the impact of Planck on reionisation

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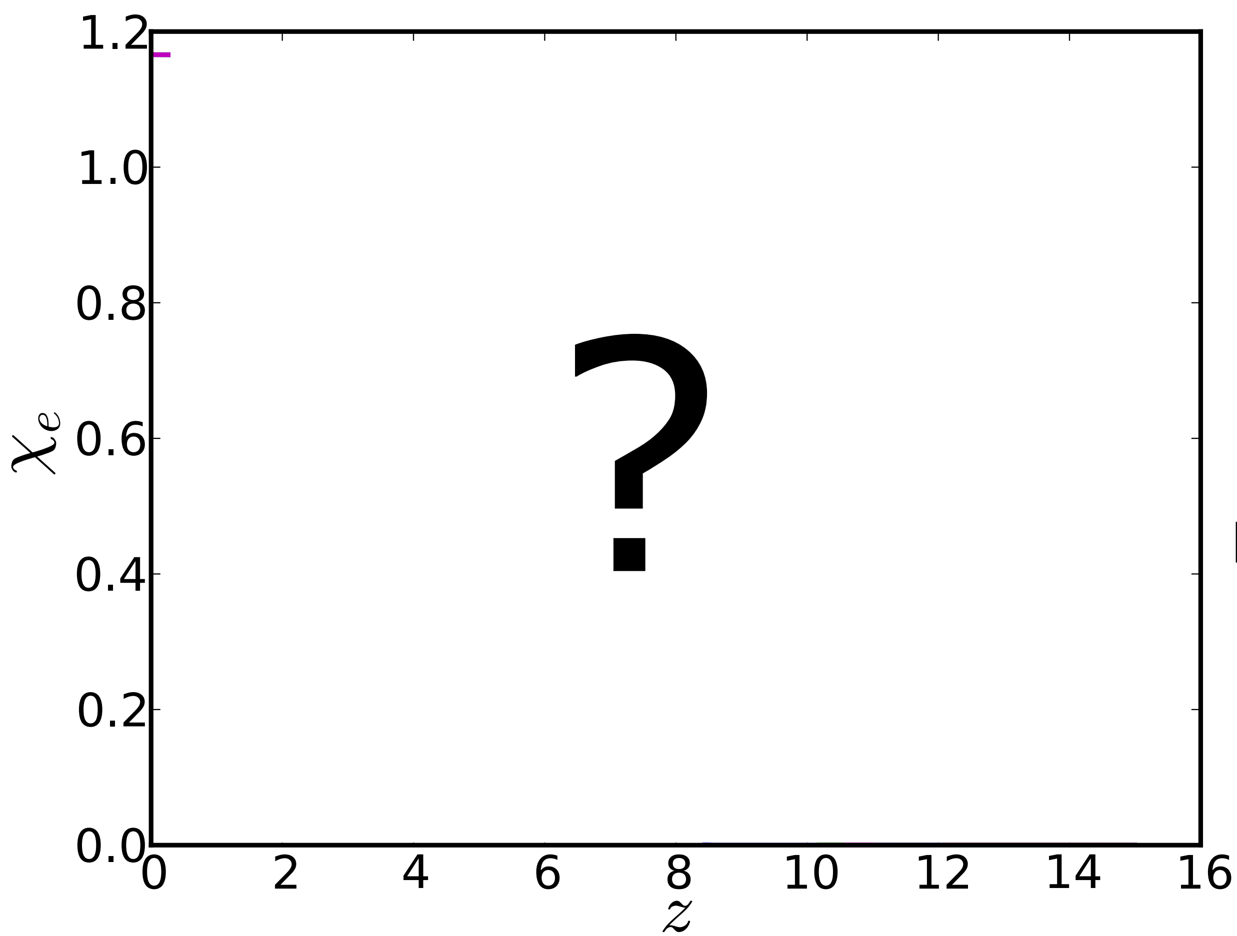
reionisation

The Epoch of Reionisation (EoR) describes the period during which the cosmic gas went from neutral to ionised at the onset of the first emitting sources.



χ_e is the ionisation fraction as a function of the redshift

reionisation optical depth is defined as

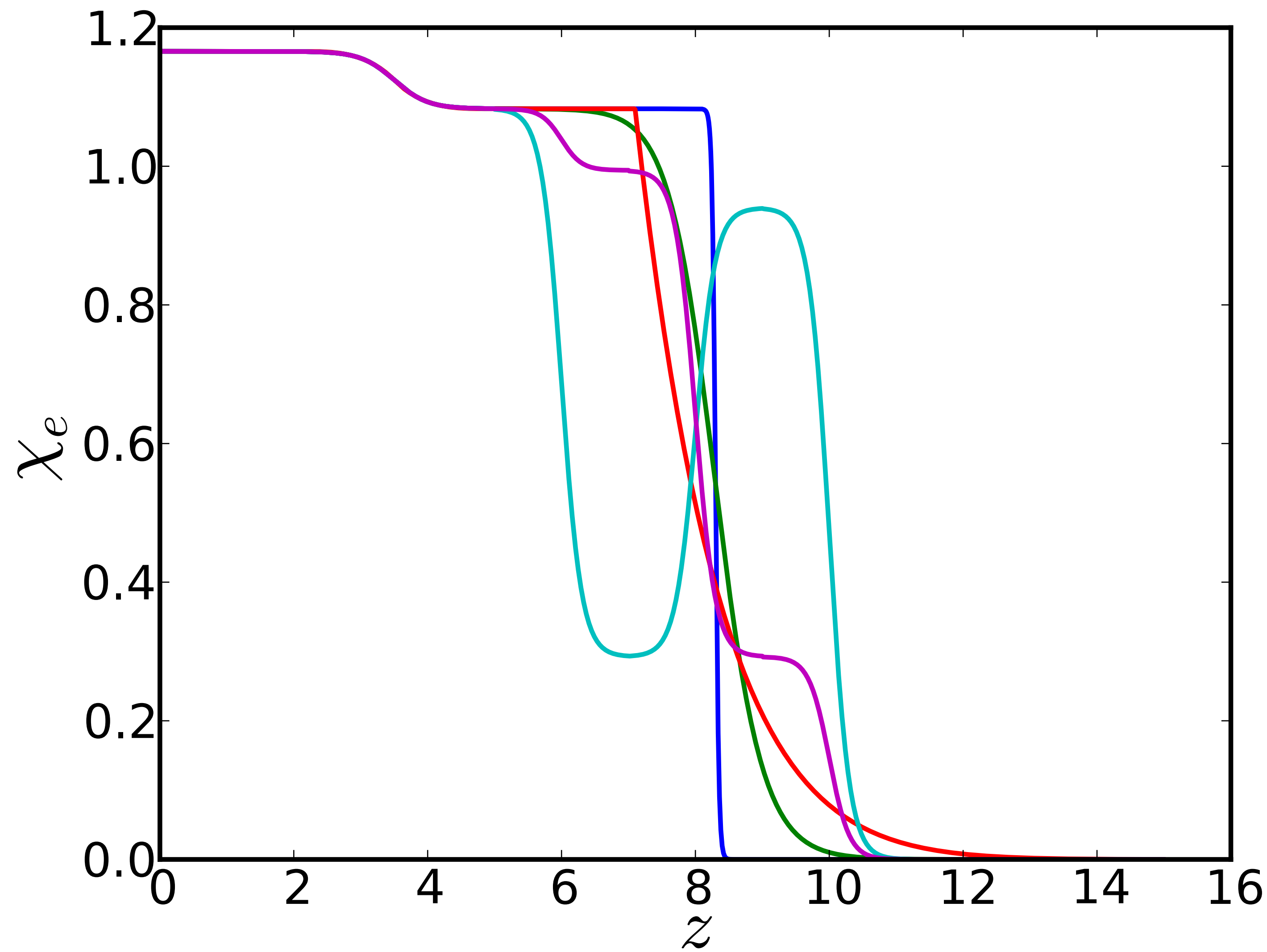
$$\tau = \int_0^{\eta_0} a n_e \sigma_T d\eta$$

reionisation history

- **symmetric** (standard tanh)
  - 2 parameters : z_{re}, Δz
- **asymmetric**
  - 2 sources :
    1. “gentle” : stars & DGs
    2. “abrupt” : QSOs finish
  - phenomenological description :

  $\mathbf{z_{start}, z_{end}, z_{trans} \leftrightarrow z_{re}, \Delta z_{begin}, \Delta z_{end}}$

- **model independent**
  - $x_e(z)$ in redshift bins
  - Principal Component Analysis



CMB & reionisation

planck

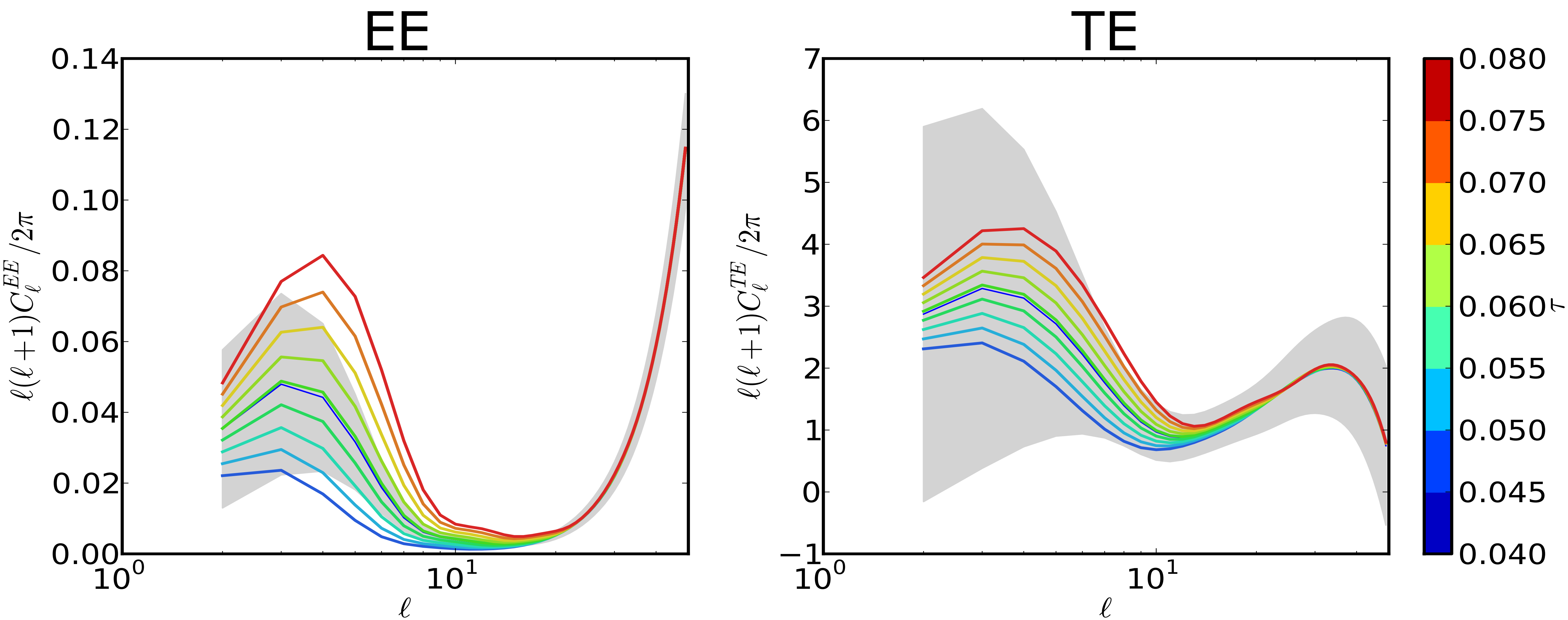
CMB can give information on EoR through

- **temperature anisotropies**
  - suppression of TT power at high multipole
    (very degenerate with other cosmological parameters and foregrounds)

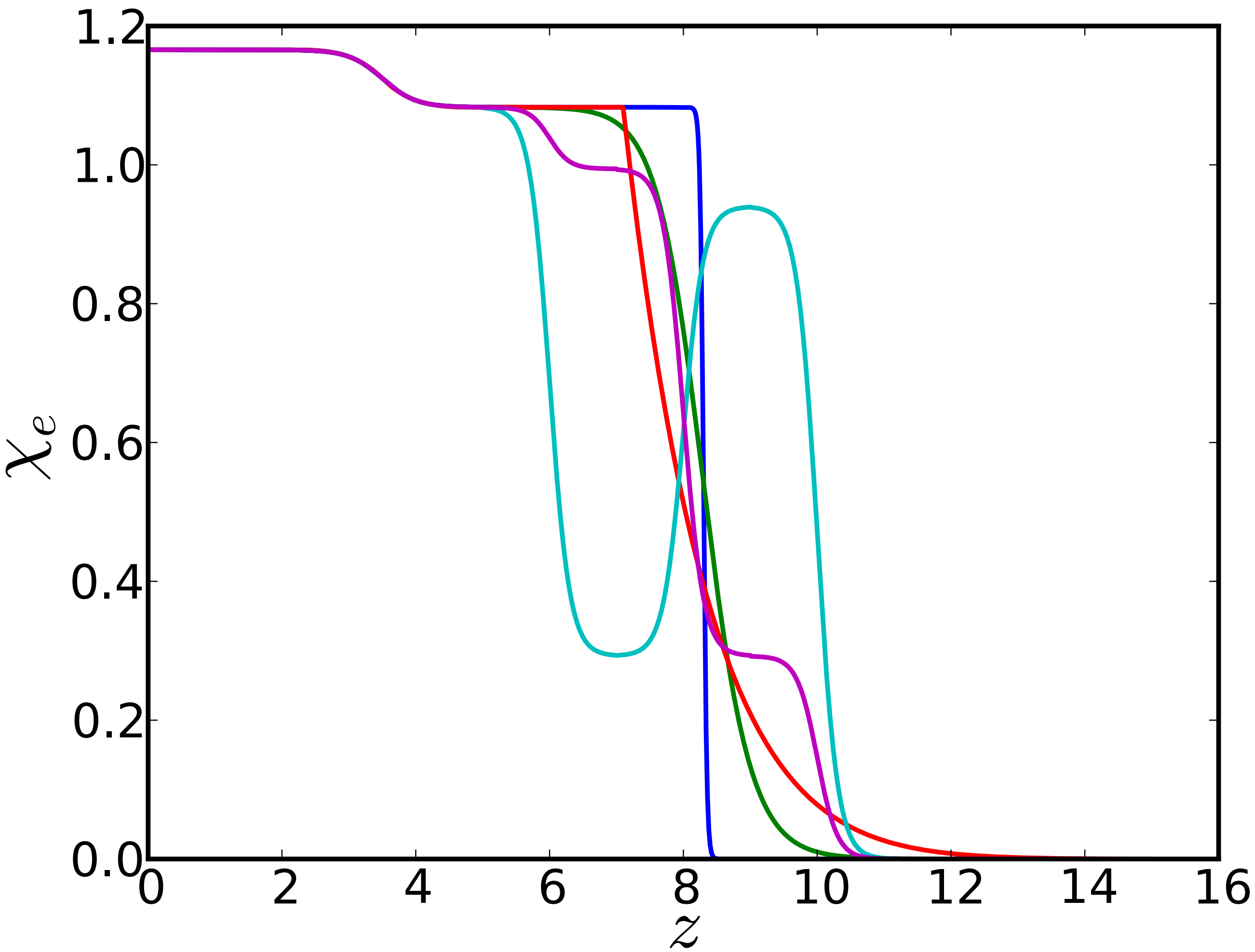
- **large scale CMB anisotropies in polarisation**
  - new polarisation anisotropy at large angular scale because the horizon has grown to a much larger size by that epoch

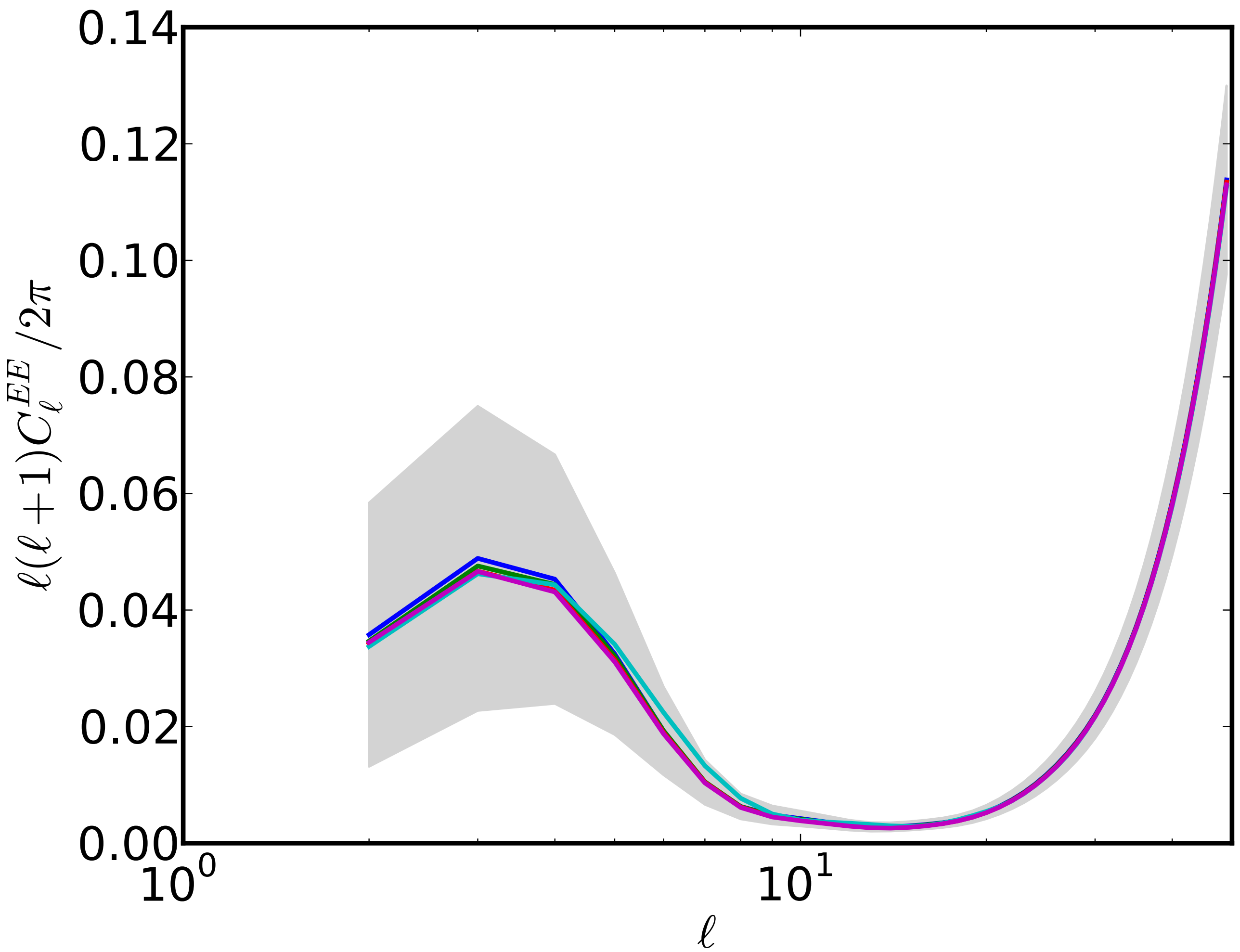
- **kinetic Sunyaev-Zel'dovich effect**
  - re-scattering of photons off newly liberated electrons [Sunyaev & Zel'dovich 1980]

effect on CMB polarisation at low-ℓ



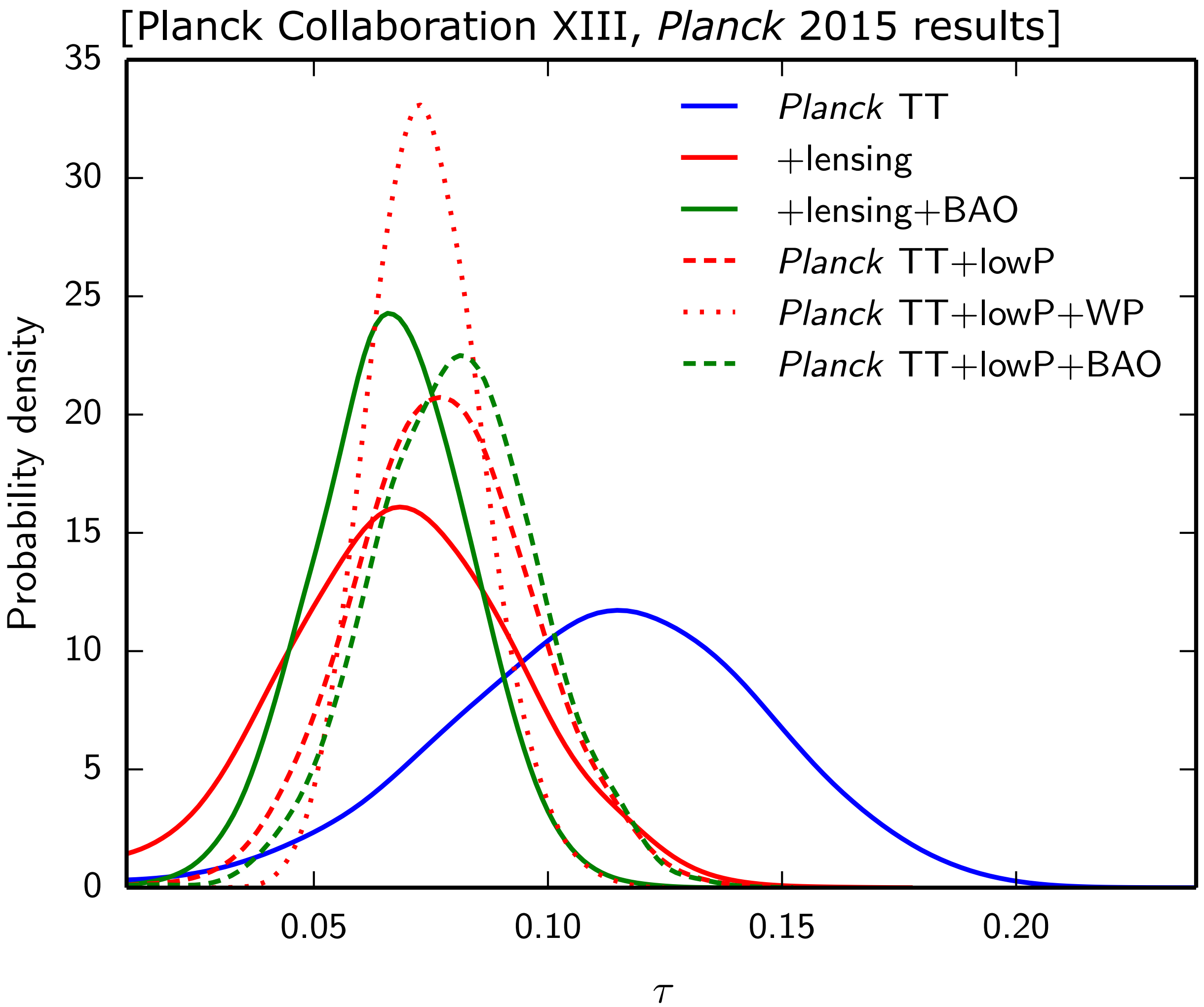
CMB degeneracies





reionisation optical depth

From CMB data:



1. **WMAP 9yr**
   - $\tau = 0.089 \pm 0.014$
2. **Planck 2013**
   - $\tau = 0.089 \pm 0.014$ (TT with WP)
   - $\tau = 0.075 \pm 0.013$ (TT with Planck dust)
3. **Planck 2015**
   - $\tau = 0.078 \pm 0.019$ (TT + lowP)
   - $\tau = 0.066 \pm 0.016$ (TT + lowP + lensing)
   - $\tau = 0.067 \pm 0.016$ (TT + lensing + BAO)
4. **Planck HFI EE low-l**
   - decreasing trend continues…

Planck-HFI low-ℓ data

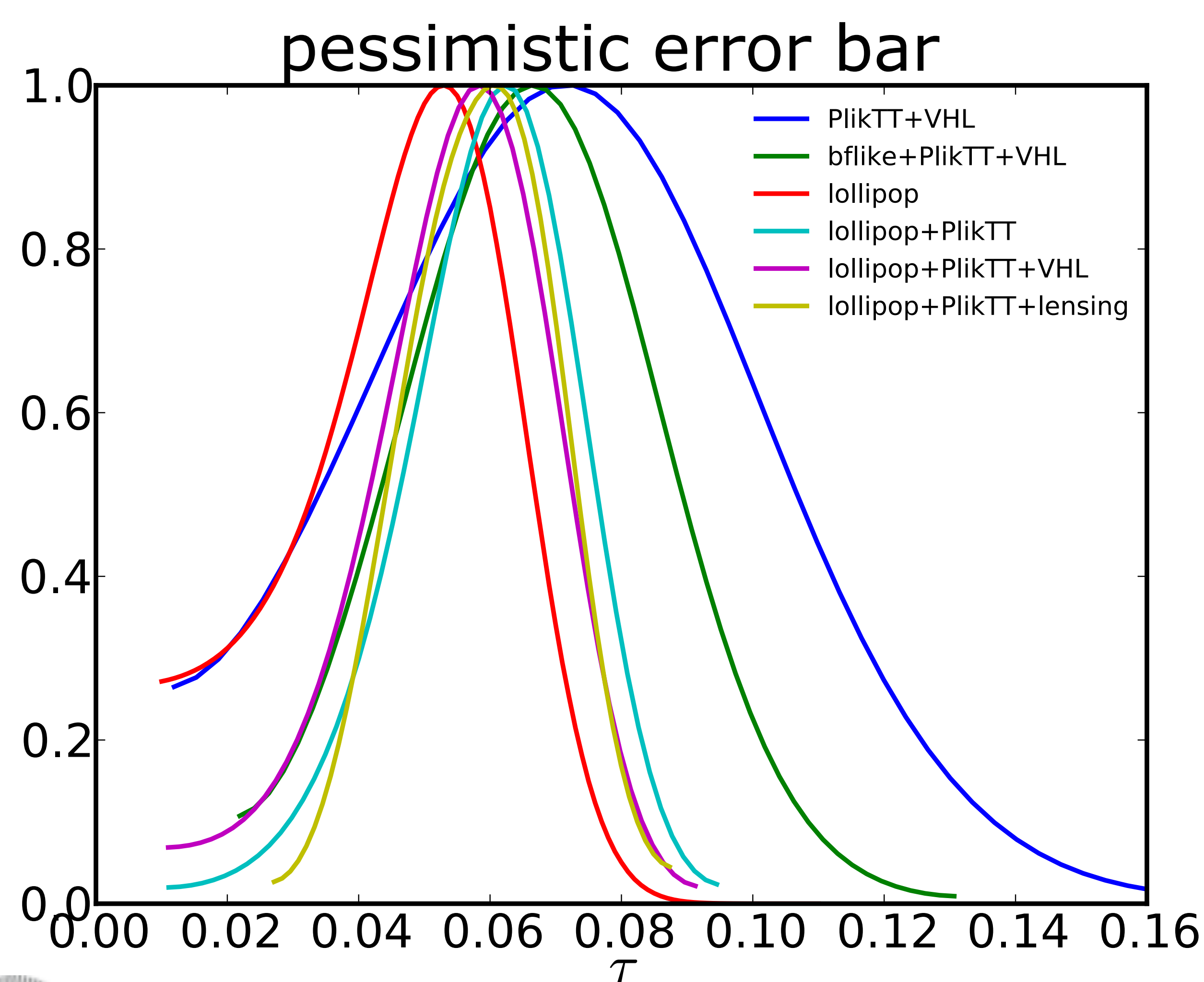
1. **in previous Planck data, the biggest systematic was ADC-NL**
   - has been reduced by a factor almost 10 but still not negligible on frequency maps
2. **we have now identified all dominant sources of residual systematics that matter for low-ℓ data analysis**
3. **first results on E2E Monte-Carlo simulations including ADC-NL**
   - no bias on cross-spectra
   - more work still to be done on a reliable propagation of uncertainties
4. **likelihood based on cross-spectra between Planck frequency maps**
   - [Hamimeche&Lewis 2008] approximation modified for cross-spectra [Mangilli+2015]

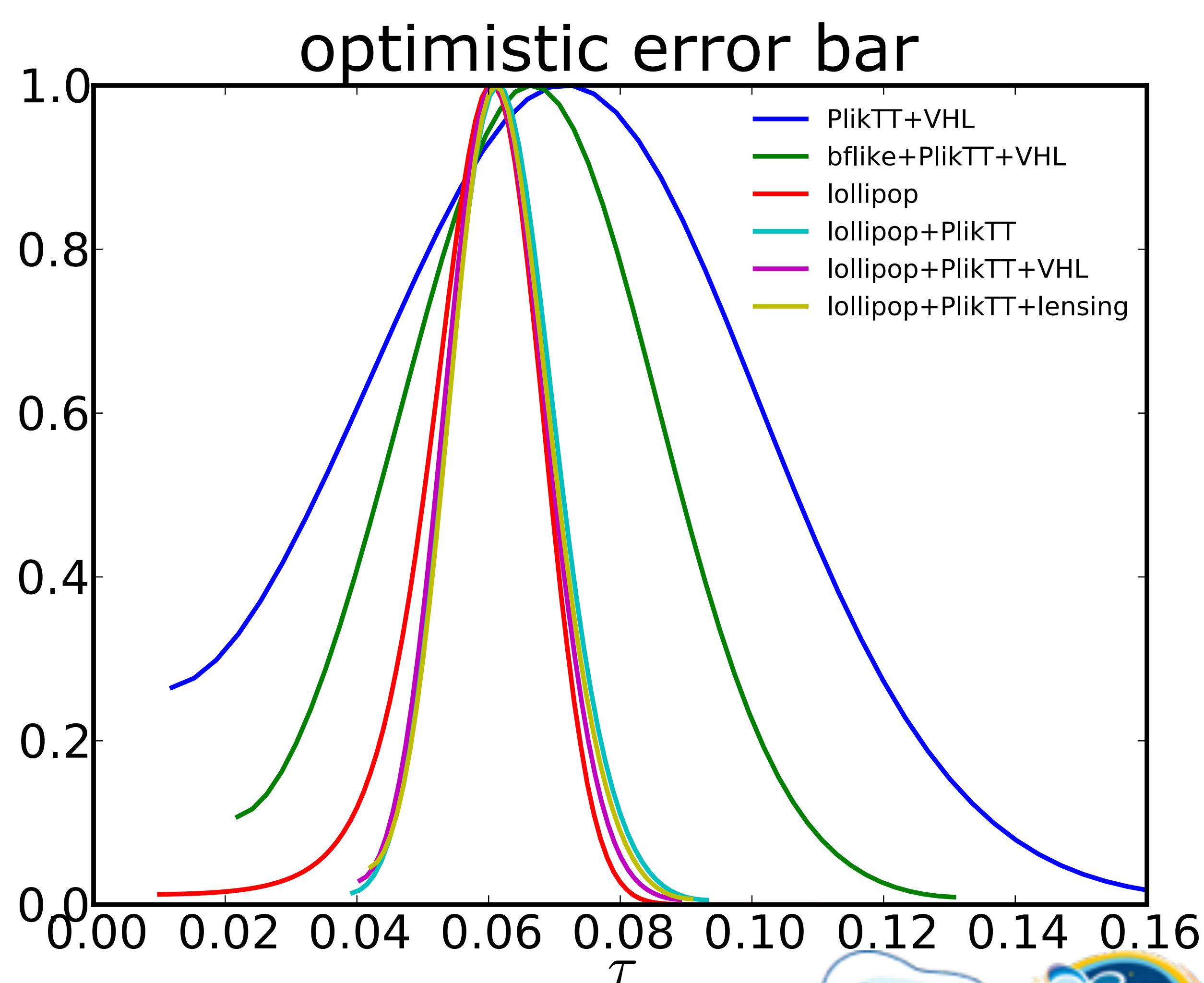
next results are two preliminary versions of Planck analysis based on two different noise/syste statistics

reionisation optical depth

Example of results as a combination of

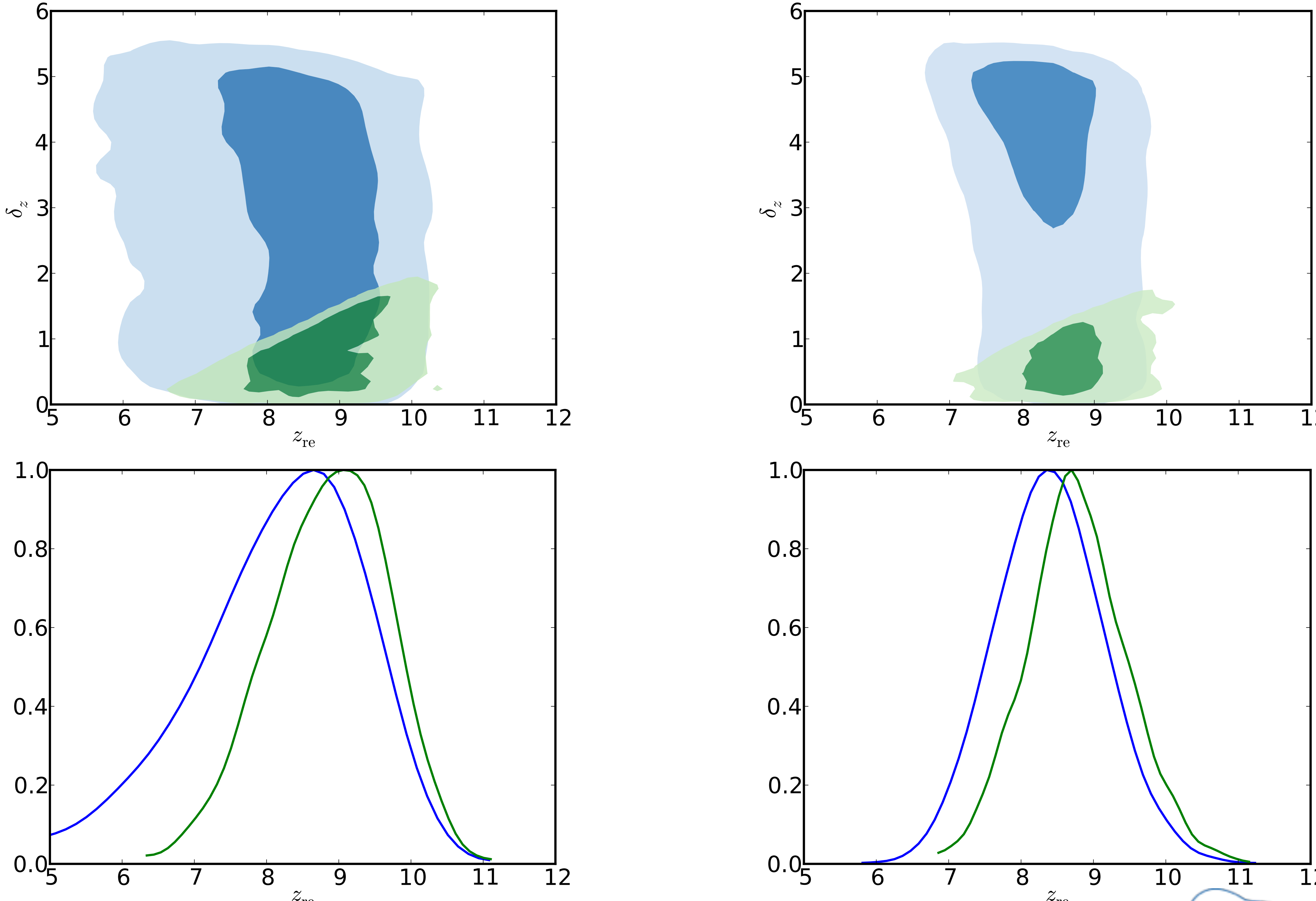
1. Planck TT CMB spectrum (2015)
2. two versions of Planck EE low-ℓ
   value and error bar not yet finalized !
3. Very High-ℓ ground-based experiments (ACT & SPT)





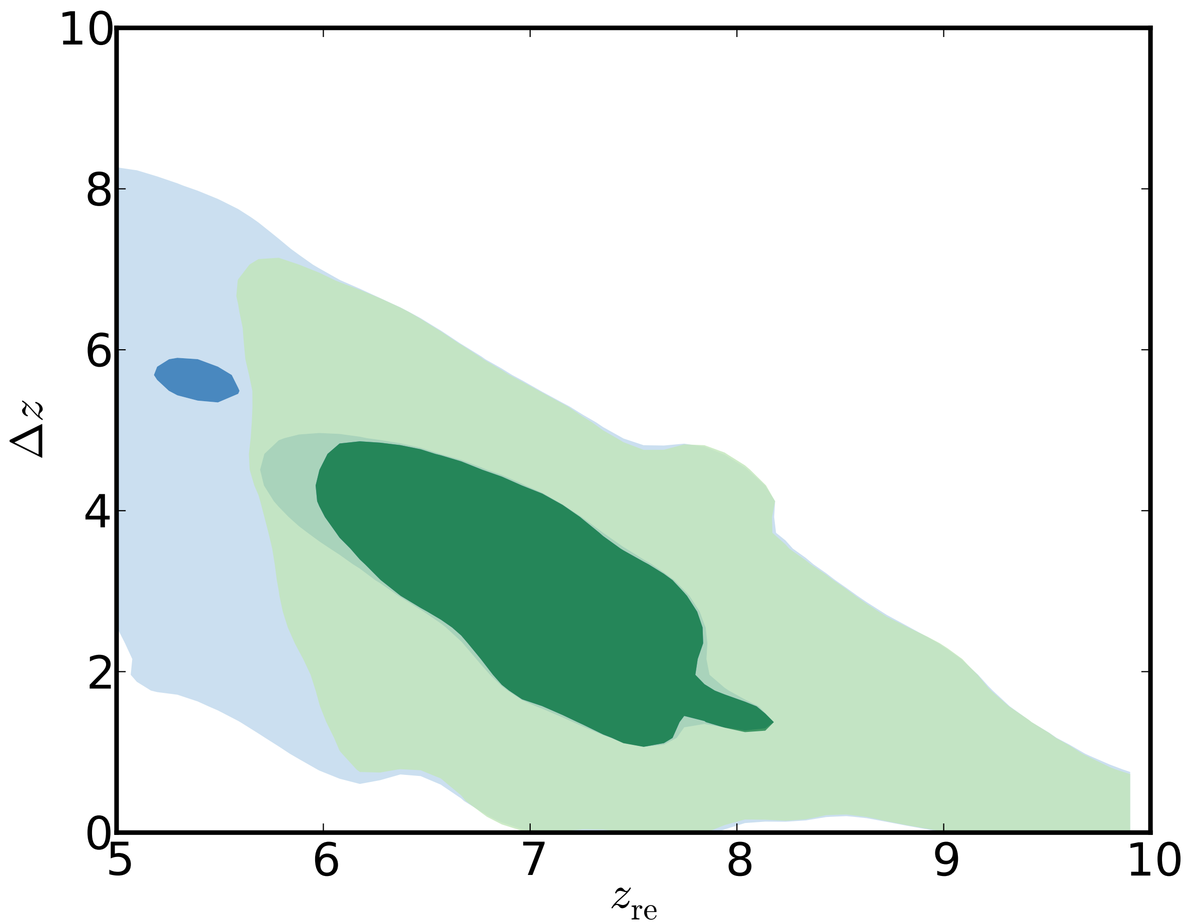
preliminary

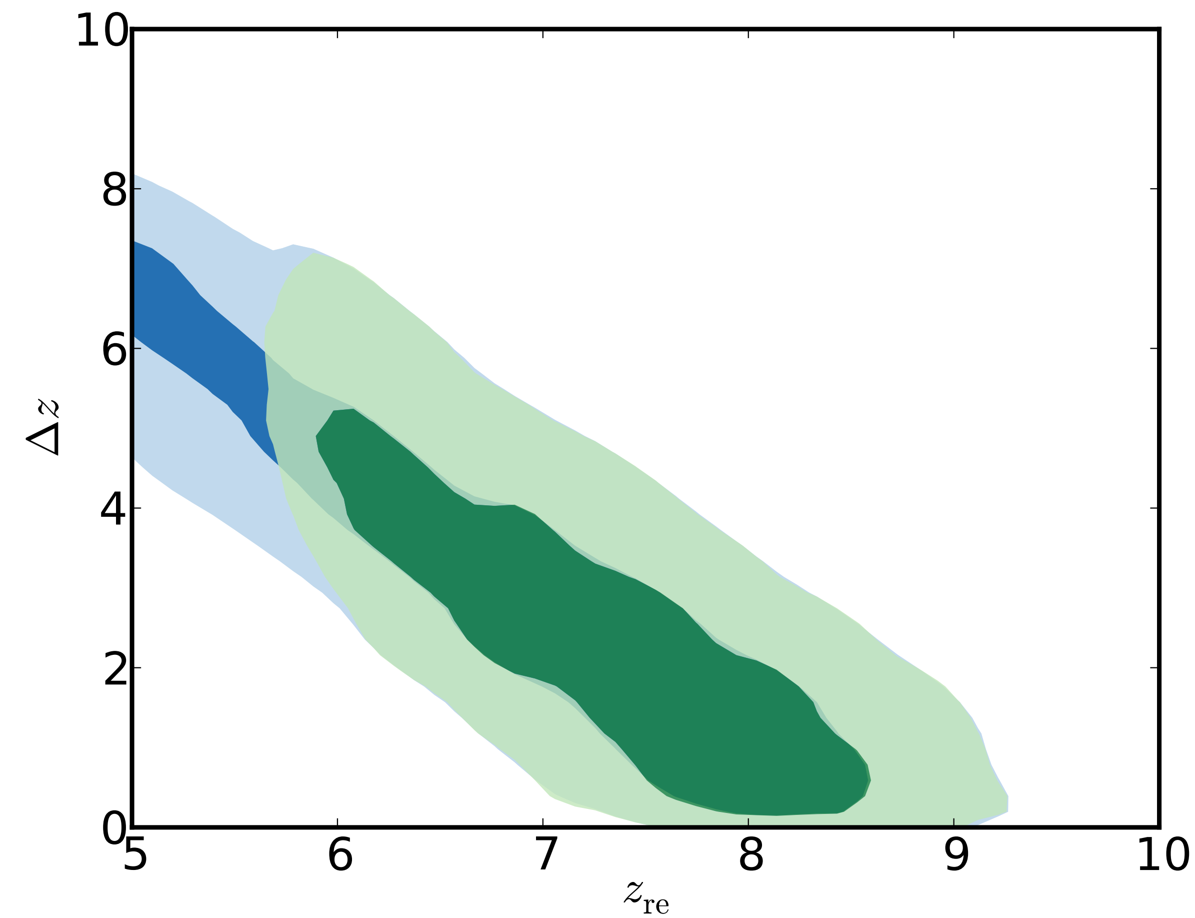
symmetric model



preliminary

asymmetric model





preliminary

reionisation and kSZ

second-order effect of photons scattering off electrons moving with bulk velocity which is called "kinetic Sunyaev Zel'dovich" effect (kSZ, Sunyaev & Zeldovich, 1980)

1. **homogeneous kSZ**
   arising when the reionisation is complete [Ostriker & Vishniac 1986]

$$D_\ell^{h-kSZ} \propto \left(\frac{\tau}{0.076}\right)^{0.44}$$

[Shaw et al., 2012]

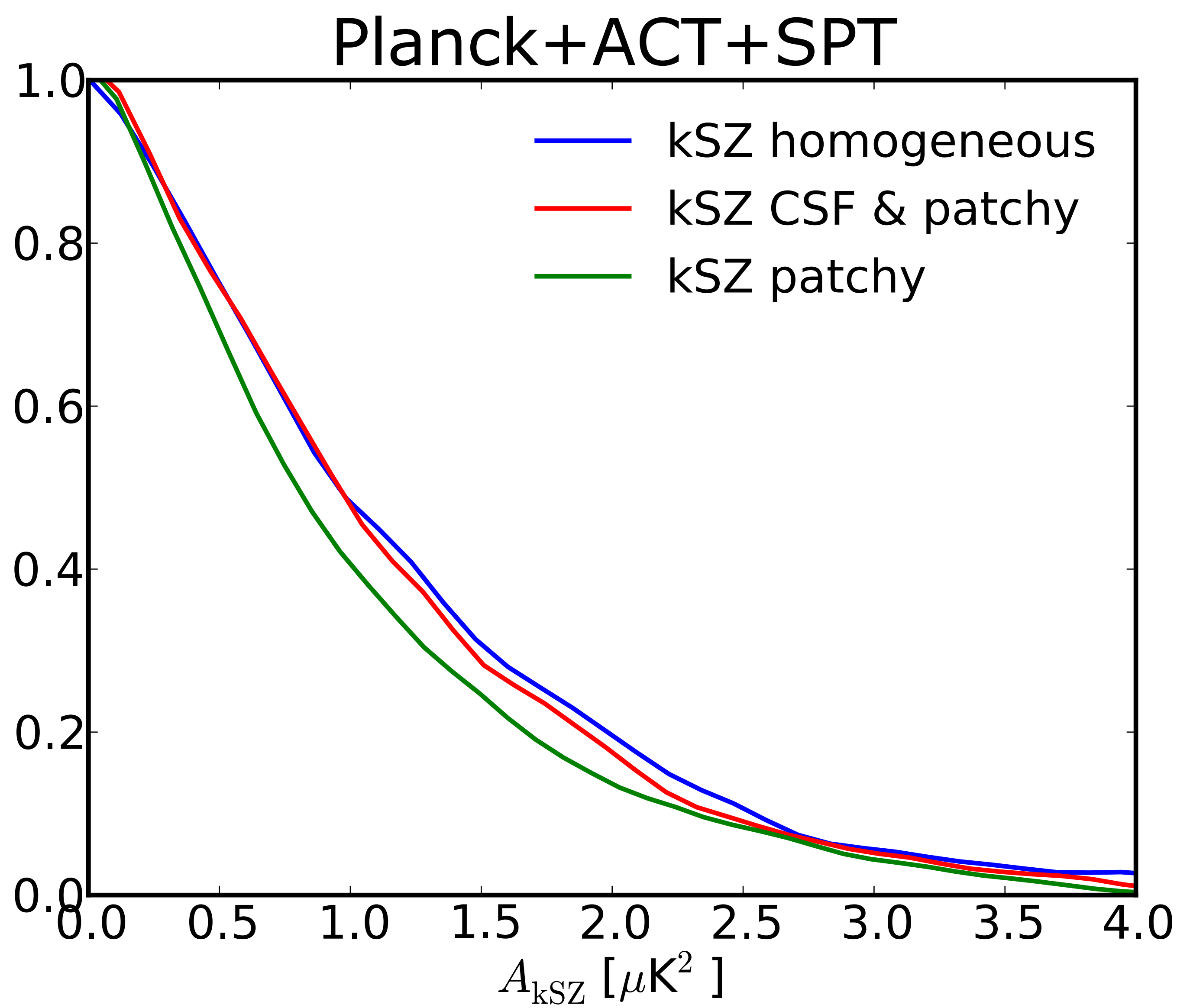
2. **patchy (or inhomogeneous) reionisation**
   before the reionisation is complete from the proper motion of ionised bubbles around emitting sources [Aghanim+1996]

$$D_\ell^{p-kSZ} \propto \left[\left(\frac{1+z_{reio}}{11}\right) - 0.12\right]\left(\frac{\Delta_z}{1.05}\right)^{0.51}$$

[Battaglia et al., 2013]

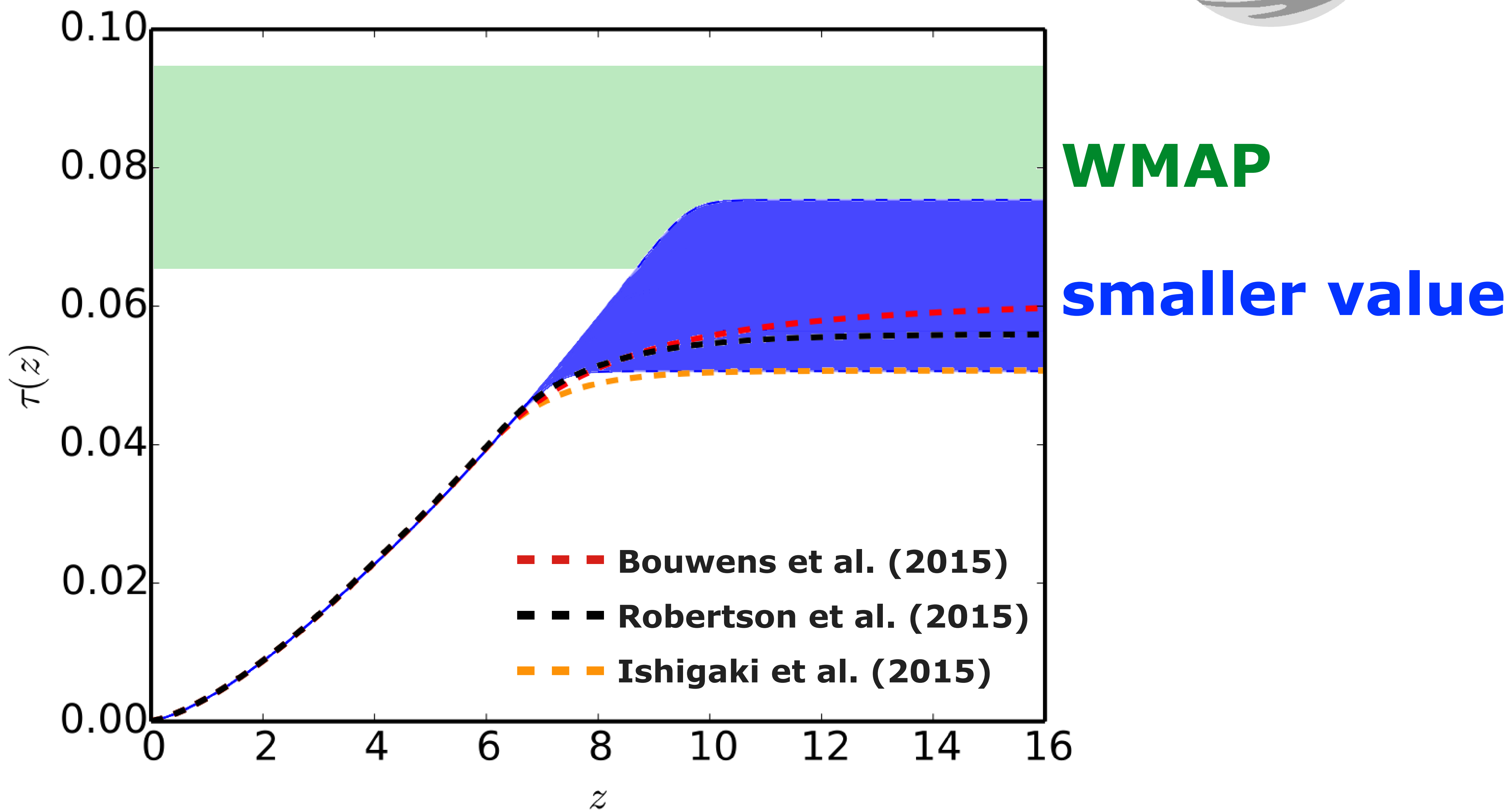
constraints on kSZ

- **Planck is not able to measure kSZ independently**
  - need high resolution CMB data (ACT, SPT)



anyway, constraints from CMB on kSZ amplitude are very weak and model dependent

optical depth & redshift



- **integrated optical depth for the symmetric model (tanh, δz = 0.5).**
- **models from Bouwens et al. (2015), Robertson et al. (2015), Ishigaki et al. (2015), using high redshift galaxy UV and IR flux and/or direct measurements.**

discussion

1. a lower value for τ as suggested by preliminary Planck data would be
   - **consistent with a fully reionised Universe at z ~ 6** (Gunn-Peterson effect showing Universe is mostly ionized up to z ~ 6 [Fan et al.])
   - in **good agreement with recent constraints on reionisation in the direction of particular objects** (in particular distant GRB and Ly-α emitters)

2. constraints on the reionisation history with such a low optical depth would **disfavor large abundances of star-forming galaxies beyond z = 15**

3. maintaining a UV-luminosity density at the maximum level allowed by the luminosity density constraints at redshifts z < 9 and considering only the currently observed galaxy population at MUV < −17 seems to be **sufficient to comply with all the observational constraints without the need for high redshift (z = 10 to 15) galaxies.**

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.