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Scaling in Cosmology and the Arrow of Time

MENAS KAFATOS[1,2,4] , SISIR ROY[1, 5] AND RICHARD AMOROSO[3, 6]

[1] *Center for Earth Observing and Space Research, Institute of Computational Sciences and Informatics, and*
[2] *Department of Physics, George Mason University, Fairfax , VA 22030-4444, USA*
[3] *The Noetic Institute, Orinda, CA 94563-2502, USA*

EMail : [4] mkafatos@gmu.edu
[5] sroy2@osf1.gmu.edu
[6] Cerebroscopic@mindspring.com

ABSTRACT
A new type of scaling applicable to a variety of physical parameters in the universe is proposed here. This utilizes a relation linking the fundamental masses and fundamental constants in nature and an axiomatic approach is developed for the relations between microscopic and macroscopic found by Eddington and Dirac. In this approach, the fundamental constants are changing with time and the variation is related to the changing of the scale of the universe. The variation of the fundamental constants leads to an arrow of time in the present universe as well as scale-invariant relationships linking all scales. All lengths in the universe are proportional to the scale of the universe *R*, and similar relations exist for other physical parameters.

Key words: arrow of time - fundamental constants - scale of the universe - big bang.

1 INTRODUCTION

Cosmological theories and theories of fundamental physics must ultimately not only account for the structure and evolution of the universe, the physics of fundamental interactions but also lead to an understanding of why this particular universe follows the physics that it does. Such theories must lead to an understanding of the values of the fundamental constants themselves. Moreover, the understanding of universe has to utilize experimental data from the present to deduce the state of the universe in distant regions of the past and also account for certain peculiarities or coincidences observed.

The prevalent view today in cosmology is the big bang, inflationary evolutionary model. Although certain nagging problems have remained, e.g. the need to postulate cold, dark matter in amounts much larger than all the observable matter put together, dark matter not detected so far in the laboratory or the recent need to re-introduce the cosmological constant, the big bang cosmology has, nevertheless, achieved impressive results (Silk 1989).

In this paper we take a different approach than the usual evolutionary picture where the physics itself is assumed invariable. We study some numerical relations among fundamental constants starting from relationships first proposed by Weinberg (1972), which turn out to be equivalent to the relations found by Dirac (1937), and explore a new scaling hypothesis relating the speed of light *c* and the scale of the universe *R*. We then develop an axiomatic approach which results in an *apparent* expanding universe, yielding the same successes as present big bang cosmology but without the need to postulate inflation, cold dark matter, cosmological constant or any of the artificialities of current theory. The "coincidences" of Dirac (1937) and Eddington (1931) concerning large numbers and ratios of fundamental constants are not to explained, rather they are accepted and in the process yield a fundamentally different view of the cosmos. The fundamental constants can be assumed to vary with time and this variation leads to an *apparent* expansion of the universe. The variations of the fundamental constants lead to a changing universe, e.g. the number of nucleons varies, etc. The increase of the number of nucleons *appears* to be related to an arrow of time as perceived by an observer in the present universe. Possible implications of this new approach are discussed.

2 FINE TUNING AS IMPLIED BY COSMOLOGICAL OBSERVATIONS

There are a number of observations which must be applied in any cosmological theory which attempts to explain the observed structure of the universe:

a) The universe appears to be quite flat, in other words the density of the universe is close to the so-called closure or critical density,

$$r_{crit} = 2\times10^{-29}\left(H_0 / 100\text{km s}^{-1}\ \text{Mpc}^{-1}\right)^2 \text{gr cm}^{-3} \qquad (1)$$

where H_o is the Hubble constant defined as the apparent rate of expansion with distance, $\dot{R}/R$ and where R is the scale of the universe. In big bang cosmology, this so-called "constant" is actually a function of cosmic time, i.e. it is a variable. Its present-day value seems to be ~ 75 km s^{-1} Mpc^{-1}. The universe appears to be *close* to a flat, Euclidean, Einstein-de Sitter state as indicated from (1), and yet it is still not clear what the geometry of the universe is; *exactly* flat (which would be required by the inflationary scenario); open (yielding a forever-expanding, negatively curved space-time); or closed (yielding a maximum expansion and a positively curved space-time).

b) If one is to assume that the universe followed an inflationary period in the distant past, then the universe must be *exactly* flat to one part in 10^{50} near the time of big bang. This is the so-called *flatness problem*: This is such a remarkable requirement that the usual interpretation proposed in the early 80's is that early on, the universe was in an inflationary state, washing out any departures from flatness on time scales of 10^{-35} sec. The inflationary model proposed by Guth and others (cf. Guth and Steinhardt 1984) has been developed in various forms to account for the flatness of the universe and also is proposed to solve the *horizon problem*, or apparent homogeneity of the 2.73 K black body radiation seen by *COBE* (Smoot 1996). The latter problem involves the observation that although the 2.73 K radiation was emitted ~ 10^5 years after the beginning, opposite sides of the sky at that time were out of causal contact, separated by ~ 10^7 light years. Other structures involving large-scale correlations in the universe exist such as very large structures in the distribution of matter (Geller and Huchra 1989). These structures may be progressively hierarchical all the way to the scale of the universe itself.

c) If the universe is indeed flat, observations indicate that baryons (and luminous matter) can only contribute at most ~ 0.05 of the closure density at present. We should ultimately be able to detect the other 90% or more of the matter required to give closure density, presumed to be in the form of cold dark matter (Novikov 1996). Nevertheless, attempts to detect such exotic matter in the laboratory have, so far, failed. Moreover, the recent realization that the cosmological constant L may have to be re-introduced (Peebles 1998) has also led to the probability of L itself varying and other similar notions (Glanz 1998). Without though some direct laboratory verification or overwhelming requirements imposed by particle theory (neither of which presently exists), the nature of dark matter remains elusive. This is clearly a very unsatisfying situation.

d) As we saw, present-day approximate flatness yields to an *exact* flatness in the distant past (this was one of the main reasons why the inflationary scenario was introduced to begin with). The alternative is to accept fine tuning in the universe. In fact, the flatness of the universe is not the only fine tuning. In considering other fundamental observed facts, the universe appears to be extremely fined tuned. It was Eddington (1931, 1939) and Dirac (1937) who noticed that certain cosmic "coincidences" occur in nature linking microscopic with macroscopic quantities (cf. Kafatos 1989). A most unusual relationship is the ratio of the electric forces to gravitational forces (this ratio is presumably a constant in an expanding universe where the physics remains constant), or

$$e^2 / G m_e m_p \sim 10^{40} \tag{2}$$

while the ratio of the observable size of the universe to the size of an elementary particle, or

$$R / \left(e^2 / m_e c^2 \right) \sim 10^{40} \tag{3}$$

where in the latter relationship the numerator is changing as the universe expands because the scale of the universe R is constantly changing in an expanding universe.

Dirac formulated the so-called *Large Number Hypothesis* which simply states that the two ratios in (2) and (3) are in fact equal for all practical purposes and postulates that this is not a mere coincidence. Various attempts were made to account for the apparent equality: A possibility that constants such as the gravitational constant may be varying was proposed by Dirac (1937) himself and others (cf. Dyson 1972). Other ratios such as the ratio of an elementary particle to the Planck length,

$$\frac{e^2/m_e c^2}{\left(\hbar G/c^3\right)^{1/2}} \sim 10^{20} \tag{4}$$

can also be constructed (Harrison 1981) yielding to the conclusion that fine tuning is prevalent in the universe. These relationships may be indicating the existence of some deep, underlying harmonies involving the fundamental constants and linking the microcosm to the macrocosm. Physical theory has not, however, accounted for these in a self-consistent way, waiting perhaps the anticipated unification of all physical forces at the quantum gravity or superstring levels.

e) Evidence (Barrow and Magueijo 1998) has recently been found which seems to be consistent with a time-varying fine structure constant $\alpha = e^2/(\hbar c)$. A varying speed of light theory (with $\hbar \ \alpha$ c) has also been proposed by Albrecht and Magueijo (1998). These two theories correspond to different representations of a varying a in terms of varying dimensional constants. The minimal varying-c theory is of interest because it offers a means of solving the so-called cosmological problems: the horizon, flatness, cosmological constant, entropy and homogeneity problems. Barrow and Magueijo (1998) tried to show that there exists a set of duality transformations between these two representations. On the other hand, recent observations of astrophysical events at high redshifts (Schaefer 1998 & Amelio 1998) can be used to place severe limits on the variation of the speed of light itself (Dc/c), as well as the photon mass (M_g).

f) Although other, less traditional ways, such as the Anthropic Principle (Barrow and Tipler 1986) have been proposed to account for the above fine tuning properties of the universe, there may be another approach involving quantum-like correlations (Roy and Kafatos 1998).

3 NUMERICAL RELATIONS AND CONCEPT OF SCALING

The critical density of the universe in (1) is defined as

$$r_{crit} = \frac{3H_0^2}{8\pi\ G} \tag{5}$$

Let N_p be the number of nucleons in the universe, then

$$m_p = \frac{M}{N_p} = \frac{R\dot{R}^2}{2GN_p} \qquad (6)$$

where m_p and M are the mass of the nucleon and mass of the universe, respectively.

Weinberg (1972) noticed that one can find a relationship linking the masses of elementary particles to the Hubble constant and other fundamental constants

$$m_p \sim \left(\frac{8\hbar^2 H_0}{Gc}\right)^{1/3} \qquad (7a)$$

and, correspondingly,

$$m_e \sim \left(\frac{\hbar e^2 H_0}{(8\pi)^3 Gc^2}\right)^{1/3} \qquad (7b)$$

where, m_p and m_e are the pion and electron masses, respectively.

These relations can be rewritten as

$$m_p \sim c_{pp} \left(\frac{8\hbar^2 \dot{R}/R}{Gc}\right)^{1/3} \text{ with } c_{pp} = \frac{m_p}{m_\pi} \qquad (8)$$

$$\text{and } m_p \sim c_{pe} \left(\frac{\hbar e^2 \dot{R}/R}{Gc^2 (8\pi)^3}\right)^{1/3} \text{ with } c_{pe} = \frac{m_p}{m_e}$$

From (6) and (7a) one easily gets

$$G^2 \hbar^2 c^{-1} \sim c_{pp}^{-3} N_p^{-3} \frac{R^4 \dot{R}^5}{64} \qquad (9)$$

We also have $$m_p = c_{p*} \sqrt{\frac{\hbar C}{G}} \qquad (10)$$

where $c_{p*} = \frac{m_p}{m_*}$, m_* being the Plank mass and the suffix * indicates Planck quantities.

Combining (10) and (6), yields

$$cG\hbar \sim \tfrac{1}{4} N_p^{-2} c^{-2}_{p*} R^2 \dot{R}^4 \qquad (11)$$

Similarly, from (9) and (10)

$$c \sim 2^{2/3} N_p^{-1/3} c^{-4/3}_{p*} c_{pp} \dot{R} \qquad (12)$$

The multiplier factor for in (12) is equal to $2^{2/3} N_p^{-1/3} c_{p*}^{-4/3} c_{pp}$, and is ~ 1.

Conversely, if we choose to set $2^{2/3} N_p^{-1/3} c_{p*}^{-4/3} c_{pp} = 1$, one gets the simple relationship linking the speed of light to $\dot{R}$, c = $\dot{R}$ with $N_p \sim 3.7 \times 10^{79}$, which is a good estimate of the number of particles in the current universe. The relationship c = $\dot{R}$ could be interpreted as the Hubble Law $\dot{R} \sim$ c, although we emphasize that this is just a relationship and in no way implies that an expansion is indeed taking place.

Similar considerations apply if one chose to work with the relations applying to electrons.

If we start by assuming a heuristic relation

$$c \equiv \dot{R} \qquad (13)$$

i.e. the speed of light is *identical* to the rate of change of the scale of the universe, we construct an axiomatic approach equivalent to the Hubble Law. This axiomatic approach can be considered as an alternative approach to the mysterious coincidences of Eddington and Dirac which Weinberg called "so far unexplained... a real though mysterious significance."

It can be further shown that all lengths, such as the Planck length, l_*, the classical electron radius, r_e, etc., are also proportional to

$$R, l_*, r_e, \sim (\ldots) R \qquad (14)$$

For example,

$$l_* \sim (2^{-7/3} N_p^{-1/3} c^{5/3}_{p*} c^{-2}_{pp}) R \qquad (15)$$

Similar relations can be found for r_e and r_p where r_e and r_p be the electron and proton radii.
Combining (11) with (14) we obtain

$$G\hbar = \frac{R^2 \dot{R}^3}{4} N_p^{-2} c^{-2}_{p*} \sim 3.4 \times 10^{-122} R^2 \dot{R}^3 \qquad (16)$$

A relationship linking the gravitational and Planck's constant to R and $\dot{R}$, and where the last relationship in (16) holds for the current values of $N_p^{-2} c^{-2}_{p*}$ in the universe.

Let us now set the following initial conditions, i.e.,

$$R \to l_* \tag{17}$$

$$\dot{R} \to \frac{l_*}{t_*} = c \tag{18}$$

where l_* and t_* are the Planck length and Planck time, respectively.

Then $N_p^{-2}\chi_{p^*}^{-2}/4 \to 1$ at those initial conditions, while for the present universe the value of this quantity is ~ 3.4 x 10^{-122}.

The limit $N_p \to 1$ indicates that in our model "in the beginning" there was only one bubble-like object or a "cosmic egg" (Israelit 1989). Moreover, $R \to l_*$ and $N_p \to 1$ imply that c_{p*} à 1 as well (similarly for all ratios of masses c's), which in turn indicates that the masses of all particles were equal to each other at these initial conditions. Also,

"in the beginning" $R/\left(e^2/m_e c^2\right) \sim \dfrac{e^2/m_e c^2}{\left(\hbar G/c^3\right)^{1/2}} \sim 1$,

rather than the large values of 10^{40} and 10^{20} which these ratios are equal to, respectively, today. "In the beginning" all lengths were equal, all masses were equal and there was only one particle or cosmic egg. Today, these ratios are not unity, there is a very large number of particles in the universe and R is equal to ~ 10^{28} cm. However, scale-invariant relationships such as $c \equiv \dot{R}$; all lengths are proportional to each other, etc. still hold. Israelit and Rosen (1989) proposed a cosmological model where the universe emerges also from a small bubble ("cosmic egg") at the bounce point of a de Sitter model filled with a cosmic substrate ("prematter").

In other words, $c \equiv \dot{R}$, at the "initial time" when $N_p \to 1$ and all c's = 1, and this relationship remains invariant even at the present universe (cf. (12) and (14)). The self-consistency is obtained by calculations for the value of N_p from (12) and (16). This relation is a type of a scaling law and connects the microcosm and the macrocosm.

Now if irrespective (and it is even immaterial) of whether there is expansion of the universe or not, if R itself is changing from the Planck scale to the size of the observable universe, then the fundamental constants like G, $\hbar$, and c also *all* are changing. Note, however, that we cannot deduce the actual variation or the initial value of c and other constants from observations: The relationship $c \equiv \dot{R}$ is not enough to tell us the actual variation or even over "how long" it takes place. It is a scale invariant relationship. If we re-write it as a scale-invariant relationship, $c(t_*)/c(t_0) = \dot{R}(t_*)/\dot{R}(t_0)$ where t_* and t_0 could be conveniently taken as the Planck time and the present "age" of the universe, then this relationship is not enough to give us the evolution of $\dot{R}$ or even the values of t_* and t_0. Hence it cannot tell us how c itself is varying or even if it is varying. If we wanted to insist that c *is constant*, then all the other "constants" like G and $\hbar$ *are really constant* as well. But if c is not constant, then all the other "constants" are varying as well. In both cases, however, the number of particles is changing, the ratios of masses are changing and the ratios of scales or lengths are also changing. An arrow of time *could*, therefore, be introduced. In this picture, invariant relationships hold and from unity, there is evolution into diversity. One cannot though conclude how the variations are taking place, over what timescales they are taking place or even how old the universe is. The universe could be 10^{10} years old or 5 x 10^{-44} sec (the Planck time) old, or any time in between. *Time is strictly a parameter* that can be introduced in the scale-invariant relatiosnhips. It has no meaning by itself. The universe *appears to be evolving* as the number of particles and ratios are varying.

4. DISCUSSION AND CONCLUSIONS

The existence of horizons of knowledge in cosmology, indicate that as a horizon is approached, ambiguity as to a unique view of the universe sets in. It was precisely these circumstances that apply at the quantum level, requiring that complementary constructs be employed (Bohr 1961). At the *initial time*, which could be conveniently taken as the Planck time, if we set the conditions like $c = \dot{R}$, as proposed in this paper, we can axiomatize the numerical relations connecting the microcosm and the macrocosm. One then has scale-invariant relationships. During the *evolutionary* process of the universe, the fundamental constants are changing or they may be constant. In the former case, we don't know *how* or even over *what* timescales they are changing. In the latter case, one gets the usual evolutionary universe. This is a clear case where complementarity applies.

In other words, as N_p is changing from the initial value of 1 (unity) to the present large value of ~ 10^{80} (diversity), more particles are created as R and all length scales as well as all masses are changing. This could be interpreted by an observer as an "expansion of the universe". An observer, who is inside the universe will perceive an "arrow of time" and an "evolving universe". But equivalently, as the "constants" change (in contrast to previous works, they would *all* have to be changing), or even if they are truly constant, there *appears* to be an evolution. As $N_p \rightarrow 10^{80}$, the present number of the nucleons in the universe, the fundamental "constants" achieve their present values.

To recapitulate, the arrow of time can be related to a kind of complementarily between two constructs, i.e., the fundamental "constants" *are truly constant*, on the one hand; and the fundamental "constants" *are changing*, on the other hand.

In summary, we found that by adopting Weinberg's relationship (which can be shown to be equivalent to Dirac's relationships (2) and (3) when the latter are equated to each other), we can obtain a relationship linking the speed of light *c* to the rate of change of the scale of the universe. In fact, the proportionality factor is ~ 1 if one substitutes for values of fundamental quantities like the present number of particles in the universe, etc. The next step assumes that the relationship linking c and R is an identity, i.e. $c \equiv \dot{R}$ (for example, at the Planck time, one observes that this relationship still holds if the ratios of all masses $\rightarrow$ 1 and the number of particles also $\rightarrow$ 1). As such, it is possible (but not necessary) to state that *all* the fundamental constants are changing and not just one of them as was assumed in past works. It is interesting that, recently, the possibility of the cosmological constant L itself changing (Glanz 1998) has been suggested. As such, what we are suggesting here as a framework for the universe is a natural extension of previous ideas. Therefore, as N_p changes from an initial value of 1 to the present value of 10^{80} ($1 \rightarrow 10^{80}$), the universe would be appearing to be evolving to an observer inside it or an arrow of time is introduced. Finally, the outcomes of this prescription are not just that an arrow of time is introduced and the mysterious coincidences of Dirac and Eddington now can be understood as scale-invariant relationships linking the microcosm to the macrocosm; but in addition, all scales are linked to each other and what one calls, e.g. *fundamental length,* etc. is purely a convention. In the same way, time itself is not as fundamental as the scale-invariant relationships linking the microcosm to the macrocosm.

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