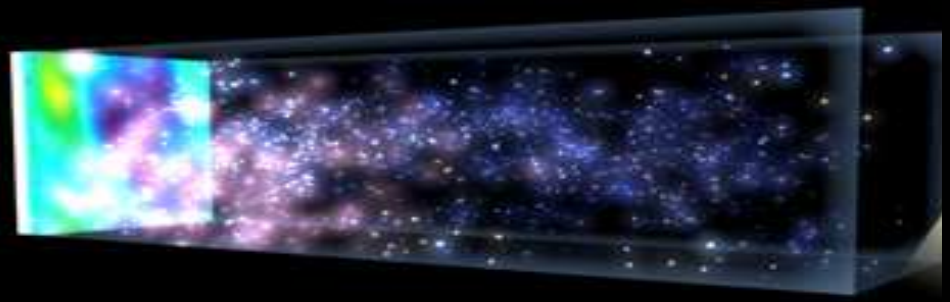
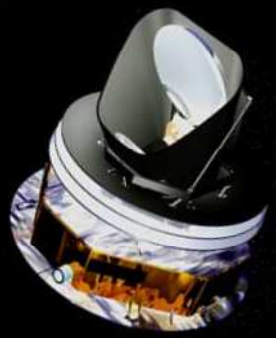
CMB Lensing Reconstruction on PLANCK simulated data





L. Perotto, J. Bobin, S. Plaszczynski, J.-L. Starck, A. Lavabre

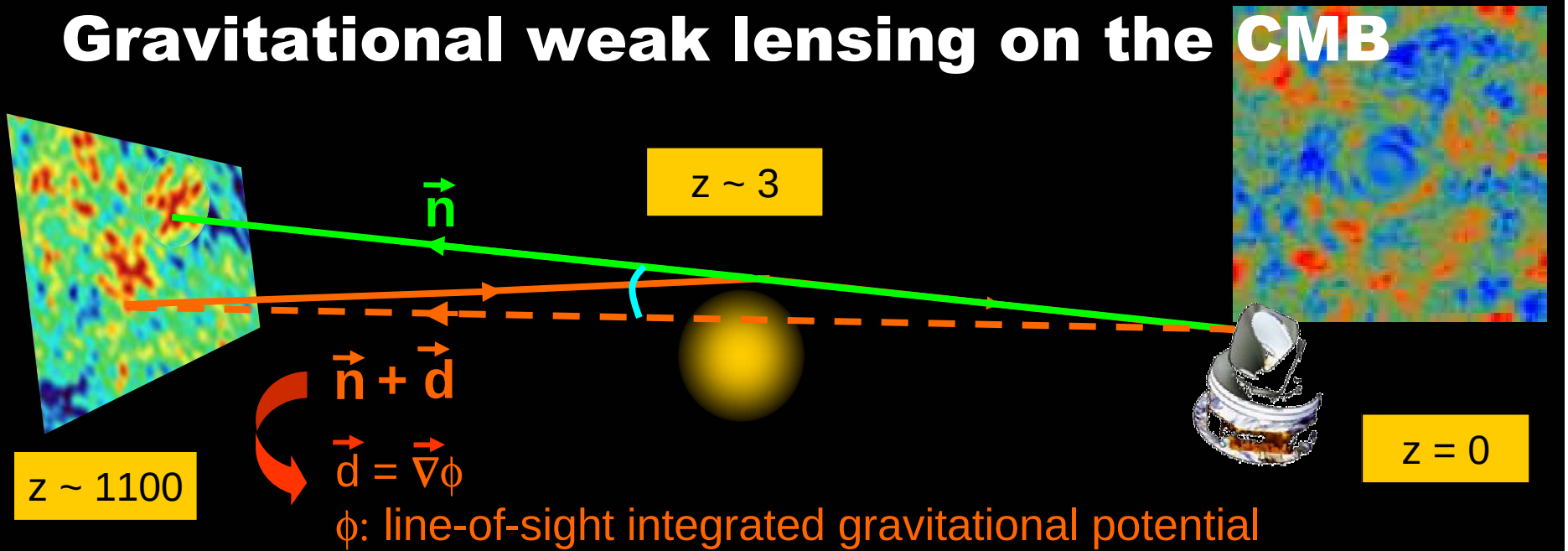
Laurence Perotto - LAL Orsay

ADA V, may 7-9

Outlines

- CMB lensing as a cosmological tools
- Full sky analysis on PLANCK simulated maps
  i. Simulation of lensed CMB maps
  ii. Detection of the lensing effect
  iii. Reconstruction of the deflection
- Robustness against foreground residuals
- Summary/Perspectives

Gravitational weak lensing on the CMB



ϕ: line-of-sight integrated gravitational potential

Weakly perturbating the statistical properties of the CMB observables:

➡ introducing non-gaussianities

➡ From the CMB maps,
the gravitational potential can be statistically reconstructed

Observational status

First evidence in WMAP data (at 3.4σ) on may 2007!

WMAP III + NRAO VLA Sky Survey (NVSS)

Detection of Gravitational Lensing in the Cosmic Microwave Background
Kendrick M. Smith, Oliver Zahn, Olivier Doré [**arXiv:0705.3980**]

Confirmated (at 2.5σ) on january 2008

WMAP III + NRAO VLA Sky Survey (NVSS) + SDSS (LRG + quasars)

Correlation of CMB with large-scale structure : Weak lensing
C.M. Hirata, S. Ho, N. Padmanabhan, U. Seljak, N. Bahcall [**arXiv:0801.0644**]

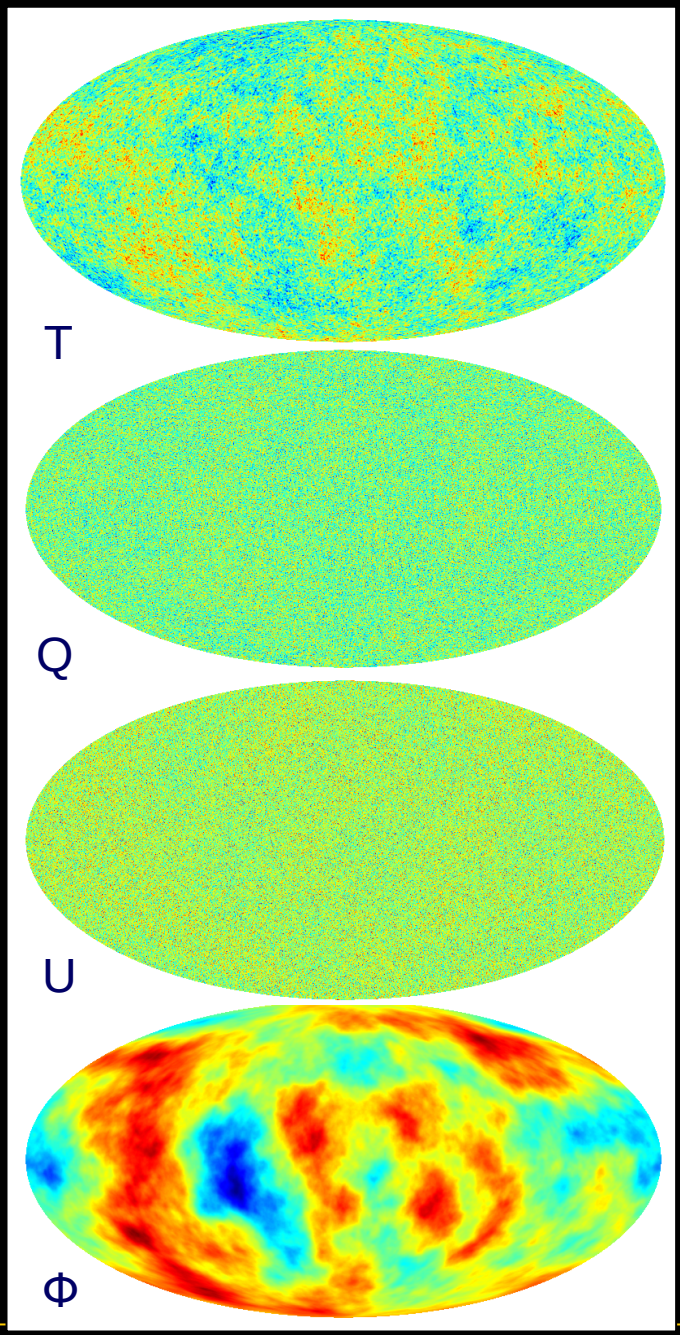
PLANCK : a first measurement is reachable

The PLANCK mission

The third generation of CMB satellite:

- 2 embedded instruments
- 11 radiometers, 52 bolometers
- full sky coverage
- 9 frequency channels (30 to 857 GHz)
- resolution ≥ 5 arcmin
- sensitivity 10xWMAP

Measuring the integrated gravitational potential:



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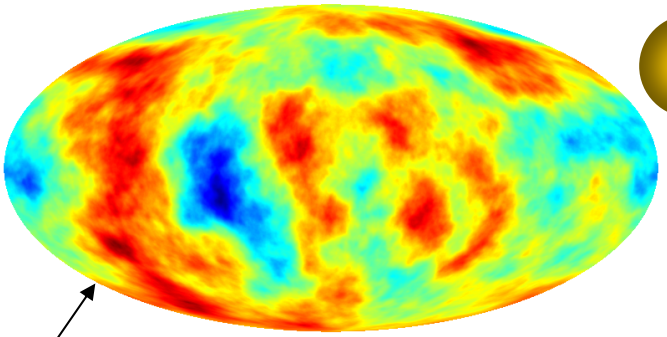
How to simulate the CMB lensing for PLANCK? principle

1

CAMB

$C_l^{\phi\phi}$
$C_l^{T\phi}$
C_l^{TT}

Projected potential: ϕ



3

Gradient on the sphere

$e\pm \cdot \nabla_n Y_{lm} \propto \pm 1 Y_{lm}$

deflection:

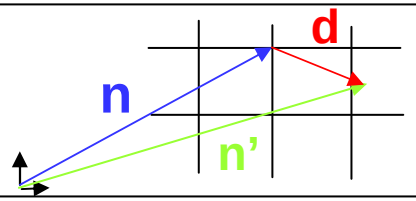
$d = \nabla_n \phi$

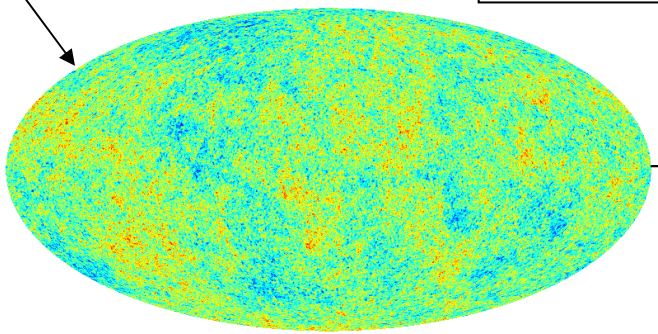
2

Gaussian random

$T^{lens}(n) = T^{unlens}(n')$

where $n' = n + d$

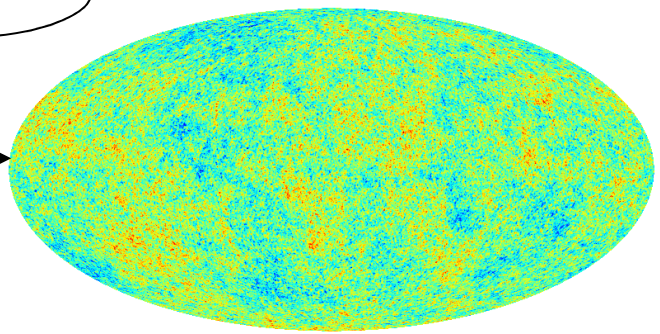




Unlensed CMB: T^{unlens}

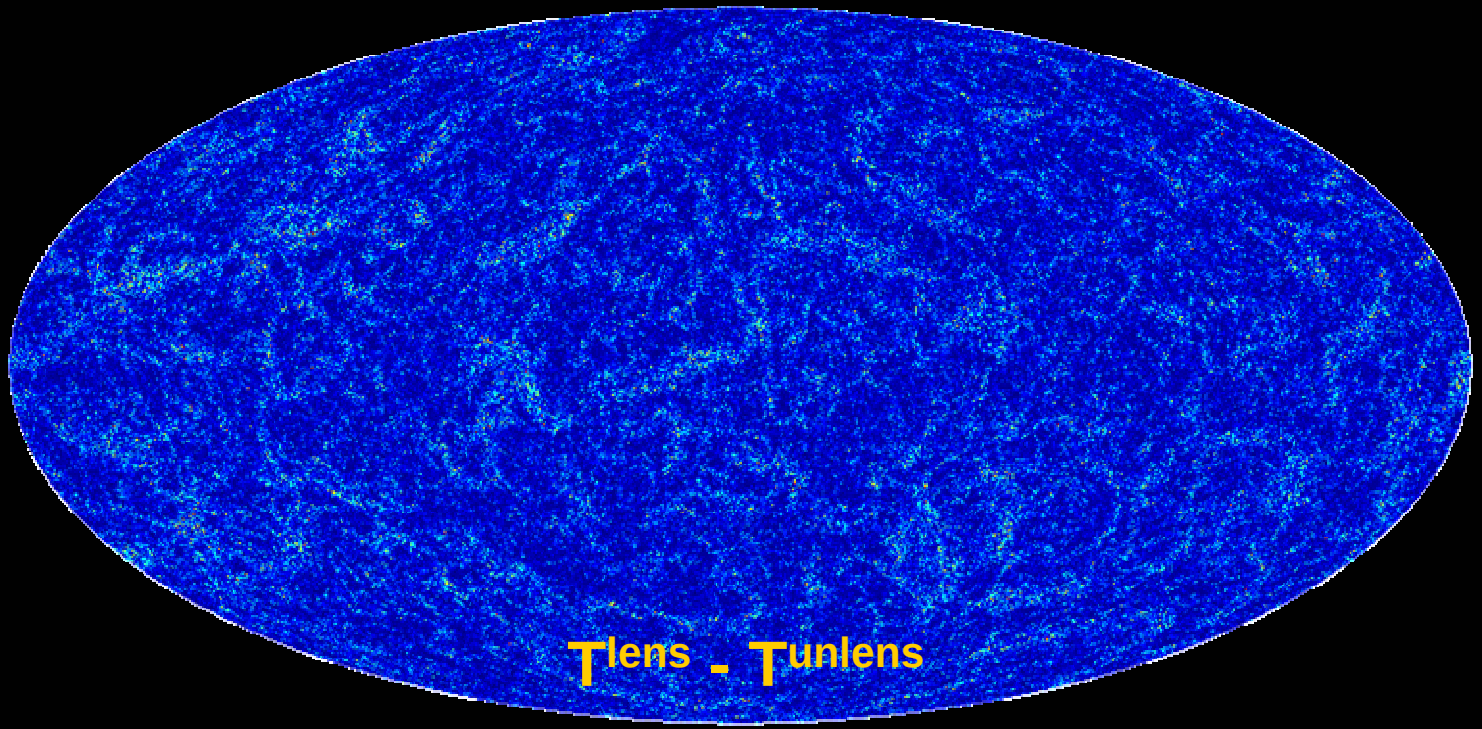
Remapping

4



Lensed CMB: T^{lens}

How to simulate the CMB lensing for PLANCK? LensPix



Collaboration *lensing*@LAL + Antony Lewis (Cambridge) :

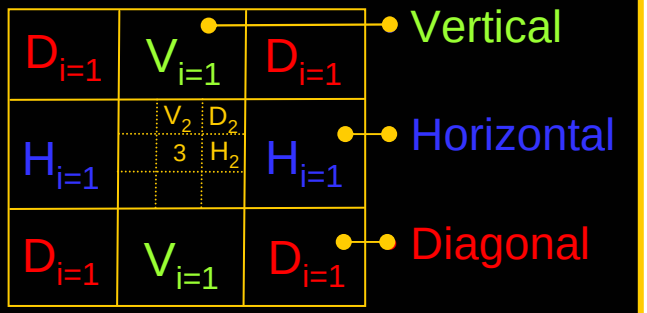
- new update of AL's LENSPIX code
- integrated within the PLANCK pipeline (DPC)
- 10 min for a set of nside=2048 I, Q, U maps @CCin2p3

Detection of the CMB lensing on the maps

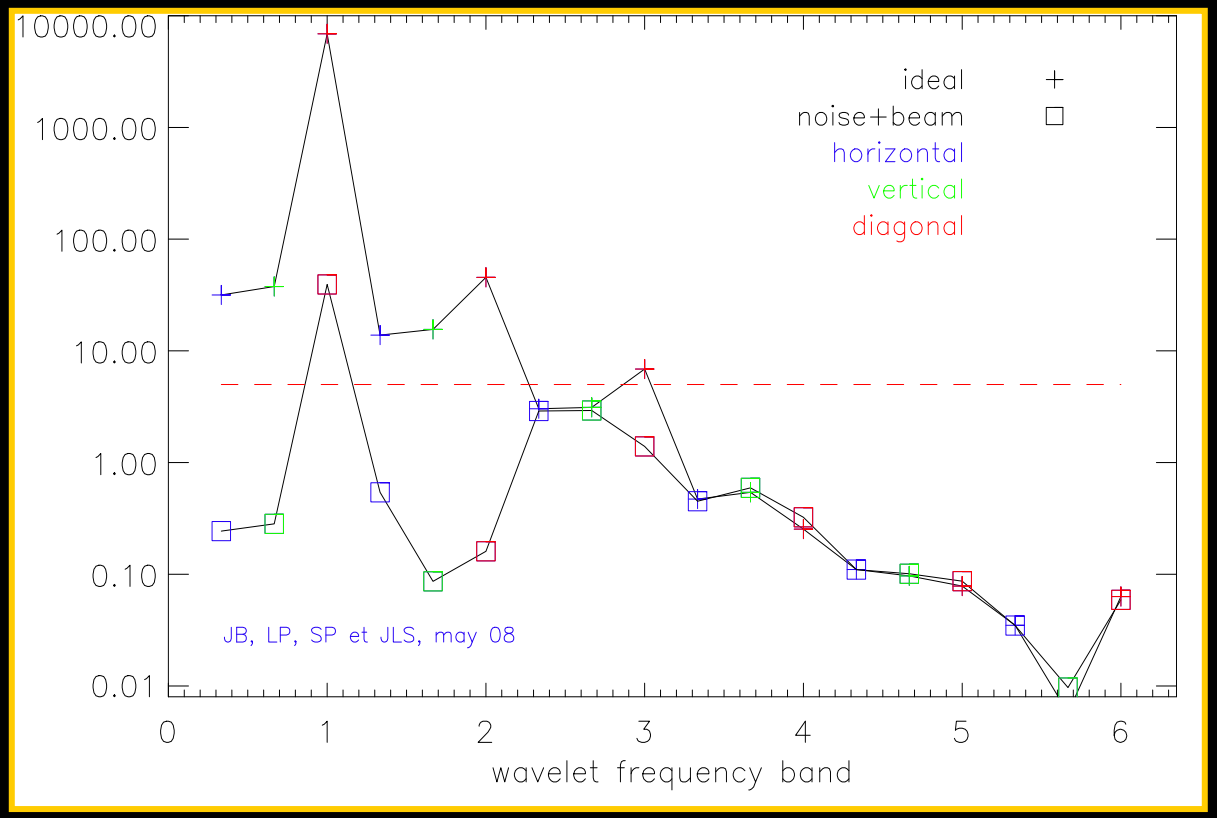
Multiscale orthogonal wavelet analysis:

- 50 realisations
- full-sky
- 1.7 arcmin of resolution
- coadded noise and beam of PLANCK HFI

Smaller scales details:



kurtosis in units of variance

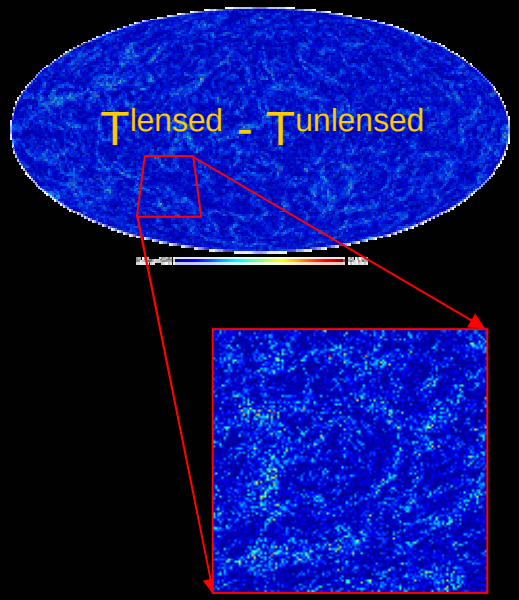


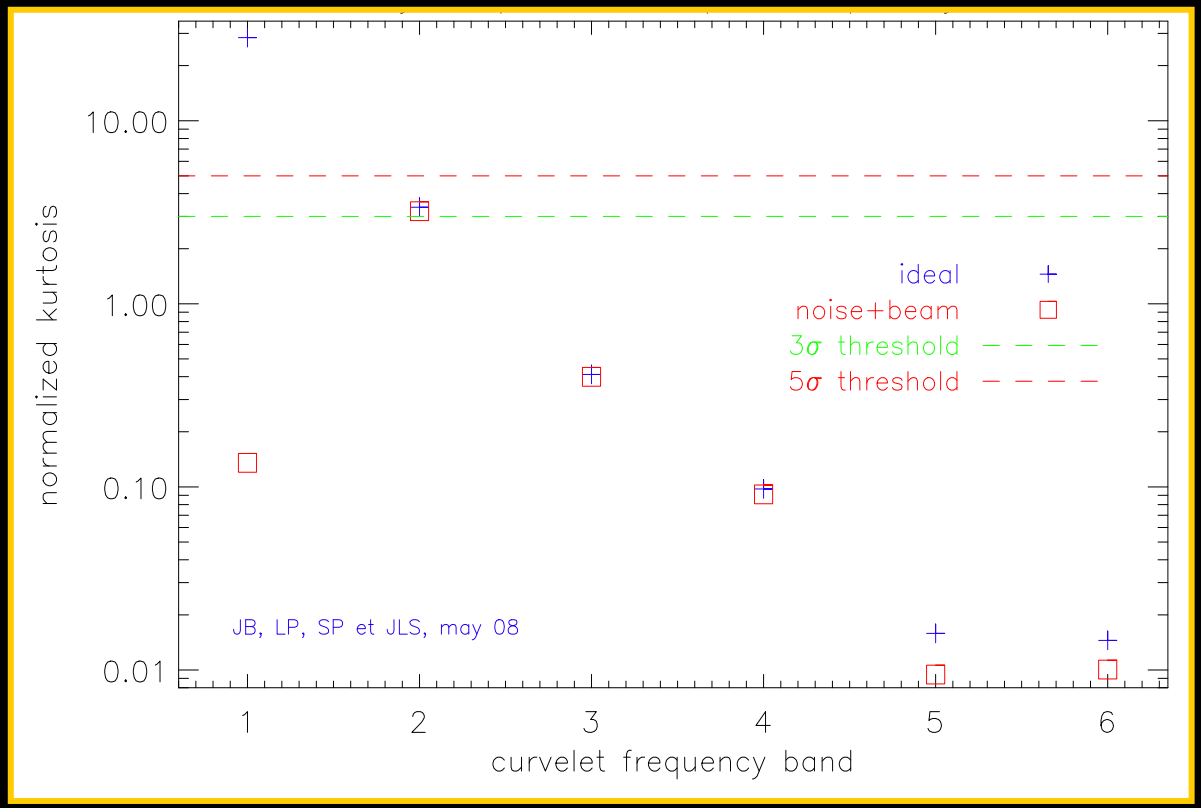
➡ ~ 40σ detection of a departure from Gaussianity in the PLANCK simulated lensed CMB maps

Detection of the CMB lensing on the maps

The results of the multiscale analysis depends on the wavelet dictionnary

Curvelets
(directional wavelet basis)





- Hot spots have probably the main contribution
- Beam effect preserves the ~3σ indication at the 2^{d} scale

Full sky reconstruction

T. Okamoto & W. Hu [astro-ph/0301031]

Real-space formulation of the deflection estimator:

$$\hat{d}_{LM} = \frac{-N_L^{\mathrm{TT,TT}}}{\sqrt{L(L+1)}} \int d\hat{\vec{n}}\ \vec{\nabla} \cdot \left[T^{(hp)}(\hat{\vec{n}}) \vec{\nabla} T^{(w)}(\hat{\vec{n}}) \right] Y_L^M(\hat{\vec{n}})$$

- Filtered fields:

$$\begin{cases} T^{(w)}(\hat{\vec{n}}) = \sum_{lm} \frac{\tilde{C}_l^{\mathrm{TT}}}{C_l^{\mathrm{TT}}} a_{lm}^T Y_L^M(\hat{\vec{n}}) \\ T^{(hp)}(\hat{\vec{n}}) = \sum_{lm} \frac{1}{C_l^{\mathrm{TT}}} a_{lm}^T Y_L^M(\hat{\vec{n}}) \end{cases}$$

- Gradient on the sphere:

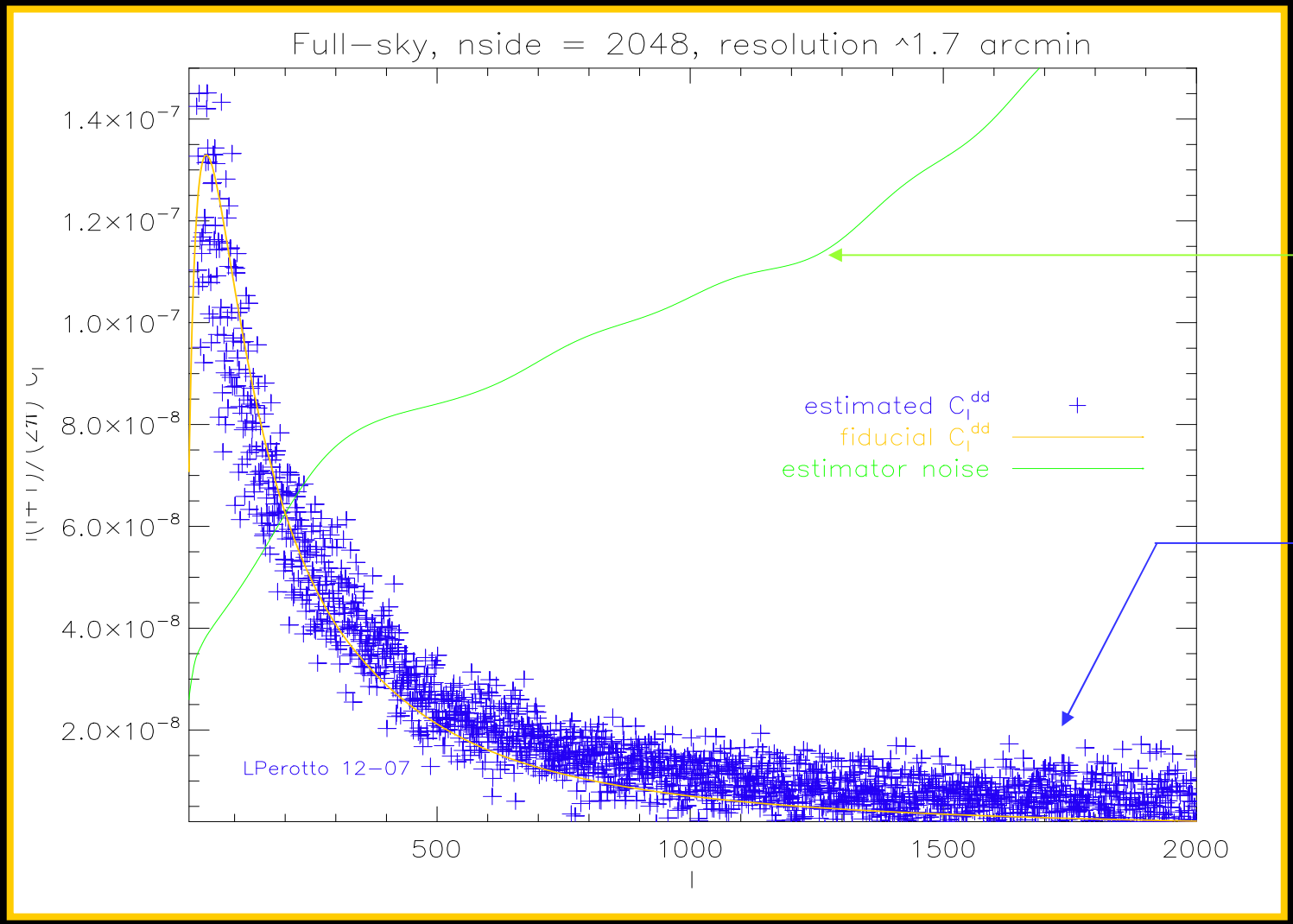
$$\vec{\nabla} Y_l^m = \frac{\sqrt{l(l+1)}}{2} \left[(\hat{e}_\theta + i\hat{e}_\phi)\, {}_{-1}Y_l^m - (\hat{e}_\theta - i\hat{e}_\phi)\, {}_{+1}Y_l^m \right]$$

⇨ Calculated with the HEALpix C++ lib (M. Reinecke)

Deflection power spectrum estimator:

$$< \hat{d}_{LM}^* \hat{d}_{L'M'} >_{\mathrm{CMB}} = \delta_{LL'} \delta_{MM'} \left[C_L^{\mathrm{dd}} + N_L^{\mathrm{TT,TT}} \right]$$

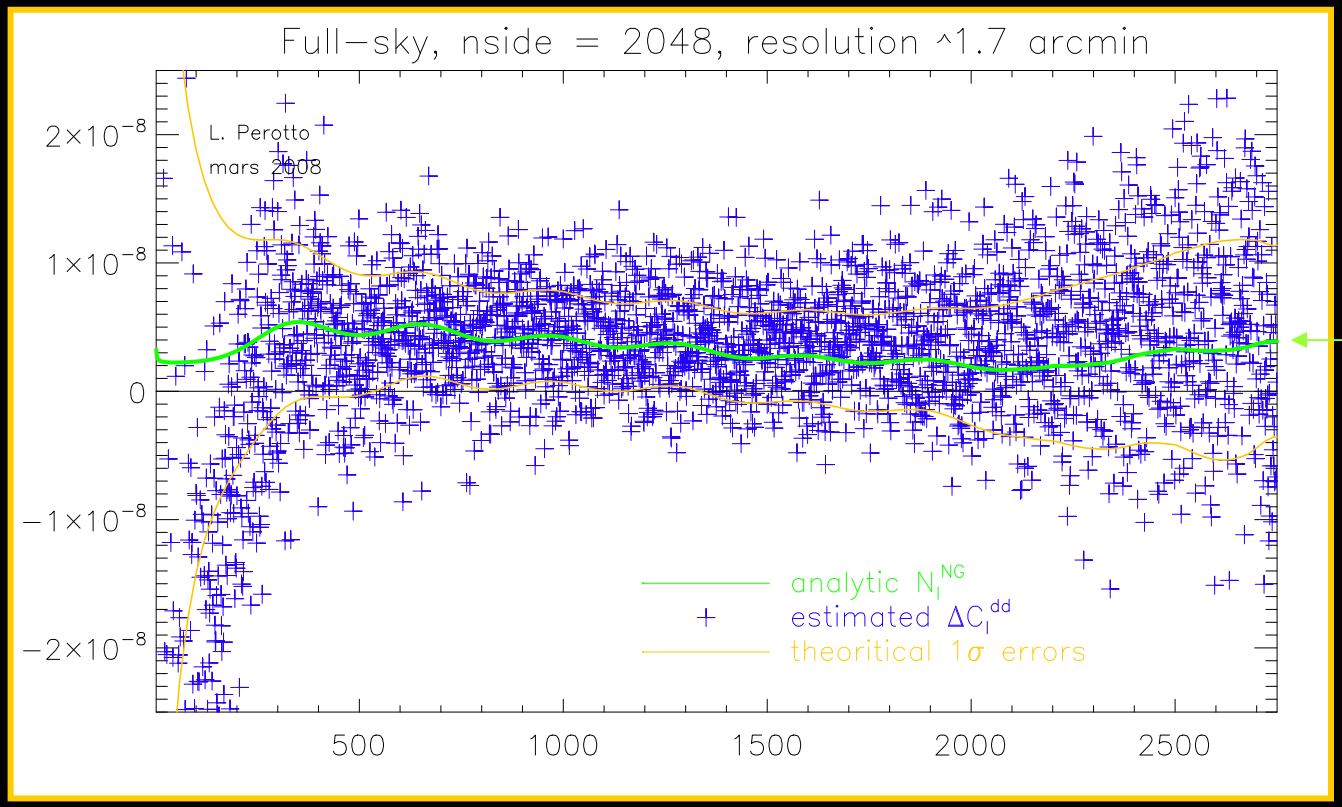
Deflection power spectrum reconstruction



$N_L^{\mathrm{TT,TT}}$

C_L^{dd}

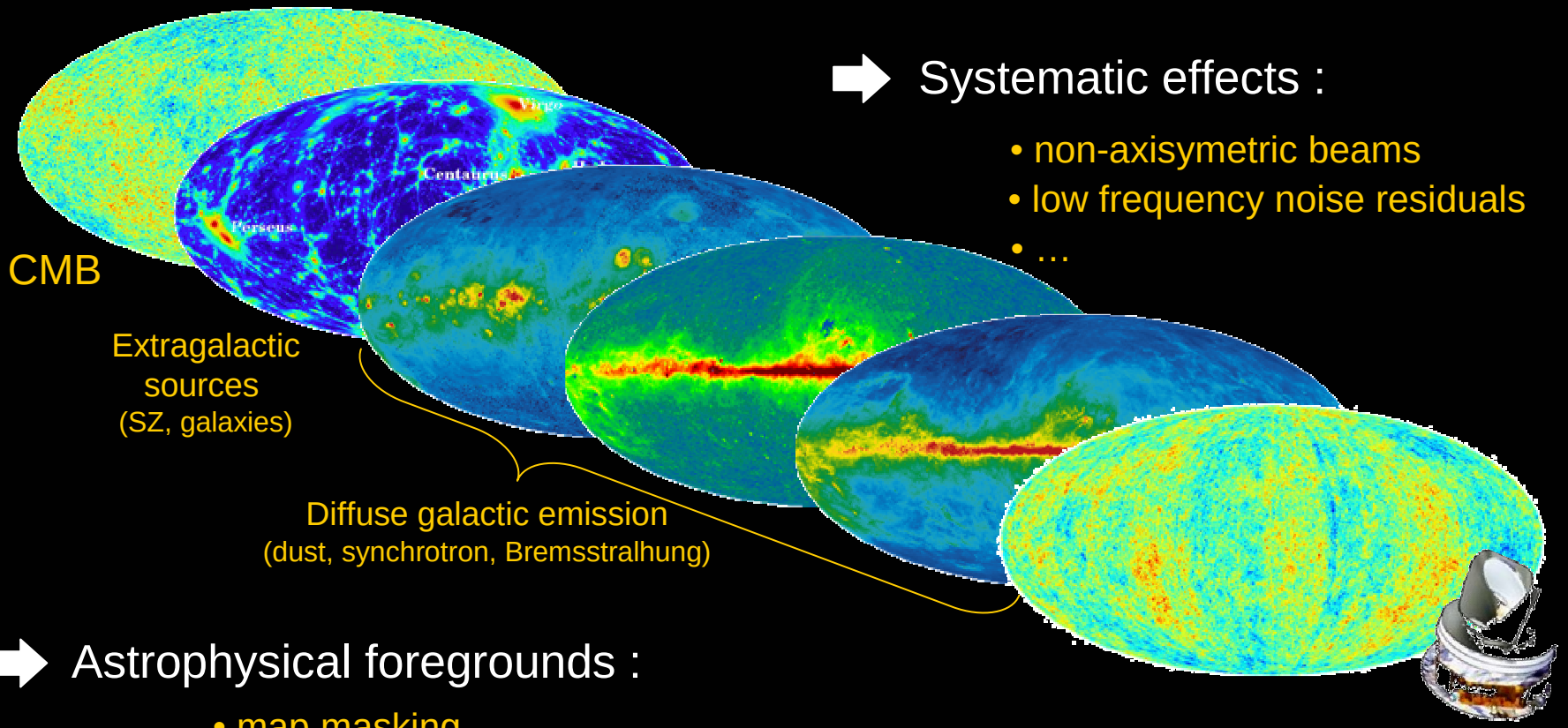
Residuals non-gaussian noise evaluation



~ 3.5 x10^{-9}
(Kesden, Cooray & Kamionkowsky)

Application to realistic simulations of PLANCK

Testing the estimator robustness against effects which could mimick the CMB lensing effect



➡ Systematic effects :

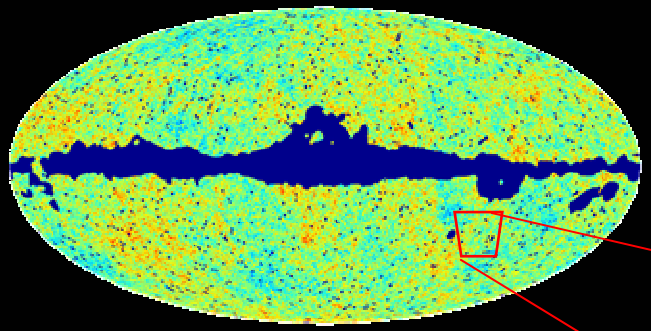
- non-axisymetric beams
- low frequency noise residuals
- …

➡ Astrophysical foregrounds :

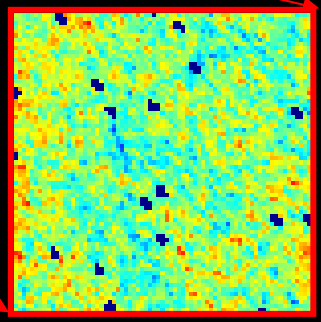
- map masking
- non-gaussian residuals after component separation
- …

« multi-patches» reconstruction

Numerical limitation/issue of the full-sky methods on PLANCK maps



Taking into account the masking issue 'à la' WMAP is prohibitive at the PLANCK resolution ($N_{pix}^{PLANCK} = 16 N_{pix}^{WMAP}$)



10x10 degrees flat patch

~ 250 available patches

An alternative/competitive approach

Characteristical scales of the deflexion field:

- rms ~ 2.5 arcmin
- spatial coherence over several degrees

➡ The flat sky limit analysis is appliable and competitive

«multi-patches» analysis tools

1. Creation of a CMB lensing simulation module
2. Development of a quadratic lensing estimator
   (W. Hu & T. Okamoto)
3. Creation of an estimator noise calculation tool
4. Residuals non-Gaussian bias calculation

→ PLANCK Data Processing Center

➡ Assessing the impact of the foregrounds residuals by full MC simulation

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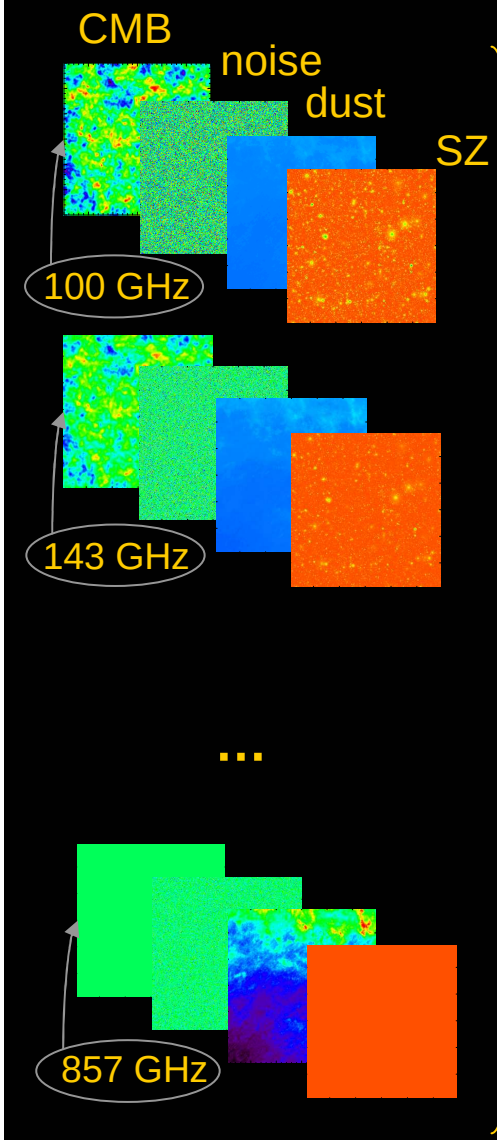
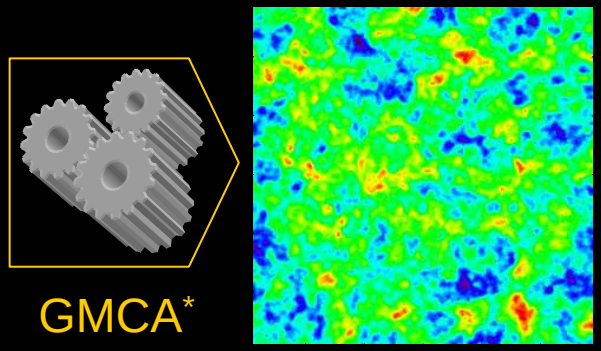
Impact of the foreground residuals:
'a demo model'



PLANCK sky model

CMB (lensed)
+ noise
+ foregrounds residuals

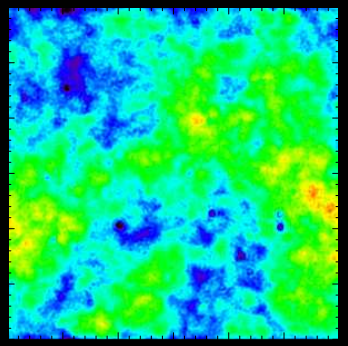


GMCA*

*Generalized Morphological Component Analysis [arXiv:0712.0588]

Component separation

deflection field



DPC-lensing

Reconstruction of the deflection

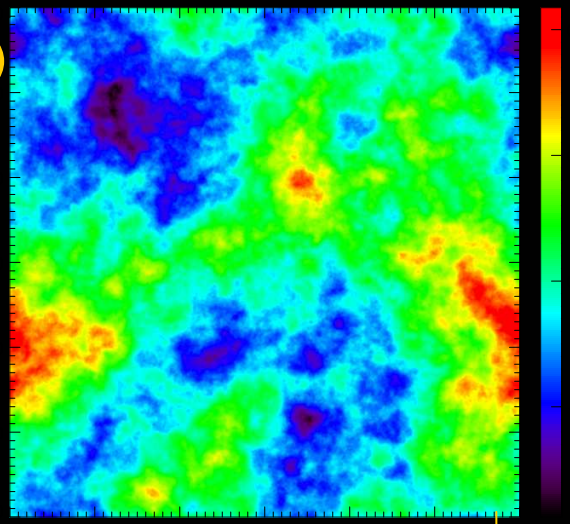
2007-2008 : collaboration CEA/LAL
LP, S. Plaszczynski, J.-L. Starck, J. Bobin

Création d'un package intégré au DPC : simulation et reconstruction

Reconstruction of the deflection field : without any residuals

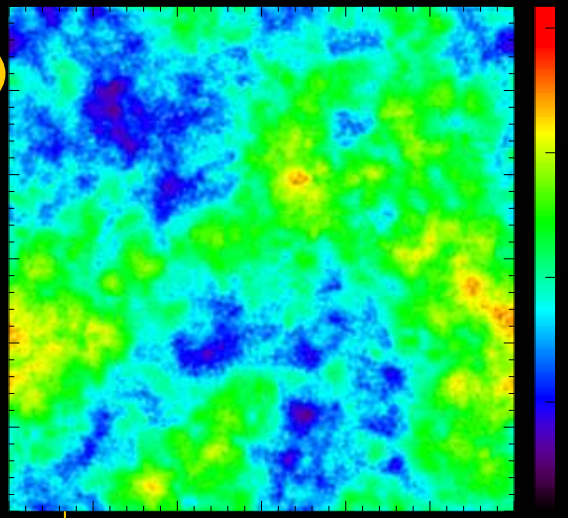
Input deflection

$d(\hat{\mathbf{n}})$

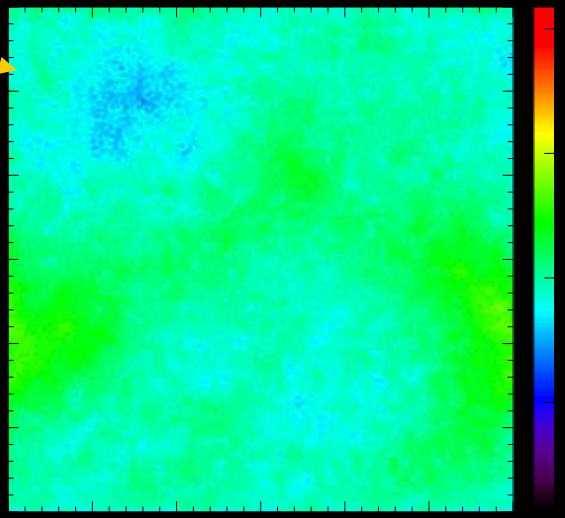


Reconstructed deflection

$\langle d_{TT}(\hat{\mathbf{n}})\rangle_{\mathrm{CMB}}$



difference



NB: $\mathrm{d}(\mathbf{n}) \equiv \mathrm{FT}^{-1}[\, \mathrm{L}\, \phi\, (\mathrm{L})^{\rightarrow}]$

Input CMB maps:

- 10x10 sq.degrees on the sky
- 2 arcmin of resolution
- 100 CMB realisations

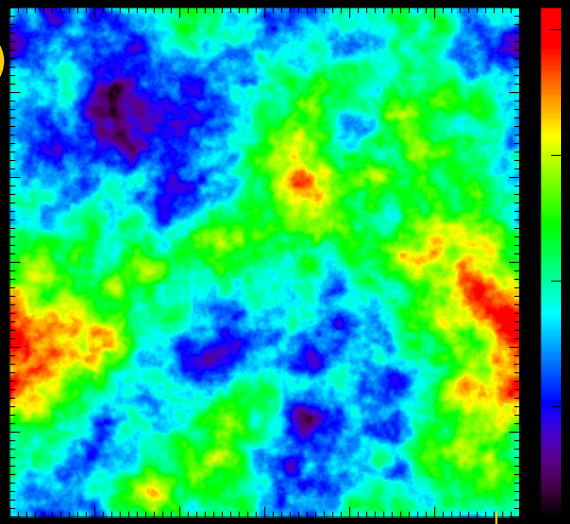
containing:

- Lensed CMB temperature
- gaussian white noise at the HFI level

Reconstruction of the deflection on GMCA maps

Input deflection

$d(\hat{\mathbf{n}})$



Reconstructed deflection

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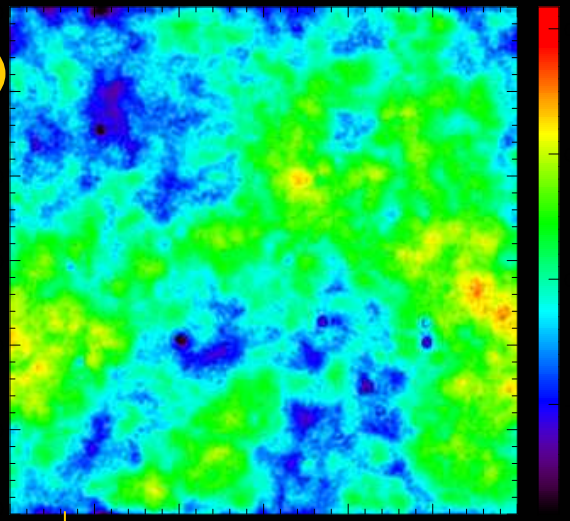
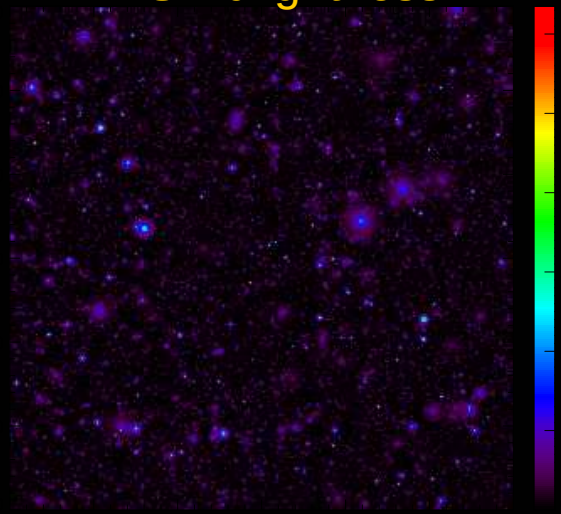
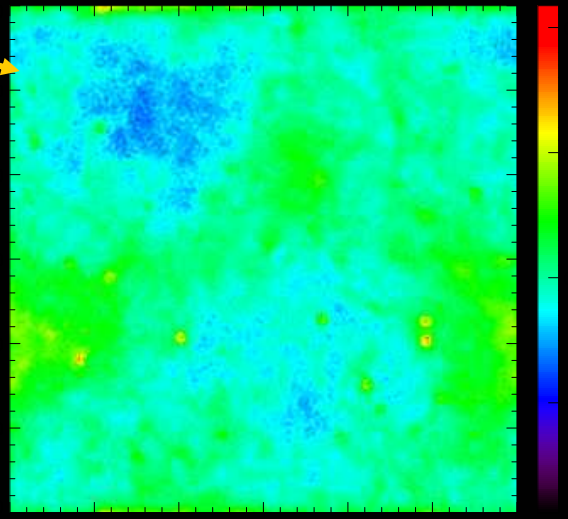
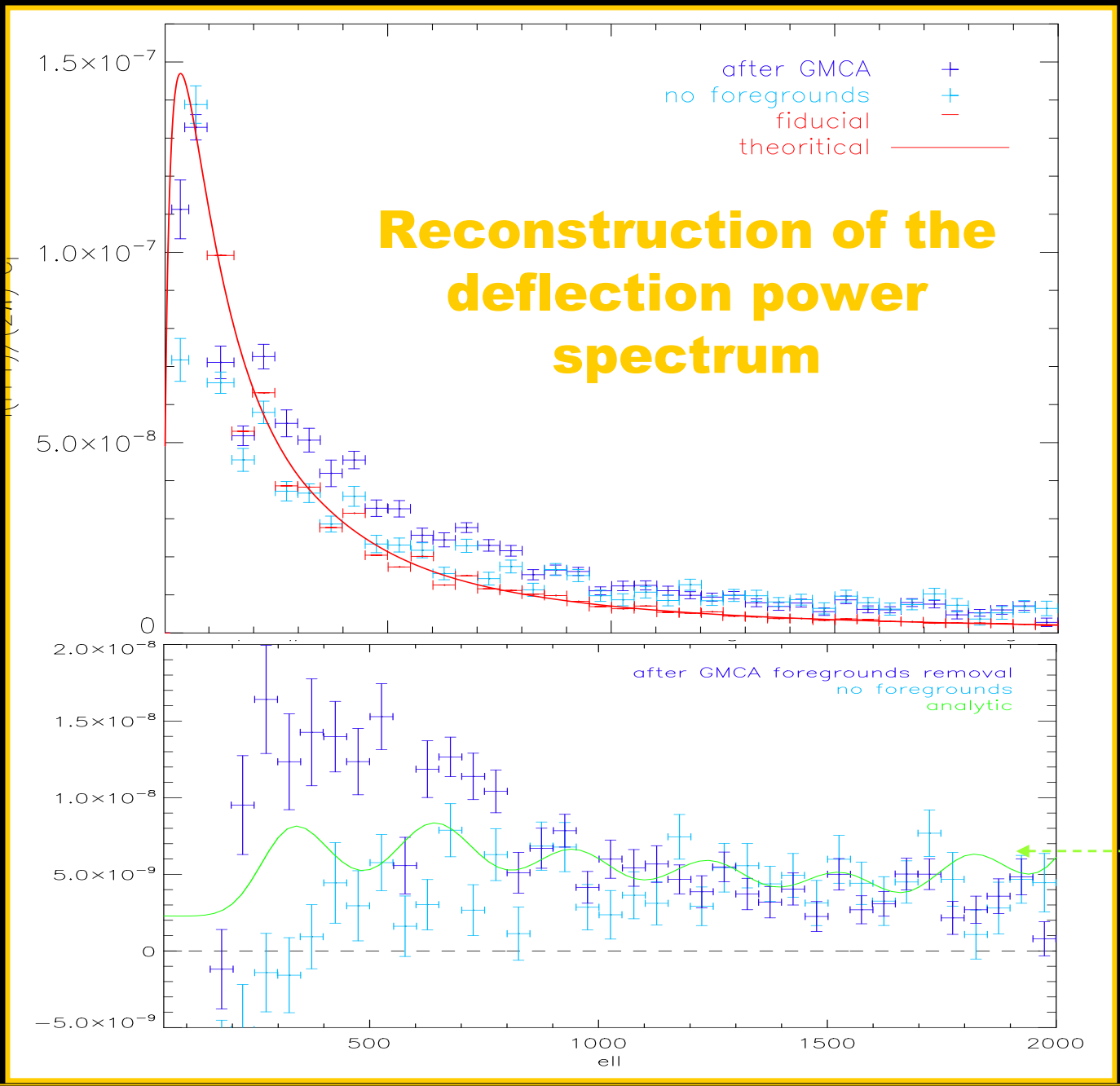


difference

SZ brightness







Reconstruction of the deflection power spectrum

residuals
ideal

theoritical
underliing
realisation

non-Gaussian residual bias

(Kesden et al.)

Article en prep.
L.Perotto, J. Bobin,
S. Plaszczynski,
J.-L. Starck

Conclusion

- **Planck** makes a first exploitation of the CMB lensing feasible.
  - ➡ CMB lensing reconstruction is a scientific priority of PLANCK
  - ➡ a growing commitment/interest of the PLANCK-France community

- Our team has developped efficient tools
  - for simulating, detecting and reconstructing the CMB lensing
  - within both flat-sky and full-sky analysis

- The firsts tests are encouraging:

  Deflection reconstruction is not jeopardized by the component separation processes (LAL+SAP/CEA)

- Our 2 short-view priorities:
  - full-sky: encounting the masking (is an inpainting approach do the job?)
  - flat-sky: the sphere-to-plan projection effects (see ALavabre's poster)

- The biggest required effort: confront to realistic Planck synthetic data

Let's imagine it's achieved...

Providing a deflection map would be a major scientific result of PLANCK

- Opening a lot of possible scientific development:
  - ISW reconstruction: $\phi^{(CMBL)} + T$
  - Correlation with other LSS probes

    $\phi^{(CMBL)} +$ LSS or LSS = { $\phi^{(WL)}$ (CFHT-LS), g (SDSSIII), …}
  - The larger redshift bin in an tomographic study of the LSS evolution:

    $\phi^{(z = 1100)} + \phi^{(z = i)}$ où i in]0,5]

- An important issu for the primordial B-mode measure:
  - CMB lensing produces a secondary B-mode contribution : E → B

We need to know deflection field well enought to allow a 'delensing' process of the CMB maps

Deflection power spectrum reconstruction