Planck
&
The Epoch of Reionization

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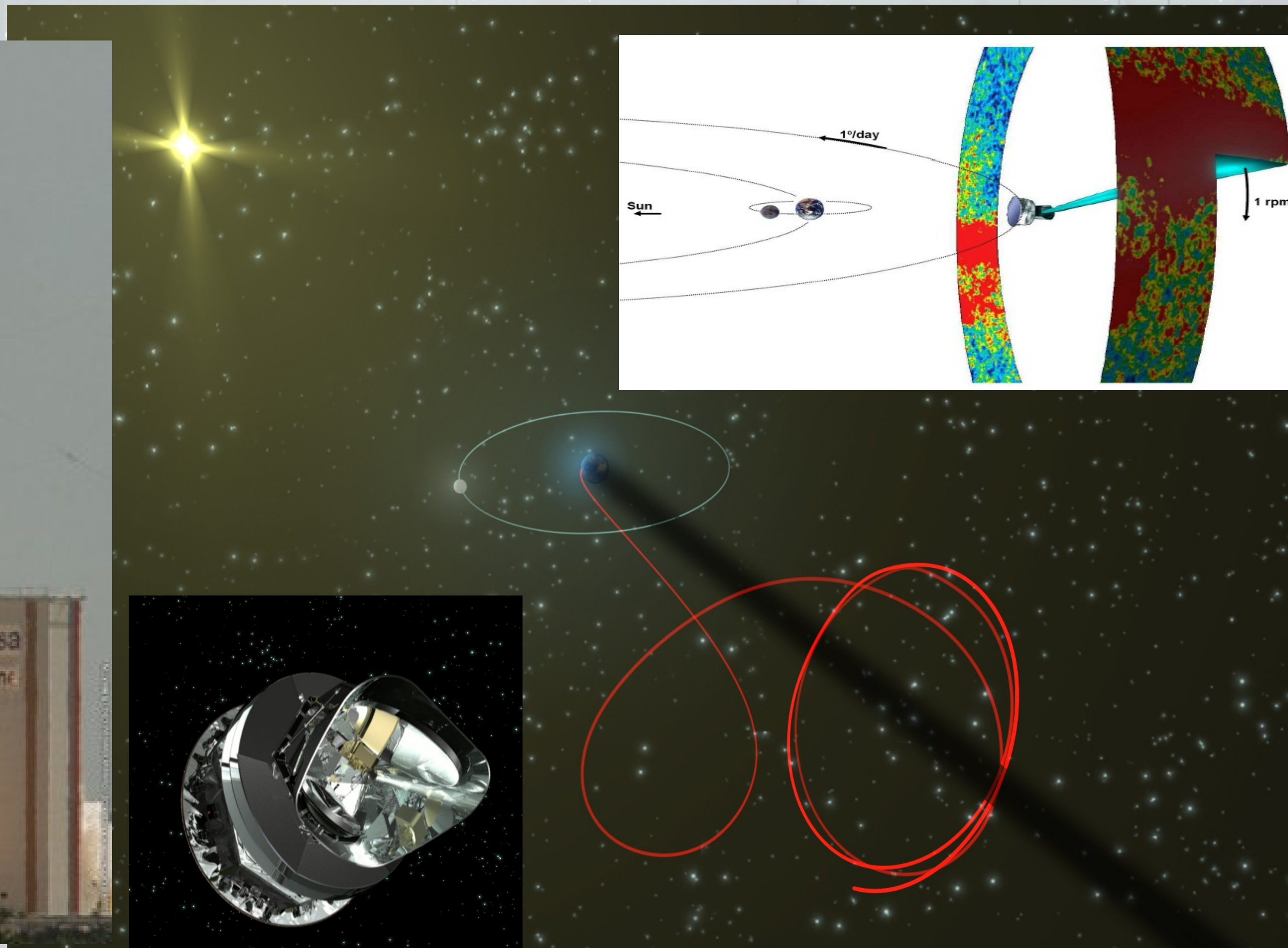
Outline

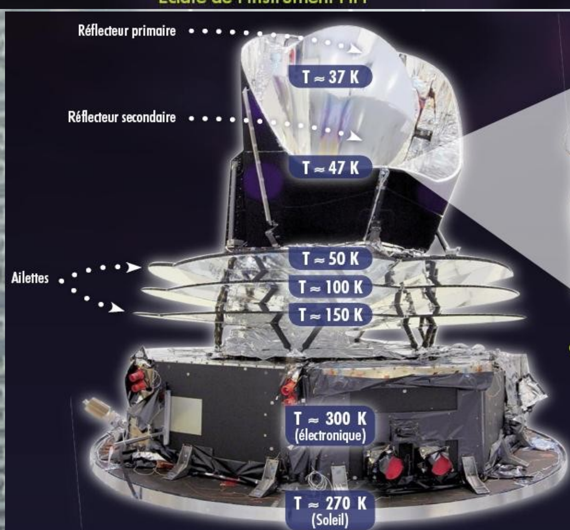
- Planck status
- Planck and EOR
- EOR with Planck and 21cm

Planck Status

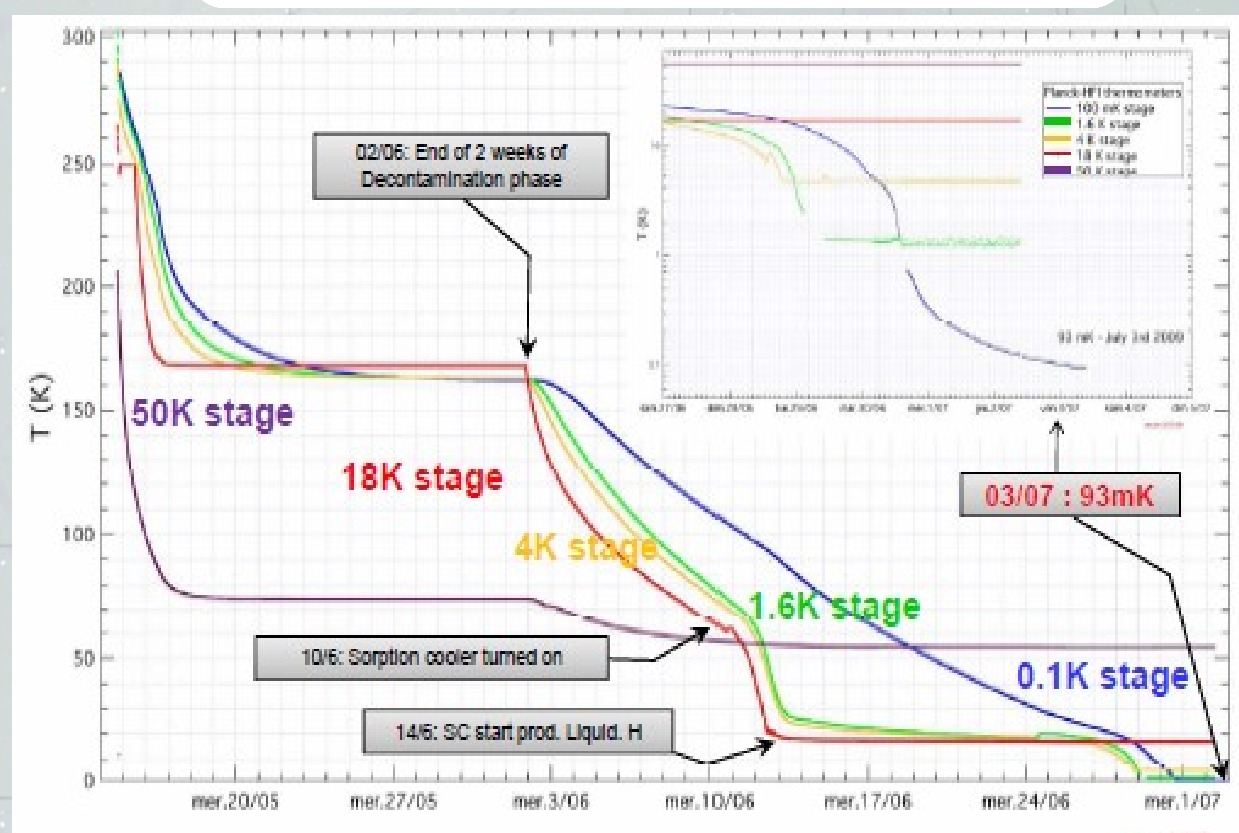
14 May 2009



Planck Status

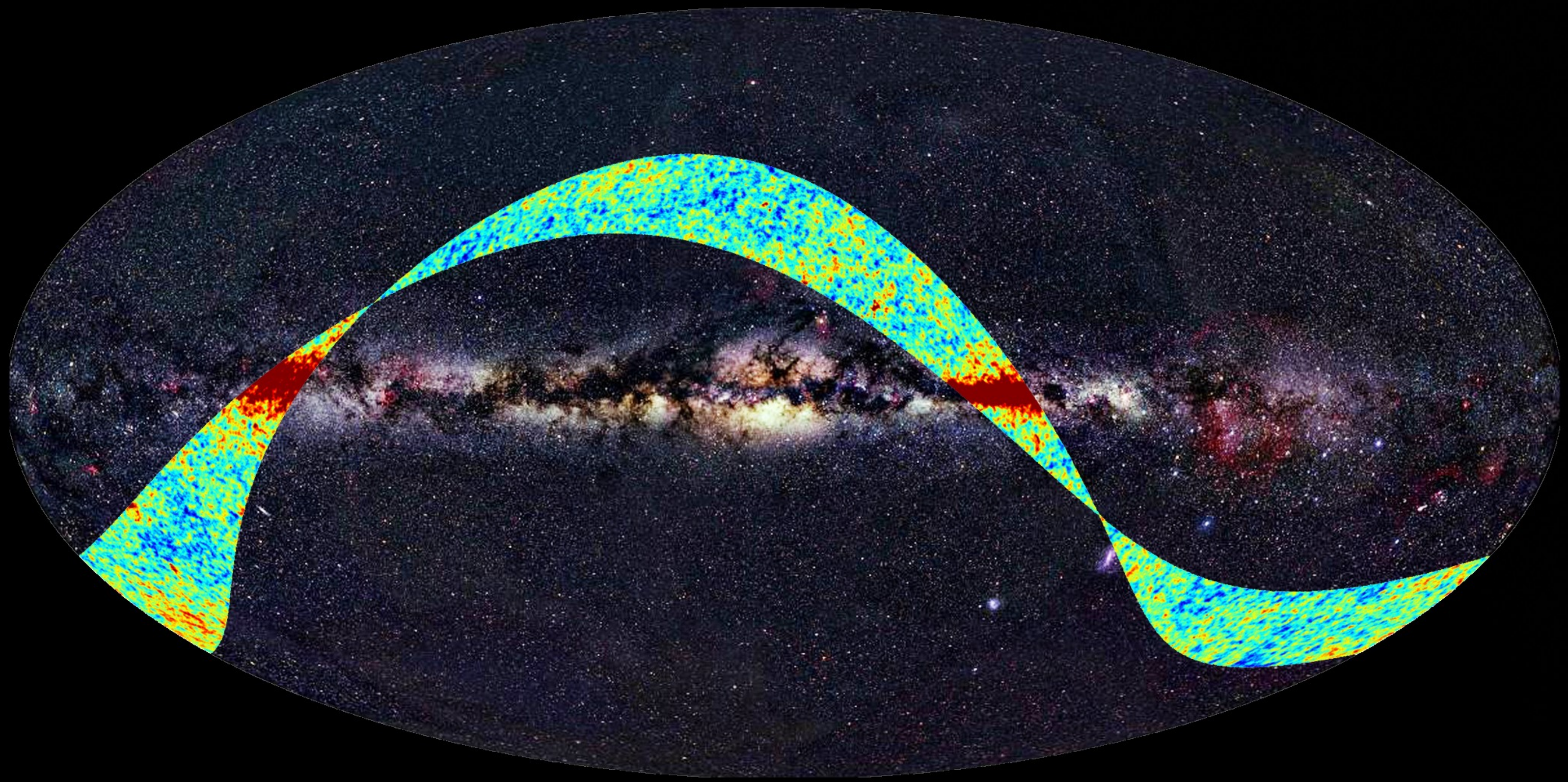


- All stages are very stable
- Sensitivity is as expected



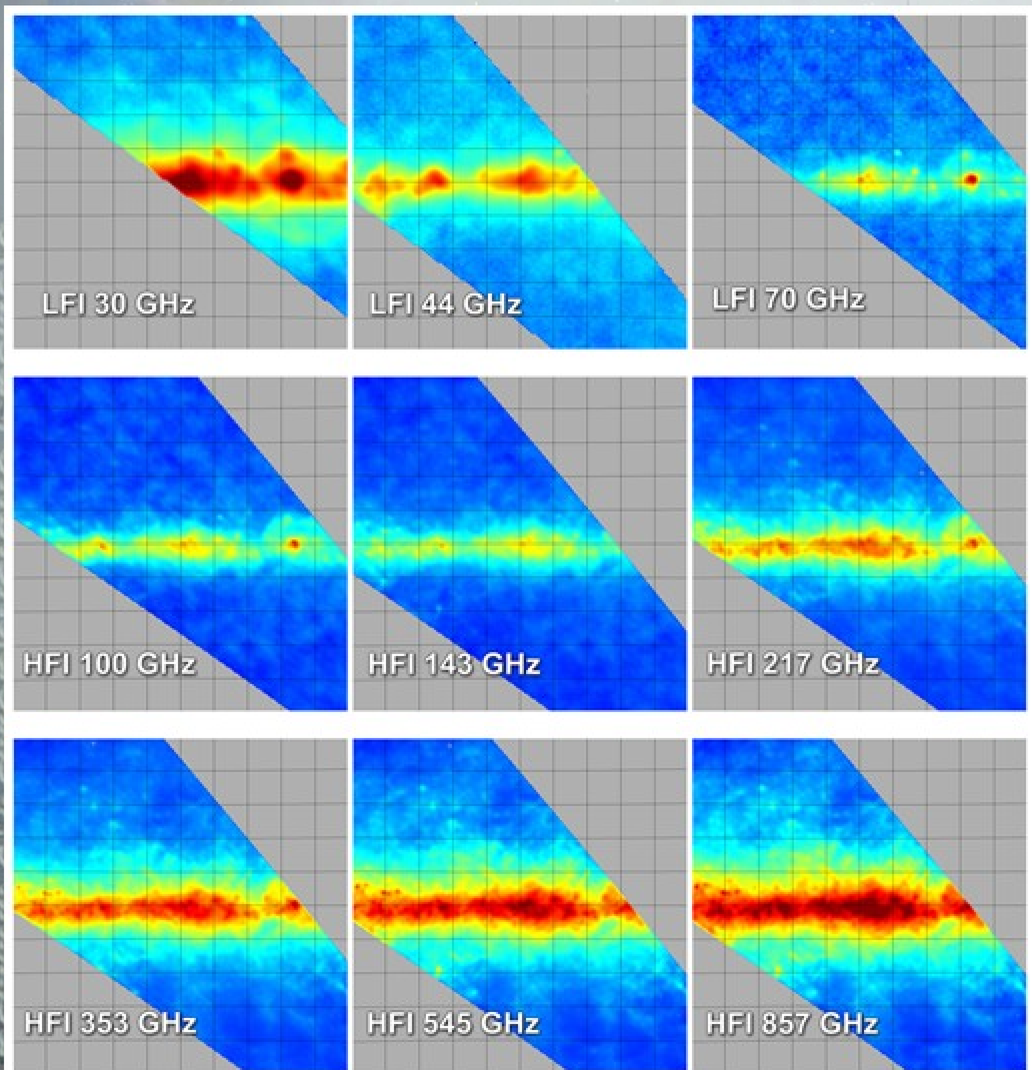
Planck first light

- From August 11th to 26th : First Light Survey
- From August 26th: Survey routine mode

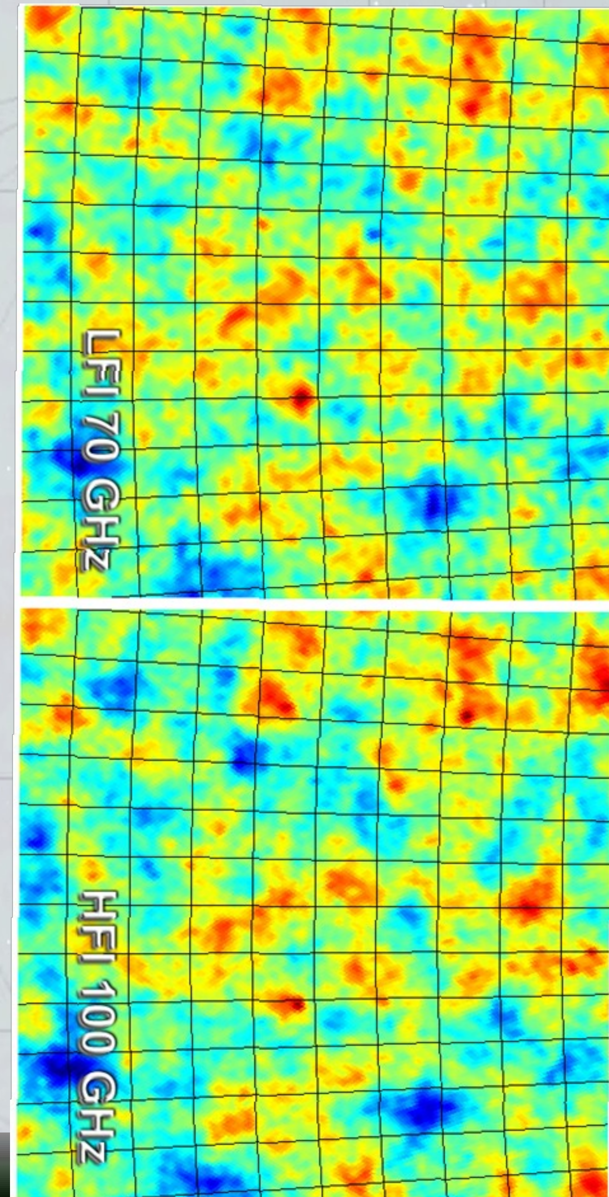


Press release, ESA/HFI/LFI 17/09/2009 (credit:ESA, LFI&HFI consortium (Planck) Background image: Axel Mellinger)

Planck first light

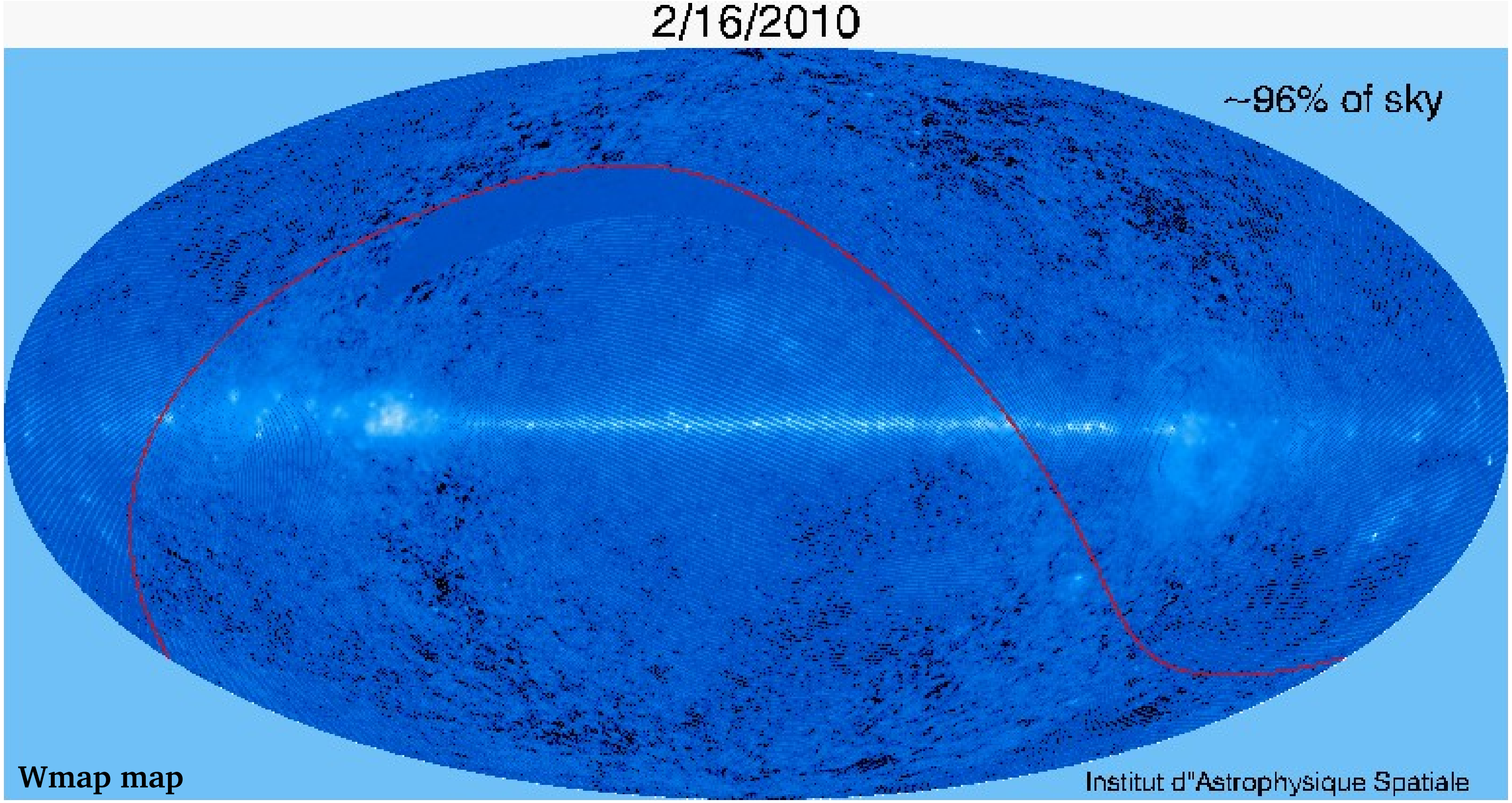


Press release, ESA/HFI/LFI 17/09/200



Planck Status

From of August 26th : Survey routine mode
Today : end of the First Survey (96% of the sky) / 5 possible



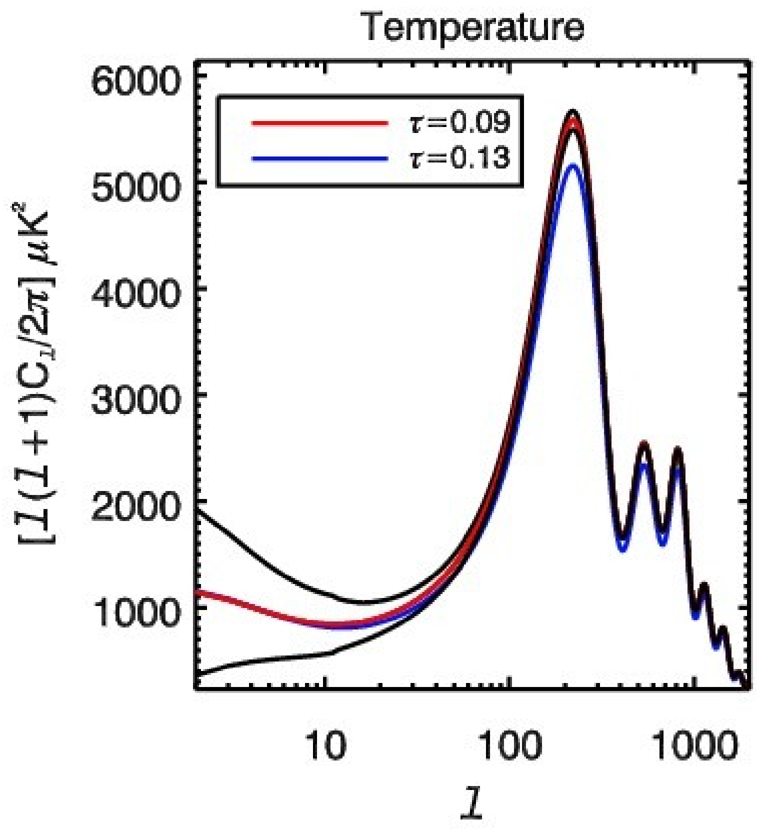
Planck and EOR

- In CMB studies:
  - instantaneous reionisation usually assumed
  - reionisation effects often summarised with one parameter τ : optical depth

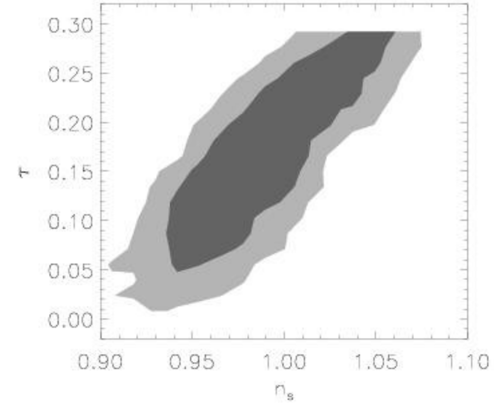
- 2 main effects
  - Damping small scales in Temperature
  - Bump and damping in Polarisation

- Other weak small scales effects

Planck and EOR (T)



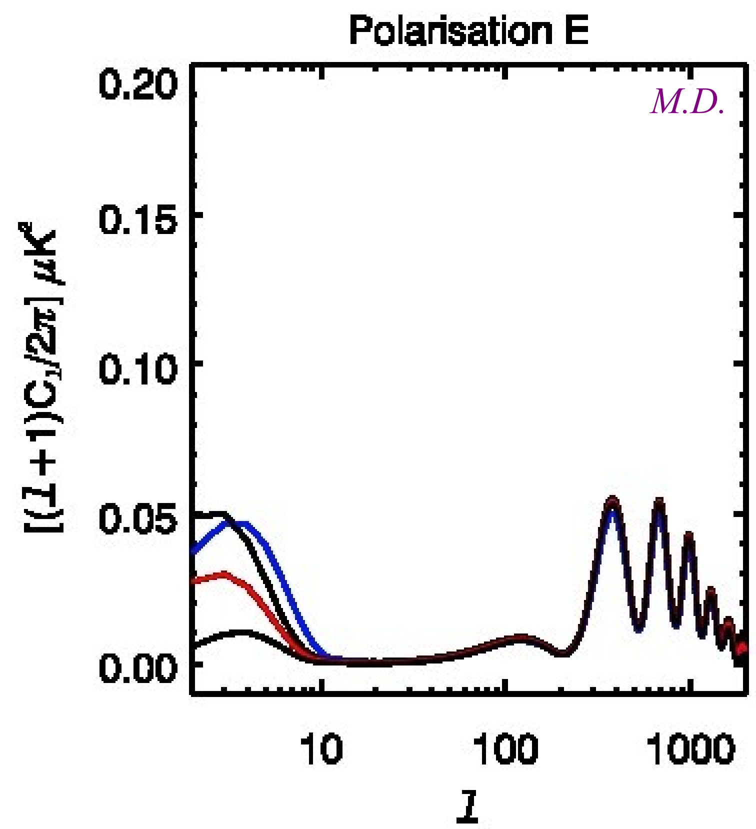
- Damping by exp(-2 τ)



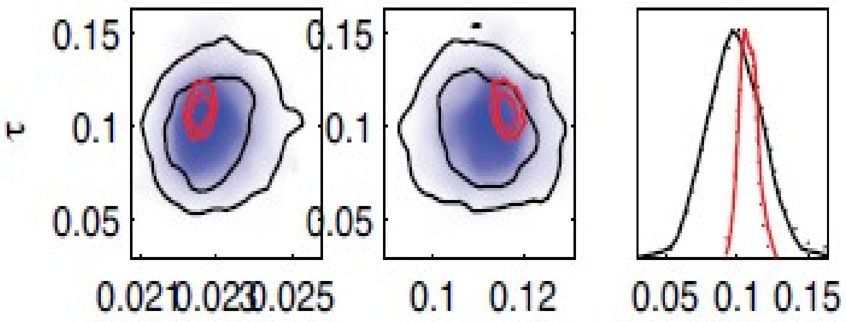
Spergel et al. 2003 WMAP 1

- Degeneracies with ns & $\Omega_b h^2$ if T only

Planck and EOR (P)



- **Break degeneracies on τ**



Planck BlueBook

- **Extra information from shape of bump on history of reionization**

(Kaplinghat et al 03, Hu & Holder 03)

Planck and EOR

- More info than τ is maybe available
  - Reconstruction of the ionisation fraction x_e
  - Reconstruction of the visibility function

$$\tau(z) = \sigma_T c \int_{t(z)}^{t_0} n_e(t)dt$$

$$= 0.88\sigma_T c n_b(0) \int_0^z \frac{(1+z)}{H(z)} x_e(z)dz$$

$x_e(z) =$ Fraction of free electrons

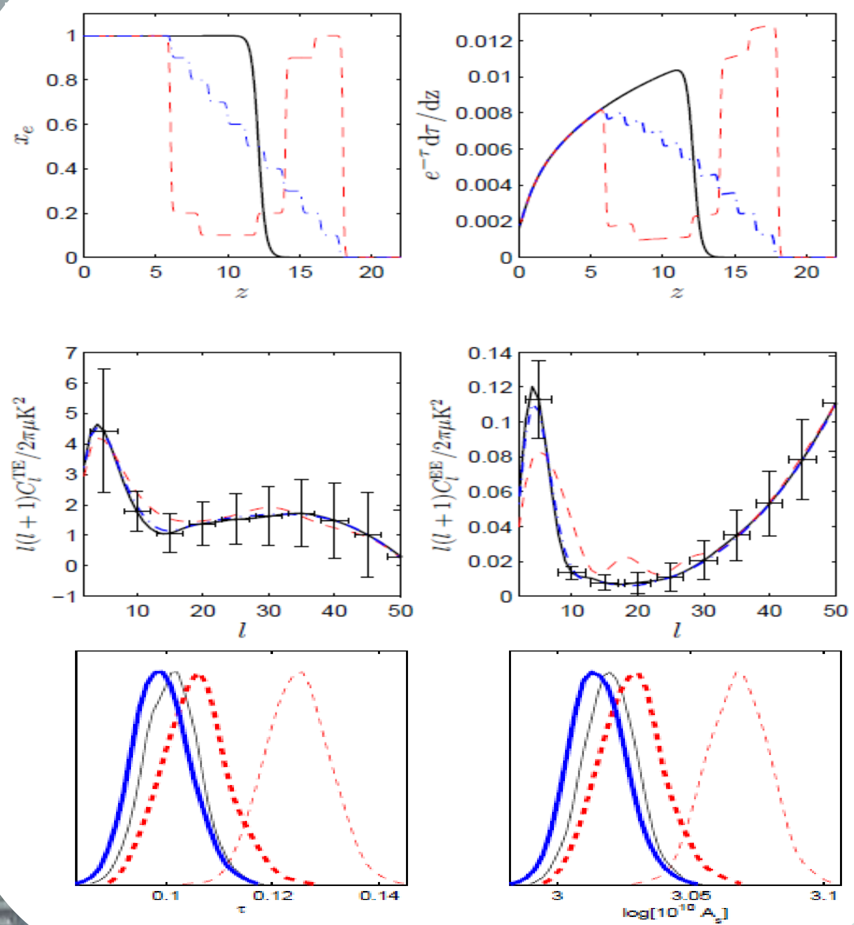
$v(z) = \frac{d\tau}{dz} \exp[-\tau(z)]$ - Visibility function

$$\tau_{\rm reion} \propto (1+z_{\rm re})^{3/2} - 1$$

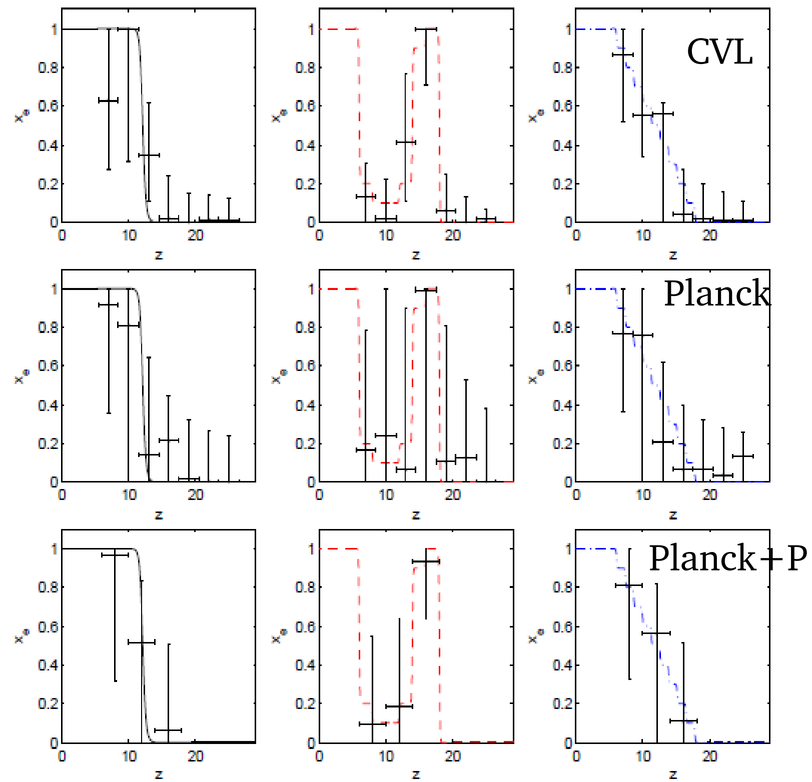
If instantaneous reionisation is assumed

Planck and EOR

Ionisation fraction in bins



$$x_e(z) = x_i\ , \qquad z_i - \frac{\Delta z}{2} < z < z_i + \frac{\Delta z}{2}$$

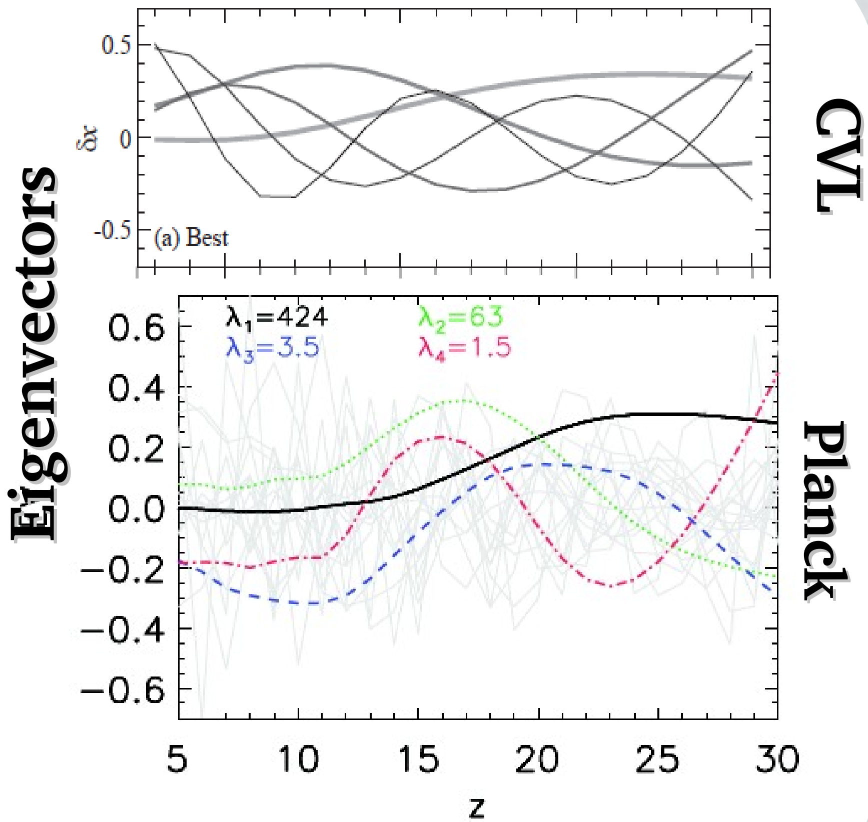


Lewis Weller Battye 06

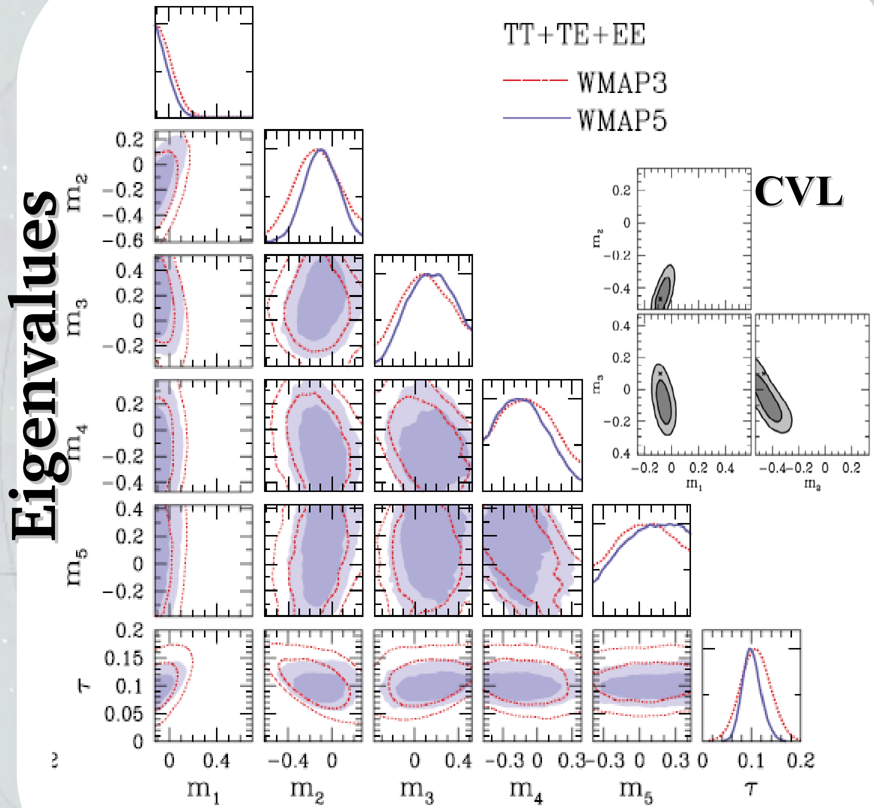
Planck and EOR

Ionisation fraction in Principal Component Analysis

Hu & Holder 03



Weller & Battye, ongoing work in Planck WG5



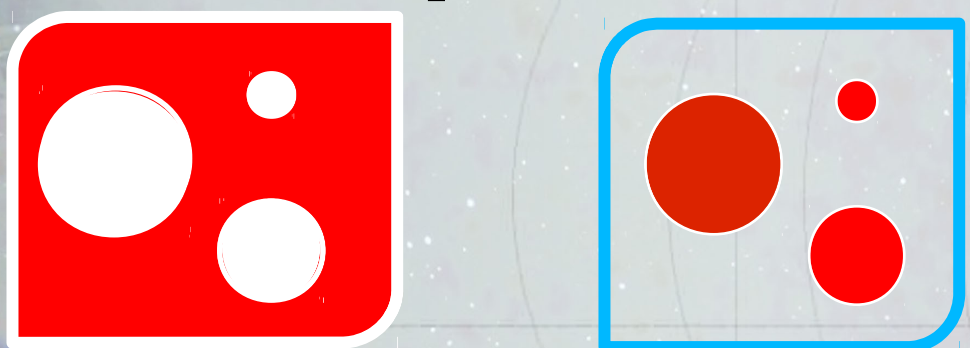
Mortonson & Hu 08

Planck and 21cm

CMB photons scatter off ionised bubbles produced @ the EoR

→ secondary CMB anisotropies thermal SZ effect, kinetic SZ effect & imprint on polarisation

kSZ – EoR map "should" anti-correlate



EoR map $\delta T_{EoR} \sim n_H$

KSZ map $(\delta T/T)_{kSZ} \sim n_e$

$n_e \cong 1 - n_H$

Anti-correlation !

21-cm experiments (e.g. 21CMA, LOFAR, MWA & SKA)

Planck & 21cm

Secondary anisotropies from Kinetic SZ

$$\left(\frac{\delta T}{T}\right)_{\rm kSZ} = -\sigma_{\rm T}\bar{n}_{\rm H(0)}\int\frac{(1+z)^2}{H}{\rm e}^{-\tau}\bar{\chi_e}\cdot(1+\delta+\delta_{\chi_e}+\delta\delta_{\chi_e})v_{\rm r}{\rm d}z$$

$$C_\ell^{E-21}(z_{\rm obs}) = \langle\, a_{\ell m}^{E}\;\; a_{\ell m}^{21}(z_{\rm obs})\,\rangle$$

Cross-correlation 21cm-CMB (P & T)

$$C_l^{21-D}(z) \;=\; \langle a_{lm}^{21}(z)a_{lm}^{D*}\rangle$$

theoretical approach + simulations

$$\delta T_{\rm b} \;=\; 26\,{\rm mK}\,\bar{x}_{\rm HI}(1+\delta+\delta_{x_{\rm HI}}+\delta\delta_{x_{\rm HI}})\;{\rm F}({\rm T_s})$$

21 cm transitions of HI

- Absorb 21cm line from CMB for $T_{cmb} > T_g$
- Emit 21cm line to CMB for $T_g > T_{cmb}$

21cm – CMB (T) - theo.

Signal to Noise ratio analysis @ large scale *(Tashiro et al. 2008, 2009)*

$$\left(\frac{S}{N}\right)^2 = f_{\rm sky}\sum_{\ell=\ell_{\rm min}}^{\ell_{\rm max}}(2\ell+1)\frac{|C_\ell^{21-\alpha}|^2}{|C_\ell^{21-\alpha}|^2+(C_\ell^{21}+N_\ell^{21})(C_\ell^{\alpha}+N_\ell^{\alpha})} \qquad \alpha = D \text{ or } E$$

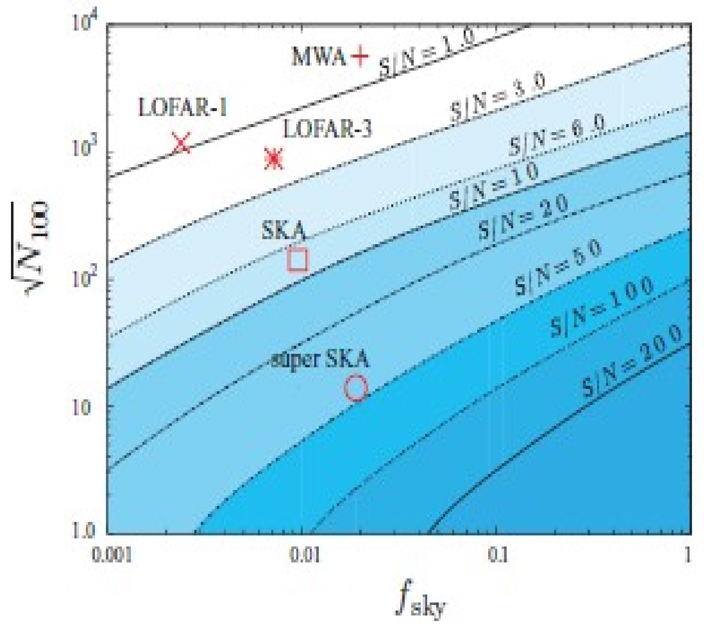
- **CMB noise**
  - Primordial CMB+planck noise
- **21cm noise**
  - Experimental noise:

$$\frac{\ell^2 N_\ell^{21}}{2\pi} = \left(\frac{\ell}{100}\right)^2 \frac{1}{t_{\rm obs}\Delta\nu}\left(\frac{100\ell_{\rm max}}{2\pi}\frac{\lambda^2}{A/T}\right)^2$$

A/T is the sensitivity

$t_{\rm obs}$ is the total integration time

$\ell_{\rm max} = 2\pi\frac{D}{\lambda}$ is the maximum multipole



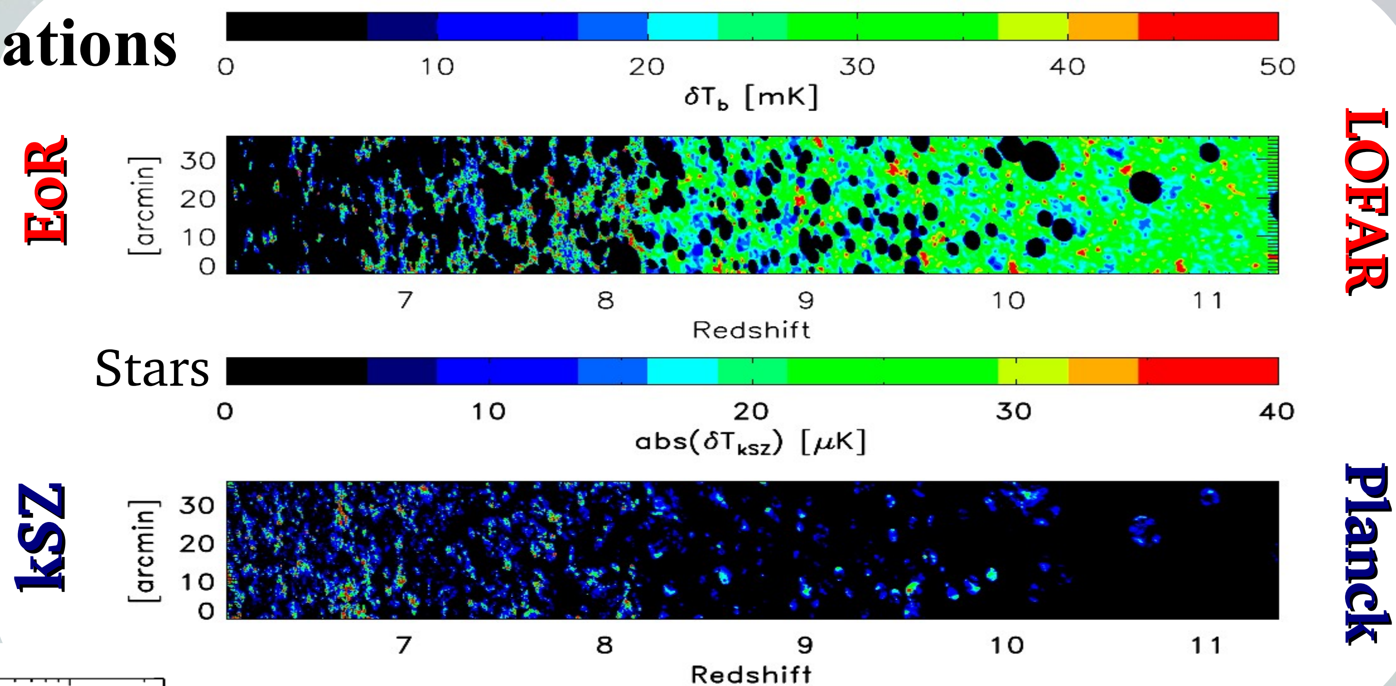
(Δz=0.01, z_{re}=10, z_{obs} =10)

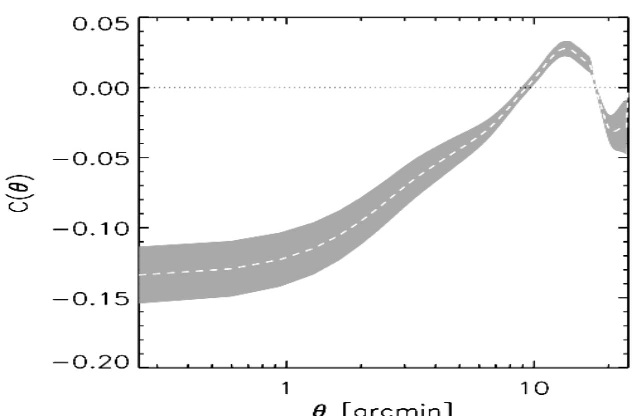
Signal stronger for short reionisation.

21cm – CMB (T) - simu.

Coherent simulations

Jelic et al. 2009
Thomas et al 2008





$C(0) = -0.16 \pm 0.02$ (without primary CMB)

$C(0) = 0.0 \pm 0.3$ (with primary CMB = noise)

CMB is the main noise for cross-correlation at small scale

Conclusions

- First order effects (bump & damping) will be well measured by Planck leading to strong constraints on τ
- Reionisation history will be harder to determine in detail (3-4 indep. components)
- Cross correlation with 21cm may be helpful but really hard (few σ for LOFAR now, better with SKA soon)
- Planck is starting its 2^d survey of the sky