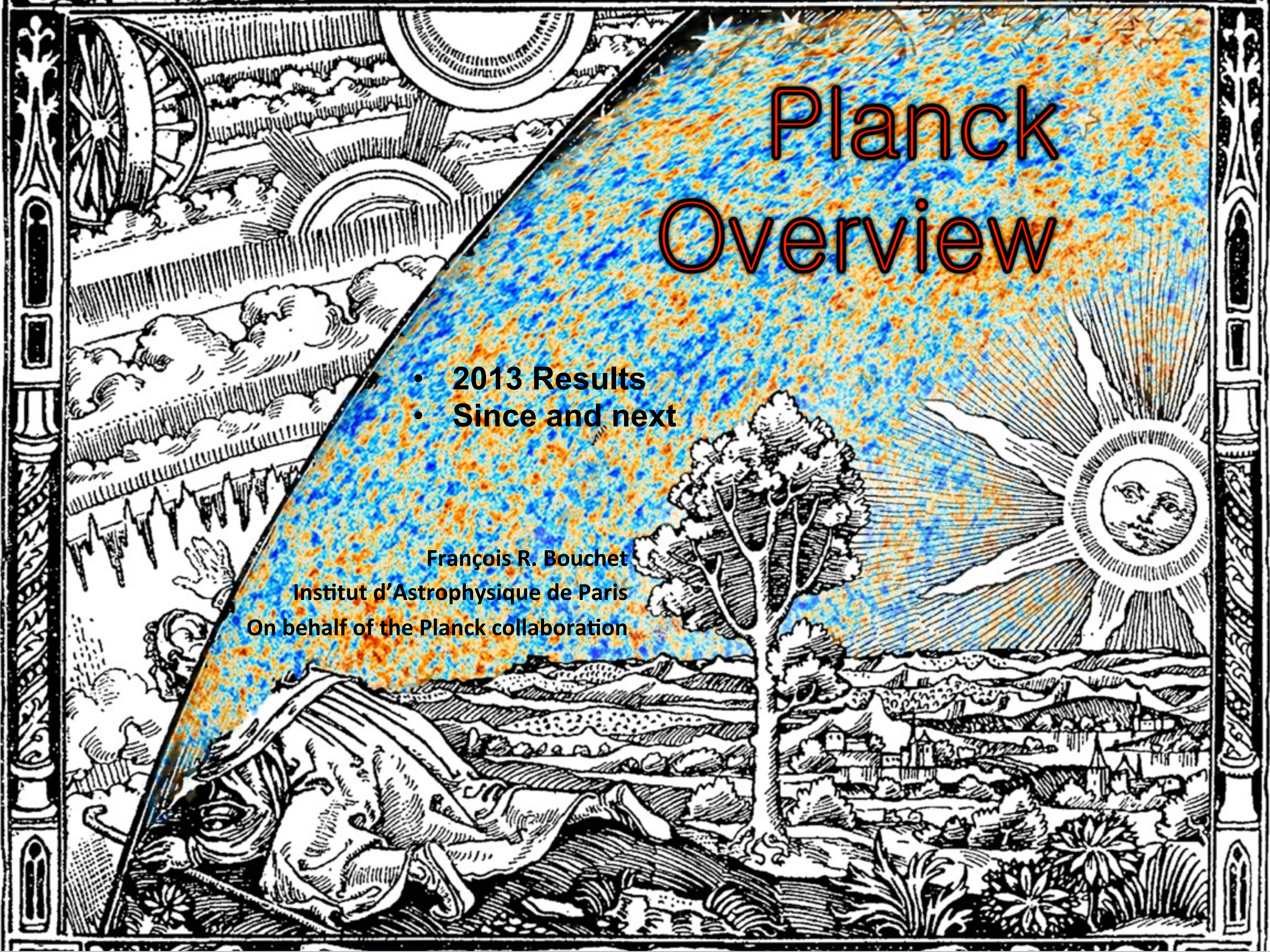


Planck Overview

- 2013 Results
- Since and next

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

DUSTING IT OFF…

AFTER 16 YEARS OF HOPES & WORK

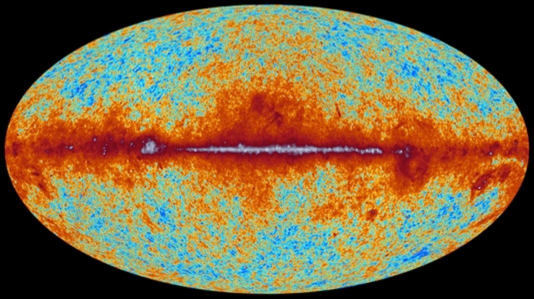
Planck Milestones

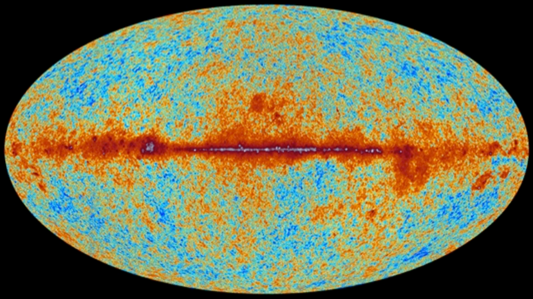
- 1993: CNES & ESA (accepted) proposals, followed by a 3 years phase A study with ESA
- 1996 Selection by ESA (for a 2003 launch)
- …. (industry in, consortia in, design & tests…)
- 2009 May 14th : Launch from Kourou, French Guyana.

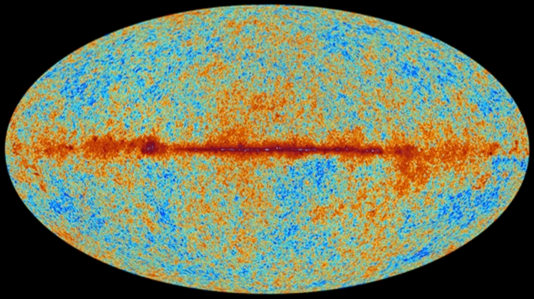
- 2009 August 13th : beginning of survey: Instruments <u>very</u> stable; Essentially no hiccups since, till the end of HFI: Details in 16 monthly reports to MOC, 13 bi-monthly to PSO (150 p. each), 138 « operation » teleconf. minutes, 169 weekly reports to MOC, 91 « cryo » teleconf., 8 coordination meetings, 978 daily quality reports & 127 HFI weekly health reports (97 800 plots), 1278 pages wiki écrites ou co-écrites …:

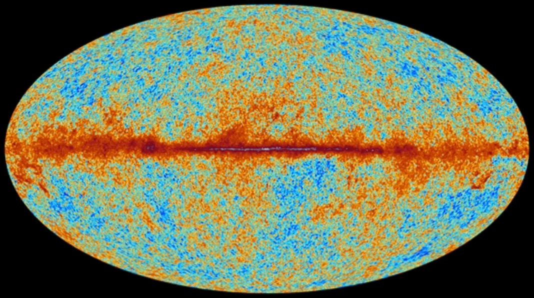
- 2010 June : first complete coverage of the sky by all detectors obtained with the first nearly 10 months of survey data. ERCSC release & 25 "Planck early results" papers submitted **Jan 2011**;
- 2010 November 27th : Nominal mission completed, having collected about 15.5 months of survey data insuring that all the sky at been seen at least twice by each detector:
  - *22 "Planck Intermediate results" papers on CMB foregrounds results submitted **in 2012**-14*
  - *public T data delivery on **March 21st 2013**, together with 28 "Planck 2013 results" papers (→ 32)*
- 2012 Jan 14th**:** all HFI survey data acquired! 885 days of acquisition, 900 billion samples, 5 surveys, full mission = twice the nominal duration. With some additional LFI data, will be the basis of our next data delivery (DD2), including polarization & TOI. **Target date of end of October (<dec 1st) 2014**, together with ~ 35 papers.
- 2013 Oct 23rd: last command (off!) to the spacecraft from Darmstadt control room…
- 2015-end of: "legacy release".

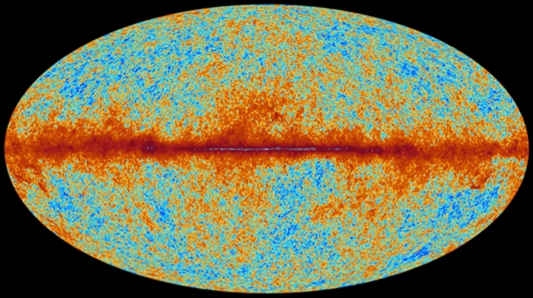
The sky as seen by Planck

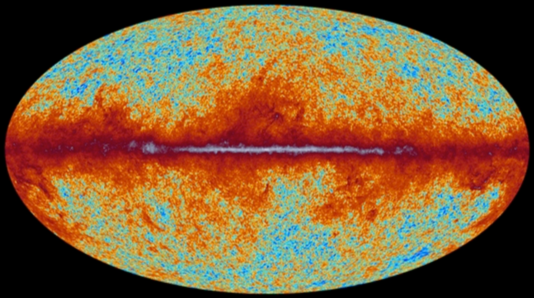

30 GHz

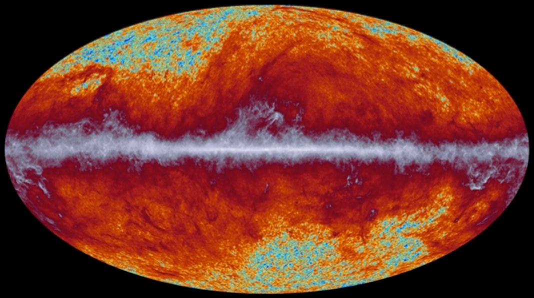

44 GHz

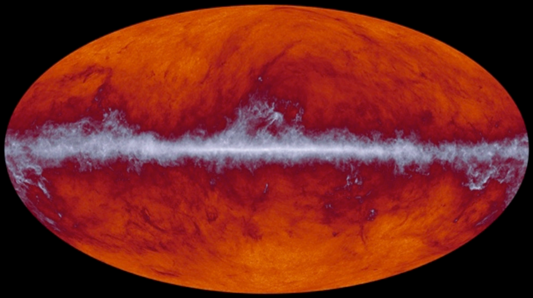

70 GHz

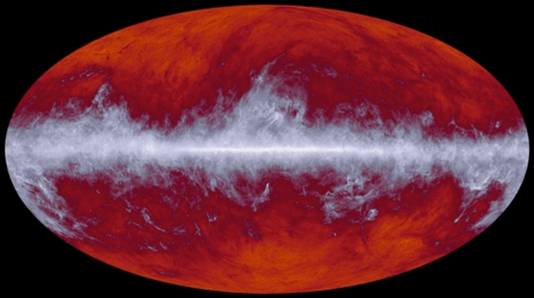

100 GHz


143 GHz


217 GHz


353 GHz

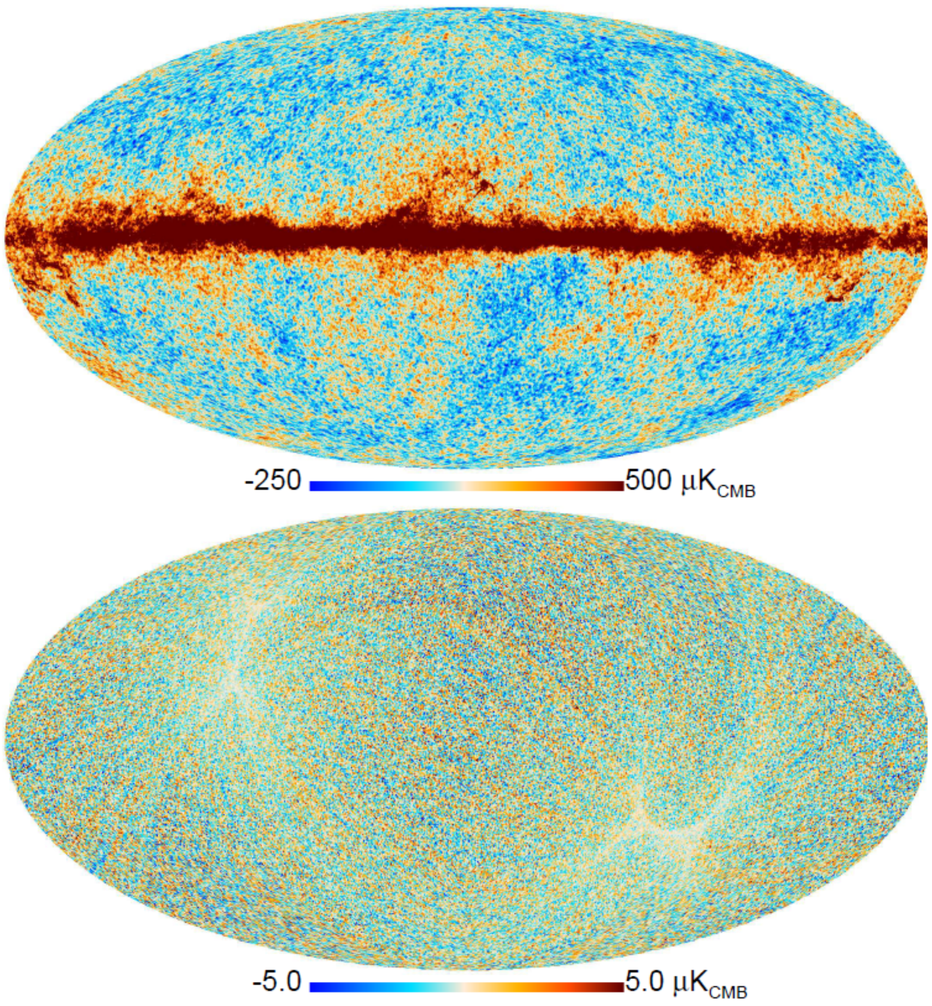

545 GHz


857 GHz

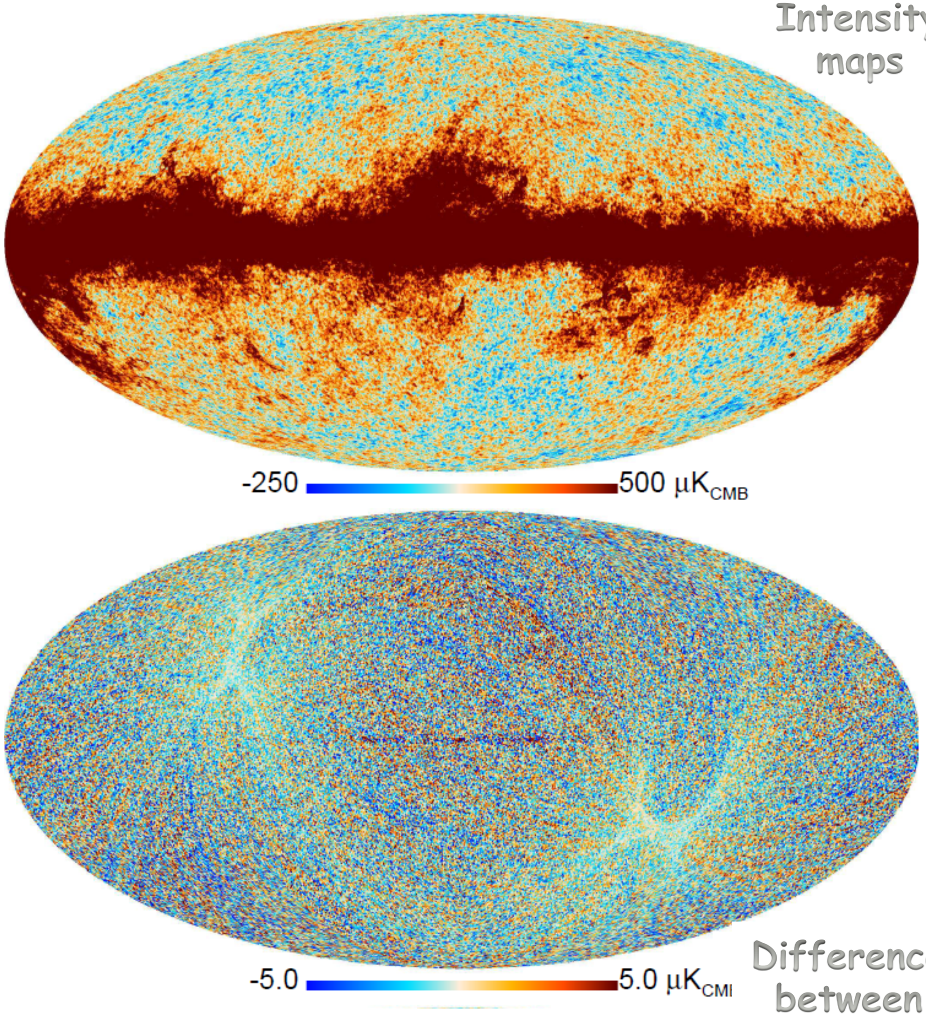
lanck coming out of March 21st 2013

143 GHz & 217 GHz maps

Planck Collaboration: HFI data processing



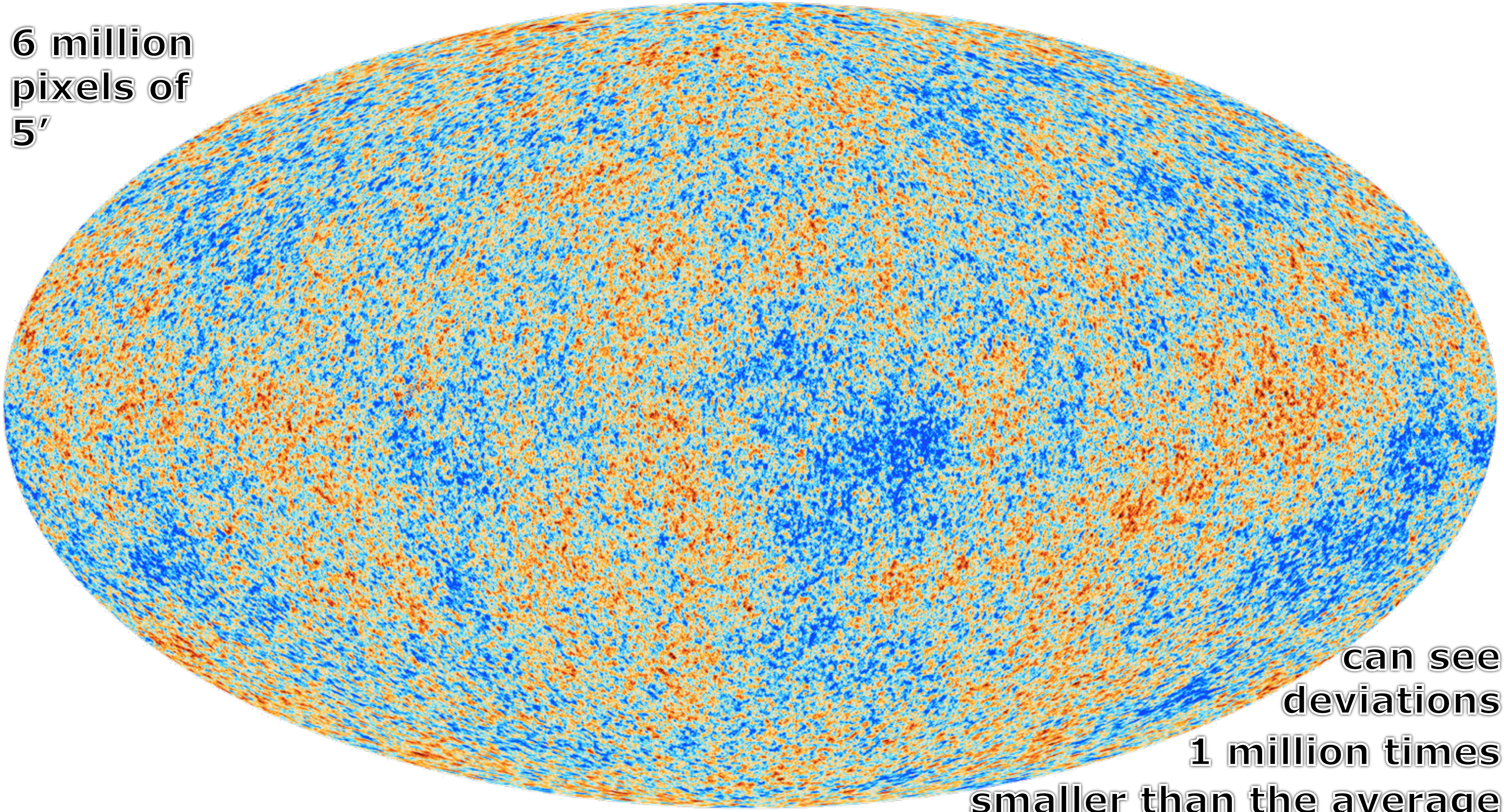
Planck Collaboration: HFI data processing



Intensity maps

Difference between Half-ring maps

The cosmic microwave background Temperature anisotropies

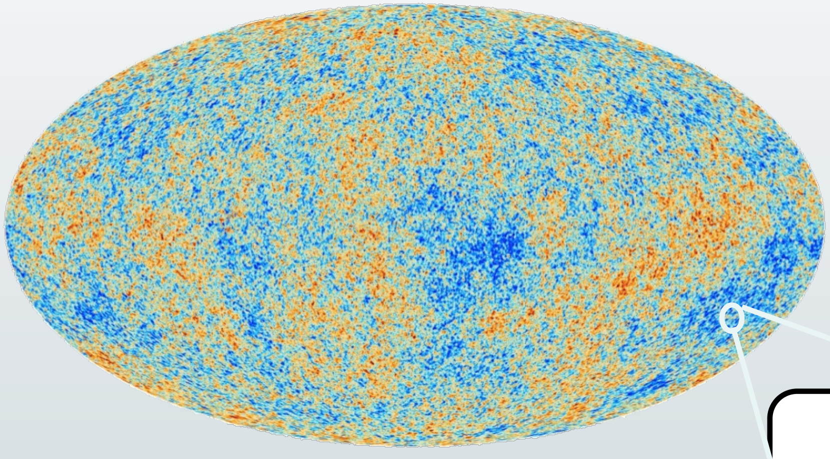


6 million pixels of 5′

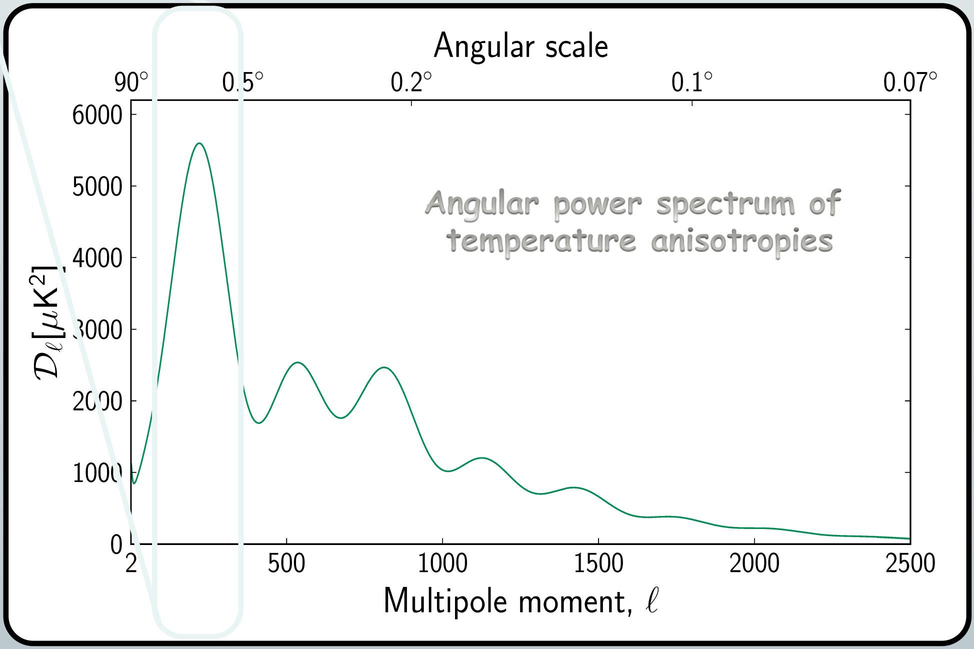
can see deviations 1 million times smaller than the average

What theory said…

(well before any observations…)



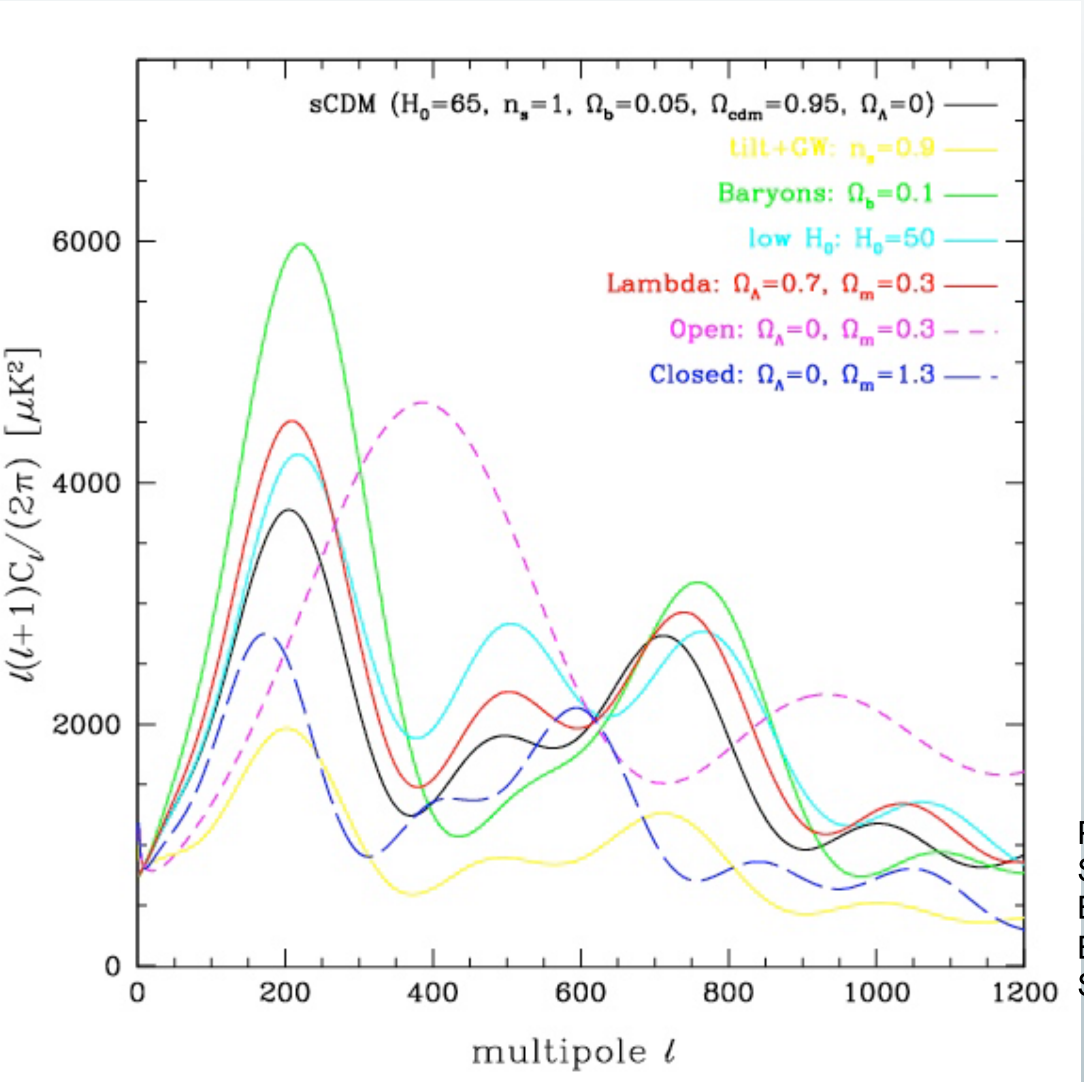
We cannot predict the map of the anisotropies...



Angular power spectrum of temperature anisotropies

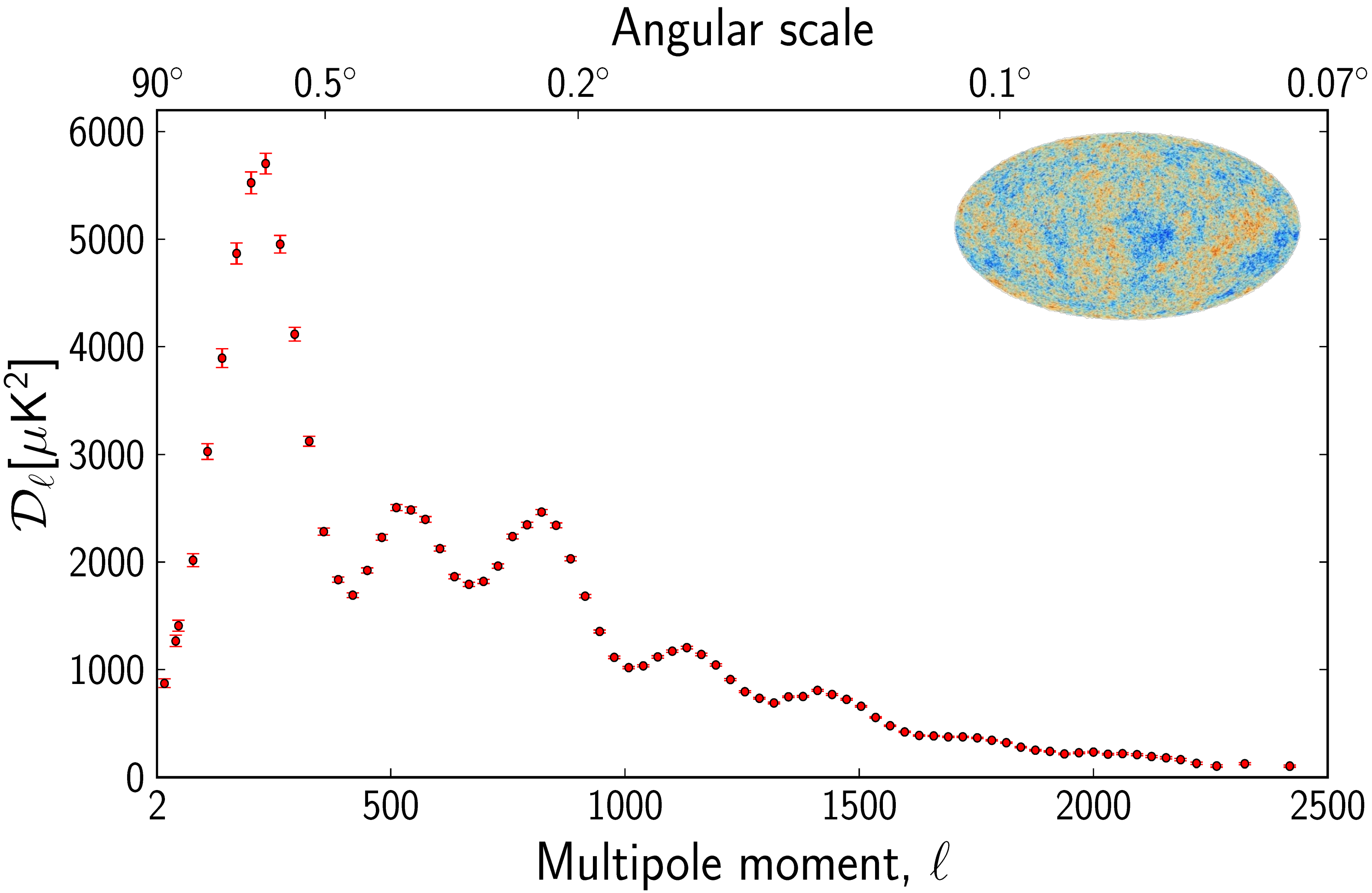
But we can predict its statistical properties ! (like the typical height of the waves as a function of their length

Cosmic imprints

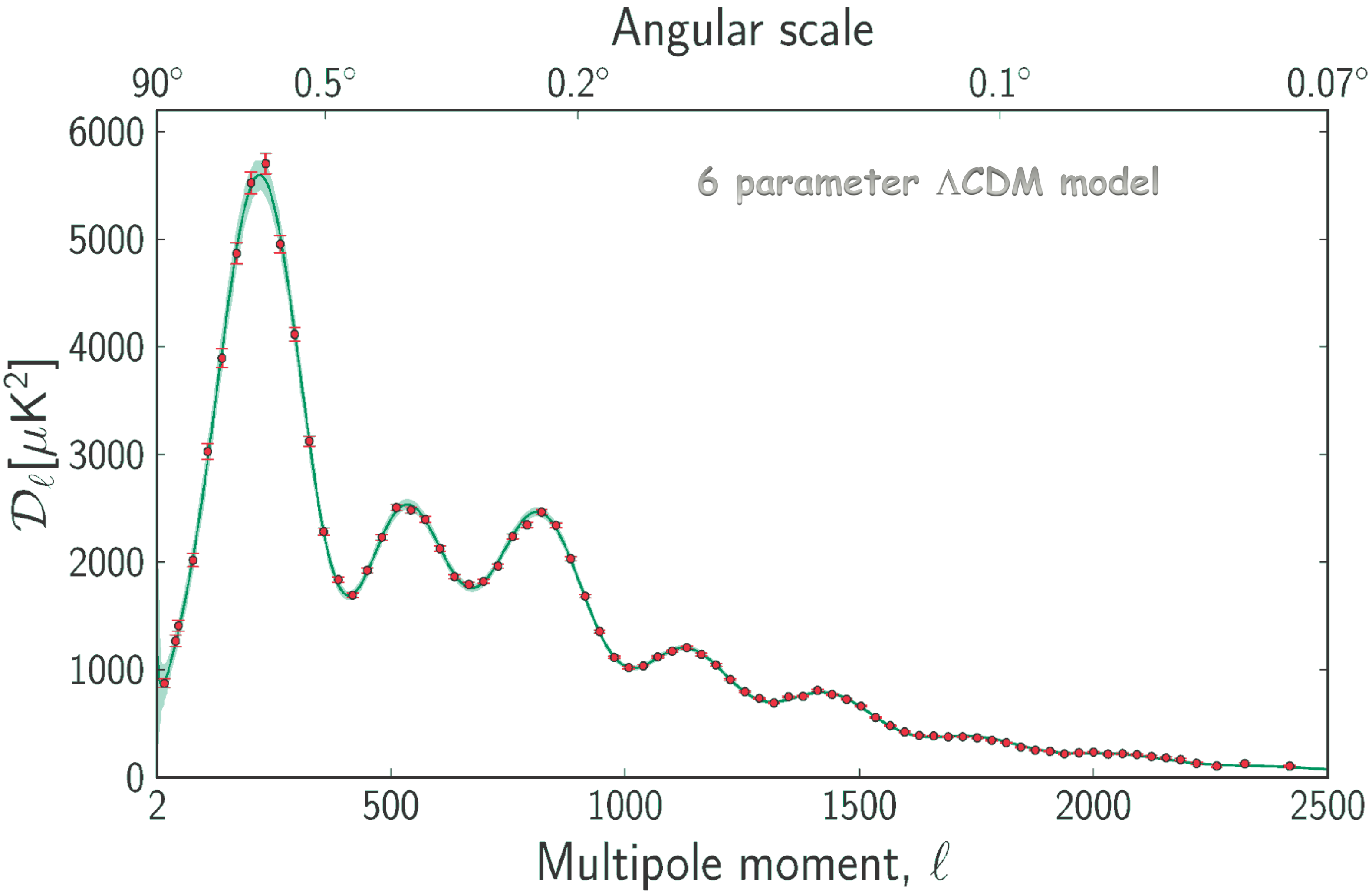


Peebles, Yu, Sachs & Wolf, Sunyaev, Zeldovich, Silk, Vittorio, Wilson, Mukhanov, Chibisov, Bardeen, Linde, Bond, Efstathiou, Bouchet, Bennett, Gott, Kaiser, Stebbins, Allen, Shellard, Seljack, Zaldariaga, Kamionkowski, Hu, …

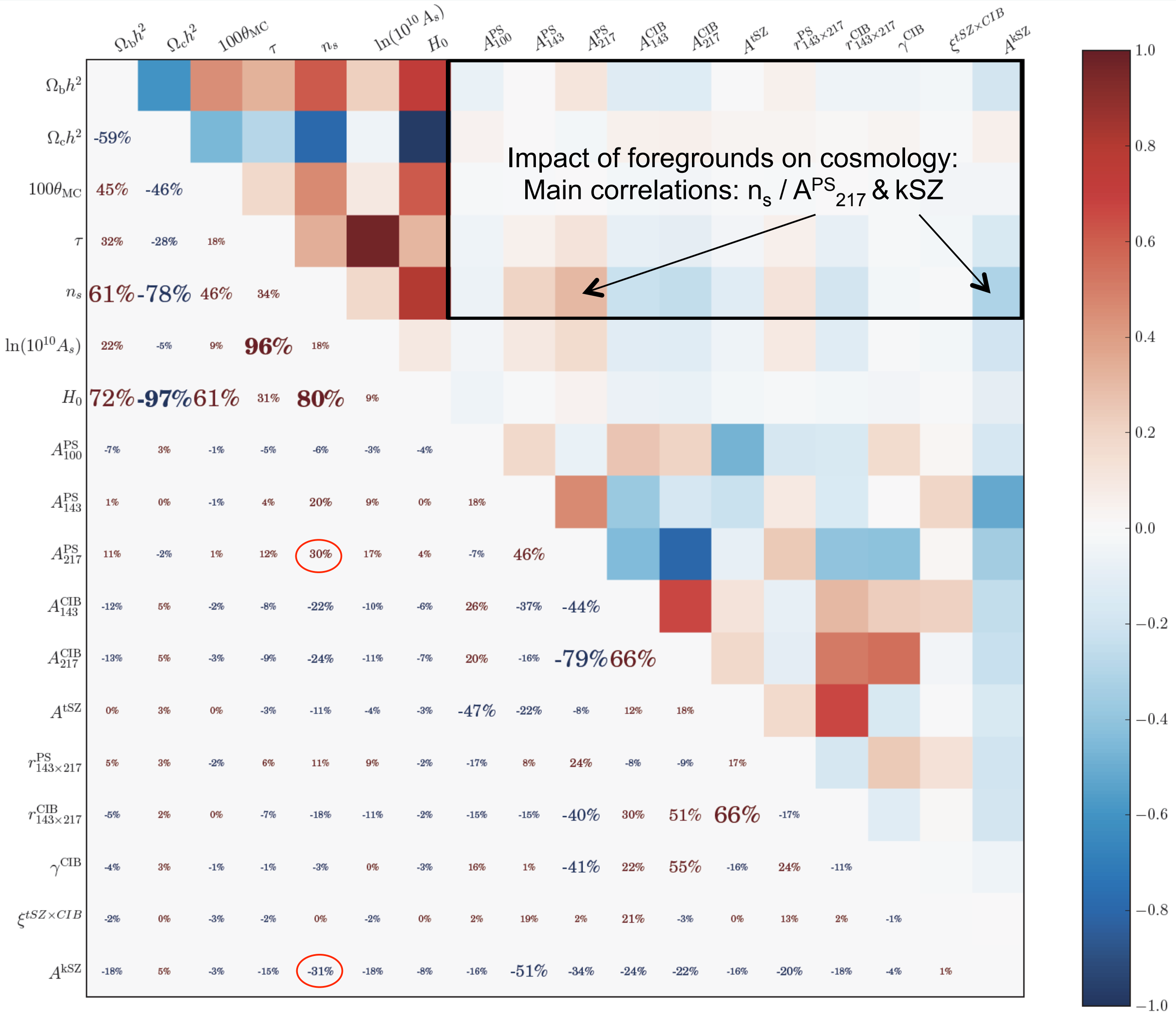
The Planck power spectrum of Temperature anisotropies



Theory confronts data



HL posterior correlations

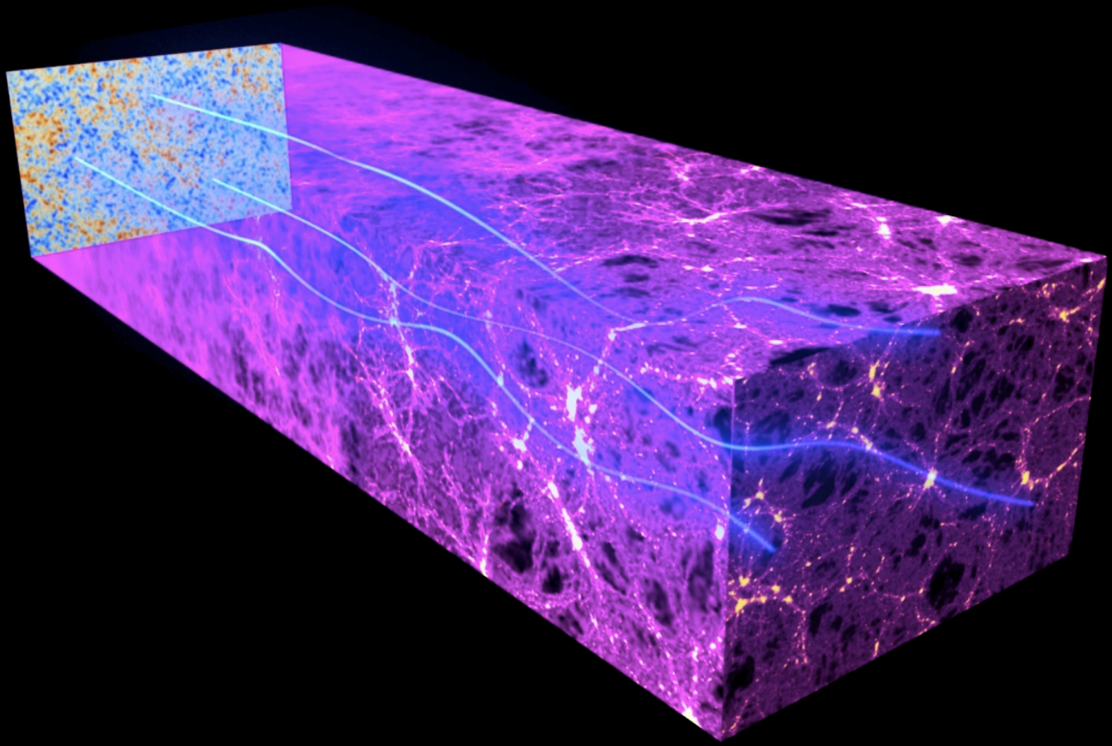


Impact of foregrounds on cosmology:
Main correlations: n_s / A^{PS}_{217} & kSZ

	$\Omega_b h^2$	$\Omega_c h^2$	$100\theta_{MC}$	τ	n_s	$\ln(10^{10} A_s)$	H_0	A^{PS}_{100}	A^{PS}_{143}	A^{PS}_{217}	A^{CIB}_{143}	A^{CIB}_{217}	A^{tSZ}	$r^{PS}_{143\times217}$	$r^{CIB}_{143\times217}$	γ^{CIB}	$\xi^{tSZ\times CIB}$	A^{kSZ}
$\Omega_b h^2$																		
$\Omega_c h^2$	-59%																	
$100\theta_{MC}$	45%	-46%																
τ	32%	-28%	18%															
n_s	61%	-78%	46%	34%														
$\ln(10^{10} A_s)$	22%	-5%	9%	96%	18%													
H_0	72%	-97%	61%	31%	80%	9%												
A^{PS}_{100}	-7%	3%	-1%	-5%	-6%	-3%	-4%											
A^{PS}_{143}	1%	0%	-1%	4%	20%	9%	0%	18%										
A^{PS}_{217}	11%	-2%	1%	12%	30%	17%	4%	-7%	46%									
A^{CIB}_{143}	-12%	5%	-2%	-8%	-22%	-10%	-6%	26%	-37%	-44%								
A^{CIB}_{217}	-13%	5%	-3%	-9%	-24%	-11%	-7%	20%	-16%	-79%	66%							
A^{tSZ}	0%	3%	0%	-3%	-11%	-4%	-3%	-47%	-22%	-8%	12%	18%						
$r^{PS}_{143\times217}$	5%	3%	-2%	6%	11%	9%	-2%	-17%	8%	24%	-8%	-9%	17%					
$r^{CIB}_{143\times217}$	-5%	2%	0%	-7%	-18%	-11%	-2%	-15%	-15%	-40%	30%	51%	66%	-17%				
γ^{CIB}	-4%	3%	-1%	-1%	-3%	0%	-3%	16%	1%	-41%	22%	55%	-16%	24%	-11%			
$\xi^{tSZ\times CIB}$	-2%	0%	-3%	-2%	0%	-2%	0%	2%	19%	2%	21%	-3%	0%	13%	2%	-1%		
A^{kSZ}	-18%	5%	-3%	-15%	-31%	-18%	-8%	-16%	-51%	-34%	-24%	-22%	-16%	-20%	-18%	-4%	1%	

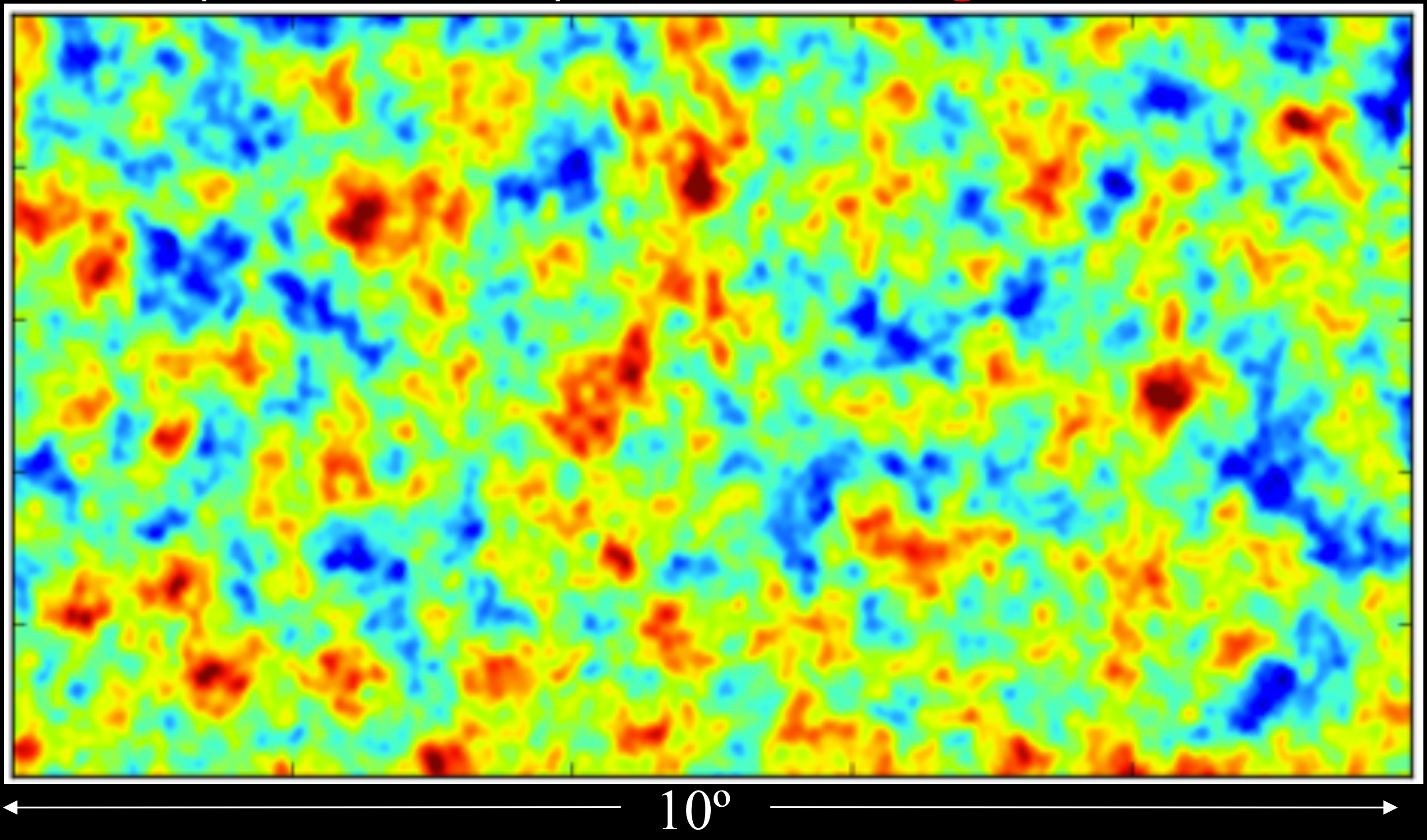
GRAVITATIONAL LENSING DISTORTS IMAGES

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



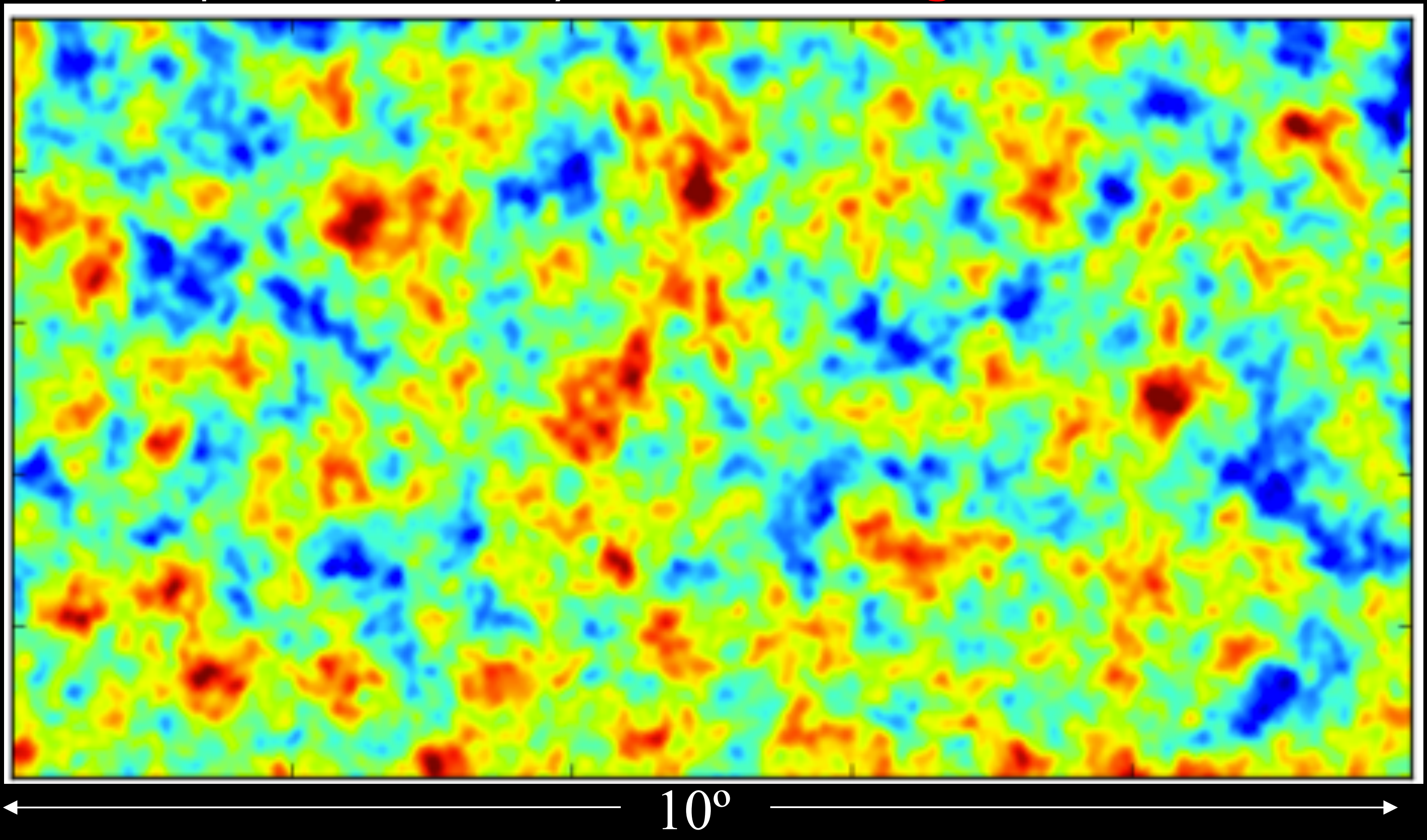
GRAVITATIONAL LENSING OF THE CMB

A simulated patch of CMB sky – **before lensing**



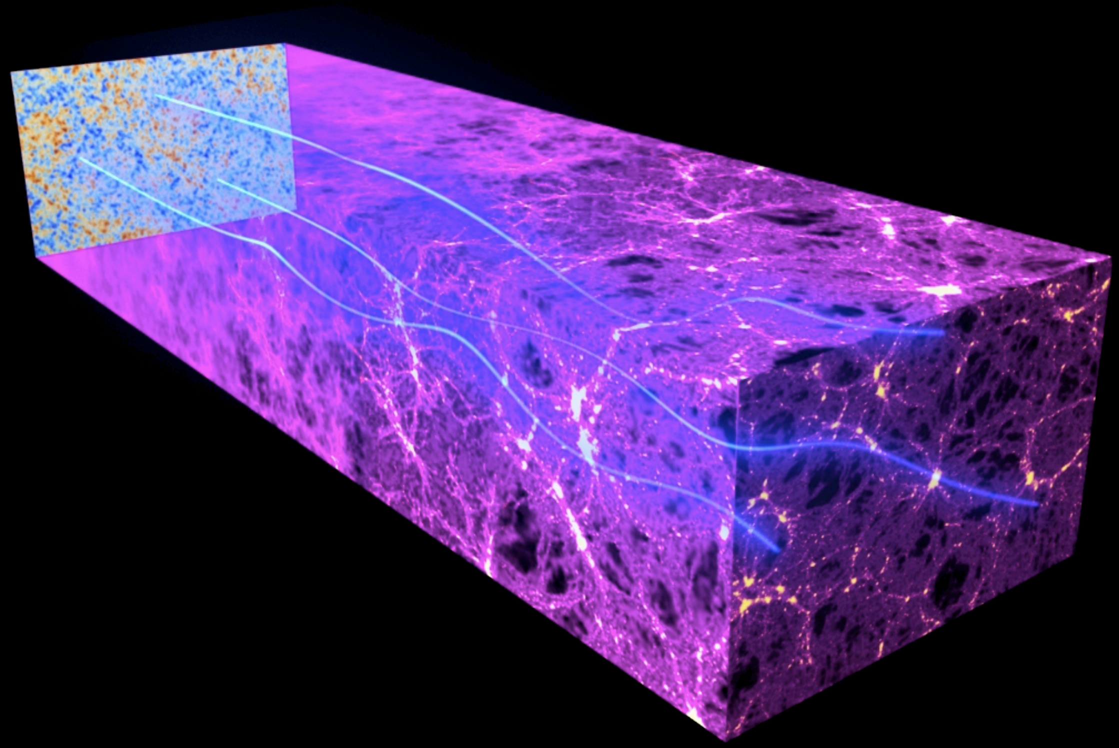
GRAVITATIONAL LENSING OF THE CMB

A simulated patch of CMB sky – **after lensing**



GRAVITATIONAL LENSING DISTORTS IMAGES

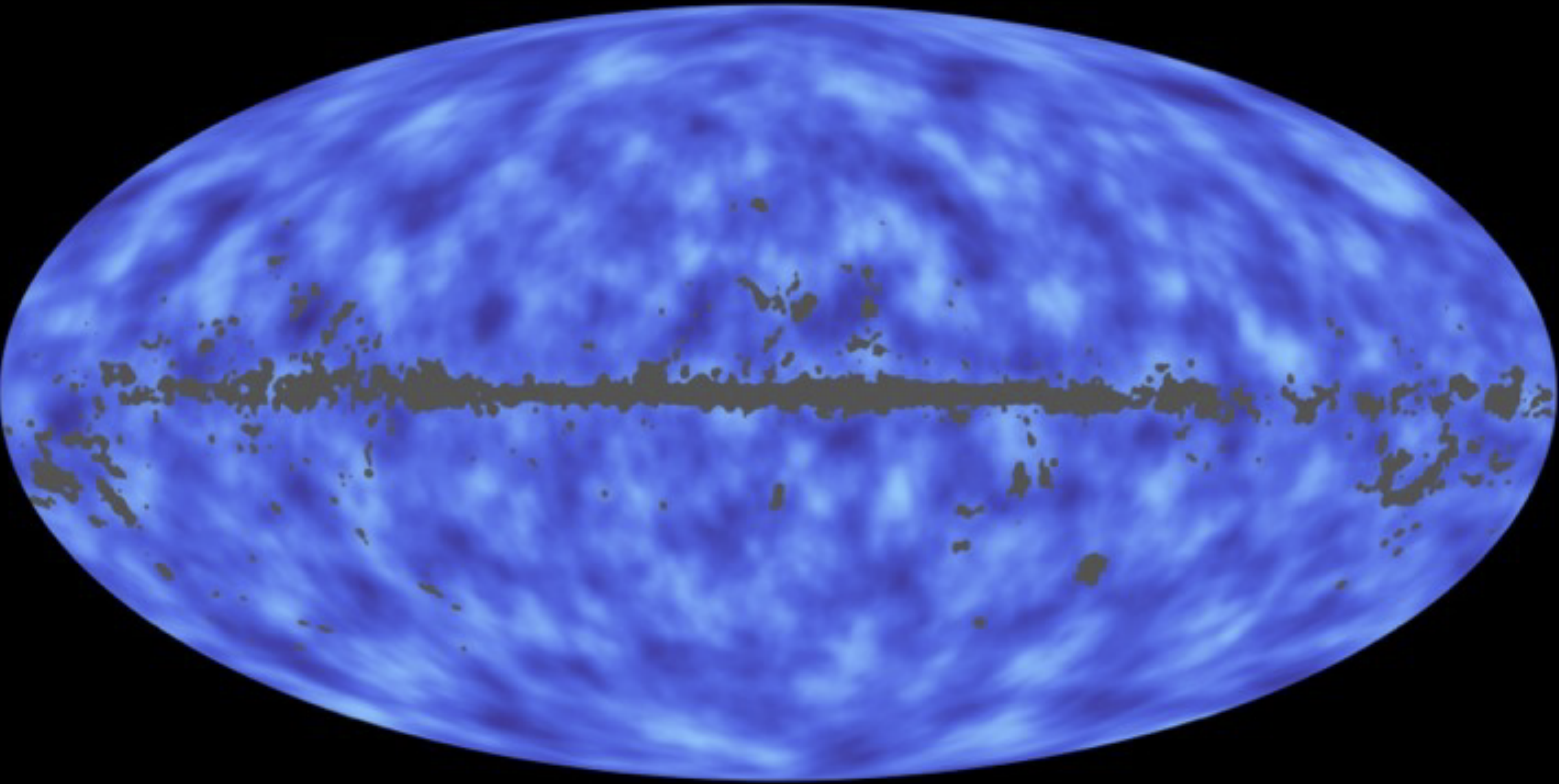
The gravitational effects of intervening matter bend the path of CMB light on its way from the early universe to the Planck telescope. This “gravitational lensing” distorts our image of the CMB (smoothing on the power spectrum, and correlations between scales)



$$\hat{T}(\vec{\theta}) = T(\vec{\theta} + \vec{\nabla}\phi) \approx T(\vec{\theta}) + \vec{\nabla}\phi \cdot \vec{\nabla}T(\vec{\theta}) + \dots$$

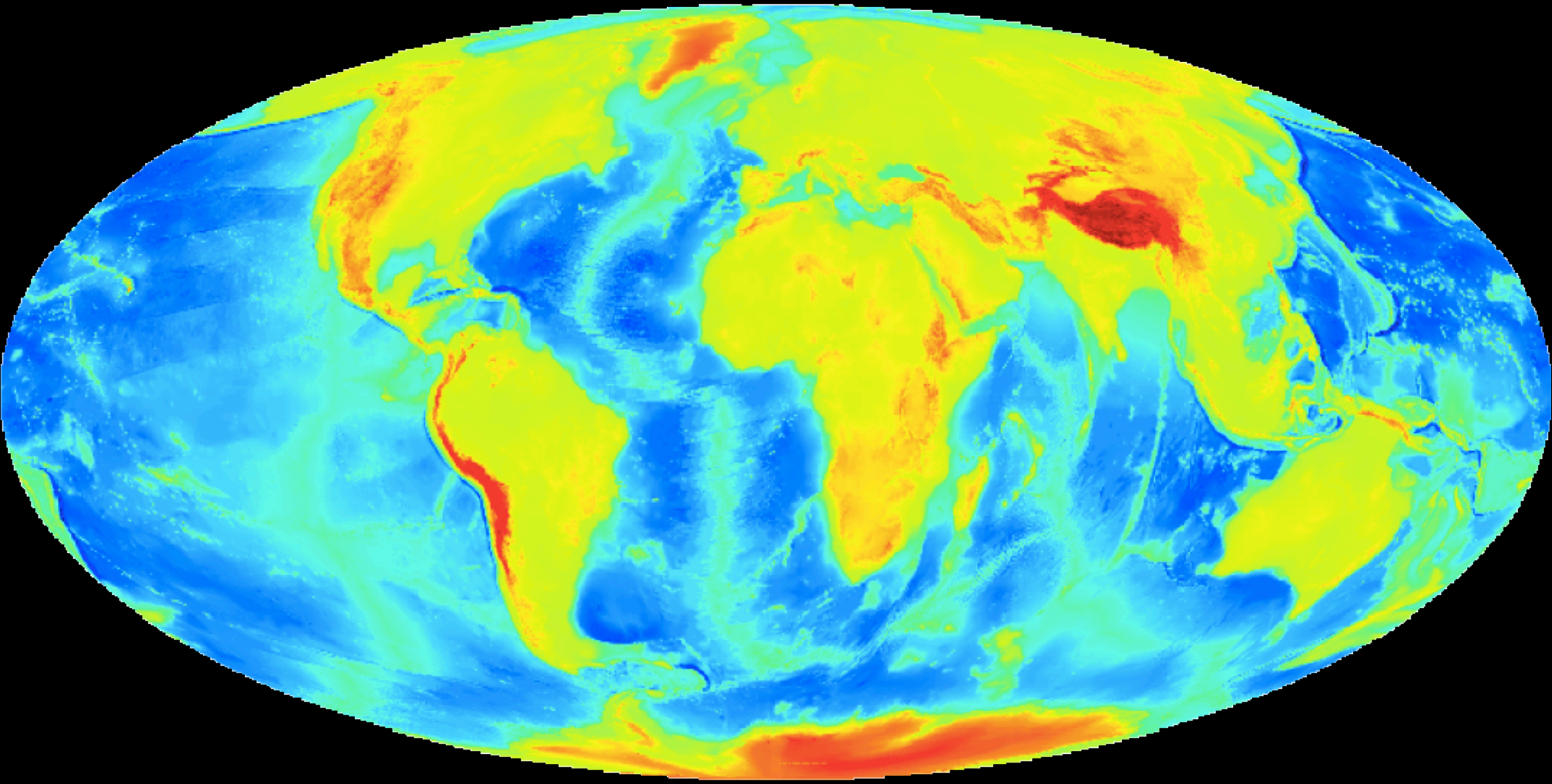
$$\bar{\phi} = \Delta^{-1}\vec{\nabla} \cdot [C^{-1}T \, \vec{\nabla}(C^{-1}T)]$$

Projected mass map

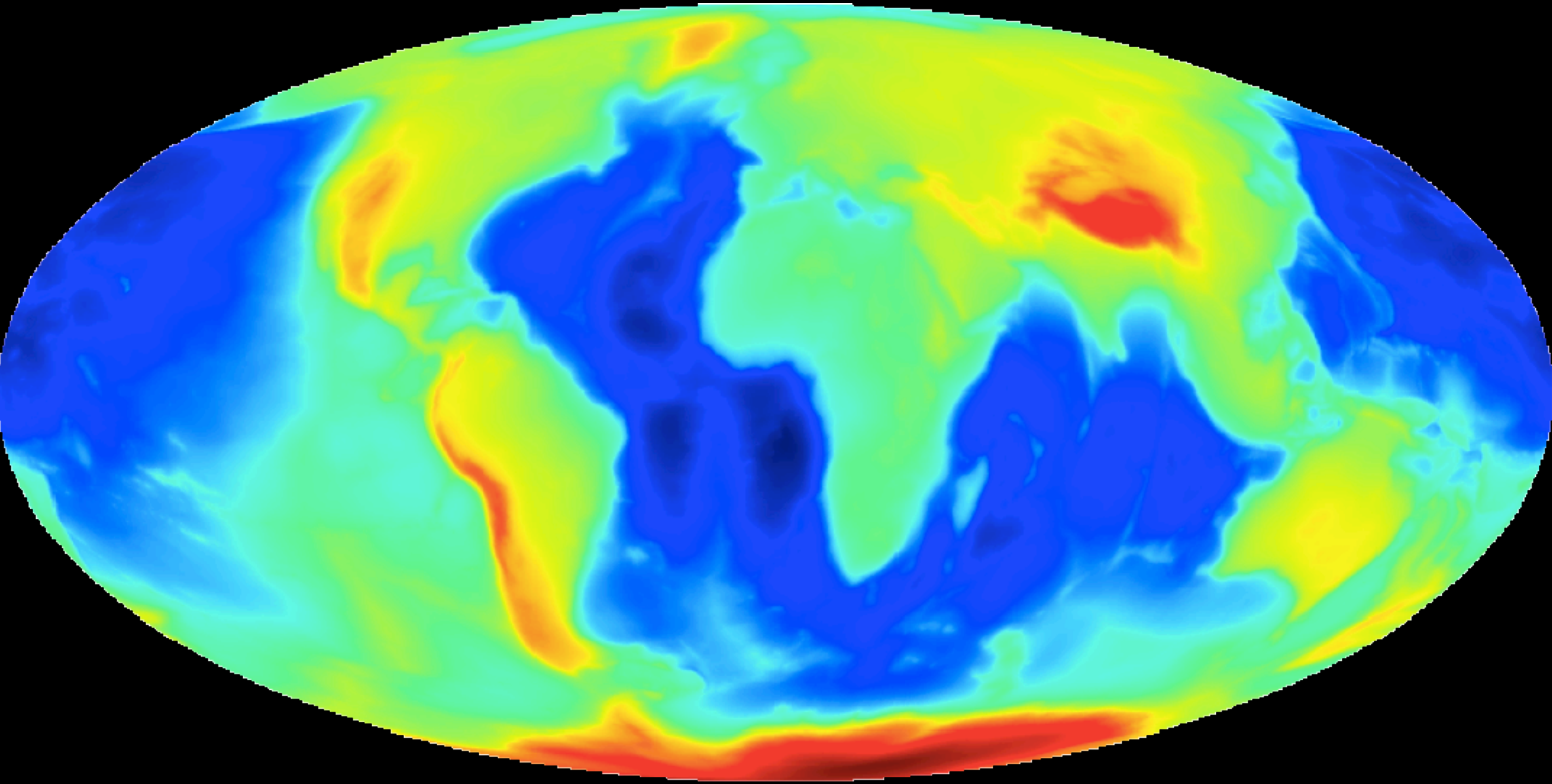


The (grey) masked area is where foregrounds are too strong to allow an accurate reconstruction

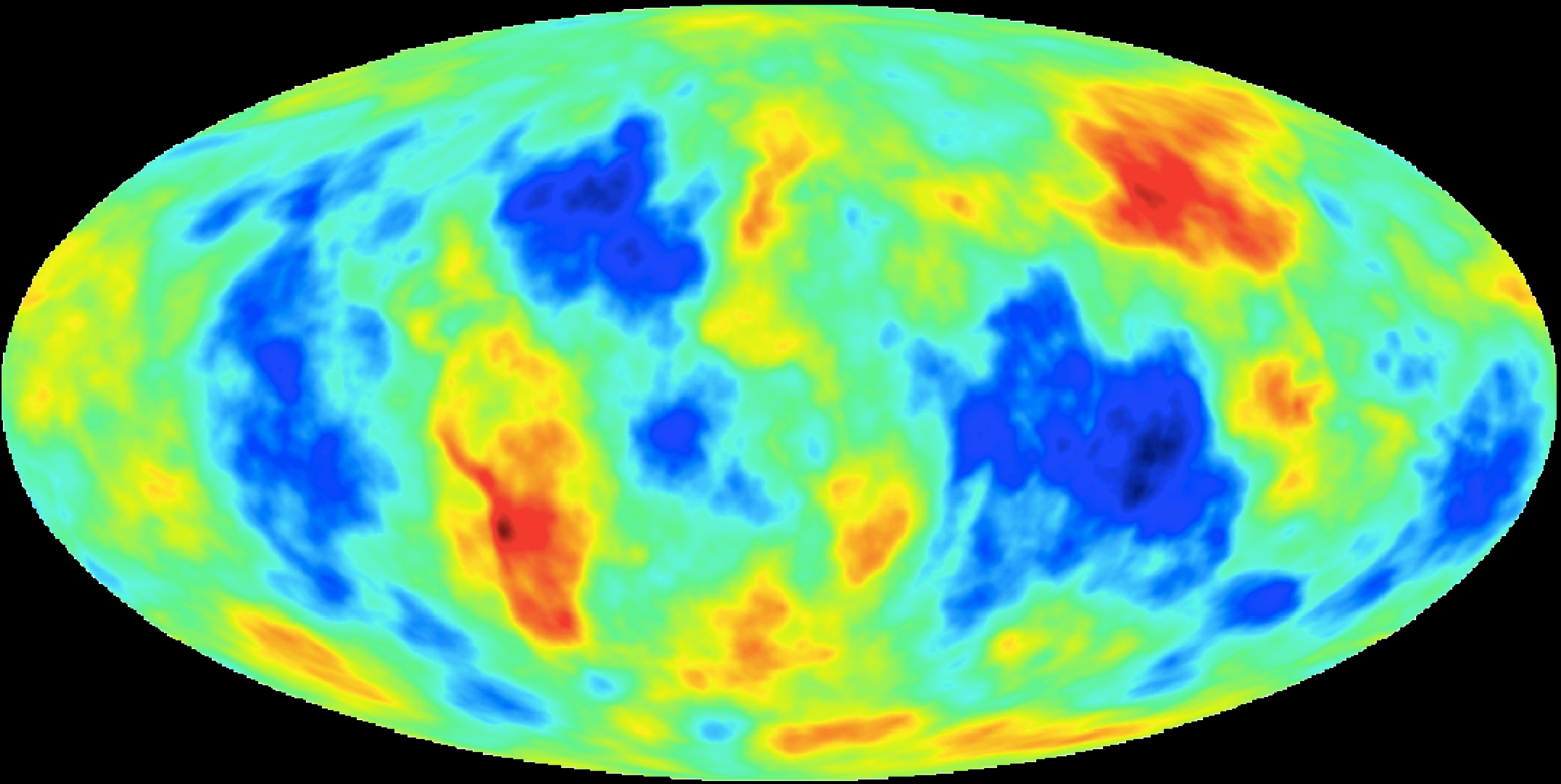
Another full sphere distribution



at our angular resolution…

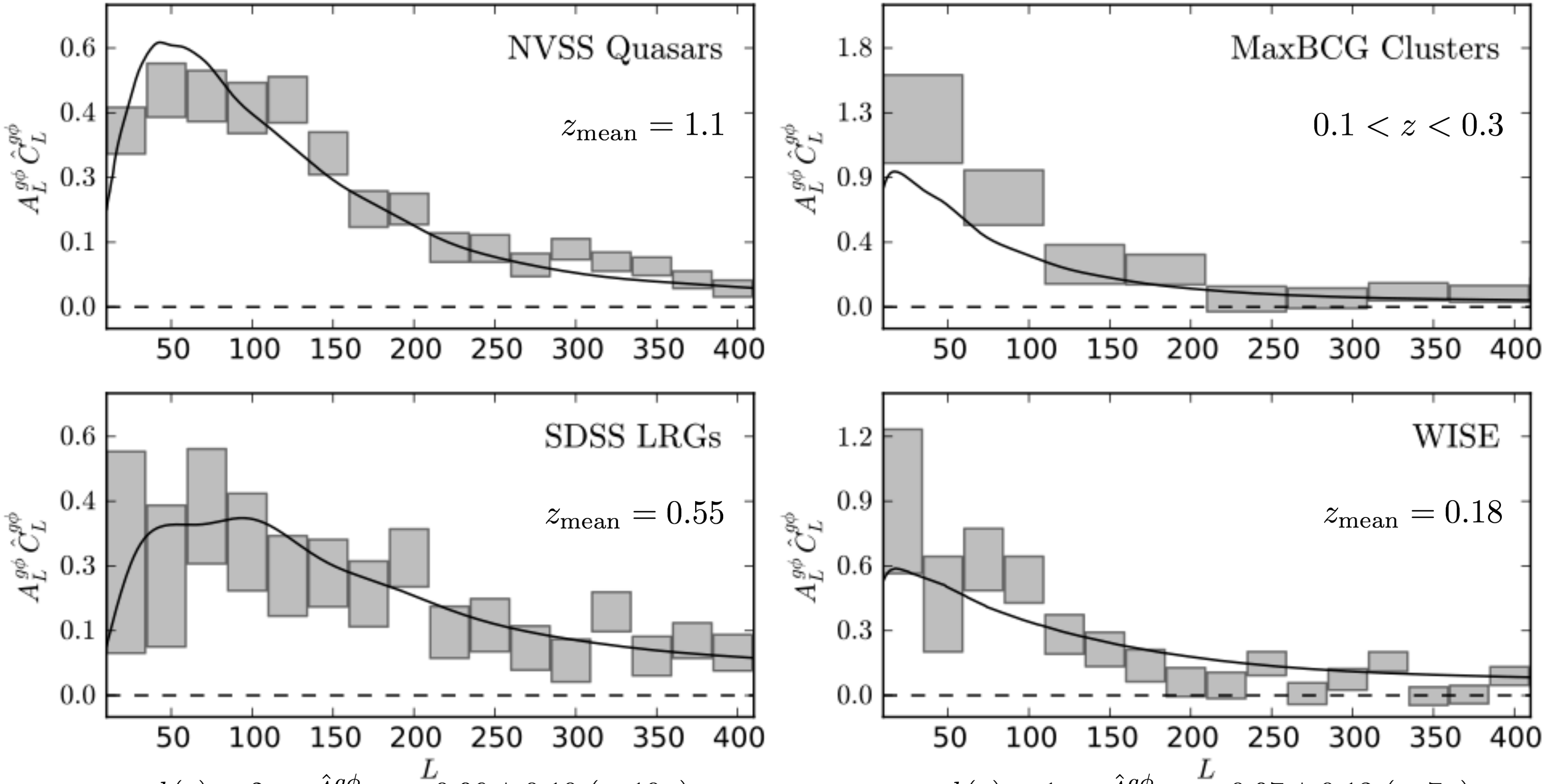


and noise level!



Lensing potential versus distribution of external tracers

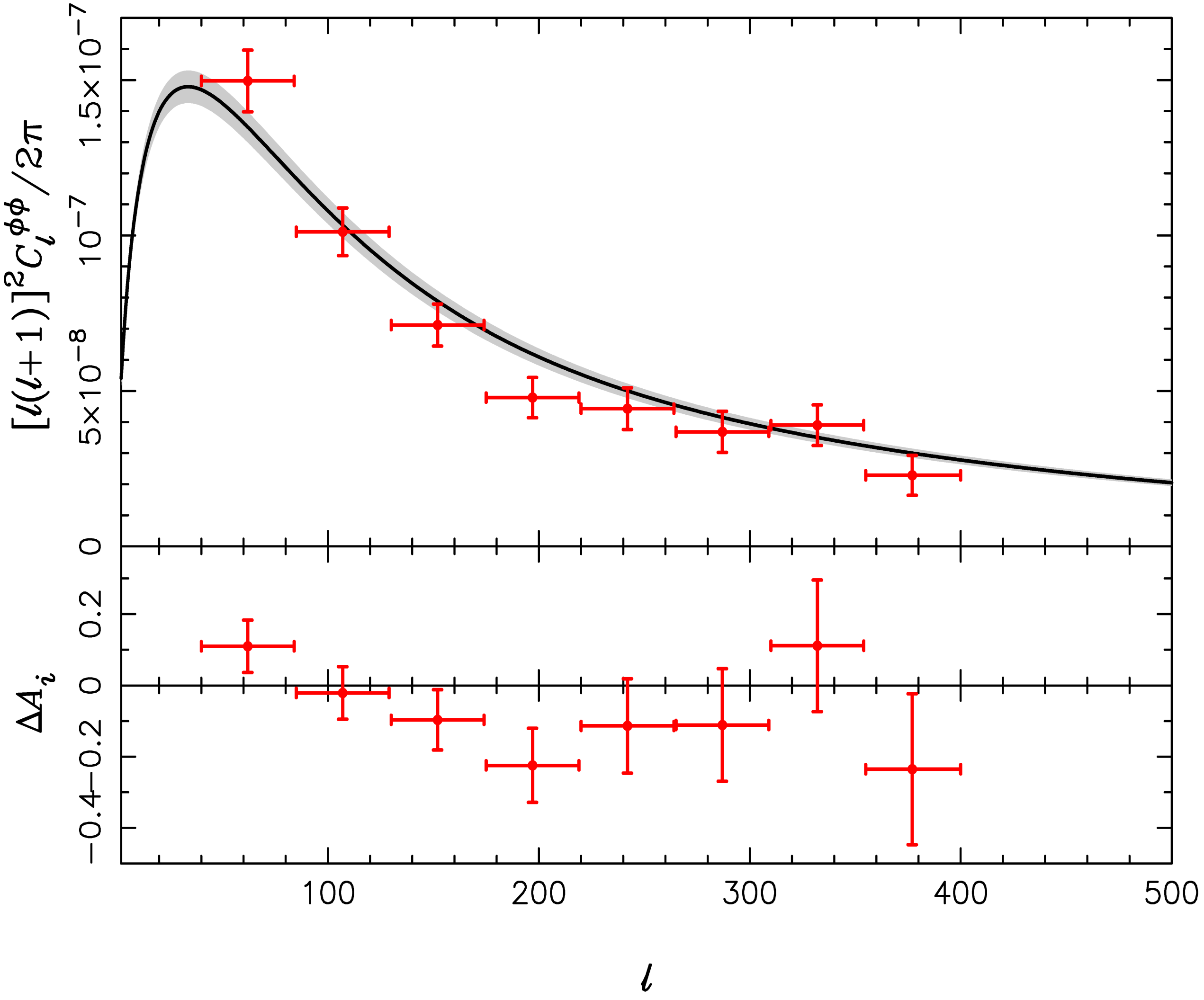
$b(z) = 1.7 \rightarrow \hat{A}^{g\phi}_{\rm NVSS} = 1.03 \pm 0.05 \ (\approx 20\sigma)$ $b(z) = 3 \rightarrow \hat{A}^{g\phi}_{\rm MaxBCG} = 1.54 \pm 0.21 \ (\approx 7\sigma)$



$b(z) = 2 \rightarrow \hat{A}^{g\phi}_{\rm LRGs} = 0.96 \pm 0.10 \ (\approx 10\sigma)$ $b(z) = 1 \rightarrow \hat{A}^{g\phi}_{\rm WISE} = 0.97 \pm 0.13 \ (\approx 7\sigma)$

Our lensing map overlaps with YOUR survey…

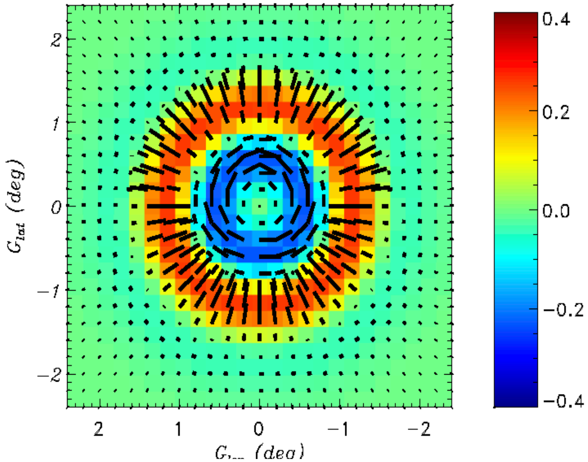
The lensing potential spectrum



(26 detection)

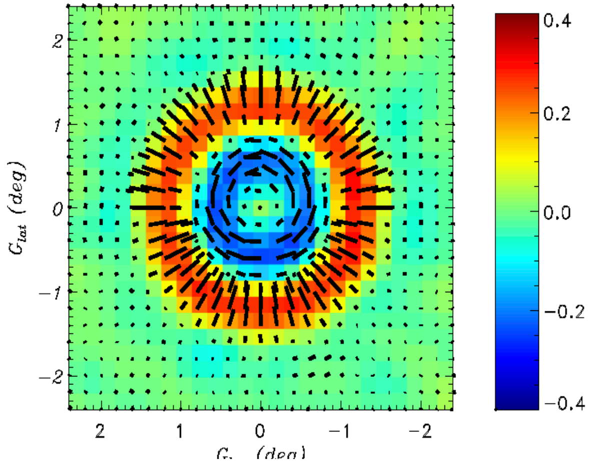
➔ Agrees well with the prediction from T alone

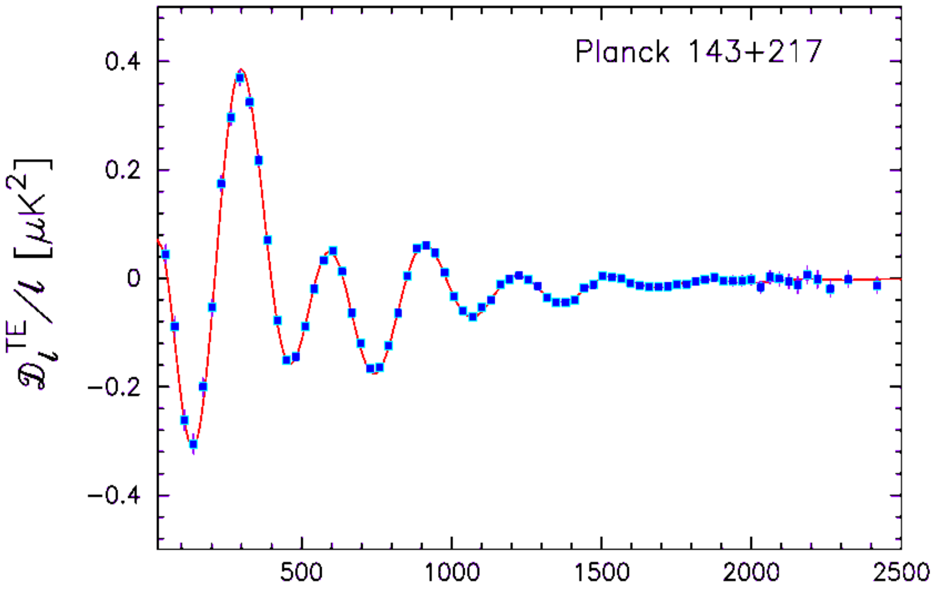
Polarisation around hot spots

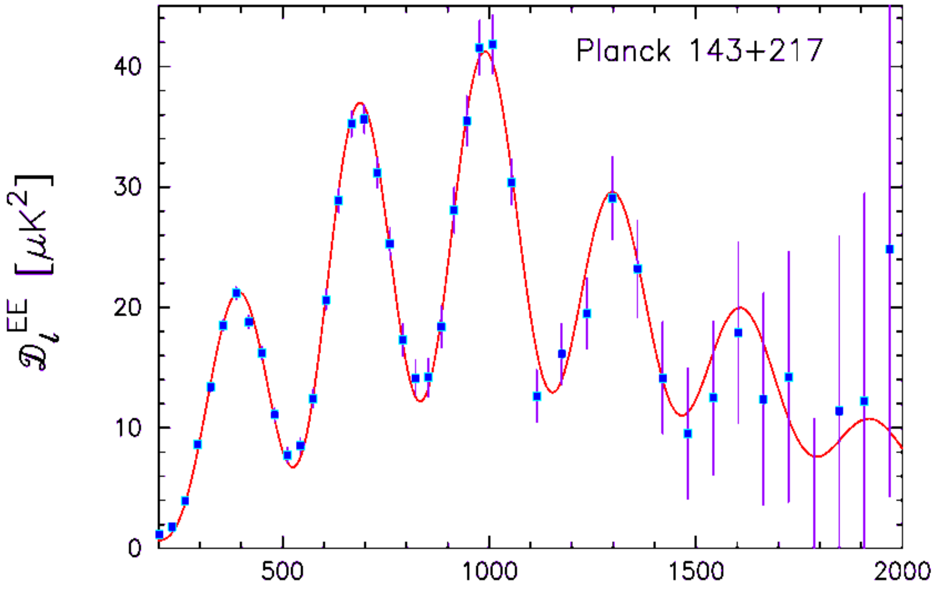


Planck "sees" precisely the dynamics of fluctuations, at ~380 000 years:

T-based expectation (left) versus Planck data (right)



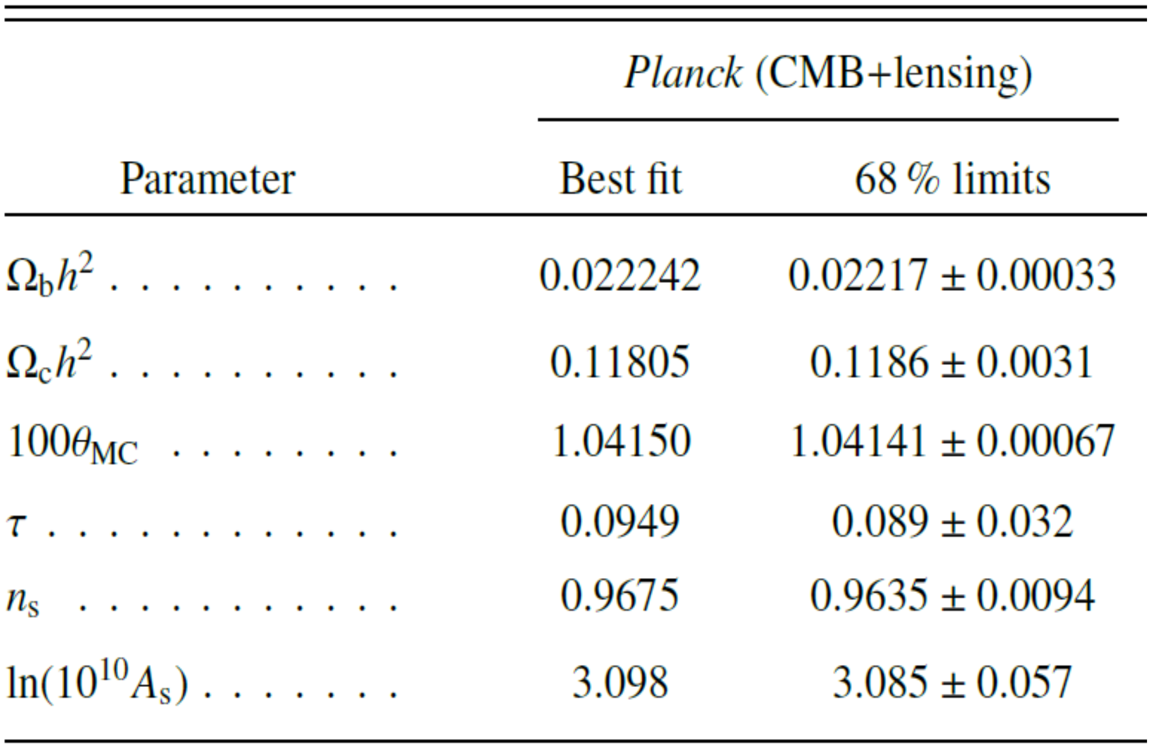




Red is prediction in base model from fitting T alone

Base ΛCDM model 6 parameters

Planck alone



	Planck (CMB+lensing)	
Parameter	Best fit	68 % limits
$\Omega_b h^2$	0.022242	0.02217 ± 0.00033
$\Omega_c h^2$	0.11805	0.1186 ± 0.0031
$100\theta_{MC}$	1.04150	1.04141 ± 0.00067
τ	0.0949	0.089 ± 0.032
n_s	0.9675	0.9635 ± 0.0094
$\ln(10^{10} A_s)$	3.098	3.085 ± 0.057

- $\Omega_b h^2$ Baryon density today
- $\Omega_c h^2$ Cold dark matter density today
- Θ Sound horizon size when optical depth τ reaches unity at t ~380 000y)
- τ Optical depth at reionisation, i.e. fraction of the CMB photons re-scattered during it
- A_s Amplitude of the curvature power spectrum
- n_s Scalar power spectrum power law index (n_s-1 measures departure from scale invariance)

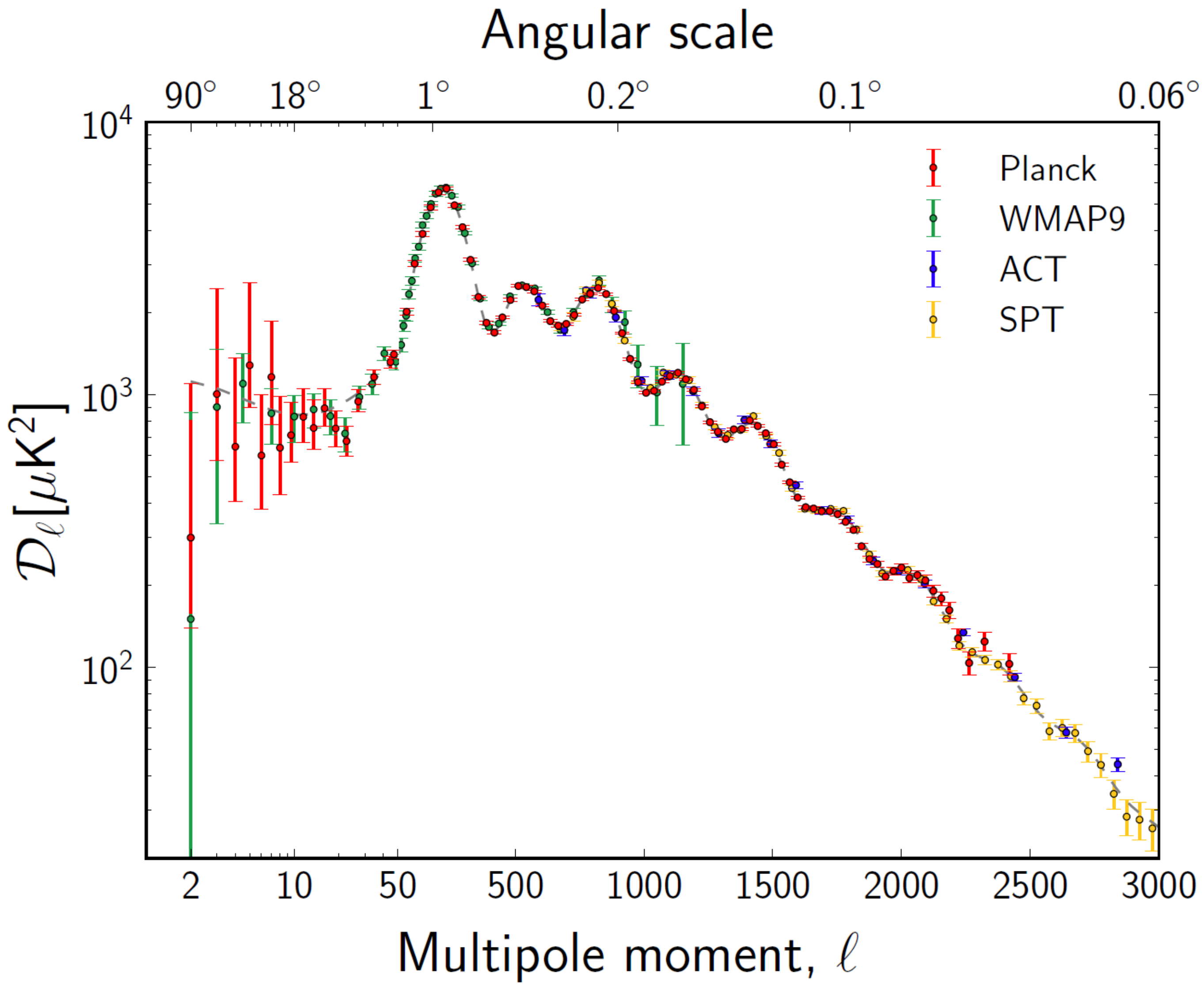
The sound horizon, Θ, determined by the positions of the peaks (7), is now determined with 0.07% precision
(links together $\Omega_b h^2$, $\Omega_c h^2$, H_0 - here as $\Omega_m h^3$)

Exact scale invariance of the primordial fluctuations is ruled out, *at ~4σ*

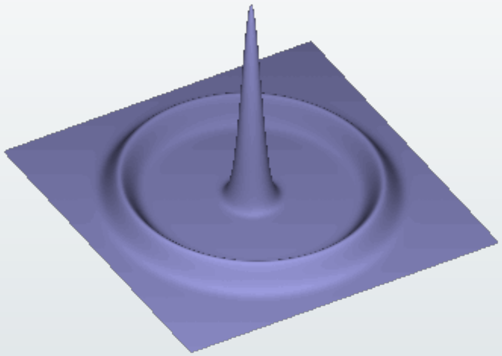
(as predicted by base inflation models)

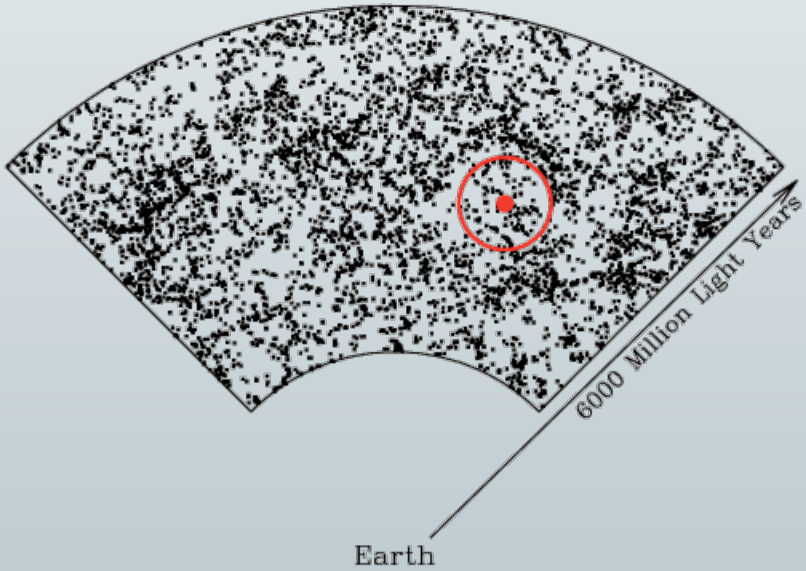
$$\theta_* = (1.04148 \pm 0.00066) \times 10^{-2} = 0.596724° \pm 0.00038°$$

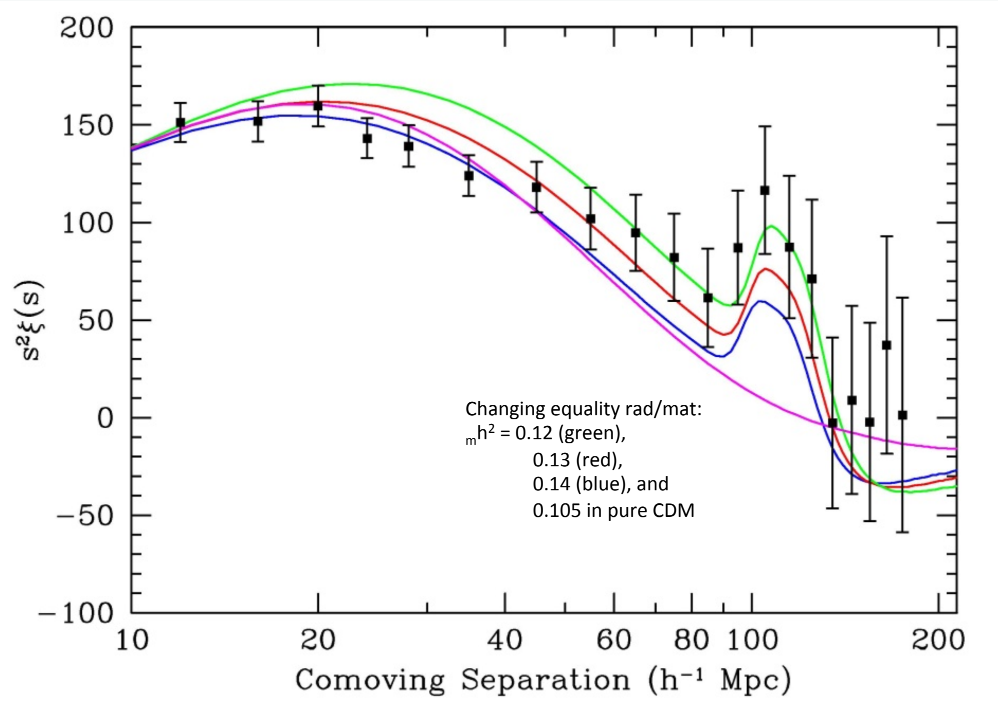
The 2013 CMB temperature landscape



Echos of the primordial drum…



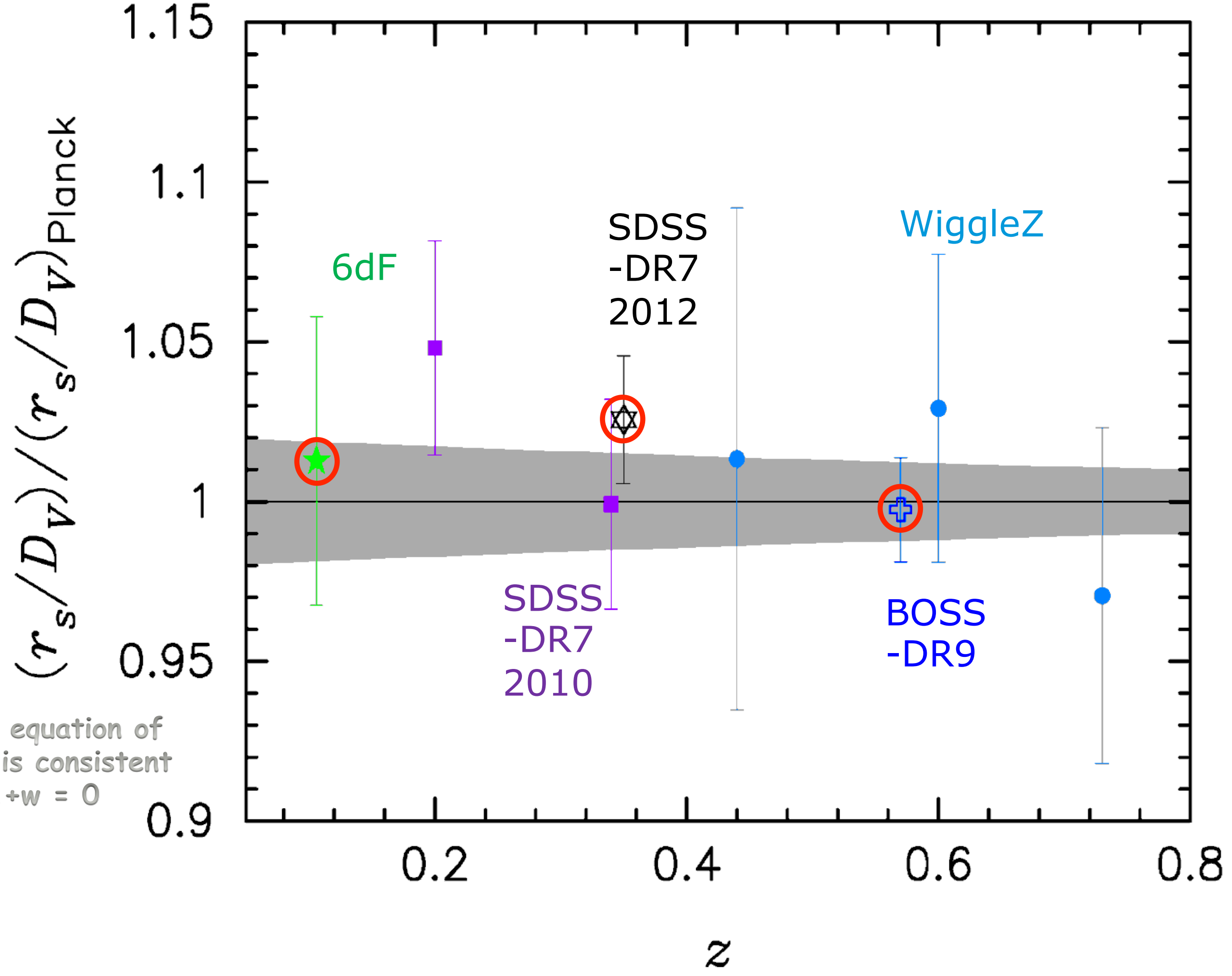


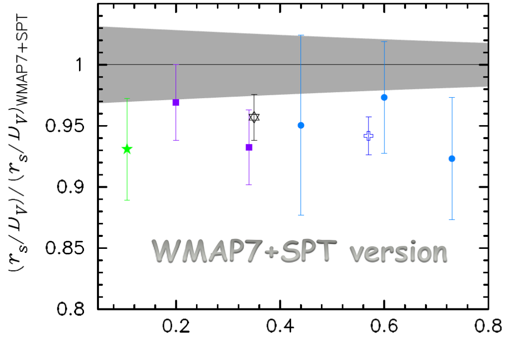


Changing equality rad/mat:
$_m h^2$ = 0.12 (green),
0.13 (red),
0.14 (blue), and
0.105 in pure CDM

BAO (Baryon Acoustic Oscillations) probe the sound travel distance at z close to 0

BAO acoustic-scale distance ratio





(see Hu etal12 for explanations by extensions)

Planck Prediction (±1σ shaded area)

→ Planck & BAO are all in quite tight agreement

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

Base ΛCDM model 6 parameters

CMB+LSS - 2013

	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	$\boxed{0.9608 \pm 0.0054}$
$\ln(10^{10} A_s)$	3.098	3.085 ± 0.057	3.0973	3.091 ± 0.025

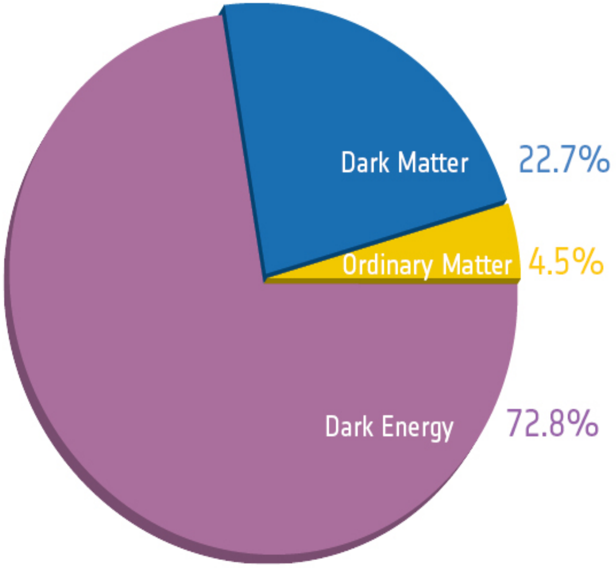
The sound horizon, Θ, determined by the positions of the peaks (7), is now determined with 0.05% precision
(links together $\Omega_b h^2$, $\Omega_c h^2$, H_0 - here as $\Omega_m h^3$)

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

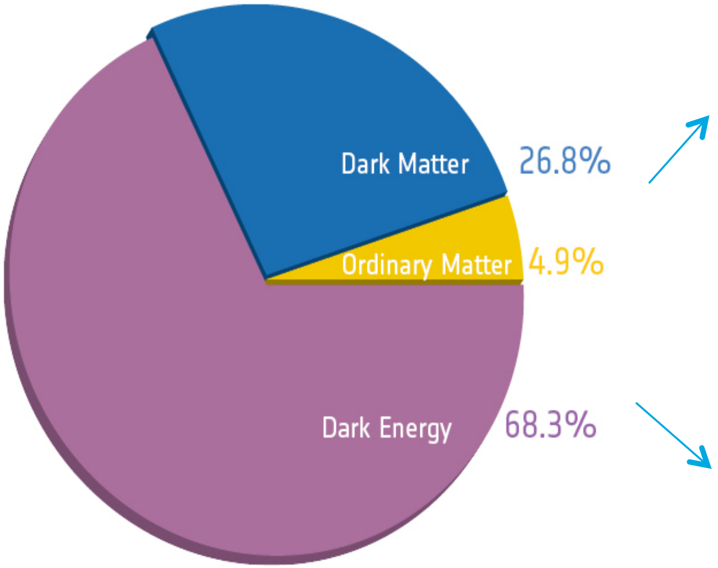
(as predicted by base inflation models)

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

The basic content of the Universe



Before Planck



After Planck

...has changed!

The rate of expansion

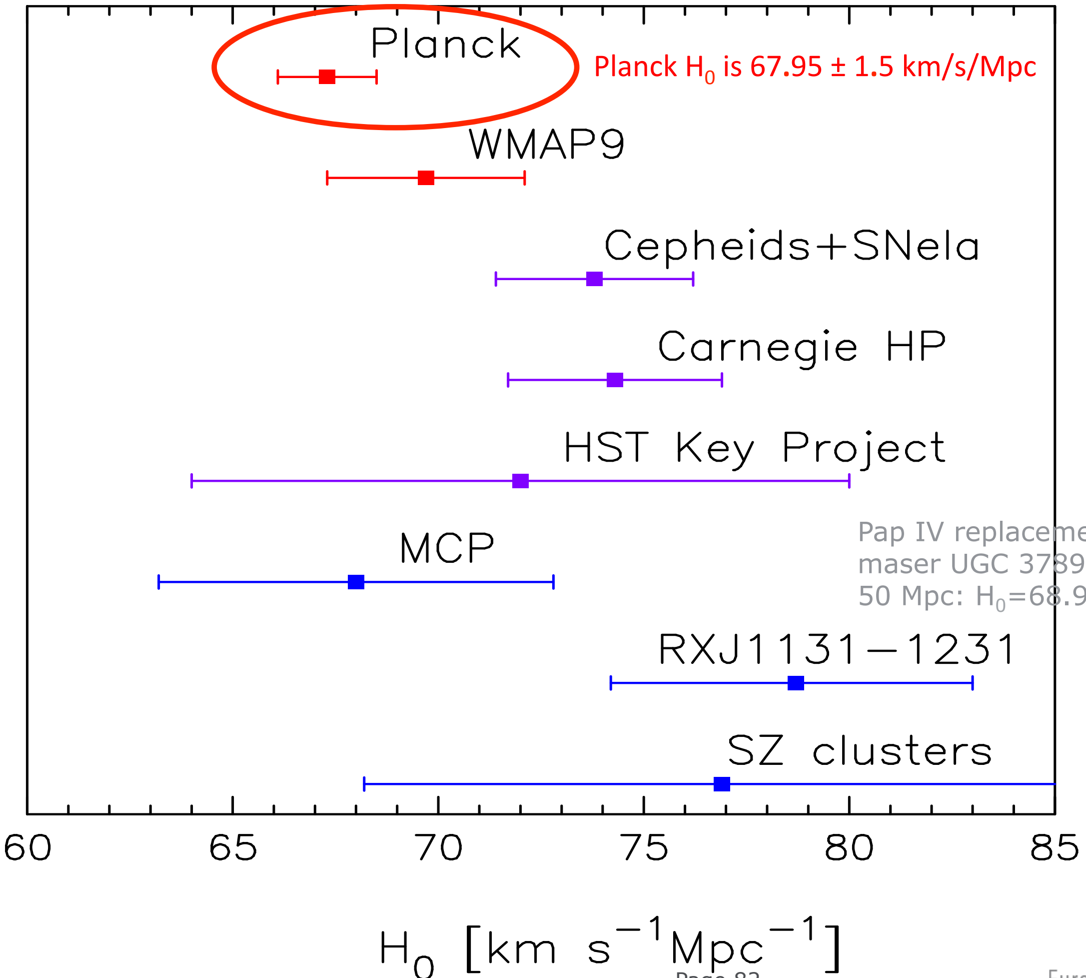
Direct determinations of the distance ladder:

Riess et al. (2011)

Freedman et al. (2012),

Freedman et al. (2001)

Humphreys et al. (2013) revision of NGC4258 distance to (7.60±0.23) Mpc leads to a lowering of the Hubble value from Riess, $H_0=(74.8\pm3.1)$ to $H_0=(72.0\pm3.0)$ km s^{-1} Mpc^{-1}



Planck H_0 is 67.95 ± 1.5 km/s/Mpc

Pap IV replacement on water maser UGC 3789: it is now at ~ 50 Mpc: H_0=68.9±7.1km/s/Mpc

Summary on base tilted LCDM

- Base LCDM is a very good fit to Planck T spectrum, with parameters (n_s, Ω_b, Ω_c, θ/H_0) accurately determined by Planck alone, with the exception of the (A_s, τ) degeneracy which can be broken by adding WP.
- The model is fully consistent with two other Planck observables, Lensing and Polarization spectra.
- This model is also fully consistent with BAO, and show some tension with a direct H_0 determination. The situation regarding Ω_m from Supernovae surveys was unclear at the time of writing (but see below).
- CMB+LSS now exclude scale invariance (n_s=1) at ~7σ

Beyond the standard model

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

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

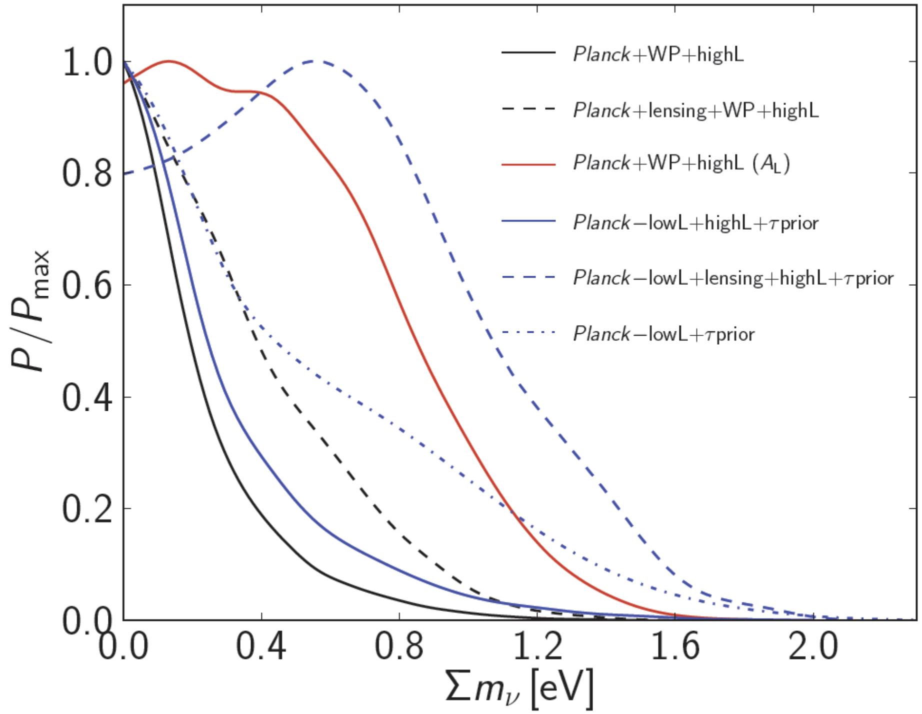
→ **no compelling evidence for any of them** ↓

	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…

Neutrinos masses



Planck constrains neutrino masses mostly through their effect via lensing:
removing that constraint (marginalising over A_L) weakens considerably the limit:
$\Sigma m\nu <$ 0.66eV (95CL PT+WP+HL)
becomes
$\Sigma m_\nu <$ 1.08eV (95CL PT+WP+HL)

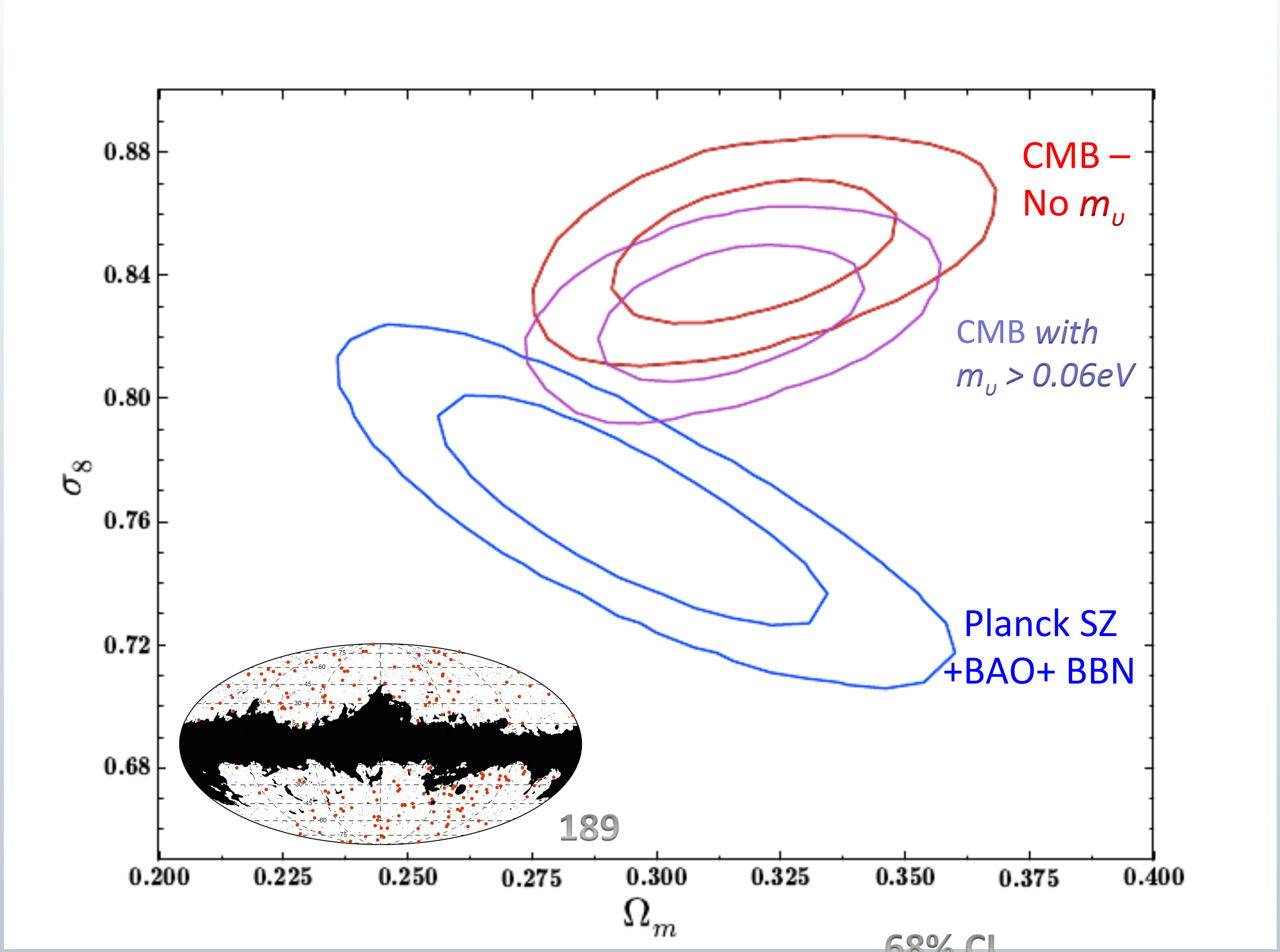
NB: the (4-pt based) lensing likelihood would prefer higher values for Σm_ν (i.e. it weakens the constraints): time will tell

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

With BAO:
$\Sigma m_\nu <$ 0.23eV (95CL PT+WP+HL)

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)

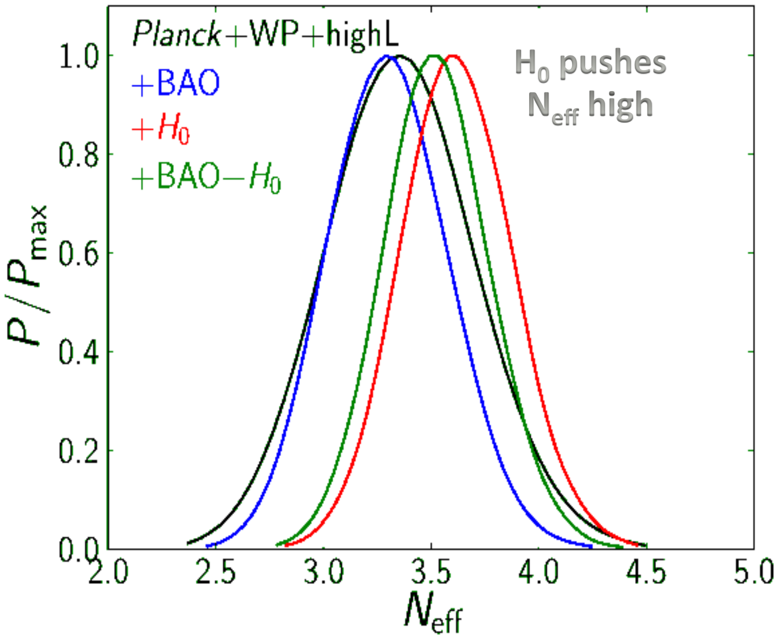
SZ / CMB tension

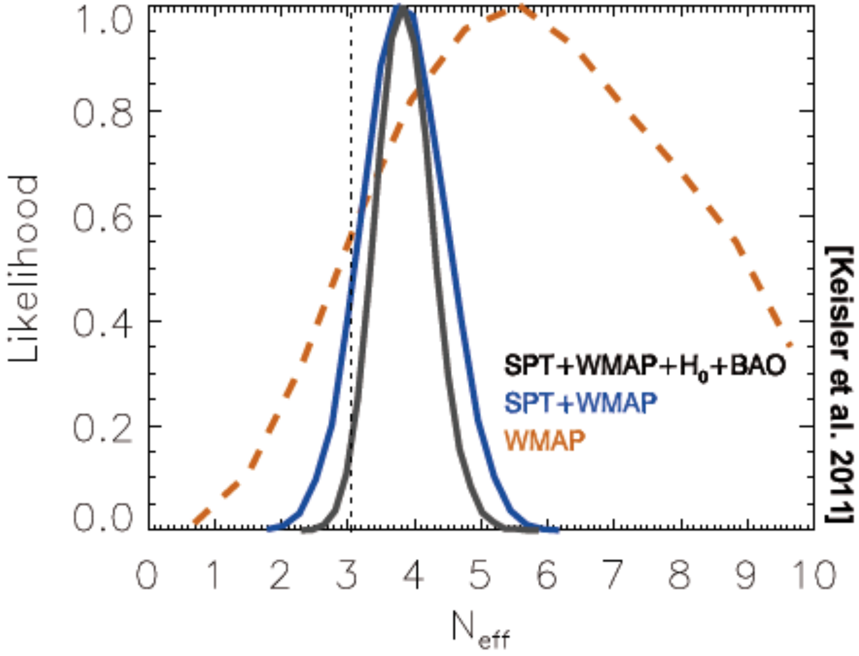


68% CL

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

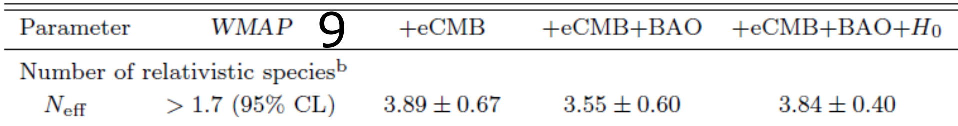
Neutrinos number (relativistic dof at decoupling)



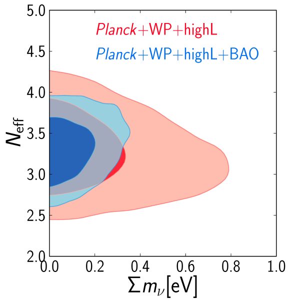


➔No evidence for additional neutrino-like relativistic particles beyond the three families of neutrinos in the standard model

(N_{eff} = 3.3±0.27;Σm_ν<0.23 eV)



Parameter	*WMAP* 9	+eCMB	+eCMB+BAO	+eCMB+BAO+H_0
Number of relativistic species[b]				
N_{eff}	> 1.7 (95% CL)	3.89 ± 0.67	3.55 ± 0.60	3.84 ± 0.40

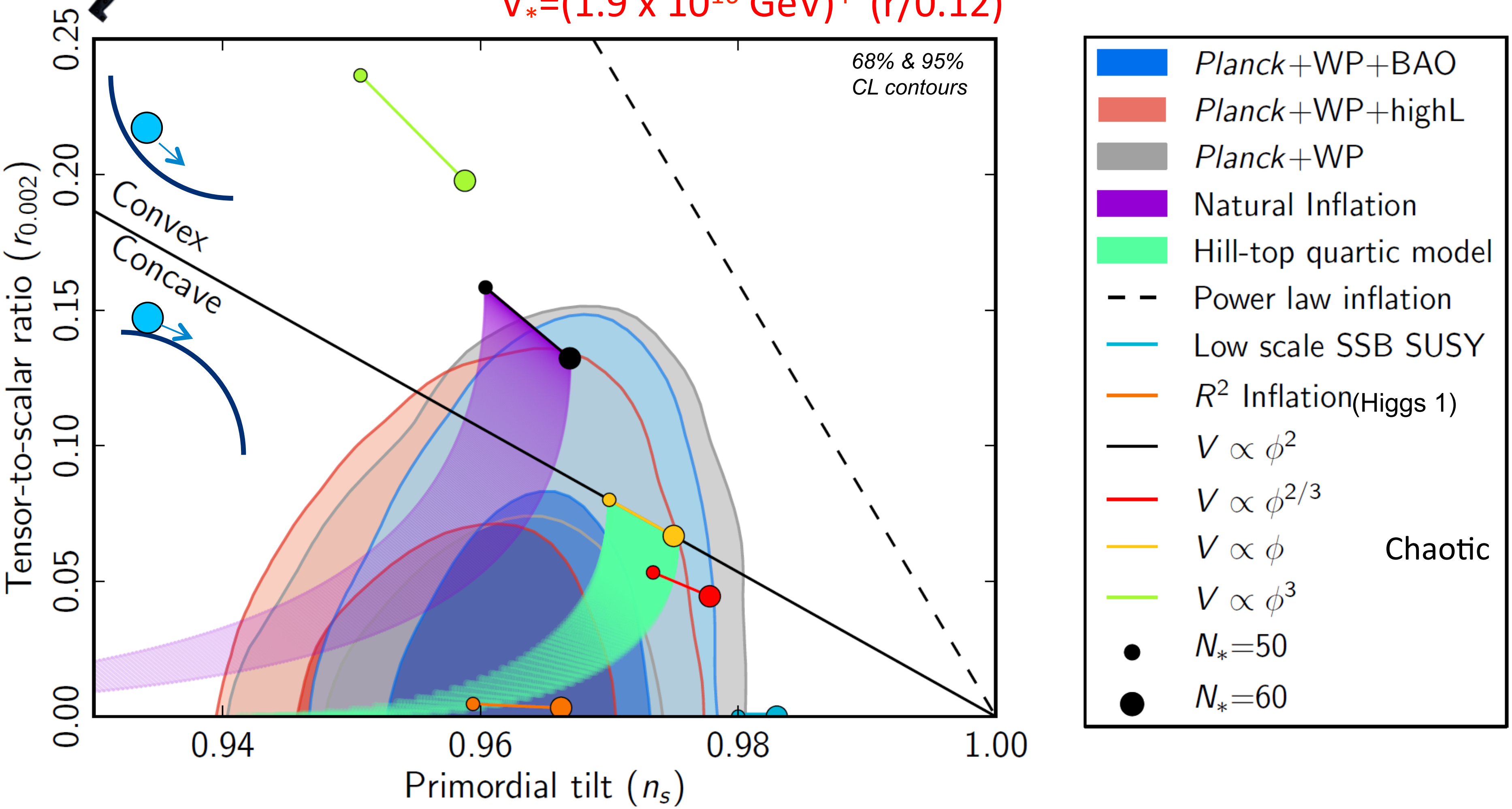


Wmap9+ excluded 3 neutrinos at more ~2.5σ (Bennett et al. 2013, v2)

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

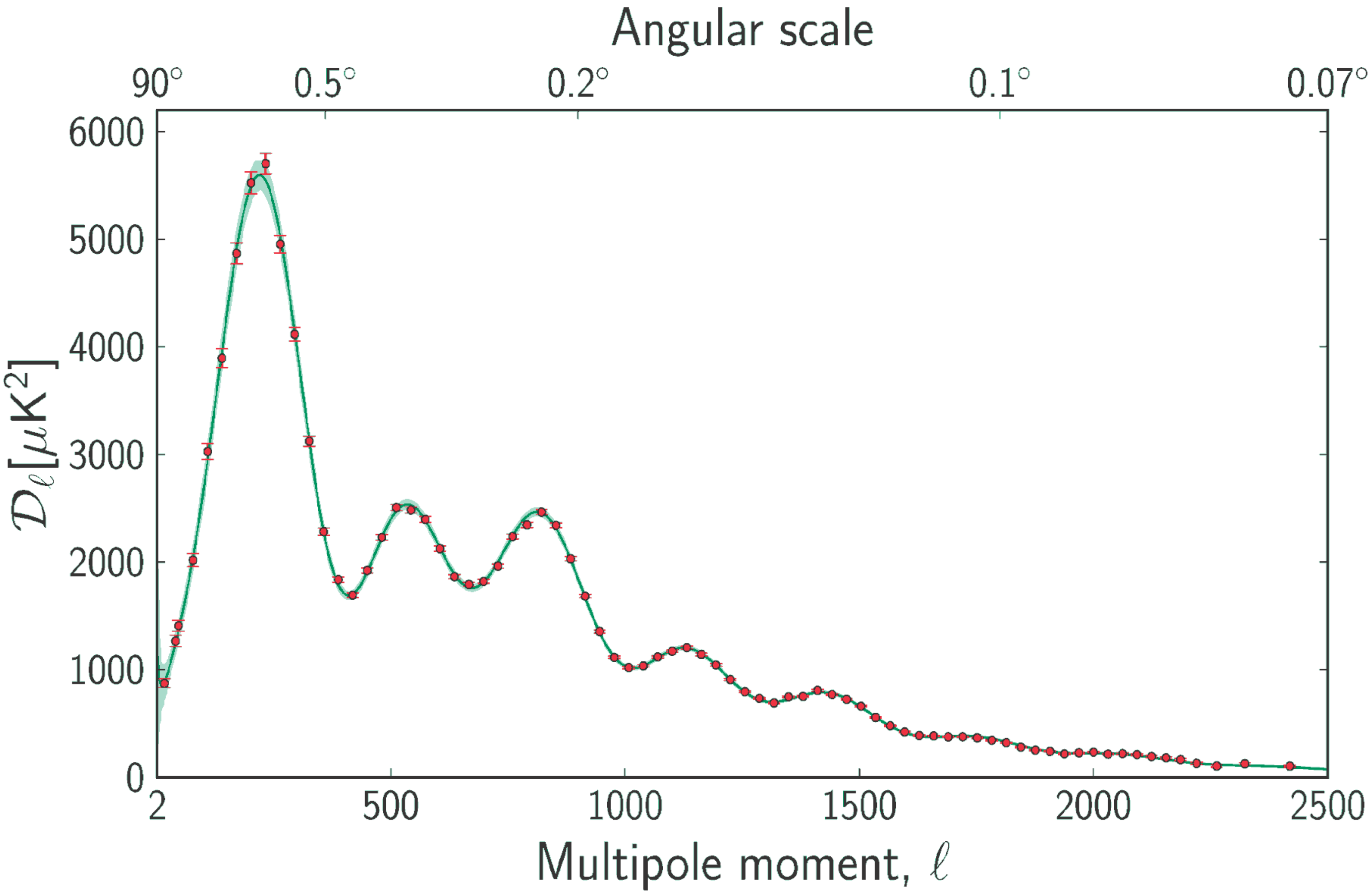
Constraint on representative Inflation models

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

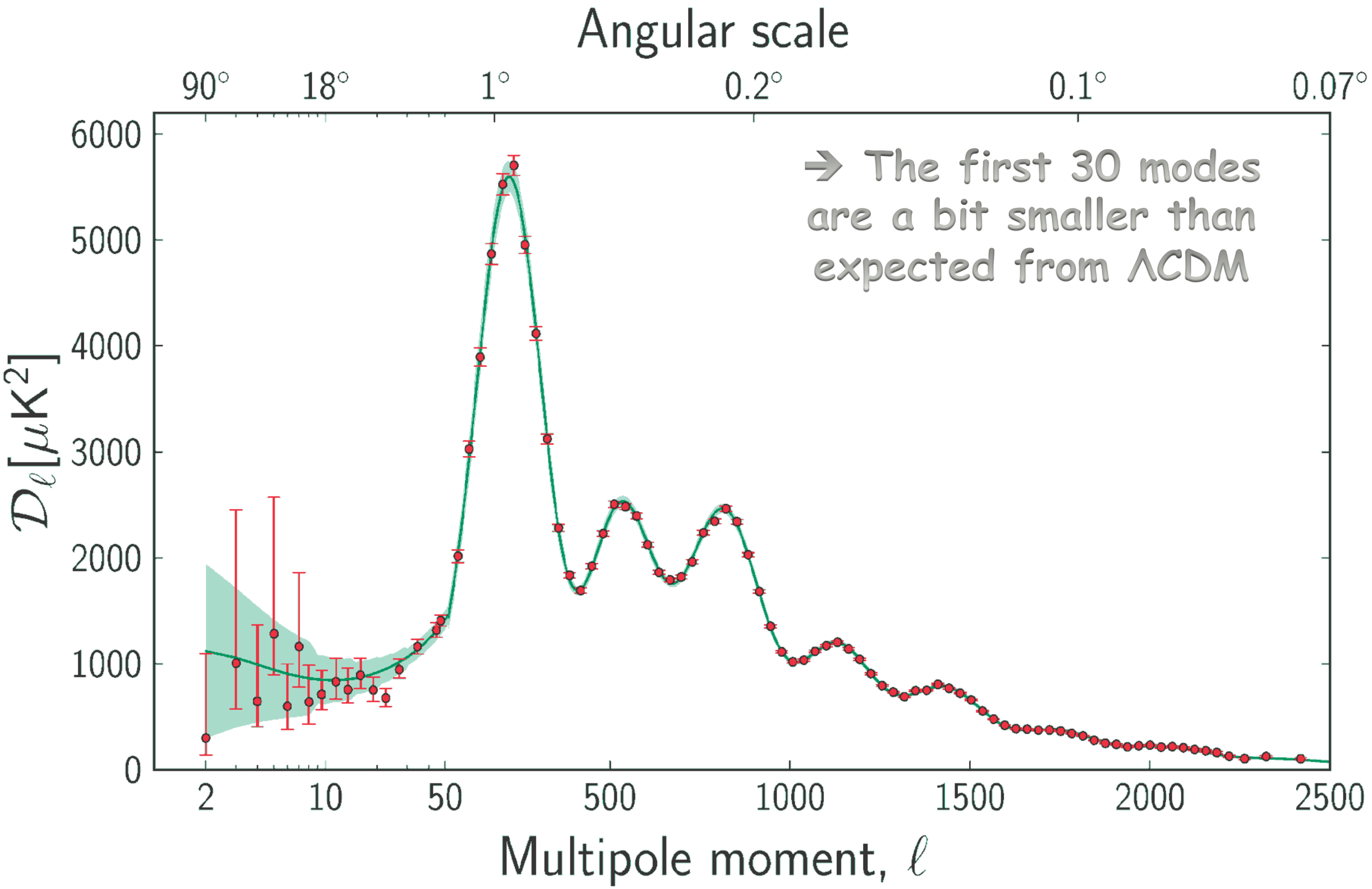


→Exponential potential models(power-law inf.), simplest hybrid inflationary models (SB SUSY), monomial potential models of degree n >2 do not provide a good fit to the data.

A theorist dream, or nightmare?

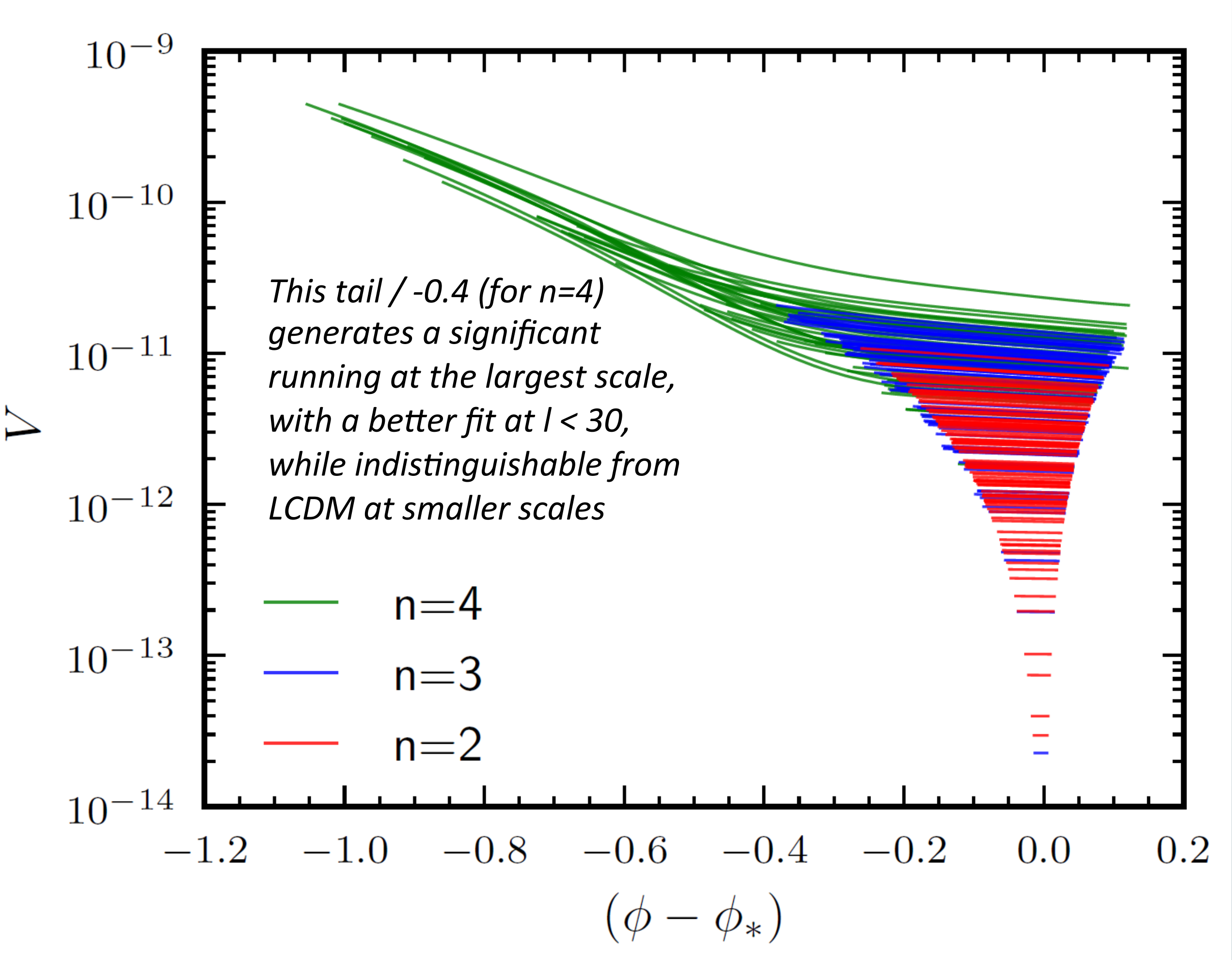


Zooming on the very largest scales, l<50...



→ The first 30 modes are a bit smaller than expected from ΛCDM

Inflaton potential reconstruction



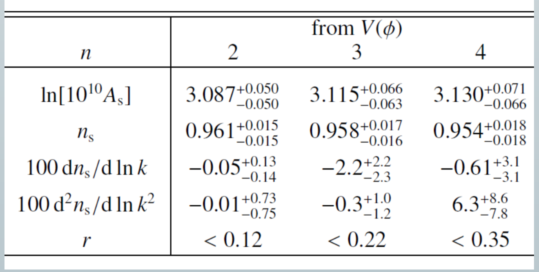
This tail / -0.4 (for n=4) generates a significant running at the largest scale, with a better fit at l < 30, while indistinguishable from LCDM at smaller scales

Best fitting potentials, when V(ϕ) is Taylor expanded at the n-th order around the pivot scale;

Planck-T+WP;

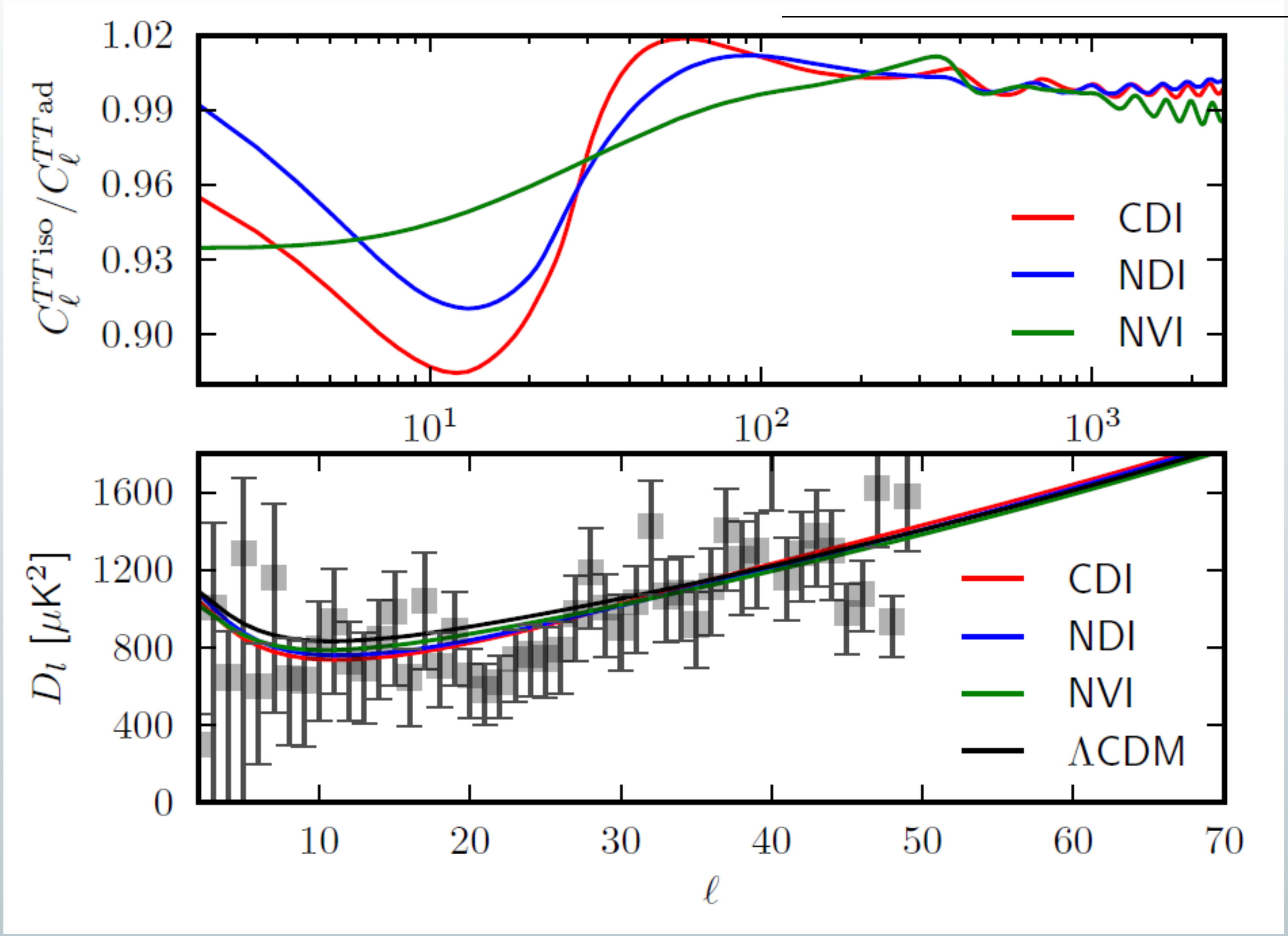
Flat priors on ε, η, ξ^2;

Φ_* in natural units / $(8\pi)^{1/2}$Mp=1.



n	from $V(\phi)$ 2	 3	 4
$\ln[10^{10}A_s]$	$3.087^{+0.050}_{-0.050}$	$3.115^{+0.066}_{-0.063}$	$3.130^{+0.071}_{-0.066}$
n_s	$0.961^{+0.015}_{-0.015}$	$0.958^{+0.017}_{-0.016}$	$0.954^{+0.018}_{-0.018}$
$100\,dn_s/d\ln k$	$-0.05^{+0.13}_{-0.14}$	$-2.2^{+2.2}_{-2.3}$	$-0.61^{+3.1}_{-3.1}$
$100\,d^2n_s/d\ln k^2$	$-0.01^{+0.73}_{-0.75}$	$-0.3^{+1.0}_{-1.2}$	$6.3^{+8.6}_{-7.8}$
r	< 0.12	< 0.22	< 0.35

Assuming a single isocurvature mode



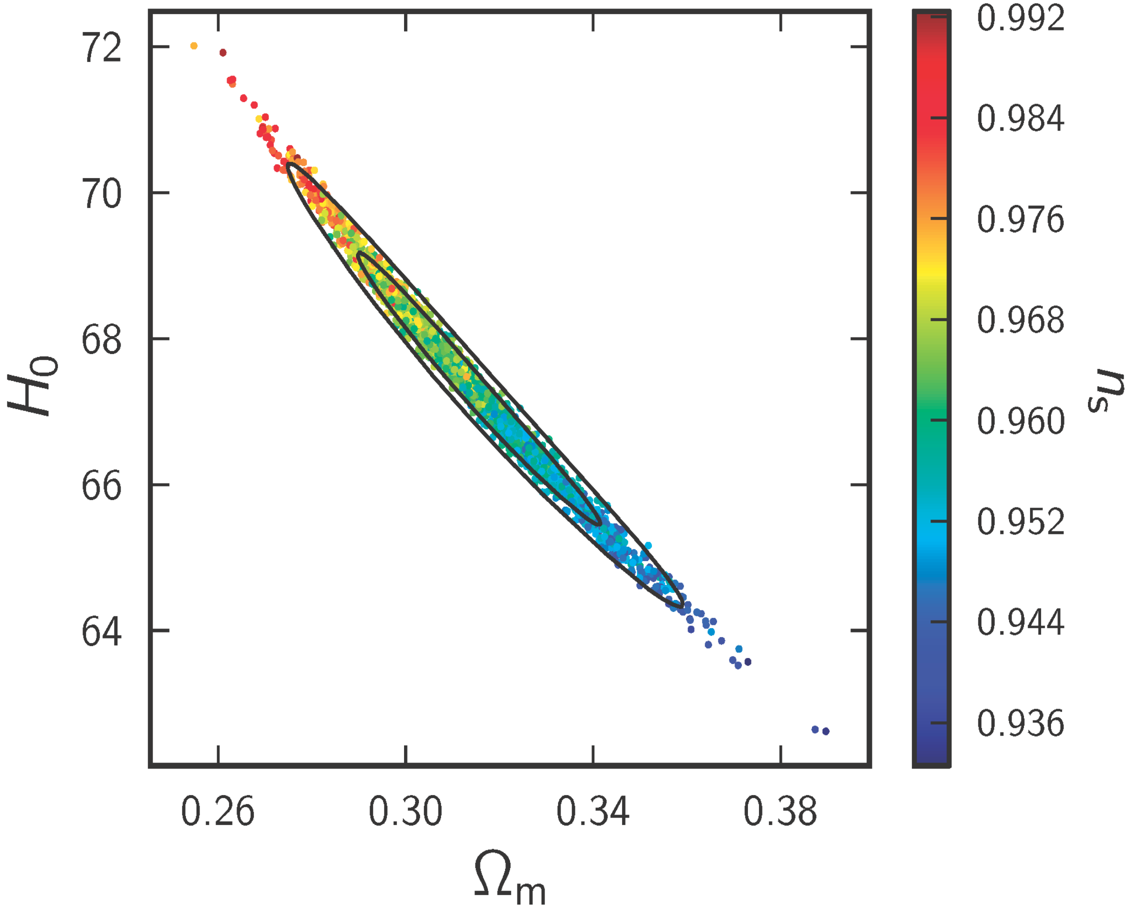
… helps (somewhat) at low-l (again!)

NB

- Planck did confirm the COBE/WMAP anomalies (even if with somewhat different significance), relieving possible concerns about measurement technology and foreground contamination

Since then… (>march 2013)

Sound Horizon



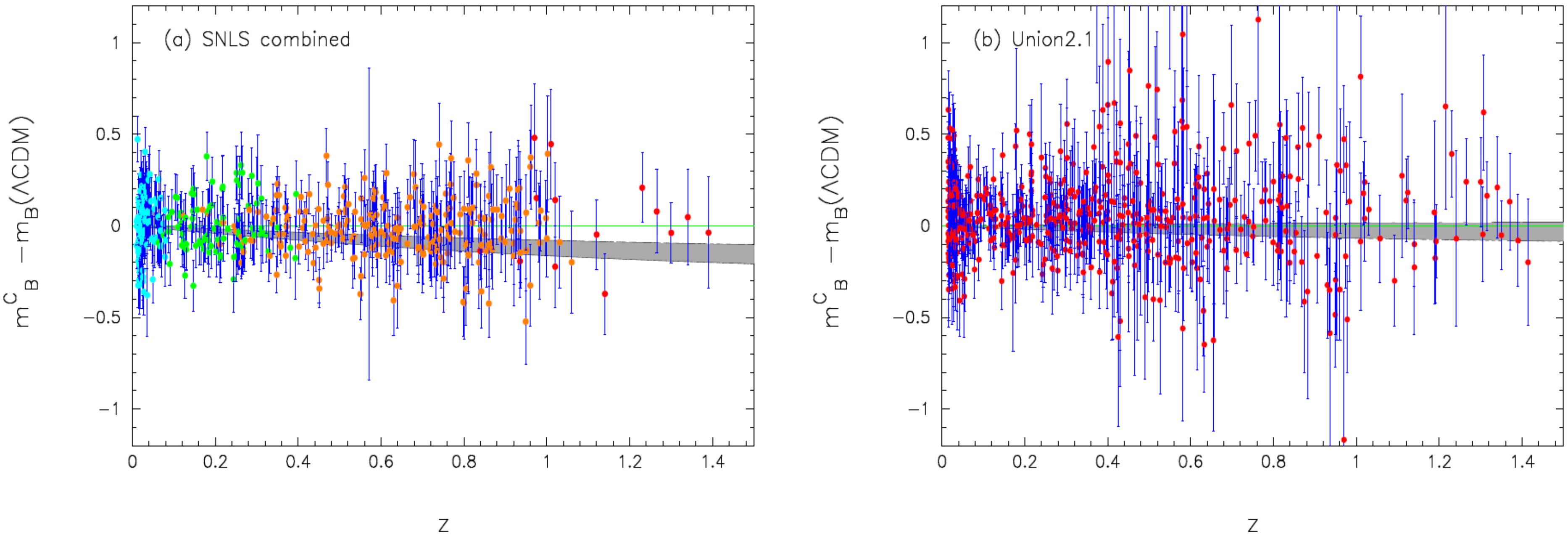
Samples are for Planck only.

Tighter contours along the degeneracy direction are from Planck +lensing+ WP

r_s is constrained transversally

r_s constrains $\Omega_m h^3$ very tightly in LCDM; High Ω_m corresponds to low n_s and H_0

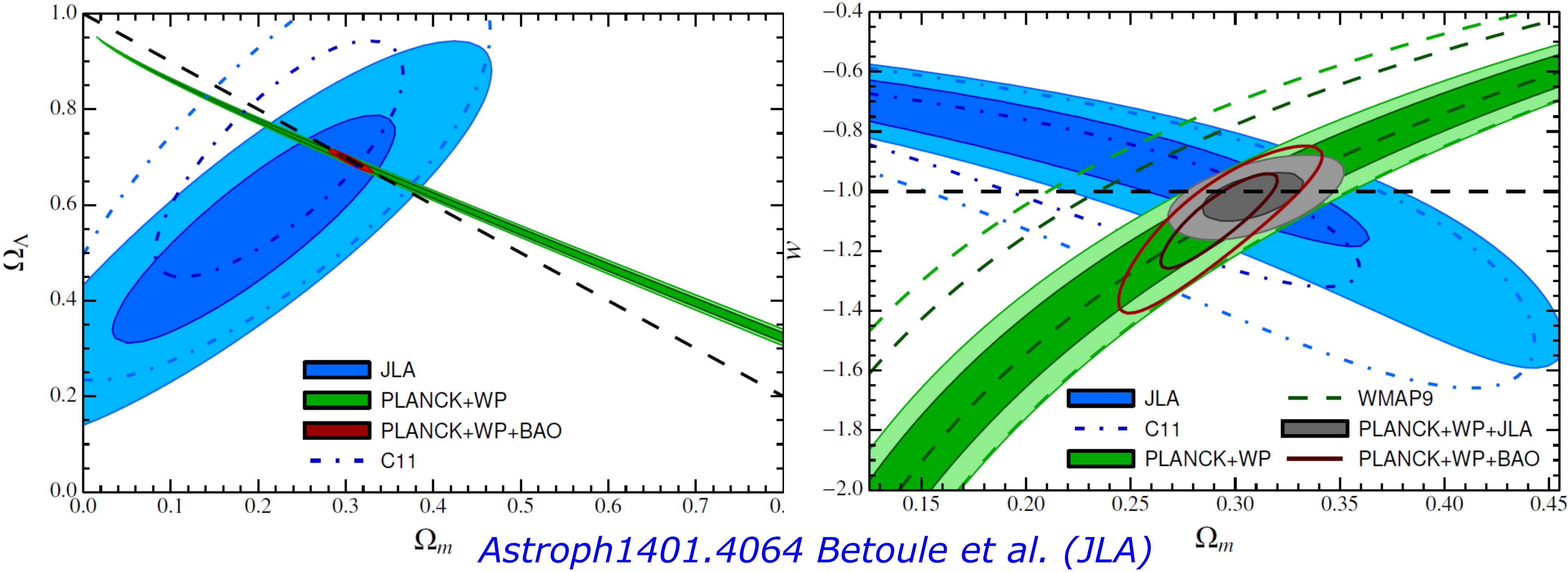
Tension with SNLS results...



Data, BF model and Planck Prediction (±1σ shaded area)

Fig. 18. Magnitude residuals relative to the base ΛCDM model that best fits the SNLS combined sample (left) and the Union2.1 sample (right). The error bars show the 1 σ (diagonal) errors on m_B. The filled grey regions show the residuals between the expected magnitudes and the best-fit to the SNe sample as Ω_m varies across the $\pm 2\,\sigma$ range allowed by *Planck*+WP+highL in the base ΛCDM cosmology. The colour coding of the SNLS samples are as follows: low redshift (blue points); SDSS (green points); SNLS three-year sample (orange points); and *HST* high redshift (red points).

Planck versus JLA (SNLS +SDSS)



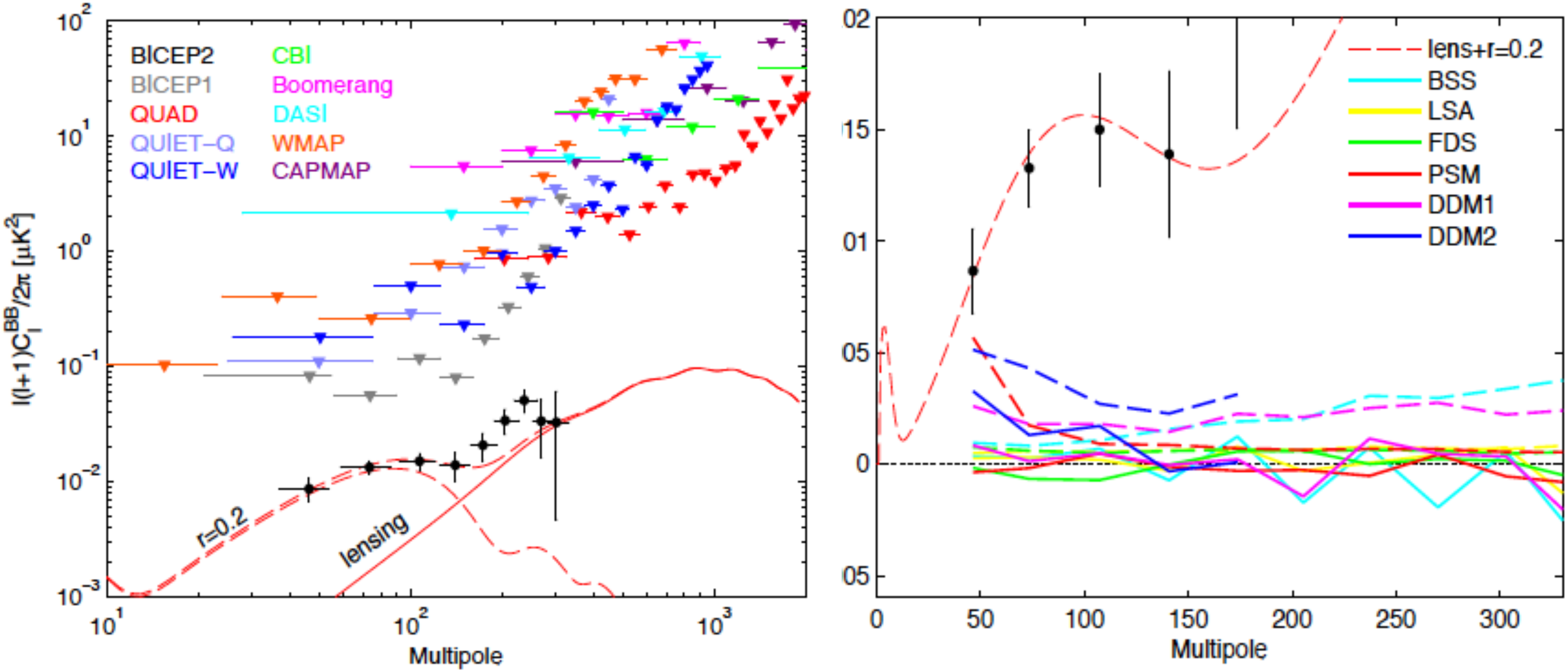
Astroph1401.4064 Betoule et al. (JLA)

	Ω_m	w	H_0	$\Omega_b h^2$
Planck+WP+BAO+JLA	0.303 ± 0.012	-1.027 ± 0.055	68.50 ± 1.27	0.0221 ± 0.0003
Planck+WP+BAO	0.295 ± 0.020	-1.075 ± 0.109	69.57 ± 2.54	0.0220 ± 0.0003
Planck+WP+SDSS	0.341 ± 0.039	-0.906 ± 0.123	64.68 ± 3.56	0.0221 ± 0.0003
Planck+WP+SDSS+SNLS	0.314 ± 0.020	-0.994 ± 0.069	67.32 ± 1.98	0.0221 ± 0.0003
Planck+WP+JLA	0.307 ± 0.017	-1.018 ± 0.057	68.07 ± 1.63	0.0221 ± 0.0003
WMAP9+JLA+BAO	0.296 ± 0.012	-0.979 ± 0.063	68.19 ± 1.33	0.0224 ± 0.0005
Planck+WP+C11	0.288 ± 0.021	-1.093 ± 0.078	70.33 ± 2.34	0.0221 ± 0.0003

May 5th 2014: 4 papers on dust polarisation

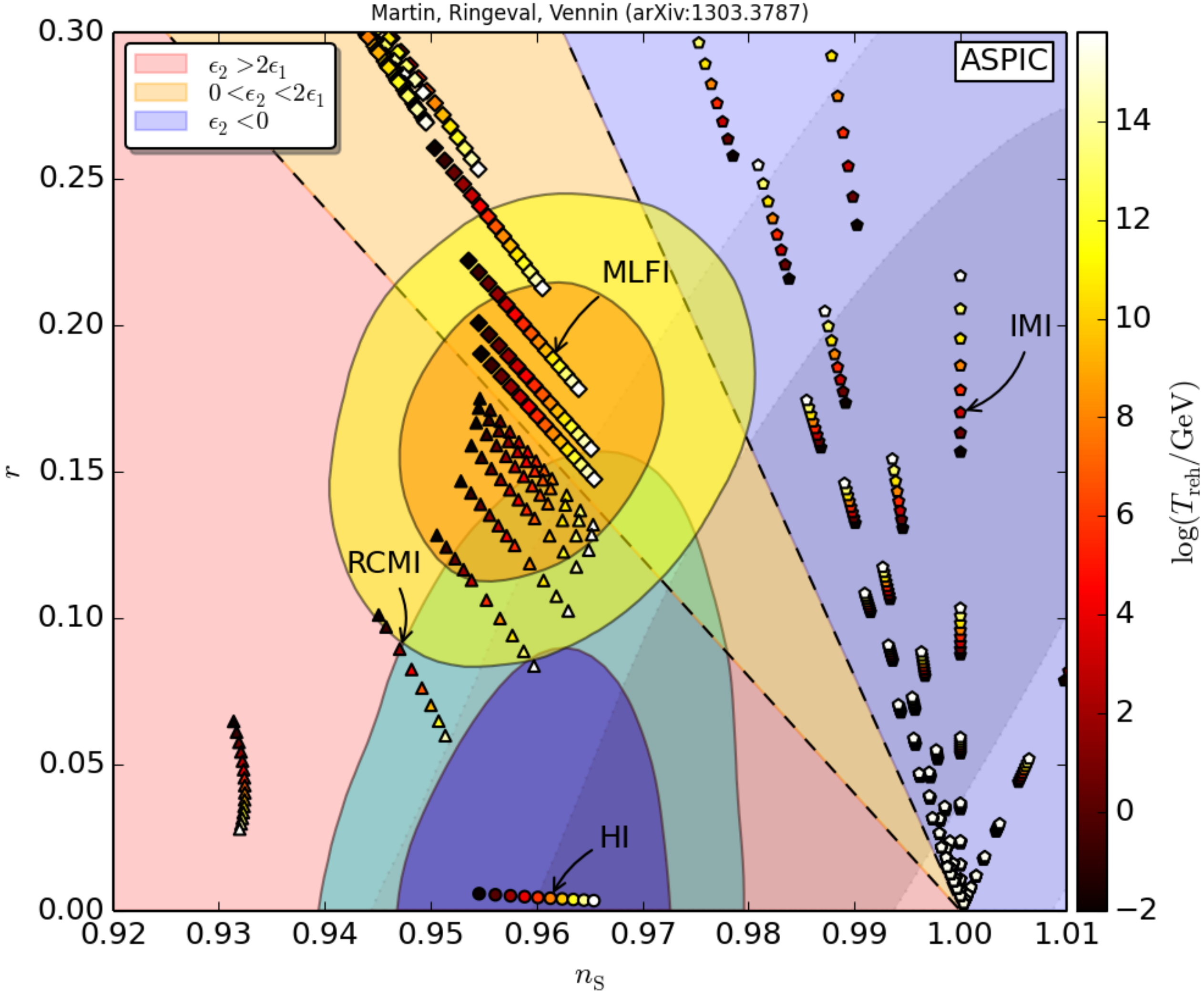
- In march 2013, we did not deliver polarisation data, nor performed quantitative analyses, due to concerns on that data quality, preventing its general use.
- We still put out preliminary results at ESLAB and in the papers of 3 weeks ago on what we believe can be already extracted safely from the data (mostly at 353GHz), i.e. on regions of the sky where the signal is strong enough for Galactic studies, purposely excluding the (more demanding) high Galactic sky.
  - *Planck intermediate results. XIX. An overview of the polarized thermal emission from Galactic dust*
  - *Planck intermediate results. XX. Comparison of polarized thermal emission from Galactic dust with simulations of MHD turbulence*
  - *Planck intermediate results. XX. Comparison of polarized thermal emission from Galactic dust with simulations of MHD turbulence*
  - *Planck intermediate results. XXII. Frequency dependence of thermal emission from Galactic dust in intensity and polarization*
- We are working on another PIP (intermediate paper) on the statistical characterisation of dust polarisation at high Galactic latitude which may appear earlier than the ~October data release, if and when ready.
- NB: As of now, we are still working on an improved processing of our 353GHz maps to make the 2014 delivery as useful as possible for general use.

BICEP2, on March 17th



NB: using 100 X 150 GHz, Dust spectral index disfavoured at 2.2 sigma level

Adding Bicep2 as stated



Coming soon (October 2014?)

- Delivery through the Planck Legacy archive of the Full mission data (HFI 29months, LFI 48): O(10^4) maps
  - *T, Q, U maps at 6 frequencies, 30-354GHz+ T@545-857GHz*
  - *"Half-Ring", yearly, survey, detset maps*
  - *Ancillary maps (CO, dust, BP leakage, Zodi correction…)*
  - *IMO (beams, spectral bandpasses…)*
  - *CMB & FG maps & Compact sources catalogues (SZ)*
  - *PS & likelihood (& many model parameters)*
  - *TOIs of all detectors, clean & calibrated*
  - *10 000 simulation of maps (CMB, FG, Noise…) – O(10^5)*
  - *Explanatory supplement*
- Through astroph: ~ 35 papers

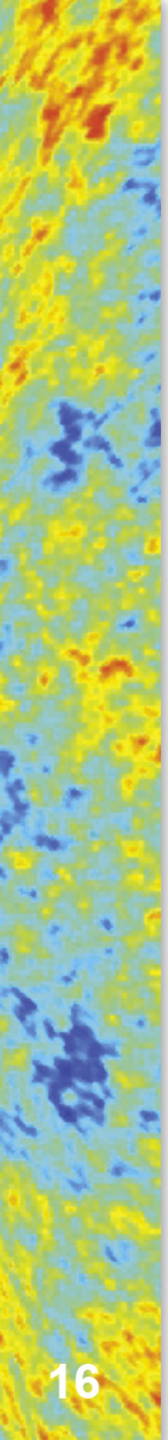
To do what?

- *Less «conservative» temperature analyses, and further checks of tantalising hints/anomalies*
- *Polarisation frontier!*
- *Expected results:*
  - Better Temperature science (higher sensitivity, more redundancy & checks, improved analyses, eg on FG modelling, bispectrum osc.)
  - E polarisation: tau, independent parameters determination (with similar constraining power to T), fnl tigher, anomalies (large l)…
  - T+E: joint constraints (constraints improve eg Isocurvature modes)
  - B modes polarisation from dust, from reionisation (l<15) and recombination bump, and in lensing dominated regime
  - Upper limits (?) from EB, TB (TBC)

Conclusions

- ***Excellent agreement between the Planck 2013 temperature spectrum at high l and the predictions of the tilted 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?)***

  - *n_s=0.963 ±0.006 from PT+WP+BAO; → HZ robustly excluded*
  - *Ω_K=-0.006±0.018 at 95%CL from Planck-T+L → flat spatial geometry*
  - *f_{NL}^{LEO} (and others) consistent with zero; → most stringent test of Gaussianity 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).*
  - *$r_{0.002} < 0.12$ (PT+WP alone) → inflation energy scale < 1.9×10^{16} GeV at 95%CL.*
  - *Concave potentials preferred.*
  - *Strong constraints on parameters values of specific inflationary scenario*
  - *Potential reconstructed in observable window shows that allowing a fourth order leads to deviation to slow-roll, and allows a better fit to the low-l data (improvement of $\Delta\chi^2_{eff}$ ~4). Idem when allowing for CDI isocurvature.*



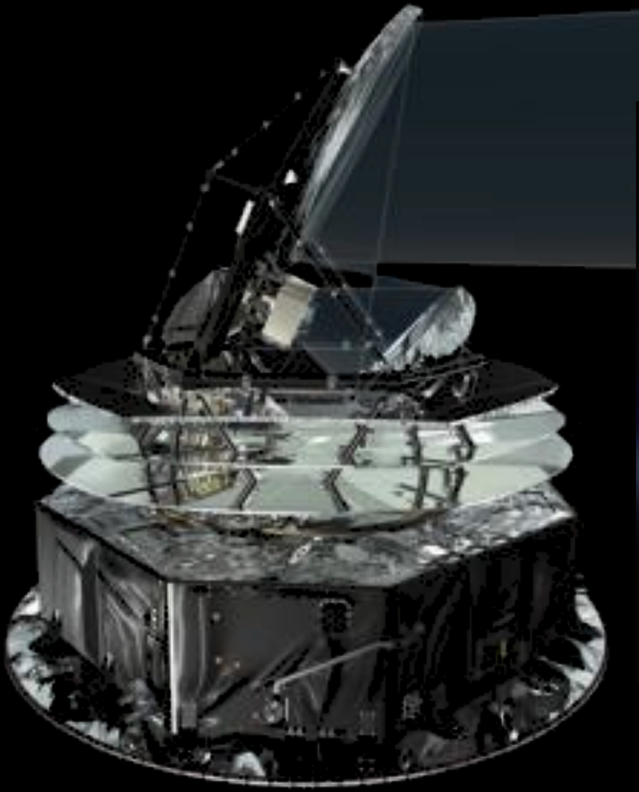
The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

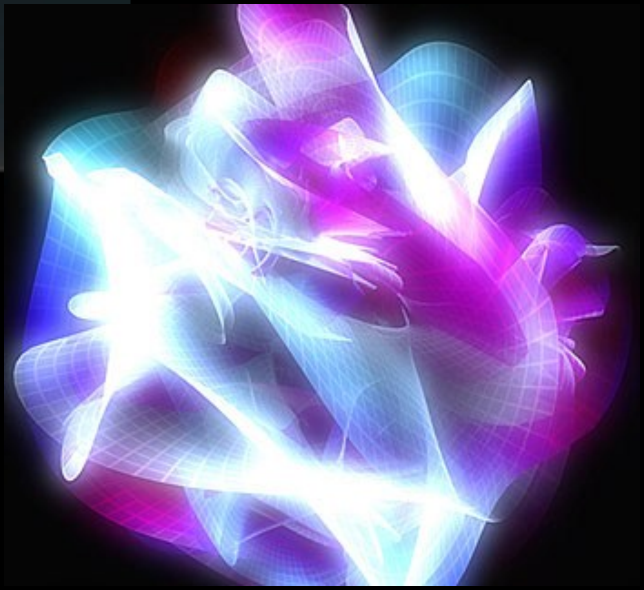
esa
planck
cnes
asi agenzia spaziale italiana
PLANCK LFI
HFI PLANCK
a look back to the birth of Universe
NASA
CNRS
DTU Space
National Space Institute
INAF ISTITUTO NAZIONALE DI ASTROFISICA
Science & Technology Facilities Council
CSIC
National Research Council of Italy
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
IAS orsay
IAP
INAF - IASF BO
ISTITUTO NAZIONALE DI ASTROFISICA
ISTITUTO DI ASTROFISICA SPAZIALE E FISICA COSMICA DI BOLOGNA
CSA ASC
DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
UK SPACE AGENCY
MAX-PLANCK-GESELLSCHAFT

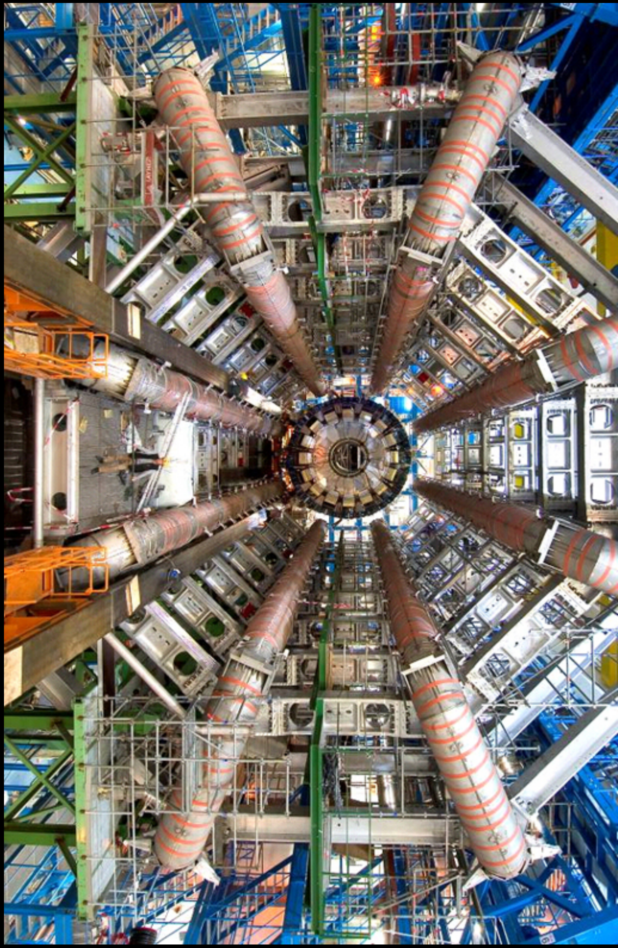
A" Aalto University
APC
ioa
Kavli Institute for Cosmology Cambridge KICC
CAVENDISH ASTROPHYSICS
UNIVERSITY OF CAMBRIDGE
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD
irfu cea saclay
CEFCA
CESR
CITA–ICAT
IASF
CNRS INSU Observer & comprendre
CNRS IN2P3 Les deux infinis
ipac
HELSINKI INSTITUTE OF PHYSICS
INSTITUTO DE ASTROFISICA DE CANARIAS IAC
IFCA Instituto de Física de Cantabria
Imperial College London
Università degli Studi di Milano
NÉEL institut
IPAG Institut de Planétologie et d'Astrophysique de Grenoble
ISDC DATA CENTRE FOR ASTROPHYSICS
JPL
LAL LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE
l'Observatoire de Paris LERMA
LPSC Grenoble Laboratoire de Physique Subatomique et de Cosmologie
The University of Manchester
MilliLab
Max-Planck-Institut für Astrophysik
NUI MAYNOOTH
INAF OSSERVATORIO ASTRONOMICO DI PADOVA
UNIVERSITY OF OXFORD
Dipartimento di Fisica SAPIENZA Università di Roma
Science & Technology Facilities Council Rutherford Appleton Laboratory
TOR VERGATA
OSSERVATORIO ASTRONOMICO TRIESTE
UBC
UC UNIVERSIDAD DE CANTABRIA
UCSB
SISSA
ALMA
ESO
US University of Sussex
HAVERFORD
esa
UNIVERSITY OF HELSINKI
UNIVERSITÉ DE GENÈVE
UNIVERSITY OF TORONTO
UNIVERSITÉ DE PARIS-SUD XI
ISTI
asdc ASI Science Data Center

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.

Exciting times







Still Lie ahead

The journey
Just began!