The Planck Temperature & Polarization CMB maps

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On behalf of the Planck collaboration

Planck 2014 – The Microwave sky in Temperature and Polarization
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Overview

- In this presentation I will be talking about Separation of Diffuse Foregrounds in Planck maps

- There are 2 different purposes:
  - To generate the CMB map with Diffuse Foreground removed
  - Pull out the Foregrounds themselves *(see Wehus talk)*

- The CMB maps with Diffuse Foreground removed still have Extragalactic Foreground residuals – these are treated at the Likelihood level and marginalized over
- The Component Separation methods have been refined for Temperature and newly applied to Polarization data

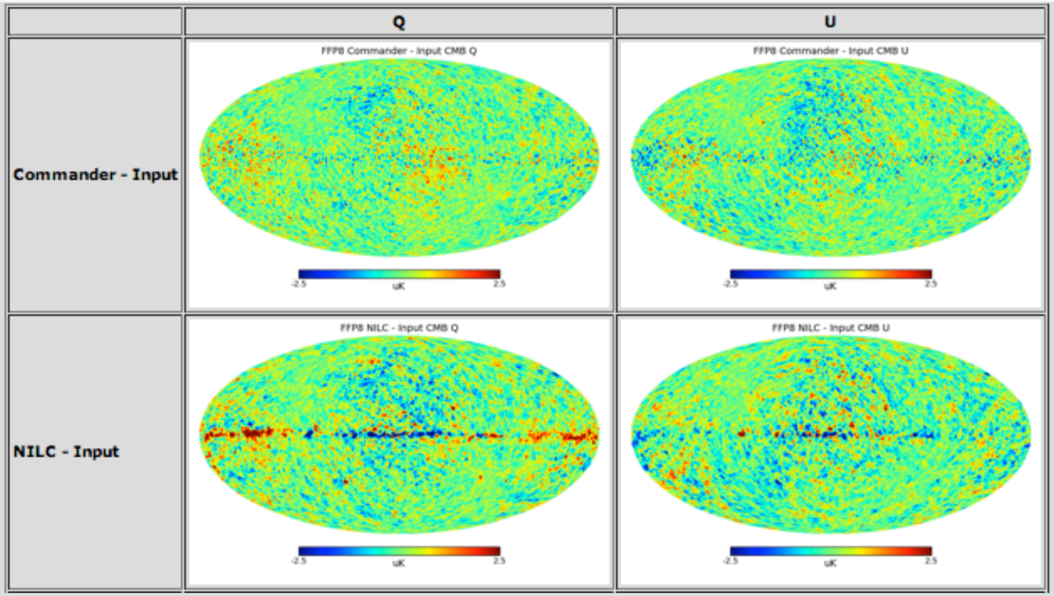
✧ Official delivery
  - **CMB T,Q,U maps**
    - a post-processing High-Pass-Filtering (HPF) has been applied to CMB polarization maps in order to mitigate residual large scale systematics
  - **CMB E, B maps**
    - produced by pipelines and being considered for possible delivery

Four Methods

- Commander – parametric model fitting in pixel space
- NILC – needlet (wavelet) internal linear combination
- SEVEM – template fitting in pixel space
- SMICA – non-parametric (low rank) spectral fitting and filtering

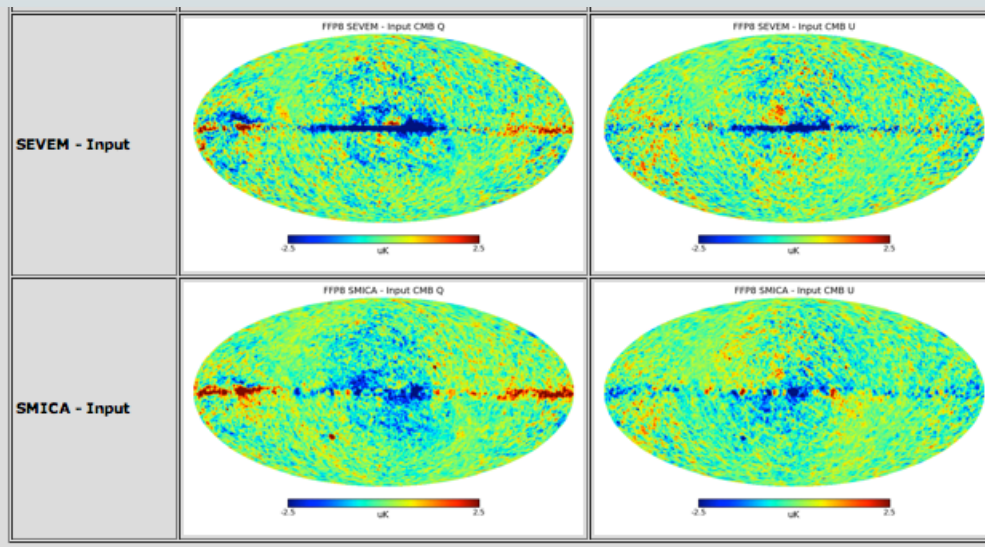
RESULTS

Planck Simulations (FFP8)



(Output – Input) CMB maps

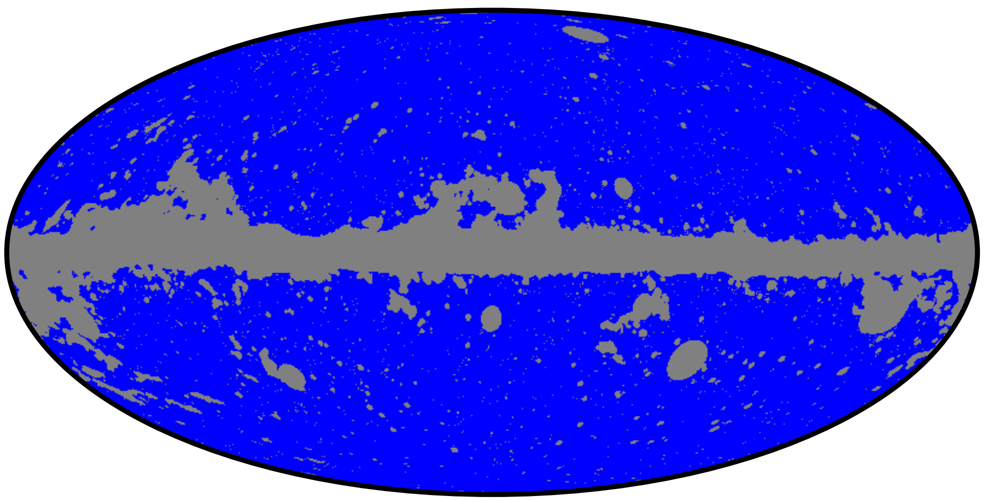
Preliminary



FFP8 simulations (*see Borrill's talk*)

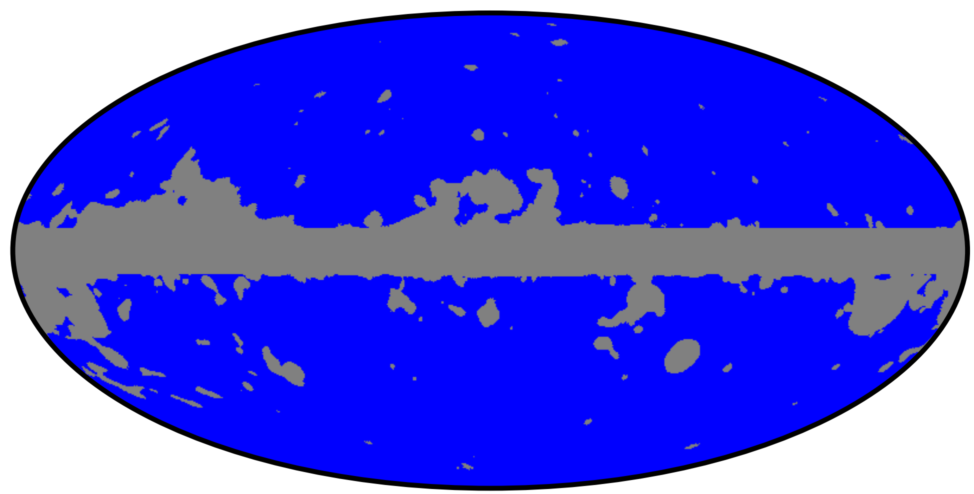
Confidence-Masks

T



Preliminary

Pol



$f_{sky} = 0.78$

CMB maps (T,Q,U)

Preliminary

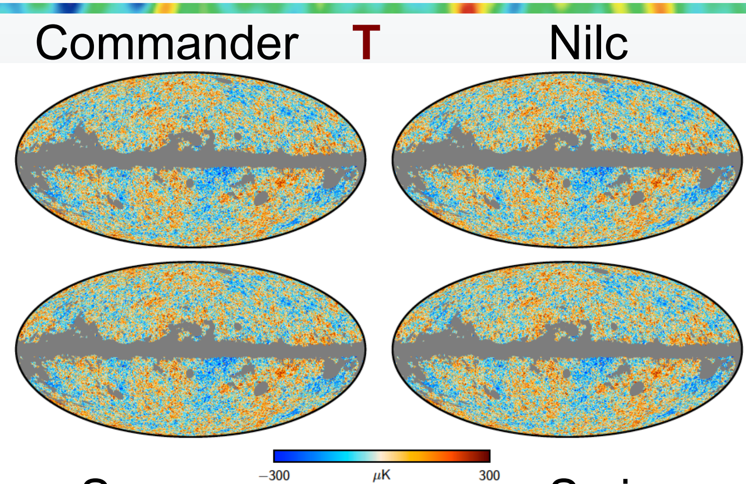


Fig. 1. Component separated CMB T maps for COMMANDER (top left), NILC (top right), SEVEM (bottom left), SMICA (bottom right).

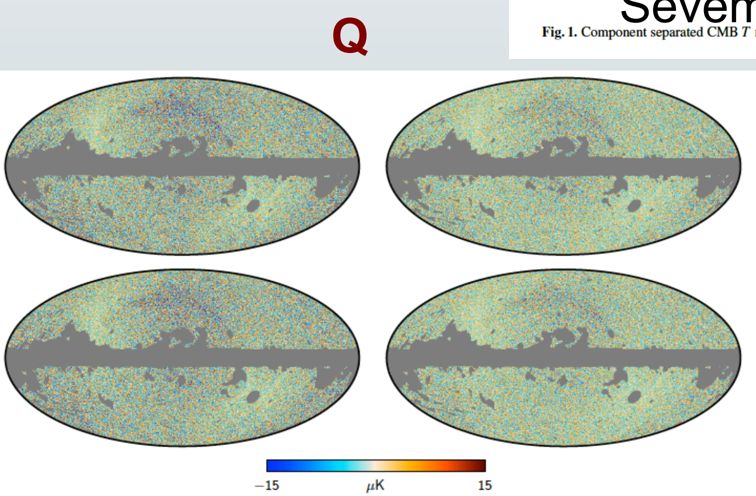


Fig. 3. Component separated CMB Q maps for COMMANDER (top left), NILC (top right), SEVEM (bottom left), SMICA (bottom right).

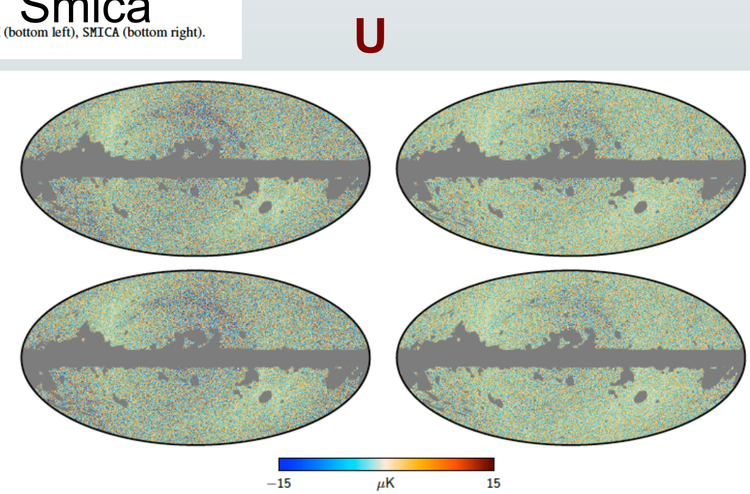


Fig. 4. Component separated CMB U maps for COMMANDER (top left), NILC (top right), SEVEM (bottom left), SMICA (bottom right).

	Commander	NILC	SEVEM	SMICA
HMHD RMS @ 60’	0.64	0.76	0.76	0.70

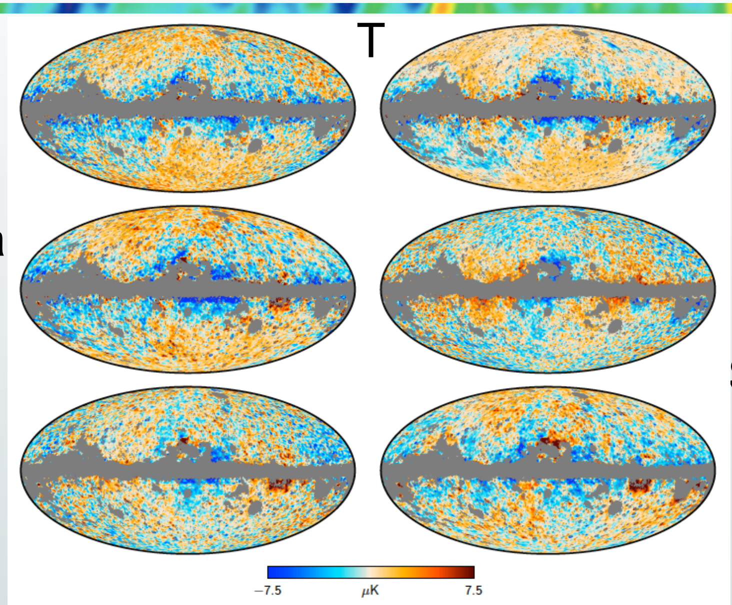
CMB maps pairwise differences T,Q,U

Comm-Nilc

Comm-Smica

Nilc-Smica

Preliminary



Comm-Sevem

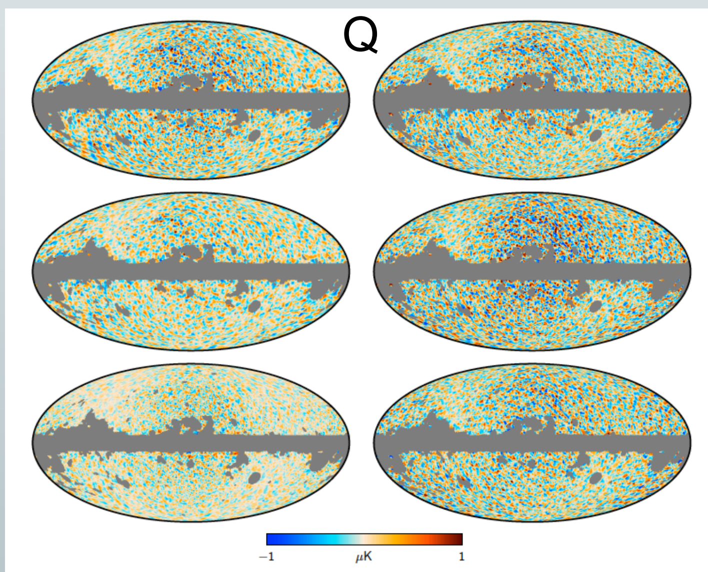
Nilc-Sevem

Sevem-Smica

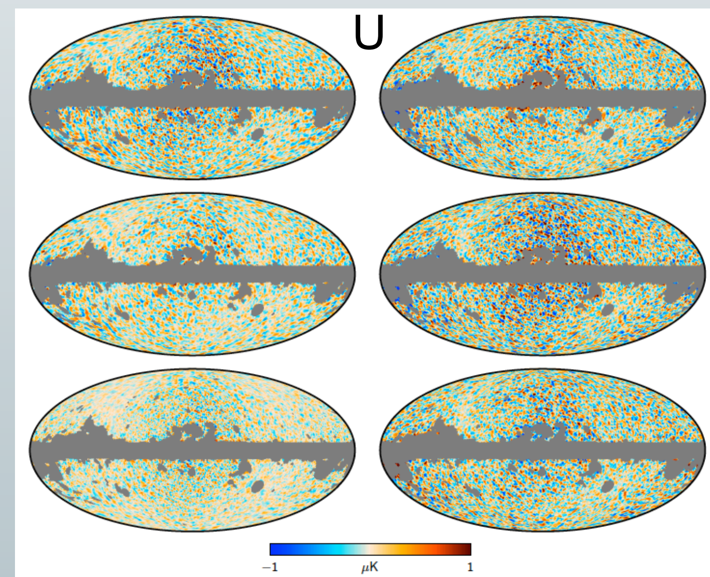
T
Level of discrepancies and Morphology similar to 2013

Large differences on the Galactic plane

At higher latitudes, differences are due to strong, localized sources, or residual dipole differences between maps



Q and U
(Commander and SEVEM)
(NILC and SMICA)
solutions closest
to each other



CMB maps 2013 vs 2014 (subtracted ZLE)

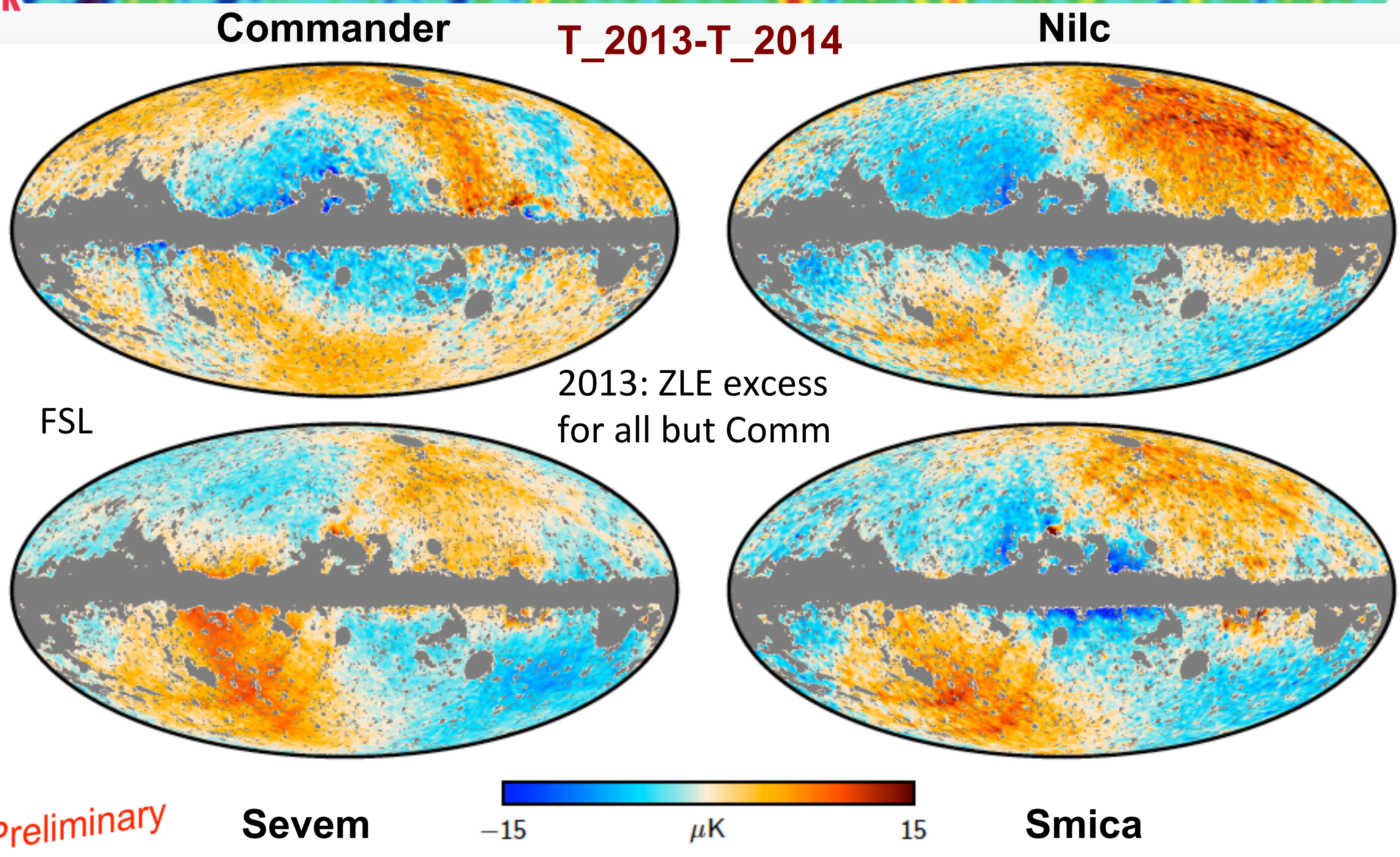
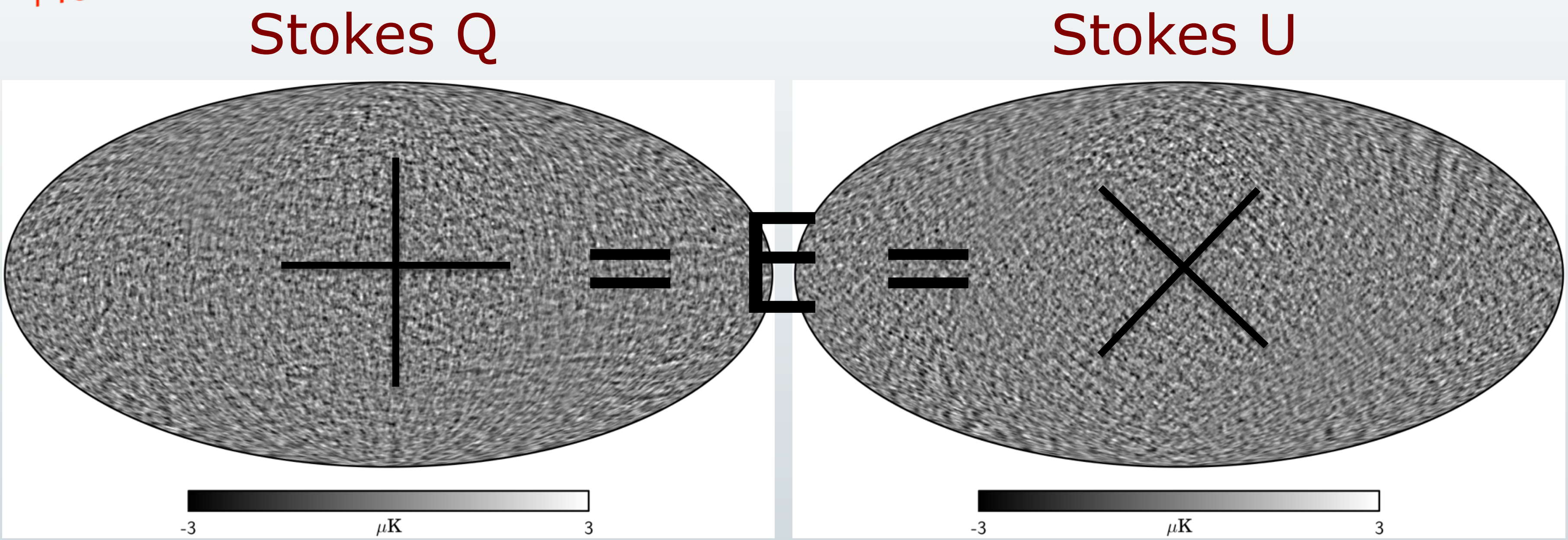


Fig. 2. 2013-2014 differences for each CMB component separation solution in total intensity for COMMANDER (top left), NILC (top right), SEVEM (bottom left), SMICA (bottom right).

Commander polarization map @ 1 degree resolution

Preliminary



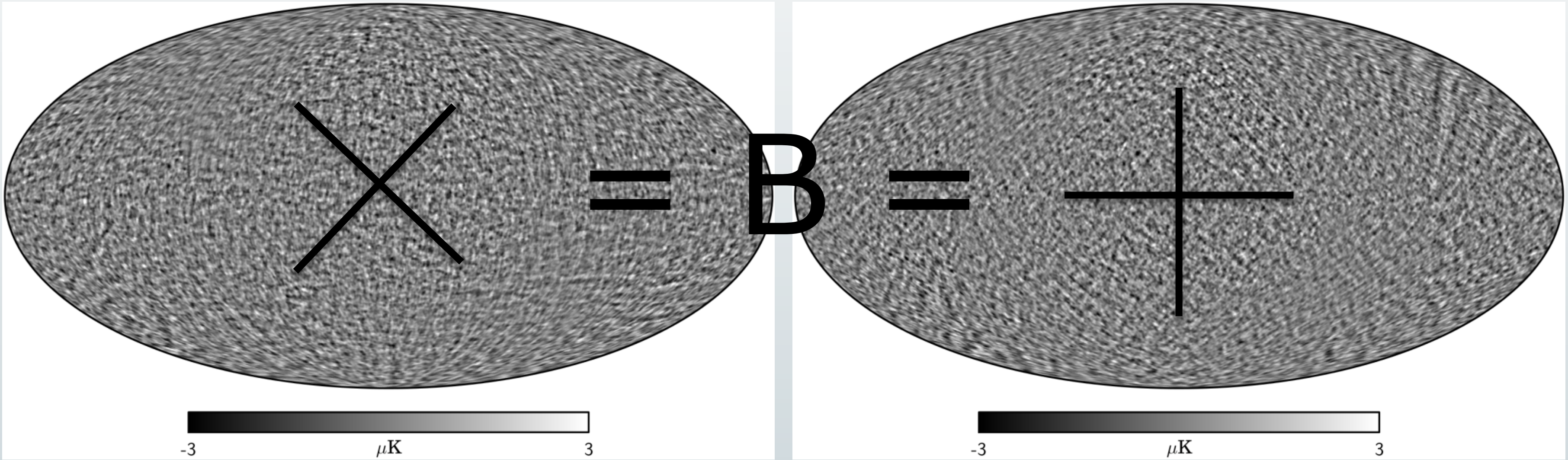
Processing steps:

- Smoothed to 1 FWHM
- High-pass filtered with l=20-40 cosine filter
- Replaced Galactic plane with constrained Gaussian realization

Commander polarization map @ 1 degree resolution

Preliminary

Stokes Q | Stokes U



Processing steps:

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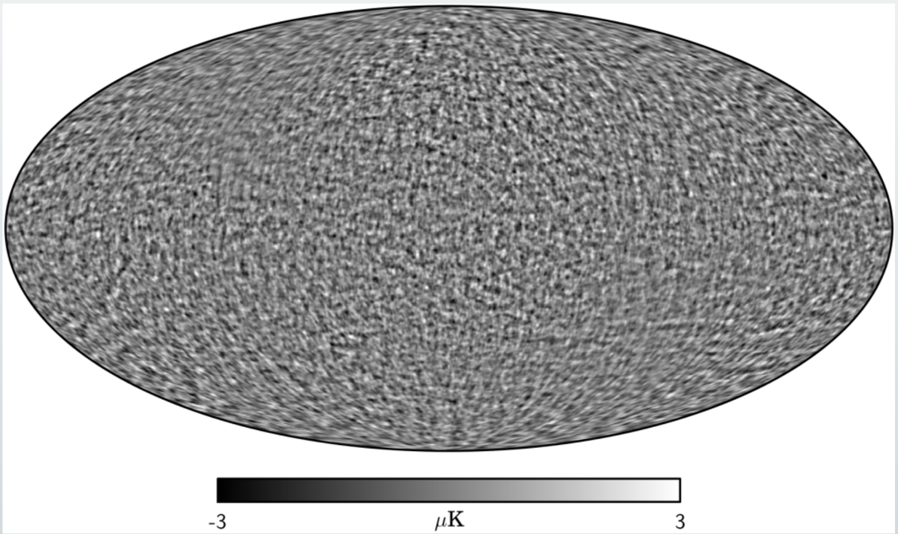
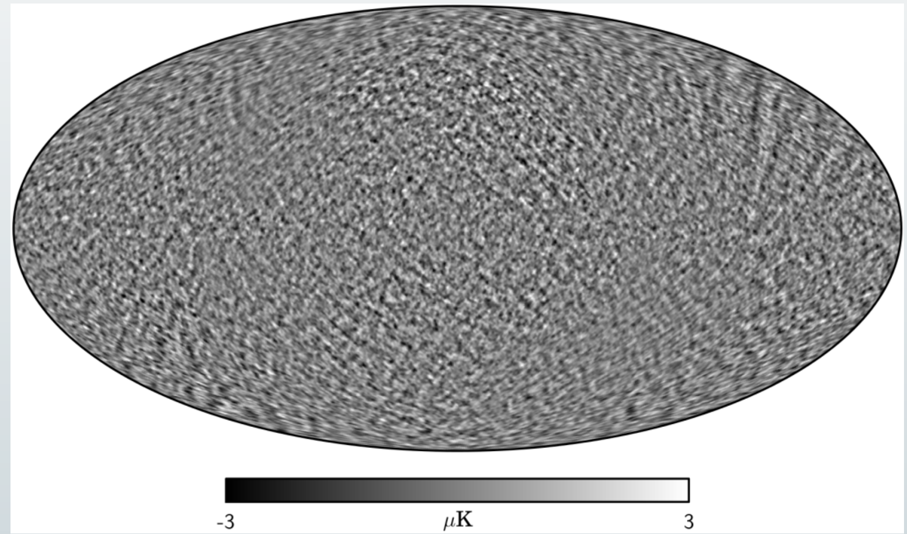
Commander polarization map @ 1 degree resolution

Preliminary

Stokes Q



Stokes U



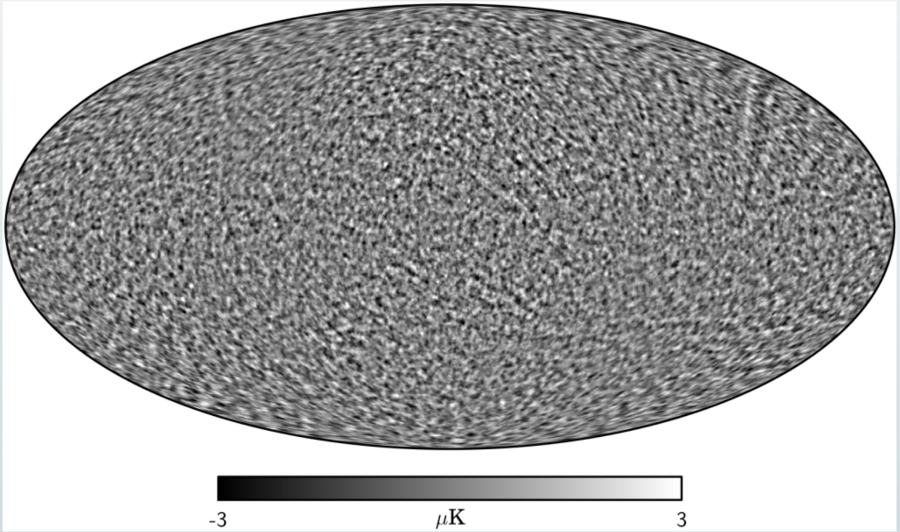
Processing steps:

- Smoothed to 1 FWHM
- High-pass filtered with l=20-40 cosine filter
- Replaced Galactic plane with constrained Gaussian realization

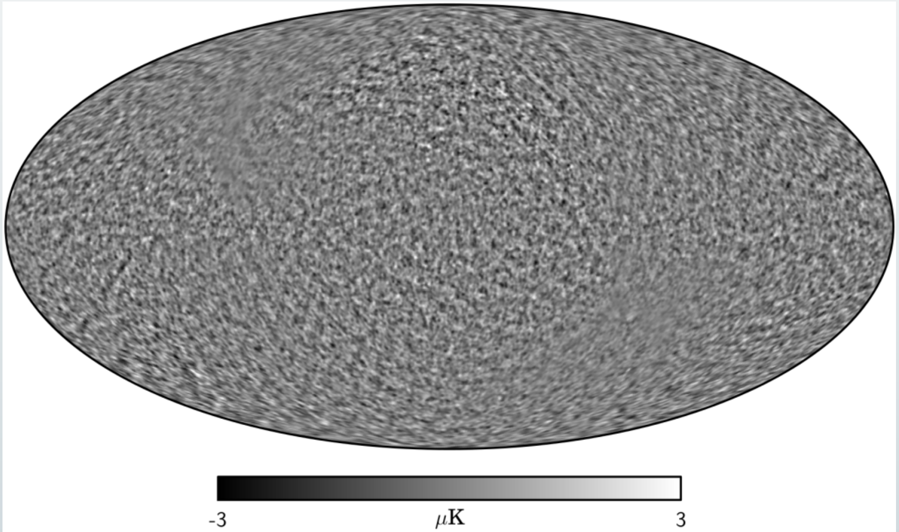
Commander polarization map @ 1 degree resolution

Preliminary

E



B

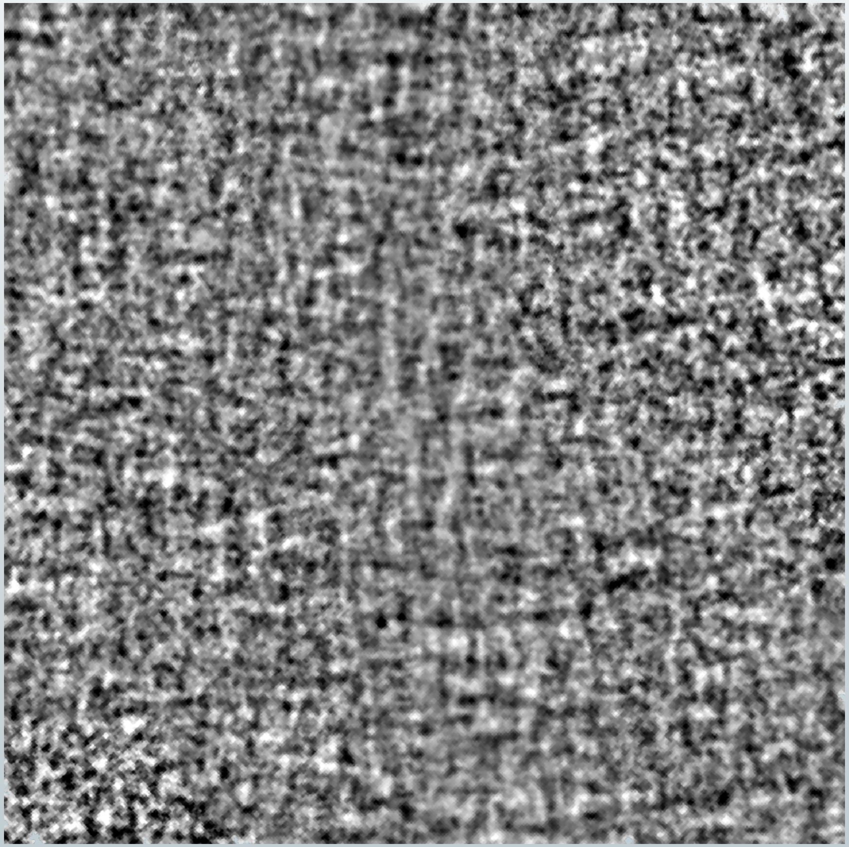
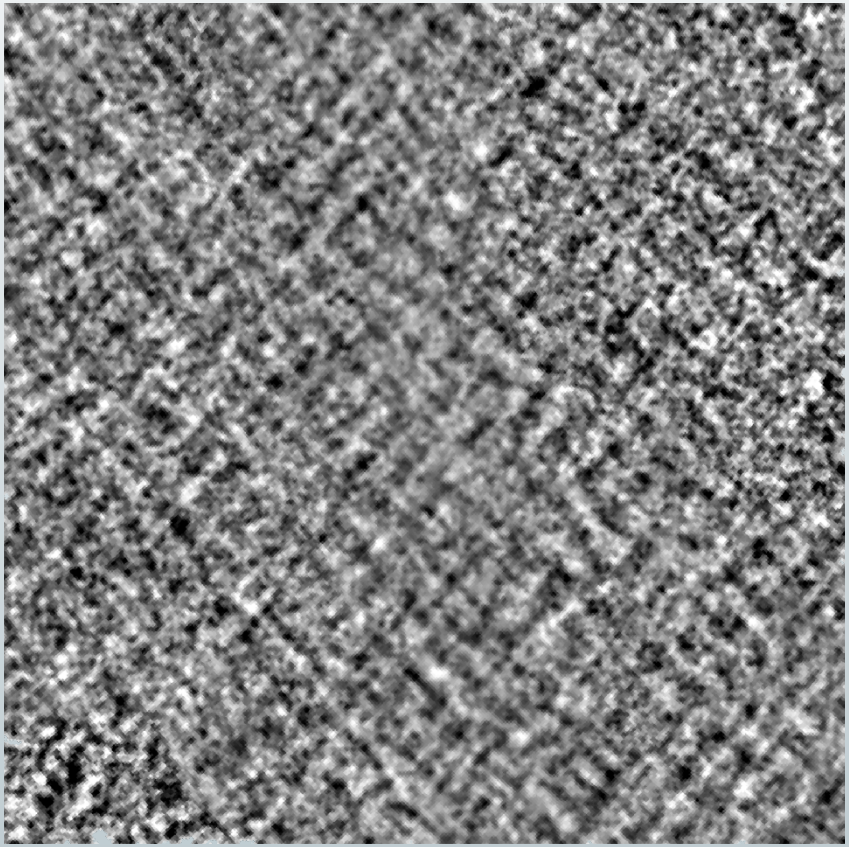


Processing steps:

- Smoothed to 1 FWHM
- High-pass filtered with l=20-40 cosine filter
- Replaced Galactic plane with constrained Gaussian realization

Commander polarization map @ 10 arcmin

Preliminary

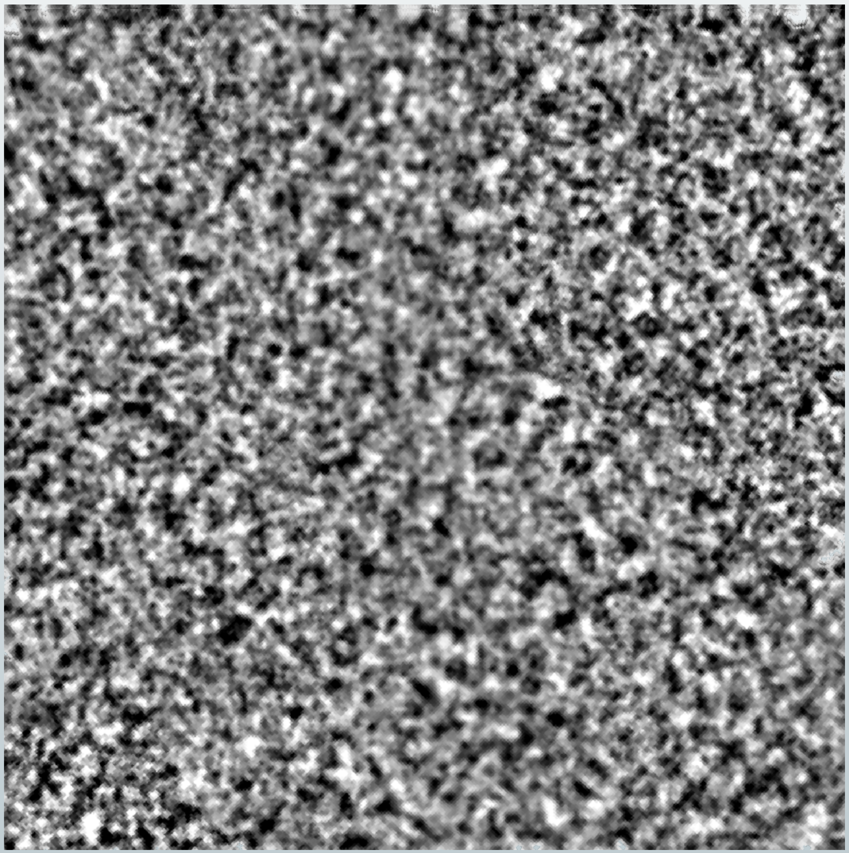
Stokes Q	Stokes U
	

10° x 10° zoom-in of North Ecliptic Pole

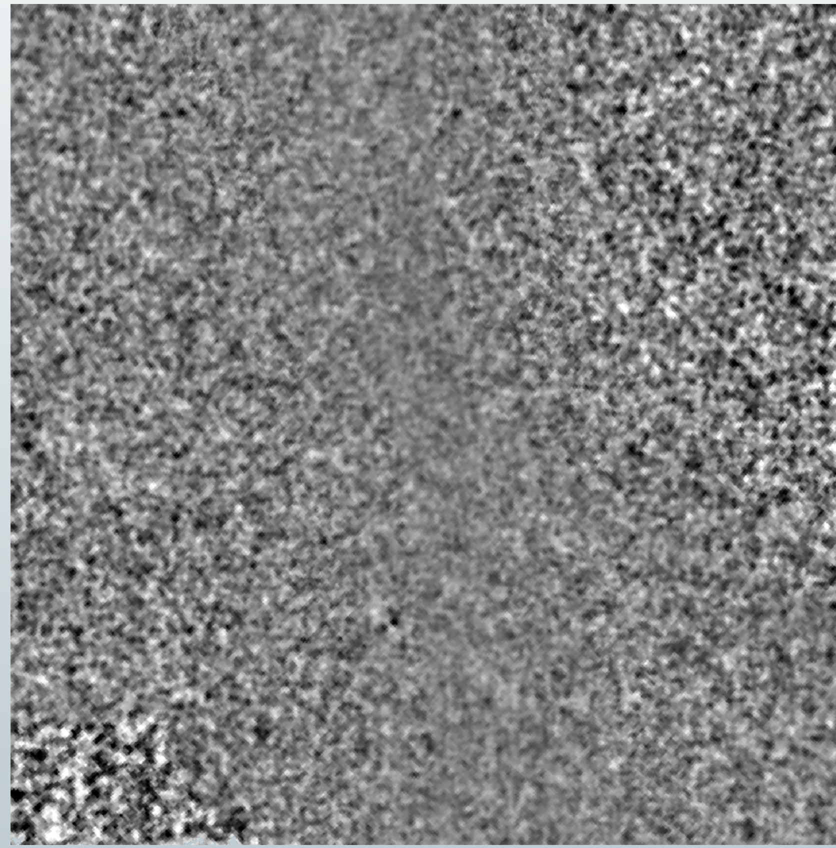
Commander polarization map @ 10 arcmin

Preliminary

E



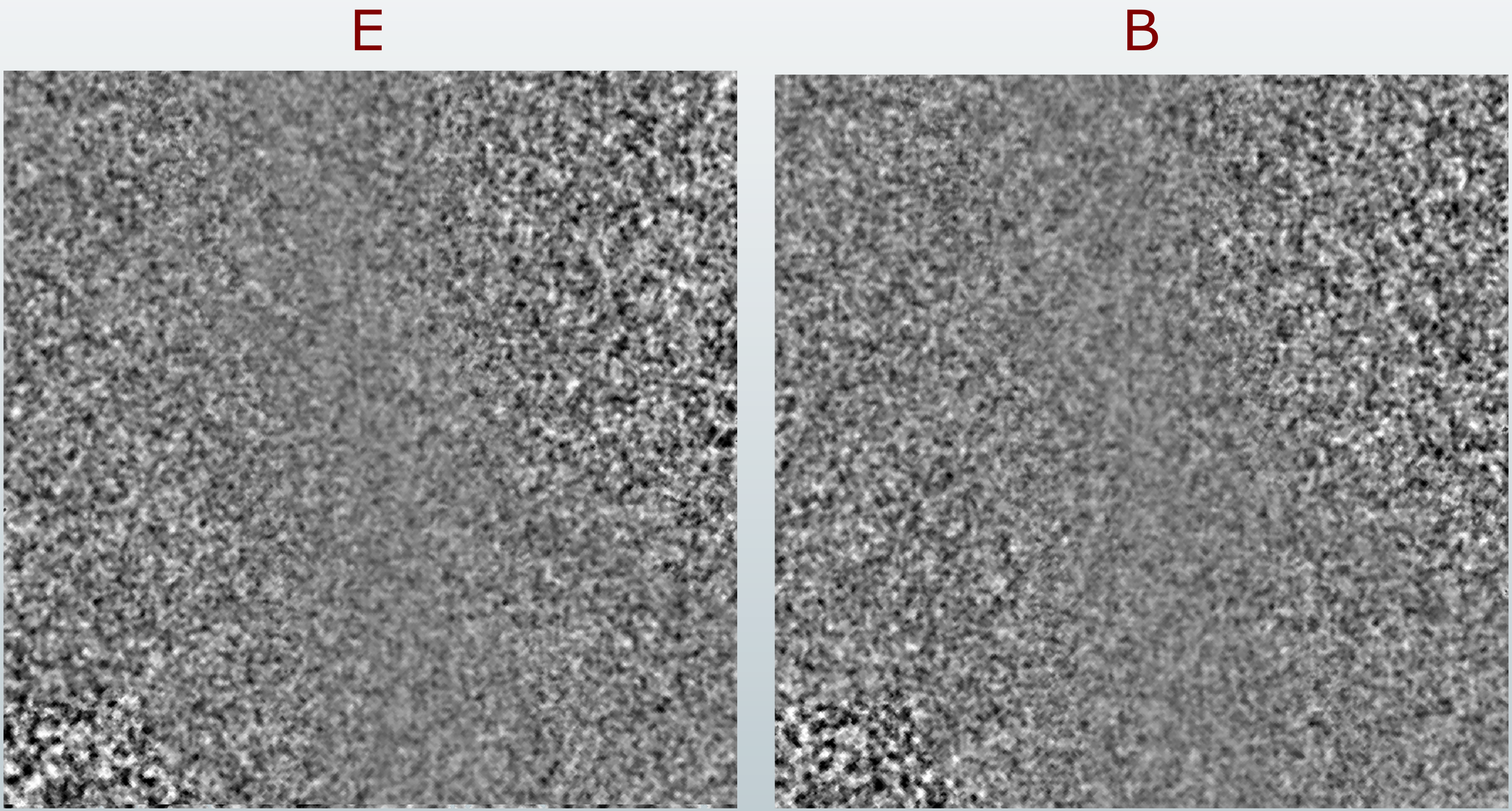
B



10° x 10° zoom-in of North Ecliptic Pole

Commander half-difference half-ring polarization map @ 10 arcmin

Preliminary



10° x 10° zoom-in of North Ecliptic Pole

Assessment of CMB maps

- To assess and inter-compare the CMB maps, beyond map differences and RMS of Half-Difference maps (ie residual noise power spectra), we further estimate:

- Cross-Correlations with external templates

- Power Spectra
- Parameters

Compare to baseline Likelihood PLIK (and CamSpec)

(see Efstathiou, Elsner, Gratton talks)

- Non-Gaussianity

Foreground residual contamination of CMB maps

For Temperature the cross-correlations are null within 1 sigma

Table 3. Cross-correlation coefficients for total intensity and polarization.

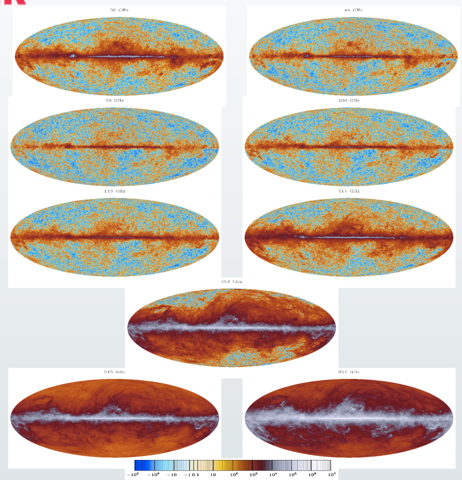
Foreground	Correlation Coefficient			
	Commander	NILC	SEVEM	SMICA
TOTAL INTENSITY				
H_α	0.065 ± 0.088	0.061 ± 0.088	0.076 ± 0.088	0.048 ± 0.066
CO	-0.118 ± 0.301	-0.115 ± 0.301	-0.101 ± 0.301	-0.105 ± 0.301
857 GHz	-0.021 ± 0.080	-0.010 ± 0.080	-0.015 ± 0.080	-0.010 ± 0.080
Haslam	-0.035 ± 0.109	-0.028 ± 0.109	-0.036 ± 0.109	-0.007 ± 0.079
POLARIZATION				
WMAP	0.0016 ± 0.0029	0.0017 ± 0.0034	0.0127 ± 0.0028	0.0061 ± 0.0030

- Foreground templates:
  - ✧ the full-sky H template of *(Finkbeiner 2003*)
  - ✧ the velocity integrated CO map of (*Dame et al. (2001)*)
  - ✧ Planck 857 GHz channel map
  - ✧ the 408 MHz radio survey of *(Haslam et al. 1982*)

Interpretation of polarization cross-correlation depends on understanding how the Galaxy responds to high-pass filtering.

Preliminary

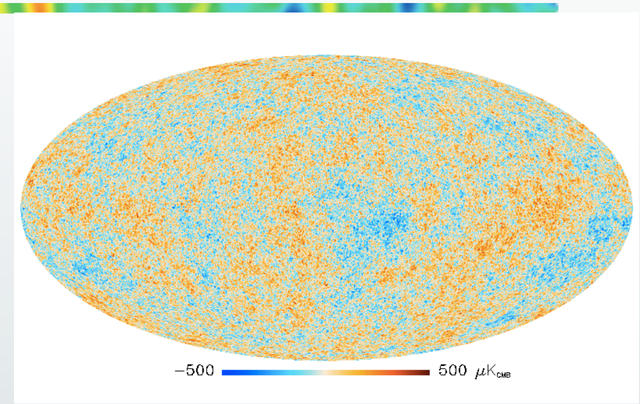
Parameter Extraction from the CMB Sky Maps (in a Nutshell)



Frequency maps

(see Bersaneli's talk)

Component Separation



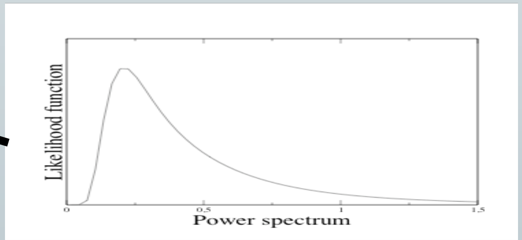
Diffuse-foreground-cleaned CMB map

directly from sky maps to the likelihood

n_s Ω_b σ_8 Ω_0 H_0 τ

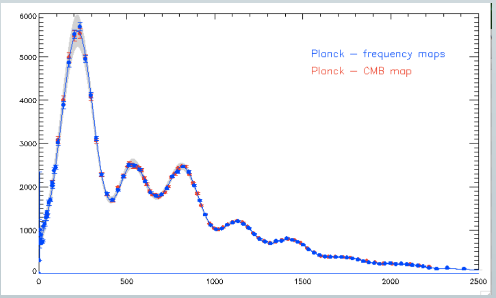
Cosmological parameters

MCMC



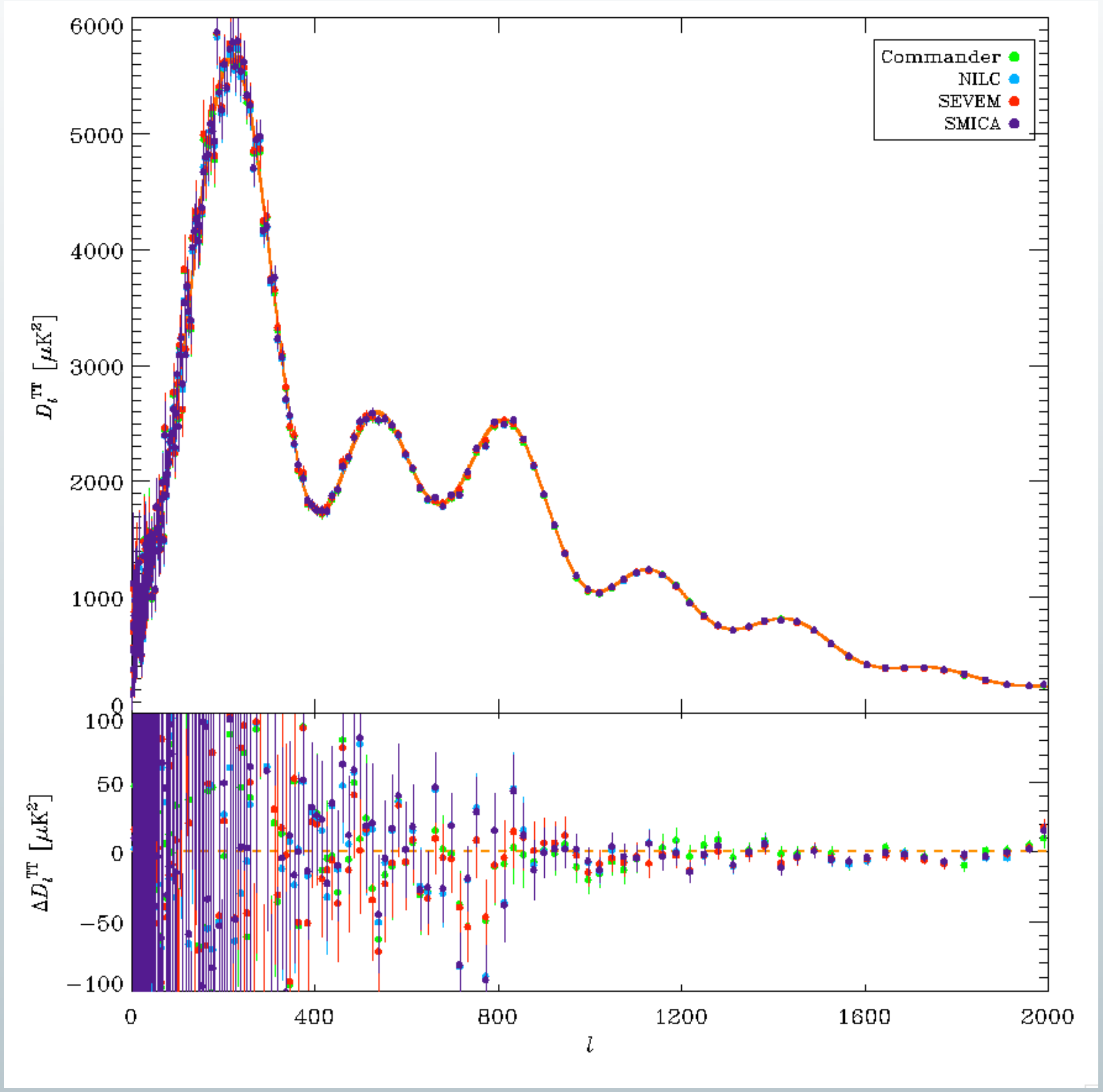
Likelihood

Remove discrete foregrounds



Angular Power spectrum

Power spectra and (CMB, FG) Best Fit Model TT



Preliminary

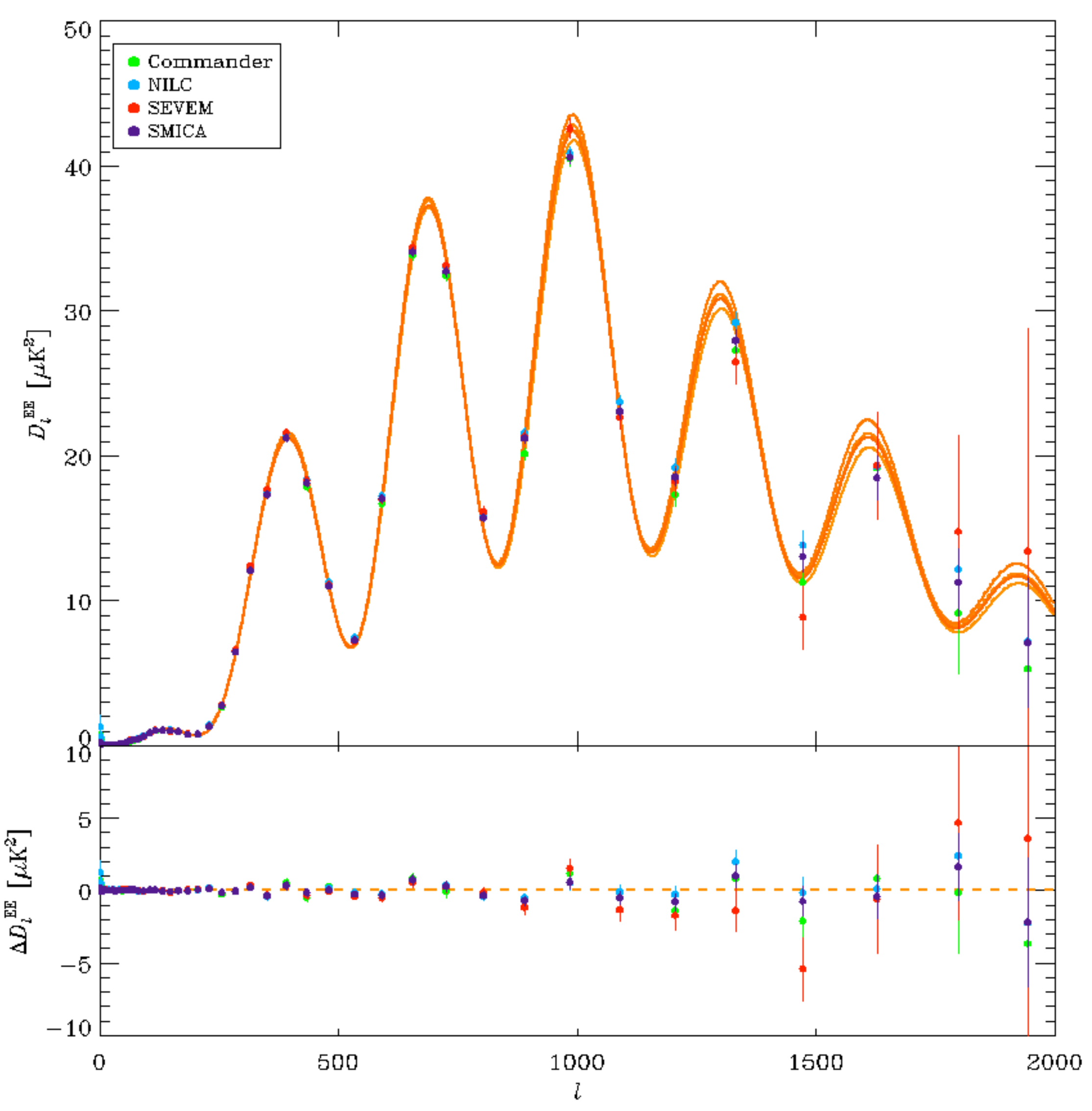
Top: Foreground subtracted bandpowers and covariance matrices estimated with XFaster *(Rocha etal 2011)*

Extragalactic foreground best fit model (egfg_bfm) estimated with CosmoMC

The solid line(s) is (are) the CMB reference model(s)

Bottom: Residuals with respect to the CMB reference model after subtracting the egfg_bfm

Power spectra and (CMB, FG) Best Fit Model EE



Preliminary

Top: Foreground subtracted bandpowers and covariance matrices estimated with XFaster *(Rocha etal 2011)*

Extragalactic foreground best fit model (egfg_bfm) estimated with CosmoMC

The solid line(s) is (are) the CMB reference model(s)

Bottom: Residuals with respect to the CMB reference model after subtracting the egfg_bfm

Parameters

- Band powers estimated with XFaster for each of the CMB maps generated by COMMANDER, NILC, SEVEM, SMICA

XFaster: is an approximation to the iterative, Maximum likelihood, quadratic band power estimator based on a diagonal approximation to the quadratic Fisher matrix estimator

- The iterative scheme starts from either a flat spectrum or the Planck CMB model - the result is a band power spectrum and the associated Fisher matrix (hence uncertainty of the band powers)

➢ Half-Difference of data splits are used to estimate the noise bias in the power spectra extracted from the Half-Sum maps

- Use a Gaussian Correlated likelihood and a MCMC sampler (CosmoMC) for 50<l<2000
  - 6 cosmological parameters
    - impose a Gaussian prior on tau: $\tau = 0.07 \pm 0.006$
    - use low_l Likelihood (TEB)
  - 5 (6) foreground parameters: $\left(A_{ps}^{TT}, A_{ps}^{EE}, A_{cib}, (n_{cib}), A_{tsz}, A_{ksz}\right)$
    - A_{ps} for TT and EE - the amplitude of a Poisson component , $C_l=A_{ps}$=constant, for EE this template is used to account for possible noise correlations present in the data
    - A_{cl} ie $_{ACIB}$ - the amplitude of a clustered component with shape $D_\ell = \ell(\ell+1)C_\ell / 2\pi \propto \ell^{0.8}$, D_l at l = 3000 in units of μK^2
    - A_{tsz}, A_{ksz} Amplitude of thermal and kinetic SZ template with amplitude set at l=1000
  - Consider code tailored FG templates based on FFP8 simulations

Higher order statistics

- Non Gaussianity

f_{NL}	Component Separation Pipeline			
	Commander	NILC	SEVEM	SMICA
TE local	6.06 ± 5.64	3.5 ± 5.1	5.29 ± 5.22	0.72 ± 5.08
TE equilateral	18.12 ± 48.79	8.78 ± 45.46	10.07 ± 48.59	3.33 ± 44.54
TE orthogonal	38.67 ± 23.95	27.9 ± 22.04	41.38 ± 23.70	24.59 ± 21.69

No major surprises

(see Wandelt's talk)

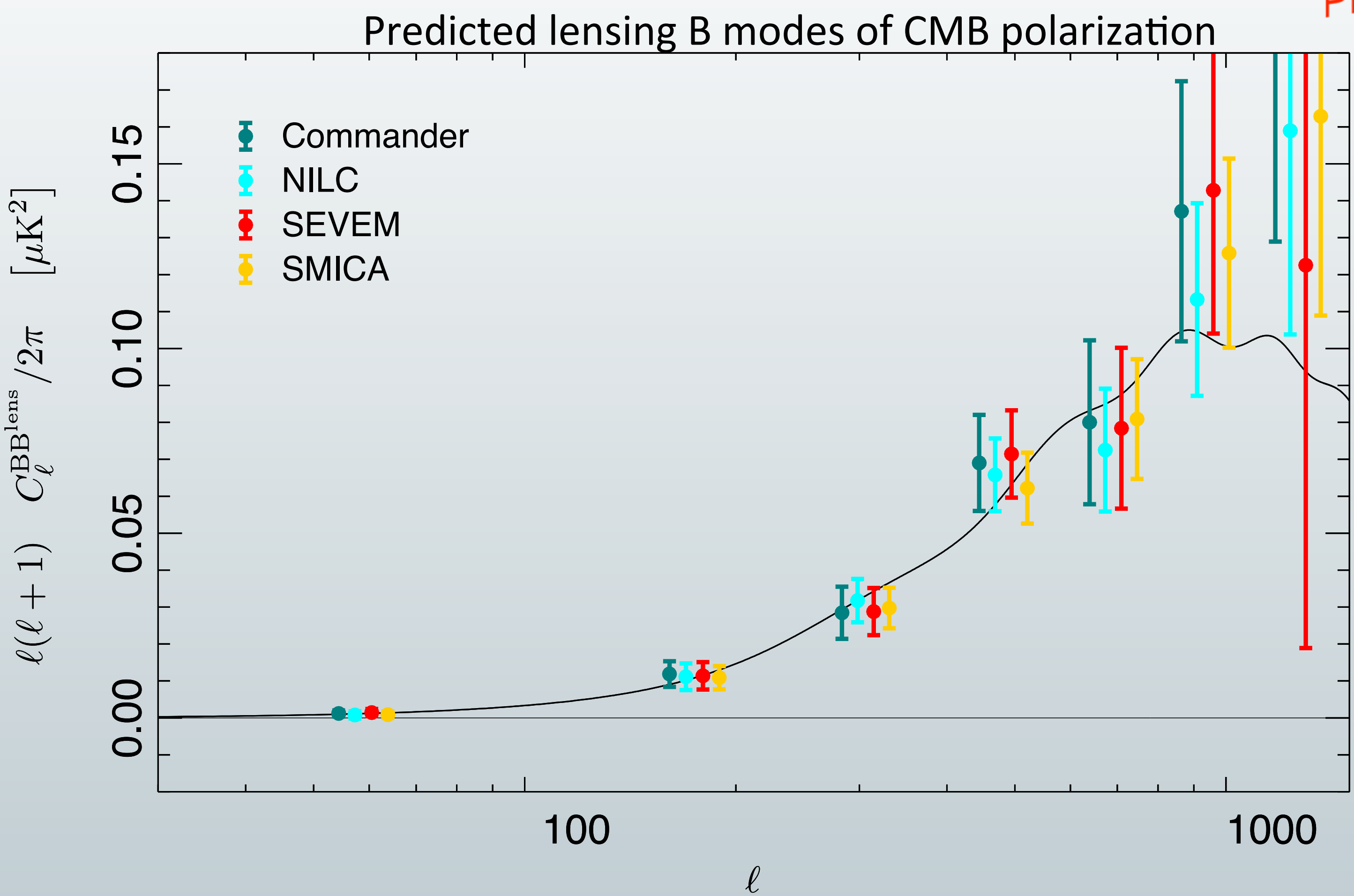
Consistency with Gaussianity

Preliminary

Gravitational lensing by large scale structure

- Gravitational lensing by large scale structure

Preliminary



By cross-correlating the map of the E modes from component separated CMB maps with the reconstructed lensing potential, it is possible to derive a reconstruction of the predicted lensing B modes of CMB polarization *(see Perotto's talk)*

Summary

- Planck component separation pipelines have been extended to polarization

- Polarization results show good quality

- Preliminary analysis of the results shows good consistency among methods, and with the power spectrum/likelihood parameters

- As said in other talks: Large-angular-scale results in polarization will be reported next year

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.