# The mask effect in non-Gaussian analyses in CMB data


Armando Bernui

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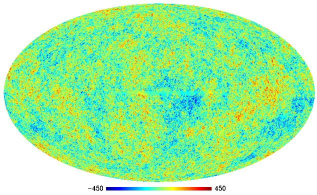


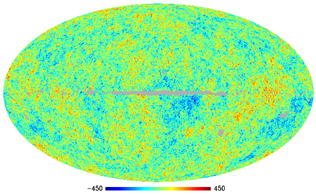

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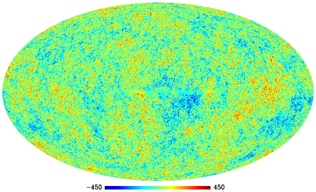
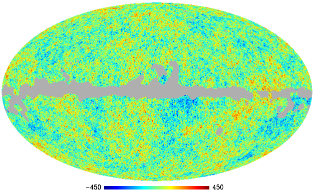



PLANCK: SMICA

SMICA + VALidation MASK

# Non-Gaussian (NG) analyses in CMB data

## We look for NG of any origin in CMB data

- there are various foreground sources $\Rightarrow \exists$ several types of NG
- they have different intensities and angular scale dependence
- they appear mixed: primordial with non-primordial NG

# NG analyses in CMB data

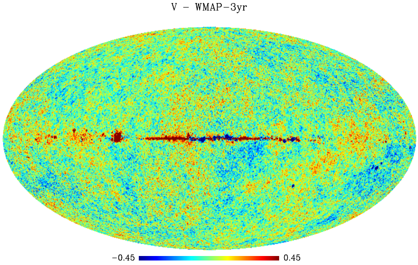
## $\exists$ an optimal estimator for prim. NG: bispectrum

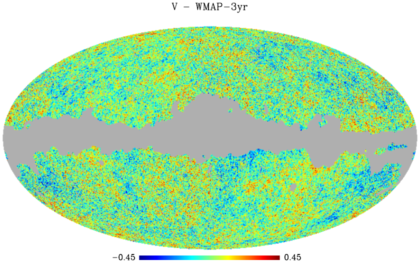
**However**, maps also contain non-primordial NG and a single estimator is not **sensitive** to all possible NG contaminations in CMB maps:

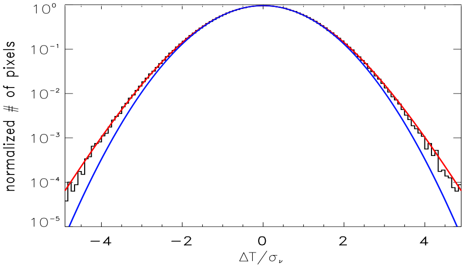
- residual foregrounds and point sources
- instrumental systematic effects
- secondary CMB anisotropies
- non-linear second order perturbations, etc.

Consider, for instance, the 1-pdf

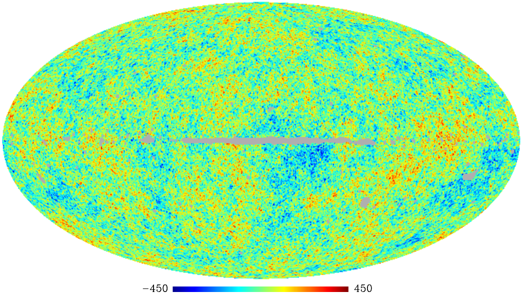
# CMB from WMAP3: 1-point distribution function

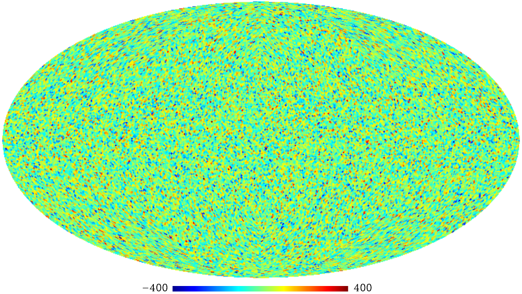


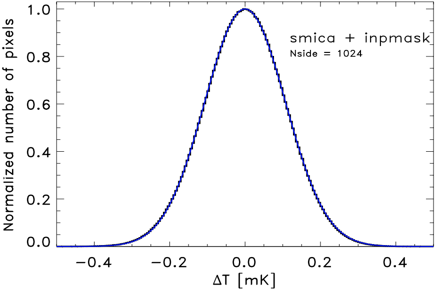



# CMB from Planck: 1-point distribution function



# NG analyses in CMB data

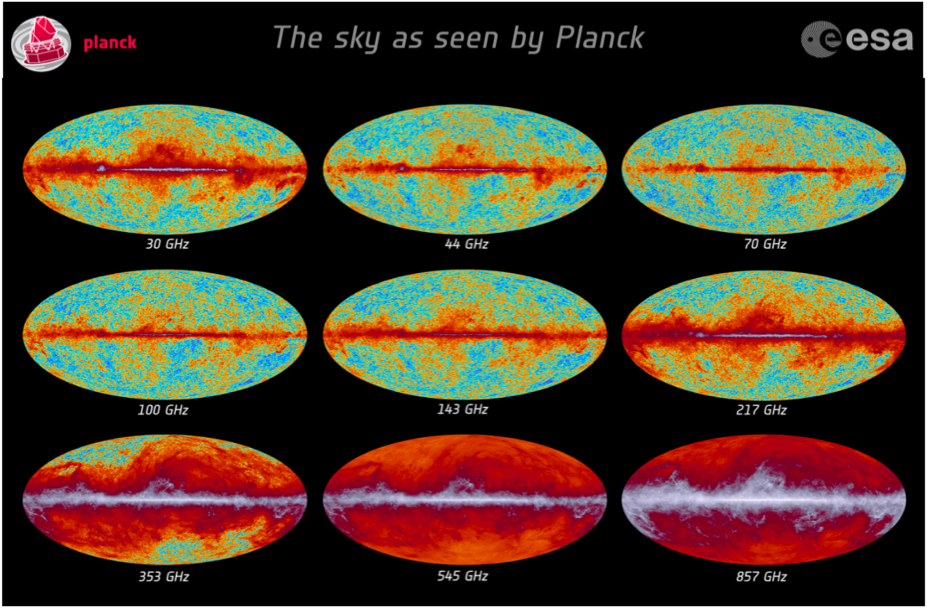
Different NG estimators are useful: to detect, to discriminate -between mixed contaminations-, to constrain, or to corroborate previous results,...and can be complementary!

For this, ... $>$ NG estimators are welcome!

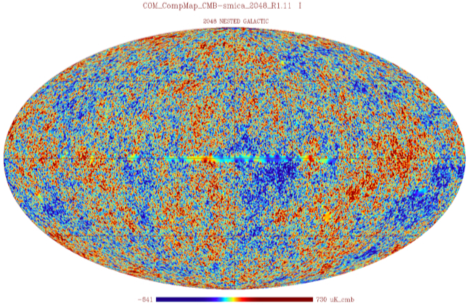
# Systematic effects: incomplete CMB maps

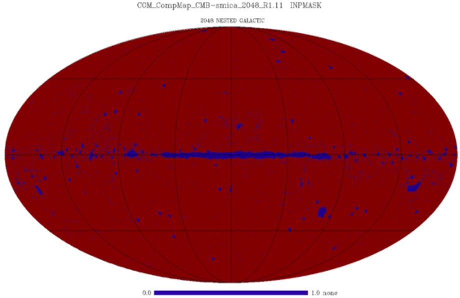
- One of the most important systematics is the masking effect, which seems unavoidable!

# In real maps ... masks are necessary!



# and also in the synthetic ones:



# What is the problem with using a mask?

In a Gaussian CMB map, a cut-sky does not modify the *Gaussian props.*

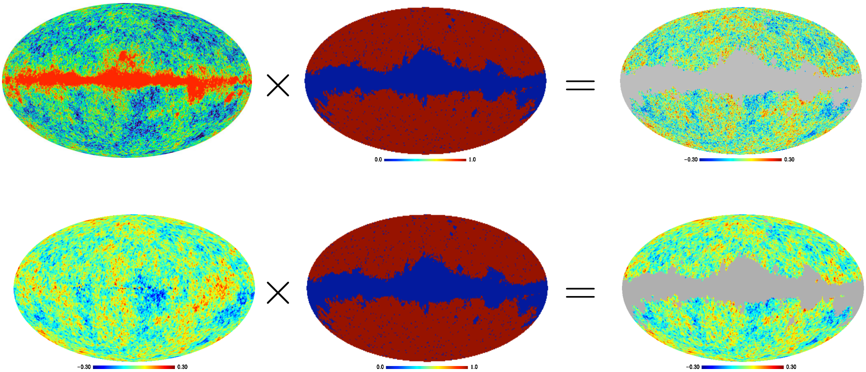
**In a non-Gaussian CMB map this, in general, is not true!**

# Masks are necessary:

We know: $\widetilde{\Delta T} \propto \tilde{\Phi} \Rightarrow \langle \Delta T(\theta_1, \varphi_1)\, \Delta T(\theta_2, \varphi_2)\, \Delta T(\theta_3, \varphi_3) \rangle$ full-sky CMB map

But a full-sky CMB map is not available:

**masks needed to cut-off the foreground contaminations (g and e-g)**



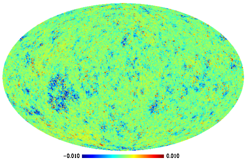
# MASKED CMB-MAP: HOW TO DEAL WITH IT?

- **In the literature***: calculations looking for NG assume a numerical factor **$f_{sky}$** to quantify the effect of the mask on NG estimations; e.g.

$$\text{for KQ-75 9yr mask} \quad \longrightarrow \quad \mathbf{f_{sky}} = 71\%$$

In other words NG is assumed isotropically distributed and a 29% cut-sky *implies* 29% less contamination, **independent of the $f_{NL}$ vaues**

- **Be careful**: this assumption may not be correct. Take a look at this example, imagine it is a WMAP map: what happen after the cut-sky?

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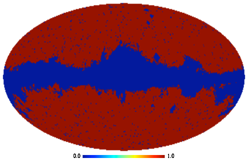



$= \ ?$

* Yadav & Wandelt, arXiv:0712.1148; Creminelli et al., astro-ph/0509029

- To investigate masked vs. full-sky maps we shall consider simulated maps contaminated with **local NG**

# CMB: A PROBE OF PRIMORDIAL UNIVERSE

- Cosmic Microwave Background (CMB) temperature fluctuations $\Delta T/T_0$ contain information from primordial Universe. **Inflation** provides a source for curvature perturbation $\Phi = \Phi(\vec{x}, t_{\rm dec})$, which generates large-scale CMB fluctuations, through the comoving scalar curvature perturbation $\zeta$

$$\frac{\zeta}{5} = \frac{\Phi}{3} = \frac{\Delta T}{T_0}$$

- $\Delta T/T_0$ are expected to be a stochastic realization of a Gaussian random field plus small non-Gaussian contributions due to primordial processes. The curvature perturbation in the real space can be split into two components: the linear term $\Phi_{\rm L}$ (representing the Gaussian component) plus a NG term

$$\Phi(\mathbf{x}) = \Phi_{\rm L}(\mathbf{x}) + f_{\rm NL}\left(\Phi^2_{\rm L}(\mathbf{x}) - \langle \Phi^2_{\rm L}(\mathbf{x}) \rangle\right),$$

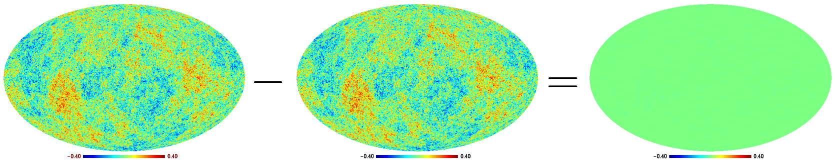
$f_{\rm NL}$ is a dimensionless parameter. $f_{\rm NL} = 0 \implies$ purely Gaussian case.

# CMB: looking for primordial NG

- A non-null three-point correlation function for $\tilde{\Phi}$, that is,

$$\langle\, \tilde{\Phi}(\vec{k}_1)\, \tilde{\Phi}(\vec{k}_2)\, \tilde{\Phi}(\vec{k}_3)\,\rangle = \delta(\vec{k}_1 + \vec{k}_2 + \vec{k}_3)\, B_\Phi(k_1, k_2, k_3)$$

suggests primordial NG from a CMB. $B_\Phi$ is the bispectrum.
Interesting: **local** non-Gaussianities $k_1 \approx k_2 \gg k_3$. For exm. $f_{\rm NL}^{\rm local} = 100$




$$\{a^{G}_{\ell\, m} + 100 \times a^{NG}_{\ell\, m}\} \;-\; \{a^{G}_{\ell\, m}\} \;=\; \{100 \times a^{NG}_{\ell\, m}\}$$

# CMB: looking for primordial NG

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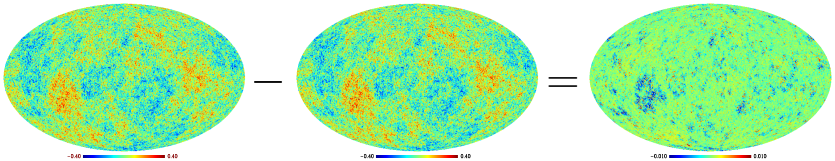



$$\{a^{G}_{\ell\, m} + 100 \times a^{NG}_{\ell\, m}\} \;-\; \{a^{G}_{\ell\, m}\} \;=\; \{100 \times a^{NG}_{\ell\, m}\}$$

$$\boxed{-10 \le 17 \le f_{\rm NL}^{\rm local} \le 57 \le 74} \quad \text{WMAP-9yr}$$

- To investigate masked vs. full-sky maps

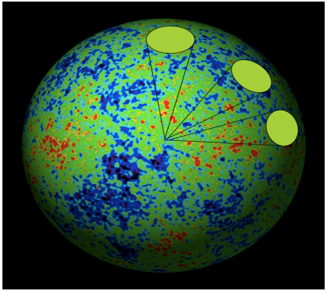
  we shall investigate simulated maps

  contaminated with **local NG** using

  two new Gaussian statistical estimators

# NG estimators for CMB maps: Skewness-map

Consider a CMB sphere

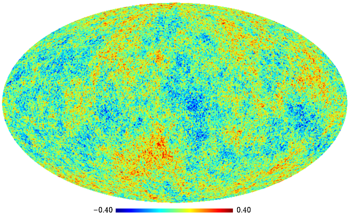


- Consider a hemisphere centered at the north pole $C_1$. Calculate the skewness inside and save the value $S_1$ associated to $C_1$.
- Consider a hemisphere centered at another point $C_2$. Calculate the skewness inside and save the value $S_2$ associated to $C_2$.
- Assuming you have started with a uniform distribution of points: $\{C_1, C_2, ..., C_N\}$, then you get a set of real values $\{S_1, S_2, ..., S_N\}$.
- HealPix helps you to get a colored map!

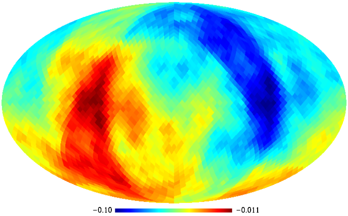
# NG estimators for CMB maps: S-map

Calculate the SKEWNESS values on $N$ hemispheres (= caps of 90° aperture) whose centers are uniformly dist.: this set **S** form the SKEWNESS-MAP

$$\mathbf{S} = \{S_j, j = 1, \ldots, N_{\text{caps}}\}, \text{ where } S_j \equiv \frac{1}{N_{\text{p}}\,\sigma_j^3} \sum_{i=1}^{N_{\text{p}}} \left( \Delta T_i - \overline{\Delta T_j} \right)^3$$




Temperature map: T

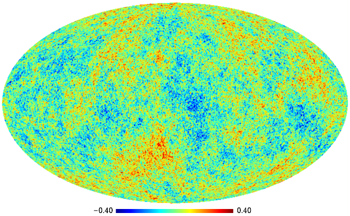



Skewness-map: **S**(T)

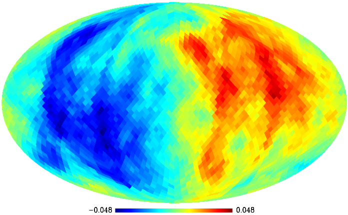
# NG estimators for CMB maps: K-map

Calculate the KURTOSIS values on $N$ hemispheres (= caps of 90° aperture) whose centers are uniformly dist.: this set **S** form the KURTOSIS-MAP

$$\mathbf{K} = \{K_j, j = 1, \ldots, N_{\text{caps}}\}, \text{ with } K_j \equiv \frac{1}{N_\text{p}\,\sigma_j^4} \sum_{i=1}^{N_\text{p}} \left( \Delta T_i - \overline{\Delta T_j} \right)^4 - 3$$

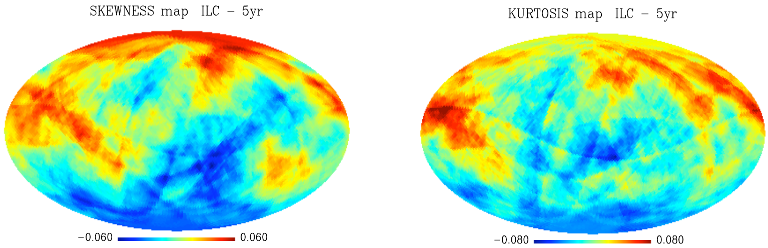



Temperature map: T




Kurtosis-map: **K**(T)

# NG estimators for CMB maps: S & K-maps

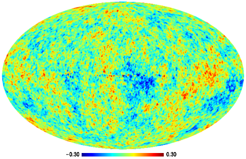


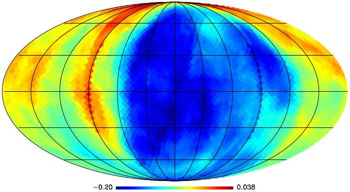

Then we calculate their power spectra:

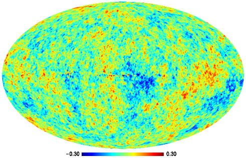
and use the $\chi^2$ – statistics to evaluate the results

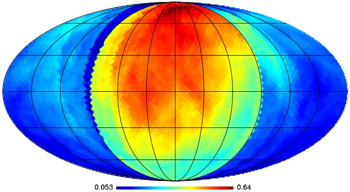
# We do have –or not– a nearly full-sky map?

- Masks are necessary!

S( 

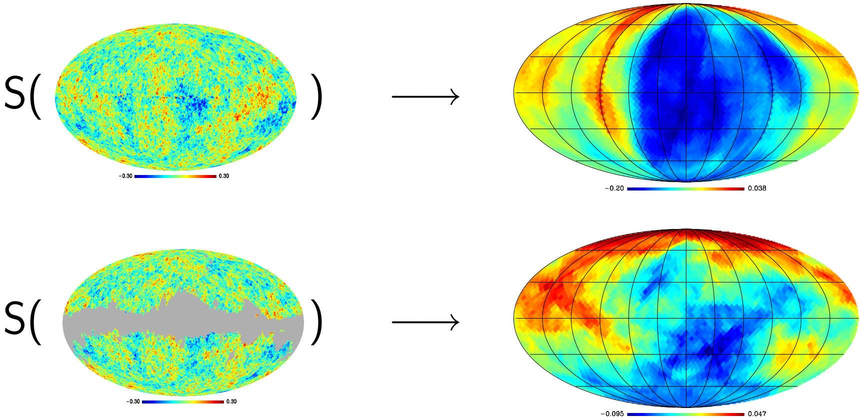
) $\longrightarrow$ 


K( 

) $\longrightarrow$ 

# Masks are necessary? … they are!

- Full-sky *versus* Masked maps: take a look!



# masked CMB-map: a contaminating effect?

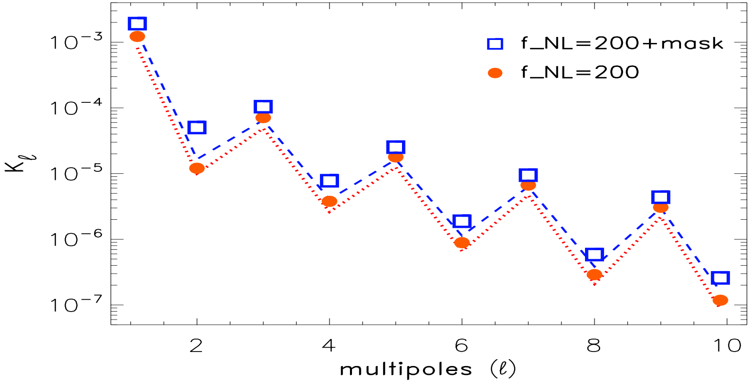
- We are curious about: NG estimatives are independent of the value $f_{\rm NL}^{\rm local}$ present in the MC map?

- We study the effect of masking procedure in non-Gaussian CMB analyses. Using thousands of simulated CMB maps containing different amounts of primordial NG of local type: $f_{\rm NL}^{\rm local} = 0, 11$, 53, 200, 500, we quantify the effect produced by KQ-75 9yr WMAP mask.

# Results 1

## Gaussian analyses: Kurtosis-maps spectra

Red line = mean full-sky Gaussian maps  Blue line = mean Gaussian maps + KQ-75




$\chi^2|_{\text{masked}} \,/\, \chi^2|_{\text{full-sky}}$=3.4 (GoF); $\chi^2|_{\text{masked}} \,/\, \chi^2|_{\text{full-sky}}$=5.4 ($\chi^2$-statistics)

# $\chi^2$ – STATISTICS

$$\chi^2 = \sum_{i,j=1}^{\#bins} (f_i - \langle f_i \rangle) \mathbf{M}_{ij}^{-1} (f_j - \langle f_j \rangle) ,$$

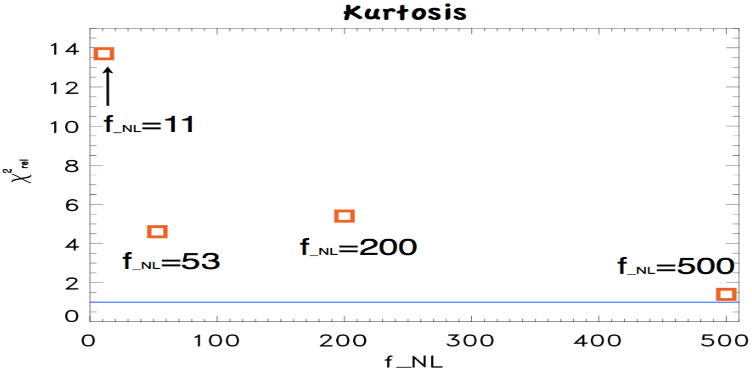
where,

$$\mathbf{M}_{ij} \equiv \langle f_i f_j \rangle - \langle f_i \rangle \langle f_j \rangle ,$$

is the covariance matrix, and $\langle f_i \rangle$ corresponds to the **mean** of the function determined by the MC CMB maps for the *i*-th bin.

# Results 2

- $\chi^2$–statistics for the above spectra ($NG^{masked}_{full\text{-}sky}$ *versus* $G^{masked}_{full\text{-}sky}$ maps) gives low values. Instead relative $\chi^2$, i.e. $\chi^2|_{masked} \,/\, \chi^2|_{full\text{-}sky}$ leads to a quantitative comparison between the mean-spectra corresponding to masked and unmasked cases.



# Conclusions

- Contaminations are underestimated in masked maps with small $f_{\rm NL}^{\rm local}$: lower is the $f_{\rm NL}^{\rm local}$ value worse is the fit to the correspon-ding Gaussian spectrum case, as compared with similar evaluation for the full-sky case.
- Estimatives of NG *via* $\mathbf{f}_{\rm sky}$ depends on $|f_{\rm NL}^{\rm local}|$: i.e., $\mathbf{f}_{\rm sky} \neq$ const. To say it simple: masks seems to introduce NG in a non-trivial way. We conclude that the masking process is not innocuous at all and deserves accurate examination.

## Bibliography


A. Bernui and M.J. Rebouças, Phys. Rev. **D85**, 023522 (2012)


## Acknowledgements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