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Origin and Evolution of Life Constraints on the Solar Model

Karo Michaelian[1], Oliver Manuel[2]
[1]*Instituto de Física, Universidad Nacional Autónoma de México, Cto. de la Investigación Científica, Cuidad Universitaria, Mexico City, Mexico*
[2]*Associate, Climate & Solar Science Institute, Former Apollo PI for NASA, Cape Girardeau, USA*
E-mail: karo@fisica.unam.mx, omatumr@yahoo.com
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Abstract

Life arose as a non-equilibrium thermodynamic process to dissipate the photon potential generated by the hot Sun and cold outer space. Evidence from the geochemical record of the evolutionary history of life on Earth suggests that life originated in a hot aqueous environment dissipating UV light and evolved later to dissipate visible light. This evidence places constraints on models of solar origin and evolution. The standard solar model seems less compatible with the data than does the pulsar centered solar model.

Keywords: Pulsar Centered Solar Model (PCS), Standard Solar Model, Origin of Life, Ultraviolet and Temperature Assisted Replication (UVTAR), Constraints on Solar Model

1. Introduction

Life is an out of equilibrium, thermodynamic process. As such, its origin, persistence, and evolution are strictly dependent on the dissipation of an external thermodynamic potential (entropy production) and the evolution of this potential in time. By far the most important thermodynamic potential which has promoted the existence of life on Earth is the temperature gradient provided by the hot photosphere of the Sun (~5,800 K today) and the cool volume of outer space (2.7 K). Life arose as an entropy producing thermodynamic process in response to the Earth being located between the Sun's hot photosphere and the cool space environment. The origin and evolution of life on Earth must, therefore, in some way (to be explored below) parallel the origin and evolution of our Sun. The evolutionary history of life on Earth thus provides constraints on models for the origin and evolution of our Sun. Here we show that these constraints yield convincing arguments for distinguishing between competing solar models.

2. Appearance of Life Constraints on Earth's Solar Environment

The most probable first molecules of life, RNA or DNA [1,2], are transparent to visible light. However, in the ultraviolet, in a region centered on 260 nm of width of 100 nm, the aromatic rings of the nucleic acid bases (adenine, thymine, guanine, cytosine, and uracil) absorb light very strongly [3,4]. If RNA and DNA are in water, they dissipate this photon-induced collective electronic excitation energy extremely rapidly (sub pico-second) [5] and efficiently to heat that can be easily absorbed by the water. These molecules when exposed to ultraviolet light are thus very efficient producers of entropy. Therefore, if RNA and DNA were the first molecules of life, and if indeed life arose as a response to dissipating the photon potential generated on Earth by the Sun and outer space, then the solar spectrum in the ultraviolet between about 200 and 300 nm arriving at the surface of the Earth at the beginning of life (~3.8 billion years ago) must have been sufficiently intense for nature to have embarked on a program of constructing uphill, endergonic, organic molecules for the dissipation of these photons.

Furthermore, since water is an important solvent for the formation of the nucleic acids from more simple organic molecules such as hydrogen cyanide under electric discharge or UV light sources [6], and since the dissipation of the electronic excitation energy of the nucleic acid bases only occurs efficiently in the presence of liquid water (non-radiatively to mainly the vibrational degrees of freedom of the water molecules), the incident intensity and absorption of sunlight at the surface of the

Archean Earth must have been such as to maintain water in its liquid phase.

Today, ozone and oxygen in the Earth's atmosphere block all but one in 10^{30} photons from the Sun at 250 nm [7]. During the Archean, however, there was very little oxygen or ozone in the Earth's atmosphere, and the most likely atmospheric gases, CO_2, N_2, H_2O, and methane are transparent to UV photons in this wavelength region [8]. High surface temperatures (see below) would have implied a much greater amount of water vapor in the atmosphere than today, effectively blocking most solar infrared radiation from reaching the surface. Also, UV photochemical reactions on the most common volcanic gasses, carbon dioxide, water vapor and sulfur dioxide, would have produced a thin layer of sulfuric acid clouds very reflective in the visible (as on Venus today, albedo 0.77). Ultraviolet light in the 200 - 300 nm region could thus have been the most important (enthropically speaking) part of the solar spectrum reaching the Earth's surface and would have been responsible for a large part of surface heating during the Archean.

3. Evolution of Life Constraints on Models for the Evolution of Earth's Solar Environment

The most copious life in the biosphere today, both in terms of number and mass, are the photosynthesizing cyanobacteria and plant life. These phototrophic organisms employ chlorophyll to absorb sunlight in the visible and utilize the free energy in this light to fix carbon from the carbon dioxide in the atmosphere, the process of photosynthesis. However, photosynthesis utilizes only about 0.1% of the free energy available in sunlight incident on the plant [9]. By far the greatest amount of free energy available in sunlight is utilized in transpiration (evaporation of water) from the leaves of the plant or from phytoplankton floating on the surface of bodies of water. In most phototrophic organisms, a large array of organic pigments absorb in a continuous spectrum from about 200 nm (far ultraviolet) to 700 nm (red). Therefore, the most important thermodynamic function that these autotrophs perform is the absorption and dissipation of photons from the most intense region of the Sun's spectrum. Still other irreversible thermodynamic process, such as the water cycle, hurricanes, and ocean and wind currents, are spawned in the process, dissipating established heat gradients and thereby promoting still further entropy production [10].

There is evidence that while the organic pigment inventory was increasing over the evolutionary history of life on Earth, the absorption maxima of the newly added pigments was also increasing in wavelength. RNA and DNA were probably the first pigments, absorbing strongly at 260 nm. The three aromatic amino acids, phenylalanine, tyrosine, and tryptophan have strong absorption maxima at 260, 280, and 295 nm respectively [8]. These amino acids are generally believed to have appeared shortly after RNA and DNA in life's history. The reaction center of anoxic purple bacteria, the most ancient photosynthesizing organisms known, contains bacteriochlorophyll and the aromatic amino acids and thus also absorb strongly at 280 nm [11]. Recently discovered pigments absorbing over the range 310 to 400 nm, mycosporines, appeared early in the history of life but are less ancient than the amino acids [12]. The earliest porphyrins (e.g. chlorophyll) and phycobilins, absorbing in the visible, 400 to 700 nm, have been discovered in Precambrian rock dating from 1.7 to 2.6 Ga [13]. Besides chlorophyll, there exist other contemporary visible absorbing pigments such as the carotenoids in green plants and the phycobilins in phytoplankton, also absorbing over the range 400 to 700 nm.

If indeed the primordial function of life was, and is, to dissipate the imposed photon gradient, then the apparent gradual incorporation in phototrophic life of pigments of ever increasing wavelength of maximum absorption suggests a gradual increase in wavelength of the peak intensity of the spectrum of sunlight reaching the Earth's surface. This light would, of course, be dependent on, not only the solar spectrum, but also on the absorption properties of Earth's atmosphere. However, a thermodynamic perspective on life would suggest that life has continually adjusted the gases of the atmosphere (in the sense of Gaia [14]) in such a manner so as to lead to transparency for the most intense (enthropically speaking) part of the solar spectrum. This situation is, indeed, what we observe today for our present atmosphere.

4. The Sun

Harkins reported that seven elements with even atomic numbers (Fe, O, Ni, Si, Mg, S and Ca) comprise 99% of the material in ordinary meteorites and concluded "... *in the evolution of elements much more material has gone into the even-numbered elements than into those which are odd* ..." [15]. Later Payne [16] and Russell [17] reported high abundances of hydrogen, an odd numbered element, in the solar atmosphere. They did not suggest that the interior of the Sun is hydrogen. The Standard Solar Model (SSM) came later, after Goldschmidt suggested [18] in 1938 that rocky planets and ordinary meteorites lost volatile elements. However, Hoyle [19] acknowledges that he, Eddington, and other astronomers thought "... *the Sun was made mostly of iron* ..." until the end of World War II [19]. Then in 1946 Hoyle wrote at least 99% of the initial mass of stars "*must be in the form of hydrogen*" [20] and he tried to show how heavier elements were made from hydrogen [21], as originally suggested by Prout [22].

Hoyle [19] expressed surprised at sudden, worldwide acceptance of the idea "*that the high-hydrogen, low-iron solution was to be preferred for the interiors as well as for the atmospheres*" of stars [19]. Hoyle's 1946 papers [20,21] and the 1952 hydrogen bomb explosion greatly impacted opinions on the Sun. According to the classical B2FH [23] paper on element synthesis: "*It seems probable that the elements all evolved from hydrogen*" [23], and "*Hydrogen burning is responsible for the majority of the energy production*" [23].

4.1. The Standard Solar Model (SSM) of a Hydrogen-Filled Sun

Textbooks of astronomy and astrophysics [24-26] and research reports [27-30] generally assume the standard solar model (SSM) of a hydrogen-filled Sun, produced by the collapse of an interstellar cloud of primordial hydrogen and helium and contaminated with a small portion of heavier elements from previous generation stars. Bethe suggested [31] that ^{12}C might serve as a catalyst for fusion of hydrogen into helium in stars via the CNO cycle. But the low flux of solar neutrinos reported in 1968 [27] showed that H-fusion via the CNO cycle generates little if any solar energy. Subsequent measurements in the 20th Century [28,29] confirmed *less solar neutrinos than expected from any known path for H-fusion*. H-fusion *via* the proton-proton chain generates the least amount of energetic neutrinos and thus gained popularity as the main source of solar luminosity [24-30].

According to the SSM, the Sun now generates energy in the core mainly *via* the proton-proton chain reaction at T ~ 15,000,000 K. After a significant fraction of hydrogen was consumed, the fusion rate decreased and gravitation caused the density and temperature in the core to increase. Then the fusion rate and the luminosity of the star increased. Thus *our star is predicted to be about 30% more luminous now than at the time of the origin of life on Earth* [32,33].

Neutron repulsion was recognized as an energy source near the start of the 21st Century and it was suggested that the solar neutrino puzzle might indicate a neutron star in the Sun's core [34-36]. The SNO group [37,38] proposed that solar neutrinos instead oscillate into three flavors because neutrinos have mass and transmute on passing through matter. A later study [39] casts doubt on the SNO group's interpretation of solar neutrino data [37,38], but most members of the solar physics community accept the SSM and seem confident of its ability to describe the evolutionary history of our Sun correctly. However, early questions about an interstellar cloud collapsing gravitationally to form the Sun [40] were kept alive by space age observations that seemed to conflict with the standard solar model.

4.2. The Model of a Pulsar Centered Sun (PCS)

Analysis of meteorites, planets, the Moon and the Sun revealed evidence that our Sun may have formed on a pulsar—the collapsed core of the star that gave birth to the solar system [41]. Baade and Zwicky [42] suggested that a collapsed supernova core might change into a neutron star, and Wolszczan and Frail [43] reported Earth-like planets orbiting a pulsar in 1992. Exotic, superfluid material has been suggested in the centers of ordinary stars and neutron stars [44,45]. Below is a summary of implications for the early Earth and the evolution of life [41]:

a) The precursor star exploded axially ~5 Gyr ago, based on ^{244}Pu and ^{238}U age dating [46], probably driven by neutron repulsion.

b) Neutron repulsion causes continuous emission of neutrons from the pulsar. These decay into the glowing ball of hydrogen seen in the photosphere.

c) Layers of elements and isotopes from the precursor star were still present in the equatorial plane when solids started to condense.

d) Flash heating, perhaps from ignition of H-fusion partially melted early solids to produce chondrules—the aerodynamically quenched droplets seen in meteorites. The photosphere slowly evolved into its current mix of hydrogen and helium.

e) Earth accreted in layers, beginning with the formation of an iron core.

f) Beneath the photosphere the Sun also formed a mantle of mostly Fe, O, Ni, Si, S, Mg and Ca—like the material in rocky planets and ordinary meteorites.

g) Following neutron-emission and neutron-decay, H^+ ions are accelerated upward by the pulsar's magnetic field. The upward flow of this "carrier gas" maintains mass separation in the Sun [47].

h) Circular polarized (CP) light from the pulsar separated the d- and l-amino acids in meteorites [48] *before* CP light from the pulsar itself was blocked by radiation from the solar photosphere.

i) Early radiations from the pulsar were more energetic (shorter wavelength) than current solar radiation. Pulsars release a greater proportion of γ-rays, x-rays and ultraviolet (UV) radiation [49], and a very old pulsar (~5

× 10^9 years old) was reported to still be observable in the extreme ultraviolet [50].

j) Based on current solar luminosity and the emission rate of neutrons from the solar core, we estimate that solar luminosity was higher by ~1% - 4%, rather than being lower by ~30%, in the critical origin-of-life period when the SSM predicts frozen oceans and a "faint early Sun" [32,33].

In the following section, we present arguments from the life sciences for reconsidering the standard solar model in favor of the pulsar centered solar model.

5. Arguments for a New Solar Model

5.1. The Faint Young Sun Paradox

$^{18}O/^{16}O$ ratios found in cherts of the Barberton greenstone belt of South Africa suggest that Earth had liquid water and a temperature of around 80˚C at the time of the origin of life at 3.8 Ga [51] and (70 ± 15)˚C during the 3.5 - 3.2 Ga era [52]. Surface temperatures of around 80˚C would have allowed a polymerase chain reaction (PCR) type of mechanism for RNA and DNA reproduction (Ultraviolet and Temperature Assisted Reproduction—UV-TAR) to have been operating at the beginning of life [2], thereby avoiding the difficulty of early RNA or DNA reproduction fidelity necessary for the codification of complicated denaturing enzymes. However, the standard solar model predicts that at 3.8 Ga the solar luminosity should have been from 25% - 30% less than at present [33]. For such a luminosity, under reasonable assumptions for greenhouse gases and other atmospheric conditions, the Earth's surface should have been completely frozen over, a "snow ball Earth", in stark contradiction to the evidence. This has become known as the "faint young Sun paradox" [33]. Furthermore, evidence for liquid water on Mars at 3.0 Ga is a fact even more difficult to reconcile with the faint young Sun of the standard solar model [53].

The faint young sun paradox has been addressed by a number of ingenious, but evidence lacking, hypothesis, such as the possible migration of the planets from earlier more inner orbits due to early large solar mass loss [54]. The suggestion receiving the most attention until recently, however, has been that of a greenhouse gas early atmosphere [55]. An upper limit exists for atmospheric carbon dioxide determined by the prevalence of magnetite in the Archean sediments [56], and it was later shown that neither ammonia (NH_3) nor methane (CH_4) could have weathered the intense UV radiation during the Archean [57,58]. Most importantly, however, after years of searching, there is now a conspicuous lack of evidence for high greenhouse-gas concentrations on early Earth [58,60-62]. Recent attempts to resolve the issue have recurred to even less evidence substantiated theories, such as more extent heat absorbing oceans and a lack of cloud forming seeds leading to reduced Earth albedo during the Archean [56] and fractal shaped smog which purportedly blocks methanelysing UV light while permitting visible light to penetrate to the surface [63].

The standard solar model remains inconsistent with the data. The pulsar centered solar model predicts that the solar luminosity at the origin of life on Earth would have been up to 4% greater than that of today, and not the 25% - 30% less predicted by the standard solar model, and thus resolves the "faint young Sun paradox".

5.2. Early Life Metabolized UV Light

Besides the proliferation of organic pigments in the ultraviolet and conservation of the codification for these in the genomes of present day phototrophs, there is also evidence of a period when life may have been dependent upon UV-C dissipation. Bacteriochlorophyll and its associated reaction center, used by the most ancient purple bacteria, strongly absorbs at 280 nm [11]. It is also a remarkable fact that the protein bacteriorhodopsin, that promotes ATP production in Archaea by acting as a proton pump through the absorption of a photon at 568 nm in the visible, also works perfectly well by absorbing at 280 nm in the ultraviolet [64]. The UV photon energy is absorbed on the aromatic amino acids tyrosine and tryptophan and the energy transmitted to the chromophore.

Pigments based on rhodopsins used by bacteria to perform anoxygenic photosynthesis were shown through phylogenetic analyses by Xiong and Bauer [65] to have already been present when oxygenic photosynthesis developed. These pigments are all are robust to far ultraviolet (UV-C) light, while this does not appear to be the case for more recent oxygenic photosynthetic pigments associated with chlorophyll [66].

This life history of phototrophs thus suggests an early high UV-C environment on Earth. An analysis of young proxy G-type stars near the main sequence has shown that the young Sun was probably much more active in the extreme UV and X-ray region [67]. The strong absorption of these short wavelengths in the atmosphere by N_2, CO_2, and other Archean gases would have implied significant degradation into the 200 - 300 nm window of atmospheric transparency. This data requires, at the very minimum, a re-thinking of the standard solar model but may be completely consistent with a pulsar centered solar model.

5.3. Incorporation of Organic Pigments of Ever Longer Wavelength Absorption

The evidence that the peak in absorption of newly added organic pigments gradually increased in wavelength over the evolutionary history of life on Earth (see Section 3) is consistent with the gradual increase in wavelength of the peak in the intensity of the spectrum from a cooling pulsar star centered Sun. To be compatible with the standard solar model, in which the peak wavelength of emission instead decreases over the lifetime of the Sun (as the Sun became hotter), would require an unexplained shift in the atmospheric window of transparency in the opposite direction, towards longer wavelengths, and a fortuitous coincidence of the window of transparency coinciding with the maximum of intensity of the solar spectrum today. It seems more probable that the overlap that we see today is not at all a coincidence, but rather the result of a biotic-abiotic coupling of irreversible processes operating to increase the overall entropy production of the Earth in its solar environment through photon dissipation [2].

5.4. Amino Acid Handedness in Meteorites

The molecules of life are chiral, *i.e.* they come in two mirror images that absorb light of either right- or left-handed circular polarization preferentially within a given wavelength region. Abiogenisis of these molecules shows no preference for one enantiomer over the other. However, almost all amino acids used by life are left-handed (L), while the nucleotides and RNA and DNA are right-handed (R). How life acquired such homochirality has been the subject of much controversy (see Michaelian [68] for a review), but one suggestion has it that the Earth was seeded with left-handed amino acids from space. One possibility being that highly circularly polarized light of a pulsar preferentially photo-lysed the right-handed amino acids existing in one of its hemispheres [69,70].

Up to 15% L-enantiomer excess has been claimed for some non-biological α-methyl amino acids delivered to the Earth in carbonaceous chondrite meteorites such as Murchinson. Biological amino acids found in these meteorites, however, have little, if any, enantiomer excess [71]. High temperatures, cosmic rays, and UV light all cause racemization (the equilibration of any initial enantiomer excess). The α-methyl amino acids found with non-negligible enantiomer excess in meteorites have significant stability against racemization [72], but the α-hydrogen amino acids composing the 22 natural amino acids of today's proteins do not [73].

The pulsar star centered solar model may thus explain the abundance of L-enantiomer non-biological amino acids found in meteorites. Whether some of the initial L-enantiomer excess in the less stable biological amino acids (α-hydrogen) could have survived the radiation environment of space and the heat of entry into the Earth's atmosphere and thereby provided the seeds for the homochirality of life today remains to be investigated in more detail.

6. Conclusions

Data from the life sciences indicates a warm Earth with liquid water at the origins of life ca 3.8 Ga. It appears that life began dissipating UV light and gradually incurporated pigments of ever greater wavelength, probably following the peak in the emission spectrum of the evolving Sun. If life's origin and evolution is indeed concerned with solar photon dissipation, then this evidence becomes very difficult to reconcile with the SSM (standard solar model). The PCS (pulsar centered sun) model [41] seems more compatible with the concurrent evolution of life on Earth and nuclear evolution in the Sun, as three reactions there successively release ~1.2%, ~0.1% and ~0.7% of nuclear rest mass (m) as photo-energy (E), $\Delta E = \Delta mc^2$ [41].

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