Probing Large-Angle Correlations with CMB Temperature and Lensing Cross Correlations

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arXiv: 1310.7603

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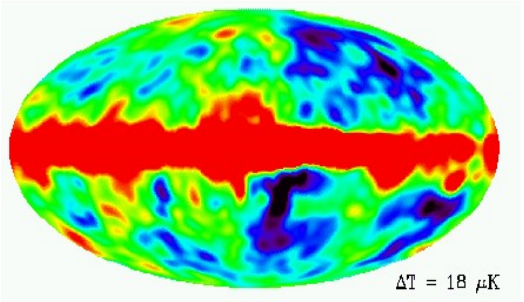
Glenn D. Starkman
Craig Copi

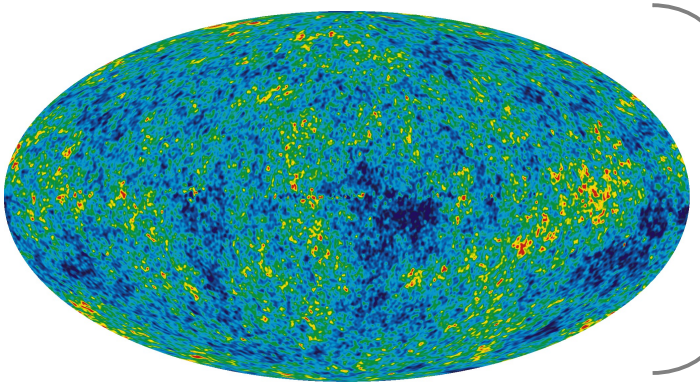
University of Pittsburgh

Arthur Kosowsky

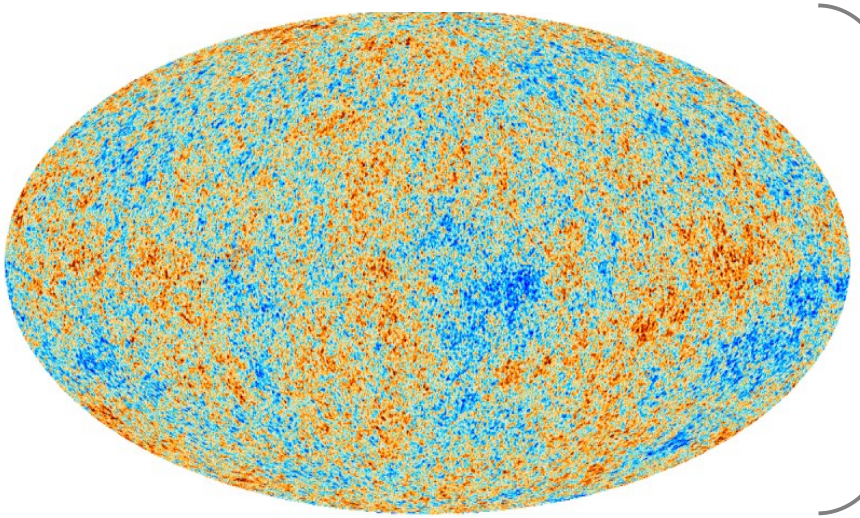
A history of CMB observations



COBE (1992)

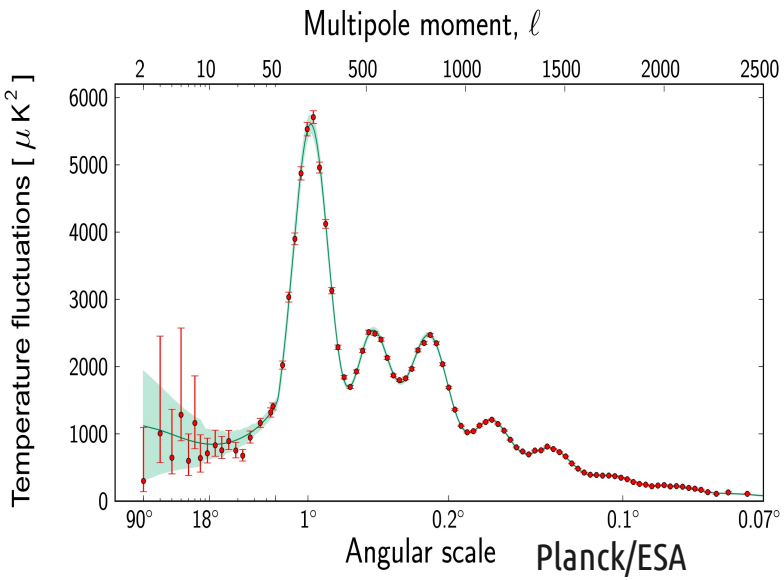


WMAP (2003)



Planck (2013)

WMAP and Planck have given us excellent measurements of the temperature power spectrum which (mostly) support LCDM cosmology...



(very) brief background

$$\Delta T(\mathbf{n}) = \sum_{l>0} \sum_{m=-l}^{l} a_{lm} Y_{lm}(\mathbf{n})$$

$$\langle a_{lm} a^*_{l'm'} \rangle = \delta_{ll'}\, \delta_{mm'}\, C_l$$

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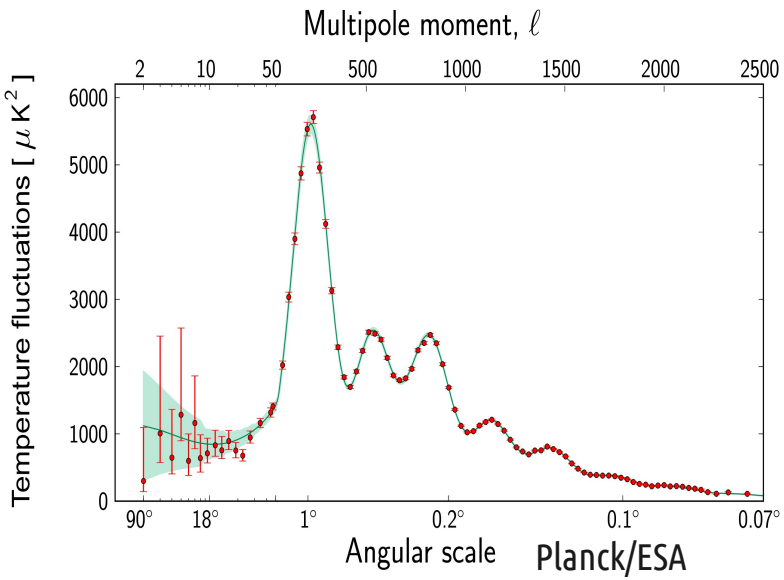

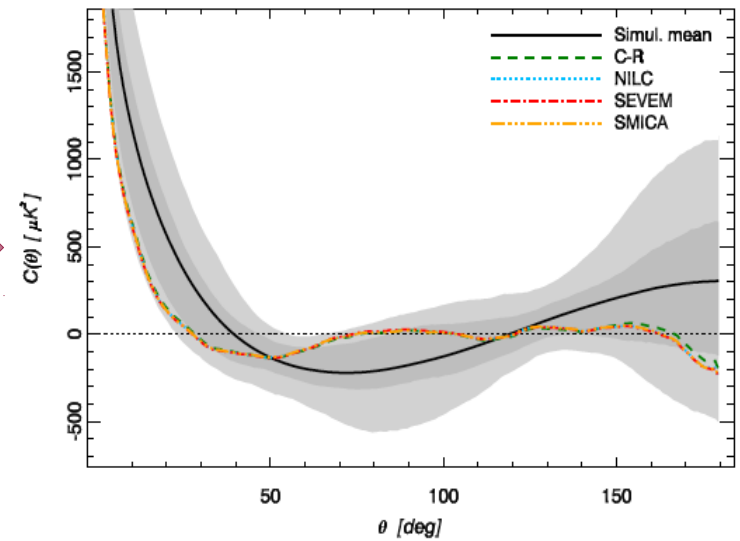

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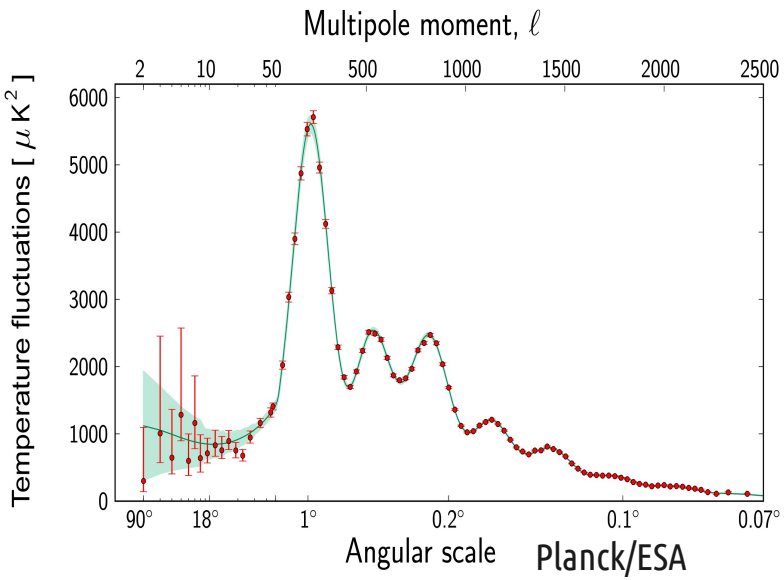

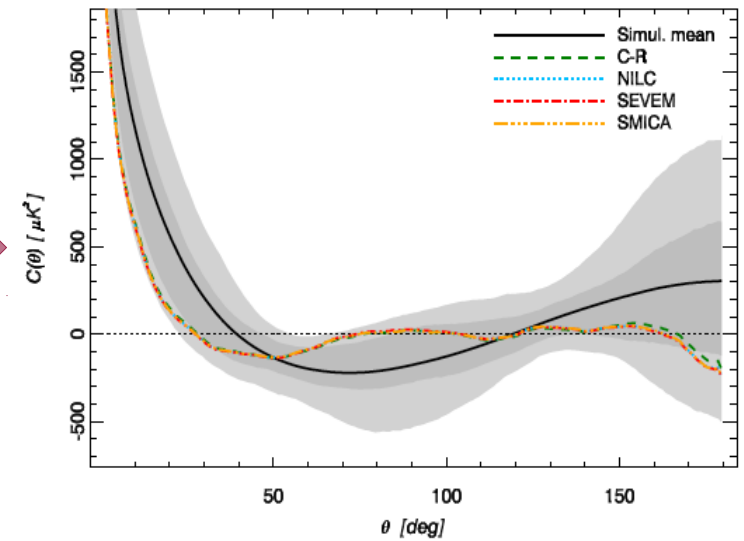

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See talks by Holder, Ferreira

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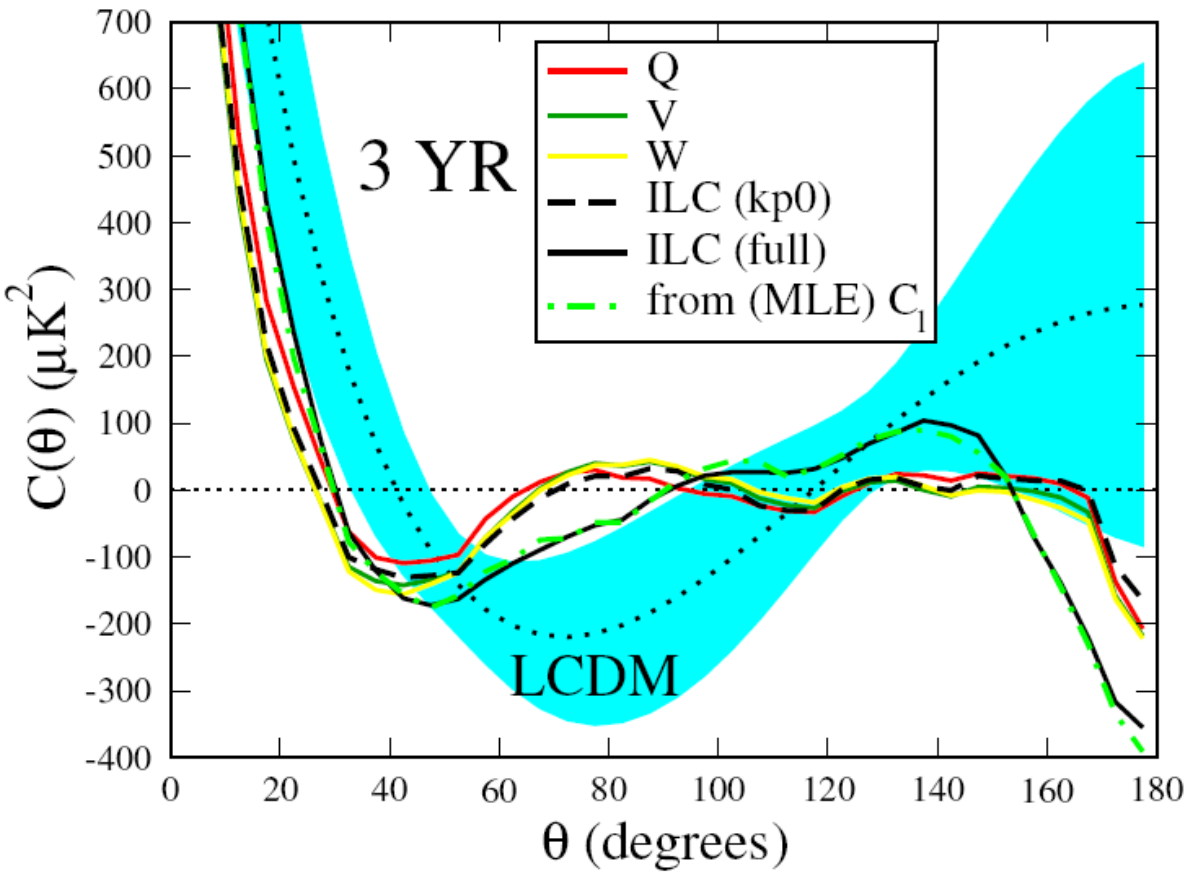
ACF measurements from WMAP



Defined a statistic:

$$S_{1/2} = \int_{1/2}^{-1} d(\cos\theta)\, C(\theta)^2$$

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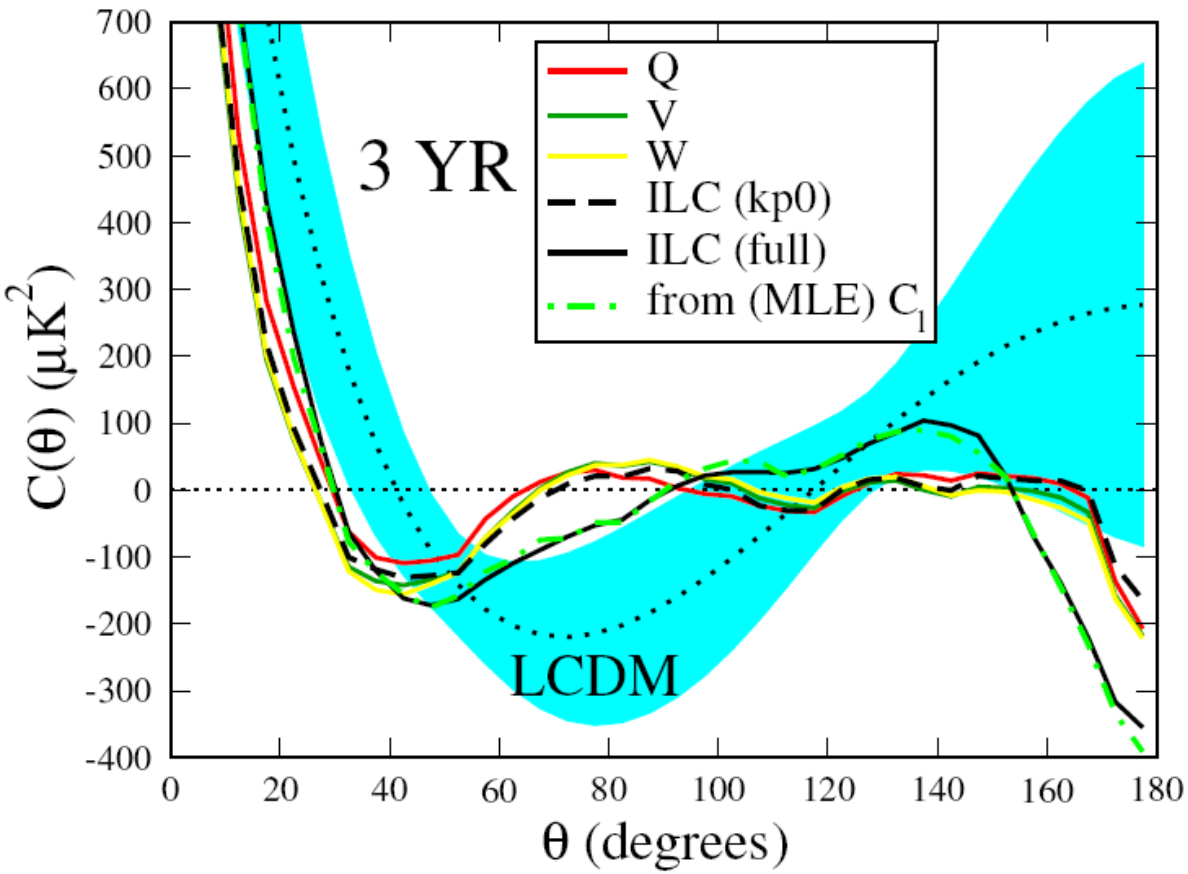

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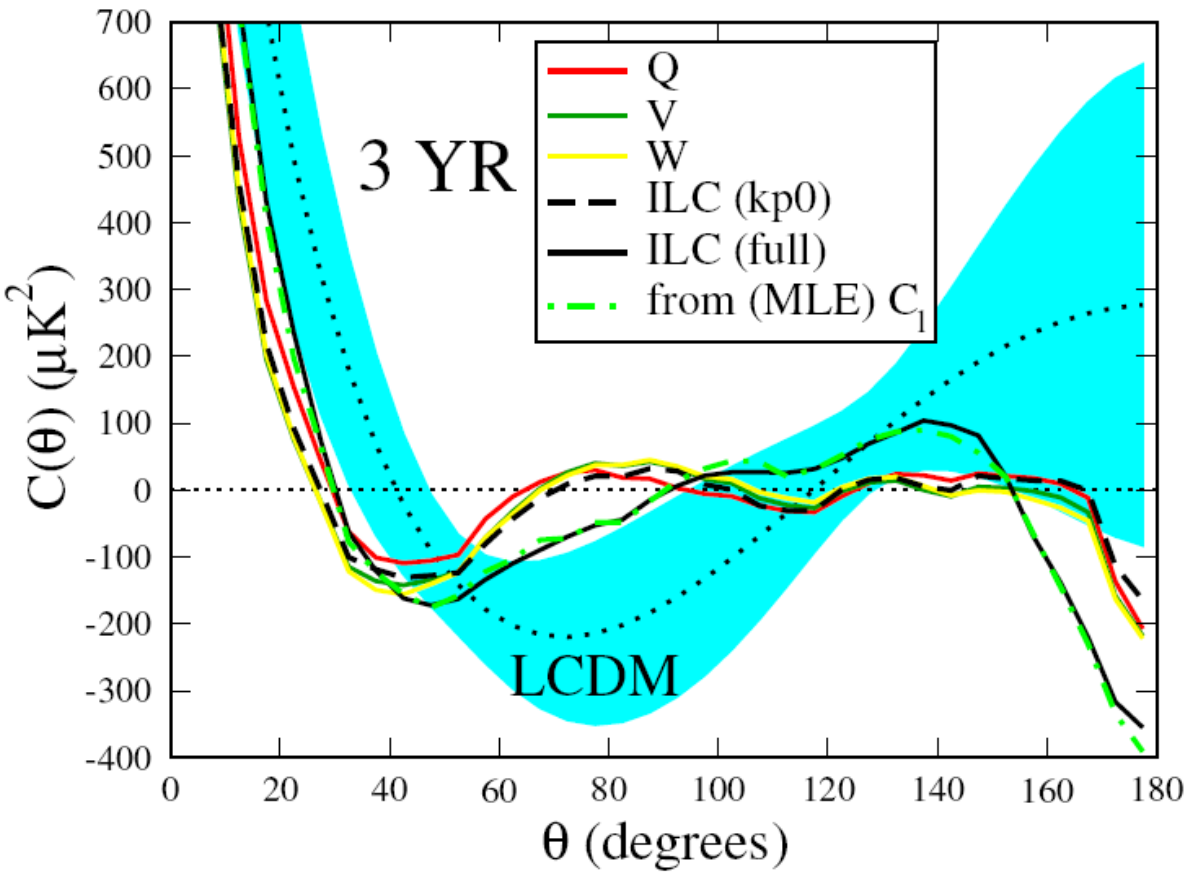

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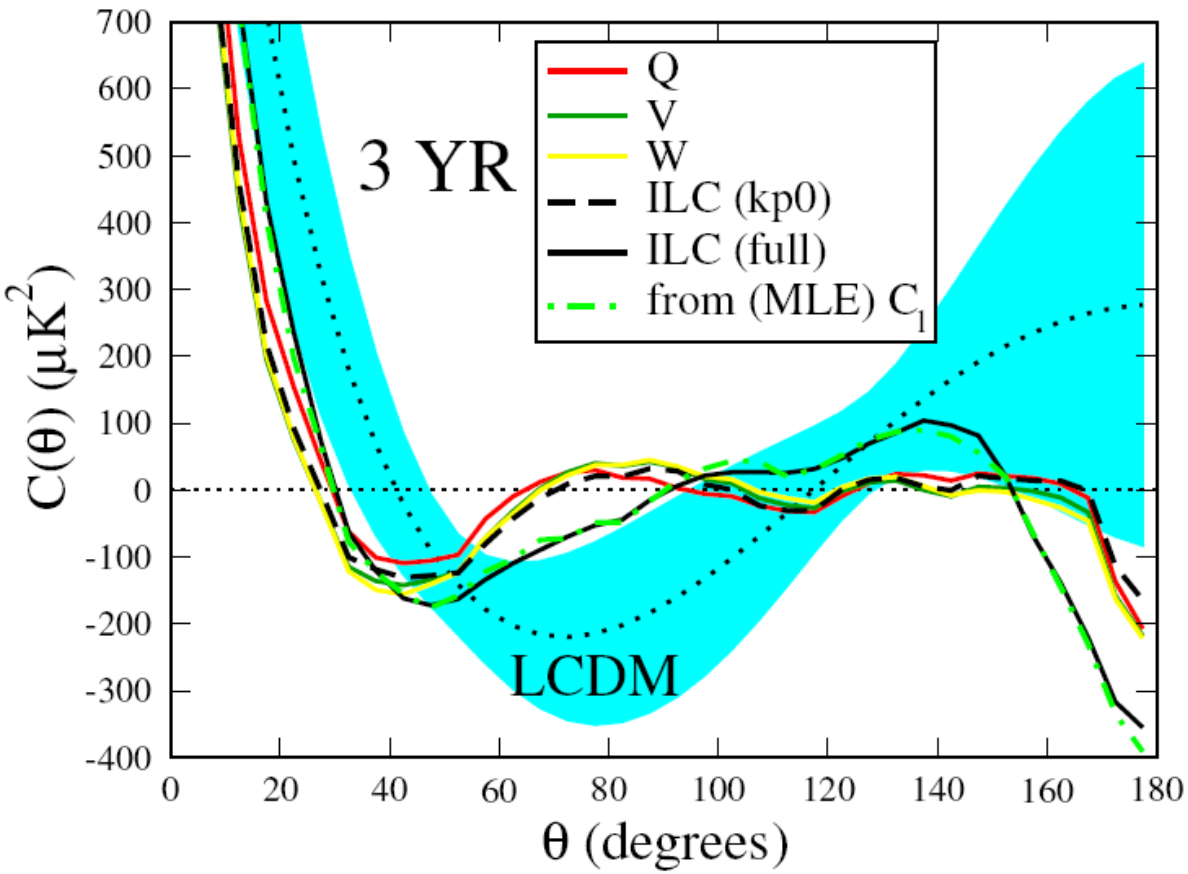

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This is an *a posteriori* statistic

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Lots of work has gone into characterizing the lack of correlation in temperature data...

Recent analysis of Planck maps by Copi, Huterer, Schwarz, Starkman – arXiv: 1310:3831

A nice (short) review of the lack of correlation at large angles arXiv: 1201.2459

Detailed comparison of WMAP to Planck large angle anomalies arXiv: 1303.5083

But we need to move beyond temperature to learn something new

Our goal:

Find an optimal *a priori* measure for investigating the lack of correlation at large angles

The 2-point Angular Correlation Function

$$\tilde{C}^{TT}(\theta) \equiv \langle \Theta(\hat{\mathbf{n}}_1)\Theta(\hat{\mathbf{n}}_2)\rangle$$

$$\Theta(\hat{\mathbf{n}}) = \Theta_{\rm SW} + \Theta_{\rm ISW}$$

$$\Theta_{\rm SW}(\hat{\mathbf{n}}) = -\frac{1}{3}\Phi(\chi_*\hat{\mathbf{n}}, \chi_*)$$

CMB photons climbing out of gravitational wells at the LSS

$$\Theta_{\rm ISW}(\hat{\mathbf{n}}) = -2\int_0^{\chi_*} d\chi \dot{\Phi}(\chi\hat{\mathbf{n}}, \chi)$$

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$$C^{TT}(\theta) = \text{Stuff}\times\langle\Phi(\chi_*\hat{\mathbf{n}}_1)\,\Phi(\chi_*\hat{\mathbf{n}}_2)\rangle + \int \text{Stuff}'\times\langle\Phi(\chi_*\hat{\mathbf{n}}_1)\,\Phi(\chi_2\hat{\mathbf{n}}_2)\rangle + \int \text{Stuff}''\times\langle\Phi(\chi_1\hat{\mathbf{n}}_1)\,\Phi(\chi_2\hat{\mathbf{n}}_2)\rangle$$

Starting point: find cross correlation which traces same physics as CMB temperature data

Correlate with the lensing potential:

$$\varphi = 2\int_0^{\chi_*} d\chi \, \frac{\chi_* - \chi}{\chi_* \chi} \Phi(\chi \hat{\mathbf{n}}, \chi) \qquad C^{T\varphi}(\theta) = \langle \varphi(\hat{\mathbf{n}}_1)\, \Theta_{SW}(\hat{\mathbf{n}}_2) \rangle + \langle \varphi(\hat{\mathbf{n}}_1)\, \Theta_{ISW}(\hat{\mathbf{n}}_2) \rangle$$

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$$C^{T\varphi}(\theta) = -\frac{2}{3} F(\eta_0 - \chi_*) \int_0^{\chi_*} d\chi_1 F(\eta_0 - \chi_1) \frac{\chi_* - \chi_1}{\chi_* \chi_1} \langle \Phi(\chi_1 \hat{\mathbf{n}}_1)\, \Phi(\chi_* \hat{\mathbf{n}}_2) \rangle$$

$$-4 \int_0^{\chi_*} d\chi_1 \int_0^{\chi_*} d\chi_2 F(\eta_0 - \chi_1) \frac{dF}{d\eta}(\eta_0 - \chi_2) \frac{\chi_* - \chi_1}{\chi_* \chi_1} \langle \Phi(\chi_1 \hat{\mathbf{n}}_1)\, \Phi(\chi_2 \hat{\mathbf{n}}_2) \rangle$$

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If new physics is to blame, we should see it in the lensing-temperature correlation

Use this to test the Null Hypothesis:

We want to tell whether our Universe is a statistical fluke within LCDM or if it has more interesting physics.

Necessary details...

Realizations for LCDM are straight forward...

constrained realizations require a little more work.

We want to mimic the lack of large-angle auto correlation in temperature
AND
have a power spectrum that is consistent with measurements

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- Make realizations of Cls from the measured spectrum
- Draw coefficients from these Cls
- Calculate S(1/2) on a cut sky and compare to experimental bound
- Keep only the realizations which have a smaller S(1/2)
- Use constrained temperature realizations to constrain phi

Full detail about constrained realizations can be found in Copi, Huterer, Schwarz, Starkman arXiv:1303.4786

Broad Recipe

Use the harmonic coefficients from our realizations
To calculate an input spectrum that we use here

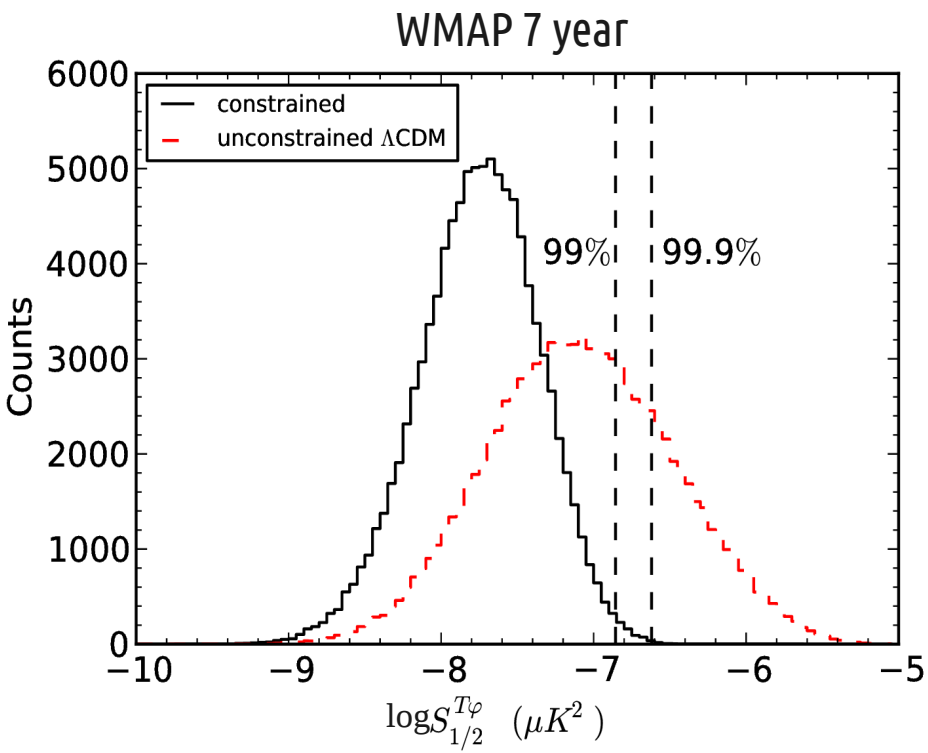
$$C^{T\varphi}(\theta) = \sum_{\ell} \frac{\ell(\ell+1)}{4\pi} C_{\ell}^{T\varphi} P_{\ell}(\cos\theta)$$

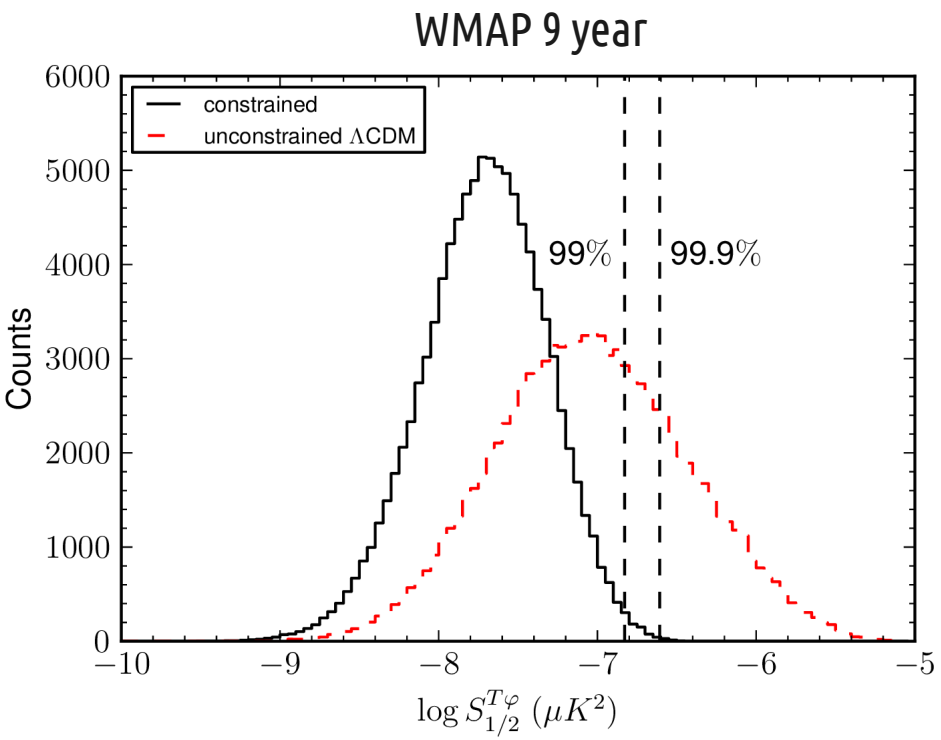
and then we can calculate this

$$S_{1/2}^{T\varphi} = \int_{1/2}^{-1} d(\cos\theta)\, C^{T\varphi}(\theta)^2$$

in order to get a distribution of the statistic for our model.

Statistic Distributions





1.39e-7	Constrained 99% value	1.48e-7
38.3%	% of LCDM above that	39.6%

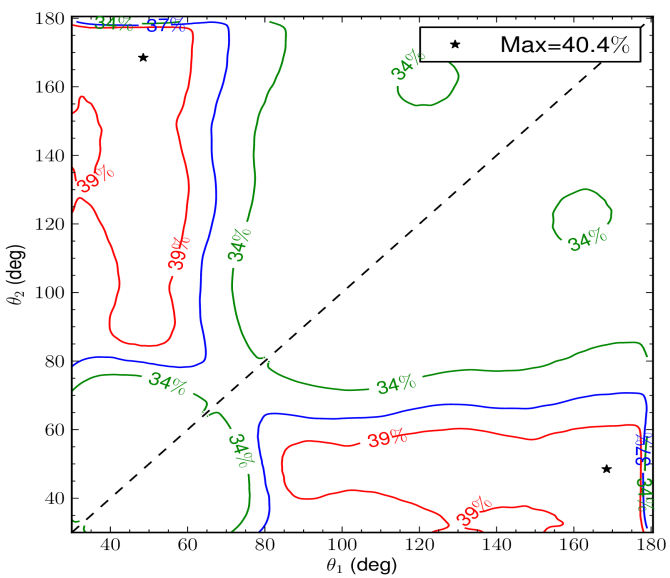
Optimizing Statistics

Maybe S(1/2) isn't the best choice.

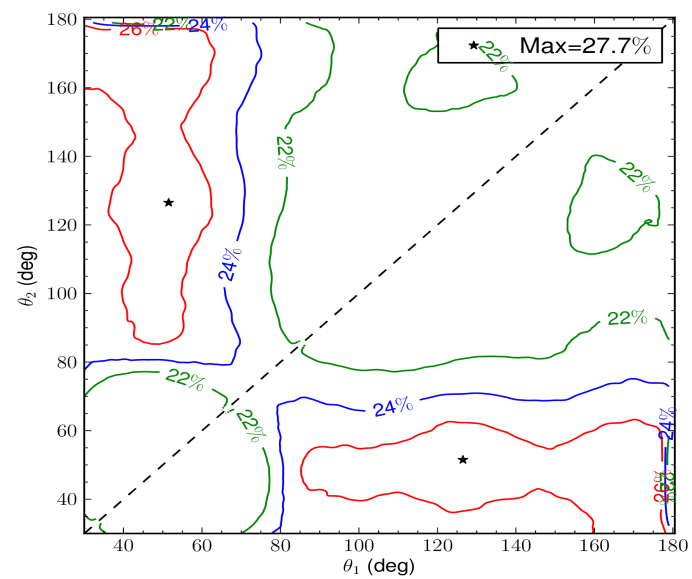
We don't know at what angle constrained realizations (for correlations other than TT) will be suppressed.

$$S^{XY}_{a,b} = \int_a^b \mathrm{d}(\cos\theta)[C^{XY}(\theta)]^2$$

Marginalize over angle to find (*a priori*) the most definitive statistic between LCDM and constrained realizations.

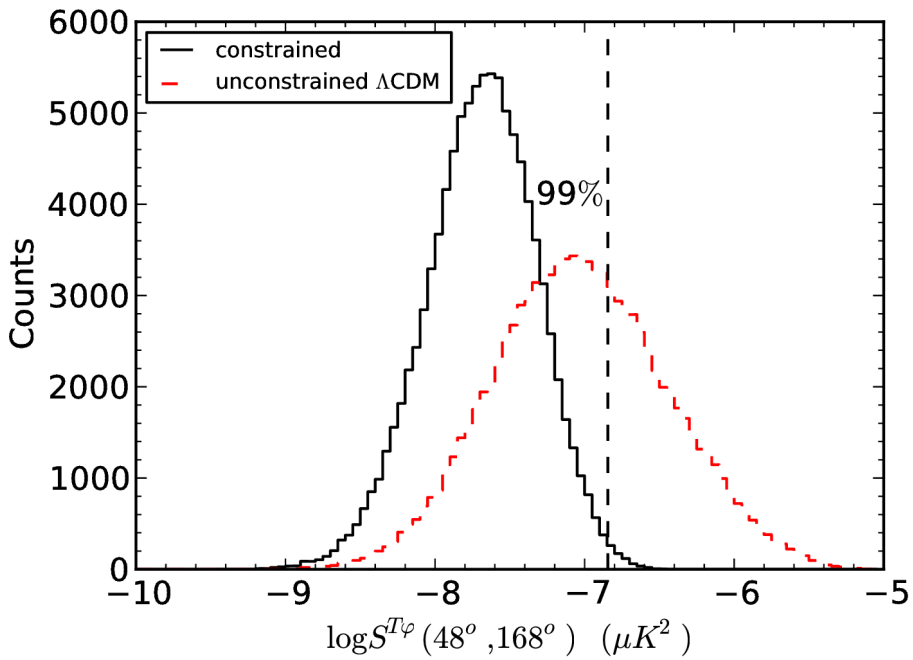


Optimizing for 99% C.L.



Optimizing for 99.9% C.L.

Optimizing Statistics



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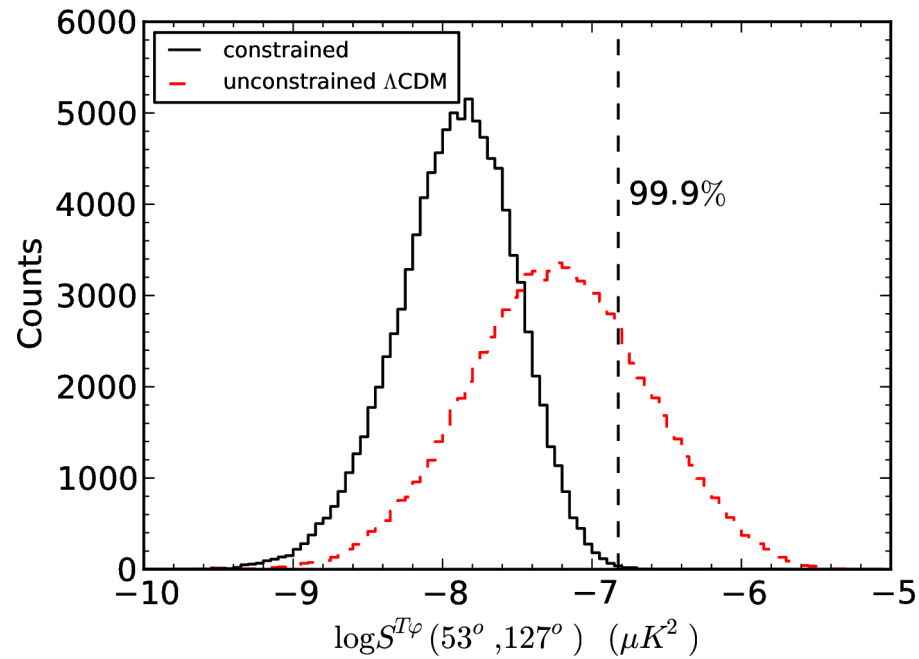

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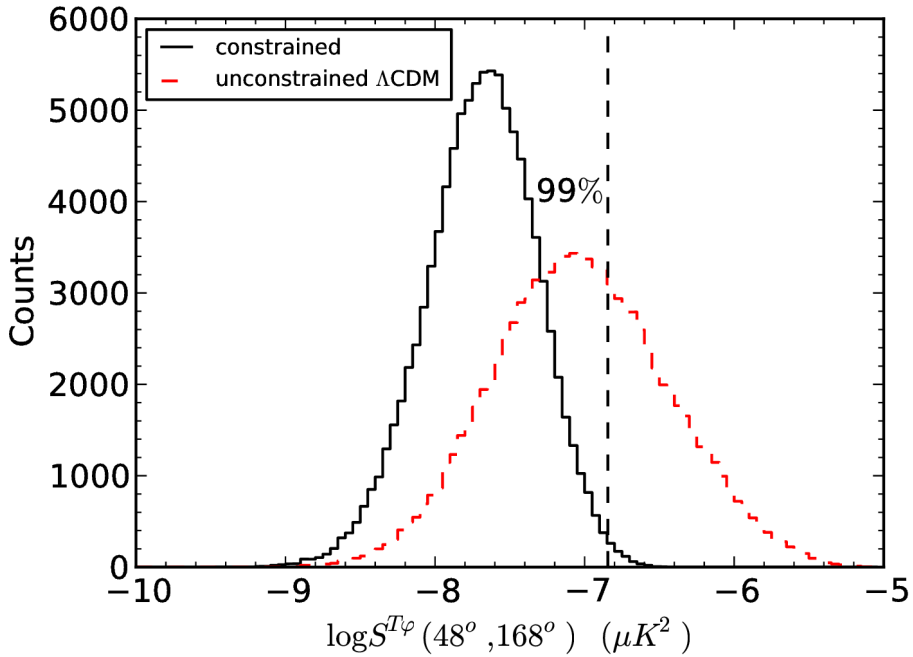

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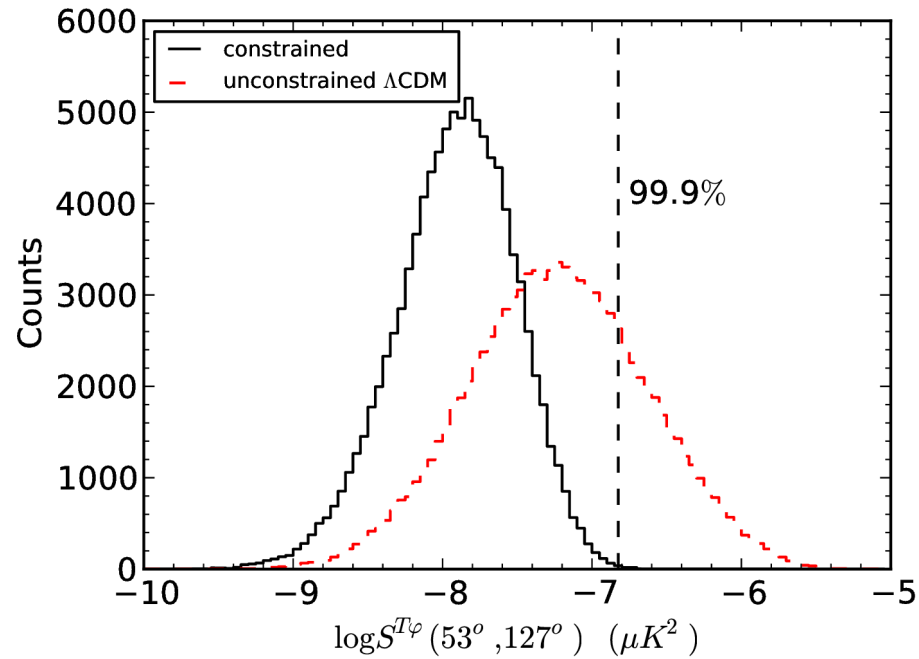


Optimizing for 99.9% C.L.

1.43e-7	Constrained value	1.50e-7
40.4%	% of LCDM above that	27.8%

Summary

The lack of correlation at large angles may point to interesting physics

Numerical analysis of constrained **LCDM** realizations can give us a handle on likelihood of our universe

- Can help characterize whether our realization is a statistical fluke
- We calculate values for S(1/2) for both LCDM and constrained realizations
- Showed that measurement of a large S(1/2) will allow us to rule out null hypothesis at the appropriate confidence level

Statistics can be **optimized** *a priori*

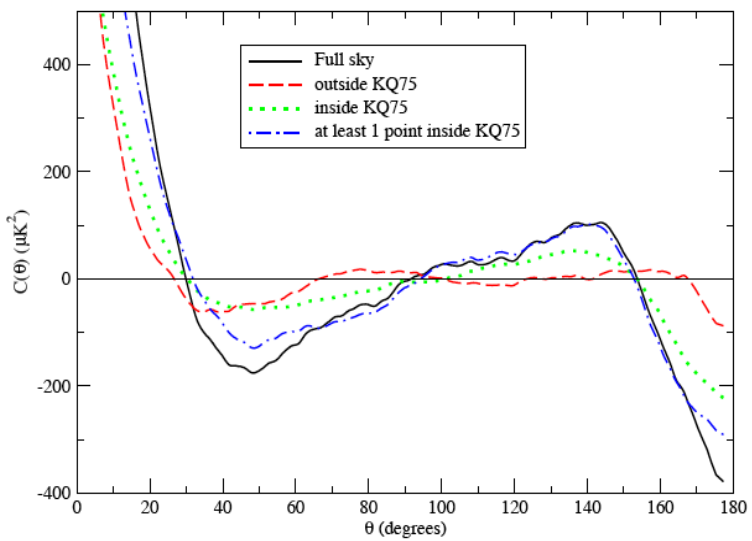
- There may be a more optimal choice for the statistic
- For Temperature and Lensing there is a some improvement over S(1/2)

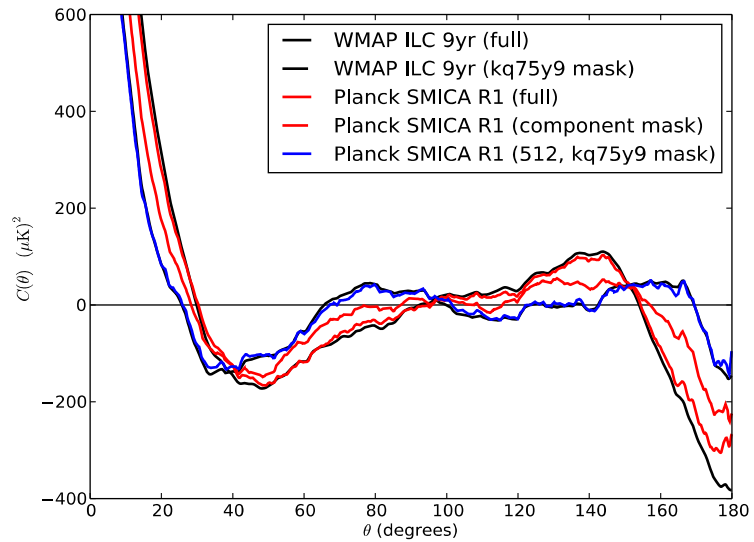
Ongoing work

- Checking viability of other cosmological quantities to provide better tests
- Provide theoretical prediction for shape of ACF with a length-scale cutoff

An aside: Why a cut sky?

The reported values for S(1/2) are very different from cut sky maps versus reconstructed ILC maps





If you trust the full-sky reconstruction, ALL of the correlation for angles larger than 60 degrees comes from behind the galaxy.

$S_{1/2}$ on a cut-sky just means $C(\theta)$ is calculated with $\tilde{C}_\ell$