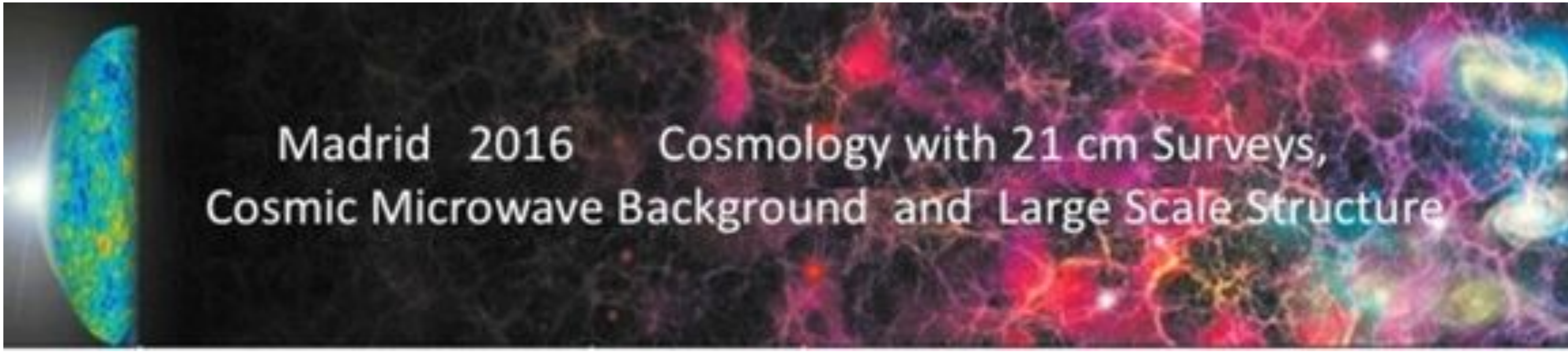


The new Planck polarization data at large angular scales

Anna Mangilli
On behalf of the Planck Collaboration

Institut d'Astrophysique Spatiale

Paris Sud University

Instituto de Física Teórica (IFT), Universidad Autónoma de Madrid (UAM)

OUTLINE

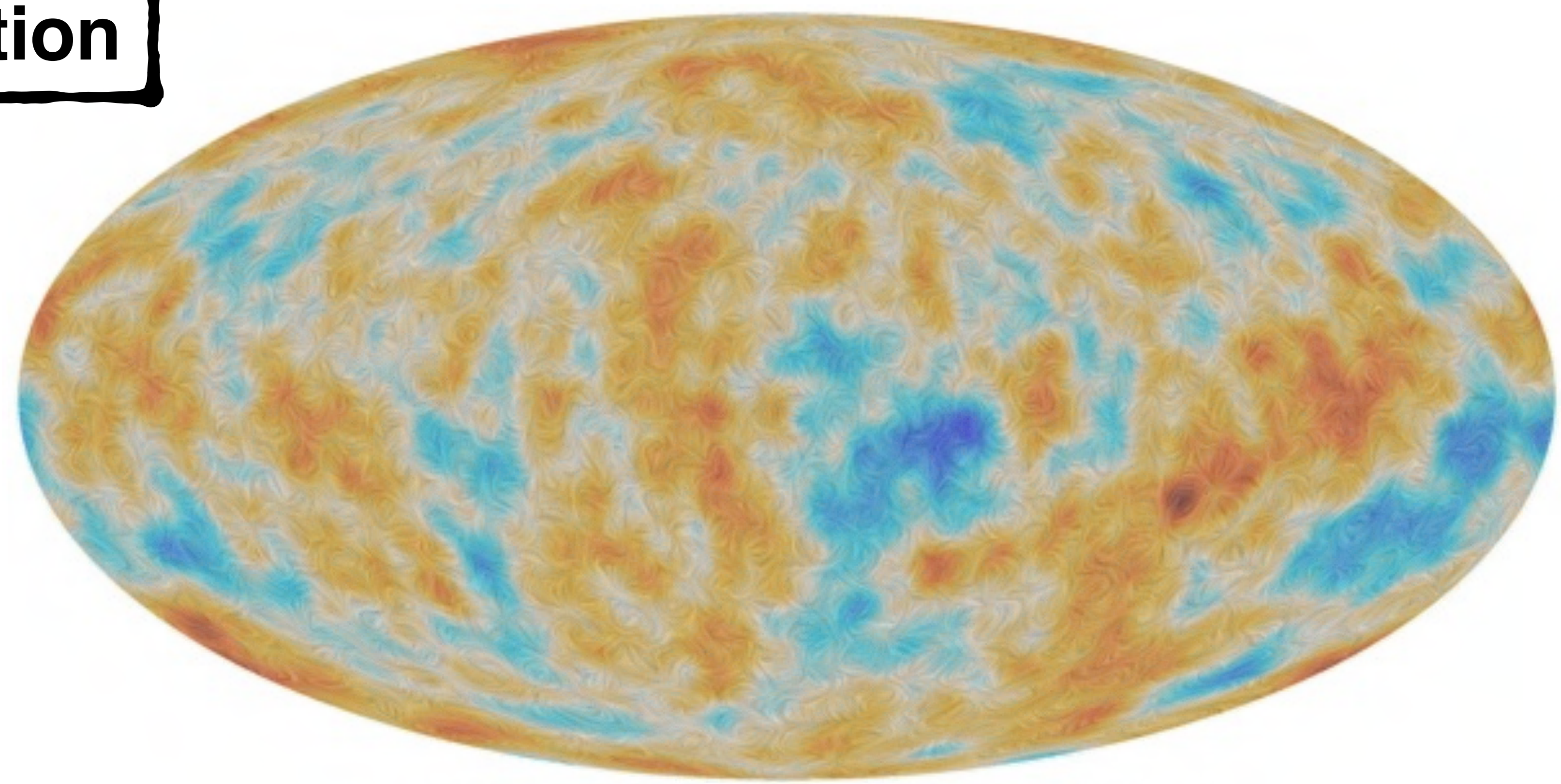
- **The CMB polarization at large angular scales**
- **The challenge for Planck: systematics and statistics**
- **The new Planck HFI results**

The Planck Coll. A&A 2016: "**Planck constraints on the reionization history**" (arxiv:1605.03507)
The Planck Coll. A&A 2016: "**Improved large angular scale polarization data**"(arxiv:1605.02985)

The CMB polarization

Polarization

Planck



CMB polarization signal: orders of magnitude weaker than temperature

E-modes

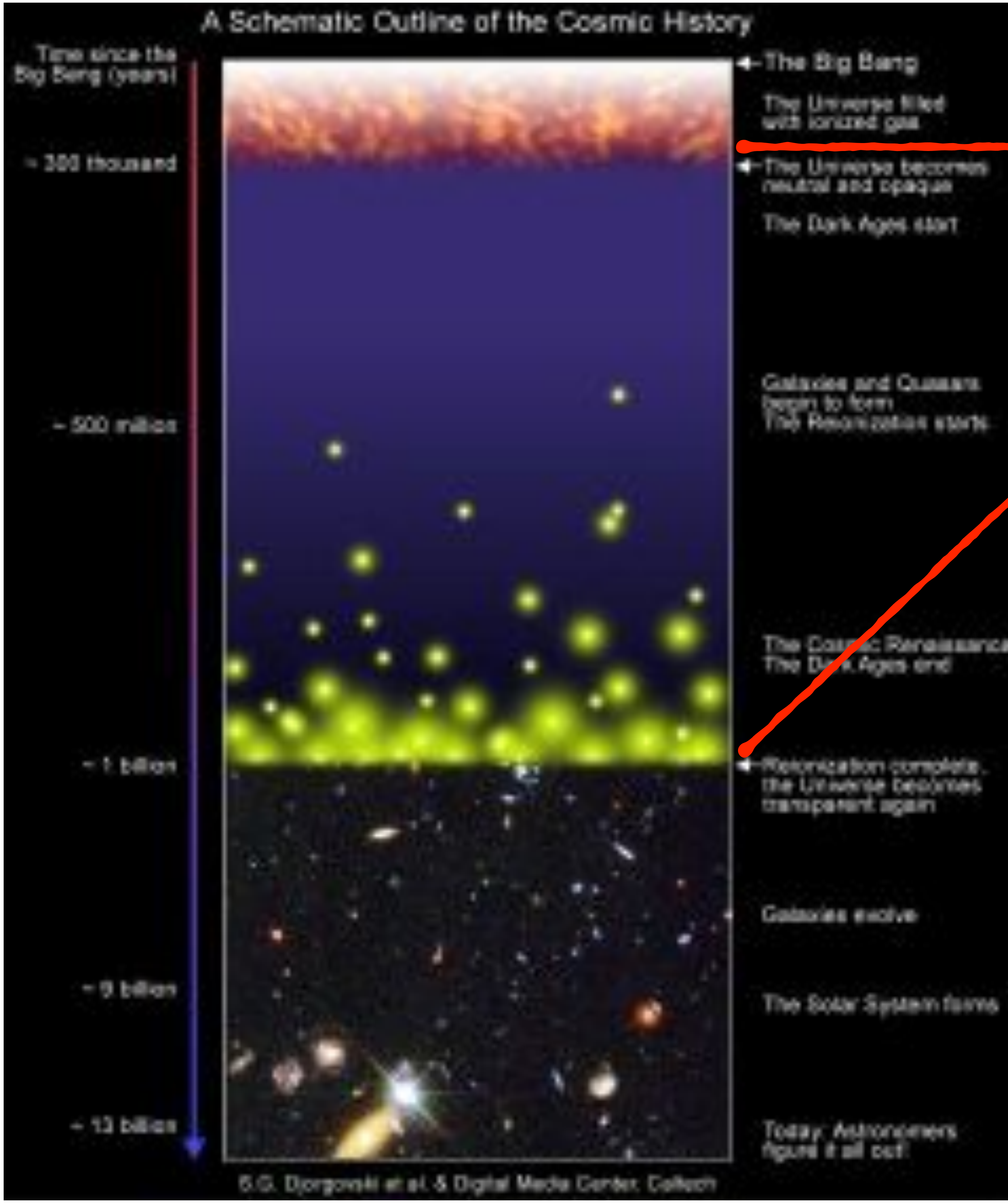
- Electric type polarization field.
- Generated by scalar density perturbations.

B-modes

- Magnetic type polarization field.
- Can be generated only by primordial tensor modes i.e. **primordial gravitational waves**
- Contribution from lensing

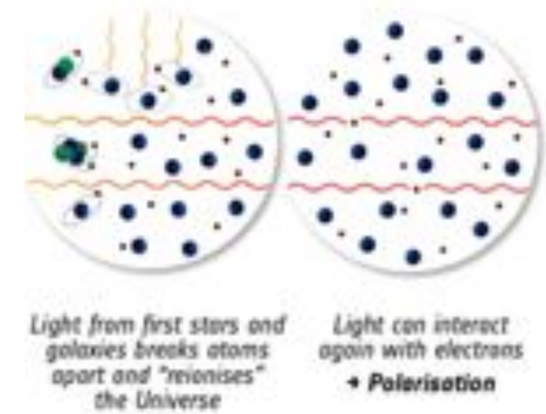
planck

Generation of the CMB polarization



DECOUPLING

REIONIZATION



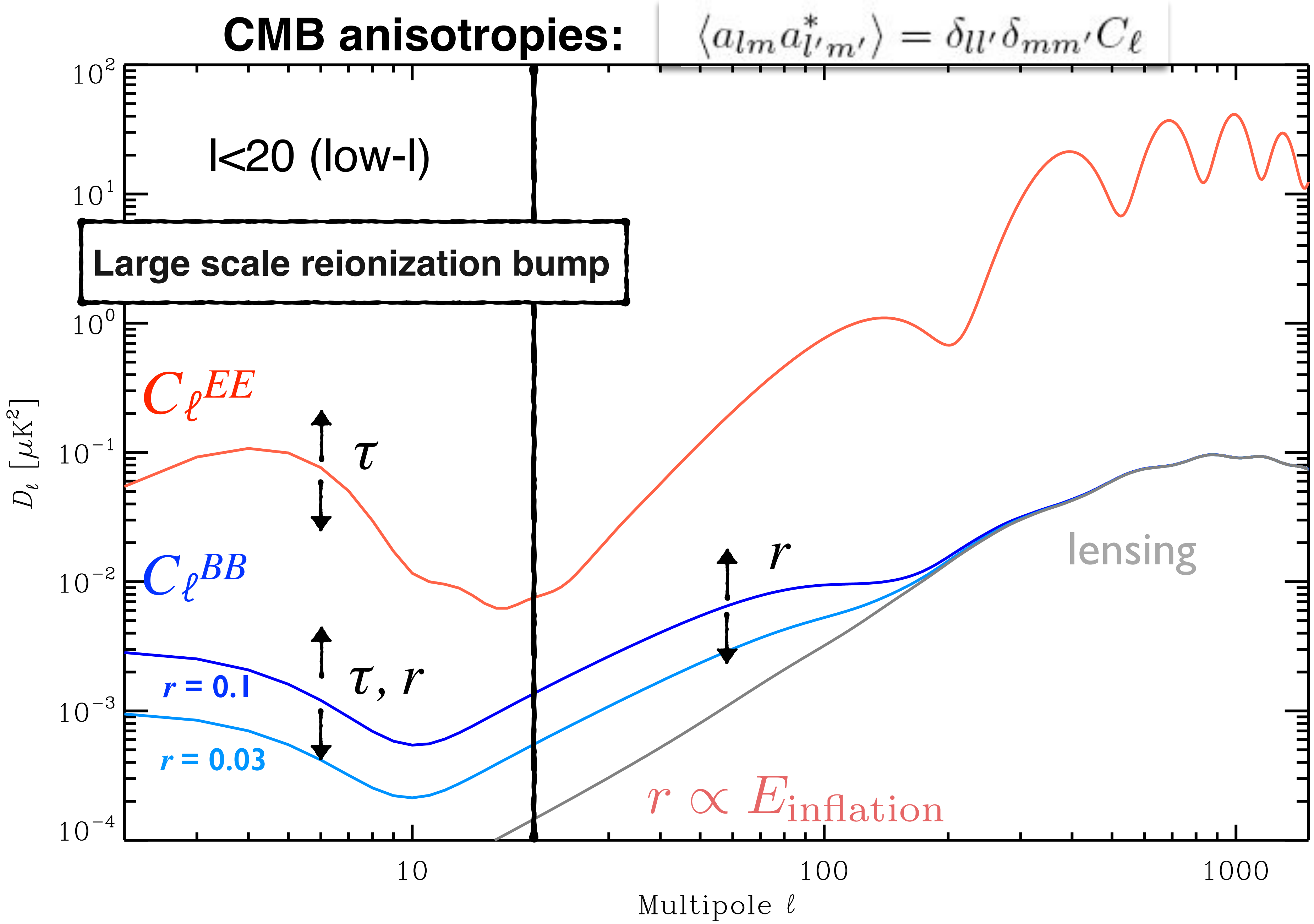
Thomson scattering optical depth:

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

$$x_e(z) \equiv n_e(z)/n_H(z)$$

Enhancement of the E&B modes at large angular scales: REIONIZATION BUMP

The CMB E & B angular power spectra



Scientific goals

Reionization history: C_ℓ^{EE} at large angular scales to constrain τ

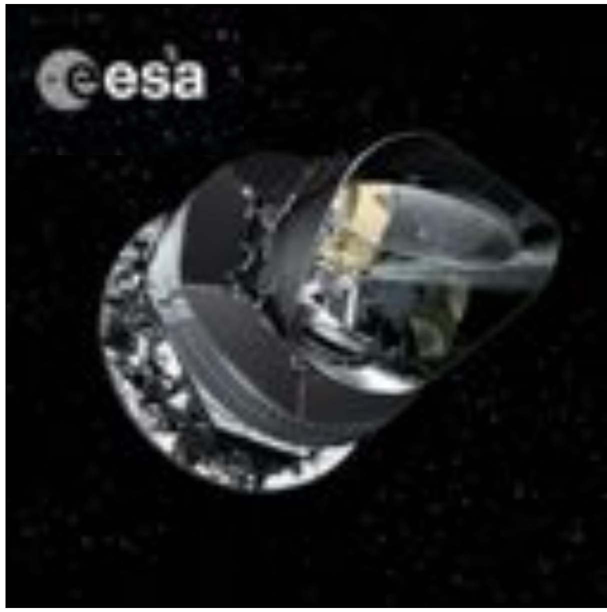
Inflation: C_ℓ^{BB} at large and intermediate scales to constrain r

OUTLINE

- The CMB polarization at large angular scales
- The challenge for Planck: systematics and statistics
- The new Planck HFI results

The Planck Coll. A&A 2016: "**Planck constraints on the reionization history**" (arxiv:1605.03507)
The Planck Coll. A&A 2016: "**Improved large angular scale polarization data**"(arxiv:1605.02985)

The Planck satellite



- ➡ 9 frequency bands (7 polarized: 30GHz-353GHz)
- ➡ Two instruments:

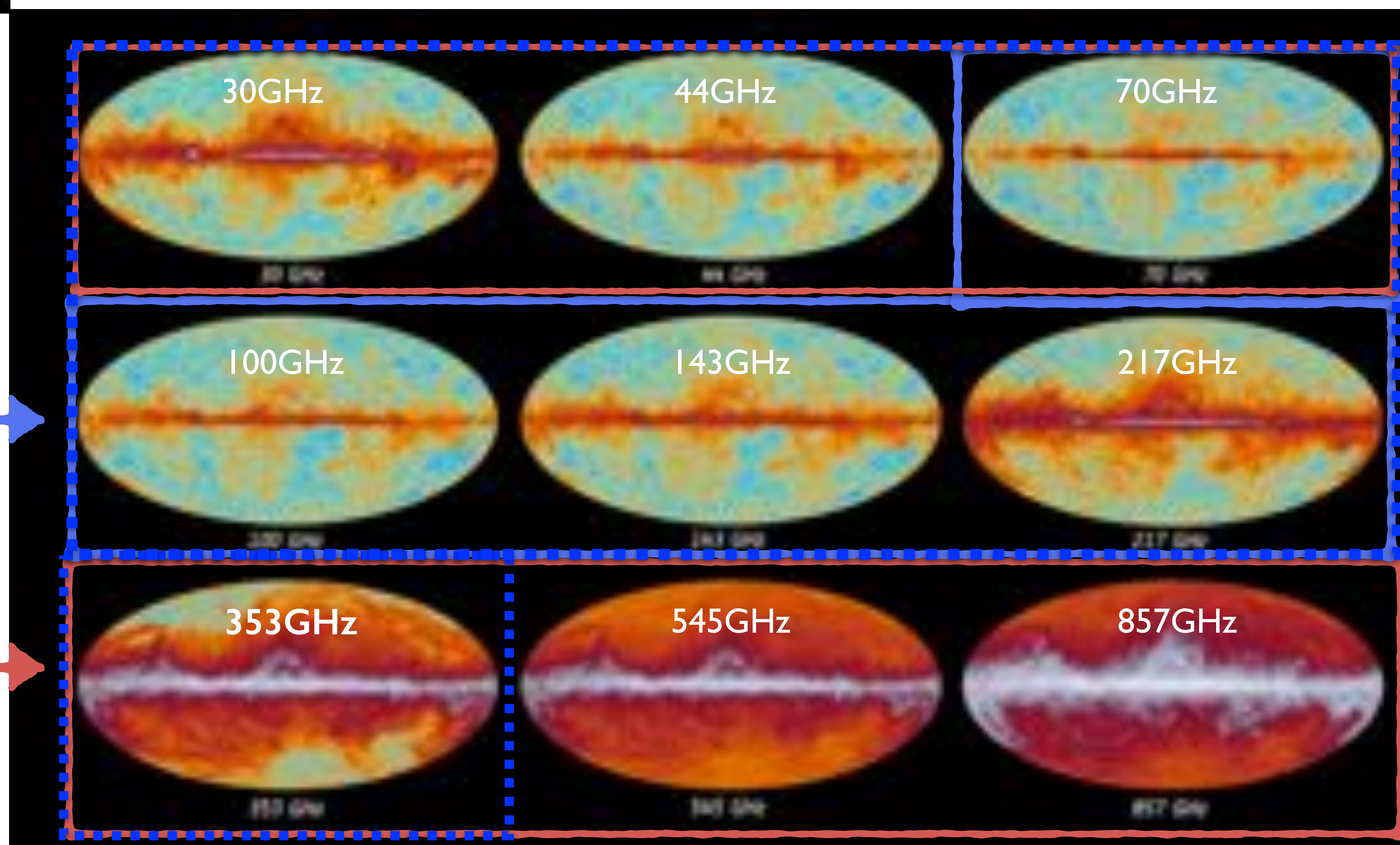
LFI: 30GHz, 44GHz, 70GHz

HFI: **100GHz, 143GHz,** 217GHz

353GHz, 545GHz, 857GHz

Channels for CMB characterization

Foregrounds characterization



planck

Large scale polarization issues

- Planck detectors are sensitive to one polarization direction

  Polarization reconstruction: detector combinations

- Mismatch between detectors will create spurious polarization signal

Major systematics in polarization at large angular scales:

Intensity to Polarization leakage

LFI: negligible residuals with respect to noise, **LFI 70GHz released**

HFI has higher sensitivity, lower noise: residuals systematics

HFI 100GHz, 143GHz, 217GHz NOT used for the 2015 low-l analysis

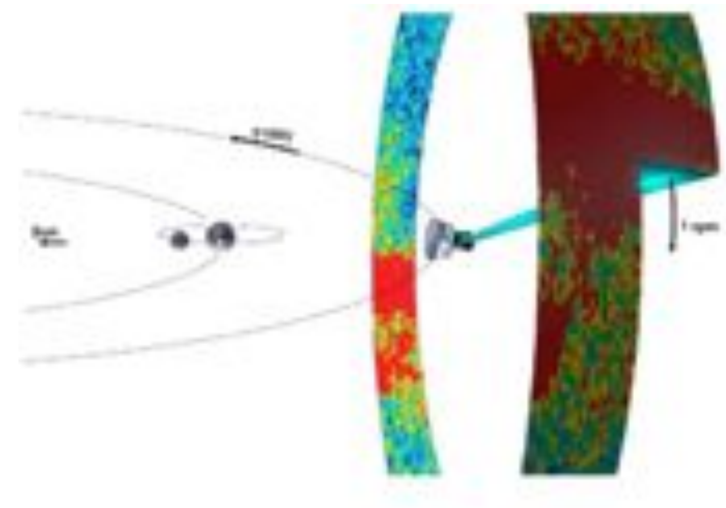
→ **NEW HFI results 2016**

The challenge I: control of systematics

Measuring the large scale polarization is difficult!

Major HFI systematic residuals:

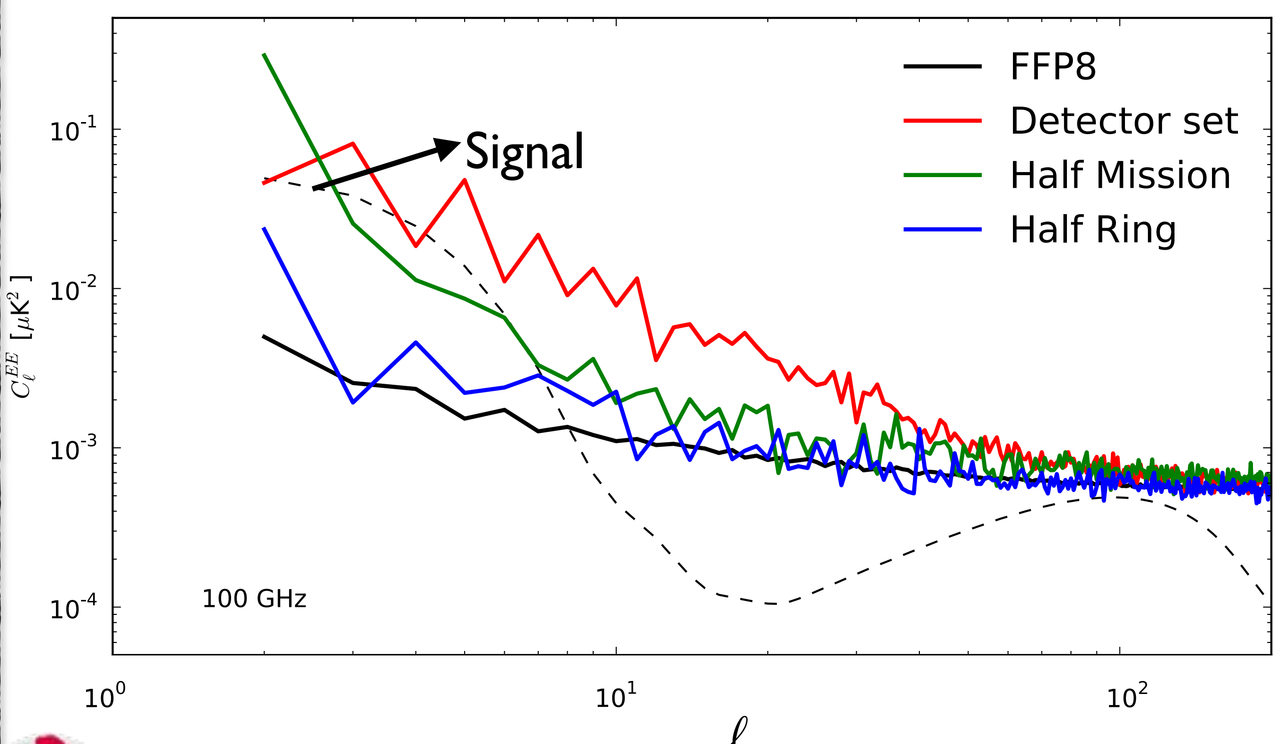
- inter-calibration leakage
- ADC non-linearity residuals
- correlated 1/f noise residuals
- foreground residuals



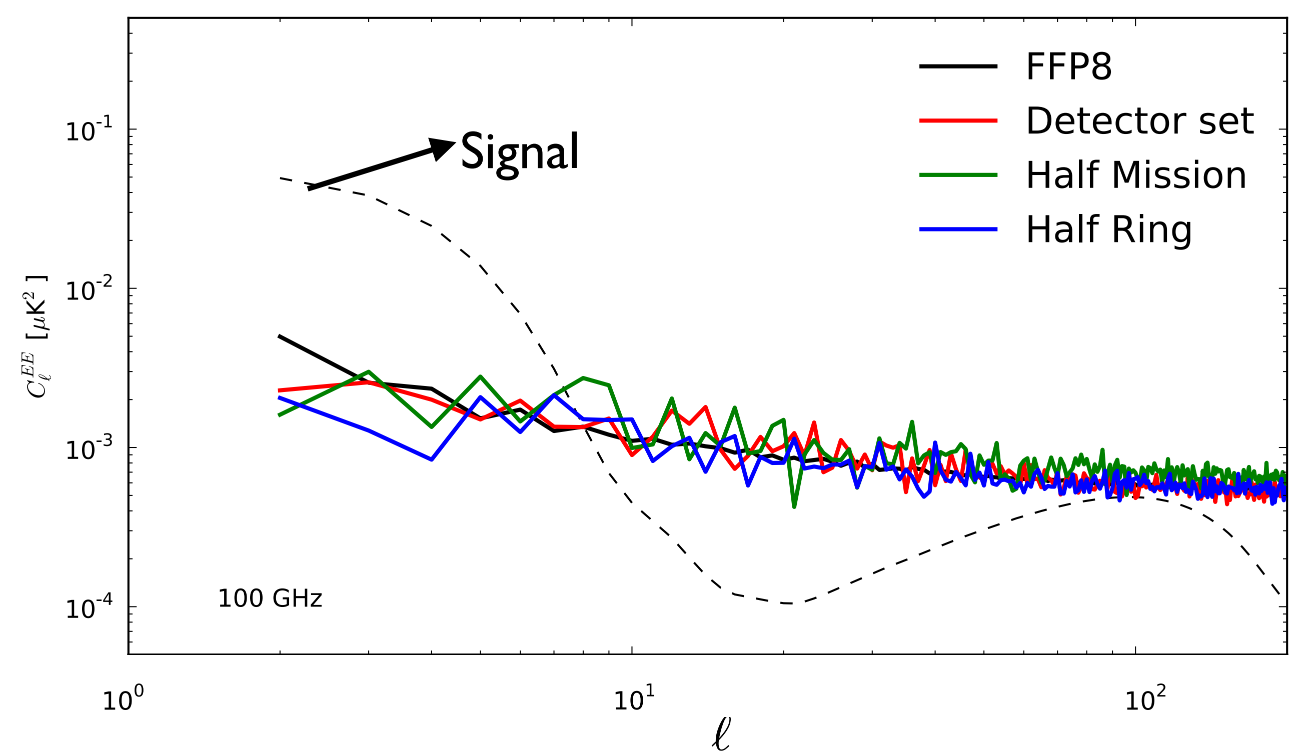
All these effects are important at low-l

E-Modes: noise&systematics

Planck-HFI 2015



Planck-HFI NEW



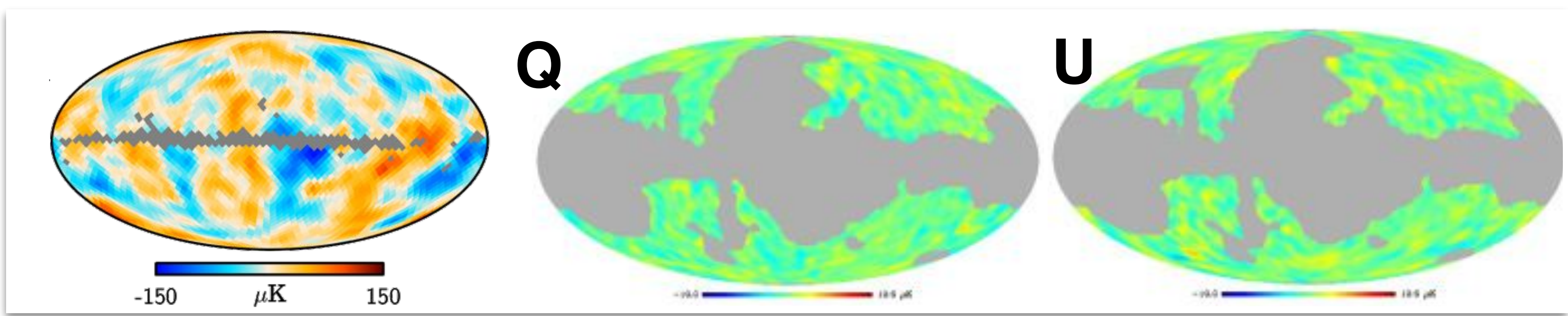
The challenge II: low-l data analysis

Statistical method(s) optimized to CMB analysis @ large angular scales

So far (WMAP, Planck 2013, 2015): Gaussian likelihood **in map space**

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

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 likelihood at large 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 likelihood at large scales

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

- **Modified Hamimeche&Lewis (2008) likelihood for cross-spectra (oHL)**

$$-2ln\mathscr{L}(C_\ell|\hat{C}_\ell^{A\times B}) = \sum_{\ell\ell'}[OX_g]_\ell^T[M_f^{-1}]_{\ell\ell'}[OX_g]_{\ell'}$$

- "Gaussianization"

$$g(x) = sign(x-1)\sqrt{(2(x-ln(x)-1))}, \qquad [X_g]_\ell = \mathrm{vecp}\left(\mathbf{C}_{fid}^{1/2}\mathbf{U}(\mathbf{g}[\mathbf{D}(\mathbf{P})])\mathbf{U}^\mathbf{T}\mathbf{C}_{fid}^{1/2}\right)$$

$$\mathbf{P} = \mathbf{C}_{mod}^{-1/2}\hat{\mathbf{C}}_{data}\mathbf{C}_{mod}^{-1/2}$$

"Offset" terms: $\propto N_{eff}$

$$\mathbf{C}_\ell^{A\times B} \rightarrow O(\mathbf{C}_\ell^{A\times B}) = \begin{pmatrix} C_\ell^{TT}+o_\ell^{TT} & C_\ell^{TE} & C_\ell^{TB} \\ C_\ell^{TE} & C_\ell^{EE}+o_\ell^{EE} & C_\ell^{EB} \\ C_\ell^{TB} & C_\ell^{EB} & C_\ell^{BB}+o_\ell^{BB} \end{pmatrix}$$

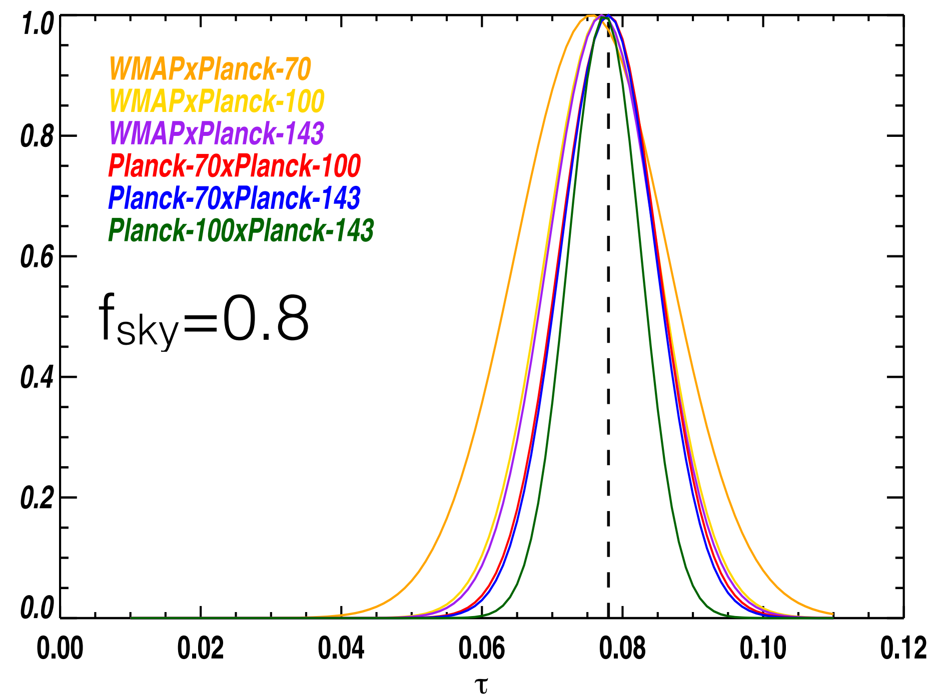
Full temperature and polarization analysis

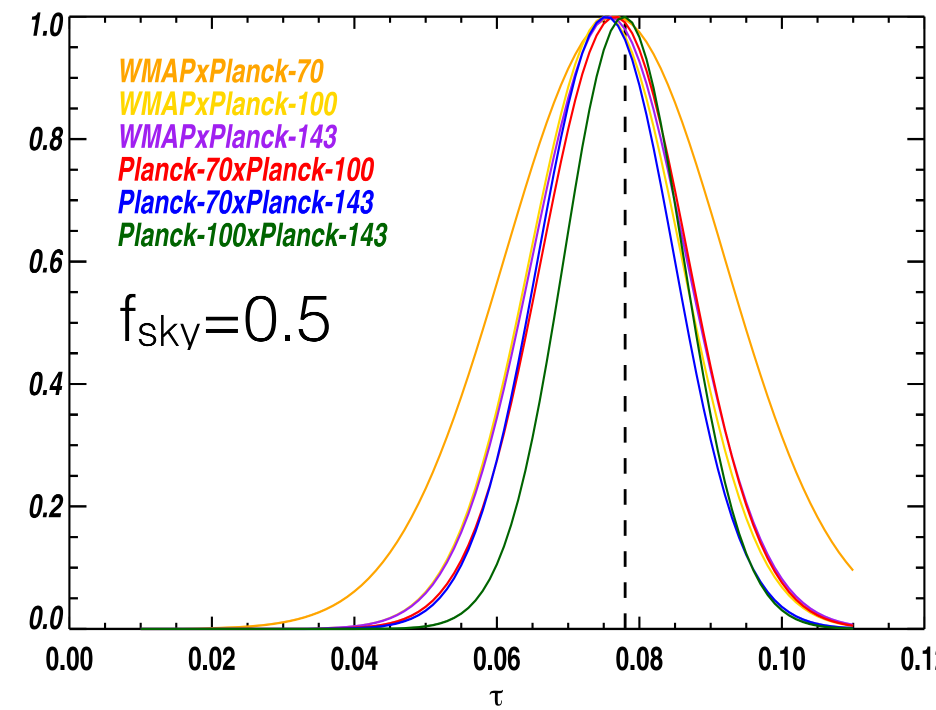
Cross-spectra oHL: τ estimation

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

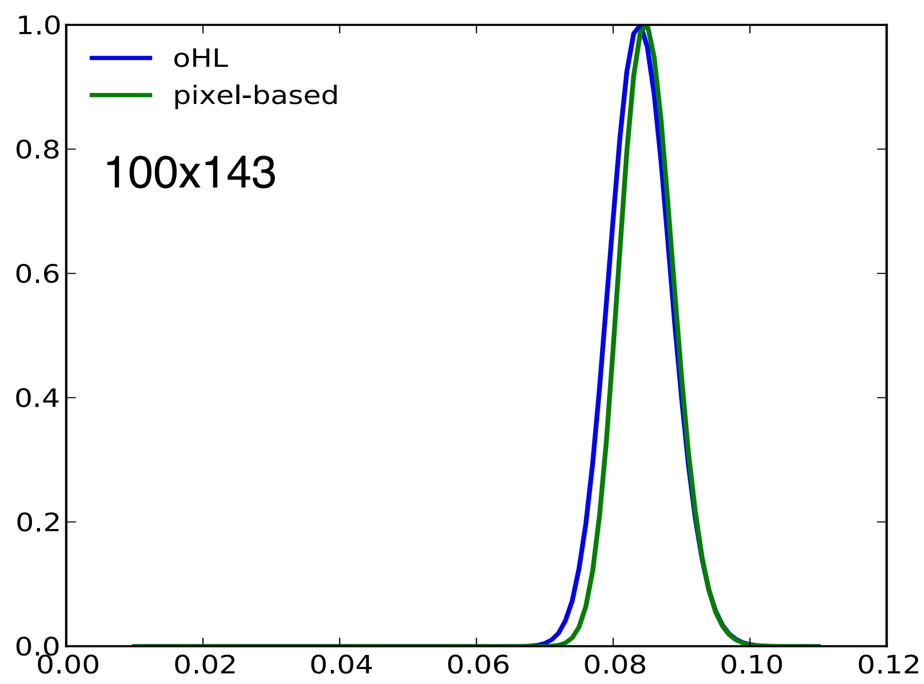
τ posterior from realistic MC simulations, different noise levels, l=[2,20]

Unbiasedness





Optimality



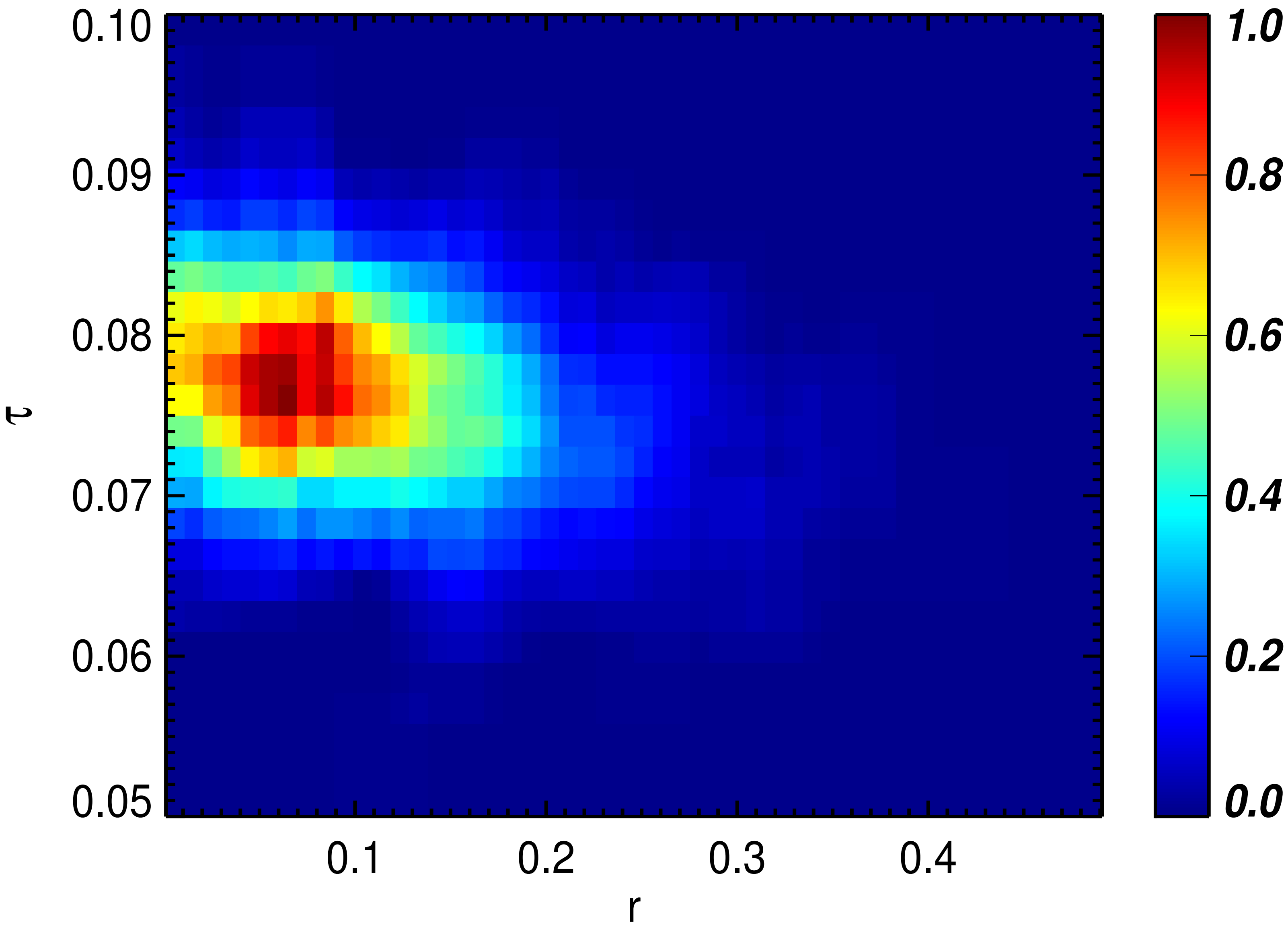
Best constraints expected from HFI 100GHzx143GHz

Comparison with the pixel-based approach: compatible error bars estimation at better than 10%

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



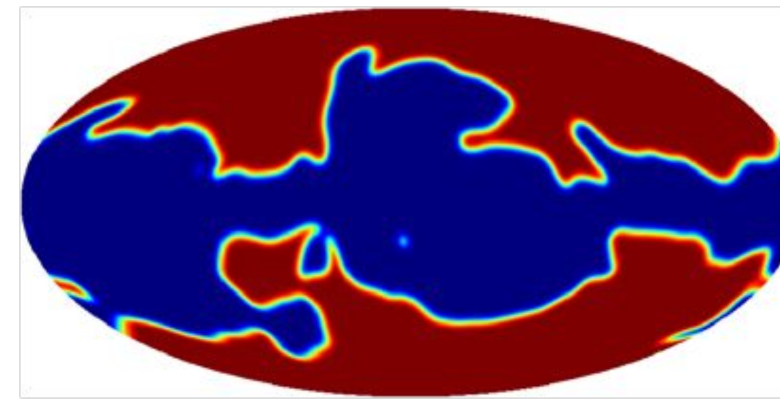
OUTLINE

- **The CMB polarization at large angular scales**
- **The challenge for Planck: systematics and statistics**
- **The new Planck HFI results**

The Planck Coll. A&A 2016: “**Planck constraints on the reionization history**” (arxiv:1605.03507)
The Planck Coll. A&A 2016: “**Improved large angular scale polarization data**”(arxiv:1605.02985)

The new Planck-HFI results

- Large scale Polarization l=[4-20] + l_{min}=2,3
- E-modes 100GHzx143GHz cross spectra (PCL, Xpol)
- Sky fraction: 50% + validation 60%
- Polarization foreground cleaning



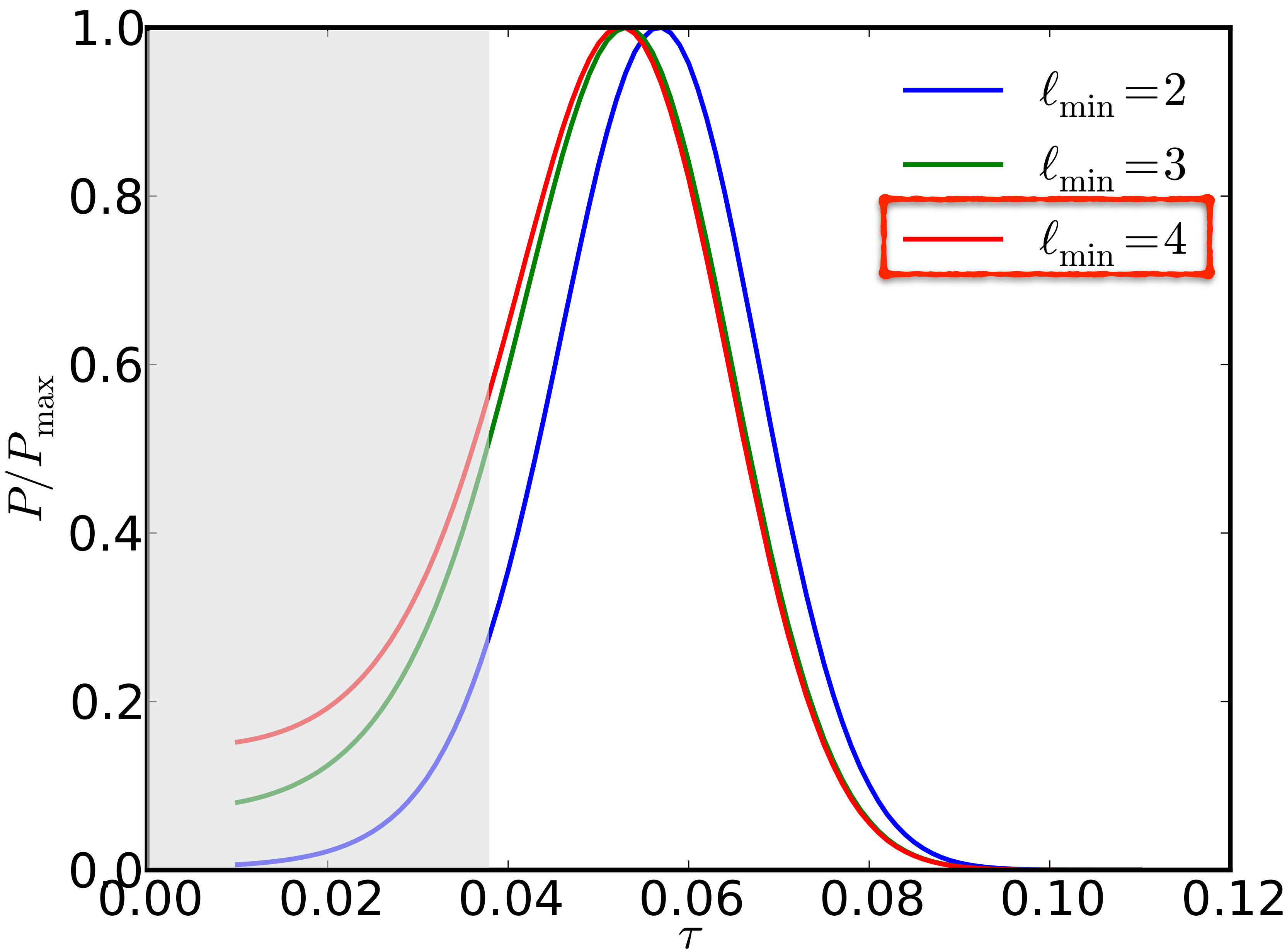
Planck frequencies corrected for polarization leakage:

- 30GHz for polarized synchrotron
- 353GHz for polarized dust

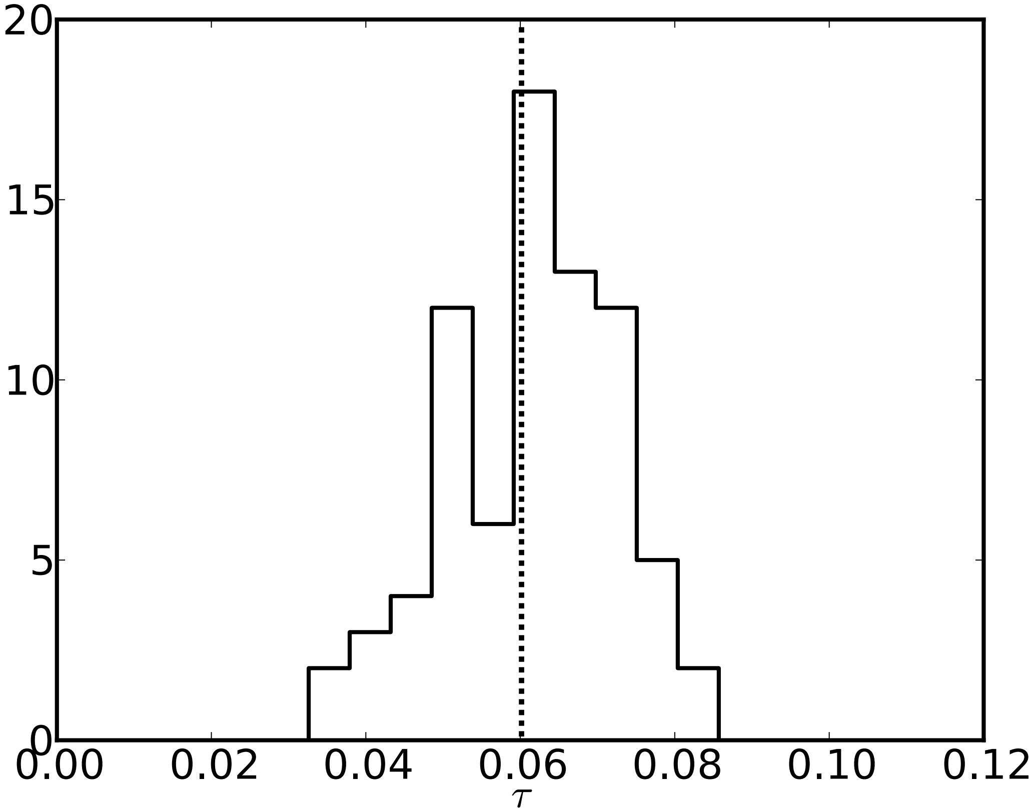
- Cross-spectra based likelihood analysis oHL (Mangilli et al. MNRAS 2015)

Planck HFI 100GHzx143GHz E-modes at low-l: first τ constraint from CMB polarization data alone

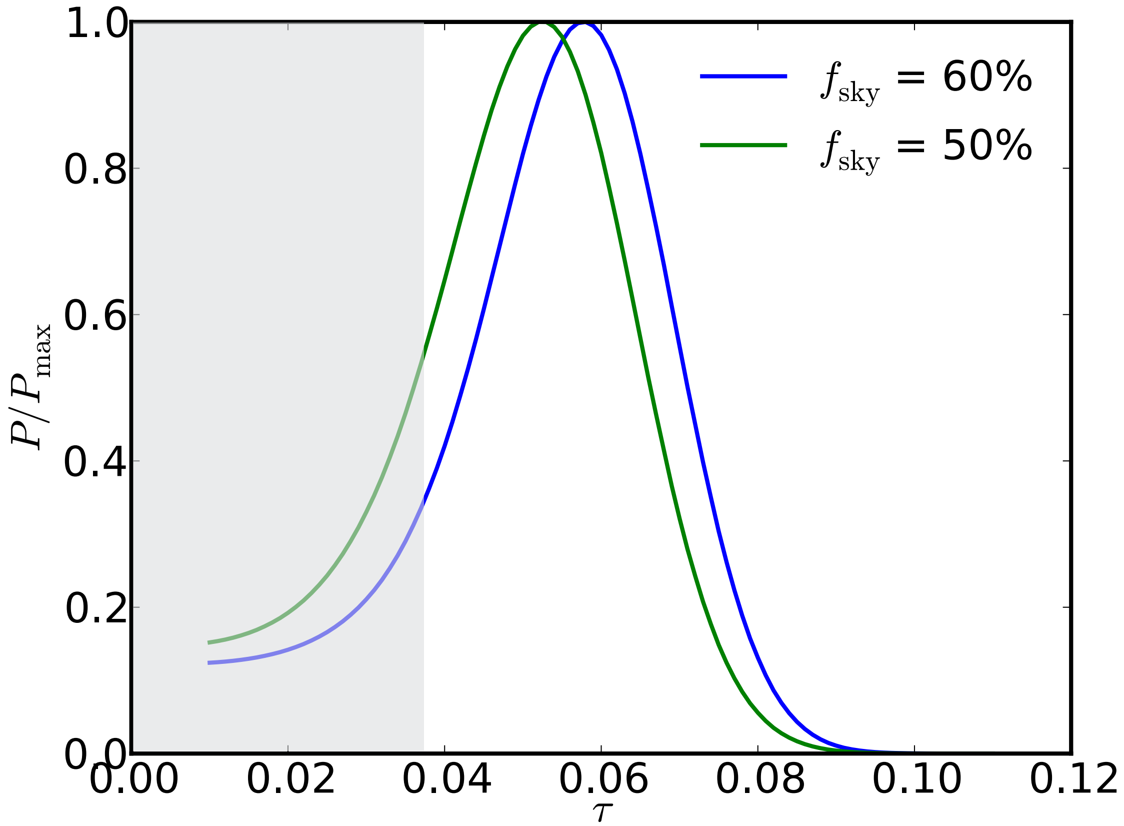
$$\tau = 0.053^{+0.014}_{-0.016}$$



planck



End-to-end simulations

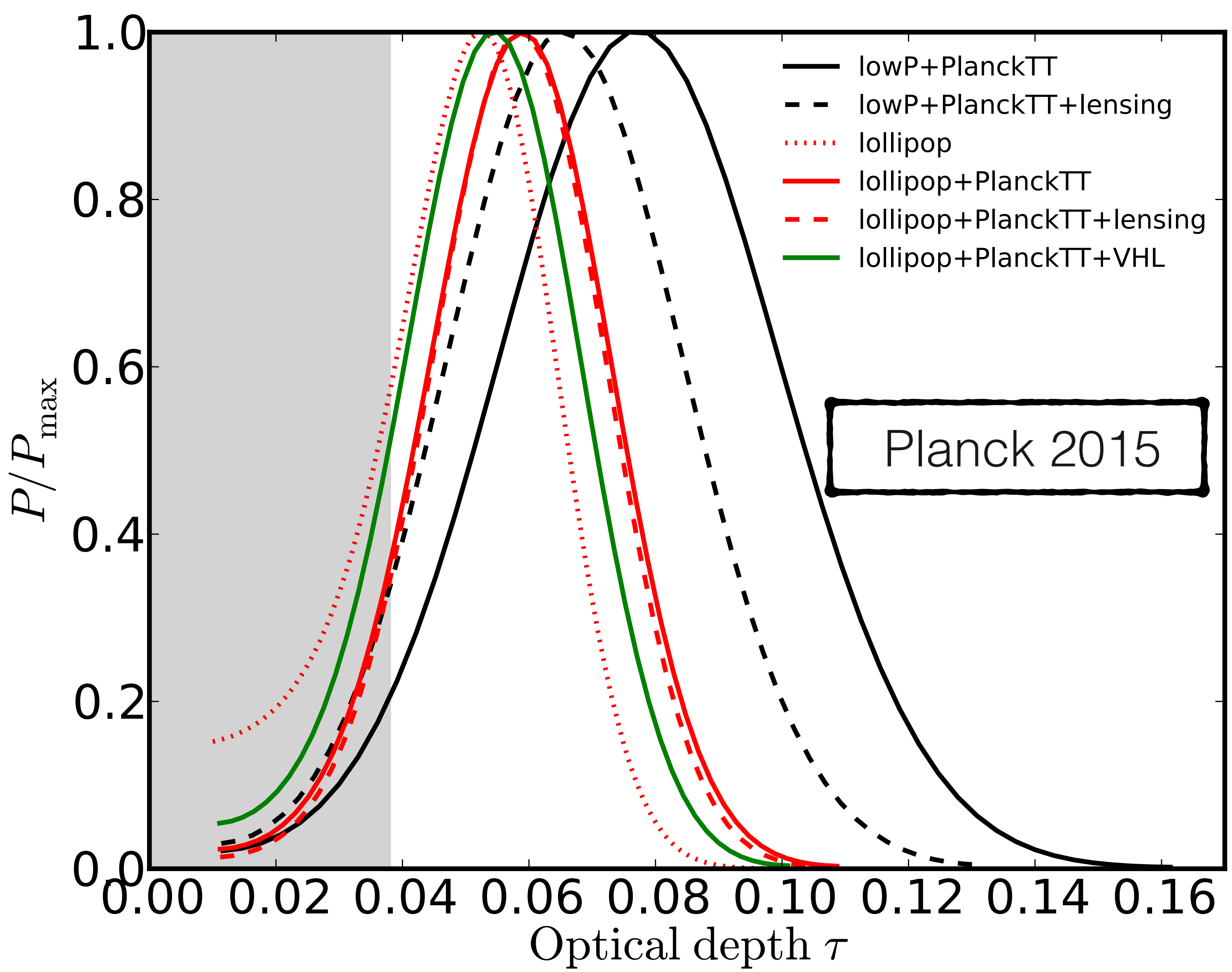


Sky fraction

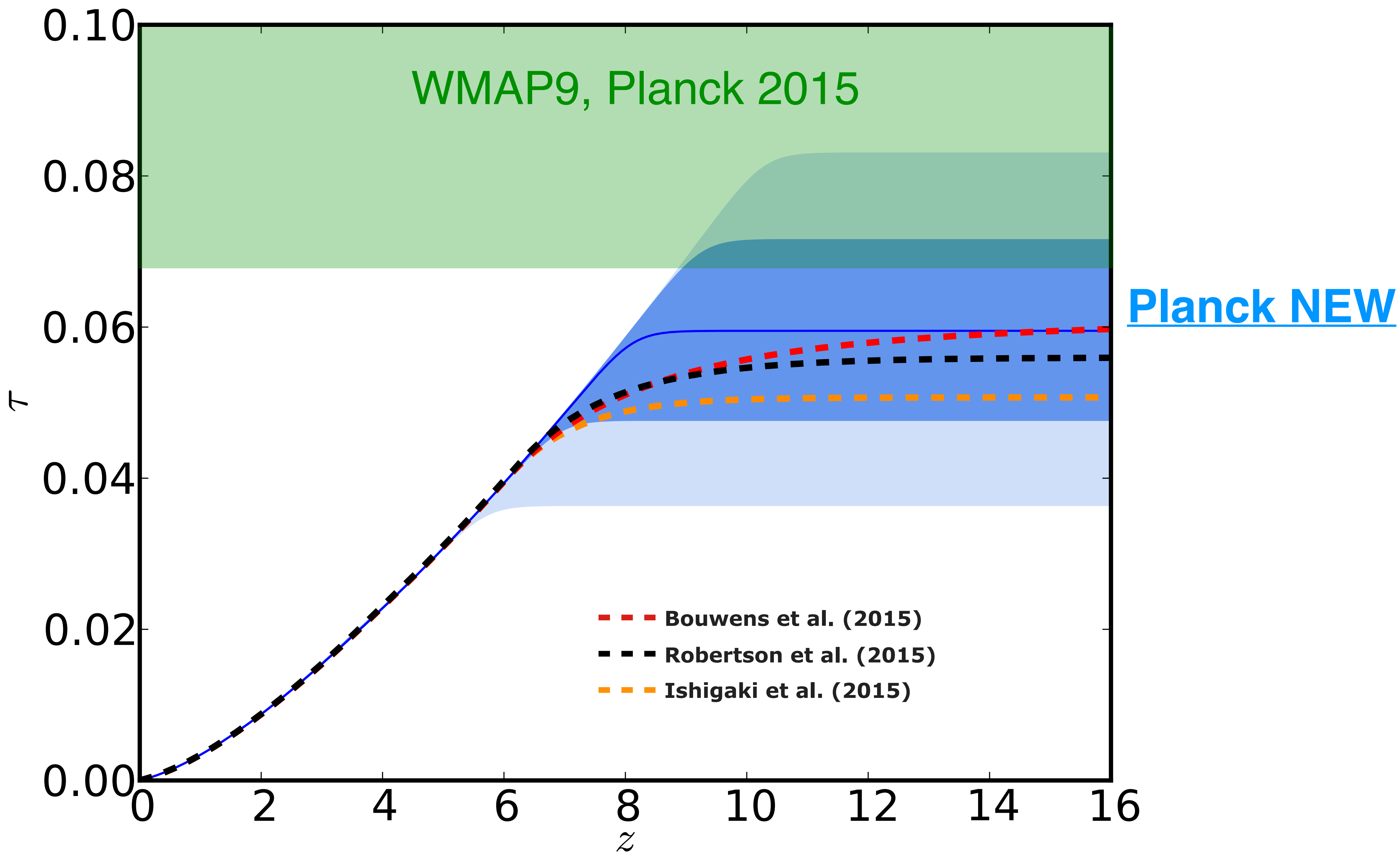
Planck low-l polarization + other data

Combination of low-l HFI with:

1. **+Planck TT/lensing** (2015) New $\tau = 0.058^{+0.011}_{-0.012}$
2. **+Very High-l** ground-based experiments (ACT & SPT)

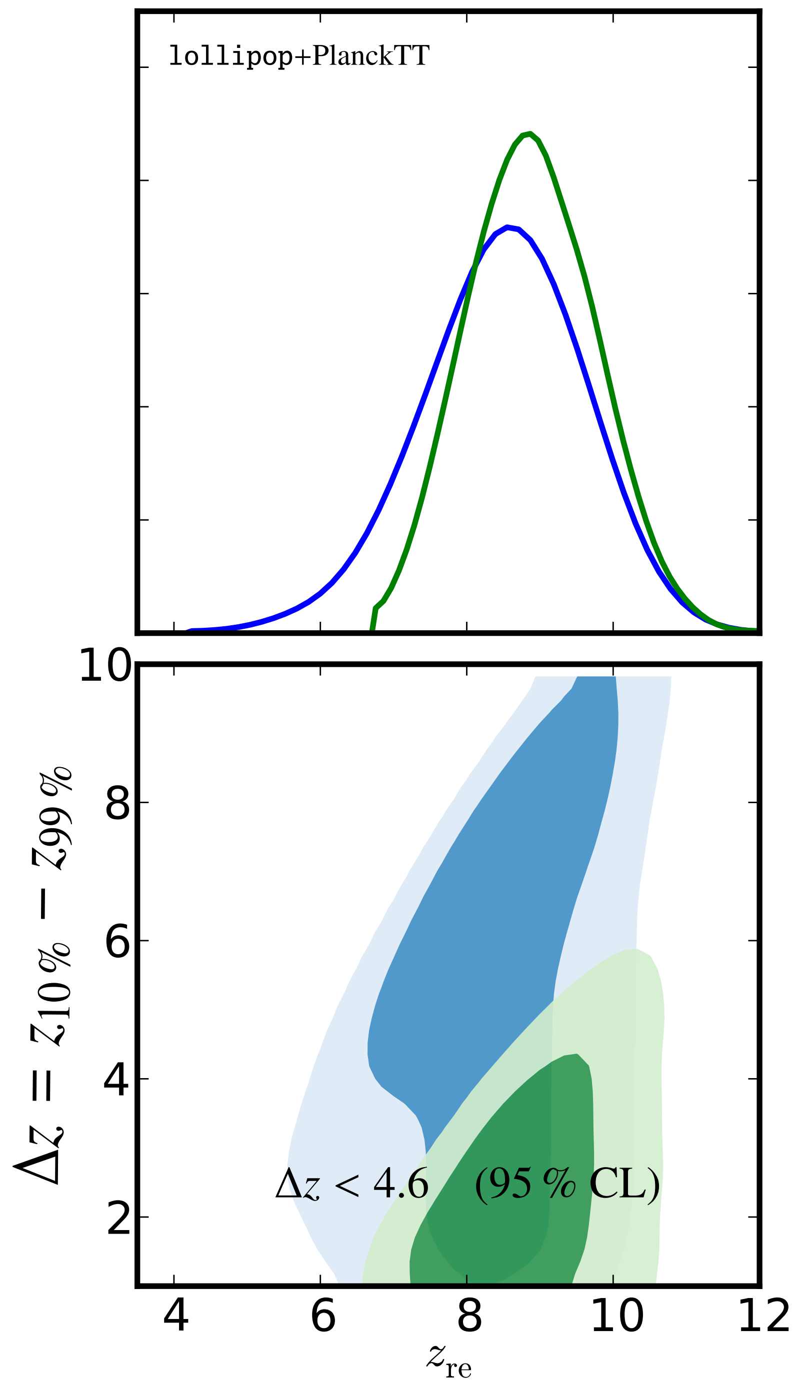


Better agreement with astrophysical data

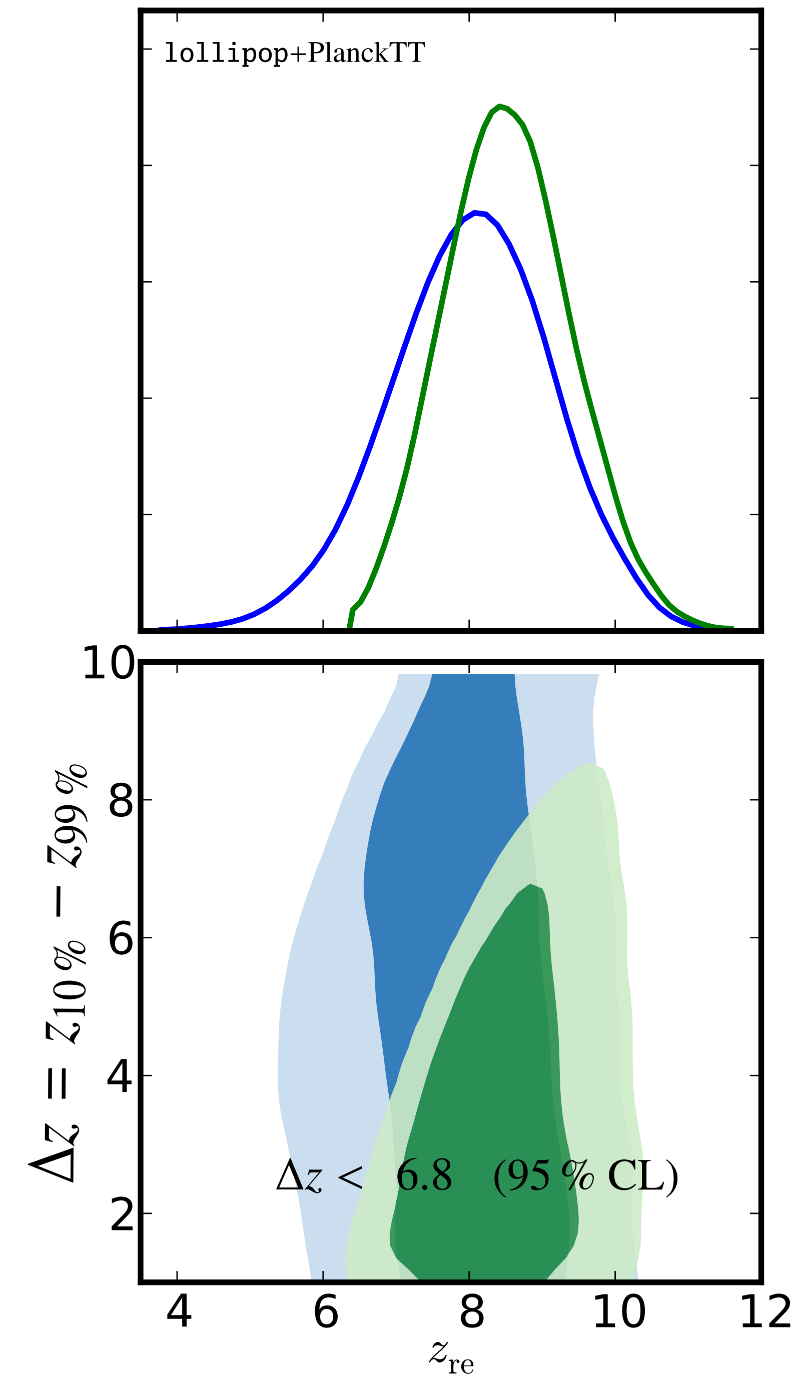


EoR: z_{re} and duration

$z_{\rm re} = 8.8^{+0.9}_{-0.9}$



$z_{\rm re} = 8.5^{+0.9}_{-0.9}$



Symmetric model:

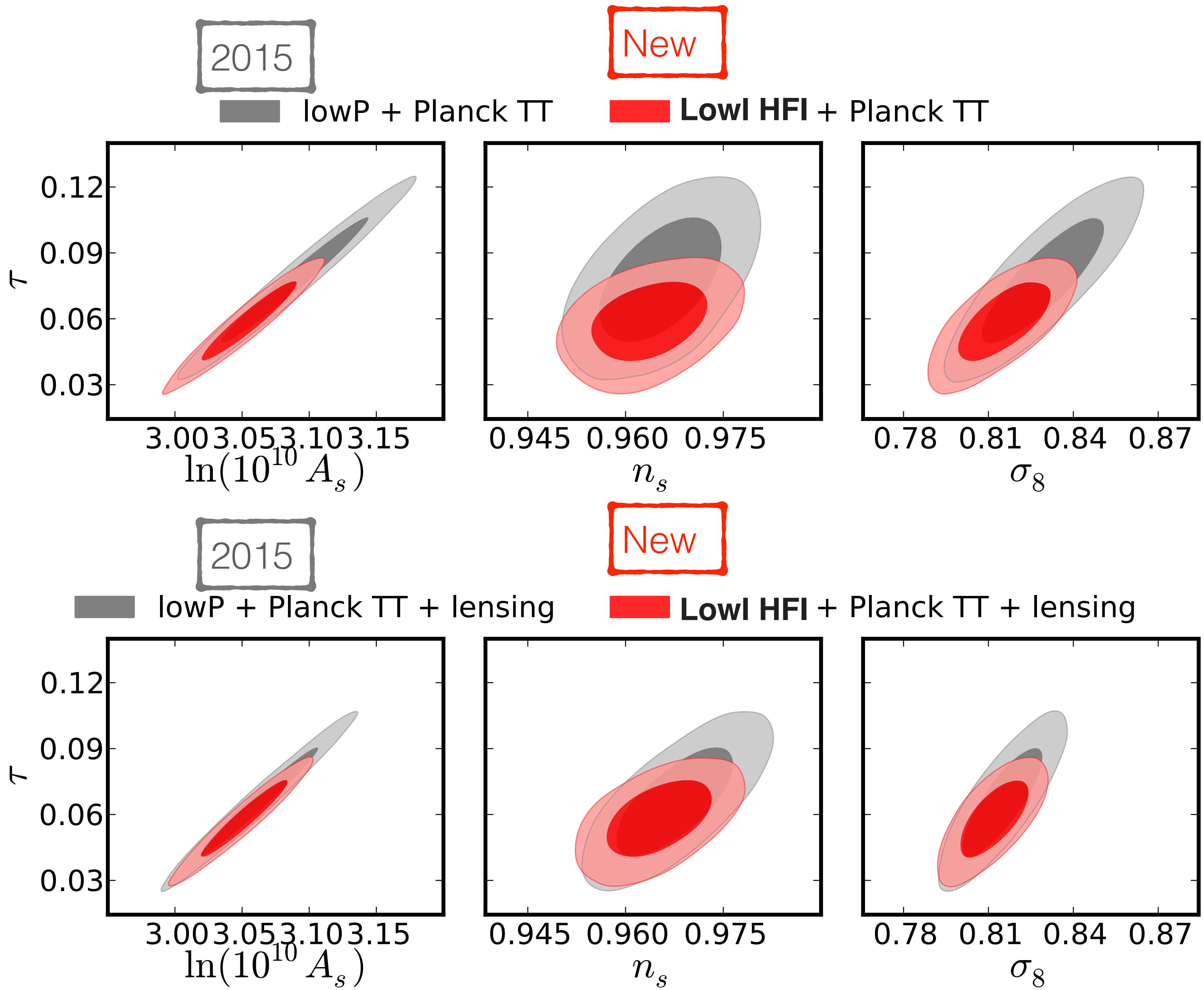
$$x_{\rm e}(z) = \frac{f}{2}\left[1 + \tanh\left(\frac{y - y_{\rm re}}{\delta y}\right)\right] \qquad y = (1+z)^{3/2}, \quad \delta y = \frac{3}{2}(1+z)^{1/2}\delta z$$

Asymmetric model:

$$x_{\rm e}(z) = \begin{cases} f & \text{for } z < z_{\rm end}, \\ f\left(\frac{z_{\rm early} - z}{z_{\rm early} - z_{\rm end}}\right)^{\alpha} & \text{for } z > z_{\rm end}. \end{cases} \qquad z_{\rm early} = 20,$$

planck

Improved and lower τ: impact on parameters



planck

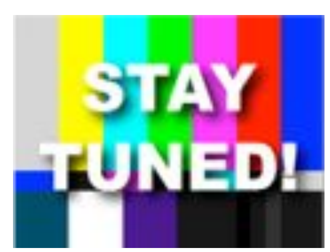
Conclusions

planck

$$\tau = 0.058^{+0.011}_{-0.012} \qquad z_{re} = 8.8^{+0.9}_{-0.9} \qquad \Delta z < 4.6 \quad (95\,\%\ \mathrm{CL})$$

- A **significantly lower value for the reionization optical depth:**
  - is consistent with a fully reionized Universe at z ~ 6
  - is in better **agreement with recent astrophysical constraints**
  - **disfavors** high-z reionization tail and complicated reionization histories
  - makes the **quest of B-modes at low-l more challenging**
- **Improved τ constraint:** tighter constraints on cosmological parameters A_s, n_s, σ_8, Σm_ν

The Planck Coll. A&A 2016: "**Planck constraints on the reionization history**" (arxiv:1605.03507)
The Planck Coll. A&A 2016: "**Improved large angular scale polarization data**"(arxiv:1605.02985)



What's next:

- Further Planck data improvement at map-making level on going
- Primordial B-modes at low-ell:
  - improved S/N, lensing is not a contaminant
  - full sky needed: future CMB satellites (PIXIE, LiteBIRD, M5, ?)

Thank you!