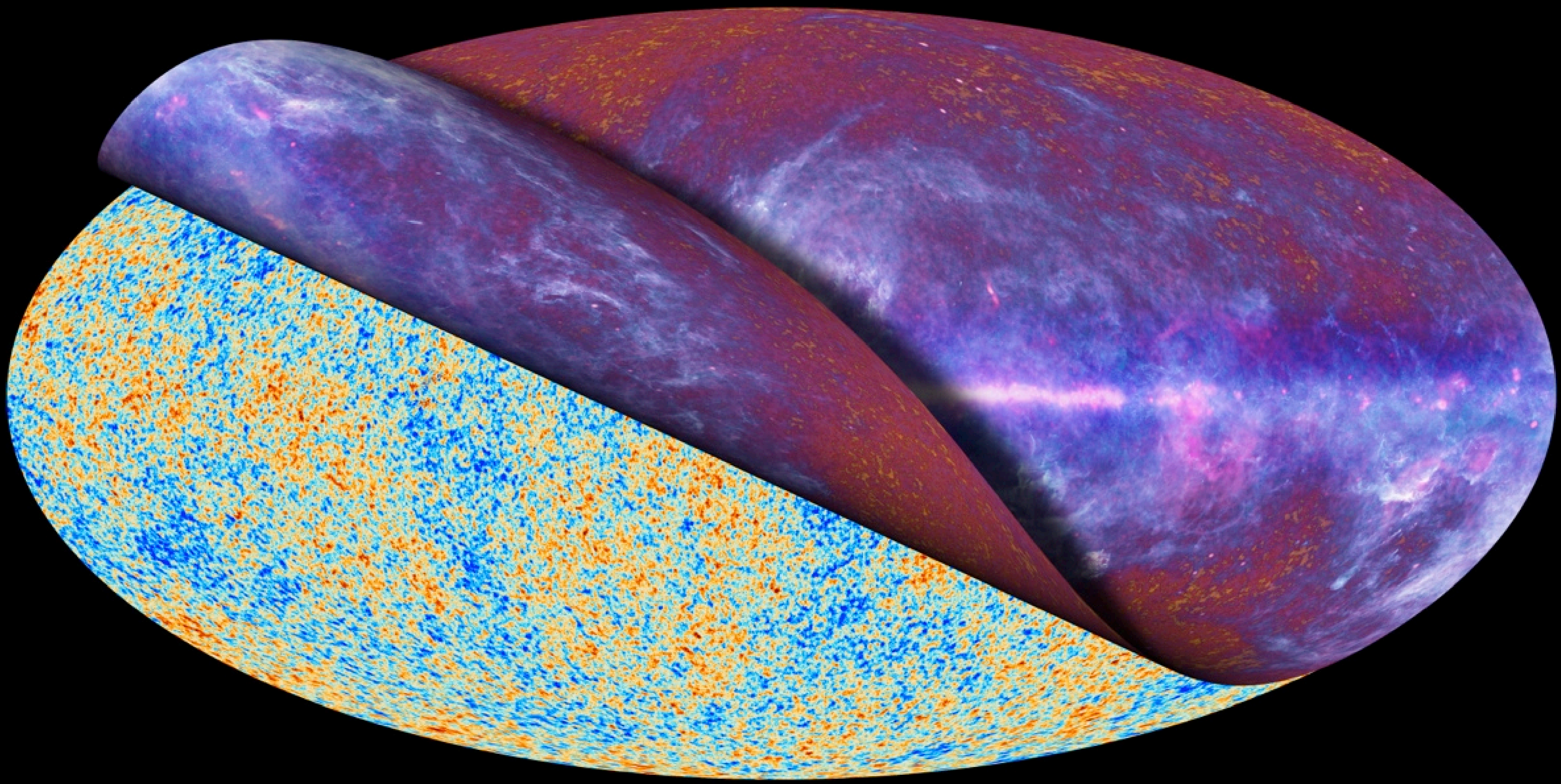
planck

esa

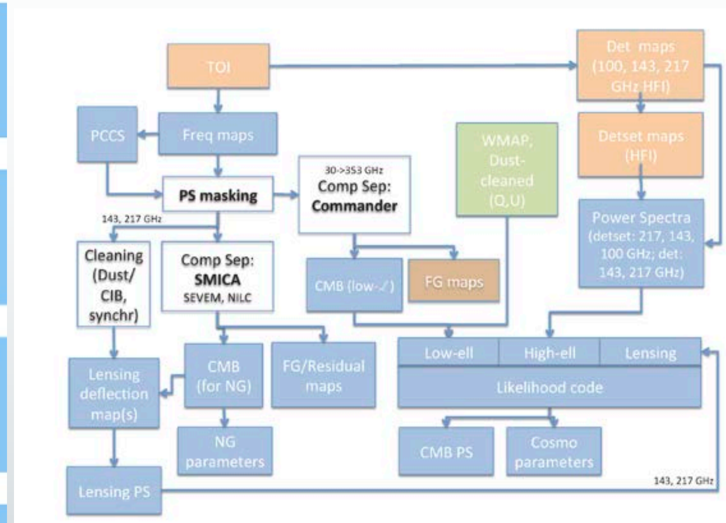


Planck unveils the Cosmic Microwave Background

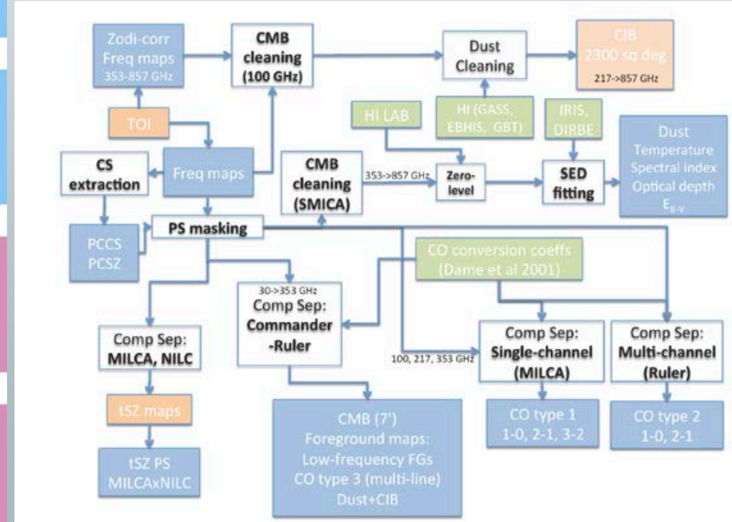
Planck 2013 data and results

- I — Overview of products & results
  - Frequency Maps
  - Component Maps
  - Power Spectra
  - Parameters
- II — LFI Processing
  - III — LFI Systematics
  - IV — LFI Beams
  - V — LFI Calibration
- VI — HFI Processing
  - VII — HFI Time Response & Beams
  - VIII — HFI Calibration
  - IX — HFI Spectral Response
  - X — HFI Particle effects
- XI — Consistency of the Data
- XII — Component Separation
  - XIII — Galactic CO
  - XIV — Zodiacal Emission
- XV — Power Spectra & Likelihood
- XVI — Cosmological Parameters
- XVII — Lensing by LSS
- XVIII — Lensing by Star-forming Galaxies
- XIX — The Integrated Sachs-Wolfe Effect
- XX — Cosmology from SZ Counts
- XXI — Compton Parameter Map
- XXII — Inflation
- XXIII — Isotropy & Statistics
- XXIV — Primordial Non-Gaussianity
- XXV — Strings & Other Defects
- XXVI — Background Geometry & Topology
- XXVII — Special Relativistic Effects on the Dipole
- XXVIII — Catalogue of Compact Sources
- XXIX — Catalogue of SZ Sources

> 1000 pages



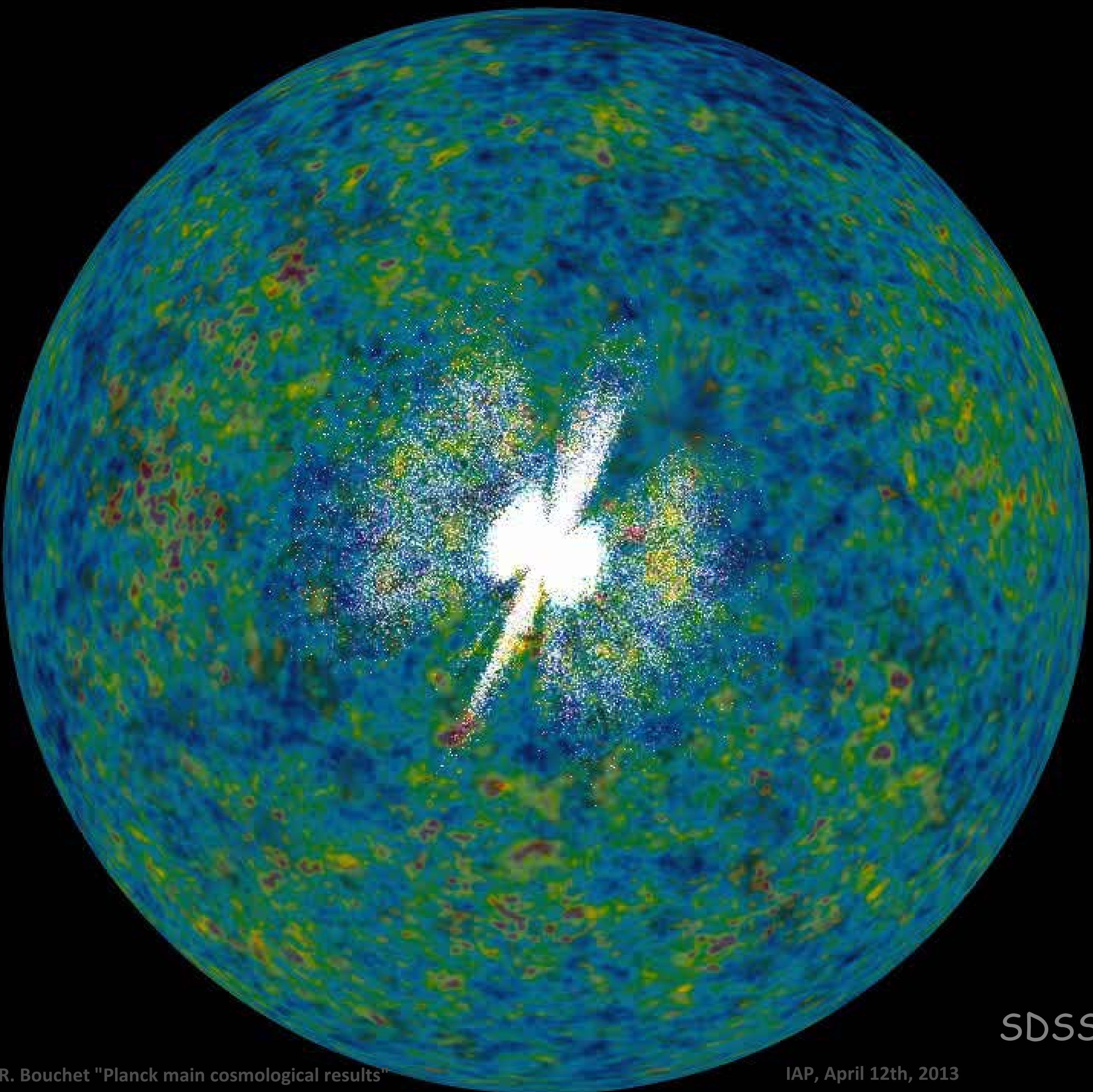
http://www.sciops.esa.int/index.php?page=Planck_Legacy_Archive&project=planck



Planck main cosmological results

XVI. Cosmological parameters
XXII. Constraints on inflation
XXIV Constraints on primordial non-Gaussianity
XXV. Searches for cosmic strings and other topological defects

François R. Bouchet
Institut d'Astrophysique de Paris
On behalf of the Planck collaboration



SDSS & WMAP

The Planck concept

- to perform the “ultimate” measurement of the Cosmic Microwave Background (CMB) temperature anisotropies:
  - *full sky coverage & angular resolution / to survey all scales at which the CMB primary anisotropies contain information (~5’)*
  - *sensitivity / essentially limited by ability to remove the astrophysical foregrounds*

  $\Rightarrow$ *enough sensitivity within large frequency range [30 GHz, 1 THz]*
  (~CMB photon noise limited for ~1yr in CMB primary window)

- get the best performances possible on the polarization with the technology available

$\Rightarrow$ ESA selection in 1996 (after ~ 3 year study)

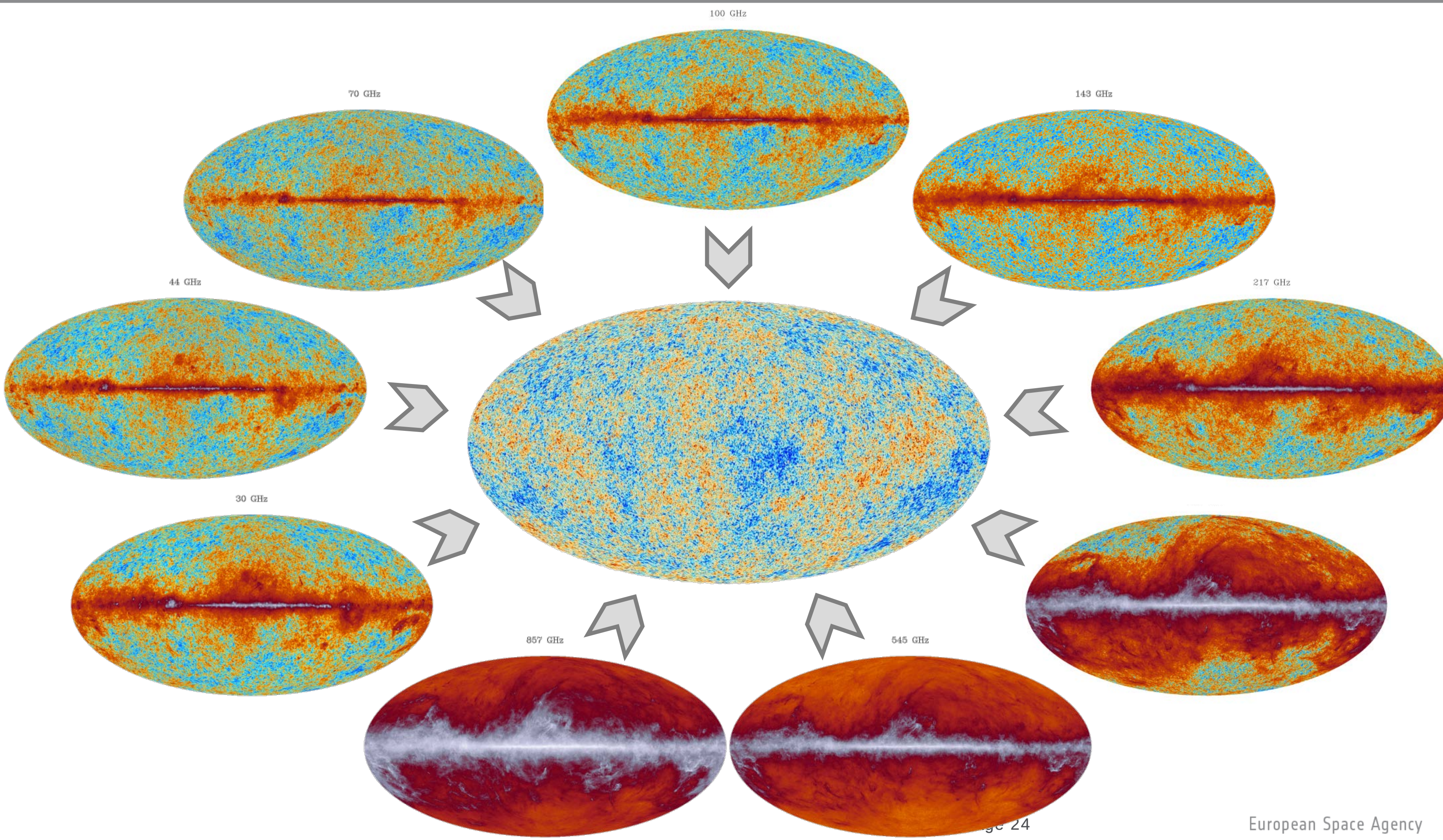
NB: with the Ariane 501 failure delaying us by several years (03 → 07) and WMAP then flying well before us, polarization measurements became more and more a major goal


Ariane 5 ECA Launch • HERSCHEL – PLANCK - May 14, 2009

Log Book (abridged)

- Instruments very stable, continuously mapping the sky, with essentially no hiccups from the beginning of survey, on August 13th 2009, till the end of HFI, **on Jan 14th 2012**;
- Expectations on sensitivities confirmed in flight: HFI reaches or exceeds its goals
- First complete coverage of the sky by all detectors was obtained in June 2010 with the first nearly 10 months of survey data. ERCSC release & batch of 25 papers on “Planck early results” submitted **in Jan 2011**;
- Nominal mission was completed on November 27th 2010, having collected about 15.5 months of survey data insuring that all the sky at been seen at least twice by each detector:
  - *12 “Planck Intermediate results” papers on CMB foregrounds results submitted **in 2012**.*
  - *public data delivery on **March 21st 2013**, together with 28 “Planck 2013 results” papers*
- All HFI survey data acquired! 885 days of survey, 900 billion samples, 5 surveys, twice the nominal duration. With some additional LFI data (~6months) will be the basis of our next data delivery (DD2) in **mid 2014.** (including polarisation)

Cleaning the background from its 7 veils

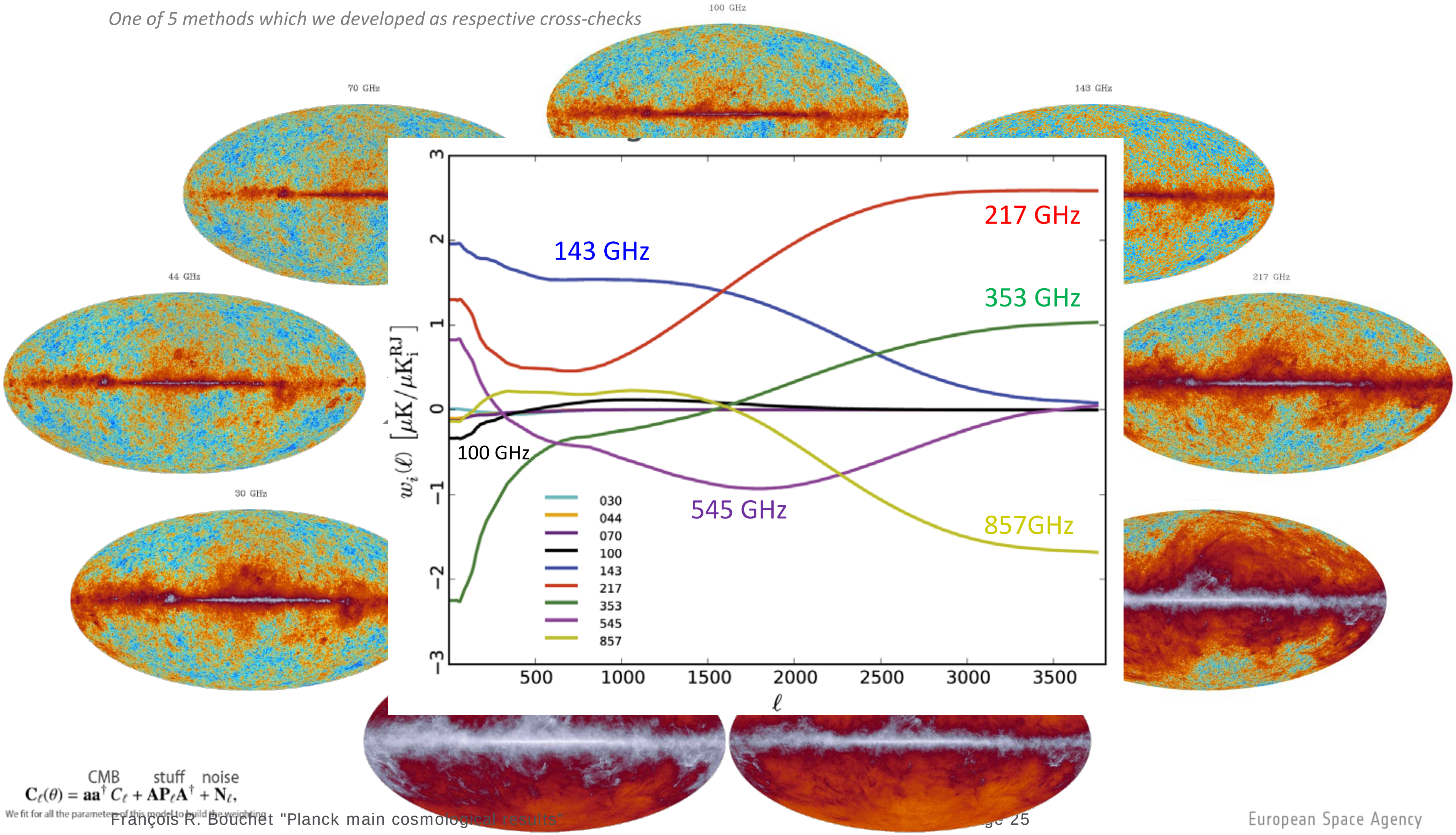


François R. Bouchet "Planck main cosmological results"

3% of the CMB sky replaced by a Gaussian Random realisation

Cleaning the background with an l-dependent linear combination

One of 5 methods which we developed as respective cross-checks



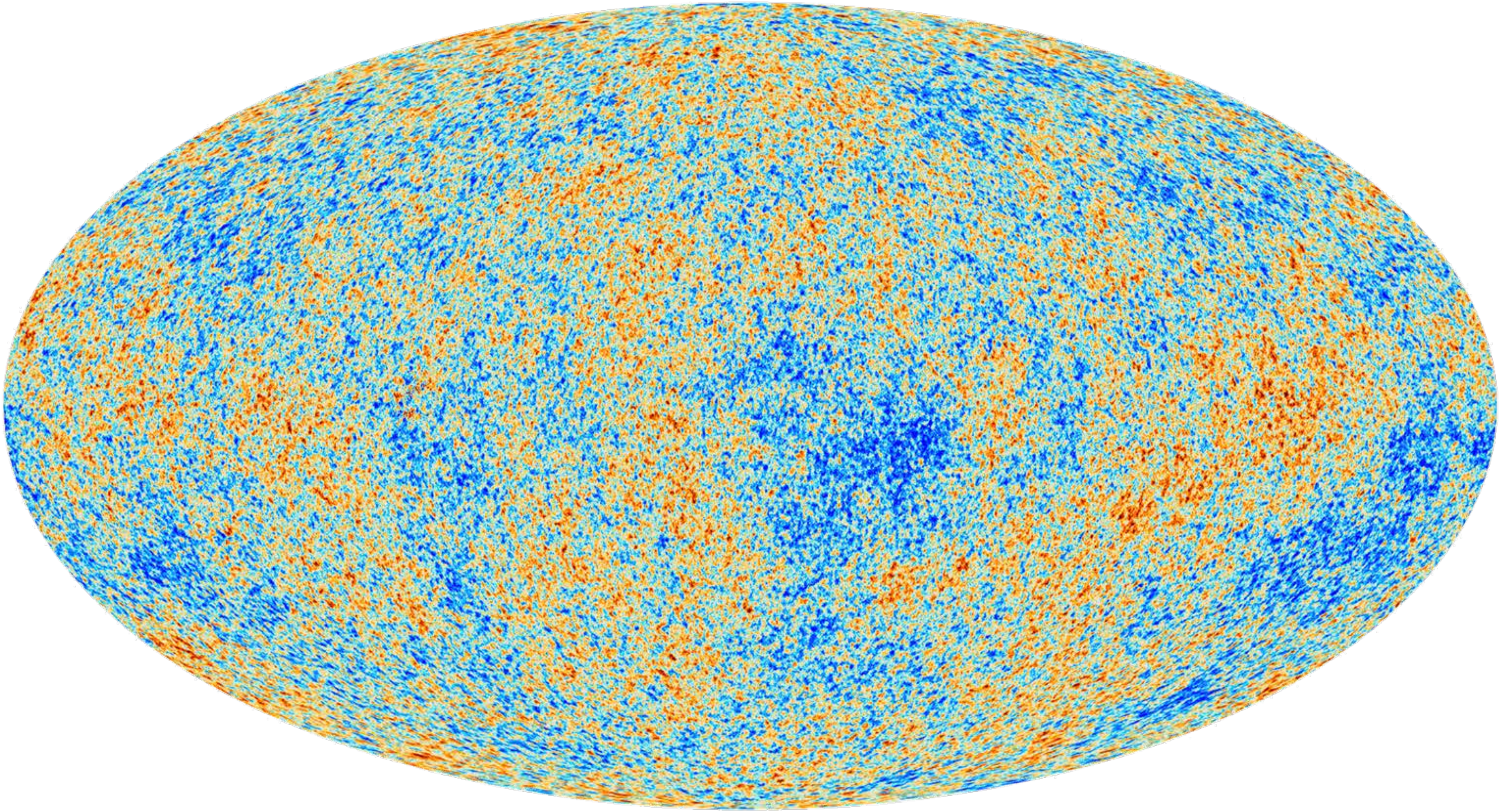
$$\underbrace{\mathbf{C}_\ell(\theta) = \mathbf{a}\mathbf{a}^\dagger C_\ell}_{\text{CMB}} + \underbrace{\mathbf{A}\mathbf{P}_\ell\mathbf{A}^\dagger}_{\text{stuff}} + \underbrace{\mathbf{N}_\ell}_{\text{noise}},$$

We fit for all the parameters of this model to build the weighting

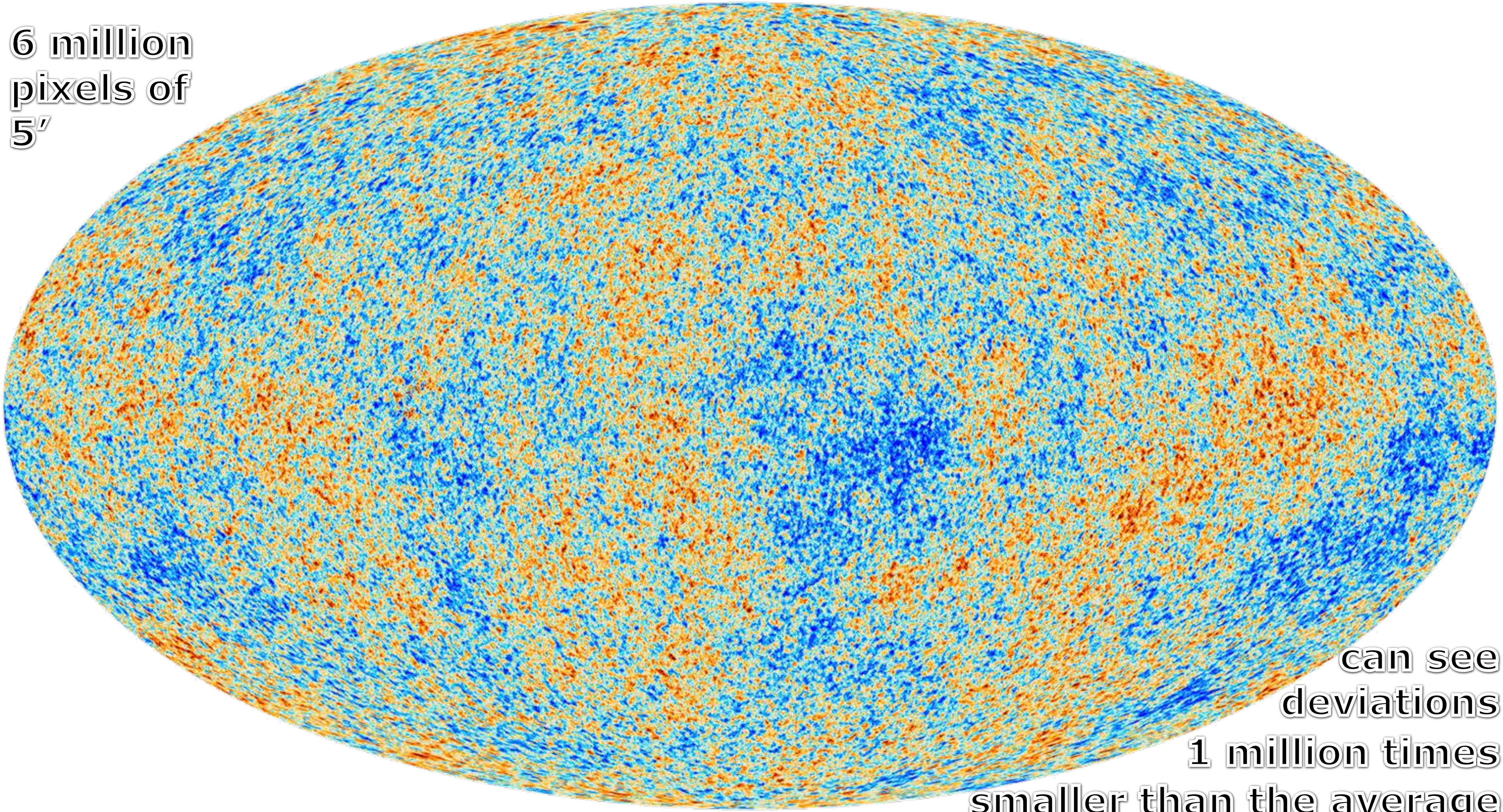
$$\mathbf{w}_\ell = \frac{\mathbf{C}_\ell^{-1}\mathbf{a}}{\mathbf{a}^\dagger\mathbf{C}_\ell^{-1}\mathbf{a}},$$

3% of the CMB sky replaced by a Gaussian Random realisation

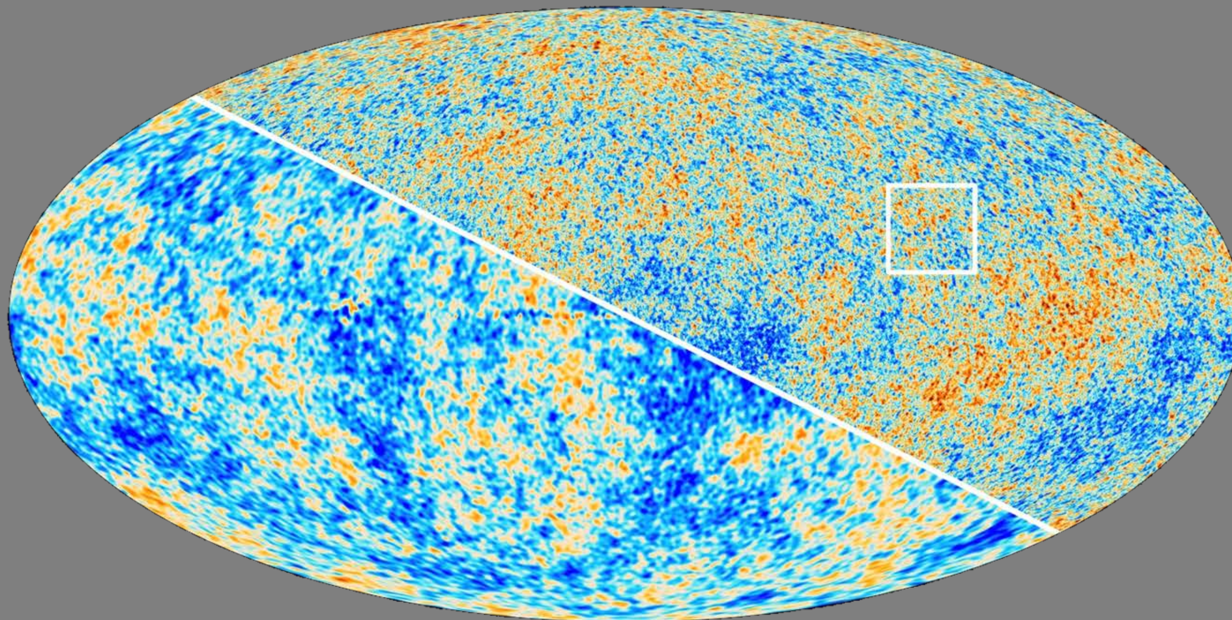
The cosmic microwave background Temperature anisotropies

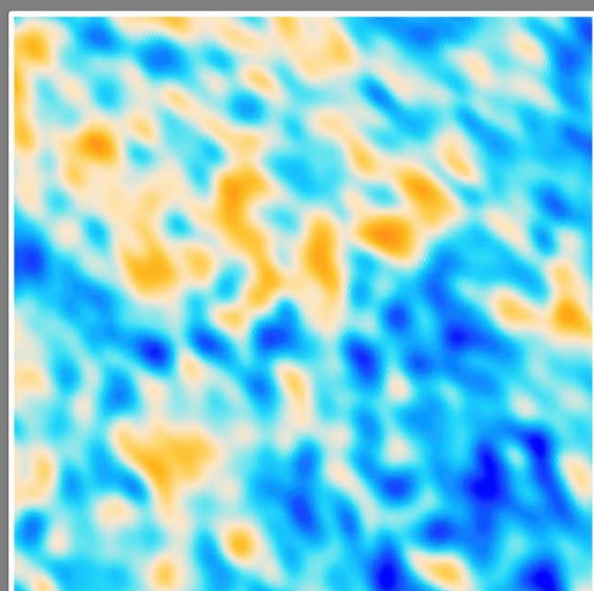


The cosmic microwave background Temperature anisotropies

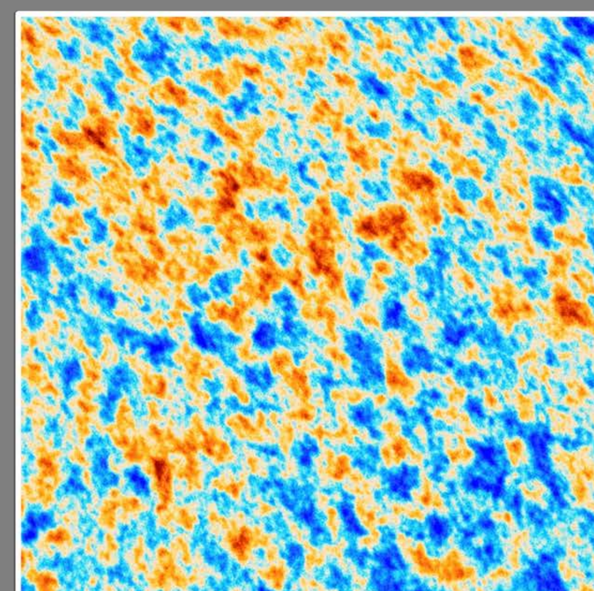


The Cosmic Microwave Background as seen by Planck and WMAP





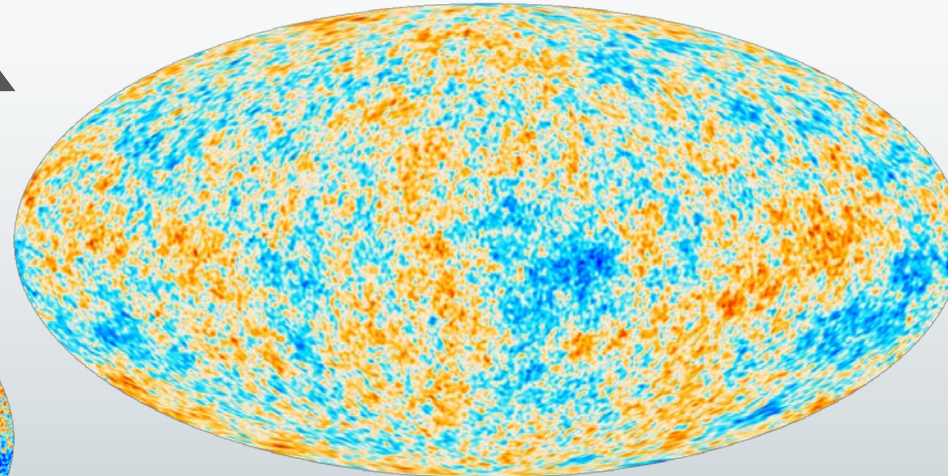
WMAP

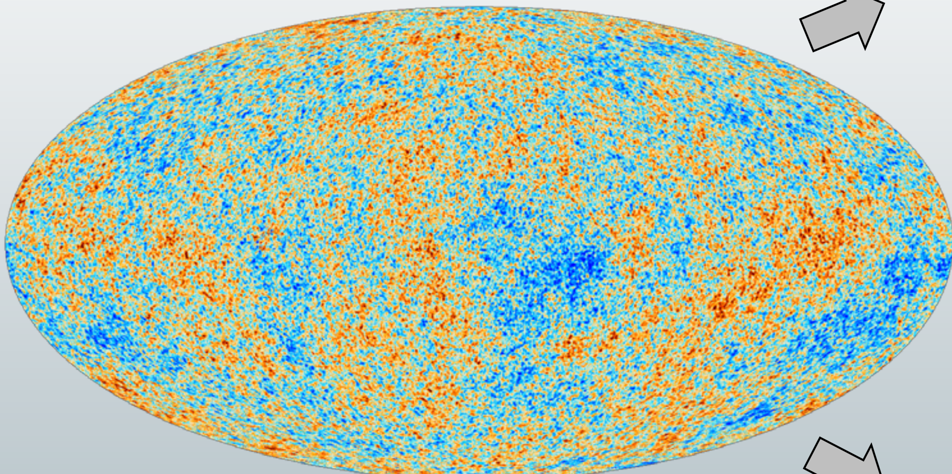


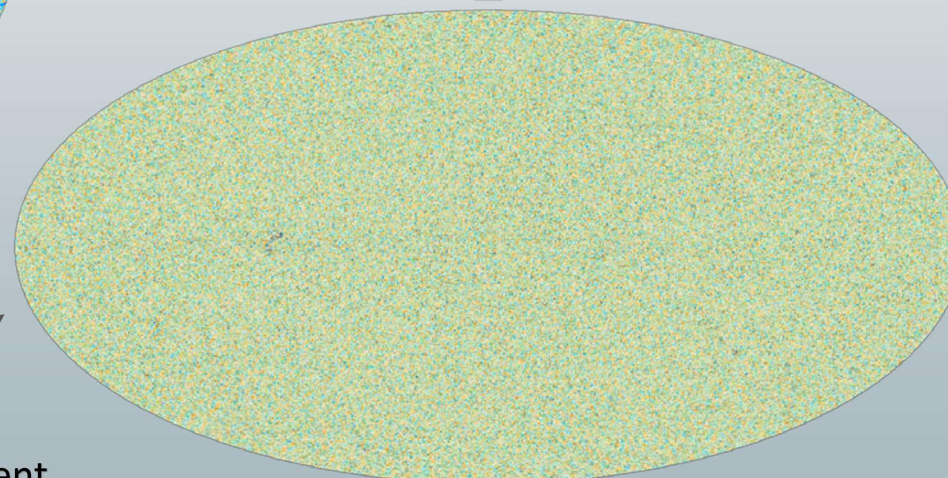
Planck

Our window

Smoothed map (suppressing scales θ < 1 deg) :
Quantum Fluctuations imprinted
When the age of the Universe was in the interval [10^{-39}, 10^{-12}] seconds

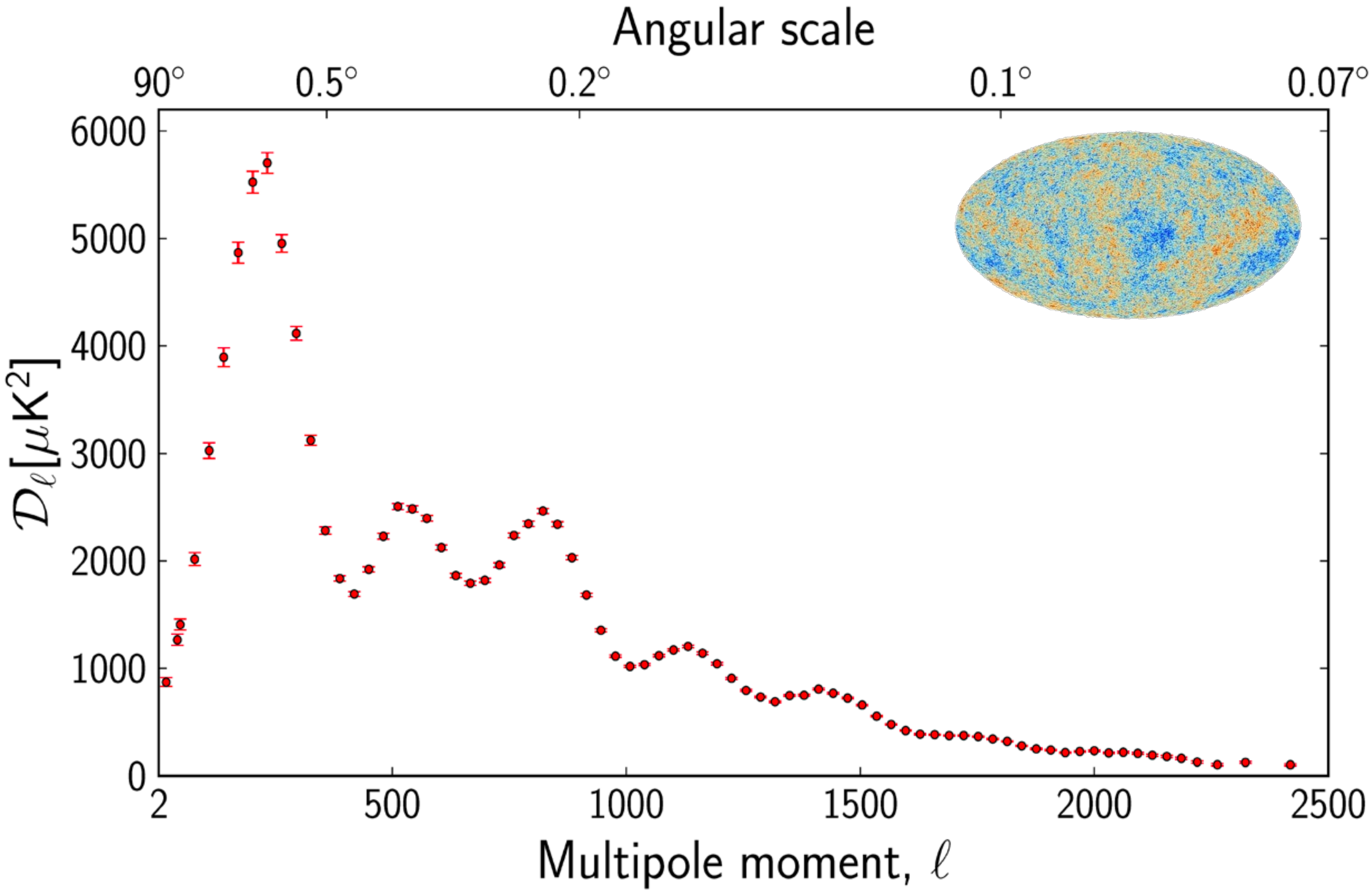






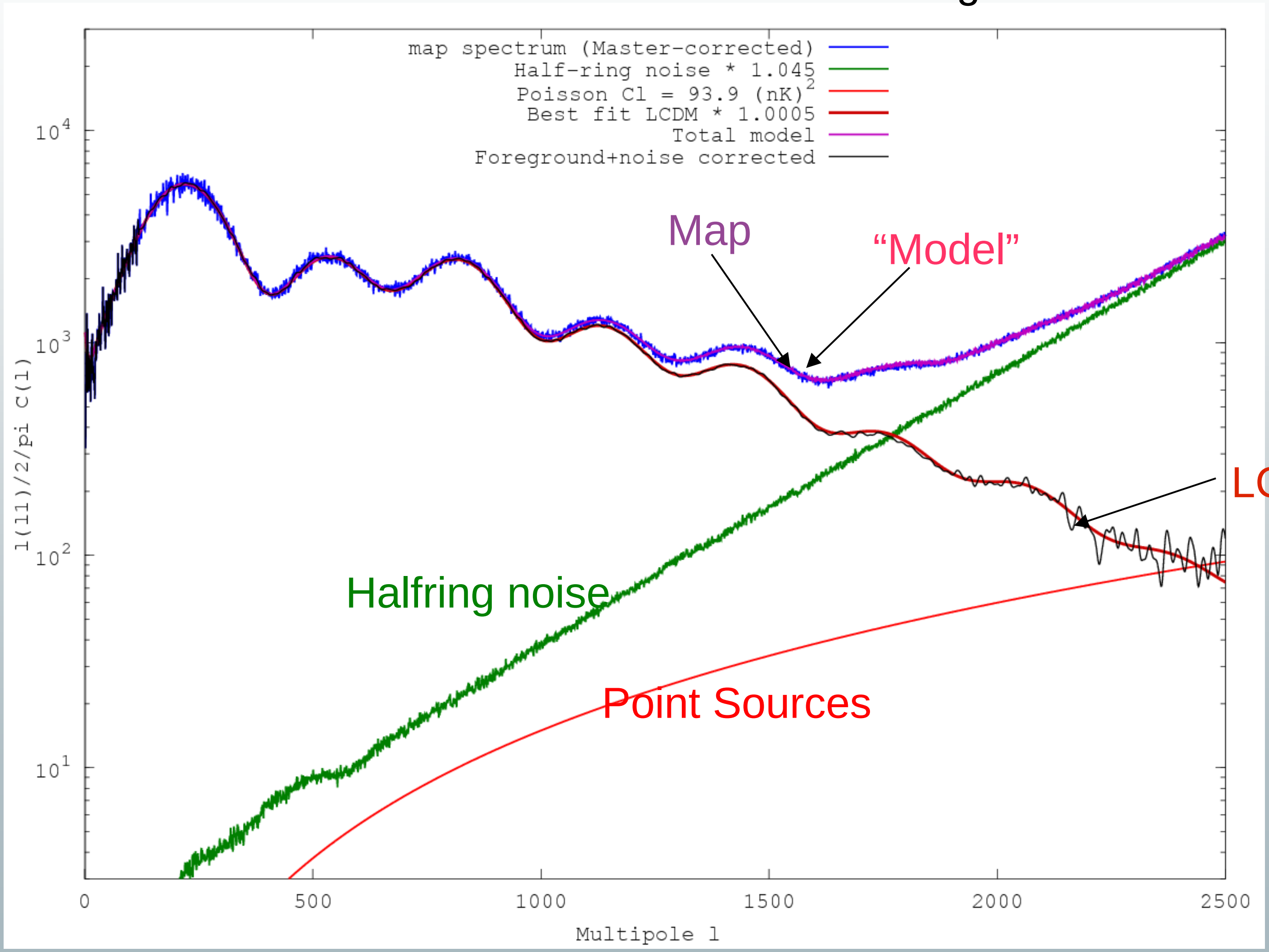
Difference map (scales θ < 1 deg) :
Acoustic oscillations at small scales
< ct when t=380 000 years (~150 Mpc today).
Which allows to take a census of the Universe content

The Planck spectrum of Temperature anisotropies



Checking consistency of the CMB PS/map

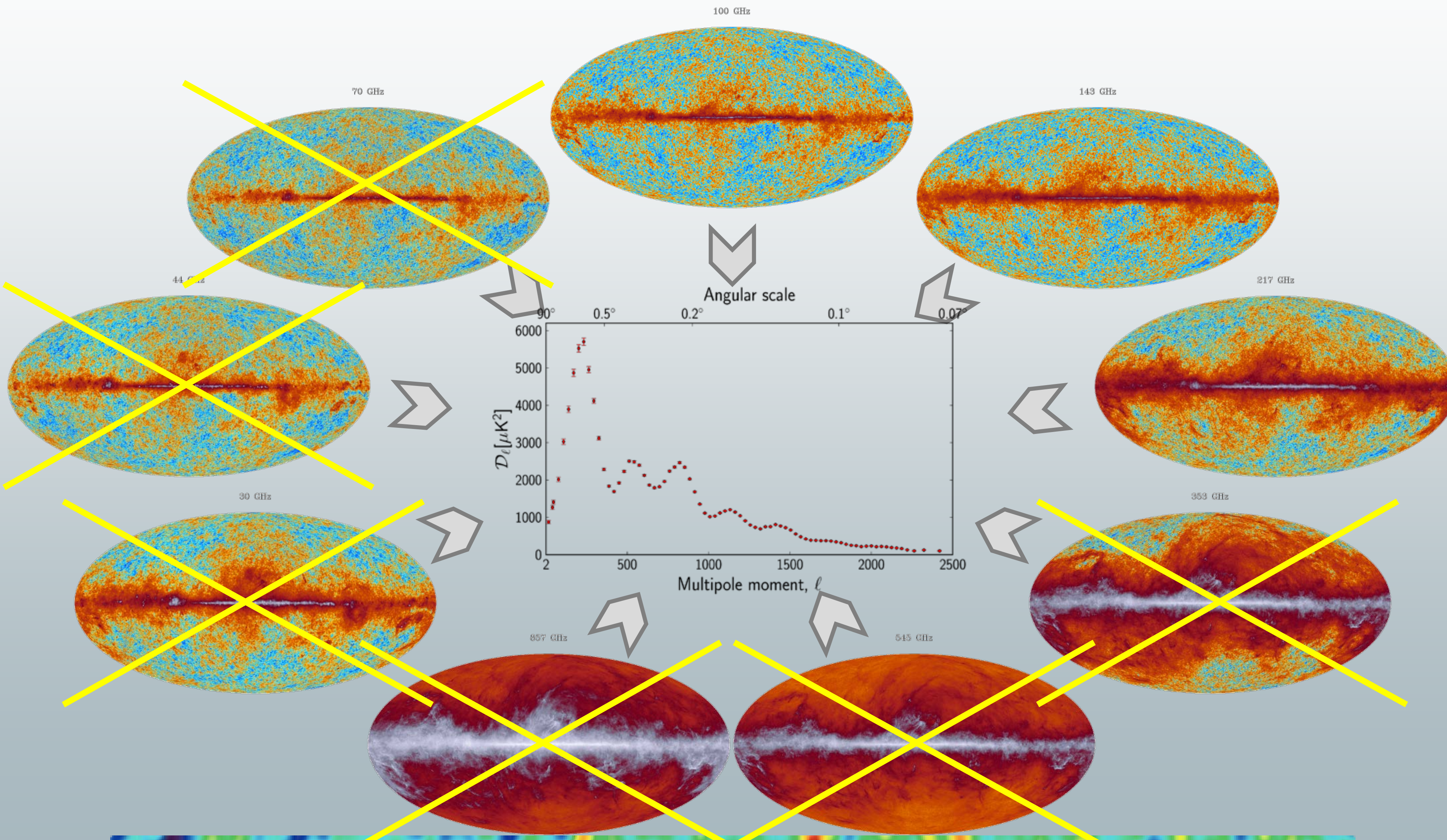
Over 89% of the sky, explain the map spectrum with:
best fit Planck + Point Source + Half-Ring noise



Likelihood Methodology

- Need to provide P(C^{theory}(l) | Planck)
- Hybrid multi-frequency likelihood approach
  - *Large scales (LL): Gaussian likelihood on maps*
  - *Small scales (HL): Gaussian likelihood approx. on spectra*
- Foregrounds:
  - *LL: Parametrised at the map level, Gibbs marginalisation*
  - *HL: Parametrised at the spectral level*
- Validation:
  - *Data selection & technical choices*
  - *Null tests*
  - *Simulations*
  - *Foreground cleaned CMB maps, LFI 70 GHz (HL)*

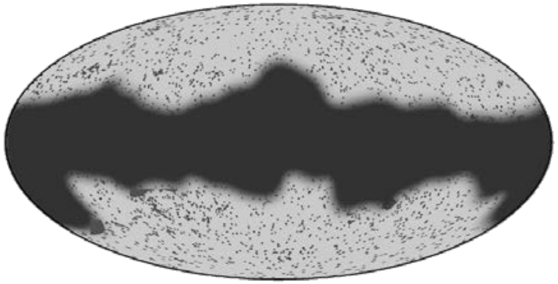
Cleaning the background power spectrum from its 7 veils

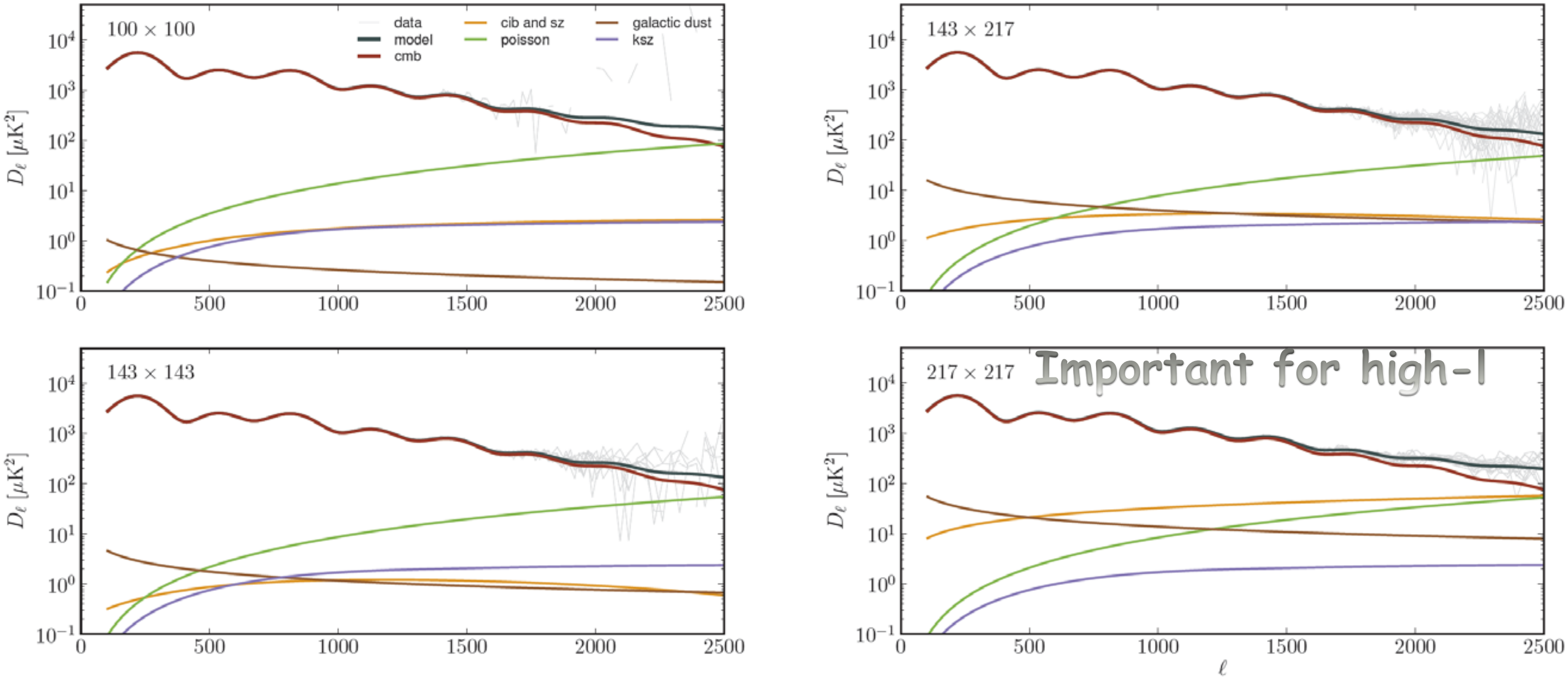


3% of the CMB sky replaced by a Gaussian Random realisation

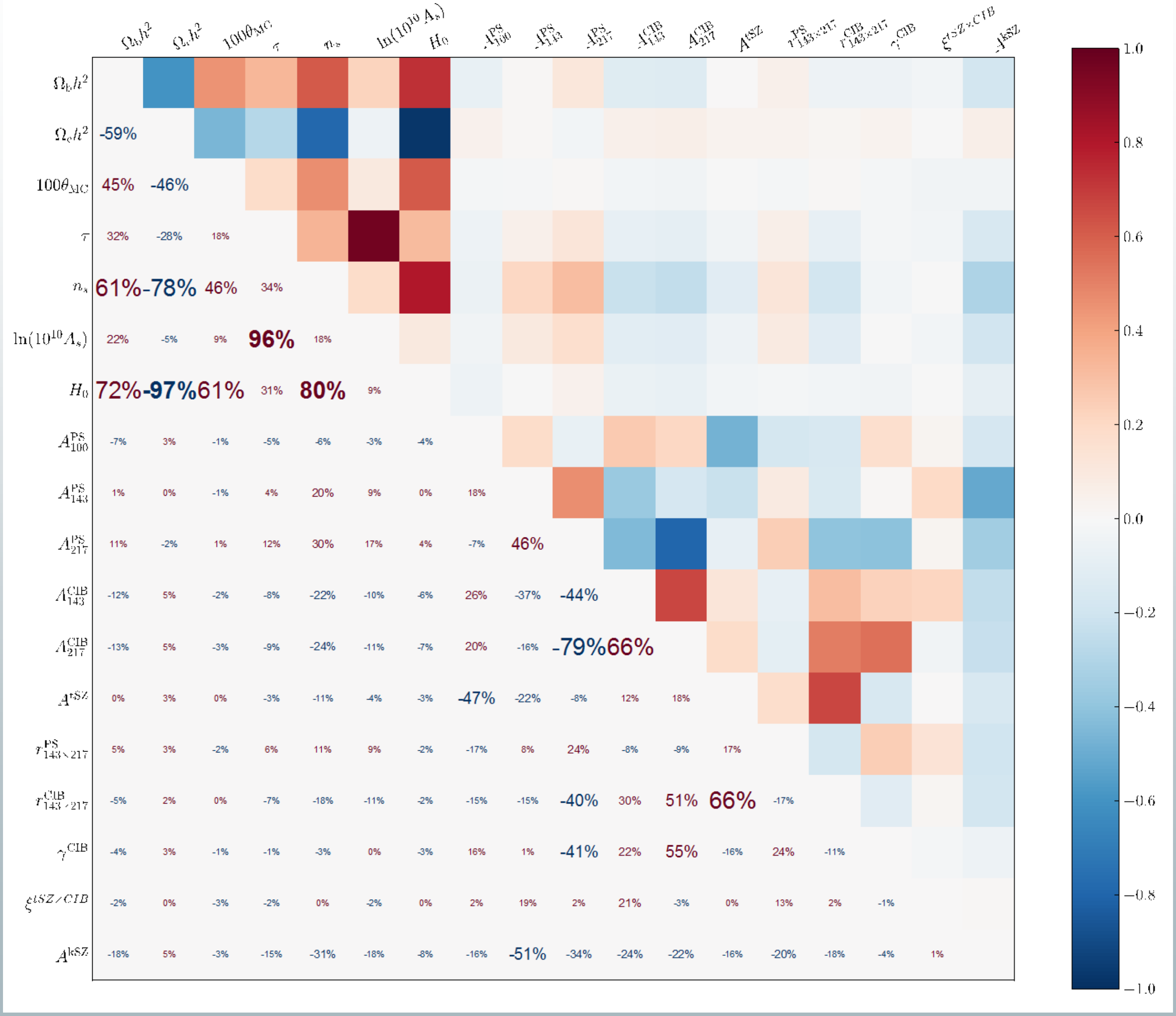
Origin of the CMB spectrum

We need to mask the galactic plane and model:
- Residual galactic dust emission
- Point sources (radio or infrared sources=Poisson)
- Infrared background (clustered = CIB)
- Thermal SZ
- Kinetic SZ

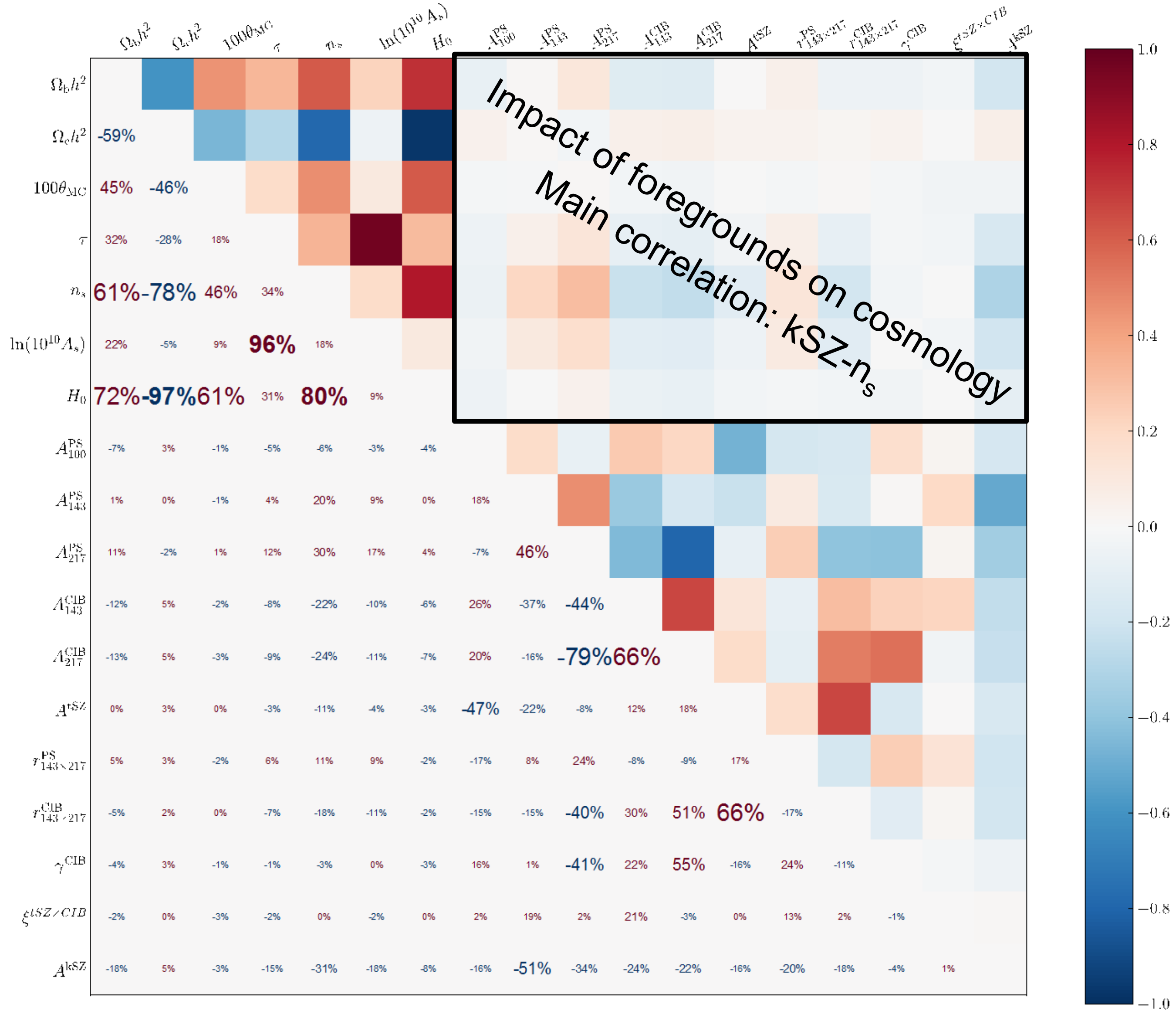




HL posterior correlations

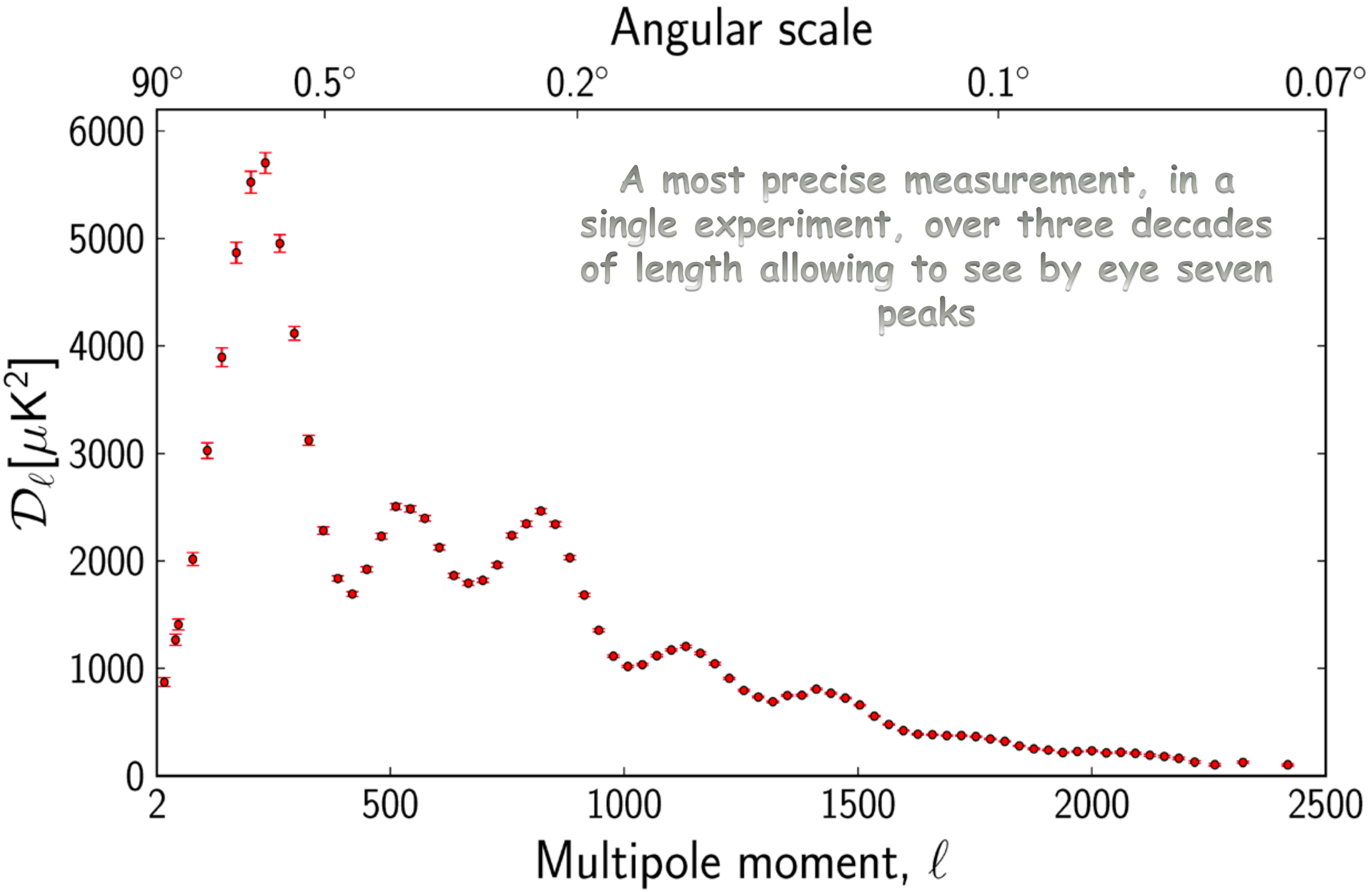


HL posterior correlations

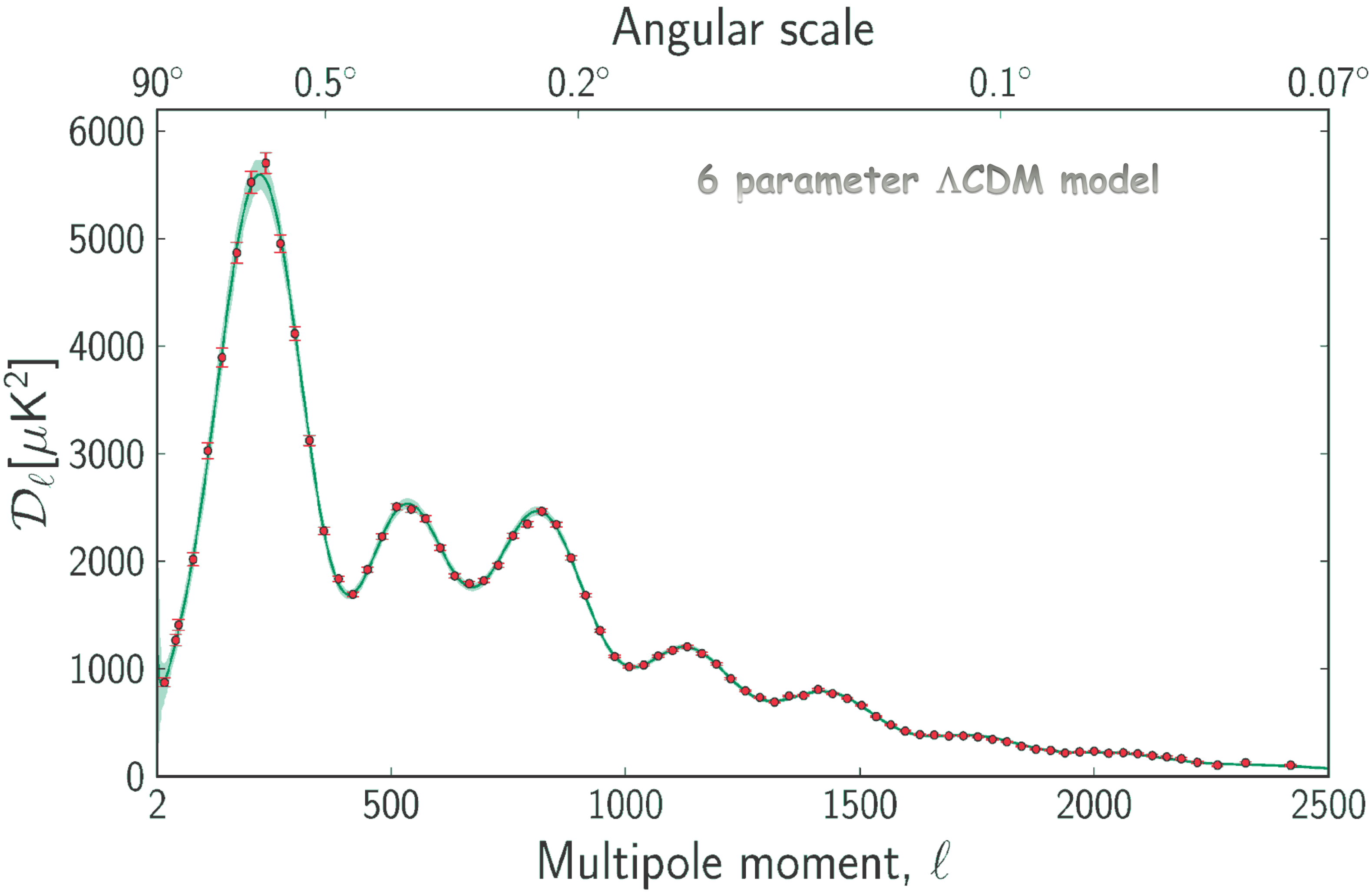


NB: H0 derived parameter

The Planck spectrum of Temperature anisotropies



Theory confronts data

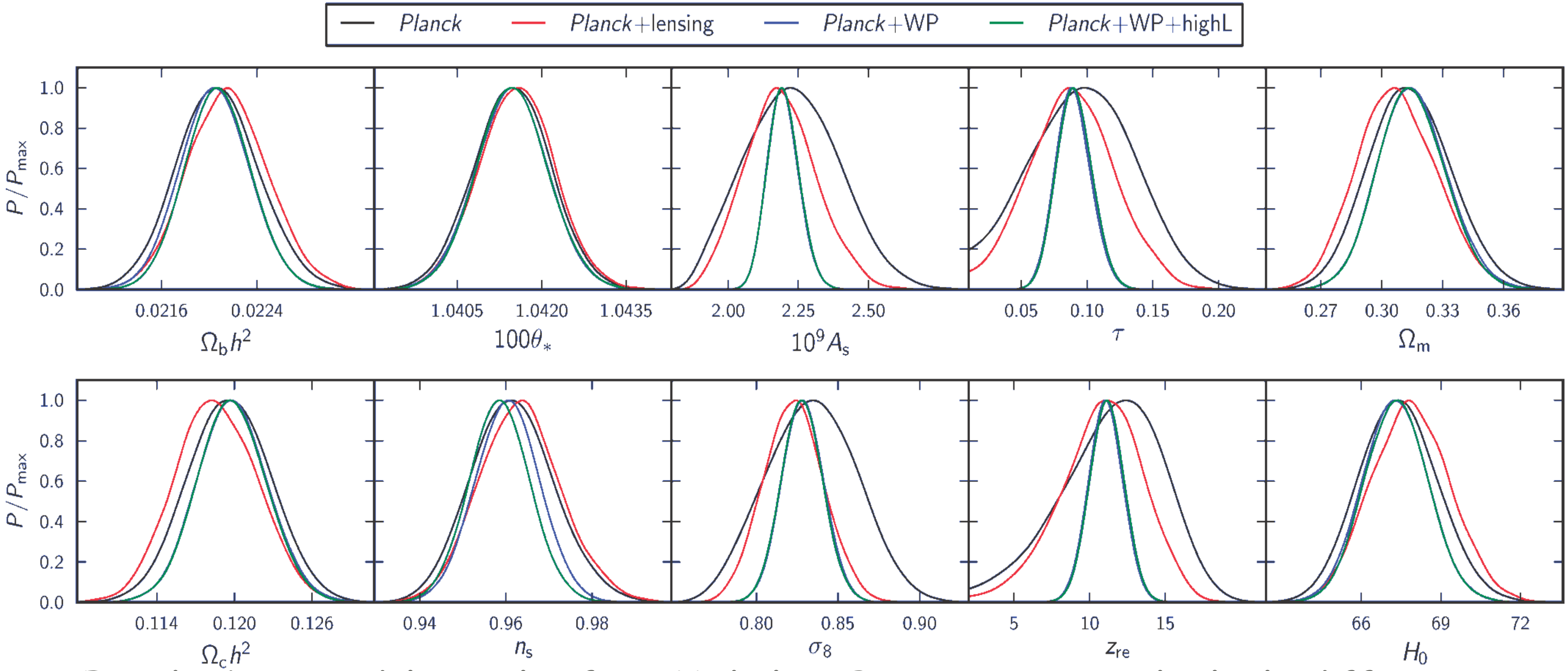


Base ΛCDM model with 6 parameters

3 parameters to set (though General Relativity) the dynamics of the universe, 1 parameter to capture the effect of reionisation (end of the dark ages), 2 parameters to describe the primordial fluctuations.
Flat spatial geometry.

- $\Omega_b h^2$ Baryon density today - The amount of ordinary matter
- $\Omega_c h^2$ Cold dark matter density today – only weakly interacting
- Θ Sound horizon size when optical depth τ reaches unity
  (Distance traveled by a sound wave since inflation, when universe became transparent at recombination at t ~380 000 years)
- τ Optical depth at reionisation (due to Thomson scattering of photons on e^-), i.e. fraction of the CMB photons re-scattered during that process
- A_s Amplitude of the curvature power spectrum (Overall contrast of primordial fluctuations)
- n_s Scalar power spectrum power law index (${n_s}$-1 measures departure from scale invariance)
- Others are *derived* parameters within the model, in particular
  - Ω_Λ "Dark Energy" fraction of the critical density (derived only if assumed flat)
  - H_0 the expansion rate today (in km/s per Mpc of separation)
  - t_0 the age of the universe (in Gy)

Base ΛCDM model 6 parameters

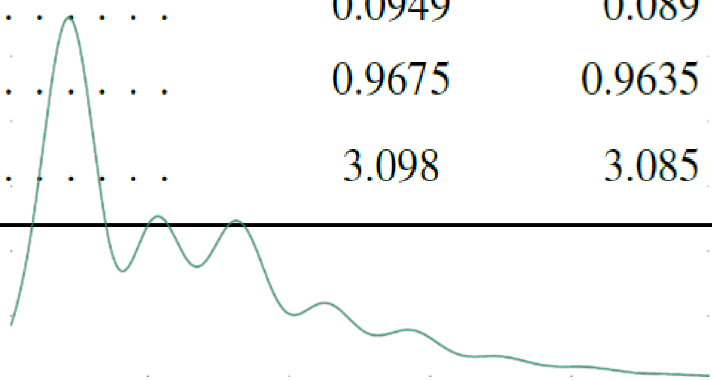


For the base model, results from High-l CMB experiments make little difference

High-l CMB experiments = ACT + SPT (600 & 2540 deg^2, 2 & 3 freq.)

Base ΛCDM model 6 parameters

	Planck (CMB+lensing)		*Planck*+WP+highL+BAO	
Parameter	Best fit	68 % limits	Best fit	68 % limits
$\Omega_b h^2$	0.022242	0.02217 ± 0.00033	0.022161	0.02214 ± 0.00024
$\Omega_c h^2$	0.11805	0.1186 ± 0.0031	0.11889	0.1187 ± 0.0017
$100\theta_{MC}$	1.04150	1.04141 ± 0.00067	1.04148	1.04147 ± 0.00056
τ	0.0949	0.089 ± 0.032	0.0952	0.092 ± 0.013
n_s	0.9675	0.9635 ± 0.0094	0.9611	0.9608 ± 0.0054
$\ln(10^{10} A_s)$	3.098	3.085 ± 0.057	3.0973	3.091 ± 0.025



28 fold diminution in constraint volume / WMAP9
18 fold diminution / WMAP9 + SPT

Base ΛCDM model 6 parameters

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The sound horizon, Θ, determined by the positions of the peaks (7), is now determined with 0.05% precision
(links together $\Omega_b h^2$, $\Omega_c h^2$, H_0)

Exact scale invariance of the primordial fluctuations is ruled out, *at more than 7σ*

(as predicted by base inflation models)

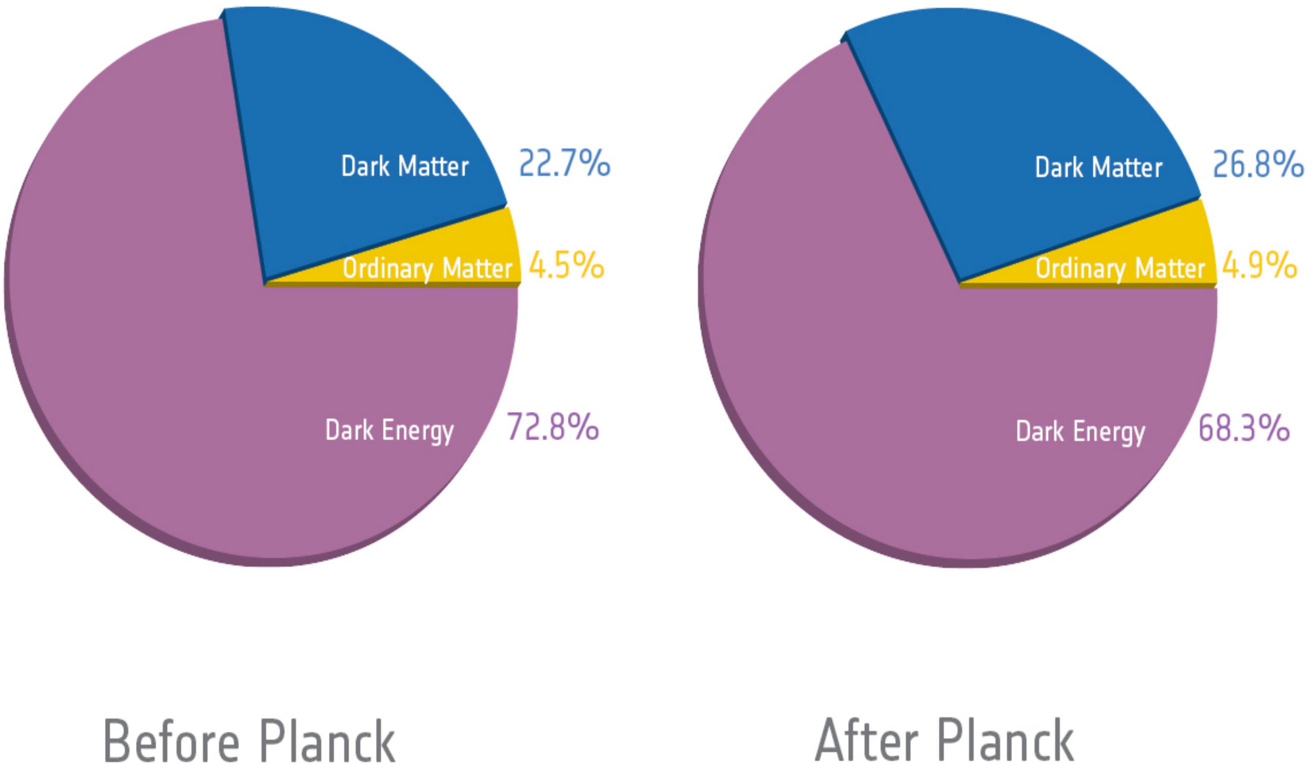
$$\theta_* = (1.04148 \pm 0.00066) \times 10^{-2} = 0.596724° \pm 0.00038°$$

Derived parameters (base model)

Parameter	*Planck* Best fit	*Planck* 68% limits	*Planck*+lensing Best fit	*Planck*+lensing 68% limits	*Planck*+WP Best fit	*Planck*+WP 68% limits
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

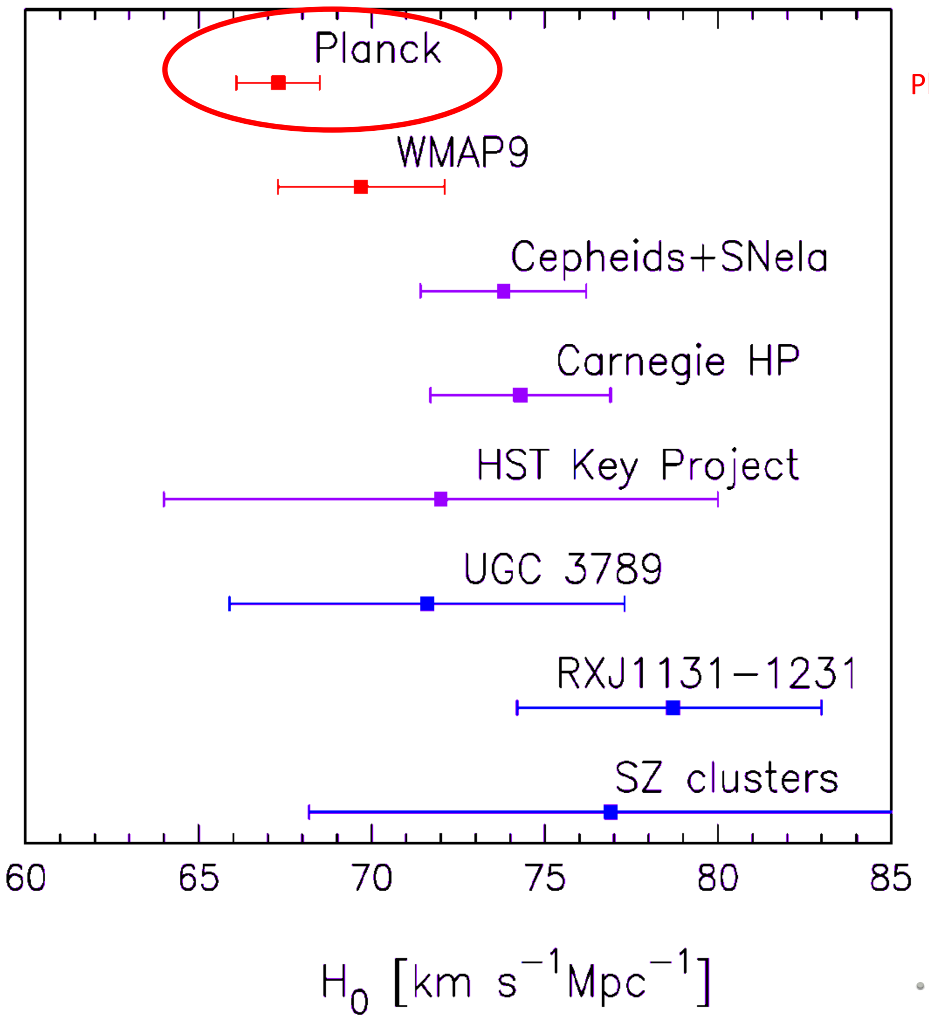
Sorry, you just grew older by $\gtrsim$ 50 million years ☺!

The basic content of the Universe



...has changed!

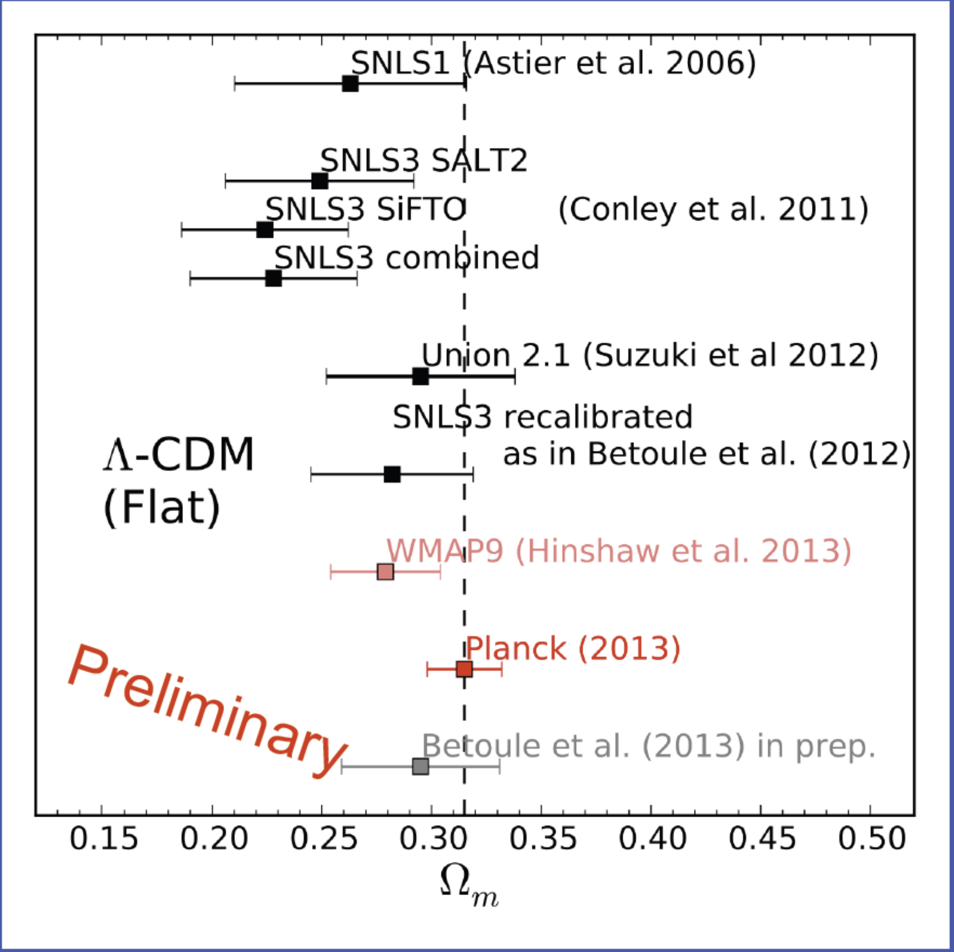
The rate of expansion



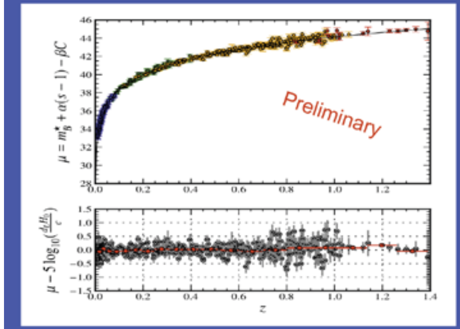
Planck H_0 is 67.95 ± 1.5 km/s/Mpc

… has changed also

Comparison with Planck results



SNLS-SDSS joint Hubble diagram



Predicted halo power spectrum

3D power spectrum of the dark matter field, as deduced by analyzing the galaxy distribution of the SDSS

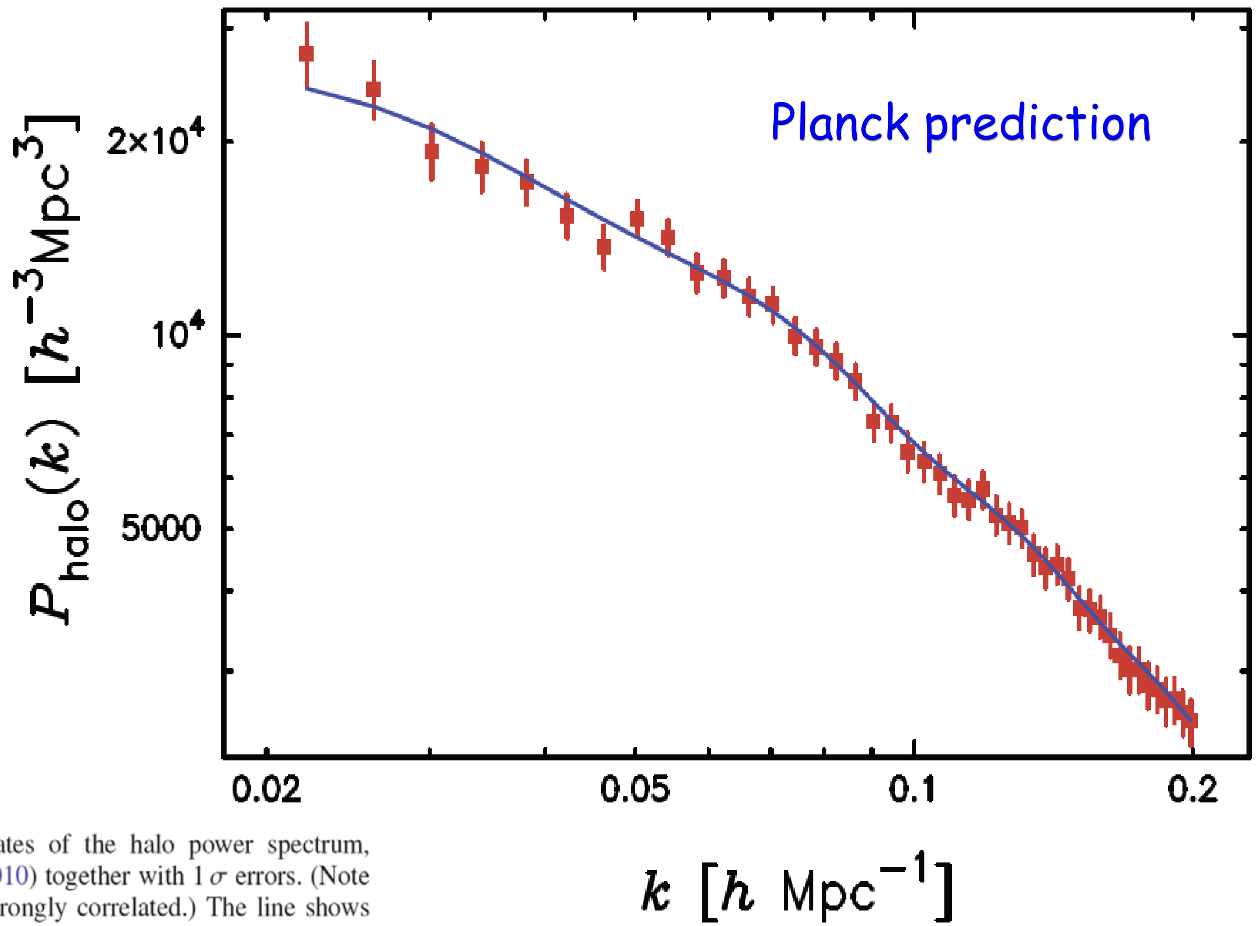
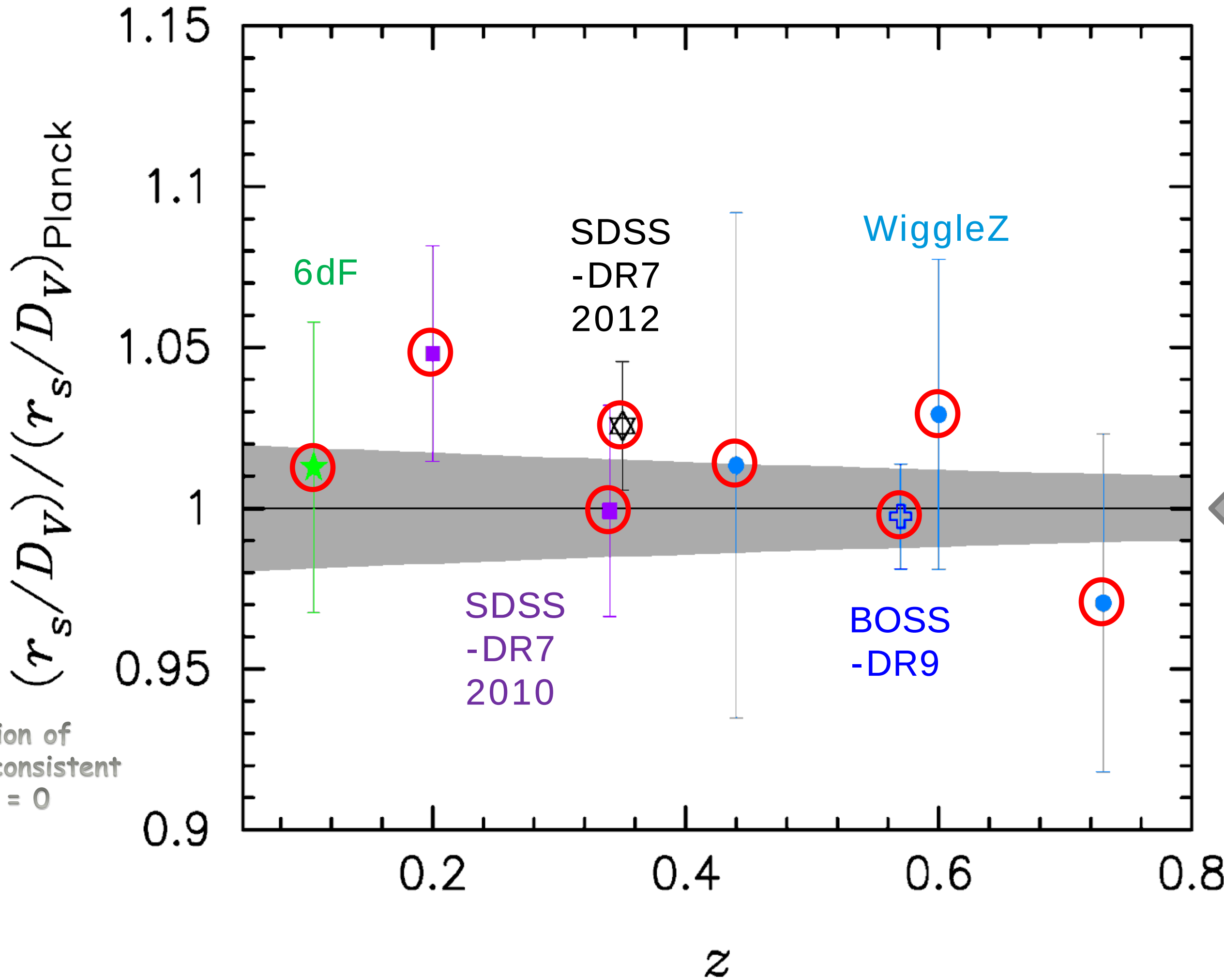


Fig. 20. Band-power estimates of the halo power spectrum, $P_{\rm halo}(k)$, from Reid et al. (2010) together with 1 σ errors. (Note that these data points are strongly correlated.) The line shows the predicted spectrum for the best-fit *Planck*+WP+highL base ΛCDM parameters.

BAO acoustic-scale distance ratio

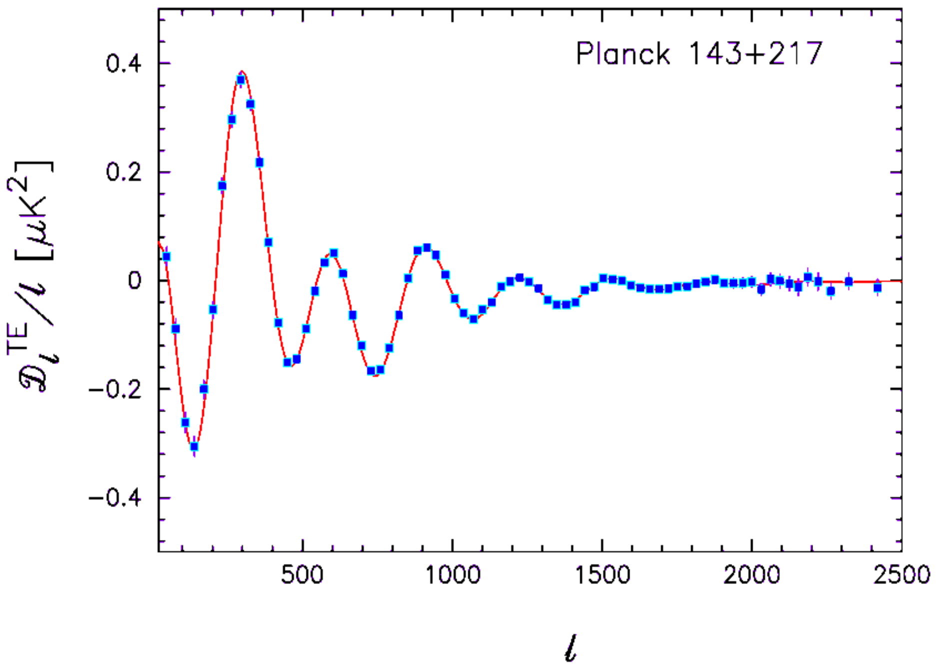


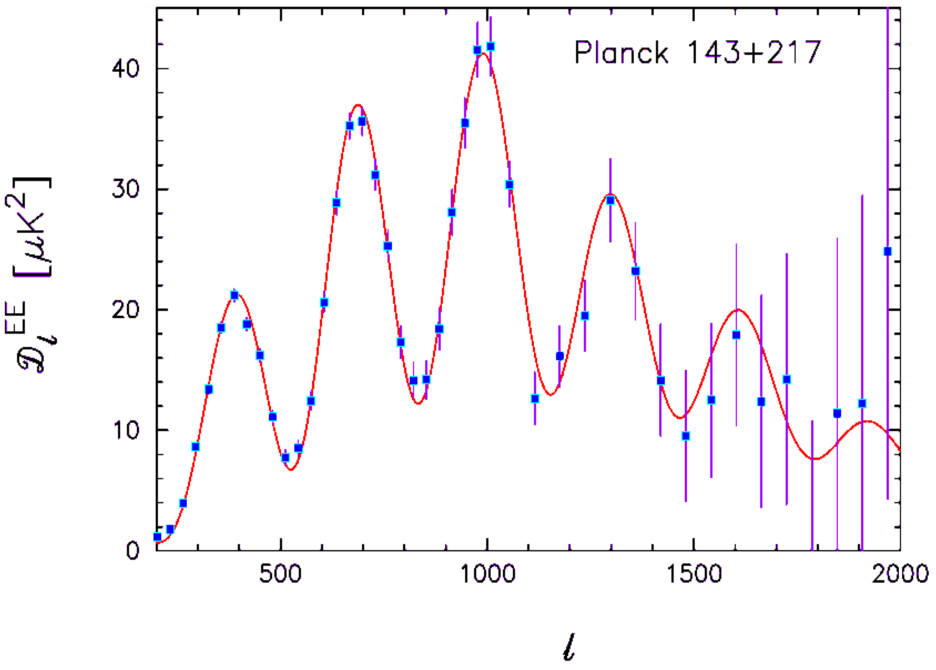
Planck Prediction (shaded area)

→ Planck & BAO are in tight agreement (and thus can be used jointly)

DE equation of state is consistent with 1+w = 0

Polarisation spectra – check passed!

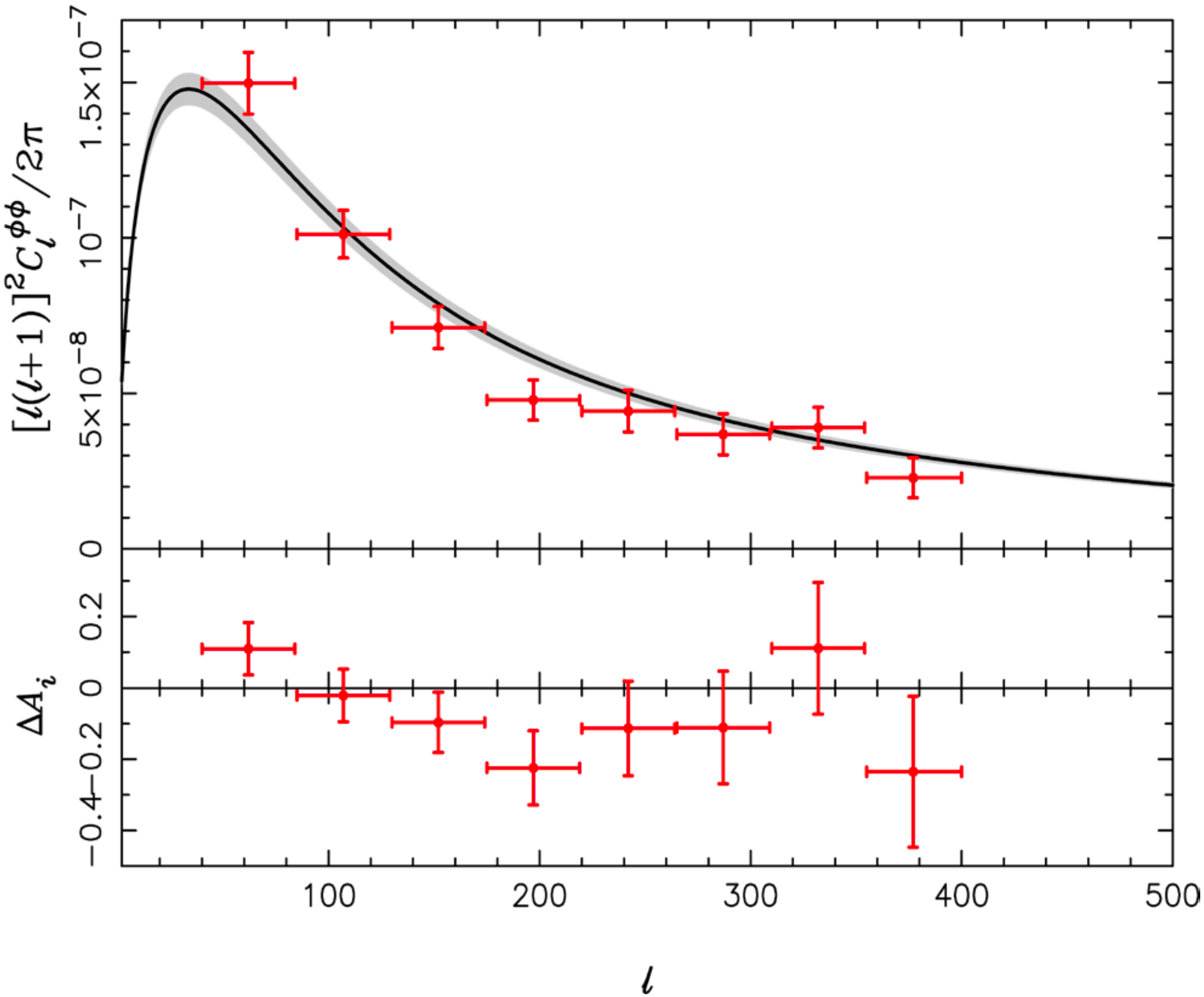




Red is prediction in base model from fitting T alone

The lensing potential power spectrum

This potential gives the displacement field

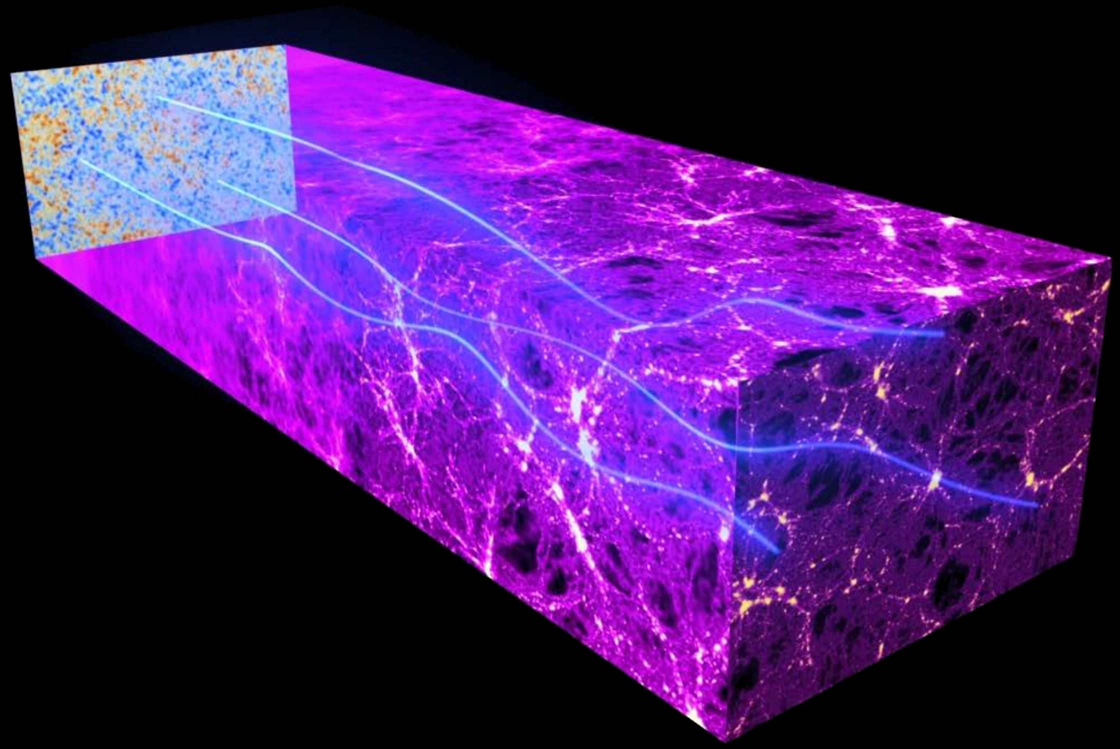


(26σ detection)

➔ Agrees well with the prediction from T alone

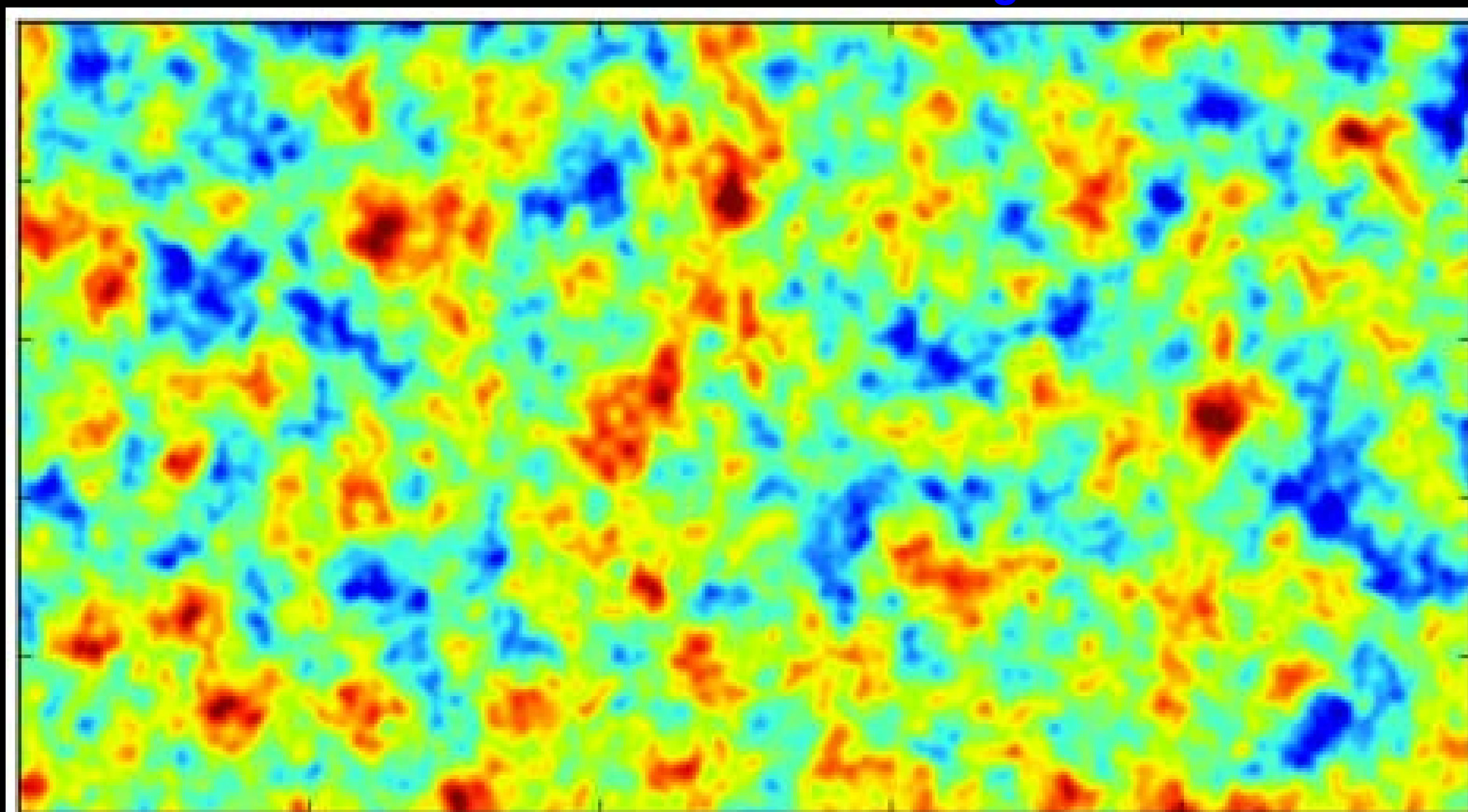
GRAVITATIONAL LENSING DISTORTS IMAGES

The gravitational effects of intervening matter bend the path of CMB light on its way from the early universe to the Planck telescope. This "gravitational lensing" distorts our image of the CMB



GRAVITATIONAL LENSING OF THE CMB

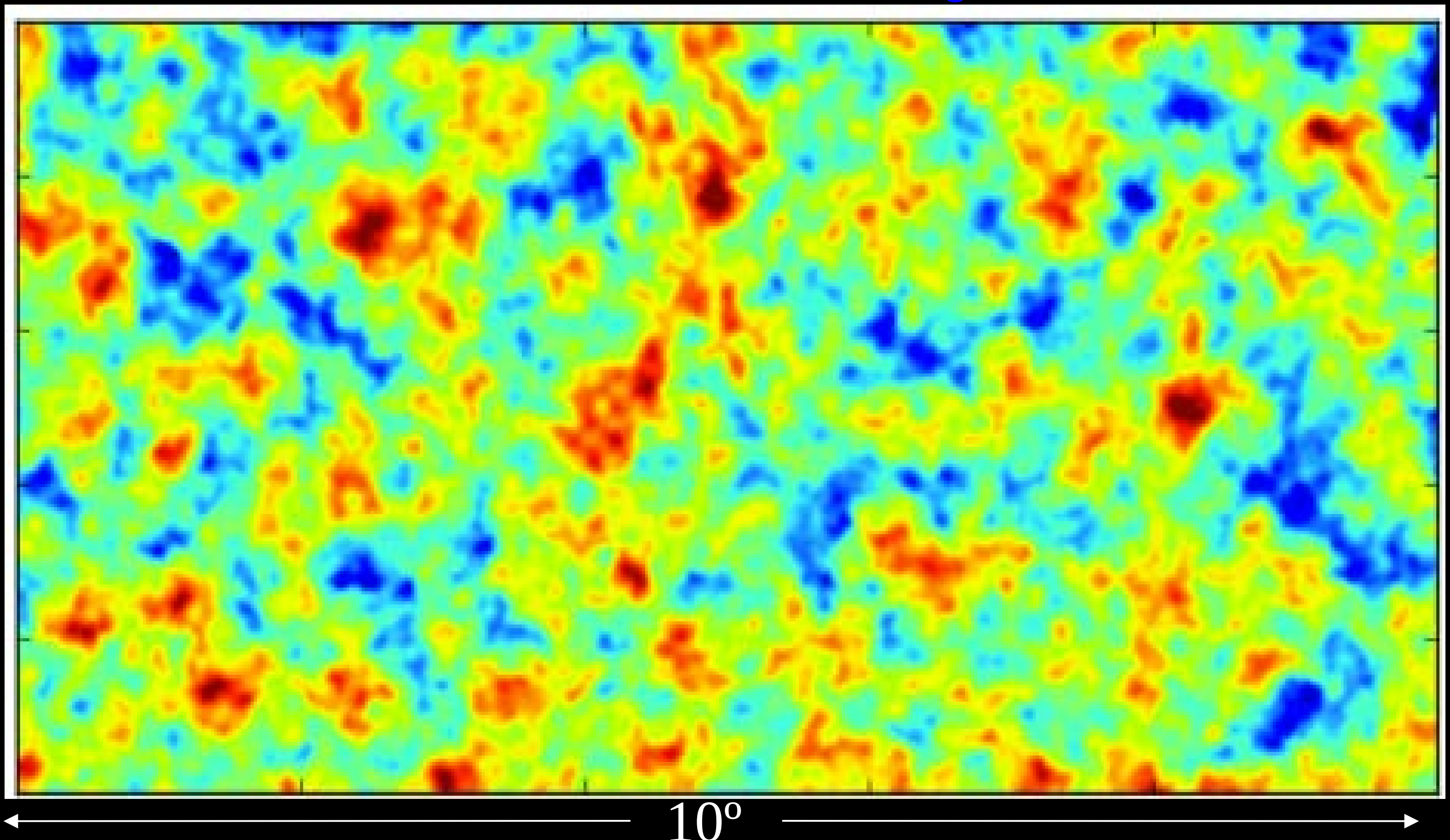
before lensing



10º

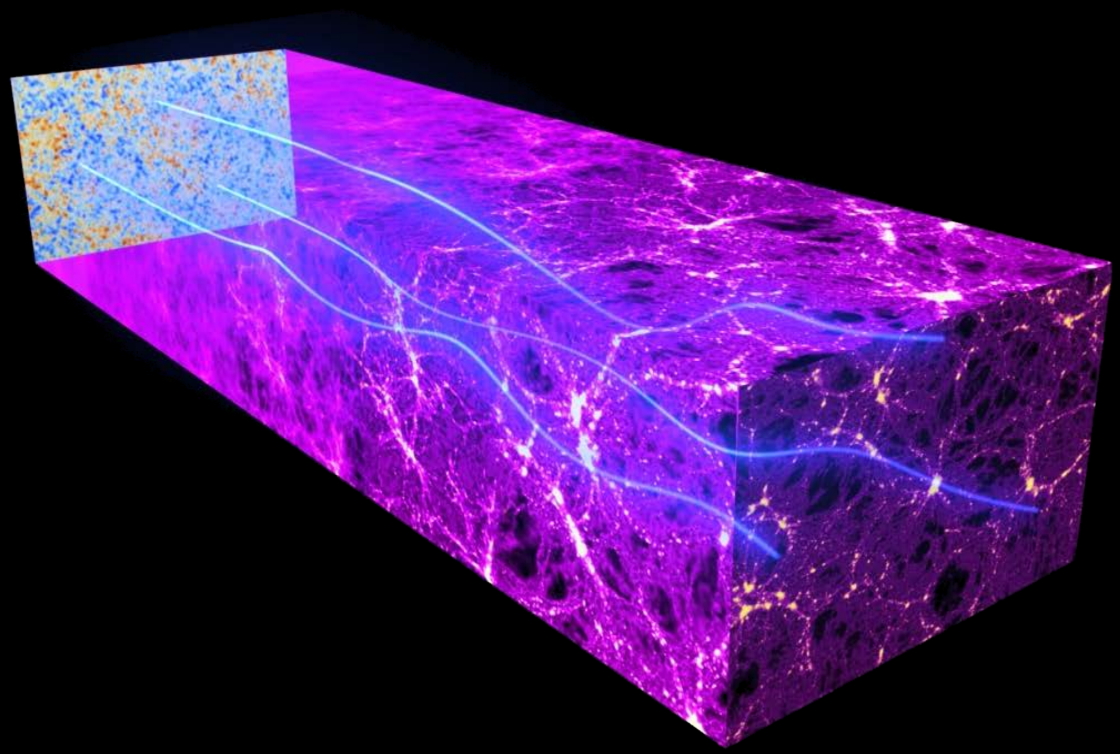
GRAVITATIONAL LENSING OF THE CMB

after lensing



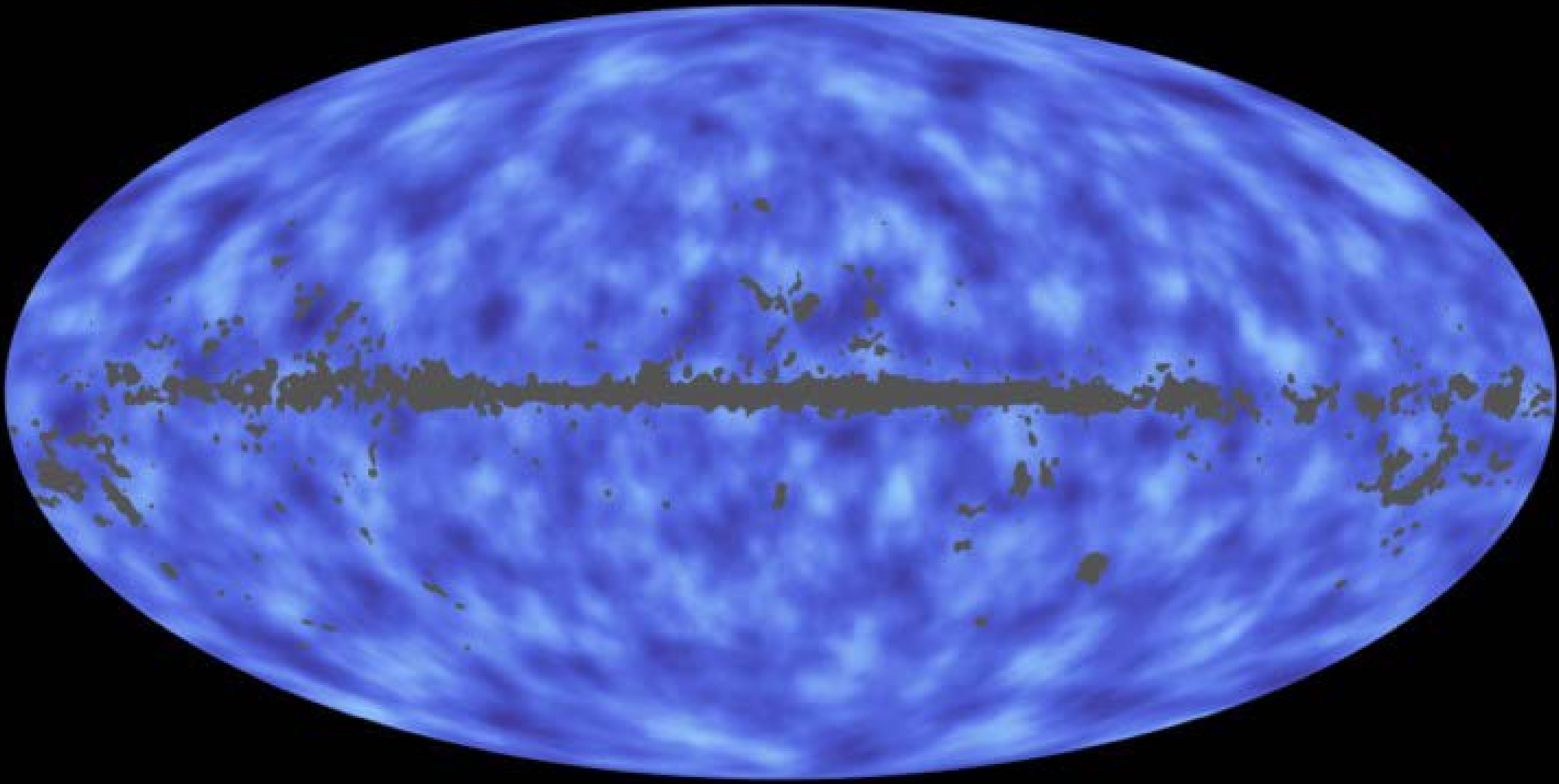
GRAVITATIONAL LENSING DISTORTS IMAGES

The gravitational effects of intervening matter bend the path of CMB light on its way from the early universe to the Planck telescope. This “gravitational lensing” distorts our image of the CMB (smoothing on the power spectrum, and correlations between scales)



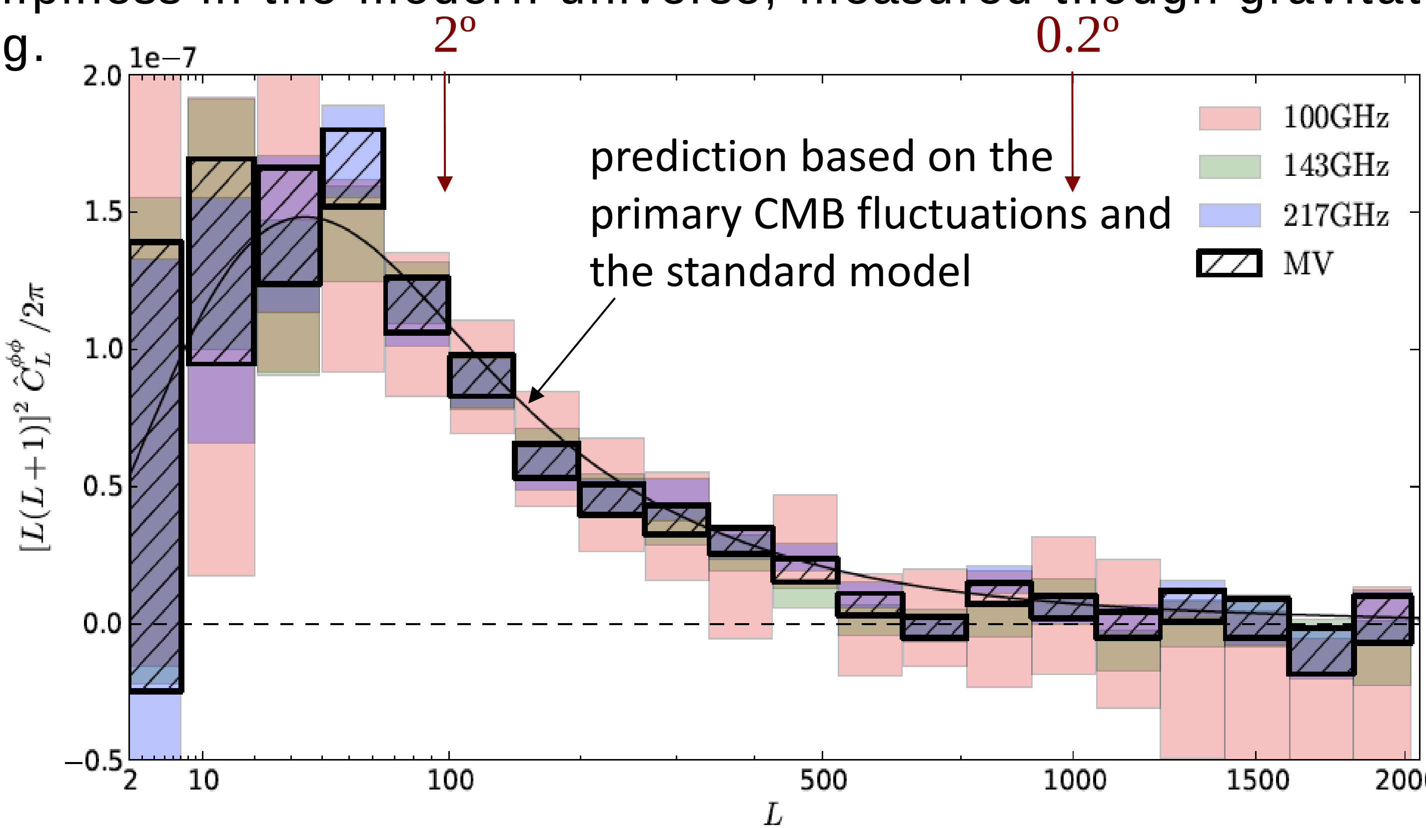
$$\hat{T}(\vec{\theta}) = T(\vec{\theta} + \vec{\nabla}\phi) \approx T(\vec{\theta}) + \vec{\nabla}\phi \cdot \vec{\nabla}T(\vec{\theta}) + \ldots$$
$$\bar{\phi} = \Delta^{-1}\vec{\nabla} \cdot [C^{-1}T\ \vec{\nabla}(C^{-1}T)]$$

Projected mass map

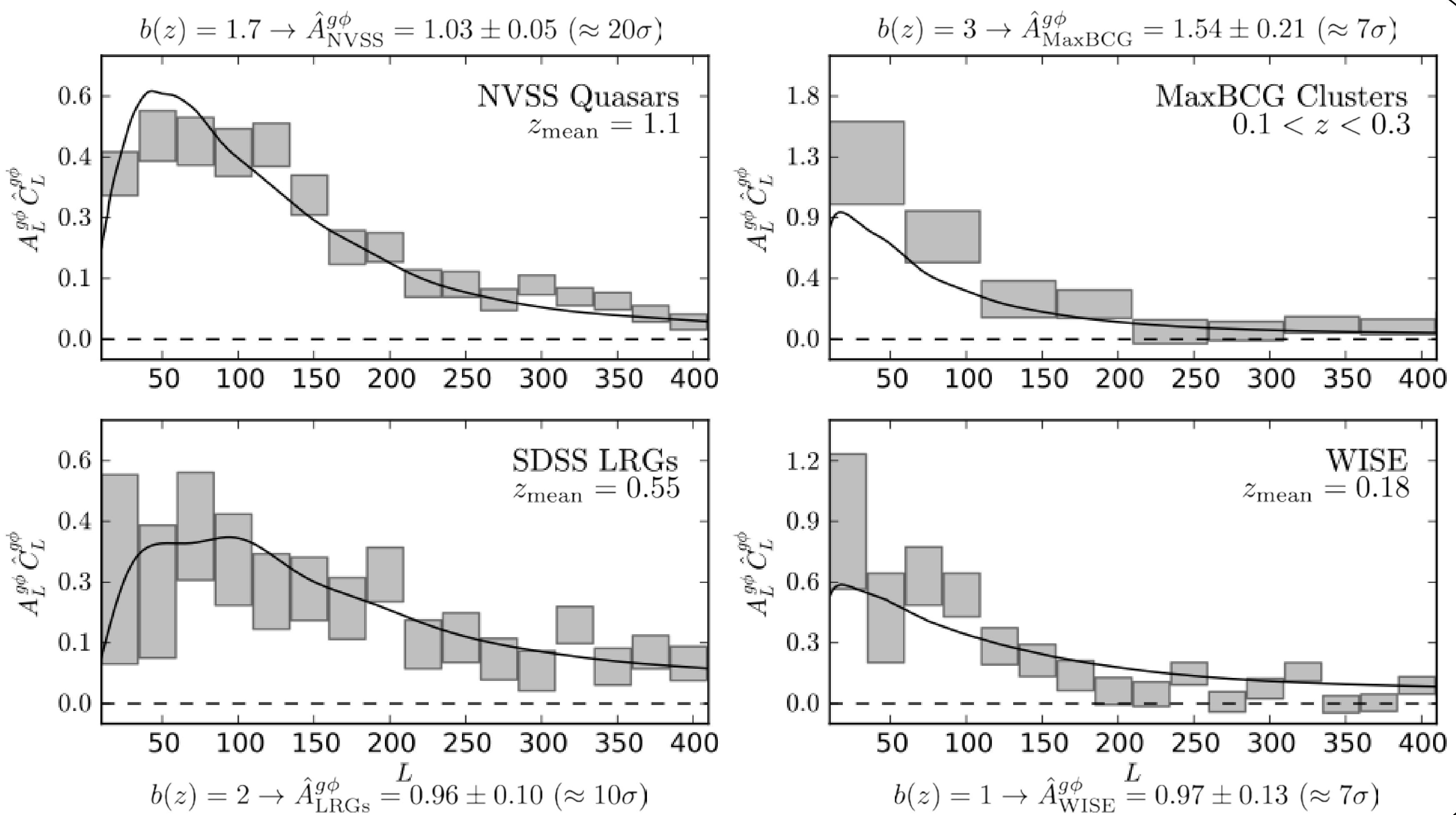


THE CLUMPINESS OF THE PLANCK MASS MAP

Fluctuations in the Planck mass map as a function of angular scale. This is clumpiness in the modern universe, measured though gravitational lensing.



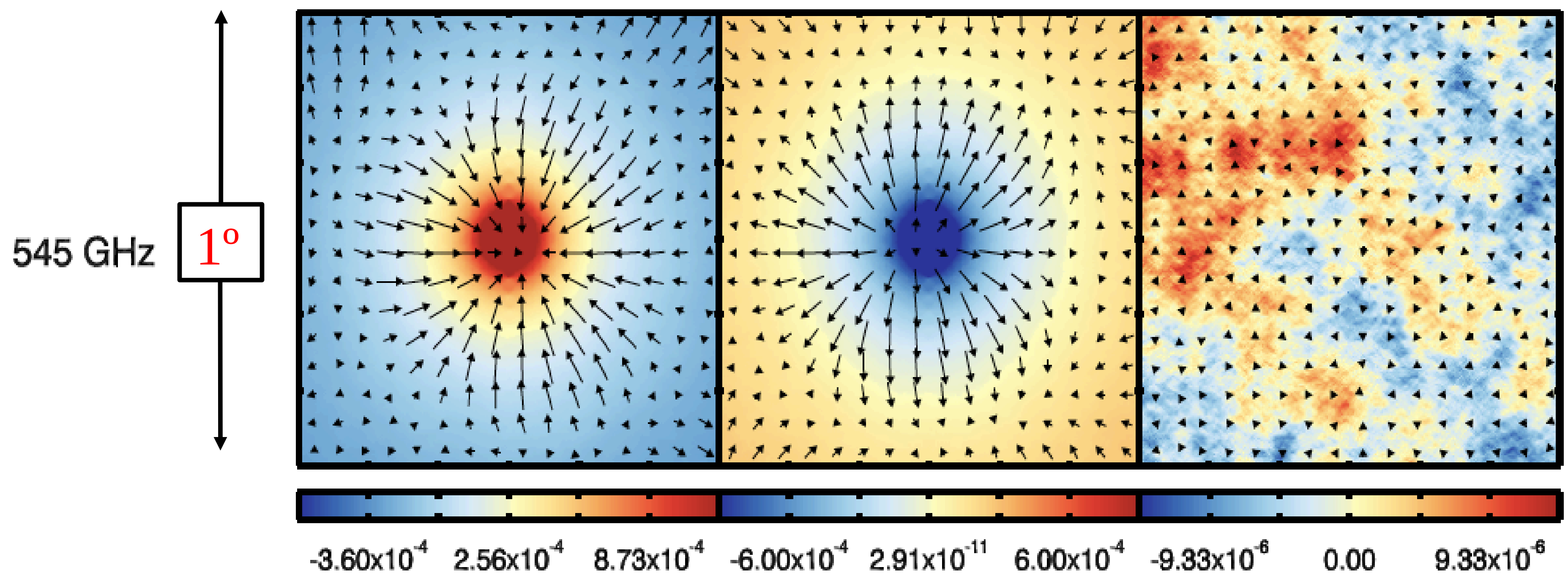
Lensing potential versus distribution of external tracers



No particular effort here to optimize the model for the external survey

CIB X Lensing

Stacking the Planck mass maps at the positions of peaks and troughs of Cosmic Infrared Background leads to a strong detection of the mass associated with these distant star forming galaxies.



Beyond the standard model

We tested many extension to the simplest, base, 6 parameters, LCDM model:

- Curved space, Ω_k ($\neq$ 0 ?)
- Dynamical dark energy, w ($\neq$ -1 ?)
- Non-standard abundance of primordial Helium fraction, Y_P ($\neq$ 0.2477 ?)
- Neutrino properties, i.e. how many and how massive (N_{eff}, Σm_ν $\neq$3.046, 0.06 ?)
- Curvature of the power spectrum of primordial fluctuations (running $dn_s/d\ln k \neq 0$?)
- Existence of primordial gravitational waves, $r_{0.002}$ ($\neq$ 0 ?)

→ no compelling evidence for any of them

	Planck+WP		*Planck*+WP+BAO		*Planck*+WP+highL		*Planck*+WP+highL+BAO	
Parameter	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits
Ω_K	−0.0105	$-0.037^{+0.043}_{-0.049}$	0.0000	$0.0000^{+0.0066}_{-0.0067}$	−0.0111	$-0.042^{+0.043}_{-0.048}$	0.0009	$-0.0005^{+0.0065}_{-0.0066}$
Σm_ν [eV]	0.022	< 0.933	0.002	< 0.247	0.023	< 0.663	0.000	< 0.230
$N_{\rm eff}$	3.08	$3.51^{+0.80}_{-0.74}$	3.08	$3.40^{+0.59}_{-0.57}$	3.23	$3.36^{+0.68}_{-0.64}$	3.22	$3.30^{+0.54}_{-0.51}$
$Y_{\rm P}$	0.2583	$0.283^{+0.045}_{-0.048}$	0.2736	$0.283^{+0.043}_{-0.045}$	0.2612	$0.266^{+0.040}_{-0.042}$	0.2615	$0.267^{+0.038}_{-0.040}$
$dn_s/d\ln k$	−0.0090	$-0.013^{+0.018}_{-0.018}$	−0.0102	$-0.013^{+0.018}_{-0.018}$	−0.0106	$-0.015^{+0.017}_{-0.017}$	−0.0103	$-0.014^{+0.016}_{-0.017}$
$r_{0.002}$	0.000	< 0.120	0.000	< 0.122	0.000	< 0.108	0.000	< 0.111
w	−1.20	$-1.49^{+0.65}_{-0.57}$	−1.076	$-1.13^{+0.24}_{-0.25}$	−1.20	$-1.51^{+0.62}_{-0.53}$	−1.109	$-1.13^{+0.23}_{-0.25}$

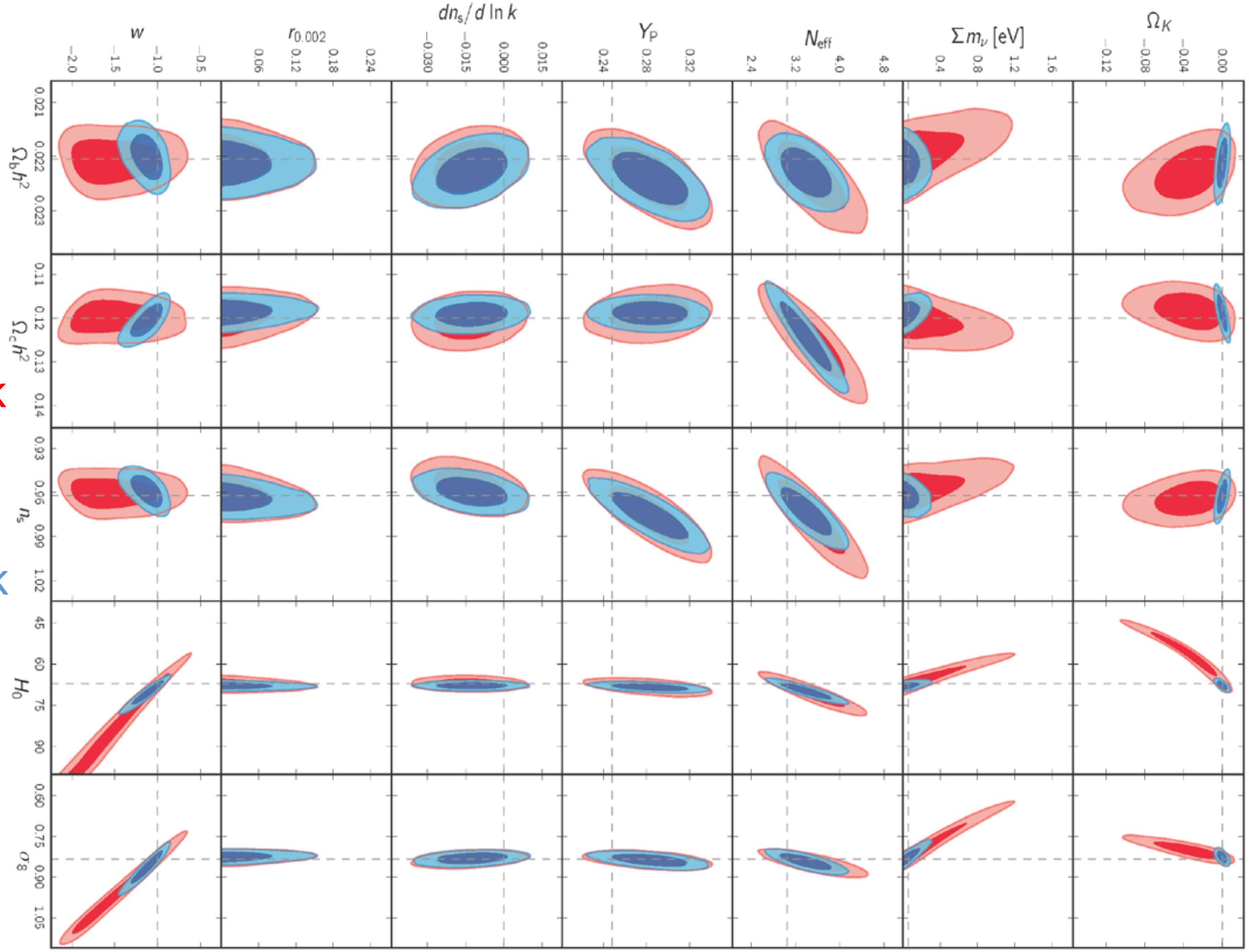
NB: no compelling evidence either for:

- Existence of an "isocurvature" part in the primordial fluctuations
- Existence of cosmic strings ($G\mu/c^2<1.3\ 10^{-7}$)
- Non-Gaussian signatures of non-minimal inflation (f^{local}=2.7±5.8, f^{equil} =-42±75,f^{ortho}=-25±39 68%CL)
- Evolution of the fine structure constant, dark matter annihilation, primordial magnetic fields…

Full grid of results available on line

Planck
+WP

Planck
+WP
+BAO

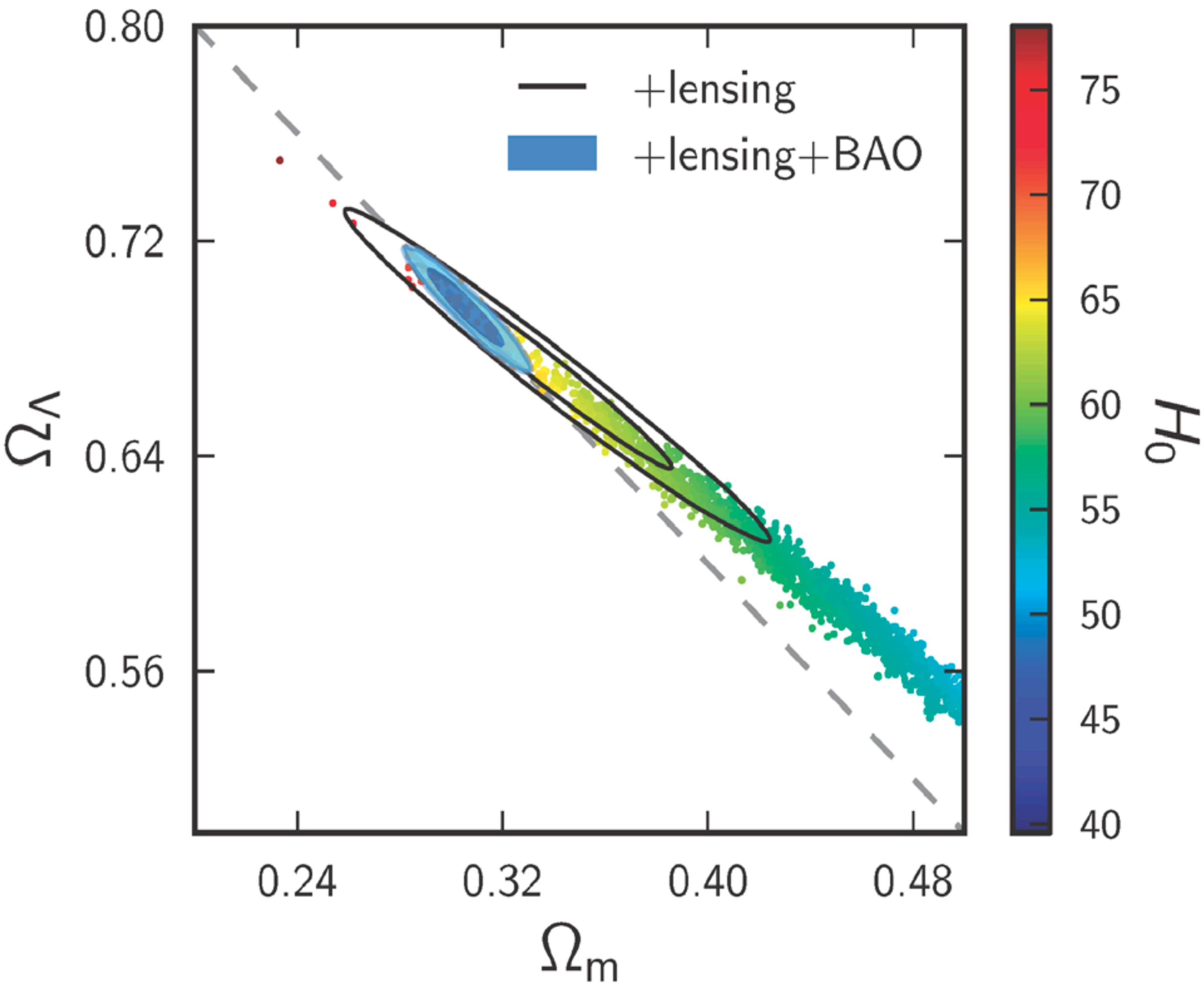


Vertical lines indicates the fixed baseline model parameter value

Horizontal lines shows the mean posterior value in the baseline model

➔ no compelling evidence for deviations from the baseline model

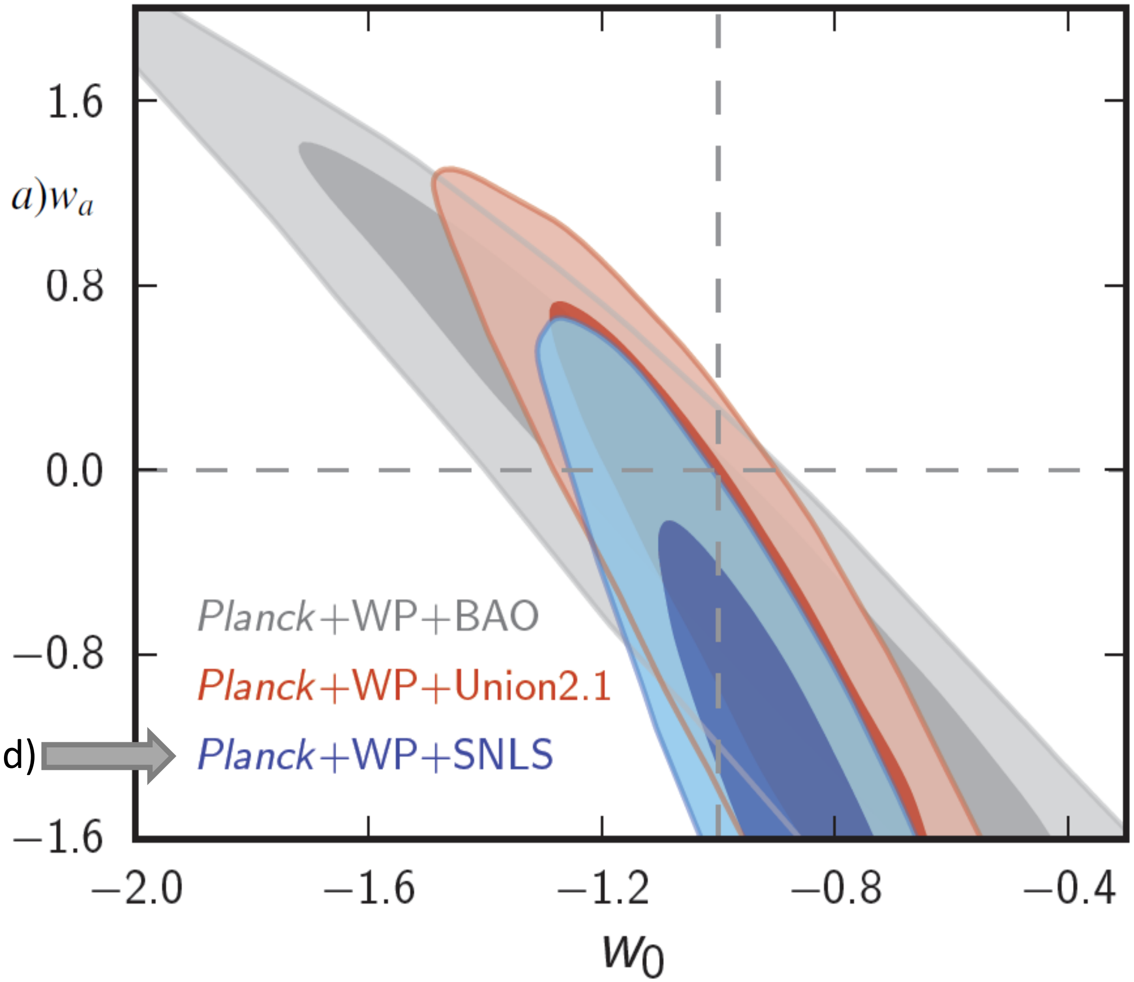
Geometry



→ a precisely flat spatial geometry

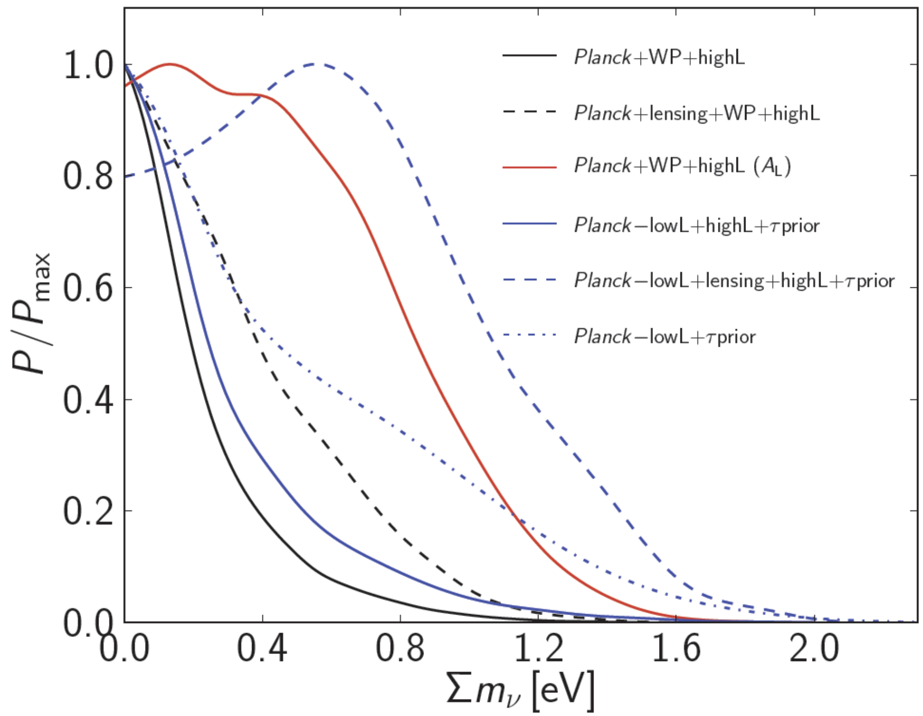
Dynamical dark energy?

$$w(a) \equiv \frac{p}{\rho} = w_0 + (1-a)w_a$$



(has changed)

Neutrinos



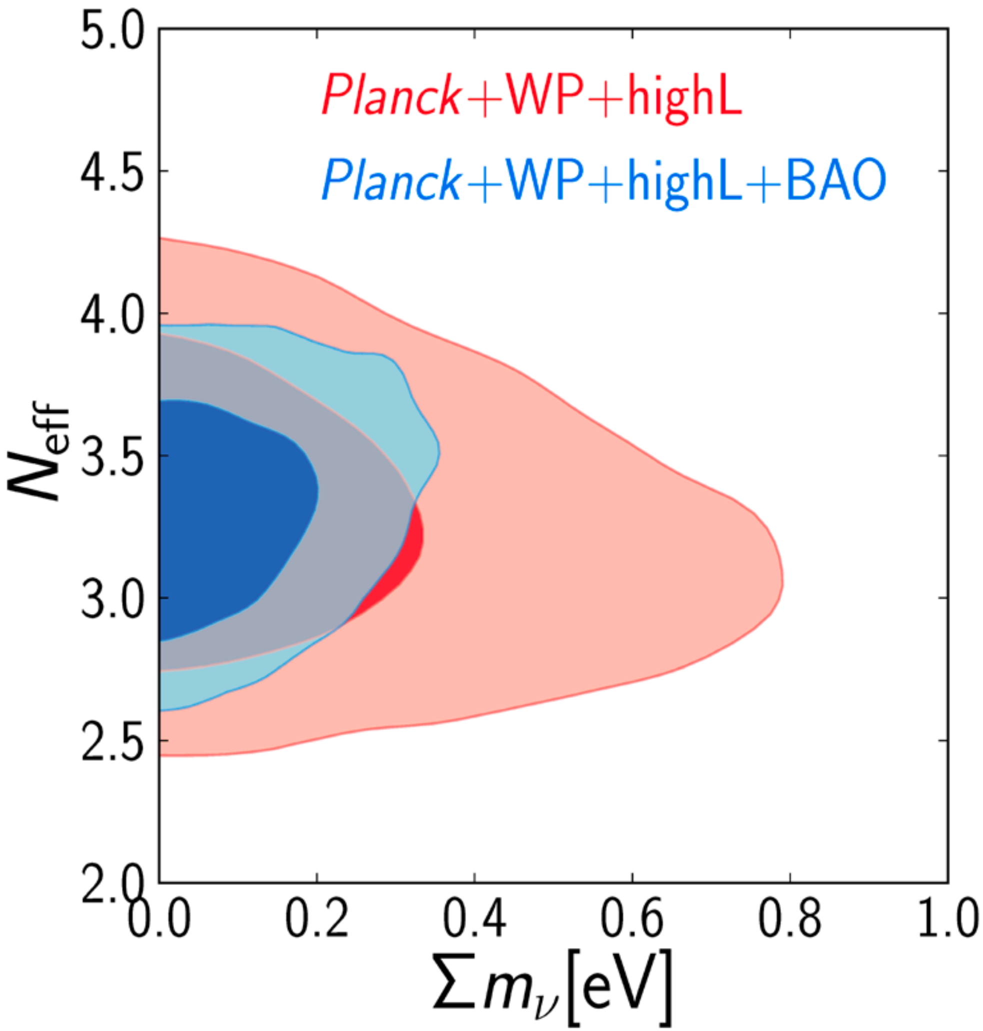
Planck constrains neutrino masses mostly through their effect via lensing:
removing that constraint (marginalising over A_L) weakens considerably the limit:
$\Sigma m_\nu < 0.23$eV (95CL PT+WP+HL)
becomes
$\Sigma m_\nu < 1.08$eV (95CL PT+WP+HL)

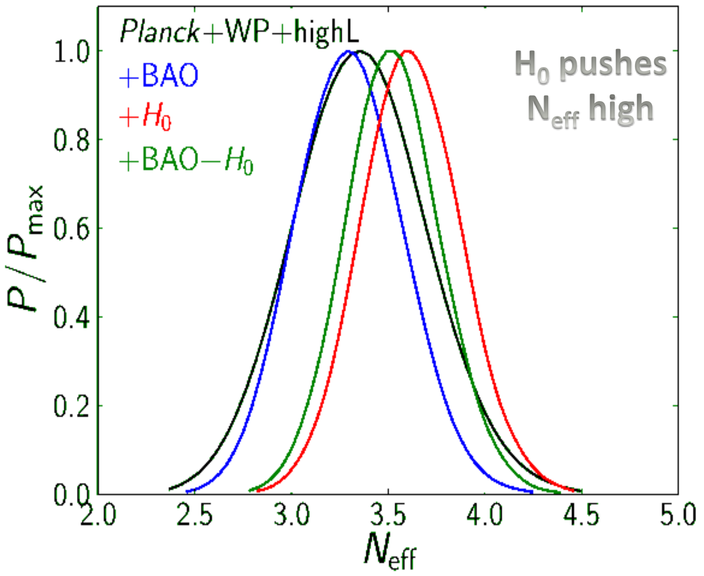
NB: the (4-pt based) lensing likelihood would prefer higher values for Σm_ν (i.e. it weakens the constraints): time will tell

by l=1000 the lensing potential is suppressed by ~10% in power for Σm_ν=0.66eV.

Case of 3 active nus of mass $m_\nu = \Sigma m_\nu/3 > 0.06$eV; $N_{eff} = 3.046$ (i.e. no additional ν-like relativistic particles)

Neutrinos



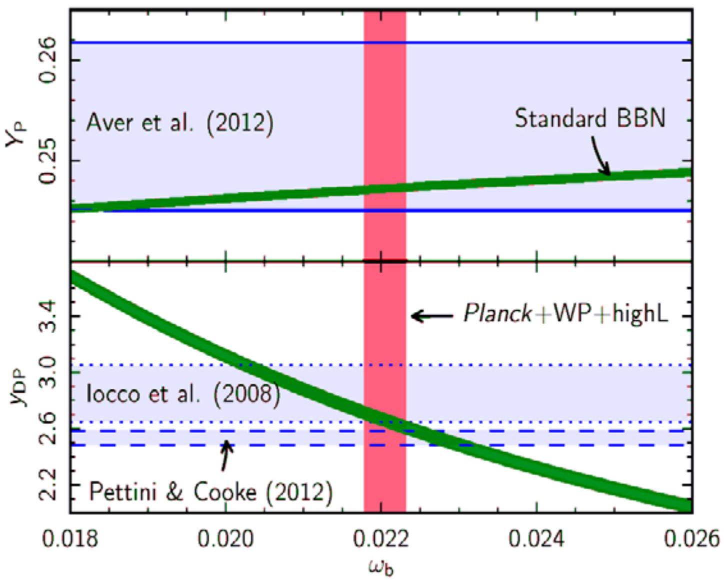


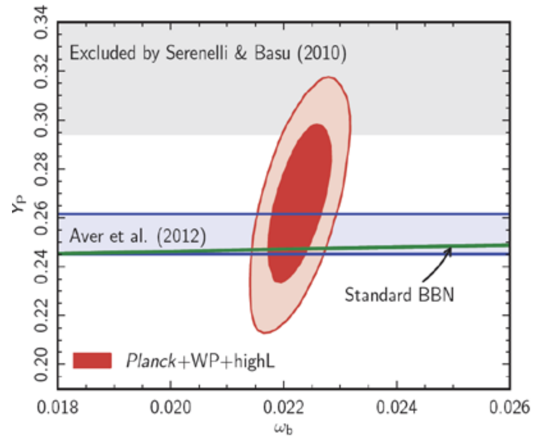
→No evidence for additional neutrino-like relativistic particles beyond the three families of neutrinos in the standard model

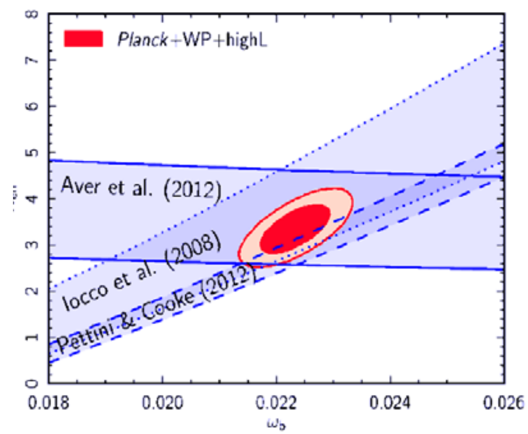
(N_{eff} = 3,3±0,27;Σm_ν<0.23 eV)

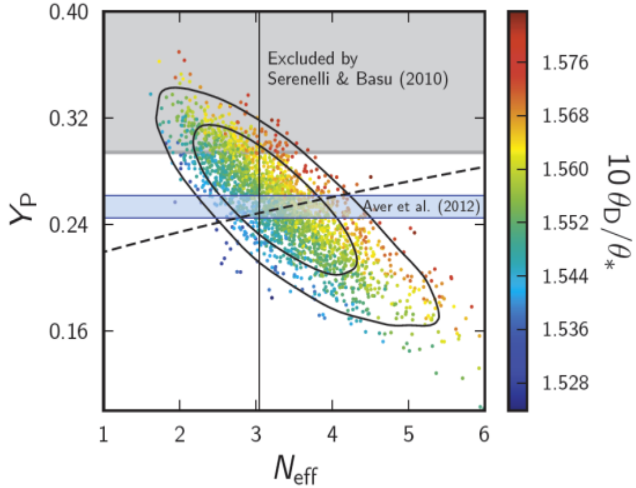
Case of 3 active nus of mass $m_\nu = \Sigma m_\nu/3$; $\Delta N_{eff} = N_{eff} - 3.046$ for possible extra massless relics (if >0)

Primordial nucleosynthesis







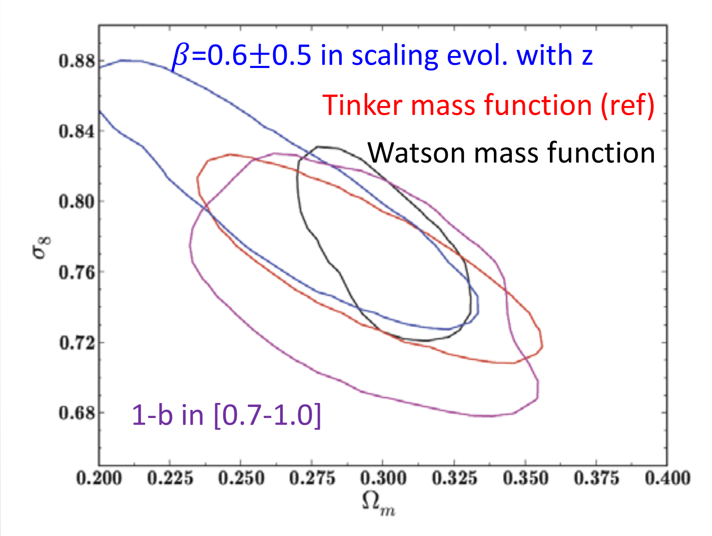


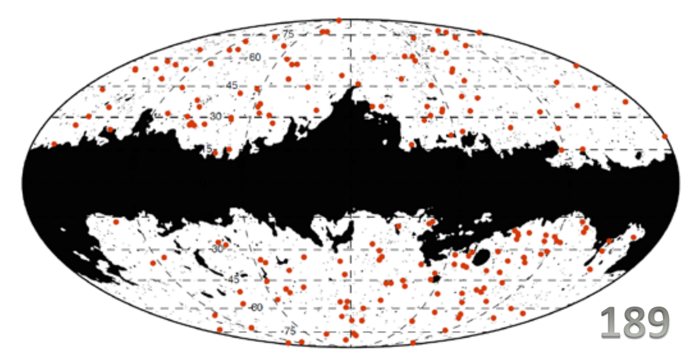
Y_p = 0.2477 ± 0.0001
(as a derived quantity)

$$N_{\mathrm{eff}} = 3.046$$

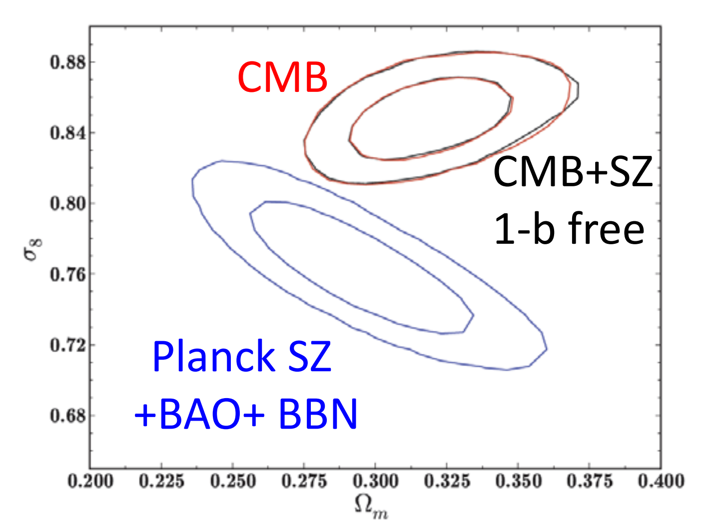
$$\rho_\nu = N_{\mathrm{eff}} \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} \rho_\gamma$$

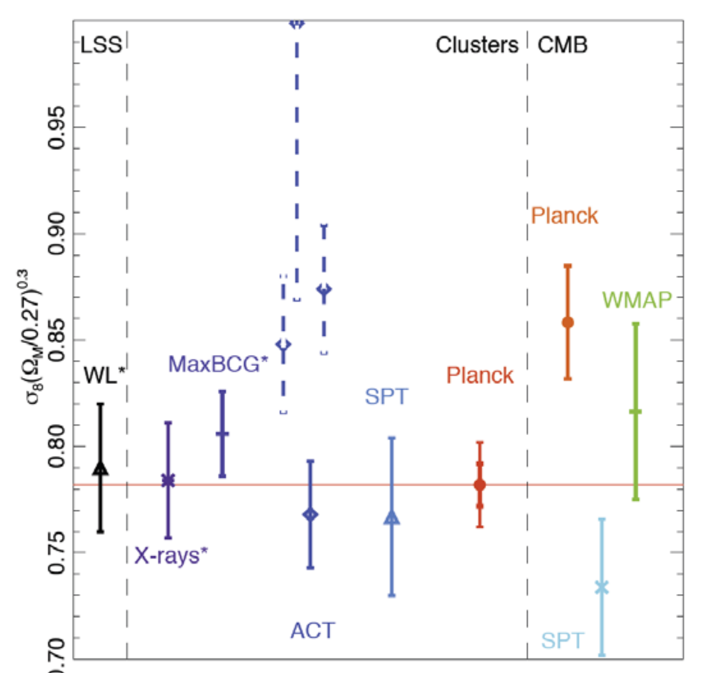
SZ / CMB tension





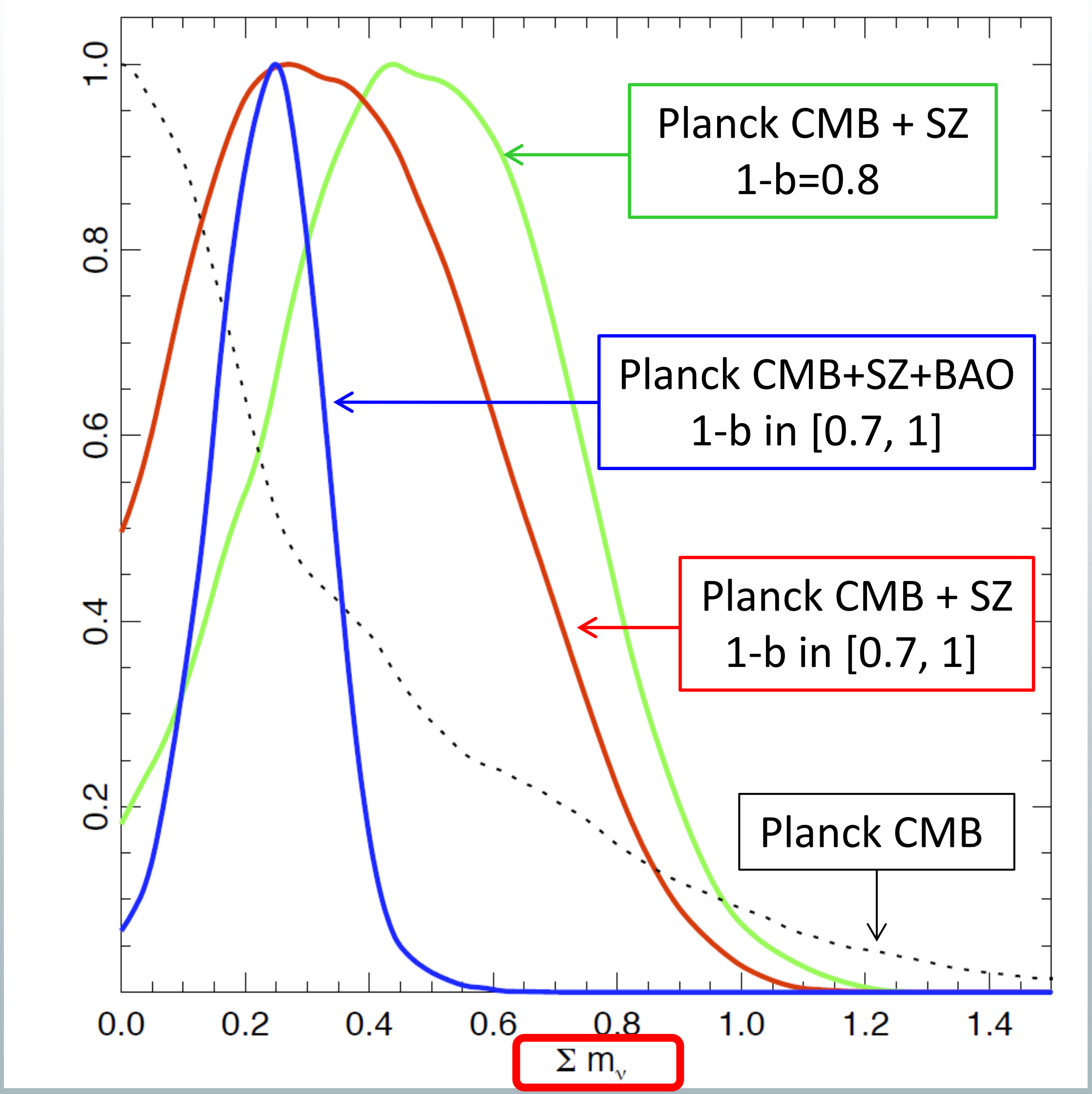
σ_8 measures the amplitude of fluctuations on $8h^{-1}$ Mpc scale today; $\sigma_8 = F(A_s)$





68% CL

Physics rather than gastrophysics?



Cosmology with clusters

- To carry out a prediction of the counts expected in a survey, given cosmological assumptions, one needs:
  - *a mass function giving the number distribution of clusters with mass and redshift;*
    - ➔ *Trinker et al 2008*

$$\frac{dN}{dM_{500}}(M_{500}, z) = f(\sigma)\,\frac{\rho_{\rm m}(z=0)}{M_{500}}\,\frac{d\ln\sigma^{-1}}{dM_{500}}\,,$$

$$f(\sigma) = A\left[1 + \left(\frac{\sigma}{b}\right)^{-a}\right]\exp\left(-\frac{c}{\sigma^2}\right),$$

  - *scaling relations that can predict observable quantities from the mass and redshift;*

$$E^{-\beta}(z)\left[\frac{D_{\rm A}^2(z)\,\bar{Y}_{500}}{10^{-4}\,{\rm Mpc}^2}\right] = Y_*\left[\frac{h}{0.7}\right]^{-2+\alpha}\left[\frac{(1-b)\,M_{500}}{6\times10^{14}\,{\rm M_{sol}}}\right]^{\alpha}$$

$$E^2(z) = \Omega_{\rm m}(1+z)^3 + \Omega_\Lambda$$

$$\bar{\theta}_{500} = \theta_*\left[\frac{h}{0.7}\right]^{-2/3}\left[\frac{(1-b)\,M_{500}}{3\times10^{14}{\rm M_{sol}}}\right]^{1/3} E^{-2/3}(z)\left[\frac{D_{\rm A}(z)}{500\,{\rm Mpc}}\right]^{-1}$$

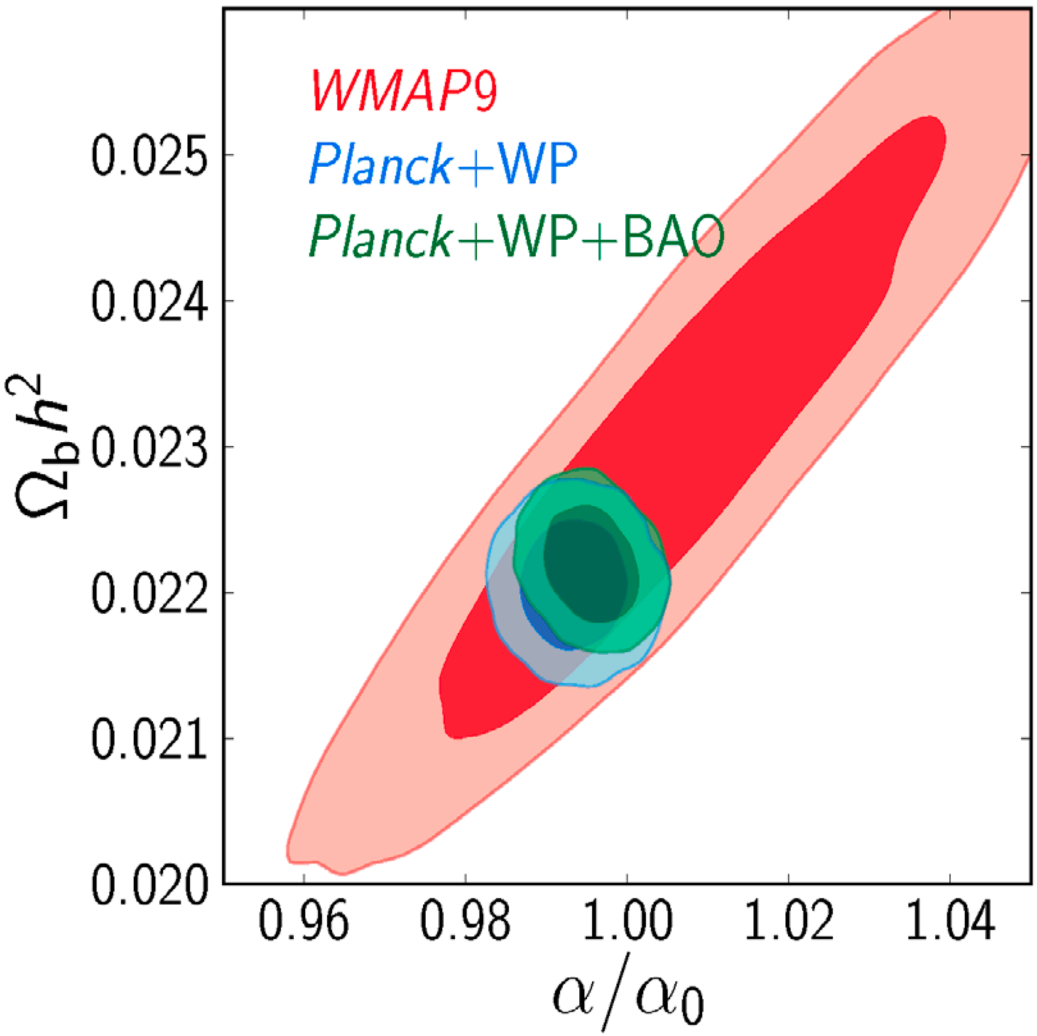
  - *the completeness of the survey in terms of those observables, which tells the probability that a model cluster would make it into the survey catalogue.*

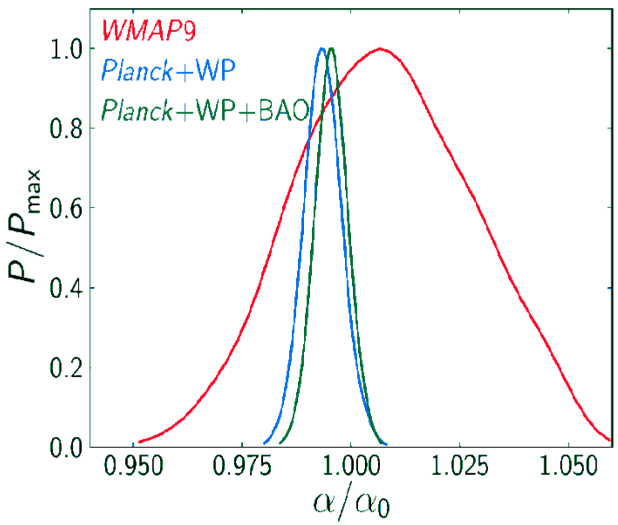
$$\chi_{\rm erf}(Y_{500}, \theta_{500}, l, b) = \frac{1}{2}\left[1 + {\rm erf}\left(\frac{Y_{500} - X\,\sigma_{Y_{500}}(\theta_{500}, l, b)}{\sqrt{2}\,\sigma_{Y_{500}}(\theta_{500}, l, b)}\right)\right]$$

- NB: The calibration of the Y/M scaling relation requires to know M in some case, e.g. from X-ray analysis using hydrostatic equilibrium, or from Gravitational lensing, which both have dispersion and bias…(as simulations tell us).
  - *Planck-XX established and used it's own version of the M_{500}-Y_X relation for our mass proxy*

Fine structure constant variation?

This would shift the energy levels and binding energy of hydrogen and helium, inducing a modification of the ionization history of the Universe…





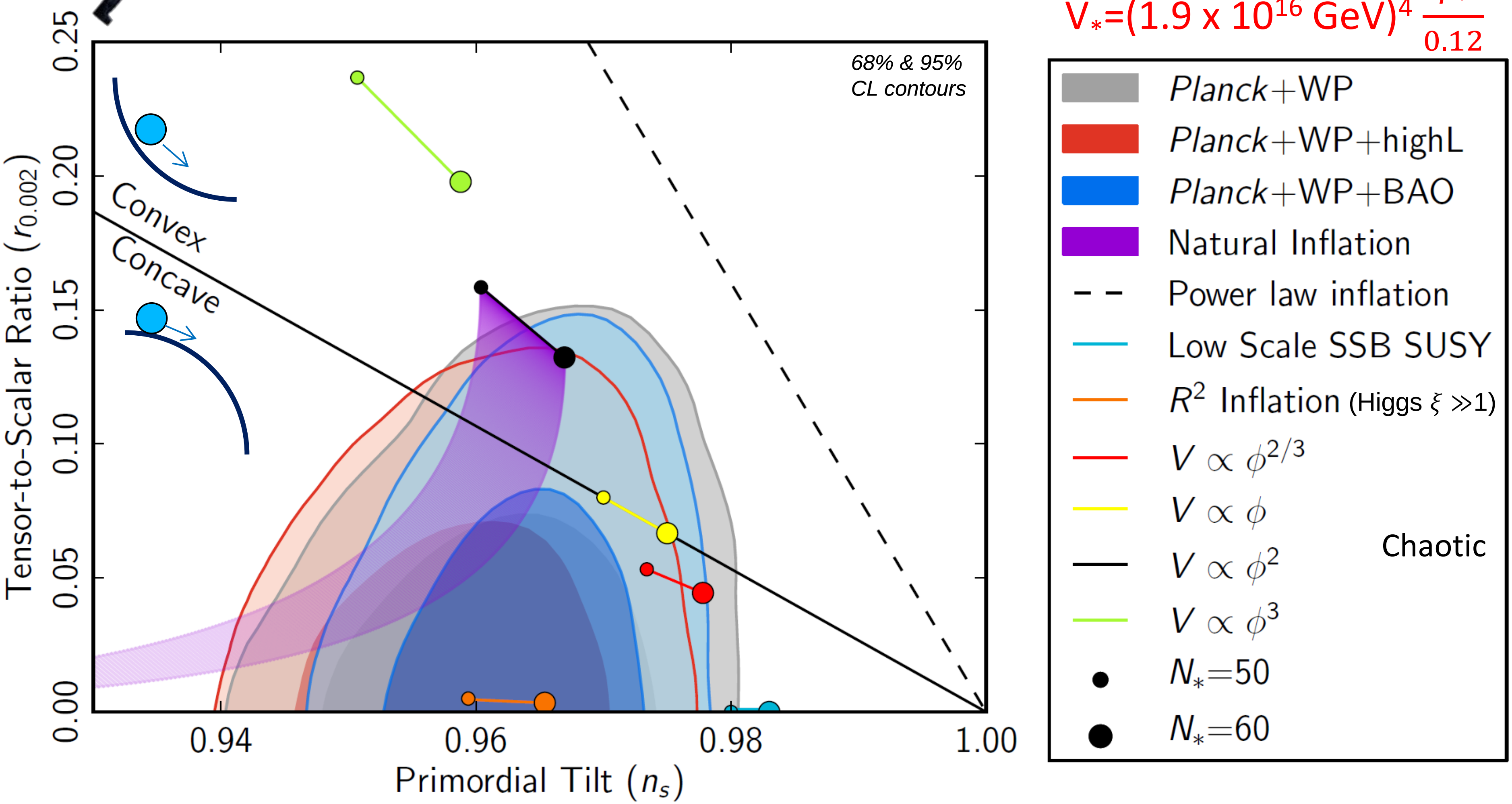
→No evidence of time variation of the fine structure constant

(α/α_0=0.9989 ± 0.0037)

(WMAP9: 1.008±0.020)

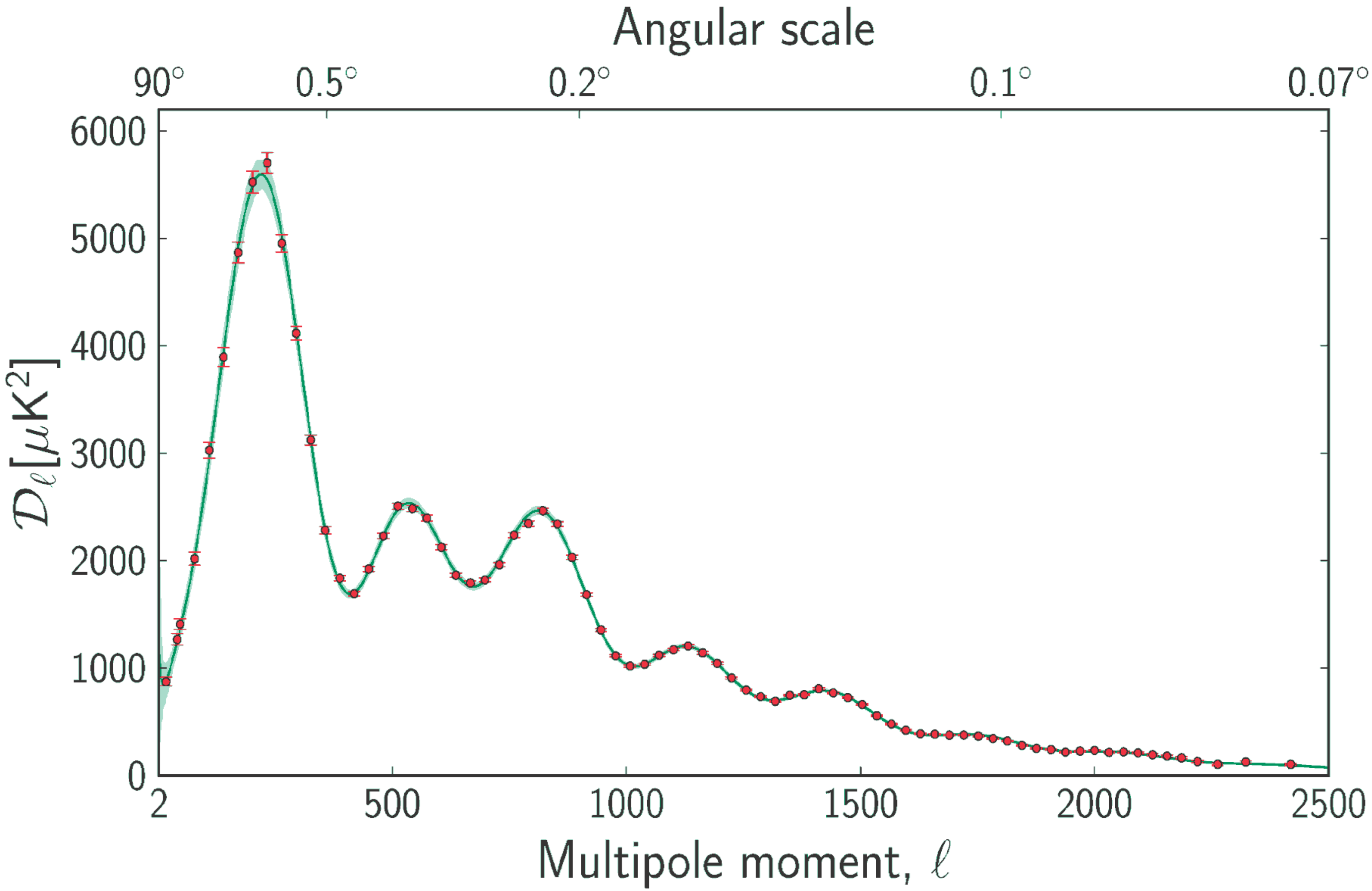
Constraint on representative Inflation models

$V_* = (1.9 \times 10^{16}\ \mathrm{GeV})^4 \dfrac{r_*}{0.12}$

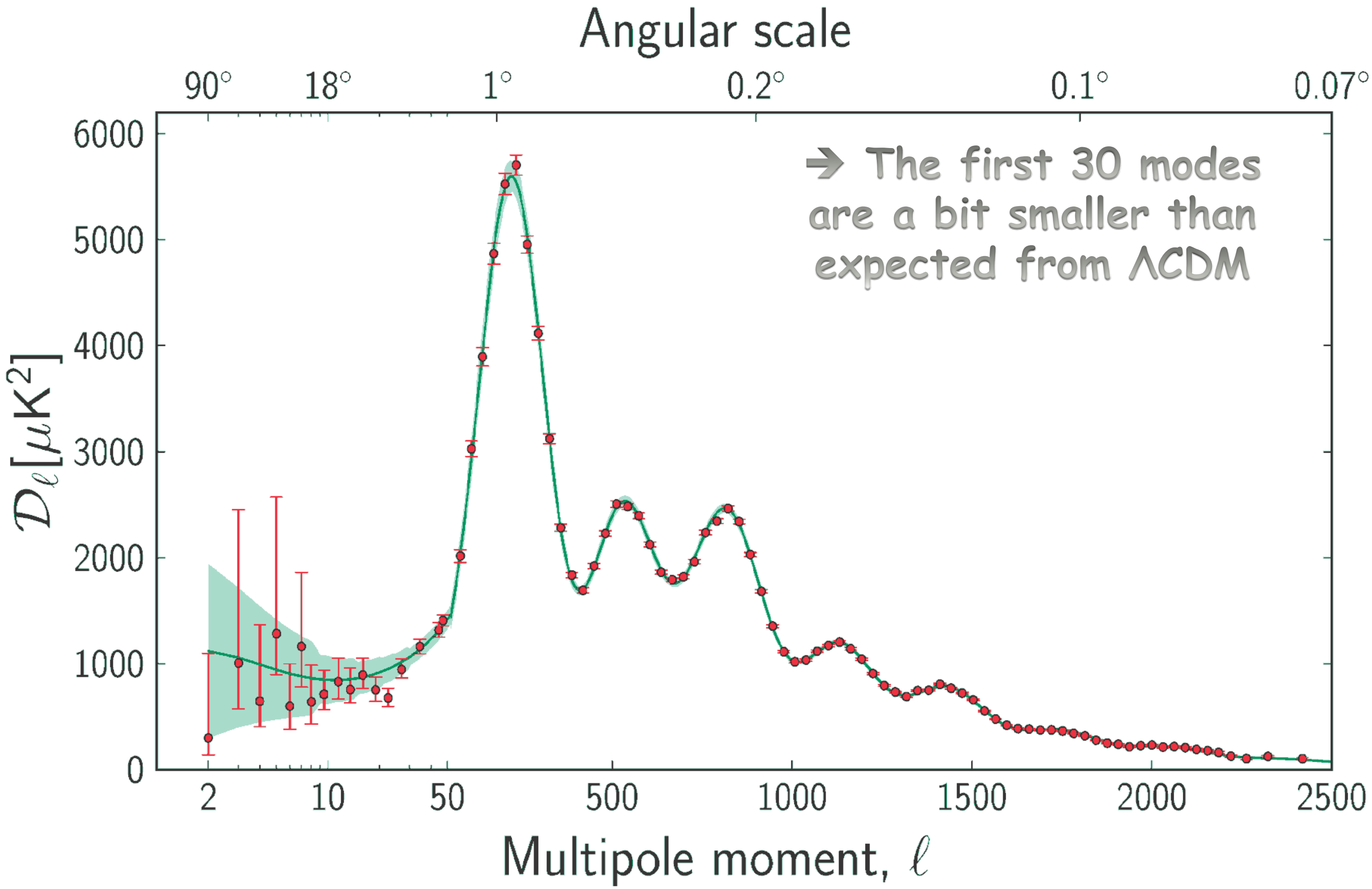


➔Exponential potential models(power-law inf.), simplest hybrid inflationary models (SB SUSY), monomial potential models of degree n >2 do not provide a good fit to the data.

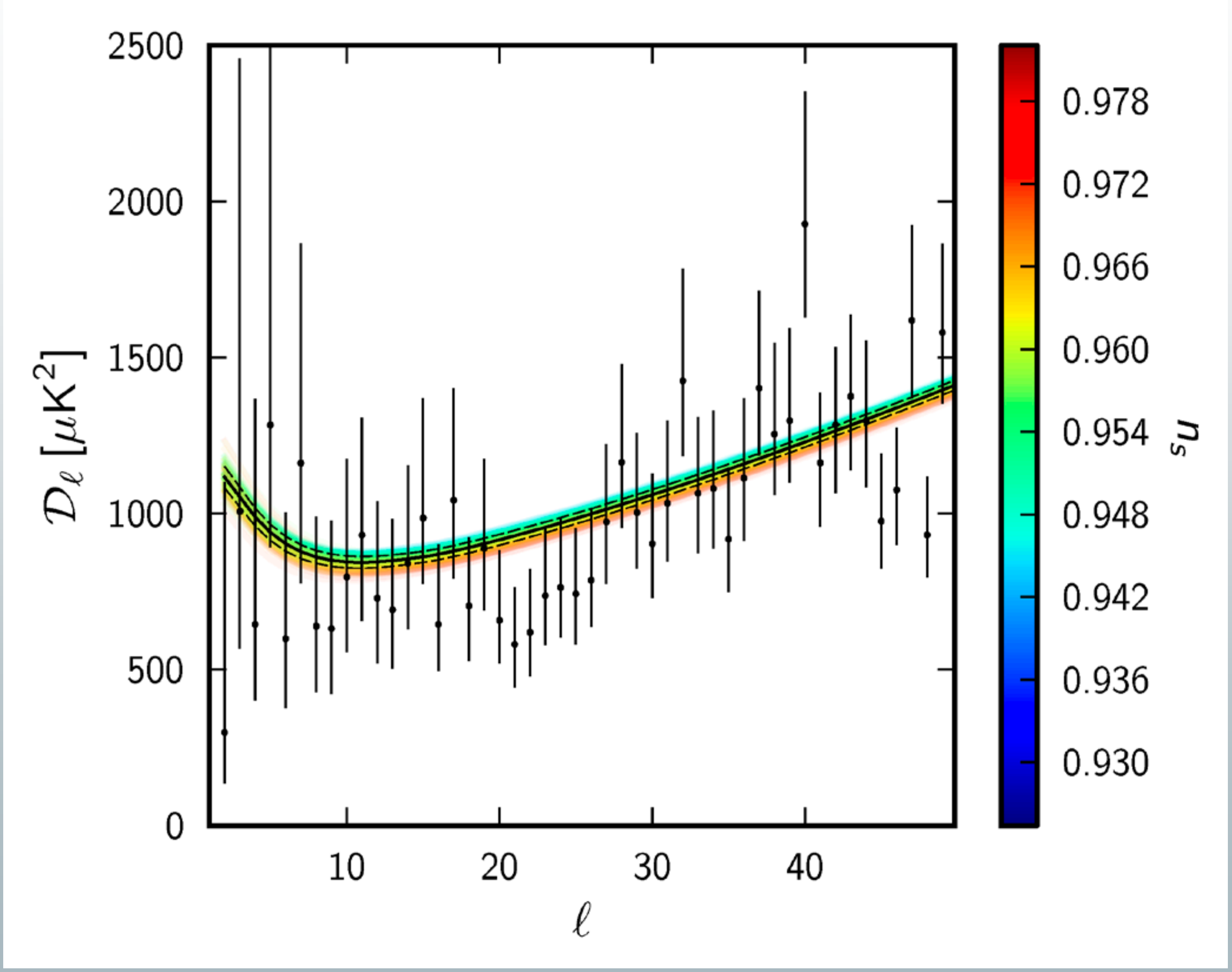
A theorist dream, or nightmare?



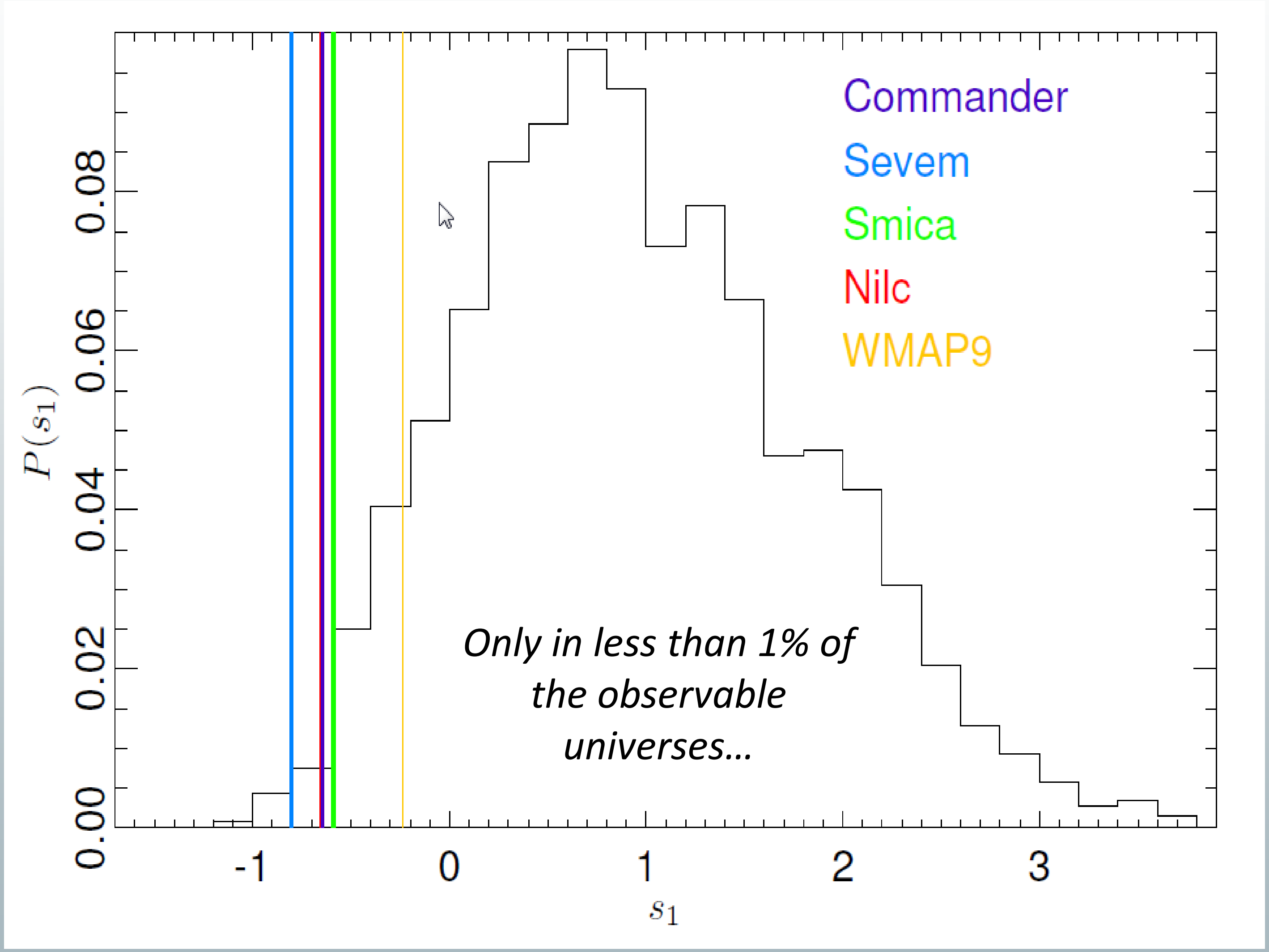
Zooming on the very largest scales, l<50...



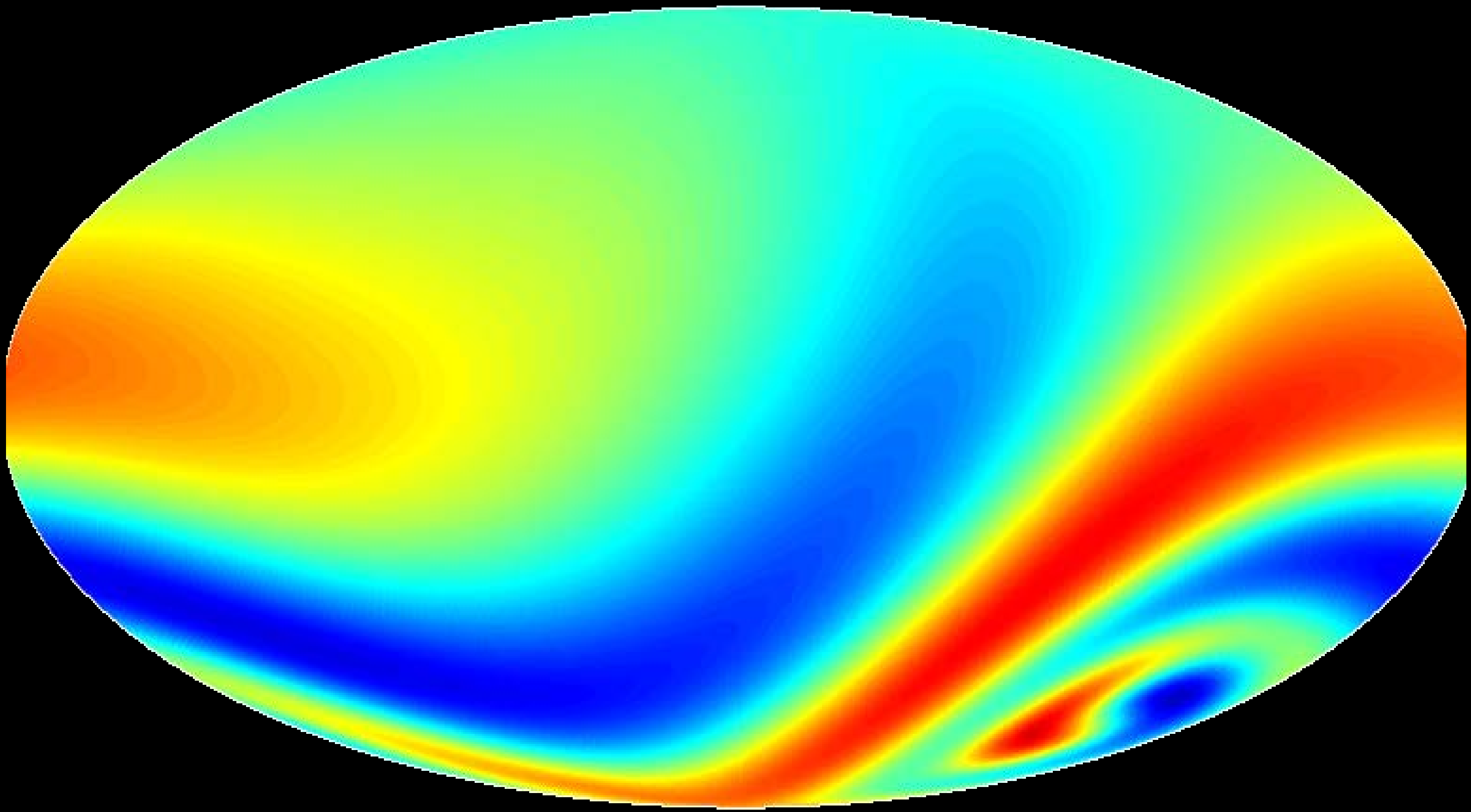
The low-multipole surprise/tension



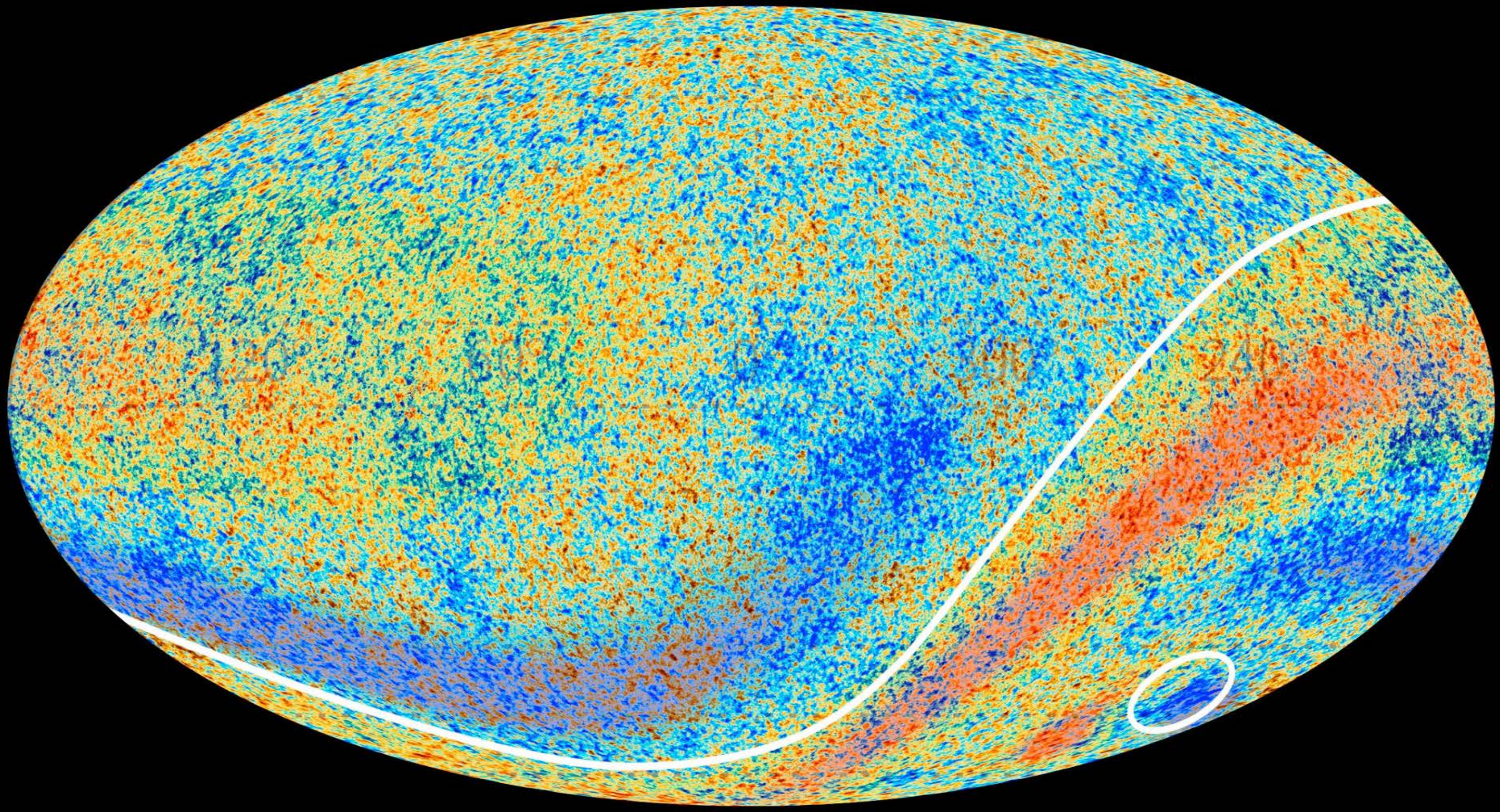
How significant is the anomaly?



Bianchi model VII

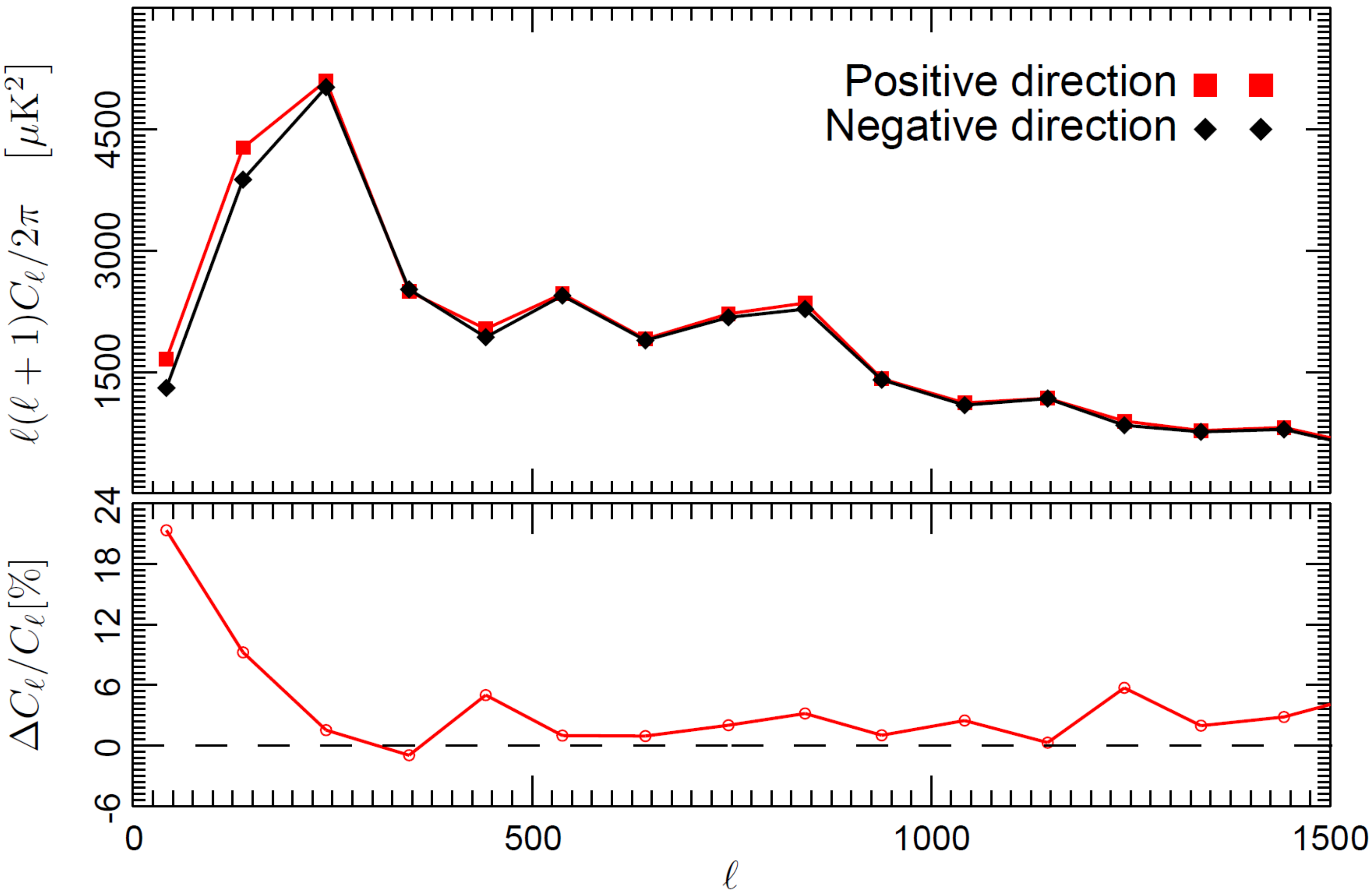


Does Mr Bianchi get along with Mr Planck?



Hemispherical Power asymmetry

Power spectrum computed with $(l, b) = (224°, 0°)$



But there <u>is</u> a simple reference model

- Ω_k =0, single inflaton field, obeying slow-roll conditions (small derivatives of the potential, ε,η,ξ), deriving from a standard Lagrangian, with fluctuations behaving as in flat space at asymptotically early times and short distances (Bunch-Davies Initial conditions)

→ Adiabatic fluctuations, $P_R(k)=A_s\,(k/k_*)^{ns-1}$, $n_s < 1$, no running, $N_* \in [50,60]$, with negligible non-Gaussianity.

- We shall probe Ω_k, n_s, running ($dn_s/d\ln k$), non-slow-roll, features in P(k) (parametric and non-parametric), isocurvature fluctuations, existence of defects, non-gaussianity – LEO & a few more types…

Conclusions 1/2

- Ω_K=-0.006±0.018 at 95%CL from Planck-T+Planck-L (PT+PL).
- f_{NL}^{LEO} (and others) is consistent with zero; most stringent test of Gaussianity performed to date.
- No evidence for cosmic defects. Nambu-Goto strings have $G\mu/c^2 < 1.3 \times 10^{-7}$ ($\eta < 4.7 \times 10^{15}$ GeV).

- n_s=0.963 ±0.006 from PT+WP+BAO; HZ robustly excluded (even N_{eff} or Y_p worse by $\Delta\chi^2_{eff}$ = 4.6 or 8)
- No evidence for running (nor running of running)
- $r_{0.002} < 0.12$ (PT+WP) → inflation energy scale < 1.9×10^{16} GeV (or $H_* < 3.7 \times 10^{-5} M_p$) at 95%CL
- Concave potentials preferred.
  - *Exponential potential, monomial with p>2, hybrid driven by quadratic term are all disfavored at more than 95% confidence. Simple Quadratic large field at the edge…*
- Strong constraints on parameters values of specific inflationary scenario (e.g. limit on scale parameter of natural inflation),
- Planck limits possibilities for unknown physics between end of inflation and the beginning of the radiation era (w_{int}).
- Potential reconstructed in observable window shows that allowing a fourth order leads to deviation to slow-roll, and allows a better fit the low-l (improvement of $\Delta\chi^2_{eff}$ ~4)
- Penalized Likelihood reconstruction of primordial spectrum hints at features;
  - *parameterized models (as motivated by NBD, axion monodromy or step in the potential) improve $\Delta\chi^2_{eff}$ by ~10, but no strong Bayesian evidence. Polarization will help .*
- No strong evidence for non-decaying isocurvature modes
  - *(one at a time, but arbitrarily correlated to adiabatic mode). Axion and curvaton scenario (either uncorrelated or fully correlated) are not favored. But arbitrary correlation help lowering the low-l part of the spectrum ($\Delta\chi^2_{eff}$ >4)*

- ***Excellent agreement between the Planck temperature spectrum at high l and the predictions of the ΛCDM model using the simplest slow-roll inflationary models;***
- ***But with tantalizing hints both at low-l (<30) and high-l... (is there a model tying all Large Scale anomalies?)***

Conclusions 2/2

- Planck data allows *much* additional exciting science (often in conjunction):
  - *Lensing science (cross-correlations with LSS probes)*
  - *SZ clusters science (the rarest ones, with X-ray, LSS, low-z lensing)*
  - *CIB science (high-redshift galaxies)*
  - *Galactic Interstellar Medium (CO, dark gaz, polarisation…)*
- Next Planck data release will be mid - 2014
  - *Twice as much data*
    - HFI, ~900 billions samples, complete since Jan 12th 2012, after 885 days of survey, 5 sky surveys
    - LFI is still in operation; in August 2013 it will reach 8 observed sky surveys.
  - *Polarisation!*
  - *Expected results:*
    - Better Temperature science (more redundancy & checks, improved analyses...)
    - By measuring B modes polarisation, Planck may detect primordial gravitational waves
      - From B modes we can measure the energy scale of inflation and constrain the nature of the “inflaton”
    - Polarisation will help foray deeper into Non-Gaussianity analysis
    - Further handles to understand if the “deviations” are fundamental and if we need a “new physics”

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.