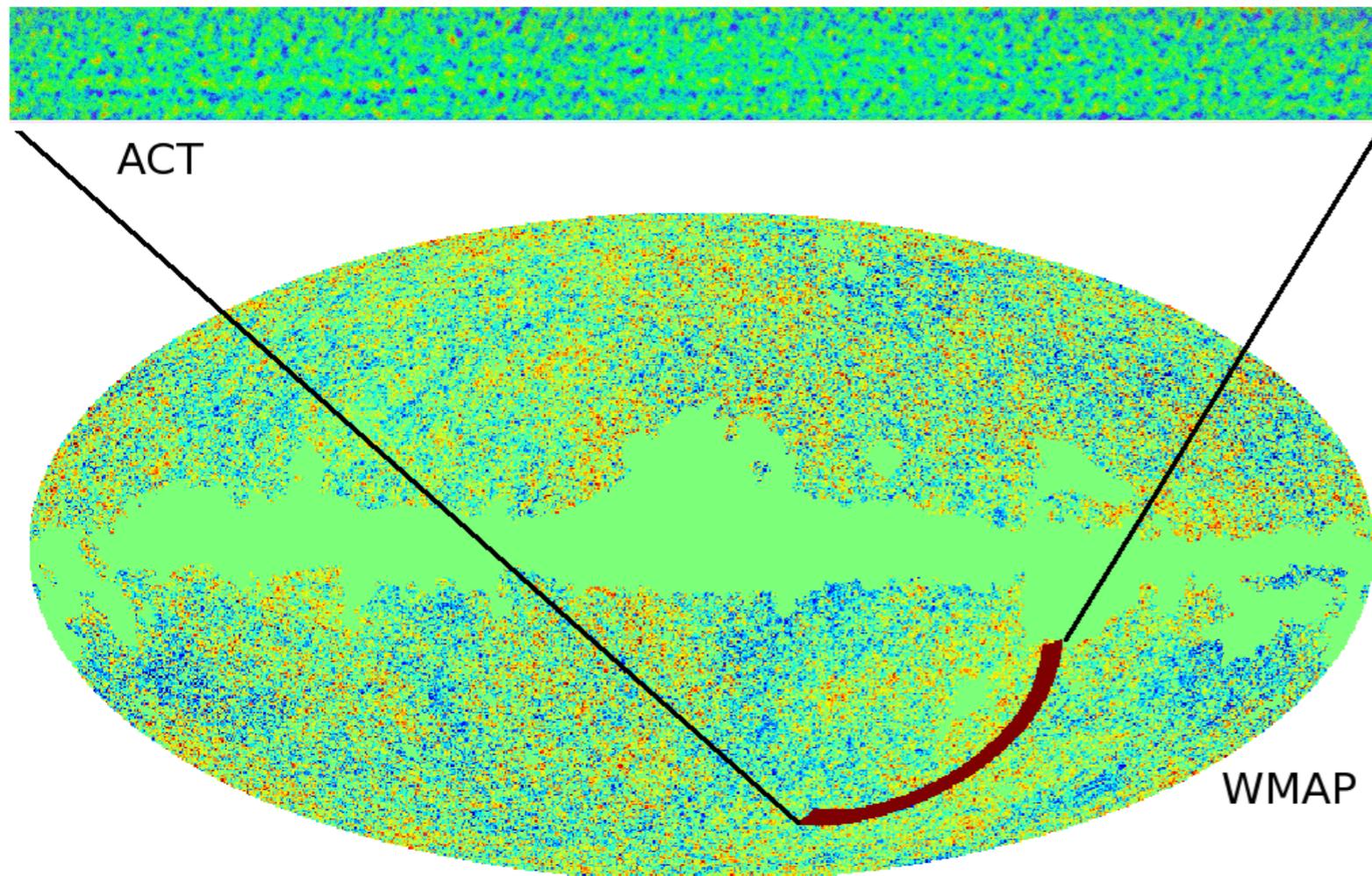
- 300 deg²
- 1' resolution
- 3 bands

148 GHz (~2.0 mm)
218 GHz (~1.4 mm)
277 GHz (~1.1 mm)

Overlap:
BLAST-SEP Field
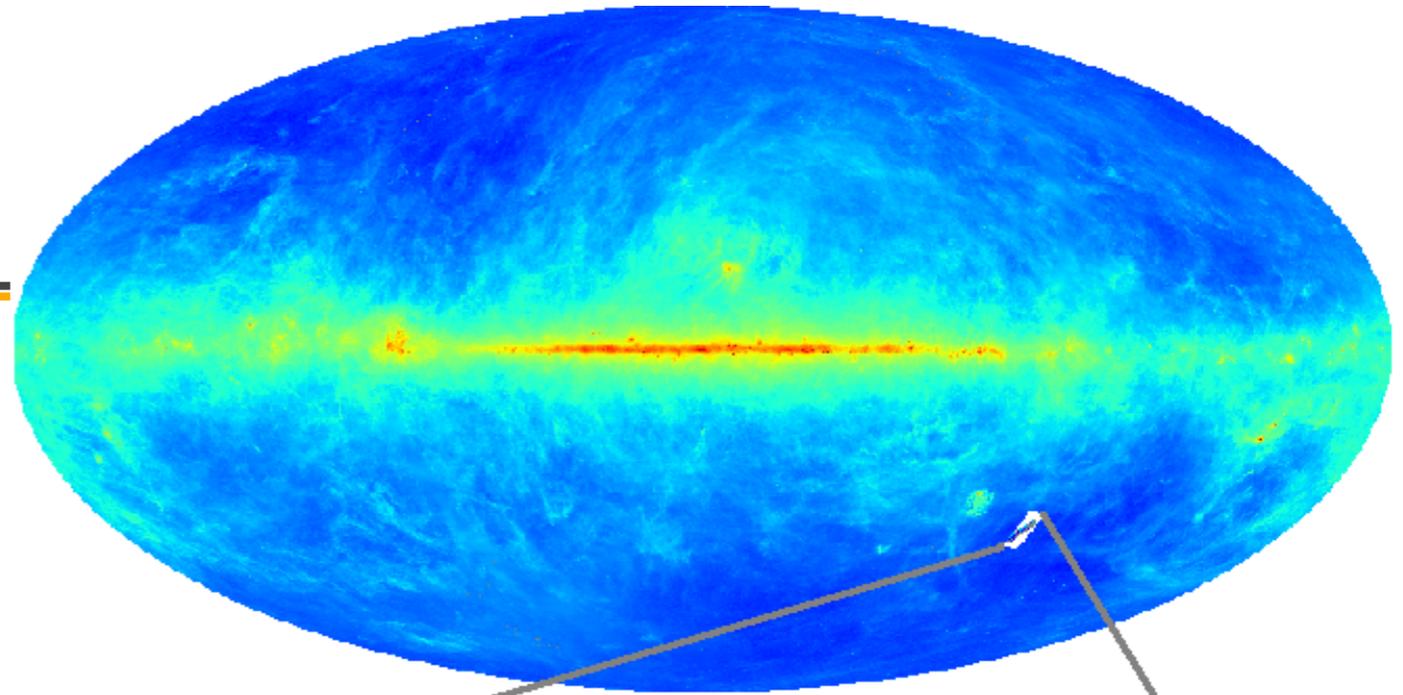
ACT 148 GHz (2 mm)

IRAS 100 μm

~9 deg²
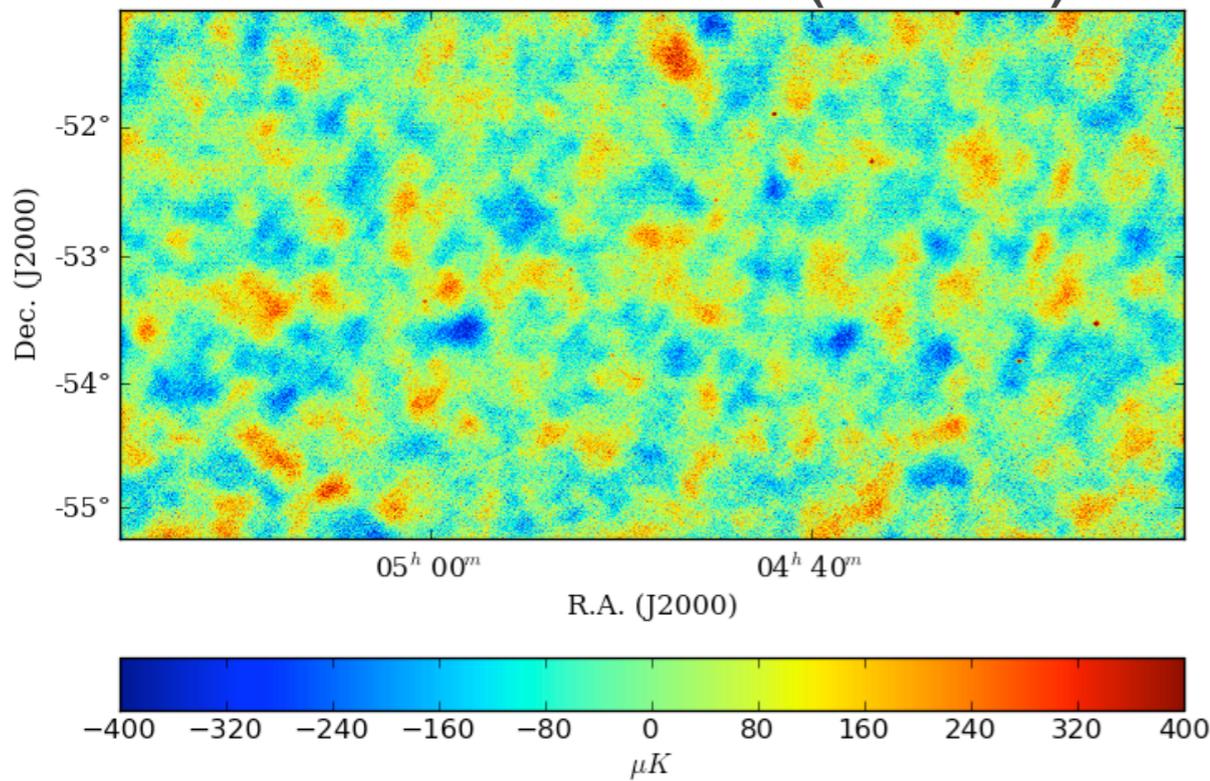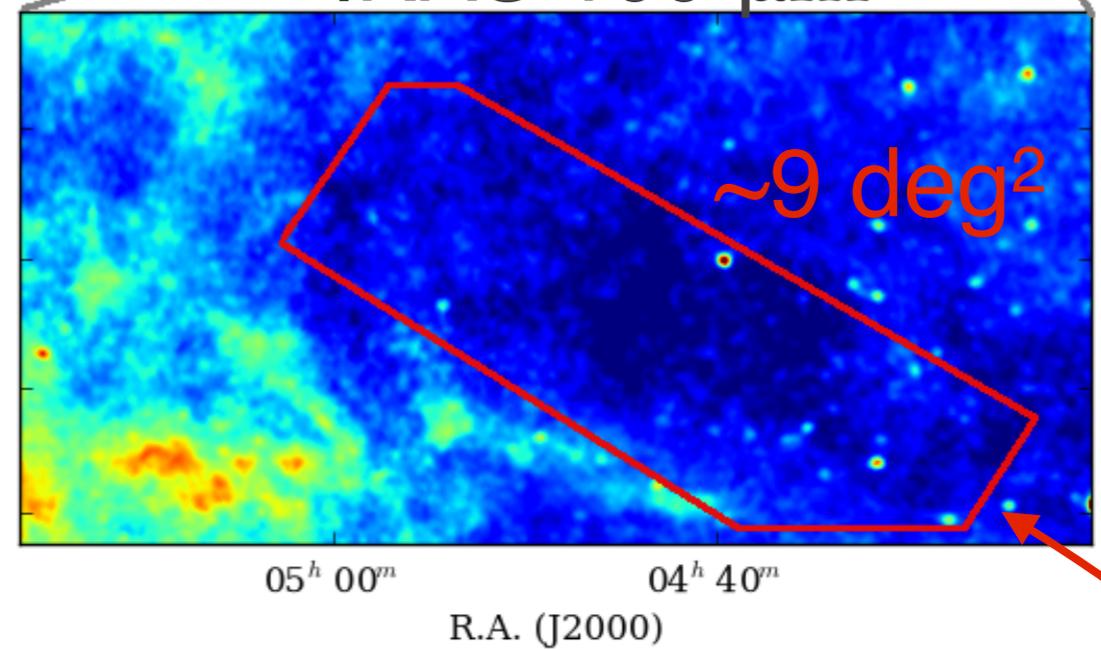
Mean Flux ~ 1.1 MJy/sr

CMB Maps are Made Up of Many Contributions
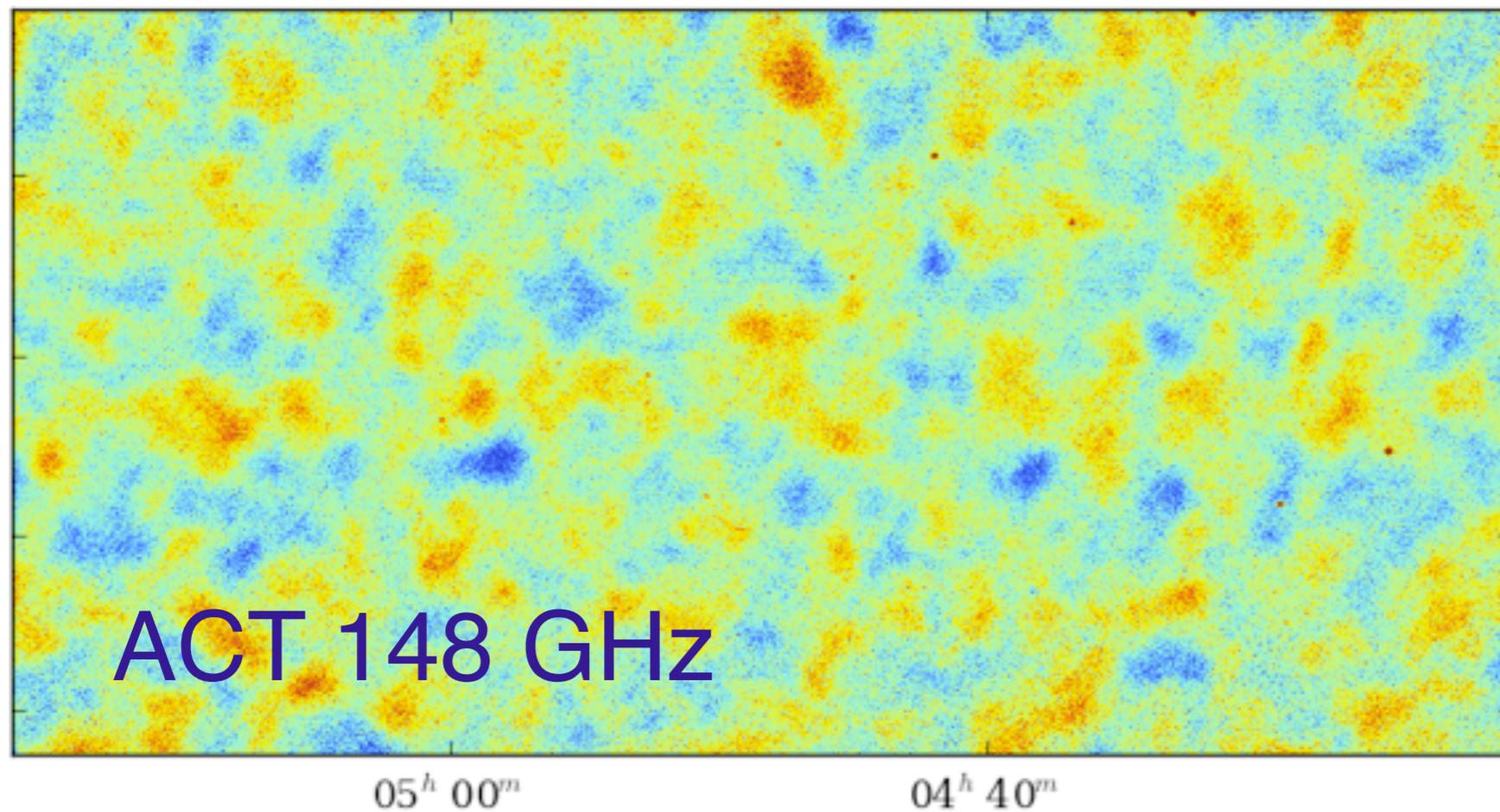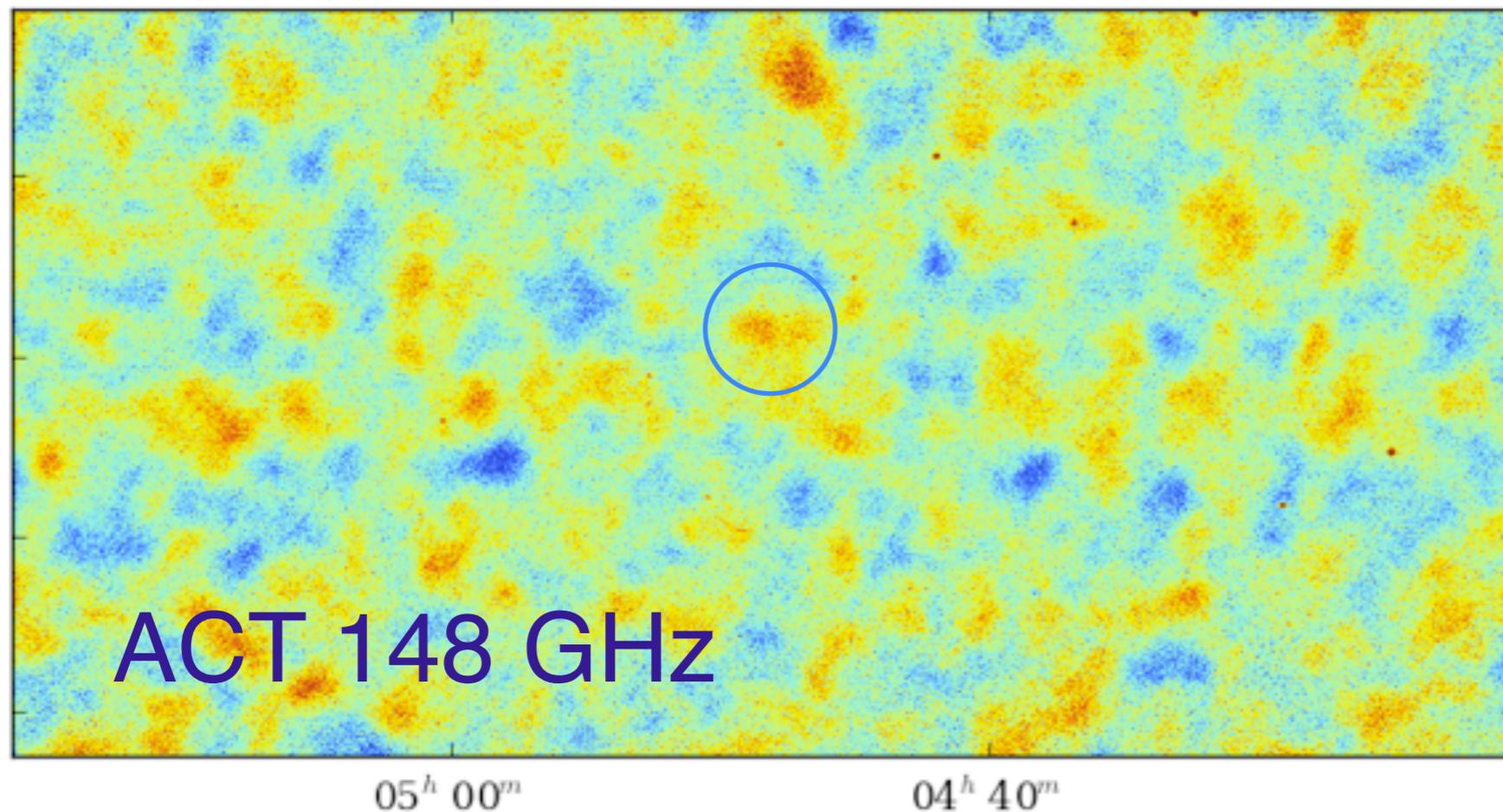
ACT 148 GHz

$05^h\ 00^m$ $04^h\ 40^m$

CMB Maps are Made Up of Many Contributions

CMB

ACT 148 GHz

CMB Maps are Made Up of Many Contributions

CMB

Galaxies

ACT 148 GHz
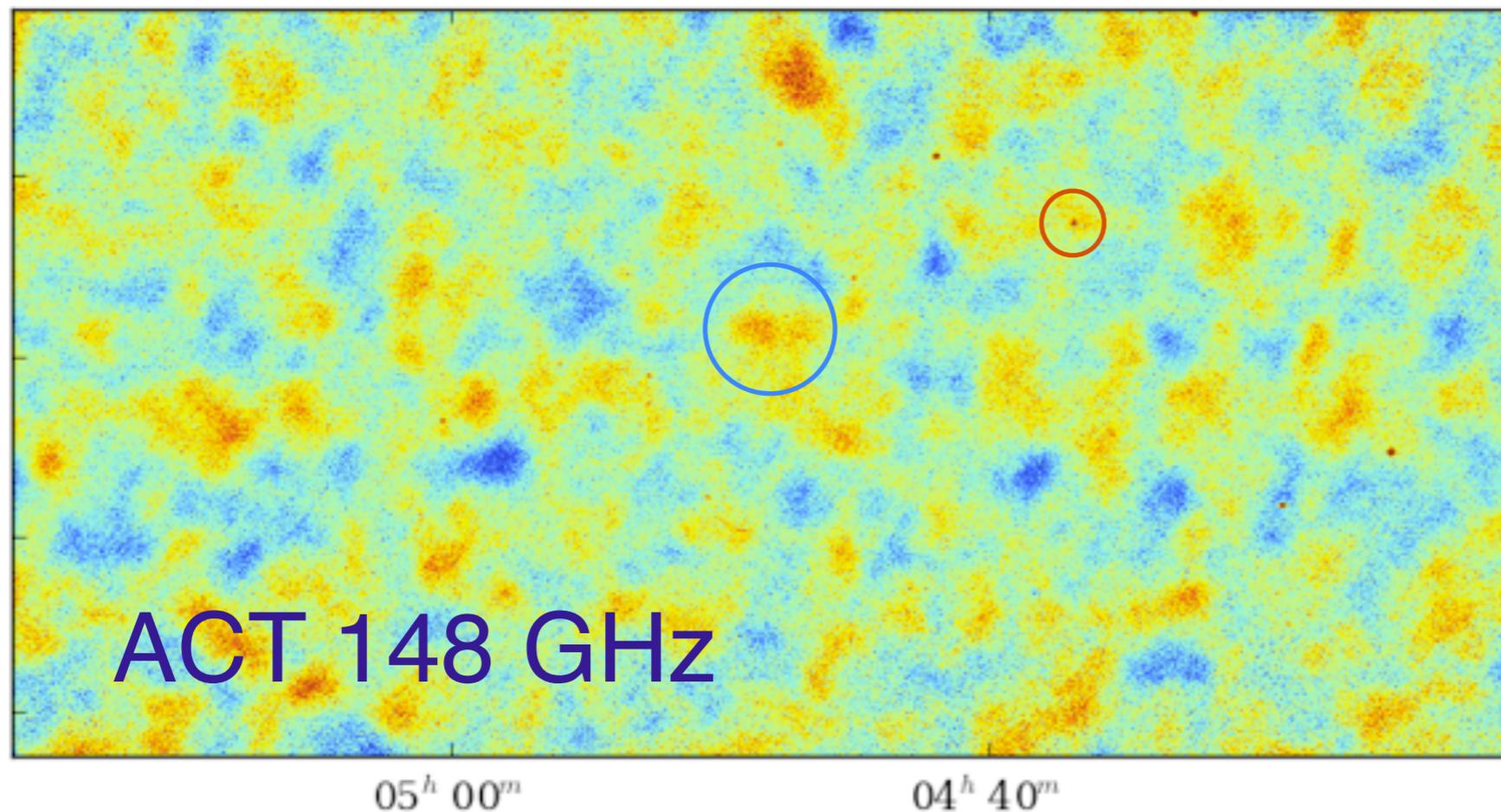
CMB Maps are Made Up of Many Contributions

CMB

Galaxies

SZ Clusters

ACT 148 GHz

marco viero   25
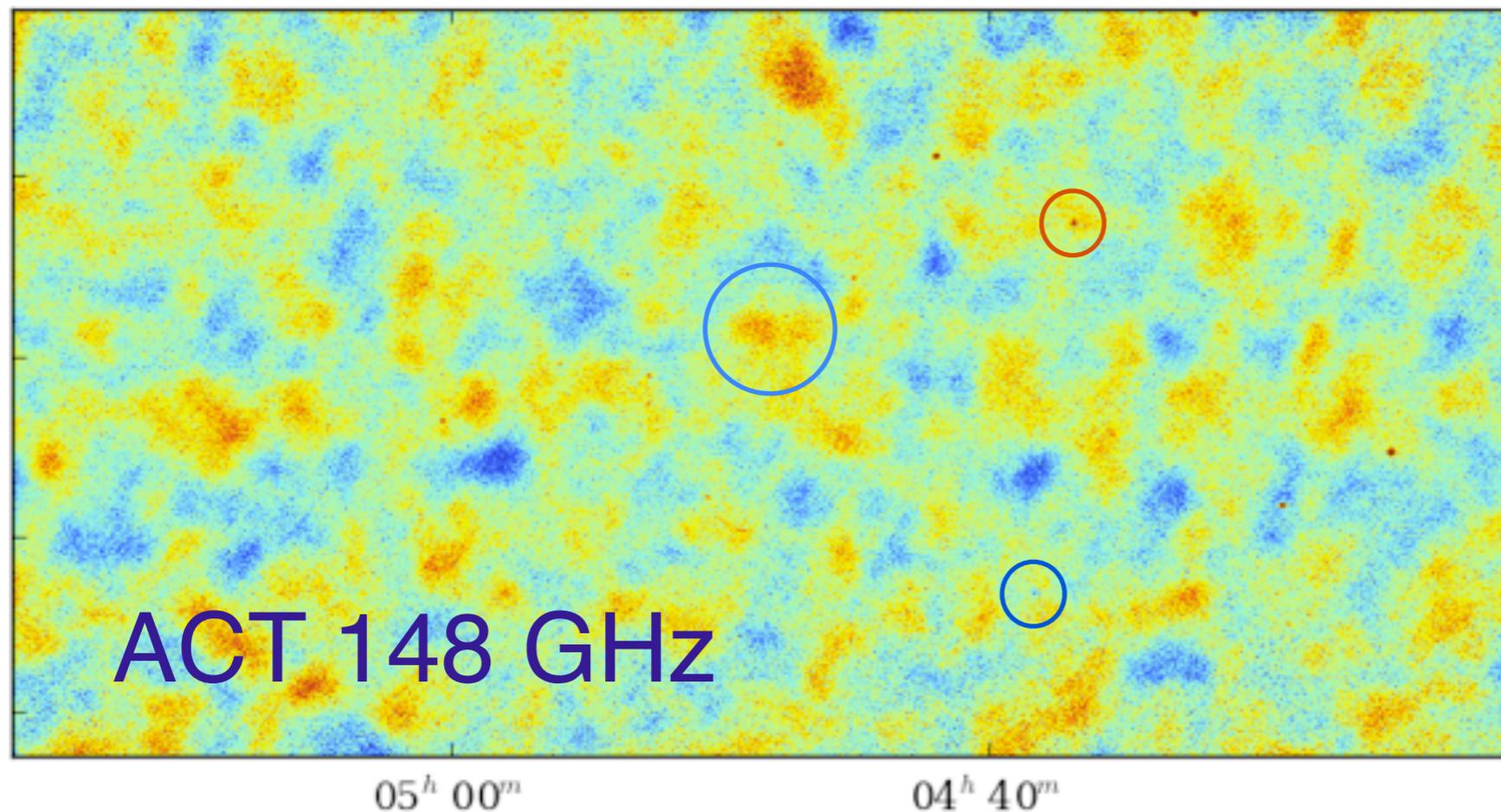
Cross-Correlations Isolate Dusty Galaxies from the Rest

BLAST 250 μm

ACT 148 GHz

9 deg²

05ʰ 00ᵐ   04ʰ 40ᵐ

marco viero   26
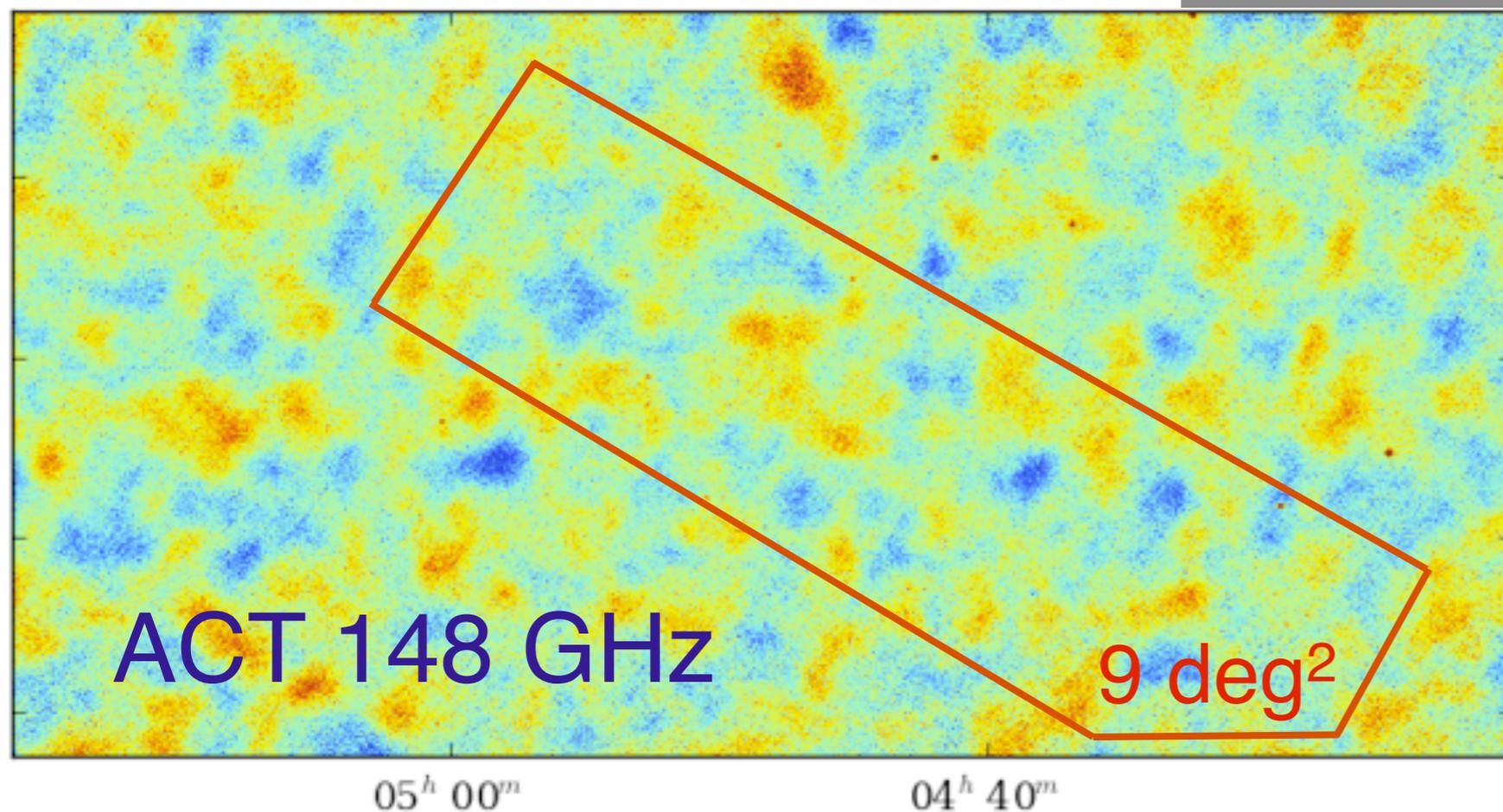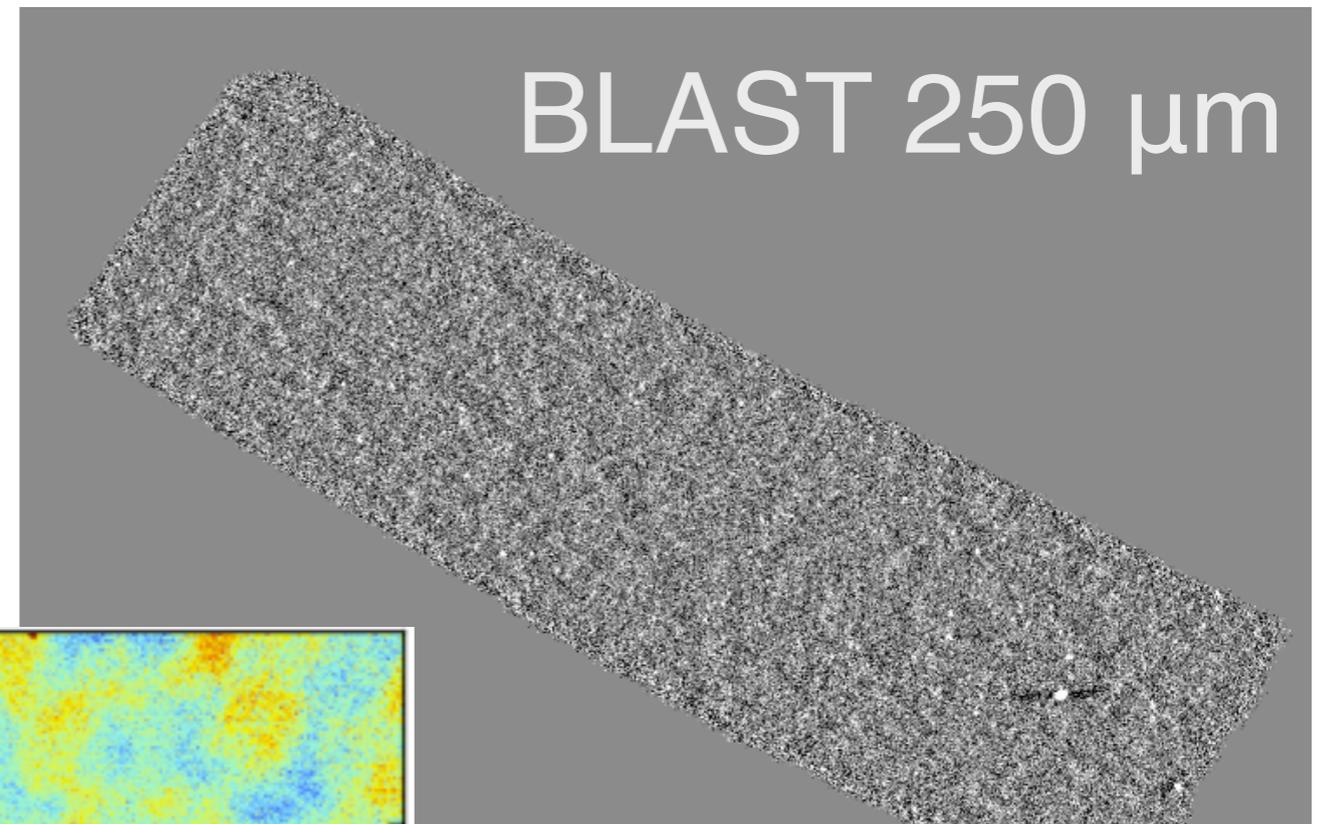
Cross-Correlate BLAST and ACT

Two days ago!

Hajian & Viero et al. 1101.1517

250 μm

$P(k_\theta)$ (Jy^2 sr^{-1})

k_θ (arcmin^{-1})

250 μm

2030 μm

250 μm

350 μm

500 μm

Best-fit
Best-fit
Galactic
CMB
This Pop
This Pop
Viero et

Hajian & Viero et al. 1101.1517

marco viero   27

250 µm

$P(k_\theta)$ (Jy^2 sr^{-1})

10^5

10^4

1.3e+04

0.05   0.20

500 µm

$P(k_\theta)$ (Jy^2 sr^{-1})

10^4

10^3

0.05   0.20

k_θ (arcmin^{-1})

030 µm

250 µm

350 µm

500 µm

Best-fit Poiss
Best-fit Total
Galactic Cirrus
CMB
This Paper: S
This Paper: C
Viero et al. (2

0.05   0.20
k_θ (arcmin^{-1})

Hajian & Viero et al. 1101.1517

250 μm

350 μm

350 μm

2030 μm

250 μm

350 μm

500 μm

$P(k_\theta)$ (Jy^2 sr^{-1})

k_θ ($arcmin^{-1}$)

Best-fit P
Best-fit T
Galactic
CMB
☐ This Pape
+ This Pape
× Viero et a

Hajian & Viero et al. 1101.1517

marco viero 27

250 μm

350 μm

500 μm

2030 μm

250 μm

350 μm

500 μm

$P(k_\theta)$ $(Jy^2\ sr^{-1})$

k_θ $(arcmin^{-1})$

1.3e+04

1e+01

1e+02

9e+01

Best-fit P
Best-fit T
Galactic
CMB
This Pape
This Pape
Viero et a

Hajian & Viero et al. 1101.1517

250 μm

1380 μm

500 μm

030 μm

$P(k_\theta)$ (Jy^2 sr^{-1})

$P(k_\theta)$ (Jy^2 sr^{-1})

10^5

10^4

1.3e+04

10^3

1.5e+02

10^2

0.05   0.20

k_θ (arcmin^{-1})

Best−fit Poiss
Best−fit Total
Galactic Cirrus
CMB
This Paper: SI
This Paper: Ci
Viero et al. (2

0.05   0.20   0.05   0.20   0.05   0.20

k_θ (arcmin^{-1})

250 μm

350 μm

500 μm

250 μm

2030 μm

2030 μm

250 μm

350 μm

500 μm

500 μm

10^5

$1.3\mathrm{e}{+}04$

$P(k_\theta)$ $(\mathrm{Jy}^2 \ \mathrm{sr}^{-1})$

$P(k_\theta)$ $(\mathrm{Jy}^2 \ \mathrm{sr}^{-1})$

10^3

10^2

$5.9\mathrm{e}{+}01$

$1\mathrm{e}{+}01$

$1\mathrm{e}{+}02$

$9\mathrm{e}{+}01$

0.05

0.20

k_θ (arcmin^{-1})

0.05   0.20   0.05   0.20   0.05   0.20

k_θ (arcmin^{-1})

Best-fit
Best-fit
Galactic
CMB
This Pape
This Pape
Viero et

Fit a Linear bias simultaneously to each effective band

Source model of Béthermin et al. 1010.1150 & Linear bias model of Graeme Addison

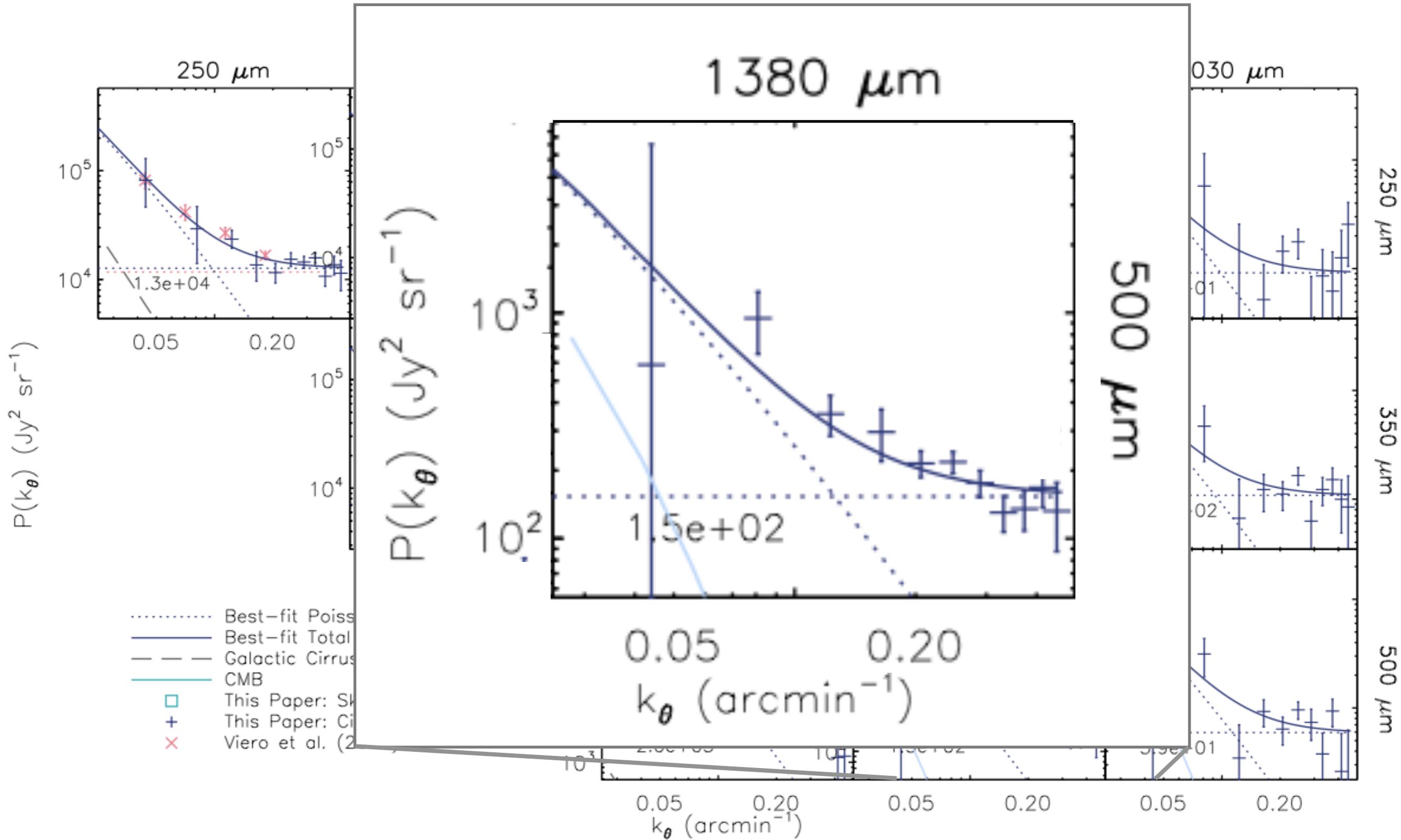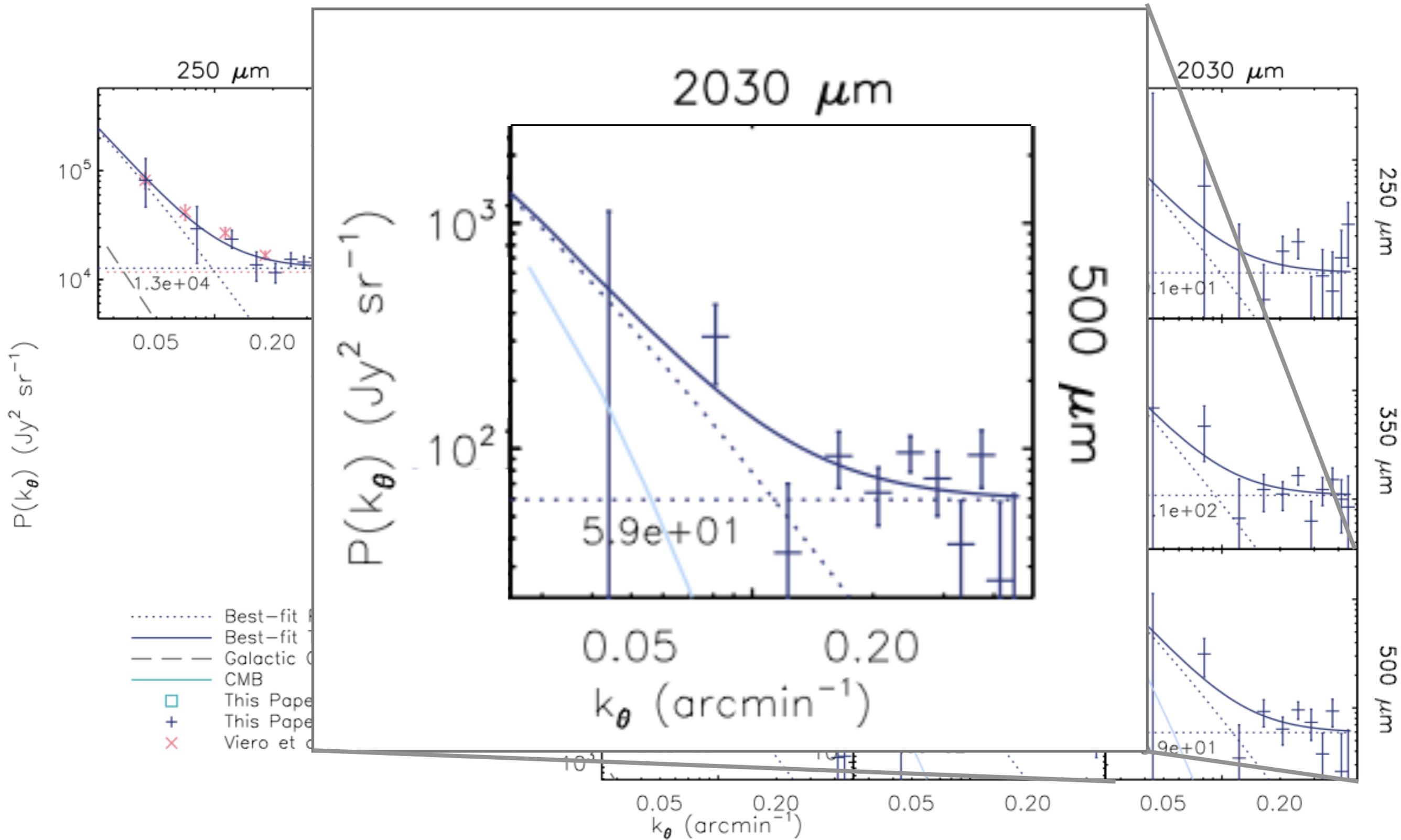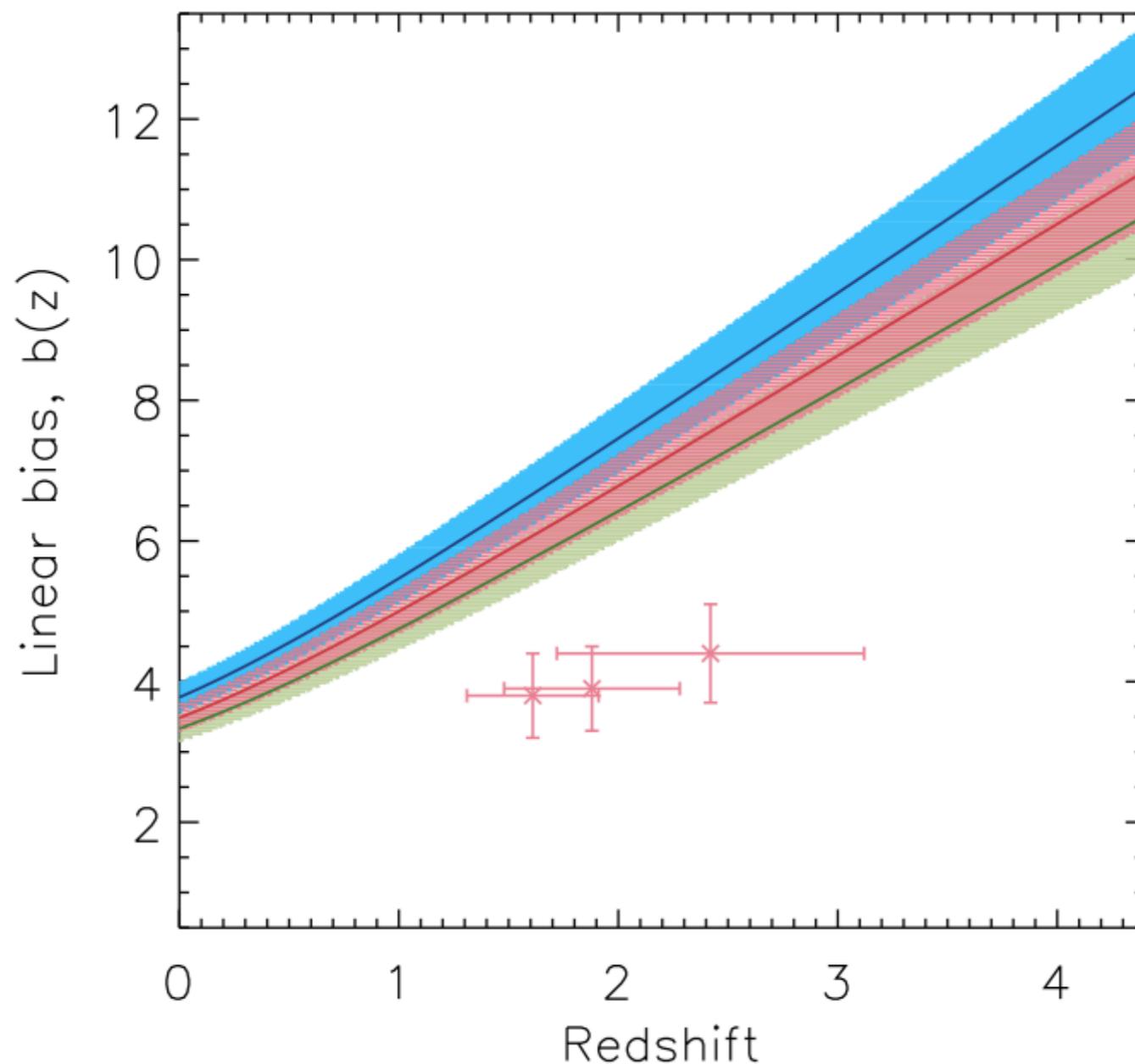Constrains the evolution using redshift information

Finds bias strongly dependent on model

Fit a Linear bias simultaneously to each effective band

Source model of Béthermin et al. 1010.1150 & Linear bias model of Graeme Addison

see poster #25

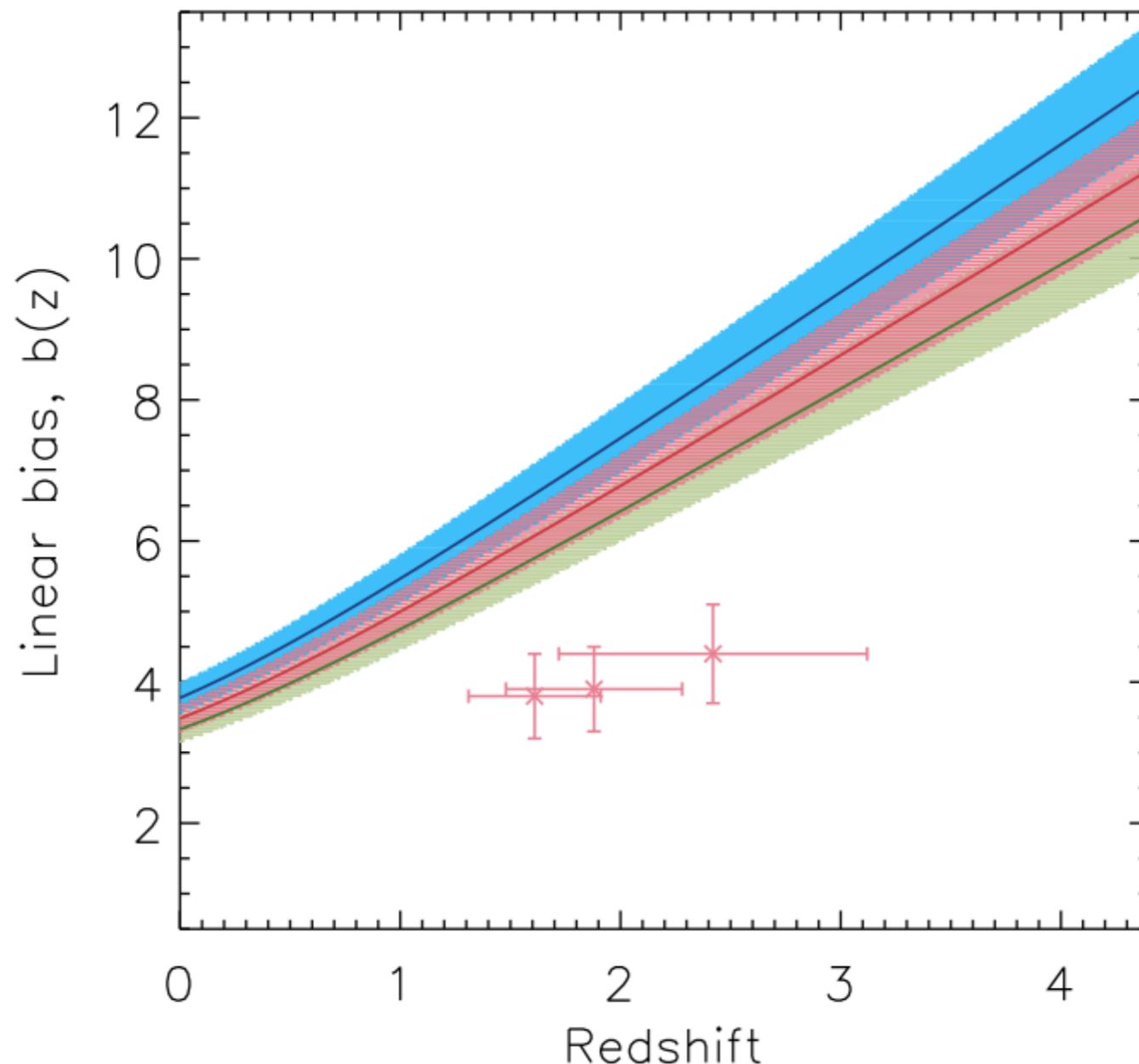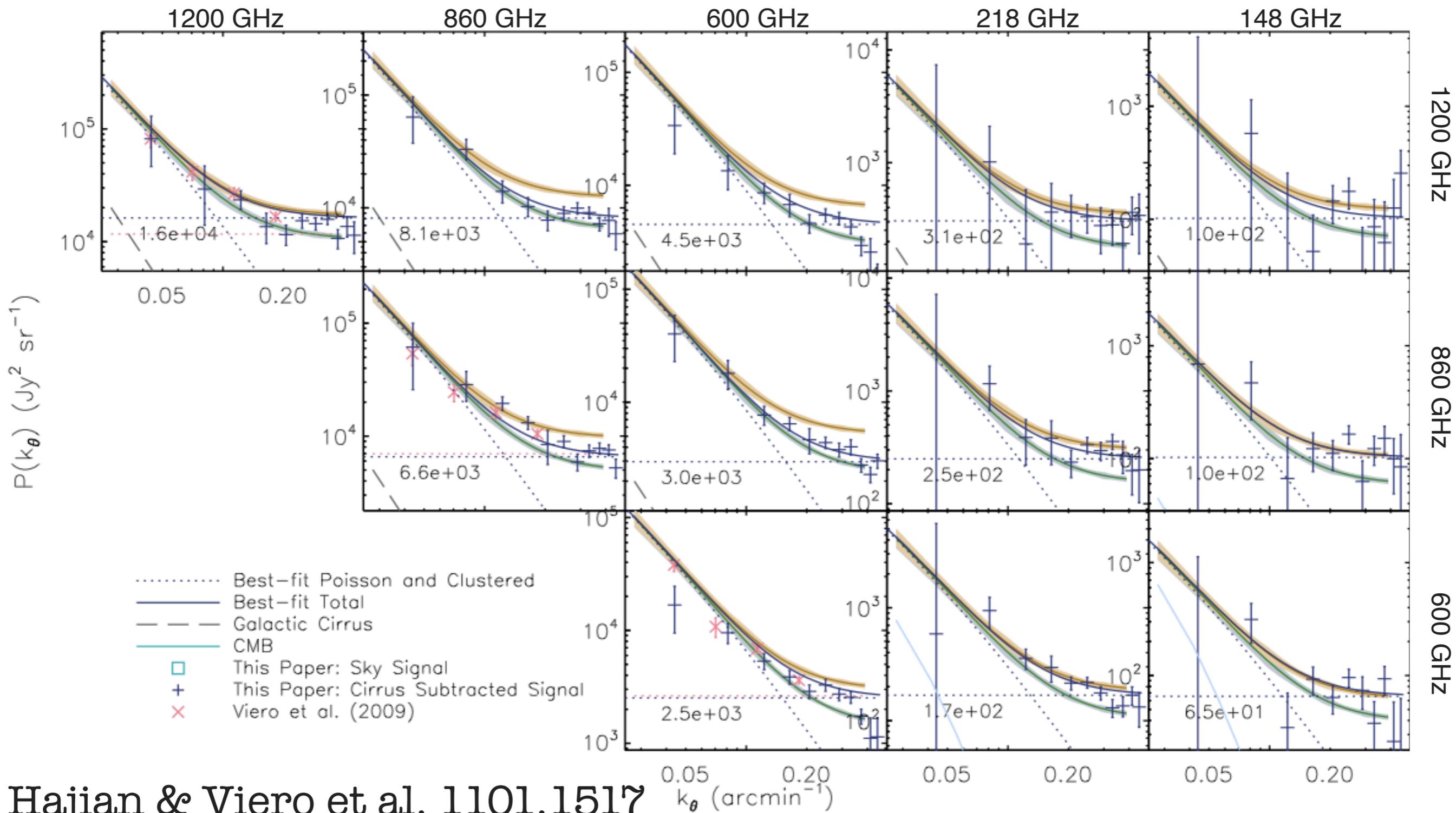Constrains the evolution using redshift information

Finds bias strongly dependent on model

Powerful Tool for Constraining Models

Hajian & Viero et al. 1101.1517
Model: Marsden et al. 1010.1176
Model: Béthermin et al. 1010.1150

marco viero 73

Summary

Summary

✦ **Auto-Frequency Correlations**:

Summary

✦ Auto-Frequency Correlations:

　✓ Measure Clustering of DSFGs

Summary

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  ✓ Constrain physical properties of
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Summary

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  ✓ **Identify** the **High-z Clustering** Signal

  ✓ **Constrain** Phenomenological **Galaxy Models**

end