Power Spectrum of the CIB

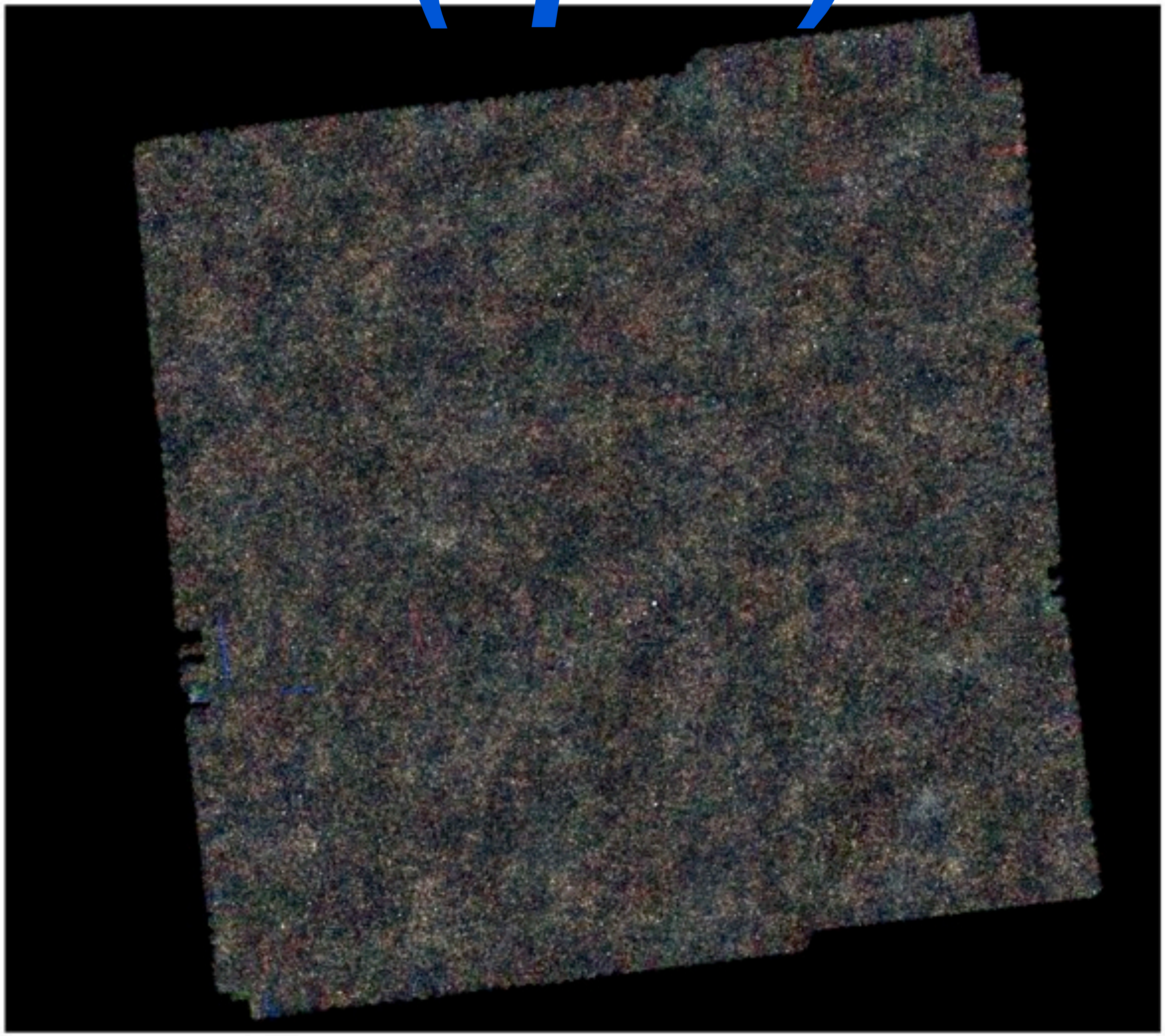
Gil Holder
McGill University (Montreal, Canada)

Outline

- power spectra principles
  - ⋆ flat sky approximation
  - ⋆ cross-spectra
  - ⋆ diversion on cross-linking
- incomplete overview of CIB detections

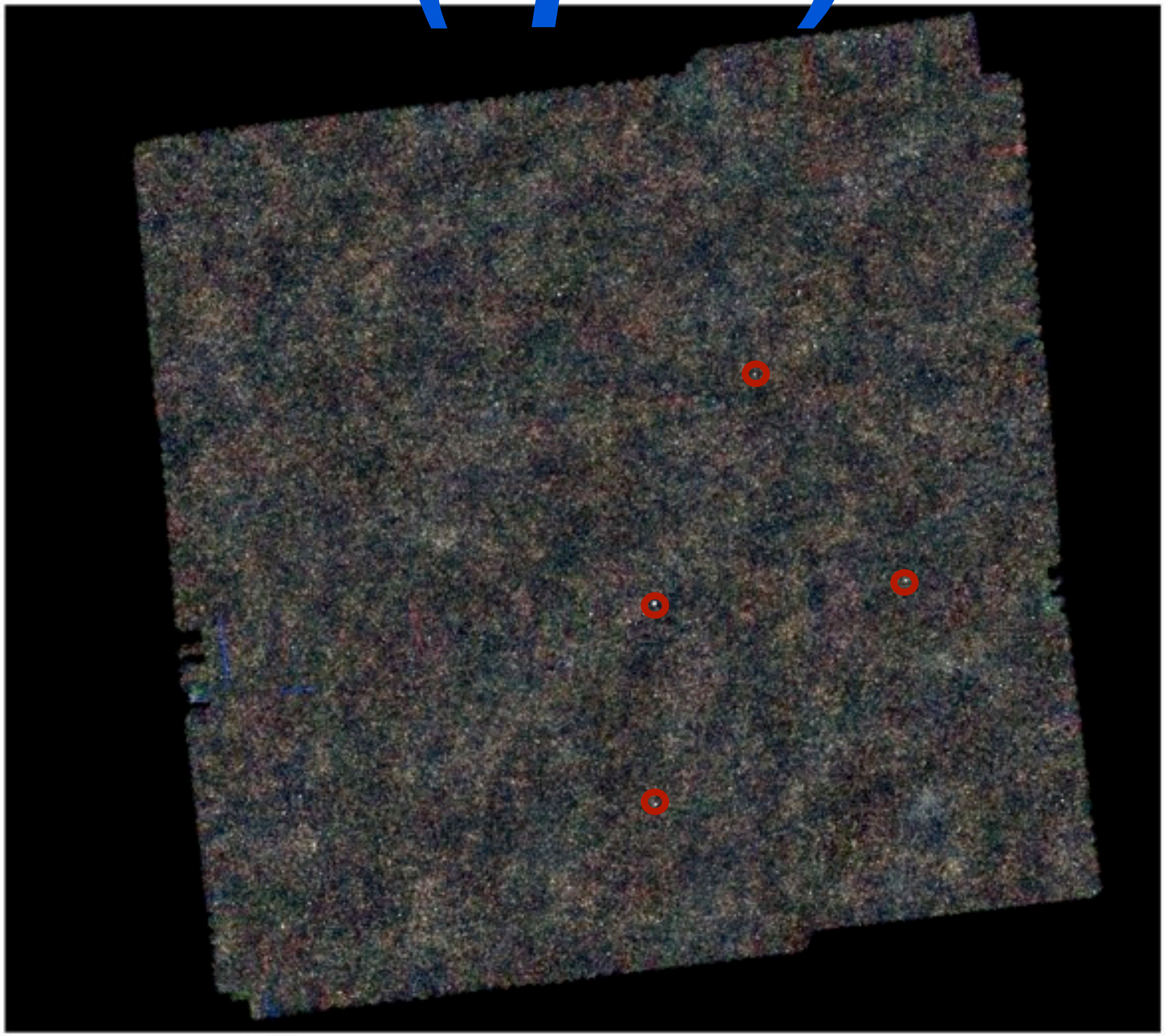
Herschel (Spire)

- 100 sq deg with full overlap with SPT deep field (23h30,-55d)
- 250,350,500 um

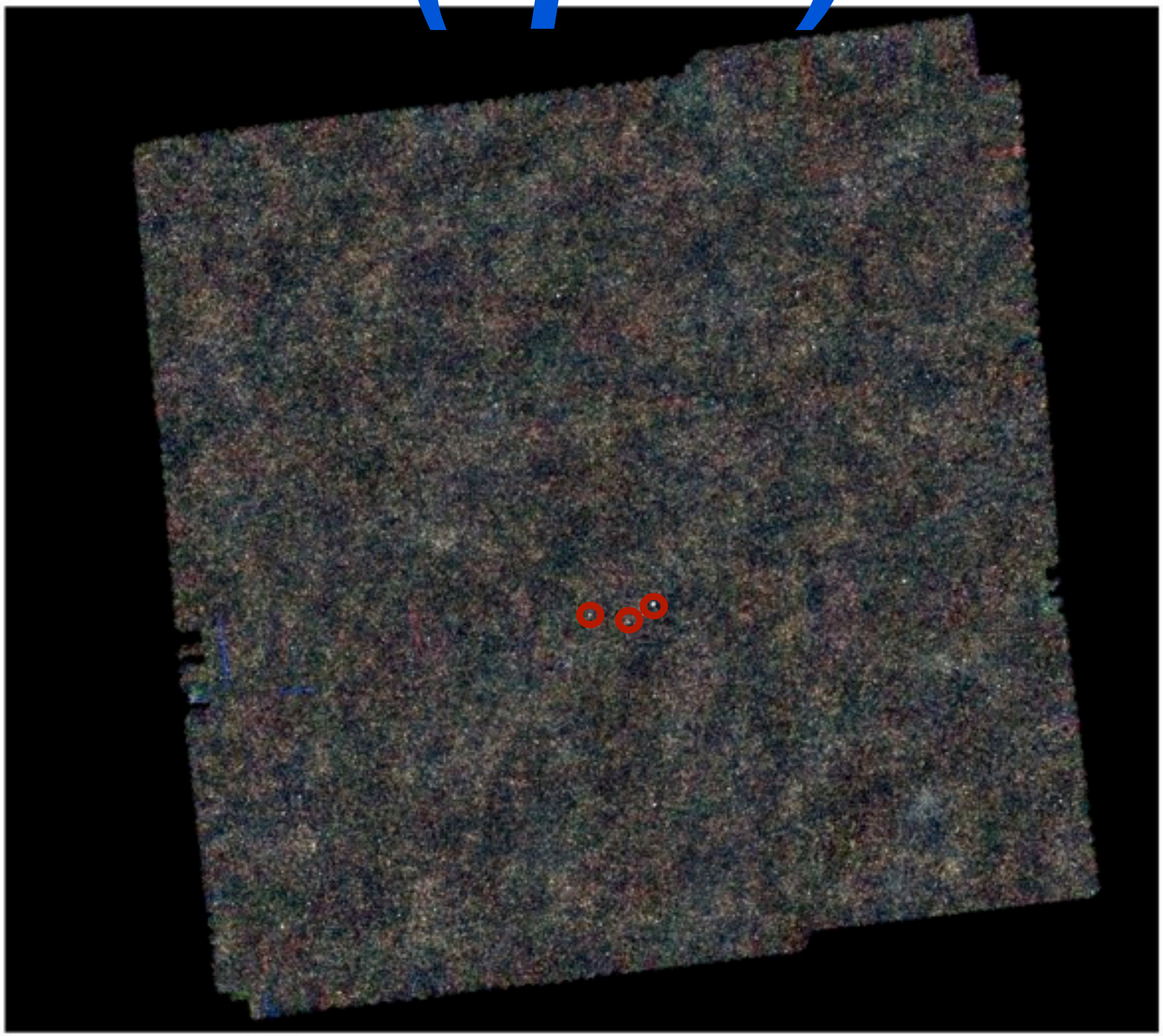


Herschel (Spire)

- can do source counts
- 1 pt probabilities



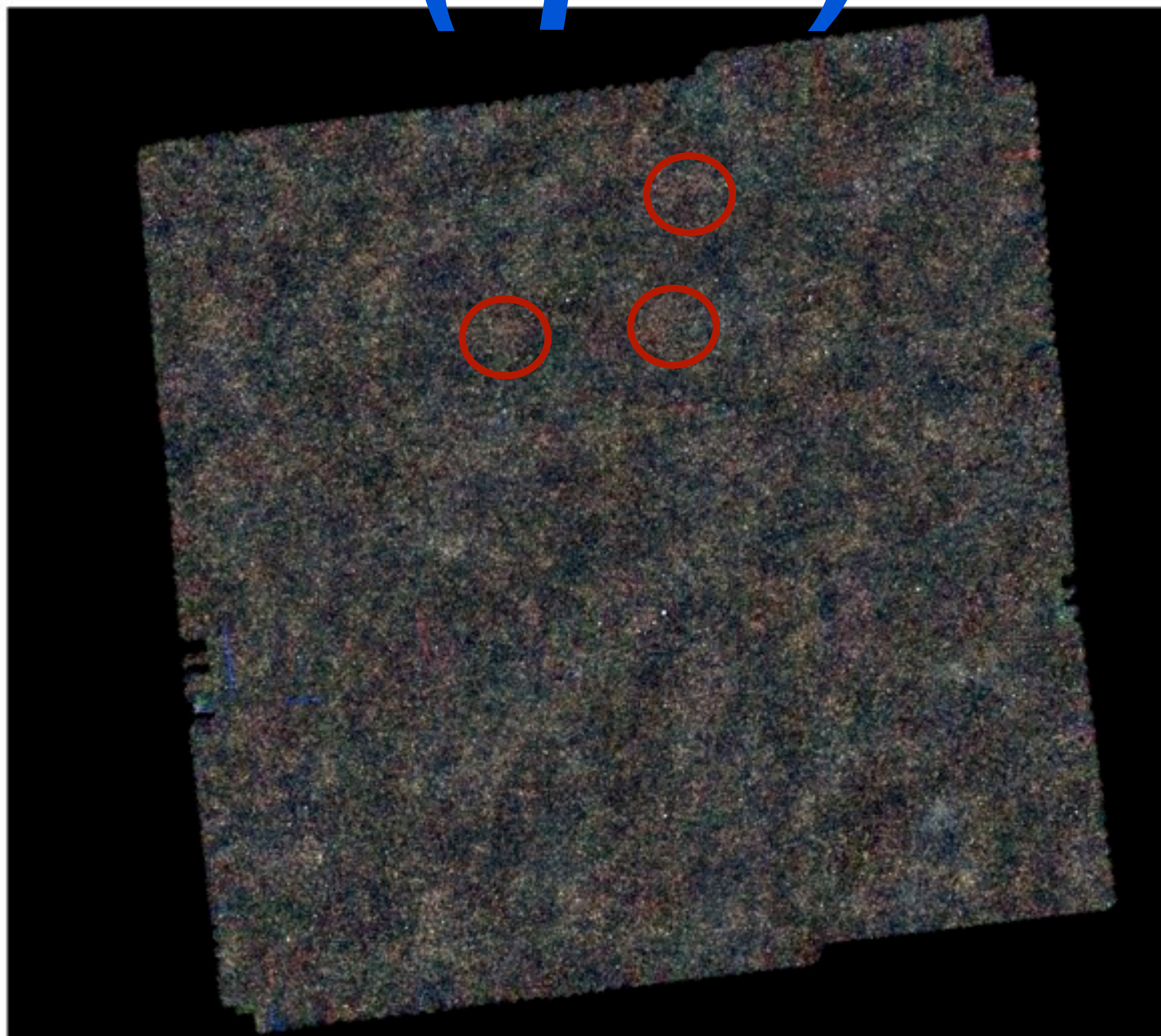
Herschel (Spire)



- are sources too close to each other?
- 2 pt probabilities

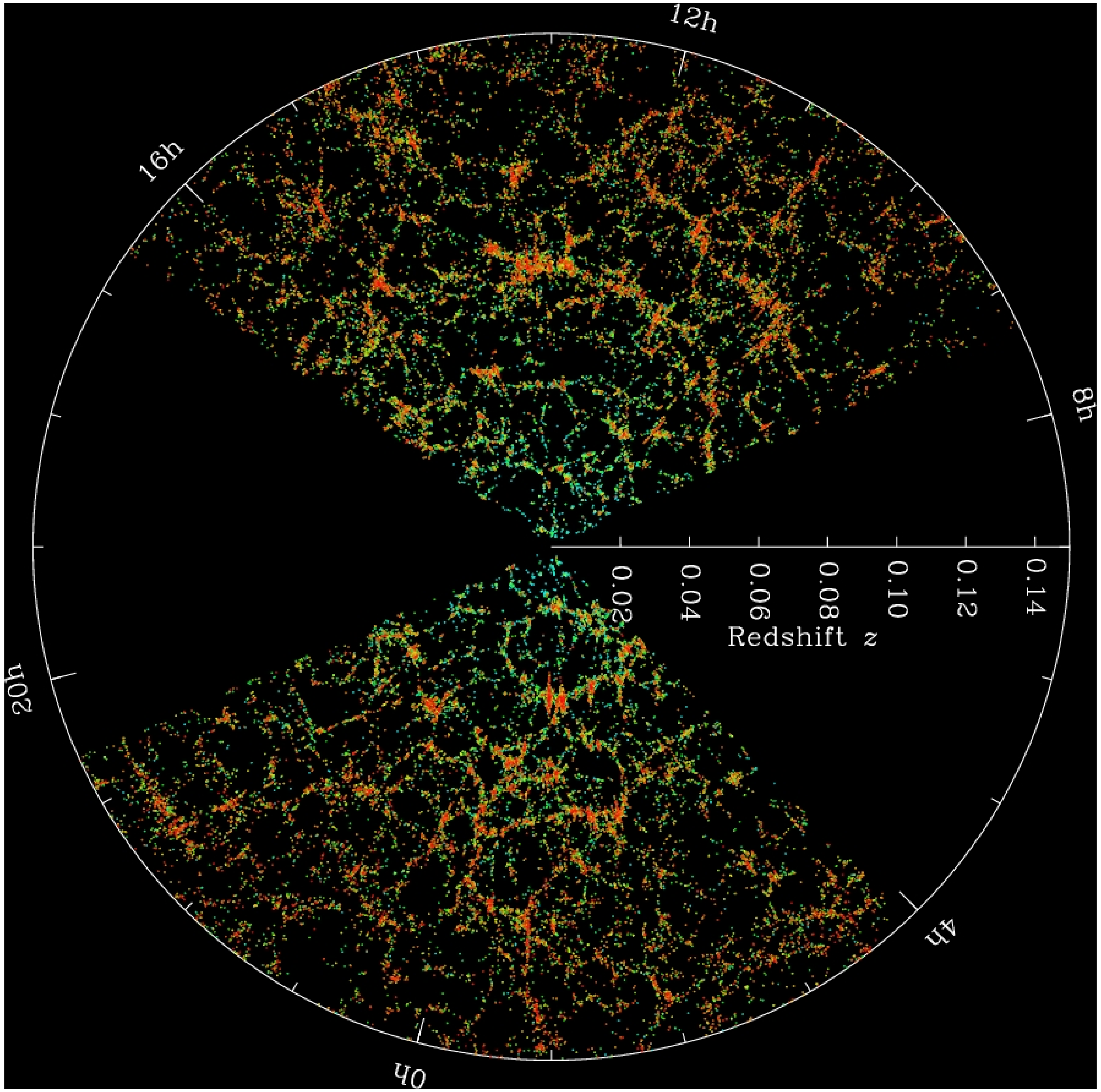
Herschel (Spire)

- what about large scale structure in the map?
- general splotchiness in the map seems to not be fully captured by bright source counts



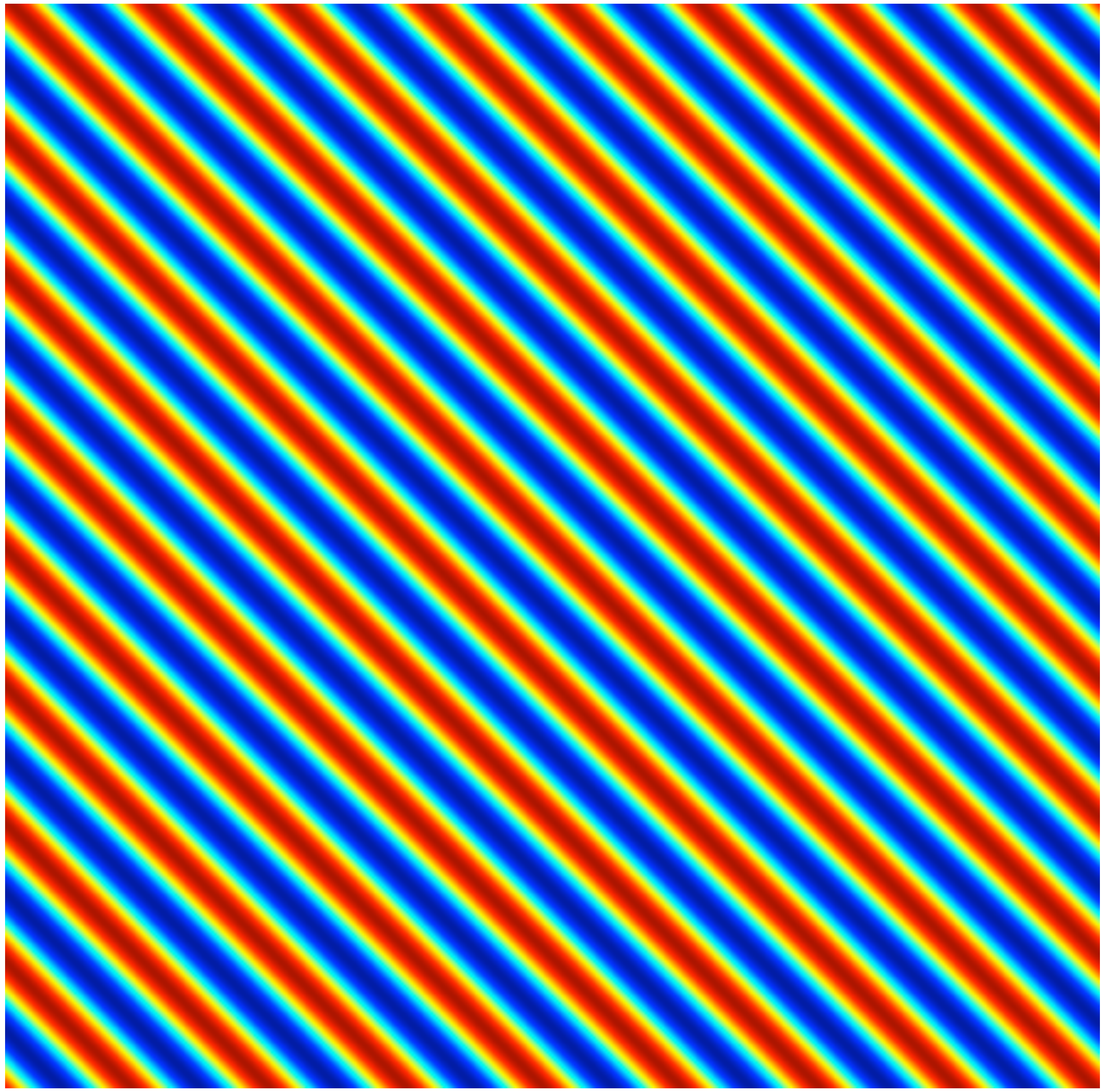
Clustering of Point Sources

- Radio and IR/submm sources presumably trace the large scale matter fluctuations
- Back of the envelope:
  - Power spectrum contribution: mean T^2 x projected clustering amplitude
  - Arcminute scales: few Mpc has clustering ~1 in 3D, divide by number of independent cells along line of sight => 1e-3
  - end result dT/T~10%



Poisson Power Spectrum

- single point source leads to a corrugation in Fourier space
- sum over N sources: $T^2 \propto N\, S^2$
- no preferred scales: white noise

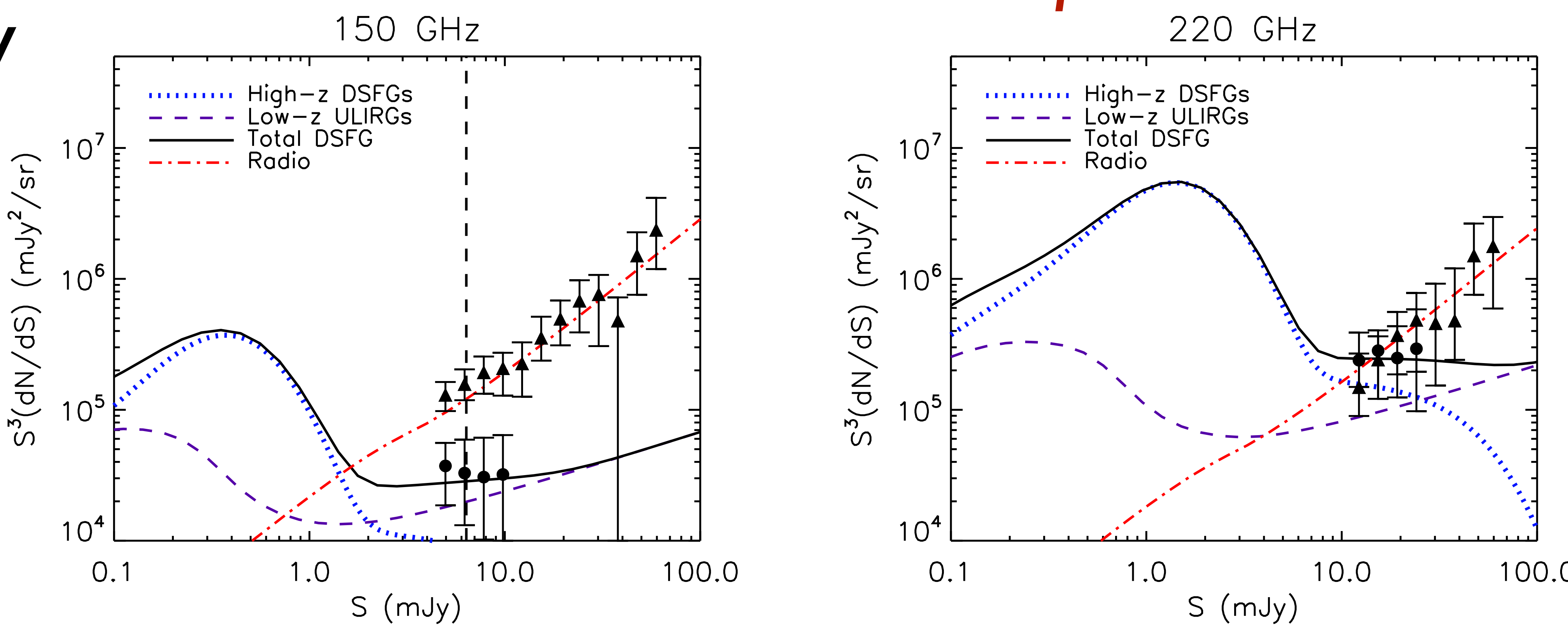


Real part of Fourier transform of 1 source

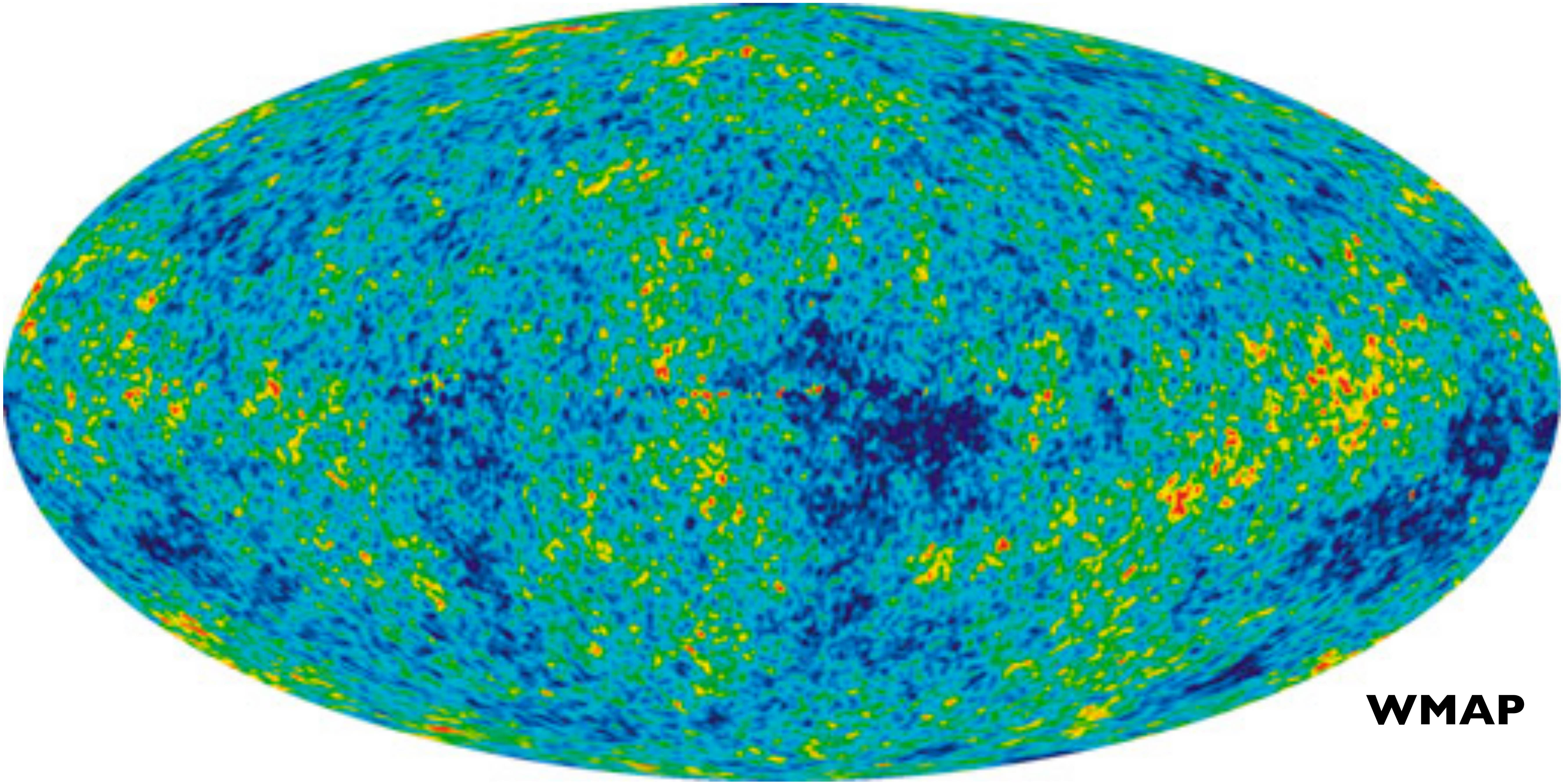
Which Sources?

- CIB mainly comes from dim sources (faint end of classic SMGs?)

Contributions to Poisson power



Hall et al 2010



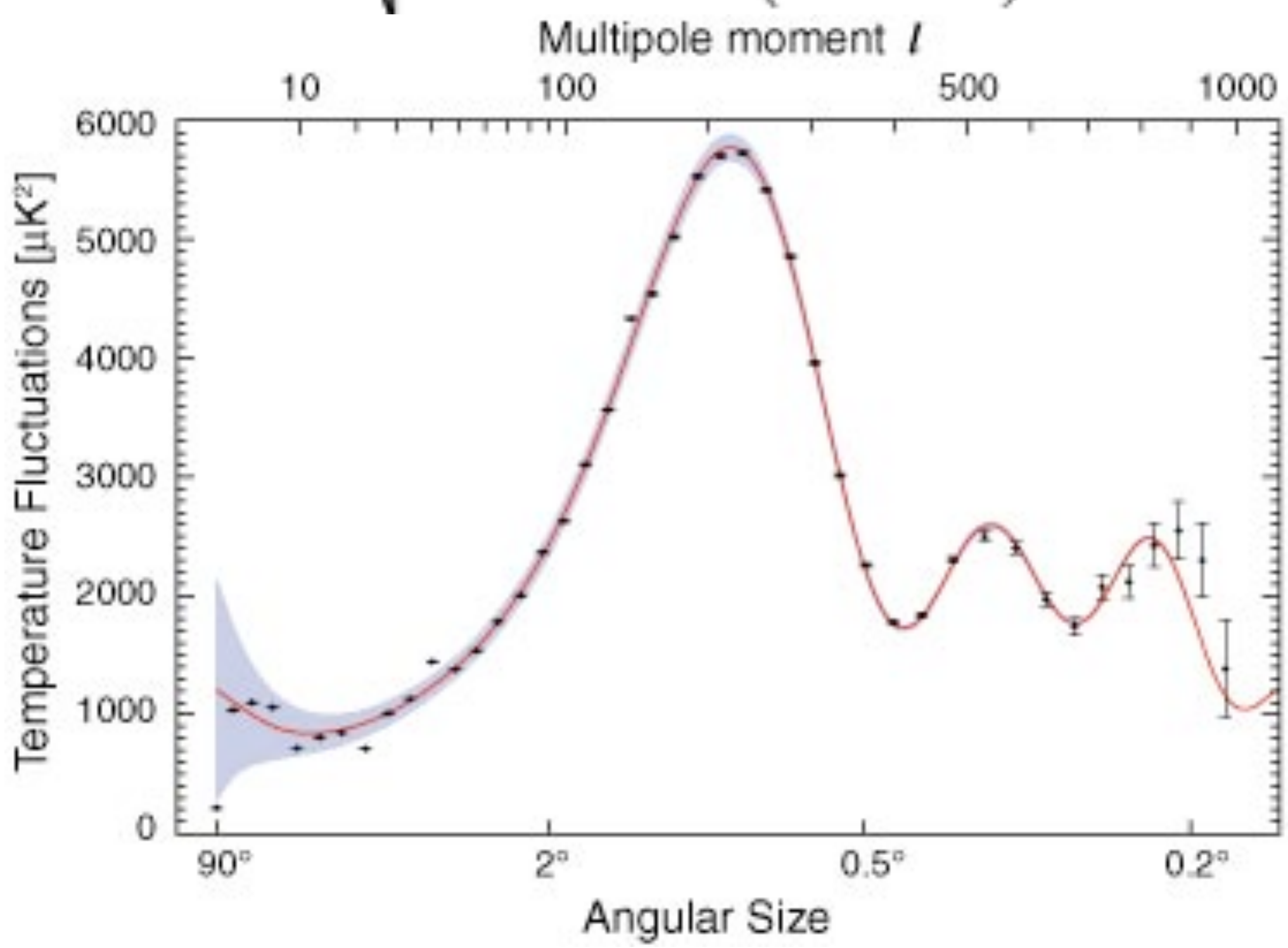
WMAP

What do we do with CMB maps?

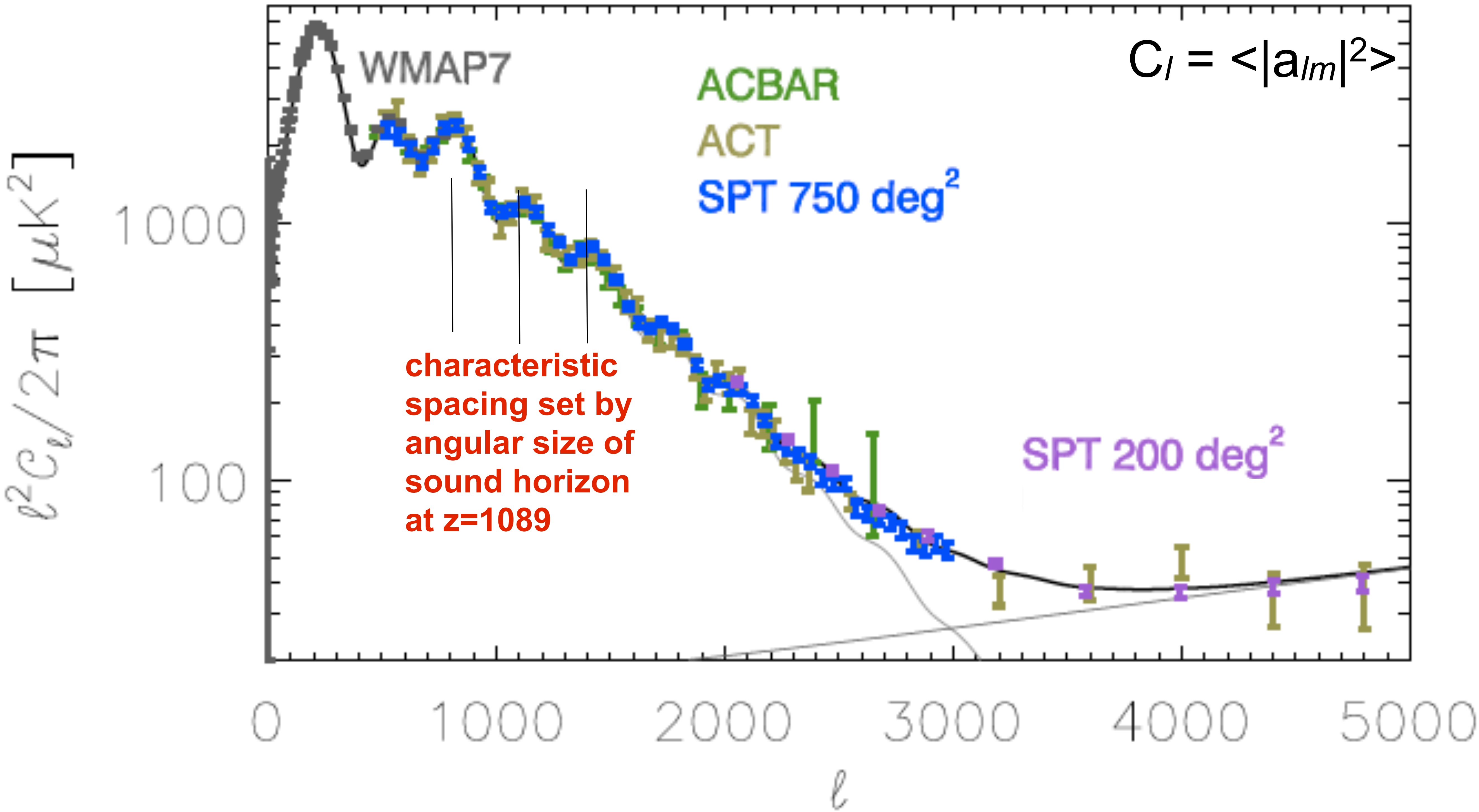
Spherical Harmonics

$$T(\theta, \phi) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\theta, \phi).$$

$$Y_\ell^m(\theta,\varphi) = \sqrt{\frac{(2\ell+1)}{4\pi}\frac{(\ell-m)!}{(\ell+m)!}}\, P_\ell^m(\cos\theta)\, e^{im\varphi}$$



CMB Power Spectrum



Fourier Transforms

$$s(t) = \int_{-\infty}^{\infty} S(f)\, e^{i2\pi ft}\, df$$

Does one have to choose between Fourier coefficients and spherical harmonics?
(no)

From a_{lm} to $a_{k_x k_y}$

Equation satisfied by Plm(x):

$$(1-x^2)\,y'' - 2xy' + \left(\ell[\ell+1] - \frac{m^2}{1-x^2}\right) y = 0,$$

For x~0:

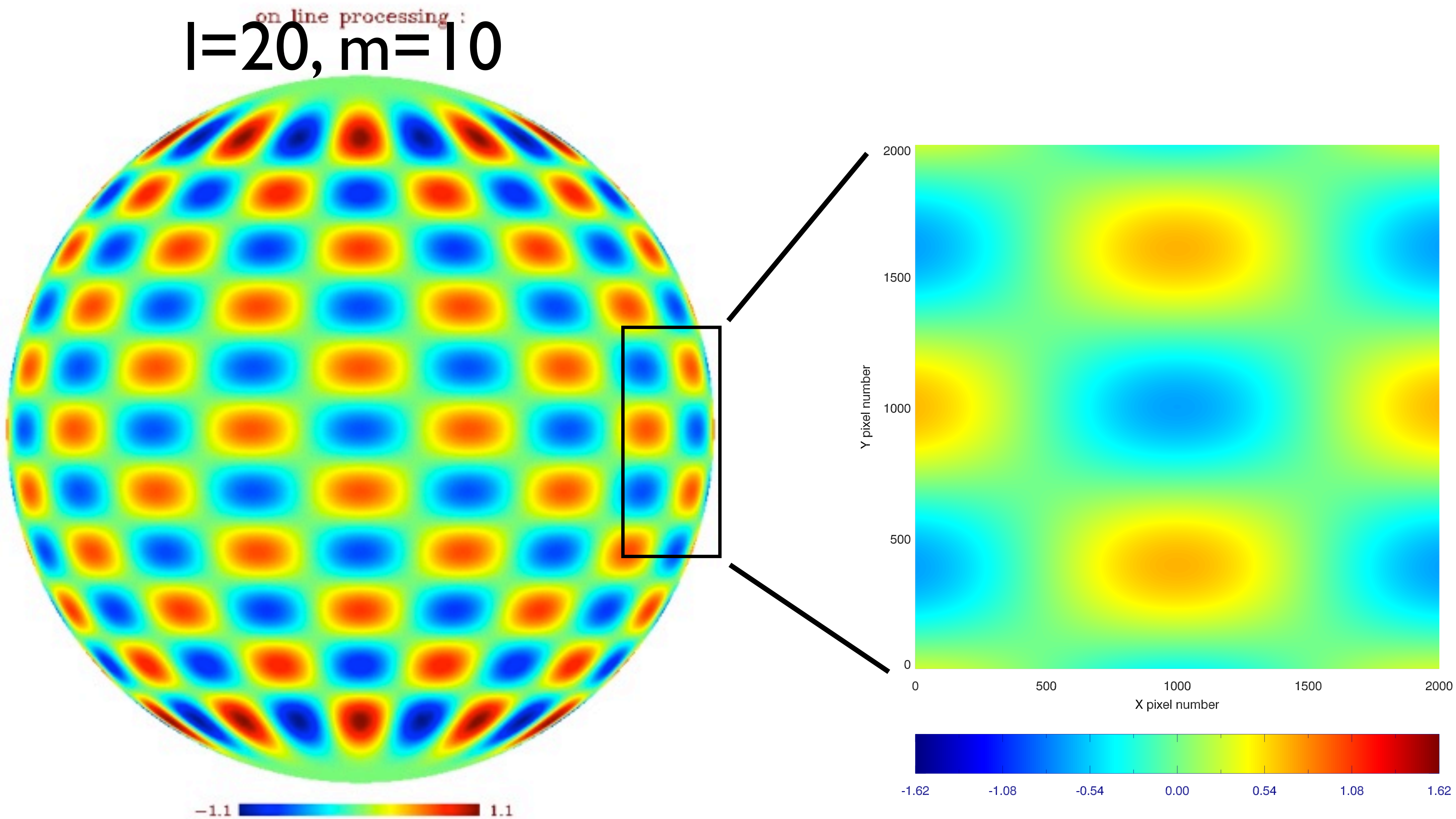
$$(1-\cancel{x^2})\,y'' - 2\cancel{x}y' + \left(\ell[\ell+1] - \frac{m^2}{1-\cancel{x^2}}\right) y = 0,$$

Harmonic Oscillator with ***k=l(l+1)-m²***

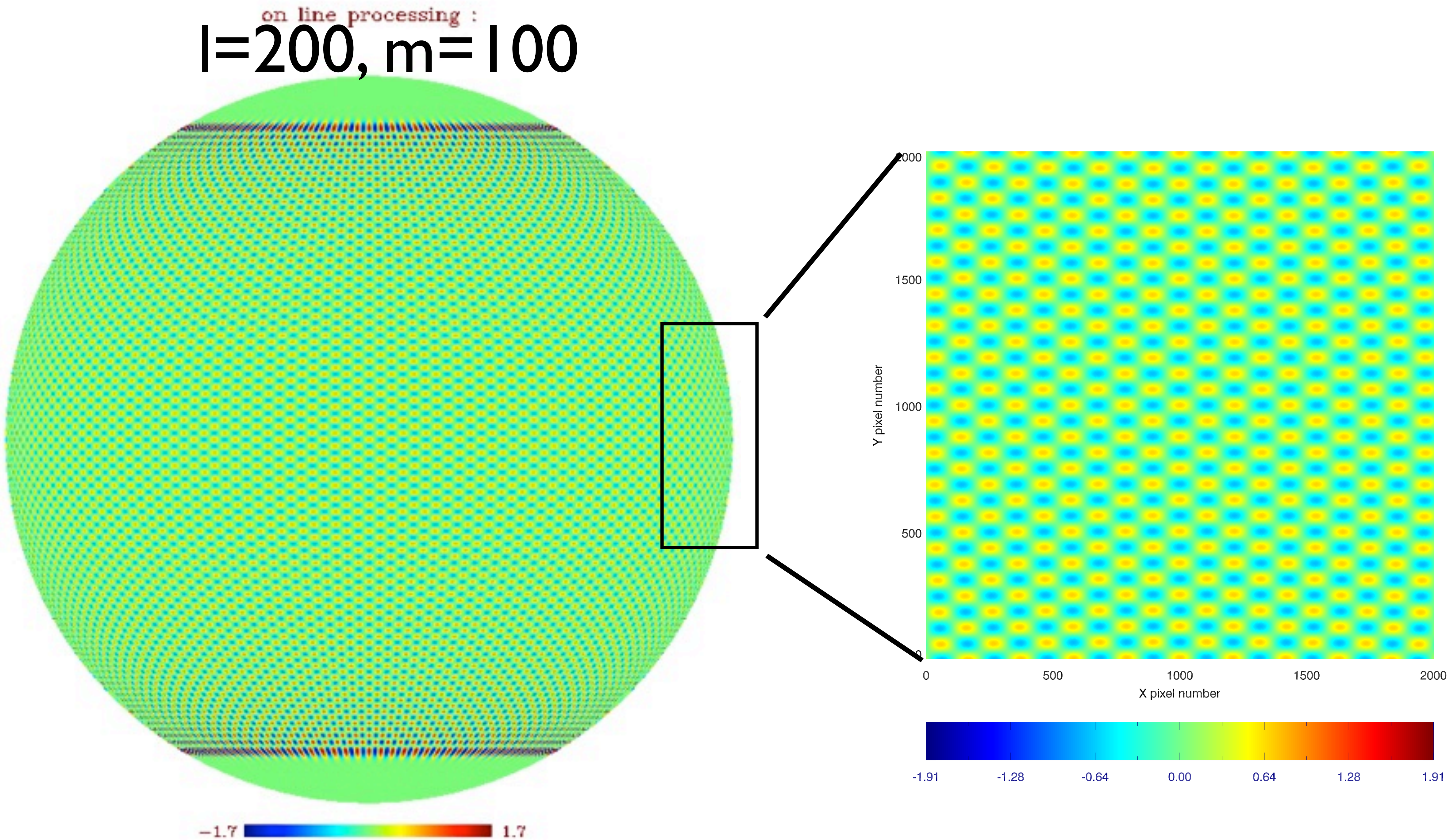
(Fourier modes!)

Projecting a_{lm}

$l=20$, $m=10$

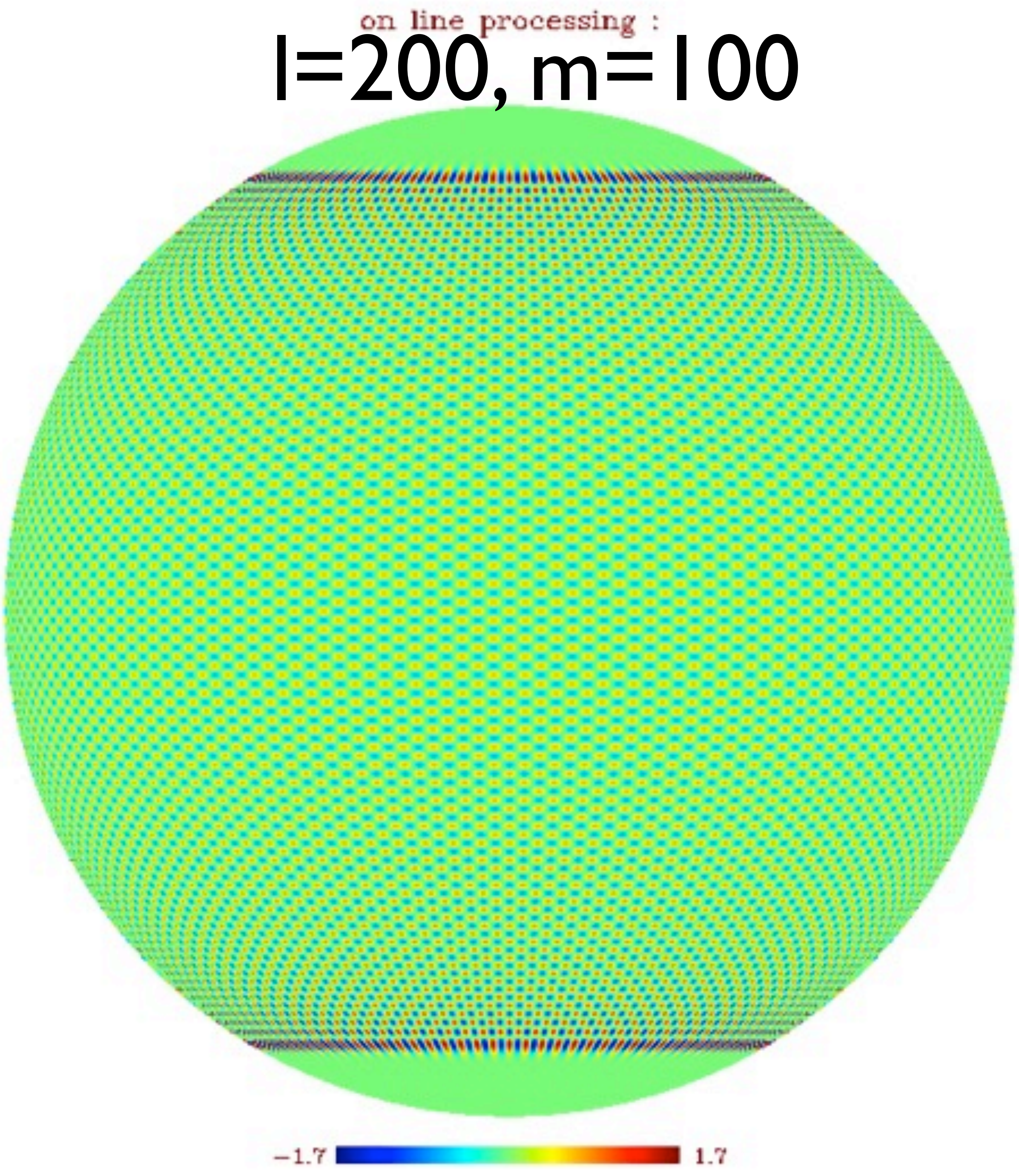


Projecting a_{lm}

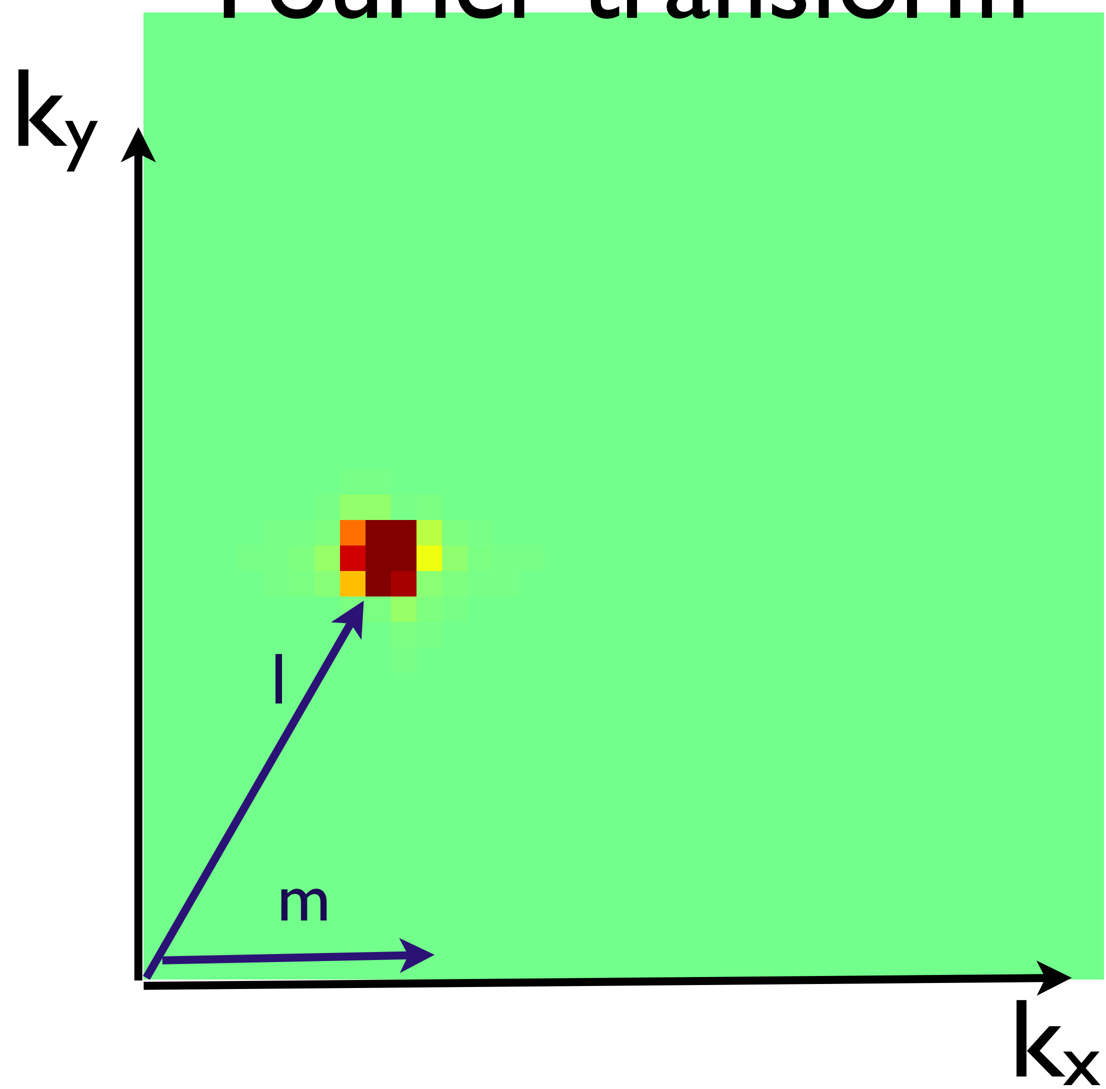


Projecting a_{lm}

l=200, m=100



Fourier transform



“Flat Sky” vs multipoles

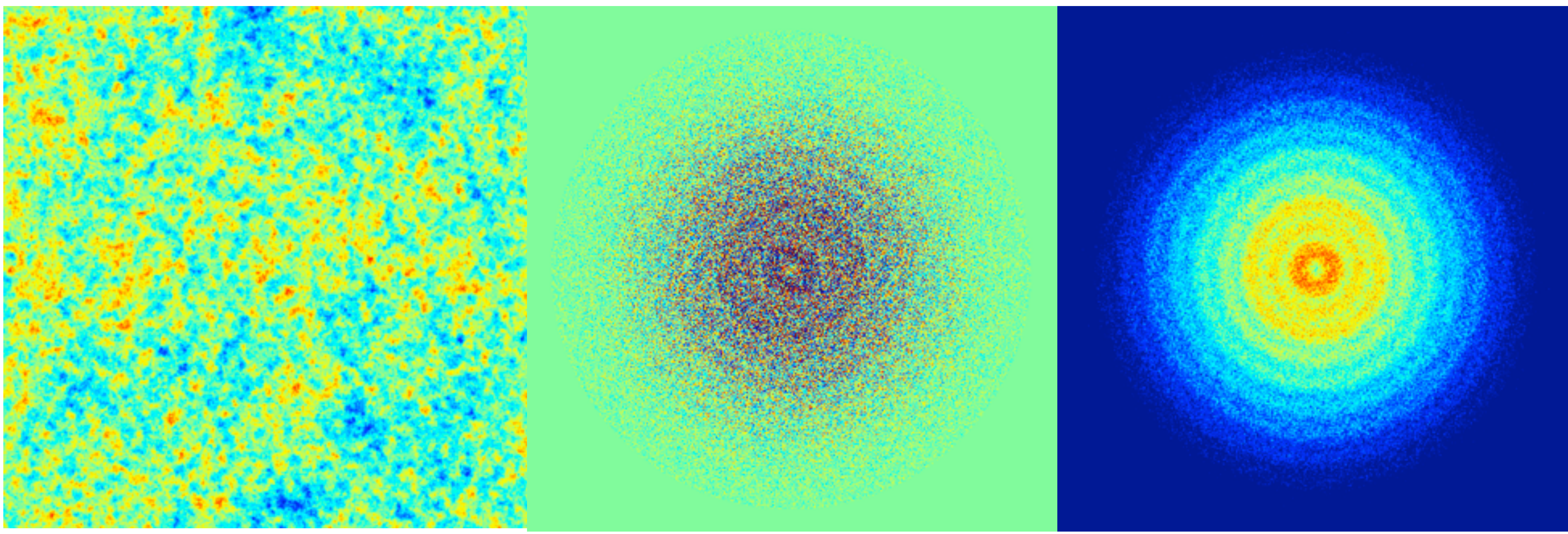
- for chunk of map extracted at equator, the two are basically identical for all but the largest angles (l<30)
- choice of pole shouldn’t matter (statistical isotropy), so Fourier or multipole, up to you
- $l \sim 21600\, k_{\varphi}(\mathrm{arcmin}^{-1})$

Power spectrum Uncertainties

- fundamentally limited by number of independent measurements, noise
- $C_{l;meas}=C_{l;true}+C_{l;noise}$ *in any single map you can't tell the difference*
- $Var(C_l) \sim 2/n_{meas} C_l^2$ ***"sample variance"***
- more modes means better measurement of $C_{l;true}+C_{l;noise}$
- lower noise gives better measure of $C_{l;true}$

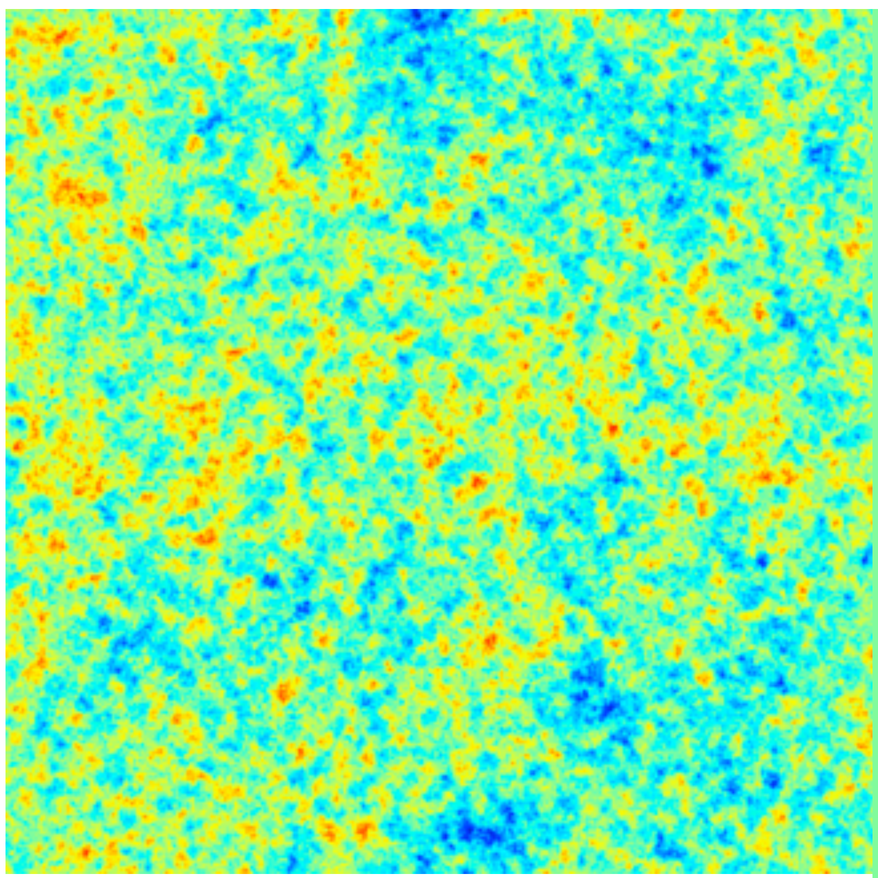
Simulated CMB

Map | Real part of FFT | $\log_{10}(|\mathrm{FFT}|^2)$

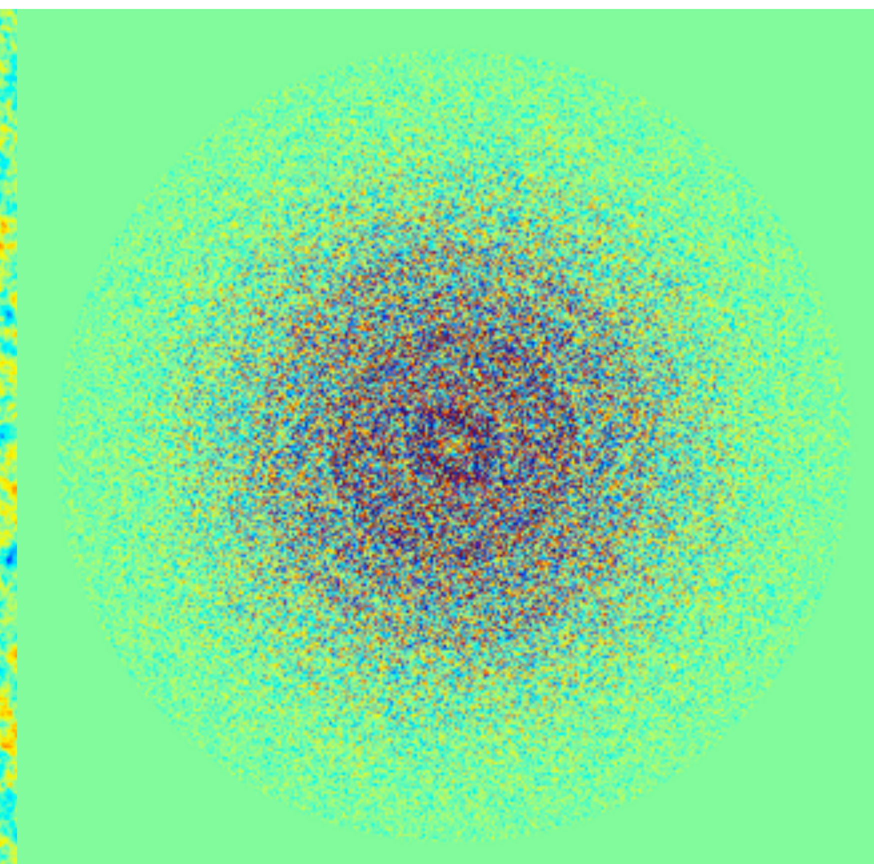


Simulated CMB

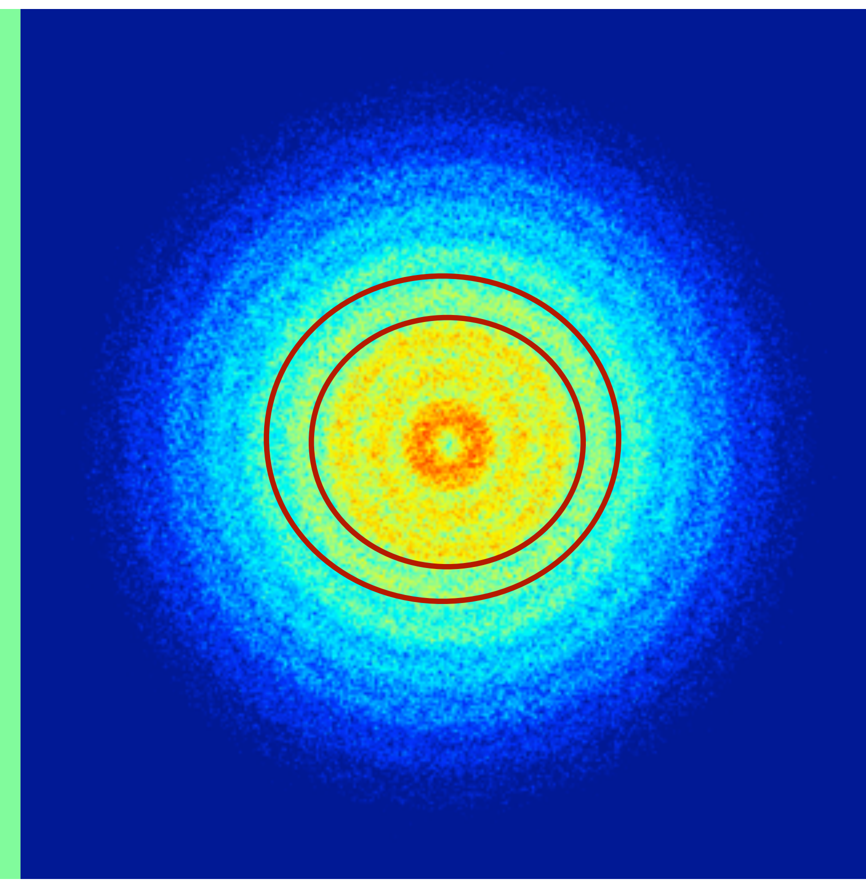
Map



Real part of FFT

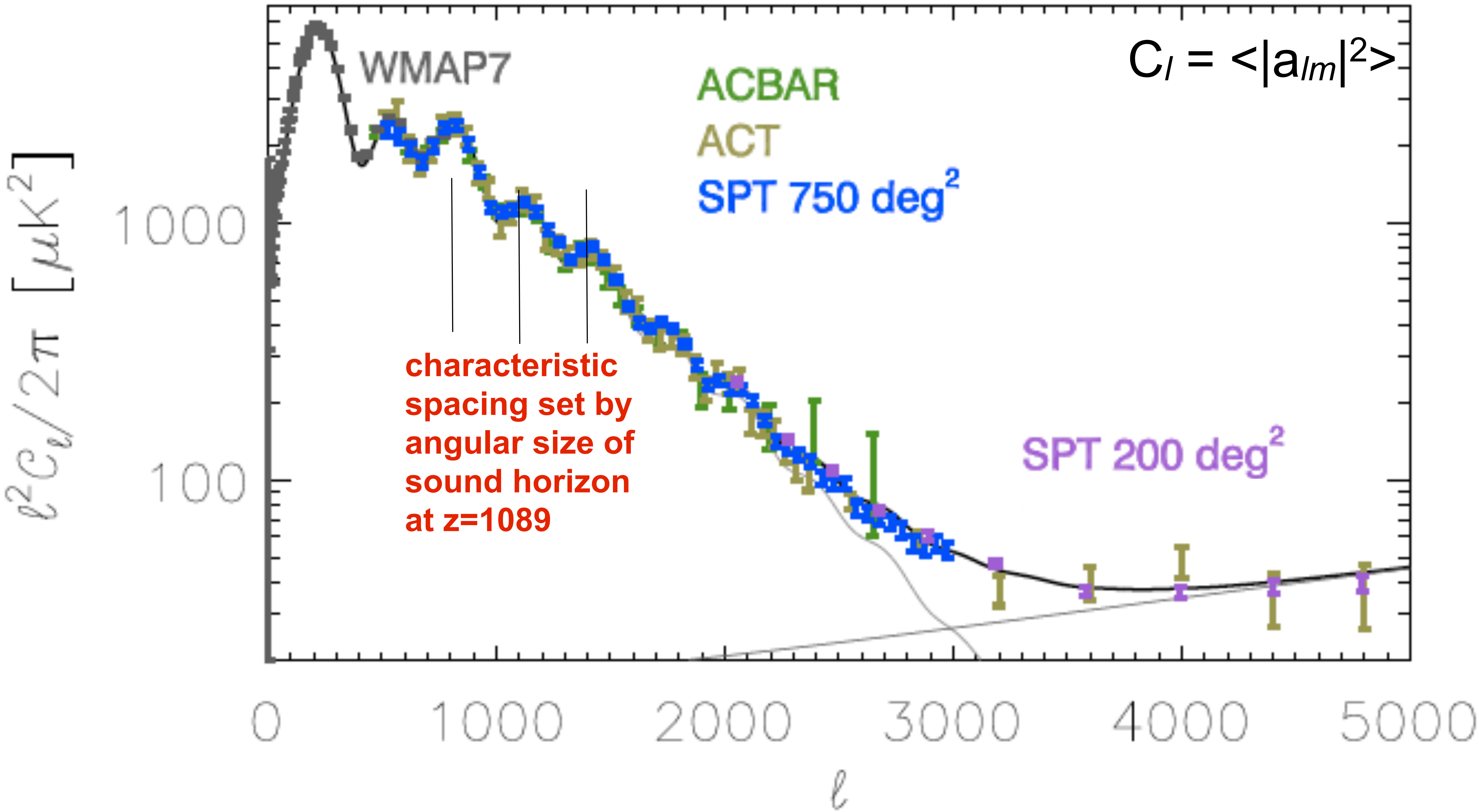


$\log_{10}(|FFT|^2)$



# of independent samples set by map size

CMB Power Spectrum



Cross Spectra

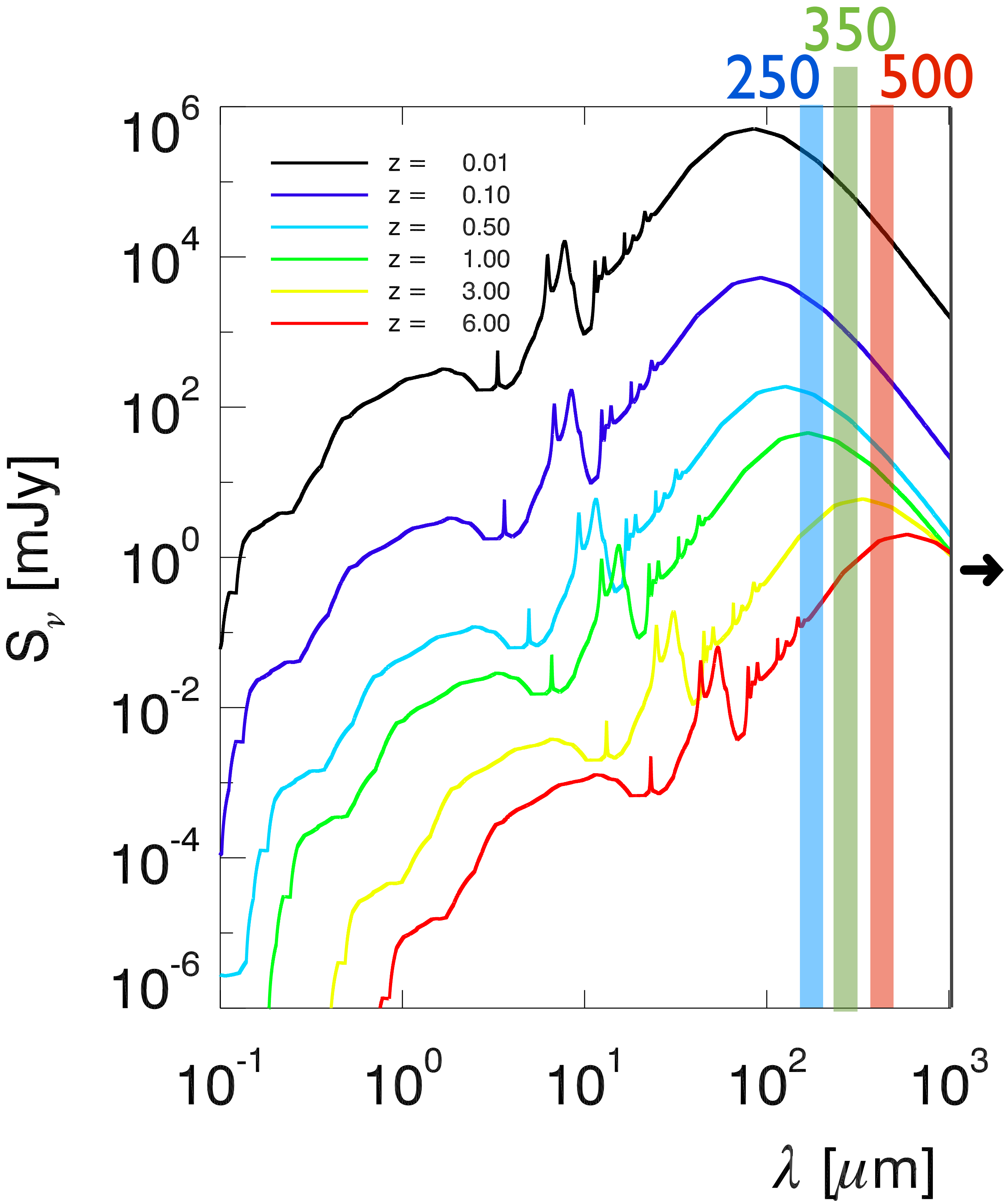
all quantities are Fourier space!

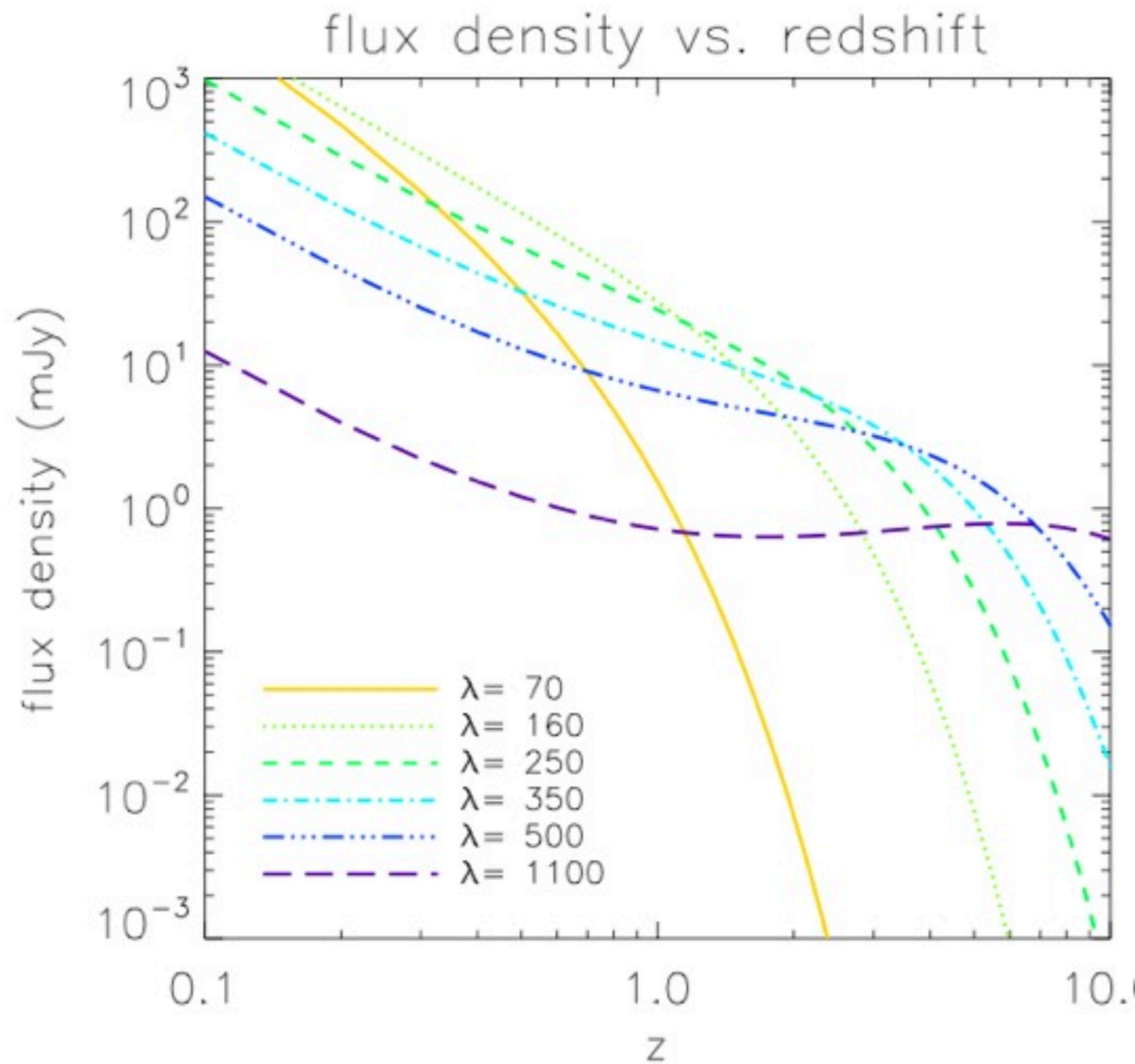
- $T_m=T+n$
- $<T_{1;m}\,T_{2;m}>=<T_1 T_2>+<n_1 n_2>+\cancel{<T_1 n_2+T_2 n_1)>}$
- for $1=2$ (map auto power spectrum), $<n_1 n_2>=\sigma^2$
- if $1\neq 2$, $<n_1 n_2>=0$, so no bias
- quirks in your noise model don't affect cross spectrum!

Cross-Spectra in Action

- if you have mapped a field 2 times, you can combine them: $T=(T_1+T_2)$
- the autospectrum of T is $\sim T_1T_1+T_2T_2+2T_1T_2$
- but $T_1T_1+T_2T_2$ have noise bias, so with a hit in sensitivity you can ignore these
- in the limit of large number of maps, hit in sensitivity goes to 0 while robust against problems of not knowing your detector noise

Multi-frequency is good!

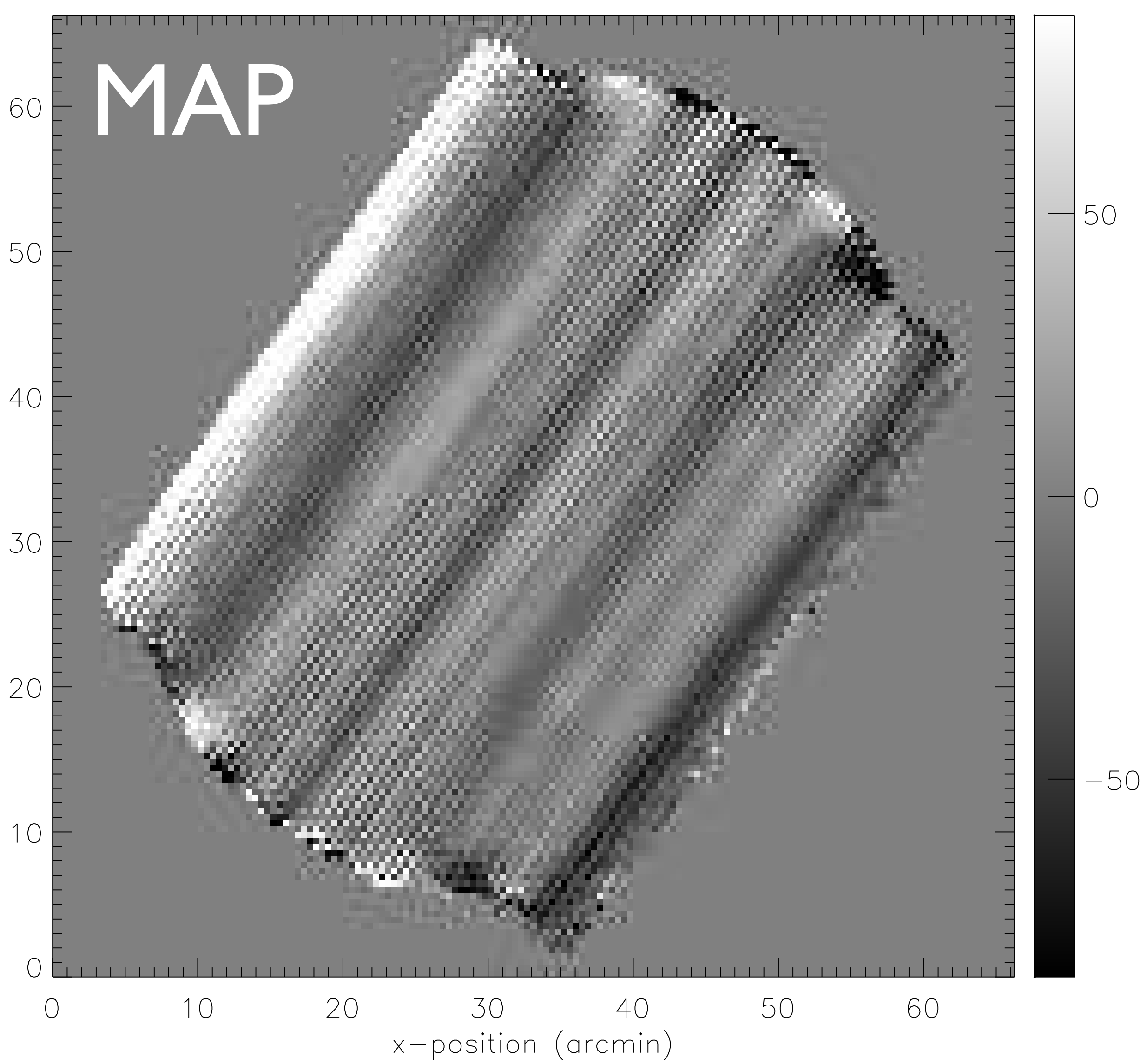


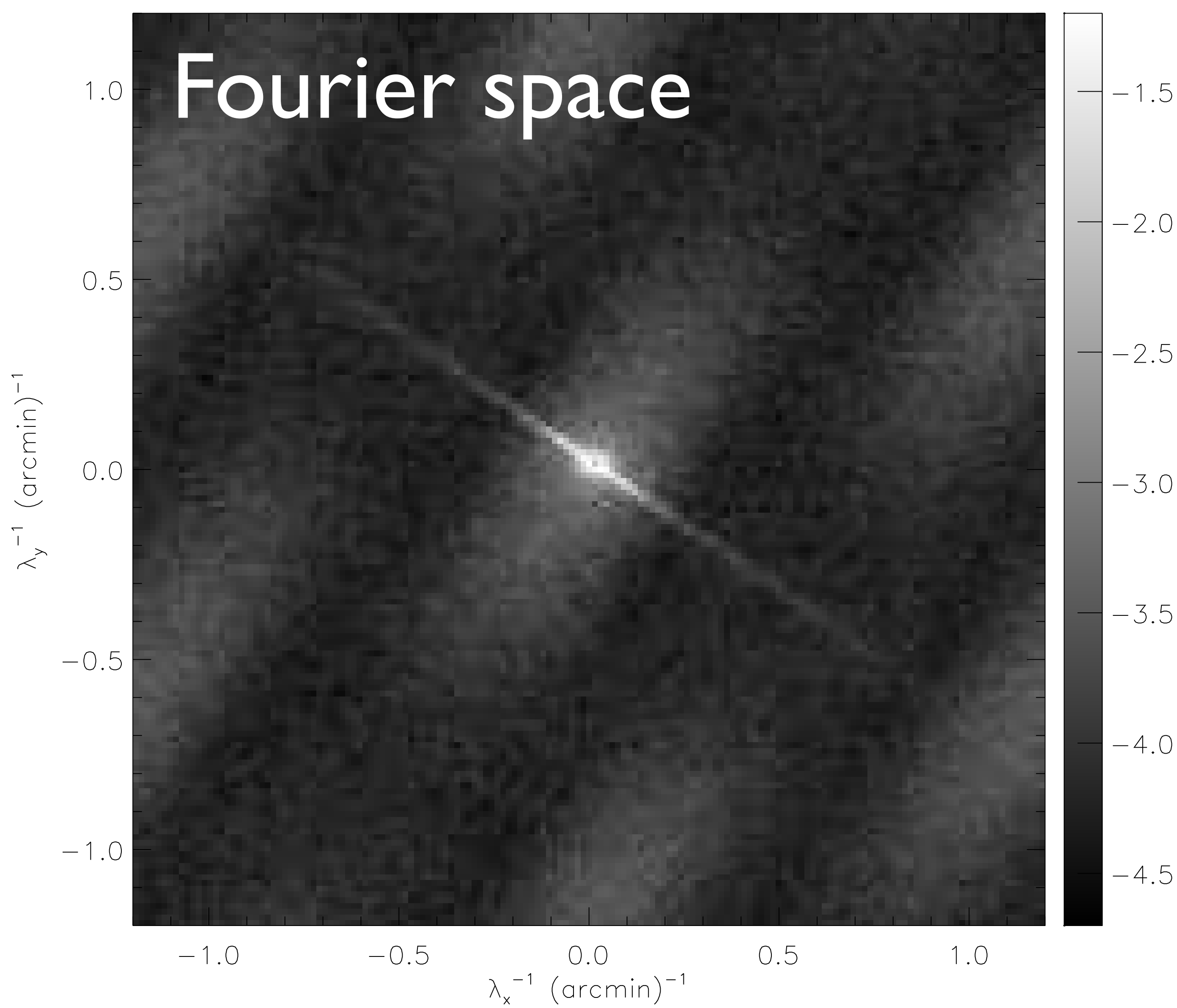


negative *K*-correction

M.Viero

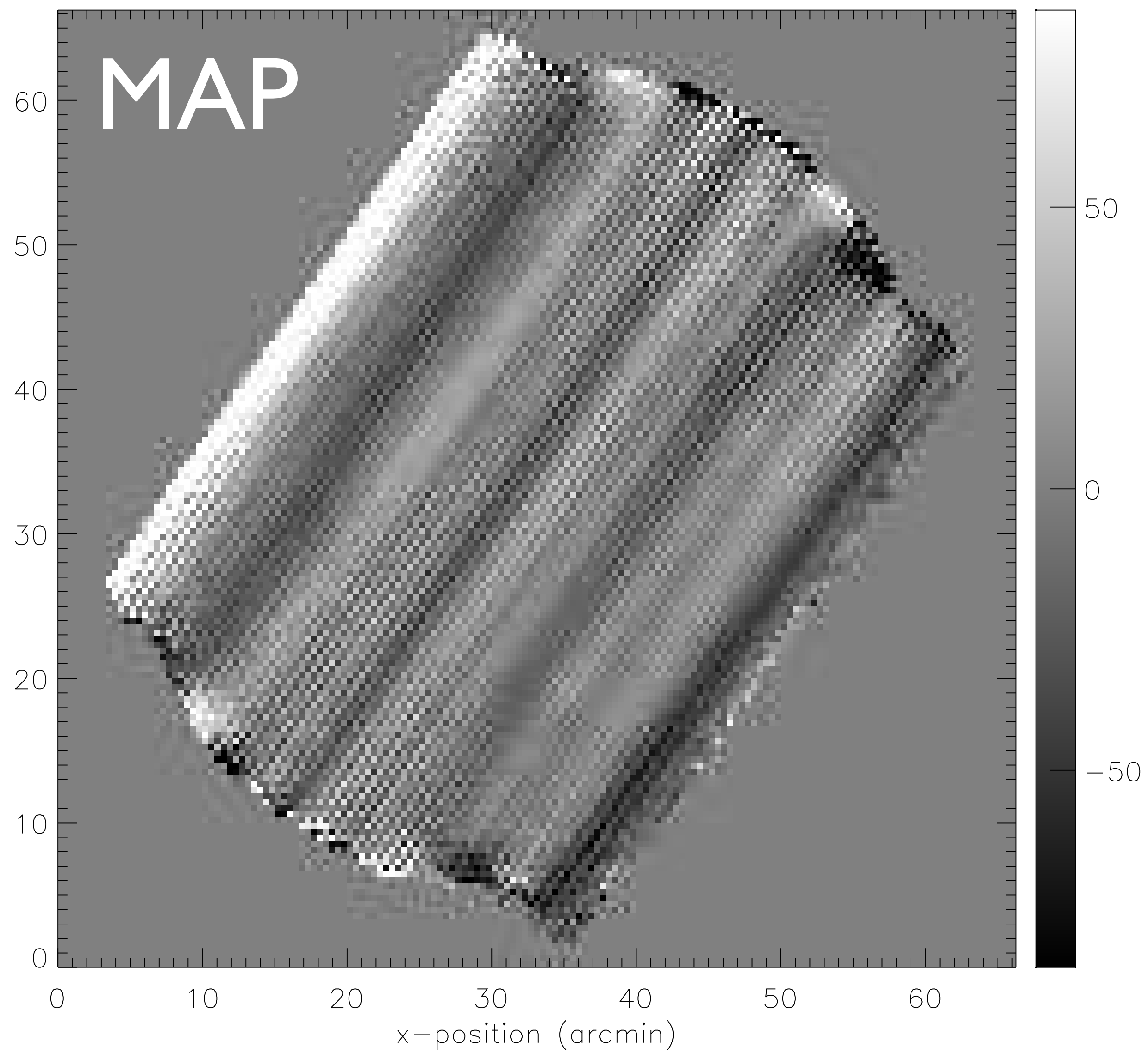
Power Spectra: Anisotropic Noise

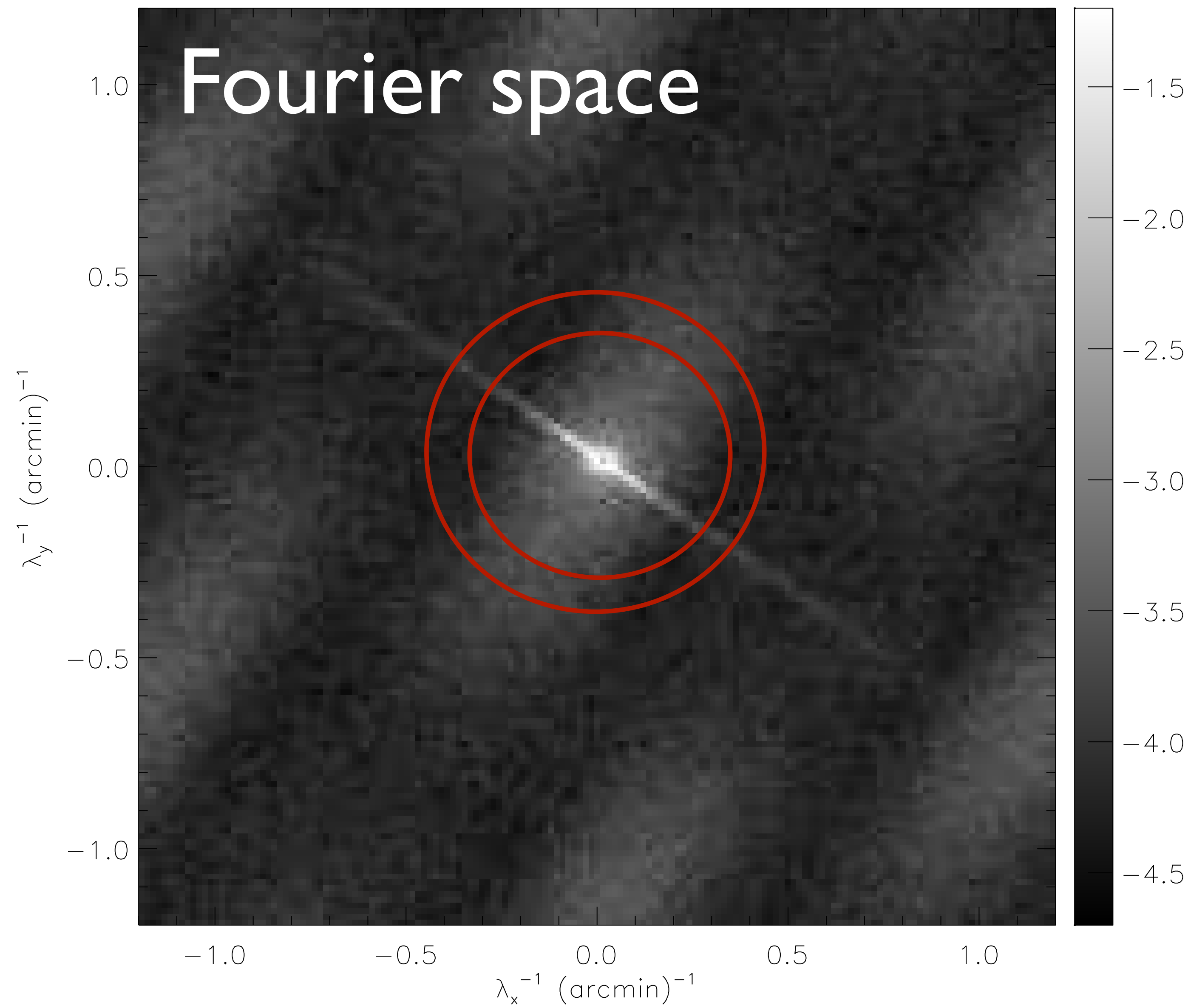




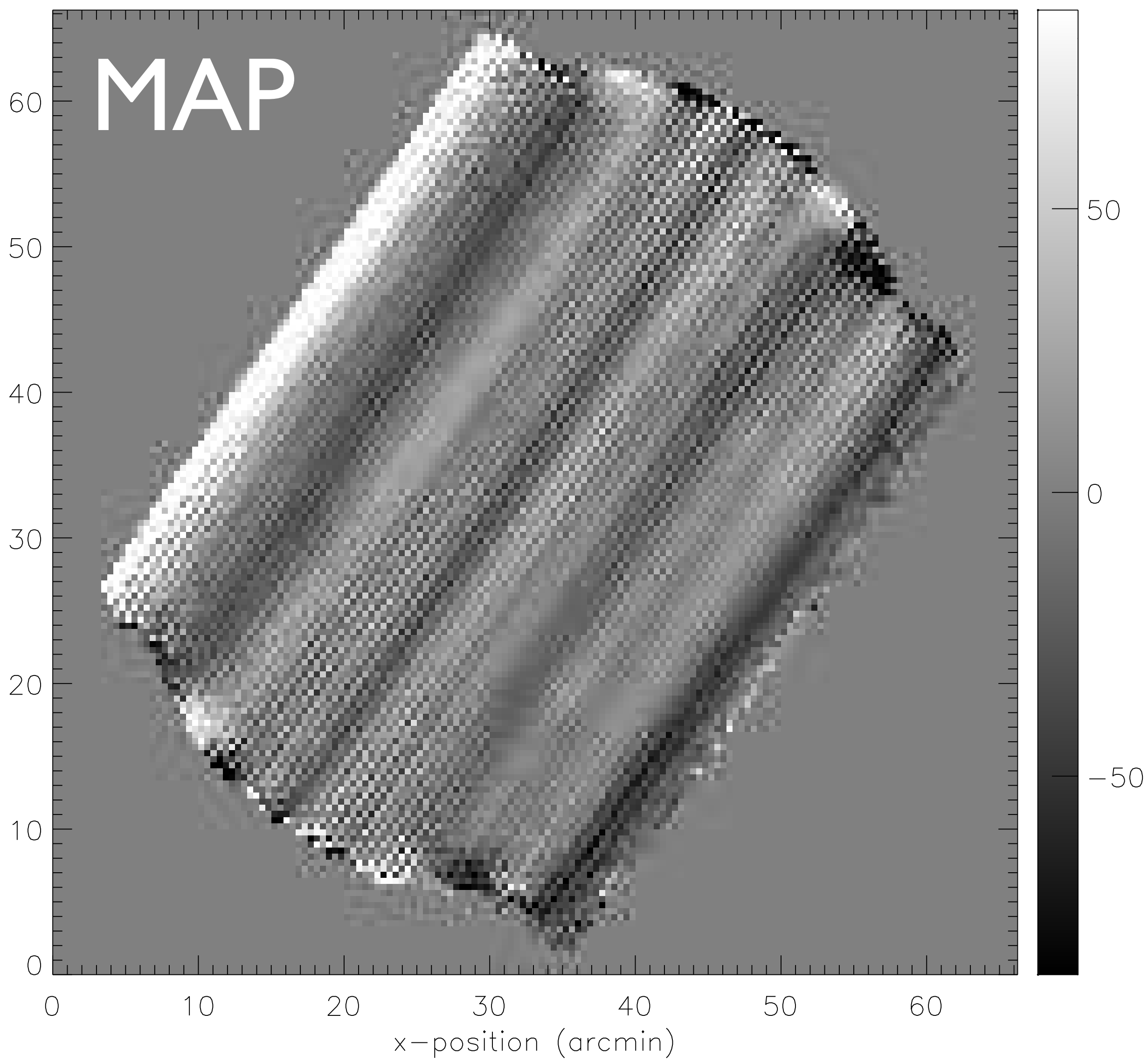
simulated BLAST noise map; Patanchon et al 0711.3463

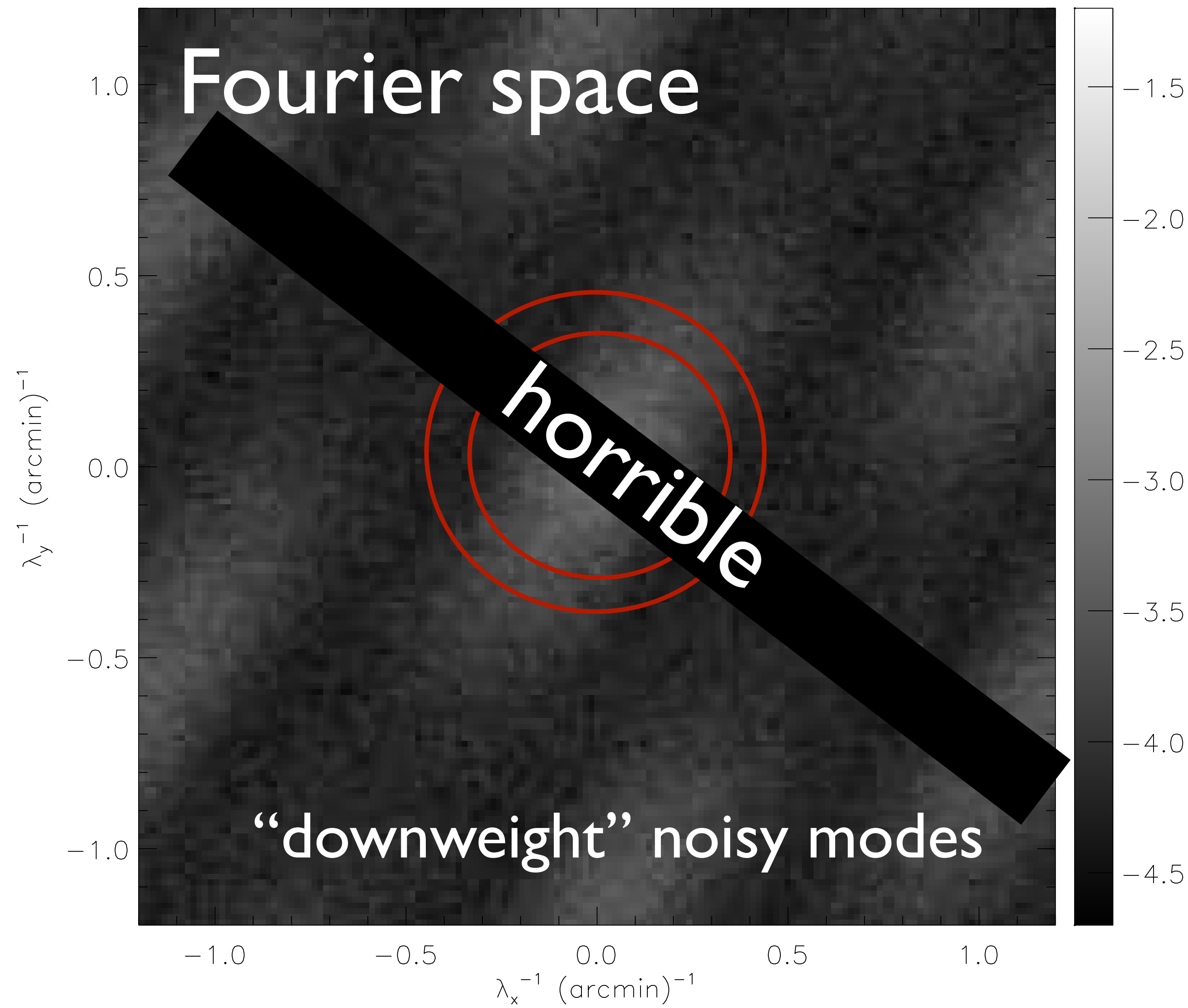
Power Spectra: Anisotropic Noise





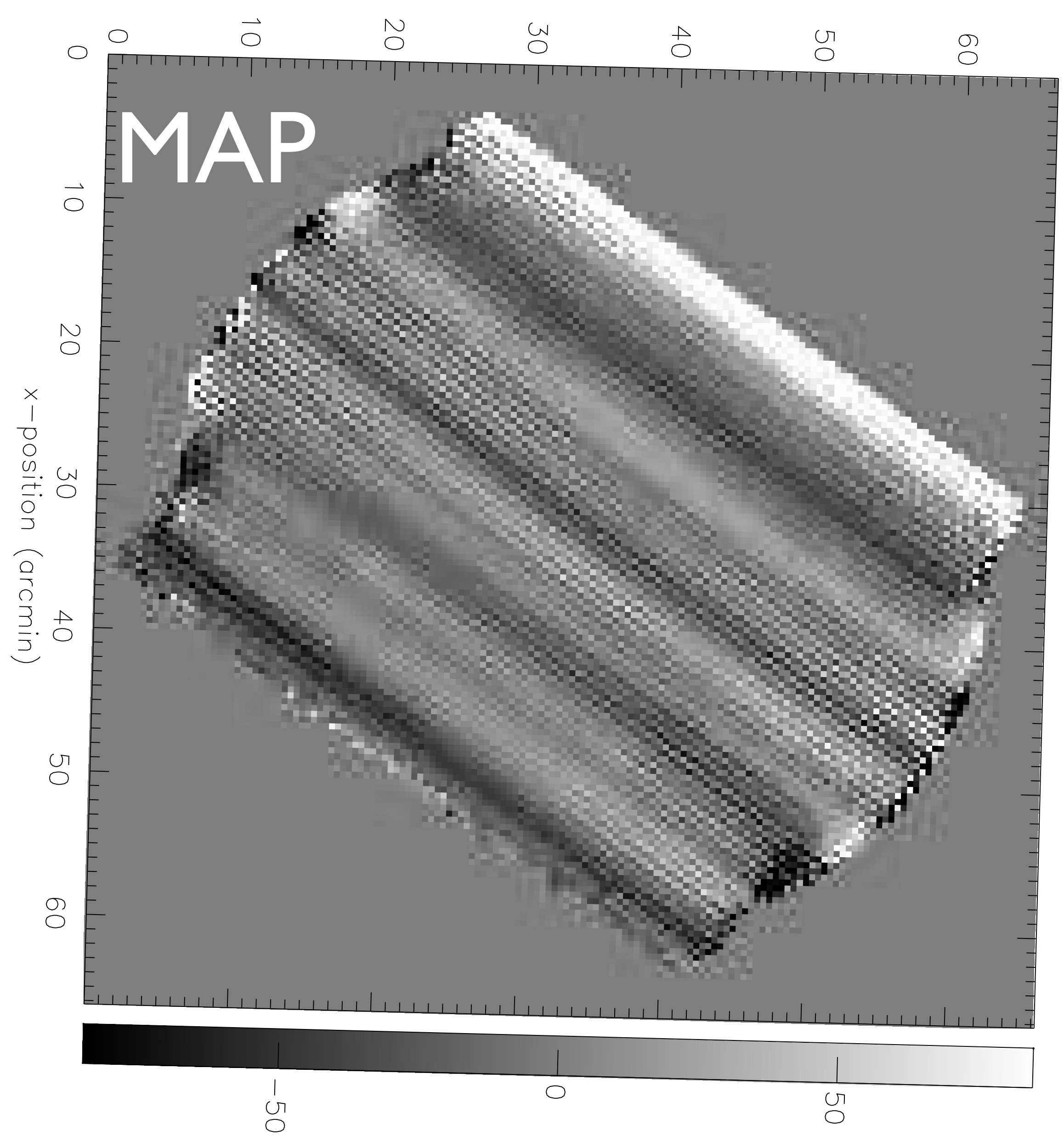
Power Spectra: Anisotropic Noise

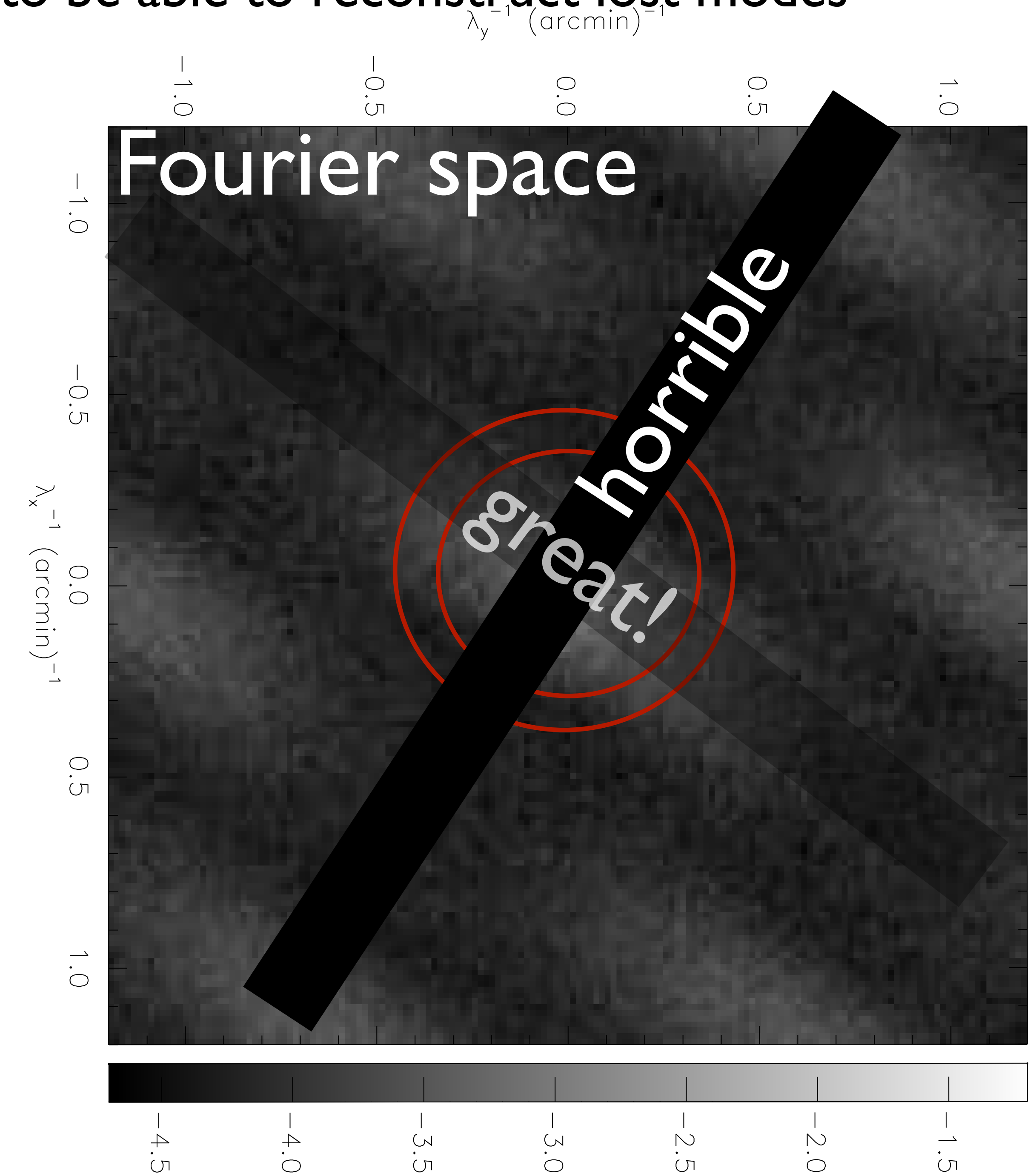




Cross Linking

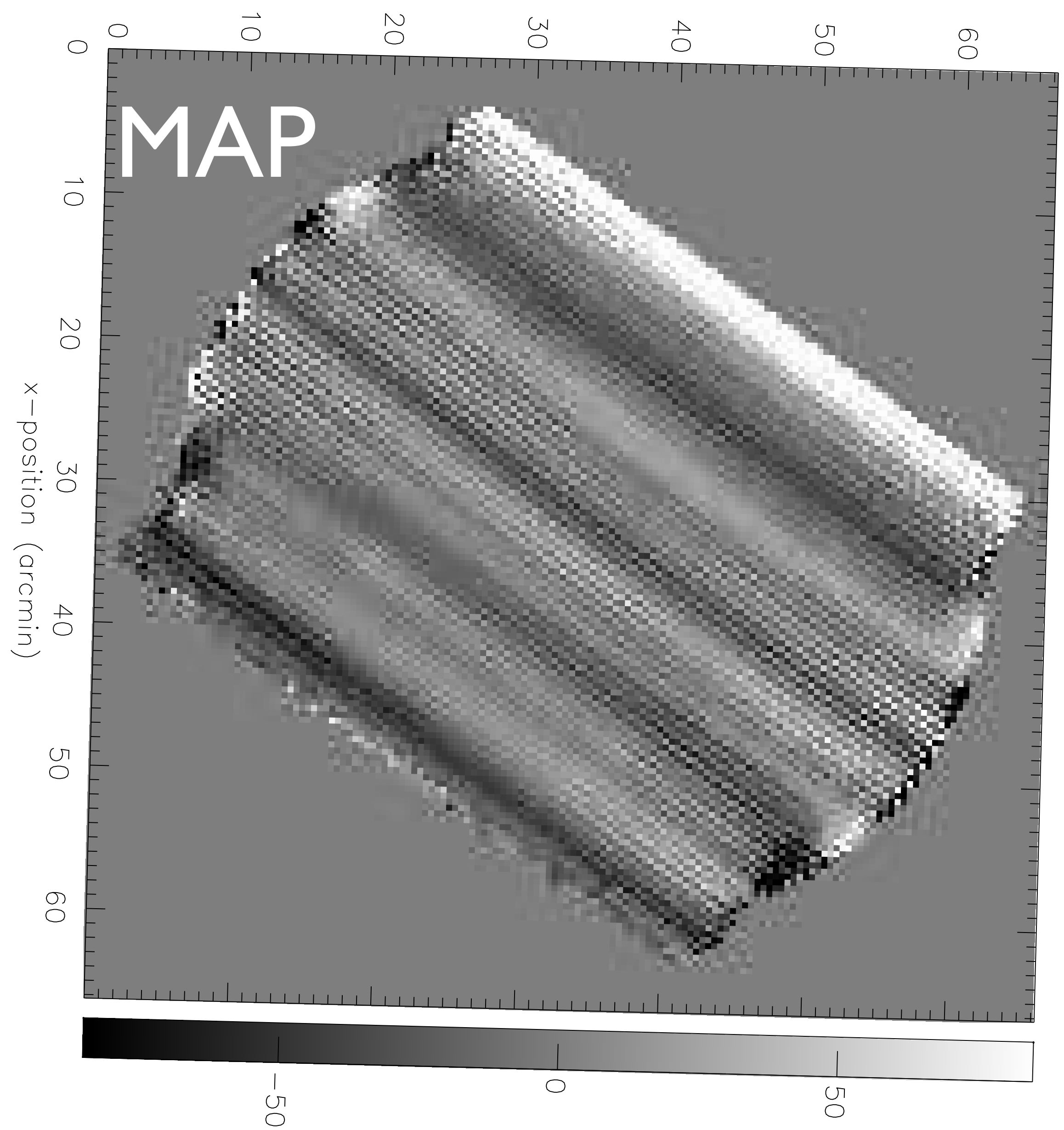
Make a map with artifact at different angle to be able to reconstruct lost modes

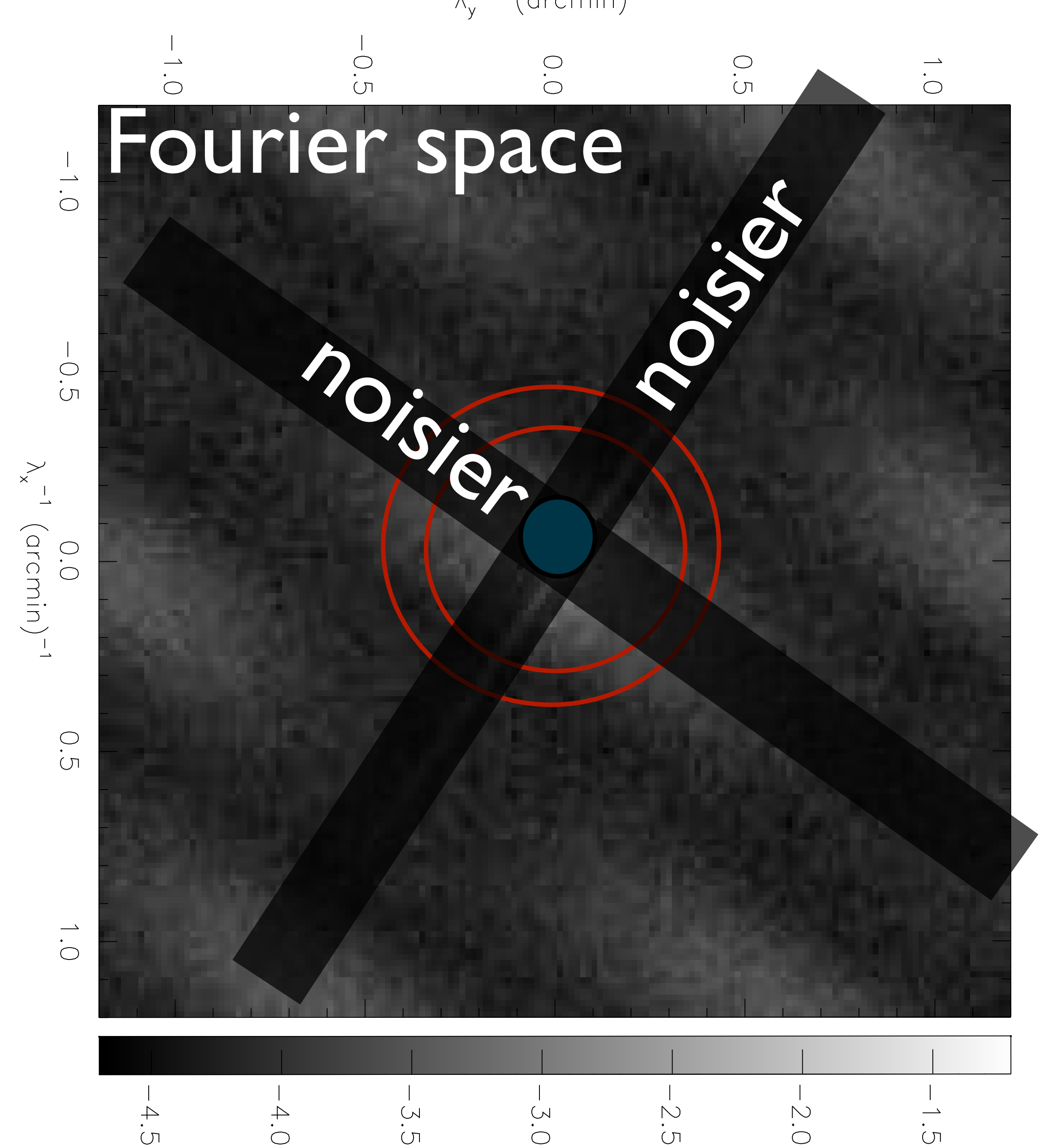




Cross Linking

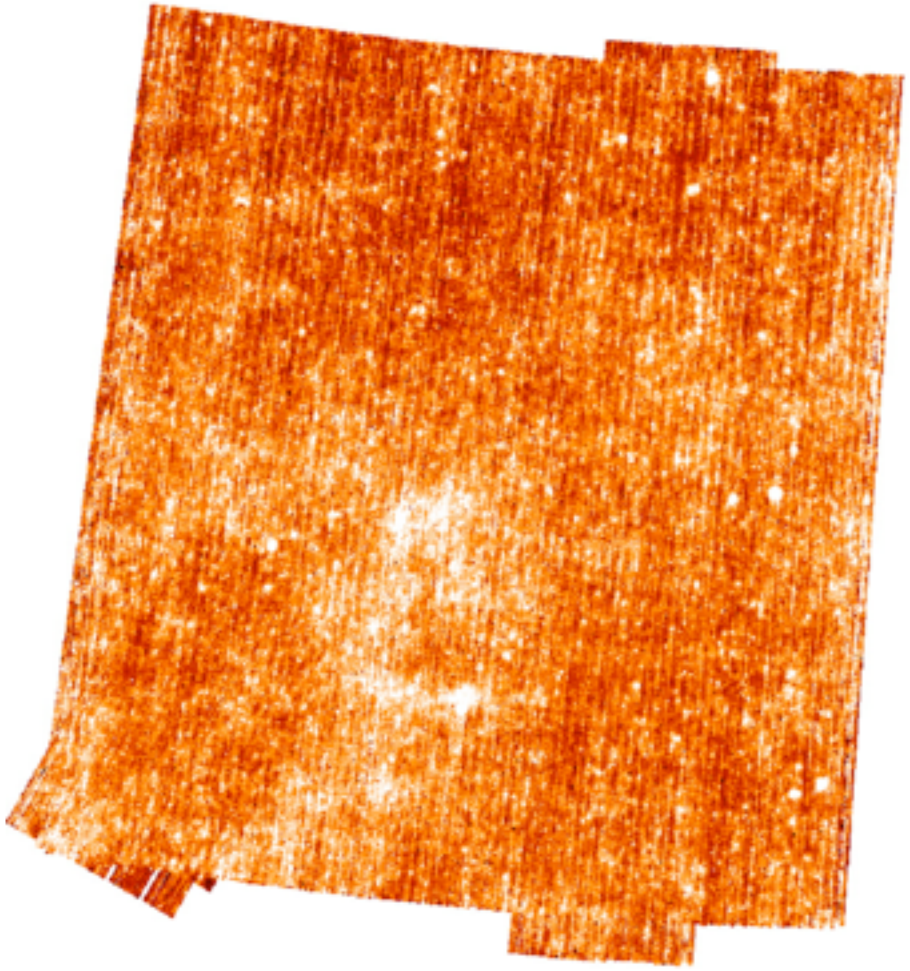
Drawback: you now have 2N sort of noisy modes instead of N horrible ones





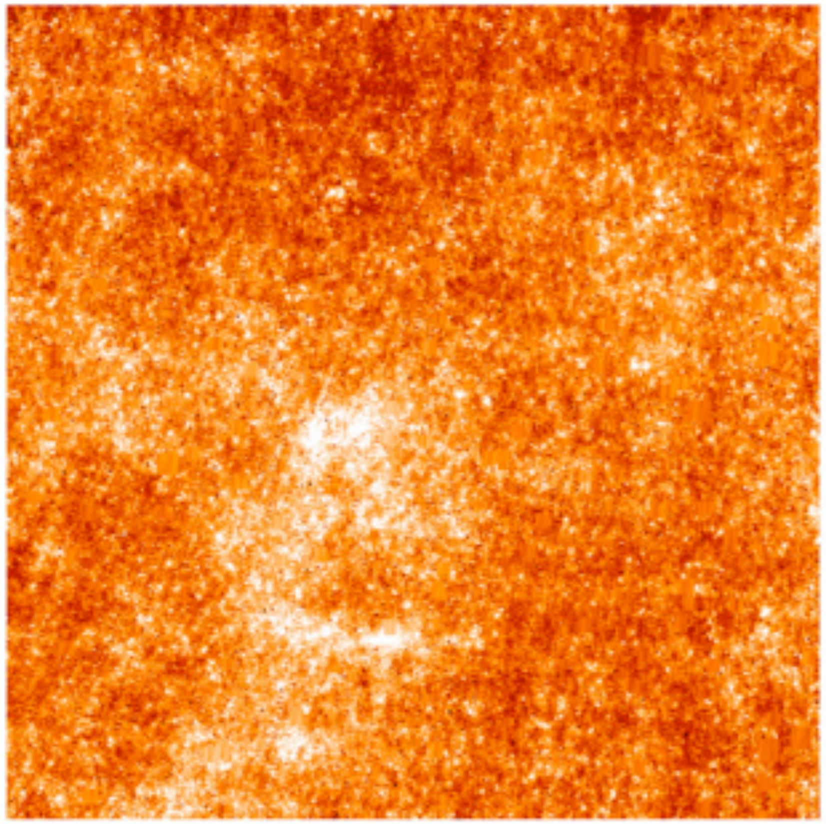
160 um Maps

"standard" reduction



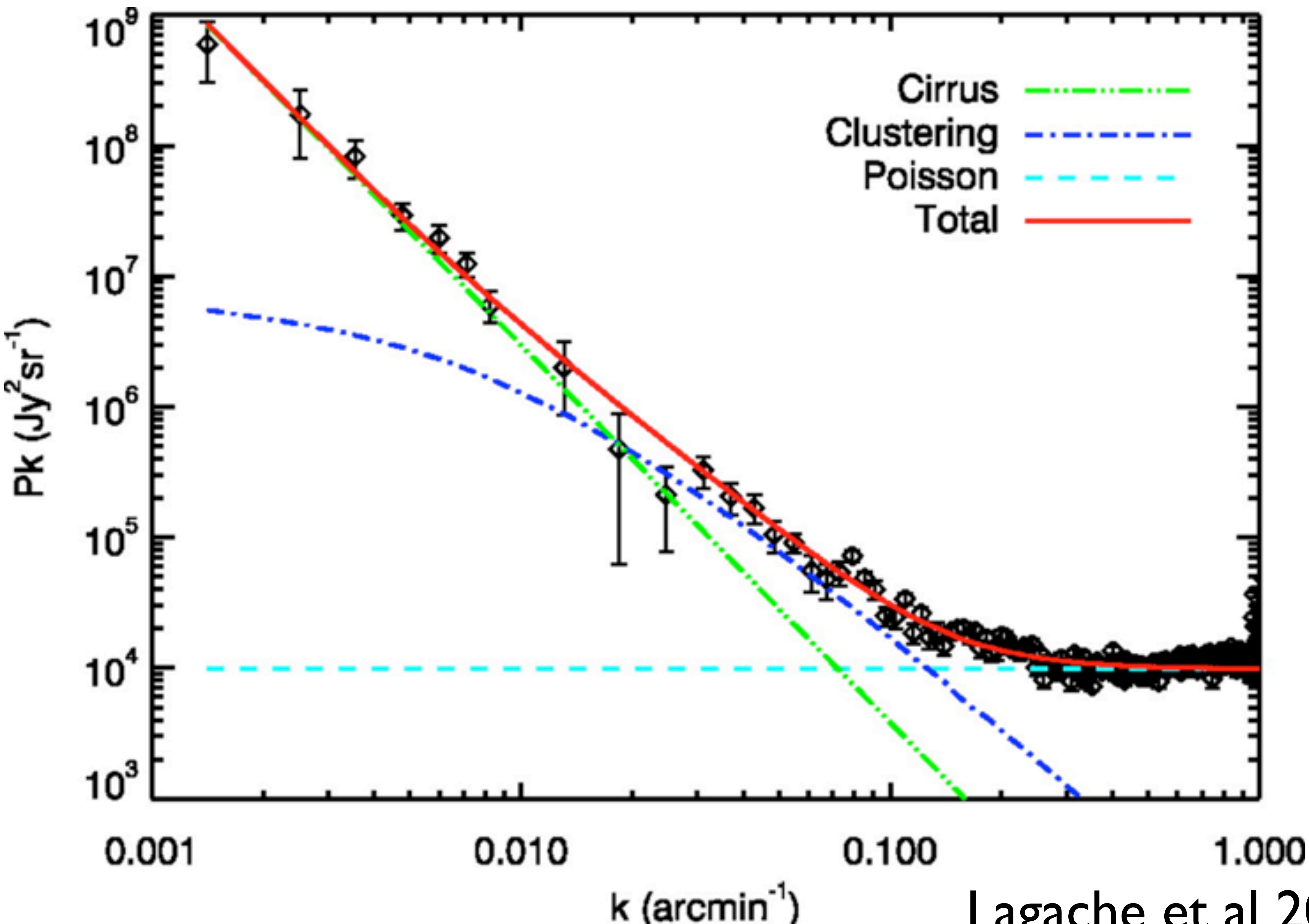
10 deg^2
with
Spitzer

corrected map



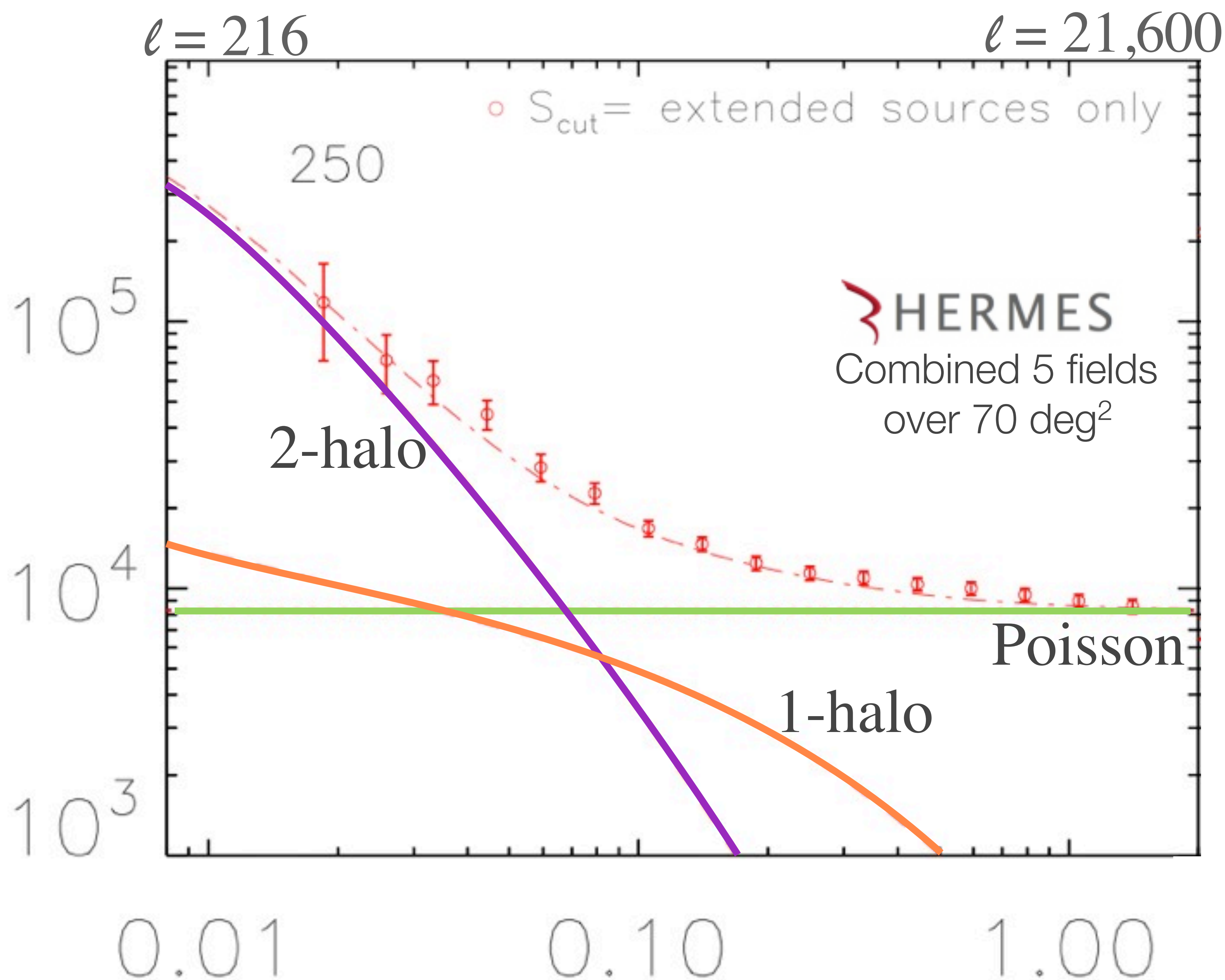
Lagache et al 2007

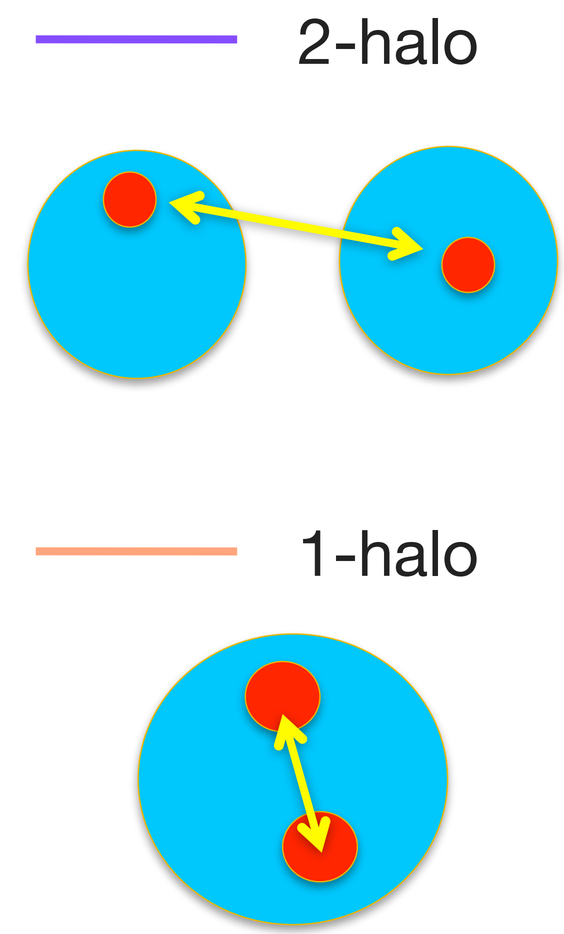
160 um Power Spectrum



Lagache et al 2007

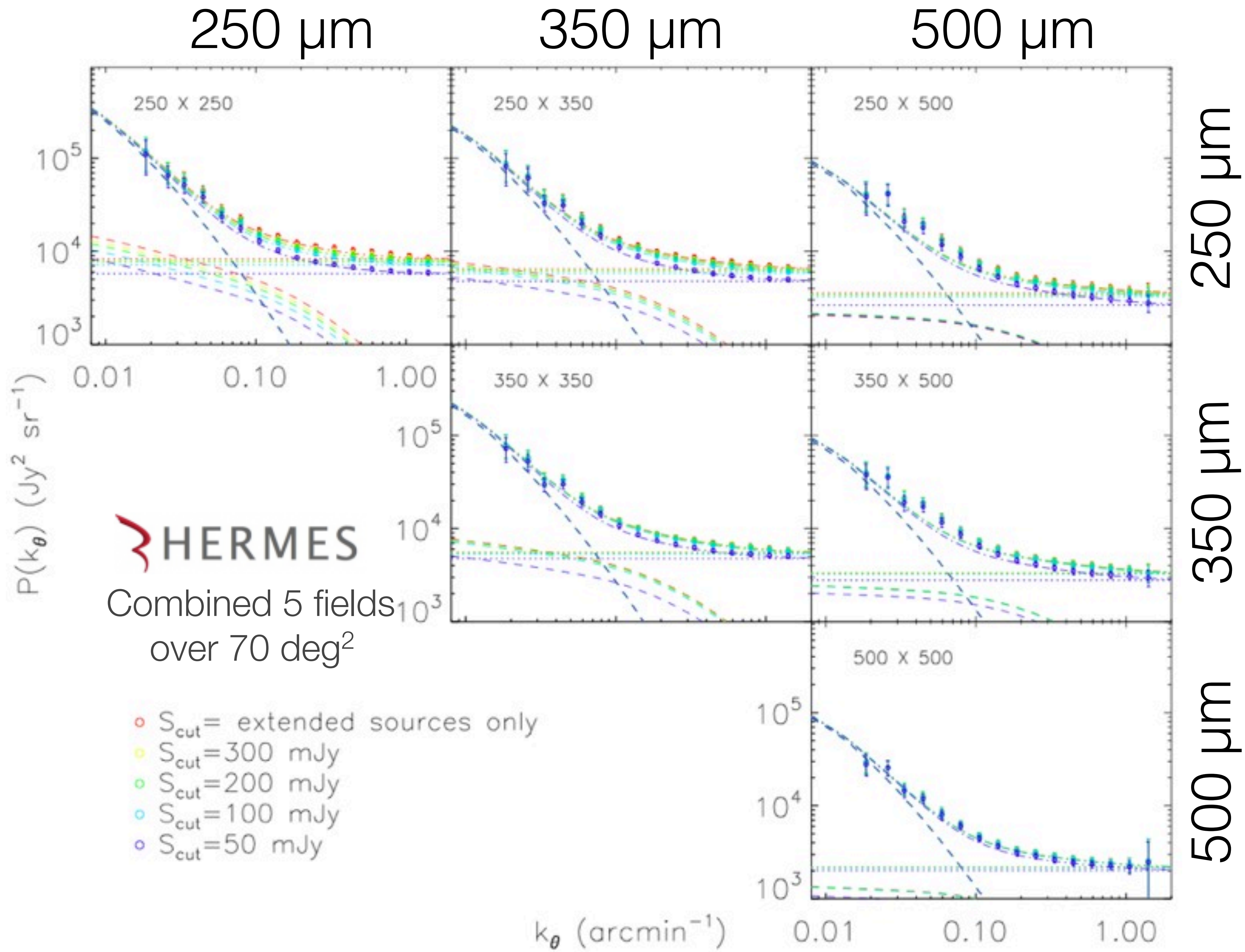
HerMES power spectra





Viero & Wang et al. (2012b)
arXiv: 1208.5049

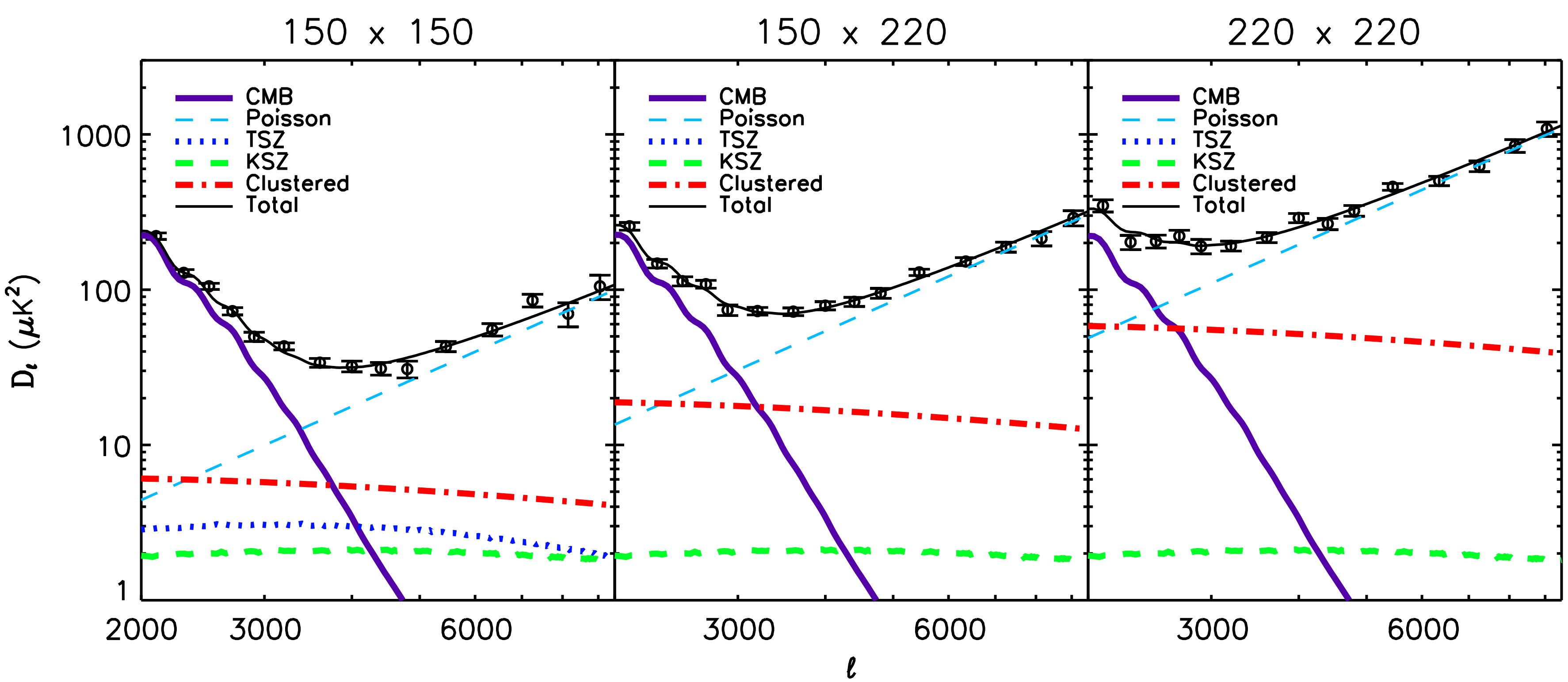
HerMES power spectra

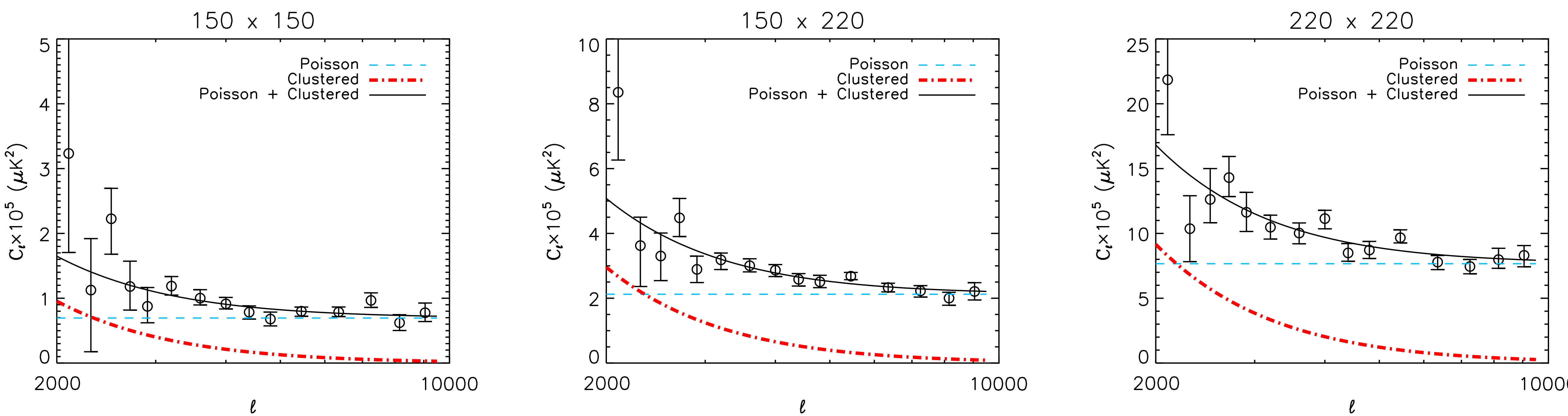


M.Viero

Viero & Wang et al. (2012b) arXiv: 1208.5049

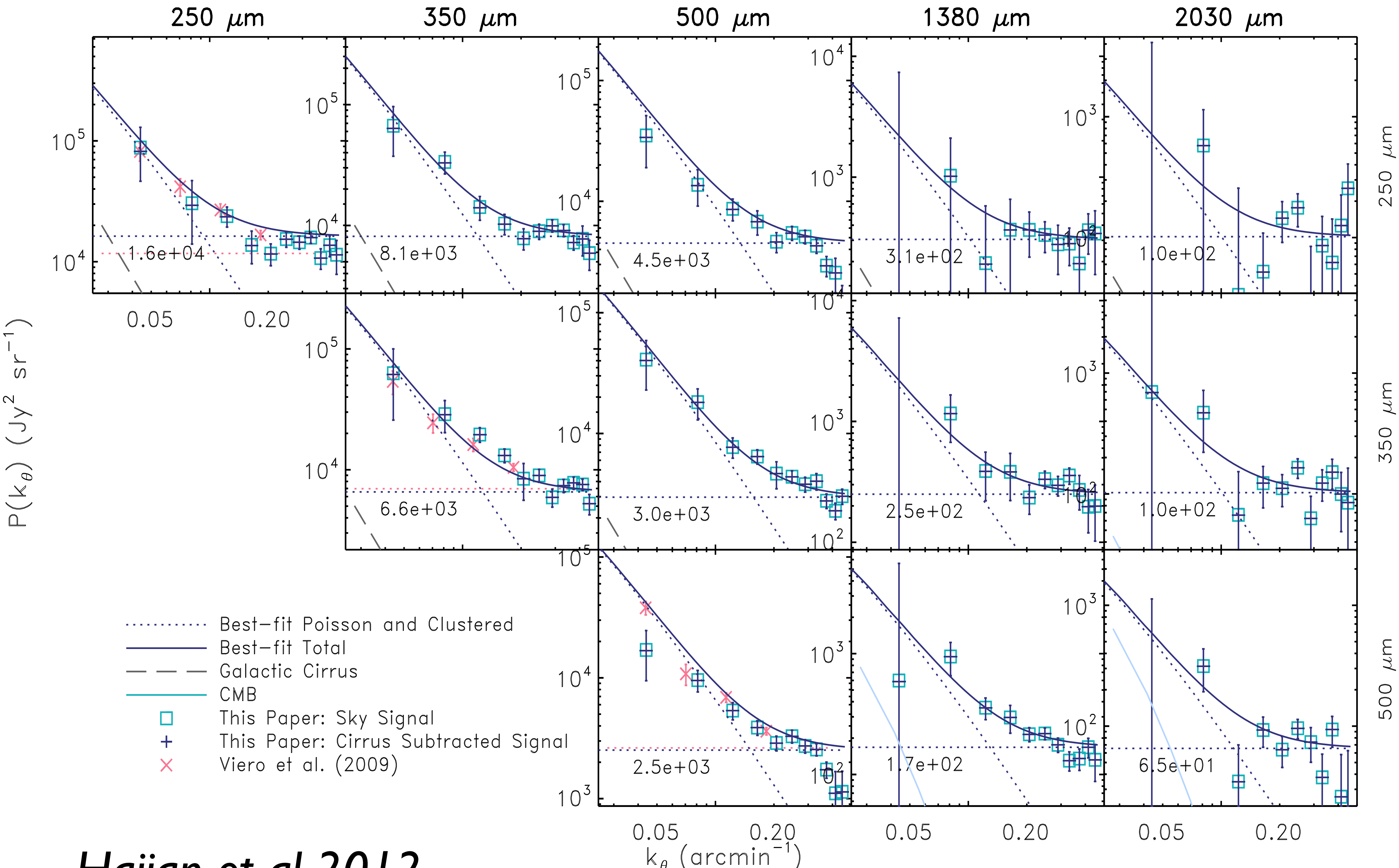
SPT CIB Detection





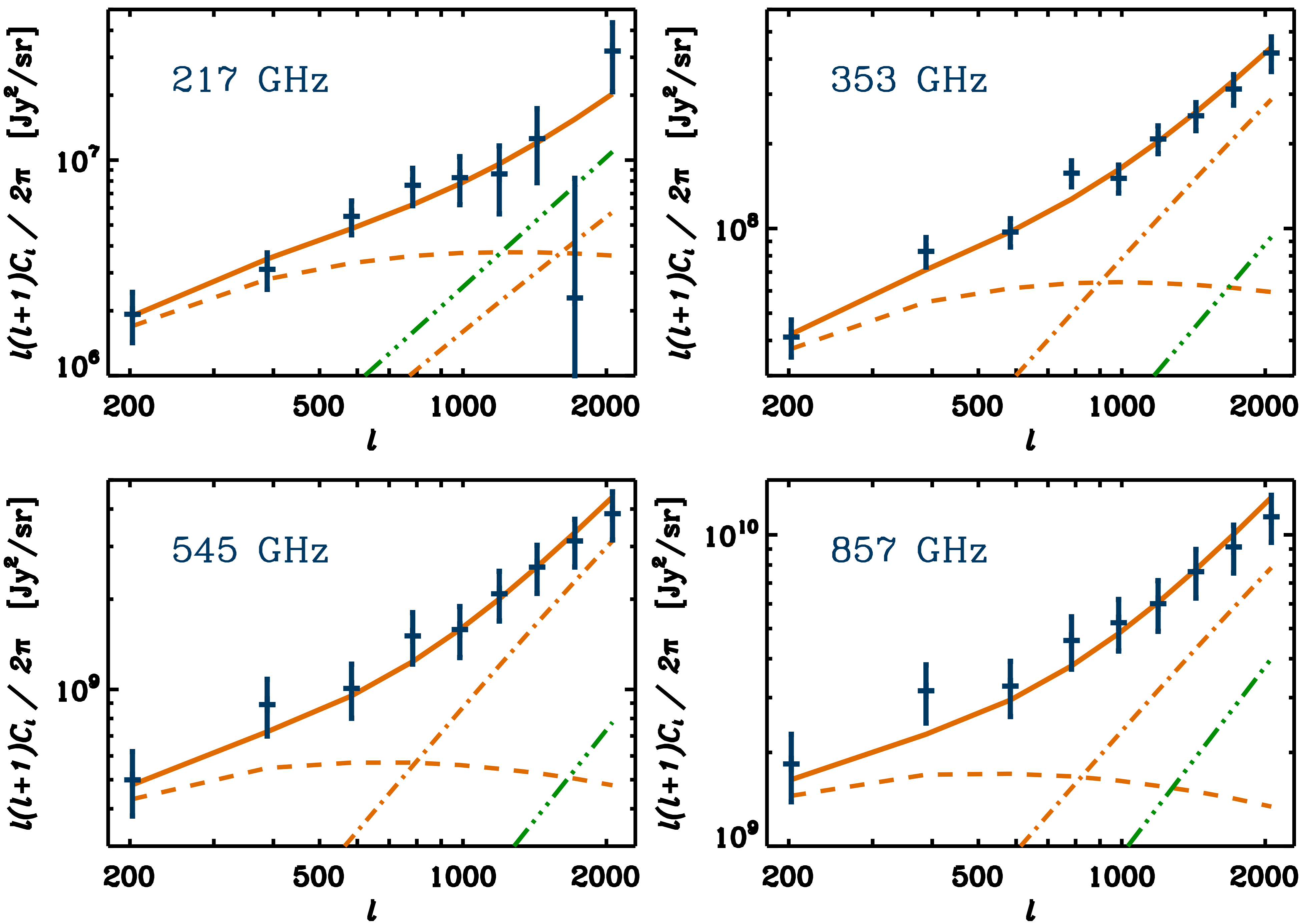
Hall et al 2010

ACT X BLAST



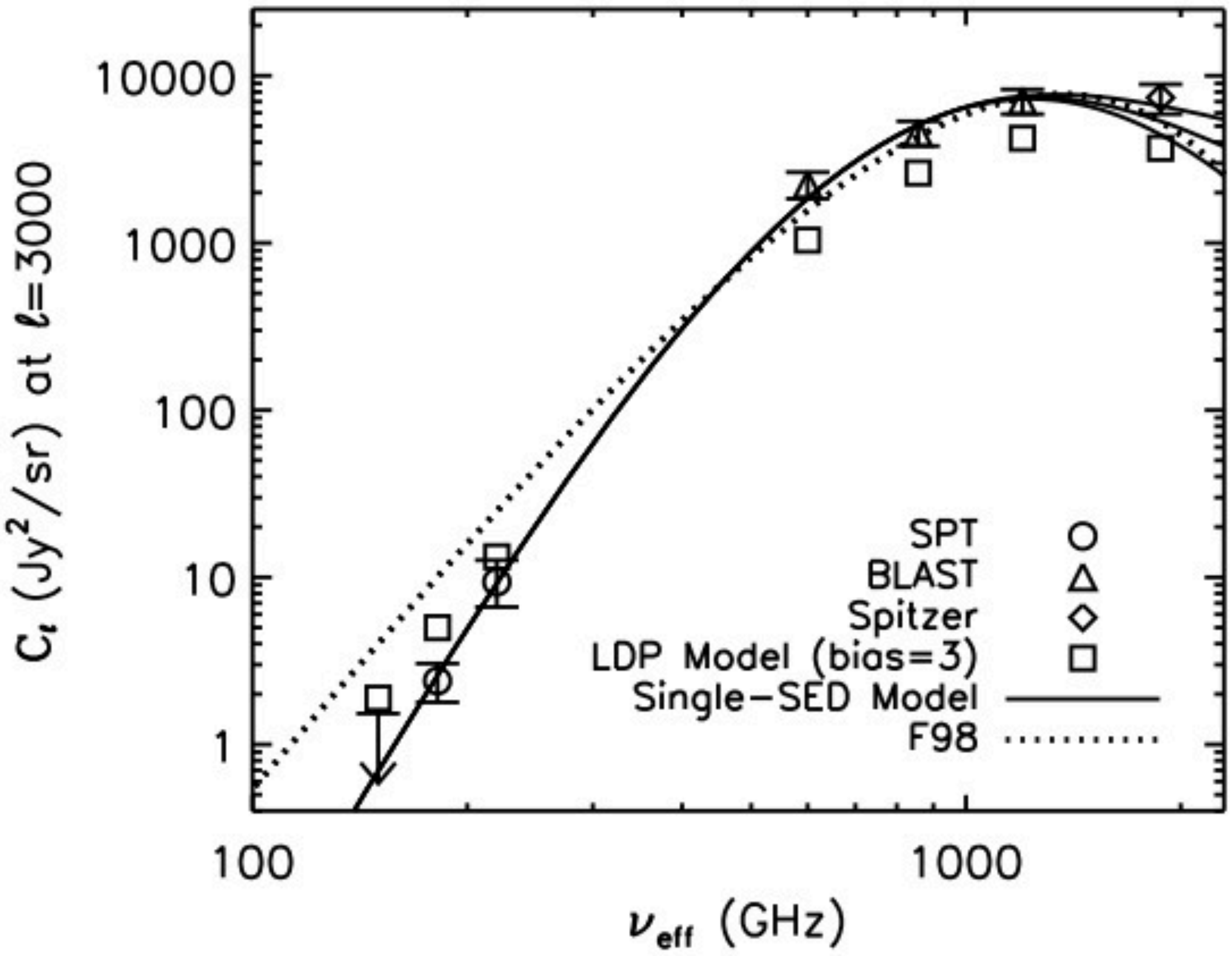
Hajian et al 2012

Planck CIB Measurements



Planck collaboration 2012

Frequency scaling of Dusty Galaxy Backgrounds

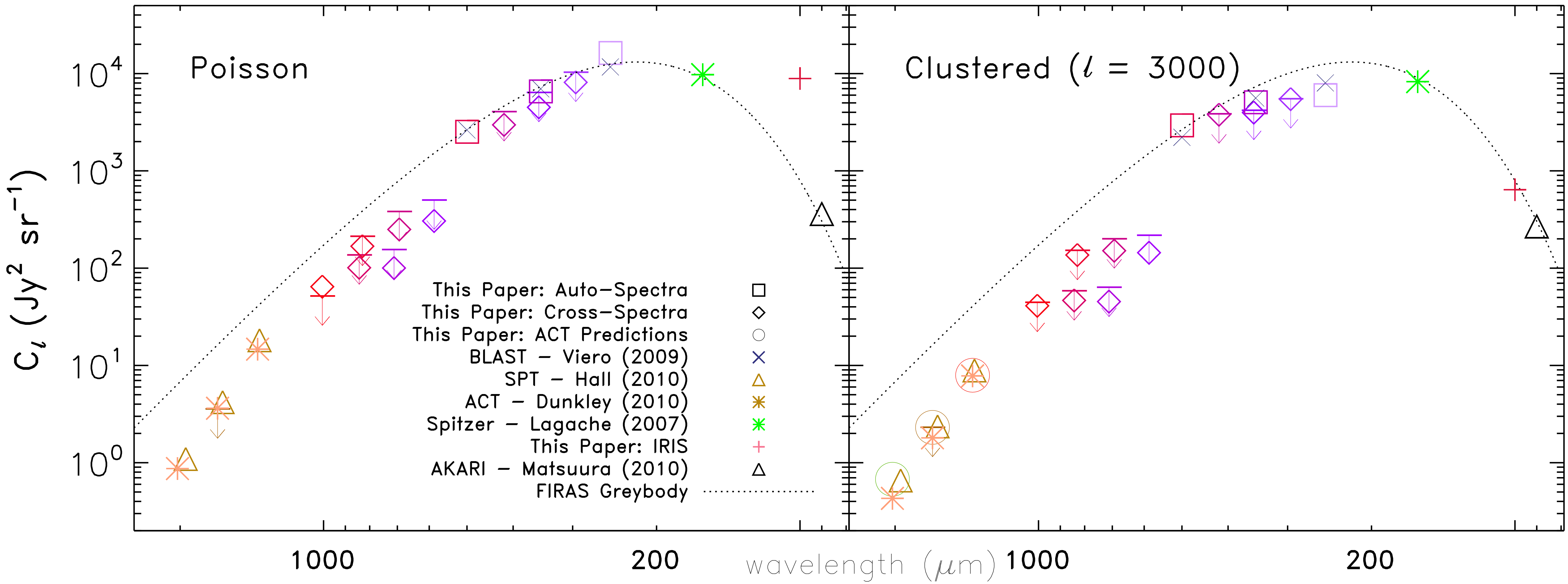


Single-SED model assumes all galaxies have same rest-frame properties (T=34 K, β=2) spread over a broad range in redshift (peaking at z=2)

First detection of clustered point source power from CIB sources in the mm bands

Hall et al 2010

Frequency Scaling of the CIB



Hajian et al 2012

Summary

- lots more information in a map than just source counts (1 pt function)
- power spectrum of CIB map is providing measurements of clustering at many wavelengths (2 pt function)
  - SPT, ACT, Planck turn out to be CIB experiments