



planck



Planck Cosmological Results

13 papers

About 500 pages !

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On behalf of the Planck Collaboration



3€⁹⁹ COLLECTION
LE MONDE EST MATHÉMATIQUE
N°1
EN KIOSQUES DÈS AUJOURD'HUI
EN FRANCE MÉTROPOLITAINE

Le Monde

**LE MONDE
DES LIVRES**
SUPPLÉMENT
12 PAGES

CRISE CHYPRIOTE : L'ULTIMATUM DE FRANCFORT

ÉCONOMIE – LIRE PAGE 12



En Tunisie, le drame des disparus de la révolution

ENQUÊTE – LIRE PAGE 16



DES GTI POUR ROULER DES MÉCANIQUES

CULTURE & STYLES – LIRE PAGE 24

Vendredi 22 mars 2013 - 69^e année - N°21204 - 1,80 € - France métropolitaine - www.lemonde.fr —

Fondateur : Hubert Beuve-Méry - Directrice : Natalie Nougayrède

Moins d'impôts et plus d'austérité, Londres persiste

- Le Royaume-Uni fait cavalier seul en matière fiscale et décide 13 milliards d'euros de coupes budgétaires
- En panne de croissance comme le reste de l'Europe, Londres mise toujours plus sur la Banque d'Angleterre
- L'efficacité des politiques d'austérité en question

LIRE P. 13 ET LA CHRONIQUE D'ALAIN FRACHON P. 20



LE MONDE DES LIVRES

Spécial Salon du livre de Paris

- Barcelone ville invitée, Roumanie à l'honneur
- Quelle littérature enseignée au collège et au lycée ? Regards d'auteurs et d'enseignants
- Le livre numérique peine à décoller

SUPPLÉMENT, DÉBATS P. 18-19 ET P. 14

C'ÉTAIT L'UNIVERS IL Y A 13,8 MILLIARDS D'ANNÉES

■ Des images inédites du satellite européen Planck dévoilent l'enfance du monde. Ni étoile ni galaxie, mais des particules microscopiques, des électrons et des protons **LIRE PAGES 2-3**

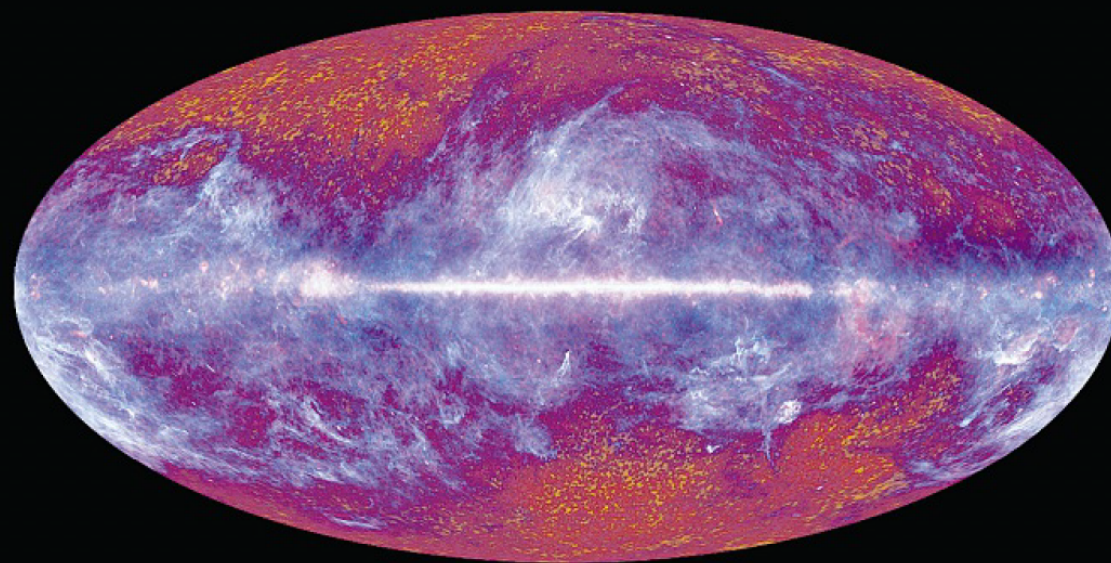
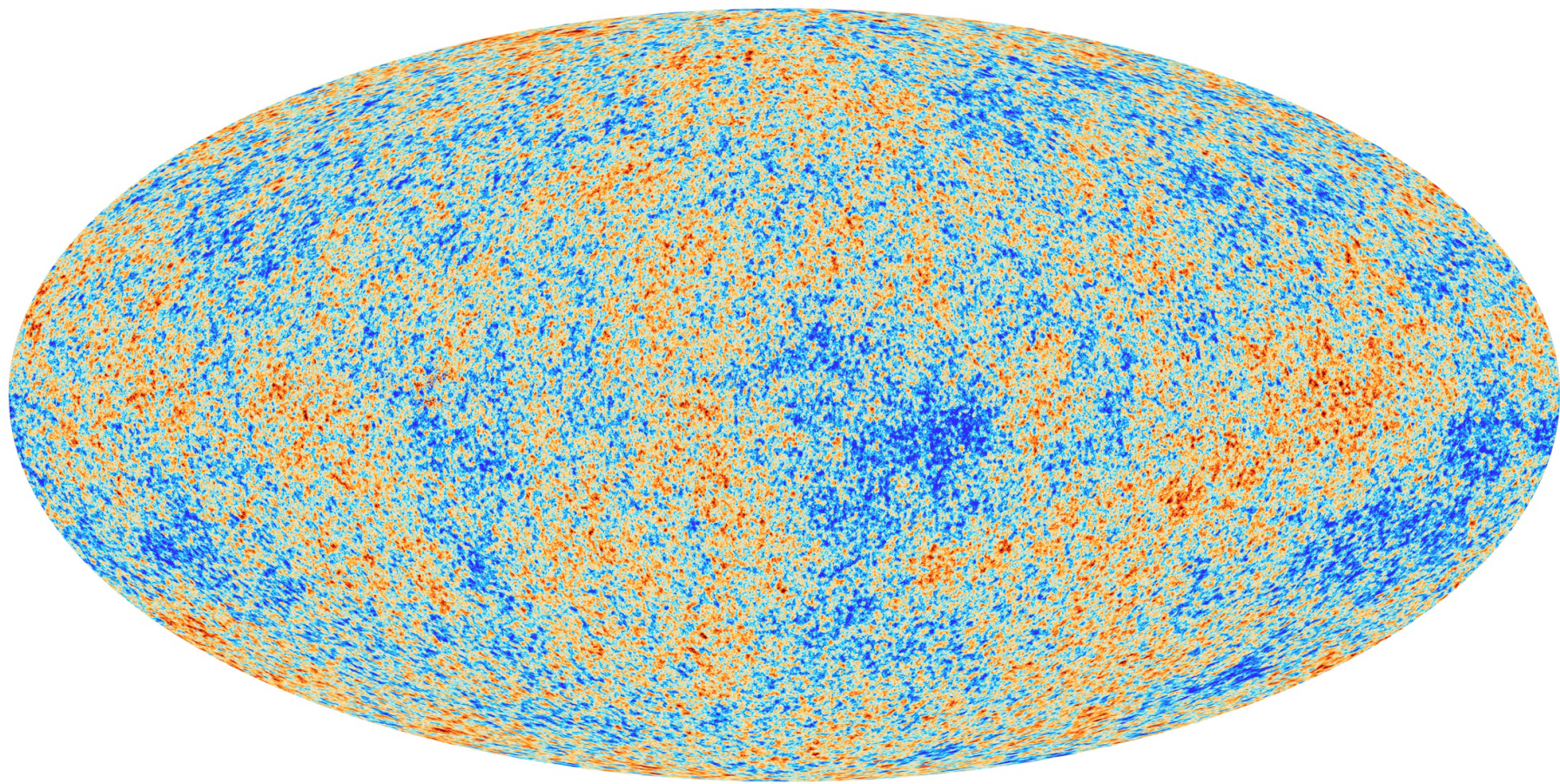


Image du rayonnement
primordial de l'Univers
prise par le satellite
européen Planck. ESA



Outline

- ➔ • The Planck mission
 - Planck data and CMB results
 - Cosmological astrophysics
 - The future

The Planck satellite



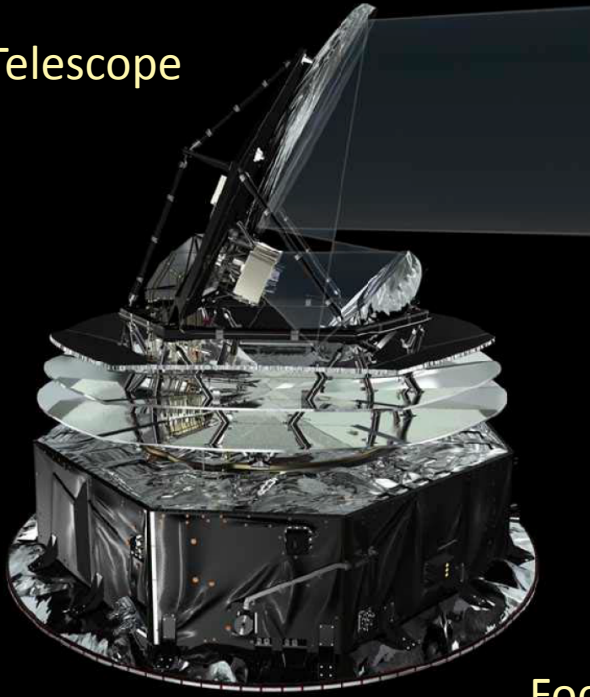
The Planck design

- **The "ultimate" measurement of CMB temperature**
 - Down to the "smallest CMB scales" (5 arcminutes)
 - Large telescope (1.5 m projected diameter)
 - Some channels at small wavelengths ($\theta \approx \lambda/D$)
 - Sensitivity (fraction of a μK per square degree)
 - Not limited by instrumental noise
 - In some channels, photon noise dominates
 - Cryogenic mission (100 mK bolometers, 20K radiometers)
 - Intrinsic limitations due to foreground emissions
 - Full sky survey at 9 frequencies from 30 to 850 GHz
 - Identify unambiguously CMB by its spectral emission law
 - Subtract foreground contamination to Planck accuracy (!)
 - Two instruments LFI (radiometers) and HFI (bolometers)
- **A very good measurement of CMB polarisation**

Planck fact sheet - 1

- 52 bolometers (HFI) et 22 radiometers (LFI)
- Off-axis Gregorian telescope: primary 1.5m, secondary 1m, main axis pointing at 85 degrees away from the spin axis
- Cryogenic mission:
 - warm launch
 - passive cooling of the telescope
 - complex cryogenic chain
 - 2 cryo-coolers (20 and 4 K)
 - open-cycle dilution ^3He - ^4He fridge fo 1.6K and 0.1K (48.000 litres of Helium)
- 2kW power

Telescope

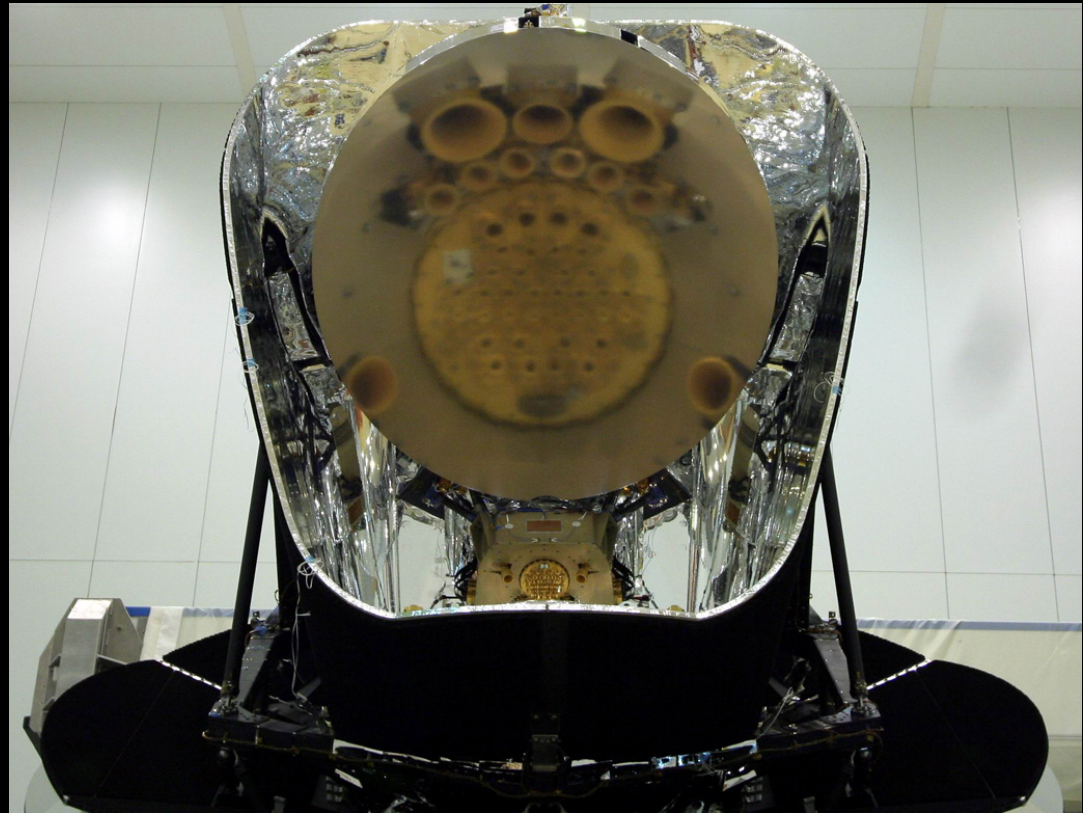
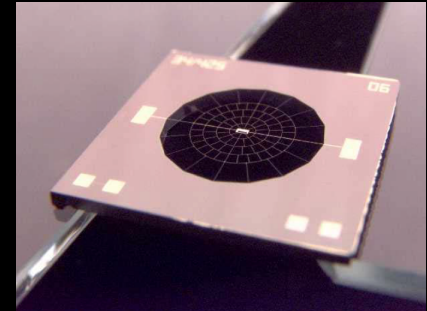


Focal
plane

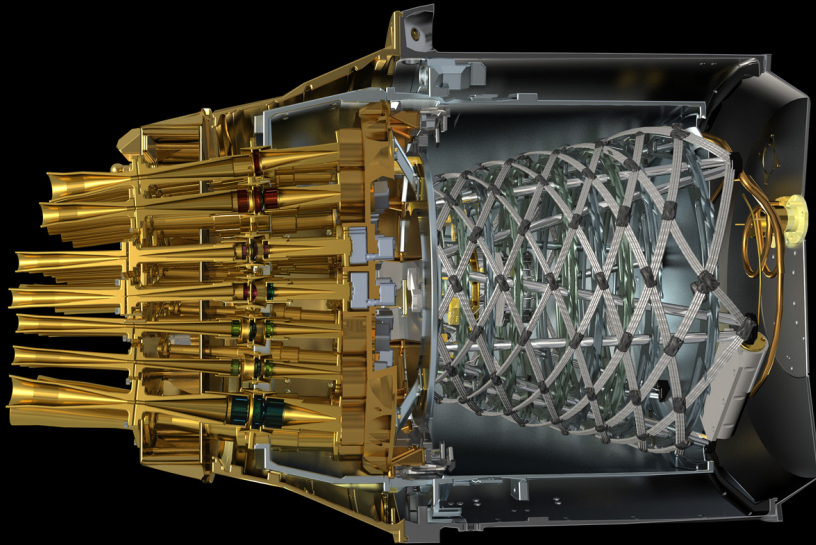


The Payload

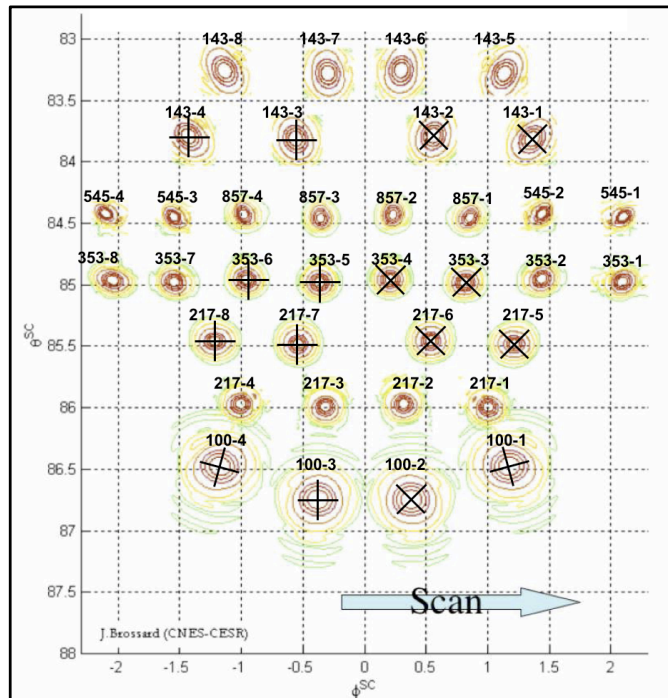
Spiderweb
bolometer



Planck HFI and global view

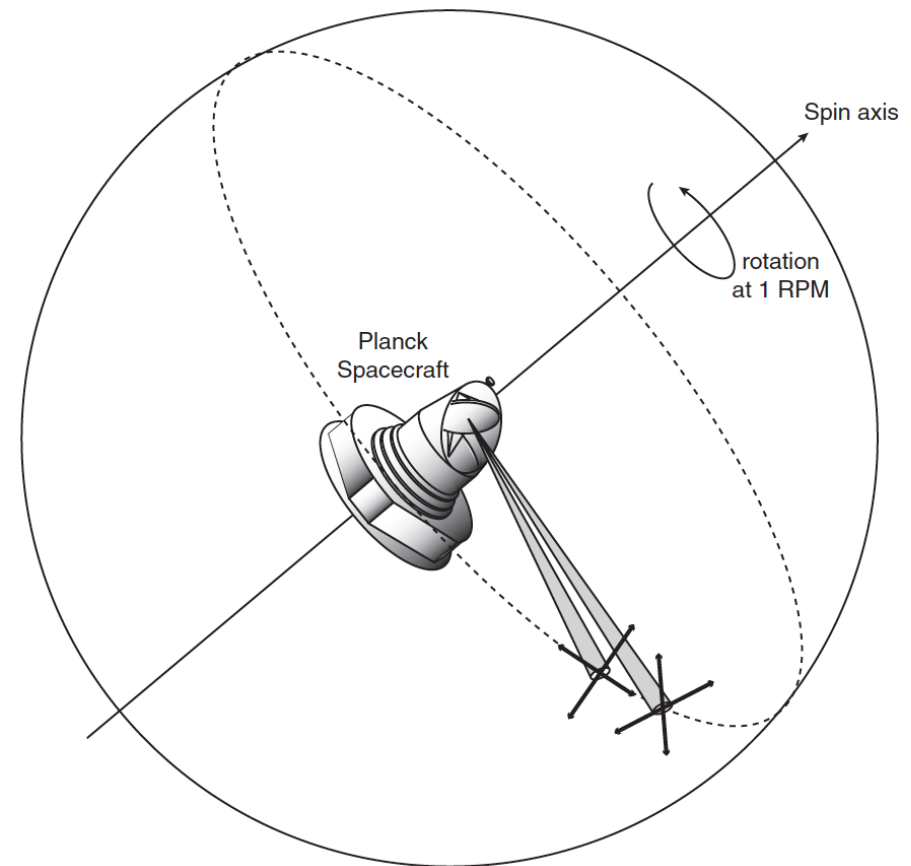


Planck scanning the sky



Measure 3 Stokes parameters

$$\begin{aligned}
 I &= |E_0|^2 + |E_{90}|^2 \\
 Q &= |E_0|^2 - |E_{90}|^2 \\
 U &= |E_{45}|^2 - |E_{135}|^2
 \end{aligned}$$



Planck fact sheet - 2

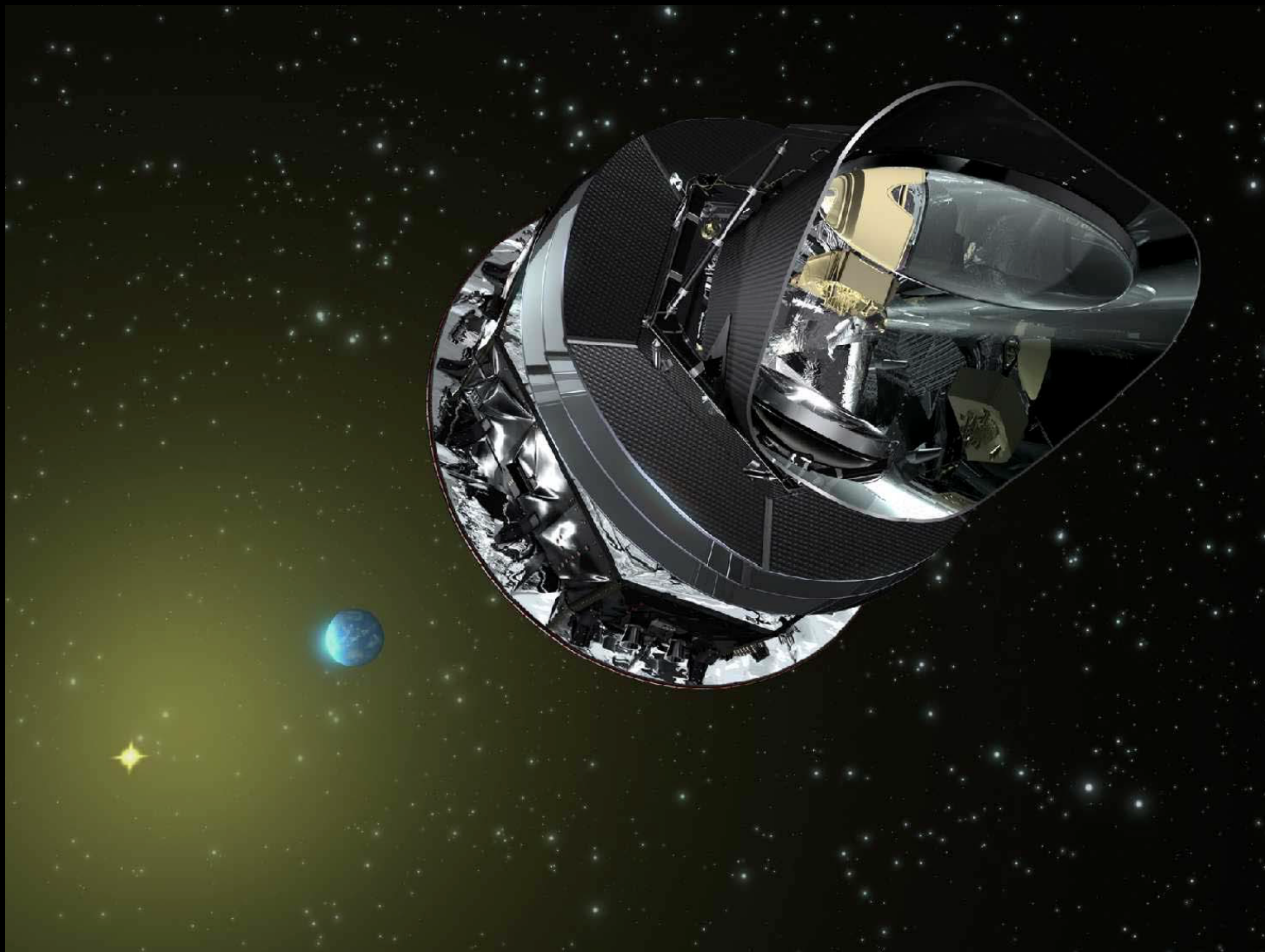
- 1900 kg at take-off
 - (Ariane 5, 14 may 2009)
- Small halo orbit
 - around Lagrange point L2
- Scanning at 1 rpm
- 4 complete maps of the continuum sky at 9 frequencies:
30-850 GHz (1 cm - 350 microns)
- Telemetry: 100 kbit/s (3 hours download per day), 2 TBytes per year



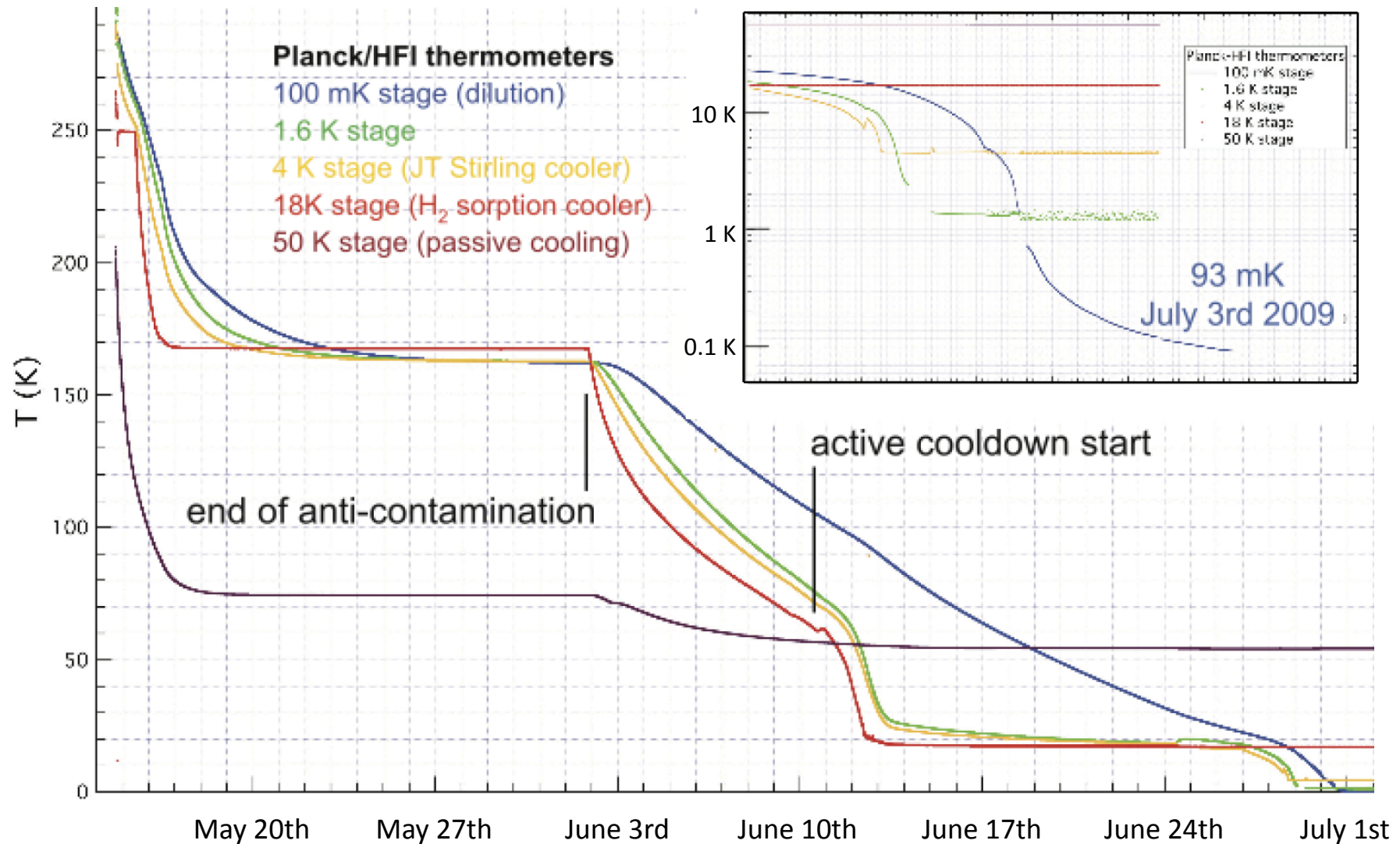
Kourou, 14th May 2009 !



En route to L2



Planck cooling down



Planck fact sheet - 3

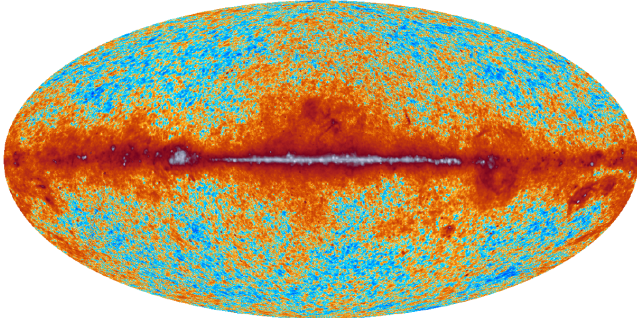
- Made by
 - Agencies: ESA, CNES, ASI, NASA
 - Industry: Thales-Alenia Space, Air Liquide
 - Research and higher education: CNRS, CEA, universities, 13 labs
- The scientists
 - 29 laboratories, 300-600 scientists
- Cost
 - About 650 M€ total (mission + instruments)
 - 450 M€ ESA cost (M mission)
 - HFI instrument: 150 M€, (56% France)

Outline

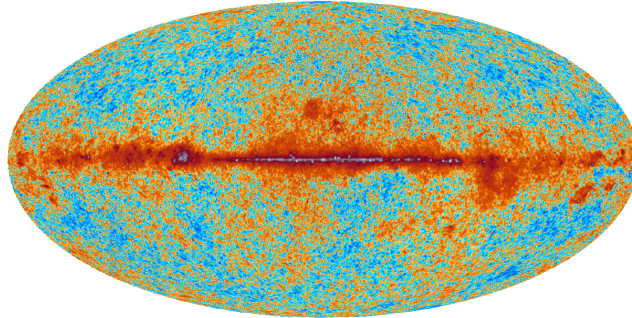
- The Planck mission
- ➔ • Planck data and CMB results
- Cosmological astrophysics
- The future

Observed maps

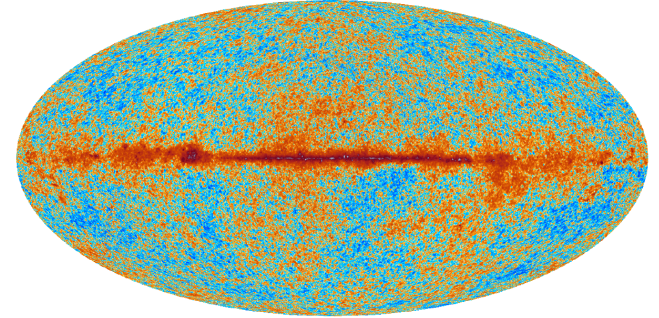
30 GHz



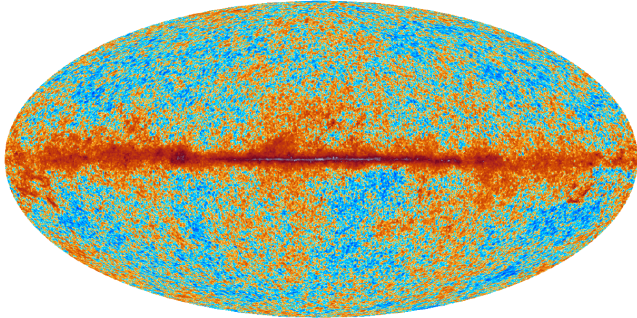
44 GHz



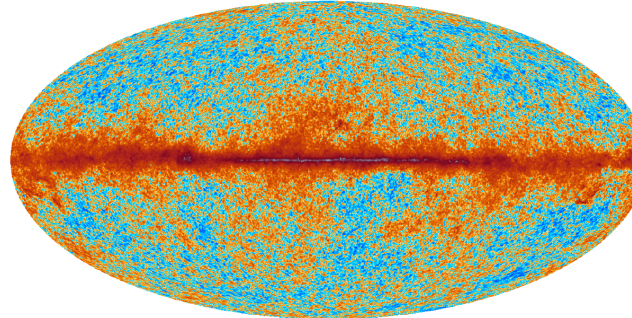
70 GHz



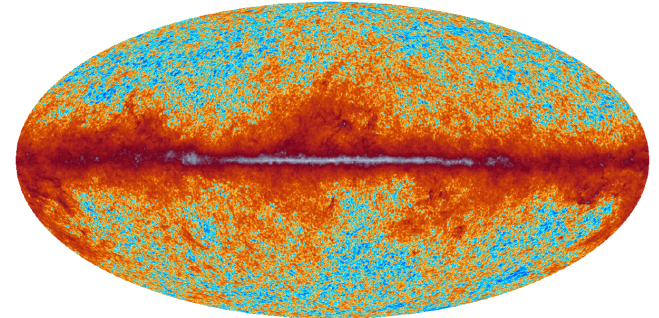
100 GHz



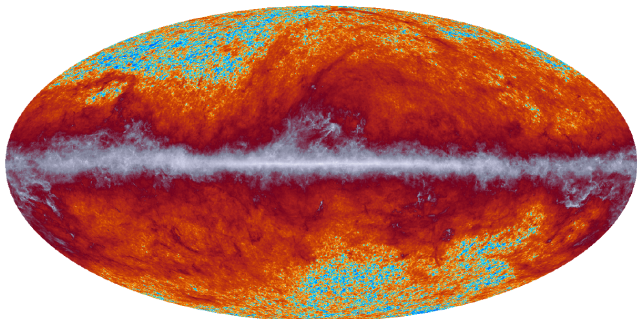
143 GHz



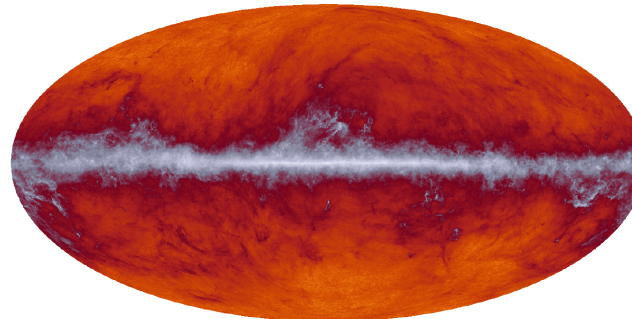
217 GHz



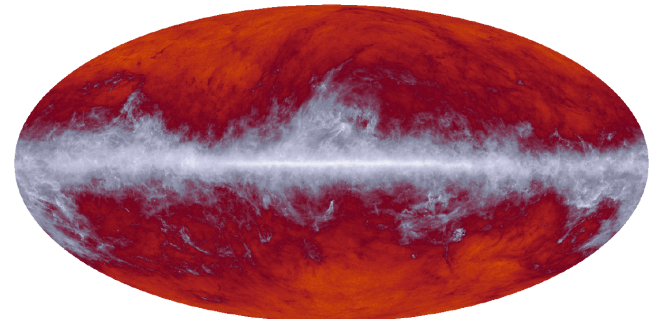
353 GHz



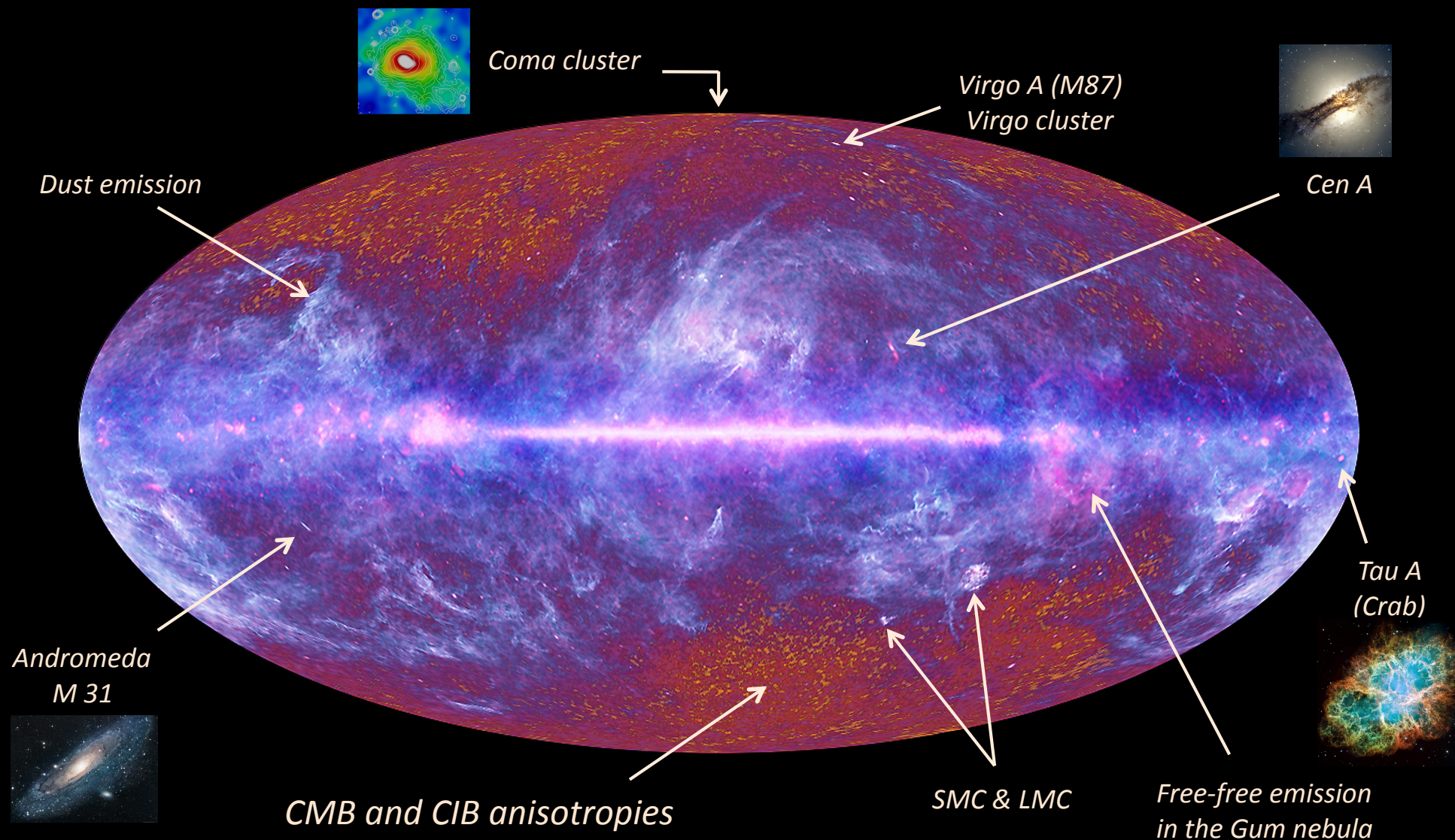
545 GHz



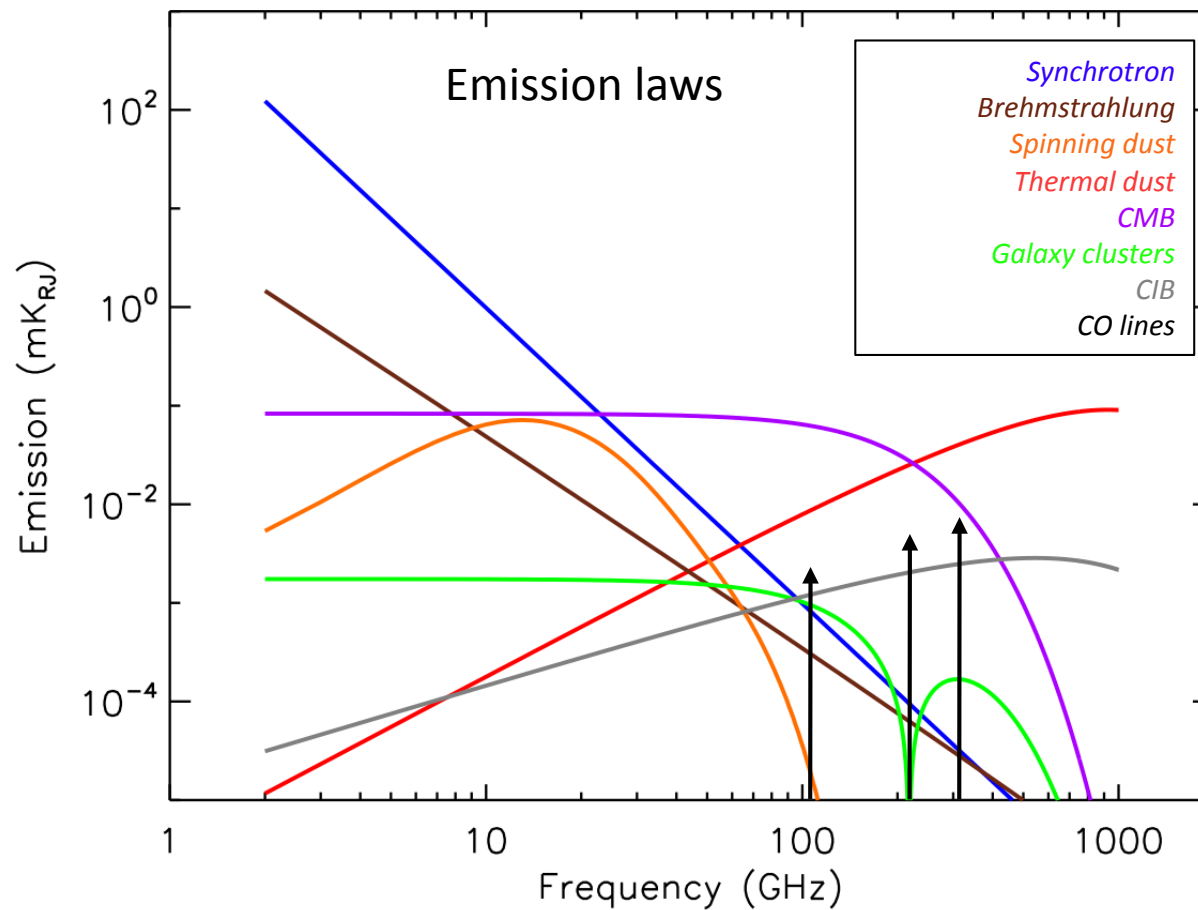
857 GHz



The sub-millimetre sky seen by *Planck*

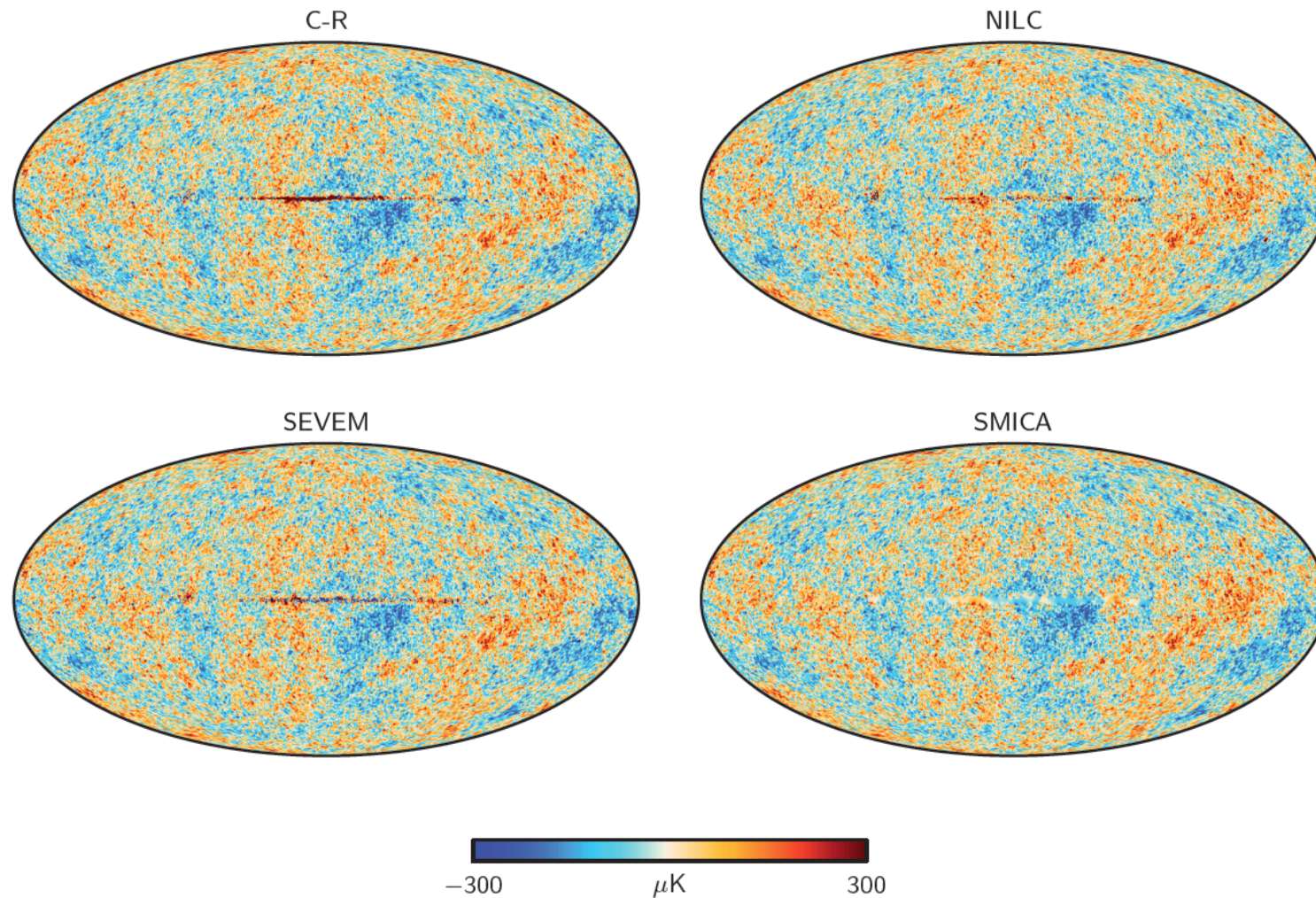


Component separation

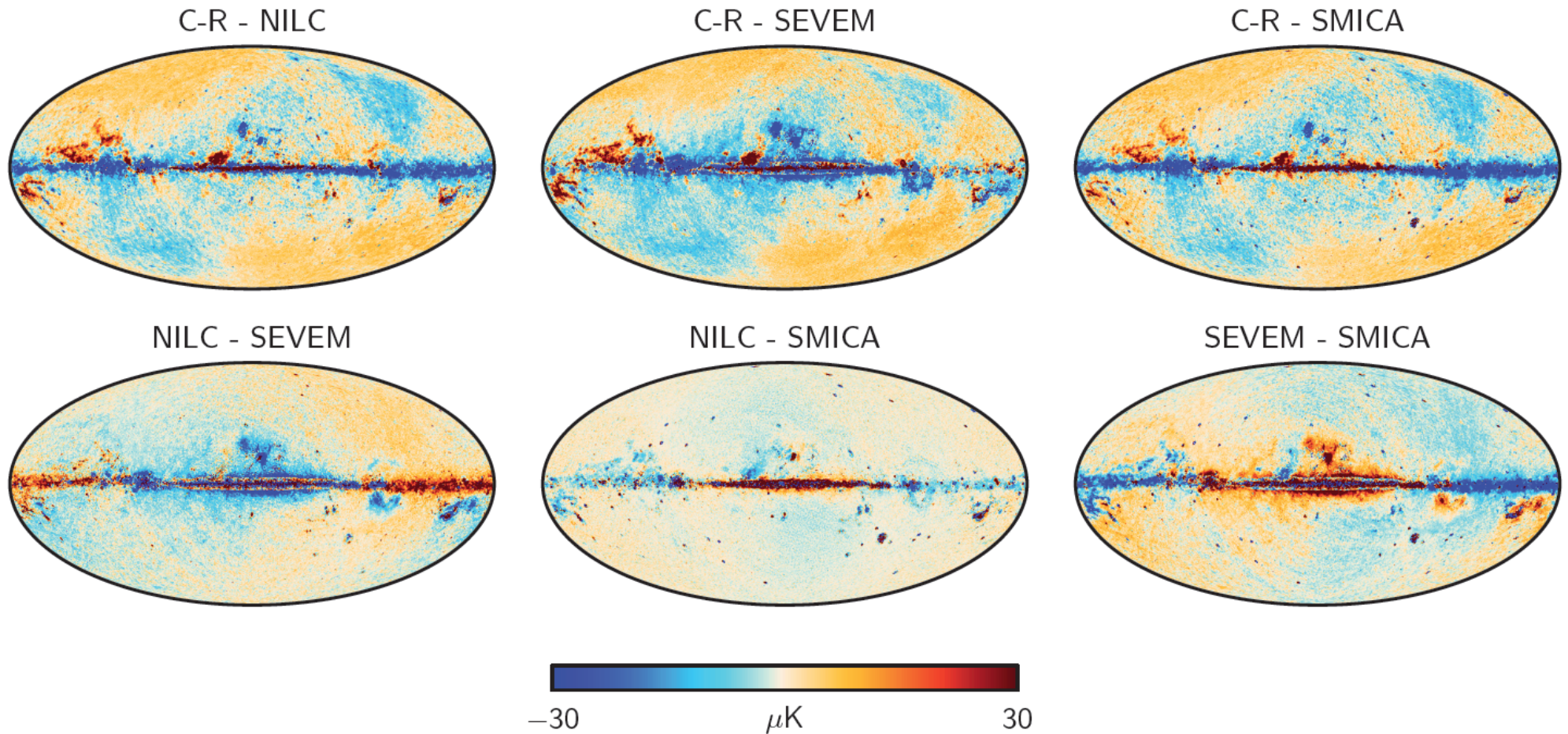


Different methods give similar maps

Planck 2013 results. XII.

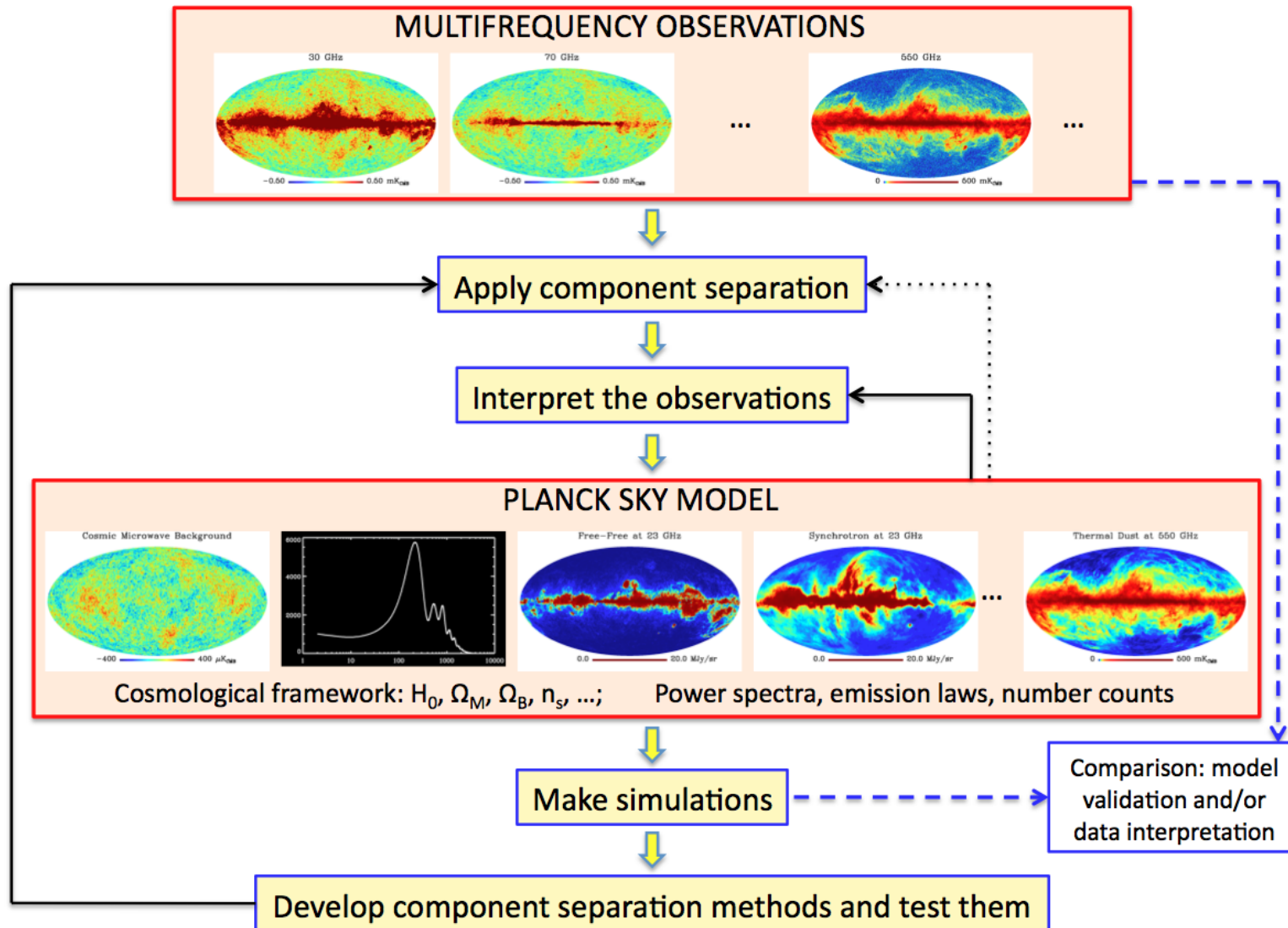


Differences exist



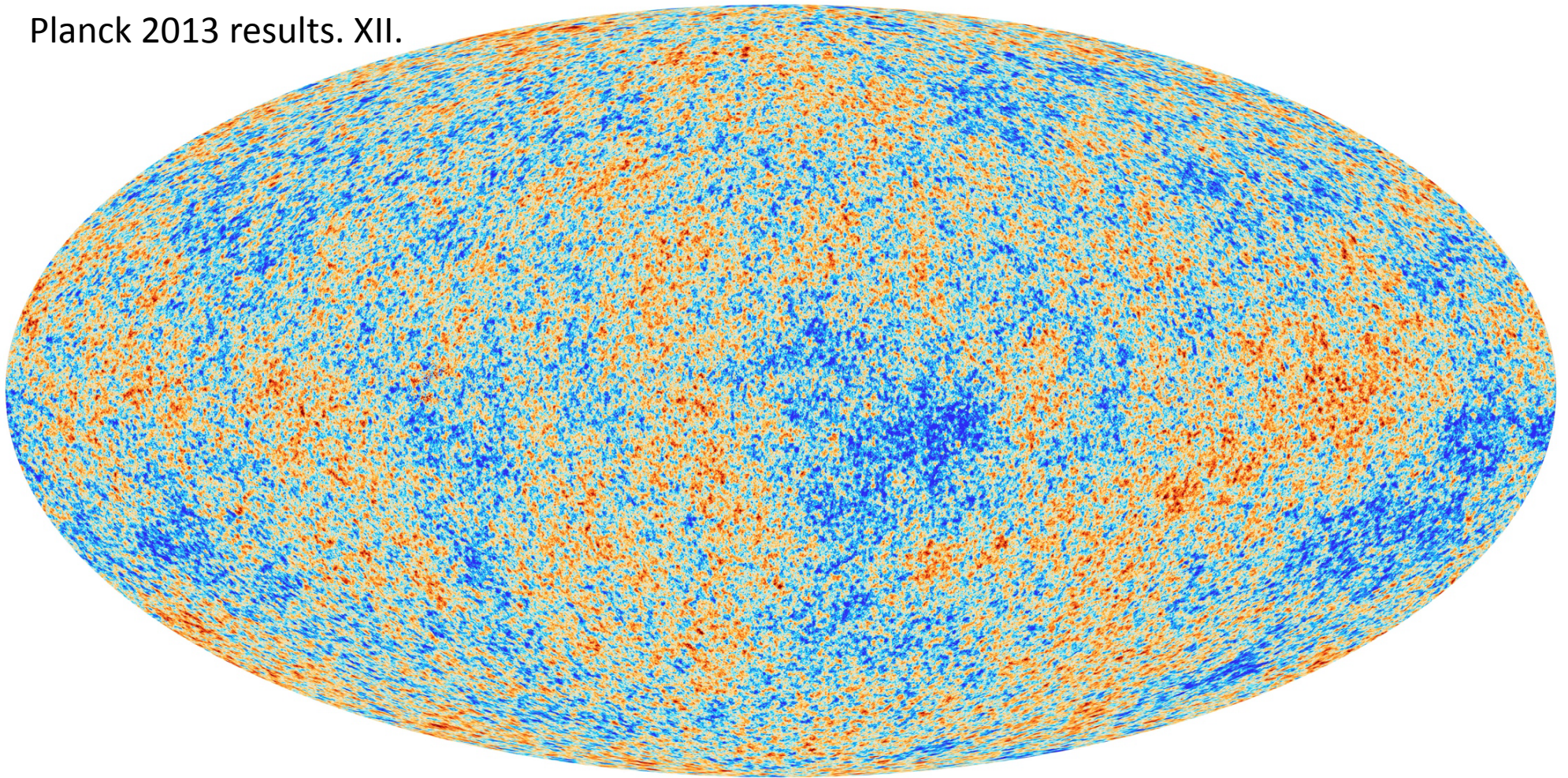
- Maps have been downgraded to $N_{\text{side}} = 128$ to show large scale features
- Large-scale features could be due to zodiacal light emission at high-frequencies
- Residuals are typically less than $5 \mu\text{K}$ at high Galactic latitude

Validation on simulations



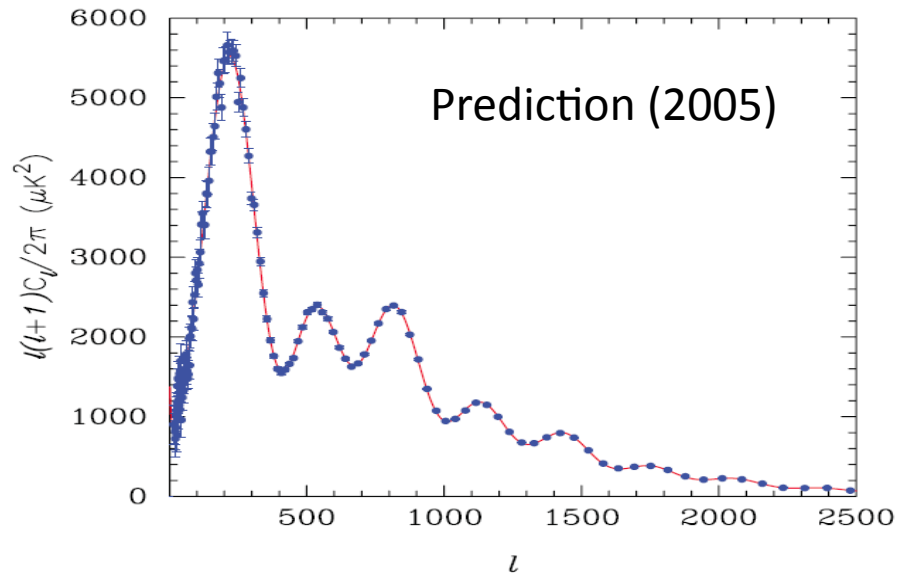
CMB map (SMICA)

Planck 2013 results. XII.

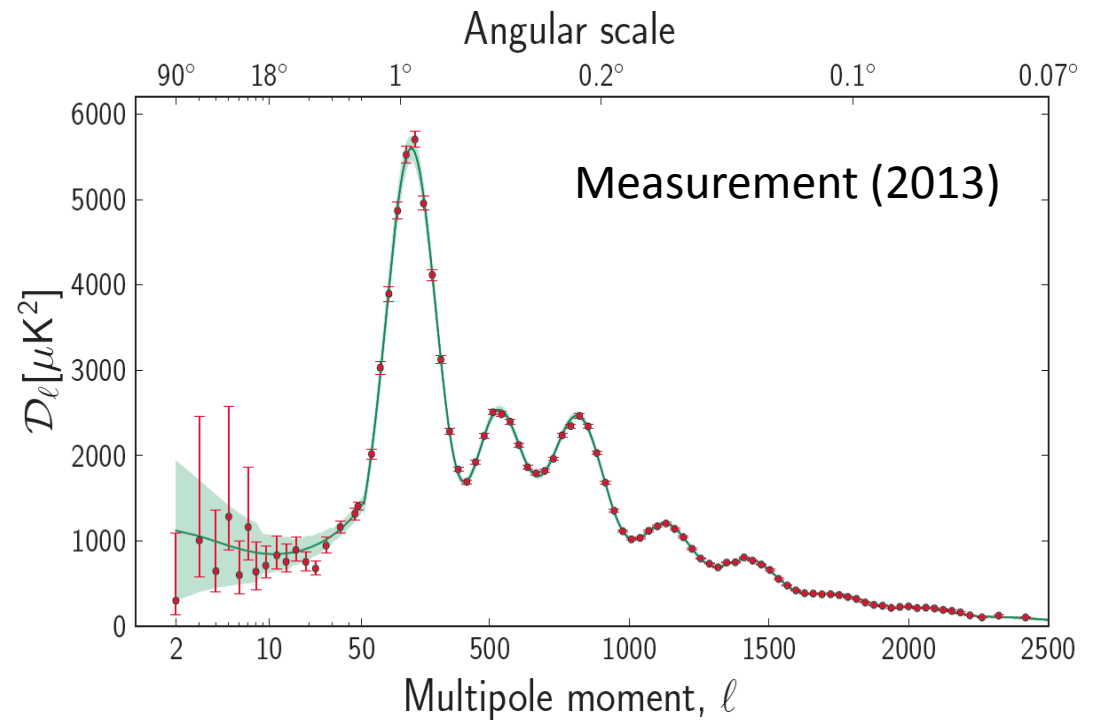


Method: Delabrouille et al. 2003, Cardoso et al. 2008

The Planck CMB power spectrum



Planck 2013 results. XV.



6-parameter model

Parameter	<i>Planck</i>		<i>Planck</i> +WP	
	Best fit	68% limits	Best fit	68% limits
$\Omega_b h^2$	0.022068	0.02207 ± 0.00033	0.022032	0.02205 ± 0.00028
$\Omega_c h^2$	0.12029	0.1196 ± 0.0031	0.12038	0.1199 ± 0.0027
$100\theta_{MC}$	1.04122	1.04132 ± 0.00068	1.04119	1.04131 ± 0.00063
τ	0.0925	0.097 ± 0.038	0.0925	$0.089^{+0.012}_{-0.014}$
n_s	0.9624	0.9616 ± 0.0094	0.9619	0.9603 ± 0.0073
$\ln(10^{10} A_s)$	3.098	3.103 ± 0.072	3.0980	$3.089^{+0.024}_{-0.027}$
Ω_Λ	0.6825	0.686 ± 0.020	0.6817	$0.685^{+0.018}_{-0.016}$
Ω_m	0.3175	0.314 ± 0.020	0.3183	$0.315^{+0.016}_{-0.018}$
σ_8	0.8344	0.834 ± 0.027	0.8347	0.829 ± 0.012
z_{re}	11.35	$11.4^{+4.0}_{-2.8}$	11.37	11.1 ± 1.1
H_0	67.11	67.4 ± 1.4	67.04	67.3 ± 1.2
$10^9 A_s$	2.215	2.23 ± 0.16	2.215	$2.196^{+0.051}_{-0.060}$
$\Omega_m h^2$	0.14300	0.1423 ± 0.0029	0.14305	0.1426 ± 0.0025
Age/Gyr	13.819	13.813 ± 0.058	13.8242	13.817 ± 0.048
z_*	1090.43	1090.37 ± 0.65	1090.48	1090.43 ± 0.54
$100\theta_*$	1.04139	1.04148 ± 0.00066	1.04136	1.04147 ± 0.00062
z_{eq}	3402	3386 ± 69	3403	3391 ± 60

Approx. to acoustic scale
Reionisation optical depth

For $k_0=0.05 \text{ Mpc}^{-1}$

Derived parameters

6-parameter model

Parameter	<i>Planck</i>		<i>Planck</i> +WP		
	Best fit	68% limits	Best fit	68% limits	
$\Omega_b h^2$	0.022068	0.02207 ± 0.00033	0.022032	0.02205 ± 0.00028	1%
$\Omega_c h^2$	0.12029	0.1196 ± 0.0031	0.12038	0.1199 ± 0.0027	2%
$100\theta_{MC}$	1.04122	1.04132 ± 0.00068	1.04119	1.04131 ± 0.00063	0.06%
τ	0.0925	0.097 ± 0.038	0.0925	$0.089^{+0.012}_{-0.014}$	15%
n_s	0.9624	0.9616 ± 0.0094	0.9619	0.9603 ± 0.0073	0.8%
$\ln(10^{10} A_s)$	3.098	3.103 ± 0.072	3.0980	$3.089^{+0.024}_{-0.027}$	0.9%
Ω_Λ	0.6825	0.686 ± 0.020	0.6817	$0.685^{+0.018}_{-0.016}$	
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z_{eq}	3402	3386 ± 69	3403	3391 ± 60	

Inflationary constraints

Planck 2013 results. XXII.

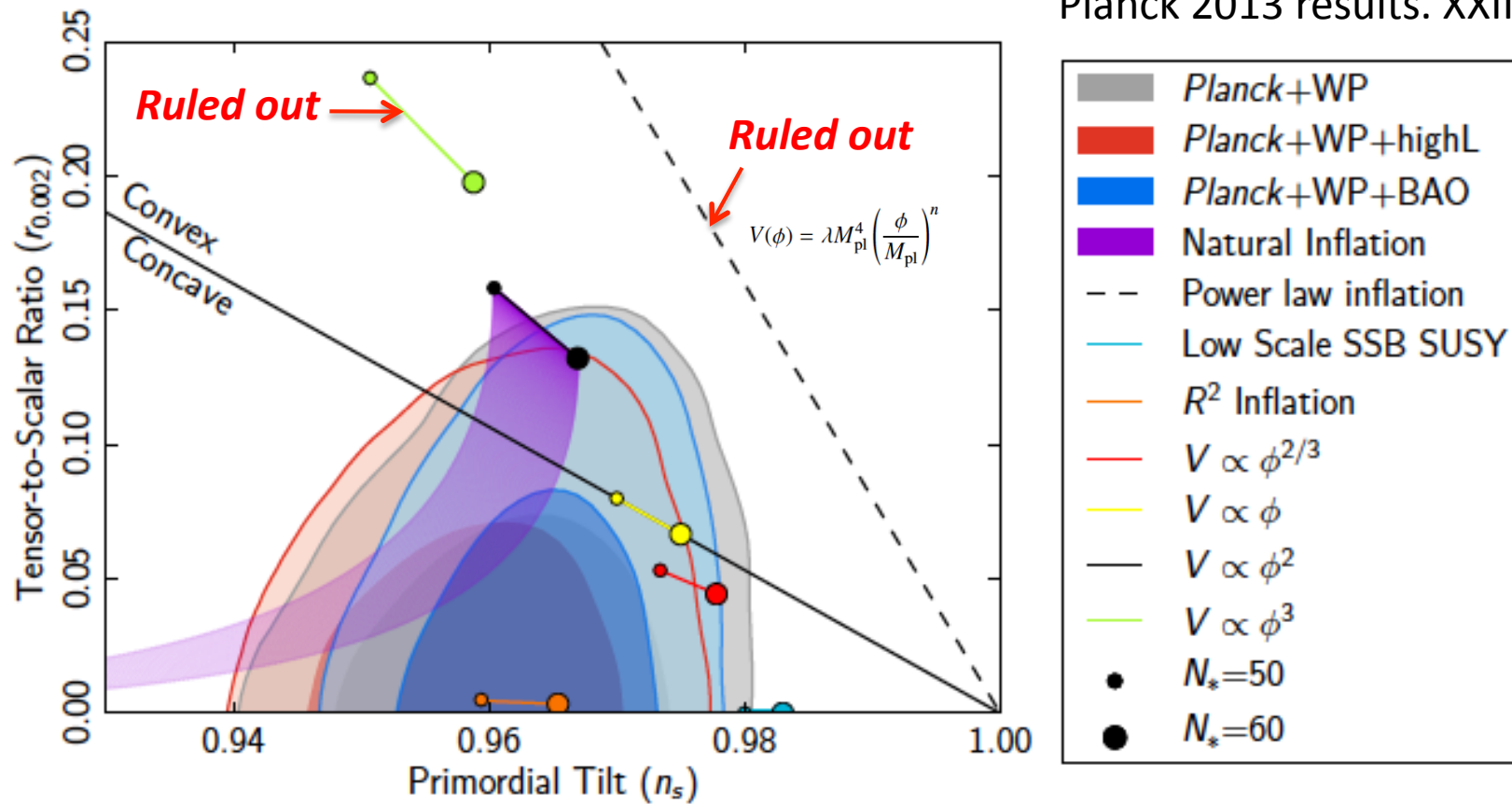
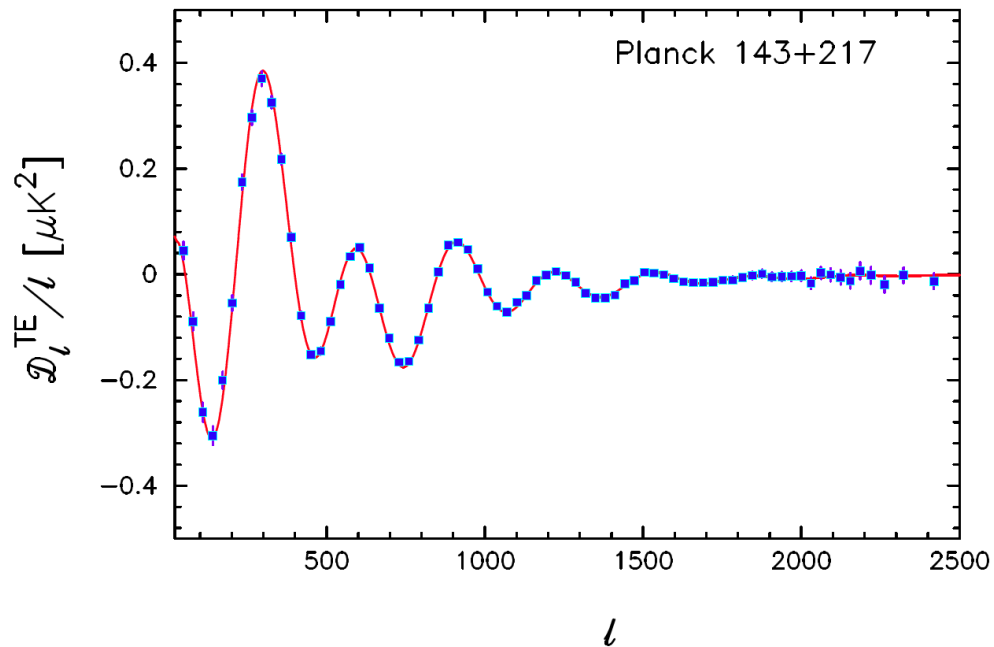
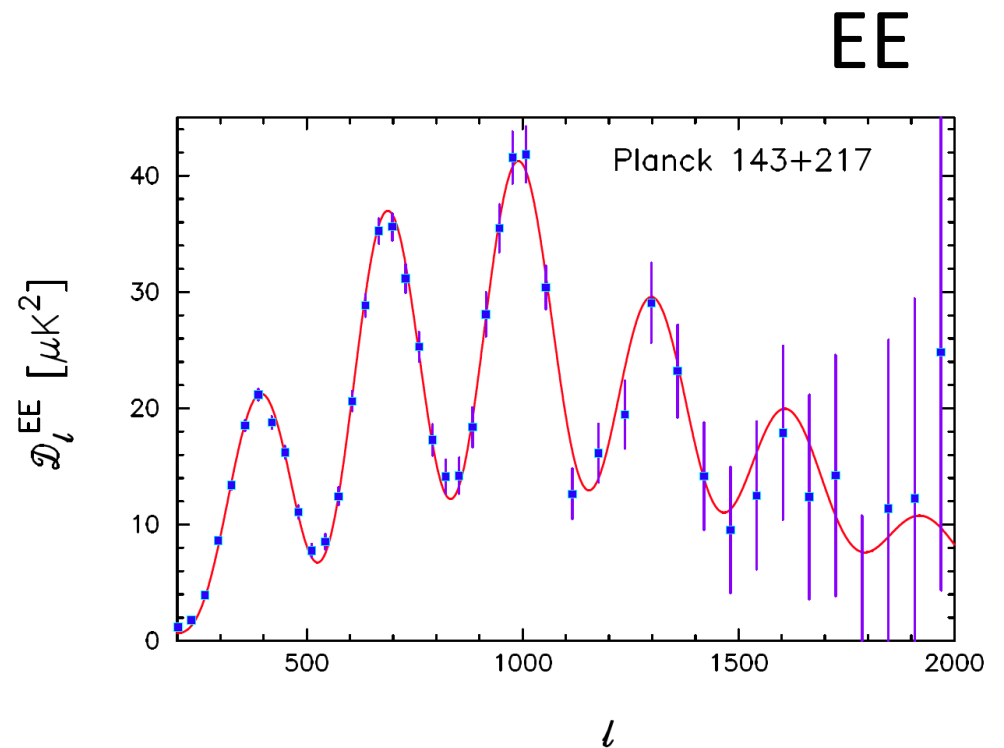


Fig. 1. Marginalized joint 68% and 95% CL regions for n_s and $r_{0.002}$ from *Planck* in combination with other data sets compared to the theoretical predictions of selected inflationary models.

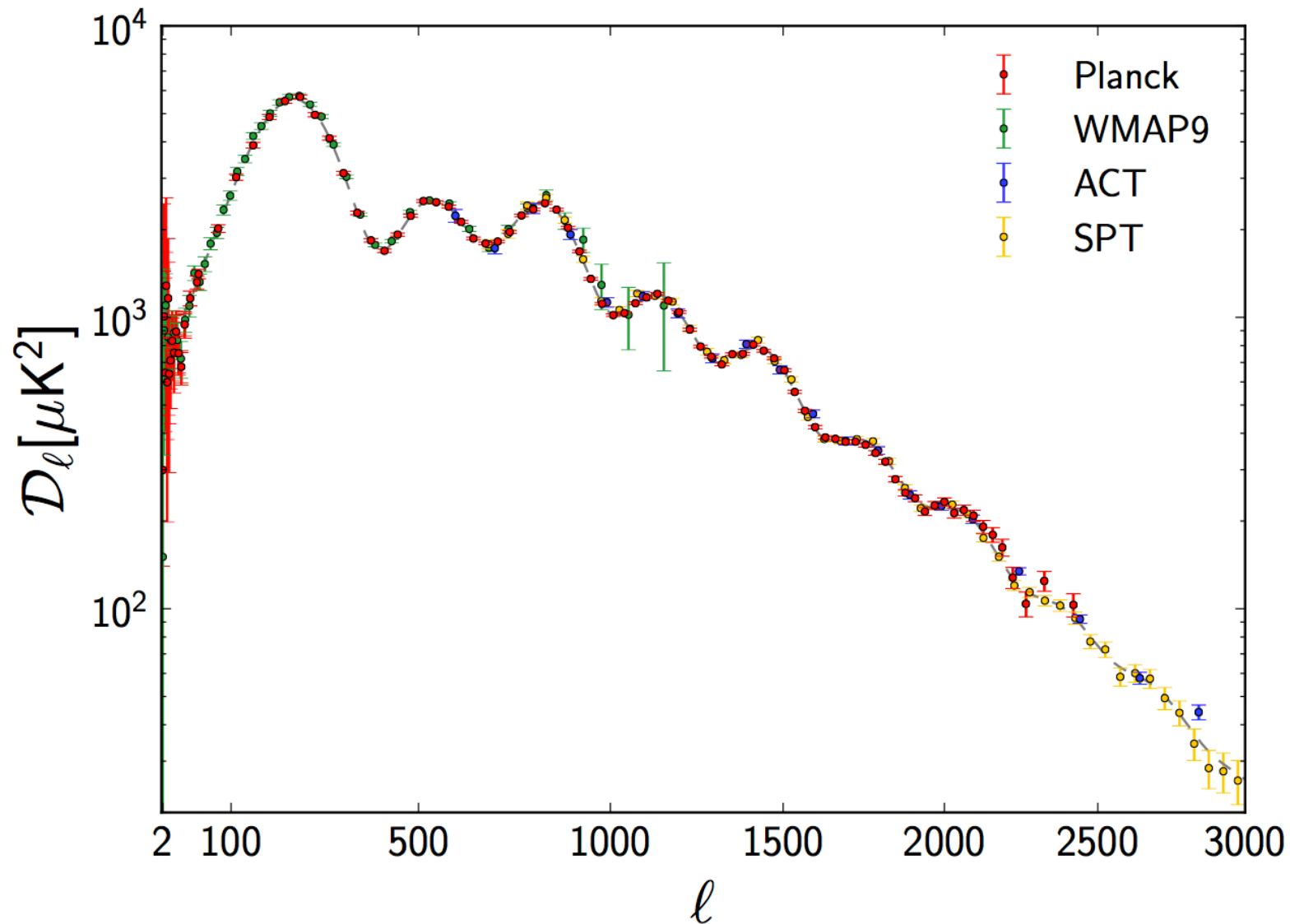
Polarisation spectrum in agreement



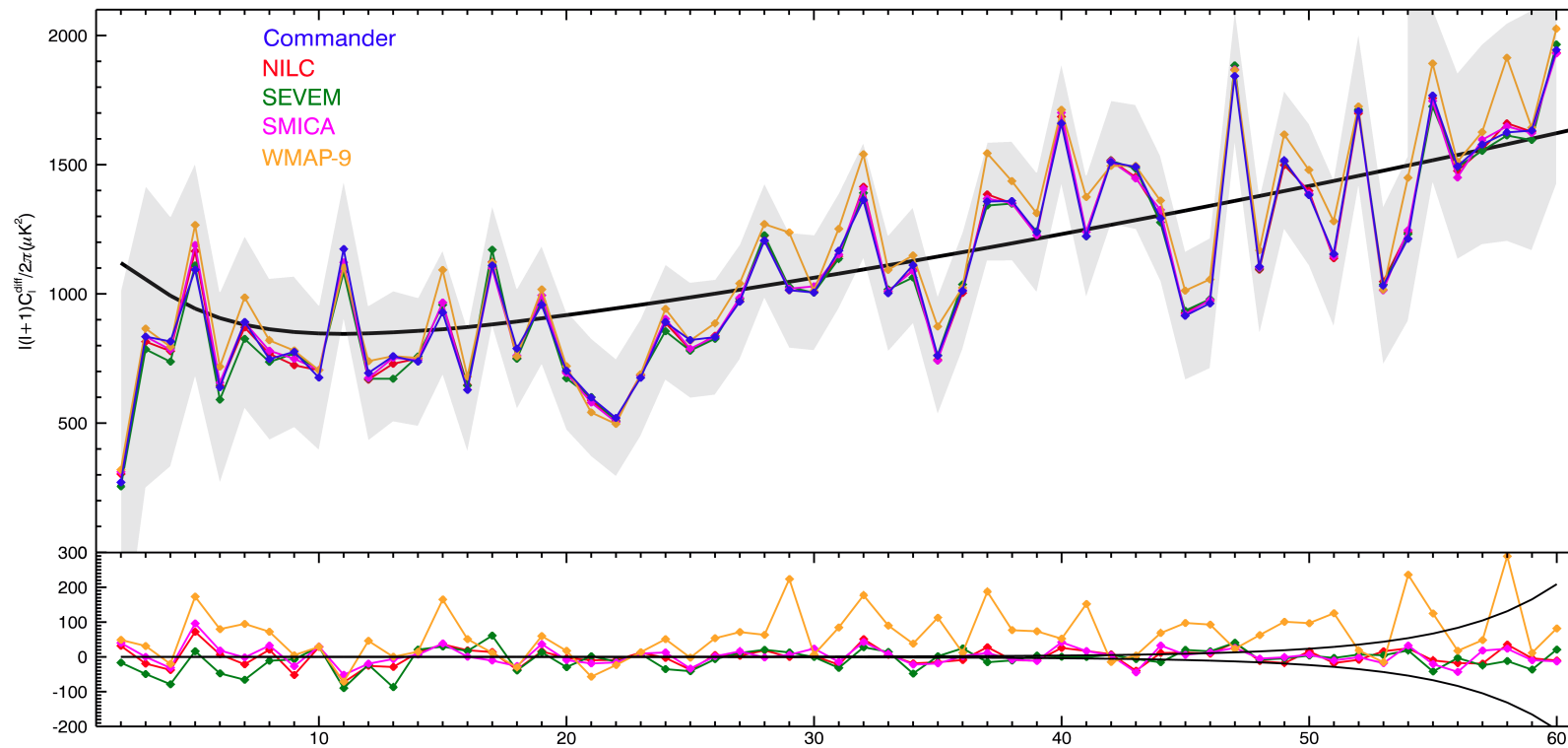
Red curves: prediction based solely on the temperature best fit.



Consistency...



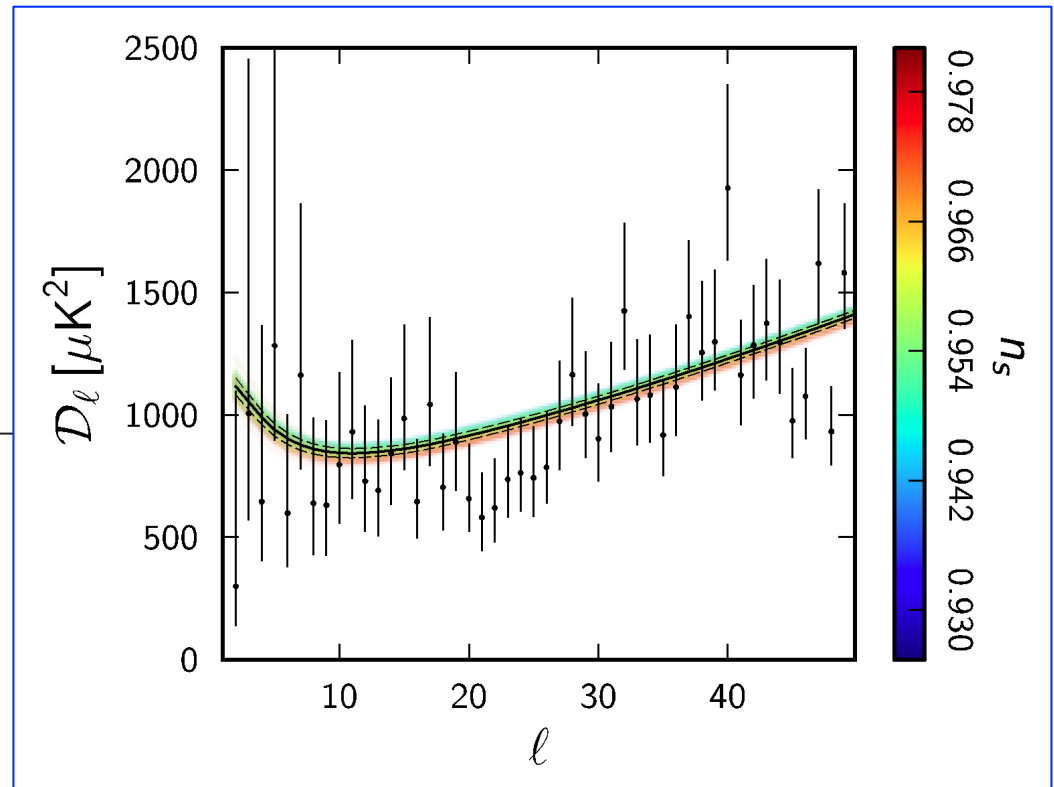
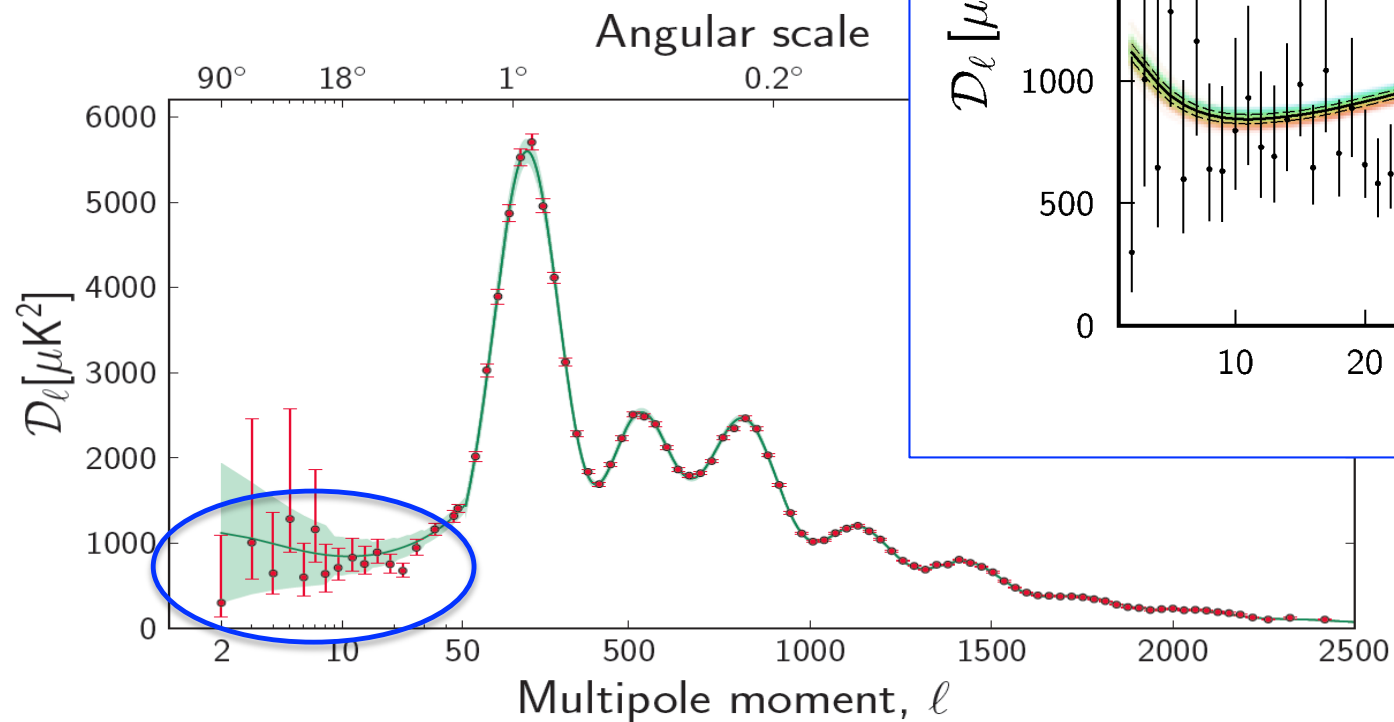
...and discrepancy



WMAP power spectrum 2.5 – 3% higher than Planck

Tensions ?

The measured CMB spectrum on large scales is lower than expected



Significance ?

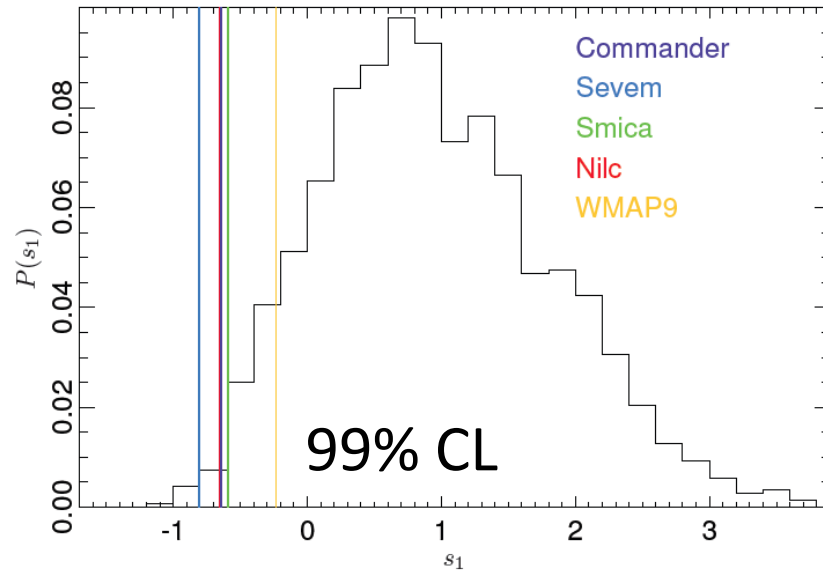


Figure 38. Results of the Hausman test applied to the temperature power spectrum for $2 \leq \ell \leq 32$. The black histogram shows the expected distribution, estimated with simulations, of the s_1 test statistic. The vertical bars represent *Planck* CMB maps and the 9-year *WMAP* ILC map. Note that the statistic is indistinguishable for the NILC and Commander maps.

$s_1 = \sup_r B(\ell_{\max}, r)$, where

$$B(\ell_{\max}, r) = \frac{1}{\sqrt{\ell_{\max}}} \sum_{\ell=2}^{\text{int}(\ell_{\max} r)} H_{\ell}, r \in [0, 1]$$

$$H_{\ell} = \frac{\hat{C}_{\ell} - C_{\ell}}{\sqrt{\text{Var } \hat{C}_{\ell}}},$$

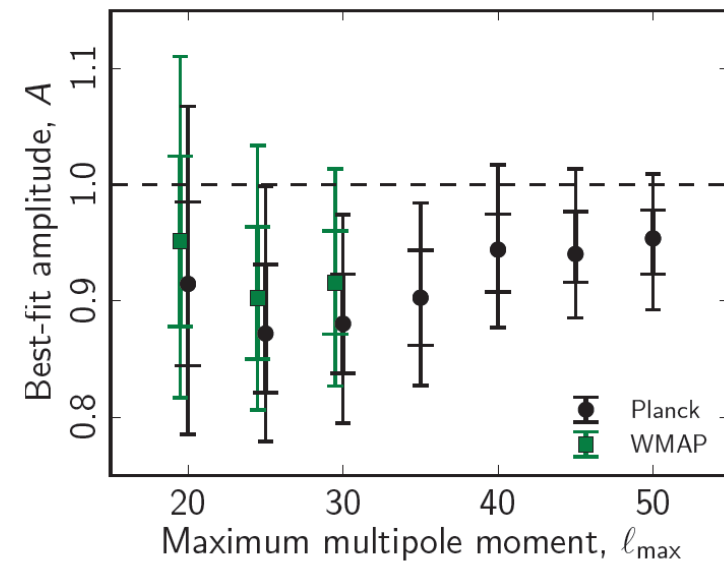
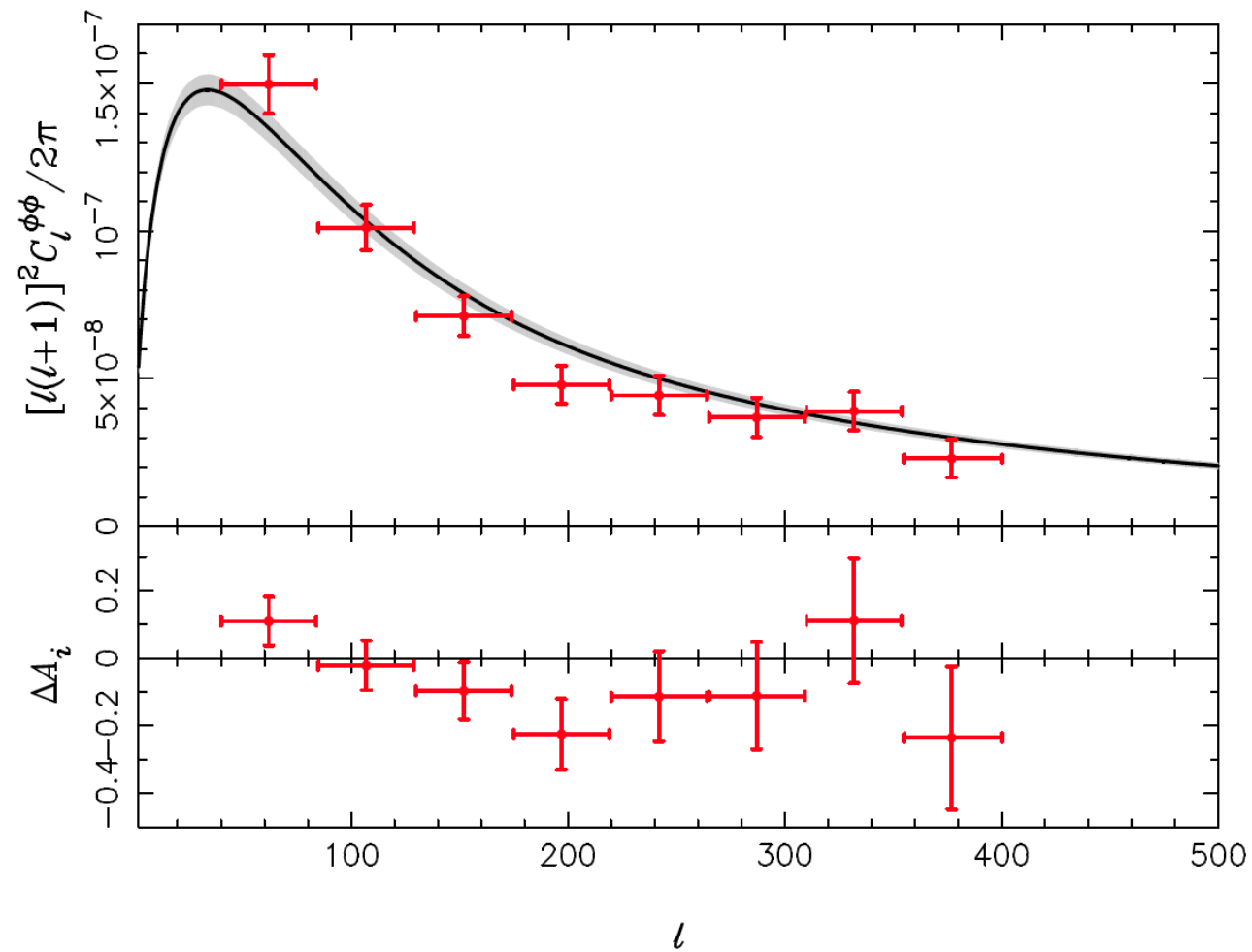


Figure 39. Power spectrum amplitude, q , relative to the best-fit *Planck* model as a function of $\ell_{\max}$, as measured by the low- ℓ *Planck* and *WMAP* temperature likelihoods, respectively. Error bars indicate 68 and 95% confidence regions.

2.5σ

Lensing in good general agreement



Intermediate conclusion

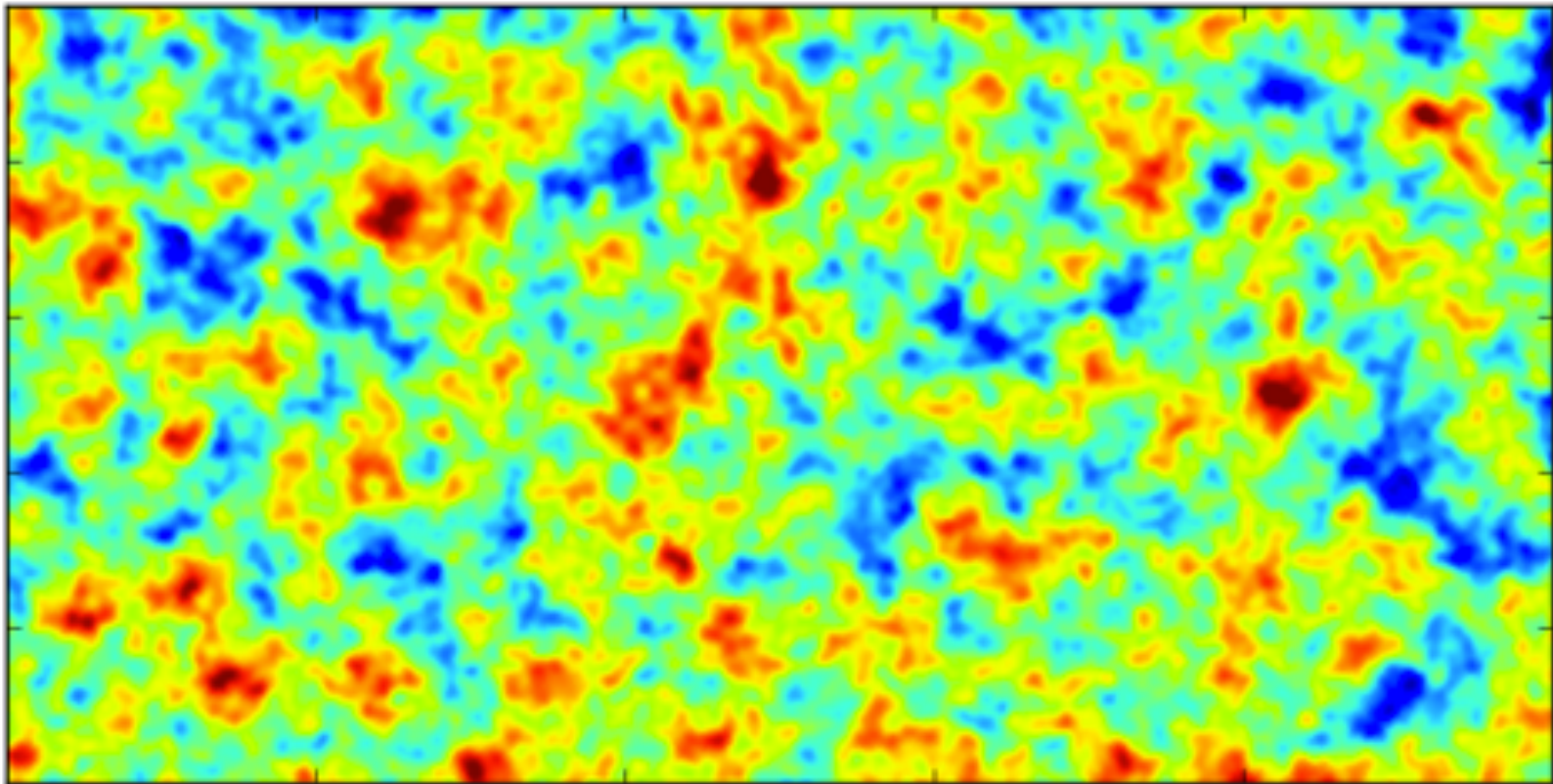
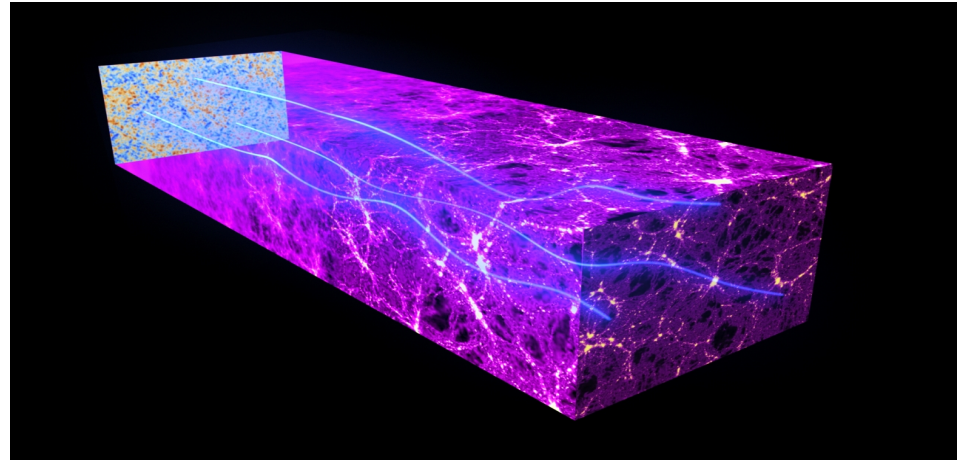
Very good fit of the CMB TT spectrum
With a 6-parameters Λ CDM

No compelling need for extensions

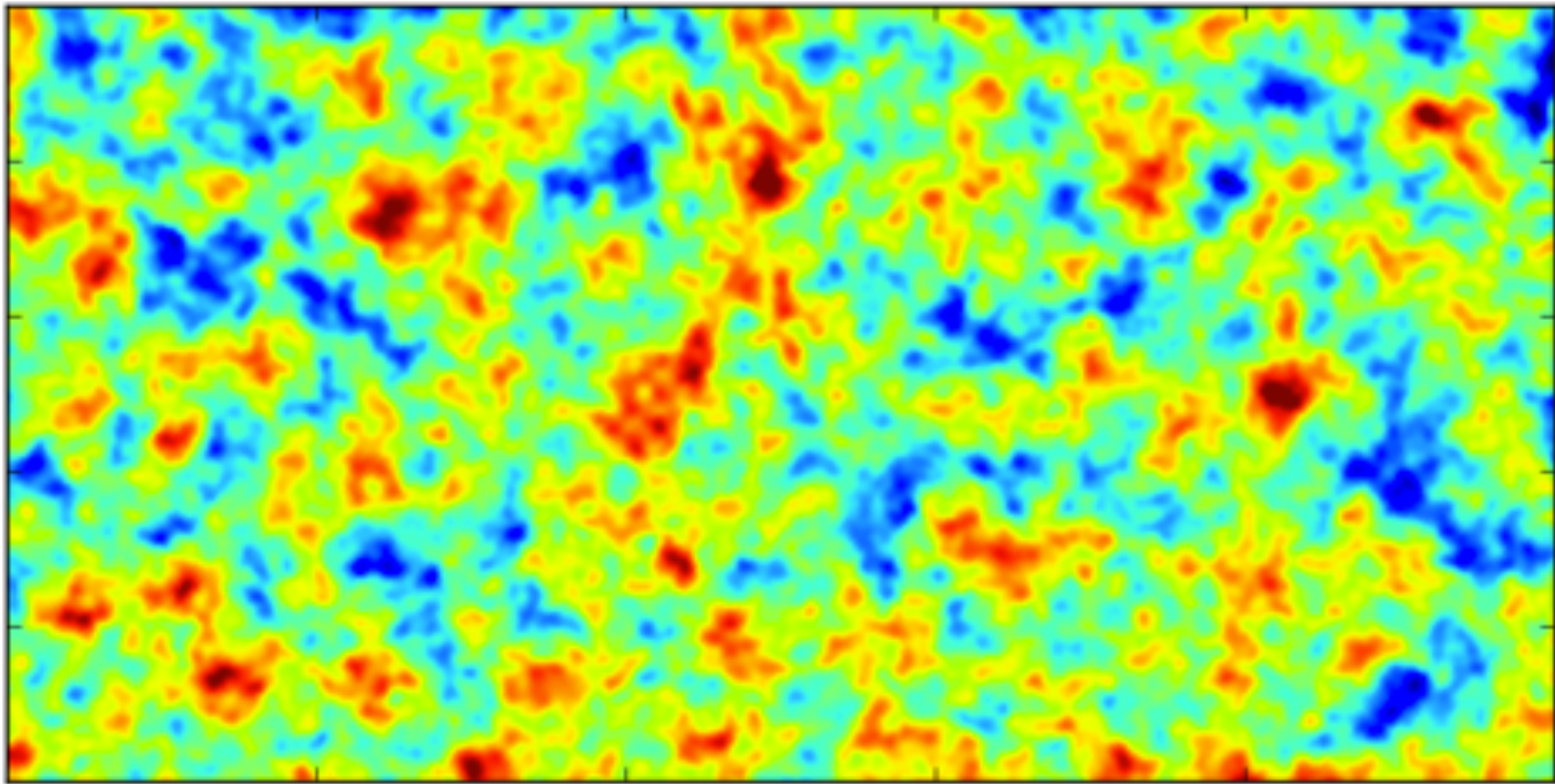
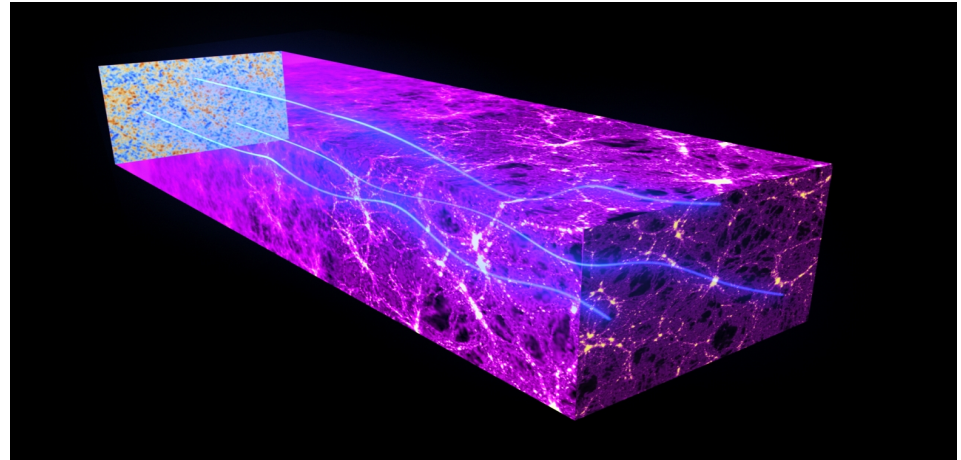
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Lensing

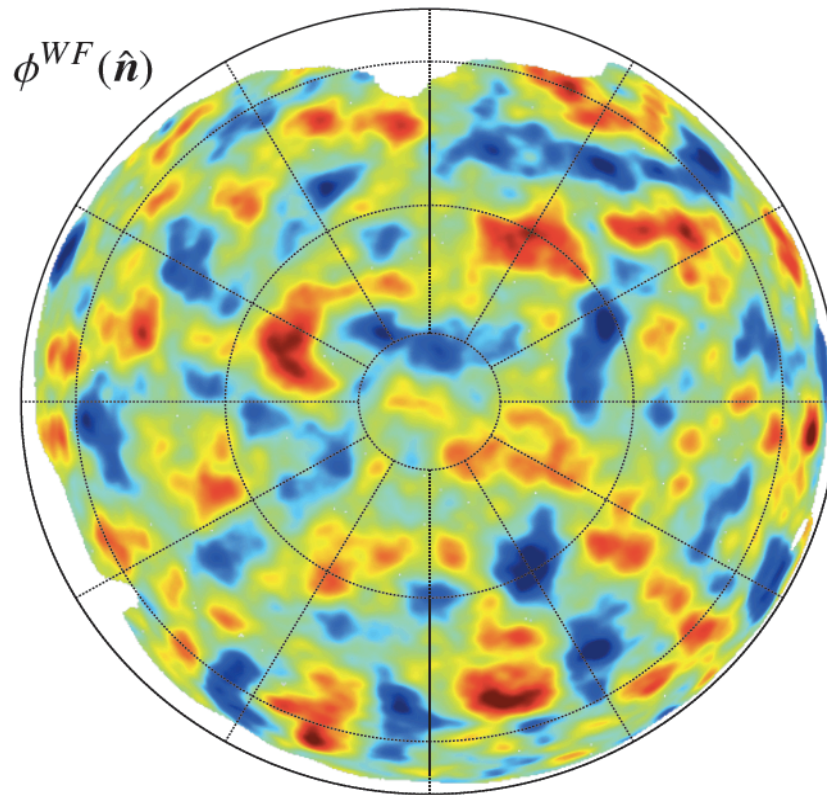


Lensing

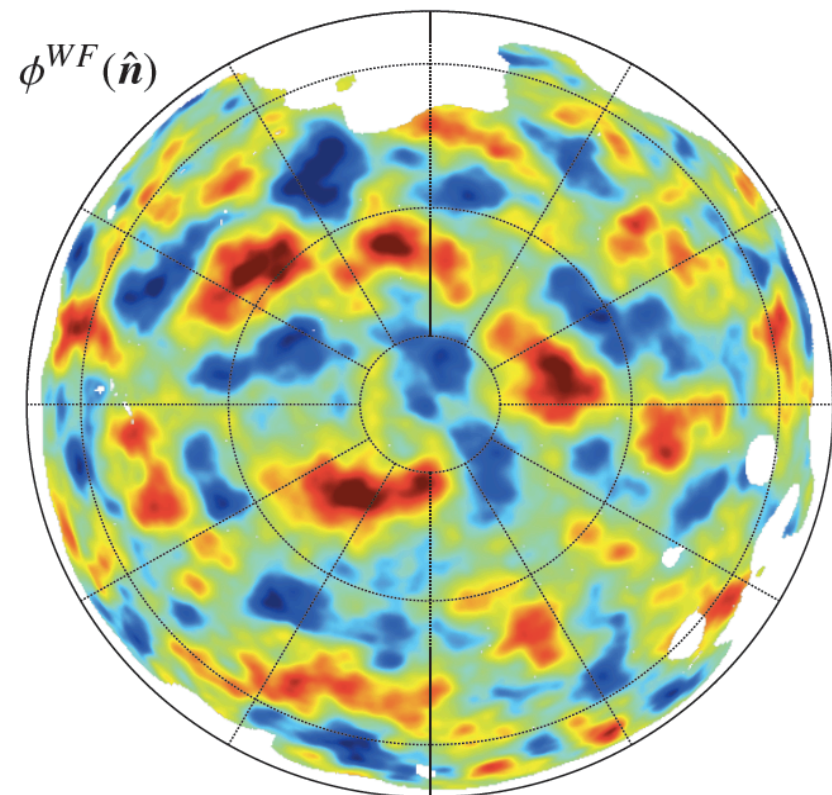


Reconstruction of the lensing potential

Planck 2013 results. XVII.



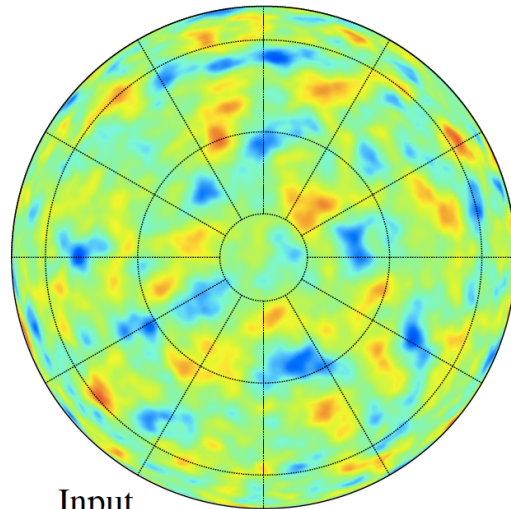
Galactic North



Galactic South

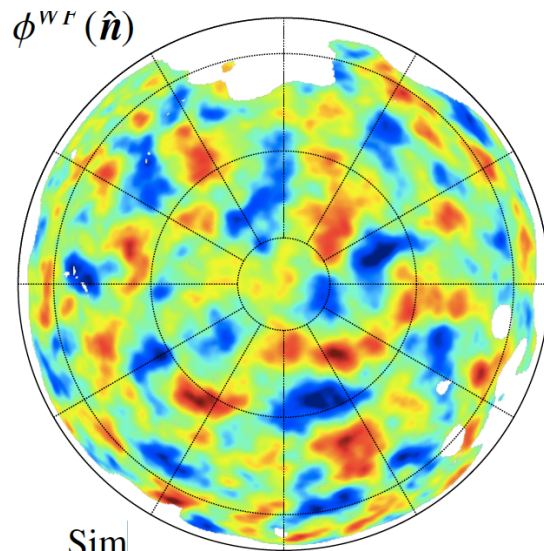
The reconstruction is noisy ($S/N \approx 0.6$ – more noise than signal here)

Noise in the lensing potential map



Input

Noiseless simulation
of lensing potential
for Λ CDM matching
Planck CMB



Sim

Reconstructed
lensing potential

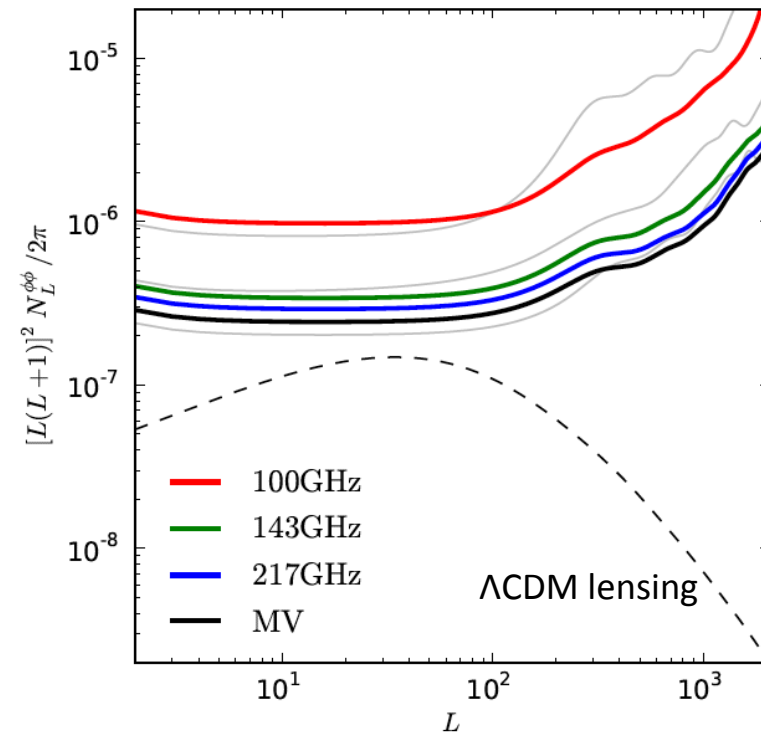


Fig. 1. Sky-averaged lens reconstruction noise levels for the 100, 143, and 217 GHz *Planck* channels (red, green, and blue solid, respectively), as well as for experiments that are cosmic-variance limited to a maximum multipole $\ell_{\max} = 1000, 1500, \text{ and } 1750$ (upper to lower solid grey lines).

Lensing potential power spectrum

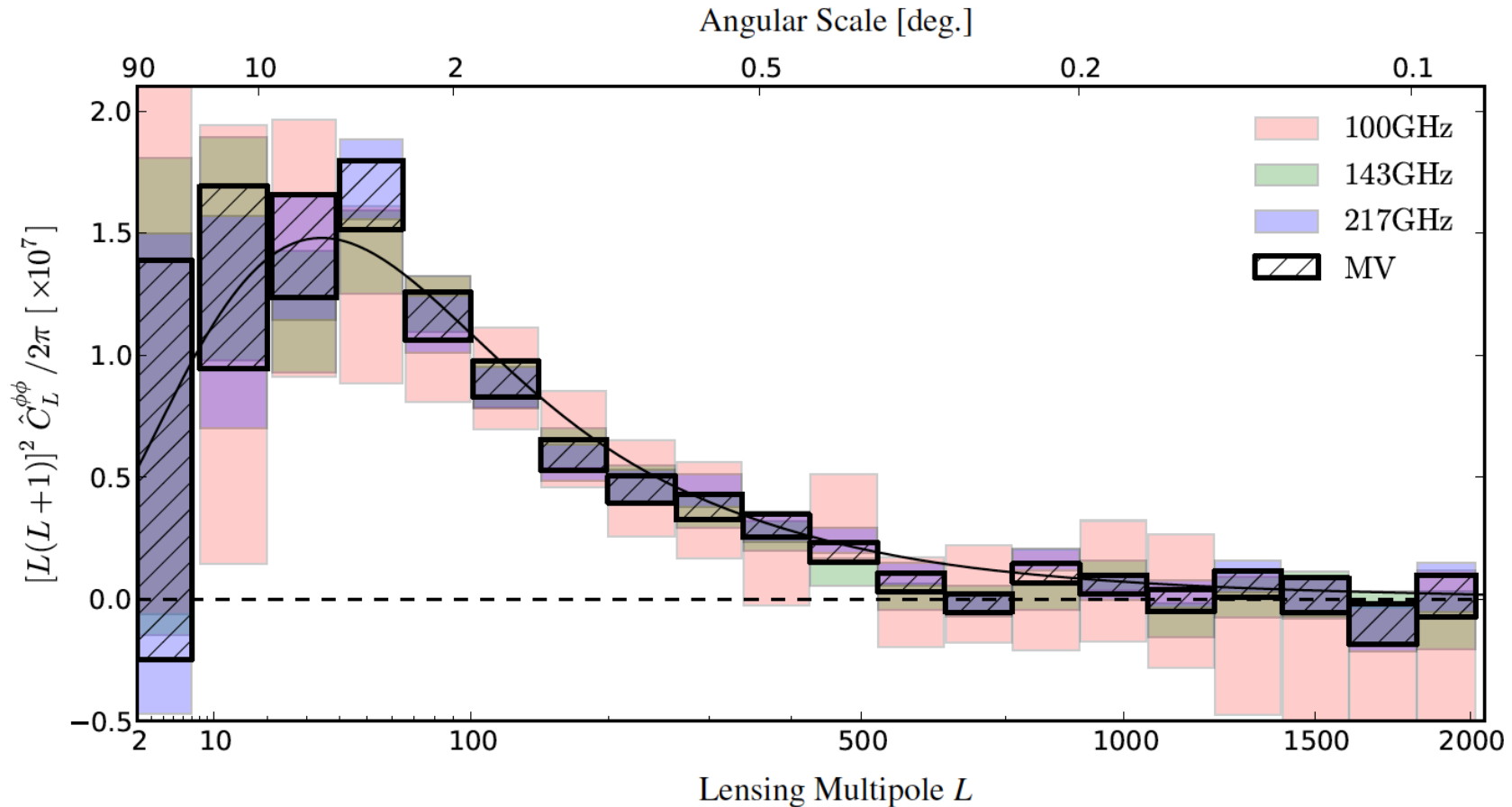


Fig. 10. Lensing potential power spectrum estimates based on the individual 100, 143, and 217 GHz sky maps, as well our fiducial minimum-variance (MV) reconstruction which forms the basis for the *Planck* lensing likelihood. The black line is for the best-fit Λ CDM model of [Planck Collaboration XVI \(2013\)](#).

Correlation lensing – galaxies

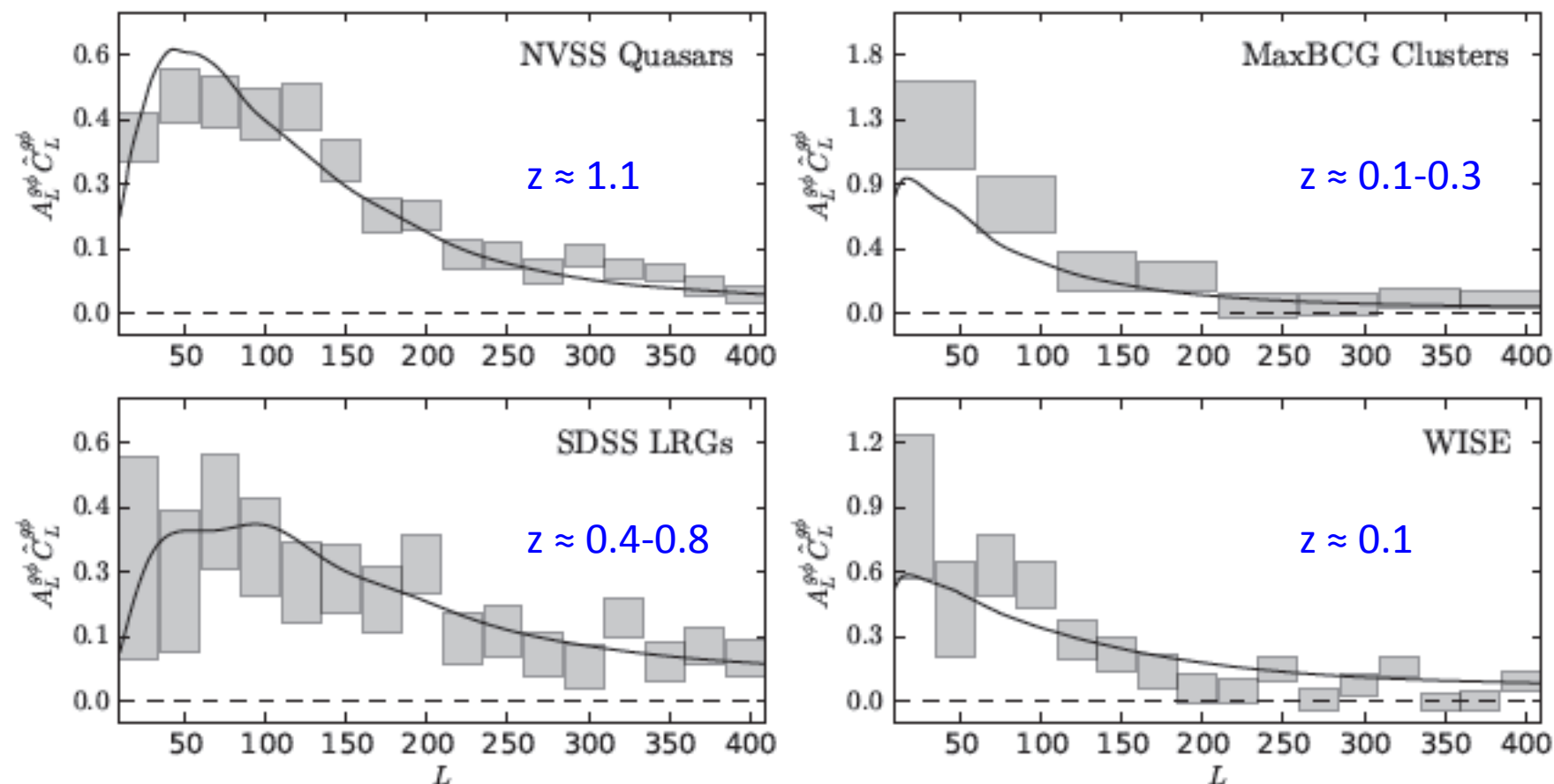
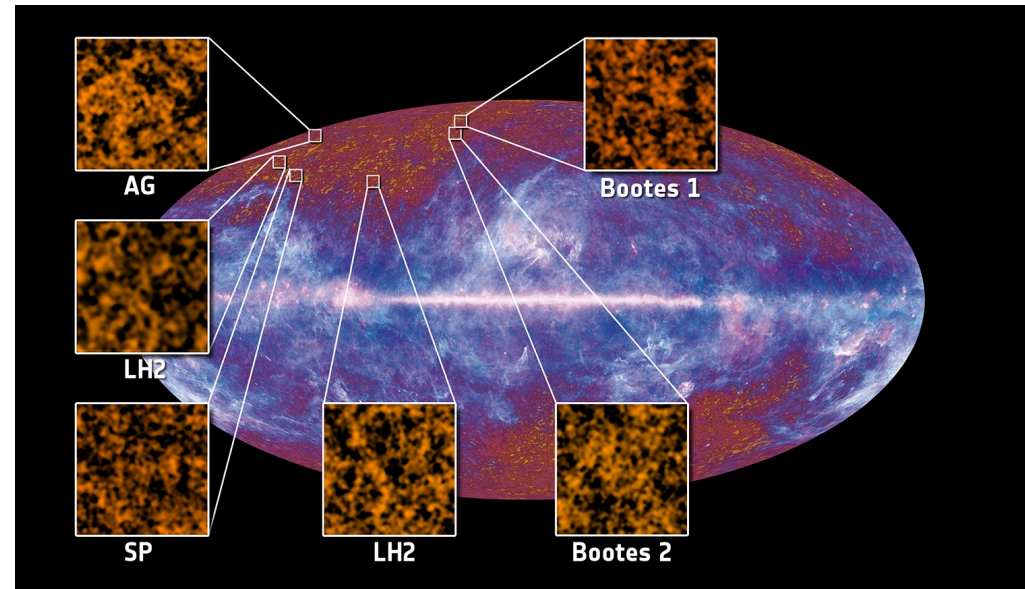
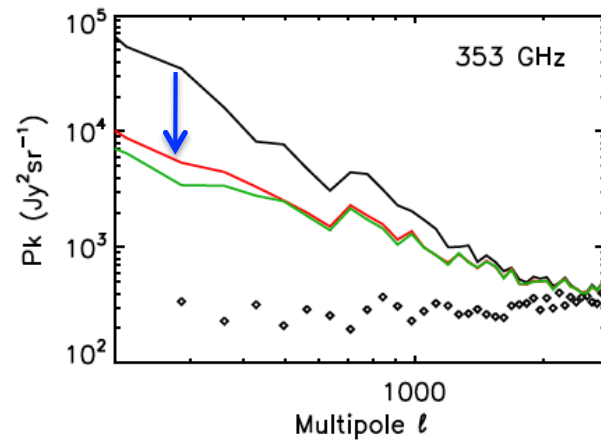
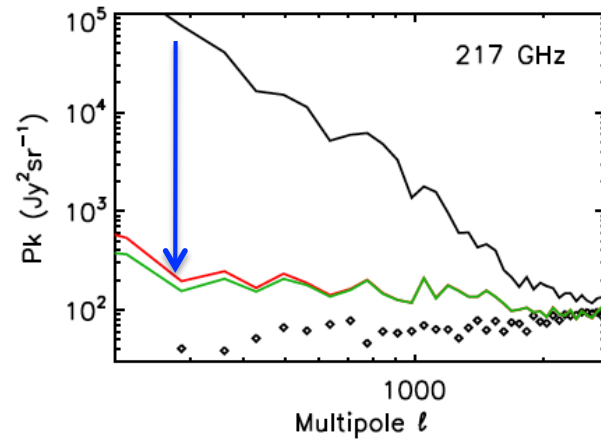
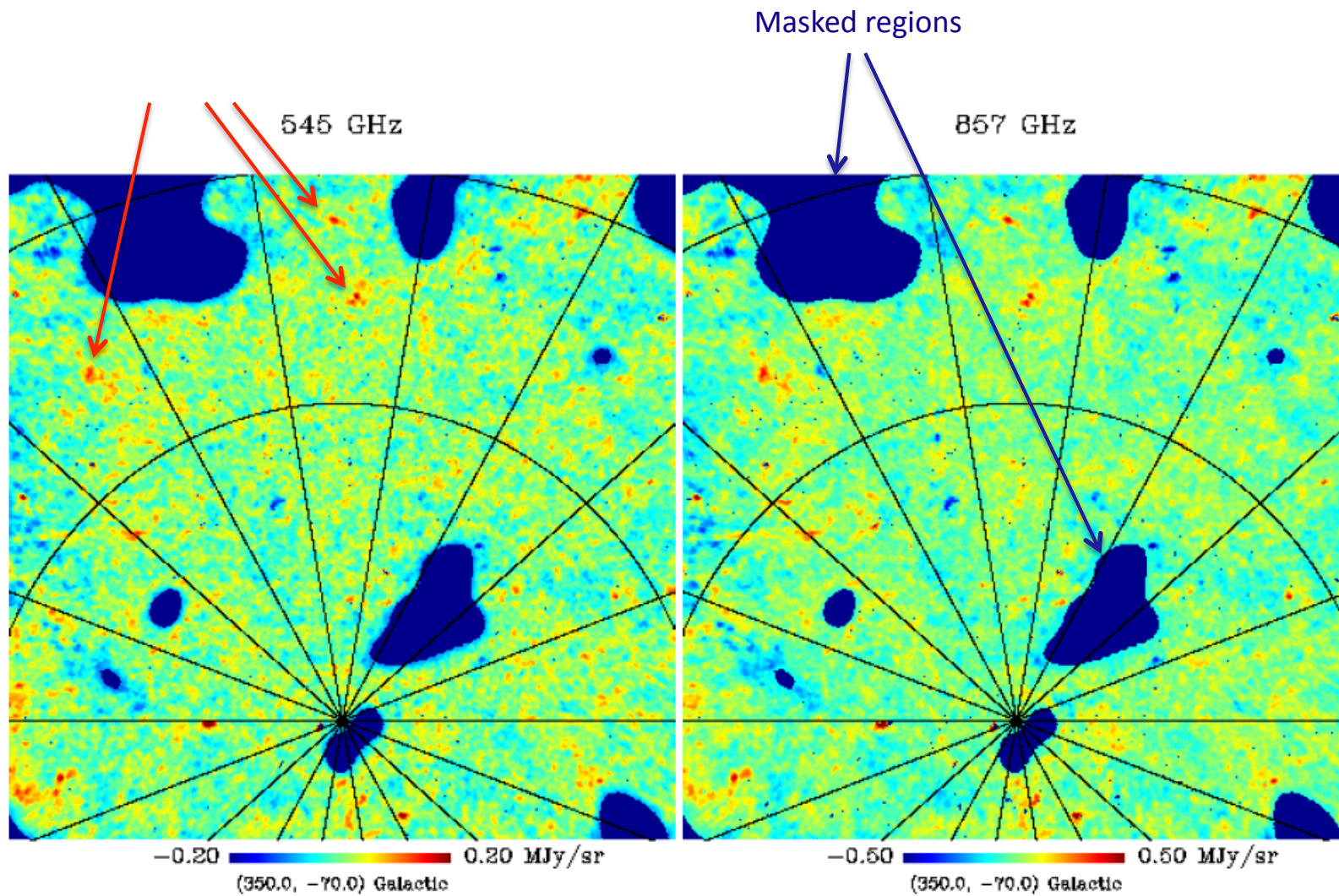


Fig. 17. Cross-spectra of the *Planck* MV lensing potential with several galaxy catalogs, scaled by the signal-to-noise weighting factor $A_L^{g\phi}$ defined in Eq. (52). Cross-correlations are detected at approximately 20σ significance for NVSS, 10σ for SDSS LRGs and 7σ for both MaxBCG and WISE.

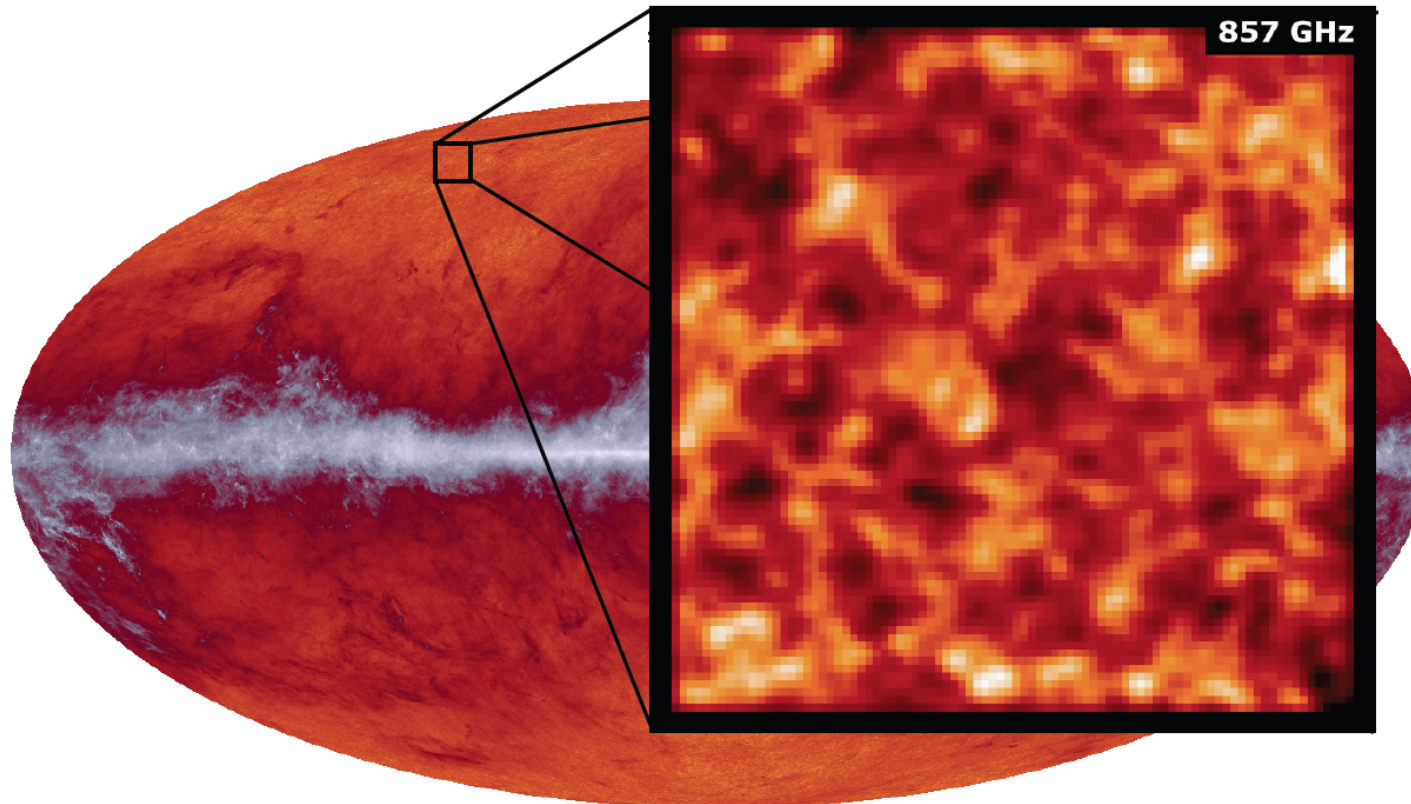
Cosmic infrared background



CIB fluctuations

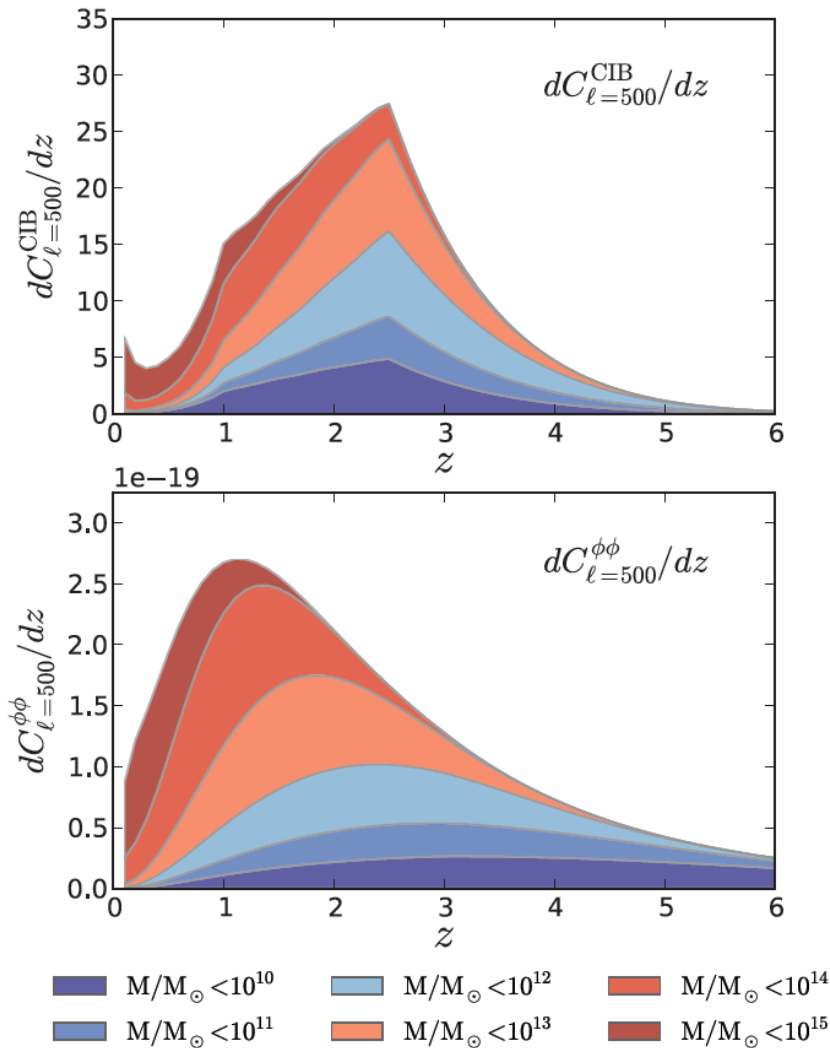


CIB – 545 GHz



- At 545 GHz ($\sim 550 \mu\text{m}$) (and all frequencies above 143 GHz), a large fraction of the signal we are mapping is composed of the Cosmic Infrared Background (CIB).
- The CIB represents the cumulative emission of high- z , dusty, star forming galaxies.
- These galaxies live in lump of (dark) matter that gravitationally lens the CMB.

A correlation lensing – CIB is expected



Origin of CIB

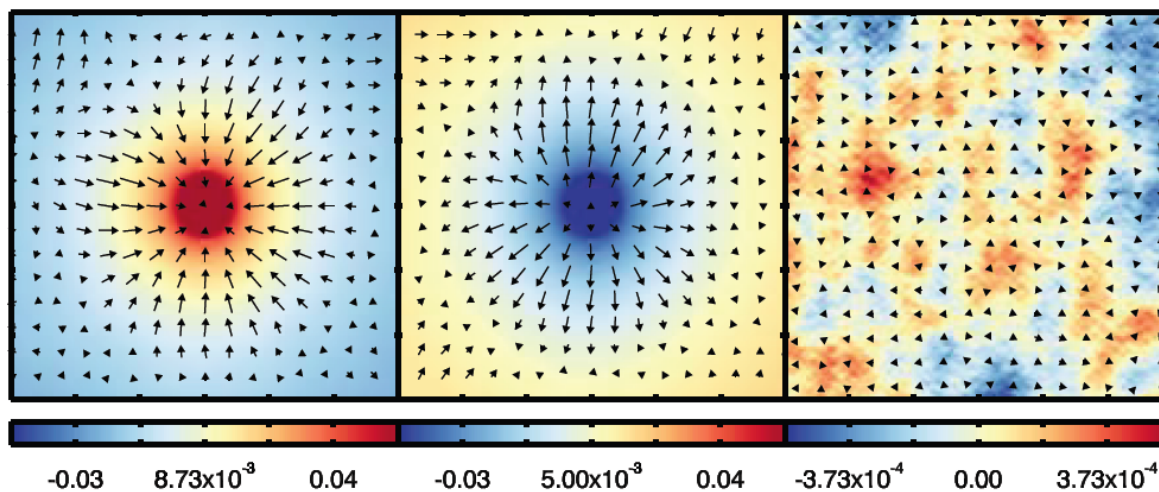
Béthermin (2012) model
(sharp features are artefacts)

Origin of lensing potential

Béthermin (2012) model
(sharp features are artefacts)

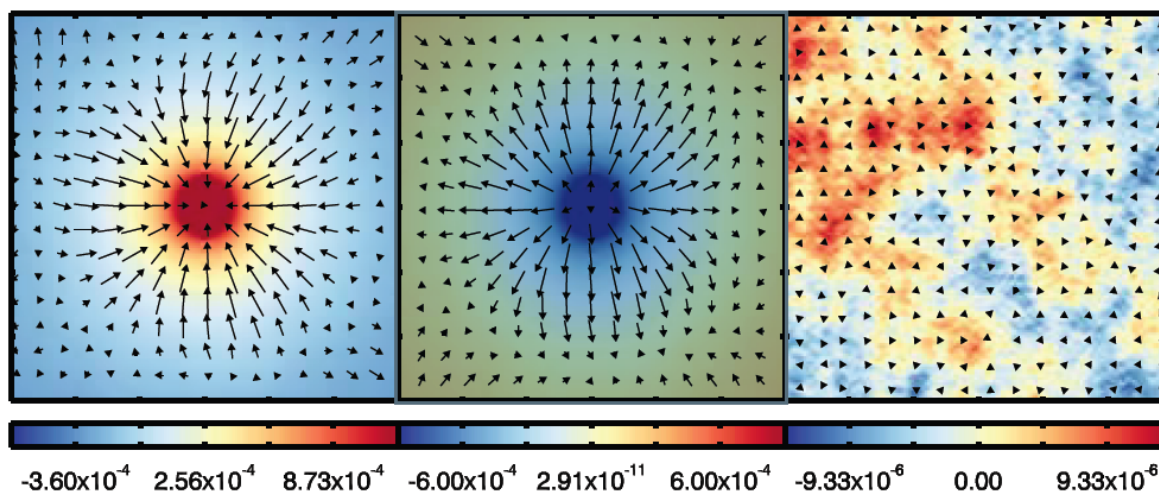
Correlation lensing – CIB

857 GHz



1 deg.

545 GHz



Stacking on:

20,000 T extrema

20,000 T minima

Random location

Correlation lensing – CIB

Planck 2013 results. XVIII.

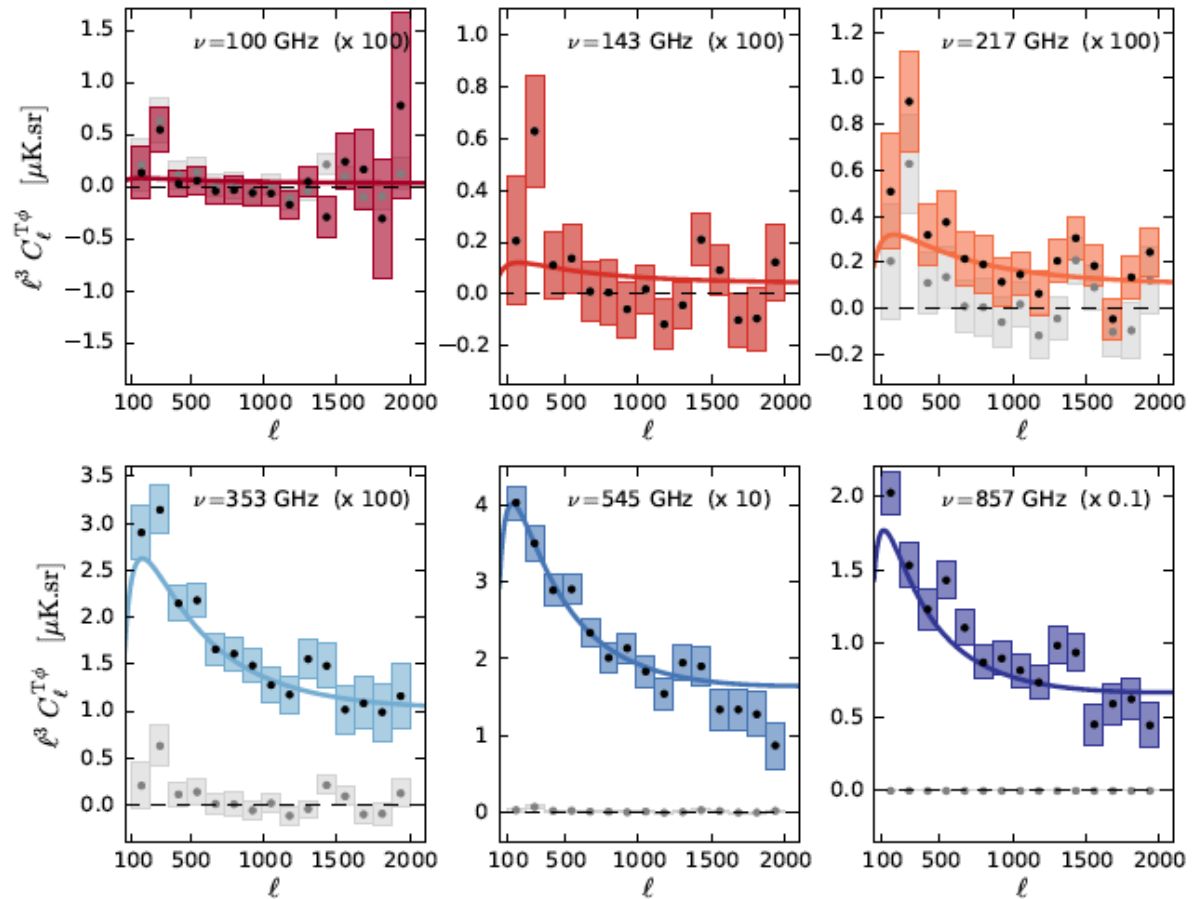
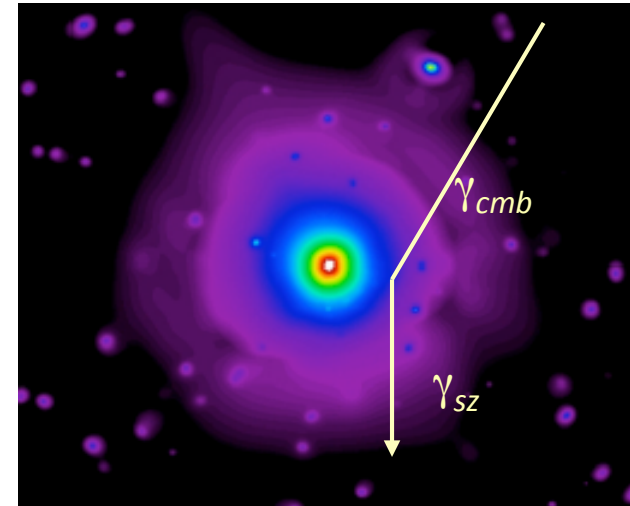
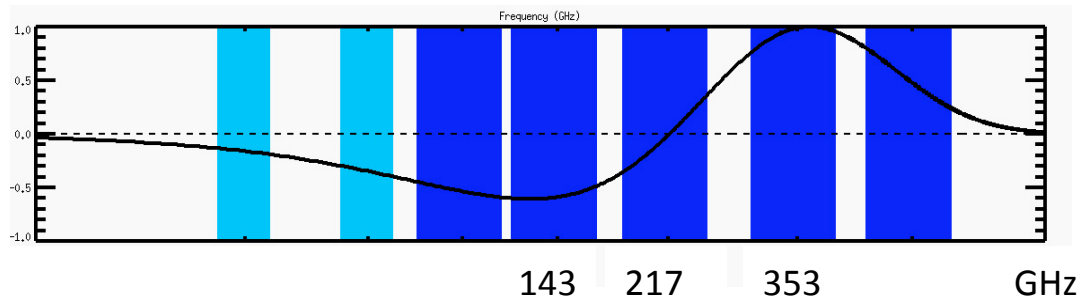


Fig. 3. Angular cross-spectra between the reconstructed lensing map and the temperature map at the six HFI frequencies. The error bars correspond to the scatter within each band. The solid line is the expected result based on the PER model and is *not* a fit to these data (see Fig. 16 for an adjusted model), although it is already a satisfying model. In each panel we also show the correlation between the lens reconstruction at 143 GHz and the 143 GHz temperature map in grey. This is a simple illustration of the frequency scaling of our measured signal and also the strength of our signal as compared to possible intra-frequency systematic errors.

SZ effect

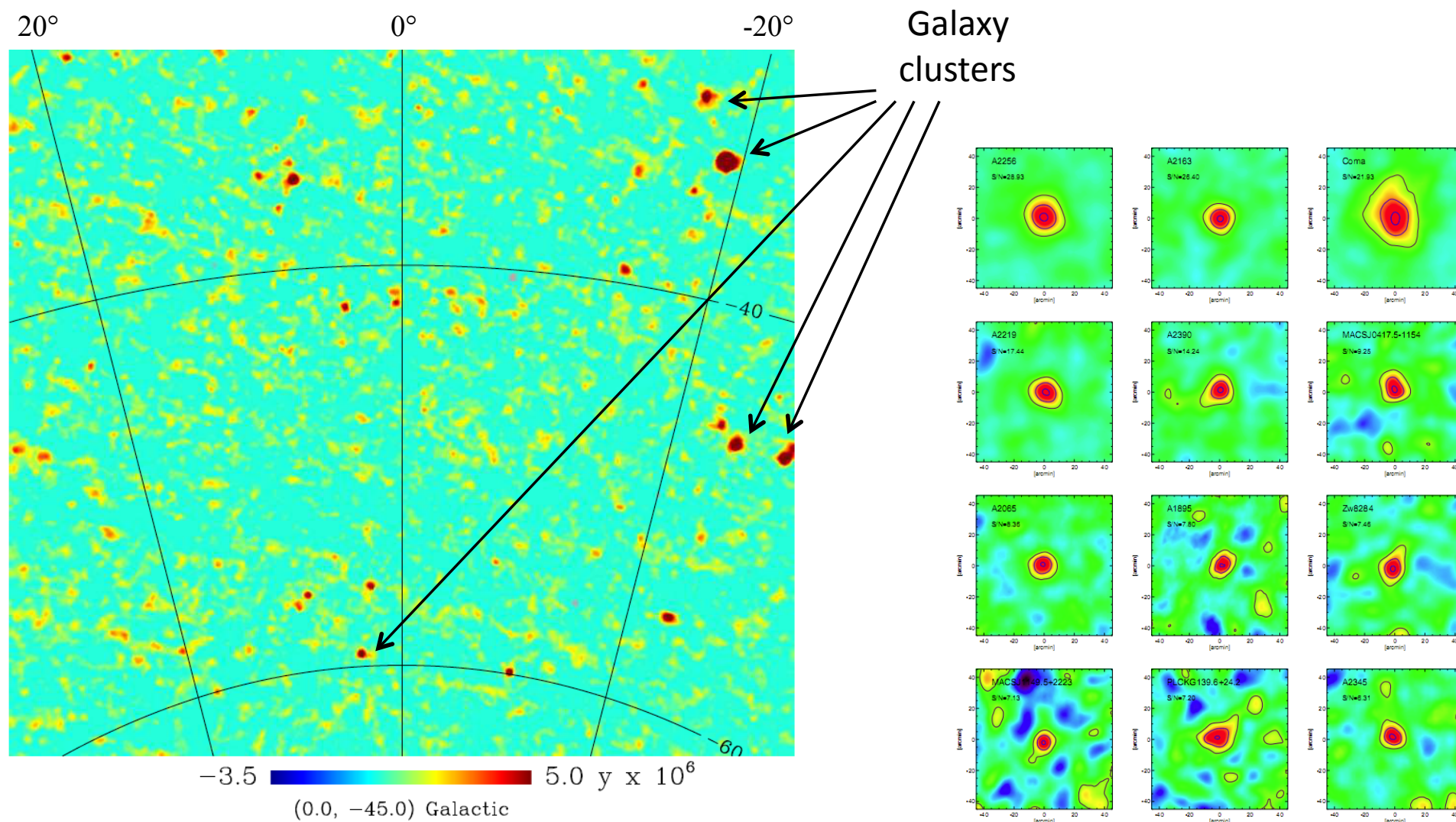
Clusters of galaxies are the largest gravitationally bound structures

- Sunyaev and Zel'dovich
 - Compton Interaction on *hot electron gas*
 - Detection possible at high redshift z
 - The SZ distortion is a very good mass proxy

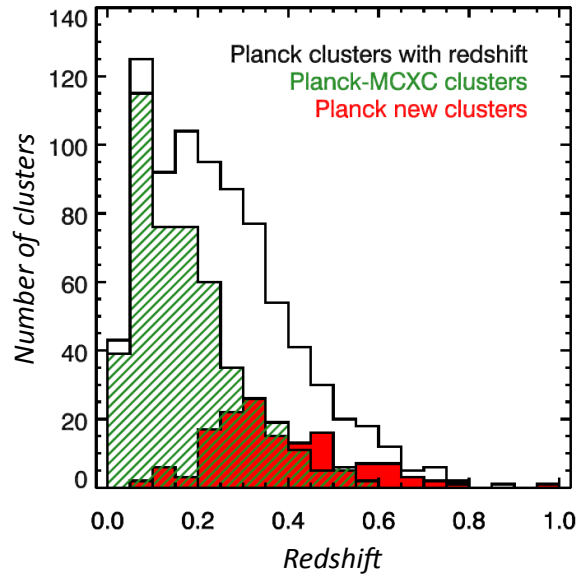


- Gas fraction $M_g/M_{tot} \rightarrow$ (universal) ratio between atoms and matter (Ω_b/Ω_m)
- Angular size vs. Physical size $\rightarrow D_A(z)$
- Number counts $dN/dMdz \rightarrow P(k)$ (depends in particular on Ω_m and σ_8)

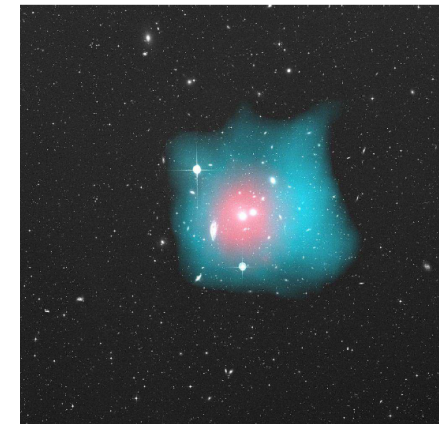
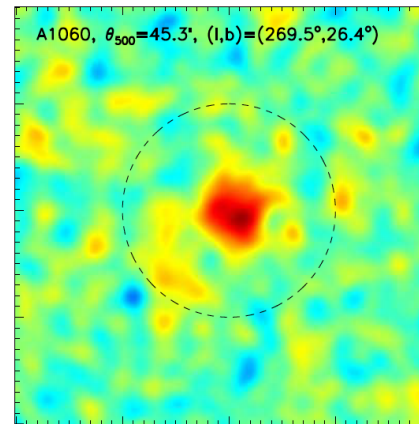
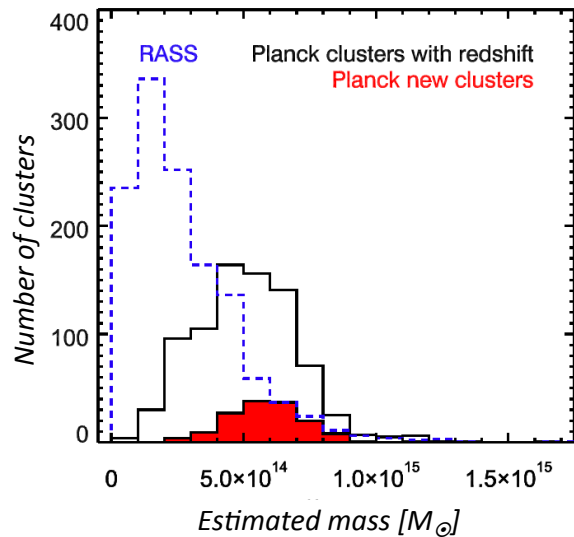
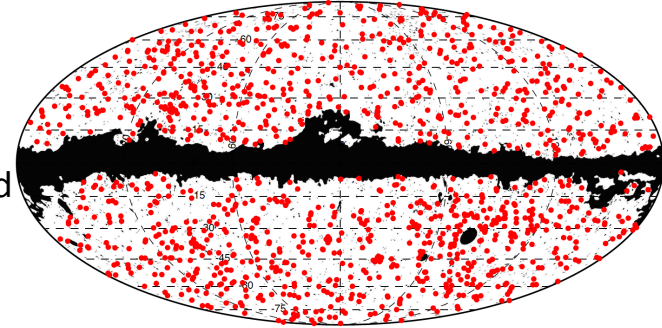
Map of Sunyaev Zel'dovich clusters



Clusters of galaxies

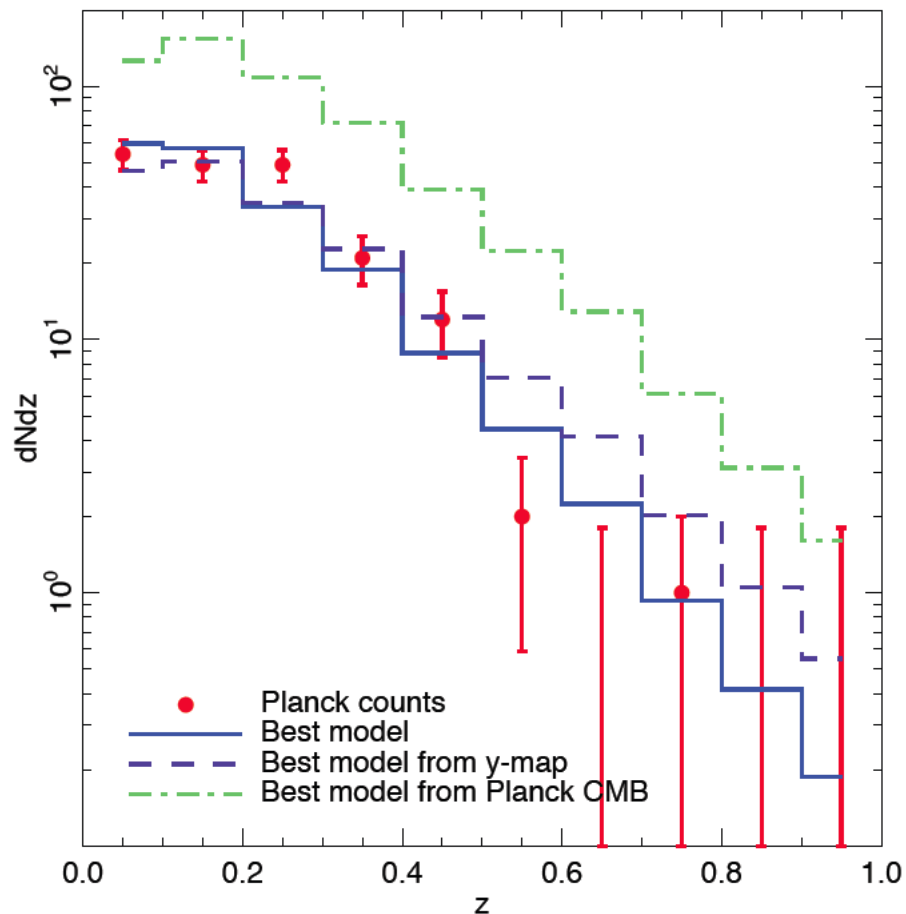


1227 + 5 detections
683 + 5 already known
178 new and confirmed
366 candidates not yet confirmed



The clusters detected by Planck are farther away and more massive than previously known clusters.

Cluster number counts and cosmological parameters



Using 189 well detected clusters

Cosmological parameters from the CMB best fit overpredict the number of observable clusters !

Two possible explanations

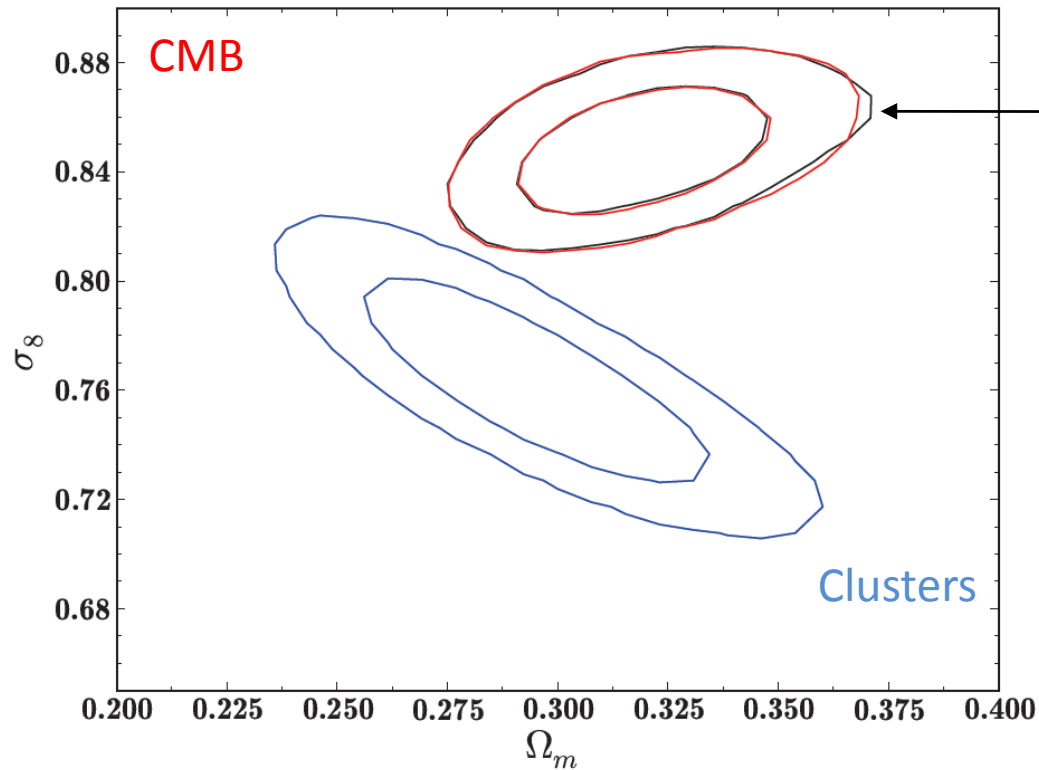
- 1) Possible error on connection between flux and mass of clusters.

Revise cluster physics !

- 2) Cluster physics is well understood, but the connection between fluctuations at $z=1000$ et at $z<1$ is not!

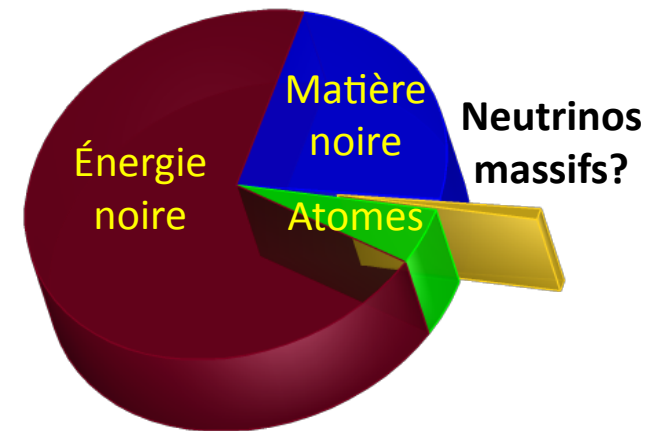
Revise matter and energy content at late times.

Cluster counts and cosmological constraints



Joint constraint with free Y - M relation

(find $M_{\text{predicted}} = 0.55 M_{\text{true}}$)



Other way to reconcile CMB and SZ
 $\Sigma m_\nu \approx 0.3 \text{ eV}$

Outline

- The Planck mission
- Planck data and CMB results
- Cosmological astrophysics
-  • The future

Planck polarisation

- **Planck polarimetry**

- Planck detectors are sensitive to linear polarisation

$$s = \frac{1}{2} \left[(1 + \epsilon) \mathcal{I} + (1 - \epsilon) \left(\mathcal{Q} \cos(2\psi) + \mathcal{U} \sin(2\psi) \right) \right]$$

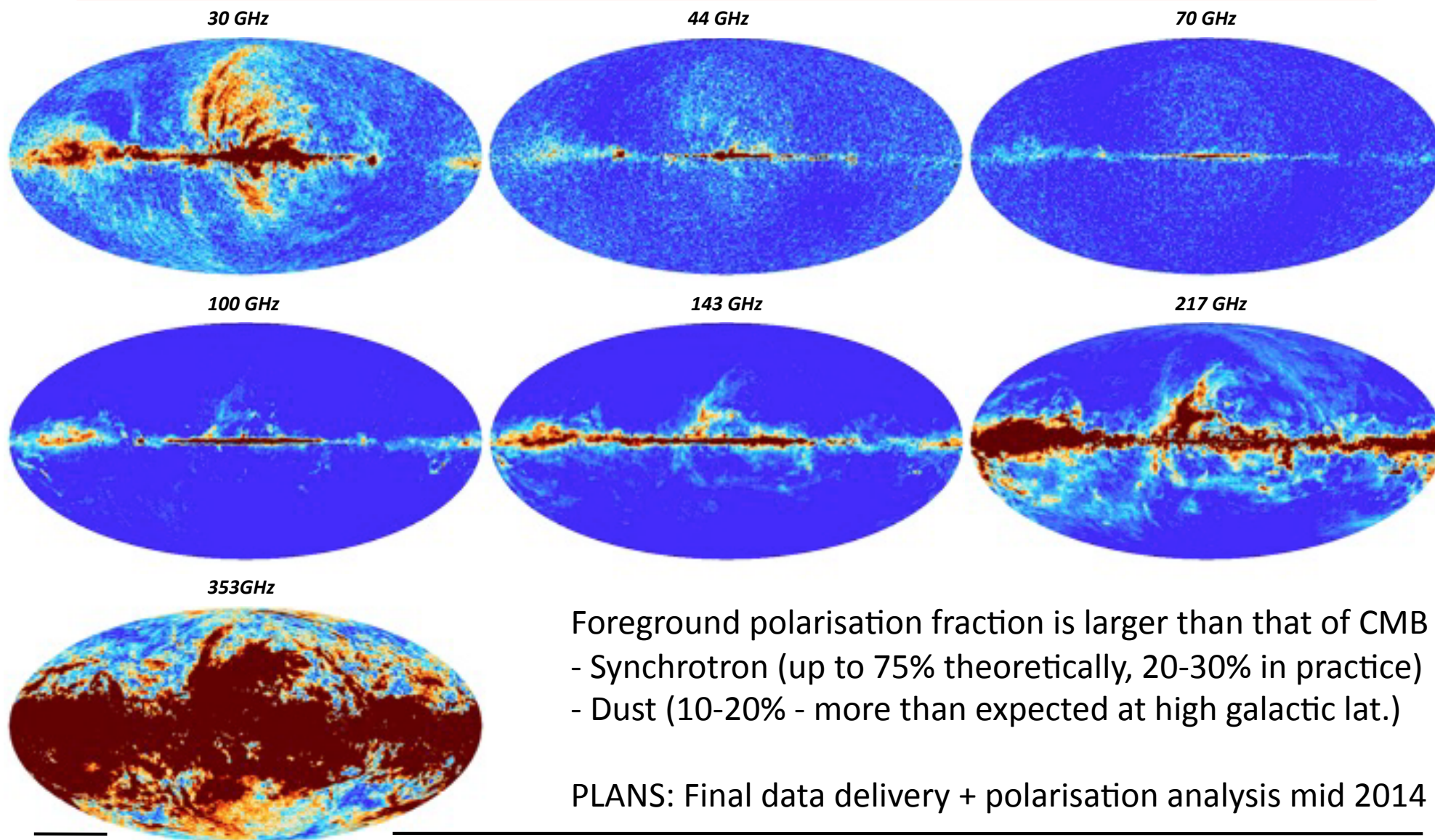
- Planck uses combination of orthogonal detectors to get Q and U :



- **polarisation is challenging**

- any **differential calibration error** between pairs of detectors causes **leakage** of total intensity into the polarization maps (such as gain calibration error or different spectral transmissions),
- the response of each detector to polarization is difficult to **calibrate** (due to the lack of celestial standard sources),
- the amplitude of the **polarized CMB signal is low**

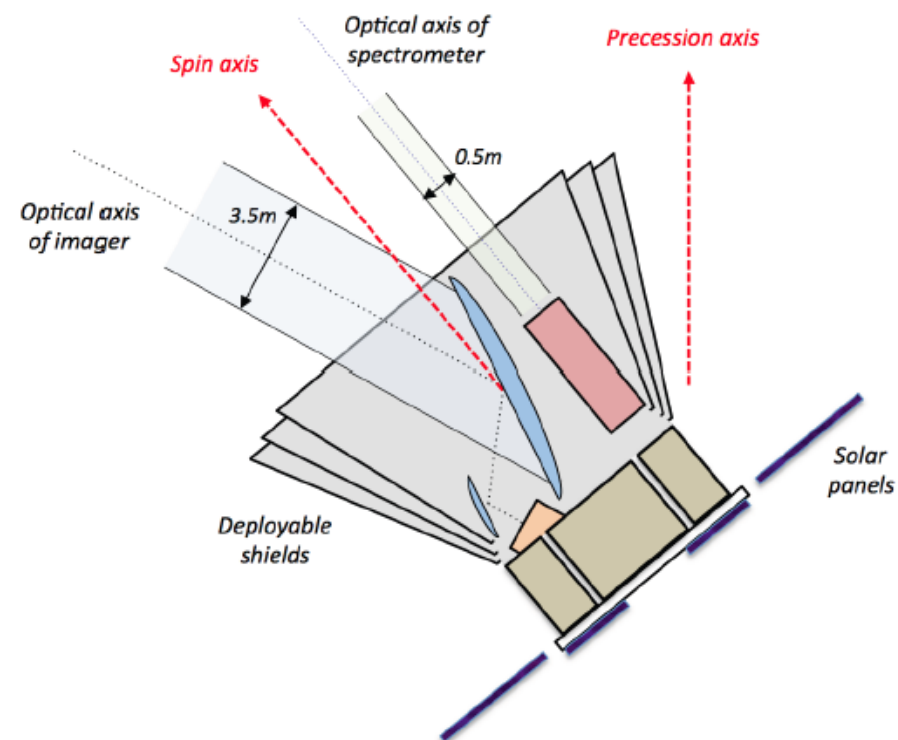
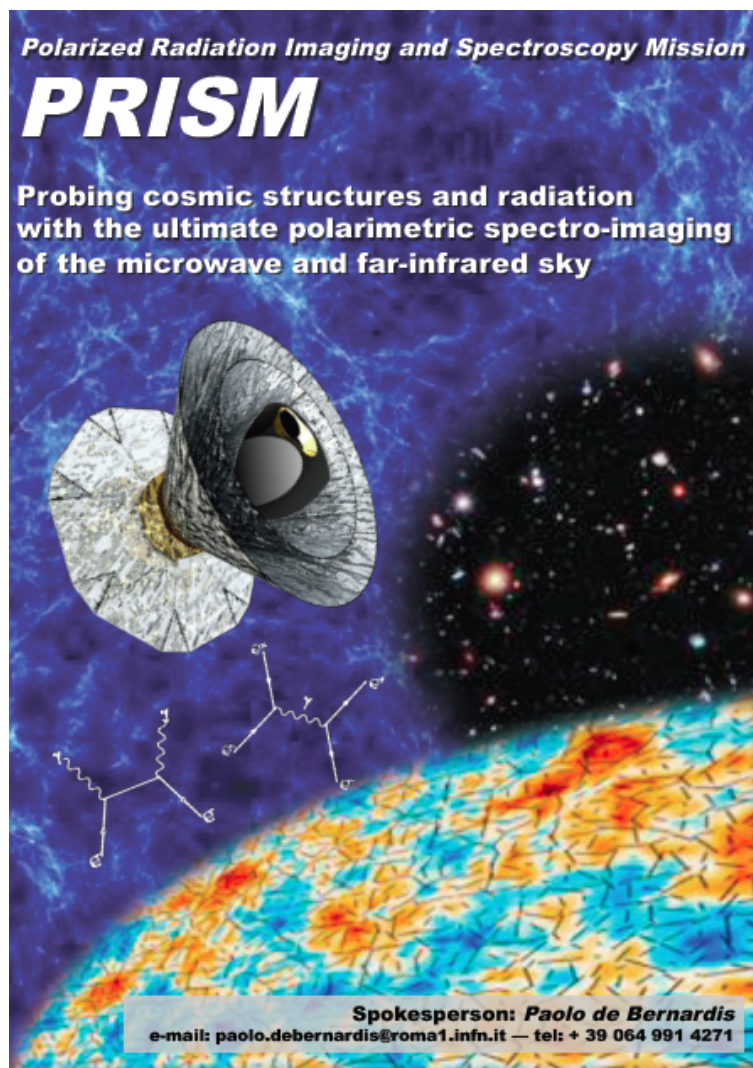
Polarised foreground emission



Foreground polarisation fraction is larger than that of CMB
- Synchrotron (up to 75% theoretically, 20-30% in practice)
- Dust (10-20% - more than expected at high galactic lat.)

PLANS: Final data delivery + polarisation analysis mid 2014

After Planck ?



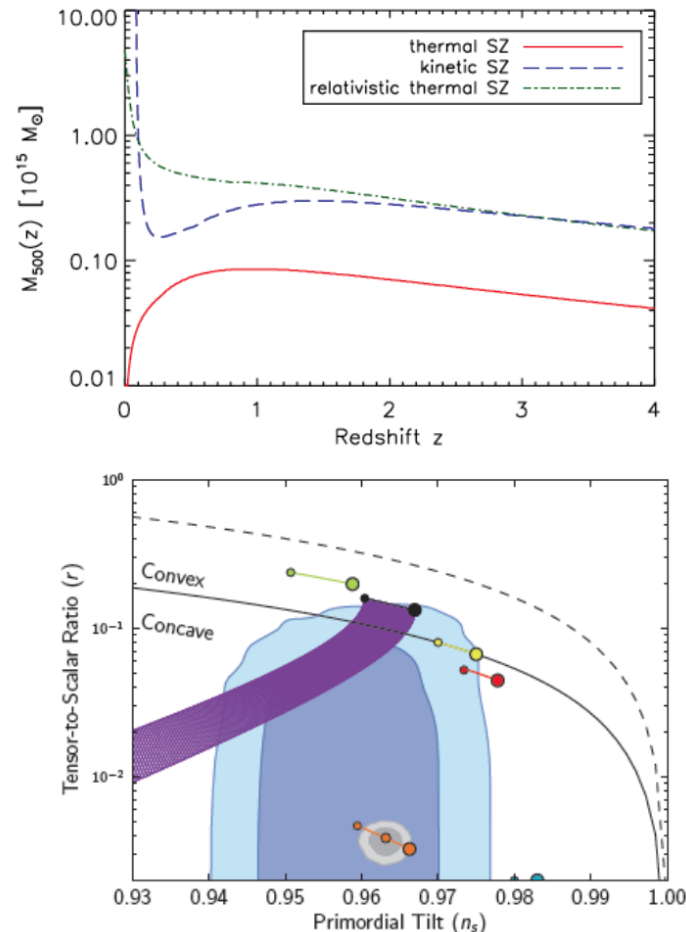
Two instruments:

- An imager with 32 broad frequency bands and 300 narrow bands from 30 GHz to 6 THz
- A spectrophotometer to measure the absolute spectrum in the same freq. range

After Planck ?

PRISM: Science Highlights

- A) **Clusters of galaxies** detected by means of SZ effect. All clusters with masses 10^{14} Msun. Relativistic corrections $\rightarrow$ gas temperature.
- B) **Cosmic Infrared Background.** Dusty galaxies forming the CIB. Dusty torus around AGNs.
- C) **Primordial gravitational waves.** At 5-sigma, it will reach $r=0.0005$. Gravitational lensing.
- D) **CMB spectral distortions.** Cases: y-distortions from the re-ionized gas and from clusters; decaying dark matter; primordial power spectrum on very small scales; recombinational lines.



<http://www.prism-mission.org>

The scientific results of Planck 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.