

Problems in a weakless universe

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Abstract

The fact that life has evolved in our universe constrains the laws of physics. The anthropic principle proposes that these constraints are sometimes very tight and can be used to explain in a sense the corresponding laws given that life exists on at least one planet. Recently it has been proposed [1] that a universe without weak interactions, but with other parameters suitably tuned can nevertheless allow life to develop. If a universe with such different physics from ours can generate life, the scope of the anthropic principle is reduced. We point out, however, that on closer examination the proposed “weakless” universe strongly inhibits the development of life in several different ways. One of the most critical barriers is that a weakless universe is unlikely to produce enough oxygen to support life. Since oxygen is an essential element in both water, the universal solvent needed for life, and in each of the four bases forming the DNA code for known living beings, we strongly question the hypothesis that a universe without weak interactions could generate life. Other impediments to the rise of advanced life forms in a weakless universe are also discussed.

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1 Introduction

It cannot be disputed that the fact that we are here making observations on nature implies that the laws of physics are such as to have made this possible (observer bias). A problem

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perhaps comes from the prospect that the AP can be used as an explanation for the tightly constrained aspects of physical law. Certainly the principle does not provide an explanation in the traditional sense nor suggest that explanations of the traditional type do not generally exist. Nevertheless there is widespread discomfort in the science community typified perhaps by the remarks of Burton Richter at the June 2006 conference on Supersymmetry [2]. Richter points out that, from the point of view of physics, the AP is “an observation not an explanation”. Even if a certain physical property of our universe is a prerequisite for life, the physicist must still show how it is implemented in our world and how it is related to other properties and perhaps to an effective Lagrangian of the world. Nonetheless, selection effects do constitute a form of at least partial explanation for physical phenomena given the fact that life has arisen. Presumably no experimentalist would deny that many deep explanations in physics began with a seemingly coincidental observation. In particular, for the case at hand, it cannot be considered uninteresting that, billions of years before life existed, the laws of physics were such as to allow the generation of life. A sufficiently intelligent observer having only a sufficiently detailed understanding of the universe as it existed one second after the big bang would note that there was, from at least that point on, a non-negligible probability for the emergence of life.

The string landscape [3] postulates that there are a large number, of local minima of the effective potential each of which is a potential universe with a set of particles, fundamental forces, and space time topology. Because of the sheer number of these universes it is proposed that there is a non-negligible probability that one or more of these would have the requisite properties for life to evolve. Transitions among these would guarantee that eventually the universe would arrive at the one we observe and then life would arise. The string landscape proposal is, therefore, an attempt to provide a physics explanation of the anthropic observation that the cosmological constant and perhaps other properties of our universe are as they need to be for the rise of life.

For the AP to be any guide and for the landscape to be an efficient explanation, the number of life-supporting universes must be reasonably small. As Richter [2] has emphasized, if there are numerous life supporting universes and, among them, ours is not highly probable, the string landscape makes no contribution to a physics understanding of why our particular universe has come to exist. Thus, to understand our universe, it might be necessary to study alternatives that would still have allowed the evolution of life. Along these lines, it has recently been suggested [1] that at least one alternative universe might have supported life, namely the one with no weak interactions and other properties simultaneously altered to allow nucleosynthesis and biochemistry. If it is true that such a universe would have allowed the evolution of life and if it is true that such alternatives are in fact numerous then there would be no understanding as yet of why our universe is as it is. A single such alternative does not, of itself, render the AP and the string landscape powerless since one does not necessarily demand uniqueness but only a reasonable probability of landing in the observed universe. Two recent works [4] suggest that, in order to maintain the understanding that might come from the string landscape, the weakless universe should either be extremely improbable among the potential local minima or the rise of life in such a universe should itself be extremely improbable. In fact, Harnik et al did not demonstrate that life would arise in a weakless universe but claim only an “apparent habitability” of such a universe.

Their primary demonstration was that a weakless universe could generate heavy elements and disperse them throughout the universe. Nevertheless, the important question is whether the weakless universe is, in fact, capable of supporting advanced life forms. This invites further investigation of potential problems in a weakless universe relative to the rise of life. Harnik et al. recognize certain obvious potential problems and show how other choices of certain parameters might eliminate the obstacles. In the spirit of their work we point out some additional problems that could inhibit the rise of intelligent life. We also remark that the anthropic principle should require the rise of advanced life forms and not only of lower forms such as bacteria which might be found more widely even in our universe.

In our universe, as currently understood, the weak interactions play several important roles. They probably provide the CP violation thought to be crucial in developing the baryon-antibaryon asymmetry essential to the development of life. Even the CP violation that might derive from supersymmetry depends on the higgs couplings and hence belongs to the weak sector. The spontaneous breaking of the electroweak gauge group allows for small Fermion masses. An exact electroweak symmetry would have massless quarks and leptons. A universe without weak interactions would be expected to have elementary Fermion masses at the Planck scale. Weakly interacting neutrinos were important in big bang nucleosynthesis and later in the stellar nucleosynthesis of heavy elements essential to life. In our universe, they play a role in stellar cooling and are crucial in the distribution of heavy elements throughout the universe in Type II supernovae. If one is to construct theoretically a life-supporting weakless universe, all of these functions of the weak interactions in our universe need to be replaced by other mechanisms. This is precisely what the authors of ref. [1] have attempted to do. In addition, although not conclusively proven, it has long been proposed that the parity violation of the weak interactions was important in producing the essential left-right asymmetry of many organic molecules and of the human body, as reviewed for example in ref. [5]. The weakness of the weak interactions pose challenges for this hypothesis [6] but alternative mechanisms face equally serious challenges. In any case it is clear that proteins in all known life forms consist of left handed amino acids. The Thalidomide tragedy of the late 1950's arose from introducing an isomer of incompatible handedness into the human body [5]. Ab initio calculations [7] of the effect of the weak interactions on molecular energy levels have indicated an effect in the right direction although other studies [8] found that the sign of the effect depended on certain parameters of the carboxylate group in the gas phase and in solution. The issue is, therefore, at present unresolved. However, if examples of extraterrestrial life are found with the same handedness as terrestrial biomolecules, that would be supportive of a role for the basic and universal parity violating weak interactions. It has also been proposed that the weak interaction effect on the homochirality of life was magnified in Type II supernovae [10]. If this connection becomes established a weakless universe would be definitively lifeless both because of the absence of weak interactions and because of the non-existence of Type II supernovae.

The proposed weakless universe has many other constants that are tuned for life although these are "natural" in the sense of not having quadratic renormalization once they are chosen as needed. If we had in fact become conscious in a weakless universe there would have been no fewer mysteries than in our present one.

However, beyond that, we question any definitive assertion that the weakless universe could in fact be life-generating. As we remark in the next section, the weakless universe does not have an adequate mechanism to distribute oxygen through the universe as would be needed to make water and the four essential bases of DNA. Although we recognize that the anthropic principle does not require life forms similar to ours, no one has succeeded at present in presenting a plausible model of how life could exist without these. Other potential problems with a weakless universe are also noted.

2 Oxygen deprivation in the weakless universe

The authors of ref. [1] have chosen the primordial abundances in such a way as to make deuterium plentiful in the early universe. This allows them a pathway to stellar nucleosynthesis of the heavy elements without the weak interactions that are so important in our universe. In our universe, such heavy elements are dispersed through space mainly by supernovae of two types: massive stars undergoing core collapse (Types II & Ib) and white dwarfs being pushed over their Chandrasekhar upper mass limits by accretion in stellar binary systems (Type Ia). In a weakless universe, as ref. [1] acknowledge, core-collapse supernovae will likely not occur, because weak interactions are responsible for both the core collapse which initiates the explosion, as well as the energy deposition which unbinds the outer layers of the star. If core collapse supernovae require neutrino cooling and/or neutrino energy deposition to proceed, there would be no core collapse supernovae in a weakless universe. The absence of core collapse supernovae in a weakless universe is crucial, because most of the oxygen in our universe comes from such supernovae.

Therefore, in a weakless universe, supernovae (Type Ia) from accreting white dwarfs pushed over their Chandrasekhar mass limit would, as noted in ref. [1], be the main source of heavy elements in the interstellar medium. However, in the process of collapse, the carbon and oxygen in such stars undergo rapid fusion to heavier elements and it is primarily these heavy elements that emerge from the supernova. In our universe the elements ejected from Type Ia supernovae are dominated by iron, in particular ^{56}Fe , which results from the radioactive decay of ^{56}Ni (via ^{56}Co) synthesized in the explosion. A weakless universe lacks radioactivity, so such supernovae are likely to generate more nickel than iron.

It is also unlikely that novae, thermonuclear flashes from the surfaces of accreting white dwarfs, could oxygenate the universe. The ejecta from novae are oxygen deficient (apart from producing the relatively rare isotope ^{17}O). They contain primarily the light elements, hydrogen and helium, from the outer shells of white dwarfs. In addition, although novae are several thousand times more frequent than supernova, they each eject only a millionth of the mass of a supernovae [11]. Therefore, we believe one can neglect novae as an adequate source of oxygen. Observationally, carbon and oxygen are not found in the remnants of SN Ia [12]. Even considering the full range of current theoretical numerical models for exploding white dwarfs [13]-[14], they would produce only $\sim 3 - 8\%$ of the oxygen mass, per supernova, as does a typical core collapse supernova (as suitably averaged over the yields and mass function of progenitors with a range of masses).

Furthermore, to account for present day abundances in our galaxy, historical core collapse supernovae have outnumbered SN Ia by a factor of ~ 5 in galaxies like our own [14]. Thus, even assuming neutrinoless alternative models are confirmed, less than about 1% of our oxygen comes from SN Ia. In addition, Harnik et al. are led to a universe with only about 1% of the matter in our universe relative to photons. This would naturally lead to a similar reduction in the abundances of stars and planets of any given mass. Thus they propose that life would arise in the vicinity of stars of about 1% of solar mass. Stars of near solar mass capable of producing a Type Ia supernova would have abundances near 1% of their abundances in our universe. Thus the oxygen abundance in the weakless universe would likely be reduced by this additional factor of 1% down to a level of 10^{-4} relative to that of our universe.

This oxygen deficiency in a weakless universe will strongly inhibit the formation of planets and the development of life. The incidence of extrasolar planets around nearby stars is found to be strongly correlated with the iron abundance of the host stars [15]: 25% of sample stars with an iron abundance of three times solar have planets, while only 2% of stars with one third solar iron abundance have planets. Of 29 stars in the sample of ref.[15] with less than one third solar iron abundance, none are observed to have planets. Since the oxygen abundance is observed to be correlated with the iron abundance in such stars [16], and oxygen and iron are the dominant elements by mass in rocky planets in the current universe, rocky planet formation will be inhibited in a weakless universe.

Oxygen is thought to be particularly important for life via liquid water, which provides a solvent to facilitate complex chemistry. The human body is 65% oxygen by weight as are the bodies of other mammals. It is unlikely that a universe without an abundant source of oxygen in liquid compounds will evolve life. Although most of the oxygen on earth is in the form of solid silicates, this component is probably not efficient in the rise of life and both this component and the water component would be expected to be reduced by the factors discussed above. In addition there are many studies finding a correlation between oxygen deficiency and various brain abnormalities including Alzheimer's and Parkinson's disease. It is not clear whether other life forms could evolve a defense against these effects of oxygen deficiency. The onset of star formation will be postponed by two orders of magnitude of time in a weakless universe. Since dark matter dominates the overall mass, gravitational structure formation in the proposed weakless universe will be largely unaltered. But the density of baryons is 100 times less in [1], so the cooling time for the condensation of baryons within dark matter halos will be 100 times longer than in the current universe. The radiative cooling time is $t_c \approx \frac{3kT}{n\Lambda_c}$, where $n^2\Lambda_c(T)$ is the energy loss rate (per unit volume) due to collisional cooling. The temperature is set by the gravitational potentials of dark matter halos, which are postulated to be the same in the proposed weakless universe, but the gas densities n are 100 times less than in the current universe. Thus, cooling times associated with the onset of galaxy and star formation will be extended by a similar factor, to 10^{10-11} years. This delay is inconveniently close to the onset of Λ -dominated acceleration of the universe. Objects that have not become gravitationally bound by this time, will probably never become so. Furthermore, if the dark energy has a pressure to energy ratio of less than -1 , a so-called "phantom energy", the galaxies would, in any case, be torn apart by the dark energy in a time that would be greatly reduced in the cooler weakless universe [17].

The lack of radioactivity in a weakless universe provides another challenge to the development of life. Harnik, et al. acknowledged that the lack of radioactivity would lead to very different evolution of rocky planets, since radioactive heat drives vulcanism, but this was not viewed as a serious obstacle to the model. This may be a very serious obstacle, however, since vulcanism is thought to be essential for maintaining a stable greenhouse effect, provided it is tempered by feedback processes due to the presence of liquid water [6]. Temperature stability on the Earth's surface is thought to be due to atmospheric carbon dioxide levels set by an interplay between volcanic generation versus dissolution and precipitation in liquid water oceans [18]-[19]. A weakless universe would have much less water and no radioactive heating, so the time scale for rocky planets to have stable surface temperatures is substantially reduced. The interior heating of rocky planets will be only due to gravitational compression, which will dissipate after a billion years. In the present universe, the radioactive decay of thorium and uranium provides heat on a timescale 10 times longer. In a weakless universe these decay chains would be terminated at an early stage by the absence of beta decays thus greatly reducing the energy release.

In addition, the heating from radioactive nuclei in the earth is thought to be largely responsible for the sustaining of an atmosphere and also for maintaining the magnetic field which seems essential to shielding the planet from low energy cosmic rays which might otherwise be expected to both degrade the atmosphere and cause life threatening mutations [9]. The recent KamLand data on geoneutrinos [20] is consistent with this picture.

Furthermore, to be considered on a par with the current universe and not introduce additional puzzles, the weakless universe should be part of a grand unified theory. This is probably not possible unless the sum of the charges of the elementary constituents is zero unlike in the proposed weakless universe. However, if this problem is overcome, perhaps by adding new charged particles at the GUT scale, then, after breaking, the strong and electromagnetic couplings should run according to

$$\frac{d\alpha^{-1}}{d\ln(M^2)} = -\frac{1}{3\pi} \sum Q_i^2 \quad (2.1)$$

and

$$\frac{d\alpha_s^{-1}}{d\ln(M^2)} = \frac{33 - 2n_f}{12\pi} \quad (2.2)$$

where the number of flavors is $n_f = 6$ in our universe and $n_f = 3$ in the proposed universe.

Thus, at lowest order the couplings will satisfy

$$\alpha^{-1} = \alpha_0^{-1} - \frac{1}{3\pi} \sum Q_i^2 \ln(M^2/M_X^2) \quad (2.3)$$

$$\alpha_s^{-1} = \alpha_0^{-1} + \frac{33 - 2n_f}{12\pi} \ln(M^2/M_X^2) \quad (2.4)$$

Here α_0 is the unification coupling and M_X is the unification mass. These are strongly constrained by the requirement that the strong coupling constant at low energies does not

significantly differ between our and the weakless universe in order to preserve the triple Carbon coincidence that is essential to produce heavy elements.

If α_0^{-1} is much less than α^{-1} at low energies as holds in our universe, then, independent of M_X to lowest order,

$$\alpha_{\psi} = \frac{8}{3}\alpha \quad . \quad (2.5)$$

That is, the low energy fine structure constant in a weakless universe would be expected to be more than twice as strong as in our universe. This would have major effects on atomic and molecular energy levels and on the size of atoms and thus cause significant changes in chemical binding. In addition, increasing the Coulomb barrier by more than a factor of two would greatly increase the temperature required for fusion. In a cooler, weakless universe fusion might then never efficiently produce heavy elements. It is possible that all, or the great majority of, the local minima in string theory have a high degree of symmetry such as to allow for a grand unification. This would explain the reduced probability of a weakless universe in line with the arguments of ref. [4].

3 Conclusions

In ref. [1], it is proposed that a universe without weak interactions could support life. If there are many hospitable alternative universes, the anthropic principle based on observer selection would no longer be a useful guide to understanding the properties of our world except for the smallness of the cosmological constant. Faced with a plethora of life supporting alternative universes, the string landscape ideas [3] would also lose whatever predictive power they might have unless the weakless universe or other alternatives could be shown not to be among the local minima of string theory.

Obviously, however, much further theoretical analysis would be necessary to confirm that a universe without weak interactions would, indeed, allow the evolution of life. The nuclear reactions proposed by the authors of ref. [1] as an alternate mechanism for stellar nucleosynthesis would need to be studied in greater detail.

In addition to such open questions, however, we have proposed that a serious problem in a weakless universe from the point of view of generating life is the difficulty of distributing oxygen through the universe in anywhere near the required abundance. Such a universe would be extremely deficient in oxygen and life would, in effect, have been frustrated at an early stage.

Our observations reduce the probability of generating life by perhaps 10^{-4} below what is already thought to be a low number. If, however, the universe is infinite or many orders of magnitude larger in size than the visible universe, it cannot be ruled out that a statistical fluctuation in the oxygen abundance produces a life sustaining region in the weakless

universe. In this case, a definitive proof of the lifelessness of the weakless universe would have to await a proof that the weak interactions are the sole feasible source of the homochirality of life as discussed in the introduction. Conversely a proof that a weakless universe could support life would require a demonstration that alternate sources of homochirality are effective and that the other potential problems discussed in this note are avoidable.

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