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Accelerating universe and the time-dependent fine-structure constant

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I start with assuming a gravitational scalar field as the dark-energy supposed to be responsible for the accelerating universe. Also from the point of view of unification, a scalar field implies a time-variability of certain "constants" in Nature. In this context I once derived a relation for the time-variability of the fine-structure constant α: $\Delta\alpha/\alpha = \zeta\mathcal{Z}(\alpha/\pi)\Delta\sigma$, where ζ and $\mathcal{Z}$ are the constants of the order one, while σ on the right-hand side is the scalar field in action in the accelerating universe. I use the reduced Planckian units with $c = \hbar = M_{\rm P}(= (8\pi G)^{-1/2}) = 1$. I then compared the dynamics of the accelerating universe, on one hand, and $\Delta\alpha/\alpha$ derived from the analyses of QSO absorption lines, Oklo phenomenon, also different atomic clocks in the laboratories, on the other hand. I am here going to discuss the theoretical background of the relation, based on the scalar-tensor theory invented first by Jordan in 1955.

An important issue of this theory is the presence of different conformal frames, connected by the conformal transformations to each other. Of particular significance are the Jordan frame with the nonminimal coupling term expressed by the scalar field ϕ, so with the time-dependent gravitational constant, and the Einstein frame with the standard Einstein-Hilbert term, with the re-expressed scalar field σ. Brans and Dicke proposed an added assumption on the decoupling of ϕ from the matter Lagrangian to save the idea of Weak Equivalence Principle (WEP), to be called the BD model.

As it turns out, choosing this model is closely connected with the question which of the conformal frames is "physical." I point out that the required criterion is the constancy of matter particle masses, which provide with fundamental units of microscopic time and length, to be used for the astronomical measurements. Notice that these masses are constant or variable depending on the choice of the frame. The argument is affected, however, crucially by the presence of Λ leaving no room to define the physical frame. To be blamed is the BD model, which is replaced by what is called the scale-invariant model to identify the Einstein frame with the physical frame, at least at the classical level. Quantum effects introduce some deviations resulting in a small amount of WEP violation, implemented by the calculation in terms of quantum anomalies. This is the way the relation mentioned at the beginning is derived.

Finally I add a comment on the cosmological solutions I used. The observed acceleration is fitted by $\Lambda_{\rm eff}$ as small as 10^{-120} in the Planckian units. This small number has symbolized a fine-tuning problem. Remarkably, however, the obtained attractor solution in the Einstein frame does include $\Lambda_{\rm eff} \sim t_{*0}^{-2}$, where the asterisk in the subscript implies the cosmic time defined in the Einstein frame, and the present time $\sim 1.4 \times 10^{10}$y corresponds to $\sim 10^{60}$ in units of the Planck time. In other words, I no longer need a fine-tuning process; $\Lambda_{\rm eff}$ is small only because we are old! This is a major success of the scalar-tensor theory extended by including Λ, unparalleled by any other phenomenological approaches.