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

Ivan de Martino

IberiCOS 2015, March, 31st 2015


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Outline

1. \( T_{\text{CMB}} \) redshift evolution

2. Data and Methodology

3. Results

4. Conclusions
$T_{\text{CMB}}$ redshift evolution

**Adiabatic evolution**

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

**No adiabatic evolution**

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


**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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  $\alpha = 0.009 \pm 0.017$ [Hurier G. et al. (2014) A&A, 561:A143].
Temperature anisotropies due to SZ effects are given by

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

and their frequency dependence by

\[ x = \frac{h\nu(z)}{k_B T(z)} \quad g(\nu) = x \coth(x) - 4. \]

### 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, \( x = x_0(1 + z)^{\alpha} \).
Methodology: a previous work...

Redshift evolution of the temperature of the Cosmic Microwave Background radiation


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.
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

$$\frac{\Delta T}{T} = g(\nu)[y_c(\theta) * b(\theta)],$$

\[ R(\nu_1, \nu_2, \alpha) = \frac{g(\nu_1, \alpha)}{g(\nu_2, \alpha)} \]
Cleaning procedure: $\mathcal{P}(\nu, \mathbf{x}) = P(\nu, \mathbf{x}) - w(\nu)P(857\text{GHz}, \mathbf{x})$

Coma Cluster (A1656): $l = 57.8^\circ; b = 88.0^\circ; z = 0.02310$
Cleaning procedure: $P(\nu, \mathbf{x}) = P(\nu, \mathbf{x}) - w(\nu)P(857\text{GHz}, \mathbf{x})$

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PSZ G355.07+46.20: \( l = 355.07^\circ; \ b = 46.20^\circ; \ z = 0.2153 \)
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 $\alpha$ 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.
Ratio Method: \[ R(\nu_1, \nu_2, \alpha) = \frac{g(\nu_1)[y_c(\theta) \ast b_1(\theta)]}{g(\nu_2)[y_c(\theta) \ast b_2(\theta)]} = \frac{g(\nu_1, \alpha)}{g(\nu_2, \alpha)} \]

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

<table>
<thead>
<tr>
<th>Subset</th>
<th>(N_{cl})</th>
<th>(\alpha_{Lx})</th>
<th>(\sigma_{\alpha_{Lx}})</th>
<th>(N_{cl})</th>
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All -- -- -- -- --

Ivan de Martino, Universidad de Salamanca

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

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B: \(0.0 < z < 0.05\)

D: \(0.05 < z < 0.10\)

E: \(0.10 < z < 0.15\)

D: \(0.15 < z < 0.20\)

E: \(0.20 < z < 0.25\)

F: \(0.25 < z < 0.30\)

All
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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A factor 1.3 of improvement

$\alpha = 0.009 \pm 0.017$ [Hurier G. et al. (2014). A&A, 561:A143.]
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 $\Rightarrow$ we are looking for other techniques that do not require any CMB template in the cleaning process.
Thanks
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 \( \alpha = -0.007 \pm 0.013 (-0.02) \).