Extragalactic Foregrounds and Lens Reconstruction

Stephen Osborne, Duncan Hanson & Olivier Doré

Planck

Launched 14 May 2009

Completed 3 surveys, expect 5

Movie Credit: ESA, C. Carreau

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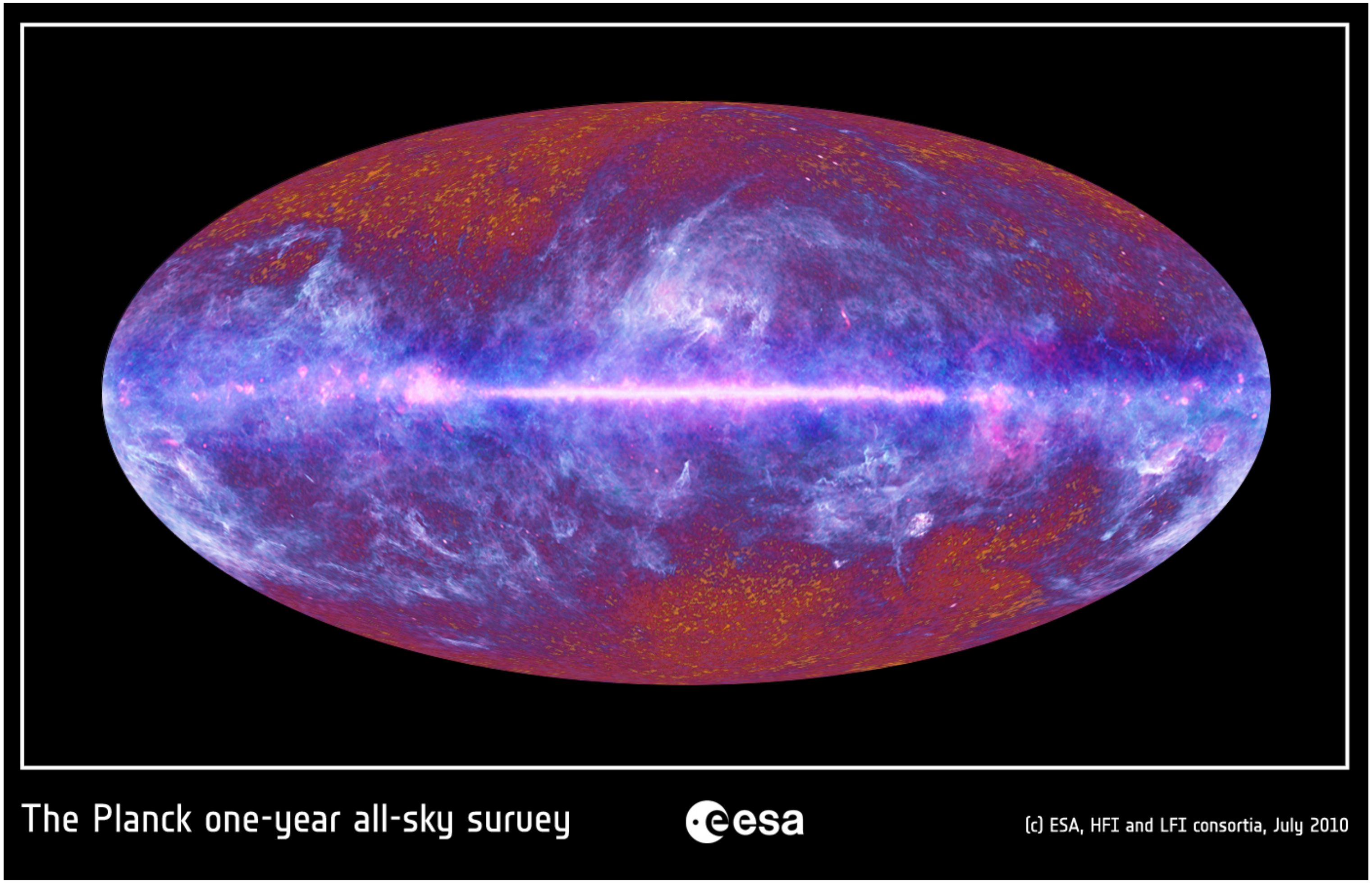
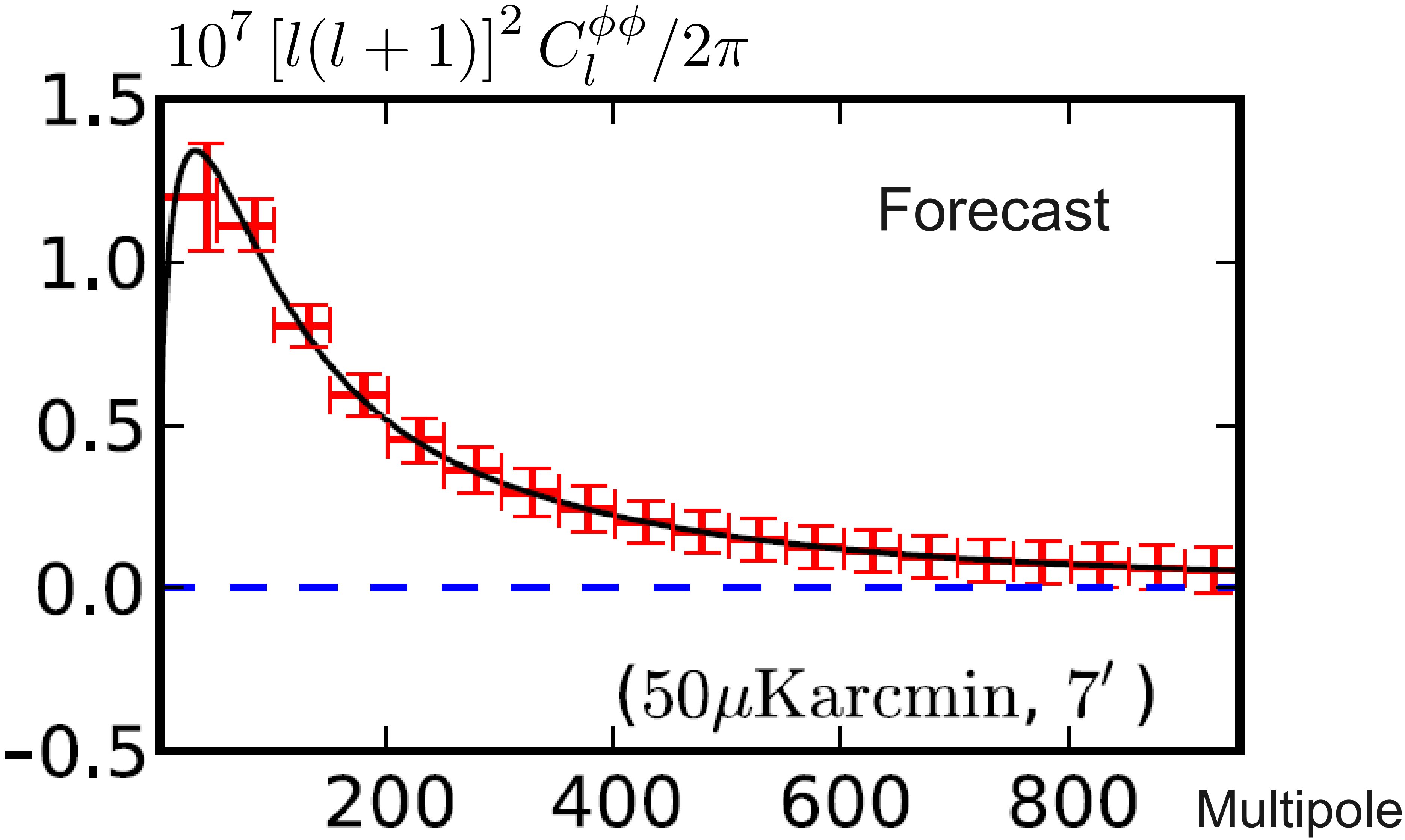


Movie Credit: ESA, C. Carreau

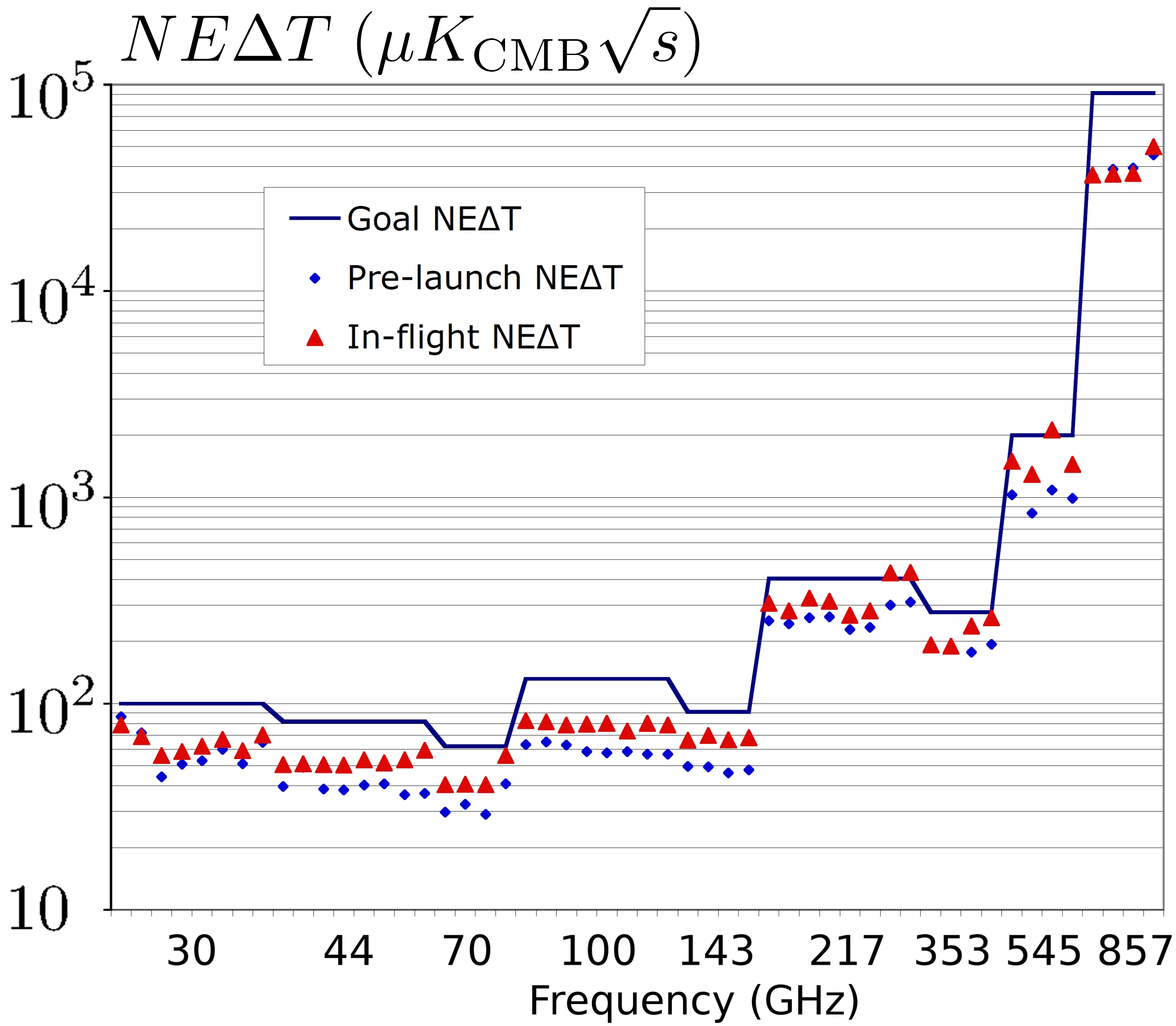
Allows for a great lens reconstruction

Highest sensitivity at 143GHz



And it's working as expected!

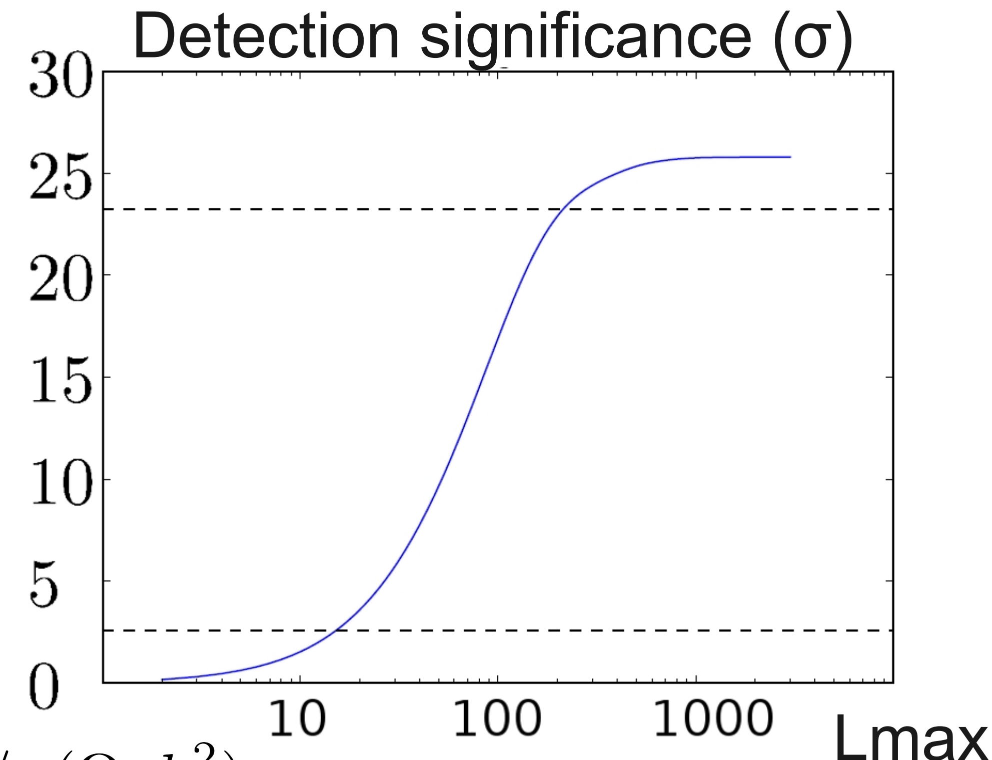
From HFI in-flight performance paper (arXiv:1101.2039v1):



Where is the information?

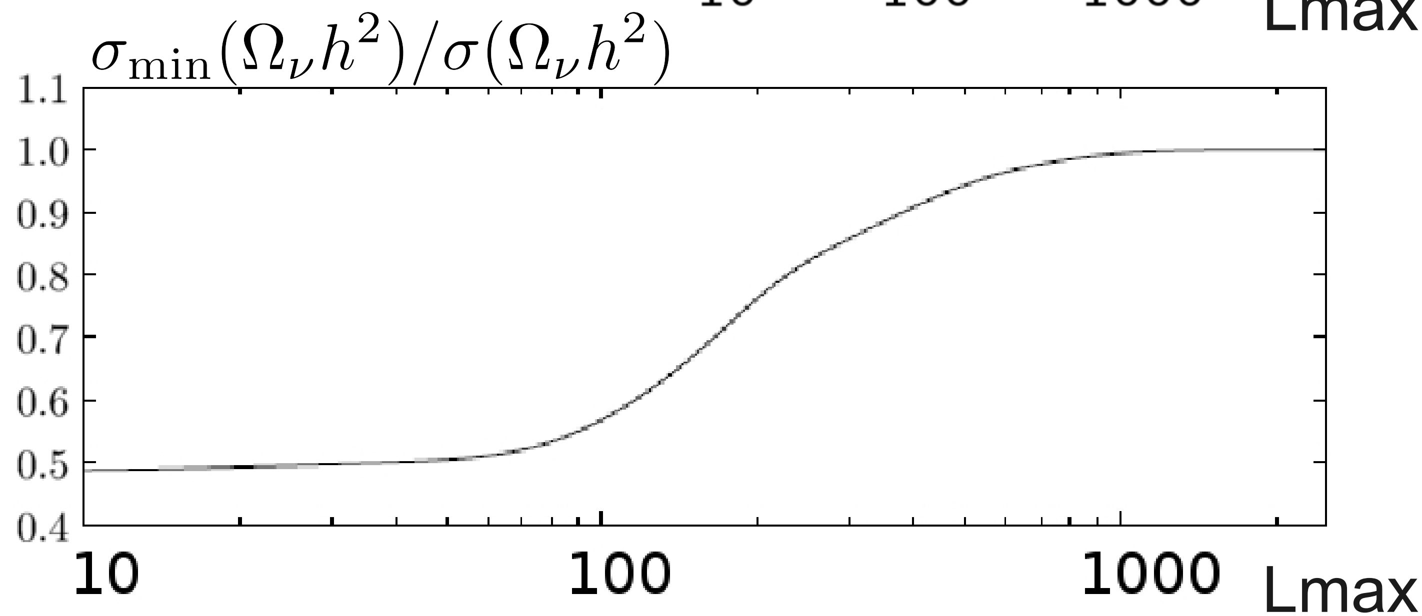
- Lensing potential signal

  For 50 μK-arcmin noise



- Cosmological information

  Hanson (2010)



Foregrounds at relevant scales

Radio Poisson sources are the dominant foreground

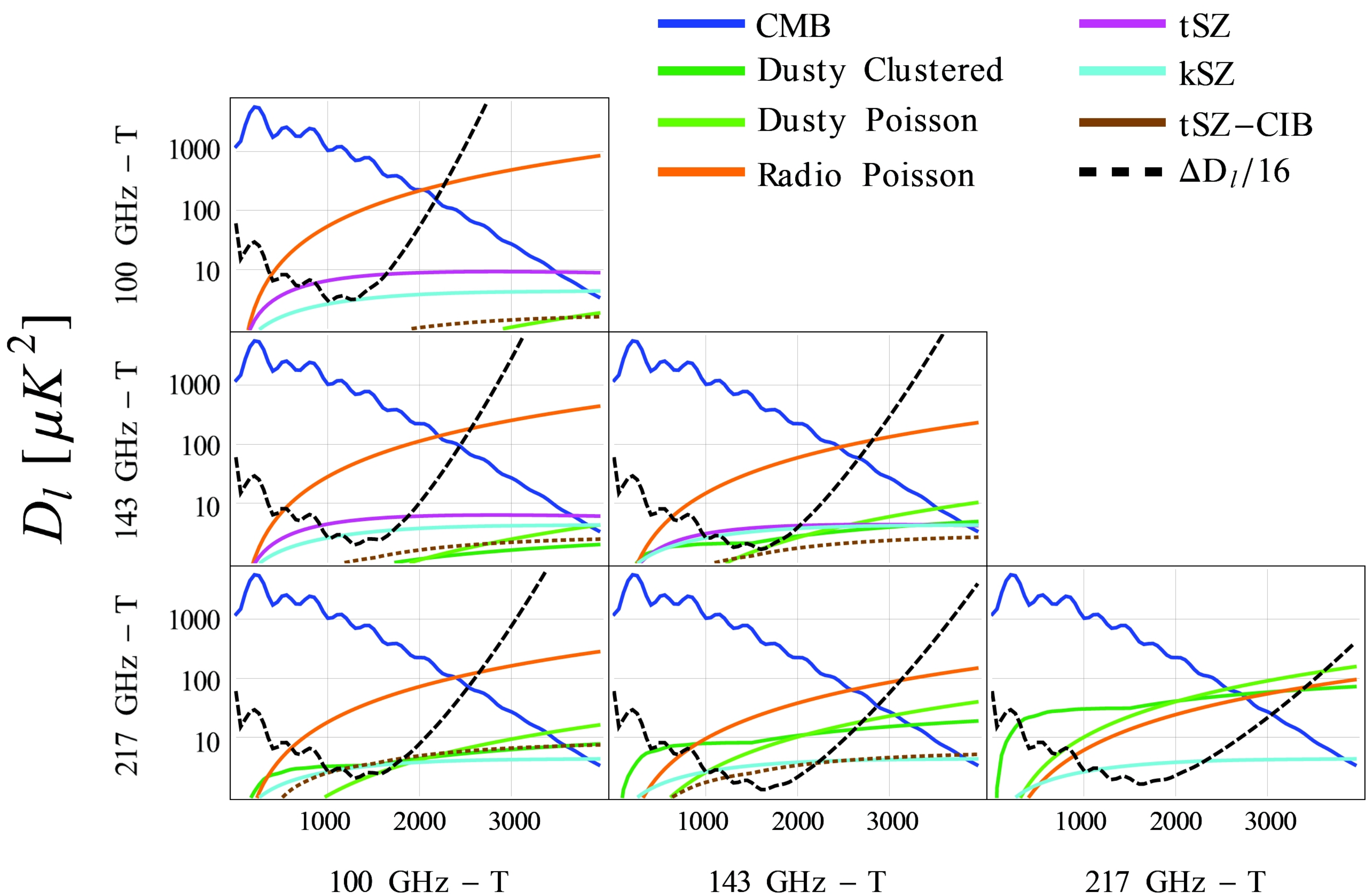


Image from Millea (2011)

How is the estimator affected?

$$\phi_{LM} = \frac{1}{2} A_L \sum_{l_i m_i} (-1)^M \begin{pmatrix} l_1 & l_2 & L \\ m_1 & m_2 & -M \end{pmatrix} g_{l_1 l_2}(L) \frac{\Theta_{l_1 m_1} \Theta_{l_2 m_2}}{C_{l_1}^{\Theta\Theta} C_{l_2}^{\Theta\Theta}}$$

Planck $l_{\max} \sim 1500$

ACT/SPT $l_{\max} \sim 2000 - 3000$

$$C_L^{\phi\phi} \sim \langle \Theta_{l_1 m_1} \Theta_{l_2 m_2} \Theta_{l_3 m_3} \Theta_{l_4 m_4} \rangle_c + \langle \Theta_{l_1 m_1} \Theta_{l_2 m_2} \Theta_{l_3 m_3} \Theta_{l_4 m_4} \rangle_d$$

Includes non-Gaussian and Gaussian terms

Gaussian—removed along with the noise bias eg:

$$\langle \Theta_{l_1 m_1} \Theta_{l_2 m_2} \rangle \langle \Theta_{l_3 m_3} \Theta_{l_4 m_4} \rangle$$

Our foreground model

$$\Theta \approx \tilde{\Theta}^{\rm CMB} + \nabla\tilde{\Theta}^{\rm CMB} \cdot \nabla\phi + \Theta^{\rm ISW} + \sum_i F_i + n$$

$$C_L^{\phi\phi} \sim \langle \Theta_{l_1 m_1} \Theta_{l_2 m_2} \Theta_{l_3 m_3} \Theta_{l_4 m_4} \rangle$$

- CL contains non-Gaussian Poisson terms like F^4 and Gaussian clustering terms like F^2 x F^2

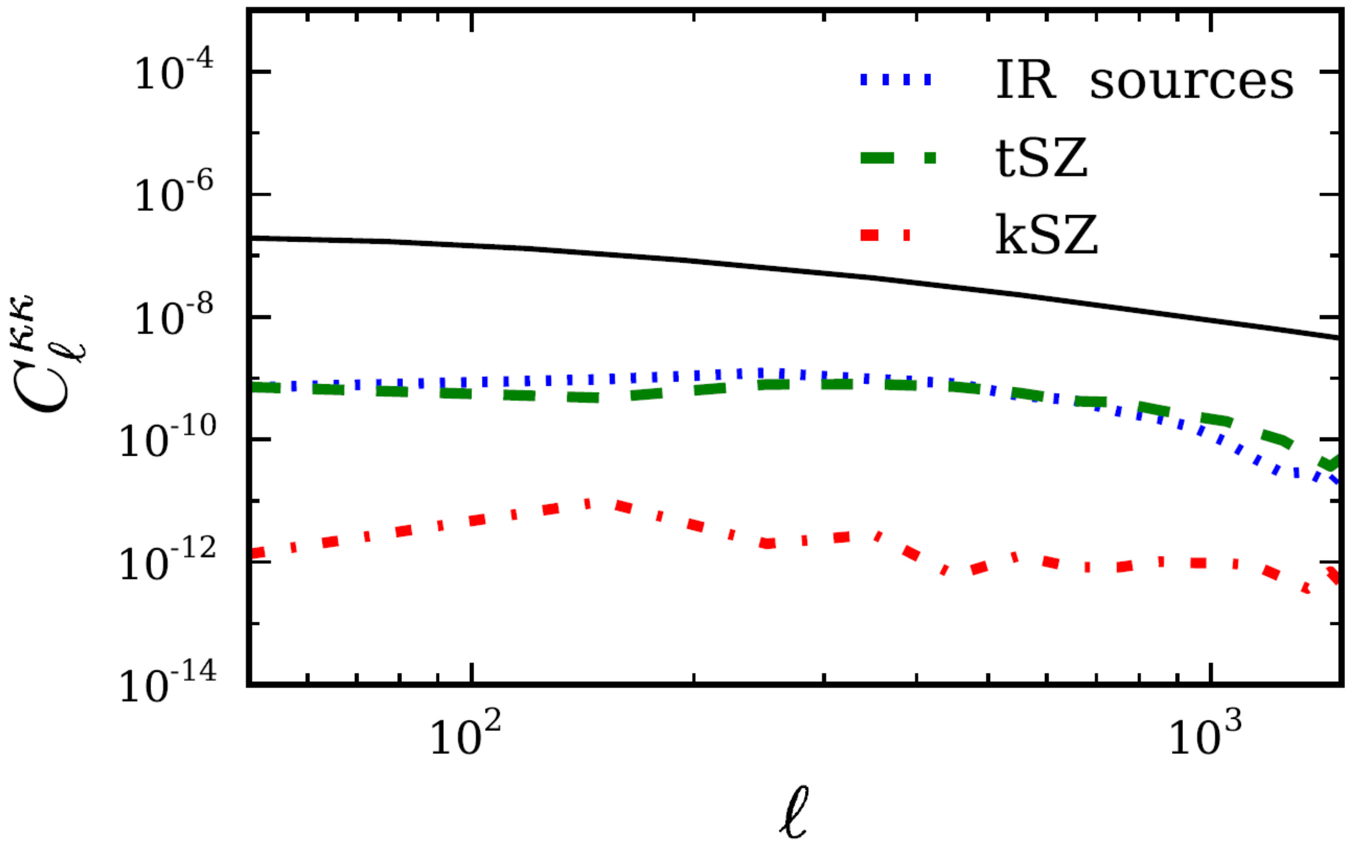
$$F^2 \sim \int_0^{S_{max}} dS \frac{dN}{dS} S^2$$

$$\frac{dN}{dS}(\hat{\mathbf{n}}) = \frac{d\bar{N}}{dS}(\hat{\mathbf{n}}) \left[1 + b \int dz n(z) \delta(\hat{\mathbf{n}}, z) \right]$$ Babich (2008)

- Ignore ISW since we can throw away low-l CMB data
- Also have point source lensing with $dN/dS \sim 1 - 2\kappa$

What has been done already?

- Das 2011, Cooray 2010 use simulations
- Instead we use an analytical approach calibrated on data



- Smith (2007) and Hirata (2008) looked at φ-g bias from extragalactic foregrounds (and masking bias)
- Polarized foregrounds in Smith (2008, 2011)

Image from Das (2011)

All terms

$$C_L^{\phi\phi} \sim \langle \Theta_{l_1 m_1} \Theta_{l_2 m_2} \Theta_{l_3 m_3} \Theta_{l_4 m_4} \rangle$$

$$\theta = \tilde{\Theta}^{\rm CMB} + \nabla \tilde{\Theta}^{\rm CMB} \cdot \nabla \phi + \Theta^{\rm ISW} + n$$

One Source

F^4	Poisson term
$F^3 \theta$	F^3 ISW correlation
$F^2 \theta^2$	F^2 ϕ correlation
$F \theta^3$	ISW correlation

Two Source (work in progress)

$F^3 F$	Non-zero due to point source clustering
$F^2 F^2$	
$F F \theta^2$	F Fϕ correlation
$F^2 F \theta$	ISW correlation

Three Source

$F F F^2$	Two correlation functions
$F F F \theta$	ISW correlation

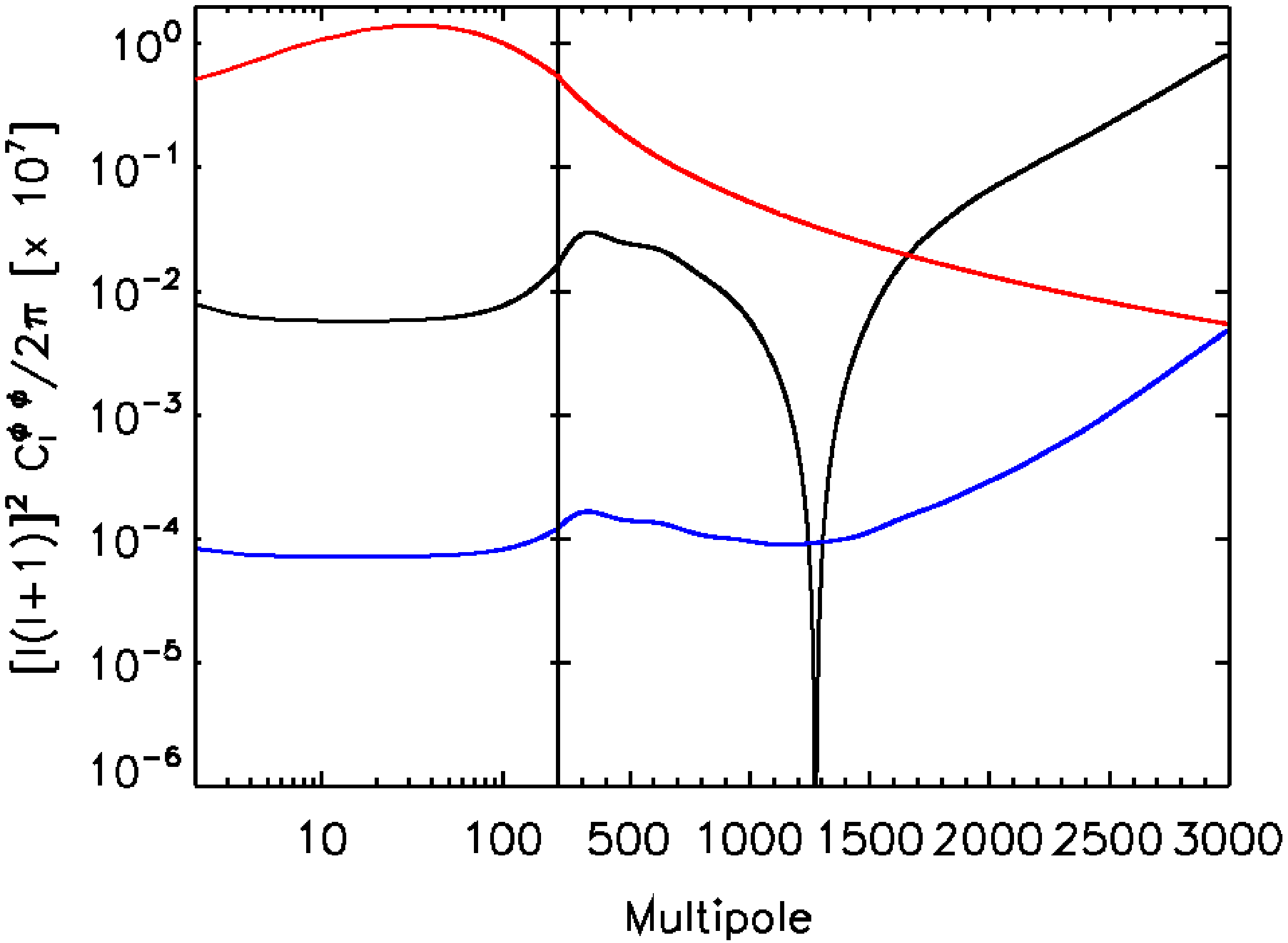
Four Source

$F F F F$	Three correlation functions

One source terms

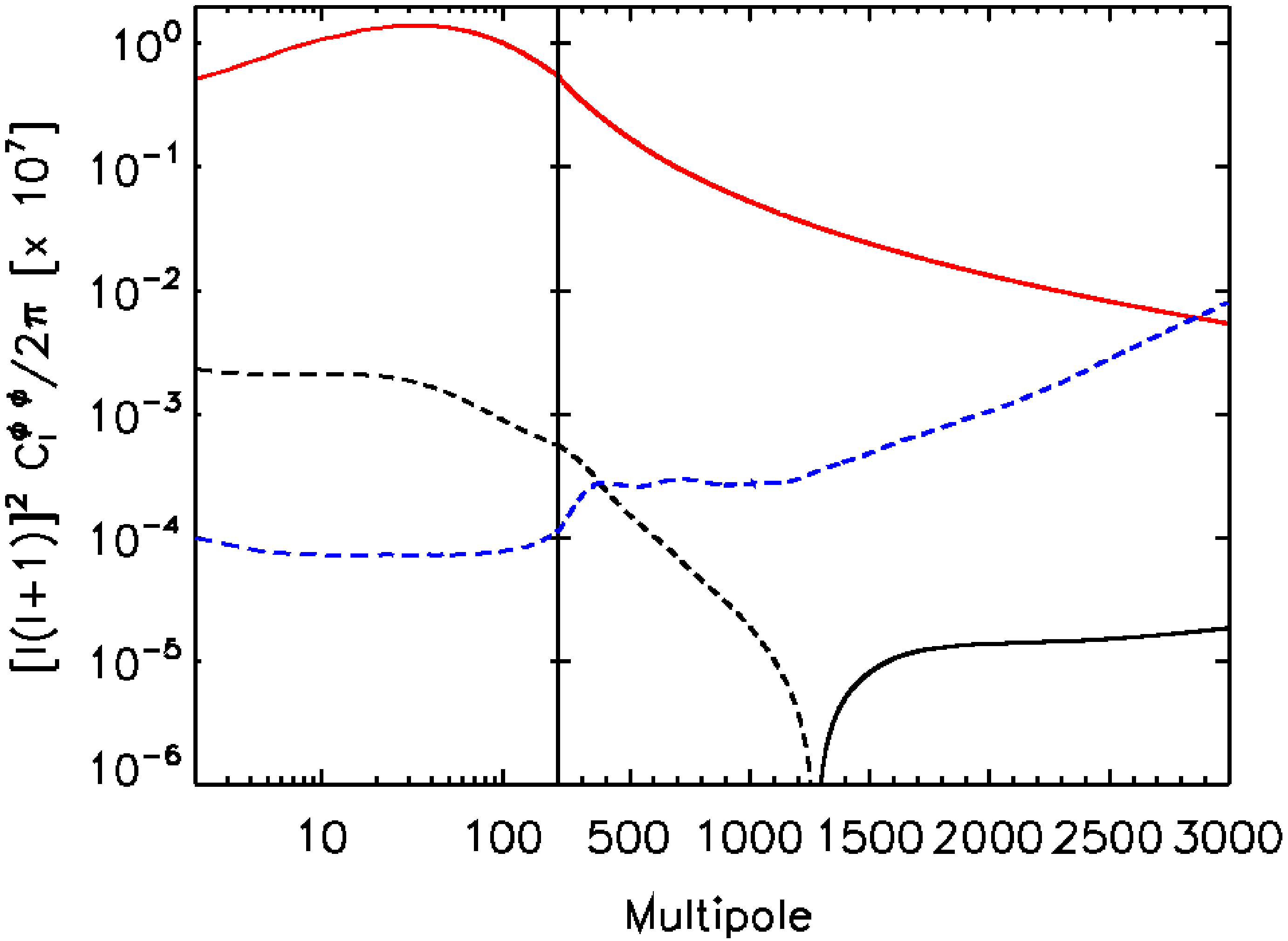
$$C_L^{\phi\phi} = \sum_{l_i m_i} W_{l_1 m_1 l_2 m_2} W_{l_3 m_3 l_4 m_4} \left(\langle F_{l_1 m_1} F_{l_2 m_2} F_{l_3 m_3} F_{l_4 m_4} \rangle \right.$$

$$\left. + \langle F_{l_1 m_1} F_{l_2 m_2} \rangle \langle F_{l_3 m_3} F_{l_4 m_4} \rangle \right)$$



One source terms II

$$C_L^{\phi\phi} = \sum_{l_i m_i} W_{l_1 m_1 l_2 m_2} W_{l_3 m_3 l_4 m_4} \left(\langle F_{l_1 m_1} F_{l_2 m_2} \theta_{l_3 m_3} \theta_{l_4 m_4} \rangle + 2 \ \langle F_{l_1 m_1} \theta_{l_2 m_2} F_{l_3 m_3} \theta_{l_4 m_4} \rangle \right)$$



How do we test the model?

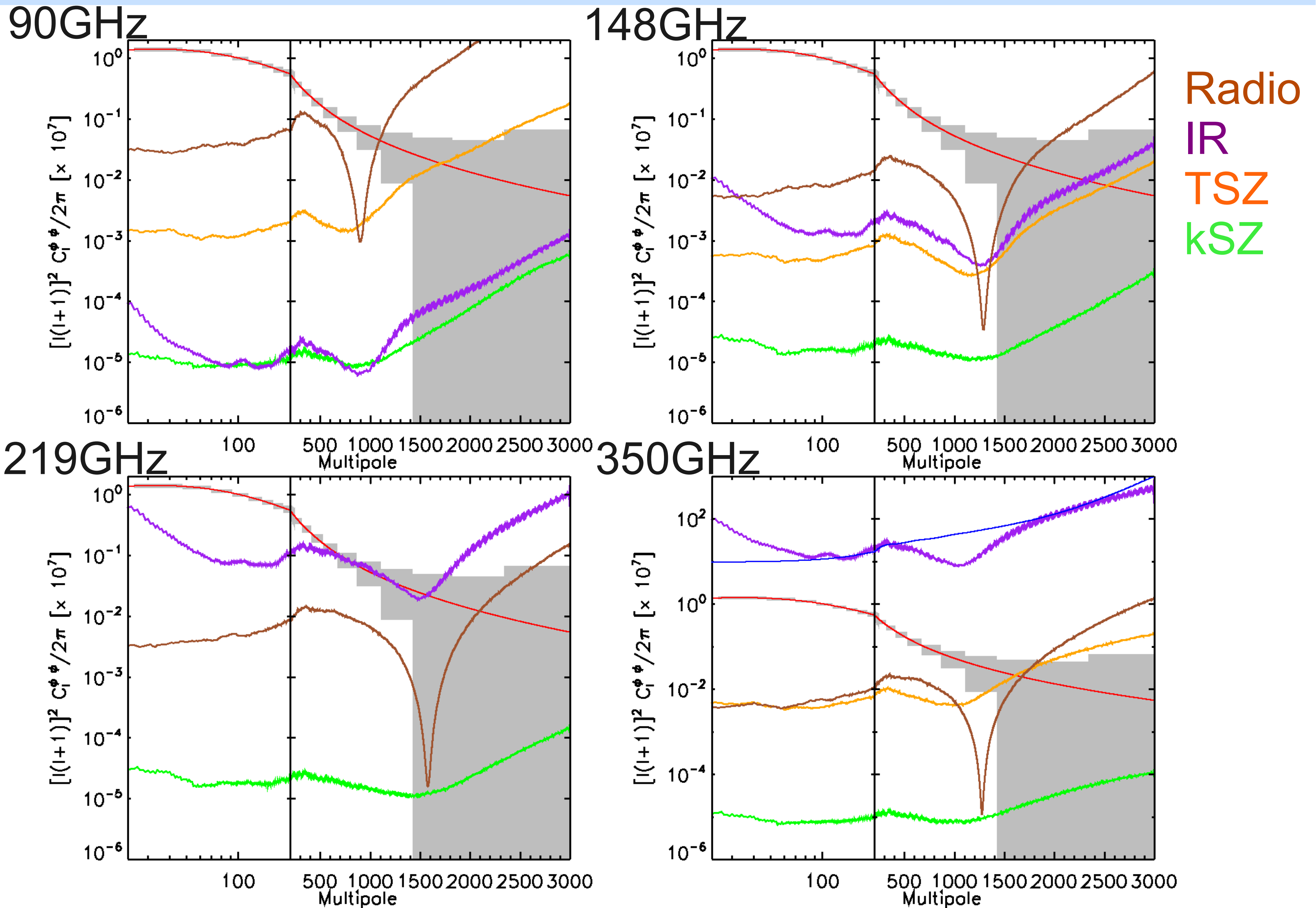
- Sehgal (2009) simulations at 90, 148, 219 & 350GHz

  Includes cross-correlation between components

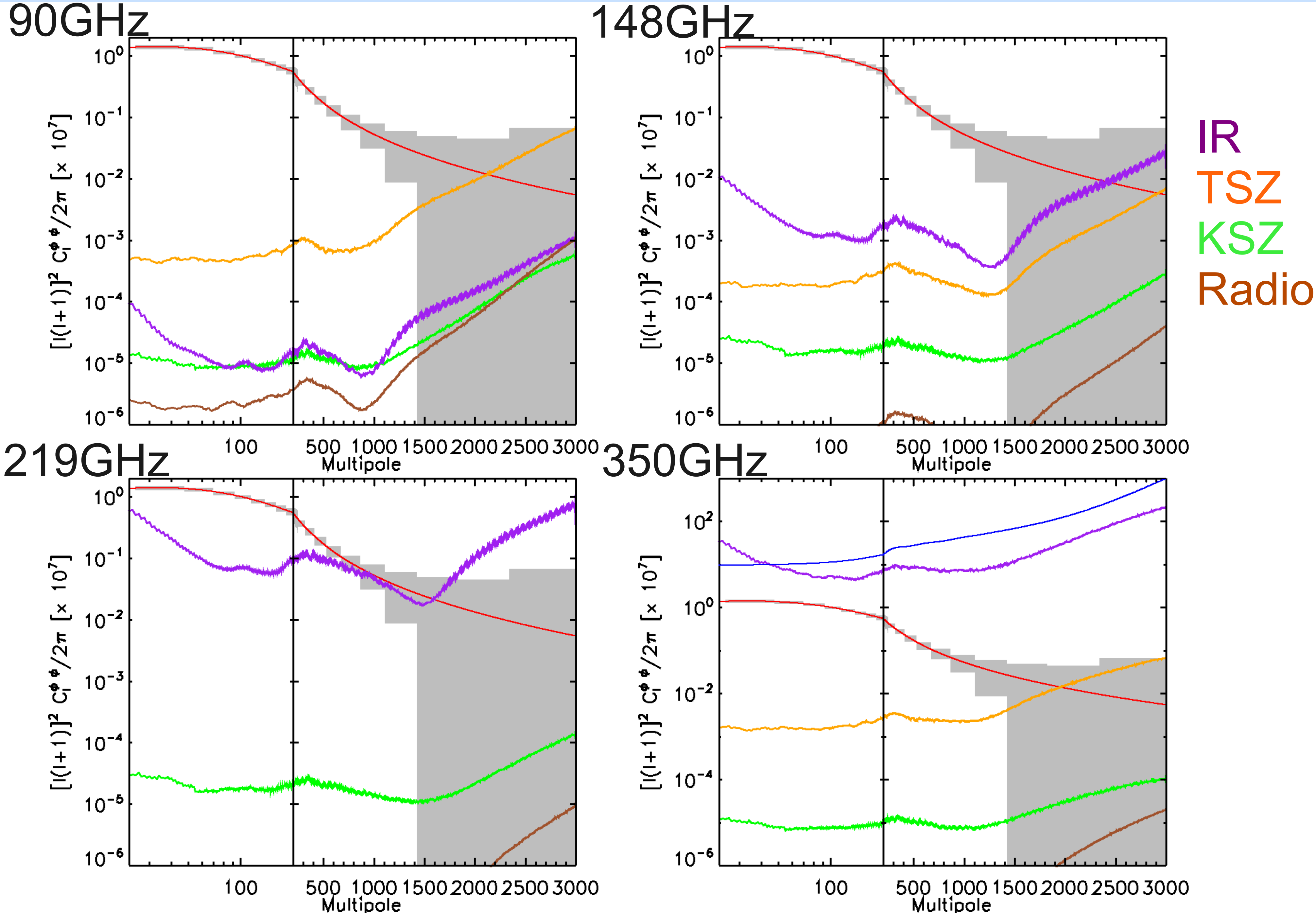
- Two flux sensitivities used:

Planck	250, 200, 190, 290 mJy 3000 clusters masked
ACT/SPT	6 mJy 12000 clusters masked

Simulations—Planck



Simulations—ACT/SPT



How to do it in practice?

Construct:

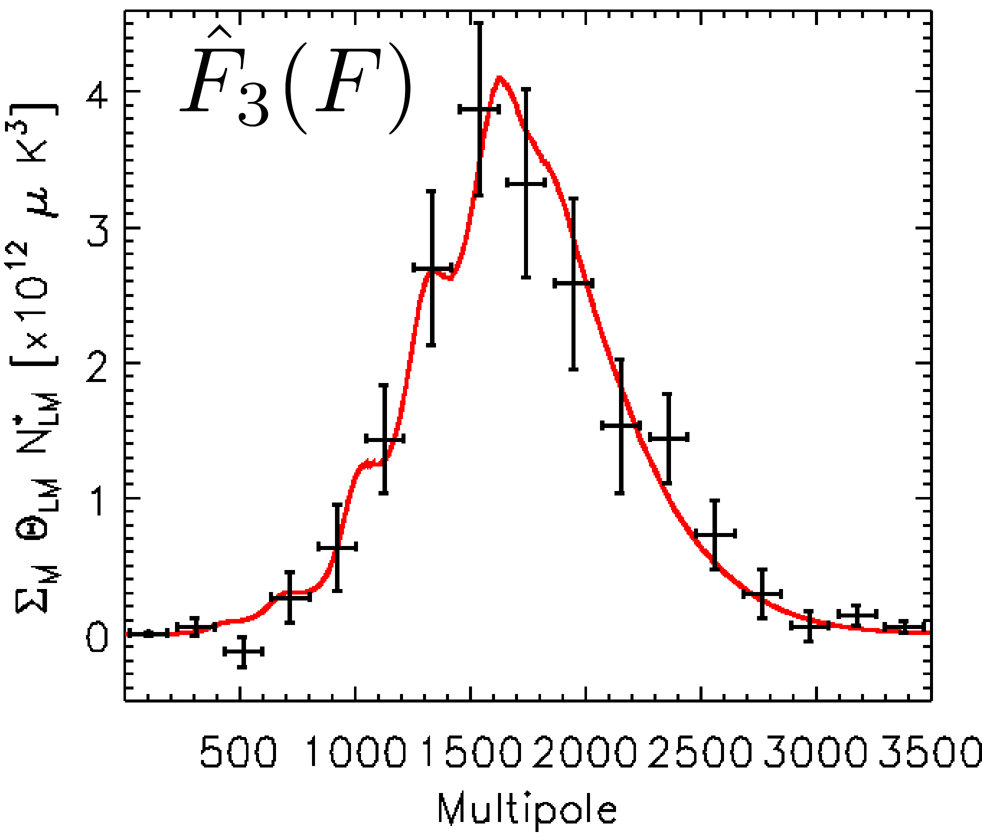
$$\langle F^3 \rangle = A_3 \sum_{LM} \left(\bar{\Theta}_{LM} N^*_{LM} - \langle \bar{\Theta}_{LM} N^*_{LM} \rangle_d \right)$$

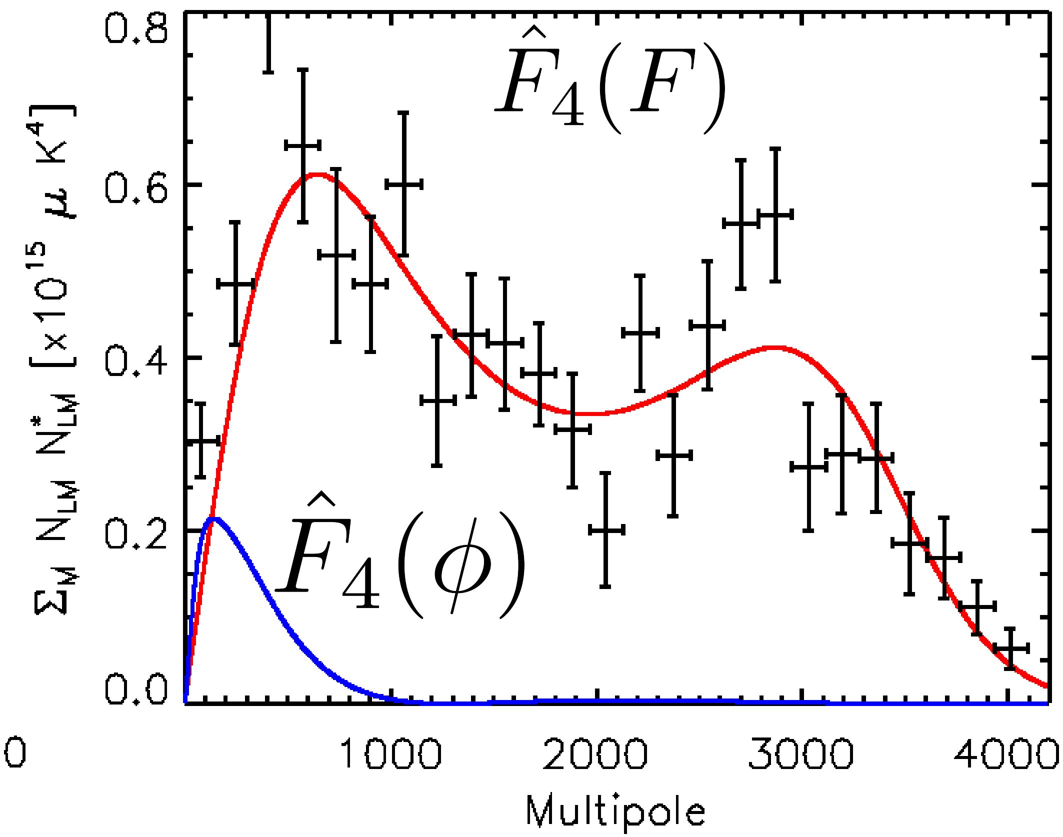
$$\langle F^4 \rangle = A_4 \sum_{LM} \left(N_{LM} N^*_{LM} - \langle N_{LM} N^*_{LM} \rangle_d \right)$$

Munshi & Heavens (2009)

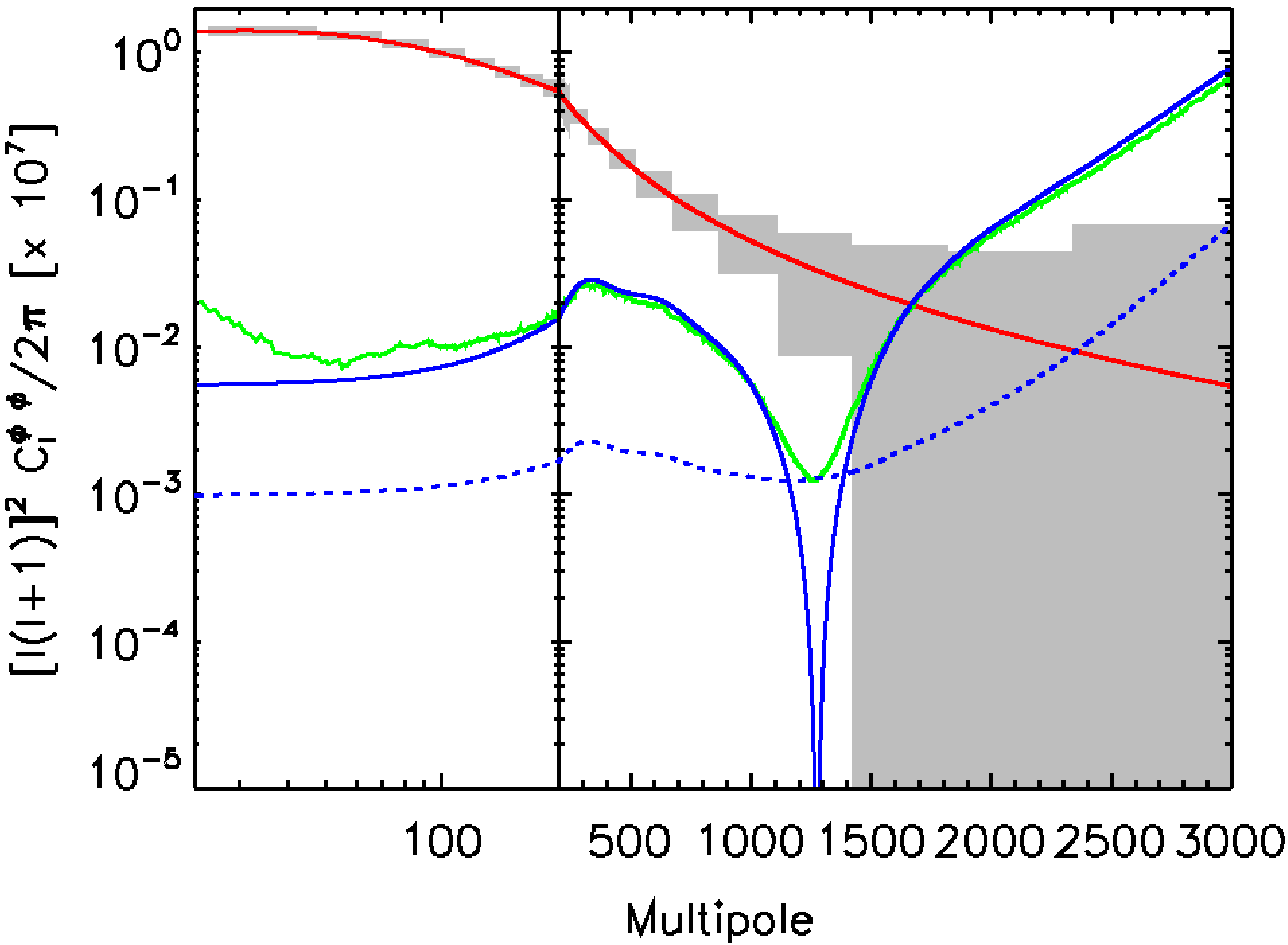
From QE:

$$N_{LM} = \sum_{l_i m_i} \int Y^*_{LM} Y_{l_1 m_1} Y_{l_2 m_2} \bar{\Theta}_{l_1 m_1} \bar{\Theta}_{l_2 m_2}$$





Works well on the simulations



Conclusions

- Planck will get a significant lensing detection (26σ for 50μK-arcmin noise)
- The lensing estimator is biased by unresolved foregrounds
- The foreground bias can be modeled
- and the shot noise amplitude can be measured
- Data and results released in January 2013!