CMB anomalies in an inhomogeneous Universe

No universe model provides a CMB simulation map morphologically conform to the Planck map

However, statistical conformity CMB standard model map – versus – CMB observation map is globally very good

CMB is a keystone of the ΛCDM model of cosmology

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Inhomogeneous Cosmologies IV
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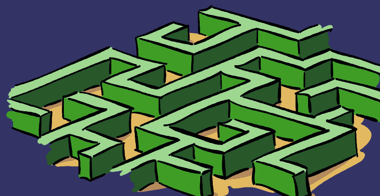
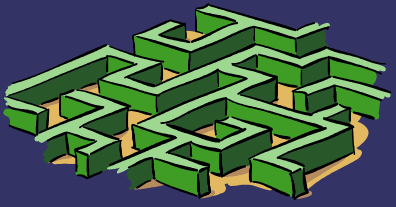


From Earth (Planck probe) we observe a CMB nearly homogeneous and isotropic, nearly Gaussian and of quasi zero mean

The CMB sky is almost perfect fit to the predictions of the model said ΛCDM

But, within the admitted limits of the CMB temperature anisotropies (2.7255 +/- 0.0006K), the CMB sky shows several strange features named CMB anomalies...



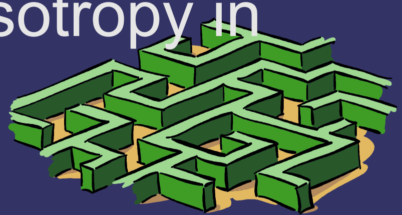
Two of these CMB anomalies compared to the ΛCDM expectations:

– On average, a CMB map sample in a ΛCDM model shows a standard deviation ~59.2uK, while the unique Planck map has ~51.6uK claimed low

Is it a CMB sky anomaly regarding the ΛCDM ? Probably not, because hundreds out of 100000 individual sample maps show a standard deviation close to the Planck map value

– On average, the ΛCDM sample shows at any angle a far from zero two point correlation function (2-pcf) while the Planck map 2-pcf is zero above 60°

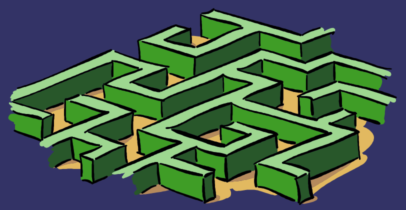
There is, with this vanishing 2-pcf, violation of the isotropy in the CMB sky...



The probability of having such a vanishing 2-pcf in the CMB of the ΛCDM is below 10/100000, while the 2-pcf of the Planck map is even more vanishing when the foreground contamination due to our galaxy is carefully corrected

The result is of importance as the 2-pcf (or equivalently the power spectrum) determines entirely a Gaussian random field...

The more Gaussian is a random field the less there is room for anomalies

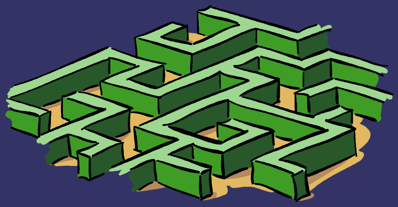


The more Gaussian is a random field the less there is room for anomalies, clarify ?

Gaussianity of a random field has the nice property to be predictable for a large class of estimators,

each descriptor should be able to provide an additional information about the random field,

so let's apply some to the CMB scalar temperature random field treated as an excursion set upon the 2-sphere :



The more Gaussian is a random field the less there is room for anomalies, clarify?

Having $T_0^{(CMB)} = (2.7255 \pm 0.0006K)$,

the CMB temperature anisotropy is defined by $\delta T := T - T_0^{(CMB)}$,

with σ_0^2 the variance and σ_0 the standard deviation,

the normalized CMB temperature is $\nu = \delta T/\sigma_0$.

Upon the 2–sphere $\mathcal{S}^2$ (support manifold of the CMB),

the excusion set,

$$Q_\nu := \left(\Theta = \Theta(\theta, \phi) \ in \ \mathcal{S}^2 \ such \ as \ \frac{\delta T(\Theta)}{\sigma_0} > \nu \right) .$$

The more Gaussian is a random field the less there is room for anomalies, clarify?

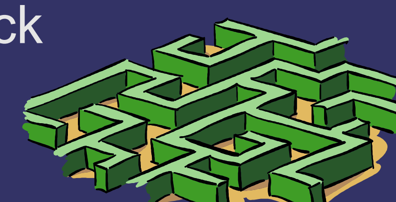
The 2-sphere support manifold of the CMB is of dimension d=2 with constant curvature +1.

From Hadwiger's theorem (1957) one derives that a morphological descriptor is a linear combination of d+1 functionals, the Minkowski Functionals (MFs) v0,v1,...,vd

Over an excursion set Q under the hypothesis of smoothness, for the 2-dimensional CMB the MFs
v1 and v2 are simple surface integrals

We consider 4 relevant estimators: PDF, v0, v1 and v2

Ref.: "Model-independent analyses of non-Gaussianity in Planck CMB maps using Minkowski functionals", 2017, T Buchert, M France, F Steiner CQG 34 094002



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The three normalized Minkowski functionals upon $\mathcal{S}^2$ are defined by,

$$v_0(Q_\nu) := \int_{Q_\nu} da = area(Q_\nu) ,$$

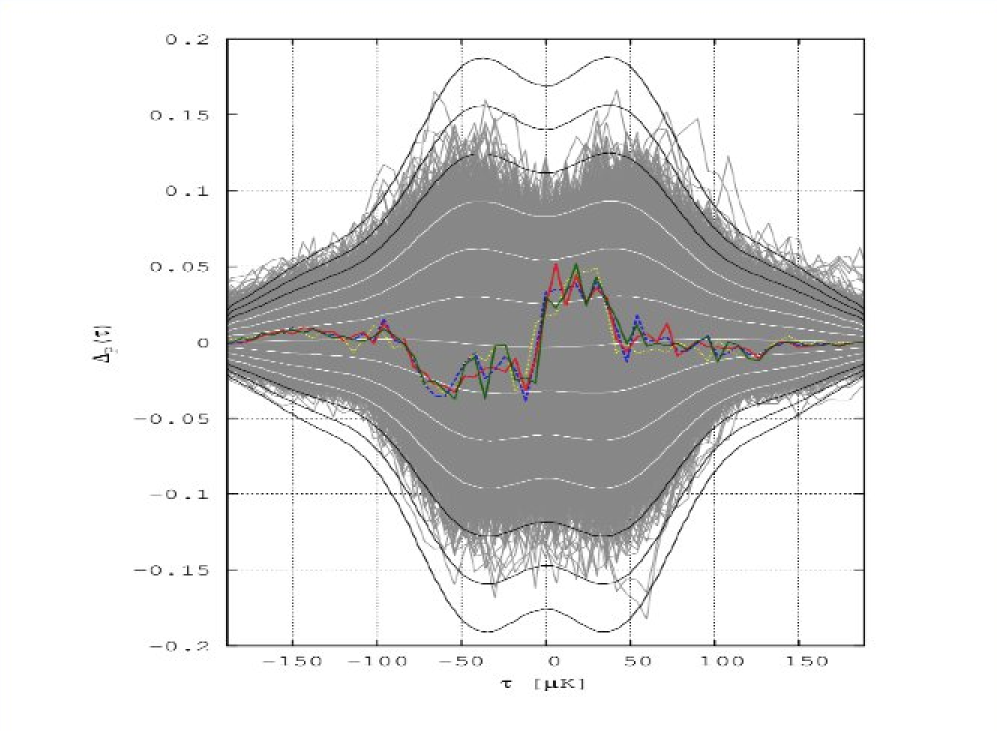
$$v_1(Q_\nu) := \frac{1}{16\pi} \int_{\partial Q_\nu} ds = \frac{1}{16\pi} length(\partial Q_\nu) ,$$

$$v_2(Q_\nu) := \frac{1}{8\pi^2} \int_{\partial Q_\nu} \kappa(s) ds ,$$

where da is the area element of Q_ν,

ds the line element along ∂Q_ν and

$\kappa(s)$ the geodesic curvature of ∂Q_ν.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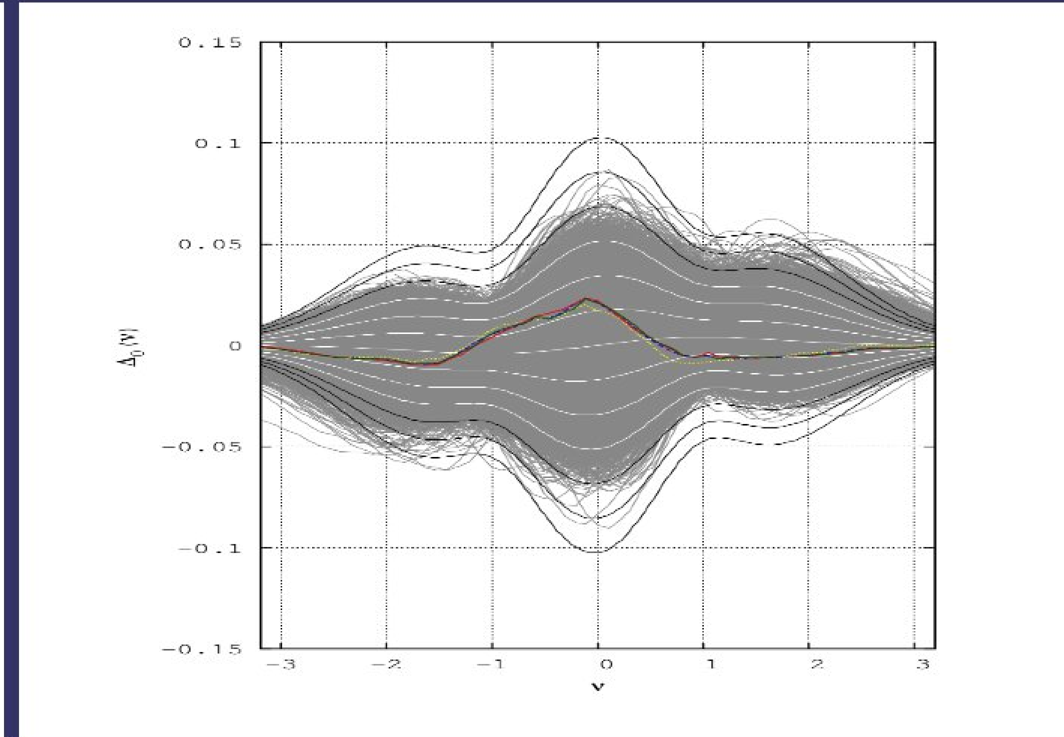
τ [μK]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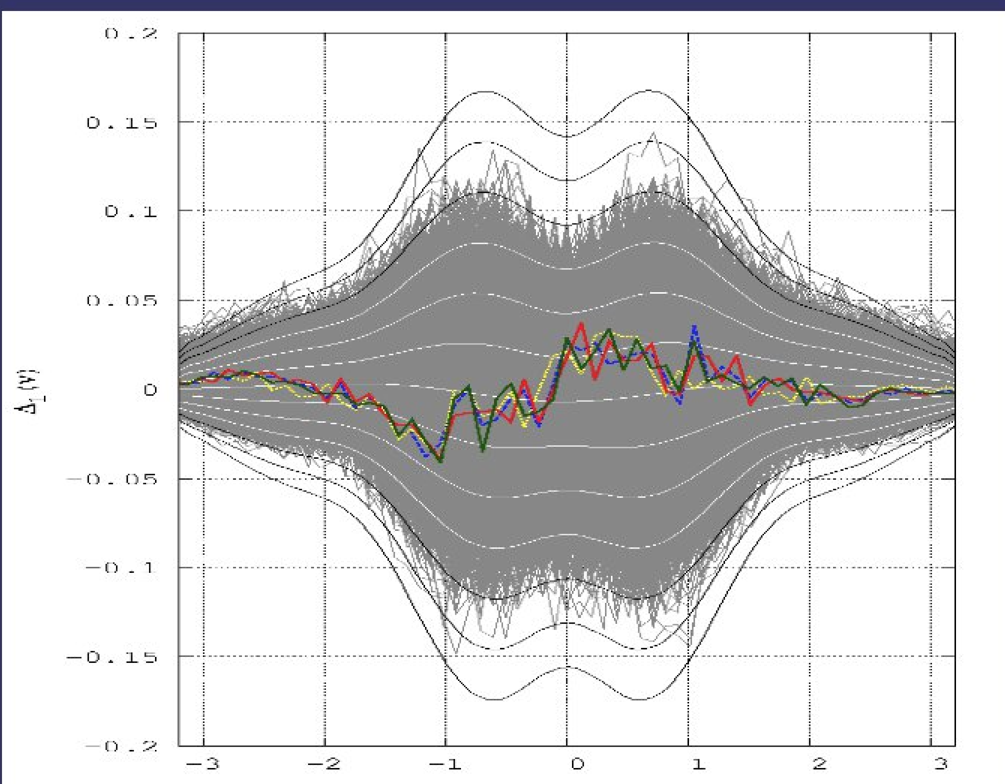
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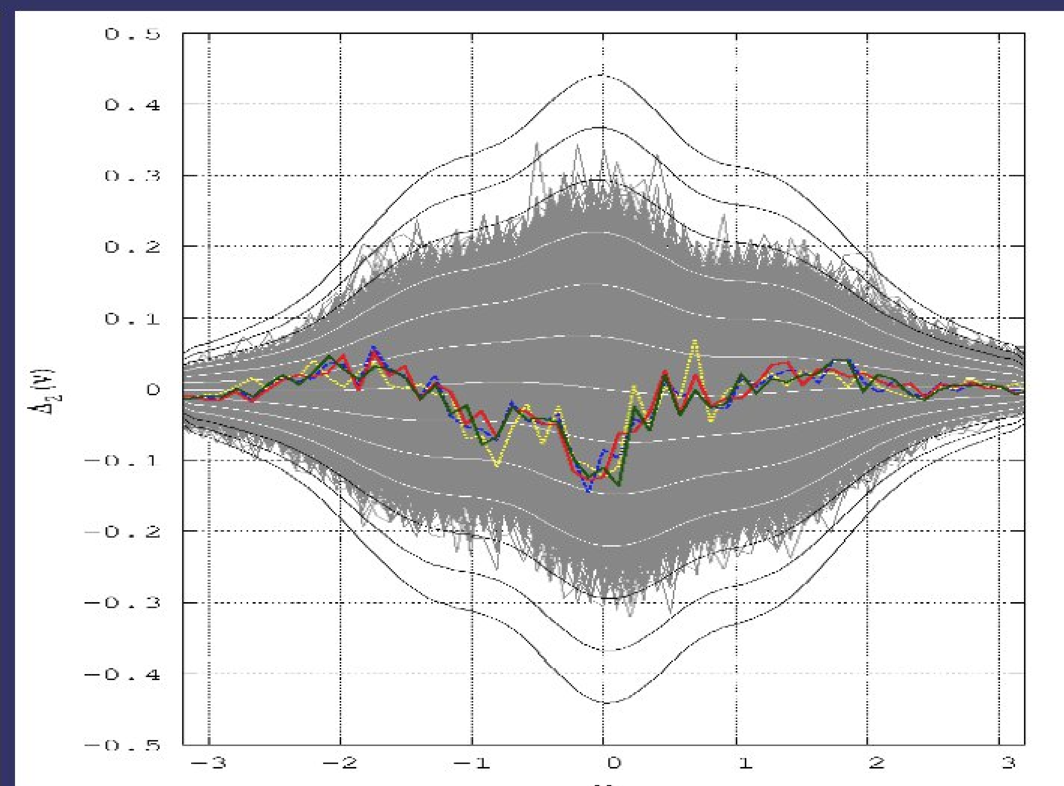
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ν

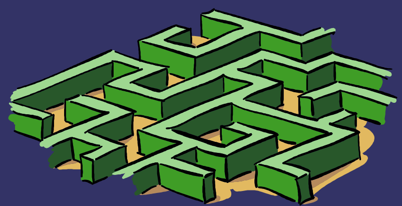
The more Gaussian is a random field the less there is room for anomalies, clarify?

Thanks to the Integral Geometry, these 4 discrepancy functions show different aspects of the non-Gaussianity which are complementary in terms of morphology

For instance a random field with an ideally Gaussian PDF is compatible with a strong anisotropy, or with a strong inhomogeneity
Conversely, morphological estimators such as the MFs detect the anisotropic deviation from Gaussianity

Pathologies which would be detectable with the 3 Minkowski functionals...

But we see clearly that the Planck CMB is highly Gaussian even in terms of these MFs : non-Gaussianity is below 2σ , but hundreds of ΛCDM maps are non-Gaussian up to 5σ
BUT, this global weak non-Gaussianity allows for many small CMB anomalies...



Origins of the anomalies on the CMB are unknown

Once rejected, the likelihood of having the observed CMB sky by chance in the simulation samples

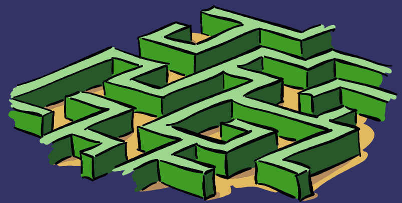
Major attempts to clarify are:

1 - Milky Way foreground contamination and separation

2 - Large scale structures correlated

3 - Bianchi models homogeneous and anisotropic

4 - Universe models with multi-connected topology (MCT)



Origins of the anomalies on the CMB are unknown

1 – Milky Way foreground contamination and separation?

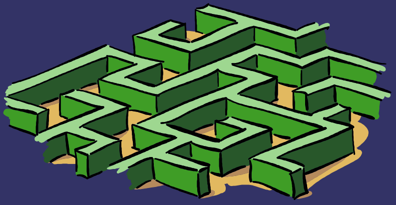
A better suppression of the galactic contamination strengthens the CMB anomaly concerning the vanishing 2-pcf

The minimum variance optimization technique reduces the quadrupole amplitude

2 – Large-scale structures correlated?

Integrated Sachs-Wolfe effect due to a big void in the LSS would yield a cooler CMB region such as the frequency-independent observed Cold Spot anomaly, but no candidate region is sufficiently void to give the temperature contrast of the Cold Spot

And besides, the Sunyaev-Zeldovich effect should be a frequency-dependent Cold Spot

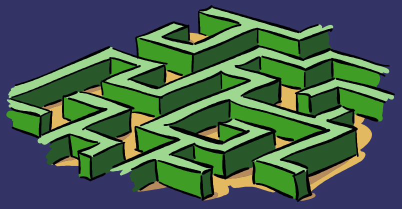


Origins of the anomalies on the CMB are unknown

3 - Bianchi models, homogeneous and anisotropic are source of anomalies?

Many Bianchi universes (those quasi isotropic at large scale) contain the infinite FLRW universe in a sub-class

But, the most promising VII-h Bianchi model gives CMB simulation maps which are not conform to the Planck temperature and polarization maps



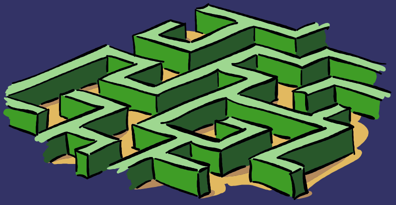
Origins of the anomalies on the CMB are unknown

4 - Universe models with multi-connected topology

It has been proven in 2008 (*"Do we live in a "small Universe?", Aurich, Janzer, Lustig and Steiner*) and later in other studies that the simulations of a CMB in a universe model with multi-connected topology, such as the flat 3-Torus revealed a 2-pcf closer to the 2-pcf of the WMAP CMB sky than the one of the ΛCDM sample

But the expected patterns of circles in the CMB appear clearly only in MCT simulation maps, and not in the Planck map where the noise and the foreground contamination dominate so a MCT cannot be ruled out or confirmed this way

We currently try to see if the MCT would be detectable and confirmed with other observables...



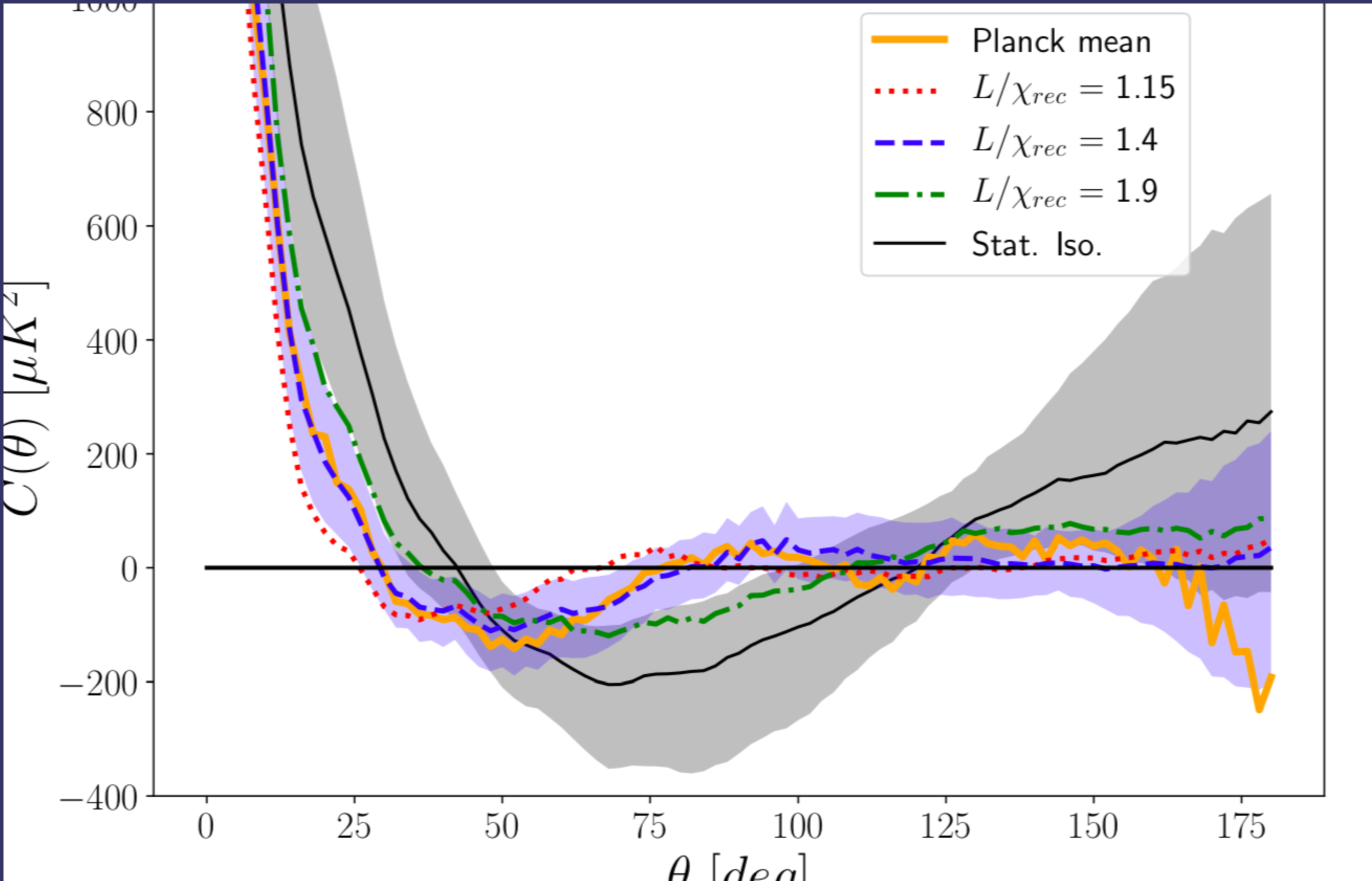
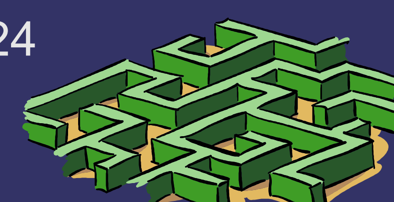


Image courtesy A Bernui et al., arXiv 1809.05924

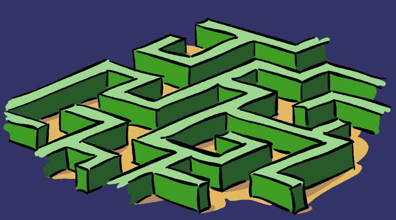


- The optimal slab space side length ~ 4.4 Hubble lengths (H.l.)
- The optimal 3-Torus side length ~ 3.86 H.l.

With the cosmological parameters according to Planck 2015 and the concordance model, the distance to the CMB is 13909Mpc,

and the Hubble length is
c/H_0=4425Mpc,

the ratio CMB diameter to the side length of a 3-Torus at L=1H.l. is
6.29 .



CONCLUSION

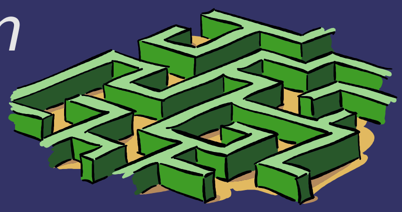
The CMB sky analyzed with various observables is weakly non-Gaussian

But many deviations from the Standard Model of Cosmology are confirmed on the CMB of COBE, WMAP, Planck 2018

Attempts to correlate these CMB anomalies with large-scale properties of the Universe are not conclusive, but still promising

In the ΛCDM model the CMB anomalies are mostly uncorrelated so are highly unlikely and traced back to different causes but in other models (inhomogeneous Universe) the anomalies can be correlated and linked to the same cause

Still origins of the CMB anomalies... is an open question



Thank you!