Title: The Sunyaev Zel'dovich contribution in CMB power spectra analysis : from contaminant to usefull signal

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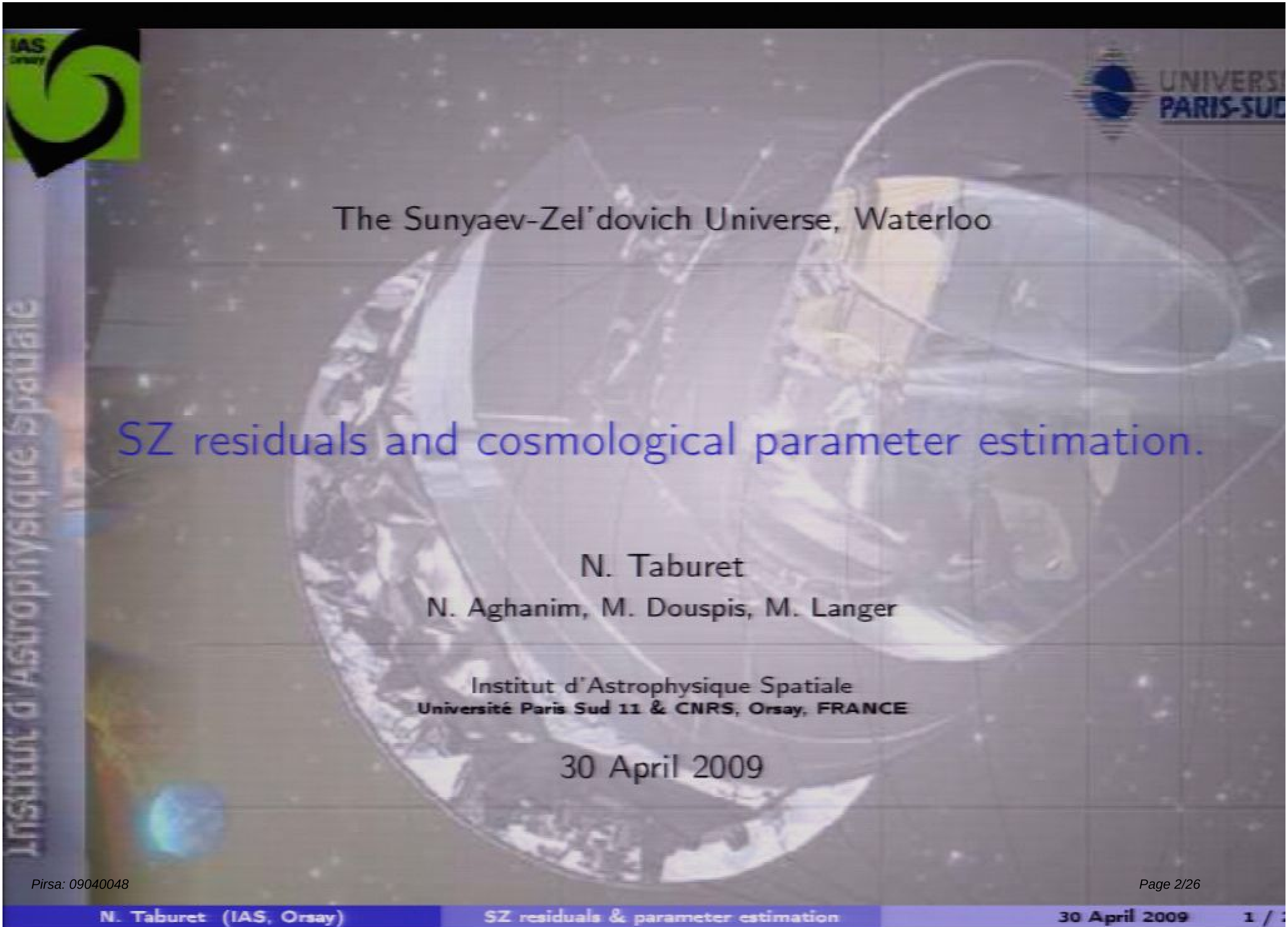
Abstract: The Sunyaev Zel'dovich effect is expected to be one of the major contaminants at arcminutes scales in CMB analysis. I will present a method we developed at IAS to quantify the biases on parameter determination when any additive signal is not taken into account in the analysis. I will then present an application of this method in order to quantify the biases induced on cosmological parameter estimation when the SZ residuals are not properly taken into account in the analysis of the CMB. The important biases that would result from such a treatment encouraged us to developed a joint analysis of the CMB plus SZ signal that consists in determining the cosmological parameters fitting both signals. I will compare various methods to carry out such an analysis and will emphasize that only the coherent method that takes into account the dependency of the SZ spectrum with all the cosmological parameters allows an unbiased determination of the parameters. I will conclude by discussing the improvement on parameters error bars du to the extra information included in the SZ power spectrum and by pointing out the difficulties that our incomplete understanding of the intra cluster gas physics can set.



The Sunyaev-Zel'dovich Universe, Waterloo
SZ residuals and cosmological parameter estimation.
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30 April 2009
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SZ residuals & parameter estimation
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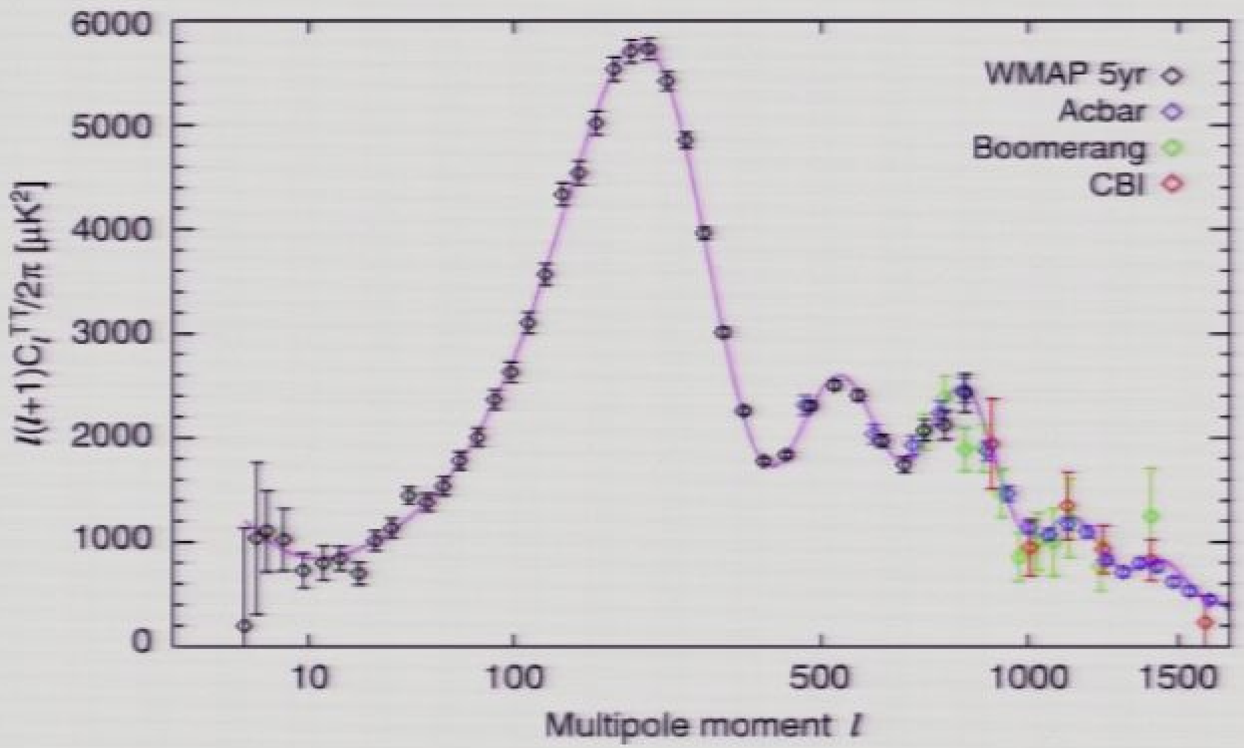
Context

- Large scale temperature and polarisation CMB observations => concordance model



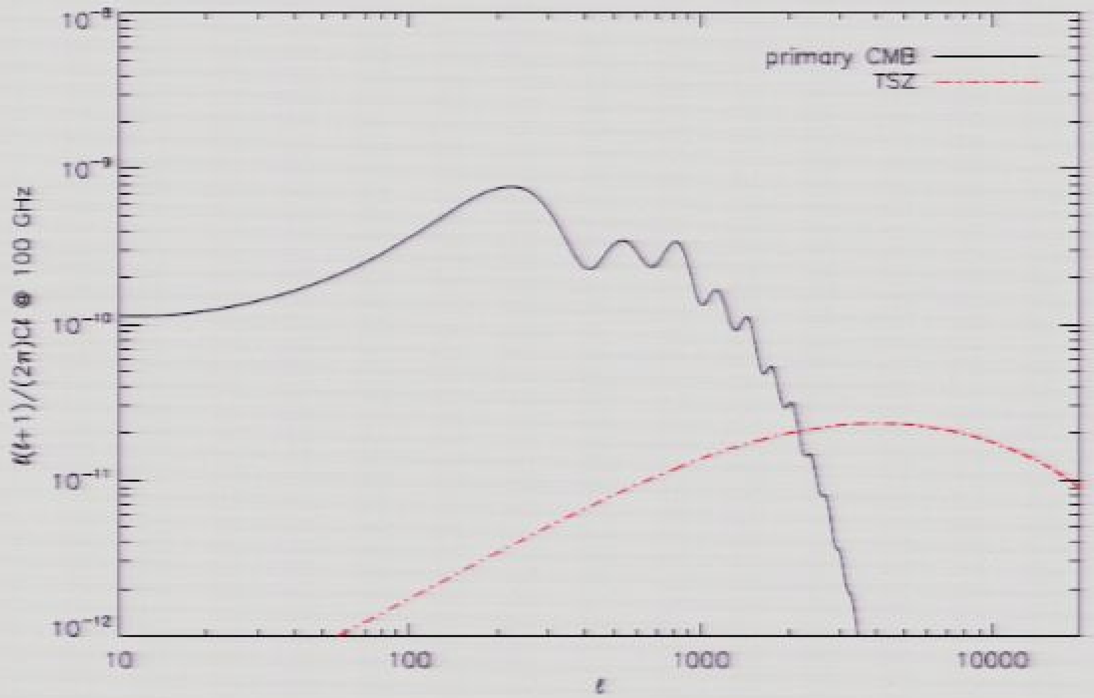
Nolta et al., 2009

⇒ exquisite precision (a few percent) on the cosmological parameters values e.g. $n_s = 0.963 \pm 0.014$ **(Dunkley et al., 2009)**

- Complementary experiments are observing anisotropies at small scales : excess power in respect to primary CMB.

Secondary anisotropies affect the primary CMB

- Gravitationnnal effects
- Scattering effects



Thermal SZ main contribution at small scales and dominates over primary CMB above $\ell \simeq 2500$

How to deal with this SZ signal ?

Different approaches can be considered :

- Fit the total signal with $C_\ell^{\rm CMB} + C_\ell^{\rm SZ}$: cf M. Douspis' talk
- Remove SZ contribution of detected clusters $\Rightarrow$ left with residuals

I studied the 2$^{\rm nd}$ approach in order to determine if it is a valuable method.

$\Rightarrow$ need for a method to calculate the biases induced on parameter values when residuals are neglected.

Outline

1. Our general method for bias calculation   Taburet et al., MNRAS, 2009, 392, 1153
2. Analytical calculation of the TSZ residuals
   - Detection of galaxy clusters
   - The TSZ residuals angular power spectrum
3. Different methods to deal with SZ : the biases remain !

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Biases induced by an additive signal

Dataset $(C^{\rm D}_{\ell_1},\dots,C^{\rm D}_{\ell_d})$=primary signal + additive signal

- Fitting the data with a model describing **primary signal + additive signal**
  $\Rightarrow$ best model ${}_1\hat{\theta}$
  This is the fiducial model
- Fitting the data with a model describing **only primary signal**
  $\Rightarrow$ best model ${}_2\hat{\theta}$
  But this parameter set is shifted from the fiducial model

Bias on the values of the parameters :

$$\hat{b} = {}_2\hat{\theta} - {}_1\hat{\theta}$$

$\Rightarrow$ We want an analytical method that can calculate biases even when neglected signal dominates over primary one.

Analytical prediction of the biases Taburet et al., MNRAS, 2009, 392, 1153

Assumptions (similar to the widespread Fisher matrix analysis) :

- Gaussian distribution of the associated errors to each C_ℓ data point

⇒ To estimate the best fitting parameter set : minimise the associated χ^2

$$\chi^2(\hat{\theta}) = \sum_{\ell} \sum_{X,Y} \mathrm{cov}_\ell^{-1}(C_\ell^X C_\ell^Y)(C_\ell^{DX} - C_\ell^{Xmod}(\hat{\theta}))(C_\ell^{DY} - C_\ell^{Ymod}(\hat{\theta}))$$

where X, Y =TT, EE, TE.

- cov_ℓ variance-covariance matrix coefficients independant of the parameters. function of the instrumental caracteristics

Fitting with full signal : $C_\ell^{Xmod} = C_\ell^{X\mathrm{CMB}} + C_\ell^{X\mathrm{add}}$
Neglecting the additive signal : $C_\ell^{Xmod} = C_\ell^{X\mathrm{CMB}}$

Analytical prediction of the biases (2) Taburet et al., MNRAS, 2009, 392, 1153

We calculated that bias on parameter θ_i is :

$$b_i = \sum_j G_{ij}^{-1} \sum_\ell \sum_{X,Y} \mathrm{cov}_\ell^{-1}(C_\ell^X C_\ell^Y) \left[C_\ell^{Y\mathrm{add}} \left.\frac{\partial C_\ell^{X\mathrm{mod2}}}{\partial \theta_j}\right|_{\hat\theta={}_1\hat\theta} + C_\ell^{X\mathrm{add}} \left.\frac{\partial C_\ell^{Y\mathrm{mod2}}}{\partial \theta_j}\right|_{\hat\theta={}_1\hat\theta} \right]$$

where **G** is :

$$G_{ij} = \sum_\ell \sum_{X,Y} \mathrm{cov}_\ell^{-1}(C_\ell^X C_\ell^Y) \left[\left.\frac{\partial C_\ell^{Xmod2}}{\partial \theta_i}\right|_{\hat\theta={}_1\hat\theta} \left.\frac{\partial C_\ell^{Ymod2}}{\partial \theta_j}\right|_{\hat\theta={}_1\hat\theta} + \left.\frac{\partial C_\ell^{Xmod2}}{\partial \theta_j}\right|_{\hat\theta={}_1\hat\theta} \left.\frac{\partial C_\ell^{Ymod2}}{\partial \theta_i}\right|_{\hat\theta={}_1\hat\theta} - C_\ell^{X\mathrm{add}} \left.\frac{\partial^2 C_\ell^{Ymod2}}{\partial \theta_i \partial \theta_j}\right|_{\hat\theta={}_1\hat\theta} - C_\ell^{Y\mathrm{add}} \left.\frac{\partial^2 C_\ell^{Xmod2}}{\partial \theta_i \partial \theta_j}\right|_{\hat\theta={}_1\hat\theta} \right]$$

Advantages of our method :

- Faster than an MCMC based study
- Applicable for any C_ℓ^{add} (**negligible or not**).(When negligible we recover a formula used by Zahn et al., 2005...)
- Usable for different additive signal (systematics, point sources...) (example : Schaefer et al. 2008. uncertainties in the evolution of matter bias)

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Analytical calculation of the TSZ residuals

Large upcoming **multifrequency surveys** (Planck, SPT...) + galaxy clusters **typical SZ spectral signature** ⇒ detection of galaxy clusters ⇒ build up **SZ cluster catalogues**

SZ residuals

Are these residuals a problem ?

Can we neglect them ?

To answer this question :

- consider an experiment ⇒ *Planck*
- calculate the TSZ residuals

Our approach :

1. Build up a theoretical selection function
2. Compute the residual TSZ angular power spectrum for various detection thresholds

- Calculate biases on the values of cosmological parameteres when this residual is neglected.

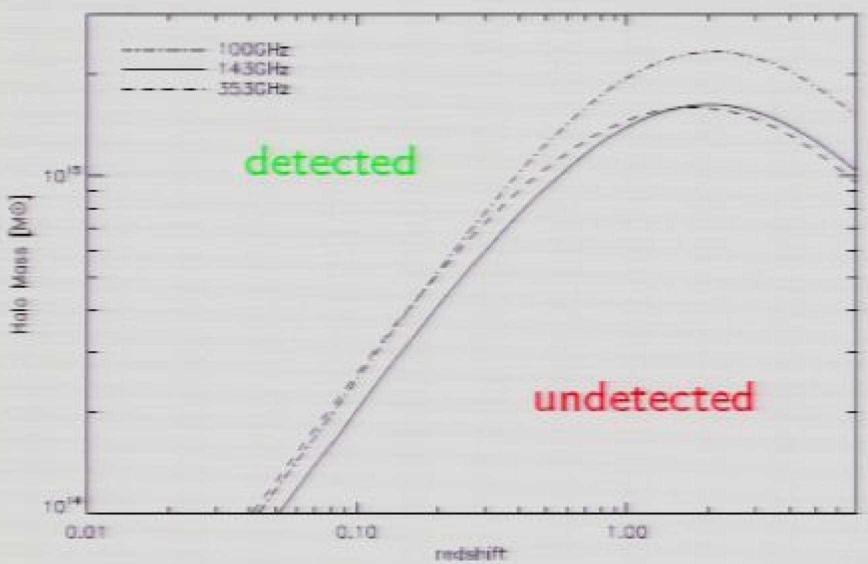
The theoretical SZ selection function

Galaxy cluster detected if : **(following Bartelmann, 2002)**

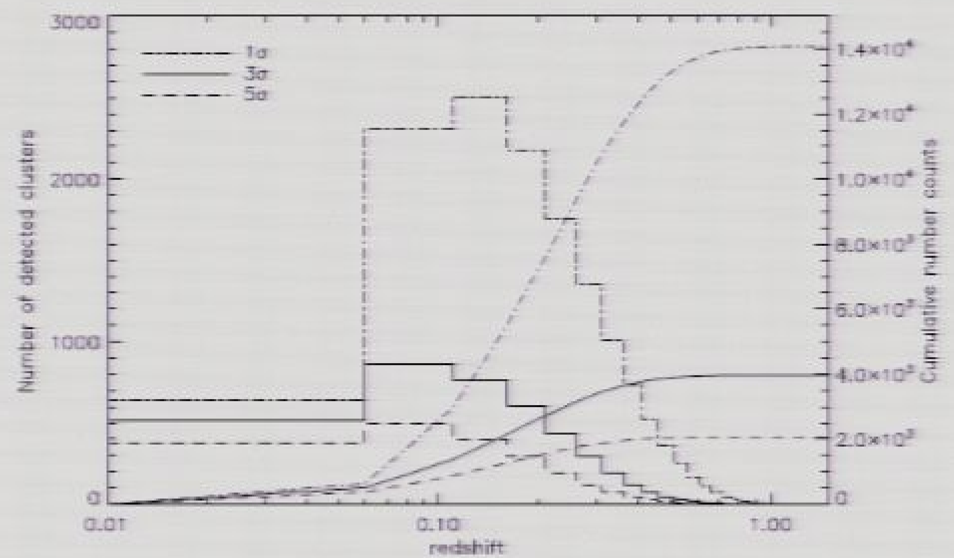
- its beam-convolved Compton parameter emerges from the confusion noise, $\bar{y}(\theta) \geq \Delta y_{\rm bg}$
- its integrated signal is above the instrumental limit, simultaneously in the 3 channels of interest (100, 143 and 353 GHz) :

$$\overline{\Delta F(\nu)} = \mathrm{I}_0 g(\nu) \int \bar{y}(\theta) d\Omega \geq \mathrm{I}_0 g(\nu) \lambda \bar{Y}_{\rm lim}$$

Idealised selection function :



Clusters detected by *Planck* per redshift slices :



The TSZ residuals angular power spectrum

For each multipole ℓ 2 contributions :

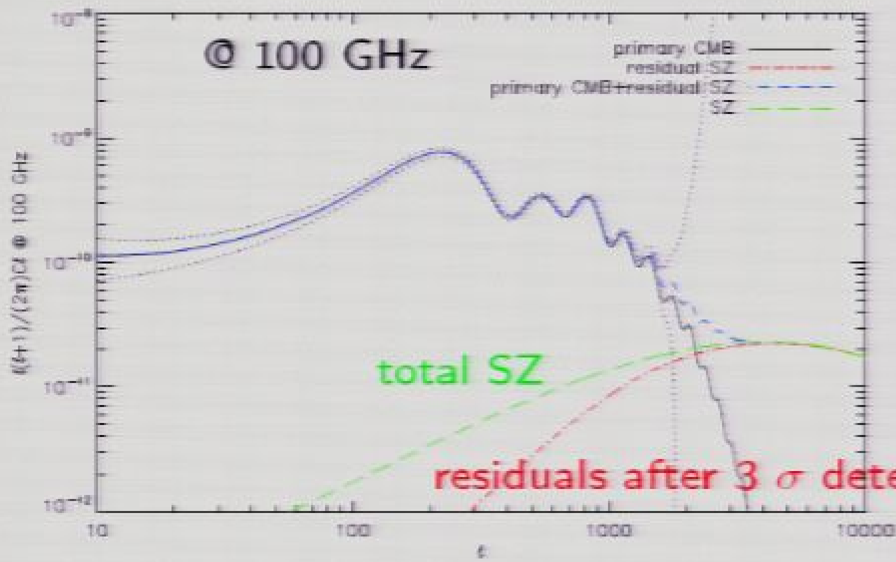
- poisson contribution
- the correlation between the clusters (negligible at $\ell > 300$ - **Komatsu & Kitayama, 1999**)

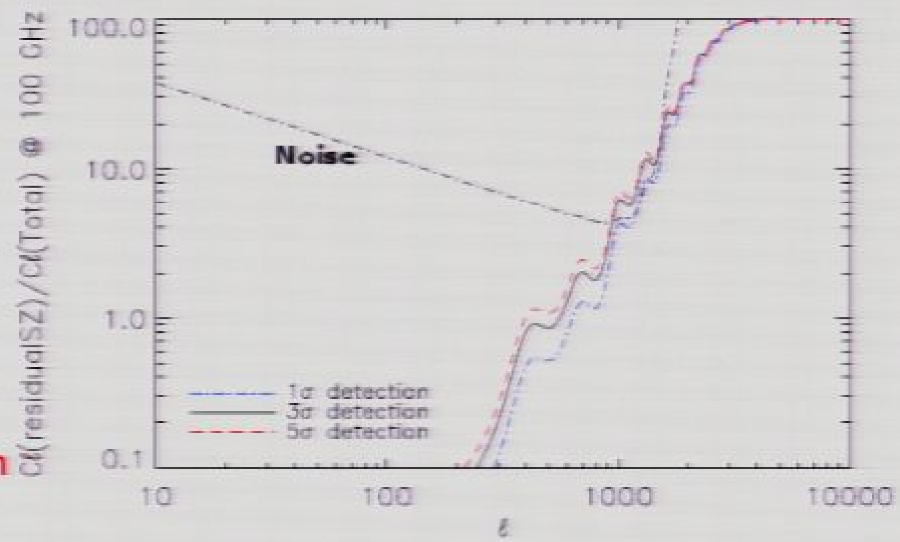
The poissonian contribution to the TSZ angular power spectrum writes **(Komatsu & Seljak, 2002)** :

$$C_\ell = f_\nu^2 \int_0^{z_{\rm dec}} dz \frac{dV}{dz} \int_{M_{\rm min}}^{M_{\rm max}} dM \frac{dn(M,z)}{dM} |\tilde{y}(M,z)|^2$$

It thus depends on the cosmology and the distribution of the intra-cluster gas.

- isothermal β-model to describe the hot intra-cluster gas
- Sheth & Tormen mass function
- $M_{\rm max} = M_{\rm lim}(z)$ (from selection function) to calculate the residual TSZ angular power spectrum





Massive and low z clusters removed : quite a lot of residuals. What is their impact ?

Relative contribution of the TSZ residual to the signal @100GHz for a 1, 3 and 5 σ detection compared to the uncertainties on the C_ℓ (dot-dashed line).

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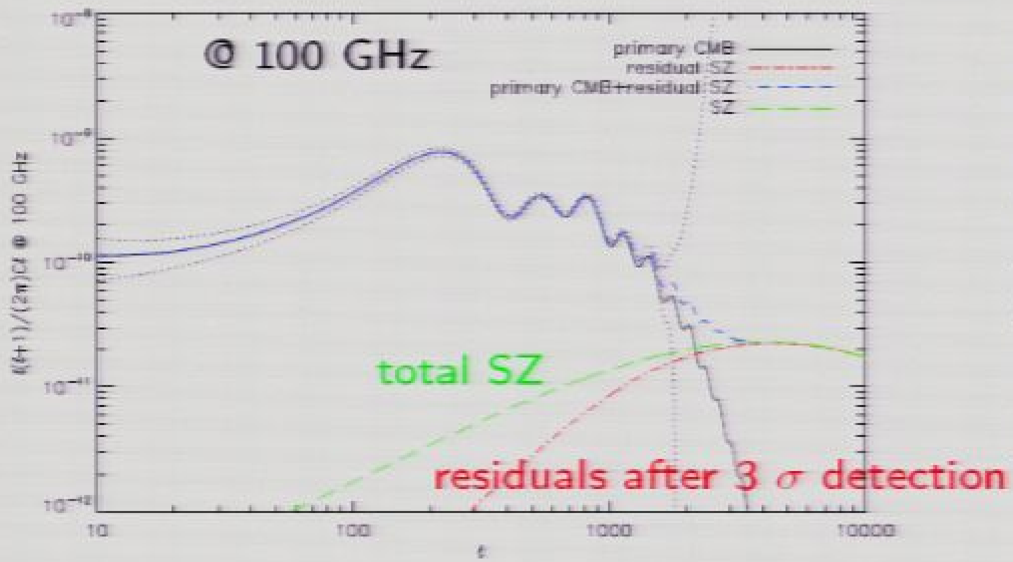

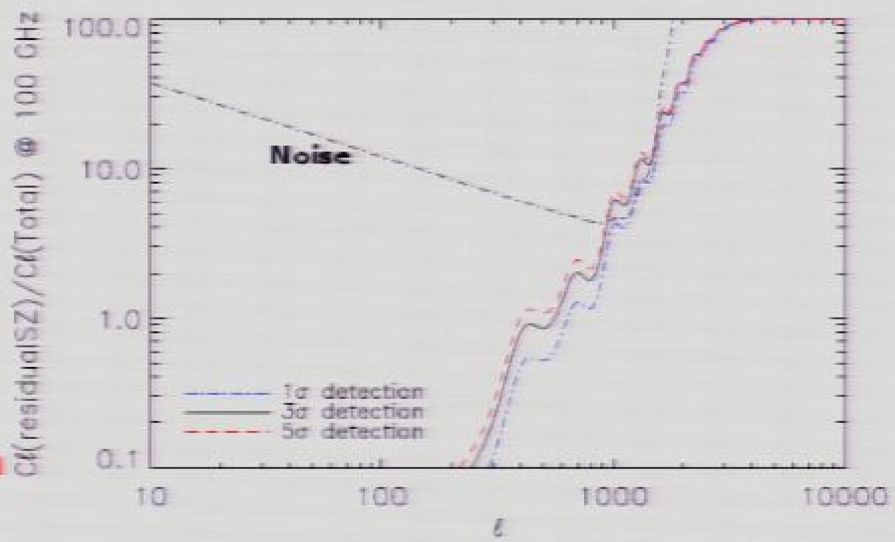

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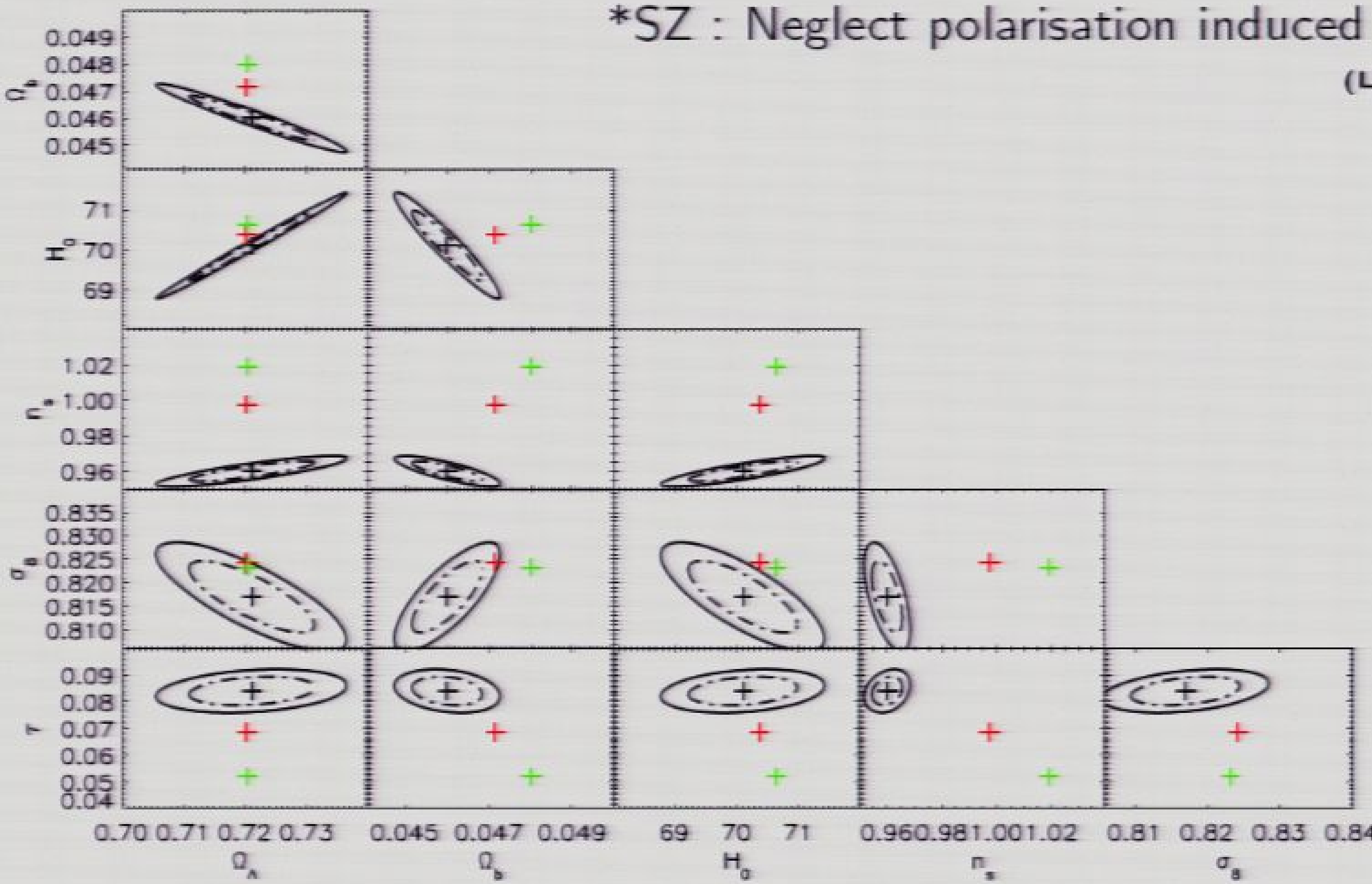
Biases on cosmological parameters due to TSZ residuals

*CMB : TT, EE and TE. *Planck* @ 100 GHz

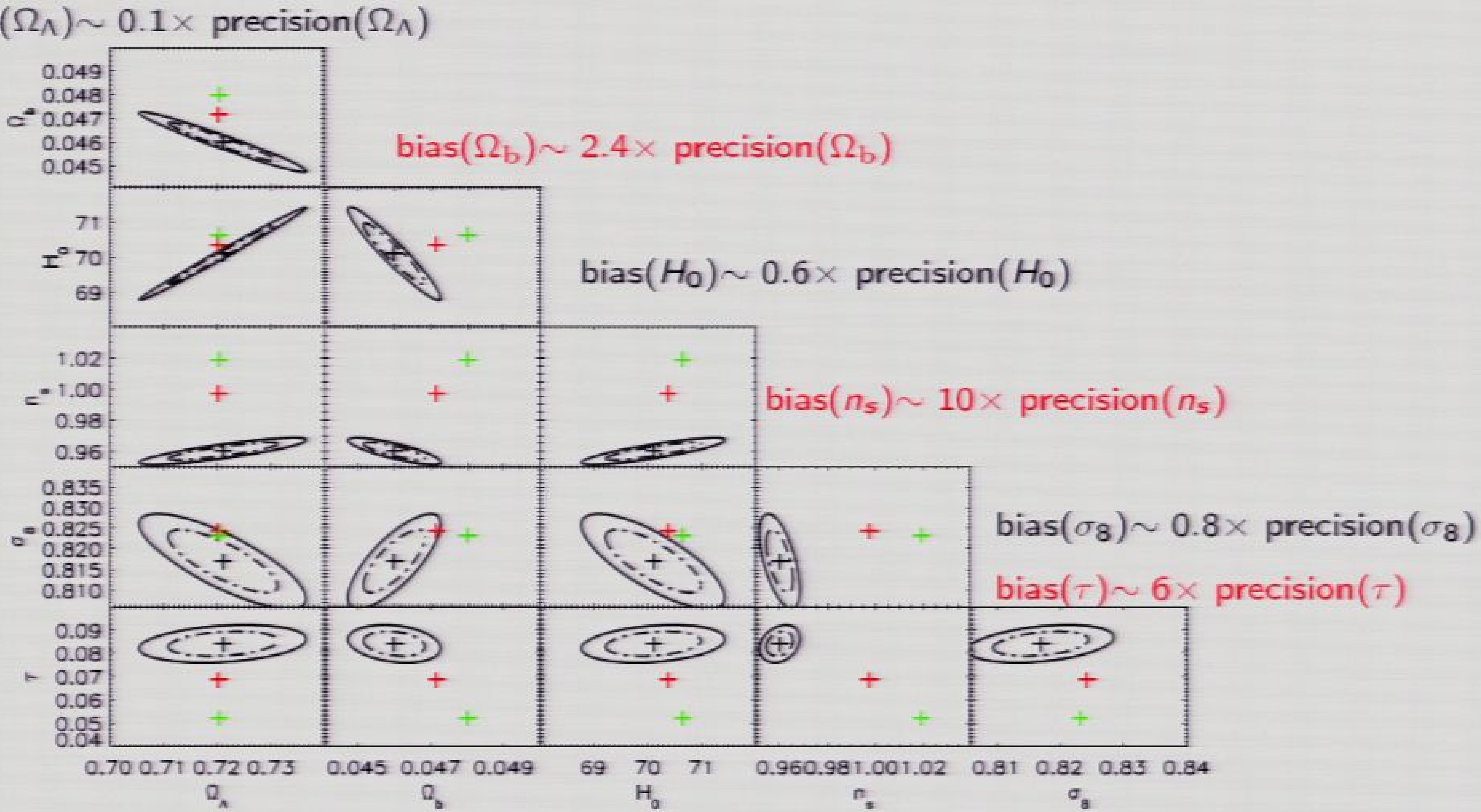
*SZ : Neglect polarisation induced by galaxy cluste

(Liu et al. 2005)



68.3% joint confidence regions. Black : reference model

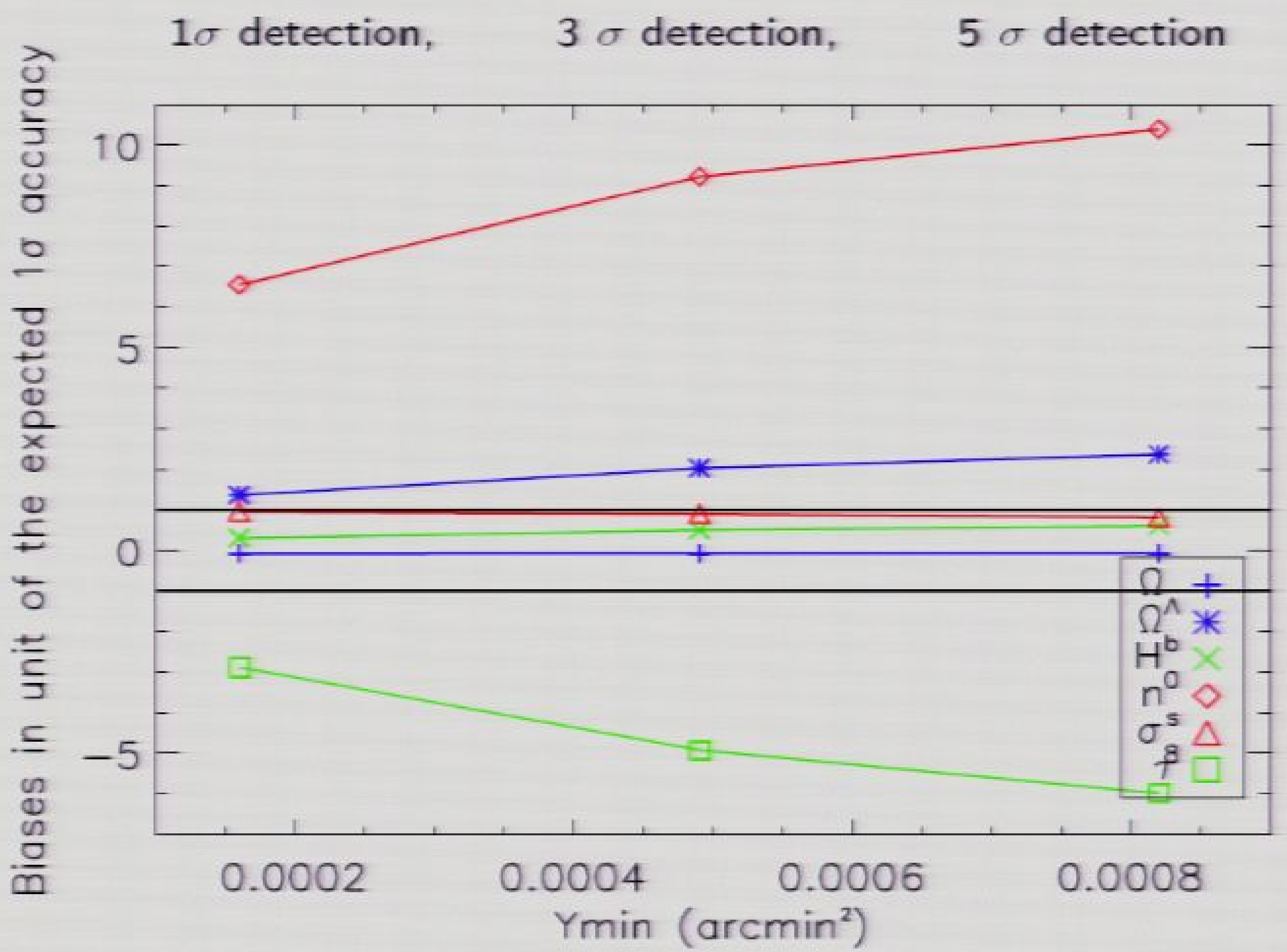
Biases on cosmological parameters due to TSZ residuals



68.3% joint confidence regions. Black : reference model, Red and Green : biases induced by the TSZ residuals after a 1σ and 5σ detection threshold.

Biases on cosmological parameters due to TSZ residuals

Important biases on σ_8, Ω_b and to a higher extent on n_s and τ.

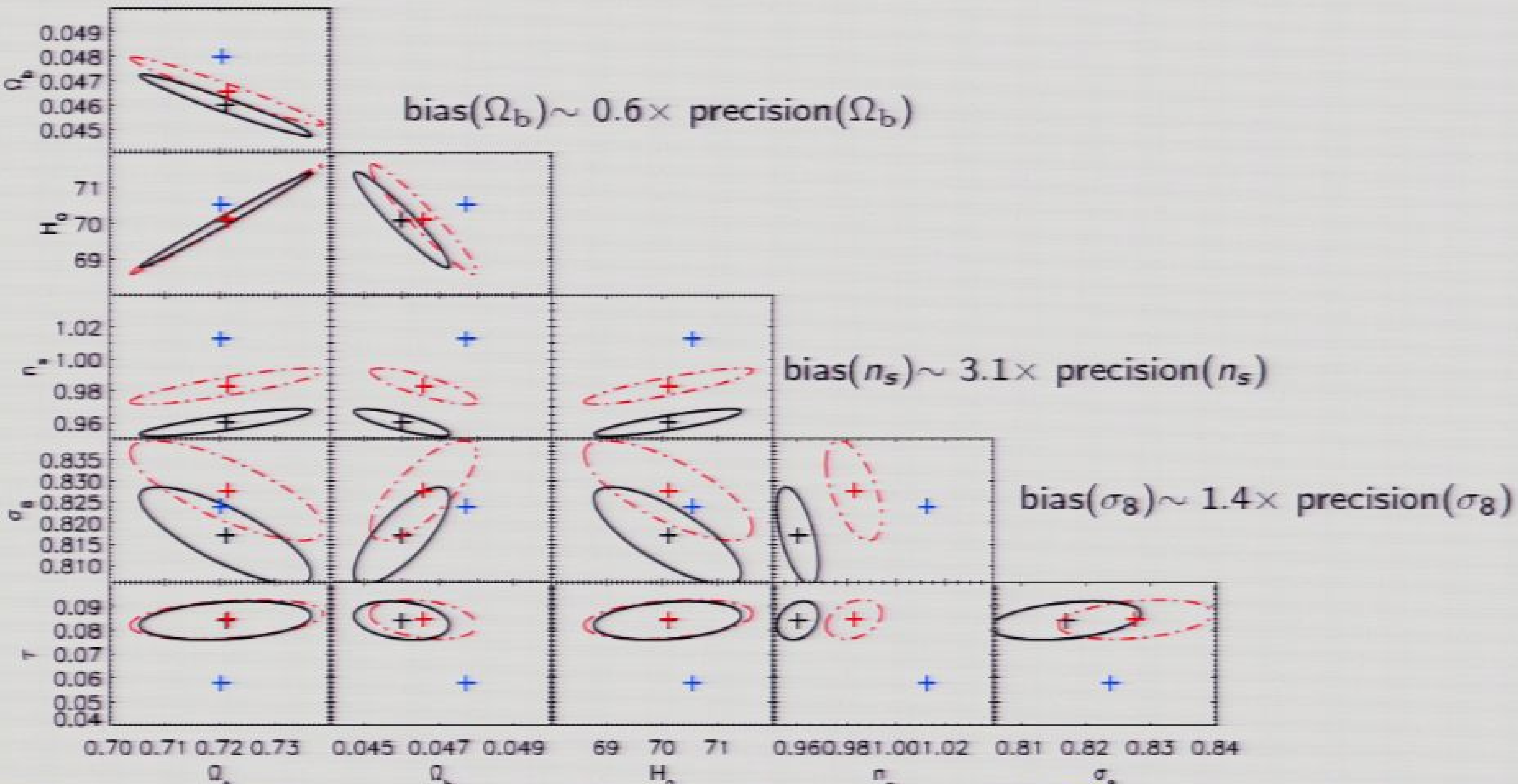


$\Rightarrow$ Problem due to TSZ residual contribution.

a solution ? Do not use TT data with $\ell > 1000$. (Zahn et al. 2005, context of reionisation)

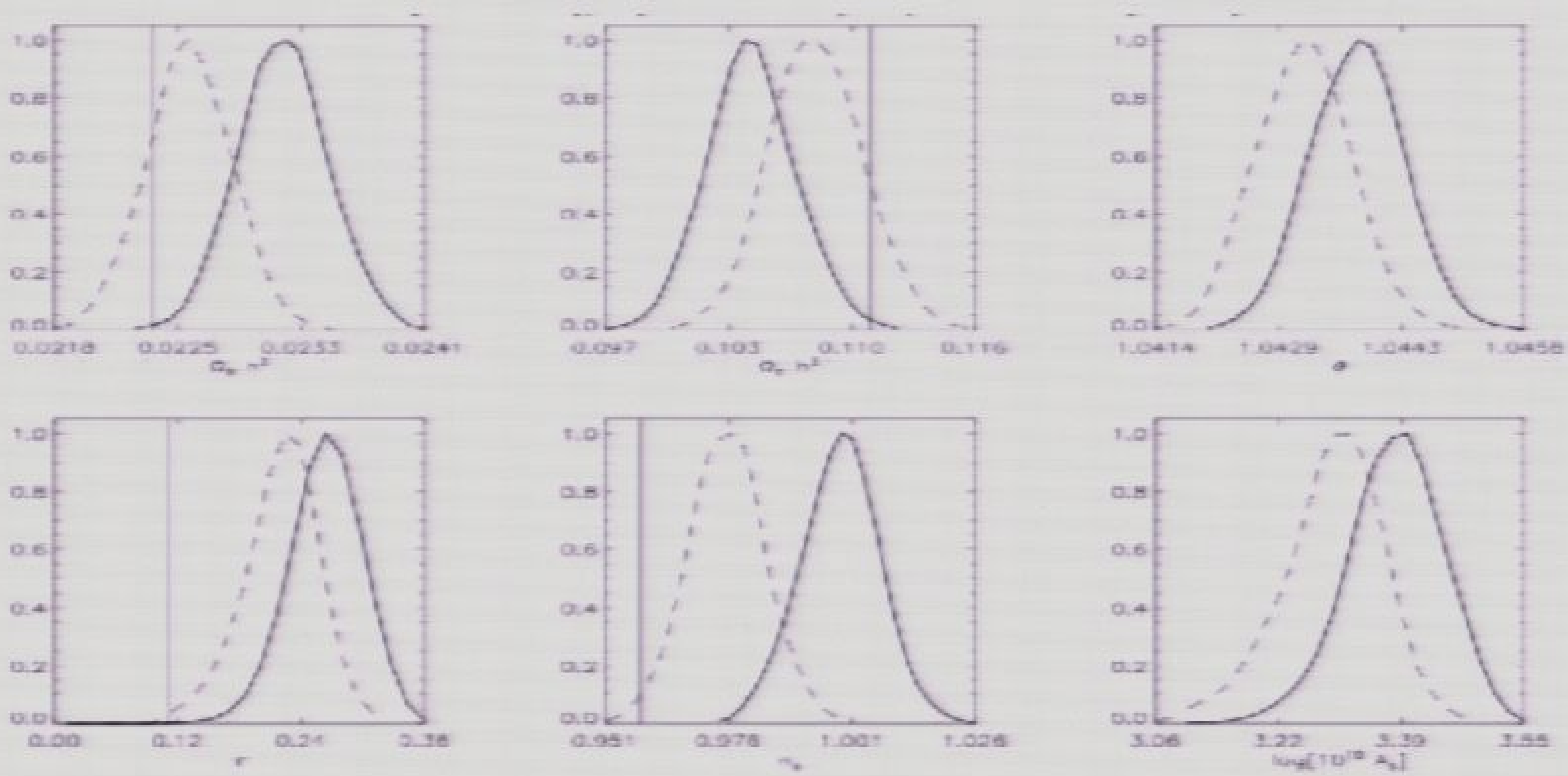
- Expect lower biases on cosmological parameters
- What about the accuracy of parameter estimation ?

Cut TT spectrum at $\ell = 1000$ for parameter estimation ?



68.3% joint confidence regions. Black : reference model, Blue : biases induced by the TSZ residuals after a 3σ detection. Red : biases and accuracy degradation induced by the TSZ residuals after a 3σ detection and cut TT at $\ell = 1000$.

- Component separation to remove SZ contribution. problem : not perfect : still residuals (filaments...)

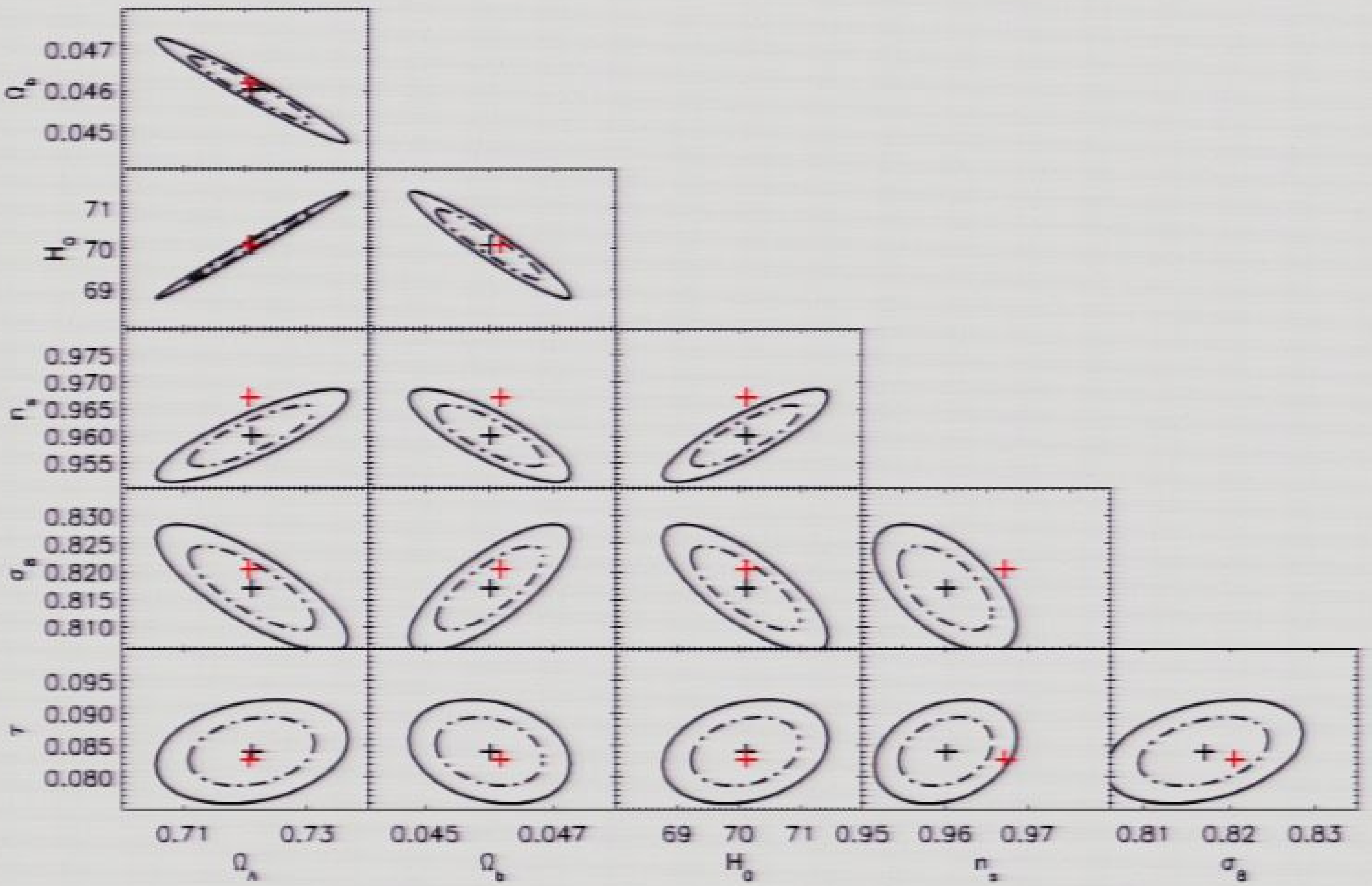


CosmoMC + residuals from Planck WG2 challenge component separation
from J-A Rubino-Martin

Let's suppose component separation allows to remove all TSZ.

$\Rightarrow$ still have point sources, kSZ...

217 GHz, biases induced by kSZ only



Biases on inflation related parameters n_s and σ_8.

Conclusions :

- Exact and analytical method to calculate biases induced by any additive signal (astrophysical or systematics)
- **residuals in CMB analysis $\Rightarrow$ significant biases on Ω_b and particulary n_s and τ**
  Planck : several times the expected accuracy on these parameters !
- Cut TT at $\ell = 1000$: some parameters are still biased + degraded accuracy
- 217 GHz : kSZ (+ other foregrounds) $\Rightarrow$ biases.

Ongoing work :

- SZ not only a contaminant : use it to constrain gas physics
- consistent analysis CMB + secondary anisotropies (cf M. Douspis' talk)