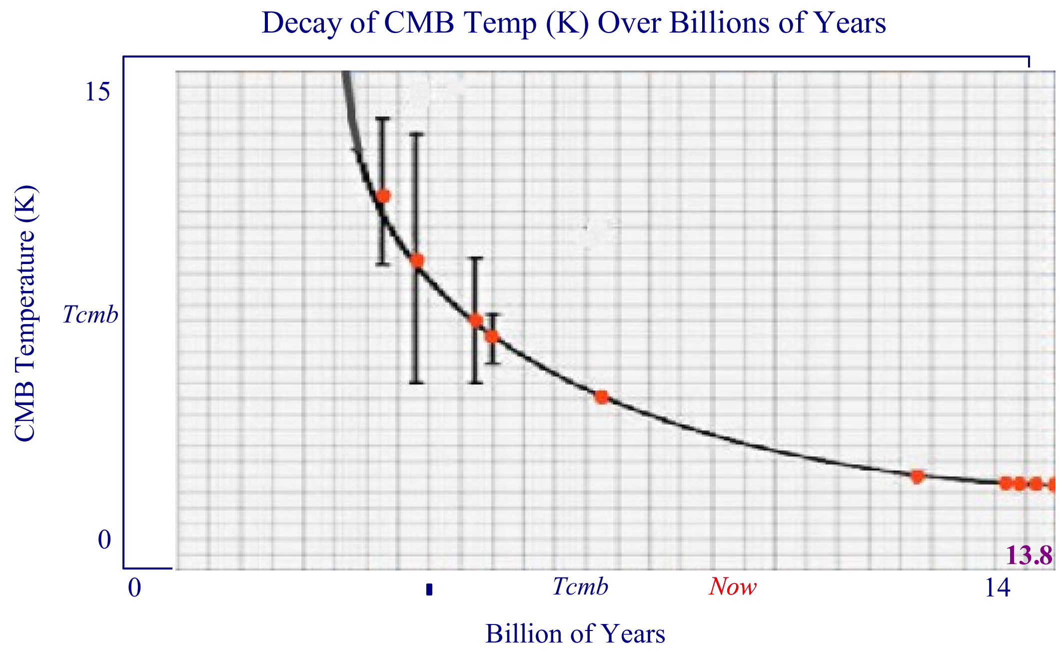
XXIA. Evidence for Λ-CDM "Big Bang" Model

What are the strongest physical evidences for the big bang?

Thanks to technological advances, astronomers can measure the current temperature of radiation lingering from the cosmic origin event as well as the temperature of this radiation at various times in the past. As the figure below shows, actual temperature measurements match the cooling curve a ΛCDM model (creation model)predicts, given the age of the cosmos (≈13.8 billion years old) and its measured expansion rate. The most accurate of these past measurements is the one in the middle of the cooling curve. This measurement fits the curve so closely that its error bar can’t be seen in this graph. Figure 2: Evidence of Cooling from the ΛCDM Creation Event. The curve is the predicted cooling of the universe according to the ΛCDM creation model with a cosmic age of 13.79 billion years and an average cosmic expansion rate at 68.65 kilometers/second/megaparsec.The dots and error bars are actual temperature measurements of the Cosmic Microwave Background Radiation.

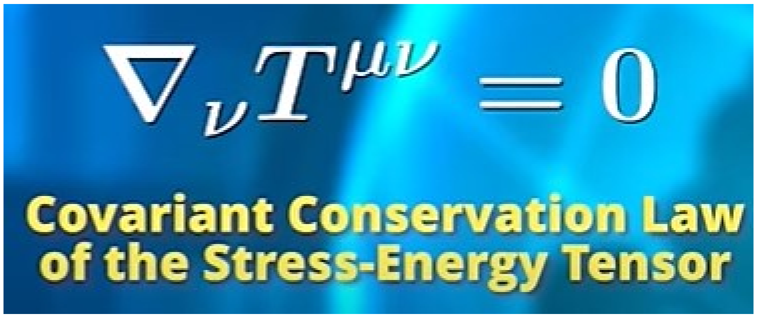


Does the Law of Conservation of Energy Apply to the ΛCDM.

As the Universe expands, Dark Energy is created. Energy by itself is not conserved. Energy can increase or decrease whenever space itself changes in time. Photons have an energy that is inversely proportional to their wavelength. As space expands, the wavelength of photons increases and it energy decreases. So where it go? This is why the Cosmic Microwave Background Radiation is so cold. In GR, we have a more complicated theory of Energy Conservation.

Generalized Energy Conservation

It Generalized Energy Conservation of Covariant Conservation Law of the Stress-Energy Tensor. The change in energy in the photon has to match the change in energy of space.



$$\nabla_\nu T^{\mu\nu} = 0$$

Covariant Conservation Law of the Stress-Energy Tensor

Test for Expansion: Comparison of Theoretical (Ideal) vs. Measured CMB Temp. from VLT

Data Source: *The evolution of the cosmic microwave background temperature Measurements of T CMB at high redshift from carbon monoxide excitation,* P. Noterdaeme , P. Petitjean, R. Srianand, C. Ledoux, and S. López

A milestone of modern cosmology was the prediction and serendipitous discovery of the cosmic microwave background (CMB), the radiation leftover after decoupling from matter in the early evolutionary stages of the Universe. A prediction of the standard hot Big-Bang model is the linear increase with redshift of the black-body temperature of the CMB (T_{CMB}). This radiation excites the rotational levels of some interstellar molecules, including carbon monoxide (CO), which can serve as cosmic thermometers. Using three new and two previously reported CO absorption-line systems detected in quasar spectra during a systematic survey carried out using Very Large Telescope,VLT / European Southern Observatory, UVES, we constrain the evolution of T_{CMB} to $z \approx 3$. Combining precise measurements with previous constraints, we obtain $T_{CMB}(z) = (2.725 \pm 0.002) \times (1 + z)^{1-ß}$ K with $ß = -0.007 \pm 0.027$, a more than two-fold improvement in precision. The measurements are consistent with the standard (i.e. adiabatic, $ß = 0$) Big-Bang model and provide a strong constraint on the effective equation of state of decaying dark energy (i.e. $w_{eff} = -0.996 \pm 0.025$).

$$T_{cmbdat} := READPRN(\text{"Redshift vs Tcmb to z1 G Hurier 2014C.txt"})$$

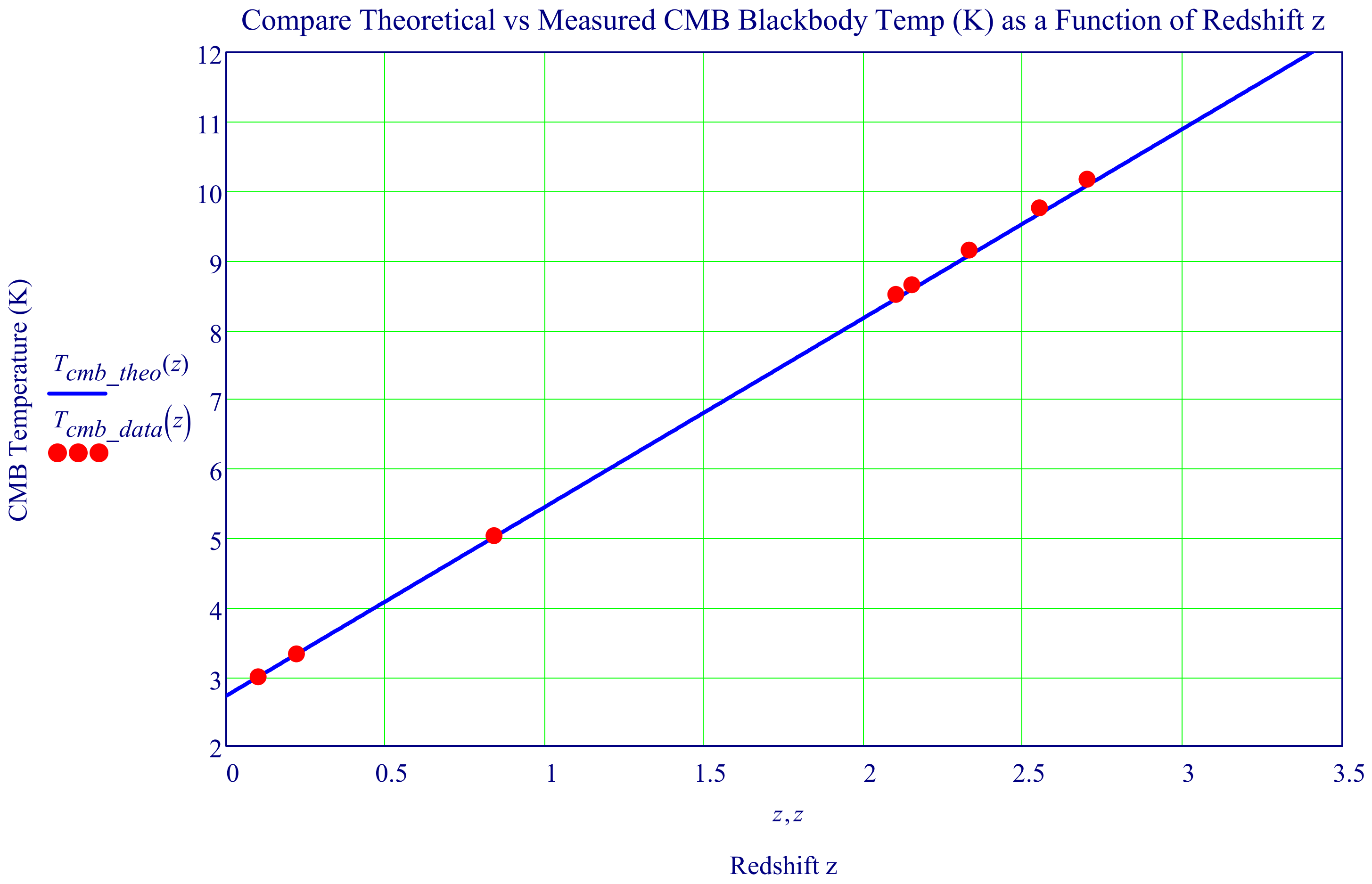
Theoretical (Ideal) CMB Temperature vs Redshift z

$$T_{cmb\_theo}(z) := 2.725 \cdot (1 + z)$$

Measured CMB Temperature vs Redshift z

$$\beta := -0.007 \qquad T_{cmb\_data}(z) := 2.725 \cdot (1 + z)^{1-\beta}$$

Measurements are based on the rotational excitation of CO molecules are represented by red dots.



The evolution of the cosmic microwave background temperature (2011)

Measurements of TCMB at high redshift from carbon monoxide excitation

P. Noterdaeme1, P. Petitjean2, R. Srianand3, C. Ledoux4, and S. López

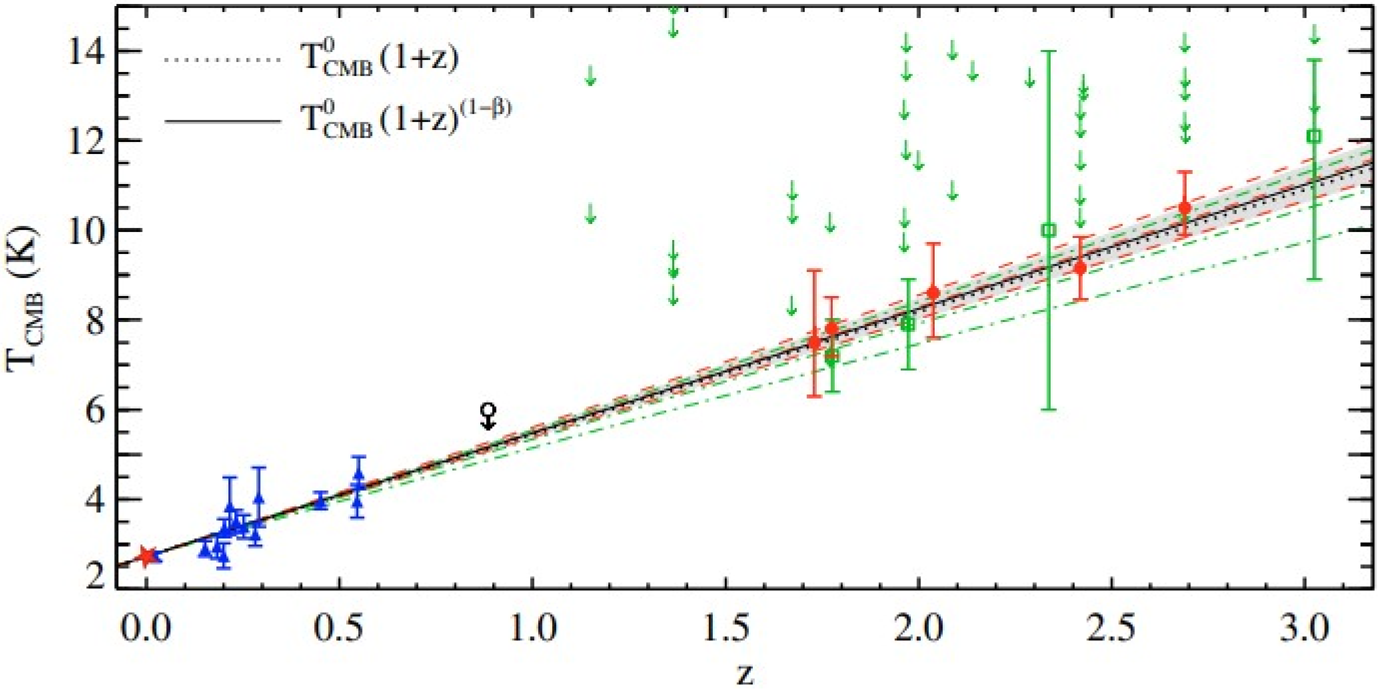
ABSTRACT

A milestone of modern cosmology was the prediction and serendipitous discovery of the cosmic microwave background (CMB), the radiation leftover after decoupling from matter in the early evolutionary stages of the Universe. A prediction of the standard hot Big-Bang model is the linear increase with redshift of the black-body temperature of the CMB (T_{CMB}). This radiation excites the rotational levels of some interstellar molecules, including carbon monoxide (CO), which can serve as cosmic thermometers. Using three new and two previously reported CO absorption-line systems detected in quasar spectra during a systematic survey carried out using VLT/UVES, we constrain the evolution of T_{CMB} to $z \sim 3$.

Combining our precise measurements with previous constraints, we obtain

$$T_{CMB}(z) = (2.725 \pm 0.002) \times (1 + z)^{1-\beta}\ \mathrm{K}$$

with $\beta = -0.007 \pm 0.027$, a more than two-fold improvement in precision. The measurements are consistent with the standard (i.e. adiabatic, $\beta = 0$) Big-Bang model and provide a strong constraint on the effective equation of state of decaying dark energy (i.e. $w_{eff} = -0.996 \pm 0.025$).



Black-body temperature of the cosmic microwave background radiation as a function of redshift. The star represents the measurement at $z = 0$ (Mather et al. 1999). Our measurements based on the rotational excitation of CO molecules are represented 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 et al. 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 et al. 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 the literature and our UVES sample, see Srianand et al. 2008) and from the analysis of molecular absorption lines in the lensing galaxy of PKS 1830-211 (open circle at $z = 0.9$, Wiklind & Combes 1996).

The dotted line represents the adiabatic evolution of TCMB as expected in standard hot Big-Bang models. The solid line with shadowed errors is the fit using all the data and the alternative scaling 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 and errors using S-Z + CO measurements (resp. S-Z + atomic carbon).