The Planck data products

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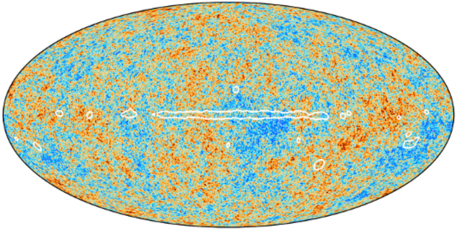
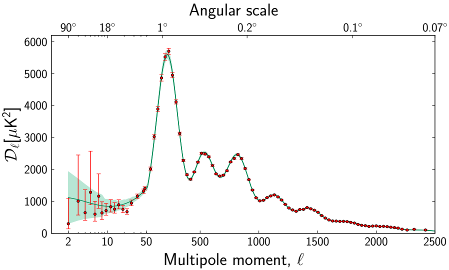
on behalf of the Planck collaboration

Rencontres du Vietnam, July 28th - August 3rd 2013, Qui Nhon

The Planck CMB map

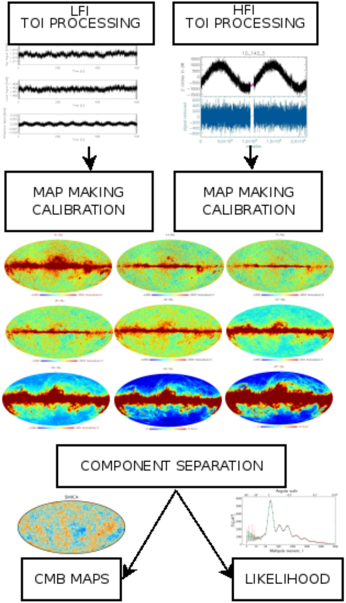


The Planck likelihood software



$\rightarrow$ used to derive the cosmological parameters

The Planck data processing



Outline of this talk

- Mapmaking + calibration
- General intro. to component separation
- CMB products
  - The Planck CMB maps
  - The Planck likelihood

The Planck data products

- Available on line :

http://pla.esac.esa.int/pla/aio/planckProducts.html

- correspond to the nominal mission : 12 august 2009 → 27 november 2010.

Cosmology PRODUCTS	Sky MAPS	Source CATALOGUES	MISCELLANY
Cosmological parameter Likelihood CMB power spectrum Sky power spectra	Frequency maps CMB maps Foreground maps	Point sources SZ clusters	Explanatory supp. RIMO

The explanatory supplement :

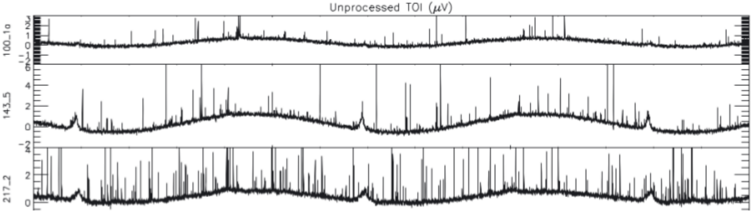
- describes the diverse and numerous Planck products
- and how they have been obtained

→ read it carefully to choose between the Planck products and make a good use of them.

Mapmaking : from the timelines to the frequency maps

The processing includes

1. TOI cleaning : subract cosmic rays
2. TOI calibration : using CMB dipole



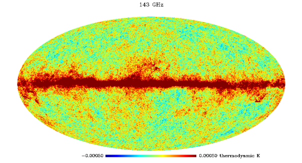
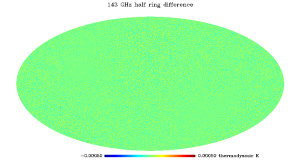
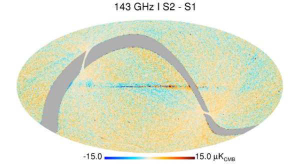
3. Projection on the sky : solving $As = d$ using pointing reconstruction

$\rightarrow$ for all individual detectors
$\rightarrow$ independently for LFI and HFI

Mapmaking : from the timelines to the frequency maps

Methodology :

- Use data redundancy : first/last ring, survey maps
  $\rightarrow$ 6500 sky maps for HFI

143GHz	Half ring difference	Survey difference
		
$\pm 500 uK$	noise level (5uK)	time varying gain $\pm 15 uK$

- Simulation of systematic effects
- Comparison of the angular power spectra of the maps

Relative calibration accuracy

Recall :

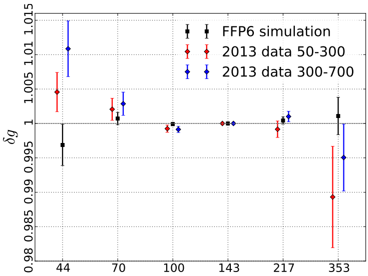
- From individual detector (LFI indep. HFI)
- Fit on CMB dipole

→ 0.2% from 44GHz to 217GHz
→ 0.8% for the 30GHz and 353GHz

An independant measure :

- Using frequency maps (LFI + HFI)
- Fit on other CMB multipoles [50-700]

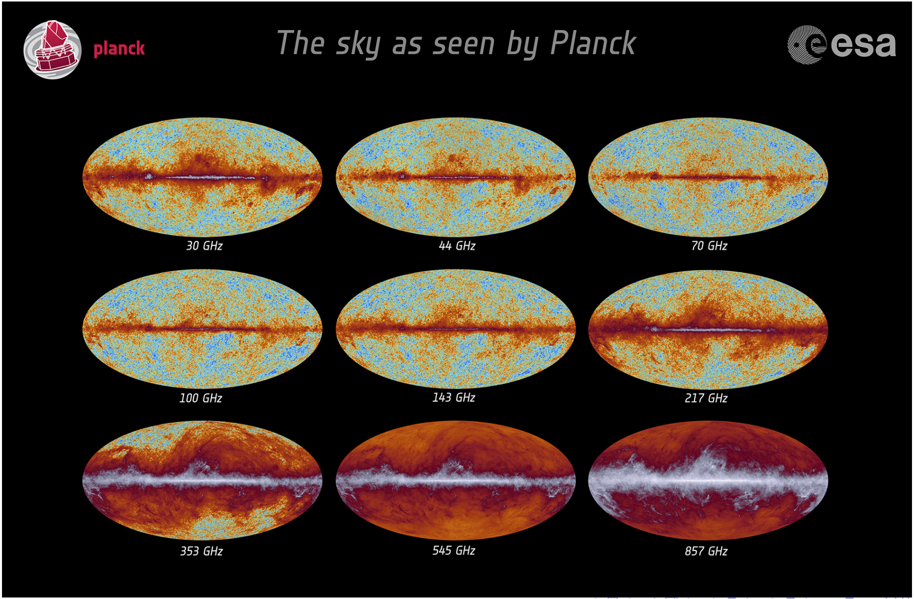
→ same numbers !



For the submillimeter channels [545GHz - 857GHz]

- fit flux density of neptune and uranus → 2% calibration uncertainties

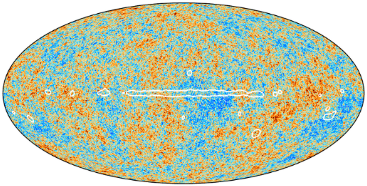
From the calibrated frequency maps to the CMB products



Two CMB products, two different pipelines

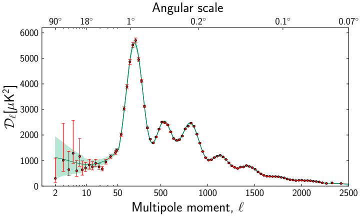
1 We want to deliver a **CMB map** :
→ used for : non Gaussianity studies, lensing detection, etc

- being full sky
- full resolution (ie 5 arcmin)
- with minimum foreground AND noise in it.



2 A **likelihood software** which can propagate :

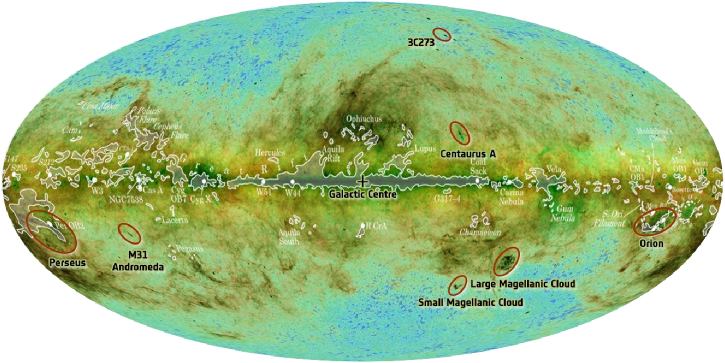
- astrophysical uncertainties : foregrounds residuals
- instrumental uncertainties : calibration and beam
- at high precision, up to $\ell_{max} = 2500$



→ used to derived the CMB power spectrum and cosmological parameters

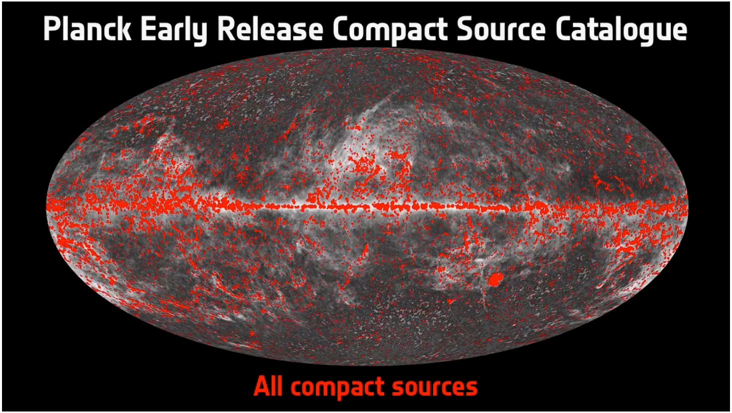
CMB signal is contaminated by

- the galactic emission (in the galactic plane)
- some extended regions (molecular clouds, magellanic clouds) at intermediate galactic latitude



CMB signal is contaminated by

- Point sources (stars, galaxies, galaxy clusters) all over the sky

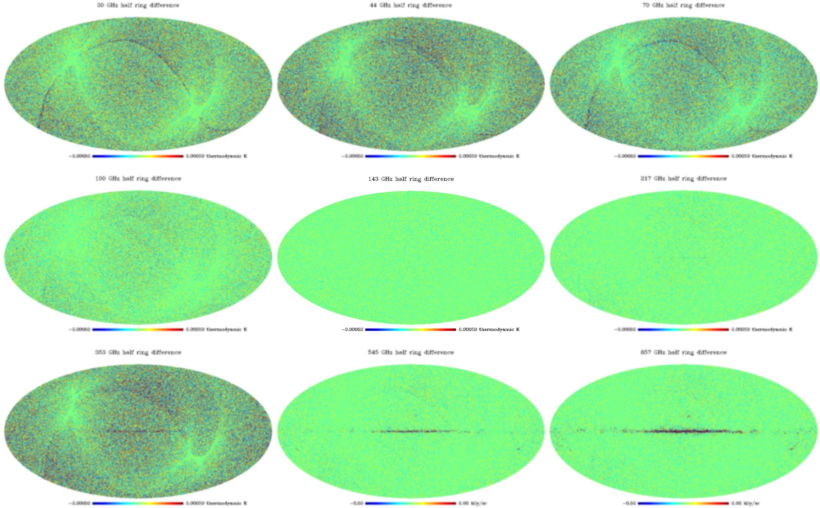


5σ detections above 5 degree in latitude

30GHz	44GHz	70GHz	100GHz	143GHz	217GHz	353 GHz
1140	725	860	2600	5520	8900	10 800

CMB signal is contaminated by

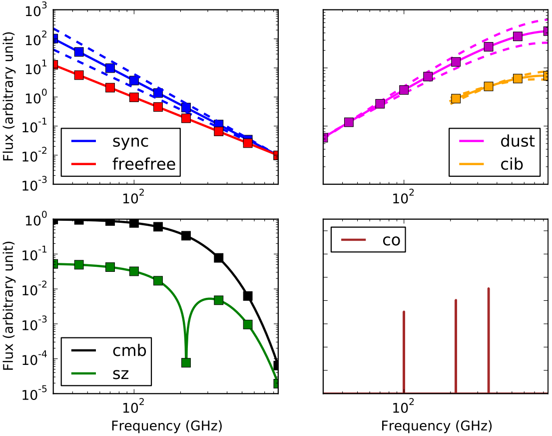
- Instrumental noise (inhomogeneous)



General scheme for the CMB cleaning

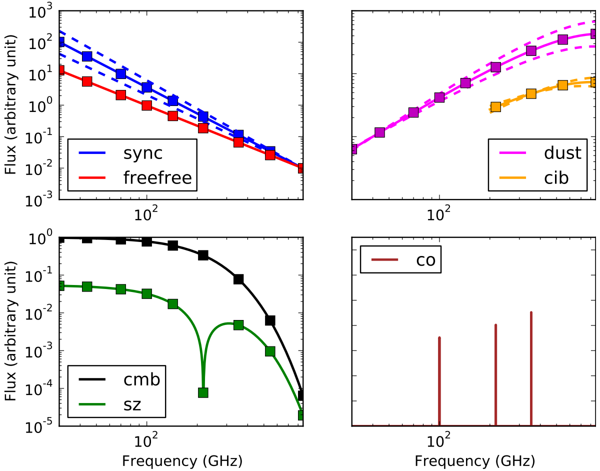
CMB cleaning can be done thanks to :

- The spectral diversity of diffuse foregrounds (wrt CMB) → linear combination of the frequency maps with optimal weights
  - Noise is independant from channel to channel
  - Point sources are localized → masking of subtraction of the sources



Different classes of method depending on :
- use of other priors
- choice of the analysis domain

Use of other priors : blind or non blind methods ?



Pros :

- refine the foreground models

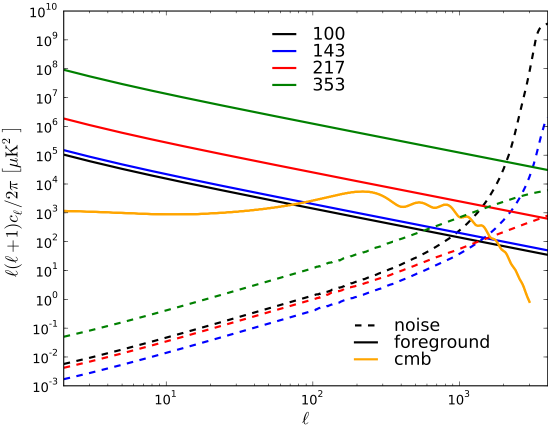
Drawbacks :

- rely on calibration
- small number of dof.

→ Use blind AND non blind techniques then check the consistency

Choice of the analysis domain

- **Pixel based** : galactic plane, spatial variation of the spectral indices



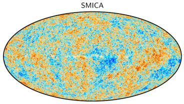
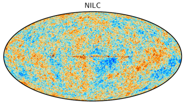
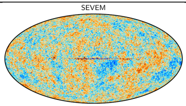
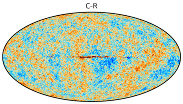
A lot of dynamic in the harmonic space

- wrt foregrounds (2 orders of mag. above at $\ell < 100$, 1 order below at the first peak !)
- wrt noise : SNR depends on channel resolution. 217GHz $\rightarrow$ 5arcmin.

- **Harmonic based** : optimal weight wrt foreground and noise residuals.

$\rightarrow$ Again, use both (even wavelet domain) then check the consistency

4 CMB maps, 4 different approaches

SMICA	NILC	SEVEM	Commander-Ruler
			
harmonic domain 5 arcmin semi parametric	wavelet domain 5 arcmin non parametric	pixel/harmonic 5 arcmin non parametric	pixel domain $\sim$ 7.4 arcmin parametric

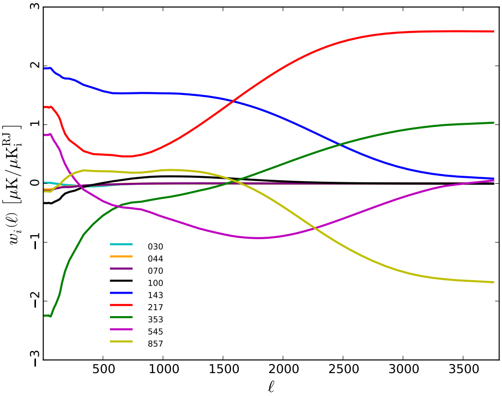
- at the margin : input channels, point source preproc. , ...

Assessing the consistency of the results

- Comparisons between products on real data
- Using a realistic set of simulations

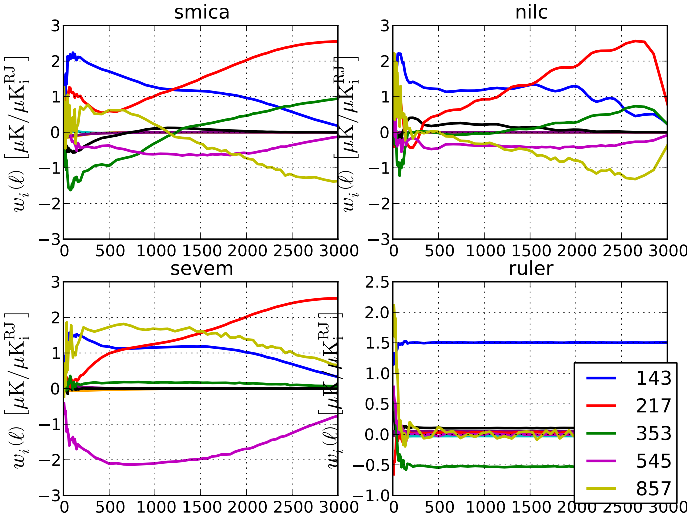
The component separation machinery

A linear combination of the 9 LFI+HFI Planck channels in the harmonic domain



- the cleanest channels have the biggest weight (143 at low ell, then 217).
- the high frequency channels (857-545-353) work as a template regression.

The component separation machinery



Harmonic based maps :

- 143/217 SNR transition
- Dust template regression (857-545-353)

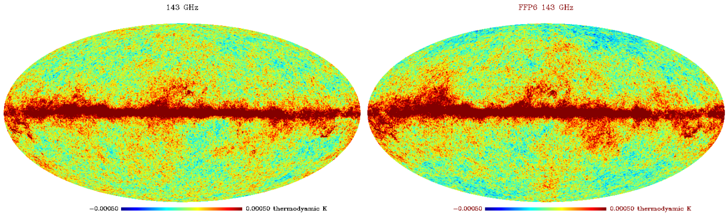
Pixel based map :

- Weights vary with pixels
- Resolution close to the 143GHz map (7arcmin).

Assessing the consistency of the results : simulations

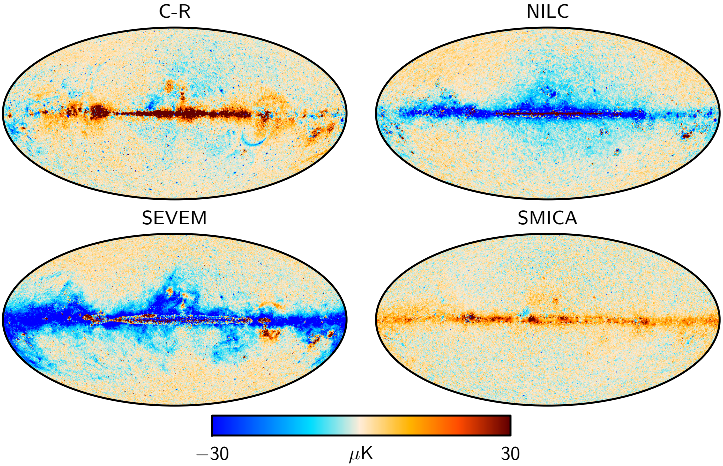
A realistic and complete simulation

- Astrophysical components from the Planck Sky Model
- Instrumental effect from real data (noise, beams)



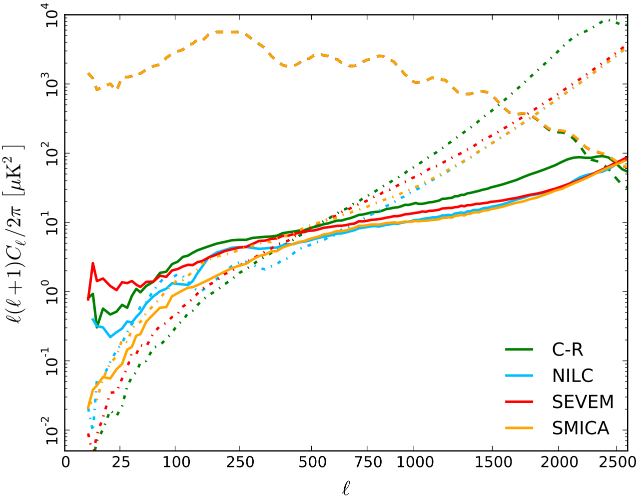
1. Use the same setup on real data and simulations :
   $\rightarrow$ look at the residual.
2. Propagate individual component maps :
   $\rightarrow$ decompose the residual into foreground + noise.

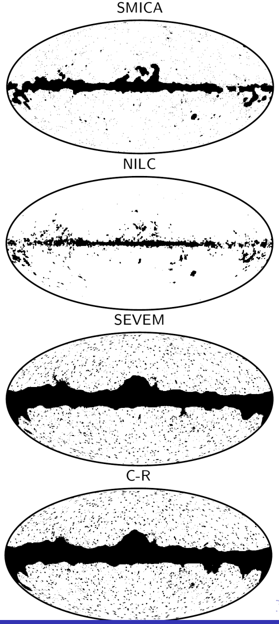
Difference between input and reconstructed CMB maps



- Maps are smoothed to show the large scale structure.
- Visually, residuals seems to be well contained into the 80% confidence mask

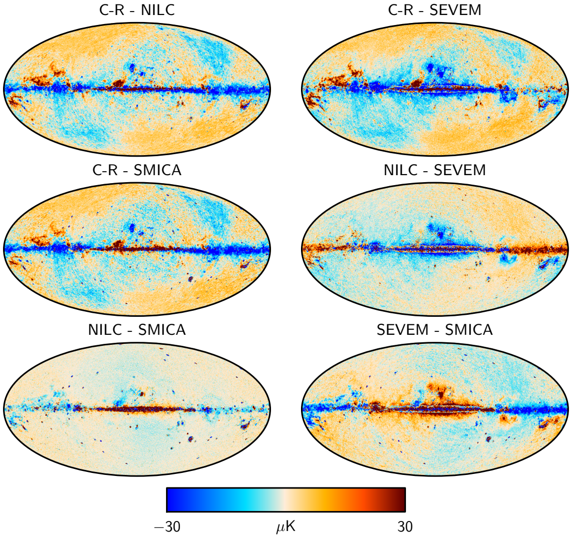
Power spectra of the foreground and noise residuals





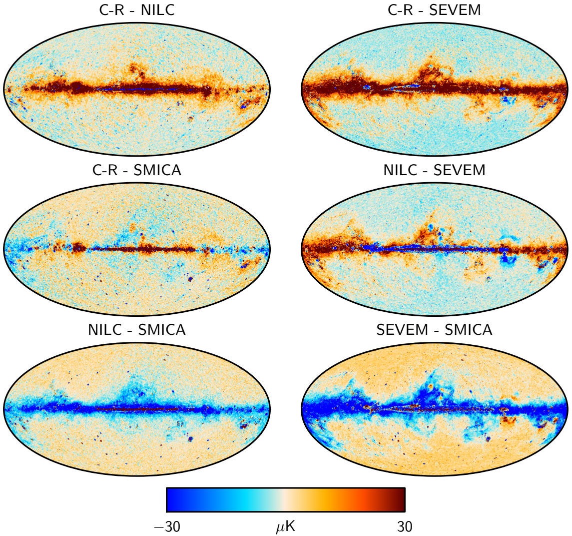
- Large scale differences are still visible on the 80% mask ...
- ... but 3 orders of magnitude below the CMB signal !
- No discrepancy on the noise contamination

Pairwise differences on real data



- Maps are consistent at the 5uK level at high galactic latitude.
- The main foreground residuals can be contained in a 80% galactic mask (the confidence mask).
- Zodiacal light is our first suspect wrt C-R differences (not included in the model)

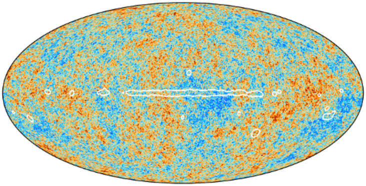
Pairwise differences on simulation

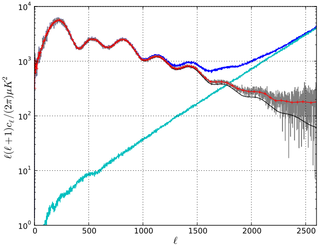


- Differences are larger than on real data → taken as a conservative residual.

Summary

- Maps are consistents at the 5uK level at high galactic latitude.
- Confidence masks built from simulation are expected to be conservative.
- Noise contamination is fully characterized by the jackknife maps.
- CMB and noise MC simulations have been easily propagated to the pipelines
- CMB maps used for low ell likelihood, non Gaussianity, lensing studies, syst. use the 4 maps and various masks to propagate foreground uncertainties





$\rightarrow$ High ell contamination by CIB and unresolved sources

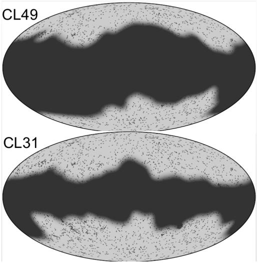
Likelihood and power spectra

Hybrid approach :

- Low-ell [2-49] at the map level (30-353GHz) : **Commander** pipeline
- High-ell [50-2500] at the power spectrum level (100-143-217GHz)

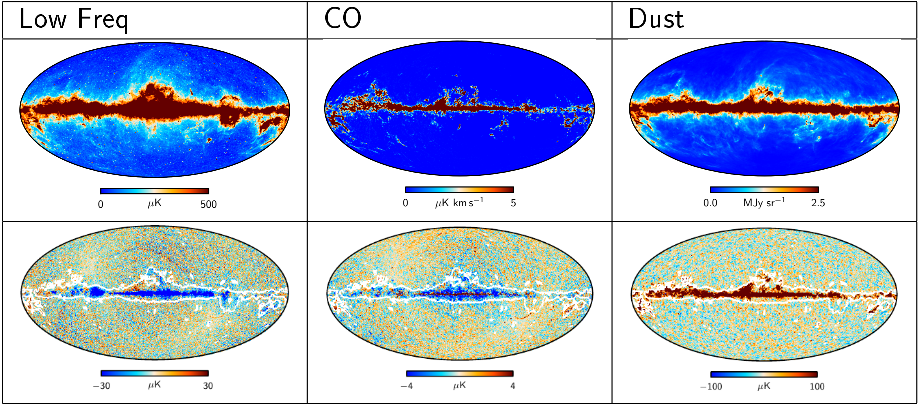
$\rightarrow$ conservative data selection

  - **Camspec** : the baseline (full covariance matrix)
  - **Plik** : faster (binned power spectra) to assess the robustness against data selection, foreground and instrumental model



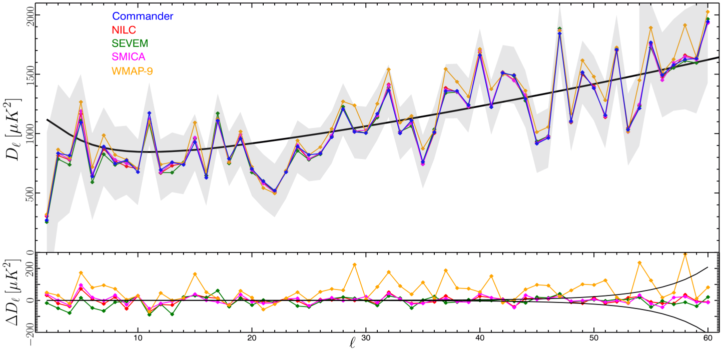
- Validation on simulations
- Internal consistency
  (including with CMB map products)

Low ell likelihood : The C-R solution



- Commander provides the unique sky decomposition into individual foreground components
- with associated χ^2 map

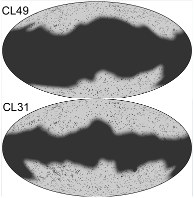
Low ell power spectra



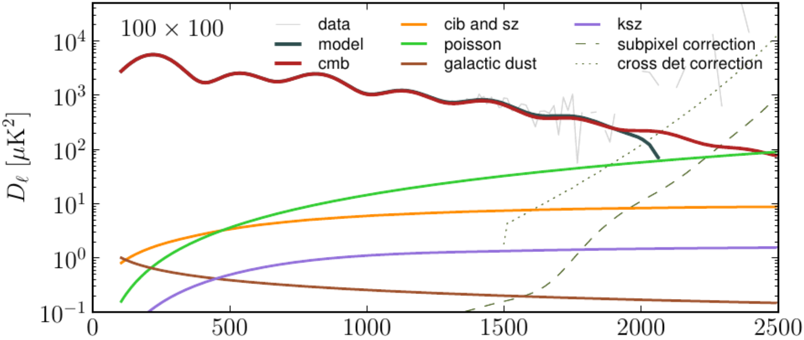
- Power spectra are computed by quadration maximum likelihood estimator (BolPol) over the common mask. (78%)
- Internal Planck residual around $50uK^2$ for $\ell \geq 10$
- WMAP residual around $100uK^2$ for $\ell \geq 30$ → see next talk

Recall :

- propagate foreground + instru. uncertainties
- with simple model
- where is feasible

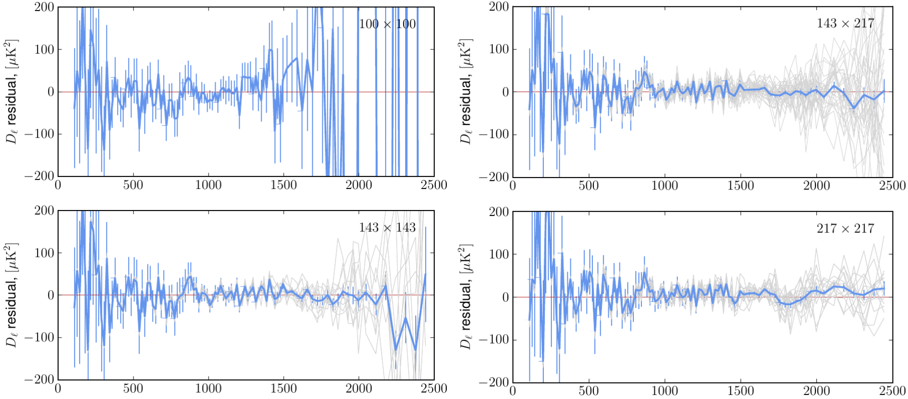


Decomposition of the angular spectra :



High ell likelihood : accuracy of the model

Residual = input spectra - sum components at max. likelihood value



- Low ell : below cosmic variance
- High ell : CIB and unresolve sources are well fitted

High ell likelihood : robustness tests

Foreground parameters

- Dust template regression as a preprocessing
- CIB clustered
- Poisson from unresolved point sources
- Thermal SZ, Kinetic SZ
- Thermal SZ · CIB correlation

Instrumental parameters

- Relative calibration
- Beam error modes
- Subpixel noise effect
- Correlated noise

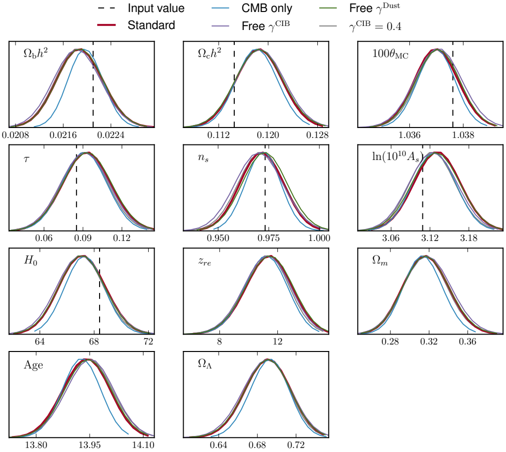
Use plik to make industrial tests :

- For each parameter : fit or fix it ?
- Data selection : sky fraction, lmax, choice of frequency channels

$\rightarrow$ check the impact up to the cosmological parameter posteriors

Playing with simulations

Measure of the impact of the foreground model specific choices on cosmological parameter posteriors

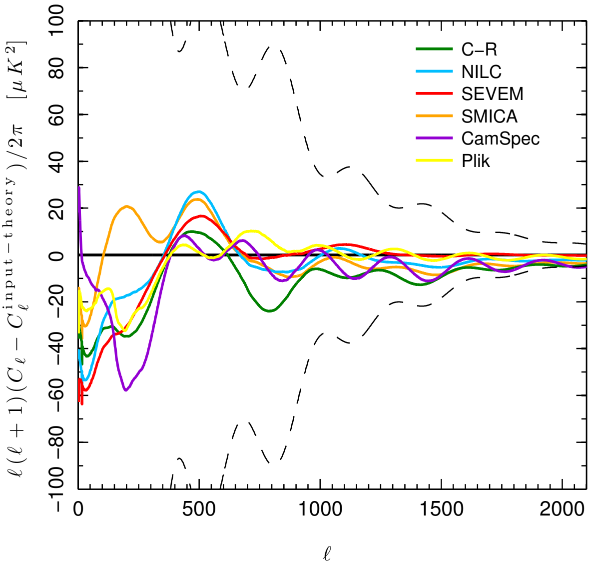


- CIB spectral index freely adjusted, or fixed at 2 σ away from the peak posterior value.

→ negligible impact of the foreground model assumptions.

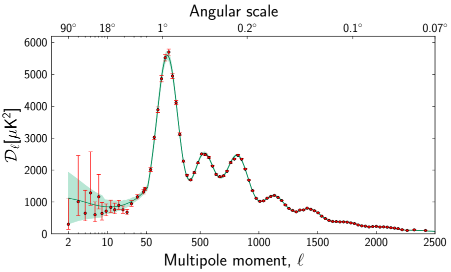
Consistency between high ell likelihood and CMB maps

High ell likelihood versus CMB map :



- Residual smaller than $40 \mathrm{u}K^2$ at low ell, and $10\ uK^2$ at high ell.

Summary



- Precise measurement of the CMB power spectrum up to lmax=2500.
- A lot of robustness tests
- Consistency at the power spectrum level around $40uK^2$ at low ell, and $10uK^2$ at high ell.
- See "cosmological parameter" talk this afternoon

Foreground maps : Thermal dust

- C-R solution : use 30GHz-353GHz @ 40 arcmin.

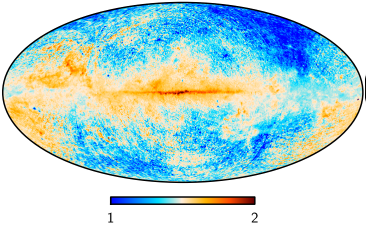
$$I = AB_\nu(T)\nu^\beta \tag{1}$$

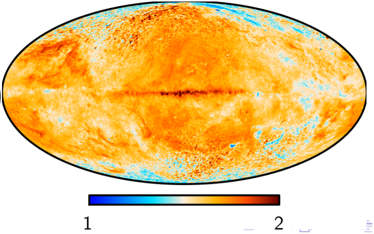
with prior on $T = 18 \pm 0.005$K and $\beta = 1.5 \pm 0.3$

- Dust optical depth map (MAMD) : 353GHz-857GHz + IRAS 100μ.

$$\tau_\nu = I_\nu / B\nu(T) = A\nu^\beta \tag{2}$$

with β fitted at 35 arcmin. $\rightarrow$ $T = 19.6 \pm 1.3K$ and $\beta = 1.63 \pm 0.09$





Foreground maps : CO

- C-R solution : use 30GHz-353GHz, constant line ratio over the full sky.
  → best SNR, high galactic latitude follow up.
- CO type 1 products : use all bolometer maps at a single frequency to provide 3 maps : J=1→0 (100GHz), J=2→1 (217GHz), J=3→2 (353GHz).
  → less contaminated by dust.