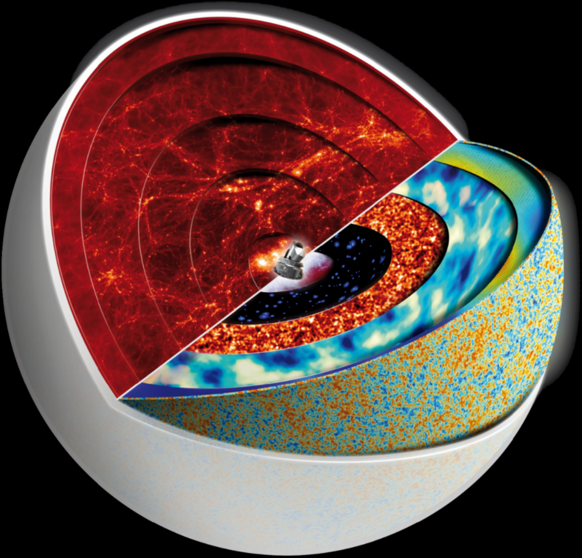
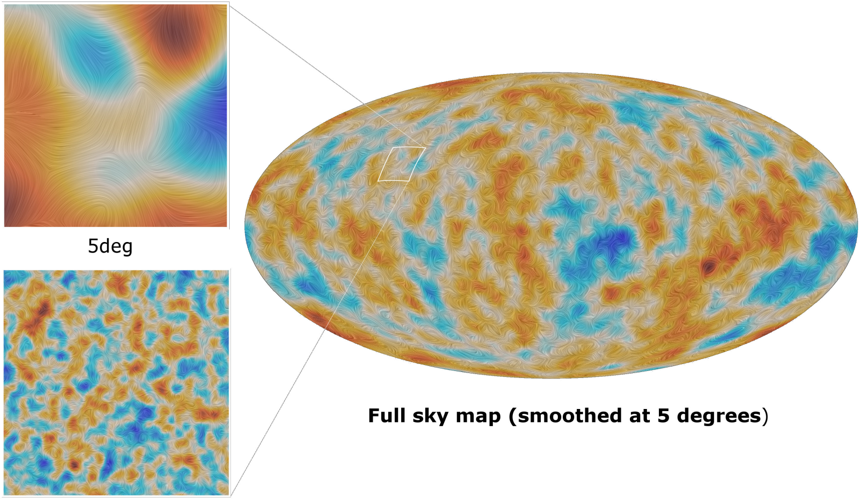
Planck polarization at low ℓ and reionization



Anne Ducout, on behalf of the Planck collaboration

Outline

The *Planck* 2015 CMB polarization



20 arcmin

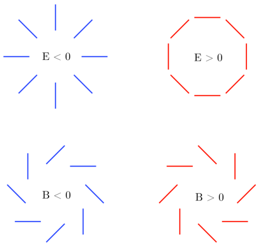
Full sky map (smoothed at 5 degrees)

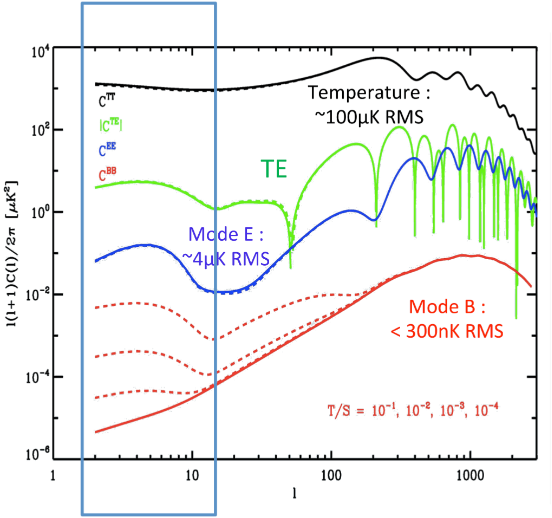
LFI : 30, 44, 70 GHz, **HFI : 100, 143, 217, 353, 545, 857 GHz**

New : HFI low-ell polarization

The CMB angular power spectra

- 3 observables : T, E, B



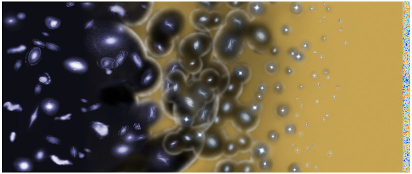


- Low-ell polarization :

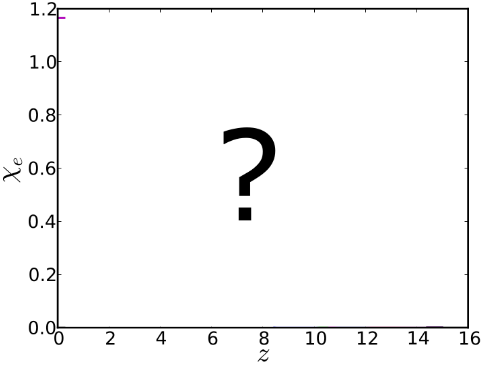
  Reionization "bump" around $\ell \lesssim 10$

$$\theta \sim \frac{180}{\ell}$$

Reionization



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.



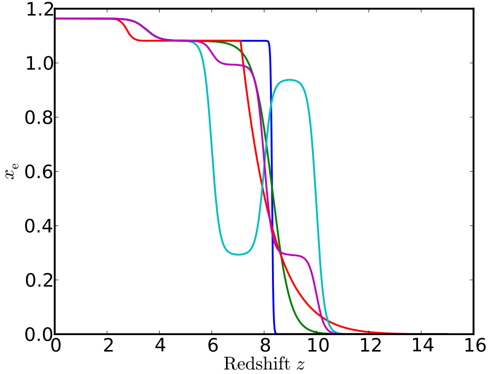
χ_e is the ionisation fraction as a function of the redshift.

Reionisation optical depth is defined as

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

Reionization history

- **symmetric** (standard tanh)
  - 2 parameters : z_{re}, Δz (δz)
    includes “instantaneous" reionization
- **asymmetric**
  - 2 sources :
    1. “gentle” : stars & DGs
    2. “abrupt” : QSOs finish
  - phenomenological description :
    z_{begin}, z_{end}, z_{re}
- **model independent**
  - $x_e(z)$ in redshift bins
  - Principal Component Analysis

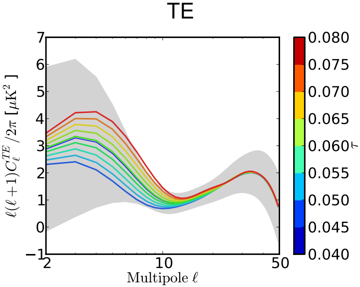


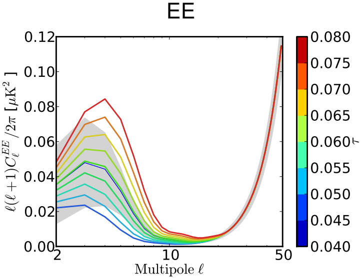
CMB & Reionization

CMB can give information on EoR through :

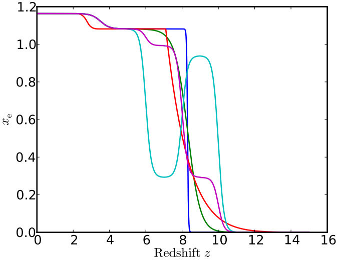
- **temperature anisotropies :**
  suppression of TT power at high multipole (very degenerate with other cosmological parameters and foregrounds)
- **large scale CMB anisotropies in polarisation :**
  new polarisation anisotropy at large angular scale because the horizon has grown to a much larger size by that epoch
- **kinetic Sunyaev-Zel'dovich effect :**
  Scattering of photons off newly liberated electrons [Sunyaev & Zel'dovich 1980] (generates CMB temperature anisotropies)

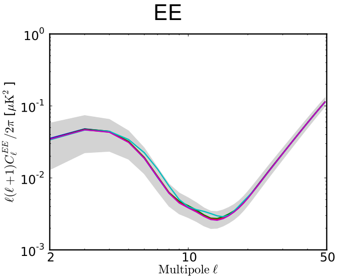
Effect on CMB polarisation at low-ℓ



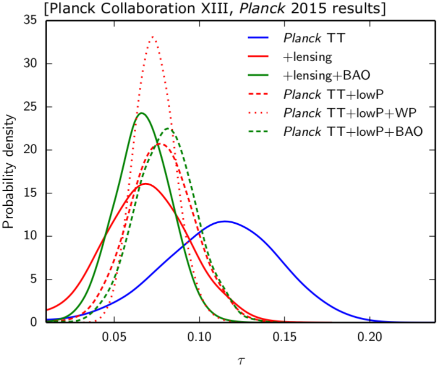


CMB degeneracies :





Reionization optical depth



From CMB data :

- **WMAP 9yr**
  $\tau = 0.089 \pm 0.014$
- **Planck 2013**
  $\tau = 0.089 \pm 0.014$ (TT with WP)
  $\tau = 0.075 \pm 0.013$ (TT with Planck dust)
- **Planck 2015**
  $\tau = 0.078 \pm 0.019$ (TT with 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...

Case of standard instantaneous reionization model

Planck-HFI low-ℓ data [Planck PIP XLVI, 2016]

- **In previous Planck data, the biggest systematic was ADC-NL**
  still the case, but has been reduced by a factor almost 10, and produces very low levels of residuals in the maps.

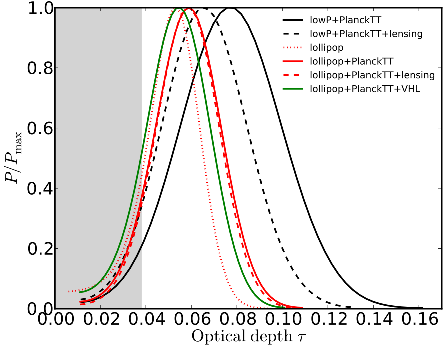
- **Updated mapmaking procedure :**
  significant reduction of systematic effects in the maps, including leakage from temperature to polarization, and very good calibration (better than 0.001$\%$).

- **Results on E2E Monte-Carlo simulations including ADC-NL**
  bias remaining : very low and accounted for in the likelihoods.

- **Component separation** : Main data at 100 & 143 GHz
  use of 30 and 353 GHz for synchrotron and dust templates.

- **Likelihood based on cross-spectra between Planck frequency maps**
  Lollipop : [Hamimeche $\&$ Lewis 2008] approximation modified for cross-spectra [Mangilli+2015]
  Simbal : biases removed with simulations.

Results : Reionization optical depth and redshift



- **Data used, likelihood :**
  - Planck Temperature (PlanckTT)
  - Planck Lensing
  - ACT and SPT (VHL)
  - Planck HFI polarization EE at low-ℓ (lollipop)

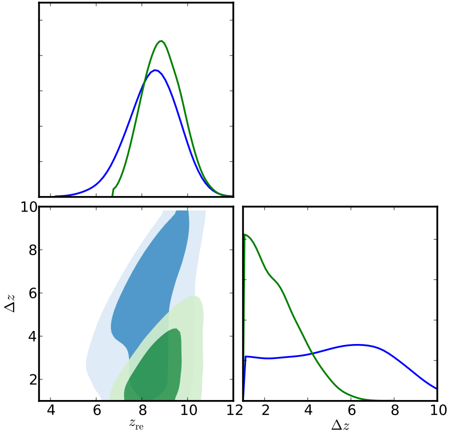
- **Optical depth**
  $\tau = 0.058 \pm 0.012$ (Planck TT + lollipop)

- **Redshift**
  $7.8 \leq z_{re} \leq 8.8$ (All data)

  $\Delta z < 2.8$ (All data)

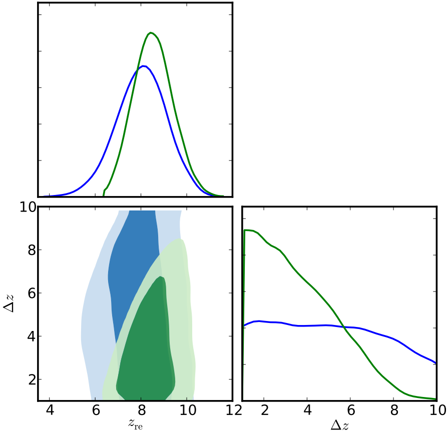
  The Universe is ionized at less than 10% level at redshifts above $z \simeq 10$.

Symmetric / asymmetric model (Planck TT+lollipop)



Symmetric

$z_{re} = 8.8 \pm 0.9$ (with prior)



Asymmetric

$z_{re} = 8.5 \pm 0.9$ (with prior)

$\Delta z < 6.8$ (with prior)

Green Contour : added prior $z_{\rm end} > 6$

Using the kSZ effect (+VHL)

$\Rightarrow$ allows to break the degeneracy with Δz.

2 types of kSZ :

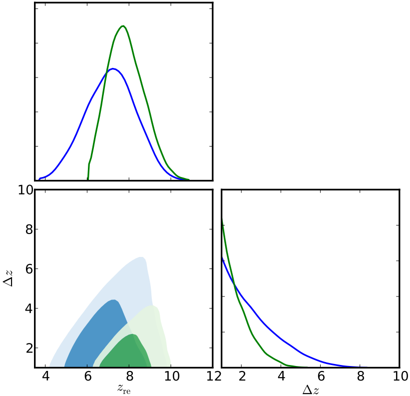
- Homogeneous (h) kSZ : scattering on electrons in bulk motion from clusters, when **reionization is complete**.
- Patchy (p) kSZ : **during the process of reionization**, from proper motion of ionized bubbles around emitting sources.

Different spectra for the different types of kSZ :

$$\mathcal{D}_\ell^{\mathrm{kSZ}} = \mathcal{D}_\ell^{\mathrm{h-kSZ}} + \mathcal{D}_\ell^{\mathrm{p-kSZ}}$$

Amplitude of p-kSZ power primarily depends on duration of reionization.

But very model-dependent...



$\Delta z < 2.8$ (with prior $z_{\mathrm{end}} > 6$)
(symmetric model)

Conclusion

- A lower value for τ as suggested by Planck data would be
  - **consistent with a fully reionised Universe at $z \sim 6$**
    (Gunn-Peterson effect showing Universe is mostly ionized up to $z \sim 6$ [Fan et al. 2006a])
  - 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 **disfavour 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 $M_{\mathrm{UV}} < -17$ 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.