Epoch of reionisation
Cosmology with SZ clusters

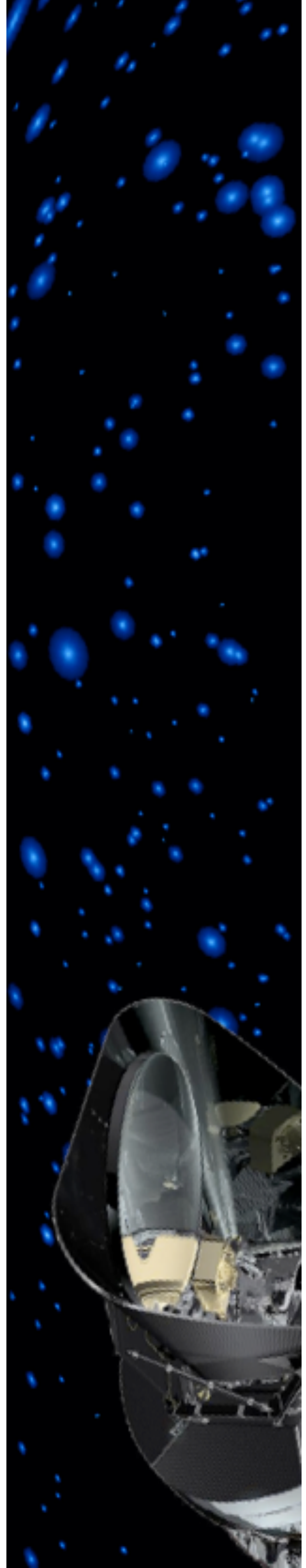
(mostly from CMB/Planck)

M. DOUSPIS

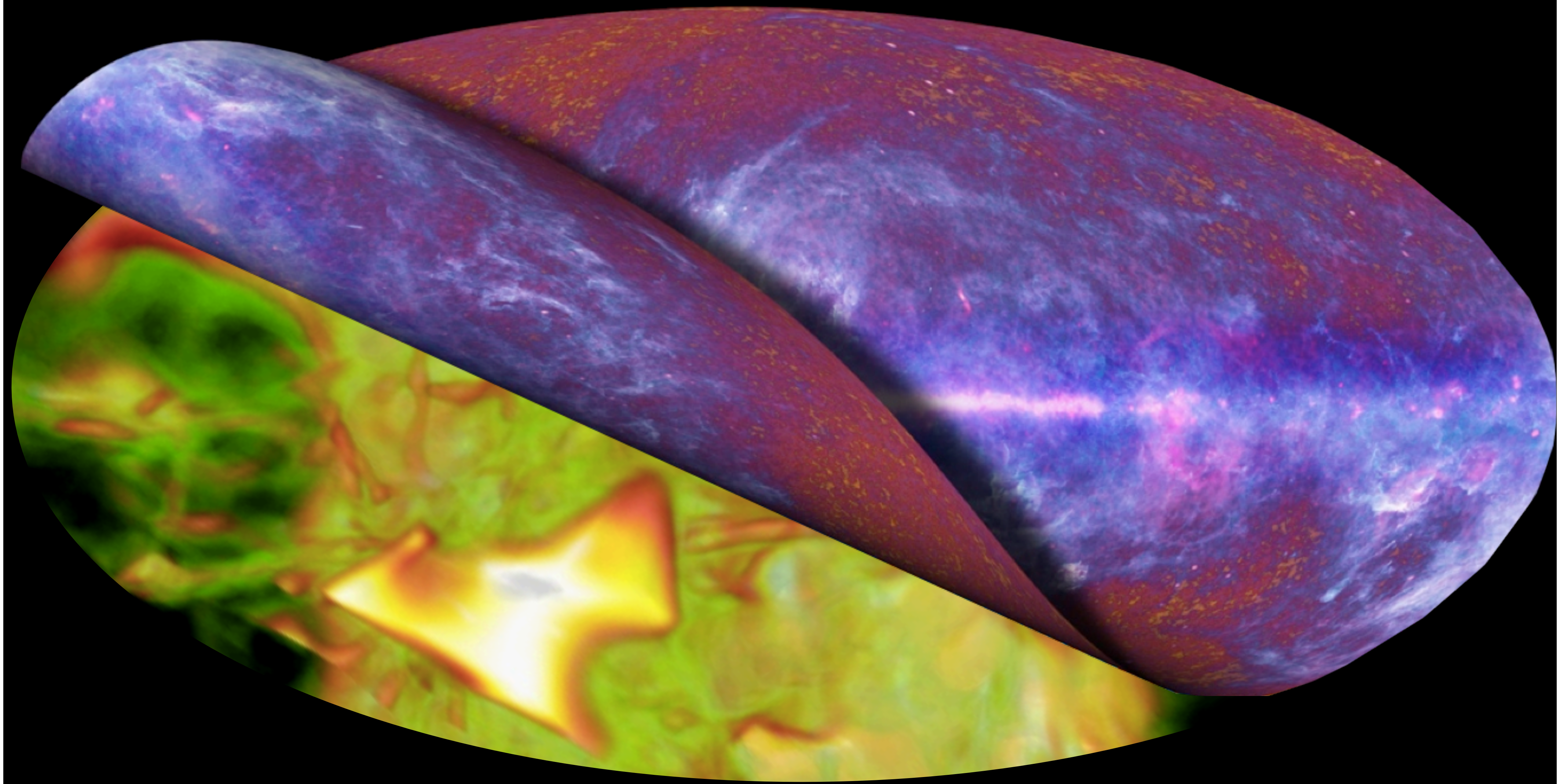
(IAS, Orsay)

based on Planck results 2013 and 2015+
Douspis et al. 2015a,b, Ilic 2015
with

N. Aghanim, A. Blanchard, S. Ilic, M. Langer, M. Tristram



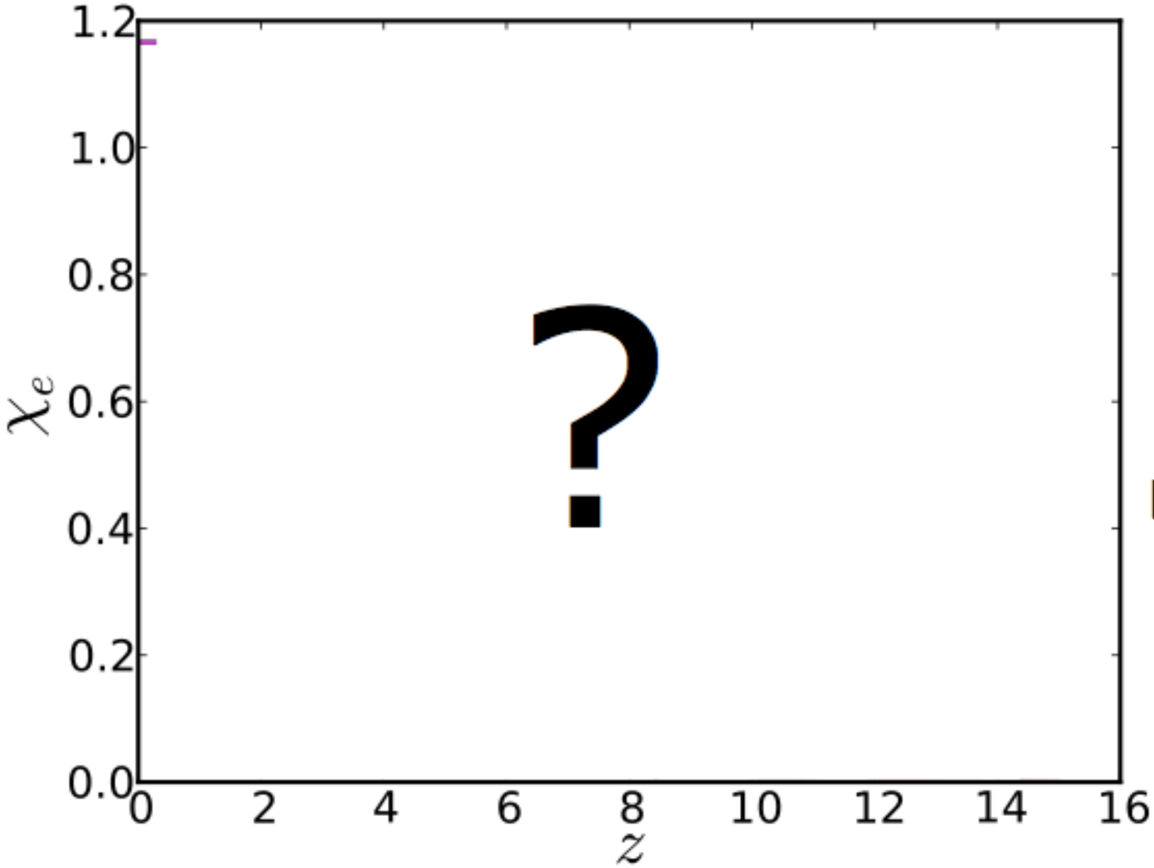
Unveiling the epoch of Reionisation



EoR simulation from Aubert et al.

Reionisation

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.



Parametrize the complex history of reionisation in one function

$X_e(z)$ is the **ionisation fraction** as a function of the redshift ($\equiv Q_{HII}$)

$$\chi_e(z) = n_e(z)/n_H(z)$$

Reionisation **optical depth** is defined as:

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

Reionisation in CMB

- **Symmetric** (standard tanh)
  - 2 parameters : zre, Δz
- **Asymmetric**

  motivated by data and sims

  Douspis et al. 2015

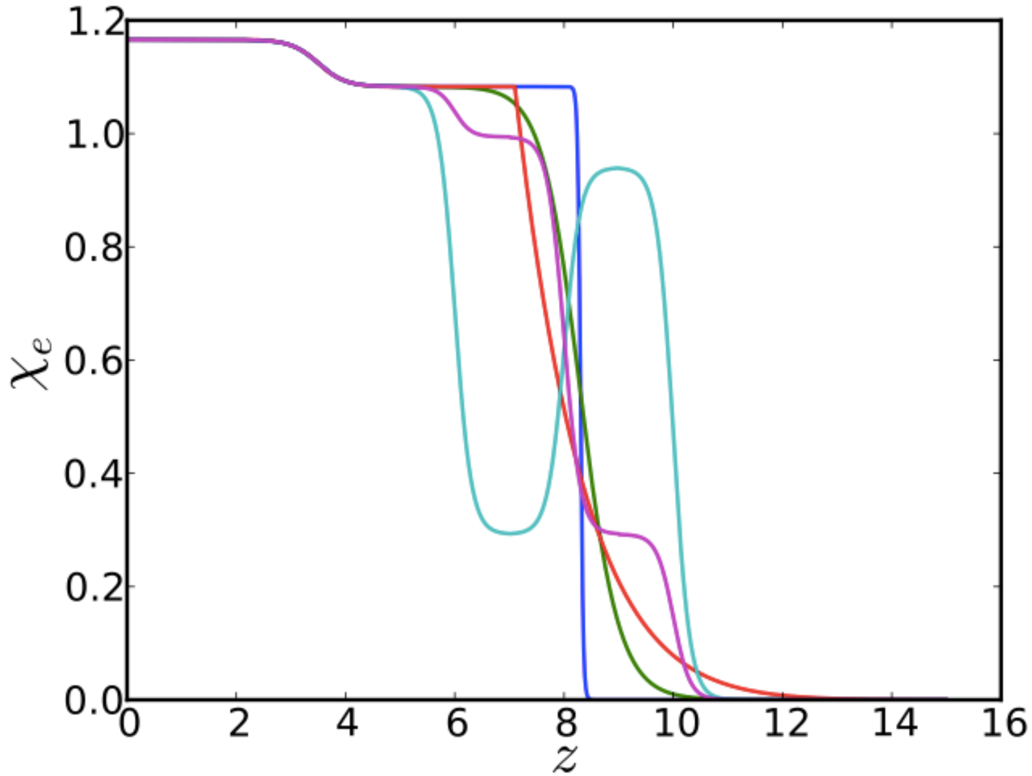
  - 2 sources :

    1. "gentle" : stars & galaxies

    2. "abrupt" : QSOs finish

  phenomenological description :

  zstart, zend, ztrans ↔ zre, Δz_{begin}, Δz_{end}



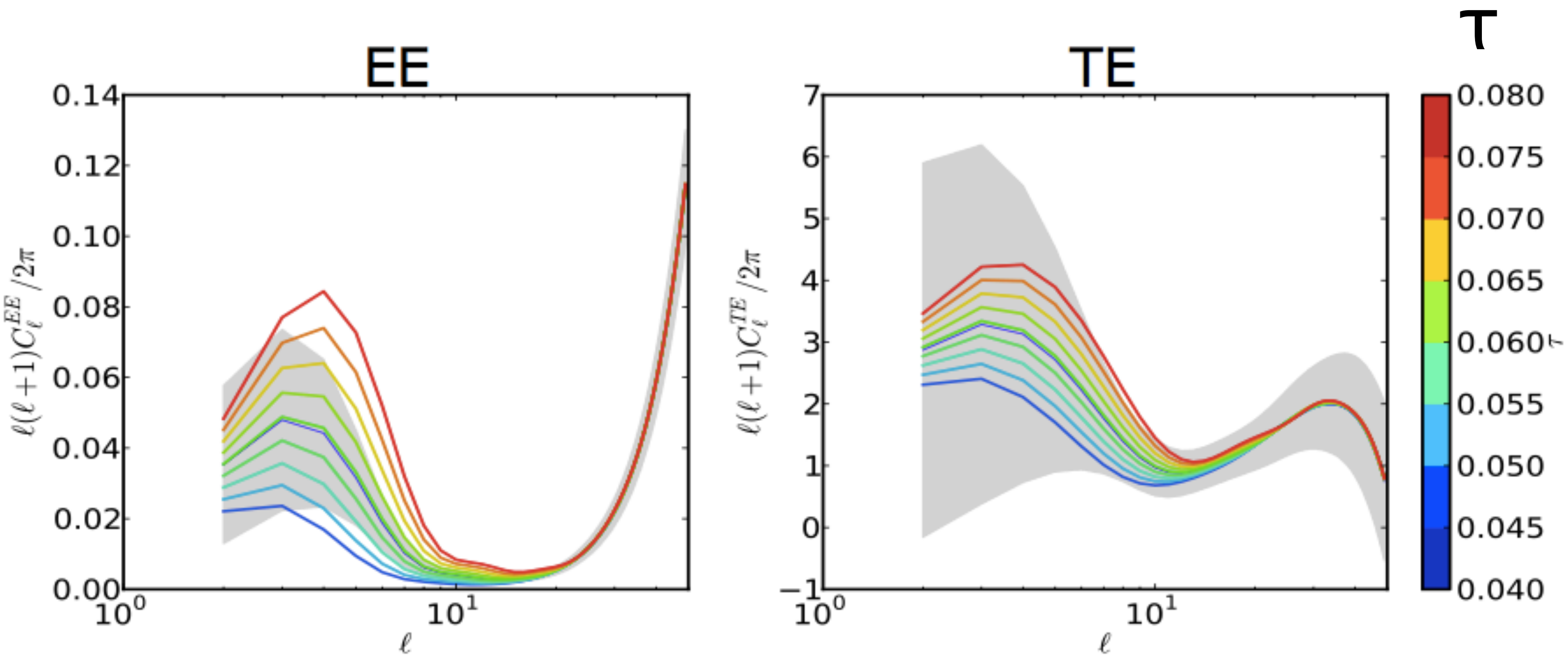
- **Model independent**
  - $X_e(z)$ in redshift bins
  - Principal Component Analysis

CMB & Reionisation

CMB gives information on Reionisation through:

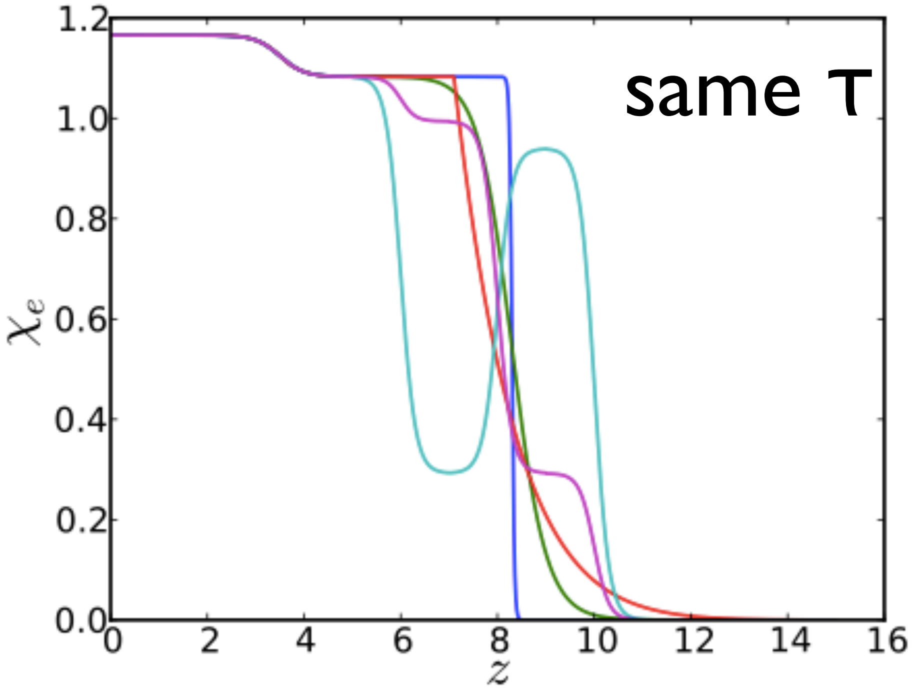
- Temperature anisotropies
  - suppression of TT power at high multipole
    (very degenerate with other cosmological parameters and foregrounds)
- Polarisation anisotropies
  - suppression of EE power at high multipole
  - new polarisation anisotropy at large angular scale because the horizon has grown to a much larger size by that epoch
- Kinetic Sunyaev-Zel'dovich effect
  - re-scattering of photons off newly liberated electrons [Sunyaev & Zel'dovich 1980]

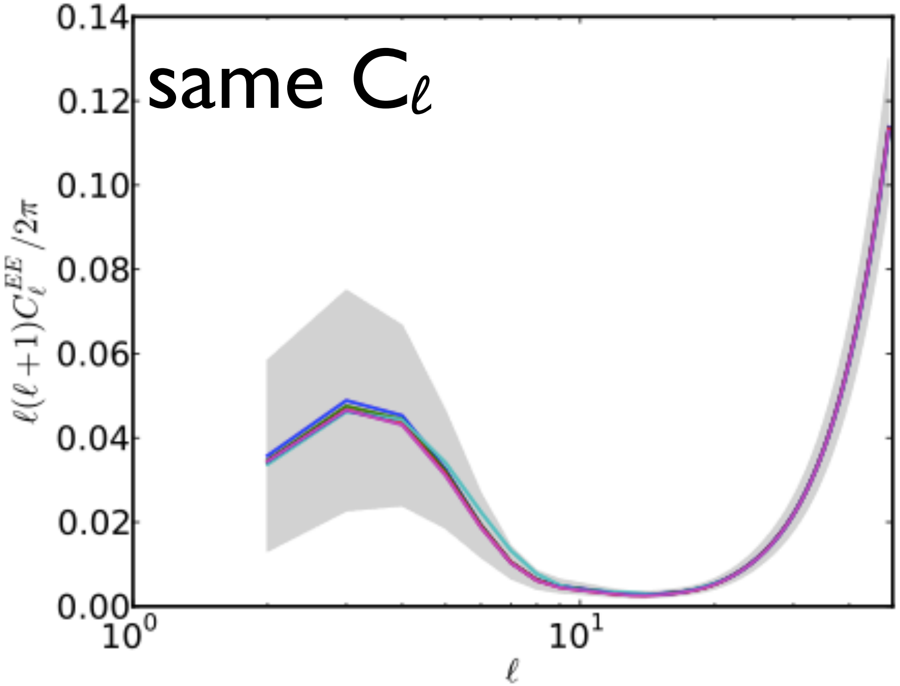
low-ℓ effect



CMB is a good tracer of the optical depth τ

CMB degeneracies





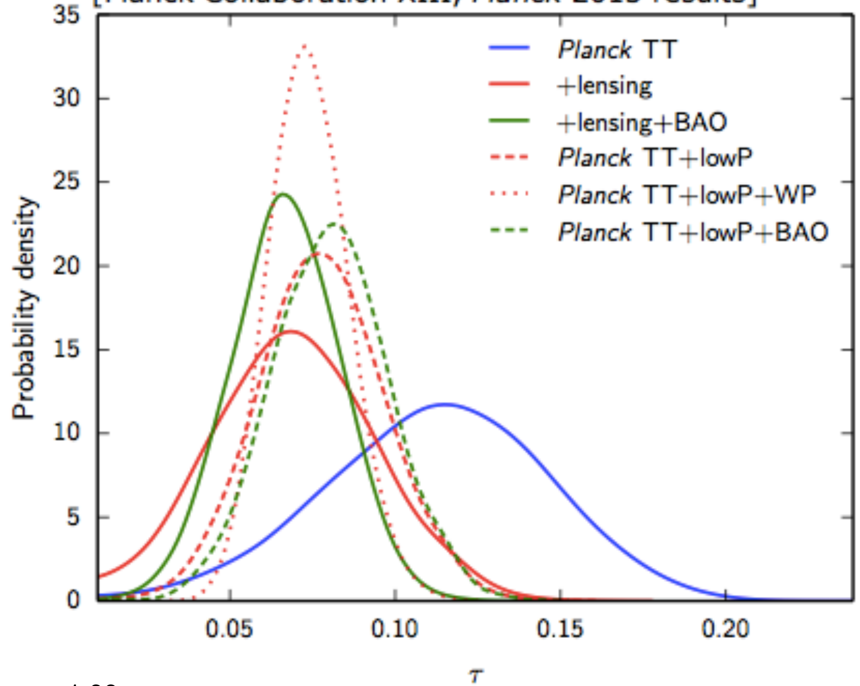
CMB is not a good tracer the reionisation history

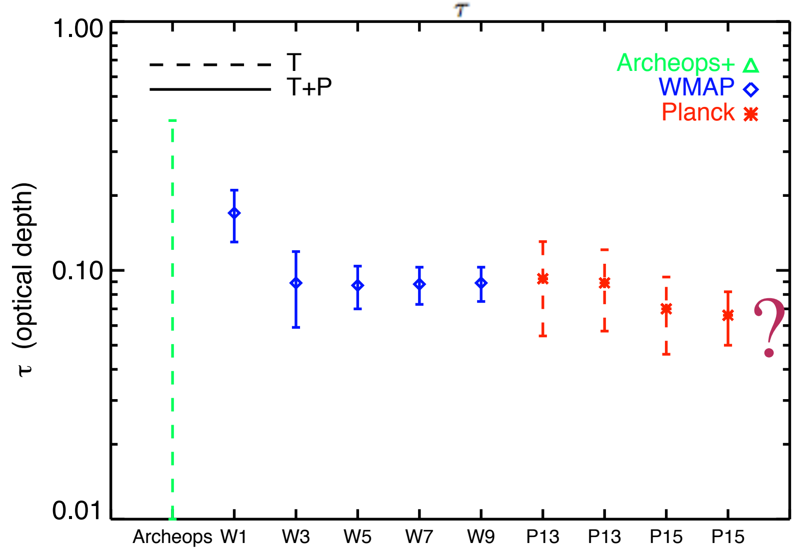
Reionisation optical depth

CMB data

- **WMAP**
  - τ = 0.089 ± 0.014
- **Planck 2013**
  - τ = 0.089 ± 0.014 (TT with WP)
  - τ = 0.075 ± 0.013 (TT with Planck dust)
- **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)
- **Planck HFI EE low-l**
  - decreasing trend continues … ?

[Planck Collaboration XIII, *Planck* 2015 results]





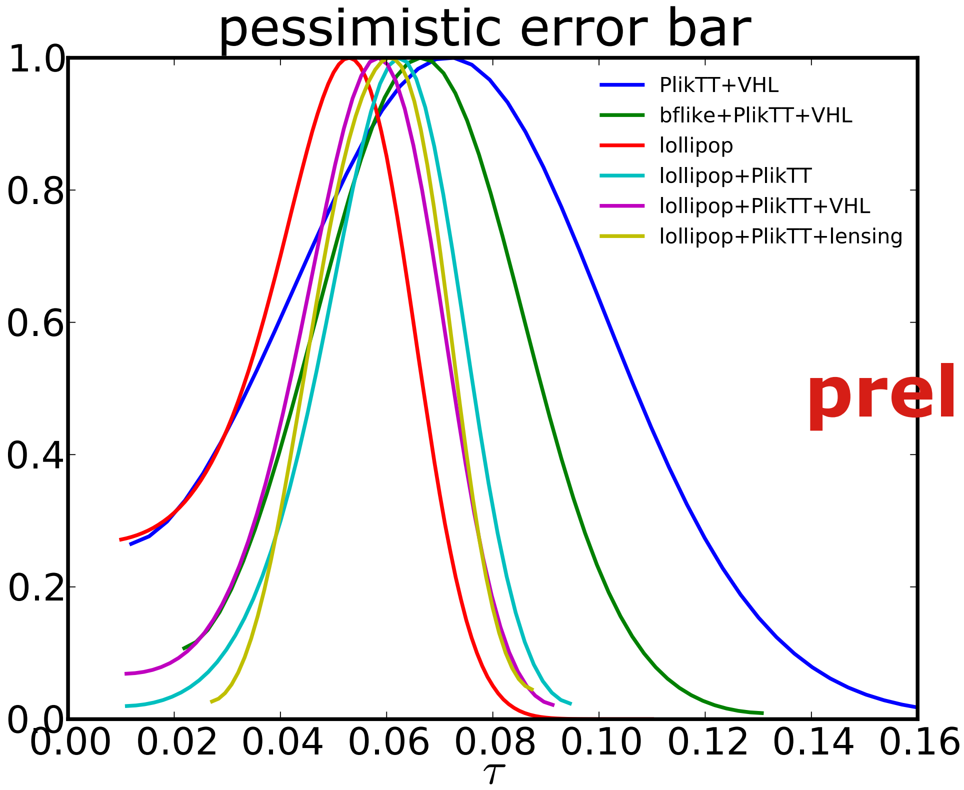
Planck HFI low-ℓ

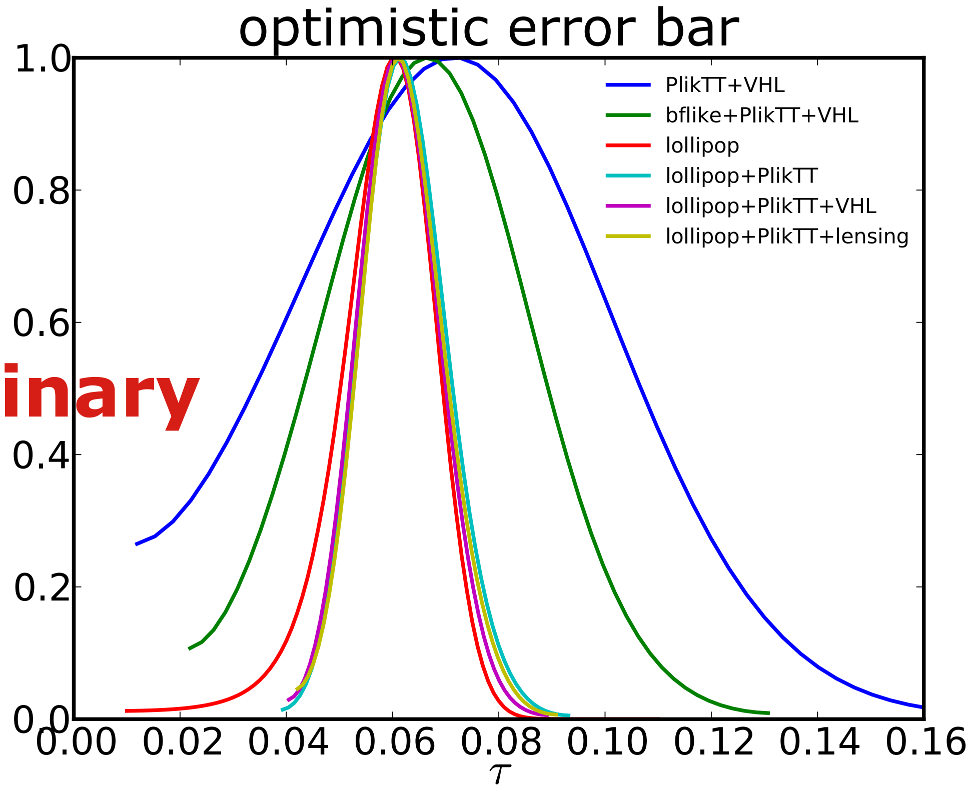
- **In previous Planck data, the biggest systematic was ADC-NL**
  - has been reduced by a factor almost 10 but still not negligible on frequency maps
- **We have now identified all dominant sources of residual systematics that matter for low-ℓ data analysis**
- **First results on E2E Monte-Carlo simulations including ADC-NL**
  - no bias on cross-spectra
  - more work still to be done on a reliable propagation of uncertainties
- **Likelihood based on cross-spectra between Planck frequency maps**
  - Lollipop likelihood: Hamimeche&Lewis 2008 approximation modified for cross-spectra, Mangilli, Tristram et al. 2015

next results are two preliminary versions of Planck analysis based on two different noise/syste statistics

Reionisation optical depth

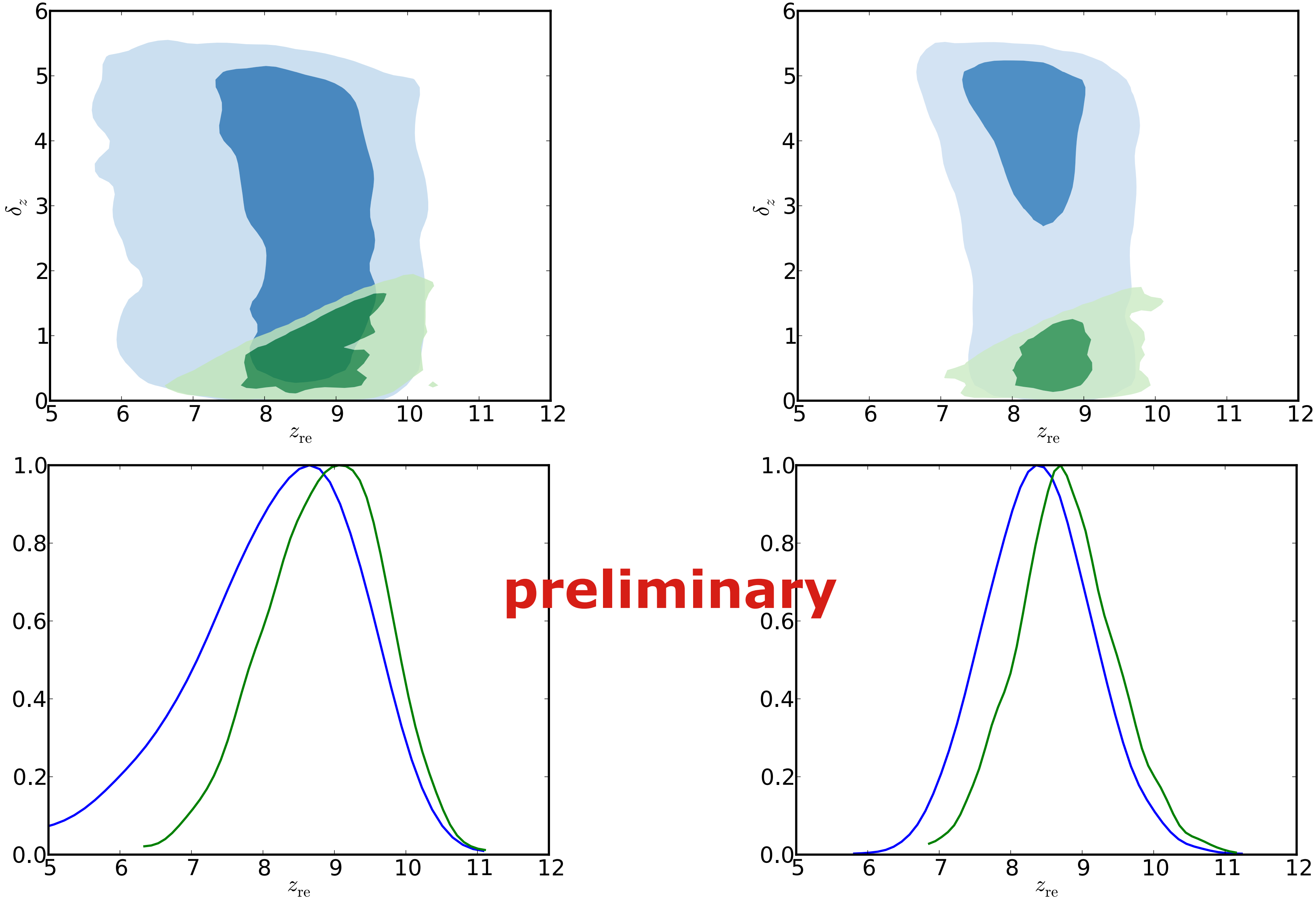
- **Example of results as a combination of**
  - Planck TT CMB spectrum (2015)
  - two versions of Planck EE low-ℓ
    value and error bar not yet finalized !
  - Very High-ℓ ground-based experiments (ACT & SPT)



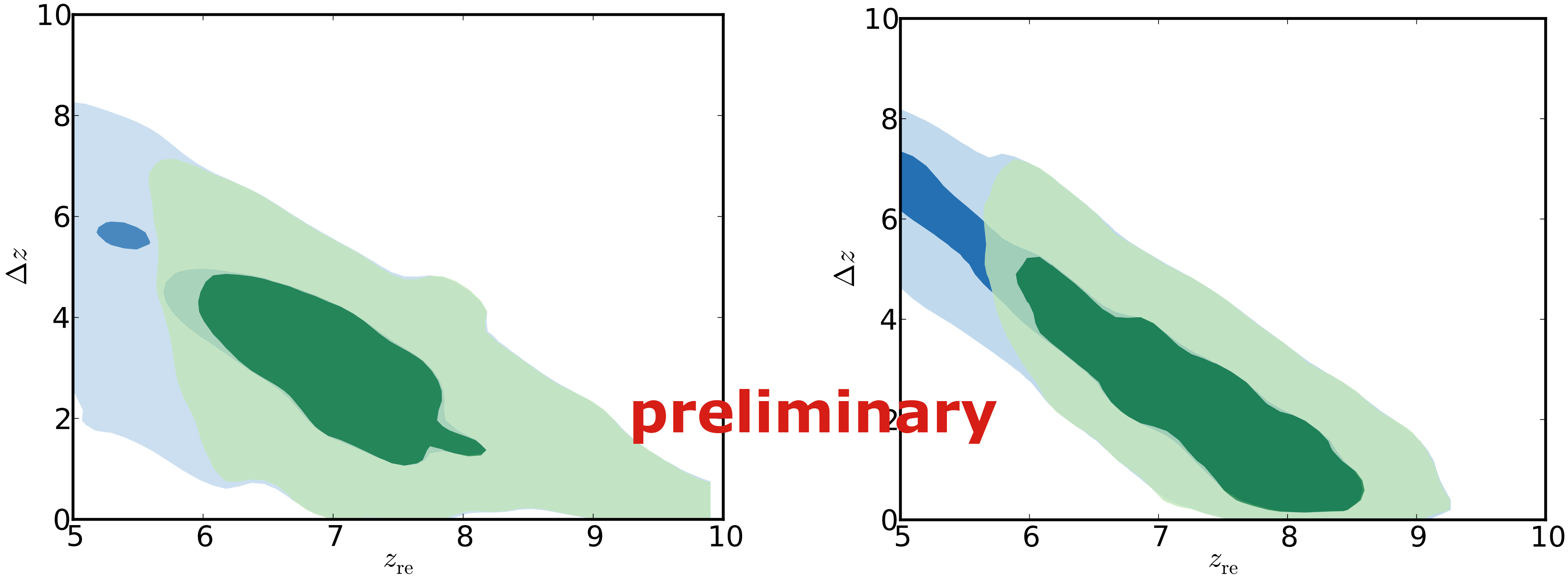


preliminary

symetric model



Asymetric model



kSZ

Second-order effect of photons scattering off electrons moving with bulk velocity which is called "kinetic Sunyaev Zel'dovich" effect (kSZ, Sunyaev & Zeldovich, 1980)

- Homogeneous kSZ
  - arising when the reionisation is complete [Ostriker & Vishniac 1986]

$$D_\ell^{h-kSZ} \propto \left(\frac{\tau}{0.076}\right)^{0.44}$$

Shaw et al. 2012

- Patchy (or inhomogeneous) reionisation
  - before the reionisation is complete from the proper motion of ionised bubbles around emitting sources [Aghanim+1996]

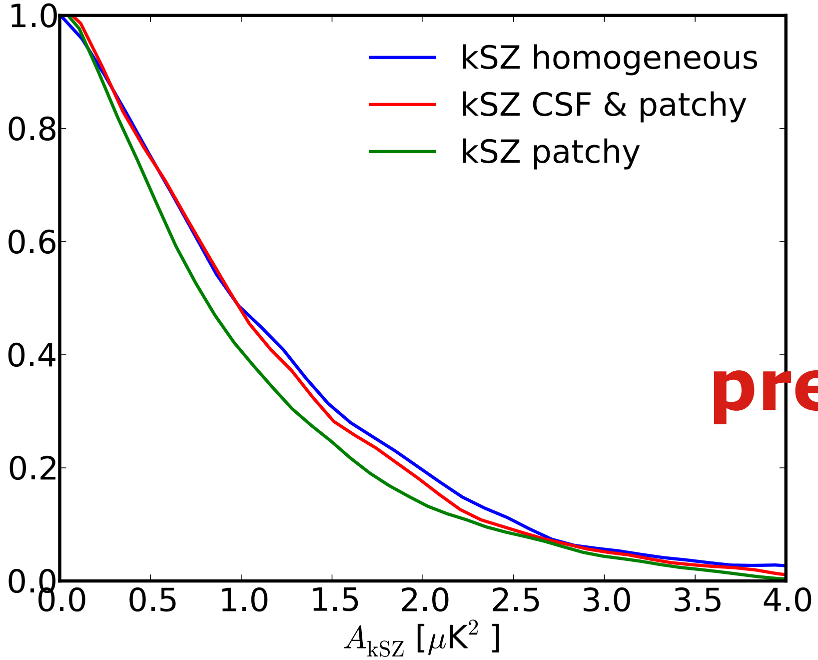
$$D_\ell^{p-kSZ} \propto \left[\left(\frac{1+z_{reio}}{11}\right) - 0.12\right]\left(\frac{\Delta_z}{1.05}\right)^{0.51}$$

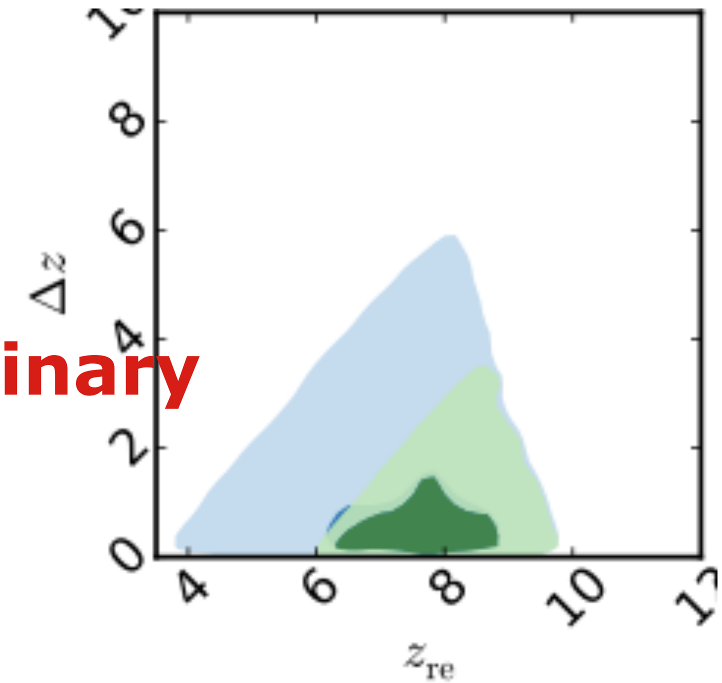
Battaglia et al. 2013

constraints on kSZ

- Planck is not able to measure kSZ independently, thus needs high resolution CMB data (ACT, SPT)

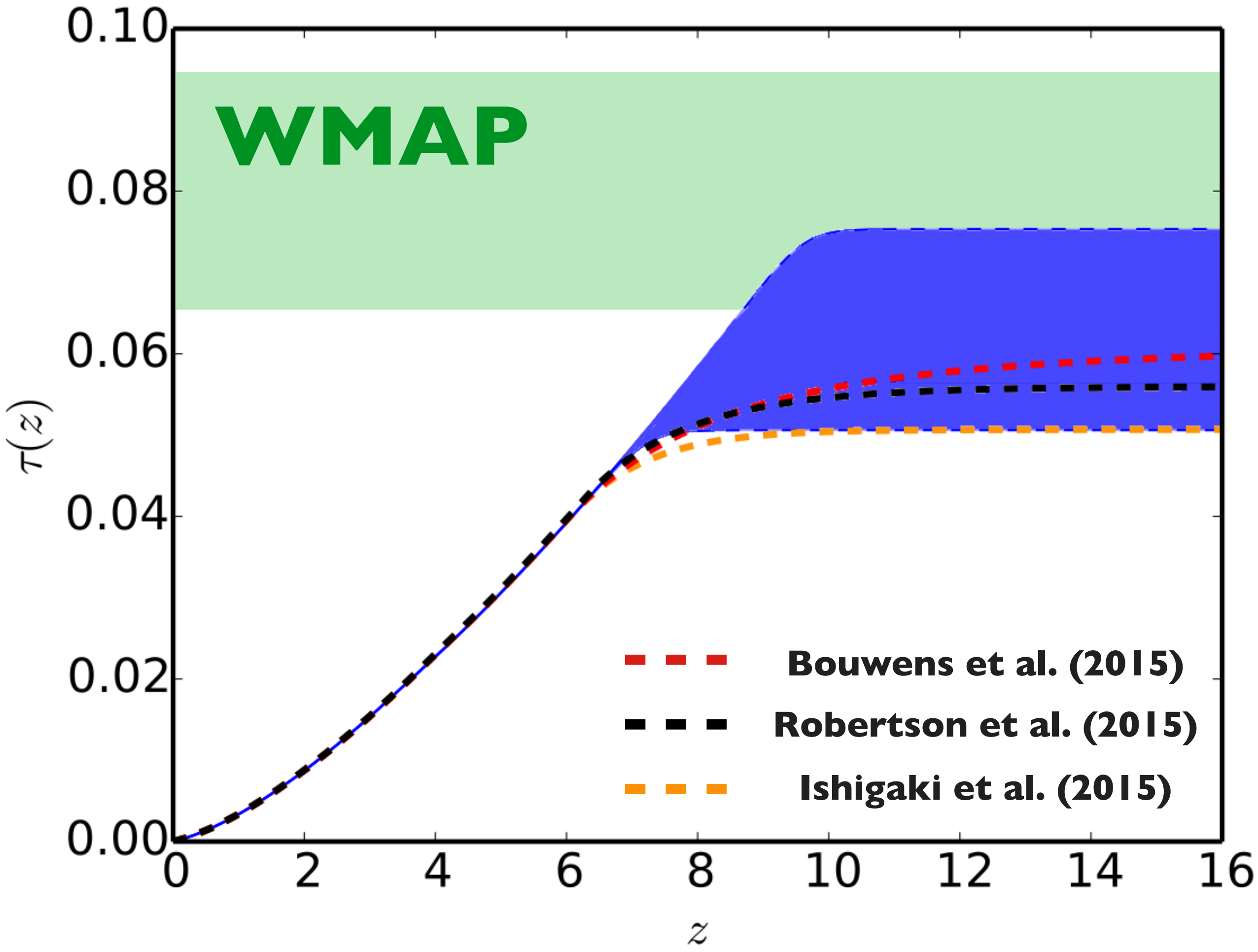
Planck+ACT+SPT





preliminary

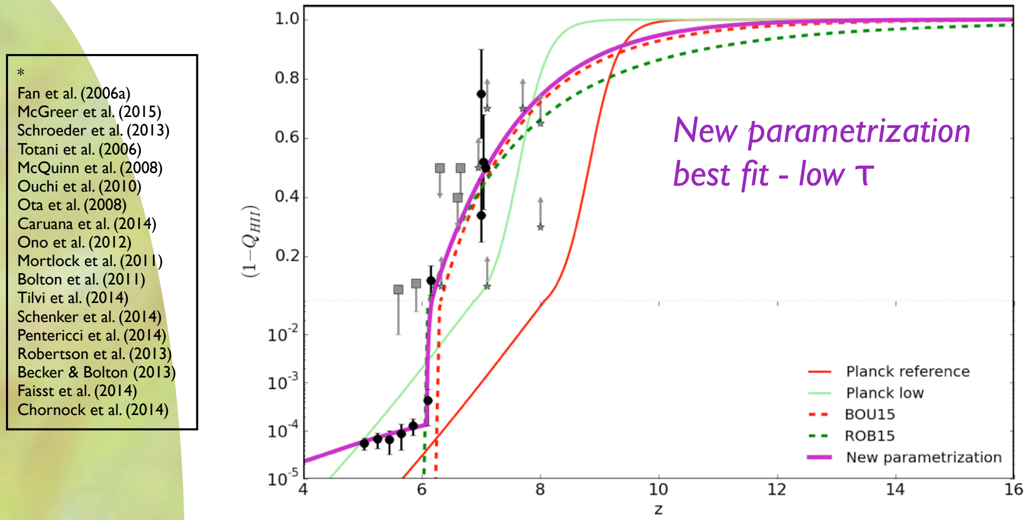
optical depth comparison

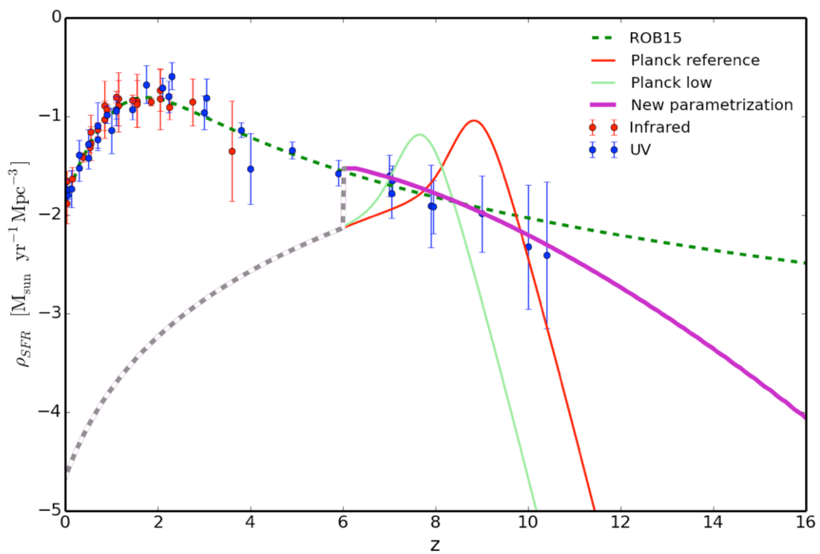


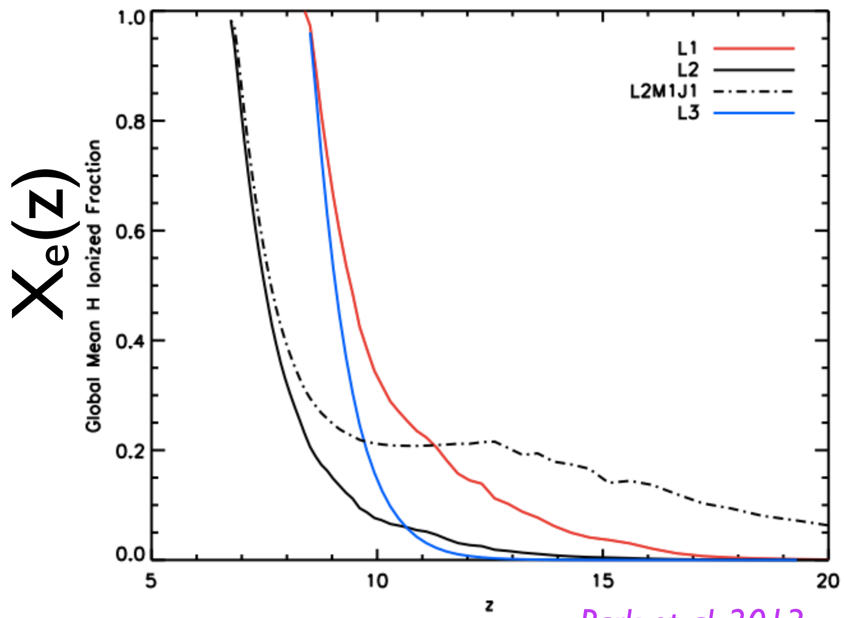
Planck Agreement

- integrated optical depth for the symmetric model (tanh, $\delta z = 0.5$).
- 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.

Low redshift probes







Park et al, 2013

New parametrization

$$Q_{HII}(z) \propto \begin{cases} -(1+z)^{\sim 3} & z < z_t \\ exp(-\lambda(1+z)^{3/2}) & z > z_t \end{cases}$$

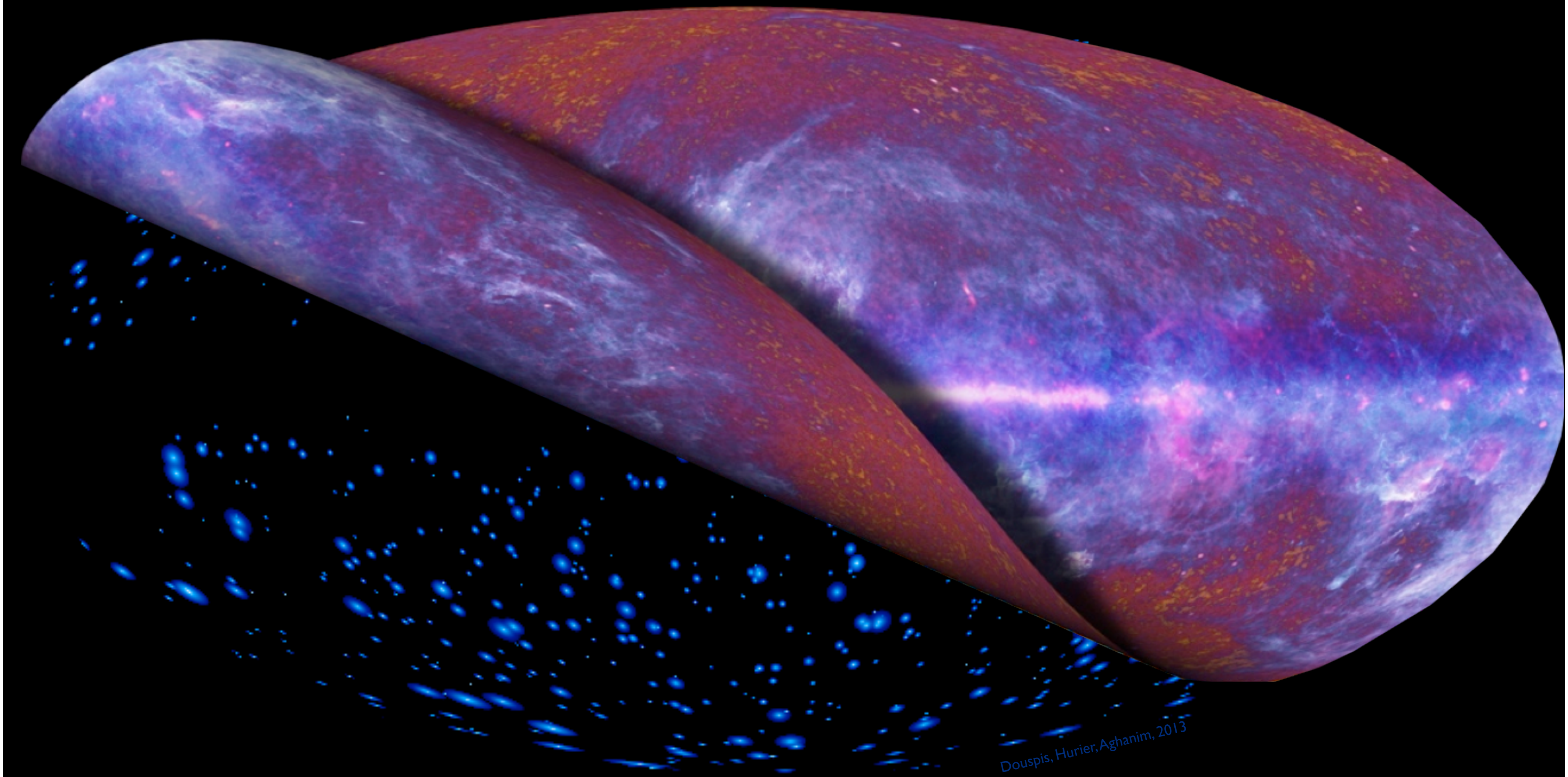
Douspis, Aghanim, Langer, Ilic, A&A, 2015

$$\frac{dQ_{HII}}{dt} = \dot{N}_{ion} - \frac{Q_{HII}}{t_{rec}} \qquad \dot{N}_{ion} \propto \rho_{SFR}$$

Discussion

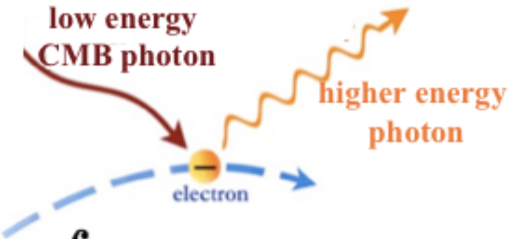
- A lower value for τ as suggested by preliminary Planck data would be
  - consistent with a fully reionised Universe at $z \sim 6$
    Gunn-Peterson effect showing Universe is mostly ionized up to $z \sim 6$ [Fan et al.]
  - in good agreement with recent constraints on reionisation in the direction of particular objects (in particular distant GRB and Ly-α emitters)
- Constraints on the reionisation history with such a low optical depth would disfavor 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 $M_{UV} < -17$ seems to be sufficient to comply with all the observational constraints without the need for high redshift ($z = 10$ to 15) galaxies.
- More news from Planck-HFI (hopefully) soon !

SZ Cluster cosmology



Looking for clusters

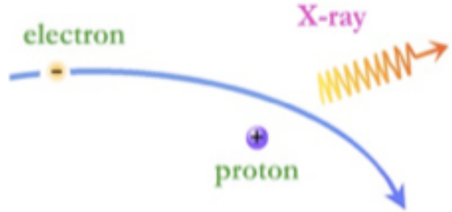
Inverse Compton
→ SZ effect



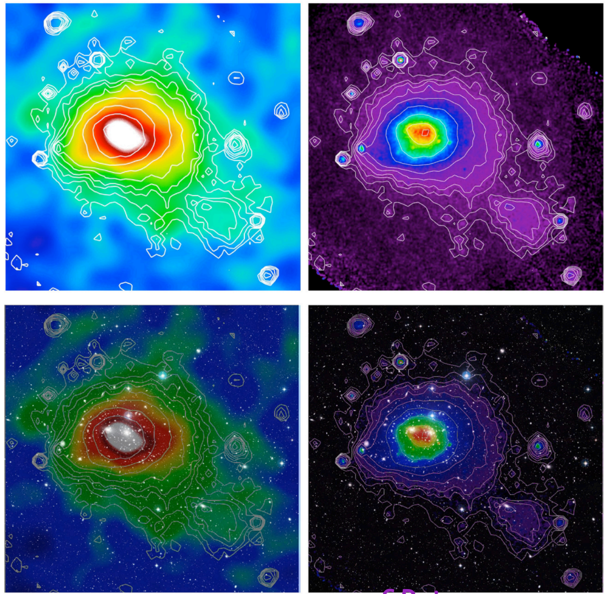
$$F_\nu \propto \int_\Omega (P = n_e T) d\Omega$$

Hot Gas

Bremsstrahlung
→ X-ray emission



$$E_X \propto \int_V n_e^2 \Lambda(T) dV$$



courtesy of Pointecouteau

Number of galaxies
→Optical/IR

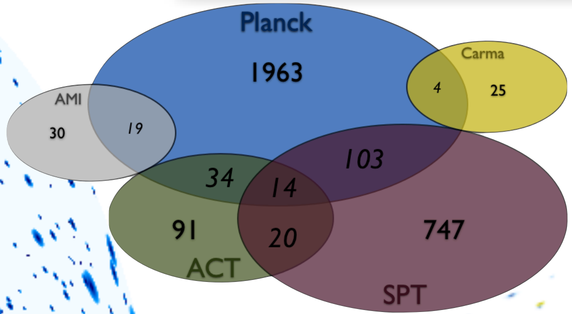
Cold Gas

non thermal emission
→radio

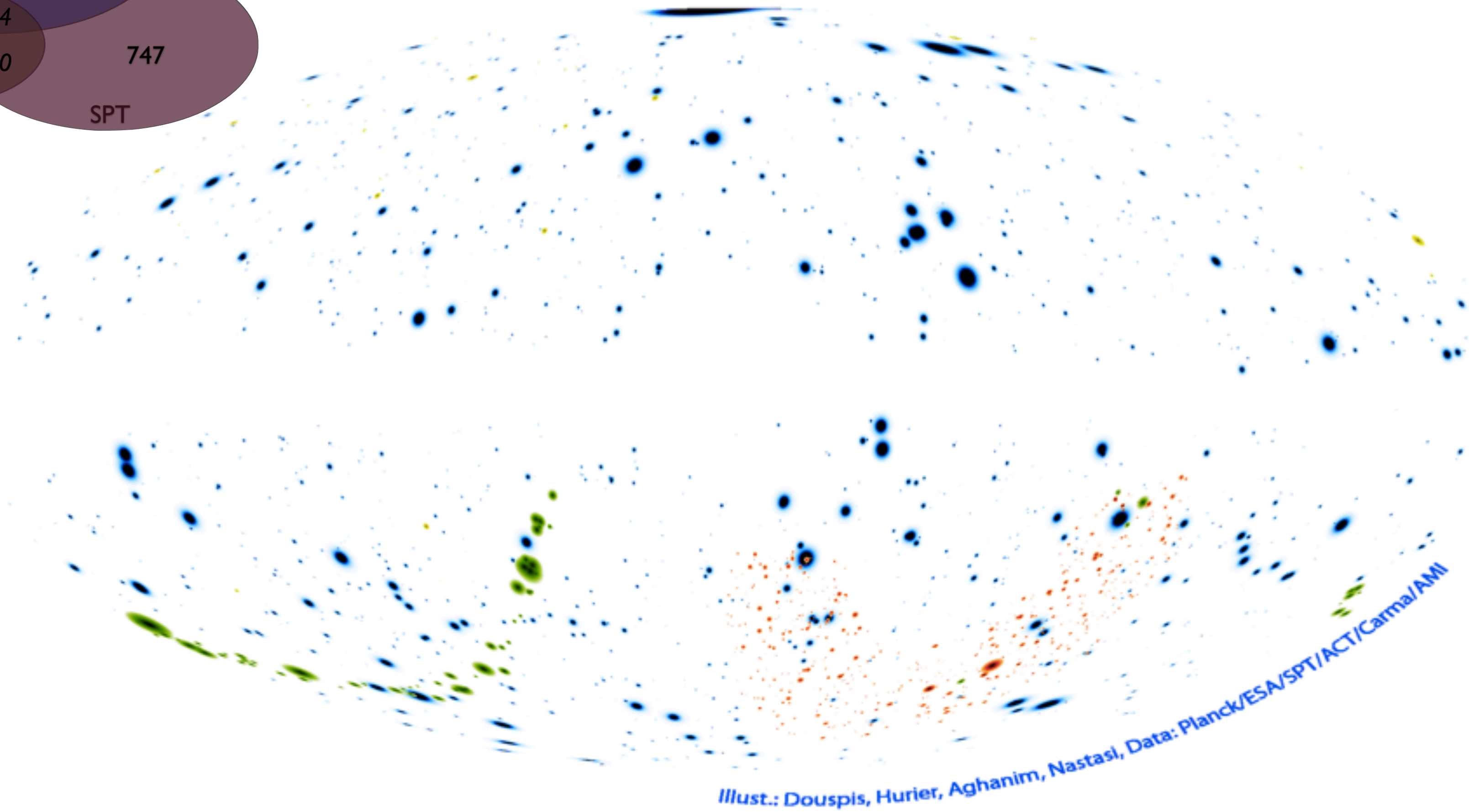
Weak/Strong lensing
velocity dispersion
→Optical/IR

+Dark Matter

SZ clusters



2690 clusters and candidates



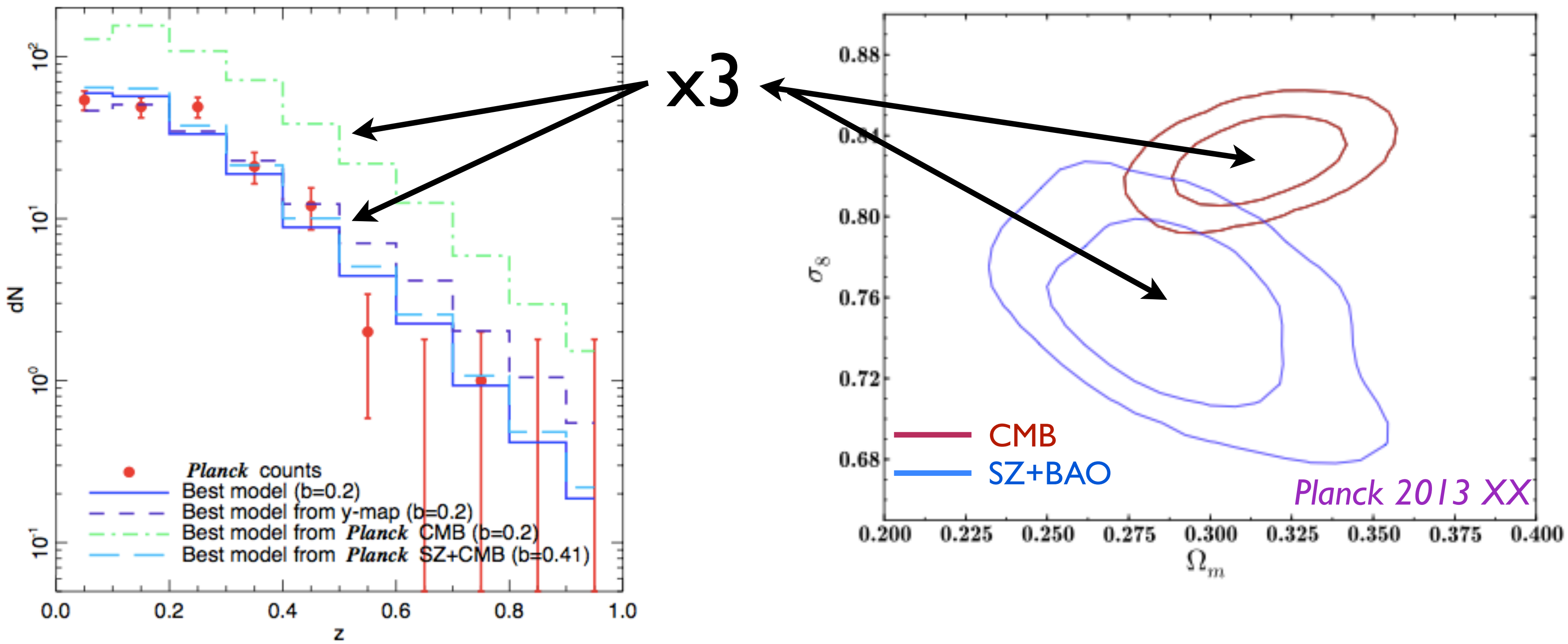
high purity and well behaved completeness → cosmological samples (200-400)

SZ metacatalogue available at szcluster-db.ias.u-psud.fr, Douspis et al. sub A&A, 2015

SZ cosmology

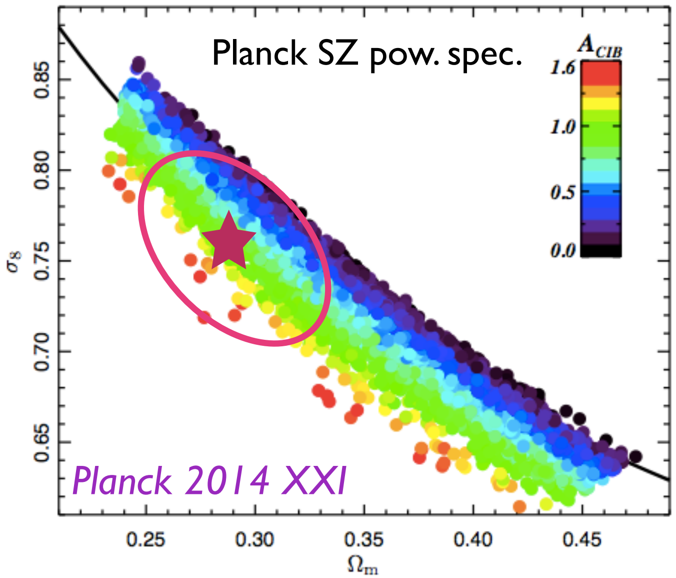
$$\frac{dN}{dz} = \int d\Omega \int dM_{500}\, \hat{\chi}(z, M_{500}, l, b)\, \frac{dN}{dz\, dM_{500}\, d\Omega}$$

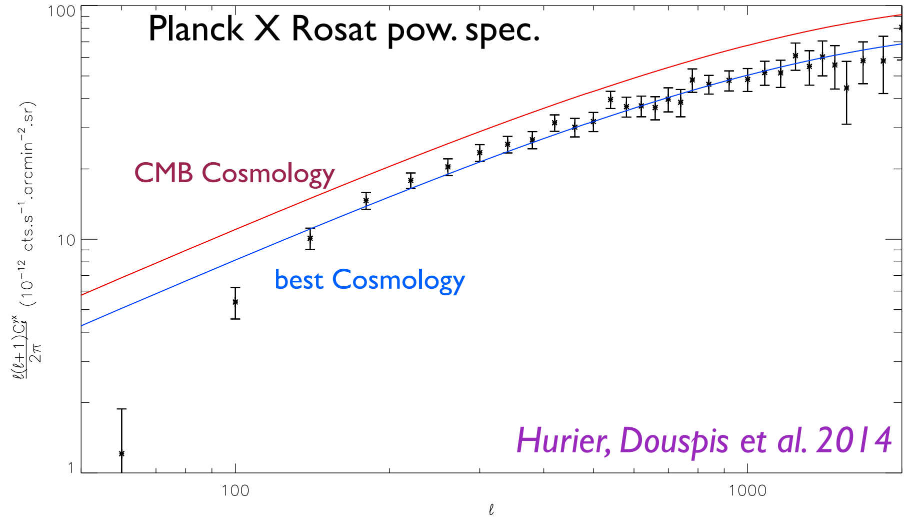
Planck 2013 XX showed

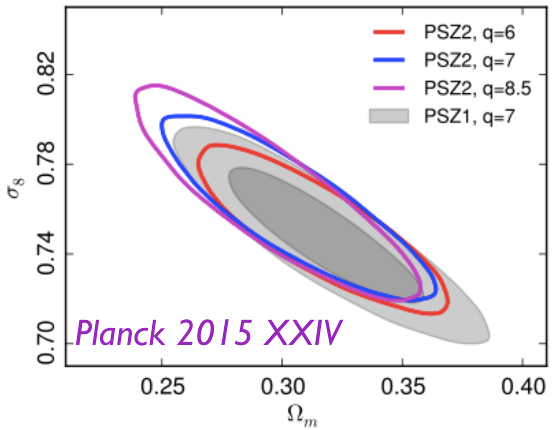


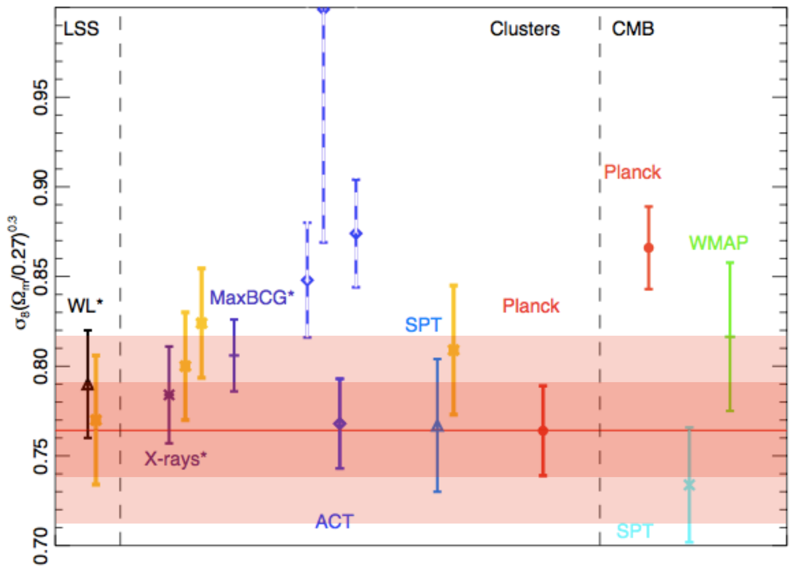
(Slight) discrepancy !

are we wrong?



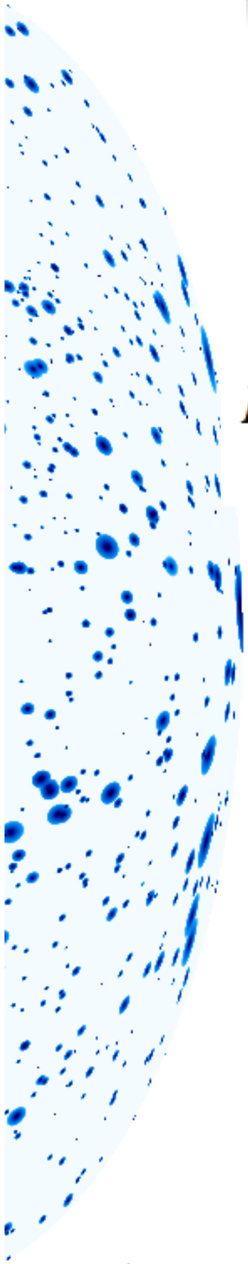






Agreement with other cluster and SZ studies

tricky ingredient: the Mass



- Masses obtained from scaling relations

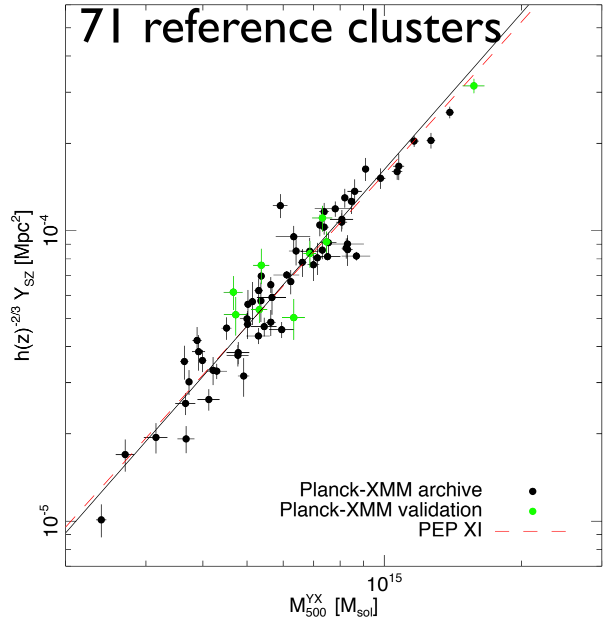
$$E^{-\beta}(z)\left[\frac{D_A^2(z)\,\bar{Y}_{500}}{10^{-4}\,\mathrm{Mpc}^2}\right] = Y_*\left[\frac{h}{0.7}\right]^{-2+\alpha}\left[\frac{(1-b)\,M_{500}}{6\times10^{14}\,\mathrm{M_{sol}}}\right]^{\alpha}$$

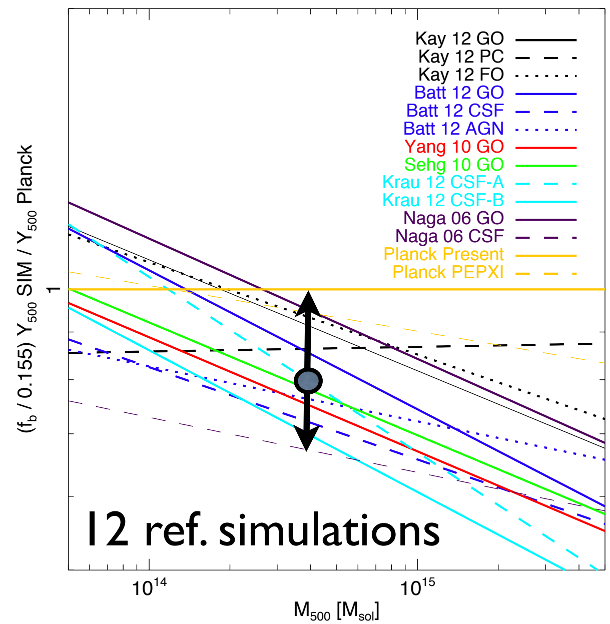
$$M^{YX} = (1-b)M_{true}$$

- Our study converges towards

$$\Rightarrow\ (1-b) = 0.8\ in\ [0.7-1.0]$$

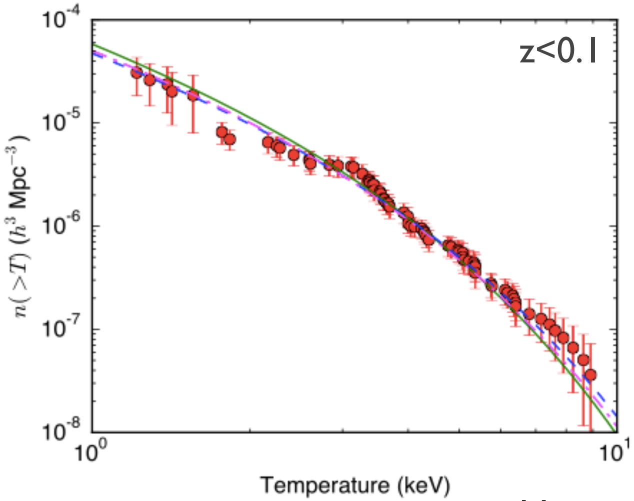
Agreement on CMB cosmology if (1-b)~0.6

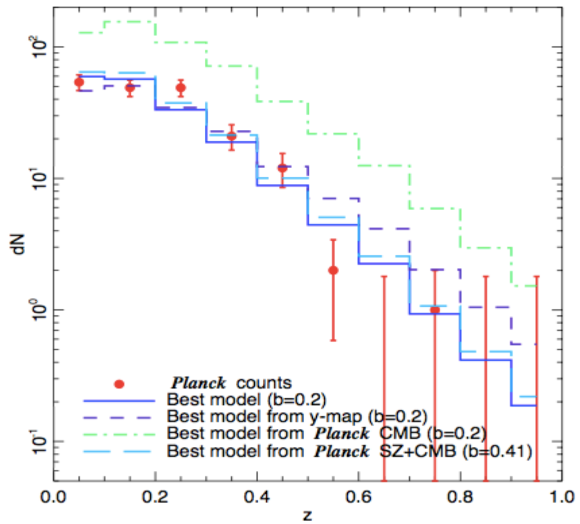




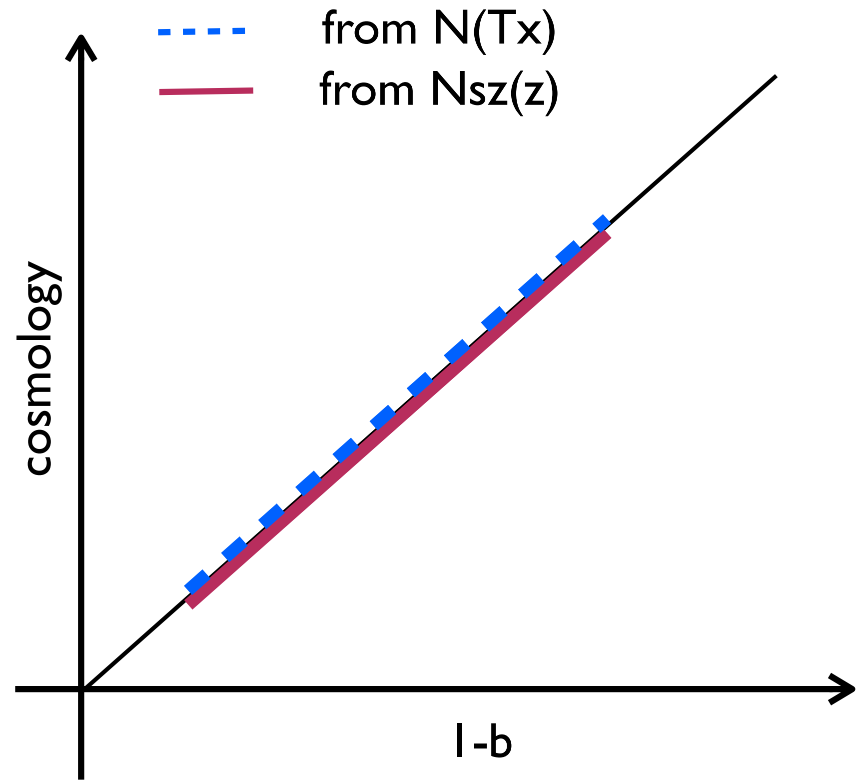
Indirect comparison

Comparison of abundances of Xray local clusters (Tx) with SZ clusters (z=[0-1])





Masses for a cosmo

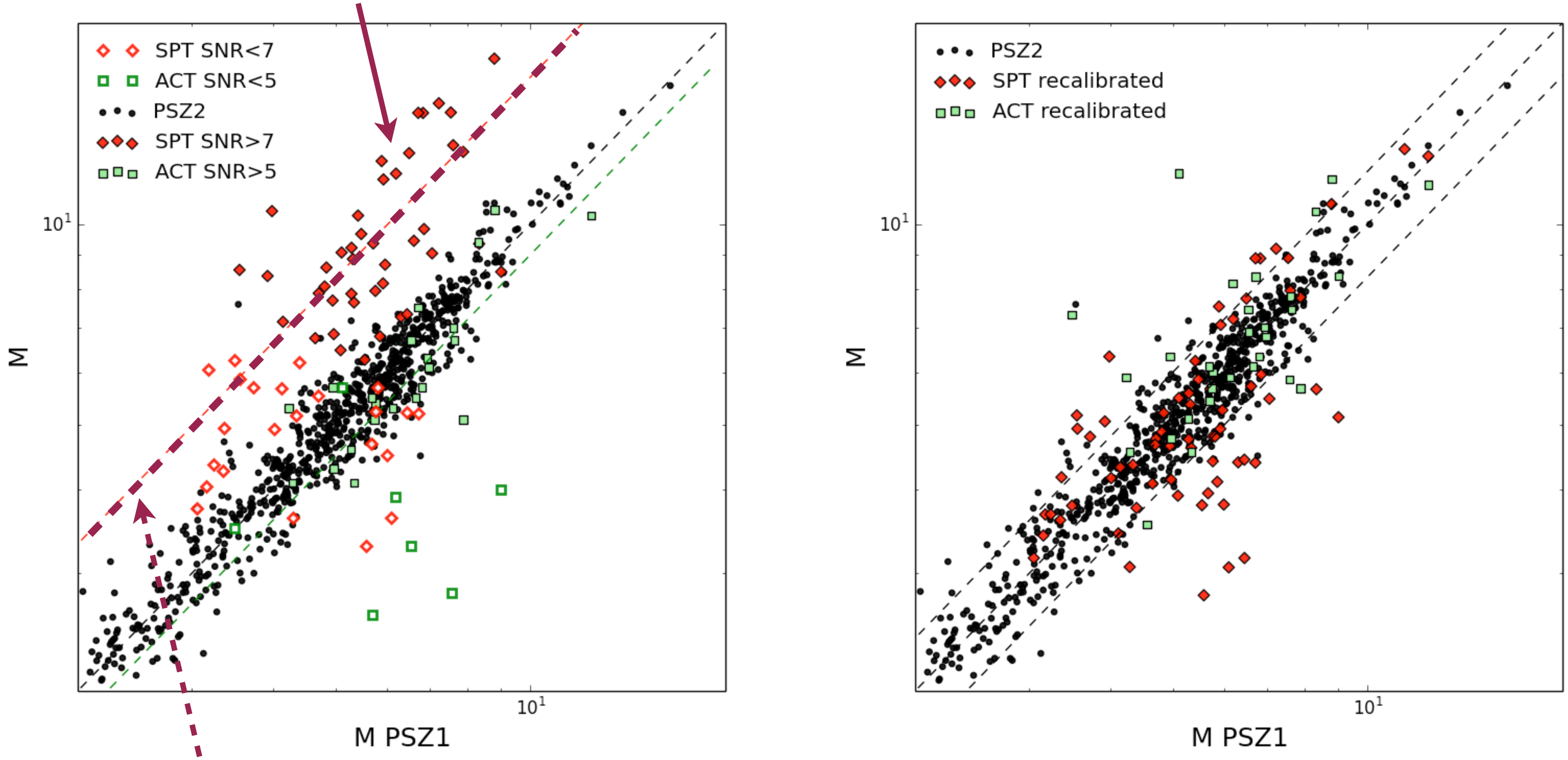


Ilic, Blanchard, Douspis, A&A, 2015

Indirect comparison

Comparison of masses from SPT (abundance) and Planck (HydM)

SPT masses assume CMB cosmology

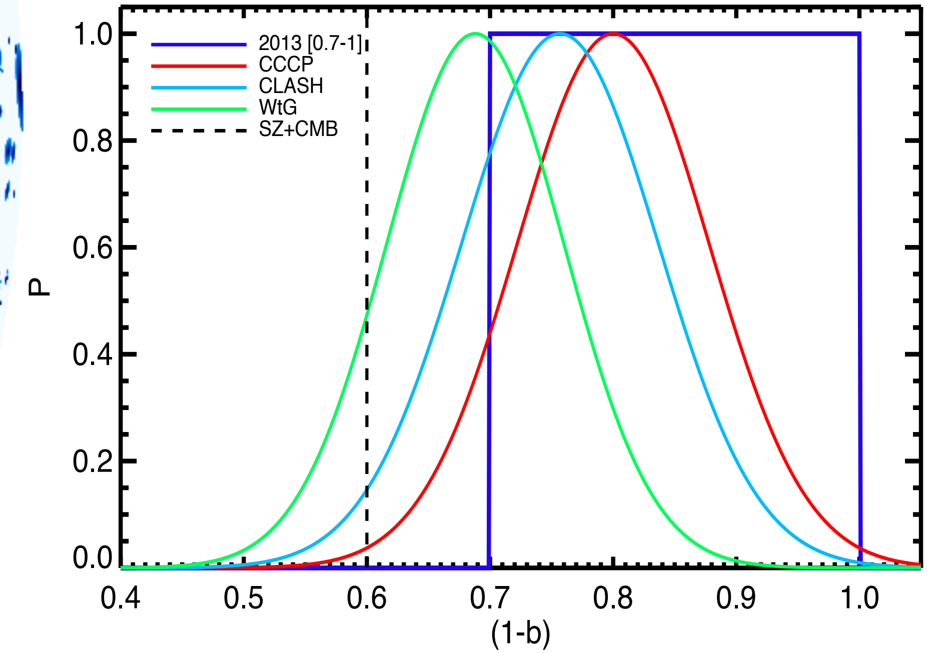


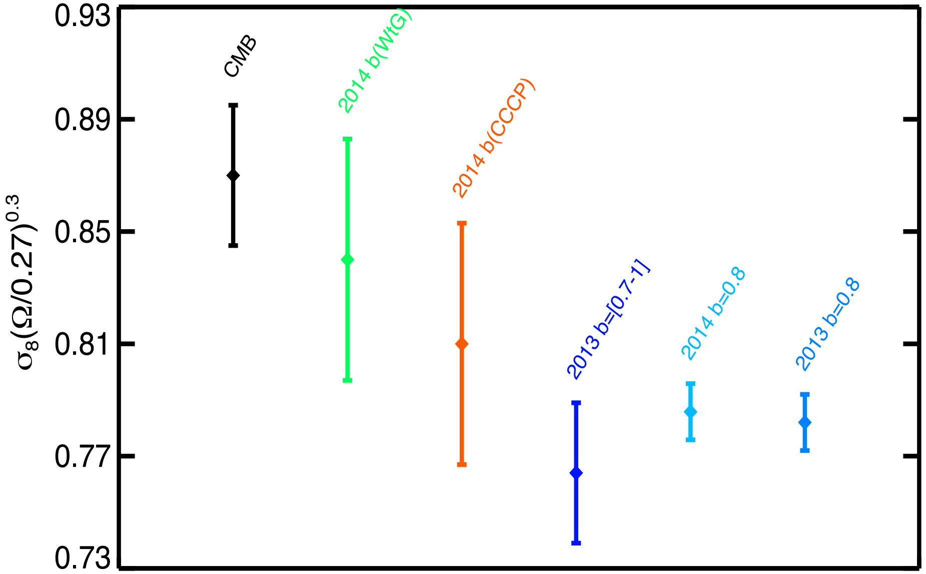
$M_{PSZ} = 0.6\, M_{SPT}$ → consistency SPT-Planck (at least for high SNR/masses)

Douspis, sub. A&A, 2015

non SZ/X information?

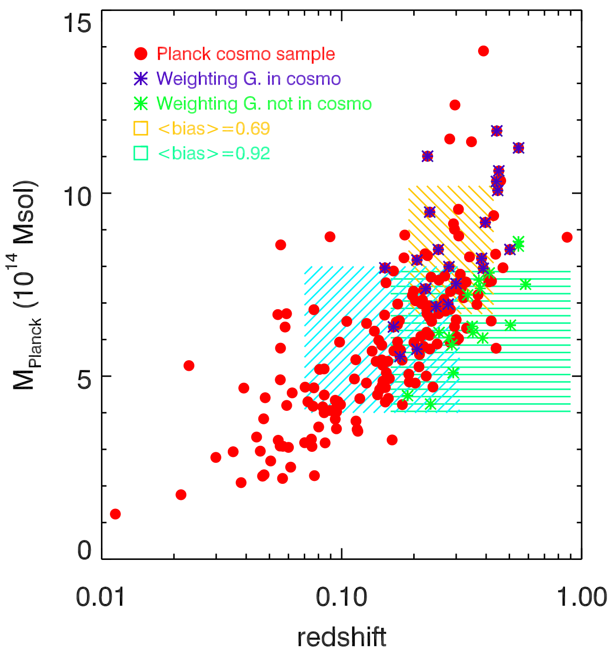
- Weak Lensing for the mass estimation:
  - ➡ traces directly the total mass (for few clusters)
  - ➡ recalibrate your masses: $Y_{SZ} \propto M^{YX} = (1-b)M_{WL}$





Weak Lensing

- Several studies on small (not necessarily representative) samples

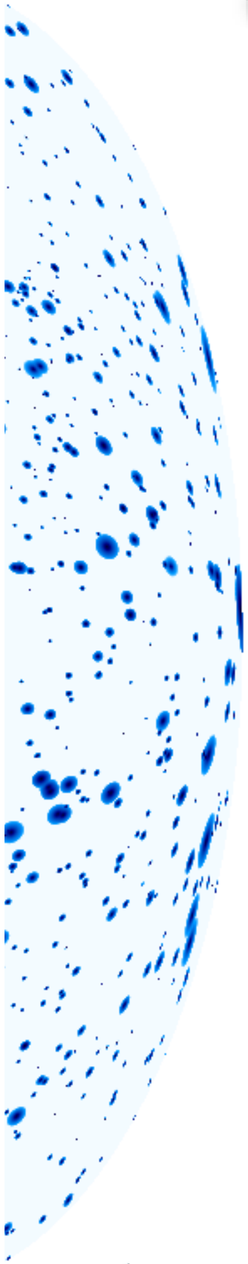


$$(1-b) = 0.8\ in\ [0.7-1.0]$$

Zhang+10	X/WL	~0.9
Mahdavi+13	X/WL	~0.9
Israel+14,15	X/WL	~1Chandra ~0.8 XMM
Donahue+14	X/WL	~0.7-1.1
Gruen+14	X/WL	~1
Smith+15	X/WL	~1
Okabe+15	X/WL	~0.8
Applegate+15	X/WL	~1
Simet+15	X/WL	~0.8
von der linden+14	SZ/WL	~0.7
Hoekstra+15	SZ/WL	~0.8
Battaglia+15	SZ/WL	~1
Maughan+15	X/caustic	~1
Smith+15	SZ/X	~0.95
Douspis+15	SZ/SZ	~1
Ilic+15	X/SZ	~1

Weak Lensing is a good way to go but needs better/larger samples and lower systematics

Conclusions & Perspectives



- Cosmology from SZ selected clusters limited by systematics (same for other wavelenght by the way)
- Robustness of results wrt theoretical assumptions and samples used
- In agreement with some other cluster studies
- Agreement with *Planck* SZ power spectrum, and other orders

- Mass from lensing of clusters
  - (1-b) between 0.7 - 1
- Need for better mass estimate
  - larger sample
  - more representative sample
  - lower obs. systematics
  - coherent observations
- Tension with *Planck* CMB
  - still unsolved
  - neutrinos/bias/?