Universität Bielefeld

CMB anomalies — Can we learn more?

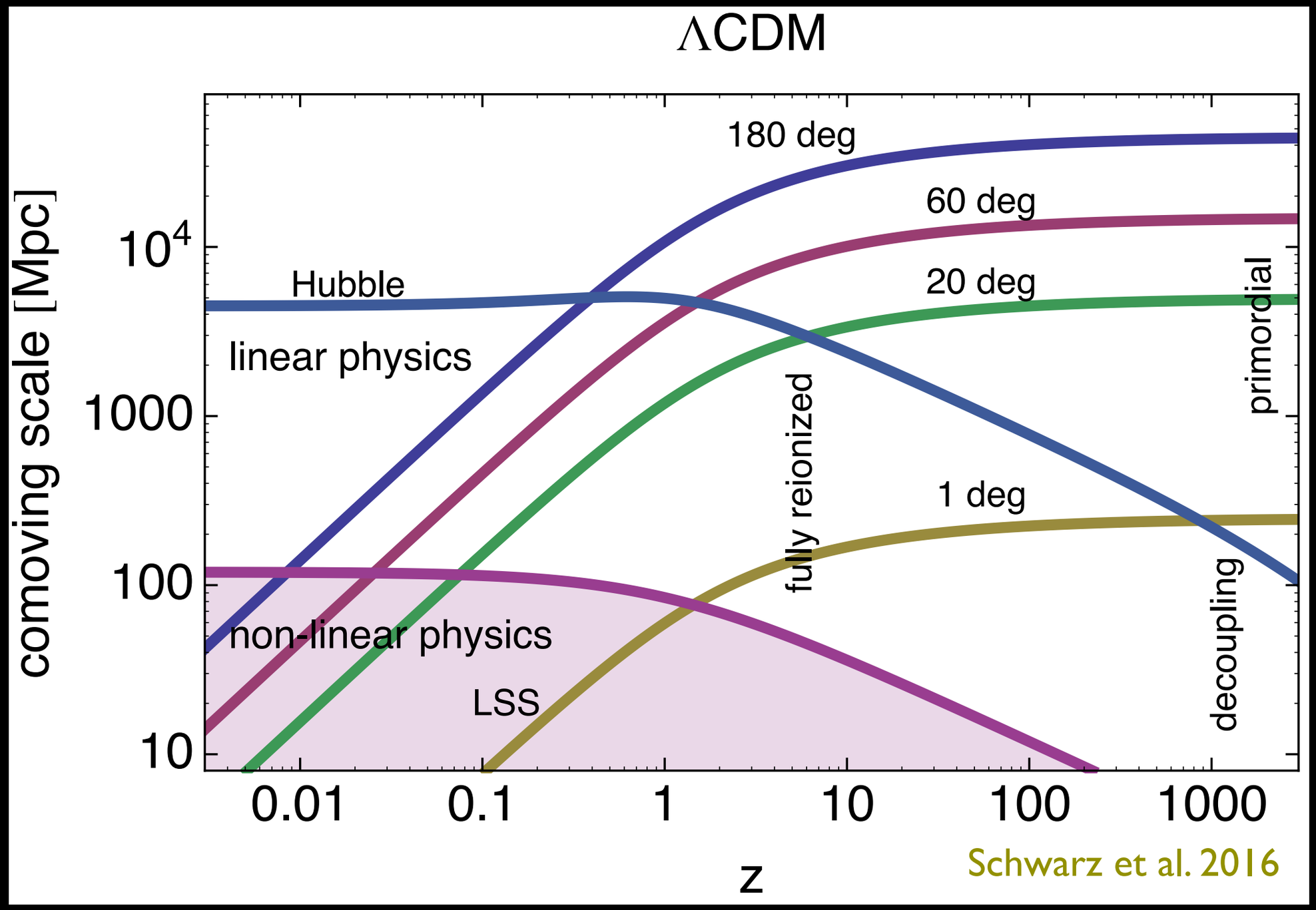
Dominik J. Schwarz
Universität Bielefeld

- Largest scales constraint primordial physics
- Evidence for CMB anomalies remains disputed
- Might hint at problems/lack of understanding
- Require new CMB and non-CMB studies to settle

see also recent review
Schwarz, Copi, Huterer & Starkman 2016

CMB in Germany 2018

Why large scales?



Large-scale questions:

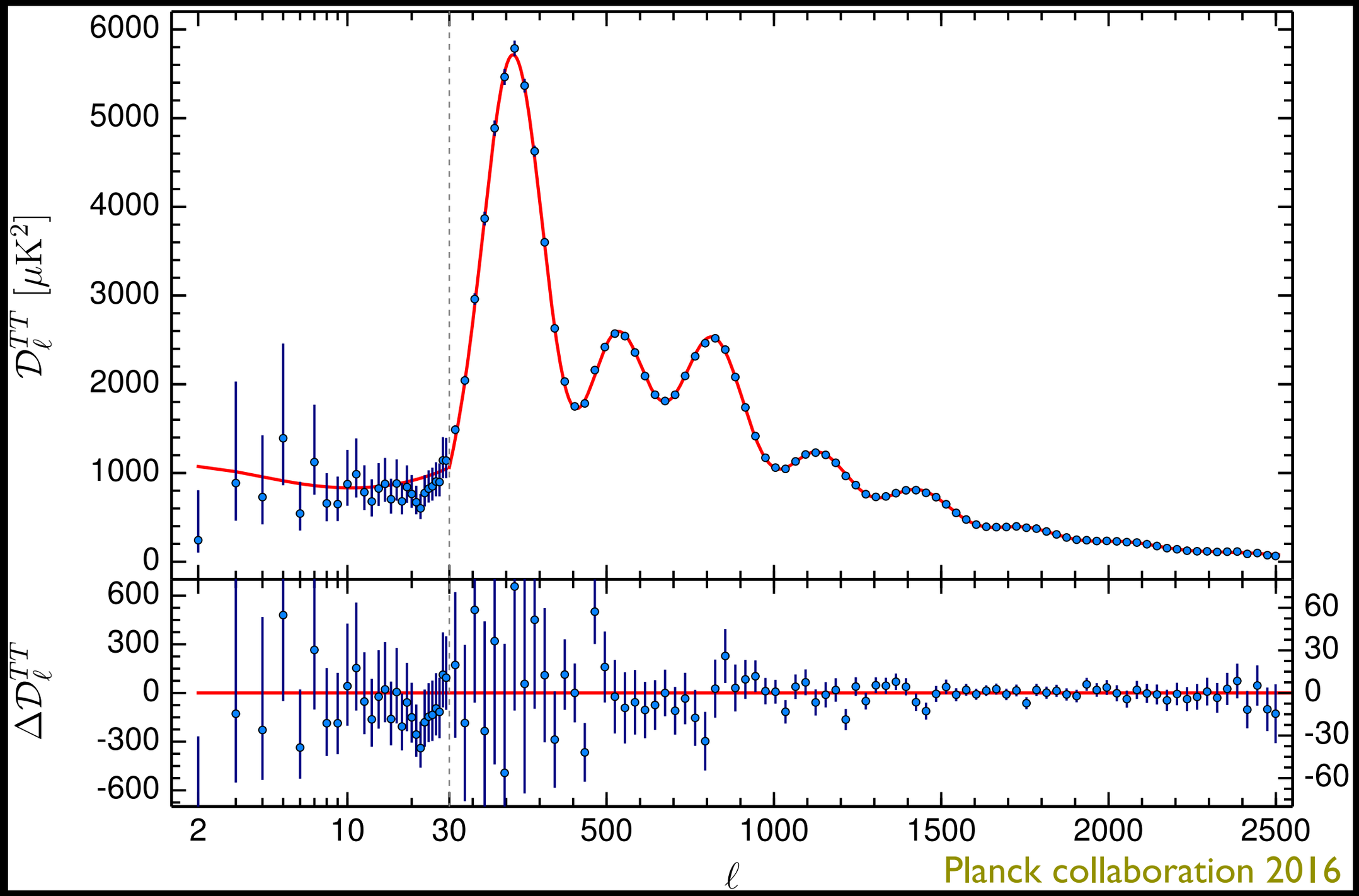
B-modes and T/S:
➜ What was the energy scale of inflation?

Large-scale primordial spectra (large-scale cut-off?):
➜ How long did it take?

Reionisation bump(s):
➜ What is the reionistion history of the Universe?

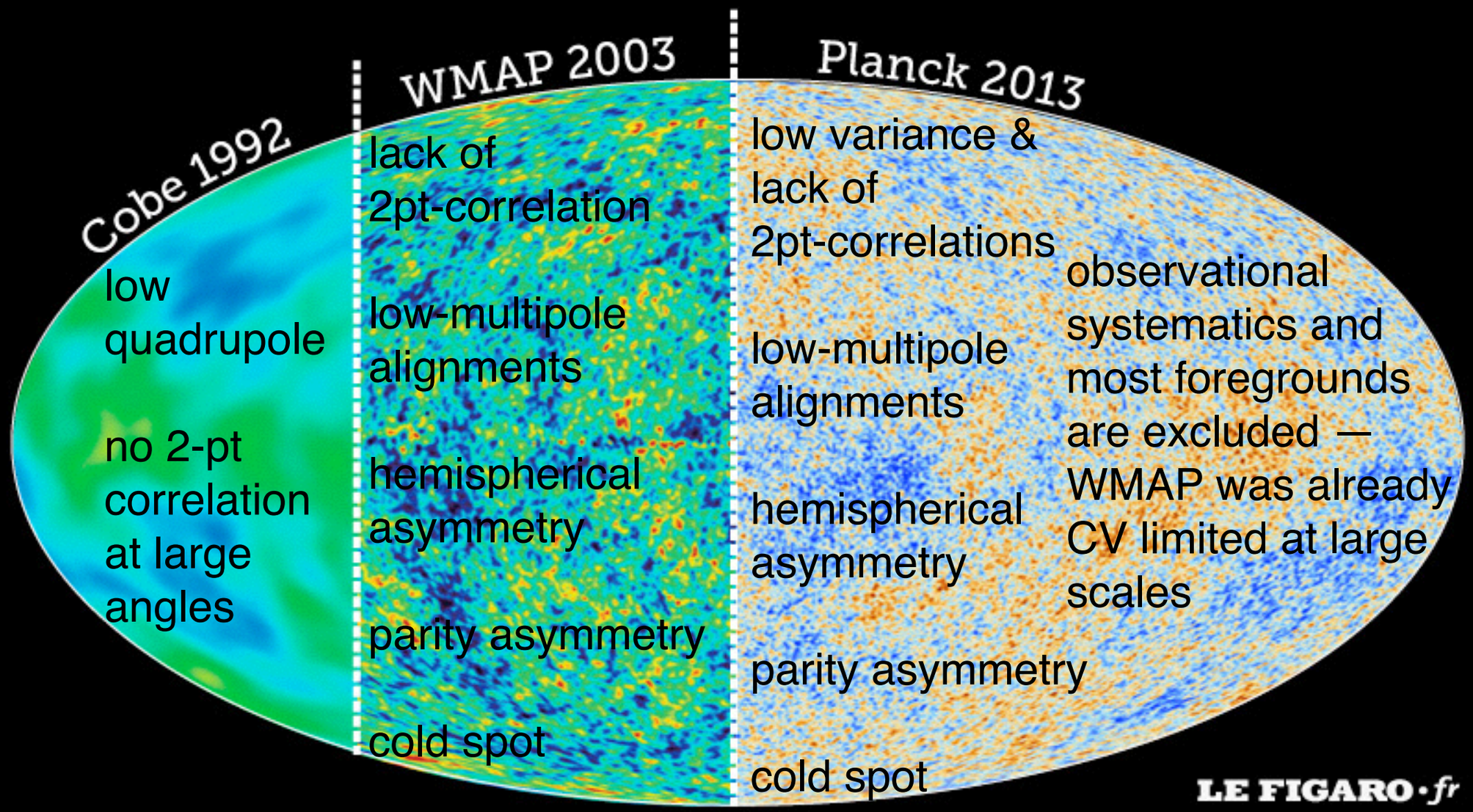
Vorticity and B-modes:
➜ Are there tiny magnetic seed fields?

The expected



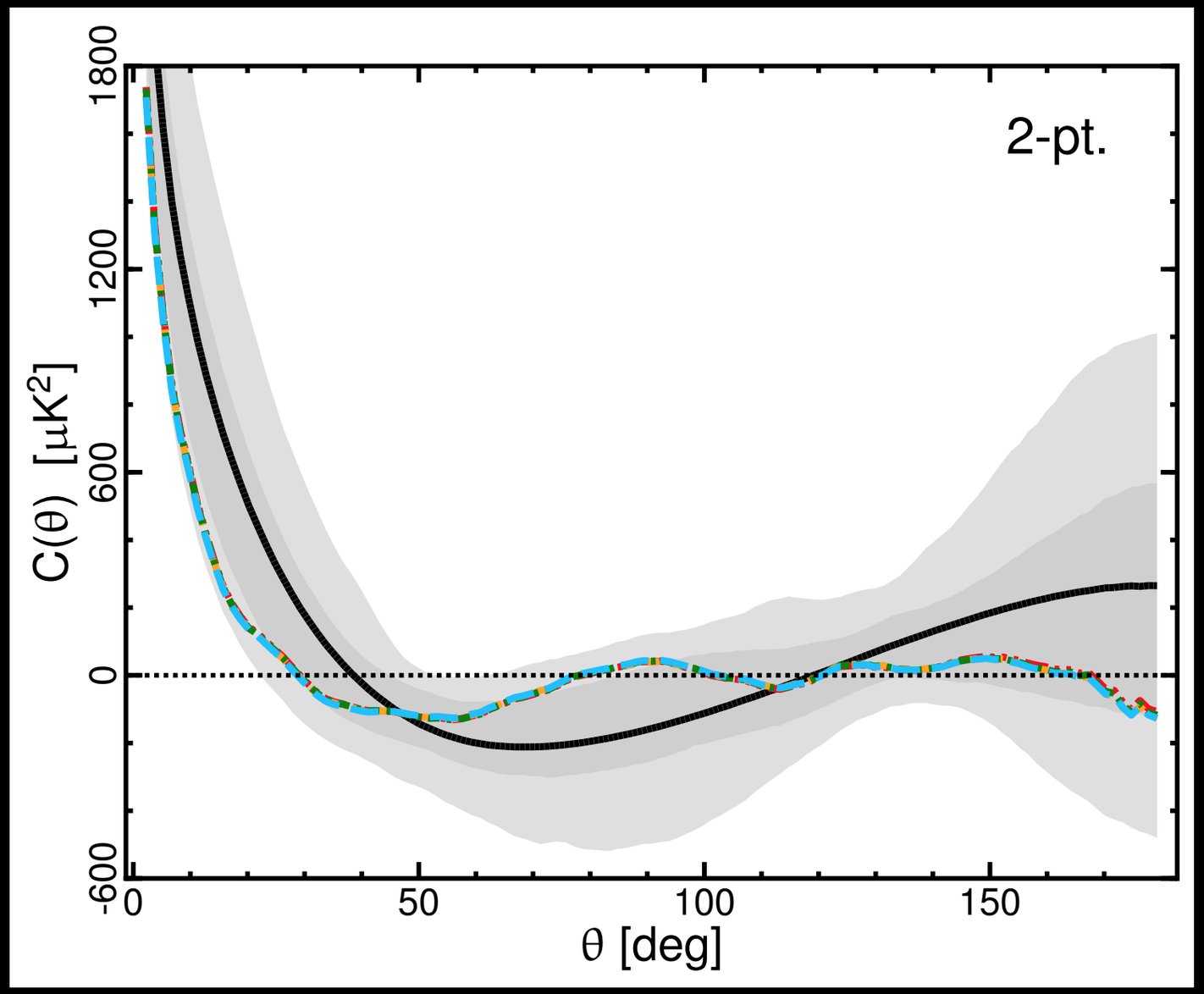
Planck collaboration 2016

The unexpected



CMB anomalies

1. Lack of correlation (COBE, WMAP & Planck)

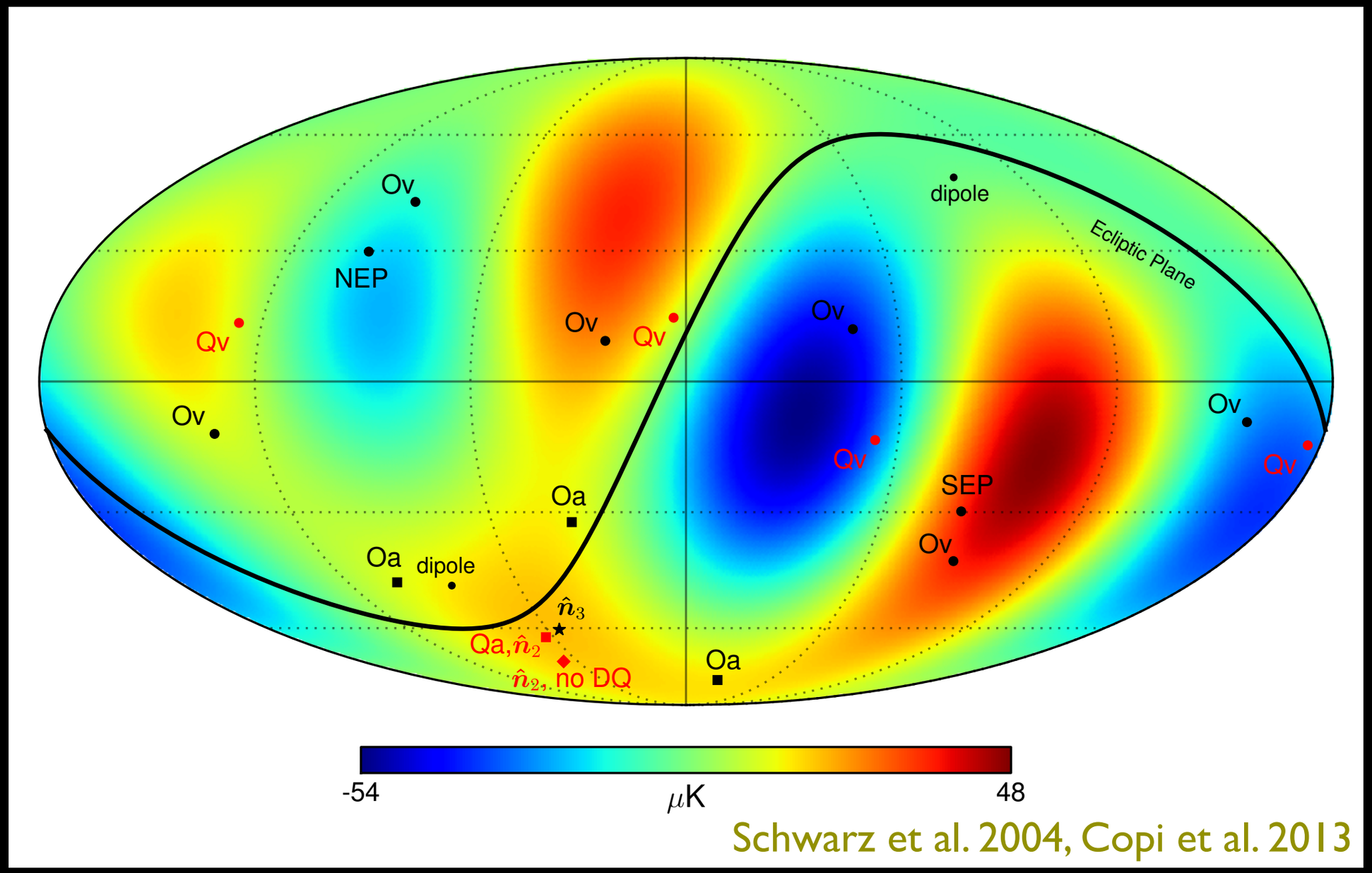


Hinshaw et al. 1996,
Spergel et al. 2003,
Planck collaboration 2016

Large angular scales are uncorrelated at > 60 deg

CMB anomalies

2. Alignements (WMAP & Planck)



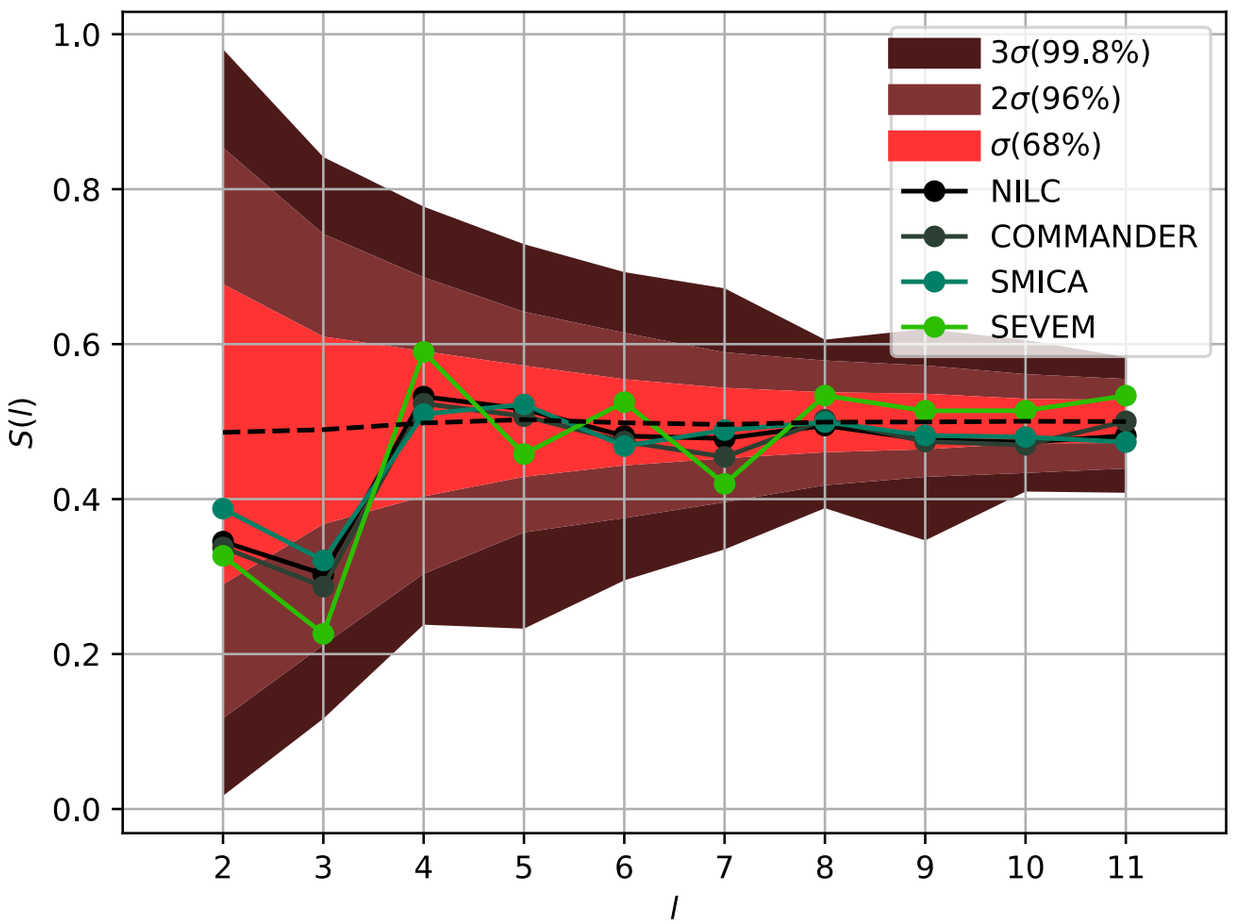
Schwarz et al. 2004, Copi et al. 2013

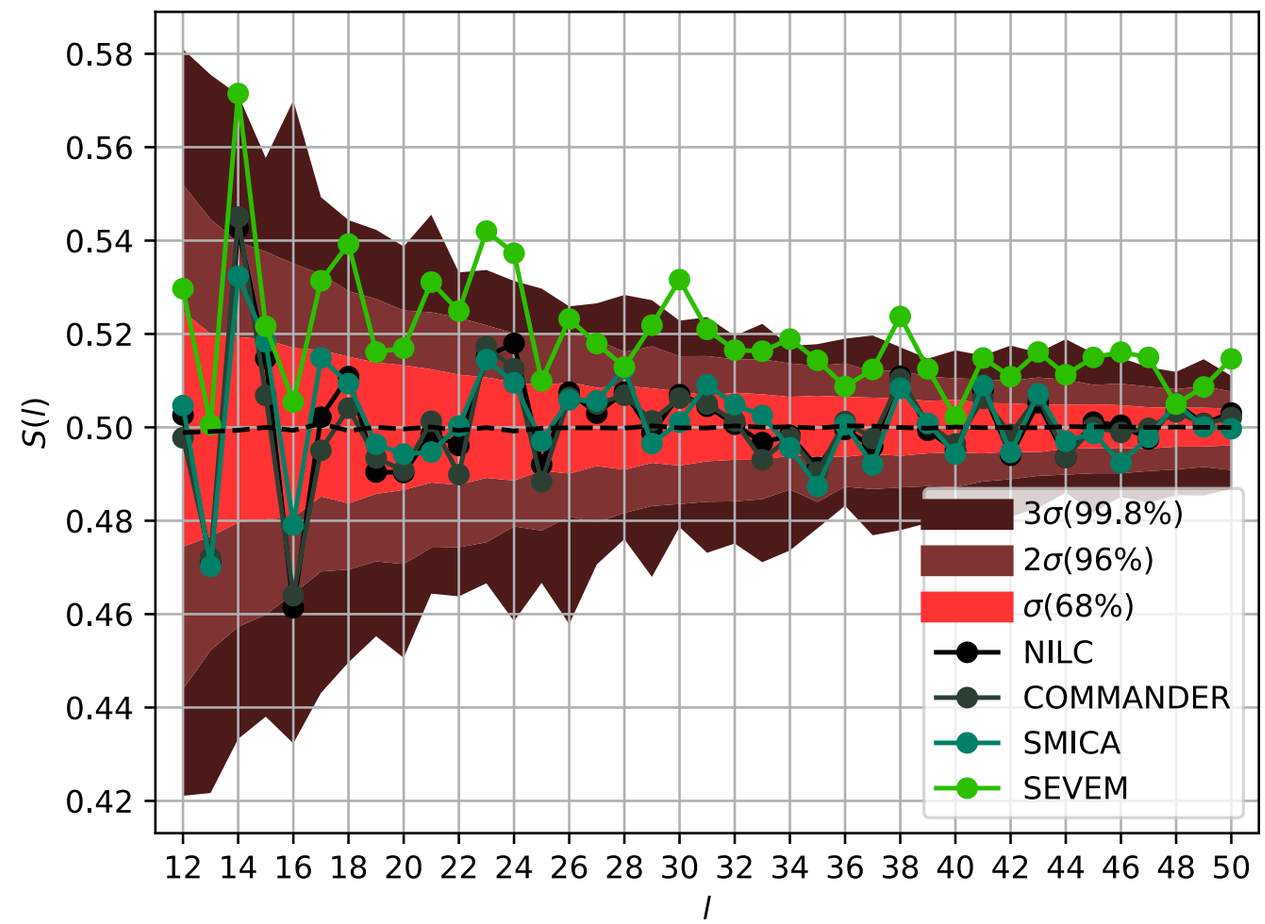
alignment of ℓ = **1,2,3** multipoles

CMB anomalies

2. Alignements

Pinkwart & Schwarz, in prep.





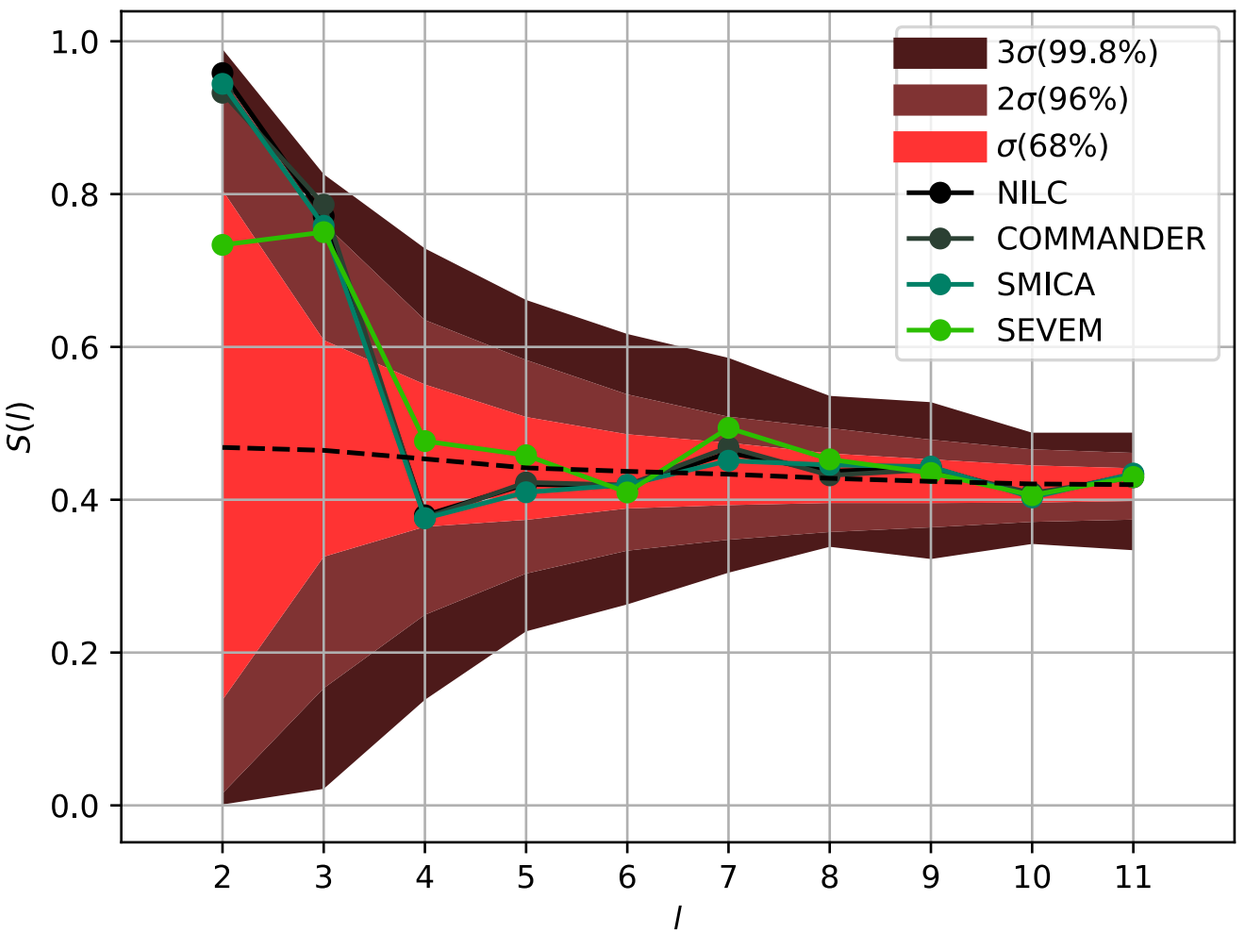
How well does the galactic plane align with a given multipole?

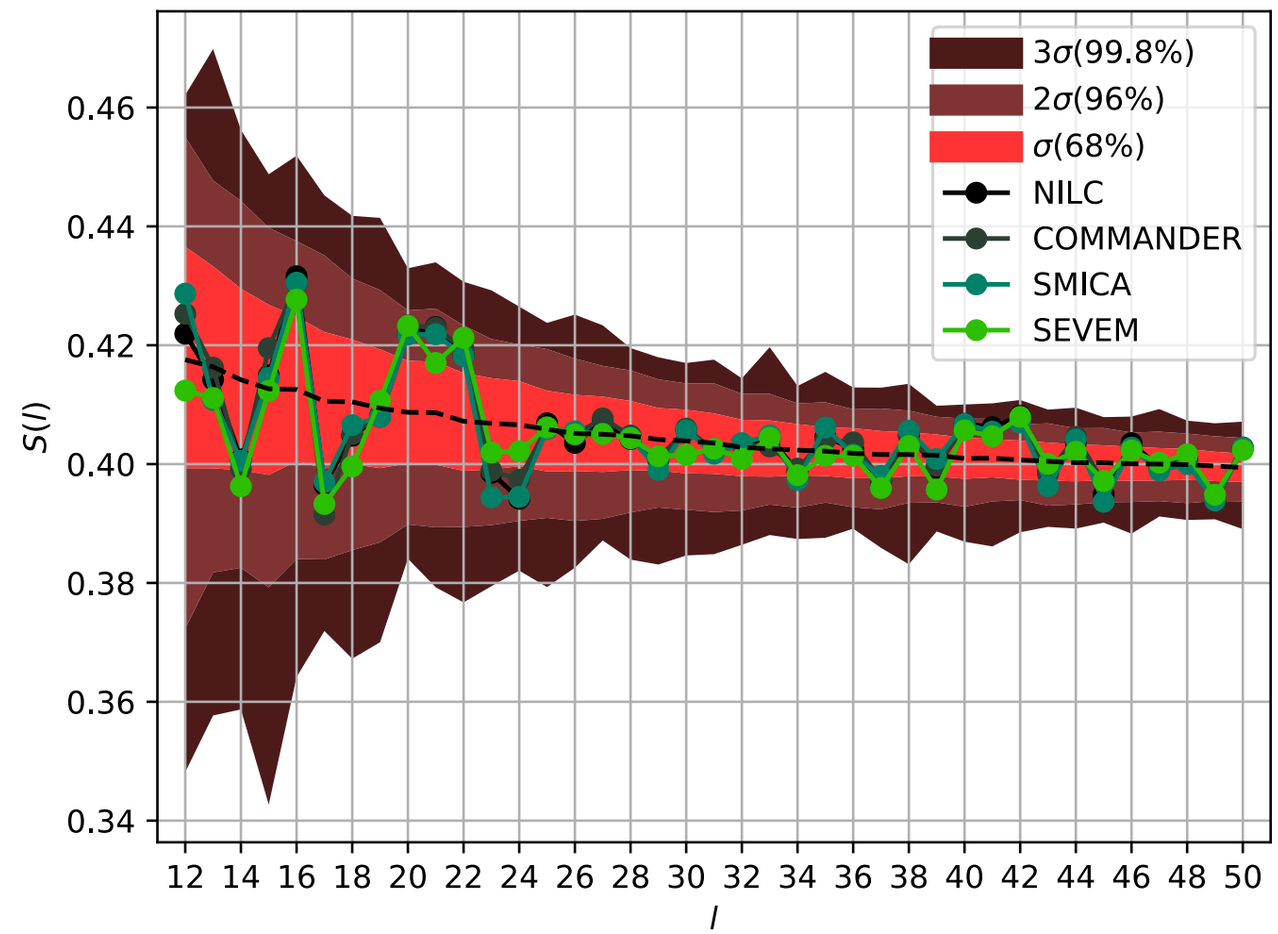
1. Test based on multipole vectors reveals remarkable consistence between Commander, NILC and SMICA, but inconsistence with SEVEM 2. No anomalous alignment with galactic plane

CMB anomalies

2. Alignements

Pinkwart & Schwarz, in prep.

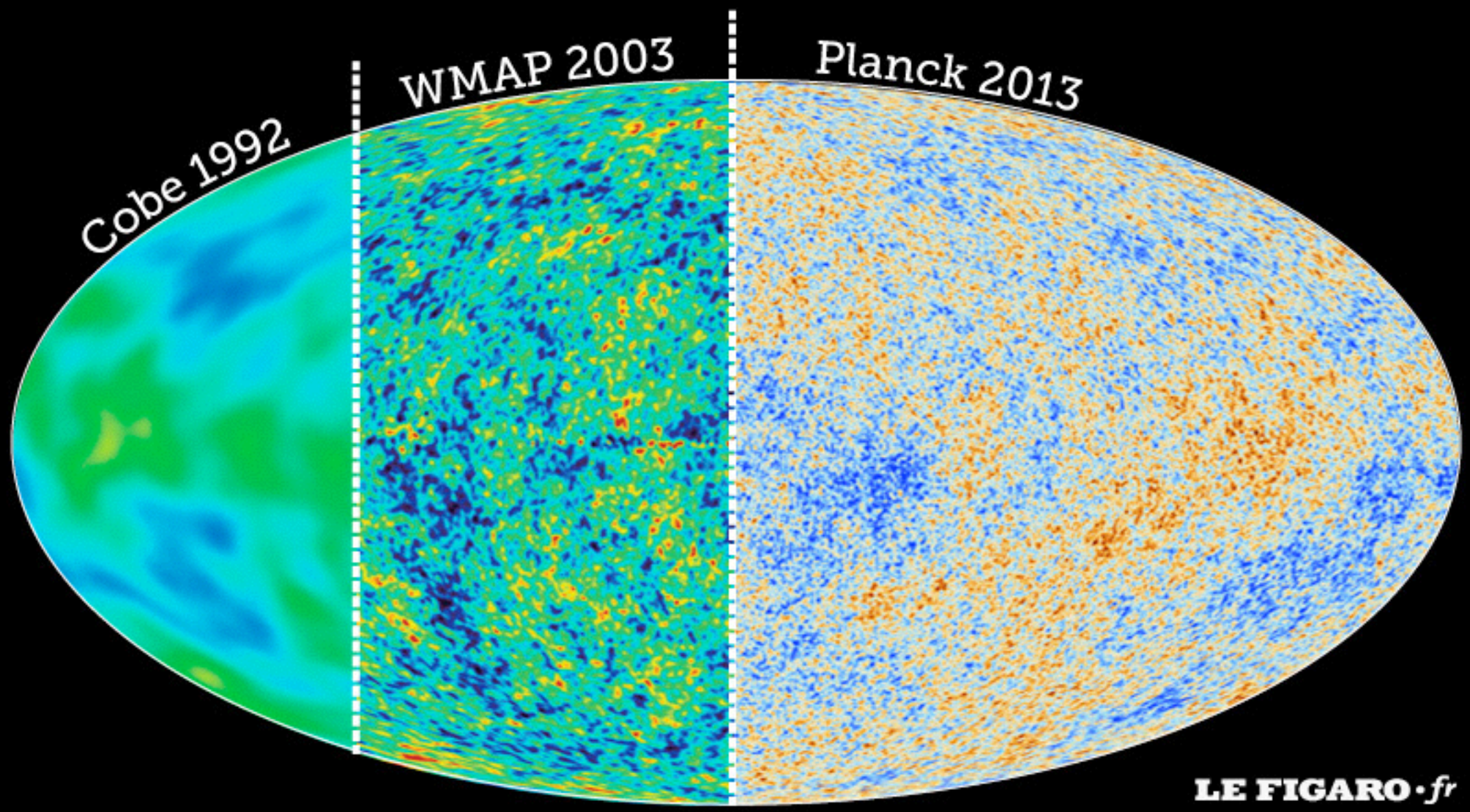




How orthogonal is the dipole to a given multipole?

p-value of quadrupole and octopole < 0.04 each, higher moments show expected behaviour

What next?



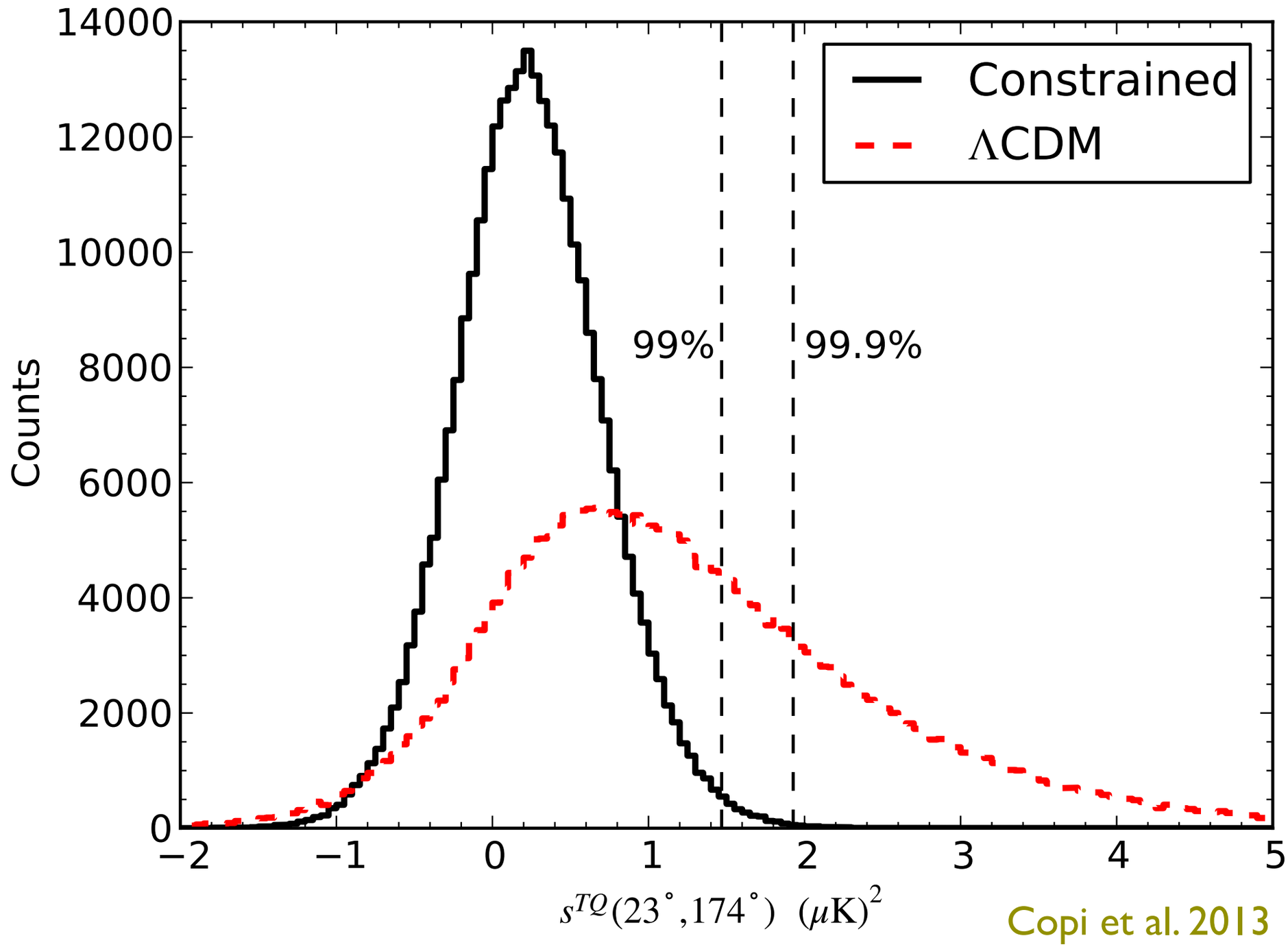
Statistical flukes? Ability to see patterns in noise?

Several test that are based on constrained predictions for patterns that we should see or should not see in the large angle polarised CMB have been put forward,
e.g. by Copi et al.

These test will be able to decide if an anomaly is a real

Problem: polarised foregrounds on the largest scales

E.g. if LCDM would be true and lack of 2pt correlation is just an unusual realisation we expect black distribution if new measurements are also unlikely wrt black curve, fluke hypothesis is excluded (here 2pt TQ cross-correlation)



Copi et al. 2013

Back to the CMB Dipole

T_0 = (2.7255 ± 0.0006) K Fixsen 2009
T_l = (3364.5 ± 2.0) μK
l = (264.00 ± 0.03) deg, b = (48.24 ± 0.02) deg Planck 2015

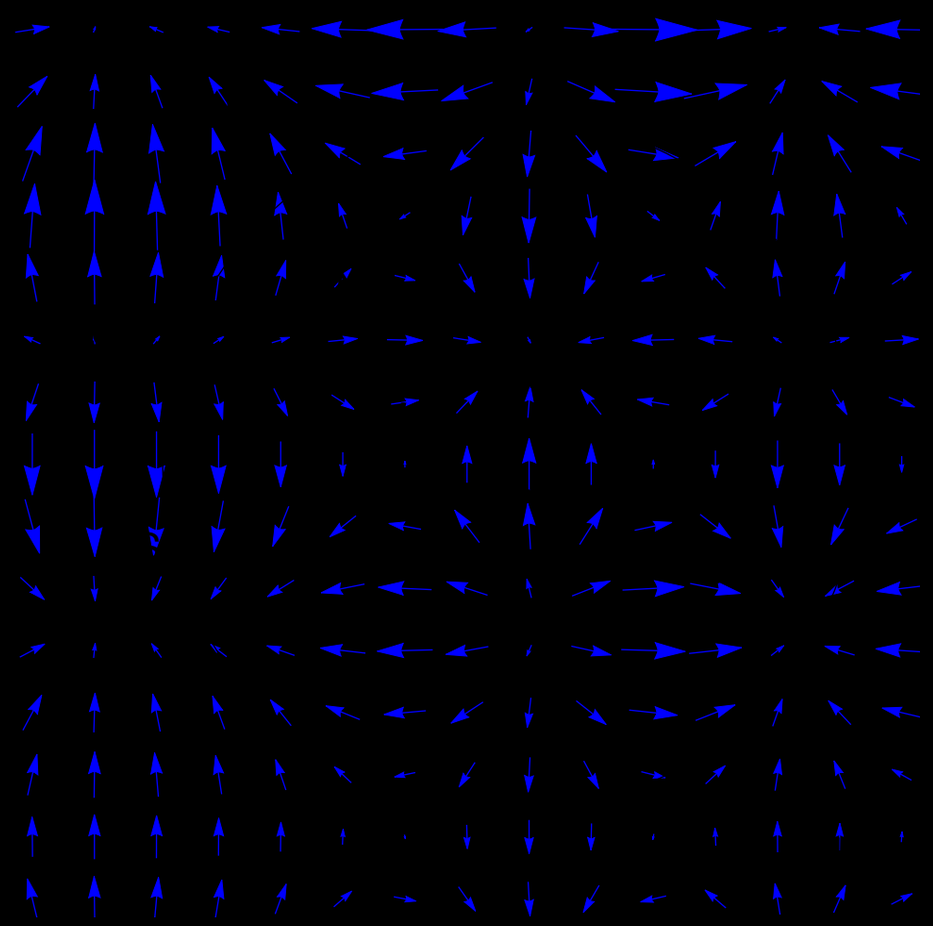
hypothesis: cmb dipole is due to peculiar motion of Solar system with v = (369 ± 0.9) km/s Planck 2015

$$T(\mathbf{e},\mathbf{v}) = \frac{\sqrt{1-\mathbf{v}^2/c^2}}{1-\mathbf{e}\cdot\mathbf{v}/c}T_0 = T_0\left[(1-\frac{v^2}{6c^2}) + \frac{v}{c}P_1(\mu) + \frac{2v^2}{3c^2}P_2(\mu) + \ldots\right]$$

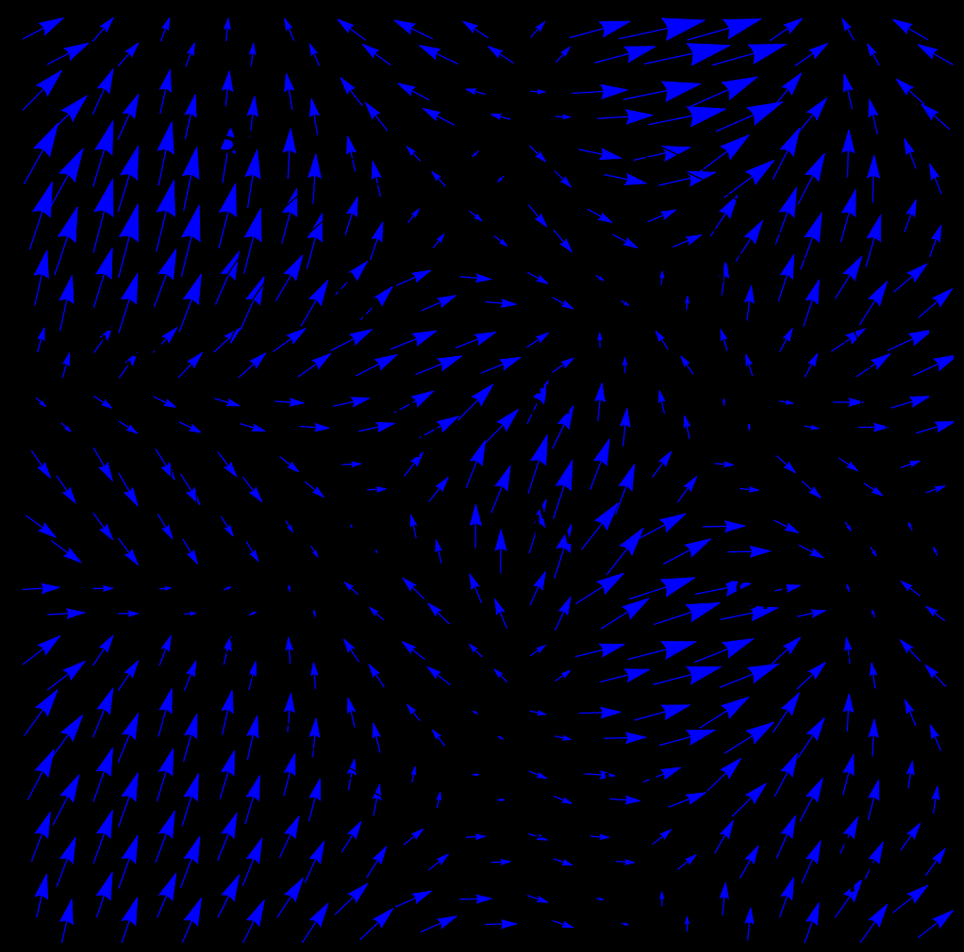
Peebles & Wilkinson 1968

But there should be a primordial dipole secondary dipole (ISW etc.)
Currently neglected, is that justified?

Why bother?
1. Bulk flows and Hubble rate



local peculiar velocities



plus large scale bulk flow

CMB dipole defines cosmic reference frame

Hubble expansion rate

➜ H_0 = (66.89 ± 0.90) km/s/Mpc (CMB: Planck 2016)
H_0 = (73.24 ± 1.74) km/s/Mpc (SN1a: Riess et al. 2016) … debated conflict

➜ measurement of H_0 assumes that redshifts of cepheids and SN1a are given in comoving cmb frame

ideal situation
(isotropic
source distribution)

$$H_0 = \frac{1}{N}\sum_{i=1}^{N}\frac{cz_i + v_{pi}}{d_i} = \frac{1}{N}\sum_{i=1}^{N}\frac{cz_i}{d_i} + O(\frac{1}{\sqrt{N}})$$

➜ error in determination of comoving frame:

$$\text{if } \Delta v_p = 100 \text{ km/s} \Rightarrow \frac{\Delta H_i}{H_0} \sim \frac{h^{-1}\text{Mpc}}{d_i}$$

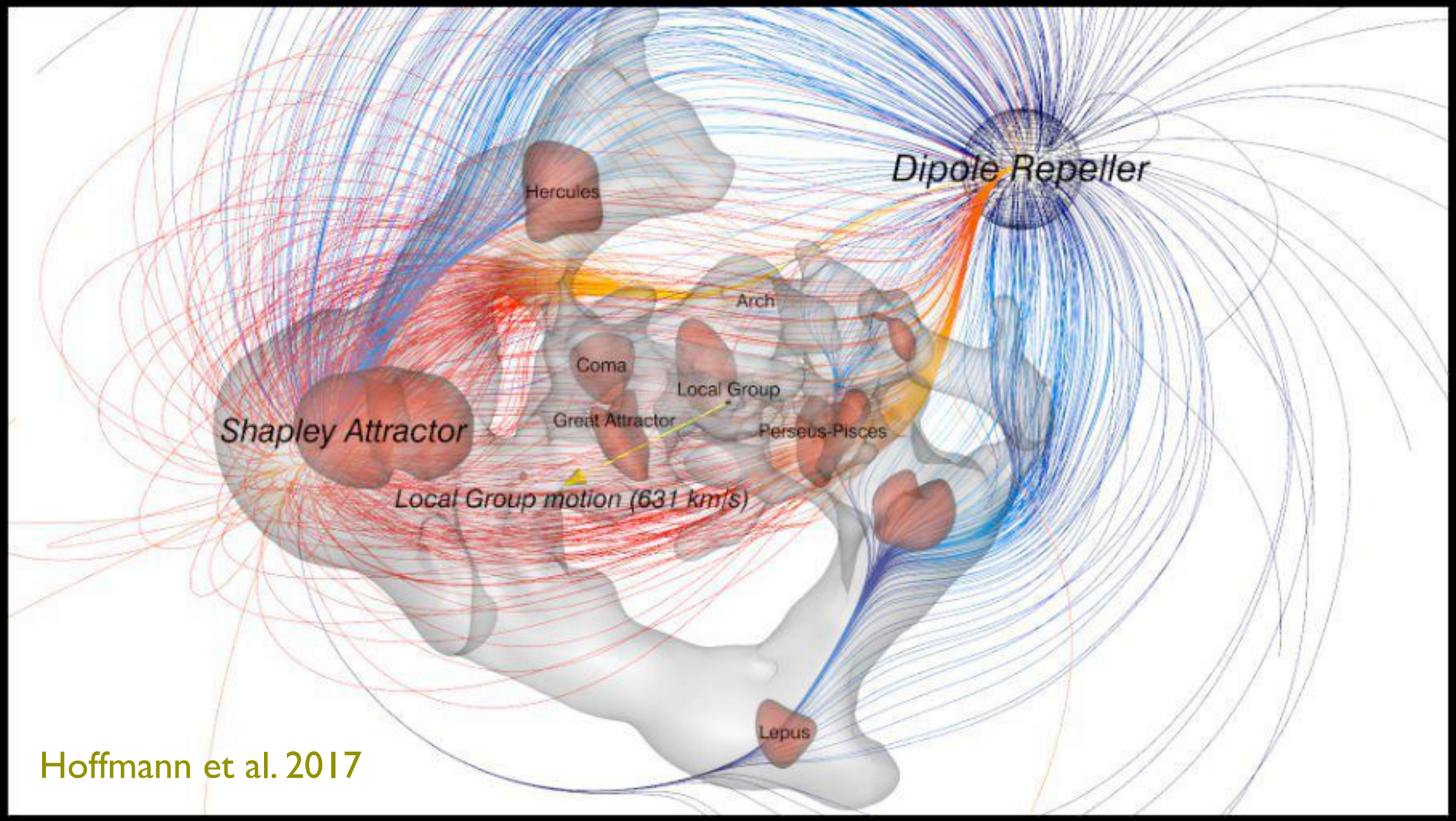
➜ realistic N/S anisotropic sample with ⟨d⟩ = 150 Mpc:

important for
precision cosmology,

$$\Delta H_0 \sim \frac{1}{2}\frac{h^{-1}\text{ Mpc}}{150\text{ Mpc}} H_0 \sim 0.3 \text{ km/s/Mpc}$$

larger effect on cepheid calibrators (luminosity distance is not boost invariant)

Why bother?
2. The local Universe



Hoffmann et al. 2017

CMB Dipole:

The proper motion hypothesis makes a prediction:

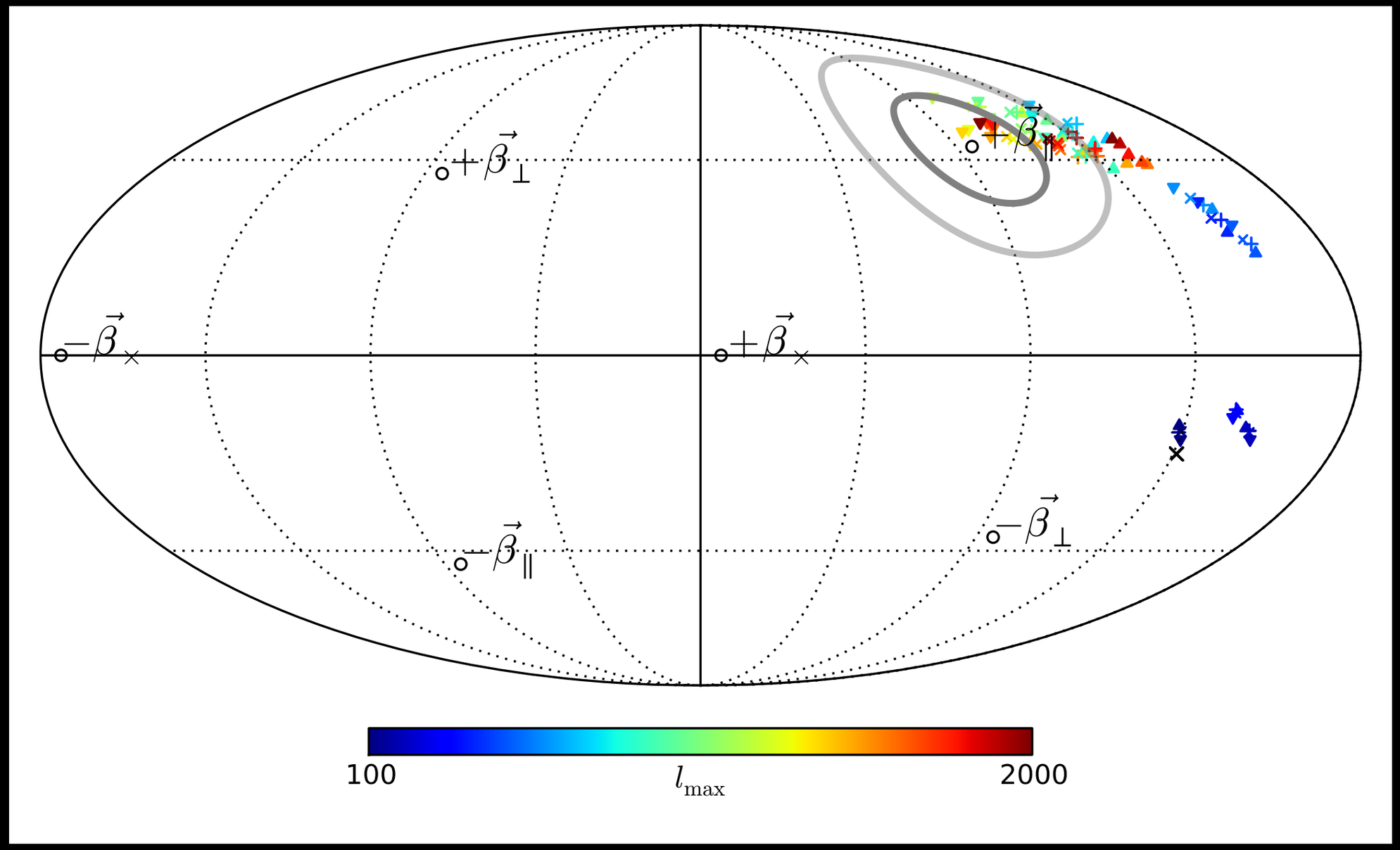
Doppler shift and aberration
for all objects at cosmological distances and at any frequency

➜ test with high-ℓ multipoles in CMB Planck 2013/2015
(coupling of ℓ to $\ell \pm 1$ multipoles)

➜ test with radio sky (as $\langle z \rangle > 1$, unlike IR or optical)

➜ test with in CMB via secondary effects,
e.g. lensing, kSZ, etc.

CMB proper motion test

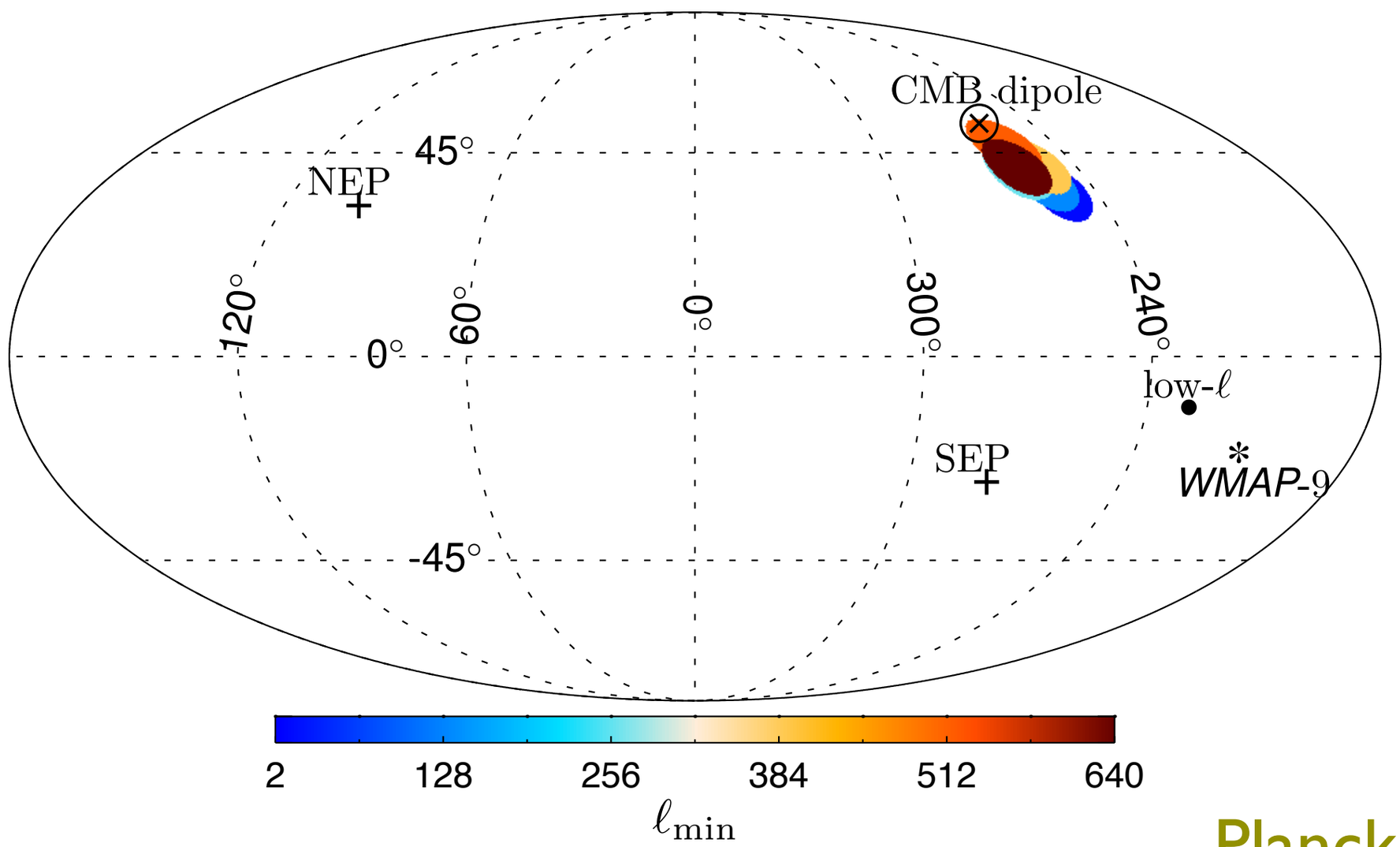


v = 384 km/s ± 78 km/s (stat.) ± 115 km/s (sys.)

compare with CMB dipole: v = (369 ± 0.9) km/s; analysis fixes direction

Planck 2013

CMB proper motion test

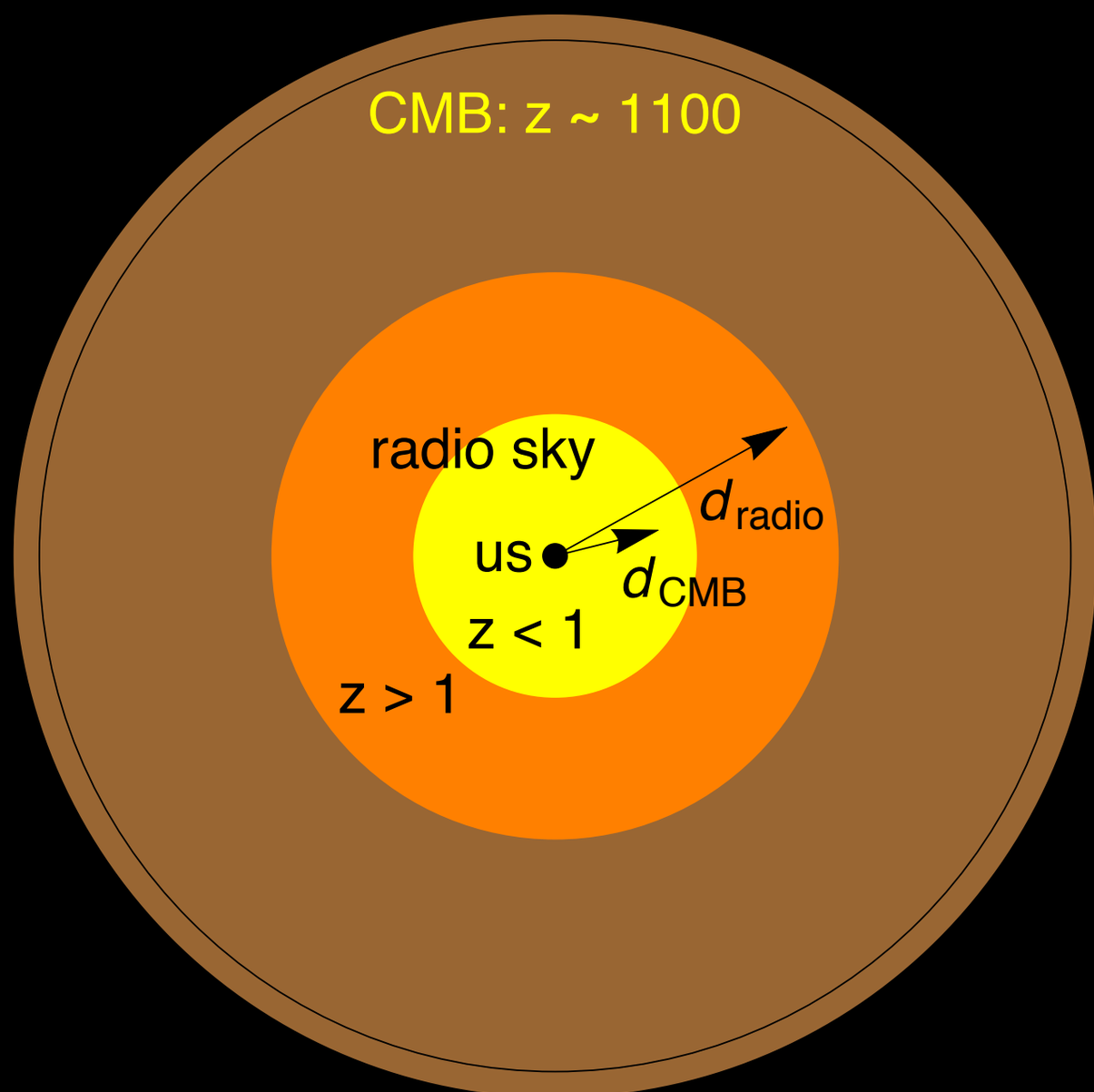


Planck 2015

Bipolar Spherical Harmonics

allows for 40% non-kinetic contribution to CMB-dipole

Cosmic Radio Dipole



$d_{radio} = d_{kin} + d_{matter}$

in LCDM = O(0.005) + O(0.001)

radio galaxies: **mean z > 1**

d_{matter} expected to be small

kinetic dipole

Ellis & Baldwin 1984

$$\frac{\mathrm{d}N}{\mathrm{d}\Omega}(>S) = aS^{-x}[1 + d\cos\theta + ...]$$

$$d = [2 + x(\alpha + 1)]\frac{v}{c}, \quad S \propto \nu^{-\alpha}$$

aberration & Doppler shift

Conclusions

- check for similar anomalies in polarisation — no a posteriori statistics
- improve cosmic matter rest frame (CMB and non-CMB observations)
- improve understanding of (polarised) foregrounds

coordinate CMB and non-CMB surveys