Higher Order Momentum Analysis as a Powerful Test of the Planck CMB Maps

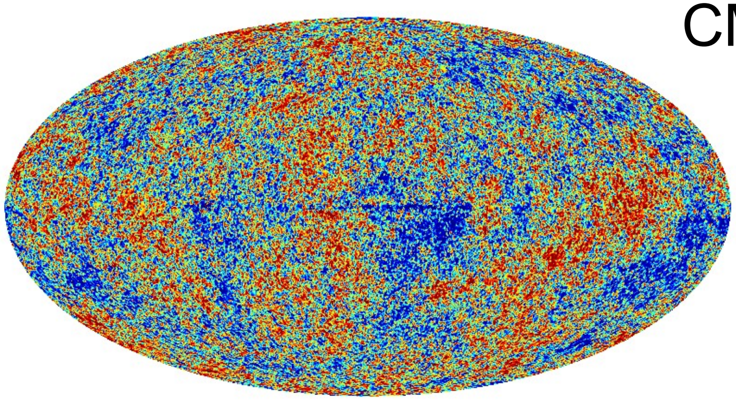
D. Molinari
on behalf of Planck Collaboration

CosmoCruise, 03 September 2015

Outline

- Introduction of the variance and the higher order momenta
- Temperature and Polarization extraction methods
- Examples to show the strength of this simple test applied to the CMB maps
- Planck Temperature results
- Status of the Planck component separation results in Polarization

Introduction



CMB observed map

Introduction

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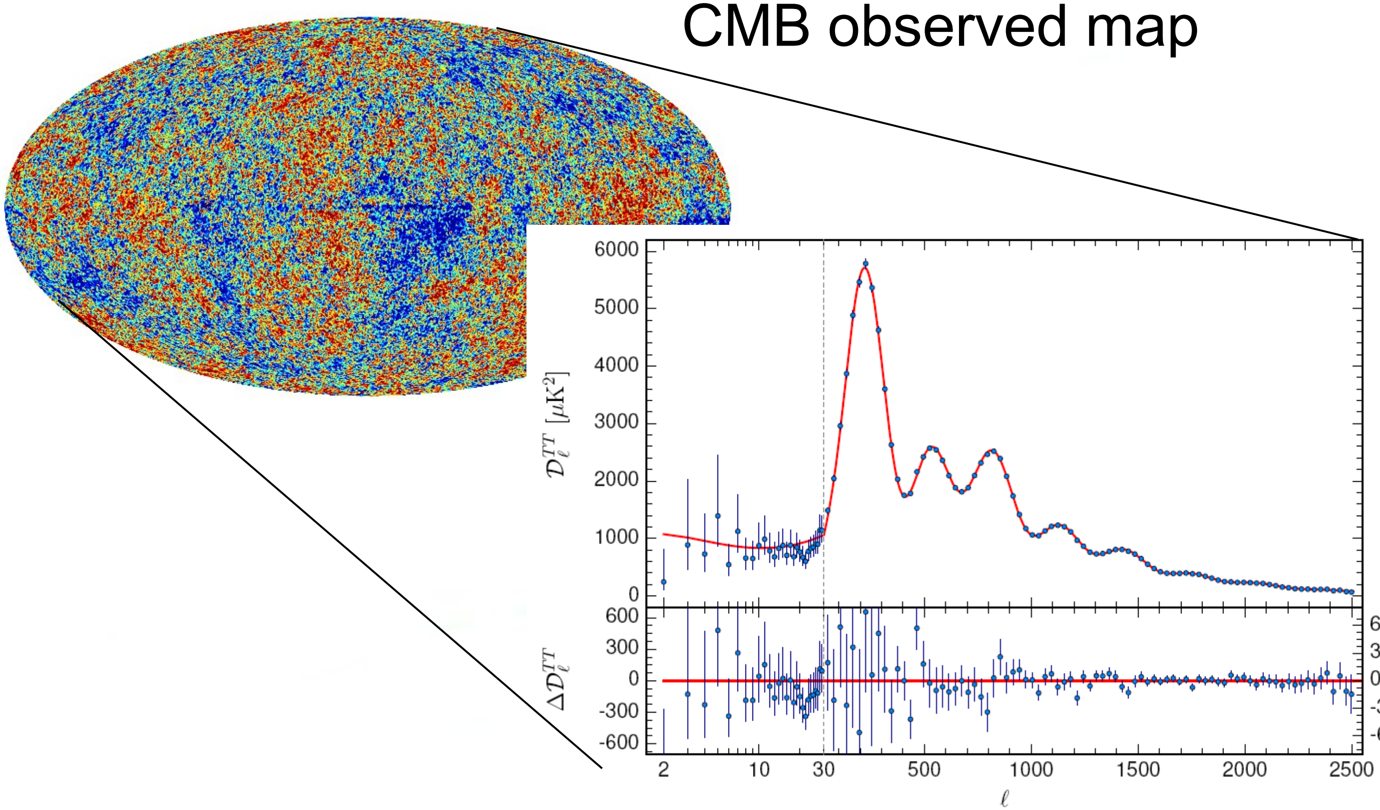

APS extraction and Likelihood building

Introduction

CMB observed map

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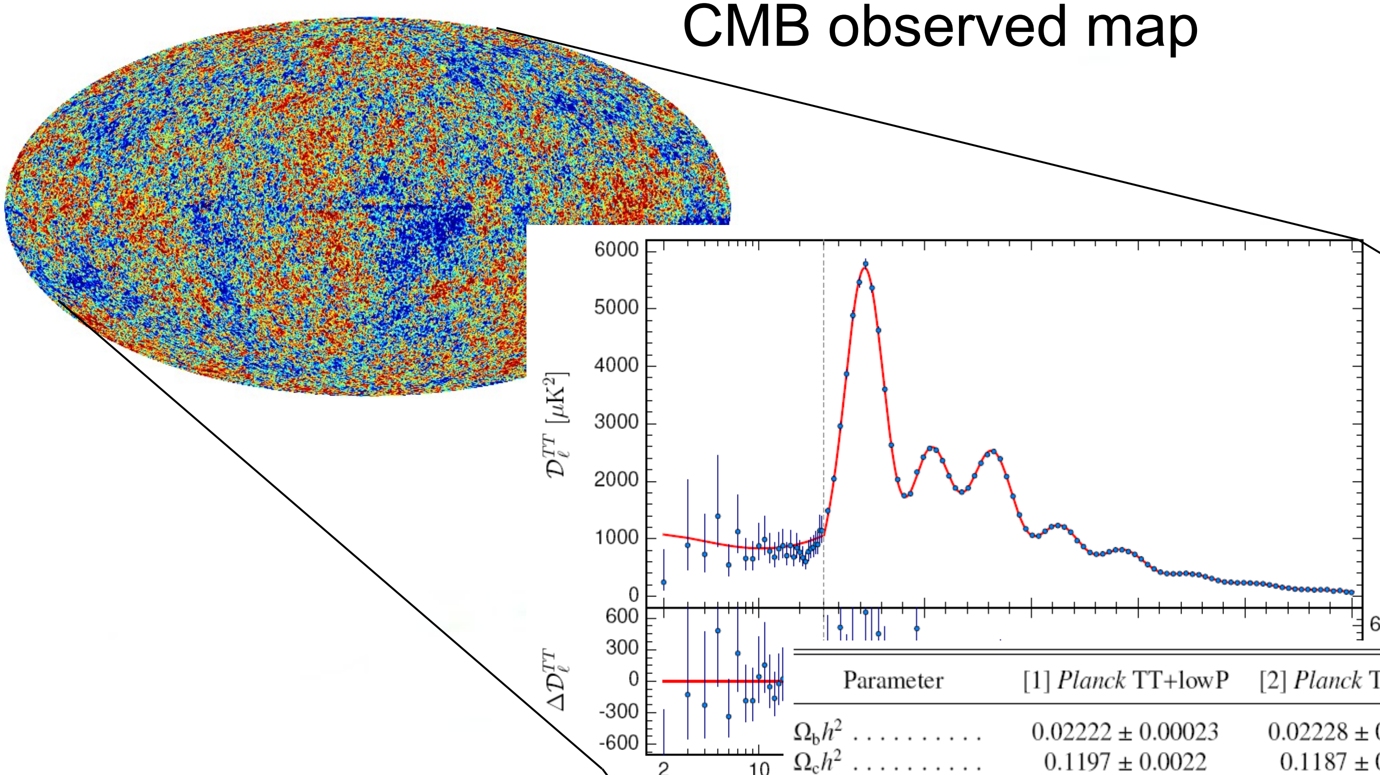

Cosmological parameters extraction

Parameter	[1] *Planck* TT+lowP	[2] *Planck* TE+lowP	[3] *Planck* EE+lowP	[4] *Planck* TT,TE,EE+lowP
$\Omega_b h^2$	0.02222 ± 0.00023	0.02228 ± 0.00025	0.0240 ± 0.0013	0.02225 ± 0.00016
$\Omega_c h^2$	0.1197 ± 0.0022	0.1187 ± 0.0021	$0.1150^{+0.0048}_{-0.0055}$	0.1198 ± 0.0015
$100\theta_{MC}$	1.04085 ± 0.00047	1.04094 ± 0.00051	1.03988 ± 0.00094	1.04077 ± 0.00032
τ	0.078 ± 0.019	0.053 ± 0.019	$0.059^{+0.022}_{-0.019}$	0.079 ± 0.017
$\ln(10^{10}A_s)$	3.089 ± 0.036	3.031 ± 0.041	$3.066^{+0.046}_{-0.041}$	3.094 ± 0.034
n_s	0.9655 ± 0.0062	0.965 ± 0.012	0.973 ± 0.016	0.9645 ± 0.0049
H_0	67.31 ± 0.96	67.73 ± 0.92	70.2 ± 3.0	67.27 ± 0.66
Ω_m	0.315 ± 0.013	0.300 ± 0.012	$0.286^{+0.027}_{-0.038}$	0.3156 ± 0.0091
σ_8	0.829 ± 0.014	0.802 ± 0.018	0.796 ± 0.024	0.831 ± 0.013
$10^9 A_s e^{-2\tau}$	1.880 ± 0.014	1.865 ± 0.019	1.907 ± 0.027	1.882 ± 0.012

Planck 2015 results. XIII. Cosmological parameters, arXiv:1502.01589

Introduction

Statistical tests of the CMB maps

Why?

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Isotropy

I.e. the same properties in **all directions**, is a well known property of the CMB that motivates the **cosmological principle**

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Gaussianity

Primordial CMB fluctuations are predicted to be **very close** to Gaussian in the **simplest inflationary scenarios**.

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Gaussianity

Primordial CMB fluctuations are predicted to be **very close** to Gaussian in the **simplest inflationary scenarios**.

Others

Isotropy and Gaussianity are **assumed** in the derivation of power spectra and cosmological parameters

Introduction

A battery of statistical tests have been applied to the Planck data:

- Variance, skewness and kurtosis
- N-pdf (at low resolution)
- N-point correlation functions
- Minkowski functionals
- Multiscale analysis
- Stacking
- Others...

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In addition a great number of tests looking for anomalies in the CMB maps:

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- Bipolar spherical armonics
- Cold Spot
- Variance asymmetry
- Point-parity asymmetry
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- Local peak statistics
- Others...

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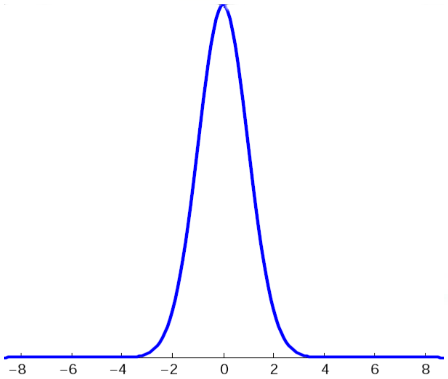
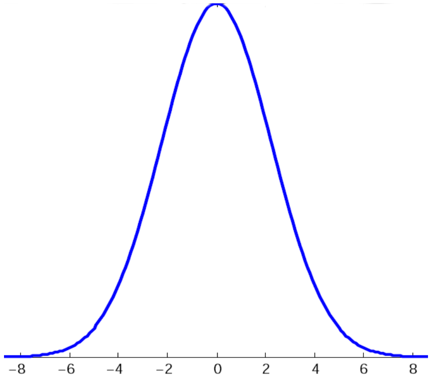
Introduction

Variance

A measure of the dispersion of the pixels value of a map





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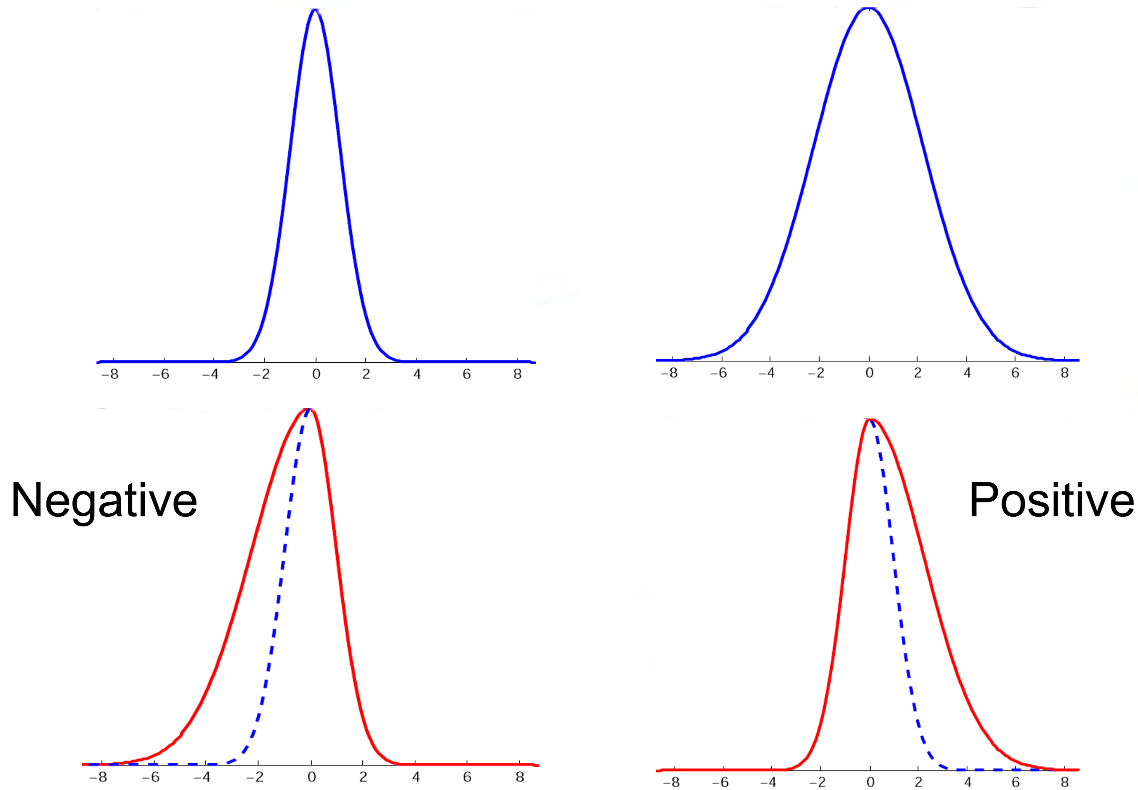
Variance

A measure of the dispersion of the pixels value of a map

Skewness

A measure of the asymmetry of the distribution around the mean value



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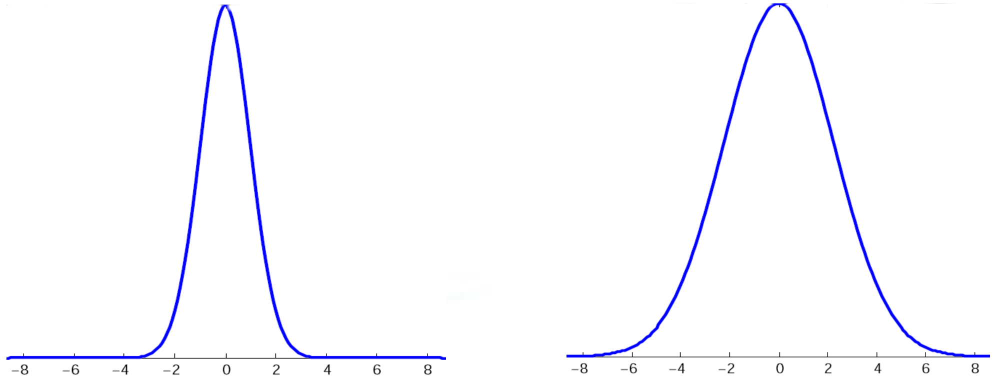

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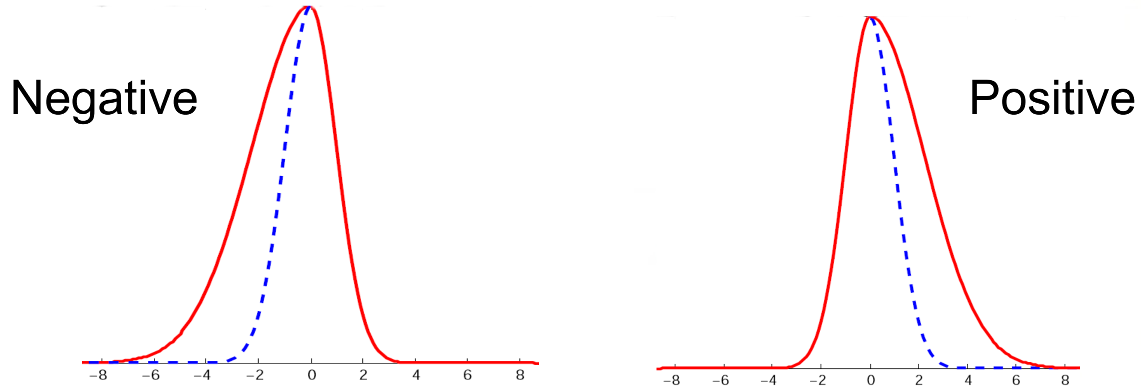
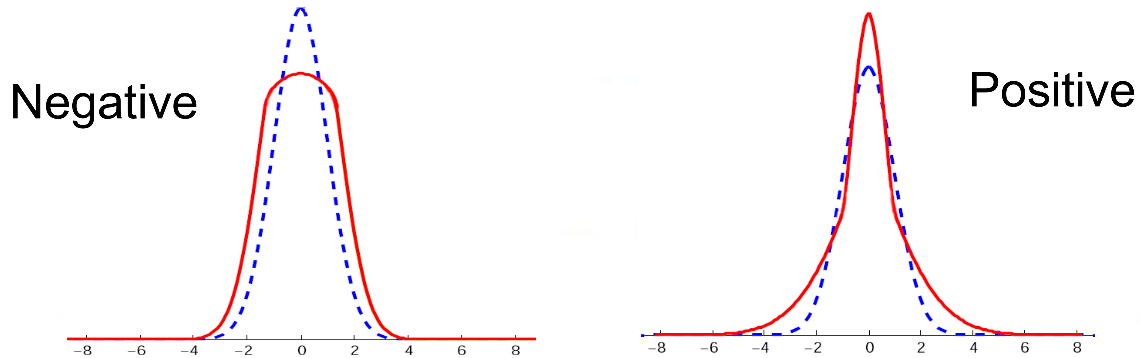


Kurtosis

A measure of the peakedness of the distribution and the heaviness of its tails



The estimators

Temperature

Variance (unit variance estimator)

$$u_i(s^2(X)) = \frac{X_i}{\sqrt{s^2(X) + \sigma^2_{noise}}}$$

$$\sigma^2_{CMB}(X) = s^2 : min||var(u_i(s^2(X))) - 1||$$

Skewness

$$\gamma(X) = \frac{\langle X - \langle X \rangle \rangle^3}{(\sigma^2_{CMB}(X))^{3/2}}$$

Kurtosis

$$\kappa(X) = \frac{\langle X - \langle X \rangle \rangle^4}{(\sigma^2_{CMB}(X))^2} - 3$$

Cruz et al., MNRAS, 412, 2383 (2011)

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Polarization

Variance

$$\sigma^2(X) = \langle X^2 \rangle - \langle X \rangle^2$$

Skewness

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Kurtosis

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Cruz et al., MNRAS, 412, 2383 (2011)

A powerful test

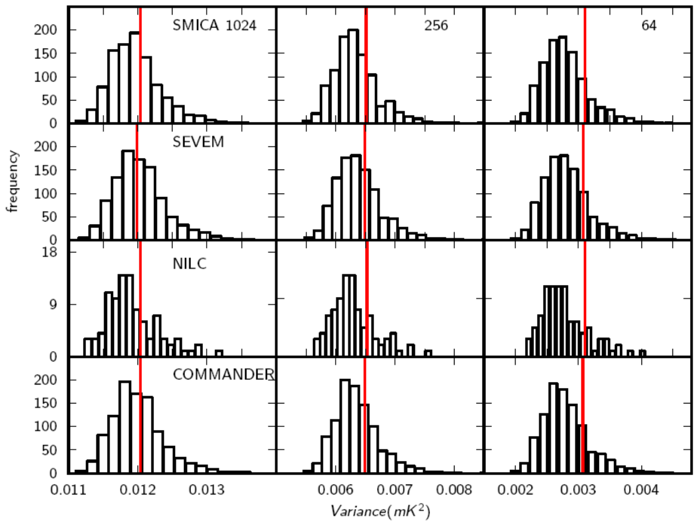
Rapid validation of the component separation methods:

FFP8 Temperature
simulations

A powerful test

Rapid validation of the component separation methods:

Variance



FFP8 Temperature simulations

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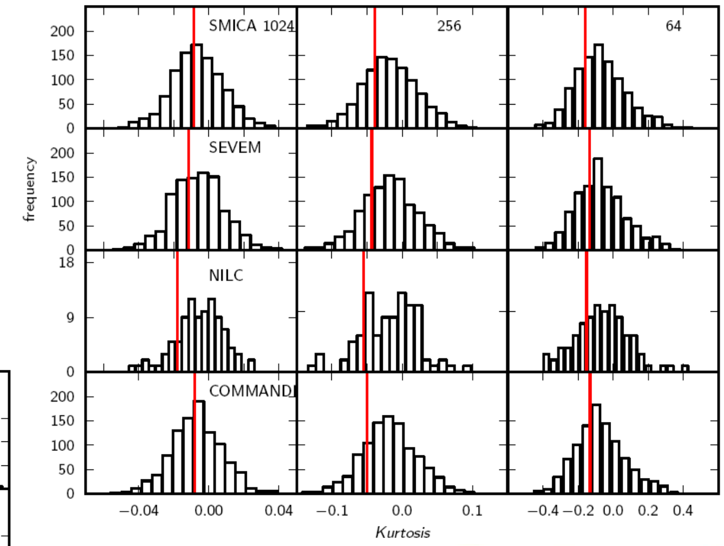
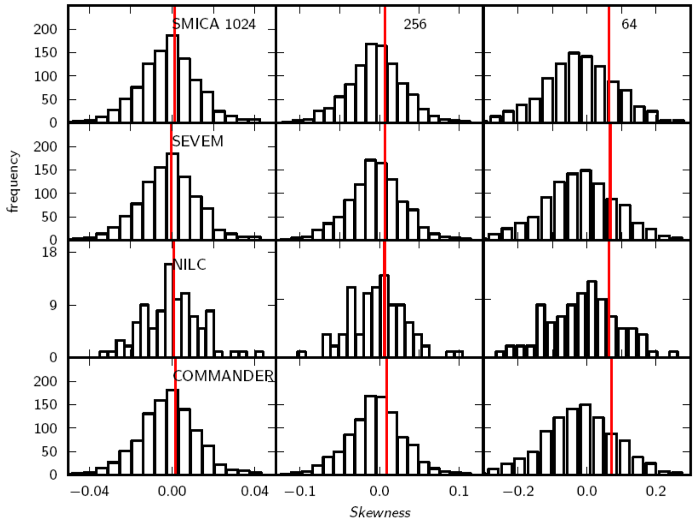


Skewness



A powerful test

Good method to detect and identify any problem in the comp sep methods

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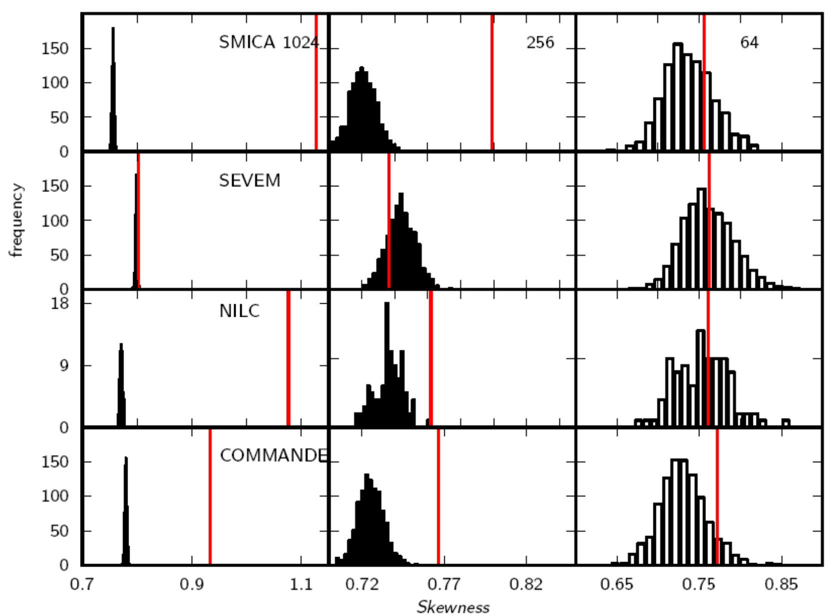
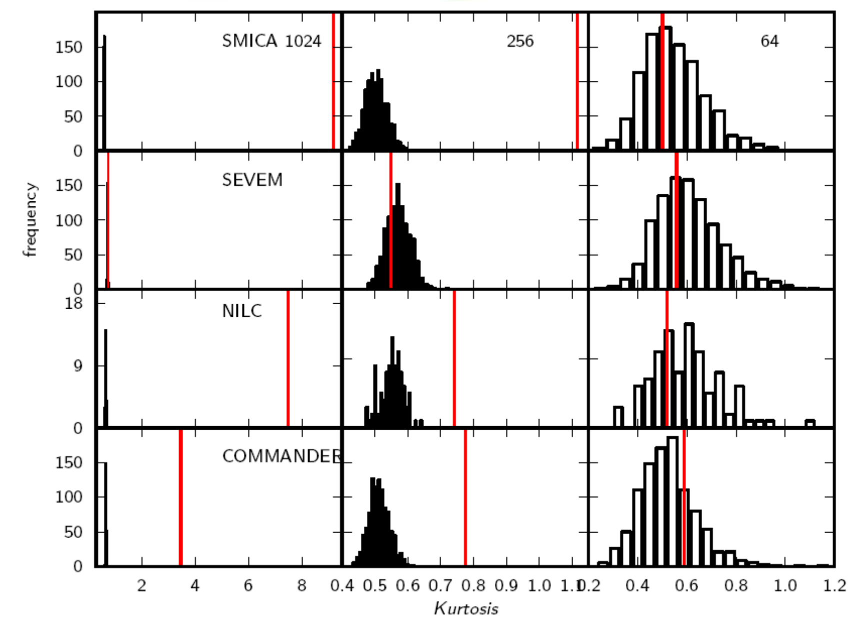
Skewness



Kurtosis



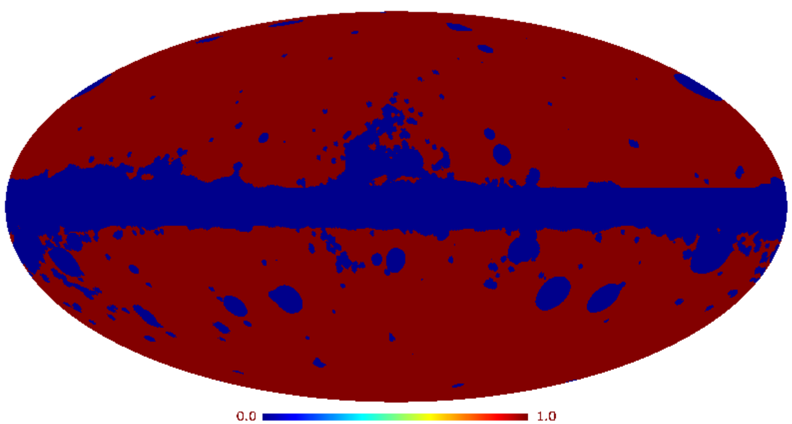
Strong **excesses** in skewness and kurtosis of the simulated real polarization sky map with respect to the MC simulations at high resolutions for some comp sep methods

A powerful test

Good method to detect and identify any problem in the comp sep methods

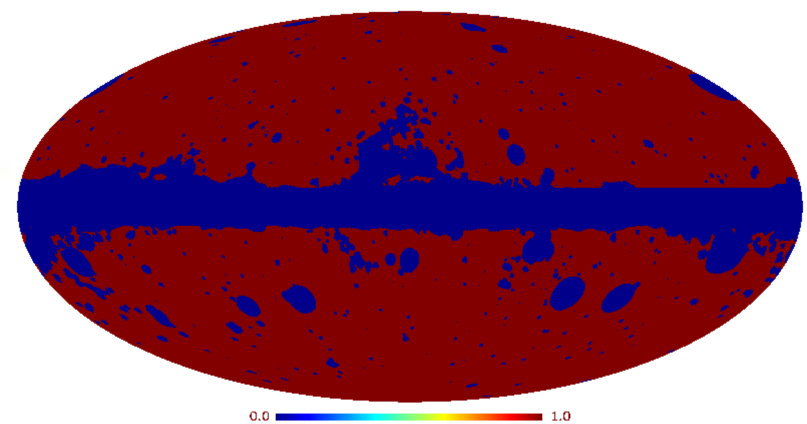
This effect was identified as a **point source contamination** in the polarized sky
It was solved by masking the polarized point sources

Original mask



f_{sky} = 76.3%

Original mask + point sources



f_{sky} = 75.6%

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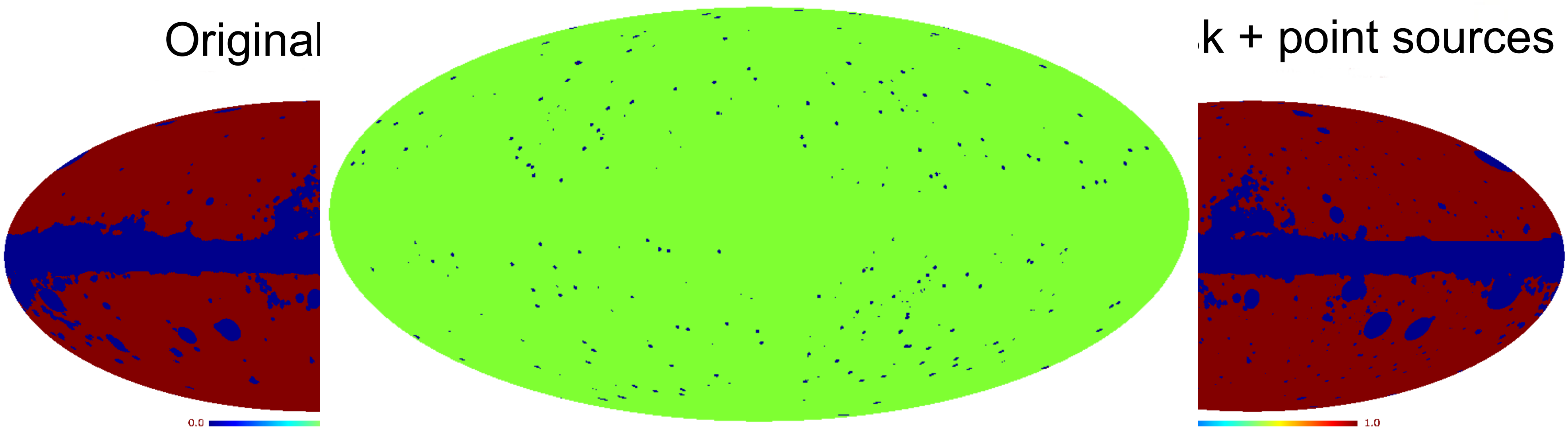
This effect was identified as a point source contamination in the polarized sky
It was solved by masking the polarized point sources

Original

.k + point sources



f_{sky} = 76.3%

f_{sky} = 75.6%

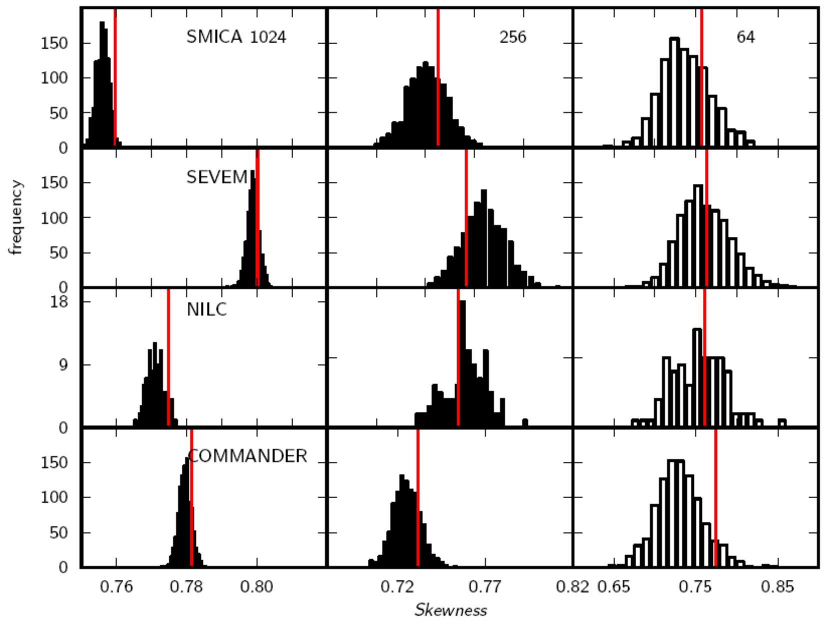
The difference in sky fraction is less than 0.7%...

A powerful test

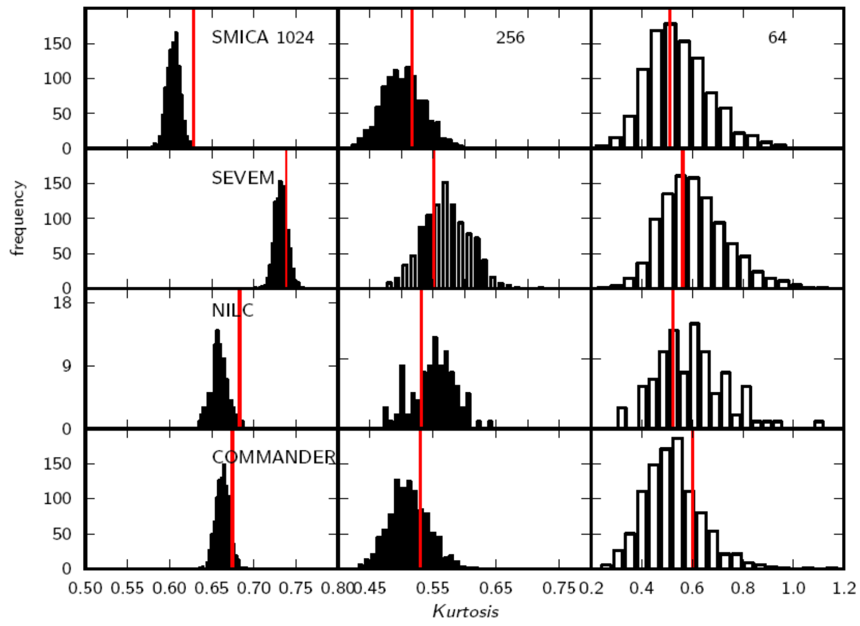
Good method to detect and identify any problem in the comp sep methods

... but enough to solve the excess problems!

Skewness



Kurtosis



Data set

- The Planck best-fit ΛCDM model is compared to the Planck CMB maps extracted from four component separation methods: Commander, NILC, SEVEM and SMICA.

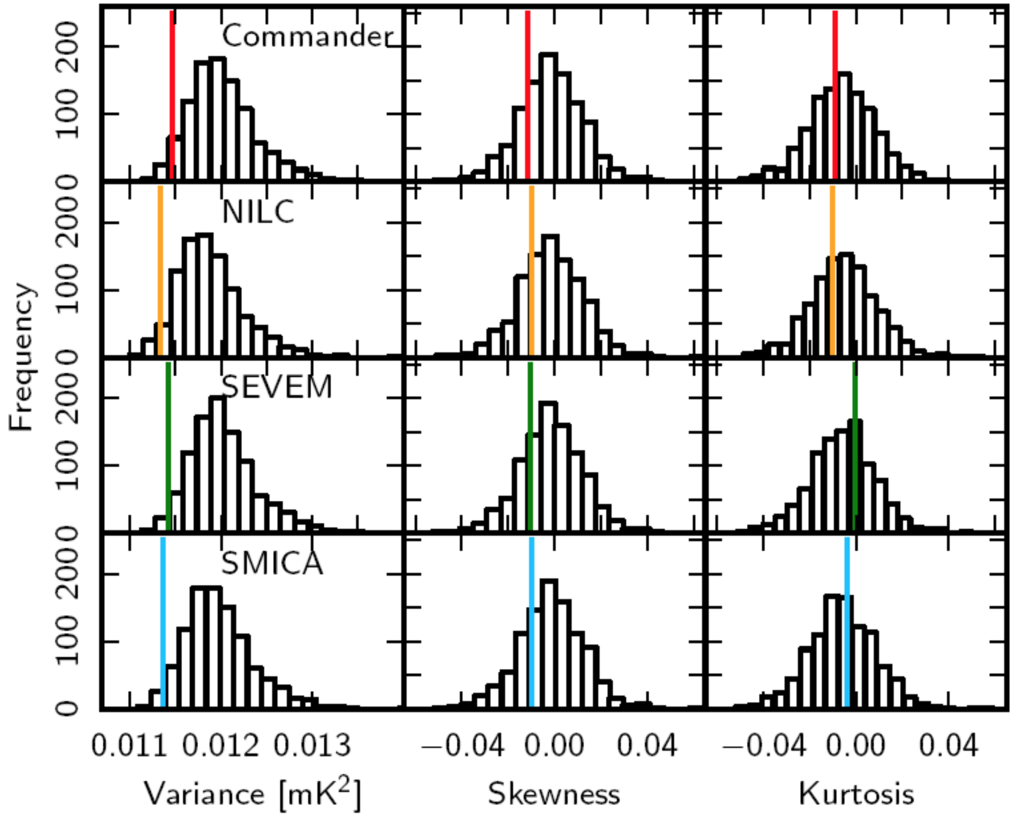
- The common mask is used to remove the contaminated pixels from the analysis.

- The Planck best fit model is represented by realistic (FFP8) Planck simulations that, in addition to the statistical properties of the CMB signal, also contain the most relevant characteristics of the observational process (e.g., beam, noise, Doppler boosting, lensing, …).

- 1000 (FFP8) simulations

PLANCK results: Temperature

Comparison at high resolution



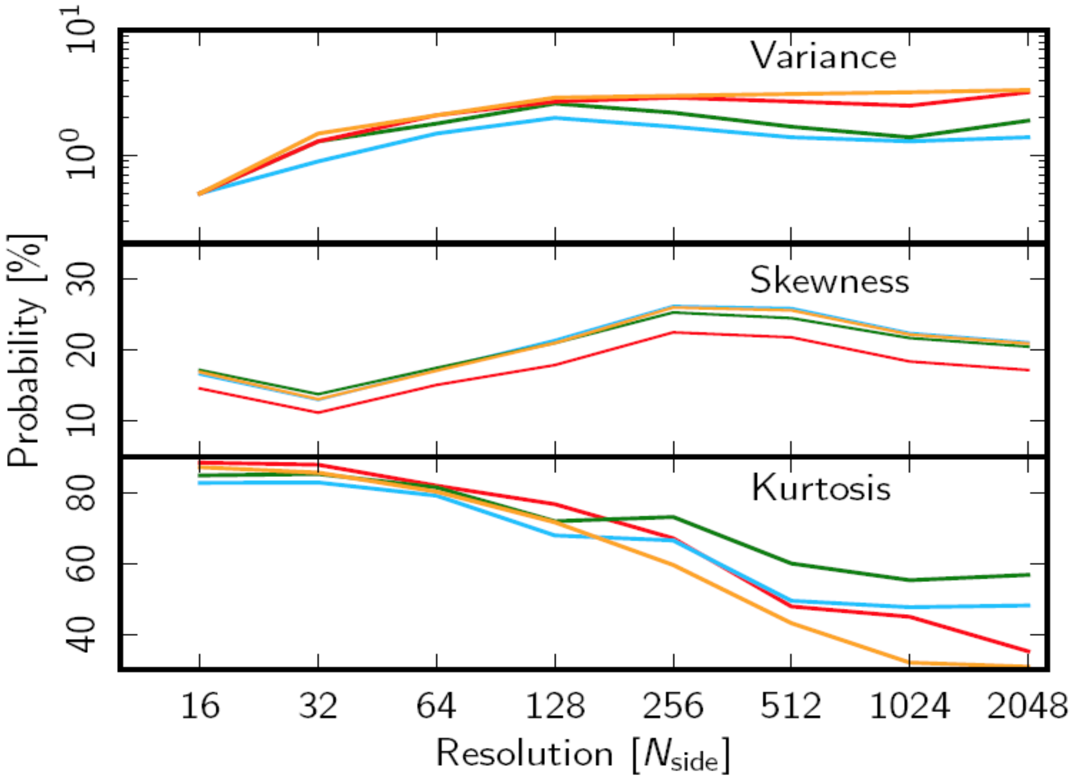
	Probability [%]		
Method	Variance	Skewness	Kurtosis
Commander	3.2	17.2	35.3
NILC	3.3	20.9	30.9
SEVEM	1.9	20.5	56.8
SMICA	1.4	21.1	48.2
SEVEM-100	3.4	13.4	67.5
SEVEM-143	2.4	16.9	61.2
SEVEM-217	3.4	11.4	58.3

Good agreement with the Planck ΛCDM model but with a significantly **low variance**

Planck 2015 results. XVI. Isotropy and statistics of the CMB, arXiv:1506.07135

PLANCK results: Temperature

Comparison at all the angular scales



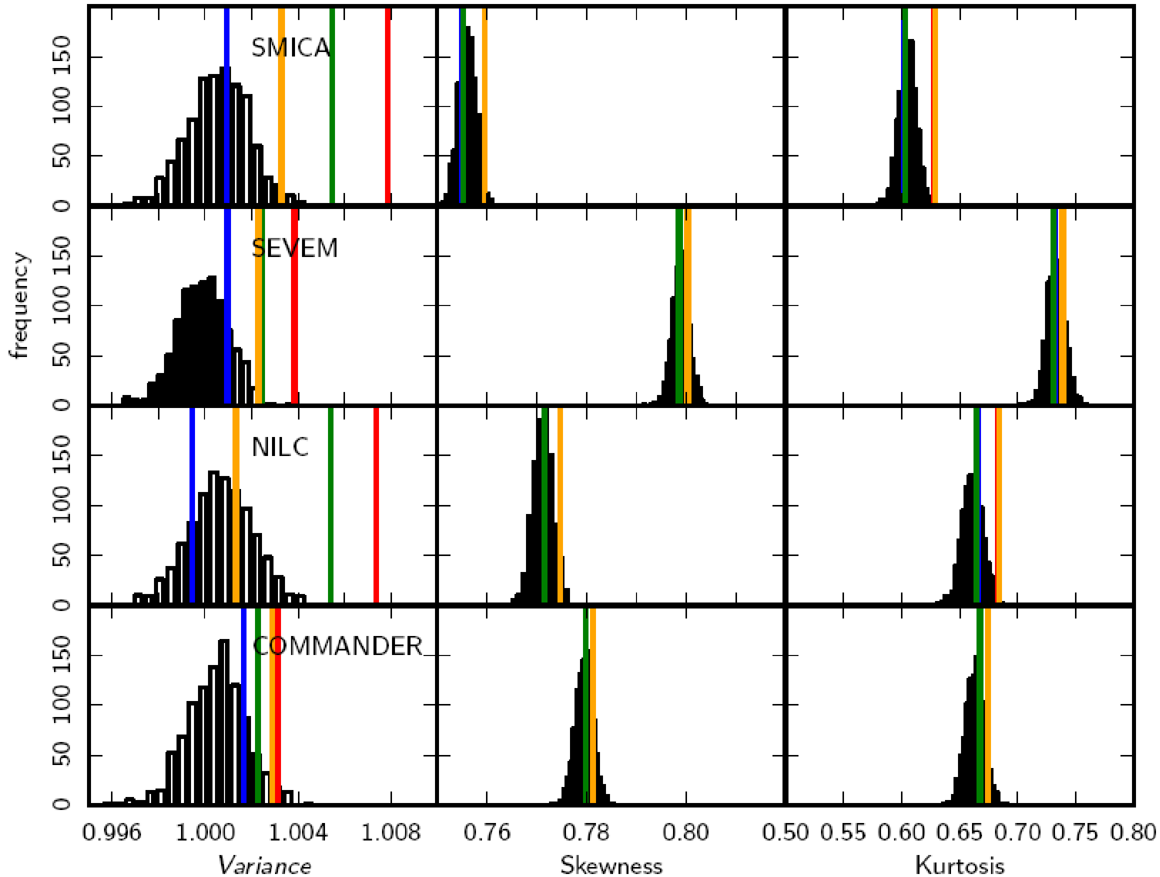
Method	Probability [%] Variance	Skewness	Kurtosis
Common mask ($f_{sky} = 58\,\%$)			
Commander	0.5	14.6	88.4
NILC	0.5	16.9	87.1
SEVEM	0.5	17.2	84.8
SMICA	0.5	16.6	82.7
$f_{sky} = 48\,\%$			
Commander	0.1	29.4	65.0
NILC	0.1	29.6	60.8
SEVEM	0.1	29.4	62.4
SMICA	0.1	29.4	57.3
$f_{sky} = 40\,\%$			
Commander	0.4	35.2	32.4
NILC	0.4	34.4	28.7
SEVEM	0.4	34.3	30.2
SMICA	0.4	33.8	25.5

A significantly **low variance** is consistently found at different resolutions, component separations, frequencies and masks. The **lowest probabilities** are found at the **lowest resolutions**. In agreement with Planck Collaboration XXIII (2014).

Planck 2015 results. XVI. Isotropy and statistics of the CMB, arXiv:1506.07135

PLANCK Polarization status

Validation of FFP8 simulations (high-pass filtered) in polarization at high resolution (N_{side} = 2048)



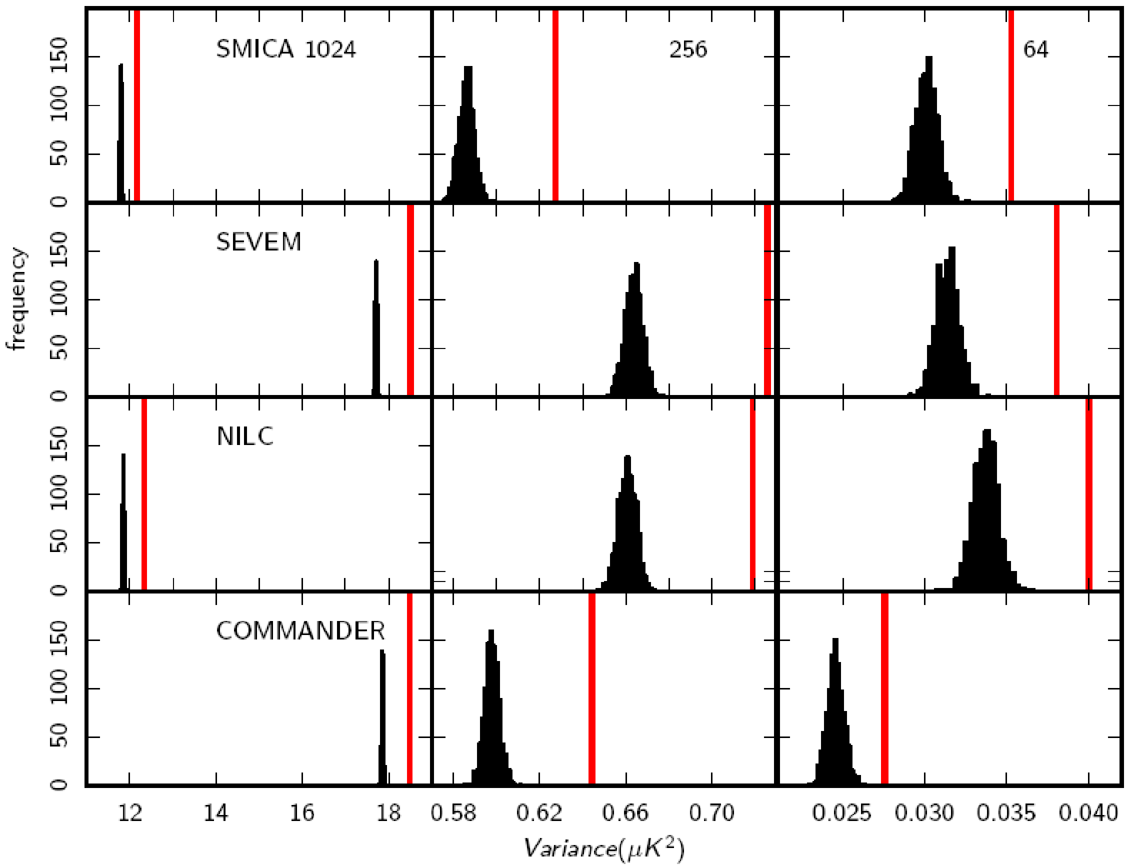
CMB+noise (blue)
CMB+noise+th dust (green)
CMB+noise+radio ps (orange)
CMB+noise+all foregrounds (red)

Still a **small amount** of contaminants at small scales plausibly caused by the additional complexity of the FFP8 foreground model with respect to the real sky.

Planck 2015 results. IX. Diffuse component separation: CMB maps, arXiv:1502.05956

PLANCK Polarization status

Variance of the polarization amplitude observed map compared to the PLANCK ΛCDM model



Excess in variance at all the resolutions of about 3-4% at N_{side}=1024 up to 10-20% at N_{side}=64

This is caused by an underestimation of the noise in the FFP8 simulations due to a systematic effect introduced in the pre-processing pipeline.

Planck 2015 results. IX. Diffuse component separation: CMB maps, arXiv:1502.05956

Conclusions

• Tests of isotropy and Gaussianity provide the basis to support the assumptions made in the derivation of the power spectra and the cosmological parameters.

• In addition they also probe physics beyond the standard cosmological model.

• We demonstrated the helpfulness of the higher order momentum tests for the developing of the component separation methods.

• In Temperature the PLANCK data demonstrate good consistency with the Gaussianity assumption apart from the known anomaly of the low variance.

• In polarization there are still some issues both at large and small scales. The work is still in progress to solve them for the next release.

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada.

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.