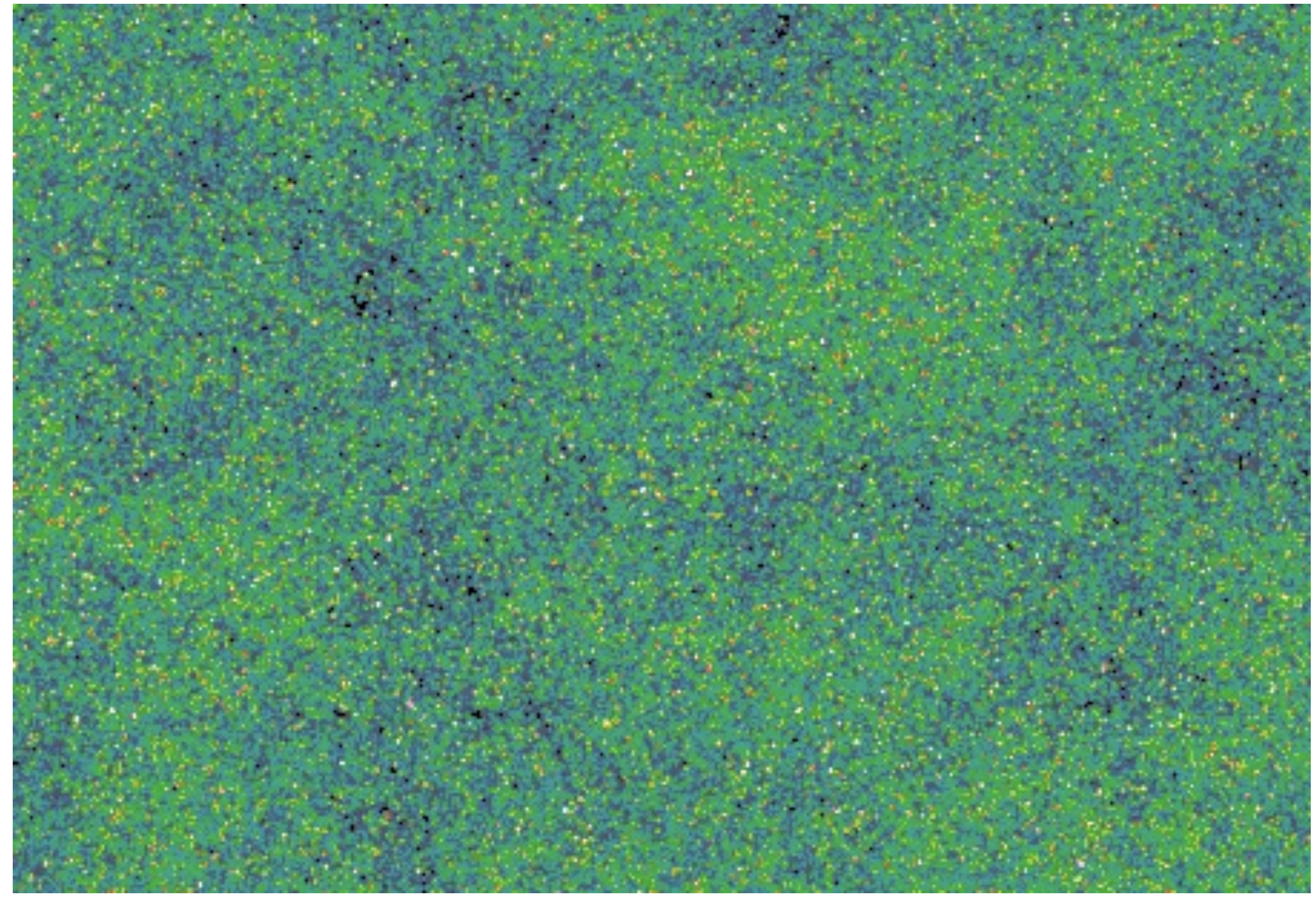


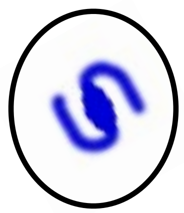
Implications of Galaxy Clustering on the CMB

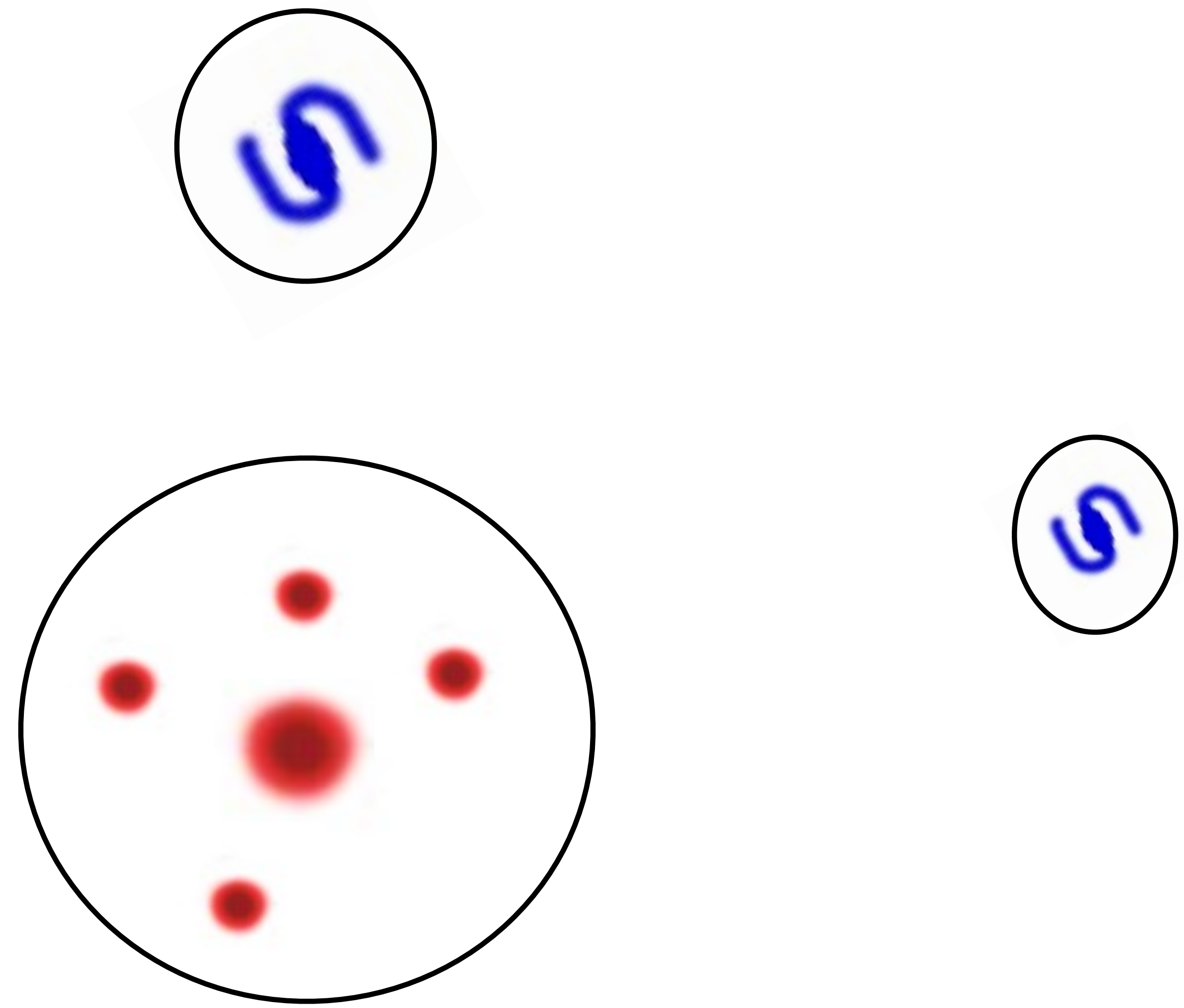
Marco Viero - Caltech

Blue
Star-Forming
Galaxy

Red
Quiescent
Galaxy

Brief History of Clustering

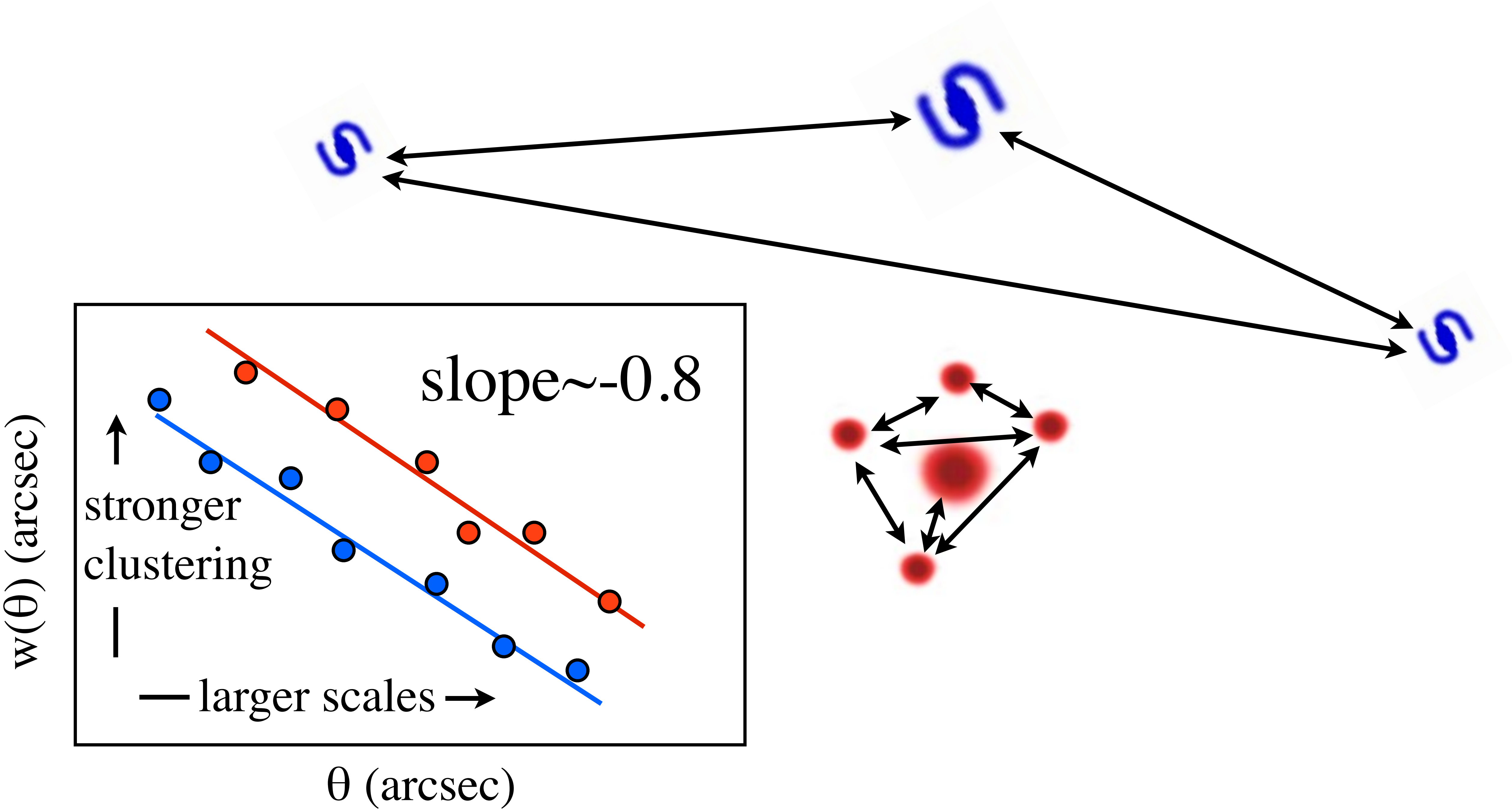




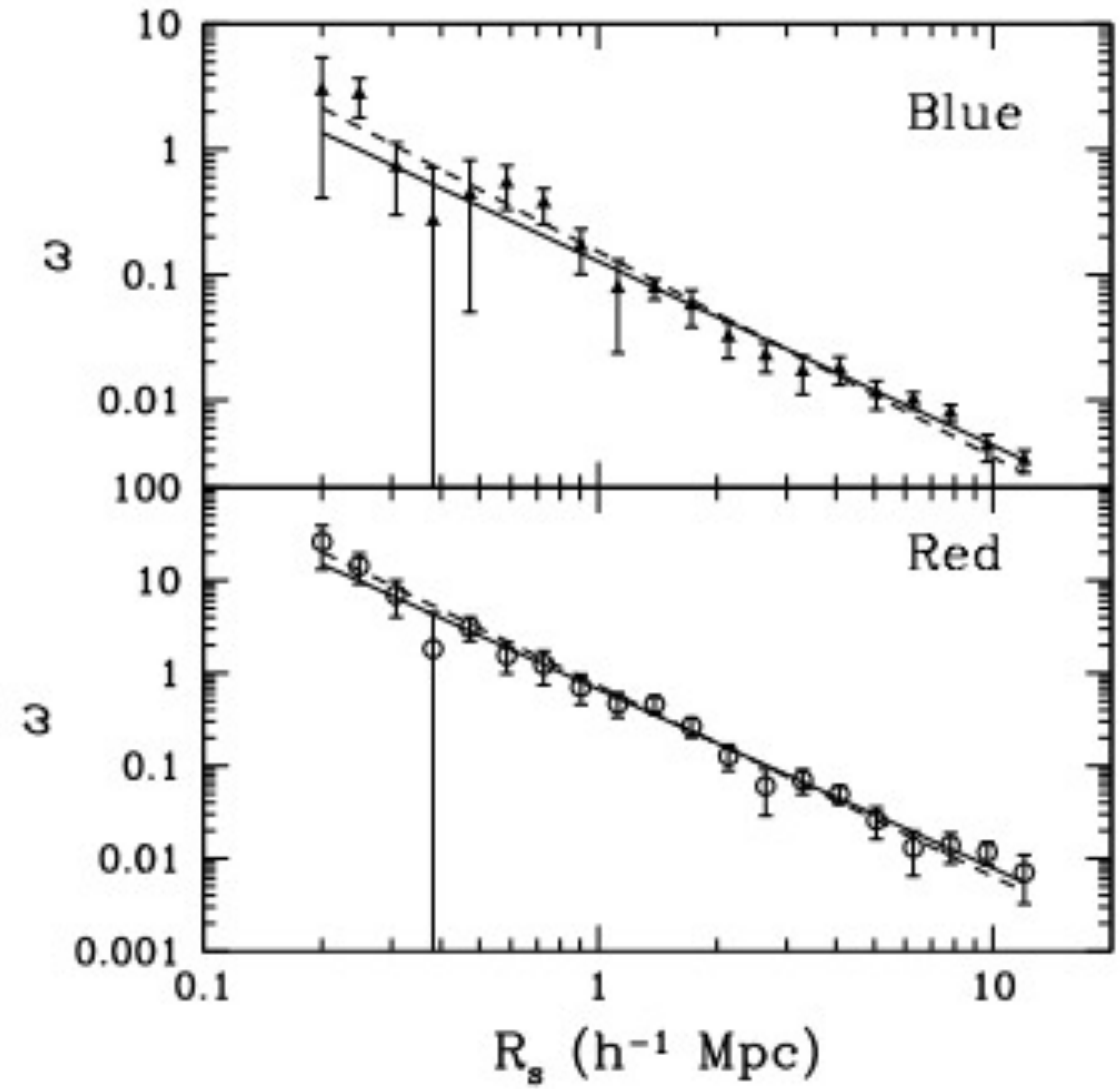
More Strongly Clustered:

- more luminous
- redder

Brief History of Clustering



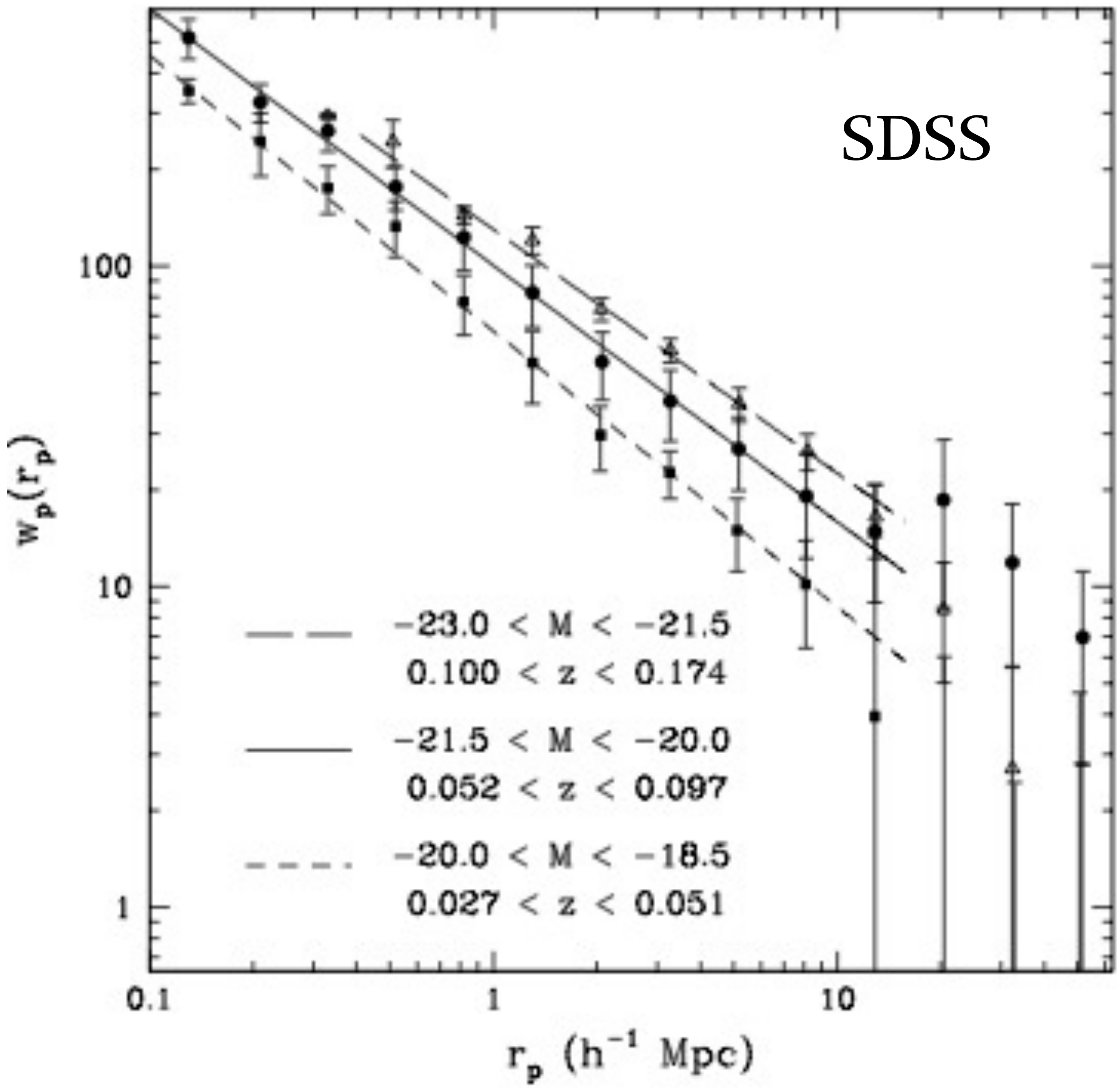
Brief History of Clustering



DEEP2

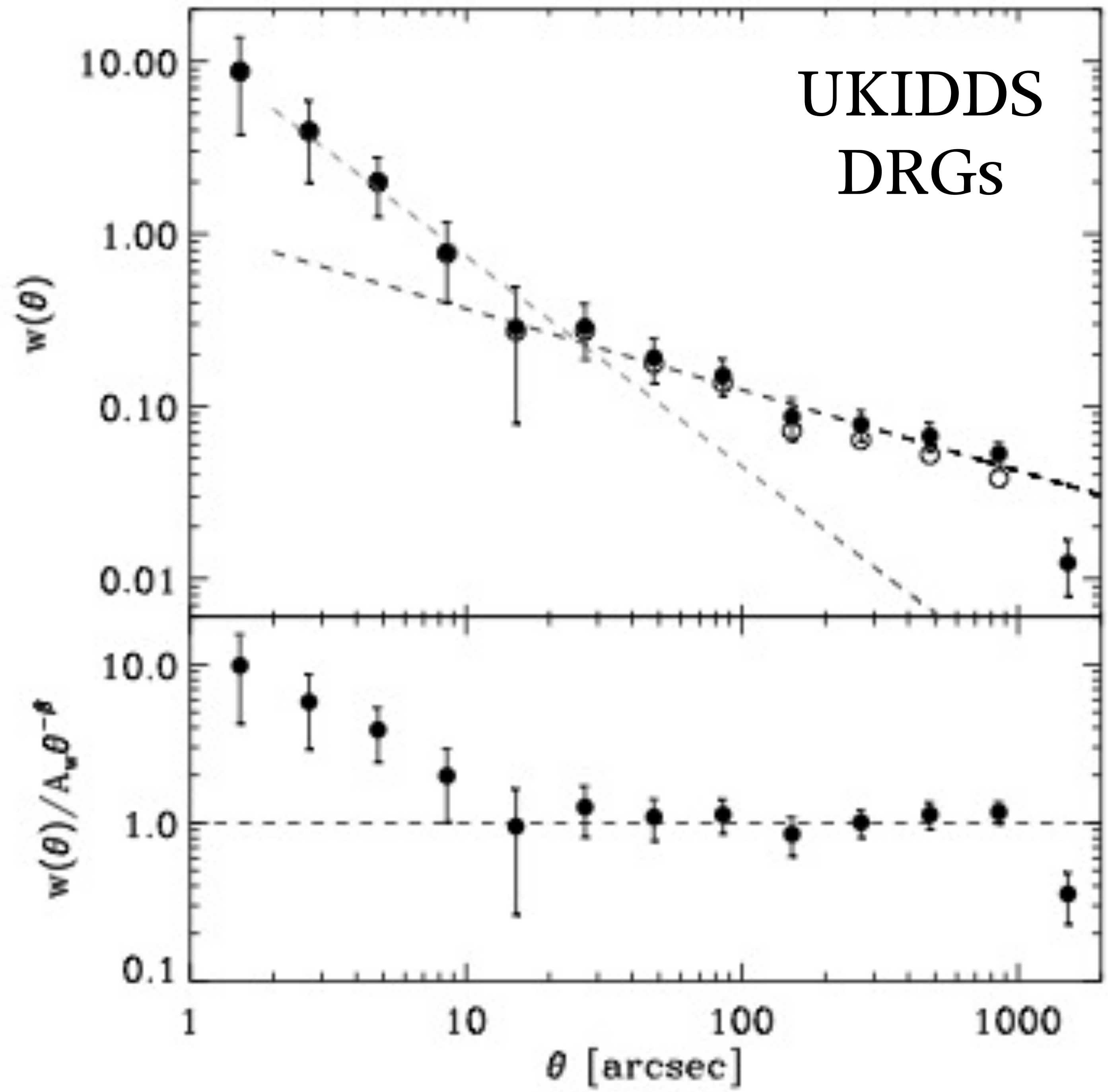
Coil (2008)

Brief History of Clustering



Zehavi (2003)

Brief History of Clustering

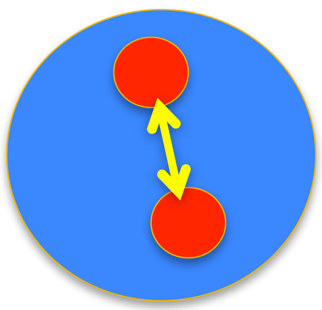


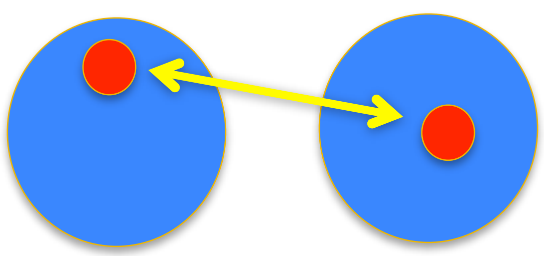
Quadri (2008)

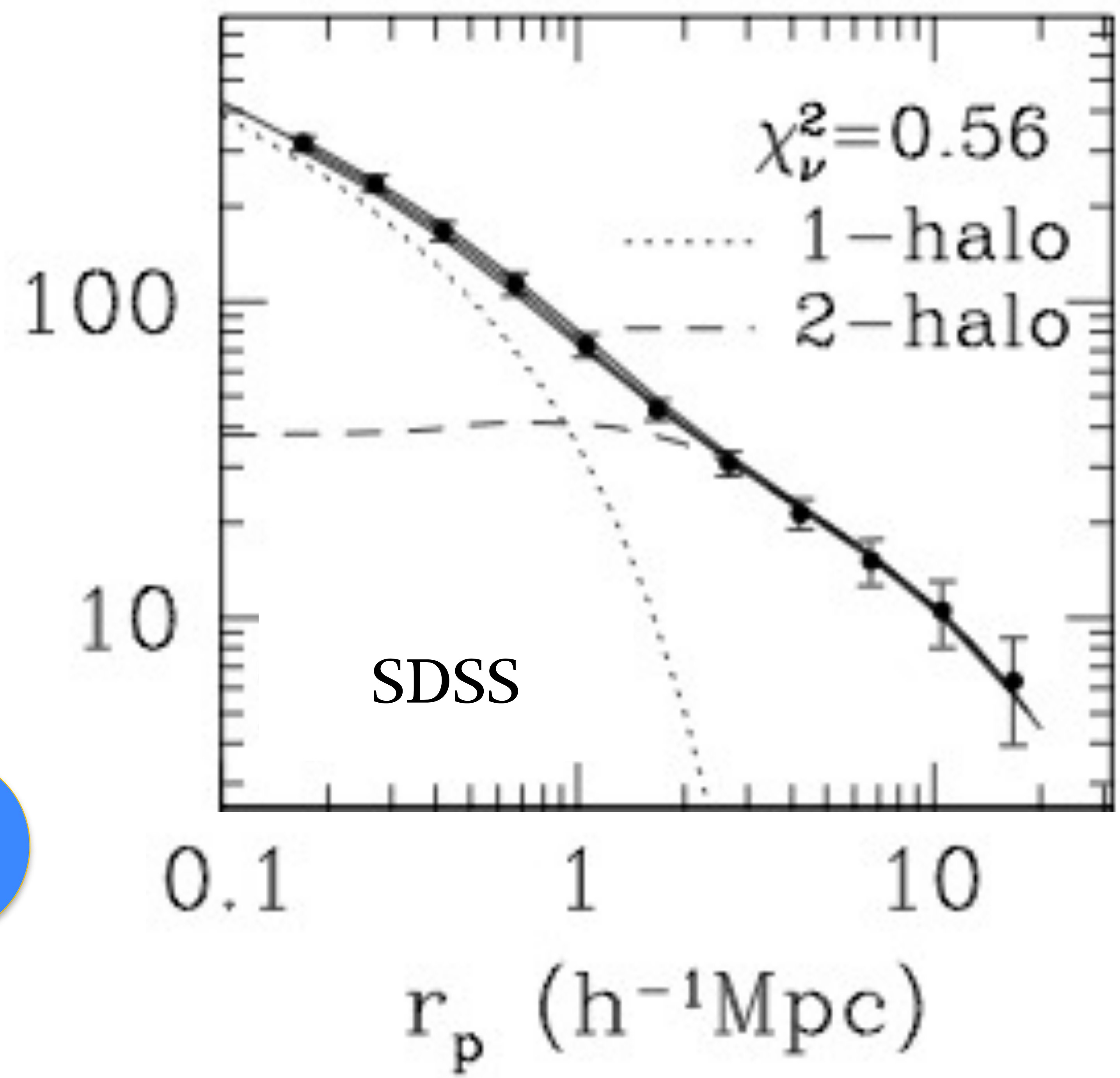
Brief History of Clustering

Halo Model

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

One-halo: 

Two-halo: 



Zheng (2007)

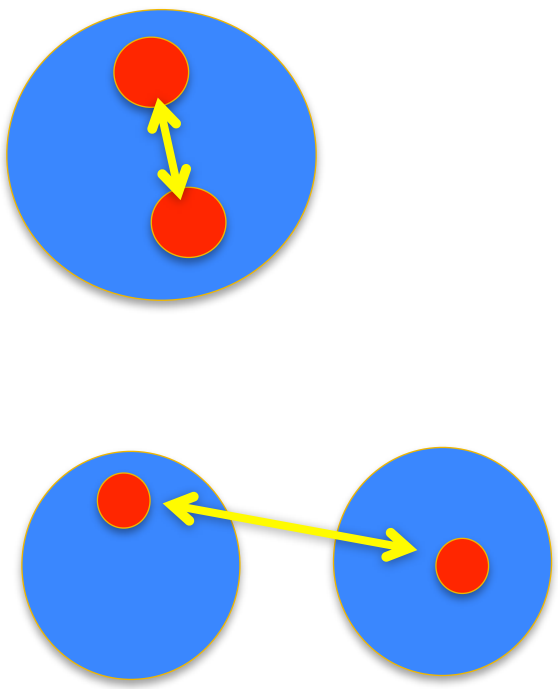
Brief History of Clustering

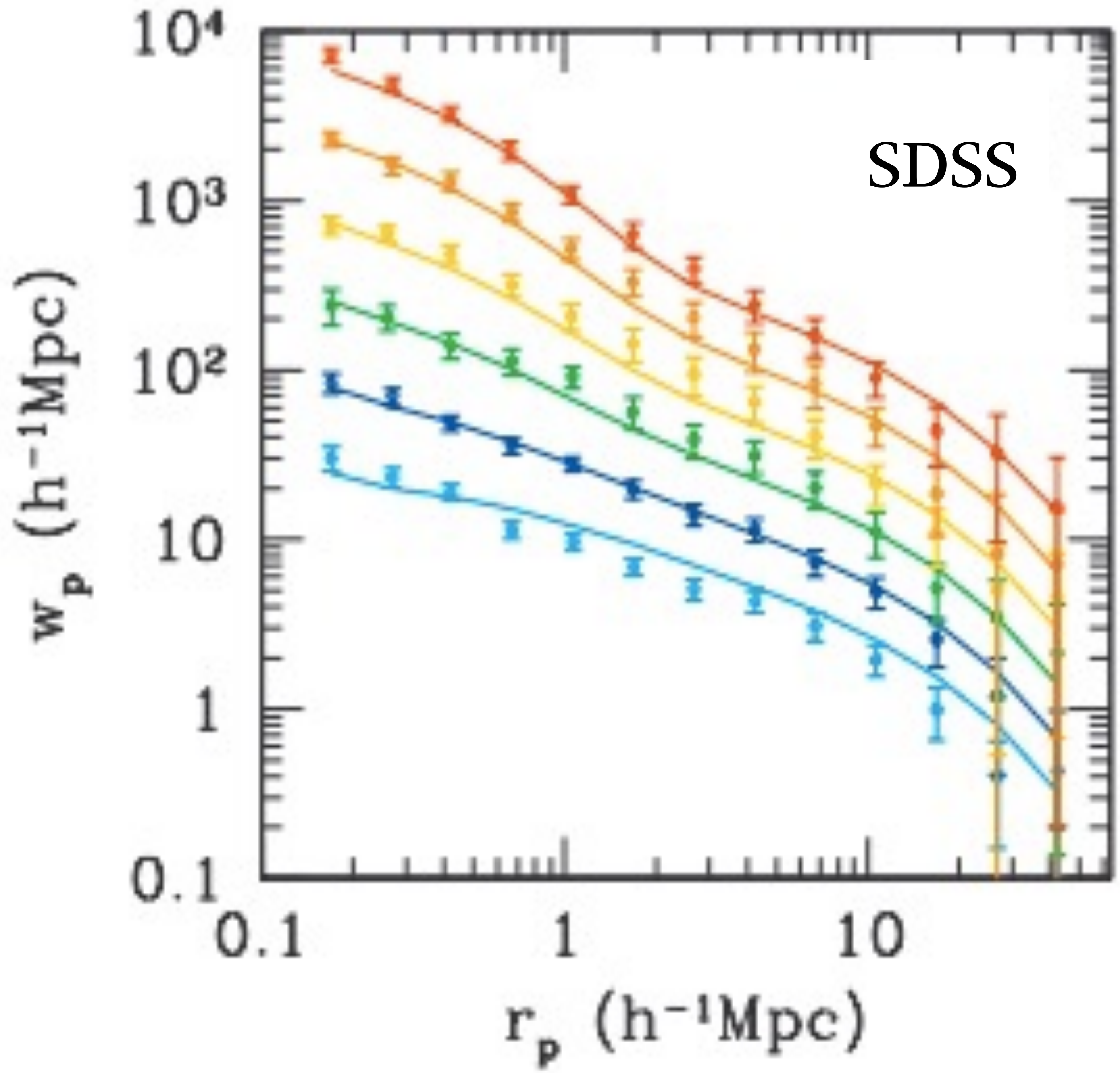
Halo Model

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

One-halo:

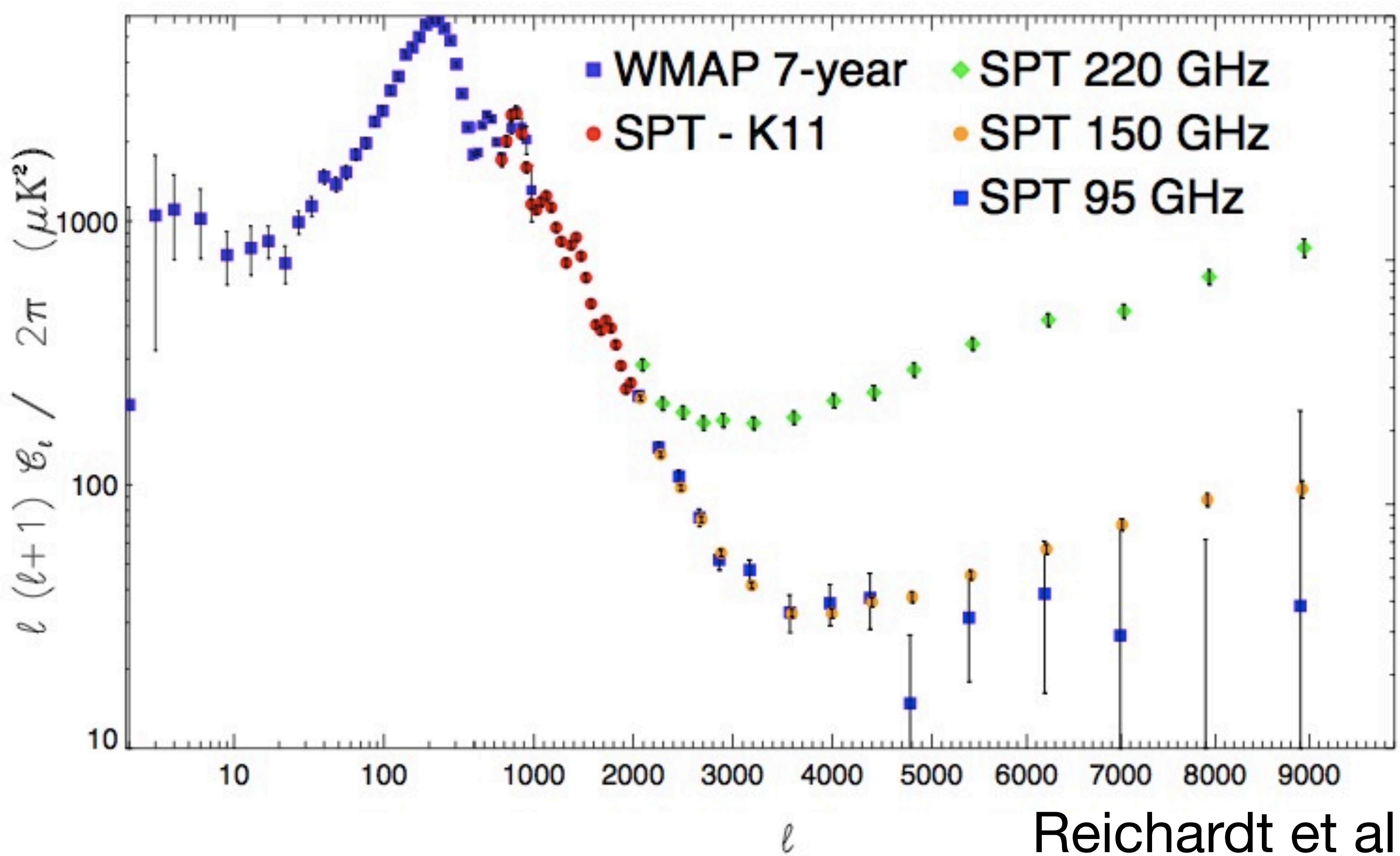
Two-halo:





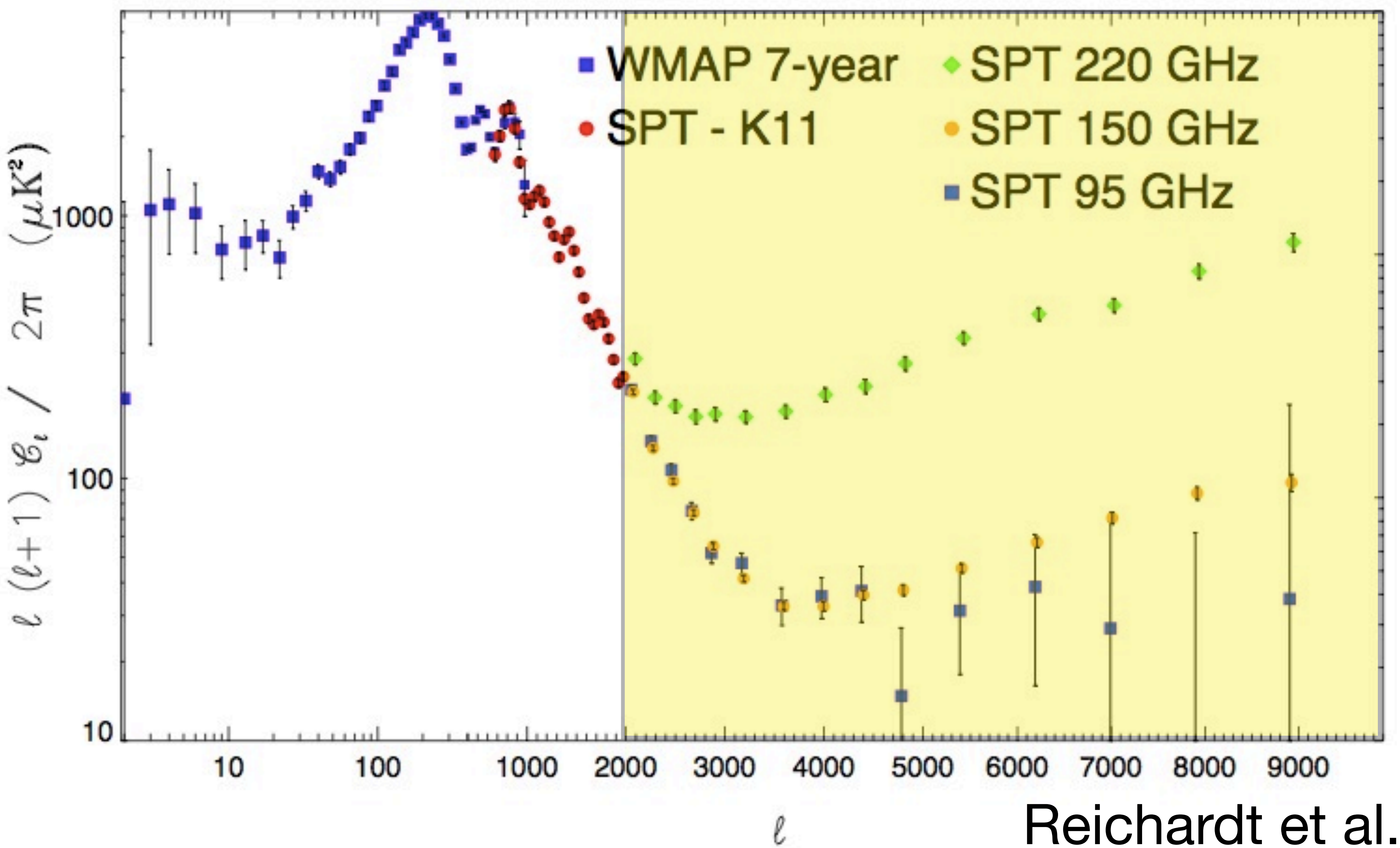
Zehavi (2011)

Brief History of Clustering



Reichardt et al. 2011

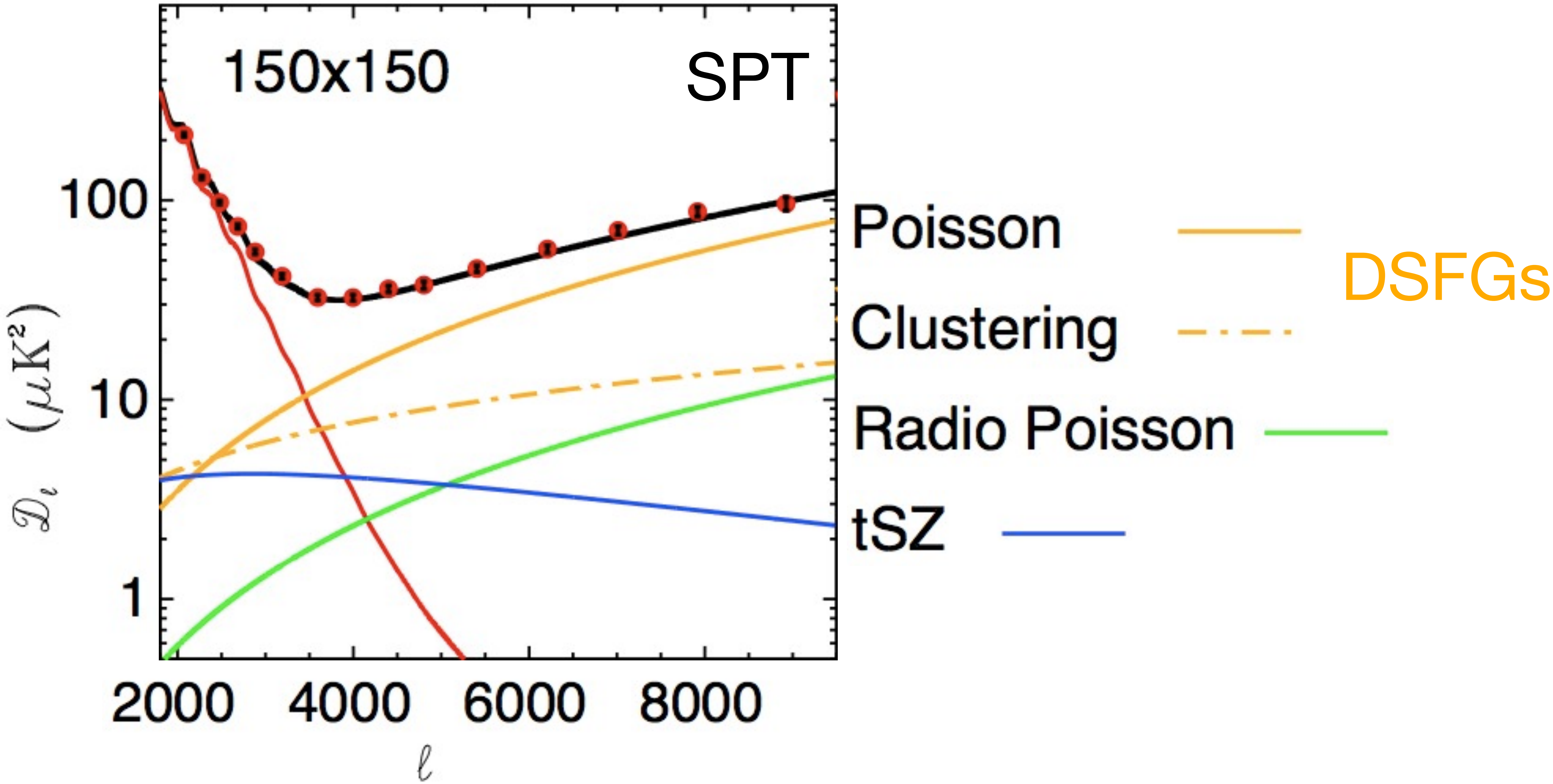
Motivation



Reichardt et al. 2011

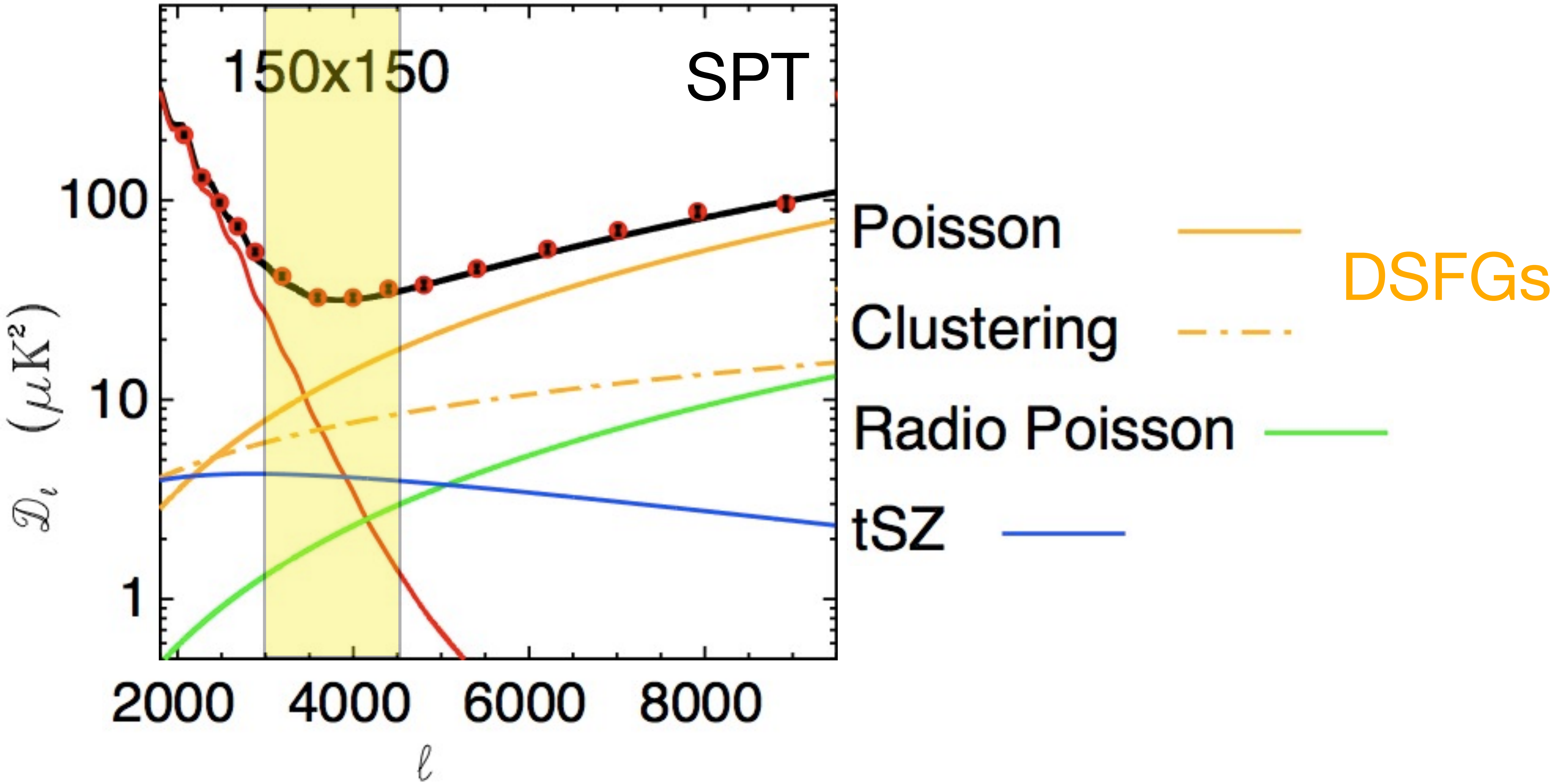
- $\ell > 2000$ dominated by secondary anisotropies

Motivation



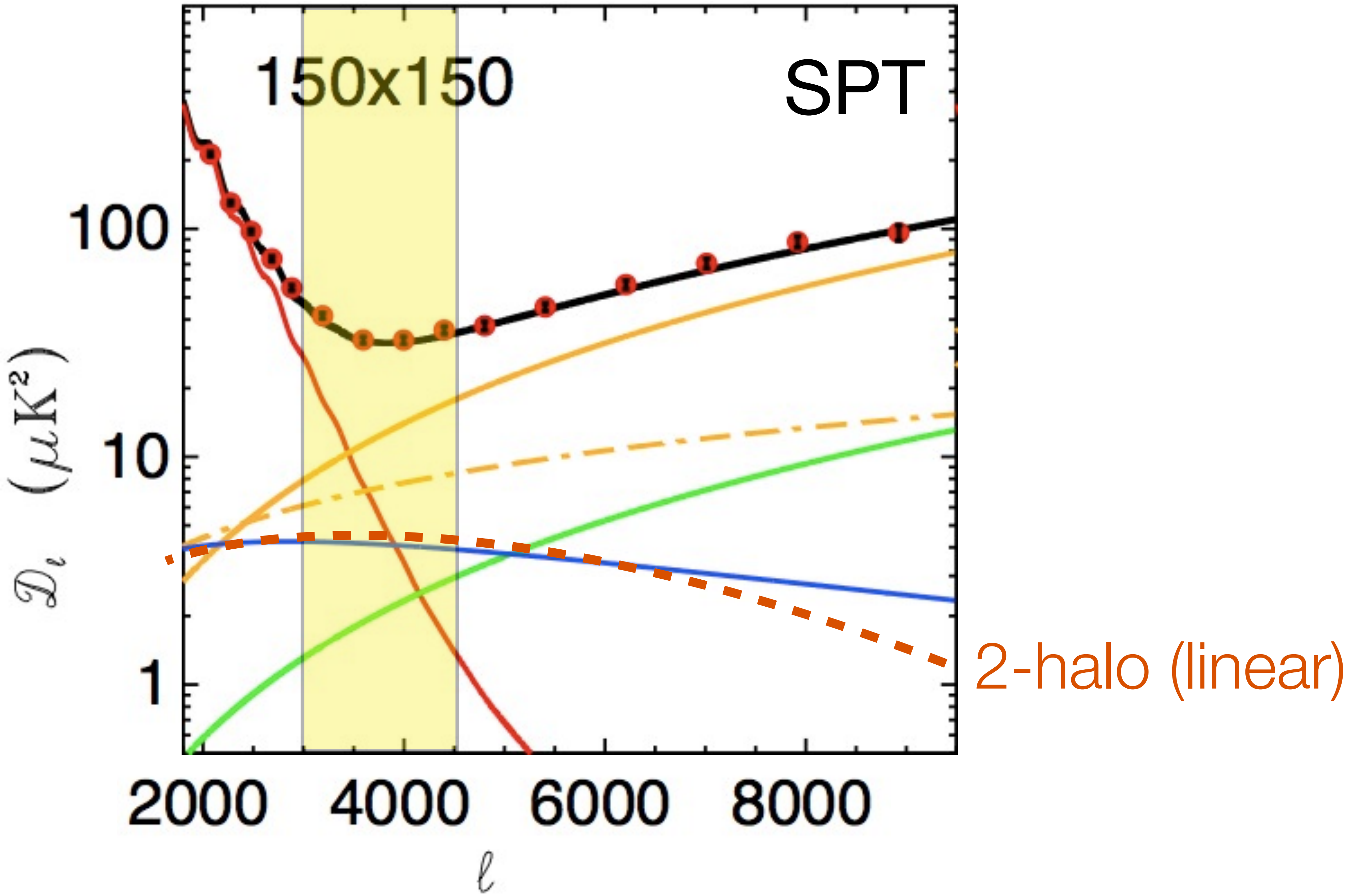
Reichardt et al. 2011

Motivation (i)

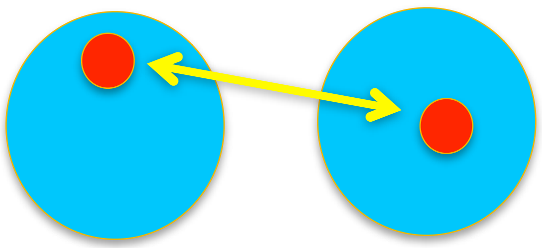


Reichardt et al. 2011

Motivation (i)



Reichardt et al. 2011



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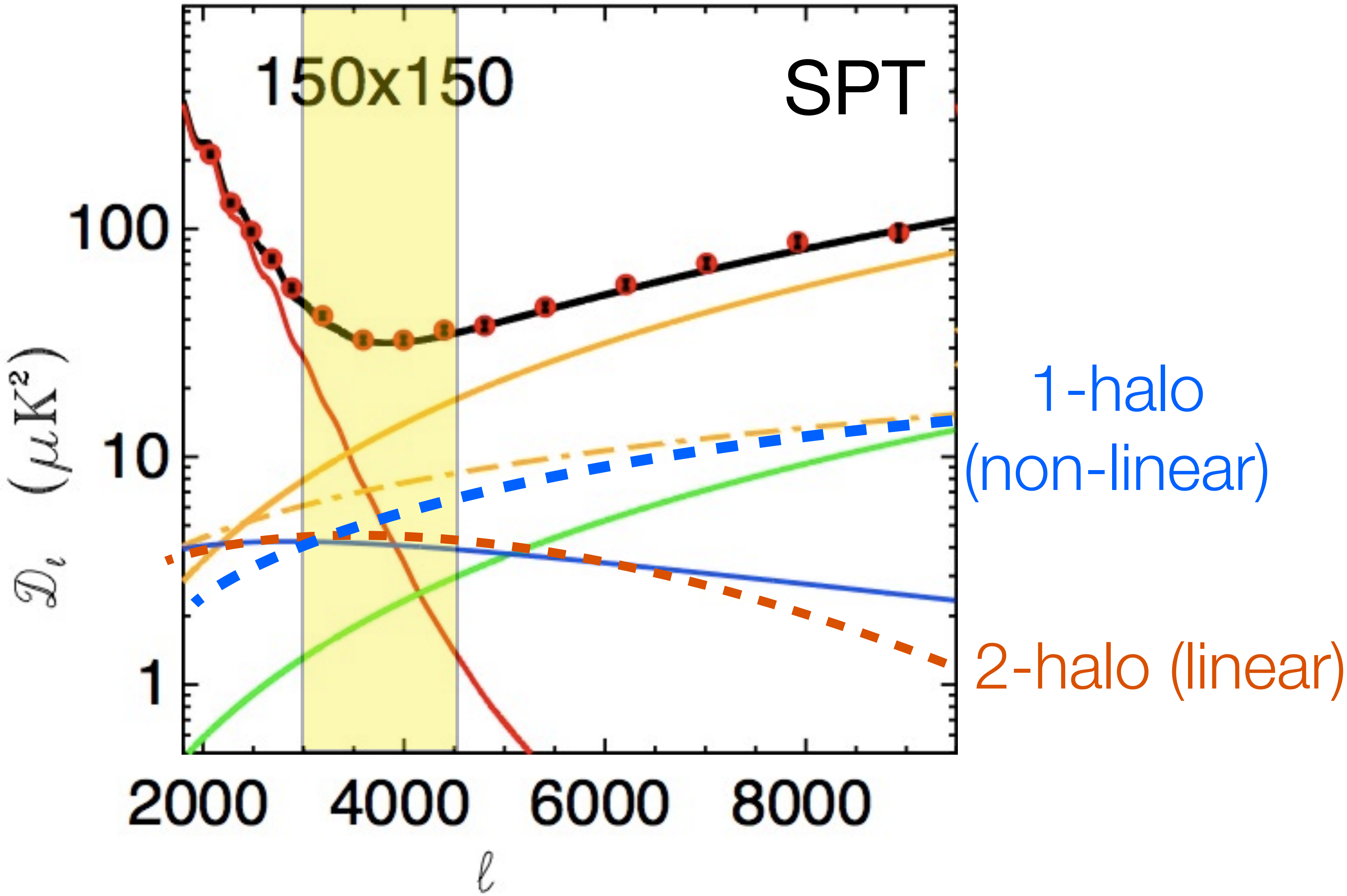
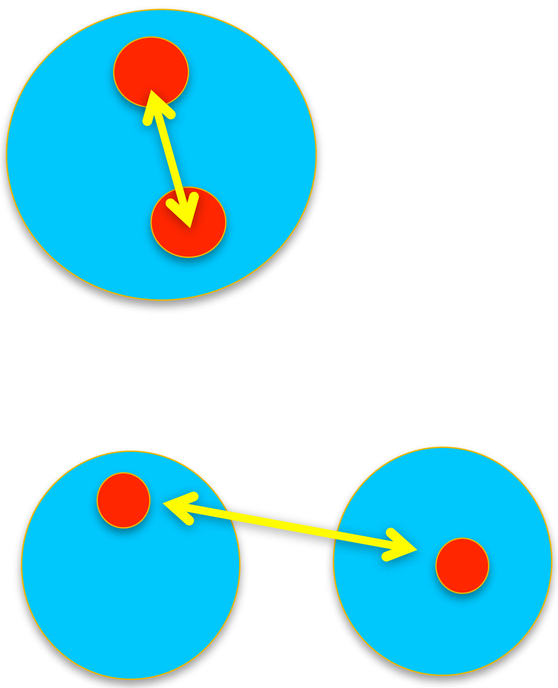


Reichardt et al. 2011



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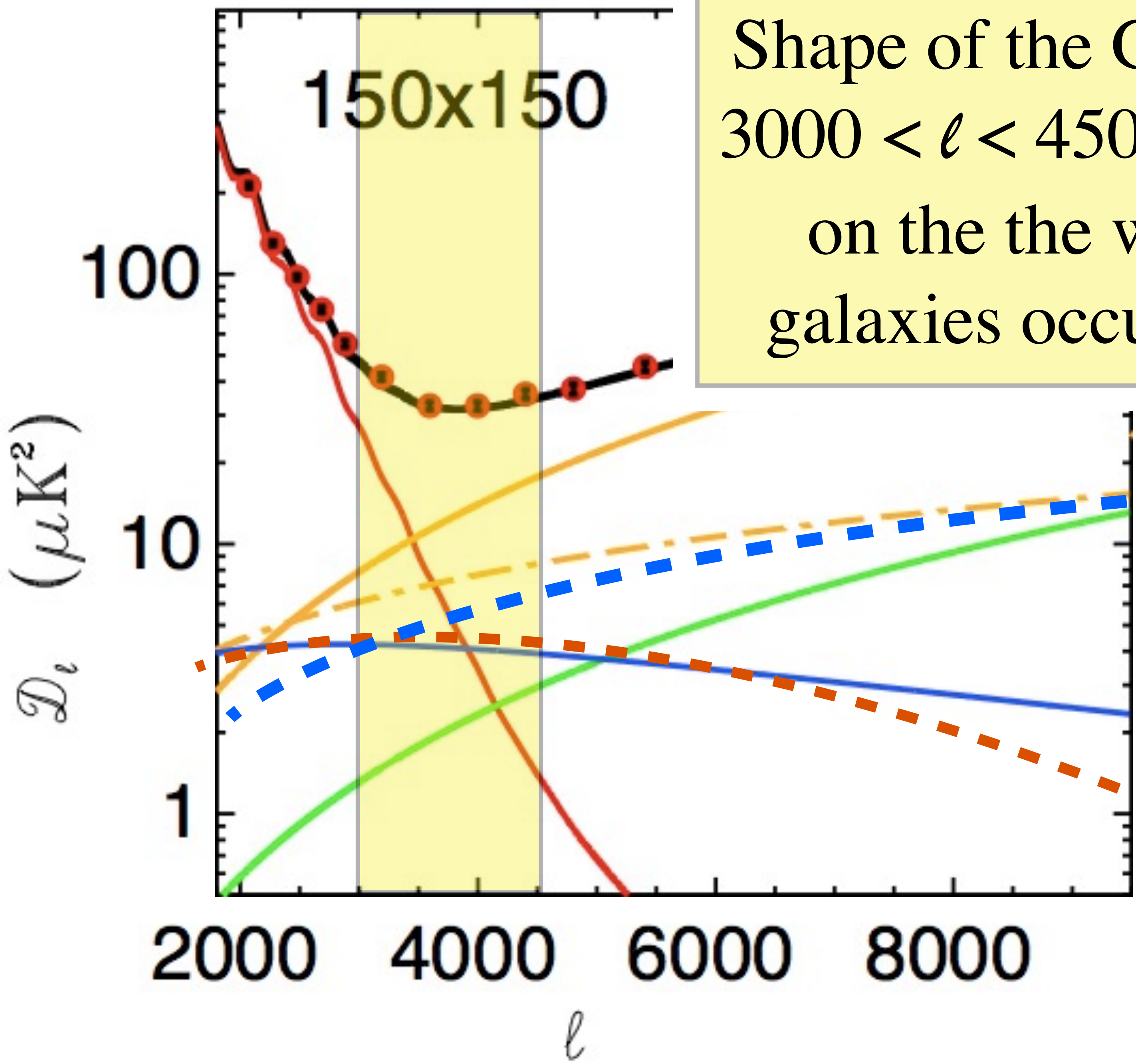
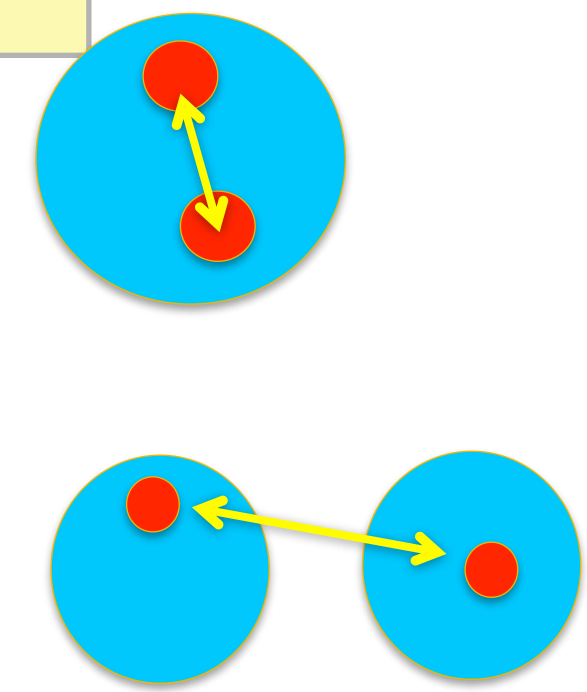


Shape of the Galaxy Spectrum at $3000 < \ell < 4500$ highly dependent on the the way star-forming galaxies occupy massive halos

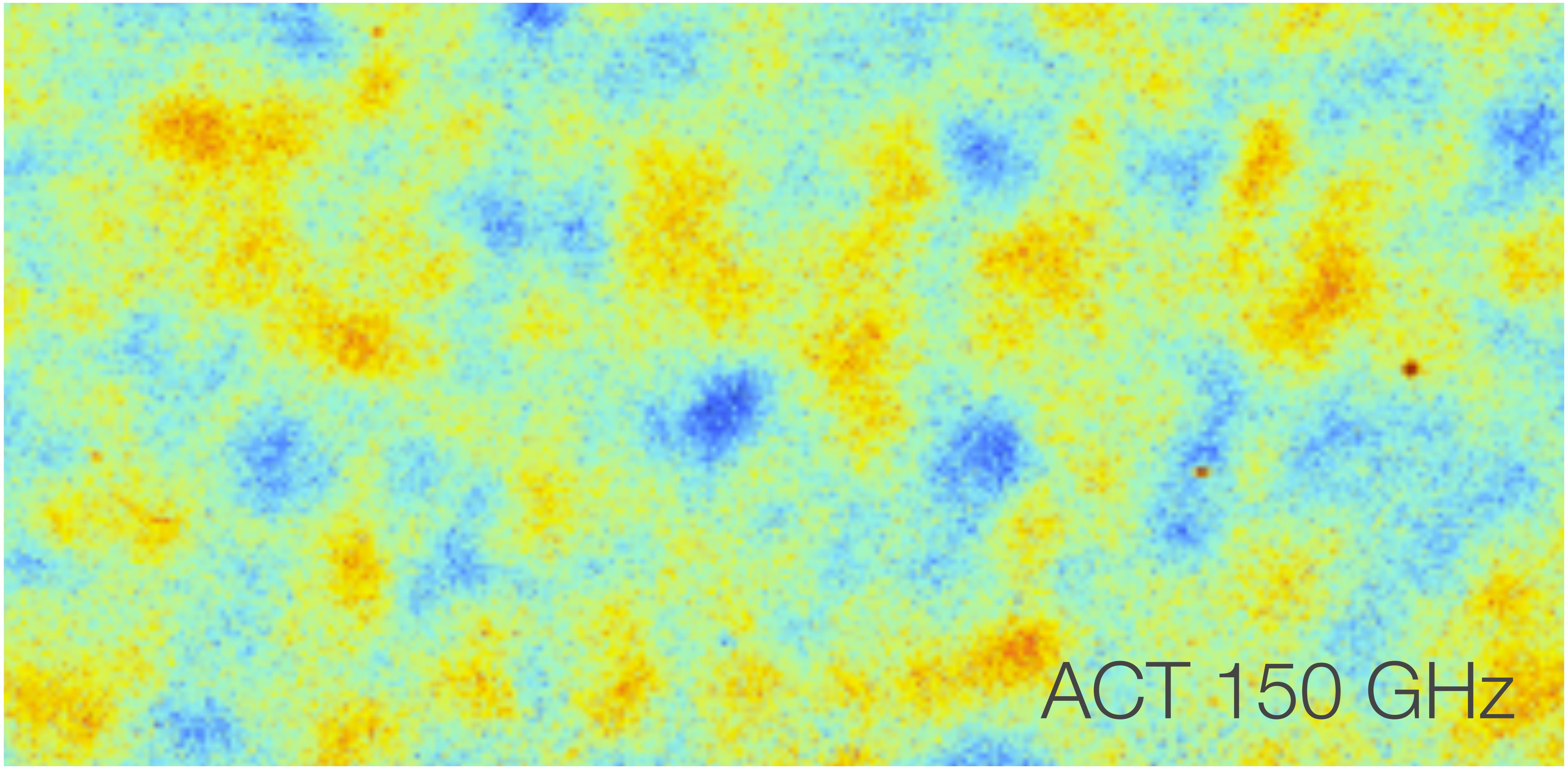
1-halo (non-linear)

2-halo (linear)

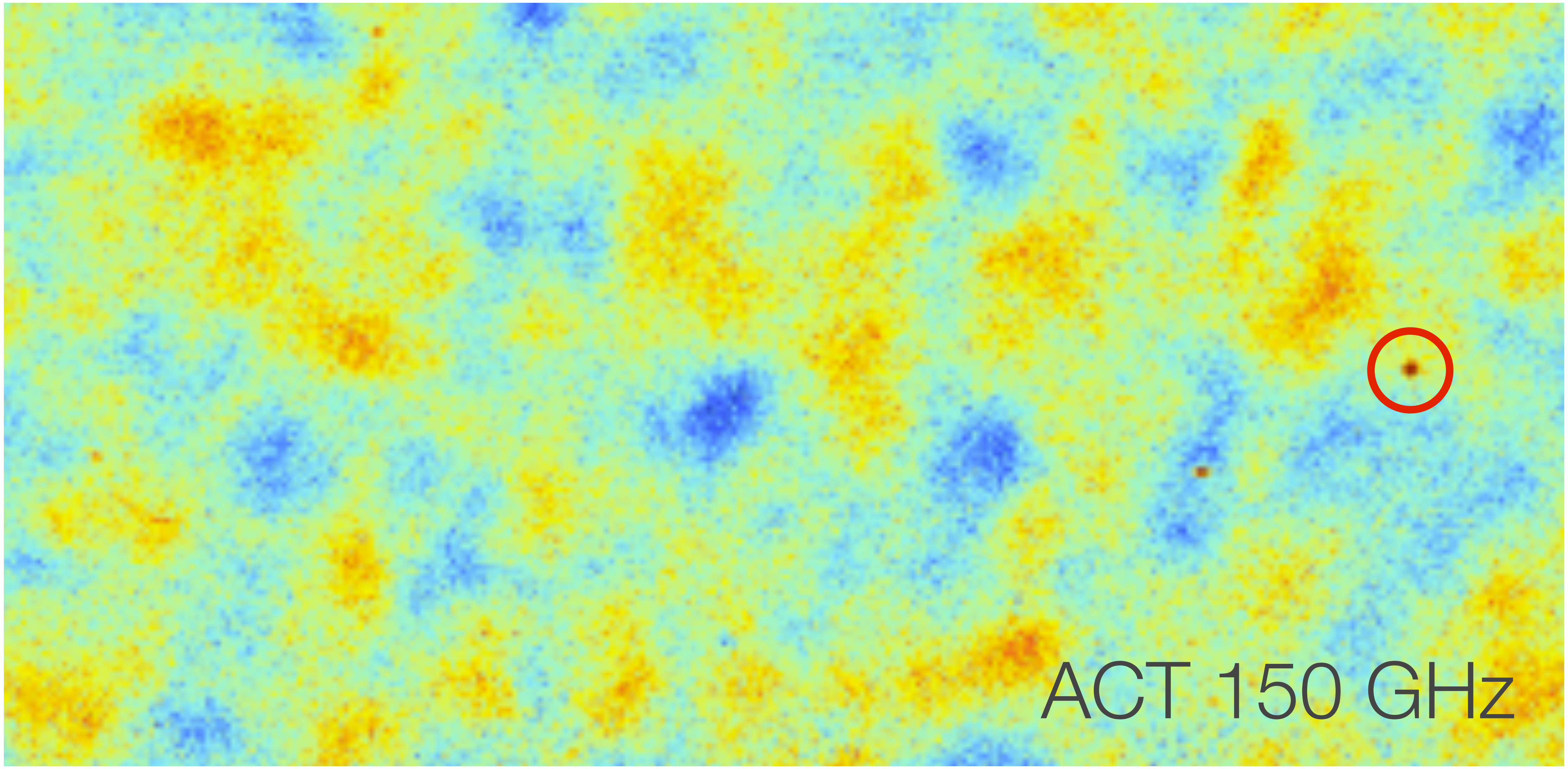


Reichardt et al. 2011

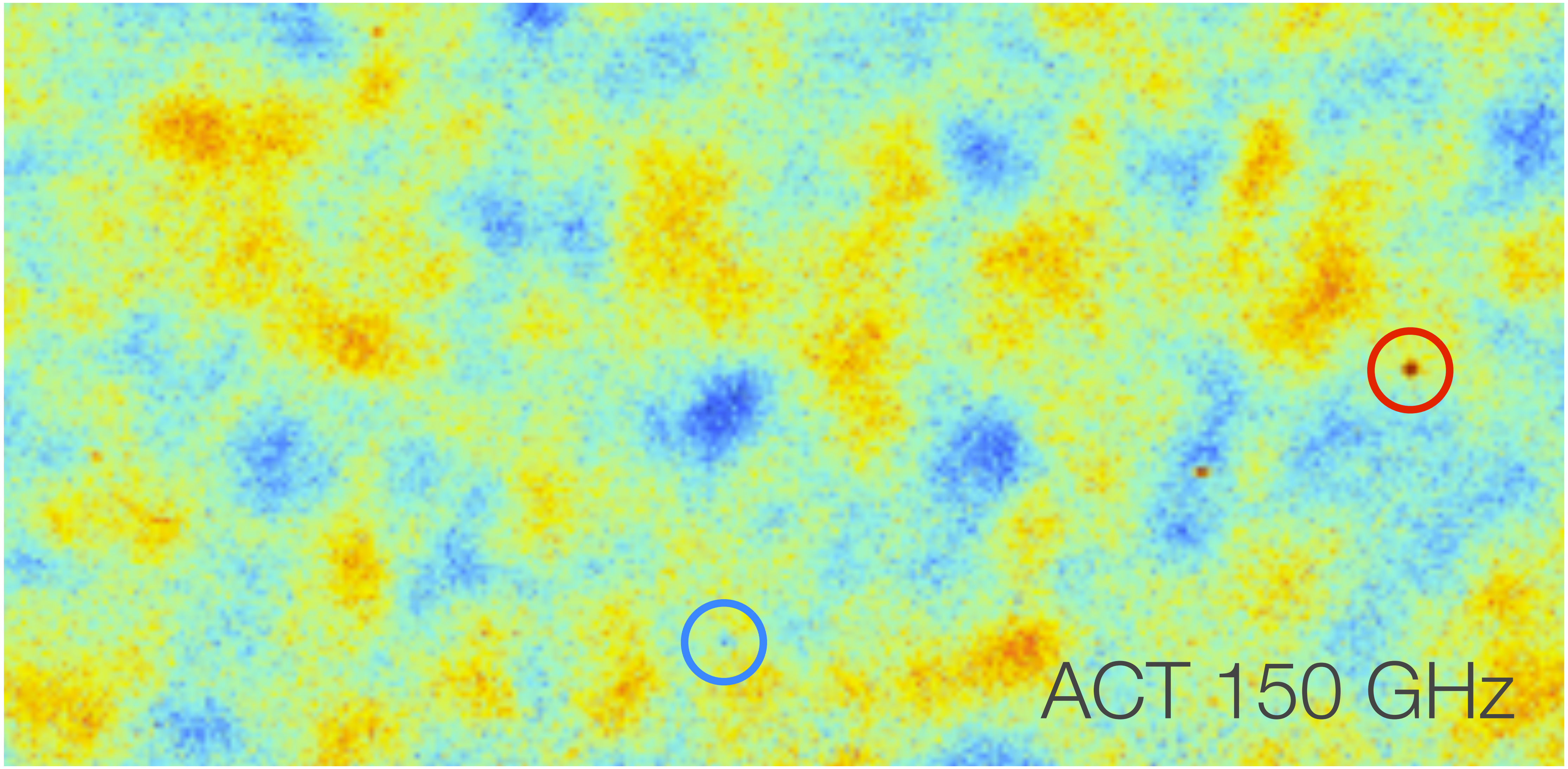
Motivation (i)



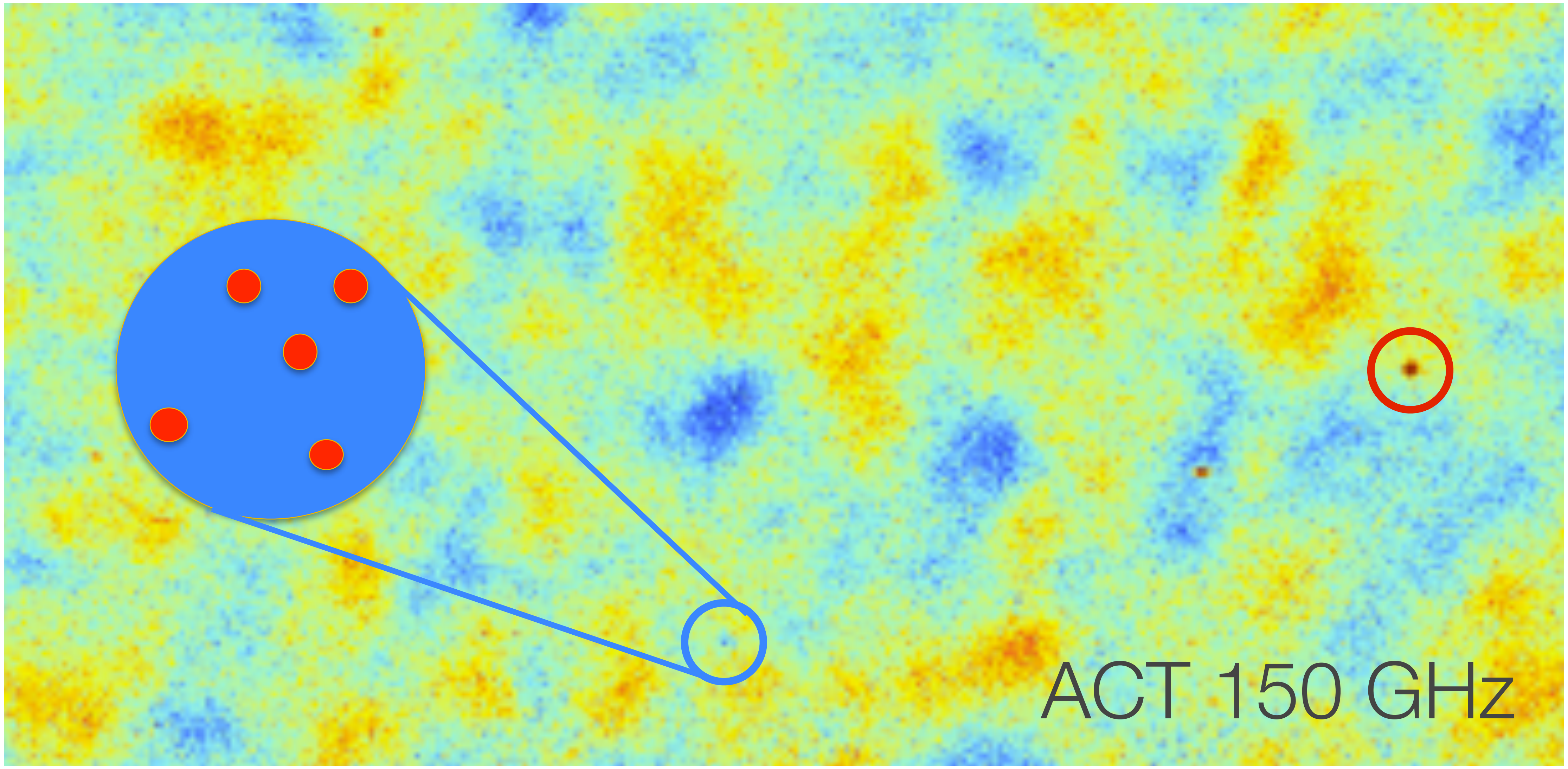
Motivation (ii)



Motivation (ii)

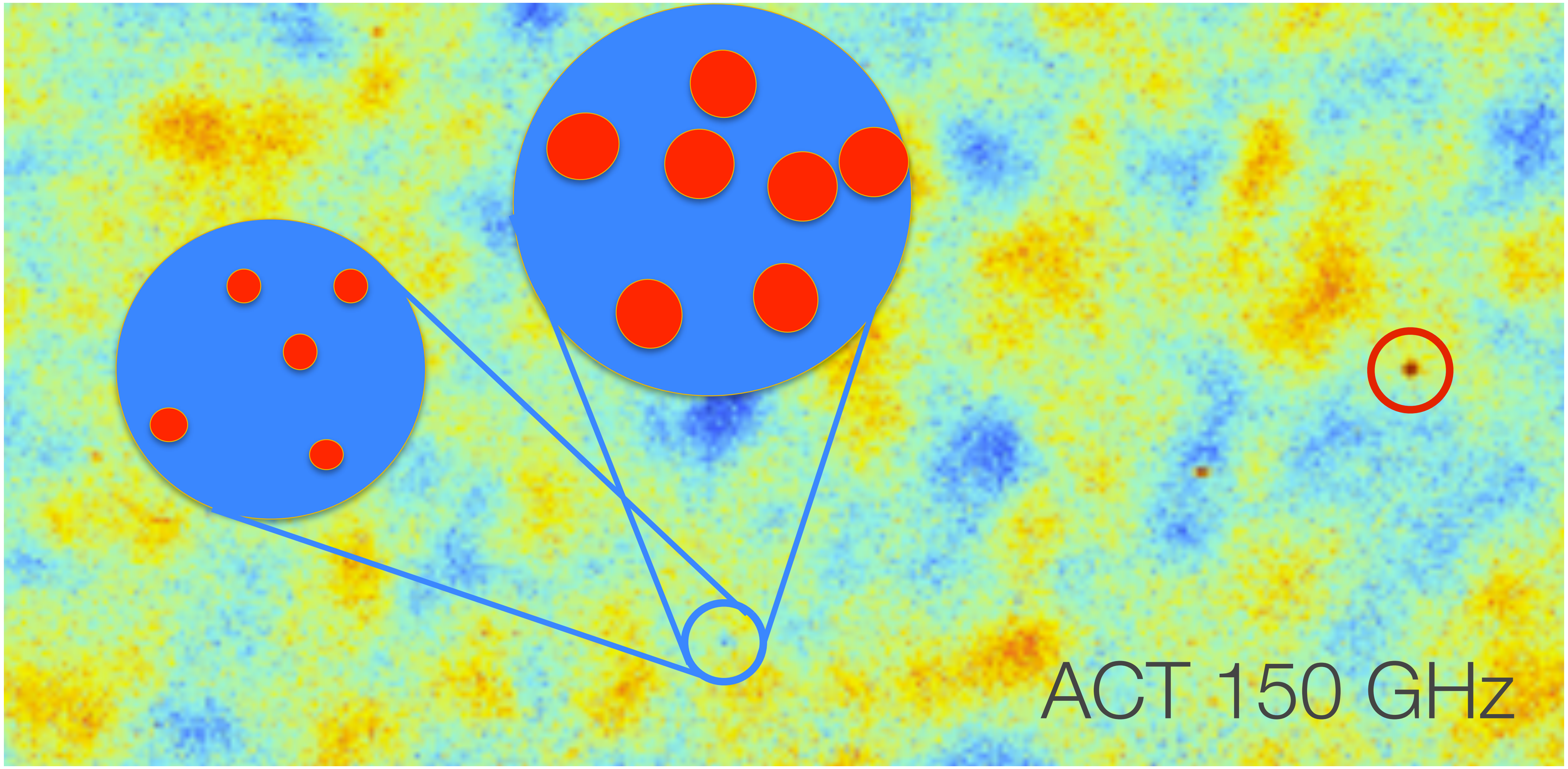


Motivation (ii)



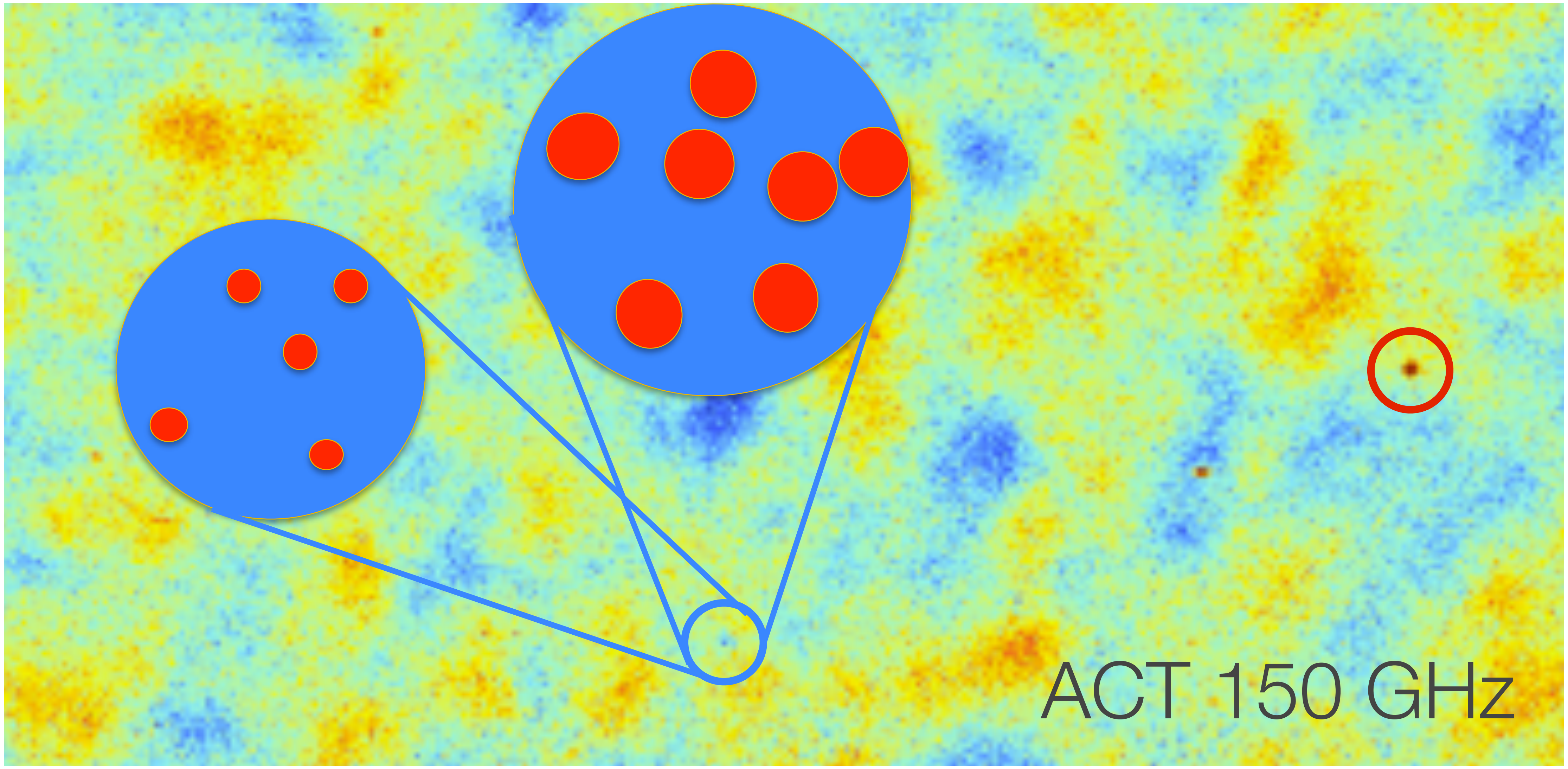
- Halo Occupation Distribution (HOD):
  - How many satellites per given halo mass?

Motivation (ii)



- Halo Occupation Distribution (HOD):
  - How many satellites per given halo mass?
  - Luminosity-Mass relation?

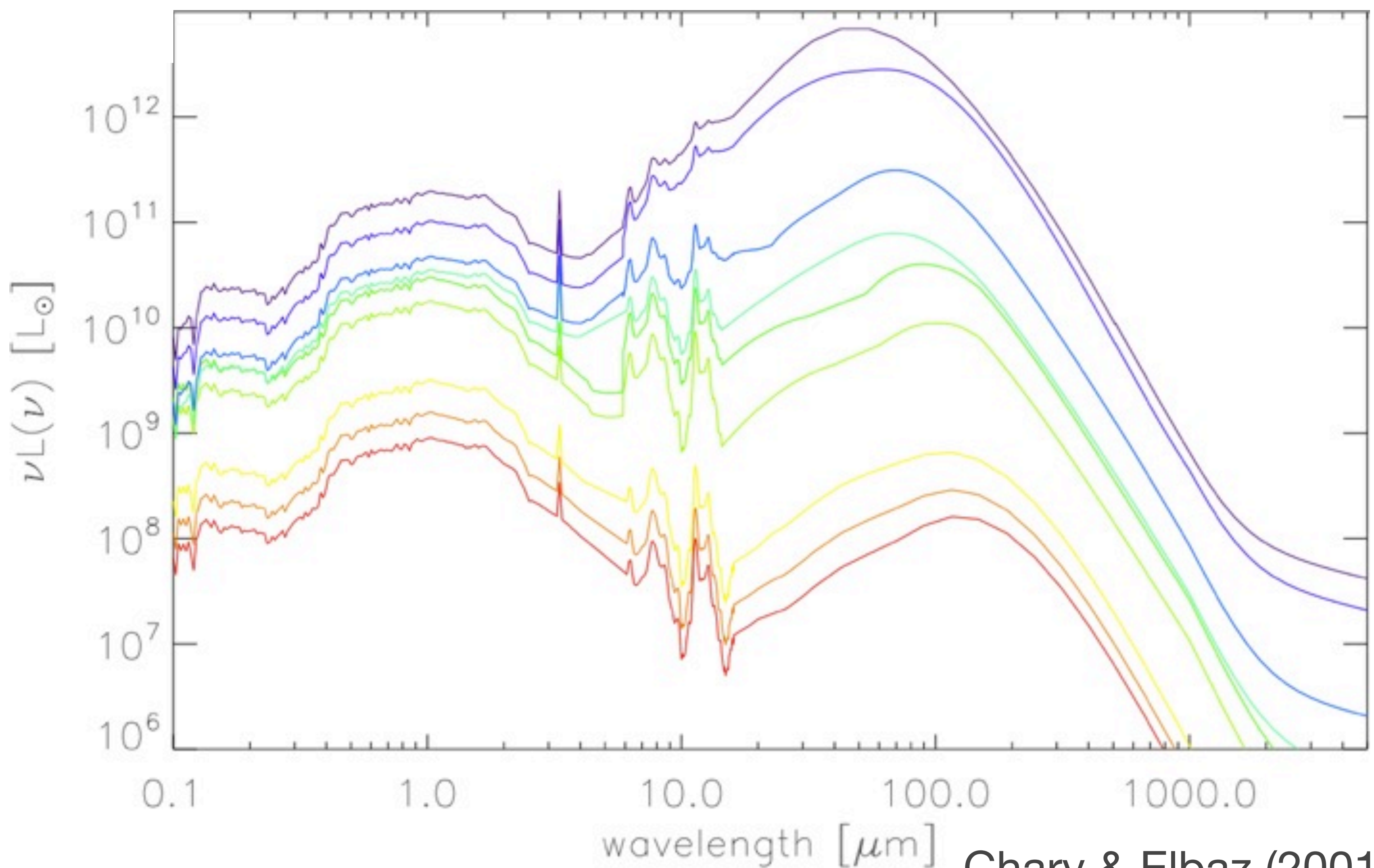
Motivation (ii)



- Halo Occupation Distribution (HOD):
  - How many satellites per given halo mass?
  - Luminosity-Mass relation?
- This is imprinted on the 1-halo term of the CIB power spectrum!

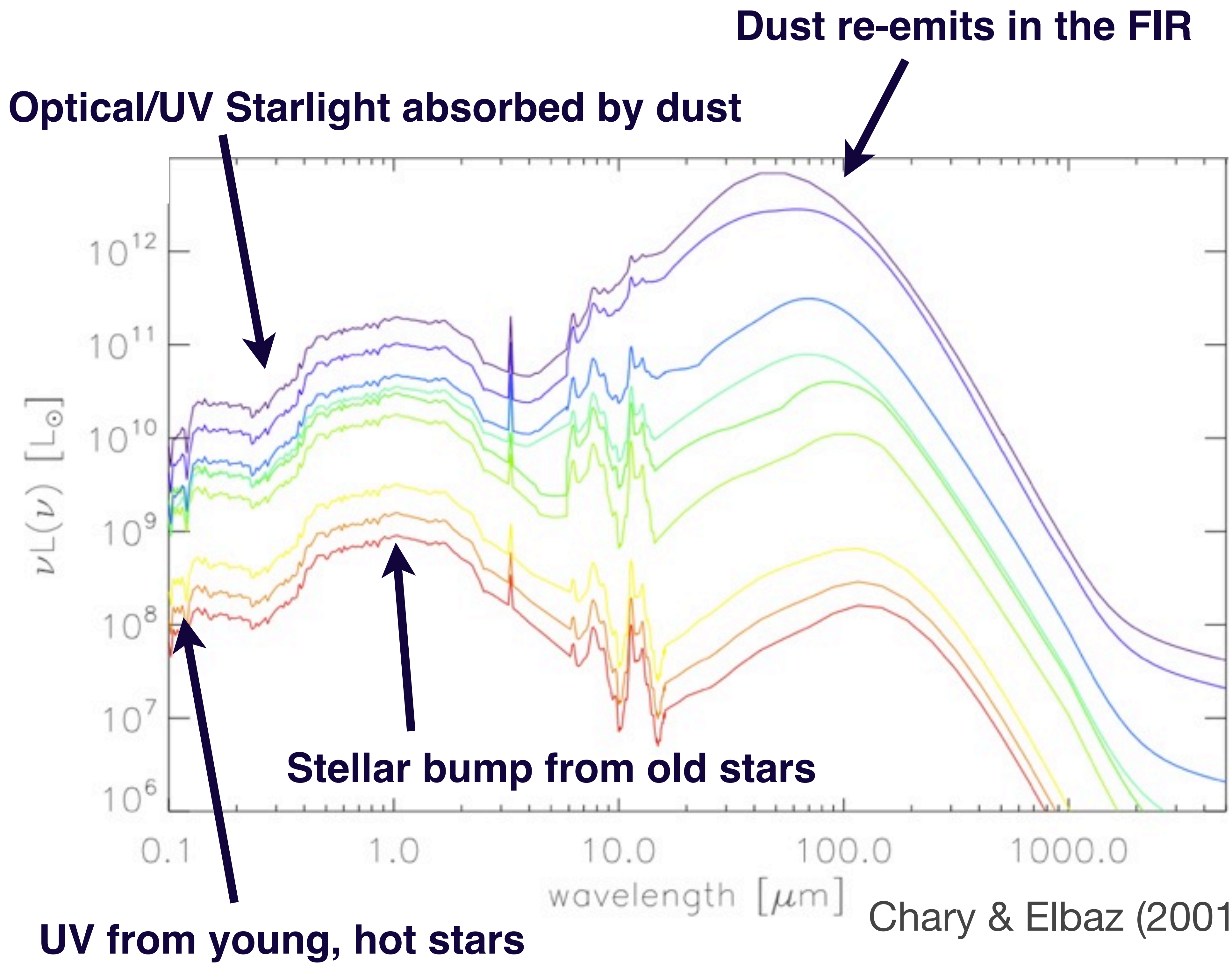
Motivation (ii)

Cosmic Submillimeter Background



Chary & Elbaz (2001)

Galaxy SEDs



Chary & Elbaz (2001)

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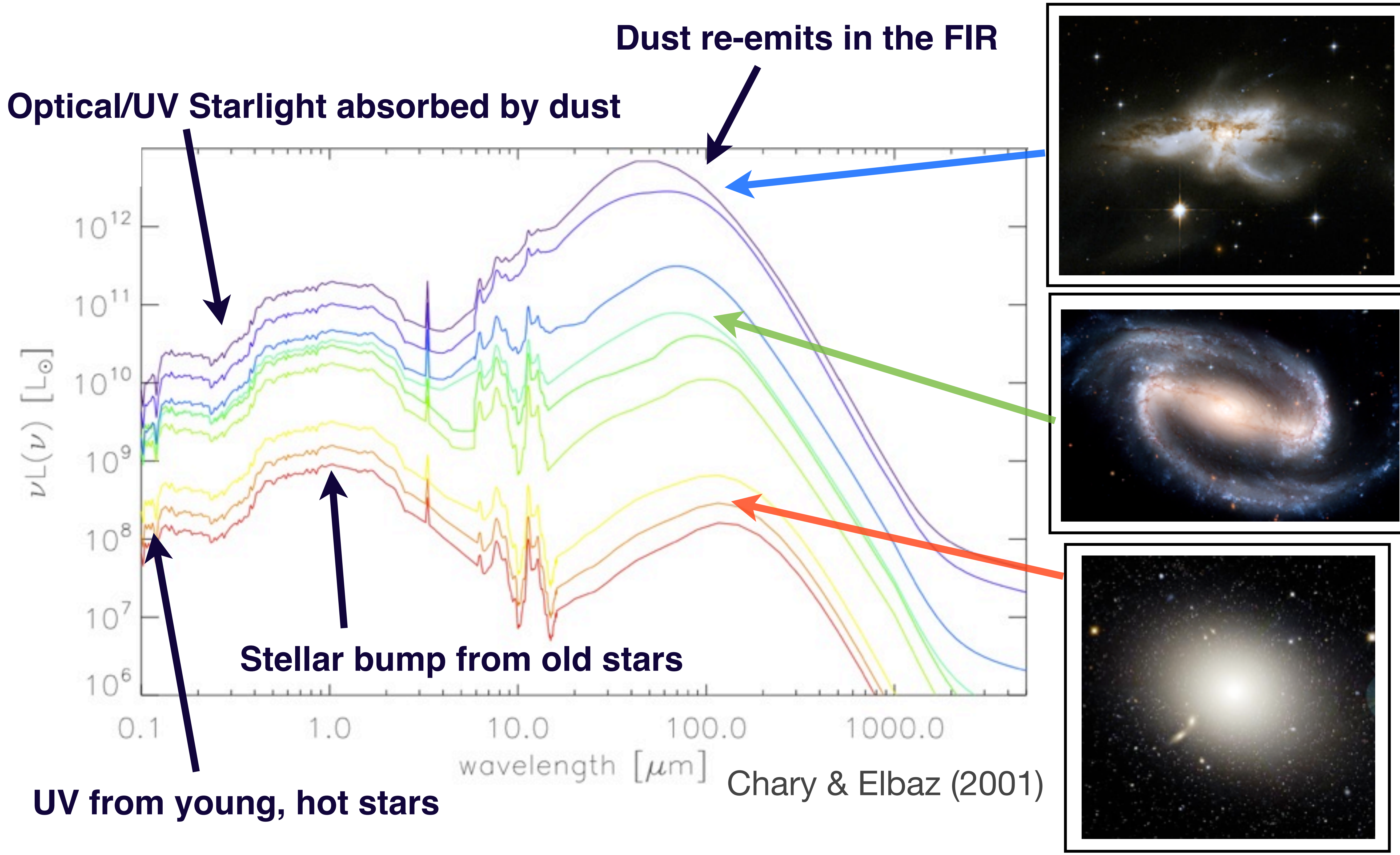

Chary & Elbaz (2001)

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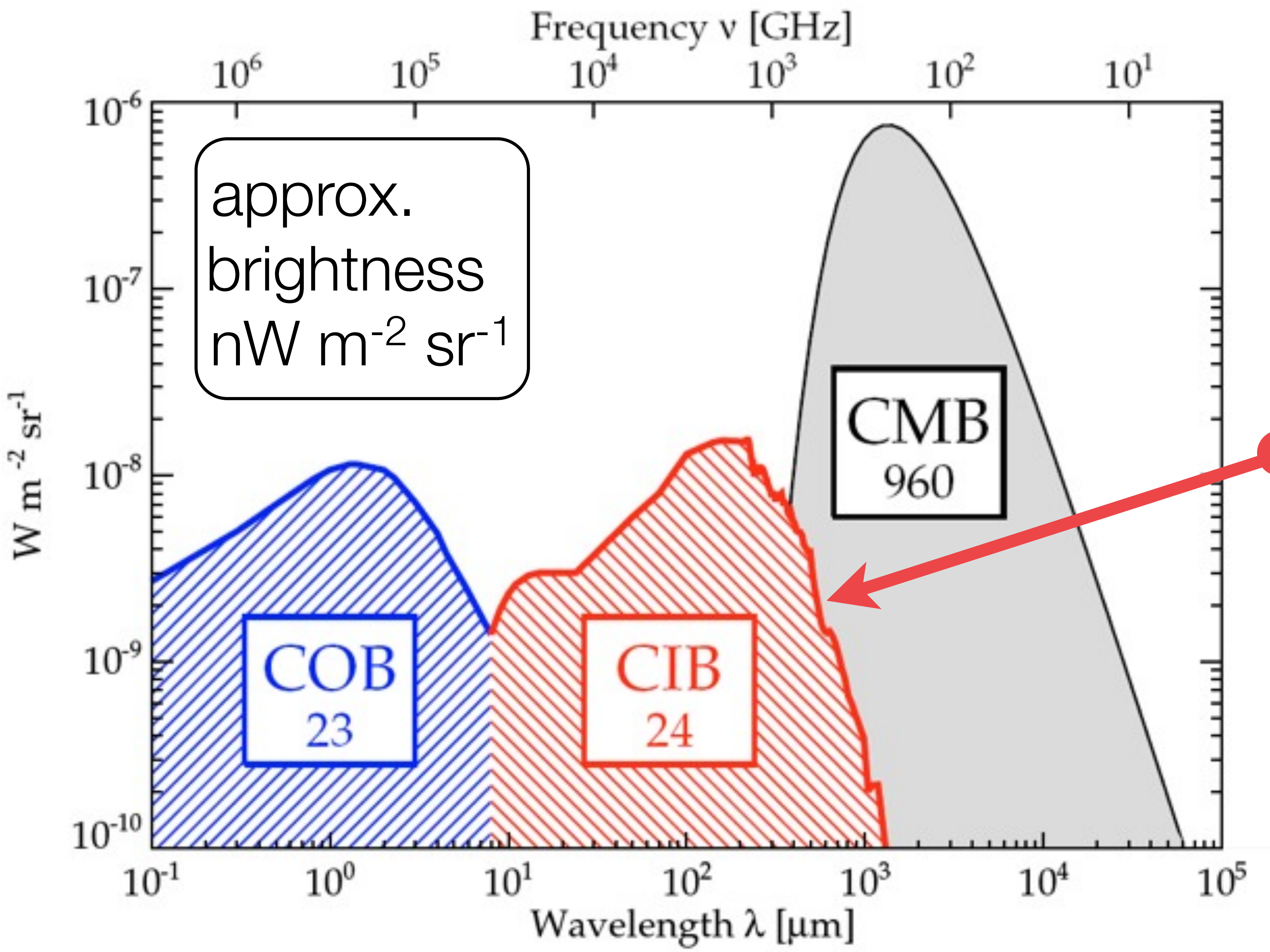
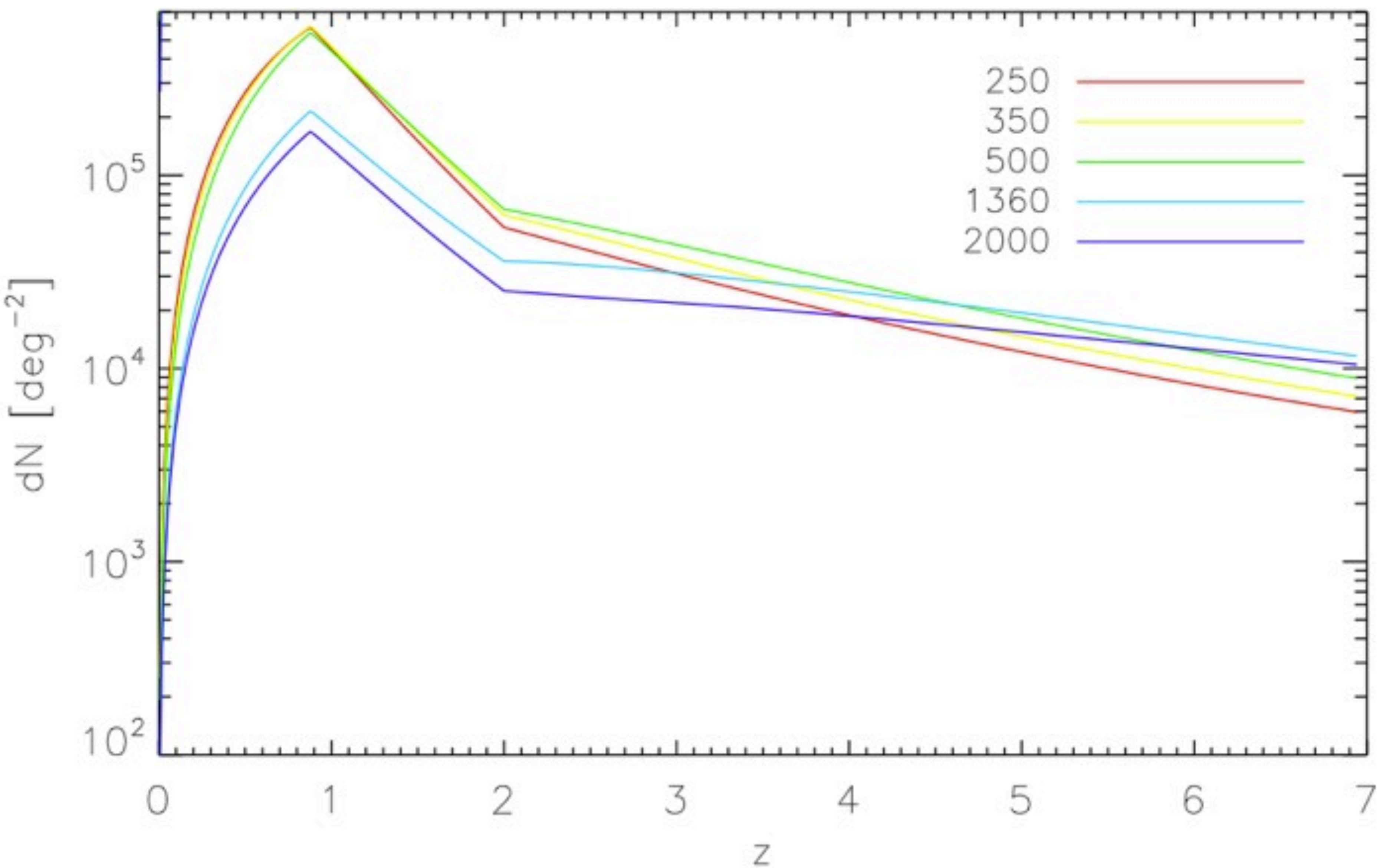


Half the light emitted by stars is absorbed and re-emitted in the IR

Dole et al. (2006)

Extragalactic Background

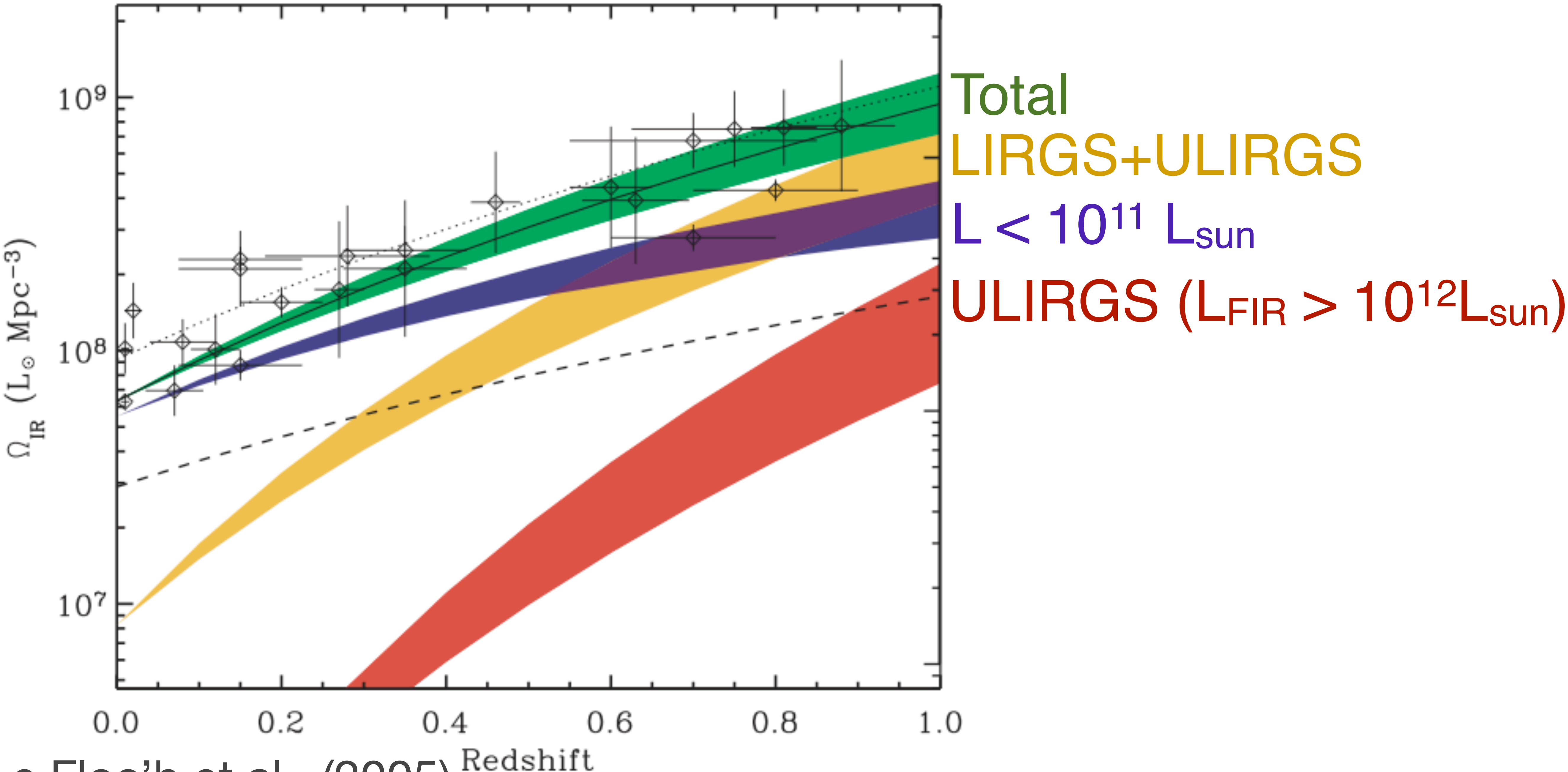
get this model @ http://www.ias.u-psud.fr/irgalaxies/model.php#Counts



Béthermin et al. (2011)
arXiv:1010.1150

Redshift Distribution of Sources

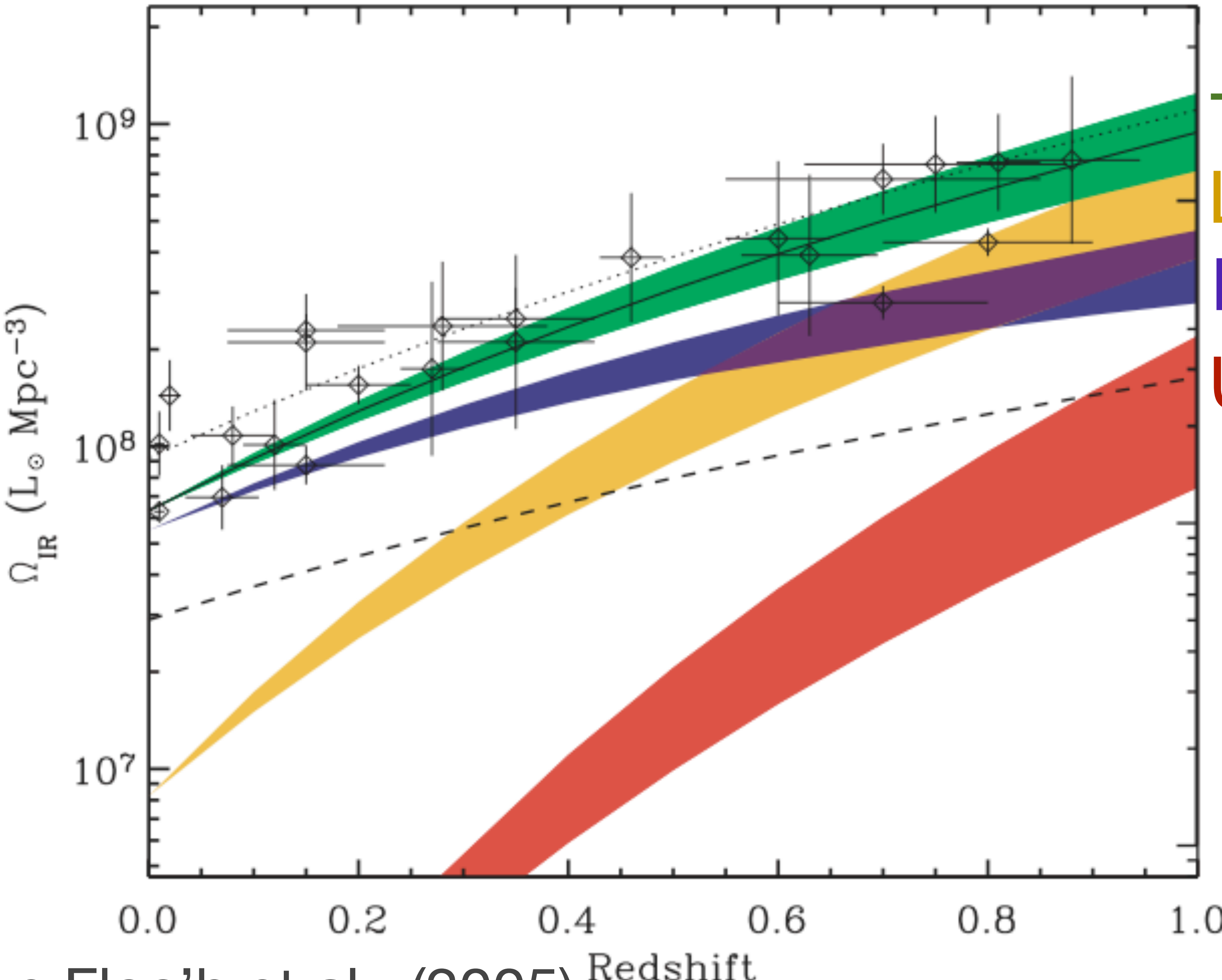
Comoving IR Energy Density



Le Floc'h et al. (2005)

Deconstructing the CIB

Comoving IR Energy Density



Le Floc'h et al. (2005)

Total

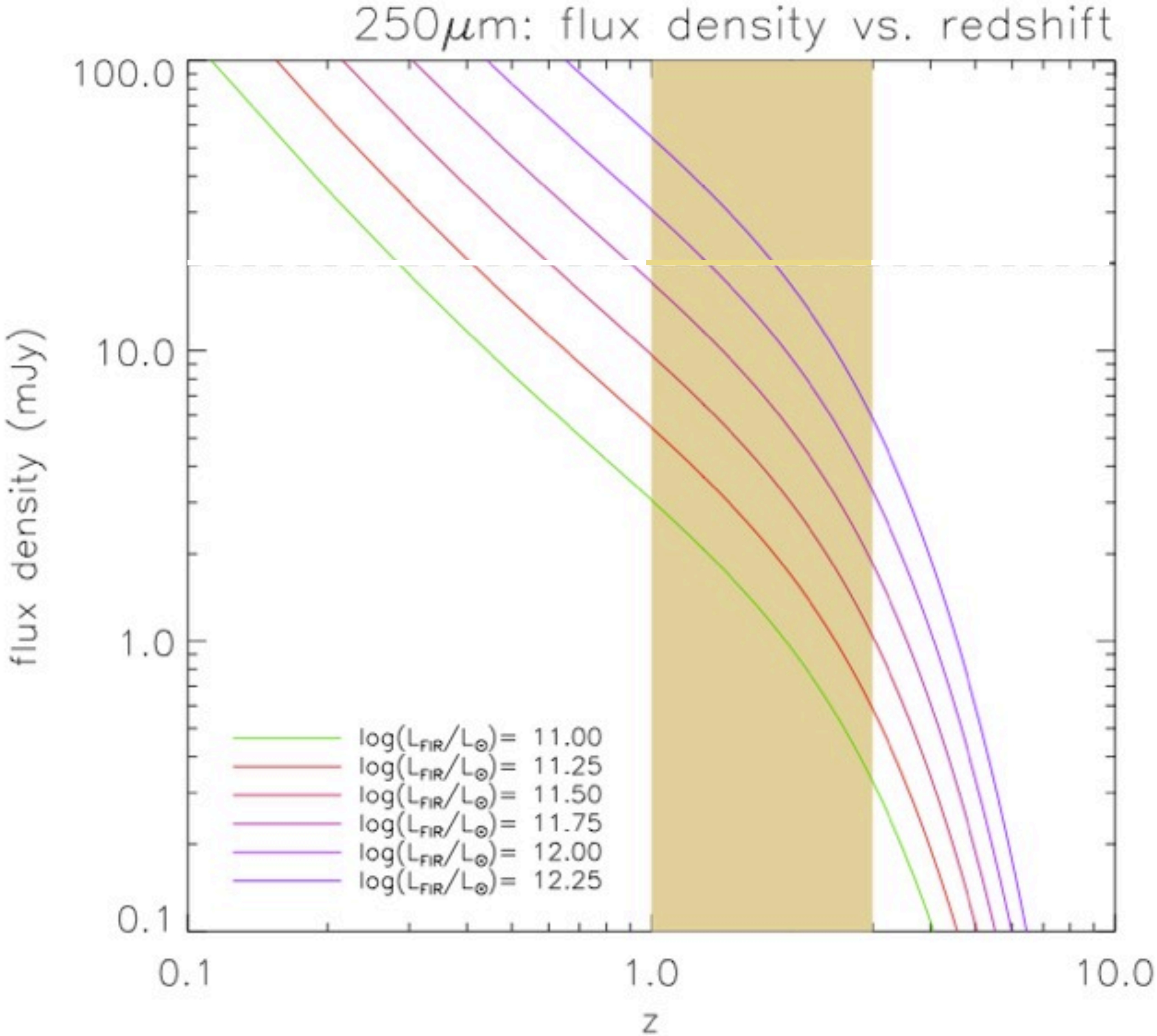
LIRGS+ULIRGS

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

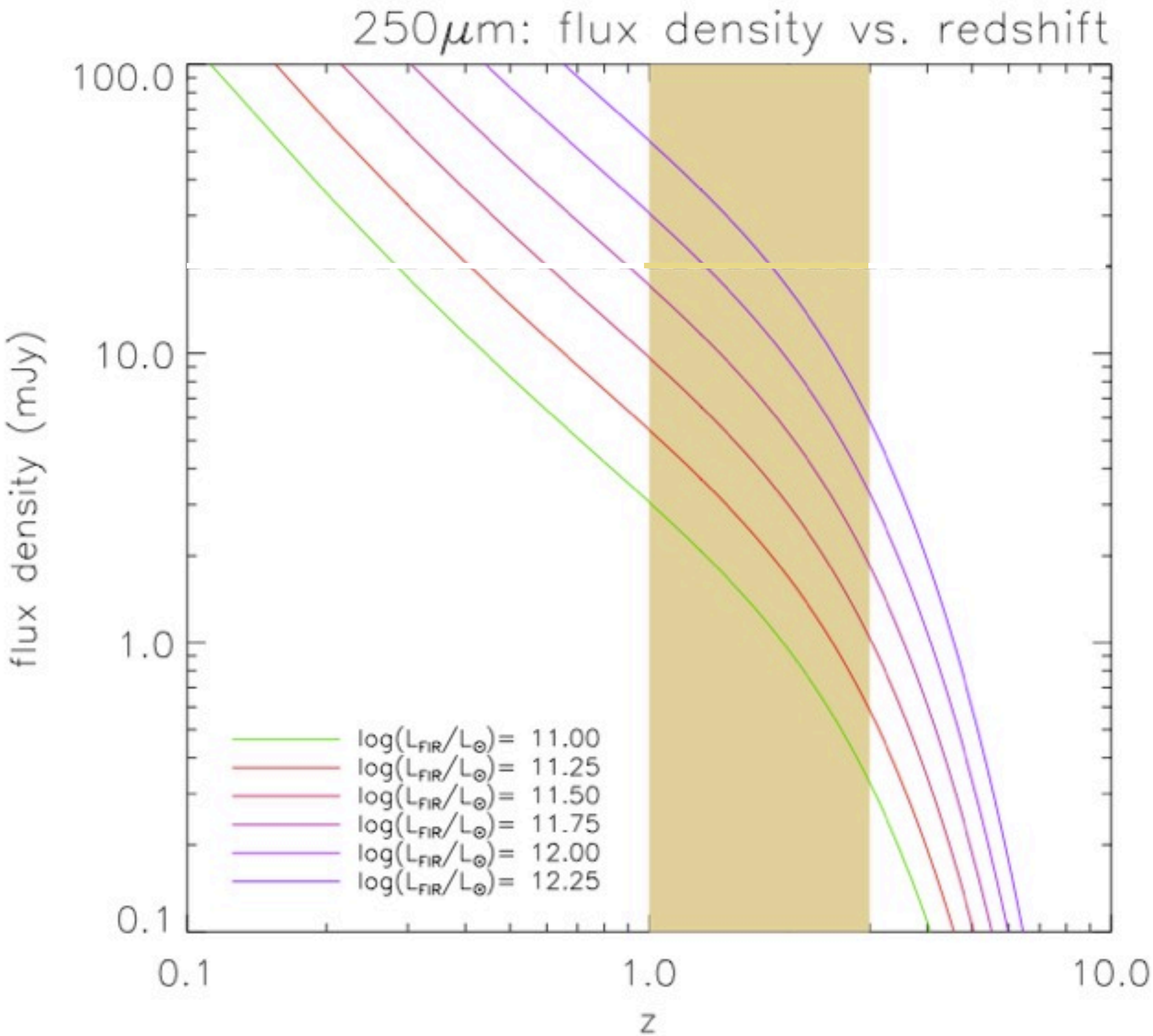
ULIRGS ($L_{FIR} > 10^{12} L_{sun}$)

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

Deconstructing the CIB

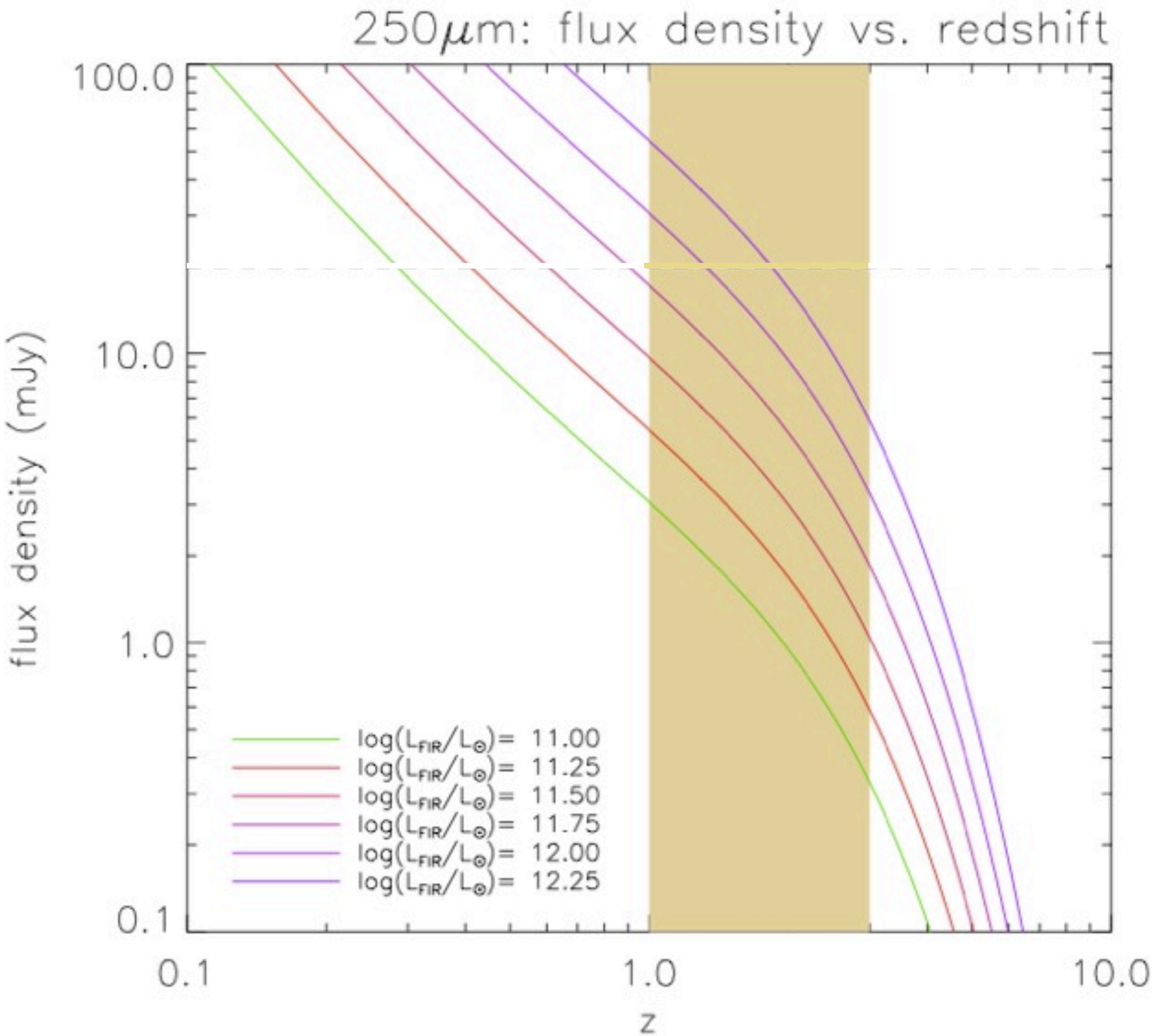


Deconstructing the CIB



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

Deconstructing the CIB



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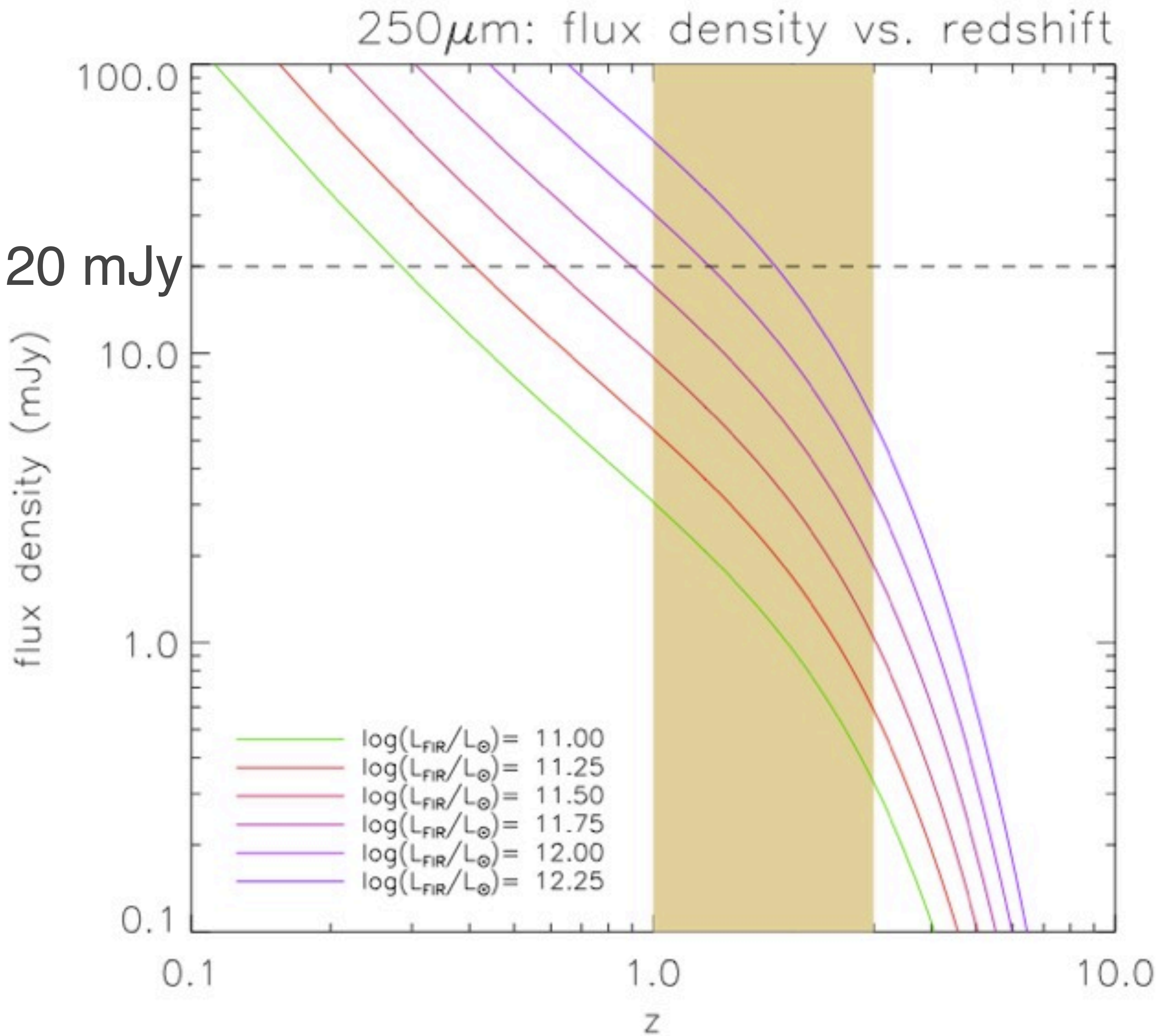
SPIRE can resolve *at best* sources with S_{250} >~ 20 mJy

Deconstructing the CIB



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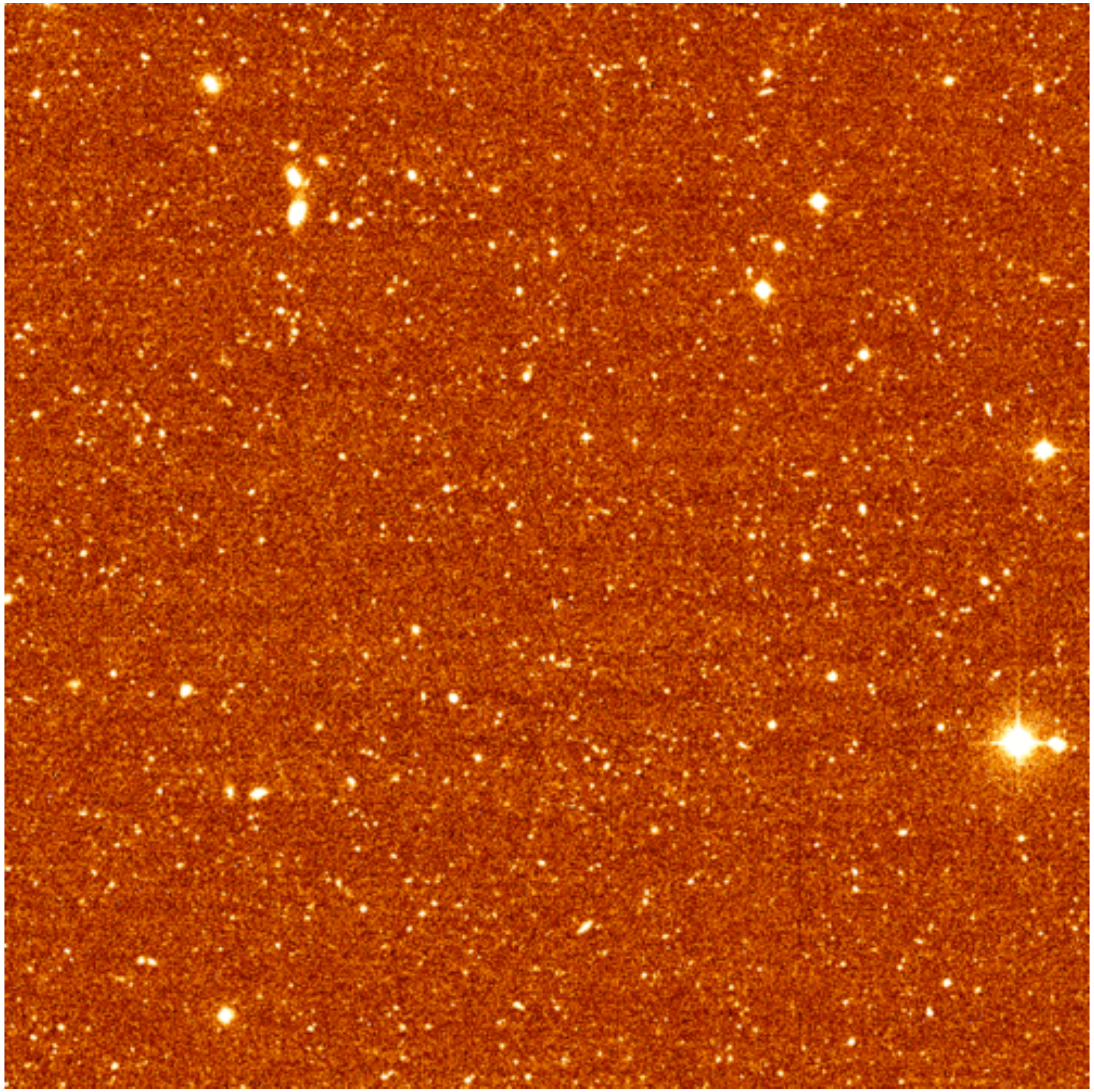
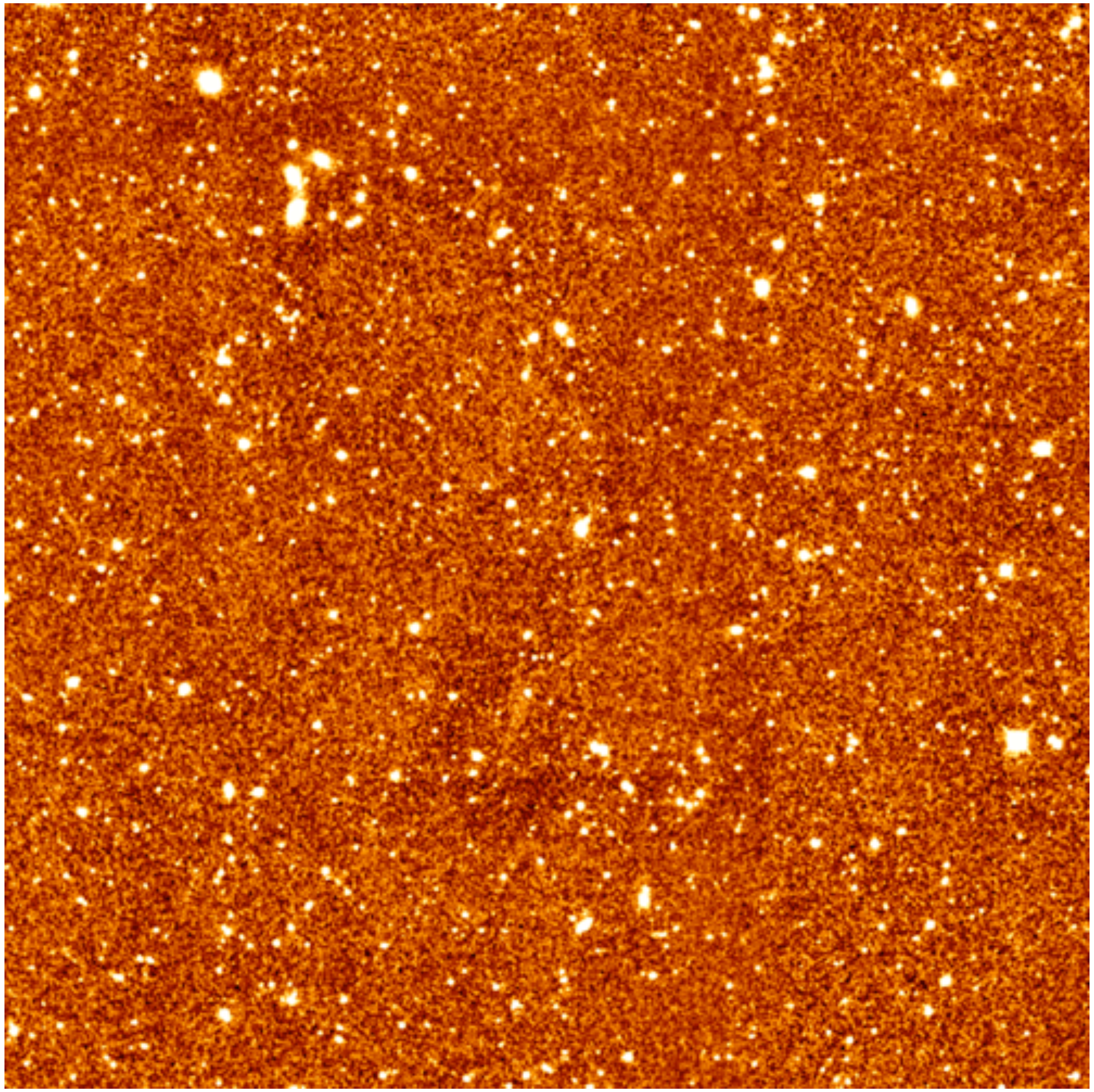


U-band : MUSYC

10 ‘

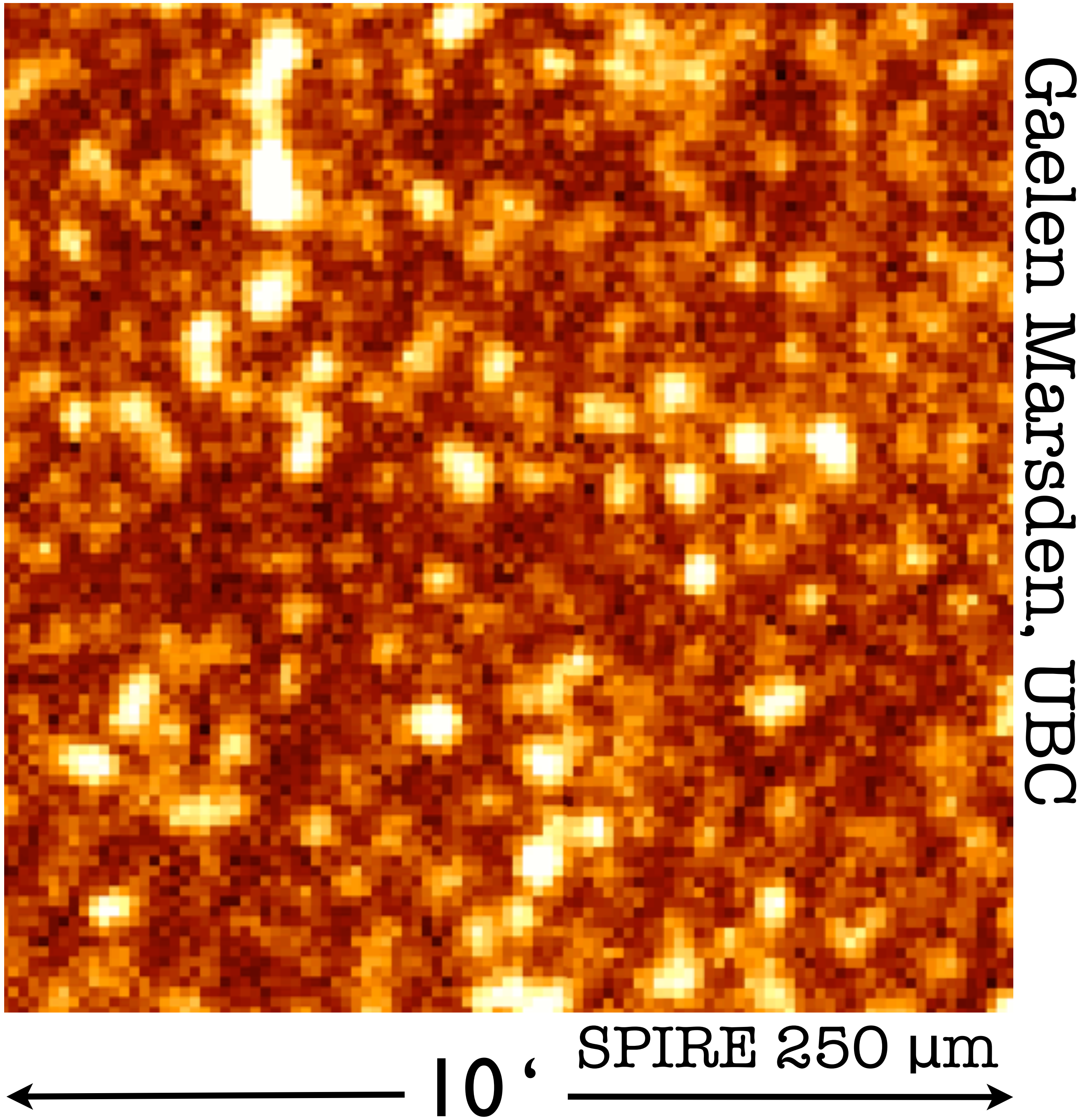
Confusion



K-band : MUSYC

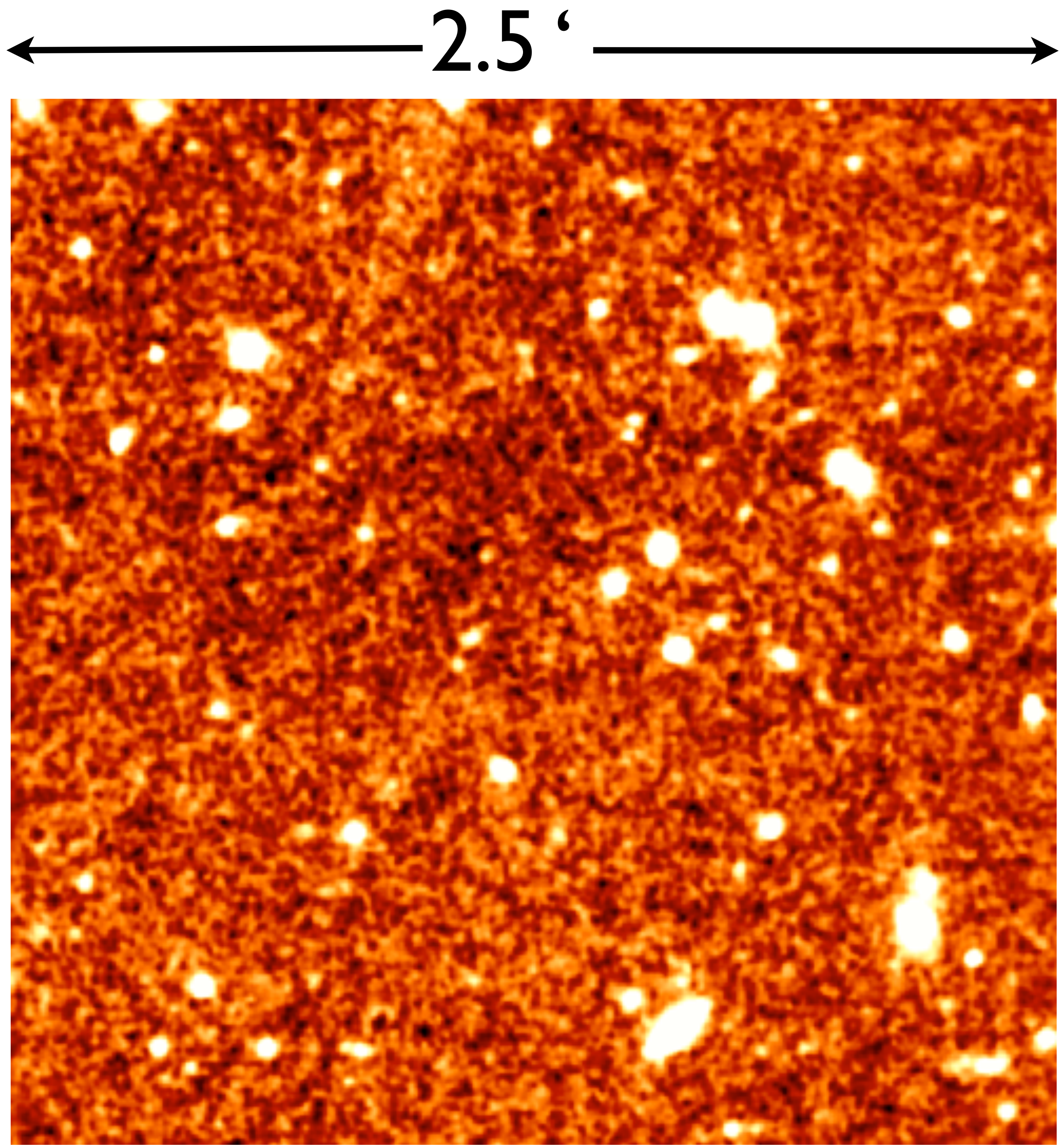
10 ‘

Confusion



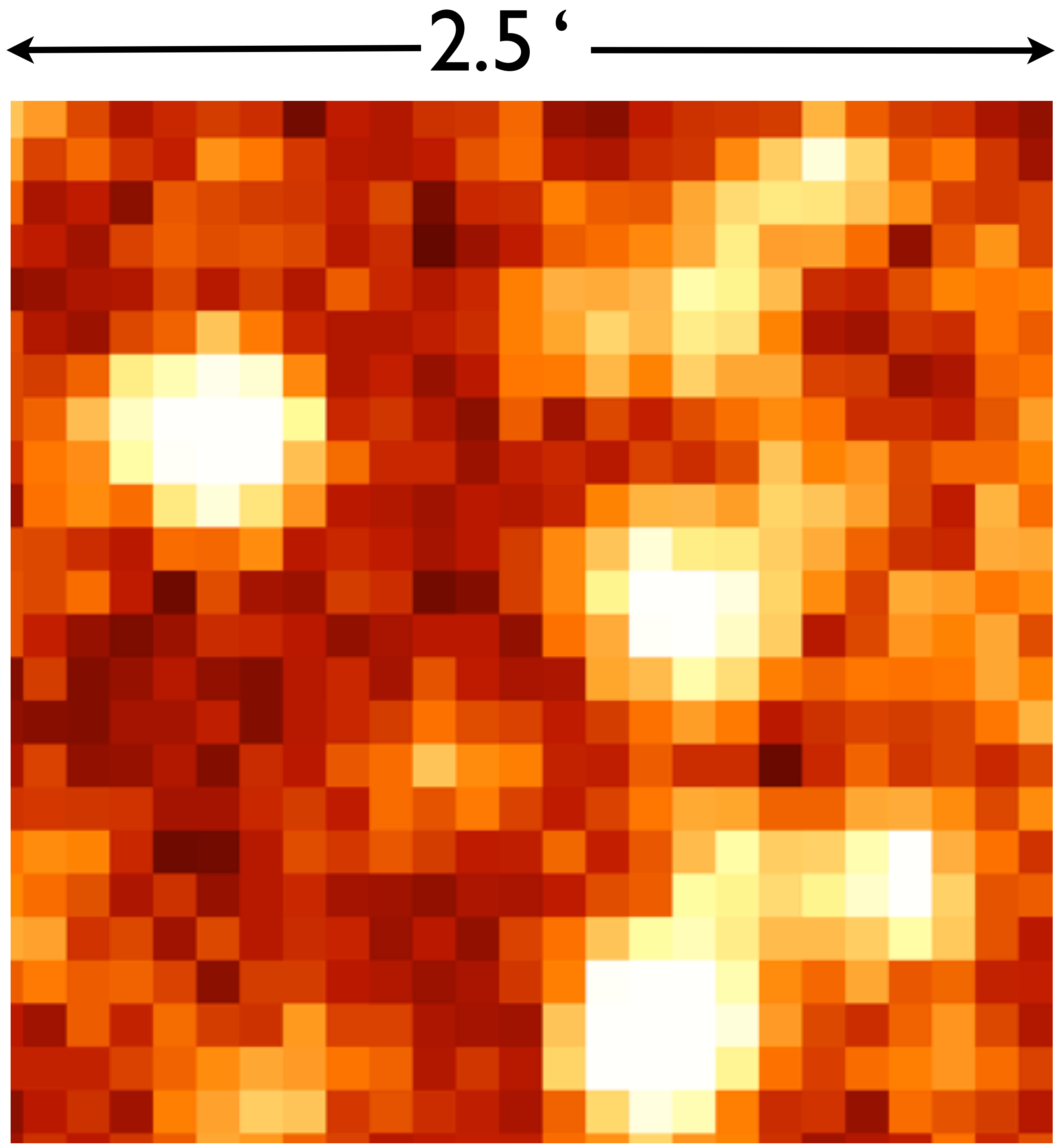
SPIRE
~18, 25, 36" FWHM
@ 250, 350, 500 µm

Confusion



K-band

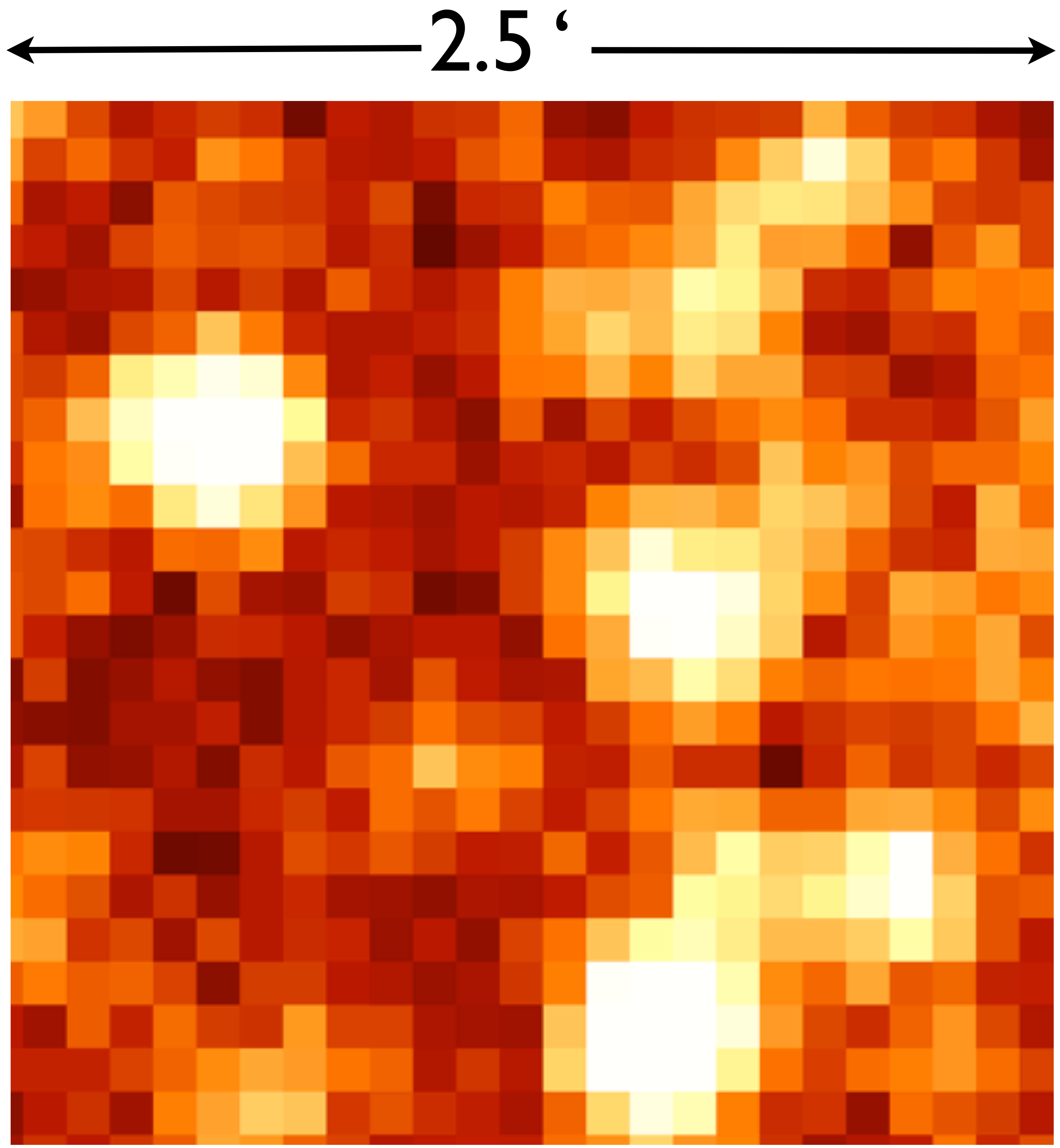
Confusion



SPIRE 250 µm

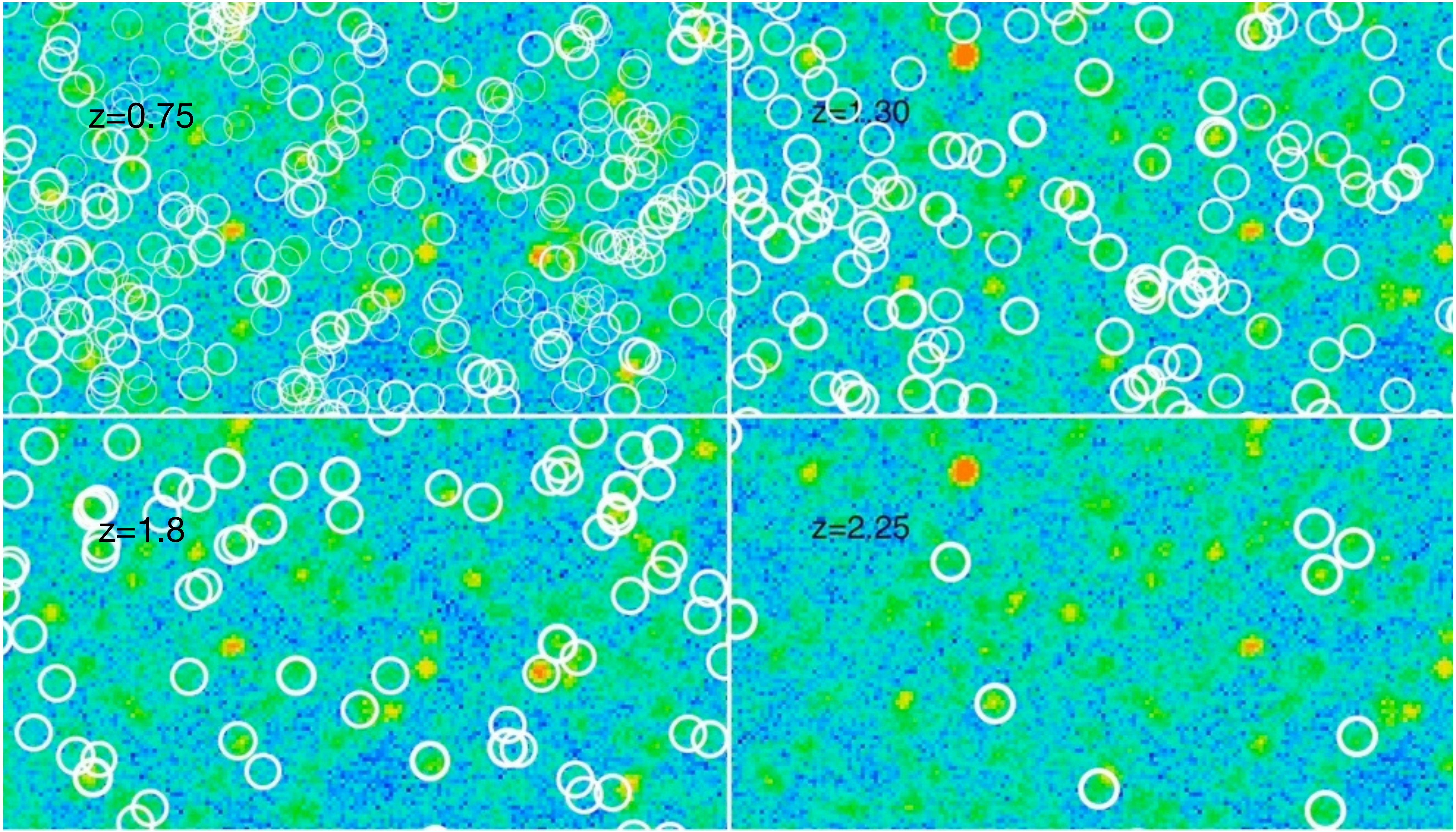
Confusion

Confusion



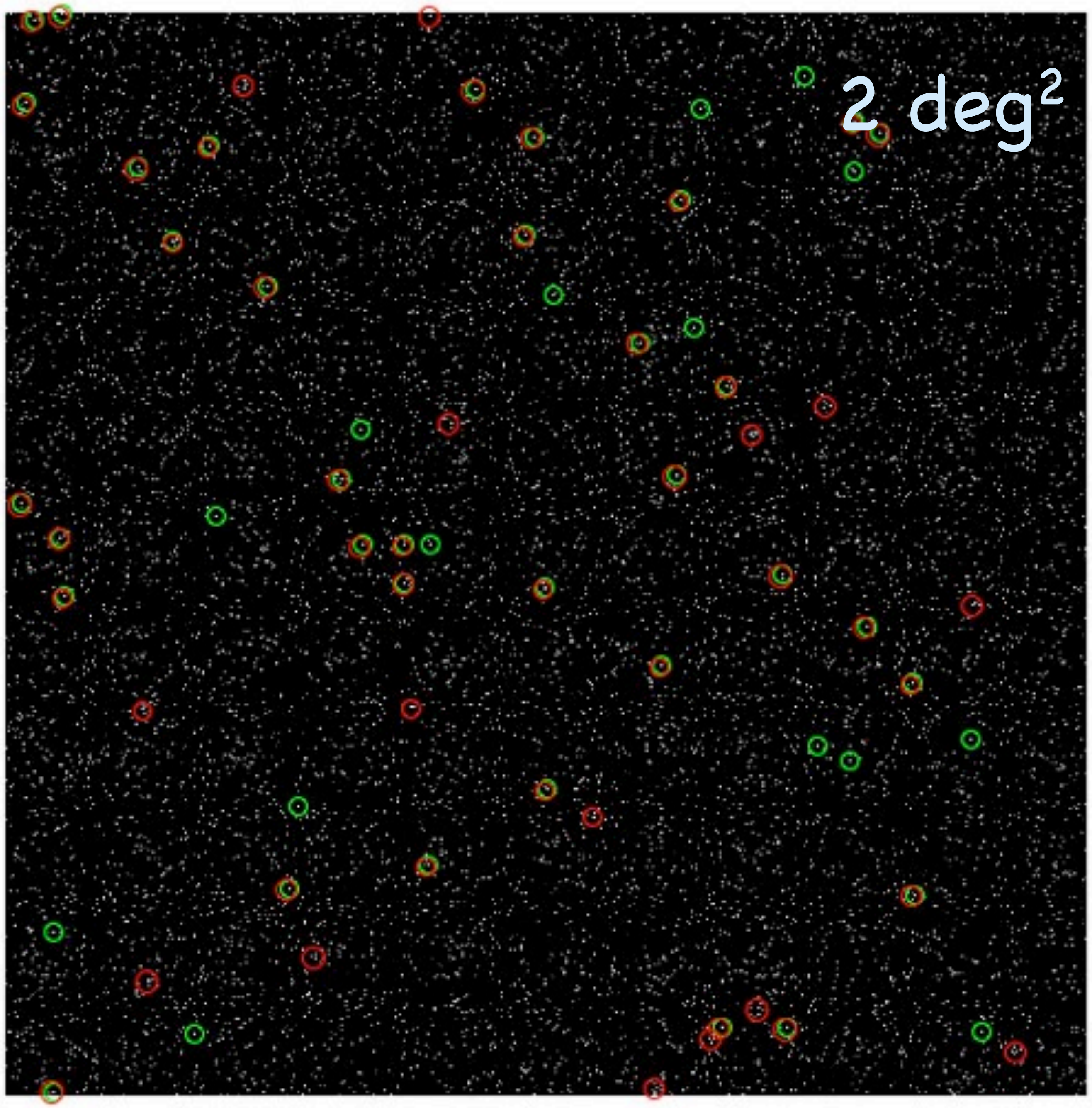
SPIRE 250 µm

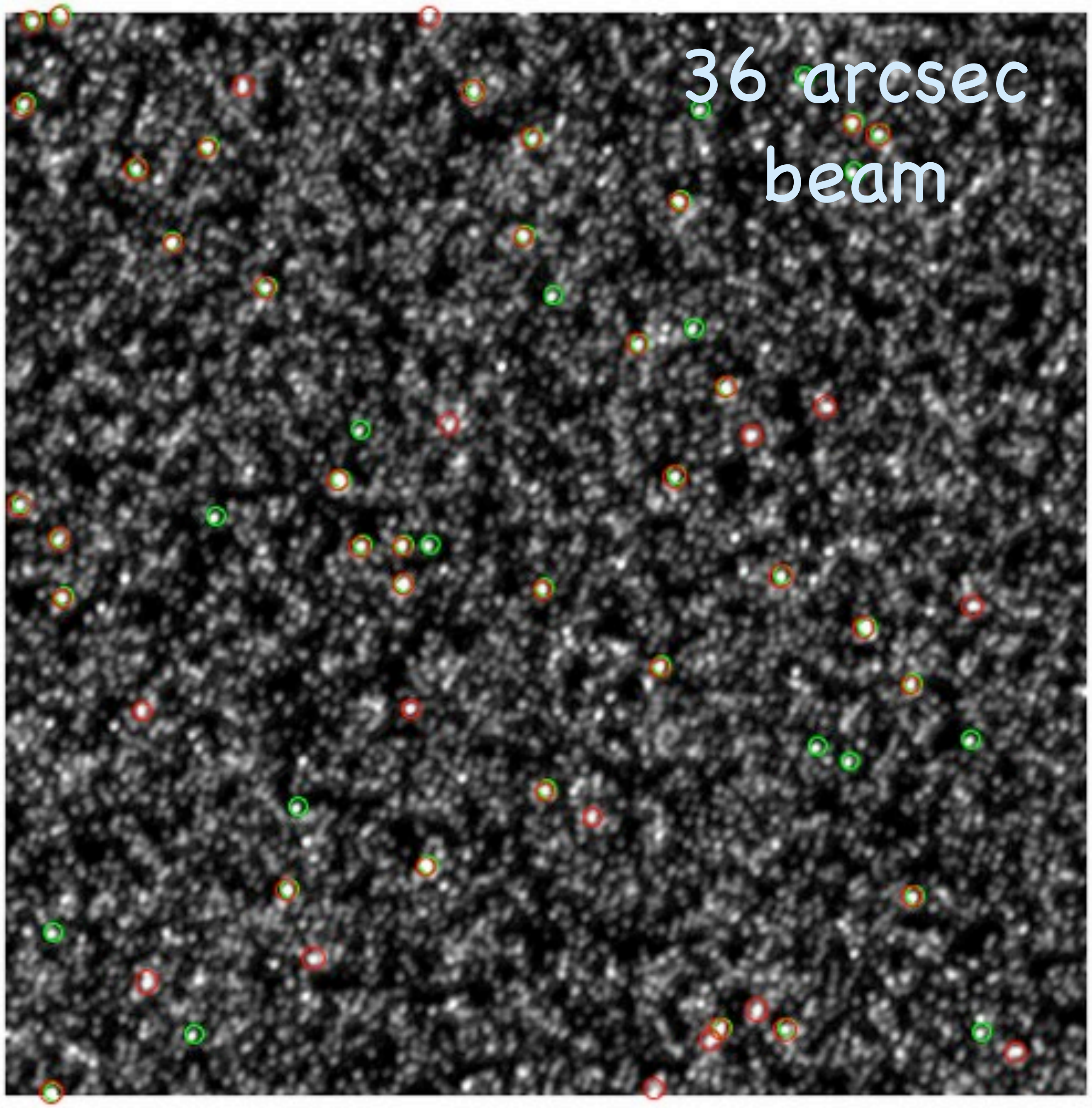
S>20mJy
(at best 15% of all flux, i.e., 0.5% of all sources) is resolved



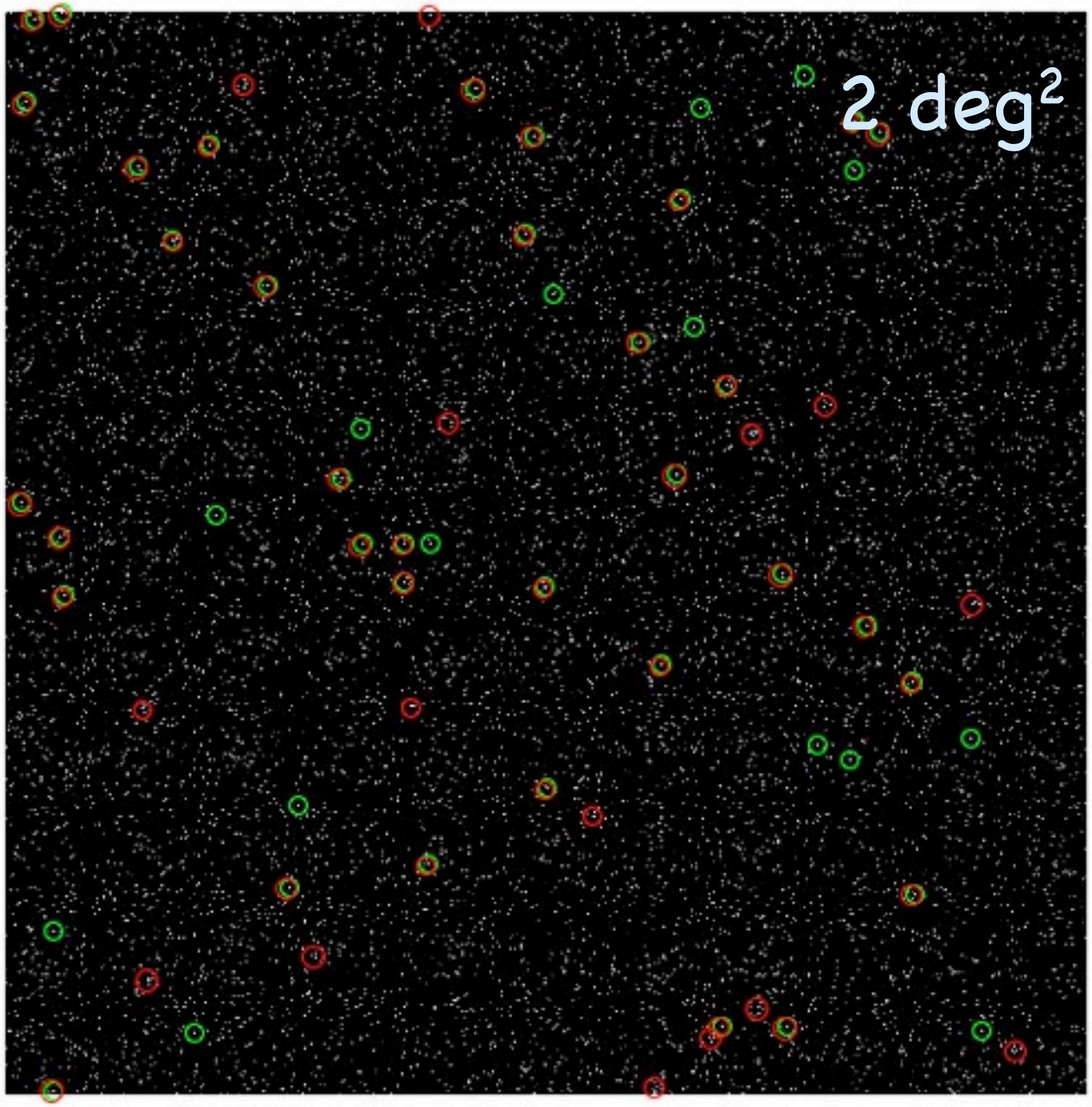
Confusion

Confusion

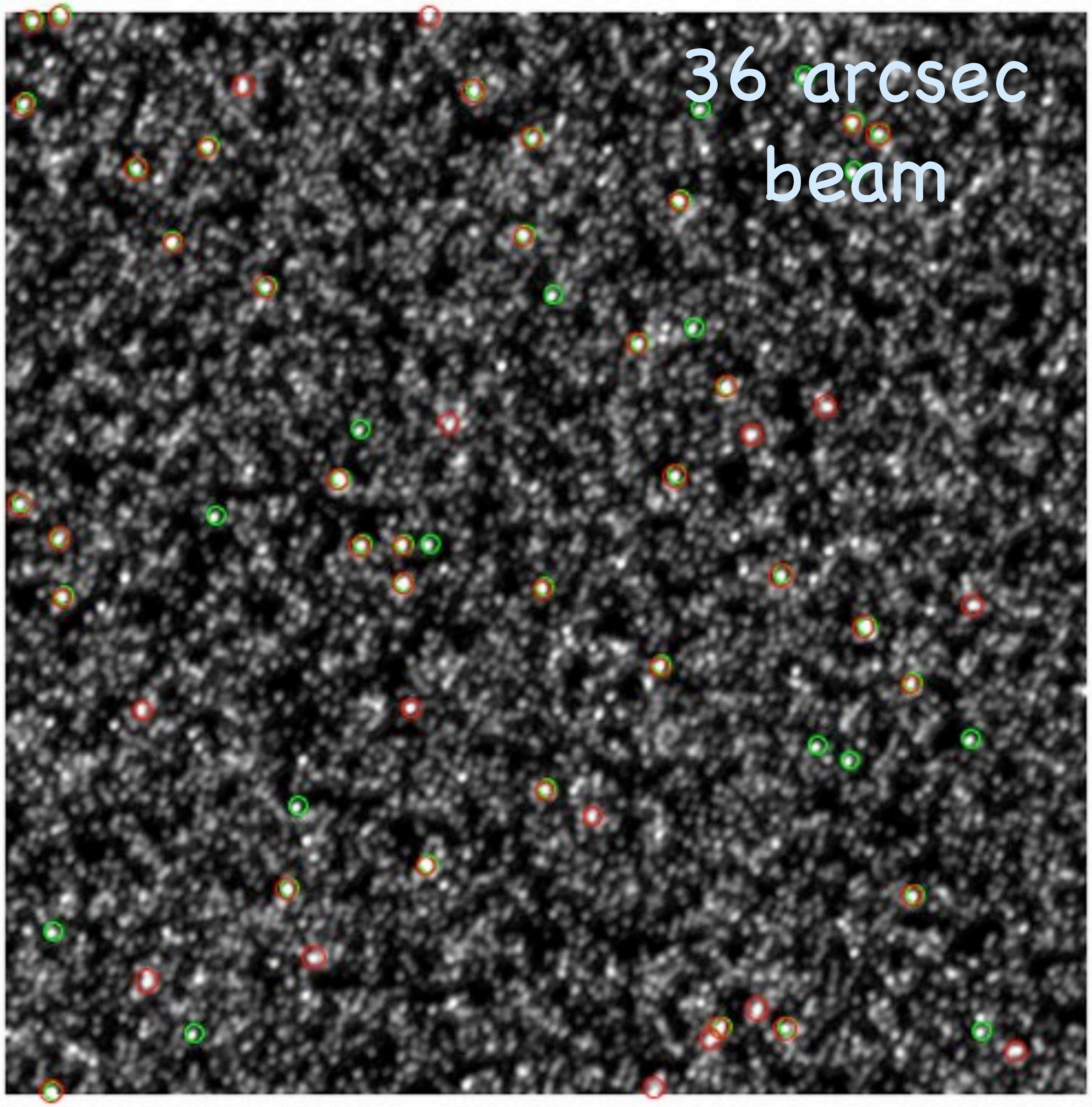




Confusion

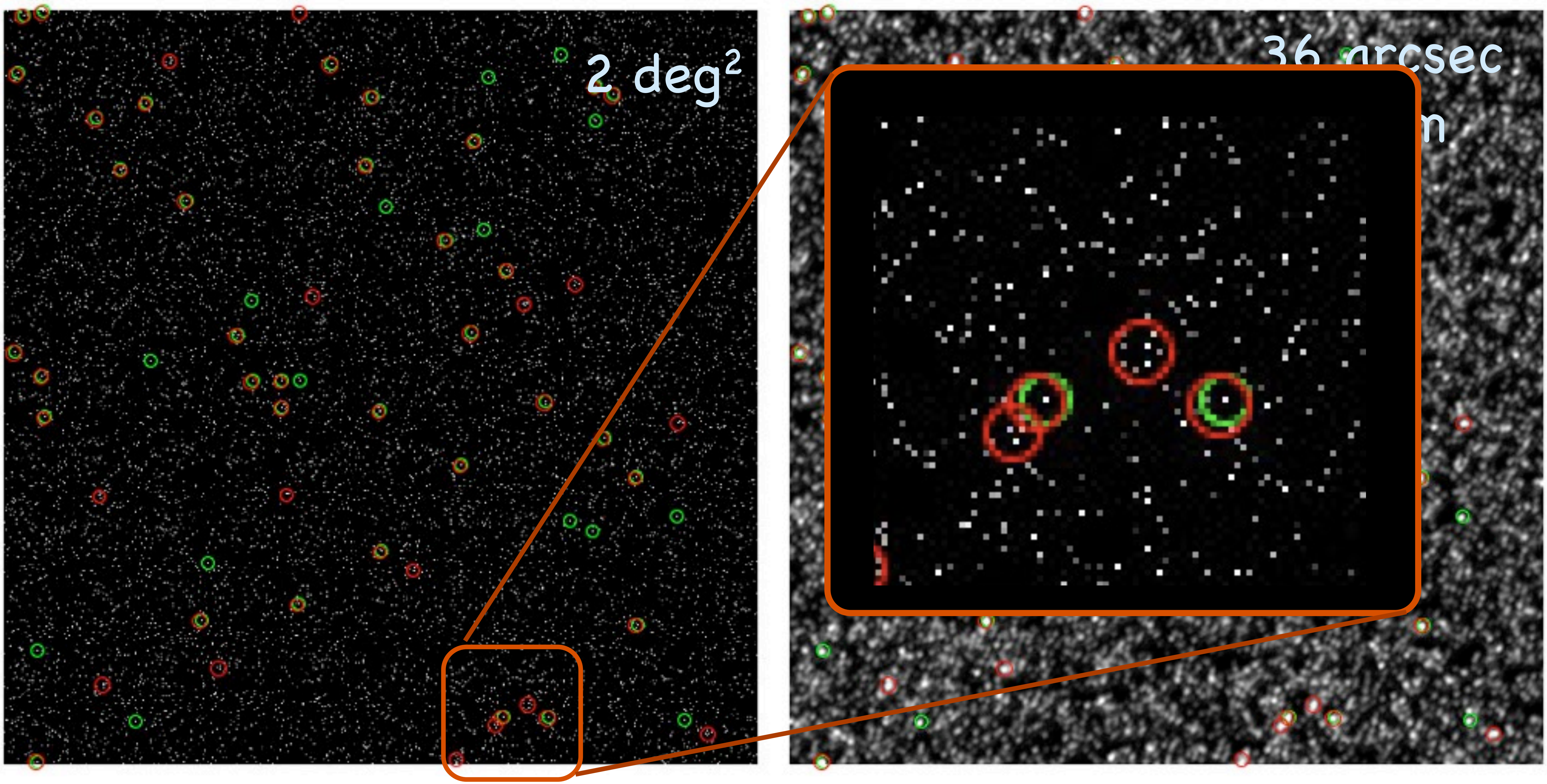


50 brightest
(top 0.5%)

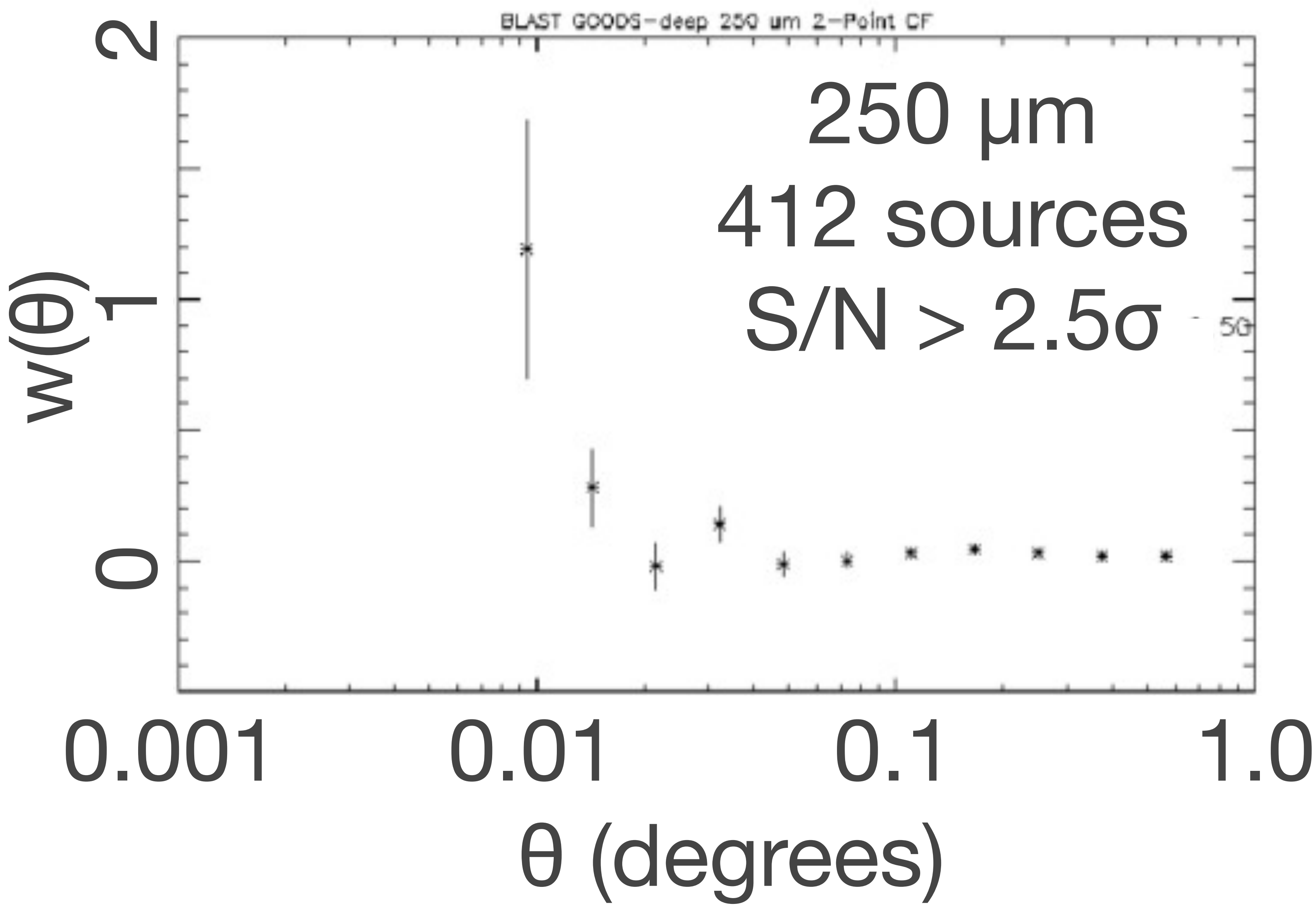


50 brightest
recovered

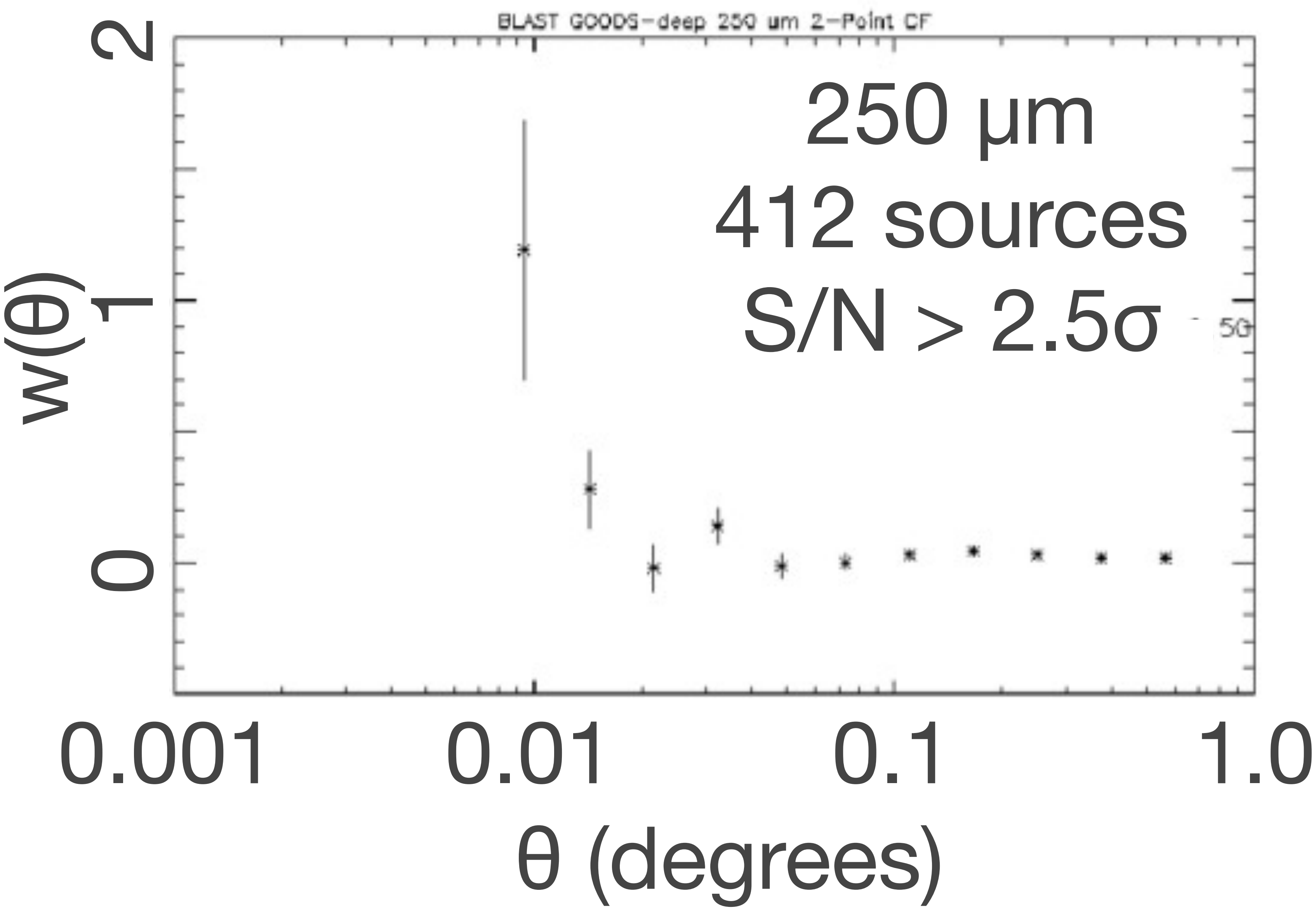
Confusion



70% of top
0.5%
recovered

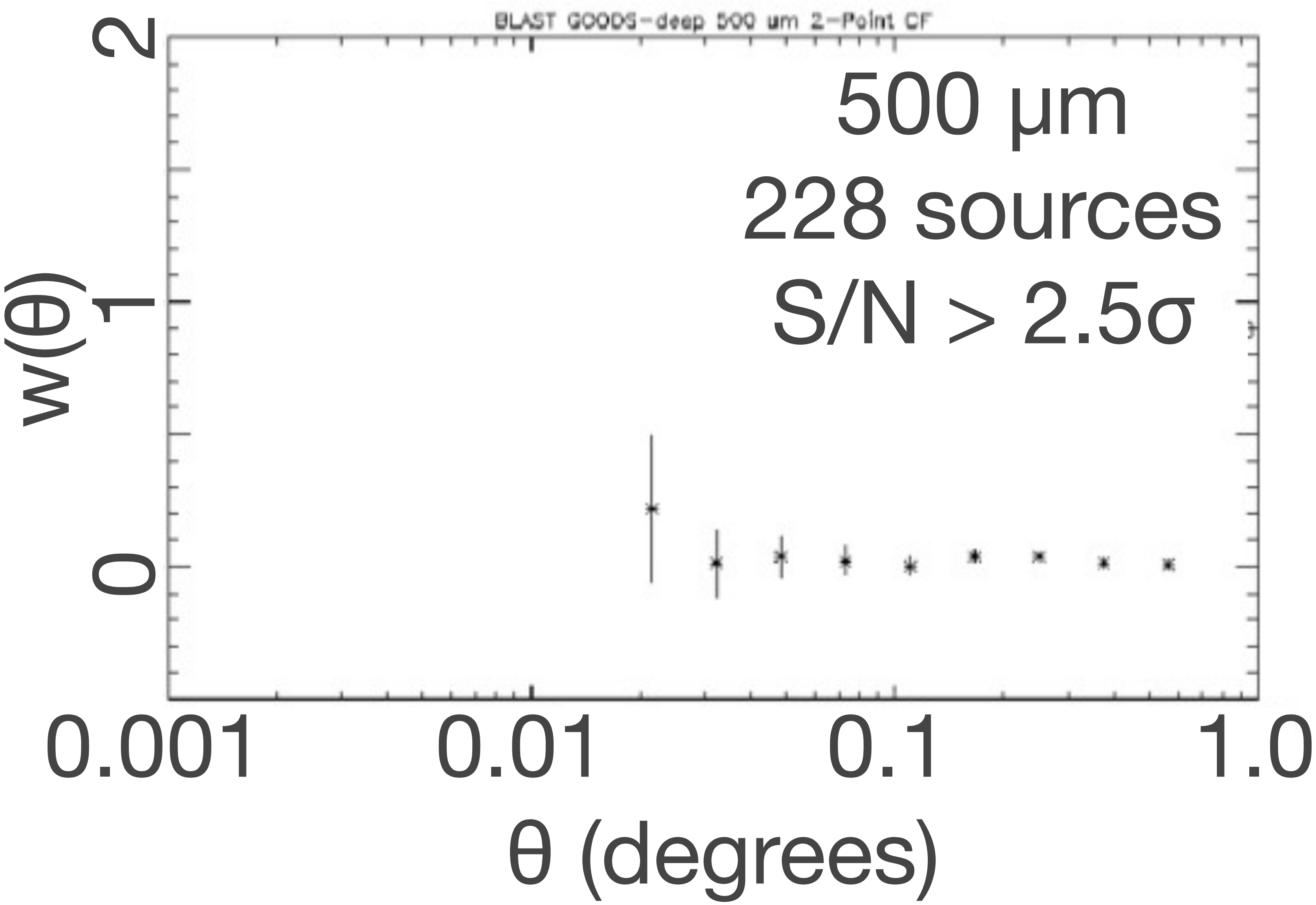


Resolved Source Clustering



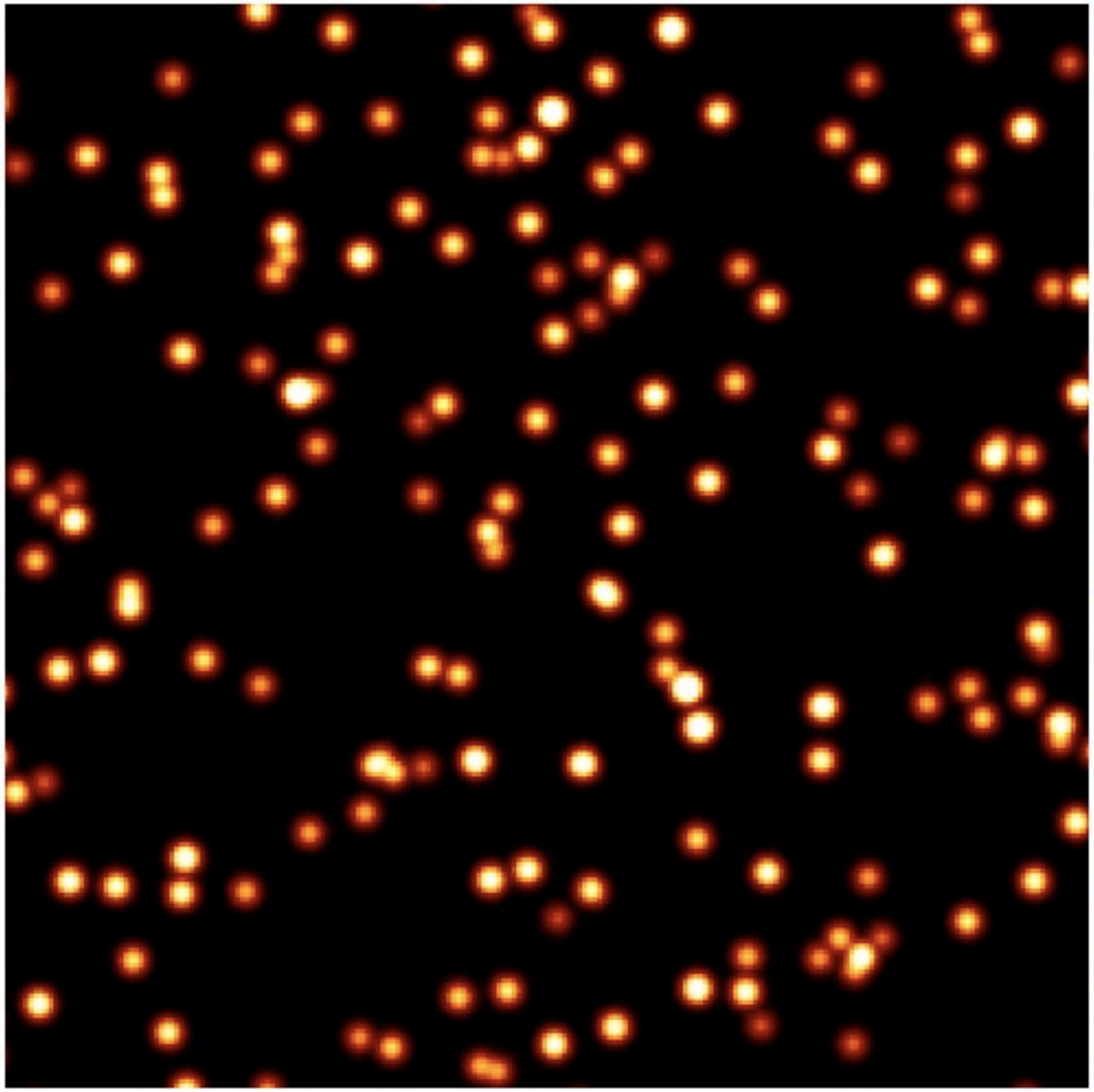
- Marginal Signal at 250 um

Resolved Source Clustering

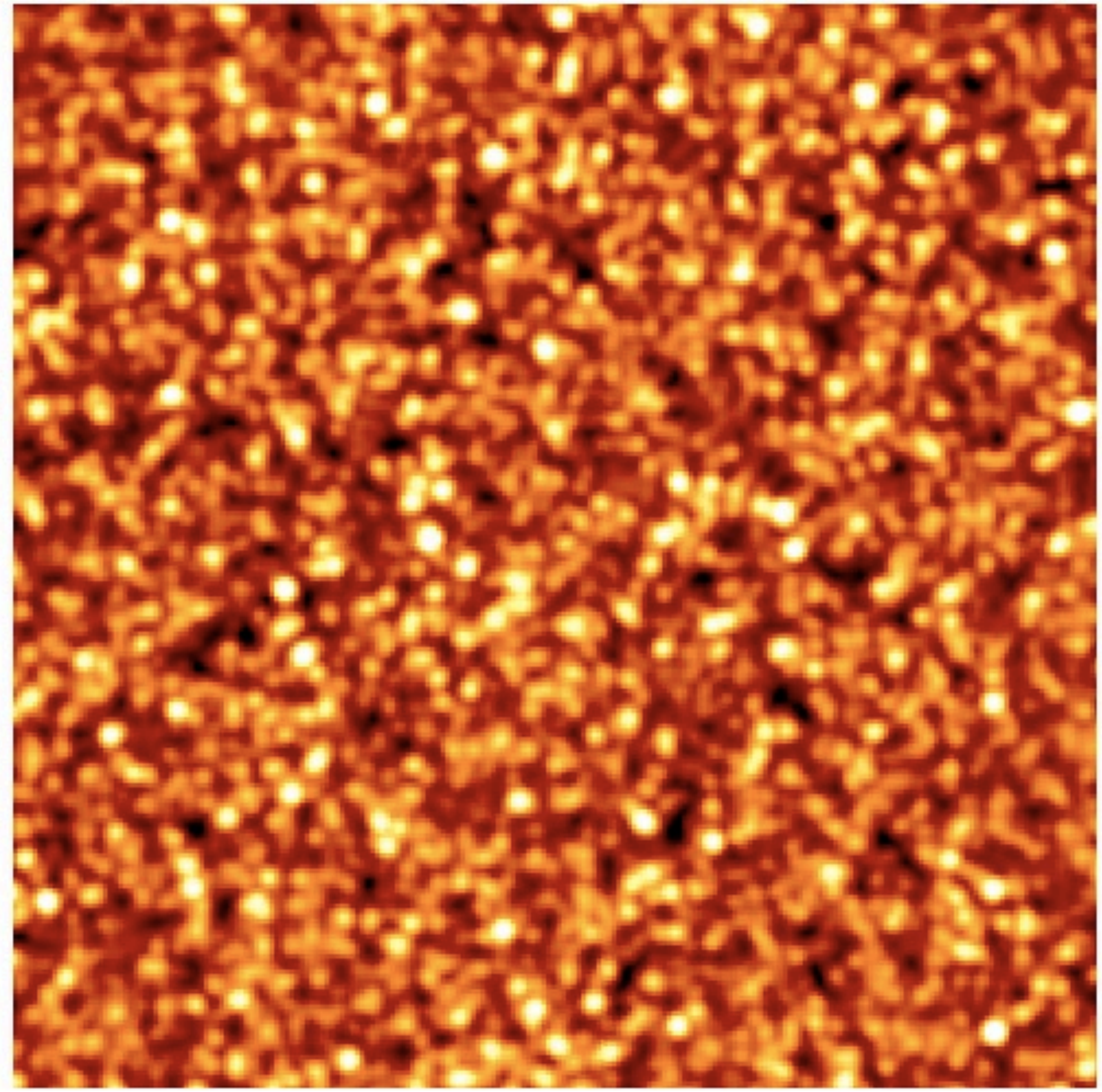


- Marginal Signal at 250 um
- Consistent with zero at 500 um

Resolved Source Clustering

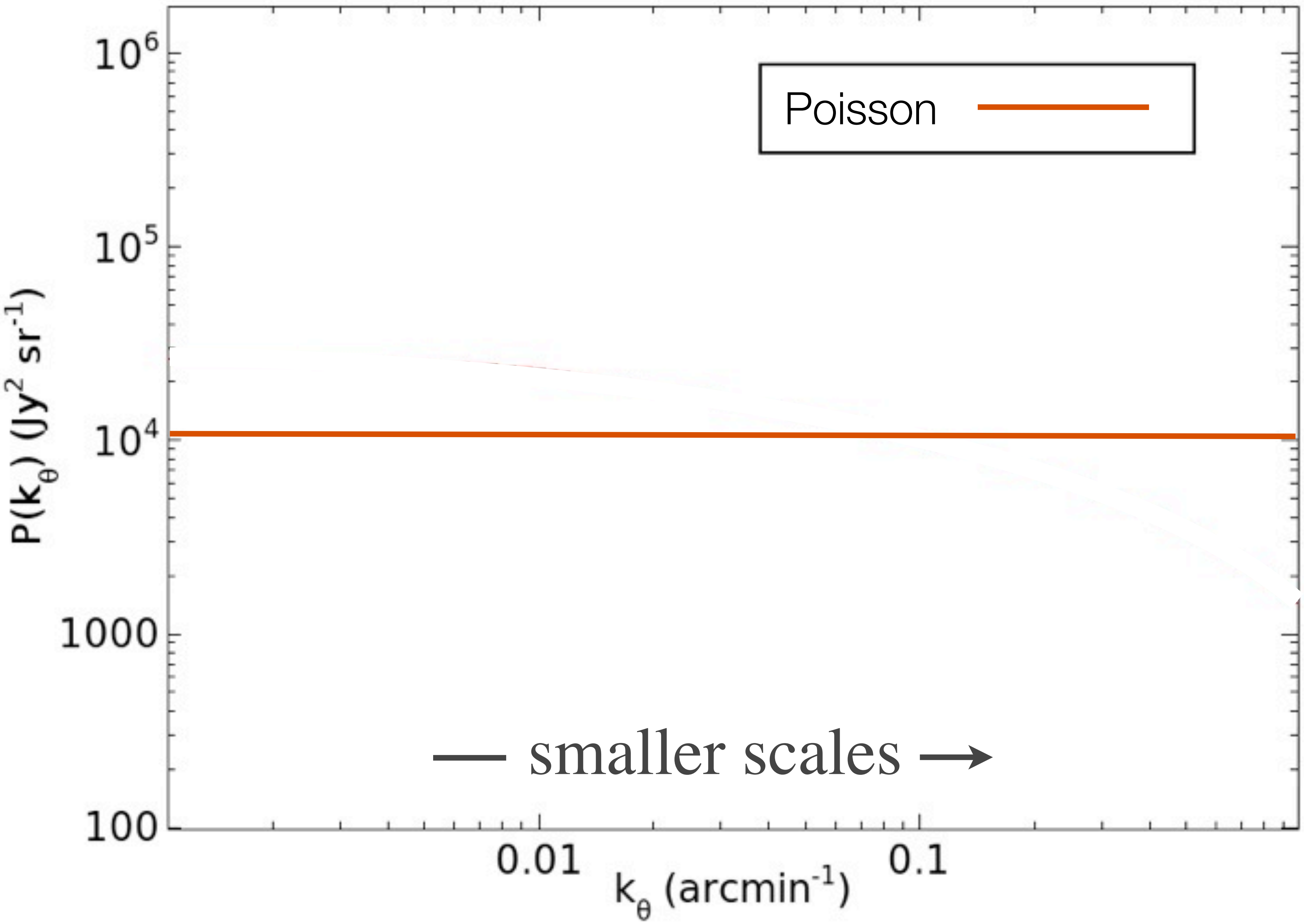


$S > 20$ mJy : 1,200/deg^2

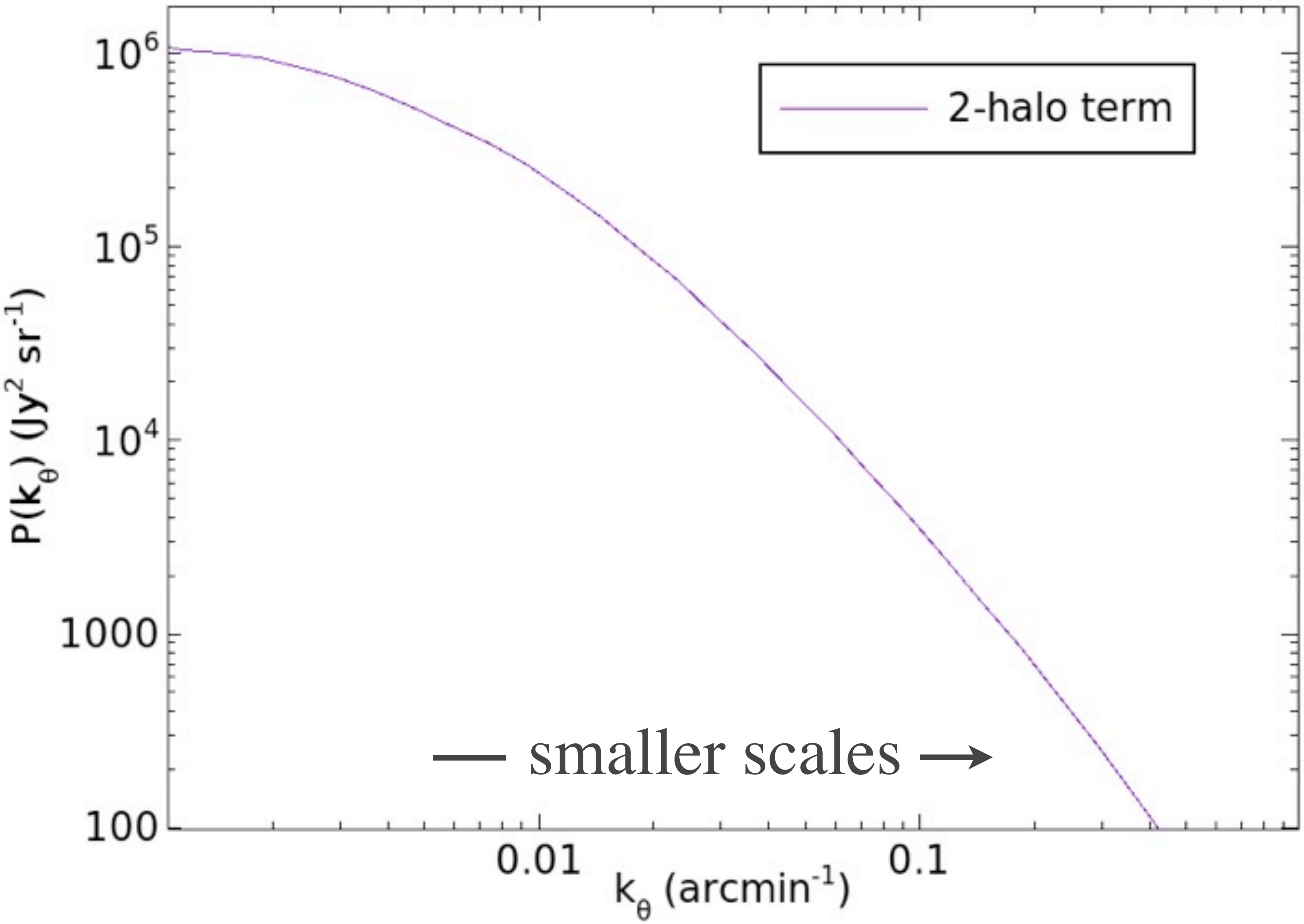


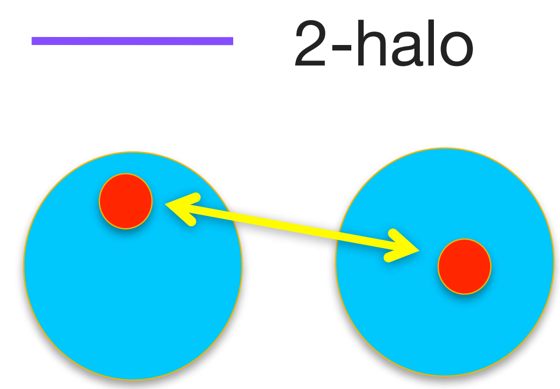
$S < 20$ mJy : 480,000/deg^2

Confusion

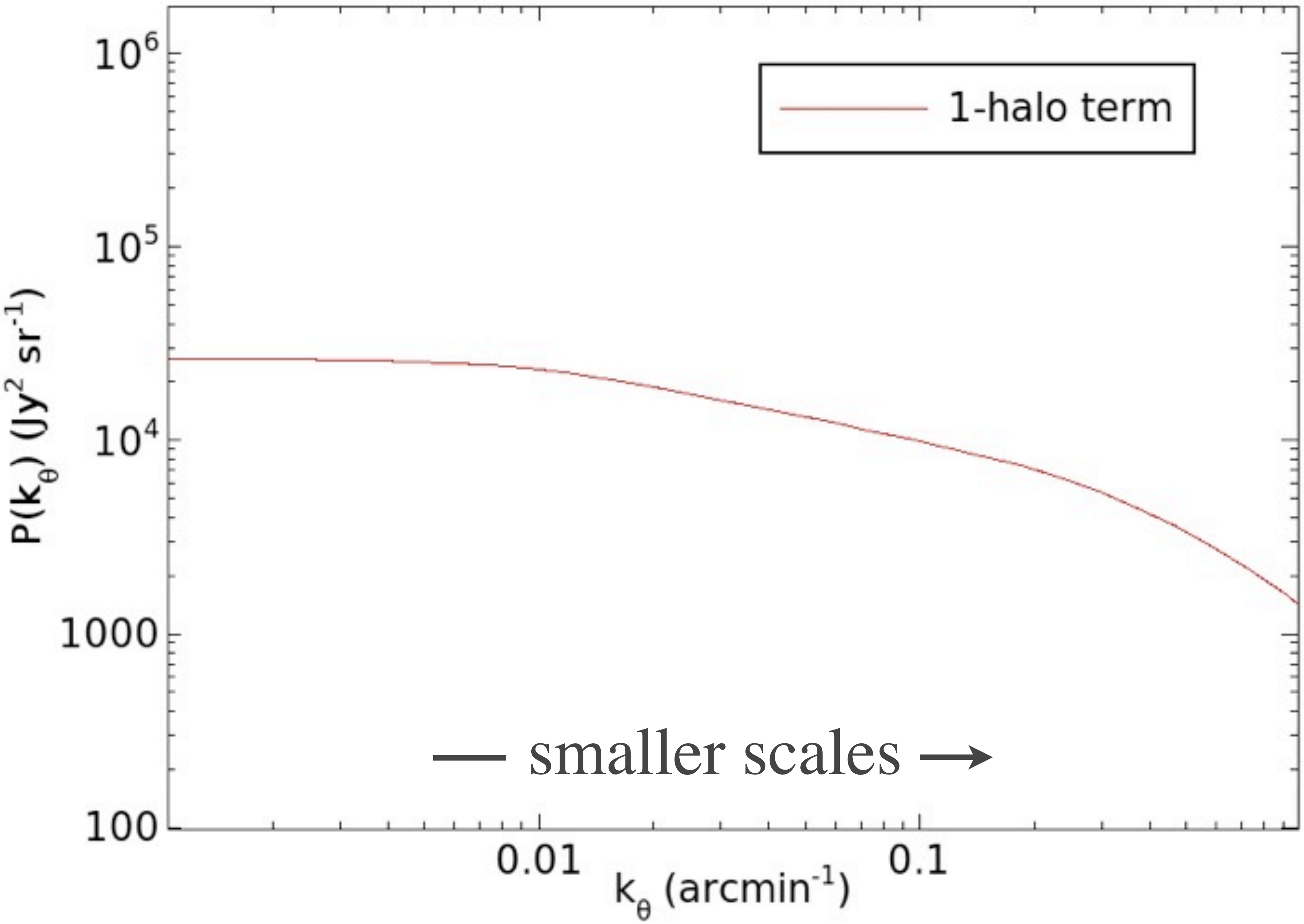


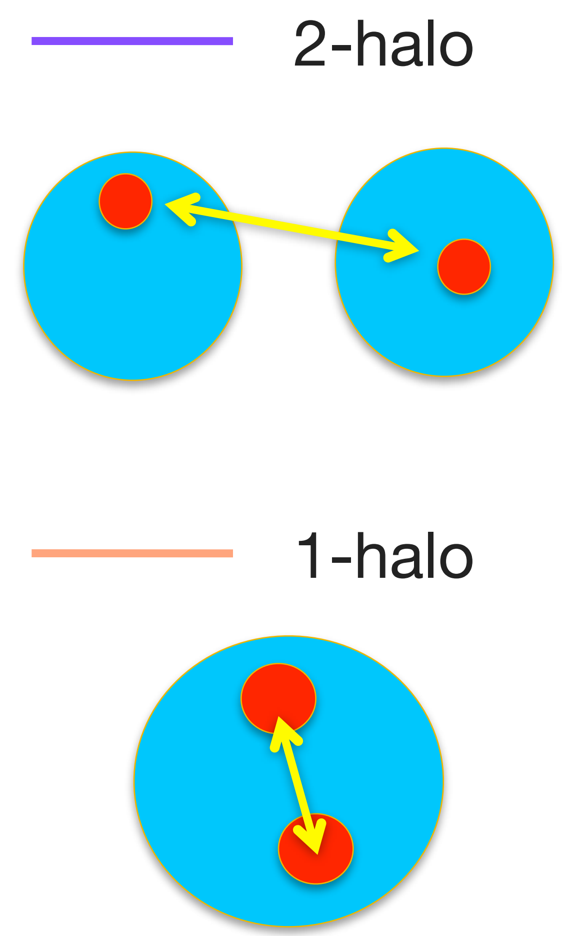
Power Spectrum



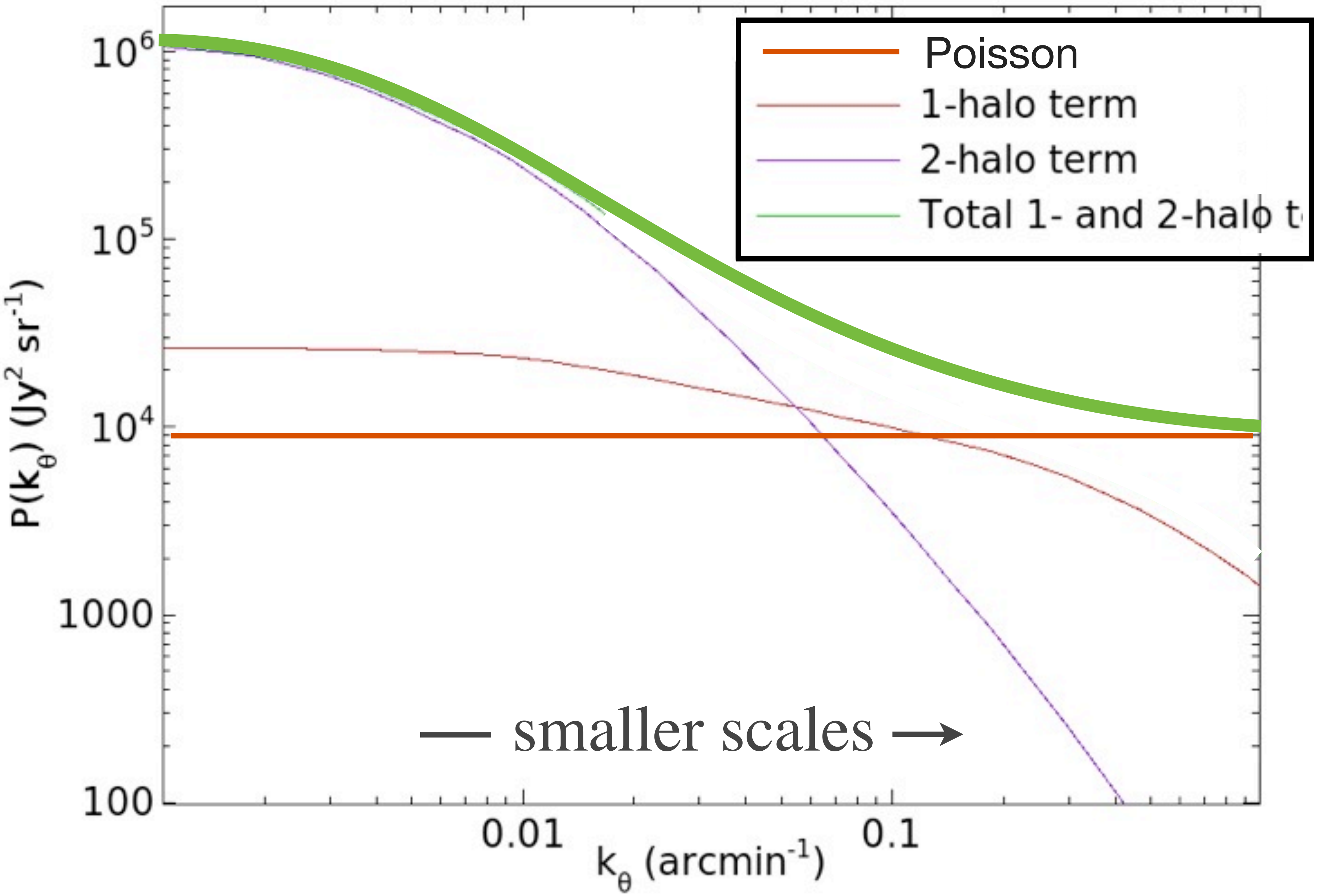


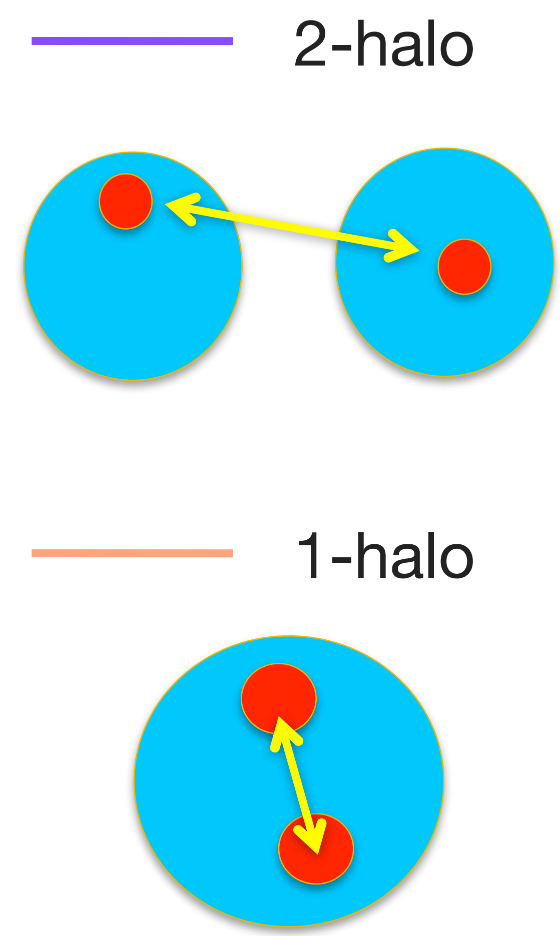
Power Spectrum



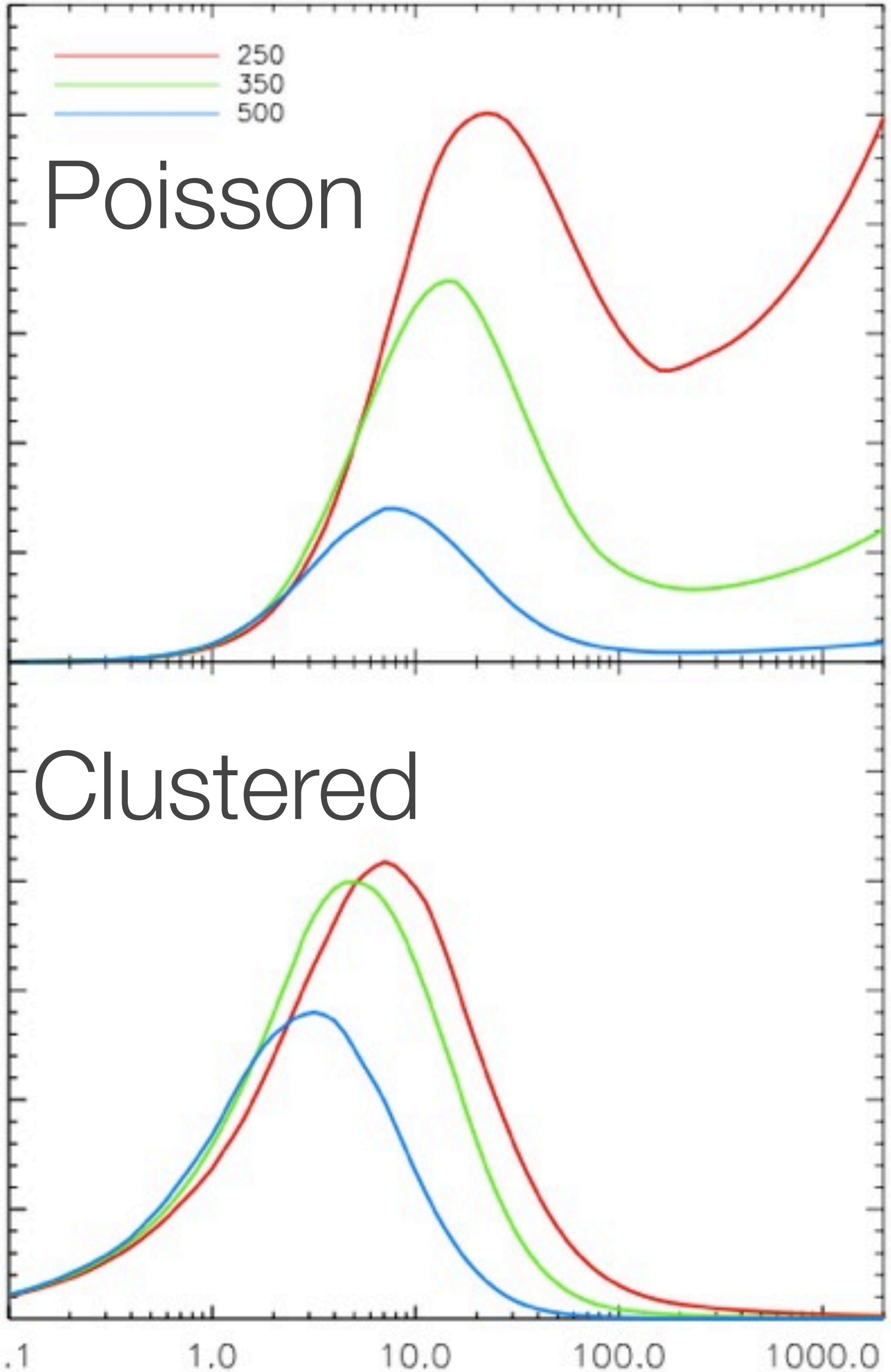


Power Spectrum



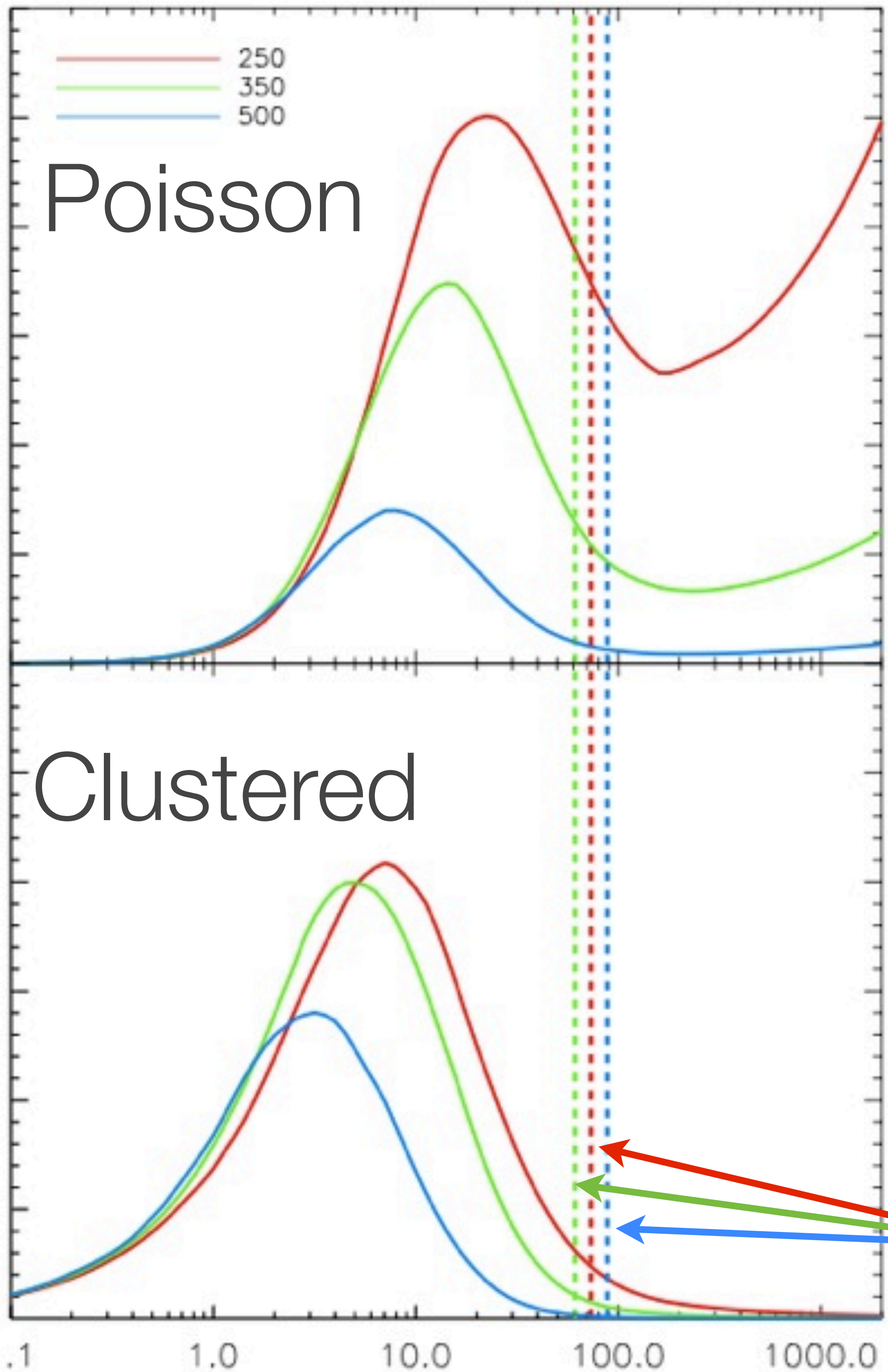


Power Spectrum



- Bulk of CIB power from ~10 mJy sources
- Masking has much less impact at longer λ

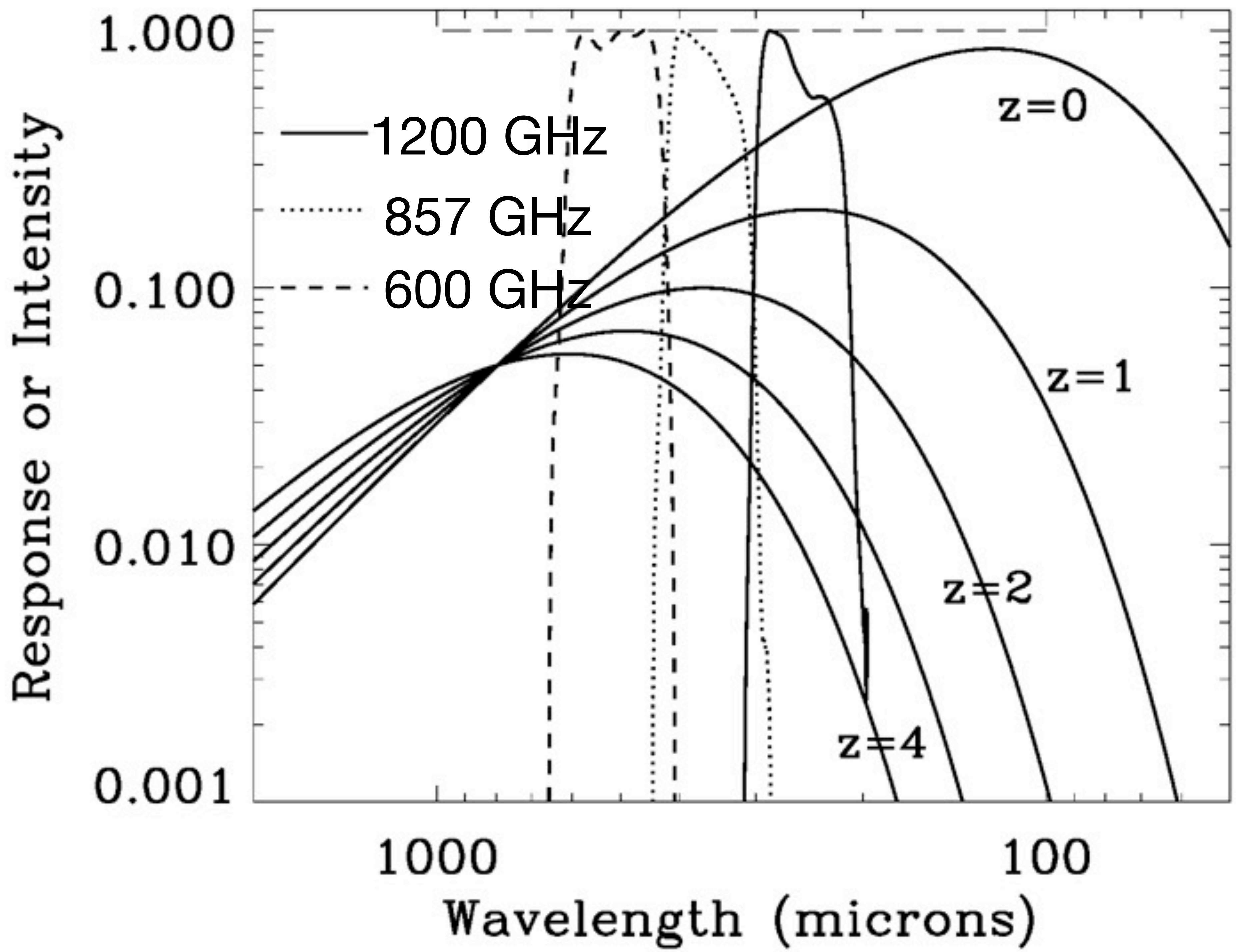
Contribution to Power



- Bulk of CIB power from ~10 mJy sources
- Masking has much less impact at longer λ

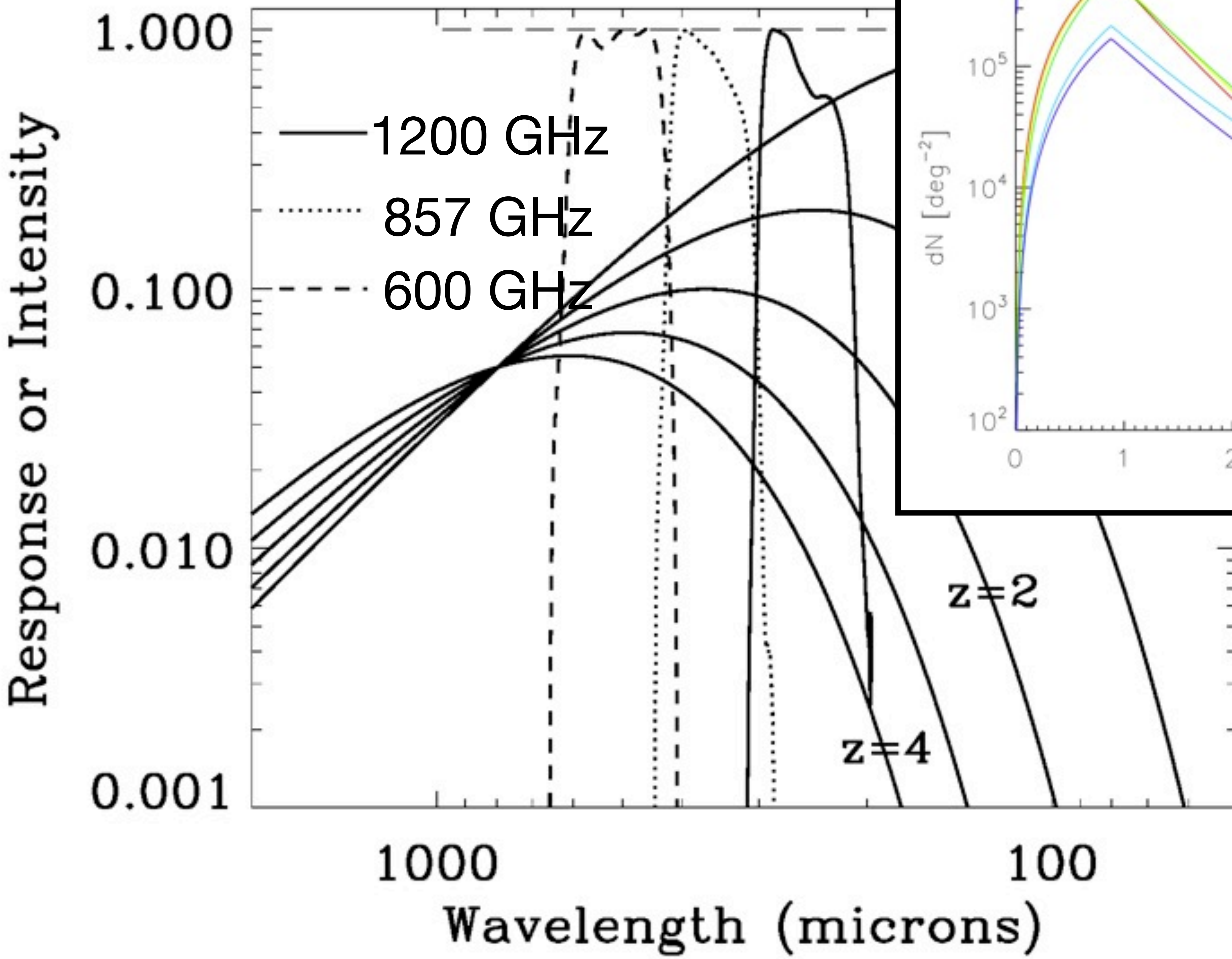
Vertical lines are 5-σ confusion noise limits

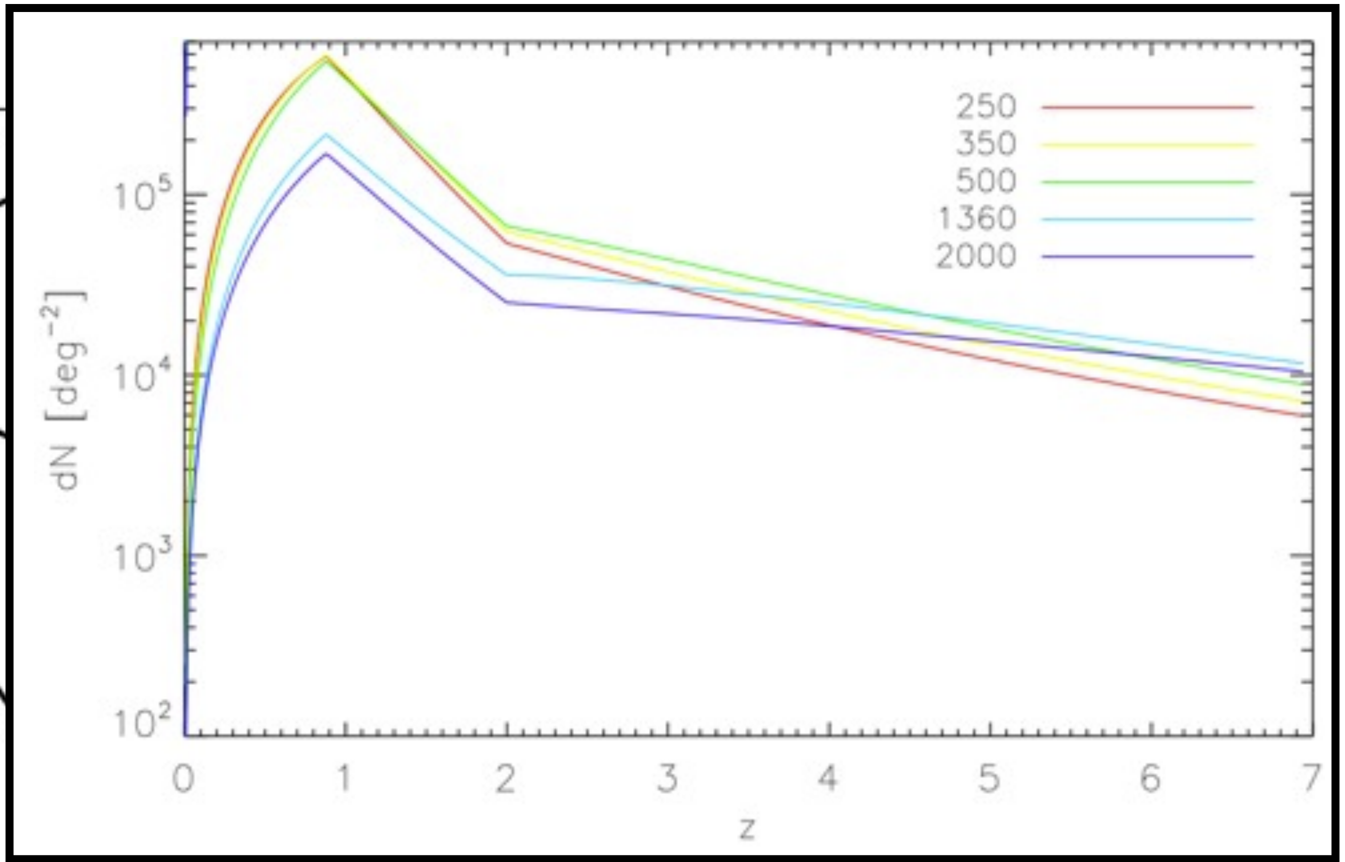
Contribution to Power



redshifted dust SED (T~35) peaks at λ~200-800μm

Submillimeter light





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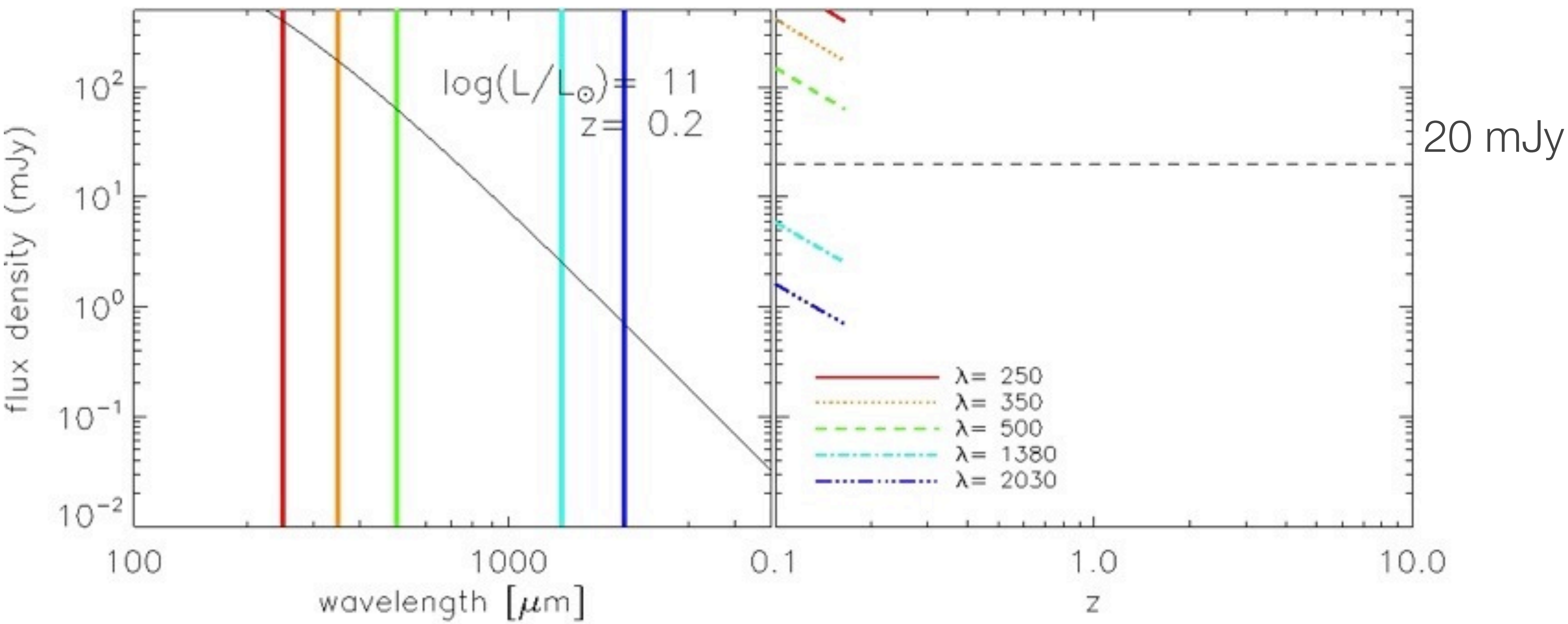
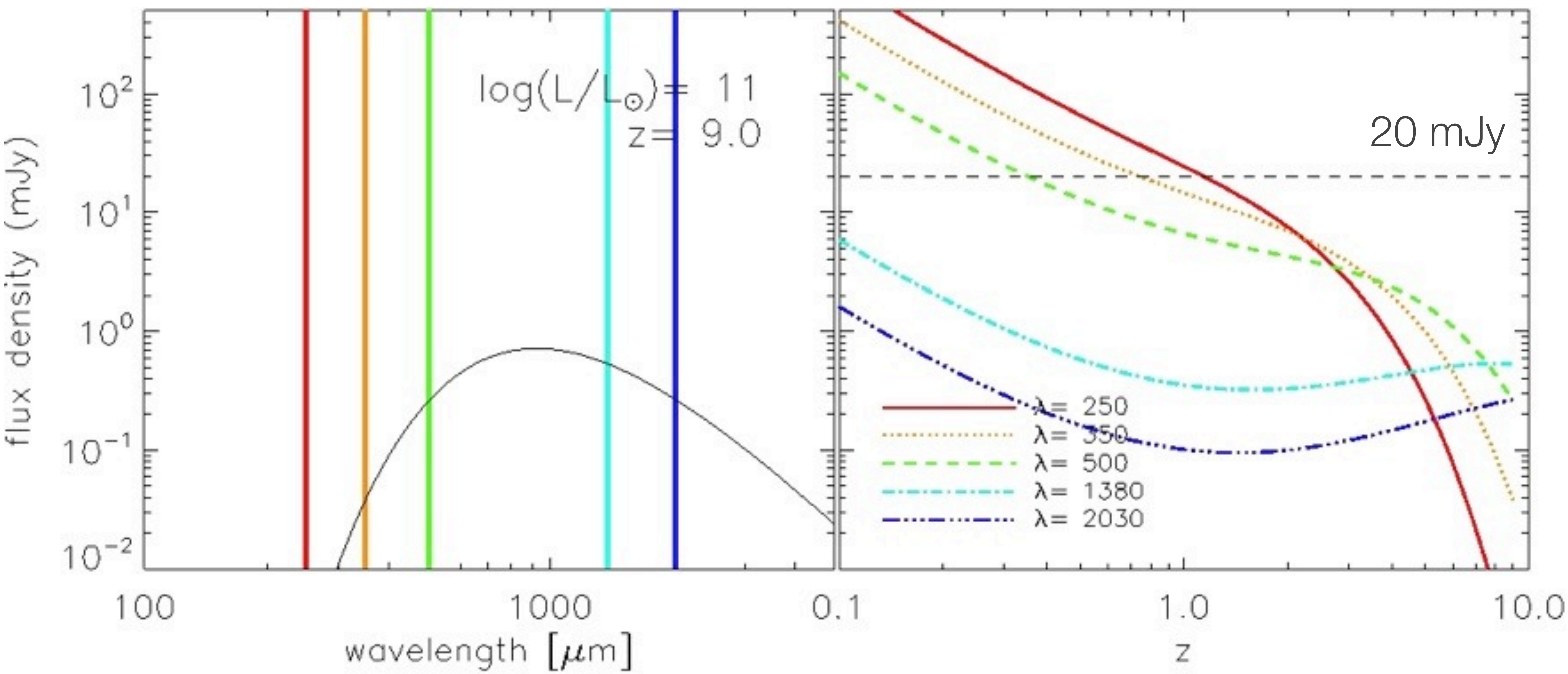


- Longer wavelengths more sensitive to higher redshifts

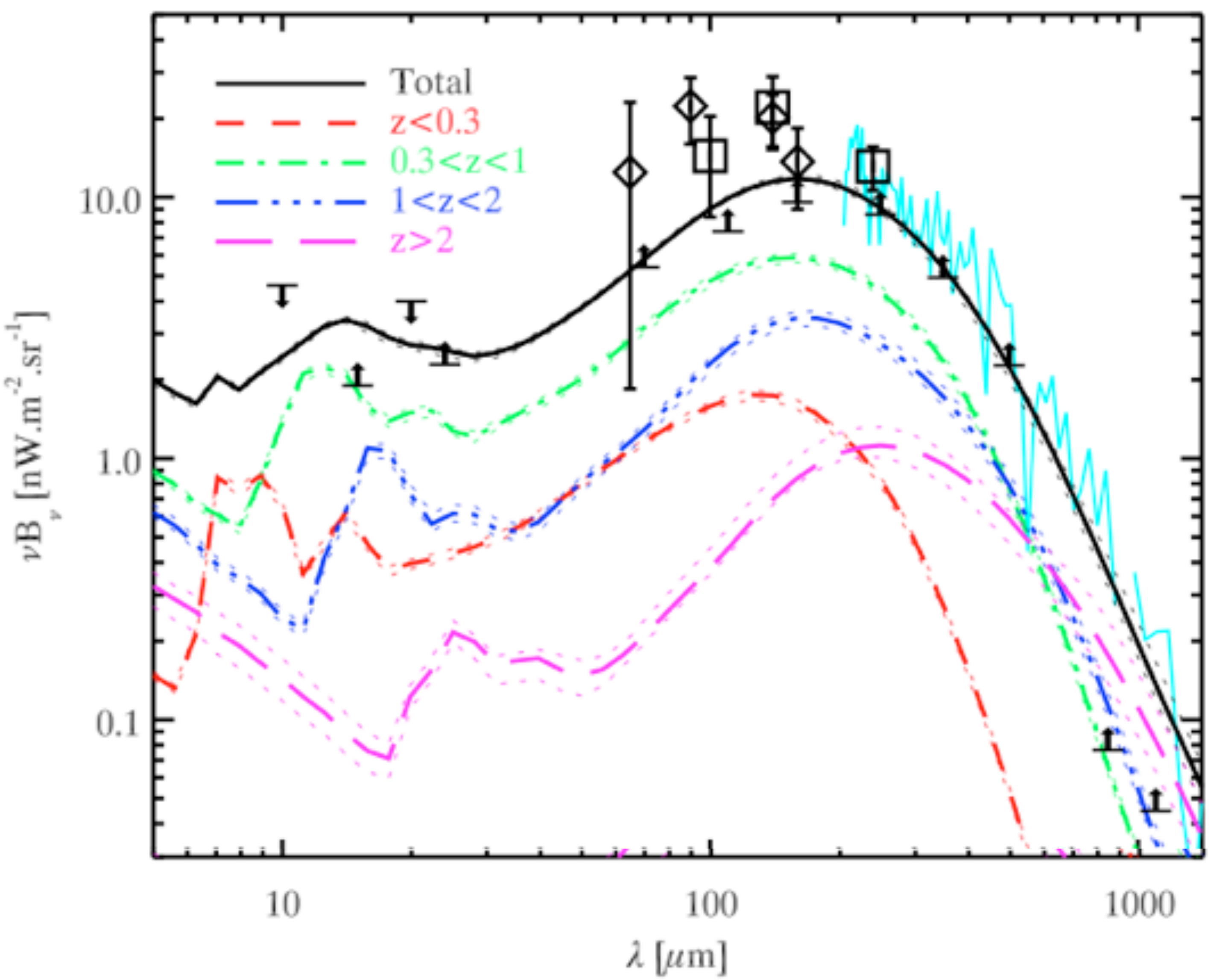
Negative K-Correction



- Longer wavelengths more sensitive to higher redshifts

Negative K-Correction

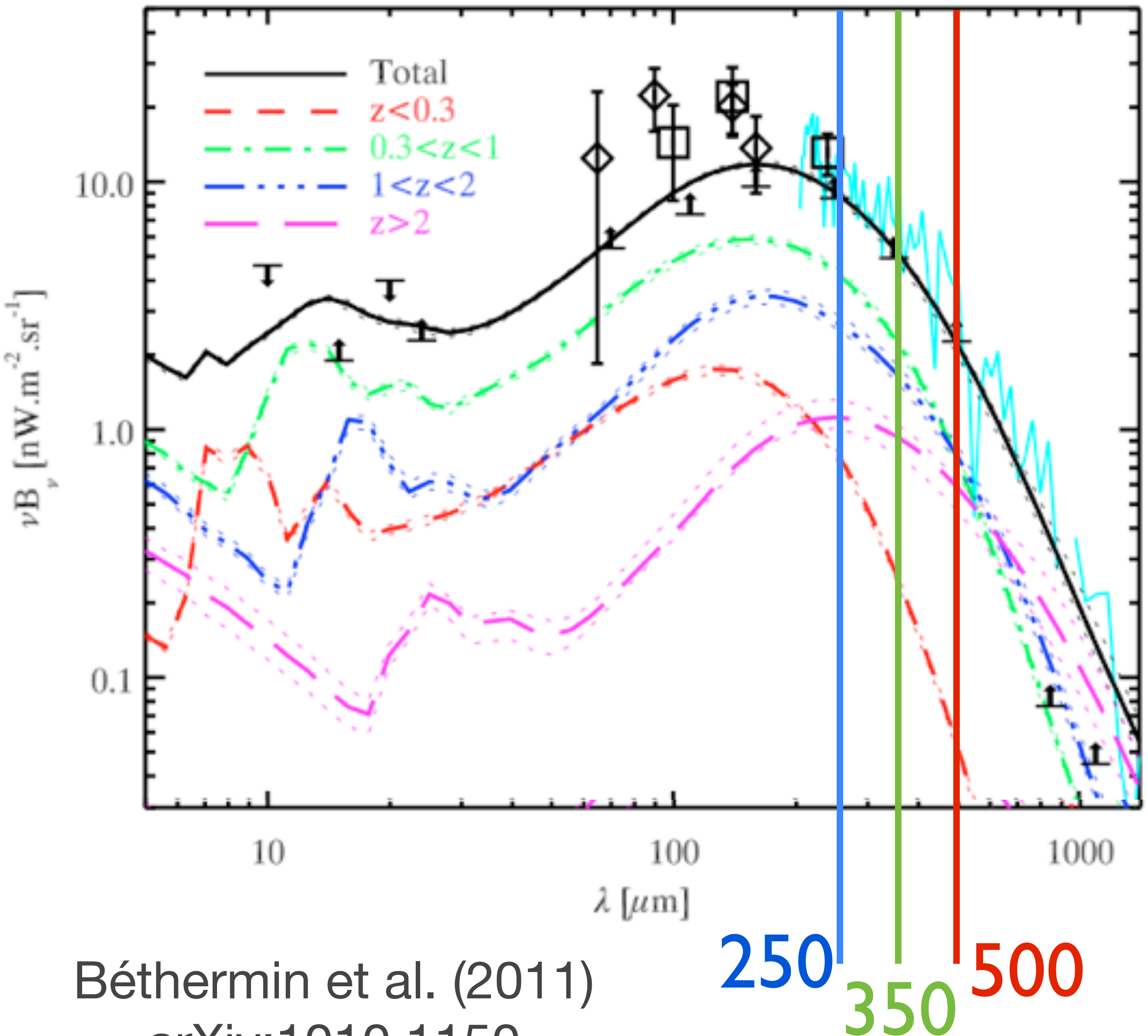
CIB in redshift slices



Béthermin et al. (2011)
arXiv:1010.1150

Redshift Distribution of CIB

CIB in redshift slices



Béthermin et al. (2011)
arXiv:1010.1150

Infrared Background at submm wavelengths probes z ~ 0.3 to 2

Redshift Distribution of CIB

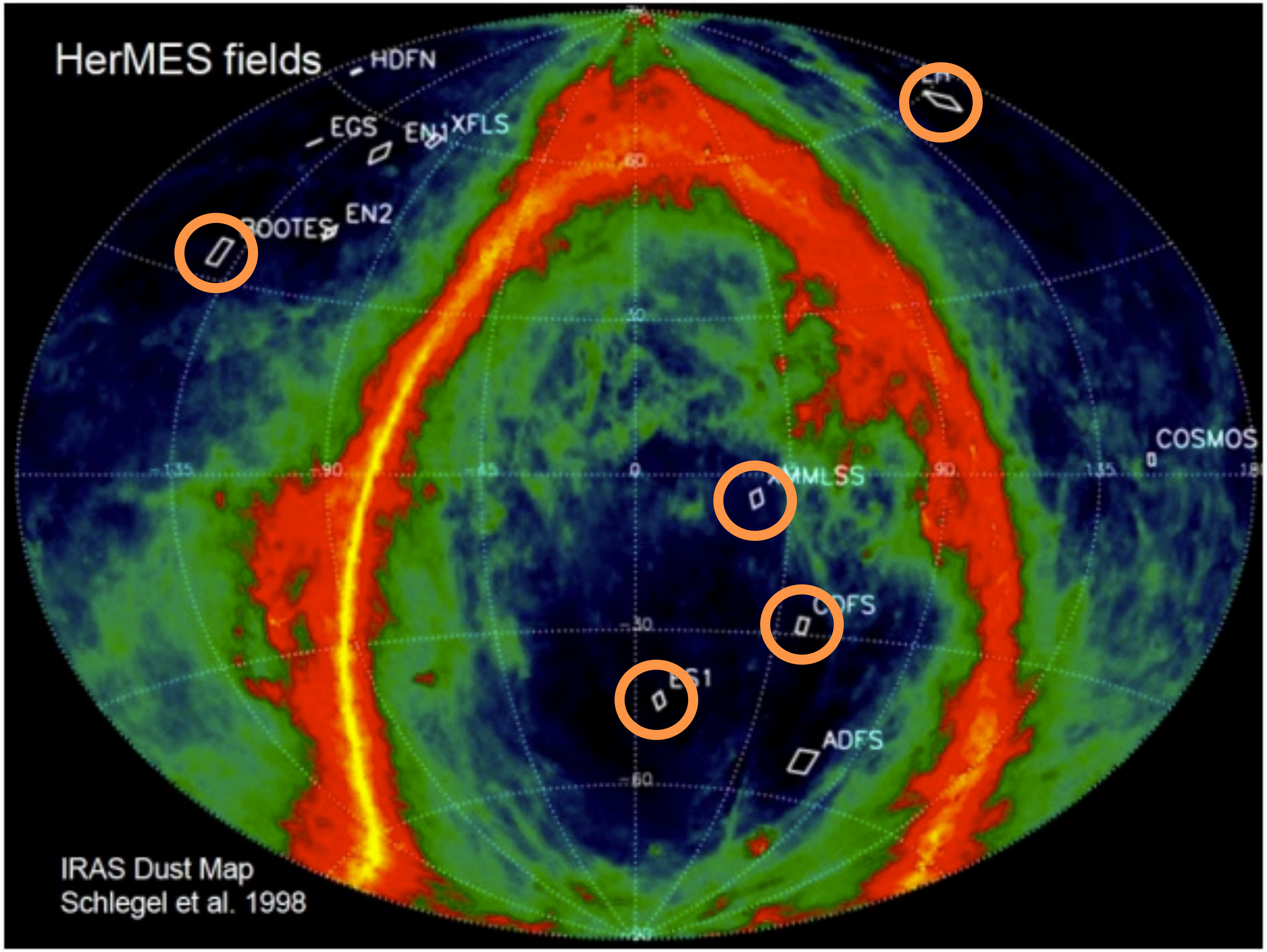
HERMES

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 Orieux, 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

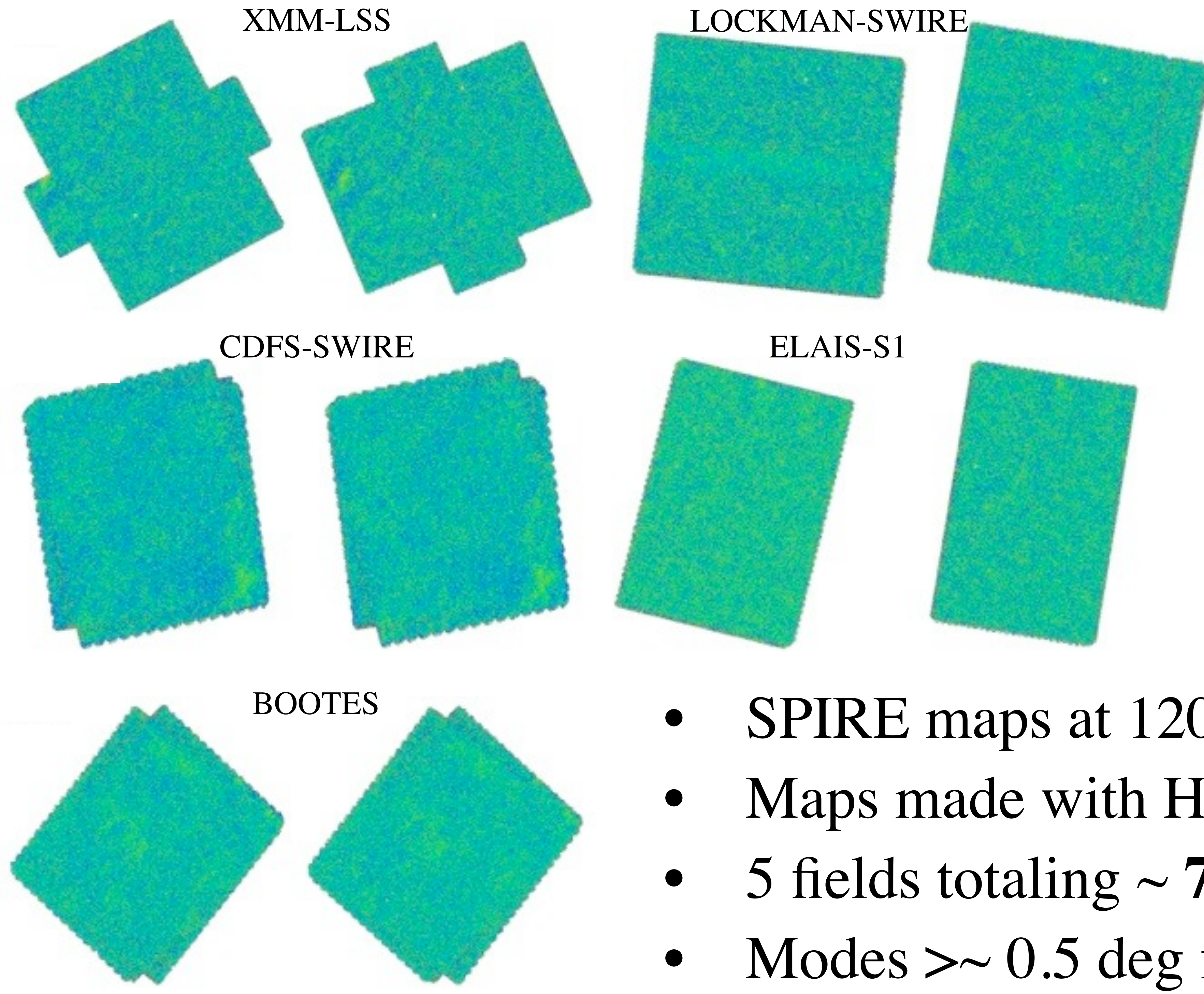
Plus engineers, instrument builders, software developers etc.


HerMES fields
HDFN
EGS
EN1
XFLS
BOOTES
EN2
COSMOS
XMMLSS
CDFS
ES1
ADFS
IRAS Dust Map
Schlegel et al. 1998

HERMES

Data

Data

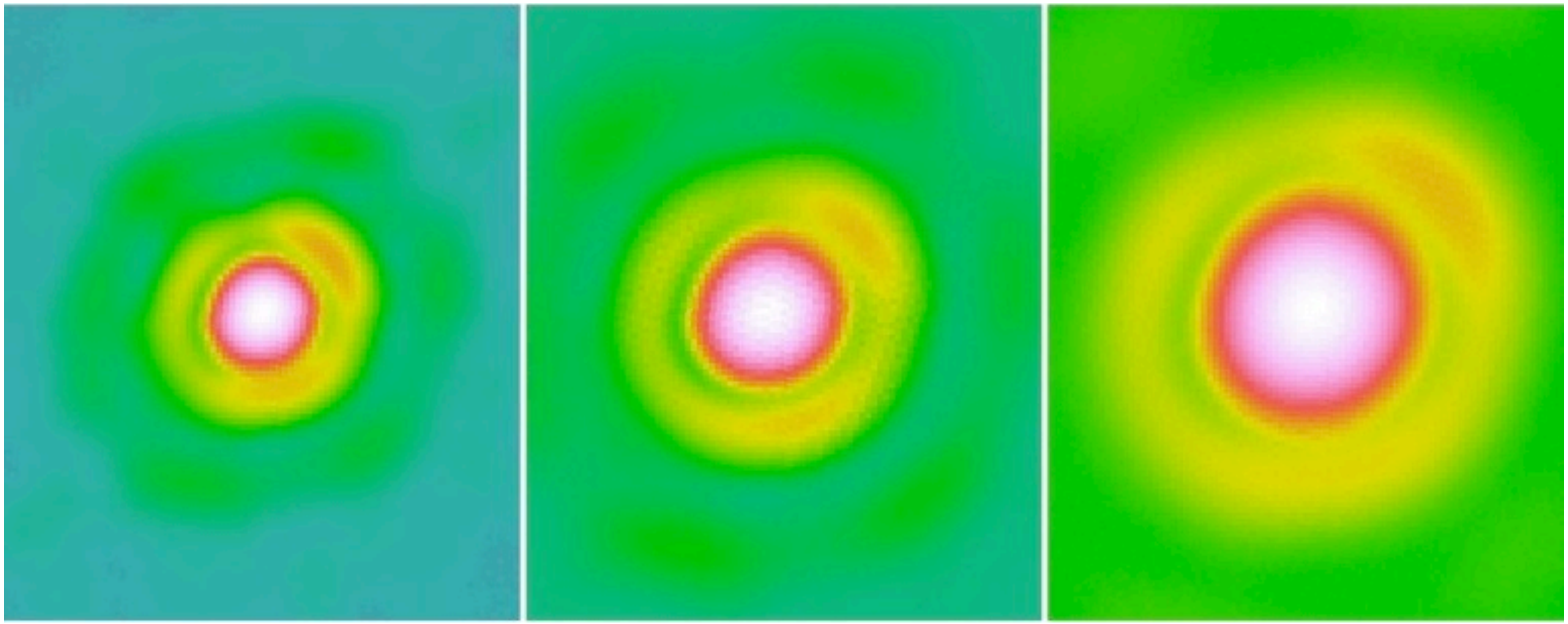


HERMES

SMAP Team
Alex Conley
Louis Levenson
Gaelen Marsden
Marco Viero
Mike Zemcov

- SPIRE maps at 1200, 857, and 600 GHz
- Maps made with HeRMES SMAP pipeline
- 5 fields totaling ~ **70** deg^2
- Modes >~ 0.5 deg filtered
- Sources > 50, 100, 200, 300 mJy masked

250 μm (1200 GHz) | 350 μm (857 GHz) | 500 μm (600 GHz)

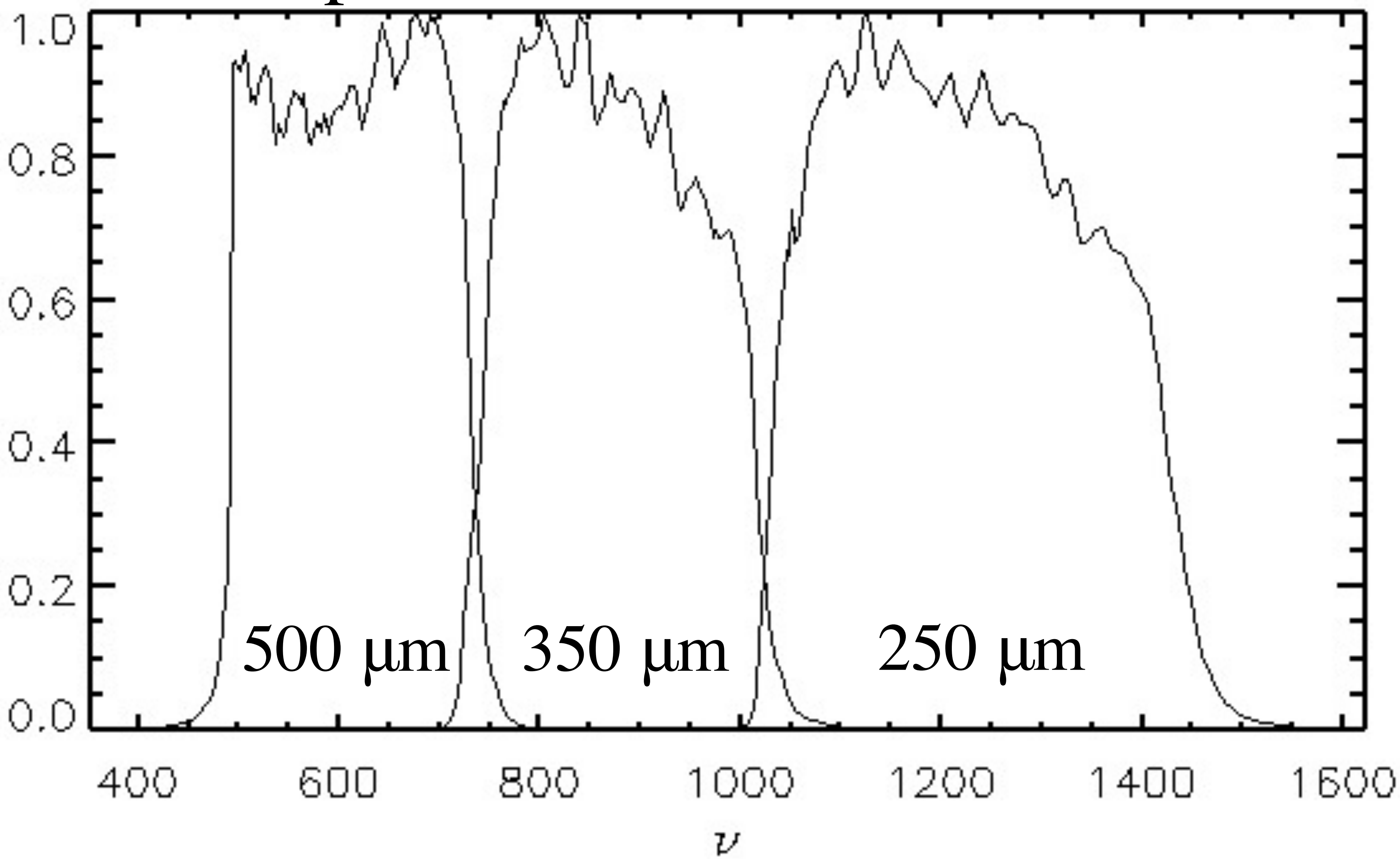


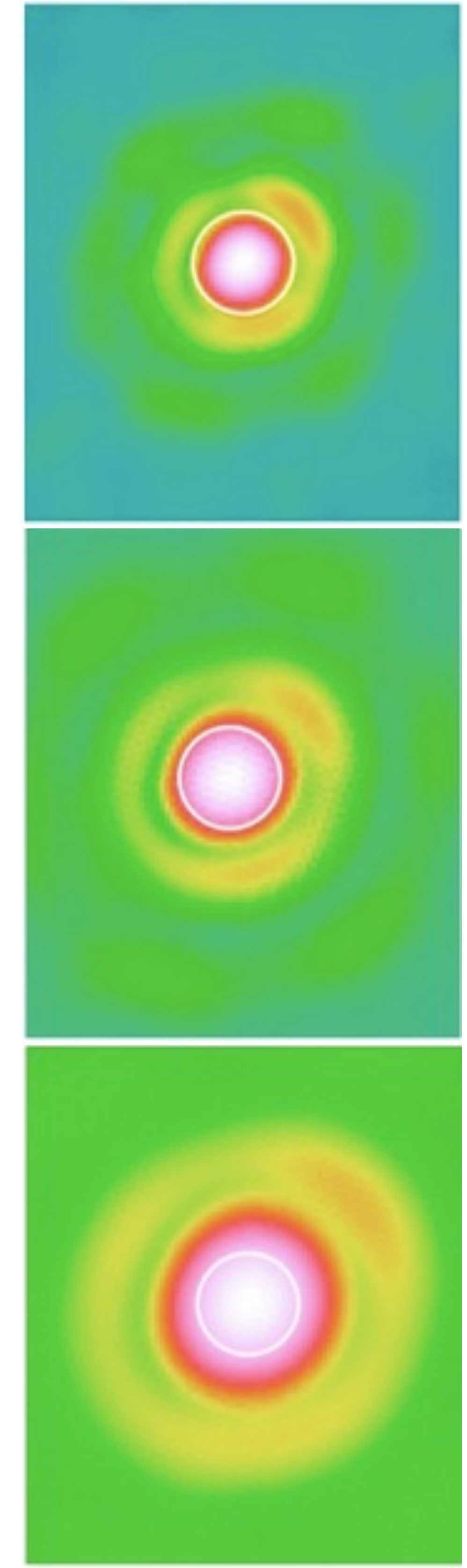
FWHM = 18.2" | 25.4" | 36.6"

- SMAP maps of Neptune

calibration

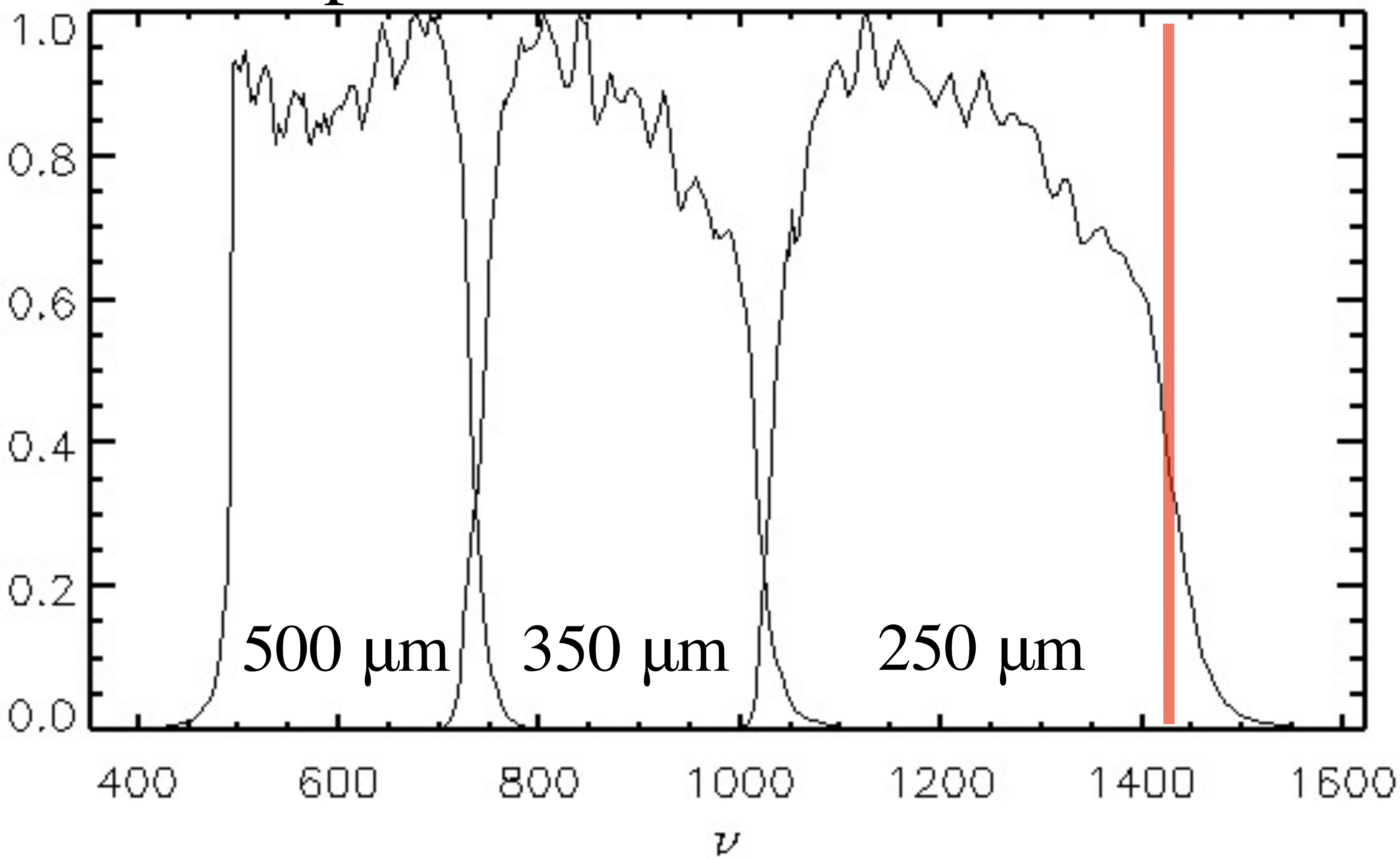
- SPIRE passbands

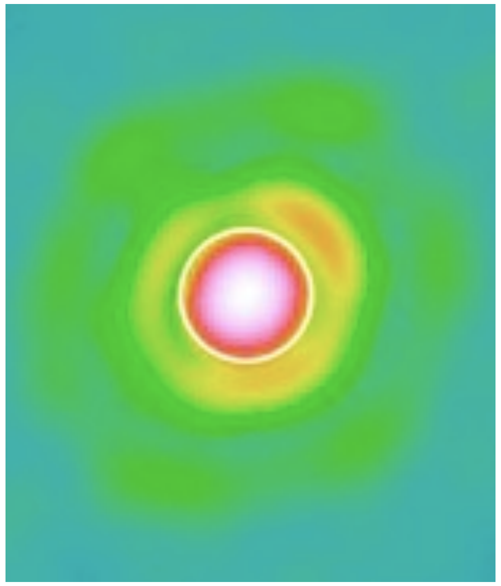




calibration

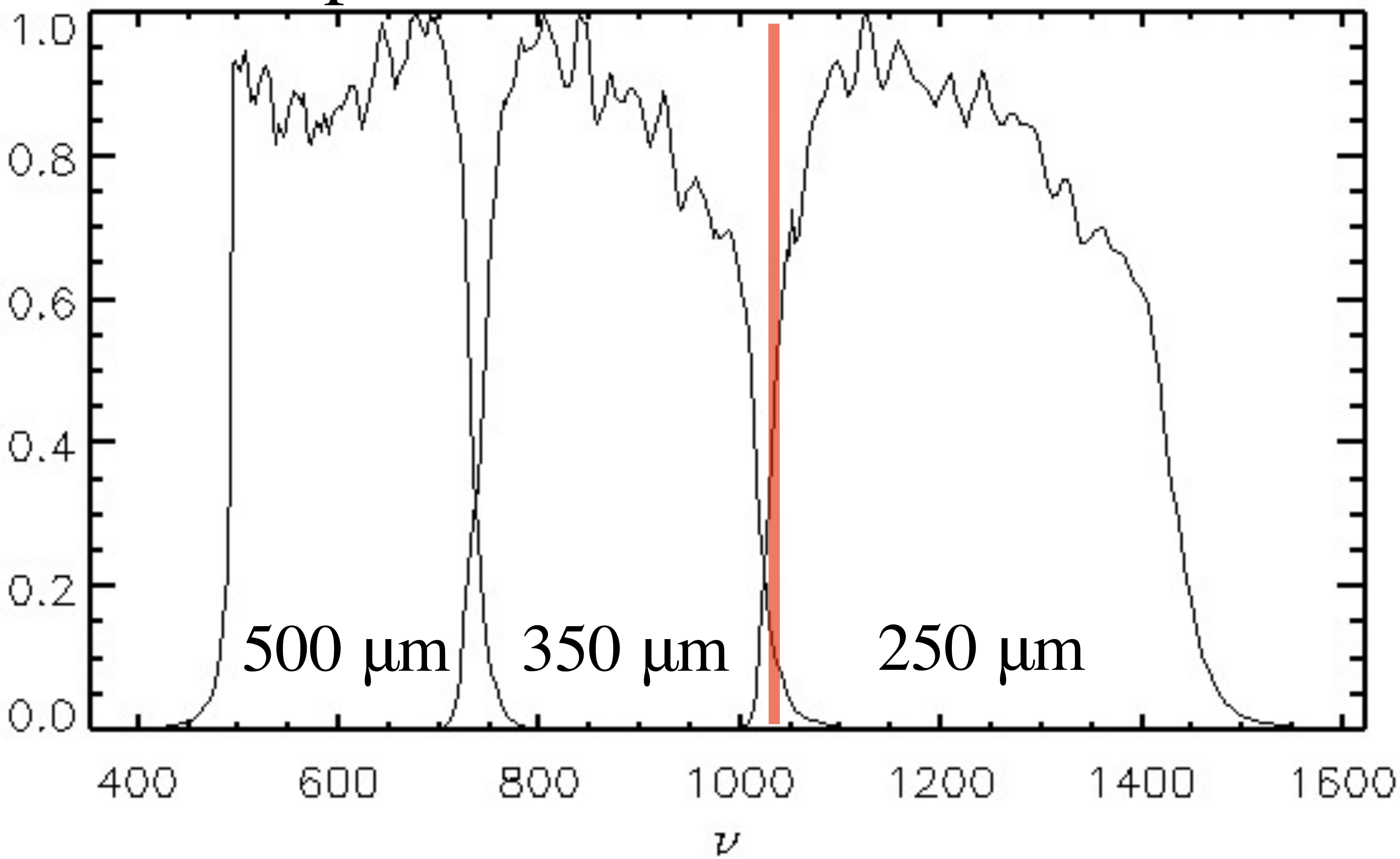
- SPIRE passbands

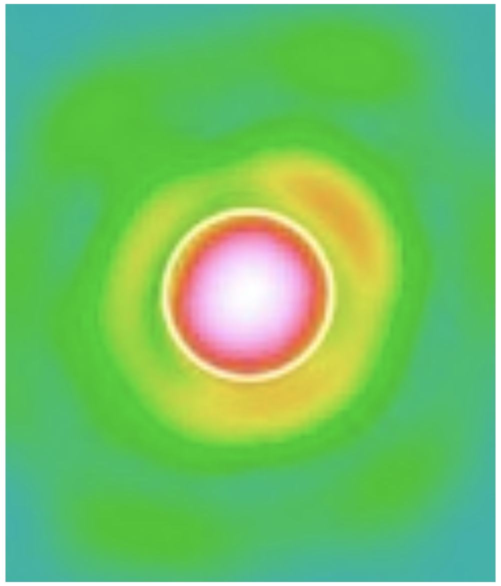




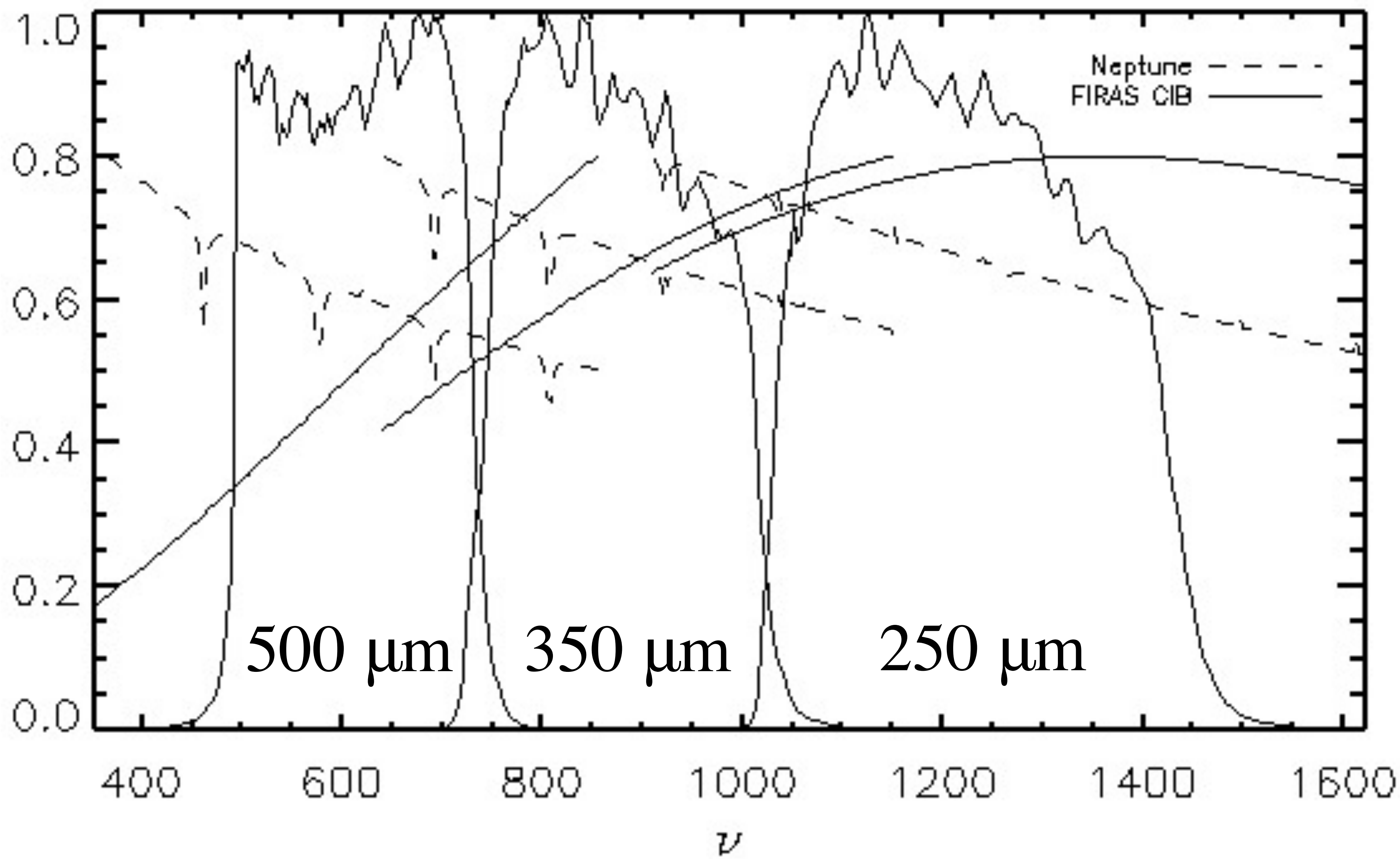
calibration

- SPIRE passbands



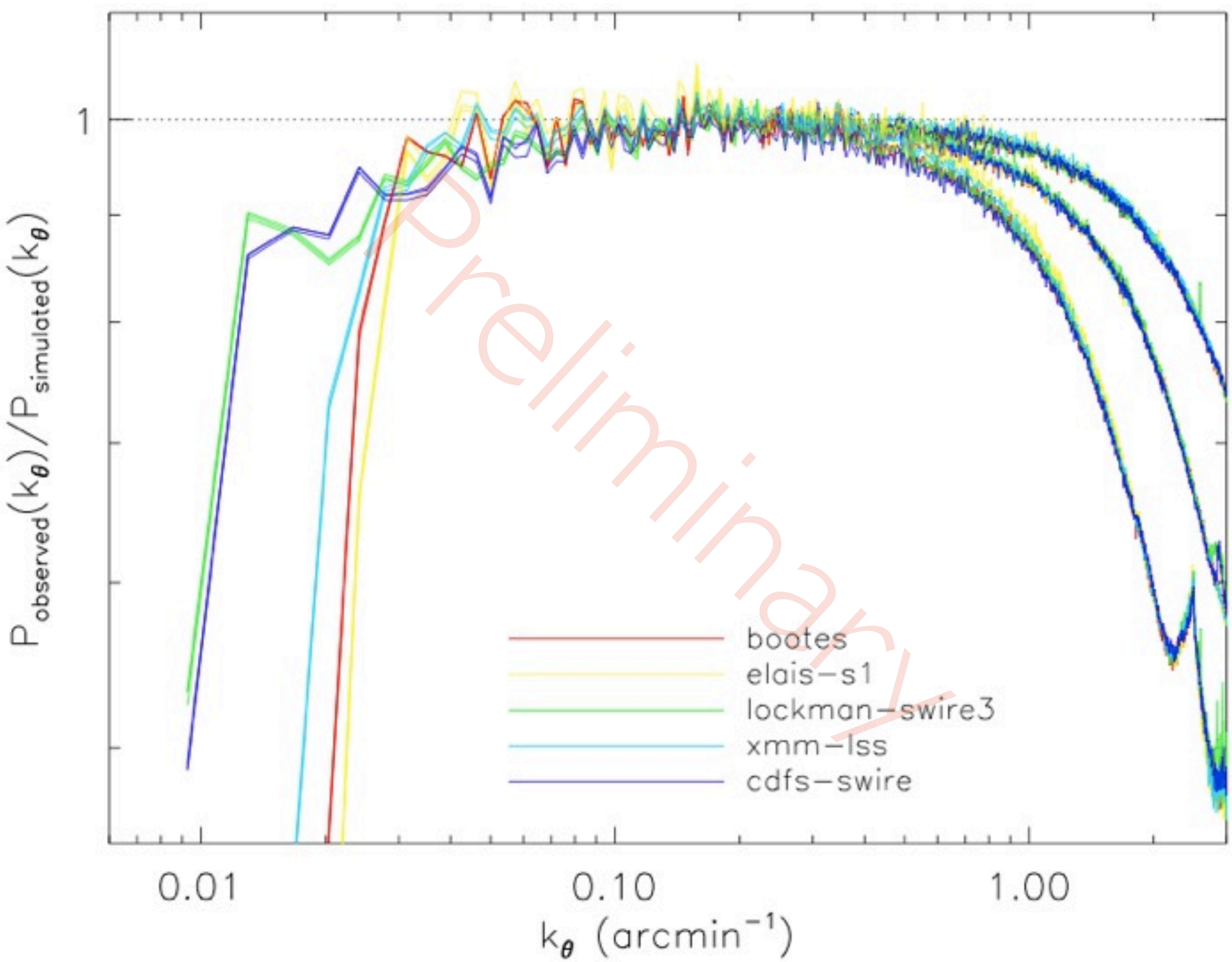


calibration



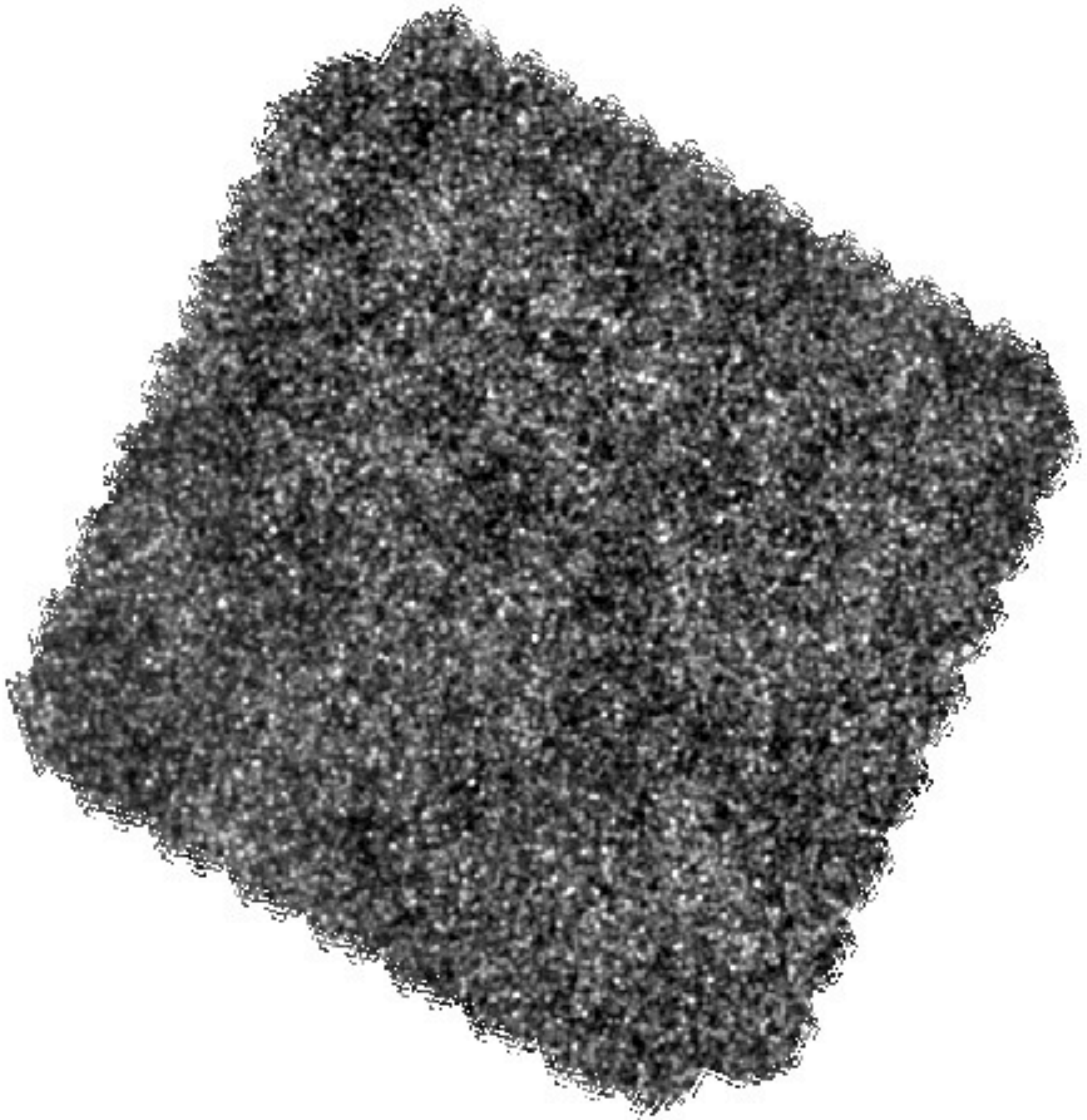
- Spectral weight different for Neptune and CIB
- Beam corrections = 0.99, 0.98, 0.95 at 250, 350, and 500 μm

effective beam area



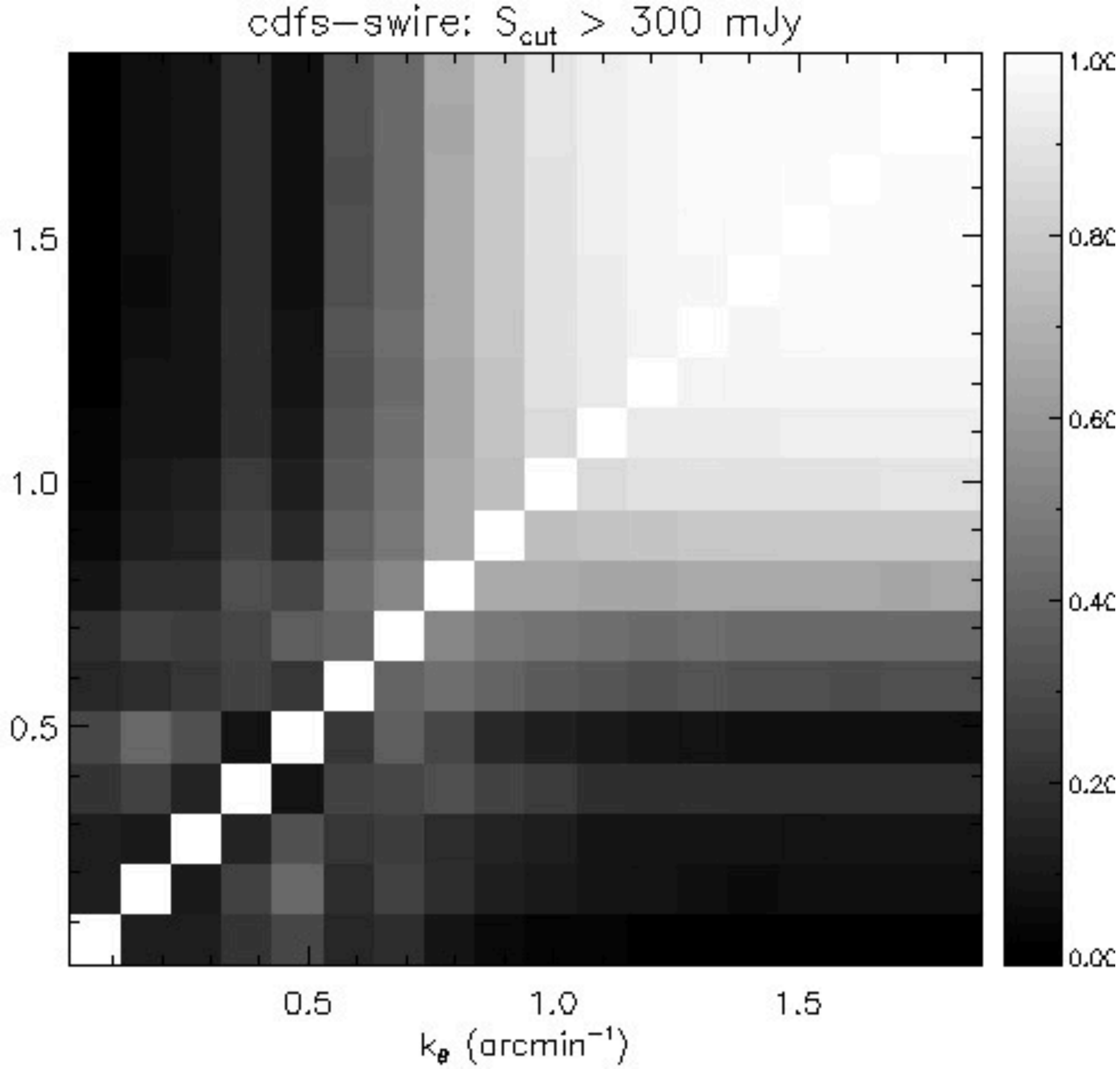
Transfer Function

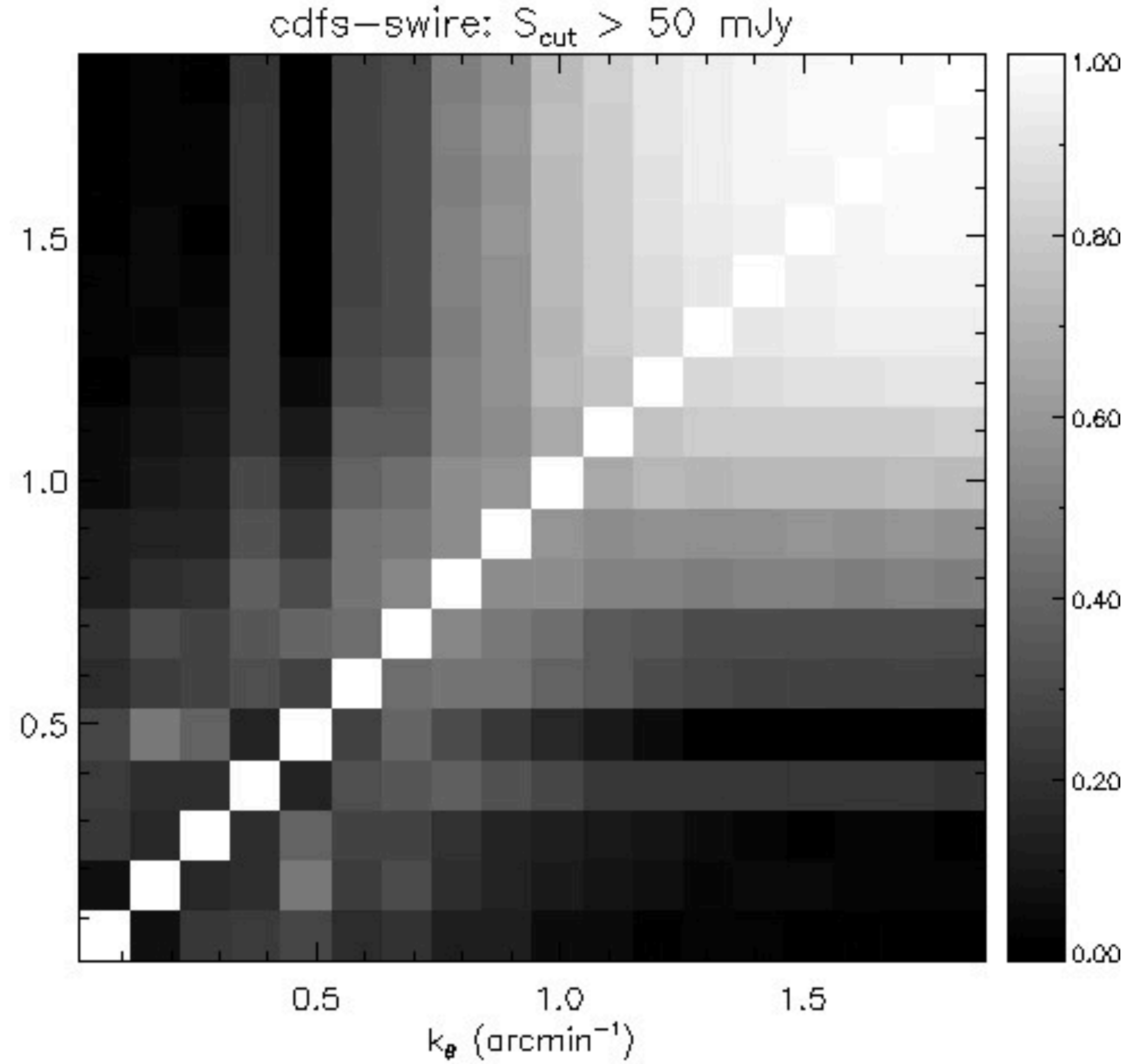
After “Observing” Simulation



- Monte Carlo Simulation of “observed” maps

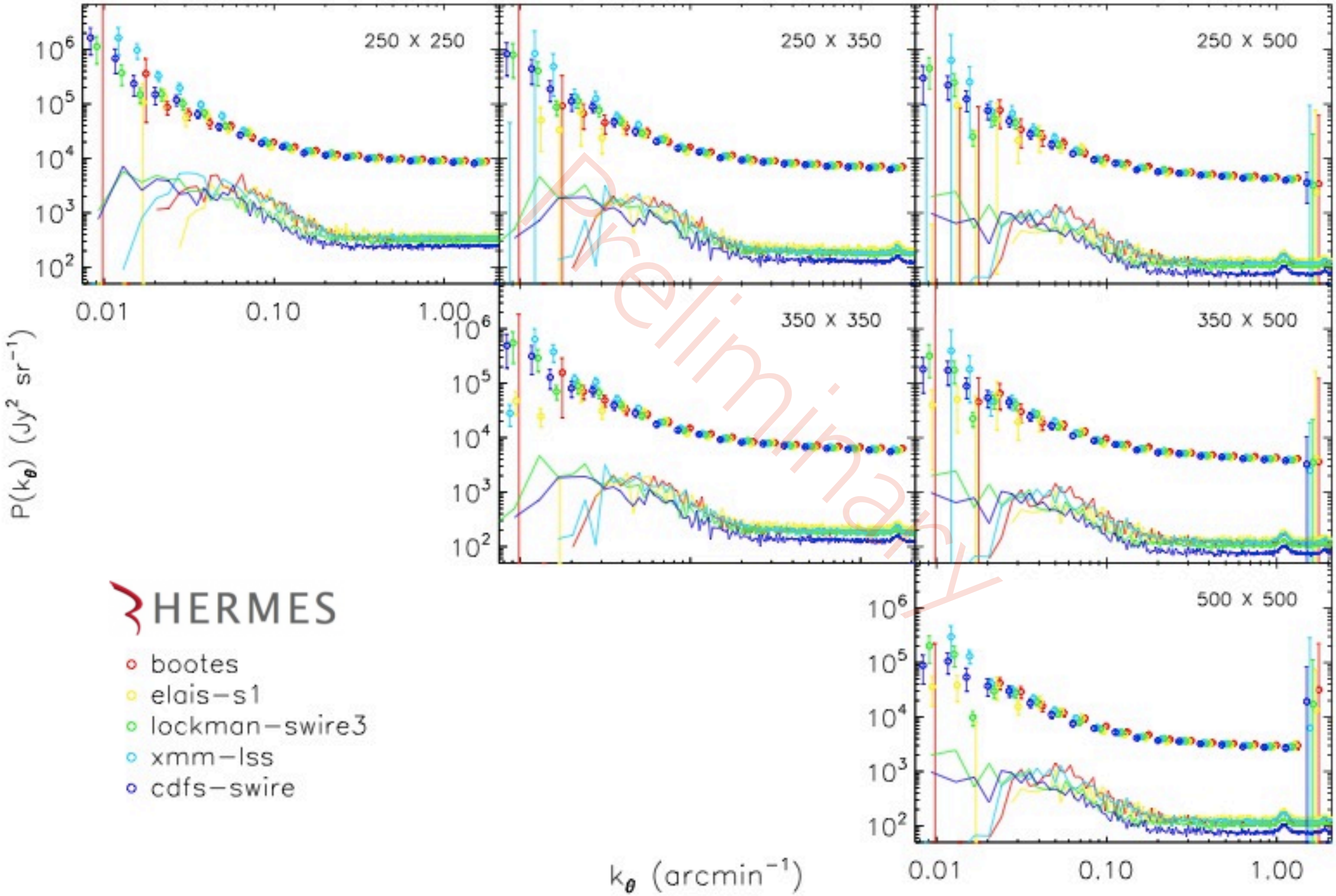
Error Estimate



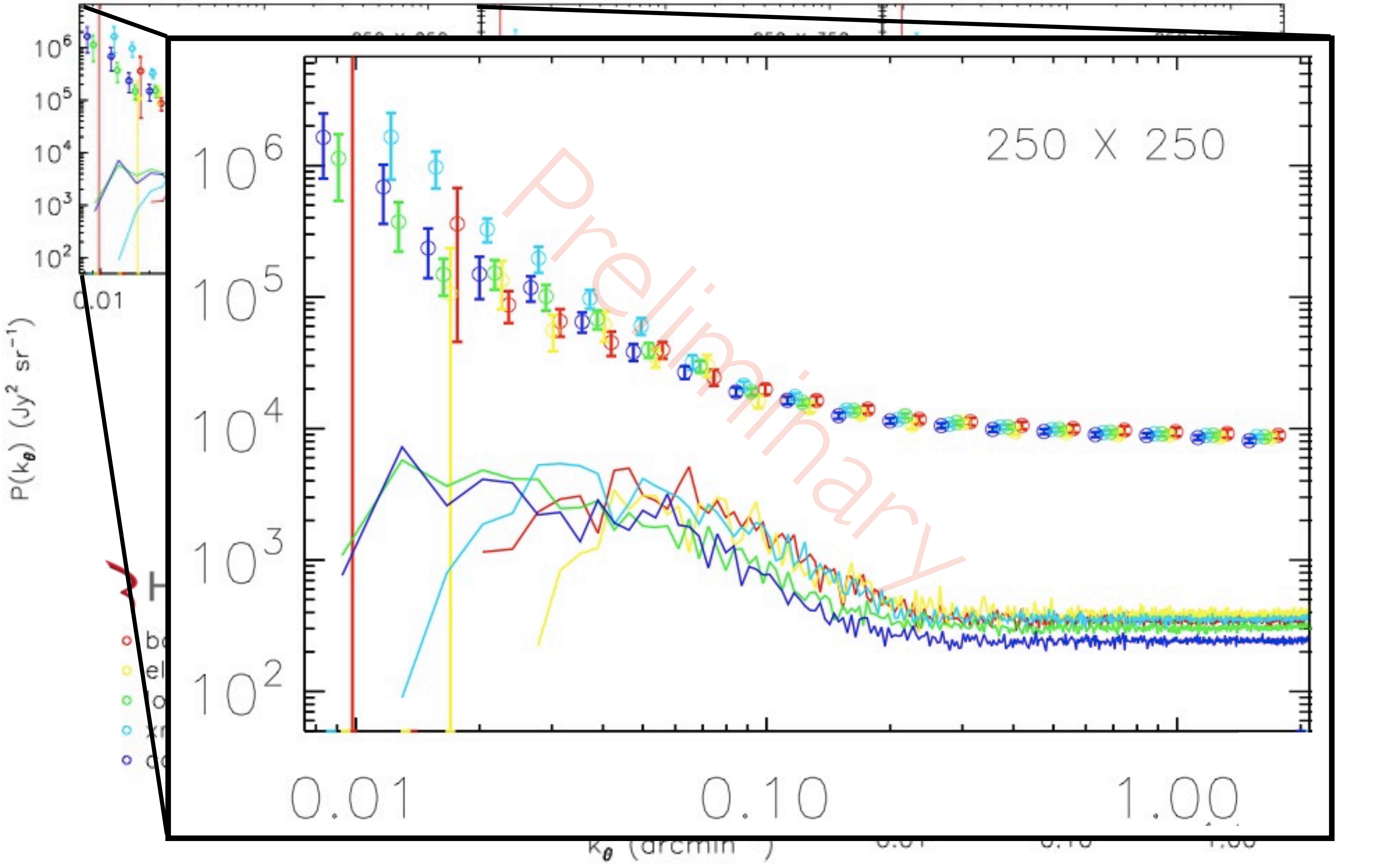


- Poisson error arising from non-Gaussian part of the four-point function correlates bins on small scales

Correlation Matrix



Field-to-Field Variation



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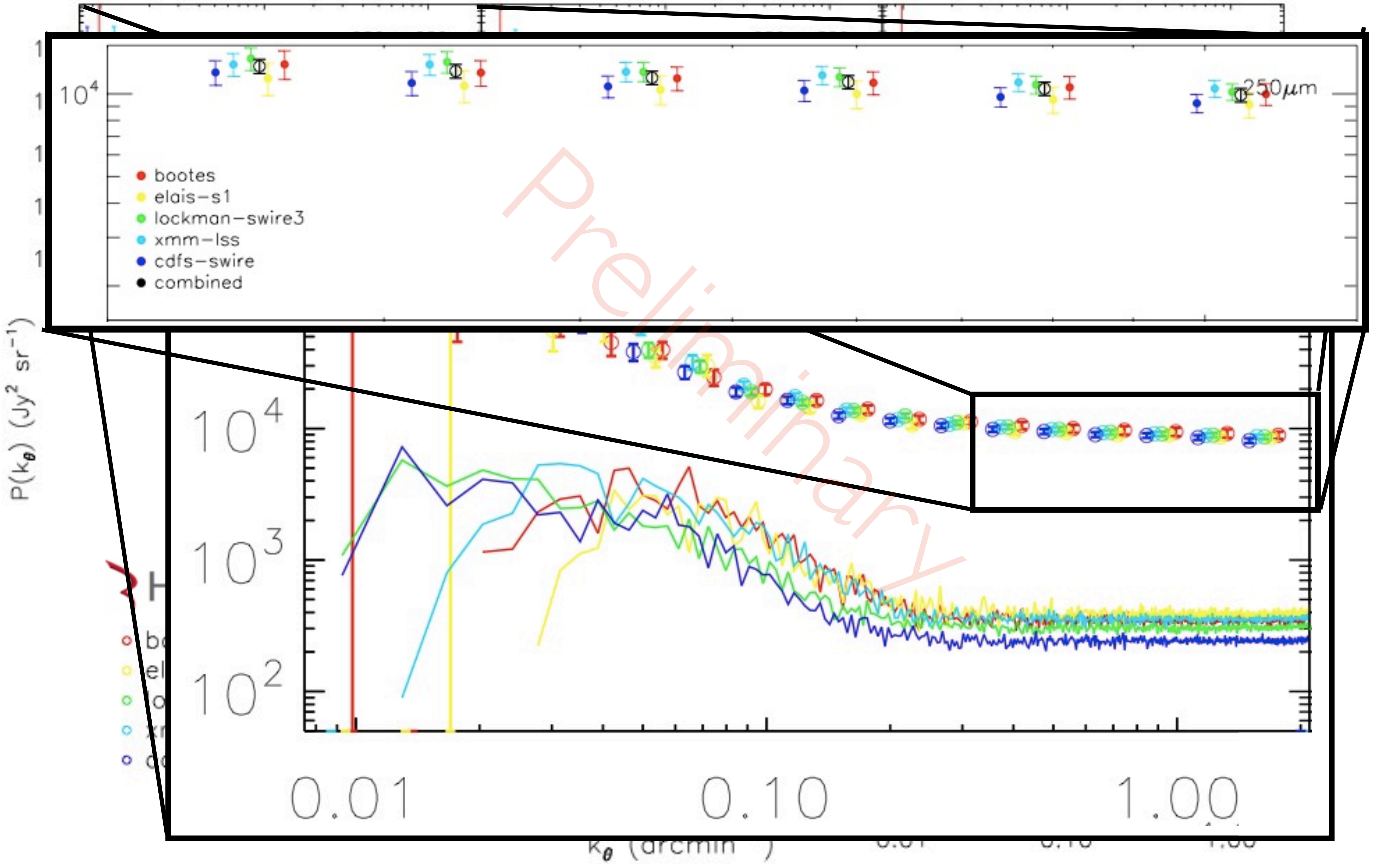
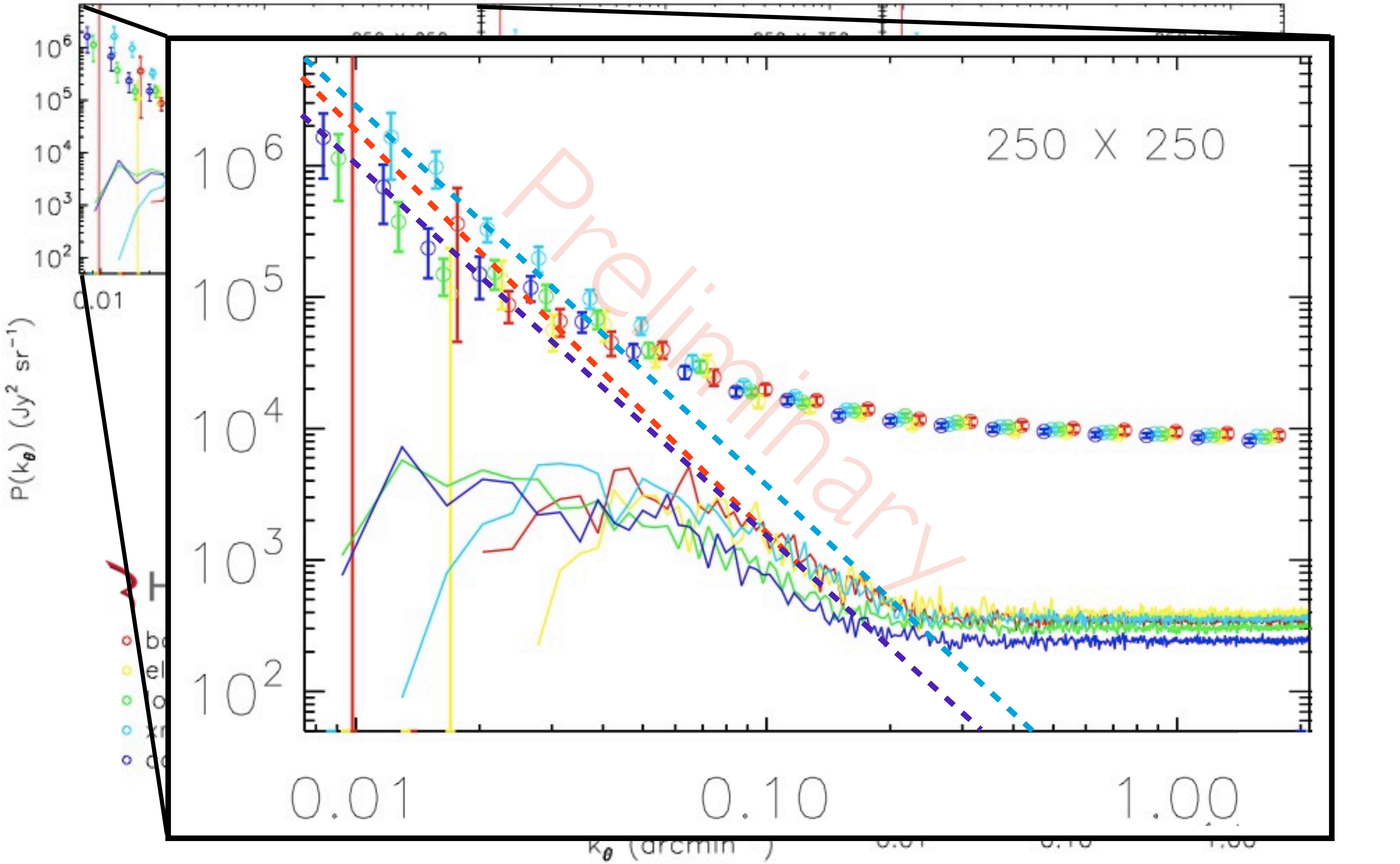
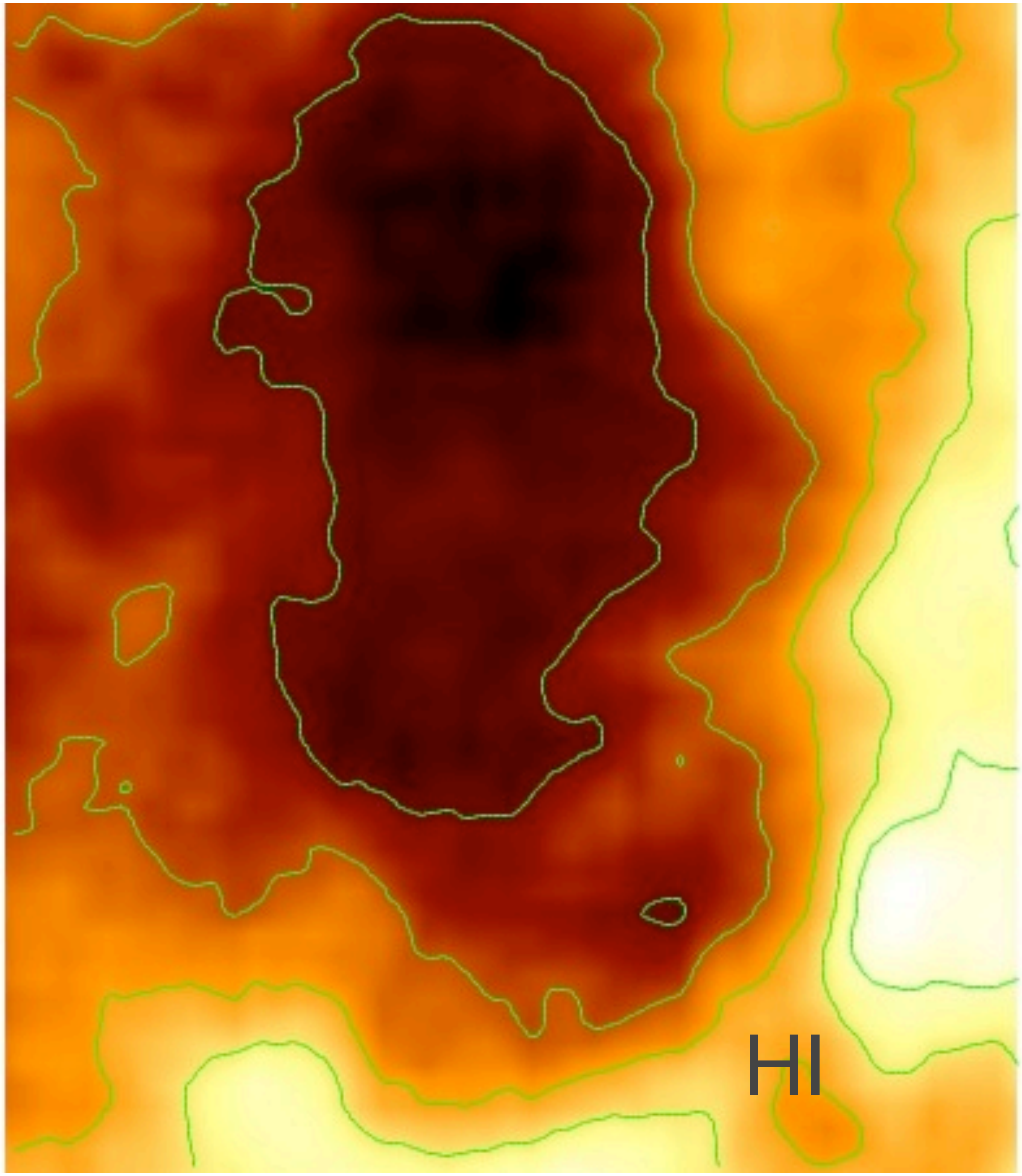
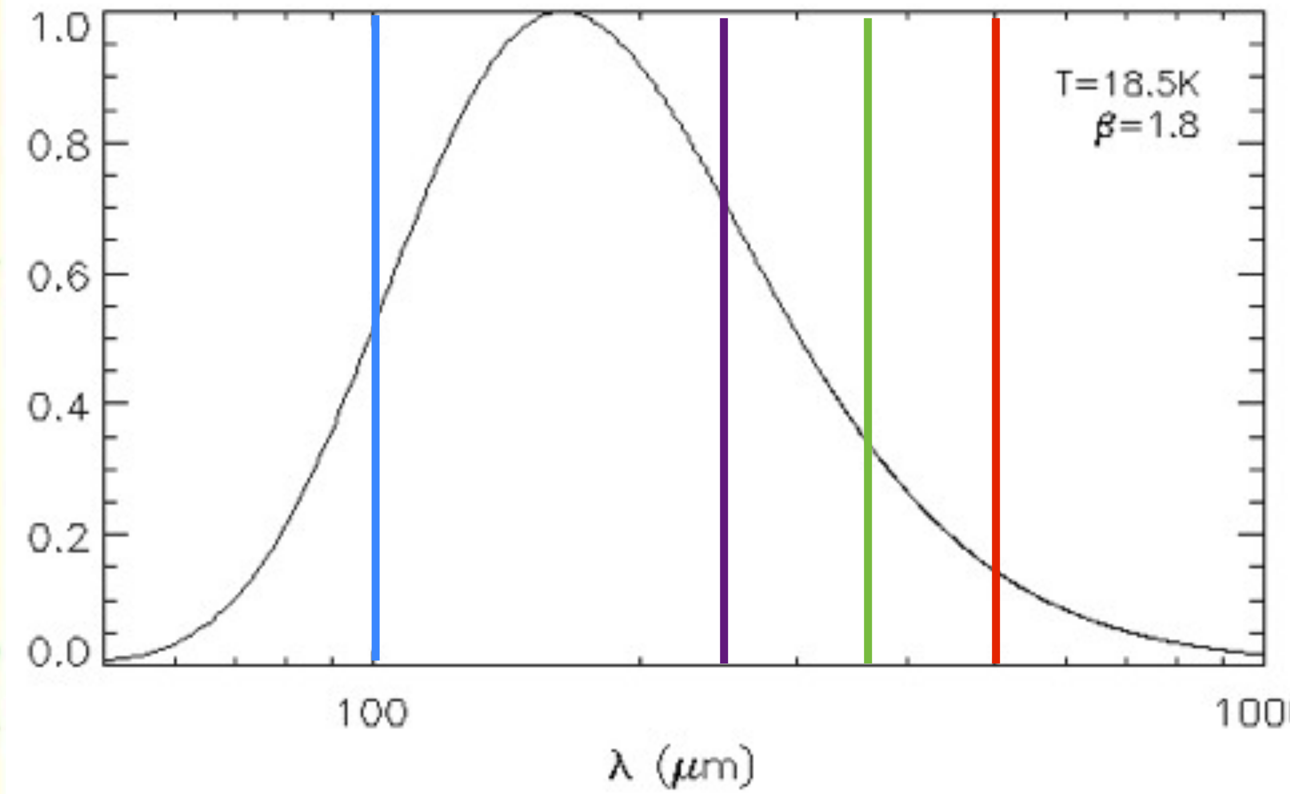


Field-to-Field Variation



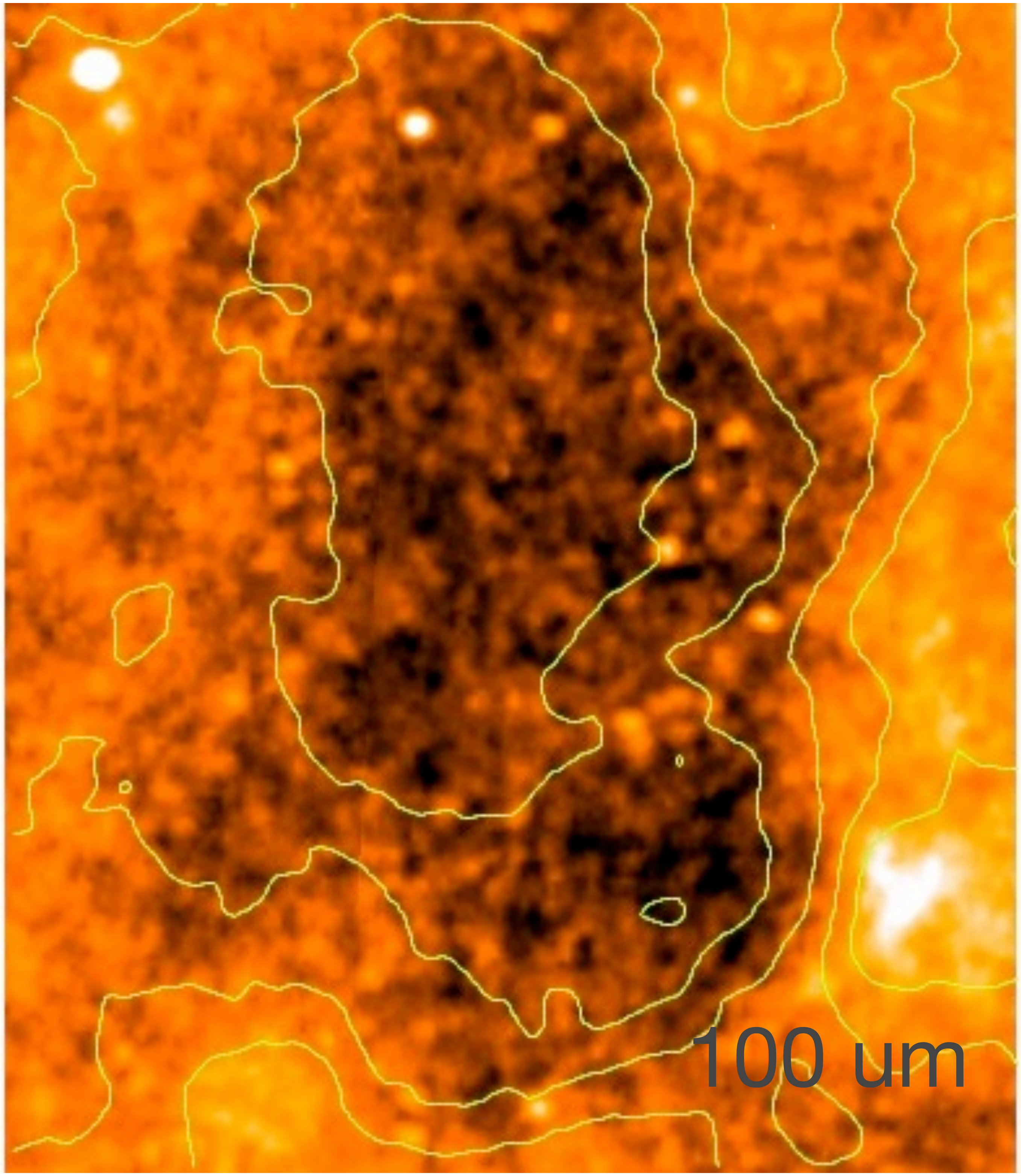
Field-to-Field Variation

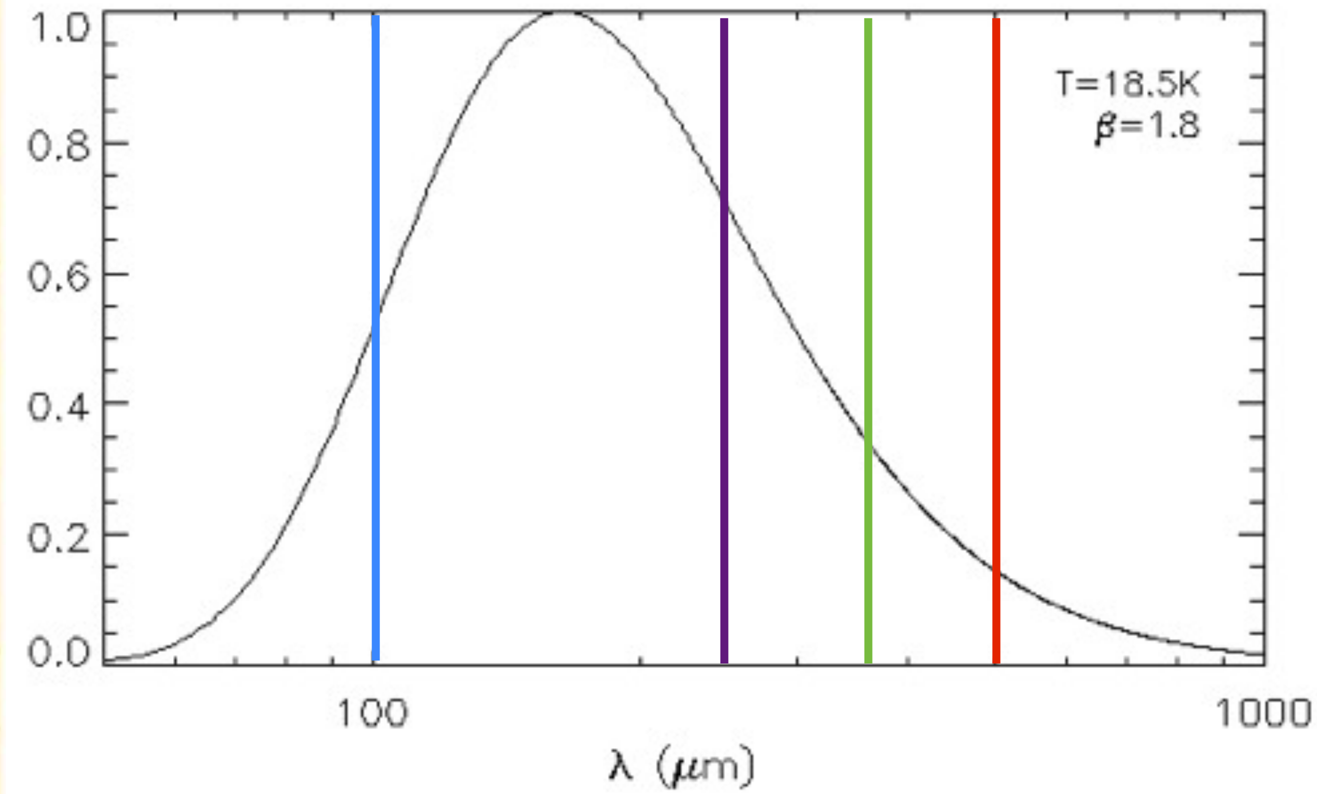




- In regions of diffuse cirrus, dust traces gas
  - Typical dust SED peaks at ~ 170 μm

Gas as dust tracer





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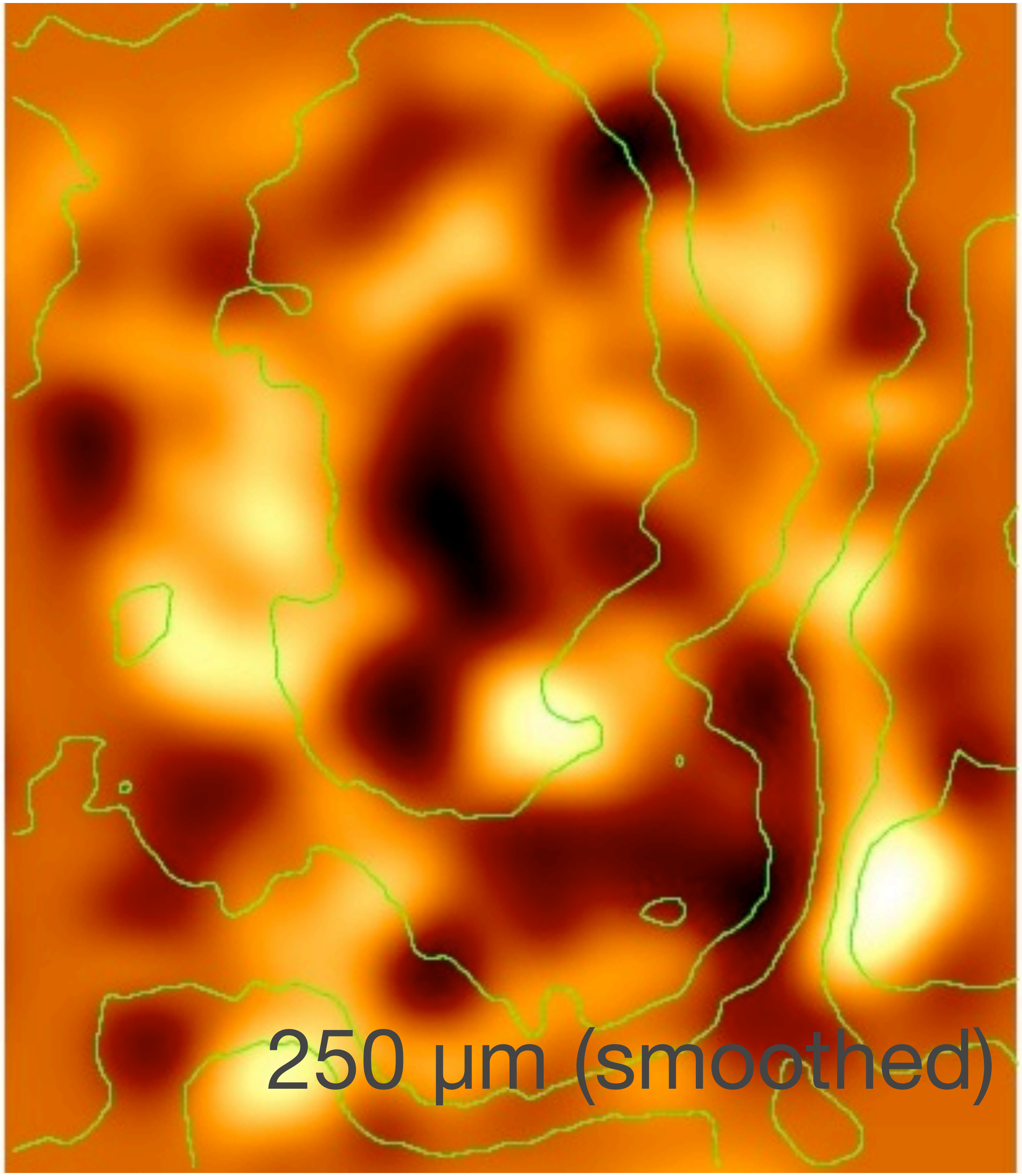

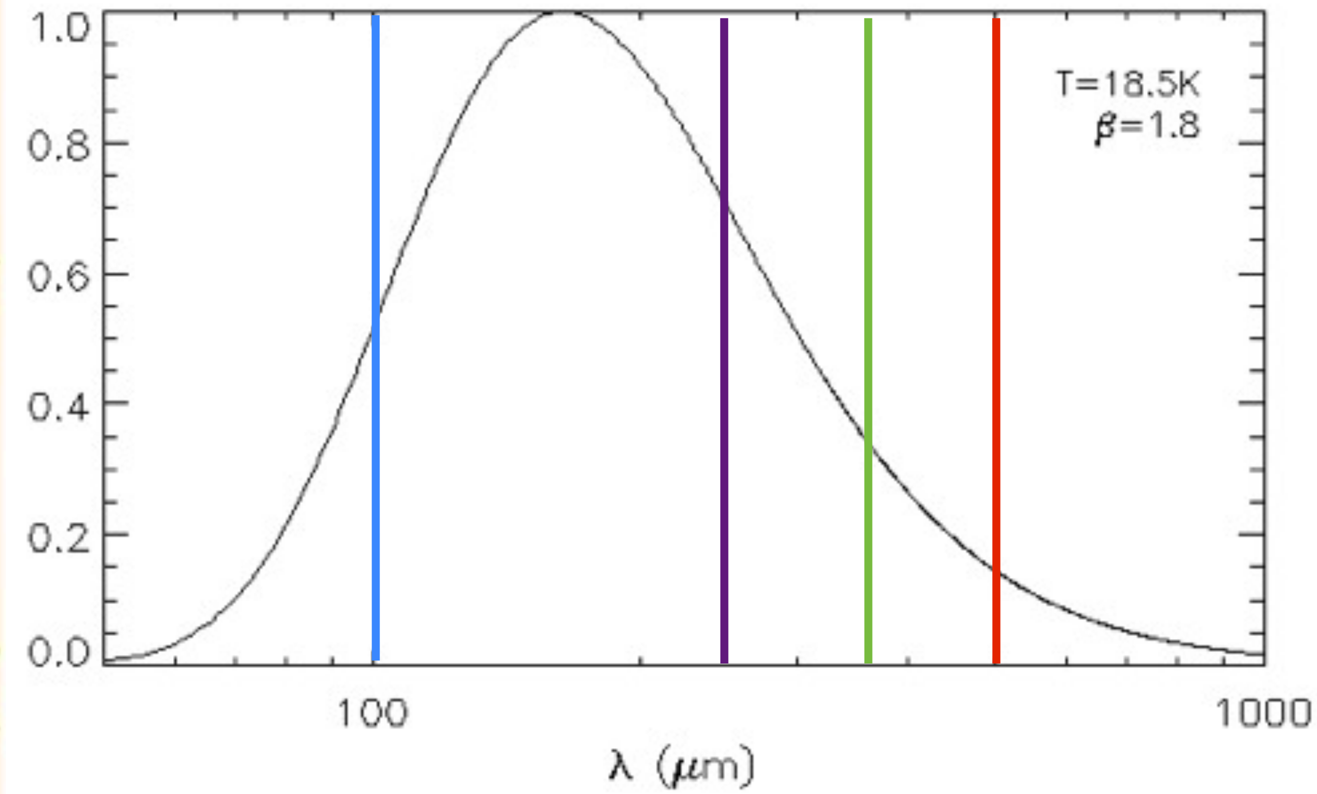

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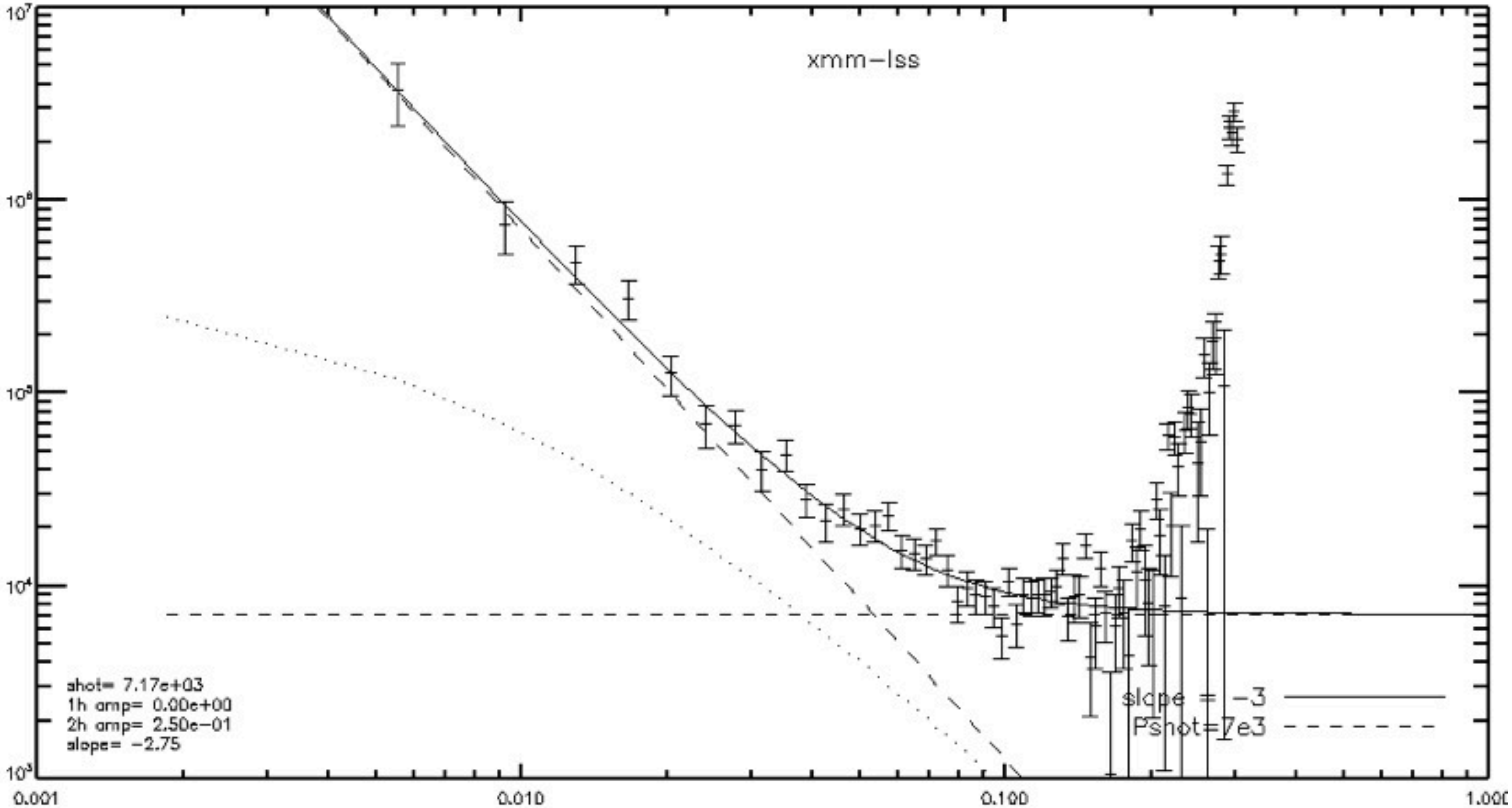
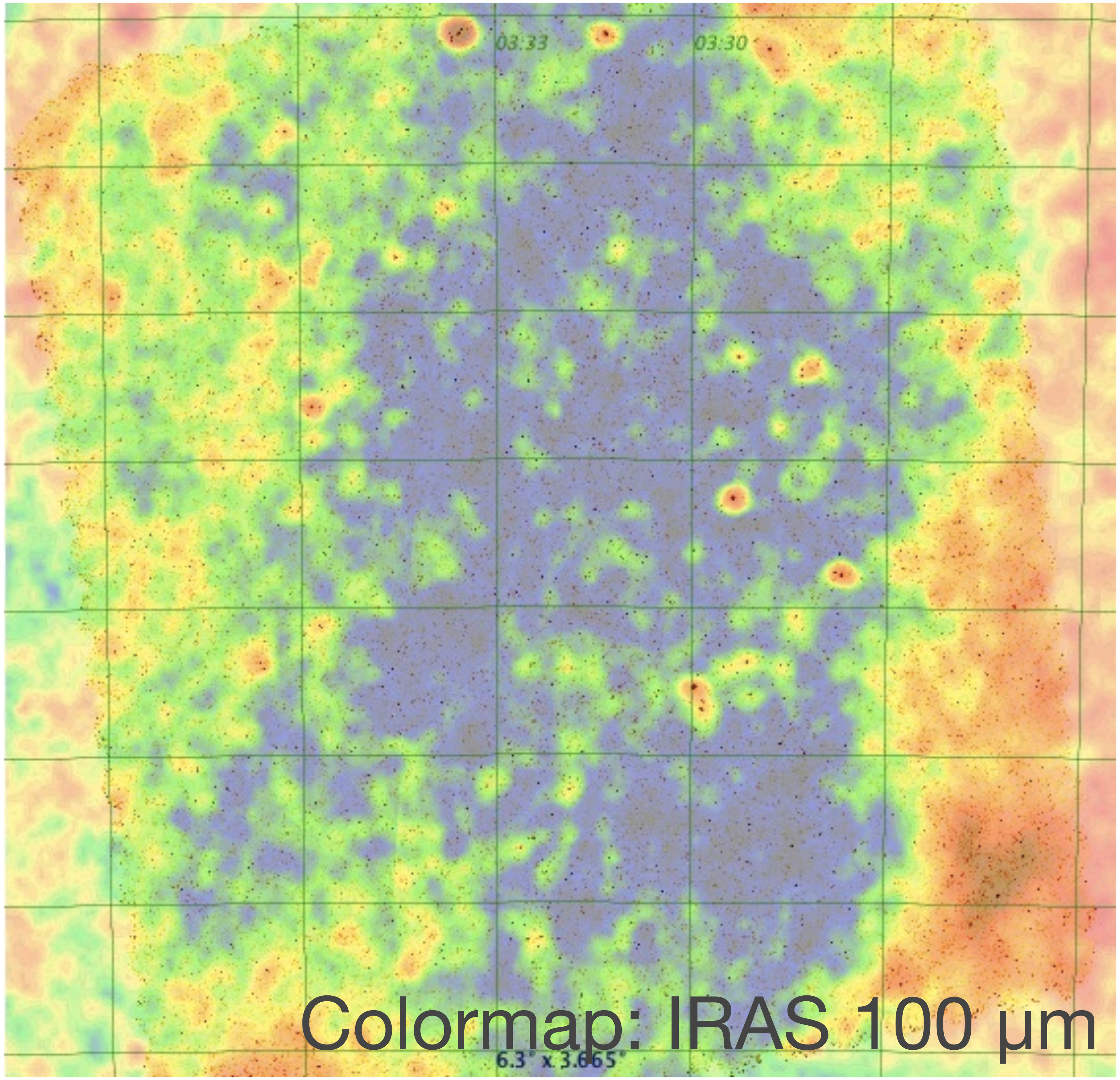
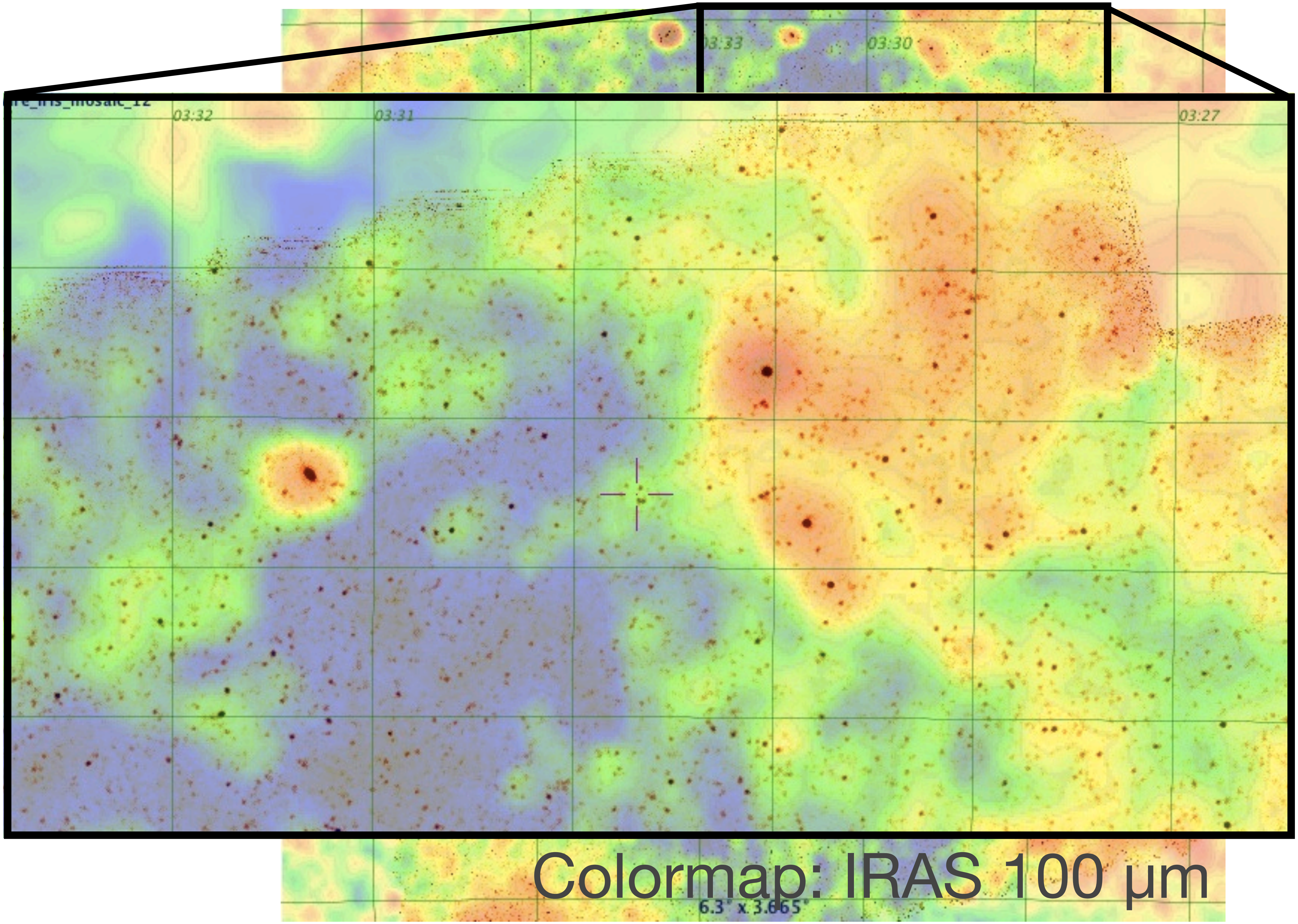


- IRAS maps probe large scales very well (unlike SPIRE)
- Cirrus has slope ~ -3.0, but varies field-to-field
- Clustered Galaxy Contribution(?)

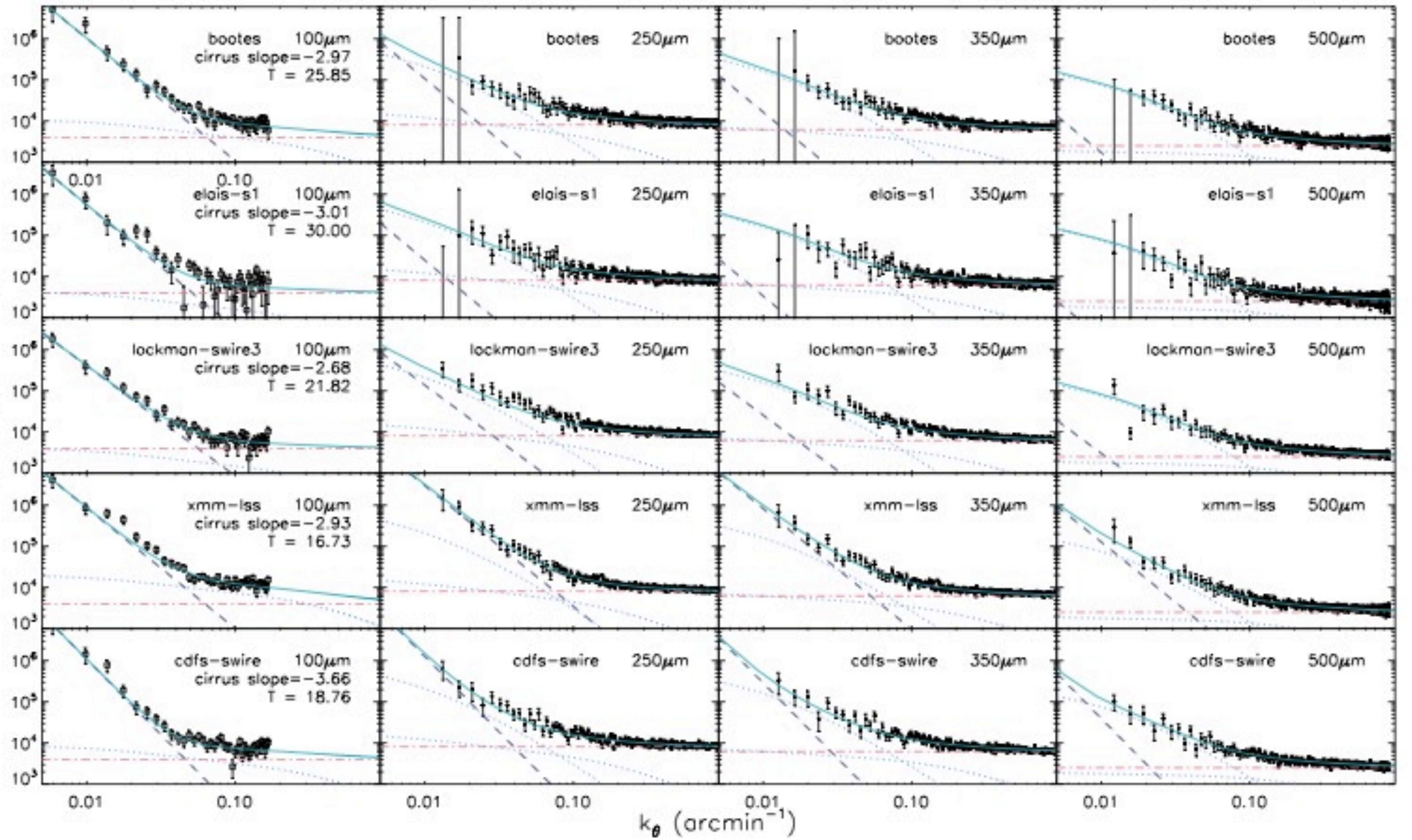
Estimating Cirrus Spectra



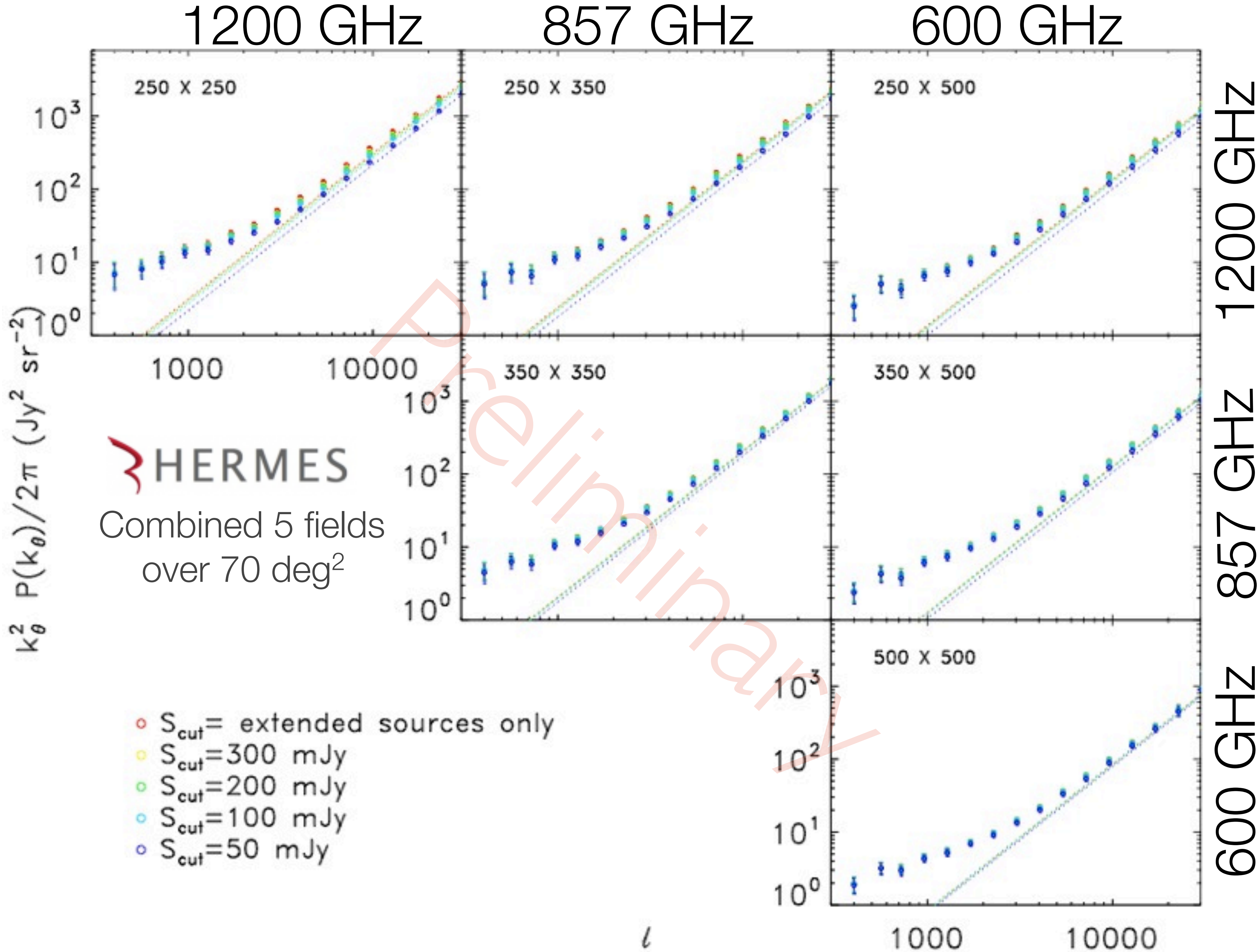
Estimating Cirrus Spectra



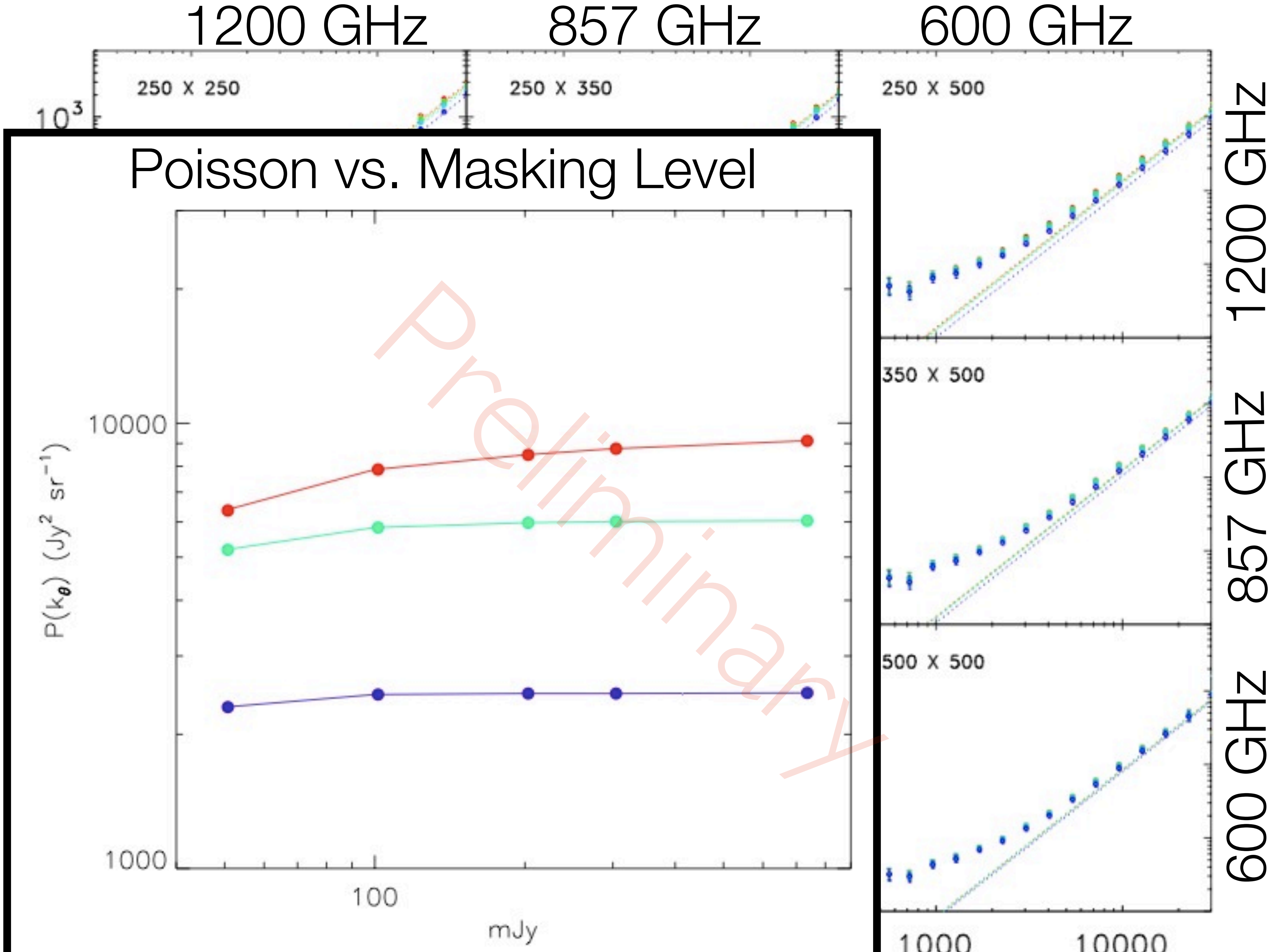
Estimating Cirrus Spectra



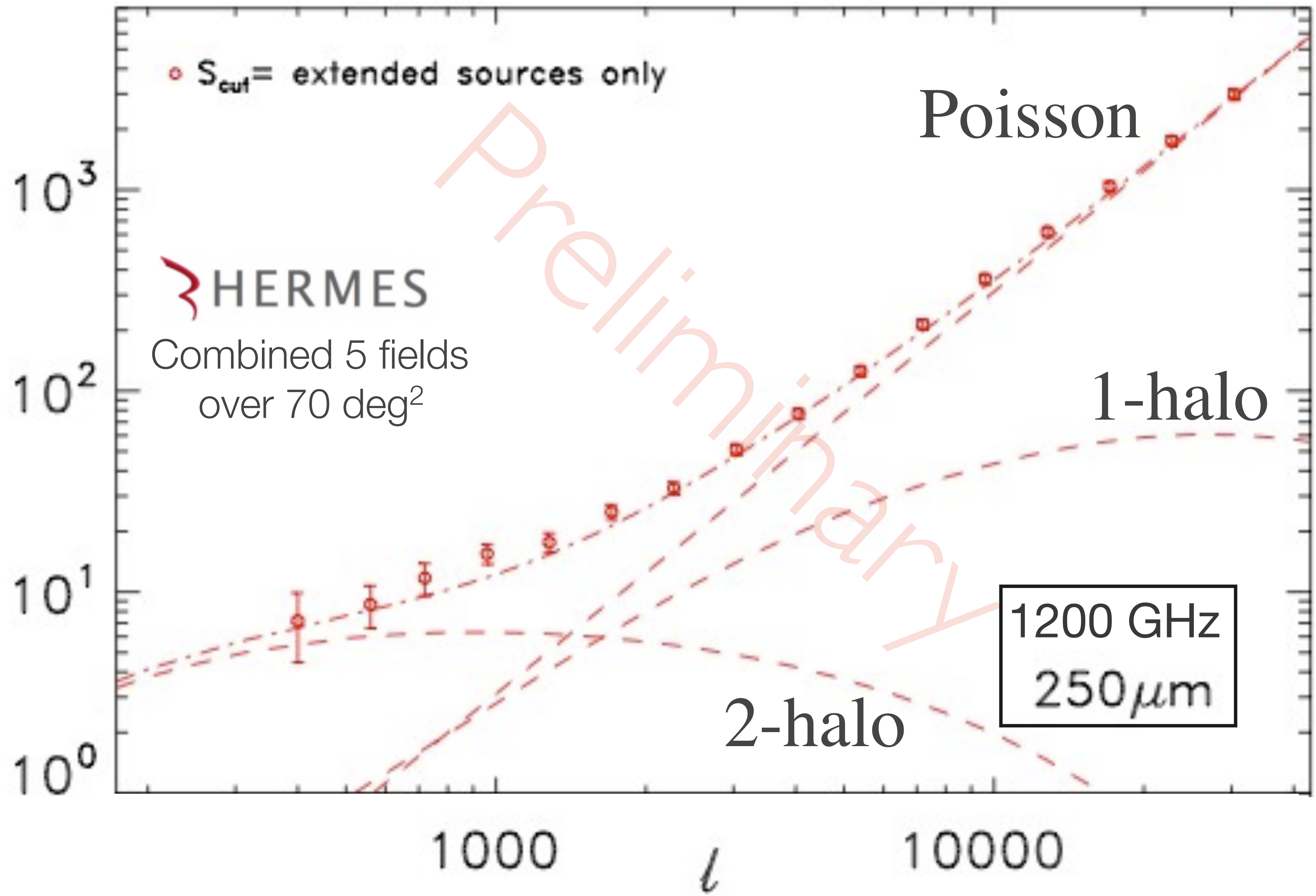
Estimating Cirrus Spectra



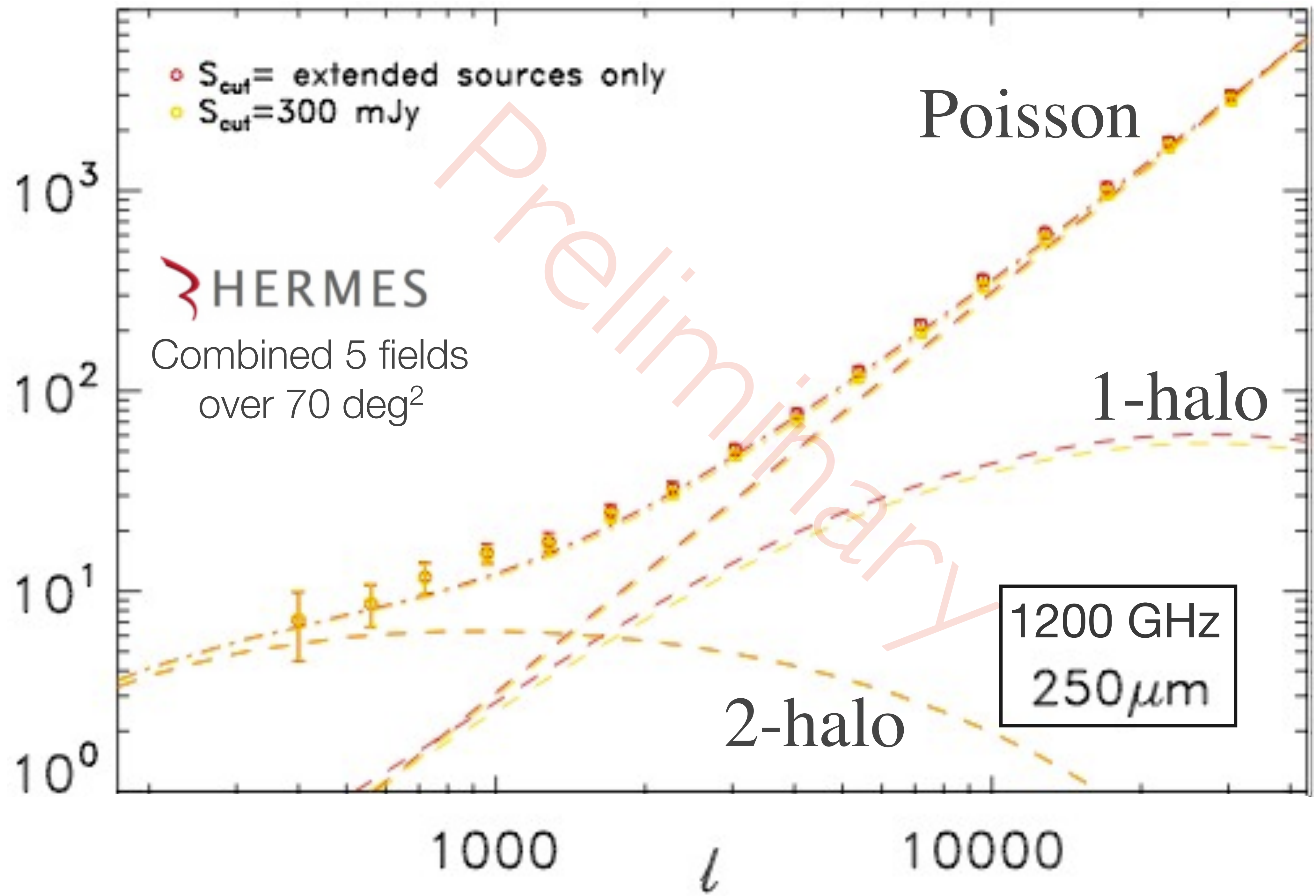
CIB Power Spectra



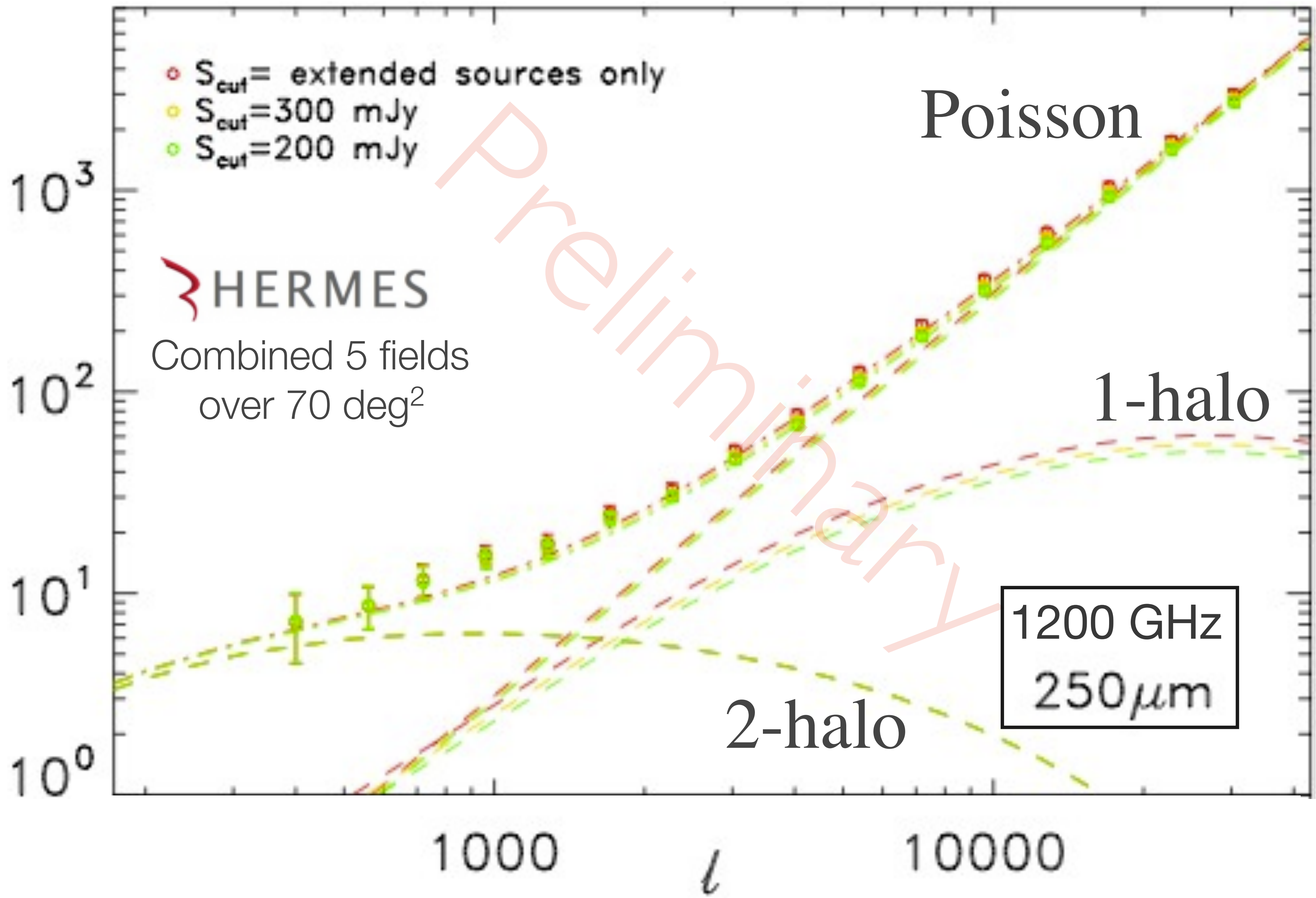
CIB Power Spectra



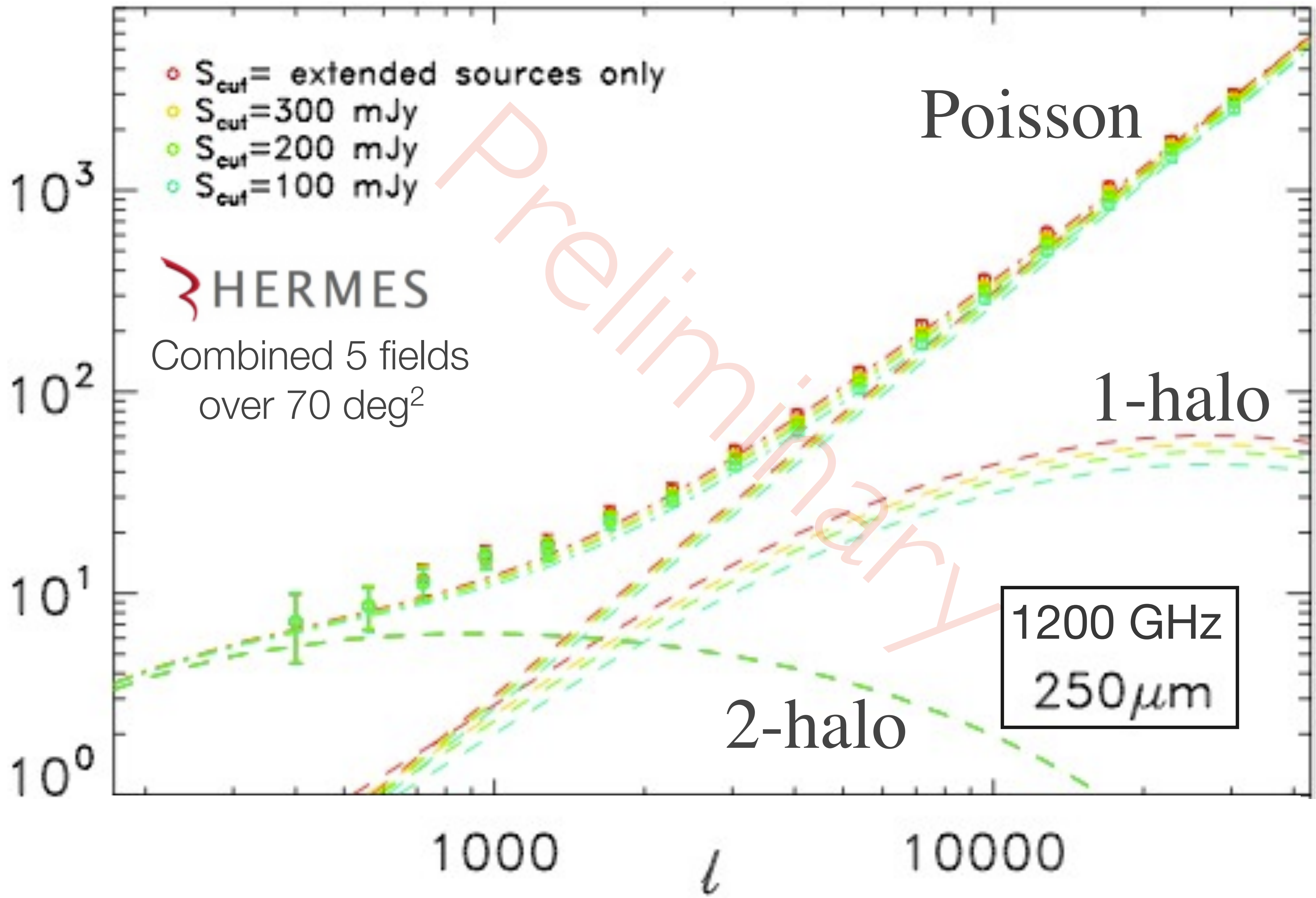
1-halo power vs. Masking



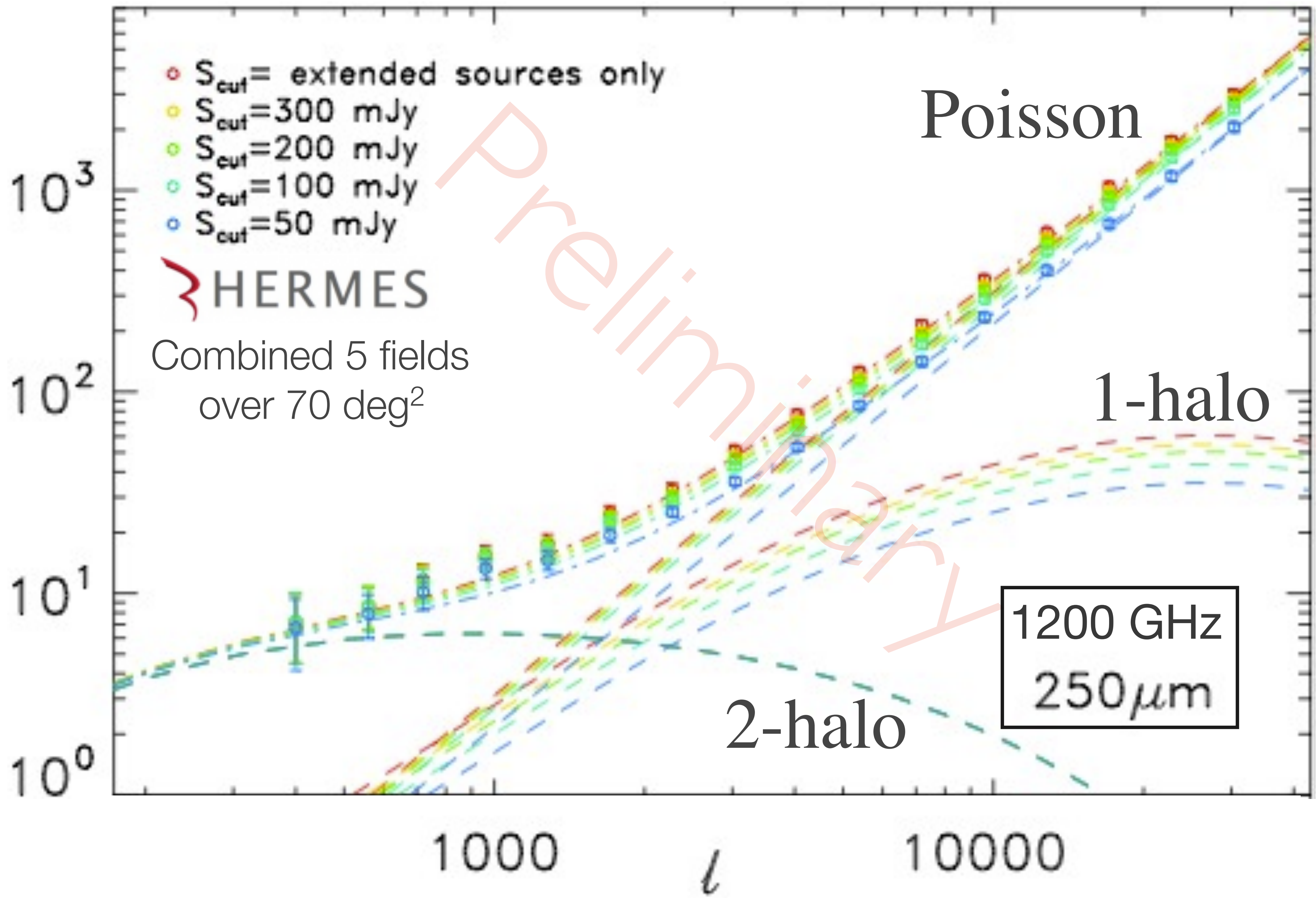
1-halo power vs. Masking



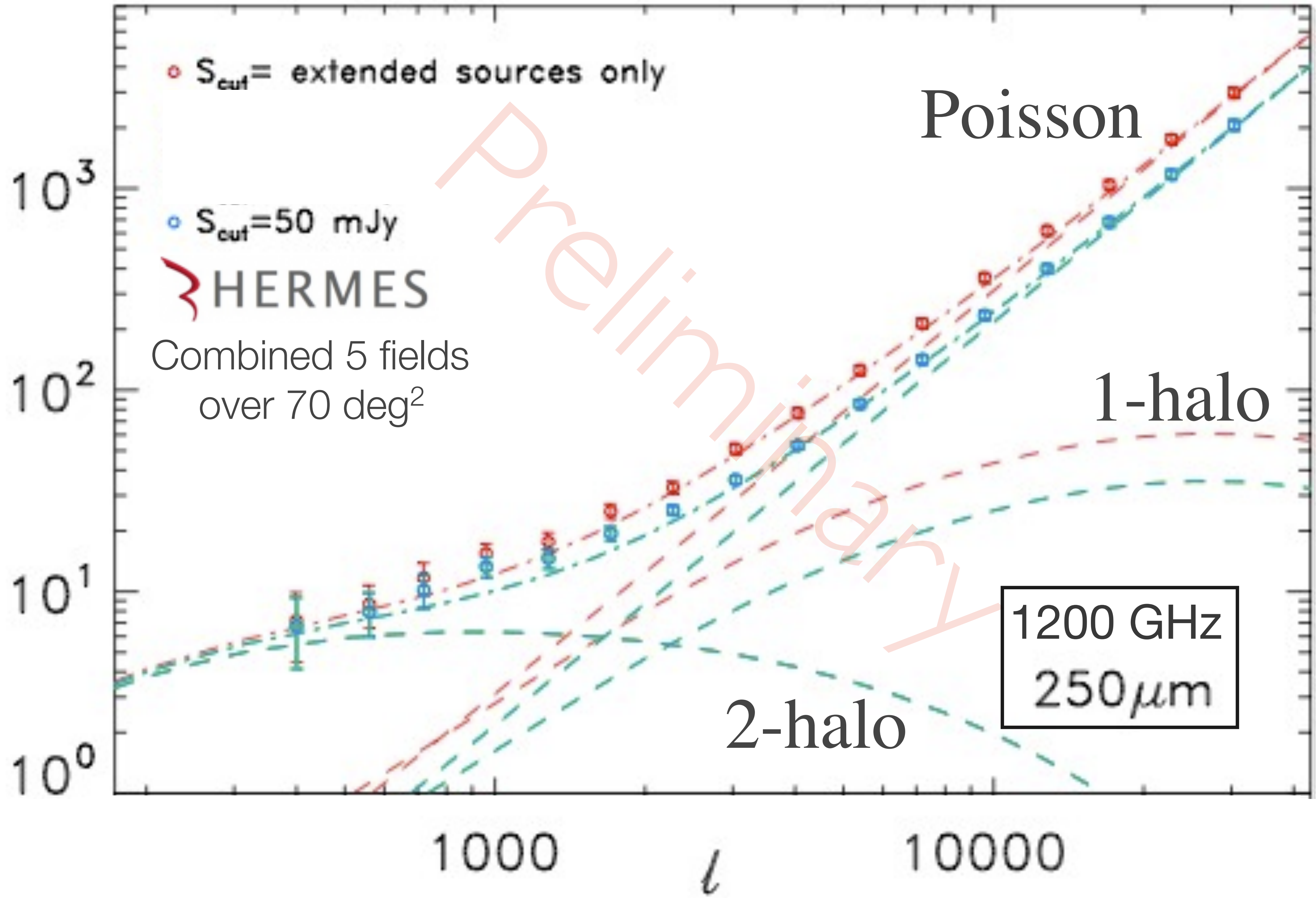
1-halo power vs. Masking



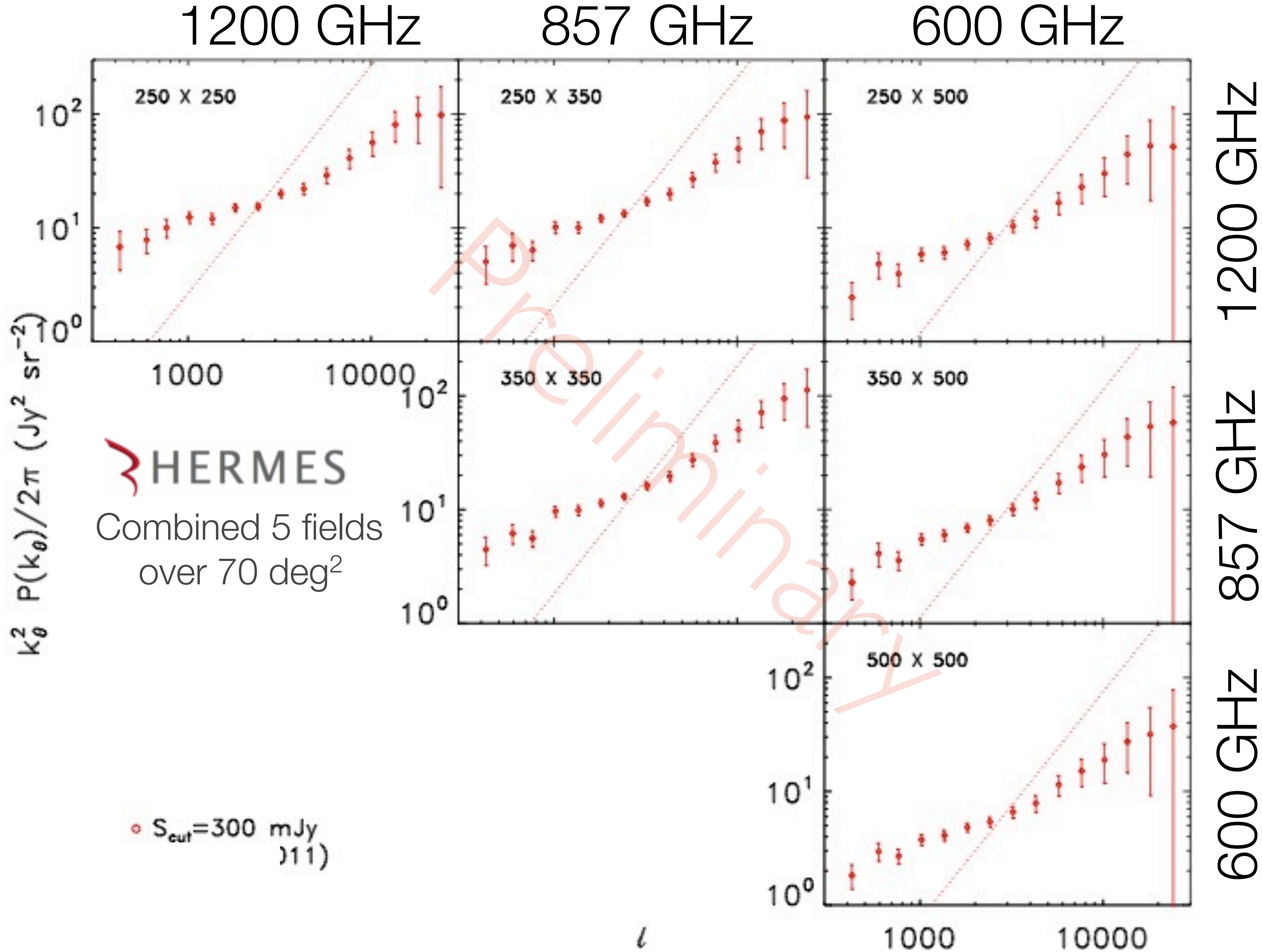
1-halo power vs. Masking



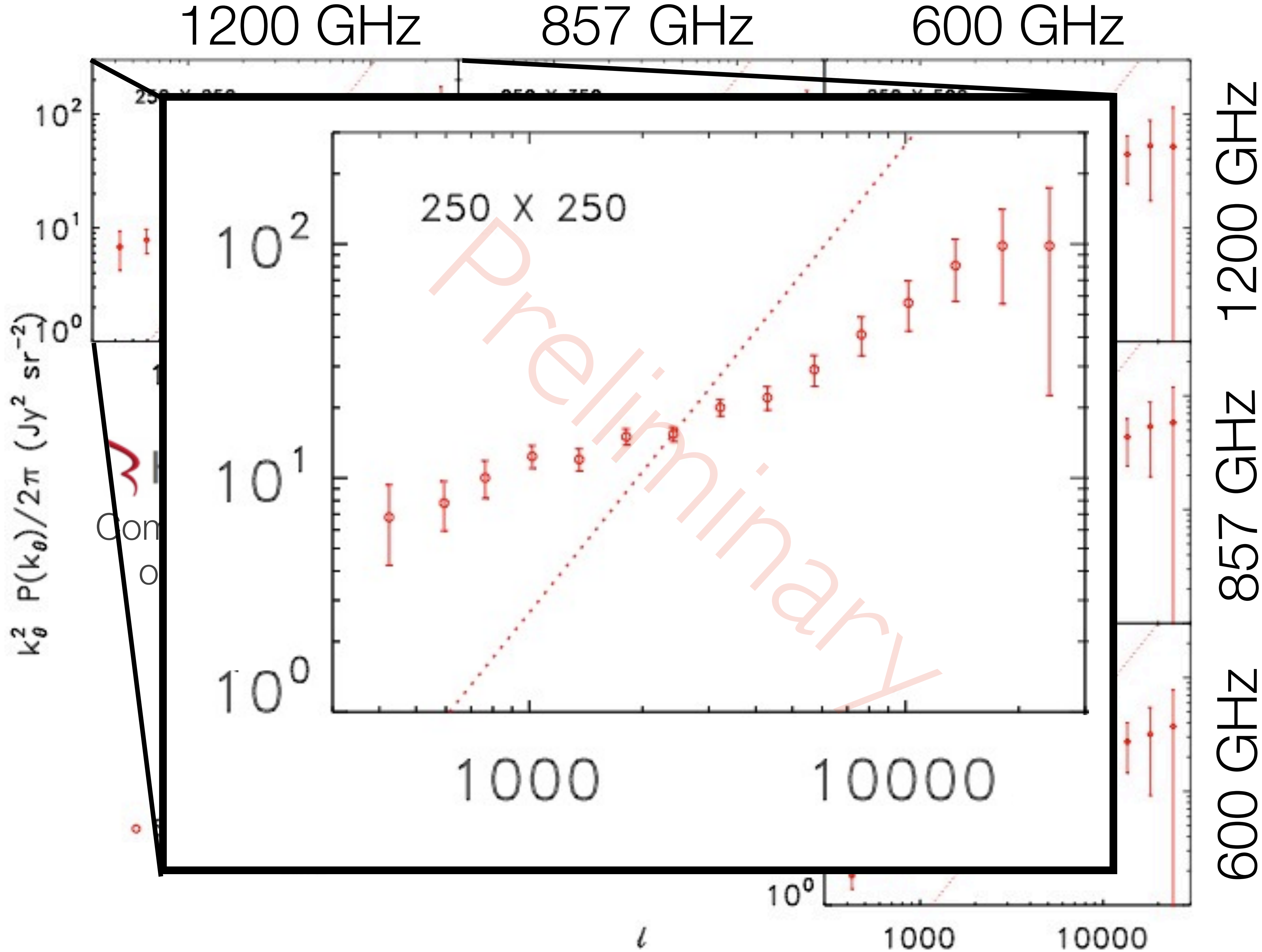
1-halo power vs. Masking



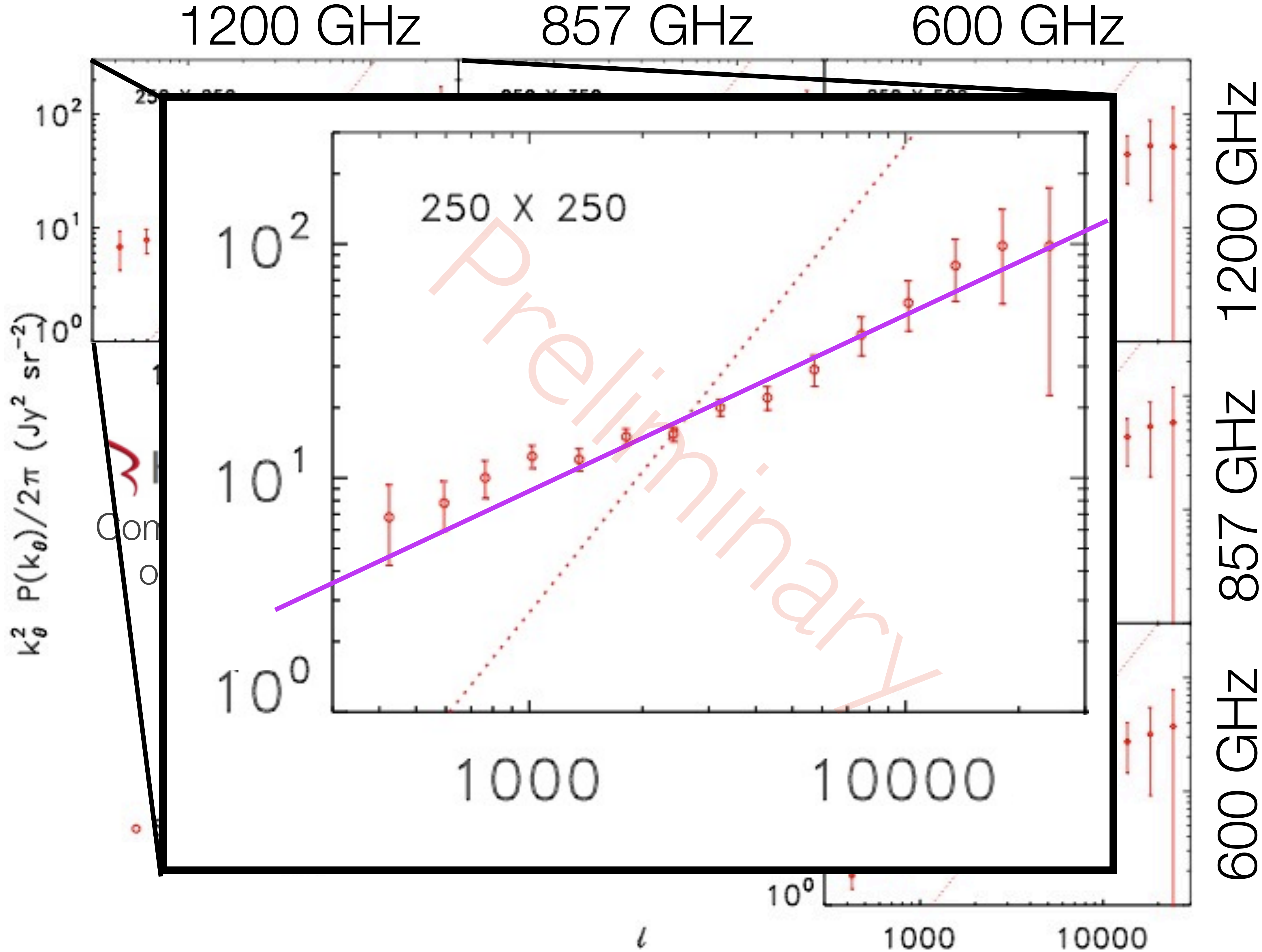
1-halo power vs. Masking



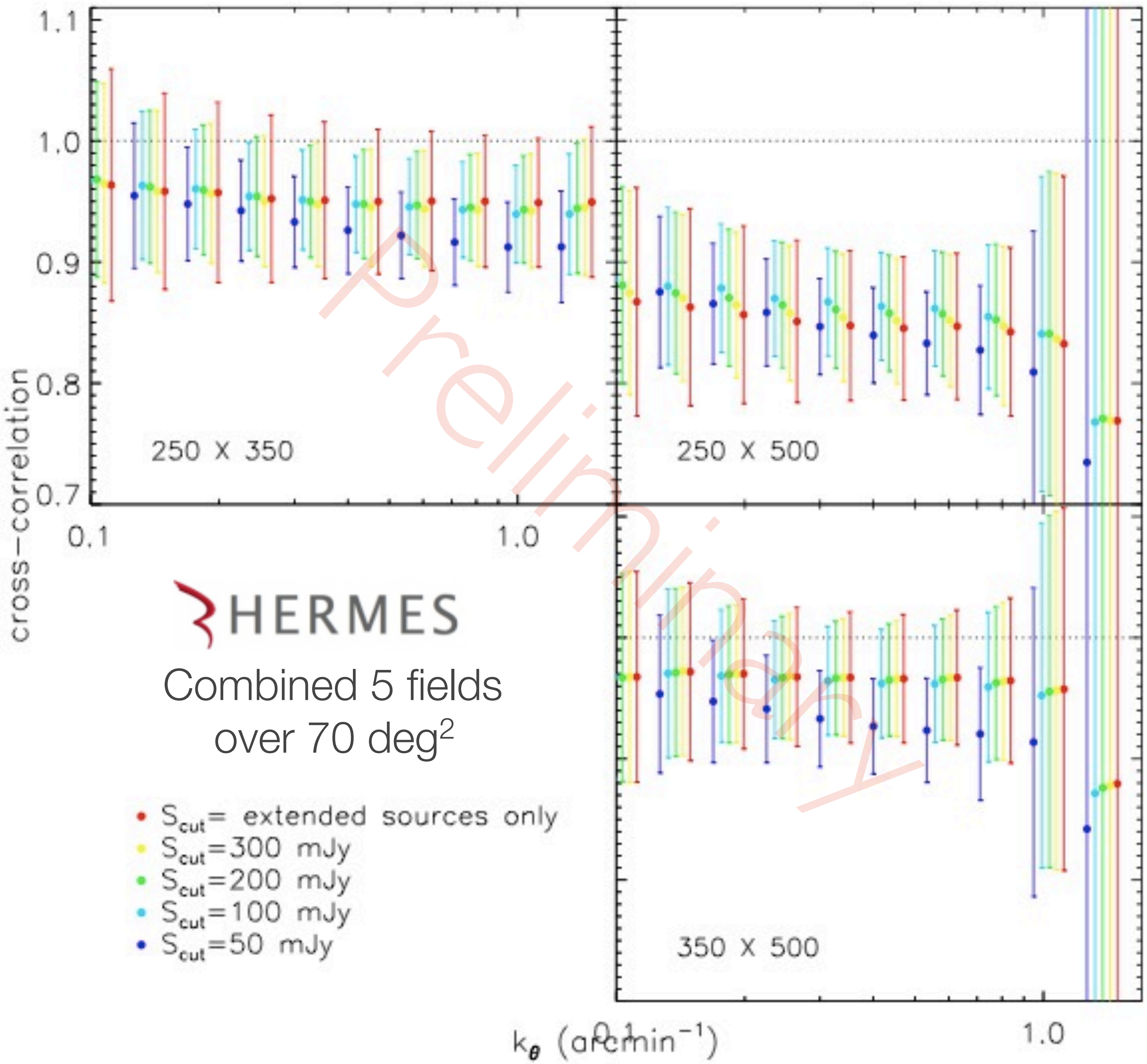
Clustering Spectra



Clustering Spectra



Clustering Spectra



- Neighboring bands more correlated
- Smaller scales (probing higher z) reduced correlations
- Faint background less correlated

Cross-correlations

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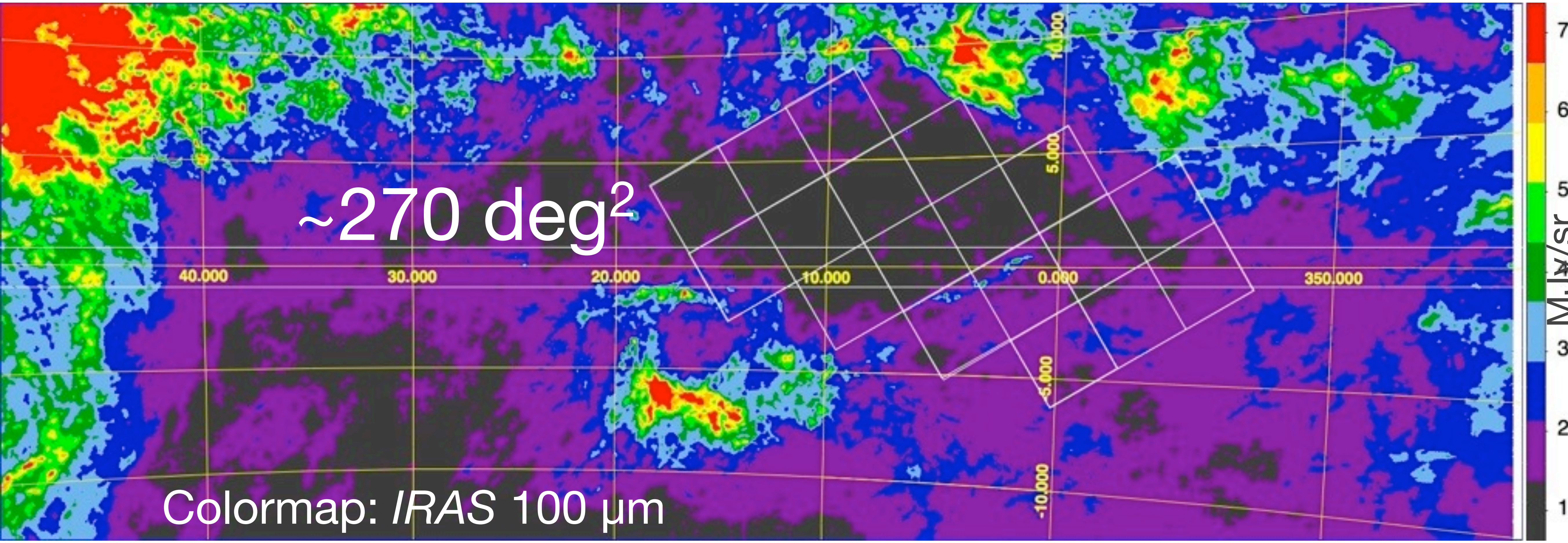
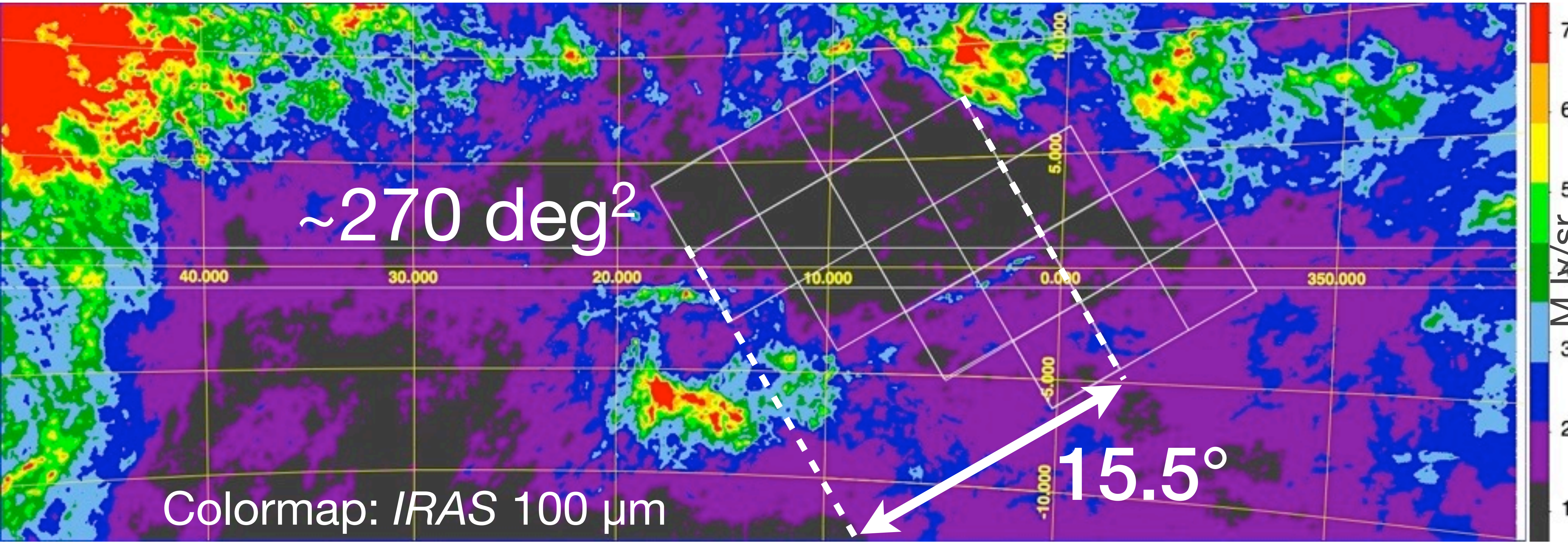
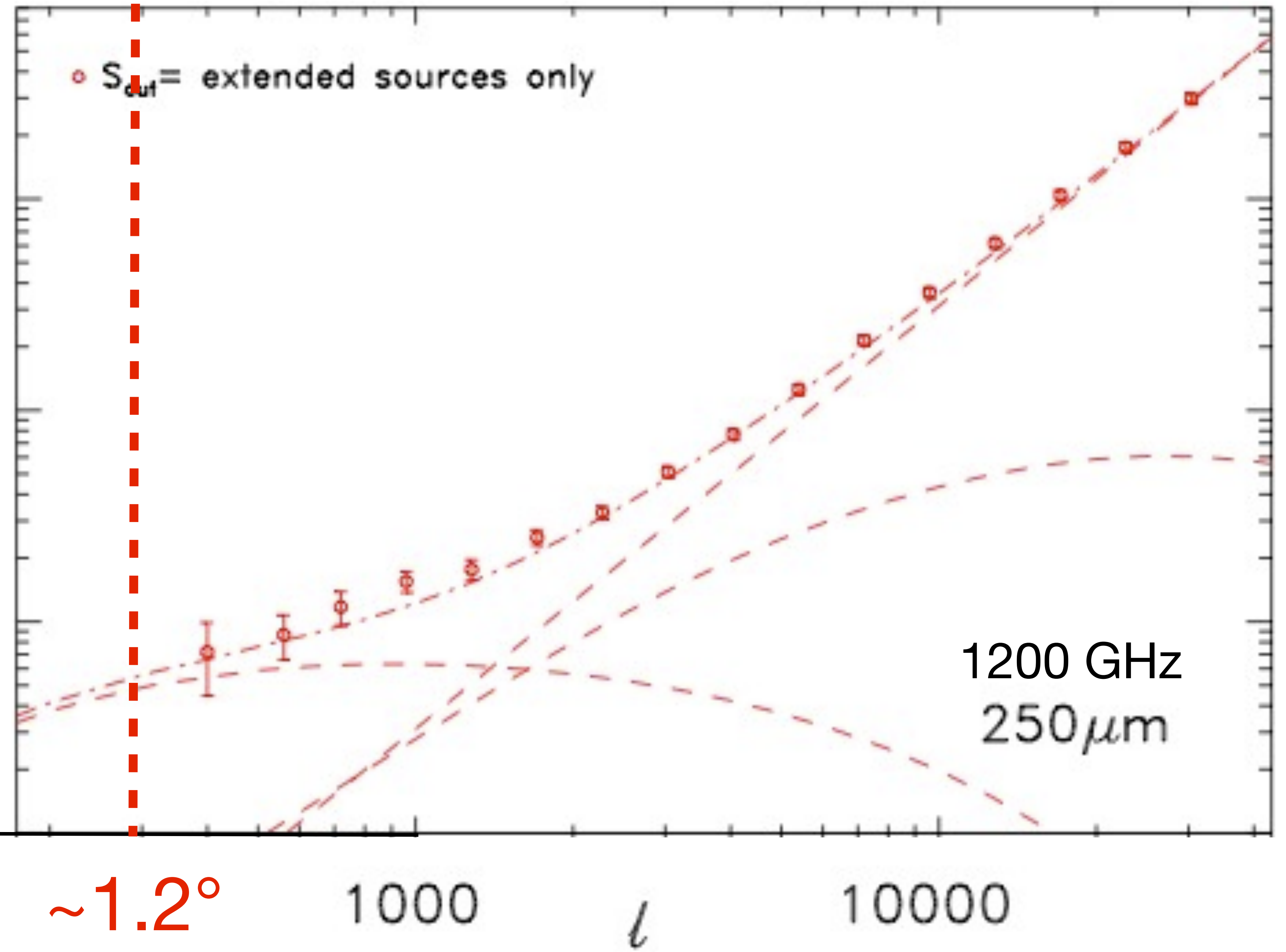


HerMES Large-Mode Survey (HeLMS)

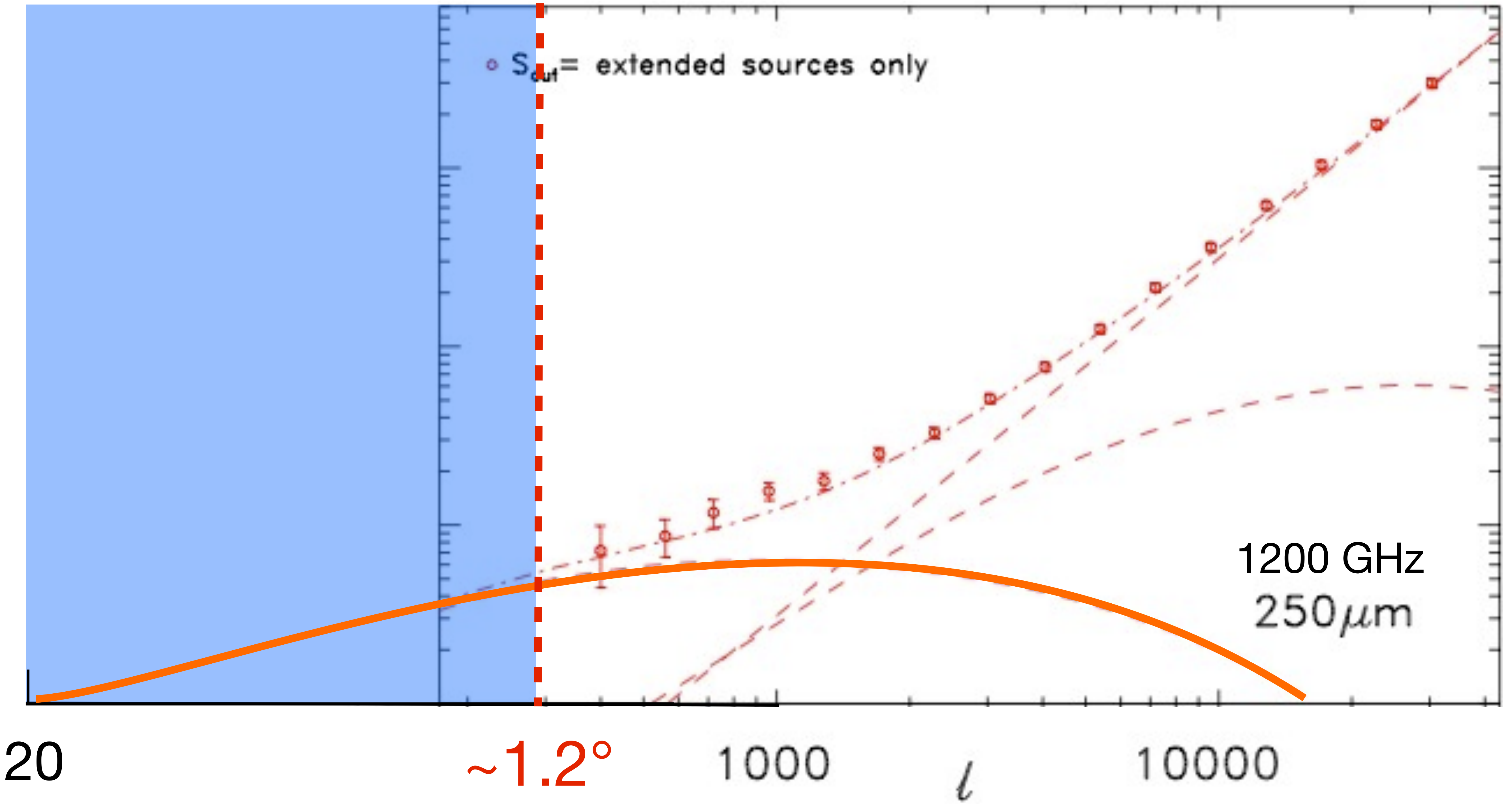
HERMES



HerMES Large-Mode Survey (HeLMS)



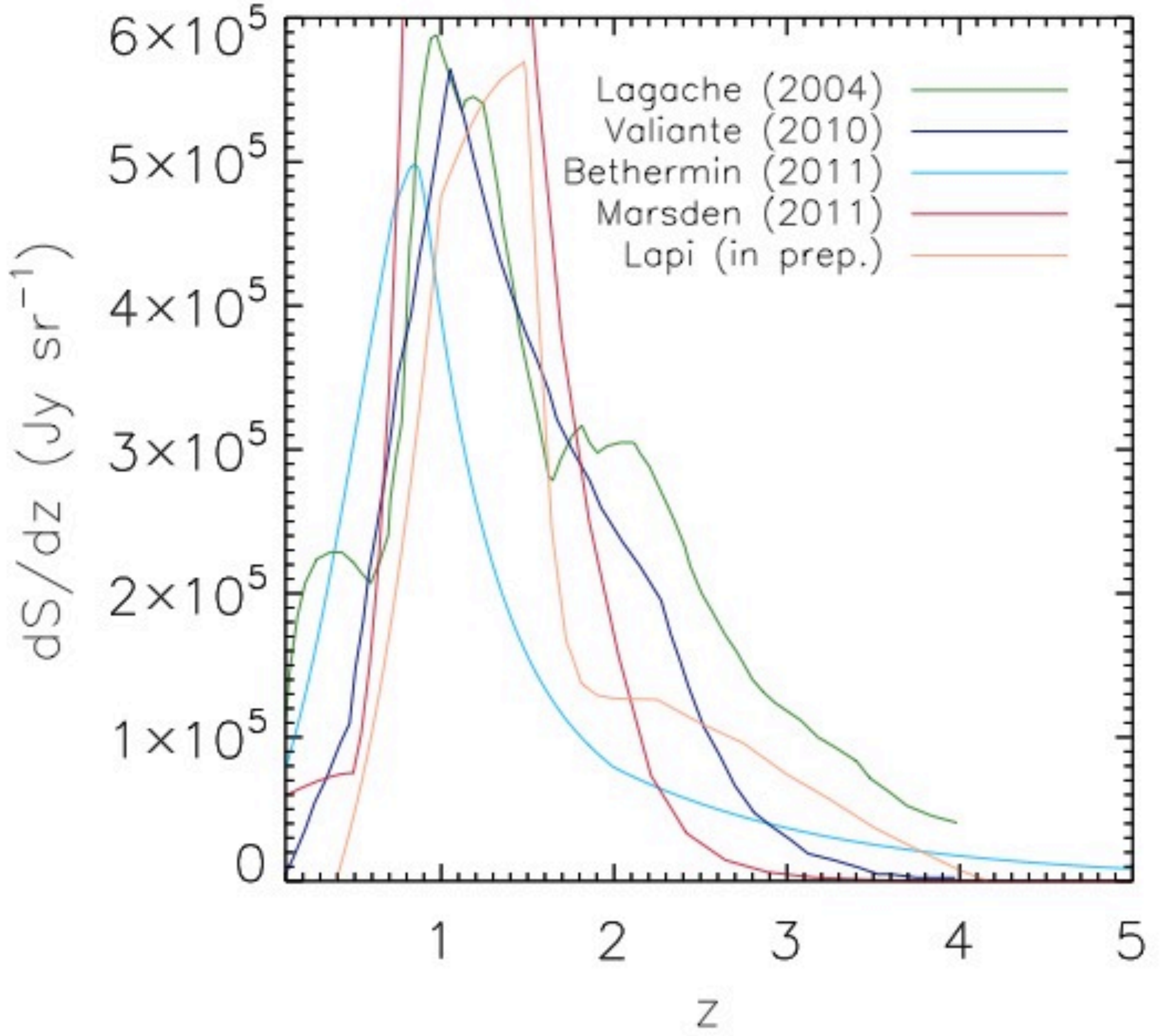
HeLMS



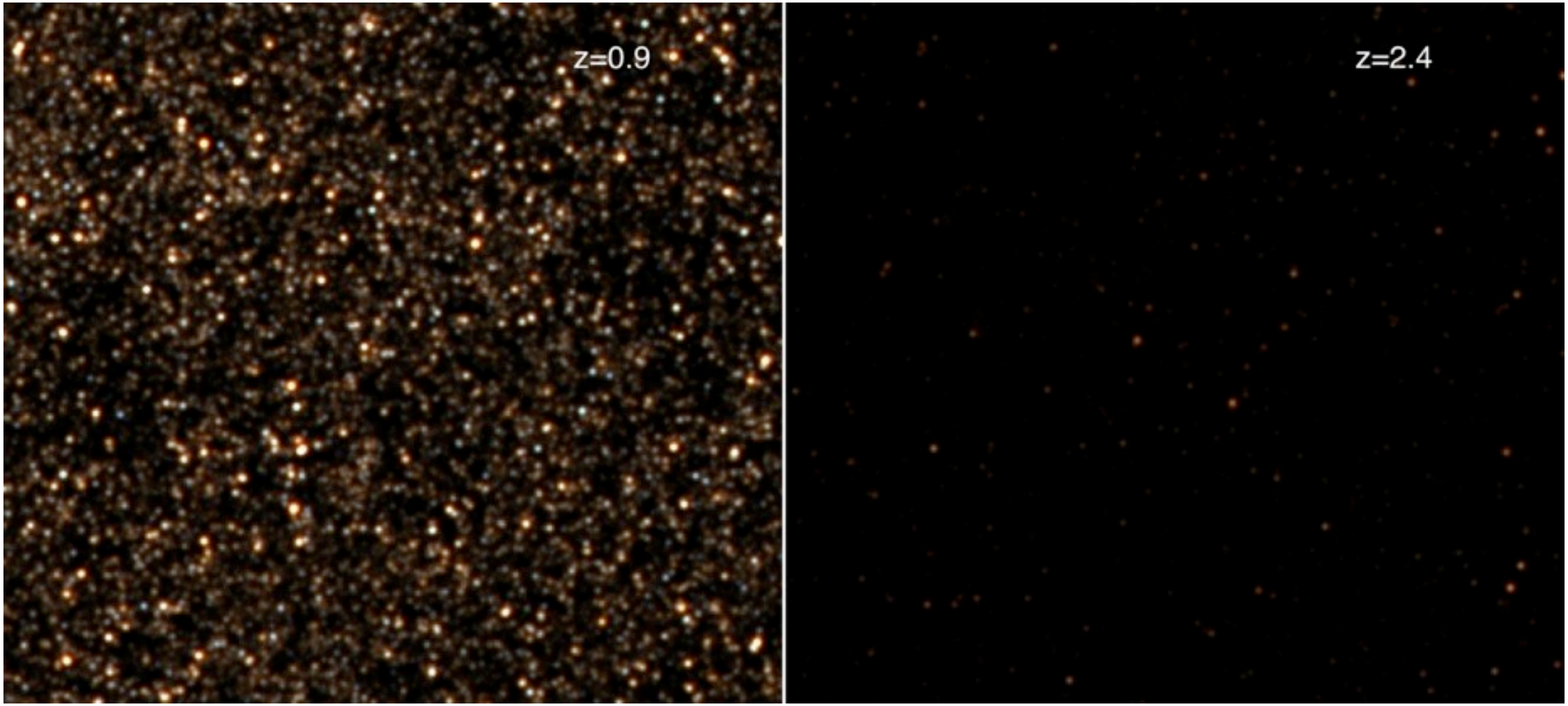
S_{cut}= extended sources only
1200 GHz
250μm
20
~1.2°
1000
l
10000

HeLMS

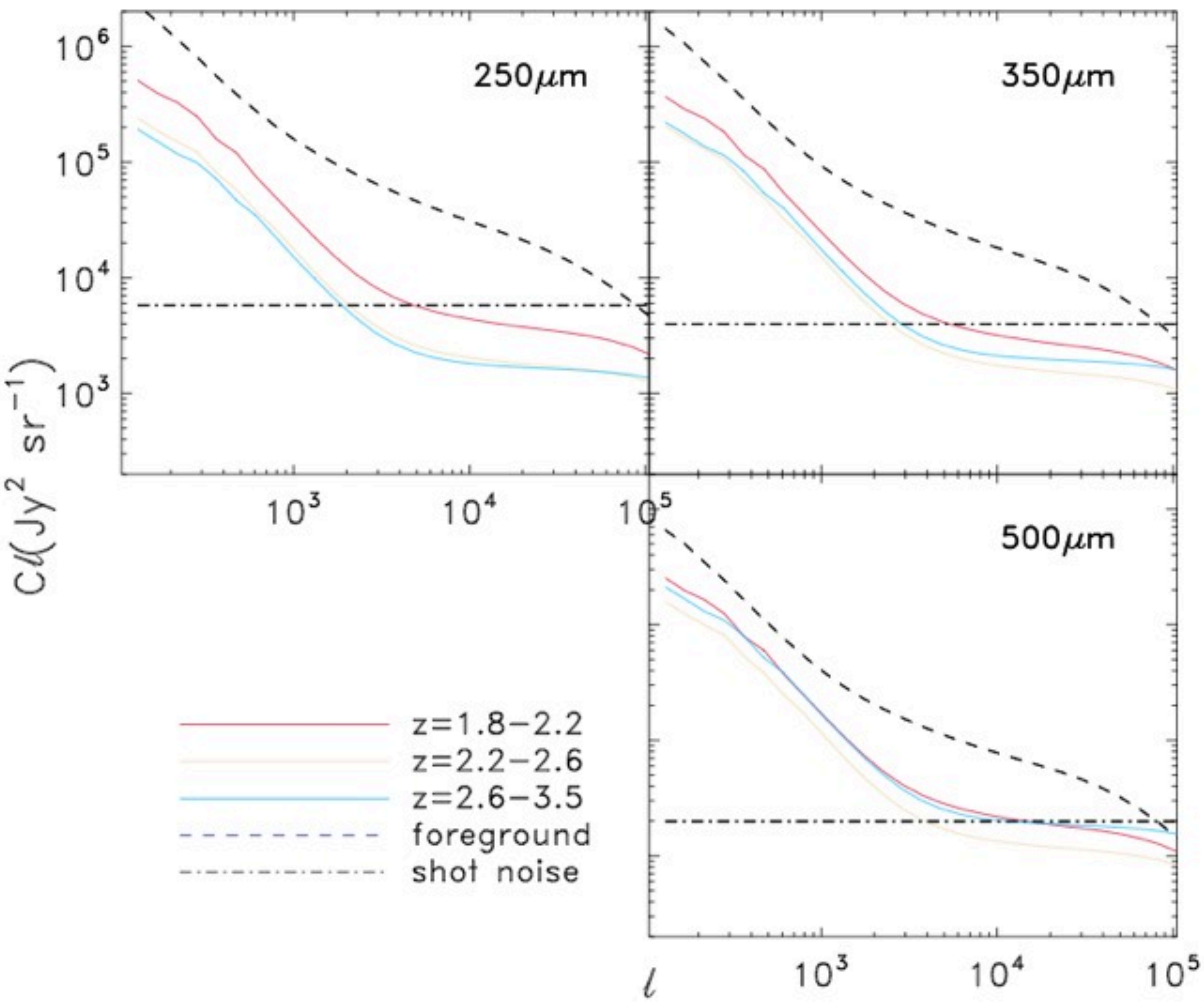
Redshift distribution of CIB



- dS/dz the redshift distribution of background light
- Models do not agree on dS/dz for z > 1

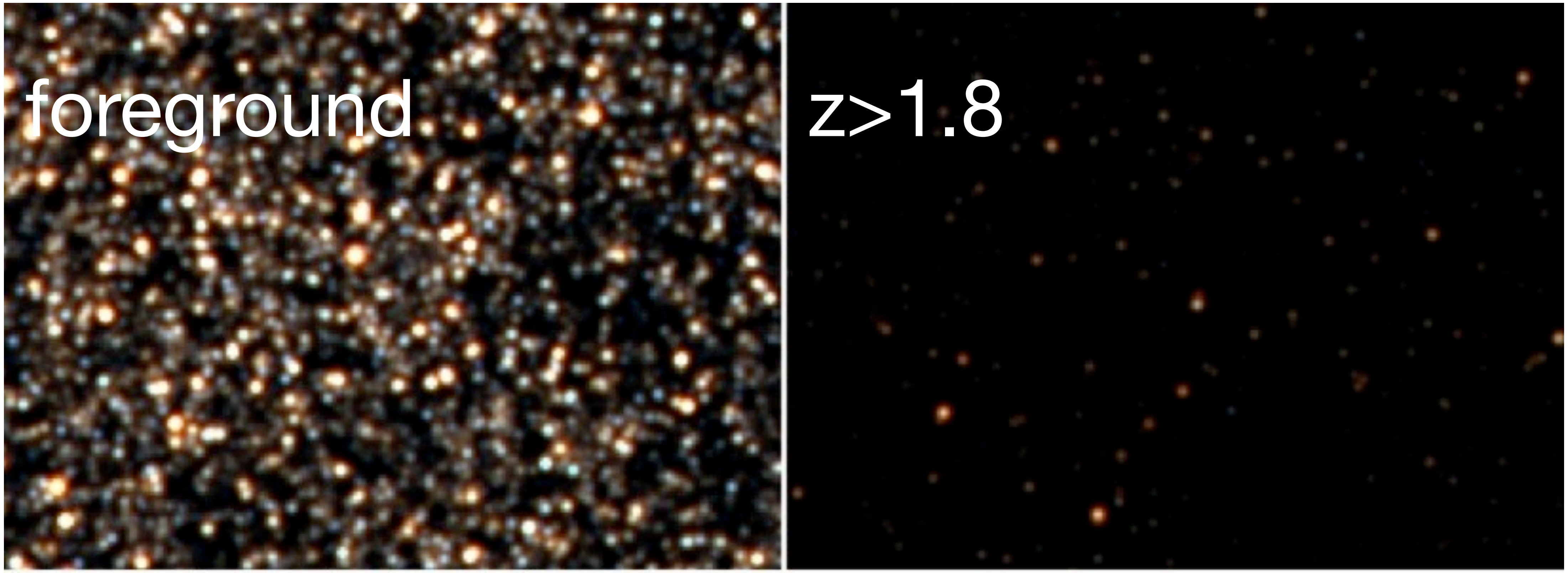


CIB as foreground



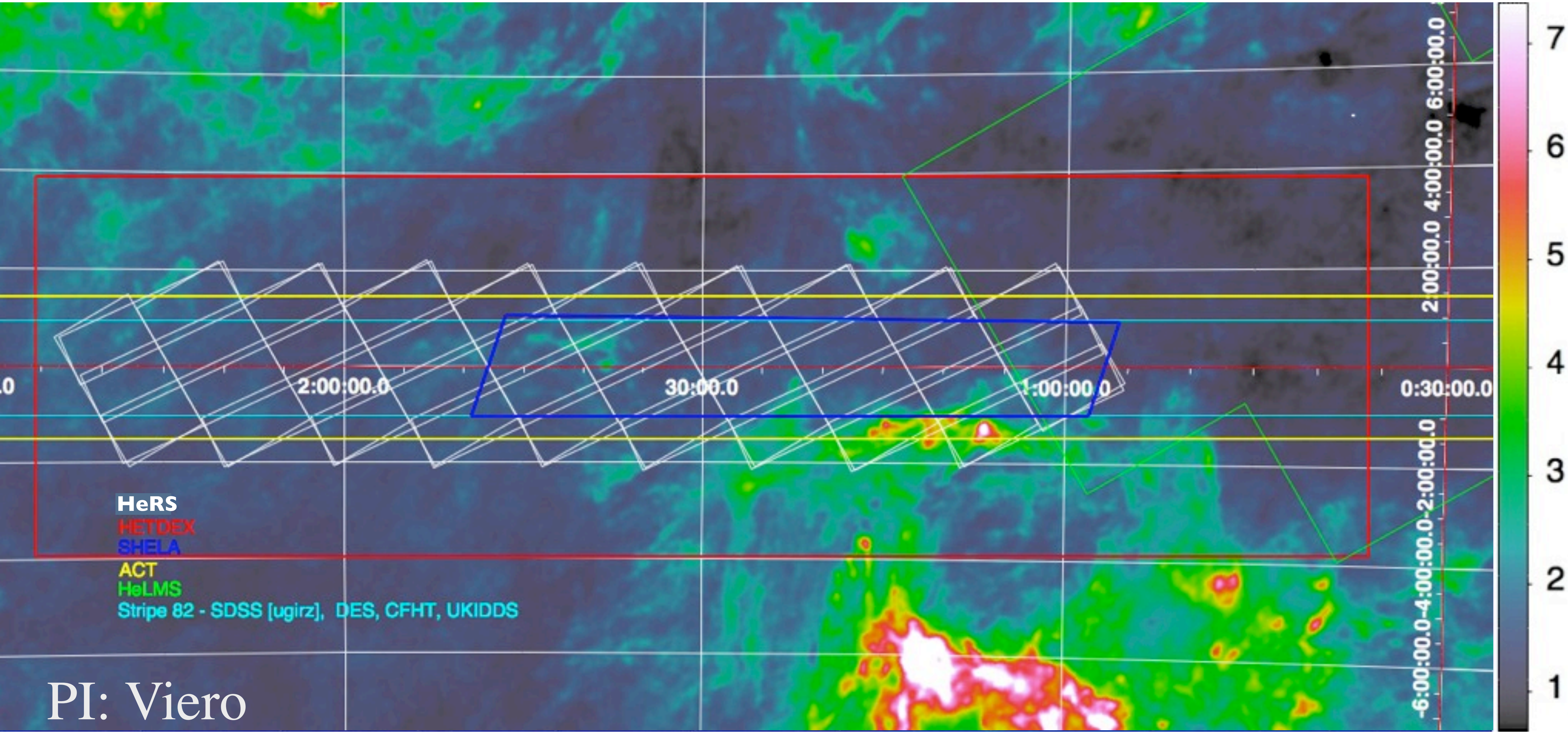
- z > 2 population sub-dominant contribution to total power

Foreground Spectra



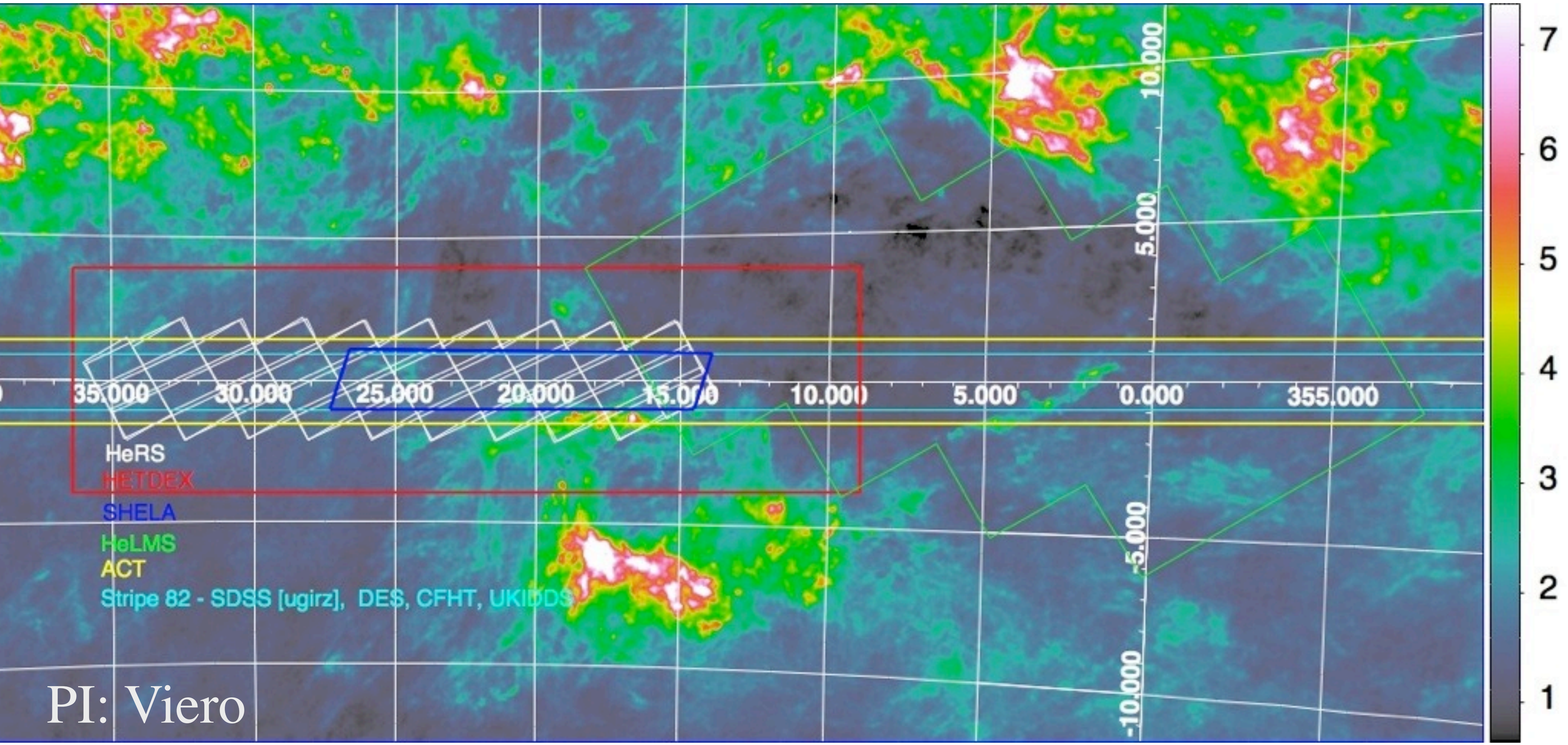
- HETDEX LAEs from $1.8 < z < 3.5$
- Biased tracer of the dark matter, bias known to 1-2%

Herschel Redshift Survey (HeRS)



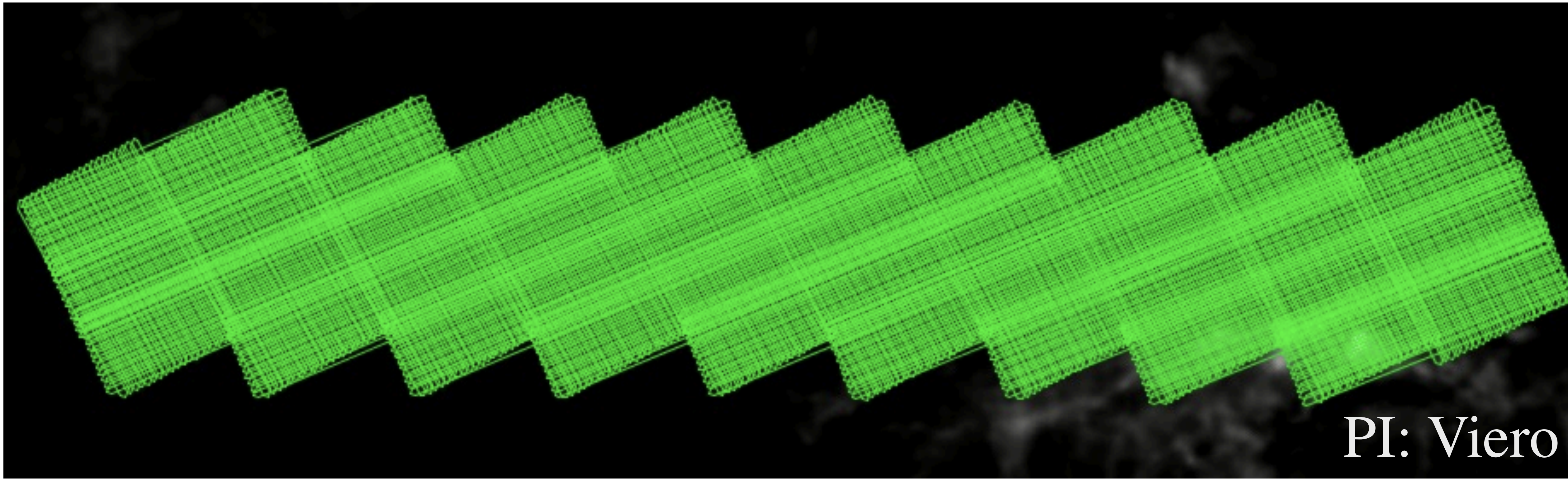
100 μm map (Galactic cirrus)

Herschel Redshift Survey (HeRS)



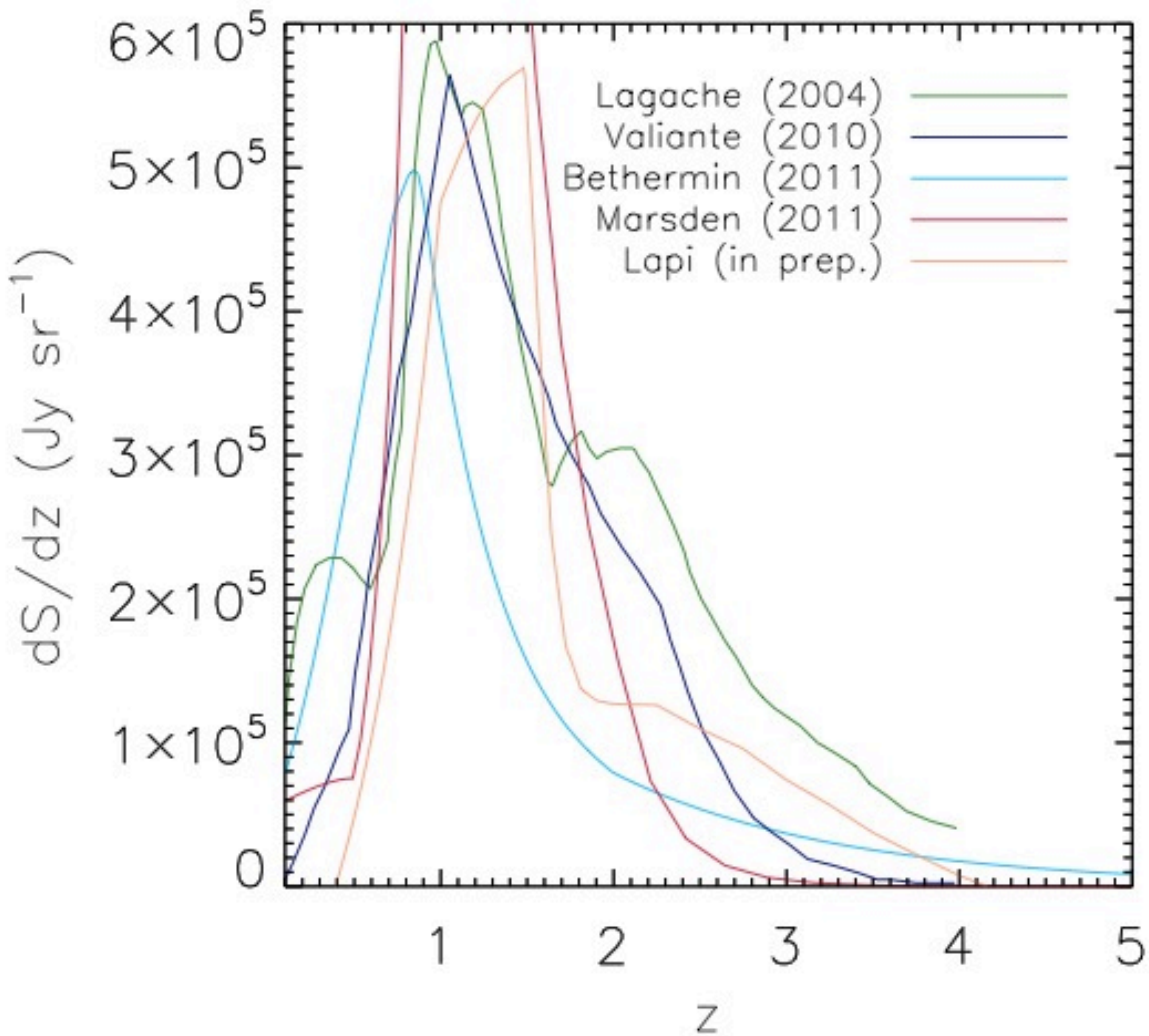
100 μm map (Galactic cirrus)

Herschel Redshift Survey (HeRS)

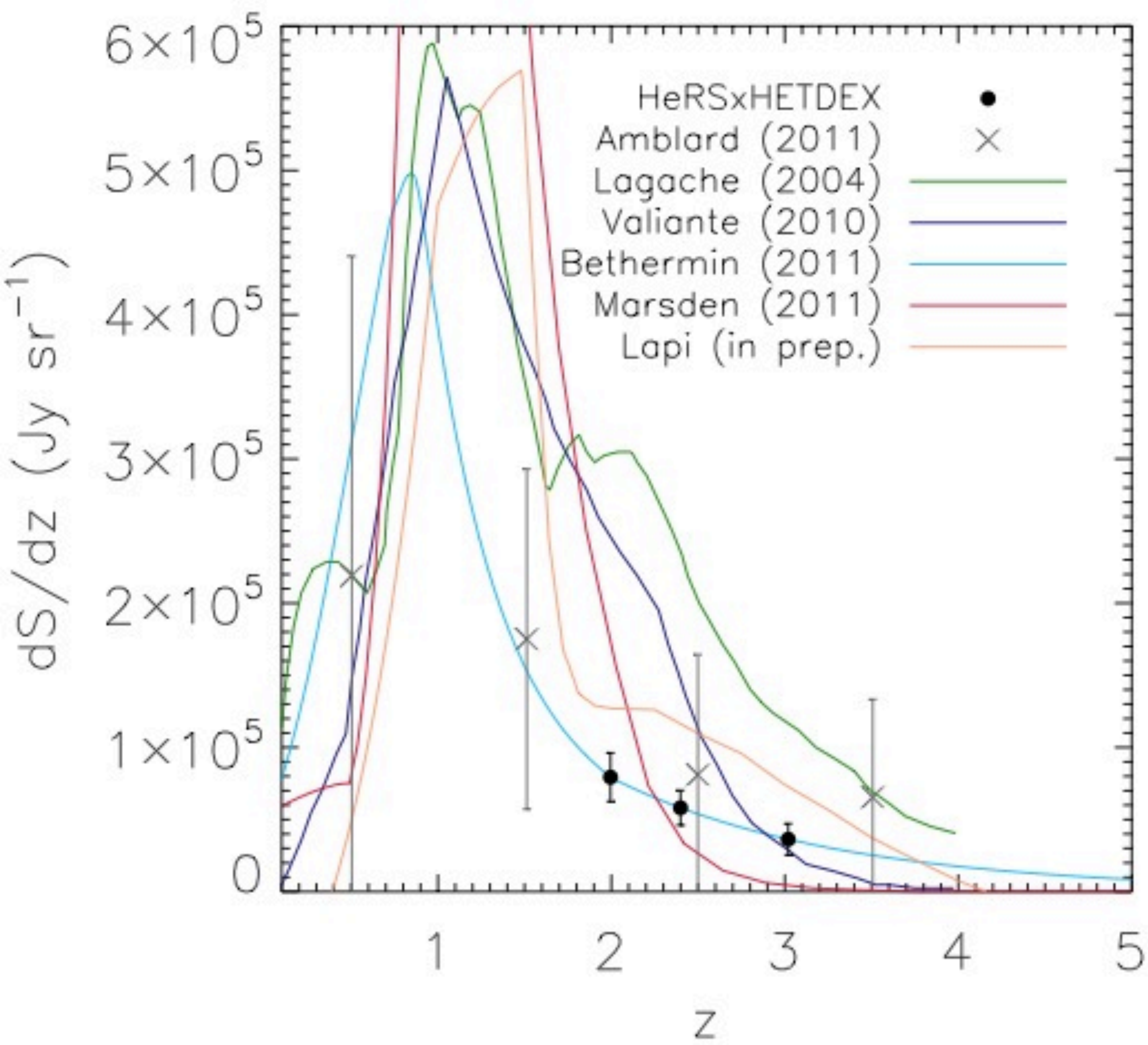


- 250, 350, 500 μm with SPIRE
- 35 hours for 70 deg^2 (Priority 1)
- Fast (60”/s) scans with 90° cross-linking

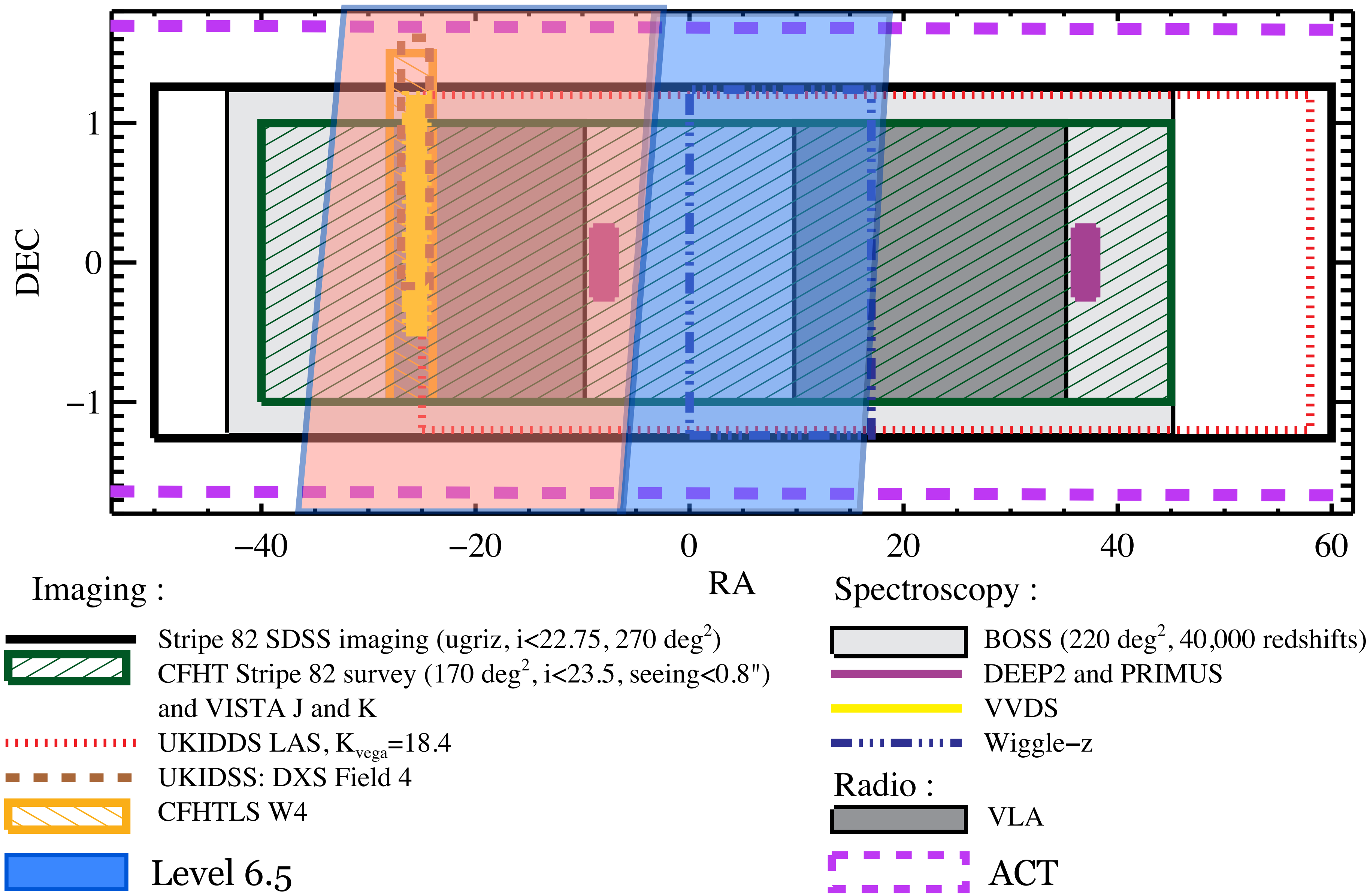
HeRS AORs



Herschel Redshift Survey (HeRS)



Herschel Redshift Survey (HeRS)



Today

- SDSS optical
- ACT (150 deg^2)
- CFHT
- UKIDDS
- VLA
- Wiggle-z
- BOSS

Tomorrow

- ALMA
- ACTpol
- Spitzer Warm
- HETDEX
- Visible from most sites

HeLMS/HeRS ancillary data

conclusions

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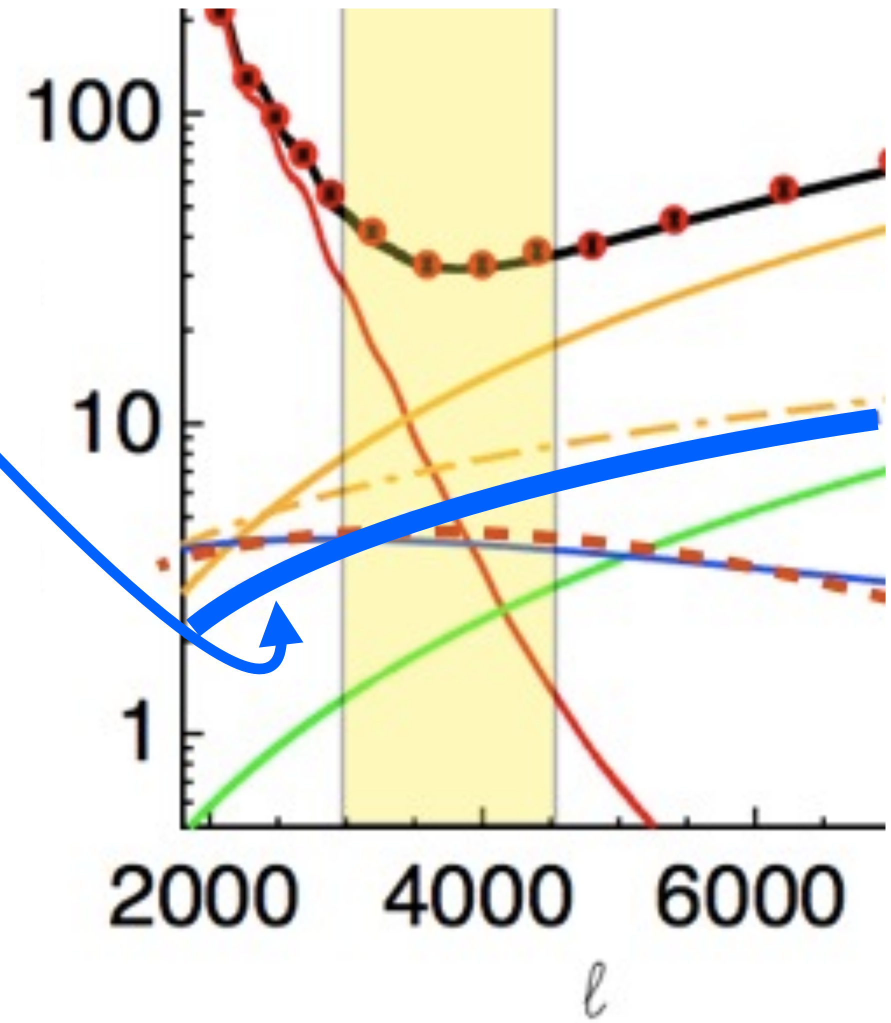
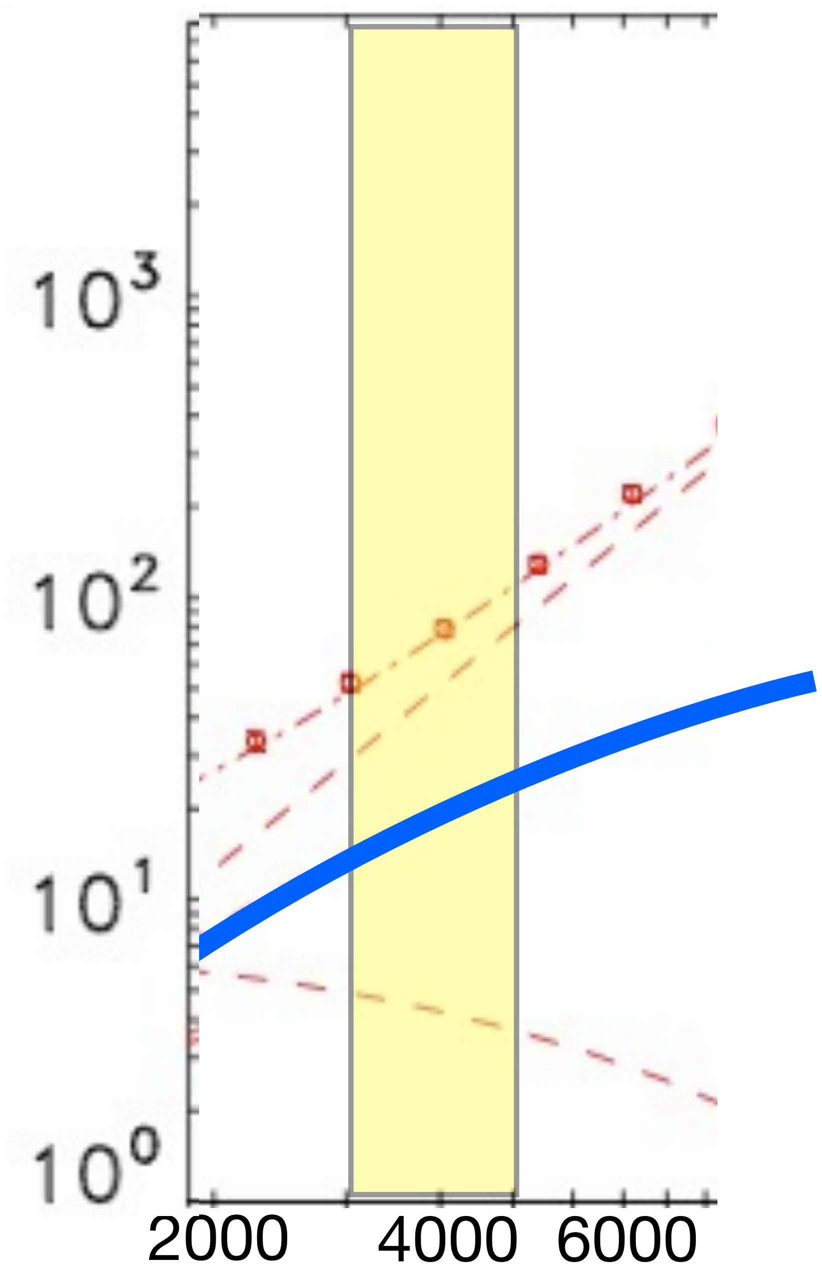


conclusions

- Measure clustering in the Power Spectrum because at best only 15% of flux is "resolved"
- Strength of 1-halo clustering term a strong function of the masking level
- Fitting an HOD to the CIB spectra should provide insight on how DSFGs occupy dark matter halos



conclusions