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

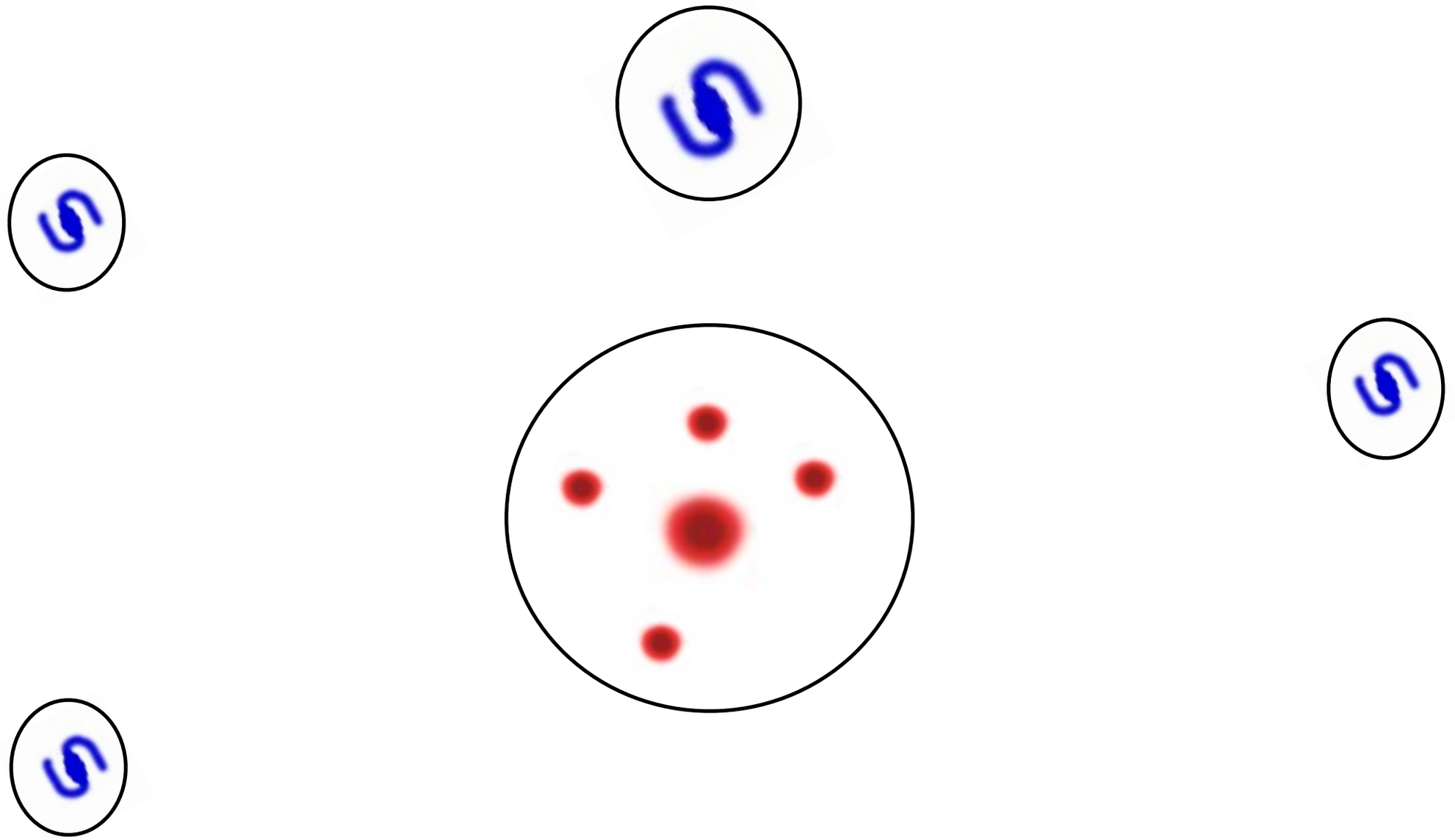
marco viero / california institute of technology

Galaxy Formation is Not Independent of Environment

Blue
Star-Forming
Galaxy

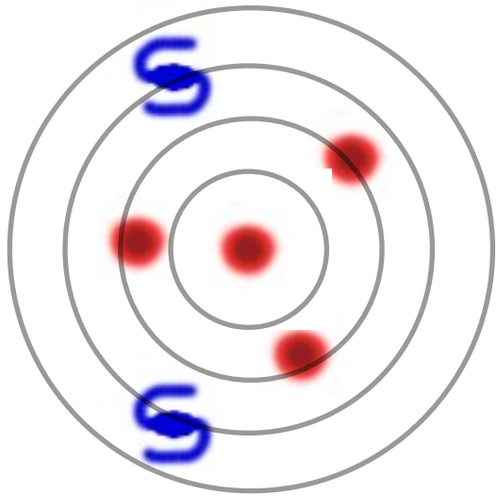
Red
Quiescent
Galaxy

Galaxy Formation is Not Independent of Environment

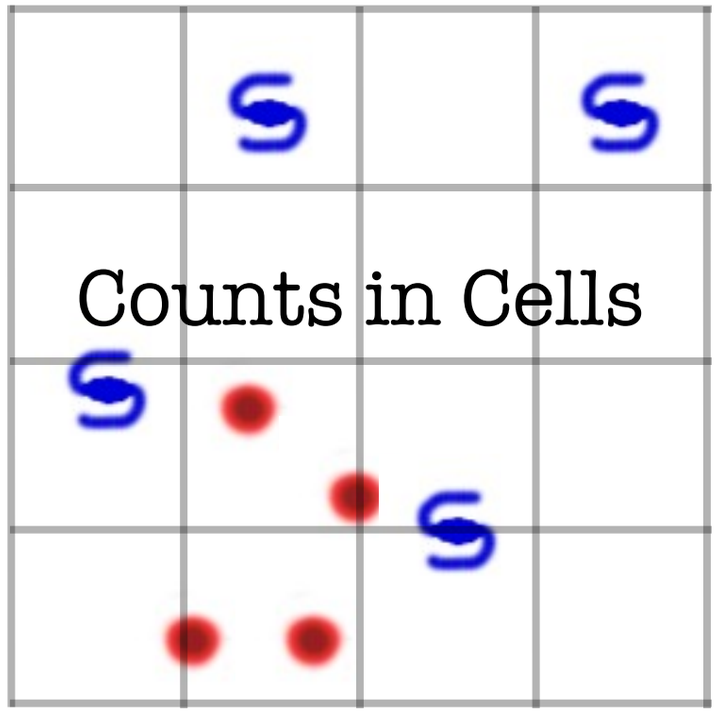


Clustering Relates Galaxies to Their Environment

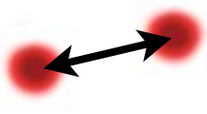
2-Point Correlation Function



Counts in Cells



Nearest Neighbor



Clustering Relates Galaxies to Their Environment

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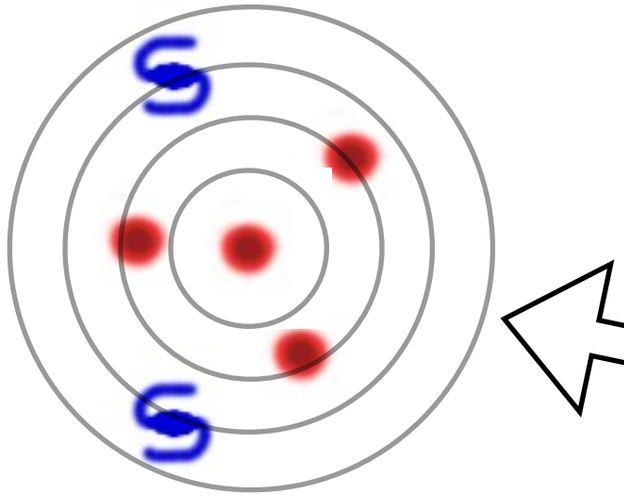
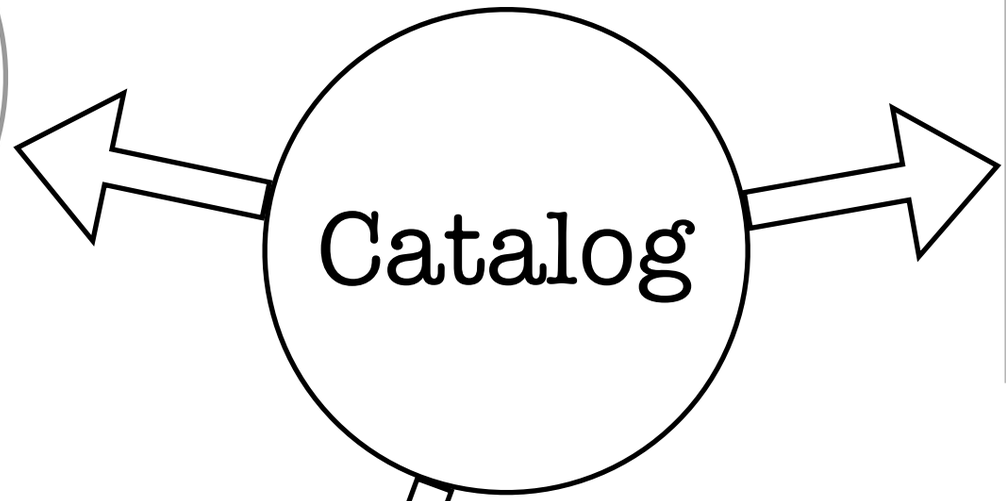
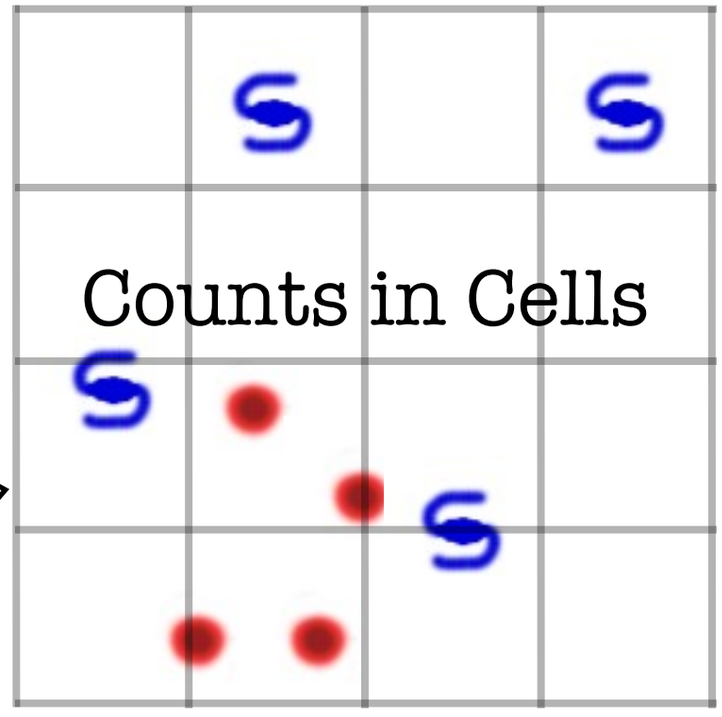
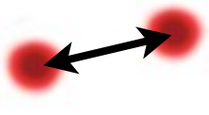


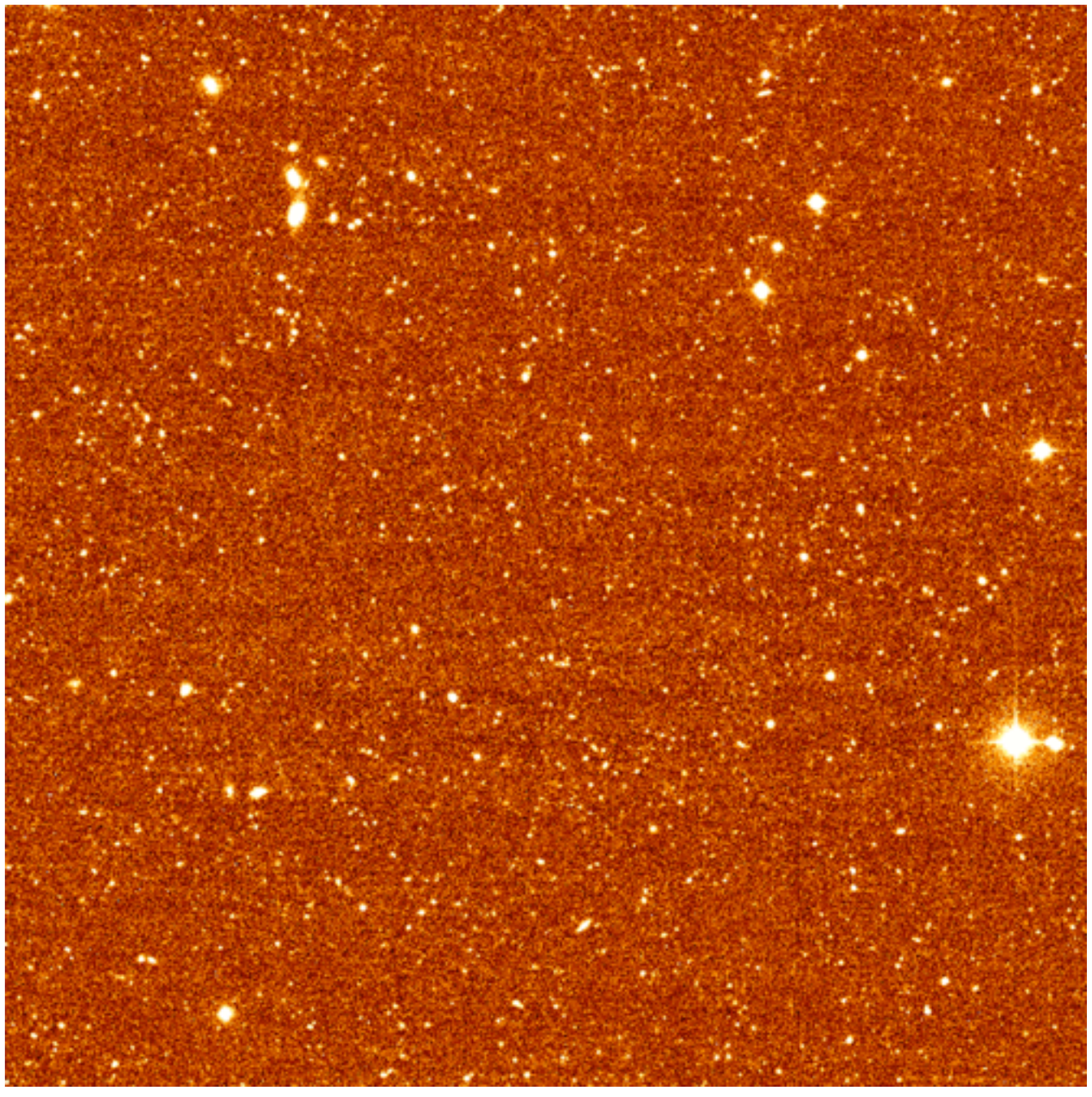




Nearest Neighbor



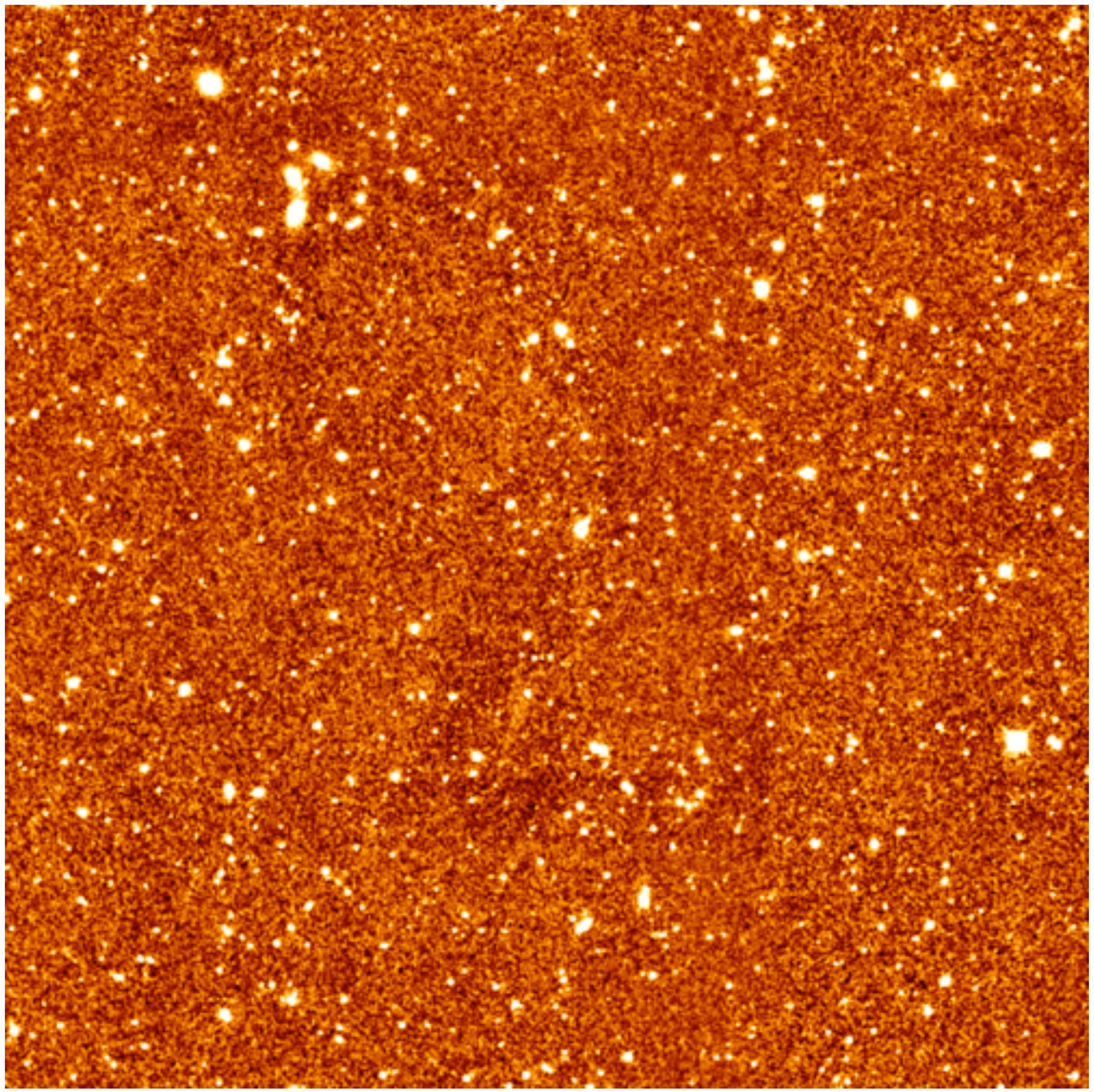
Submm Maps/Catalogs are NOT Like Those at Shorter - Wavelengths



10‘ U-band : MUSYC

U-band
~ 60 sources/
arcmin^2

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

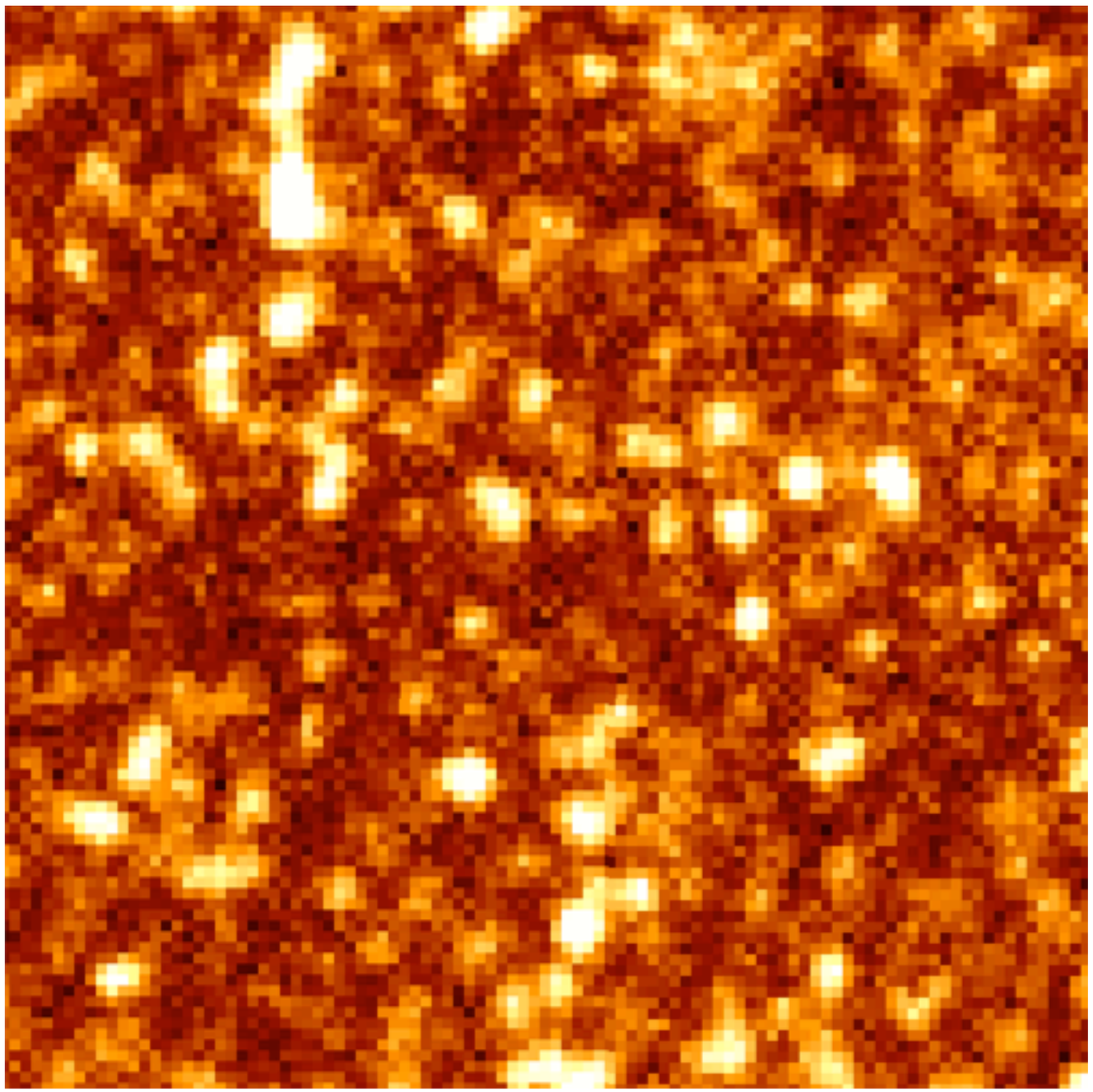


10‘ K-band : MUSYC

U-band
~ 60 sources/ arcmin^2

K-band
~ 45 sources/ arcmin^2

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



Gaelen Marsden, UBC

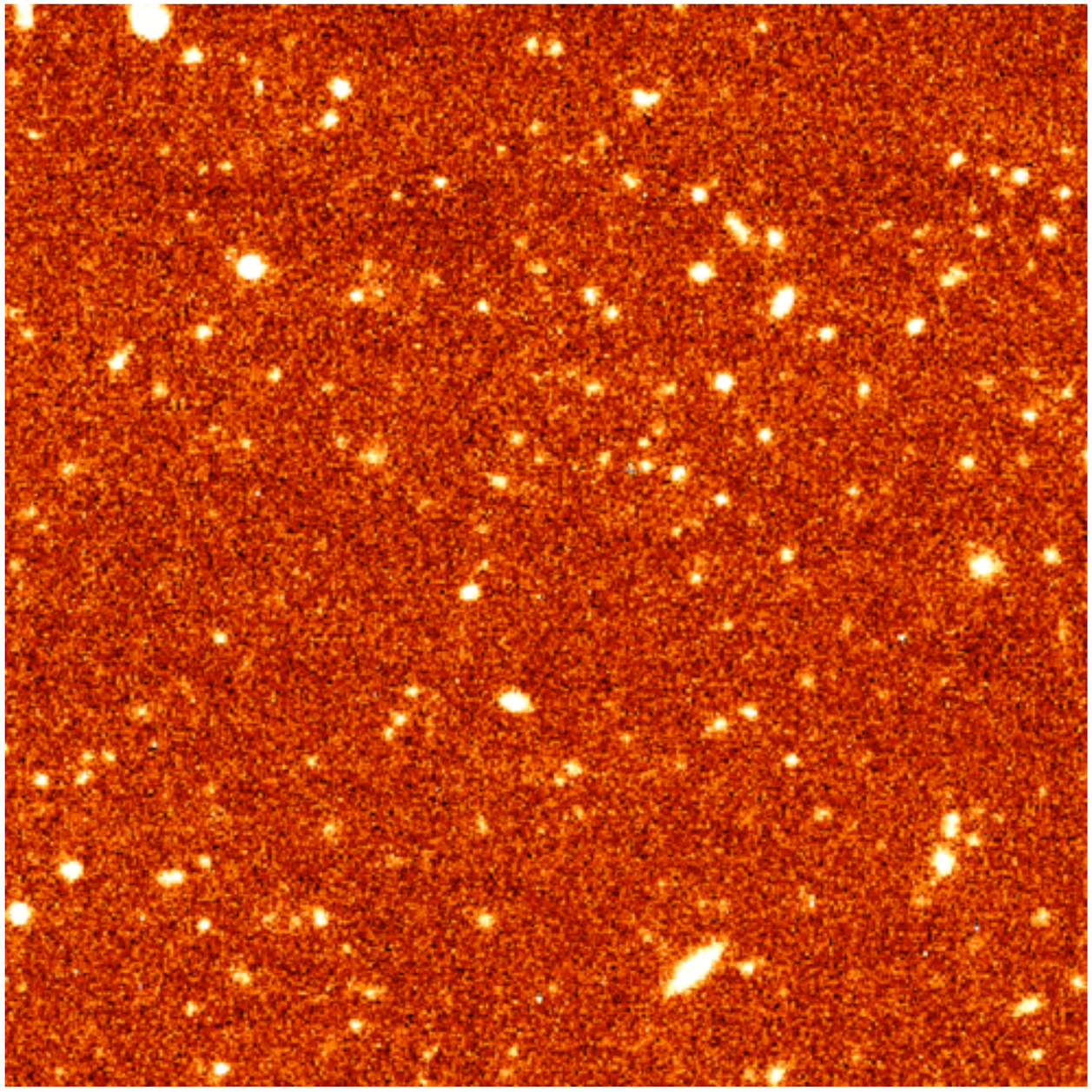
10‘ SPIRE 250 μm

U-band
~ 60 sources/ arcmin^2

K-band
~ 45 sources/ arcmin^2

SPIRE
~ 0.5 sources/ arcmin^2

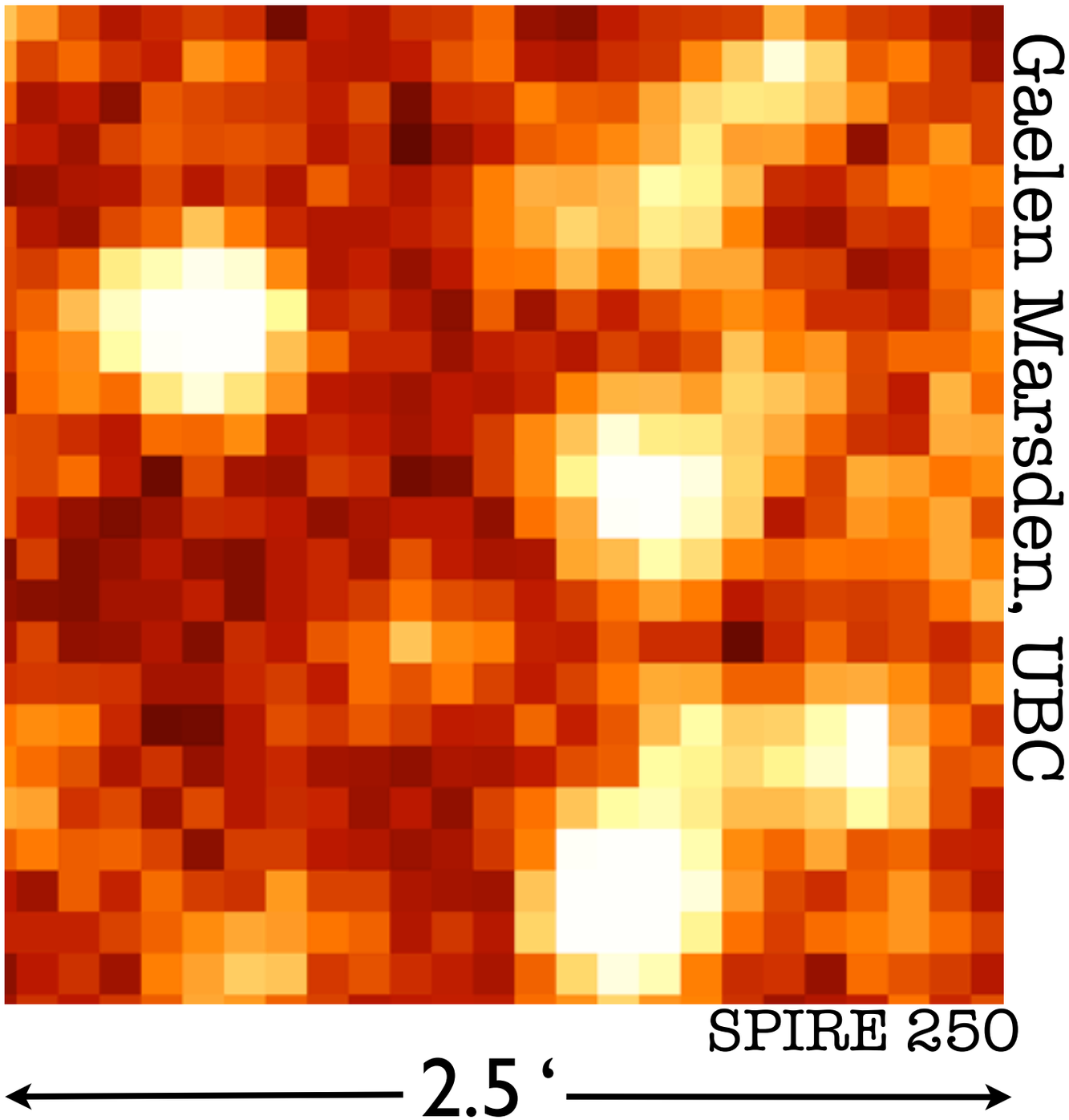
~ 85% of Sources in the Map Appear as Fluctuations



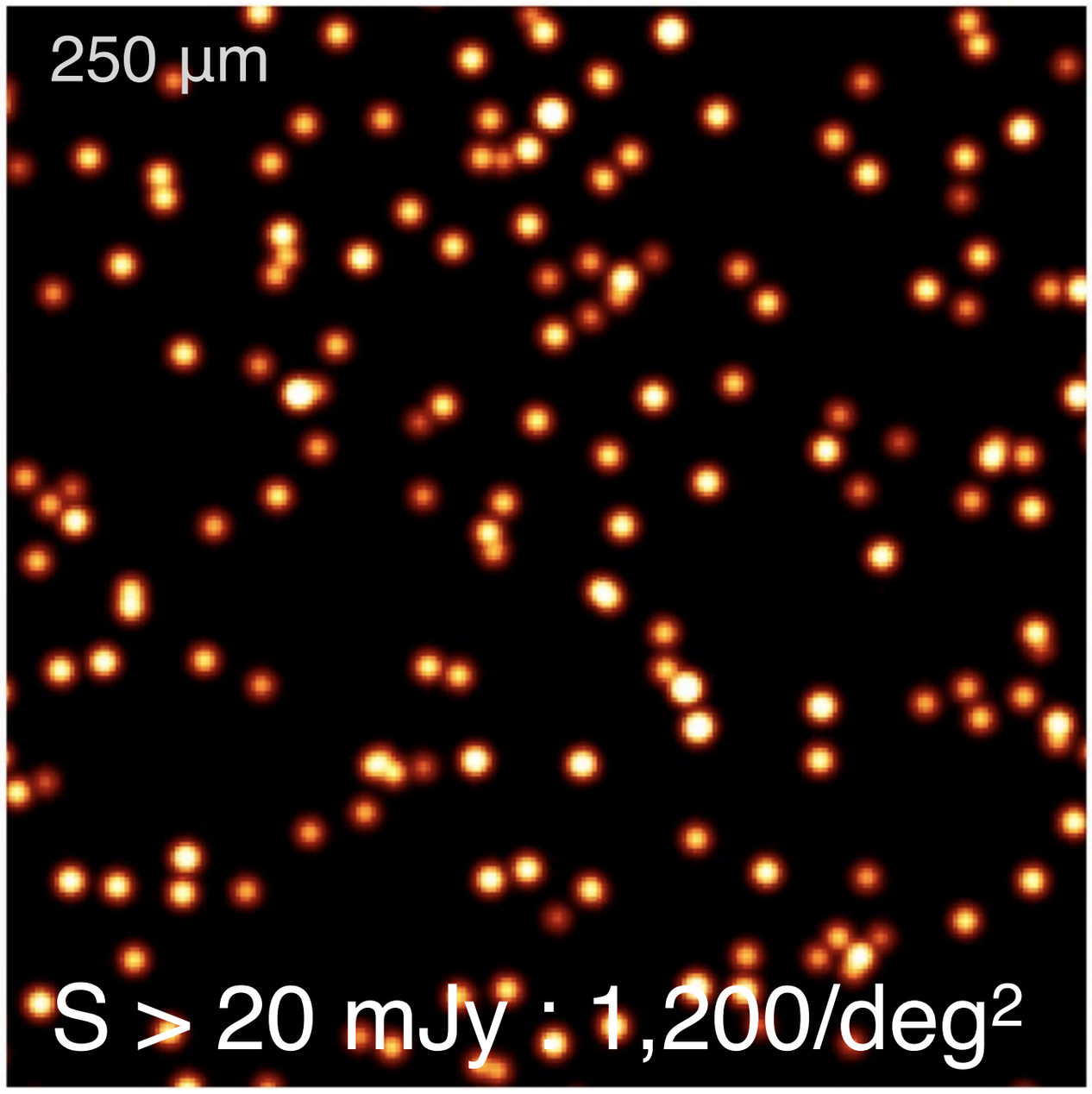
U-band : MUSYC

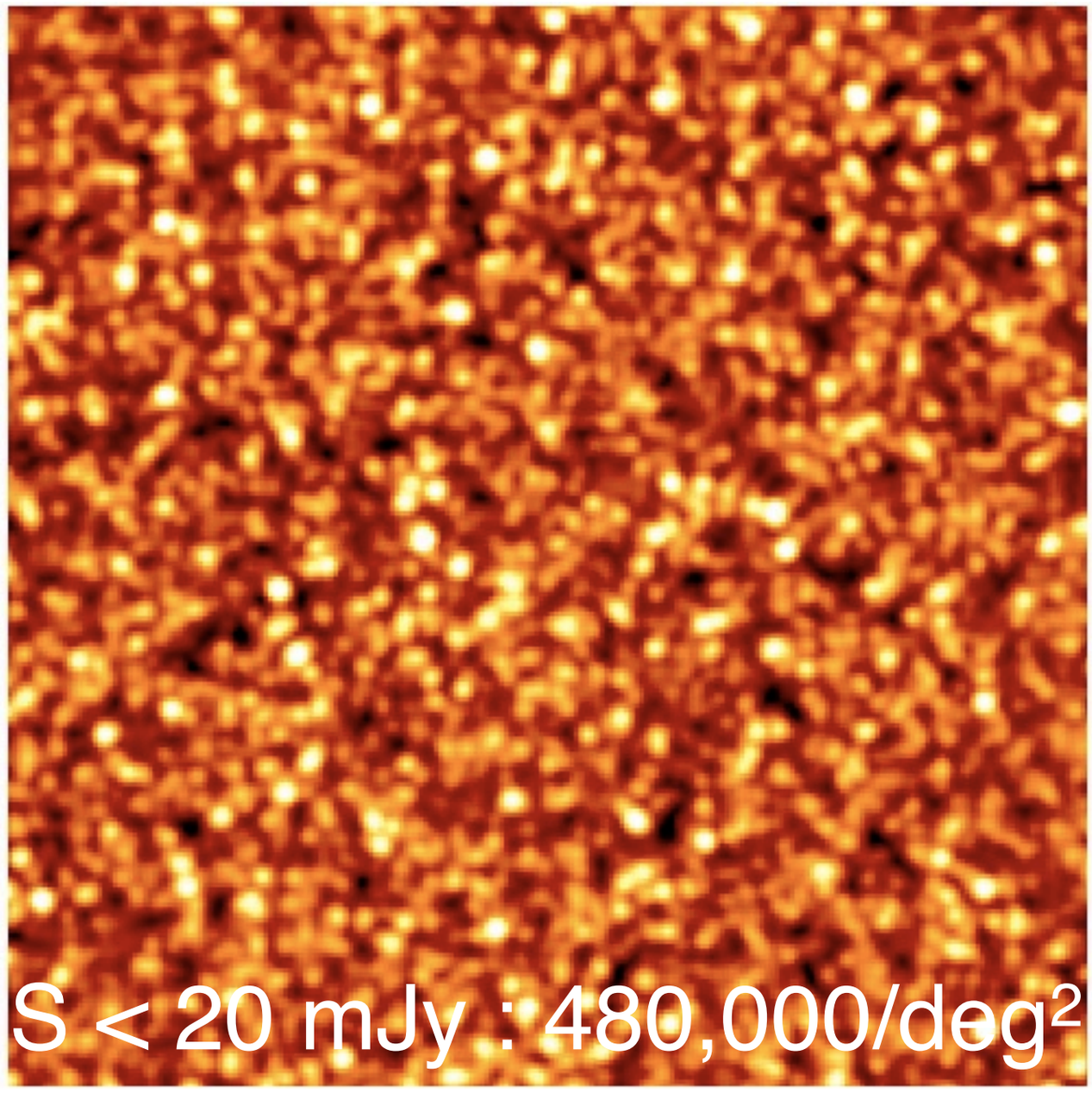
2.5 ‘

~ 85% of Sources in the Map Appear as Fluctuations



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





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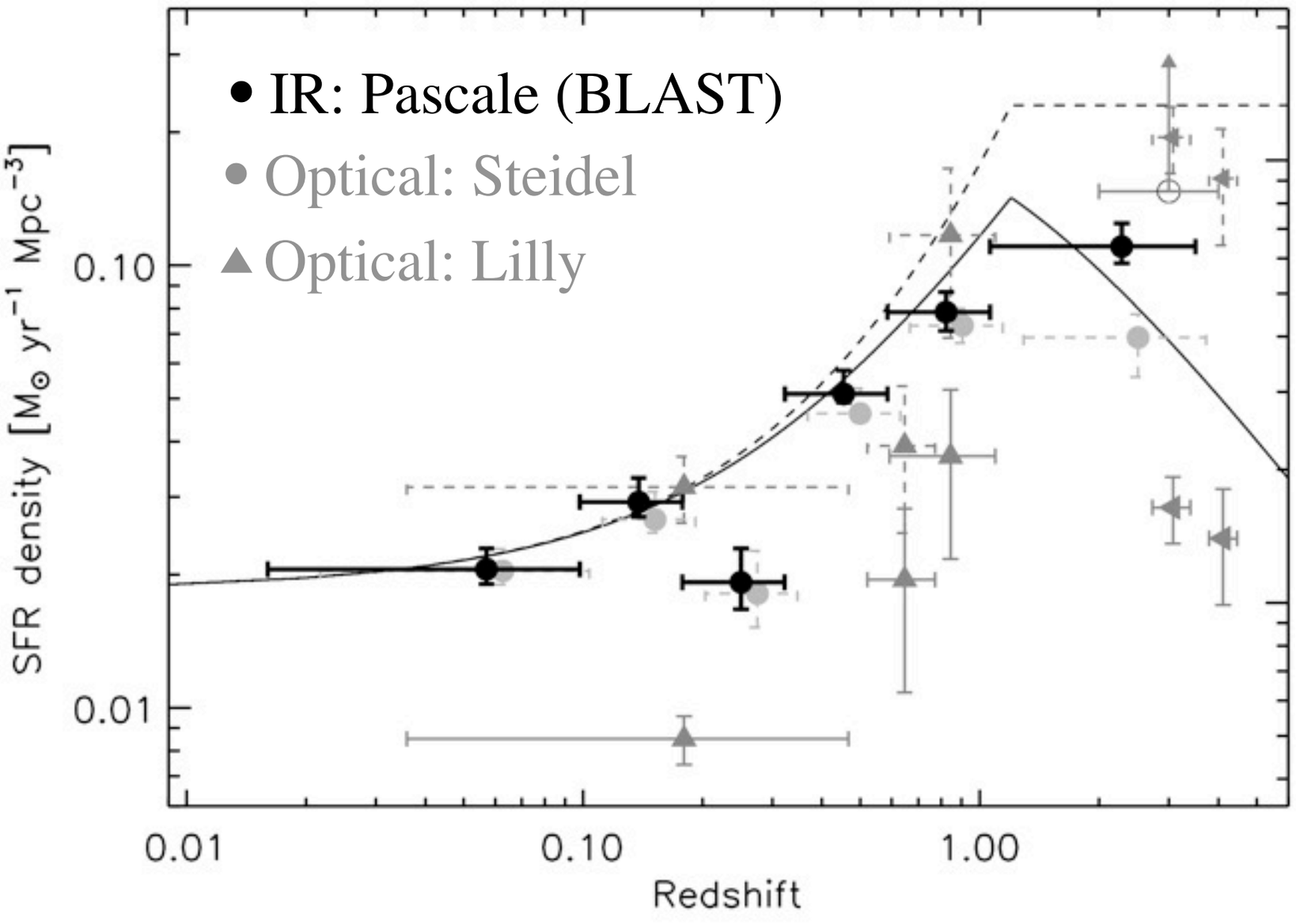
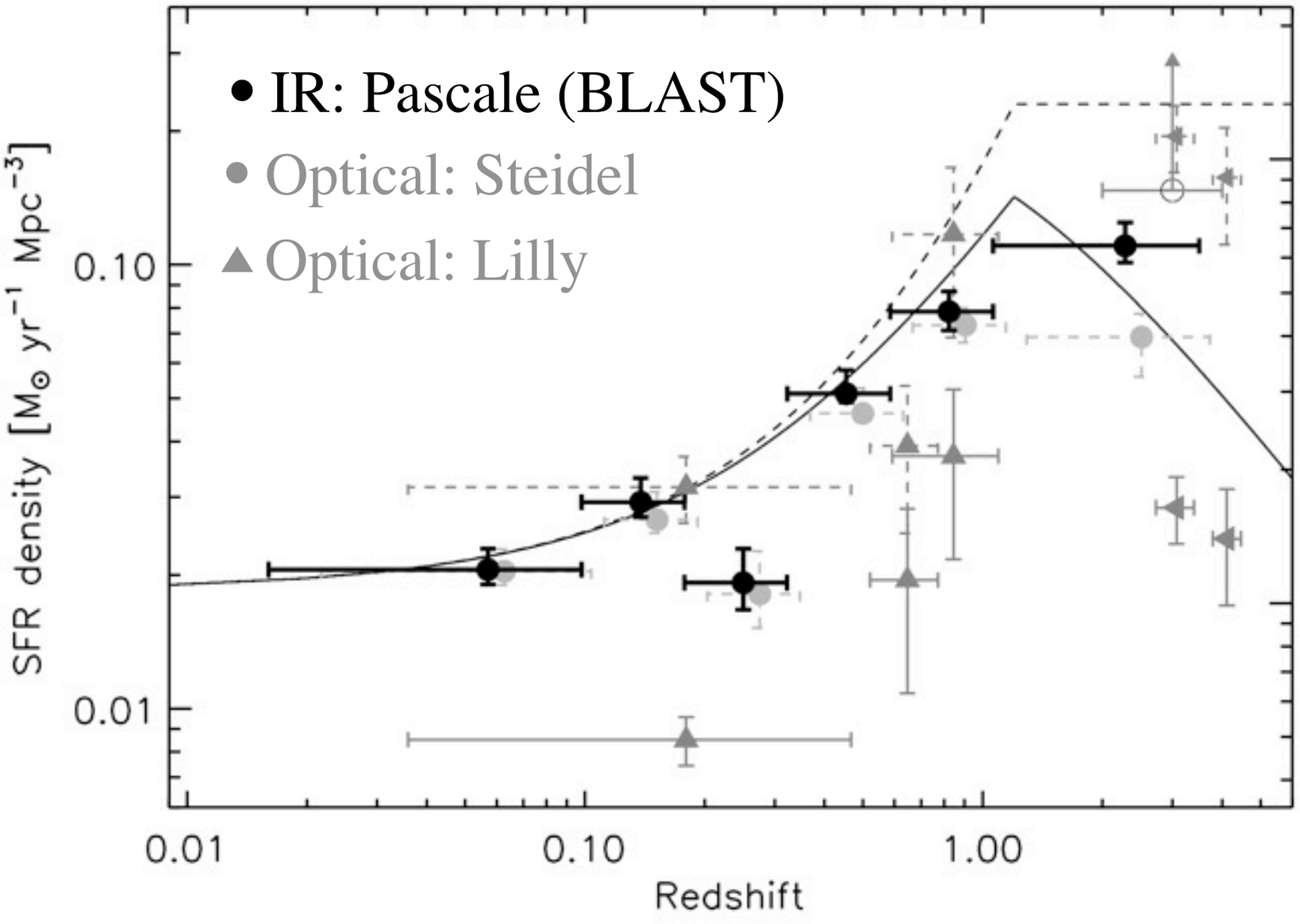


Pascale et al. (2009) - 0904.1206

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

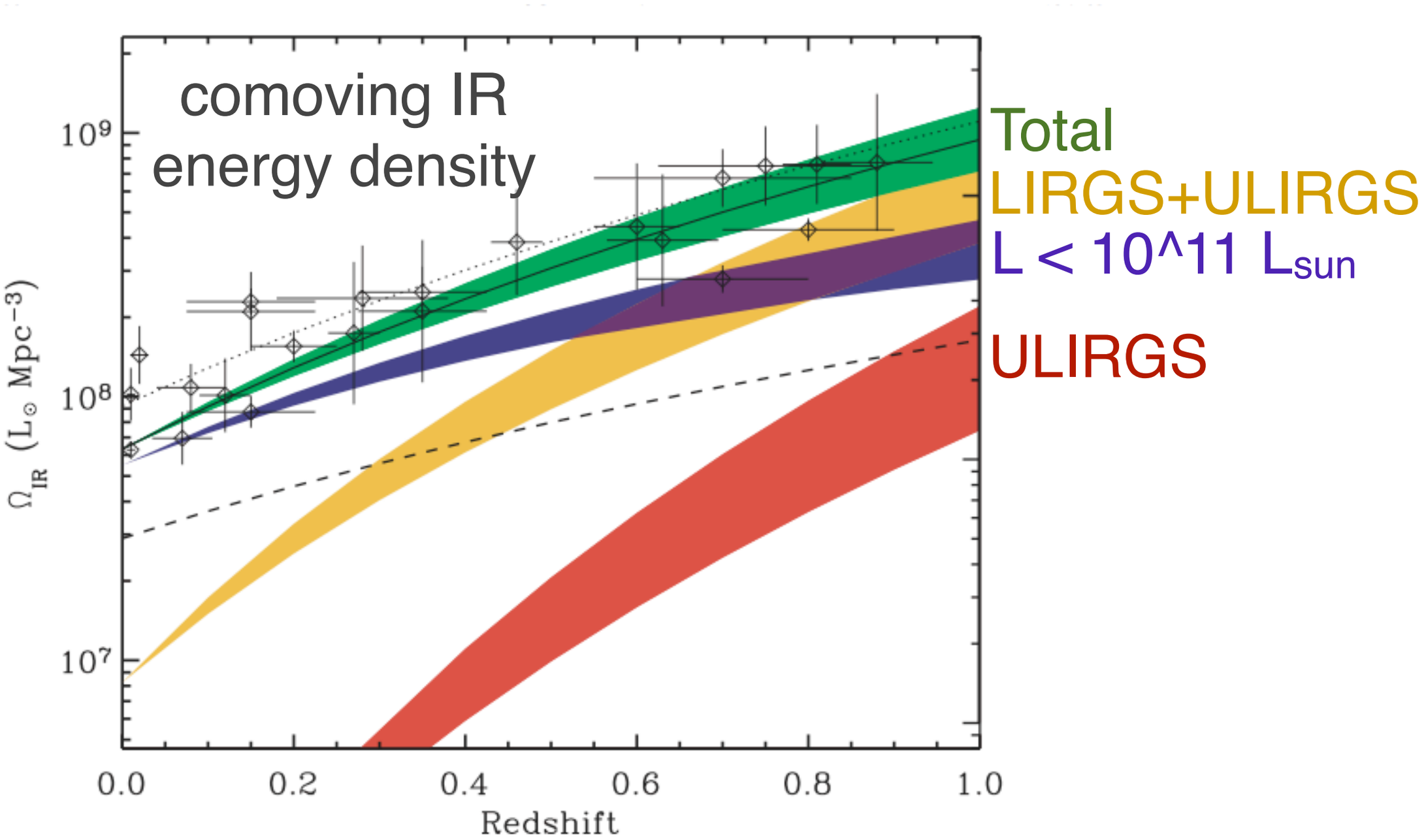


Pascale et al. (2009) - 0904.1206

Peak Epoch of Star Formation

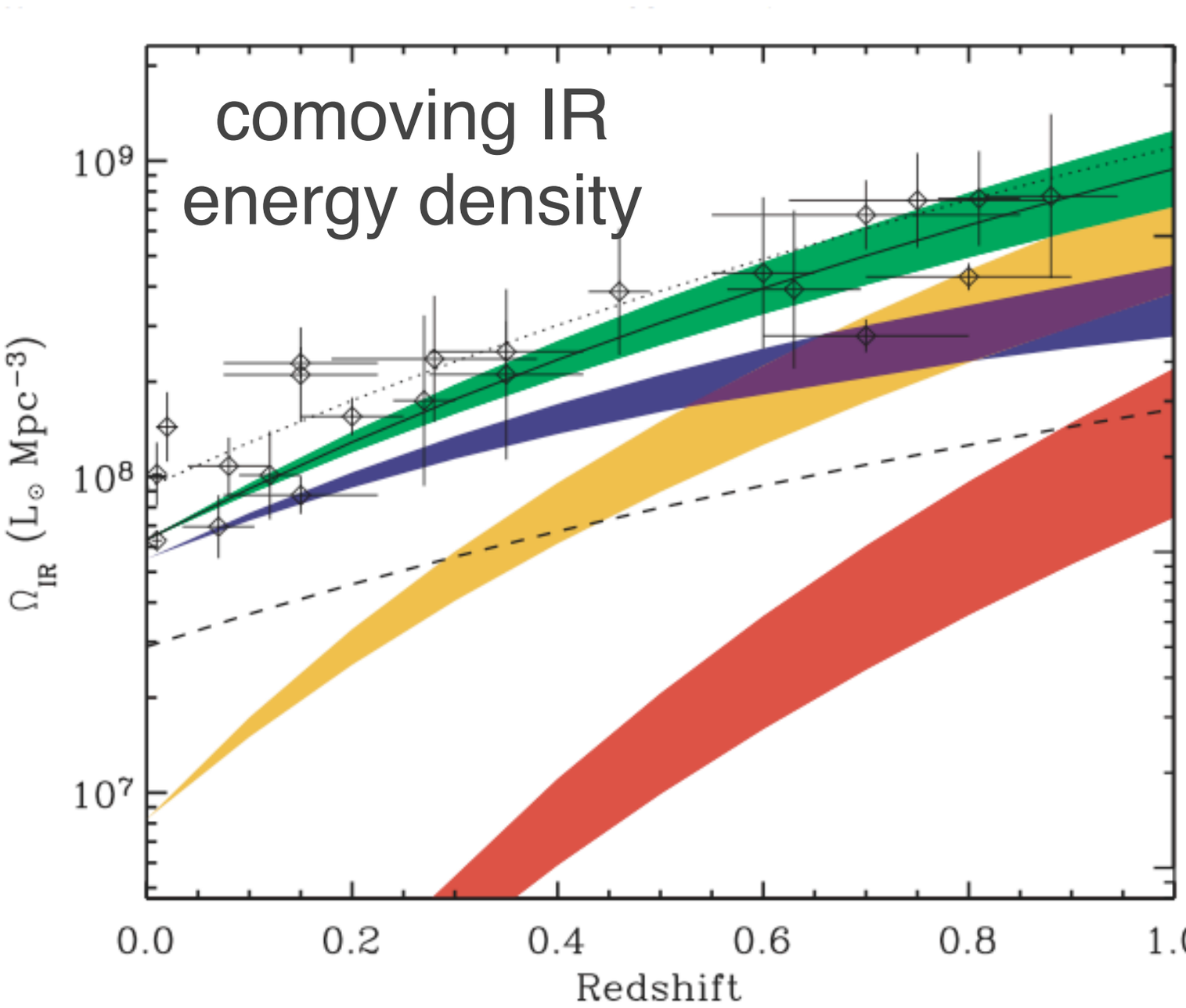
z ~ 1-3

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



Le Floc'h et al. (2005)

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



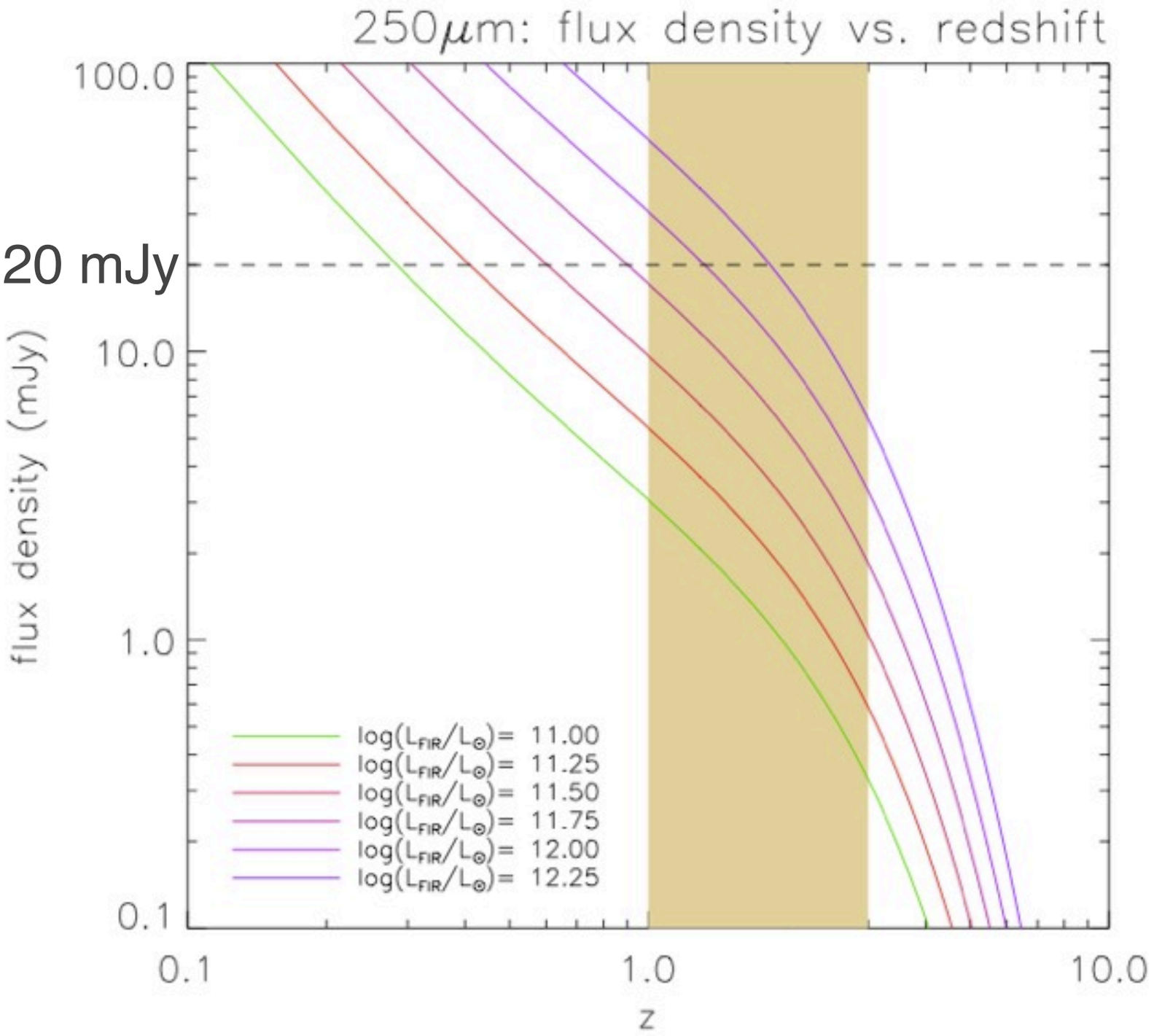
Le Floc'h et al. (2005)

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

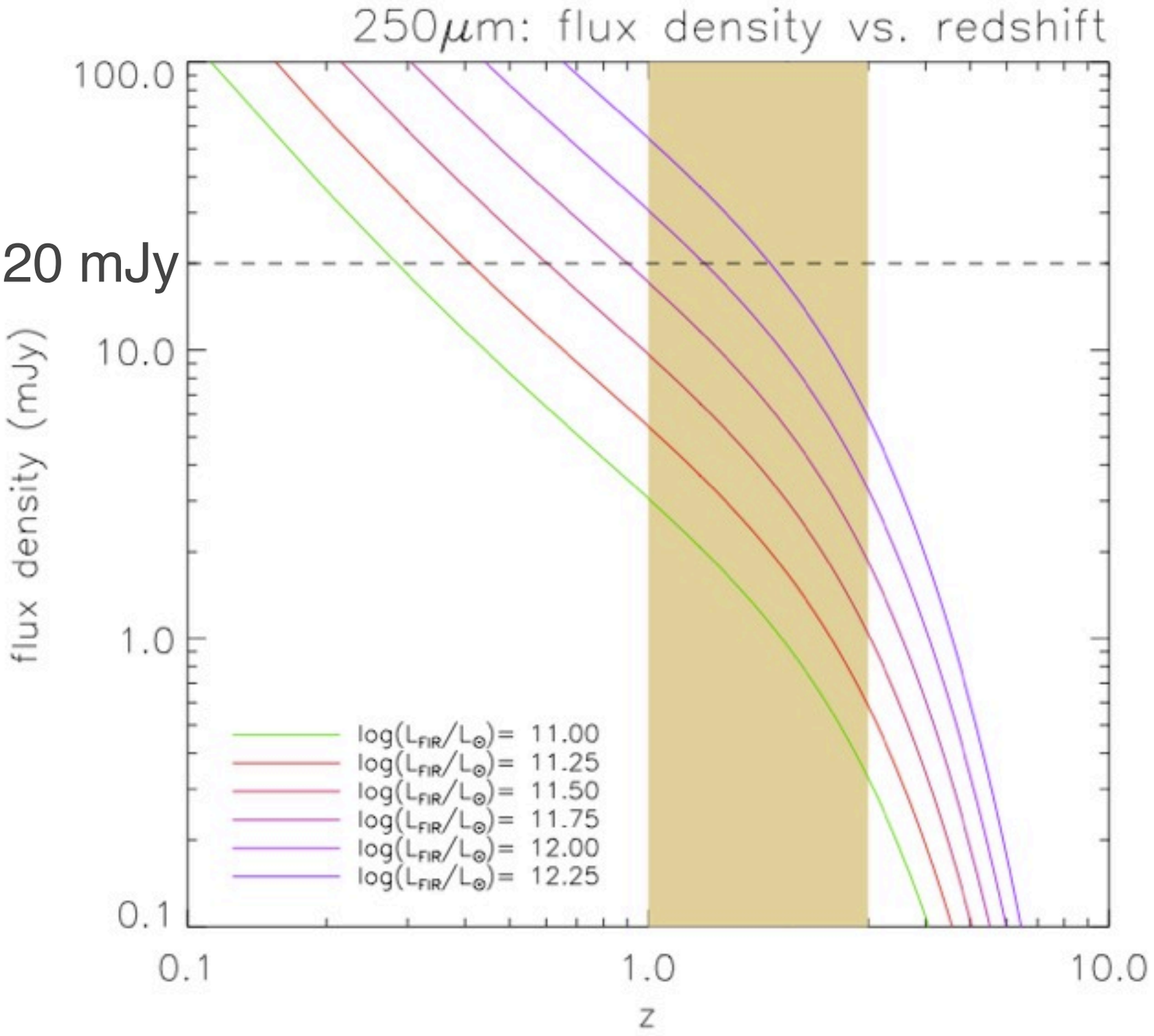
ULIRGS

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

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



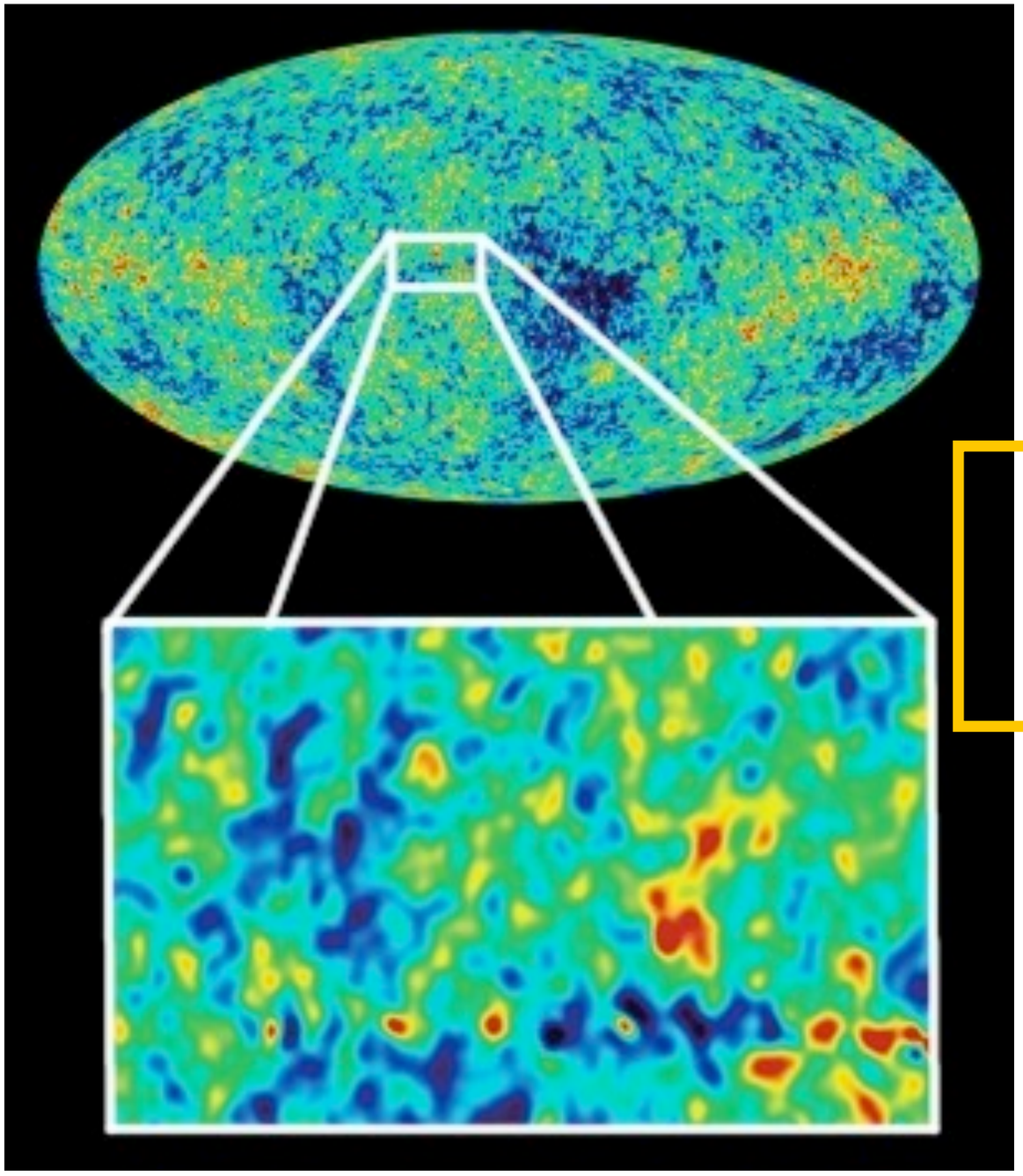
Why care about the ~ 85% of Flux that is unresolved?



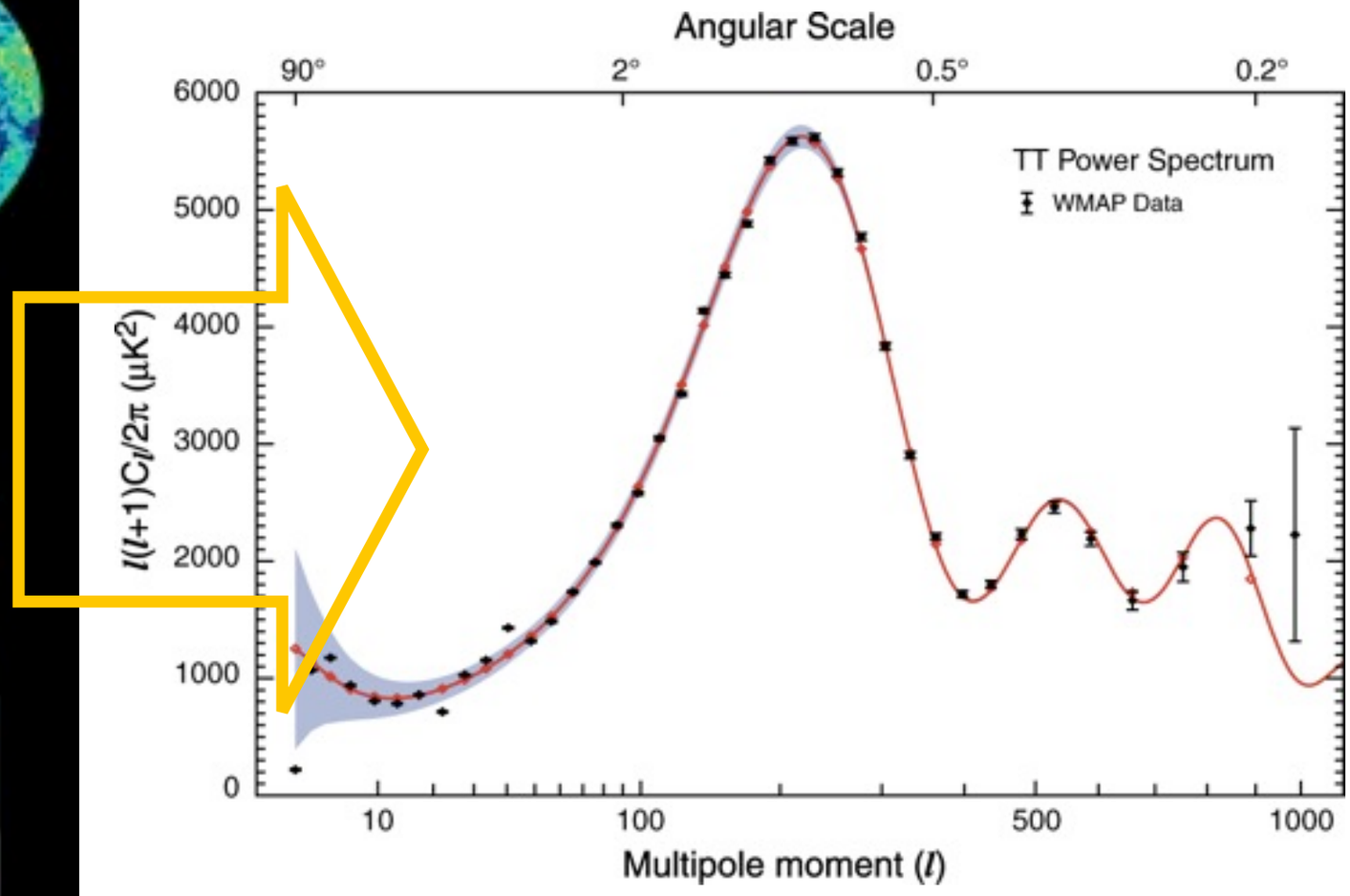
Typical LIRGS at z ~ 1-3 have flux densities S_{ave} ~ 1-10 mJy (at 250um)

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!

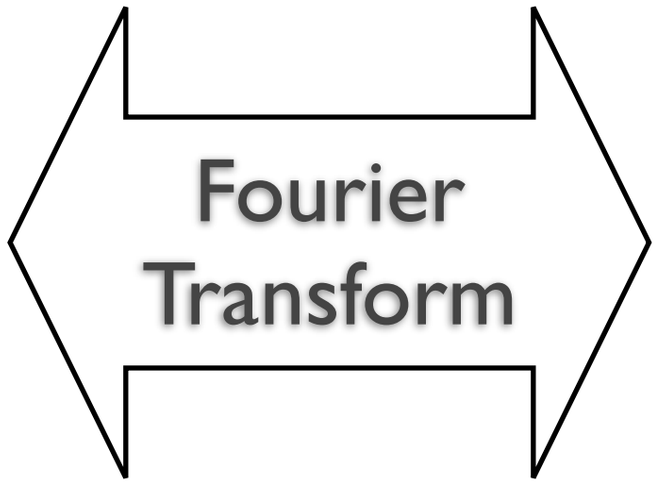


WMAP



Measure Clustering Directly from Correlations in the Fluctuations!

Power Spectrum



2-Point Correlation Function

BLAST

UBC
Ed Chapin
Mark Halpern
Gaelen Marsden
Douglas Scott
Don Wiebe

JPL
Jamie Bock

U of T
Peter Martin
Barth Netterfield

Brown University
Greg Tucker

CDF (France)
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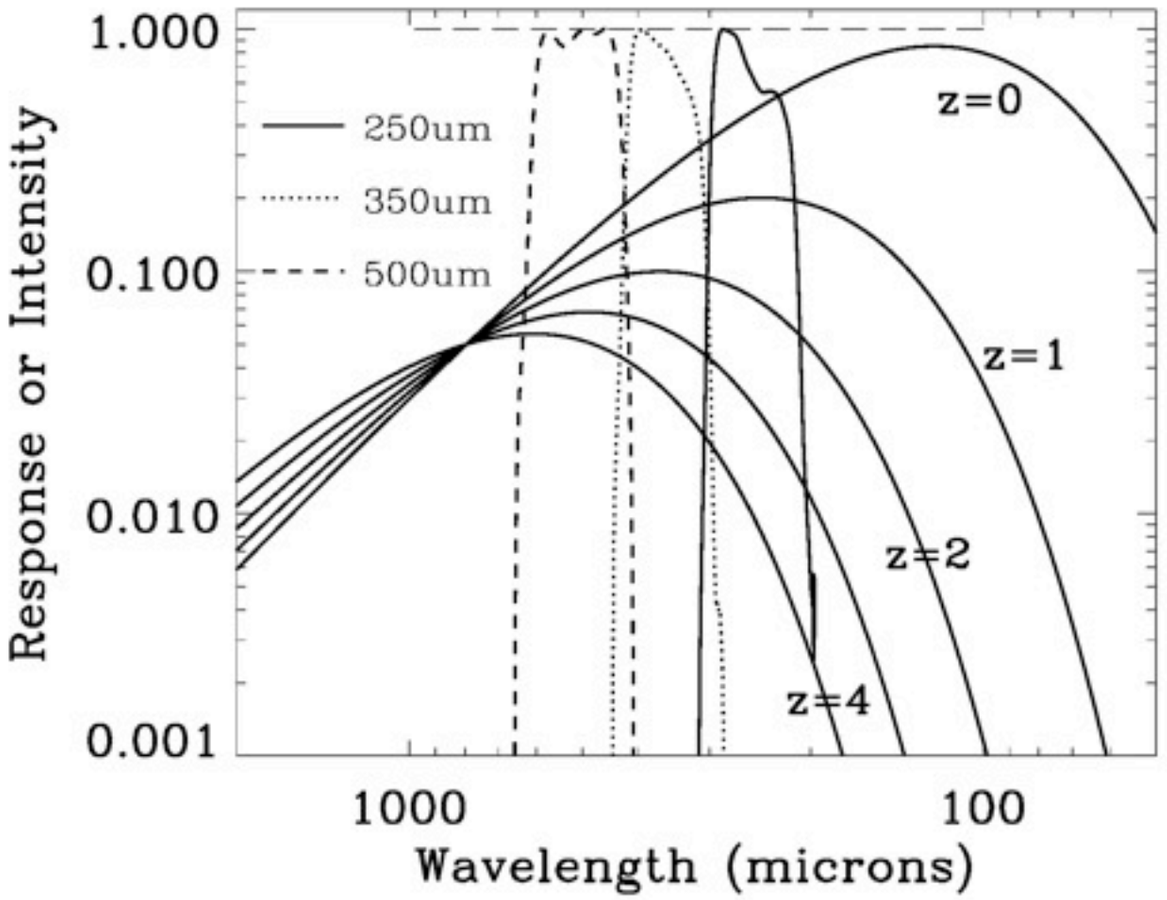
BLAST

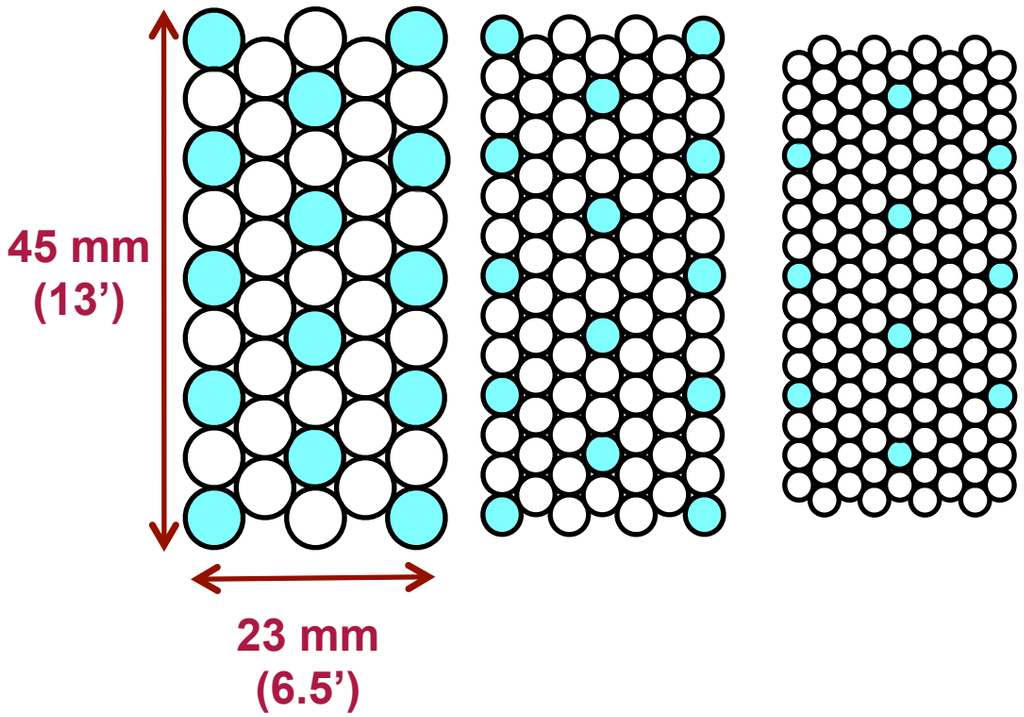
designed to bracket the redshifted peak



Balloon-borne Large Aperture Submillimeter Telescope (BLAST)

500 μm 350 μm 250 μm

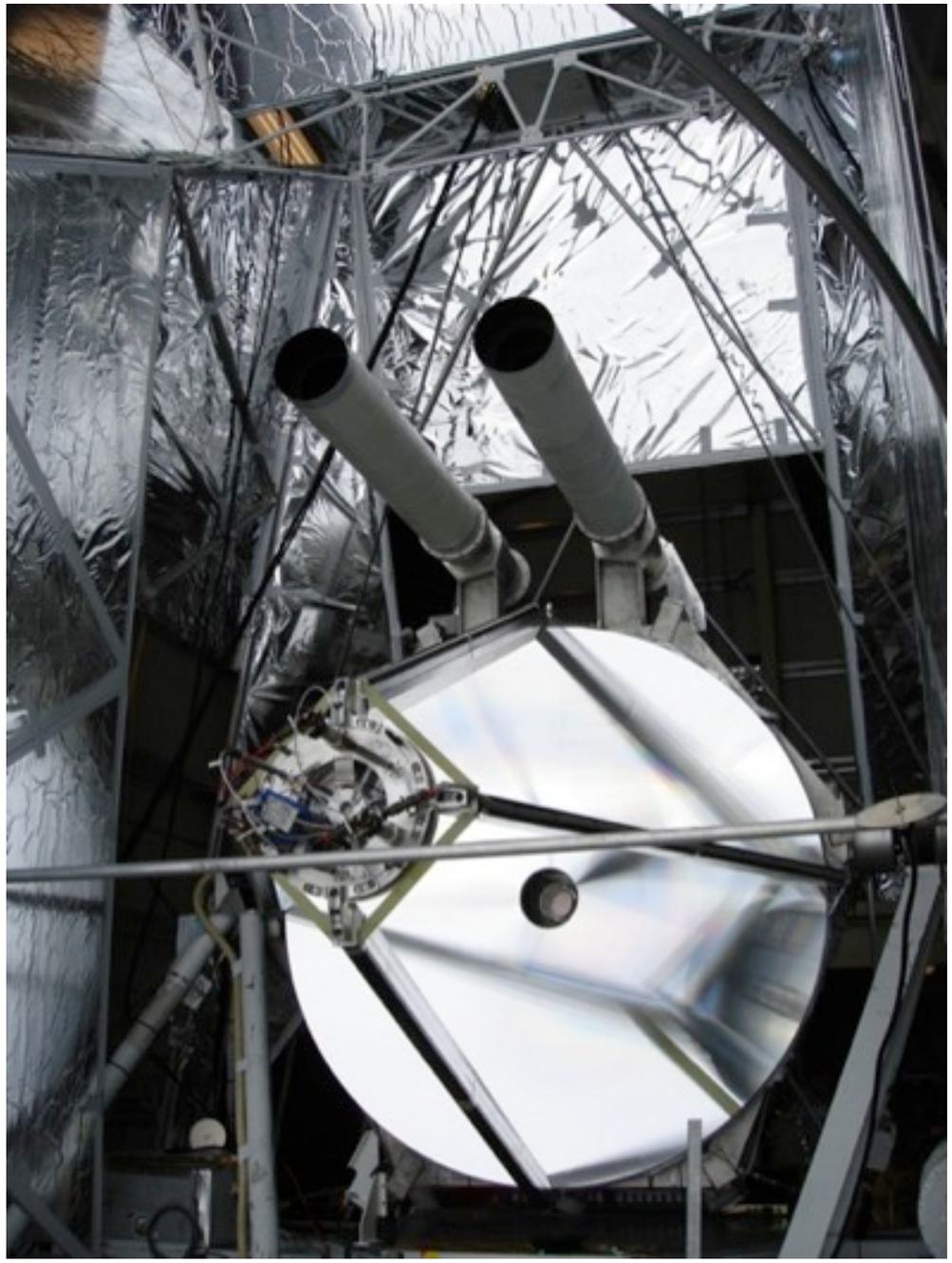
43 detectors 88 detectors 139



⇒ Overlapping beams

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

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

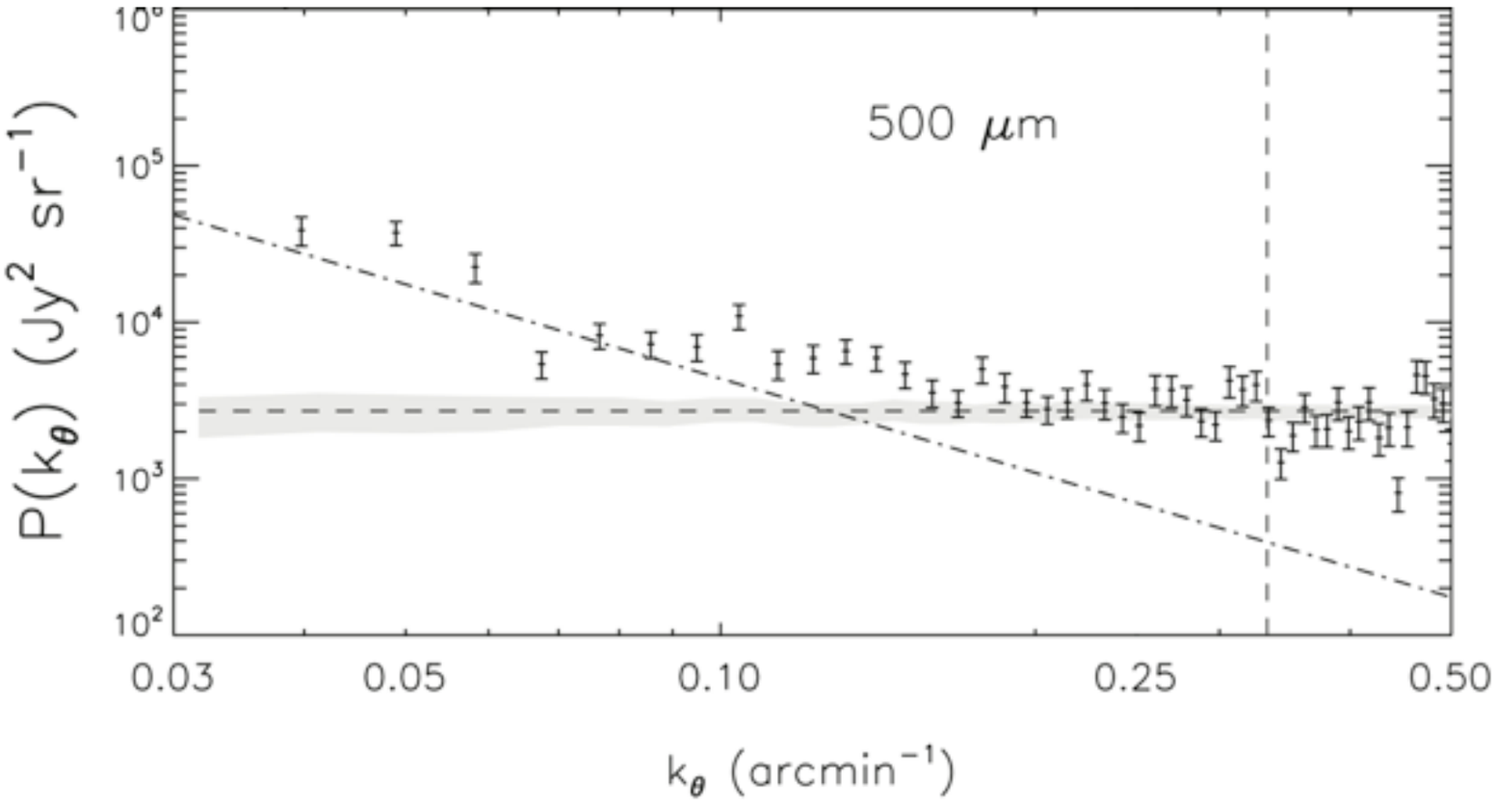
45” - 350 μm

60” - 500 μm

i.e., twice the size of SPIRE’s beams

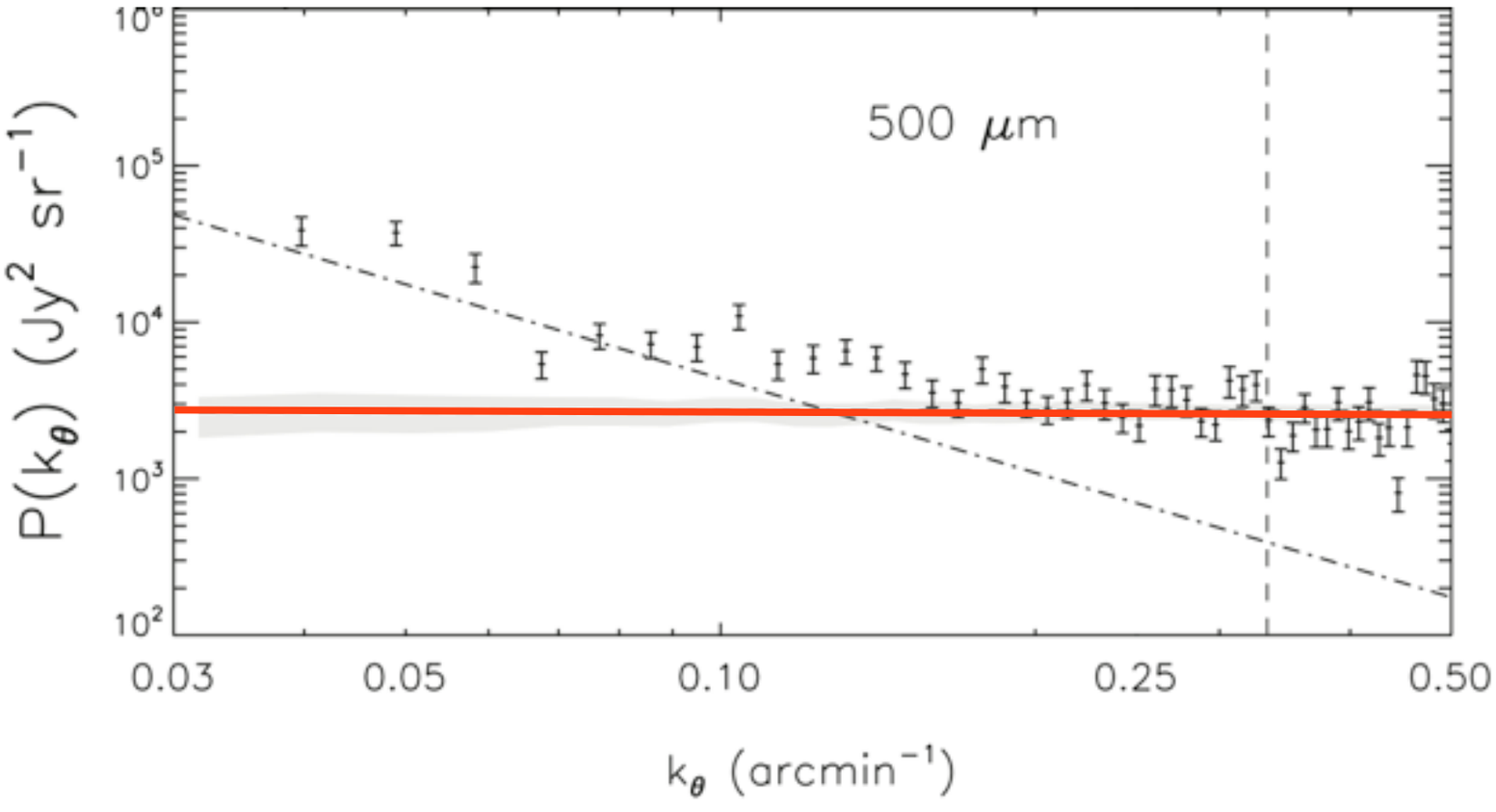
BLAST Measured Clustering from Fluctuations

BLAST Measured Clustering from Fluctuations



Viero et al. 0904.1200

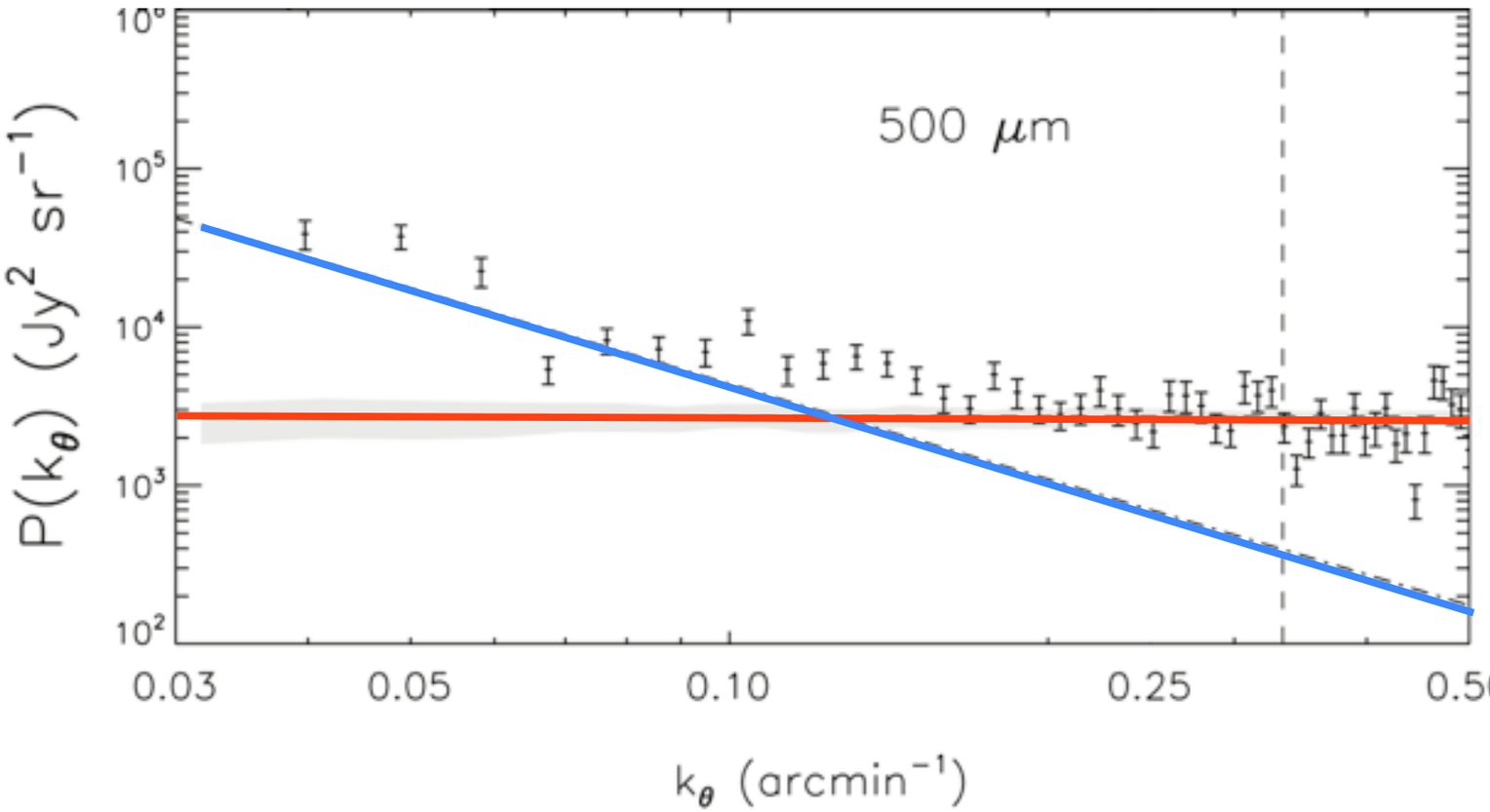
BLAST Measured Clustering from Fluctuations



Shot Noise

Viero et al. 0904.1200

BLAST Measured Clustering from Fluctuations



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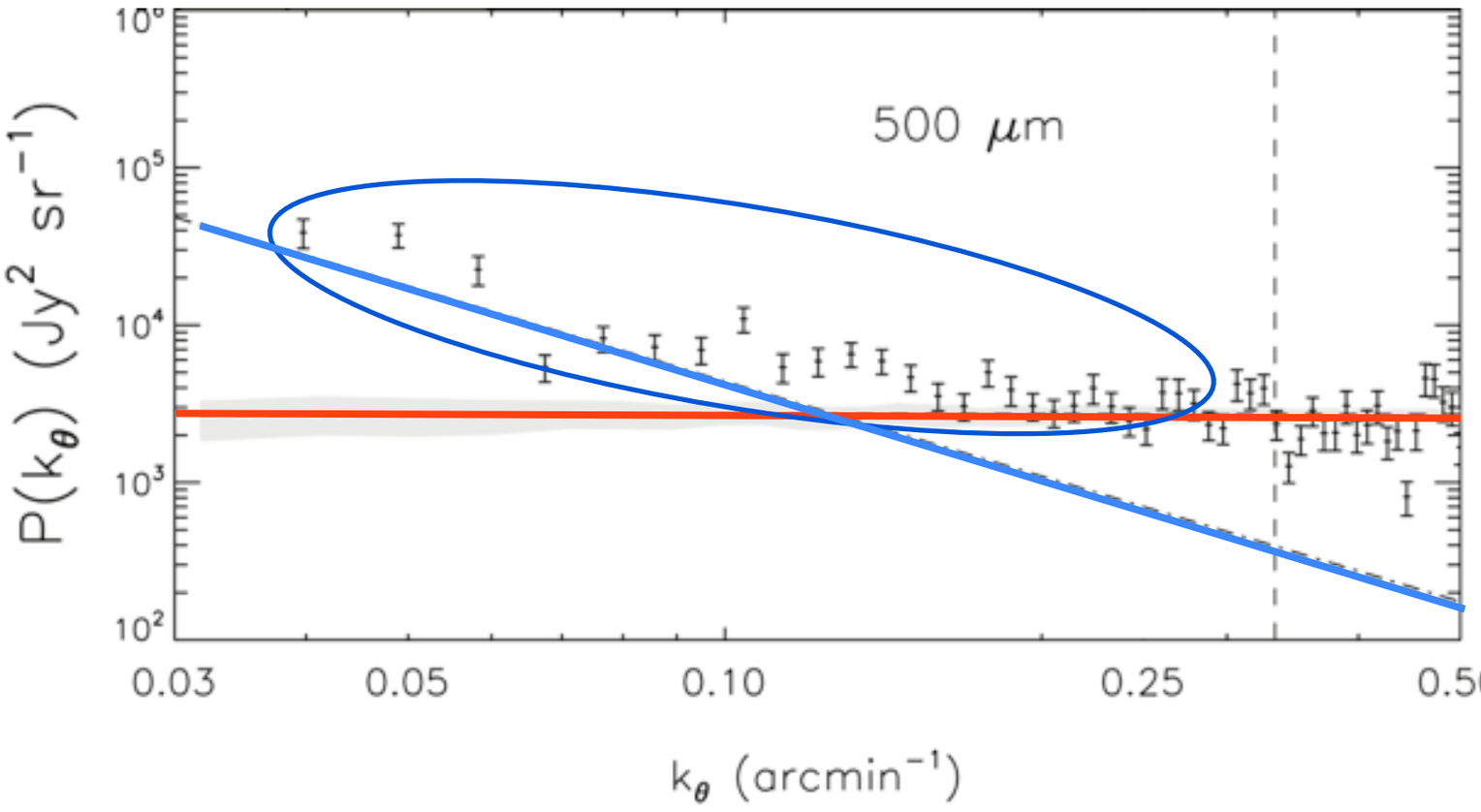
BLAST Measured Clustering from Fluctuations

Excess Signal from Galaxy Clustering



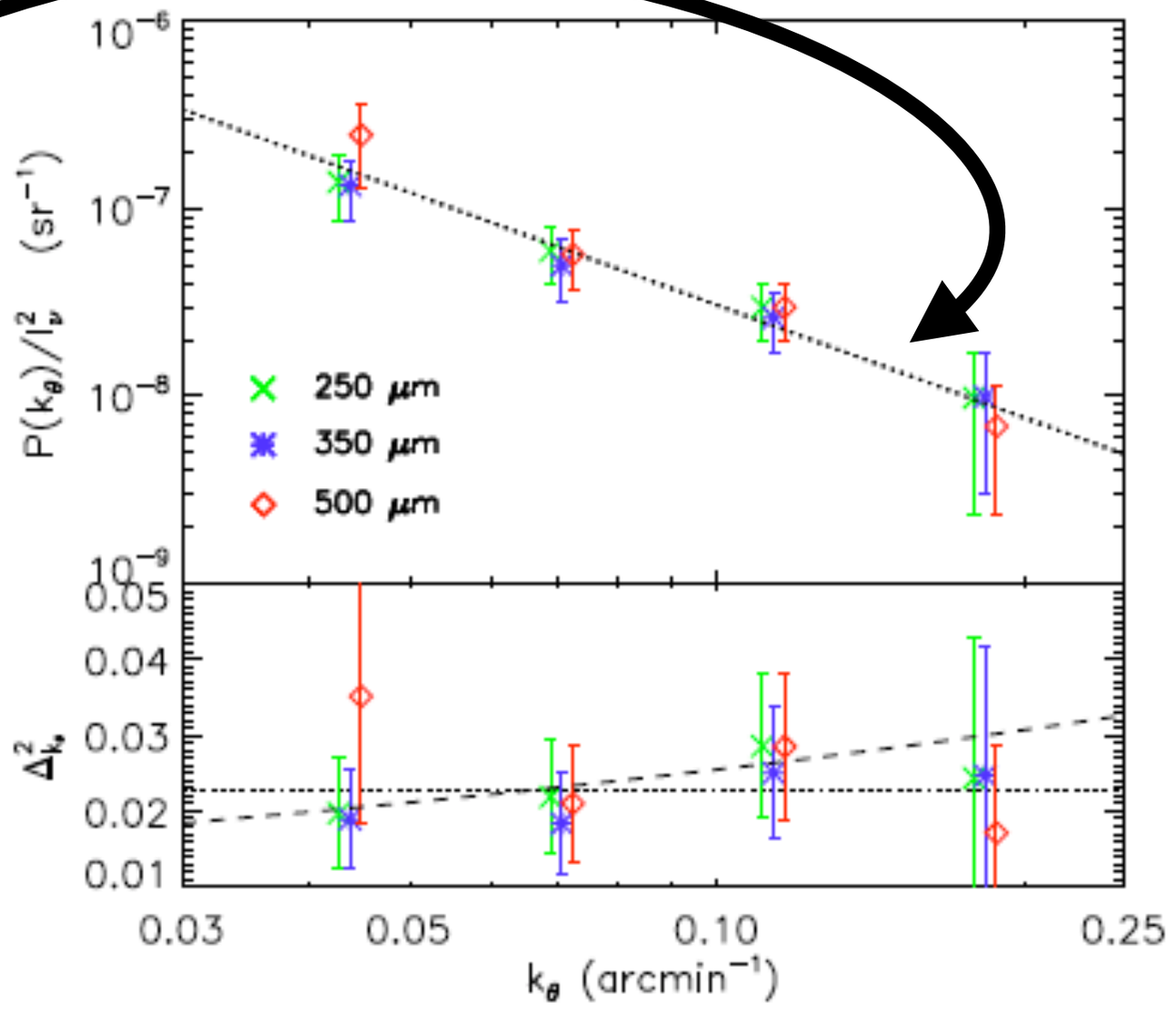
Shot Noise

Clustering

Viero et al. 0904.1200

BLAST Measured Clustering from Fluctuations

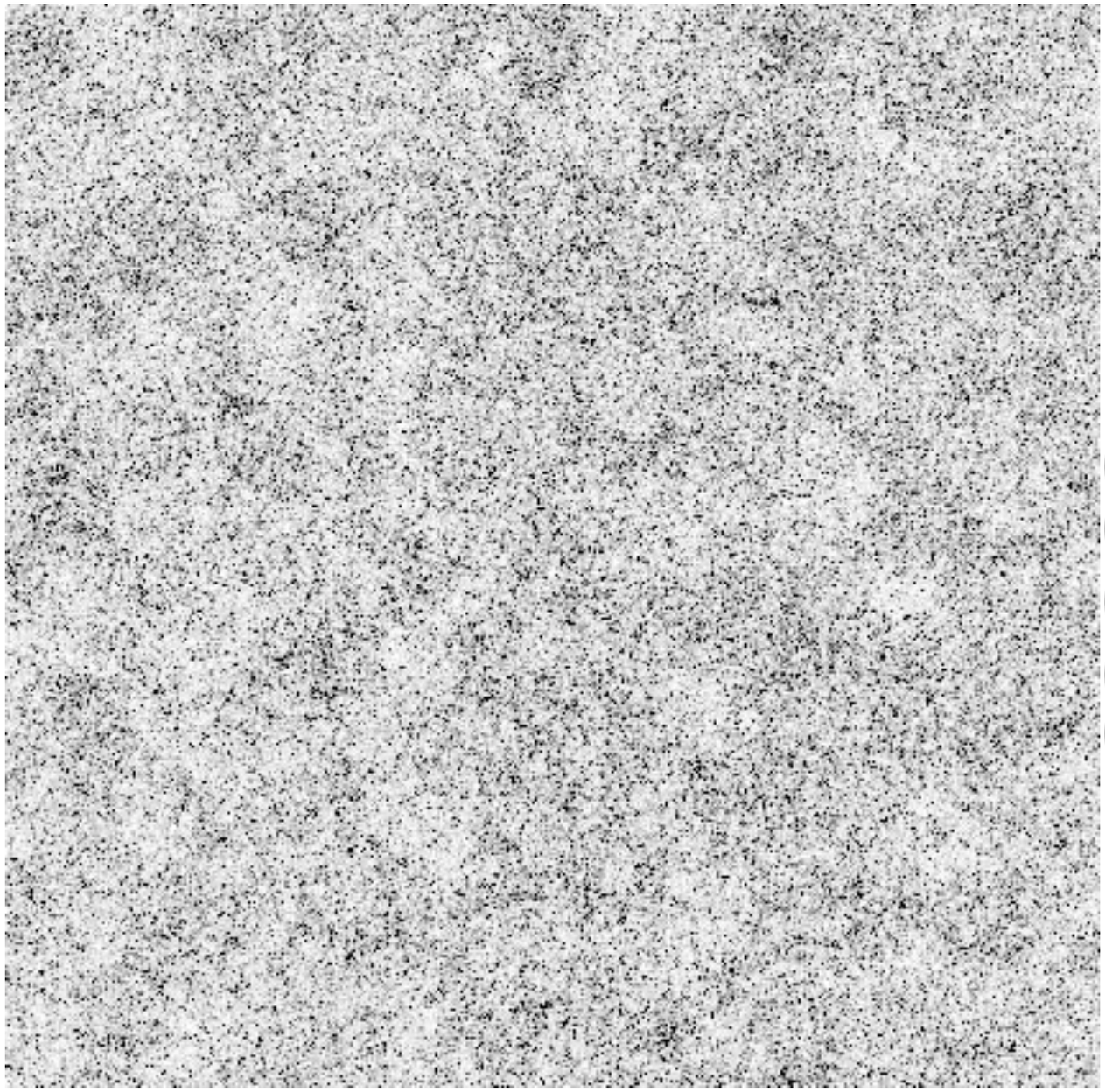
Clustering Signal After Removal of Shot Noise

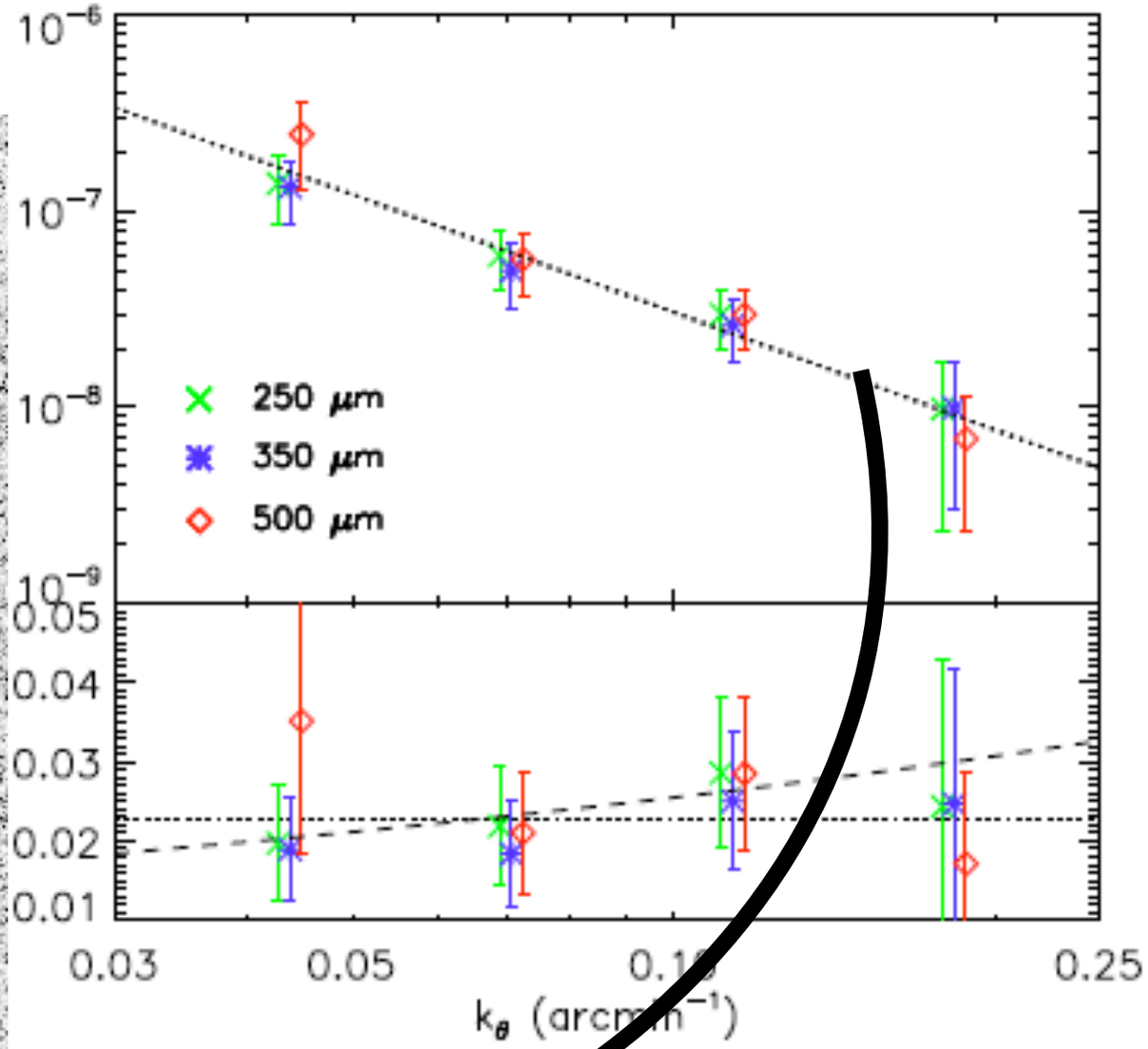


Viero et al. 0904.1200

BLAST Measured Clustering from Fluctuations

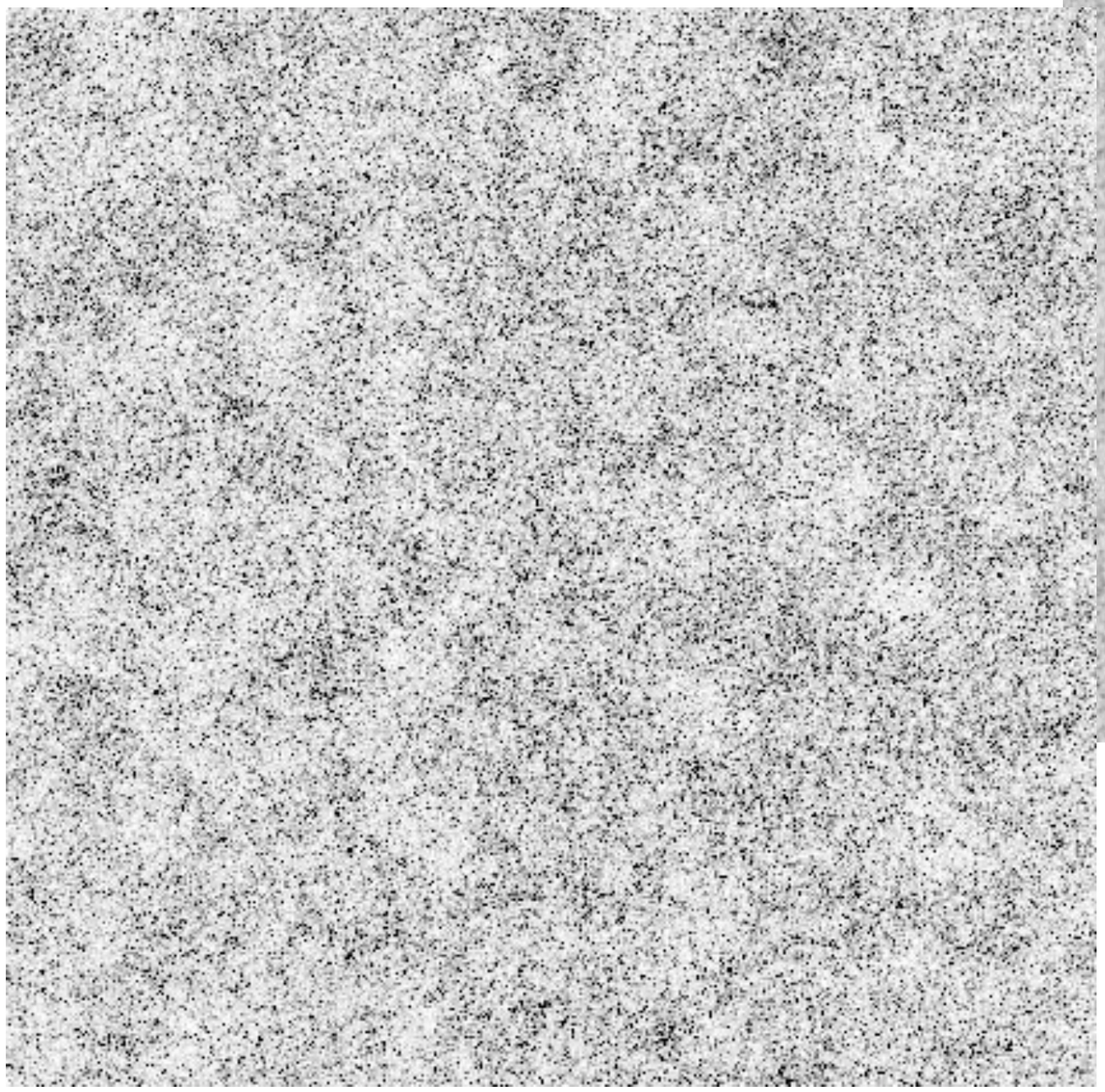
BLAST prediction...

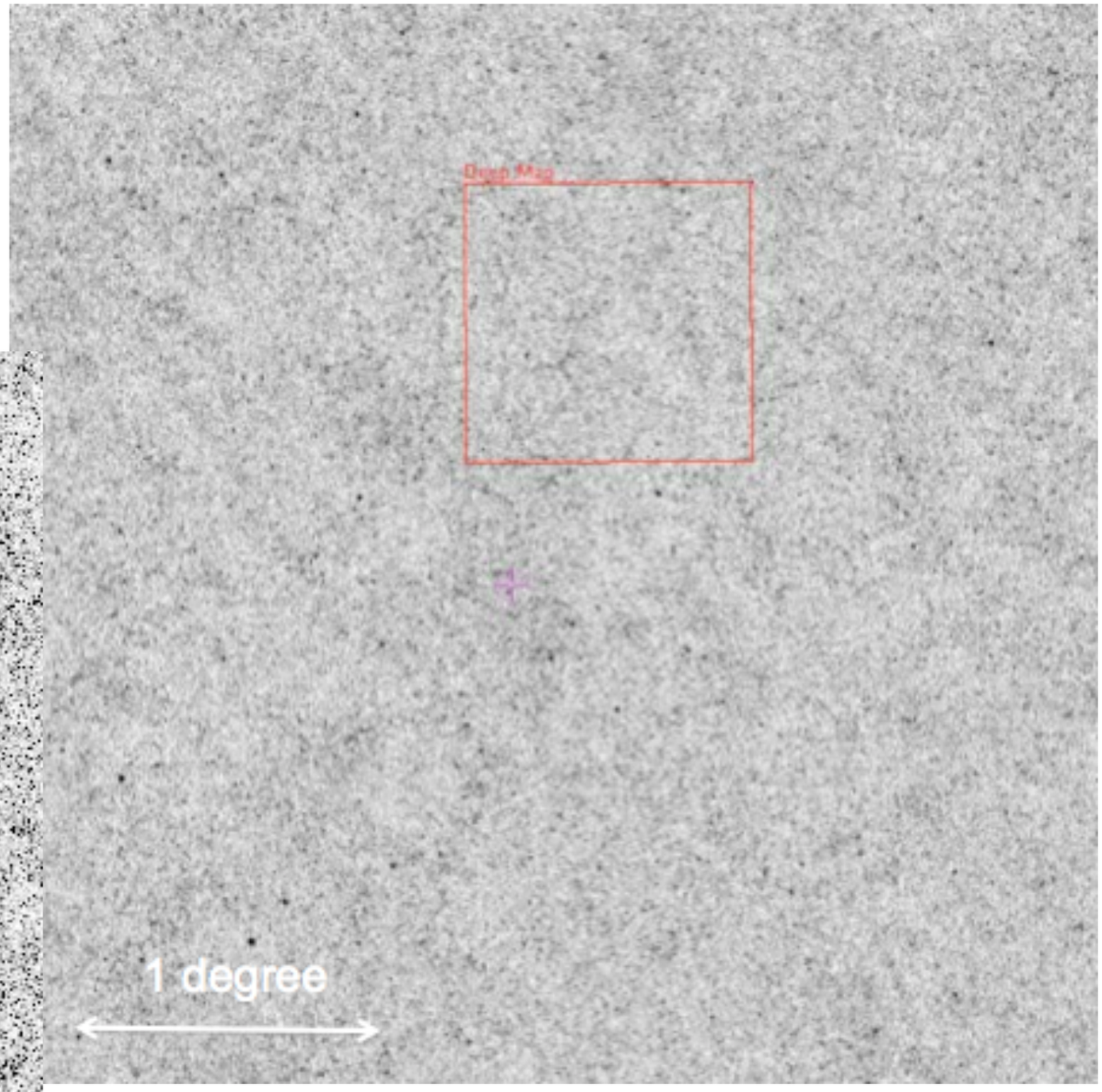




BLAST Measured Clustering from Fluctuations

BLAST prediction...



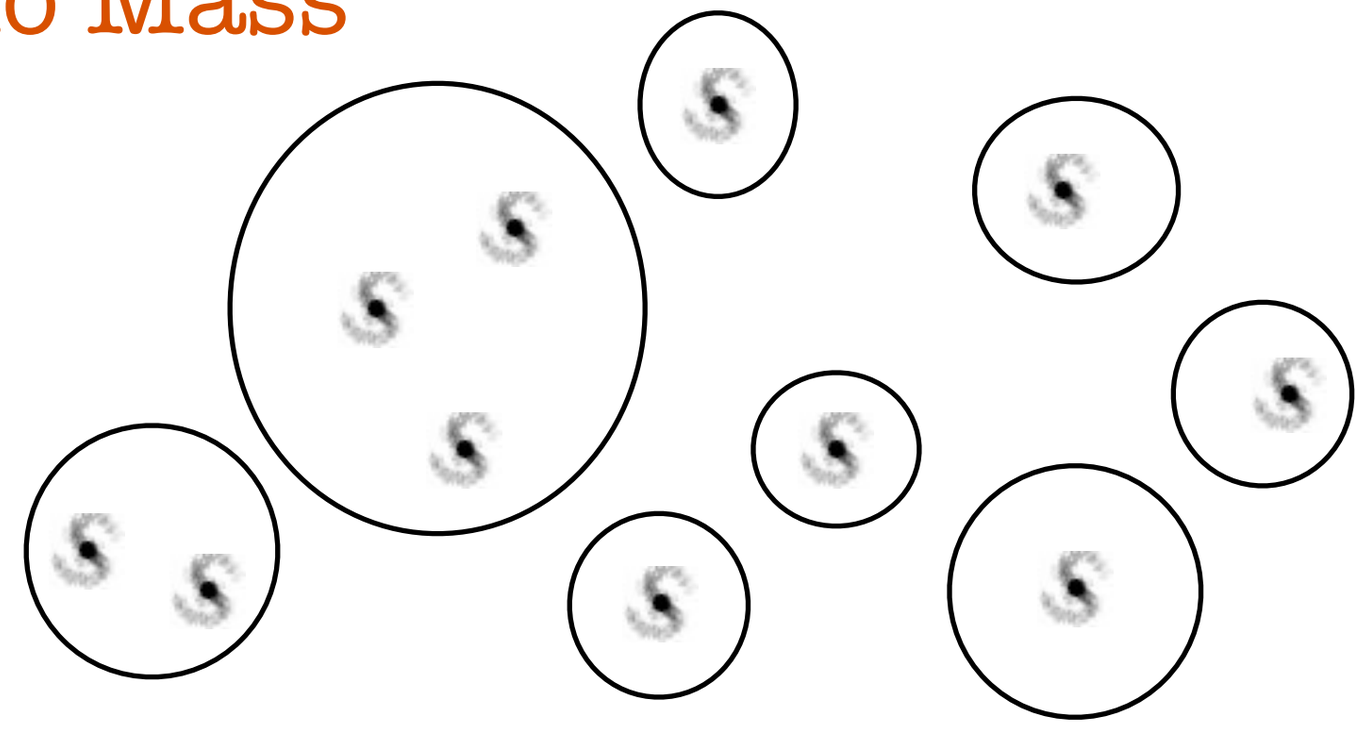


... Herschel observation

Estimated Host Halo Mass with Halo-Model

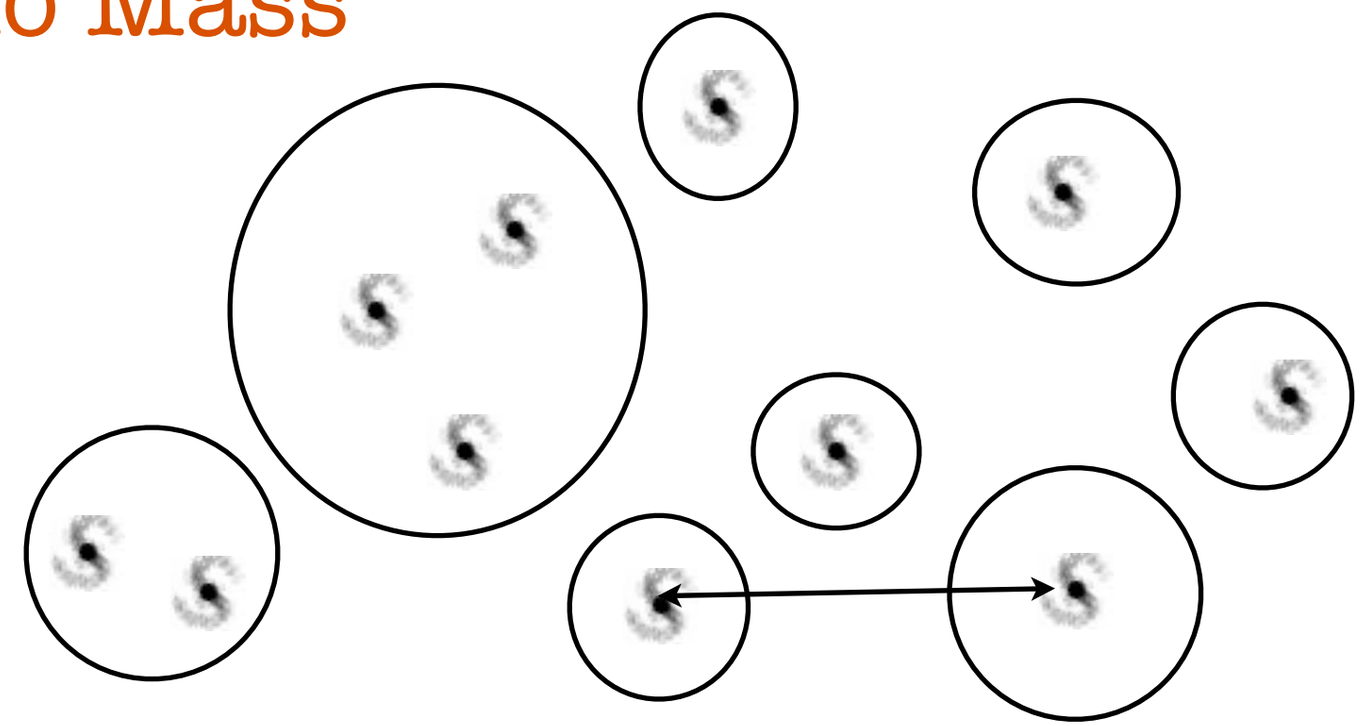
Estimated Host Halo Mass with Halo-Model

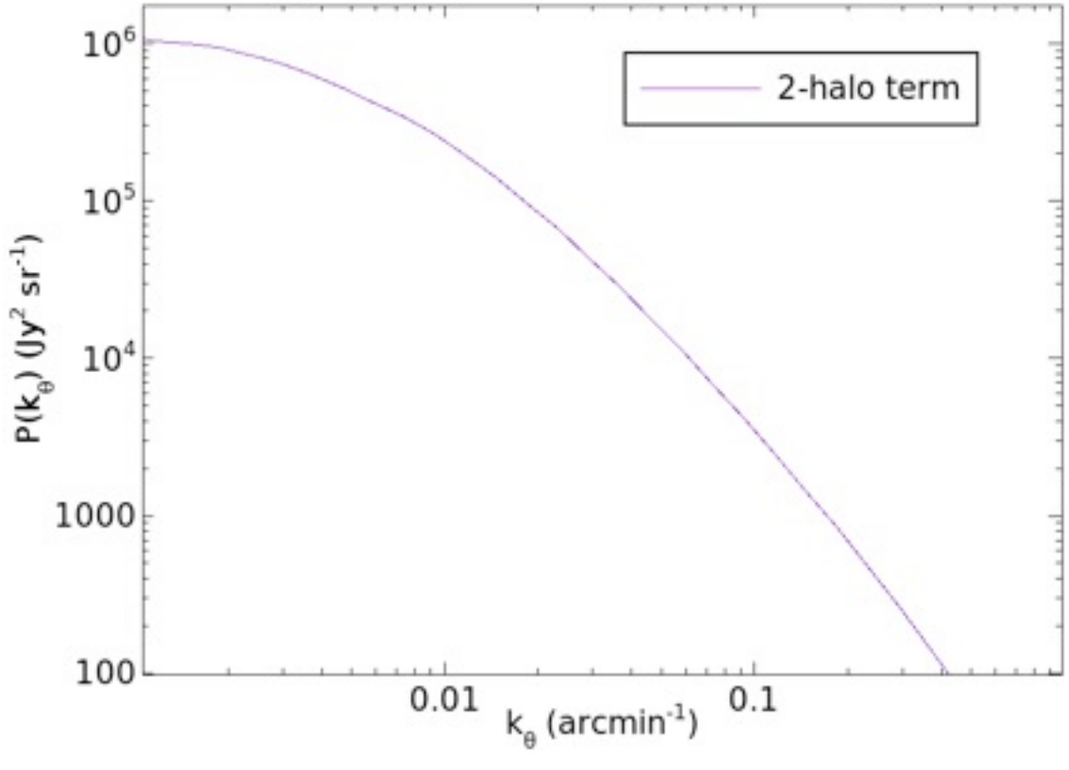
- Clustering Signal made up of two regimes



Estimated Host Halo Mass with Halo-Model

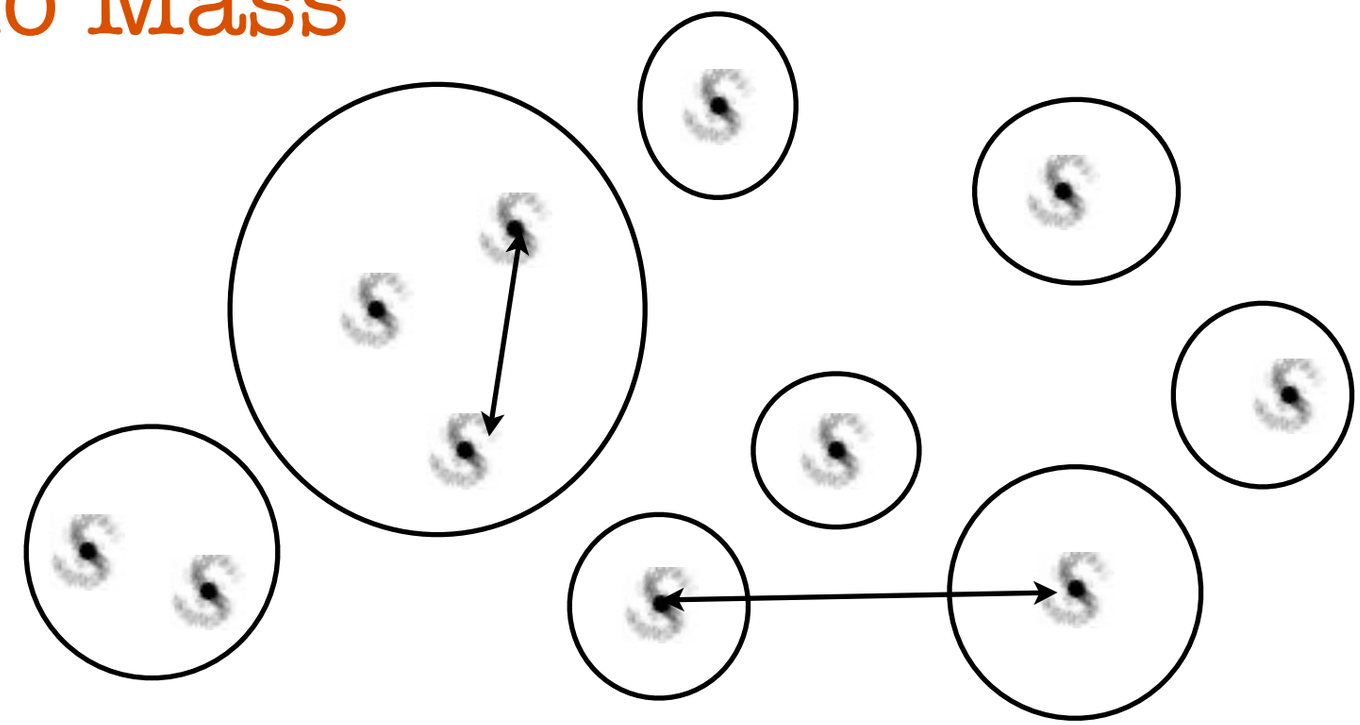
- Clustering Signal made up of two regimes
  - 2-halo: Linear Regime (large scales)

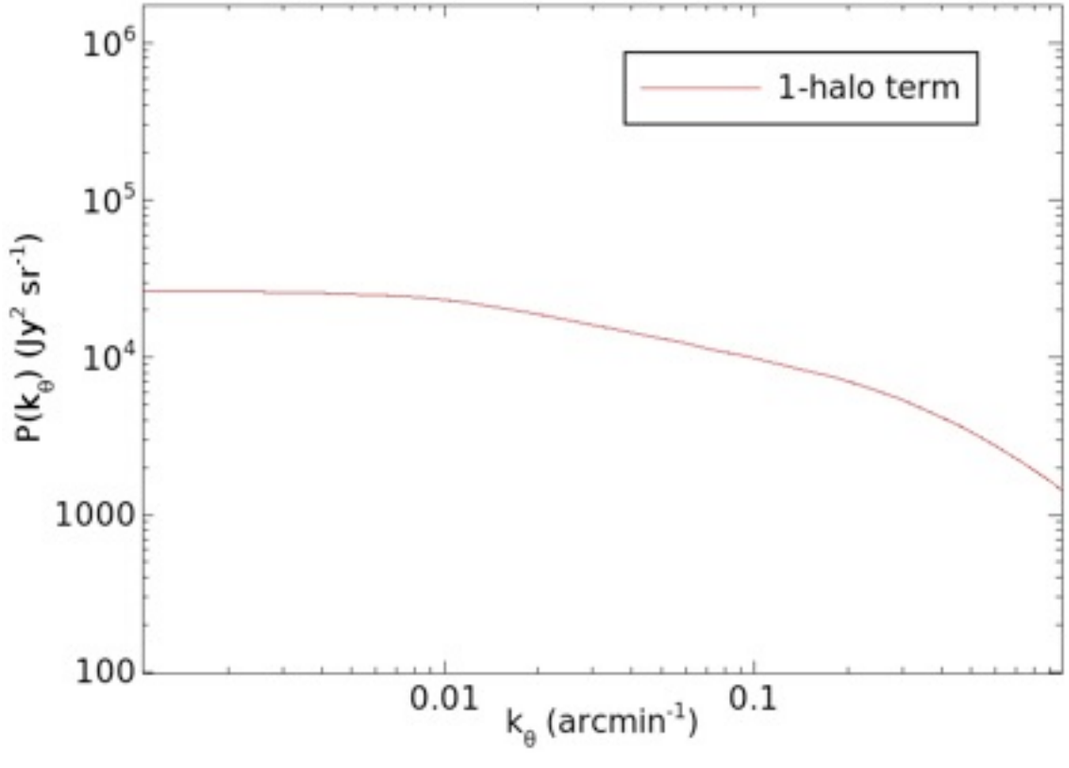




Estimated Host Halo Mass with Halo-Model

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





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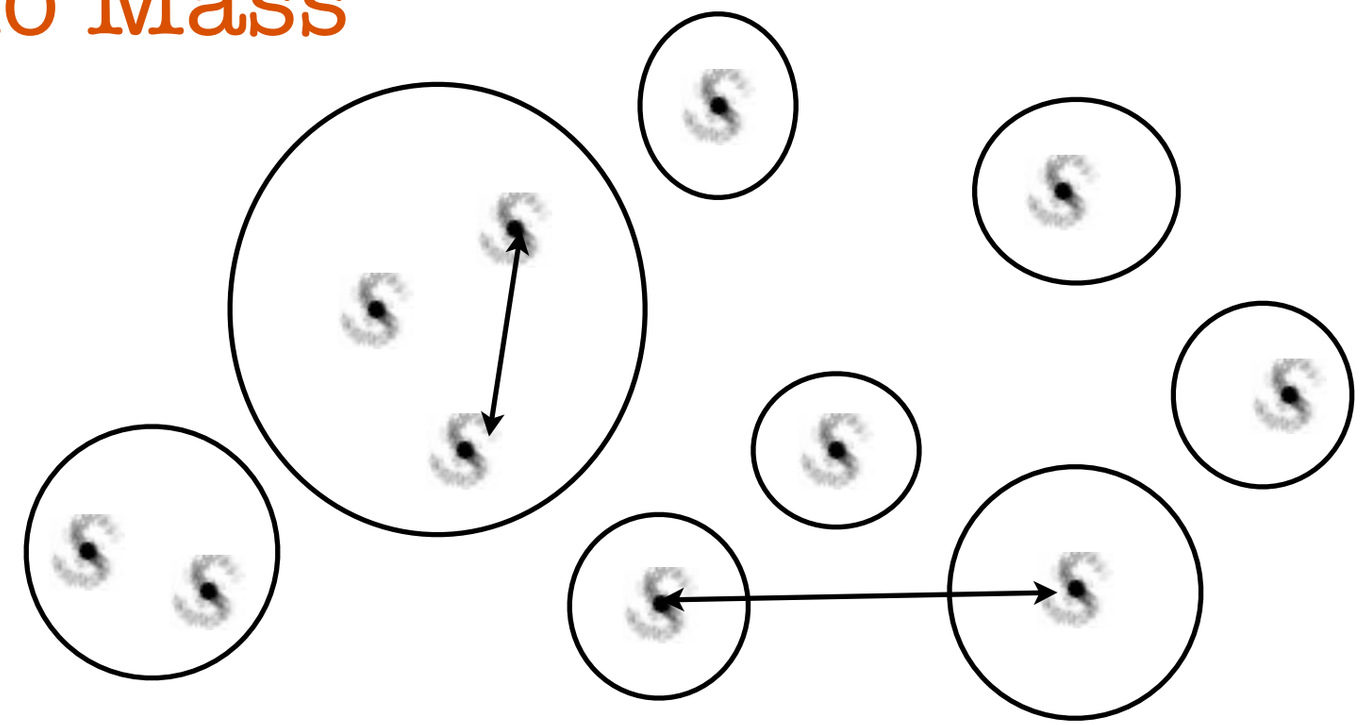

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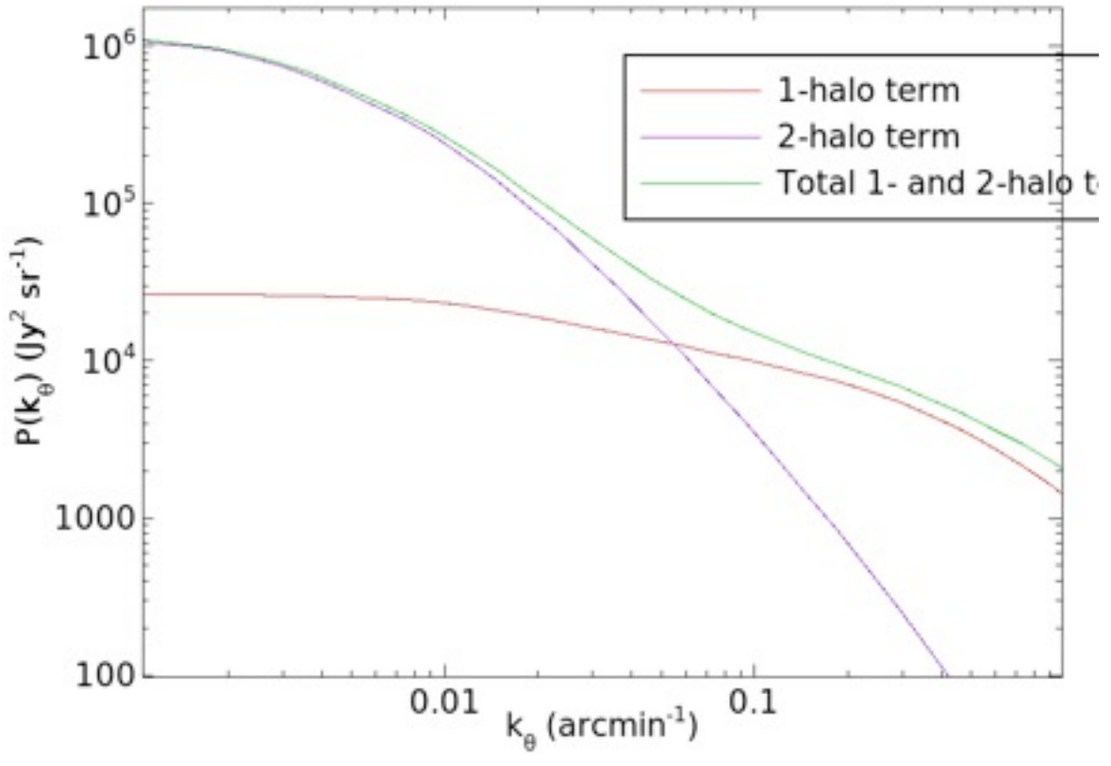
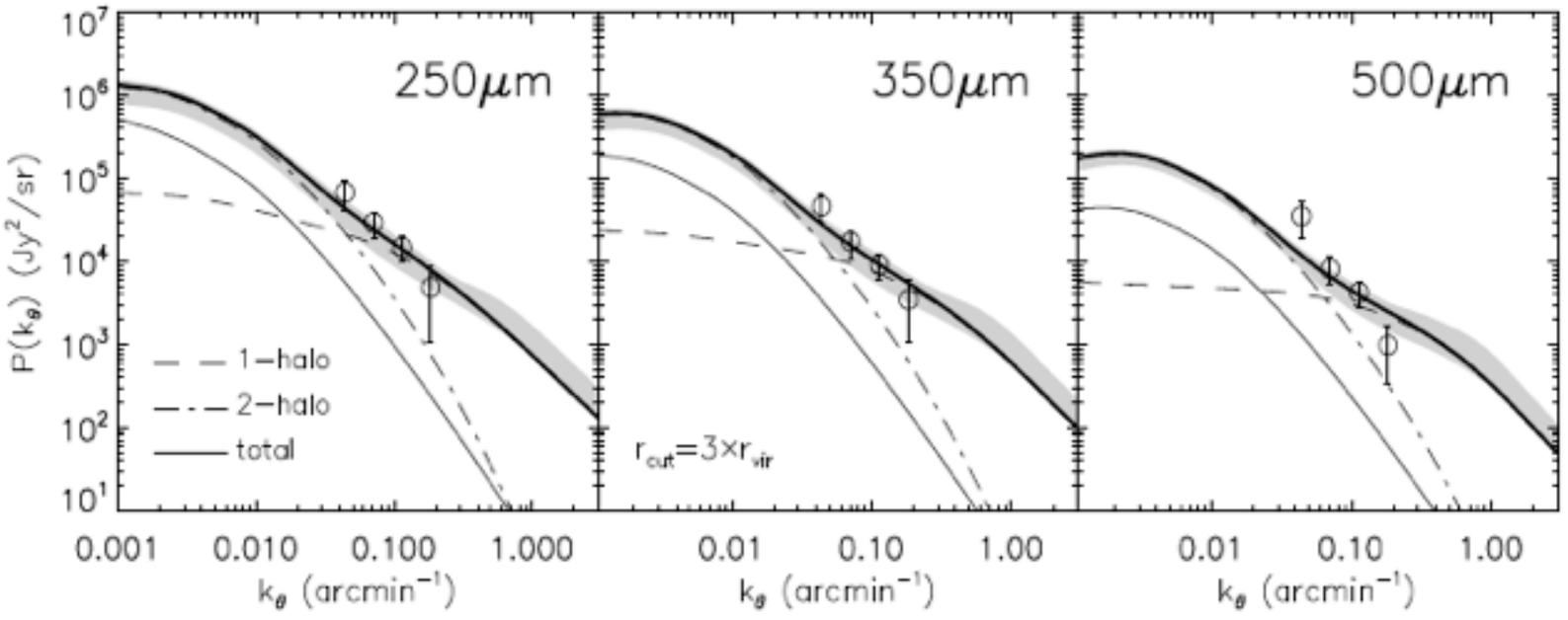


Estimated Host Halo Mass with Halo-Model

Halo Model of Mattia Negrello &
Source Model of Lagache 2004

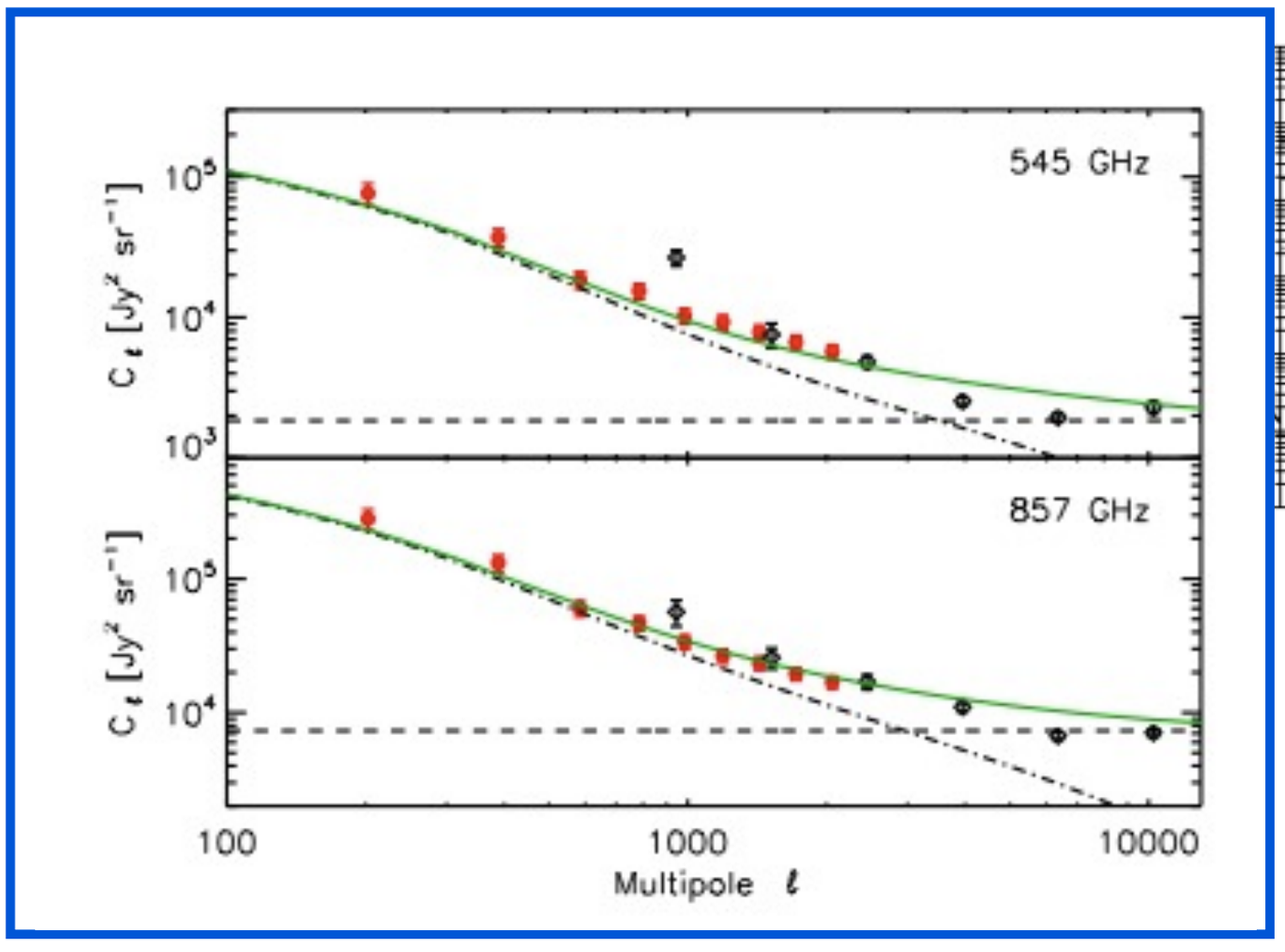


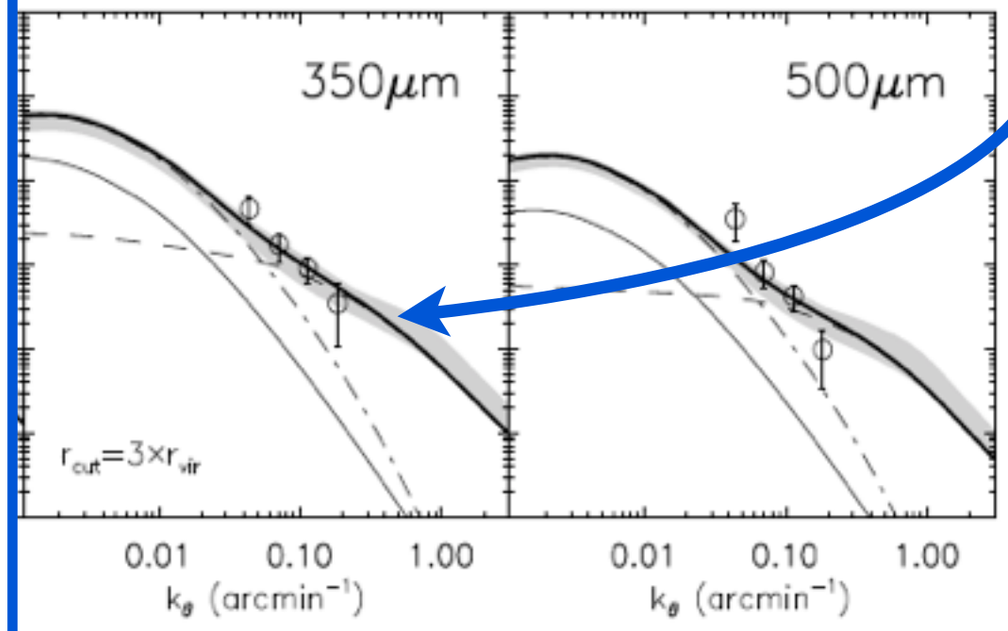
Viero et al. 0904.1200

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

At z ~ 2

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

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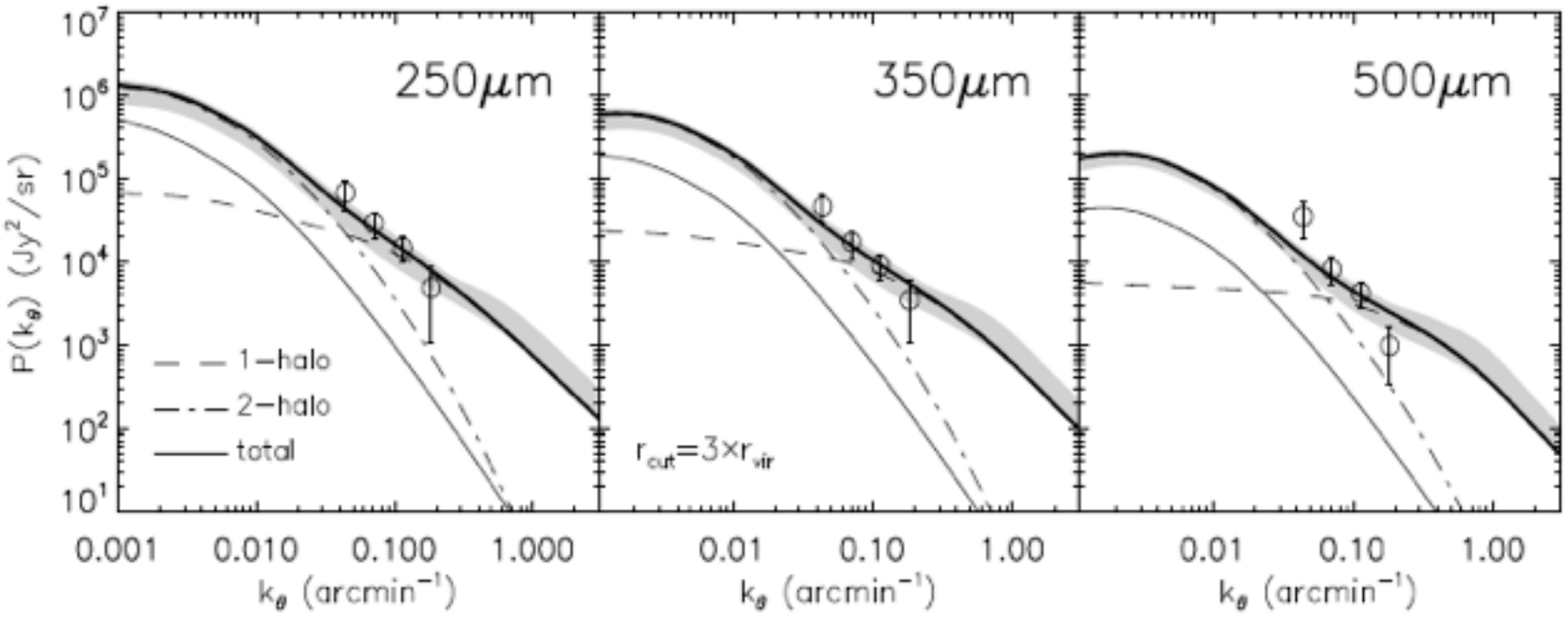

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Confirmed 5 days ago by Herschel!

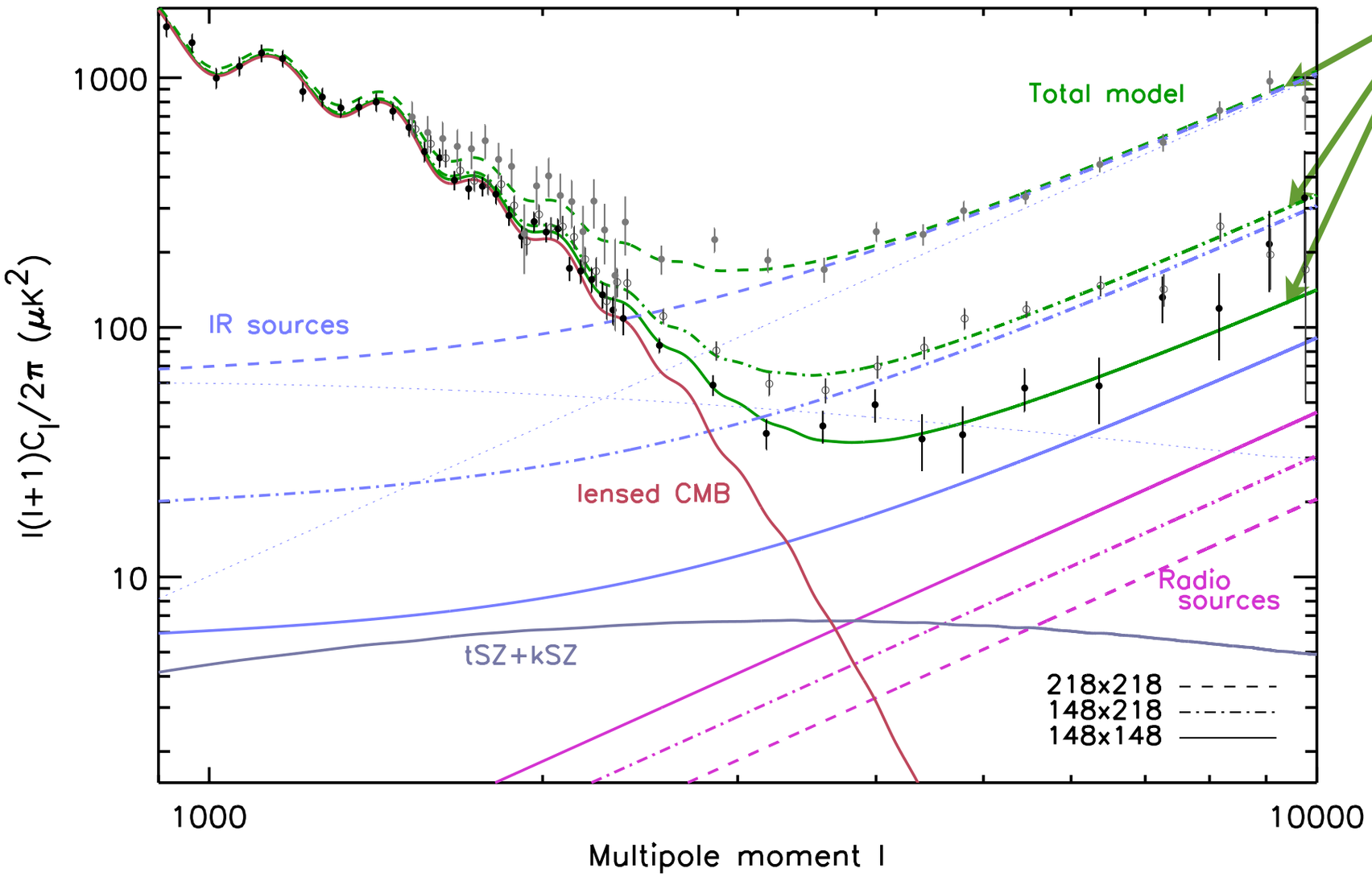
Sub-millimetre galaxies reside in dark matter halos with masses greater than 3×10^{11} $M_\odot$

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[16], 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-

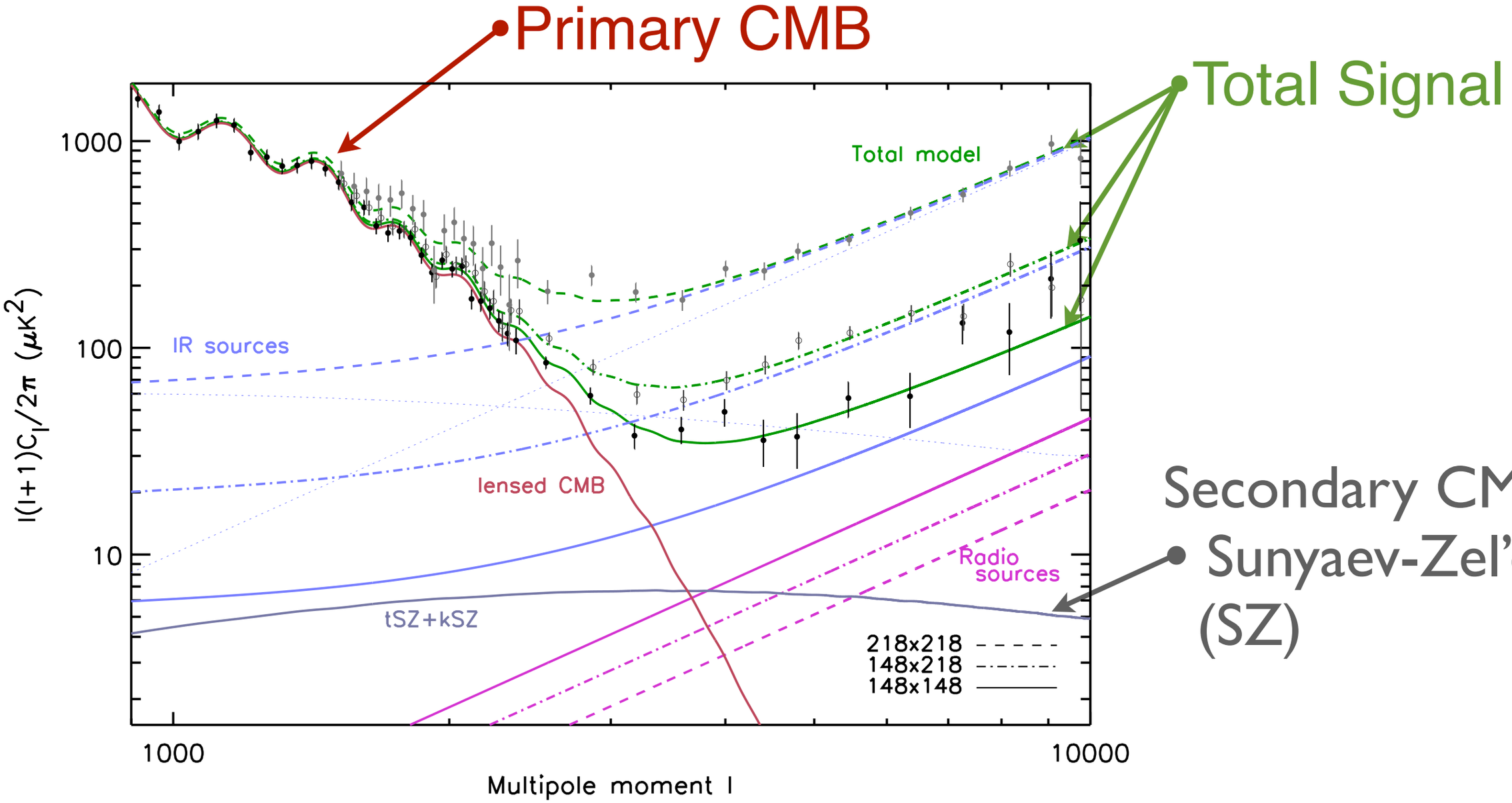
“I do CMB, so I don’t care”

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



Dunkley et al. 1009.0866

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

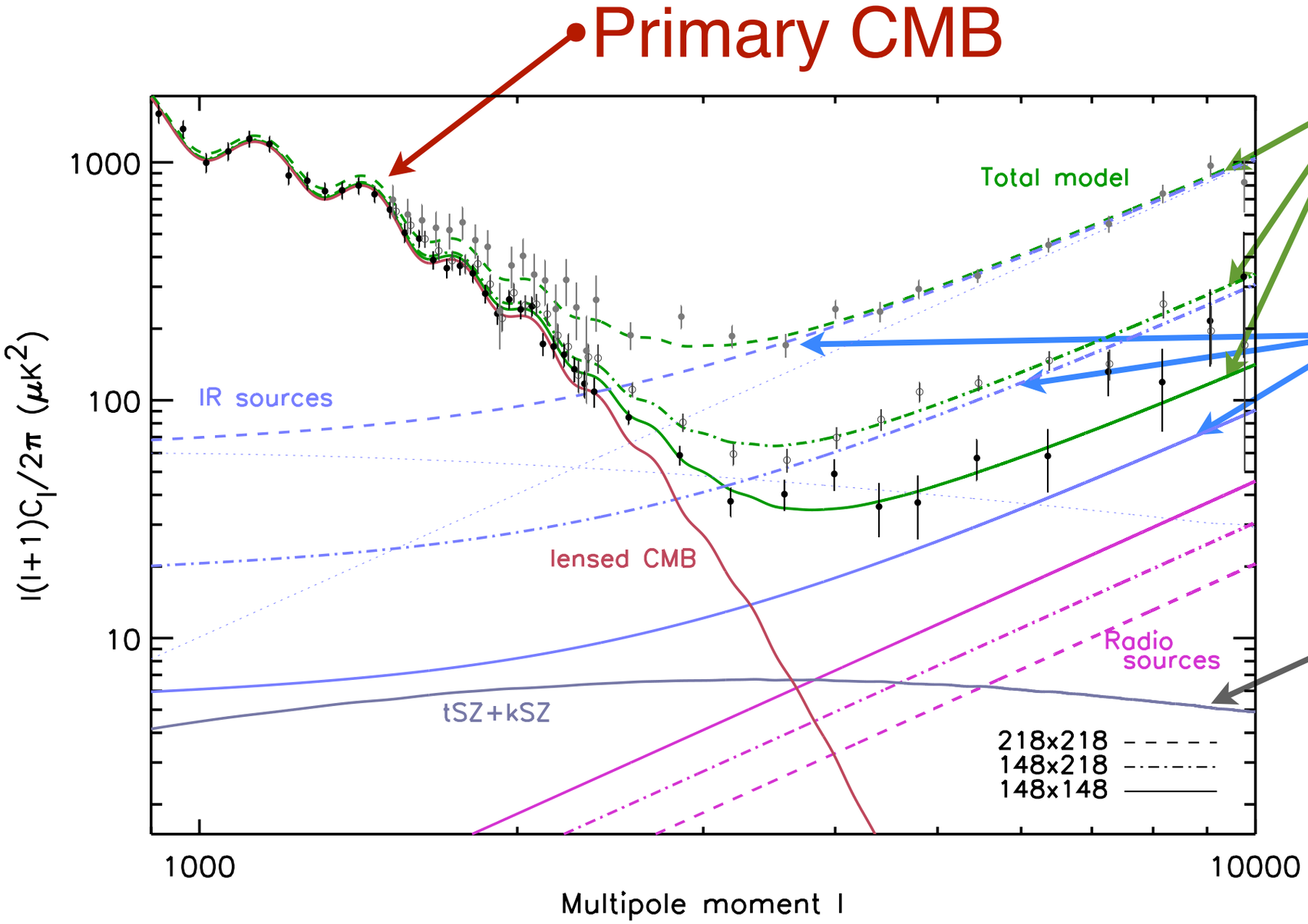


Secondary CMB:

- Sunyaev-Zel'dovich (SZ)

Dunkley et al. 1009.0866

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



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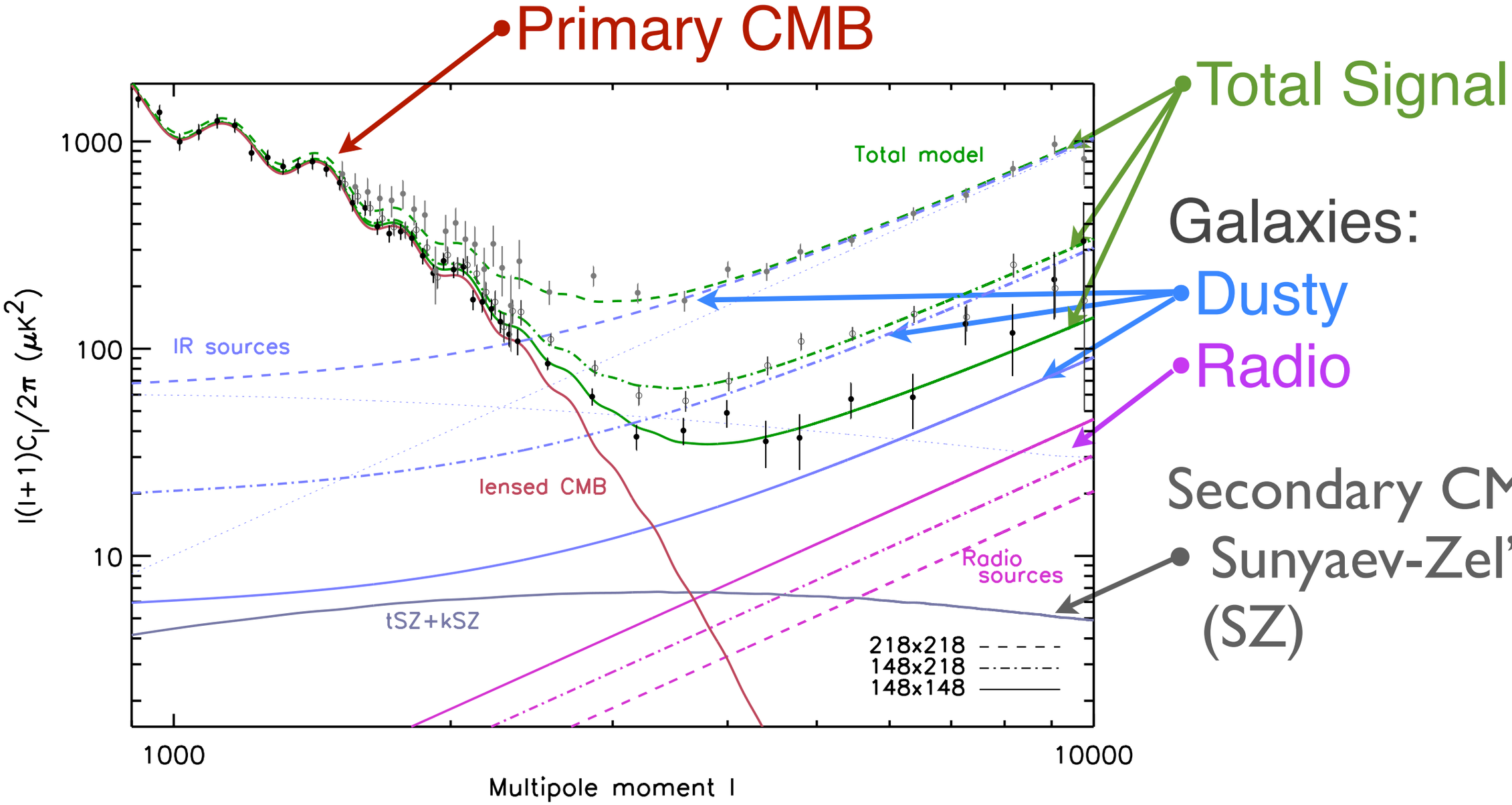
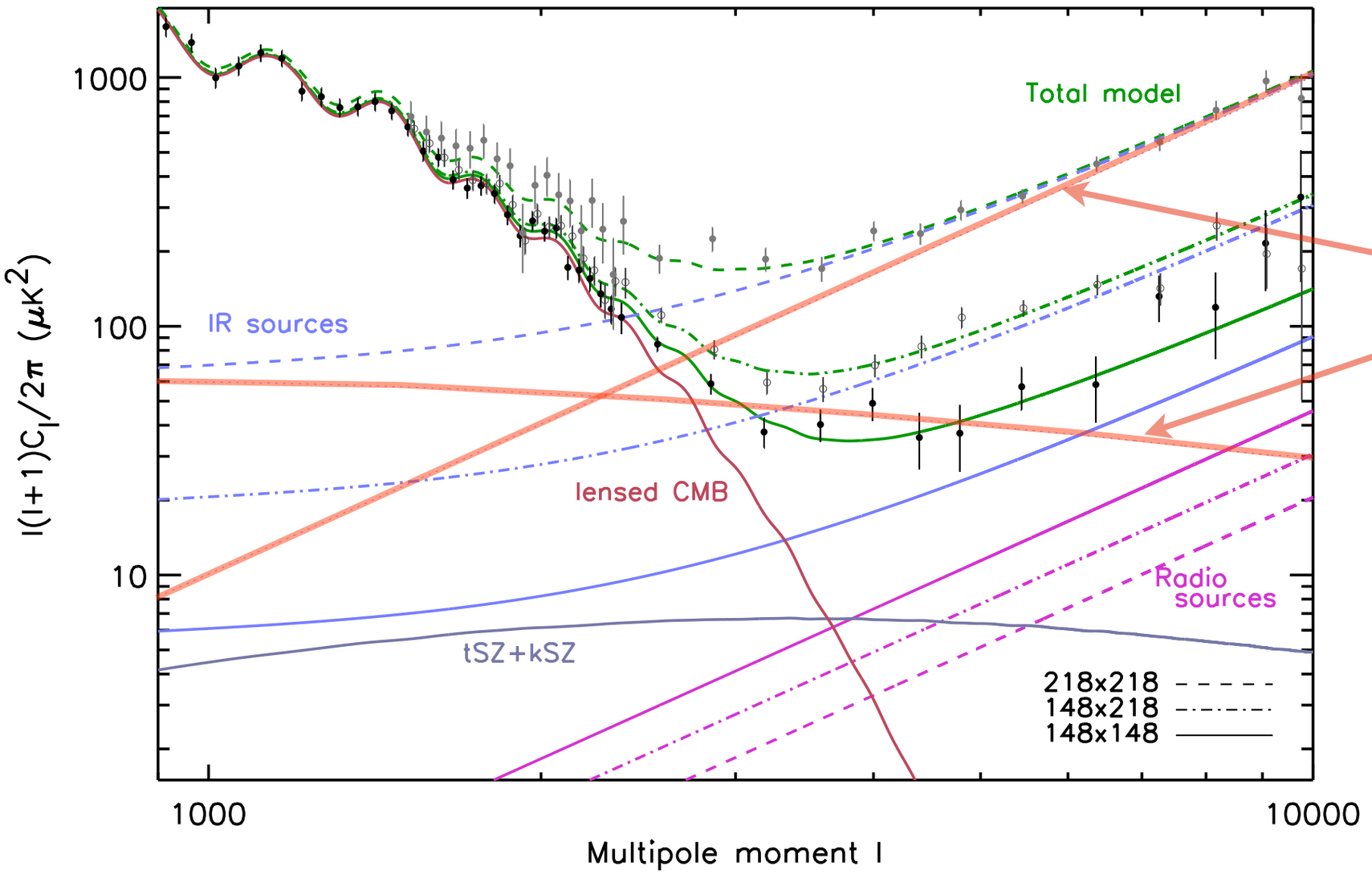


Dunkley et al. 1009.0866

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

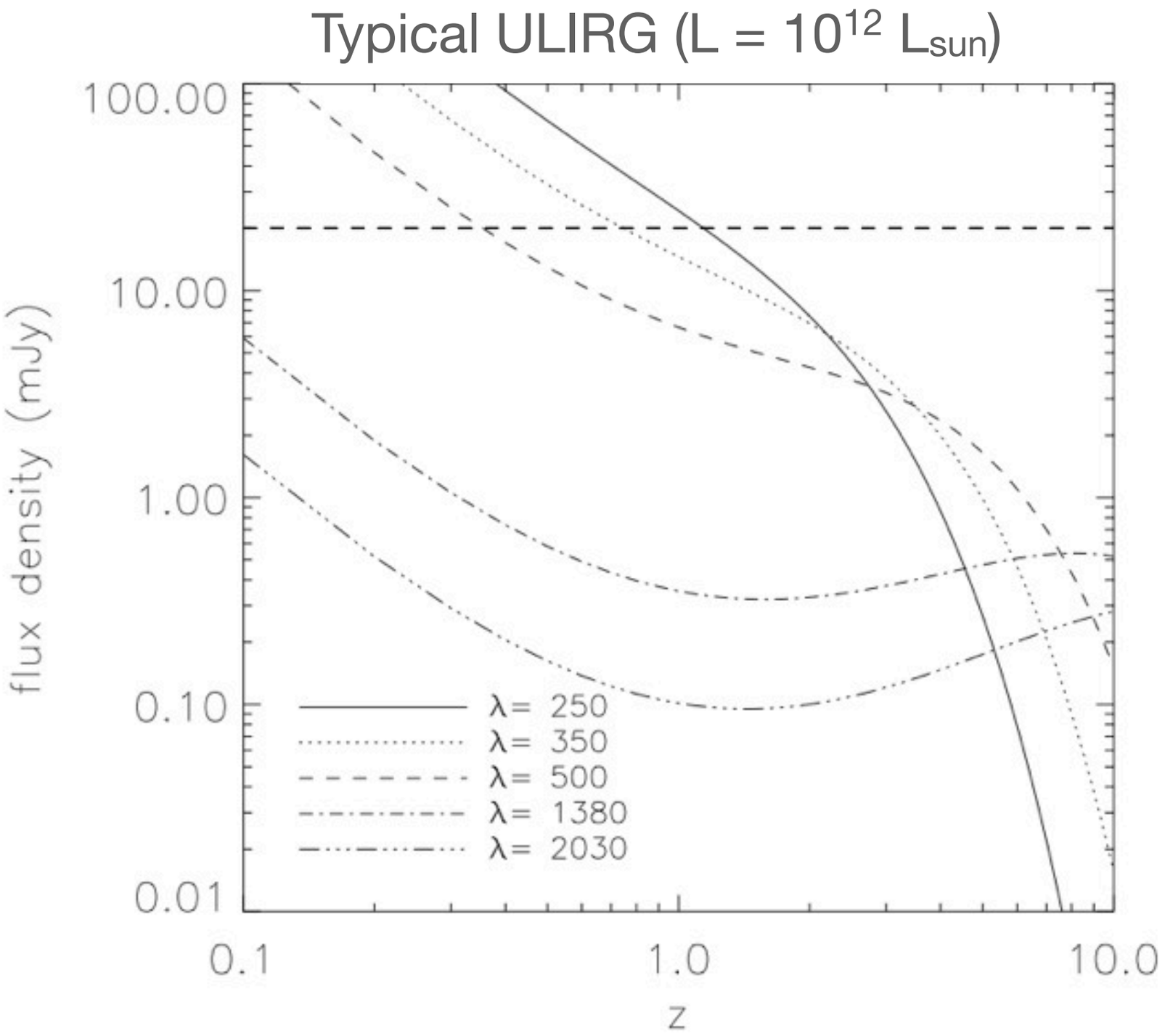


Galaxies:

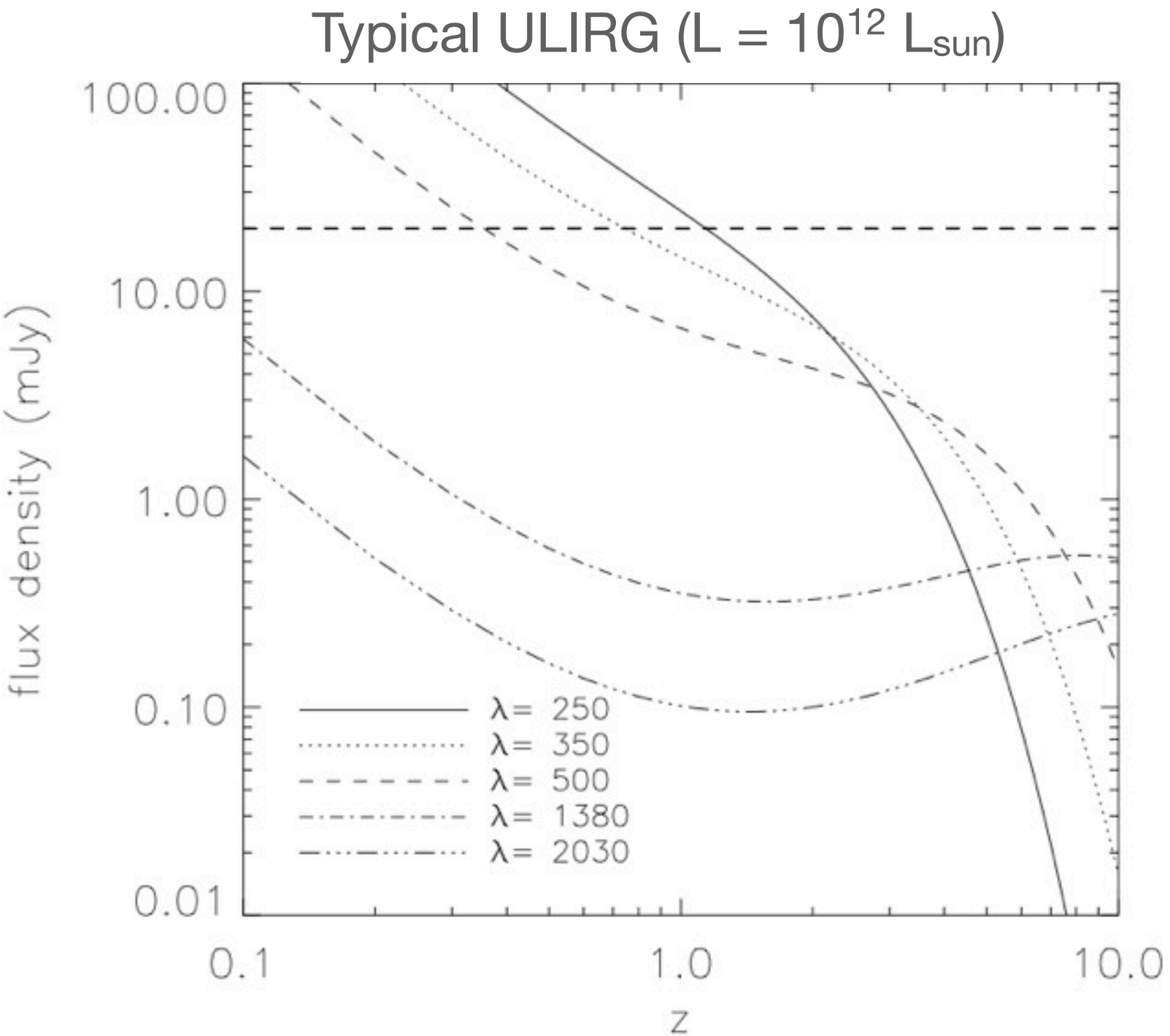
- Shot
- Clustered

Dunkley et al. 1009.0866

Negative K-correction

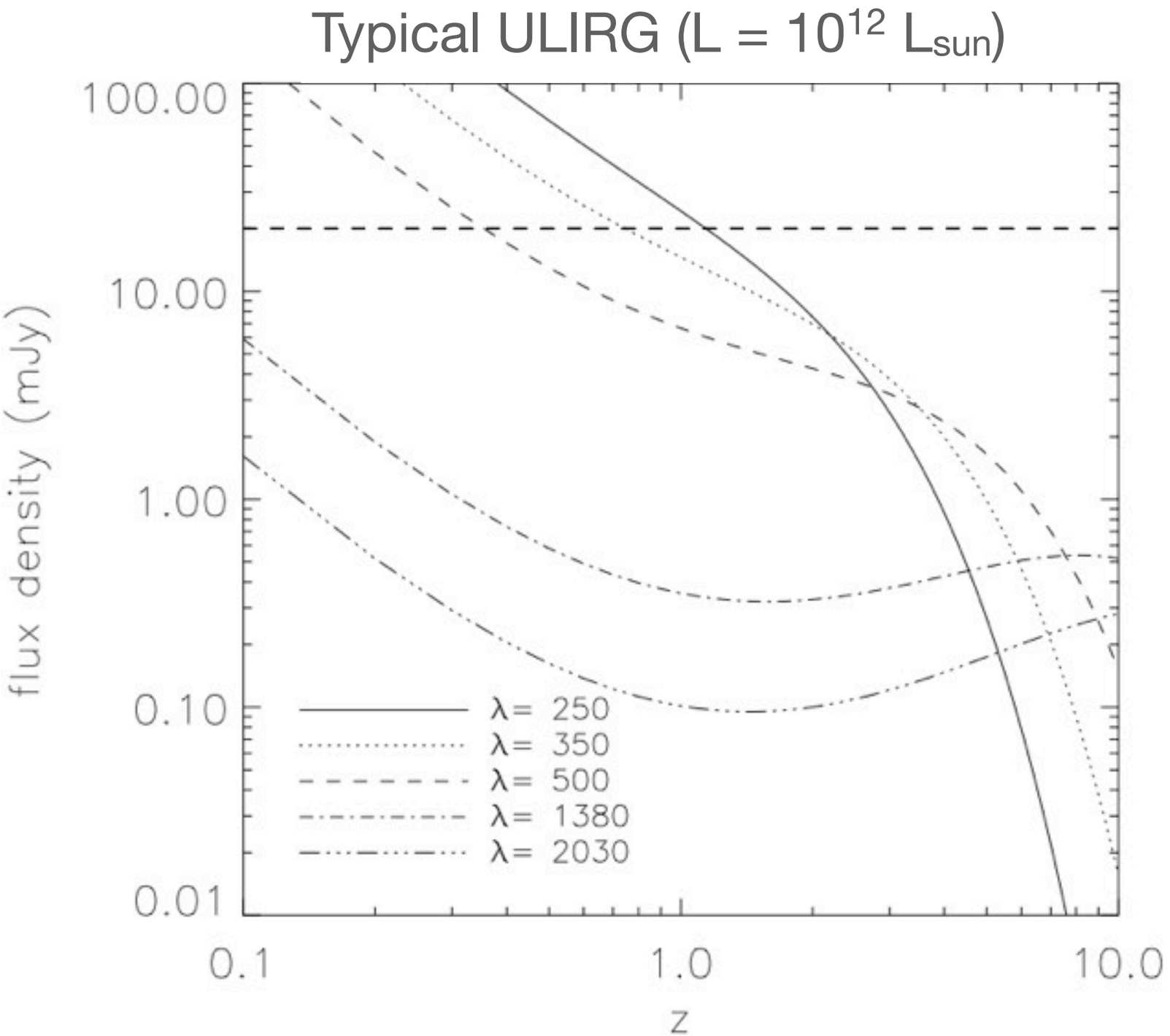


Negative K-correction



- Different Wavelengths sensitive to unique redshift ranges

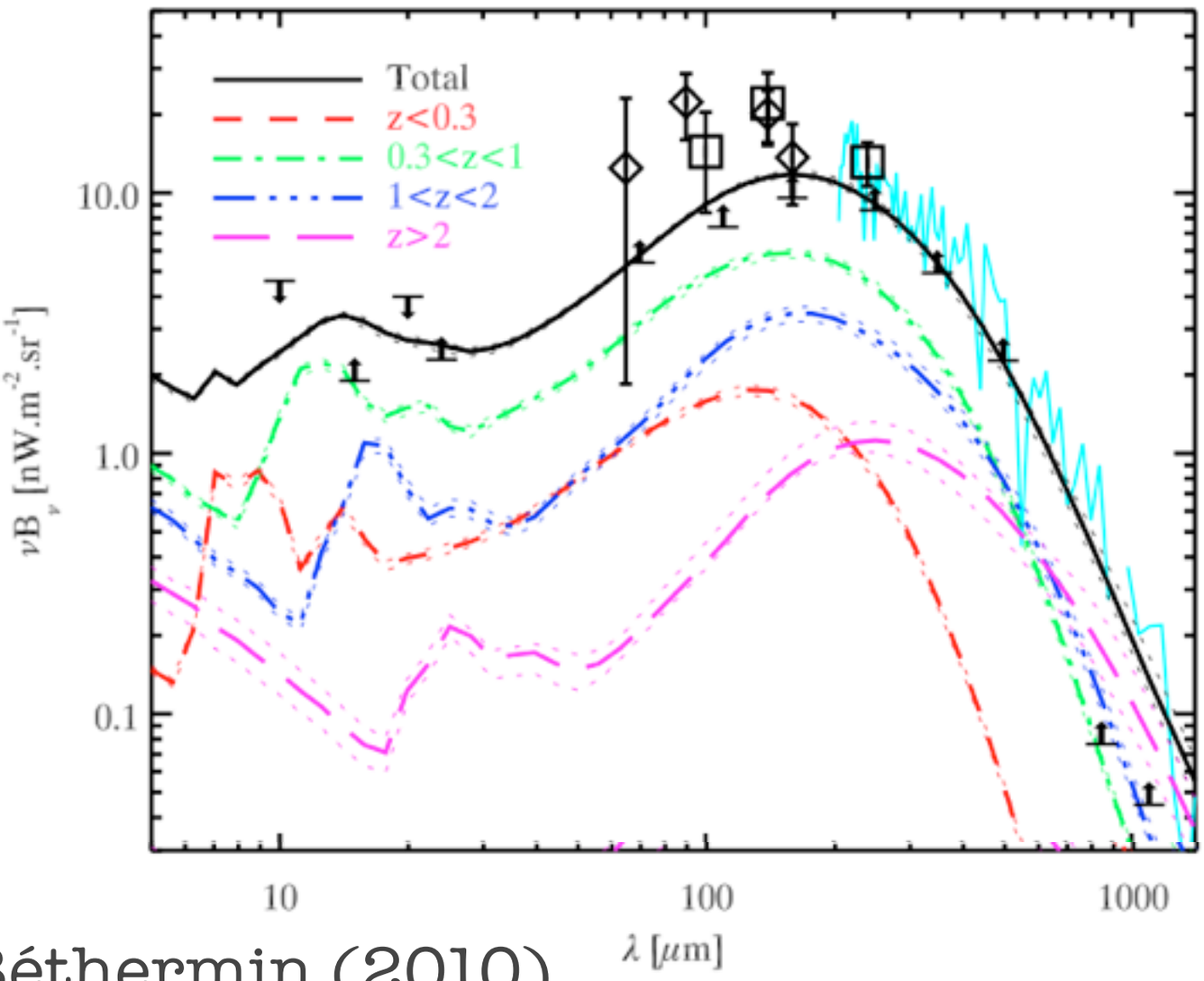
Negative K-correction



- 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

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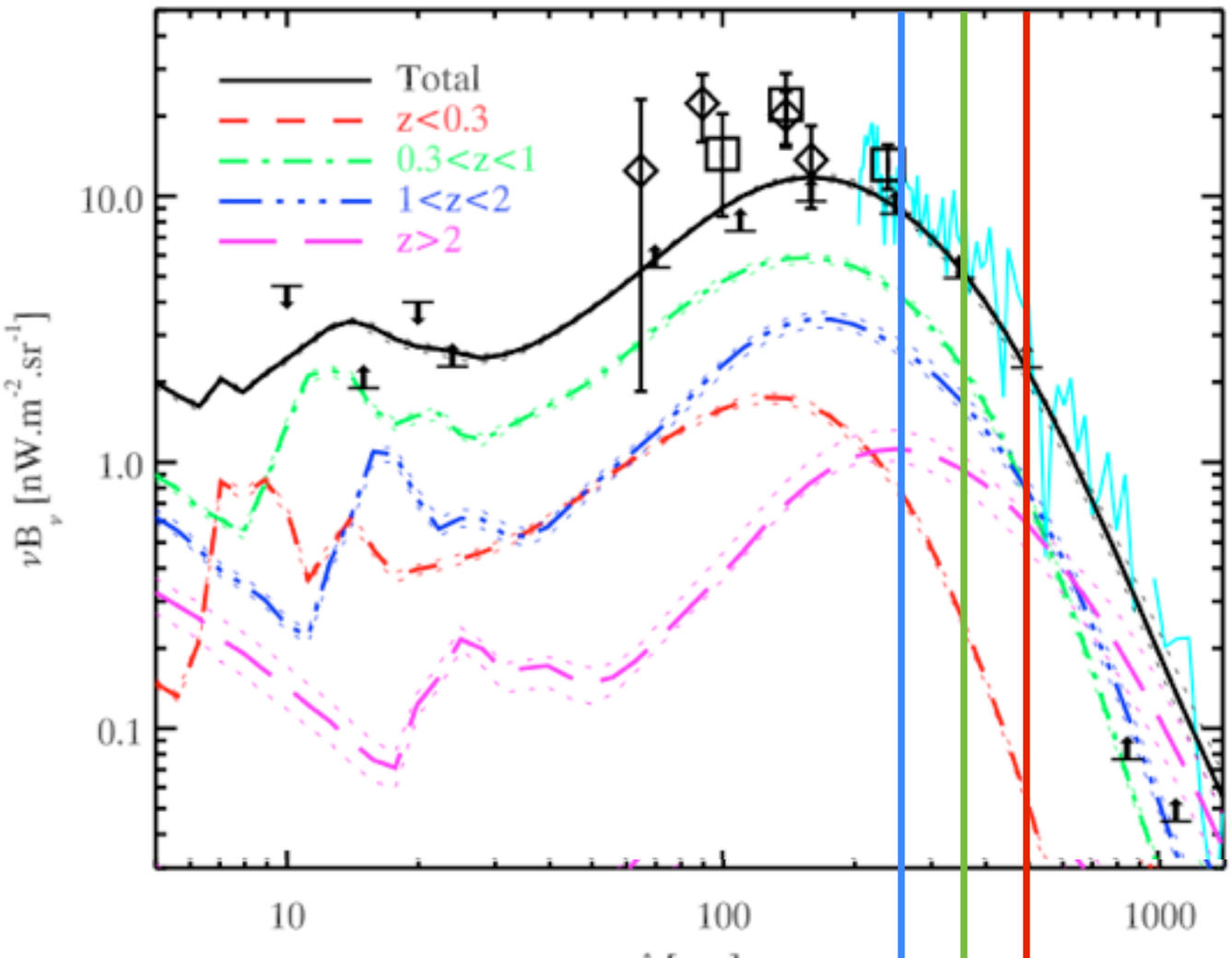

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250 350 500

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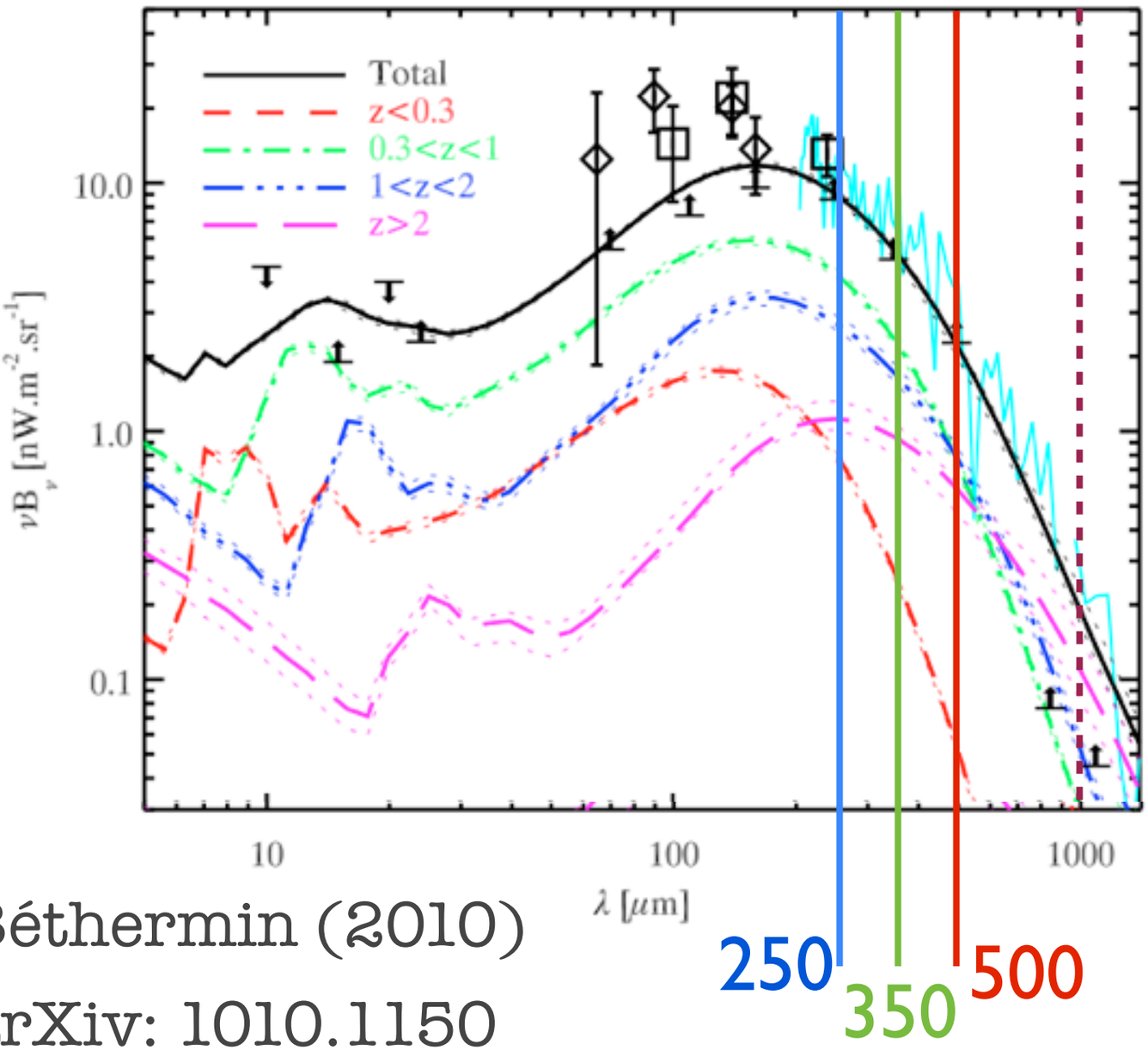

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Infrared Background at $\lambda > 1$ mm (< 300 GHz) dominated by high-redshift sources

Multi-Wavelength Data Contains Redshift Information

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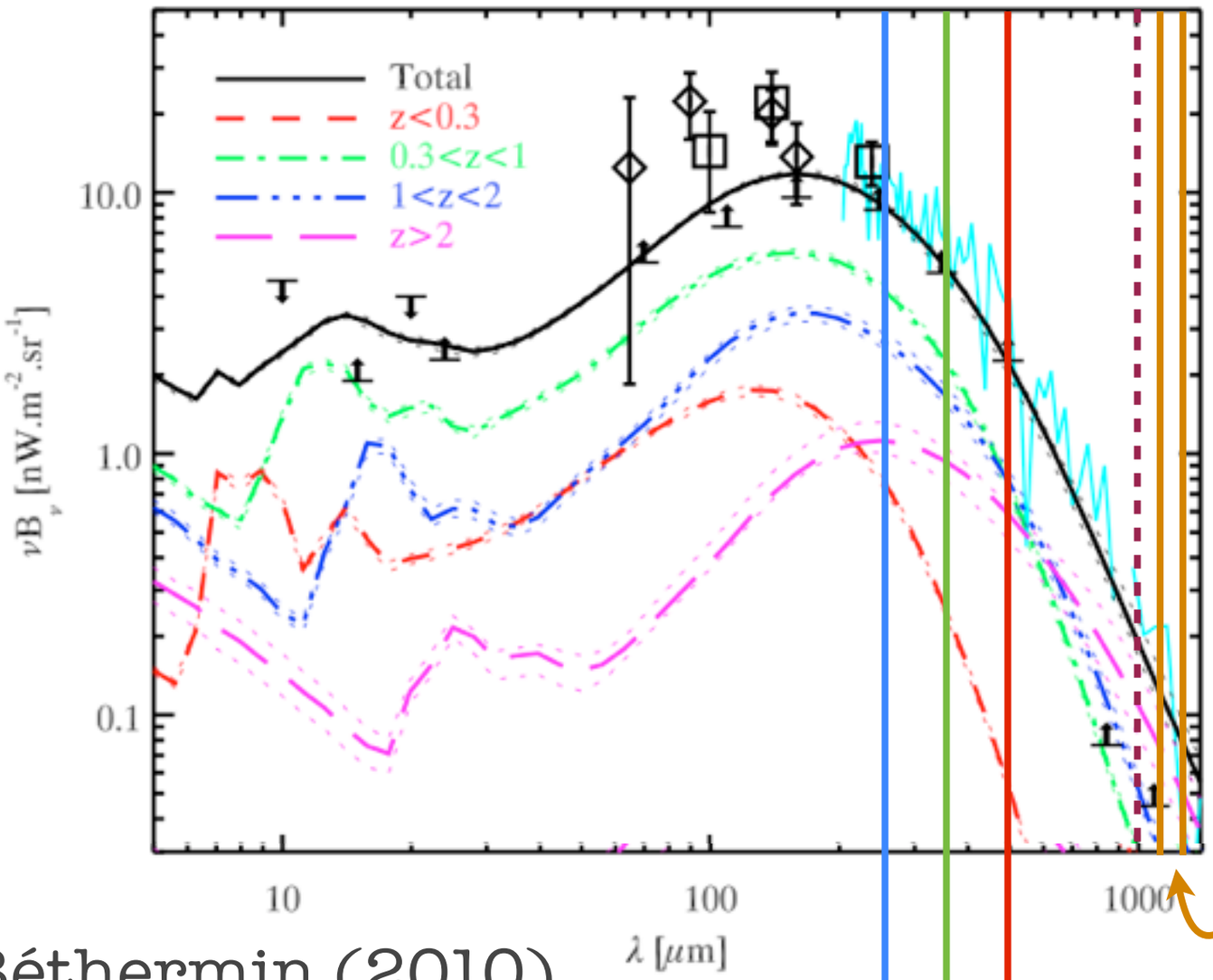

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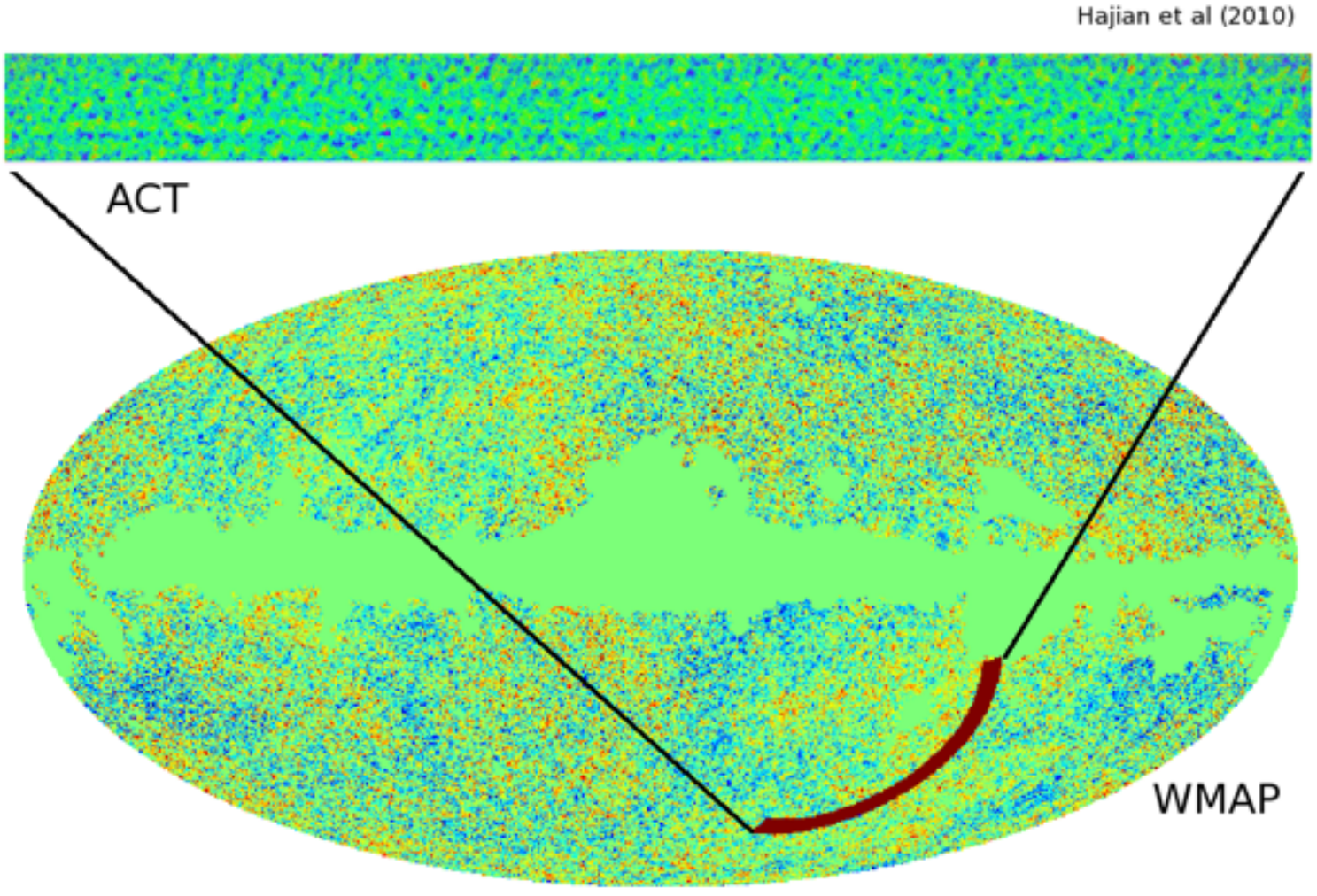
Infrared Background at $\lambda > 1$ mm (< 300 GHz) dominated by high-redshift sources

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

Atacama Cosmology Telescope (ACT)

ACT Southern Field



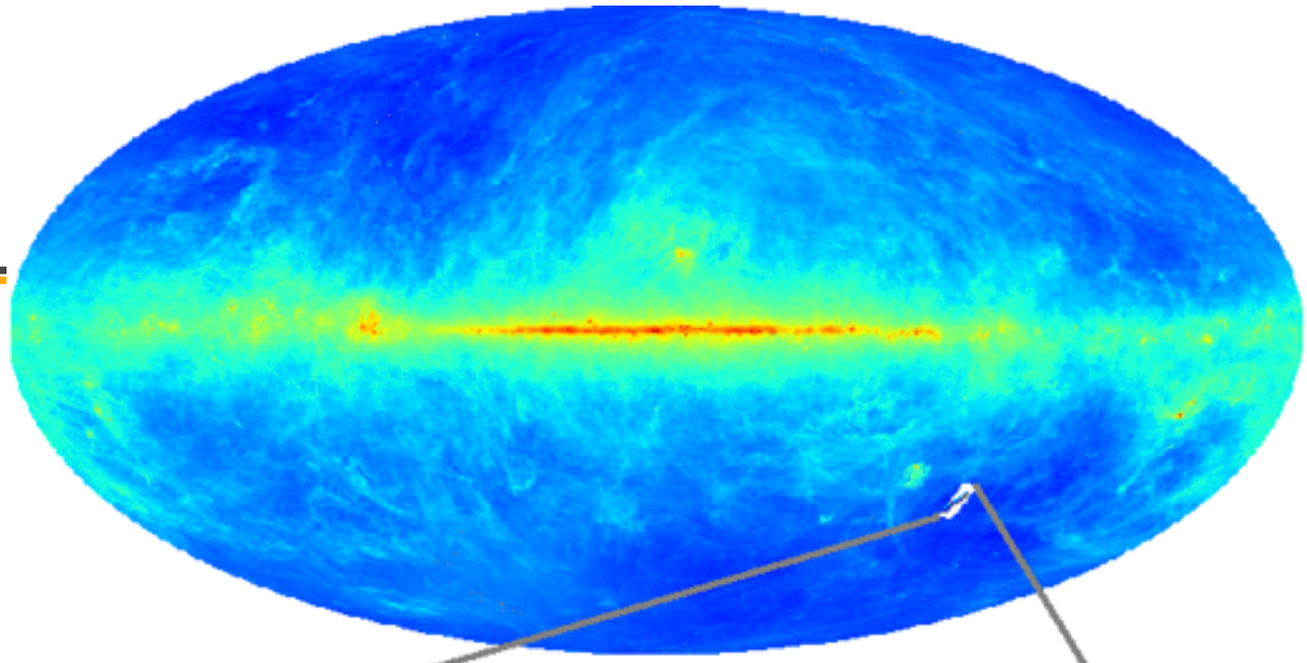
- 300 deg^2
- 1' resolution
- 3 bands

148 GHz (~2.0 mm)

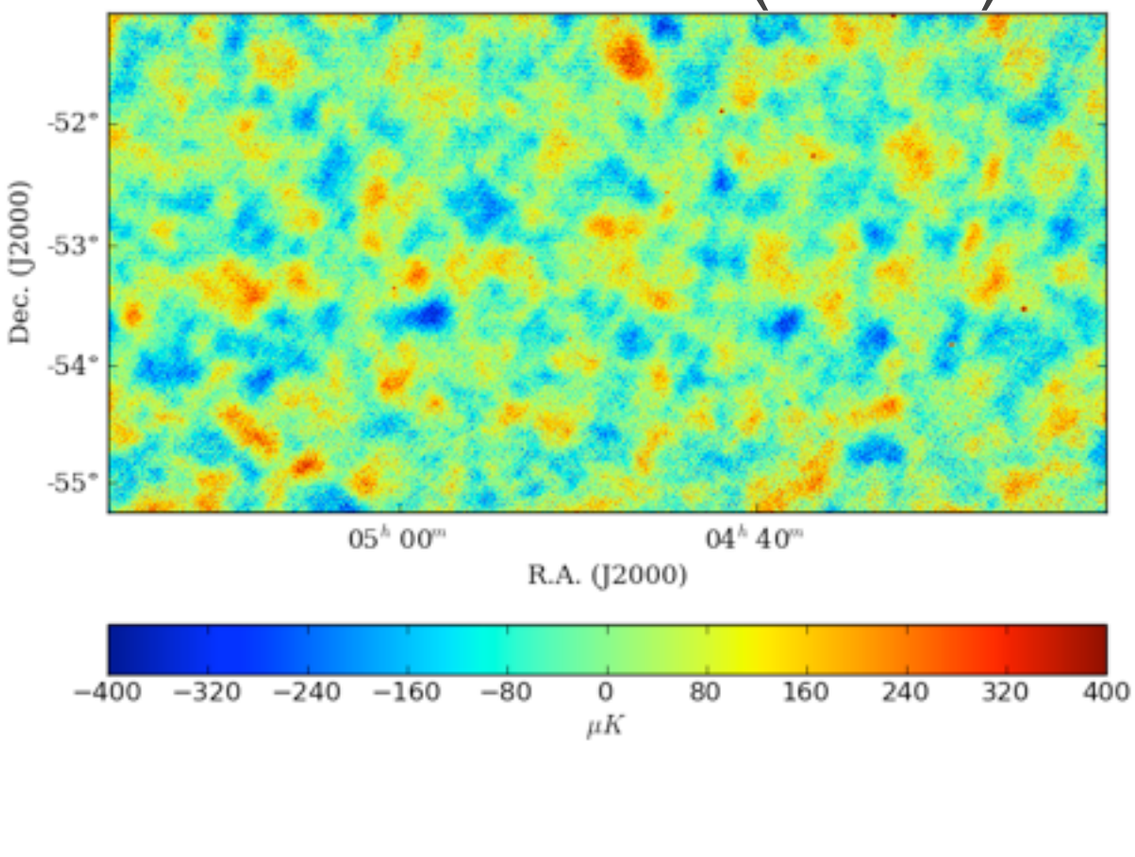
218 GHz (~1.4 mm)

277 GHz (~1.1 mm)

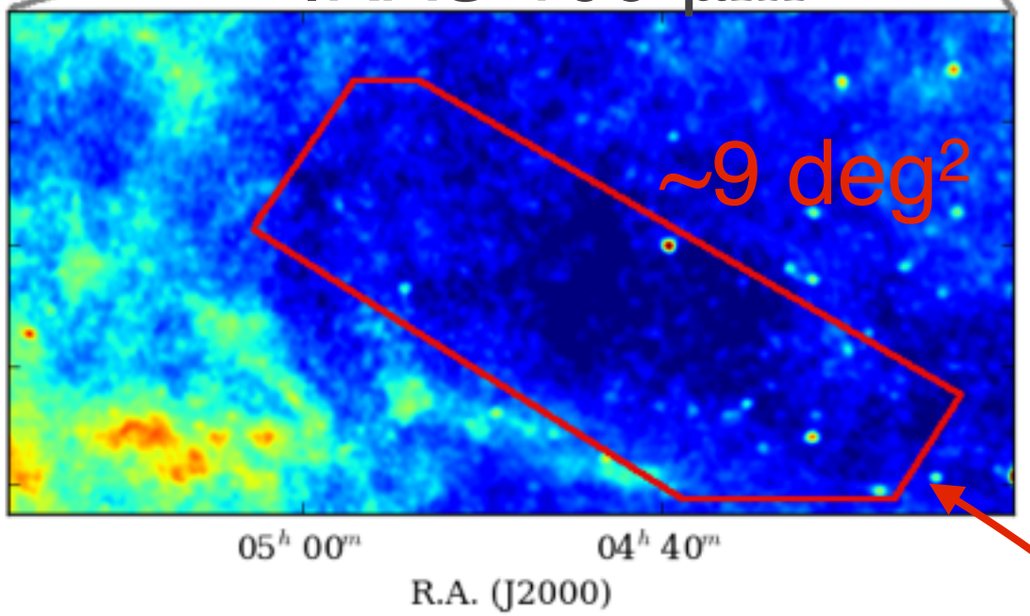
Overlap: BLAST-SEP Field



ACT 148 GHz (2 mm)

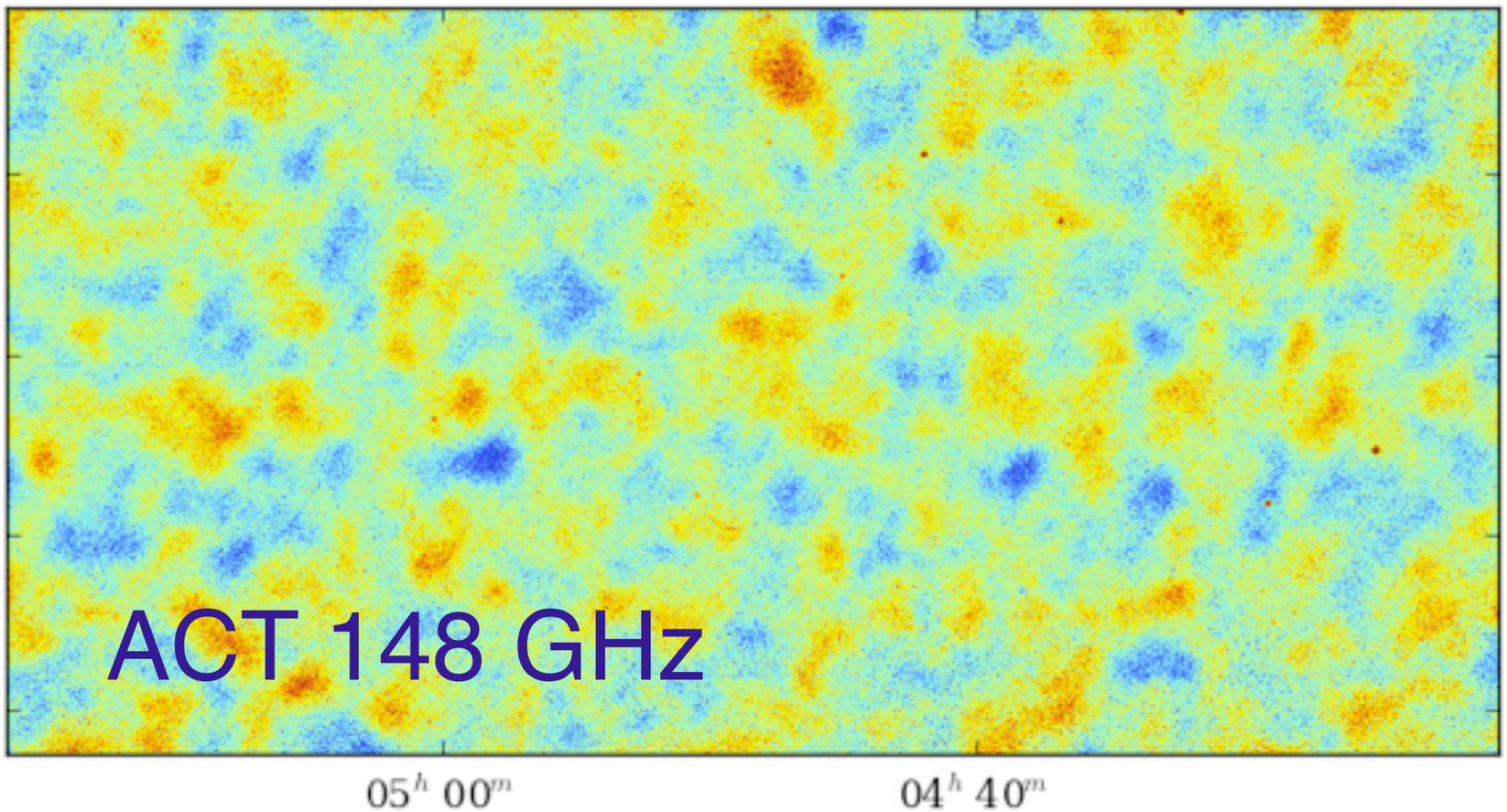


IRAS 100 μm



Mean Flux ~ 1.1 MJy/sr

CMB Maps are Made Up of Many Contributions



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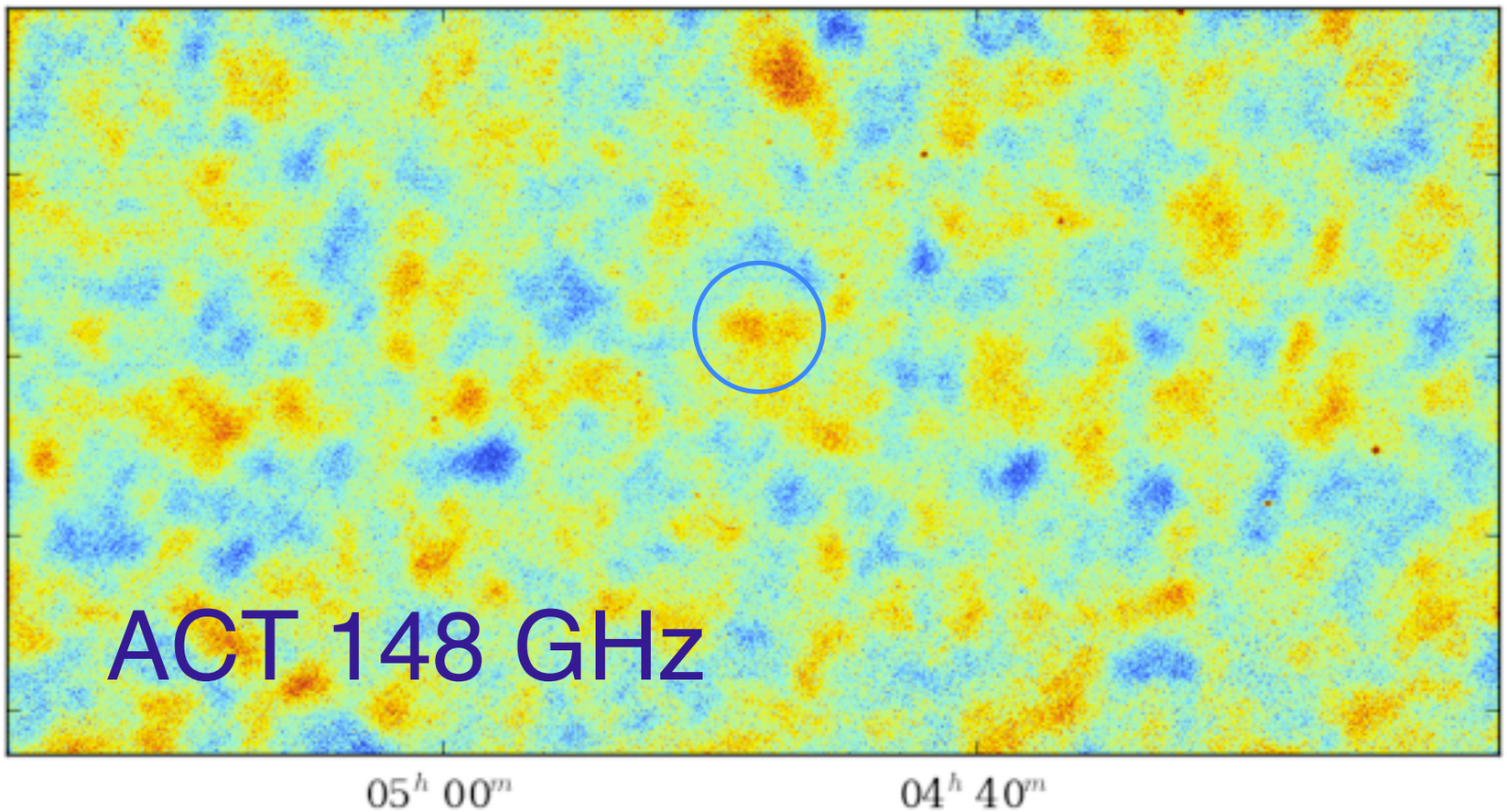
CMB



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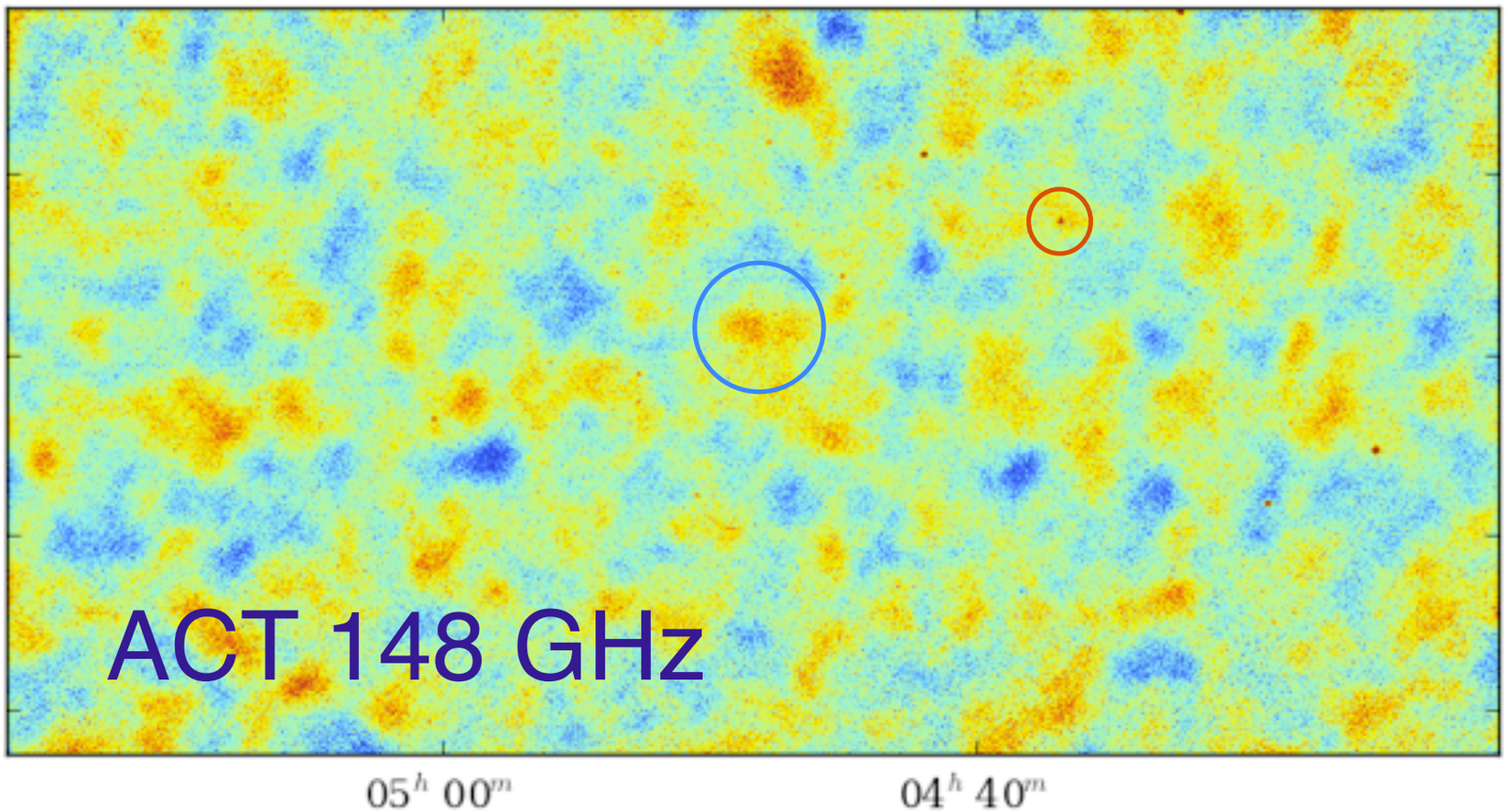
CMB

Galaxies

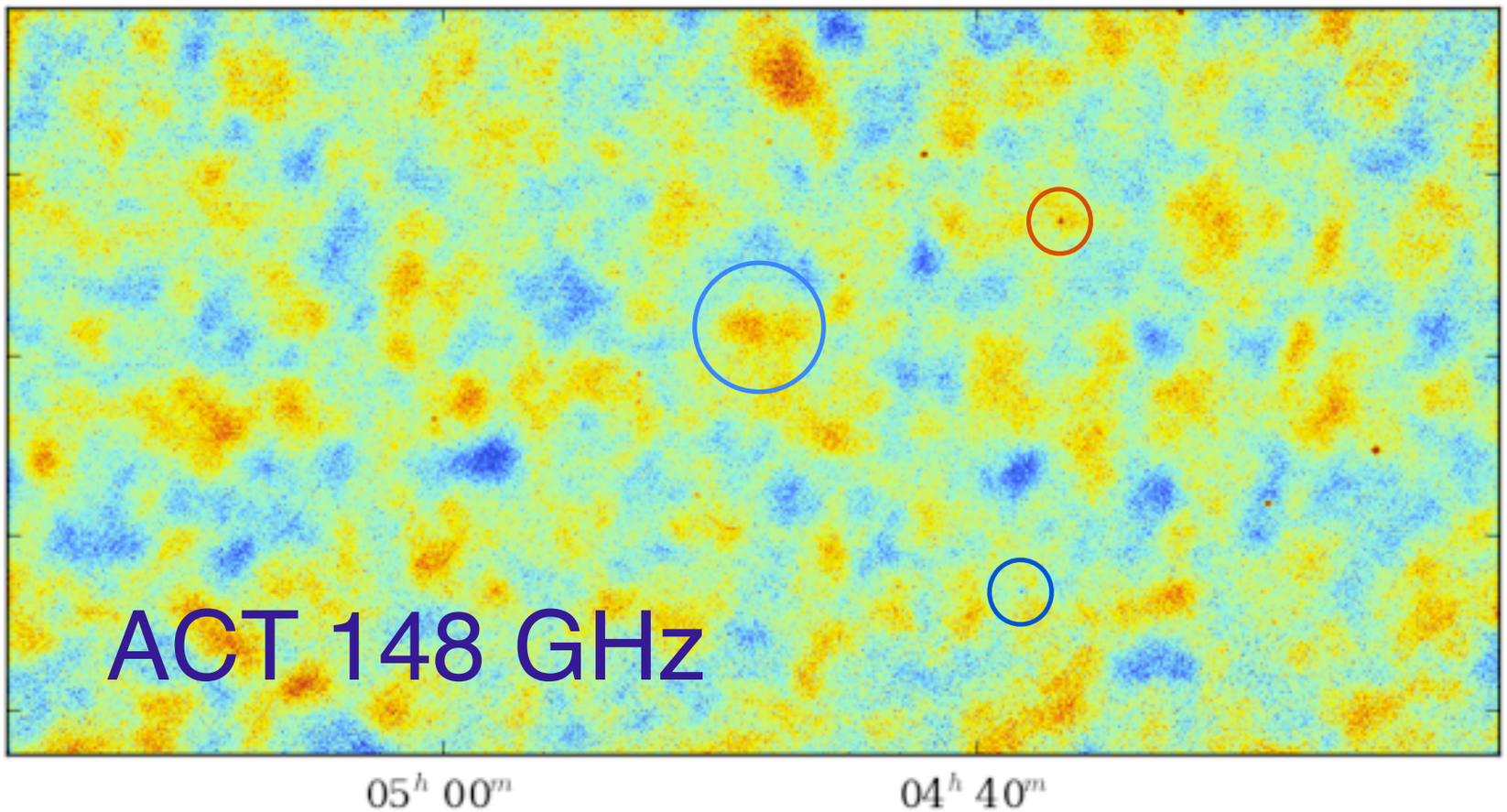


CMB Maps are Made Up of Many Contributions

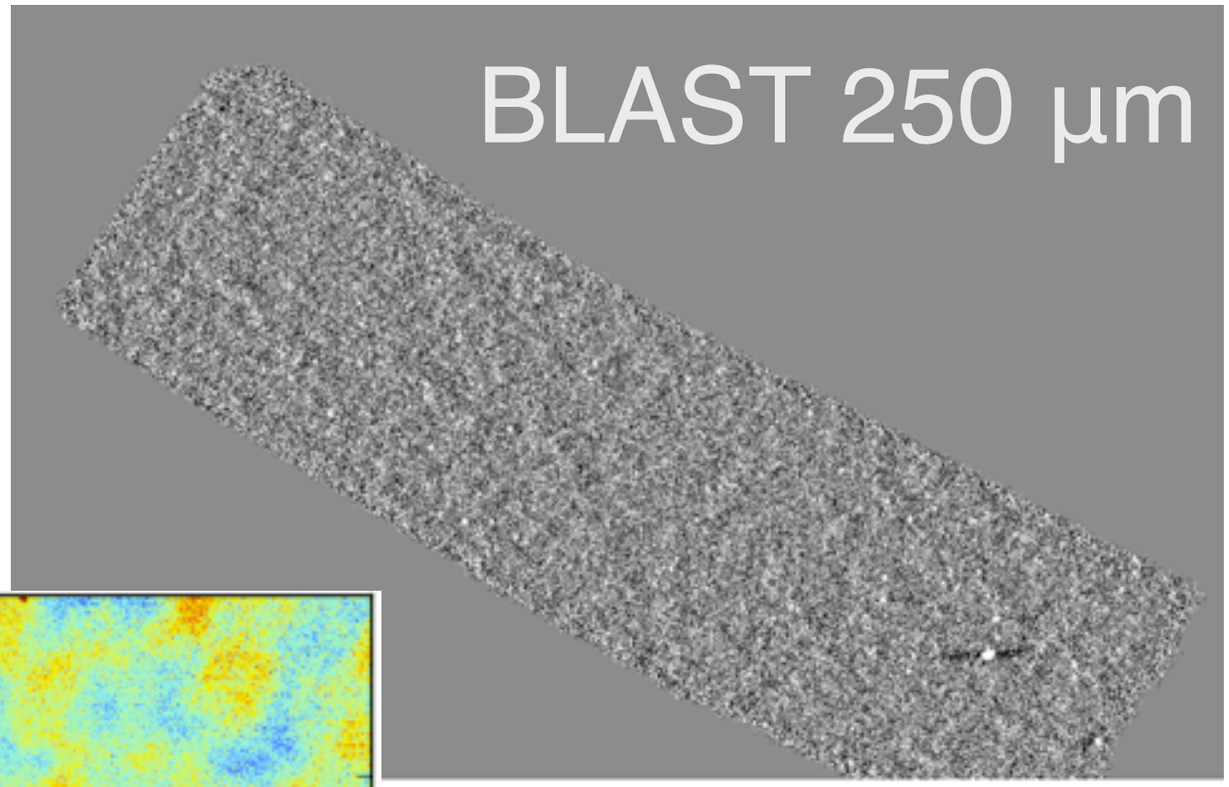
CMB

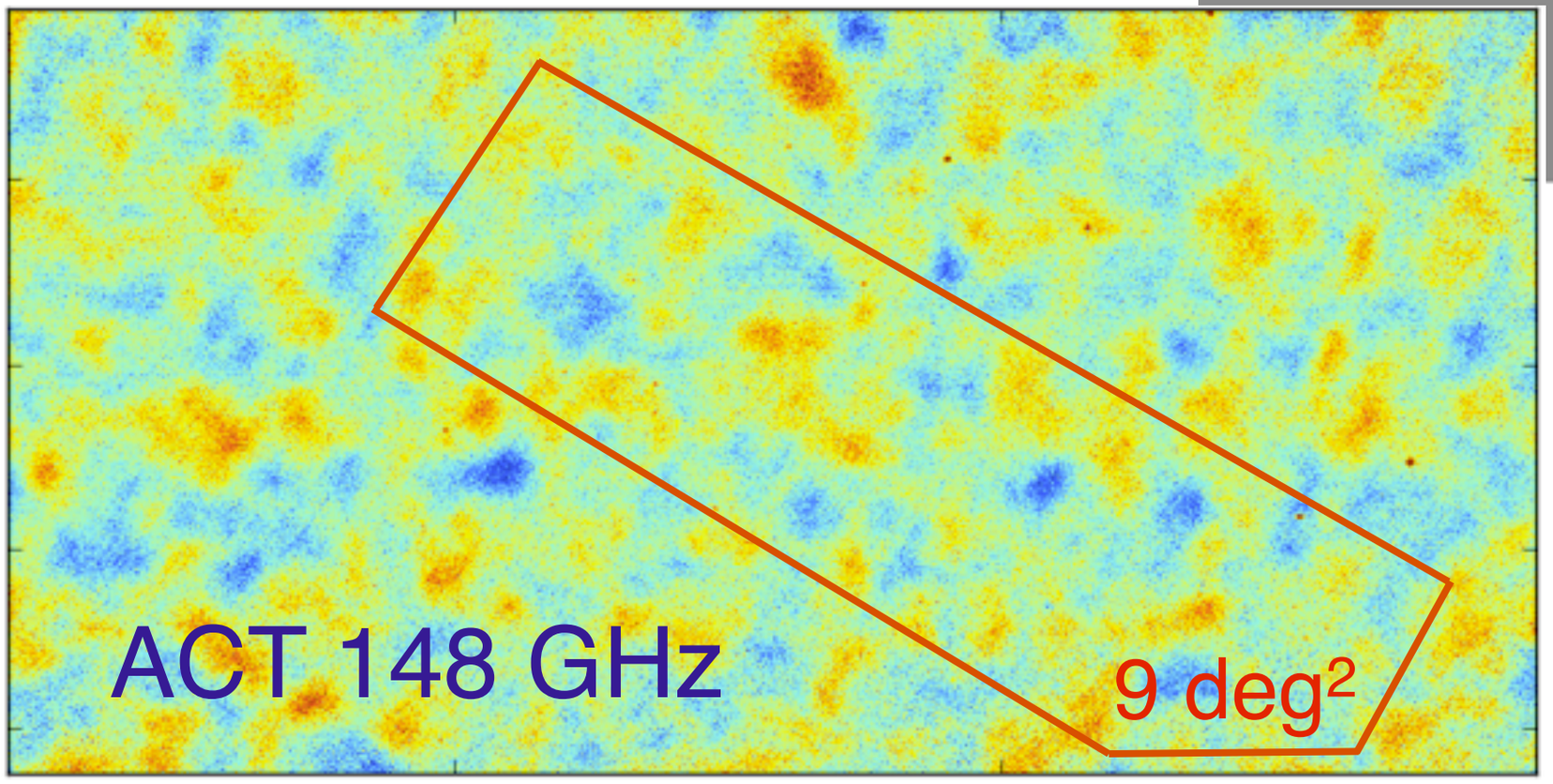
Galaxies

SZ Clusters

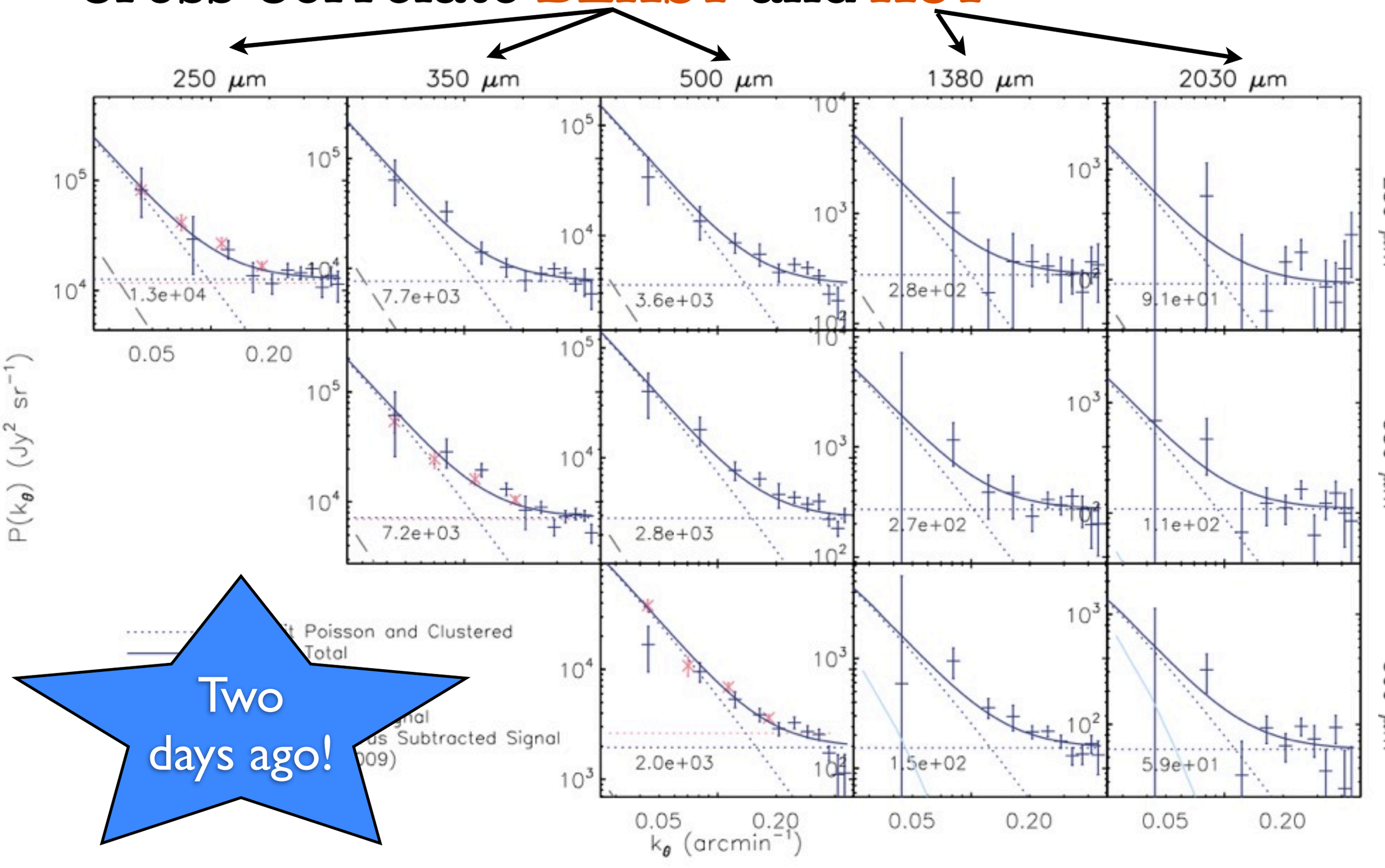


Cross-Correlations Isolate Dusty Galaxies from the Rest



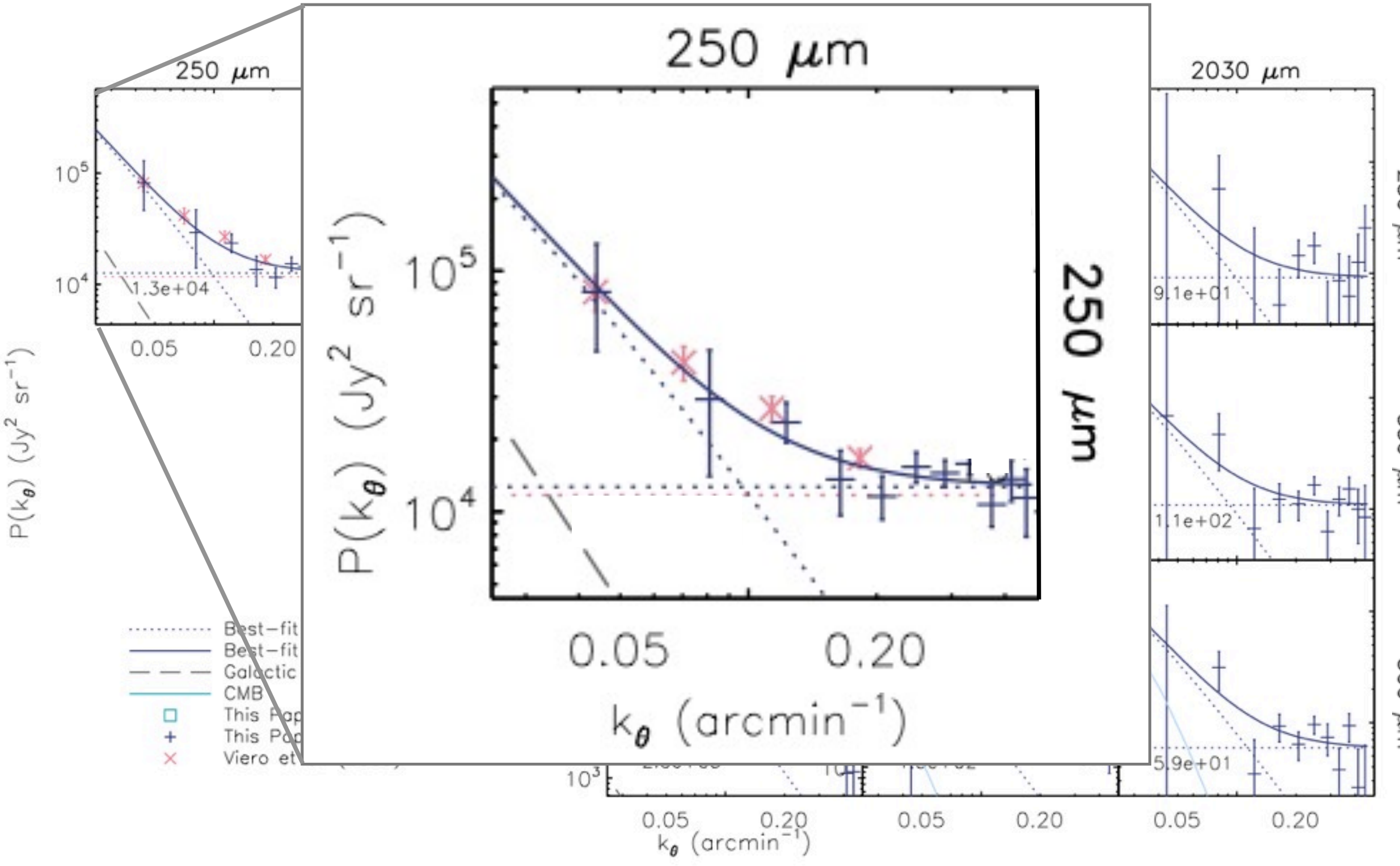


Cross-Correlate BLAST and ACT



Two days ago!

Hajian & Viero et al. 1101.1517



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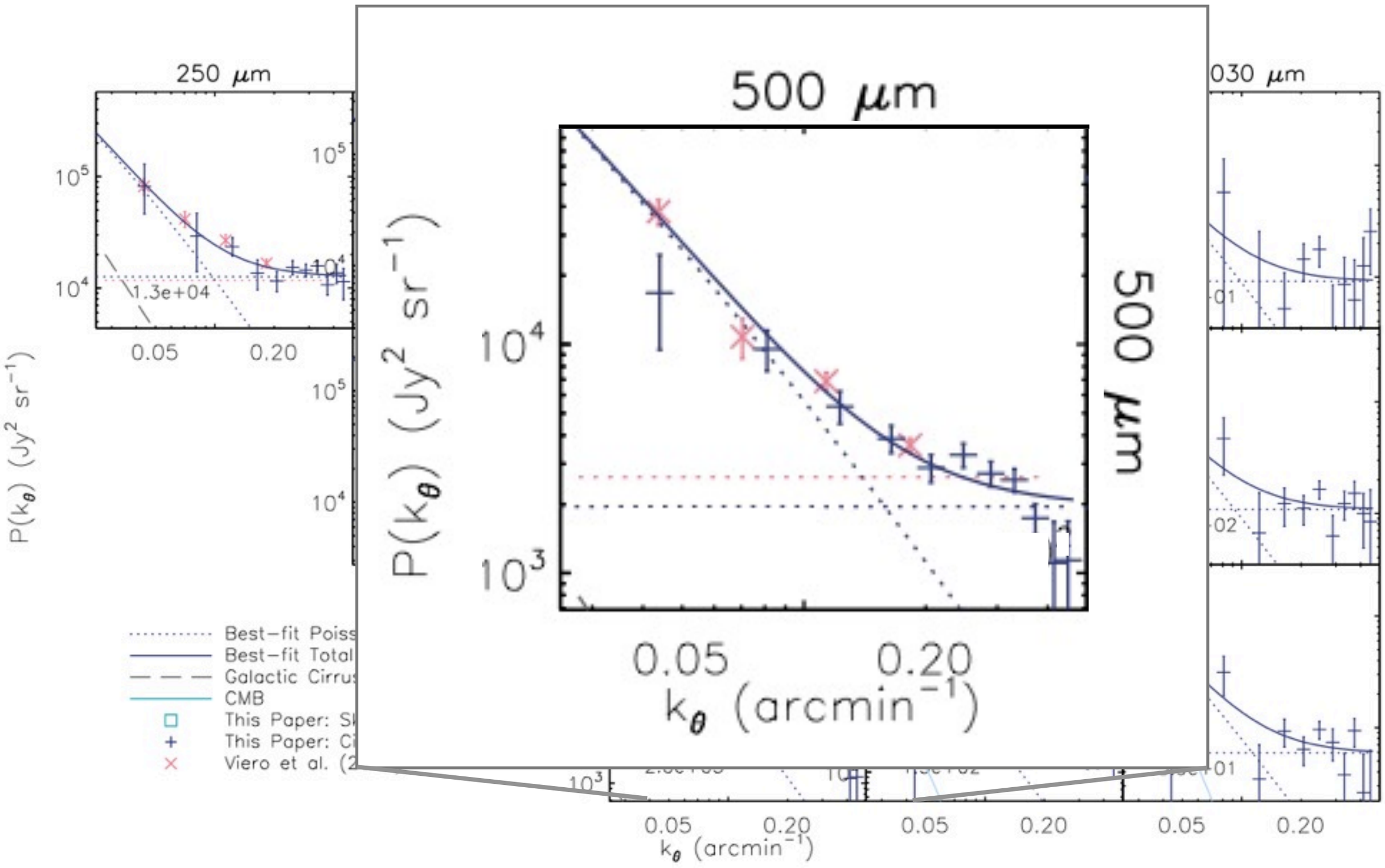
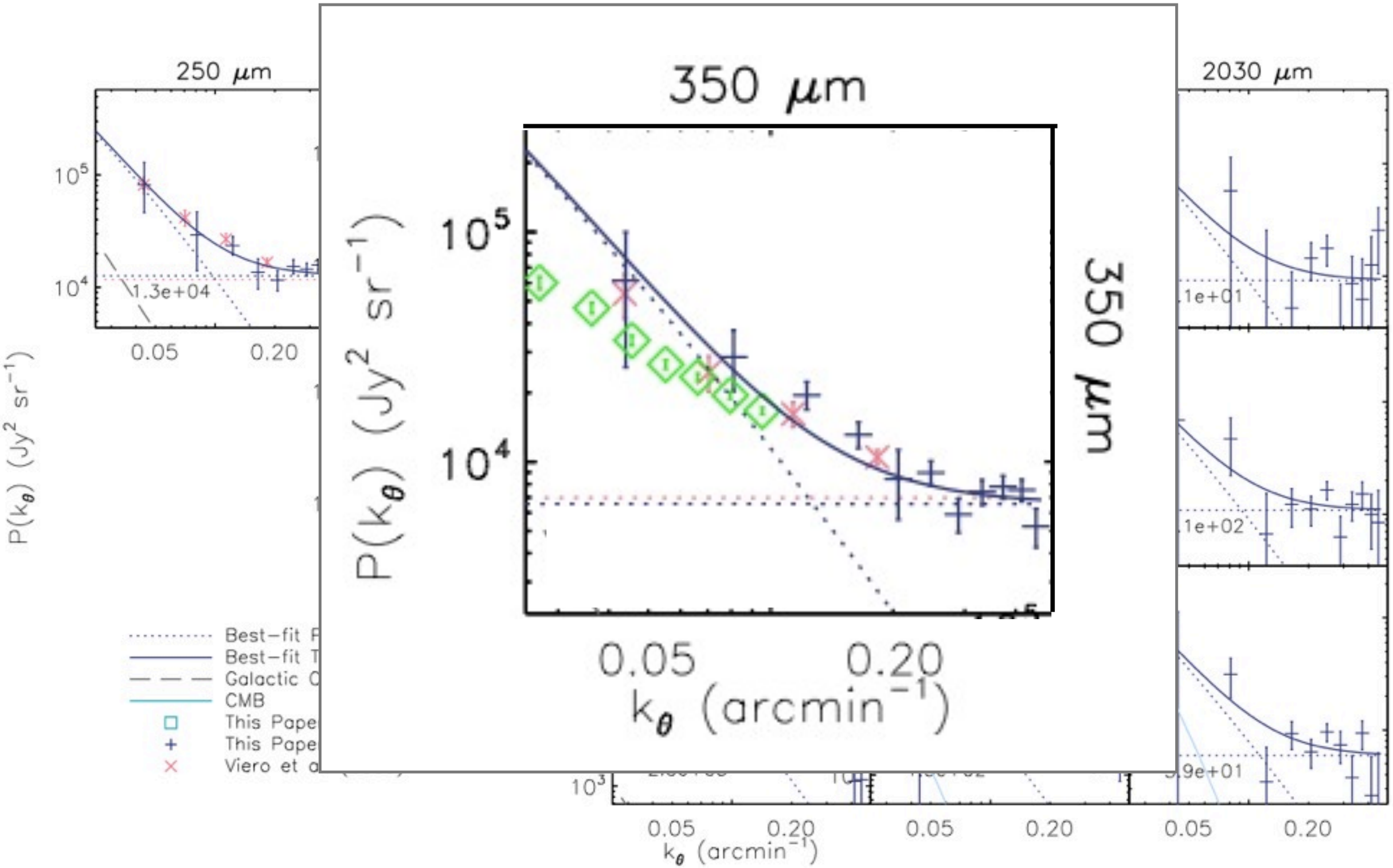
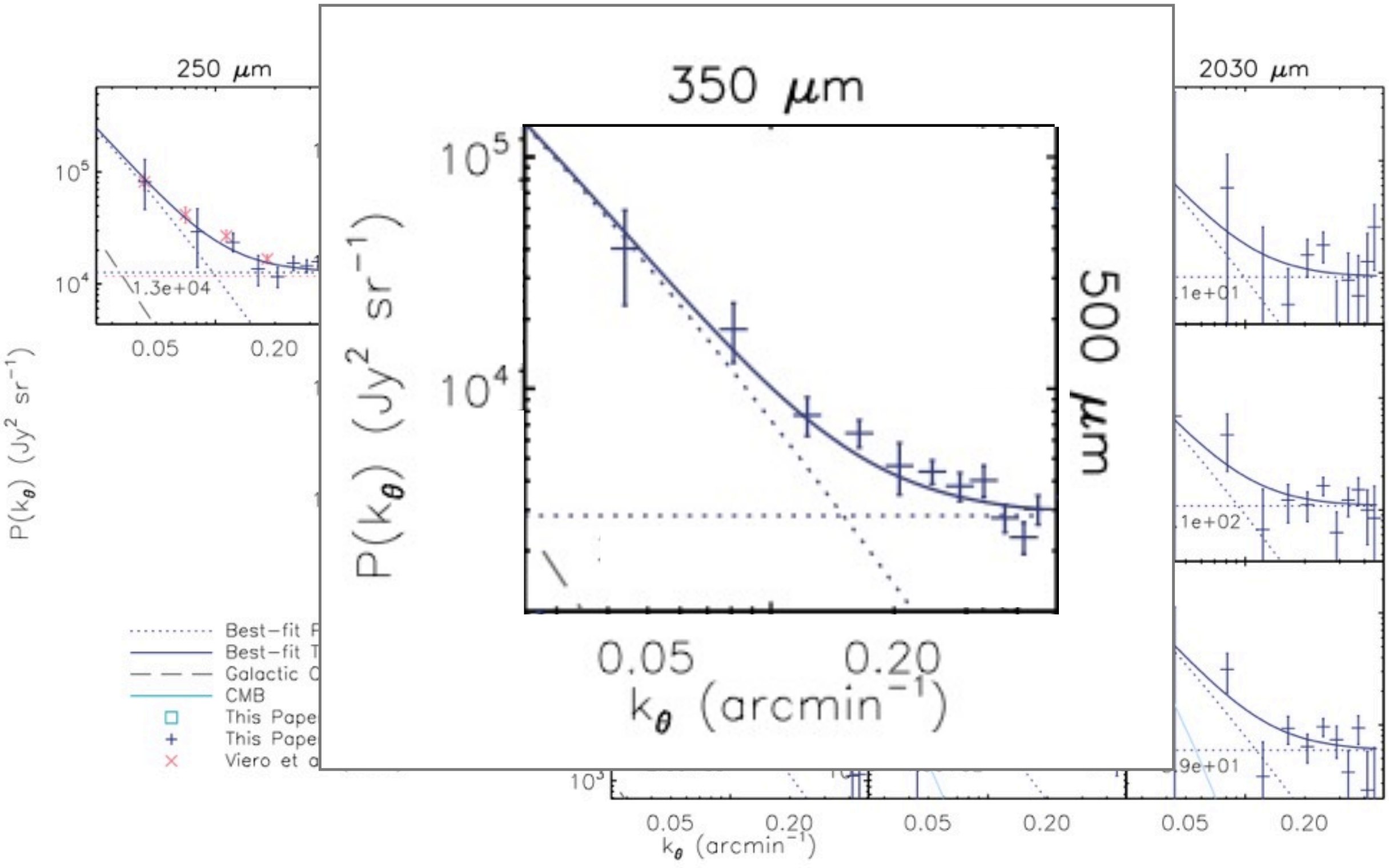


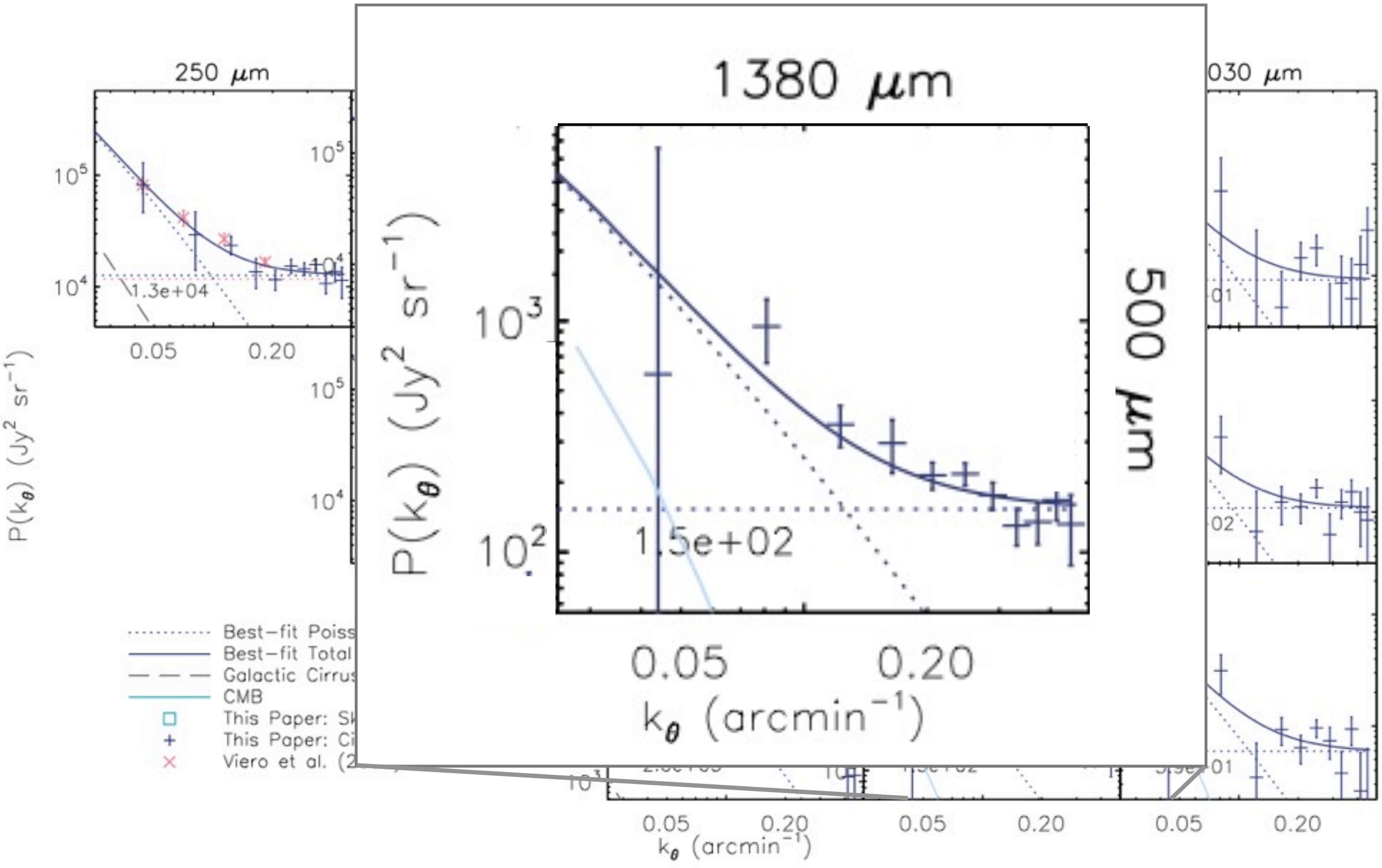
Hajian & Viero et al. 1101.1517



Hajian & Viero et al. 1101.1517



Hajian & Viero et al. 1101.1517



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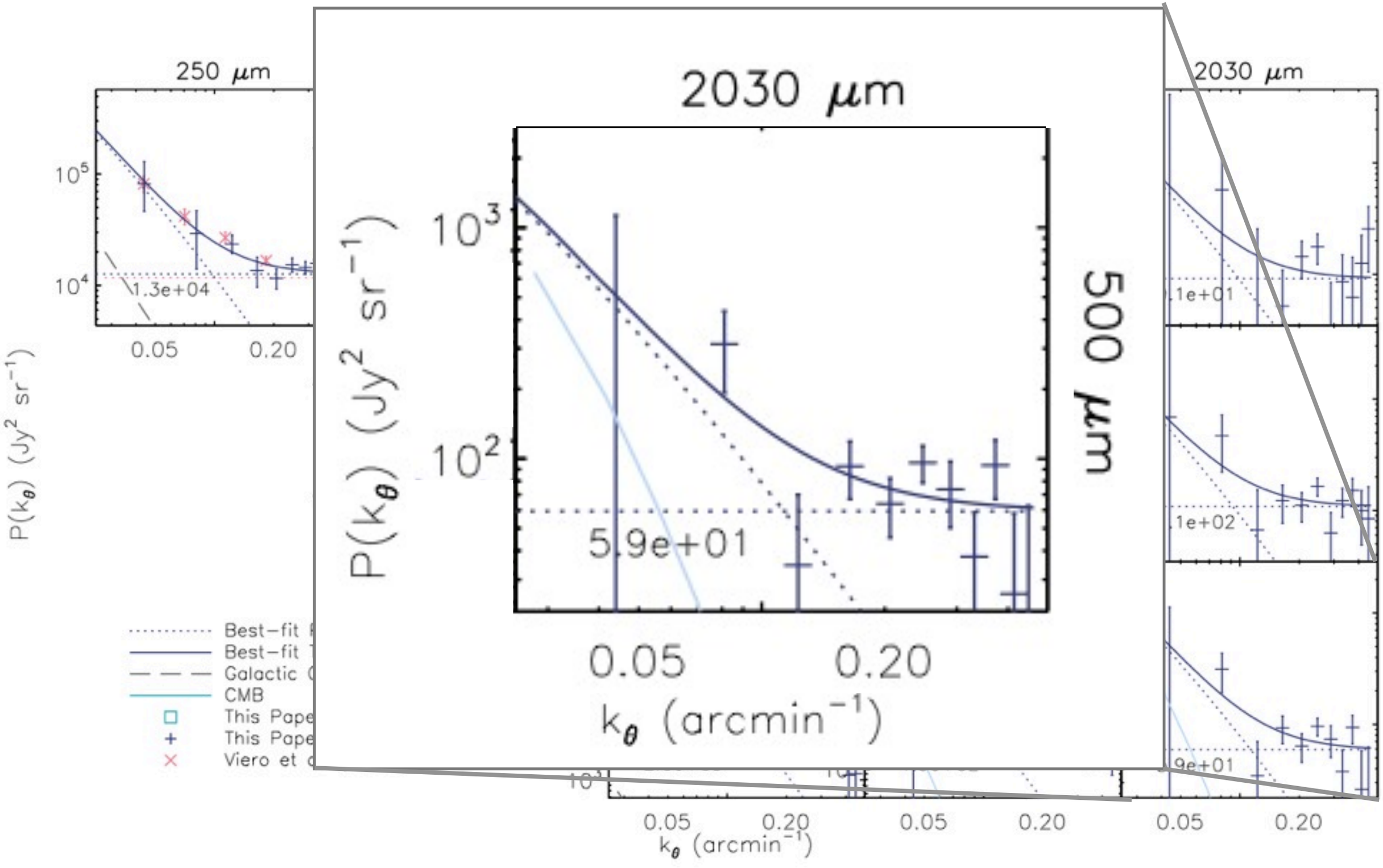
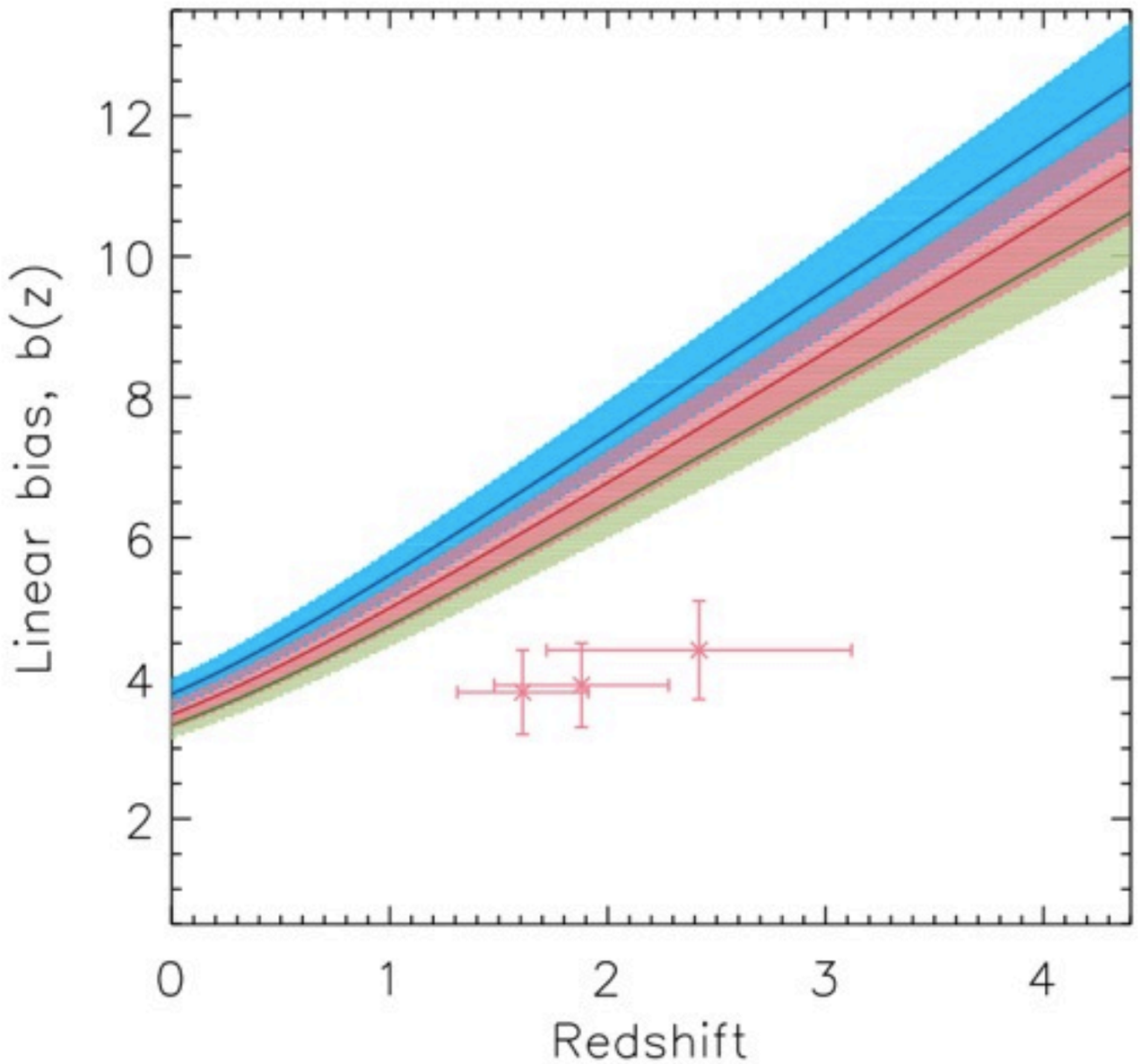


Hajian & Viero et al. 1101.1517

Fit a Linear bias simultaneously to each effective band

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



Hajian & Viero et al. 1101.1517

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
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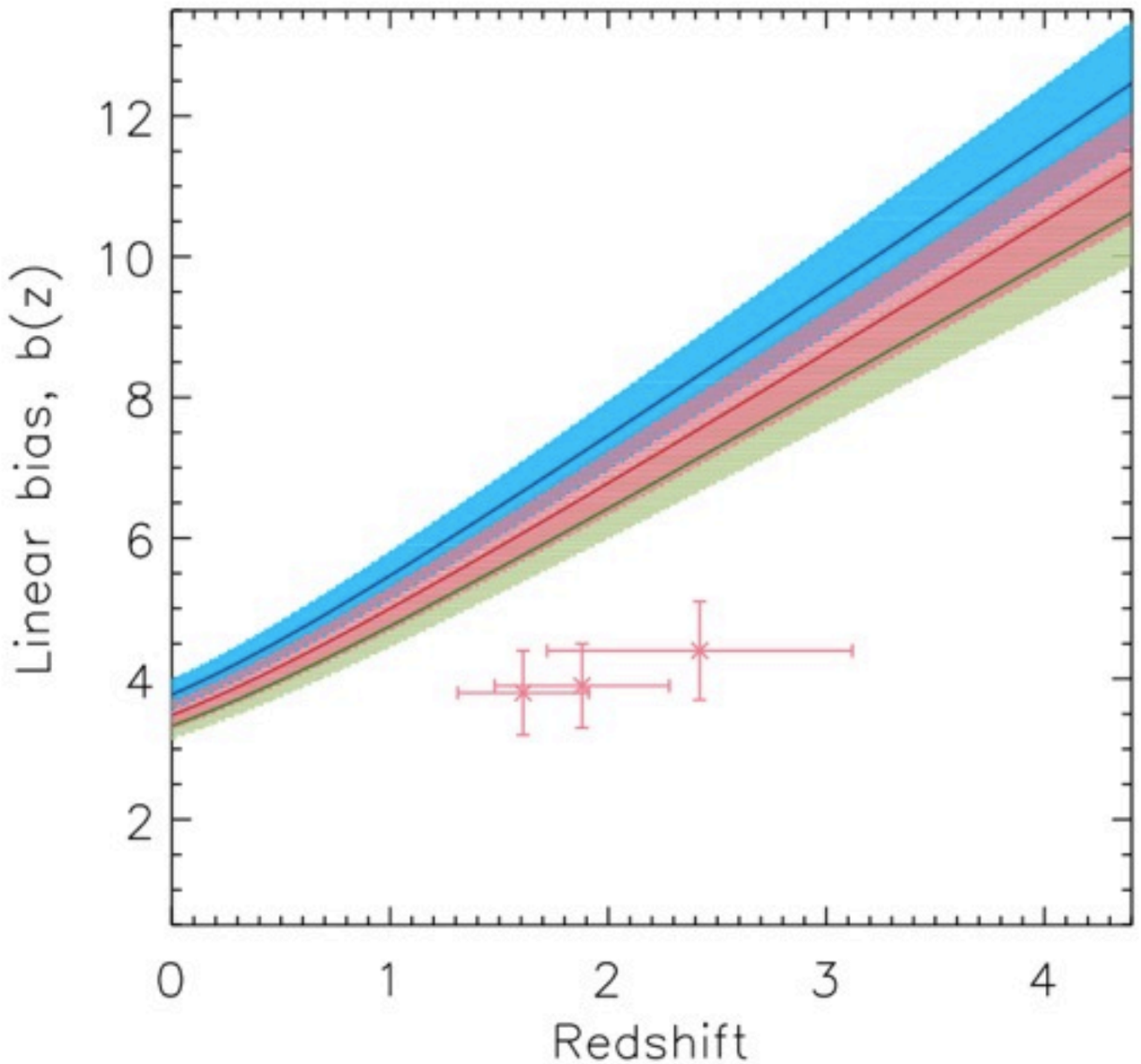

Hajian & Viero et al. 1101.1517

Constrains the evolution using redshift information

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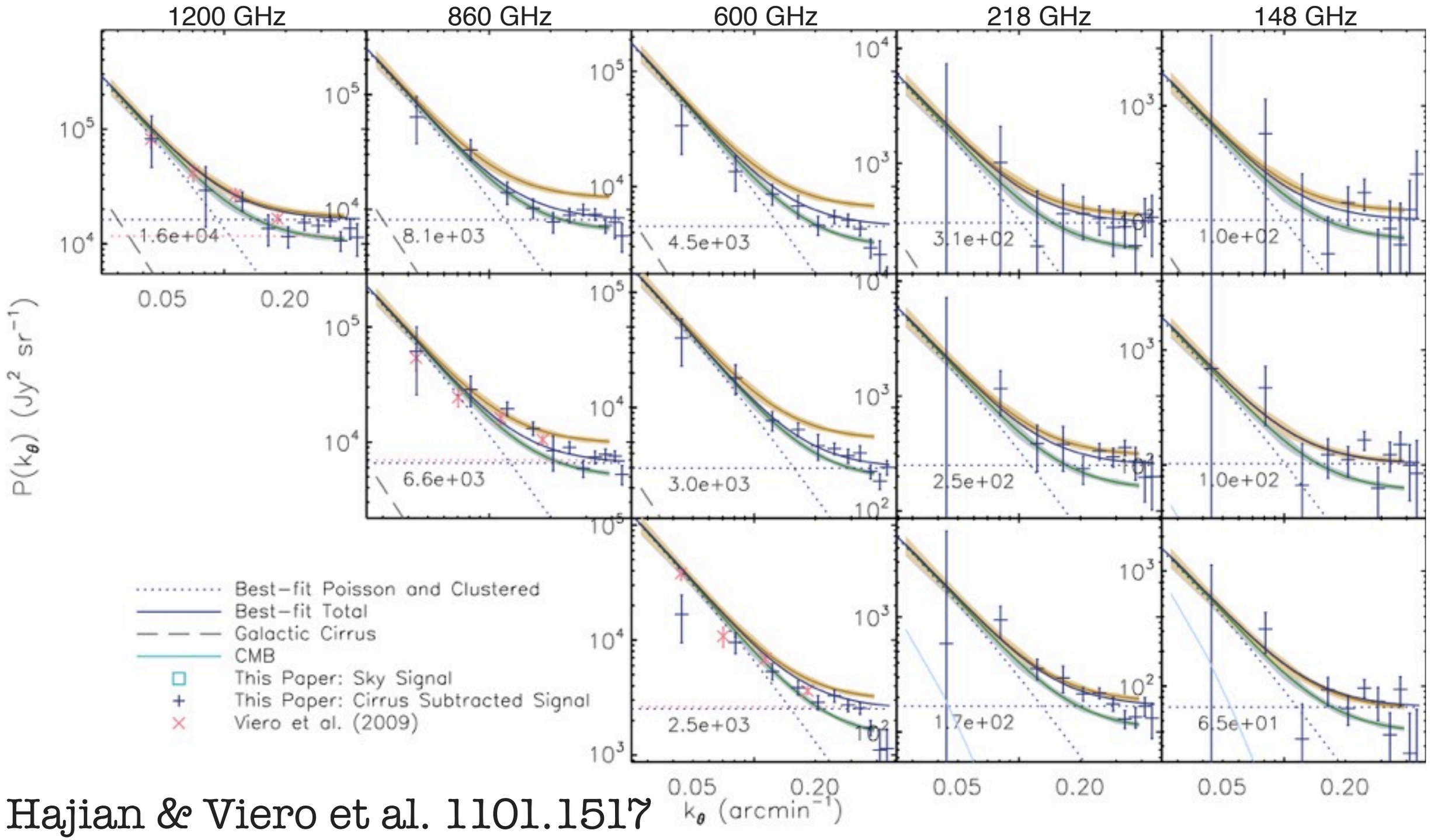
Powerful Tool for Constraining Models



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

Summary

Summary

- Auto-Frequency Correlations:

Summary

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  - ✓ Measure Clustering of DSFGs

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  - ✓ Isolate Dusty Galaxies in CMB maps

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  - ✓ Isolate Dusty Galaxies in CMB maps
  - ✓ Identify the High-z Clustering Signal
  - ✓ Constrain Phenomenological Galaxy Models

end