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Willard Mittelman
Email: wmitt@uga.edu

Abstract

We discuss a recent attempt by Gogberashvili and Kanatchikov to derive the value of the fine structure constant $\alpha$ using cosmological parameters. We correct some errors in the proposed derivation, as well as modifying the authors’ account of dark energy. As a result of these corrections and modifications, a viable derivation of $\alpha$’s value is obtained, thereby vindicating the basic approach of the above authors.

In [1], Gogberashvili and Kanatchikov (hereafter “GK”) attempt to derive the value of the fine structure constant $\alpha$ using a Machian theory in which all particles in the universe are “gravitationally entangled,” so that they interact nonlocally with each other. GK refer to the “Machian energy” of particles, by which they mean the energy arising from collective, nonlocal interactions between gravitationally entangled particles. In connection with their derivation of $\alpha$’s value, GK identify the total Machian energy of all particles in the universe with dark energy, which leads them to conclude that the ratio $M_{\text{Mach}}/M$ equals the relative dark energy density $\Omega_\Lambda$, where $M_{\text{Mach}}$ is the total Machian mass of all particles in the universe (i.e., the mass equivalent of the total Machian energy). It is important to realize that $M$, for GK, is not simply the total mass of all particles in the universe; it is the total active gravitational mass of the cosmic fluid, and hence it includes all dark components [2]. Since dark energy thus contributes to $M$, and since $M_{\text{Mach}}$ represents energy over and above the “normal” energy of matter, it is natural to associate dark energy with $M_{\text{Mach}}$, and to equate the ratio $M_{\text{Mach}}/M$ with $\Omega_\Lambda$, as GK do.

Before proceeding further, there is an important error in GK’s attempted derivation of $\alpha$ that must be noted. GK obtain their value of $\alpha$, which closely matches the measured value, from their equation (18), in which the expression that is equated with $\alpha$ contains the term “$\Omega_\Lambda^2$,” where $\Omega_\Lambda = M_{\text{Mach}}/M$. (See the appendix below for (18) and other relevant equations from [1].) This equation (18) is obtained in part from equation (17), which also contains “$\Omega_\Lambda^2$.” The occurrence of “$\Omega_\Lambda^2$” in these two equations is an error, however; the correct term is simply “$\Omega_\Lambda$,” in both (17) and (18). This can be readily verified by following the procedure mentioned in [1] itself, viz., using equations (1), (7), (8) and (16) together to obtain (17); the equation thus obtained contains “$\Omega_\Lambda$” rather than “$\Omega_\Lambda^2$.” (In obtaining this equation, the relation $R \sim c/H$, where $R$ is the radius of the universe and $H$ the Hubble constant, is also useful.) It follows immediately that equation (18) too should contain “$\Omega_\Lambda$” instead of “$\Omega_\Lambda^2$.” Unfortunately, replacing “$\Omega_\Lambda^2$” with “$\Omega_\Lambda$” here yields a value of $\alpha$ that is not particularly close to $\alpha$’s measured value, in contrast to the “good” value of $\alpha$ that GK obtain by (incorrectly) using $\Omega_\Lambda^2$. As explained below, however, this problem can be remedied by hypothesizing the existence of other nonlocal interactions, besides those involving matter-particles, that also contribute to dark energy, so that nonlocal interactions between particles give rise to only a part of the total dark energy. First, however, there is yet another issue with GK’s derivation of $\alpha$ that needs to be addressed. (N.B.: It is possible, of course, that the above-mentioned error will be corrected in a revised version of [1]. At the time of writing, however, this error is still present in [1].)

The expression for $\alpha$ in GK’s equation (18) also contains the term “$\Omega/\Omega_\nu$,” where the numerator “$\Omega_r$” denotes the relative energy density of radiation, and the denominator “$\Omega_\nu$” refers
to the relative baryon energy density. GK use here the accepted values of $\Omega_b$ and $\Omega$, established by observation. At the same time, however, they regard $\Omega_b$ as reflecting (at least in part) the Machian energy $E_b$ of baryons, which is a component of the total Machian energy $E$ whose mass equivalent is $M_{\text{Mach}}$. $E_b$, therefore, is a constituent of dark energy and hence contributes to $\Omega_b$. The accepted observational value of $\Omega_b$, however, is for the energy density of baryonic matter, which is a component of $\Omega_m$ exclusively, and not of $\Omega$. Consequently, GK’s “$\Omega_b$” is not the standard $\Omega_b$, and the value of $\Omega_b$ that GK use must be modified to reflect this fact (thereby modifying the ratio $\Omega_b/\Omega$ as well, of course). Specifically, $\Omega_b$’s value needs to be increased so as to reflect the addition of a dark-energy component.

Let us return now to the hypothesis mentioned above, according to which part of the total dark energy is due to nonlocal interactions that do not involve matter-particles. The energy of such interactions does not constitute part of the Machian energy of matter, since the interactions in question are, *ex hypothesi*, independent of matter-particles. Hence, in particular, these interactions do not contribute to the Machian energy of baryons; and as a result, they do not contribute to the above-mentioned increase in $\Omega_b$’s value, a point that must be kept in mind when calculating the amount of this increase. Now if the matter and non-matter components of dark energy are roughly equal, so that each is approximately 0.37 of the total energy density of the universe (taking $\Omega_b=0.74$, and $\Omega_b=0.046$ for the standard, unmodified $\Omega_b$), then the modified ratio $\Omega_b/\Omega_b$, when plugged into the corrected version of GK’s equation (18) in which “$\Omega_2$” is replaced by “$\Omega_b$,” yields a value of $\alpha$ that is suitably close to the measured value. “Suitably close” here means “within the margin of error for the derived value of $\alpha$,” where this margin of error reflects the margin of error of the observationally determined values of $\Omega_b/\Omega$ and $\Omega_b$. The calculations here are straightforward, and so we simply give the results: namely, the modified value of $\Omega_b$ is 0.063, which yields a modified ratio $\Omega_b/\Omega_b = 0.796 \times 10^{-3}$ (the standard value of this ratio is $1.09 \times 10^{-3}$). Plugging these values into the corrected version of GK’s equation (18), and using GK’s estimate of the margin of error, we have that $\alpha \approx 7.398 \pm 0.4 \times 10^{-3}$. This value of $\alpha$ is, obviously, suitably close to the measured value of $7.297 \times 10^{-3}$.

The question that needs to be addressed now is this: what sort of nonlocal interaction that does not involve particles of matter can give rise to a dark energy that supplies the remaining 0.37 of the energy density of the universe (where the magnitude of the universe’s energy density is $\sim V^{1/2} \sim H^2$, with $V$ being the four-volume of the universe in Planck units)? Here we appeal to recent work by the present author [3], in which nonlocal interactions between Planck-sized elements of spacetime that fluctuate in volume produce a widespread cancellation of these fluctuations. At any given time $t$, there are $\sim \sqrt{V}-$many elements whose fluctuations are uncanceled (again, $V$ is in Planck units); hence, there is a net volume-fluctuation $\Delta V \sim \pm \sqrt{V}$ at $t$ for the entire volume $V$. The volume-fluctuations here amount to fluctuations in the *density* of the spacetime elements; and we take the nature of these elements to be described by causal set theory [4]. At a given time $t$, the widespread cancellation of these density-fluctuations, combined with the presence of sparsely distributed uncanceled fluctuations, gives rise to a quantum potential $Q$ of spacetime with energy density $\rho_Q$. If the net volume-fluctuation is a *contraction*, i.e. if $\Delta V \sim -\sqrt{V}$, we have $\rho_Q \approx 0.35V^{1/2}$; and for $\Delta V \sim +\sqrt{V}$, we have $\rho_Q \approx 0.39V^{1/2}$. Hence, the average value of $\rho_Q$ is approximately $0.37V^{1/2}$, which is just what is needed here. We conclude, therefore, that when GK’s derivation of $\alpha$’s value is corrected and modified appropriately, and is supplemented by certain additional ideas concerning dark energy, this derivation does indeed yield a suitable value of $\alpha$. In our view, the existence of such a derivation...
is potentially of great significance, a fact which indicates that the Machian perspective developed in [1, 2, 5] deserves serious consideration.

REFERENCES

    M. Gogberashvili, “Thermodynamic gravity and the Schrodinger equation” [arXiv:1008.2544].

APPENDIX

Equations from [1]:

(1) $c^2 \approx \frac{MG}{R}$

(7) $-mc^2 \Delta t \approx -2\pi \hbar$
(The rationale for this equation is explained in [1].)

(8) $\Delta t \sim \frac{1}{NH}$
(N here is the number of particles in the universe; in the simplified model of [1], these particles are all identical, and each particle has mass m.)

(15) $\alpha = \left(\frac{\Omega}{\Omega_\Lambda}\right) \left(2NGm^2/ct\right)$

(16) $M_{\text{Mach}}/M = \Omega_\Lambda \approx N^2m/M$

(17) $m^2/\hbar = \left(2\pi c/NG\right) \Omega_\Lambda^2$

(18) $\alpha \approx 4\pi \Omega_\Lambda^2(\Omega/\Omega_\Lambda)$
(Note that (18) is obtained by plugging (17) into (15).)