

Life as a Non-Local Phenomenon Generated by the Quantum Potential of the Vacuum

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Abstract. Based on the idea that quantum physics plays a crucial role in the origin of life, in this paper a model of the likelihood of planetary “origin of life”-type events in terms of the quantum potential of a three-dimensional non-local quantum vacuum is proposed. In this picture, life emerges as a non-local global phenomenon expressed by a nonlocalized series of assembly steps or processes that lead directly and irreversibly to an evolvable living universe as a consequence of the non-local action of the quantum potential of the vacuum.

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1 Introduction

One of the most fundamental questions in exoplanetary science is to determine whether a given planet is habitable. The rapid advances in the discovery of exoplanets over the past two decades suggest that there are a large number of Earth-sized planets in the habitable zone – the region capable of sustaining liquid water on the planet’s surface – and in particular, in the Milky Way, it has been estimated that there may exist $\sim 10^{10}$ planets in the habitable zone of their host stars [1–3]. In this regard, most of the recent discoveries have been performed on low-mass stars, especially M-dwarfs, as they are more numerous and any habitable planets orbiting them are easier to detect and analyze.

We can mention, in particular, the discovery of an Earth-mass exoplanet in the habitable zone around Proxima Centauri, the nearest star to our Solar system at only 4,2 light years away [4] and the discovery of at least seven Earth-sized planets transiting the ultracool dwarf star TRAPPIST-1 at a distance of 39,5 light years [5, 6], where there are three planets in the habitable zone around TRAPPIST-1 that may host life [7].

However, it must be emphasized that the existence of a planet in the habitable zone does not mean necessarily that life is present in this planet or that life existed in it in the past. It becomes then natural to ask ourselves: what is the ultimate origin of life in a planet? The deepest question of all science is how it

is possible that the same atoms and inert molecules present in rocks and rocks can transform themselves every day into living organisms that run, jump, fly, orient themselves, think. Why does matter behave in such a different way when it is part of a living organism compared to when it manifests itself in a stone? In his famous book of 1944 entitled *What Is Life?*, Schrödinger suggested that life is different from the inorganic world because it is a phenomenon dominated by order, from top to bottom, starting from the macroscopic level passing then through the stormy thermodynamic ocean, until to arrive at the molecular level, in a framework in which the dynamics are in delicate equilibrium, so that the events at the quantum level are able to influence the macroscopic world, as for example Pascual Jordan claimed in the '30s [8].

In his brilliant book *La fisica della vita*, Jim Al-Khalili argues that, although at present, despite significant advances in genetic engineering, we have not yet been able to produce any living organism from inert material, at least one of the missing pieces in the puzzle of life can be identified in quantum mechanics: life seems to have a foot in the classical world of tangible objects of everyday experience and the other planted in the depths of the bizarre and exotic quantum world. If the visible characteristics of most of the objects that surround us seem to be rooted in the macroscopic level described by Newton's laws of mechanics or in the thermodynamic level, namely the intermediate level that describes the phenomena concerning liquids and gases, in which we have particles moving in almost completely random, living organisms have behaviours and characteristics that originate down into the most intimate level, i.e. in the quantum foundations of reality. Jim Al-Khalili compares the living cell to a sailing ship whose keel penetrates down to the quantum level, and therefore can capture phenomena such as the tunnel effect, or the correlation to keep alive. This behaviour must be actively maintained by living cells that harness thermodynamic storms (molecular noise) to maintain quantum coherence [9].

In this paper, in the light of some current research, by starting from the hypothesis that quantum physics plays a fundamental role as regards the features of life, our purpose is to provide new keys of reading of the ultimate origin of life as a phenomenon generated by the quantum potential of a fundamental non-local vacuum. This paper is structured in the following way. In Section 2 we will review some recent results about the likelihood of life in exoplanets, based on the Metabolic Theory of Ecology and atmospheric escape, as a starting-point in order to quantify important ecological patterns and parameters concerning life as we know it. In Section 3 we will introduce a new approach, which extends and completes the Metabolic Theory of Ecology, which provides the frequency of planetary "origin of life"-type events in terms of the quantum potential of a fundamental non-local quantum vacuum. Finally, in Section 4 we will conclude with some considerations about the epistemological perspectives introduced by our approach and its grade of agreement with the foundations of other interesting current models.

2 About the Metabolic Theory of Ecology and the Atmospheric Escape and Their Role in the Likelihood of Life in Exoplanets

As regards the development of life in a planet, before all, it must be underlined the relevance of the role of temperature in modelling a diverse array of ecological and evolutionary parameters and processes [10–15] and, in this regard, we consider the perspective that biochemical reactions corresponding to metabolism are universal on all life-bearing exoplanets [16–18]. As regards the treatment of ecosystems on other planets, at least for those capable of sustaining life-as-we-know-it, a plausible starting-point model which attempts to quantify important ecological patterns and parameters by adopting a mechanistic perspective based on generic physical and chemical considerations, without the necessity for invoking complex (and specific) biological factors, can be considered the Metabolic Theory of Ecology. According to the Metabolic Theory of Ecology, a crucial role in governing macroecological processes is assumed by the metabolic rate B of organisms which scales as

$$B \propto m^{3/4} \exp\left(-\frac{E}{k_b T}\right), \quad (1)$$

where m is the mass of the organism, k_b is the Boltzmann constant, T is the absolute temperature and E is the average activation energy which is associated to the appropriate rate-limiting step in metabolism [19]. By starting from the metabolic rate (1), one can define a “mean” metabolic rate \bar{B} across all species by introducing the distribution function for the number of individuals with a given mass $N(m)$ given by expression

$$\bar{B} = \frac{\int B(m, T) N(m) dm}{\int N(m) dm} \propto \exp\left(-\frac{E}{k_b T}\right) \quad (2)$$

The last scaling follows if $E(m, T) \approx E(T)$, i.e. provided that the activation energy displays a weak dependence on the organism’s mass. This turns to be a fairly robust and coherent assumption on our planet, since E is comprised in a fairly narrow band of energies ranging between 0,6–0,7 eV, for unicellular organisms, plants, ectotherms and endotherms [11, 19, 20]. According to the results of Gillooly *et al.* [21] as well as of Yvon-Durocher *et al.* [22], the mean value of $E = 0,65$ eV is nearly equal to the average activation energy of 0,66 eV that is generated from the rate of ATP synthesis in isolated mitochondria.

The Metabolic Theory of Ecology predict that several ecological parameters – such as the production and turnover of biomass, the rates of genetic divergence and speciation, species diversity and coexistence – are determined by the metabolic rate and are thus expected to depend on the temperature via the Boltzmann factor on the basis of equation (1).

On the basis of the preceding discussion, adaptation of equation (2) leads to introduce the following likelihood factor for biodiversity

$$P_T = \exp\left(-\frac{E}{k_B T}\right) \theta(T - T_L) \theta(T_U - T), \quad (3)$$

where E and T are now taken to be the mean activation energy and temperature respectively, while θ is the Heavyside function which ensures that the likelihood becomes zero for $T < T_L$ and $T > T_U$.

In order to formulate a normalized Earth-referenced temperature-dependent function which quantifies the likelihood of life on a planetary scale, one must here take into account that the limits of Earth-based lifeforms fall within 262 K and 395 K [23,24], while the corresponding range for photosynthetic lifeforms is lowered to 348 K [25]. As a consequence, one must replace the average surface temperature T of the planet (which appears on equation (3)) by the overall planetary surface temperature. In this way, the following normalized Earth-referenced temperature-dependent likelihood function may be formulated

$$P_T = \exp[-26,7(\delta - 1)] \theta(T - T_L) \theta(T_U - T), \quad (4)$$

where T_U and T_L are the limits over which the Boltzmann factor is valid and the temperature range $T_L < T < T_U$ is not expected to exceed the Earth-based photosynthesis limits for life-as-we-know-it. Moreover, by considering life-as-we-know-it, the auxiliary parameter δ in equation (4) is expressed by relation

$$\delta = \frac{E}{E_{\oplus}} \frac{T_{\oplus}}{T} \sim \frac{T_{\oplus}}{T}, \quad (5)$$

where $E_{\oplus} = 0,66$ eV and $T_{\oplus} = 287$ K are the corresponding values for the Earth, and here $E \sim E_{\oplus}$. If we substitute $T = 218$ K for Mars, we find that $P_T = 0$ because of the Heavyside function. In contrast, the equatorial temperatures on Mars can exceed T_L , thereby giving rise to a finite value of P_T locally. If we consider Venus instead, it is evident that $P_T = 0$ since $T \gg T_U$.

Thus, to summarize, equation (4) may be adopted in order to evaluate the likelihood of evolution of complex life as a function of the planet's surface temperature. This function can be interpreted as an alternative for the (relative) metabolic rate, which, in turn, has been hypothesized to govern important biological parameters such as for example the species diversity and the rates of speciation and growth. Ad here it must be emphasized that, if life begins in a planet, the possibilities of the emergence of complex life in terms of rate of speciation and great diversity of species are expected to be correspondingly greater for higher temperatures. The metabolic theory of ecology based on equations (1)–(5), although does not imply directly the habitability of a planet and does not quantify the likelihood of abiogenesis, can be considered a plausible candidate in order to provide a more sophisticated variant of understanding the likelihood of macroecological processes and thus of generation of life on exoplanets.

On the other hand, according to several current studies, empirical and theoretical evidence which seem to imply a high-temperature origin of life seem to emerge [26–29], even if many factors still remain poorly known [30]. If life did indeed originate in a high-temperature environment, perhaps this implies that the likelihood of abiogenesis events could manifest a Boltzmann factor dependence on the temperature similar to equation (2), thus favoring thermophilic ancestral lifeforms [31]. However, an important point that must be taken into consideration is that the temperature in the discussion about abiogenesis events always represents the in situ value (for example, at hydrothermal vents), and not the global planetary temperature.

As regards the role of the metabolic theory of ecology in the understanding of the evolution of life on exoplanets, in the recent interesting paper “Physical constraints on the likelihood of life on exoplanets”, Lingam and Loeb proposed a generalization of the likelihood function of life in a planet (4) which is given by relation

$$P = P_T P_A, \quad (6)$$

where P_A is an opportune quantity that takes into account the atmospheric escape of the planet. In Lingam’s and Loeb’s model, one has

$$P_A = \left(\frac{P_s}{1 \text{ atm}} \right) \left(\frac{R_P}{R_\oplus} \right) \left(\frac{\langle F_{EUV} \rangle}{\langle F_\oplus \rangle} \right)^{-1} \quad (7)$$

if the lifetime of the planet’s atmosphere is less than the timescale of atmospheric loss for unmagnetized planets, while

$$P_A = \left(\frac{P_s}{1 \text{ atm}} \right) \left(\frac{a}{1 \text{ AU}} \right)^2 \left(\frac{R_P}{R_\oplus} \right)^{-1,7} \left(\frac{\dot{M}_\star}{\dot{M}_\odot} \right)^{-1} \quad (8)$$

if the lifetime of the planet’s atmosphere is bigger than the timescale of atmospheric loss for unmagnetized planets [32]. In equations (7) and (8), $P_s = \frac{gM_{\text{atm}}}{4\pi R_P^2}$ is the surface pressure of the atmosphere (M_{atm} is the mass of the atmosphere, R_P is the radius of the planet), $\langle F_{EUV} \rangle$ is the average extreme ultraviolet flux, F_\oplus is the value of $\langle F_{EUV} \rangle$ for the Earth, R_\oplus is the radius of the Earth, a is the semi-major axis of the planet, \dot{M}_\star is the stellar mass loss rate, \dot{M}_\odot is the Sun’s mass loss rate. The function (6), according to Lingam and Loeb, is useful in order to determine the likelihood of a planet being conducive to life with respect to Earth and, at this purpose, presents the advantage that nearly all of the parameters are direct observables, or can be deduced indirectly, by means of numerical simulations (except for uncertainties concerning the surface pressure and the surface temperature). From their analysis, Lingam and Loeb would have concluded that Earth-sized exoplanets in the habitable zone around M-dwarfs (and, in particular, Proxima b and TRAPPIST-1e) would seem to display much

lower prospects of being habitable relative to Earth, owing to the higher incident ultraviolet fluxes and closer distances to the host star.

Now, as regards the likelihood of life on planets, our question is the following: can the approach based on the metabolic theory of ecology, supplemented with the considerations regarding the atmospheric escape of the planet, in the light of the results obtained by Lingam's and Loeb's, be considered the end of the history about the origin of life in a planet? Can Lingam's and Loeb's results be considered conclusive, namely that we must acknowledge that the possibilities of evolution of life in Proxima b and TRAPPIST-1e are quite smaller relative to the Earth? Our answer is not: we think that, as regards the possibility of the evolution of life in exoplanets, new scenarios can be thrown by taking account of quantum theory. Here, we want to introduce a new reading of the origin of life, which is based on the fact that quantum physics plays a crucial role as regards the evolution and features of life, in line with the considerations made by Jim-Al-Khalili in [9]. Our approach, which involves a fundamental non-local quantum vacuum as an ultimate arena of the universe, can be considered as an appropriate "quantum extension" of Lingam's and Loeb's formulas (6)–(8), and at the same time represents an alternative model with respect to the model developed by Lingam and Loeb in [32].

3 Origin of Life and the Quantum Potential of a Non-Local Quantum Vacuum

In a series of recent papers [33–36], the author has proposed a model in which all the events of our everyday life derive from elementary processes of a fundamental, deep arena, a three-dimensional (3D) timeless non-local quantum vacuum characterized by RS processes of creation/annihilation of quanta corresponding to opportune fluctuations of the quantum vacuum energy density. In this model, the ground state of the universe is defined by the Planck energy density given by equation

$$\rho_{PE} = \frac{m_p c^2}{l_p^3}, \quad (9)$$

where m_p is Planck's mass, c is the light speed and l_p is Planck's length. The Planck energy density (9) physically corresponds to the total average volumetric energy density, owed to all the frequency modes possible within the visible size of the universe, expressed by

$$\rho_{PE} = \frac{c^7}{\hbar G^2} \approx 4,641266 \cdot 10^{113} \text{ J/m}^3, \quad (10)$$

\hbar being Planck's reduced constant, G the universal gravitation constant.

Each material particle is associated to a specific excited state of the 3D quantum vacuum characterized by a diminishing of the quantum vacuum en-

ergy density and corresponding to opportune elementary RS processes of creation/annihilation of quanta. In other words, there is a fundamental symmetry between the property of mass and the changes of the quantum vacuum energy density on the basis of relation

$$\rho_{qvE} = \rho_{PE} - \frac{m c^2}{V}, \quad (11)$$

where ρ_{qvE} is the energy density of quantum vacuum inside the physical object, ρ_{PE} is the Planck energy density (given by (10)) and V is the volume of the physical object. Another crucial property of the excited states of the 3D quantum vacuum is that the motion of the virtual particles corresponding to the elementary fluctuations of the quantum vacuum energy density generates in space-time a virtual radiation with frequency

$$\omega = \frac{2\Delta\rho_{qvE}V}{\hbar n}, \quad (12)$$

where n is the number of the RS processes of virtual sub-particles characterizing the vacuum medium. Equation (12) implies that each elementary fluctuation of the quantum vacuum energy density in a given volume produces an oscillation of the vacuum at a peculiar frequency and thus that each structure of our physical world somewhat corresponds to a specific vibratory state of the fundamental vacuum defined by the frequency (12).

Moreover, the evolution of the excited state of quantum vacuum which corresponds to the appearance of a material particle of mass given by (11) is determined by opportune RS processes of creation/annihilation of quanta described by a wave function $C = \begin{pmatrix} \psi \\ \phi \end{pmatrix}$ at two components satisfying a time-symmetric extension of the Klein-Gordon quantum relativistic equation

$$\begin{pmatrix} H & 0 \\ 0 & -H \end{pmatrix} C = 0, \quad (13)$$

where $H = \left(-\hbar^2 \partial^\mu \partial_\mu + \frac{V^2}{c^2} (\Delta\rho_{qvE})^2 \right)$ and $\Delta\rho_{qvE} = (\rho_{PE} - \rho_{qvE})$ is the change of the quantum vacuum energy density. Equation (13) corresponds to the following two equations:

$$\left(-\hbar^2 \partial^\mu \partial_\mu + \frac{V^2}{c^2} (\Delta\rho_{qvE})^2 \right) \psi_{Q,i}(x) = 0 \text{ for creation events and} \quad (14)$$

$$\left(\hbar^2 \partial^\mu \partial_\mu - \frac{V^2}{c^2} (\Delta\rho_{qvE})^2 \right) \varphi_{Q,i}(x) = 0 \text{ for destruction events.} \quad (15)$$

The virtual particles-antiparticles corresponding to the RS processes of creation/annihilation of the 3D quantum vacuum give rise to a total zero spin, thus

constituting an organized Bose ensemble, which acts as a superfluid medium, in analogous way to a model proposed by Sbitnev in a series of recent papers [37–40]. The crucial result which derives from the superfluid nature of the 3D quantum vacuum lies in the fact that it can provide a unifying view of gravity, electromagnetic fields and quantum behaviour of matter as different aspects of the same fluctuations of the quantum vacuum energy density and, in this picture, the non-local features of the 3D quantum vacuum is determined by the quantum potential of the vacuum of the form

$$Q_{Q,i} = \frac{\hbar^2 c^2}{V^2 (\Delta\rho_{qvE})^2} \left(\frac{\left(\nabla^2 - \frac{1}{c^2} \frac{\partial^2}{\partial t^2} \right) |\psi_{Q,i}|}{|\psi_{Q,i}|} \right) \quad (16)$$

which is the fundamental entity which the guides the occurring of the processes of creation or annihilation in space. In particular, in the non-relativistic domain, the quantum potential of the vacuum (15) becomes:

$$Q_{Q,i} = -\frac{\hbar^2 c^2}{2V \Delta\rho_{qvE}} \left(\frac{\frac{\nabla^2 |\psi_{Q,i}|}{|\psi_{Q,i}|}}{-\frac{\nabla^2 |\phi_{Q,i}|}{|\phi_{Q,i}|}} \right). \quad (17)$$

Now, what is the role of the excited states of the 3D quantum vacuum described by equation (11)–(17) into the origin of life? What is the link between the excited states of the 3D quantum vacuum described by equation (11)–(17) and the likelihood of life events in a exoplanet? In this regard, our idea is to formulate the interconnection, mutual interaction and link between living organism and environment (namely between life and space) by starting from Grössing’s thermodynamic interpretation of the quantum potential.

In the recent articles *The vacuum fluctuation theorem: Exact Schrödinger equation via non-equilibrium thermodynamics* [41] and *On the thermodynamic origin of the quantum potential* [42] Grössing suggested that quantum phenomena have a fundamental thermodynamic origin and that the quantum potential has origin from the presence of a subtle thermal vacuum energy distributed across the whole domain of an experimental arrangement. In Grossing’s approach, quantum particles are assumed to be surrounded by a reservoir that is very large compared to the small dissipative system and are described by the following equation regarding the detection probability density provided by the environment:

$$\frac{P(\vec{x}, t)}{P(\vec{x}, 0)} = \exp\left(-\frac{\Delta Q_{hf}}{kT}\right) \quad (18)$$

with k being Boltzmann's constant, T the reservoir temperature and ΔQ_{hf} the heat that is exchanged between the particle and its environment. Here quantum particles are assumed to be actually dissipative systems maintained in a non-equilibrium steady-state by a permanent throughout of energy, or heat flow, respectively, and the detection probability density provided by the particle's environment is considered to coincide with a classical wave's intensity according to relation

$$P(\vec{x}, t) = R^2(\vec{x}, t) \quad (19)$$

(with $R(\vec{x}, t)$ being the wave's real-valued amplitude). In the light of these assumptions, in Grössing's view, equation (19) lead to obtain Schrödinger's equation from classical mechanics with only two supplementary well-known observations. The first is represented by a relation between heat and action of the form

$$\Delta Q_{hf} = 2\omega [\delta S(t) - \delta S(0)] , \quad (20)$$

while the second consists in the requirement that the average kinetic energy of the thermostat turns out to be equal to the average kinetic energy of the oscillator, for each degree of freedom, namely

$$\frac{kT}{2} = \frac{\hbar\omega}{2} . \quad (21)$$

After an appropriate mathematical treatment Grössing arrives thus to the following thermodynamic formulation of the quantum potential

$$Q = -\frac{\hbar^2}{2m} \frac{\nabla^2 Q_{hf}}{\hbar\omega} . \quad (22)$$

The physical content of this approach lies in the fact that the quantum potential (22) responsible of the quantum behaviour of a subatomic particle is determined by a more fundamental level of physical reality which, in particular, is associated with a heat flow, a thermal energy produced by the detection probability density provided by the particle's environment in a given experimental arrangement (and which coincides with a classical wave's intensity). Therefore, in Grössing's approach, the "form" of the quantum potential, as given by $-\frac{\nabla^2 R}{R}$, is ultimately connected with a Helmholtz-type dependence $-\nabla^2 Q_{hf}$ of a thermal energy Q_{hf} defining a fundamental vacuum and this thermal energy is associated with wave-diffusion waves and is distributed "non-locally" throughout the environment of the experimental arrangement into consideration. In summary, in Grössing's approach, a fundamental level of physical reality, which is described by a heat flow, a thermal energy distributed non-locally between the particle under consideration and its environment, and connected to wave-diffusion fields, can be considered as the ultimate physical structure which determines the action of the quantum potential of non-relativistic de Broglie-Bohm theory [43].

Now, by following the spirit of Grossing’s thermodynamic interpretation of the quantum potential provided in the papers [41] and [42], in our approach we provide a quantum characterization of the average activation energy E of the planet in terms of quantum properties of the environment which reproduce the fact that “origin of life”-type events are linked with the in situ temperature, by assuming that the quantum interaction between a living organism with its environment is determined by a quantum potential of the vacuum which acts as a heat reservoir that produces an “additional density” of physical space in a living organism (living matter) with respect to inert matter. This means that fractional availability of vibratory states associated with the RS processes of the 3D quantum vacuum provided by the environment, which are able to give origin to potential building blocks necessary for the development of life, can be expressed in the form:

$$f_\omega = \frac{\Delta\rho_{qvE}}{\rho_{qvE}} \exp\left(-\frac{\Delta Q_{hf}}{kT}\right), \quad (23)$$

where k is Boltzmann’s constant, T is the reservoir temperature and ΔQ_{hf} is the heat that describes and regards the interaction between the living organism and its environment. By requiring that the average kinetic energy of the living organism turns out to be equal to the average kinetic energy associated with the vibratory states of the 3D quantum vacuum, namely

$$\frac{kT}{2} = \frac{\hbar\omega}{2}, \quad (24)$$

one obtains

$$f_\omega = \frac{\Delta\rho_{qvE}}{\rho_{qvE}} \exp\left(-\frac{\Delta Q_{hf}}{\hbar\omega}\right). \quad (25)$$

In this way, always following Grossing’s mathematical treatment, the quantum potential of the 3D quantum vacuum (11) for the RS processes of creation in the relativistic domain becomes

$$Q = \frac{\hbar^2 c^2}{V^2 (\Delta\rho_{qvE})^2} \frac{\nabla^2 Q_{hf}}{\hbar\omega} \quad (26)$$

while in the non-relativistic domain is

$$Q = -\frac{\hbar^2 c^2}{2V \Delta\rho_{qvE}} \frac{\nabla^2 Q_{hf}}{\hbar\omega}. \quad (27)$$

Now, if in Grössing’s thermodynamic approach to the quantum potential, the “form” of the quantum potential and its geometrodynamical features are ultimately connected with a Helmholtz-type dependence $-\nabla^2 Q_{hf}$ of a thermal energy Q_{hf} defining a fundamental vacuum and this thermal energy is associated with wave-diffusion waves and is distributed “non-locally” throughout the environment of

the experimental arrangement into consideration, in analogous way in our approach of a 3D non-local quantum vacuum as fundamental origin of physical processes and of the evolution of life, the interaction between a living organism and its environment, which shows how an “additional density” of physical space is present in a living organism (living matter) with respect to inert matter, is determined by a quantum potential of the 3D quantum vacuum which acts as a heat reservoir, as a thermal energy which appear then as bio-photons which act non-locally in the environment itself. The instantaneous action of the bio-photons produced by the thermalized quantum potential of the vacuum imply that the distributions of the vibratory states in the environment under consideration contribute in their totality to the form of the heat distribution in the overall system and thus to the evolution of the living organism. As a consequence, the infinite propagation of the diffusion-wave fields associated with the bio-photons generated by the interaction between the living organism and the thermalized 3D quantum vacuum leads therefore to a promising perspective for a deeper understanding of the origin of life in the universe.

The fundamental consequence of the discussion made here is that the non-local action of the quantum potential of the vacuum makes life as a property that ultimately has a global feature, namely acts non-locally itself. In other words, we can say that, in the light of the quantum potential of the vacuum (27) (or (26)), life is a property of all universe, is a cosmic property, namely is not limited only to what we know about Earth, thus implying that abiogenesis events indeed refer to a non-localized series of assembly steps or processes that lead directly and irreversibly to an evolvable living universe.

The non-local features of life may also be characterized by introducing an appropriate Bell length associated with the quantum potential of the vacuum (16):

$$L_{\text{Bell}} = \sqrt{\frac{\hbar^2 c^2}{2\Delta\rho_{qv}EVQ}}, \quad (28)$$

namely

$$L_{\text{Bell}} = \sqrt{-\frac{c\hbar\omega}{\nabla^2 Q_{hf}}}, \quad (29)$$

namely, taking account of (17),

$$L_{\text{Bell}} = \sqrt{-\frac{2c\Delta\rho_{qv}EV}{n\nabla^2 Q_{hf}}}. \quad (30)$$

The condition $Q = 0$, i.e. $L_{\text{Bell}} = \infty$ provide the points where the action of the 3D quantum vacuum acting as a heat reservoir expressing the interaction between a living organism and its environment, namely where the additional density of physical space present in living matter, is delocalized, thus implying

the evolution of life and equation (30) shows that this happens when

$$|2c\Delta\rho_{qvE}V| \ll |n\nabla^2Q_{hf}|. \quad (31)$$

Equation (31) is a plausible physical condition which, for a great number of RS processes of creation/annihilation of quanta corresponding to a great number n of virtual particles/antiparticles of the vacuum, practically occurs in a specific macroscopic volume V . This means in other words that the propagation of life in the universe, owed to the action of the thermalized quantum vacuum which functions as a heat reservoir, as a thermal energy which appear then as bio-photons which act non-locally in the environment itself, occurs instantaneously in all the points of the universe, namely that life is indeed a global property which is able to transmit itself in the entire universe.

In our model, the average activation energy E determined by considering the appropriate rate-limiting step in metabolism in a given planet, which appears in equations (1)–(3) of the Metabolic Theory of Ecology can be replaced with the quantum potential of the 3D non-local quantum vacuum, which acts as a heat reservoir and expresses the interaction between a living organism and its environment, showing how an “additional density” of physical space is present in a living organism (living matter) with respect to inert matter. So, in our approach, equations (1)–(3) of the Metabolic Theory of Ecology respectively become:

$$B \propto \left(\frac{\Delta\rho_{qvE}V}{c^2} \right)^{3/4} \exp \left(\frac{\frac{\hbar^2 c^2}{2V\Delta\rho_{qvE}} \frac{\nabla^2 Q_{hf}}{\hbar\omega}}{k_B T} \right), \quad (32)$$

$$\bar{B} = \frac{\int B(\rho_{qvE}, T) N(\rho_{qvE}) d\rho_{qvE}}{\int N(\rho_{qvE}) d\rho_{qvE}} \propto \exp \left(\frac{\frac{\hbar^2 c^2}{2V\Delta\rho_{qvE}} \frac{\nabla^2 Q_{hf}}{\hbar\omega}}{k_B T} \right) \quad (33)$$

and

$$P_T = \exp \left(\frac{\frac{\hbar^2 c^2}{2V\Delta\rho_{qvE}} \frac{\nabla^2 Q_{hf}}{\hbar\omega}}{k_B T} \right) \theta(T - T_L) \theta(T_U - T). \quad (34)$$

In particular, taking account that for life as we know it in our planet the Earth-referenced temperature-dependent likelihood function (4) holds, one obtains the following condition for the quantum potential of the vacuum as a reservoir heat

relative to the parameters of the planet Earth:

$$\frac{\frac{\hbar^2 c^2}{2V \Delta \rho_{qvE}} \frac{\nabla^2 Q_{hf}}{\hbar \omega}}{k_B T} = 26,7 \left(\frac{\frac{\hbar^2 c^2}{2V \Delta \rho_{qvE}} \frac{\nabla^2 Q_{hf}}{\hbar \omega}}{E_{\oplus}} \frac{T_{\oplus}}{T} + 1 \right), \quad (35)$$

namely

$$\frac{\hbar c^2 E_{\oplus} \nabla^2 Q_{hf} - 26,7 \hbar c^2 k_B T_{\oplus} \nabla^2 Q_{hf}}{2V \Delta \rho_{qvE} \omega E_{\oplus} k_B T} - 1 = 0, \quad (36)$$

namely

$$\hbar c^2 E_{\oplus} \nabla^2 Q_{hf} - 26,7 \hbar c^2 k_B T_{\oplus} \nabla^2 Q_{hf} = 2V \Delta \rho_{qvE} \omega E_{\oplus} k_B T, \quad (37)$$

namely

$$\nabla^2 Q_{hf} (\hbar c^2 E_{\oplus} - 26,7 \hbar c^2 k_B T_{\oplus}) = 2V \Delta \rho_{qvE} \omega E_{\oplus} k_B T, \quad (38)$$

namely

$$\nabla^2 Q_{hf} = \frac{2V \Delta \rho_{qvE} \omega E_{\oplus} k_B T}{\hbar c^2 E_{\oplus} - 26,7 \hbar c^2 k_B T_{\oplus}}, \quad (39)$$

which expresses the link between the heat ΔQ_{hf} that describes and regards the interaction between the living organism and its environment, the temperature of the planet and the fluctuations of the quantum vacuum energy density in the region into consideration. An interesting advantage of equation (39) is that it reproduces correctly the fact that “origin of life”-type events are determined by the parameters of the surrounding environment and not necessarily by the global properties (such as the global temperature) of the planet.

Moreover, by replacing the activation energy E associated with the metabolism in a planet with the quantum potential of the vacuum acting as a reservoir heat which supports the interaction between the living organism and its environment, the approach of Lingam and Loeb of the likelihood function of life in exoplanets based on equations (6)–(8) may be replaced and extended in the context of a more general approach of a 3D quantum vacuum which considers the following equations:

$$(a) \quad P = \exp \left(\frac{\frac{\hbar^2 c^2}{2V \Delta \rho_{qvE}} \frac{\nabla^2 Q_{hf}}{\hbar \omega}}{k_B T} \right) \theta(T - T_L) \theta(T_U - T) \\ \times \left(\frac{P_s}{1 \text{ atm}} \right) \left(\frac{R_P}{R_{\oplus}} \right) \left(\frac{\langle F_{EUV} \rangle}{\langle F_{\oplus} \rangle} \right)^{-1}, \quad (40)$$

if the lifetime of the planet's atmosphere is less than the timescale of atmospheric loss for unmagnetized planets, and

$$(b) \quad P = \exp \left(\frac{\frac{\hbar^2 c^2}{2V \Delta \rho_{qvE}} \frac{\nabla^2 Q_{hf}}{\hbar \omega}}{k_B T} \right) \theta(T - T_L) \theta(T_U - T) \\ \times \left(\frac{P_s}{1 \text{ atm}} \right) \left(\frac{a}{1 \text{ AU}} \right)^2 \left(\frac{R_P}{R_\oplus} \right)^{-1,7} \left(\frac{\dot{M}_\star}{\dot{M}_\odot} \right)^{-1}, \quad (41)$$

if the lifetime of the planet's atmosphere is bigger than the timescale of atmospheric loss for unmagnetized planets. According to our opinion, equations (40) and (41) can be considered as a valid mathematical formulation of the Jim Al-Khalili considerations mentioned in the introduction, namely they explain in what sense life is a phenomenon which, despite having a foot in the classical world of tangible objects of everyday experience, finds its origin in the depths of the quantum world. According to equations (40) and (41), living organisms have behaviours and characteristics that originate down in the quantum foundations of reality, in the sense that the interaction between a living organism and its environment is determined by a quantum potential of a 3D quantum vacuum acting as a reservoir heat. In other words, we can say that, while the other terms (7) and (8) appearing in equations (40) and (41) are the expression of the role of classical mechanics and thermodynamics in the origin of life, instead the first term

$$\exp \left(\frac{\frac{\hbar^2 c^2}{2V \Delta \rho_{qvE}} \frac{\nabla^2 Q_{hf}}{\hbar \omega}}{k_B T} \right)$$

indicates in what sense life has origin and behaviour which emerges in the most intimate level of quantum reality. And, as regards the approach based on equations (40) and (41), the crucial point is that, even when the terms (7) and (8) for a given exoplanet seem to provide values which differ with respect to those of Earth (as Lingam's and Loeb's research demonstrate), this does not necessarily mean that the exoplanet into consideration does not host life because the quantum term

$$\exp \left(\frac{\frac{\hbar^2 c^2}{2V \Delta \rho_{qvE}} \frac{\nabla^2 Q_{hf}}{\hbar \omega}}{k_B T} \right)$$

associated with the quantum potential of the vacuum, as a consequence of its non-local action, makes life a non-local property which can originate also in that peculiar exoplanet.

4 Conclusions and Perspectives

Why does life exist? Popular hypotheses invoke the existence of a primordial soup, a bolt of lightning and a colossal stroke of luck. This paper, by taking account quantum theory and in particular the role of the quantum potential of a fundamental three-dimensional quantum vacuum defined by fluctuations of its energy density occurring in correspondence to elementary RS processes of creation/annihilation of virtual particles, throws new light on the origin of life. If the provocative new theory suggested in this paper will be proved to be correct, the result will be that luck may have little to do with the origin of life, in the sense that the origin and subsequent evolution of life would follow from the physical laws which rule nature at the fundamental level.

It must be emphasized that the approach here introduced turns out to be compatible with other interesting current research. In particular, we mention that in 2013 Jeremy England of the Massachusetts Institute of Technology formulated a mathematical model, based on established physics, which indicates that when a group of atoms is driven by an external source of energy (like the sun or chemical fuel) and surrounded by a heat bath (like the ocean or atmosphere), it will often gradually restructure itself in order to dissipate increasingly more energy [44]. This could mean that under certain conditions, matter inexorably acquires the key physical attribute associated with life. England's theory, in our opinion, turns out to be in good agreement, from the point of view of the epistemological foundations, with the concept, here introduced, of the mutual interaction between a living organism and its environment in terms of a quantum potential of the vacuum which acts as a reservoir that produces an "additional density" of physical space in a living organism (living matter) with respect to inert matter. In fact, in our theory the role of England's heat bath is played by the quantum potential of the vacuum.

On the other hand, another interesting current model, published by Caleb Scharf and Leroy Cronin in the paper "Quantifying the origins of life on a planetary scale" [45], suggests an equation in order to estimate the frequency of planetary "origin of life"-type events that makes an explicit connection between "global" rates for life arising and granular information about a planet. Scharf's and Cronin's approach suggests that the probability of life beginning on a given planet is very likely connected to whether there are building blocks available on a given planet, and how much of them there might be. More specifically, Scharf and Cronin's mathematical formalism states that the odds of life emerging on a planet are driven by the number of building blocks that could possibly exist, the number of building blocks available, the probability that these building blocks will actually go on to create life (i.e. assembly), and the number of building blocks needed to produce a given life form. The approach introduced in this paper based on the quantum potential of a three-dimensional quantum vacuum as elementary source of life shows a good parallelism also with Scharf

and Cronin's results and opens the perspective to provide a new key of reading of them in terms of more fundamental vibratory states of the three-dimensional quantum vacuum.

Although our proposed methodology is by no means complete, since important (first-order) feedback mechanisms – such as the complex, nonlinear and adaptive interplay between life and planetary habitability – have not been included herein, and we have altogether neglected second-order effects in this study, however we emphasize the importance of adopting such an approach in future studies that seek to quantify the likelihood of exoplanets hosting complex and long-lived biospheres, in order to show if and in what sense life is a cosmic property. In particular, an important matter would be to find the exact predictions of this model as regards life in exoplanets similar to Earth like Proxima b and TRAPPIST-1e. In this regard, further research will give you more information.

Finally, another crucial perspective to investigate in the context of this model of a three-dimensional quantum vacuum as ultimate origin of life would be to find the frequency of “intelligent life” events in the universe. In this regard, a recent study by Frank and Sullivan showed that as long as the probability that a habitable zone planet develops a technological species is larger than $\sim 10^{-24}$, then terrestrial humanity is not the only time technological intelligence has evolved [46]. On the basis of Frank's and Sullivan's results, the probability that among the billions of billions of stellar systems present in the cosmos, there existed a form of technologically advanced civilization such as ours is very high: it happened almost 10 billion times since the days of the Big Bang! According to our opinion, the idea predicted by our model of a three-dimensional non-local quantum vacuum of life as a non-local global phenomenon expressed by a non-localized series of assembly steps or processes that lead directly and irreversibly to an evolvable living universe as a consequence of the non-local action of the quantum potential of the vacuum, can be considered plausible and coherent, on an epistemological point of view, with Frank's and Sullivan's results and has the potentiality to throw new explanatory light on it. The perspective is opened that also the cosmic frequency of technological species is determined by ultimate properties of a non-local quantum vacuum.

References

- [1] J.N. Winn and D.C. Fabrycky (2015) *Annu. Rev. Astron. Astrophys.* **53** 409-447; doi: [10.1146/annurev-astro-082214-122246](https://doi.org/10.1146/annurev-astro-082214-122246).
- [2] J.F. Kasting, R. Kopparapu, R.M. Ramirez and C.E. Harman (2014) *Proc. Natl. Acad. Sci. USA* **111**(35) 12641-12646; doi: [10.1073/pnas.1309107110](https://doi.org/10.1073/pnas.1309107110).
- [3] C.D. Dressing and D. Charbonneau (2015) *Astrophys. J.* **807** 45; doi: [10.1088/0004-637X/807/1/45](https://doi.org/10.1088/0004-637X/807/1/45).
- [4] G. Anglada-Escudé *et al.* (2016) *Nature* **536** 437-440.
- [5] M. Gillon *et al.* (2016) *Nature* **533** 221-224.

- [6] M. Gillon *et al.* (2017) *Nature* **542** 456-460.
- [7] M. Lingam and A. Loeb (2017) *Proc. Natl. Acad. Sci. U.S.A.* **114** 6689-6693.
- [8] E. Schrödinger (1944) “*What Is Life?*” (Cambridge University Press).
- [9] J. Al-Khalili (2015) “*La fisica della vita. La nuova scienza della biologia quantistica*” (Bollati Boringhieri, Torino).
- [10] M.J. Angilletta (2009) “*Thermal Adaptation: A Theoretical and Empirical Synthesis*” (Oxford University Press).
- [11] J.H. Brown *et al.* (2004) *Ecology* **85** 1771-1789.
- [12] A.R. Cossins and K. Bowler (1987) “*Temperature Biology of Animals*” (Chapman & Hall).
- [13] C.A. Deutsch *et al.* (2008) *Proc. Natl. Acad. Sci. U.S.A.* **105** 6668-6672.
- [14] M.E. Dillon, G. Wang and R.B. Huey (2010) *Nature* **467** 704-706.
- [15] J.G. Kingsolver and R.B. Huey (2008) *Evol. Ecol. Res.* **10** 251-268.
- [16] P. Ball (2008) *Chem. Rev.* **108** 74-108.
- [17] S.A. Benner, A. Ricardo and M.A. Carrigan (2004) *Curr. Opin. Chem. Biol.* **8** 672-689.
- [18] N.R. Pace (2001) *Proc. Natl. Acad. Sci. U.S.A.* **98** 805-808.
- [19] J.F. Gillooly *et al.* (2001) *Science* **293** 2248-2251.
- [20] A.I. Dell, S. Pawar, and V.M. Savage (2011) *Proc. Natl. Acad. Sci. U.S.A.* **108** 10591-10596.
- [21] J.F. Gillooly *et al.* (2006) *Funct. Ecol.* **20** 400-404.
- [22] G. Yvon-Durocher *et al.* (2012) *Nature* **487** 472-476.
- [23] C.P. McKay (2014) *Proc. Natl. Acad. Sci. U.S.A.* **111** 12628-12633.
- [24] L.J. Rothschild and R.L. Mancinelli (2001) *Nature* **409** 1092-1101.
- [25] N.Y. Kiang, J.G. Siefert and R.E. Blankenship (2007) *Astrobiology* **7** 222-251.
- [26] S. Akanuma *et al.* (2013) *Proc. Natl. Acad. Sci. U.S.A.* **110** 11067-11072.
- [27] E.A. Gaucher *et al.* (2003) *Nature* **425** 285-288.
- [28] W. Martin *et al.* (2008) *Nat. Rev. Microbiol.* **6** 805-814.
- [29] N.R. Pace (1991) *Cell* **65** 531-533.
- [30] S.L. Miller and A. Lazcano (1995) *J. Mol. Evol.* **41** 689-692.
- [31] M.C. Weiss *et al.* (2016) *Nat. Microbiol.* **1** 16116.
- [32] M. Lingam and A. Loeb (2017) [arXiv:1707.02996v1](https://arxiv.org/abs/1707.02996v1) [astro-ph.EP].
- [33] D. Fiscaletti and A. Sorli (2014) *SOP Transactions on Theoretical Physics* **1** 11-38.
- [34] D. Fiscaletti and A. Sorli (2017) *Annales de la Fondation Louis de Broglie* **42** 251-297.
- [35] D. Fiscaletti and A. Sorli (2016) *Ukr. J. Phys.* **61** 413-431.
- [36] D. Fiscaletti and A. Sorli (2016) *Annales UMCS Sectio AAA: Physica* **LXXI** 11-52.
- [37] V. Sbitnev (2014) [arXiv:1403.3900v2](https://arxiv.org/abs/1403.3900v2) [physics.flu-dyn].
- [38] V. Sbitnev (2015) [arXiv:1507.03519v1](https://arxiv.org/abs/1507.03519v1) [physics.gen-ph].
- [39] V. Sbitnev (2015) In: “*Selected Topics in Applications of Quantum Mechanics*”, edited by M.R. Pahlavani (InTech, Rijeka) pp. 345-373; doi:10.5772/59040.
- [40] V. Sbitnev (2015) <http://arxiv.org/abs/1504.07497>.
- [41] G. Grössing (2007) *Phys. Lett. A* **372** 4556; <http://arxiv.org/abs/0711.4954>.

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- [42] G. Grössing (2008) *Physica A* **388** 811-823; [arXiv: quant-ph 0808.35.39.pdf](#).
- [43] D. Fiscaletti (2018) “*The Geometry of Quantum Potential. Entropic Information of the Vacuum*” (World Scientific, Singapore).
- [44] J.L. England (2013) *J. Chem. Phys.* **139** 121923.
- [45] C. Scharf and L. Cronin (2016) *Proc. Natl. Acad. Sci. USA* **113** 8127-8132.
- [46] A. Frank and W.T. Sullivan (2016) *Astrobiology* **16** 359-362;
[doi: 10.1089/ast.2015.1418](#).