The Reionisation parameter tau measured by the Planck mission

on the behalf of the Planck collaboration

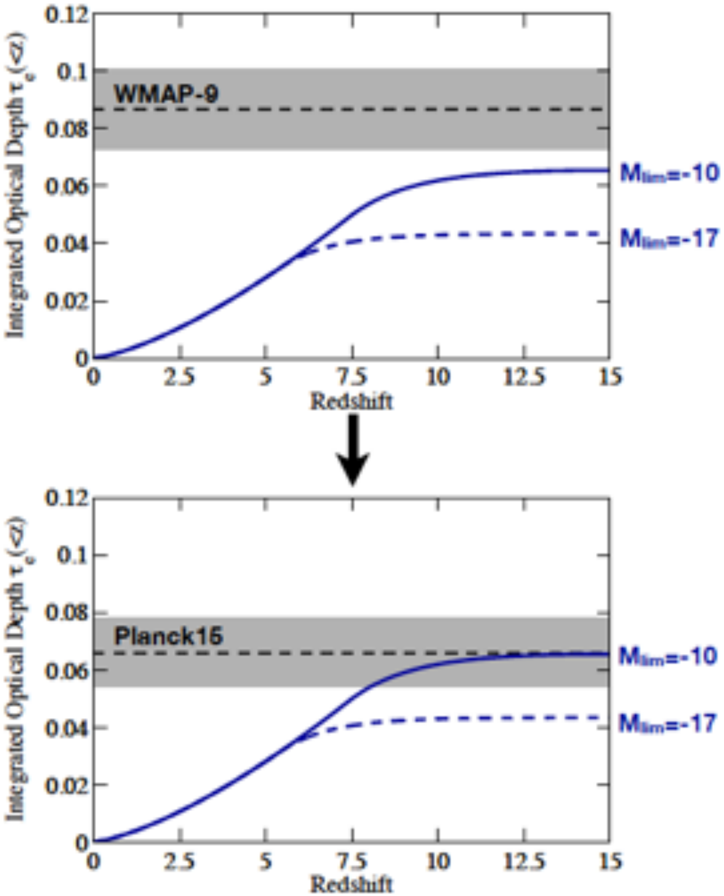
Planck2016 PIP XLVI lowL pol

ArXiv 1605.02985v1

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

Planck 2016 intermediate results. XLVII.

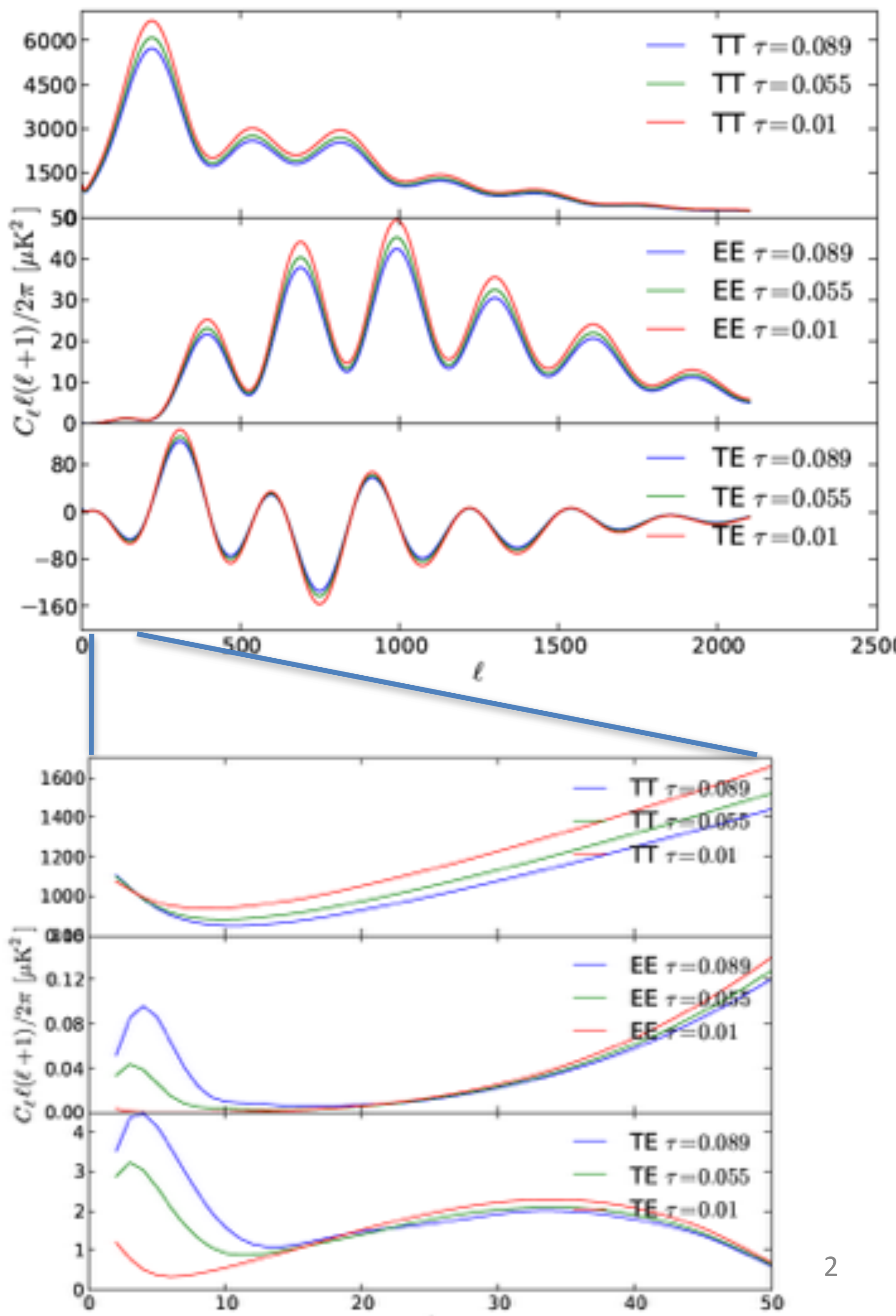
Planck constraints on reionization history



Escape Fraction = 20%?

CMB anisotropies and reionisation parameter

- the scattering of CMB creates E mode polarization
- but also reduces the amplitudes TT ~ $A_s . e^{-2t}$
- EE & TE show a feature at low multipoles EE ~ $A_s . t^2$, TE ~ $A_s . t$
- TT 1st acoustic peak 5600 μK^2 cf. EE reionization ~10^{-2} μK^2

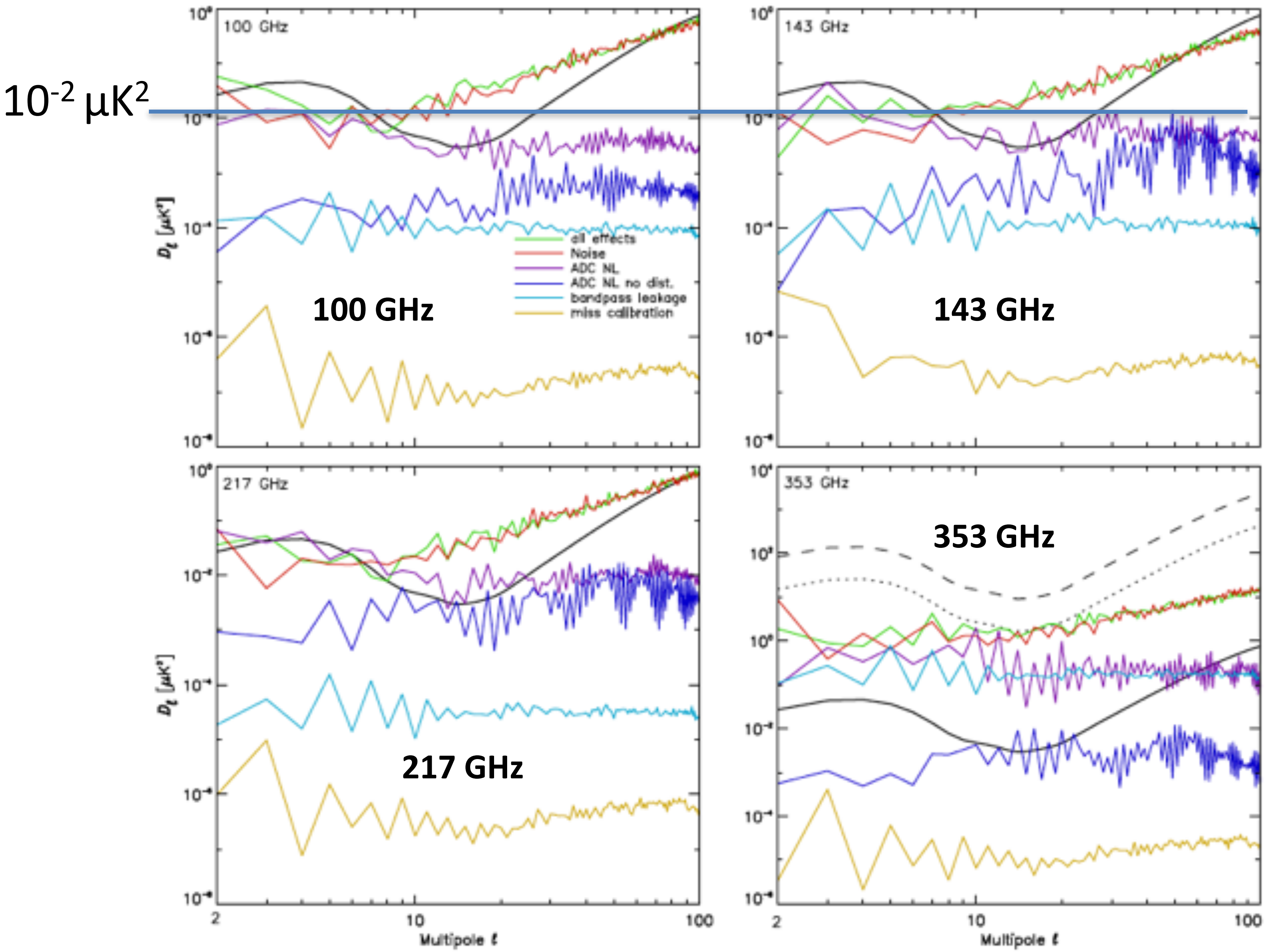


Planck 2015 parameters

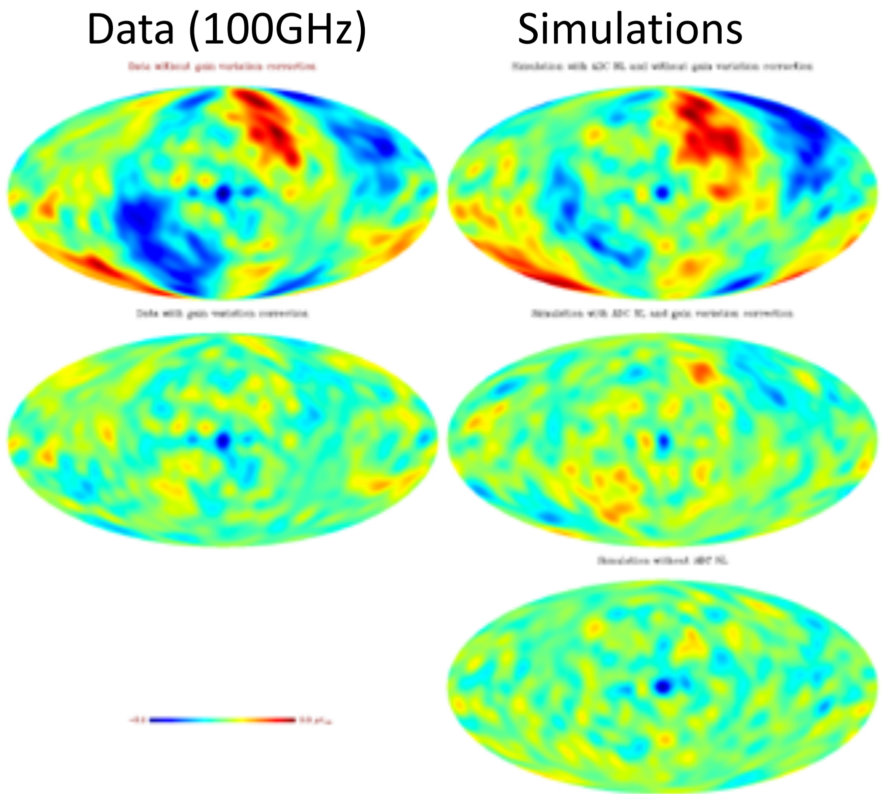
Parameter	[1] *Planck* TT+lowP	[4] *Planck* TT,TE,EE+lowP	$([1]-[4])/\sigma_{[1]}$
$\Omega_b h^2$	0.02222 ± 0.00023	0.02225 ± 0.00016	-0.1
$\Omega_c h^2$	0.1197 ± 0.0022	0.1198 ± 0.0015	0.0
$100\theta_{MC}$	1.04085 ± 0.00047	1.04077 ± 0.00032	0.2
τ	0.078 ± 0.019	0.079 ± 0.017	-0.1
$\ln(10^{10} A_s)$	3.089 ± 0.036	3.094 ± 0.034	-0.1
n_s	0.9655 ± 0.0062	0.9645 ± 0.0049	0.2
H_0	67.31 ± 0.96	67.27 ± 0.66	0.0
Ω_m	0.315 ± 0.013	0.3156 ± 0.0091	0.0
σ_8	0.829 ± 0.014	0.831 ± 0.013	0.0
$10^9 A_s e^{-2\tau}$	1.880 ± 0.014	1.882 ± 0.012	-0.1

$$10^9 A_s e^{-2\tau}$$

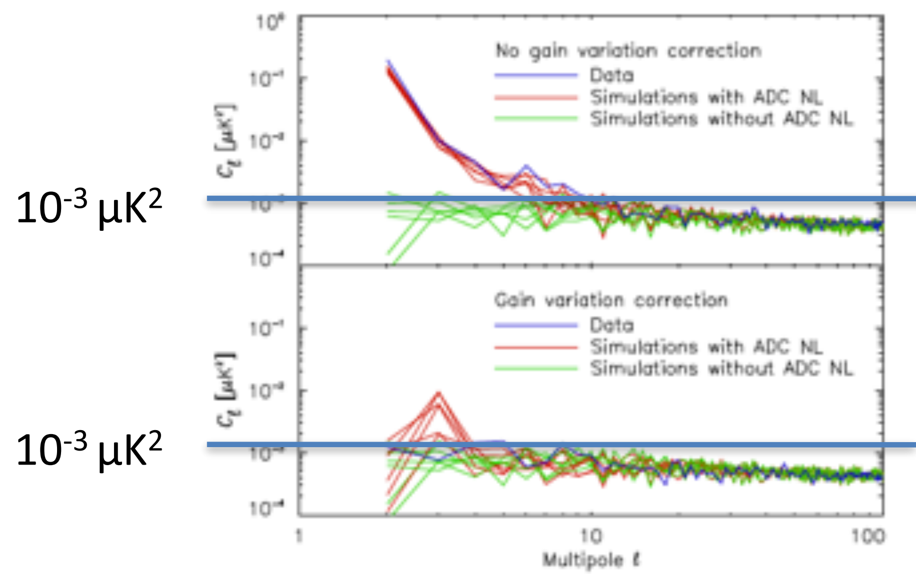
E2E simulations: all systematic residuals



- Top figure
  - 1^{st} row maps: is total ADC NL
  - 2^{nd} row maps: is apparent time dependant gain correction
  - 3rd row map: is ADC NL dipole distortion effect (for simulation only as we did not remove it in the pre2016 data)



- Bottom figure : the spectra are
  - top: full ADC NL systematics
  - bottom: after removal of apparent time gain variation

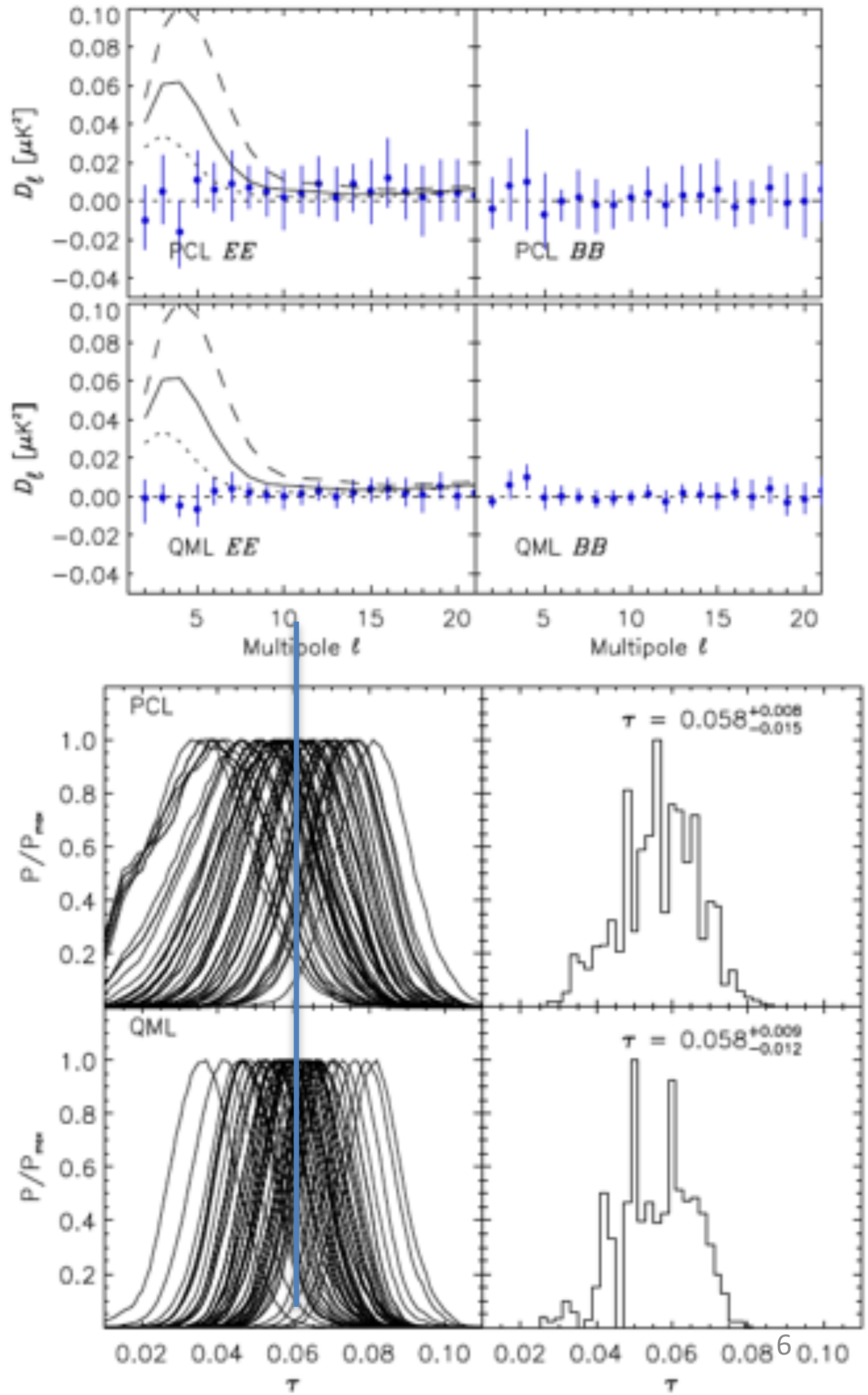


testing bias from systematics

83 E2E simulations

- simulations of the systematic residual power spectrum

- simulating 100 times the HFI data and then full processing of "End to End" simulations and t determination (input was 0.06)



PCL and QML 100x143 cross spectra

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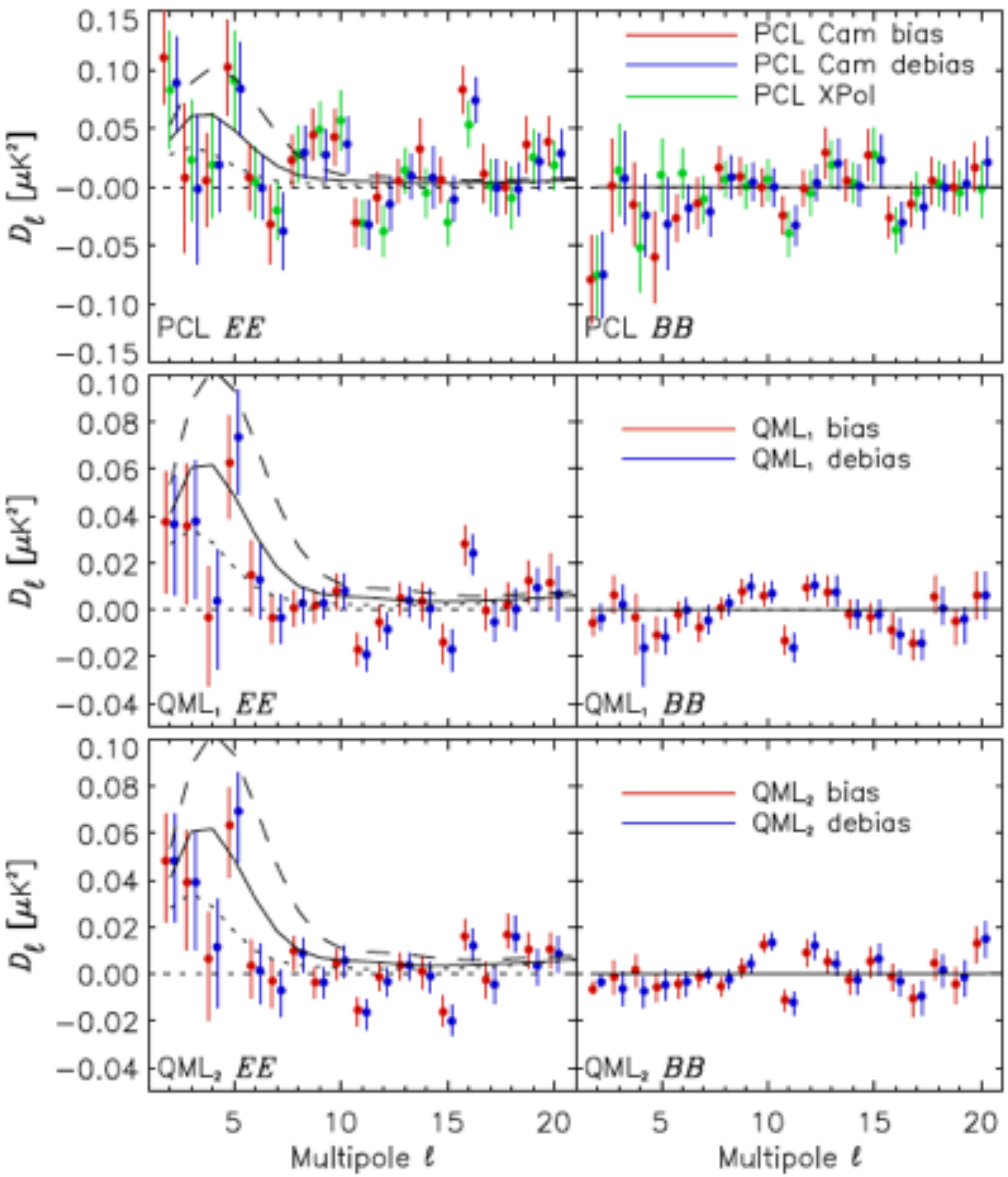
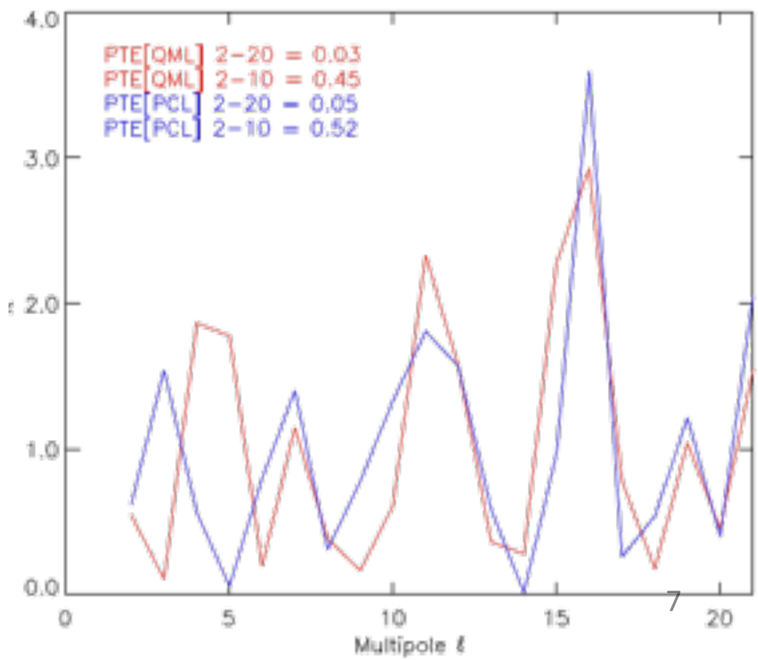


- left: 2 sets of PCL cross spectra,
  - very consistent,
  - debiasing from the ADC NL dipole distortion small (only ell<4)
  - QML consistent pattern with PCL, lower dispersion and error bars
- bottom right: PTE remain consistent in QML when using 2 independent sets of simulations for
  - i) pixel covariance matrix
  - ii) simus for noise and likelihood



τ results: baseline 100x143

consistency check

70x100 and 70x143

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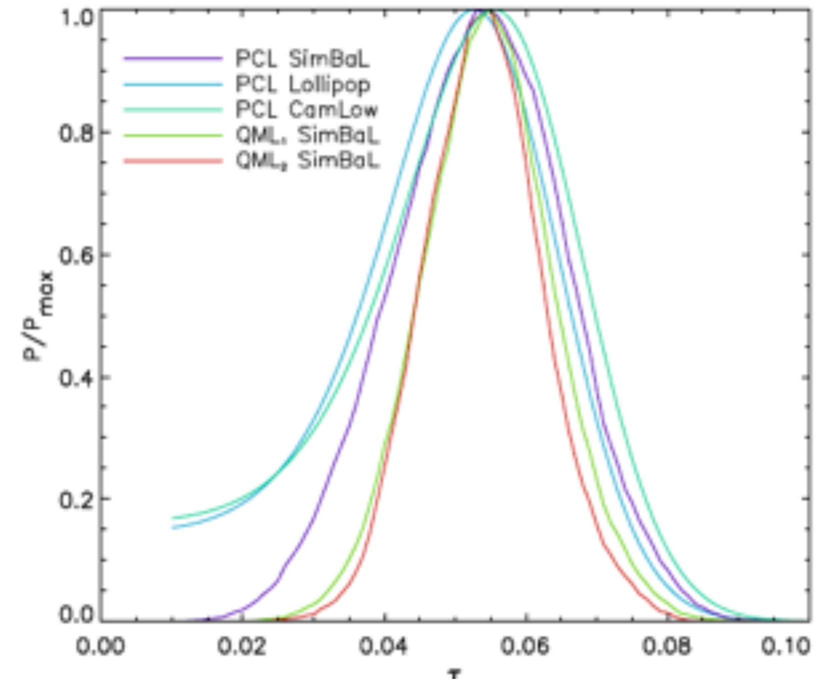
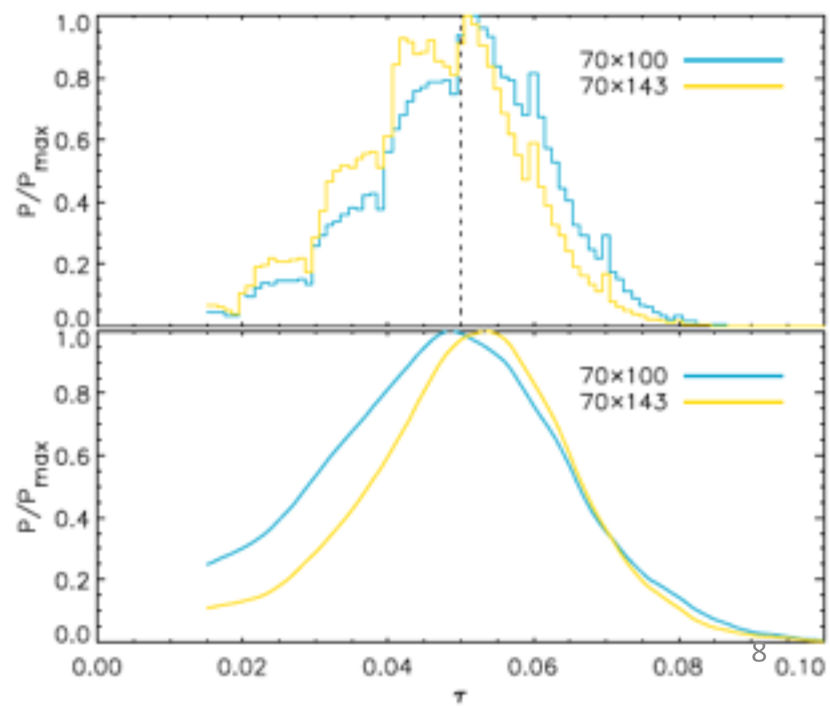
- PCL spectrum estimates have larger posterior
- the simulation based likelihood gives better results on low Tau
- QML estimator has narrower posterior distribution but the same peak value
- LFI-HFI give also nearly the same peak value but with larger uncertainties





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

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	PCL		QML	
Method	peak $\pm 1\,\sigma$	peak $+2\,\sigma$	peak $\pm 1\,\sigma$	peak $+2\,\sigma$
SimBaL1	$0.053^{+0.012}_{-0.012}$	0.076	$0.055^{+0.008}_{-0.010}$	0.073
SimBaL2	...	...	$0.055^{+0.007}_{-0.010}$	0.071
Lollipop . . .	$0.053^{+0.011}_{-0.021}$	0.075	...	...
CamLow	$0.055^{+0.011}_{-0.021}$	0.078	...	...

HFIxLFI consistency results

$$\tau = 0.049^{+0.015}_{-0.019} \text{ for the } 70\times100 \text{ cross spectra}$$
$$\tau = 0.053^{+0.012}_{-0.016} \text{ for the } 70\times143 \text{ cross spectra}$$

the new results are compatible with Planck 2015

$$\tau = 0.078^{+0.019}_{-0.019}, \; z_{re} = 9.9^{+1.8}_{-1.6}, \; \textit{Planck}\ \text{TT+lowP};$$

$$\tau = 0.070^{+0.024}_{-0.024}, \; z_{re} = 9.0^{+2.5}_{-2.1}, \; \textit{Planck}\ \text{TT+lensing};$$

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

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

$$\tau = 0.066^{+0.013}_{-0.013}, \; z_{re} = 8.8^{+1.3}_{-1.2}, \; \textit{Planck}\ \text{TT+lowP +lensing+BAO}.$$

- more accurate - lower values
- an almost independent measurement from the other cosmological parameter
- bringing reduction of some tensions between CMB and astrophysical cosmology

- consistency of all Planck t results
- improvements of uncertainties
- drift towards lower values

τ from CMB (historical)

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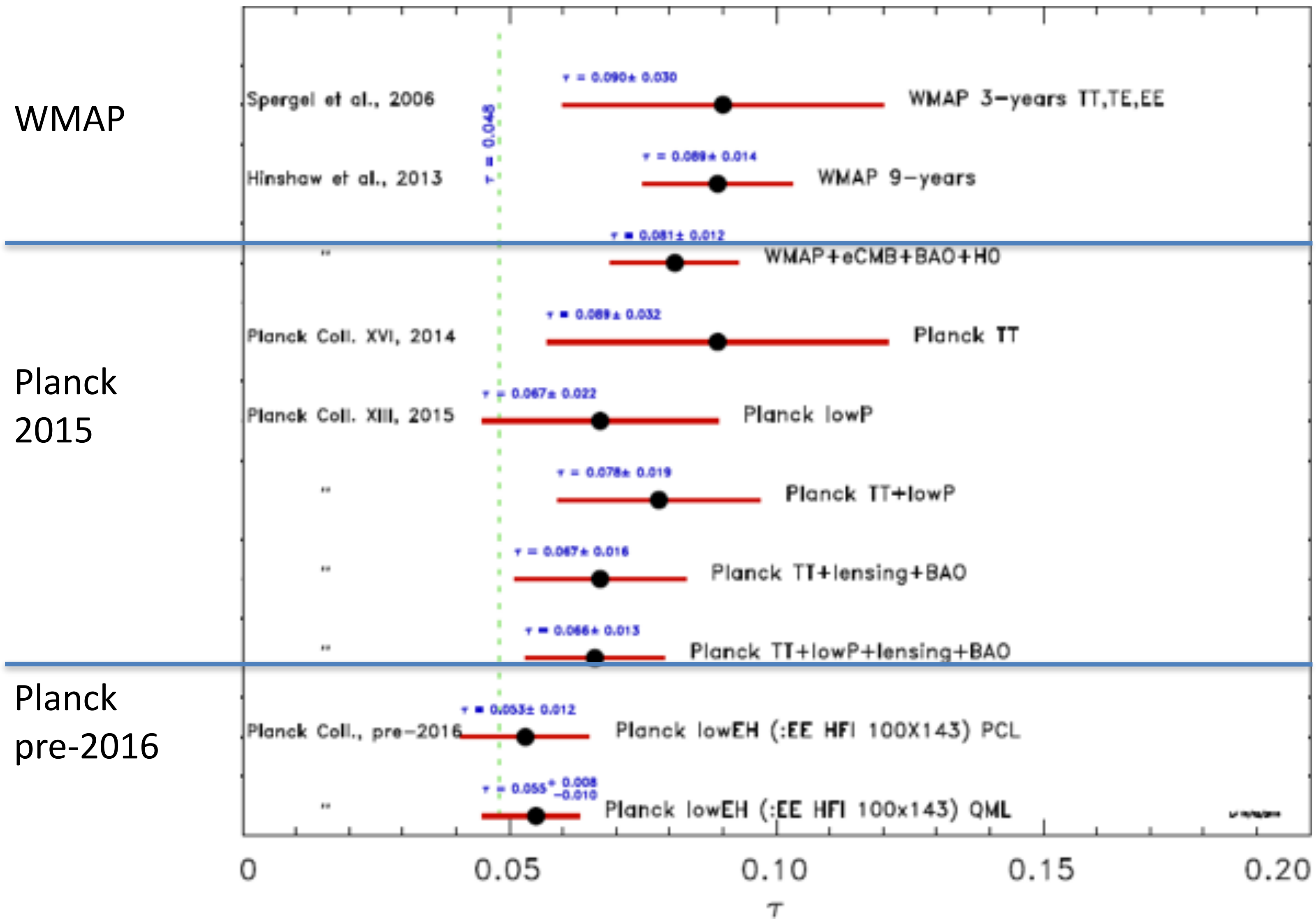
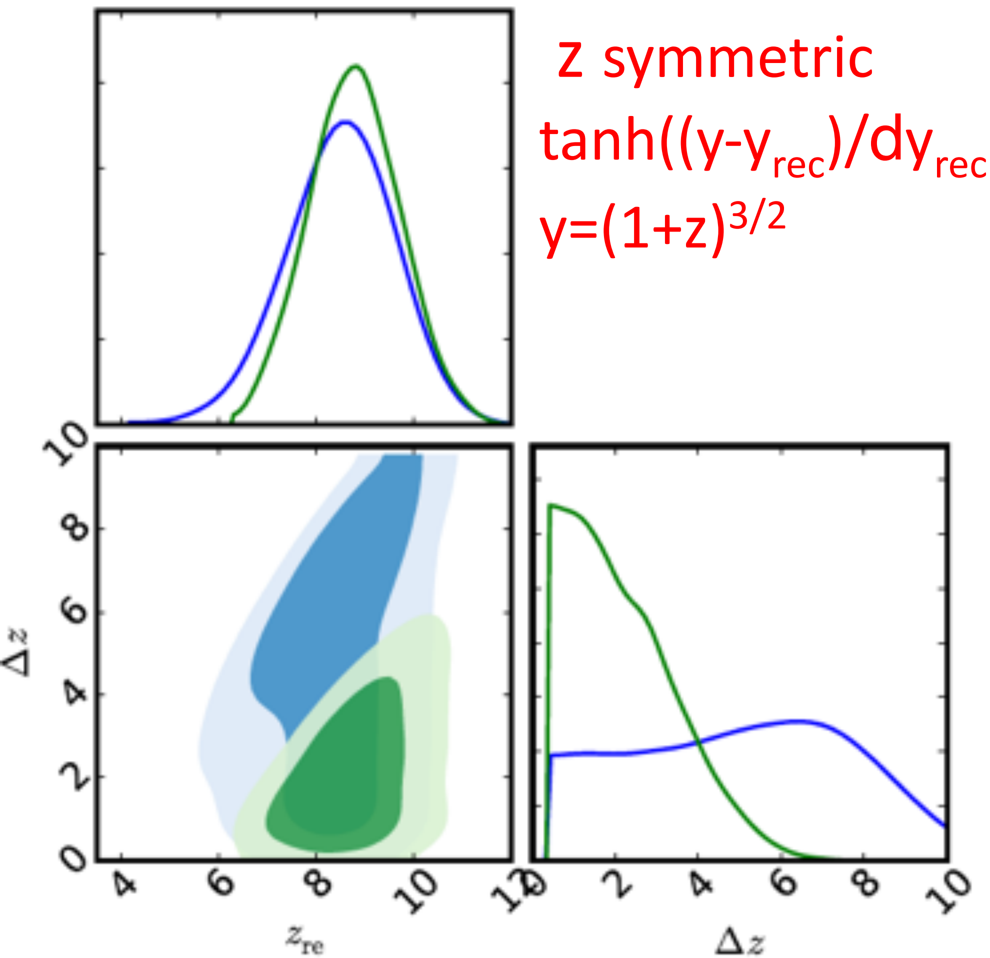


Reionisation history constraints from Planck



z symmetric

$\tanh((y-y_{rec})/dy_{rec})$

$y=(1+z)^{3/2}$

- Constraints on z_{rec} ,Δz_{rec}
  for Dz =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 $z_{re}=8.16^{+-1}$

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

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

τ, A_s, n_s degeneracies

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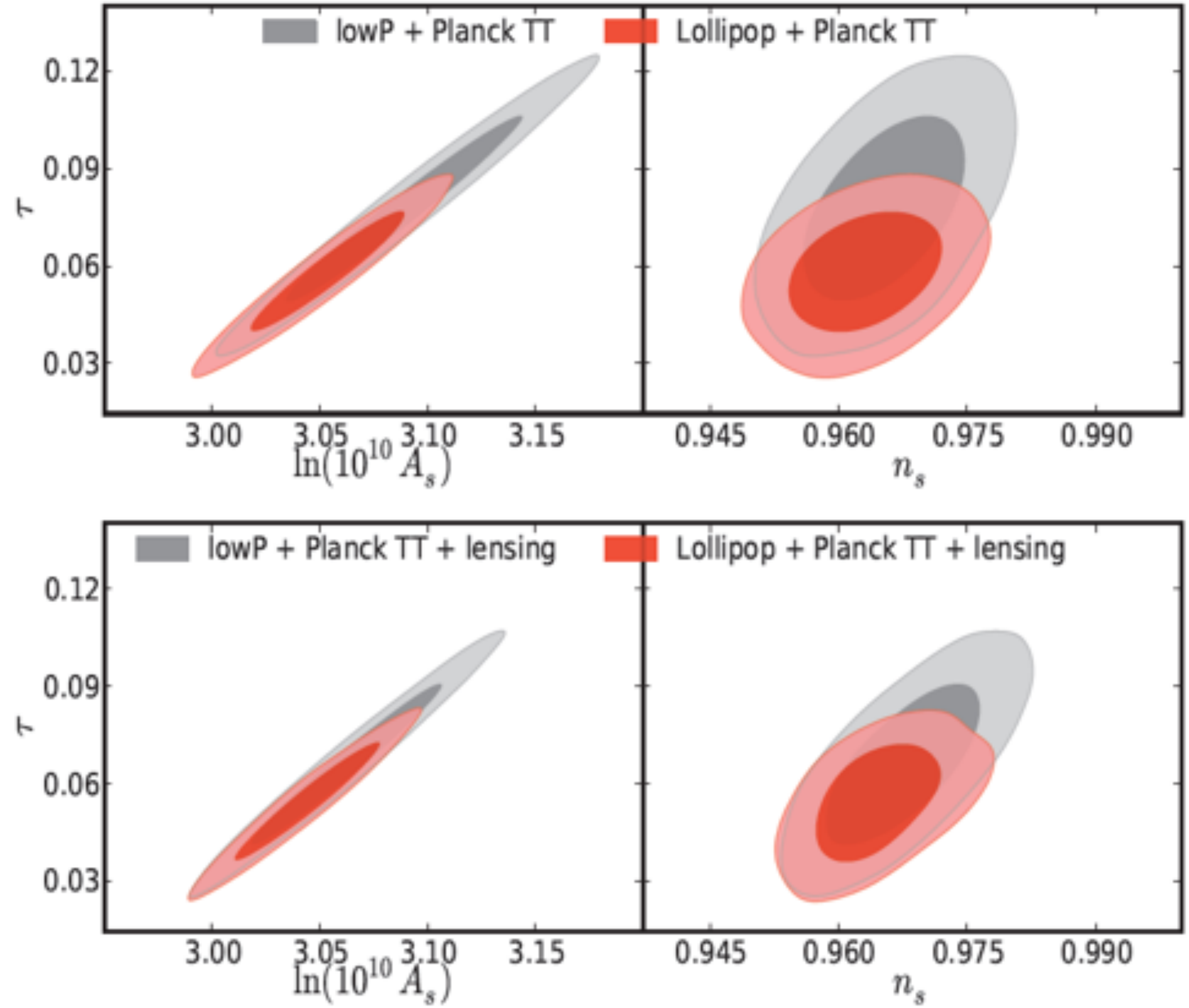
- better τ breaks almost completely the degeneracy with n_s and reduces the degeneracy with A_s

- adding lensing does not improve
- although τ breaks the degeneracy with n_s



models of reionization

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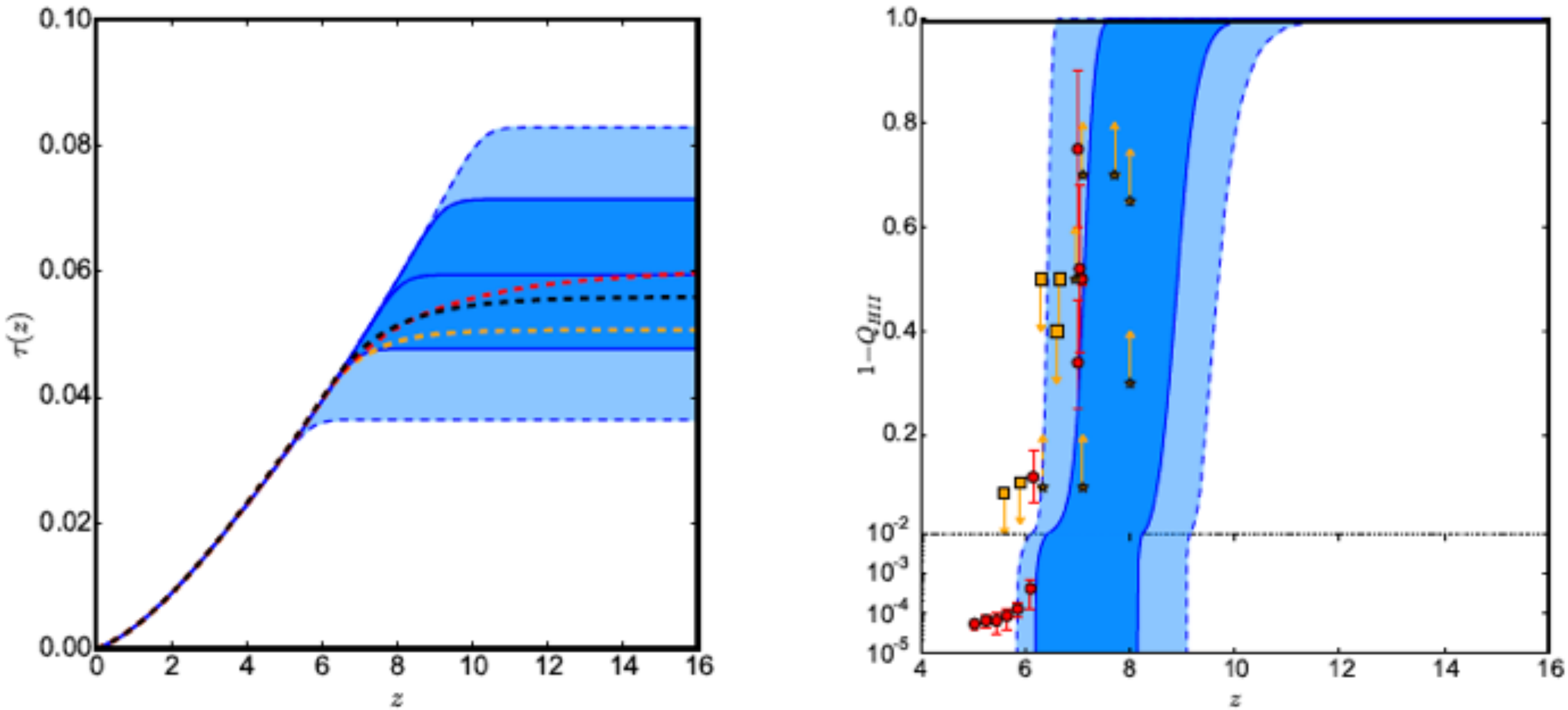

- CMB polarised EE
- high redshift sources
- HI 21cm
- other lines…

combined to constrain the first sources history

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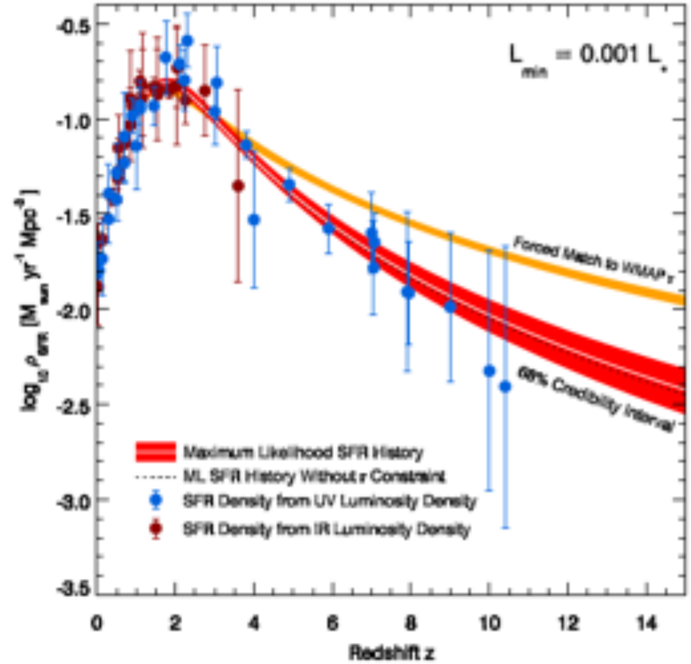
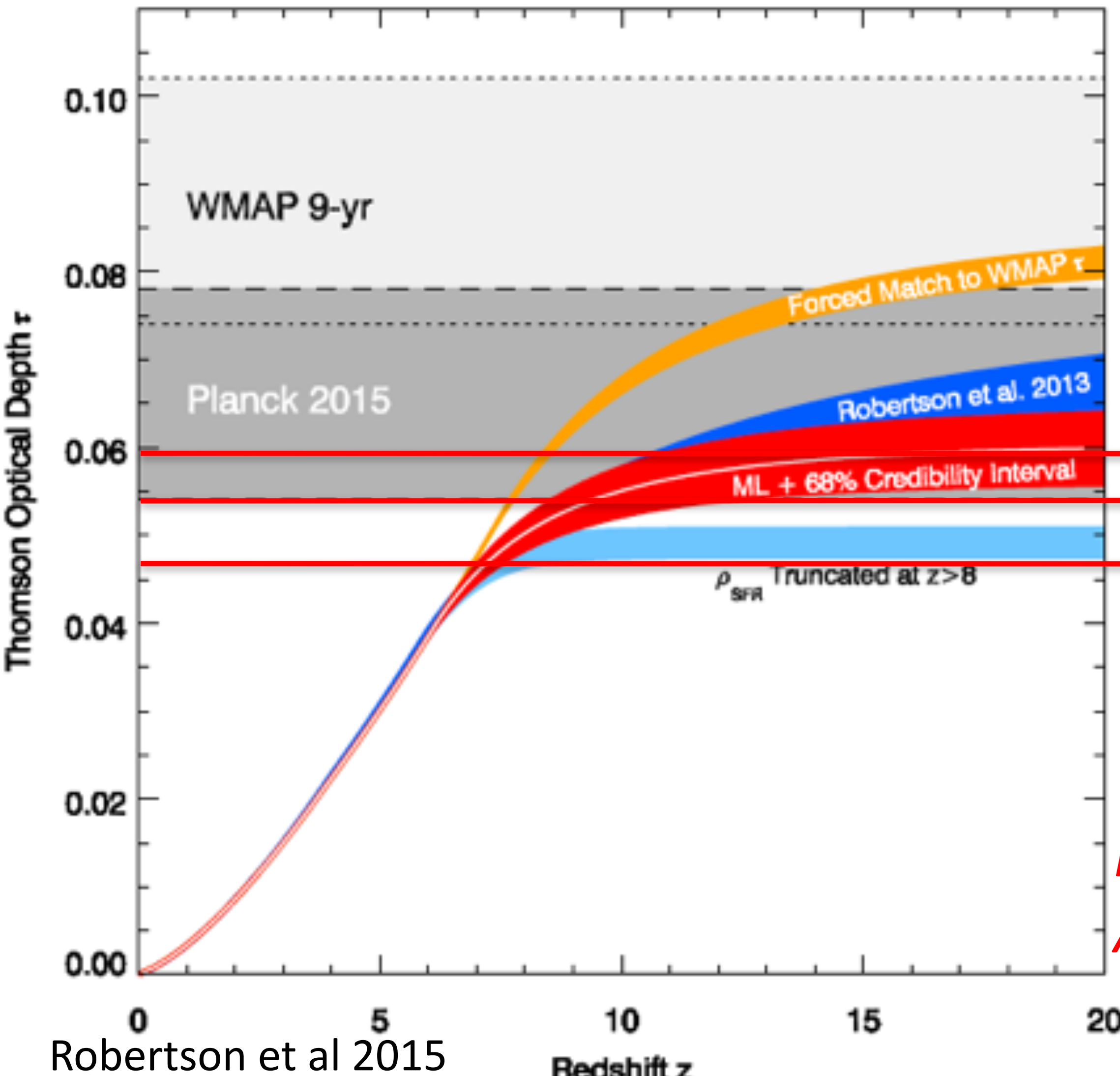
Planck constraints on reionization history

models of reionisation based on the high redshift sources observations with the new Planck constraints





Planck pre 2016

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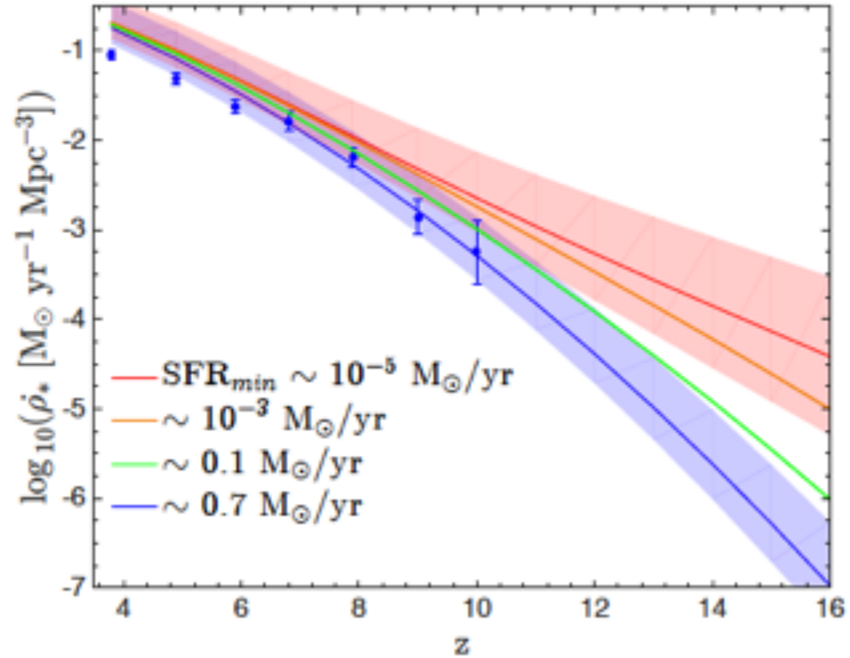
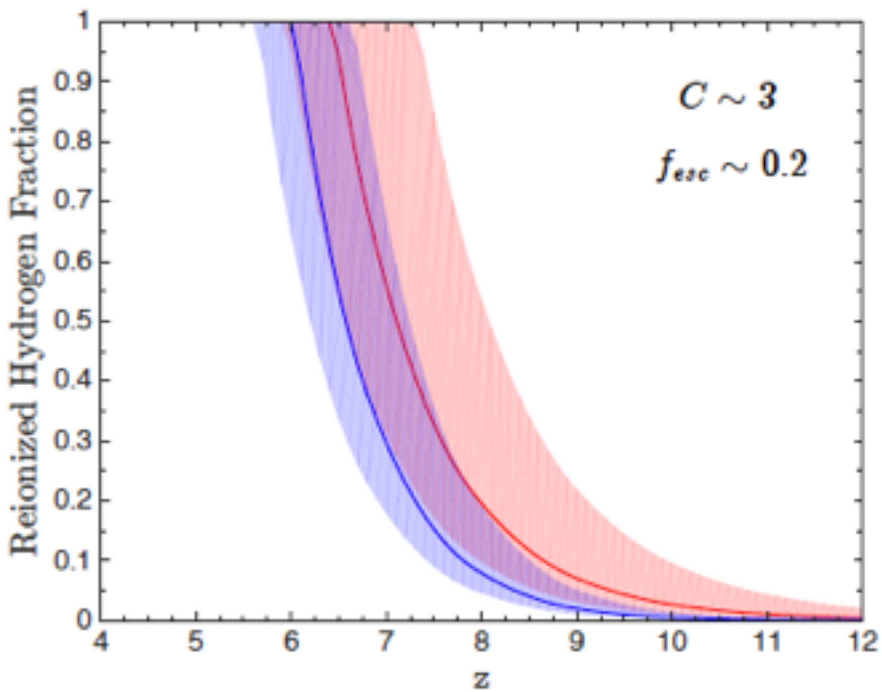
Robertson et al 2015

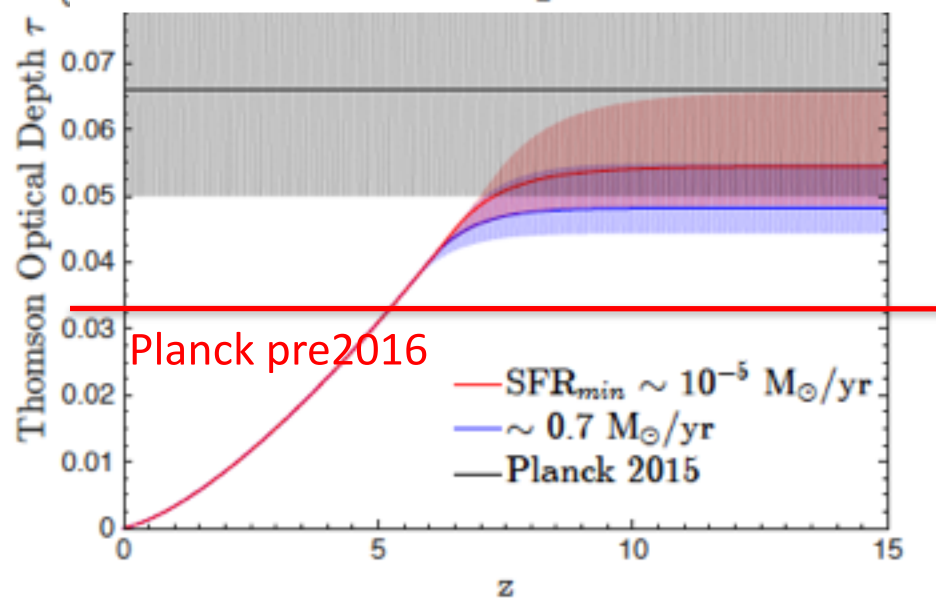
helping to constrain the SFR at very high z

In this model the Planck new t implies a steepening of the decrease of SFR at z>10

Mashian, Oesch, Loeb 2015







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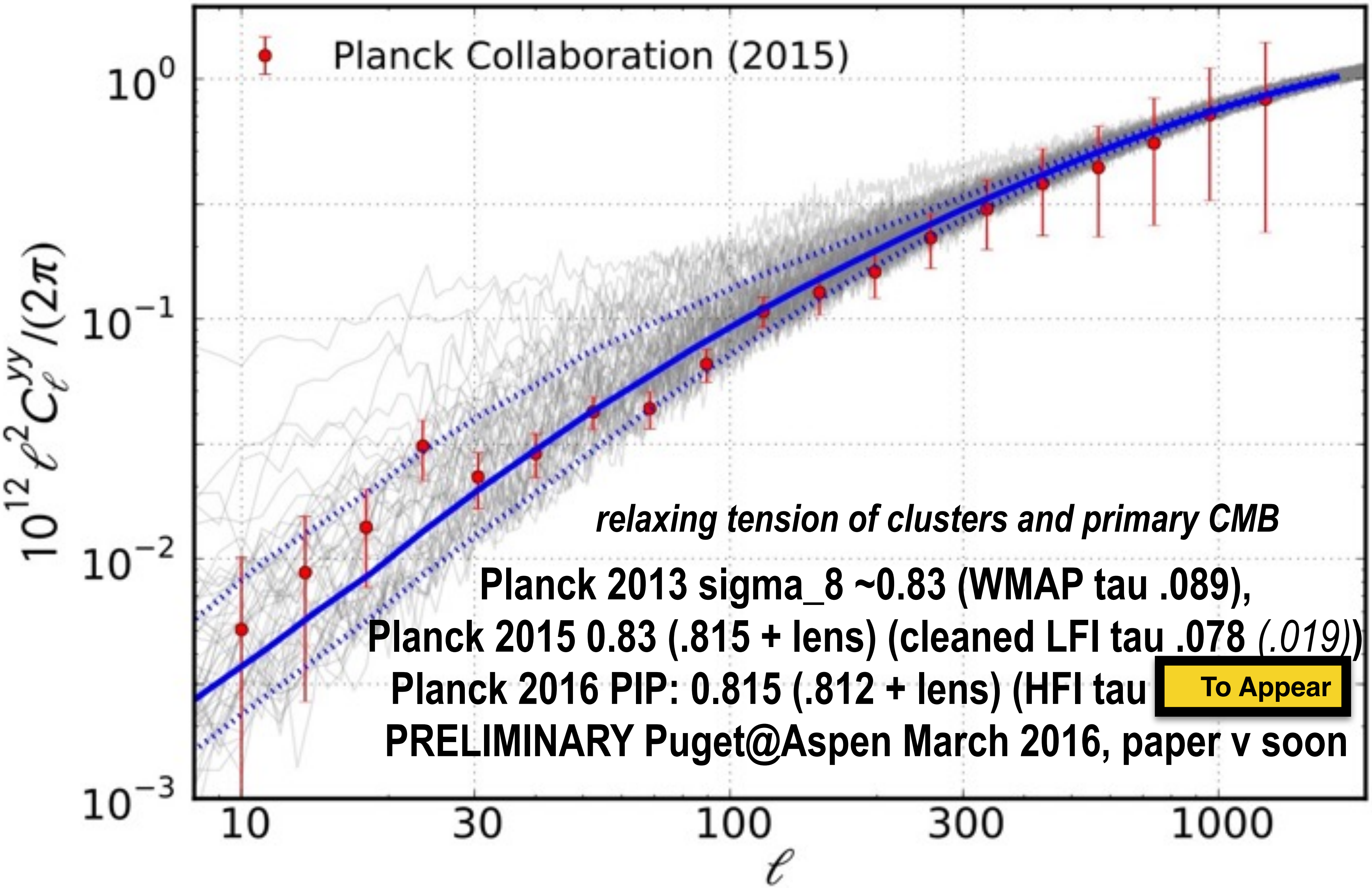
Summary

- First use of Planck HFI EE low Ell spectra and τ value with smallest uncertainties
- measurement almost independent of the other cosmological parameters
- Gives a value for τ lower than previous CMB ones
- Removes the tension between CMB and model of reionisation based on the formation of first stars and galaxies



relaxing tension of clusters and primary CMB

Planck 2013 sigma_8 ~0.83 (WMAP tau .089),

Planck 2015 0.83 (.815 + lens) (cleaned LFI tau .078 *(.019)*)

Planck 2016 PIP: 0.815 (.812 + lens) (HFI tau **To Appear**

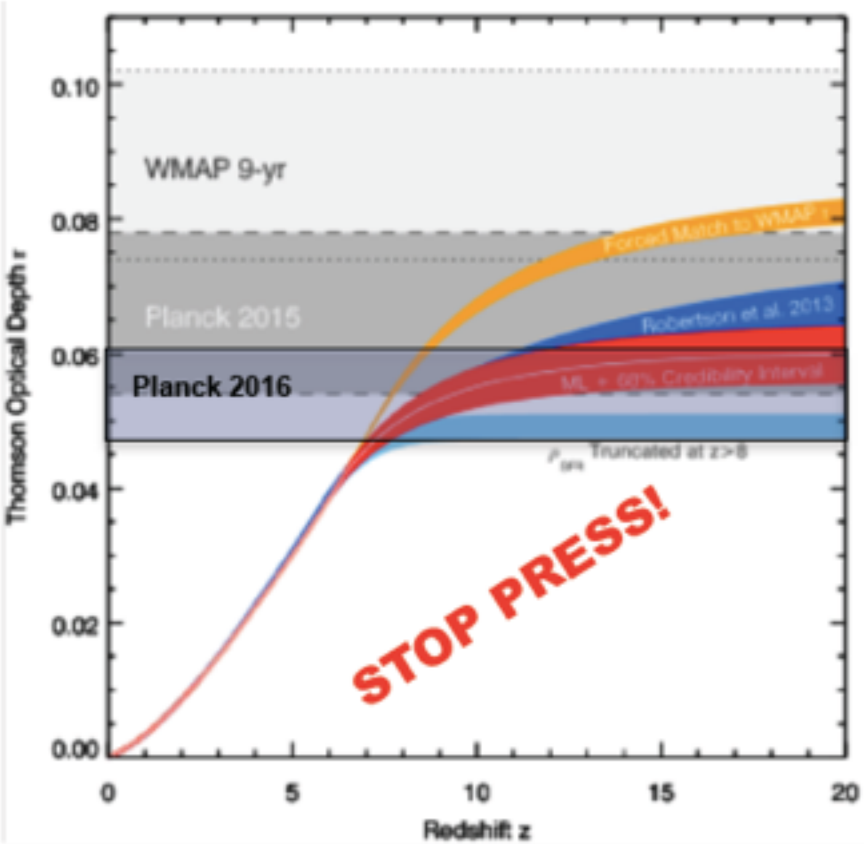
PRELIMINARY Puget@Aspen March 2016, paper v soon

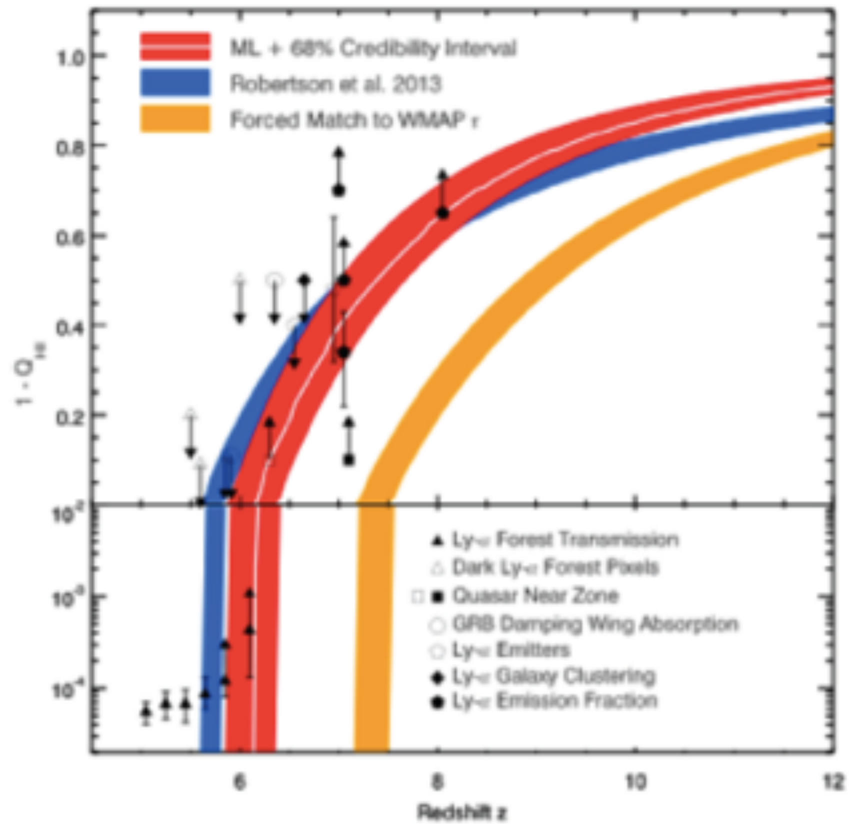
CITA mini-industry

Alvarez, Berger, Bond, Stein, Bahmanyer, Battaglia,..Huang, Frolov 2016

app: Clustering of hot electrons in groups around Planck clusters is detectable

Planck & HST: Reionisation over 6 < z < 12





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

Focus now turns to measuring the ionizing output of early galaxies

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

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 nstruments provided by two scientific Consortia funded by SA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a ollaboration between ESA and a scientific Consortium led and funded by Denmark.