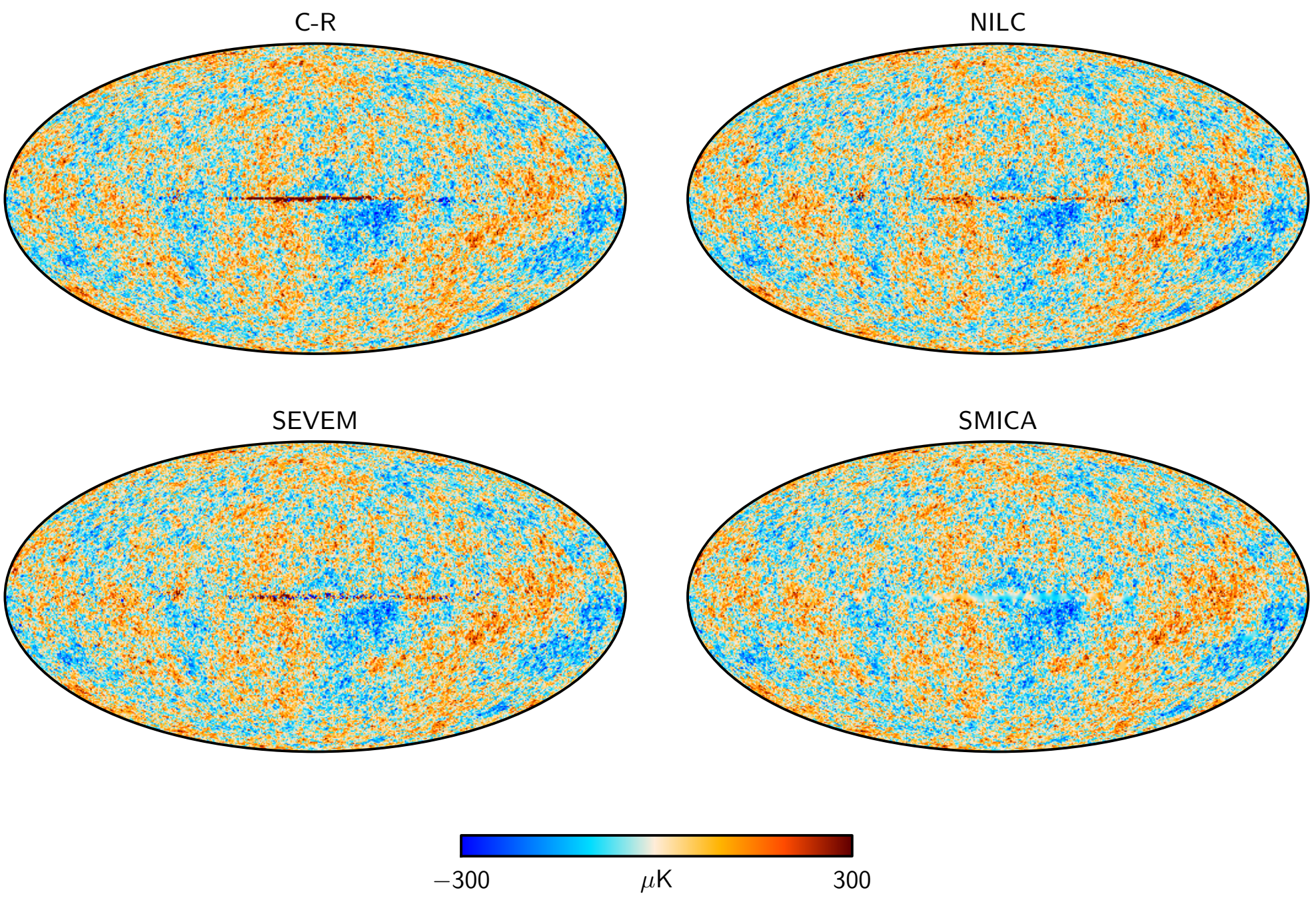
CMB anomalies
(in WMAP9 and Planck)

Dragan Huterer

Physics Department

University of Michigan

Copi, Huterer, Schwarz & Starkman
– arXiv:1310.3831 (low power)
– arXiv:1311.4862 (alignments)
review in
Adv. Astro., 847531 (2010), arXiv:1004.5602


C-R
NILC
SEVEM
SMICA
−300
μK
300

Philosophy:

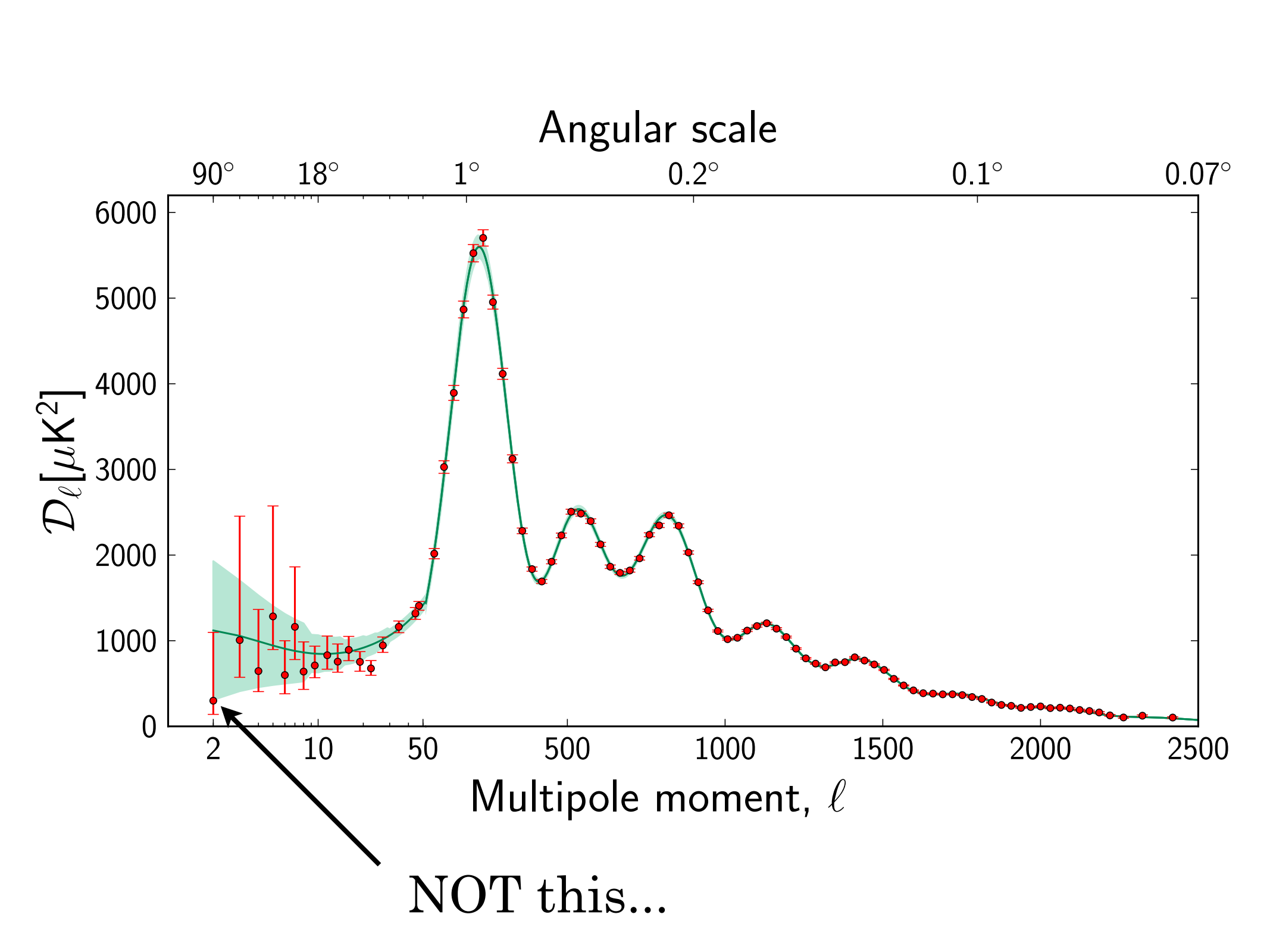
Anomalies are almost always *a posteriori* nature – they are not (*a priori*) predicted

Not every 'anomaly' is equally compelling: in this talk, the **largest-scale** anomalies

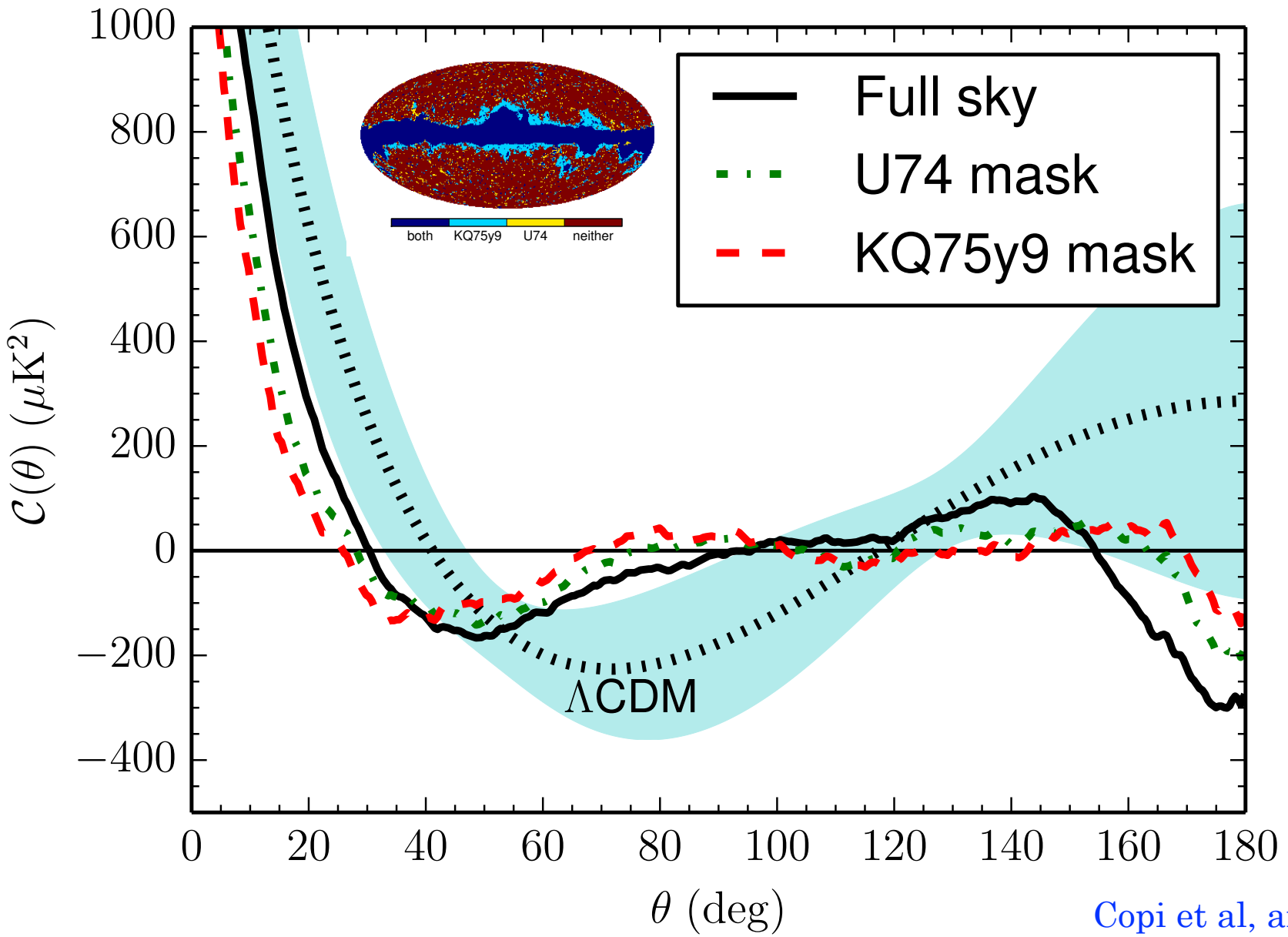
Summary:

1. Angular 2-pt function $C(\theta)$ vanishes for $\theta \gtrsim 60$ deg
2. Quadrupole and octopole are unusually planar, and the plane is nearly perpendicular to some special directions on the sky

Missing Large-Angle Power


Angular scale
90°
18°
1°
0.2°
0.1°
0.07°
6000
5000
4000
3000
2000
1000
0
$\mathcal{D}_\ell [\mu K^2]$
2
10
50
500
1000
1500
2000
2500
Multipole moment, ℓ
NOT this...

Power at θ≳60 deg vanishes in cut-sky maps



Copi et al, arXiv:1310.3831

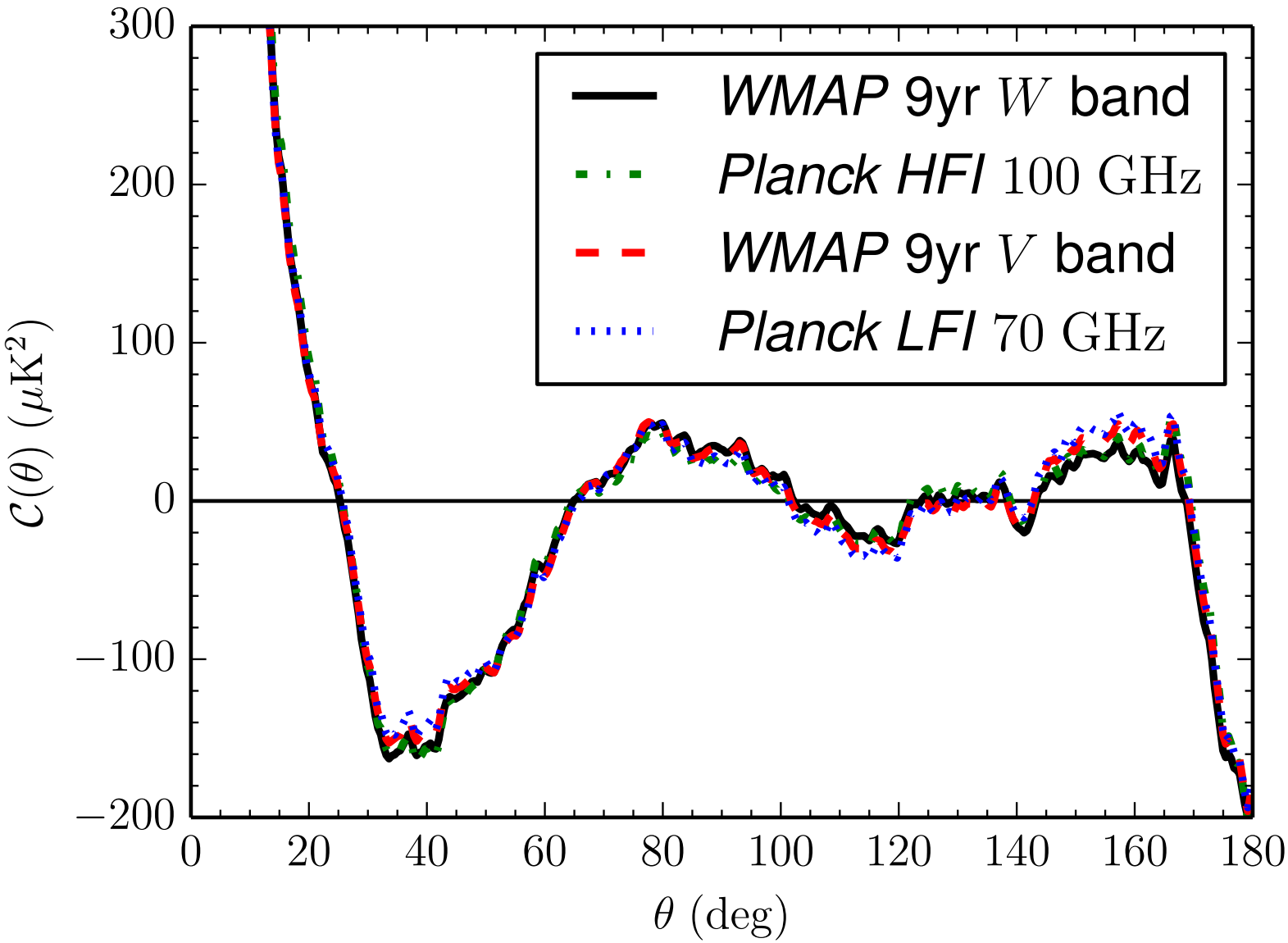
$S_{1/2}$ statistic:
(Spergel et al 2003)

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

	U74		KQ75y9	
Map	$S_{1/2}$ $(\mu\mathrm{K})^4$	p (%)	$S_{1/2}$ $(\mu\mathrm{K})^4$	p (%)
WMAP ILC 7yr	1620.3	0.208	1247.0	0.090
WMAP ILC 9yr	1677.5	0.232	1311.8	0.109
Planck SMICA	1606.3	0.202	1075.5	0.053
Planck NILC	1618.6	0.208	1096.2	0.058
Planck SEVEM	1692.4	0.239	1210.5	0.082
WMAP W 7yr	1839.0	0.304	1128.5	0.064
WMAP W 9yr	1864.2	0.317	1138.3	0.066
Planck HFI 100	1707.5	0.245	916.3	0.028
WMAP V 7yr	1829.2	0.300	1276.2	0.099
WMAP V 9yr	1840.4	0.304	1268.8	0.097
Planck LFI 70	1801.7	0.287	1282.1	0.101

(frequentist) significance $\geq 99.7\%$ in all cases

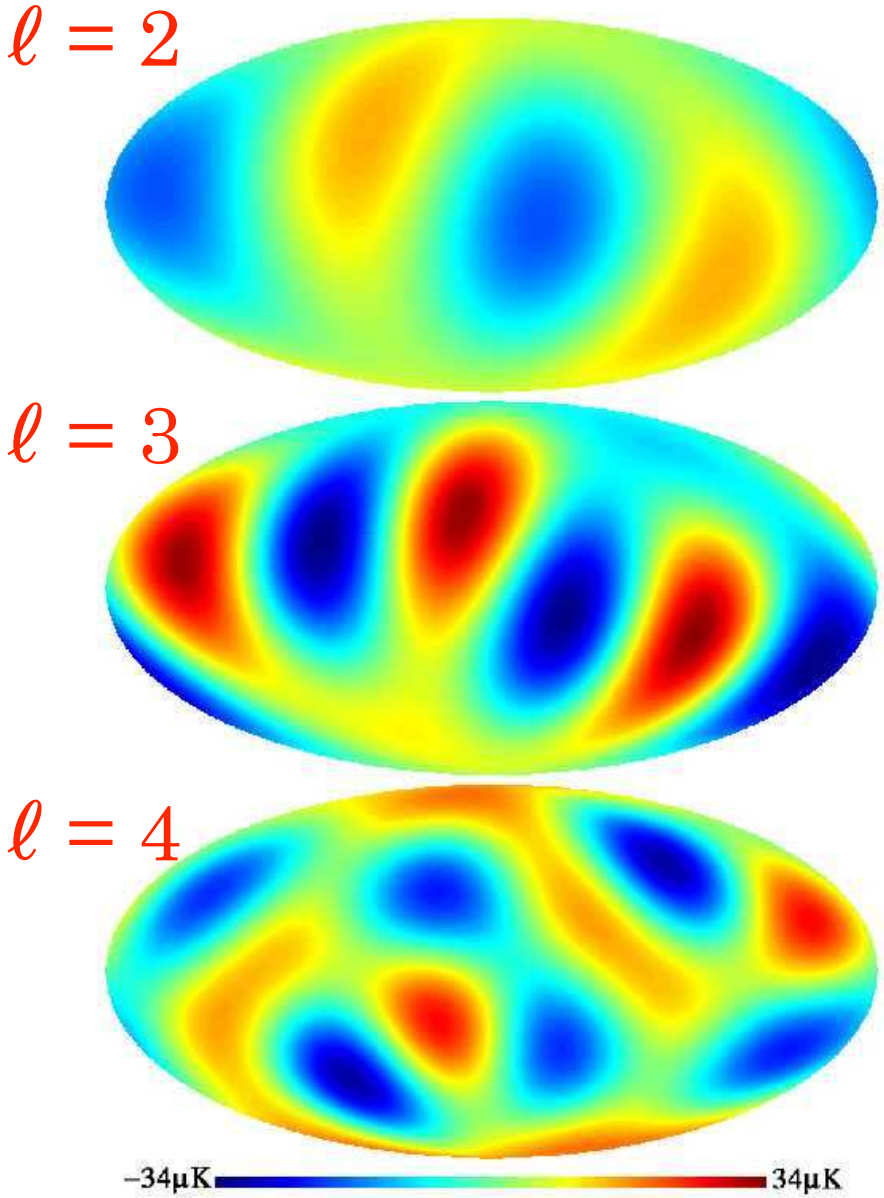
Remarkably consistent across experiments, frequencies, foreground cleanings:



$\Rightarrow$ primordial? or a statistical fluke?

Large-scale alignments

$\ell = 2, 3$ are aligned and planar



$$\hat{L}_\ell^2 \equiv \frac{\sum_{m=-\ell}^{\ell} m^2 \left|a_{\ell m}\right|^2}{\ell^2 \sum_{m=-\ell}^{\ell} \left|a_{\ell m}\right|^2}$$

ℓ=3 is planar: P~1/20

ℓ=2,3 is are aligned: P~1/60

de Oliveira-Costa, Tegmark, Zaldarriaga & Hamilton 2004

... and still are

Map	Uncorrected		DQ corrected	
	$\lvert\hat{\boldsymbol{n}}_2 \cdot \hat{\boldsymbol{n}}_3\rvert$	p-value (%)	$\lvert\hat{\boldsymbol{n}}_2 \cdot \hat{\boldsymbol{n}}_3\rvert$	p-value (%)
WMAP ILC 7yr	0.9999	0.006	0.9966	0.327
WMAP ILC 9yr	0.9985	0.150	0.9948	0.511
Planck NILC	0.9902	0.955	0.9988	0.118
Planck SEVEM	0.9915	0.825	0.9995	0.055
Planck SMICA	0.9809	1.883	0.9965	0.338

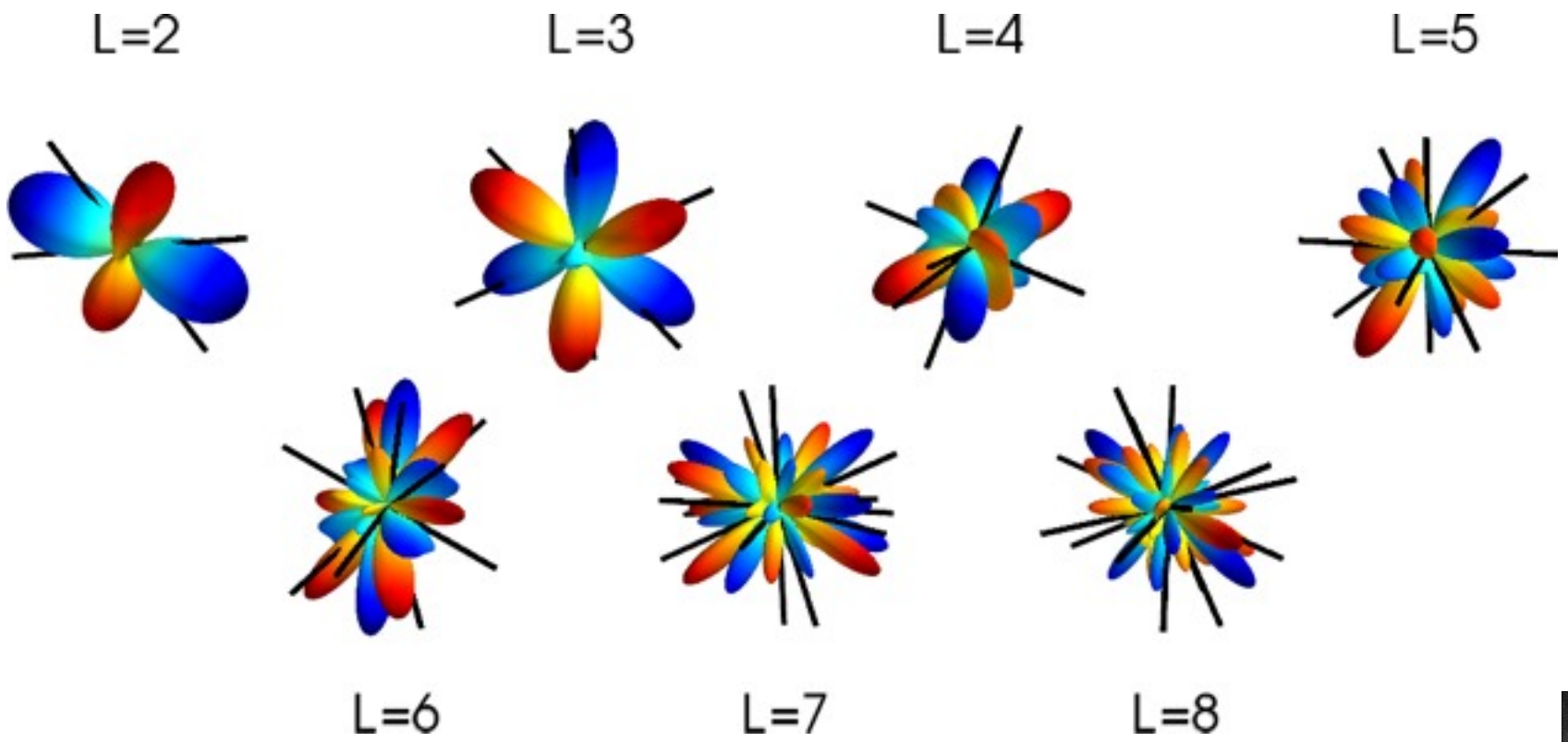
- Based on 10^6 simulated maps
- We inpaint Planck maps with Galactic cuts - numerically heavy part of calculation
- Correcting for the kinematic quadrupole (DQ) is important

Copi et al, arXiv:1311.4862

Multipole vectors

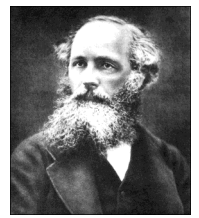
L^{th} multipole $\Leftrightarrow$ L (headless) vectors, and a constant

$$\sum_{m=-\ell}^{\ell} a_{lm} Y_{lm}(\theta,\phi) = A^{(\ell)} \left(\mathbf{v}_1^{(\ell)} \cdot \mathbf{e}\right) \cdots \left(\mathbf{v}_\ell^{(\ell)} \cdot \mathbf{e}\right)$$

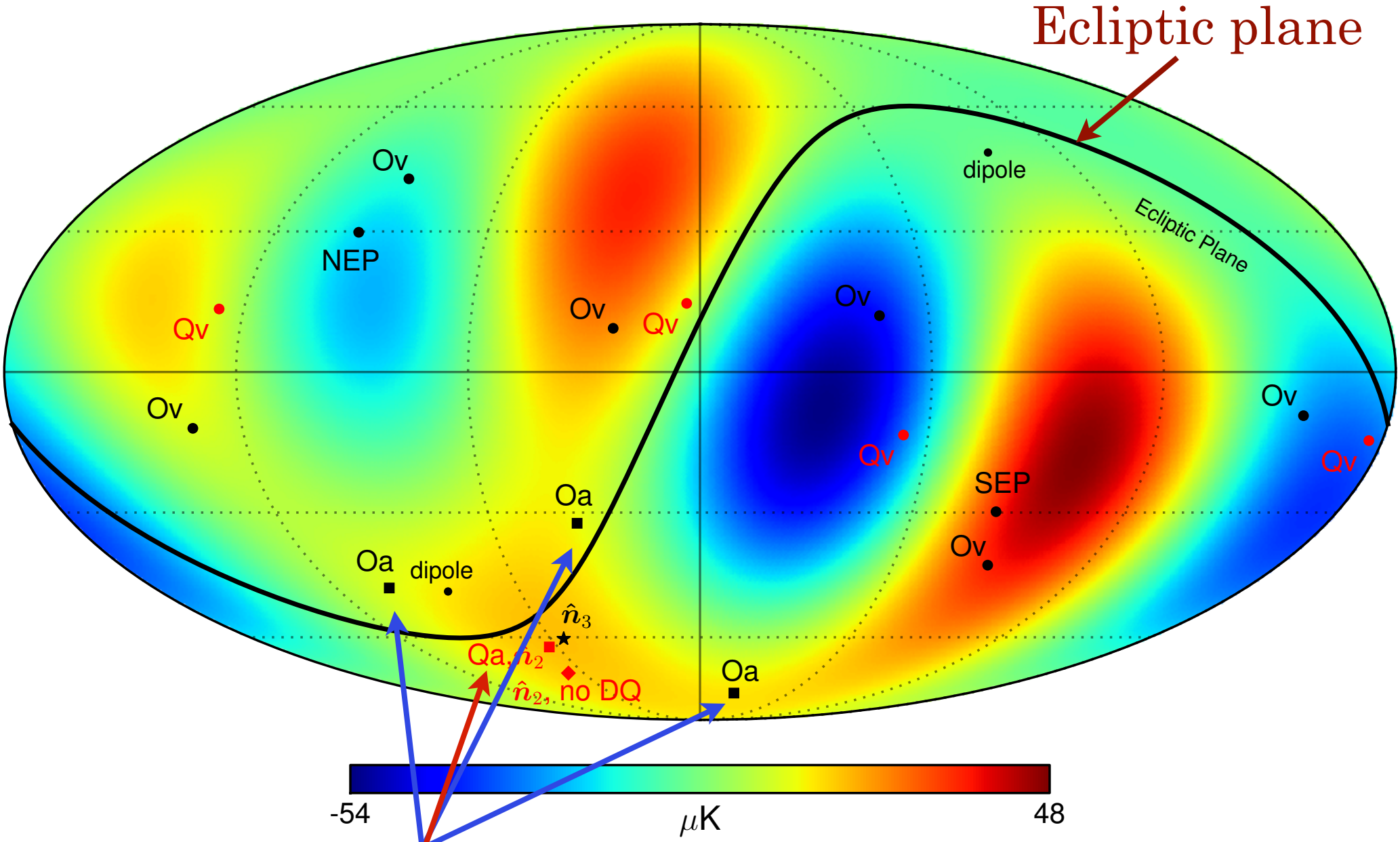


Copi, Huterer & Starkman 2003; http://www.phys.cwru.edu/projects/mpvectors/

J.C. Maxwell, "Treatise on Electricity and Magnetism", 1873



L=2+3 map


Ecliptic plane
Ov
NEP
Qv
Ov
Qv
Ov
dipole
Ecliptic Plane
Ov
Qv
Ov
Qv
SEP
Ov
Oa
Oa
dipole
$\hat{n}_3$
Qa, $\hat{n}_2$
$\hat{n}_2$, no DQ
Oa
-54
μK
48
Normals to quad, octopole

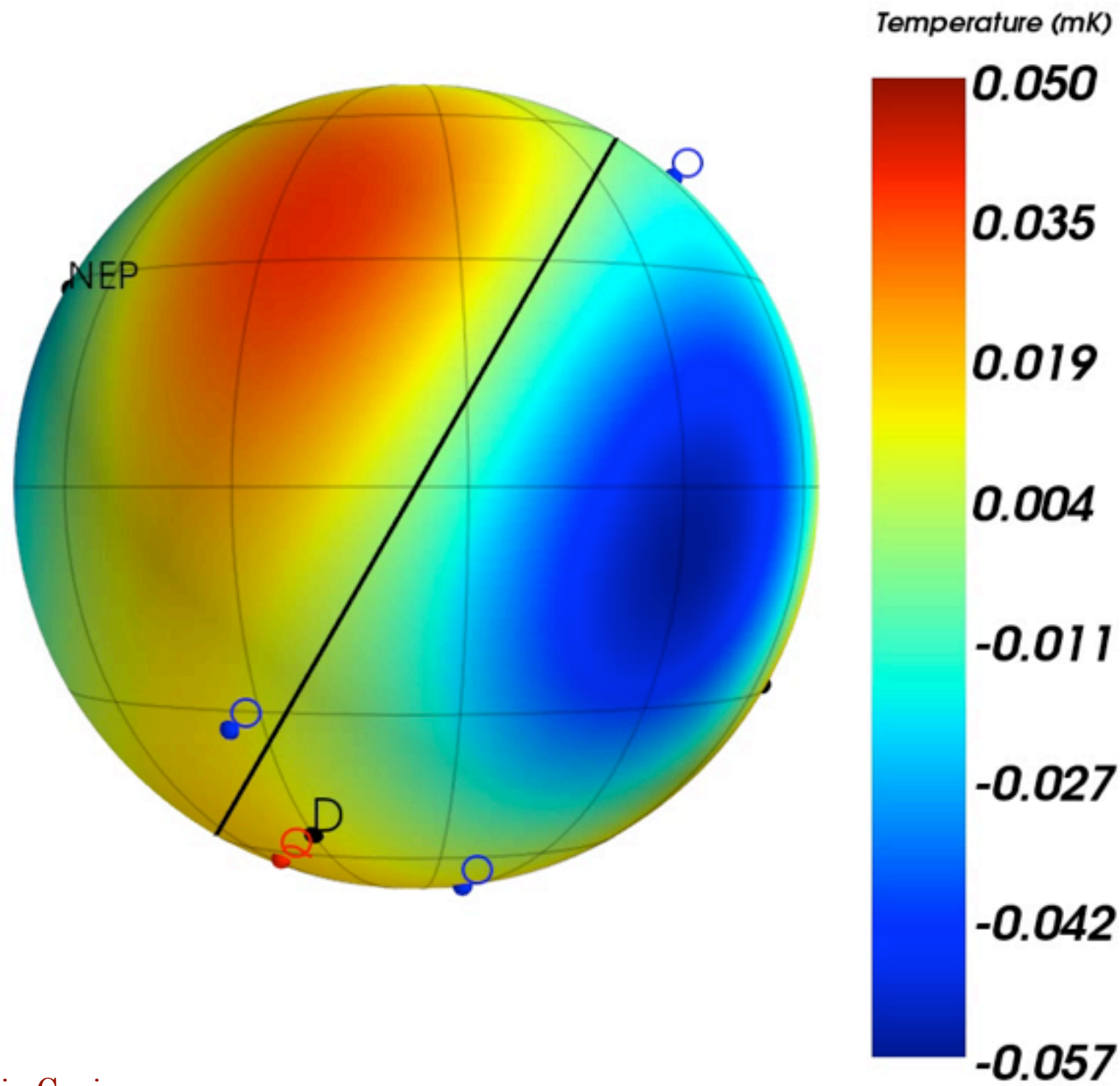
Probability for alignment of Q+O structure with Ecliptic:
2%-4%

Probability for alignment of Q+O structure with Dipole:
0.1%-0.4%

which are independent of the previously quoted

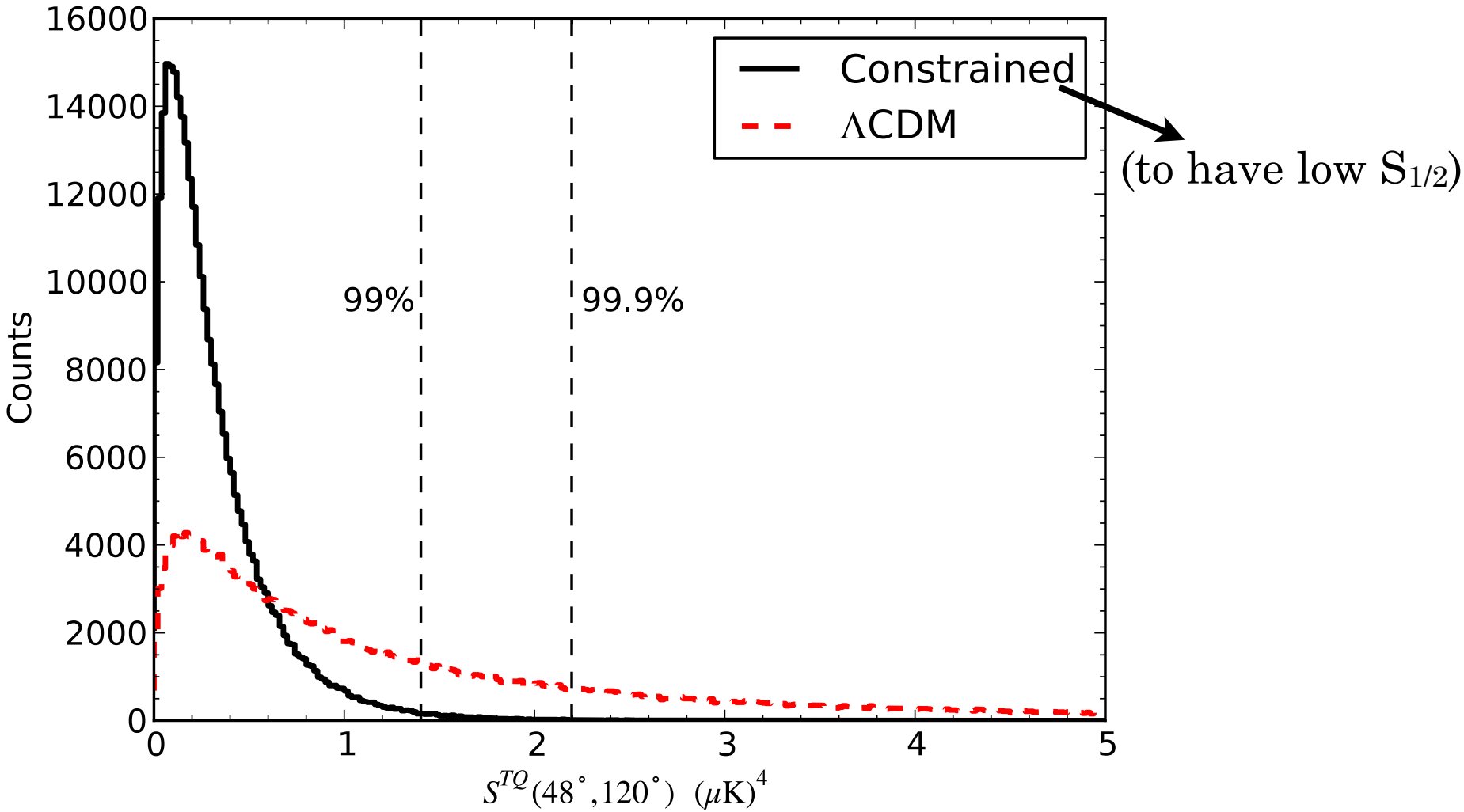
Probability for Q and O to be mutually aligned and planar
0.05%-0.3%

Copi et al, arXiv:1311.4862



Movie by Craig Copi

If this is a statistical fluke, CMB polarization may successfully confirm that



Polarization statistic

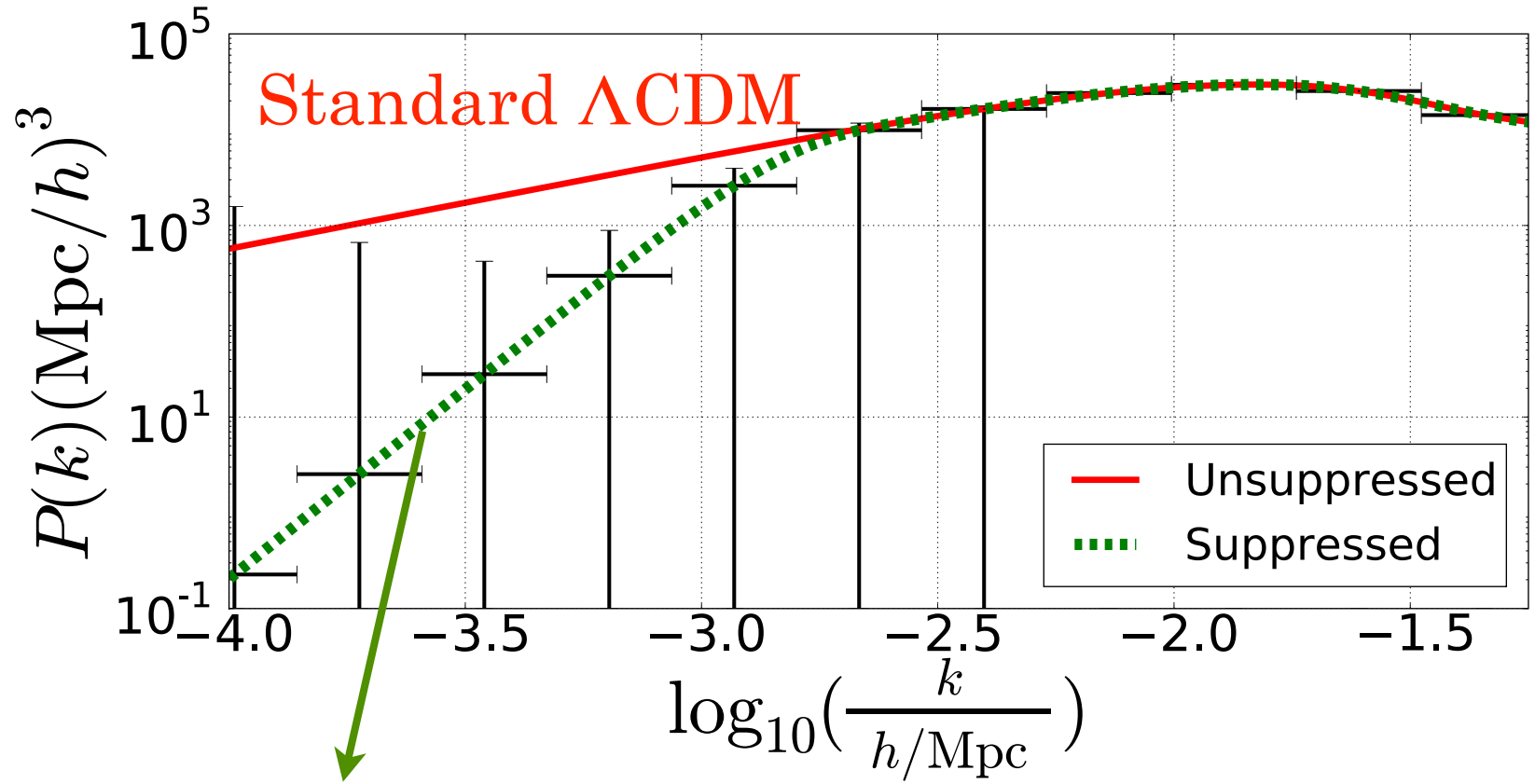
Copi et al, *MNRAS* **434,** 3590 (2013),

Conclusions

- Angular power is nearly zero at $\theta \gtrsim 60$ deg
- Quadrupole and octopole planar, nearly perpendicular to dipole and ecliptic plane
- Several separate ≳3-sigma anomalies, they are *a posteriori*...
- ... but all have to do with largest observed scales!
- Suppression of $C(\theta)$ seems *very* robust to map/ experiment choice, frequency, etc
- No compelling explanations to date, cosmological or systematic

EXTRA SLIDES

Can one see effect of such large-angle power suppression in future LSS surveys?



Consistent with suppressed large-angle CMB power

Gibelyou, Huterer & Fang 2010