large scale polarization

maps and low-ℓ analysis

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on behalf of the Planck Collaboration

B-modes from Space (Kavli IPMU, Japan, Dec 2015)

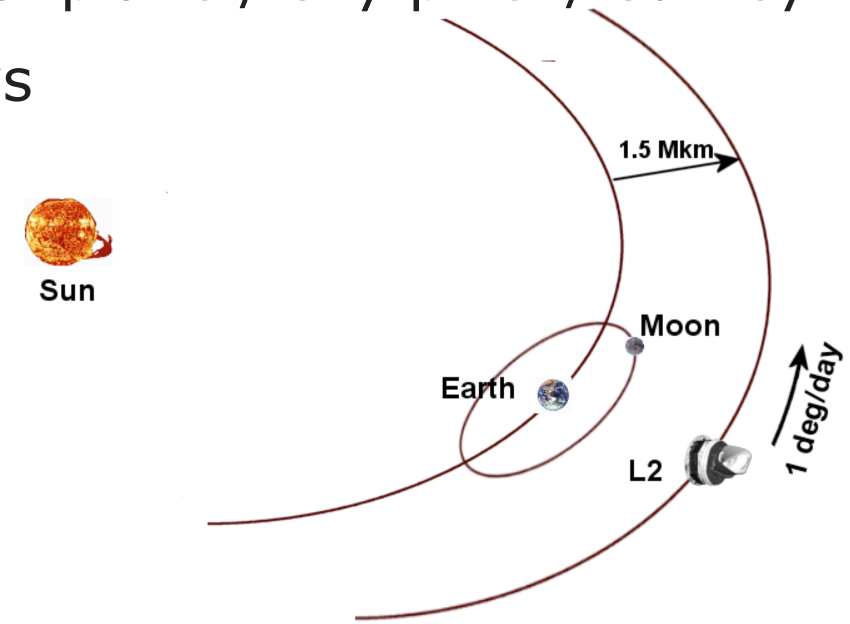
low-ℓs are difficult !

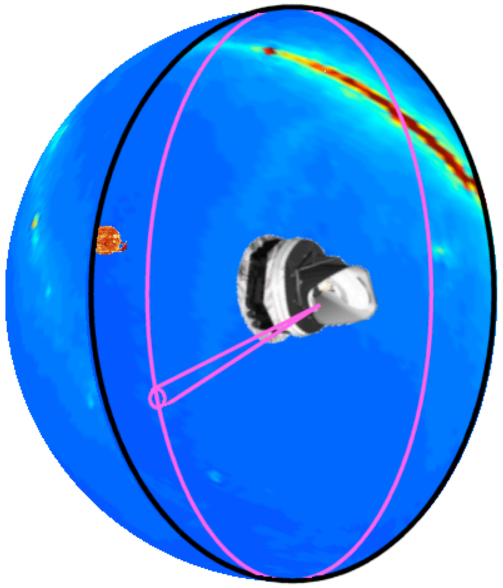
Planck Polarisation measurement

- **we need different angles to measure I,Q,U**

$$m_t = I(\vec{n}) + \rho\left[Q(\vec{n}).cos(2\psi) + U(\vec{n}).sin(2\psi)\right]$$

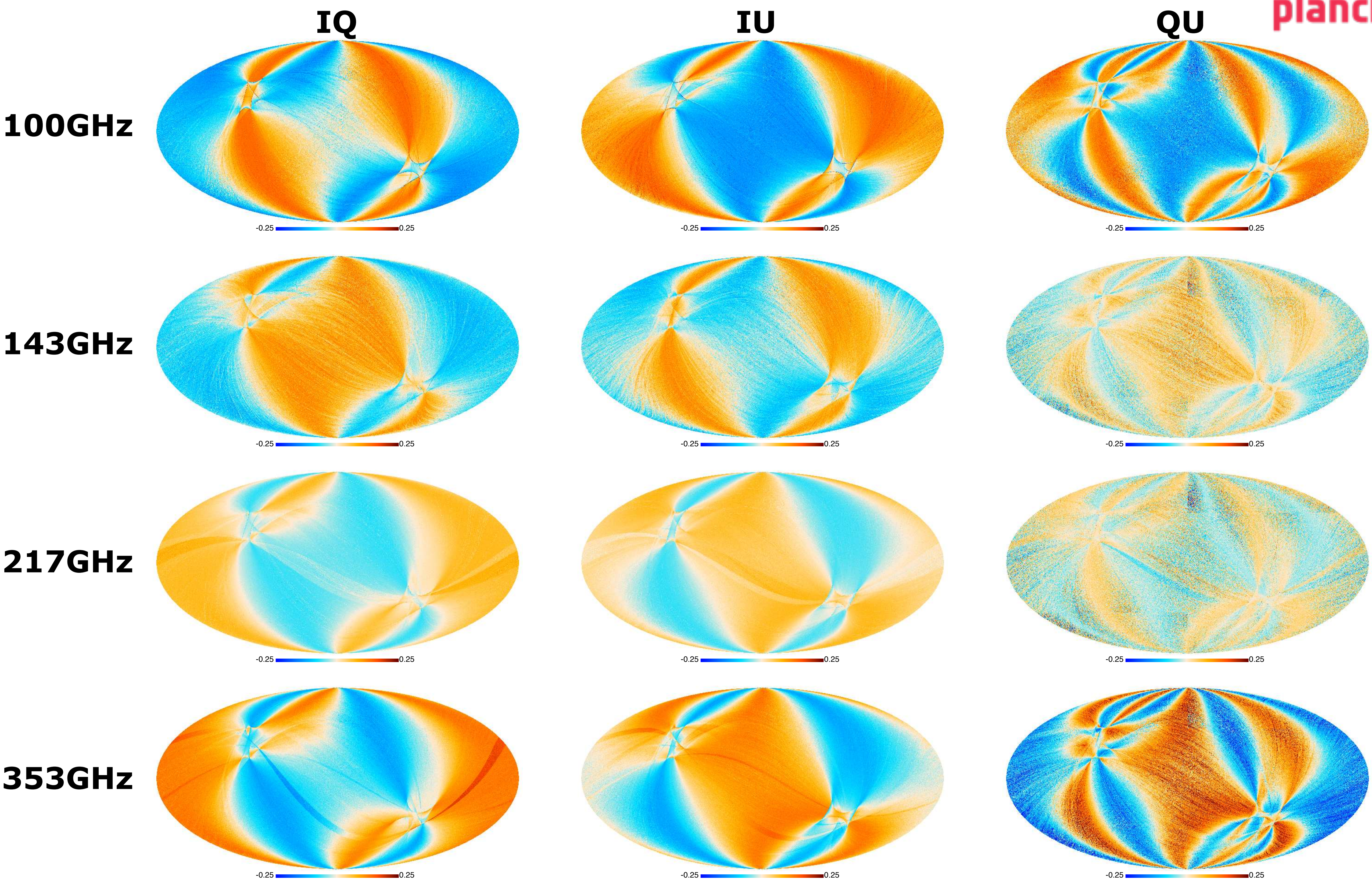
- **Planck scanning strategy is such that we have**
  - one orientation of the focal plane / sky pixel / survey
  - 2 pairs of identical surveys





- **Consequences**
  - Detector-differencing measurement (4 angles in the focal plane 0, 45, 90, 135°)
  - few angles on the sky leading to high level of I,Q,U mixing
  - need to have extremely precise control of I to reduce leakage in Q,U

Stokes correlation



[Planck 2015 results. VIII, A&A]

PLANCK map-making

before projection need to remove

- **what's not constant in time**
  - 1/f noise
  - Zodiacal light
  - orbital dipole (reference for calibration)
  - Far SideLobes
- **what's not common to all detectors within a channel**
  - Foreground emissions mismatch due to different bandpass
  - Far SideLobes
- **instrumental effects**
  - ADC non-linearity corrections
  - gain coefficients (absolute and possibly time-dependent)
  - time constant residuals

[Planck 2015 results. VIII, A&A]

PLANCK map-making

- **we include templates of systematics in the map-making**

$$d_t = g\left(\mathbf{A}S + \sum_i \mathbf{\Gamma}^{(\mathbf{i})} T^{(i)}\right) + n_t$$

$$= g\,[\mathbf{A},\mathbf{\Gamma}]\begin{bmatrix} S \\ T \end{bmatrix} + n_t$$

- **different domains:**
  - time domain (t) / ring domain (r) / pixel domain (p)

- **In practice:**

$$d_t = \mathbf{g_r}\left(\mathbf{I_p} + \rho\mathbf{Q_p} cos2\phi_t + \rho\mathbf{U_p} sin2\phi_t + D_t + \sum \mathbf{f_i} T_p^{(fg)_i} + \sum \mathbf{c_i} T_t^{(TF)_i}\right) + \mathbf{o_r} + n_t$$

→

- g **gains non-linear system → gain linearization**
- I, Q, U **sky signal**
- f **bandpass mismatch coefficients**
- c **transfer function residual coefficients**
- o **1/f offsets**

Spectra estimator

- **Compute cross-spectra between frequency maps**
- **Noise**
  - after pre-processing of data, noise could be consider as not correlated from one map to another (no noise bias, no noise Monte-Carlo needed)
- **Systematics**
  - can mitigate the impact of systematics if their correlation are under control in term of both bias and increased variance
- **Xpol code have been extensively used within Planck**
  - CMB power spectra & likelihood (Hillipop) [Planck 2015 results. XI, Couchot+2015]
  - dust power spectra [Planck Intermediate Paper XXX, arXiv:1409.5738]
  - CIB power spectra [Planck 2013 results. XXX]
  - SZ power spectra [Planck 2013 results. XXI, Planck 2015 results XXII]
  - SZ-CIB cross-power spectra [Planck 2015 results. XXIII]

[Tristram+ 2005]

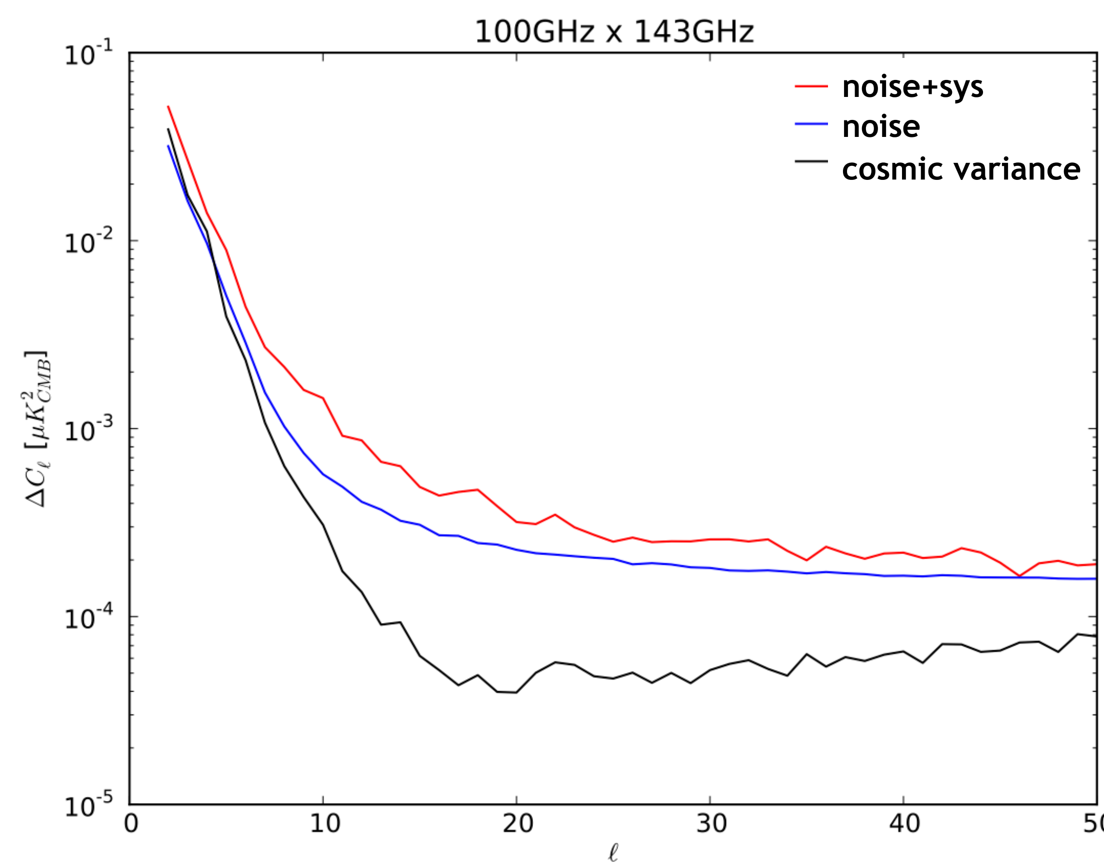
PLANCK systematics at low-ℓ

- **Systematics**
  - 1/f noise residuals
  - inter-calibration leakage
  - time-constant residuals
  - ADC non-linearity residuals
  - foreground residuals
  - glitches (increase the 1/f)

those residuals are in $\ell^{-\alpha}$

but not directly correlated between frequencies

- **Need for simulations !**
- **PLANCK E2E**
  - no bias on 100x143
  - error budget extended by a factor about 2 due to systematics uncertainties



Planck-HFI low-ℓ data status

planck

- **we have now identified all dominant sources of residual systematics that matter for low-ℓ data analysis**

- **the biggest systematic is ADC-NonLinearity**
  - has been reduced by a factor almost 10 but still not negligible on frequency maps

- **results on E2E Monte-Carlo simulations including ADC-NL**
  - no bias on cross-spectra
  - more work currently being done to derive a reliable propagation of uncertainties

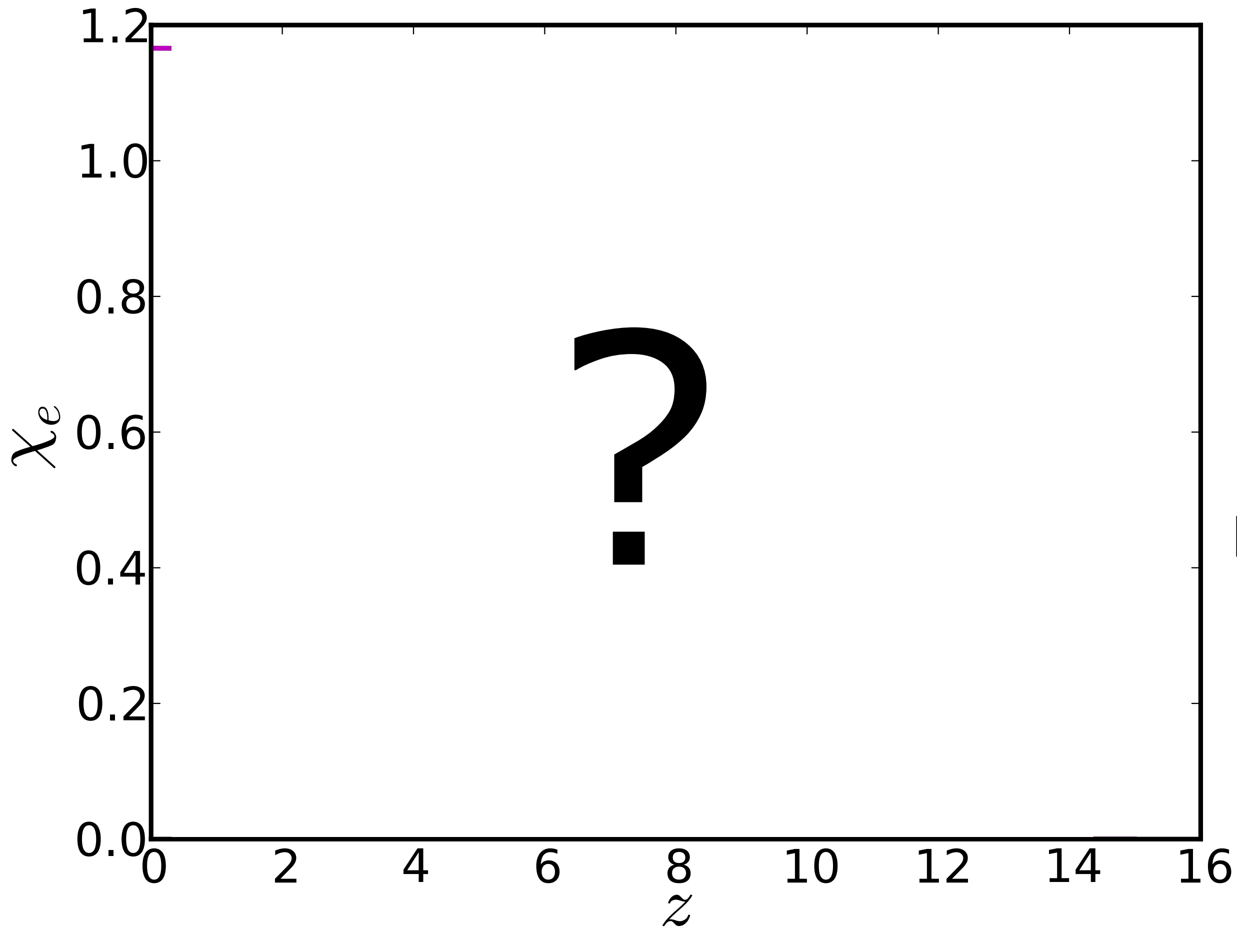
- **likelihood based on cross-spectra between Planck frequency maps**
  - [Hamimeche&Lewis 2008] approximation modified for cross-spectra [Mangilli+2015] (talk from A. Mangilli)

The Planck collaboration: “Improved large angular scale polarization data and the reionization optical depth”, to be submitted A&A 2016

The Planck collaboration: “Reionization history constraints from Planck”, to be submitted A&A 2016

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.



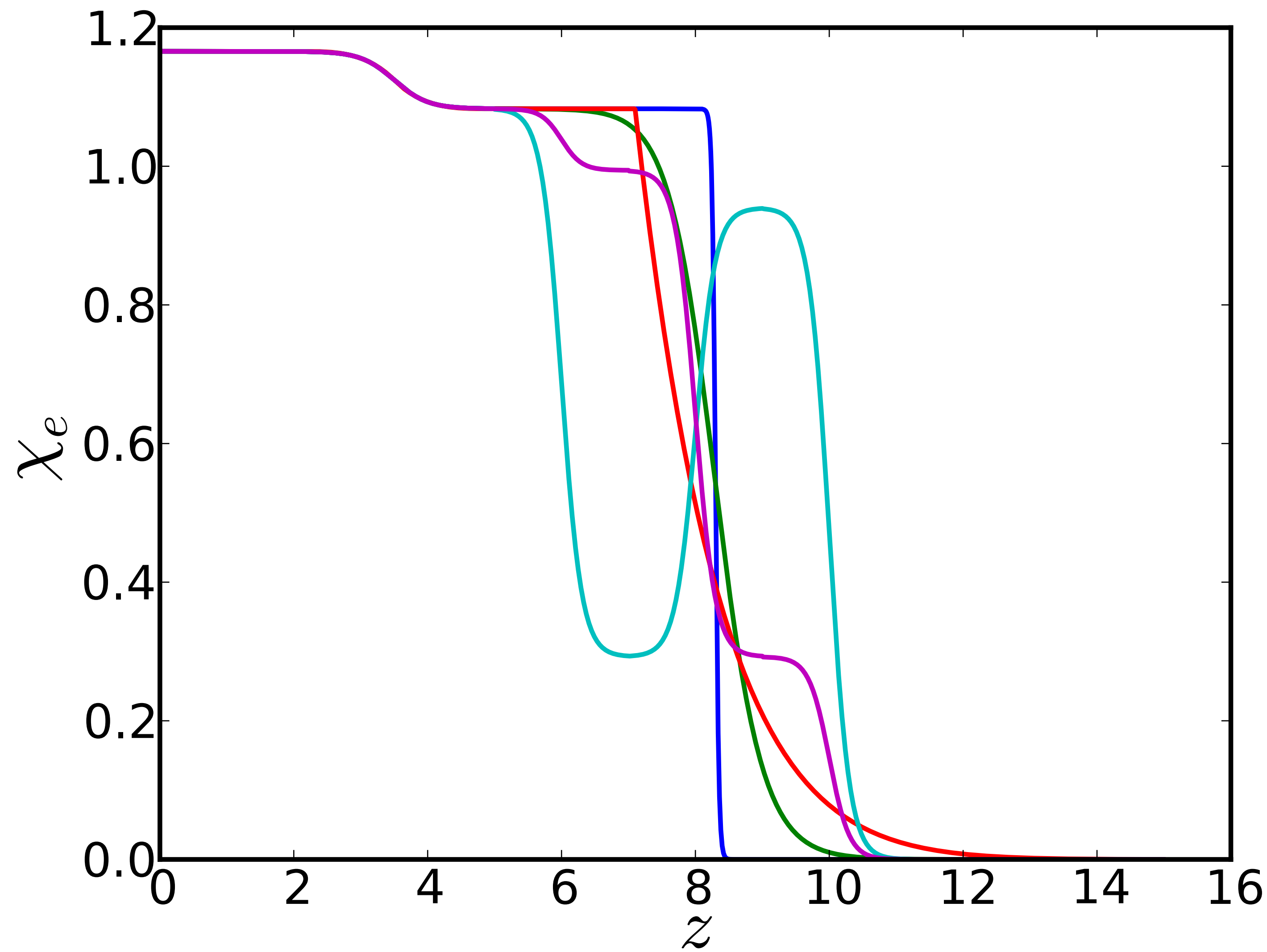
χ_e is the ionisation fraction as a function of the redshift

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

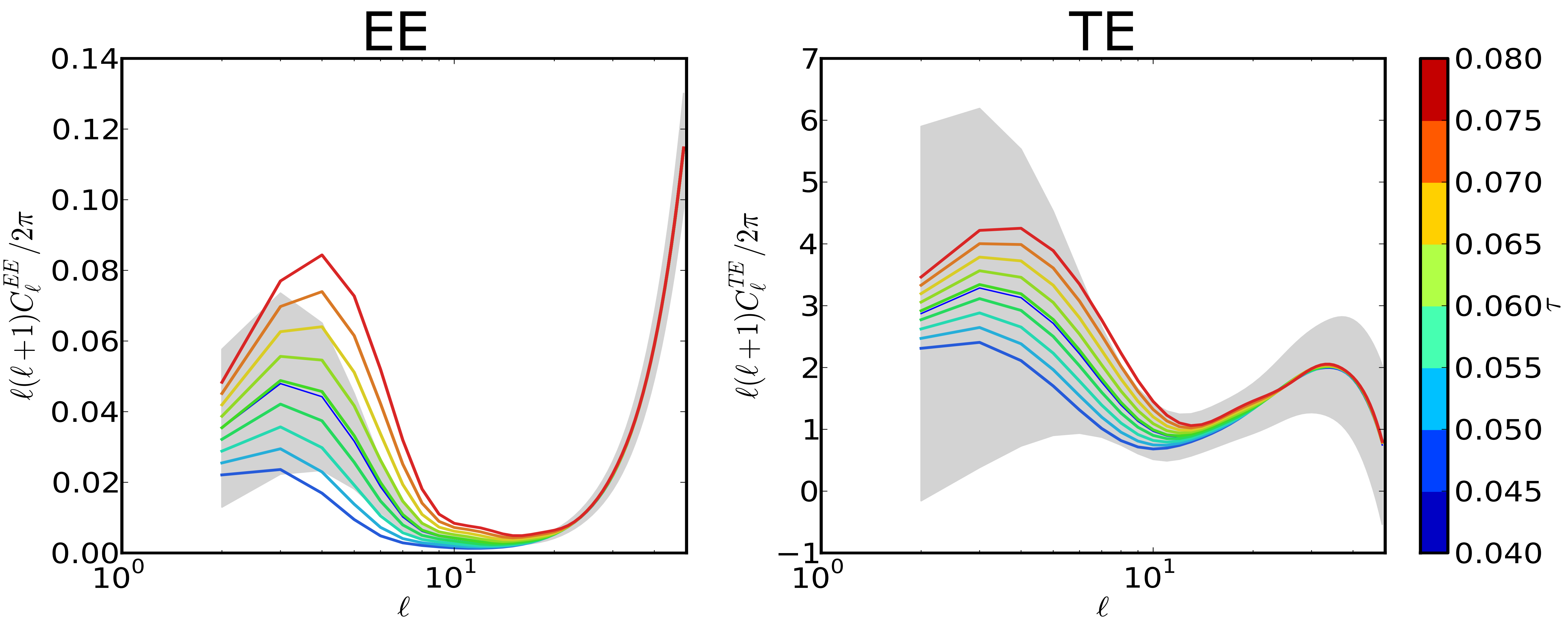
CMB can give information on EoR through

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

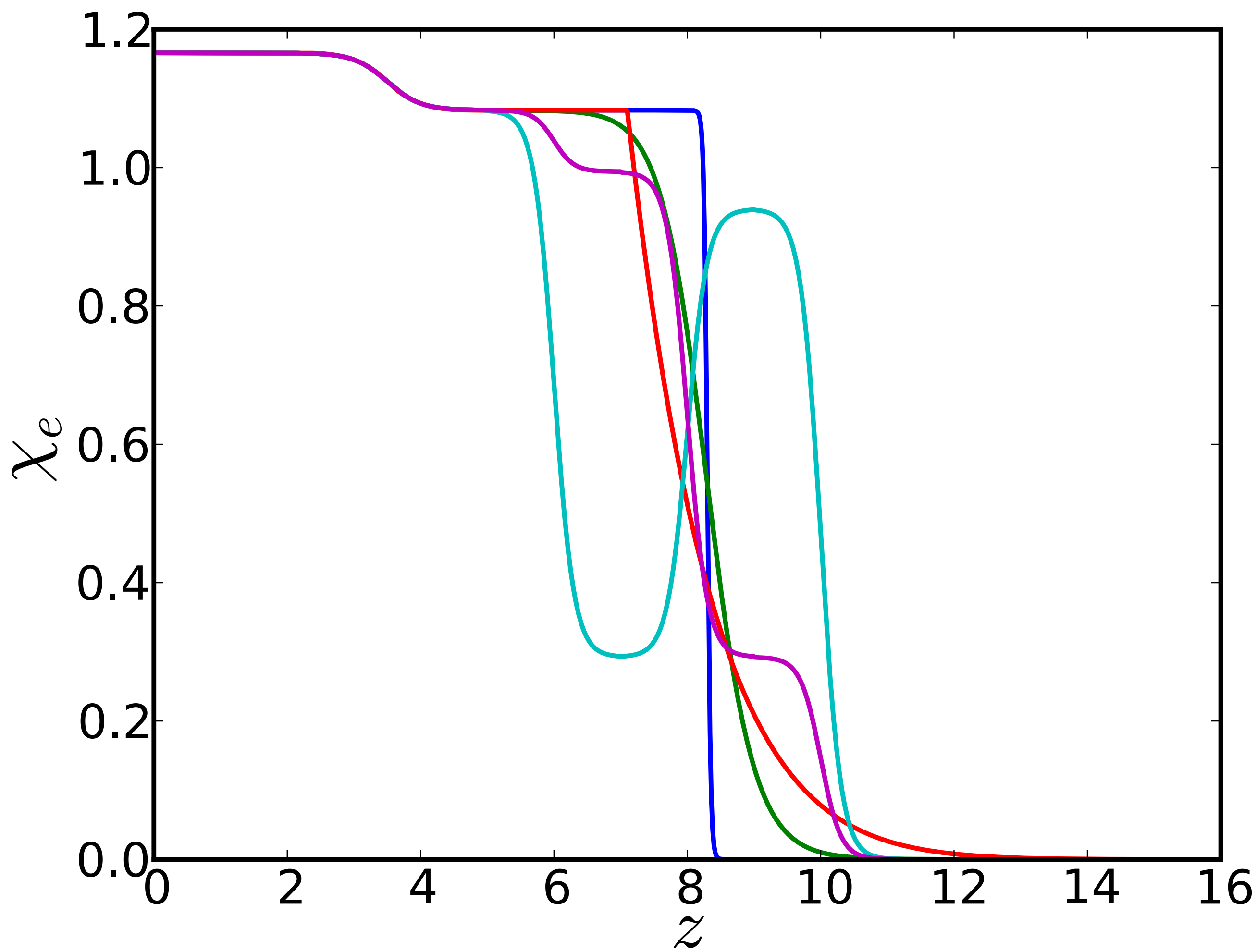
- **large scale CMB anisotropies in polarisation**
  - new polarisation anisotropy at large angular scale because the horizon has grown to a much larger size by that epoch

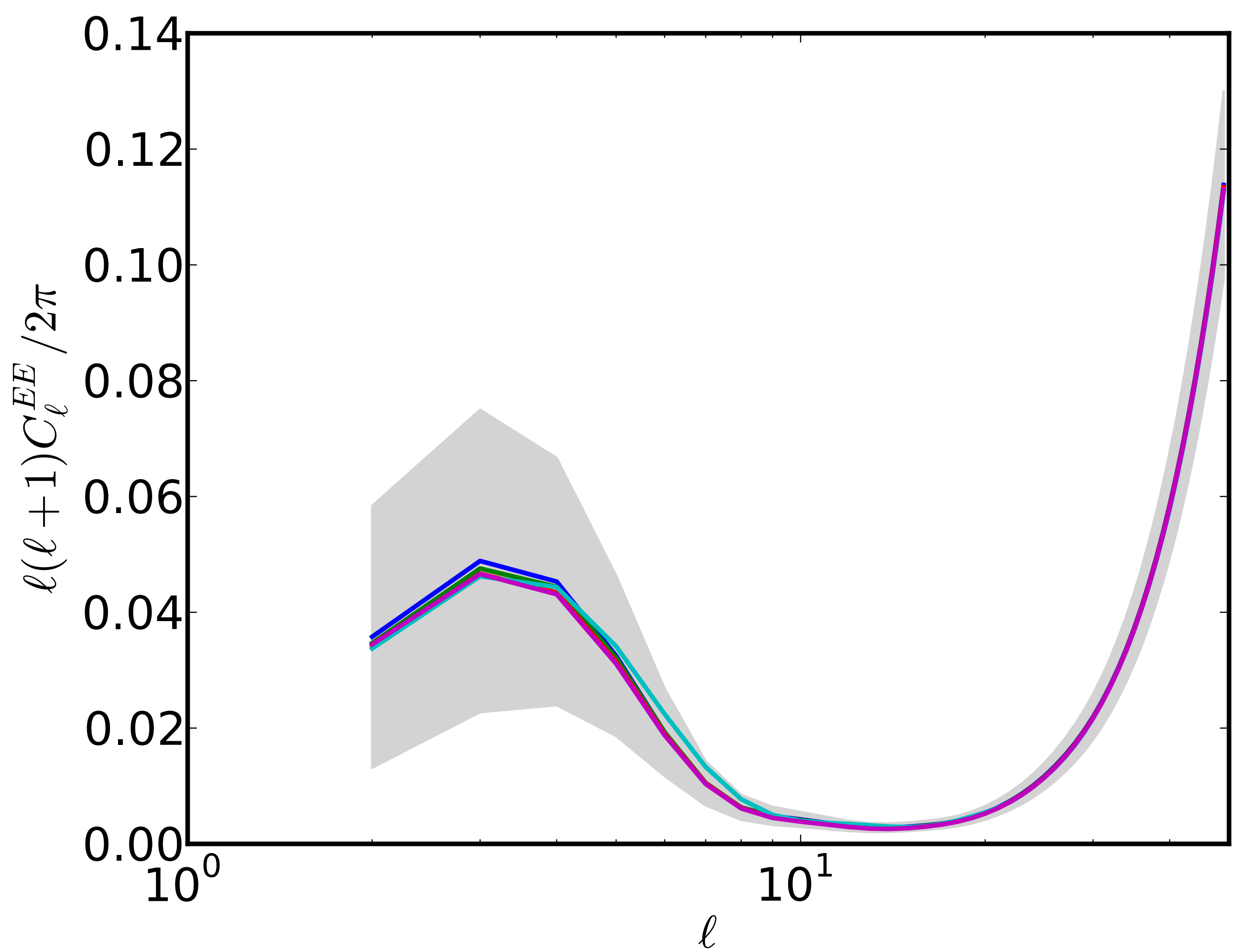
- **kinetic Sunyaev-Zel'dovich effect**
  - re-scattering of photons off newly liberated electrons [Sunyaev & Zel'dovich 1980]

effect on CMB polarisation at low-ℓ

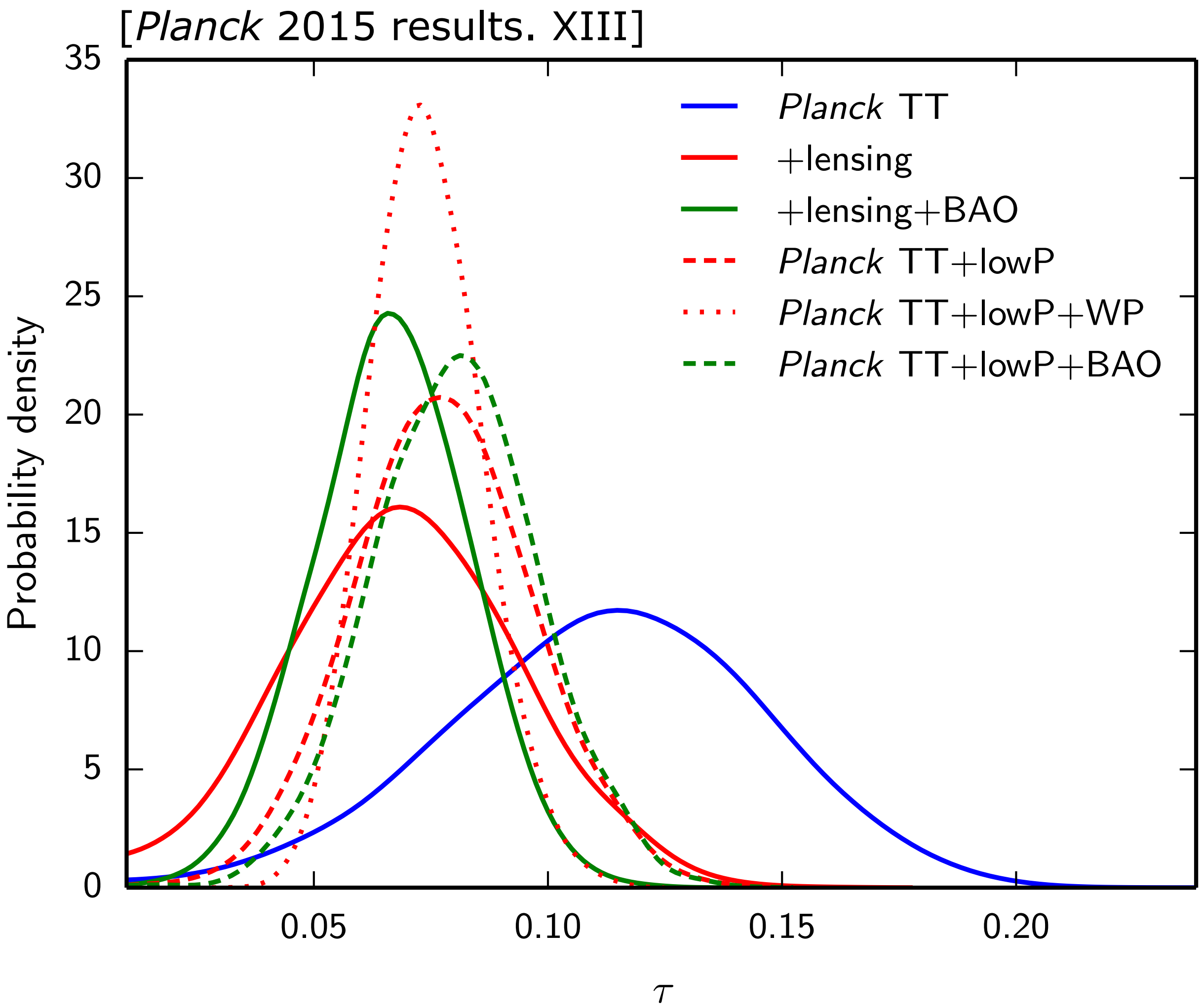


CMB degeneracies





reionisation optical depth



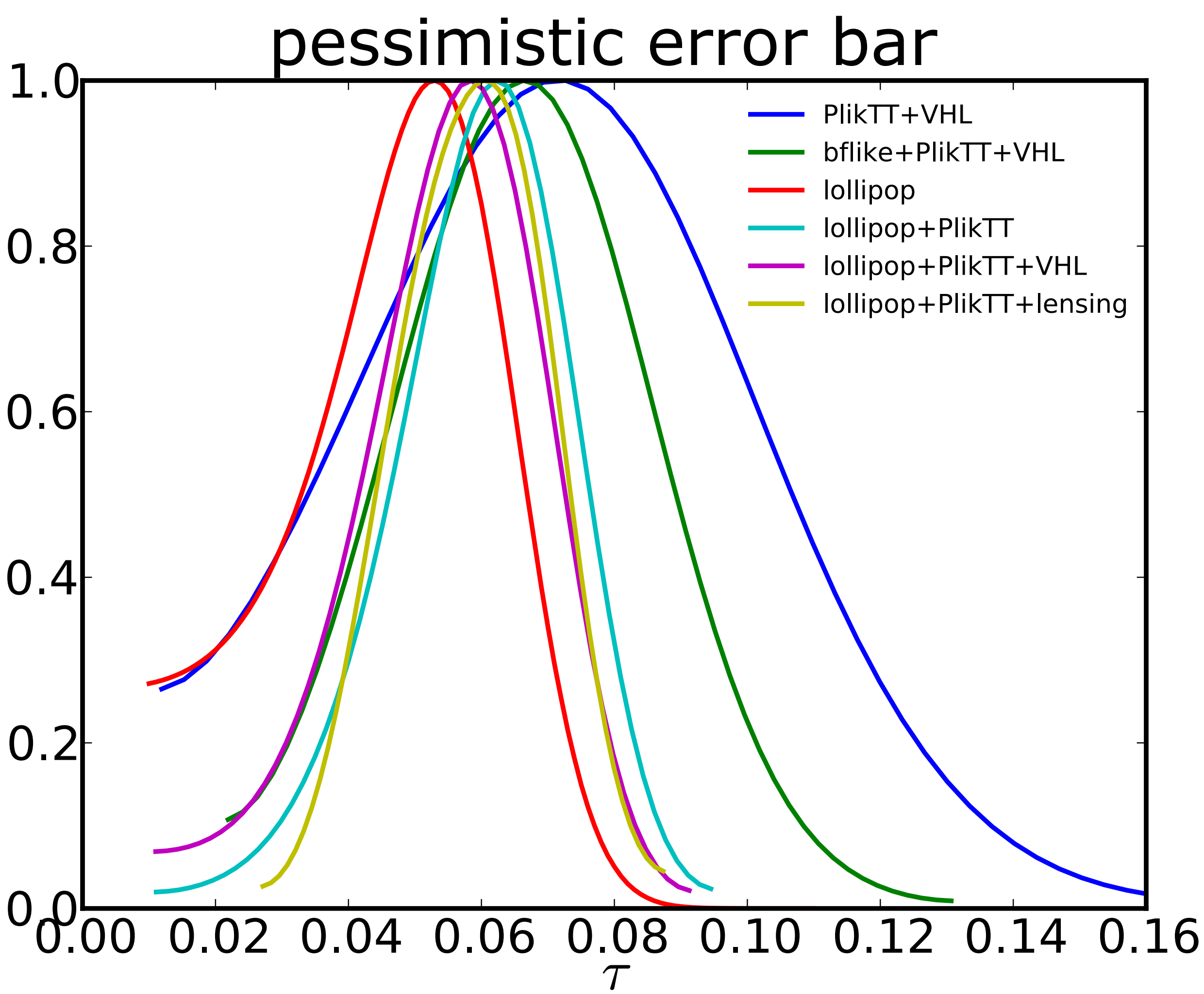
From CMB data:

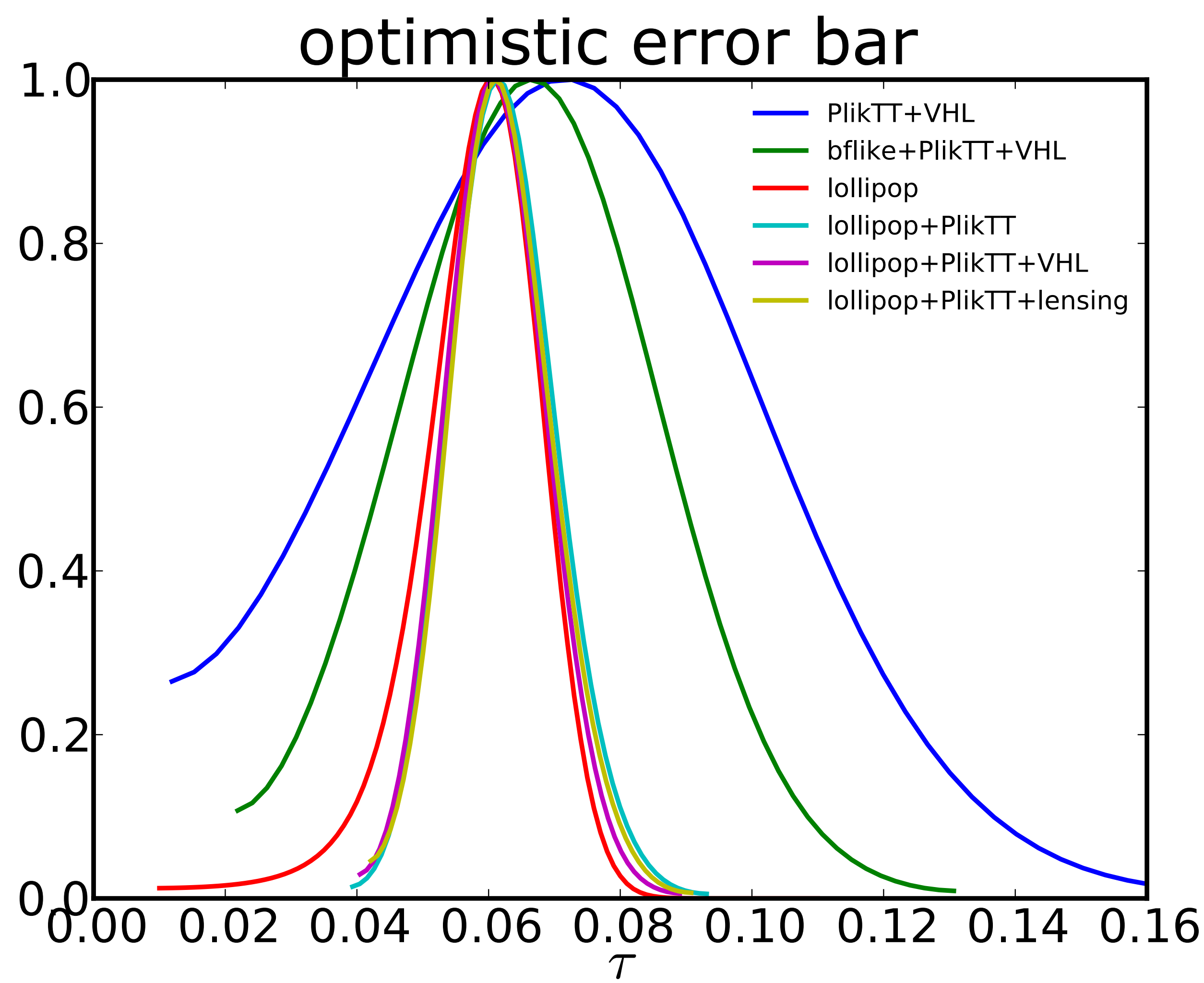
- **WMAP 9yr**
  - $\tau = 0.089 \pm 0.014$
- **Planck 2013**
  - $\tau = 0.089 \pm 0.014$ (PlanckTT, WMAP)
  - $\tau = 0.075 \pm 0.013$ (PlanckTT, WMAP+353)
- **Planck 2015**
  - $\tau = 0.078 \pm 0.019$ (TT + lowP)
  - $\tau = 0.066 \pm 0.016$ (TT + lowP + lensing)
  - $\tau = 0.067 \pm 0.016$ (TT + lensing + BAO)
- **Planck HFI EE low-l**
  - decreasing trend continues…

reionisation optical depth

Example of results as a combination of

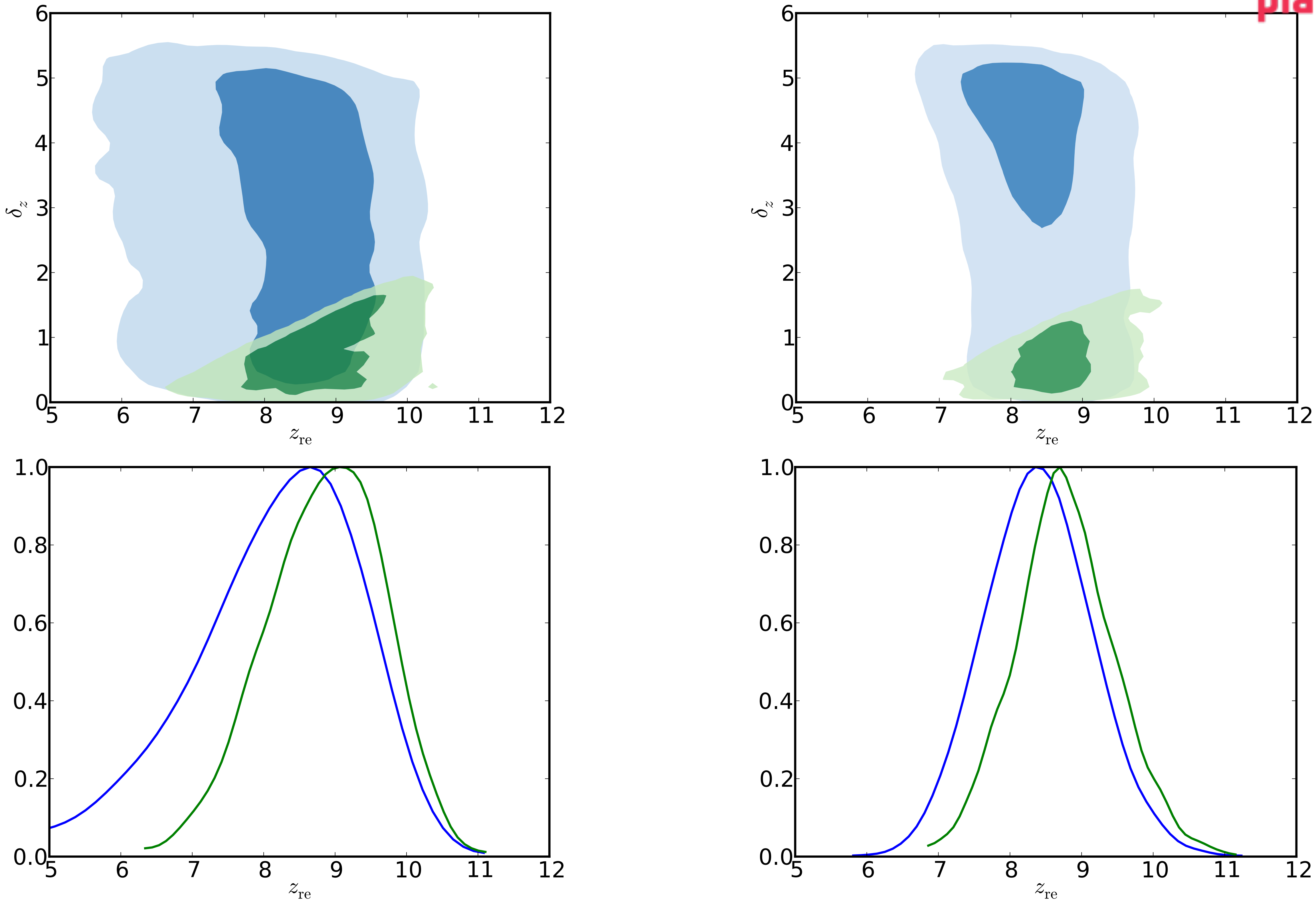
1. Planck TT CMB spectrum (2015)
2. two versions of Planck EE low-ℓ
   value and error bar not yet finalized !
3. Very High-ℓ ground-based experiments (ACT & SPT)





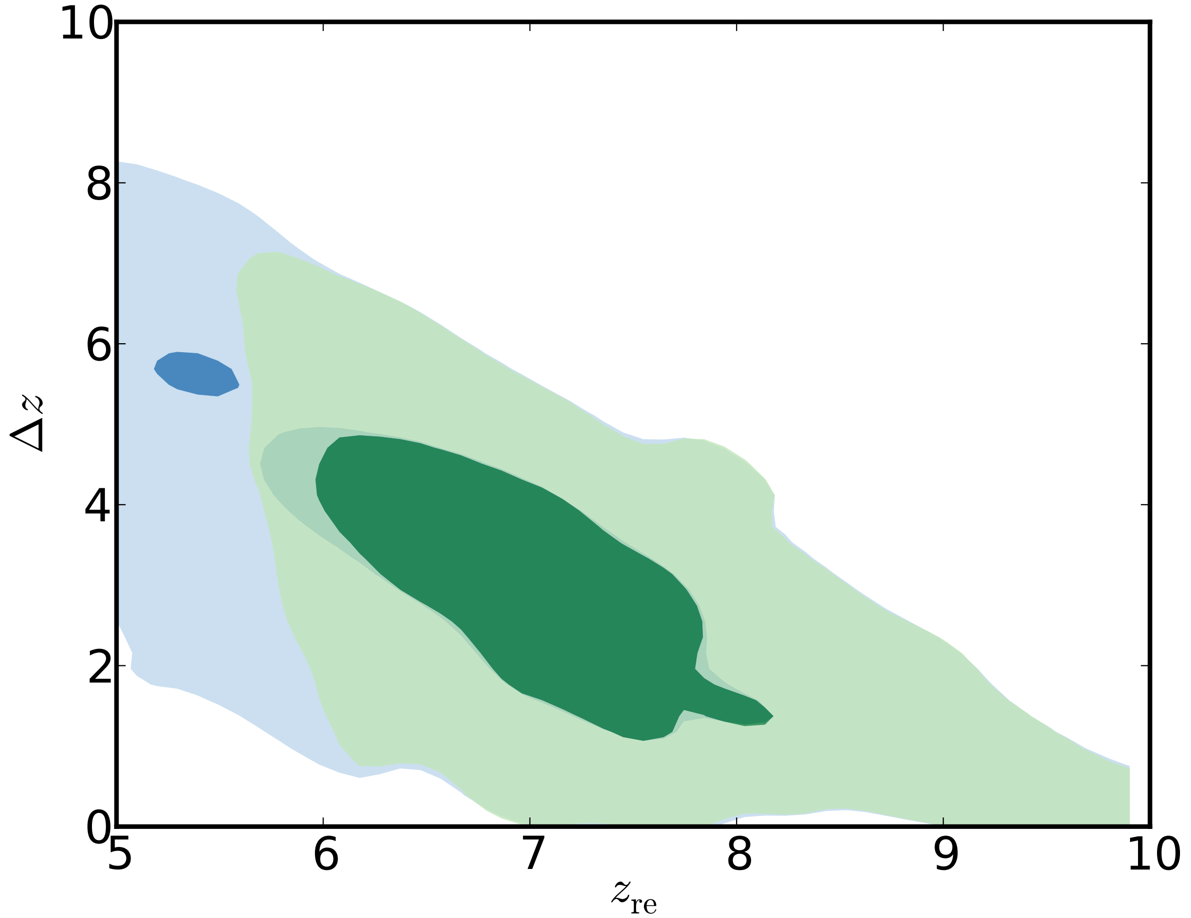
preliminary

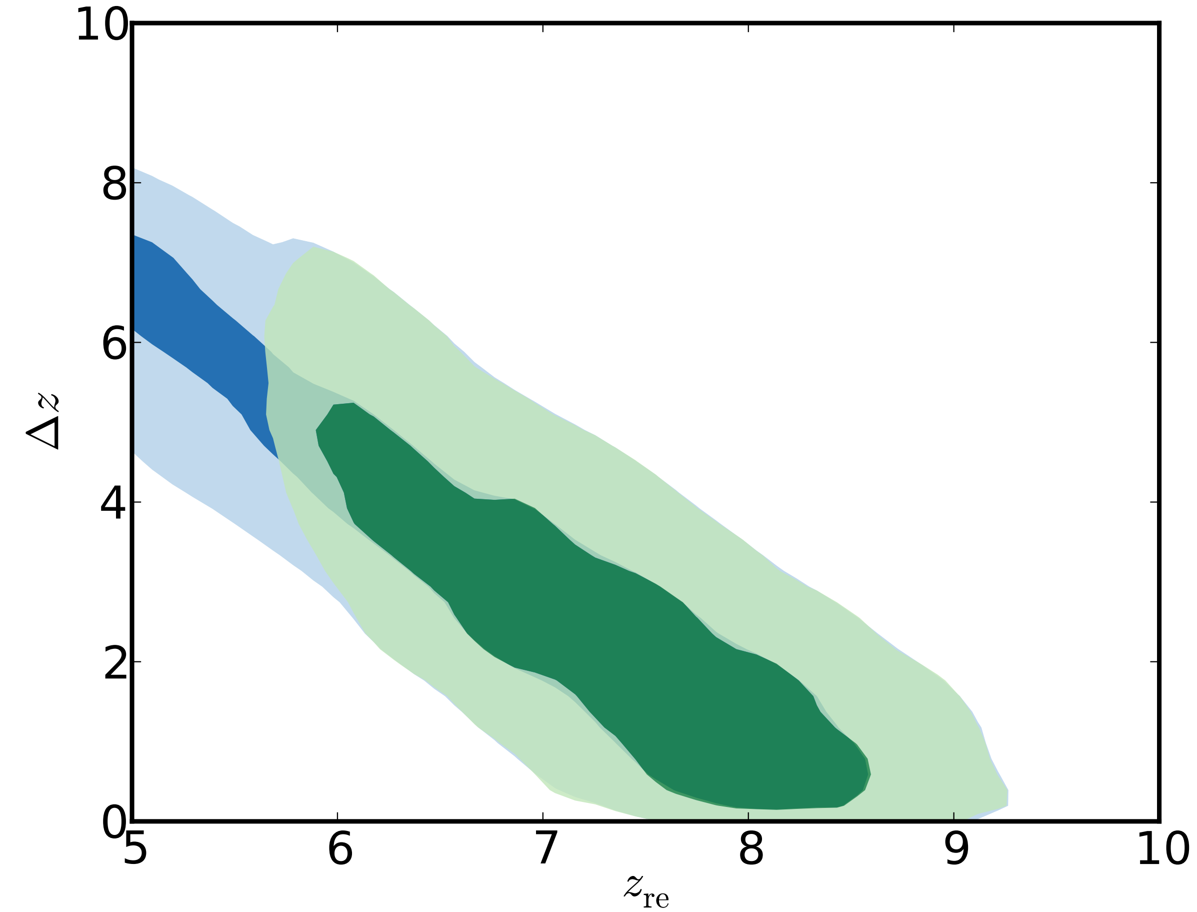
symmetric model



preliminary

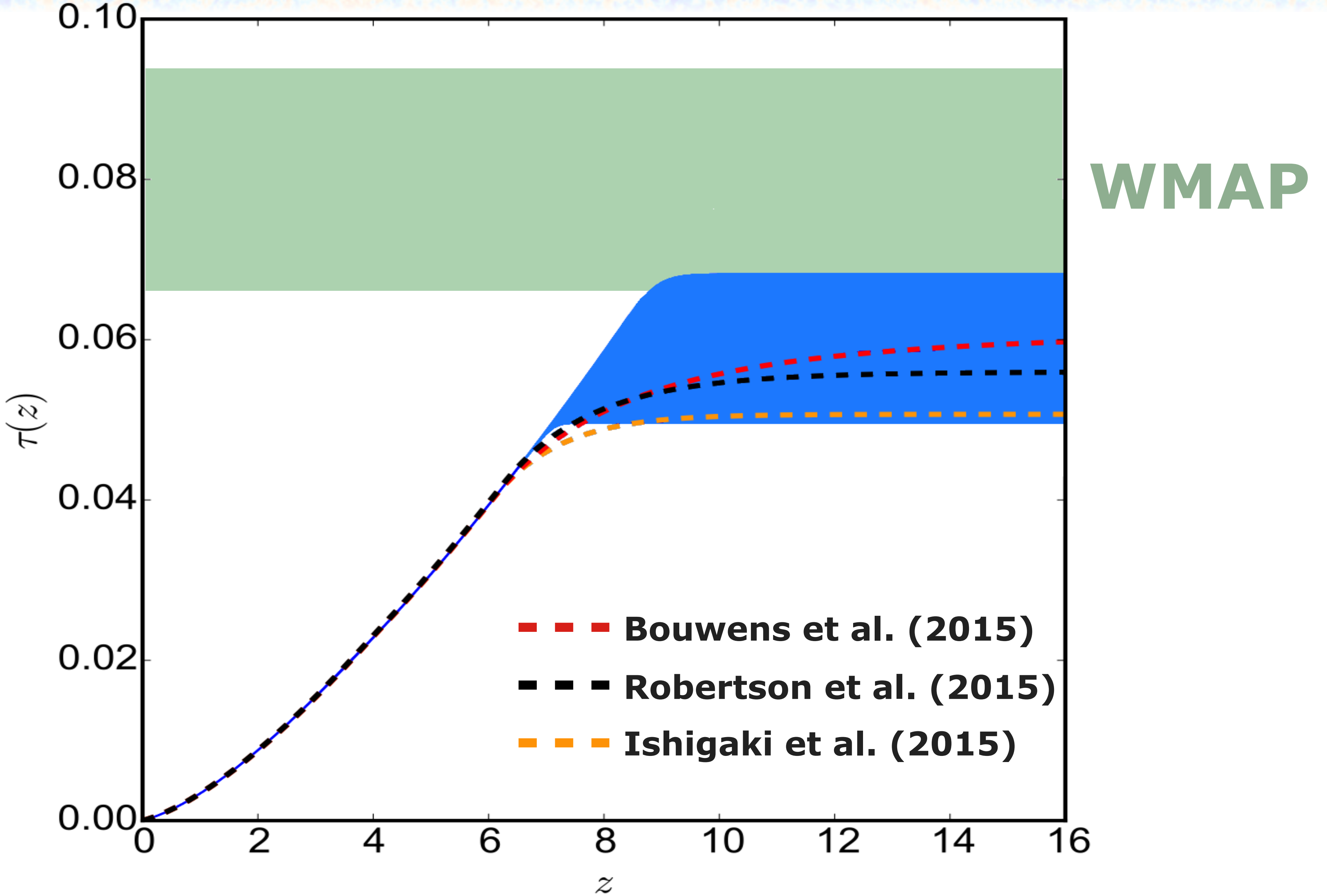
asymmetric model





preliminary

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.

preliminary

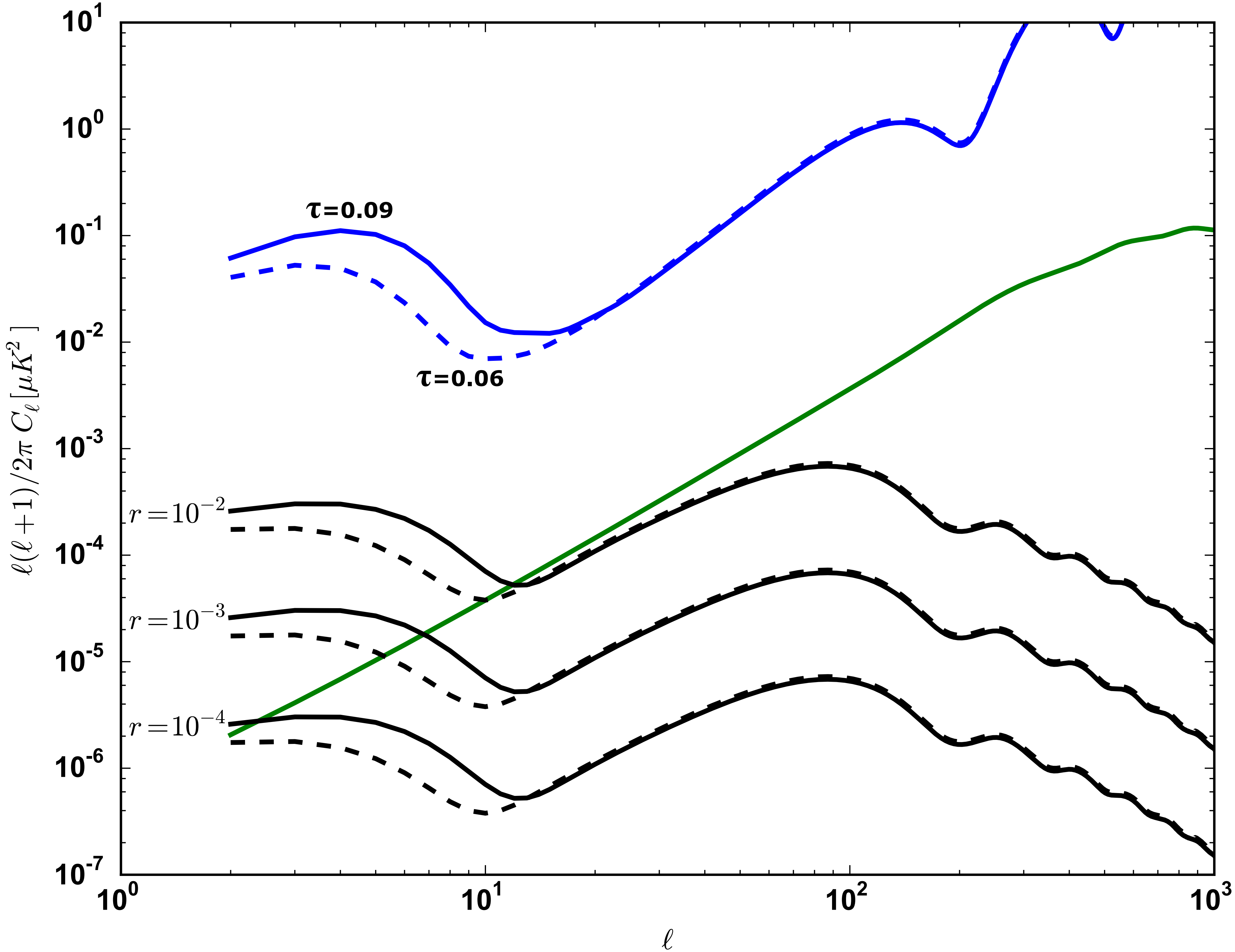
discussion

- **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)

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

- 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.**

Impact for B-modes



Conclusion

- **low-ℓ analysis difficult**
  - **processing & map-making**

    need to include more and more systematic templates and MCs

  - **power spectra**

    need to propagate uncertainties + E-B leakage from masking, filtering…

  - **need to include detailed foreground descriptions**

    see talks from Friday

  - **Reionisation Optical depth τ is low**

- **all that will certainly limit the impact of the reionisation bump in the primordial B-mode analysis**

  current effect on Planck: increase error bars by a factor ~2

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.