Constraints on the CMB temperature redshift dependence from SZ and distance measurements

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Abstract: The relation between redshift and the CMB temperature is a key prediction of standard cosmology, but is violated in many non-standard models. We present state-of-the-art constraints, using both direct and indirect measurements. In particular, we point out that in models where photons can be created or destroyed, not only does the temperature-redshift relation change, but so does the distance duality relation, and these departures from the standard behaviour are related, providing us with an opportunity to improve constraints. We also discuss how, with the next generation of space and ground-based experiments, these constraints can be improved by more than one order of magnitude.

1. Theoretical motivation

I) Adiabatic Photon Injection

$$T(z) = T_0(1+z)^{1-\beta}\,; \qquad (1)$$

where β takes into account deviations from particles number conservation. The Planckian form of the spectrum is preserved. Lima et al. MNRAS 312 (2000)

II) Photon dimming/absorption and Axion-Photon Couplings

deviations from the standard relation between luminosity and angular diameter distance:

$$d_L(z) = d_A(z)(1+z)^{2+\epsilon}\,, \qquad (2)$$

where ϵ is constant. $\epsilon = 0$ corresponds to the standard $d_L - d_A$ law.
Avgoustidis et al. JCAP 06 (2009), JCAP 10 (2010).

III) Relation between ϵ and β

As flux scales inversely with the luminosity distance squared, a change in the inferred distance would also affect the CMB flux-redshift relation, and so the CMB temperature as a function of redshift. We have found the following relation:

$$\beta = -\frac{2}{3}\epsilon \qquad (3)$$

For a review on non-standard models which violates $T(z) = T_0(1+z)$, like photon-axion mixing or varying α cosmologies see (Jaeckel et al. An. Rev. Nucl. Part. Sci 60 (2010)), (Martins Phil. Trans. Roy. Soc. Lond. A 360 (2002)).

2. Present constraints

Direct methods:

- Quasar absorption line spectra Bachal and Wolf, ApJ 152 (1968)
- SZ effect towards clusters Fabbri et al. Astrop. Space Sci. 59 (1978), Rephaeli ApJ.241 (1980)

Indirect methods:

- Distance measurements Avgoustidis, et al. [arXiv:1112.1862v1]

SZ+CO+Atomic Carbon: $\beta = -0.007 \pm 0.028$

P. Noterdaeme et al.: The evolution of the Cosmic Microwave Background Temperature

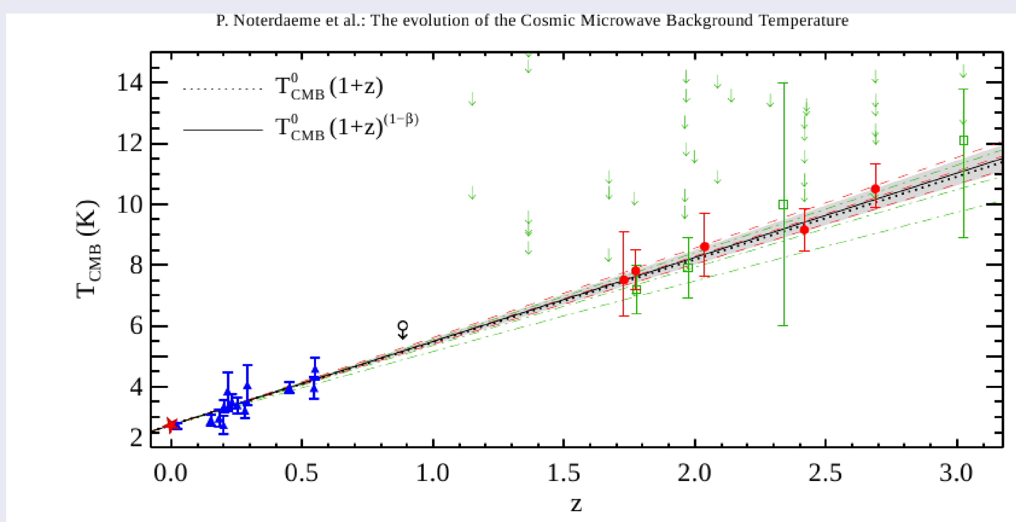
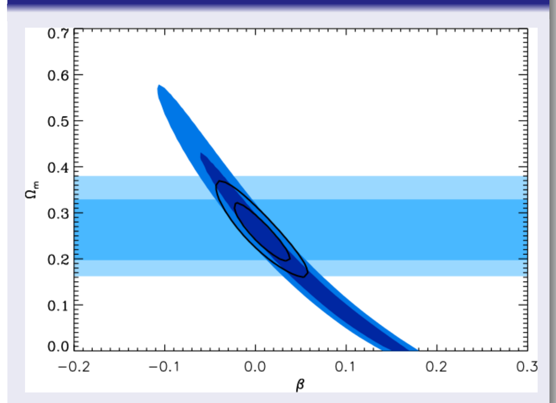


Fig. 4. The black-body temperature of the Cosmic Microwave Background radiation as a function of redshift. The star represent measurement at z = 0 (Mather et al. 1999). Our measurements based on the rotational excitation of CO molecules are represe by red filled circles at 1.7 < z < 2.7. Other measurements at z > 0 are based (i) on the S-Z effect (blue triangles at z < 0.6, Luzzi 2009) and (ii) on the analysis of the fine structure of atomic carbon (green open squares: z = 1.8, Cui et al. 2005; z = 2.0, Ge 1997; z = 2.3, Srianand et al. 2000; z = 3.0, Molaro et al. 2002). Upper-limits come from the analysis of atomic carbon (from literature and our UVES sample, see Srianand et al. 2008) and from the analysis of molecular absorption lines in the lensing ga of PKS 1830-211 (open circle at z = 0.9, Wiklind & Combes, 1996). The dotted line represents the adiabatic evolution of T_{CM} expected in standard hot Big-Bang models. The solid line with shadowed errors is the fit using all the data and the alternative sca of $T_{CMB}(z)$ (Lima et al. 2000) yielding $\beta = -0.007 \pm 0.027$. The red dashed curve (resp. green dashed-dotted) represents the fit

SN+H(z): $\beta = 0.01 \pm 0.04$



Two-parameter constraints on the $\beta - \Omega_m$ plane. Dark blue contours correspond to 68% and 95% confidence levels obtained from SN data alone (SCP Union2 compilation), light blue contours are for $H(z)$ data (Stern et al. JCAP 02 (2010)), and solid line transparent contours show the joint SN+$H(z)$ constraint.

3. Forecasts (I): Planck HFI (clusters)

ΔI_{SZ} depends on frequency ν through the nondimensional ratio $x = h\nu/kT$, which can be written as $x = x_0(1+z)T_0/T_{CMB}$: small dilation-contraction of the SZ spectrum.

a) Catalog

166 clusters using X-Rays Clusters Databased (BAX): z, positions, X-ray Flux and Luminosity, gas temperature, core radius, slope of the gas density profile (isothermal β model).

b) Simulation

We have simulated the observation of ~ 40 well known clusters already observed by Planck (ESZ Planck catalog, Planck collaboration, A&A 536, A7 (2011)), taking into account Planck HFI instrumental characteristics and observing strategy. Frequency bands: (100, 143, 217, 353)GHz

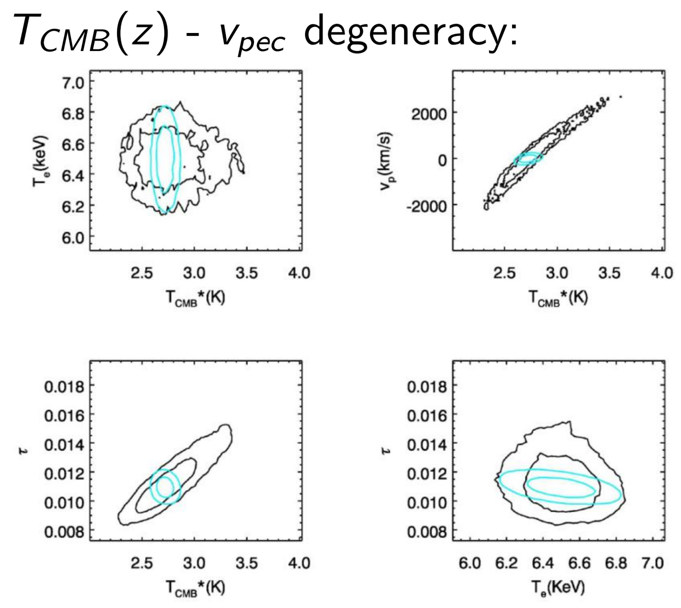
The method for the $T_{CMB}(z)$ extraction at cluster redshift is the one developed in Luzzi et al ApJ 705 (2009); use of $\Delta I_{SZ}(\nu)$, single likelihoods for each clusters.

c) Data analysis

Mock dataset analysed to recover the original input cluster parameters.

- MCMC algorithm: cluster parameters $(\tau,\, v_p,\, T_e)$ + T_{CMB}+calibration uncertainty
- prior over cluster gas temperature, as provided by X-ray data.
- final cluster sample selected with the conditions of non flat τ posterior and $S/N(\tau) \geq 6$

$T_{CMB}(z)$ - v_{pec} degeneracy:

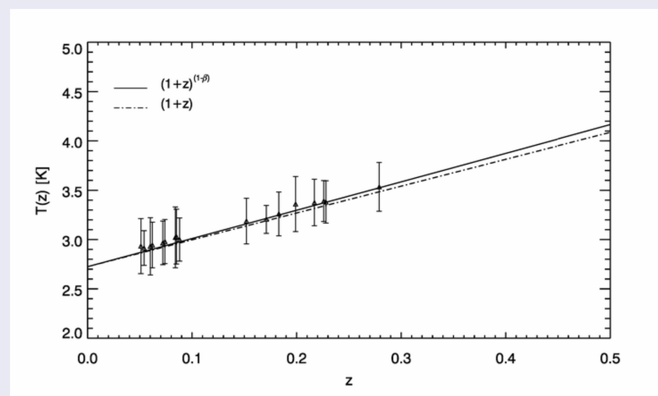


Multifrequency coverage allows to remove KSZ as a first step in cleaning maps of CMB contribution.

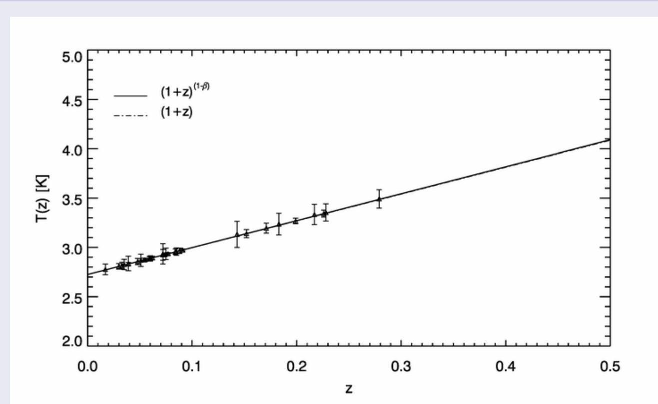
sensitivity on $T_{CMB}(z)$

- KSZ yes: $\sim 7\%$ on $T_{CMB}(z)$
- KSZ no: $\sim 0.6\%$ on $T_{CMB}(z)$

with KSZ: $\beta = -0.047 \pm 0.079$



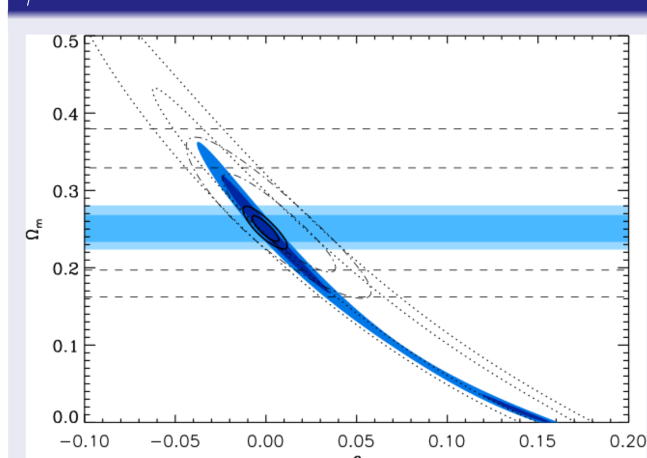
without KSZ $\beta = -0.003 \pm 0.016$



4. Forecasts (II): distance measurements and spectroscopy

Forecast constraints which could be achieved by combining H(z) measurements from upcoming spectroscopic BAO surveys with future SN data.

Intermediate z: EUCLID/SNAP $\beta = 0.01 \pm 0.004$



Two-parameter constraints on the $\beta - \Omega_m$ plane. Dark blue contours correspond to 68% and 95% confidence levels from SNAP alone, light blue contours are for EUCLID, and solid line transparent contours show the joint SNAP+EUCLID forecast constraint. Also shown are current constraints from $H(z)$ 'chronometer' data (dashed), SN data (dotted), and joint $H(z)$+SN (dot-dashed).

ESPRESSO and CODEX, two forthcoming ESO high-resolution, ultra-stable spectrographs: will look for CO systems at high redshift $z \sim 2.8 - 4.0$ with uncertainties on T_{CMB} about $\Delta T_{ESP} \sim 0.35\,K$, $\Delta T_{COD} \sim 0.07\,K$. ESPRESSO will accurately measure $T(z)$ in 10 systems, while CODEX will measure 20 systems.

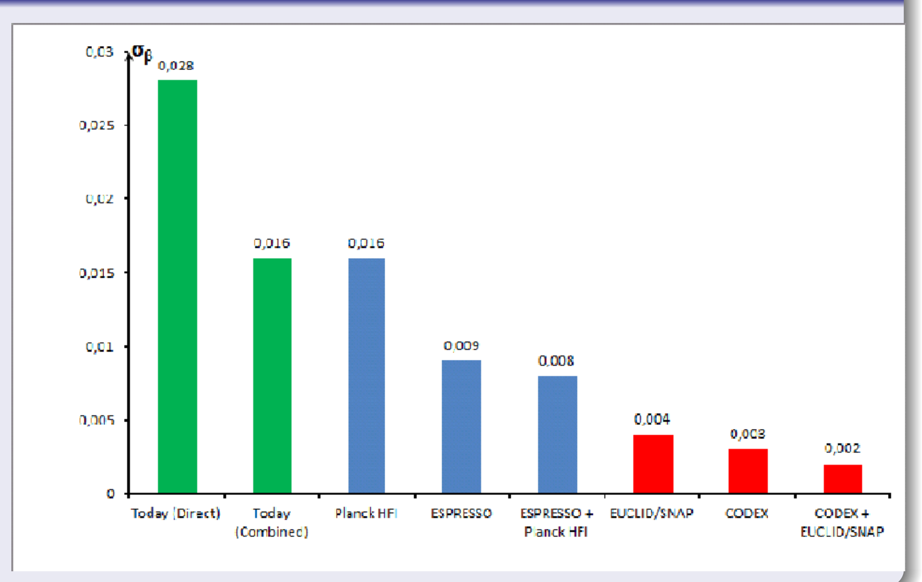
High z: ESPRESSO and CODEX (spectroscopy)

1. ESPRESSO: $\sigma_\beta = 0.009$
2. CODEX: $\sigma_\beta = 0.003$

5. Conclusions

- By combining the direct constraints from SZ+ Atomic carbon+ CO with the indirect ones from SN + H(z) we obtain: $\beta = 0.004 \pm 0.016$, which is a 40% improvement on the direct constraint.
- The three probes (clusters, distance measurements and spectroscopy) are complementary: each having different systematics and/or redshift coverage.

Current and future constraints



- Planck alone: as well as current data (SZ+Atomic Carbon+CO+H(z)+SN) with only tens of clusters.
- Planck with the whole ESZ sample (189 clusters with $S/N > 6$): $\sigma_\beta \sim 0.008$

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