Sunyaev-Zel’dovich contribution in CMB analyses

N. Taburet*, M. Douspis, N. Aghanim,
Institut d’Astrophysique Spatiale, Université Paris-Sud 11 & CNRS (UMR 8617), Bât. 121, 91405 Orsay Cedex, France

ABSTRACT
The Sunyaev-Zel’dovich (SZ) effect has long been identified as one of the most important secondary effects of the Cosmic Microwave Background (CMB). On the one hand, it is a potentially very powerful cosmological probe providing us with additional constraints and on the other hand it represents the major source of secondary fluctuations at small angular scales ($\ell \gg 1000$). We investigate the effects of the SZ modelling in the determination of the cosmological parameters. We explore the consequences of the SZ power spectrum computation by comparing three increasingly complex modelling, from a fixed template with an amplitude factor to a calculation including the full cosmological parameter dependency. We also examine the dependency of the cosmological parameter estimation on the intra-cluster gas description used to calculate the SZ spectrum. We show that methods assuming an SZ template bias the cosmological parameters (by up to 2$\sigma$ on $\sigma_8$) when the cosmology used in the template deviates from the reference one. A joint CMB-SZ analysis with a full cosmological dependency of the SZ spectrum does not suffer from such biases and moreover improves the confidence intervals of $\sigma_8$ and $\Omega_{\text{dm}} h^2$ (2.5 and 2 times respectively) with respect to a pure CMB analysis. However, the latter method is quite sensitive to the intra-cluster gas parameters and hence requires extra information on the clusters to alleviate the induced biases.

Key words: cosmology: theory – methods: statistical – cosmic microwave background – cosmological parameters – galaxies: clusters: general

1 INTRODUCTION
Over the last decade, the low multipole observations of the Cosmic Microwave Background (CMB) angular power spectrum, in intensity and polarisation, show that a $\Lambda$CDM concordance model describes accurately the Universe (Komatsu et al. 2008) with the basic cosmological parameters constrained (Dunkley et al. 2009) with a precision of the order of a percent. To obtain even better constraints on "standard" cosmological parameters and in order to further constrain the cosmological model (dark energy, running of the spectral index, etc.), various experiments are collecting data especially at high multipoles (CBI, BIMA, ACBAR, SZA) (Holzapfel et al. 2000; Dawson et al. 2001; Padin et al. 2001; Runyan et al. 2003; Muchovej et al. 2007). These experiments discussed the existence of a power excess at large $\ell$ values that could be accounted for by point sources, SZ effect or more exotic physics -non standard inflation, primordial voids, features in the primordial spectrum, primordial non-Gaussianity, etc.- (Elgarøy et al. 2002; Cooray & Melchiorri 2002; Griffiths et al. 2003; Bond et al. 2005; Dawson et al. 2006; Douspis et al. 2006; Reichardt et al. 2009; Sievers et al. 2009; Sharp et al. 2009). This highlights the necessity to carry out a consistent analysis of the CMB signal, based on a model that describes both primary anisotropies and also the secondaries arising from the interaction of CMB photons with matter between the last scattering surface and the observer.

In the case of experiments that have access to high multipoles ($\ell \gg 1000$), the secondary SZ anisotropies and the point sources contribution will dominate over the primary CMB. A joint analysis of the CMB and SZ power spectra is thus necessary. Different parameterisations of the SZ spectrum have already been used to analyse the data from WMAP, CBI, ACBAR, and BIMA (Spergel et al. 2003; Bond et al. 2005; Douspis et al. 2006; Spergel et al. 2007; Kuo et al. 2007; Reichardt et al. 2009; Dunkley et al. 2009; Sievers et al. 2009). In the present analysis, we address the issue of the calculation of the SZ spectrum used to fit the data. We examine the effect each SZ description (power spectrum and intra-cluster gas model) induces on cosmological parameter estimation in terms of accuracy and possible biases.

In section 2, we briefly introduce the thermal SZ effect and the calculation of its power spectrum. We then present in section 3 the different methods used to jointly fit the CMB + SZ data. We compare and discuss in section 4 the accuracy of the parameter estimation for each of these methods and the possible induced biases. We summarize our results in section 5. Throughout the study we assume a flat $\Lambda$CDM cosmological model and use the WMAP5 cosmological parameters (Komatsu et al. 2009): $\sigma_8 = 0.817$, $n_s = 0.96$, $\Omega_{\text{m}} = 0.279$, $\Omega_{\text{b}} = 0.046$, $h = 0.701$. 

* E-mail: nicolas.taburet@ias.u-psud.fr
2 THE THERMAL SZ ANGULAR POWER SPECTRUM

The Sunyaev-Zel’dovich (SZ) (Sunyaev & Zel’dovich 1972) is the main secondary anisotropy source at arcminute scales. It is made of two terms: the first is the thermal SZ (TSZ) due to the inverse Compton scattering of the CMB photons off the hot electrons in the intracluster gas, and the second is the kinetic SZ (KSZ), a Doppler shift due to the proper motion of clusters with respect to the CMB. The KSZ power spectrum is approximately 2 orders of magnitude smaller than the TSZ. We thus neglect its contribution in the present analysis. The TSZ has a characteristic spectral signature, namely a decrease of the CMB intensity in the Rayleigh Jeans part of the spectrum and an increase in the Wien part that is due to energy transfer from the hot intracluster electrons to the CMB photons. This characteristic frequency signature, given in the non-relativistic approximation, by

\[ f(x) = x \exp(x) - 1, \]

where \( x = \frac{kT_e}{m_e c^2} \).

In the context of the analysis of CMB data, it is necessary to take into account the contribution of the TSZ effect. The most useful tool to account for this contribution as a function of the angular scale on the sky is the TSZ power spectrum. It can be obtained either from hydrodynamical simulations or from analytical calculations. Each of these approaches has its own limitations and drawbacks. In the first case, the amplitude of the SZ spectrum as well as its shape are sensitive to the simulation characteristics. The box-size and resolution, or smoothing length, of the simulation affect the relative amplitudes on large and small scales respectively. When the box-size is too small, the number of massive clusters is underestimated and so is the SZ power at large scales. The resolution of the simulation, or the smoothing length, artificially decreases the SZ power at small angular scales (see for example White et al. 2002). The physical model used to describe the gas is another important source of alteration of the SZ spectrum. For example, it has been showed that preheating (due to energy feedback from supernovae for instance) as well as radiative cooling, that depends on the gas metalicity (Dolag et al. 2005), respectively increases or decreases the amplitude of the TSZ spectrum by a factor of 2 (da Silva et al. 2001). The influence of radiative cooling on the SZ spectrum has also been studied with an analytical treatment by Zhang & Wu (2003) and has been shown to significantly affect the amplitude of the SZ spectrum.

In the second case, the analytical calculation of the TSZ power spectrum is based on two major ingredients: the halo mass function (Komatsu & Kitayama 1999), respectively the mass function \( f(M,z) \) given by the theoretical expression of Press & Schechter (1972) or by fitting formulae to N-body numerical simulations (Sheth & Tormen 1999; Jenkins et al. 2001; Warren et al. 2006). The different mass function can lead to different predictions in terms of the predicted numbers of halo, and thus may induce differences in the power spectrum (Komatsu & Seljak 2002). The shape of the TSZ angular power spectrum depends on the intra-cluster gas distribution and properties through the two-dimensional Fourier transform on the sphere of the 3D radial profile of the Compton y-parameter for individual clusters,

\[
\hat{y}_z = \frac{4\pi}{D_A^2} \int_{0}^{\theta_{max}} y_{sz}(r) \sin(\theta/r) D_A r^2 dr,
\]

where \( y_{sz}(r) = \sigma_T \frac{k T_e(r)}{m_e c^2} n_e(r) \). Several models for the electronic distribution \( n_e(r) \) can be used. The most commonly used are the \( \beta \)-profile (Cavaliere & Fusco-Femiano 1976) and the polytropic gas distribution (Komatsu & Seljak 2001) and extensions of these two. The mean gas mass fraction, \( f_g \), is taken to be 0.086h (LaRoque et al. 2006). As for the intra-cluster gas temperature \( T_e \), it is usually assumed to be isothermal and equal to the virial temperature : \( k_B T_e = \frac{g m_p}{m_e} \), where \( g \) is the mean molecular weight and \( r_{vir} \) is calculated using the formula in Bryan & Norman (1998). The shape of the TSZ angular power spectrum also depends on the cosmological model through the comoving volume \( V_c \), the angular diameter distance \( D_A \) and the mass function \( n(M,z) \).

3 SZ IN CMB ANALYSIS

The estimation of cosmological parameters from the CMB would ideally require a pure primary signal. However the measured CMB data will contain additional contributions, of which the TSZ dominates. The TSZ characteristic frequency signature allows us in principal to remove the secondary contribution of the detected galaxy clusters from the CMB in multi-frequency experiments. However, on the one hand the residual SZ signal, if not taken into account in the analysis, biases the cosmological parameters see (see Taburet et al. 2009), and on the other hand taking it into account requires a good knowledge of the selection function. An alternative method to extracting the SZ contribution and modelling the residuals is to model the total CMB plus SZ spectra and to determine the cosmological parameters using both primary and secondary signals. This is the approach used in all the present high \( \ell \) study.

We can naturally fit the total signal \( C_\ell^{tot} \) with the expression

\[
C_\ell^{tot} = C_\ell^{CMB}(\hat{\theta}) + C_\ell^{SZ}(\hat{\theta})
\]

with \( C_\ell^{SZ}(\hat{\theta}) \) given by Eq. (1) as in Douspis et al. (2006), where \( \hat{\theta} \) stands for the set of cosmological parameters we want to determine.

The main advantage of this, hereafter method 3, is that it includes the full cosmological parameter dependency of the SZ power spectrum. Parameterisations of the SZ power spectrum are also used to fit the CMB data. They are very efficient from the point of view of computation time since they do not require the full calculation of the SZ spectrum at each step of the Monte Carlo Markov Chains (MCMC). As a result, parameterisations of the SZ spectrum can reduce the chains convergence time by a factor of the order of 2. However, the drawback is that they do not reflect the full cosmological dependency of the SZ spectrum. Two methods fall in this category. In the first one, the total CMB power spectrum can be fitted with

\[
C_\ell^{tot} = C_\ell^{CMB}(\hat{\theta}) + A_{SZ} C_\ell(\theta_0),
\]

hereafter method 1, where \( A_{SZ} \) is an amplitude factor multiplying an SZ spectrum template \( C_\ell(\theta_0) \) calculated analytically for a given cosmology described by the set of cosmological parameters \( \theta_0 \) and intra-cluster gas distribution, or obtained from a given numerical simulation (i.e. for a given cosmology and gas physics). In this analysis the templates we used were those used by the WMAP team.

The last method accounts for the main variations in the SZ spectrum amplitude, with the cosmological parameters \( \sigma_8 \) and \( \Omega_m h \).
following Komatsu & Seljak (2002). In this method 2, the total CMB spectrum is fitted with

\[ C_\ell^{\text{SZ}} = C_\ell^{\text{SZ}}(\theta) + \sigma_s^2 (\Omega_b h)^2 C_\ell^{\nu}(\theta), \tag{5} \]

where \( C_\ell^{\nu}(\theta) \) is the SZ spectrum for a given cosmology and intra-cluster gas distribution.

In the following (Sect. 4.1), we investigate the effects on the cosmological parameter estimation of the three methods introduced above. For methods 1 and 2, we used the same SZ spectrum template as that used by the WMAP team (Spergel et al. 2007) and which is based on Komatsu & Seljak (2001, 2002). For method 3, we computed the SZ spectra using the Sheth & Tormen (1999) mass function and the spherical \( \beta \)-profile with \( \beta = 2/3 \) for simplicity. Furthermore in Sect. 4.2, we study the effects of varying this profile on the cosmological parameter estimation.

In order to compare the three different methods, we create mock data, at 100 GHz, in the form of temperature and polarisation power spectra containing primary CMB anisotropies and SZ contribution from all clusters using equation (1). We did not consider the polarisation induced by clusters since it is negligible compared to the primary one (e.g. Liu et al. 2005). In this study, we do not analyse the CMB data produced from multi-frequency observations after component separation. This would require to monitor precisely the residual signal after component separation which is shown to mix all foregrounds and may differ from one component separation method to another. Such an approach was followed by J.-A. Rubino-Martin and gives similar results as ours (private communication). We have rather chosen to use the best channel for CMB study: the 100 GHz channel. In this channel, galactic foregrounds (free-free, dust emission, synchrotron radiation) will contaminate the CMB minimally as well as extragalactic radio and IR point sources. We also consider a Planck-like gaussian and uncorrelated noise power spectrum with a 9.5 arcminutes beam. We ran MCMC analyses, using the CosmoMC code (Lewis & Bridle 2002) with a modified version of the CAMB code (Lewis et al. 2000) including a module that calculates the SZ power spectrum with its full cosmological dependency. We followed for this module the computations detailed in Sect. 2. Given the instrumental beam we considered, we limited the MCMC analysis to multipoles smaller than \( \ell_{\text{max}} = 3500 \). We used a gaussian likelihood function since the probability distribution function of the SZ spectrum is well approximated by a gaussian for a Planck-like survey (Zhang & Sheth 2007). The MCMC were carried out on the set of parameters \( \theta: \Omega_b h^2, \Omega_m h^2 \), the ratio of the sound horizon to the angular diameter distance 100 \( \times \theta_0 \), the optical depth at reionisation \( \tau \), the spectral index \( n_s \), the CMB normalisation \( A_s \), and the SZ normalisation factor \( A_{\text{SZ}} \) when method 1 is used. The deduced parameters are \( \Omega_m, \Omega_b, \sigma_s, \tau_e, H_0 \) and the age of the universe. To ensure that the MCMC runs have converged we used the convergence criterion introduced by Dunkley et al. (2005).

4 RESULTS

4.1 Effects of the SZ modelling on cosmological parameter estimation.

As a first step we examine the choice of the SZ template (used in methods 1 and 2). We thus present the MCMC results, when the SZ template deviates from the real SZ angular power spectrum (i.e. that used to produce the mock data). To account for this possibility, the SZ template we use to fit our simulated data is based on the one used by the WMAP team (Spergel et al. 2007). We normalized this template so that its amplitude at \( \ell = 2000 \) equals the amplitude of the SZ spectrum employed to create the mock data. At such multipoles, the gas properties affect more the SZ amplitude than the cosmology. As a result, this normalisation ensures that the main difference between the SZ spectrum used to create the data, and the template used to fit them in methods 1 and 2, is due to the cosmology.

We represent in figure 2 the one-dimensional distribution of cosmological parameters obtained with the three methods. Using the SZ parameterisation of method 1 (long dashed blue lines) enlarges the 1\( \sigma \) error bars on the parameters and biases the determination of some parameters. The values of \( \Omega_m h^2 \) and \( A_s \) are biased by a few tenths in units of the standard deviation. This translates, for the derived parameters, into a one-sigma bias on \( \sigma_s \), and a few tenths in units of the standard deviation for \( \Omega_m, \Omega_b, H_0 \). These biases are due to the fact that method 1, by construction, allows to vary only the amplitude of the SZ power spectrum and not its shape.

When employing the SZ parameterisation of method 2, the confidence intervals are improved. This can be explained by the fact that in method 1 we constrained an extra parameter \( A_{\text{SZ}} \) while in method 2 the SZ amplitude is given by a combination of \( \sigma_s \) and \( \Omega_b h \). However, as shown in figure 2, the biases on some cosmological parameters become more important. The values of \( \Omega_b h^2, \Omega_m h^2 \) and \( A_s \) are biased by a few tenths in units of the expected precision which, for the derived parameters, leads to a two-sigma bias on \( \sigma_s \), whereas the values of \( \Omega_m, \Omega_b \) and \( H_0 \) suffer from a one-sigma bias. These results can be explained by two facts: first the shape of the SZ template in method 2 does not vary, and second its amplitude at \( \ell < 2000 \) is higher than the SZ spectrum used to produce the data (Fig. 1). The latter forces the estimated \( \sigma_s \) to be biased towards a lower value in order to decrease the SZ amplitude (given by \( \sigma_s^2 (\Omega_b h)^2 \), see Eq. 5) and thus to fit the data. For the same reason the \( \Omega_m \) and \( H_0 \) values are also biased. As for the second point, the “fixed” shape of the SZ template, deviating from the reference one, forces variations of \( \Omega_m, \Omega_b \) and \( \Omega_s \) so that the primary CMB spectrum compensates the shape modifications.
particularly important for compared to the pure primary CMB analysis. The improvement is by a factor 2.

Figure 2. One dimensional parameter distribution. The curves represent the distributions for the CMB+SZ signal fitted with the 3 different methods. Long dashed blue line: method 1, dot-dashed green line: method 2, solid black line: method 3. The SZ template used in method 1 and 2 (blue dotted line in figure 1) differs from that used to create the data (black line in figure 1). The vertical red lines represent the input values of the parameters we used to create our mock data. Note the substantial biases that can affect the estimation of $\sigma_8$ when using method 1 or 2.

Method 3, which does not require any SZ template with a fixed shape, gives unbiased determination of the cosmological parameters as shown by the black curves in Fig.2. The accuracy obtained with method 3 is also better than that obtained with methods 1 and 2. In order to discuss this accuracy improvement, we now compare method 3 to methods 1 and 2 using the SZ template used to create the mock data. The one dimensional parameter distributions obtained from the different methods are presented in figure 3. The black dotted lines represent the parameter distribution when we fit with pure primary CMB a signal that contains primary CMB alone. As expected, all 3 methods give unbiased parameters but their associated error bars (i.e. the accuracy of the parameter determination) differ.

Unsurprisingly, adding an extra parameter (the SZ amplitude $A_{SZ}$) in the MCMC analysis with method 1 enlarges all the error bars (Fig. 3 long dashed blue curves) that would be obtained in a pure primary CMB analysis (black dotted line). Method 2 (dot-dashed green curves) with its explicit and strong dependency of the SZ amplitude on $\sigma_8$ improves the constraints on $\sigma_8$, in comparison to the pure CMB analysis. At the same time, the accuracy on the spectral index $n_s$ is deteriorated. Increasing $n_s$ increases the CMB power at high $\ell$ values but this can be slightly compensated by a decrease of the SZ amplitude through $\sigma_8$ or $\Omega_{dm}$. The solid black curves represent the expected precisions obtained with method 3. We note that they are improved for all parameters except $n_s$ as compared to the pure primary CMB analysis. The improvement is particularly important for $\sigma_8$: a factor 2.5 better. The accuracy on $\Omega_{dm}h^2$ and on the derived parameters $\Omega_m, \Lambda$, $H_0$ is also improved by a factor 2.

Method 3 provides better constraints on the cosmological parameters because it allows to break degeneracies between models, as illustrated in figure 3b. This figure represents the 68.3% confidence region on parameters $\Omega_{dm}h^2$ and $A_s$ when the analysis is only performed on these 2 parameters. An analysis using only the primary CMB signal gives the distribution represented by the red/dark ellipse. Using our SZ module to carry out an analysis on the SZ alone power spectrum (black ellipse) shows that $A_s$ and $\Omega_{dm}h^2$ are strongly degenerated but very differently with respect to a pure CMB, which means that the SZ contains some information complementary to that included in a pure CMB signal. The analysis of the CMB + SZ signals based on method 3 results in the two dimensional distribution represented by the green/light ellipse that is smaller than the red one, taking advantage of the information included in the SZ power spectrum.

Figure 3b represents two pure primary CMB spectra calculated for the reference cosmological model (black solid line) and for a model in which the value of $\Omega_{dm}h^2$ is the reference value plus one standard deviation that was obtained using method 3 (red dotted line). Since this standard deviation is much smaller (twice) than those obtained from a pure primary CMB analysis (see figure 3), these two CMB spectra are almost identical, showing the impossibility for a pure CMB analysis to distinguish between the two cases. The green continuous and dotted lines (figure 3b) respectively represent the SZ power spectra for the reference and the shifted models. The change in the $\Omega_{dm}h^2$ value significantly affects the amplitude of the SZ spectrum. As a result, as shown by the blue curves, the CMB+SZ spectra are different and an analysis based on method 3, that uses the information encoded in the SZ spectrum shape, allows to disentangle the two cosmological models and consequently better constrains the cosmological parameters than a pure primary CMB analysis.

We note that the spectral index $n_s$ is the only parameter that is somewhat less precisely constrained through method 3 than it is in methods 1 or 2. An increase of its value raises both the CMB power and SZ spectra at small scales and lowers their power at large scales. However, while the CMB spectrum pivots at intermediate scales, this happens at large multipoles for the SZ spectrum. As a result an increase of $n_s$ has two competing effects between these domains: it increases the CMB power and at the same time decreases the SZ power. The resulting CMB+SZ spectra for different, but close, values of $n_s$ are thus more similar to each other than pure CMB spectra. That is why the spectral index is slightly
Figure 3. One dimensional parameter distribution. The coloured curves represent the distribution for the CMB+SZ signal fitted with the 3 different methods. Long dashed blue line : method 1, dot-dashed green line : method 2, solid black line : method 3. The SZ template used in method 1 and 2 is the same as that used to create the data. The black dotted line represents the parameter distributions when the signal contains only a pure primary CMB. The vertical red lines represent the input values of the parameters we used to create our mock data.

Figure 4. Left panel: Two dimensional parameter distribution. The black ellipse represents the $\Omega_{\text{DM}}h^2 / A_s$ pairs obtained from the Markov chains analysis of the pure SZ spectrum. The orange (dark grey) ellipse represents the pairs obtained from the analysis of the pure CMB spectrum. The green (light grey) ellipse presents the pairs obtained using the CMB+SZ spectrum. Right panel: The black solid and green dashed lines are superimposed. They represent the pure CMB spectra respectively for the reference cosmological model and a one with a shifted value of $\Omega_{\text{DM}}h^2$ (see text for details). The red thick solid and dashed lines represent the corresponding SZ spectra and the blue solid and dot-dashed line represent the CMB+SZ spectra.

4.2 Effects of the intra-cluster gas physics

As discussed in section 2, the computation of the TSZ power spectrum involves assumptions about the gas physics. Either, on the one hand, hydrodynamical-numerical simulations are performed with given models for the gas evolution (adiabatic cooling, preheating, feedback, etc.), or on the other hand, theoretical computations of the power spectrum choose a model for the intra-cluster gas distribution as well as scaling relations between the total mass and other cluster physical parameters (e.g. temperature). The large diversity of the possible models describing the cluster gas properties reflects the difficulty to summarise in a simple parameterisation the complexity of the intra cluster gas physics. The cluster physical description will inevitably affect the SZ spectrum and consequently the cosmological parameter estimation.

In the following, we focus only on the theoretical computations, for which modifying the cluster physics is straightforward, and we illustrate the effects of such modifications on the cosmological parameters. We restrict our study to one single intra-cluster gas distribution model: the $\beta$-profile. We vary the value of the isothermal gas temperature $T_e$ and the index $\beta$, i.e. the overall amplitude and steepness of the density distribution respectively. We run an MCMC with method 3 to fit the data created with different values of $\beta$ and $T_e$. The resulting one-dimensional parameter distributions are presented in Fig. 5.
An electron distribution with $\beta = 0.8$ (i.e. 20% larger than the reference value) corresponds to a more peaked individual SZ profile. This increases the overall SZ power and shifts the maximum of the SZ spectrum towards smaller scales. Using a primary CMB plus SZ spectrum calculated using the intra-cluster gas reference parameterisation to fit such data results in biasing the estimation of some cosmological parameters, namely $\Omega_b h^2$ (0.85 times the expected accuracy (ea)), $\Omega_{\text{dm}} h^2$ (2.6x ea) and $n_s$ (0.83x ea). This corresponds to biases equal to 2.4 for $\Omega_\Lambda$ and $\Omega_m$, 3.3 for $\sigma_8$ and 2.1 for $H_0$ in terms of the expected precision. A conservative 5% difference on $\beta$ ($\beta = 0.7$), still biases $\Omega_{\text{DM}} h^2$ value at the level of 0.5 times the expected accuracy. The values of $\Omega_\Lambda$ and $\Omega_m$, $\sigma_8$ and $H_0$ are also biased at several tenth of the expected precision (0.4, 0.8 and 0.4).

Overestimating the electron temperature at a 7% level (accuracy on the electron temperature obtained from X-SZ clusters, see [Reese et al. 2002; Bonamente et al. 2006] in the data analysis results also in a biased estimation of some cosmological parameters, namely $\Omega_b h^2$ (0.6x ea), $\Omega_{\text{dm}} h^2$ (1.7x ea) and $n_s$ (0.5x ea). This translates to biases of 1.5 for $\Omega_\Lambda$ and $\Omega_m$, 2.2 for $\sigma_8$ and 1.4 for $H_0$.

5 CONCLUSIONS

In this paper we investigate different methods to jointly fit the primary CMB and SZ signals. We emphasize that methods using a power spectrum template to describe the SZ contribution are likely to bias the cosmological parameter values in the case of an inappropriate choice of the SZ template. This is due to the frozen shape of the SZ spectrum that is inconsistent with changes in the cosmology. We also show that a joint CMB-SZ analysis with a full cosmological dependency of the SZ spectrum does not suffer from such biases. Moreover it improves the estimate of $\sigma_8$ and $\Omega_{\text{dm}} h^2$ (2.5 and 2 times respectively) with respect to a pure CMB analysis. In that respect, such a method can be presented as a coherent analysis of the primary CMB plus SZ signal. However, we point out that our incomplete understanding of the intra-cluster gas distribution and properties can result in errors in the calculation of the SZ angular power spectrum and is likely to bias the cosmological parameter estimation up to 2 sigmas for $\Omega_m$ and $H_0$ and even more for $\sigma_8$. This reinforces the need for better constraints on the description of the galaxy cluster gas properties.

ACKNOWLEDGMENTS

The authors thank the referee and they particularly thank M. Langer for enthusiastic and useful discussions. We acknowledge the use of the CAMB and COSMOMC packages.

REFERENCES

Bonamente, M., Joy, M. K., LaRoque, S. J., et al. 2006, Astrophys. J., 647, 25
Bond, J. R., Contaldi, C. R., Pen, U.-L., et al. 2005, Astrophys. J., 626, 12
Bryan, G. L. & Norman, M. L. 1998, Astrophys. J., 495, 80
Cavaliere, A. & Fusco-Femiano, R. 1976, Astron. Astrophys., 49, 137
Cooray, A. & Melchiorri, A. 2002, Phys. Rev. D, 66, 083001
da Silva, A. C., Kay, S. T., Liddle, A. R., et al. 2001, Astrophys. J. Lett., 561, L15
Dawson, K. S., Holzapfel, W. L., Carlstrom, J. E., Joy, M., & LaRoque, S. J. 2006, Astrophys. J., 647, 13
Dawson, K. S., Holzapfel, W. L., Carlstrom, J. E., et al. 2001, Astrophys. J. Lett., 553, L1
Dolag, K., Hansen, F. K., Roncarelli, M., & Moscardini, L. 2005, Mon. Not. R. Astron. Soc., 363, 29
Douspis, M., Aghanim, N., & Langer, M. 2006, Astron. Astrophys., 456, 819
Dunkley, J., Bucher, M., Ferreira, P. G., Moodley, K., & Skordis, C. 2005, Mon. Not. R. Astron. Soc., 356, 925
Dunkley, J., Komatsu, E., Nolta, M. R., et al. 2009, Astrophys. J. S. S., 180, 306
Elgarøy, Ø., Gramann, M., & Lahav, O. 2002, Mon. Not. R. Astron. Soc., 333, 93
Griffiths, L. M., Kunz, M., & Silk, J. 2003, Mon. Not. R. Astron. Soc., 339, 680
Holzapfel, W. L., Carlstrom, J. E., Grego, L., et al. 2000, Astrophys. J., 539, 57
Jenkins, A., Frenk, C. S., White, S. D. M., et al. 2001, Mon. Not. R. Astron. Soc., 321, 372
Komatsu, E., Dunkley, J., Nolta, M. R., et al. 2009, Astrophys. J. S. S., 180, 330
Komatsu, E. & Kilian, T. 1999, Astrophys. J. Lett., 526, L1
Komatsu, E. & Seljak, U. 2001, Mon. Not. R. Astron. Soc., 327, 1353
Komatsu, E. & Seljak, U. 2002, Mon. Not. R. Astron. Soc., 336, 1256
Kuo, C. L., Ade, P. A. R., Bock, J. J., et al. 2007, Astrophys. J., 664, 687
LaRoque, S. J., Bonamente, M., Carlstrom, J. E., et al. 2006, Astrophys. J., 652, 917
Lewis, A. & Bridle, S. 2002, Phys. Rev. D, 66, 103511
Lewis, A., Challinor, A., & Lasenby, A. 2000, Astrophys. J., 538, 473
Liu, G.-C., da Silva, A., & Aghanim, N. 2005, Astrophys. J., 621, 15
Muchovich, S., Mroczkowski, T., Carlstrom, J. E., et al. 2007, Astrophys. J., 663, 708
Padin, S., Cartwright, J. K., Mason, B. S., et al. 2001, Astrophys. J. Lett., 549, L1
Reese, E. D., Carlstrom, J. E., Joy, M., et al. 2002, Astrophys. J., 581, 53
Reichardt, C. L., Ade, P. A. R., Bock, J. J., et al. 2009, Astrophys. J., 694, 1200
Runyan, M. C., Ade, P. A. R., Bhatia, R. S., et al. 2003, Astrophys. J. S. S., 149, 265
Sharp, M. K., Marrone, D. P., Carlstrom, J. E., et al. 2009, ArXiv e-prints
Sheith, R. K. & Tormen, G. 1999, Mon. Not. R. Astron. Soc., 308, 119
Sievers, J. L., Mason, B. S., Weintraub, L., et al. 2009, ArXiv e-prints
Spergel, D. N., Bean, R., Doré, O., et al. 2007, Astrophys. J. S. S., 170, 377
Spergel, D. N., Verde, L., Peiris, H. V., et al. 2003, Astrophys. J. S. S., 148, 175
Sunyaev, R. A. & Zel’dovich, Y. B. 1972, Comments on Astrophysics and Space Physics, 4, 173
Taburet, N., Aghanim, N., Douspis, M., & Langer, M. 2009, Mon. Not. R. Astron. Soc., 392, 1153
Warren, M. S., Abazajian, K., Holz, D. E., & Teodoro, L. 2006, Astrophys. J., 646, 881
Figure 5. The curves represent the one dimensional parameter distribution for the CMB+SZ signal fitted with method 3. The solid black line represents the parameter distribution when the gas description used in the fitting method is in agreement with the one employed to create the data. The green long-dashed (dot-dashed) line presents the case in which the gas description used to create the data uses a $\beta = 0.8 \ (0.7)$ parameterisation. The blue dotted line stands for the case where the electronic temperature is overestimated at a 7% level in the intra cluster gas description used to fit the data. The vertical red lines represent the input values of the parameters we used to create our mock power spectra.

White, M., Hernquist, L., & Springel, V. 2002, Astrophys. J., 579, 16
Zhang, P. & Sheth, R. K. 2007, Astrophys. J., 671, 14
Zhang, Y.-Y. & Wu, X.-P. 2003, Astrophys. J., 583, 529