CMBR Temperature at High Redshifts.

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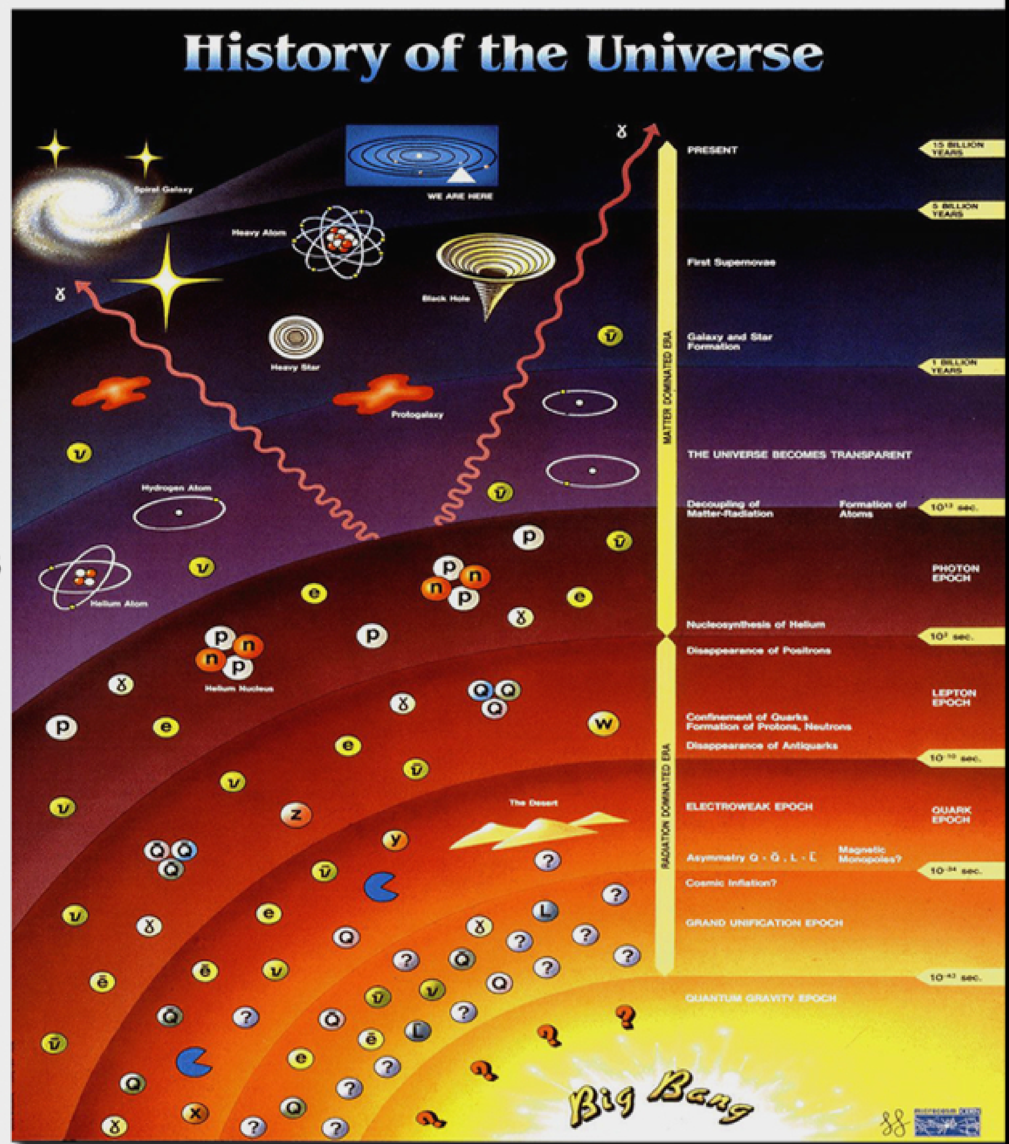
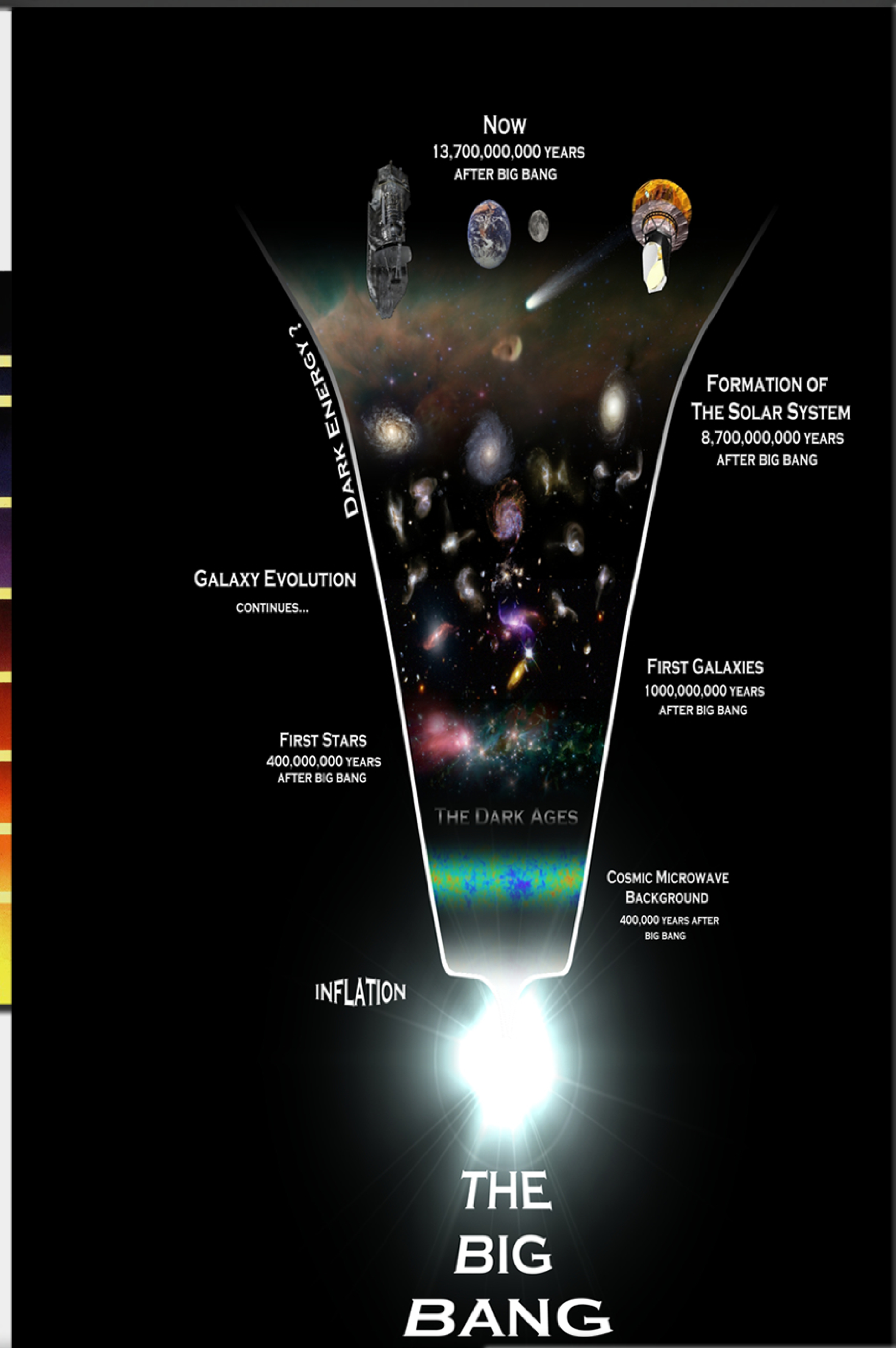
Origin of the Big Bang and CMBR

Around 13.7 billion years ago, a small dense ball of matter and energy underwent rapid expansion, which we popularly now call as The Big Bang. To get an idea of that expansion, in about 10^{-3} to 10^{-4} seconds, the universe exponentially expanded by a factor of about 10^{72} in volume. The universe is still expanding but at a smaller rate.



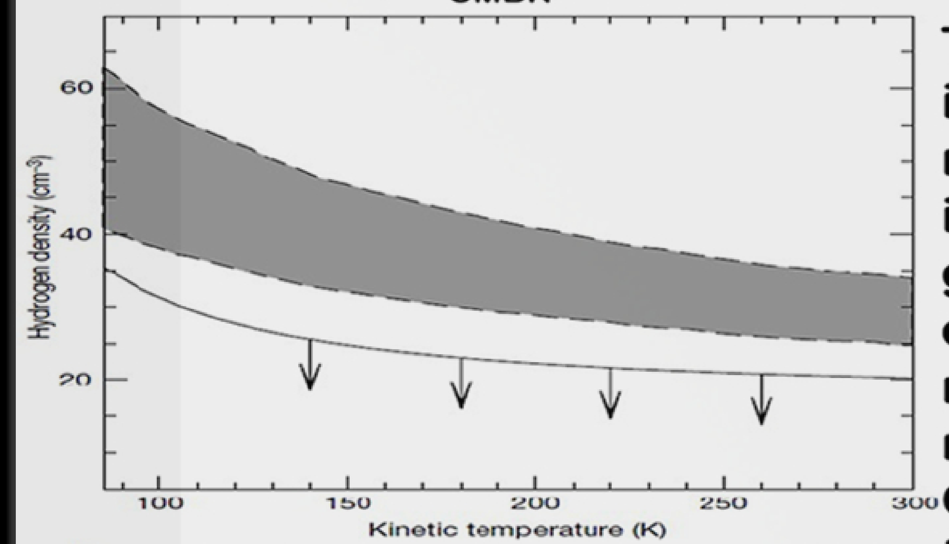
1s after The Big Bang, there was and abundance of matter, but the energy density was dominated by photons. A few minutes later, protons and neutrons combined to form Helium and Deutrium nuclei, but most of the protons remained uncombined. This universe was still opaque to radiation. After about 10^{13}s, electrons combined with the nuclei to form neutral atoms. This decoupling of matter-radiation made the universe transparent to radiation which we now see as the Cosmic Microwave Background Radiation(CMBR)

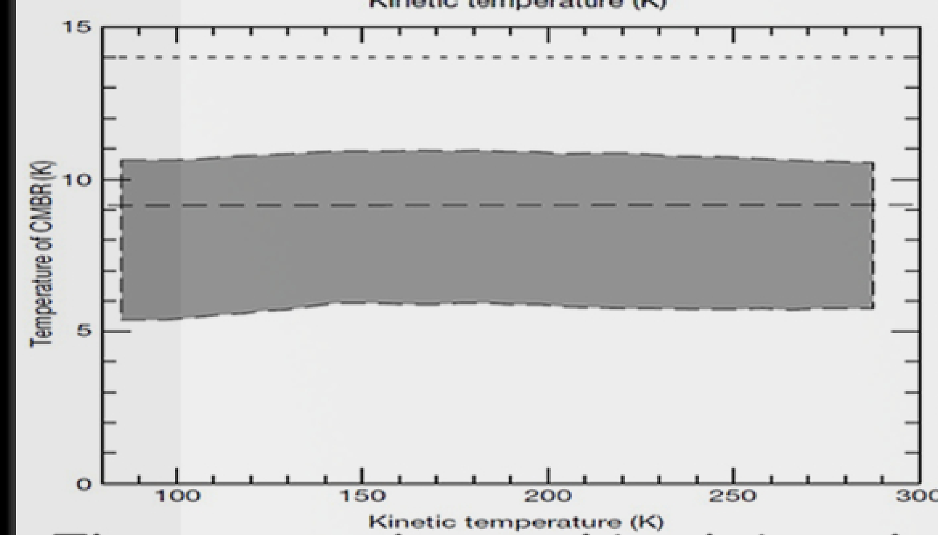
This expansion of universe was adiabatic. As this system is isolated, the temperature of the universe started falling with time. Theoretically, the radiation is isotropic and homogeneous. The measured temperature today of the blackbody spectrum is T = 2.736 K.



Observational evidence of $T(t) = T_0\,(1+z(t))$

Theoretically, the CBR temperature can be measured by considering the excited populations of fine-structure levels of atomic species. R.Srianand *et al.*, detected absorption lines from first and second fine-structure levels of neutral carbon and absorption due to several rotational transitions of molecular hydrogen and fine-structure lines of singly ionized carbon. It was determined that the background radiation in the past was warmer. At redshift of z = 2.3371, T_{CMBR} was found to lie between 6K and 14K.





The density of hydrogen molecules in the gas is estimated by considering the ratio of fine-structure excitation of C^+. This estimated density gives the maximal value of the H_2 density in the cloud. The density required to explain the population ratio's of fine-structure levels of $C_)$, assuming no CMBR, is given in the shaded region. The observed density is less than the density required to explain the population ratio's of C_0. For a given temperature, an upper limit on H_2 density is given from the C^+ fine structure populations. This is used to determine the contribution of hydrogen to the C^0 fine structure excitation.

The excess is used to determine the range for the CMBR temperature. The shaded region gives the 2σ range of the CMBR radiation temperature allowed by the observed population levels of neutral carbon fine-structure levels. The horizontal dotted line is the upper limit on CMBR temperature if CMBR is assumed to be the only excitation process while the dashed line is the predicted CMBR temperature at z = 2.3371.

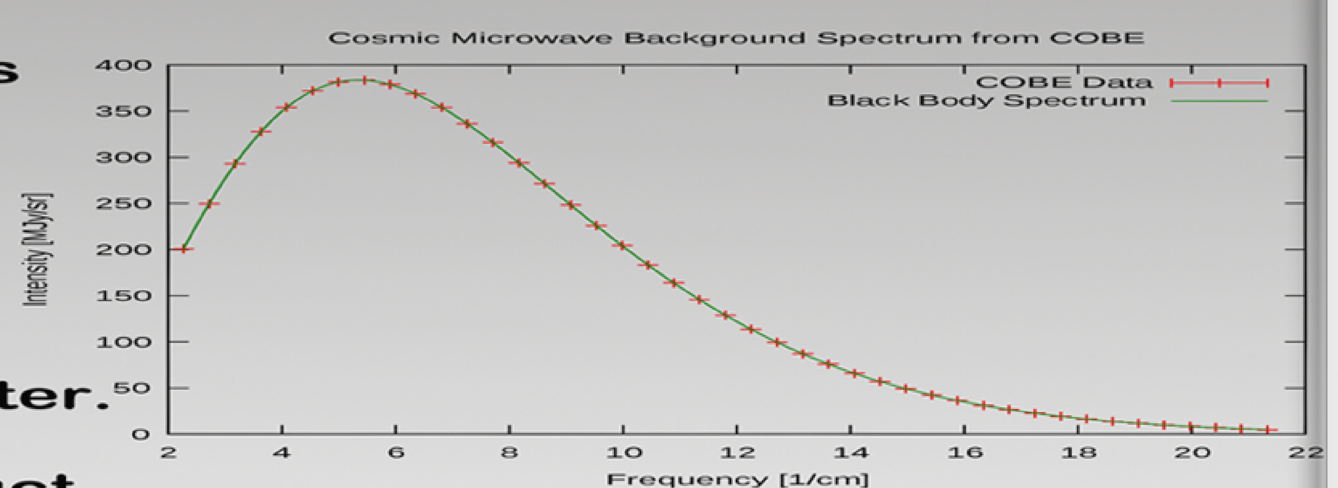
Ref: Srianand, R., Petitjean, P., & Ledoux, C. 2000, Nature, 408, 931

CMBR Temperature at different times.

The thermal black-body spectrum at a temperature T is given by:

$$B_\lambda(T) = 2hc^2/\lambda^5(1/(e^{hc/k_BT\lambda} - 1))$$

where $1/(e^{hc/k_BT\lambda} - 1)$ is the mean number of photons/mode and is also known as Plank's function.



The mean number of photons ($\mathcal{N}$) is conserved in time. Thus, $hc/k_bT\lambda$ should be a constant in time. Due to the expansion of the space, i.e., the universe, $\lambda(t)$ scales as a(t), where a(t) is the expansion parameter. Thus, $\lambda(t) \propto a(t)$. Therefore, to keep the product constant in time:

$$T(t) \propto 1/a(t)$$
$$T(t) = T_o a_o/a(t).$$

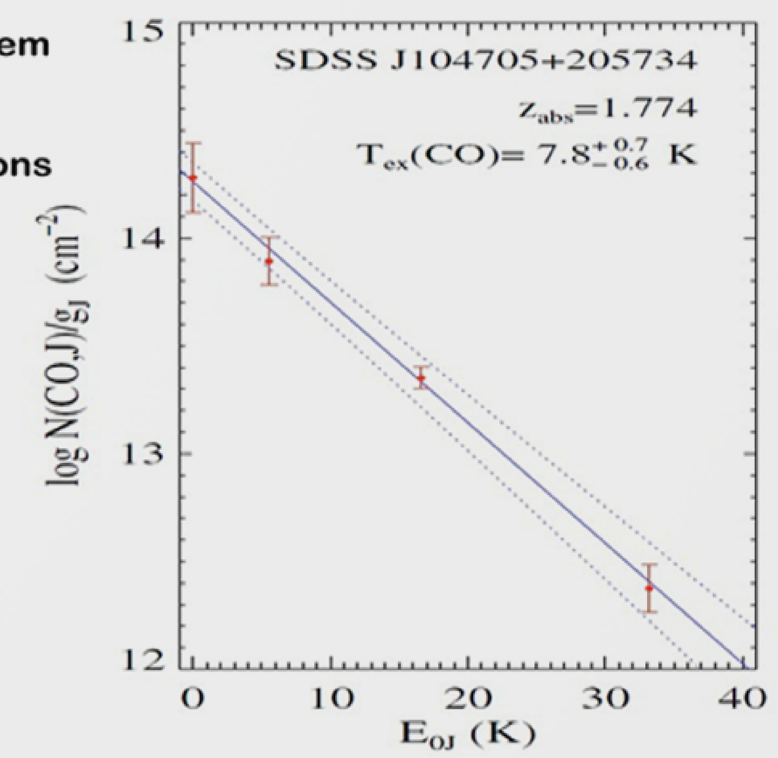
But, $a_o/a(t) = (1+z(t))$ where z(t) is the redshift at that time. Thus,

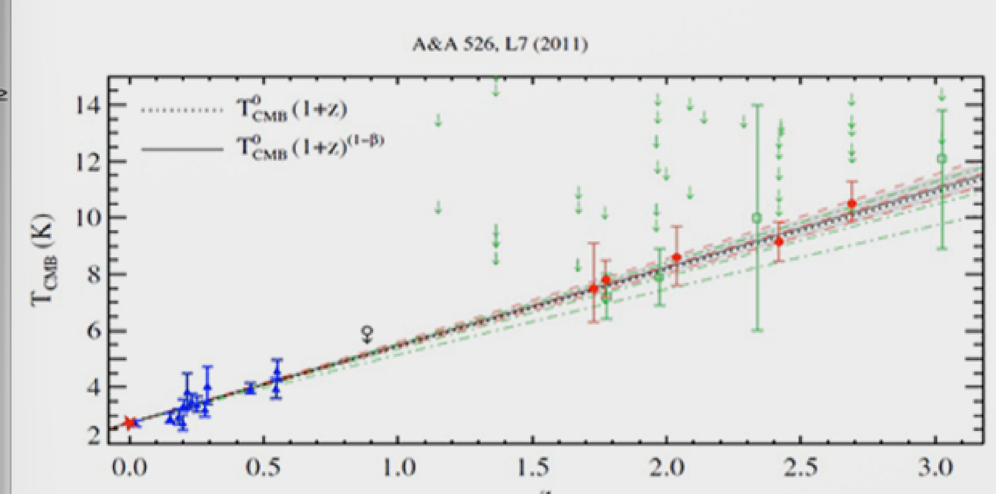
$$T(t) = T_o(1 + z(t))$$

Proving $T(t) = T_0(1+z(t))$ using CO rotational levels.

The rotational energy levels of CO are such that the energy difference between them is comparable to kT_{CMBR}. From the absorption lines, population of CO at different rotational levels can be found. Applying Boltzmann's distribution to this gives the excitation temperature of each level. We can neglect the excitations due to collisions because CO at high redshifts are found in the centre of gaseous clouds where the temperature is such that we can neglect the collision effects. So, the excitation is due to background radiation. Measured values at different redshifts give the temperature to be the CMBR temperature at that redshift.

Quasar	z_{abs}	$T_{ex}(CO)$ (K)
SDSS J085726+185524	1.7293	$7.5^{+1.6}_{-1.2}$
SDSS J104705+205734	1.7738	$7.8^{+0.7}_{-0.6}$
SDSS J123714+064759	2.6896	$10.5^{+0.8}_{-0.6}$
SDSS J143912+111740	2.4184	$9.15^{+0.7}_{-0.7}$
SDSS J170542+354340	2.0377	$8.6^{+1.1}_{-1.0}$





Let us assume that: $T(t) = T_0(1+z(t))^\beta$. If the expansion of universe is to be adiabatic $\beta = 0$. Measuring the temperature at different z gives us the value of = -0.07 ± 0.027. This value agrees with our notion of adiabatic expansion of universe.

Ref: P.Noterdaeme et. al, A&A 526, L7(2011)