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On a time varying fine structure "constant"

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February 6, 2008

Abstract

Webb et al.'s result that the fine structure "constant" α varies with time, is here considered due to time-varying electric permittivity ϵ_0 , along with an inversely varying magnetic permeability μ_0 , so as to keep the speed of light $(1/\sqrt{\epsilon_0\mu_0})$ constant. With help of Dirac's LNH, we find how the total number of nucleons of the Universe, the energy density and Newton's Gravitational"constant" evolve with time. We also estimate the present day value of the Universe' deceleration parameter finding a value compatible with the Supernovae observations, and we also found an acceptable time variation for the the cosmological "constant".

PACS 98.80 Hw.

ON A TIME VARYING FINE-STRUCTURE “CONSTANT”
MARCELO S. BERMAN and LUIS A. TREVISAN

Webb et al. [1] and Webb et al. [2] have provided experimental data on quasars that span 23% to 87% of the age of Universe, finding deviation from the average in the fine structure constant, given by $\frac{\Delta\alpha}{\alpha} \simeq -0.72 \times 10^{-5}$. Due the fact that this “constant ” (α) is defined by other ones, one can ask what is the “constant ” that is causing the variation in α . Another interesting remark is that this discovery is relating micro and macro phenomena and can have implications in the comprehension of QFT and Cosmology. There are a variety of possible physical expressions for a changing α . Bekenstein proposed a varying e theory [3]. An alternative is the varying speed of light (VSL) theory [4] in which varying α is expressed as a variation of the speed of light.

Berman and Trevisan [5] elaborated a full model containing a JBD (Jordan-Brans-Dicke) framework with time-varying speed of light. Berman and Trevisan [6] returned to the subject commenting that similar conclusions could be reached by applying Dirac’s LNH (Large Number Hypothesis) with $c = c(t)$. We now present a different scenario with α variable and LNH, keeping the speed of light and Planck’s constant really constants. One could claim that it is needed a specific gravitational theory in order to deal with this project; however, it is not certain which theory is the correct one for explaining gravitational phenomena, so we feel that Dirac’s hypothesis can guide us tentatively in the absence of a final theory. For a full appraisal of LNH we recomend Barrow’s article [24]. Even a famous researcher as Richard P. Feynman [25] admitted that among the speculators in numerical coincidences, there were “very serious mathematical players who construct mathematical cosmological models”.

In S.I. units, the fine-structure “constant” , α is given by:

$$\alpha \equiv \frac{e^2}{2\varepsilon_0 hc} \tag{1}$$

We shall consider a possible time variation of constant ε_0 .If overdots stand for time derivatives, we have

$$\frac{\dot{\alpha}}{\alpha} = -\frac{\dot{\varepsilon}_0}{\varepsilon_0} \tag{2}$$

Let us suppose that ε_0 varies with a power law of time,

$$\varepsilon_0 = At^n \quad (3)$$

($A, n = \text{consts}$). Then ,

$$\frac{\dot{\alpha}}{\alpha} = -nt^{-1} \quad (4)$$

The present Universe has been thought as an Einstein-de Sitter, with constant deceleration parameter $q = 1/2$. We may ask whether the value of this parameter could be a different constant value, say,

$$q = -\frac{\ddot{R}R}{\dot{R}^2} = m - 1 \quad (5)$$

where m is a constant to be determined and $R = R(t)$ is the scale factor in Robertson-Walker's metric.

The theory of constant q 's has been developed by Berman[7], and Berman and Gomide[8], who found that the age of Universe, t , Hubble's parameter $H = \dot{R}/R$, and constant m , are related by:

$$H = (mt)^{-1} \quad (6)$$

It should be remarked that this formula depends on the particular gravitational theory being considered. It is a property valid for Robertson-Walker's metric, and it is approximately valid also for slowly time varying deceleration parameters.

The experimental value found by Webb et al, may be interpreted as yielding the following result :

$$\frac{\Delta\alpha}{\alpha\Delta t} \simeq -\frac{0.72 \times 10^{-5}}{0.64t} \simeq -1.1 \times 10^{-5} Hm \quad (7)$$

Notice that, in the above formula $\Delta t = 0.87t - 0.23t = 0.64t$.

Even if our numerical estimate as above turns out to be incorrect, we shall employ it with the cautionary note that if a different numerical value will be published later, any competent reader will be able to remake our calculations, thus obtaining more accurate results than ours below.

From (4) and (7), we find

$$n \simeq 1.1 \times 10^{-5} \quad (8)$$

We have, thus, found how ε_0 must vary in order to comply with experimental data on $\dot{\alpha}$, provided that all other constants that appear in (1) are really constants.

From electromagnetism, we know that:

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \quad (9)$$

so that we find that μ_0 should vary inversely as ε_0 , in order to keep c constant.

We might now take a look at Dirac's large number hypothesis [9][10][11], to check how of our results could be accommodated in his framework. Calling N the total number of nucleons in the Universe, we have ,

$$\frac{cH^{-1}}{4\pi\varepsilon_0 \left(\frac{e^2}{m_e c^2}\right)} \cong \sqrt{N} \quad (10)$$

where m_e, m_p and e stand respectively for electron's and proton's masses, and electron's charge,

$$\frac{e^2}{4\pi\varepsilon_0 G m_p m_e} \cong \sqrt{N} \quad (11)$$

and

$$\frac{\rho(cH^{-1})^3}{m_p} \cong N \quad (12)$$

where ρ is the energy density of the Universe. The present value of N is roughly 10^{80} .

Eddington [22]proposed to consider another large number involving the cosmological "constant", i.e,

$$ch(m_n m_e / \Lambda)^{1/2} \cong \sqrt{N} \quad (13)$$

Then, on considering that N increases with the age of the Universe, we find that Λ is time-varying. The whole hypothesis was coined by Berman [23] as GLNH (Generalized Large Numbers Hypothesis).

By plugging relations (6), (3) and taken care of result (8), we can check that:

$$N = At^{1.99998} \quad (14)$$

where A is a constant.

$$G = Bt^{-1.0} \quad (15)$$

where B is a constant.

$$\rho = Dt^{-1.00002} \quad (16)$$

where D is a constant.

$$\Lambda = Et^{-1.99998} \quad (17)$$

where E is a constant. Next generation of experimentalists may well provide evidence in favor or against these results. The time variation obtained for Λ , is compatible with our knowledge about the value that it should have at GUT's time and in the present.

It is necessary to point out that the origin of $c = c(t)$ theories can be traced to a paper by Gomide [12], and that $\dot{\alpha} \neq 0$ theory with $c = c(t)$ was considered by Barrow and Magueijo [13]. Gomide also worked with a time varying ε_0 , but supposed that α was constant, in face of Bahcall and Schmidt's paper [14].

Confronting with observations, i.e., when we define

$$\frac{\dot{G}}{G} = \sigma H \quad (18)$$

our result is, from (14),

$$\frac{\dot{G}}{G} \cong -1.0t^{-1} = -1.0H(1 + q) \quad (19)$$

where we have, again, used relations (6) and (14).

This means that, if we would have accurate measures of σ , we could estimate the deceleration parameter q . However, we refer to Will [15] [16], in order to mention that there is no conclusive experimental value for σ . Lunar laser ranging and Viking radar measurements by Williams et al[17] and Reasenber[18] put $|\sigma| < 0.6$. In Ref.[16], Will coments that these two kinds of measurements give the best limits on \dot{G}/G [20].

This means, from (17), that:

$$-0.4 > q > -1.6 \quad (20)$$

so that the Universe would be accelerating, in accordance with Supernovae results [19]. We have thus shown that Dirac's LNH, Webb et al's fine structure constant time variation, Supernovae results and $\dot{\varepsilon}_0 \neq 0$ hypothesis are all coherent among them. It could be argued that there is one evidence [21] for a non constant q arising from a ten billion years old Supernova explosion; however, this is not a conclusive evidence for turning down the constant q hypothesis for the present Universe. Just as we have discussed above the time variation for G , from the experimental point of view, we might comment on the time variation of ρ as found by us. Unfortunately, it is very difficult to estimate with accuracy the average density of the present Universe, and then we are left without experimental clues on $\dot{\rho}$. Nevertheless, we have found a time decreasing function for ρ ; this is the kind of variation unanimously expected by researchers in the field, i.e, no one would favour an increasing function of time, because as the Universe expands, ρ should decrease.

We have thus found how N, G, ρ, Λ and ε_0 may vary and we have found bounds on the present day deceleration parameter q in agreement with observation. In the model presented here, we have $\alpha = \alpha(t)$, because $\varepsilon_0 = \varepsilon_0(t)$, but c is constant. It's important to elaborate different models and make some previews about their consequences in order to decide among them. The way, and why, α is varying with the age of Universe is one of most intriguing problem in modern physics and the understanding of this question can lead to new discoveries. In fact, a Superunification theory will only survive in case that such variations of constants with the age of the Universe, shall encounter with a theoretical explanation.

It is necessary to point out that we did not endeavour to make precise numerical predictions on the values of the quantities we did estimate, because GLNH is not a substitute for an exact gravitational theory. In fact, we only used GLNH for obtaining tentative laws of variation for these quantities, with the age of the Universe.

Acknowledgements

The authors are recognized to an anonymous source, for clarifying our manuscript. We also thank Prof. F.M.Gomide for supplying pertinent information and Prof M.M. Som for his long time support.

Both authors thank support by Prof. Ramiro Wahrhaftig, Secretary of Science, Technology , and Higher Education of the State of Paraná, and by our Institutions, especially to Jorge L.Valgas, Roberto Merhy, Mauro K. Nagashima, Carlos Fior, C.R. Kloss, J.L.Busso, and Roberto Almeida.

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