Planck2016 PIP XLVI lowL pol

Reduction of large-scale systematic effects in HFI polarization maps and estimation of the reionization optical depth

Compton Reionization depth τ

Planck 2016 intermediate results. XLVII.

Planck constraints on reionization history ***zre***

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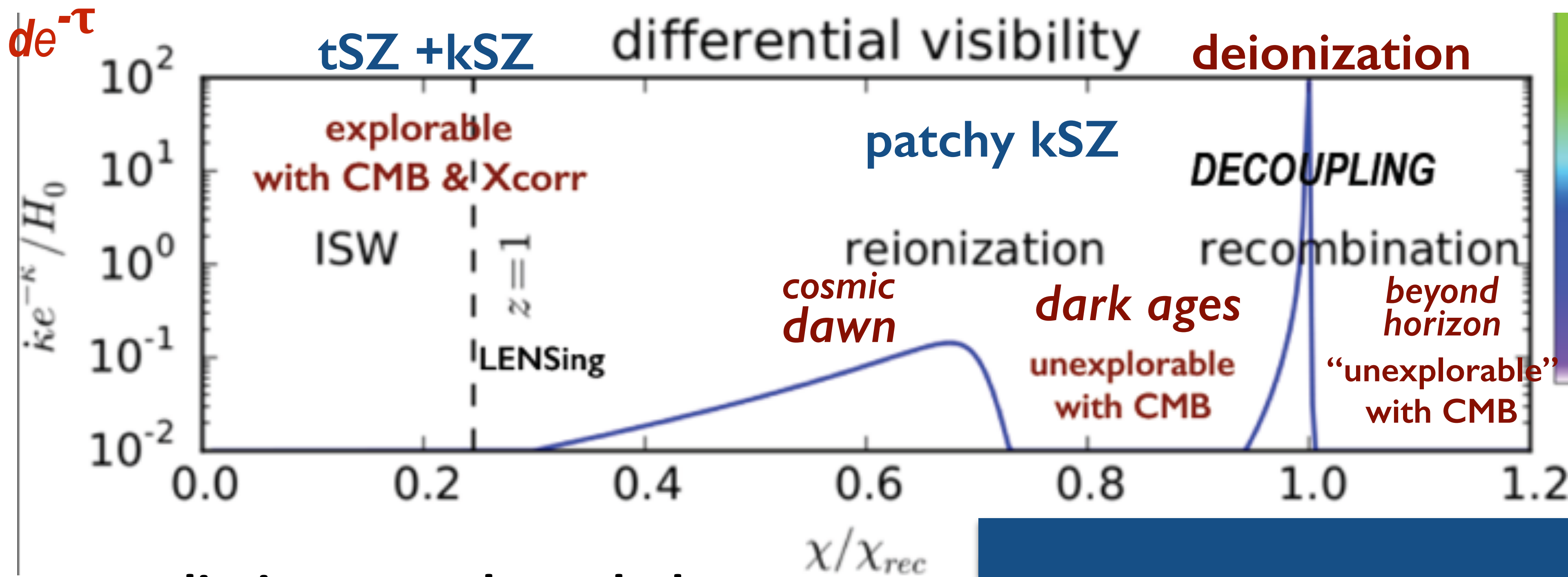
@ Great Lakes16

for the Planck collaboration

τ .055 +-*.009*

- **z_{re}=8.2-8.8 +-*1***



limits to our knowledge

CMB modes
$\sim f_{sky} L_{max}^2$

CMB *~10,000,000 T/E modes of tΛCDM*
≲500 modes of anomaly
≲100 modes reionization history

LSS tomography
$X\ k_{max}\ d_{max}$

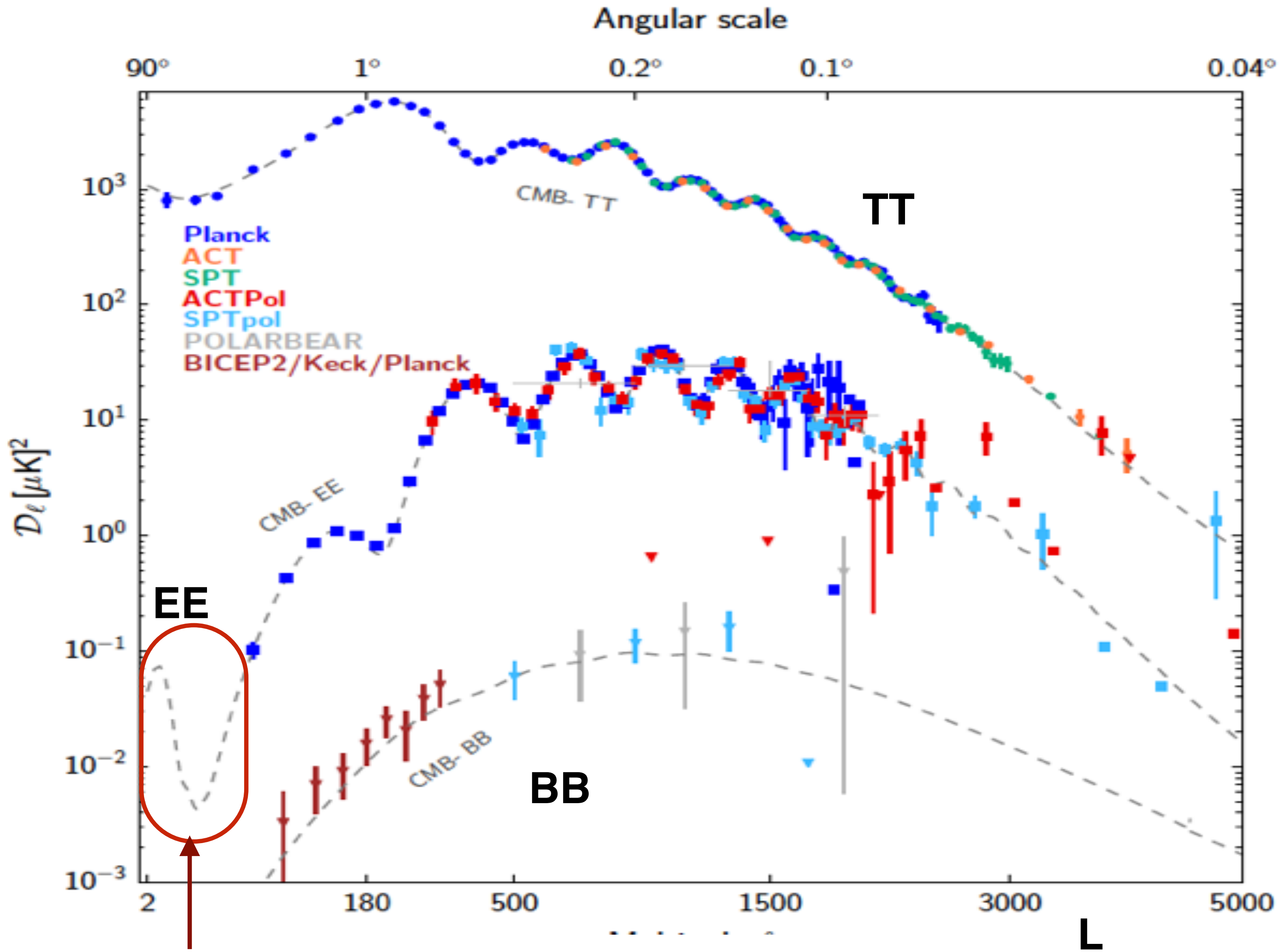
Compton depth $\tau \sim \int n_e\, cdt$
Differential Visibility $\sim de^{-\tau}$

its all just Compton scattering
Thompson $de^{-\tau}$
kinetic SZ/ Doppler LoS $v_e\ de^{-\tau}$
thermal SZ $\langle v_e^2 \rangle\ de^{-\tau}$
polarization [quadrupole] $de^{-\tau}$

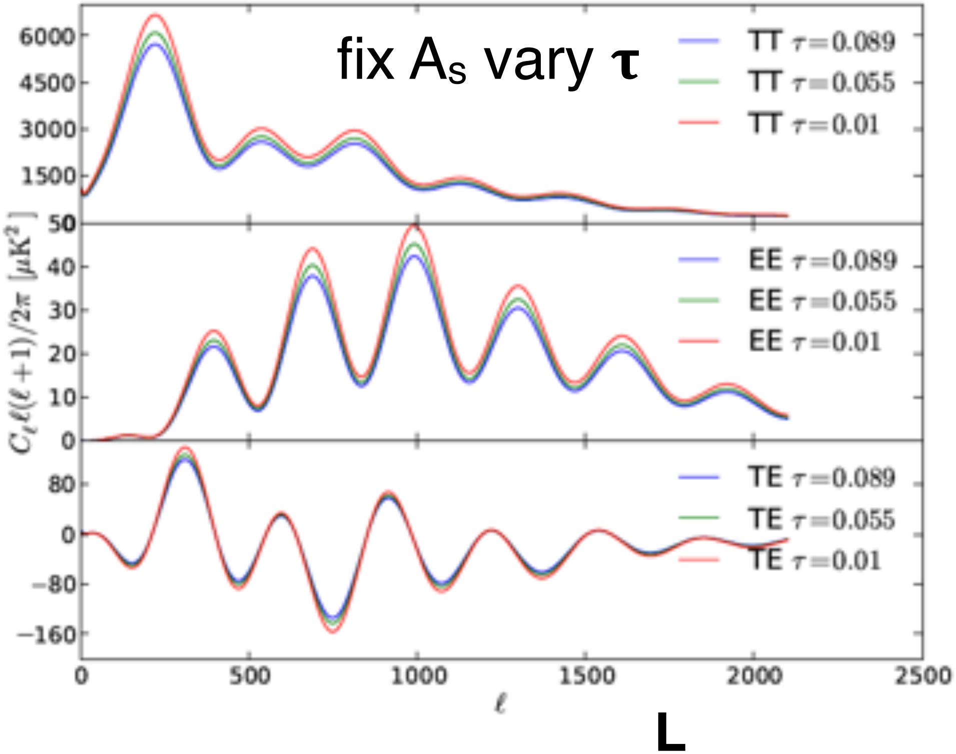
E /B pol, GW natural

Planck 2015 parameters
reconstructed *de-ionization history*
3 modes, high L EE,TE important
same for reionization history ?? NO
low L max ~10, too few modes

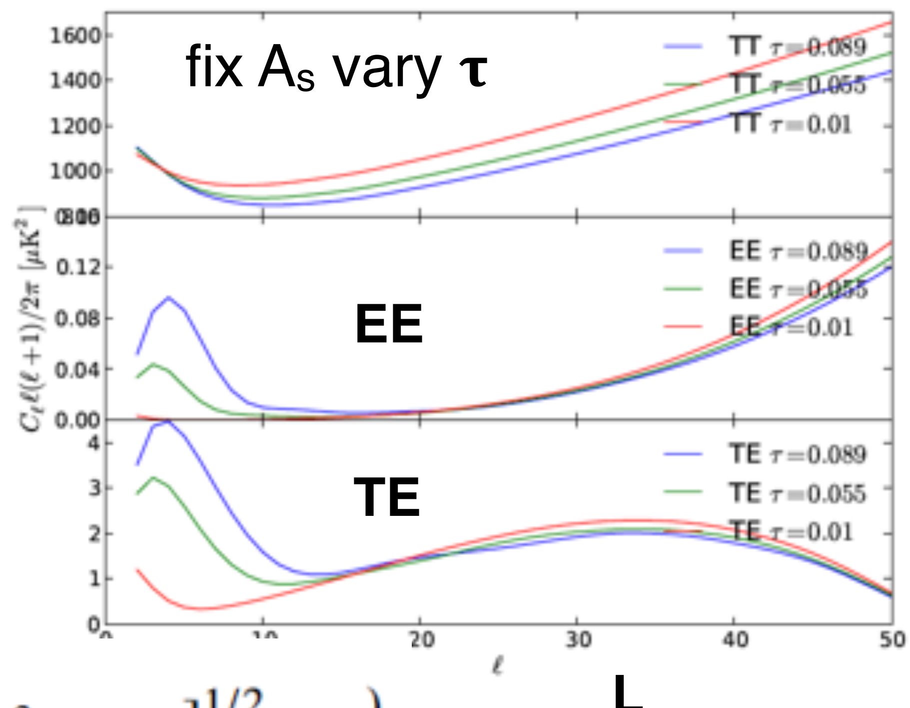
Combined CMB power spectra of Planck 2015;
EE from LFI 79 GHz below Lcut ~ 30



fill in with pre-2016 HFI



- the scattering of CMB creates E mode polarization
- amplitude TT ~ $A_s \exp[-2\,\tau]$
- EE /TE feature at low L
- EE ~ $A_s\,\tau^2$, TE ~ $A_s\,\tau$
- TT 1st acoustic peak 5600 μK^2 cf. EE reionization ~$10^{-2}\,\mu K^2$

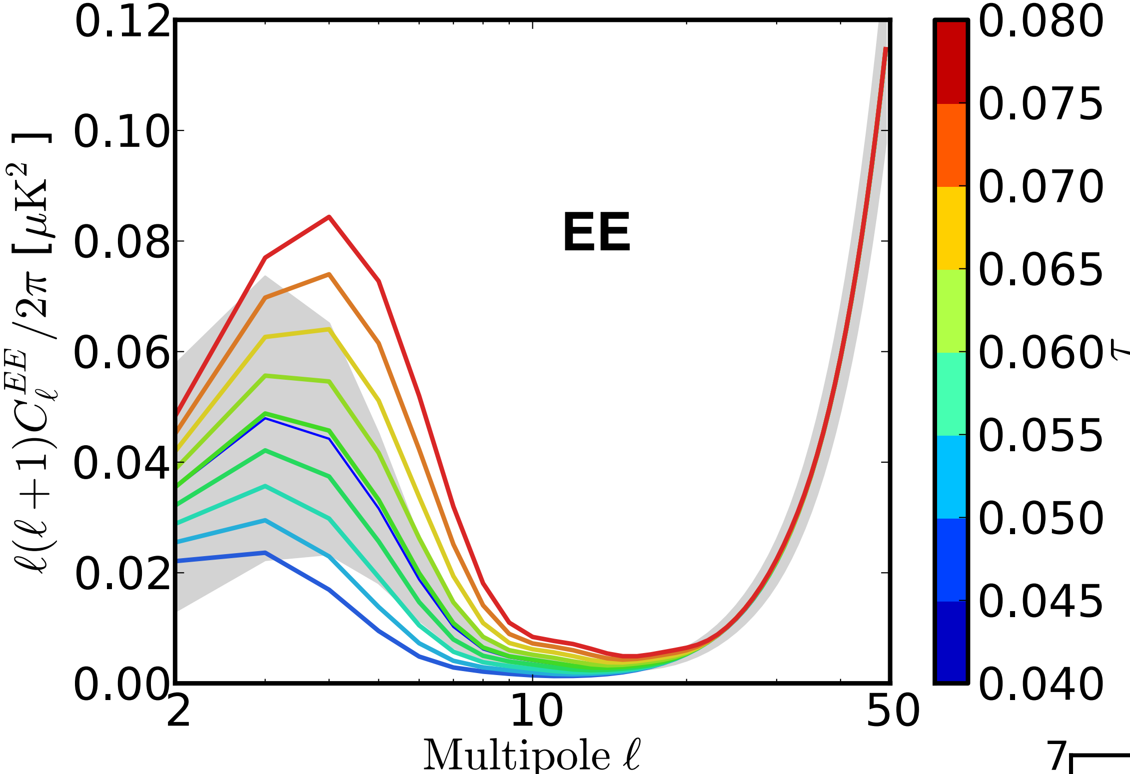


$\tau \sim .07\,[(1+z_{re})/10]^{3/2}$

Compton depth sudden reionization

$\tau \sim \int n_e\, c\, dt$

$$\tau = \frac{2c\sigma_T(1-Y_P)}{m_p}\frac{\Omega_b}{\Omega_m}\frac{H_0}{8\pi G}\left\{\left[\Omega_m(1+z_{re})^3+\Omega_\Lambda\right]^{1/2}-1\right\}$$

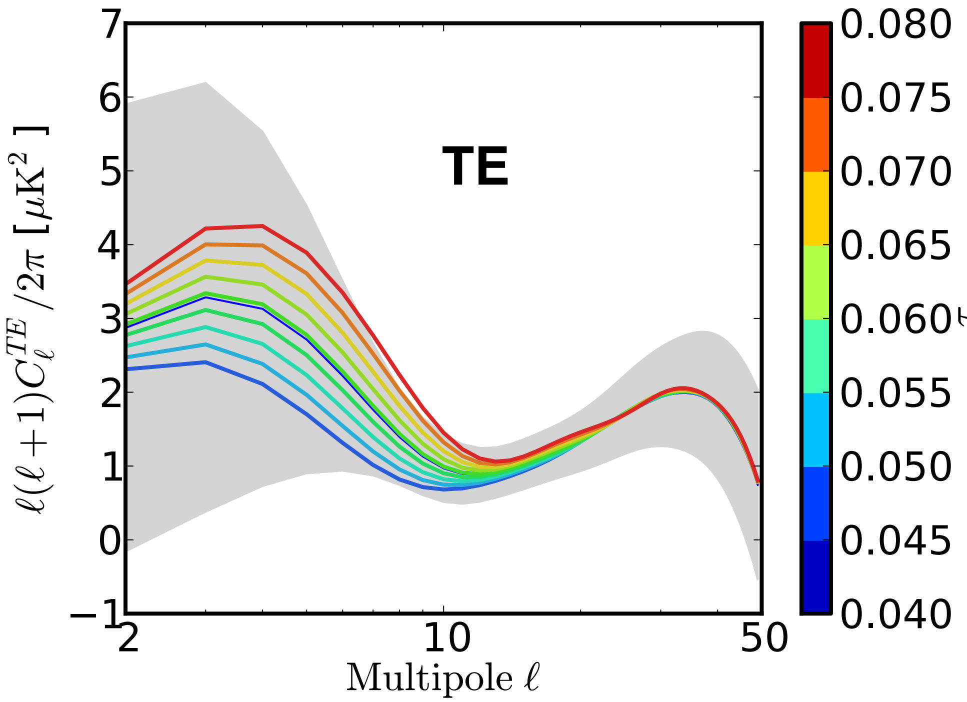


- fix $A_s \exp[-2\,\boldsymbol{\tau}]$ from high L CMB

degeneracy broken with low L EE data

but Cosmic Variance limits what we can learn about τ

CMB Lensing and LSS data also breaks this degeneracy



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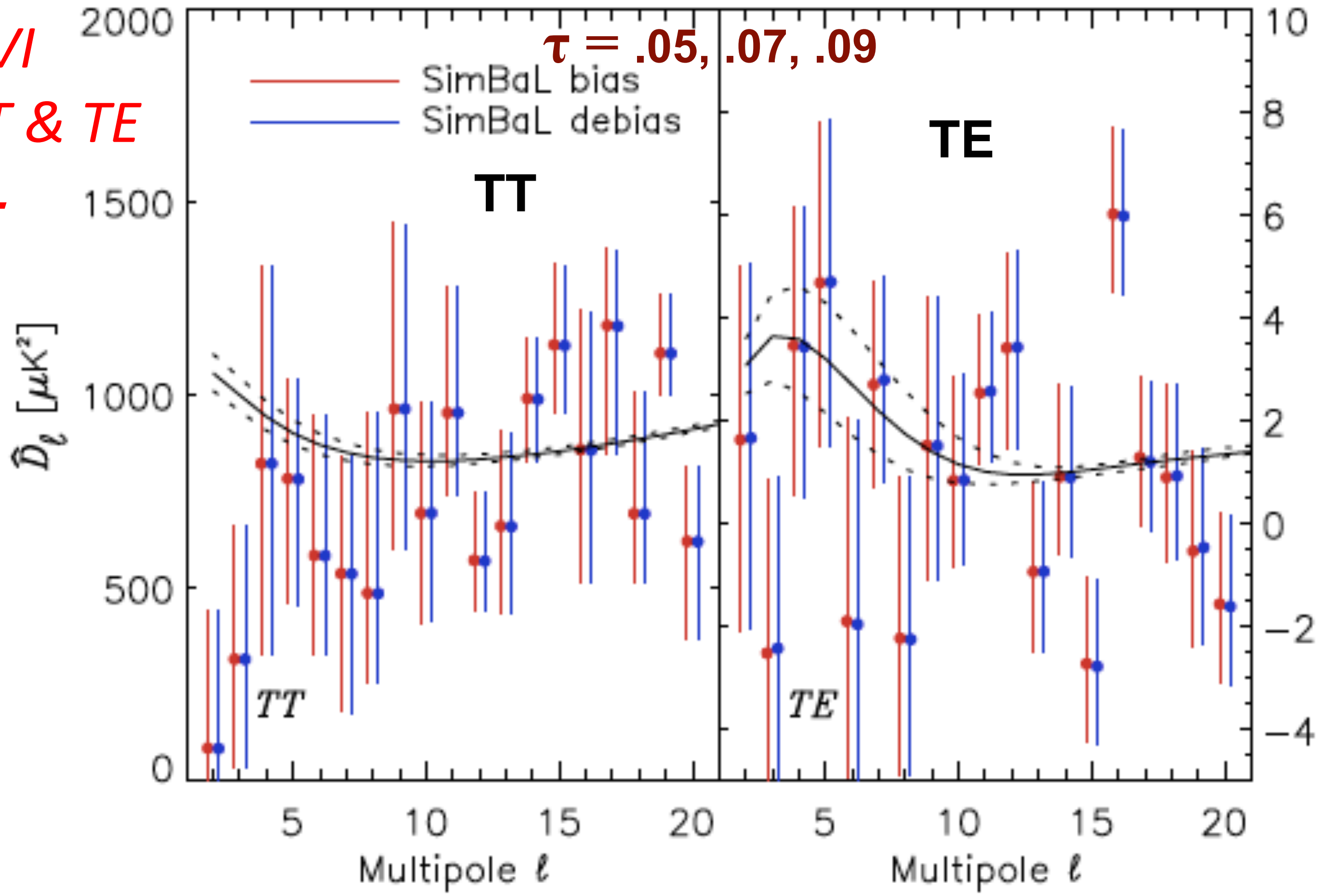

Fig. 36. *TT* and *TE* 100 × 143 cross-spectra, plotted for the SimBaL results with and without the bias correction. The black lines shows the fiducial spectra for $\tau = 0.05$, 0.07, and 0.09.

τ baseline results HFI 100x143 (283 simulations) and check of consistency HFI x LFI (10 simulations)

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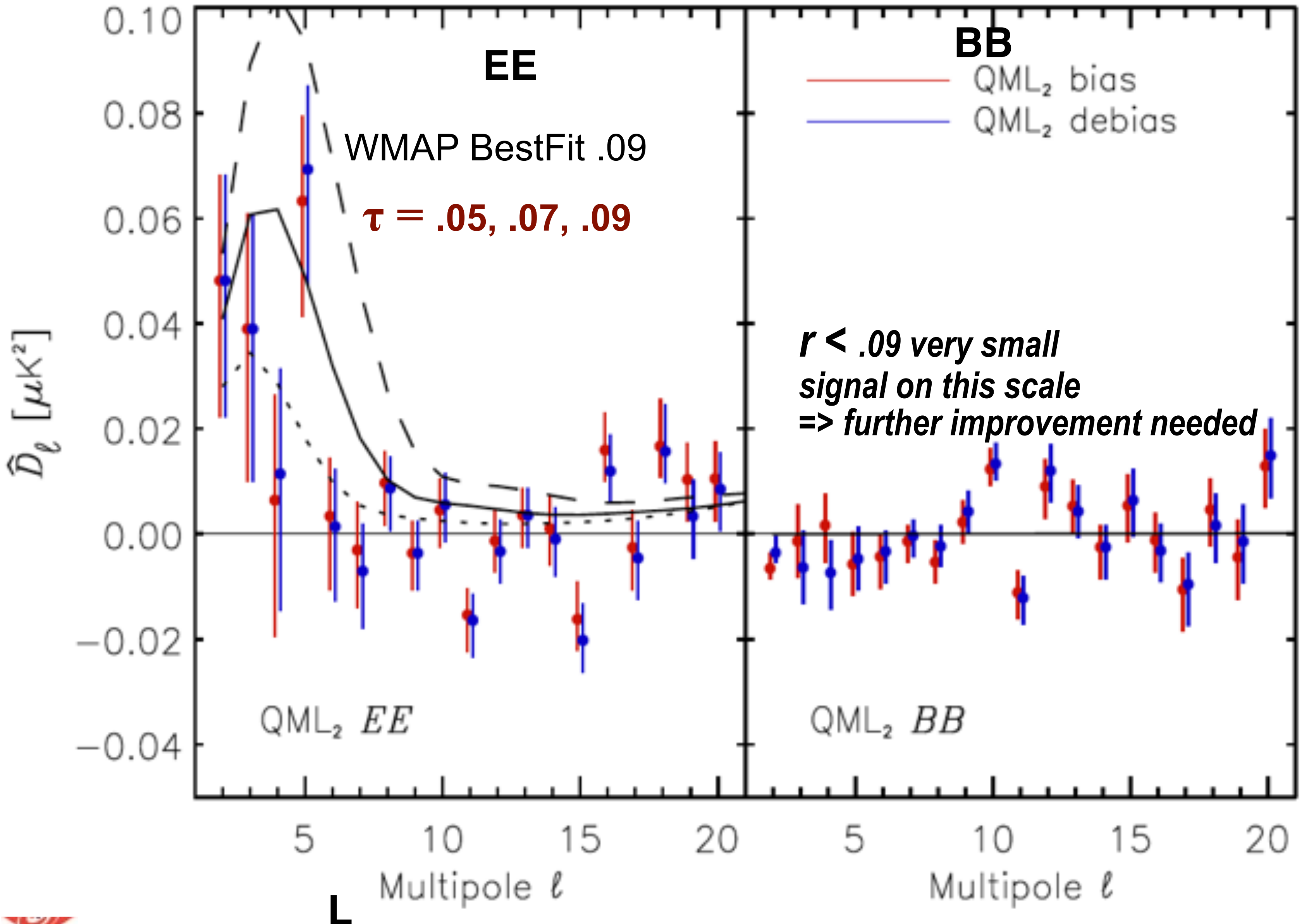
ArXiv 1605.02985v1 vast improvement in EE => on τ

QML 100x143 EE & BB cross spectra (quadratic maximum likelihood)



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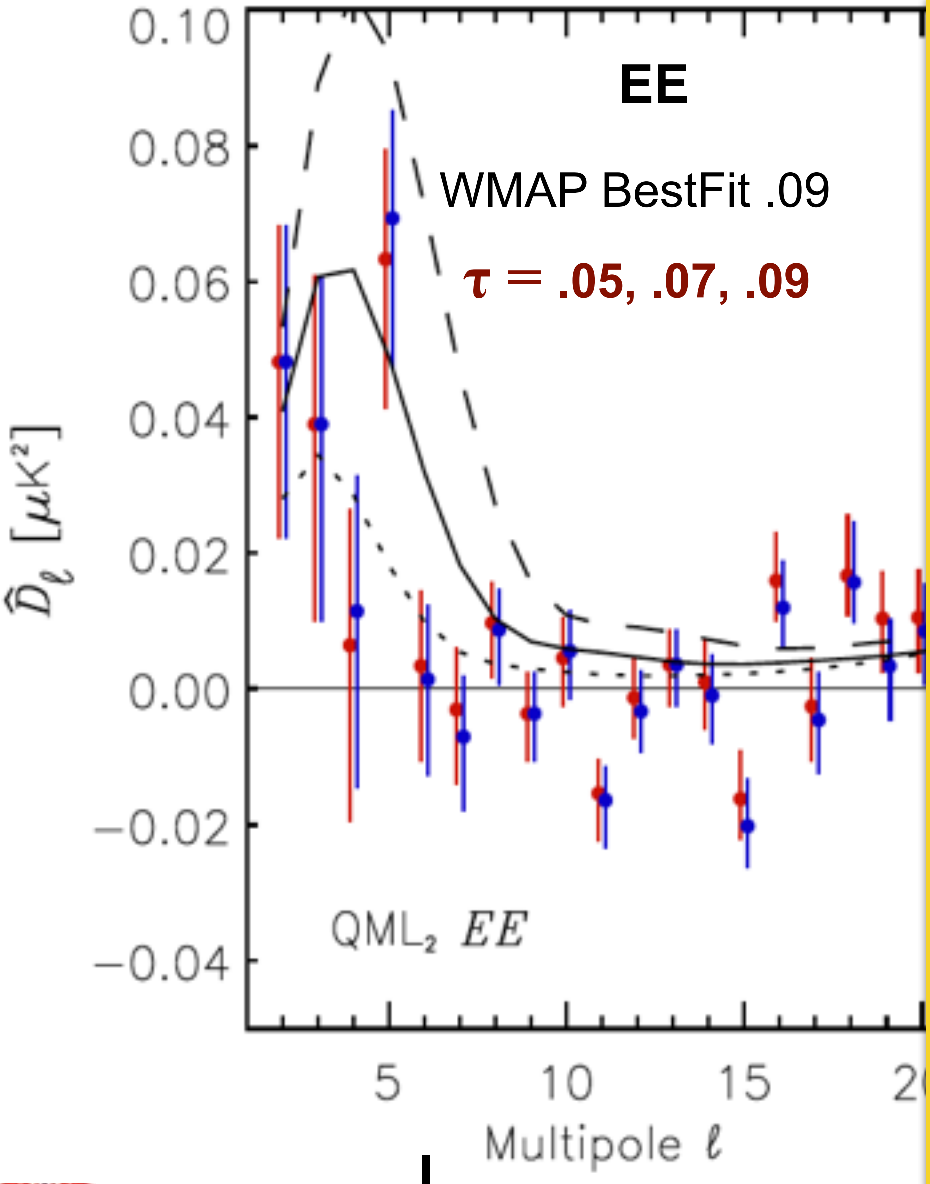

- *sets of PCL (pseudo-CL) EE cross spectra*
  - *very consistent with QML*
  - *map simulations reproduce systematics ADC*
  - *debiasing from the ADC NL dipole distortion small (only L<4)*
  - *QML lower dispersion & error bars*

ADC: Analog to Digital Conversion major systematic. Used warm HFI data to calibrate. Foreground corrections also very important

τ baseline results HFI 100x143 (283 E2E simulations) and check of consistency HFI x LFI (10 simulations)

E2E sims key to properly accounting for statistical errors in τ determination (& systematic errors)

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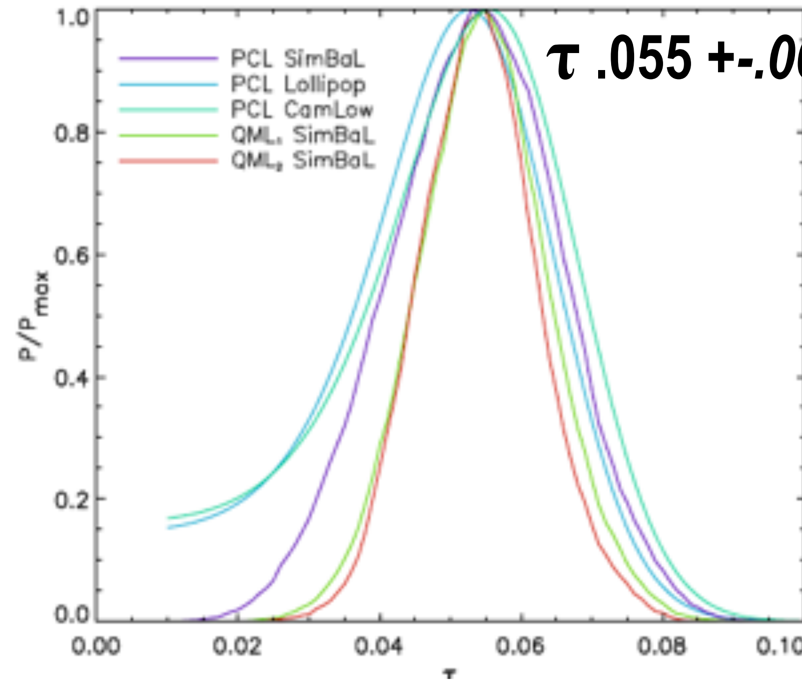
τ posterior probabilities:

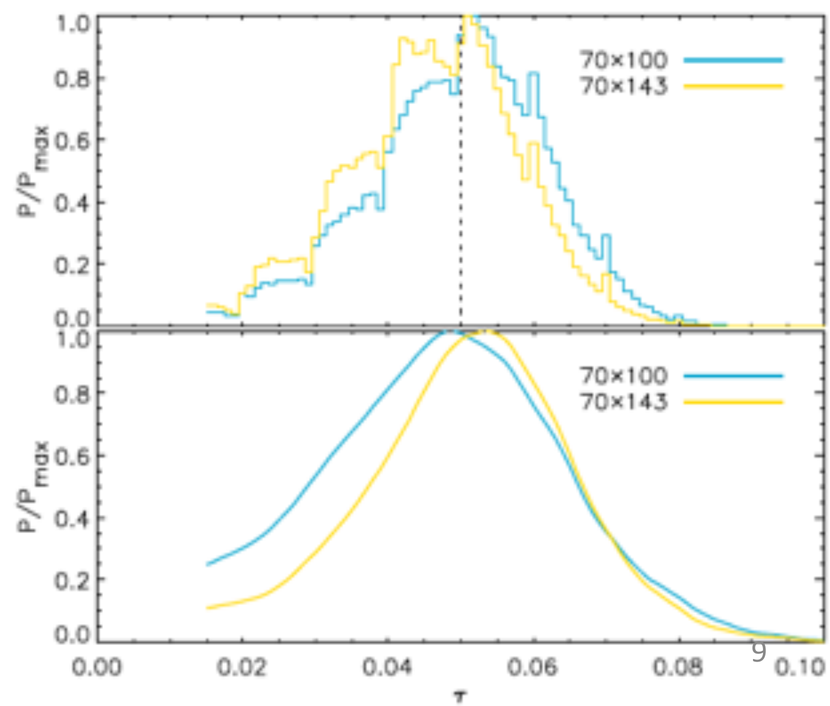
for HFI **baseline 100x143**

LFI-HFI consistency 70x100 and 70x143

- QML estimator: narrowest posterior
- simulation-based likelihood: more accurate posterior for low τ
- PCL estimator: wider posterior, same peak
- LFI x HFI cross: wider posterior still, same peak

τ .055 +-.009





τ from CMB (history)

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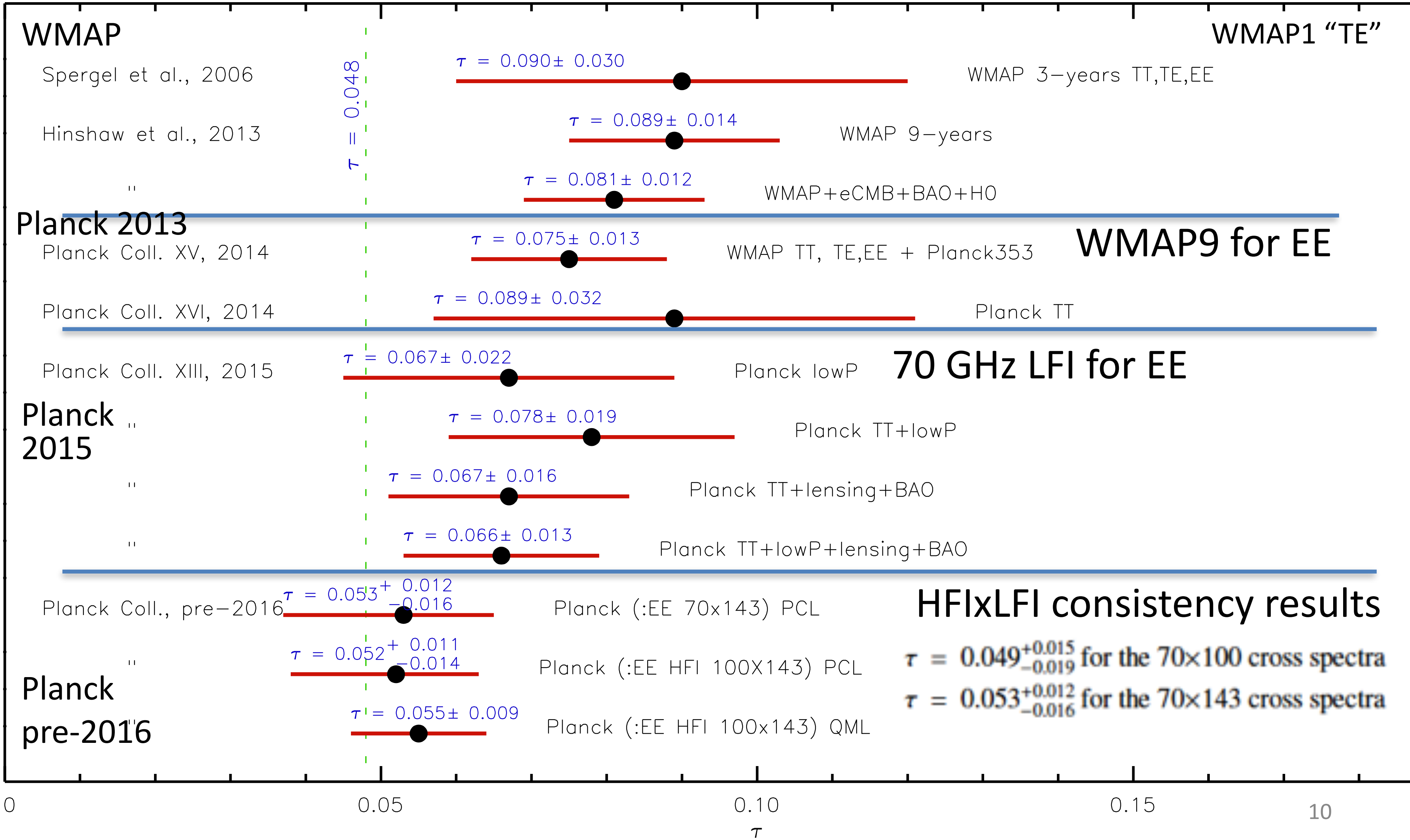
- consistency of all Planck τ results
- decreased error on τ
- mean drift to lower τ



Planck cosmic parameters *Planck 2015* *pre-2016*

Parameter	PlanckTT+lowP 68 % limits	PlanckTT+SIMlow 68 % limits	PlanckTTTEEE+lowP 68 % limits	PlanckTTTEEE+SIMlow 68 % limits
$\Omega_b h^2$	0.02222 ± 0.00023	0.02214 ± 0.00022	0.02225 ± 0.00016	0.02218 ± 0.00015
$\Omega_c h^2$	0.1197 ± 0.0022	0.1207 ± 0.0021	0.1198 ± 0.0015	0.1205 ± 0.0014
$100\theta_{MC}$	1.04085 ± 0.00047	1.04075 ± 0.00047	1.04077 ± 0.00032	1.04069 ± 0.00031
τ	0.078 ± 0.019	0.0581 ± 0.0094	0.079 ± 0.017	0.0596 ± 0.0089
$\ln(10^{10} A_s)$	3.089 ± 0.036	3.053 ± 0.019	3.094 ± 0.034	3.056 ± 0.018
n_s	0.9655 ± 0.0062	0.9624 ± 0.0057	0.9645 ± 0.0049	0.9619 ± 0.0045
H_0	67.31 ± 0.96	66.88 ± 0.91	67.27 ± 0.66	66.93 ± 0.62
Ω_m	0.315 ± 0.013	0.321 ± 0.013	0.3156 ± 0.0091	0.3202 ± 0.0087
σ_8	0.829 ± 0.014	0.8167 ± 0.0095	0.831 ± 0.013	0.8174 ± 0.0081
$\sigma_8 \Omega_m^{0.5}$	0.466 ± 0.013	0.463 ± 0.013	0.4668 ± 0.0098	0.4625 ± 0.0091
$\sigma_8 \Omega_m^{0.25}$	0.621 ± 0.013	0.615 ± 0.012	0.623 ± 0.011	0.6148 ± 0.0086
z_{re}	$9.89^{1.8}_{-1.6}$	8.11 ± 0.93	$10.0^{1.7}_{-1.5}$	8.24 ± 0.88
$10^9 A_s e^{-2\tau}$	1.880 ± 0.014	1.885 ± 0.014	1.882 ± 0.012	1.886 ± 0.012
Age/Gyr	13.813 ± 0.038	13.829 ± 0.036	13.813 ± 0.026	13.826 ± 0.025

relaxing tension of clusters and primary CMB

Planck 2013 sigma8 ~0.83 (WMAP τ .089),

Planck 2015 sigma8 ~0.83 (.815 + lens) (cleaned LFI τ .079 *(.017)*)

Planck 2016 sigma8 ~PIP: 0.817 (.812 + lens) (HFI τ .059 *(.009)*)

τ, A_s, n_s degeneracies

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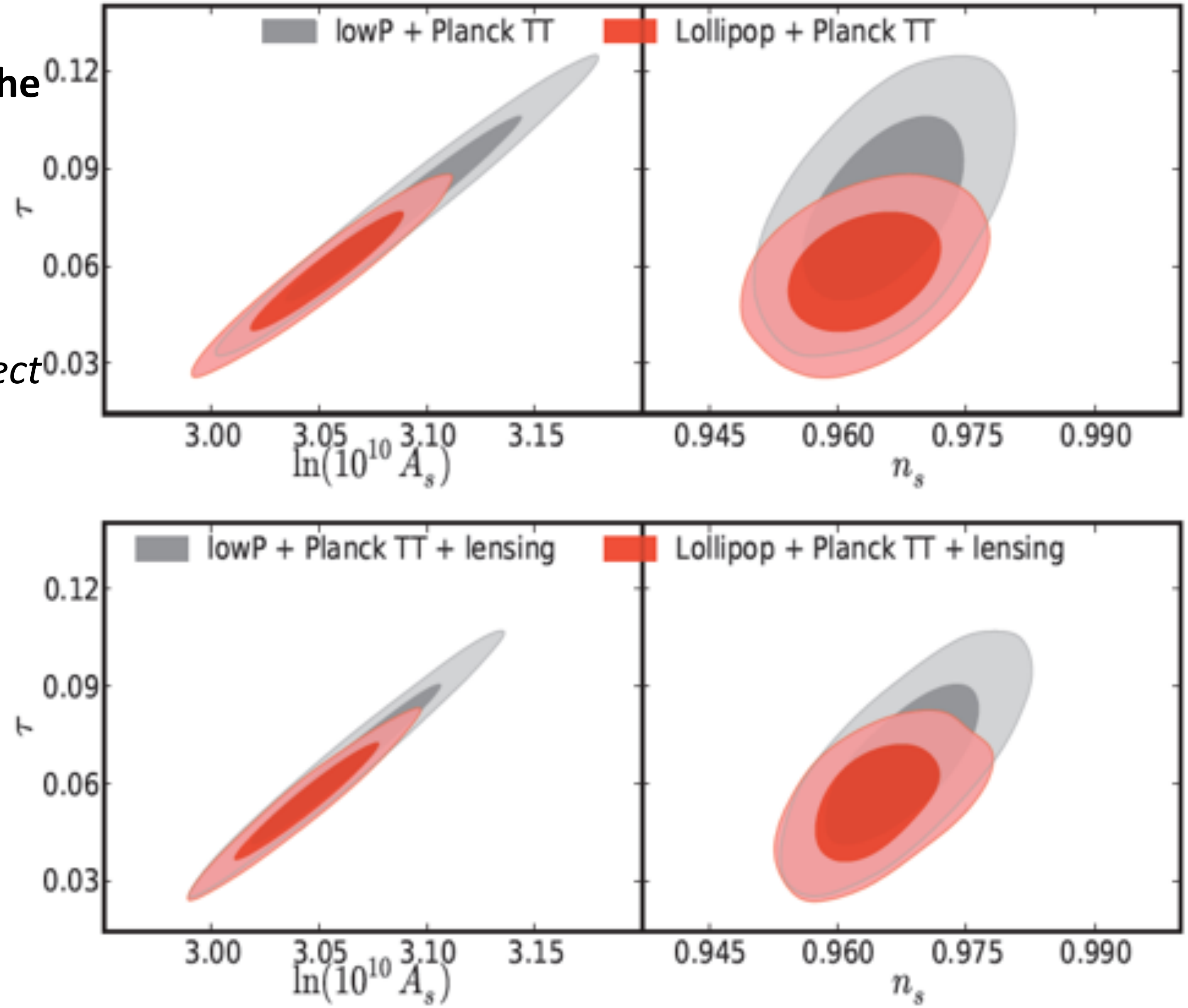
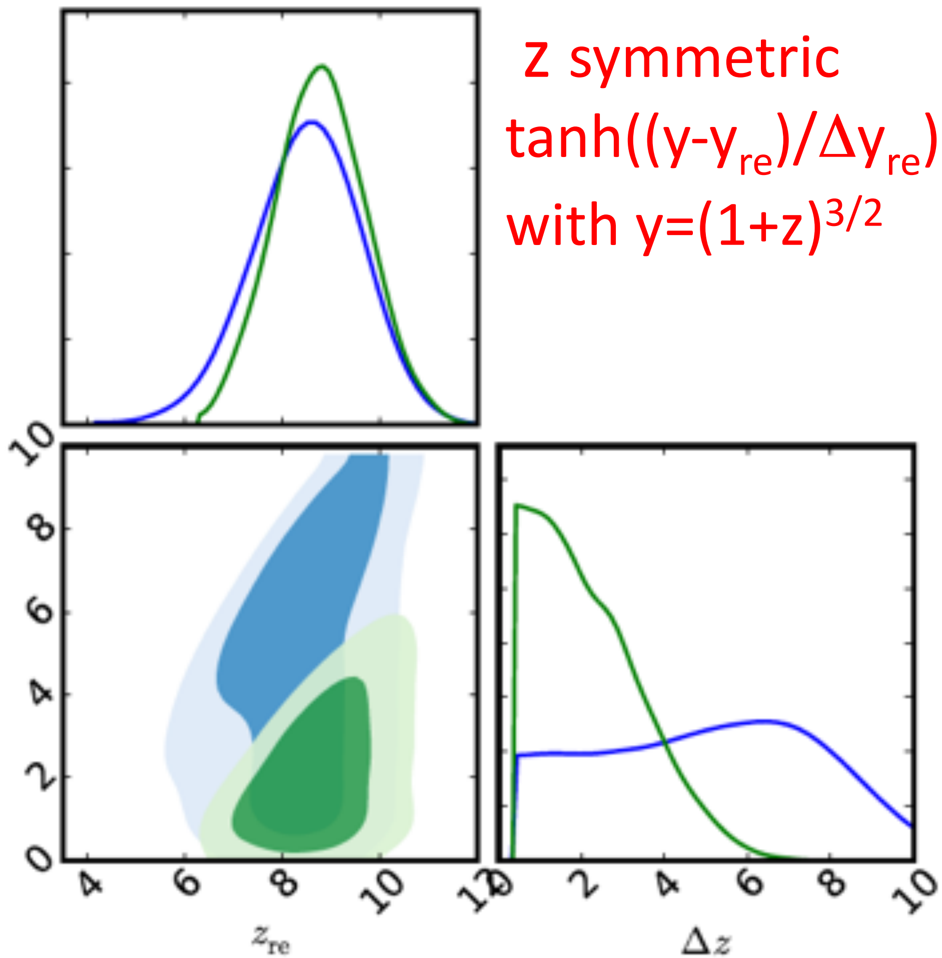
- **better-determined τ breaks the n_s degeneracy & reduces the A_S degeneracy**
- *add lensing - now a small effect*



Reionisation history constraints from Planck



z symmetric $\tanh((y-y_{re})/\Delta y_{re})$ with $y=(1+z)^{3/2}$

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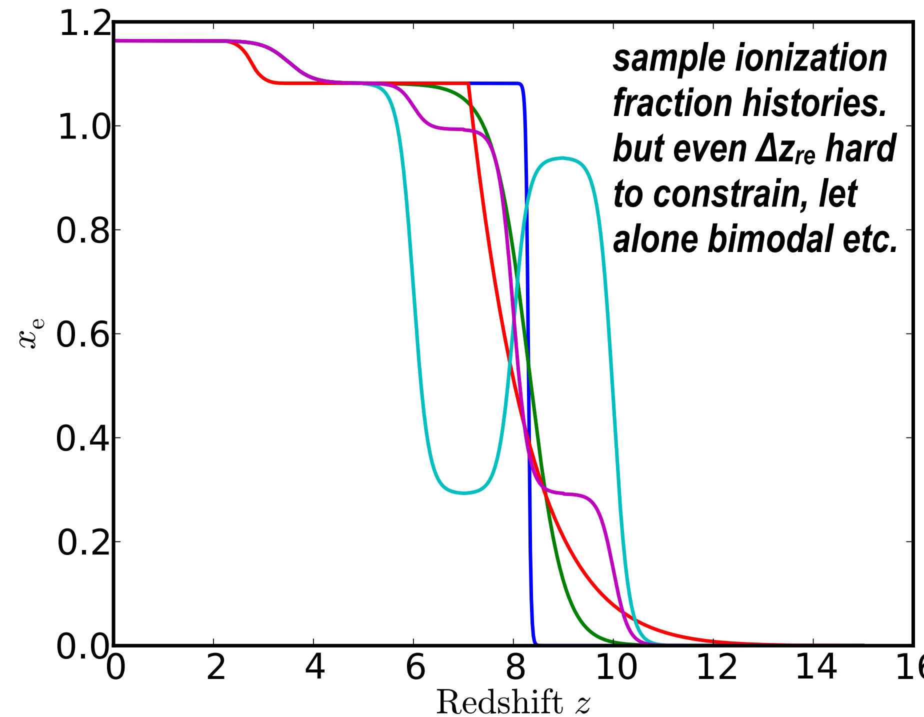
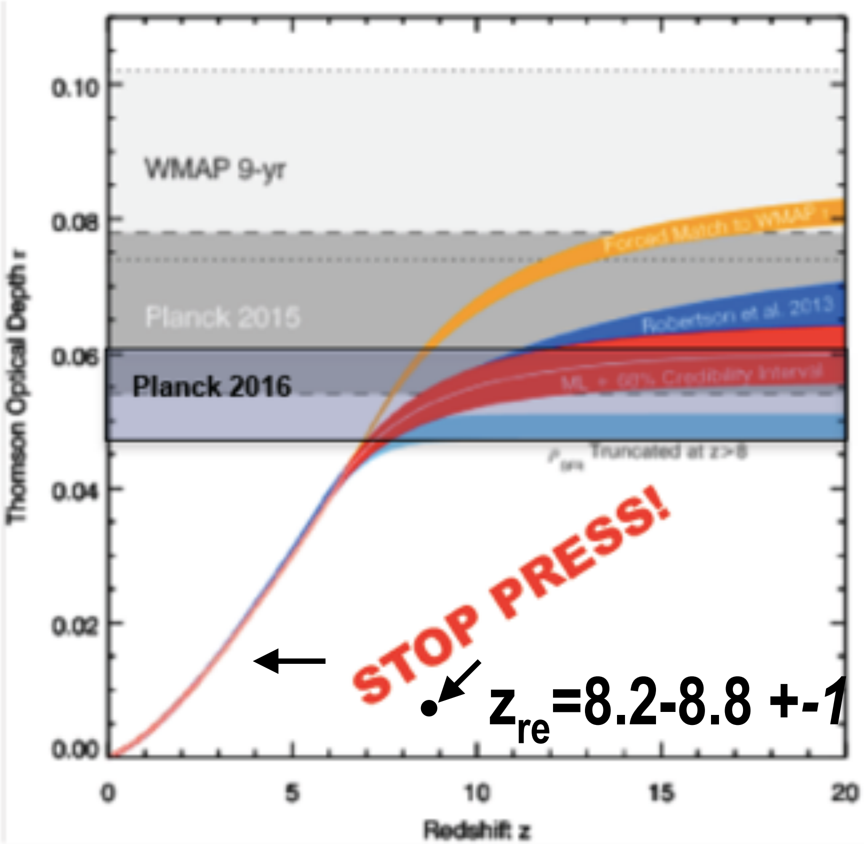
$$z_{re} = 8.53^{+1.03}_{-1.13} \quad ,$$

$$z_{re} = 8.77^{+0.94}_{-0.92} \quad (\text{with prior } z_{end} > 6) .$$

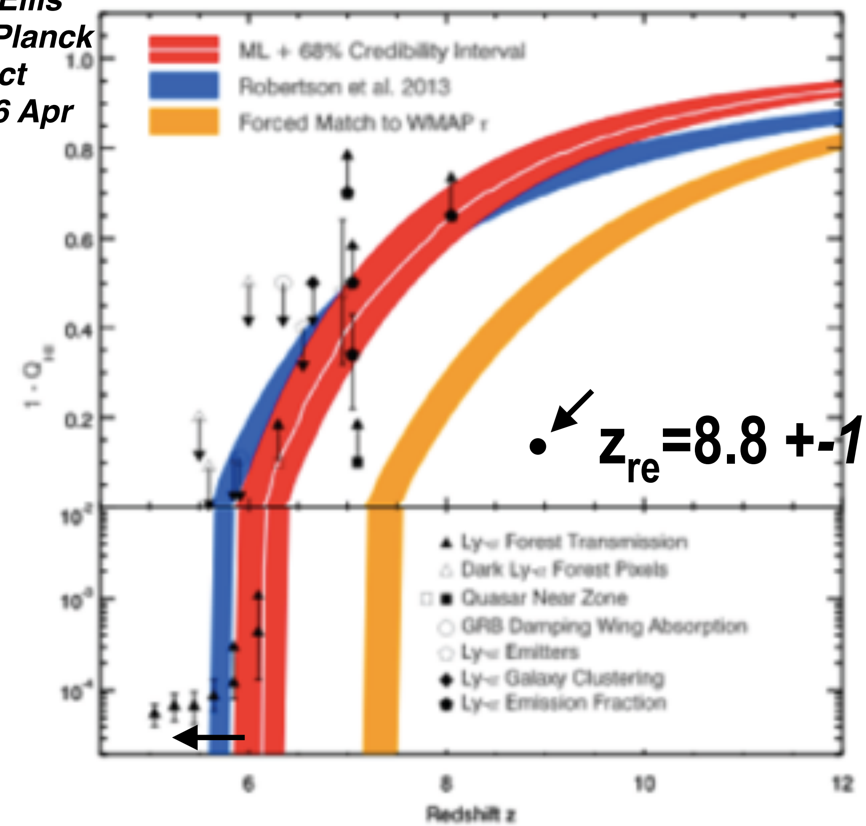
- Constraints on z_{re} ,Δz_{re} for Δz =0.5
- **WMAP 9y** z_{re} = 10.3
- **Planck2015**
- TT+lowP z_{re} = $9.9^{+-1.7}$
- TT+lowP+lens+BAO z_{re}= $8.8^{+-1.3}$
- Planck pre 2016
- lowEH+TT+BAO **z_{re}=8.16 $^{+-1}$**



Planck & HST: Reionisation over 6 < z < 12



RIchard Ellis slide of Planck z_{re} impact CIFAR 16 Apr



Planck indicates `Fast Reionization': Making (questionable) assumptions about their ionizing output the demographics of early galaxies can match the Planck τ with reionisation contained with 12 < z < 6 *Ly alpha, but OIII, CIV, CIII*

4 with z > 7.5, eg 2015 z=7.7 may, 8.68 july, what about z=11.1 ? ~March HST grism ??

Focus now turns to measuring the ionizing output of early galaxies

+ EoR redshifted 21 cm cosmic dawn experiments: P16 => shift in in frequency target

Robertson et al (2015), see also Bouwens+(2015), Mitra+(2015)

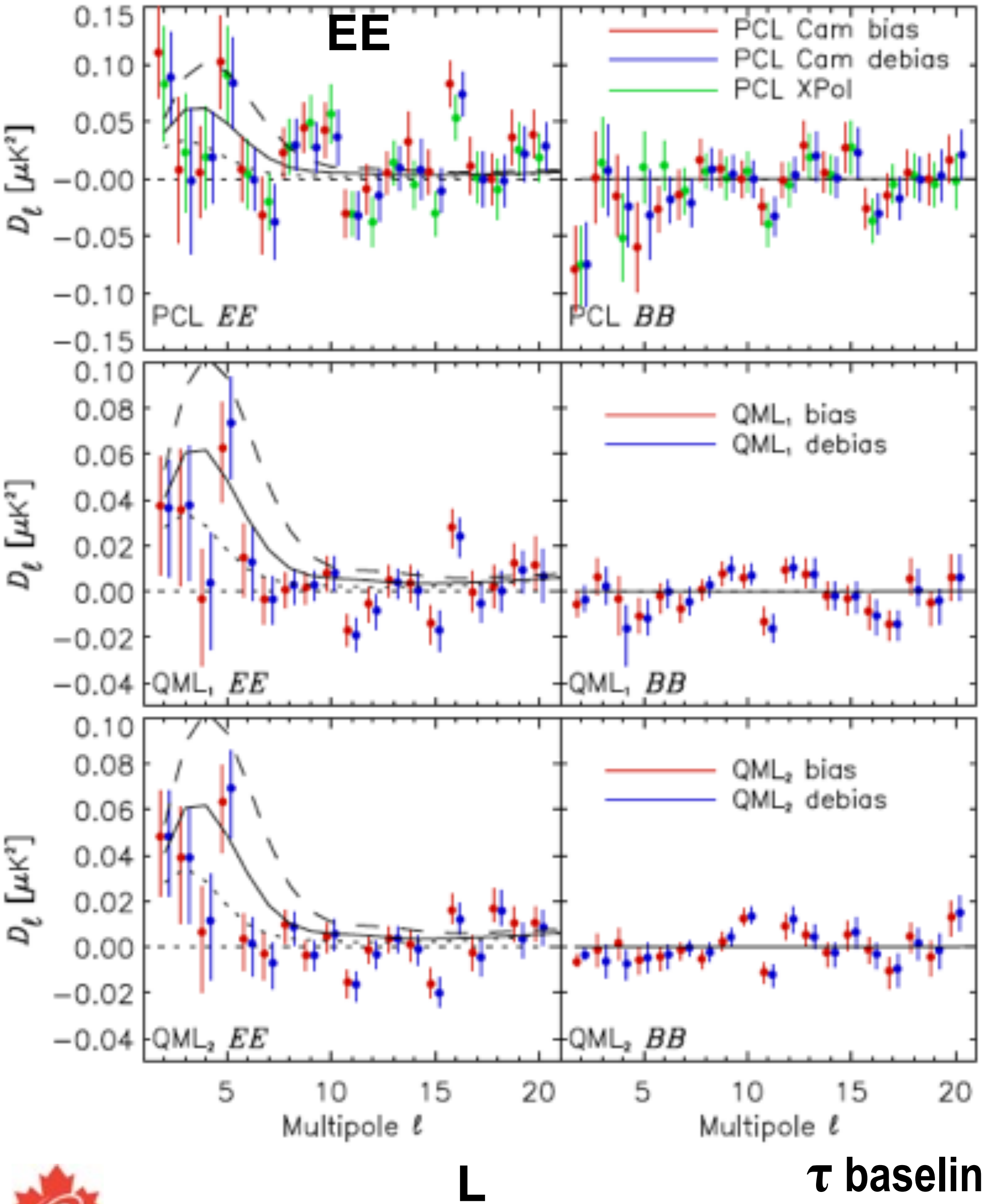
Summary

- ***Planck HFI EE spectra at low L unveiled**: major systematics improvements. accurate End-to-End HFI map simulations*
- *τ now nearly independent of other cosmic parameters*
- *τ= **.055 +-.009** & lower **z_{re}=8.2-8.8 +-1 => no tension** of CMB z_{re} with reionization models from first stars / galaxies*
- *e.g., no need for early "ring of fire" of exotic BHs at z~11+*
- *glorious **interplay with earliest "optical" galaxies** (HST, .. JWST), Ly alpha and future OIII and other metal lines*
- *width of reionization rise is poorly-determined. complex reionization history not determinable*
- ***cosmic dawn** detectability with **redshifted 21 cm** on track, though targeting lower z_{re}*
- ***no "patchy reionization" kinetic SZ detection** (yet), but cluster kSZ detection*
- *r constraint from **tensor mode reionization B-pol** very **hard** TBD (cf. recombination B-pol constraint from BKP <.09 (.07)*

Summary

- much improved maps at low multipoles: generalized destriper solution for map-making from rings, solving simultaneously for band-pass-mismatch leakage, inter-calibration errors, and ADC induced gain variations and dipole distortions (to achieve a nearly complete correction of the ADC nonlinearities).
- At HFI's 100, 143, and 217 GHz, we are now close to being noise limited on all angular scales (with small remaining systematic errors due to the empirical ADC corrections at the map making level).

PCL and QML 100x143 EE cross spectra



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sets of PCL EE cross spectra (pseudo-CL)

- ***very consistent with QML***
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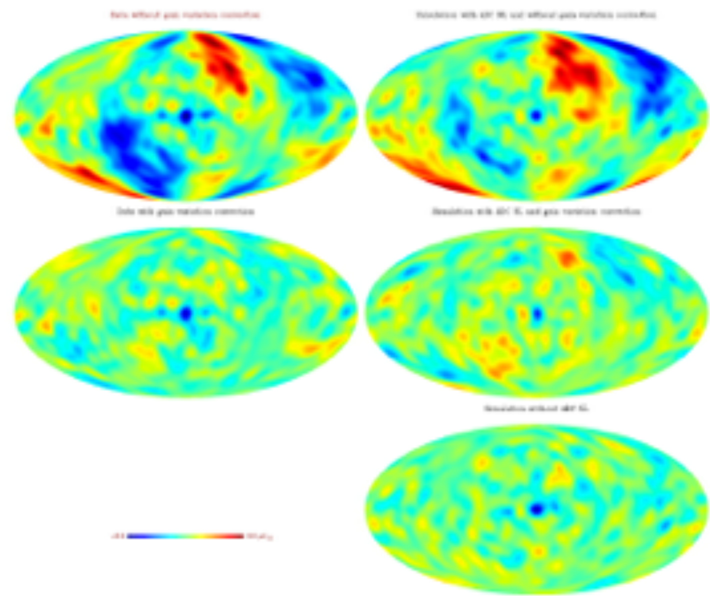
- ***QML lower dispersion & error bars***



Analog to Digital Conversion major systematic to have included. Used warm HFI data

Foreground corrections also very important

τ baseline results HFI 100x143 (283 simulations)

and check of consistency HFI x LFI (10 simulations)