Investigating the Origin of the Lack of Correlation at Large-Angles in the CMB with Temperature and Lensing

Amanda Yoho | Case Western Reserve University

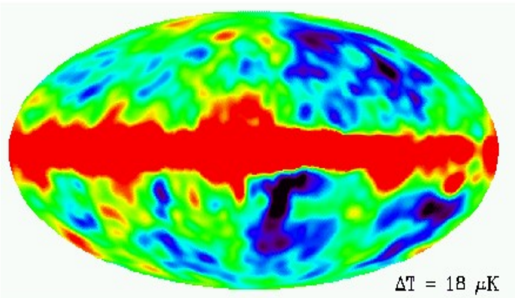
Case Western Reserve University

Glenn D. Starkman
Craig Copi

University of Pittsburgh

Arthur Kosowsky
Simone Aiola
Bingjie Wang

A history of CMB observations



COBE (1992)

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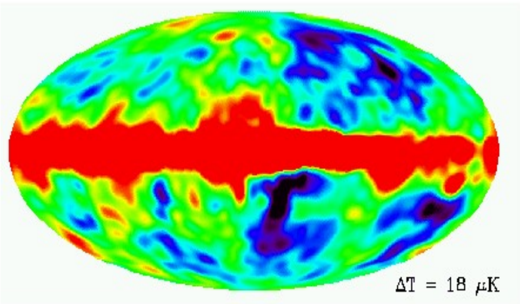

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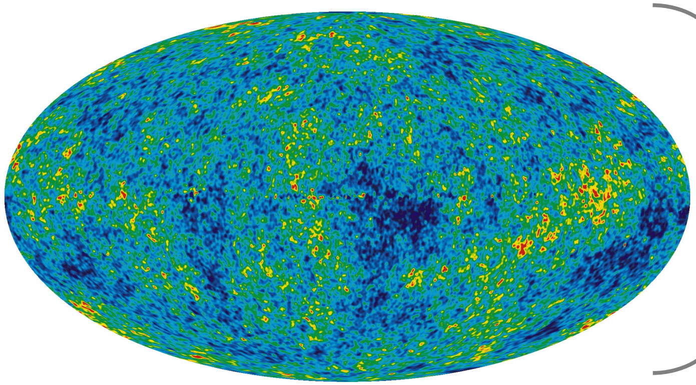

WMAP (2003)

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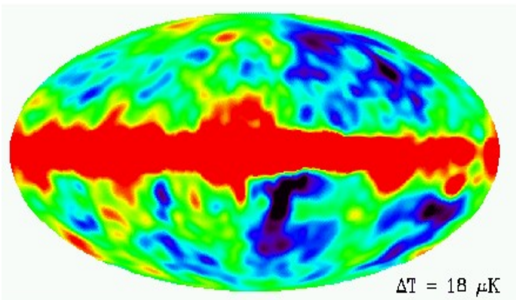

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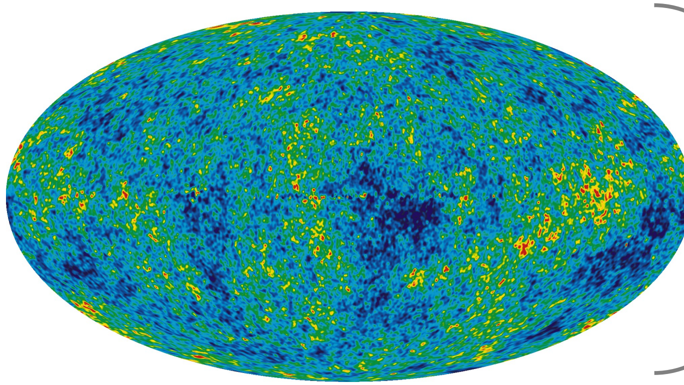

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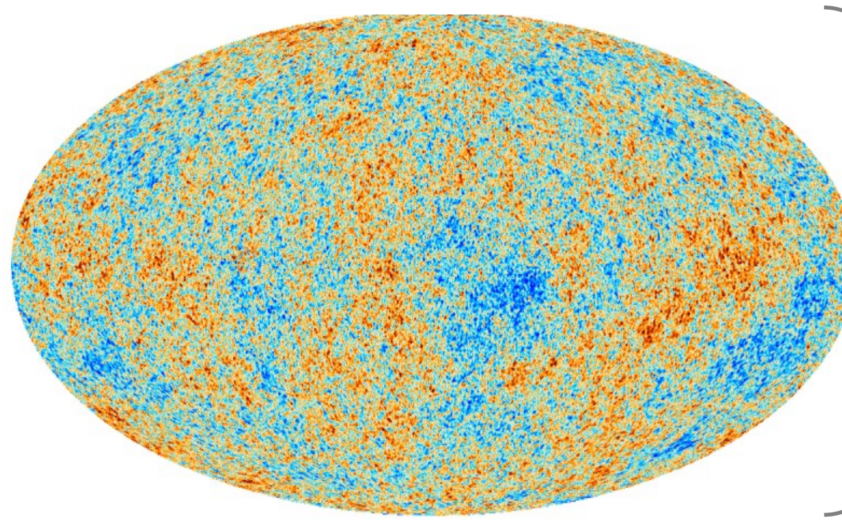
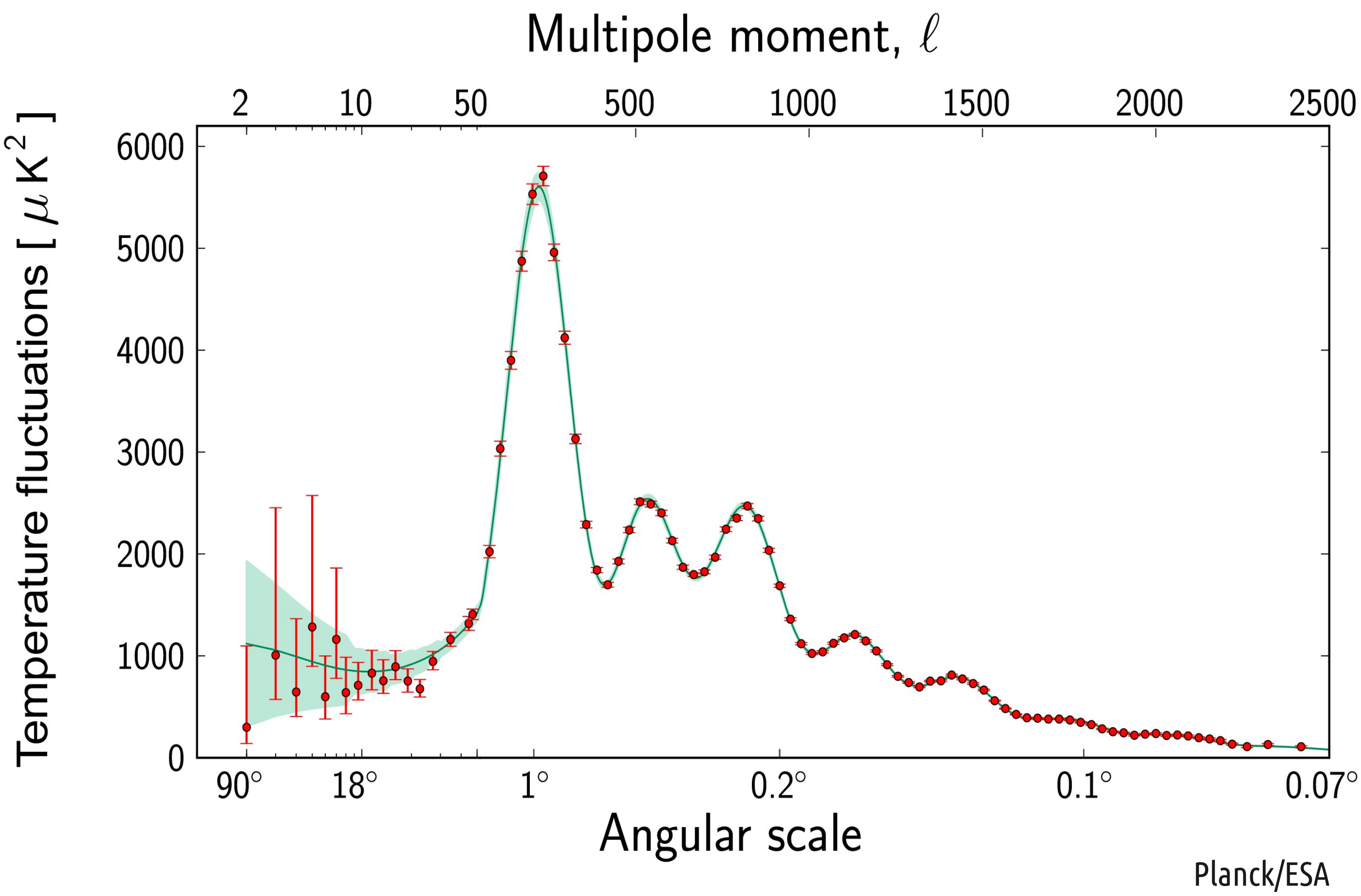


Planck (2013)

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



...but they have also highlighted some interesting discrepancies

Particularly at large angles:

- Quadrupole & Octopole Alignments
- Hemispherical power asymmetry
- Low variance on the sky
- Lack of 2-point correlation

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

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The 2-point Angular Correlation Function

Same CMB temperature data, reorganized

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

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

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

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

$$\Phi(\mathbf{x}, \eta) = \Phi(\mathbf{x})F(\eta)$$

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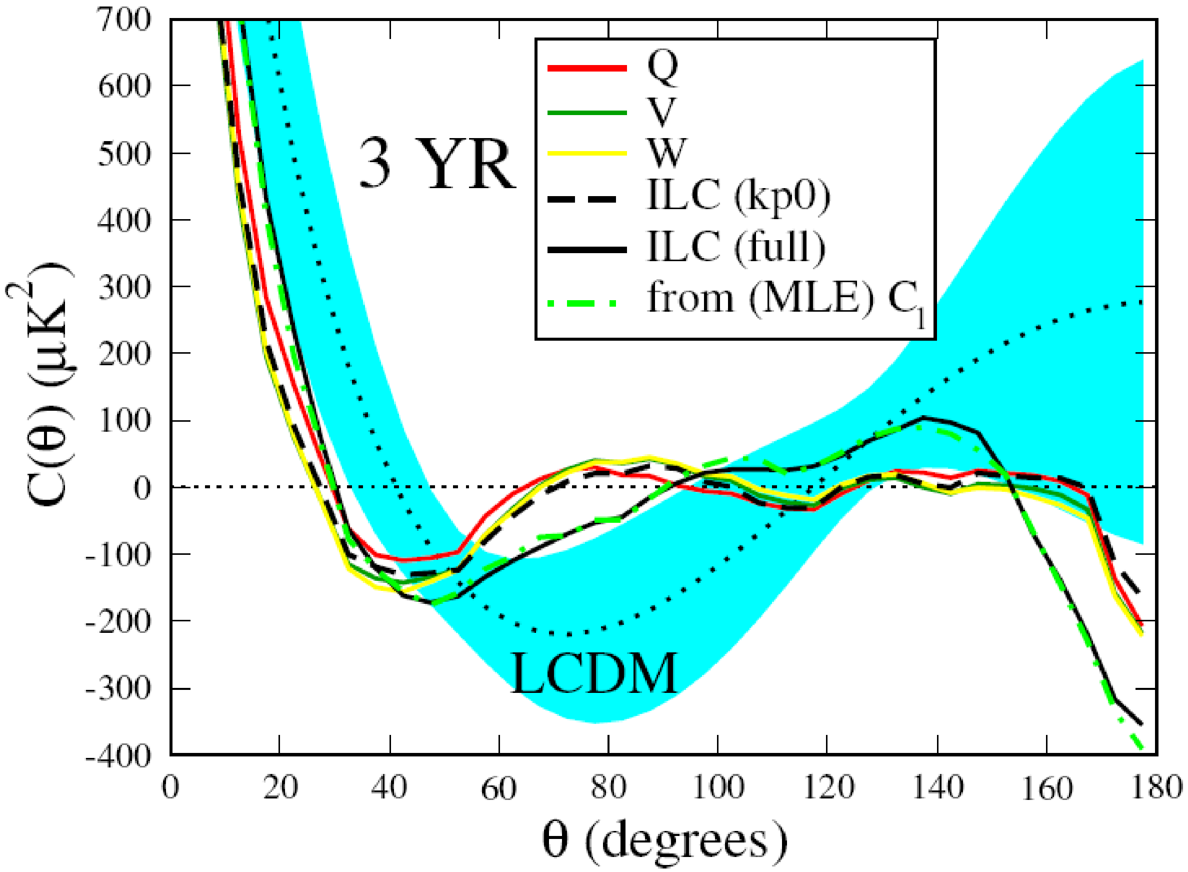
$$C(\theta) = \sum_\ell \frac{\ell(\ell+1)}{4\pi} C_\ell P_\ell(\cos\theta)$$

ACF measurements from WMAP



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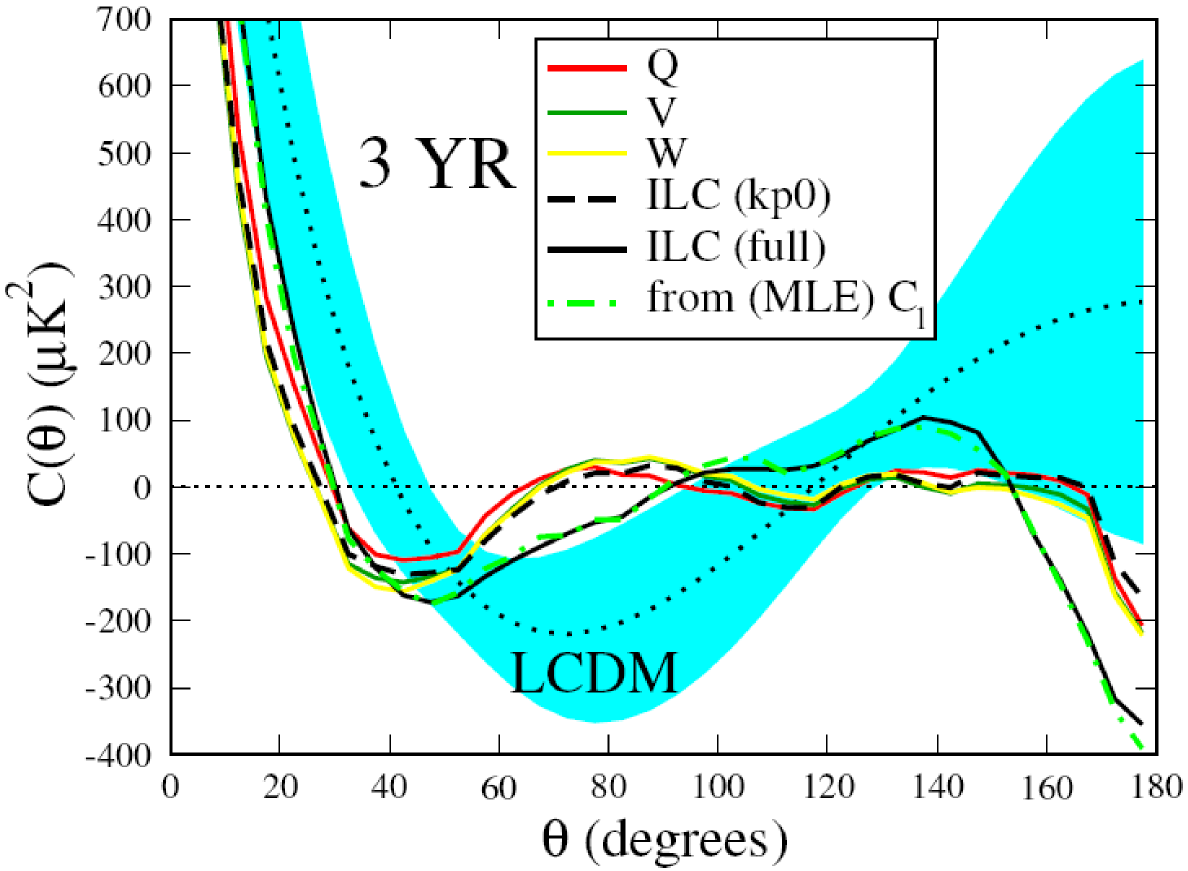

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LCDM value: ~50,000 μK^4

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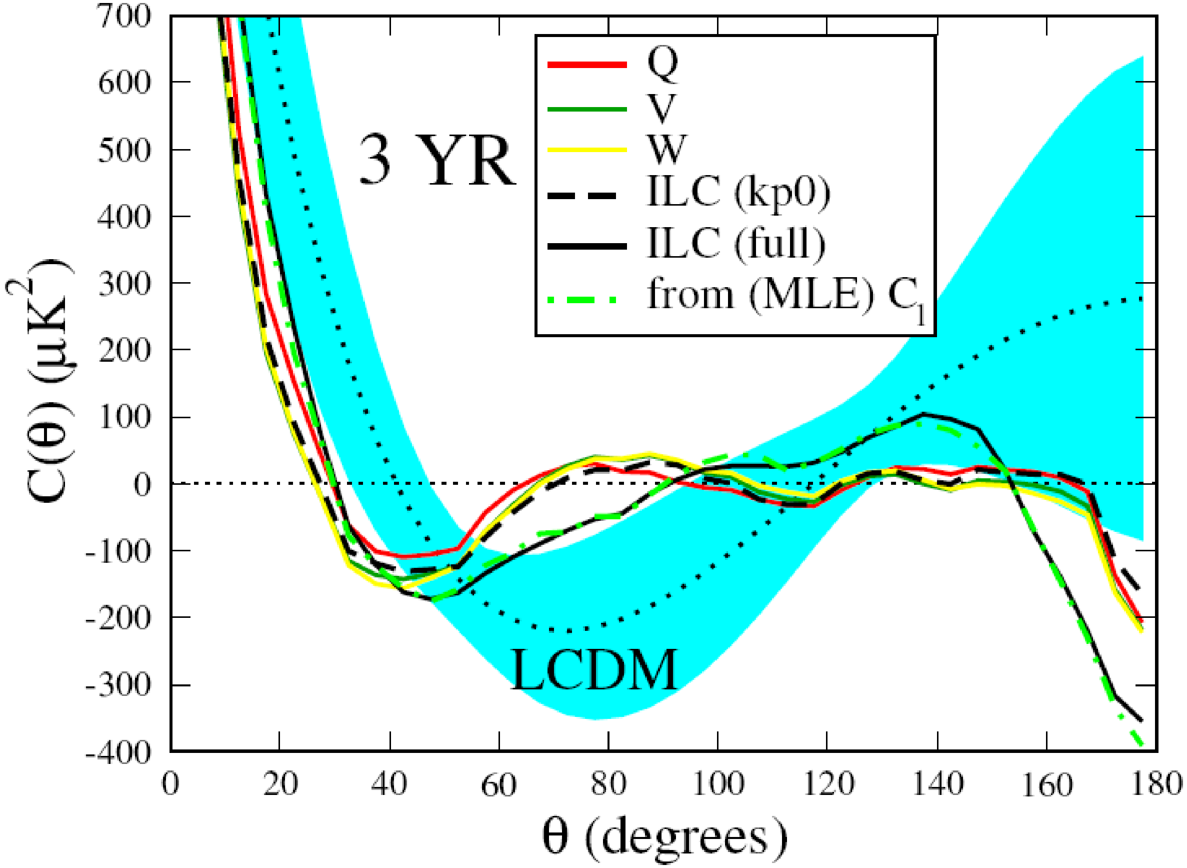

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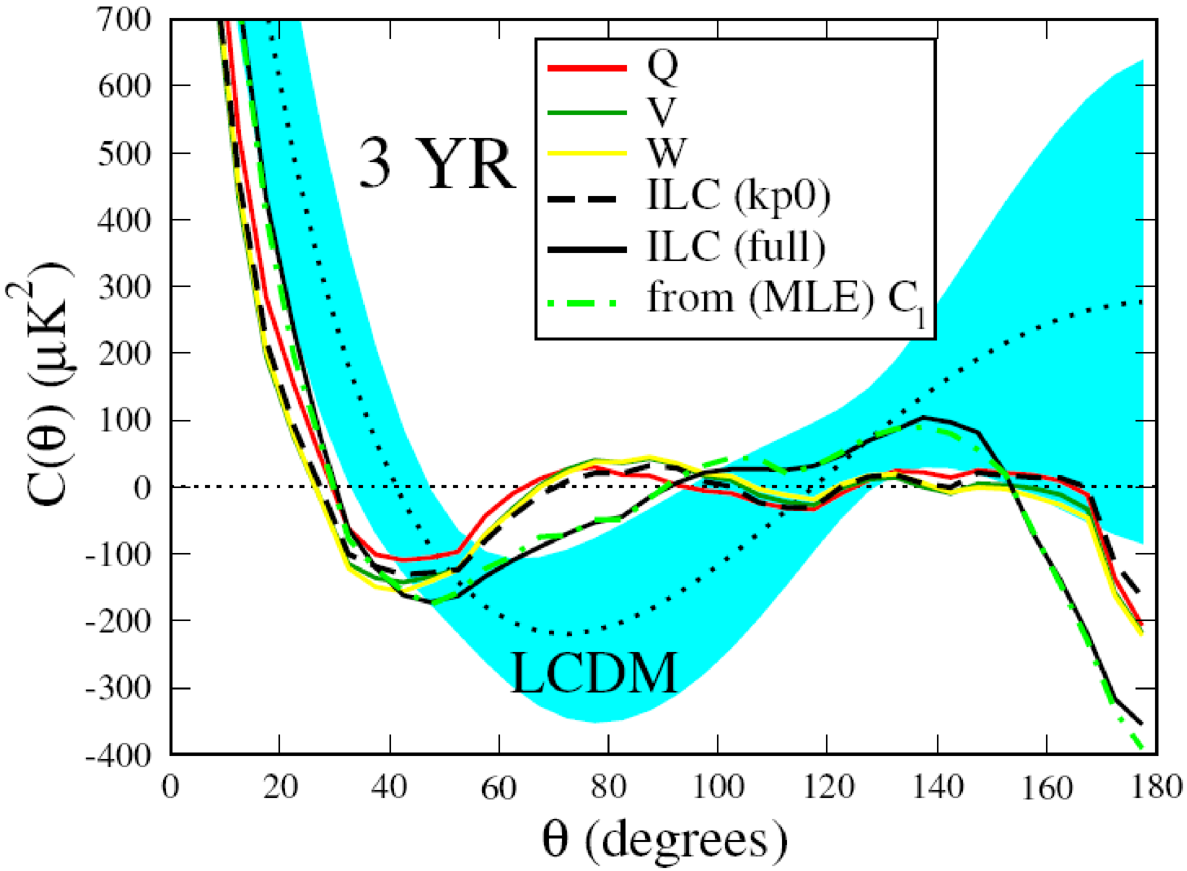

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This is an *a posteriori* statistic

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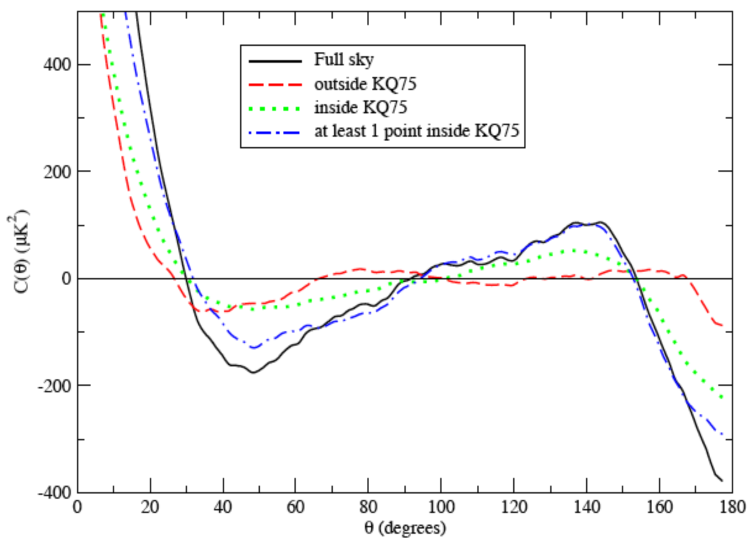
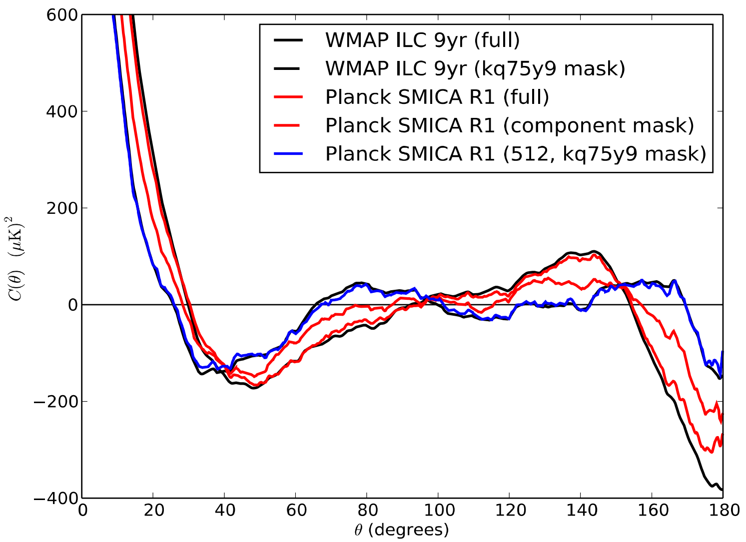
An aside: Why a cut sky?

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

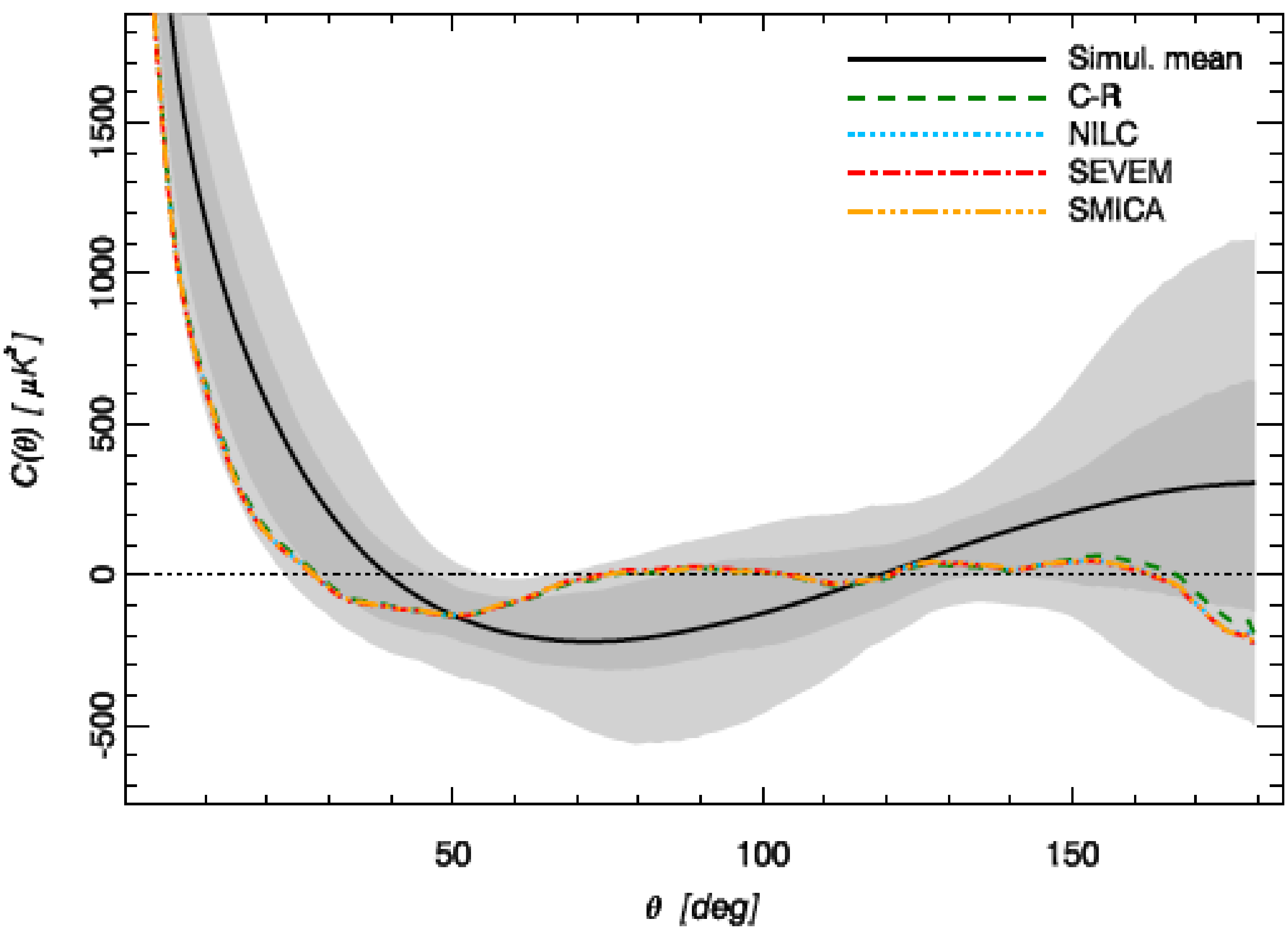




If you trust the full-sky reconstruction, ALL of the correlation for angles larger than 60 degrees comes from behind the galaxy.

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

ACF measurements from Planck



A nice (short) review of the lack of correlation at large angles can be found here -- arXiv:1201.2459

Our goal:

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

What do we mean by “optimal measure?”

We would like a 2-point function which gives
a significant difference for the **predicted**
S(1/2) statistic from LCDM
and some alternative model

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There is a physical mechanism which
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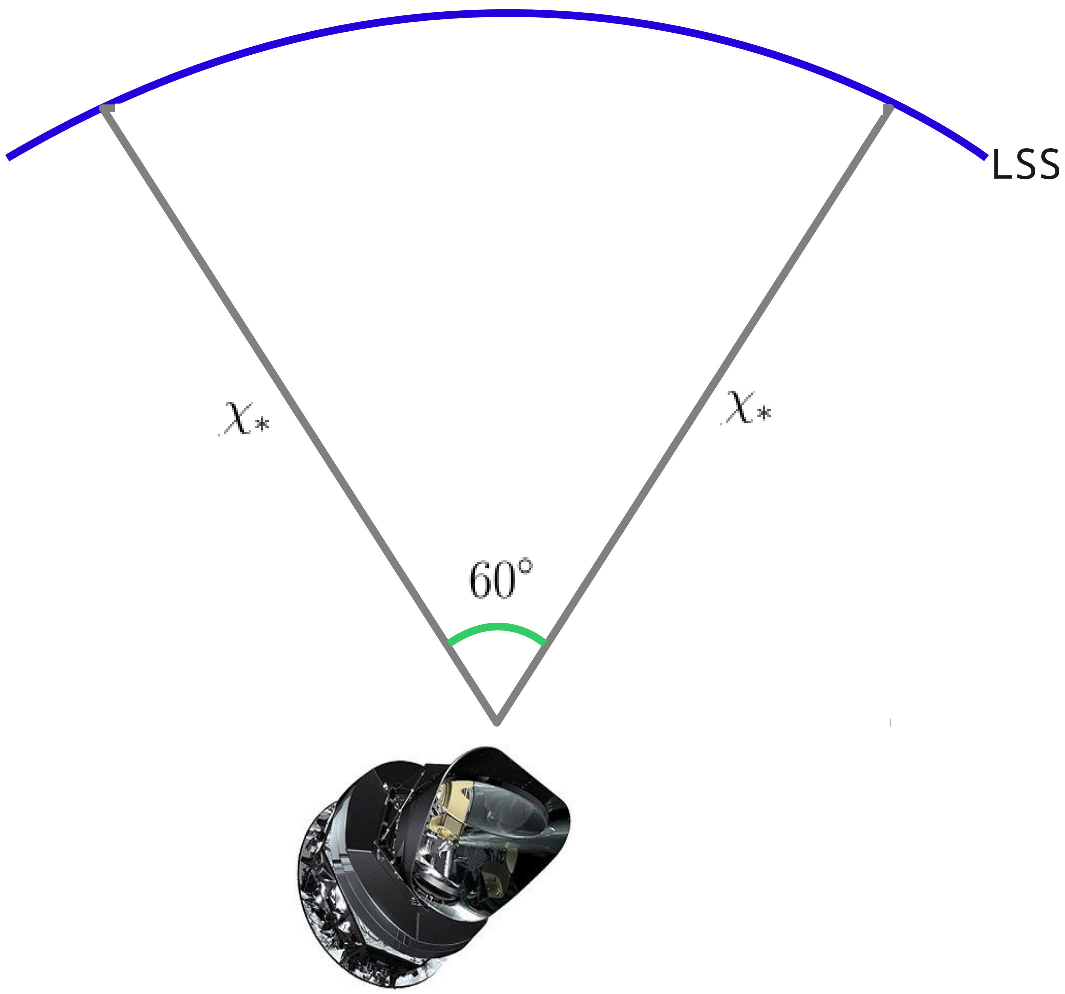
Reminder

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

What is that length scale?



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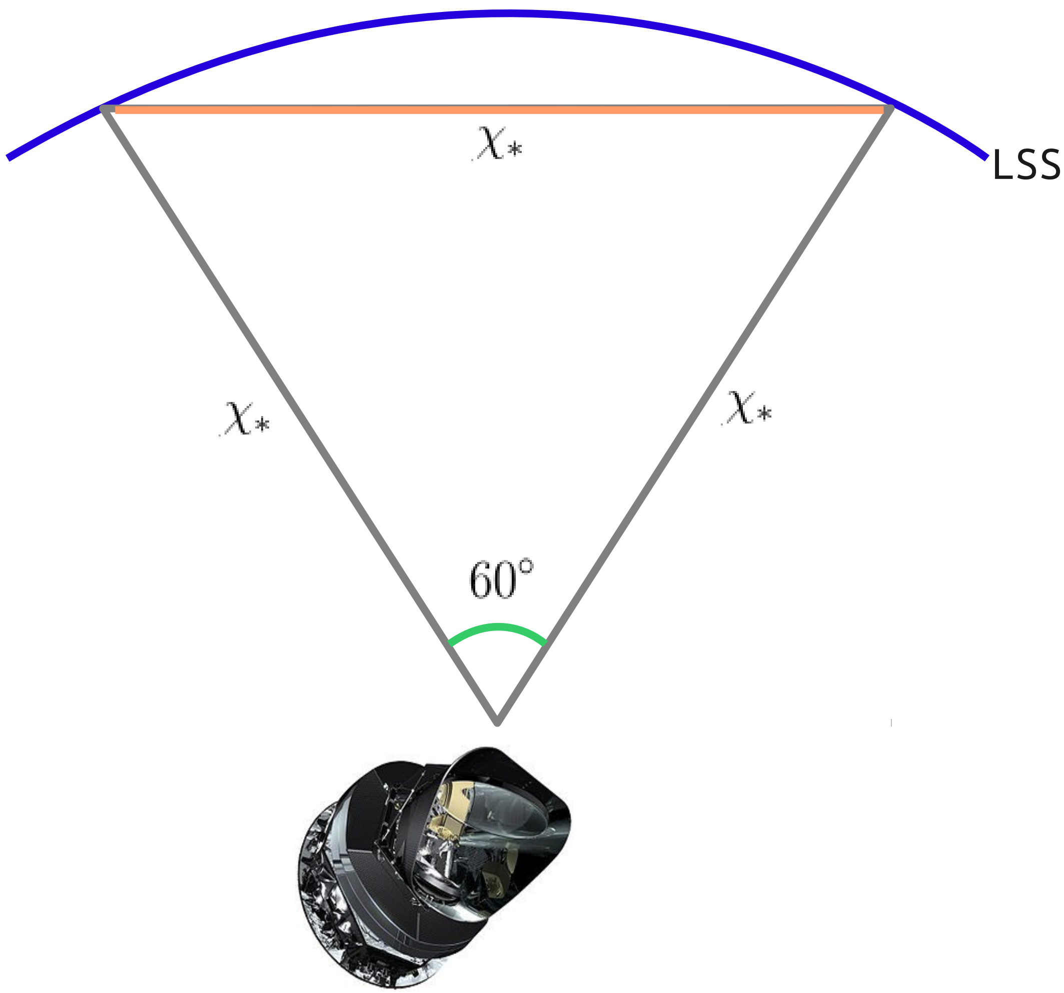
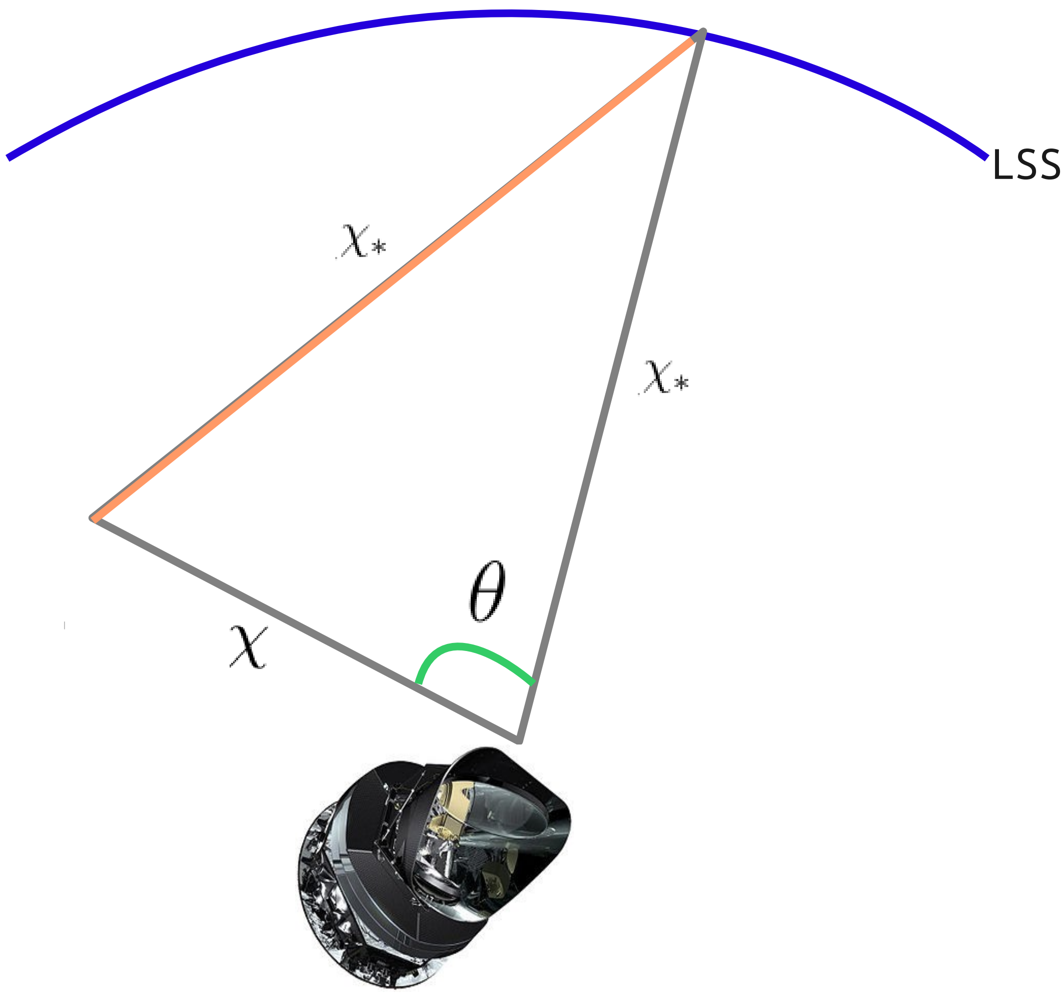


What is that length scale?

We can then investigate other probes of $\langle \Phi_1 \Phi_2 \rangle$
on the interior of our Hubble volume



A way to sample inside our Hubble volume: correlate with the lensing potential

$$\varphi = 2\int_0^{\chi_*} d\chi \,\frac{\chi_* - \chi}{\chi_*\chi}\Phi(\chi\hat{\mathbf{n}}, \chi)$$

$$C^{T\varphi}(\theta) = \langle\varphi(\hat{\mathbf{n}}_\mathbf{1})\,\Theta_{SW}(\hat{\mathbf{n}}_\mathbf{2})\rangle + \langle\varphi(\hat{\mathbf{n}}_\mathbf{1})\,\Theta_{ISW}(\hat{\mathbf{n}}_\mathbf{2})\rangle$$

$$C^{T\varphi}(\theta) = -\frac{2}{3}F(\eta_0 - \chi_*)\int_0^{\chi_*} d\chi_1 F(\eta_0 - \chi_1)\frac{\chi_* - \chi_1}{\chi_*\chi_1}\langle\Phi(\chi_1\hat{\mathbf{n}}_\mathbf{1})\,\Phi(\chi_*\hat{\mathbf{n}}_\mathbf{2})\rangle$$

$$-4\int_0^{\chi_*} d\chi_1 \int_0^{\chi_*} d\chi_2 F(\eta_0 - \chi_1)\frac{dF}{d\eta}(\eta_0 - \chi_2)\frac{\chi_* - \chi_1}{\chi_*\chi_1}\langle\Phi(\chi_1\hat{\mathbf{n}}_\mathbf{1})\,\Phi(\chi_2\hat{\mathbf{n}}_\mathbf{2})\rangle$$

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ALSO:

We need quantities that will provide the best opportunity to determine if our CMB is a statistical anomaly or if the feature is due to primordial 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
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We want to mimic the lack of large-angle auto correlation in temperature
AND
have a power spectrum that is consistent with measurements

- 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)

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

Coupled realizations for quantities beyond temperature

Your cosmology should come from the same universe.

$$a_{\ell m}^{T} = \sqrt{C_\ell^{TT}}\,\xi_1$$

$$a_{\ell m}^{\varphi} = \frac{C_\ell^{T\varphi}}{\sqrt{C_\ell^{TT}}}\xi_1 + \left(C_\ell^{\varphi\varphi} - \frac{(C_\ell^{T\varphi})^2}{C_\ell^{TT}} \right)^{1/2} \xi_2$$

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Broad Recipe

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

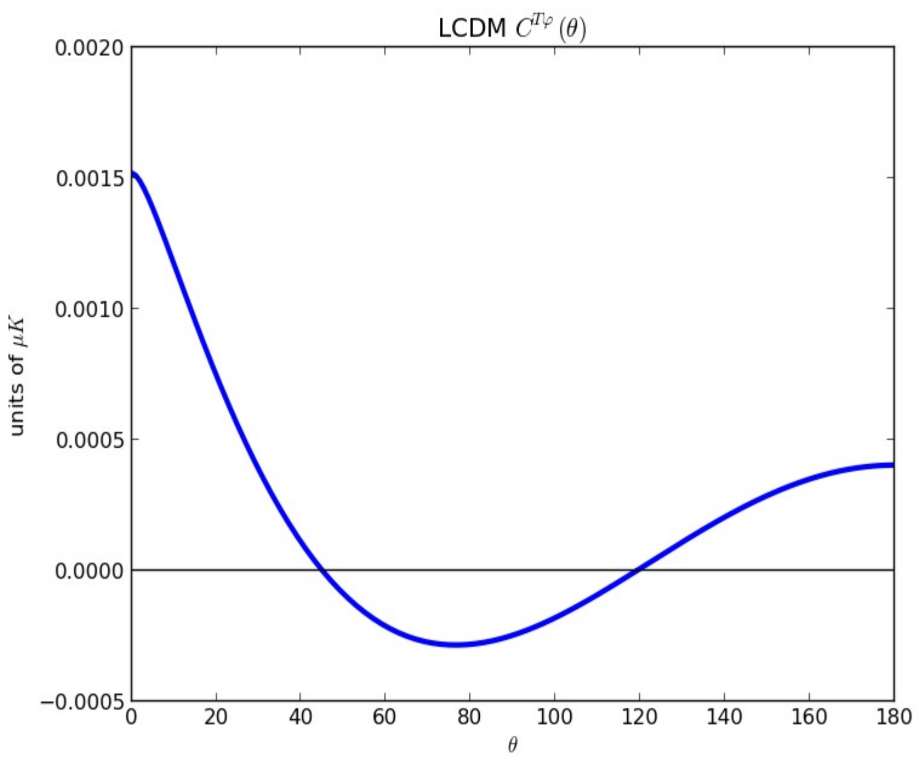
$$C^{T\varphi}(\theta) = \sum_{\ell} \frac{\ell(\ell+1)}{4\pi} C_{\ell}^{T\varphi} P_{\ell}(\cos\theta)$$

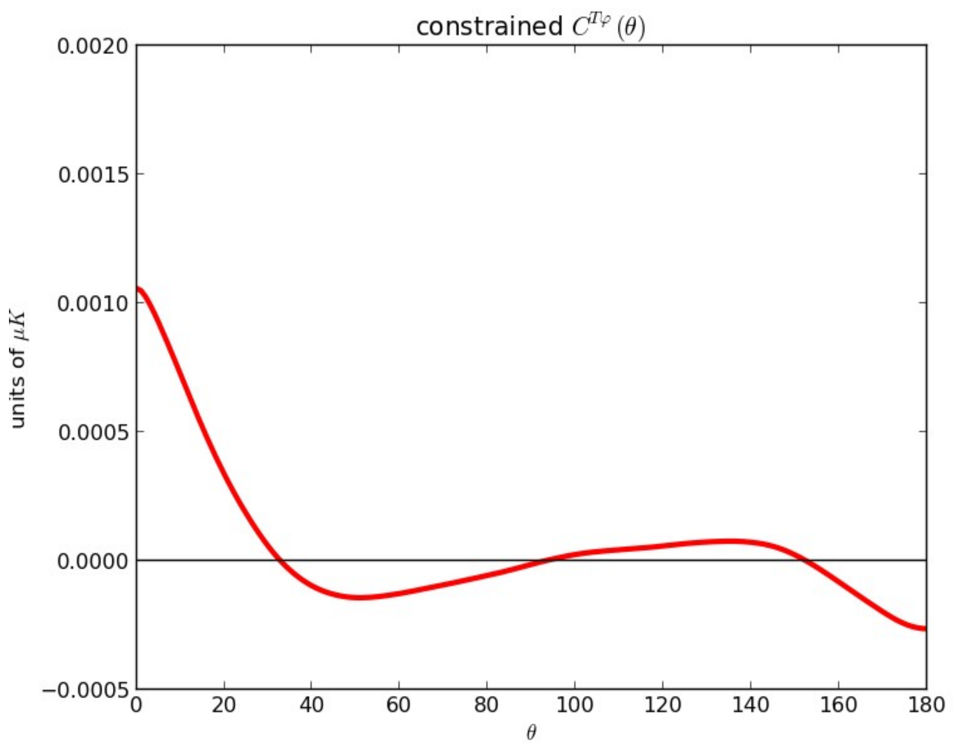
and then we can calculate this

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

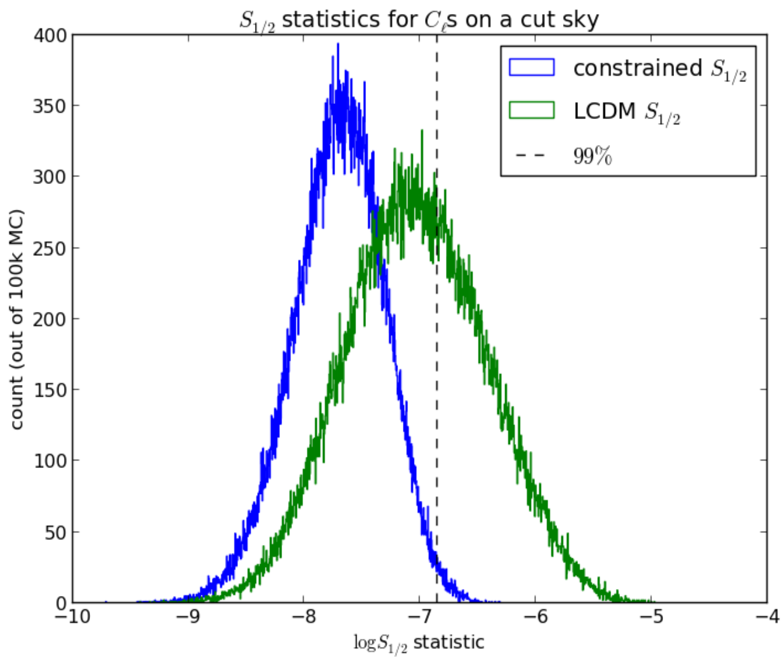
in order to get a distribution of the statistic for our model.

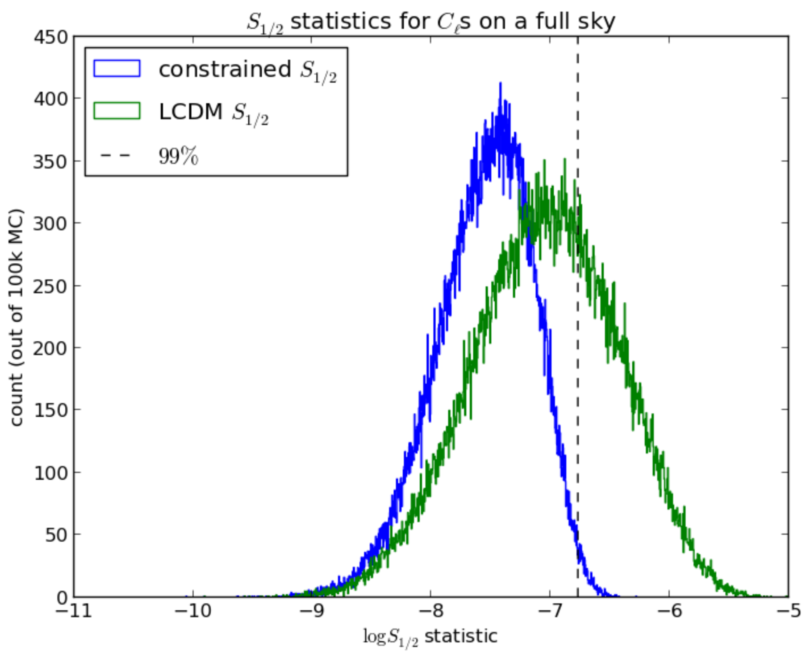
Tφ Correlation Functions





Statistic Distributions

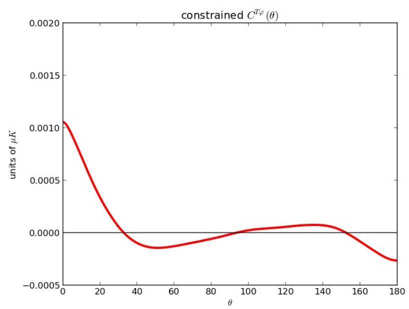




Cut sky		Full sky
1.39e-7	Constrained 99% value	1.69e-7
38.3%	% of LCDM above that	33.5%

Ongoing work

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.

$$S_x = \int_x^{-1} d(\cos\theta)\, C(\theta)^2$$

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

Provide a theoretical prediction for $C^{T\varphi}(\theta)$ in a universe that has a cutoff in $\langle \Phi_1 \Phi_2 \rangle$ to compare (eventually) to data

Summary

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

Proposal: comes from a cutoff in $\langle \Phi_1 \Phi_2 \rangle$ at a specific length scale

- We need to add information beyond Temperature to move forward
- Correlating temperature with the lensing potential accesses same physics

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Ongoing work

- Provide theoretical prediction for shape of ACF with a length-scale cutoff
- Investigate S(x) statistic for numerical realizations and theory

Look for our work on the arXiv in the next few weeks