large scale polarization

Matthieu TRISTRAM

LAL-CNRS, France

on behalf of the Planck Collaboration

Large scale polarization science

planck

Planck provides full sky measurements of the polarized sky in 7 bands from 30 to 353GHz

1. **Reionization history** [Planck intermediate results. XLVII (2016)]
   - Planck is able to measure reionization optical depth accurately (or z_{re} given a simple model)
   - but also go beyond and give constraints on ionization fraction evolution models

2. **Tensor modes**
   - Planck is able to give constraints on tensor modes in BB spectrum both
     - at the reionization bump (ℓ =2-30) **TO BE PUBLISHED IN 2017 !**
     - at the recombination bump (ℓ =50-150) [Planck 2015 results. XIII (2016)]
   - sensitivity is not at the level of ground-based measurements

3. **Foregrounds**
   - essential for large scale measurements
     - at low frequency : Synchrotron
     - at high frequency : Dust

[Planck 2015 results. X. (2016)]
[Planck 2015 results. XXV. (2016)]
[Planck Intermediate results. XXX (2016)]
...

Status of PLANCK polarization data

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- Planck detectors are sensitive to **one** polarization direction
- Planck scanning strategy do not allow for polarization reconstruction for each detector independently
  - ➡ need to **combine detectors** with different polarization orientation
- Any flux **mismatch** between detectors will create spurious polarization signal through well known **I-to-P leakage**.
  In particular : ADC non-linearity, bandpass mismatch, calibration mismatch, …

this is the major systematic we have to face in polarization at large scales

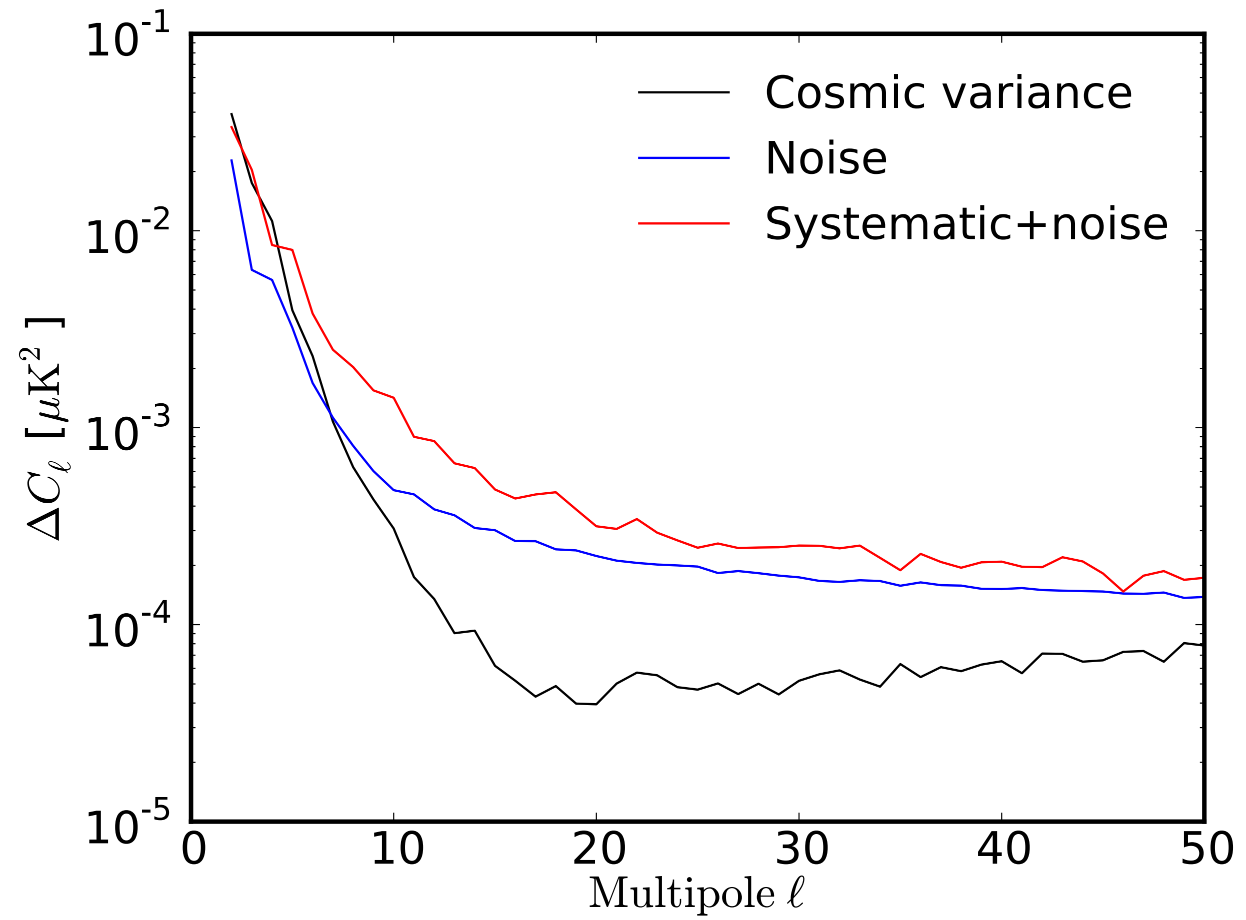
- We performed a lot of **consistency checks** in order to assess the impact on cosmological parameters
  - the radiometer from LFI have shown negligible residuals with respect to noise
  - the bolometer from HFI are more sensitive but show some residuals at the level of the noise

Planck-HFI low-ℓ data

- **results on E2E Monte-Carlo simulations**
  including systematics (ADC-NL)

  ➡ no bias on cross-spectra

  ➡ increase error bars by a factor ~2

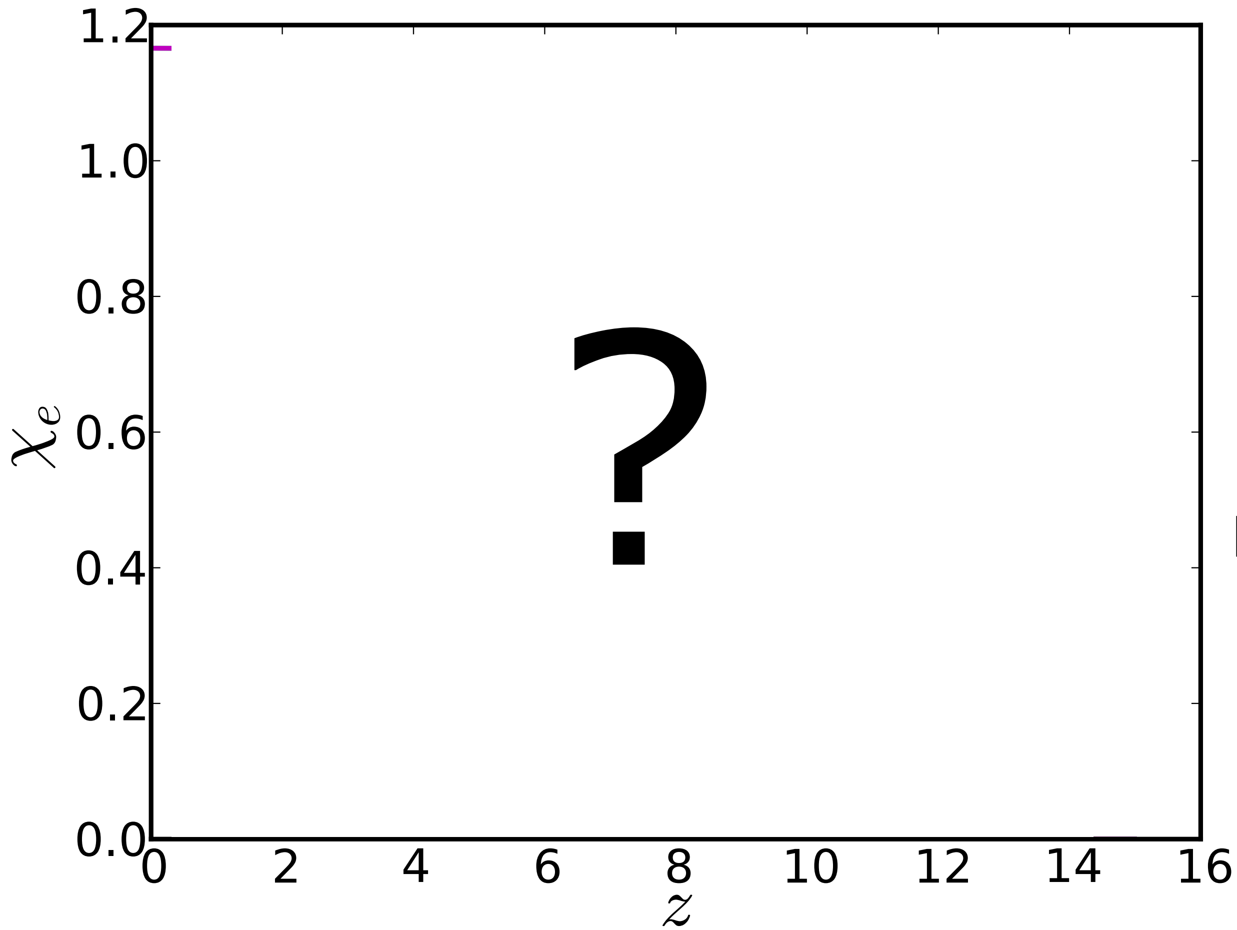


- **likelihood analysis based on cross-spectra between frequency maps (`lollipop`)** [Mangilli et al. (2015)]
  Hamimeche&Lewis approximation modified for cross-spectra

  ➡ propagates systematic uncertainties

reionization

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



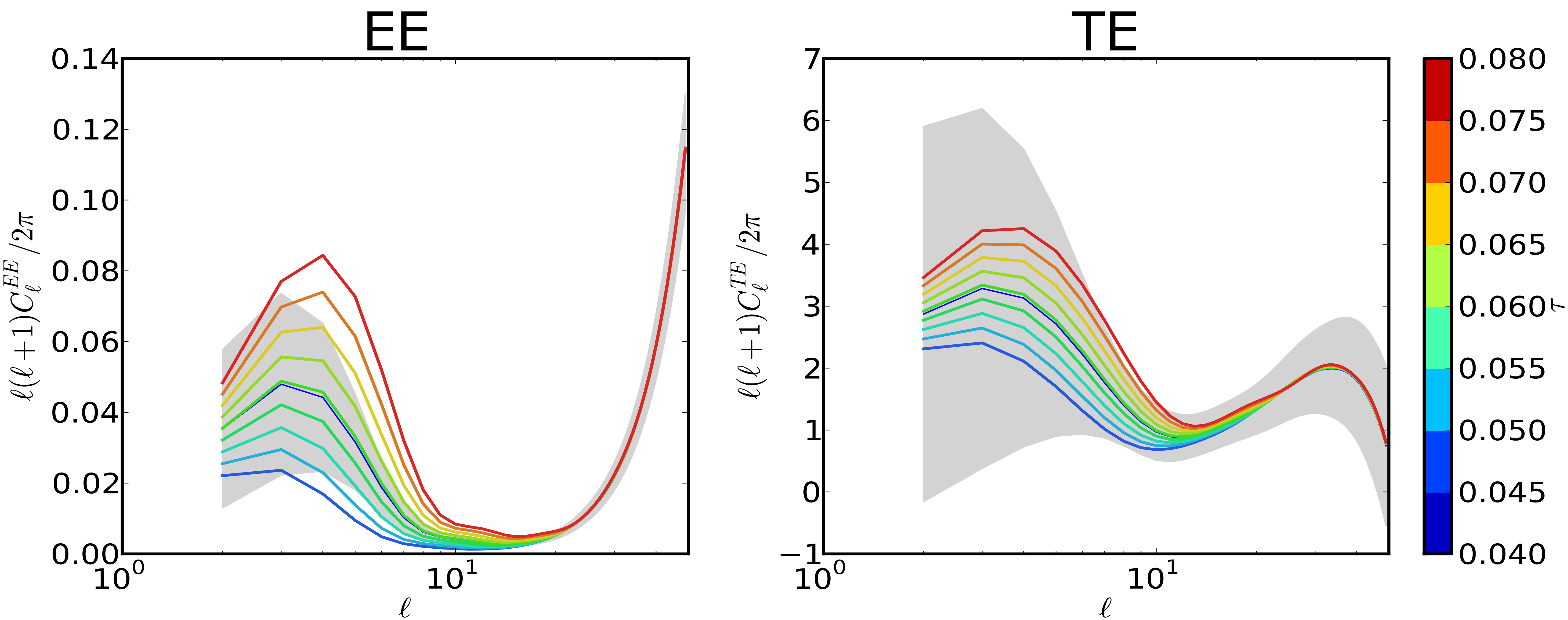
χ_e is the ionization fraction as a function of the redshift

reionization optical depth is defined as

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

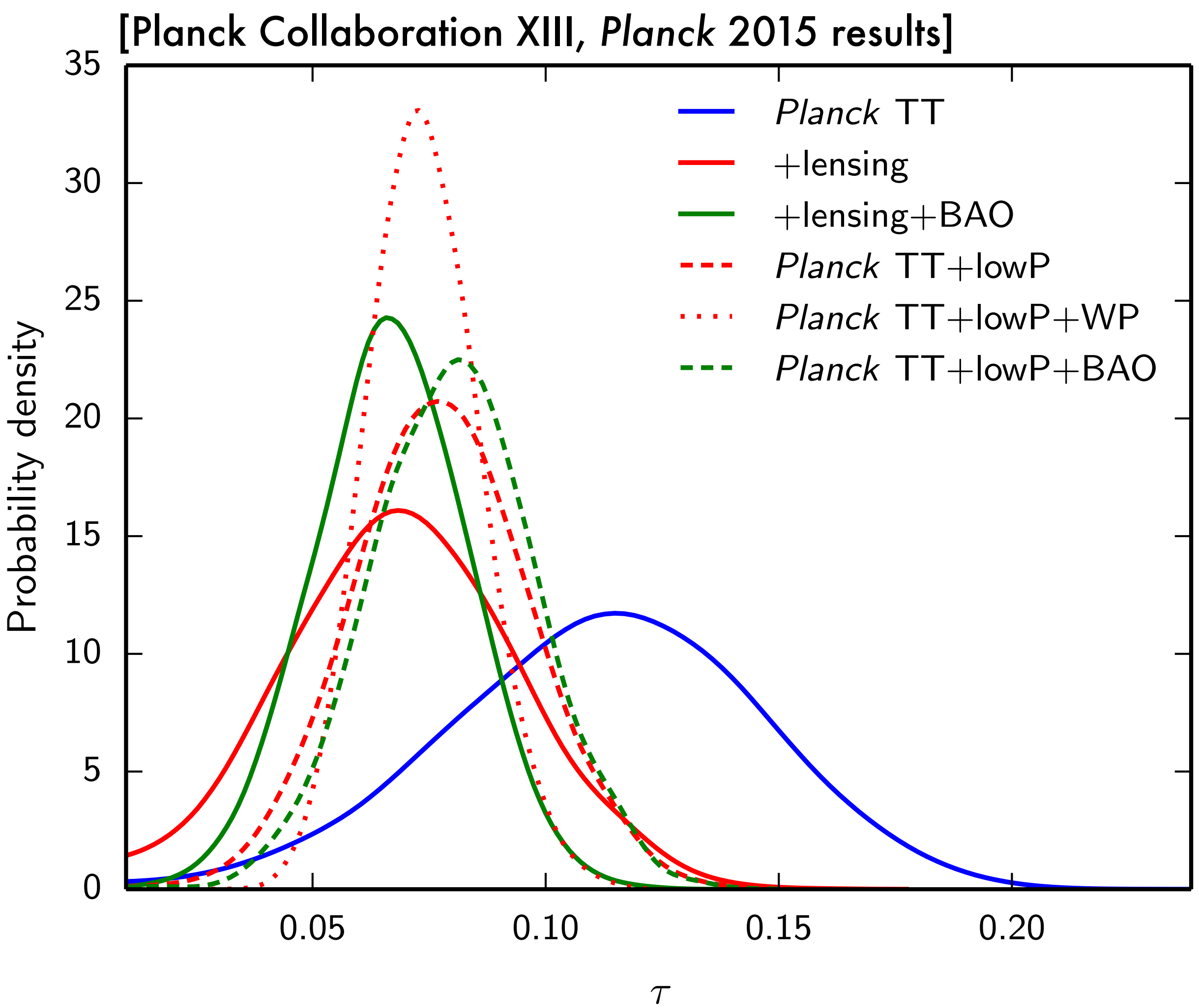
effect on CMB polarisation at low-ℓ

reionization optical depth



reionization optical depth (history)

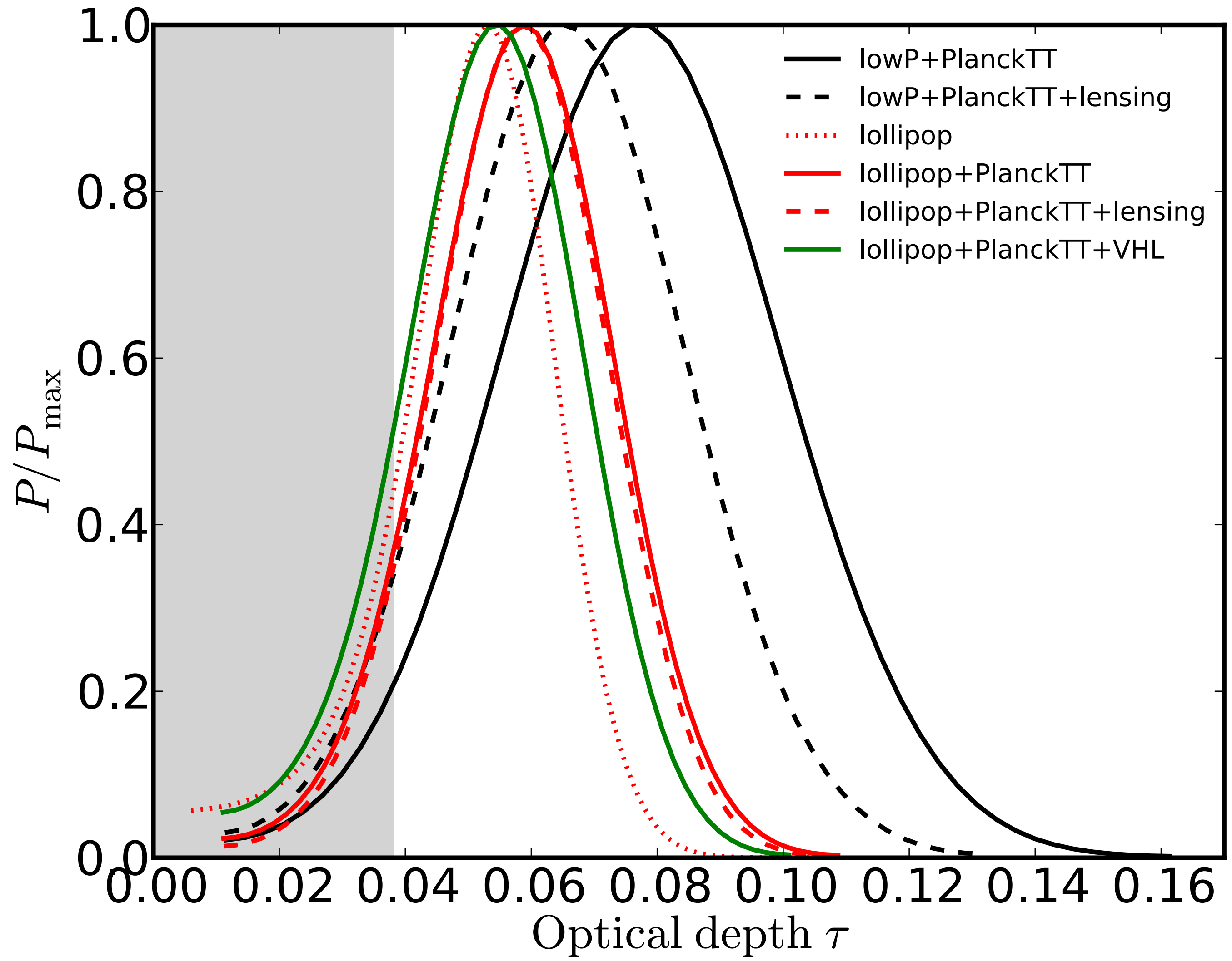
From CMB data:



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

reionization optical depth

"Planck constraints on reionization history"
[Planck intermediate results. XLVII (2016)]



now use Planck-HFI EE low-ℓ (lollipop)

$\tau = 0.053^{+0.014}_{-0.016}$, lollipop[5] ;

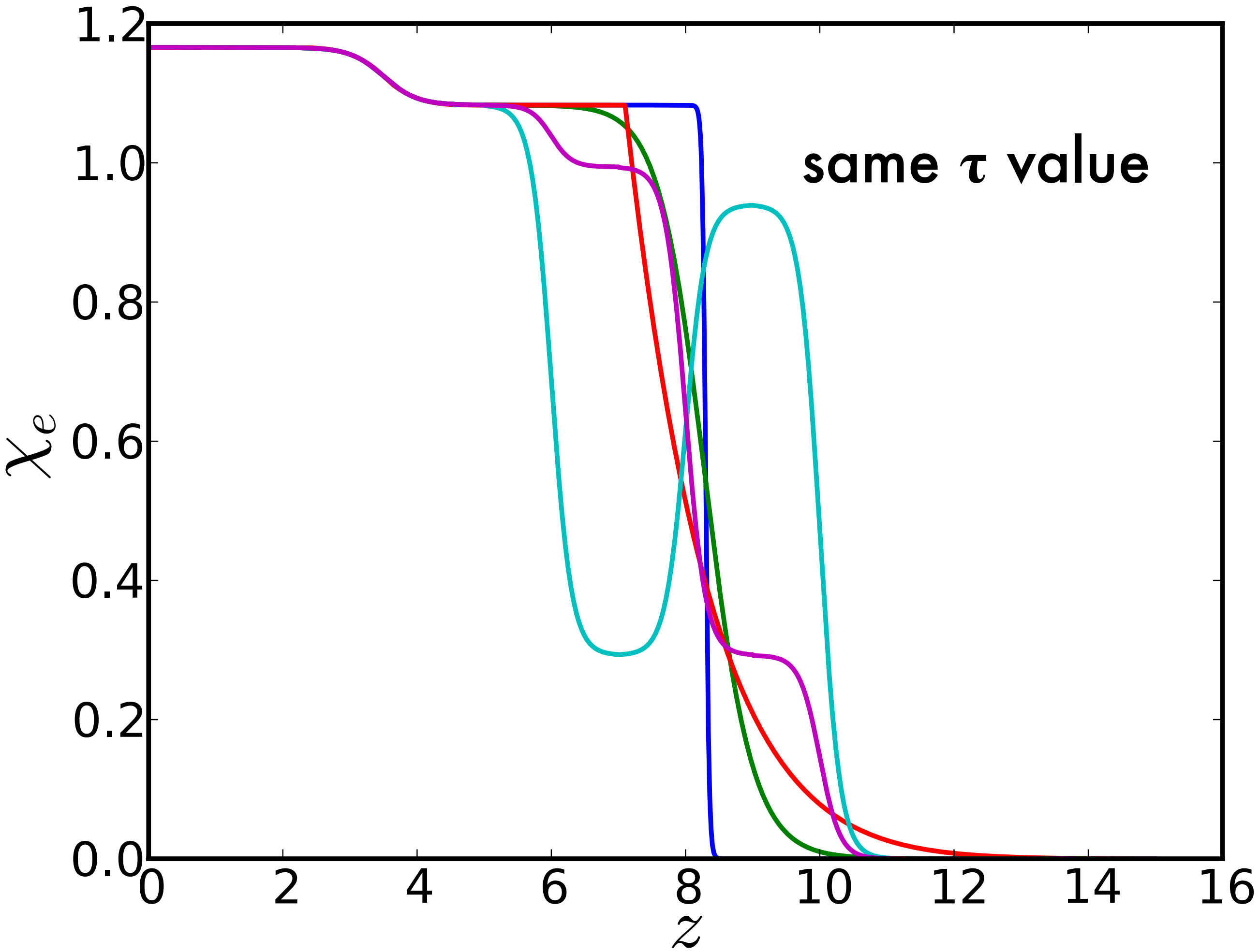
$\tau = 0.058^{+0.012}_{-0.012}$, lollipop+PlanckTT ;

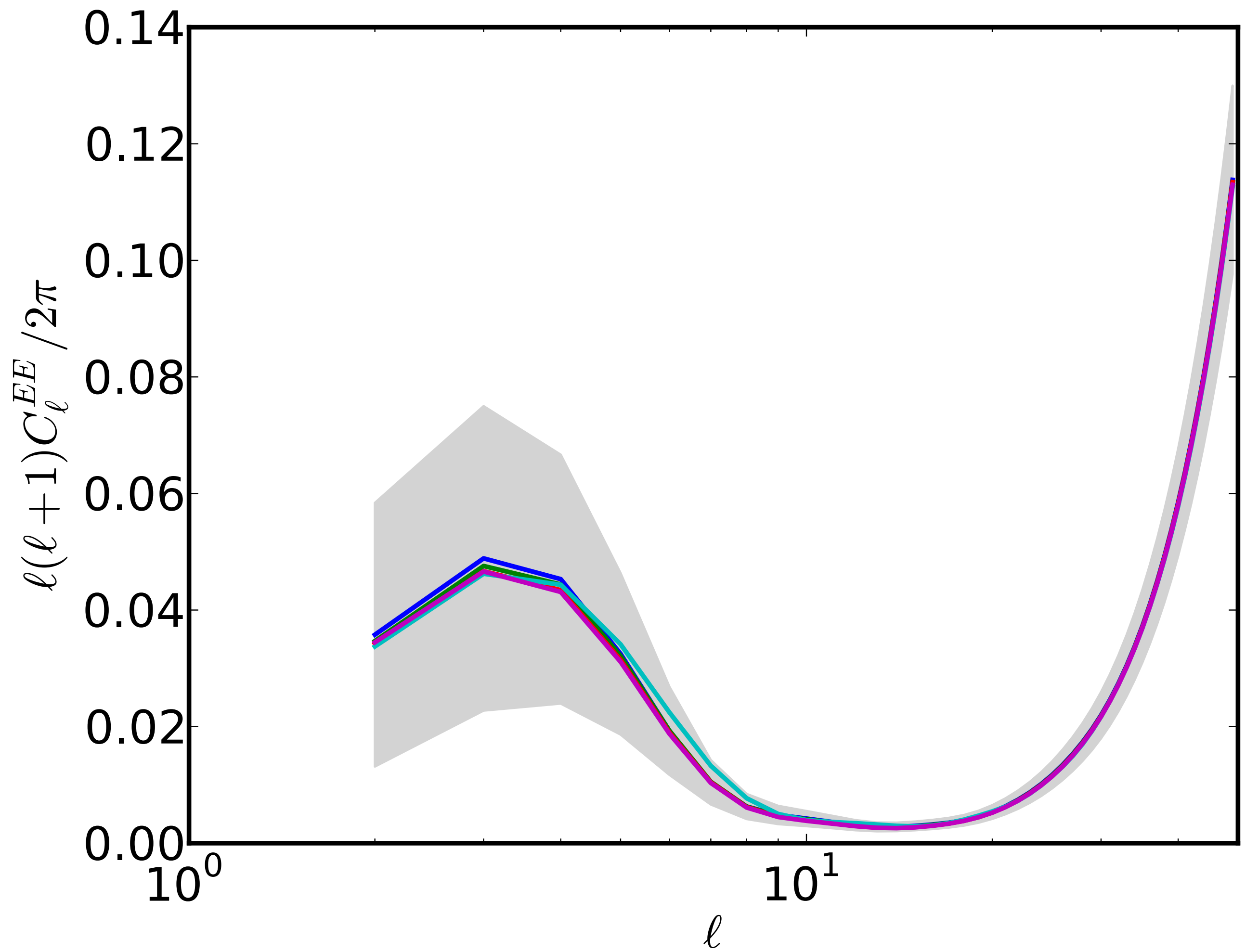
$\tau = 0.058^{+0.011}_{-0.012}$, lollipop+PlanckTT+lensing ;

$$\tau = 0.058 \pm 0.012 \begin{pmatrix} \pm\ 0.009\ \text{(stat)} \\ \pm\ 0.008\ \text{(sys)} \end{pmatrix}$$

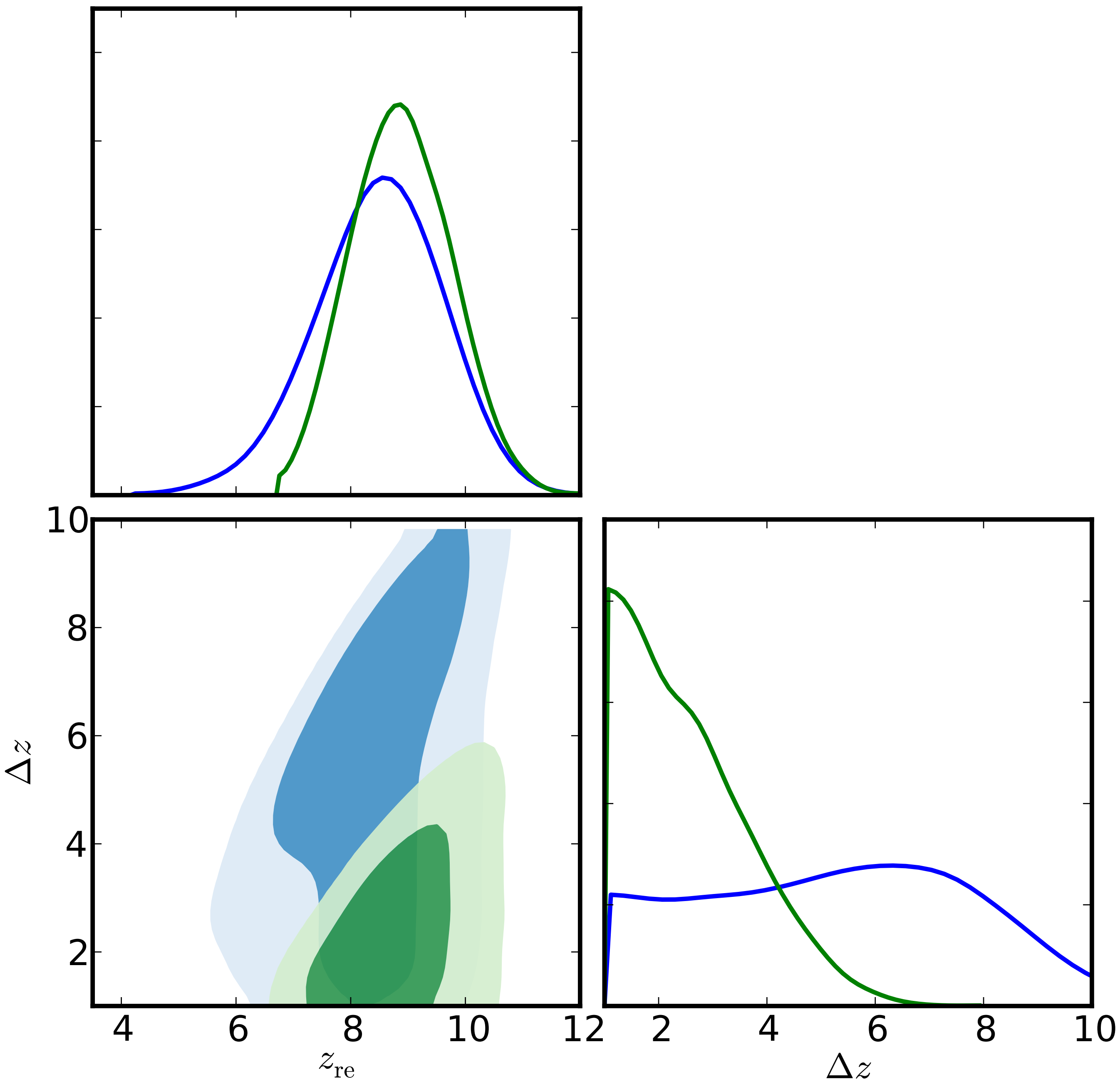
reionization history : CMB degeneracies

[Planck intermediate results. XLVII (2016)]

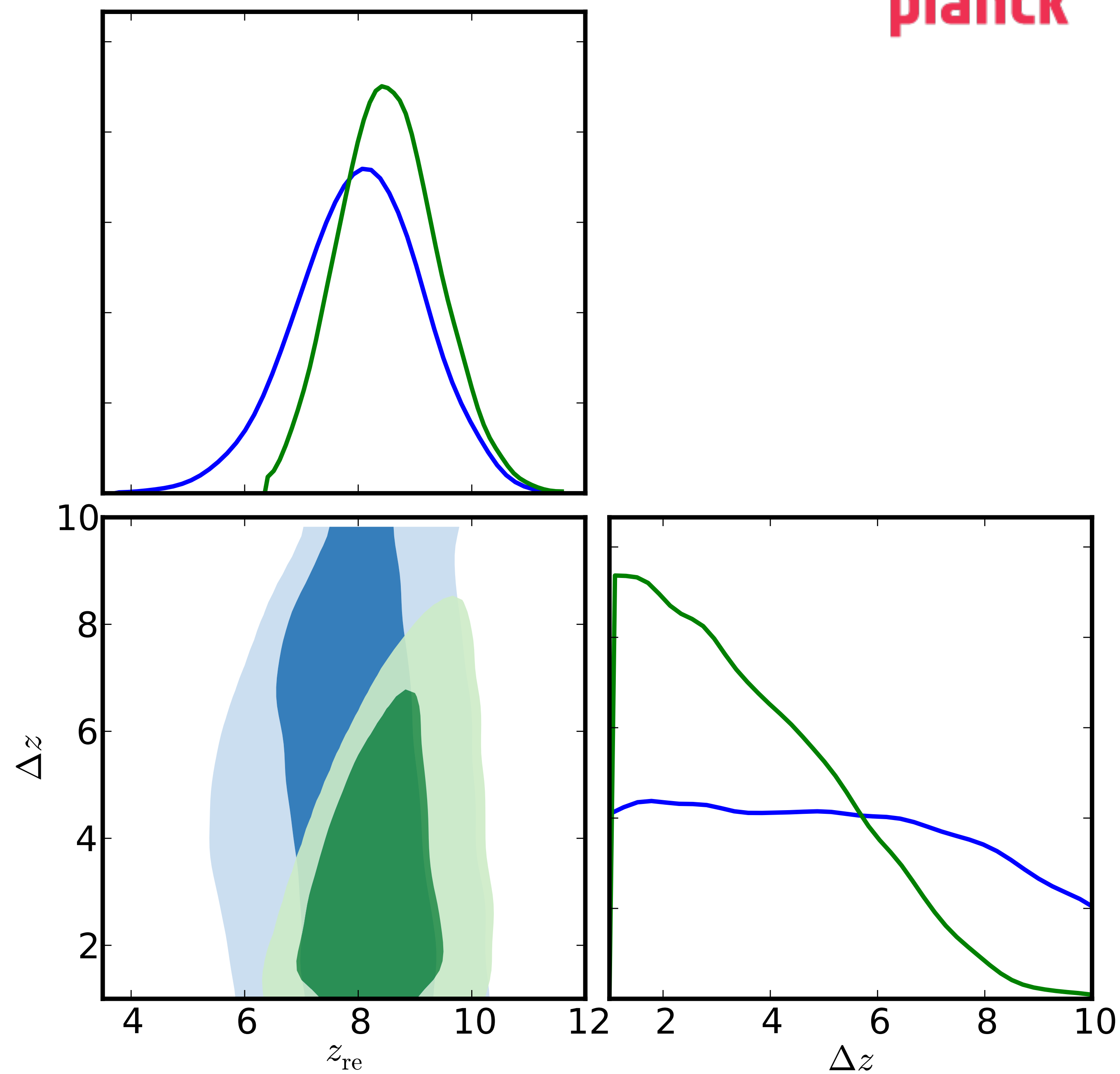




reionization models



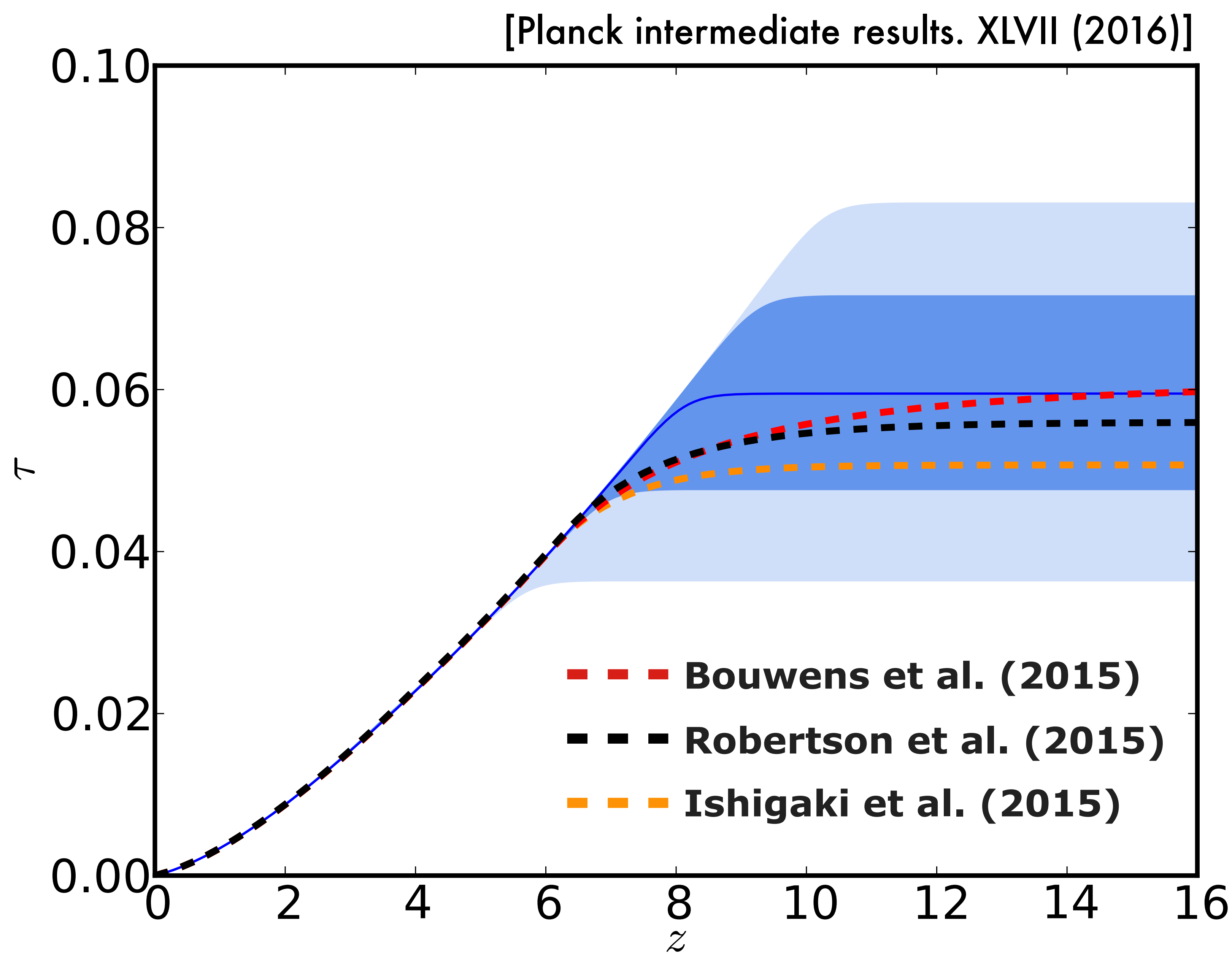
symmetric model



asymmetric model

[Planck intermediate results. XLVII (2016)]

optical depth & redshift



- integrated optical depth for an instantaneous reionization model
- 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.

Planck contraints on reionization history

$$\tau = 0.058 \pm 0.012$$

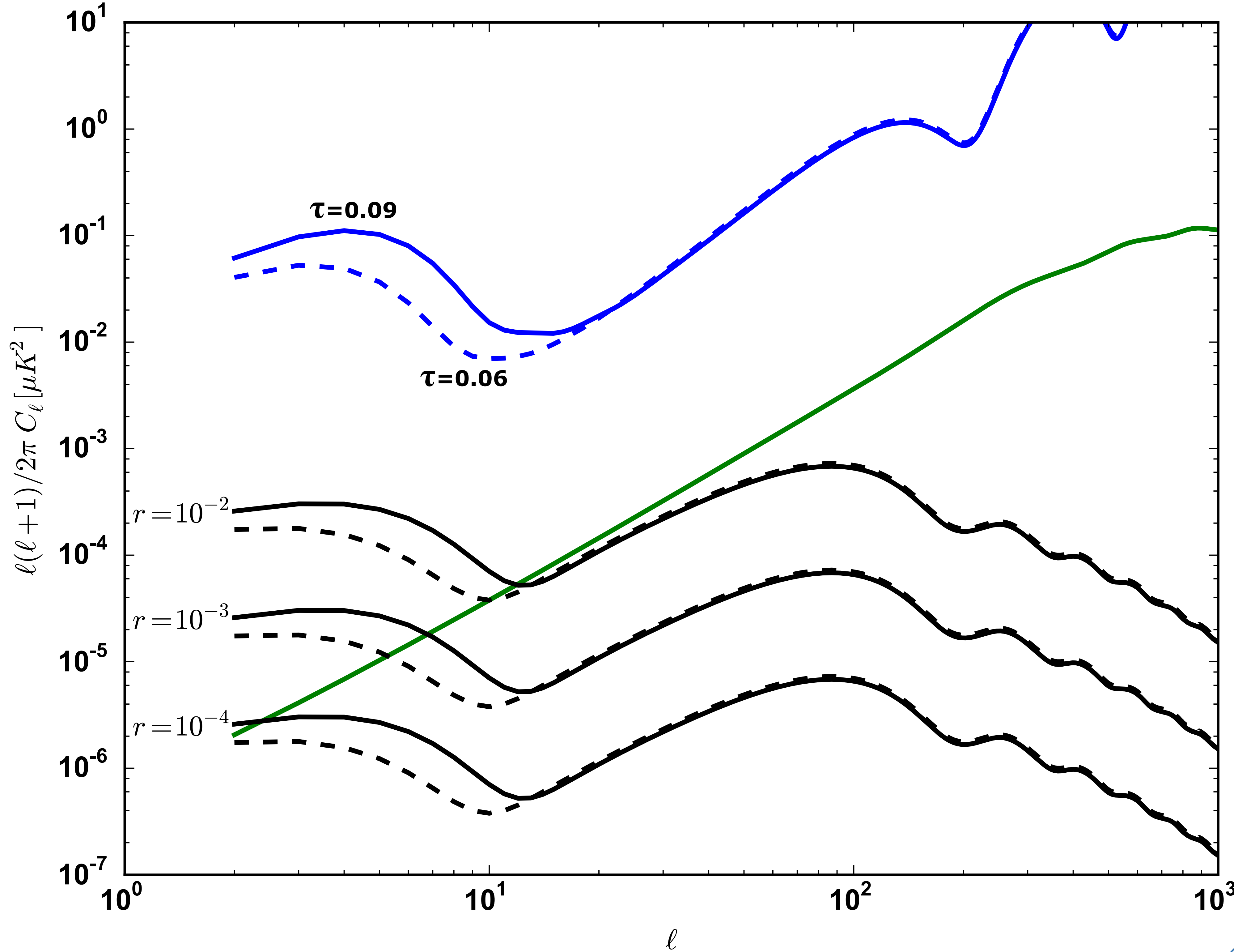
"Planck constraints on reionization history"
[*Planck* intermediate results. XLVII (2016)]

1. the lower value for τ published by Planck is
   - **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 **disfavor large abundances of star-forming galaxies beyond z = 15**

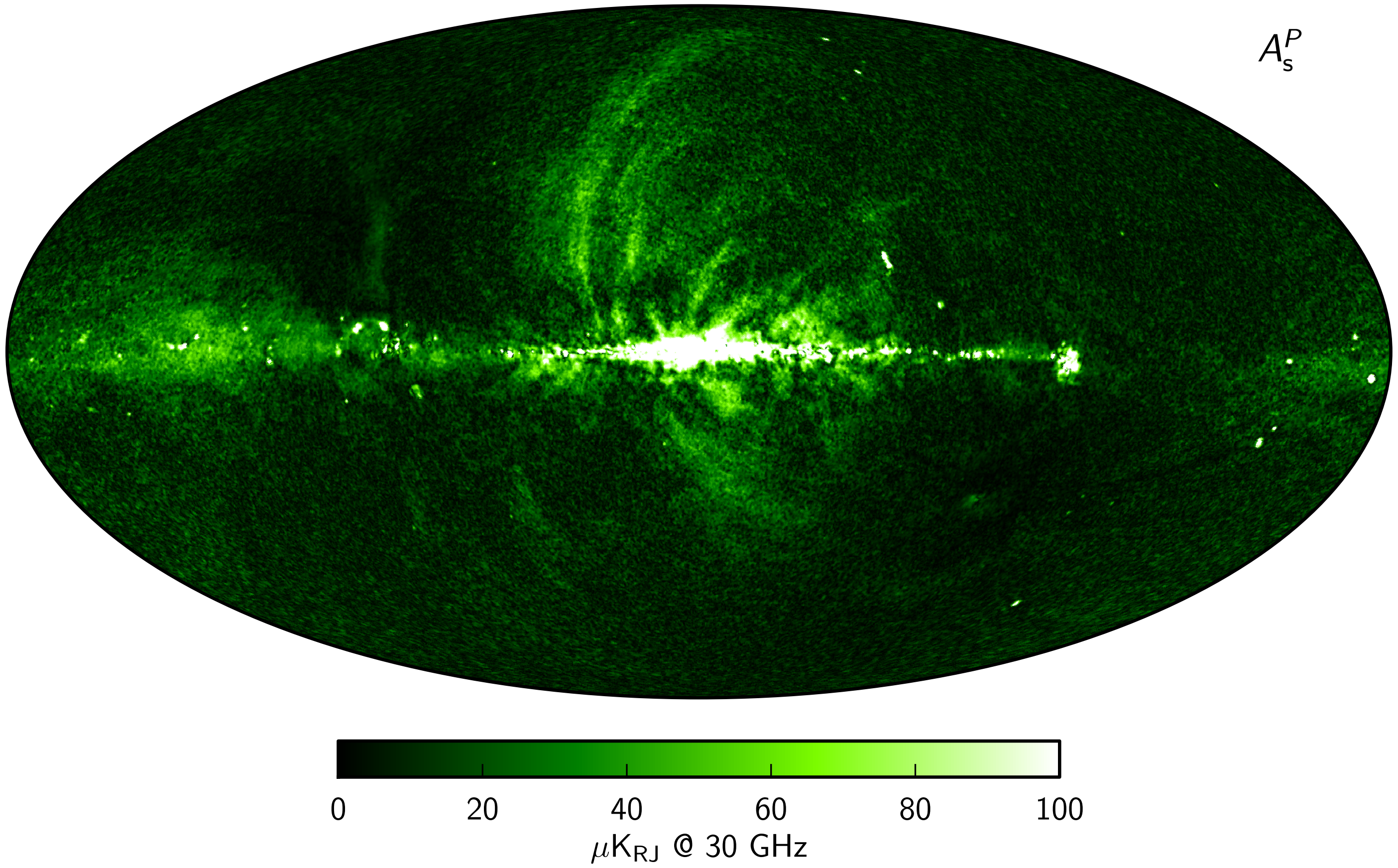
3. maintaining a UV-luminosity density at the maximum level allowed by the luminosity density constraints at redshifts z < 9 and considering only the currently observed galaxy population at MUV < −17 seems to be **sufficient to comply with all the observational constraints without the need for high redshift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

Impact for B-modes

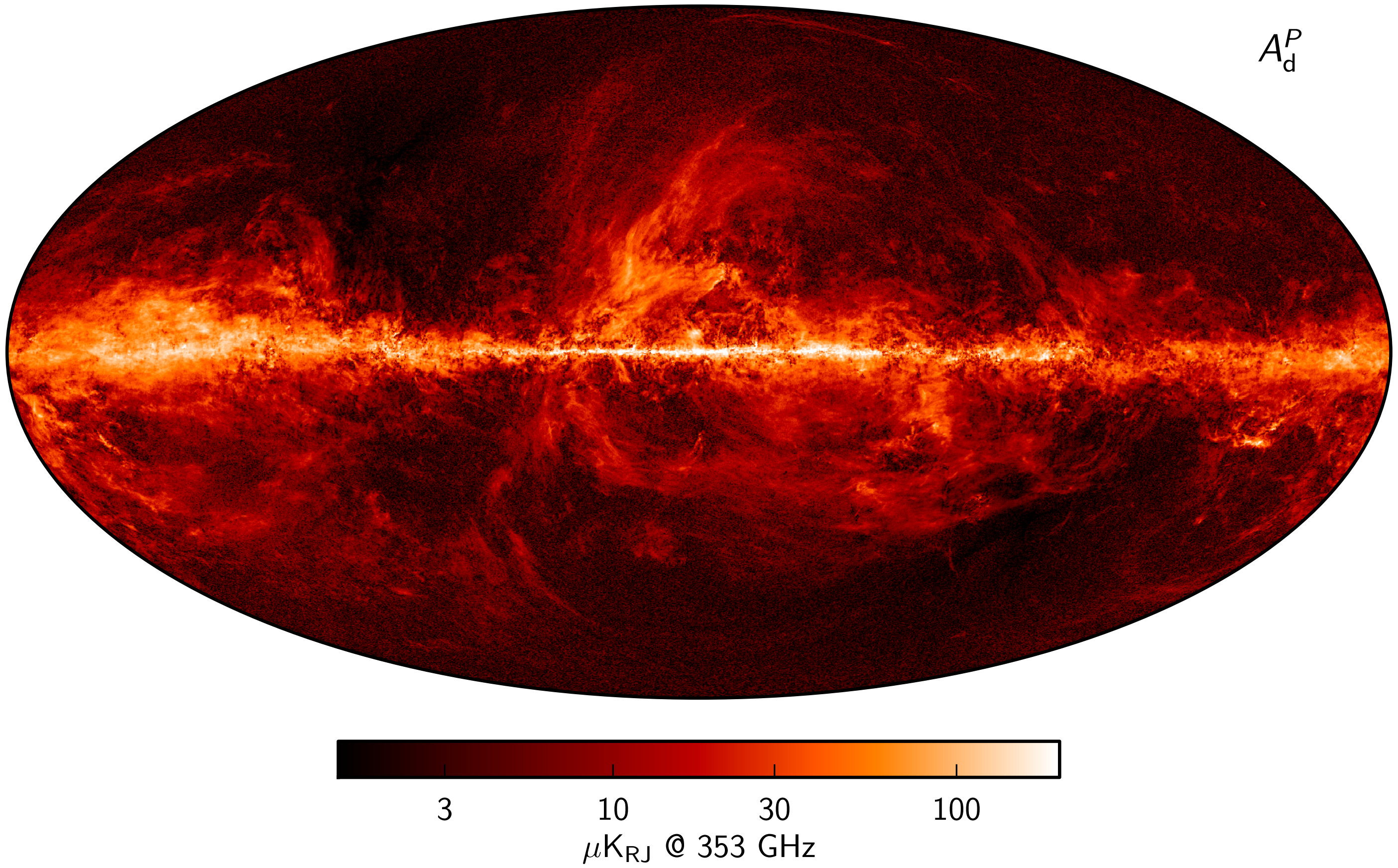


Galactic polarized foregrounds

Synchrotron



Dust

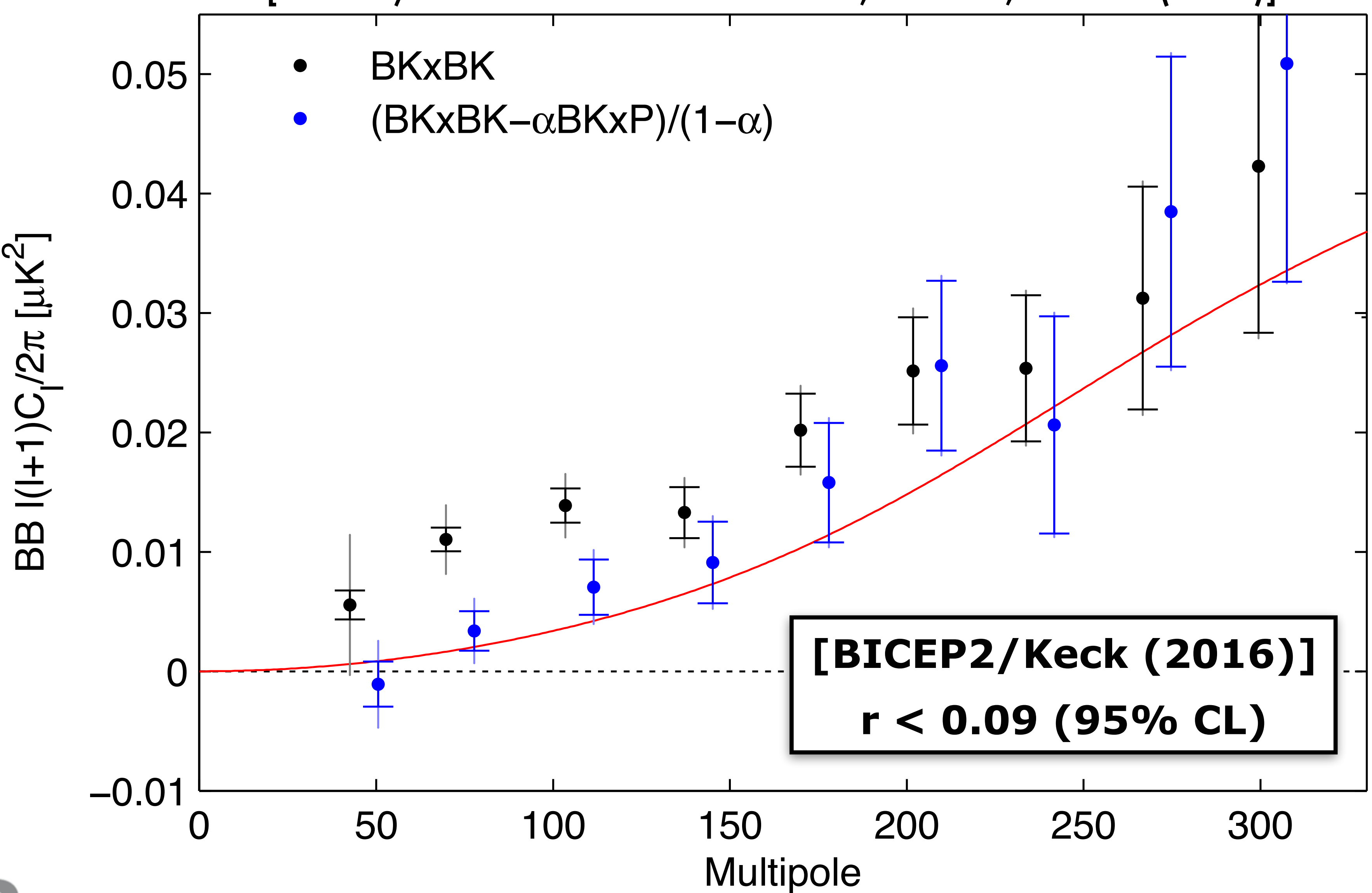


[Planck 2015 results. X. (2016)]

BICEP2

Mar. 2014	1. **BICEP2 claimed 5σ detection of primordial B-modes with r=0.2**
Sep. 2014	2. **Planck showed that BICEP2 results are compatible with dust.** **➡ polarized dust emission cannot be neglected**
Jan. 2015	3. **joint analysis Planck-BICEP2/Keck shows no primordial signal**

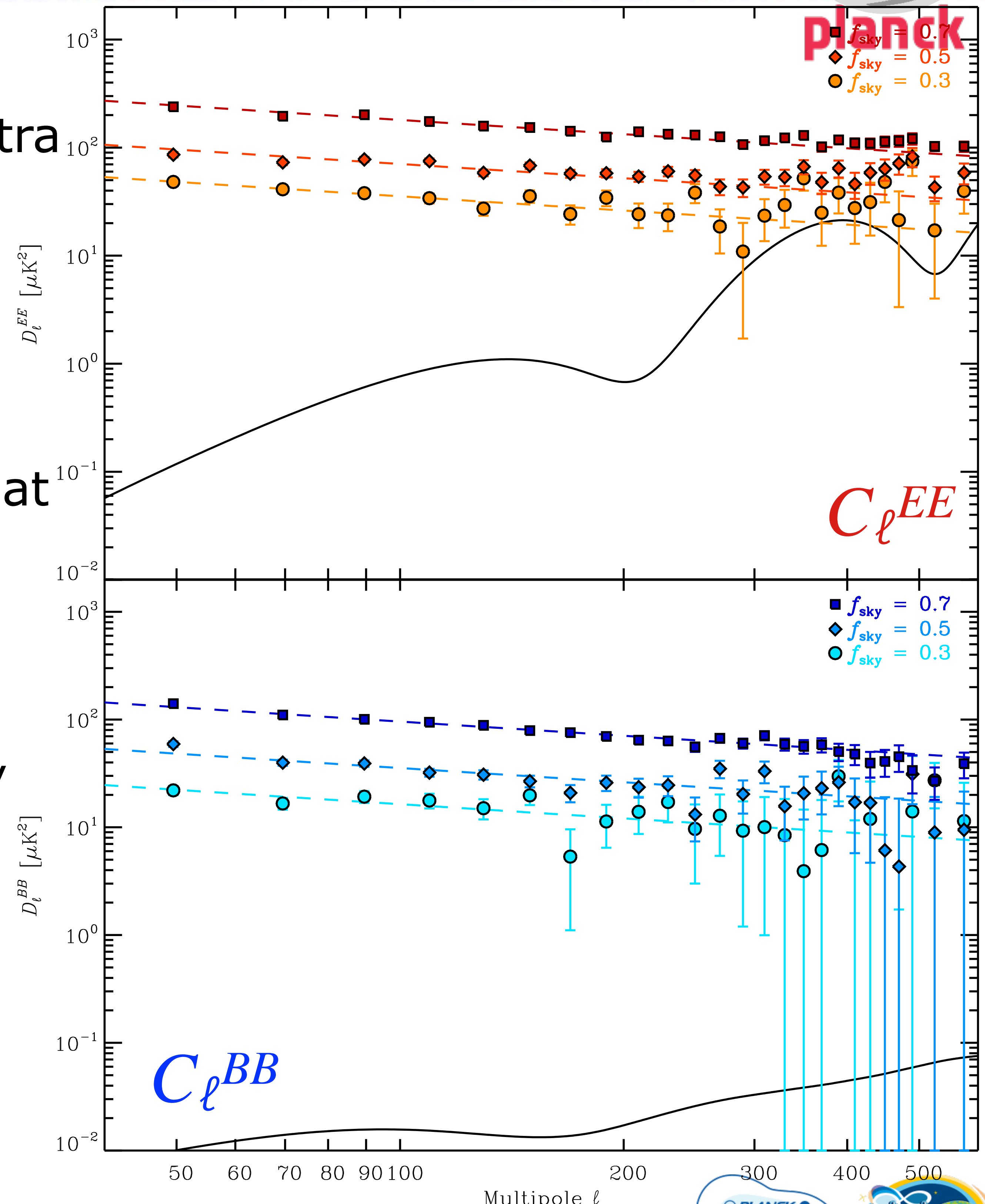
[BICEP2/Keck - Planck collaborations, PRL 114, 101301 (2015)]



Dust angular power spectra

- 353 GHz ***EE*** and ***BB*** angular power spectra
- First detection of the dust polarized angular power spectra at $\ell>10$
- Even on 30% of the sky, the dust polarized emission dominates the CMB, at all scales

1. spectra behave like power-law
2. amplitudes scales like column density
3. difference in ***BB***/***EE*** amplitudes
4. polarized SED



[Planck Intermediate XXX A&A 586, A133 (2016)]

Planck large scales polarization

[*Planck* intermediate results. XLVII (2016)]

1. Reionization

- τ =0.058 ± 0.012
- disfavor large abundances of star-forming galaxies beyond z = 15
- no need for high redshift (z = 10 to 15) galaxies.

2. B-modes

- cosmic variance limited constraint based on large scales temperature data (r<0.10 95% CL)
- polarization constraints based on BB to be published in **2017**

3. Foregrounds

- essential for large scale CMB cleaning
- lots of information already available (see Planck papers)
- work on polarized Galactic emissions (Synchrotron and dust) still continue…

PLANCK is the only experiment that can provide such large scales information for the next 10 years !

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.