Testing for Statistical Isotropy in Planck CMB E -mode data

Cosmology from Home 2021

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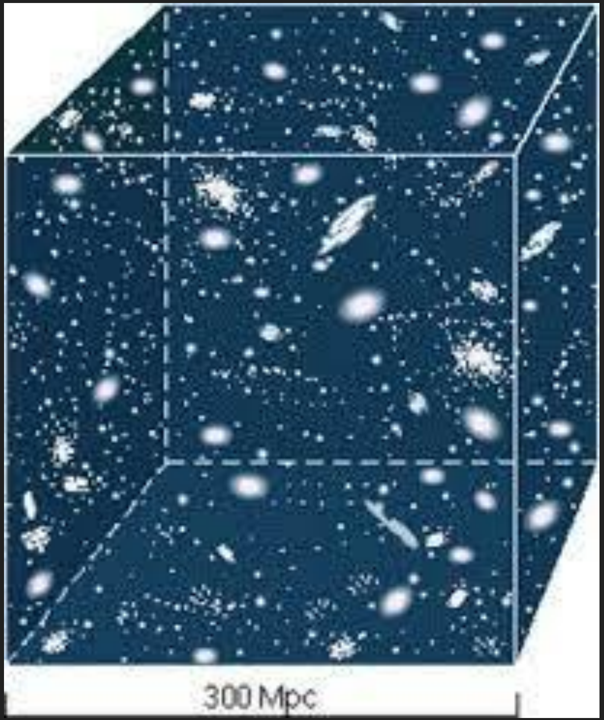
Talk based on: Phys. Rev. D **103**, 123523

Overview

- Motivation behind this work
- Test for statistical isotropy:
  - Contour Minkowski Tensor(CMT)
  - $\mathcal{D}$ Statistic
- Noise in Planck polarization data.
- Sensitivity of CMT and $\mathcal{D}$
- Results from Planck data.

Motivation



The cosmological principle assumes that the universe is homogeneous and isotropic at large scales.

This implies that the observed CMB data should be statistically isotropic.

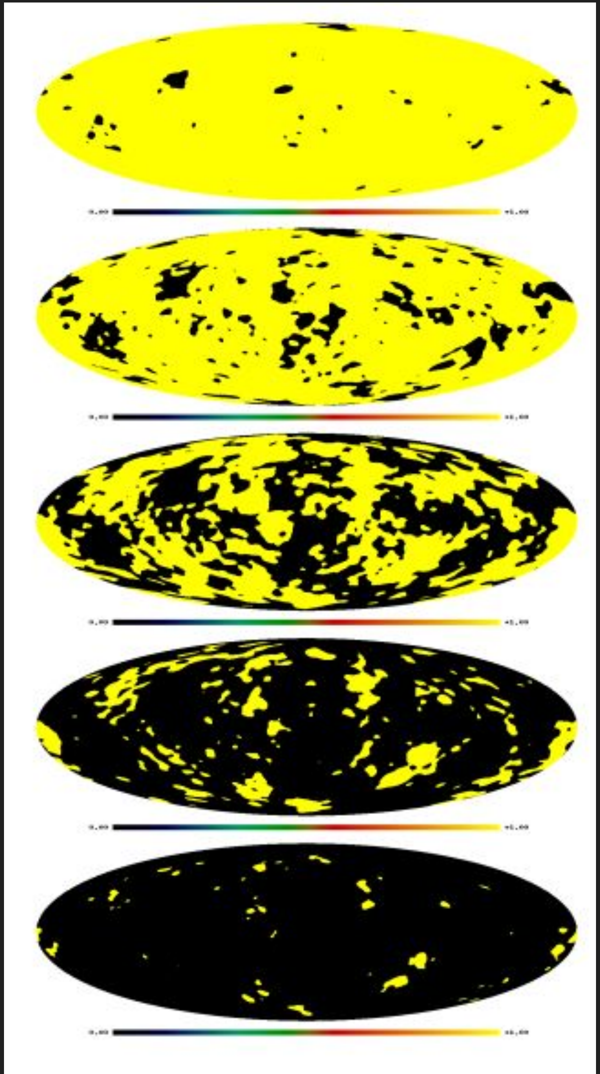
Important to test these assumptions through different independent methods.

Violation of SI can have both observational or cosmological implications.

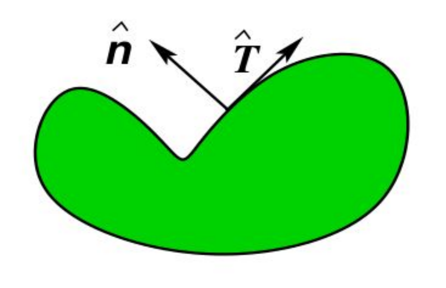
We focus on the *E* -mode polarization of the Planck 2018 data.

Contour Minkowski Tensors (CMT)

- CMTs are defined on the sphere through excursion sets.
- Given a random smooth field u on the sphere, it’s excursion sets can be constructed by choosing a threshold level.
- This will give us various curves on the sphere consisting of connected regions and holes.
- The minkowski functionals (scalar or tensor) are defined on this structures and used as probe of SI and gaussianity..



Contour Minkowski Tensor



$$\mathcal{W}_1 = \frac{1}{4}\int_C \hat{T} \otimes \hat{T} ds$$

$\mathcal{W}_1$ is a 2×2 matrix.

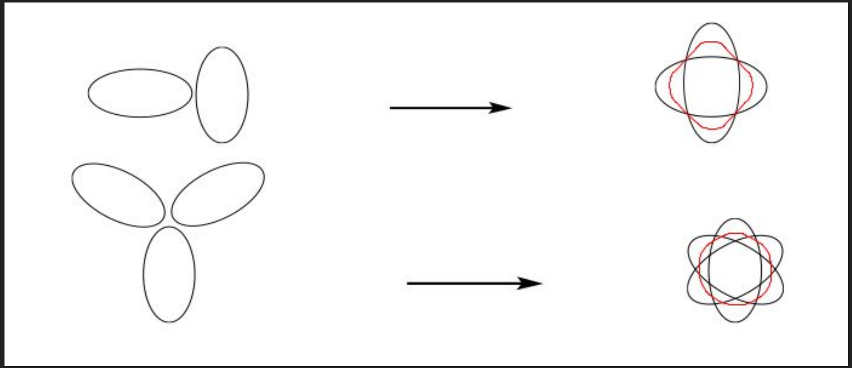
$\mathcal{W}_1$ for all the structures on the sphere are summed over.

The ratio of it's eigenvalues gives the alignment parameter, α.

$$\alpha = \frac{\lambda_1}{\lambda_2}$$

The alignment parameter : α

Pravabati Chingangbam *et al* JCAP12(2017)023



Physically the alignment parameter denotes the locus of the curves. For statistical isotropy this should come out to be unity.

The $\mathcal{D}$-statistic or Directionality test

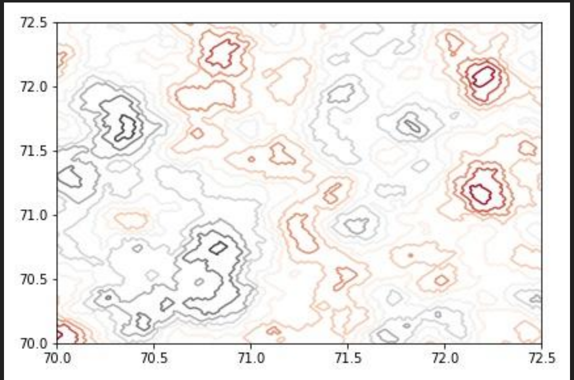
SI implies no preferred directionality in the sky.

For the smooth CMB field u , the shape of the contour maps defined on the surface will be isotropic.

In case of anisotropy, the contour maps will be squeezed or elongated in a particular direction.

This alignment towards a sky direction is captured by the gradient vectors.

Bunn and Scott
https://doi.org/10.1046/j.1365-8711.2000.03212.x



$$f(\hat{n}) = \sum_{p=1}^{N} w_p \left(\hat{n}.\vec{\nabla} u\right)^2$$

p is the pixel index, w_p the weights per pixel.

$\widehat{n}$ is the unit direction for each pixel centres.

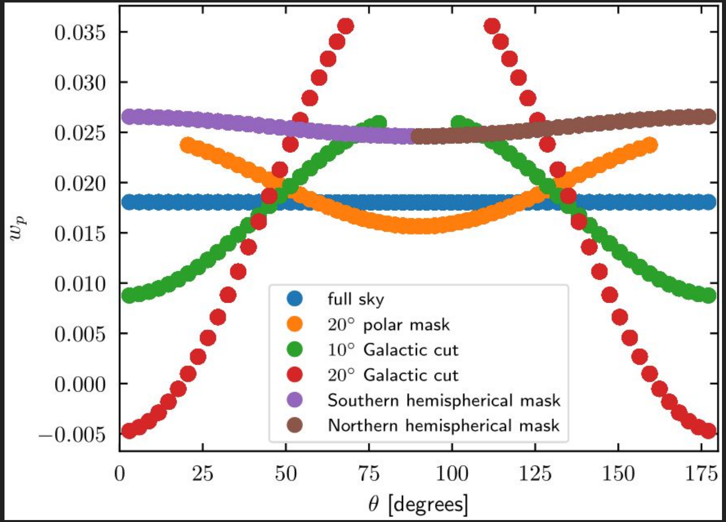
The $\mathcal{D}$-Statistics or Directionality test

Preferred directionality will lead to anomalous values of *f*.

The $\mathcal{D}$ statistic is defined through *f*, will have values close to unity in case of SI.

$$\mathcal{D} = \frac{\max(f)}{\min(f)}$$

Masking the sky will naturally lead to false directional signal. This is nullified by the use of pixel weights.

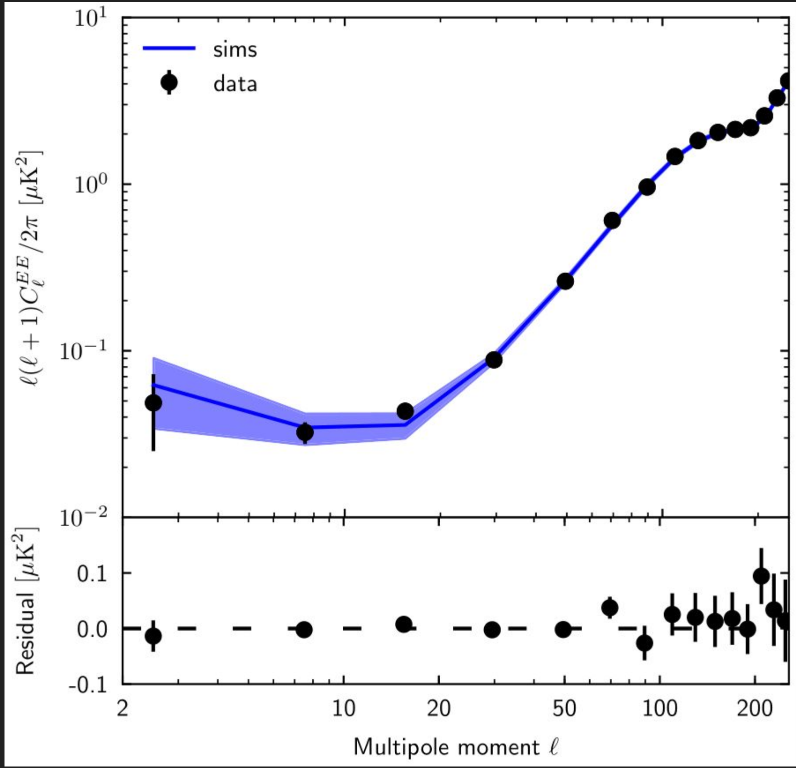


Noise in Planck data

We construct the Planck E-mode map from the component separated SMICA Stokes parameter maps.

We generate corresponding simulations from the 300 SMICA noise-only and cmb-only simulations.

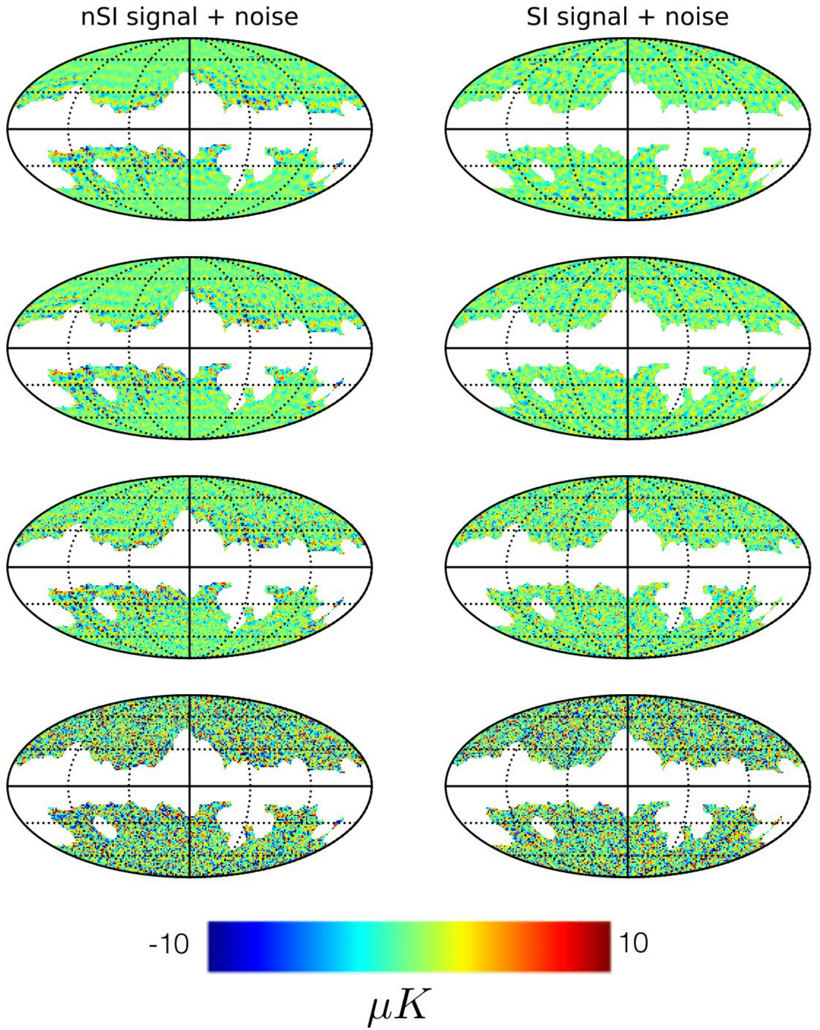
The power spectrum analysis shows that the data is consistent with the simulations upto *l*=200. And the SNR from the simulations is about 1.04.



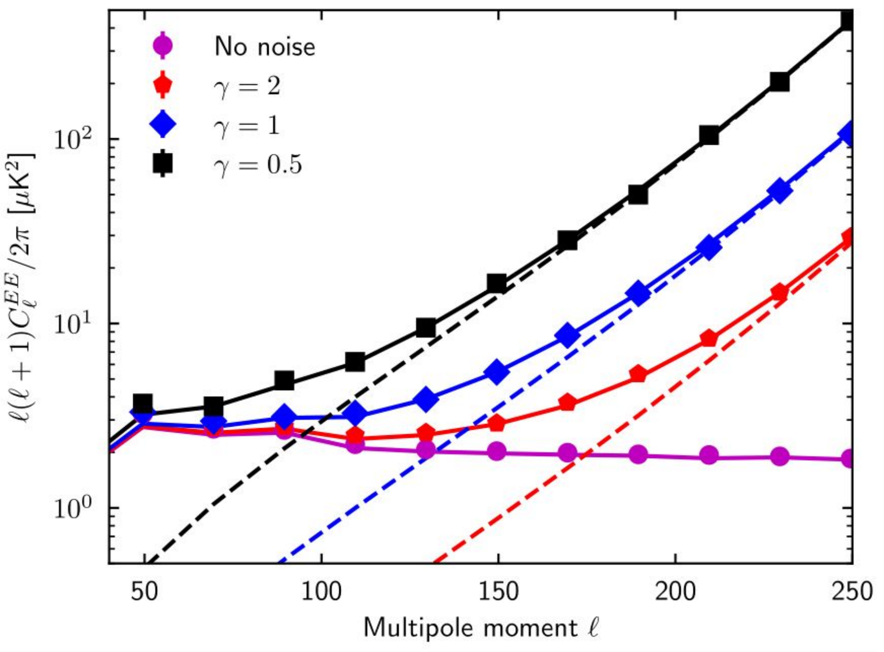
Sensitivity of the SI tests

SI properties of a noisy map can significantly be affected by the properties of noise.

We choose the 353 GHZ dust map with lower multipoles (l<40) filtered out as the nSI signal and add isotropic noise to it. The corresponding SI simulations are generated from the masked power spectrum

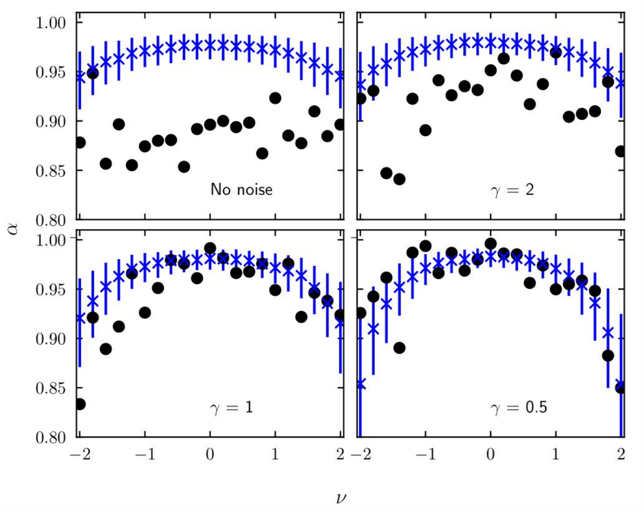


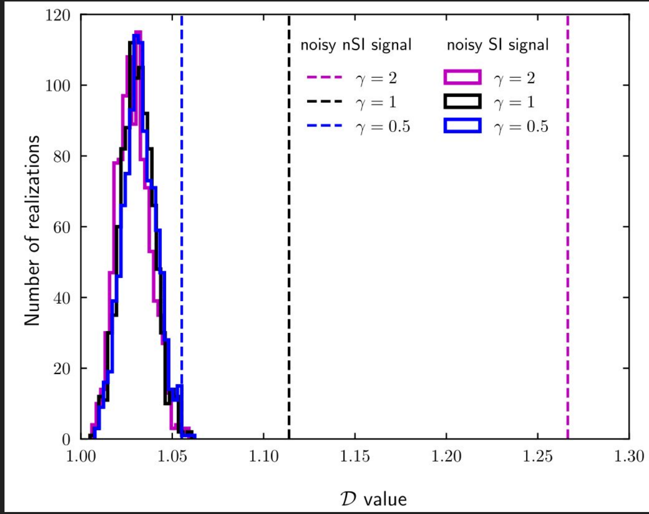
Sensitivity of the SI tests



Sensitivity of α and $\mathcal{D}$

Both the tests are sensitive for SNR =1.0.





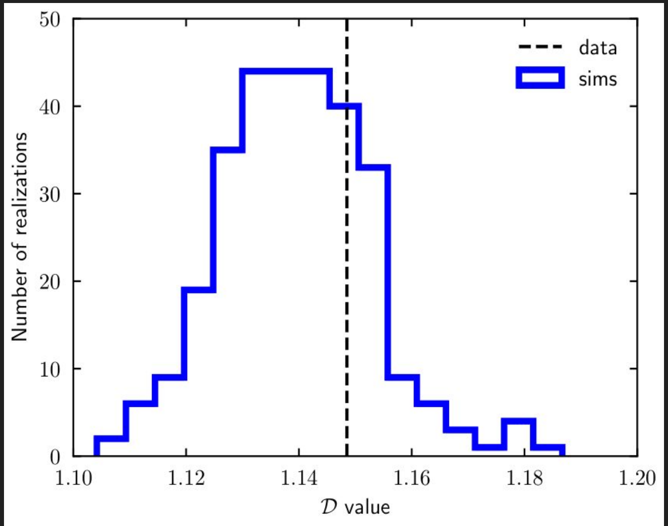
Results

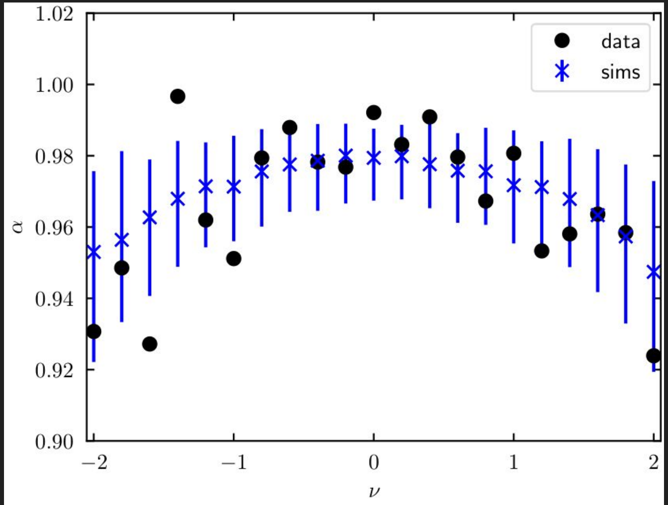
The tests are performed on maps with healpix NSIDE of 128 smoothed with 1 degree beam.

No violation of SI is detected using the two tests.

The p $-$ value for α is 0.54.

For $\mathcal{D}$ the p-value is 0.23.





Thank You !