CMB bispectrum measurements and foreground contamination

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Critical tests of inflation using non-Gaussianity
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Outline

- f_{NL} estimator
- Diffuse foreground contamination
- Diffuse foregrounds: bispectrum signature
- Testing f_{NL} diffuse foreground contamination in data: WMAP
- Planck and tests “beyond” point f_{NL} estimates
- Conclusions

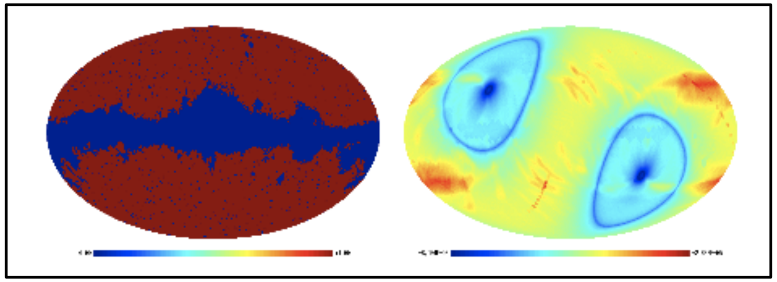
f_{NL} estimator

$$\chi^2 = \sum_{\ell_i m_i} \frac{\left[B^{observed}_{\ell_i m_i} - B^{theory}_{\ell_i m_i}\left(f_{NL}\right)\right]^2}{\sigma^2}$$

$$\hat{f}_{NL} = \frac{1}{N} \sum_{\ell_i m_i} B^{m_1 m_2 m_3}_{\ell_1 \ell_2 \ell_3} \frac{a^{m_1}_{\ell_1}}{C_{\ell_1}} \frac{a^{m_2}_{\ell_2}}{C_{\ell_2}} \frac{a^{m_3}_{\ell_3}}{C_{\ell_3}}$$

Matched filter for primordial NG. We measure the correlation between the 3-point function in the data and our theoretical template

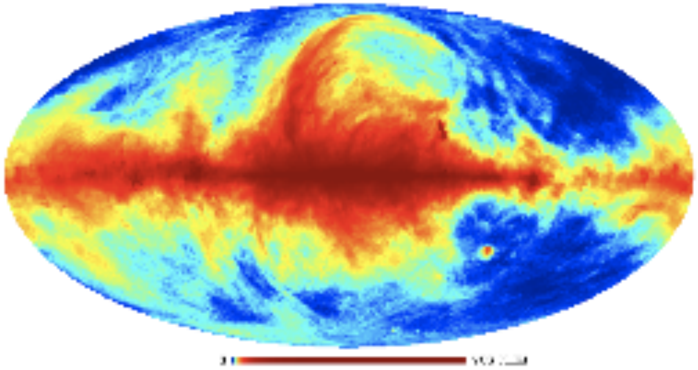
In presence of rotation invariance breaking terms



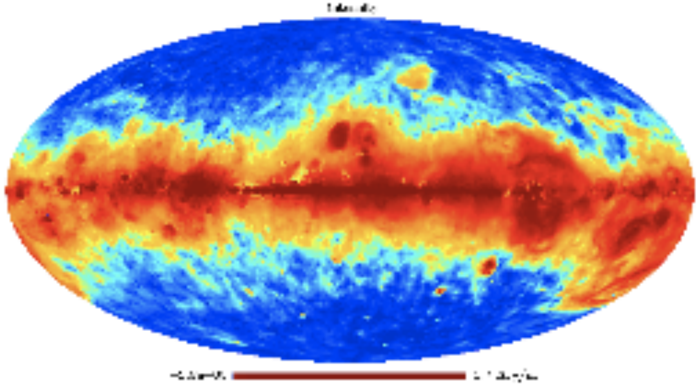
$$\hat{f}_{NL} = \frac{1}{N} \sum B^{m_1 m_2 m_3}_{\ell_1 \ell_2 \ell_3} \left[\left(C^{-1}a\right)^{m_1}_{\ell_1} \left(C^{-1}a\right)^{m_2}_{\ell_2} \left(C^{-1}a\right)^{m_3}_{\ell_3} - 3C^{-1}_{\ell_1 m_1 \ell_2 m_2} \left(C^{-1}a\right)^{m_3}_{\ell_3}\right]$$

Diffuse foregrounds

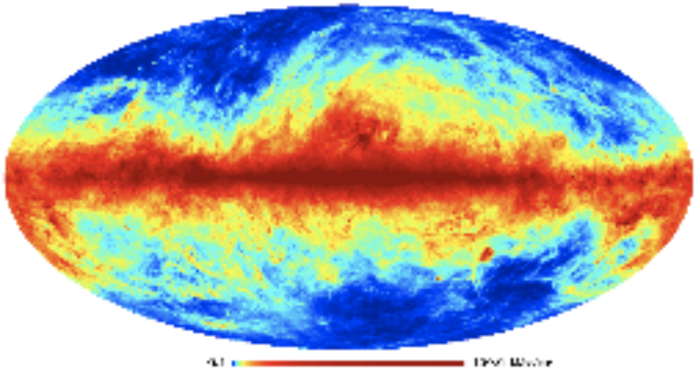
Synchrotron, 408 Mhz (Haslam et al. 1982)

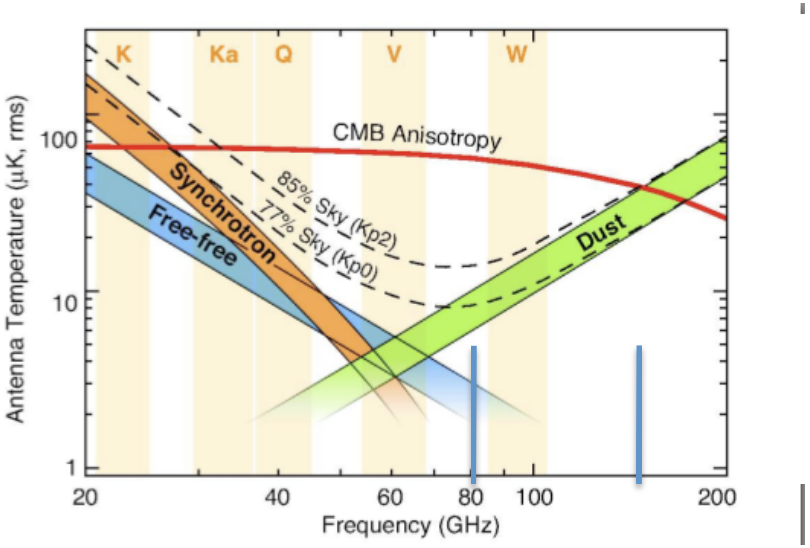


Free free, 23 Ghz (Dickinson et al. 2003)



Thermal Dust, 100 μm (Finkbeiner et al. 1999)





Planck LFI : 30, 44, 70 Ghz

Planck HFI : 100, 143, 217, 353, 545, 857 Ghz

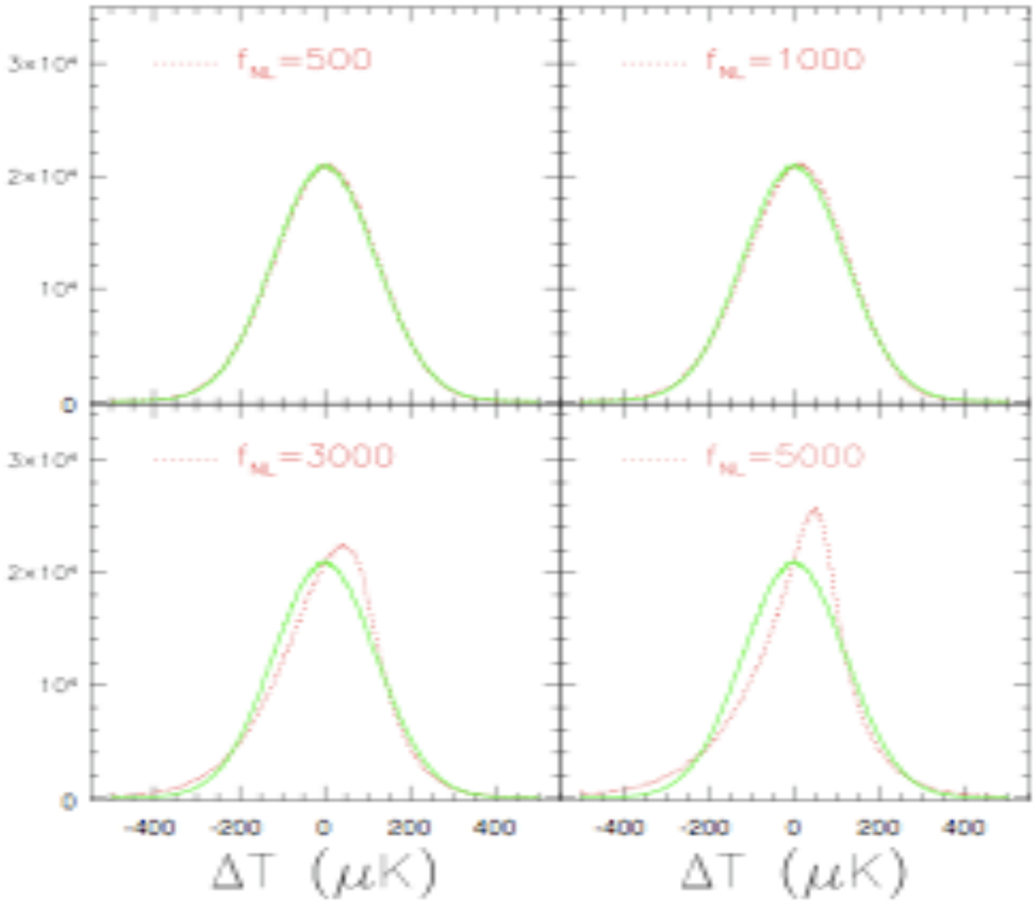
Diffuse foregrounds: bispectrum signature

$$\tilde{T}_{obs}(\hat{n}) = \underbrace{T(\hat{n})}_{\text{cmb+noise}} + \underbrace{F(\hat{n})}_{\text{foreground}}$$

$$\tilde{T}\tilde{T}\tilde{T} = TTT + TTF + TFF + FFF$$

1. FFF term dominates ⇒ large negative local f_{NL} (positive orthogonal f_{NL}), estimator is biased.

2. TFF term dominates ⇒ local f_{NL} contamination, sign is realization dependent



FFF term produce
Positive tail in 1-pt pdf,
Hence negative local f_{NL}

$$\langle TTF \rangle = 0$$

Accidental correlation between F and T can’t bias the Estimator. Effect on error bars from 6-point function

Small scales Large scales → squeezed

For WMAP 5-years, Δ_{TFF} ~ 10 from raw maps with KQ75 mask

Smith, Senatore, Zaldarriaga 2009

f_{NL} analysis in presence of foregrounds: WMAP

- Run on raw maps (with masking), quote systematic error from TTF and/or increase the mask until TTF is negligible
- Clean the maps: template fitting, template marginalization

Template marginalization:

$$C \to C + \lambda F\,, \qquad \lambda \to \infty$$

$$a \to C^{-1} a$$

Consistency checks:

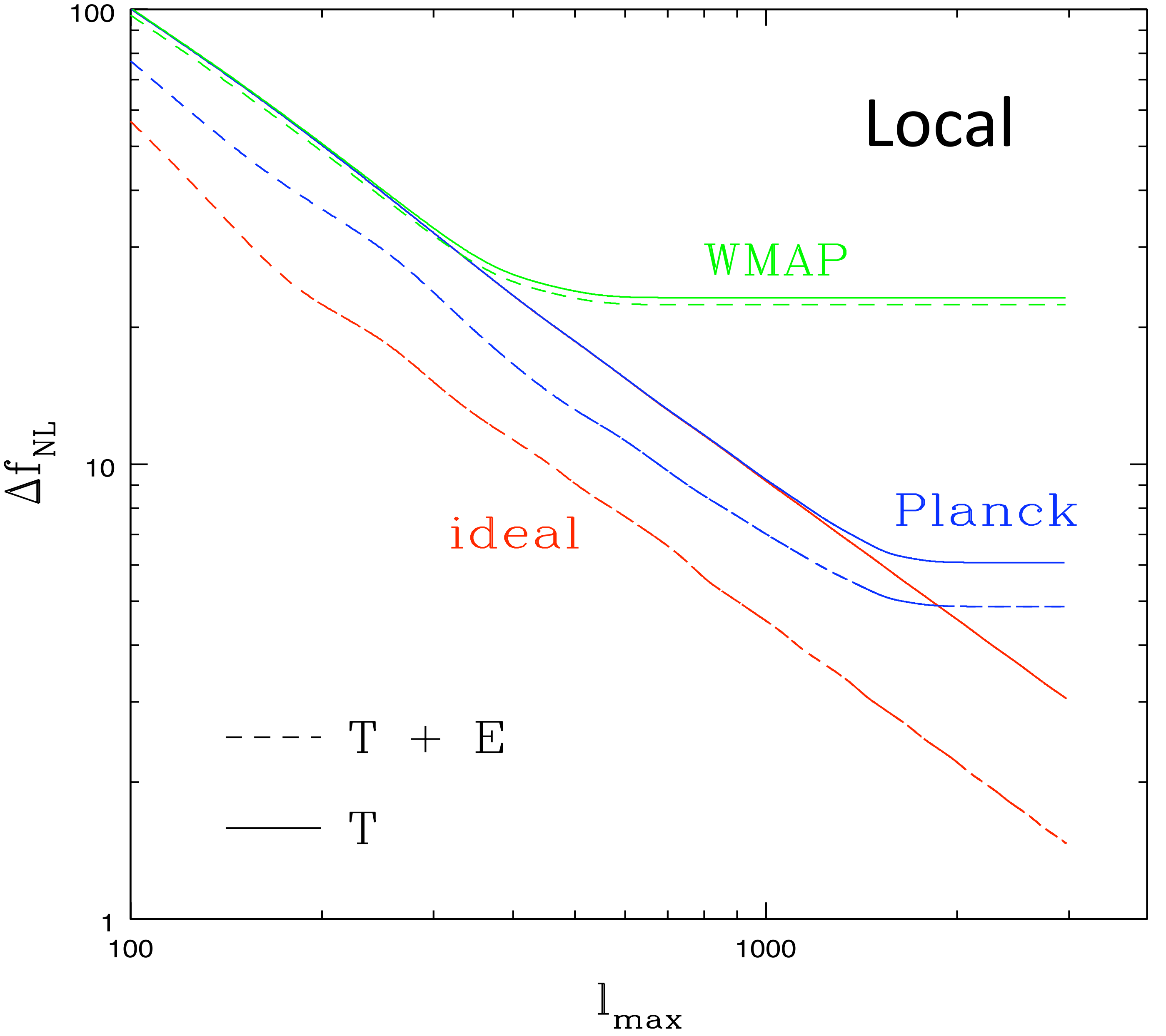
✓ Check robustness of the result for different levels of sky coverage

✓ Check consistency between different frequency channels

✓ Check effects of changing l_{min}

Smith, Senatore, Zaldarriaga 2009
Komatsu et al. 2009, 2011
Yadav and Wandelt 2008

Planck vs WMAP



Foreground issues with Planck

All the f_{NL} analysis steps shown for WMAP still apply to Planck (with several technical issues to address: e.g. Wiener filtering at Planck resolution)

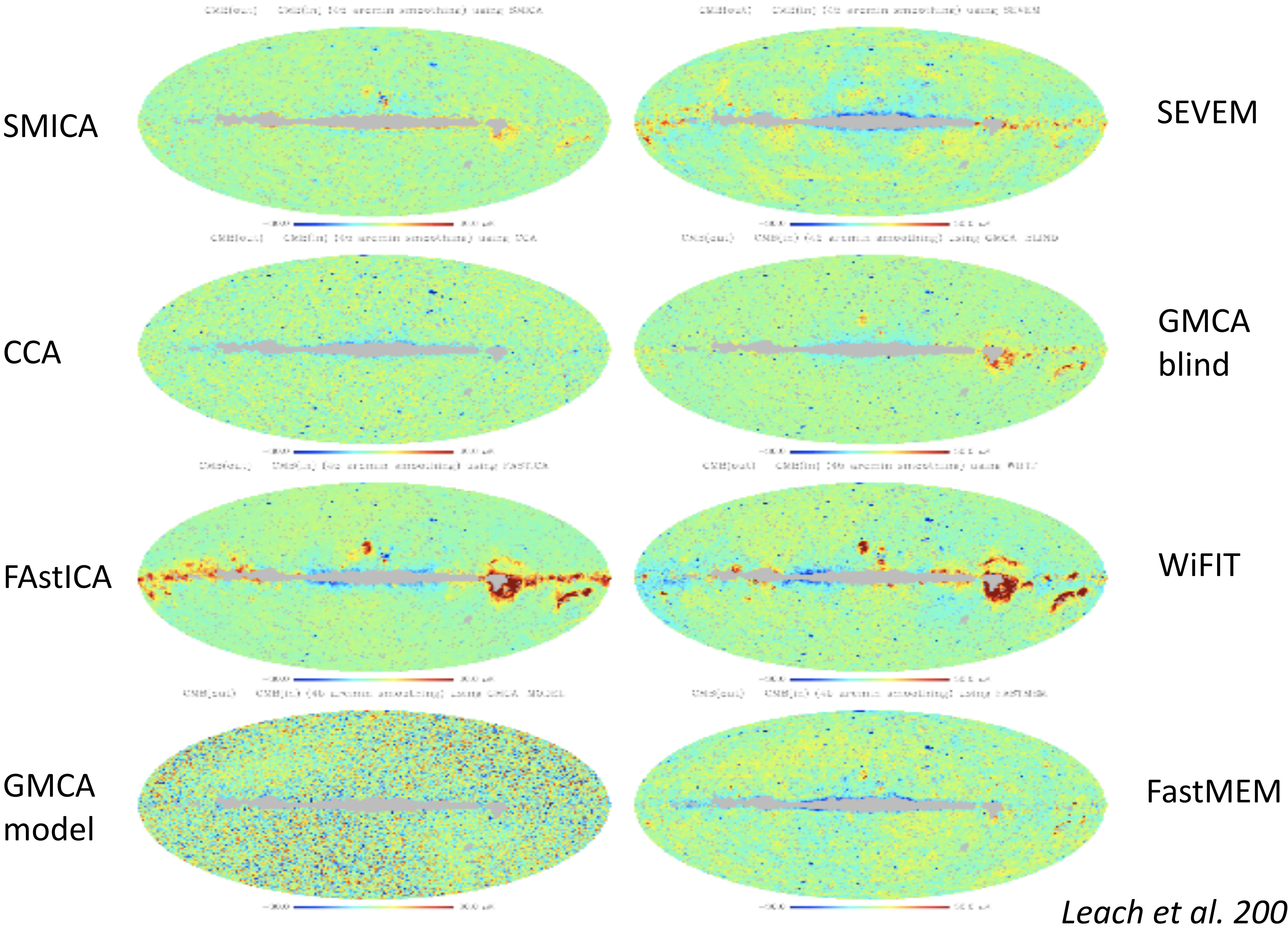
The higher sensitivity of the Planck dataset requires a better control of systematics

Foregrounds provide in principle a more significant challenge for f_{NL} measurements with Planck than WMAP

On the other hand the large frequency coverage allows an accurate subtraction of foregrounds (e.g. relying on accurate internal templates)

A large array of component separation techniques and f_{NL} estimators is also available, allowing accurate validation checks

Large amount of component separation methods available for cross-checks



Leach et al. 2008

Validation tests using Planck Sky Model and Full Focal Plane simulations

- ✓ Full Focal Plane (FFP) maps: massive numerical effort to simulate the full Planck data reduction pipeline (from TOD to map, including asymmetric beams, noise correlations, destriping…)

- ✓ Add components using the Planck Sky Model (PSM, *Delabrouille et al 2012*): galactic emission (synchrotron, free free, thermal and spinning dust, molecular lines), point source emissions (SZ, radio sources, infrared sources), CIB. Includes CMB lensing and local f_{NL}

- ✓ Run component separation pipelines on these realistic maps

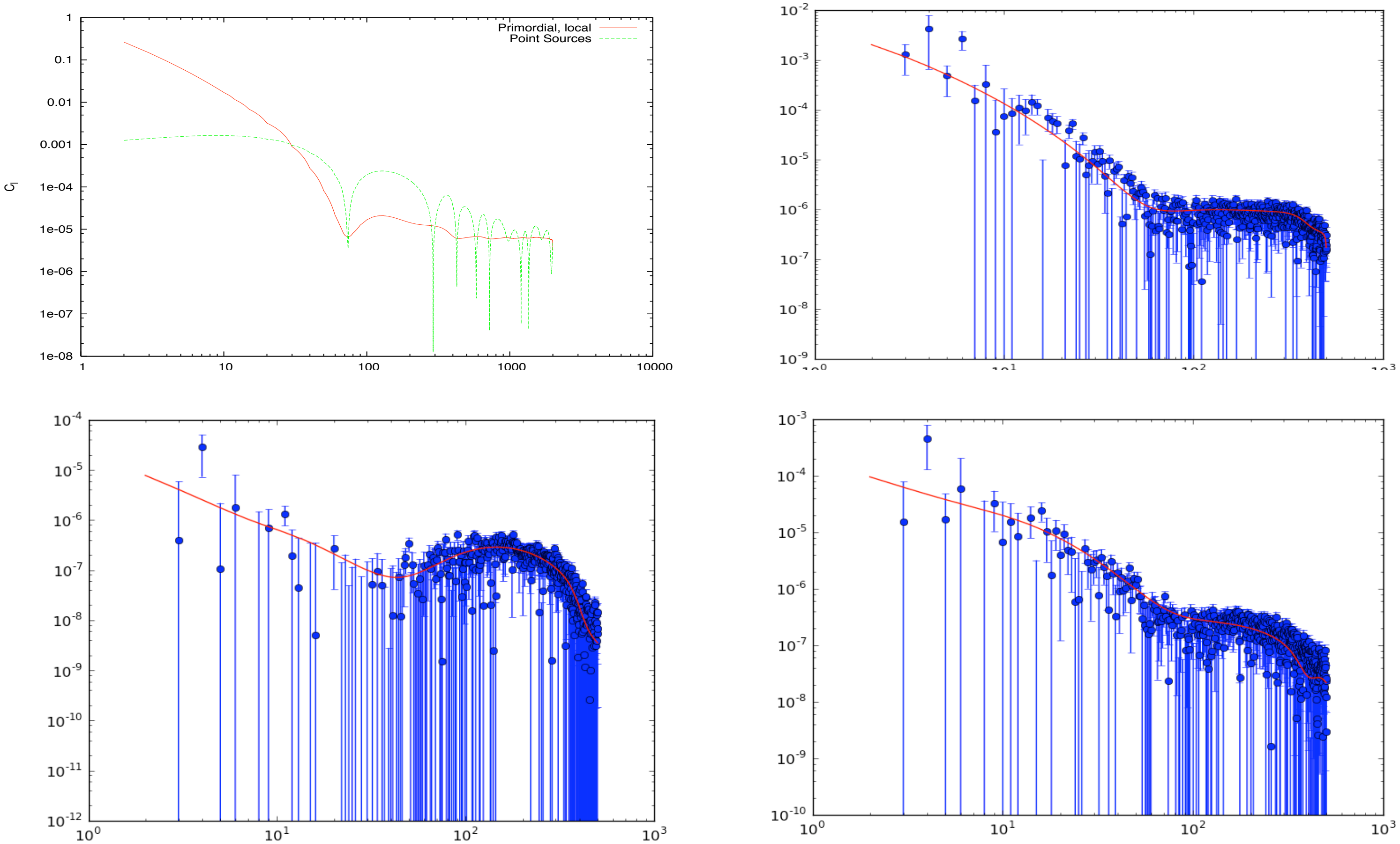
- ✓ Run a set of f_{NL} estimators on the clean maps and test for consistency between methods and between estimators. Different estimators are basically implementations of the optimal estimator based on factorizing the bispectrum template in different domains. They are expected to converge on clean maps

Skew-Cl statistics

Munshi & Heavens 2009, Renzi et al in prep.

$$C_l^{A,B^2}(r) = \frac{1}{2l+1}\sum_m \mathrm{Real}\left\{A_{lm}(r)B^{(2)}_{lm}(r)\right\},$$

$$C_l^{loc} \equiv (C_l^{A,B^2} + 2C_l^{AB,B}) = \frac{f_{NL}^{loc}}{(2l+1)}\sum_{l'}\sum_{l''}\left\{\frac{B^{loc}_{ll'l''}B_{ll'l''}}{C_l C_{l'} C_{l''}}\right\}$$



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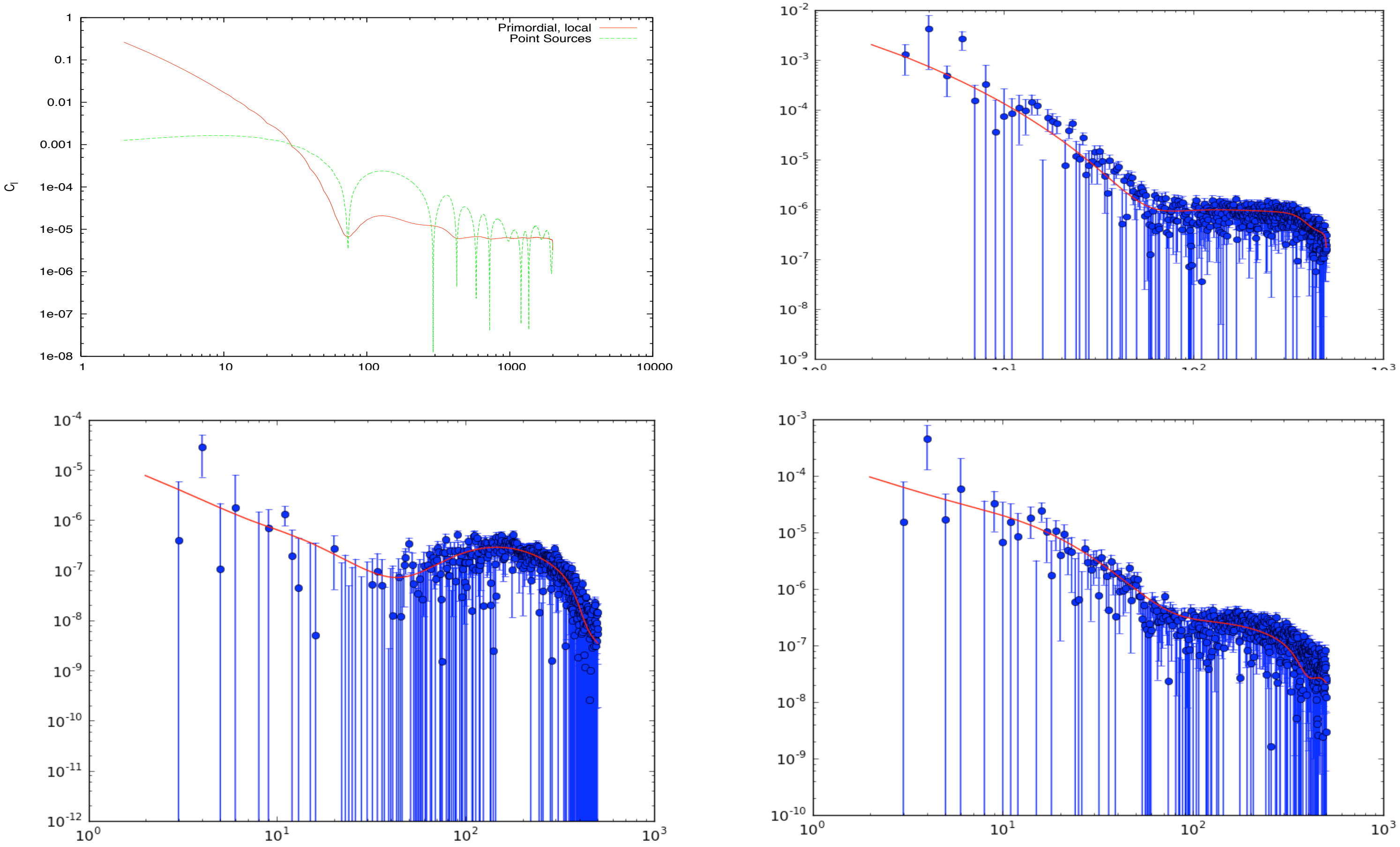
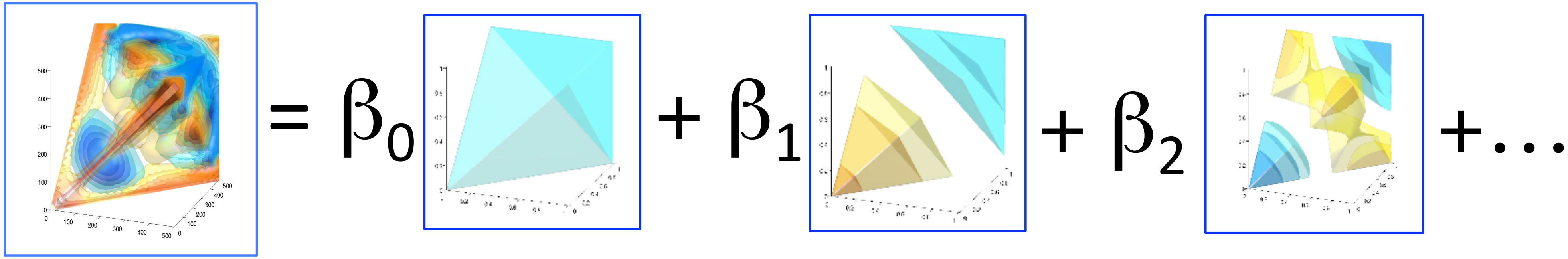


Modal reconstruction

Fergusson, ML, Shellard 2009, 2010



$$= \beta_0 + \beta_1 + \beta_2 + \ldots$$

Goal: for a given dataset, extract best-fit β_i, i=1,…,p

- The basis elements pictured on the right *are by construction factorizable*
- Apply position space cubic statistics by Komatsu, Spergel and Wandelt (2003) to each separable template on the right to estimate the amplitudes β_i
- Orthonormal basis ➔ β_i uncorrelated (in first approx.)

Modal reconstruction

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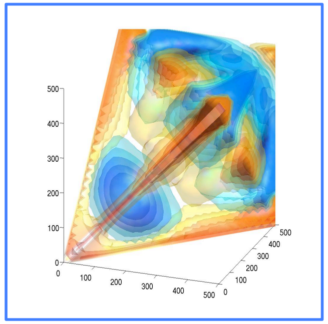
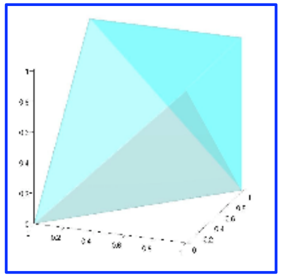
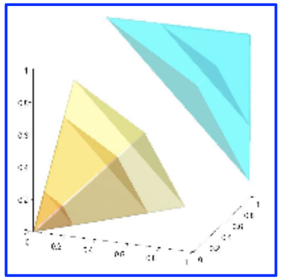


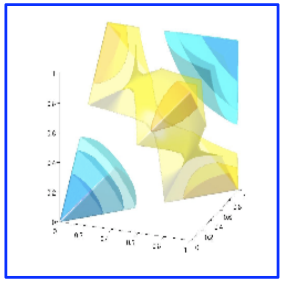
$= \beta_0$



$+ \beta_1$



$+ \beta_2$



$+ \dots$

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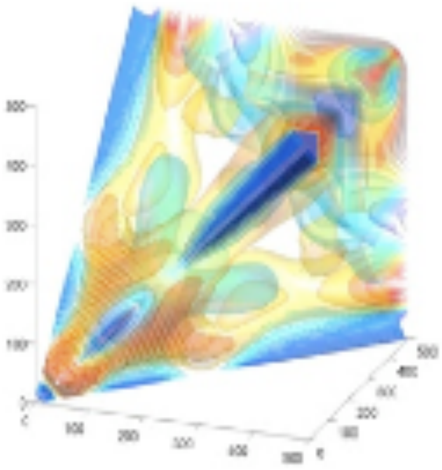
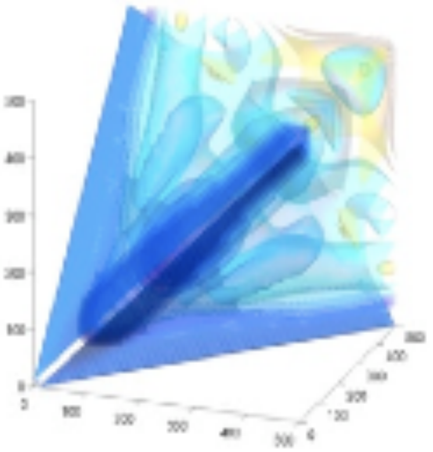
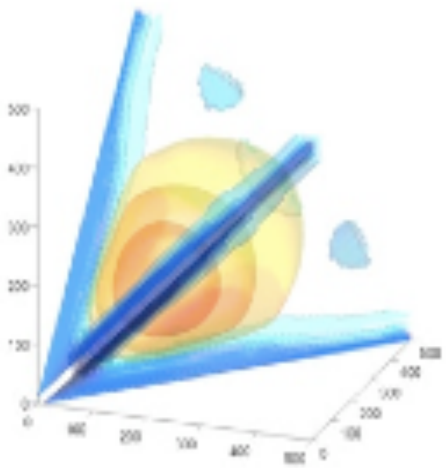


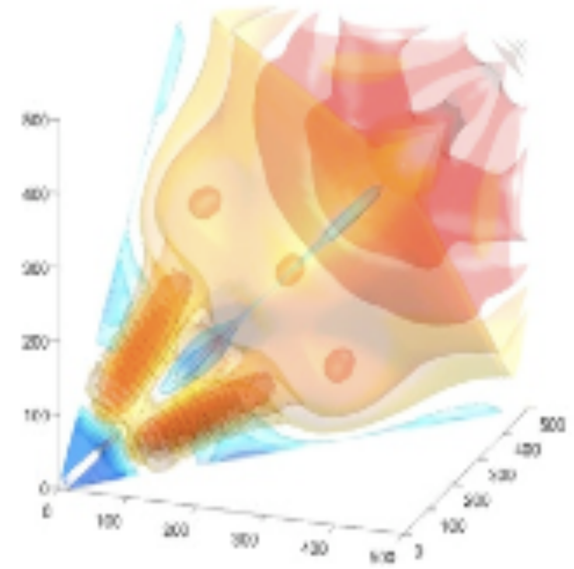
Inhomogenous noise



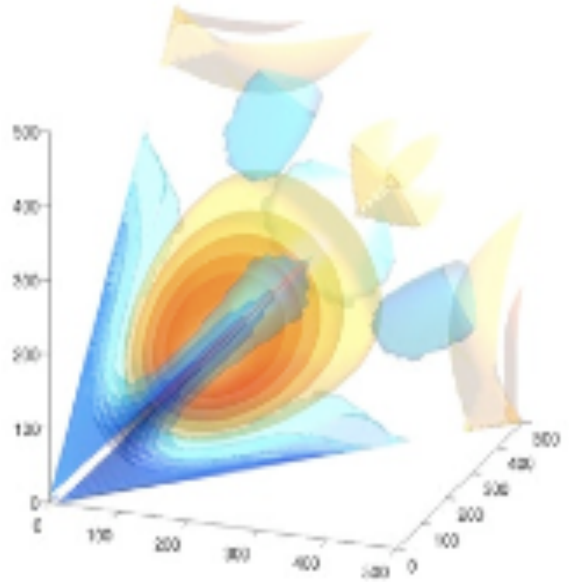
Galactic/point source mask



Local NG model

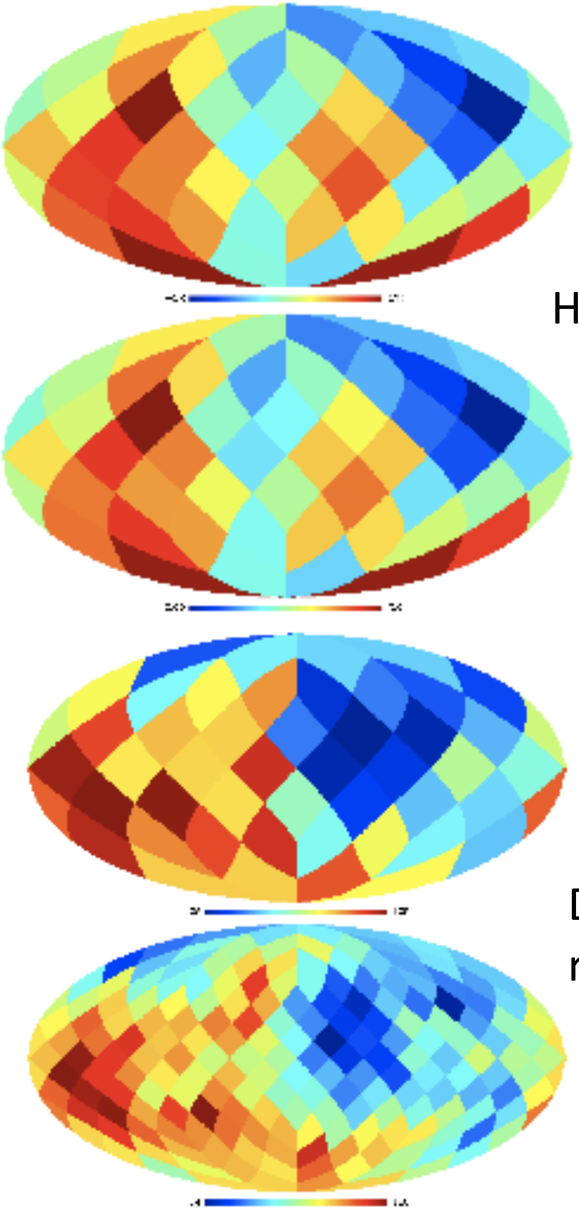


Unsubtracted point sources



Equilateral NG model

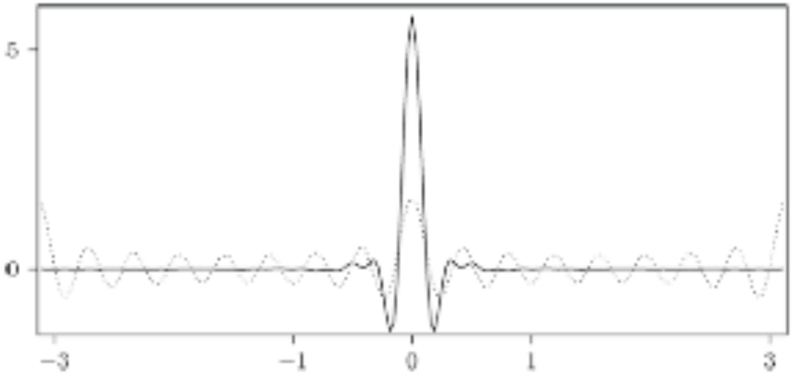
Needlet decomposition and directional f_{NL} analysis



Hemispheres

Disks, 45 degrees radius

$$\psi_{jk}(\hat{\gamma})=\sqrt{\lambda_{jk}}\sum_{\ell} b\left(\frac{\ell}{B^{j}}\right)\sum_{m} Y_{\ell m}(\hat{\gamma})Y_{\ell m}(\gamma_{k})$$



$$I_{j_1 j_2 j_3}=\sum_{k\in\Omega}\frac{\beta_{j_1 k}\beta_{j_2 k}\beta_{j_3 k}}{\sigma_{j_1 k}\sigma_{j_2 k}\sigma_{j_3 k}}$$

Rudjord, Hansen, Lan, ML, Marinucci, Matarrese 2010

Conclusions

✓ Diffuse galactic foregrounds are a potential important source of systematics for primordial f_{NL} measurements

✓ Main f_{NL} signature: accidental correlation between *large* scale foreground contamination and *small* scale CMB anisotropies → *local*

✓ WMAP: foreground contamination on f_{NL} is negligible after template fitting/marginalization

✓ Planck requires much more accurate control of systematics, due to its high sensitivity. However:

1. Large frequency coverage
2. Large set of comp. sep. methods for cross-validation.
3. Realistic synthetic datasets for accurate tests (FFP + PSM)
4. Additional tools: skew-cl statistics, modal bispectrum reconstruction, needlet decomposition…. to test contamination in the 3 point function

⇨ **We are in good shape**