THE TEMPERATURE OF THE UNIVERSE NOW
AND IN THE DISTANT FUTURE

Roger L. Mansfield, 2011 February 8

I did not mean in my PlanetPTC post of February 3 to shift the discussion away from Edwin Hubble and toward John Mather. It is just that the age and temperature of the universe are intimately related.

If Edwin Hubble can be said to have determined the age of the universe by means of his galactic recessional velocity vs. distance graph, then John Mather and his COBE colleagues can be said to have determined its temperature.

Because what the COBE team showed is that the universe, as it exists today, behaves *exactly* like a black body radiating at 2.725 degrees Kelvin.

Given that it took the universe 13.7 billion years to cool down to its present temperature of 2.725 degrees Kelvin as measured by the COBE team, how long will it take for the universe to cool down by one more degee, to 1.725 degrees Kelvin?

Using Hubble's and Mather's results, we can answer this question, at least to a first approximation, as follows.

Newton's Law of Cooling states that the rate of cooling of a body is proportional to the temperature difference between the body and its surroundings. Here the "body" is taken to be the universe, and the "surroundings" are the non-universe (the void) at 0 degrees Kelvin. We don't need Mathcad symbolics to do the math here, any more than we need a calculator to find the product of two single-digit integers. We have

$$\frac{dT}{dt} = \alpha \cdot T \qquad \text{so that} \qquad \frac{dT}{T} = \alpha \cdot dt$$

Integrating,

$$\ln(T) - \ln(T_o) = \ln\left(\frac{T}{T_o}\right) = \alpha \cdot (t - t_o)$$

Raising e to equal powers,

$$\frac{T}{T_o} = e^{\alpha \cdot (t - t_o)} \qquad \text{so that}$$

$$T = T_o \cdot e^{\alpha \cdot (t - t_o)}$$

We can select now α, then Symbolics>Variable> Solve, to arrive at the following expression for α...

$$\alpha = \frac{\ln\left(\frac{T}{T_o}\right)}{t - t_o}$$

We have a good value for the age of the universe, $13.7 \cdot 10^9$ years. We need to determine the cooling constant, α.

Ralph Alpher, Robert Herman, and George Gamow calculated in the late 1940s that, if indeed the universe originated in a Big Bang, then there should now still exist cosmic microwave background (CMB) radiation detectable in every direction of space, radiation with a spectrum characteristic of a black body at a temperature of approximately 5 degrees Kelvin.

Now in 1950 Gamow wrote (in *The Creation of the Universe,* still available as a Dover paperback), that the temperature of the universe shortly after the Big Bang was given by

$$T_o = \frac{1.5 \cdot 10^{10}}{\sqrt{t}}$$ Kelvin degrees, with t measured in seconds.

Therefore, one second after the Big Bang we have

$$T_o := 1.5 \cdot 10^{10}$$ degrees Kelvin.

Surely there is today, sixty-one years after Gamow wrote his "little" (146 page) book, a better value for T_o. But let's use Gamow's value to acknowledge his seminal contributions to cosmology (which was actually called "cosmogony" back in the 1950s).

Using the expression for α obtained above, we have

$$\alpha := \frac{\ln\left(\frac{2.725}{T_o}\right)}{13.7 \cdot 10^9} \qquad \alpha = -1.637 \times 10^{-9}$$ reciprocal years.

Now to find out how long, starting from the present epoch, that it will take for the universe to cool to 1.725 degrees Kelvin, we write again

$$T = T_o \cdot e^{\alpha \cdot (t - t_o)}$$

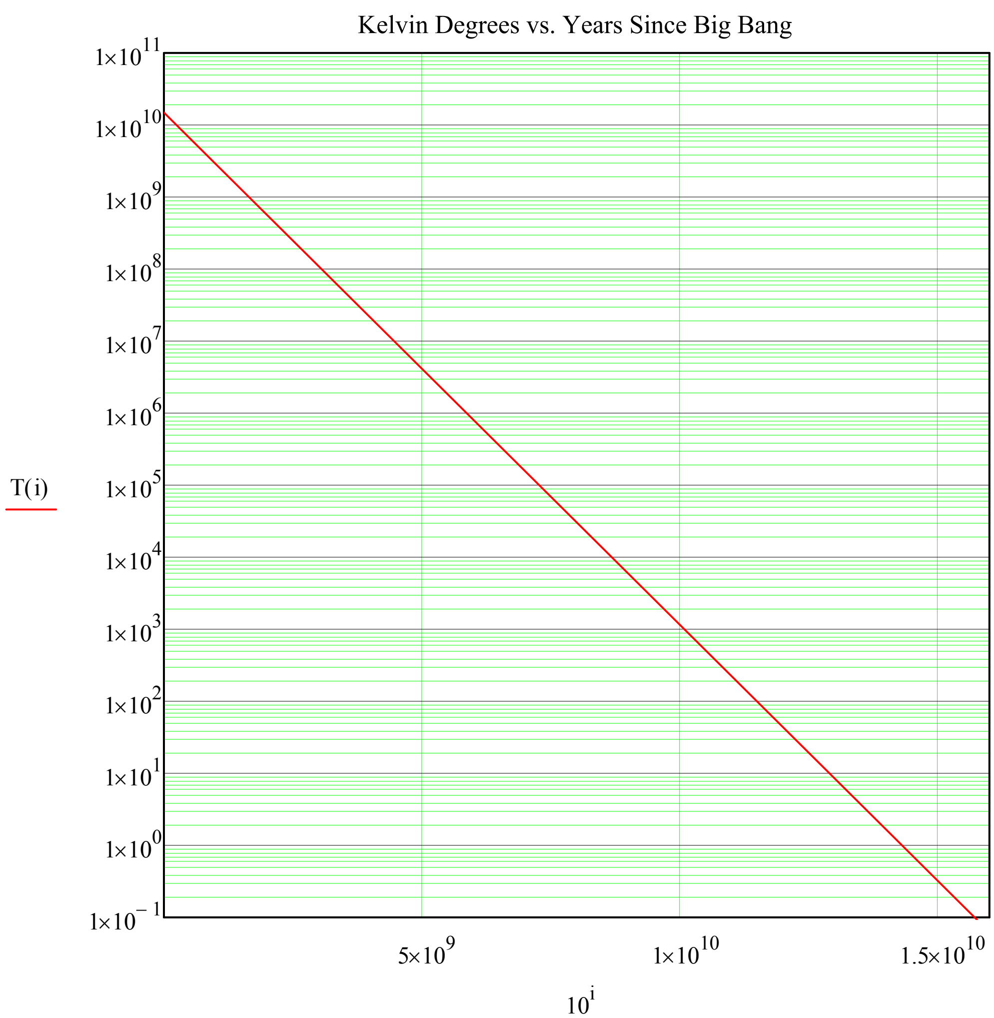
We can select t, then Symbolics>Variable>Solve, and set $t_o := 13.7 \cdot 10^9$, $T_o := 2.725$, and $T := 1.725$, to arrive at the following expression for t ...

$$t := \frac{\alpha \cdot t_o + \ln\left(\frac{T}{T_o}\right)}{\alpha} \qquad t = 1.398 \times 10^{10} \text{ years.}$$

That's 13.98 - 13.70 = 0.28 billion, or about 280 million years from now. So even if Newton's Law of Cooling doesn't hold on the scale of the universe, it seems likely that the universe will take a good while longer to cool down by even one more degree. Here's what the graph of temperature vs. time looks like.

$$i := 1 .. 11 \qquad T_o := 1.5 \cdot 10^{10}$$

$$T(i) := T_o \cdot e^{\alpha \cdot \left(10^i\right)}$$



SOME FINAL COMMENTS

1. Modern cosmology holds that the Big Bang occurred 13.7 billion years ago, and that the "let there be light" phase ("the primordial fog lifts") started some 380 million years afterward. But using 13.7 billion years doesn't invalidate the analysis -- it is just that the value for the constant α is uncertain. And of course, the temperature of the universe in the first few seconds after the Big Bang is uncertain, too.

2. George Gamow (1904-1968) was a great and prolific physicist whose native tongue was Russian. Be sure to read the entry on Gamow in Wikipedia, which is quite informative.

Many of Gamow's popular works are still in print. I take great pleasure in reading what Gamow wrote at a time when the Big Bang theory was ignored or ridiculed by Gamow's contemporaries.

Gamow's *The Age of the Universe* and *Matter, Earth, and Sky,* are highly recommended, as much for Gamow's creativity and lucid exposition as for the historical value of these two popular, but important books.