Overview of the Planck Results

Patricio Vielva

on behalf of the Planck Collaboration

Meeting on Fundamental Cosmology

Fuerteventura, 5-6 June 2014

IFCA

Instituto de Física de Cantabria

Outline

- The Past, Present and Future of the Planck publications
- What is Planck? Spain's role within Planck
- Cosmology results from temperature data
    - ΛCDM and extensions
    - Isotropy and Gaussianity
    - Secondary anisotropies: lensing, ISW and SZ
- Summary

The Past, Present, and Future of Planck Publications

2010: Planck pre-launch papers

13 publications describing the technical capabilities of Planck's instruments

2011: Planck Early papers

26 + 1 publications coming with the 1st delivered product: The Early Release Compact Source Catalogue

2012 - : Planck intermediate papers

22 publications (and rising) on galactic and extragalactic astrophysics; in particular, cluster science

2013 : Planck 2013 results

31 publications on cosmology science from CMB temperature data (most of them already accepted by A&A). Maps, C_l's and likelihoods delivered

2014 (October): Planck 2014 results

N publications on cosmology science from CMB temperature and polarization data (full mission). Update of the delivered products, including polarization.

2015 (Sept): Planck Final results

The legacy Planck publications: latest results made by the collaboration. Final products updated.

The Past, Present, and Future of Planck Publications

2010: Planck pre-launch papers

13 publications describing the technical capabilities of Planck's instruments

2011: Planck Early papers

26 + 1 publications coming with the 1st delivered product: The Early Release Compact Source Catalogue

2012 - : Planck intermediate papers

22 publications (and rising) on galactic and extragalactic astrophysics; in particular, cluster science

2013 : Planck 2013 results

31 publications on cosmology science from CMB temperature data (most of them already accepted by A&A). Maps, C_l's and likelihoods delivered

We are here!

2014 (October): Planck 2014 results

N publications on cosmology science from CMB temperature and polarization data (full mission). Update of the delivered products, including polarization.

2015 (Sept): Planck Final results

The legacy Planck publications: latest results made by the collaboration. Final products updated.

What is Planck?

Planck is an ESA satellite aiming to measure the CMB temperature and polarization at an angular resolution of ≈5 arcmin, and with a sensitivity of ≈4mK (in T) and 8 mK (in P), after ≈2 years of observation. It is made of three instruments:

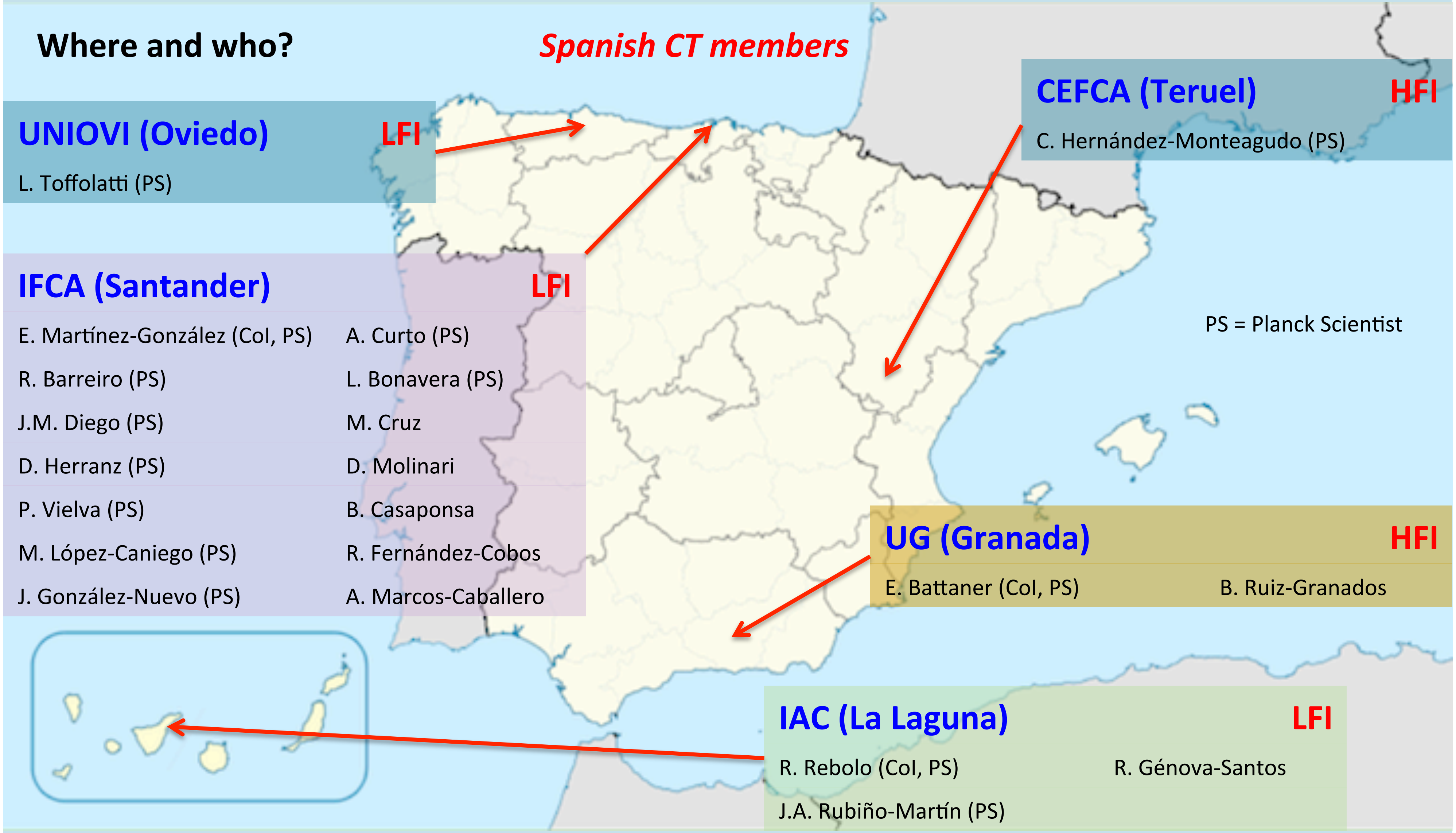
- High Frequency Instrument (HFI)
  - observing at 100, 143, 217, 353, 545 and 857 GHz (only up to 353GHz in P)
  - PI: J.-L. Puget (IAS, Orsay, France)
  - Bolometric detector array
- Low Frequency Instrument (LFI)
  - observing at 30, 44 and 70 GHz (both in T and P)
  - PI: N. Mandolesi (IASF-INAF, Bologna, Italy)
  - HEMT radio receiver array
- Telescope
  - PI: H.-U. Norgaard-Nielsen (Danish National Space institute, Denmark)
  - Off-axis tilted Gregorian telescope with baffling system

CMB data analysis is made within the HFI and LFI Core Teams (≈240 + 140 people). These are the people dealing with the data and producing all the cosmological papers, and most of the remaining publications.

Spain's role within Planck

Where and who?

Spanish CT members



UNIOVI (Oviedo) LFI

L. Toffolatti (PS)

IFCA (Santander) LFI

E. Martínez-González (Col, PS)	A. Curto (PS)
R. Barreiro (PS)	L. Bonavera (PS)
J.M. Diego (PS)	M. Cruz
D. Herranz (PS)	D. Molinari
P. Vielva (PS)	B. Casaponsa
M. López-Caniego (PS)	R. Fernández-Cobos
J. González-Nuevo (PS)	A. Marcos-Caballero

CEFCA (Teruel) HFI

C. Hernández-Monteagudo (PS)

PS = Planck Scientist

UG (Granada) HFI

E. Battaner (Col, PS)	B. Ruiz-Granados

IAC (La Laguna) LFI

R. Rebolo (Col, PS)	R. Génova-Santos
J.A. Rubiño-Martín (PS)	

Spain's role within Planck

What and who?

Instrumental responsibilities

- Back-End modules for the 30GHz and 44 GHz receivers of the LFI: IFCA, DICOM (Universidad de Cantabria) and Universitat Politècnica de Catalunya
- The Radiometer Electronics Box Assembly (REBA) of the LFI: IAC
- Pre-regulator for the HFI cooler: Universidad de Granada

Scientific responsibilities

- Coordination of the Non-Gaussianity Working Group: EMG
- Coordination of the Cluster Science Working Group: JARM
- Coordination of the integrated Sachs-Wolfe science: PV and CHM
- Coordination of the Primordial Magnetic Fields science: EB
- Production of official point source catalogues: JGN and MLC
- Production of official CMB maps: BB
- Coordination of the CT area of non-Gaussianity: PV

Spain's role within Planck

What and who?

Corresponding authorship

Early papers

- Statistical properties of radio galaxies: JGN (IFCA)

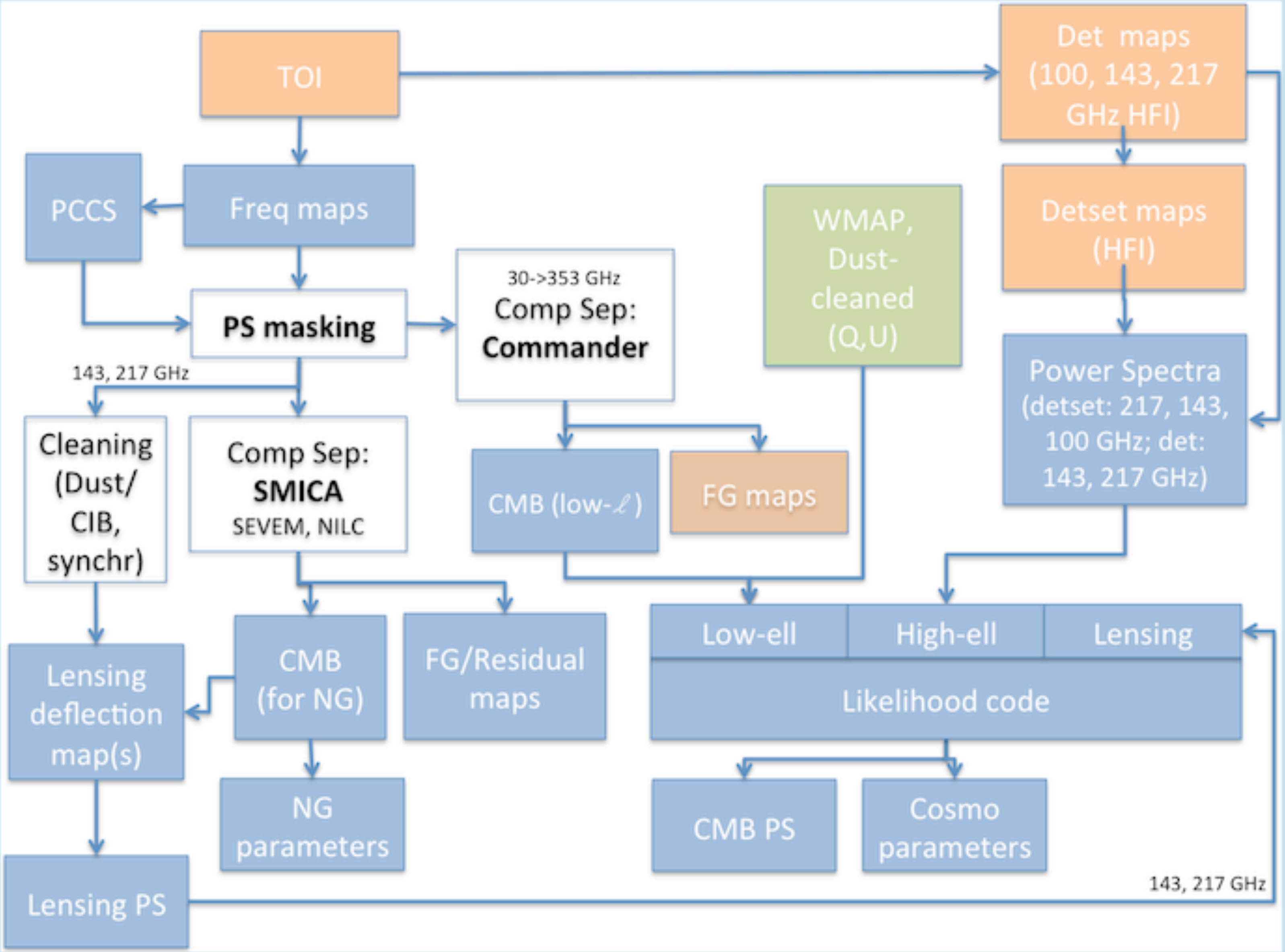
Intermediate papers

- Filaments between clusters: JMD (IFCA)
- Gas content on dark matter halos: JARM (IAC)
- Constraints on peculiar velocities: CHM (CEFCA)

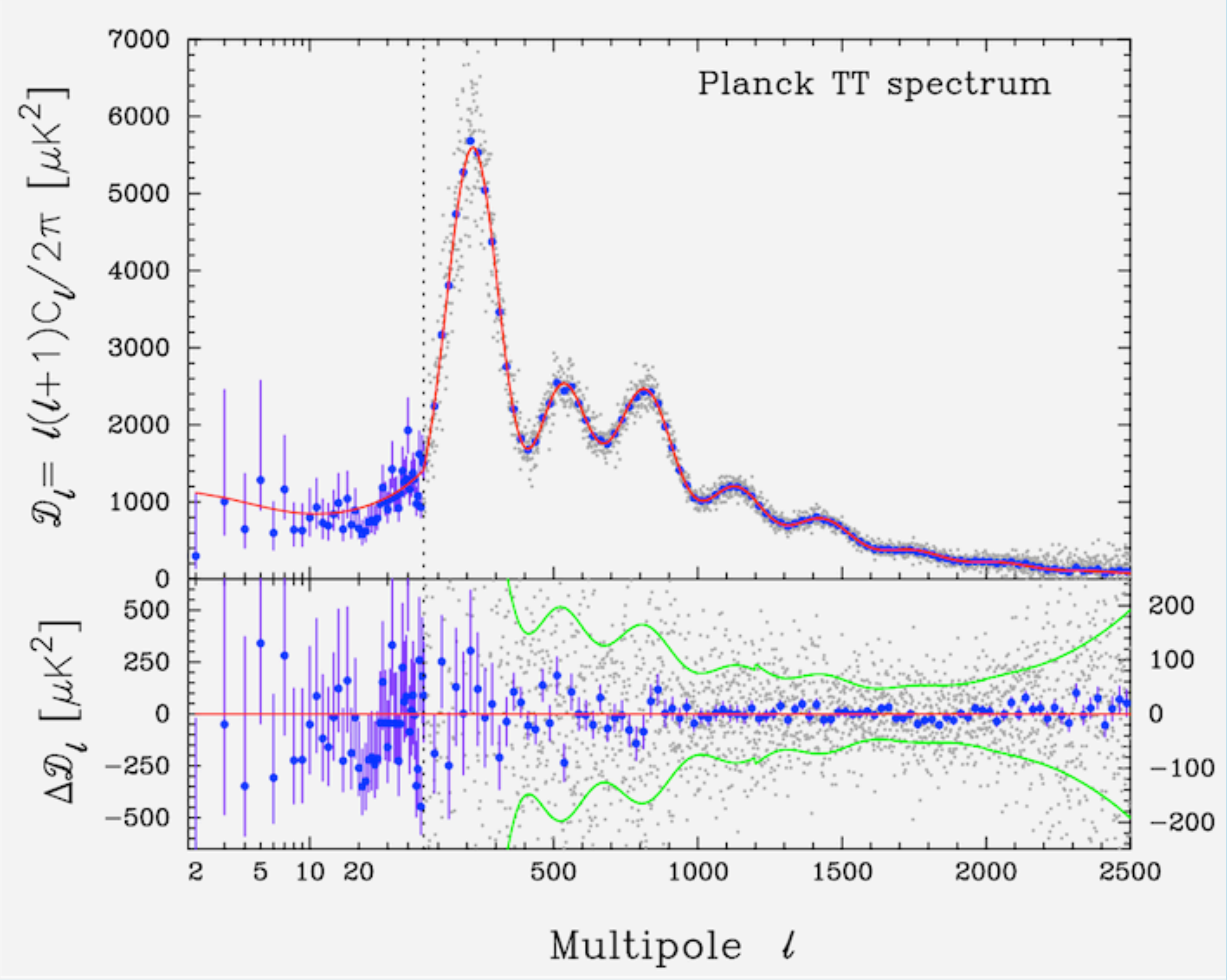
2013 CMB results

- Isotropy and Gaussianity: EMG (IFCA)
- Integrated Sachs-Wolfe: PV (IFCA)
- Compact Source Catalogue: JGN (IFCA)

Cosmology results from temperature



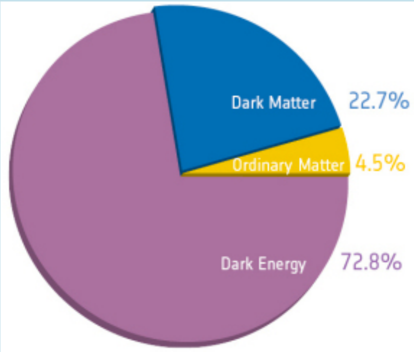
ΛCDM and extensions



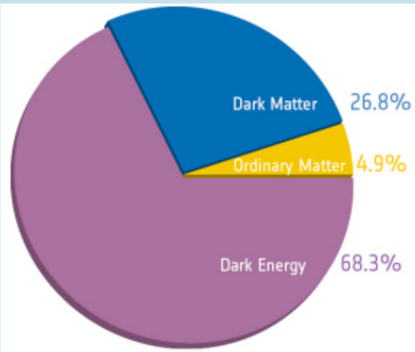
ΛCDM and extensions

Minimal ΛCDM

Before Planck



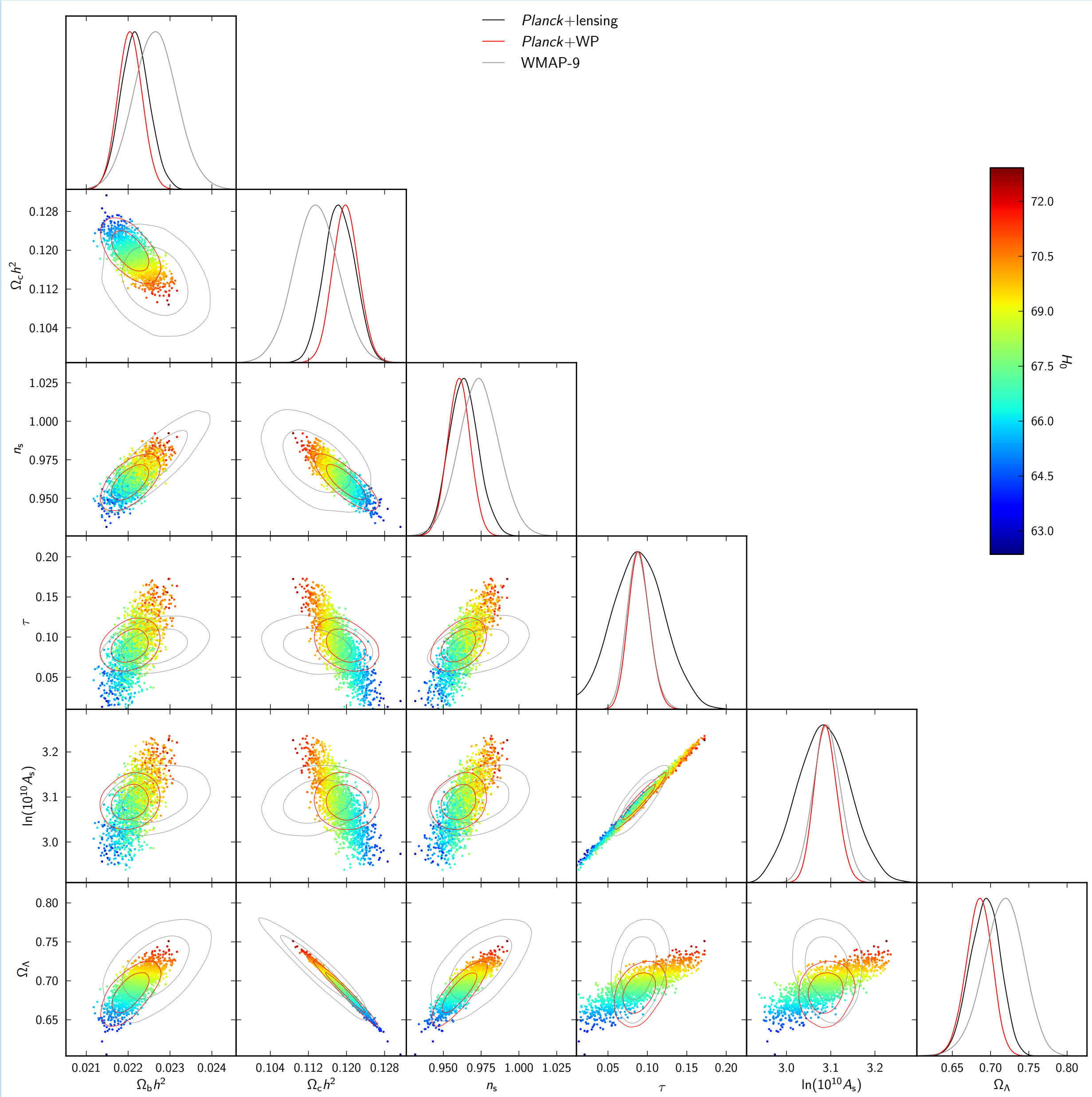
After Planck



	Planck		*Planck*+lensing		*Planck*+WP	
Parameter	Best fit	68% limits	Best fit	68% limits	Best fit	68% limits
$\Omega_b h^2$	0.022068	0.02207 ± 0.00033	0.022242	0.02217 ± 0.00033	0.022032	0.02205 ± 0.00028
$\Omega_c h^2$	0.12029	0.1196 ± 0.0031	0.11805	0.1186 ± 0.0031	0.12038	0.1199 ± 0.0027
$100\theta_{MC}$	1.04122	1.04132 ± 0.00068	1.04150	1.04141 ± 0.00067	1.04119	1.04131 ± 0.00063
τ	0.0925	0.097 ± 0.038	0.0949	0.089 ± 0.032	0.0925	$0.089^{+0.012}_{-0.014}$
n_s	0.9624	0.9616 ± 0.0094	0.9675	0.9635 ± 0.0094	0.9619	0.9603 ± 0.0073
$\ln(10^{10} A_s)$	3.098	3.103 ± 0.072	3.098	3.085 ± 0.057	3.0980	$3.089^{+0.024}_{-0.027}$
Ω_Λ	0.6825	0.686 ± 0.020	0.6964	0.693 ± 0.019	0.6817	$0.685^{+0.018}_{-0.016}$
Ω_m	0.3175	0.314 ± 0.020	0.3036	0.307 ± 0.019	0.3183	$0.315^{+0.016}_{-0.018}$
σ_8	0.8344	0.834 ± 0.027	0.8285	0.823 ± 0.018	0.8347	0.829 ± 0.012
z_{re}	11.35	$11.4^{+4.0}_{-2.8}$	11.45	$10.8^{+3.1}_{-2.5}$	11.37	11.1 ± 1.1
H_0	67.11	67.4 ± 1.4	68.14	67.9 ± 1.5	67.04	67.3 ± 1.2
$10^9 A_s$	2.215	2.23 ± 0.16	2.215	$2.19^{+0.12}_{-0.14}$	2.215	$2.196^{+0.051}_{-0.060}$
$\Omega_m h^2$	0.14300	0.1423 ± 0.0029	0.14094	0.1414 ± 0.0029	0.14305	0.1426 ± 0.0025
$\Omega_m h^3$	0.09597	0.09590 ± 0.00059	0.09603	0.09593 ± 0.00058	0.09591	0.09589 ± 0.00057
Y_P	0.247710	0.24771 ± 0.00014	0.247785	0.24775 ± 0.00014	0.247695	0.24770 ± 0.00012
Age/Gyr	13.819	13.813 ± 0.058	13.784	13.796 ± 0.058	13.8242	13.817 ± 0.048
z_*	1090.43	1090.37 ± 0.65	1090.01	1090.16 ± 0.65	1090.48	1090.43 ± 0.54
r_*	144.58	144.75 ± 0.66	145.02	144.96 ± 0.66	144.58	144.71 ± 0.60
$100\theta_*$	1.04139	1.04148 ± 0.00066	1.04164	1.04156 ± 0.00066	1.04136	1.04147 ± 0.00062
z_{drag}	1059.32	1059.29 ± 0.65	1059.59	1059.43 ± 0.64	1059.25	1059.25 ± 0.58
r_{drag}	147.34	147.53 ± 0.64	147.74	147.70 ± 0.63	147.36	147.49 ± 0.59
k_D	0.14026	0.14007 ± 0.00064	0.13998	0.13996 ± 0.00062	0.14022	0.14009 ± 0.00063
$100\theta_D$	0.161332	0.16137 ± 0.00037	0.161196	0.16129 ± 0.00036	0.161375	0.16140 ± 0.00034
z_{eq}	3402	3386 ± 69	3352	3362 ± 69	3403	3391 ± 60
$100\theta_{eq}$	0.8128	0.816 ± 0.013	0.8224	0.821 ± 0.013	0.8125	0.815 ± 0.011
$r_{drag}/D_V(0.57)$	0.07130	0.0716 ± 0.0011	0.07207	0.0719 ± 0.0011	0.07126	0.07147 ± 0.00091

ΛCDM and extensions

Planck
vs
WMAP



Patricio Vielva

ΛCDM and extensions

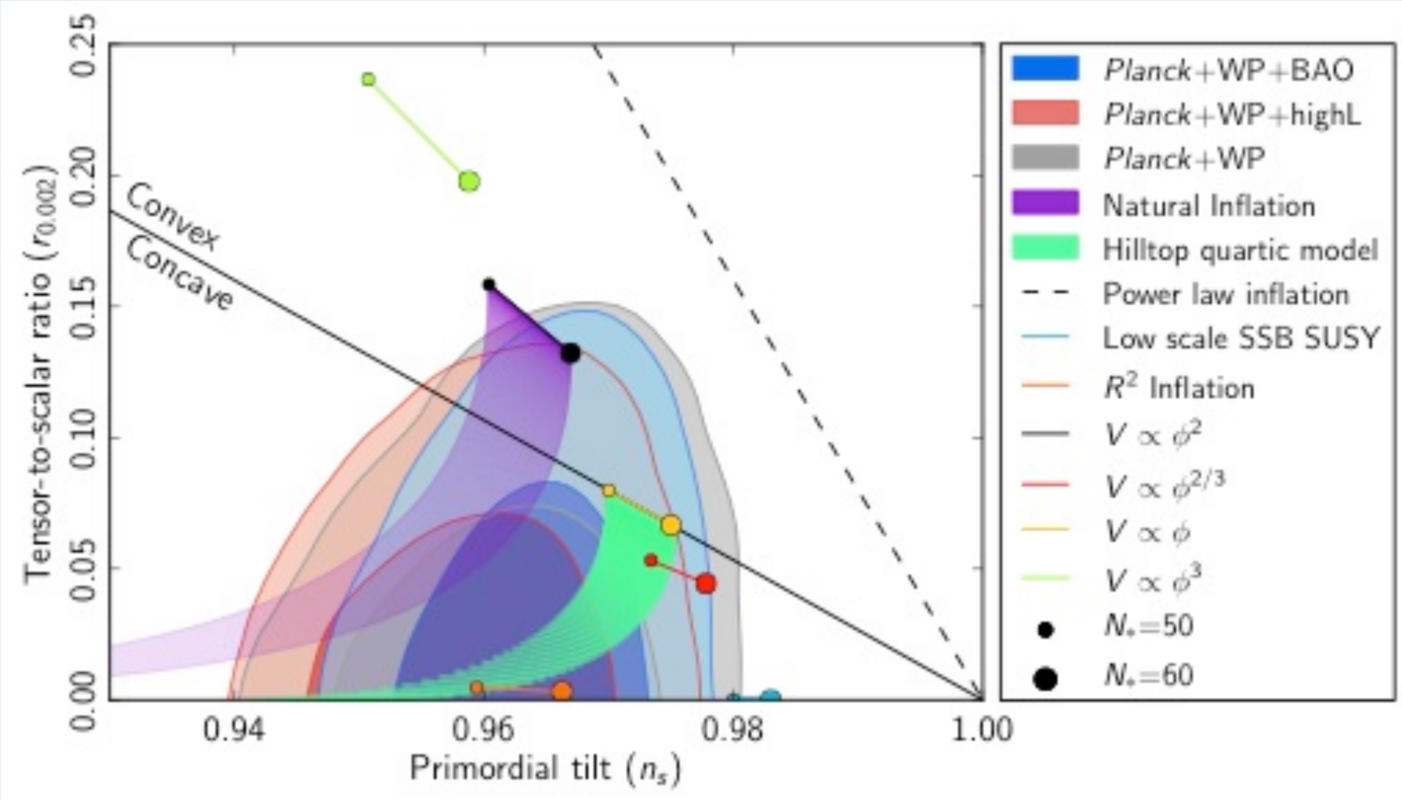
ΛCDM extensions

Including high resolution CMB experiments (SPT, ACT) and additional astrophysical data sets (as BAO, H_0, SNIa, galaxy power spectrum, cosmic shear, and counts of clusters), on the analysis it is possible to study ΛCDM extensions. None of the extensions is favoured over ΛCDM.

Parameter	*Planck*+WP		*Planck*+WP+BAO		*Planck*+WP+highL		*Planck*+WP+highL+BAO	
	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits
Ω_K	−0.0326	$-0.037^{+0.043}_{-0.049}$	0.0006	$0.0000^{+0.0066}_{-0.0067}$	−0.0389	$-0.042^{+0.043}_{-0.048}$	−0.0003	$-0.0005^{+0.0065}_{-0.0066}$
Σm_ν [eV]	0.002	< 0.933	0.000	< 0.247	0.000	< 0.663	0.001	< 0.230
$N_{\rm eff}$	3.25	$3.51^{+0.80}_{-0.74}$	3.32	$3.40^{+0.59}_{-0.57}$	3.38	$3.36^{+0.68}_{-0.64}$	3.33	$3.30^{+0.54}_{-0.51}$
$Y_{\rm P}$	0.2896	$0.283^{+0.045}_{-0.048}$	0.2889	$0.283^{+0.043}_{-0.045}$	0.2652	$0.266^{+0.040}_{-0.042}$	0.2701	$0.267^{+0.038}_{-0.040}$
$dn_{\rm s}/d\ln k$	−0.0125	$-0.013^{+0.018}_{-0.018}$	−0.0097	$-0.013^{+0.018}_{-0.018}$	−0.0146	$-0.015^{+0.017}_{-0.017}$	−0.0143	$-0.014^{+0.016}_{-0.017}$
$r_{0.002}$	0.000	< 0.120	0.000	< 0.122	0.000	< 0.108	0.000	< 0.111
w	−1.94	$-1.49^{+0.65}_{-0.57}$	−1.106	$-1.13^{+0.24}_{-0.25}$	−1.94	$-1.51^{+0.62}_{-0.53}$	−1.113	$-1.13^{+0.23}_{-0.25}$

Note 95% CL

ΛCDM and extensions



f_{NL}		
Local	Equilateral	Orthogonal
2.7 ± 5.8	−42 ± 75	−25 ± 39

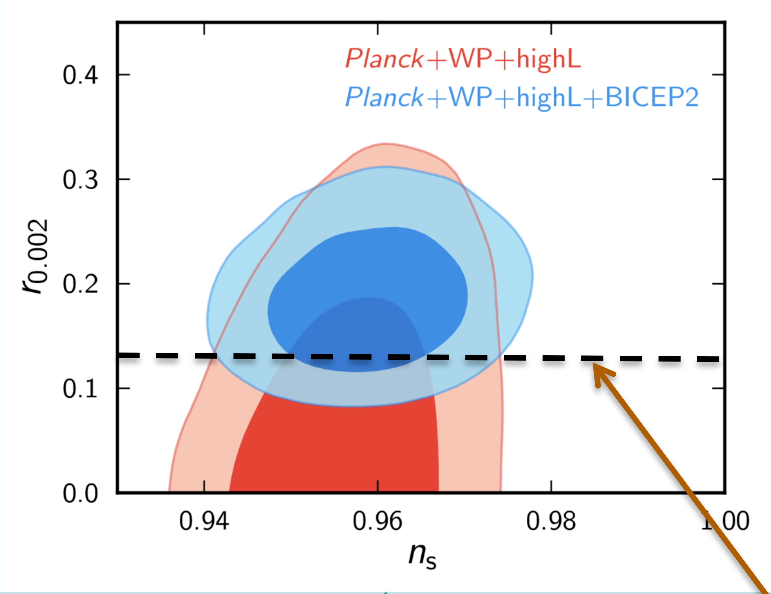
ISW-lensing and point sources biases corrected

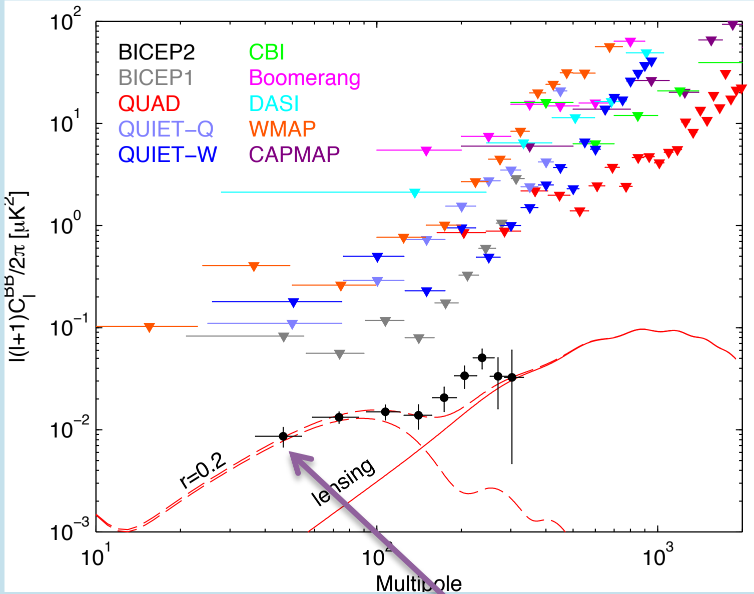
Inflationary models with concave potentials are preferred, in particular, a field with a canonical kinetic term and slowly rolling downs a features potential explains the data ➔ no evidence calling for any extension. **More details** on the **J.J. Blanco-Pillado talk**.

Let's open a parenthesis…

(

BICEP2 results appearing last St. Patrick's Day





arXiv:1403.3985

95% limit for minimal extension model

Primordial B-mode with r=0.2

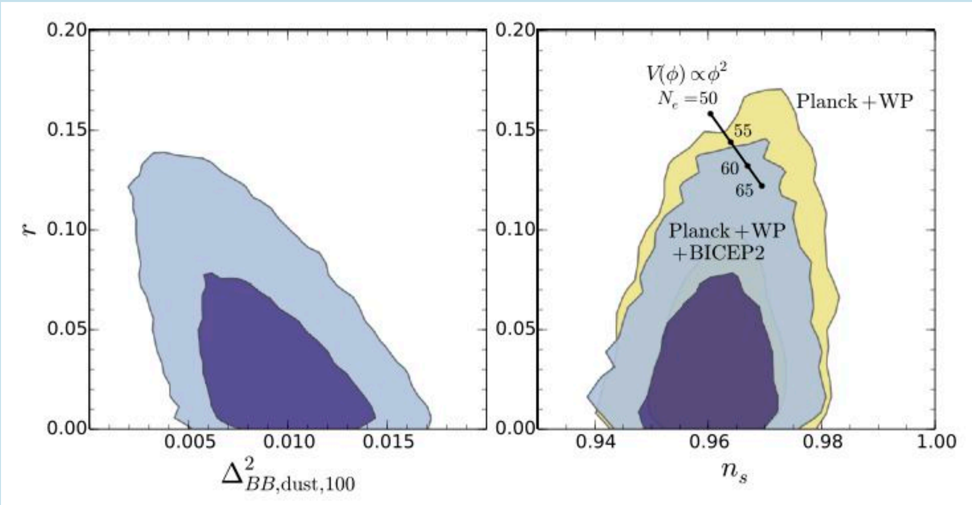
Allowing running of n_s in Planck likelihood

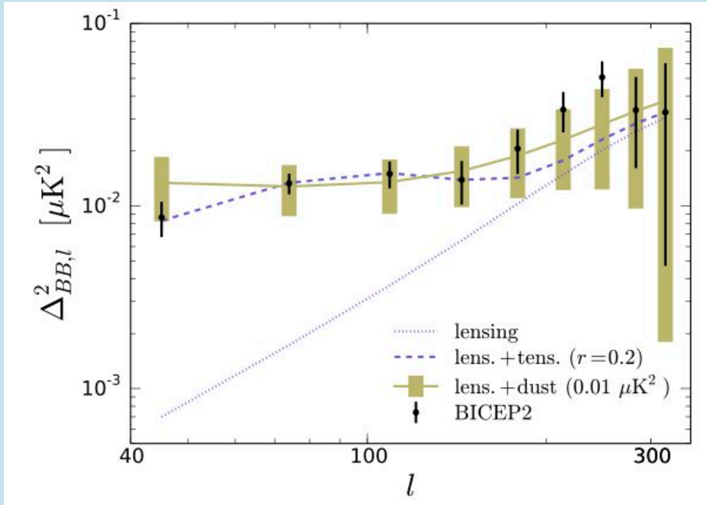
More details on BICEP2 results in the R. Génova-Santos talk

…

- Many papers came out after this result addressing its implications for inflationary models (see J.J. Blanco-Pillado talk)

- However, several authors are pointing out some doubts on the real role played by thermal dust on the B-mode signal ➔ possible biases on the claimed primordial signal (e.g., Mortonson & Seljak arXiv:1405.5857)





...

Planck has recently published information on the **thermal dust polarization**, showing the complexity of its characterization. Planck has the capabilities to clarify some pending doubts.

Polarization intensity at 353GHz

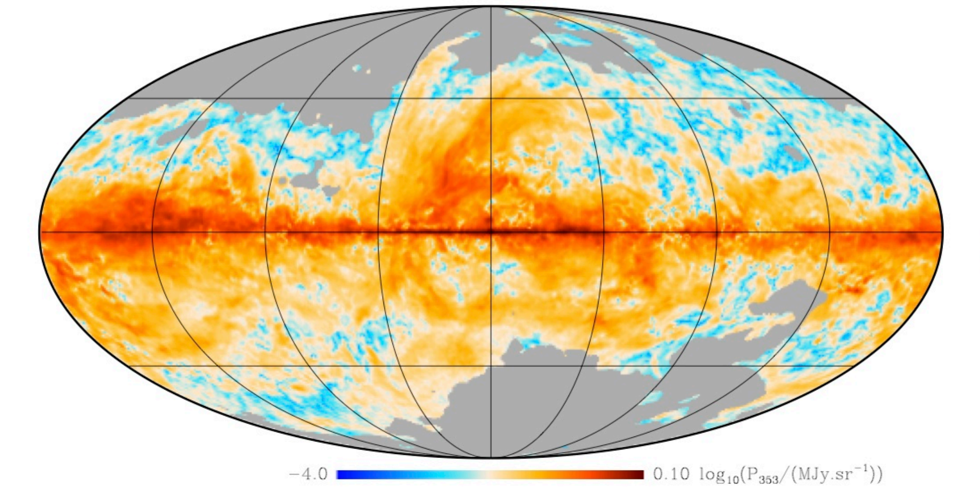
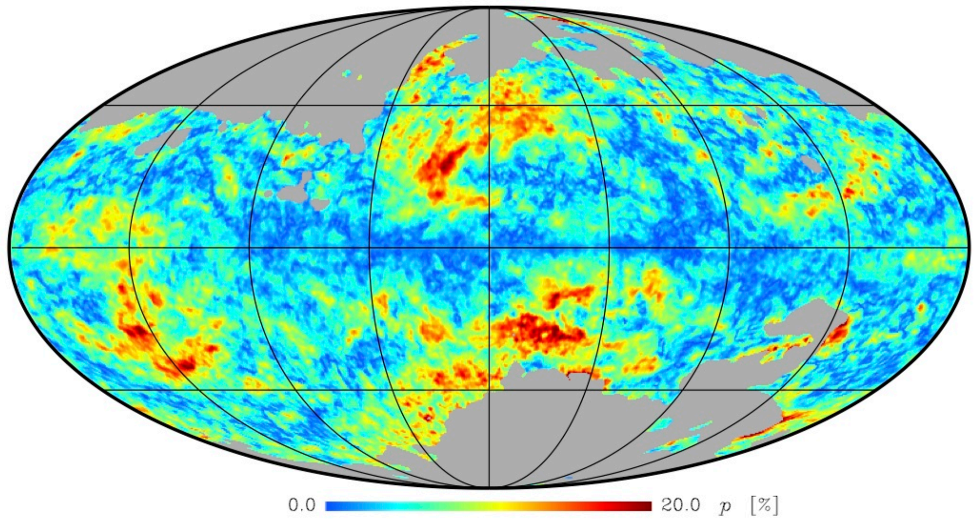


Fig. 2. *Planck* 353 GHz polarized intensity (P) map at 1° resolution in $\log_{10}$ scale. The values shown have been bias corrected as described in Sect. 2.3. The same mask as in Fig. 1 is applied. The full sky map of the unpolarized intensity I entering the calculation of P is shown in Fig. 5.

Polarization fraction at 353GHz

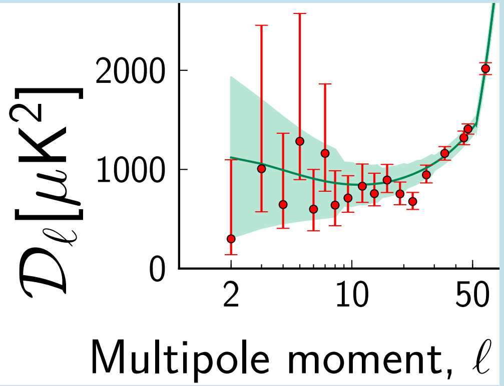


… let's close it

)

ΛCDM and extensions

Some open questions



Despite the successful description of the observations within the LCDM model, there are some issues that is worth mention:

- There is a lack of power at largest scales. Although it is not a tremendous anomaly, it could be related to large-scale anomalies found by Isotropy and NG analyses

- There are some tensions between the Planck+WP parameters and those derived with/by other observations:
  - Amplitude of the lensing power spectrum potential as compared to the lensing map
  - Amplitude of the primordial fluctuations as compared to the abundance of rich clusters and cosmic shear
  - H_0 as compared to some direct distance measurements, although good agreement with WMAP9 and BAOs

- Future analyses will show in these "early-late redshift" tensions remain or disappear.

Patricio Vielva
Instituto de Física de Cantabria

Isotropy and Gaussianity

The scope is to test the Gaussianity and statistical isotropy of the CMB, as expected from the standard cosmological scenario

Testing these fundamental properties is crucial for:

- validating the **standard cosmological scenario**
- understanding the physical nature of the Universe and the **initial conditions of structure formation**
- providing support to the common **assumptions usually made** in the power spectrum estimation and the cosmological parameters determination

Significant **deviations** of Gaussianity and isotropy **are expected**, e.g., non-linear process that lead to secondary anisotropies as **the ISW-lensing correlation**.

It also provides **insights on some anomalies previously claimed on WMAP data**

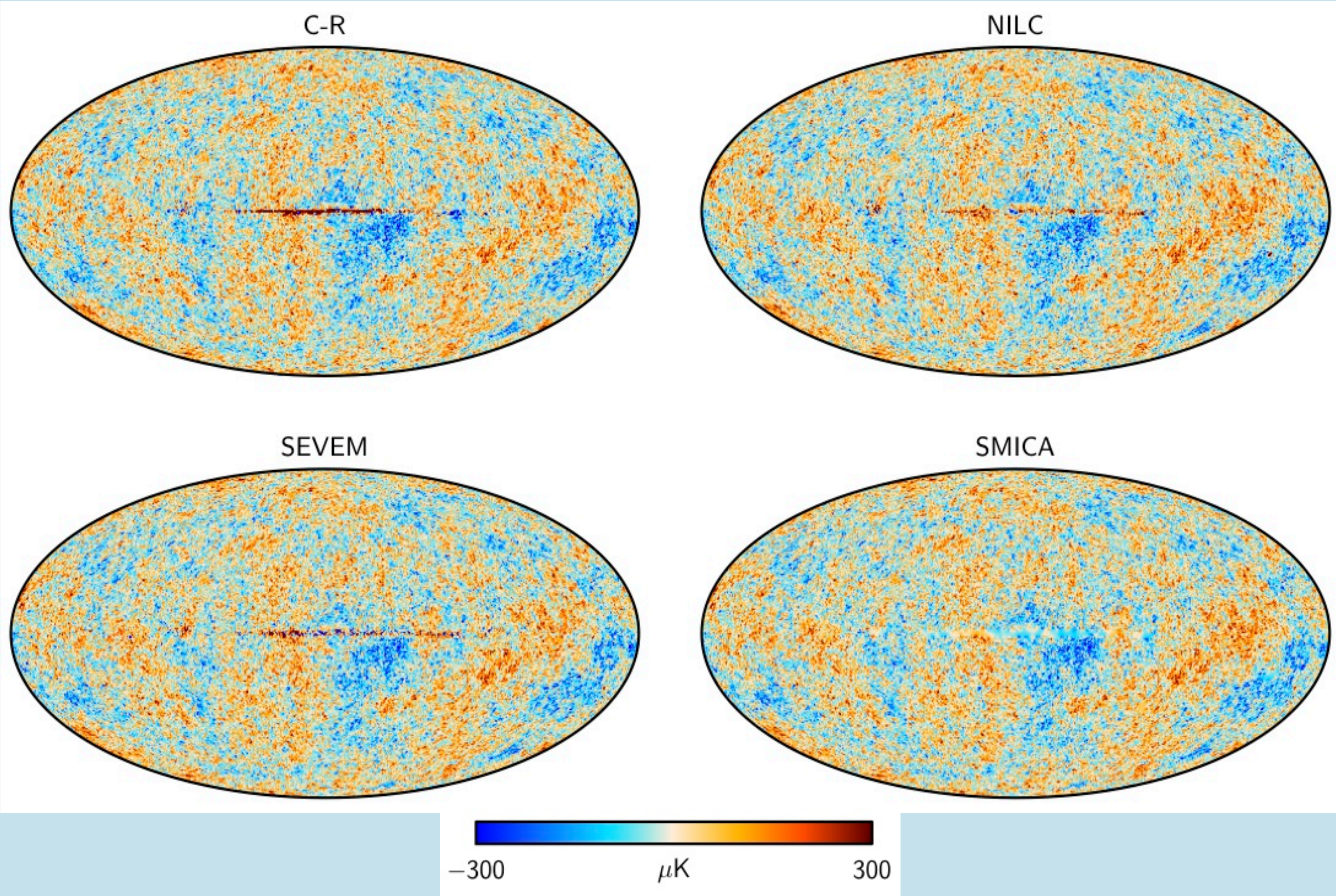
Isotropy and Gaussianity

Most of the analyses have been extensively tested against systematics introduced by foreground residuals:

The 4 clean CMB maps provided by Planck were analysed:

- Commander-Ruler (**parametric in real space**, SNR=1 @ l=1550)
- NILC (**non-parametric in wavelet space**, SNR=1 @ l =1790)
- SEVEM (**non-parametric in real space**, SNR=1 @ l=1790)
- SMICA (**semi-parametric in harmonic space**, SNR=1 @ l=1790)

Isotropy and Gaussianity



Isotropy and Gaussianity

A suite of non-parametric tools

Frequentist statistics:

- Among others, the 1-pdf, the N-pdf, the N-point correlation function, the Minkowski functionals, and the wavelet moments have been applied to the data.
- A statistical quantity (e.g., a χ^2) has been defined and confronted against coherent simulations

Assessing the CMB anomalies

Frequentist and parametric statistics:

- Probing claimed WMAP anomalies on the Planck data (also related to some features highlighted by the previous tests)
- Establishing the significance is a difficult aspect, since many of the test are *a posteriori* analyses

Patricio Vielva

Instituto de Física de Cantabria

Isotropy and Gaussianity

A suite of non-parametric tools

Frequentist statistics:

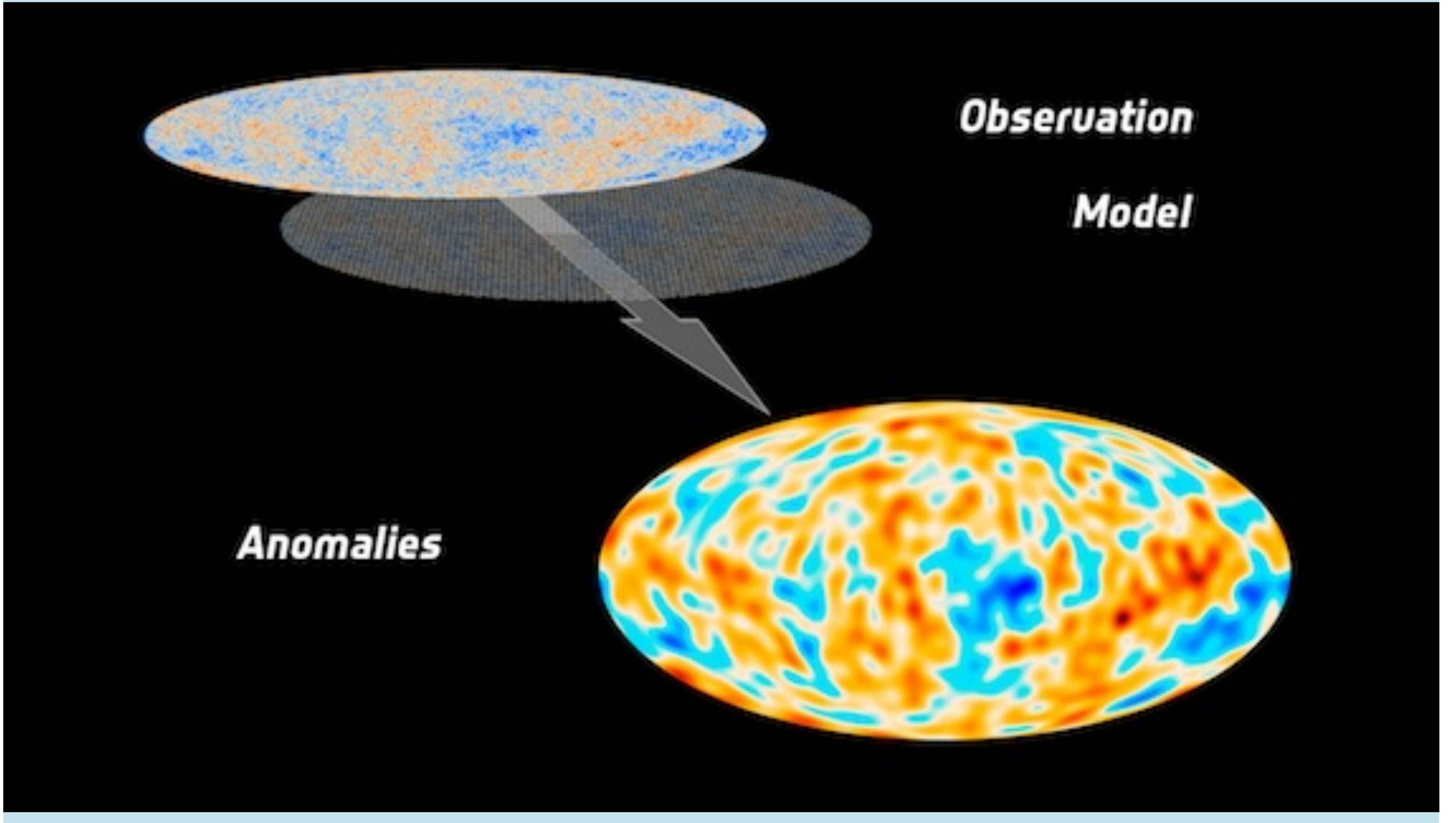
- Among others, the 1-pdf, the N-pdf, the N-point correlation function, the Minkowski functionals, and the wavelet moments have been applied to the data.
- A statistical quantity (e.g., a χ^2) has been defined and confronted against coherent simulations

Assessing the CMB anomalies

Frequentist and parametric statistics:

- Probing claimed WMAP anomalies on the Planck data (also related to some features highlighted by the previous tests)
- Establishing the significance is a difficult aspect, since many of the test are *a posteriori* analyses

Isotropy and Gaussianity



Mode alignment

Isotropy and Gaussianity

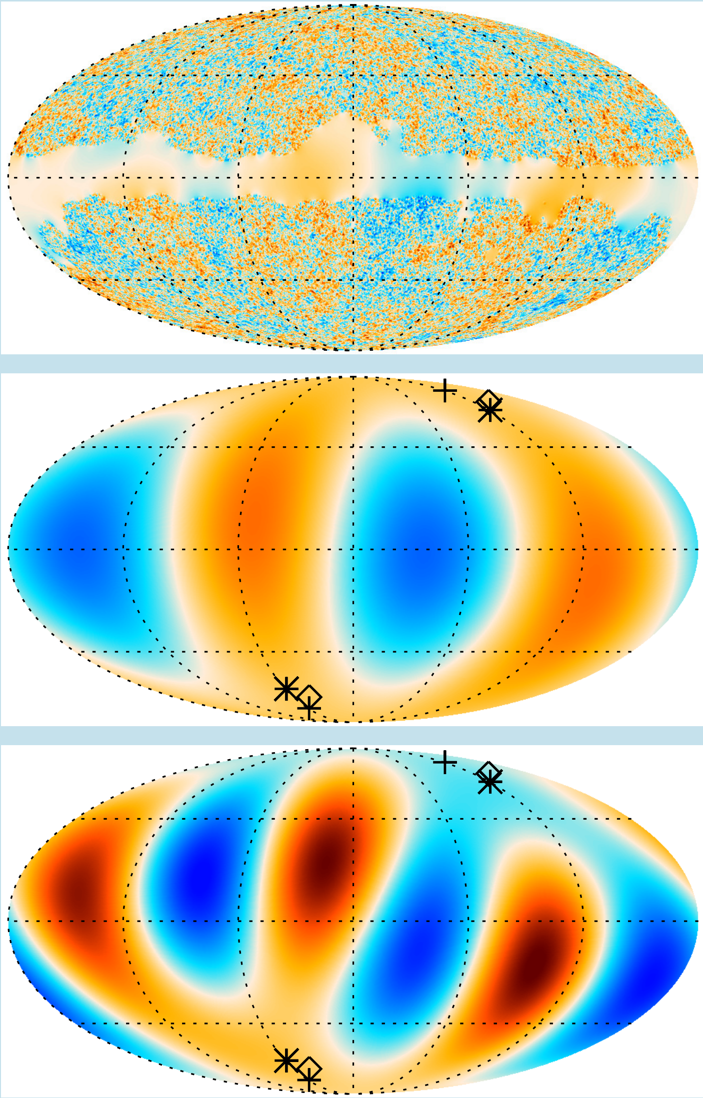


Fig. 17. *Upper*: Wiener-filtered SMICA CMB sky (temperature range ± 400 μK). *Middle*: derived quadrupole (temperature range ± 35 μK). *Lower*: derived octopole (temperature range ± 35 μK). The plus and star symbols indicate the axes of the quadrupole and octopole, respectively, around which the angular momentum dispersion is maximized. The diamond symbols correspond to the quadrupole axes after correction for the kinematic quadrupole.

- Depending on the CS method, quadrupole/octopole alignment between 9 or 13 degrees.
- WMAP reported 6 degrees, when accounting for foreground uncertainties
- Quadrupole includes a kinetic contribution, that is frequency dependent
- Corrections applied to NILC, SEVEM and SMICA, and more consistent results are found, with an alignment of around 8 degrees, implying a 99% significance

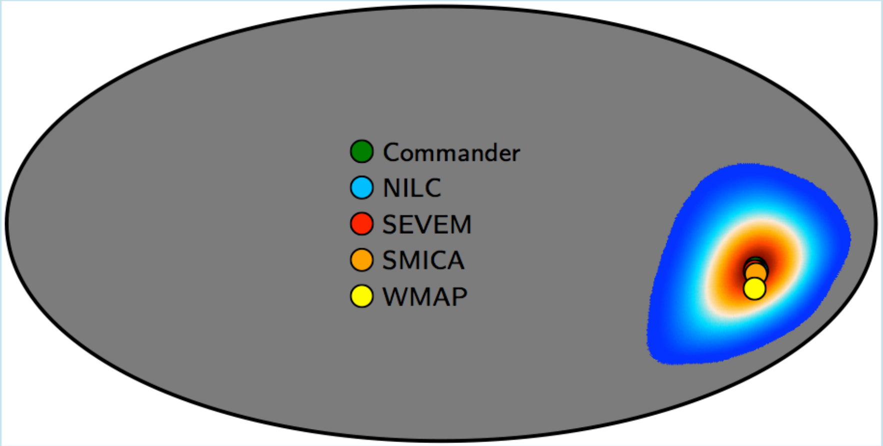
Method	(l,b) quadrupole [°]	(l,b) octopole [°]	Ang. distance [°]	Scalar product	Probability
C-R	(228.2,60.3)	(246.1,66.0)	9.80	0.985	0.019
NILC	(241.3,77.3)	(241.7,64.2)	13.1	0.974	0.033
SEVEM	(242.4,73.8)	(245.6,64.8)	9.08	0.988	0.016
SMICA	(238.5,76.6)	(239.0,64.3)	12.3	0.977	0.032
NILC, KQ corrected	(225.6,69.7)	(241.7,64.2)	8.35	0.989	0.011
SEVEM, KQ corrected	(228.3,68.3)	(245.6,64.8)	7.69	0.991	0.009
SMICA, KQ corrected	(224.2,69.2)	(239.0,64.3)	7.63	0.991	0.009

Asymmetries through Dipolar modulation

Isotropy and Gaussianity

Proposed model:

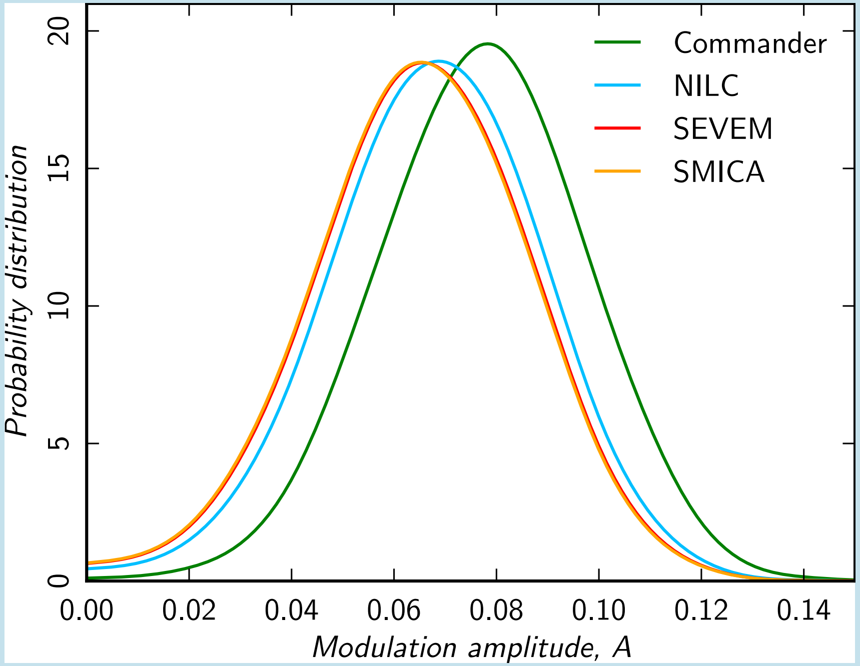
$$\mathbf{d} = (1 + A\,\boldsymbol{p}\cdot\boldsymbol{n})\mathbf{s}_{\rm iso} + \mathbf{n} \equiv \mathsf{M}\mathbf{s}_{\rm iso} + \mathbf{n}$$



(l,b)[º] = (227, -15) +- 19

Maximum-likelihood in real space:

$$\mathcal{L}(A,\boldsymbol{p},q,n) \propto \frac{e^{-\frac{1}{2}\boldsymbol{d}^{\rm T}\left(\mathsf{M}^{\rm T}\mathsf{S}\mathsf{M}+\mathsf{N}+\alpha\sum_i \boldsymbol{f}_i\boldsymbol{f}_i^{\rm T}\right)^{-1}\boldsymbol{d}}}{\sqrt{|\mathsf{M}^{\rm T}\mathsf{S}\mathsf{M}+\mathsf{N}+\alpha\sum_i \boldsymbol{f}_i\boldsymbol{f}_i^{\rm T}|}}$$



approx 3σ detection

Isotropy and Gaussianity

It relies on the **Bipolar Spherical Harmonic** (BipoSH) formalism, that is a **generalization of the angular power spectrum that captures isotropy violation**.

A simple model that results in the violation of statistical isotropy arises from the modulation of the CMB (but not necessary a cosine/dipolar modulation):

$$T(\boldsymbol{n}) = T_0(\boldsymbol{n})\,(1 + M(\boldsymbol{n}))$$

where the **modulation is assumed to be weak**, with quadratic terms neglected.

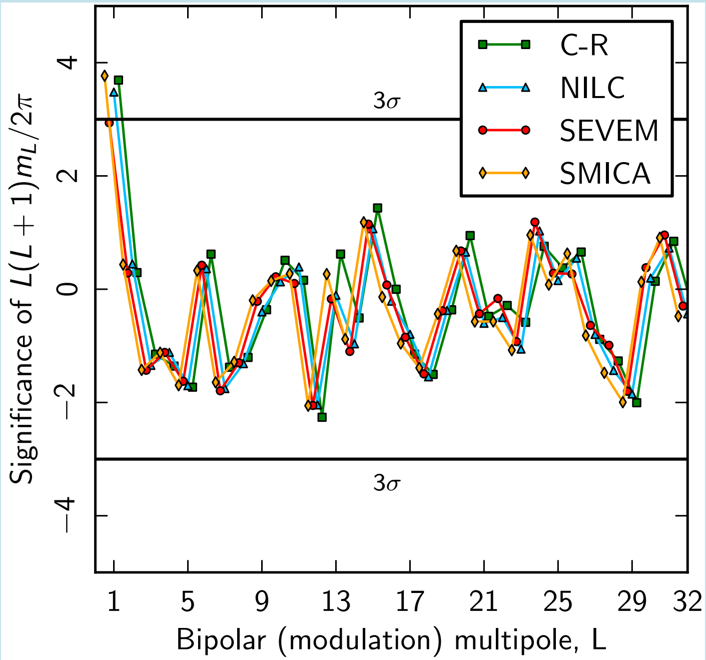


Table 29. Amplitude (A) and direction of the dipole modulation in Galactic coordinates. The measured values of the dipole amplitude and direction are consistent for all maps. The corresponding dipole power for the SMICA map is seen at a detection significance of 3.7 σ, as shown in Fig. 34. For the values in the third column ($\sigma_l = 15.4, \sigma_b = 15.1$).

Map	A	(l, b) [°]
C-R	$0.072^{+0.010}_{-0.010}$	(218.9, −21.4)
NILC	$0.070^{+0.010}_{-0.010}$	(220.3, −20.2)
SEVEM	$0.065^{+0.011}_{-0.011}$	(221.7, −21.4)
SMICA	$0.073^{+0.010}_{-0.010}$	(217.5, −20.2)

Only evidence of deviation for L=1, i.e, a dipolar modulation

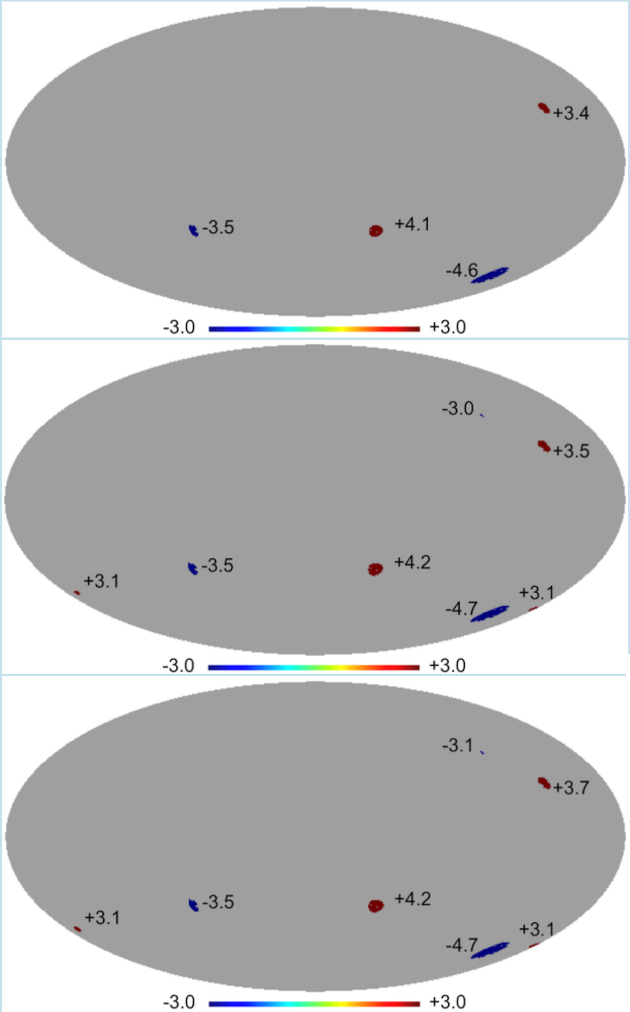
Isotropy and Gaussianity

Area of the SMHW coefficients

U73 mask

CG70 mask

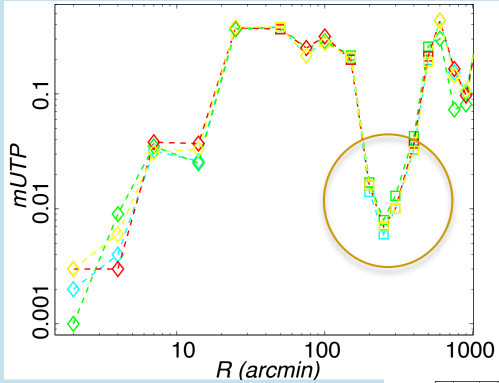
CG60 mask



UTP, $\nu>\sigma_R$

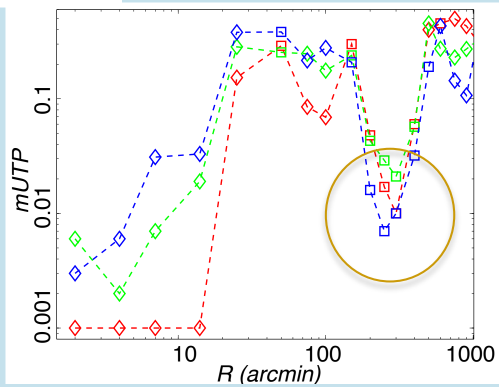
Area	Scale [′]	UTP C-R	UTP NILC	UTP SEVEM	UTP SMICA
Cold	200	1.6	1.1	1.2	1.1
	250	0.3	0.3	0.3	0.3
	300	0.3	0.3	0.3	0.3
Hot	200	2.3	1.6	1.8	1.6
	250	2.7	2.2	2.4	2.2
	300	4.9	3.7	4.1	3.8

Kurtosis of the SMHW coefficients



Commander-Ruler
NILC
SEVEM
SMICA

CG70 mask
U73 mask
CG60 mask



Isotropy and Gaussianity

- Many features previously detected in WMAP data are also presented in Planck, **which rules out systematics as a source for them**.
- There is **evidence of statistical isotropy violation on large angular scales**.
- Moreover, **a dipolar power asymmetry may extend up to l=600**
- Could be related to the **low-multipole spectrum departute from the Planck fiducial**
- Which is the origin of the anomalies?
  - Solar System emission as responsible for the large scale departures?
  - Coming from the local universe, via ISW ➔ hints of some tension reduction for some anomalies
  - Gravitational lensing, Rees-Sciama or cosmic textures responsible for the Cold Spot?

Polarization will help to respond to some of these open questions

Isotropy and Gaussianity

Besides that:

- No detection of non-trivial topology
- Good fitting of a Bianchi VII_h anisotropic model, but *non-physical*
- Upper limits on the amplitude of topological defects (strings: $G\mu/c2 < 1.3\text{x}10^{-7}$ at 95%). Limits around 6 times better from power spectrum than from NG analyses
- Upper limits on the amplitude of Alfvén waves produced by primordial magnetic fields ($A_\nu \nu^2 < 2.18\text{x}10^{-11}$ at 95%)

- Residual point sources background detected (through the bi-spectrum) at 4σ level
- Anisotropic pattern from Doppler boost detected at ≅ 2σ
- ISW-lensing detected at 2.6σ (see later)

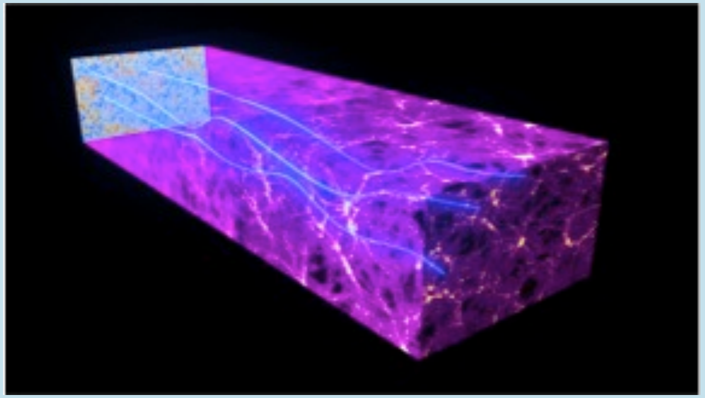
Secondary anisotropies

Planck has also provided information on secondary anisotropies caused by the LSS on the CMB photons generated in the last scattering surface:

- Deflection of the photons path ➔ **lensing**
- Gain/lost of energy caused by the gravitational potential field ➔ **ISW**
- Scattering with the free electrons in the intergalactic medium ➔ **SZ** (see **J.A. Rubiño-Martín talk**)

Lensing

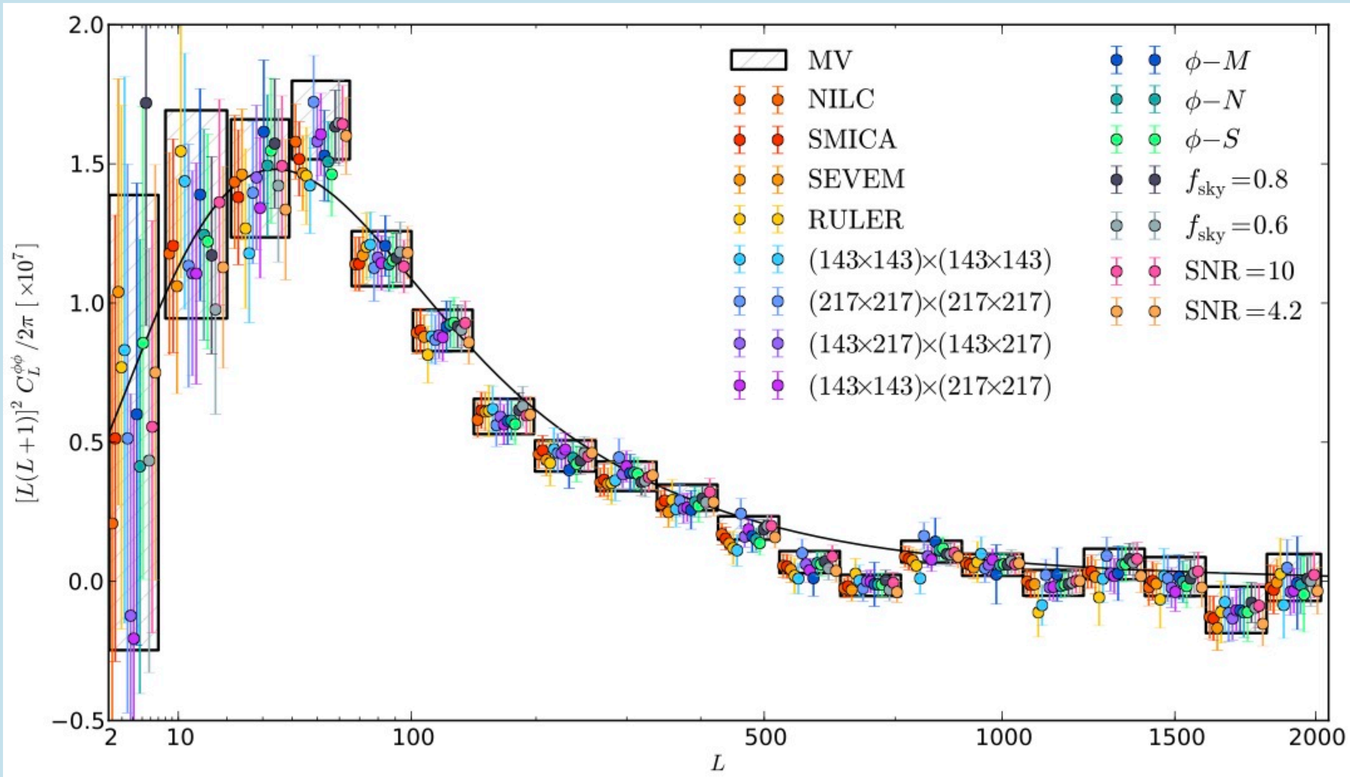
Secondary anisotropies



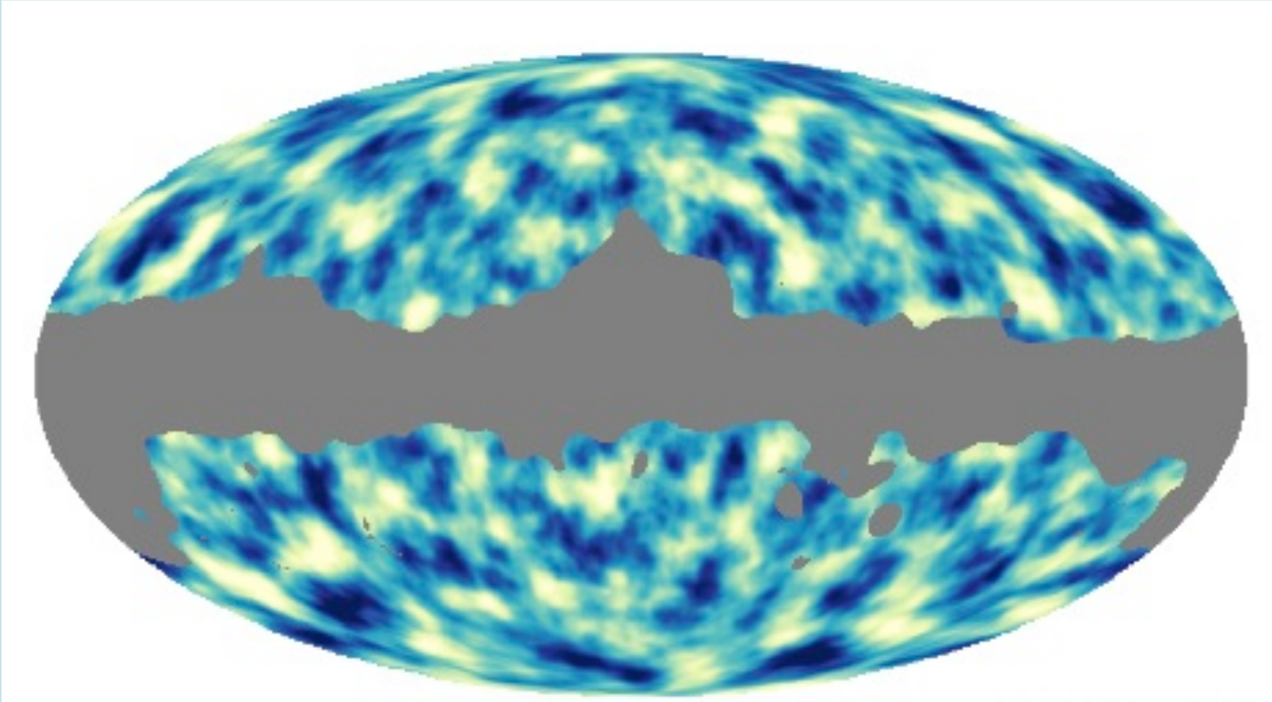
The lensing signal is detected at 25σ.

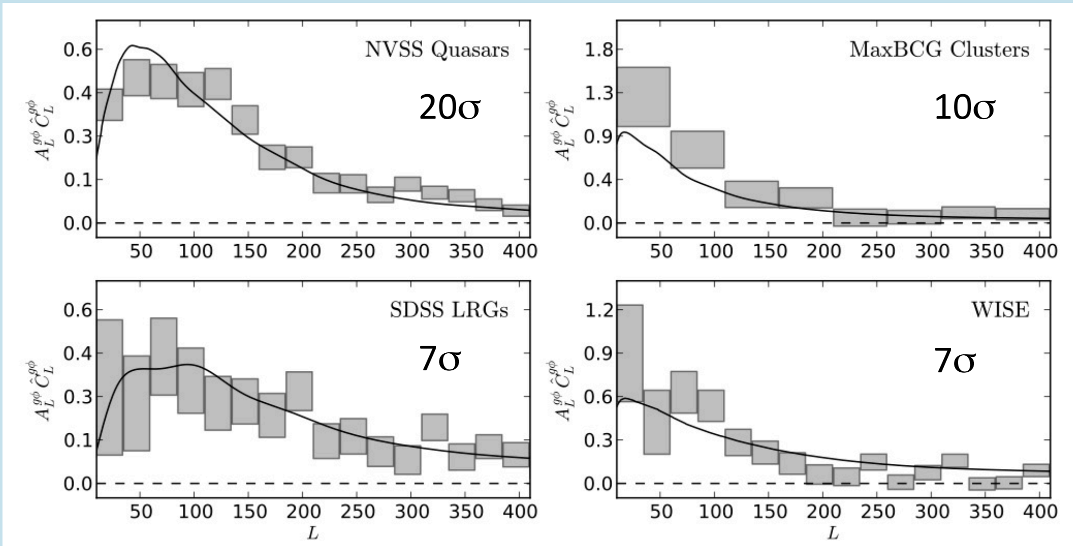
It improves constraints obtained by the Planck alone likelihood: in particular curvature and τ-A_s degeneracy

Robustness against foregrounds: consistency among CMB solutions



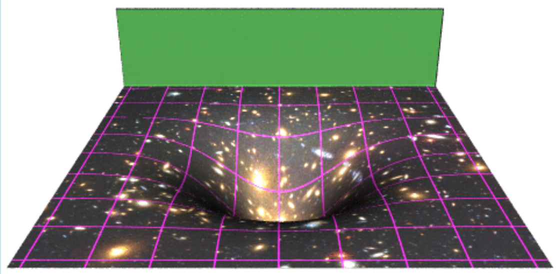
Secondary anisotropies





Correlation with LSS tracers.

Secondary anisotropies



[Granett et al.]

The **ISW** is a **weak signal**, which contribution to the CMB anisotropies is subdominant: it is **covered by the primordial fluctuations** at very large scale.

Planck has studied through 4 complementary approaches:

- ISW-lensing bispectrum
- Cross-correlation with LSS surveys
- Stacking of the CMB fluctuations on the positions of known structures
- Map recovery

Secondary anisotropies

The ISW detection: the ISW-lensing bispectrum

Planck has provided the **1st detection of the ISW by using only CMB data**, via the ISW-lensing bispectrum.

Error bars are derived from coherent simulations, according to the best-fit Planck alone parameters.

Table 2. Amplitudes $A^{T\phi}$, errors σ_A and significance levels of the non-Gaussianity due to the ISW effect, for all component separation algorithms (C-R, NILC, SEVEM, and SMICA) and all the estimators (potential reconstruction, KSW, binned, and modal). For the potential reconstruction case, an additional minimum variance (MV) map has been considered (see Planck Collaboration XVII 2013 for details).

Estimator		C-R		NILC		SEVEM		SMICA		MV	
$T\phi$	$\ell \geq 10$	0.52 ± 0.33	1.5	0.72 ± 0.30	2.4	0.58 ± 0.31	1.9	0.68 ± 0.30	2.3	0.78 ± 0.32	2.4
	$\ell \geq 2$	0.52 ± 0.32	1.6	0.75 ± 0.28	2.7	0.62 ± 0.29	2.1	0.70 ± 0.28	2.5		
KSW		0.75 ± 0.32	2.3	0.85 ± 0.32	2.7	0.68 ± 0.32	2.1	0.81 ± 0.31	2.6		
binned		0.80 ± 0.40	2.0	1.03 ± 0.37	2.8	0.83 ± 0.39	2.1	0.91 ± 0.37	2.5		
modal		0.68 ± 0.39	1.7	0.93 ± 0.37	2.5	0.60 ± 0.37	1.6	0.77 ± 0.37	2.1		

This ISW-lensing bispectrum induces **a bias on local f_{NL} of around 7**.

Secondary anisotropies

The ISW with Planck: cross-correlation with LSS tracers

Table 6. Amplitudes A, errors σ_A and significances A/σ_A of the CMB-LSS cross-correlation (survey by survey and all together) due to the ISW effect, for all component separation algorithms (C-R, NILC, SEVEM, and SMICA) for the CAPS, CCF, and SMHWcov estimators.

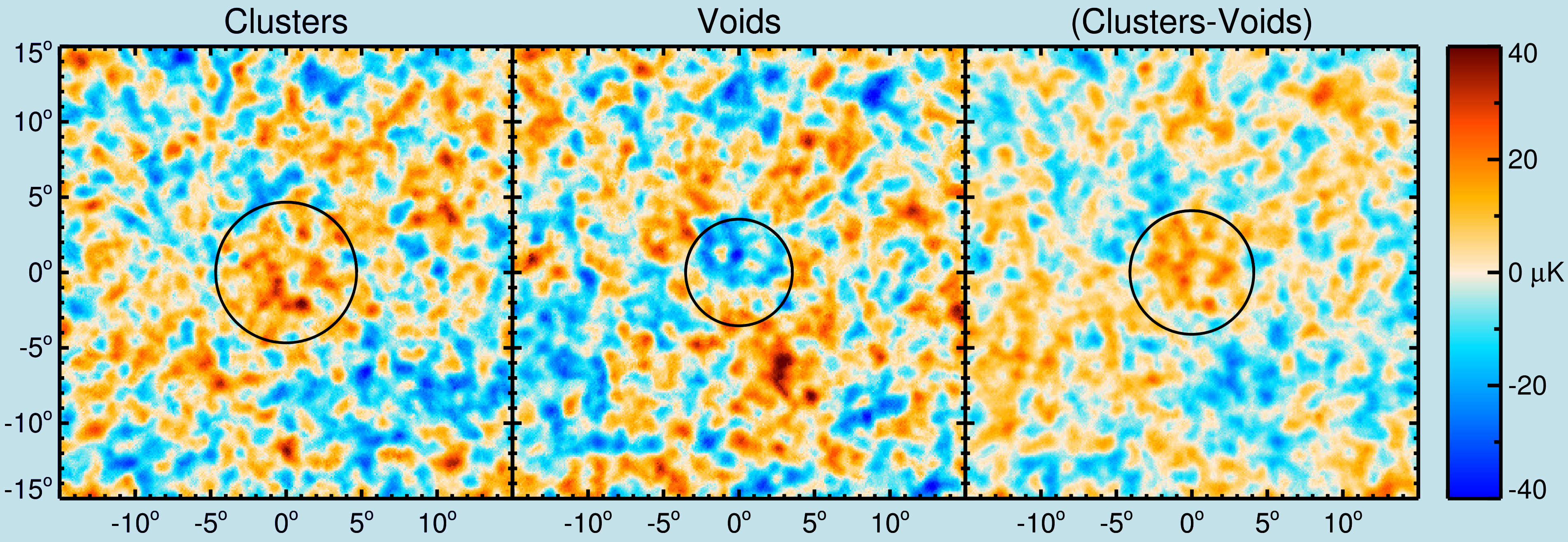
LSS data	$\hat{\xi}_a^{xy}$	C-R		NILC		SEVEM		SMICA	
NVSS	CAPS	0.86 ± 0.33	2.6	0.91 ± 0.33	2.8	0.90 ± 0.33	2.7	0.91 ± 0.33	2.7
	CCF	0.80 ± 0.33	2.4	0.84 ± 0.33	2.5	0.83 ± 0.33	2.5	0.84 ± 0.33	2.5
	SMHWcov	0.89 ± 0.34	2.6	0.93 ± 0.34	2.8	0.89 ± 0.34	2.6	0.92 ± 0.34	2.7
SDSS-CMASS/LOWZ	CAPS	0.98 ± 0.52	1.9	1.09 ± 0.52	2.1	1.06 ± 0.52	2.0	1.09 ± 0.52	2.1
	CCF	0.81 ± 0.52	1.6	0.91 ± 0.52	1.8	0.89 ± 0.52	1.7	0.90 ± 0.52	1.7
	SMHWcov	0.80 ± 0.53	1.5	0.89 ± 0.53	1.9	0.87 ± 0.53	1.6	0.88 ± 0.53	1.7
SDSS-MG	CAPS	1.31 ± 0.57	2.3	1.43 ± 0.57	2.5	1.35 ± 0.57	2.4	1.42 ± 0.57	2.5
	CCF	1.00 ± 0.57	1.8	1.11 ± 0.57	2.0	1.10 ± 0.57	1.9	1.10 ± 0.57	1.9
	SMHWcov	1.03 ± 0.59	1.8	1.18 ± 0.59	2.0	1.15 ± 0.59	2.0	1.17 ± 0.59	2.0
all	CAPS	0.84 ± 0.31	2.7	0.91 ± 0.31	2.9	0.88 ± 0.31	2.0	0.90 ± 0.31	2.9
	CCF	0.77 ± 0.31	2.5	0.83 ± 0.31	2.7	0.82 ± 0.31	2.6	0.82 ± 0.31	2.7
	SMHWcov	0.86 ± 0.32	2.7	0.92 ± 0.32	2.9	0.89 ± 0.32	2.8	0.91 ± 0.32	2.9

Lower detections than those previously reported from WMAP. Two major reasons:

- Better agreement between the estimated amplitude and the expected value: 1σ or 2σ vs 0.5σ ➔ catalogues description?
- Planck Ω_Λ **lower** than WMAP one ➔ "**less ISW effect**" **(~10%)**

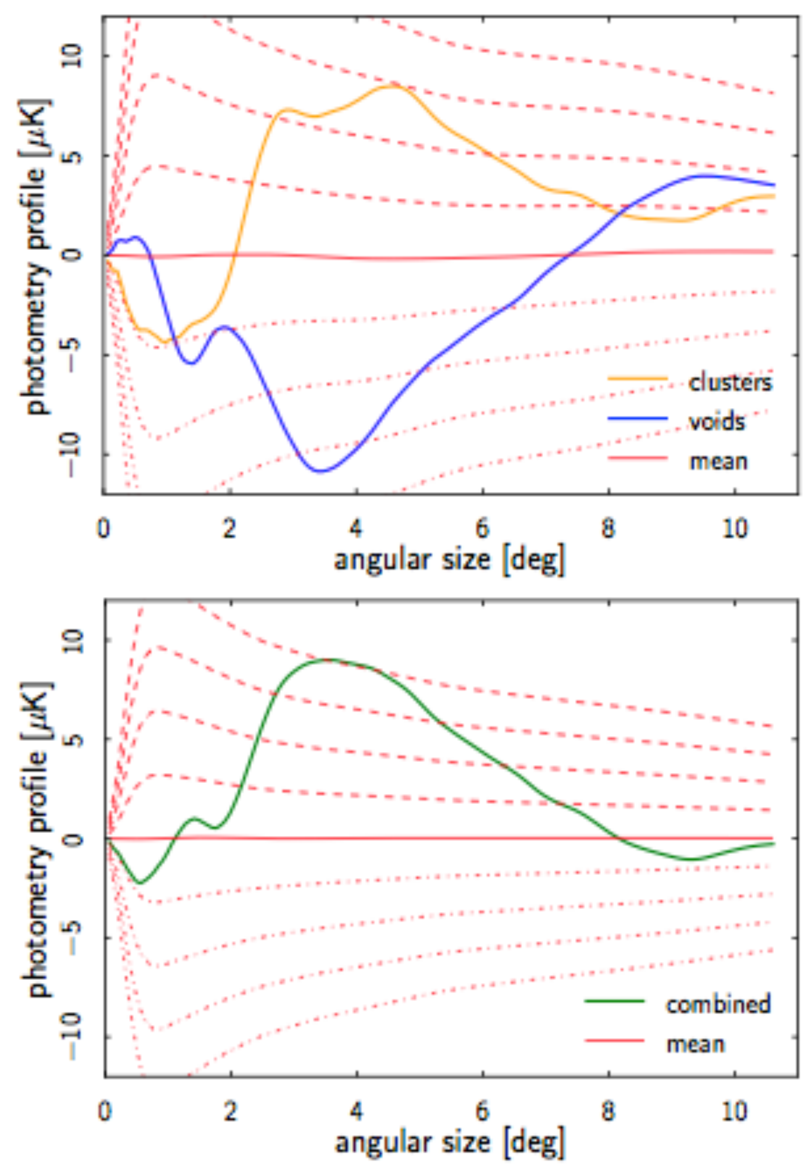
Secondary anisotropies

The ISW with Planck: Stacking on the position of large structures



Stacked regions of Planck SMICA map corresponding to the positions of the 50 superclusters (left) and 50 **supervoids** (center) of the Grannet et al. 2008 catalogue. Right ➔ **combined** structures. Circles indicate the scale at which the s2n of the photometry is maximal.

Secondary anisotropies



Amplitude and shape of the photometric profile is in tension with the ΛCDM expectations (a factor of 2 at least):

- Max void signal -11.3μK at 3.5º ➔ 3.3σ
- Max cluster signal +8.5μK at 4.7º ➔ 3.0σ
- Max combined signal +8.7μK at 4.1º ➔ 4.0σ

Voids give more signal than clusters, opposite to expectations.

The relative size at which the signal is maximum is 2.6 and 1.3 times the radius of clusters and voids, respectively. Value for clusters seems too large.

Lowest multipole removed from the maps to avoid gradients.

Secondary anisotropies

The ISW map recovery

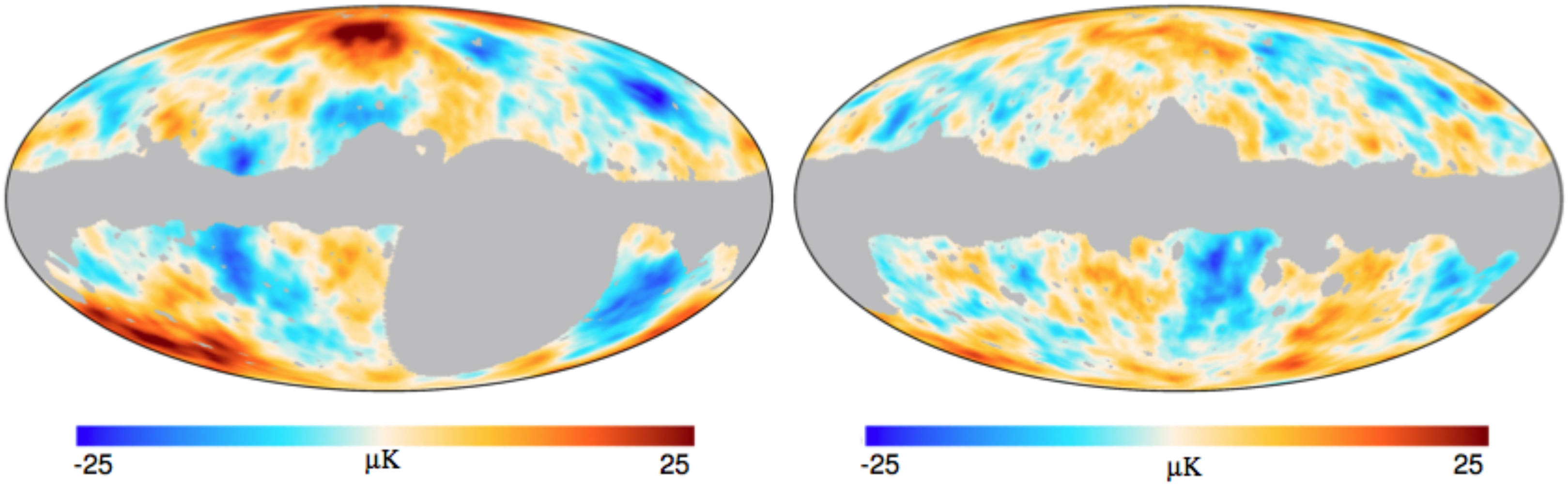


Fig. 11. Reconstructed ISW map from the *Planck* CMB and NVSS data (left) and from the *Planck* CMB and lensing potential maps (right). Note that the maps are not expected to look exactly the same, since each of them provides a partial reconstruction of the noisy ISW signal (see Sect. 6.2 for details).

$$\hat{s}_{\ell m} = \frac{L_{12}(\ell)}{L_{11}(\ell)} g_{\ell m} + \frac{L_{22}^2(\ell)}{L_{22}^2(\ell) + C_\ell^{\rm n}} \left(d_{\ell m} - \frac{L_{12}(\ell)}{L_{11}(\ell)} g_{\ell m} \right)$$

Recovered ISW ($\hat{s}_{\ell m}$)

CMB clean map ($d_{\ell m}$)

LSS tracer map ($g_{\ell m}$)

Covariance Matrix

$$\mathbf{C}(\ell) = \begin{pmatrix} C_\ell^g & C_\ell^{sg} \\ C_\ell^{sg} & C_\ell^s \end{pmatrix}$$

$$\mathbf{C}(\ell) = \mathbf{L}(\ell)\mathbf{L}^T(\ell)$$

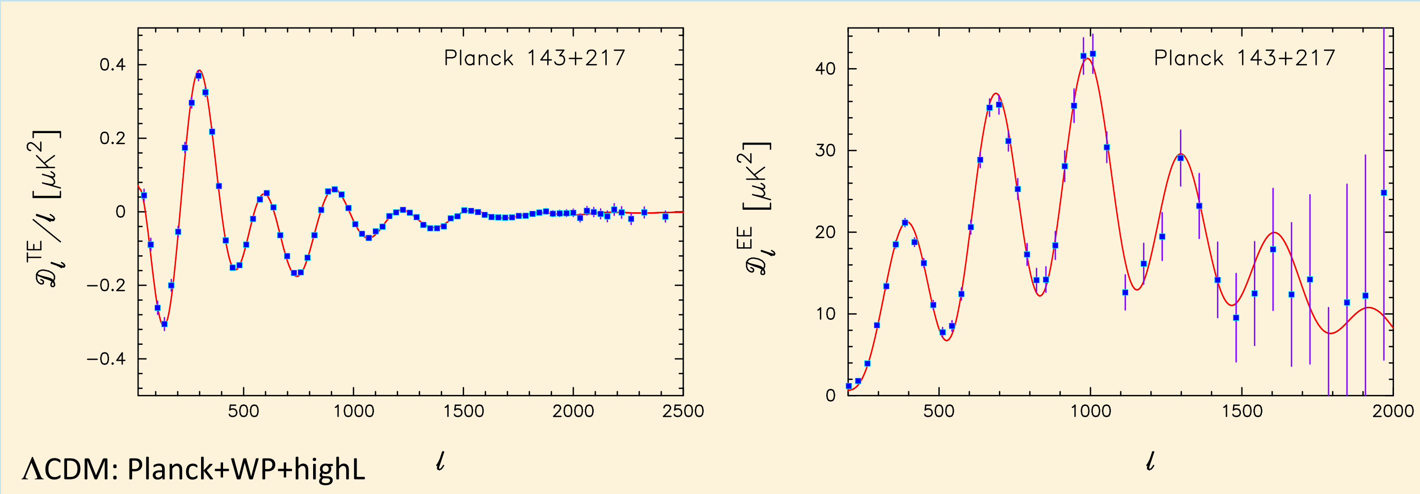
Cholesky blocks

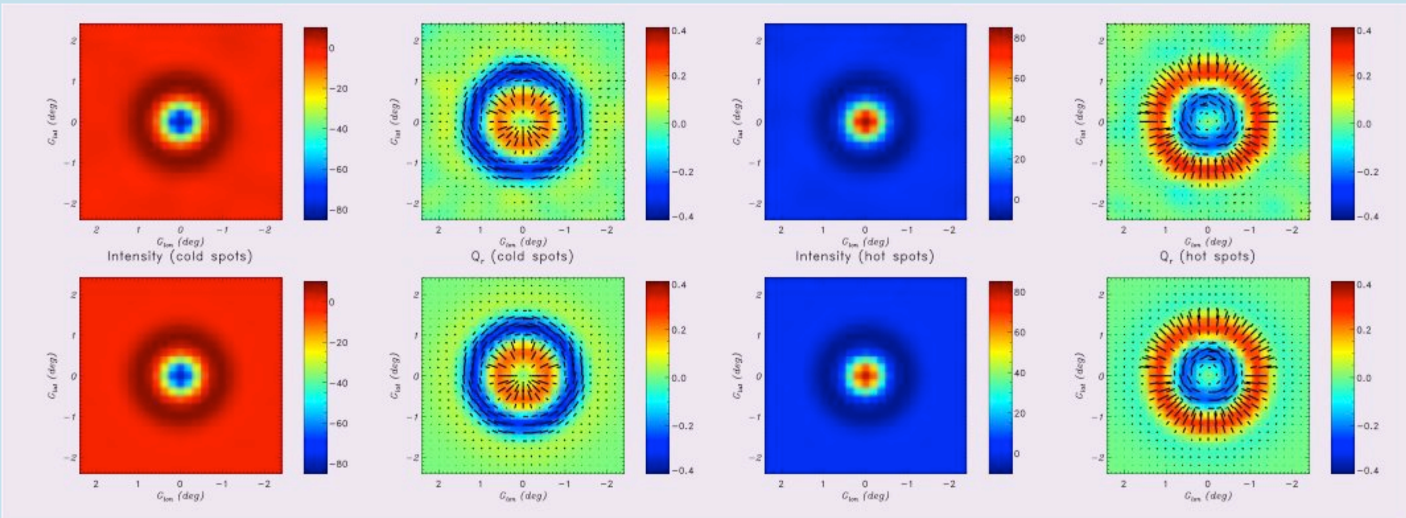
$$L_{11} = \sqrt{C_\ell^g}, L_{12} = C_\ell^{sg}/\sqrt{C_\ell^g}$$

$$L_{22} = \sqrt{|\mathbf{C}(\ell)|/C_\ell^g}$$

Polarization coming this October!

Polarization premier already shown in 2013 publications





Polarization coming this October!

Among other outcomes, we expect to:

- Provide a full description of the CMB angular power spectra and the corresponding likelihood to constrain cosmological parameters
- Reduce the uncertainties in some cosmological parameters
- Improve our knowledge of the physics of reionization
- Provide a model of the foregrounds polarization, and a description of the limitations imposed by them when constraining cosmology
- Improve our knowledge of the lensing potential
- Study the origin of the large-scale anomalies
- Probe further the anomalous ISW signal

Summary

- Planck is an amazing experiment
- It will fix the CMB science related to TT, TE and EE spectra for many years
- Besides its nominal capabilities to detect gravitational waves with r ≥0.05 (not considering here instrumental and astrophysical systematics), it will provide a capital description of the foreground emissions, which will be very important for on-going ground-based experiments
- Planck Legacy will be essential to exploit commentary cosmological probes as the galaxy surveys
- Large-scale anomalies confirmed by Planck have open an exiting opportunity for theoreticians to explore non-standard models to explain them

The scientific results here presented are a product of the Planck Collaboration, including individuals from more than 1000 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.