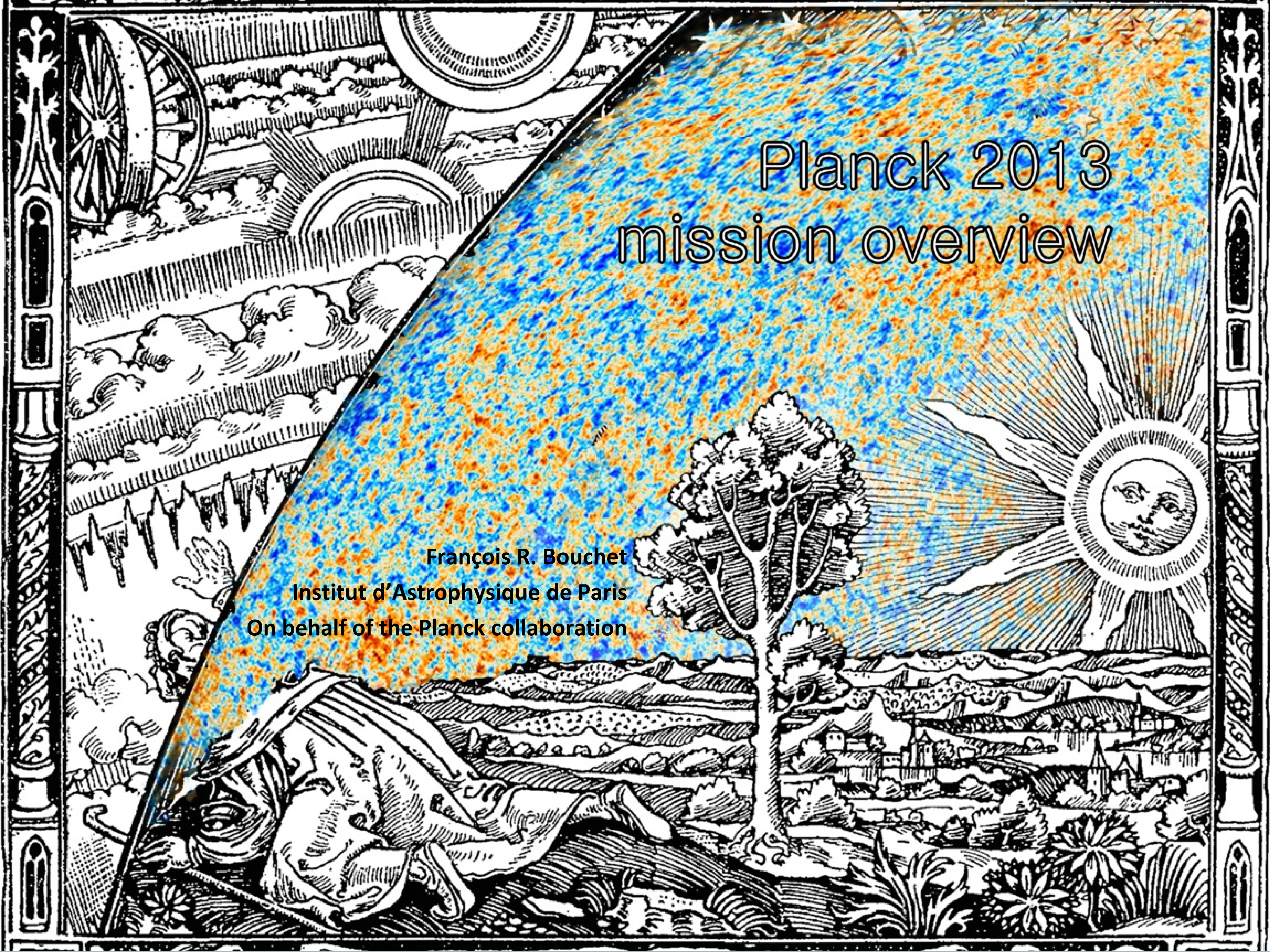


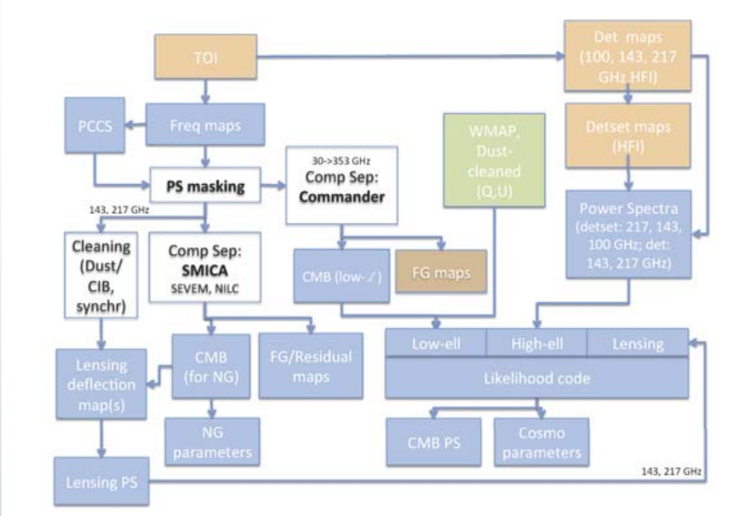
Planck 2013 mission overview

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

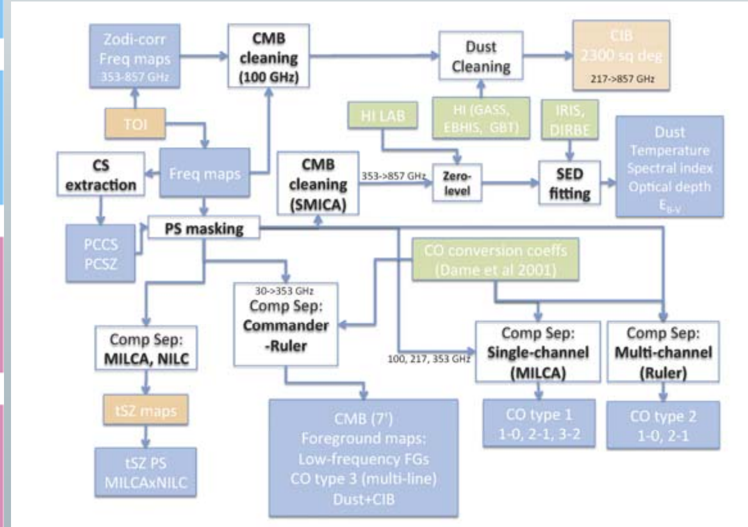
Planck 2013 data and results

- 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



The Planck concept/challenge

- 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*

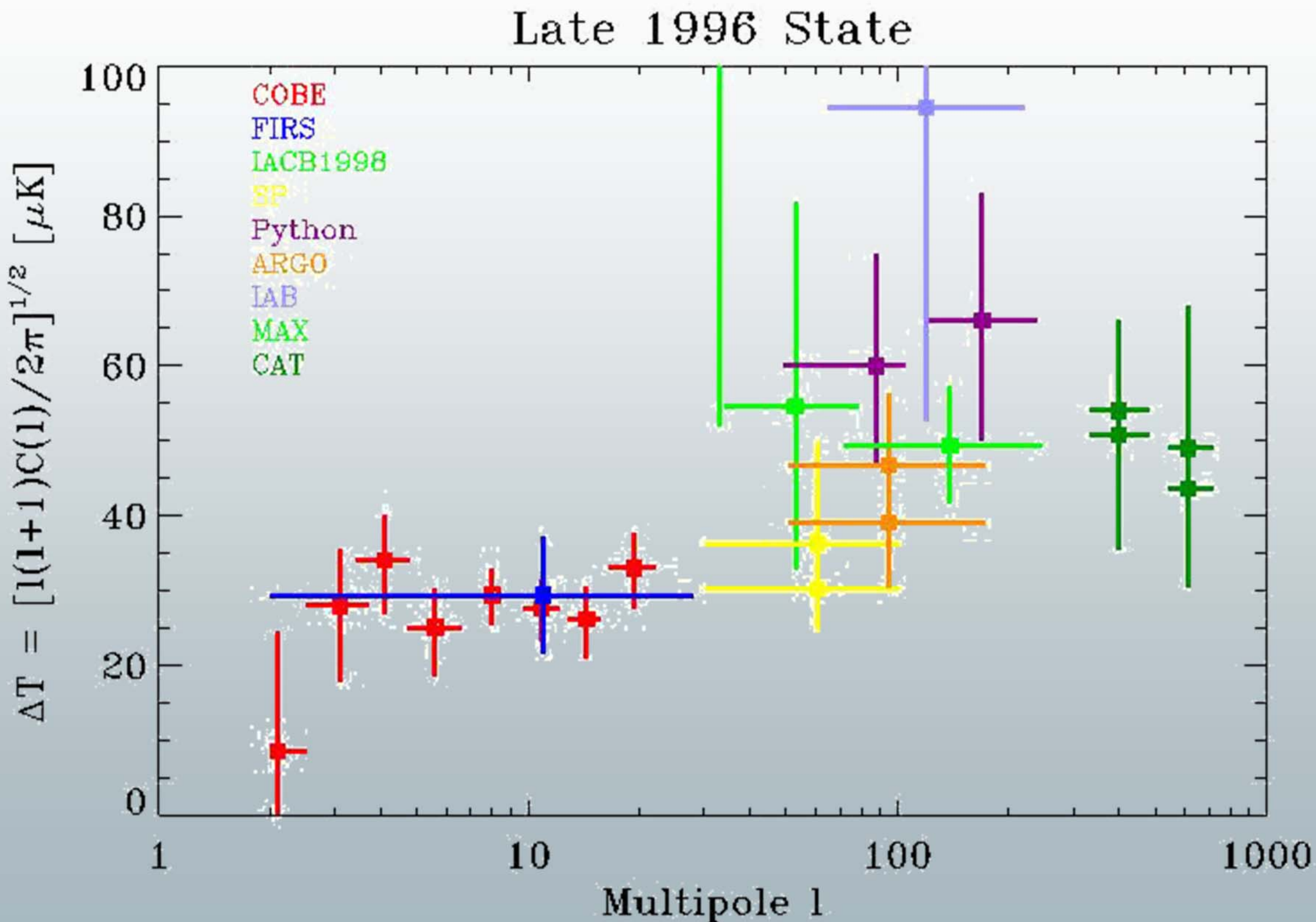
  ⇒ *enough sensitivity within large frequency range [30 GHz, 1 THz]*
  (~CMB photon noise limited for ~1yr in CMB primary window)

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

⇒ 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

When WMAP & Planck were selected



Planck needed breakthroughs

- The performance goals of Planck required several technological performances never achieved in space before
  - *Sensitive & fast bolometers with*
    - NEP< 2 10^{-17} W/Hz$^{1/2}$ & time constants typically < 5 msec

      (thus cooling them to 100 mK, very low heat capacity & charged particles sensitivity)
  - *total power read out electronics with very low noise*
    - < 6nV/Hz$^{1/2}$ from 10 mHz to 100 Hz
  - *Excellent temperature stability, from 10 mHz (1 rpm) to 100 Hz (cf. Lamarre et al. 04)*
    - < 10 μK/Hz$^{1/2}$ for 4K box (30% emissivity)
    - < 30 μK/Hz$^{1/2}$ on 1.6K filter plate (20% emissivity)
    - < 20 nK/Hz$^{1/2}$ for detector plate (~5000 damping factor needed)
  - *low noise HEMT amplifiers ($\Rightarrow$ cooled to 20K) & very stable cold reference loads (4K)*
- Additionally:
  - *low emissivity, very low side lobes, telescope (strongly under-illuminated)*
  - *no windows, minimum warm surfaces between detectors and telescope*
  - *Complex cryogenic cooling chain: 50K (passive)+20K+4K+0.1K active coolers*
    - 20K for LFI with large cooling power K (0.7W)
    - 4K, 1.6K and 100mK for HFI
    - Thermal architecture optimised to damp thermal fluctuations (active+passive)
  - *NB: 100mK cooling by dilution cooler does not tolerate micro-vibrations at sub-mg level or 7.10^{10} He atoms accumulated on dilution heat exchanger (typically He pressure 1.10^{-10} mb)*

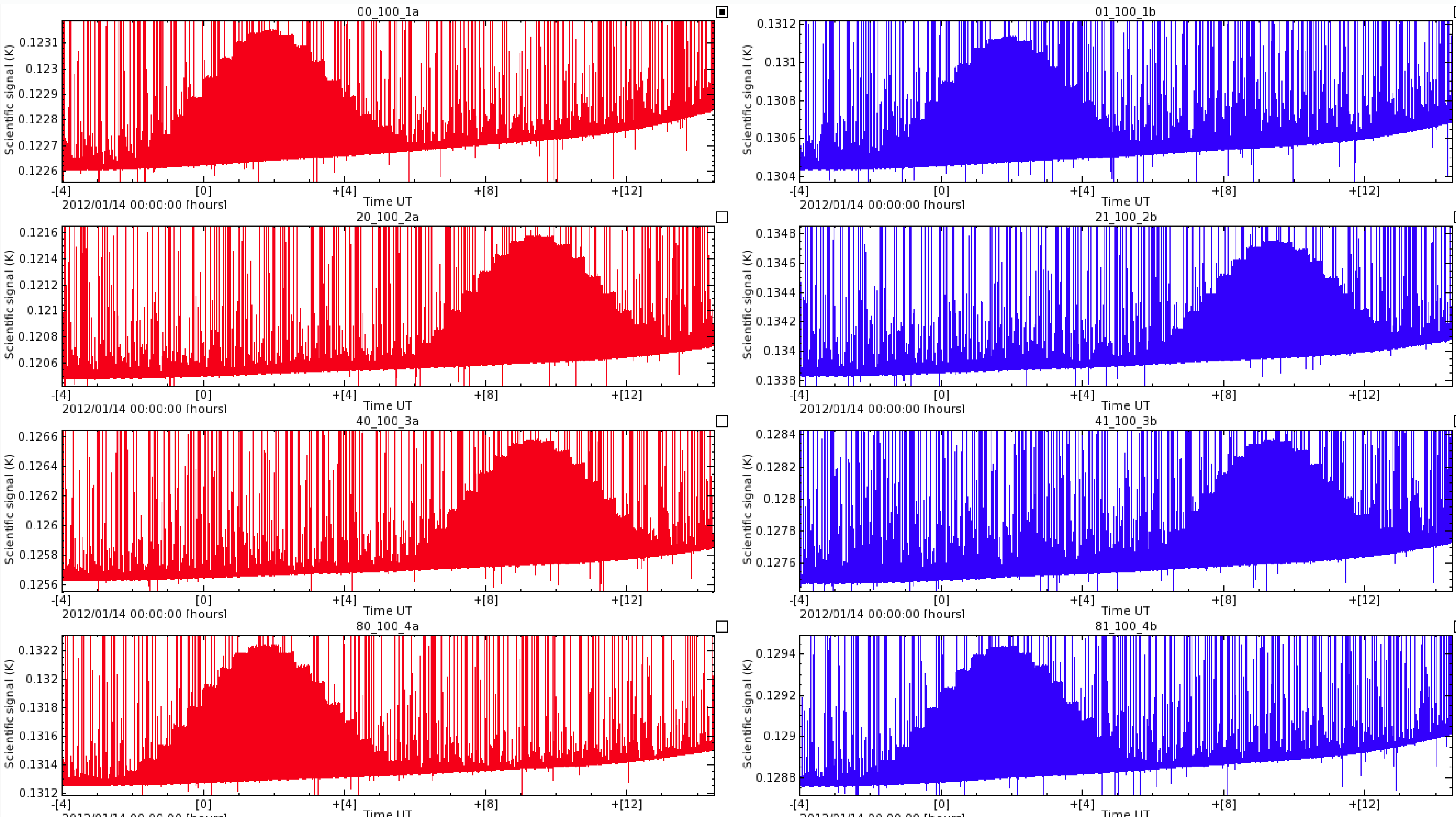
$\Rightarrow$ *Integration of 3 intertwined complex chains - optical, electronic, cryogenic*


DUSTING IT OFF...
AFTER 16 YEARS
OF HOPES & WORK
CSG
CSG


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

The Planck as last seen from the sky

The last time we saw Jupiter with HFI 100GHz on January 14th 2012...



While (HFI-local) warming was already ongoing…

Log Book (abridged)

- August 13th 2009 : beginning of survey: Instruments very stable, continuously mapping the sky
- 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 …:
- *Expectations on sensitivities confirmed in flight: HFI reaches or exceeds its goals.*

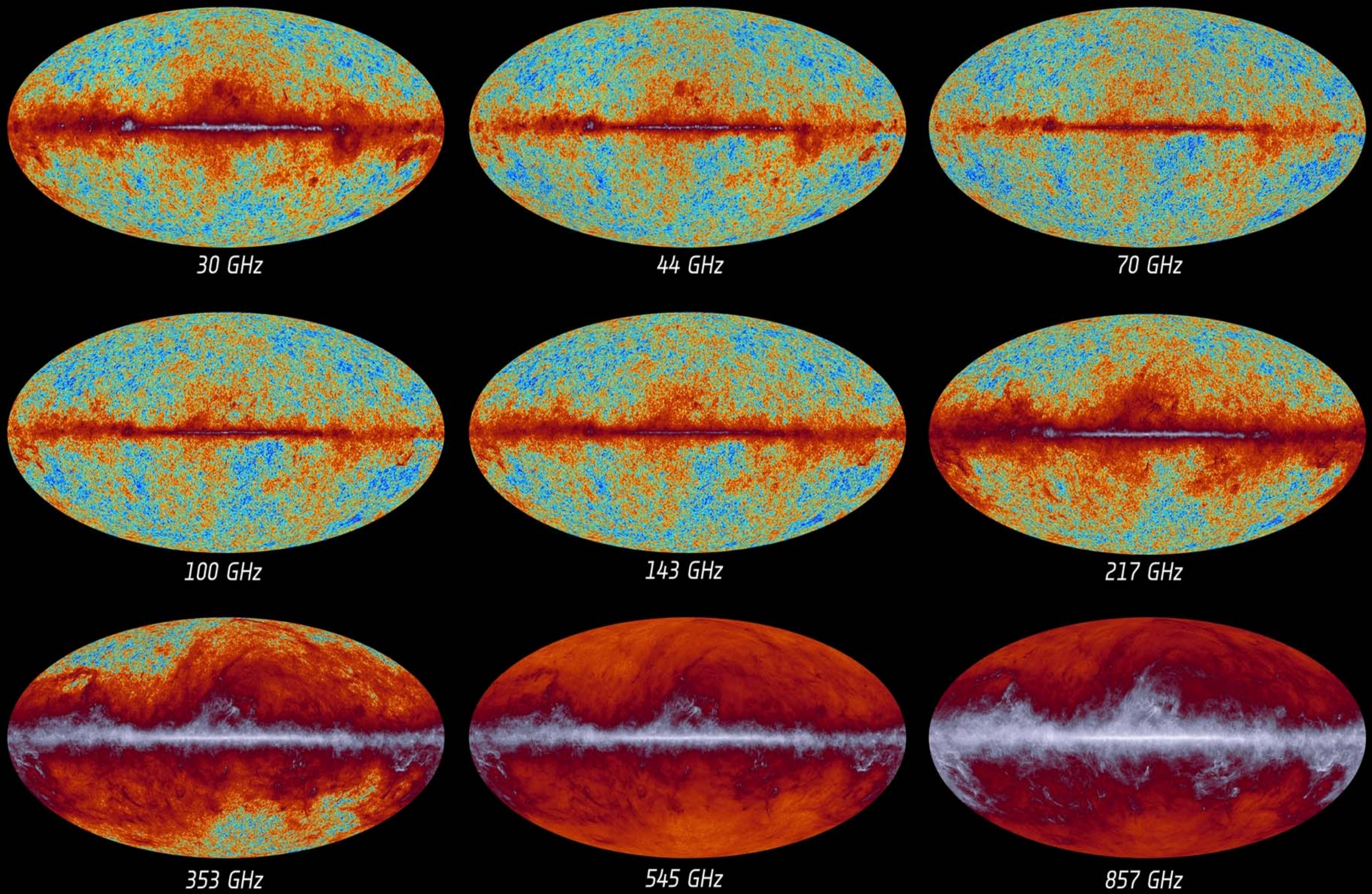
- June 2010 : first complete coverage of the sky by all detectors obtained with the first nearly 10 months of survey data. ERCSC release & batch of 25 papers on "Planck early results" submitted **in Jan 2011**;

- November 27th 2010 : 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:
  - *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*

- **Jan 14th 2012:** all HFI survey data acquired! 885 days of survey, 900 billion samples, 5 surveys, twice the nominal duration. With some additional LFI data (~3 months) will be the basis of our next data delivery (DD2) in **mid-2014.** (including polarization) planck

The sky as seen by Planck

esa



Planck 2013 data characteristics

Property	Applies to	30	44	70	100	143	217	353	545	857
		Frequency [GHz]								
Effective frequency [GHz]	Mean	28.4	44.1	70.4	100	143	217	353	545	857
Noise rms per pixel [μK_{CMB}]	Median	9.2	12.5	23.2	11	6	12	43	...	...
[$MJy\,sr^{-1}$]	Median	...	...	...	...	...	...	...	0.0149	0.0155
Gain calibration uncertainty[b]	All sky	0.82 %	0.55 %	0.62 %	0.5 %	0.5 %	0.5 %	1.2 %	10 %	10 %
Zero level[c] [$MJy\,sr^{-1}$]	All sky	0	0	0	0.0047	0.0136	0.0384	0.0885	0.1065	0.1470
Zero level uncertainty [μK_{CMB}]	All sky	±2.23	±0.78	±0.64	...	...	...	...	...	...
[$MJy\,sr^{-1}$] . . .	All sky	...	...	...	±0.0008	±0.001	±0.0024	±0.0067	±0.0165	±0.0147
Color correction unc.[d]	non-CMB emission	0.1β %	0.3β %	0.2β %	$0.11\Delta\alpha$ %	$0.031\Delta\alpha$ %	$0.007\Delta\alpha$ %	$0.006\Delta\alpha$ %	$0.020\Delta\alpha$ %	$0.048\Delta\alpha$ %
Beam Color correction unc.[e]	non-CMB emission	0.5 %	0.1 %	0.3 %	<0.3 %	<0.3 %	<0.3 %	<0.5 %	<2.0 %	<1.0 %

Band	FWHM[a] [arcmin]	Ellipticity	Ω [$arcmin^2$]
30	32.239 ± 0.013	1.320 ± 0.031	1189.51 ± 0.84
44	27.01 ± 0.55	1.034 ± 0.033	833 ± 32
70	13.252 ± 0.033	1.223 ± 0.026	200.7 ± 1.0
100	9.651 ± 0.014	1.186 ± 0.023	105.778 ± 0.311
143	7.248 ± 0.015	1.036 ± 0.009	59.954 ± 0.246
217	4.990 ± 0.025	1.177 ± 0.030	28.447 ± 0.271
353	4.818 ± 0.024	1.147 ± 0.028	26.714 ± 0.250
545	4.682 ± 0.044	1.161 ± 0.036	26.535 ± 0.339
857	4.325 ± 0.055	1.393 ± 0.076	24.244 ± 0.193

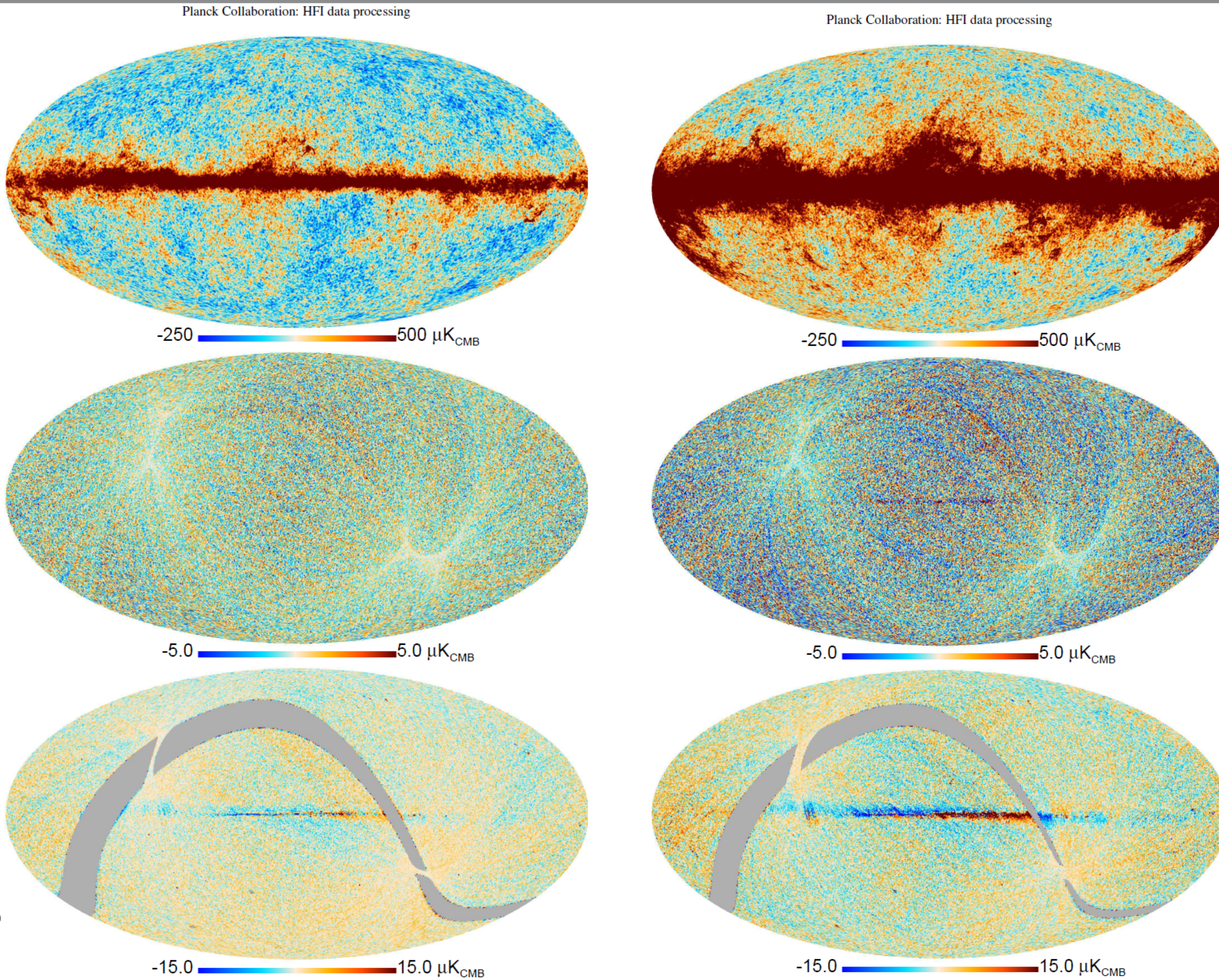
Channel	$N_{detectors}$[a]	ν_{center}[b] [GHz]	Scanning Beam[c] FWHM [arcm]	Scanning Beam[c] Ellipticity	Noise[d] Sensitivity [$\mu K_{RJ}\,s^{1/2}$]	Noise[d] Sensitivity [$\mu K_{CMB}\,s^{1/2}$]
30 GHz	4	28.4	33.16	1.37	145.4	148.5
44 GHz	6	44.1	28.09	1.25	164.8	173.2
70 GHz	12	70.4	13.08	1.27	133.9	151.9
100 GHz	8	100	9.59	1.21	31.52	41.3
143 GHz	11	143	7.18	1.04	10.38	17.4
217 GHz	12	217	4.87	1.22	7.45	23.8
353 GHz	12	353	4.7	1.2	5.52	78.8
545 GHz	3	545	4.73	1.18	2.66	0.0259[d]
857 GHz	4	857	4.51	1.38	1.33	0.0259[d]

The Planck dataset

Allows many redundancy checks and null tests:

- Multiple sensitive detectors at a given frequency
  - Compare the output from one detector to that of another
- Planck spins at 1 rpm with axis fixed for 39–65 rotations (a “ring”)
  - Compare data from the first and second halves of a ring
  - In “half-ring difference” maps, the sky signal subtracts out, leaving noise and possibly other systematic residuals
  - Half-ring differences can be constructed for single or multiple detectors, and for any period of time
- Multiple sky coverages
  - In six months (one “survey”) Planck covers most of the sky once
  - In “survey difference” maps, the sky signal subtracts out, but the effects of different beam orientations and side lobes, etc. leave residuals
- LFI and HFI. Different technologies, different systematics.
- Multiple frequencies
  - Foregrounds change, but (in appropriate units) the CMB doesn’t

143 GHz & 217 GHz maps

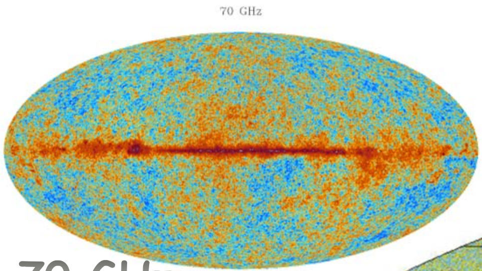


Intensity maps

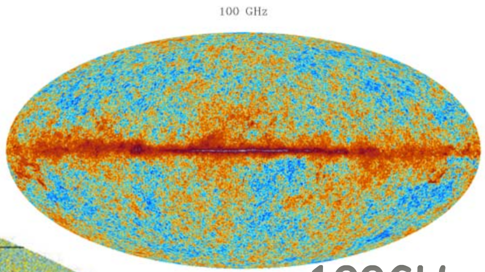
Difference between Half-ring maps

Difference between Survey 1 and Survey 2 maps

LFI-HFI consistency

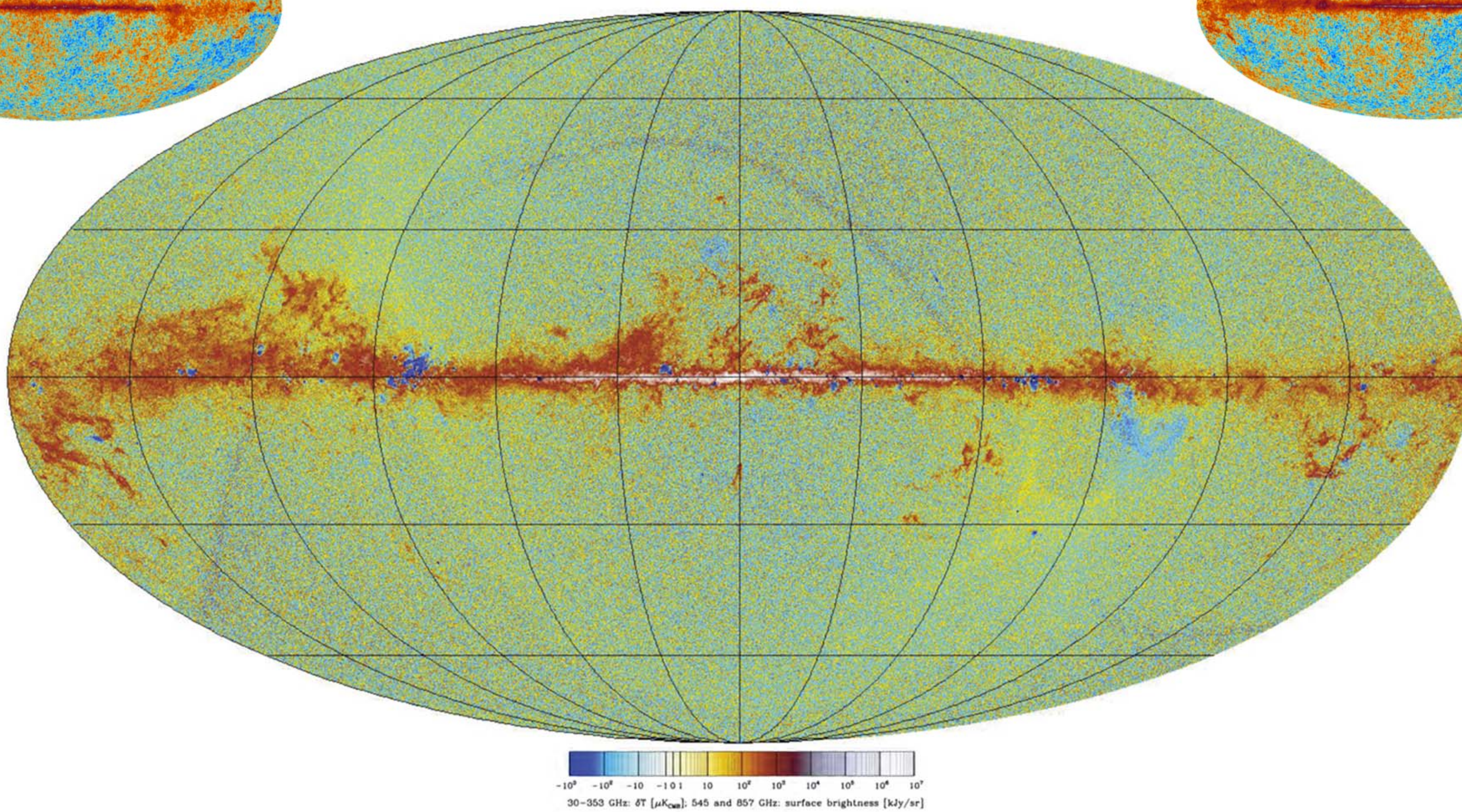


70 GHz



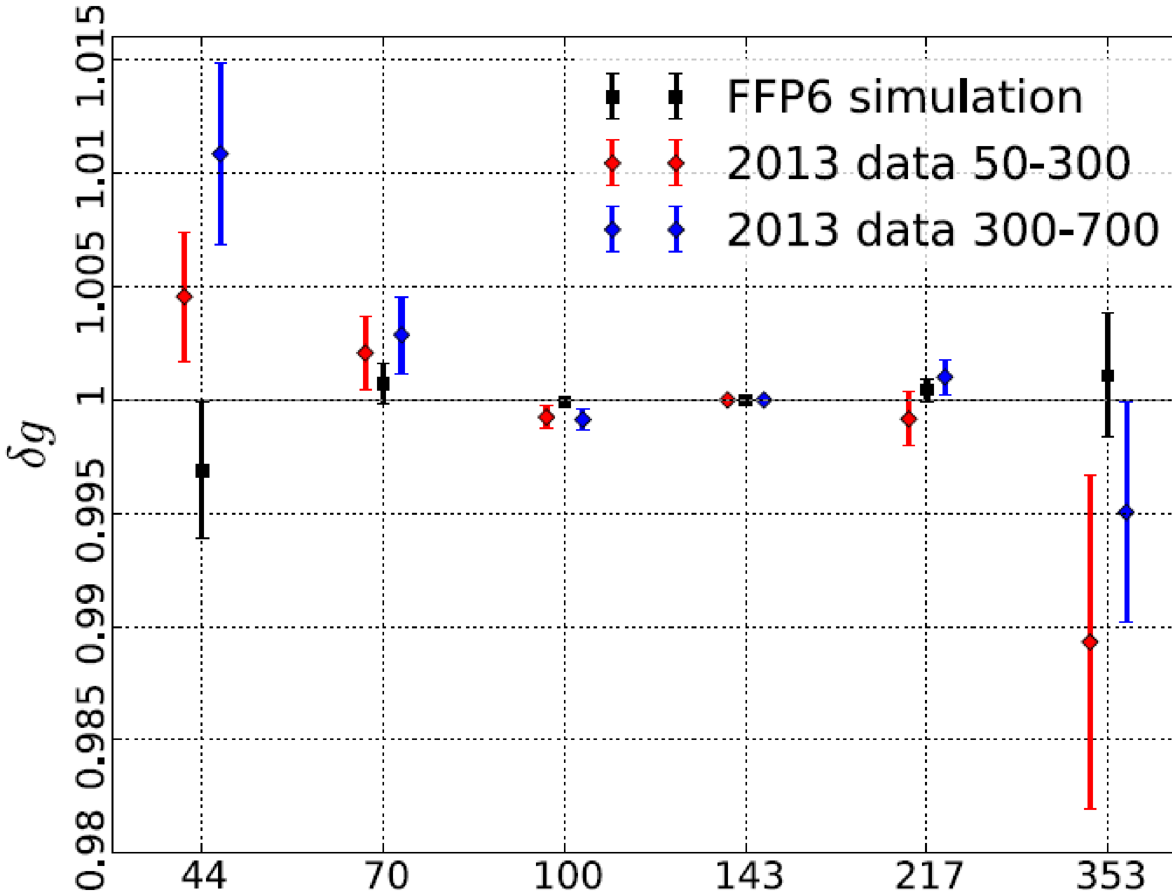
100GHz

100GHz - 70 GHz



Red is mostly CO, blue is mostly free-free. CMB is gone in inter-instrument nulling!

Checking intercalibrations with CMB anisotropies

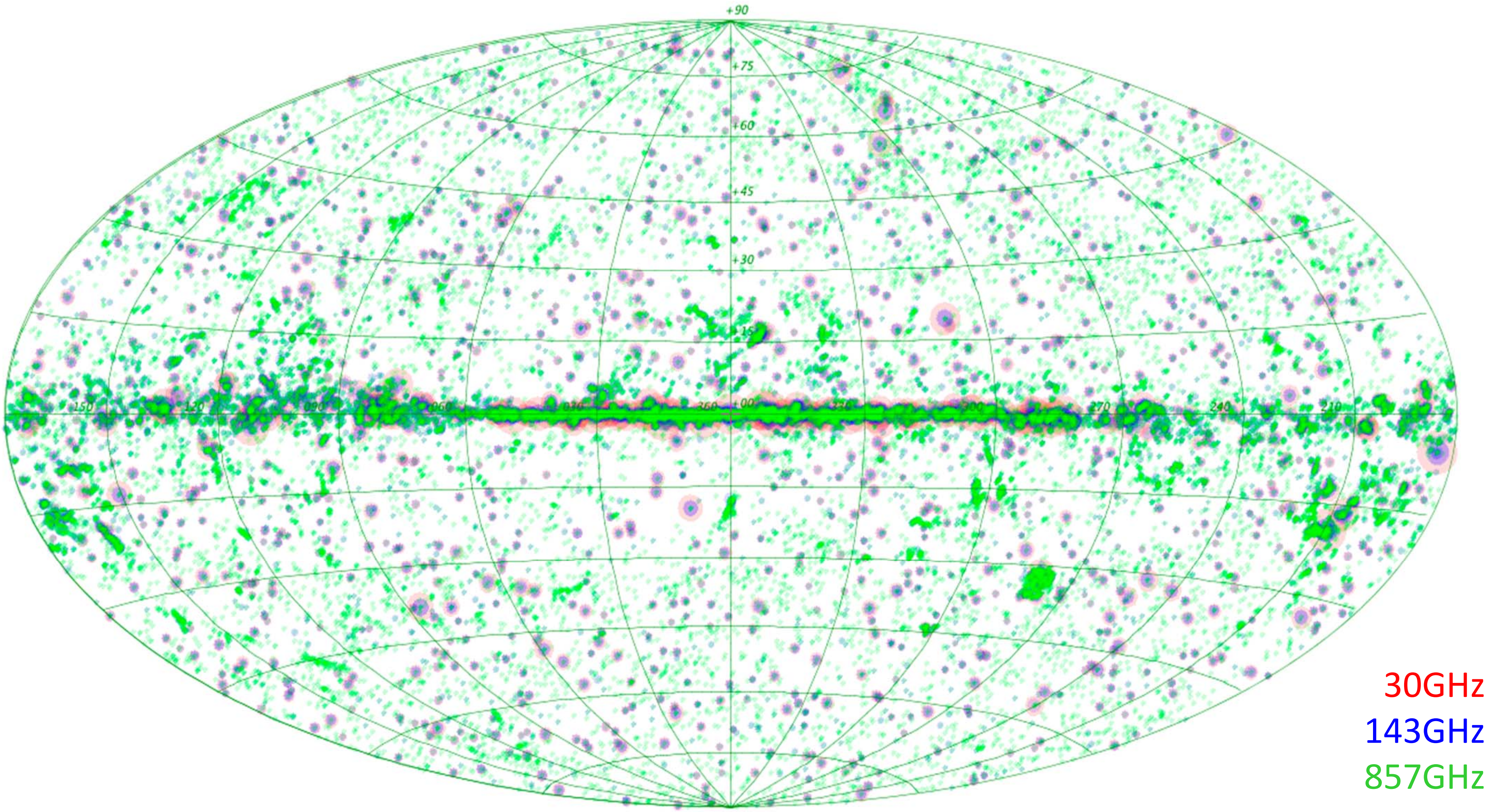


Planck Collaboration VI 2013

Recalibration factors (wrt 143GHz) maximizing CMB consistency over 40% of the sky
- for simulations
- for two multipole ranges in the data.

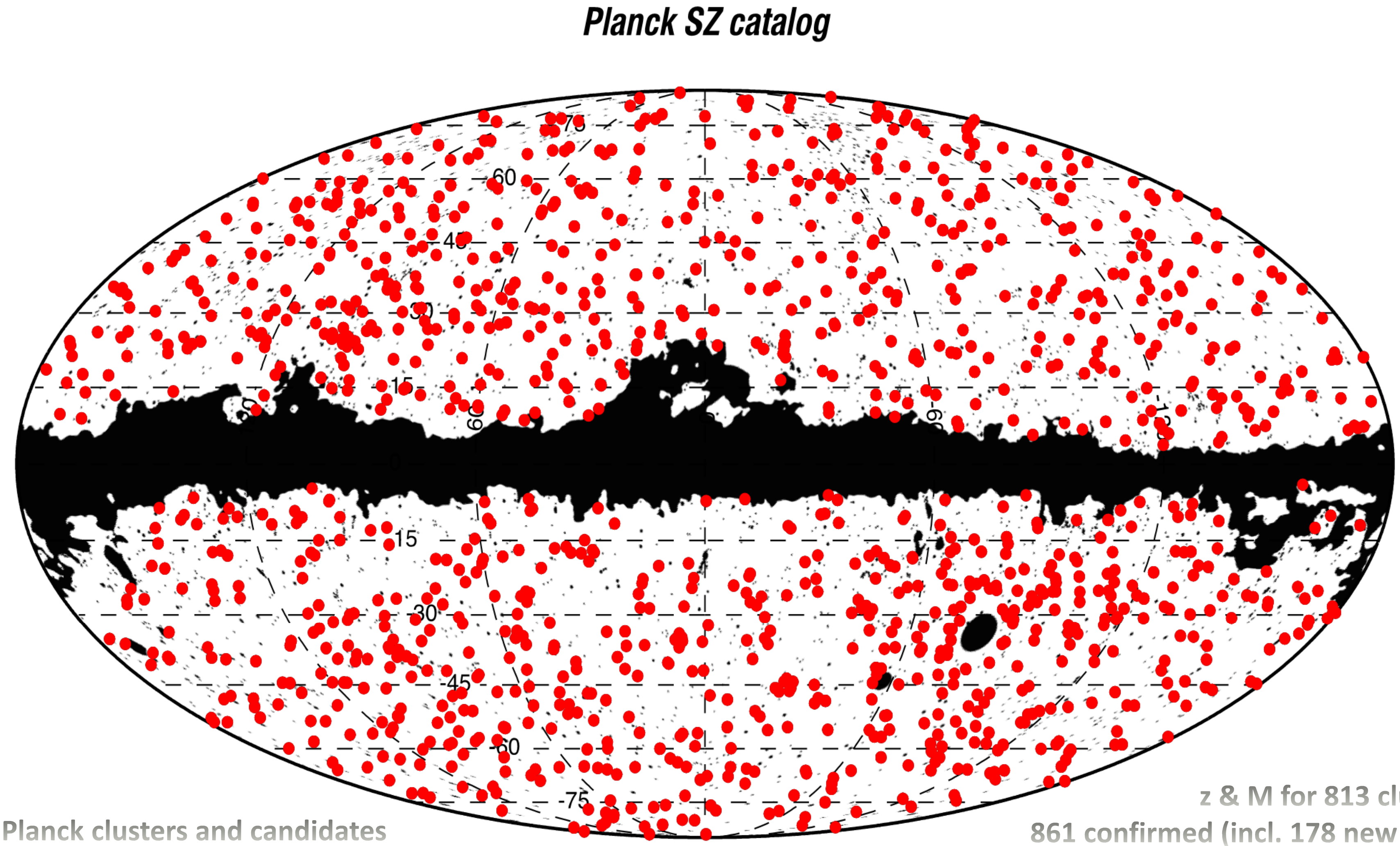
For 70–217 GHz, all are 0.3%

Compact galactic and extragalactic sources



At 850GHz: ~25 000 sources, 90% completeness level at 658mJy flux density; uncertainties: 166 mJy, 0.4 arcmin

Clusters of galaxies



1227 Planck clusters and candidates

z & M for 813 clusters

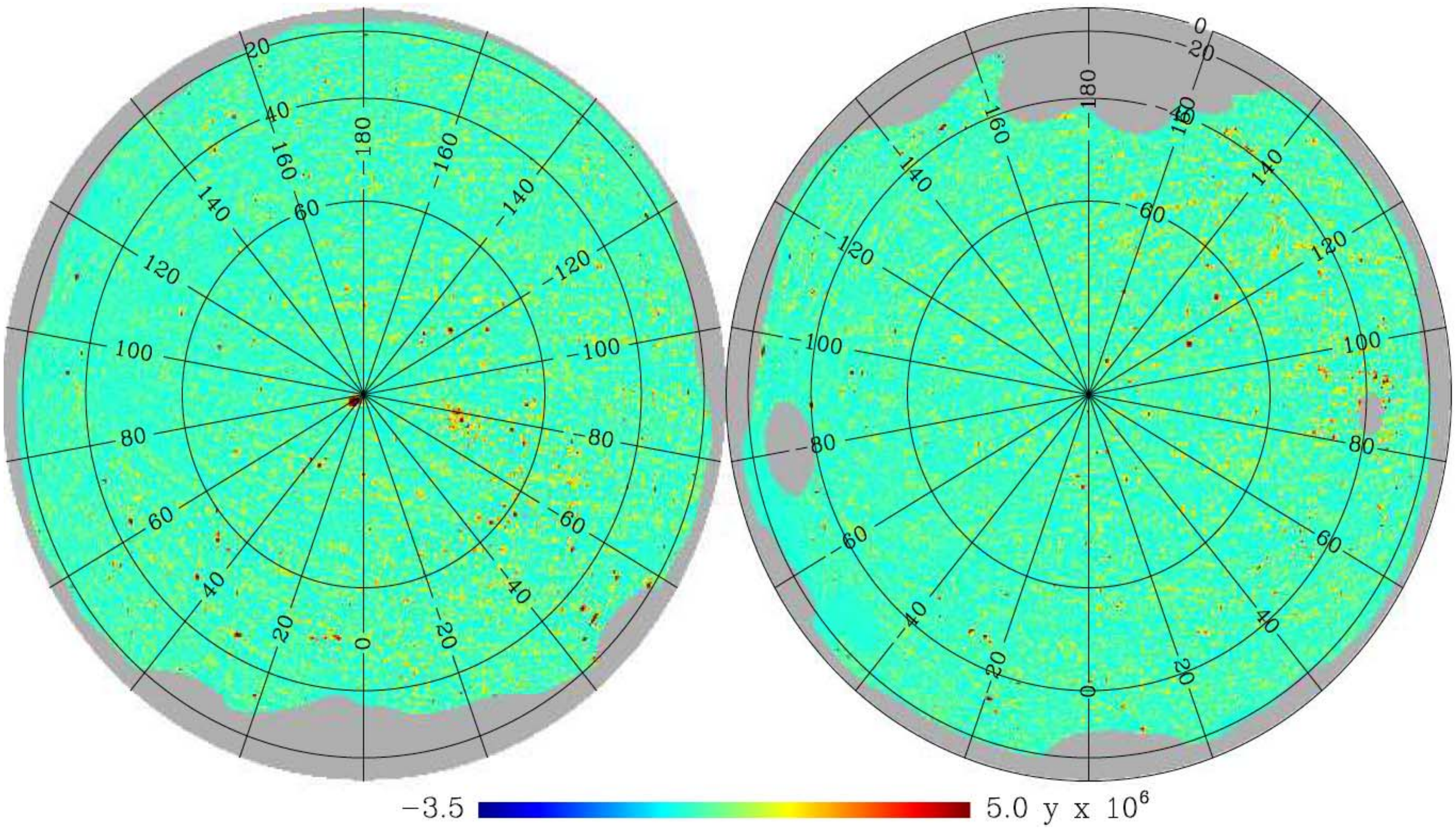
861 confirmed (incl. 178 new ones)

Galactic Foregrounds

Low frequency emission CO “discovery” map Dust emission amplituc

MAP OF THE BARYON DISTRIBUTION

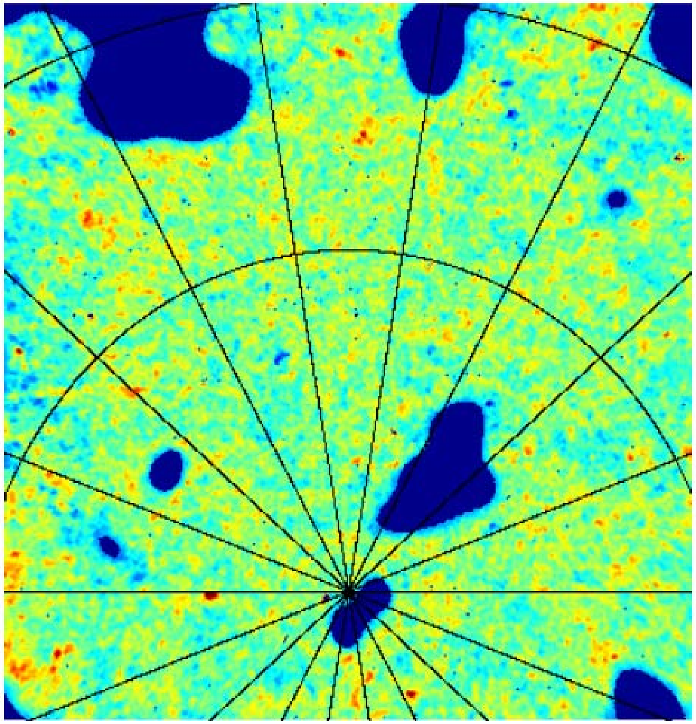
Planck imaged the gas (baryon) distribution in the low-redshift Universe using scattering of CMB photons off the electrons. This SZ effect causes a change in the shape of the CMB spectrum



THE COSMIC INFRARED BACKGROUND

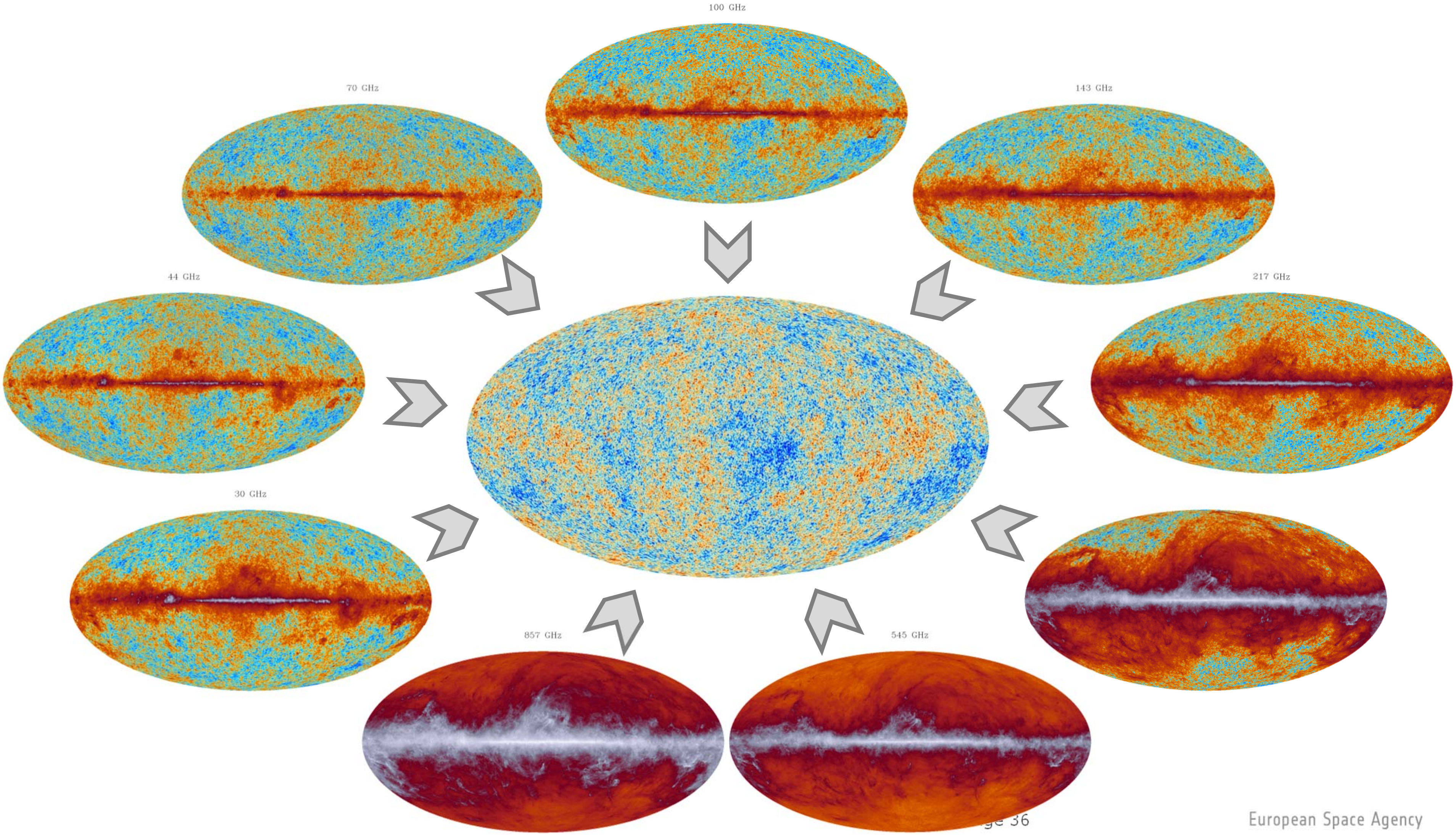
Planck image of part of the sky with little Milky Way dust emission. What is there has been removed using Galactic hydrogen maps made by other telescopes.

This map primarily shows the Cosmic Infrared Background, emission from warm dust in distant star-forming galaxies at redshifts between 1 and 3



545 GHz

Cleaning the background from its 7 veils

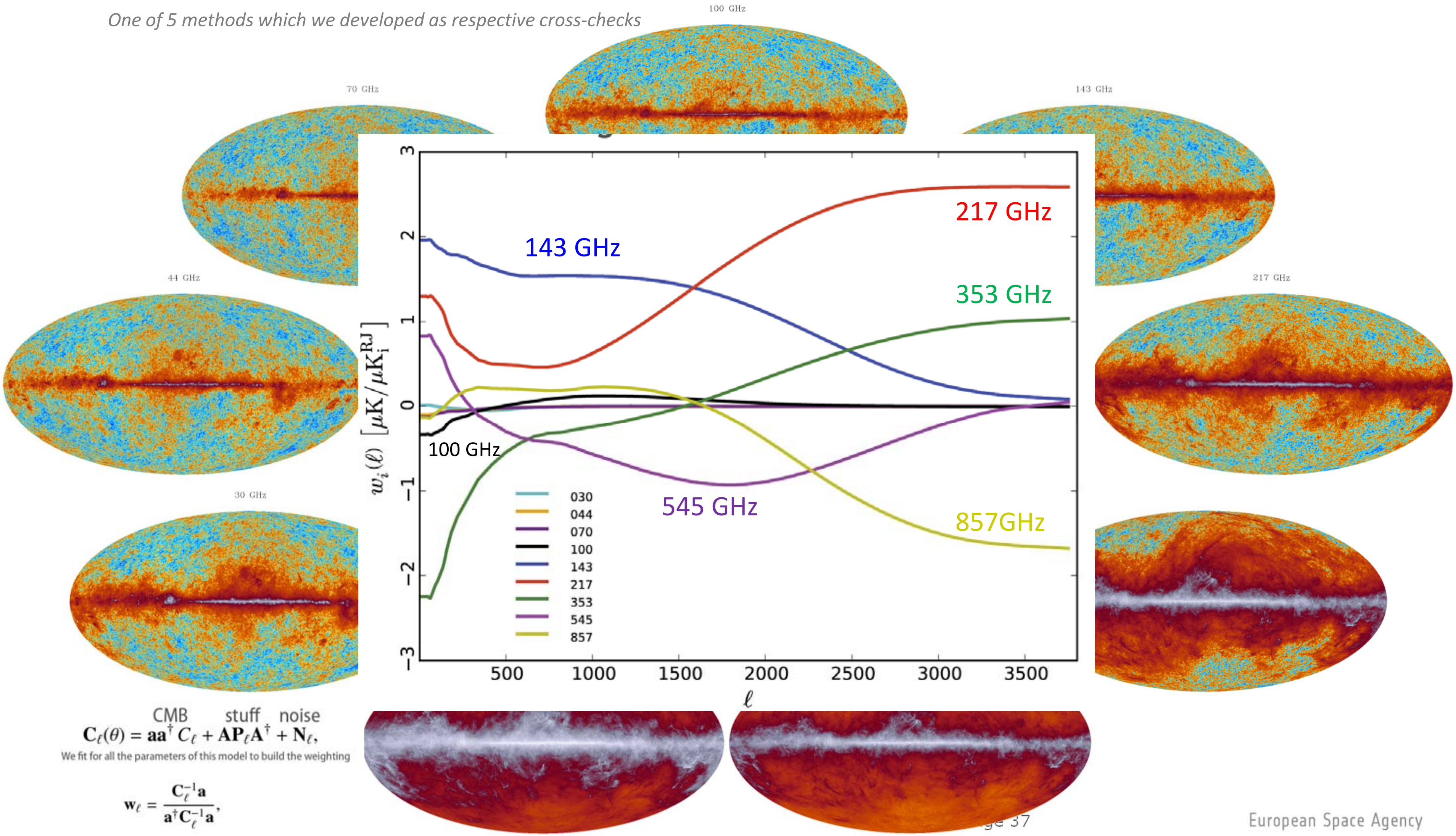


François R. Bouchet "Planck mission overview"

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



CMB stuff noise

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

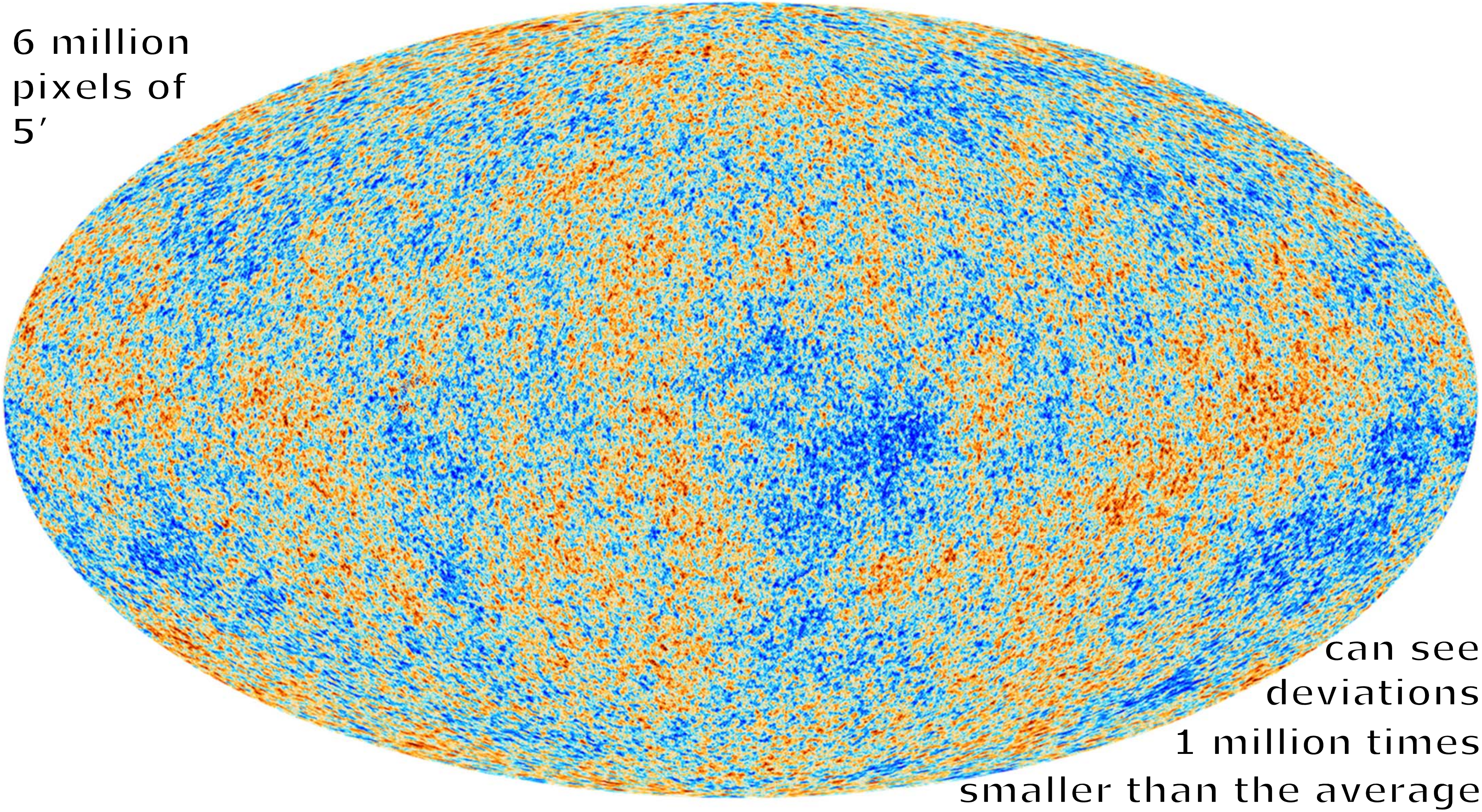
We fit for all the parameters of this model to build the weighting

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

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

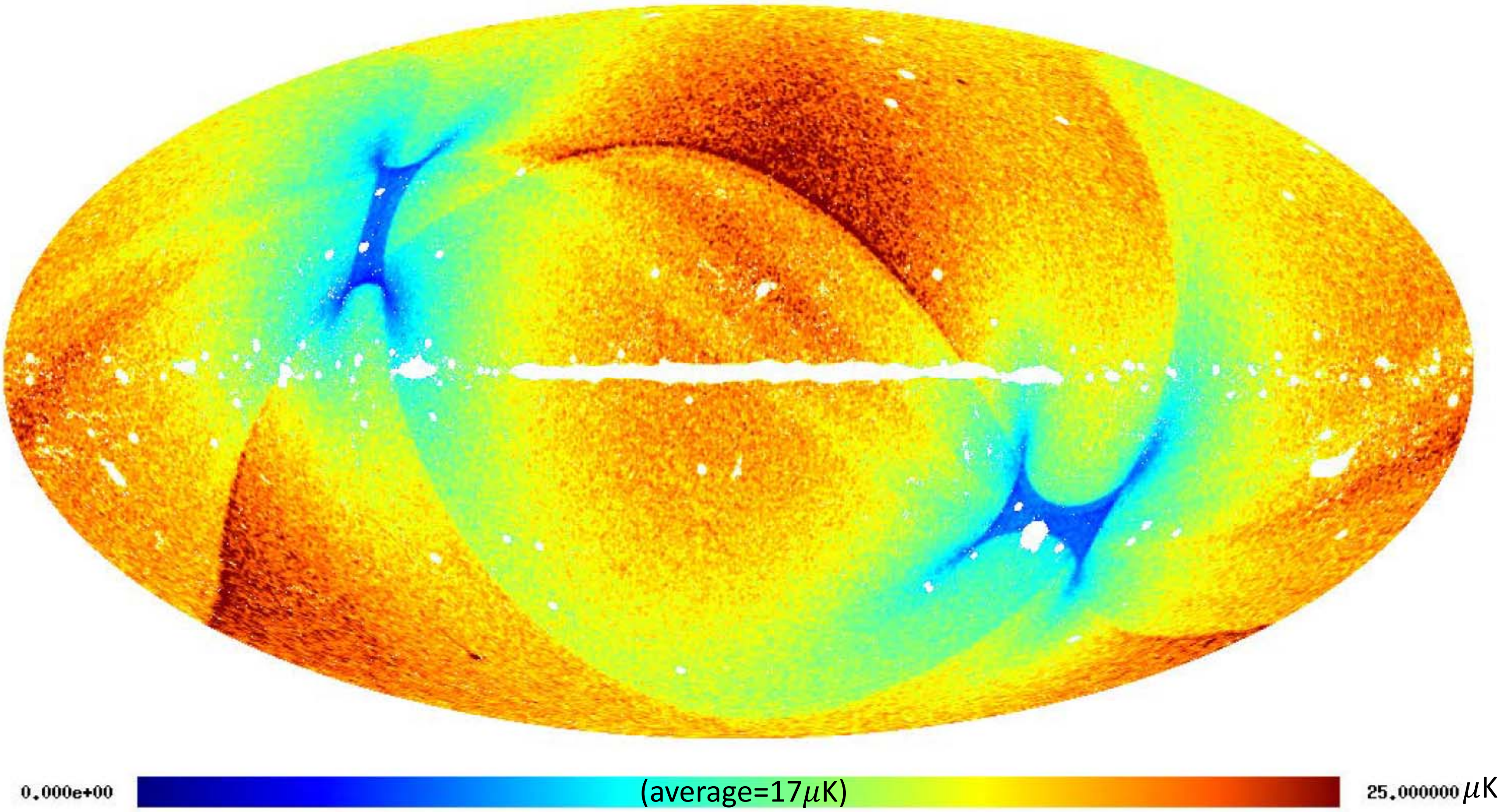
The cosmic microwave background Temperature anisotropies

6 million pixels of 5′

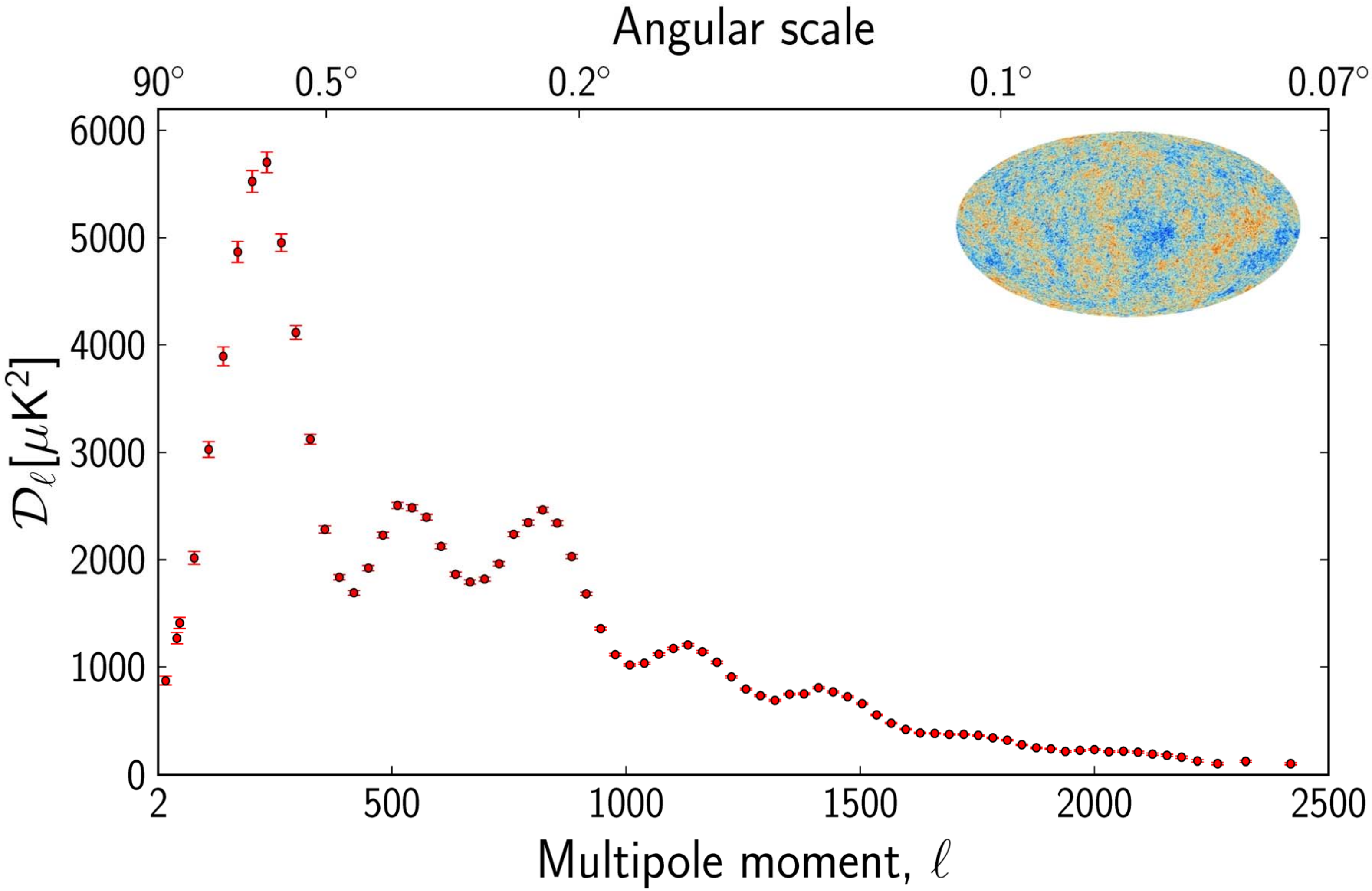


can see deviations 1 million times smaller than the average

Noise distribution

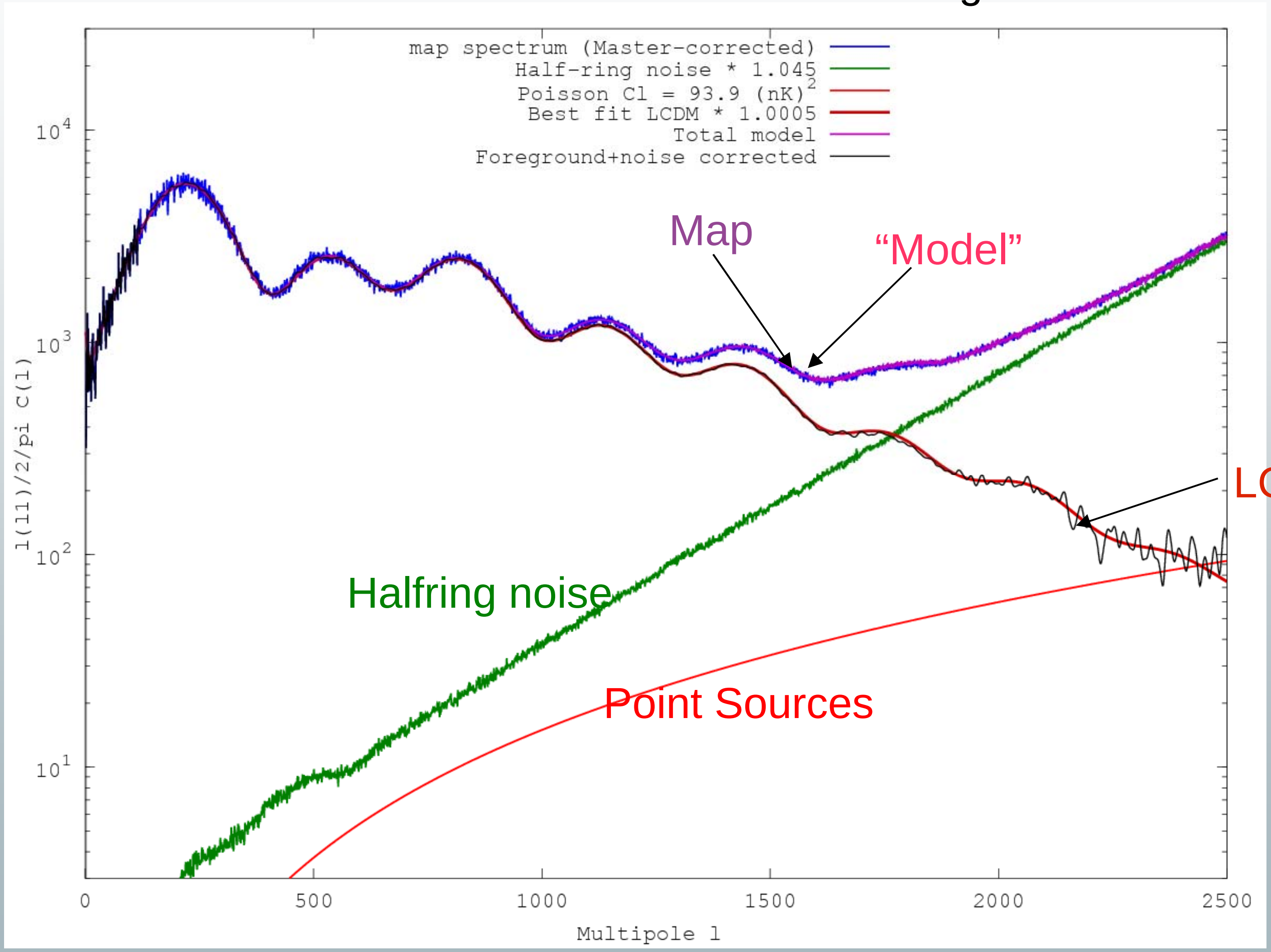


The Planck spectrum of Temperature anisotropies



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



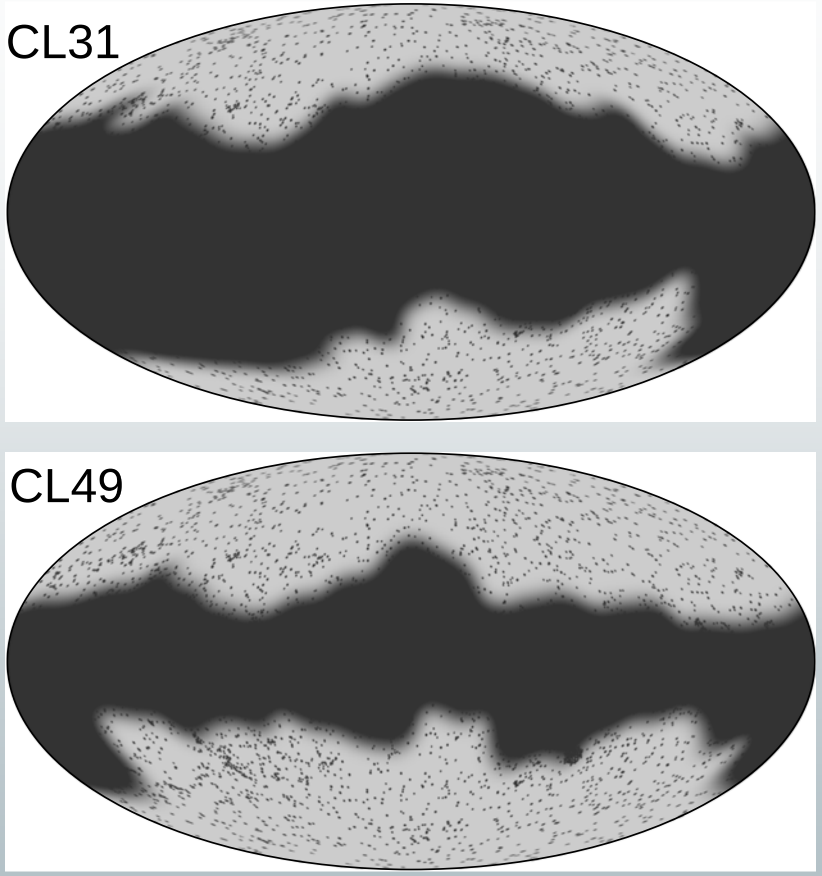
Likelihood Methodology

- 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)*

HL: conservative data selection

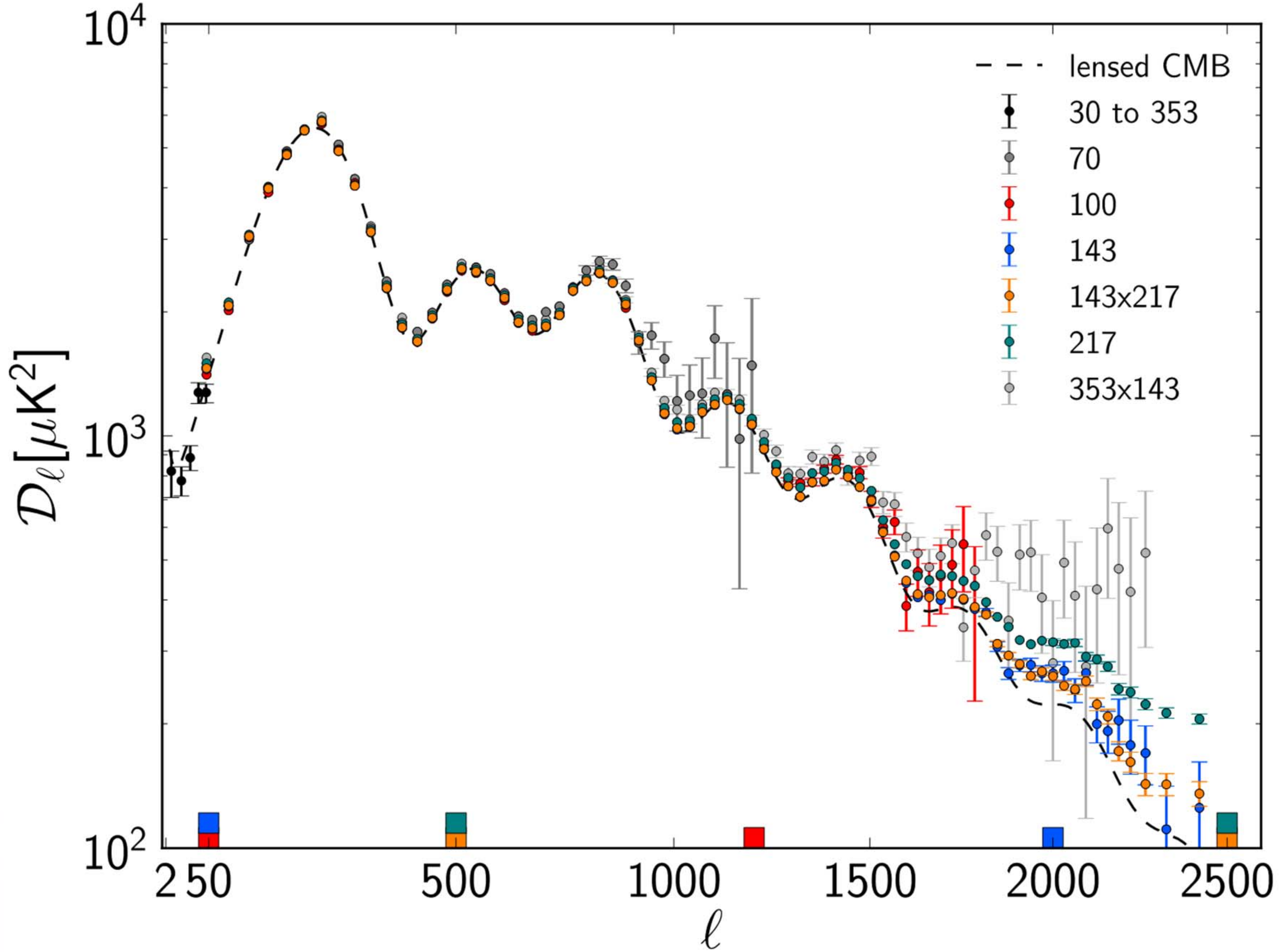
- Minimise foreground impact
  - *Spatially*
  - *In multipole space*
  - *Keeping low cosmic variance*
- Galaxy: 353 GHz thresholding
- Sources: 100-353 GHz catalog

Spectrum	Multipole range	Mask
100×100	50 – 1200	CL49
143×143	50 – 2000	CL31
143×217	500 – 2500	CL31
217×217	500 – 2500	CL31
Combined	50 – 2500	CL31/49



Galactic and sources apodised masks

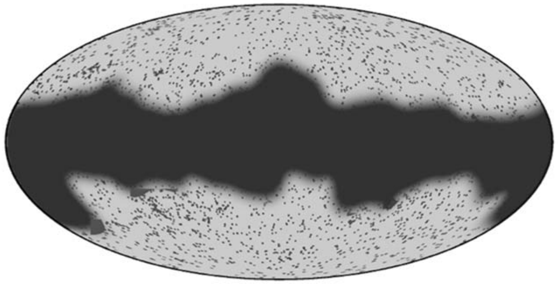
Planck angular power spectra

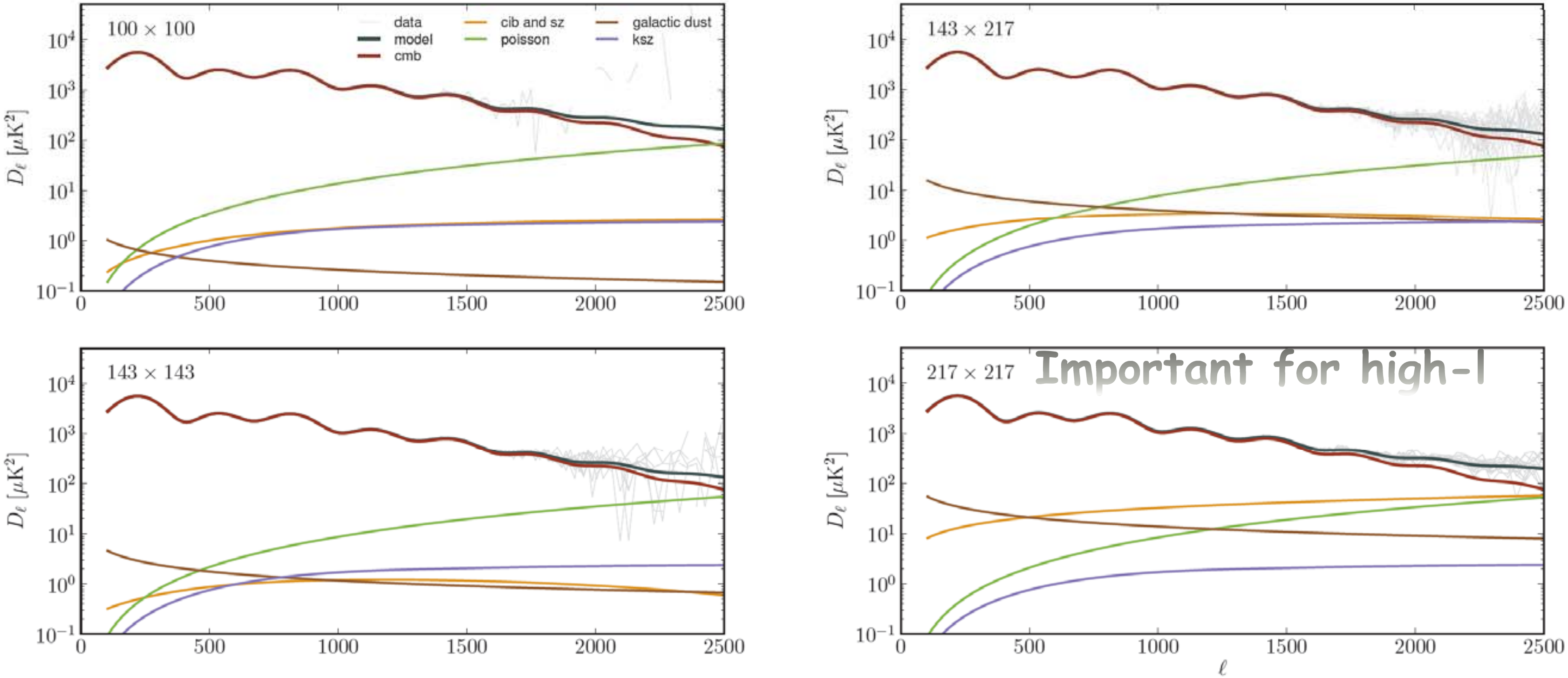


Origin of the CMB spectrum

We need to mask the galactic plane and model:

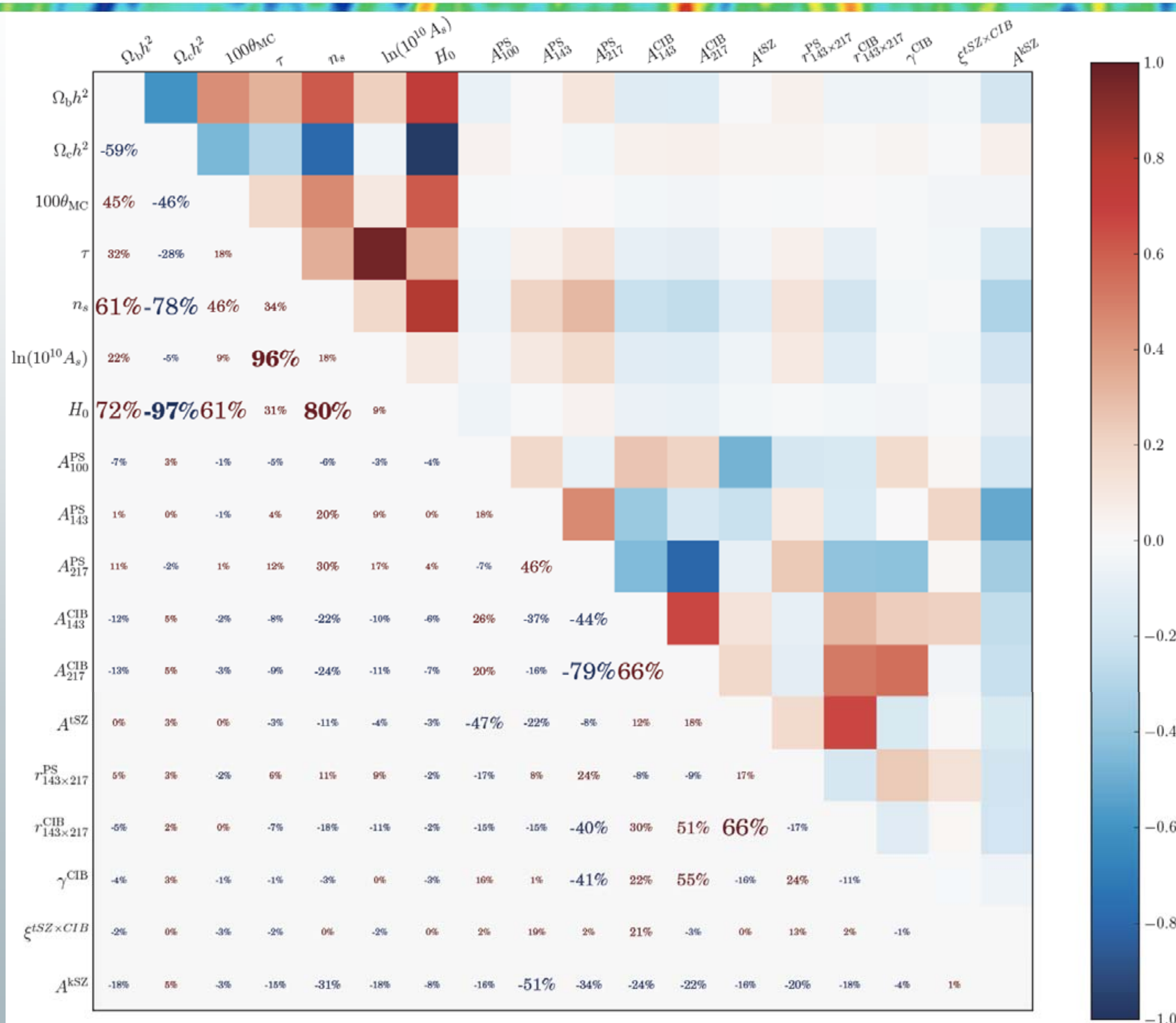
- Residual galactic dust emission
- Point sources (radio or infrared sources=Poisson)
- Infrared background (clustered = CIB)
- Thermal SZ
- Kinetic SZ



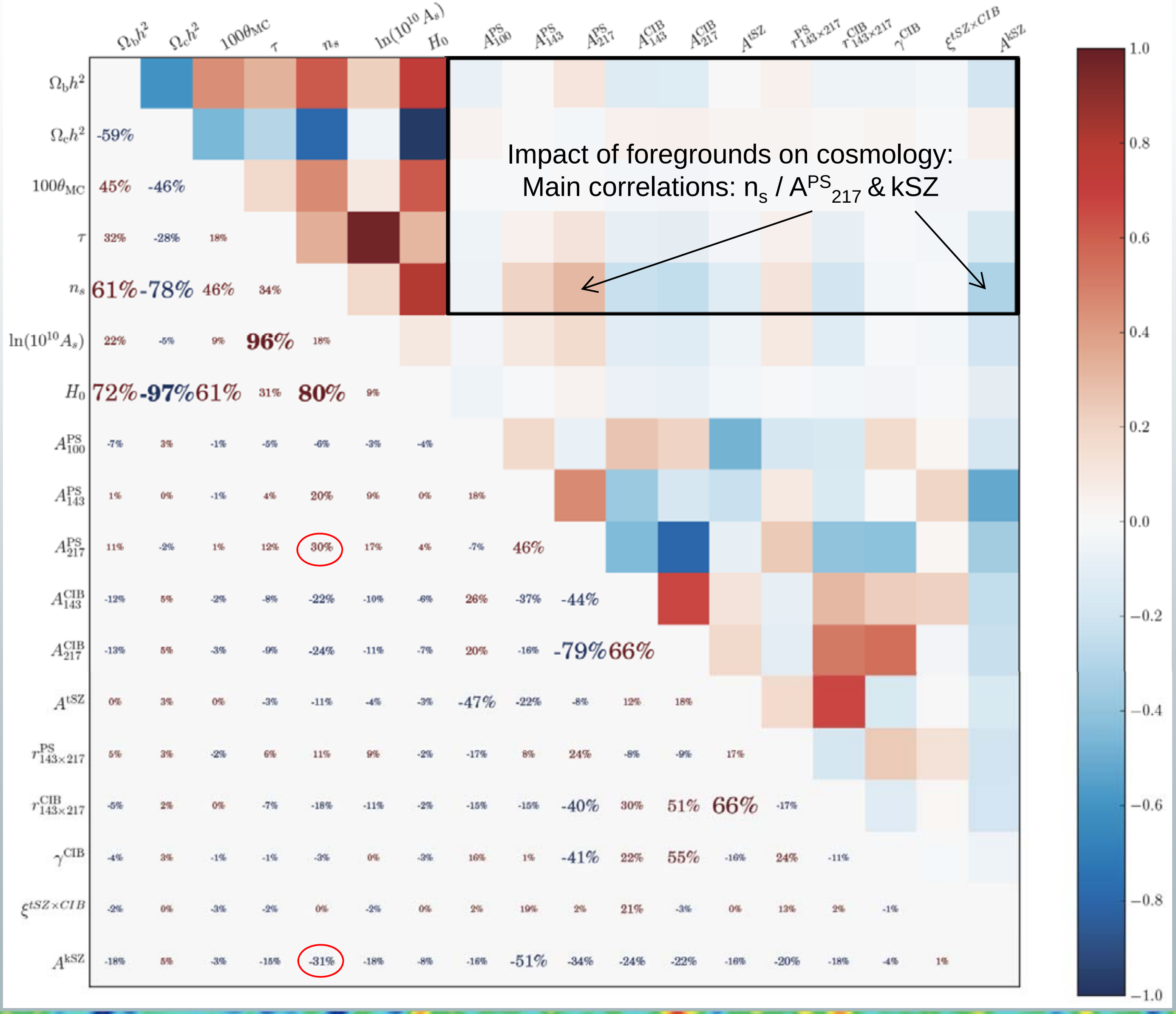


Important for high-l

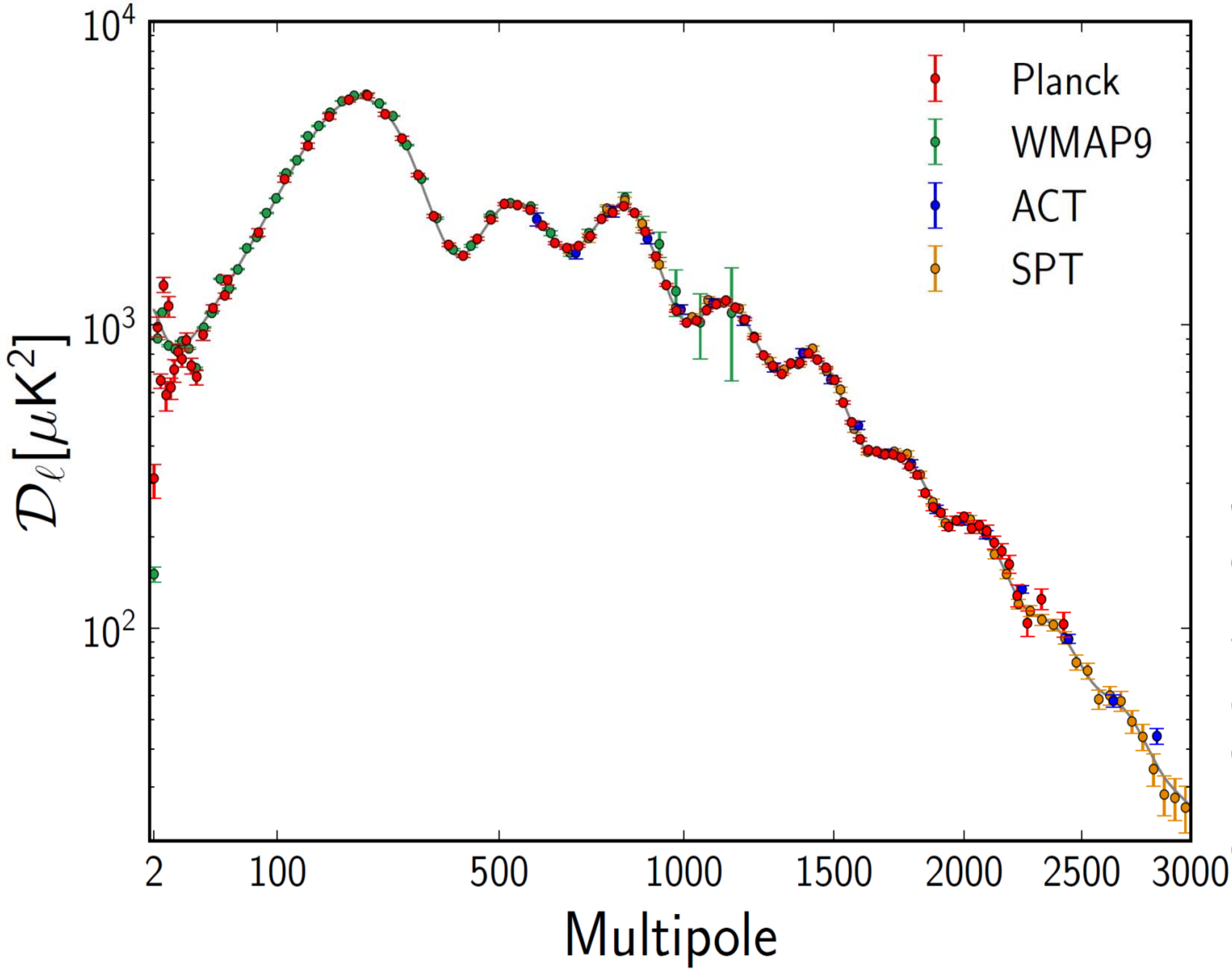
HL posterior correlations



HL posterior correlations

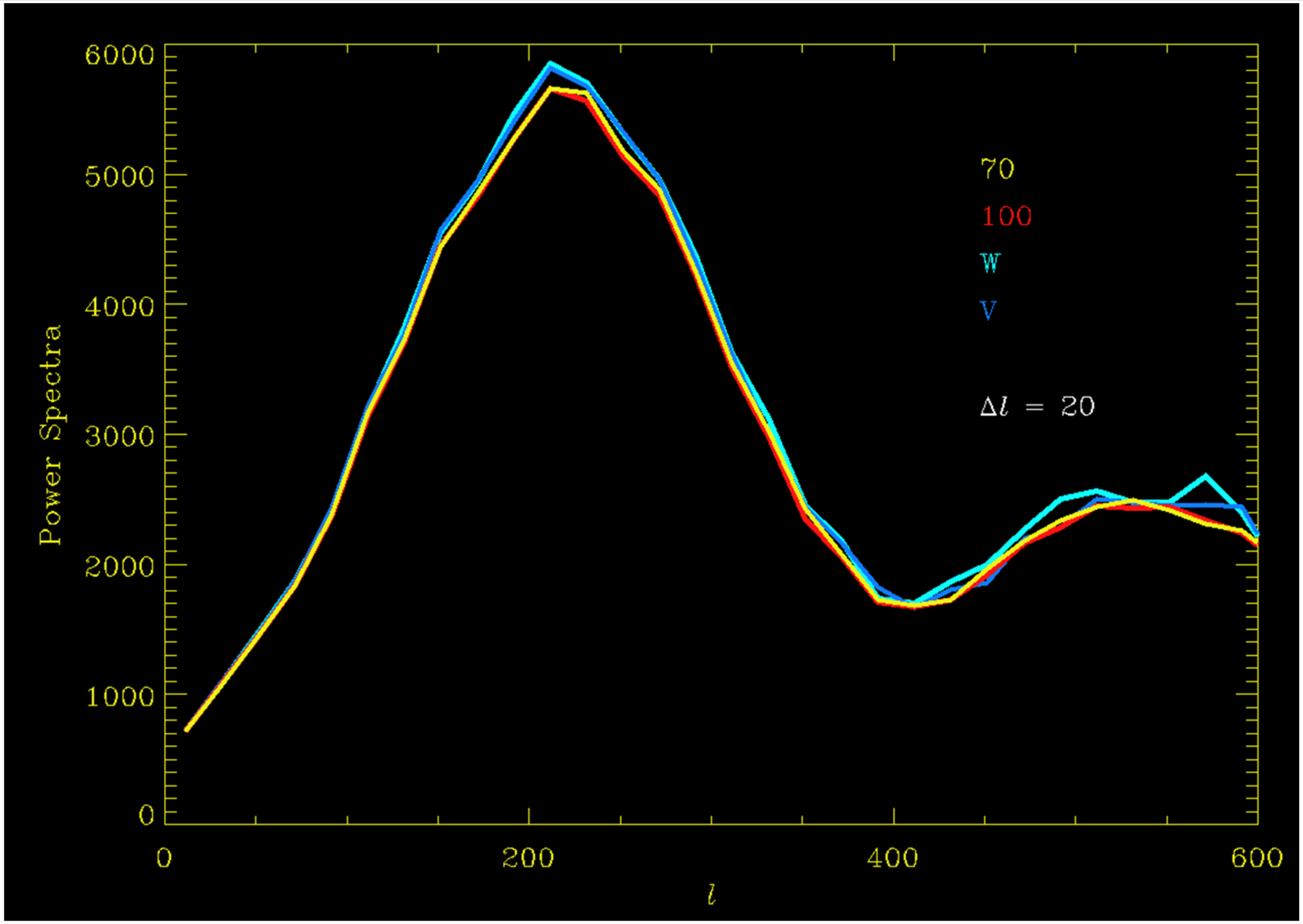


The 2013 CMB temperature landscape



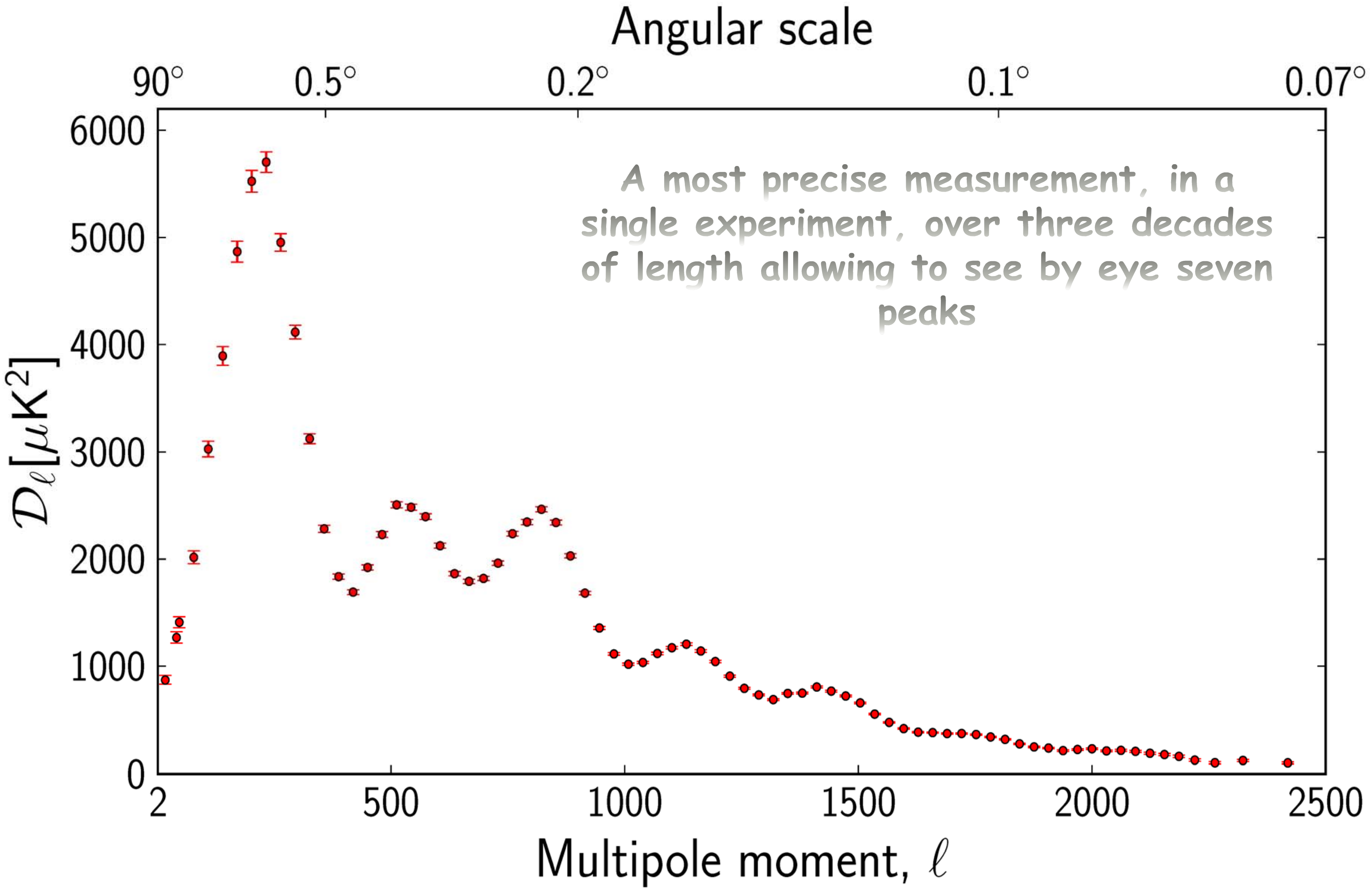
NB: on-going work for consistency paper (incl. WMAP ~2.5% difference over large l-range to be explained

There are differences in detail

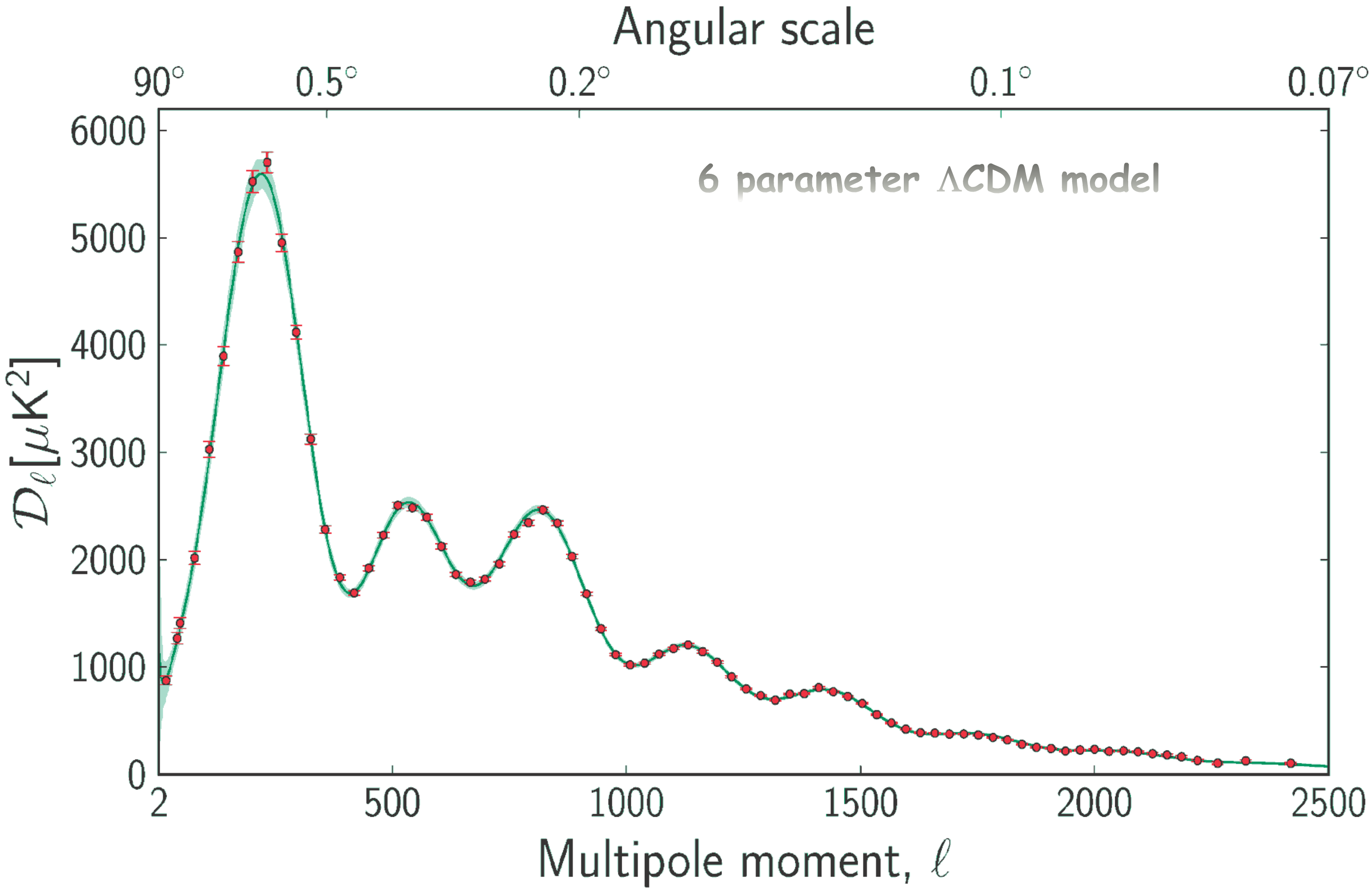


which we are analysing with the WMAP & ACT teams

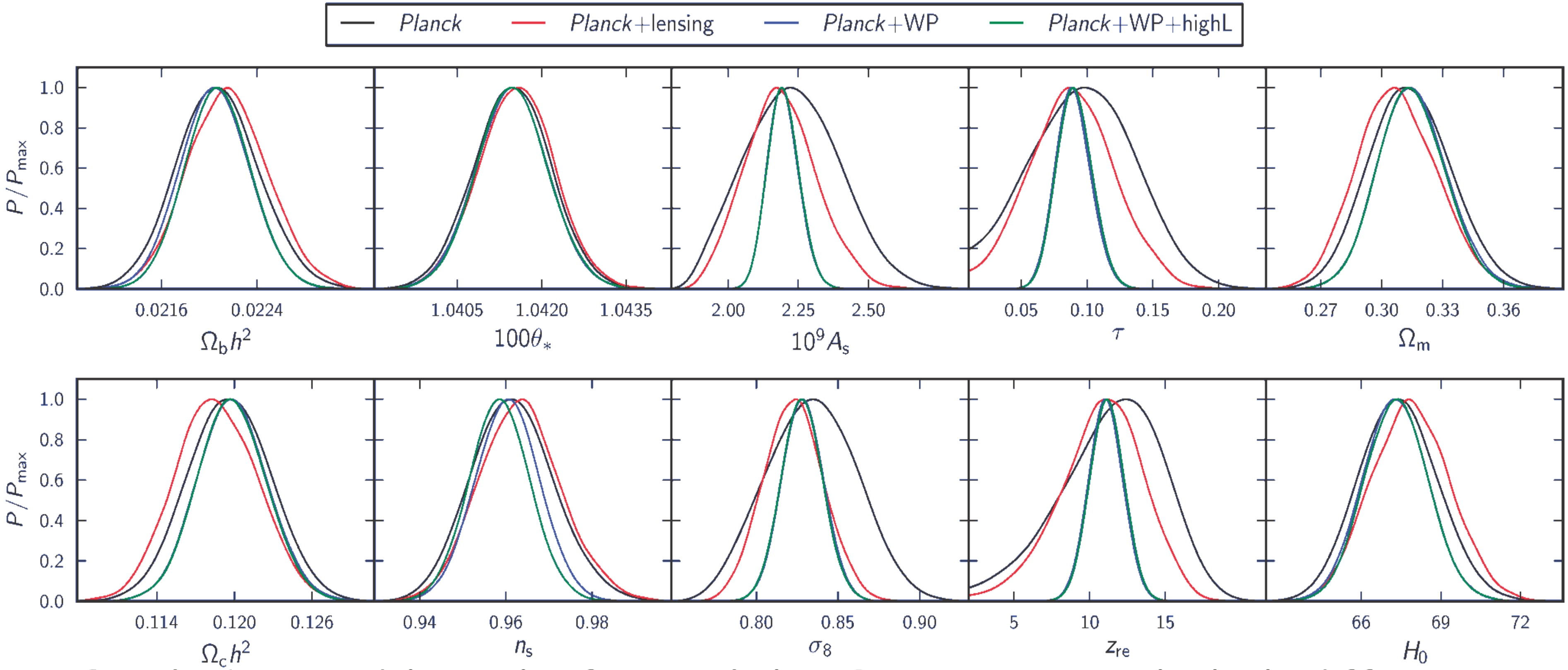
The Planck spectrum of Temperature anisotropies



Theory confronts data



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

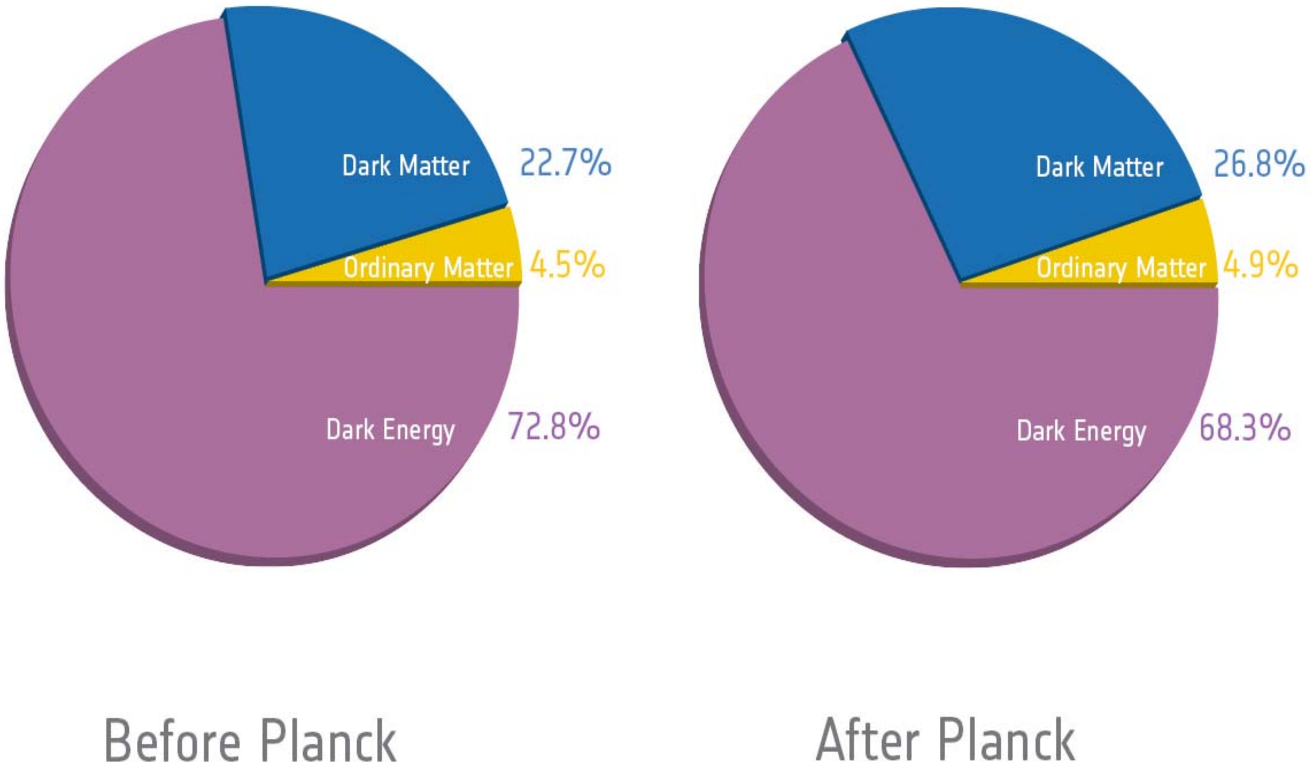
The sound horizon, θ, determined by the positions of the peaks (7), is now determined with 0.05% precision
(links together $\Omega_b h^2$, $\Omega_c h^2$, H_0 - here as $\Omega_m h^3$)

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

(as predicted by base inflation models)

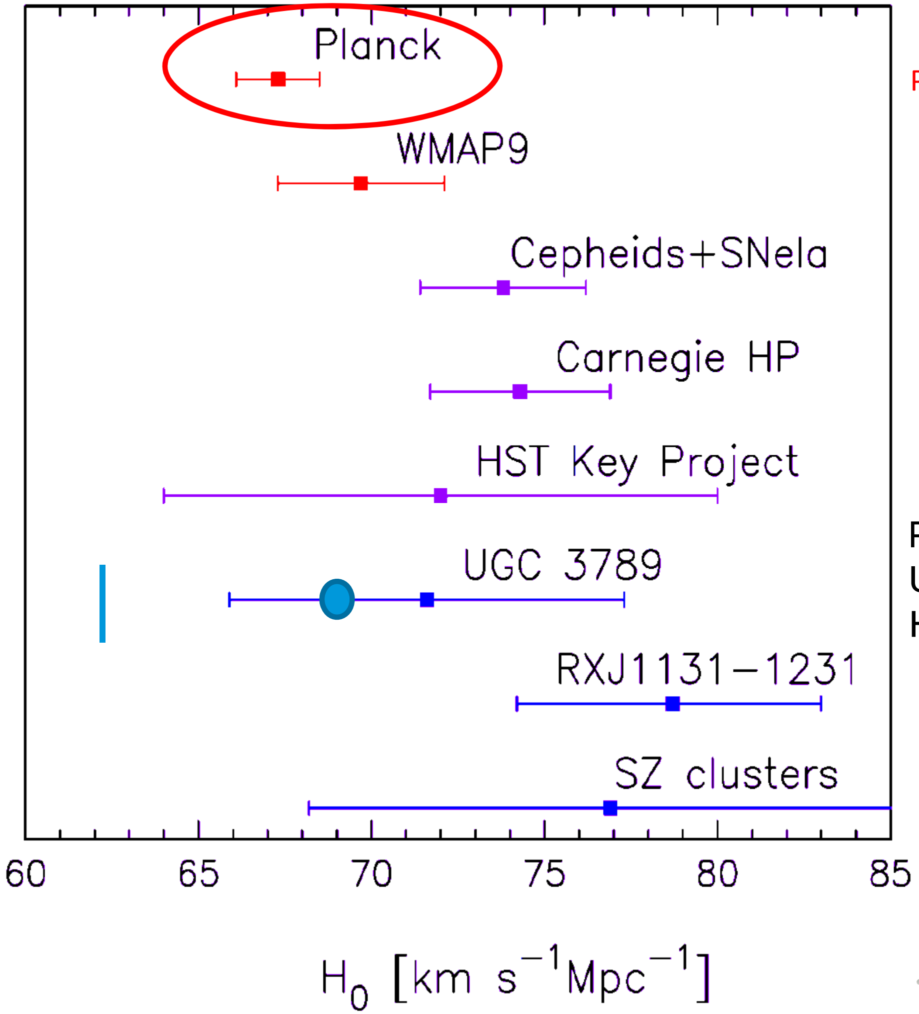
$$\theta_* = (1.04148 \pm 0.00066) \times 10^{-2} = 0.596724° \pm 0.00038°$$

The basic content of the Universe



...has changed!

The rate of expansion



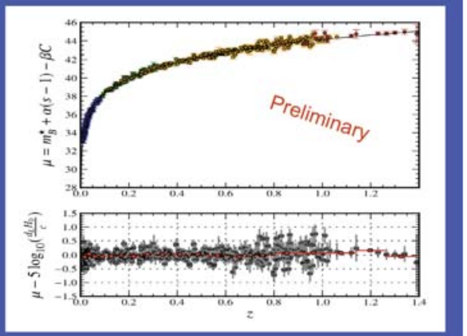
Planck H_0 is 67.95 ± 1.5 km/s/Mpc

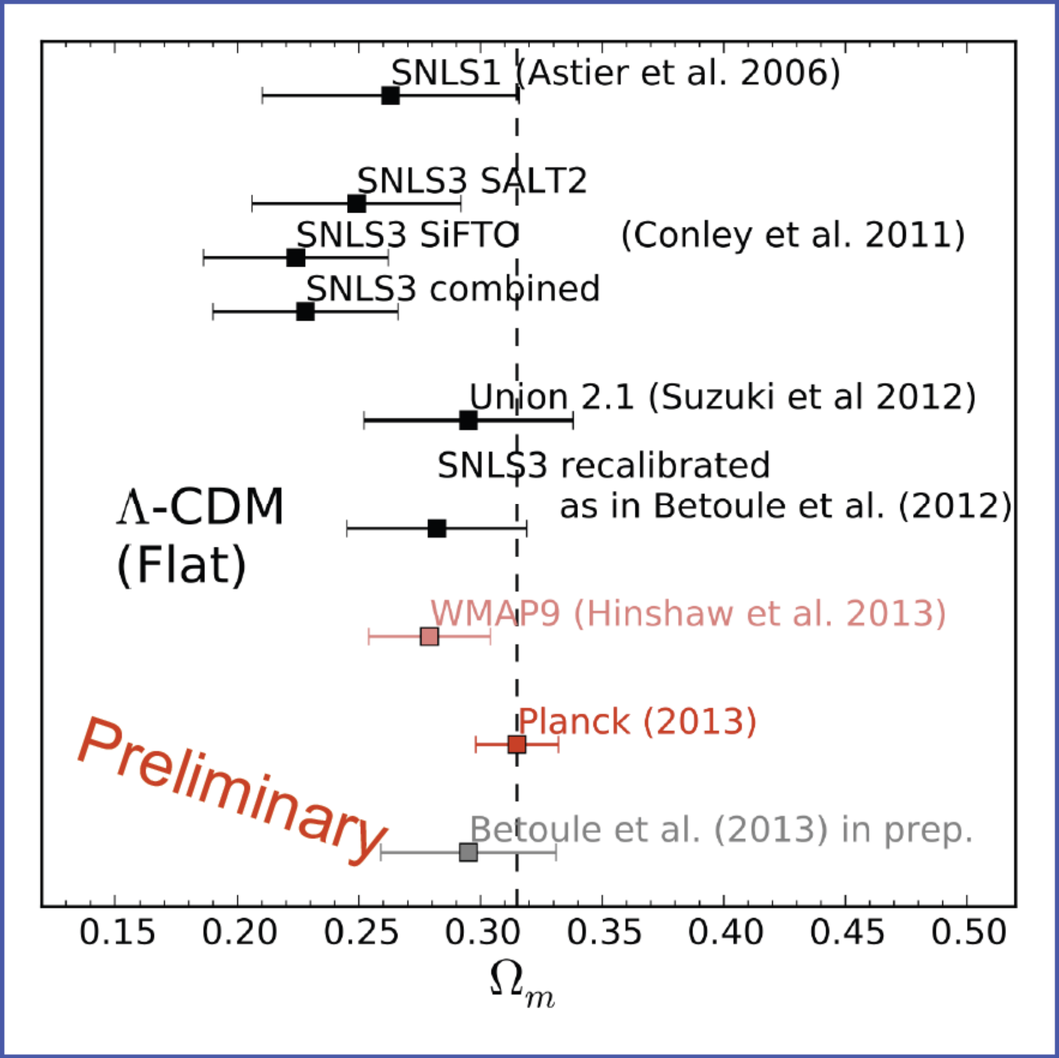
Pap IV replacement:
UGC now at ~ 50 Mpc &
H_0=68.9±7.1km/s/Mpc

... has changed also

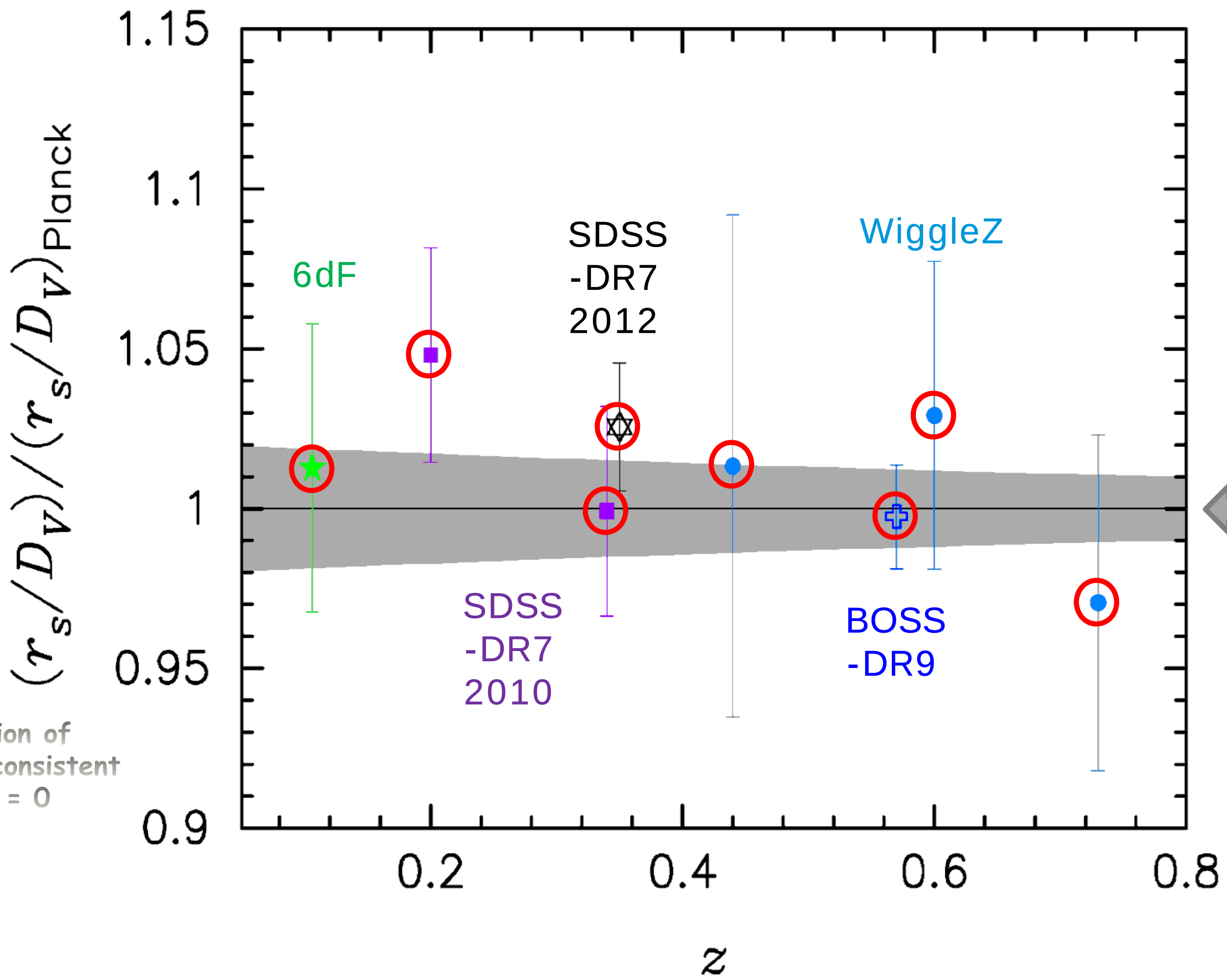
Comparison with Planck results

SNLS-SDSS joint Hubble diagram





BAO acoustic-scale distance ratio

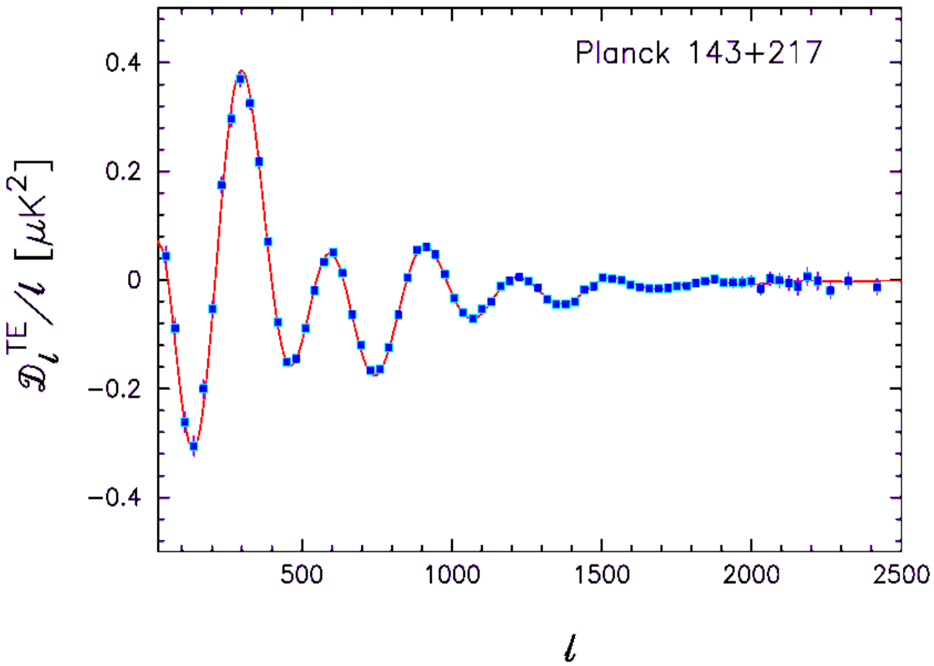


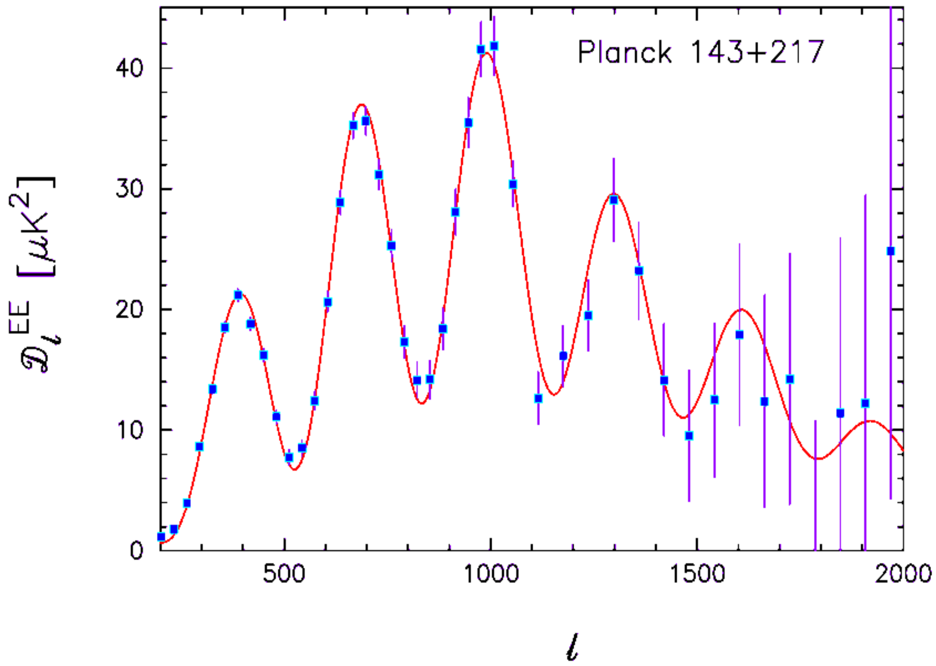
Planck Prediction (shaded area)

→ 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!



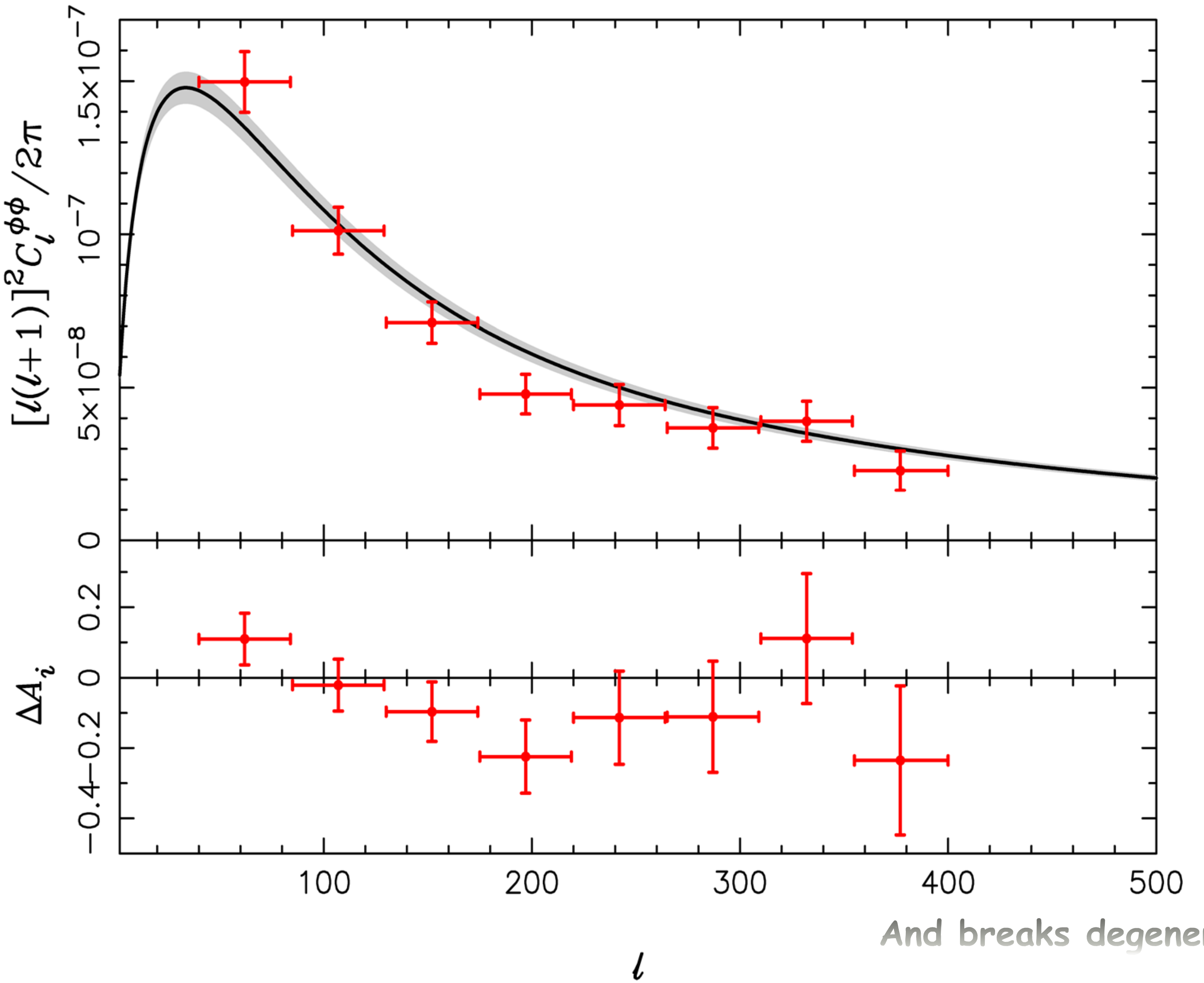


Red is prediction in base model from fitting T alone

The lensing potential power spectrum

This potential gives the displacement field

(26σ detection)



→ Agrees well with the prediction from T alone

And breaks degeneracy in open U.

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 $dn_s/dlnk \neq 0$?)
- Existence of primordial gravitational waves, $r_{0.002}$ ($\neq$ 0 ?)

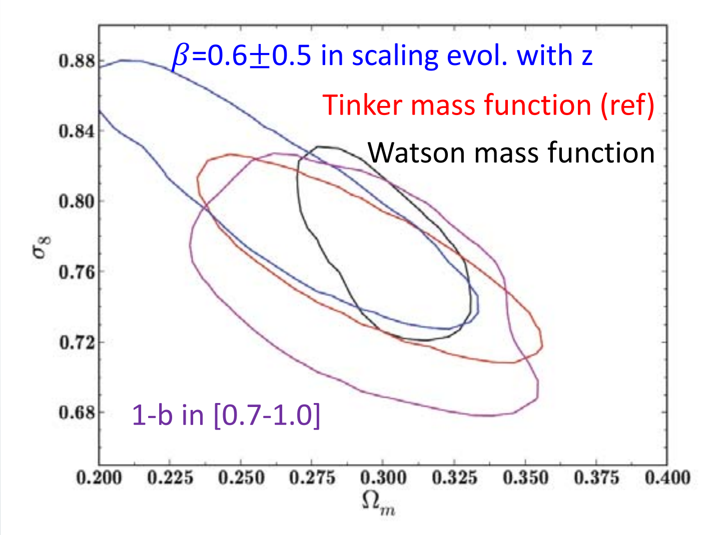
➔ no compelling evidence for any of them

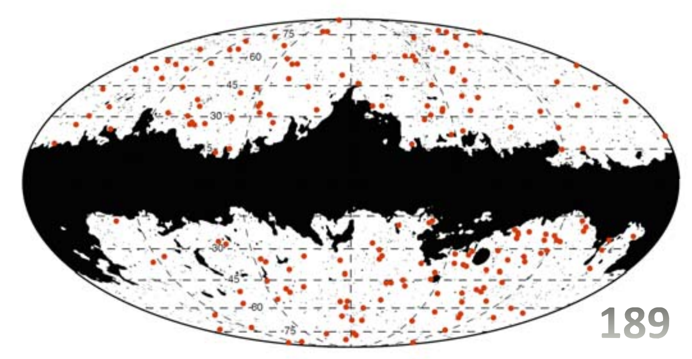
	Planck+WP		*Planck*+WP+BAO		*Planck*+WP+highL		*Planck*+WP+highL+BAO	
Parameter	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits
Ω_K	−0.0105	$-0.037^{+0.043}_{-0.049}$	0.0000	$0.0000^{+0.0066}_{-0.0067}$	−0.0111	$-0.042^{+0.043}_{-0.048}$	0.0009	$-0.0005^{+0.0065}_{-0.0066}$
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_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:

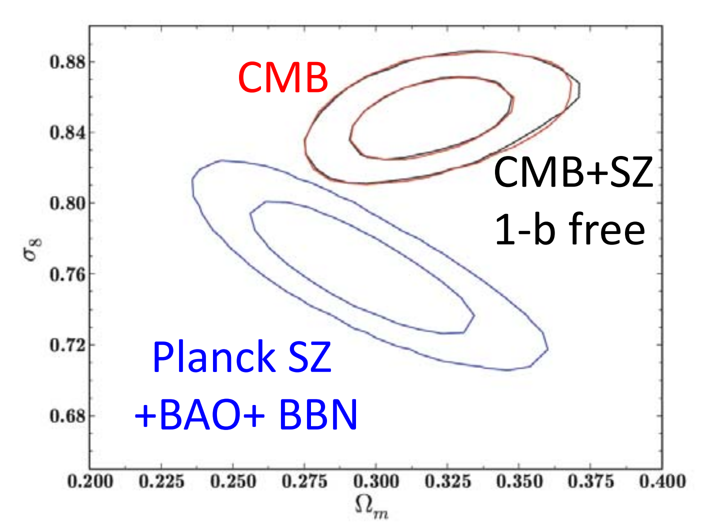
- Existence of an "isocurvature" part in the primordial fluctuations
- Existence of cosmic strings ($G\mu/c^2$<1.3 10^{-7})
- Non-Gaussian signatures of non-minimal inflation (f^{local}=2.7±5.8, f^{equil} =-42±75,f^{ortho}=-25±39 68%CL)
- Evolution of the fine structure constant, dark matter annihilation,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

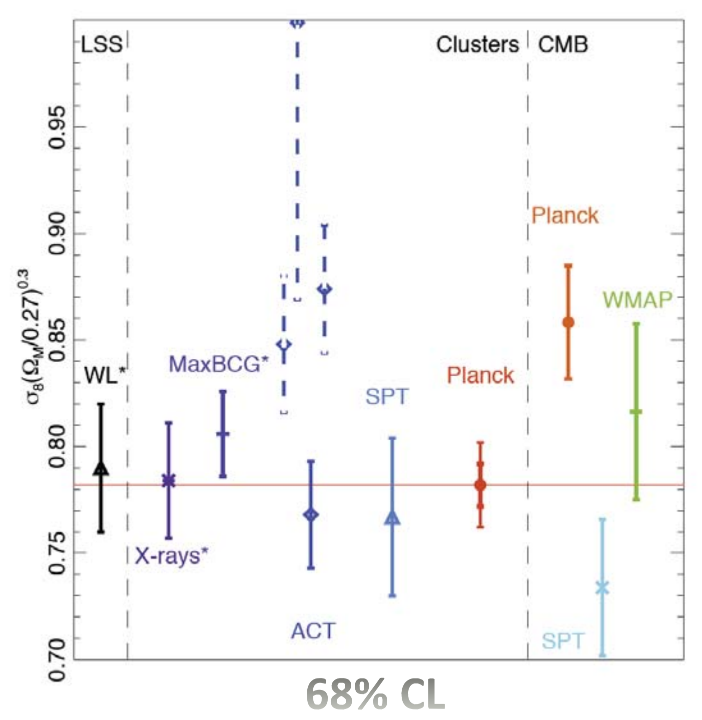
SZ / CMB tension



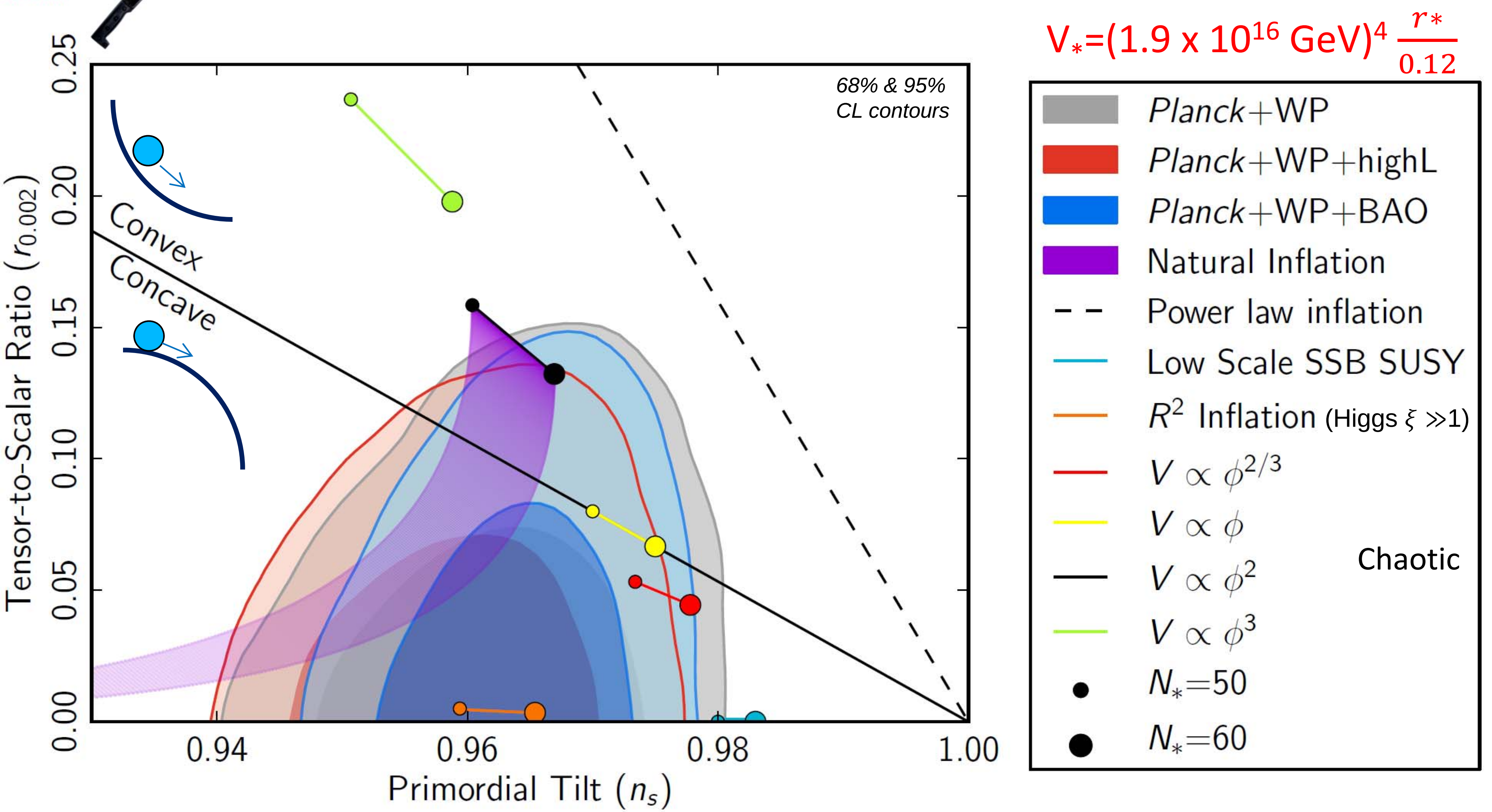


σ_8 measures the amplitude of fluctuations on $8h^{-1}$ Mpc scale today: σ_8 =F(A_s)



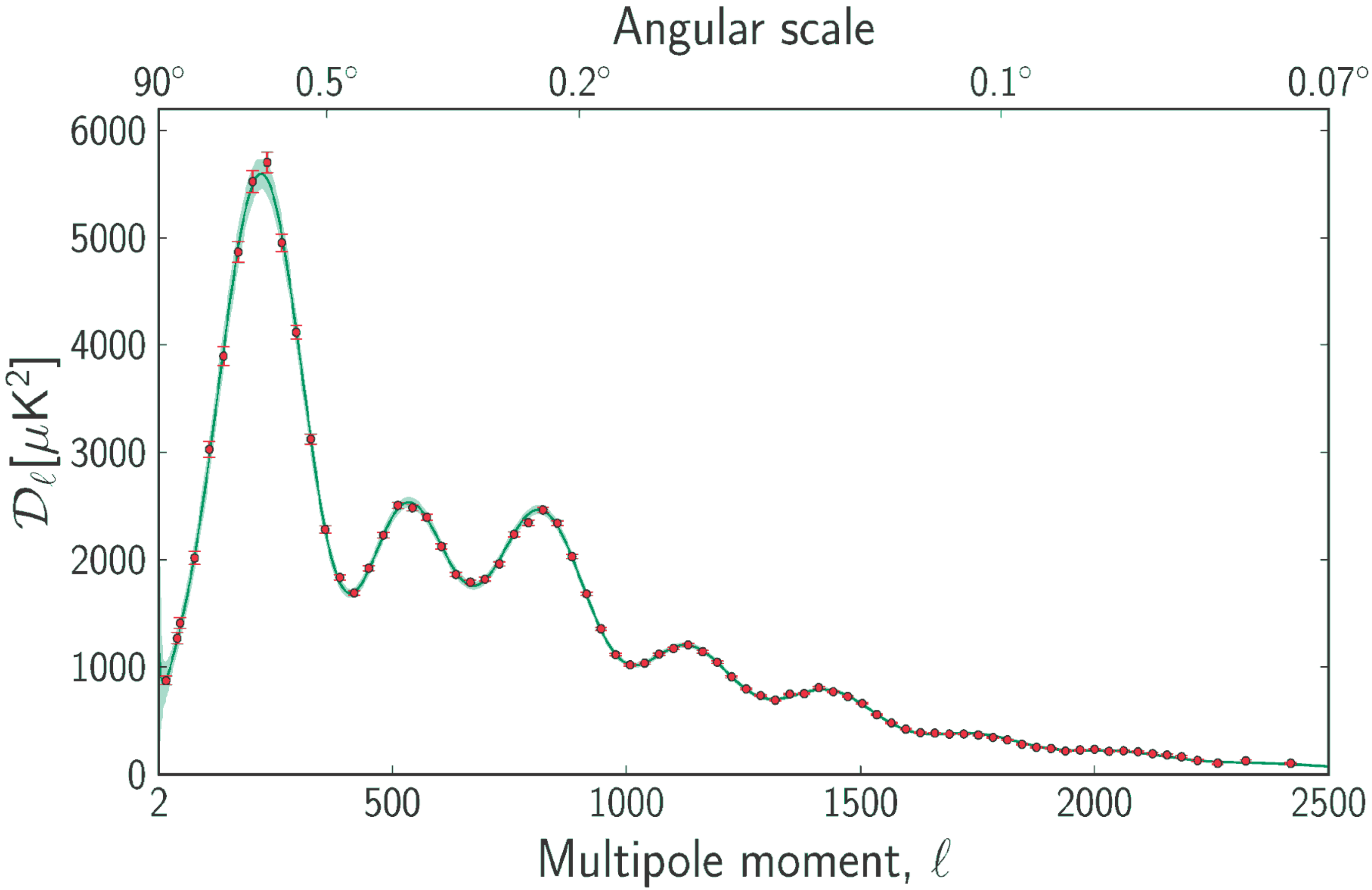


Constraint on representative Inflation models

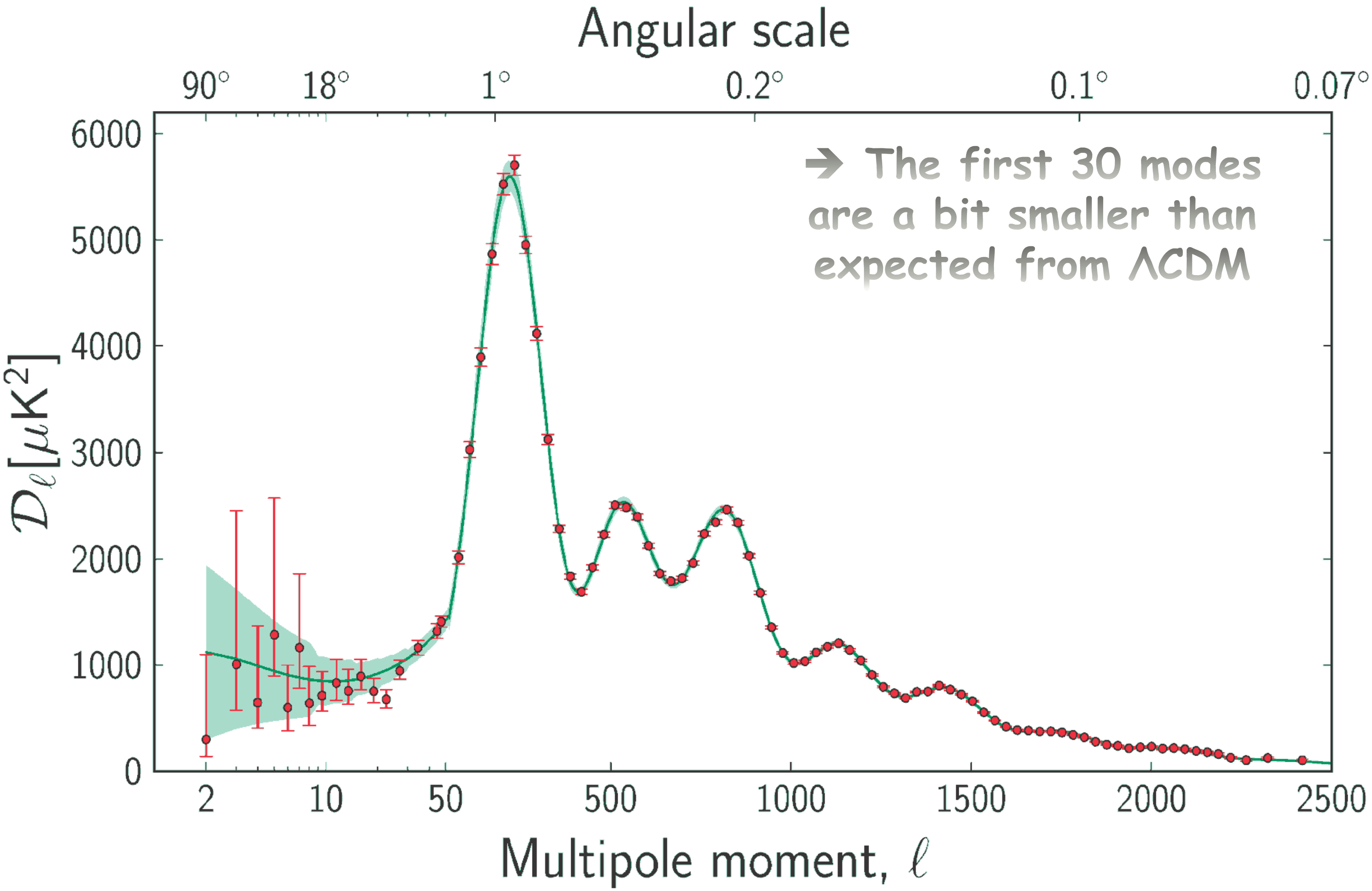


➔Exponential potential models(power-law inf.), simplest hybrid inflationary models (SB SUSY), monomial potential models of degree n >2 do not provide a good fit to the data.

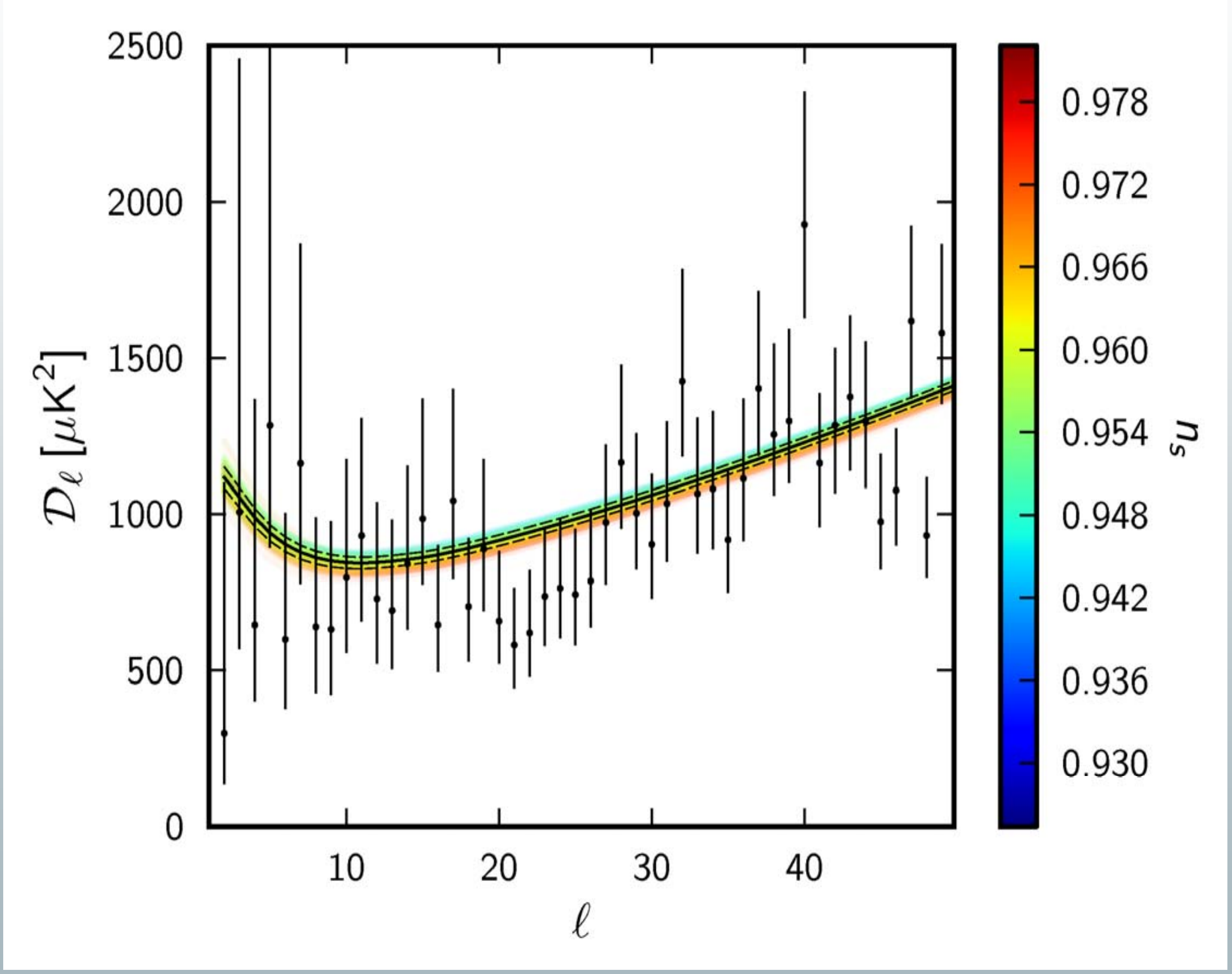
A theorist dream, or nightmare?



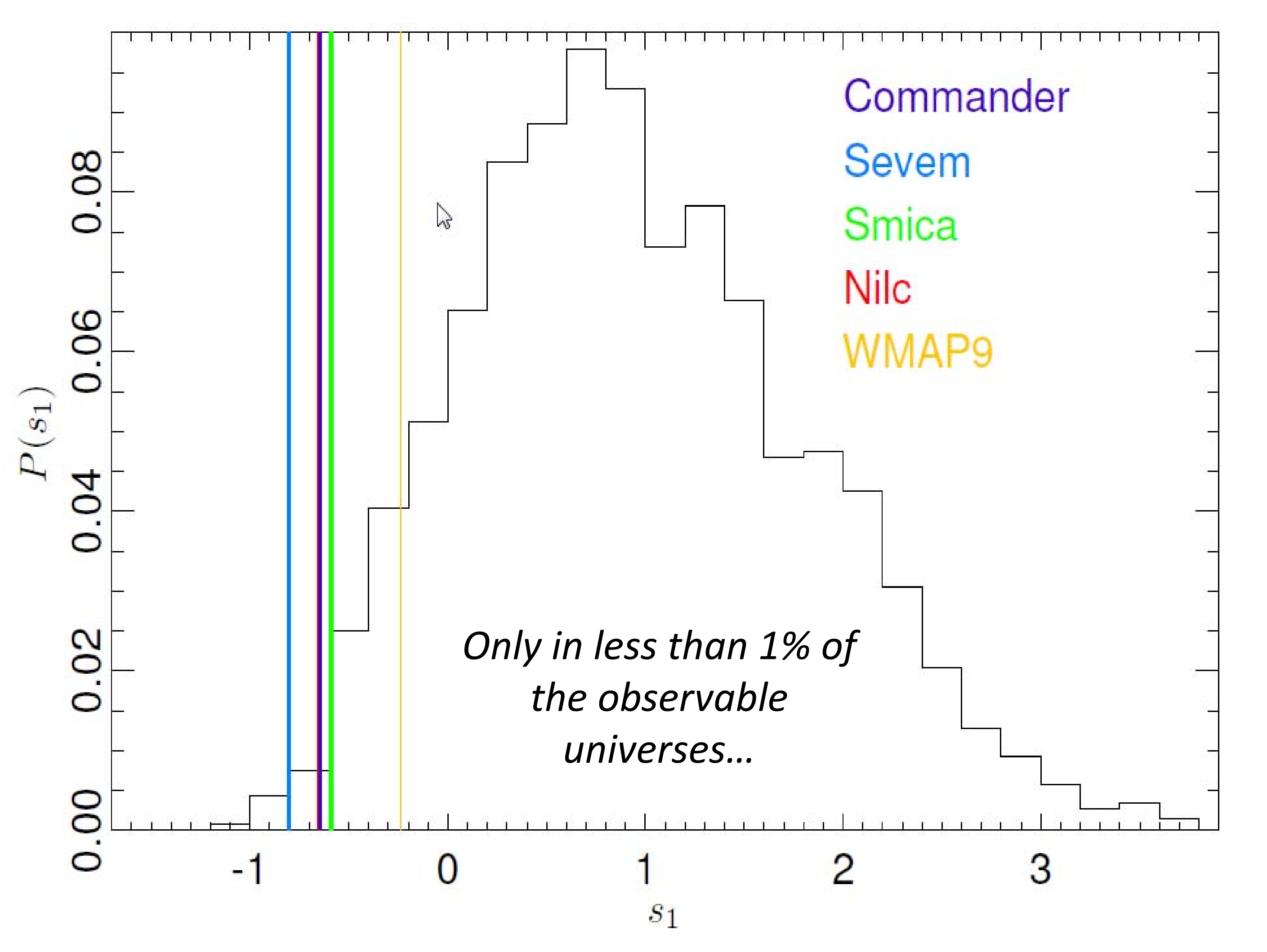
Zooming on the very largest scales, l<50…



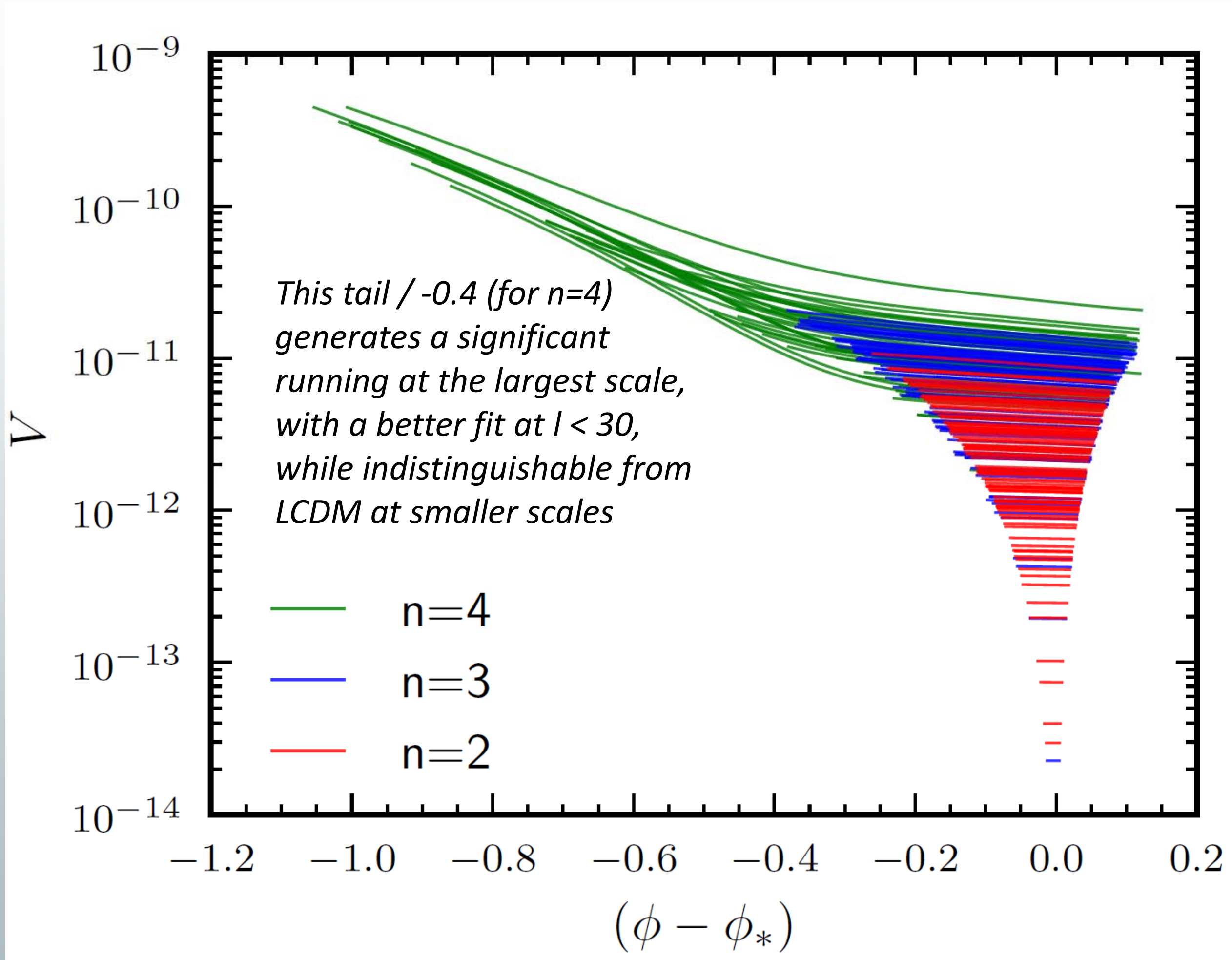
The low-multipole surprise/tension



How significant is the anomaly?



Inflaton potential reconstruction



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

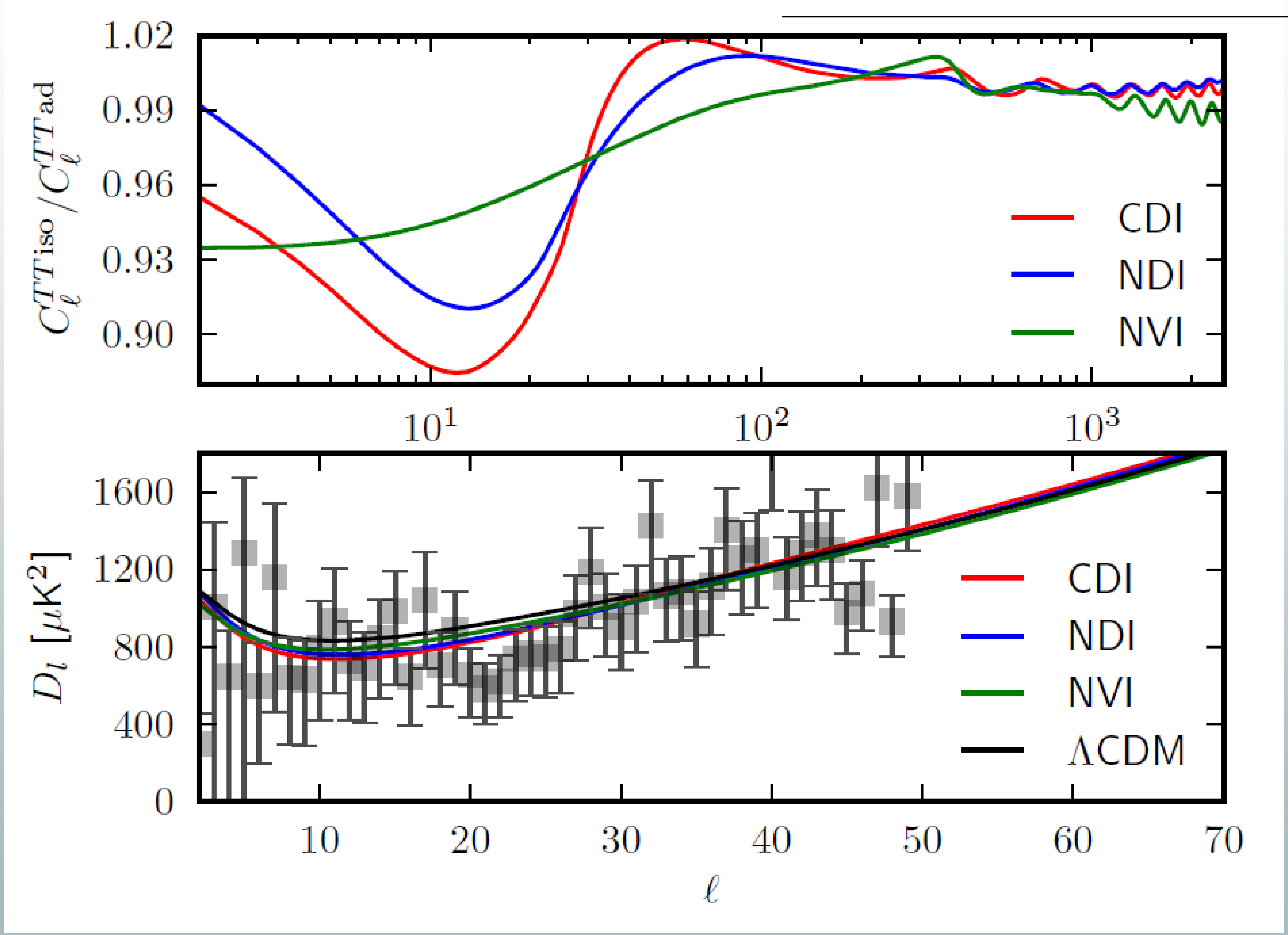
Planck-T+WP;

Flat priors on ε, η, ξ^2;

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

	from $V(\phi)$		
n	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

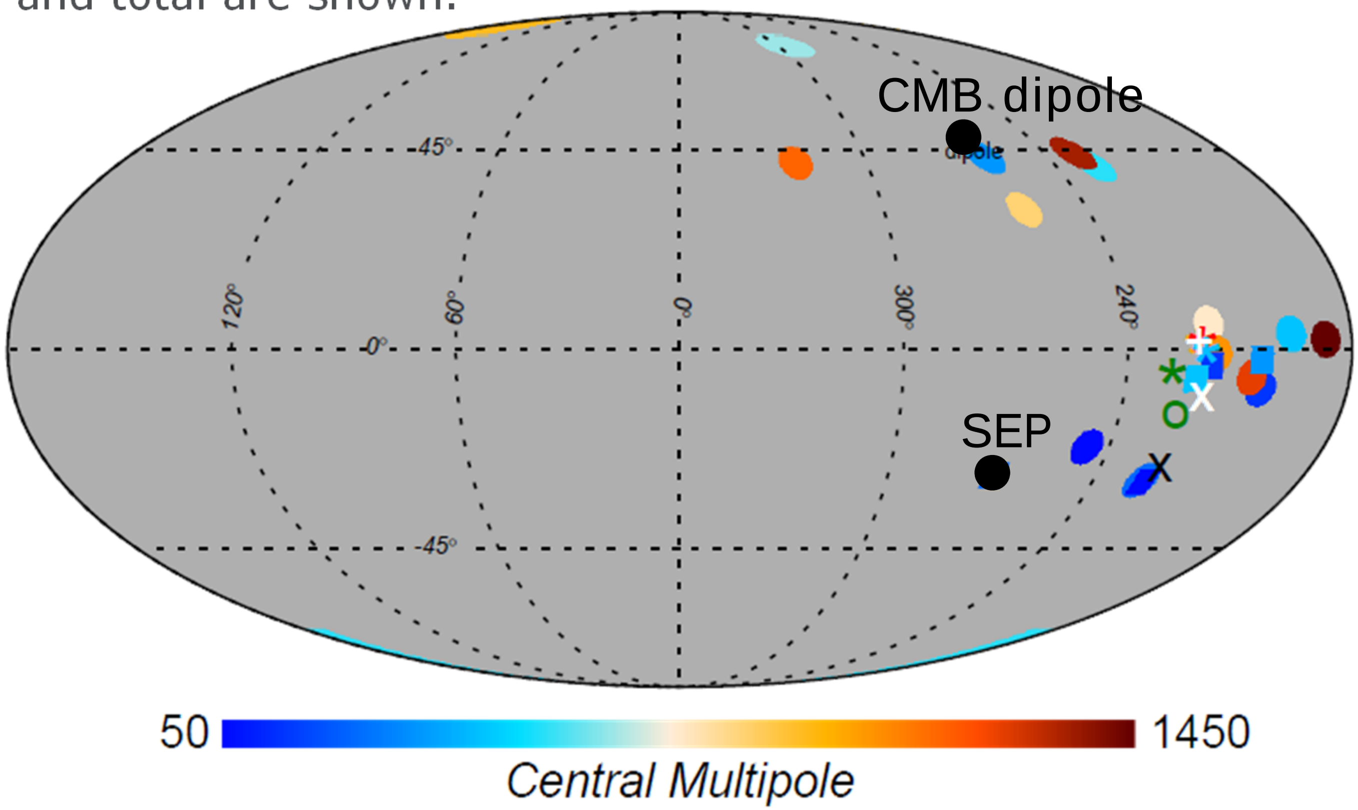
Assuming a single isocurvature mode



… helps (somewhat) at low-l (again!)

Power modulation versus scale

Following up on dipolar modulation of the anisotropies, on can compute dipole directions for 100-multipole bins of the local power spectrum distribution from l = 2-1500. Bins and total are shown.



SMICA map

$f_{sky} = 89\%$

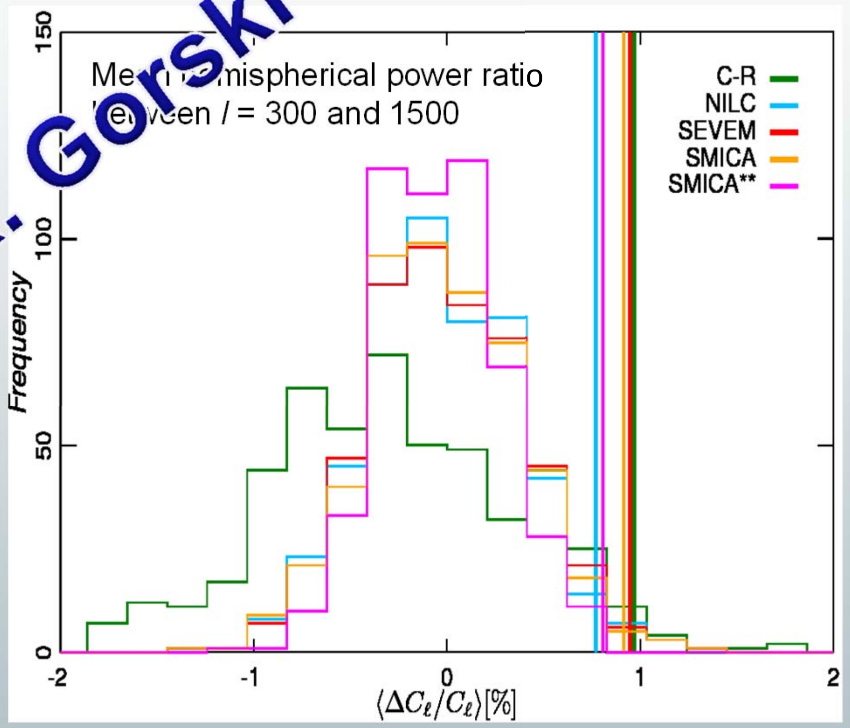
Also shown: total direction for l_max = 600 for WMAP9 (black X) and SMICA (white X) as well as for l_max = 1500 for SMICA (white big +). The stars with different colors correspond to C-R (green), NILC (deepskyblue), SEVEM (red) and SMICA (orange) with the U73 mask. The best fit dipole modulation direction from Sect. 5.5.2 is indicated by the white open circle.

Power ratio significance

- How large and how significant *is* the power ratio at high *l*'s?
- Compute mean ratio between *l* = 2 (300) and 1500 for both data and simulations, and count the fraction of simulation, *P*, with a larger ratio
- Summary of main results:

See K. Gorski's talk

Method	R [%]		P($R^{sim} > R^{data}$)	
	l_{min}= 2	l_{min}= 300	l_{min}= 2	l_{min}= 300
C-R	1.3	(1.0)	0.010	(0.030)
NILC	1.4	(0.8)	0.002	(0.038)
SEVEM	1.5	(0.9)	0.002	(0.016)
SMICA	1.5	(0.9)	0.002	(0.012)

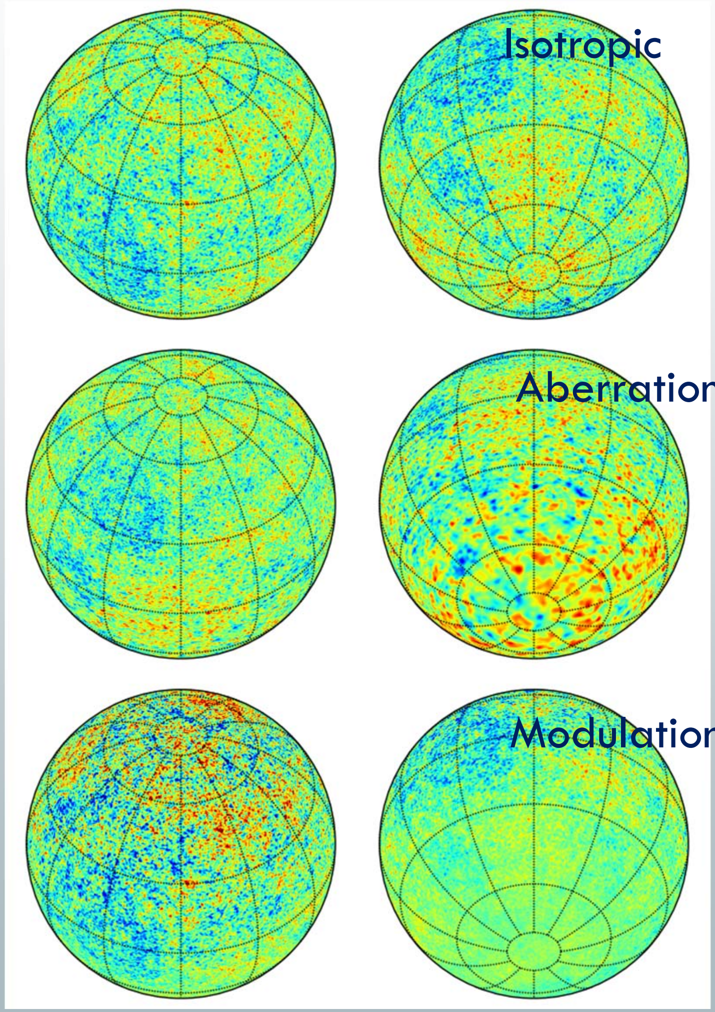


⇒ The high-*l* power asymmetry is significant at the ~3σ level, as estimated both by angle dispersion and by power ratio

Detection of Doppler boosting

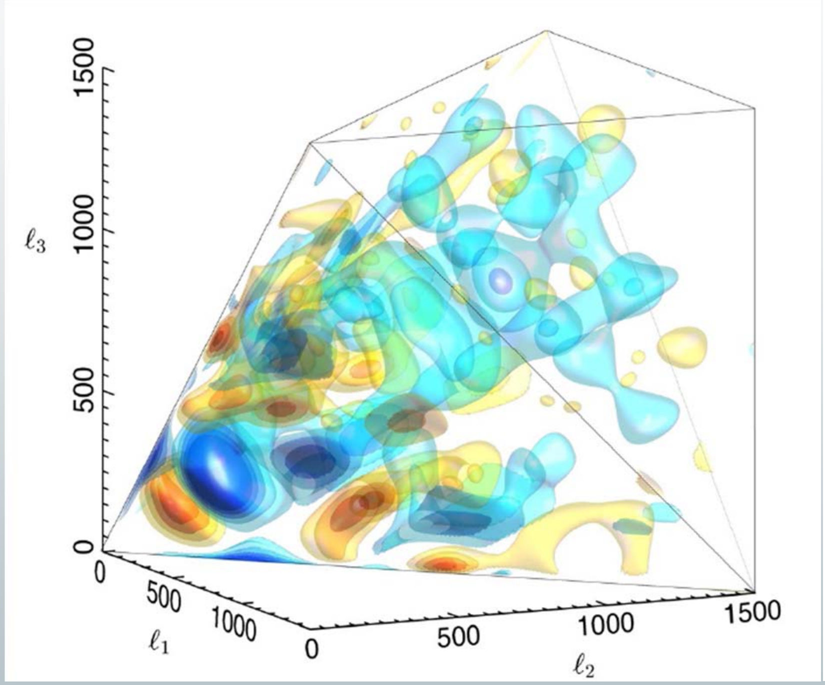
- Planck's high sensitivity and angular resolution allows for the first direct detection of relativistic Doppler boosting in the CMB fluctuations
- Two different effects are relevant, both of which are frequency-dependent:
  - Aberration: Spots are smaller in the direction of Earth's motion
  - Dipole modulation: Features are enhanced in the direction of Earth's motion
- Planck uses these to measure the Earth's velocity *independently* of the CMB dipole
  - v = 384±78 (stat)±115 (syst) km/s
- **Modulation explains at least part of the high-*l* asymmetry**

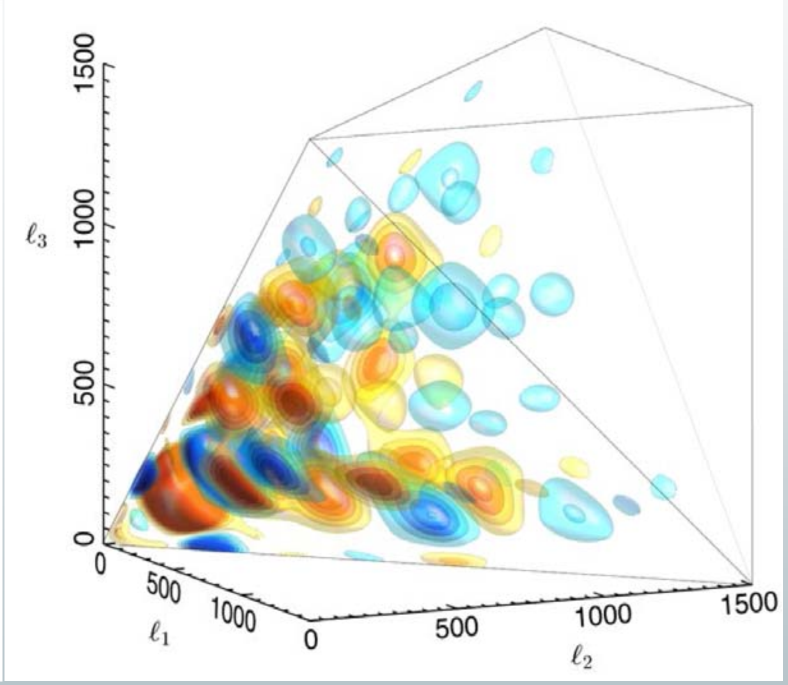
Eppur si muove



Planck 2013 XXVII

3.2-sigma hint of oscillatory feature?





Not (yet?) highly significant if “look-elsewhere” effect is taken into account.
➔ Warrants further analysis.

Conclusions 1/3

- The Planck hardware and scanning strategy afford a wide array of consistency tests.
- Planck’s performance on these tests gives confidence that its unprecedented sensitivity is being realized, and that its scientific results are robust.
- A number of corrections and improved calibration and analysis procedures are known and will be implemented for the 2014 release. Everything we known suggests that these will only improve the consistency of the data, and bring HFI and LFI into even closer agreement.

Conclusions 2/2

- 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 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?)***

Conclusions 3/3

- 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…)*
  - *All ESLAB slides at http://www.rssd.esa.int/index.php?project=PLANCK&page=47_ESLAB*
- 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.