Constraining the redshift evolution of the Cosmic Microwave Background black-body temperature with PLANCK data

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in collaboration with F. Atrio-Barandela, H. Ebeling, R. Génova-Santos, A. Kashlinsky, D. Kocevski, C.J.A.P. Martins

arxiv.org/abs/1502.06707

Outline

1. T_{CMB} redshift evolution
2. Data and Methodology
3. Results
4. Conclusions

T_{CMB} redshift evolution

Adiabatic evolution

$$T_{\rm CMB}(z) = T_0(1+z)$$

No adiabatic evolution

$$T_{\rm CMB}(z) = T_0(1+z)^{1-\alpha}$$

[Lima, J. et al. (2000). MNRAS, 312:747-752.]

Observations

- spectroscopic measurements of quasar spectra
$\alpha = 0.009 \pm 0.019$ at $z \sim 0.9$ [Muller, S., Beelen, A., Black, J.H., et al. 2013, A&A, 551, 109];
- multi-frequency measurements of the TSZ effect
$\alpha = 0.017 \pm 0.029$ [Saro et al. (2014) MNRAS 440, 2610-2615];
$\alpha = 0.009 \pm 0.017$ [Hurier G. et al. (2014). A&A, 561:A143.].

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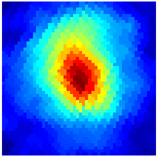
T_{CMB} redshift evolution: $T(z) = T_0(1+z)^{1-\alpha}$

Temperature anisotropies due to SZ effects are given by

$$\frac{\Delta T}{T} = g(\nu) y_c(\theta),$$

and their frequency dependence by

$$x = \frac{h\nu(z)}{k_B T(z)} \qquad g(\nu) = x\coth(x) - 4.$$



Adiabatic evolution

- $\nu(z) = \nu_0(1+z)$,
- $T(z) = T_0(1+z)$.

Then, x does not depend on redshift.

No adiabatic evolution

- $\nu(z) = \nu_0(1+z)$,
- $T(z) = T_0(1+z)^{1-\alpha}$.

Then, $x = x_0(1+z)^{\alpha}$.

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Methodology: a previous work...

Redshift evolution of the temperature of the Cosmic Microwave Background radiation

I. de Martino, F. Atrio-Barandela, A. da Silva, H. Ebeling, A. Kashlinsky, D. Kocevski, Carlos J.A.P. Martins, 2012, ApJ, 757, 144

This study was carried out before the Planck Collaboration released their nominal maps in 2013; we used ancillary data such as masks, noise inhomogeneities from WMAP data release. The cosmological parameters correspond to WMAP 5 year data.

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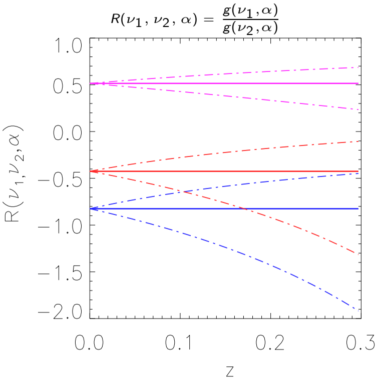
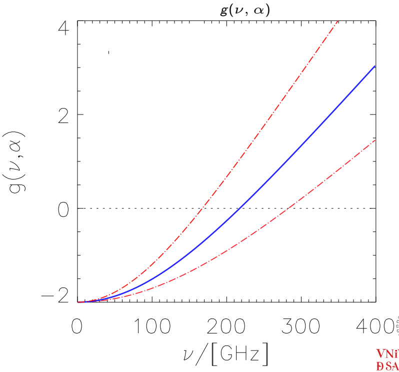
Methodology: $T(z) = T_0(1+z)^{1-\alpha}$

Ratio Method: ratio at different frequencies $R = \frac{g(\nu_1)[y_c(\theta)*b_1(\theta)]}{g(\nu_2)[y_c(\theta)*b_2(\theta)]}$

Fit Method: Fitting of the spectral dependence $\frac{\Delta T}{T} = g(\nu)[y_c(\theta)*b(\theta)]$,

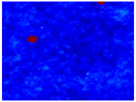




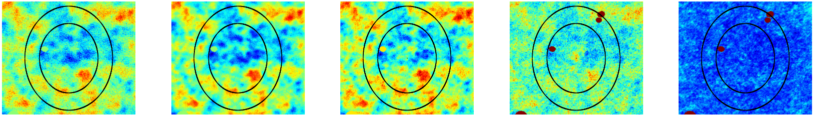
Cleaning procedure: $\mathcal{P}(\nu, \mathbf{x}) = P(\nu, \mathbf{x}) - w(\nu)P(857\mathrm{GHz}, \mathbf{x})$

857 GHz

Coma Cluster (A1656): $l = 57.8°$; $b = 88.0°$; $z = 0.02310$



100 GHz 143 GHz 217 GHz 353 GHz 545 GHz



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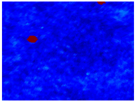

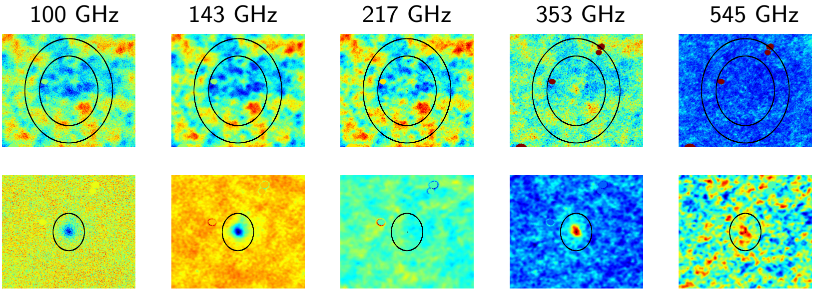

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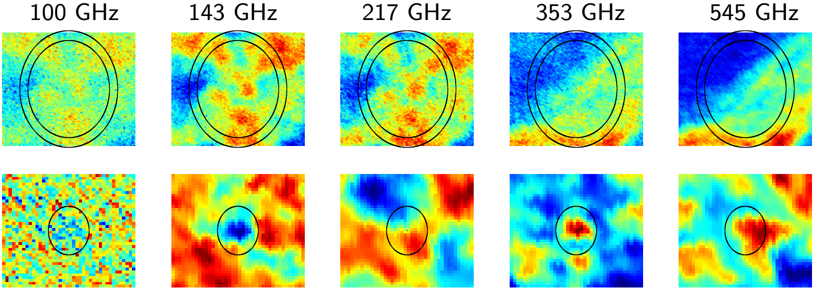
PSZ G355.07+46.20: $l = 355.07°$; $b = 46.20°$; $z = 0.2153$



Results

Error bars were computed by evaluating the mean temperature fluctuation on 1,000 random positions in foreground cleaned maps on a disc with the same angular extent than the cluster.

We considered $\alpha = [-1, 1]$, subdivided in 2001 equally spaced steps.

We divided our sample in six redshift bins of width 0.05, and we averaged the SZ temperature anisotropies over all the clusters in the bin.

Within each redshift bin we computed α in different subsamples, with clusters selected in X-ray luminosity ($L_X \geq 2.5 \times 10^{44}$ erg/s) and mass ($M_{500} \geq 2 \times 10^{14} M_{\odot}$) in order to test the relative contribution of the different cluster subsamples to the final error budget.

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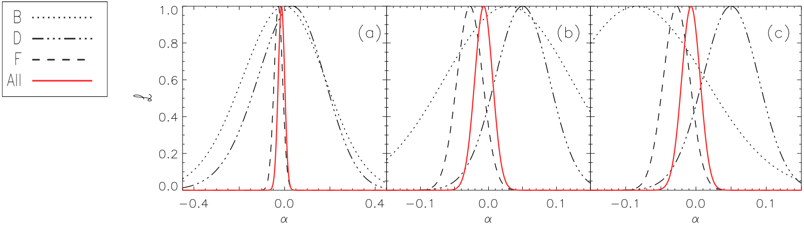
Ratio Method: $R(\nu_1, \nu_2, \alpha) = \frac{g(\nu_1)[y_c(\theta) * b_1(\theta)]}{g(\nu_2)[y_c(\theta) * b_2(\theta)]} = \frac{g(\nu_1,\alpha)}{g(\nu_2,\alpha)}$

The analysis does not take in to account the correlation between different channels.

	Subset	N_{cl}	α_{L_X}	$\sigma_{\alpha_{L_X}}$	N_{cl}	$\alpha_{M_{500}}$	$\sigma_{\alpha_{M_{500}}}$	N_{cl}	$\alpha_{\theta_{500}}$	$\sigma_{\alpha_{\theta_{500}}}$
	All	201	0.018	0.06	397	0.018	0.060	481	0.017	0.056
A	$0.0 < z < 0.05$	3	0.13	1.01	20	-0.05	0.74	32	0.03	0.67
B	$0.05 < z < 0.10$	25	0.435	0.771	121	0.15	0.41	186	0.06	0.43
C	$0.10 < z < 0.15$	36	0.945	1.27	107	0.32	0.34	114	0.264	0.291
D	$0.15 < z < 0.20$	71	0.56	0.51	83	0.065	0.169	83	0.065	0.169
E	$0.20 < z < 0.25$	46	0.007	0.096	46	0.007	0.096	46	0.007	0.096
F	$0.25 < z < 0.30$	20	-0.008	0.080	20	-0.008	0.080	20	-0.008	0.080



Ratio Method: $R(\nu_1,\nu_2,\alpha) = \frac{g(\nu_1)[y_c(\theta)*b_1(\theta)]}{g(\nu_2)[y_c(\theta)*b_2(\theta)]} = \frac{g(\nu_1,\alpha)}{g(\nu_2,\alpha)}$

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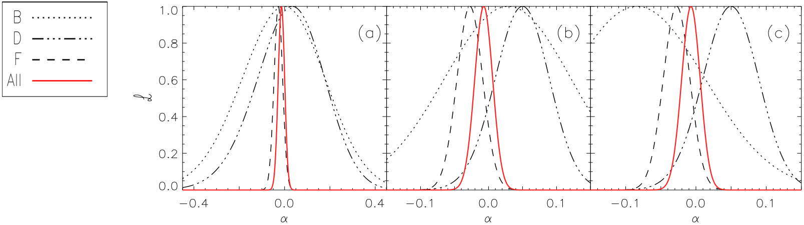

At least two times worse than SPT result

$\alpha = 0.017 \pm 0.029$ **[Saro et al. (2014) MNRAS 440, 2610-2615]**

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Fit Method: $\frac{\Delta T}{T} = g(\nu,\alpha)[y_c(\theta) * b_\nu(\theta)] = g(\nu,\alpha)[y_c(\theta) * b(\theta)]$

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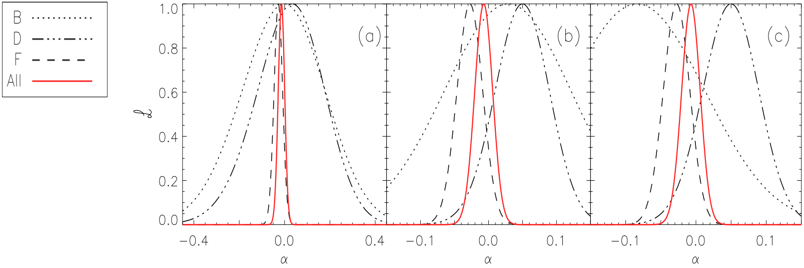
	All	201	−0.013	0.014	397	−0.006	0.013	481	−0.007	0.013
A	$0.0 < z < 0.05$	3	−0.27	0.23	20	−0.21	0.17	32	−0.155	0.158
B	$0.05 < z < 0.10$	25	−0.001	0.183	121	0.029	0.093	186	−0.084	0.098
C	$0.10 < z < 0.15$	36	0.076	0.202	107	−0.014	0.085	114	−0.033	0.074
D	$0.15 < z < 0.20$	71	0.034	0.148	83	0.05	0.039	83	0.05	0.039
E	$0.20 < z < 0.25$	46	0.006	0.022	46	0.006	0.022	46	0.006	0.022
F	$0.25 < z < 0.30$	20	−0.027	0.019	20	−0.027	0.019	20	−0.027	0.019



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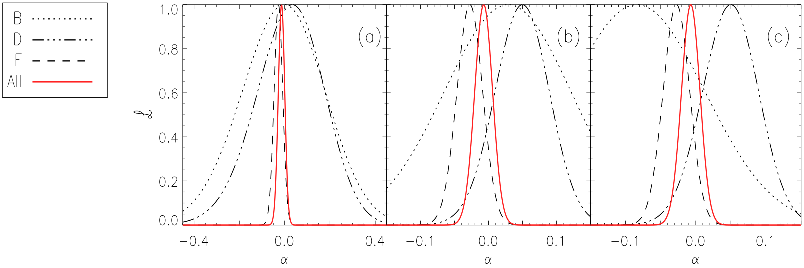

A factor 1.3 of improvement

$\alpha = 0.009 \pm 0.017$ **[Hurier G. et al. (2014). A&A, 561:A143.]**

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Conclusions

We have constrained the evolution history of the CMB blackbody temperature using Planck data.

1. Taking ratios is simpler than fitting the spectral dependence. It allow us to constrain $\alpha = 0.017 \pm 0.056$, **but** it is at least two times worse than SPT result.

2. Fitting of the spectral dependence of the TSZ effect requires to know the cluster profile. It allow us to constrain $\alpha = -0.007 \pm 0.013$. This represent the best constraint in literature from SZ effect.

3. Using CMB template could potentially bias the final results $\Longrightarrow$ we are looking for other techniques that do not require any CMB template in the cleaning process.

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Thanks

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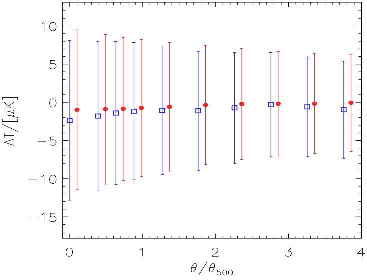
CMB Template and possible bias

The CMB template was constructed assuming the adiabatic evolution of the Universe map using the $g(\nu, \alpha = 0)$.



CMB or TSZ residuals?

The figure shows that the average temperature anisotropy at the cluster locations has $\sim -1\mu$K residual compared with the same measurement at random positions in the sky averaged over 100 realizations

Solution...

Taking into account this effect, our final constraint would be $\alpha = -0.007 \pm 0.013\ (-0.02)$.