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Abstract

We discuss a recent attempt by Gogberashvili and Kanatchikov to derive the value of the fine structure constant α 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 α'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 α 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 α'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_{Mach}/M equals the relative dark energy density Ω_Λ, where M_{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_{Mach} represents energy over and above the "normal" energy of matter, it is natural to associate dark energy with M_{Mach}, and to equate the ratio M_{Mach}/M with Ω_Λ, as GK do.

Before proceeding further, there is an important error in GK's attempted derivation of α that must be noted. GK obtain their value of α, which closely matches the measured value, from their equation (18), in which the expression that is equated with α contains the term "Ω_Λ^2," where $\Omega_\Lambda = M_{Mach}/M$. (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 "Ω_Λ^2." The occurrence of "Ω_Λ^2" in these two equations is an *error*, however; the correct term is simply "Ω_Λ" 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 "Ω_Λ" rather than "Ω_Λ^2." (In obtaining this equation, the relation R ~ 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 "Ω_Λ" instead of "Ω_Λ^2." Unfortunately, replacing "Ω_Λ^2" with "Ω_Λ" here yields a value of α that is not particularly close to α's measured value, in contrast to the "good" value of α that GK obtain by (incorrectly) using Ω_Λ^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 α 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 α in GK's equation (18) also contains the term "Ω_r/Ω_b," where the numerator "Ω_r" denotes the relative energy density of radiation, and the denominator "Ω_b" refers to the relative baryon energy density. GK use the accepted values of Ω_b and Ω_r established by observation. At the same time, however, they regard Ω_b as reflecting the *Machian* energy E_b of baryons, which is a component of the total Machian energy E whose mass equivalent is M_{Mach}. E_b, therefore, is a constituent of dark energy and hence contributes to Ω_Λ. The accepted observational value of Ω_b, however, is for the energy density of baryonic *matter*, which is a component of Ω_m exclusively, and not of Ω_Λ. Consequently, GK's "Ω_b" is not the standard Ω_b, and the value of Ω_b that GK use must be modified to reflect this fact (thereby modifying the ratio Ω_r/Ω_b as well, of course). In making this modification, we are guided by the intuitive idea that, *ceteris paribus*, the relative energy density associated with E_b, i.e. the relative density referred to above as GK's "Ω_b", should constitute the same fraction or portion of Ω_Λ that the standard or usual Ω_b constitutes with respect to Ω_m. In other words, we make the initial assumption that the contribution of the Machian energy (density) of baryons to the total Machian energy (density) of particles – taking this Machian energy, with GK, to represent dark energy – should be the same, percentage-wise, as the contribution of the usual energy density of baryonic matter to the total energy density of matter. This assumption is reasonable because, *ceteris paribus*, there is no apparent reason or motivation for taking baryons to have a different relative effect in the one case than in the other. Of course, if it turns out that other things are *not* equal here, and consequently that there *is* some reason for treating baryons differently in the case of Machian energy, then the fraction of Ω_Λ represented by GK's "Ω_b" needs to be adjusted accordingly. In fact, we will make such an adjustment below, motivated by certain ideas about dark energy that supplement GK's account of dark energy.

Consider now the idea mentioned above that part of the total dark energy is due to nonlocal interactions that do *not* involve matter-particles; in particular, we wish to consider the idea proposed in [3] that there exist nonlocal interactions of this sort that give rise to a "quantum potential of spacetime" Q that acts as dark energy, and which is coupled to dark matter. This Q can be thought of as the Machian energy of the universe-"particle", so that Q forms part of the general "pool" of the Machian energy of particles, or at least that *part* of this pool to which Q is coupled. Thus, GK's identification of dark energy with the Machian energy of particles is upheld. What we have, then, is that Machian dark energy consists of two components, a Q-component and a non-Q-component. The Q-component boosts the Machian energy of non-baryonic particles, to which it is coupled; but it does *not* affect the Machian energy of baryons, since it is not coupled to baryons. We propose that these two components of Machian dark energy are roughly equal, so that each is approximately 0.37 of the total energy density of the universe (taking Ω_Λ=0.74). This proposal is motivated by two considerations. First, the derivation of Q's value in [3] yields a value of Q that equals approximately 0.37 of the universe's total energy density (where the magnitude of this total density is ~ $V^{-1/2}$ ~ H^2, with V being the four-volume of the universe in Planck units); this is explained in more detail below. And second, taking the two components to be equal leads to a value for the fine structure constant α that is in good agreement with the measured value, as will be seen shortly. Now, the fact that the Machian energy of baryons is not affected or boosted by Q entails that the assumption described in the preceding paragraph must be rejected, with the value of GK's "Ω_b" needing adjustment as a result. Specifically, the baryonic portion of the total Machian energy is only *half* of what it would be if the assumption in question were true, given that Q represents half of the total dark energy. Keeping this point in mind, and taking each of the two components of dark energy to constitute approximately 0.37 of the total energy density of the universe, we have that the value of GK's "Ω_b" is approximately 0.065 (where Ω_b=0.046 for the standard Ω_b). It follows that the ratio Ω_r/Ω_b, for GK's "Ω_b", has the value 0.7714×10^{-3}. Plugging this value into the corrected version of GK's equation (18) in which "$\Omega_\Lambda{}^2$" is replaced by "Ω_Λ", and using GK's estimate of the margin of error, we obtain the value $\alpha \approx 7.175 \pm 0.4 \times 10^{-3}$, which is in good agreement with α's measured value of 7.297×10^{-3}.

Let us say something more about the dark energy Q described in [3]. The idea is that nonlocal interactions between Planck-sized elements of spacetime that fluctuate in volume produce a widespread cancellation of these fluctuations. At any given time t, and using Planck units for V, there are $\sim \sqrt{V}$-many elements whose volume-fluctuations are uncanceled; 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 *un*canceled fluctuations, gives rise to a quantum potential Q of spacetime with energy density ρ_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 if the net volume-fluctuation is an *expansion*, so that $\Delta V \sim +\sqrt{V}$, we have $\rho_Q \approx 0.39V^{-1/2}$. Hence, the average value of ρ_Q is approximately $0.37V^{-1/2}$, which is just what is needed in the present context, as indicated above. We conclude, therefore, that when GK's derivation of α's value is suitably corrected, and is modified due to introducing the quantum potential Q of spacetime as a component of dark energy, this derivation does indeed yield a "good" value of α. 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

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APPENDIX

Equations from [1]:

(1) $c^2 \approx MG/R$

(7) $-mc^2\Delta t \approx -2\pi\hbar$

(The rationale for equation (7) is explained in [1].)

(8) $\Delta t \sim 1/NH$

(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) $\alpha = (\Omega_r/\Omega_b)(2NGm^2/ct)$

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

(17) $m^2/\hbar = (2\pi c/NG)\, \Omega_\Lambda^{\,2}$

(18) $\alpha \approx 4\pi\, \Omega_\Lambda^{\,2}(\Omega_r/\Omega_b)$

(Note that (18) is obtained by plugging (17) into (15).)