WTHIGOW

Tau

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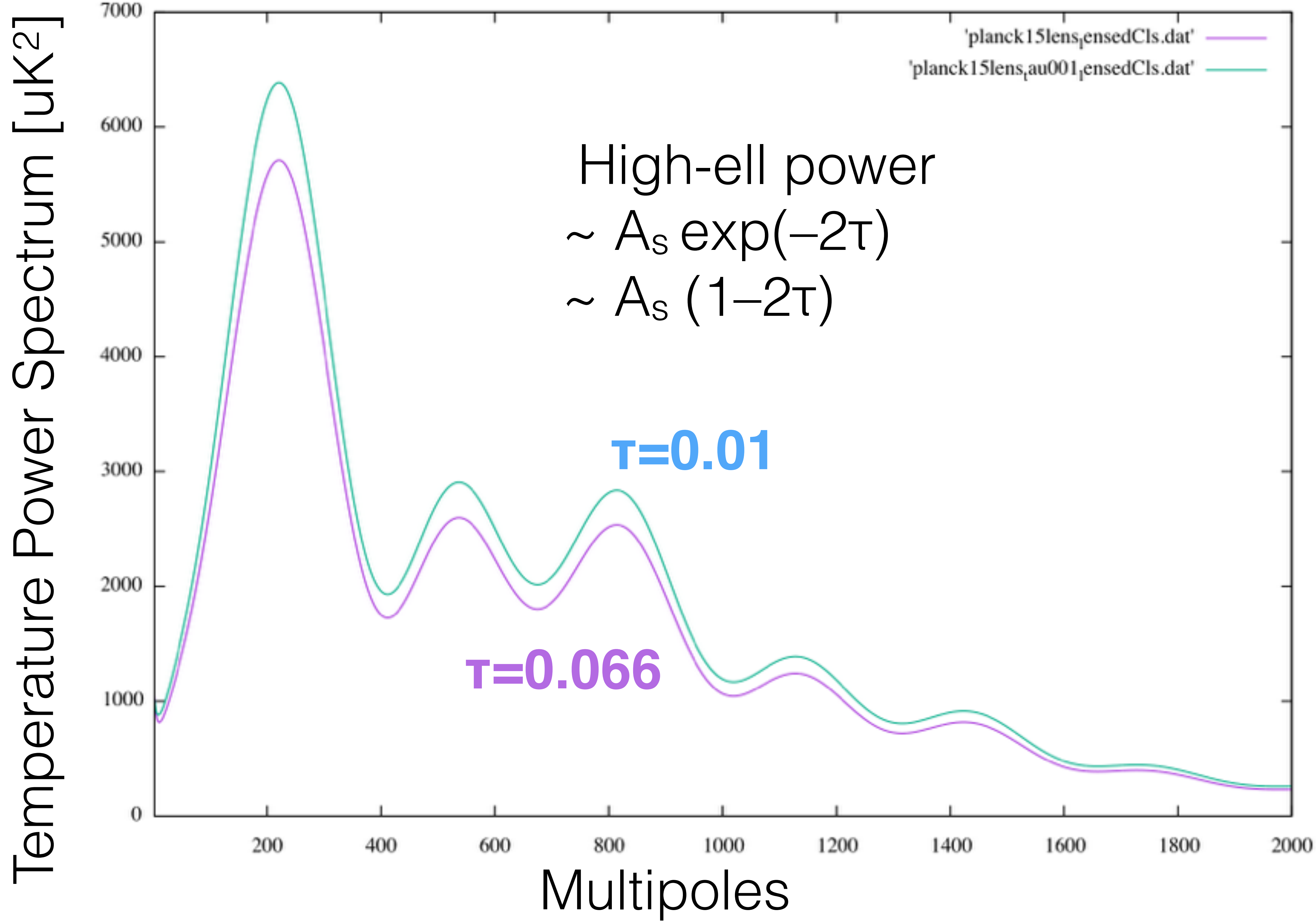
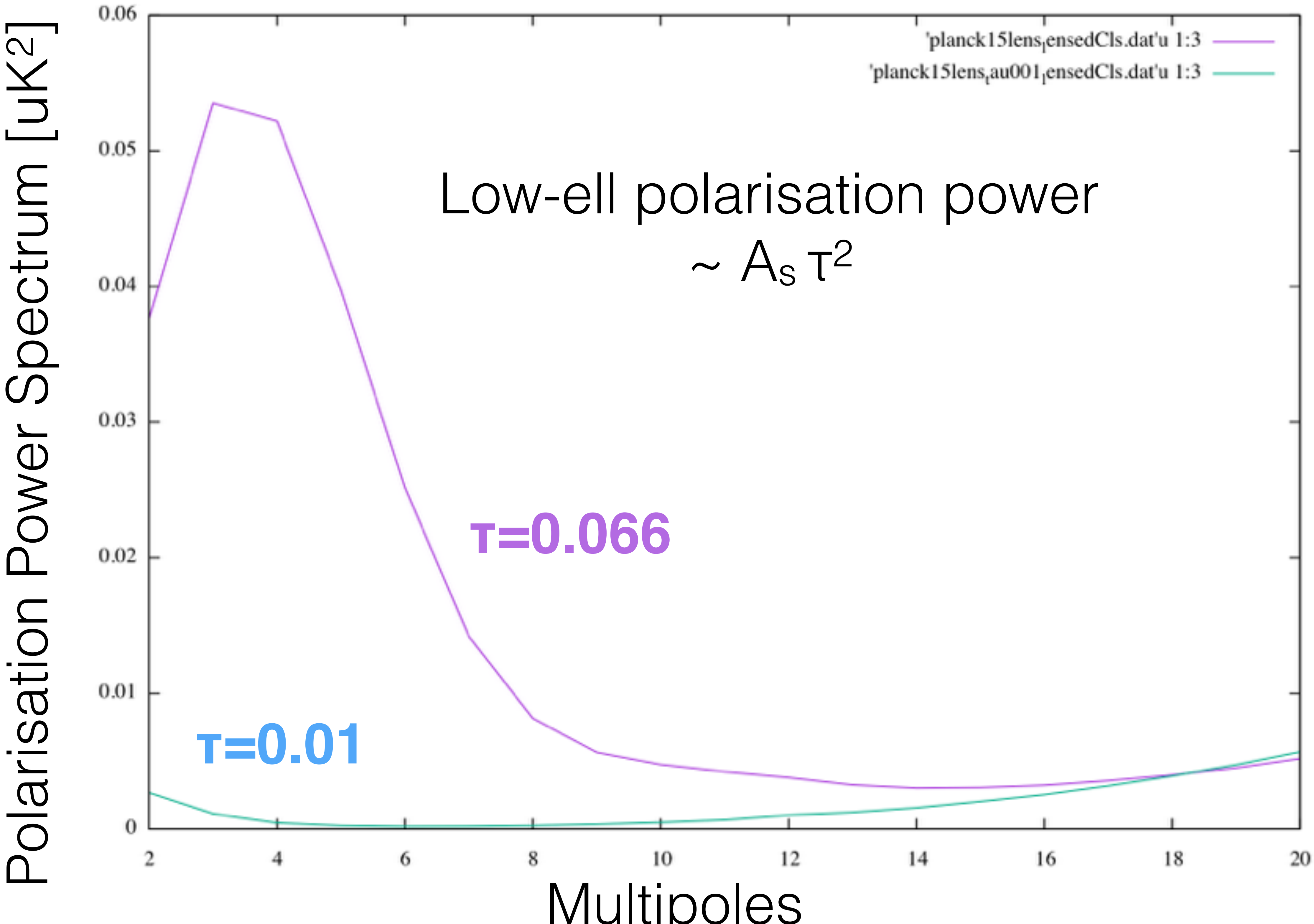
What does tau do?

- **Tau suppresses power at high multipoles**



What does tau do?

- **Tau adds polarisation power at low multipoles**



WMAP9 Paper; Planck 2015 Likelihood Paper

Optical Depth

[Temperature and Low-ell Polarisation Only;
No CMB lensing information]

	WMAP9 T+P	Planck HFI T +WMAP9 P cleaned by 353GHz	Planck HFI T +LFI P cleaned by 353GHz	Planck HFI T +WMAP9+LFI P cleaned by 353GHz
T	0.089±0.014	0.071±0.012	0.077±0.019	0.074±0.012

WMAP's Polarisation and Planck LFI's Polarisation are in very good agreement

WMAP9 Paper; Planck 2015 Likelihood Paper

Optical Depth

[Temperature and Low-ell Polarisation Only; No CMB lensing information]

	WMAP9 T+P	Planck HFI T +WMAP9 P cleaned by 353GHz	Planck HFI T +LFI P cleaned by 353GHz	Planck HFI T +WMAP9+LFI P cleaned by 353GHz
τ	0.089±0.014	0.071±0.012	0.077±0.019	0.074±0.012
$10^9 A_s e^{-2\tau}$	1.847 ⟶	1.879	1.878	1.879

An increase in the best-fit $A_s e^{-2\tau}$ (1.7%) can contribute to a downward shift τ [of order 0.017/2=0.0085].

Not just dust cleaning of the polarisation data

My Reaction
[in both 2013 and 2014]

- A drop from τ=0.089 to 0.074 (or so)
  - **Fine**. This is within the systematic error budget due to the foreground uncertainty quoted in the WMAP 5-year paper (Komatsu et al. 2009)

WMAP9 Paper; Planck 2015 Likelihood & Parameters Papers

Optical Depth

[Temperature and Low-ell Polarisation;
plus CMB lensing information]

	WMAP9 T+P	Planck HFI T +WMAP9 P cleaned by 353GHz	Planck HFI T +LFI P cleaned by 353GHz	Planck HFI T +WMAP9+LFI P cleaned by 353GHz	Planck HFI T +LFI cleaned by 353GHz + Lensing
τ	0.089±0.014	0.071±0.012	0.077±0.019	0.074±0.012	**0.066±0.016**

What happened?

WMAP9 Paper; Planck 2015 Likelihood & Parameters Papers

Optical Depth

[Temperature and Low-ell Polarisation, **plus** CMB lensing information]

	Planck HFI T +LFI P cleaned by 353GHz		Planck HFI T +LFI P cleaned by 353GHz + CMB Lensing
τ	0.077±0.019		**0.066±0.016**
$10^9 A_s e^{-2\tau}$	1.878±0.014	Little change →	1.874±0.013
$10^9 A_s$	2.191	~1σ drop →	2.139±0.063
σ_8	0.829±0.014	~1σ drop →	0.815±0.009

A drop in tau comes from a drop in the amplitude preferred by lensing

$$\tau = 0.078^{+0.019}_{-0.019},\ z_{\rm re} = 9.9^{+1.8}_{-1.6},\ \textit{Planck}\ \mathrm{TT{+}lowP}; \tag{17a}$$

$$\tau = 0.070^{+0.024}_{-0.024},\ z_{\rm re} = 9.0^{+2.5}_{-2.1},\ \textit{Planck}\ \mathrm{TT{+}lensing}; \tag{17b}$$

$$\tau = 0.066^{+0.016}_{-0.016},\ z_{\rm re} = 8.8^{+1.7}_{-1.4},\ \textit{Planck}\ \mathrm{TT{+}lowP{+}lensing}; \tag{17c}$$

$$\tau = 0.067^{+0.016}_{-0.016},\ z_{\rm re} = 8.9^{+1.7}_{-1.4},\ \textit{Planck}\ \mathrm{TT{+}lensing{+}BAO}; \tag{17d}$$

$$\tau = 0.066^{+0.013}_{-0.013},\ z_{\rm re} = 8.8^{+1.3}_{-1.2},\ \textit{Planck}\ \mathrm{TT{+}lowP{+}lensing{+}BAO}. \tag{17e}$$

My Reaction

- A drop from τ=0.074 to 0.066

  - This could be a true value in our Universe, but *it is not due to a change in the polarisation data,* i.e., ***it is not a question about the unknown systematic errors in the polarisation data.*** *It is more about the cosmological interpretation of the data* ***as a whole (T+P+CMB lensing)***

  - CMB lensing is still in its infancy, so let's proceed with caution

A question for you:

Table 4. Parameter 68 % confidence limits for the base ΛCDM model from *Planck* CMB power spectra, in combination with lensing reconstruction ("lensing") and external data ("ext," BAO+JLA+H_0). Nuisance parameters are not listed for brevity (they can be found in the *Planck Legacy Archive* tables), but the last three parameters give a summary measure of the total foreground amplitude (in μK^2) at $\ell = 2000$ for the three high-ℓ temperature spectra used by the likelihood. In all cases the helium mass fraction used is predicted by BBN (posterior mean $Y_P \approx 0.2453$, with theoretical uncertainties in the BBN predictions dominating over the *Planck* error on $\Omega_b h^2$).

Parameter	TT+lowP 68 % limits	TT+lowP+lensing 68 % limits	TT+lowP+lensing+ext 68 % limits	TT,TE,EE+lowP 68 % limits	TT,TE,EE+lowP+lensing 68 % limits	TT,TE,EE+lowP+lensing+ext 68 % limits
$\Omega_b h^2$	0.02222 ± 0.00023	0.02226 ± 0.00023	0.02227 ± 0.00020	0.02225 ± 0.00016	0.02226 ± 0.00016	0.02230 ± 0.00014
$\Omega_c h^2$	0.1197 ± 0.0022	0.1186 ± 0.0020	0.1184 ± 0.0012	0.1198 ± 0.0015	0.1193 ± 0.0014	0.1188 ± 0.0010
$100\theta_{MC}$	1.04085 ± 0.00047	1.04103 ± 0.00046	1.04106 ± 0.00041	1.04077 ± 0.00032	1.04087 ± 0.00032	1.04093 ± 0.00030
τ	0.078 ± 0.019	0.066 ± 0.016	0.067 ± 0.013	0.079 ± 0.017	0.063 ± 0.014	0.066 ± 0.012
$\ln(10^{10} A_s)$	3.089 ± 0.036	3.062 ± 0.029	3.064 ± 0.024	3.094 ± 0.034	3.059 ± 0.025	3.064 ± 0.023
n_s	0.9655 ± 0.0062	0.9677 ± 0.0060	0.9681 ± 0.0044	0.9645 ± 0.0049	0.9653 ± 0.0048	0.9667 ± 0.0040
H_0	67.31 ± 0.96	67.81 ± 0.92	67.90 ± 0.55	67.27 ± 0.66	67.51 ± 0.64	67.74 ± 0.46

0.078, 0.066, 0.067, 0.079, 0.063, 0.066

On what basis did you pick one (e.g., 0.066) among these numbers, without taking into account the spread in the interpretation?

Then I heard…

- Jean-Loup Puget gave a talk, quoting a value from the analysis of Planck **HFI** data, cross-correlated with LFI:
    - τ=0.055±0.008(?)
    - I do not know any details of the analysis, so in principle I should not say anything about it, but let's speculate for fun…
- This value seems low, *especially if nothing else in the analysis changed*; namely, if lensing etc were held fixed, it would be the polarisation data that pulled this
    - [But again, I do not know if everything else was held fixed]
- If everything else was indeed held fixed, then **I do not know how both WMAP and Planck LFI could be so off compared to the value of HFI. This is a question of the systematics!**

WMAP vs Planck: Pros and Cons

- **WMAP**: noisy, but a simple experiment in terms of the controls of systematics
- **Planck HFI**: very sensitive, but a complicated experiment with the known systematics in large-angle polarisation

Planck HFI can give you a very small statistical error.
But what about systematic errors?

Planck 2013 HFI Data Processing Paper

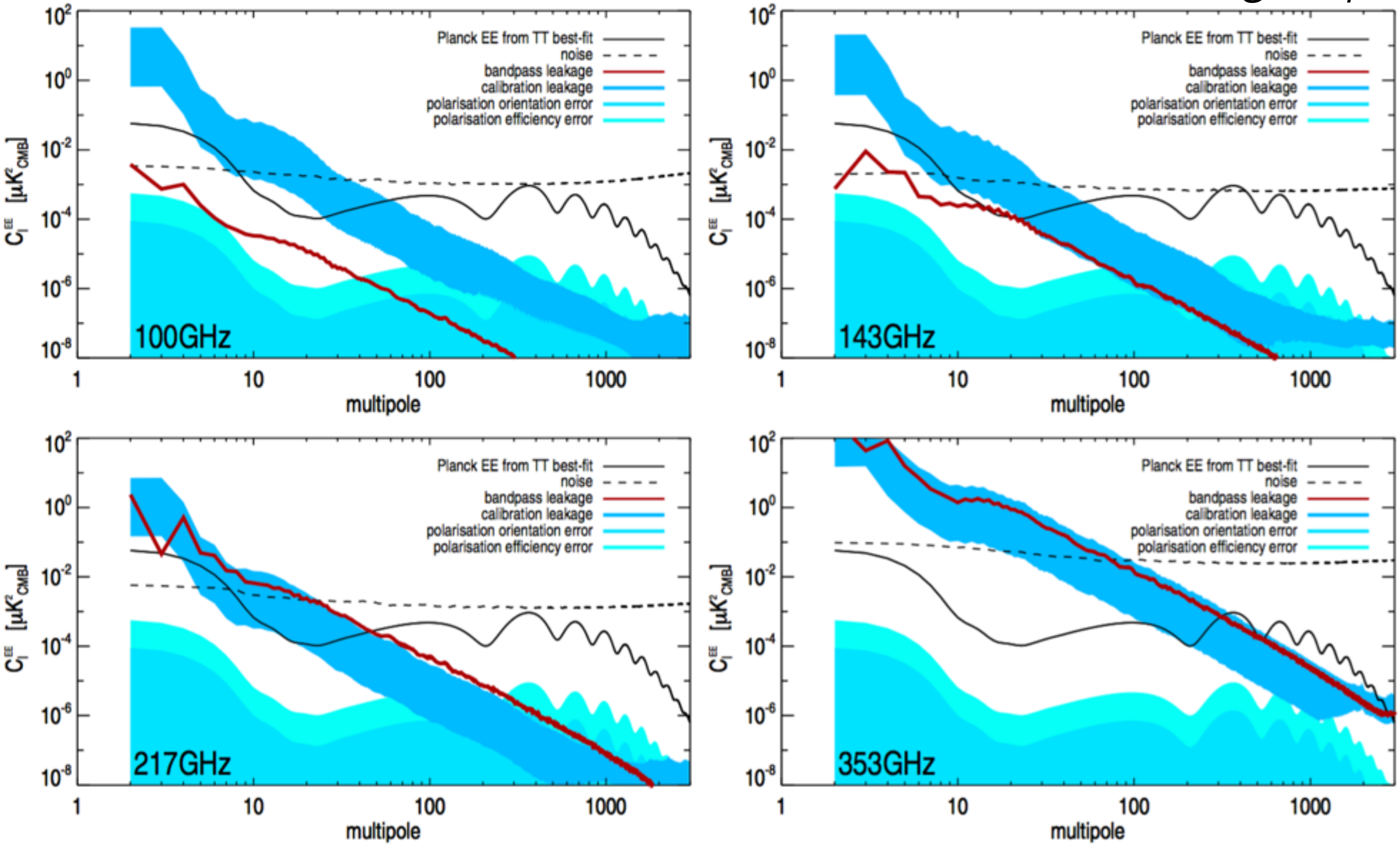
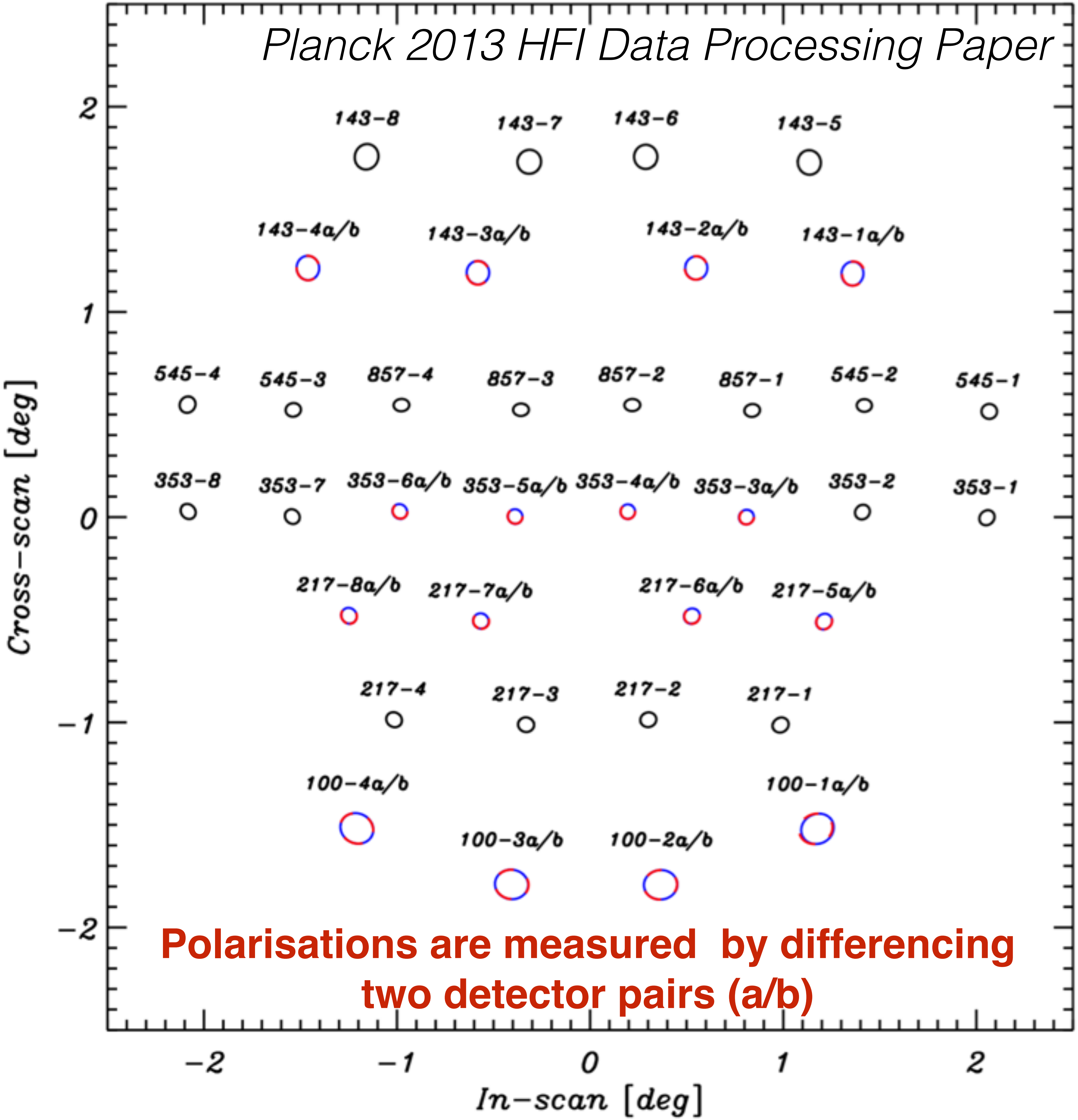
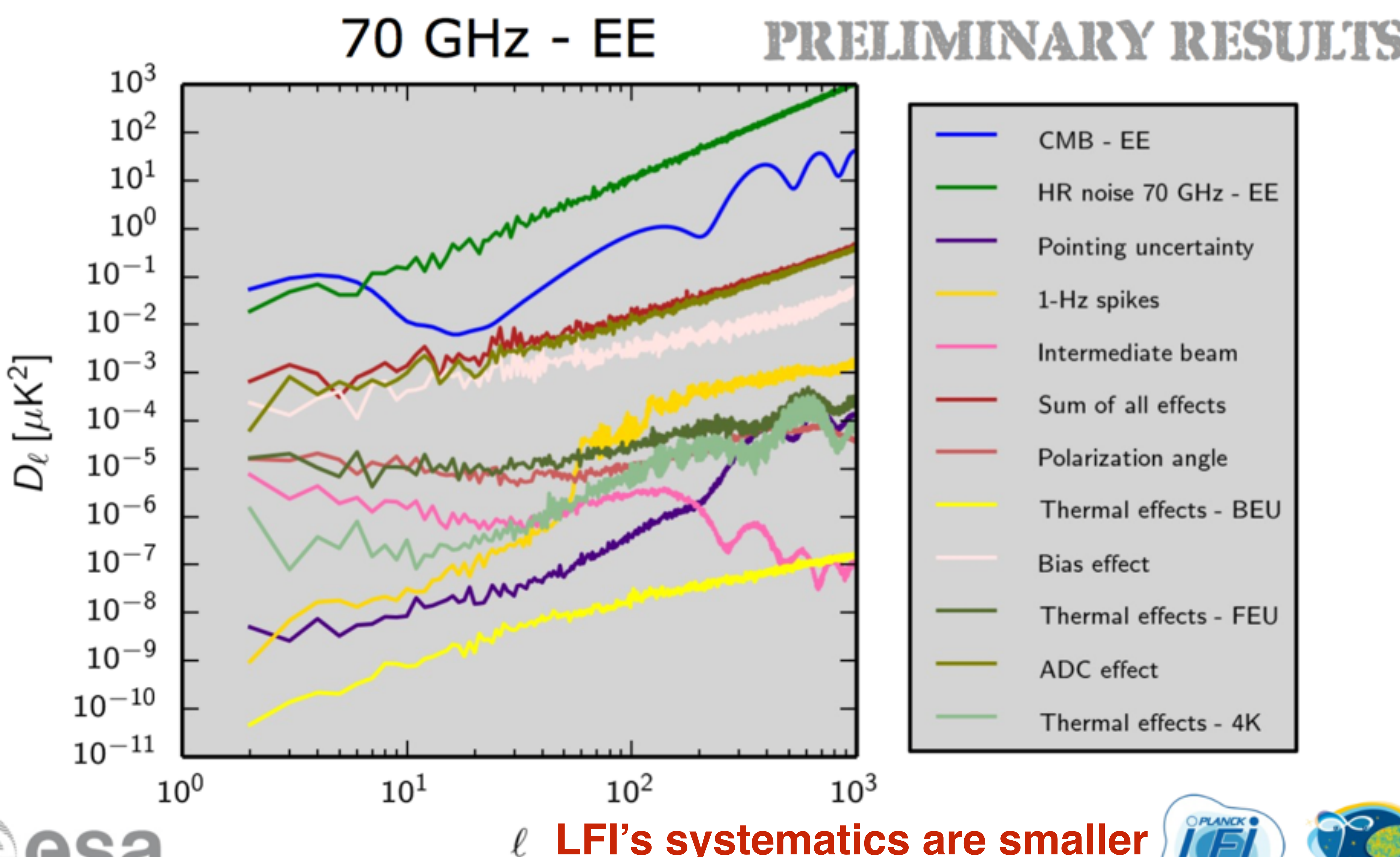


Figure 27. Uncertainties on polarized power spectra due to residual systematics in the HFI polarization maps compared to the *EE* spectrum predicted for the best-fit model from *Planck* temperature data.

HFI's <u>known</u> polarisation systematics are quite large on the reionisation bump, which needs to be subtracted. There is a way, but…


Planck 2013 HFI Data Processing Paper
143-8
143-7
143-6
143-5
143-4a/b
143-3a/b
143-2a/b
143-1a/b
545-4
545-3
857-4
857-3
857-2
857-1
545-2
545-1
353-8
353-7
353-6a/b
353-5a/b
353-4a/b
353-3a/b
353-2
353-1
217-8a/b
217-7a/b
217-6a/b
217-5a/b
217-4
217-3
217-2
217-1
100-4a/b
100-1a/b
100-3a/b
100-2a/b
Polarisations are measured by differencing
two detector pairs (a/b)
Cross-scan [deg]
In-scan [deg]
2
1
0
−1
−2
−2
−1
0
1
2

Assessment of LFI uncertainties – power spectrum



LFI's systematics are smaller than the reionisation bump

Take-home Messages

- **WMAP9 and Planck LFI polarisations are in agreement**
  - No sign of the unknown systematic errors in these data sets
- A drop from **τ=0.089** [WMAP9 T+P] to **0.071** [Planck T+WMAP9 cleaned for dust]
  - A half of the drop from dust cleaning
  - Another half from an increase in the best-fit $A_s e^{-2\tau}$ with the Planck 2015 temperature
- A further drop to **0.066** is due to CMB lensing
  - So, *~2/3 of a drop from τ=0.089 to 0.066 is due to changes in non-polarisation data!*
- It would be a surprise if Planck HFI gave a much lower value: systematics may be at play