planck

Parametric ("f_{NL}") and non-parametric ("blind") bispectrum results from Planck

using the binned bispectrum estimator

Bartjan van Tent

Laboratoire de Physique Théorique, Orsay (Paris-Sud)

On behalf of the Planck collaboration

Planck 2013 Results. XXIV. Constraints on primordial non-Gaussianity, arXiv:1303.5084

Binned bispectrum estimator: 1) f_{NL}

[M.Bucher, BvT, C.Carvalho, arXiv:0911.1642]

$$\hat{f}_{\rm NL} = \frac{1}{N} \sum_{\ell_1 \le \ell_2 \le \ell_3} \frac{(B^{\rm th}_{f_{NL}=1})^{\not 2}}{{\rm Var}_G(B^{\rm obs})} \frac{B^{\rm obs}}{\not B^{\rm th}_{f_{NL}=1}}$$

where $N = \frac{1}{{\rm Var}_G(\hat{f}_{\rm NL})} = \chi^2_{(f_{\rm NL}=1)} = \sum_{\ell_1 \le \ell_2 \le \ell_3} \frac{\left(B^{\rm th}_{f_{NL}=1}\right)^2}{{\rm Var}_G(B^{\rm obs})}$;

${\rm Var}_G(B^{\rm obs}) \sim (b^2_{\ell_1} C_{\ell_1} + N_{\ell_1})(b^2_{\ell_2} C_{\ell_2} + N_{\ell_2})(b^2_{\ell_3} C_{\ell_3} + N_{\ell_3})$, $\quad b_\ell$ = beam, N_ℓ = noise;
$B^{\rm obs}_{\ell_1\ell_2\ell_3} \to B^{\rm obs}_{\ell_1\ell_2\ell_3} - B^{\rm lin}_{\ell_1\ell_2\ell_3}$ (linear term reduces variance when rotat. invar. broken).

Binned bispectrum estimator: 1) f_{NL}

[M.Bucher, BvT, C.Carvalho, arXiv:0911.1642]

$$\hat{f}_{\rm NL} = \frac{1}{N} \sum_{\ell_1 \le \ell_2 \le \ell_3} \frac{(B^{\rm th}_{f_{NL}=1})^{\not 2}}{{\rm Var_G}(B^{\rm obs})} \frac{B^{\rm obs}}{\cancel{B^{\rm th}_{f_{NL}=1}}}$$

where $N = \frac{1}{{\rm Var_G}(\hat{f}_{\rm NL})} = \chi^2_{(f_{\rm NL}=1)} = \sum_{\ell_1 \le \ell_2 \le \ell_3} \frac{\left(B^{\rm th}_{f_{NL}=1}\right)^2}{{\rm Var_G}(B^{\rm obs})}$;

${\rm Var_G}(B^{\rm obs}) \sim (b^2_{\ell_1} C_{\ell_1} + N_{\ell_1})(b^2_{\ell_2} C_{\ell_2} + N_{\ell_2})(b^2_{\ell_3} C_{\ell_3} + N_{\ell_3})$, $\quad b_\ell =$ beam, $N_\ell =$ noise;
$B^{\rm obs}_{\ell_1\ell_2\ell_3} \to B^{\rm obs}_{\ell_1\ell_2\ell_3} - B^{\rm lin}_{\ell_1\ell_2\ell_3}$ (linear term reduces variance when rotat. invar. broken).

Binning:

$$\hat{f}_{\rm NL} \approx \frac{1}{N^{\rm binned}} \sum^{\rm bins}_{i_1 \le i_2 \le i_3} \left(\frac{\sum_{\ell_1,\ell_2,\ell_3 \in {\rm bin}} B^{\rm th}_{f_{\rm NL}=1} \; \sum_{\ell_1,\ell_2,\ell_3 \in {\rm bin}} B^{\rm obs}}{\sum_{\ell_1,\ell_2,\ell_3 \in {\rm bin}} {\rm Var_G}(B^{\rm obs})} \right)$$

with $\sum_{\ell_1,\ell_2,\ell_3 \in {\rm bin}} B^{\rm obs} = \int d\Omega \, T_{\Delta\ell_1} T_{\Delta\ell_2} T_{\Delta\ell_3}$ where $T_{\Delta\ell}(\Omega) = \sum_{\ell \in {\rm bin}} \sum_m a_{\ell m} Y_{\ell m}(\Omega)$.

One determines the optimal binning by maximizing the correlation between the binned and the exact template.
Using 51 bins (continuous but unequal-size) at Planck resolution ($\ell_{\rm max} = 2500$) gives $\geq 99\%$ correlation for e.g. local and equilateral.

Binned bispectrum estimator

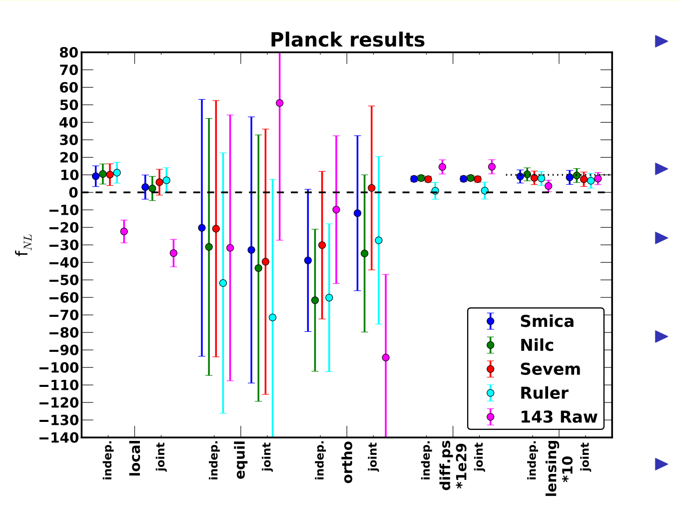
$$\hat{f}_{NL} \approx \frac{1}{N^{\text{binned}}} \sum_{\substack{\text{bins} \\ i_1 \leq i_2 \leq i_3}} \left(\frac{\sum_{\ell_1,\ell_2,\ell_3 \in \text{bin}} B^{\text{th}}_{f_{NL}=1} \sum_{\ell_1,\ell_2,\ell_3 \in \text{bin}} B^{\text{obs}}}{\sum_{\ell_1,\ell_2,\ell_3 \in \text{bin}} \text{Var}_G(B^{\text{obs}})} \right)$$

Advantages:

- Fast on a single map.
- Theoretical template does not need to be separable.
- Theoretical and observational part computed and saved separately, only combined in final sum over bins (which takes just seconds to compute) $\Rightarrow$
  - No need to rerun maps to determine e.g. f_{NL} for an additional template.
  - Full (binned) bispectrum is direct output of code.
- Easy to investigate dependence on ℓ by leaving out bins from final sum.

Disadvantages:

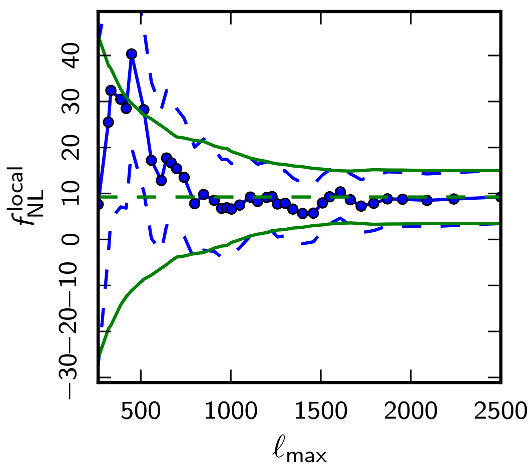
- Theoretical template must not change too much over a bin (OK for local, equilateral, orthogonal, point sources; a bit less for ISW-lensing).
- (Current implementation) Linear term cannot be precomputed, so computation time scales linearly with number of maps.



Independent and **fully joint** f_{NL} results (5 shapes).

- No (leo) primordial NG (when marginalizing/subtracting ISW-lensing)
- First detection ISW-lensing bispec.
- Good agreement different component separation methods
- Point sources in SMICA, NILC, SEVEM; more in Raw 143; not in C-R
- As expected, foreground contam. in Raw 143 (small mask)

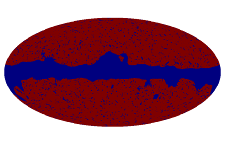
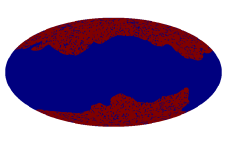
Dependence on ℓ_{max} of local f_{NL} (lensing bias not yet subtracted):



At lower resolution $\ell_{max} \sim 500$ we recover the WMAP value of around 35, which appears to have been a statistical fluctuation. The final Planck result is driven by the enormous amount of additional data at higher multipoles.

(Result double-checked with KSW estimator.)

Consistency between frequency channels:

	SMICA	70 GHz	100 GHz	143 GHz	217 GHz
	$f_{\rm sky} = 0.73$	$f_{\rm sky} = 0.32$			
Local	9.2 ± 5.9	19.7 ± 26.0	-2.5 ± 13.2	10.4 ± 9.8	-4.7 ± 9.6
Equilateral	-20 ± 73	159 ± 188	70 ± 132	48 ± 114	-9 ± 114
Orthogonal	-39 ± 39	-78 ± 139	-106 ± 81	-101 ± 64	-84 ± 63

We also checked and confirmed:

- Consistency when using different masks with the SMICA map;
- Null results on various jackknife maps (ringhalf, survey, detector set);
- Negligible impact of SMICA foreground residuals.

All these validation tests were also performed by the *modal estimator* (see Michele Liguori’s talk), further confirming the results.

Binned bispectrum estimator: 2) smoothed bispectrum

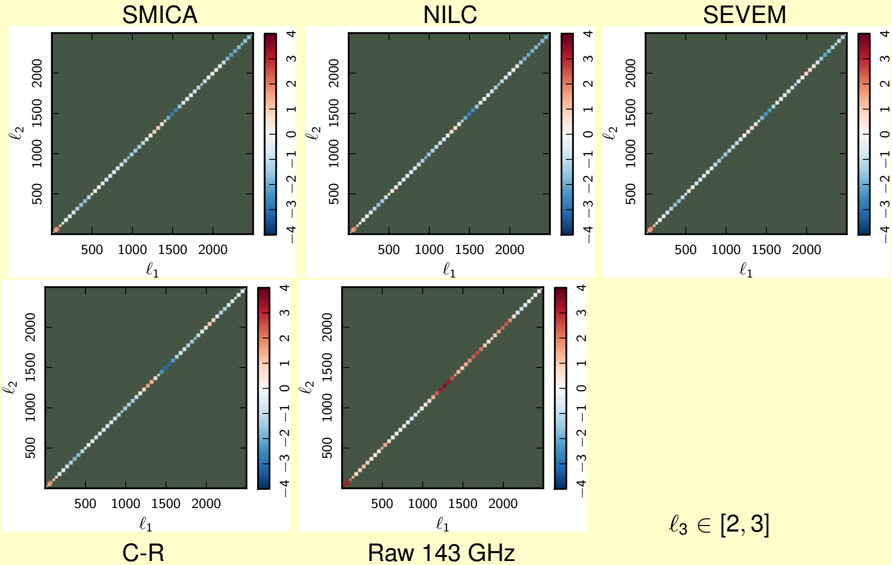
Since the binned bispectrum of the map is a direct output of the code, it can be studied explicitly, without any theoretical assumptions ("blind" / non-parametric).

To investigate if there is any significant non-Gaussianity in the maps, we consider the bispectrum divided by its expected standard deviation:

$$\mathcal{B}_{i_1 i_2 i_3} = \frac{B^{\text{obs}}_{i_1 i_2 i_3}}{\sqrt{\text{Var}_{\text{G}}(B^{\text{obs}}_{i_1 i_2 i_3})}}$$

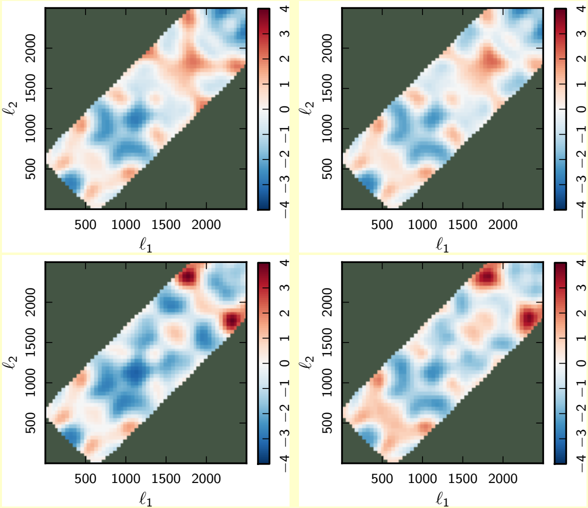
To bring out coherent features, $\mathcal{B}$ is smoothed with a Gaussian kernel with $\sigma = 2$ in bin units.

In the next slides $\mathcal{B}$ is shown as a function of ℓ_1 and ℓ_2, for a given bin in ℓ_3 (which changes with time in the movies). Very red or blue regions indicate significant non-Gaussianity.


SMICA
NILC
SEVEM
C-R
Raw 143 GHz
ℓ_1
ℓ_2
500
1000
1500
2000
−4
−3
−2
−1
0
1
2
3
4

$\ell_3 \in [2, 3]$

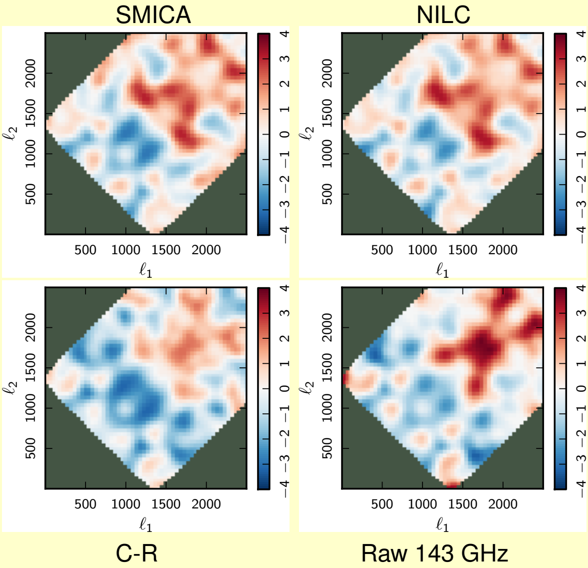
SMICA NILC SEVEM



C-R Raw 143 GHz

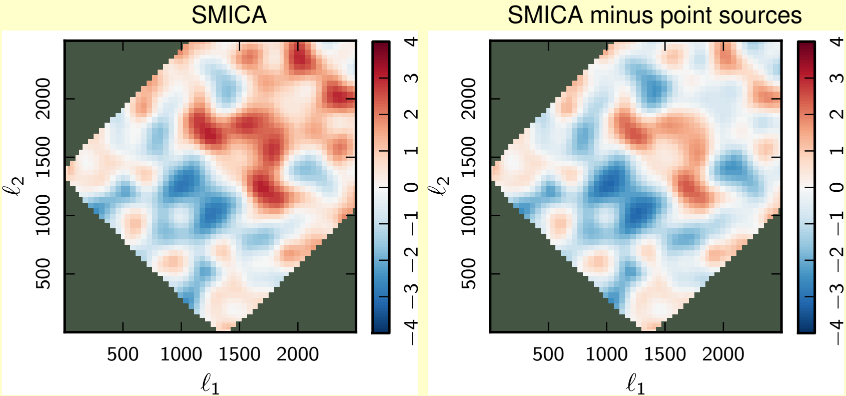
$\ell_3 \in [610, 654]$

Good agreement SMICA, NILC, SEVEM for all ℓ_1, ℓ_2. Also with C-R and Raw 143 for $\ell_1, \ell_2 < 1500$. No significant NG (at least for $\ell_1, \ell_2 < 2000$).



$\ell_3 \in [1420, 1464]$

Excellent agreement SMICA, NILC, SEVEM for all ℓ_1, ℓ_2. Some NG present, more in Raw 143, not in C-R.



$$\ell_3 \in [1420, 1464]$$

$\Rightarrow$ The NG signal at high ℓ_1, ℓ_2, ℓ_3 appears to be (mostly) point source contamination (which has negligible correlation with the other templates).

Conclusions

- The **binned bispectrum estimator** is fast, gives optimal results and has a convenient modular setup.
- Allows both parametric ($f_{\rm NL}$) and non-parametric bispectrum estimation.
- **Planck $f_{\rm NL}$ results**: no (leo) primordial NG, much smaller error bars than WMAP, first detection ISW-lensing.
- **Planck bispectrum reconstruction**: blind tests see mostly point source bispectrum; something more at high ℓ?
- **Excellent agreement** between different estimators and component separation methods.
- Huge amount of **validation tests** confirm robustness of results (dependence on $\ell_{\rm max}$, on mask, consistency raw and cleaned maps, null tests, foreground residuals, . . .).

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.