Statistical methods for large scale polarisation

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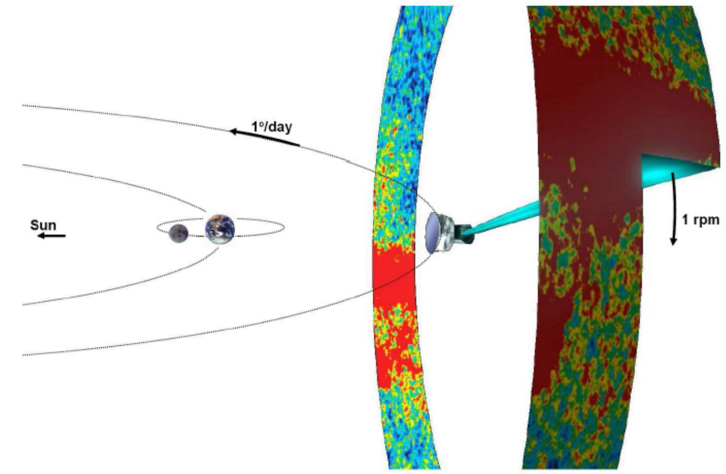
The Planck challenge I: control of systematics

Measuring the large scale polarization is difficult!

Major HFI systematic residuals:

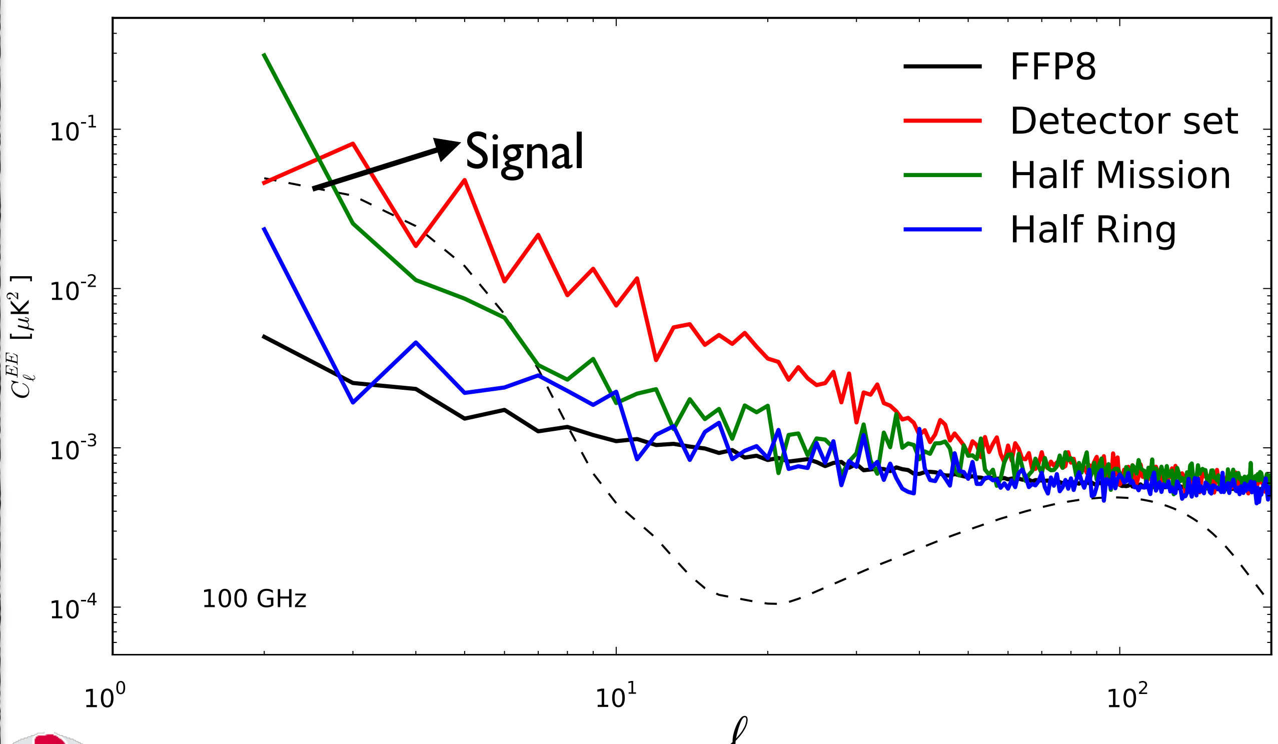
- inter-calibration leakage
- ADC non-linearity residuals
- correlated 1/f noise residuals
- foreground residuals



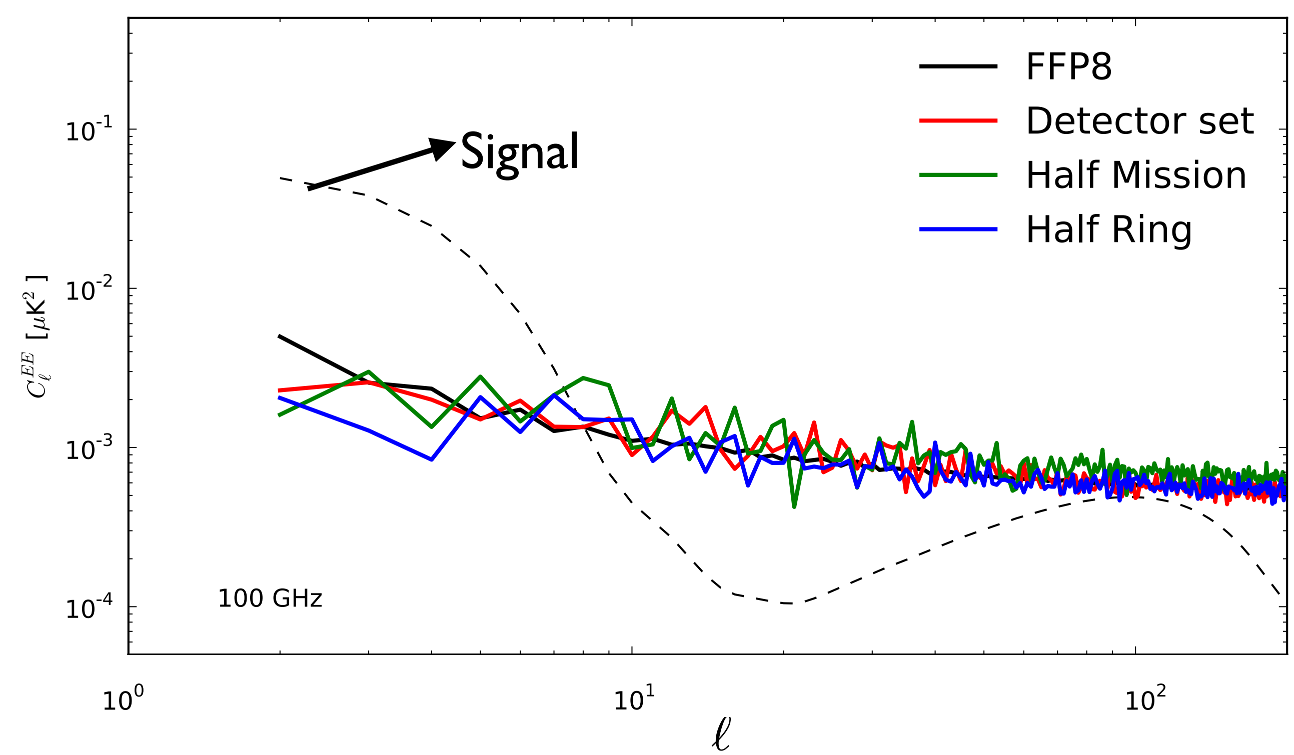
All these effects are important at low-l

E-Modes: noise&systematics

Planck-HFI 2015



Planck-HFI 2016

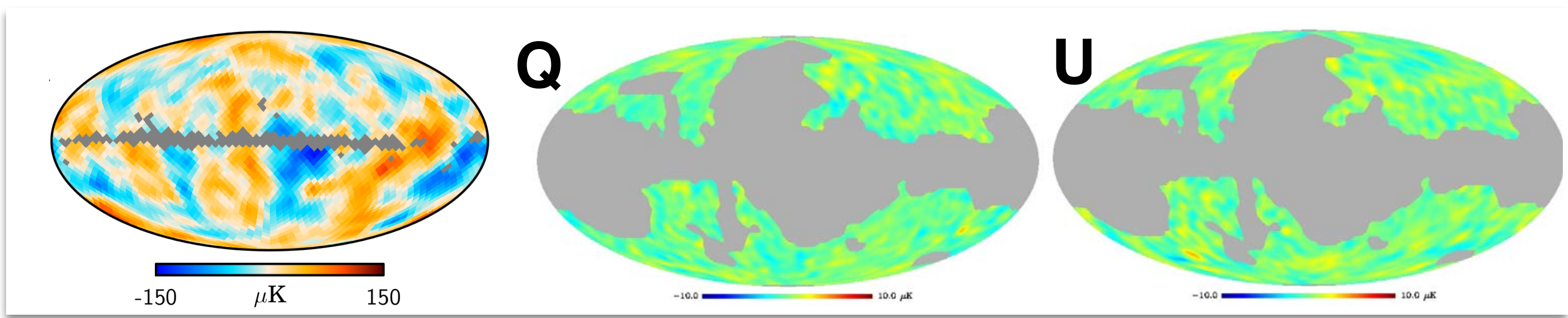


The Planck challenge II: low-l data analysis

WMAP, Planck 2013, 2015: Gaussian likelihood **in map space**

$$\mathcal{L} = \frac{1}{2\pi^{n/2}|\mathbf{M}|^{1/2}} \exp\left(-\frac{1}{2}\mathbf{m}^t \boxed{\mathbf{M}^{-1}} \mathbf{m}\right)$$

M= CMB signal+noise covariance matrix



Problem: noise covariance matrix reconstruction accuracy

- Can compromise parameter reconstruction in particular for the high sensitivity of HFI channels
- Difficult handling of noise bias/residual systematics

Cross-spectra analysis at large angular scales

[Mangilli, Plaszczynski, Tristram (MNRAS 483 2015)]

Use cross-spectra likelihood at large scales

Noise bias removed. Exploit cross dataset informations
Better handling of residual systematics/foregrounds

Two solutions to solve for the non-Gaussianity of the estimator distributions at low multipoles

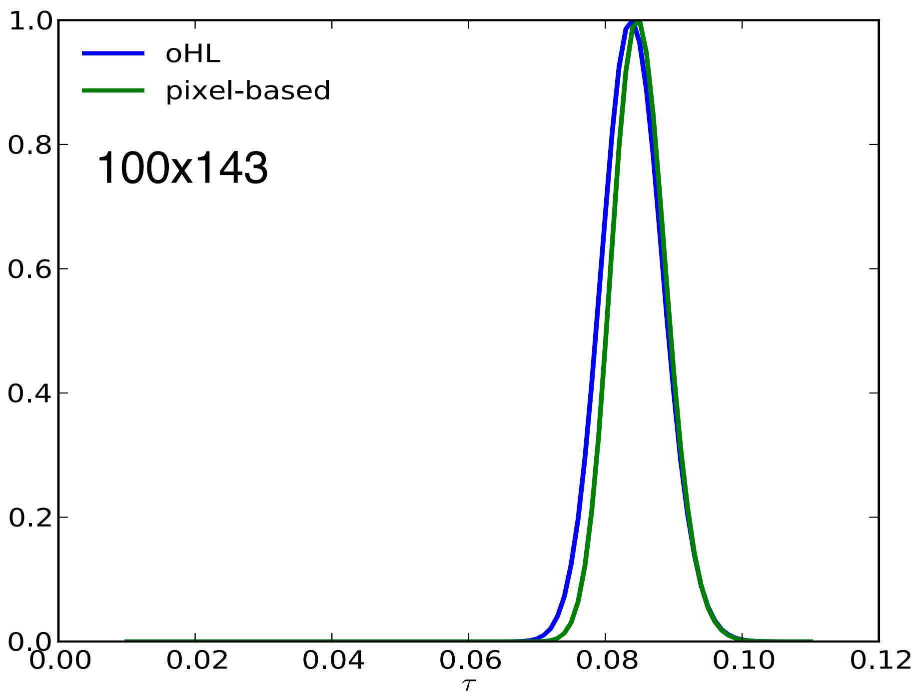
- Analytic approximation of the estimators: works for single-field and small mask
- **Modified Hamimeche&Lewis (2008) likelihood for cross-spectra (oHL)**

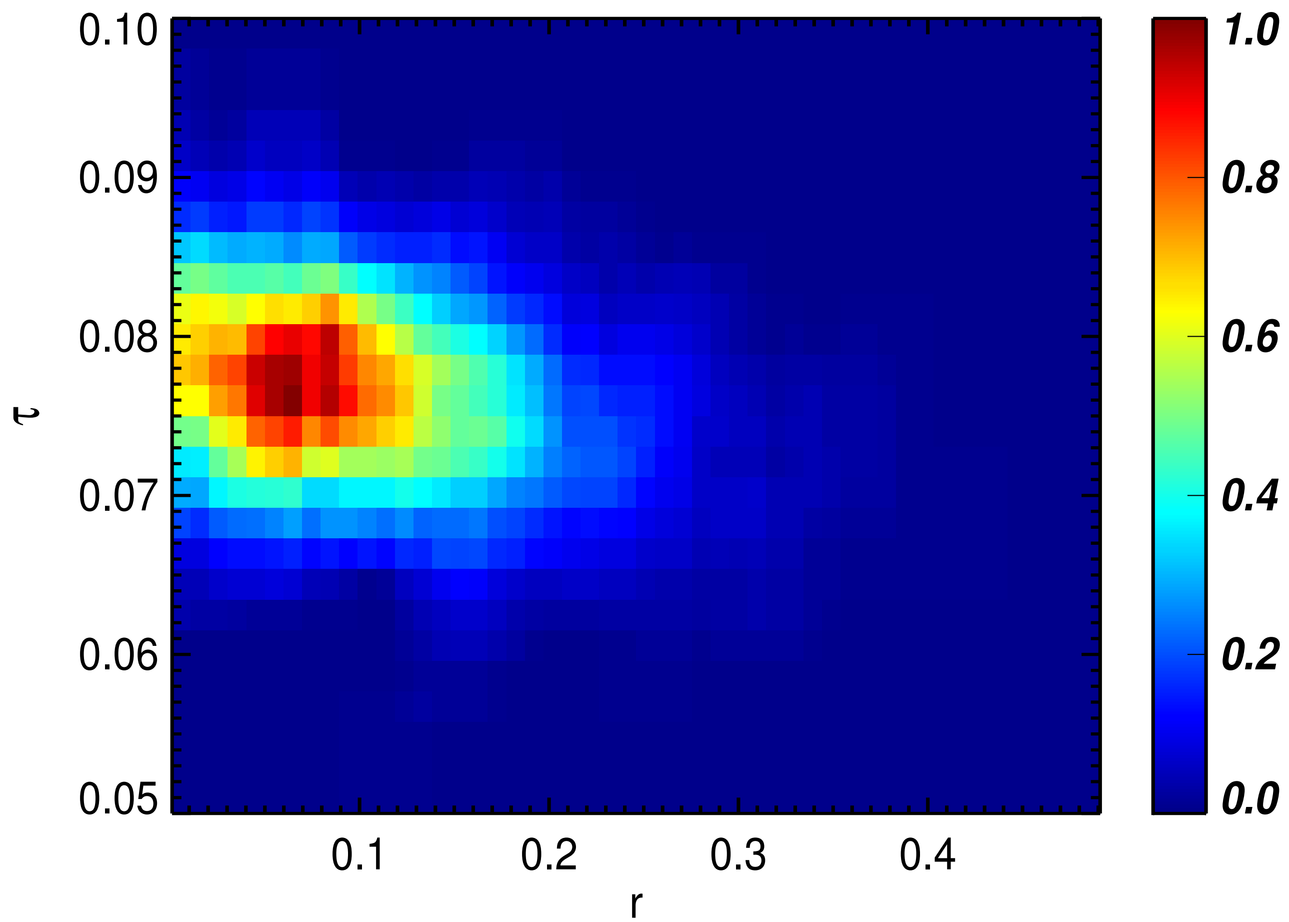
Full temperature and polarization analysis

Cross-spectra oHL: τ-r estimation

[Mangilli, Plaszczynski, Tristram (MNRAS 483 2015)]

l=[2,20], full temperature and polarization oHL likelihood
MC simulations Planck 100x143 with correlated noise

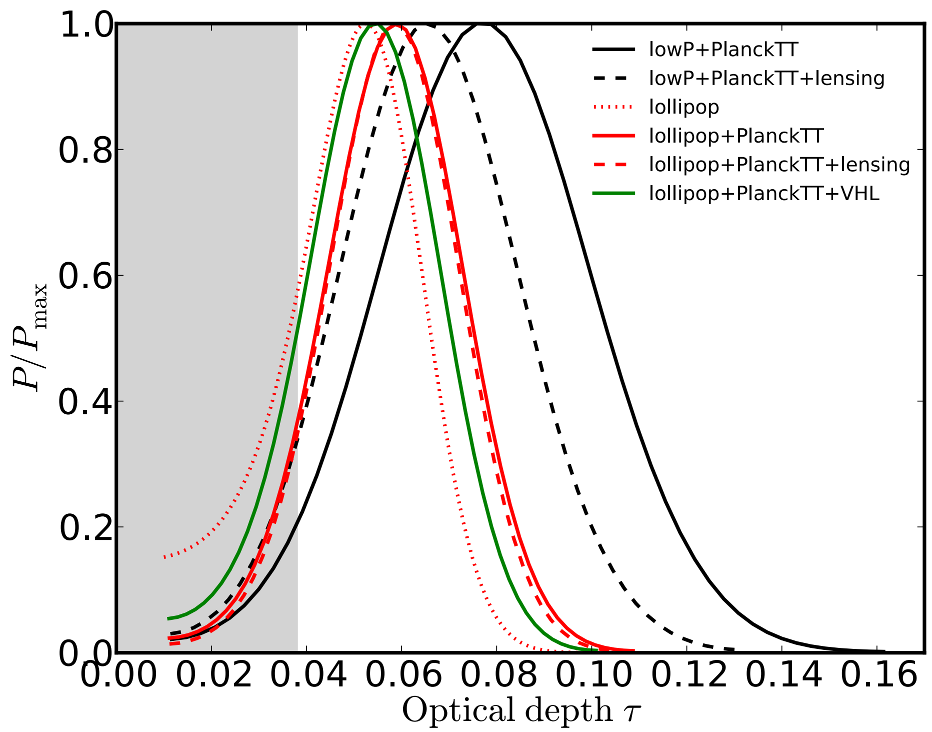




Planck low-l polarization results

Cross-spectra likelihood oHL used for the E-modes analysis at large scales

$$\tau = 0.058^{+0.011}_{-0.012}$$



Combination of low-l HFI with:

1. **+Planck TT/lensing** (2015)
2. **+Very High-l** ground-based experiments (ACT & SPT)

Astronomy & Astrophysics manuscript no. reionisation
May 24, 2016

Planck intermediate results. XLVII. Planck constraints on reionization history

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ABSTRACT

We investigate constraints on cosmic reionization extracted from the *Planck* cosmic microwave background (CMB) data. We combine the *Planck* CMB anisotropy data in temperature with the low-multipole polarization data to fit ΛCDM models with various parameterizations of the reionization history. We obtain a Thomson optical depth $\tau = 0.058 \pm 0.012$ for the commonly adopted instantaneous reionization model. This confirms, with data solely from CMB anisotropies, the low value suggested by combining *Planck* 2015 results with other data sets and also reduces the uncertainties. We reconstruct the history of the ionization fraction using either a symmetric or an asymmetric model for the transition between the neutral and ionized phases. To determine better constraints on the duration of the reionization process, we also make use of measurements of the amplitude of the kinetic Sunyaev-Zeldovich (kSZ) effect using additional information from the high resolution Atacama Cosmology Telescope and South Pole Telescope experiments. The average redshift at which reionization occurs is found to lie between $z = 7.8$ and 8.8, depending on the model of reionization adopted. Using kSZ constraints and a redshift-symmetric reionization model, we find an upper limit to the width of the reionization period of $\Delta z < 2.8$. In all cases, we find that the Universe is ionized at less than the 10 % level at redshifts above $z \simeq 10$. This suggests that an early onset of reionization is strongly disfavoured by the *Planck* data. We show that this result also reduces the tension between CMB-based analyses and constraints from other astrophysical sources.

Key words. Cosmology – cosmic background radiation – Polarization – dark ages, reionization, first stars

1. Introduction

The process of cosmological recombination happened around redshift $z \simeq 1100$, after which the ionized fraction fell precipitously (Peebles 1968; Zel'dovich et al. 1969; Seager et al. 2000) and the Universe became mostly neutral. However, observations of the Gunn-Peterson effect (Gunn & Peterson 1965) in quasar spectra (Becker et al. 2001; Fan et al. 2006b; Venemans et al. 2013; Becker et al. 2015) indicate that intergalactic gas had become almost fully reionized by redshift $z \simeq 6$. Reionization is thus the second major change in the ionization state of hydrogen in the Universe. Details of the transition from the neutral to ionized Universe are still the subject of intense investigations (for a recent review, see the book by Mesinger 2016). In the currently conventional picture, early galaxies reionize hydrogen progressively throughout the entire Universe between $z \simeq 12$ and $z \simeq 6$, while quasars take over to reionize helium from $z \simeq 6$ to $\simeq 2$. But many questions remain. When did the epoch of reionization (EoR) start, and how long did it last? Are early galaxies enough to reionize the entire Universe or is another source required? We try to shed light on these questions using the traces left by the EoR in the cosmic microwave background (CMB) anisotropies.

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Conclusion

Cross-spectra based likelihood :

- powerful and effective statistical method for analyzing low-ell polarisation data
- (slightly) suboptimal but mitigate systematics (no bias on cosmological parameters)

Power Spectra Estimators:

- Pseudo-Cl (PCL) as **Xpol** [Tristram et al. 2005], **Spice** [Hivon et al. 2002]

  Main issue: Incomplete sky coverage E->B leakage

  "pure" methods as e.g. Xpure [Grain, Tristram, Stompor 2009]
- Quasi Maximum Likelihood : cfr e.g., Gorski 1994, Tegmark 1996; Bond et al. 1998; Efstathiou 2004, 2006

High accuracy needed for future high sensitivity experiments