The Axle of Elvis and other Cosmic Quirks

Peter Coles
(Cardiff)

The Axis of Evil and other Cosmic Quirks

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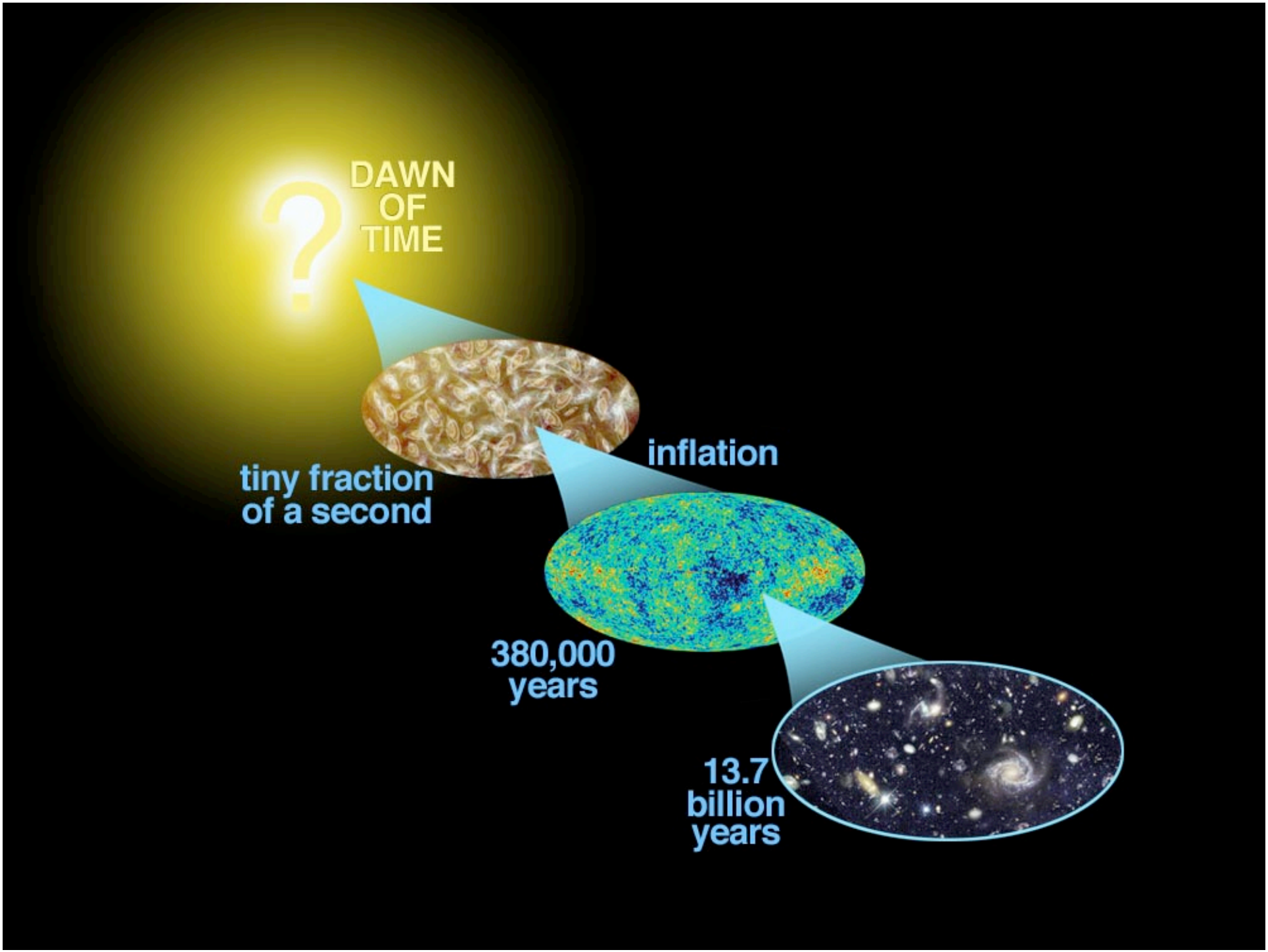
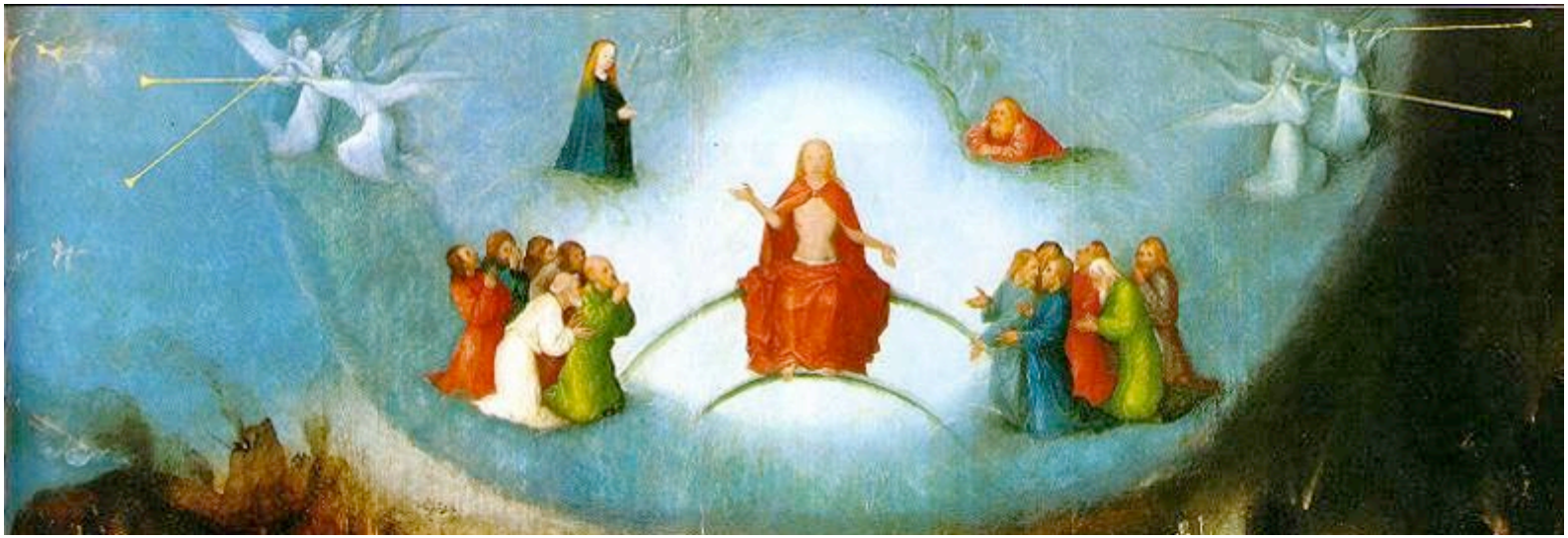
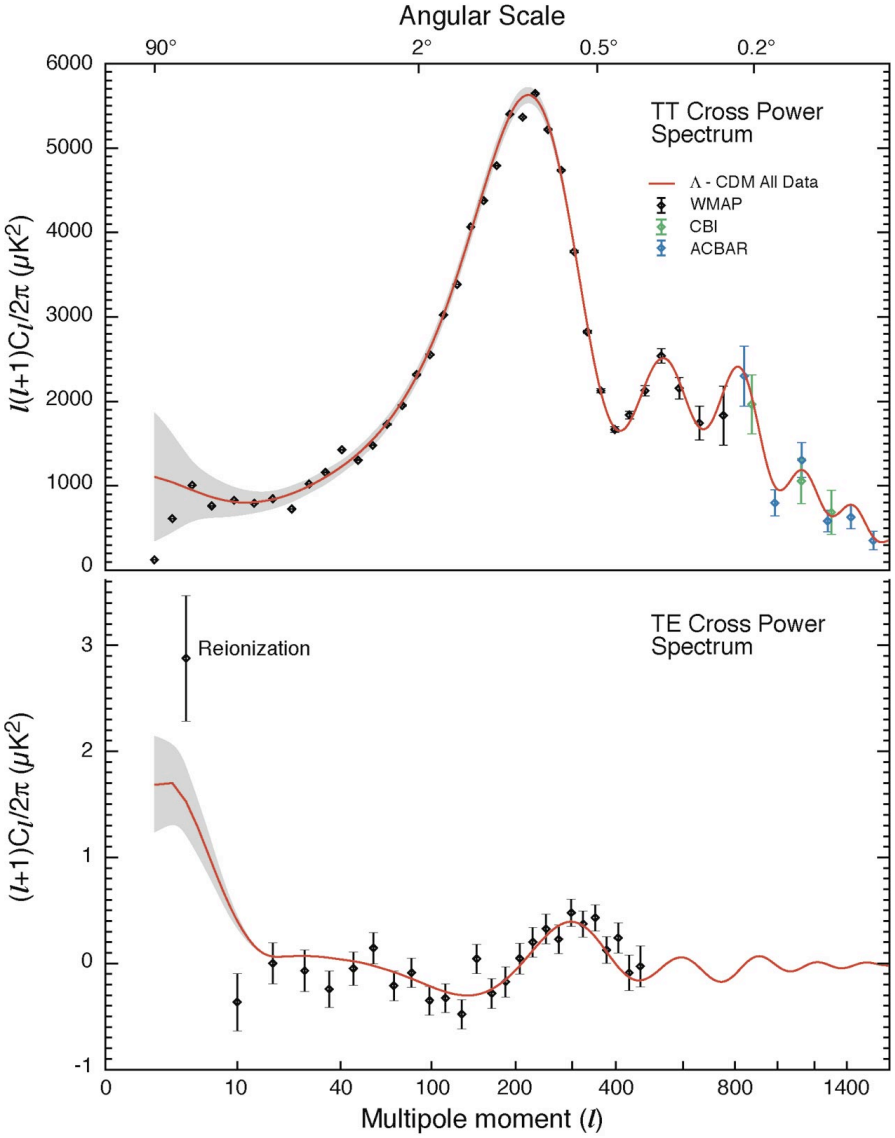

DAWN
OF
TIME
tiny fraction
of a second
inflation
380,000
years
13.7
billion
years

"CONCORDANCE"



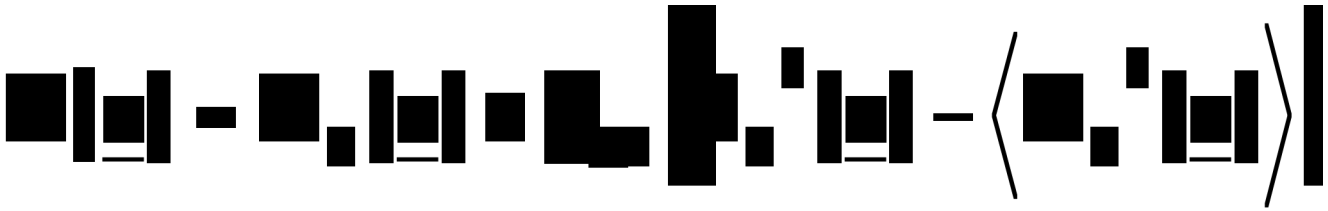

Angular Scale
90°
2°
0.5°
0.2°
TT Cross Power Spectrum
Λ - CDM All Data
WMAP
CBI
ACBAR
l(l+1)C_l/2π (μK^2)
6000
5000
4000
3000
2000
1000
0
TE Cross Power Spectrum
Reionization
(l+1)C_l/2π (μK^2)
3
2
1
0
-1
0
10
40
100
200
400
800
1400
Multipole moment (l)

How Weird is the Universe?

- The (zero-th order) starting point is FLRW.
- The concordance cosmology is a "first-order" perturbation to this
- In it (and other "first-order" models), the initial fluctuations were a statistically homogeneous and isotropic Gaussian Random Field (GRF)
- These are the "maximum entropy" initial conditions having "random phases" motivated by inflation.
- Anything else would be *weird*....

Weird Statistics

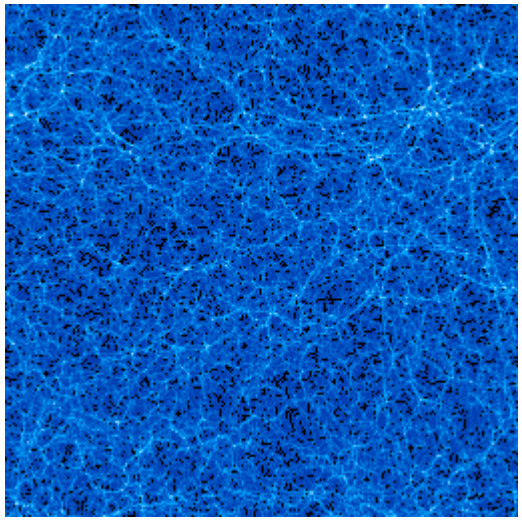
- Could be stationary non-Gaussian, such as the quadratic model:

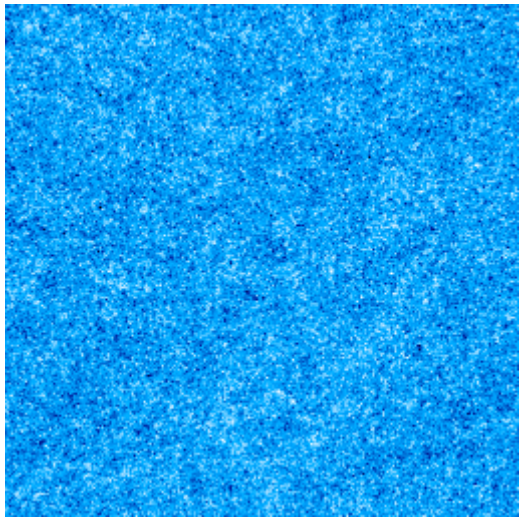


- Different levels of this kind of non-Gaussianity are predicted in various different scenarios.

Fourier Phases

- The usual thing 
- where 
- In a homogeneous and isotropic GRF then the phases  are random...
- ..apart from 
- ..as are differences, e.g.
- The power spectrum 





The Bispectrum

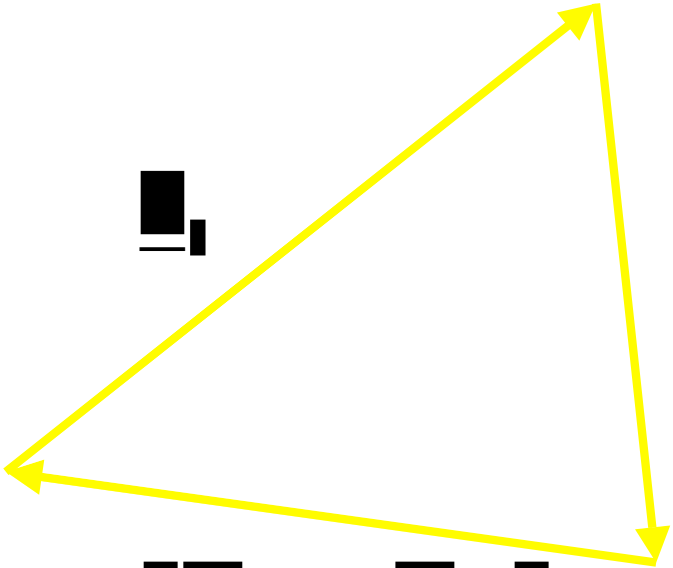
- The power spectrum is blind to phase information
- Phase information is encoded in an infinite hierarchy of polyspectra, e.g. the bispectrum:

$$\langle \delta(\vec{k}_1)\,\delta(\vec{k}_2)\,\delta(\vec{k}_3) \rangle \propto \langle \delta(\vec{k}_1)\,\delta(\vec{k}_2)\,\delta(-\vec{k}_3) \rangle$$

- Averaging is done over triangles in k-space
- This measures a specific form of phase coupling; quadratic phase coupling, so it is tailor-made for quadratic non-Gaussianity

Quadratic Phase Coupling

[redacted]



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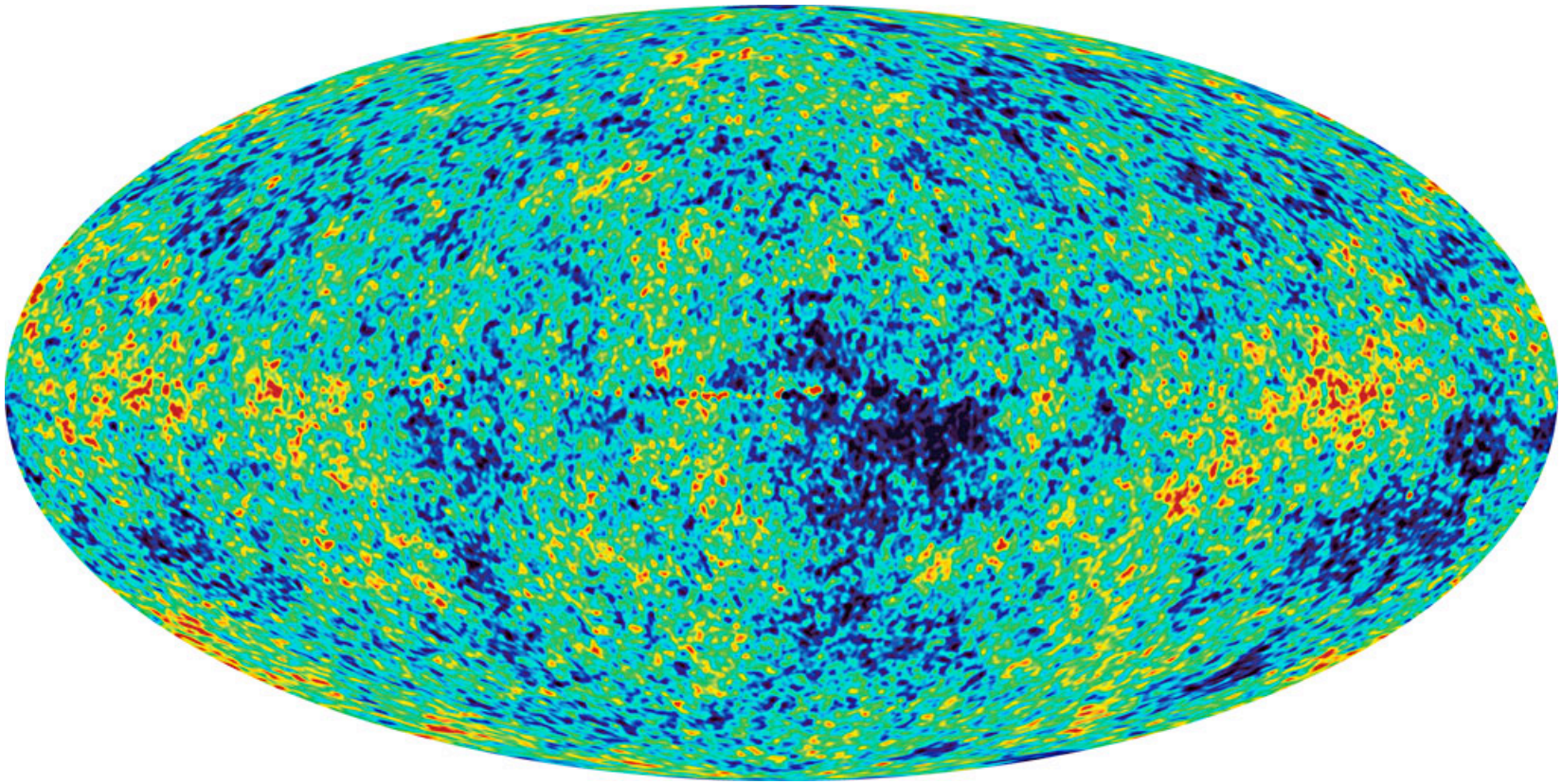

Primordial Non-Gaussianity and Topology of CMB and Large-scale Structure

C. Hikage

collaborators

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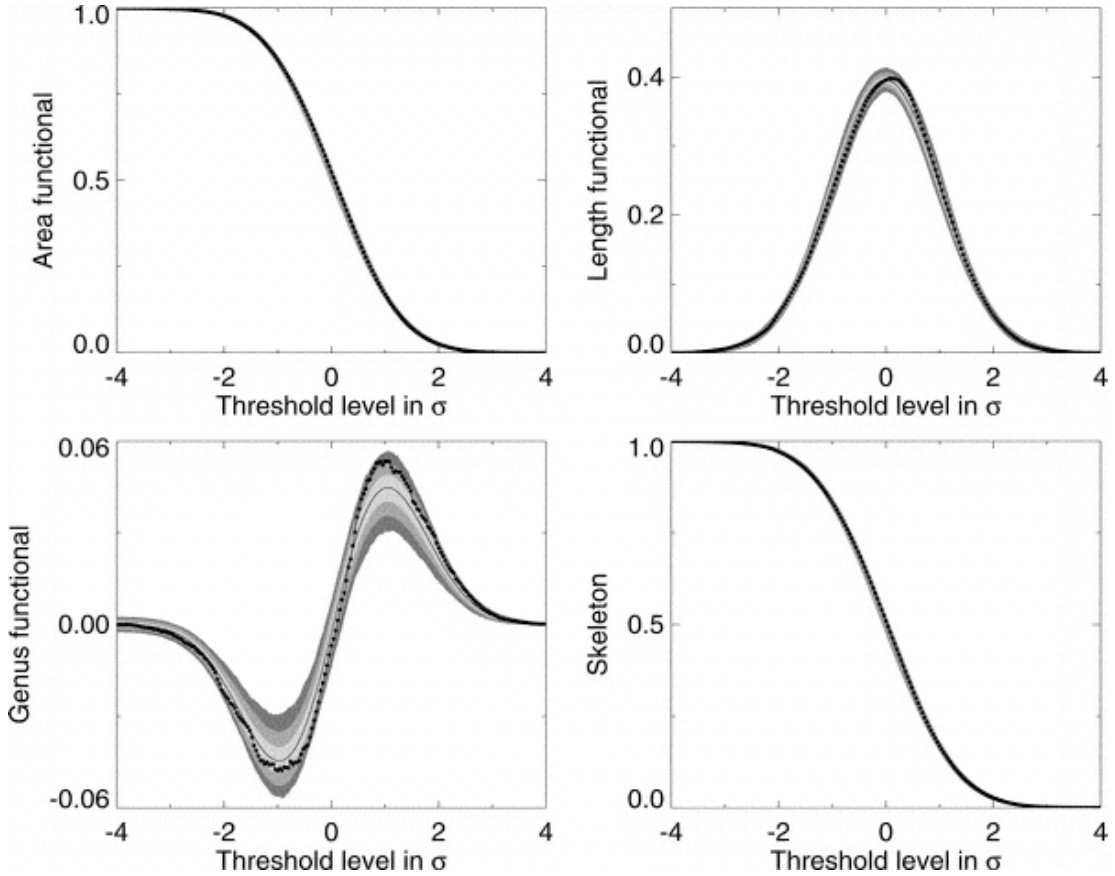
F. K. Hansen, M. Grossi, L. Moscardini,

K.Dolag, E. Branchini, S. Matarrese

Minkowski functionals

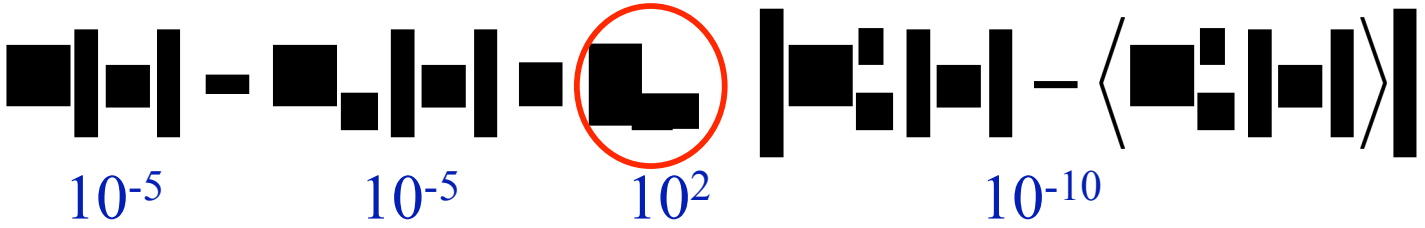
- In d spatial dimensions there are (d+1) topological invariants satisfying additivity, continuity, translation invariance and rotation invariance.
- In 3D, for example, these are the volume, area, mean curvature, and χ
- In 2D there are only two.
- These can complement the bispectrum for detecting quadratic non-Gaussianity.

Minkowski functionals in 2D (area, length and χ)



f_{NL}

Curvature Perturbation



E.g., current observational uncertainty $\Delta f_{NL} \sim 100$ around $f_{NL}=0$ means that the field is Gaussian at 0.1% level

The simplest inflation model based on single slowly-rolling scalar field predicts very small f_{NL} from 0.01 to 1.

If non-zero f_{NL} would be detected in current observations, the large class of inflation models could be

Summary: CMB

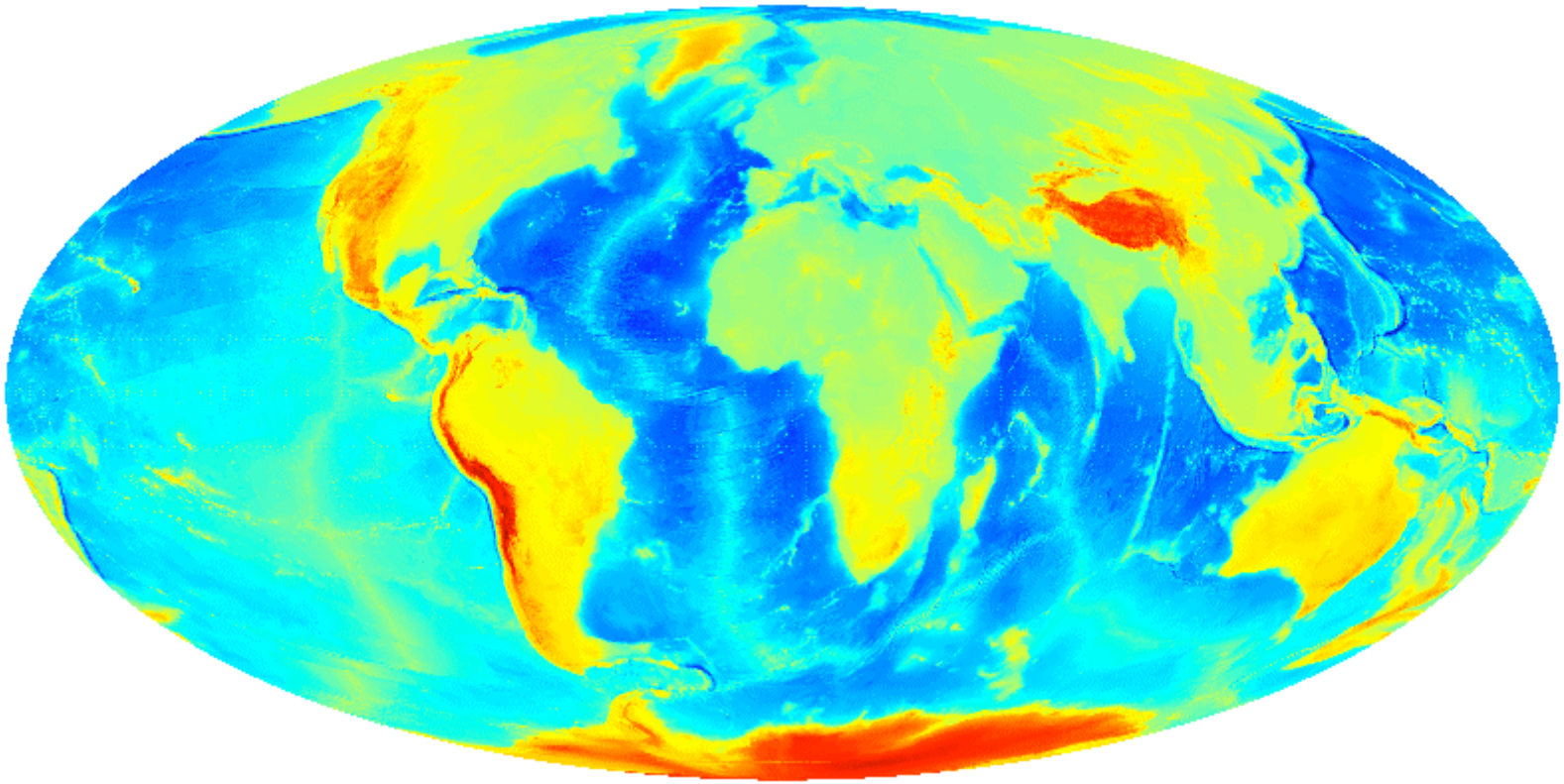
- We derive analytical formulae of MFs for CMB temperature maps with primoridal non-Gaussianity.
- They are well agreed with non-Gaussian simulations with $|f_{NL}|<<3300$ even including the various observational effects
- From WMAP 5-year data , we obtain the constraint on the primordial non-Gaussianity

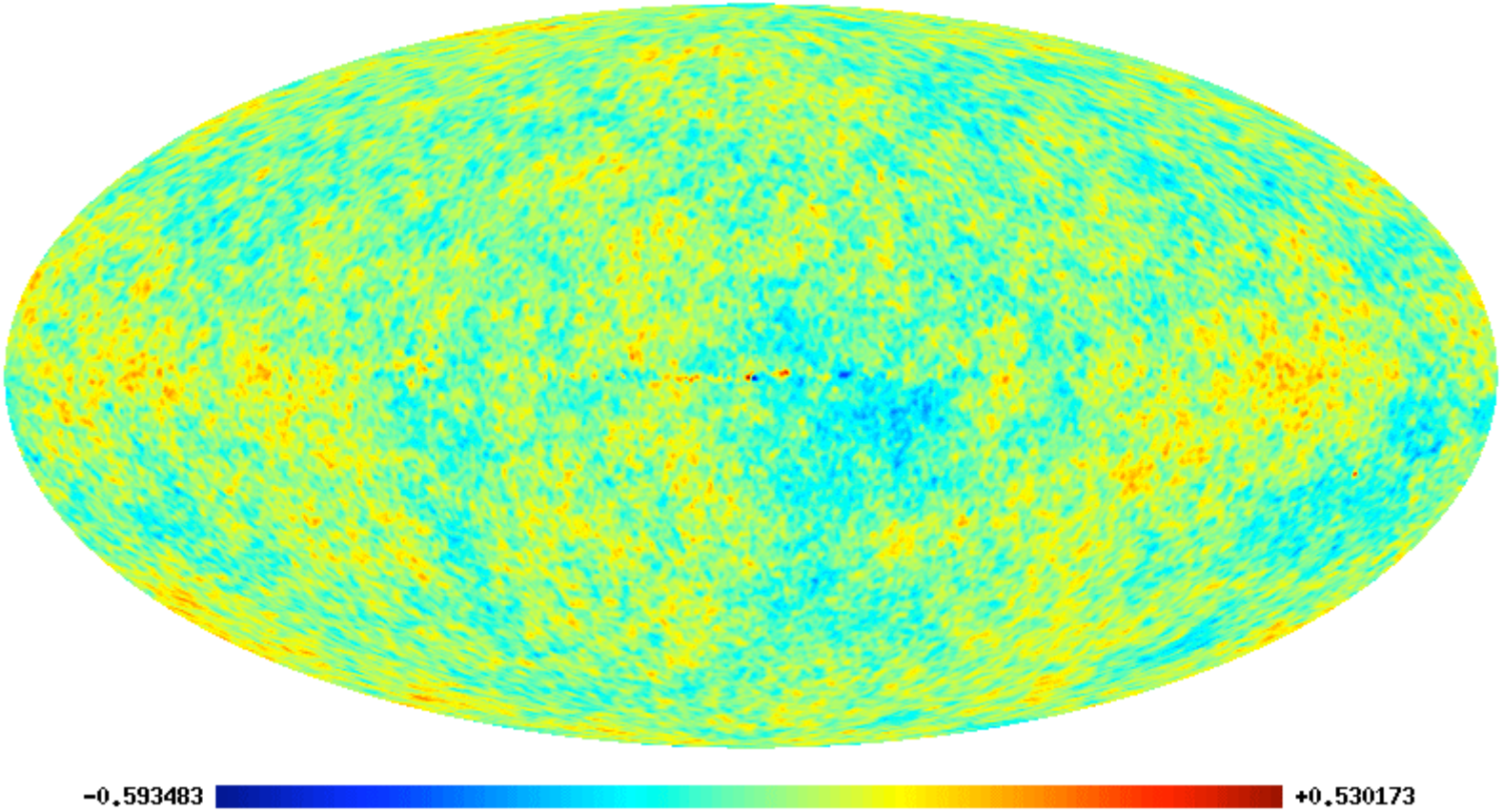
  $-63<f_{NL}<76$ (95% C.L.)

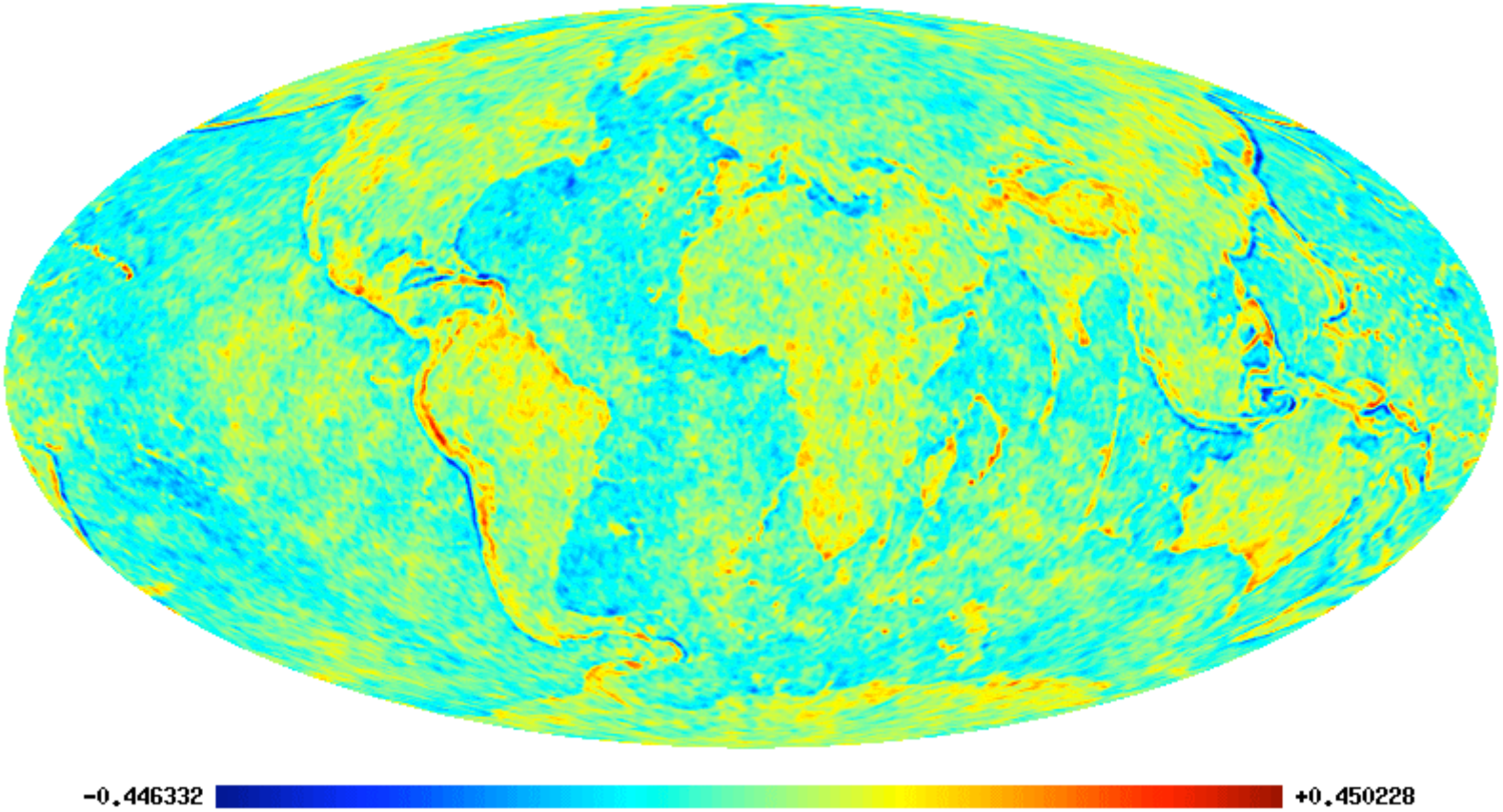
  Statistical error is comparable to the bispectrum analysis of WMAP team ($-9<f_{NL}<111$)
- In Planck survey, the more stringent constraints will be obtained with the uncertainty of $|f_{NL}|\sim 10$

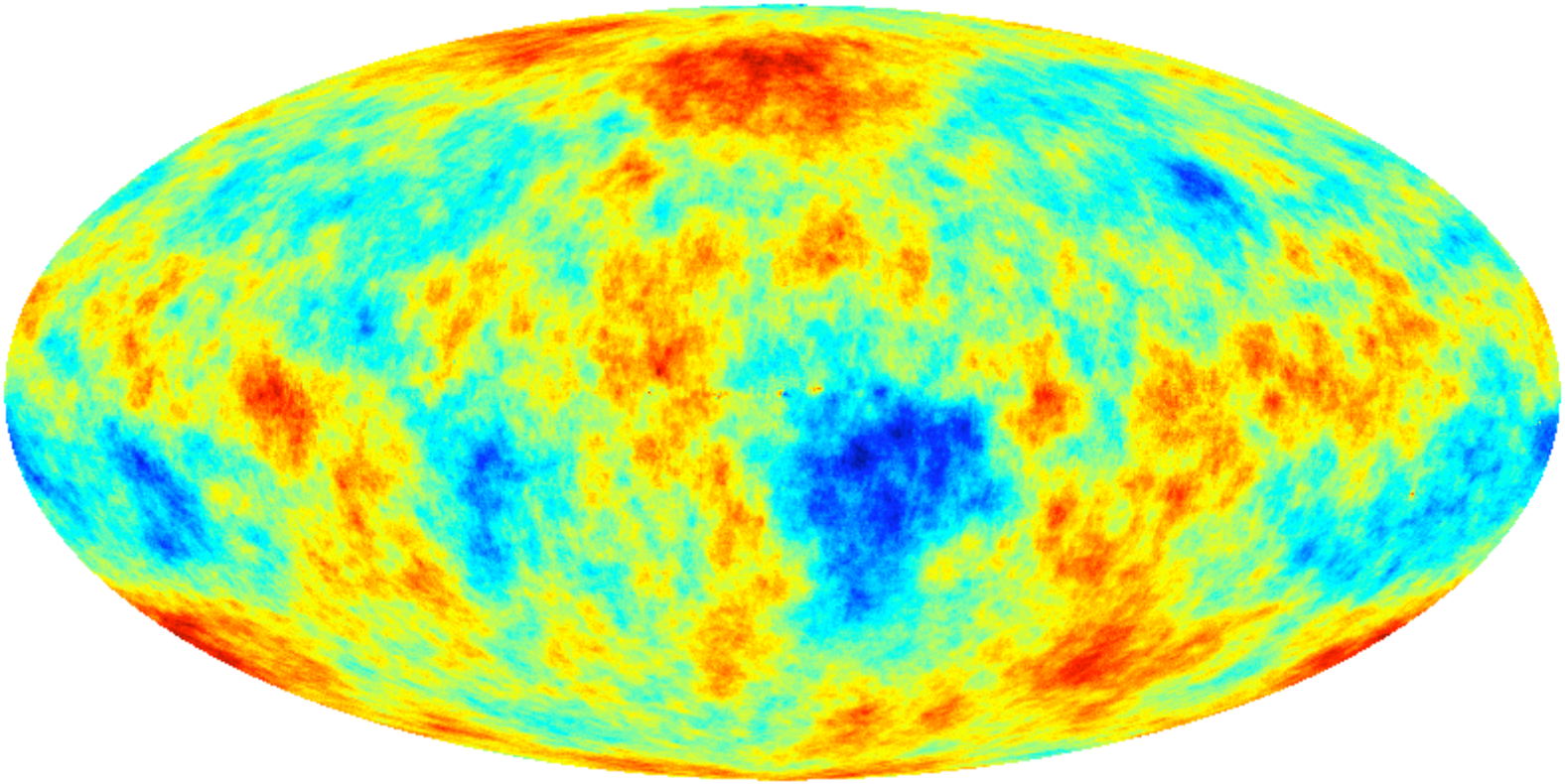
Spherical Harmonic Phases

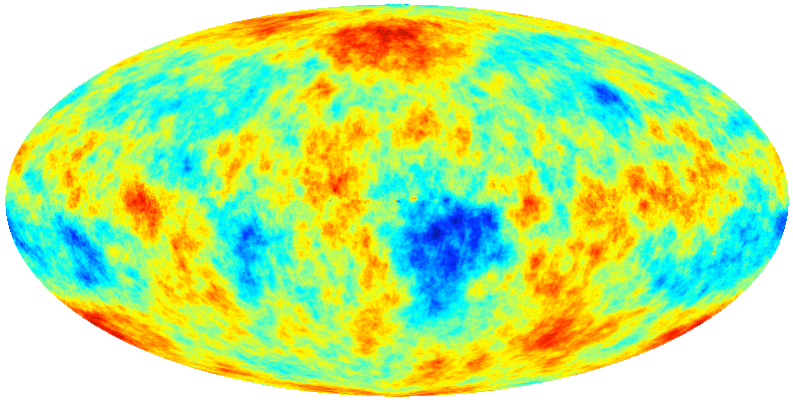
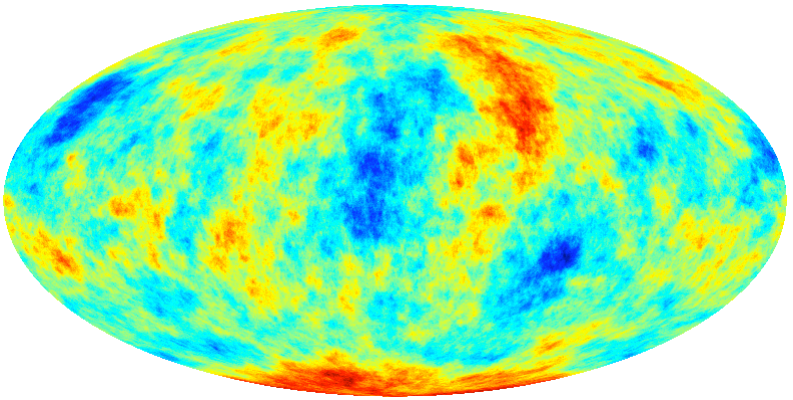
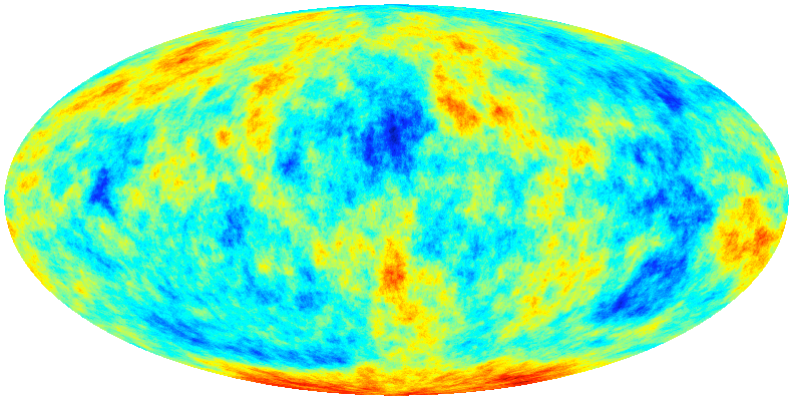
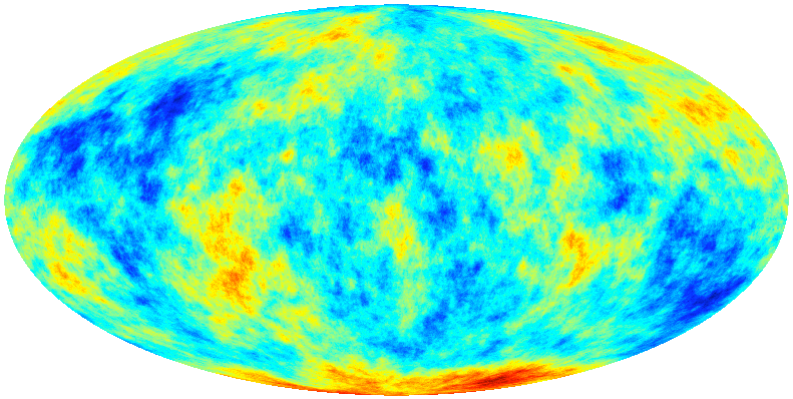
- The usual thing 
- where 
- If the fluctuations are a homogeneous and isotropic GRF then the phases are random...
- ..apart from
- ..as are differences, e.g.




-0.593483
+0.530173

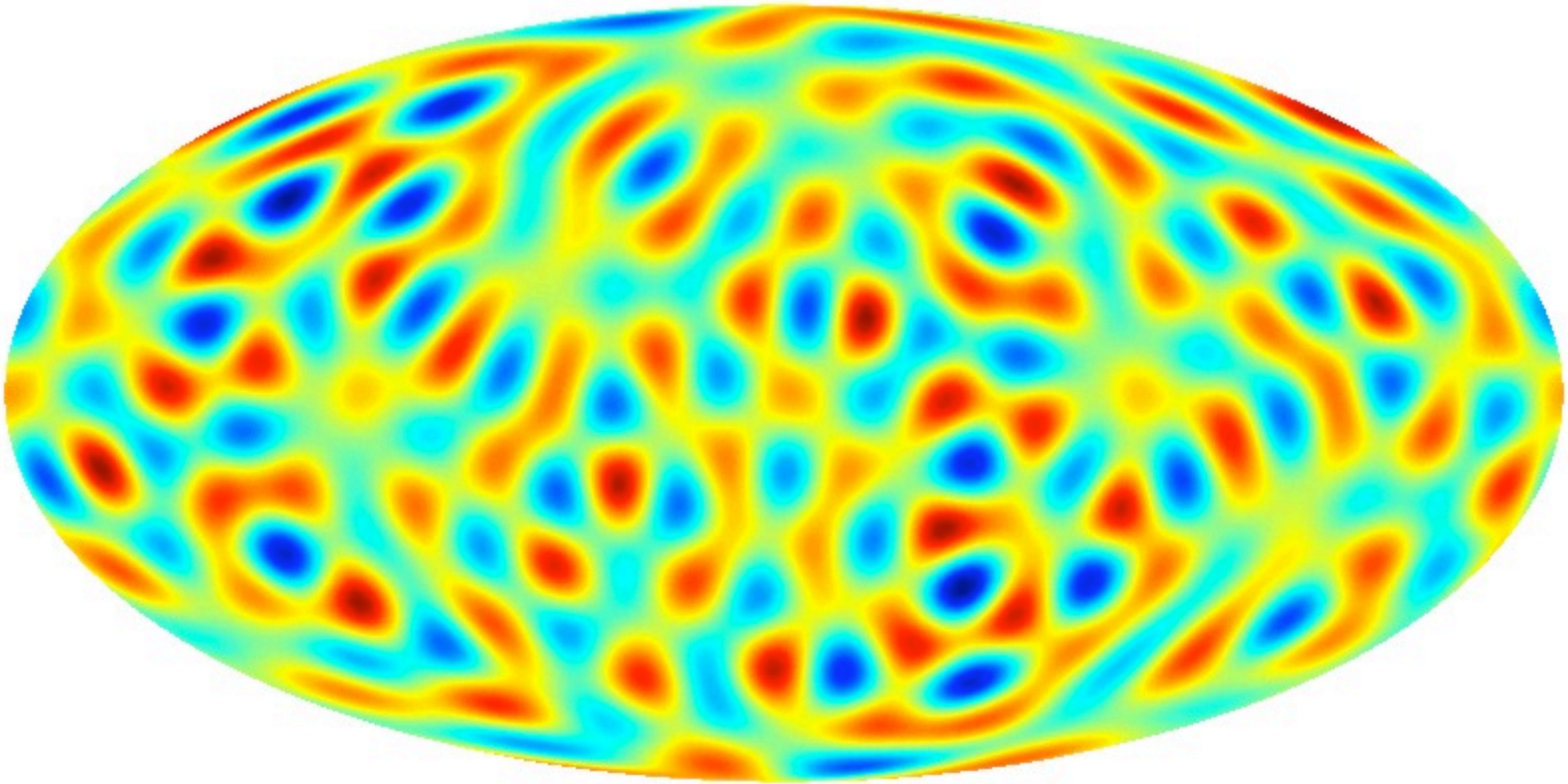

-0.446332
+0.450228

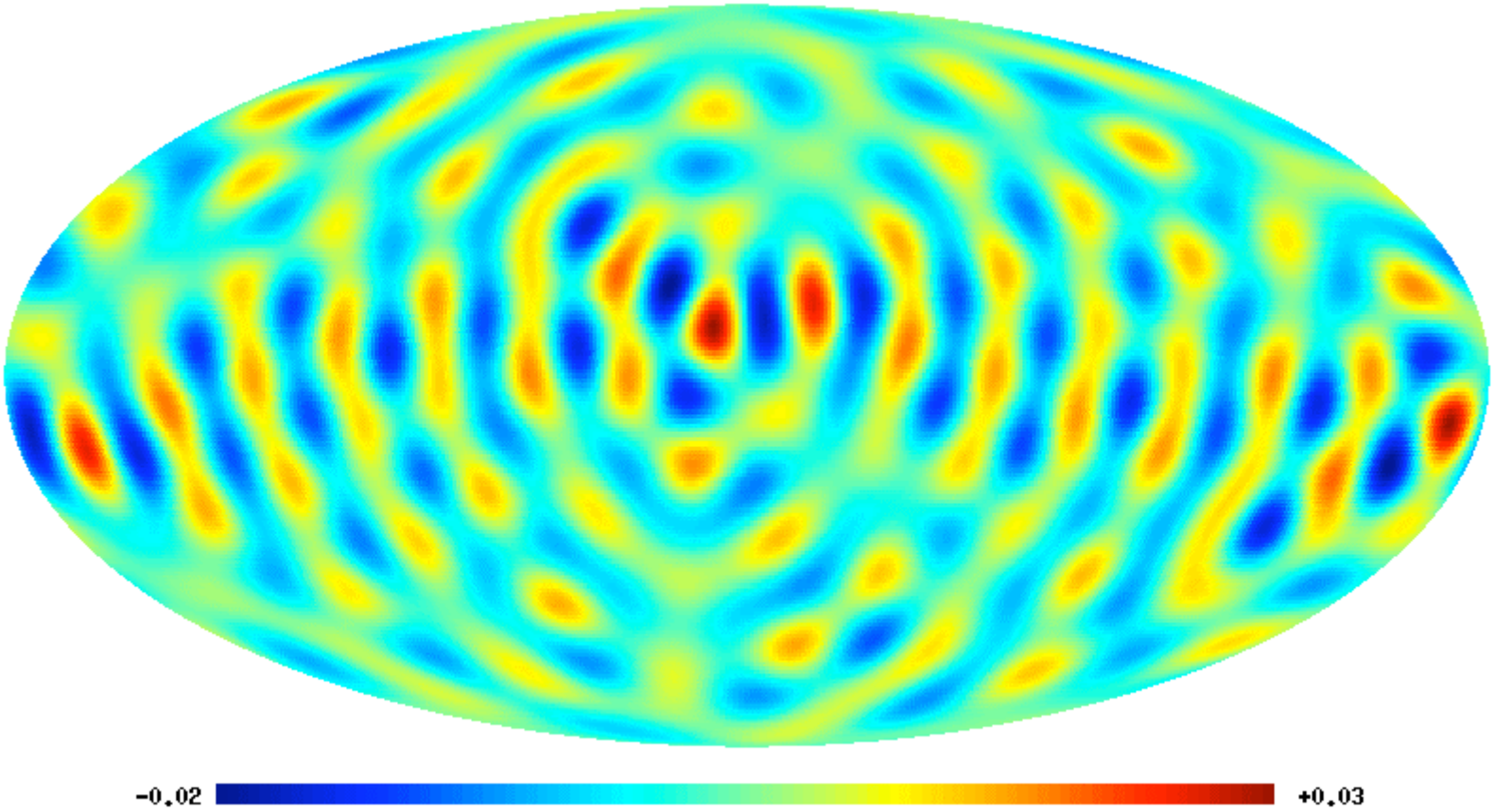


Quirks-0

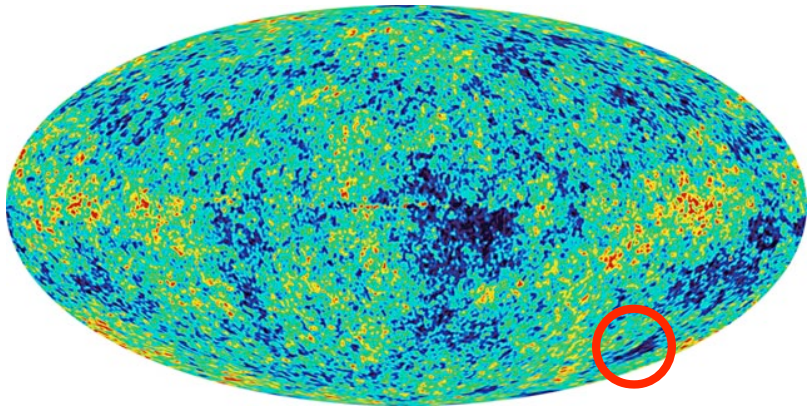
- Actually the phases of WMAP are not random…
- ..and they correlate with the foreground templates (e.g. Chiang et al, ApJ 664, 8, 2007)
- This is probably residual foreground contamination (even though modes up to l=10 are claimed to be "clean")

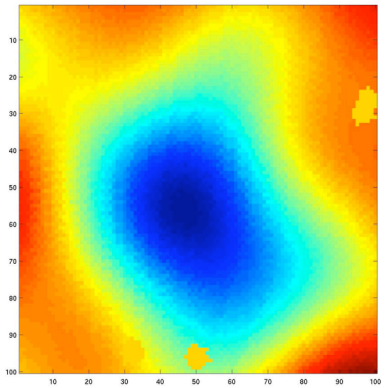



-0.02
+0.03

Quirks-II

- Some studies based on wavelets have detected a very large and very cold spot in the southern hemisphere showing a significant deviation from an isotropic GRF (Vielva et al. 2004, Cruz et al. 2005, 2006).





Anomalies-III

- Other analyses find a strong evidence for a north-south asymmetry maximized in a coordinate system with the *north pole* close to the north ecliptic pole (e.g. Eriksen et al. 2004, Hansen et al. 2004. Land & Maaueiio 2005).

(from Hansen et al. 2004)

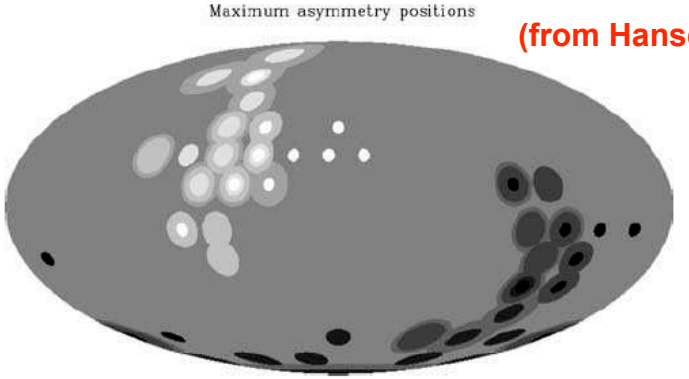


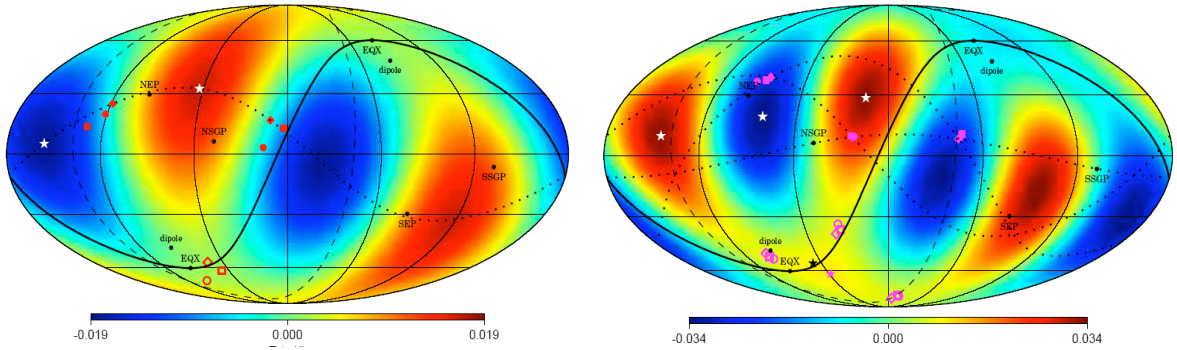
Figure 24. The discs show the positions of the hemispheres with the 10 highest (black discs) and 10 lowest (white discs) bin values. The power-spectrum bins considered were $\ell = 2$–40 (large discs), $\ell = 8$–40 (second-largest discs), $\ell = 5$–16 (second-smallest discs) and $\ell = 29$–40 (smallest discs).

Global Asymmetry?

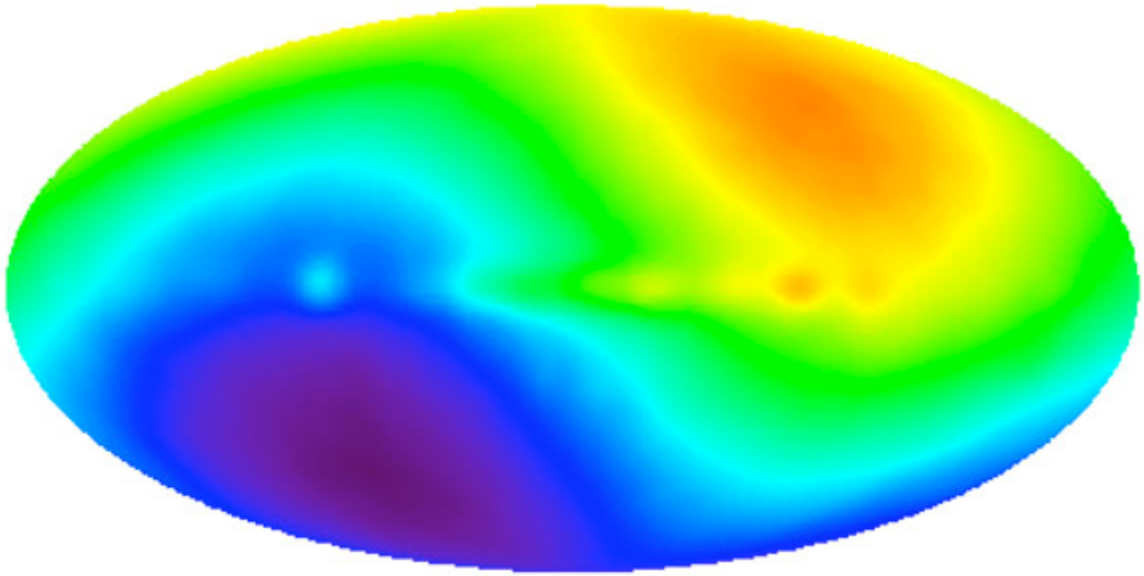
- It has been suggested that the answer may be departure from FRW cosmology, e.g. Bianchi (homogenous but anisotropic)
- This can easily be ruled out: such models produce a specific polarization pattern which is set by the temperature pattern
- This inevitably has a large B-mode…

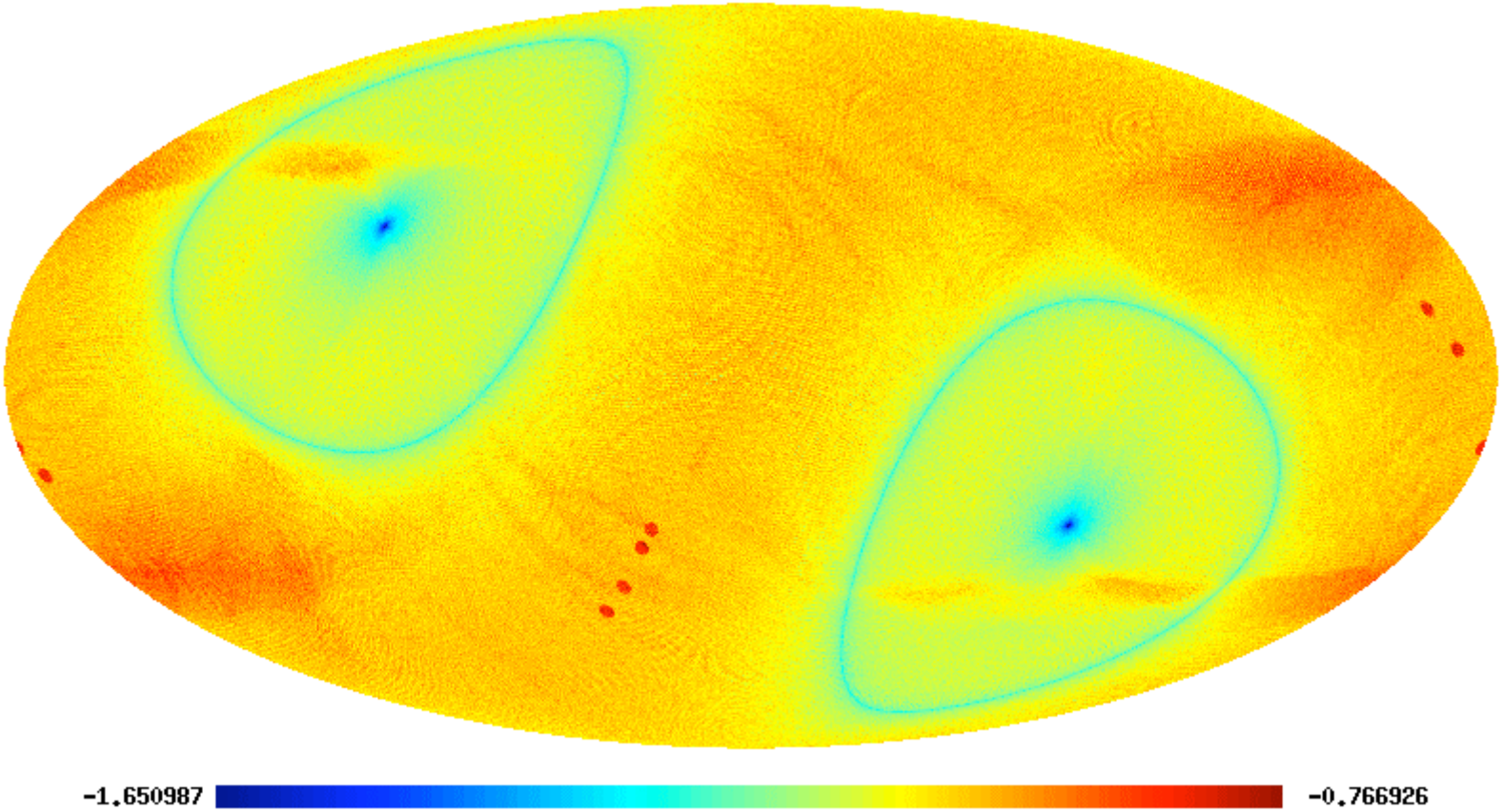
Quirks-IV

- Other works find an anomalous alignment between the low multipoles of the CMB, suggesting a preferred direction near the ecliptic plane and close to the axis of the dipole (e.g. Copi et al. 2004, 2005; Schwarz et al. 2004; de Oliveira-Costa et al., Land & Magueijo 2005).



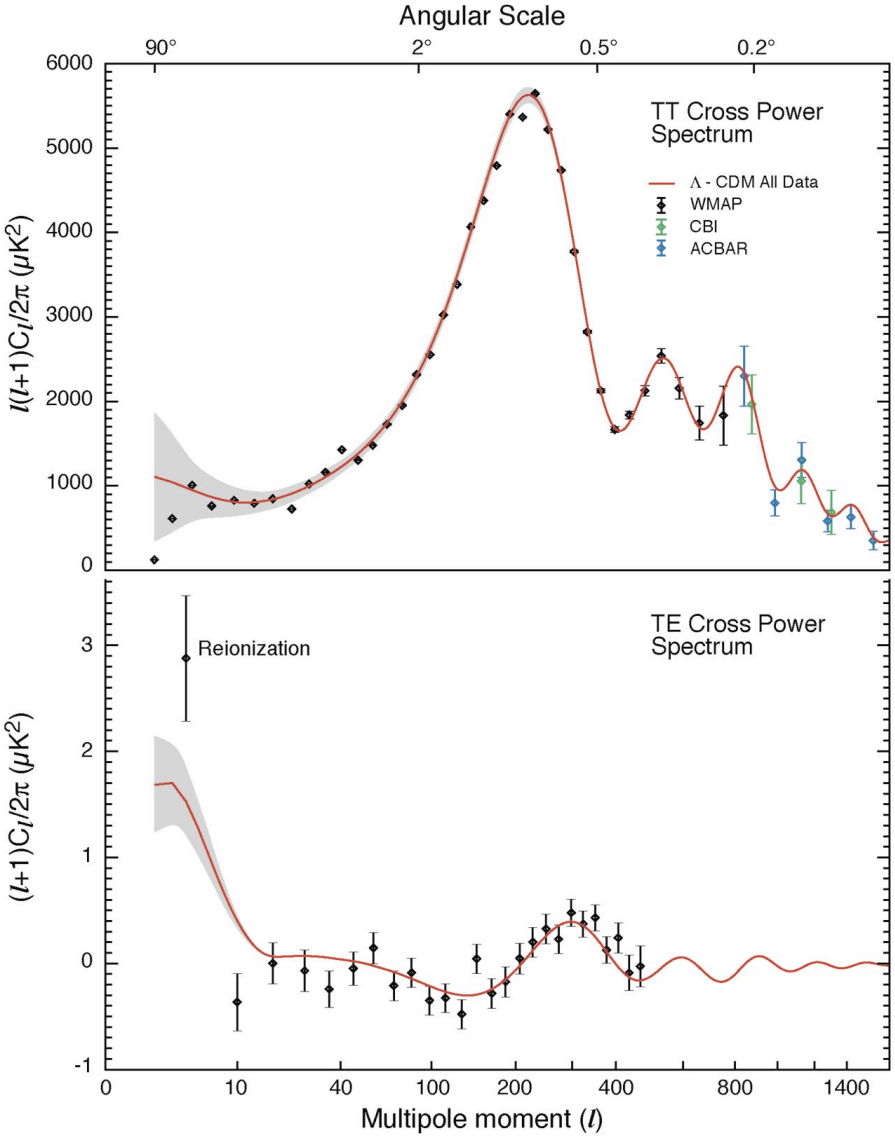
(from Copi et al. 2005)




-1.650987
-0.766926

Quirks-IVa

- There is an apparent deficit in the large-scale power of WMAP (also in COBE) which takes it marginally outside the standard result…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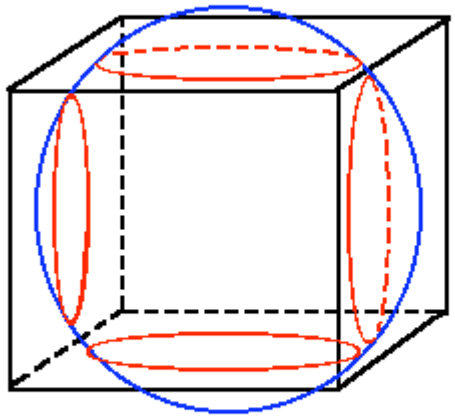
TE Cross Power Spectrum
Reionization
(l+1)C_l/2π (μK^2)
3
2
1
0
-1
0
10
40
100
200
400
800
1400
Multipole moment (l)

Weird Topology

- GR is a *local* theory
- Simplest topology chosen in standard models, e.g sphere.
- Small universes suppress power on large scales…but introduce phase correlations (Dineen, Rocha & Coles, MNRAS, 358, 1285)



Intersection of the CMB sphere with the (imaginary) walls of the fundamental domain of a 3-torus. The intersections with the front and back walls are not shown.

“If tortured sufficiently, data will confess to almost anything”

Fred Menger