

Clustering of Dusty Star-Forming Galaxies

marco viero



or
“something
confusing”

marco viero



or

marco viero



how I went
from this->



marco viero



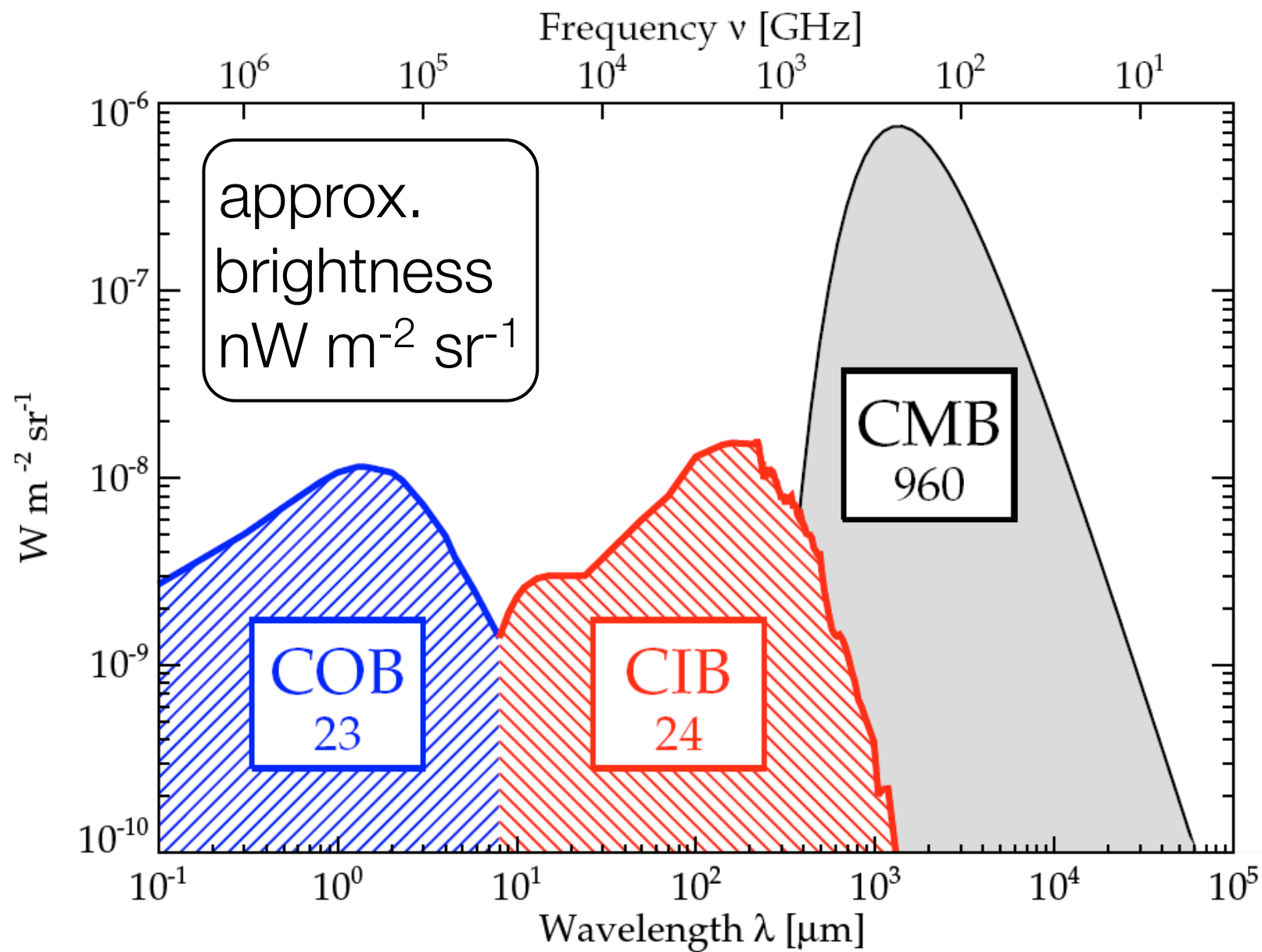
how I went
from this->



<-to this

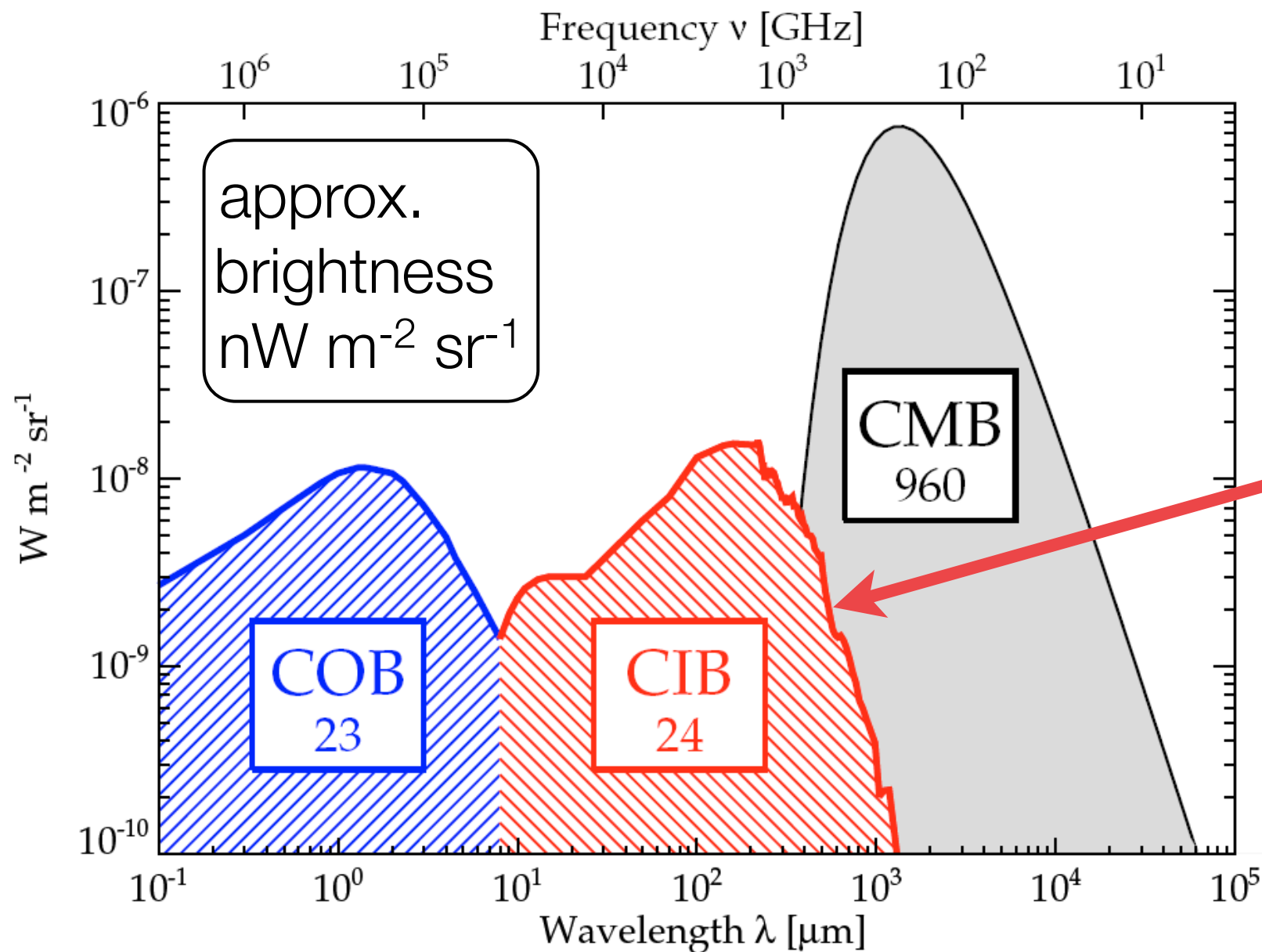
marco viero





Dole et al. 2006

Extragalactic Background Light (EBL)



Cosmic Infrared Background

- Half the light emitted by stars is absorbed and re-emitted in the IR

Dole et al. 2006

Extragalactic Background Light (EBL)

goal:

measure the clustering of
dusty star-forming galaxies

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1. provides link to descendants/
progenitors of DSFGs

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1. provides link to descendants/
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2. informs galaxy models

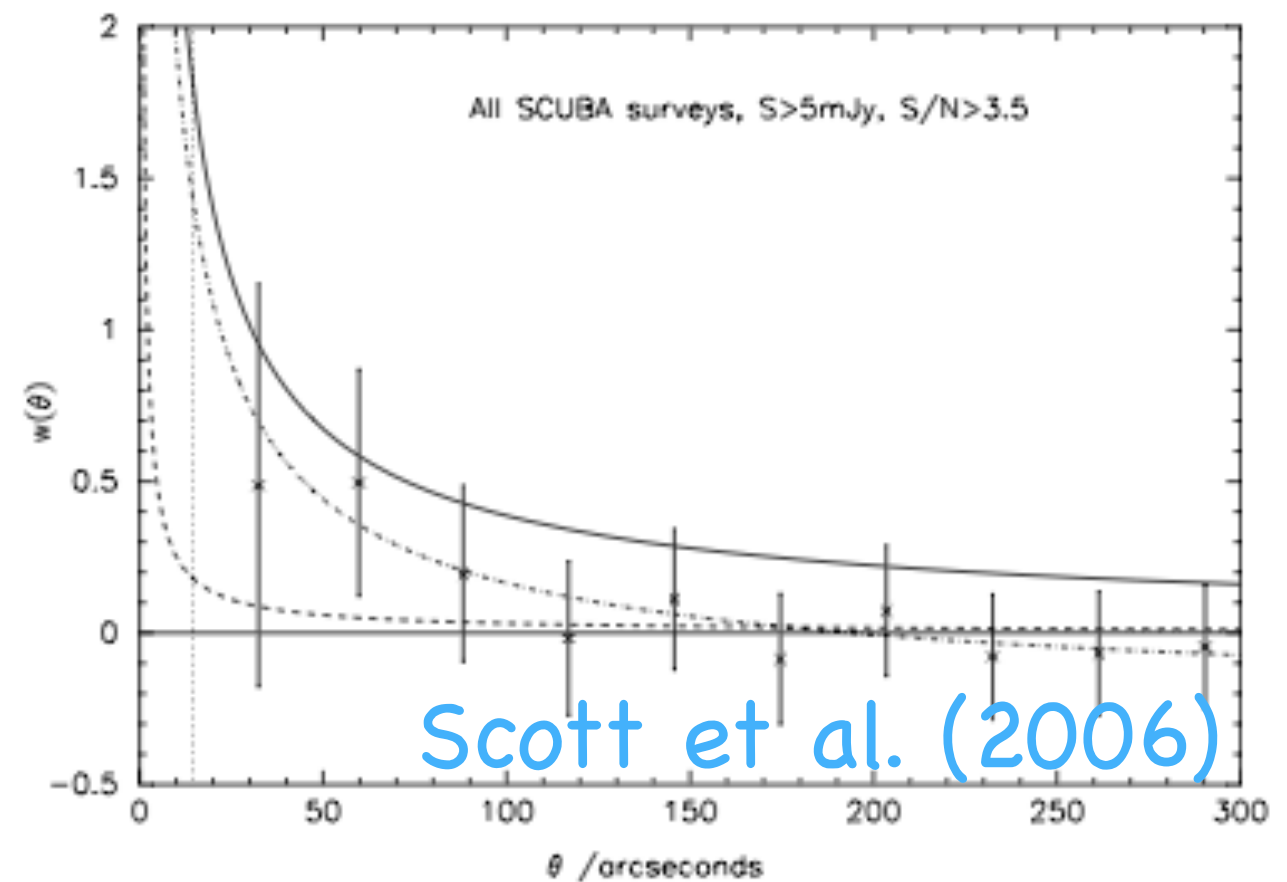
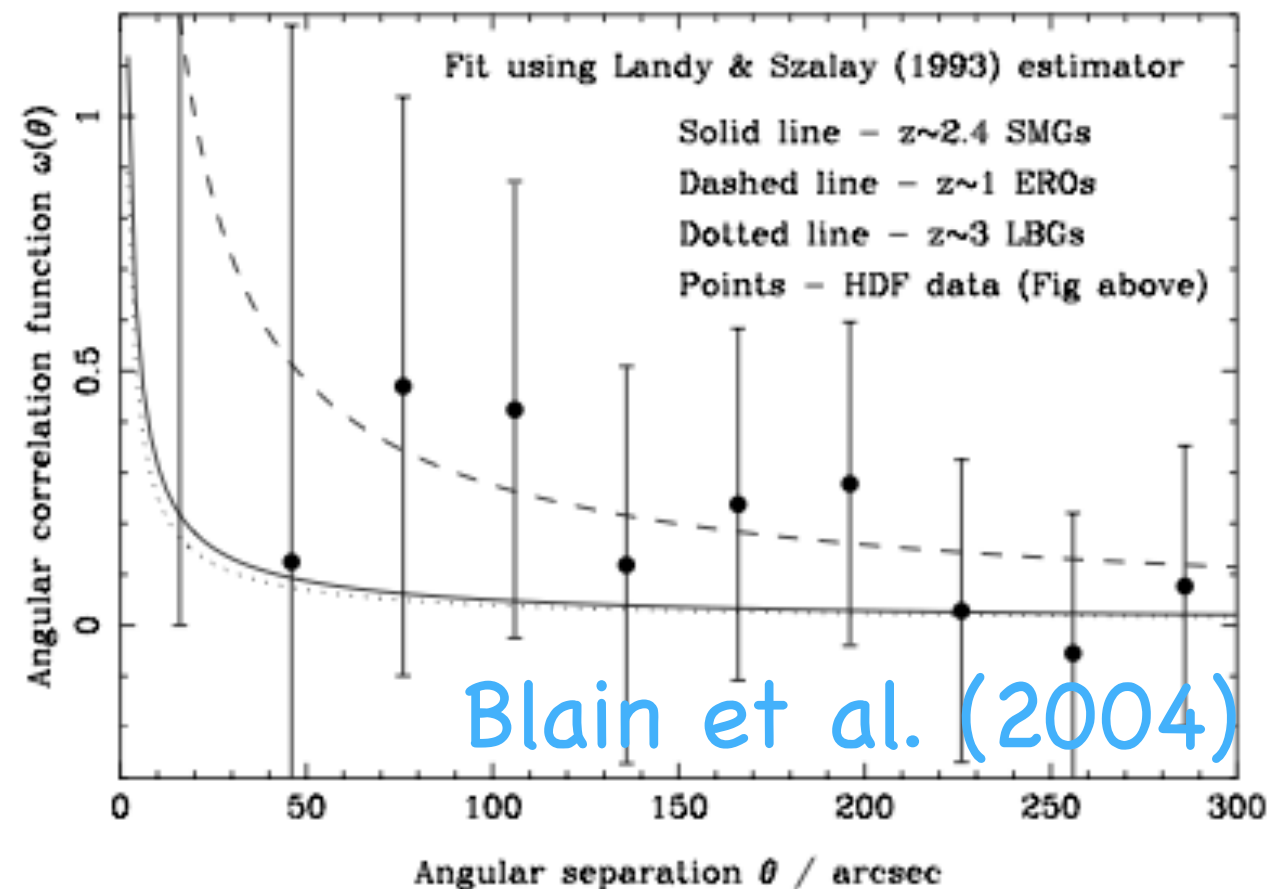
goal:

measure the clustering of dusty star-forming galaxies

1. provides link to descendants/
progenitors of DSFGs
2. informs galaxy models
3. puts limits on contaminants of
CMB secondary anisotropies

pre-2007

- surveys $\ll 1 \text{ deg}^2$
limited to < 100
sources
- strong clustering
suggested, but
noise consistent
with zero

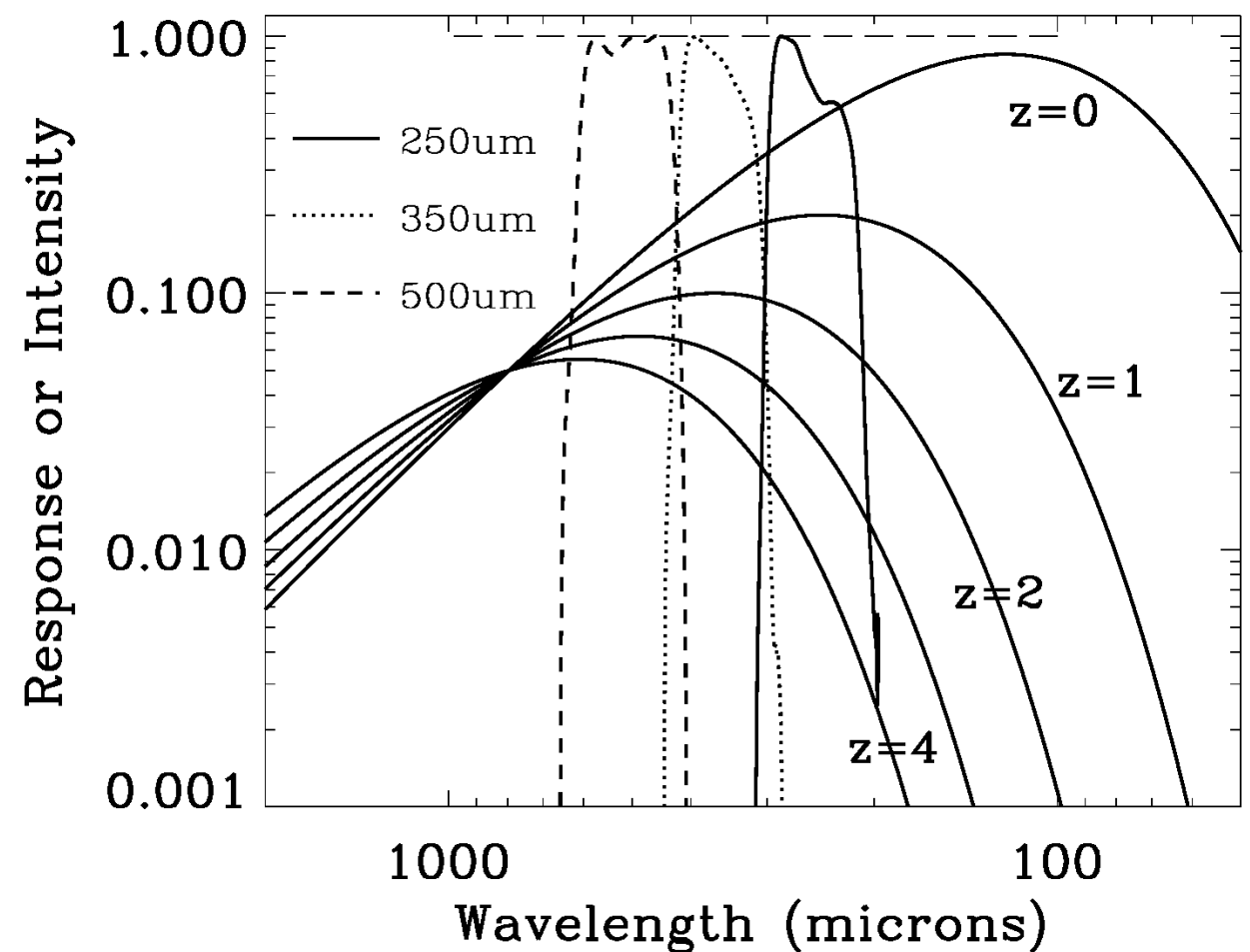




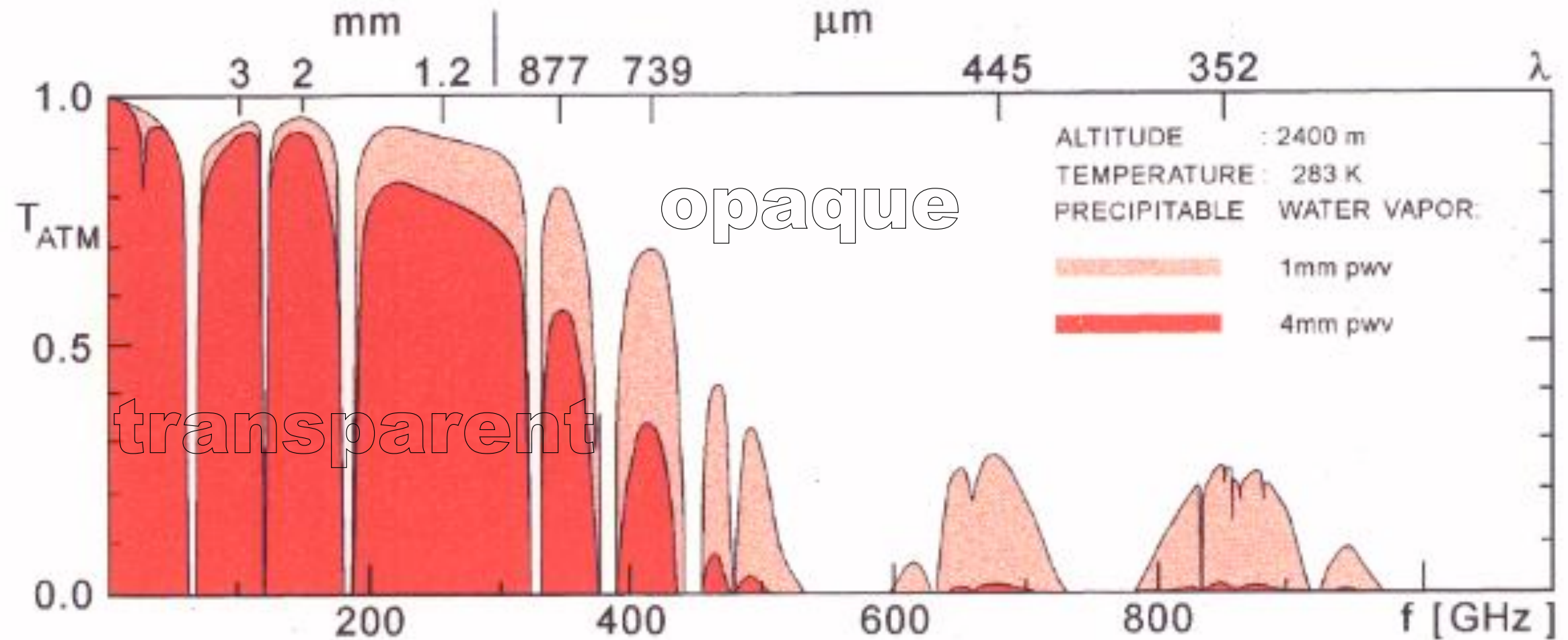
submillimeter
observations,
the next generation

selecting high- z DSFGs

- want to bracket the redshifted peak of SED of warmed dust
- SPIRE bands are 250, 350, and 500 μm

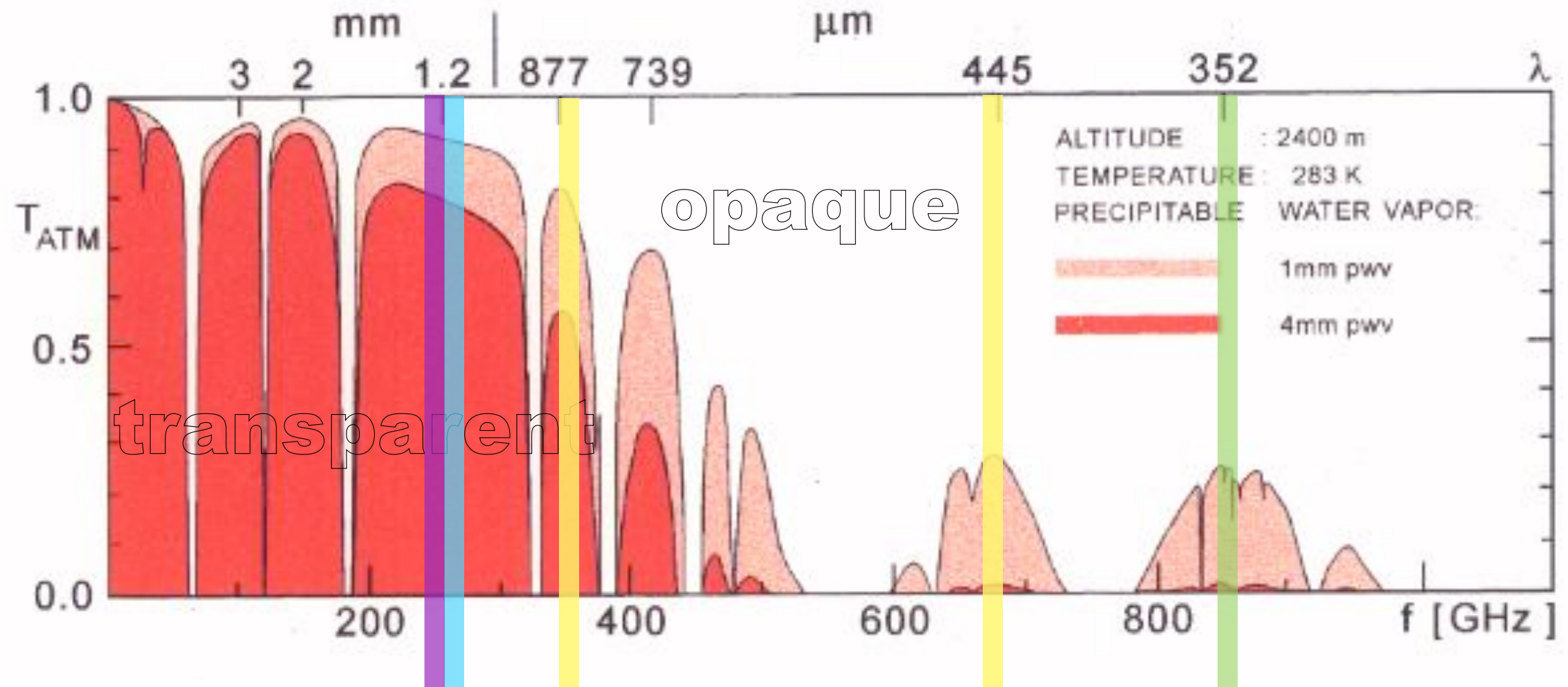


ZENITH - TRANSMISSION OF THE ATMOSPHERE IN DEPENDENCE OF THE PRECIPITABLE WATER VAPOR



Submm Observations

ZENITH - TRANSMISSION OF THE ATMOSPHERE IN DEPENDENCE OF THE PRECIPITABLE WATER VAPOR



MAMBO

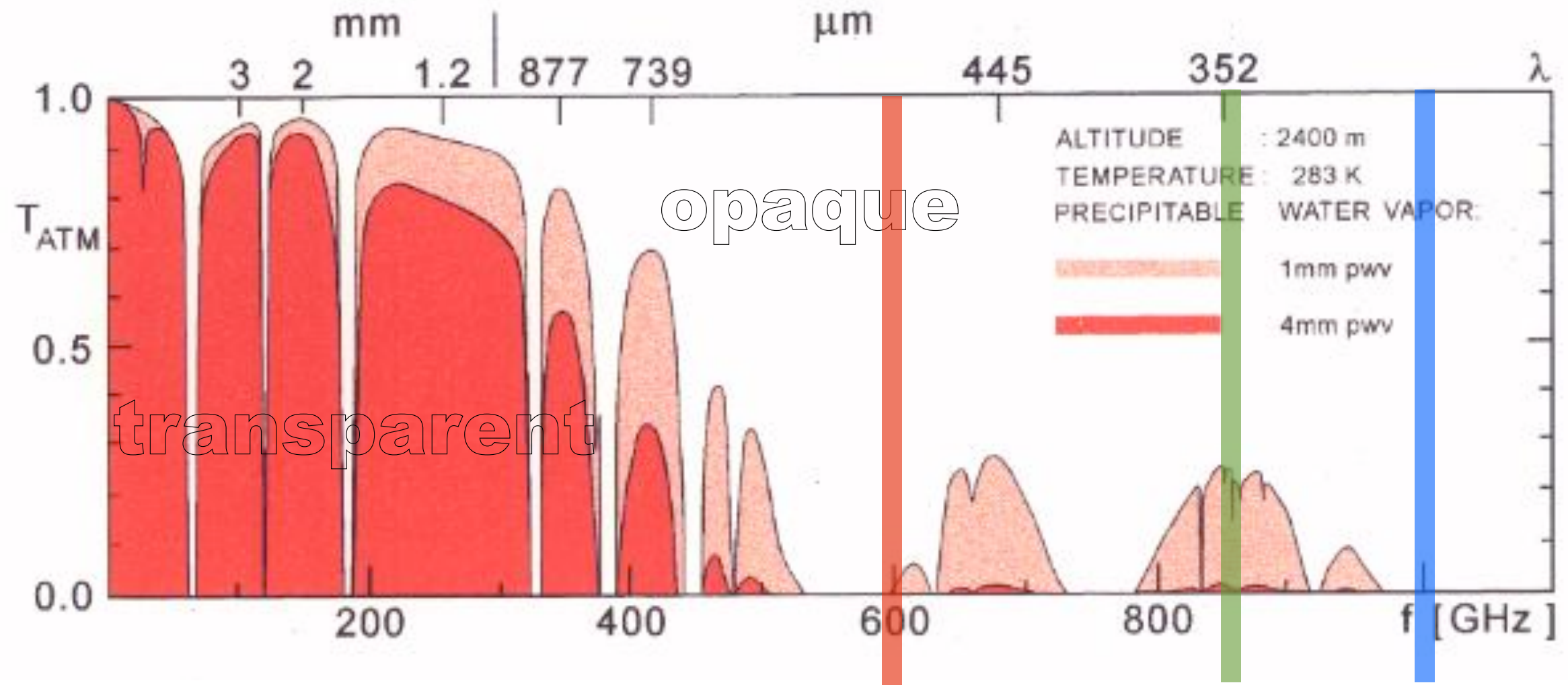
AzTEC

SCUBA

SHARC

Submm Observations

ZENITH - TRANSMISSION OF THE ATMOSPHERE IN DEPENDENCE OF THE PRECIPITABLE WATER VAPOR

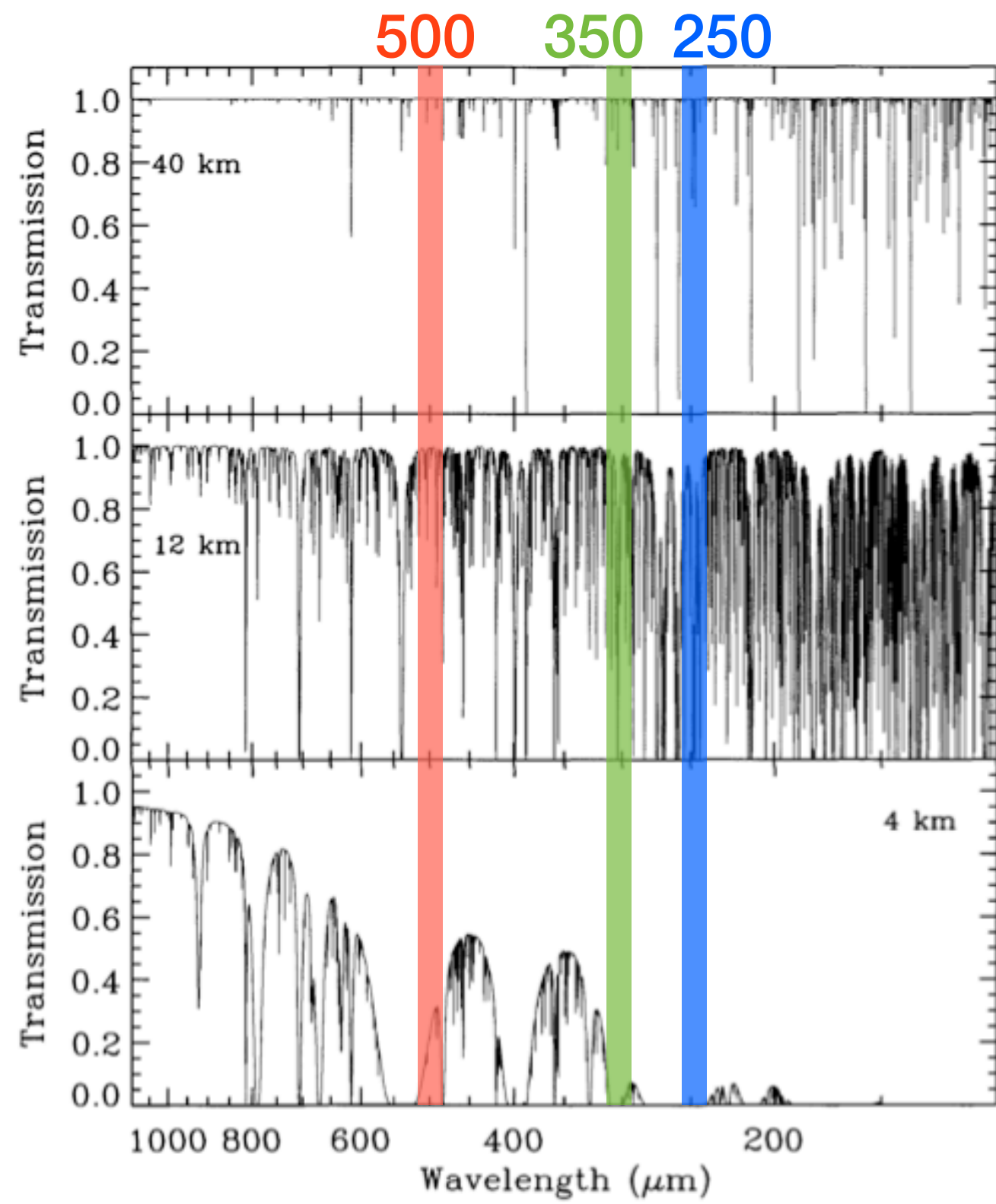


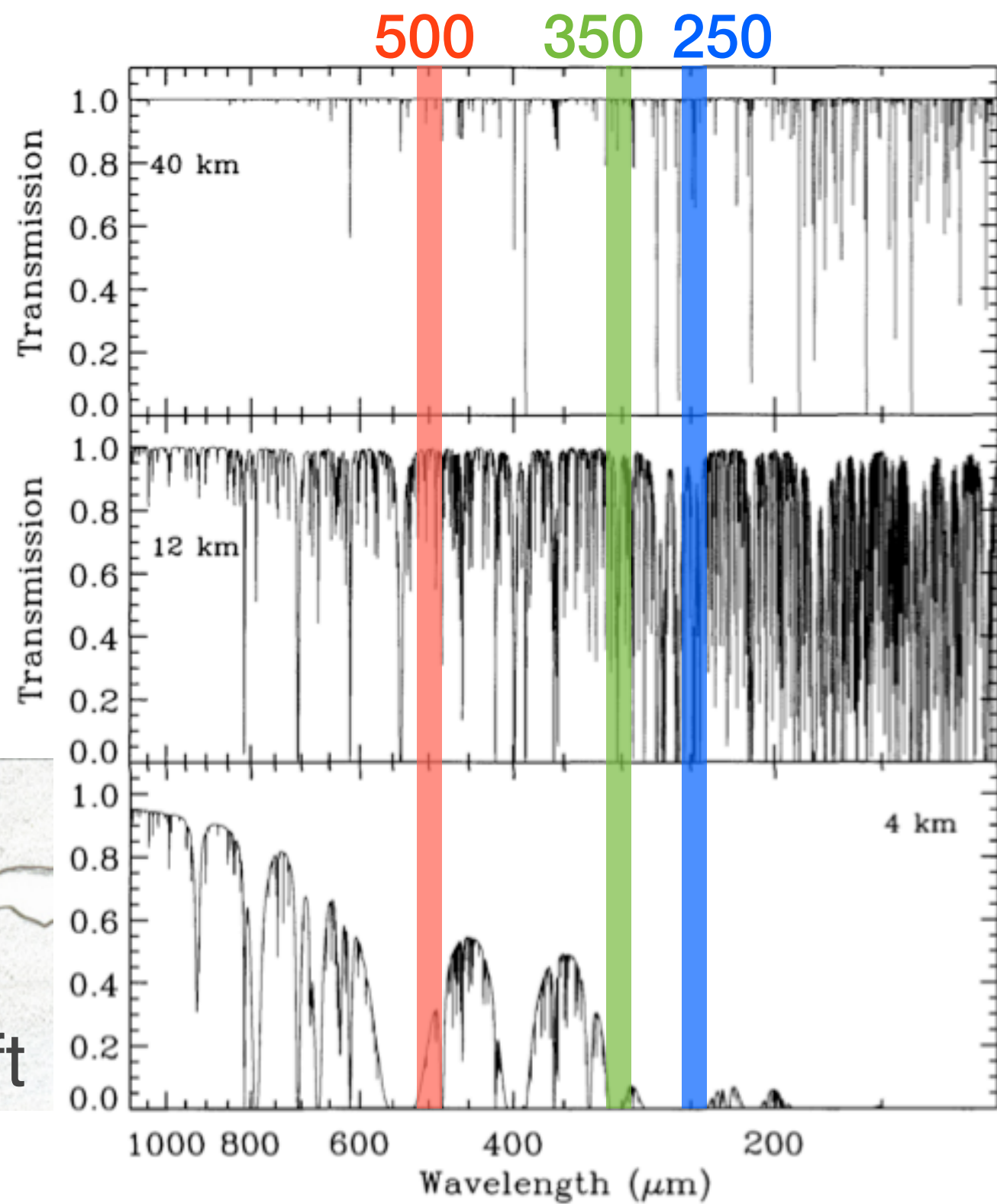
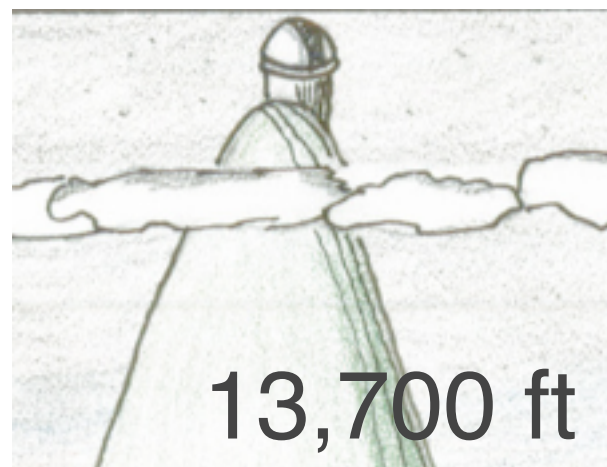
500

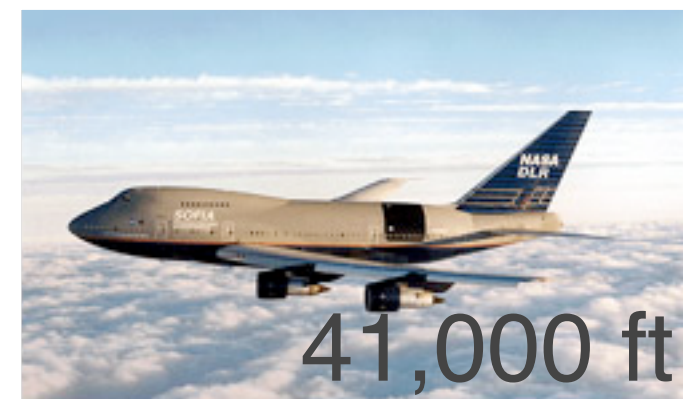
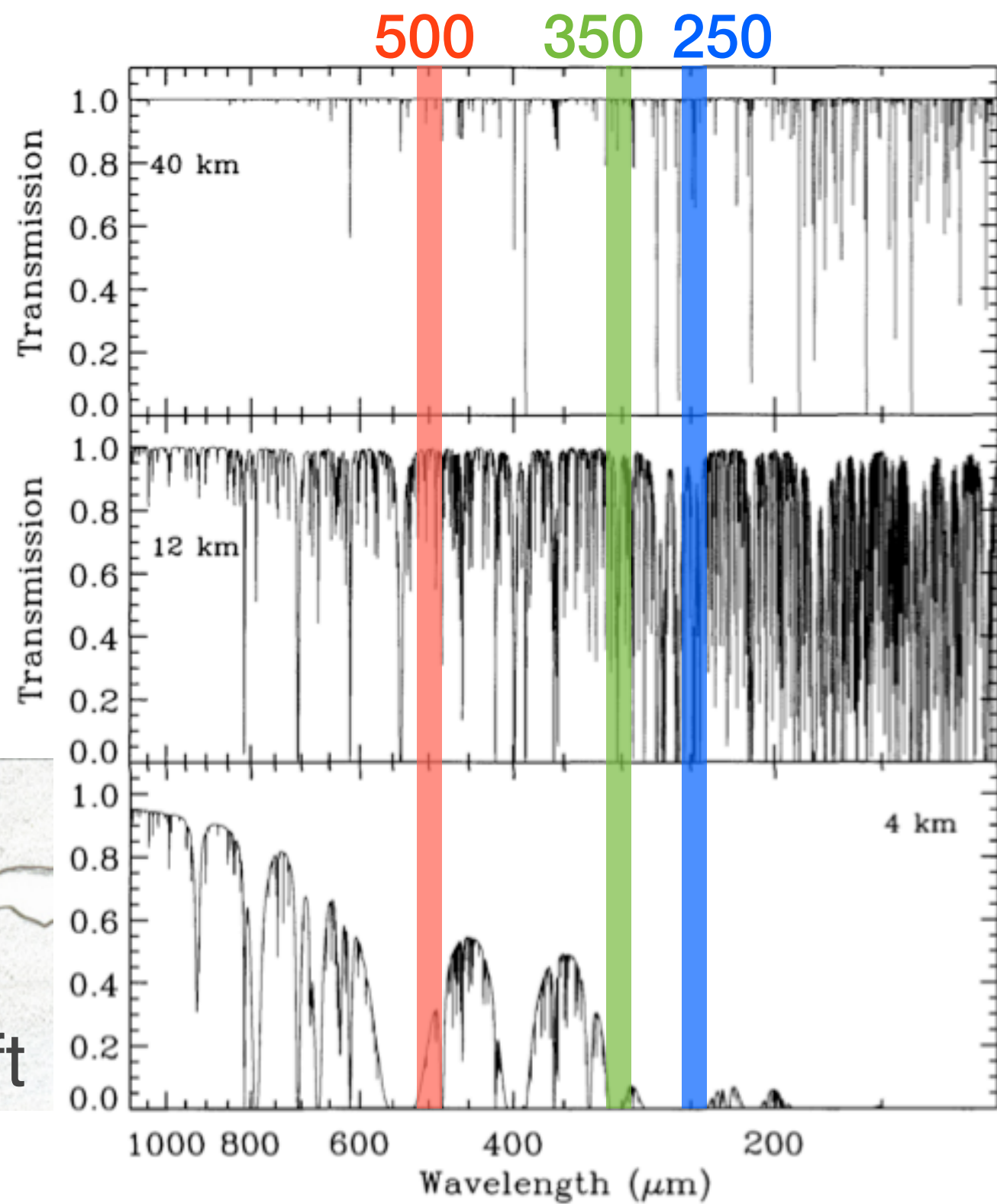
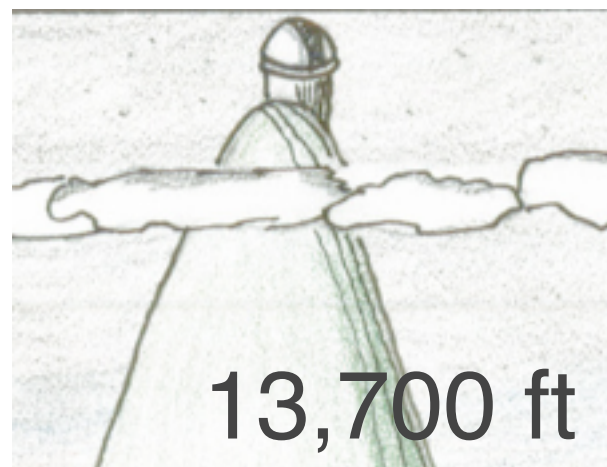
350

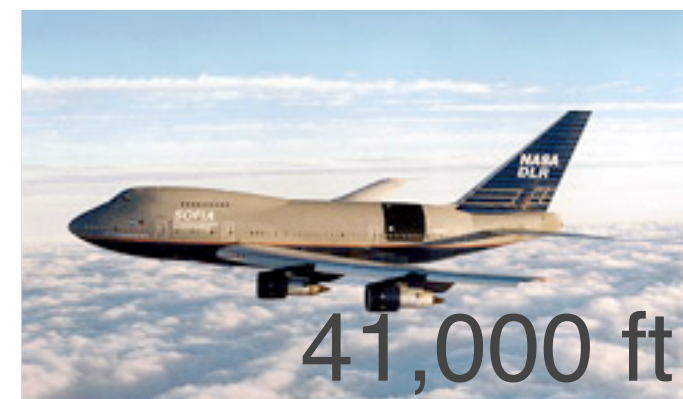
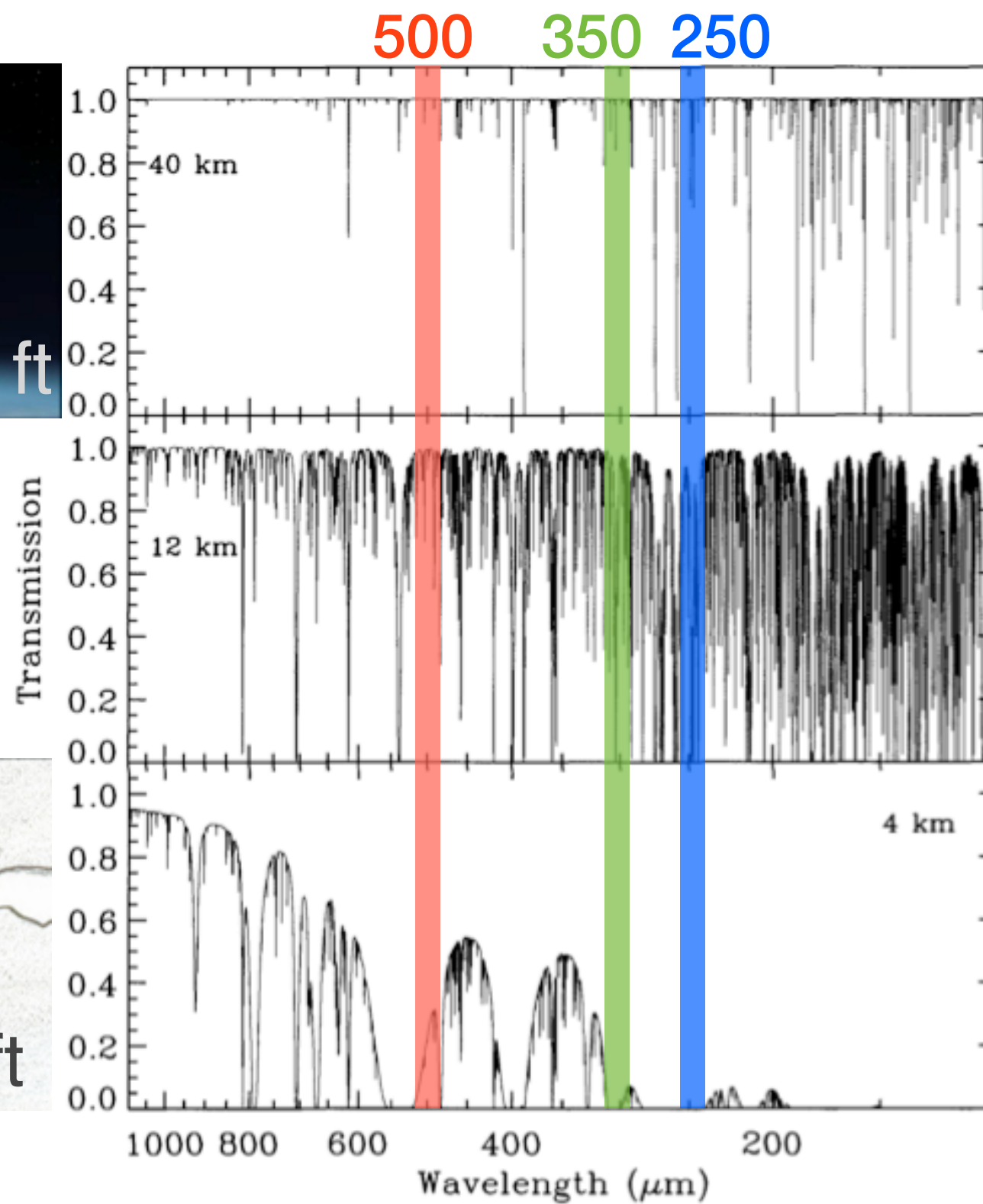
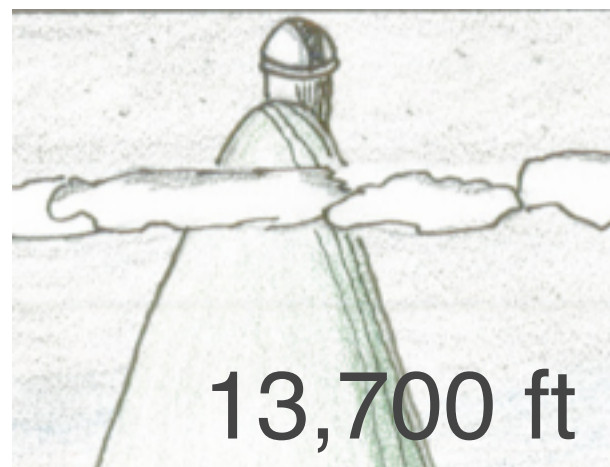
250

Submm Observations







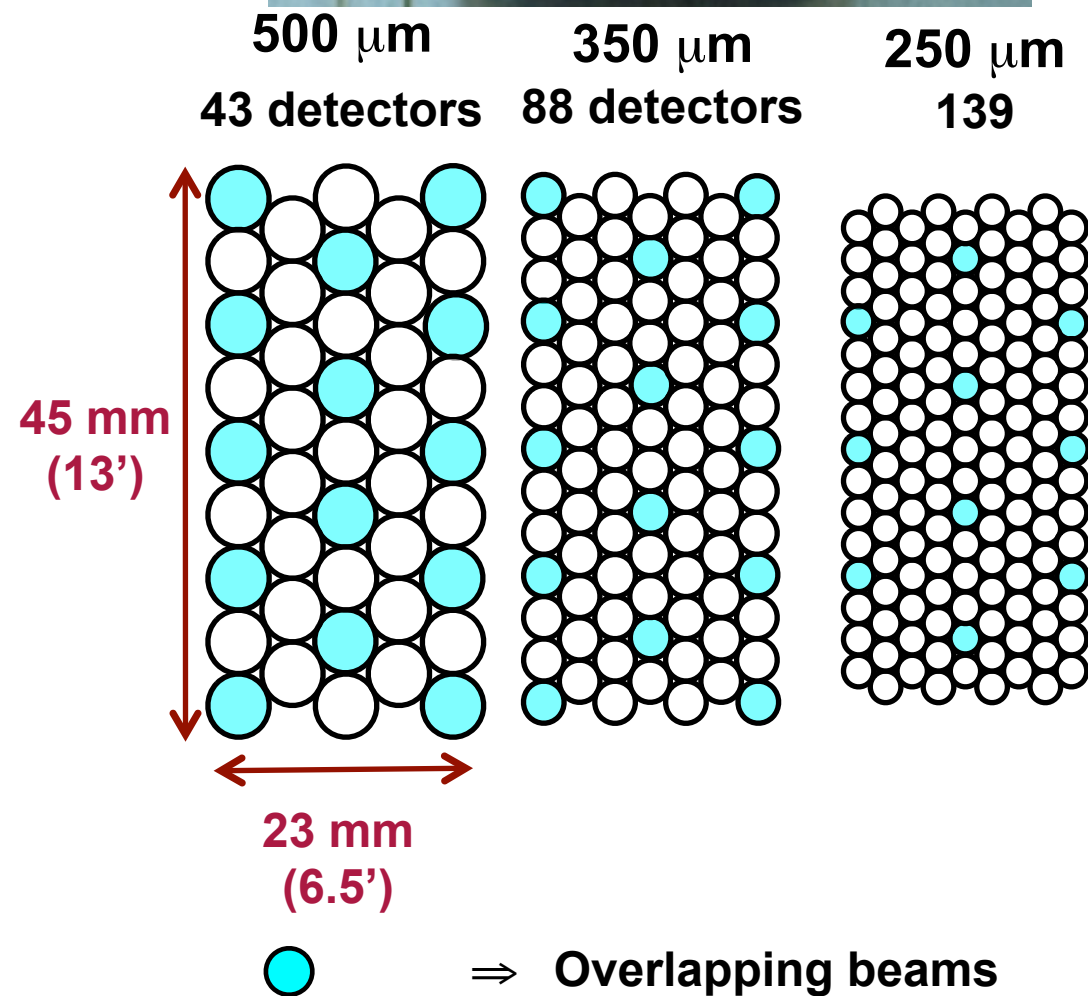


BLAST



Wednesday, June 8, 2011

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



BLAST

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

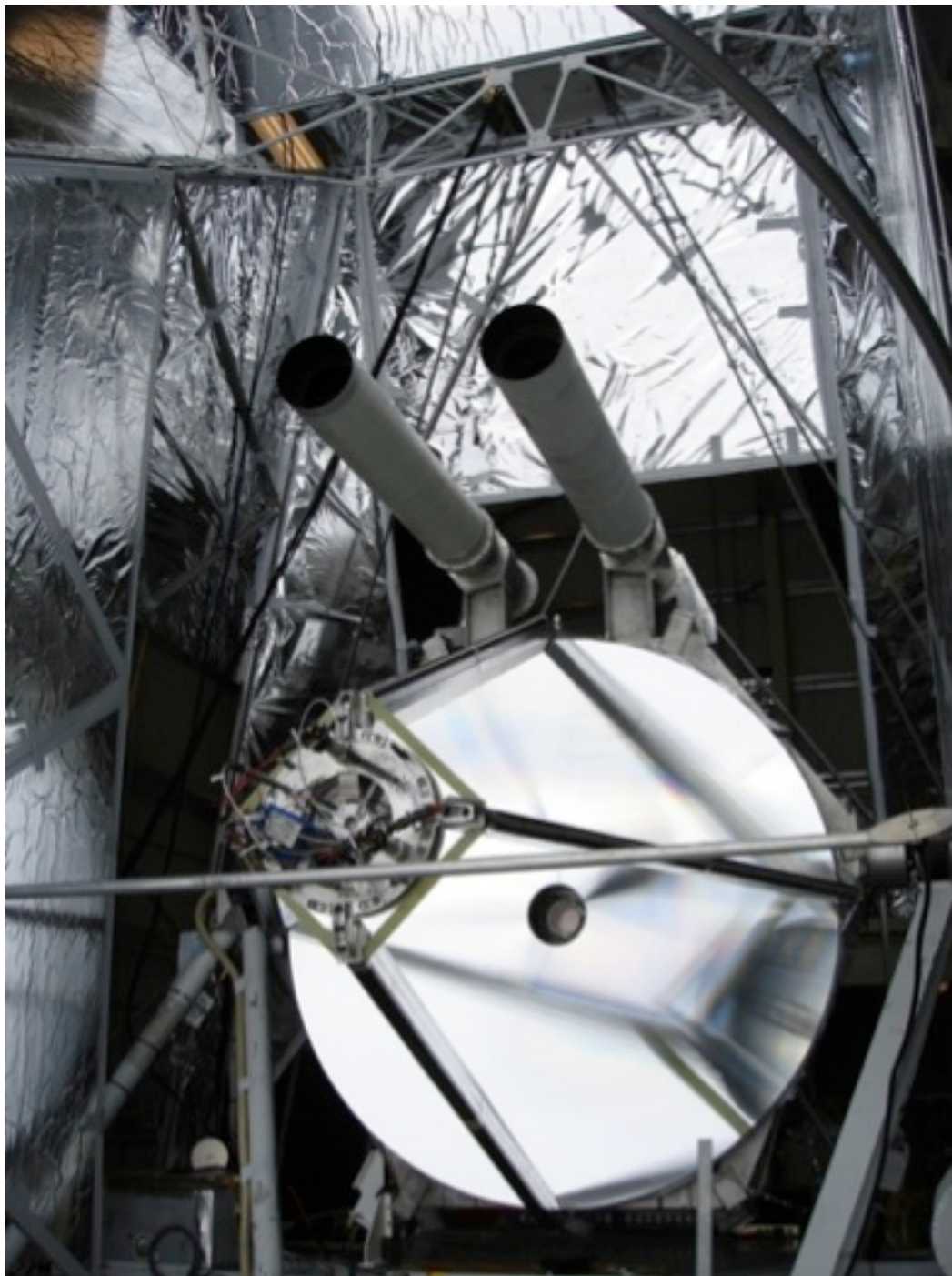
... but a 1.8 m primary
resulting in beams:

36" - 250 μm

45" - 350 μm

60" - 500 μm

i.e., twice the size of SPIRE's
beams



BLAST



Enzo Pascale:
Maps and Stacking



Ed Chapin: Modelling



Gaelen Marsden:

Counts and Stacking



Marco Viero:
Clustering



Mattia Negrello:
Halo Model



Guillaume Patanchon:
Map-making

Don Wiebe:
Data Flow

Marie Rex:
Lensing

Matt Truch:
Calibration





Wednesday, June 8, 2011



Wednesday, June 8, 2011



bye bye BLAST!

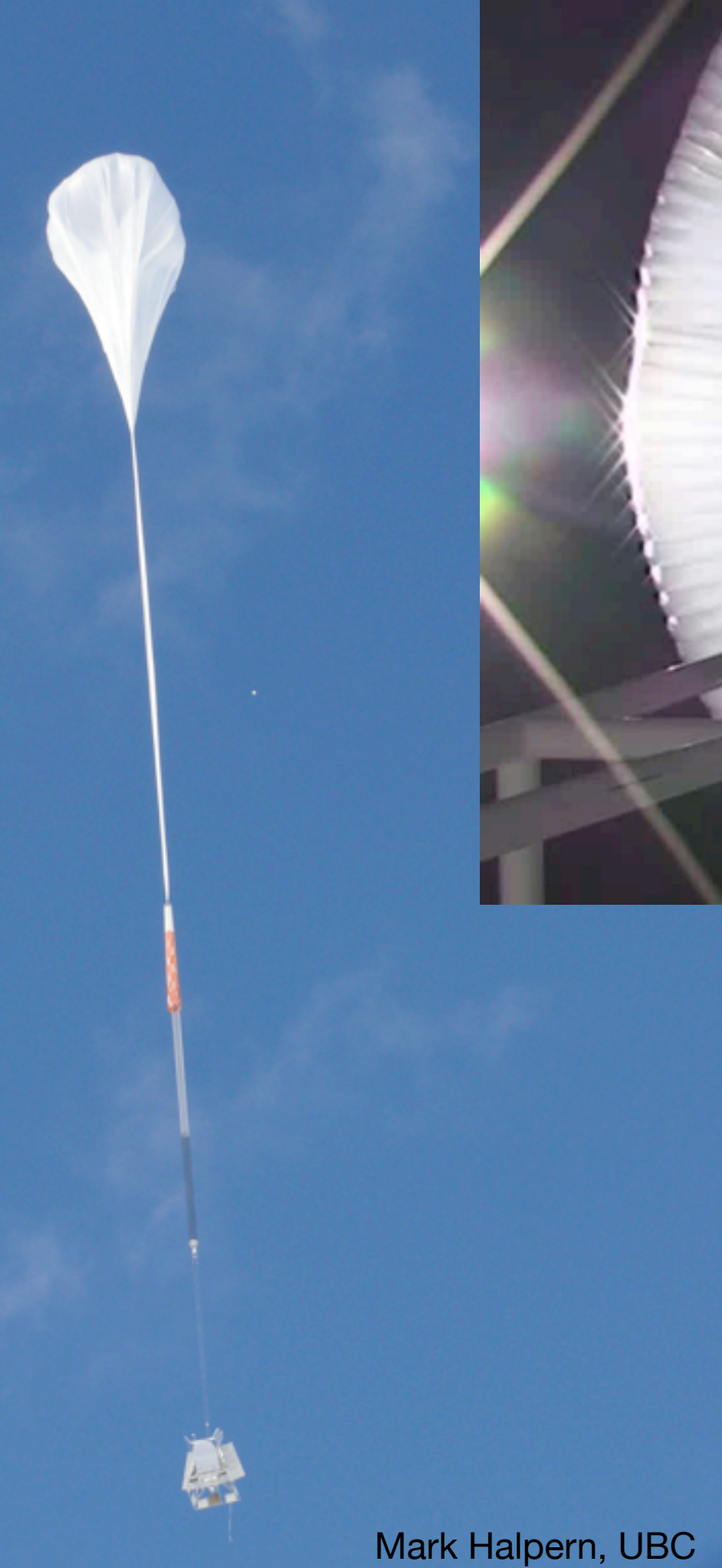


Mark Halpern, UBC

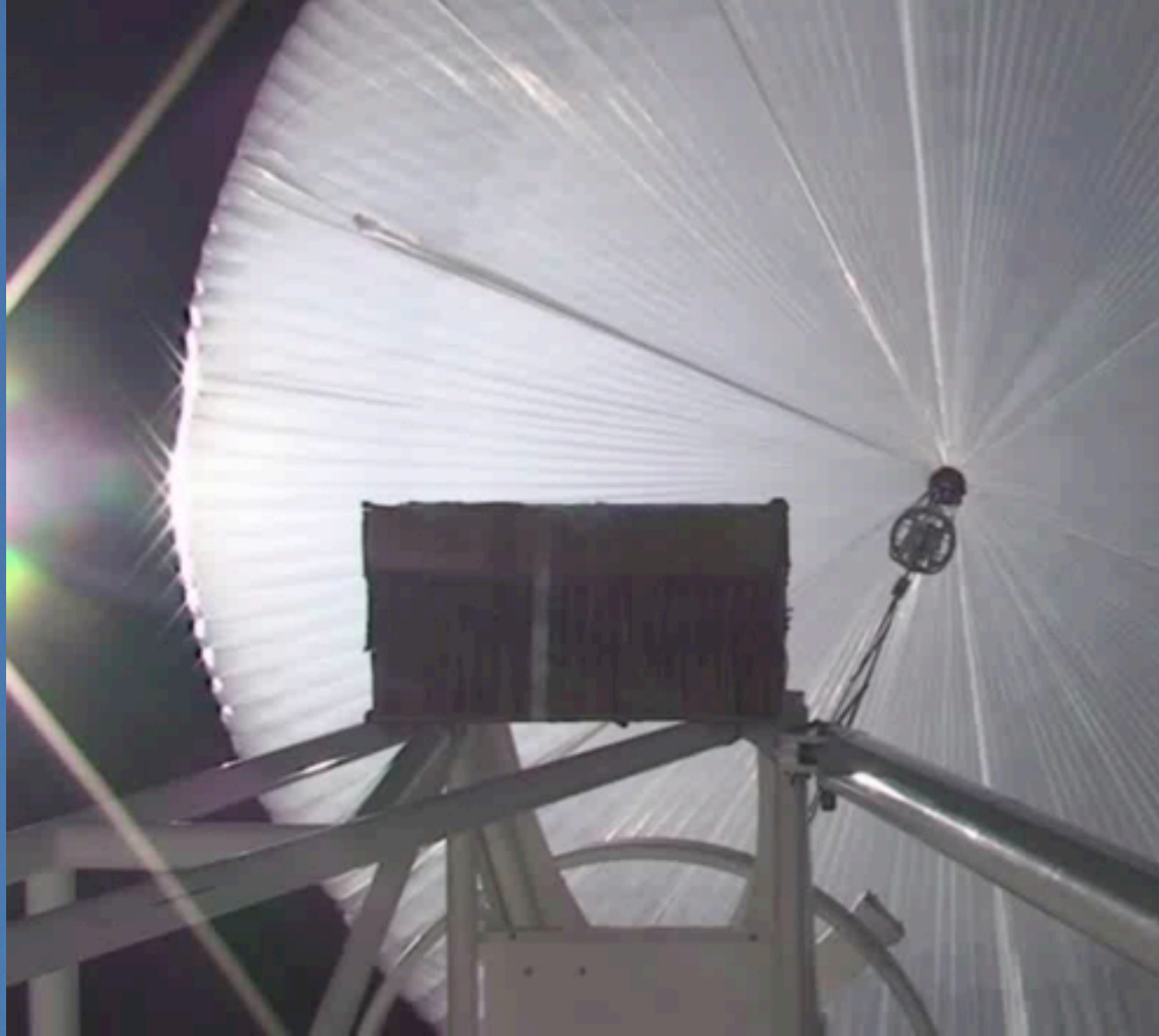


Don Wiebe, UBC

Wednesday, June 8, 2011



Mark Halpern, UBC



Perfect Flight!



Joe Martz
BLAST payload hanging from balloon
float altitude of 120,000 ft.

Perfect Landing!



BLAST

Perfect Landing?



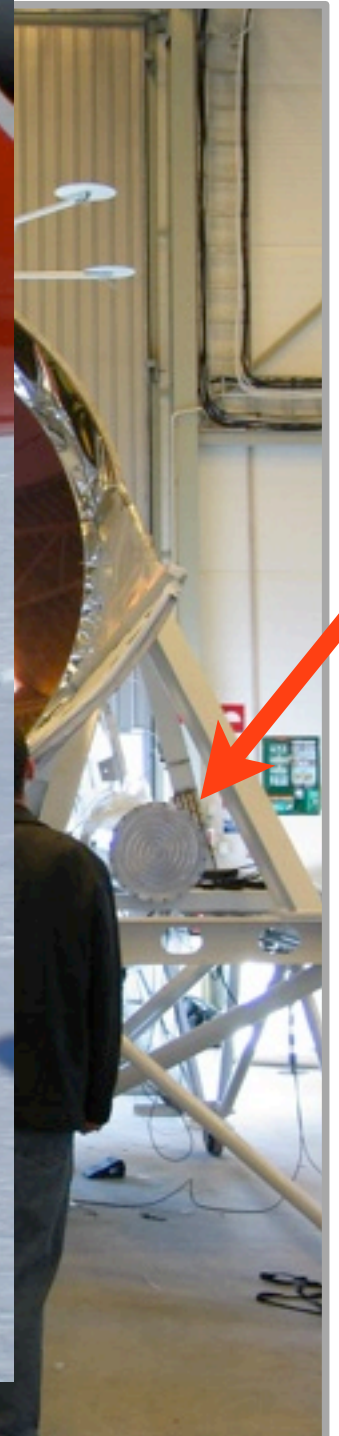
BLAST

looking for
this...



BLAST

in this



BLAST



BLAST

Wednesday, June 8, 2011

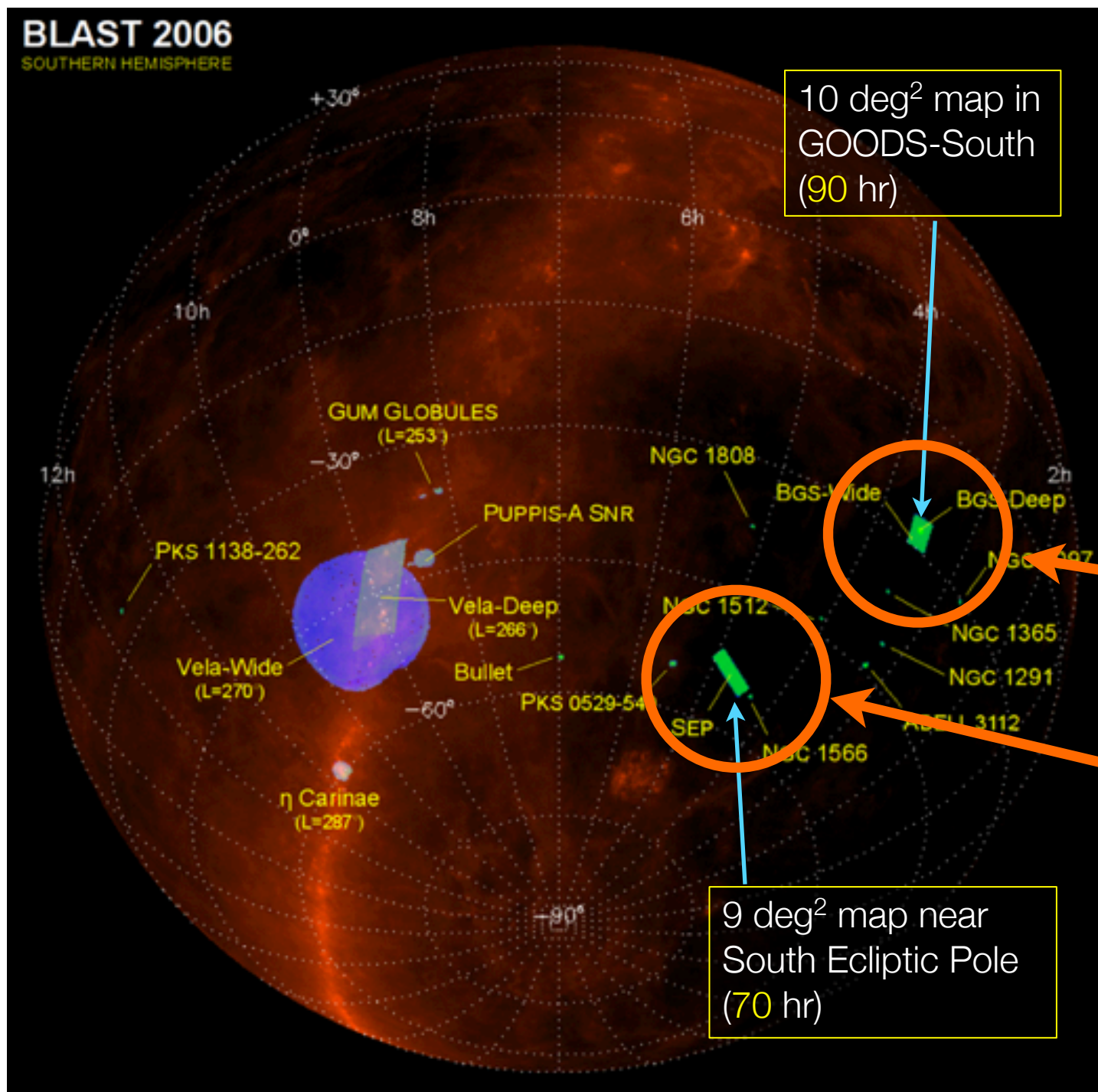


BLAST

see it all in
"BLAST!"
the movie



BLAST



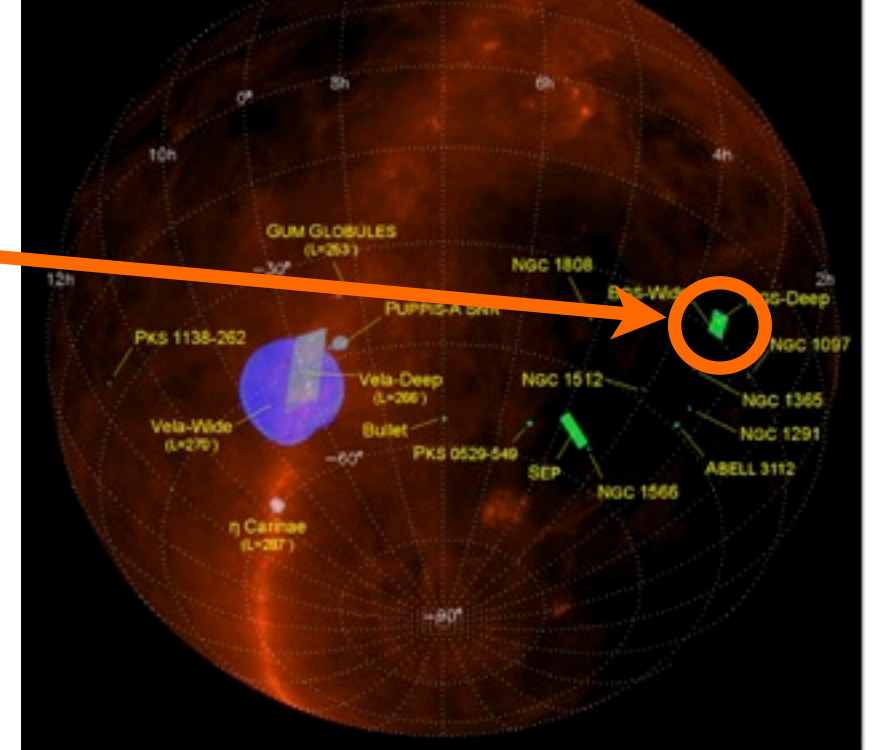
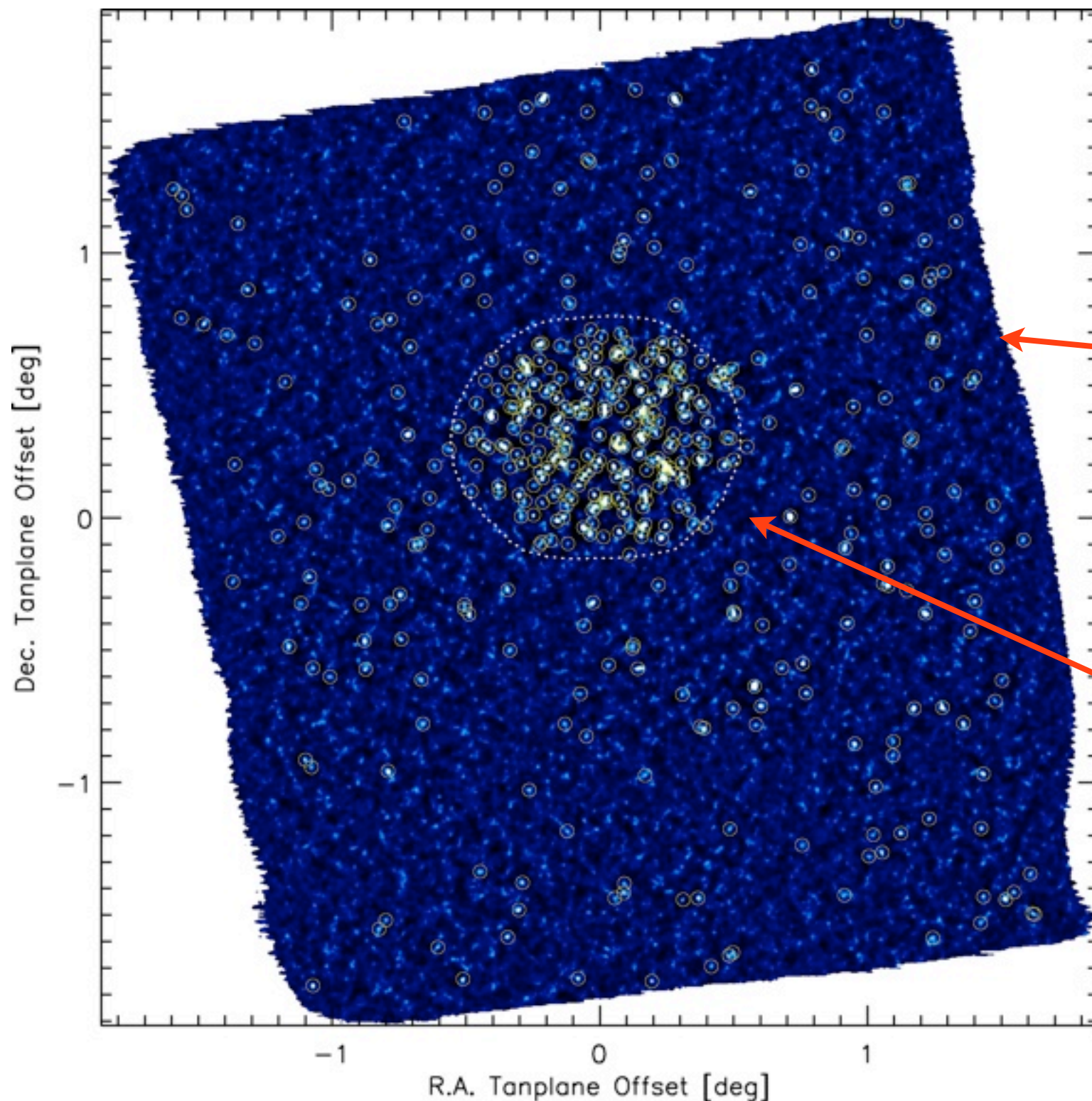
~180/260 hours (70%)
spent observing
extragalactic fields

GOODS-south

SEP

Fields Observed

BLAST GOODS-south

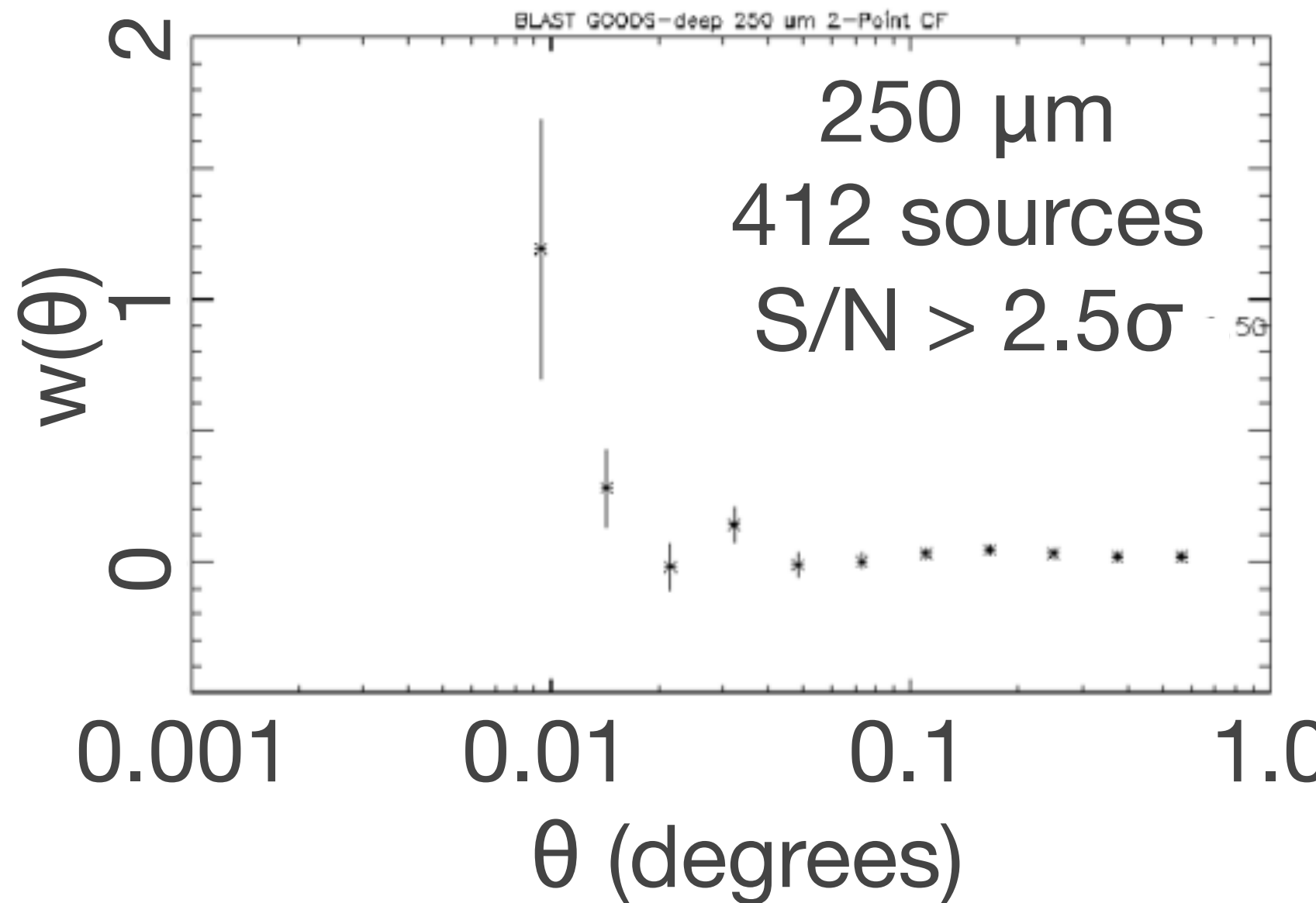


Noise BGS-wide:
36 mJy beam⁻¹
21 mJy beam⁻¹
20 mJy beam⁻¹

Noise BGS-deep:
11 mJy beam⁻¹
9 mJy beam⁻¹
6 mJy beam⁻¹

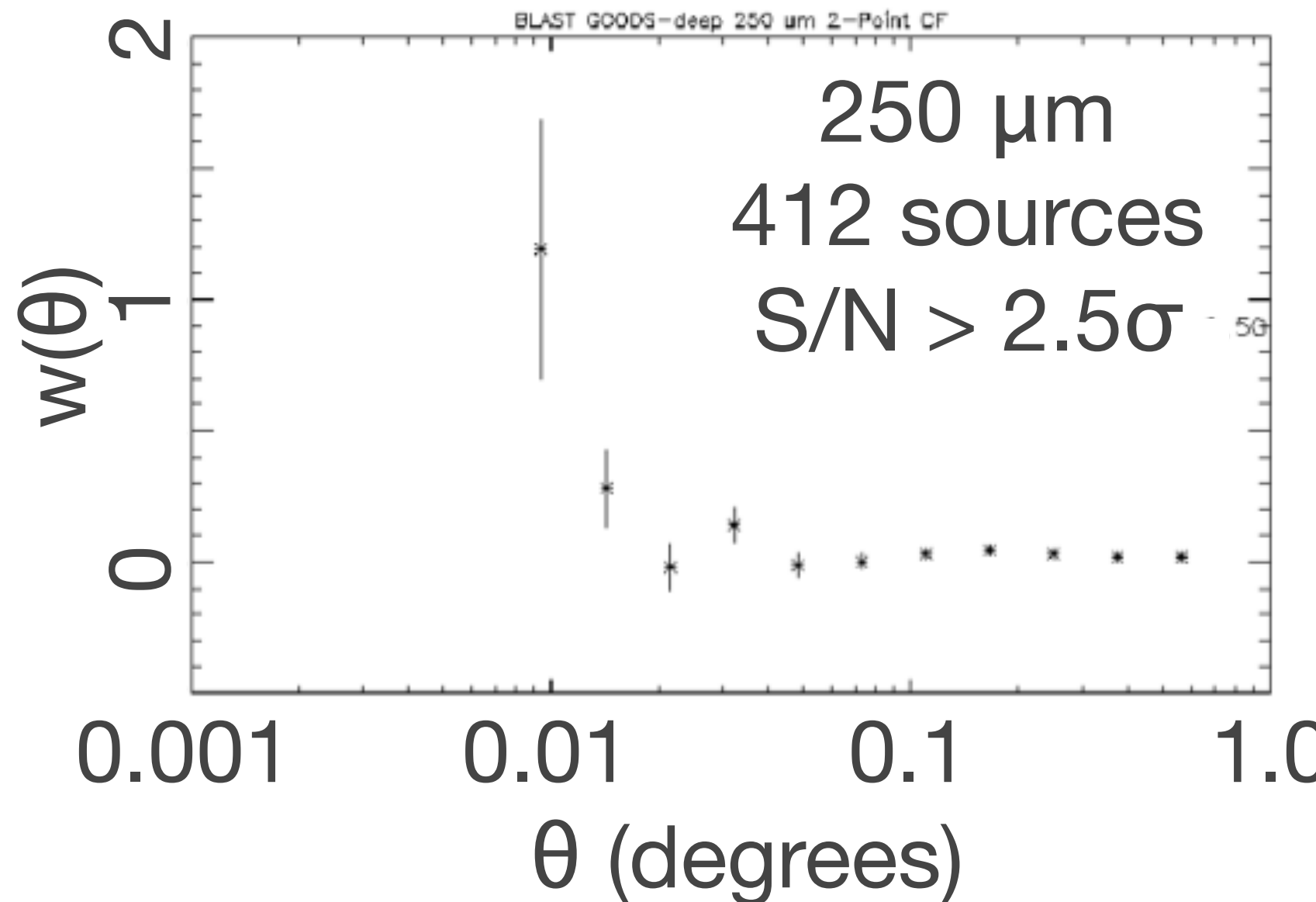
BGS

2-point correlation function of BLAST sources



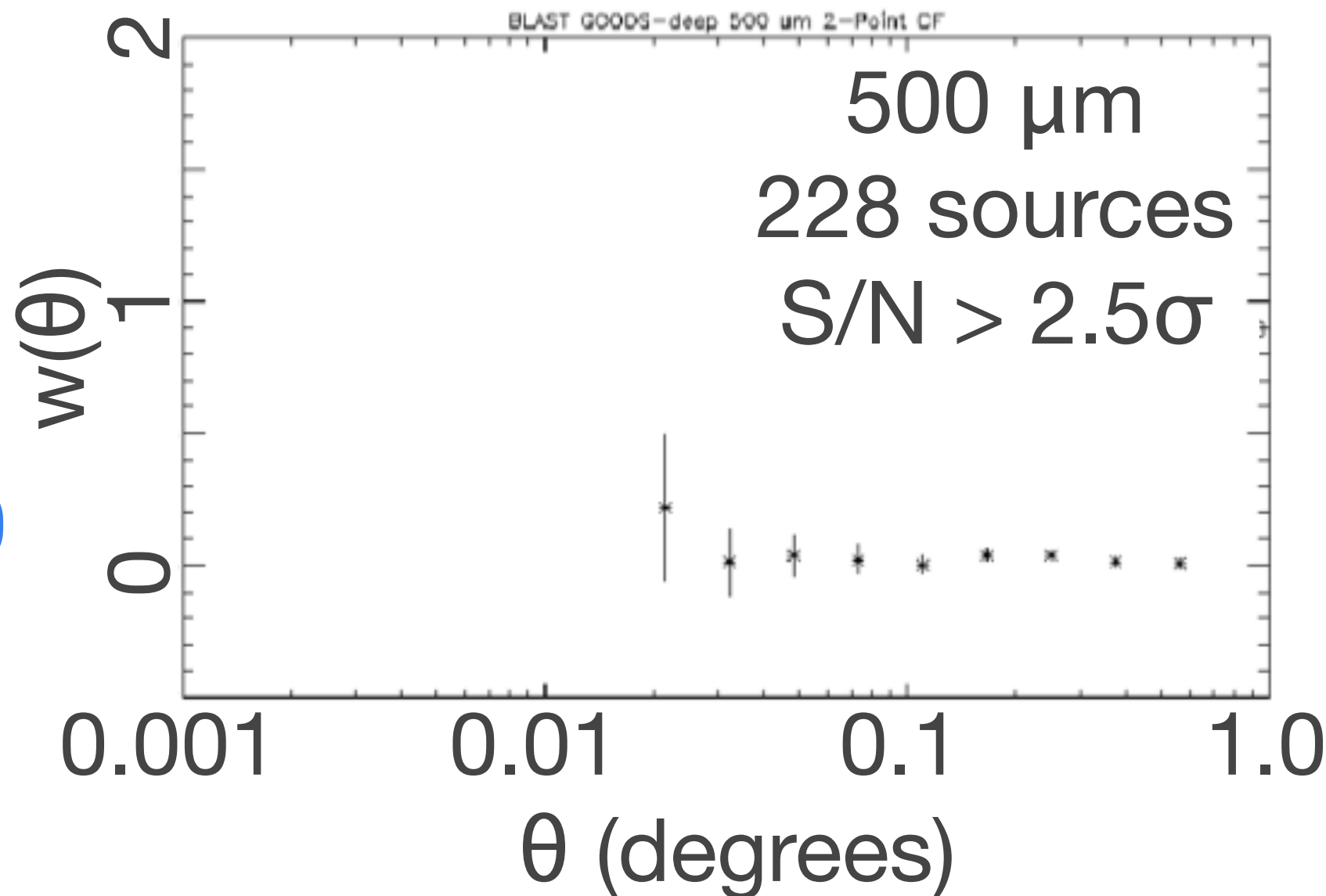
2-point correlation function of BLAST sources

- 250 μm :
marginal signal



2-point correlation function of BLAST sources

- 250 μm :
marginal signal
- 500 μm
consistent with 0



something confusing!

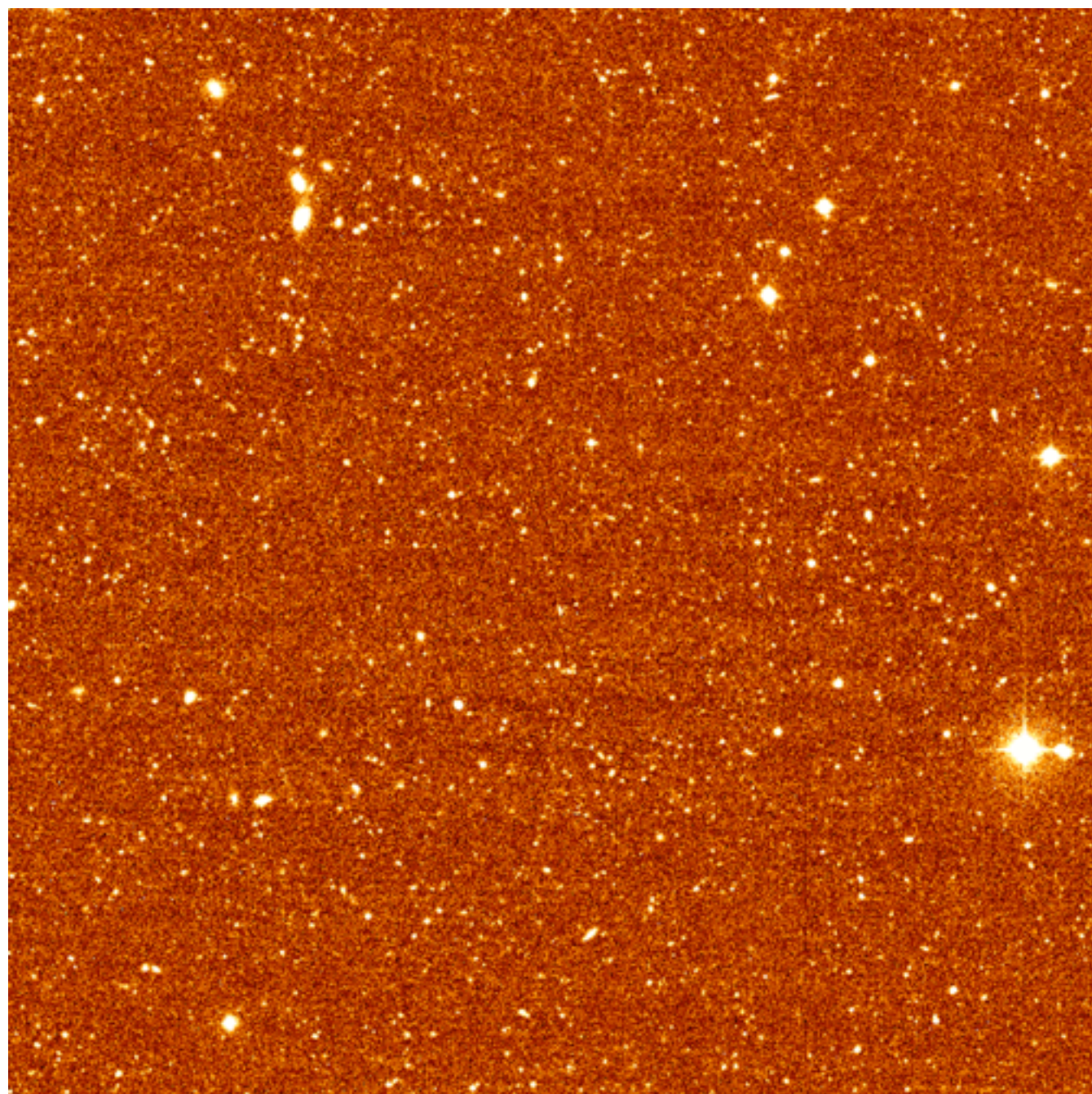
- true the angular correlation function is a projection of sources at all redshifts, diluting the signal, but still...
- why the confusion?

250 μm

$S > 20 \text{ mJy} : 1,200/\text{deg}^2$

$S < 20 \text{ mJy} : 480,000/\text{deg}^2$

Confusion



U-band
~ 60 sources/
arcmin²

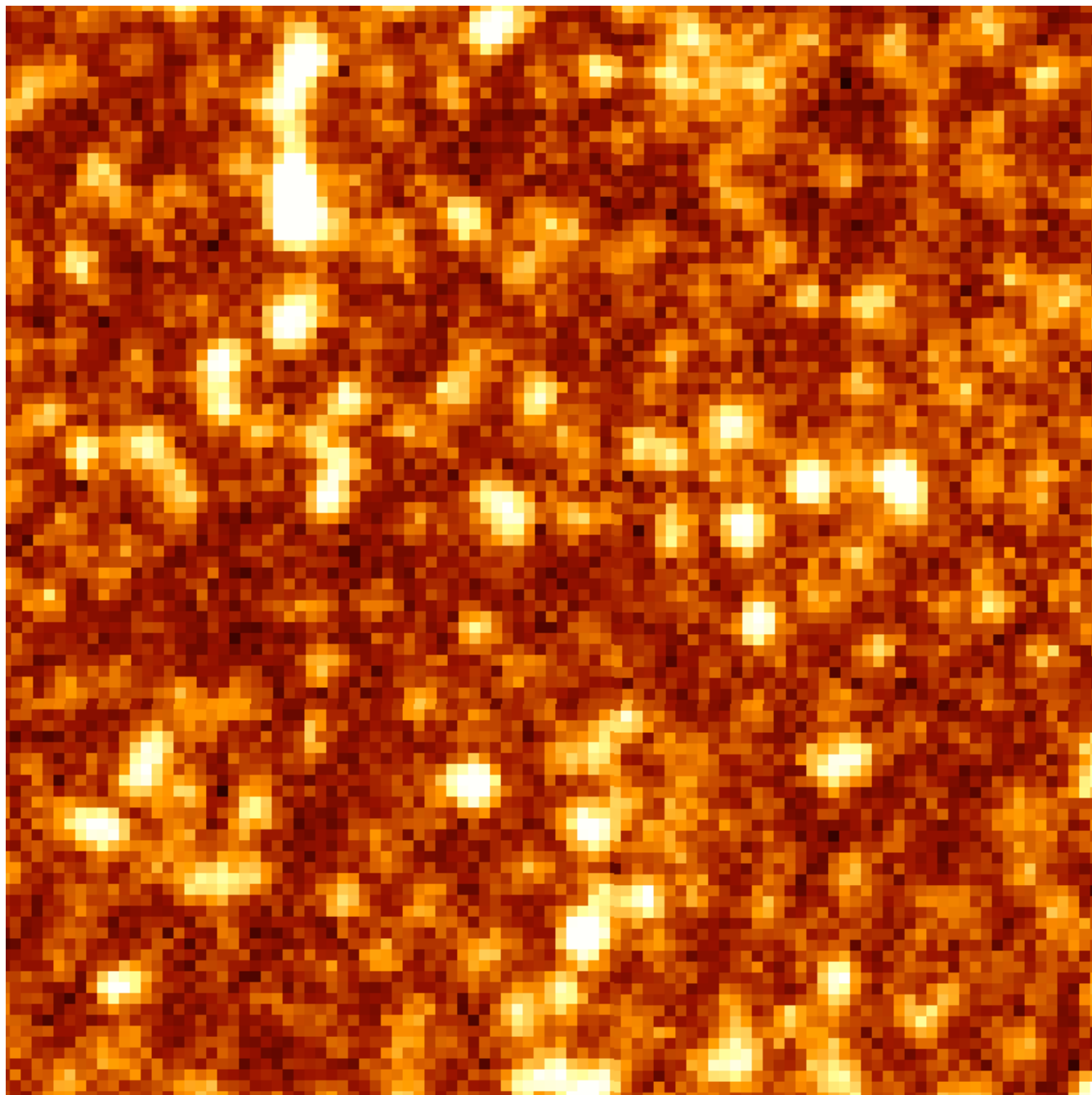
← 10' → U-band : MUSYC

Confusion

Gaelen Marsden, UBC

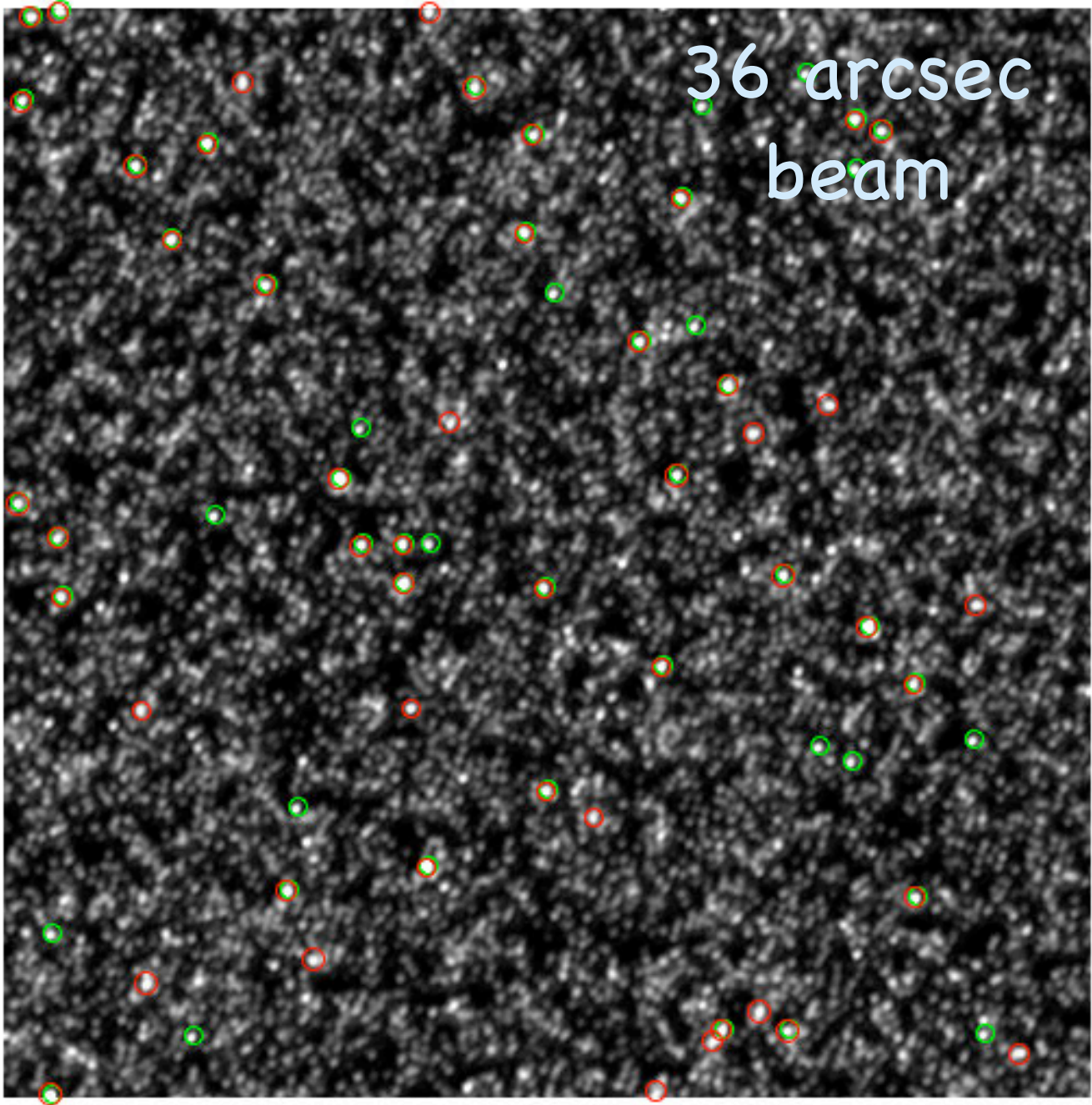
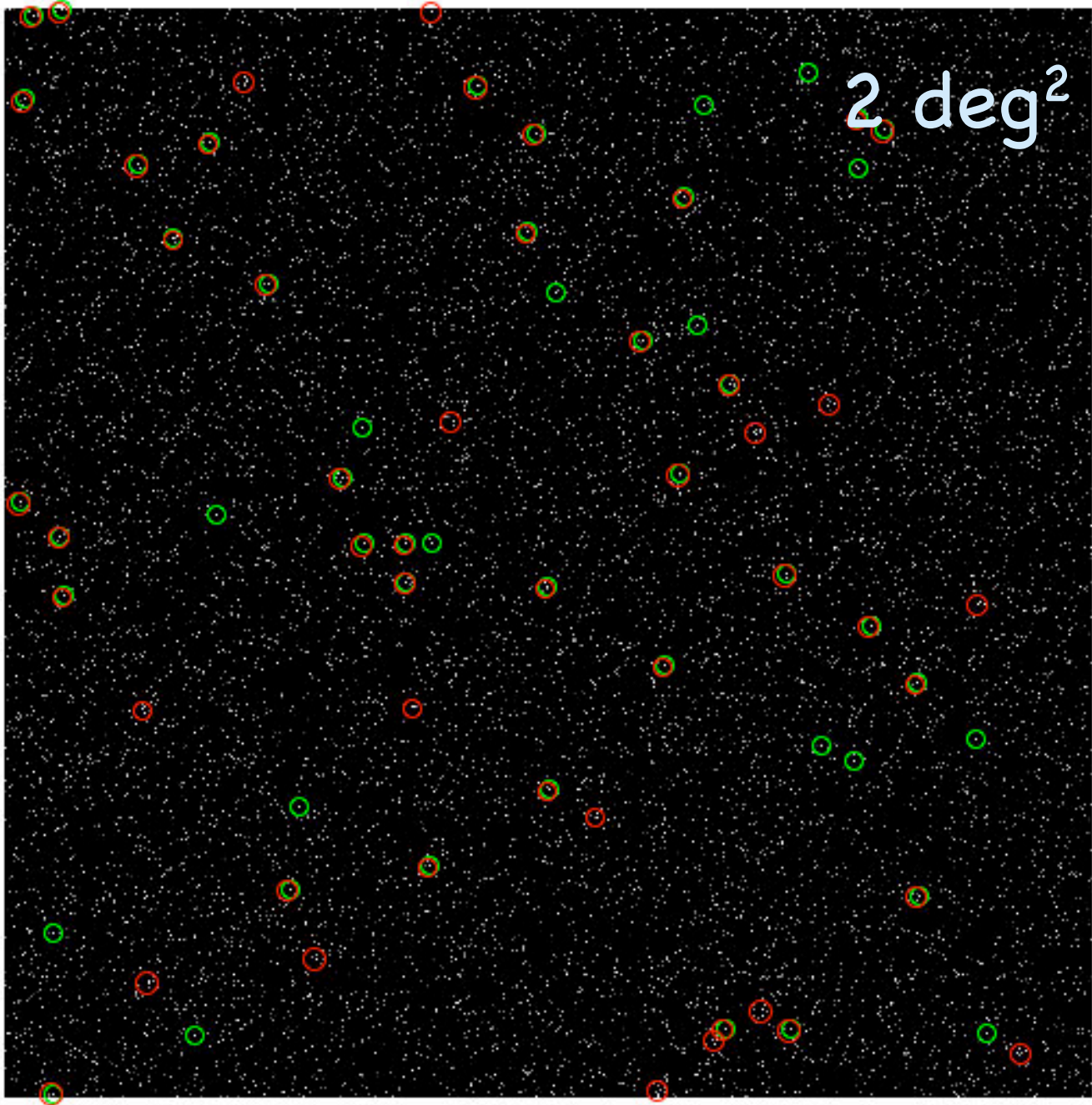
U-band
 ~ 60 sources/
 arcmin^2

SPIRE
 ~ 0.5 sources/
 arcmin^2

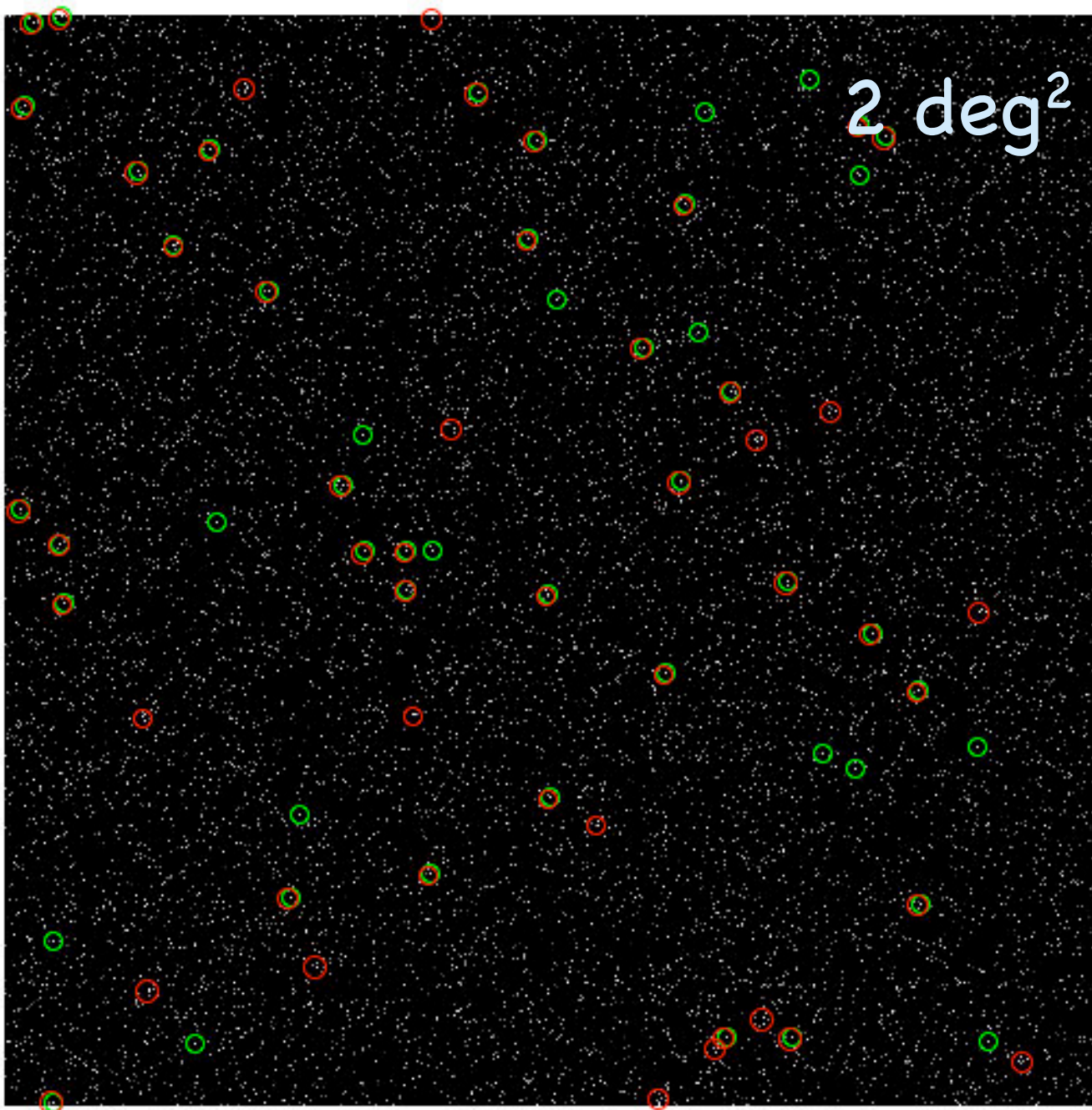


$\longleftrightarrow 10'$ SPIRE $250\ \mu\text{m}$

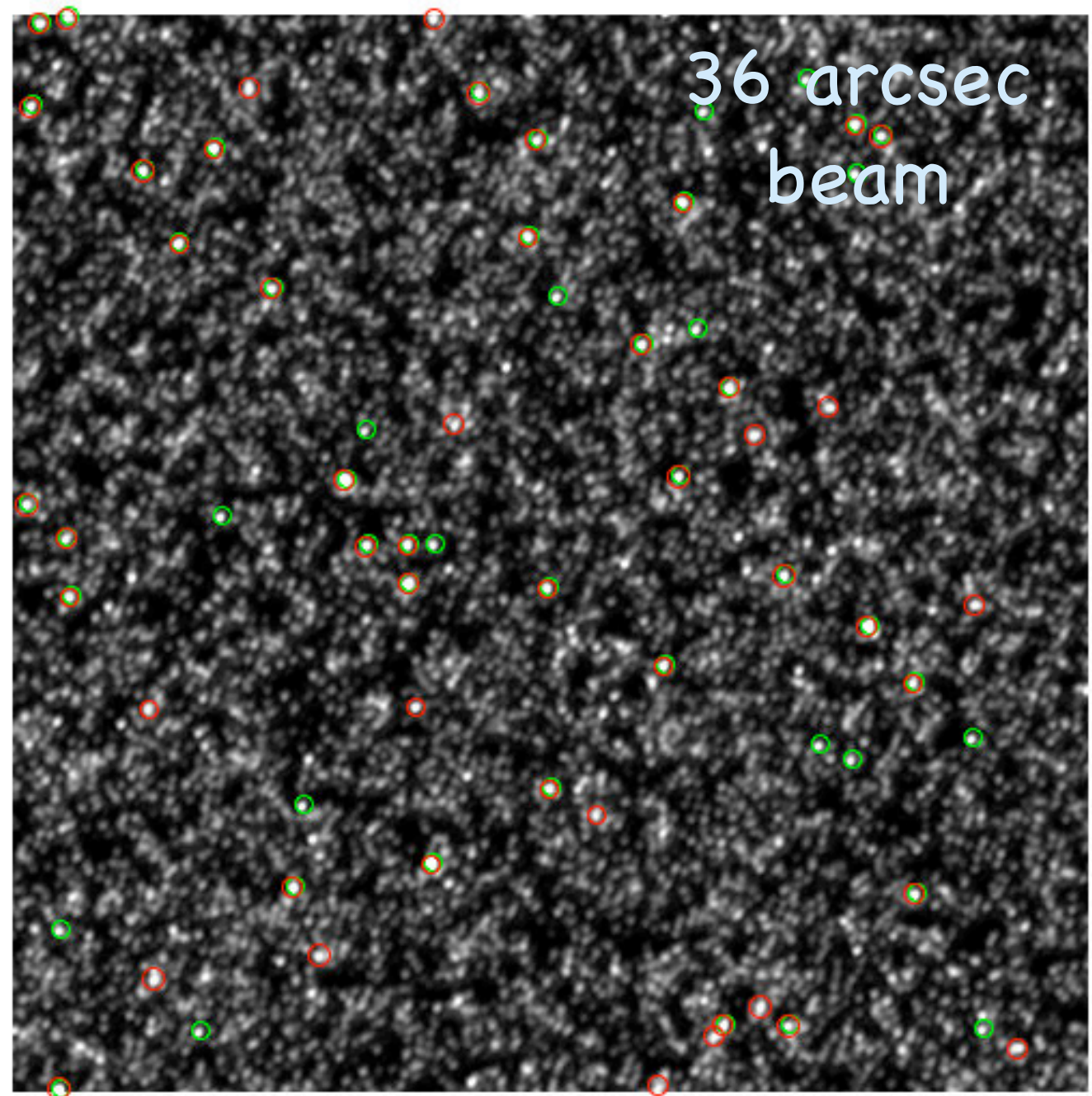
Confusion



Confusion

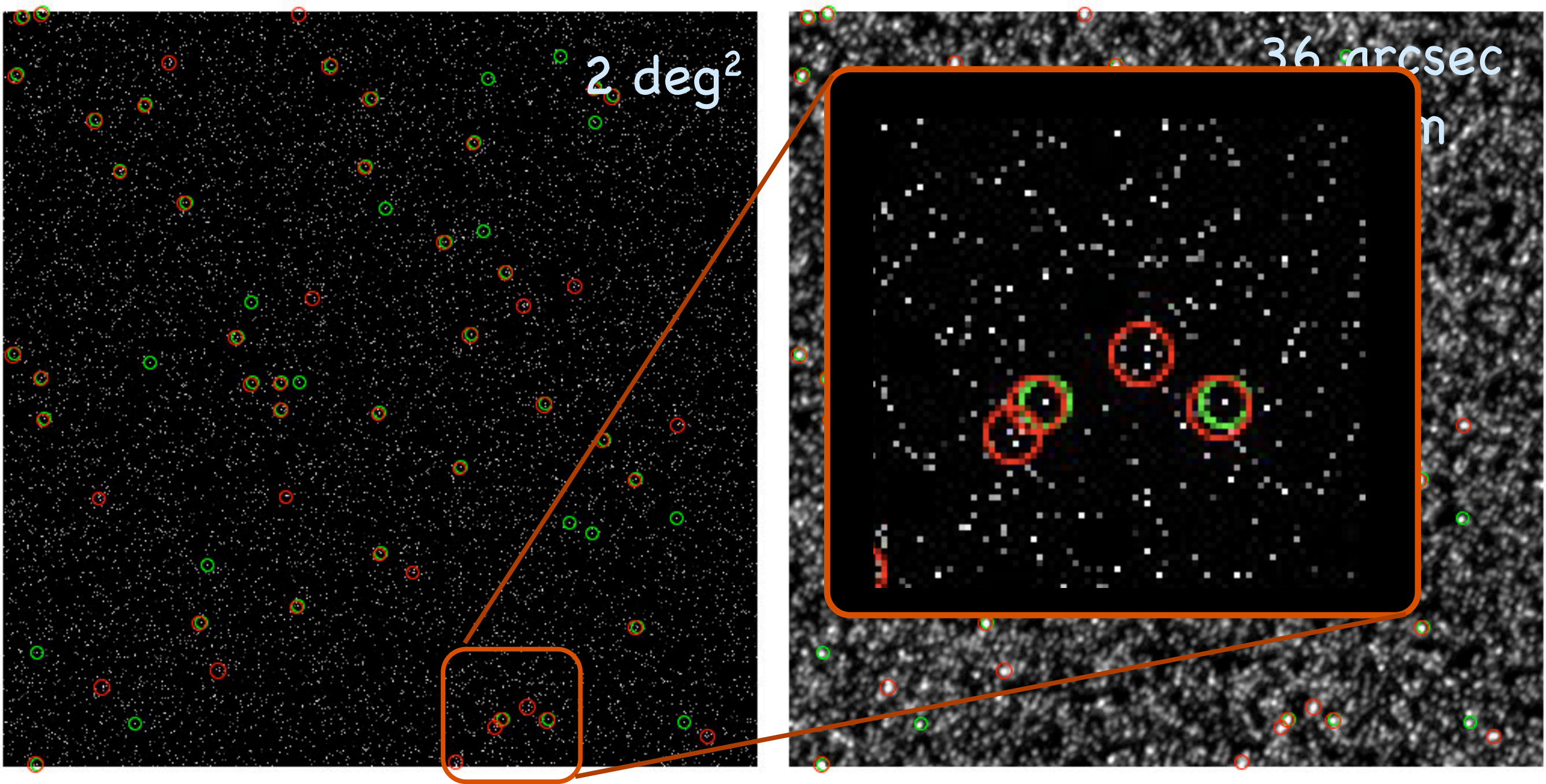


50 brightest
(top 0.5%)



50 brightest
recovered

Confusion



70% of top
0.5%
recovered

Confusion



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
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Carole Tucker
Enzo Pascale
Lorenzo Moncelsi

Open
University
Mattia Negrello

U. Arizona
Marie Rex

JPL
Jamie Bock

CDF (France)
Guillaume Patanchon

Caltech
Marco Viero

MIT balloon
Toco
Cobra
QMAP
White Dish
MAX
White Mountain
BOOMERang
QMAT
MINT
Saskatoon
Archeops
BAM
WMAP
ACT



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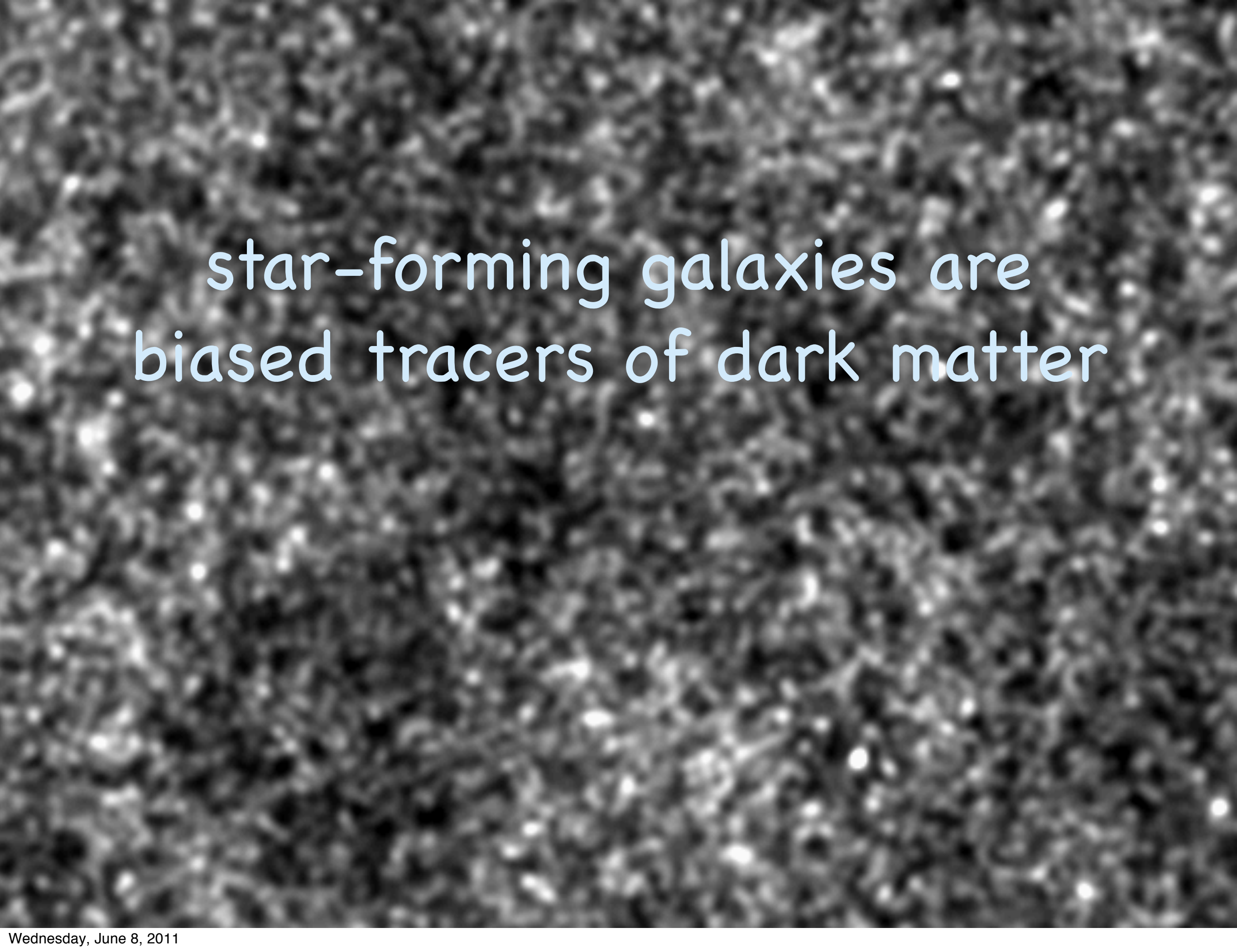
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JPL
Jamie Bock

CDF (France)
Guillaume Patanchon

Caltech
Marco Viero

star-forming galaxies are
biased tracers of dark matter

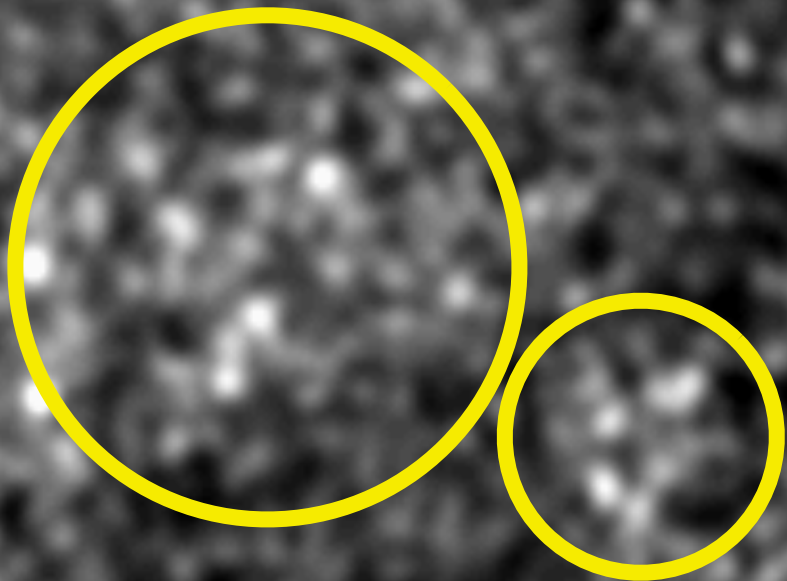


star-forming galaxies are
biased tracers of dark matter

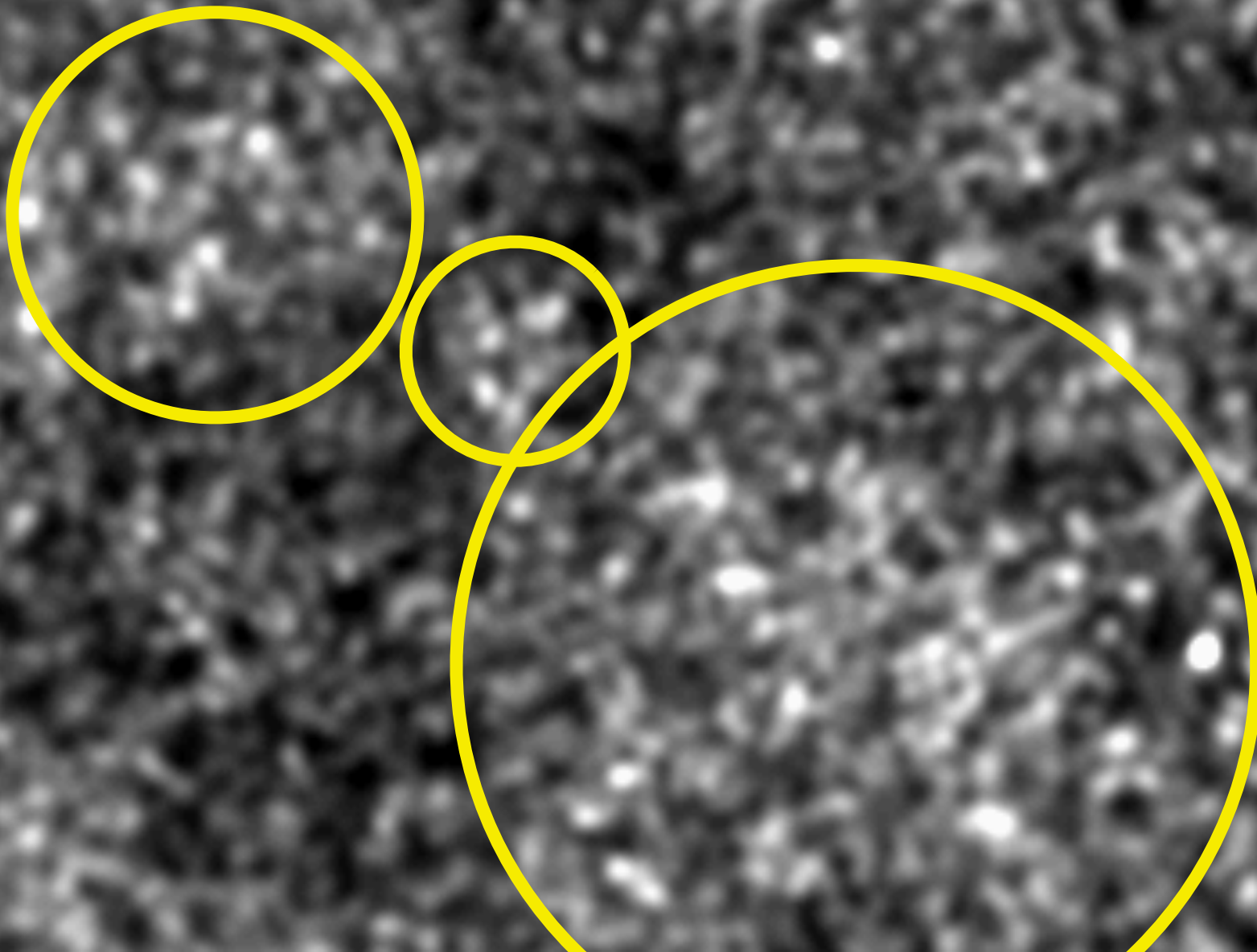
star-forming galaxies are
biased tracers of dark matter



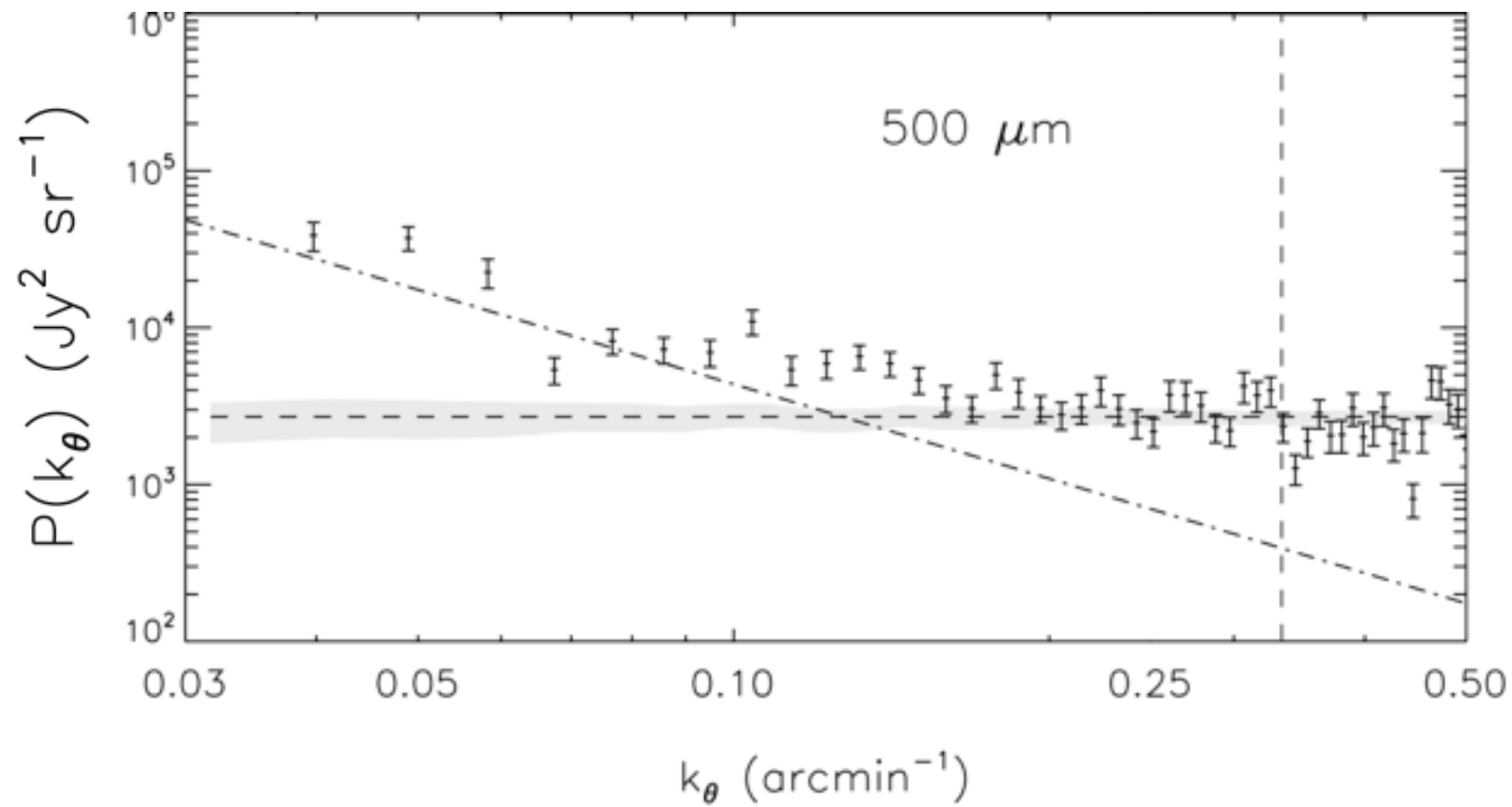
star-forming galaxies are
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star-forming galaxies are
biased tracers of dark matter



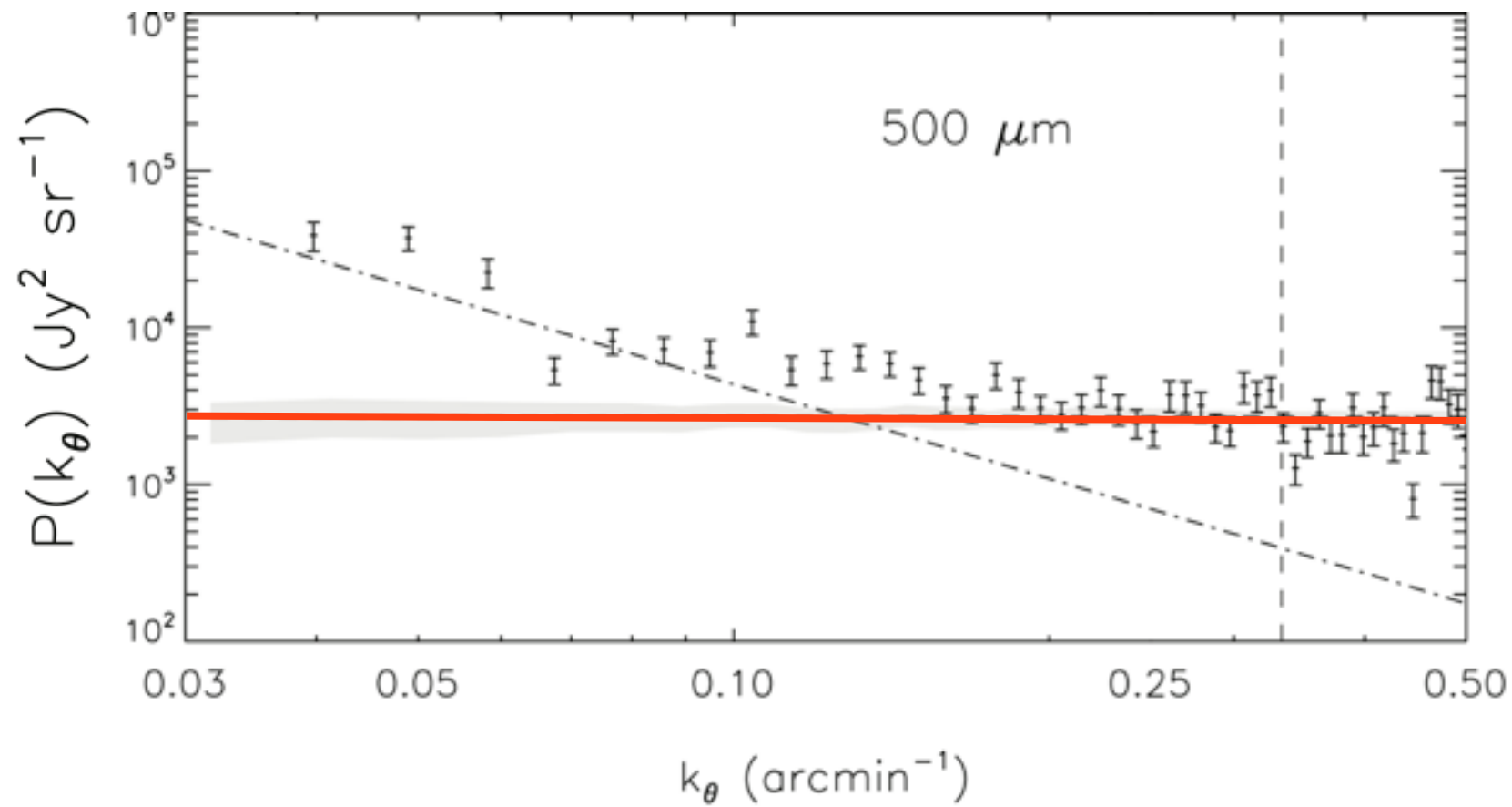
BLAST Power Spectrum



Viero et al. (2009)

arXiv: 0904.1200

BLAST Power Spectrum

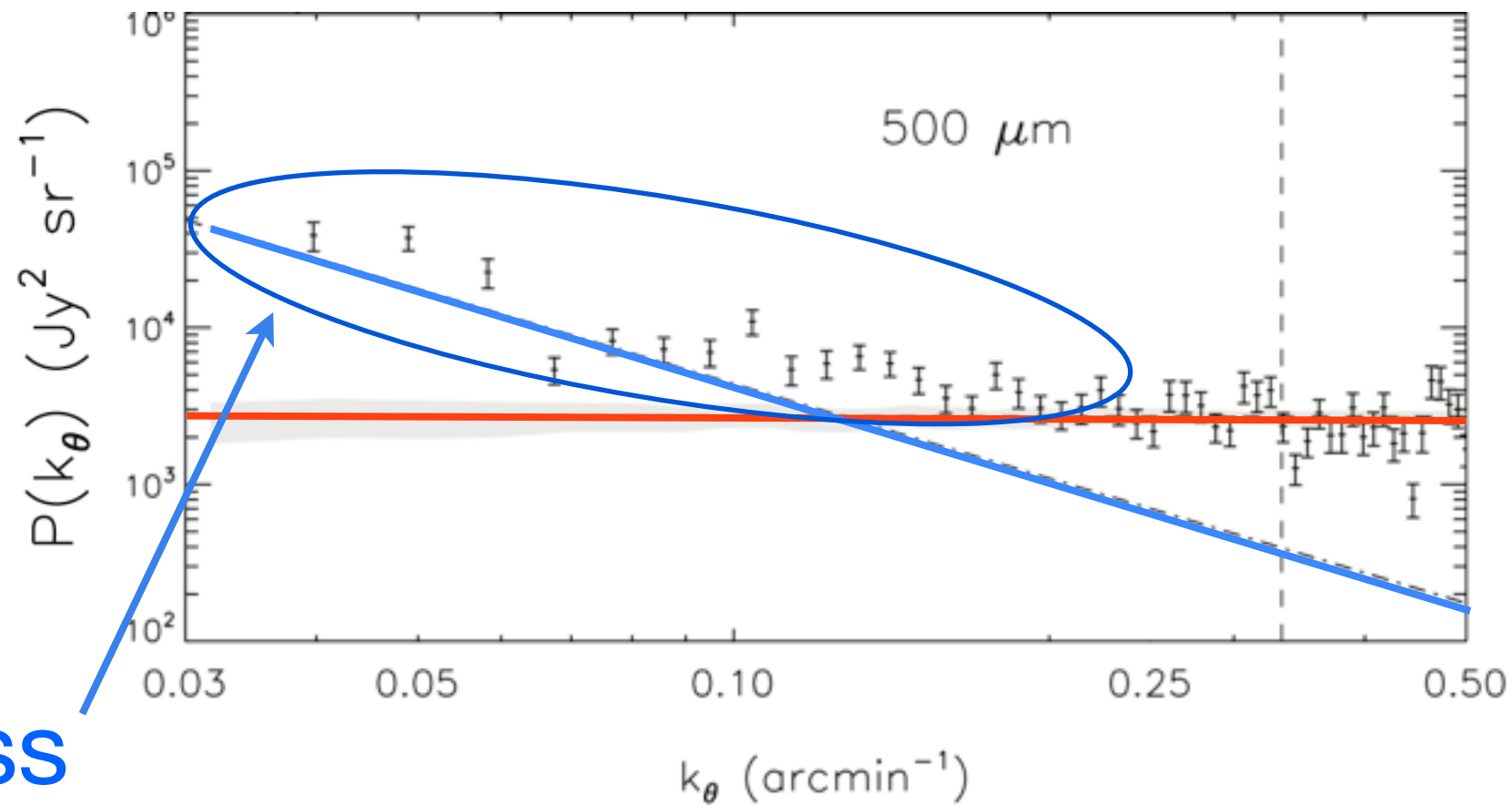


Shot
Noise

Viero et al. (2009)

arXiv: 0904.1200

BLAST Power Spectrum



Shot
Noise

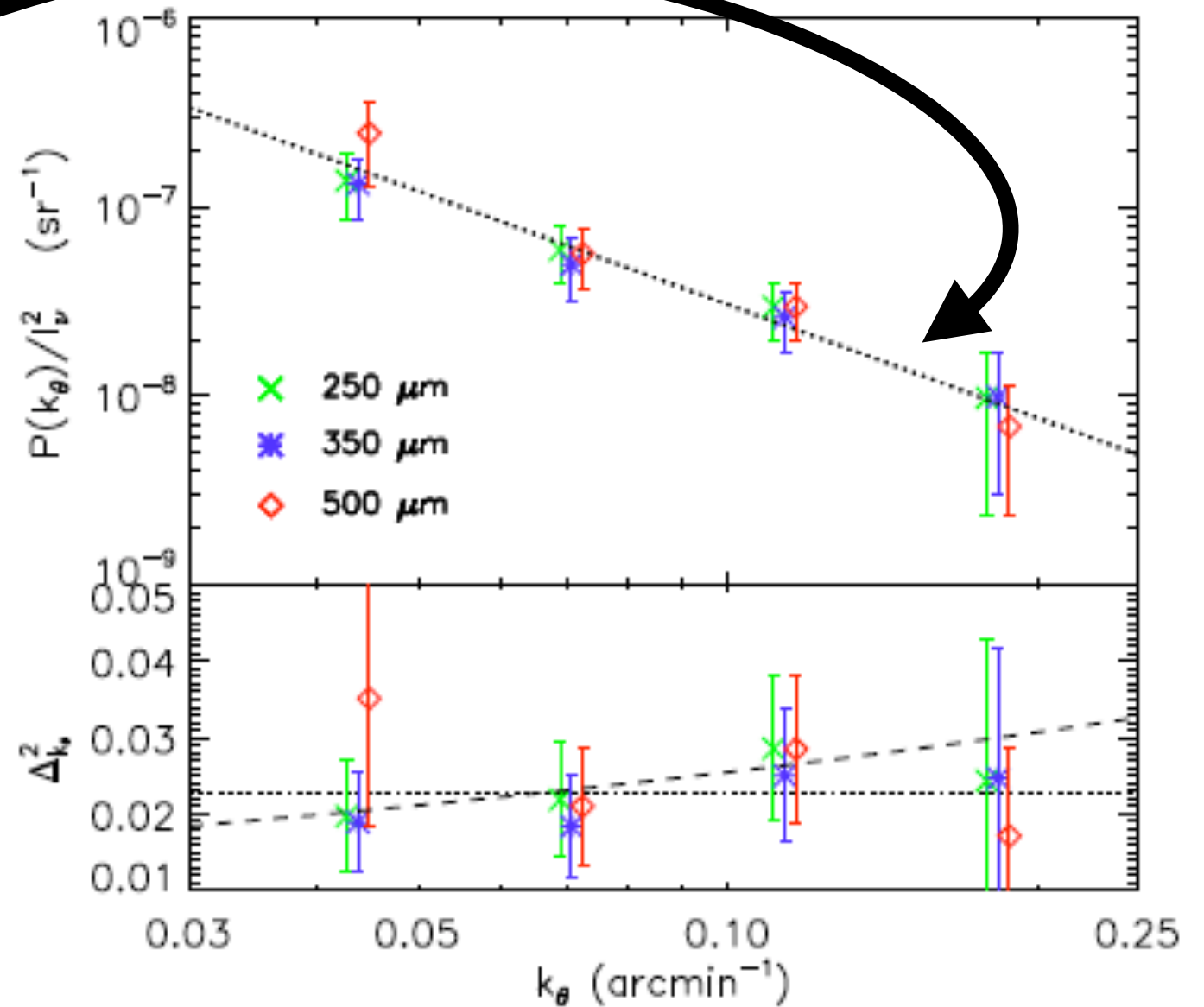
Clustering

Excess
Signal from
Galaxy
Clustering

Viero et al. (2009)
arXiv: 0904.1200

BLAST Power Spectrum

Clustering Signal
After Removal of
Shot Noise

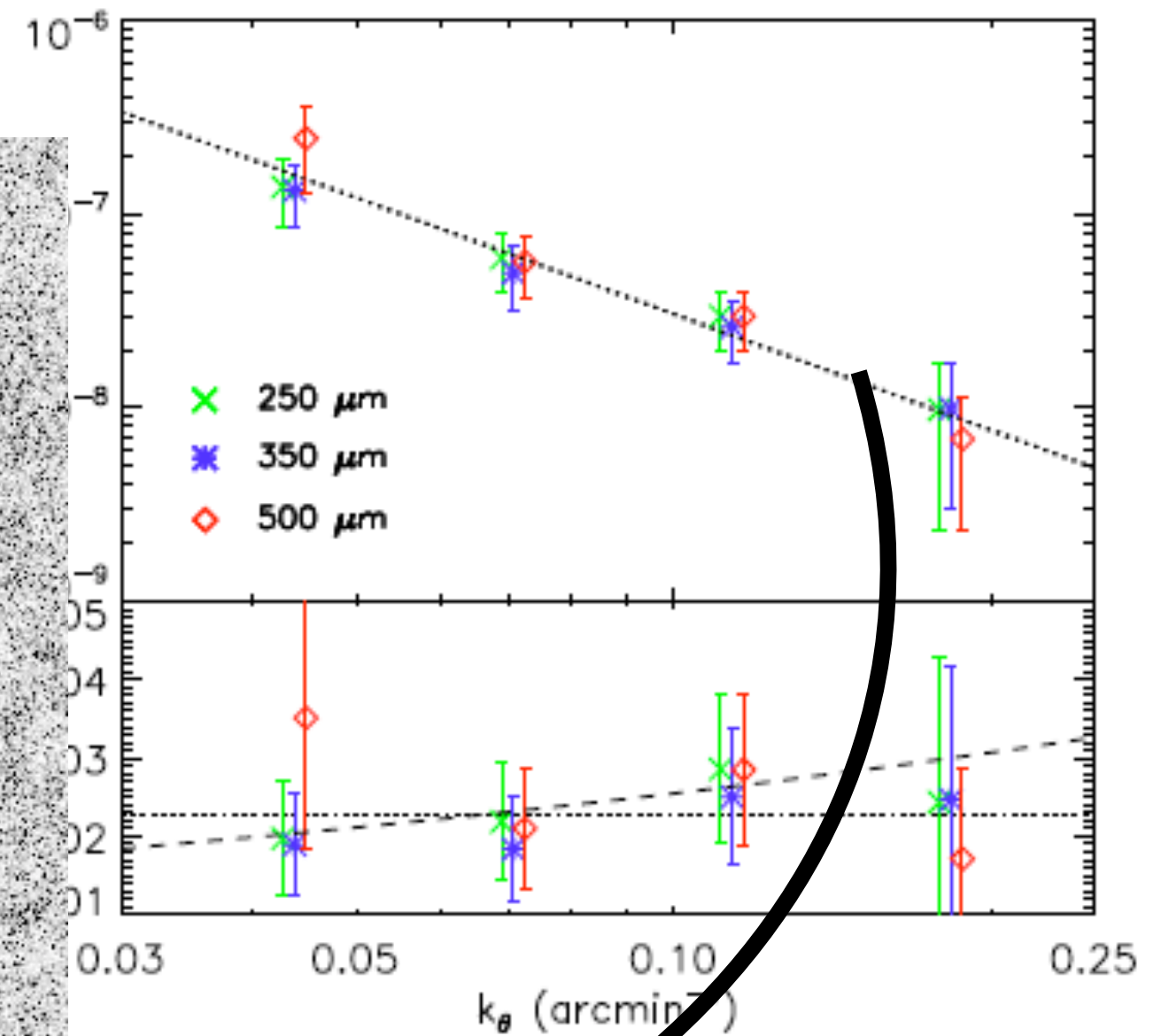
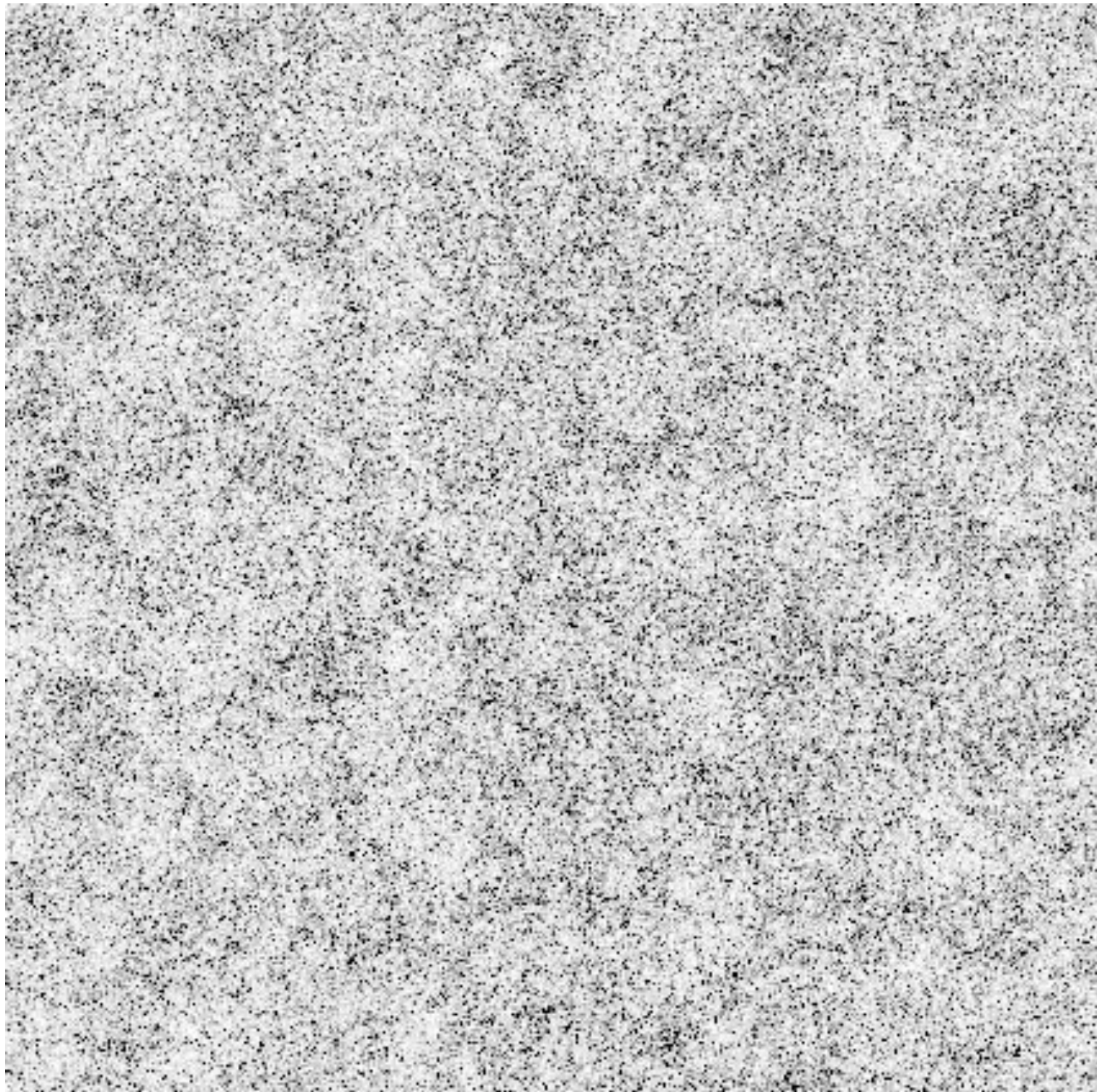


Viero et al. (2009)

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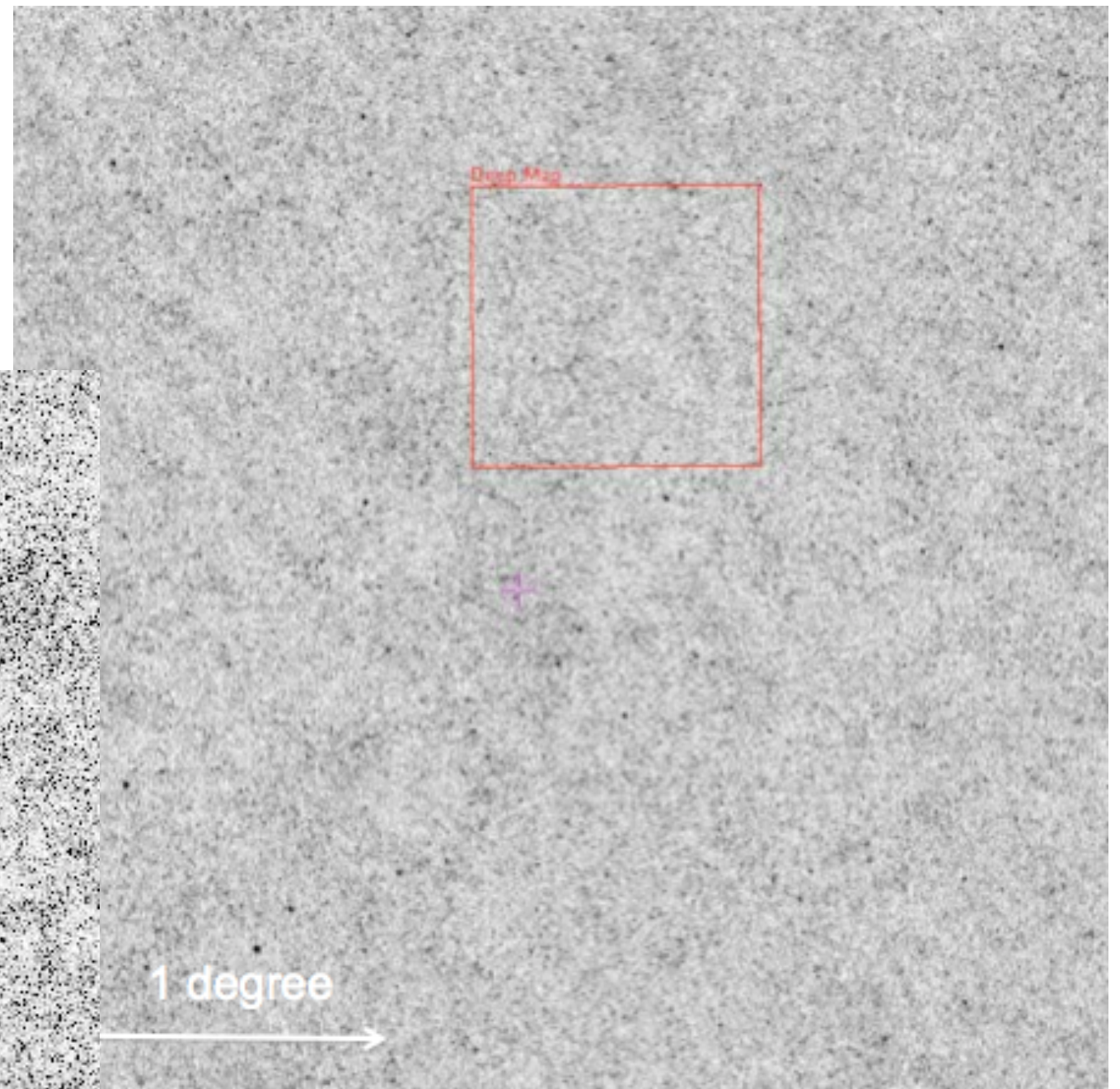
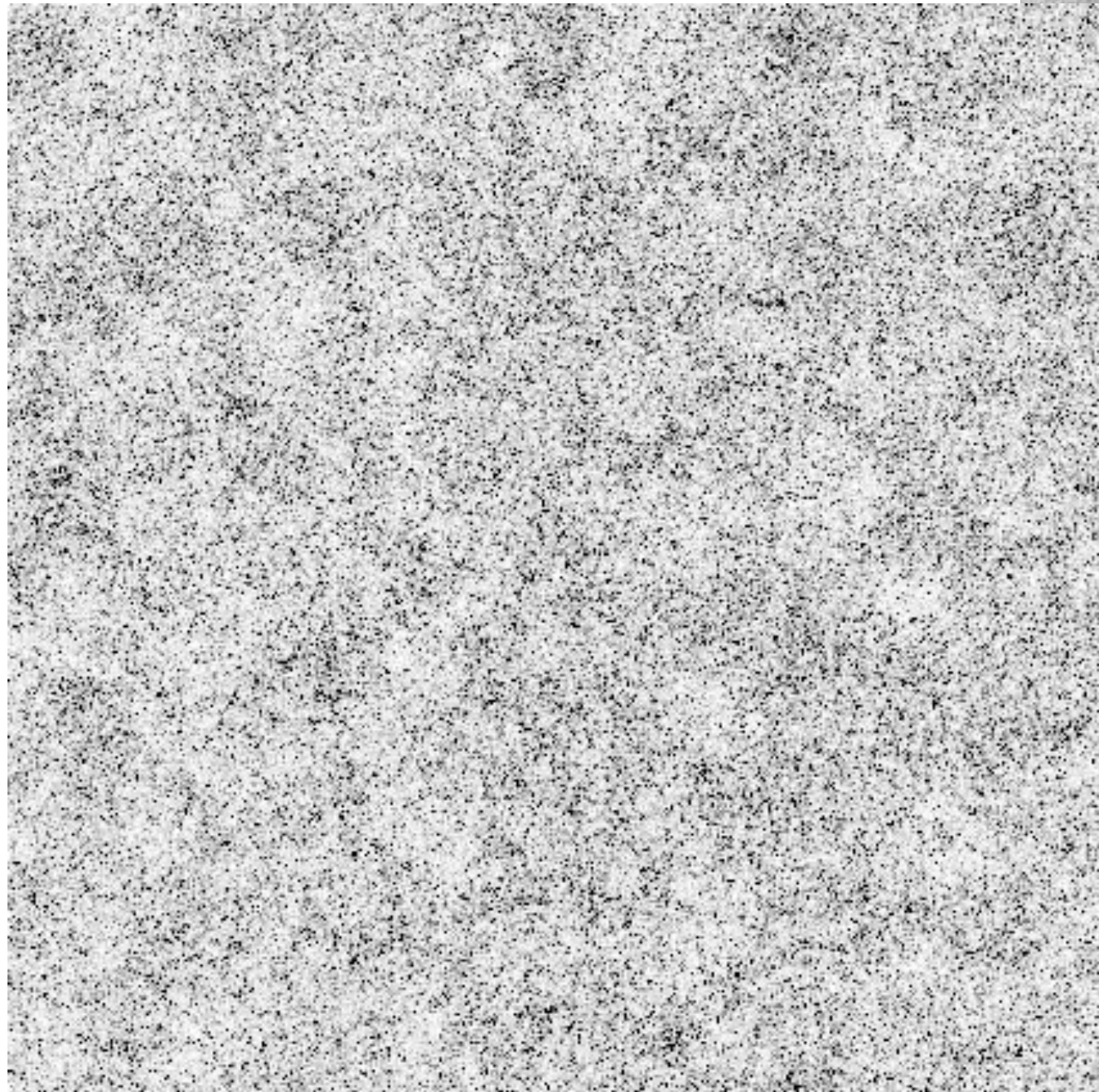
BLAST Power Spectrum

BLAST simulation...



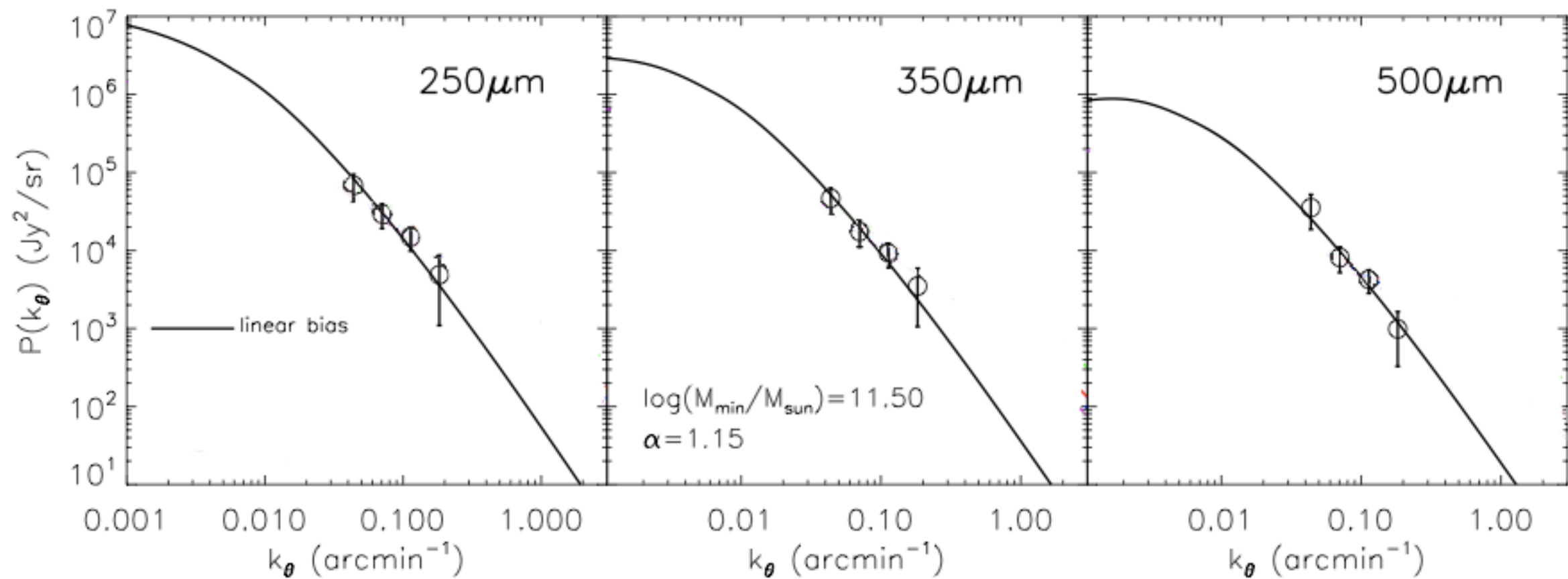
BLAST Power Spectrum

BLAST simulation...



... Herschel observation

BLAST Power Spectrum



Viero et al. (2009)

arXiv: 0904.1200

$$P(k) = b_{\text{lin}}^2 P_{\text{DM}}(k, z)$$

$$b_{\text{lin}} \approx 4$$

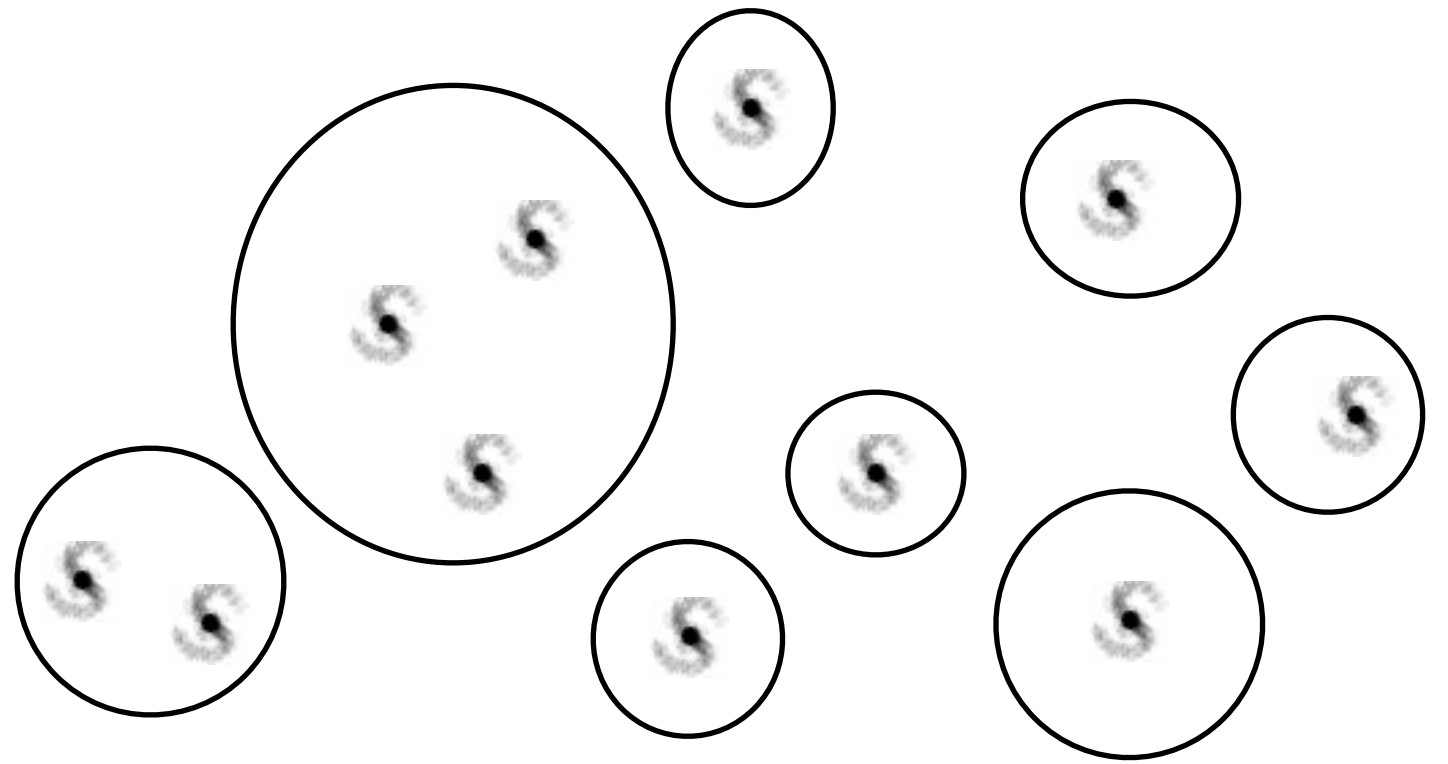
Linear Bias

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

BLAST Halo Model

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

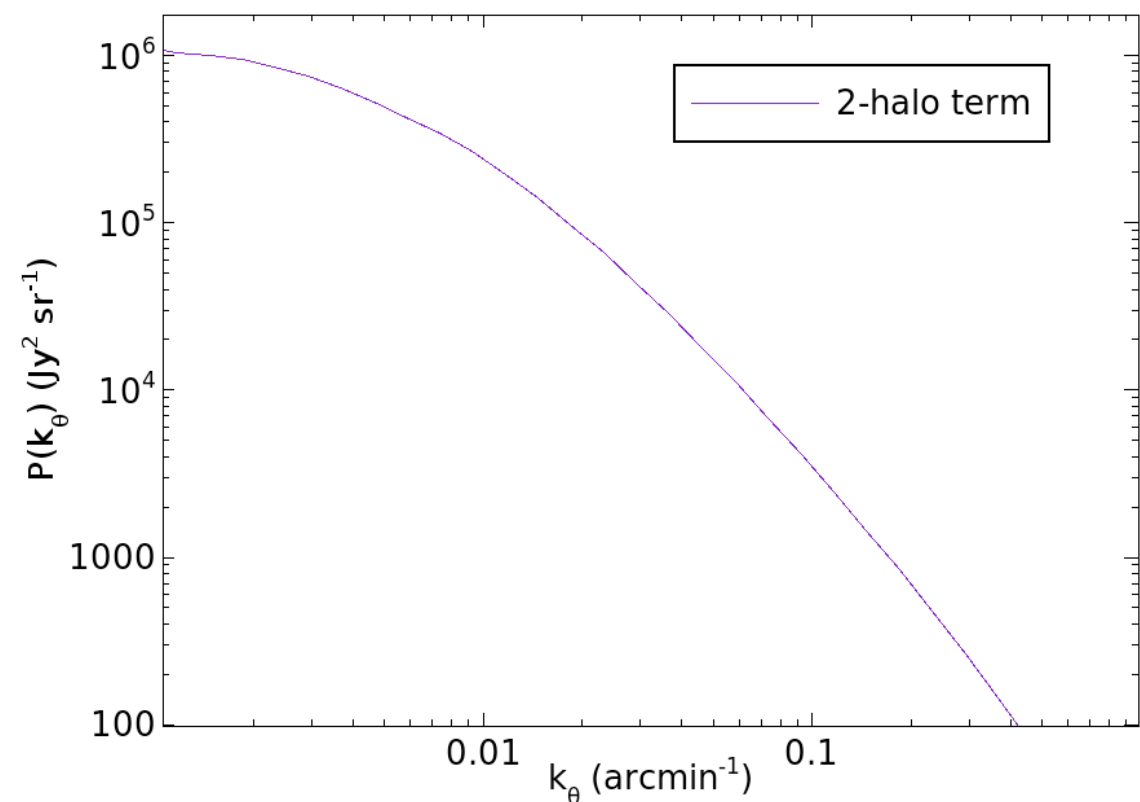
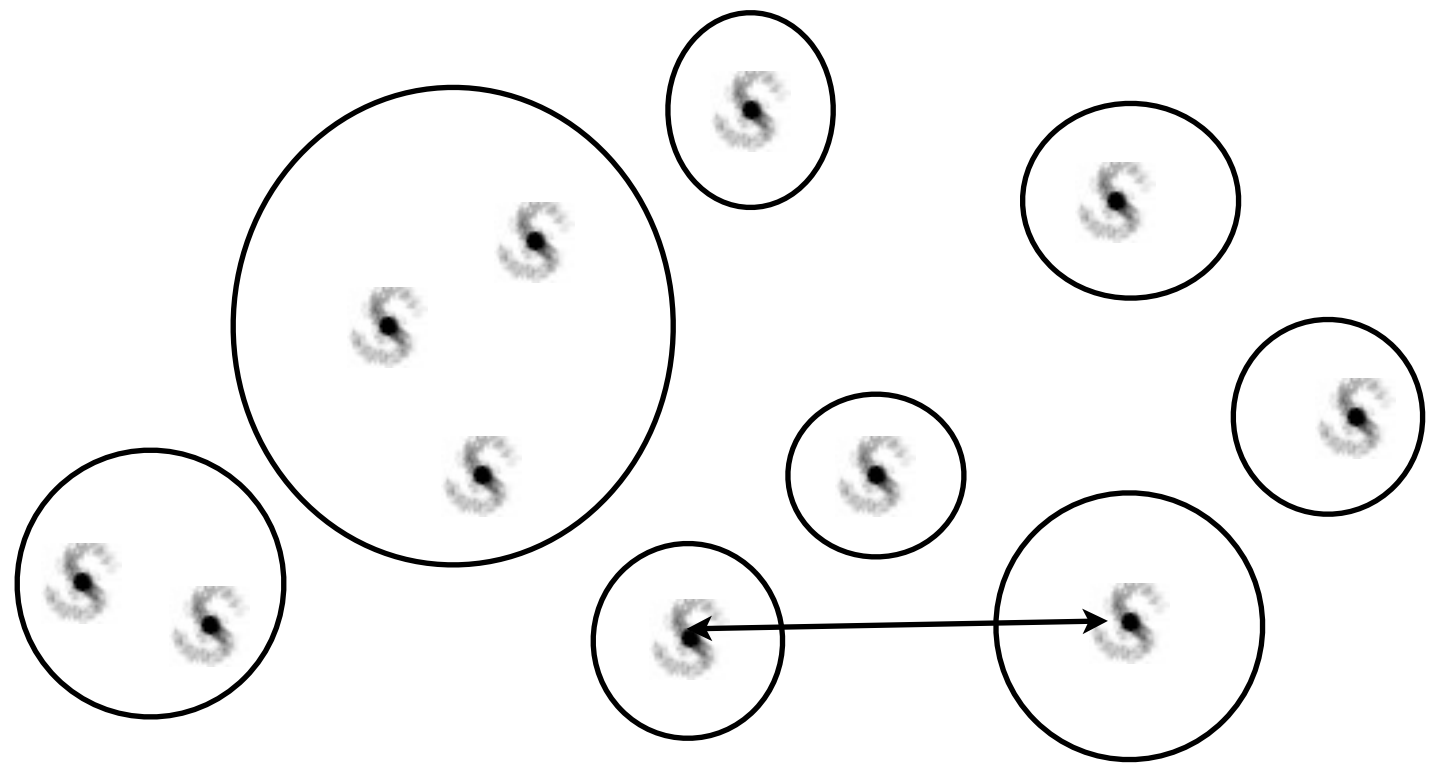
- clustering signal made up of two regimes



BLAST Halo Model

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

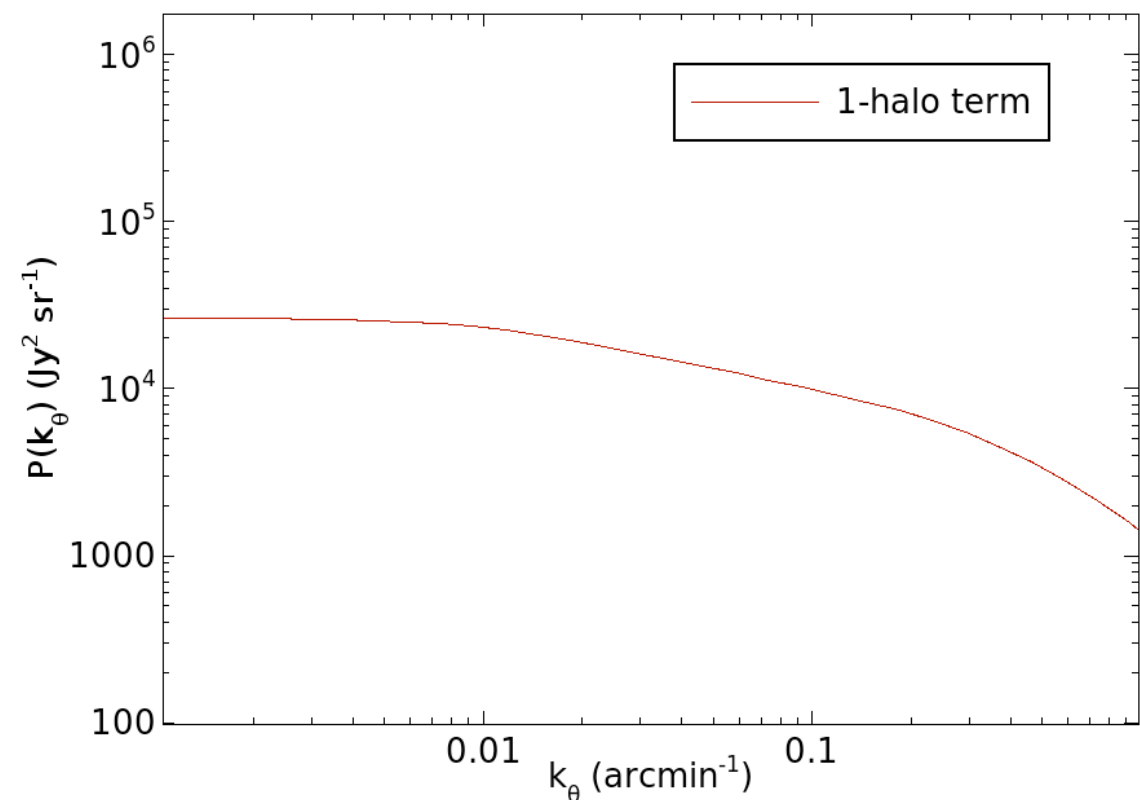
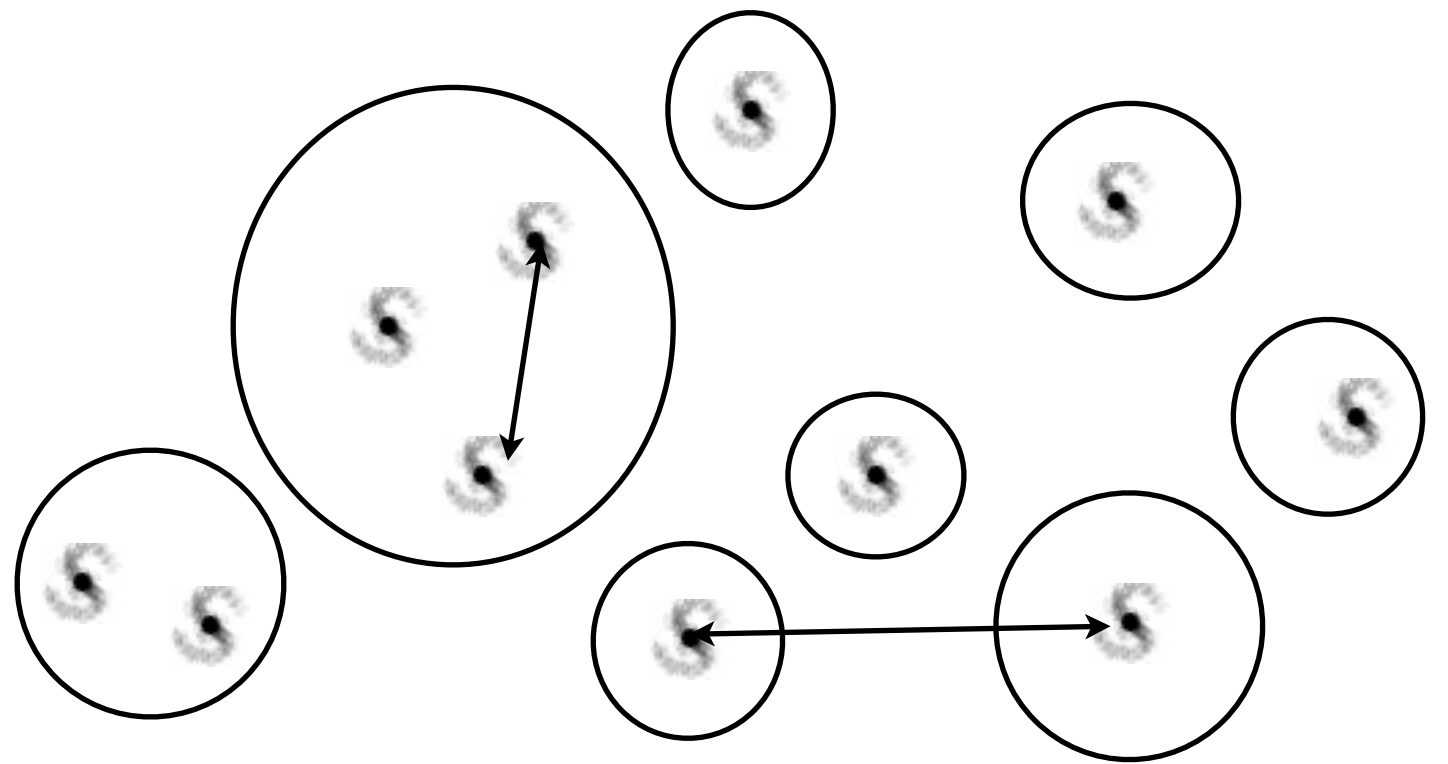
- clustering signal made up of two regimes
- 2-halo: Linear Regime (large scales)



BLAST Halo Model

“halo model”, see e.g.,
Cooray & Sheth (2000),
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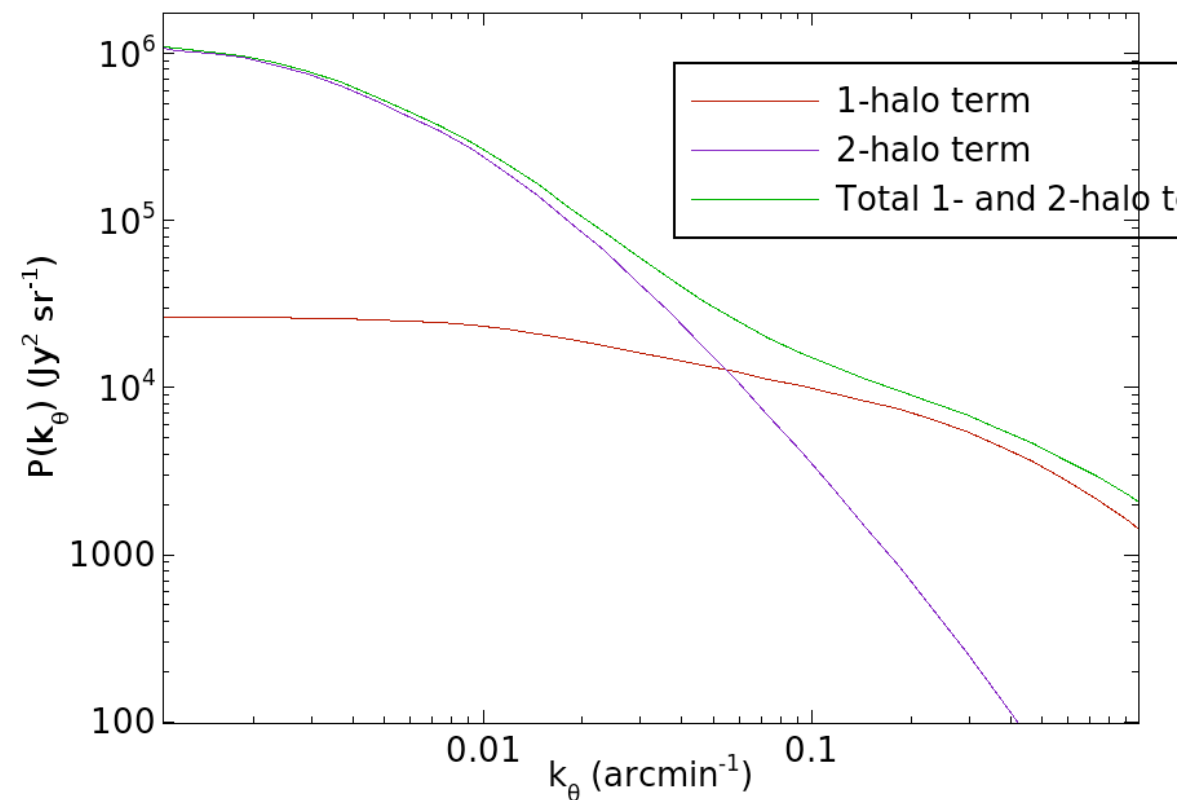
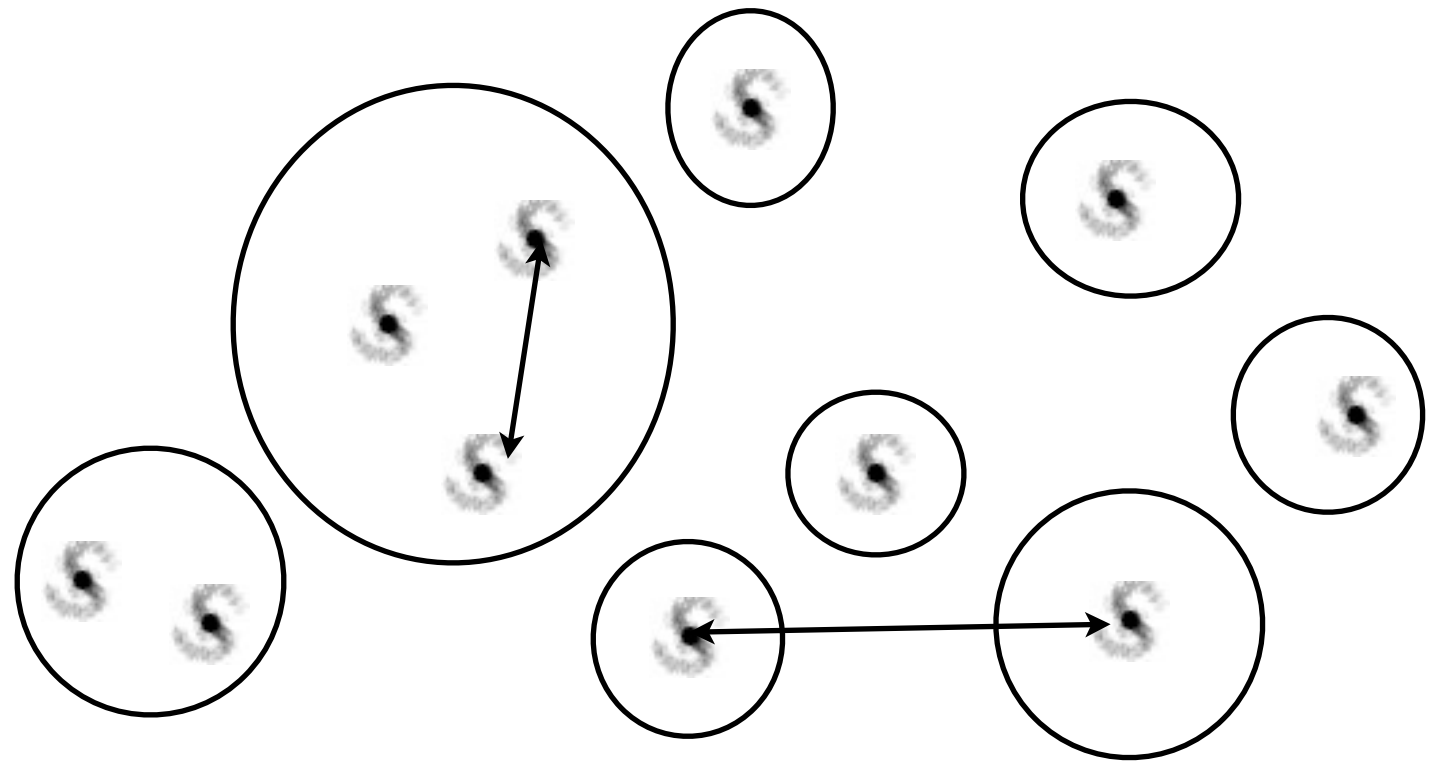
- clustering signal made up of two regimes
 - 2-halo: Linear Regime (large scales)
 - 1-halo: Non-Linear Regime (small scales)



BLAST Halo Model

“halo model”, 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)

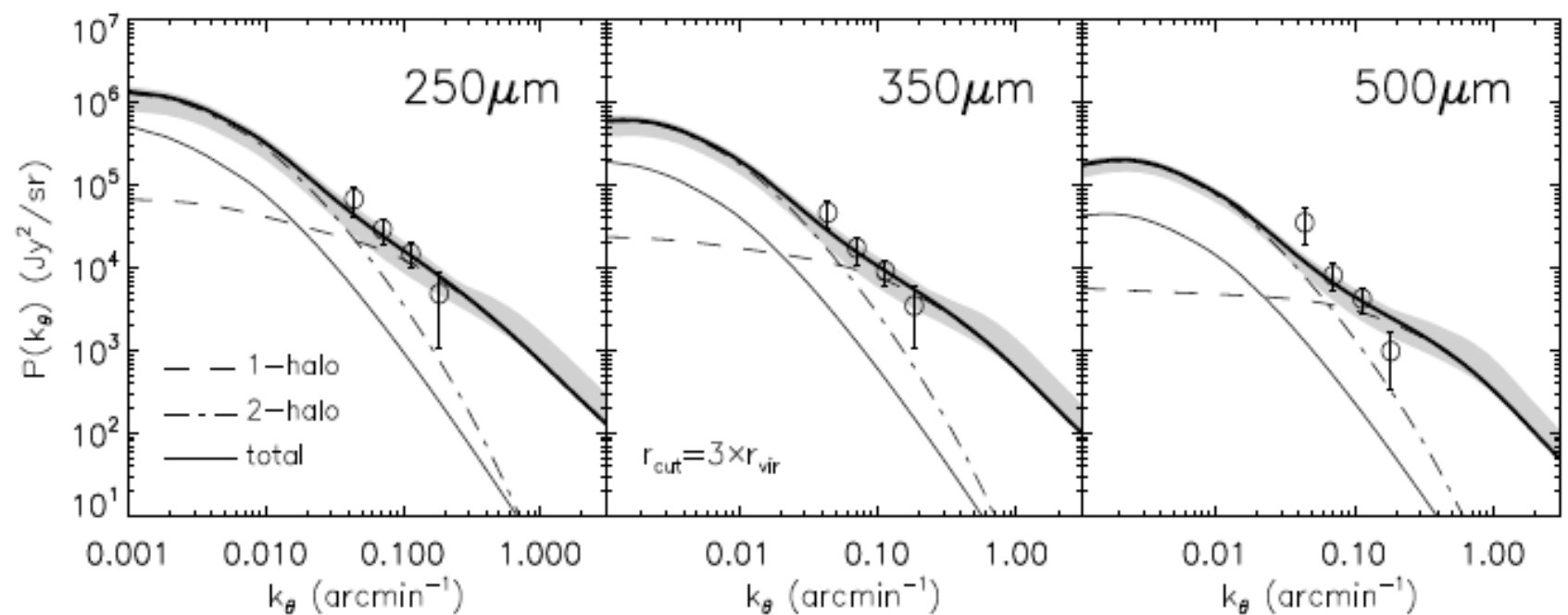


BLAST Halo Model

At $z \sim 2$

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

Halo Model of **Mattia Negrello** &
Source Model of **Lagache** 2004



Viero et al. (2009)

arXiv: 0904.1200

BLAST Halo Model

The Planck Collaboration (2011)

arXiv: 1101.2028

- 350, 550, 850, 1380 μm
- 140 deg^2
- 5' beams



Amblard et al. (2011)

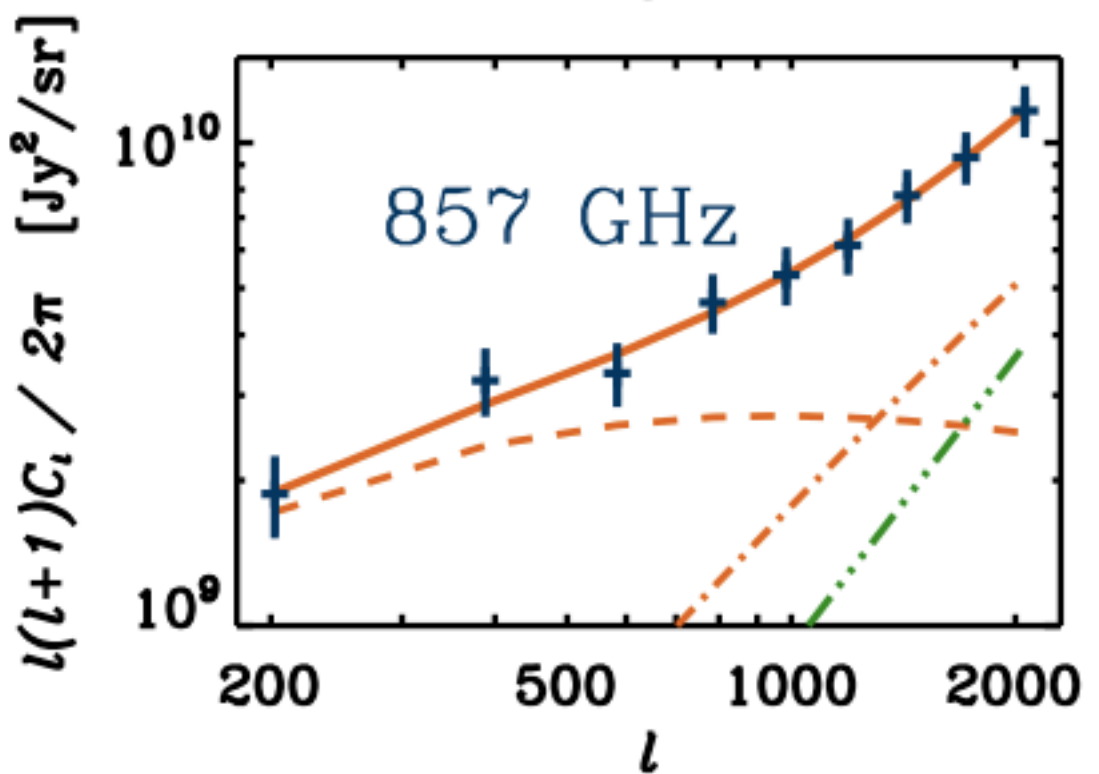
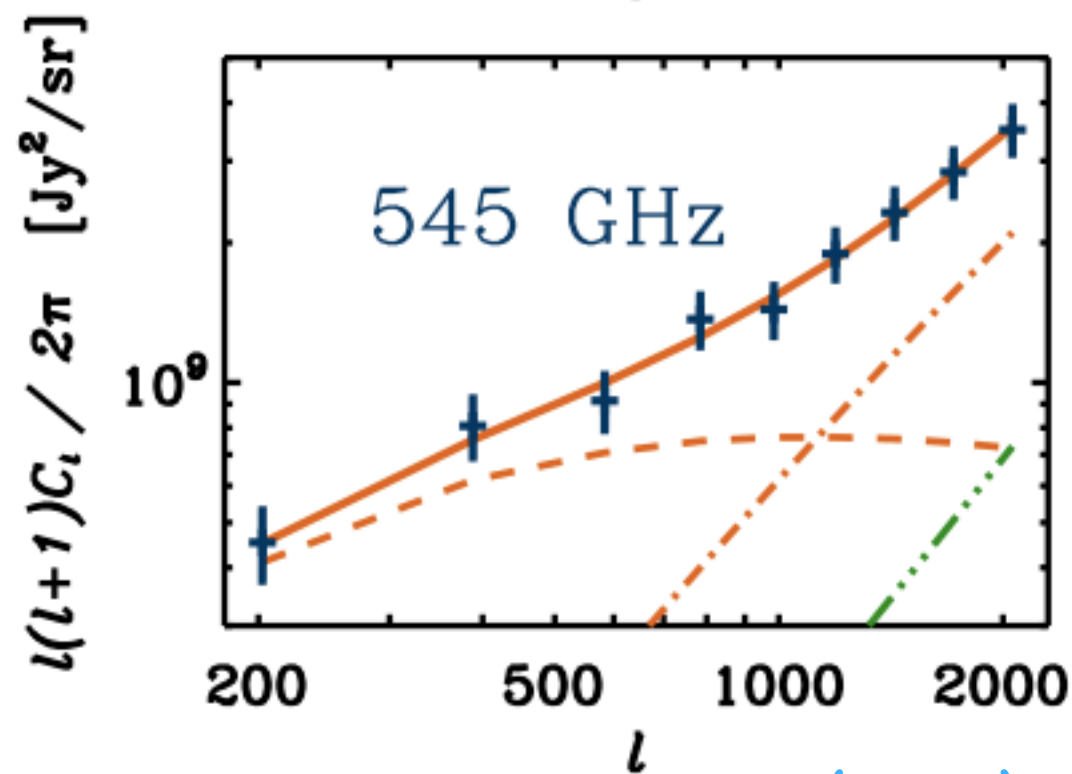
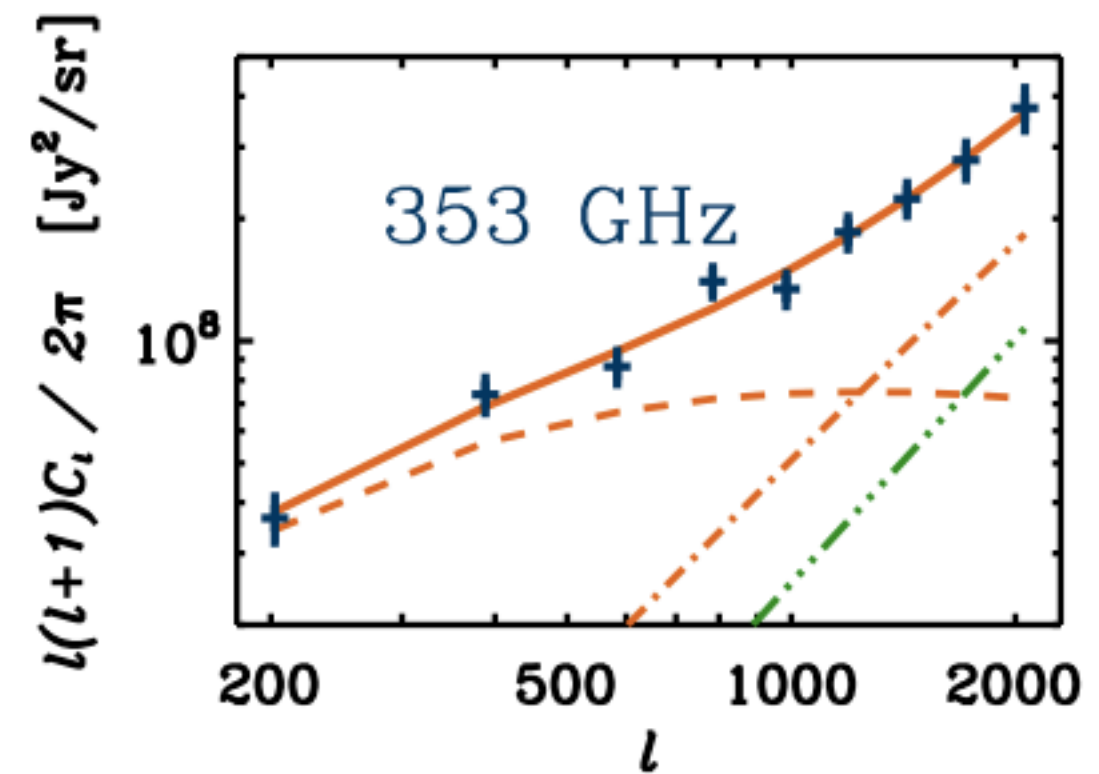
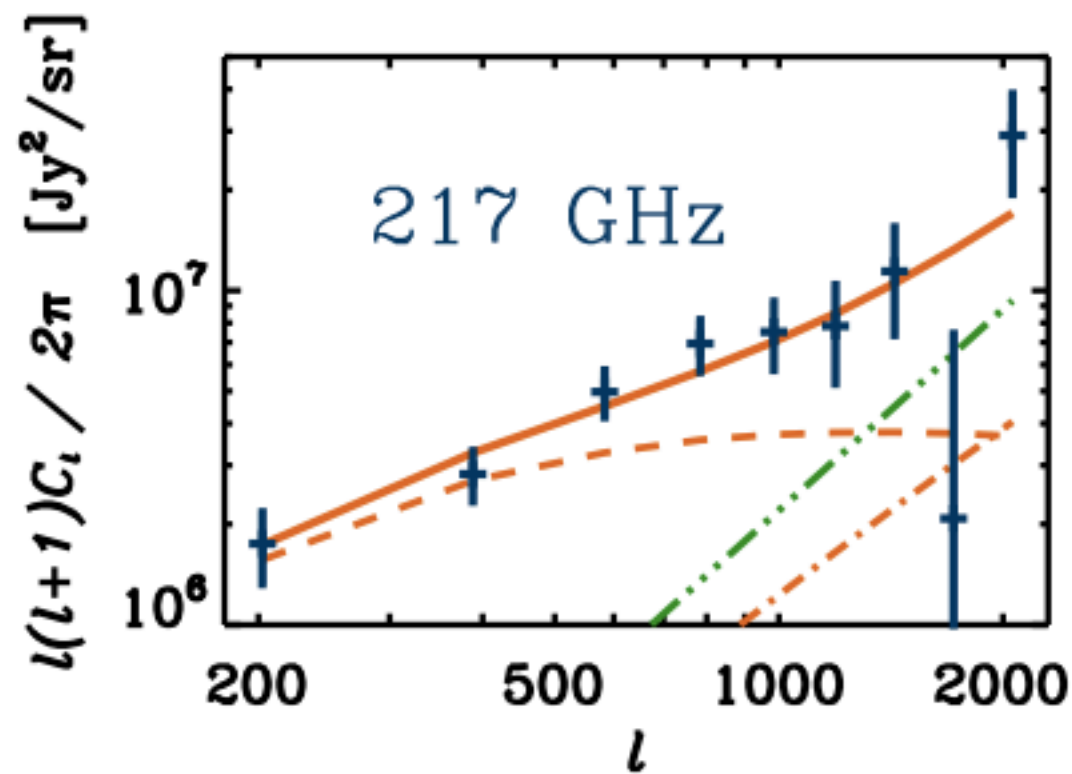
In Nature!

arXiv: 1101.1080

- 250, 350, 500 μm
- 13.5 deg^2
- 16, 25, 36" beams



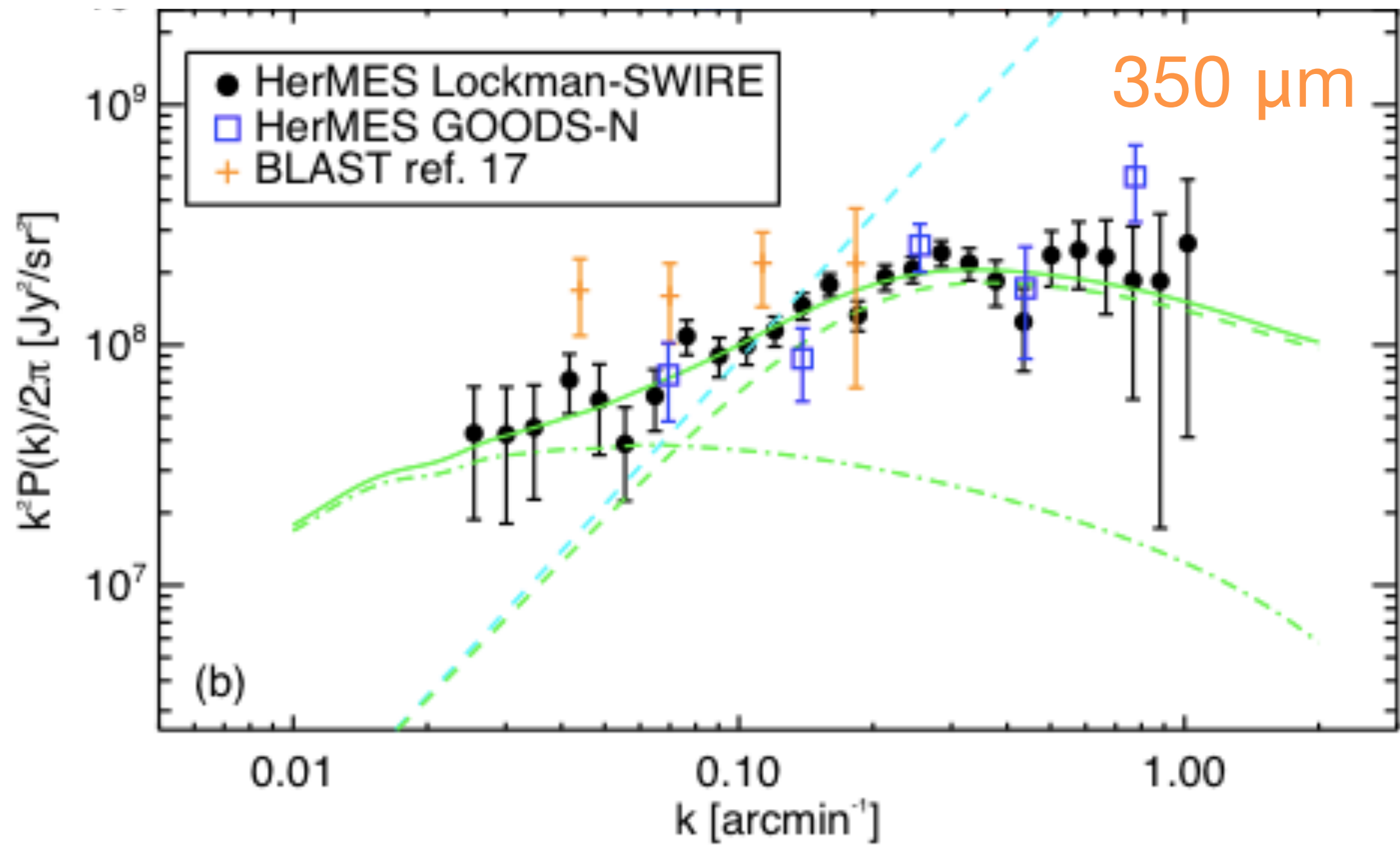
Then and Now



The Planck Collaboration (2011)

arXiv: 1101.2028

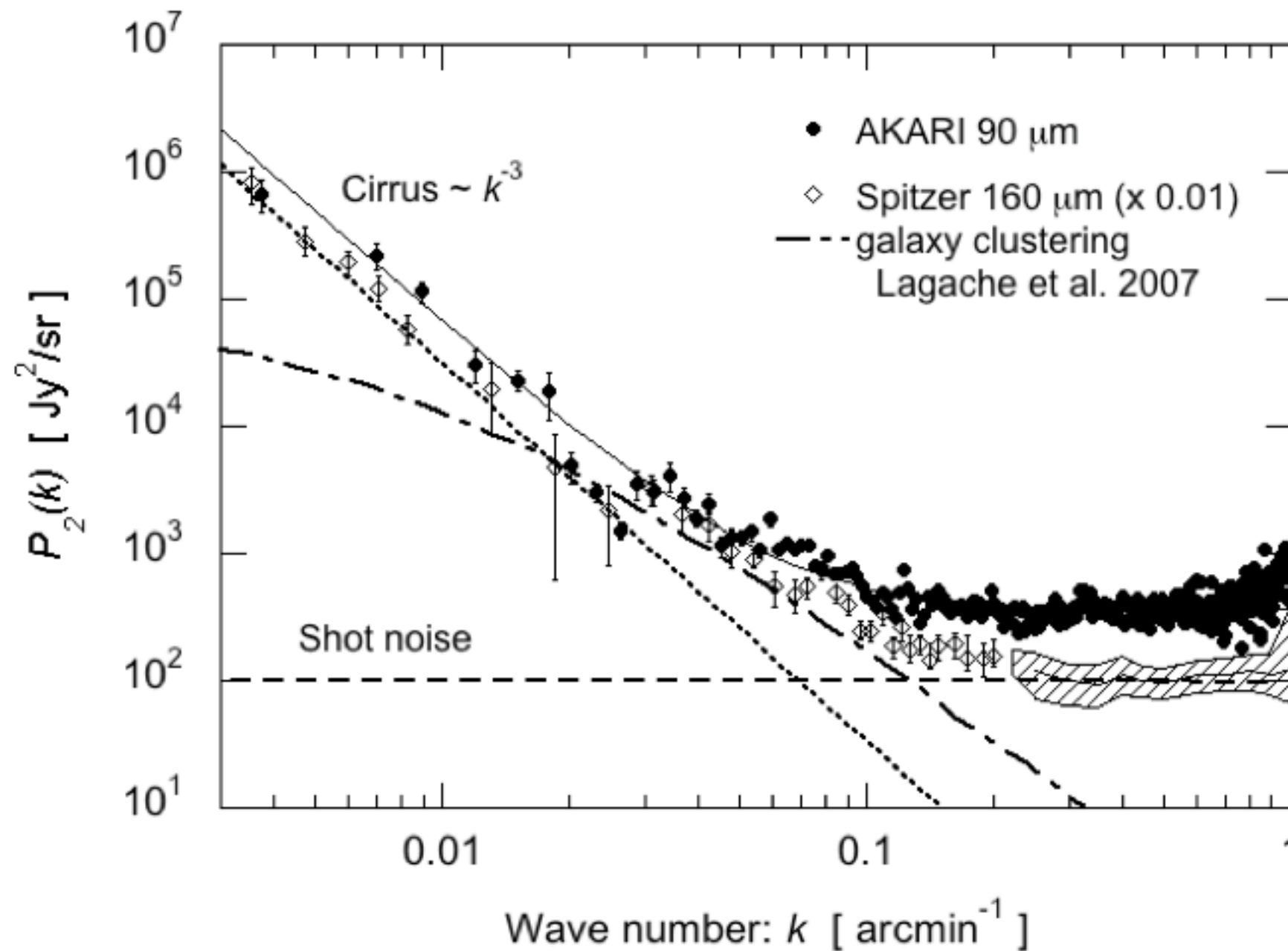
Latest Results



Amblard et al. (2011) – arXiv: 1101.1080

Latest Results

AKARI



Matsuura et al. (2010) – arXiv: 1003.3674

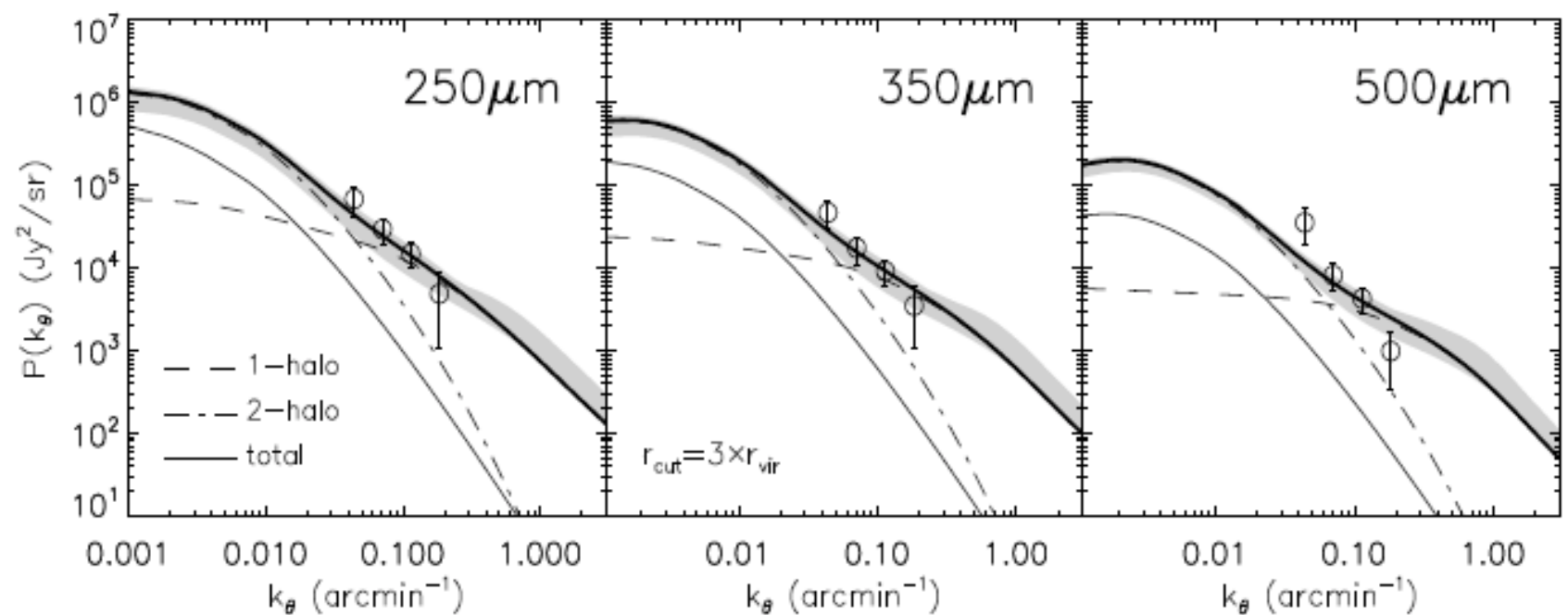
Latest Results

BLAST

At $z \sim 2$

- $b_{\text{linear}} \approx 4.0$
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- $b_{\text{eff}} \approx 2.4$

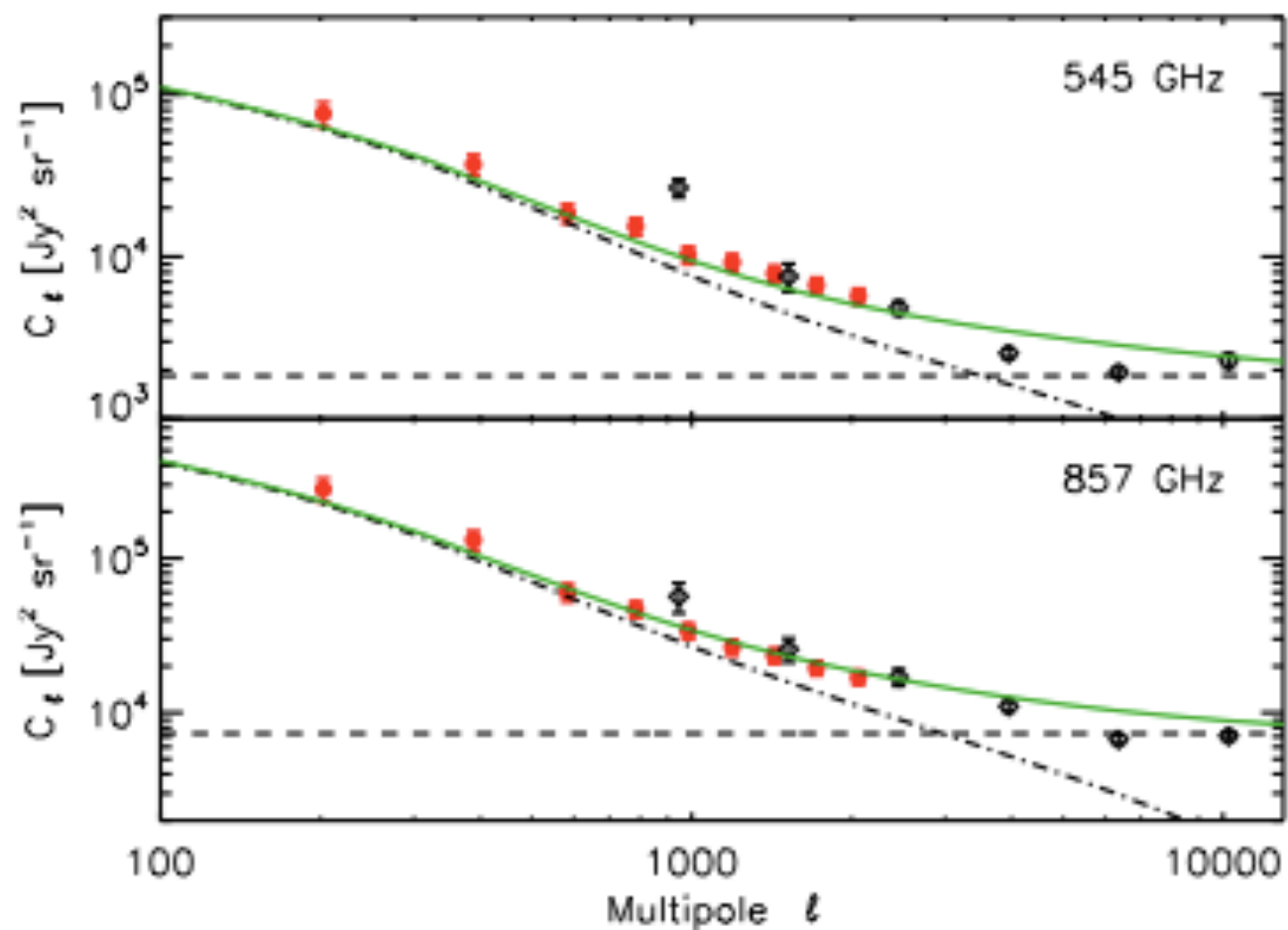
Halo Model of **Mattia Negrello** &
Source Model of **Lagache** 2004



Viero et al. (2009)

arXiv: 0904.1200

BLAST Halo Model

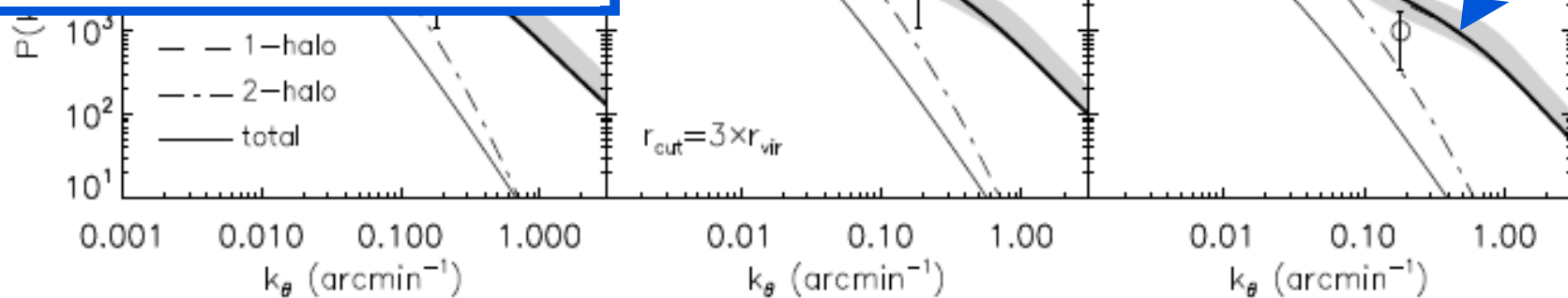


Agrees
w/ Planck!

of **Mattia Negrello** &
model of **Lagache** 2004

- $M_{\min} \approx 3 \times 10^{11} M_{\text{sun}}$

- $b_{\text{eff}} \approx 2.4$



Viero et al. (2009)

arXiv: 0904.1200

BLAST Halo Model

BLAST

At $z \sim 2$

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

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

A. Amblard¹, A. Cooray^{1,2}, P. Serra¹, B. Altieri³, V. Arumugam⁴, H. Aussel⁵, A. Blain², J. Bock^{2,6}, A. Boselli⁷, V. Buat⁷, N. Castro-Rodríguez^{8,9}, A. Cava^{8,9}, P. Chanial¹⁰, E. Chapin¹¹, D.L. Clements¹⁰, A. Conley¹², L. Conversi³, C.D. Dowell^{2,6}, E. Dwek¹³, S. Eales¹⁴, D. Elbaz⁵, D. Farrah¹⁵, A. Franceschini¹⁶, W. Gear¹⁴, J. Glenn¹², M. Griffin¹⁴, M. Halpern¹¹, E. Hatziminaoglou¹⁷, E. Ibar¹⁸, K. Isaak¹⁴, R.J. Ivison^{18,4}, A.A. Khostovan¹, G. Lagache¹⁹, L. Levenson^{2,6}, N. Lu^{2,20}, S. Madden⁵, B. Maffei²¹, G. Mainetti¹⁶, L. Marchetti¹⁶, G. Marsden¹¹, K. Mitchell-Wynne¹, H.T. Nguyen^{6,2}, B. O'Halloran¹⁰, S.J. Oliver¹⁵, A. Omont²², M.J. Page²³, P. Panuzzo⁵, A. Papageorgiou¹⁴, C.P. Pearson^{23,24}, I. Pérez-Fournon^{8,9}, M. Pohlen¹⁴, N. Rangwala¹², I.G. Roseboom¹⁵, M. Rowan-Robinson¹⁰, M. Sánchez Portal¹⁴, M. Sygga¹⁴, L. Vigor¹⁴

Using the halo model fits, we estimate the minimum dark matter mass scale for dusty star-forming galaxies at the peak of the star formation history of the universe to be $\log_{10} M_{\text{min}}/M_{\odot} = 11.5^{+0.7}_{-0.2}$ at 350 μm with a bias factor for the galaxies of $2.4^{+1.0}_{-0.2}$. The minimum halo masses $\log_{10} M_{\text{min}}/M_{\odot}$ 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-

BLAST Halo Model

BLAST

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- $M_{\text{min}} \approx 3 \times 10^{11} M_{\text{sun}}$
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Confirmed
by Herschel!

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BLAST Halo Model

what have we learned?

Summary #1

what have we learned?

- DSFGs are biased tracers of dark matter (unlike in the local Universe)

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- DSFGs are biased tracers of dark matter (unlike in the local Universe)
- The effective host halo mass is $6 \times 10^{12} M_{\text{sun}}$.
- The minimum halo mass to host a DSFG is $3 \times 10^{11} M_{\text{sun}}$, which is somewhat smaller than expected.

Summary #1

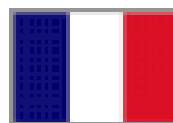
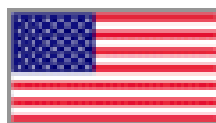


HerMES - Herschel Multi-tiered Extragalactic Survey

To study the evolution of galaxies in the distant Universe
The biggest project on the Herschel Space Observatory
A European Space Agency mission



Astronomy Technology Centre
California Institute of Technology
Cardiff University
CEA, Saclay
Cornell
ESAC
Godard Space Flight Centre



Imperial College, London
Infrared Processing Analysis Centre
Institut d'Astrophysique de Paris
Institut d'Astrophysique Spatiale
Institute Astrofisica Canarias
Jet Propulsion Lab.
Laboratory of Astrophysics of Marseilles



Mullard Space Science Laboratory
OAPd University of Padova
UC Irvine
University of British Columbia
University of Colorado
University of Hertfordshire
University of Sussex

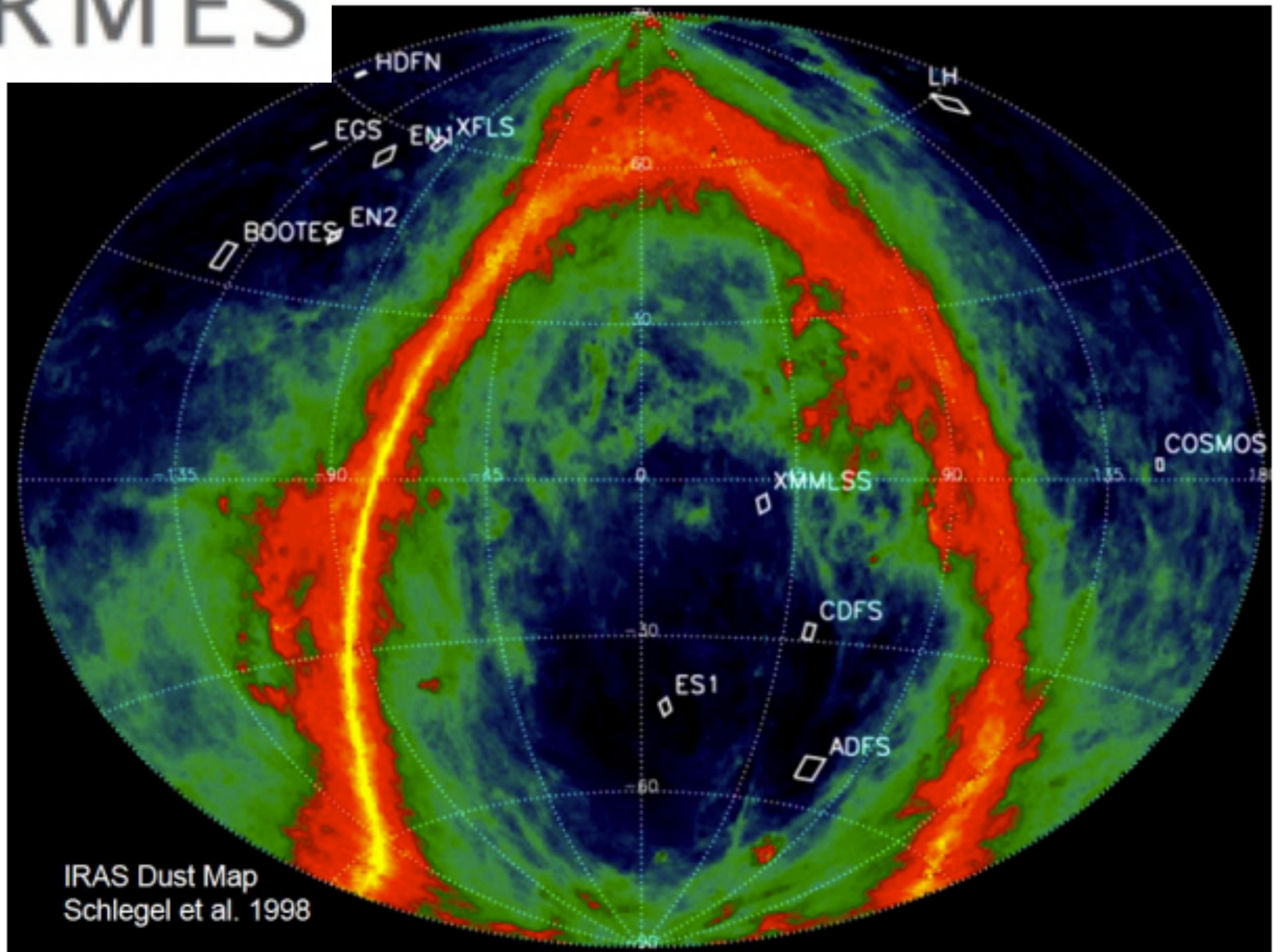


The Team

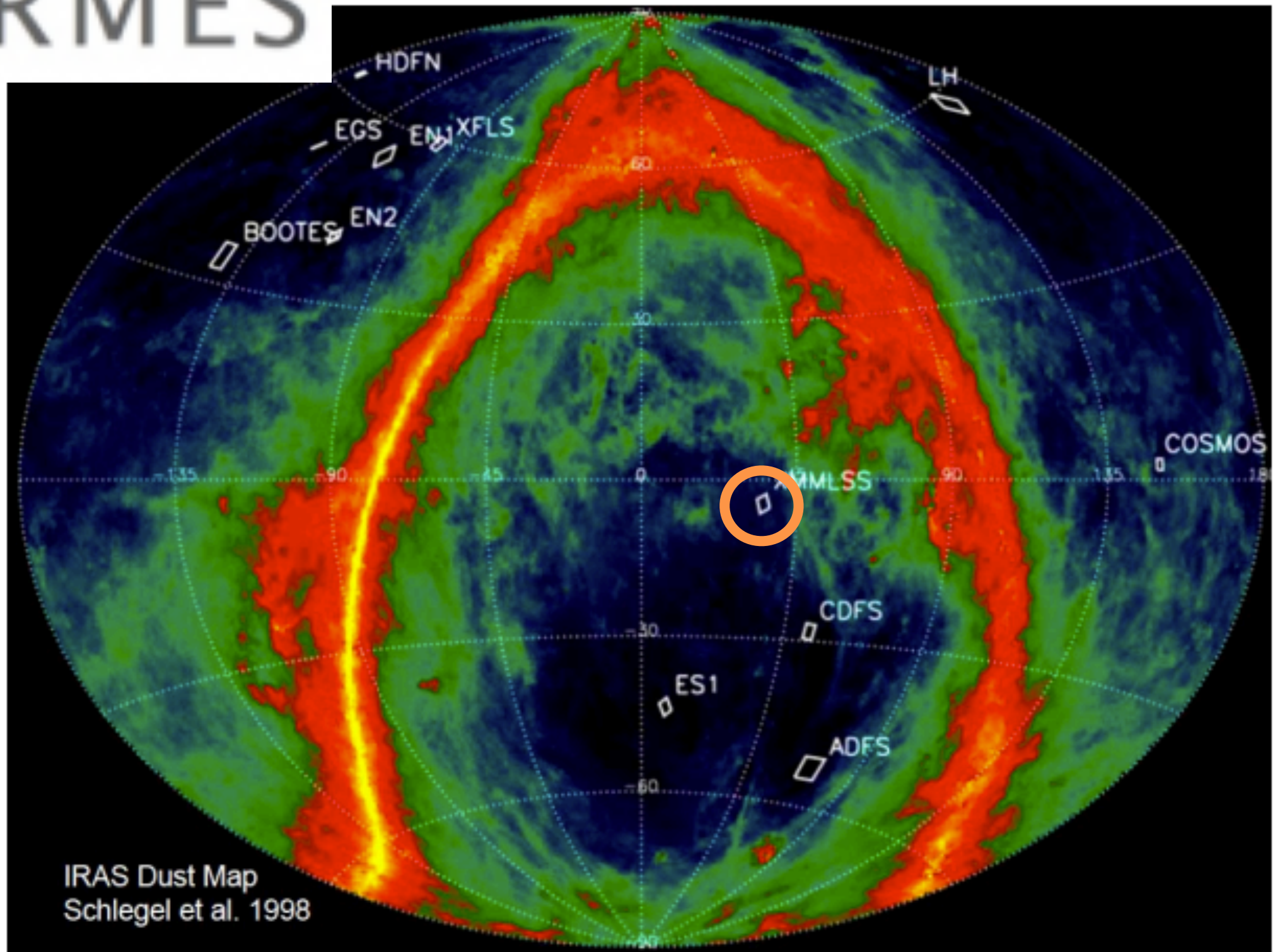
Bruno Altieri, Alex Amblard, Rick Arendt, Vinod Arumugam, Robbie Auld, Herve Aussel, Alexandre Beelen, Andrew Blain, Jamie Bock, Alessandro Boselli, Carrie Bridge, Drew Brisbin, Veronique Buat, Denis Burgarella, Nieves Castro-Rodriguez, Antonia Cava, Pierre Chanial, Ed Chapin, Michele Cirasuolo, Dave Clements, Alex Conley, Luca Conversi, Asantha Cooray, Emanuele Daddi, Gianfranco De Zotti, Darren Dowell, Jim Dunlop, Eli Dwek, Simon Dye, Steve Eales, David Elbaz, Erica Ellingson, Tim Ellsworth-Bowers, Duncan Farrah, Patrizia Ferrero, Mark Frost, Ken Ganga, Elodie Giovannoli, Jason Glenn, Eduardo Gonzalez-Solares, Matt Griffin, Mark Halpern, Martin Harwit, Evanthia Hatziminaoglou, George Helou, Jiasheng Huang, Ho Seong Hwang, Edo Ibar, Olivier Ilbert, Kate Isaak, Rob Ivison, Martin Kunz, Guilaine Lagache, Glenn Laurent, Louis Levenson, Carol Lonsdale, Nanyao Lu, Suzanne Madden, Bruno Maffei, Georgios Magdis, Gabriele Mainetti, Lucia Marchetti, Gaelen Marsden, Jason Marshall, Glenn Morrison, Angela Mortier, Hien Trong Nguyen, Brian O'Halloran, Seb Oliver, Alain Omont, Francois Orioux, Frazer Owen, Matthew Page, Biswajit Pandey, Maruillo Pannell, Pasquale Panuzzo, Andreas Papageorgiou, Harsit Patel, Chris Pearson, Ismael Perez Fournon, Michael Pohlen, Naseem Rangwala, Jason Rawlings, Gwen Raymond, Dimitra Rigopoulou, Laurie Riguccini, Guilia Rodighiero, Isaac Roseboom, Michael Rowan-Robinson, Miguel Sanchez Portal, Bernhard Schulz, Douglas Scott, Paolo Serra, Nick Seymour, David Shupe, Anthony Smith, Jason Stevens, Veronica Strazzu, Myrto Symeonidis, Markos Trichas, Katherine Tugwell, Mattia Vaccari, Elisabetta Valiante, Ivan Vatchanov, Joaquin Vieira, Marco Viero, Lingyu Wang, Don Wiebe, Kevin Xu, Michael Zemcov

Faculty & Researchers PostDocs PhD Students

Plus engineers, instrument
builders, software developers etc.

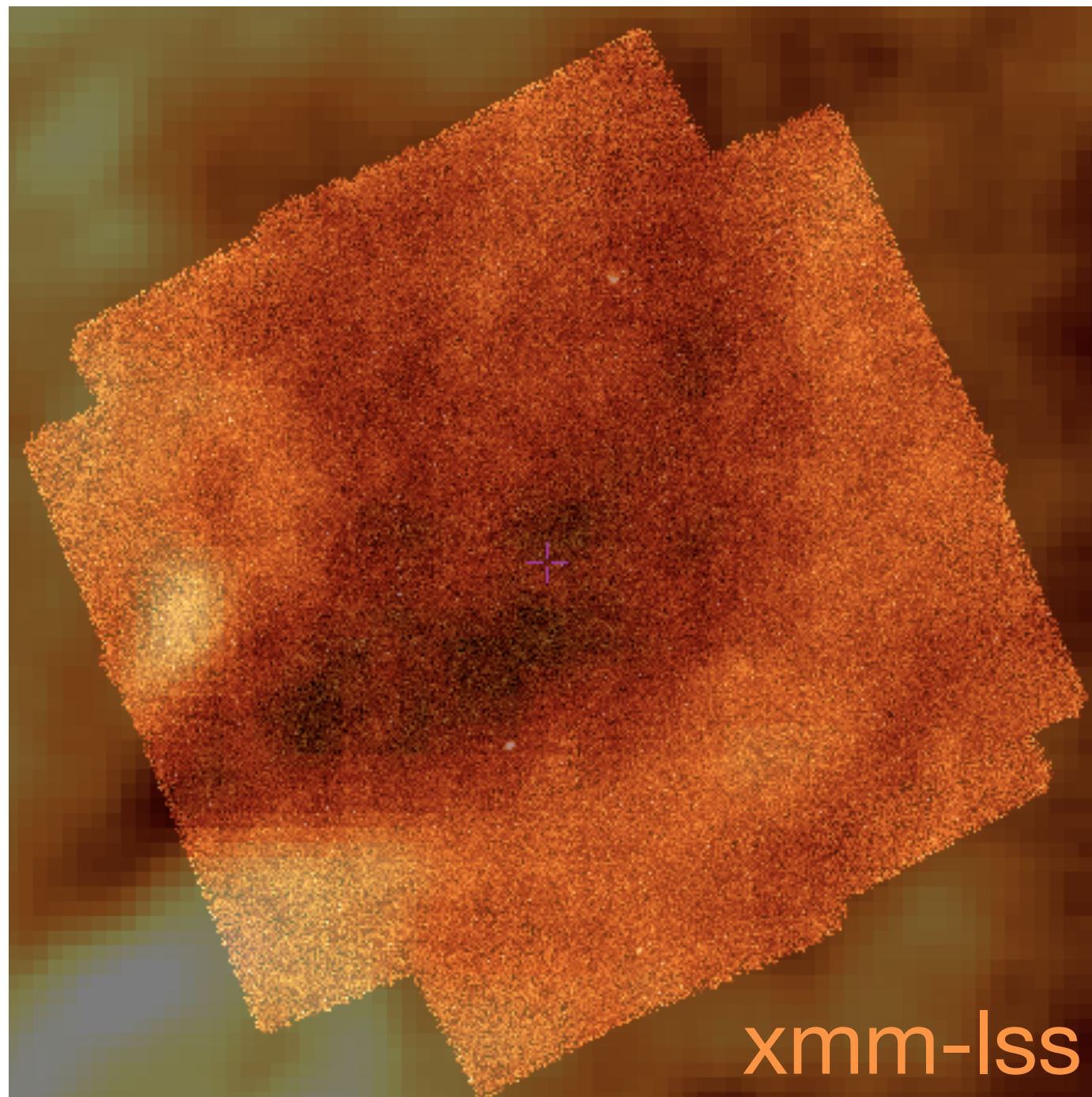


works in progress...



works in progress...

HI

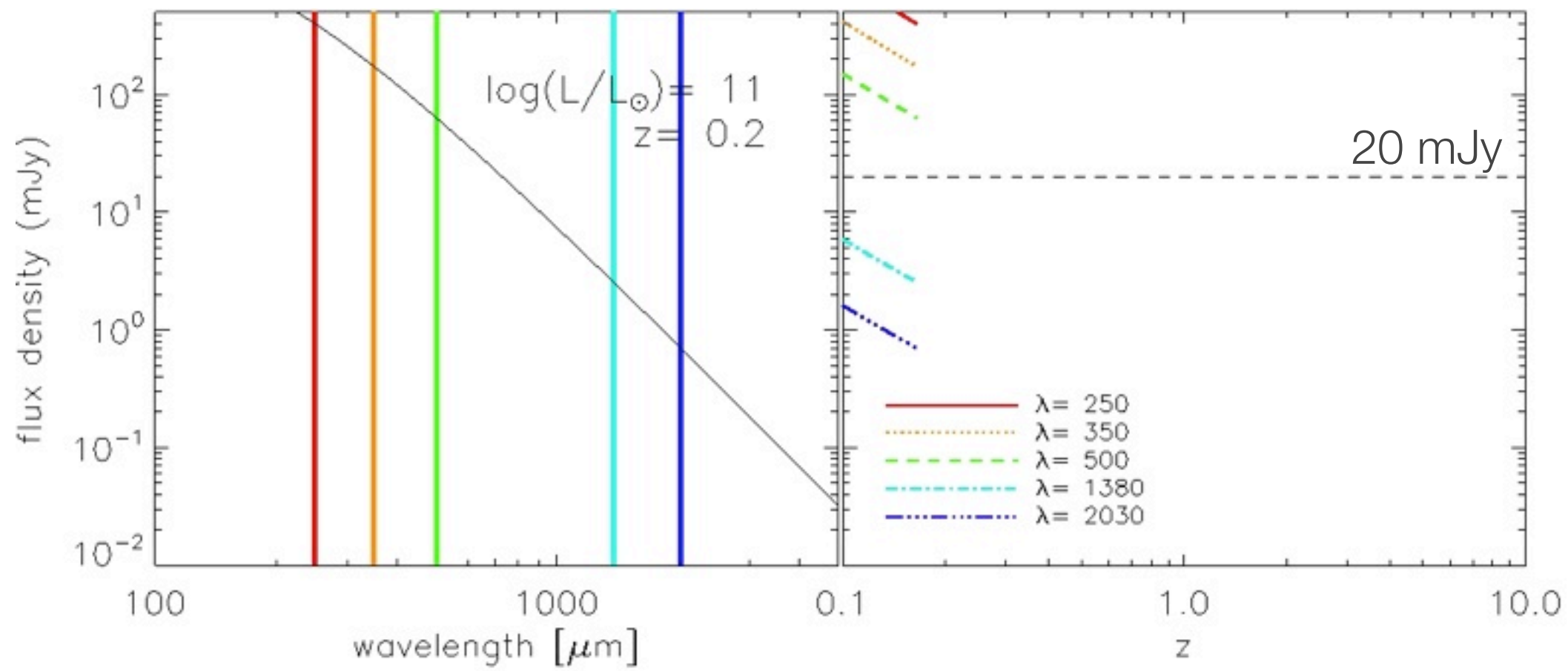


250 μ m

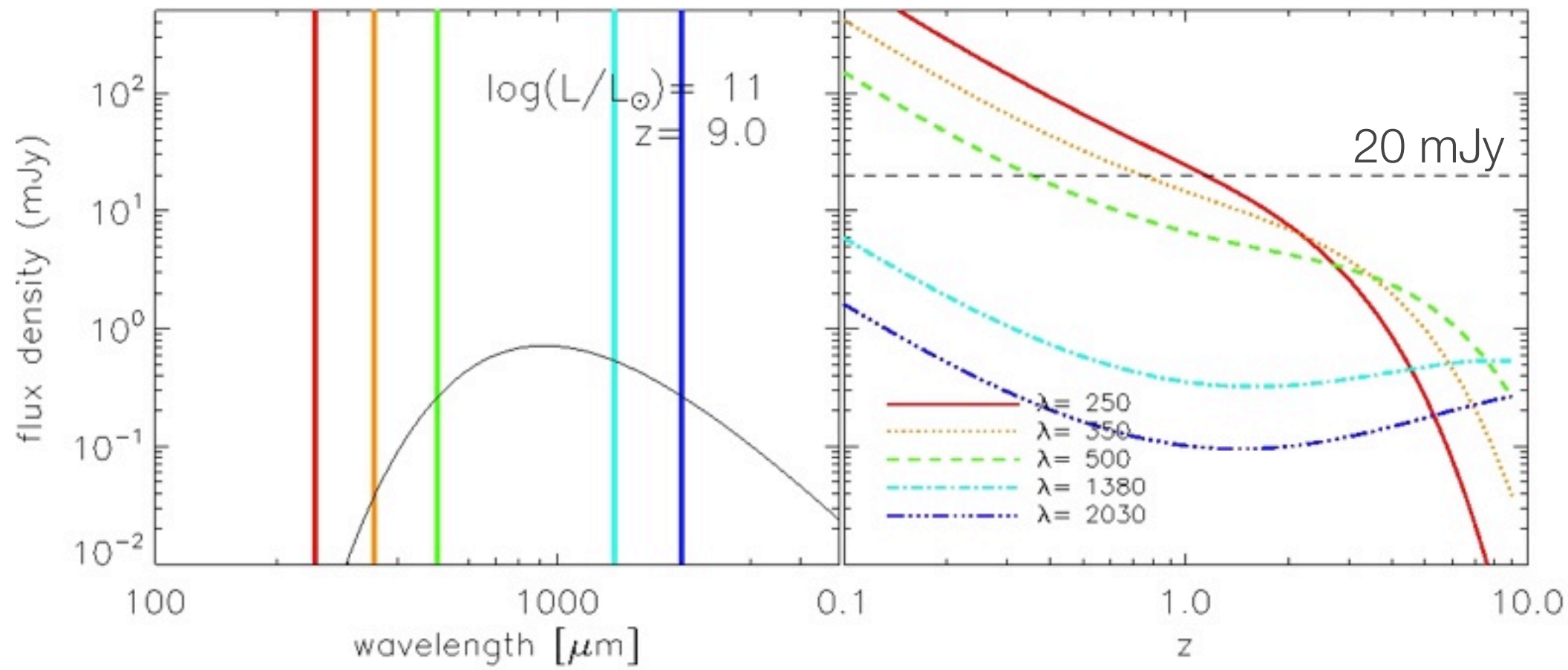
works in progress...



BUT!
BLAST not done yet!

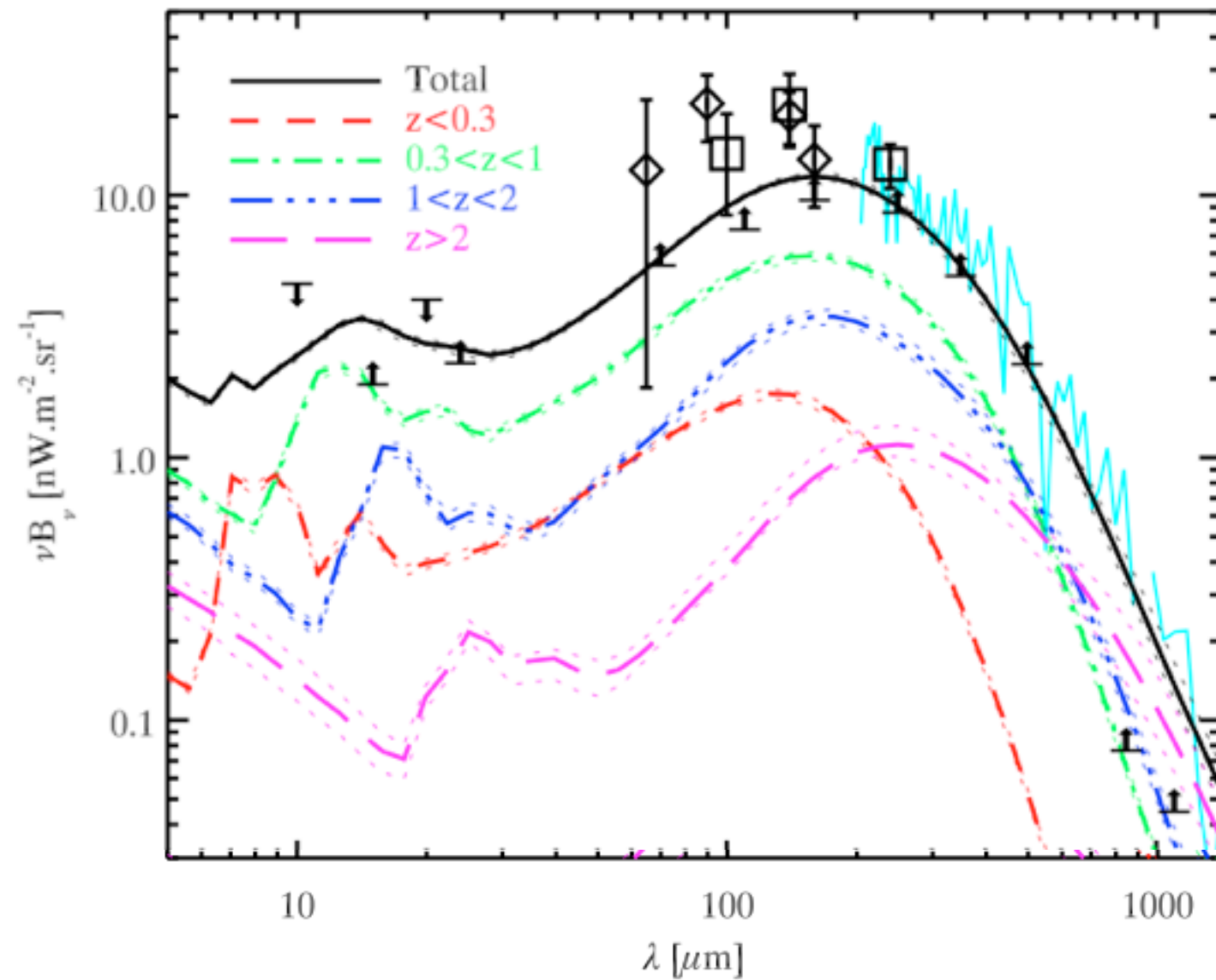


Negative K-correction



Negative K-correction

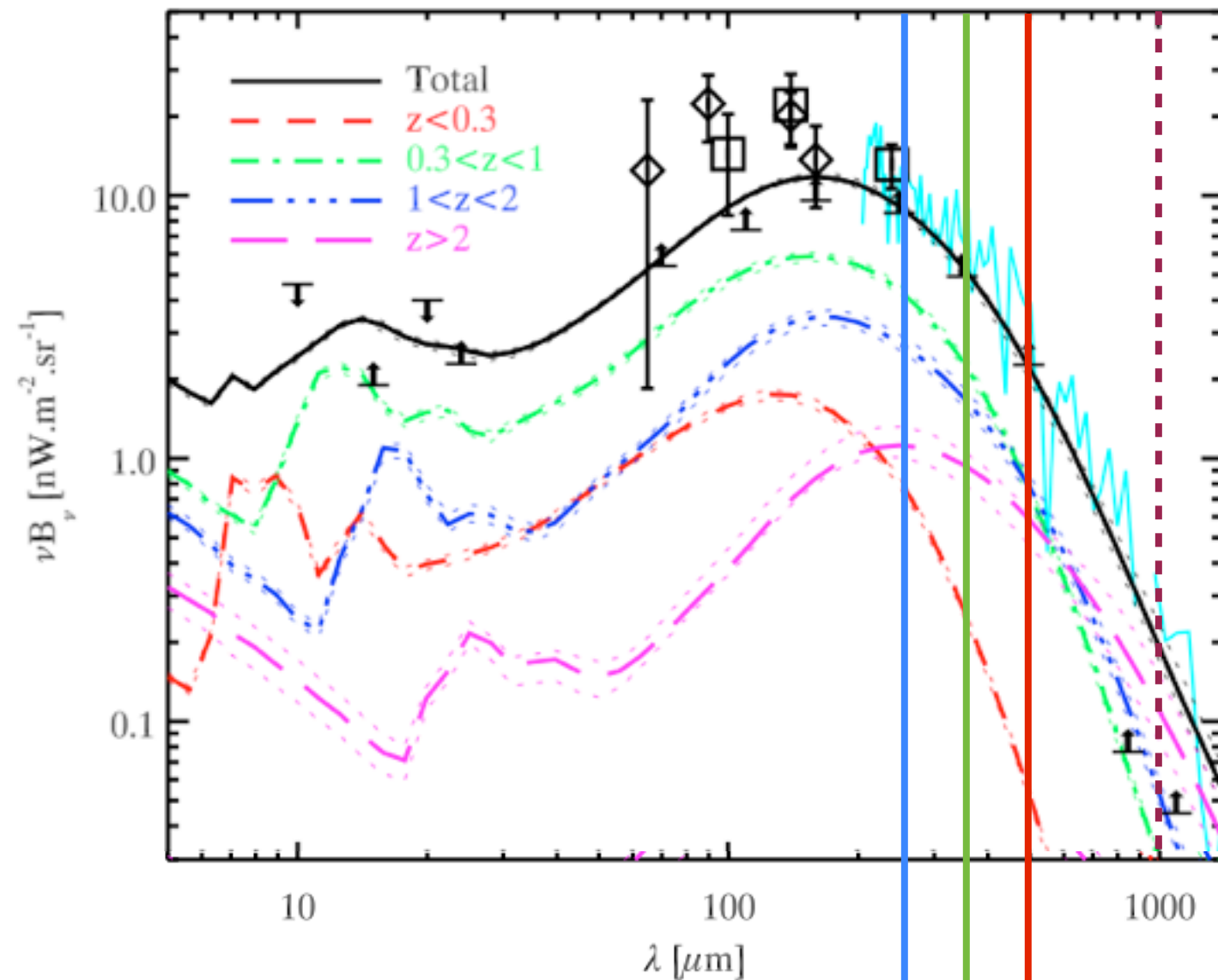
CIB in redshift slices



Béthermin et al. (2011)
arXiv:1010.1150

Targeting High-z

CIB in redshift slices



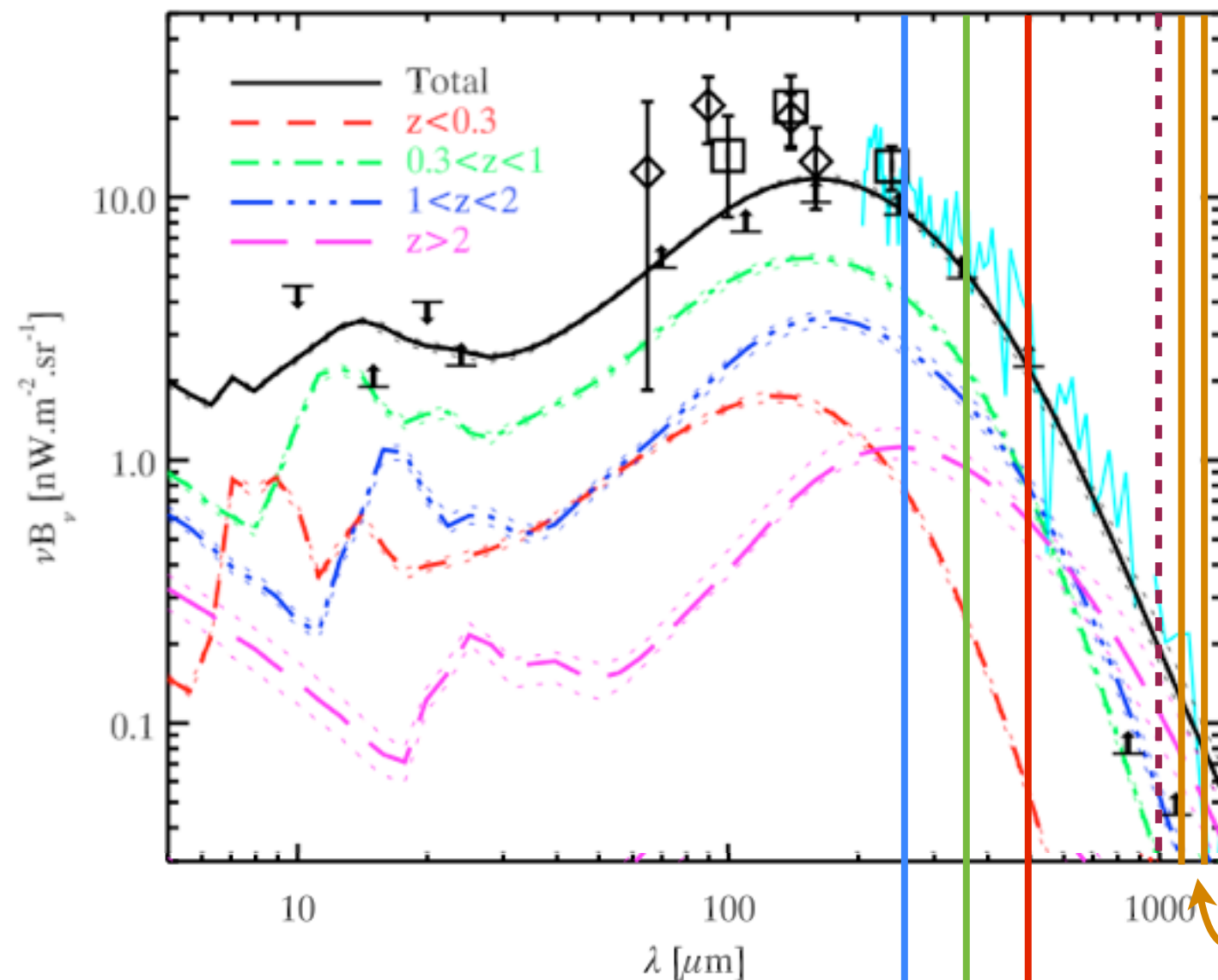
Béthermin et al. (2011)
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250 350 500

Infrared Background
at $\lambda > 1$ mm
dominated by
high-redshift sources

Targeting High-z

CIB in redshift slices



Infrared Background
at $\lambda > 1$ mm
dominated by
high-redshift sources

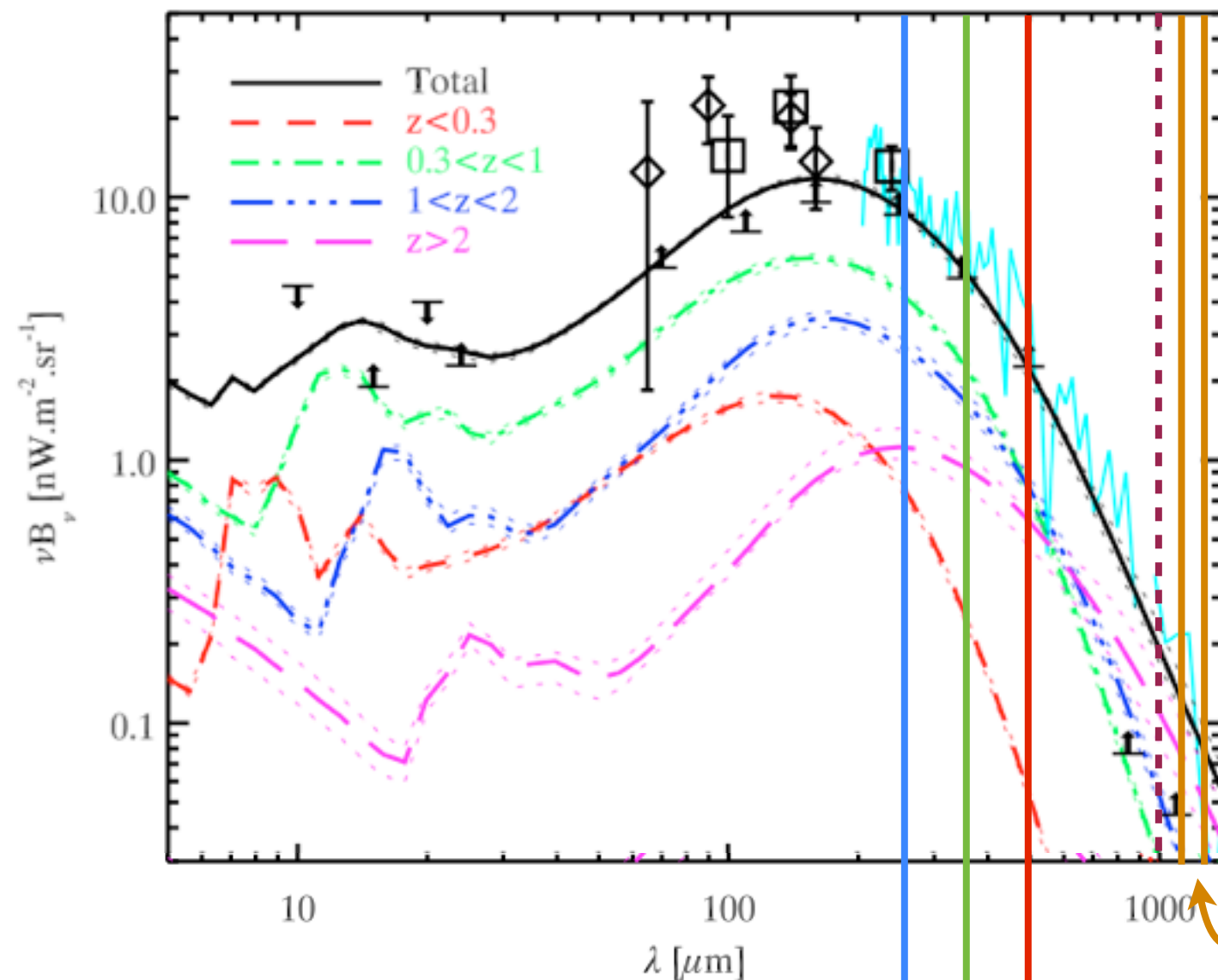
1.4 mm (220 GHz)
2 mm (148 GHz)

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Targeting High- z

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Infrared Background
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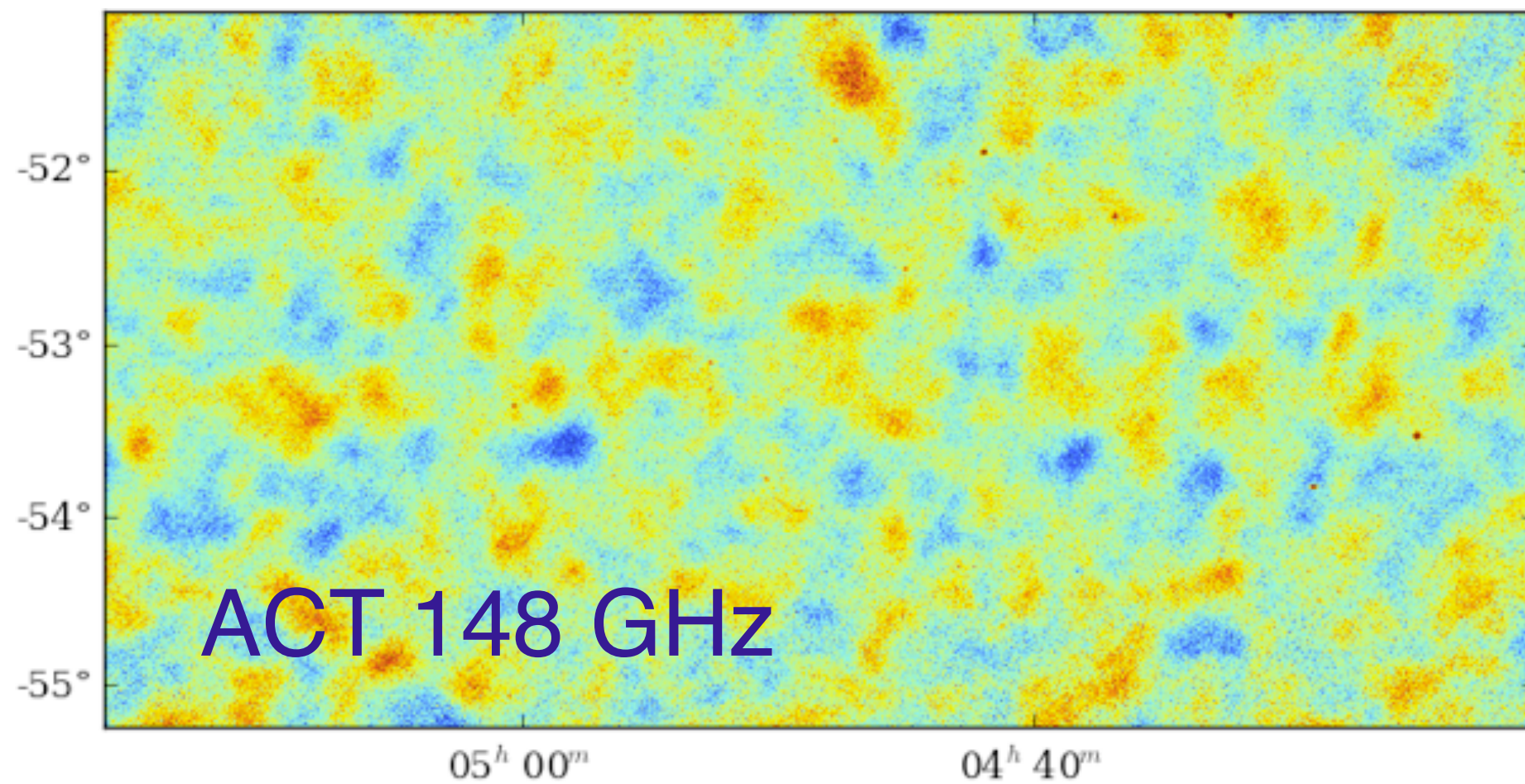
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CMB

Béthermin et al. (2011)
arXiv:1010.1150

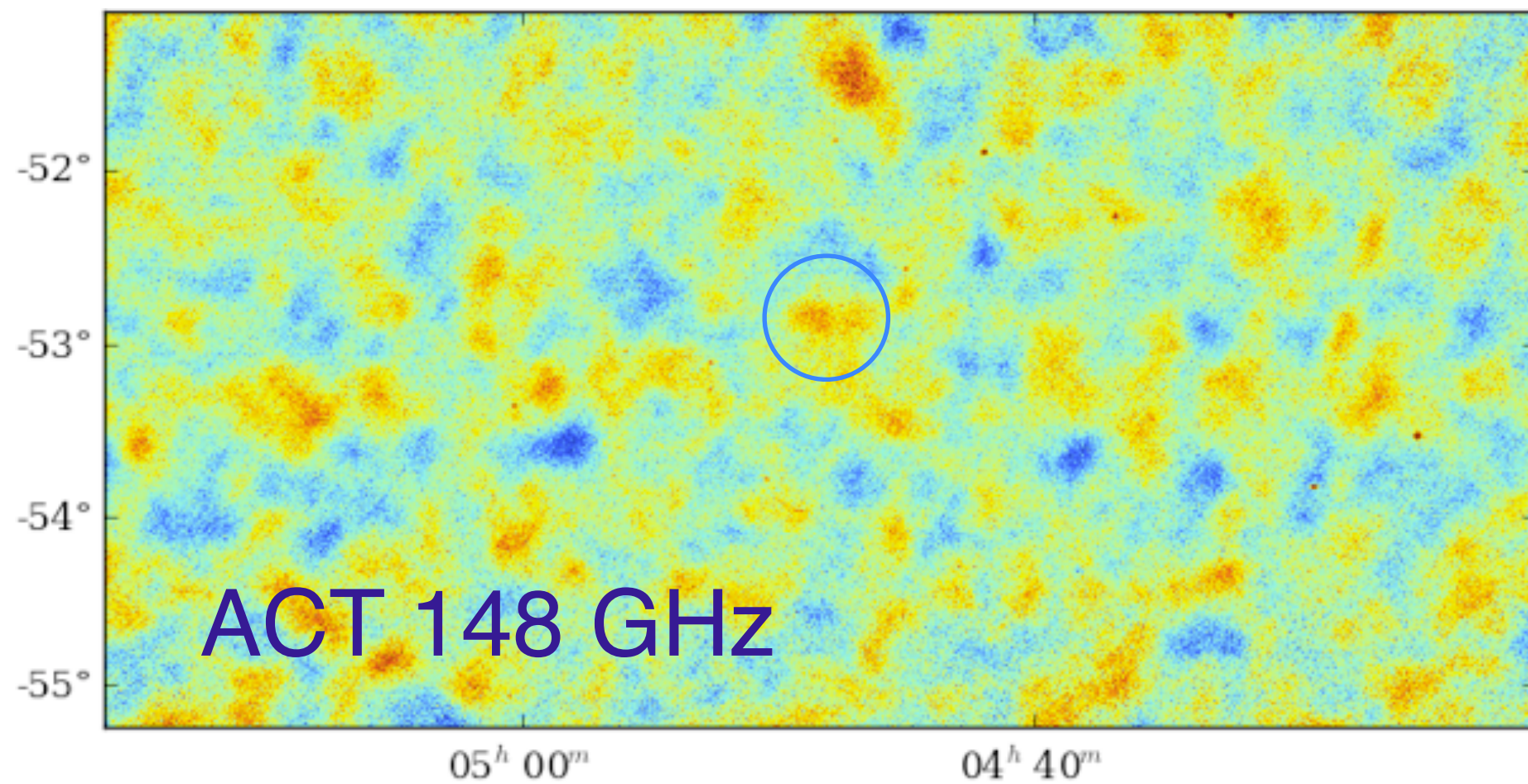
250 350 500

Targeting High- z



The CMB sky

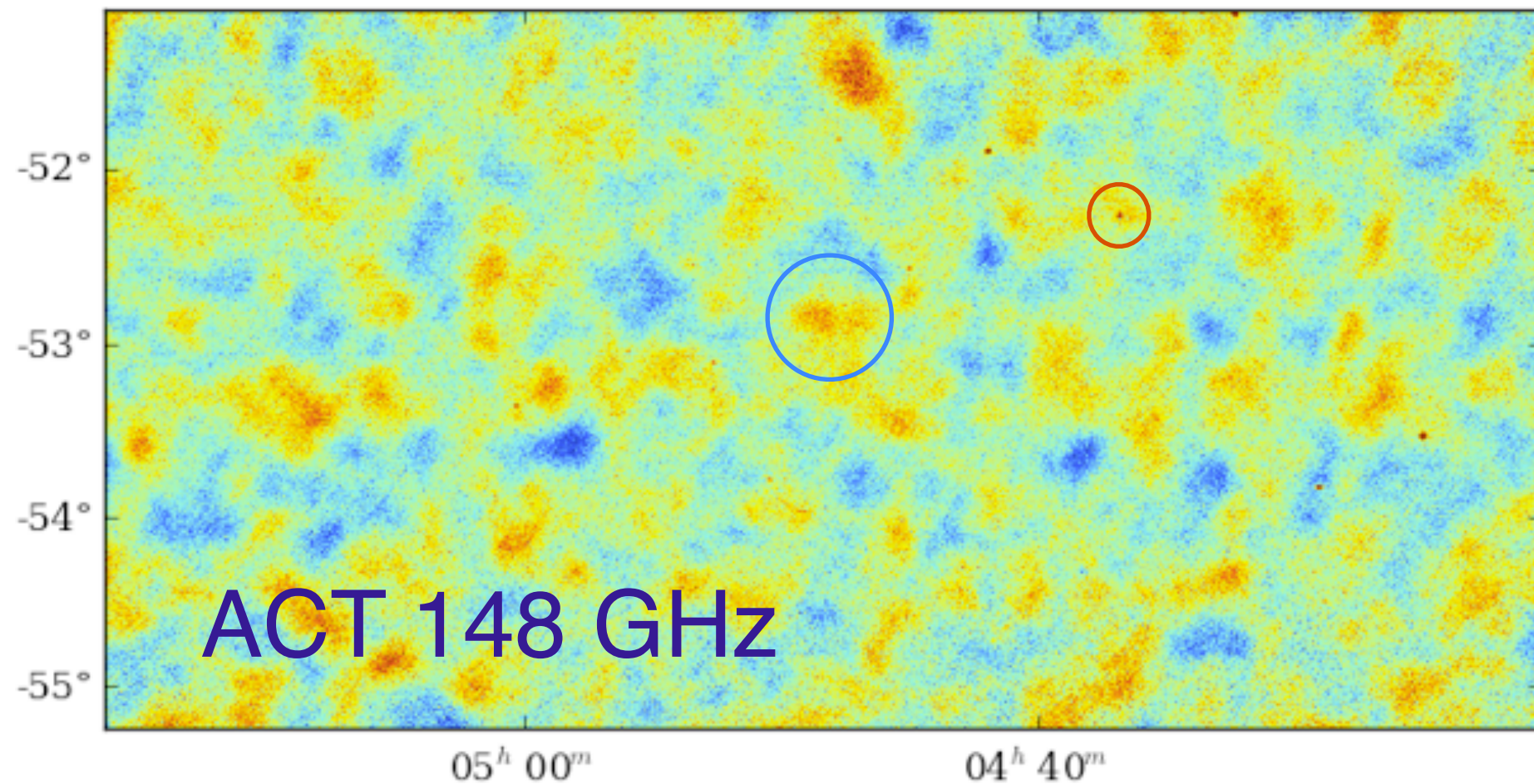
CMB



The CMB sky

CMB

Resolved Radio Galaxies

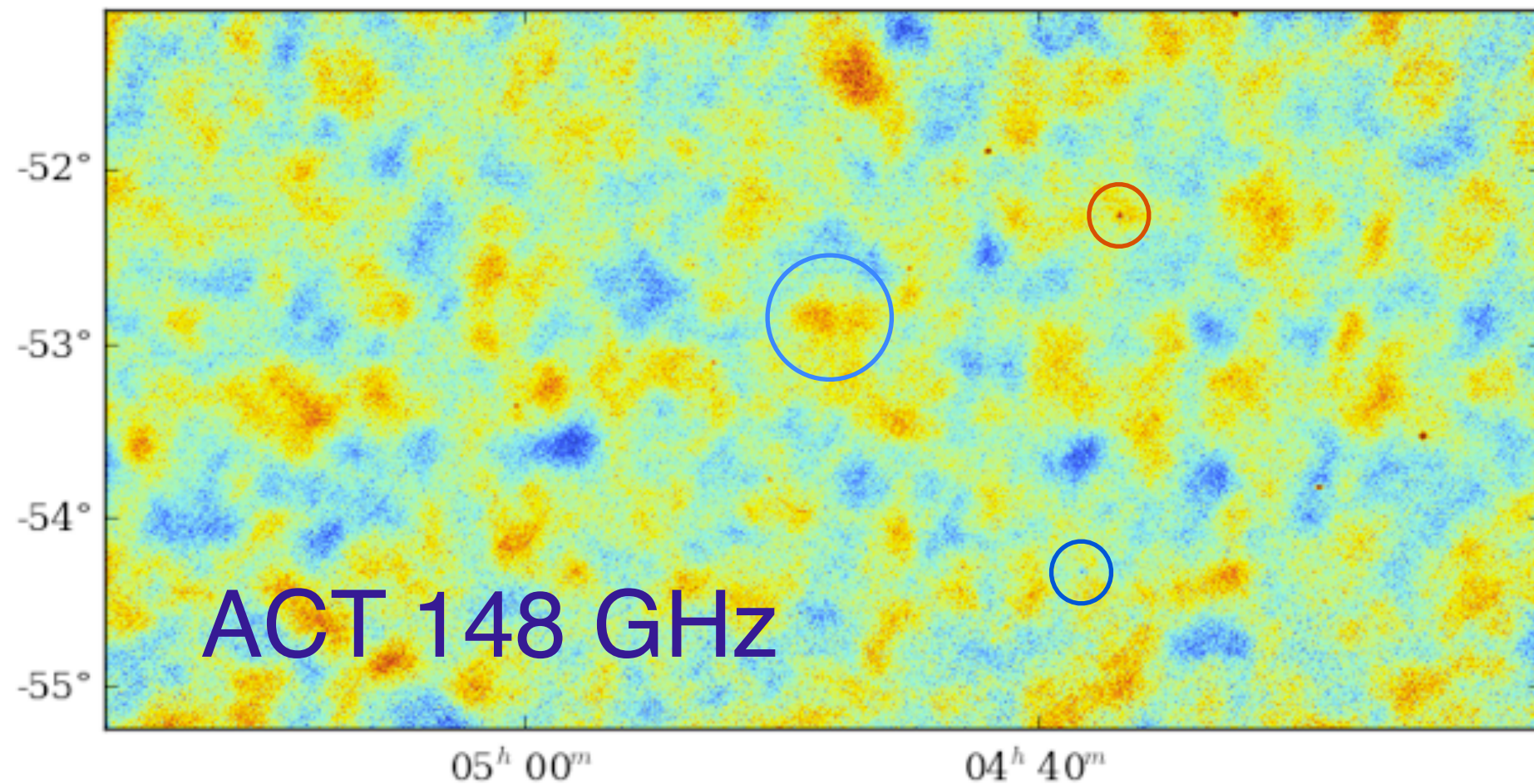


The CMB sky

CMB

Resolved Radio Galaxies

SZ Clusters



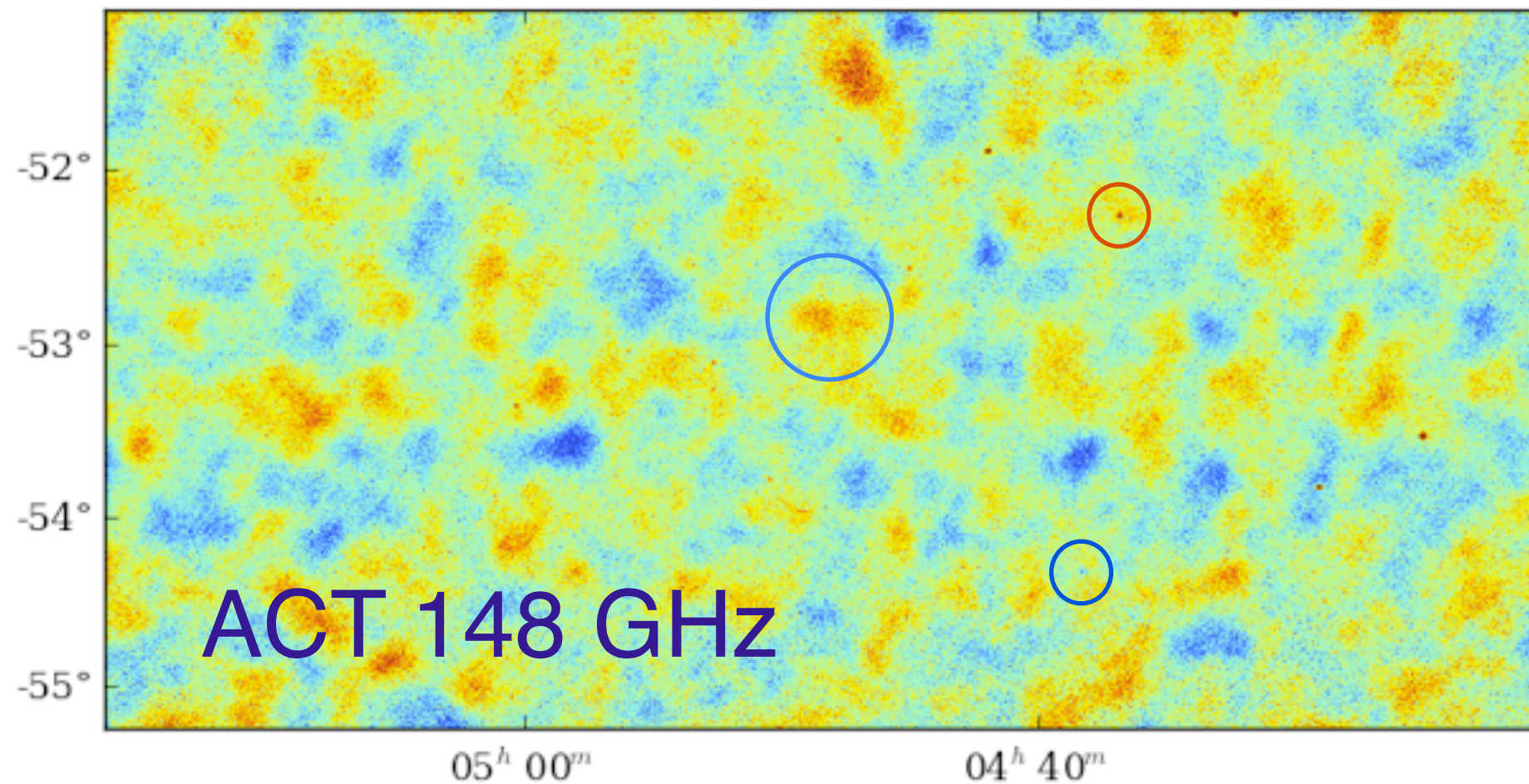
The CMB sky

CMB

Resolved Radio Galaxies

SZ Clusters

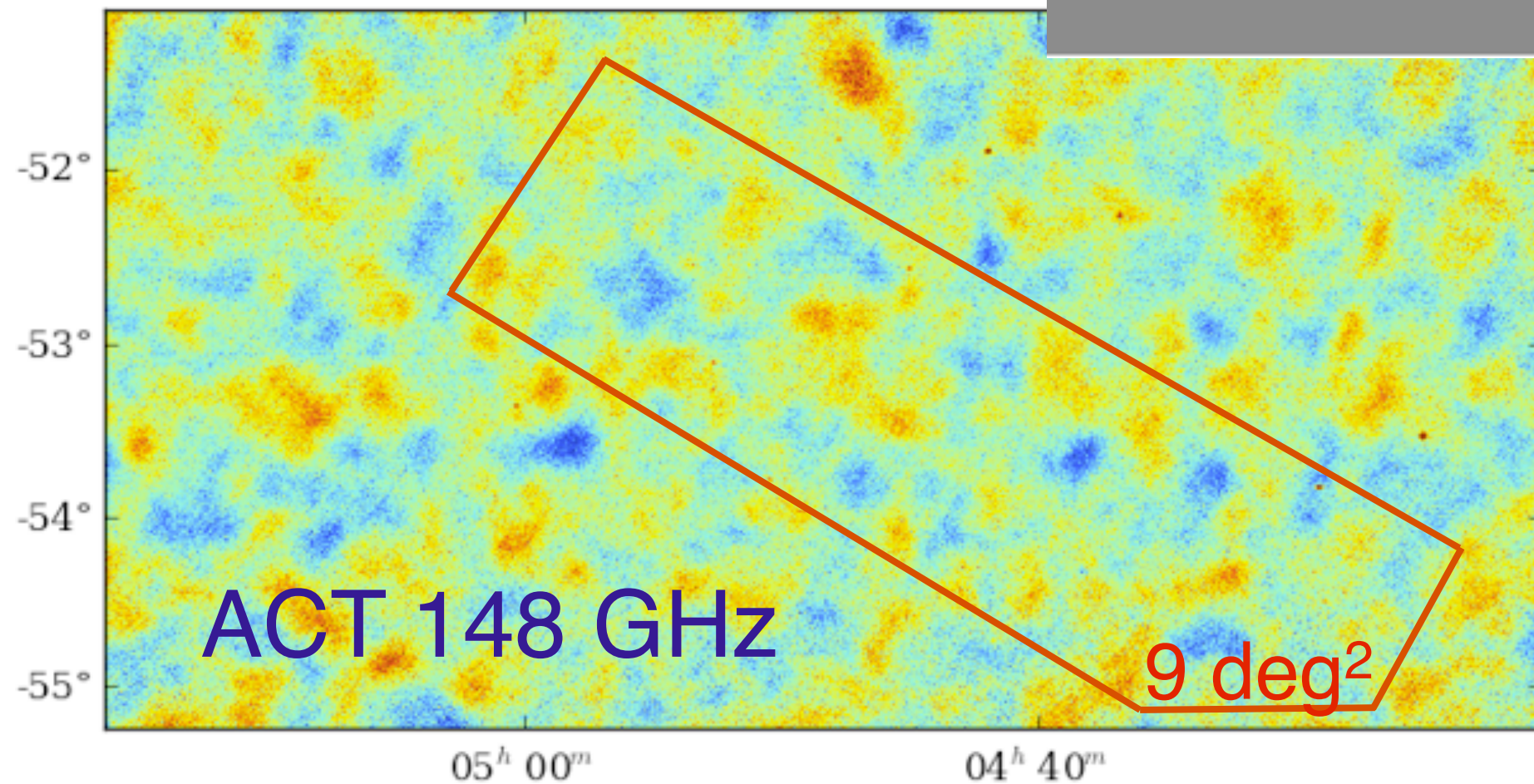
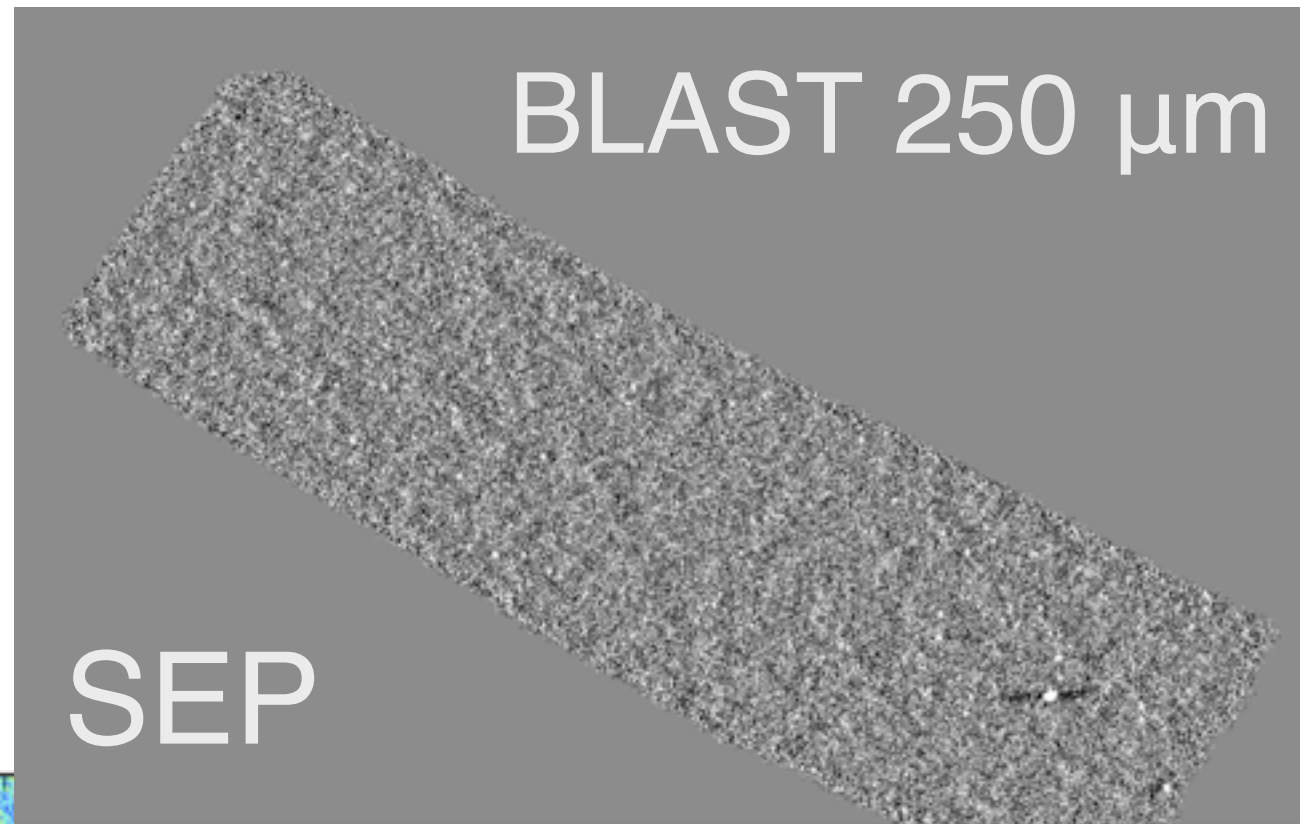
Unresolved CIB



The CMB sky

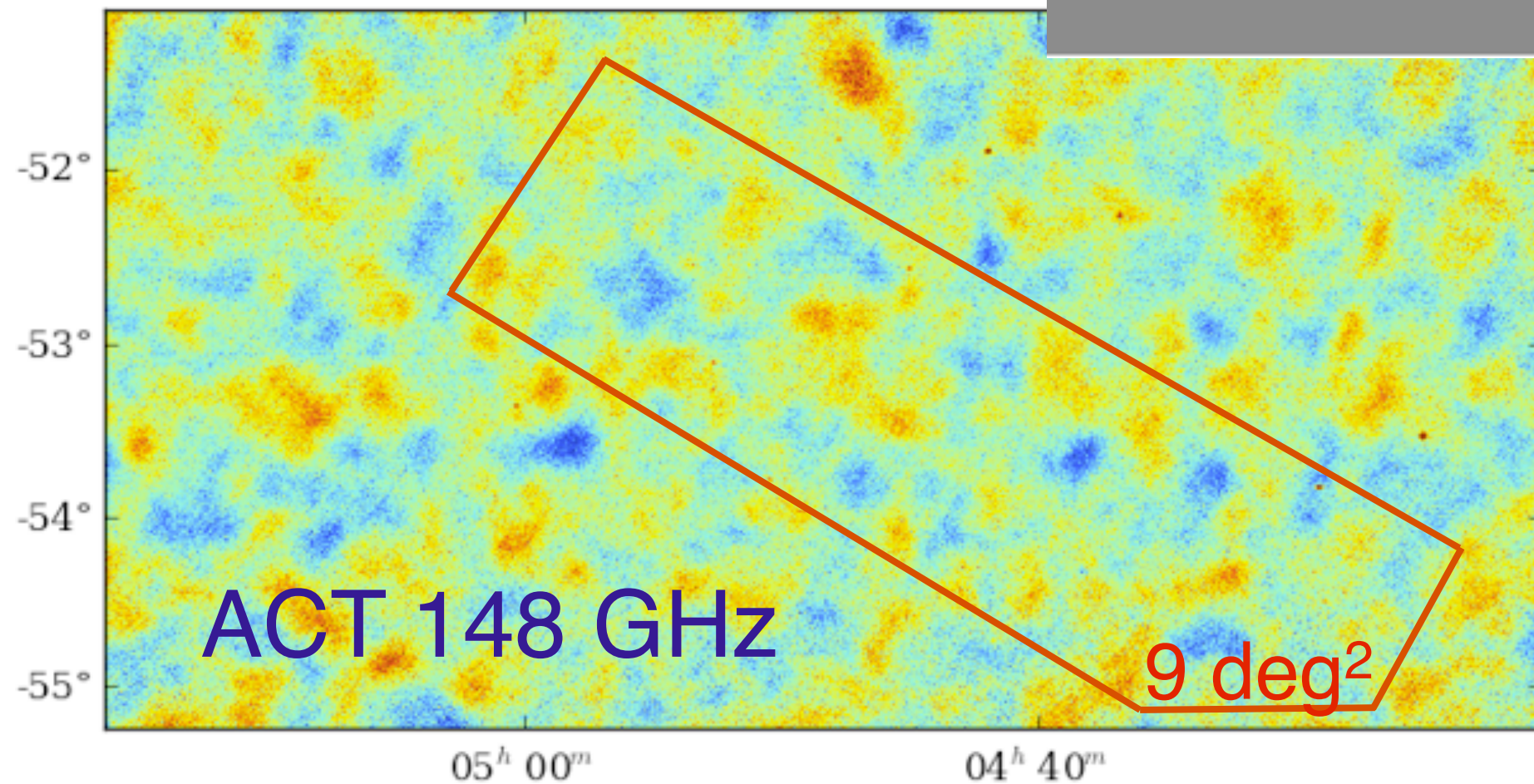
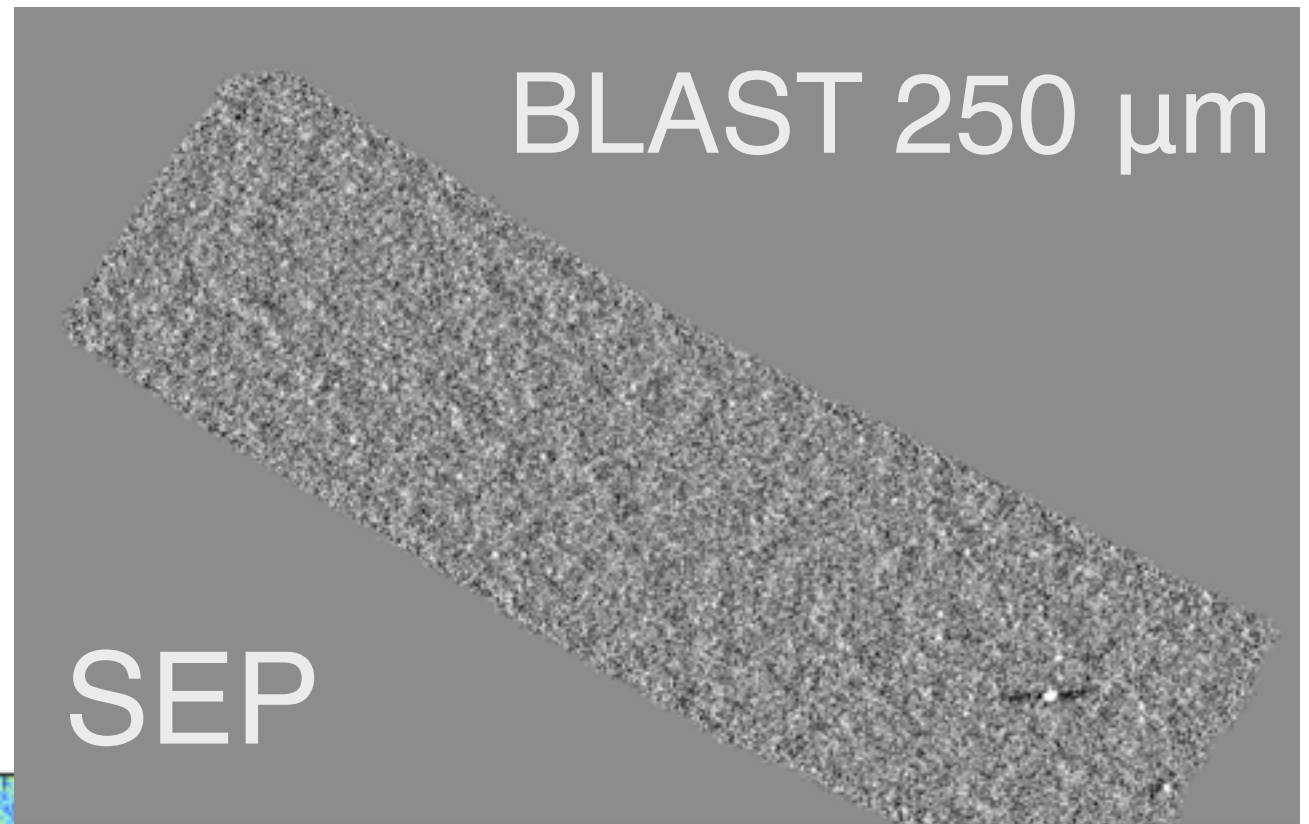
Cross-Correlations

Isolate Dusty Galaxies from the Rest



Cross-Correlations

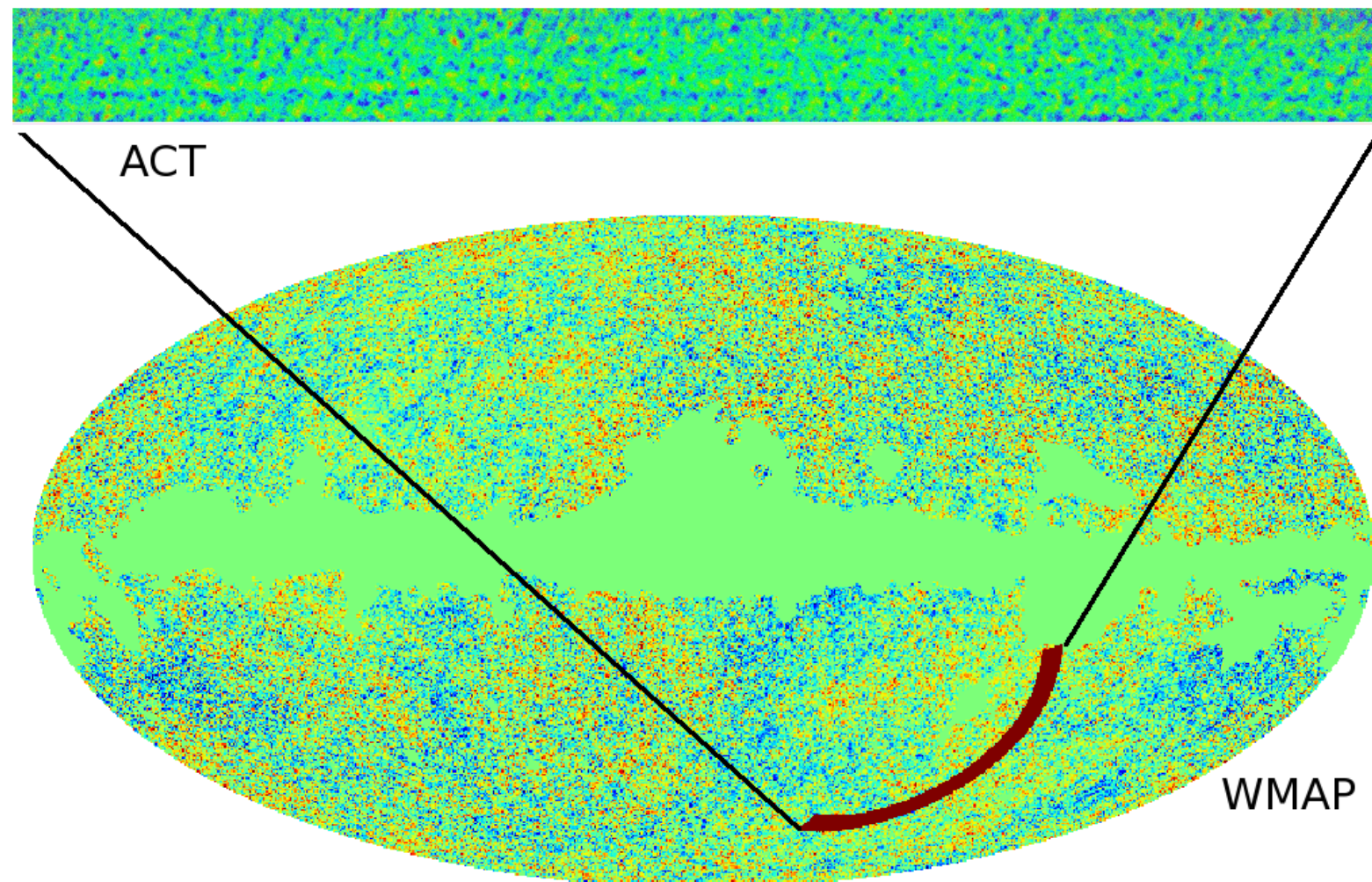
Isolate Dusty Galaxies from the Rest



ACT X BLAST

ACT Southern Field

Hajian et al (2010)

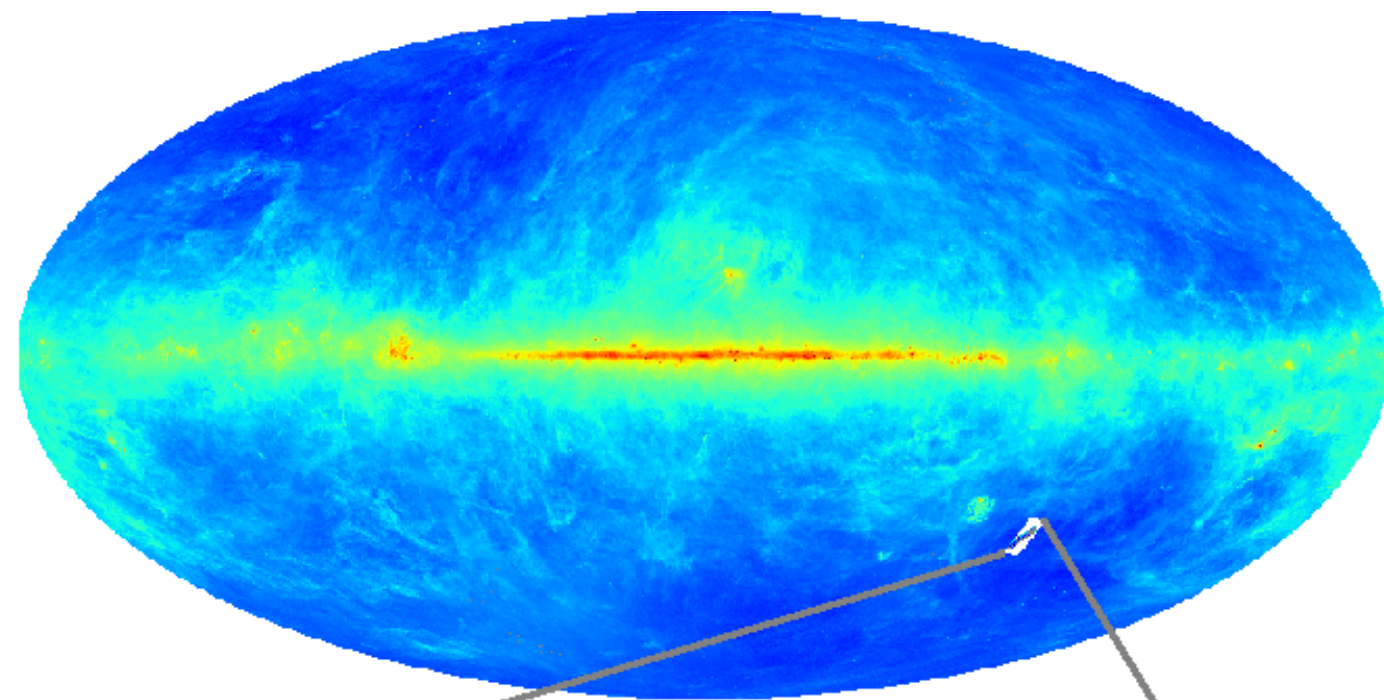
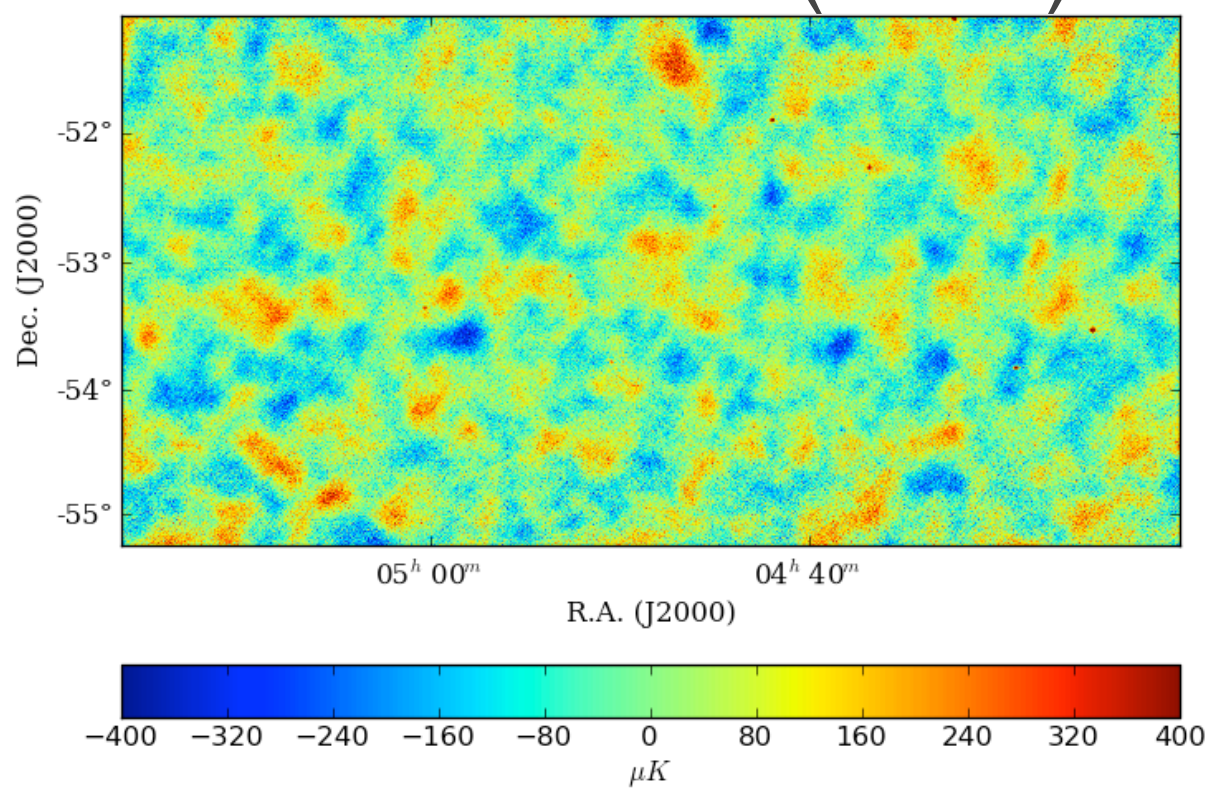


- 300 deg²
- 1' resolution
- 3 bands
 - 148 GHz (~2.0 mm)
 - 218 GHz (~1.4 mm)
 - 277 GHz (~1.1 mm)

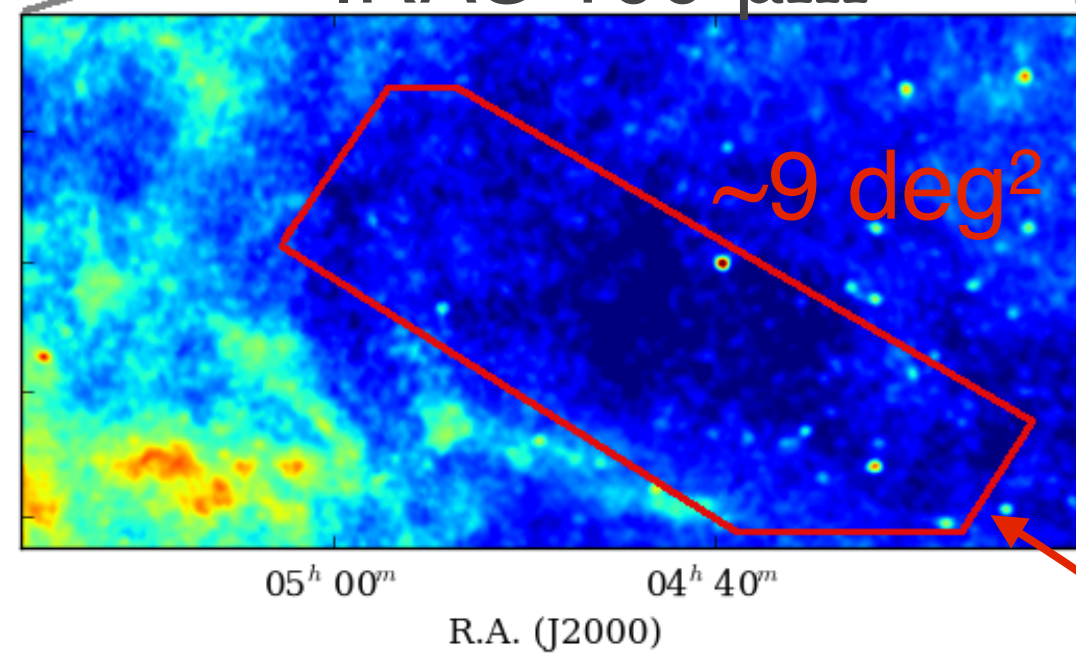


SEP

ACT 148 GHz (2 mm)

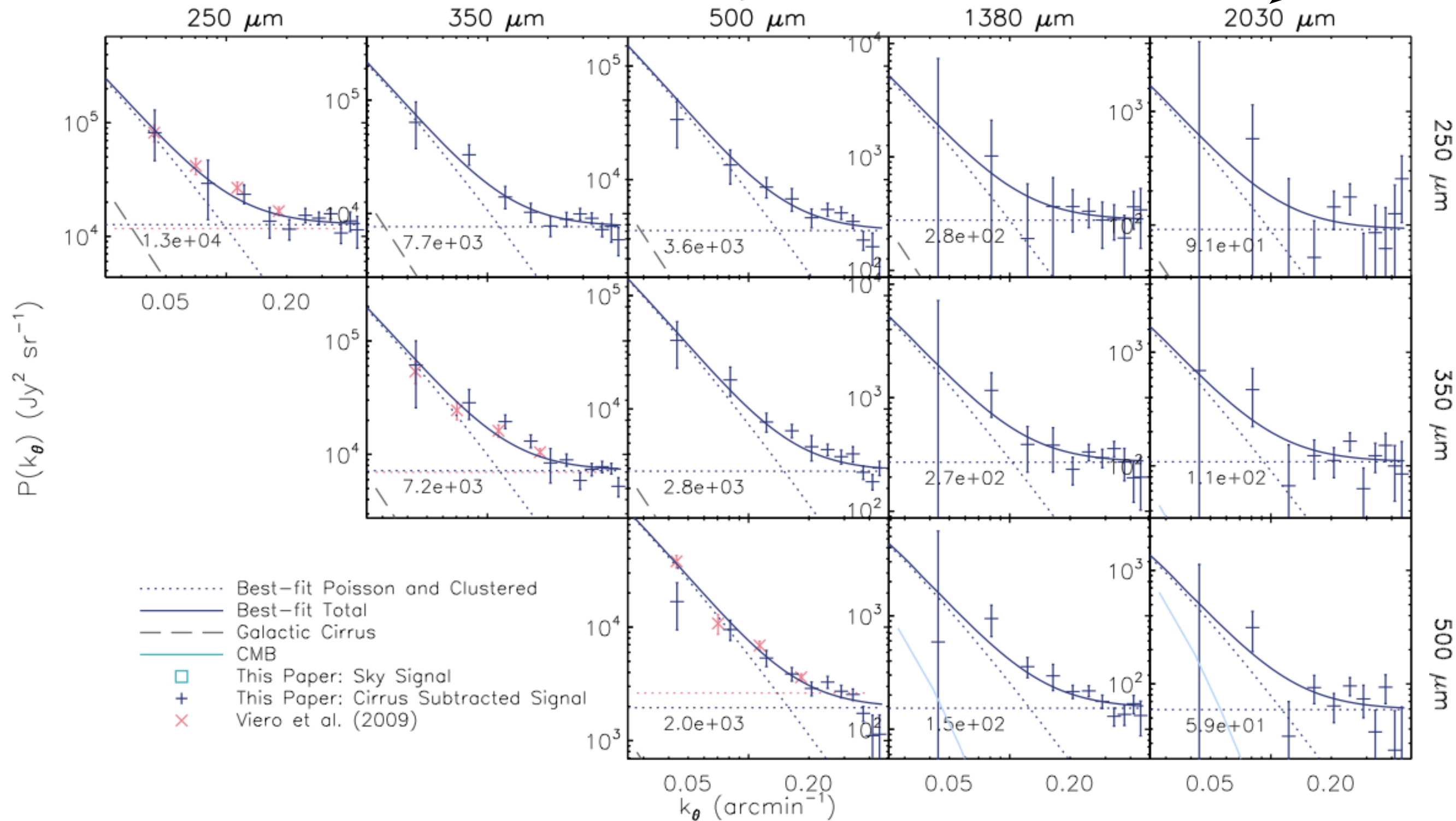


IRAS 100 μm

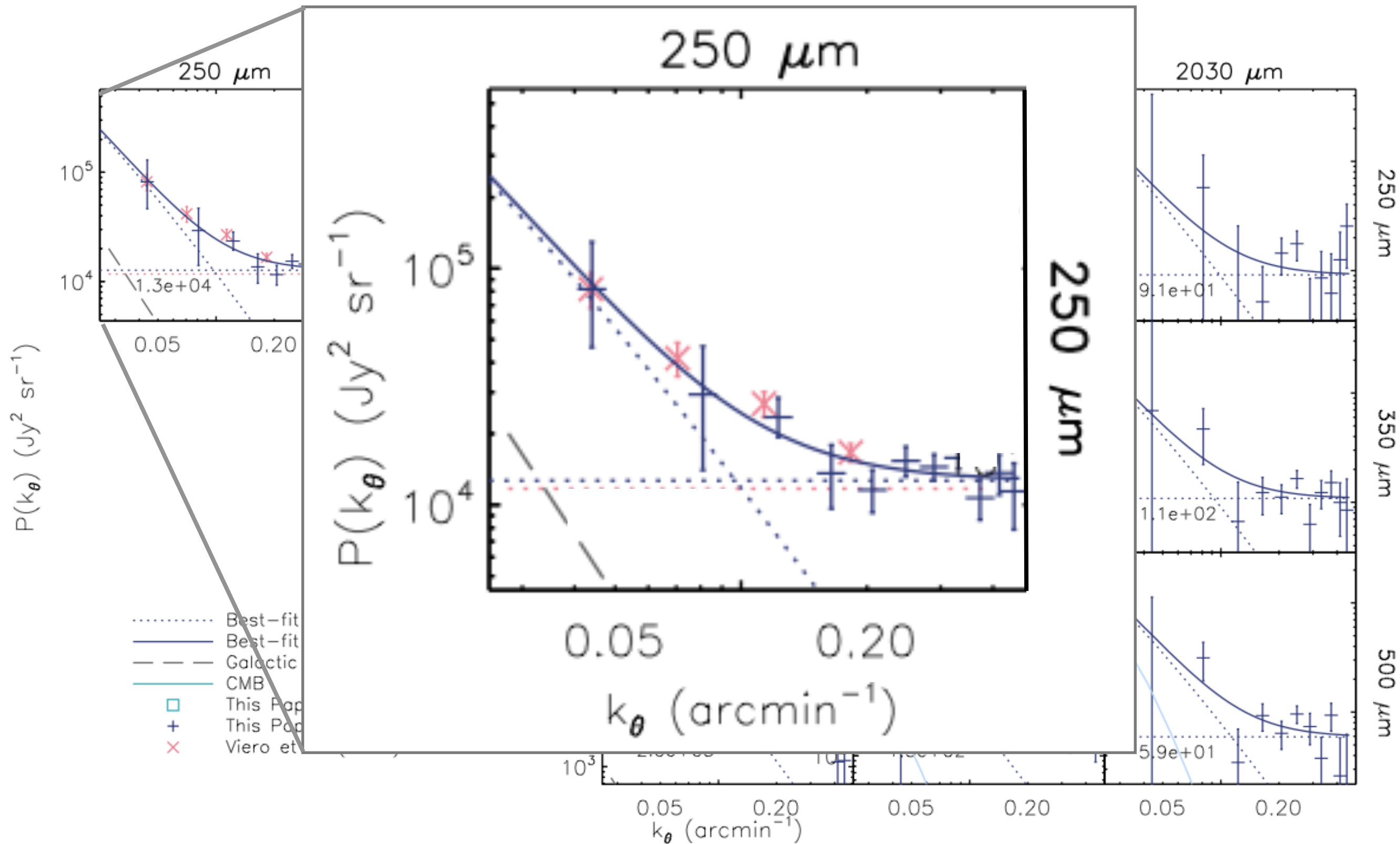


Mean Flux $\sim 1.1 \text{ MJy/sr}$

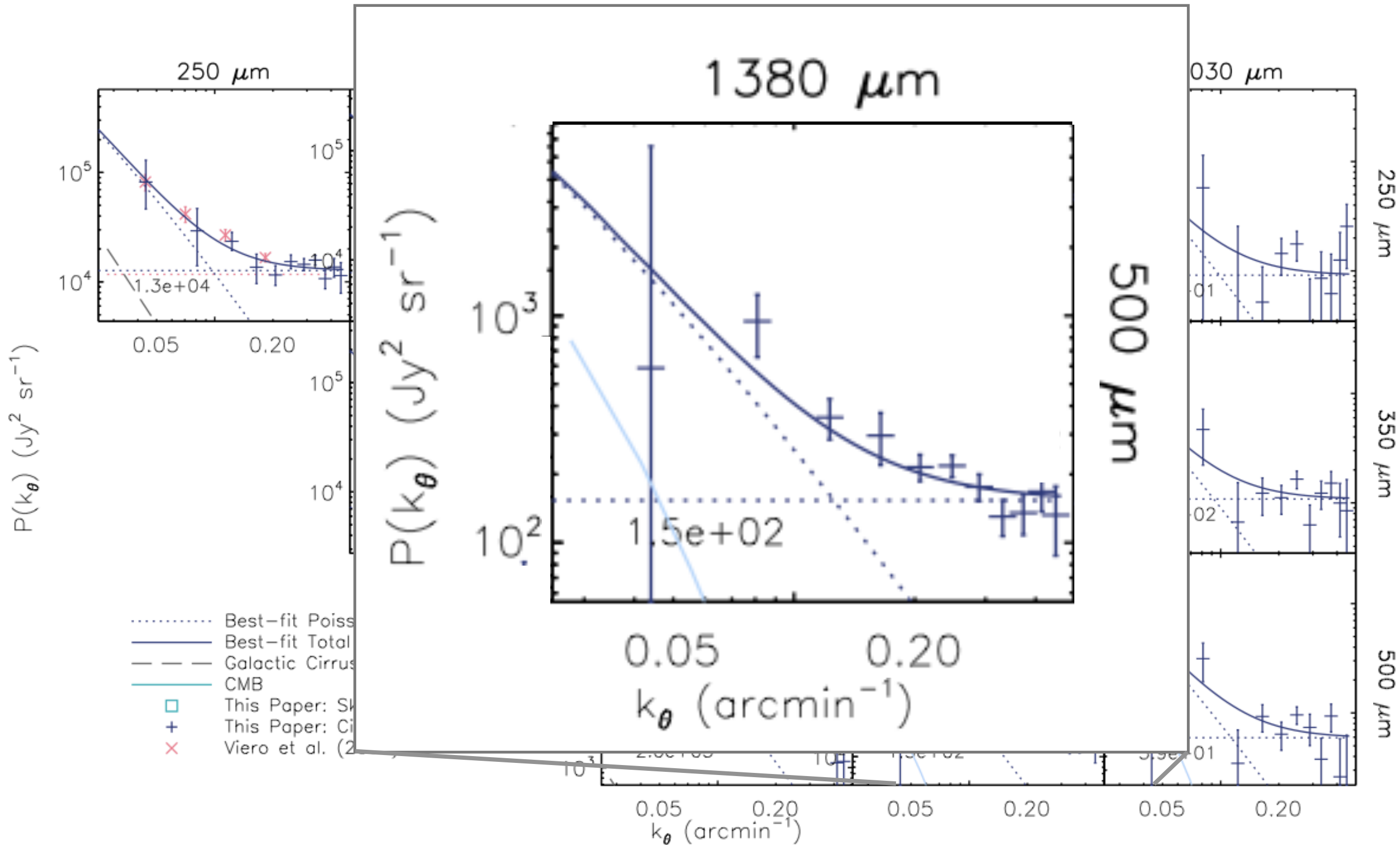
Cross-Correlate BLAST and ACT



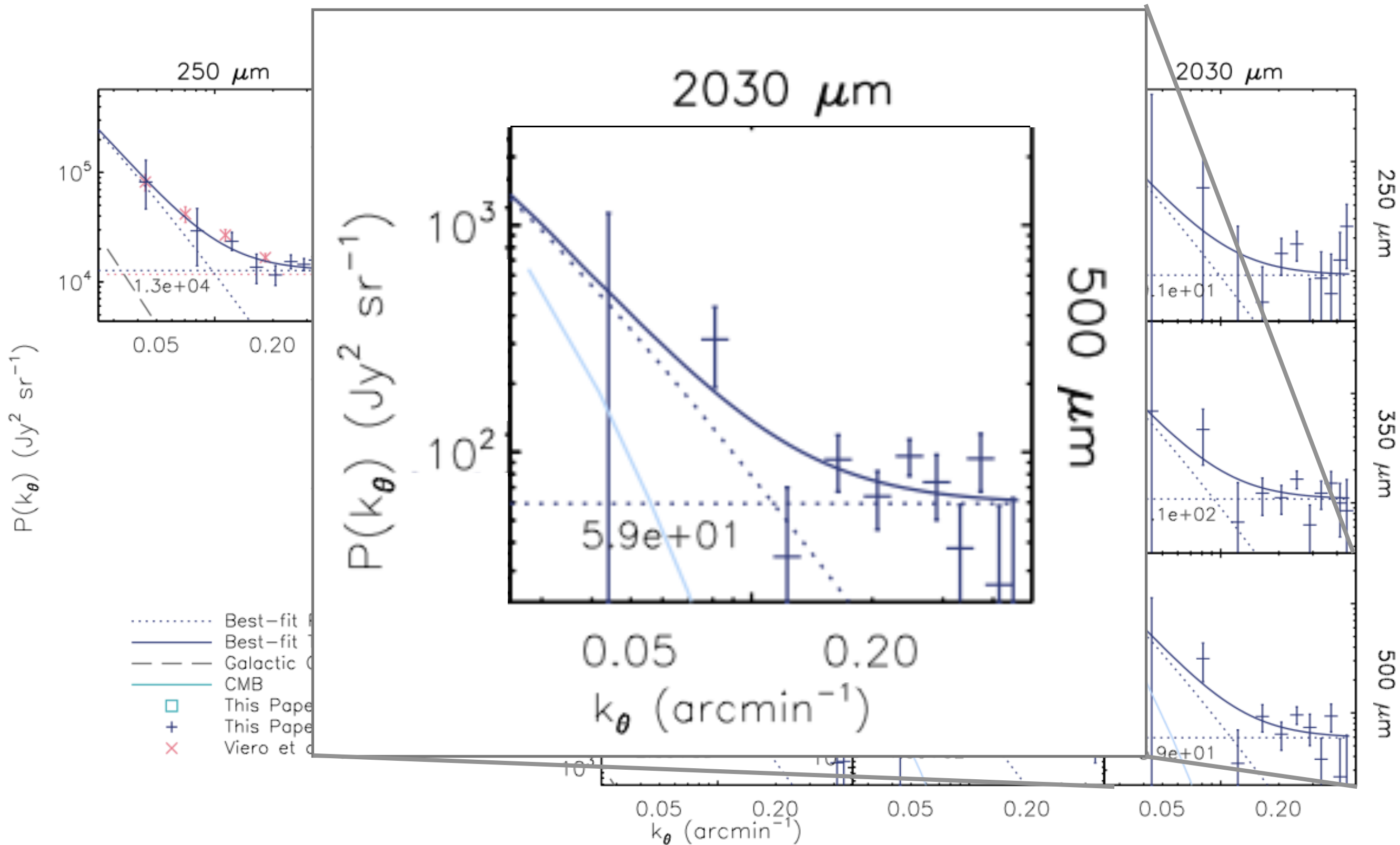
Hajian & Viero et al.
arXiv:1101.1517



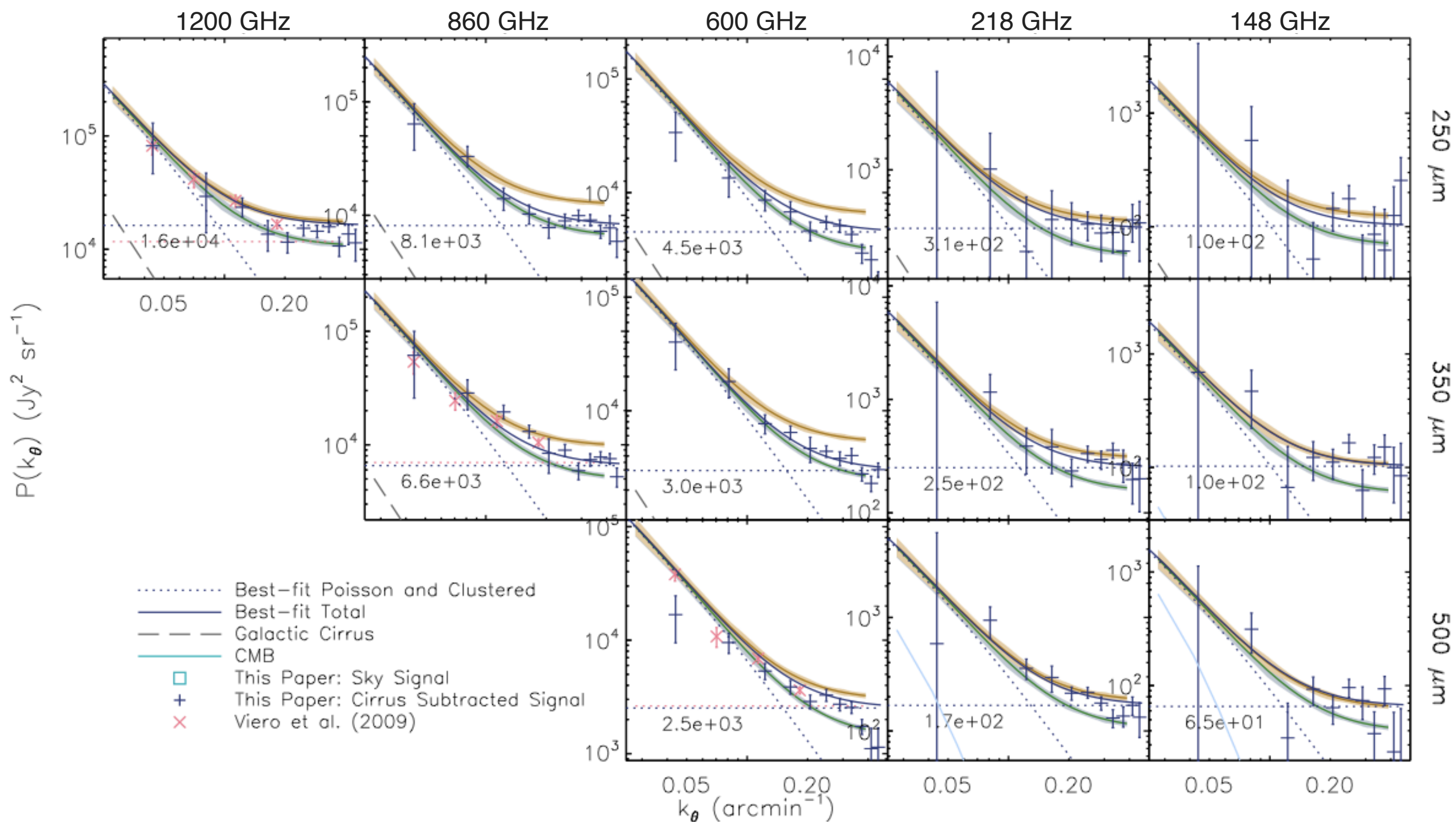
Hajian & Viero et al.
arXiv:1101.1517



Hajian & Viero et al.
 arXiv:1101.1517



Hajian & Viero et al.
arXiv:1101.1517



Model: Marsden et al. 1010.1176

Model: Béthermin et al. 1010.1150

what have we learned?

Summary #2

what have we learned?

- There is a significant population of *unresolved* clustered galaxies in CMB maps

what have we learned?

- There is a significant population of *unresolved* clustered galaxies in CMB maps
- These galaxies are mostly at high- z ($>\sim 2$)

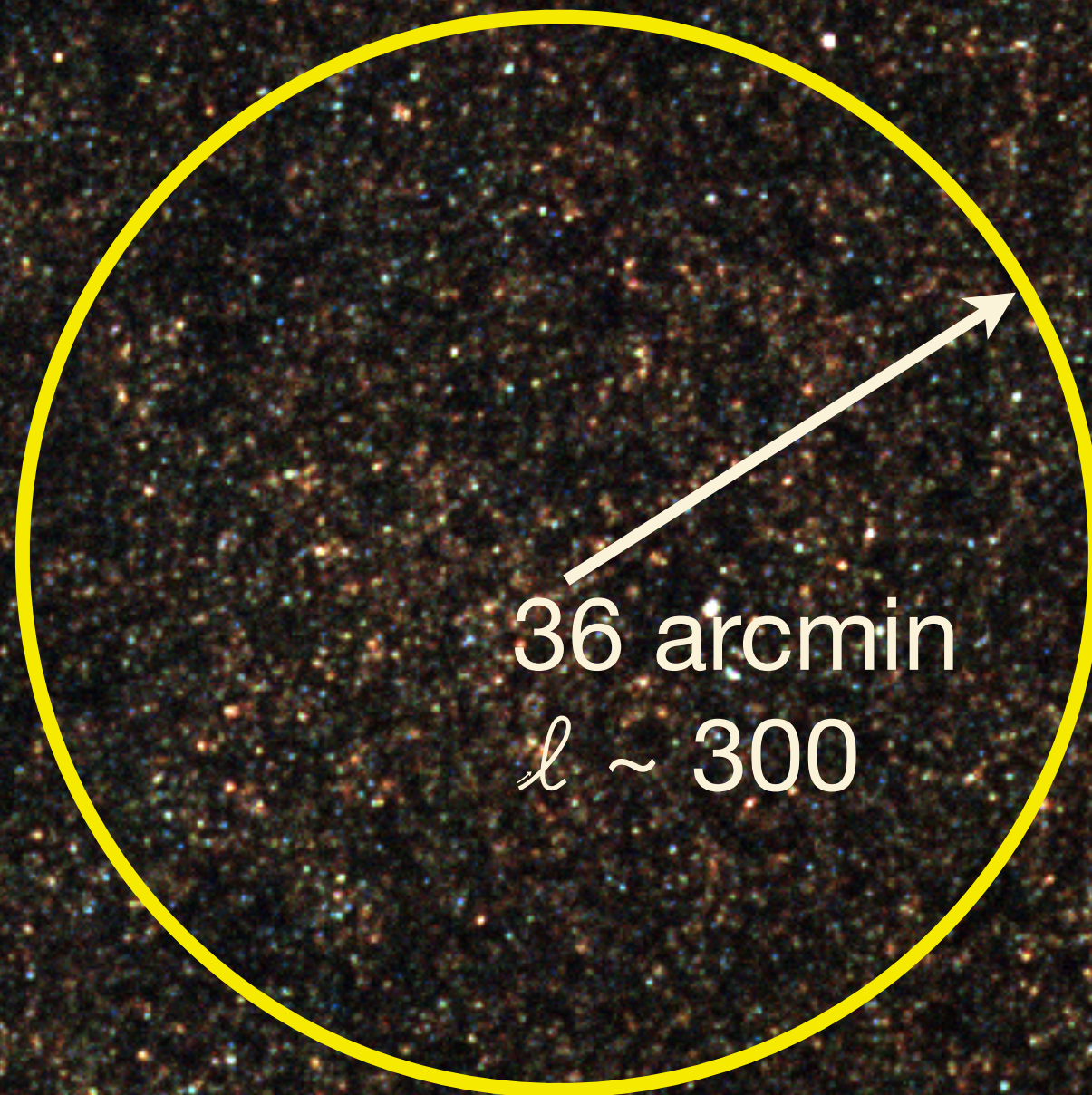
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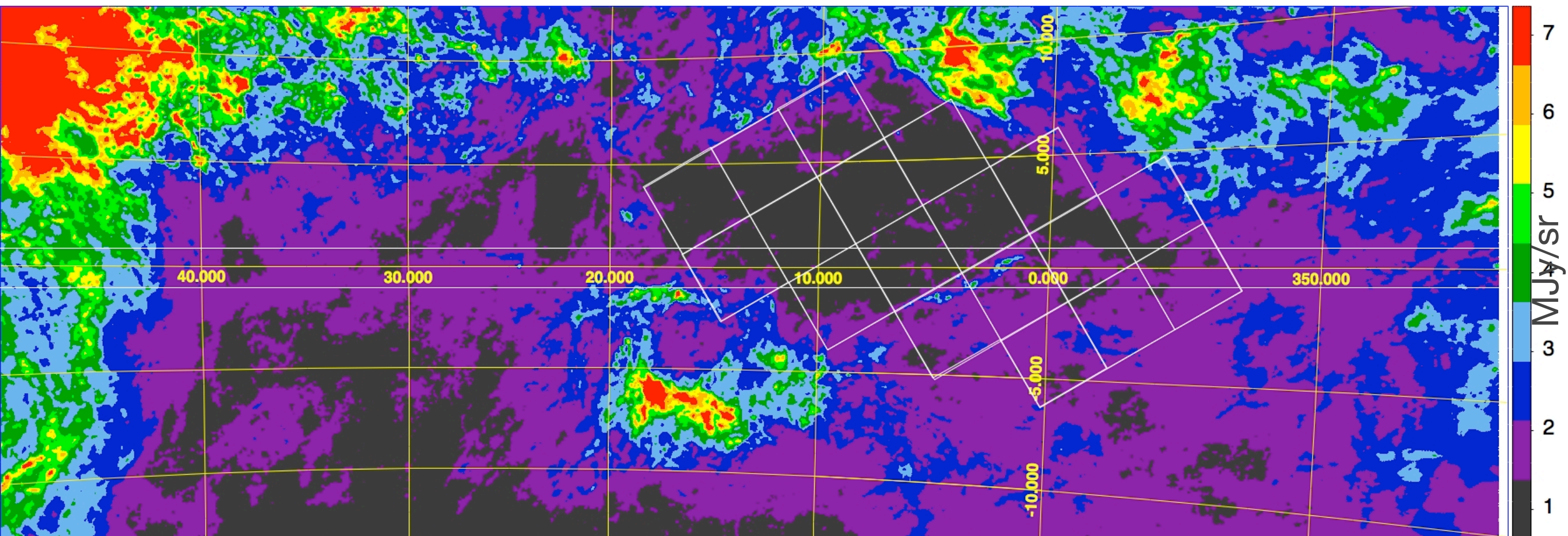
- There is a significant population of *unresolved* clustered galaxies in CMB maps
- These galaxies are mostly at high- z ($>\sim 2$)
- Galaxy models are thus far unable to reproduce the data

A deep space photograph showing a vast field of stars of various colors (yellow, orange, blue, white) against a dark background. The stars are densely packed, creating a textured, sparkling effect. The text "Looking Ahead..." is centered in a large, white, sans-serif font.

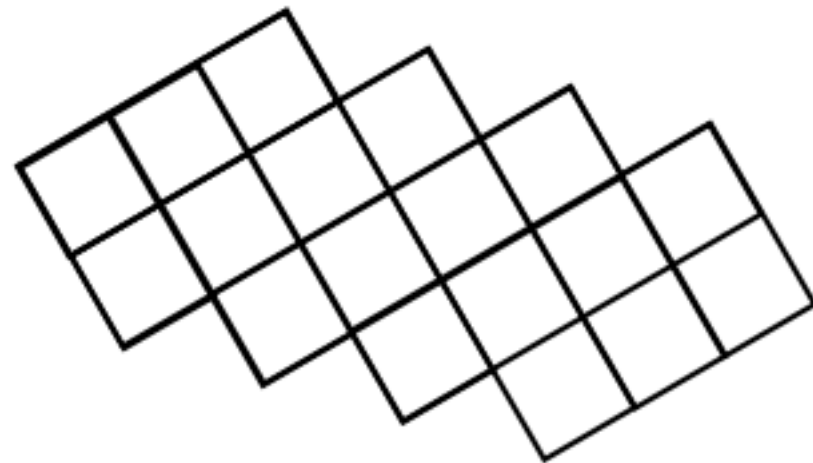
Looking Ahead...

- large scales modes constrain the linear bias
- cross-frequency spectra probe high- z clustering of galaxies





HeRMES Large-Mode Survey (HeLMS)



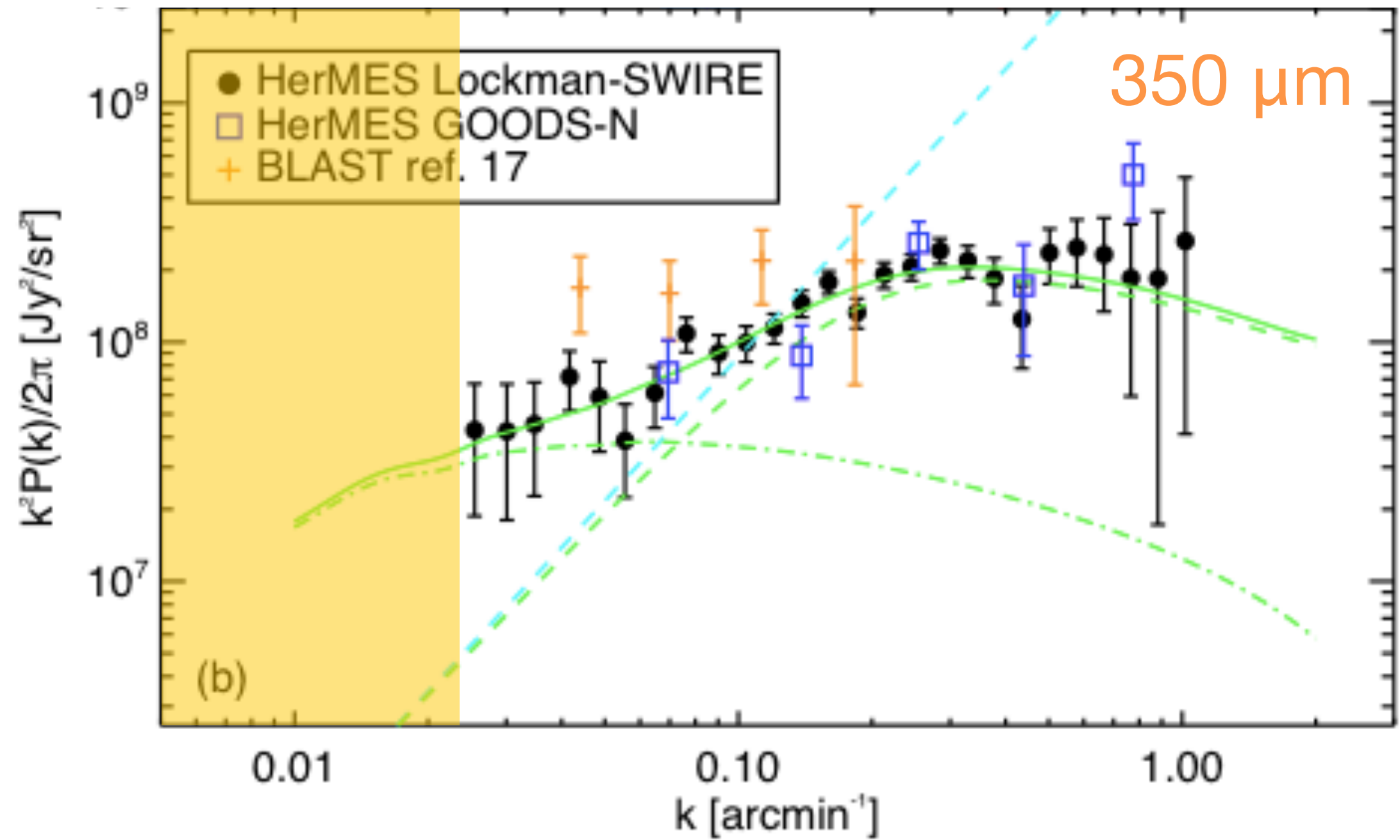
total= 106 hours
270 deg²

	aors (#)	time/aor (m)	time (h)	area (deg ²)
	5	815	68	150
	4	489	32.6	90
	2	163	5.4	30

- Designed to maximize long, fast scans (60"/s)
- Interlaced AORs for maximum cross-linking

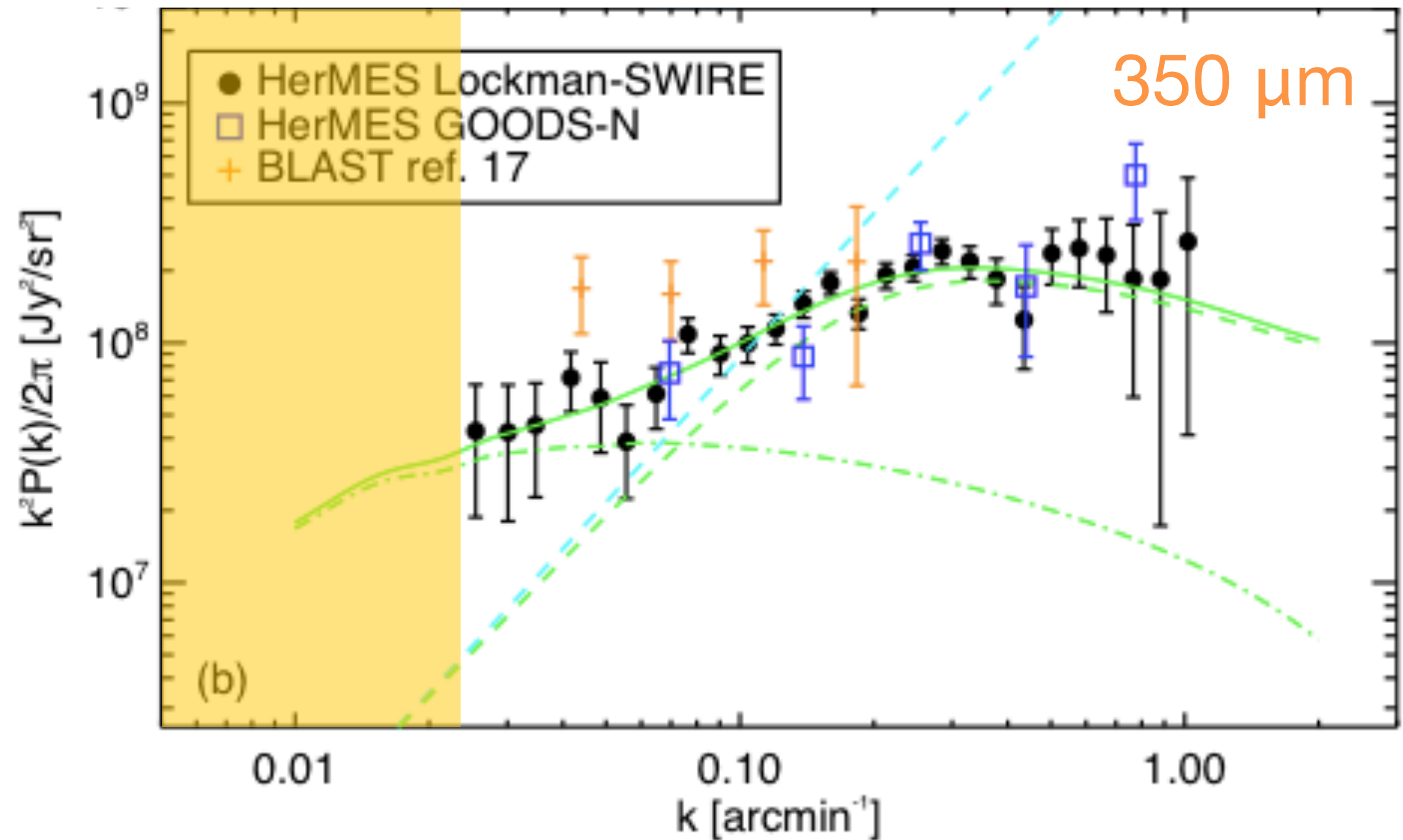
HeRMES Large-Mode Survey (HeLMS)

Amblard et al. (2011)



HerMES

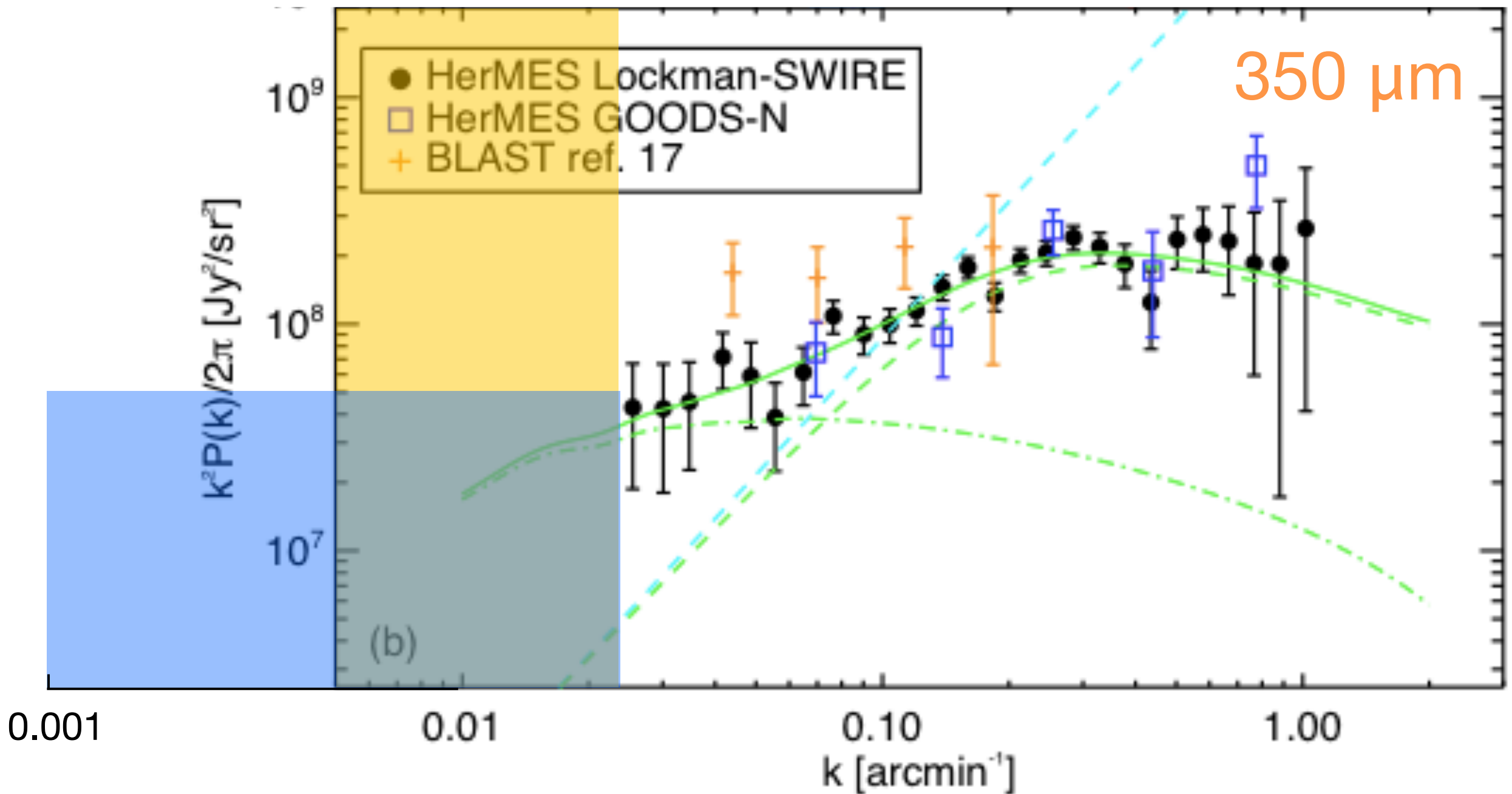
Amblard et al. (2011)



- Currently noise dominated at $\ell \leq 550$ ($k = 0.025$)

HerMES

Amblard et al. (2011)

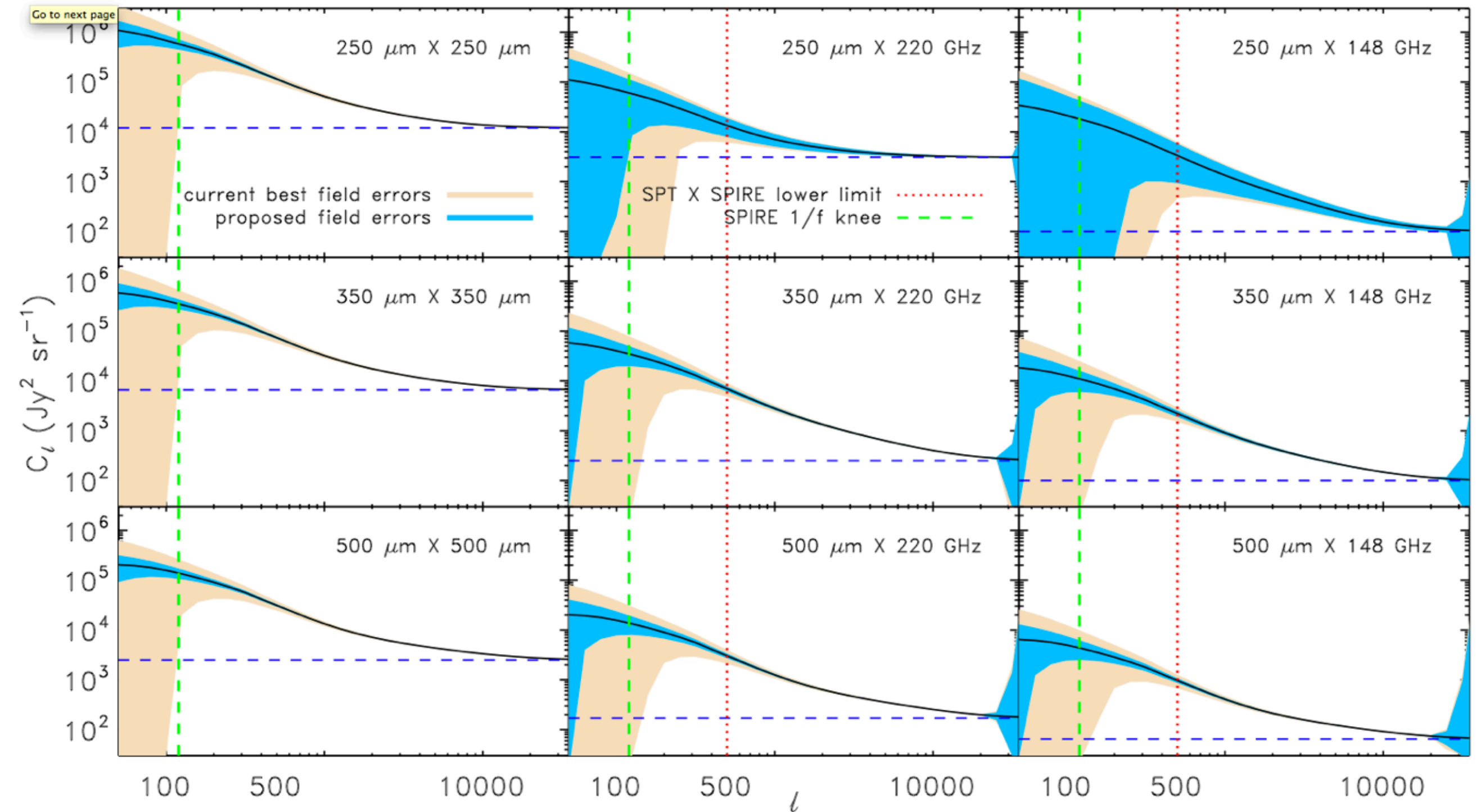


- Currently noise dominated at $\ell \leq 550$ ($k = 0.025$)
- HeLMS sensitive to $\ell \geq 200$ ($k \geq 0.001$)

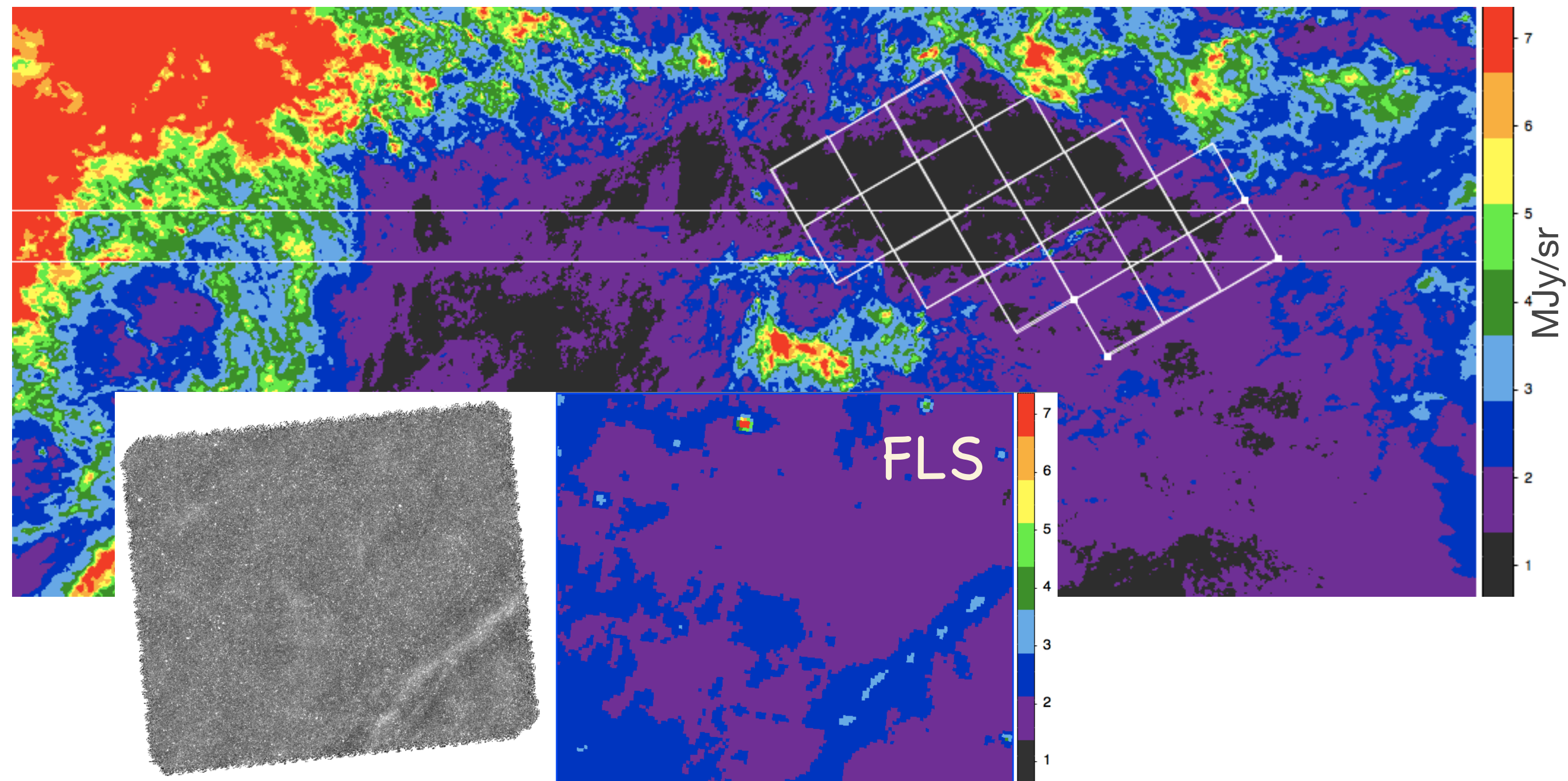
HerMES

SPIRE Only

SPIRE X ACT



Dramatically reduce noise on large-scales in auto-spectra
ACTxSPIRE will probe scales larger than SPTxSPIRE can



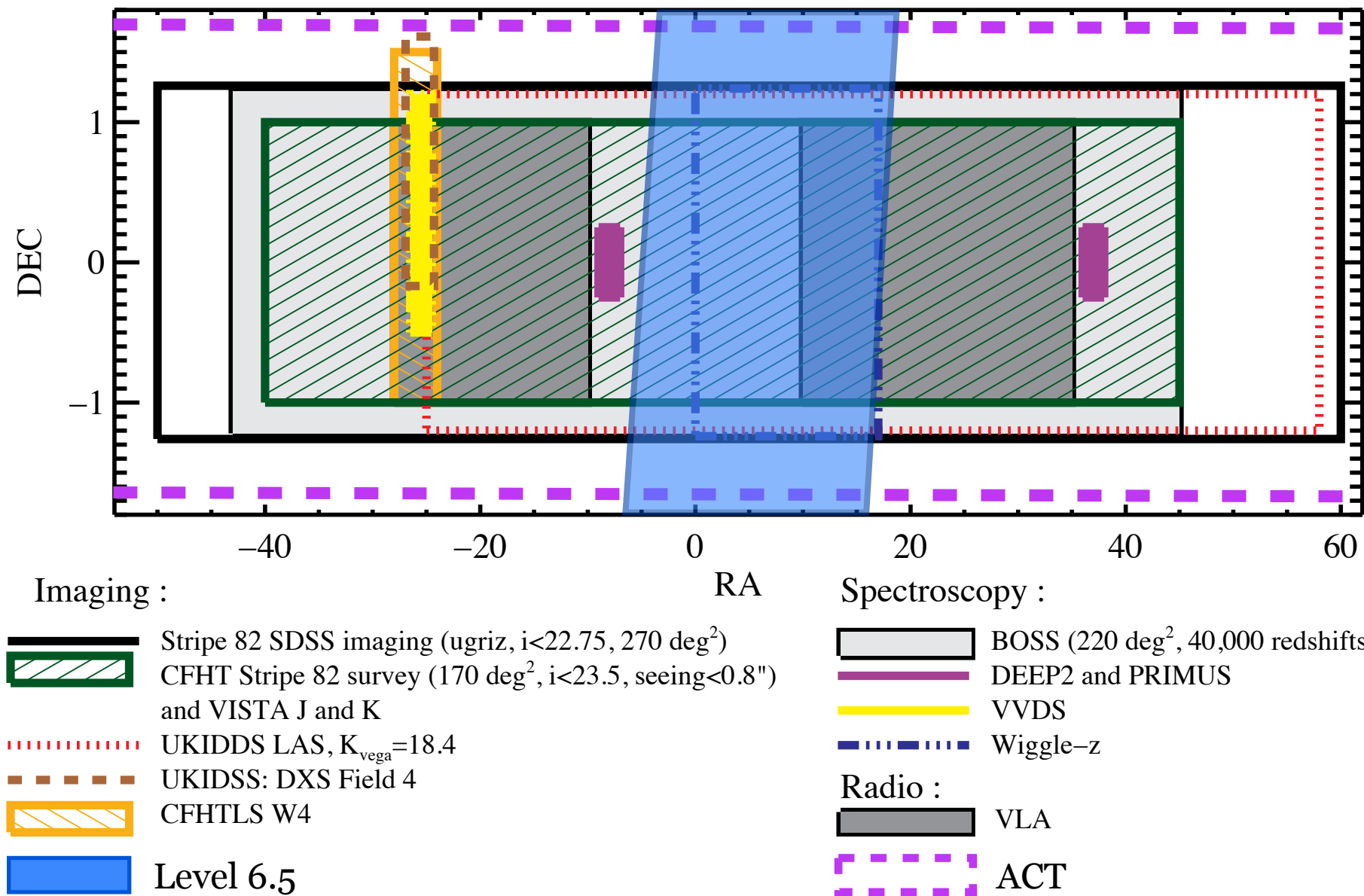
HeRMES Large-Mode Survey

Today

- SDSS optical
- ACT (80 deg²)
- CFHT
- UKIDDS
- VLA
- Wiggle-z
- BOSS

Tomorrow

- ALMA
- ACTpol
- Spitzer Warm
- Planck
- HI
- Visible from most sites



HeLMS Legacy

end