Is the Universe created from Vacuum Fluctuations?

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Abstract

It has been speculated that the universe is a zero-energy vacuum fluctuation[1]. I attempt to show how matter might be continually created in the universe from quantum fluctuations using the uncertainty and holographic principles. I derive a unique linear cosmology with a scale $R = ct$. I show that the annihilation time of a quantum fluctuation depends exponentially on R so that there is an effective cosmological horizon at that distance. Previously it has been found that a linear Big-Bang model[2, 3] fits the Hubble expansion data remarkably well[4, 5, 6]. Additionally such a model does not suffer from the classical horizon[7] and flatness[8] problems and so does not require a period of cosmological inflation.

We start from Heisenberg's quantum uncertainty principle

$$\Delta x \Delta p \sim \hbar \tag{1}$$

where Δx is the uncertainty in position and Δp is the uncertainty in momentum.

We assume a fluctuation with temperature T that is localised in a region of space with linear dimension of order R so that we have

$$\begin{aligned} \Delta x &\sim R \\ \Delta p &\sim \frac{k_B T}{c}. \end{aligned} \tag{2}$$

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Thus, by substituting (2) into (1), we find the following relationship for the temperature T given by

$$T \sim \frac{\hbar c}{k_B R}. \tag{3}$$

This temperature is analogous to the Hawking temperature for a black hole of radius R given by

$$T = \frac{\hbar c}{4\pi k_B R}. \tag{4}$$

Let us assume that there is some type of spherical horizon around us at radius R.

Following the holographic principle, we hypothesise that the entropy inside the horizon is given by the maximal-entropy black-hole Bekenstein-Hawking formula:

$$S = \frac{k_B A}{4\ell_P^2}. \tag{5}$$

where the area $A = 4\pi R^2$ and the Planck length $\ell_P = \sqrt{G\hbar/c^3}$.

Let us assume the mass-energy inside the horizon obeys the Einstein equation

$$E = Mc^2. \tag{6}$$

Finally let us assume that the system obeys the fundamental thermodynamic relationship

$$dE = TdS \tag{7}$$

where E is the internal energy, T is the temperature and S is the entropy.

By substituting (4), (5), (6) into (7) and integrating we find that

$$R = \frac{2GM}{c^2}. \tag{8}$$

Perhaps unsurprisingly (8) is identical to the Schwarzschild black hole radius formula.

In order to investigate how the space inside the horizon expands we assume Friedmann's equation for a homogeneous and isotropic universe. Since the horizon radius R is assumed to be the scale of a region of space then we expect it to expand with the universal scale factor $a(t)$ such that $R = a(t)R_0$. Therefore we can write the Friedmann equation in terms of radius R. For simplicity we assume a spatially flat universe without an explicit cosmological constant term so that we have

$$\left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G\rho}{3}. \tag{9}$$

Now the mass M inside the spherical volume enclosed by the horizon at radius R is given by

$$M = \frac{4}{3}\pi R^3 \rho. \tag{10}$$

By eliminating the mass density ρ between (9) and (10), and also the mass M using (8), we find

$$\left(\frac{\dot{R}}{R}\right)^2 = \frac{c^2}{R^2}. \tag{11}$$

Equation (11) has the linear solution

$$R = ct. \tag{12}$$

So far we have assumed that there exists some type of horizon at radius R. In order to complete this analysis we must investigate the nature of this horizon.

Let us assume that at time t_0 a quantum fluctuation occurs as described by equations (2). In order for the fluctuation to annihilate, a light signal that starts at the origin at time t_0 must reach the horizon at time t_1.

The comoving distance D_0 travelled by such a light beam is given by

$$\begin{aligned} D_0 &= \int_{t_0}^{t_1} \frac{cdt}{a(t)} \\ &= ct_0 \int_{t_0}^{t_1} \frac{dt}{t} \\ &= R_0 \ln \frac{t_1}{t_0}. \end{aligned} \tag{13}$$

where $a(t) = R/R_0 = t/t_0$.

Thus the annihilation time t_1 is given by

$$t_1 = t_0 \exp \frac{D_0}{R_0}. \tag{14}$$

Equation (14) shows that the annihilation time t_1 increases exponentially with D_0 with a length scale R_0. Thus, for all practical purposes, we do have a cosmological horizon at radius R_0.

References

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