Hubble force and vacuum energy

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Abstract

It is common knowledge that vacuum has an intrinsic energy and exerts negative pressure (force), one which acts against gravity to drive and accelerate the expansion of the Universe. Little is known, however, about the force *causing* this pressure. Indeed it is controversial whether there is any force at all behind this phenomenon so the situation must be carefully weighed. Here I shall venture to argue briefly that there does exist a force driving the expansion, the force I call the *Hubble Force*. Then, with an explicit force at hand, the whole machinery of continuum mechanics would be at our service to analyze the expansion thoroughly.

Keywords— Hubble force, gravity of light

Recall that from the assumption of homogeneity and isotropy of the universe we arrive at the FLRW metric, according to which we have

$$\mathbf{x} = \lambda(t)\mathbf{r}. \tag{1}$$

This implies that

$$\epsilon(t) = \frac{\Delta L}{L_0} = \lambda(t) - 1, \tag{2}$$

is the *strain* associated to the expansion of the Universe.

Upon differentiation (1) yields

$$\mathbf{v} = H\mathbf{x} + \mathbf{v}_{\text{pec}}, \tag{3}$$

which is the well-known Hubble's law for which abundant observational evidence exists.
The success of Hubble's law suggests that here the *derivative* operator is ontologically significant

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and it would not be a wild guess to expect that the derivative of Hubble's law *itself* might have something to reveal about the universe. Therefore

$$\mathbf{a} = H\mathbf{v} + \dot{H}\mathbf{x} + \mathbf{a}_{\text{pec}}. \tag{4}$$

For an object at rest in the co-moving frame

$$\mathbf{a} = \mathbf{x}(H^2 + \dot{H}) \tag{5}$$

which means there is an independent 'drag' force, solely due to the expansion of the universe, when we dispose of peculiar forces:

$$\mathbf{F}_H = m(H^2 + \dot{H})\mathbf{x}. \tag{6}$$

According to the Equivalence Principle this acts as a gravitational field, *but a positive one*:

$$\boxed{\mathbf{g}_H = (H^2 + \dot{H})\mathbf{x}} \tag{7}$$

From this we see that this field permeates the whole space but is a repulsive force, driving expansion of the space.

We now apply Gauss's law,

$$\nabla \cdot \mathbf{g} = -4\pi G \rho_m, \tag{8}$$

to find the energy density driving this expansion to be

$$\rho_{\text{vac}} = \frac{c^2(H^2 + \dot{H})}{4\pi G}, \tag{9}$$

which, if we neglect time variation of H, is

$$\boxed{\rho_{\text{vac}} \simeq \frac{(cH_0)^2}{4\pi G}} \tag{10}$$

which is *exactly* equal to the energy density of vacuum.

The Hubble force (6) can now be used to define the *stress* of expansion as well,

$$\boldsymbol{\sigma}_H = \frac{H^2 + \dot{H}}{A}\mathbf{x}. \tag{11}$$

Hooke's law now states that stress is proportional to strain, with the constant of proportionality being the *cosmic young modulus* field

$$\mathbf{E}_H(\mathbf{x}, t) = \frac{\boldsymbol{\sigma}_H}{\epsilon} = \frac{H^2 + \dot{H}}{A(\lambda(t) - 1)}\mathbf{x}. \tag{12}$$

For a rod whose length does not change with the co-moving time, the *temporal expansion coefficient* is just the Hubble parameter

$$\eta = \frac{1}{L}\frac{dL}{dt} = \frac{1}{\lambda l}\frac{d(\lambda l)}{dt} = H. \tag{13}$$

It now remains to be seen how (9) follows from

$$\rho = \frac{\hbar}{8\pi^3}\int \omega_k d^3k.$$

I have not yet been able to solve this problem but I can offer what little I have achieved so far.

If we are to leave

$$E = \frac{1}{2}\hbar\omega$$

unaltered, the only way the integral can be modified is via a change in the spatial structure of the momentum space; a space directly related to the velocity space. In fact, since I showed as a result of acceleration of light momentum is modified, we must have

$$p = \frac{mva}{\sqrt{a^2 + a_\star^2}} = \hbar k.$$

Specially in the 'deep-MOND' regime

$$\hbar k = \frac{mva}{a_\star}.$$

It is thus conceivable that modification of momentum might change the spatial structure of the momentum space.