International Journal of Advanced Research in Physical Science (IJARPS)
Volume 4, Issue 2, February 2017, PP 1-12
ISSN 2349-7874 (Print) & ISSN 2349-7882 (Online)
www.arcjournals.org

Dark Energy Accelerating the Expansion of the Universe: The Perspective from the Higgs Quantum Space

Jacob Schaf
Universidade Federal do Rio Grande do Sul (UFRGS), Instituto de Física, Av. Bento Gonçalves, Porto Alegre-RS, Brazil.

Abstract: *The present work investigates the nature of the vacuum energy density within the context of the Higgs theory. Current theories describe the empty universe in terms of the stress-energy tensor of a perfect fluid and estimate the vacuum energy density in terms of the zero-point energy of the vacuum fluctuations. In the view of the Higgs theory, empty space is a very strongly correlated quantum condensate with spontaneously broken U(1) symmetry, ruled by an Order Parameter and giving mass to the elementary particles by the Higgs mechanism. Its large energy gap (~200 GeV) strongly suppresses vacuum fluctuations and the zero-point energy. Therefore, estimating the vacuum energy density, in terms of the zero-point energy, certainly is inadequate. The Higgs universe is an adiabatic system whose total energy must be conserved. Contrarily than assumed in particle physics, expansion of the universe (Higgs Quantum Space) does not create energy. It only reduces the energy density. It stretches the wave-length of particles and of radiation, thereby reducing the energy and temperature of the matter universe. The present work shows that this adiabatic expansion leads to a vacuum energy density in close agreement with the actual observations. However, these observations in addition clearly indicate that the accelerating expansion of the visible universe keeps to the accelerating expansion of the HQS itself.*

Keywords: *Dark Energy, Vacuum Energy, Cosmological Constant, Higgs Quantum Space, Accelerated Expansion of the Universe.*

1. INTRODUCTION

The discussion about the cosmological constant has initiated with Einstein's General Relativity (GR), [1,2] when Friedman [3] discovered that the solution of the original field equations of GR, for a very large-scale scenario enclosing the whole universe (Robertson-Walker universe), [4.5] leads to an expanding universe. In Einstein's view, only a static universe, dominated by gravitation could be reasonable. Therefore he included the cosmological term to get solutions for a non-expanding universe. With this inclusion, the field equations took the form:

$$R_{\mu\nu} - (1/2)\, g_{\mu\nu} R + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu} \tag{1}$$

where Λ is the well known cosmological constant with dimension of length^{-2}.

In the Robertson-Walker universe, [4,5] the effect of the local gravitational sources can be seen as local perturbations. Such a universe usually is modeled in terms of the four-dimensional energy-momentum tensor of a homogeneous and isotropic perfect fluid, with an energy density ρ_v and isotropic negative pressure p:

$$T_{\mu\nu} = (\rho_v + p)\, U_\mu U_n + p g_{\mu\nu} \tag{2}$$

Where U_μ and U_n are the local four-velocities of the perfect fluid.

In the absence of ordinary matter-energy, $T_{\mu\nu}$ in Eq.(2) reduces to T_{00}, which is interpreted as the energy density of the vacuum ρ_v. From the perspective of the elementary particle physics, the cosmological constant is proportional to the energy density of the vacuum and, importantly, this energy density remains constant during the expansion of the universe.[6,7] Therefore, expansion of the universe creates energy, which leads to the odd negative pressure of the perfect fluid. The vacuum of elementary particle physics usually includes the zero-point energy, associated with the fluctuations of the various scalar fields, like the scalar Higgs field of the spontaneously broken electroweak symmetry, the broken chiral symmetry of the strong interaction etc. Altogether, these contributions lead to the theoretical vacuum energy density ρ_v^{th} of about:

$$\rho_v^{th} = \rho_\Lambda \sim 10^{110}\ erg/cm^3. \tag{3}$$

The seriousness of the discussion of the cosmological constant turned into a central problem in cosmology, during the last decade of the past century, when the experimental observations, with the help of Ia supernovae, [8,9] as well as with the help of cosmic microwave background radiation,[10] showed that the expansion of the universe is accelerating. These observations provided approximate estimates of the cosmological constant and of the vacuum energy density ρ_v^{obs}, given by:

$$\rho_v^{obs} \sim 10^{-10}\ erg/cm^3 \tag{4}$$

The gap between the theoretical estimate in Eq.(3) and the experimental observations in Eq.(4) amounts to about 120 decimal orders of magnitude and decreases not much, even with the most favorable estimates. This lets clear that something very fundamental is wrong with the assumptions in the Robertson-Walker universe about the nature of space and the origin of the vacuum energy density. This makes the discussion about the cosmological constant more actual than ever.

The stalemate about the vacuum energy, now endures more than *50* years and the hope of solving the conflict between the predictions of the current theoretical models and the experimental observations seems completely out of reach, without radical changes in the view about the nature of empty space and the origin of the gravitational dynamics. The present work challenges these problems within the new scenario of the Higgs theory. The Higgs theory has introduced the Higgs Quantum space (HQS), giving mass to the elementary particles by the Higgs mechanism.[11-13] From this viewpoint, *the form* of describing the Robertson-Walker model universe in terms of the stress-energy tensor of a perfect fluid is not necessarily wrong. However, what is flowing in this universe is not a perfect (classical) fluid, *however the HQS itself*. The HQS can in no way be seen as a perfect fluid. Classical perfect fluids are systems of uncorrelated particles with their $U(1)$ symmetry preserved. Such particles respond all individually to a perturbing field. The HQS however is formed by strongly correlated bosons, a highly phase coherent quantum condensate, with spontaneously broken $U(1)$ symmetry and *ruled by a complex Order Parameter*. The HQS is dominated by cooperative and collective effects. It behaves like one unique oscillator. The response of the HQS to any perturbation always is coordinated by the order parameter, which involves all the particles of the condensate.

According to the Glashow-Weinberg-Salam electroweak model, the energy gap between the unbroken and the spontaneously broken electroweak model is about 200 GeV. This large energy gap strongly suppresses diffuse motion of individual particles, as well as local quantum fluctuations and thus the zero-point energy. Therefore, *estimating the vacuum energy density in terms of the zero-point energy of an uncorrelated vacuum certainly is inadequate*. The vacuum fluctuations causing the Casimir effect and the Lamb shift in Quantum Electrodynamics are of the electromagnetic (EM) nature. The EM field has its $U(1)$ symmetry preserved in the electroweak symmetry break-down and is not a quantum fluid. Moreover, the contribution of the EM fluctuations to the vacuum energy density is very low. Any local excitation in the HQS involves large energies, in the order of MeVs. The HQS however is a perfectly conservative quantum fluid. Once excited, the excitations automatically become very stable and persistent. The scenario of the Higgs theory will be shown to naturally lead to the observed accelerating expansion of the universe. Moreover, experimental observations demonstrate that the accelerating expansion of the visible universe keeps to the accelerating expansion of the HQS itself. The scenario of the HQS also correctly predicts the actual vacuum energy density and naturally leads to the intriguing similar values of the total visible matter-energy and of the total vacuum energy.

The next Section II outlines the most relevant phenomenologies of the usual quantum condensates and their analogs of the Higgs condensate. Section III will discuss the origin of the accelerating expansion of the universe from the perspective of the Higgs theory, showing that, from this viewpoint, the vacuum energy density closely matches the observed value.

2. The Higgs Theory Unveils the Nature of the Empty Space

This Section highlights the most relevant aspects of the quantum condensates that have been an important guide in the Higgs theory, explaining the origin of inertial mass of the elementary particles. The Higgs Quantum Space (HQS) is a quantum condensate that gives inertial mass to matter-energy by the Higgs mechanism and thus is responsible for their mechanical properties. The present work will not discuss details of the Higgs theory that culminated in the Higgs mechanism, but will rather concentrate it in the important practical consequences and the role of the HQS in the life of the universe. The Higgs theory discloses the nature of empty space, which puts the HQS to the center of any discussion of the cosmological constant, of the vacuum energy density and of the origin of the gravitational dynamics throughout the universe.

2.1. The Reasons for Introducing the Higgs Field

The Higgs theory [11-13] introduces the scalar Higgs field to explain the break-down of the electroweak symmetry into the weak force doublet SU(2), responsible for the radioactive decay of nucleons and electromagnetism with the unbroken *U*(1) symmetry, the photon. According to the Glashow-Weinberg-Salam electroweak model, the energy gap between the unbroken and the spontaneously broken electroweak symmetry is in the order of 200 GeV. The HQS is a quantum condensate, permeating all of space that is responsible for the mass and mechanical properties of the elementary particles.

The Higgs theory introduces profound changes in Einstein's view about the nature of empty space (vacuum), about the origin of inertial mass and about the meaning of motions of matter-energy. The HQS is not only a local ultimate reference for rest and for motions of matter-energy, however literally rules these motions. Recent experimental observations in the LHC corroborate the Higgs theory. The Higgs theory achieves, by the first time, a scientifically sound explanation to the origin of inertial mass of the elementary particles.

The HQS, far from a perfect fluid of classical particles, is a perfect quantum fluid. Quantum fluids differ fundamentally from classical perfect fluids. Quantum fluids are formed by strongly correlated bosons, condensed into a long-range phase coherent quantum state with spontaneously broken *U*(1) symmetry and *ruled by a complex order parameter*. In these condensates the Principle of Uncertainty becomes singular. While the uncertainty in position of the bosons tends to be very large, the uncertainty in momentum tends to zero. This entangles the wave functions of the particles and makes the particles indistinguishable. Therefore, it is completely impossible to interact locally with a part of the condensate, without affecting all the bosons of the condensate in terms of the order parameter. In the classical perfect fluid the particles are uncorrelated, independent and have their *U*(1) symmetry preserved. They respond individually and independently to an interacting field and are unable to develop collective and cooperative effects. Therefore, they cannot confine an interacting field and cannot generate inertial mass effects for it. Because of the order parameter, quantum fluids are dominated by collective and cooperative effects leading to confinement of an interacting field causing phase disorder and generating inertial mass effects for it. The HQS is a perfectly conservative quantum fluid, in which all excitations cost real and intrinsically quantized energy that is rigorously conserved and the excitations are permanent.

The Higgs theory introduces the condensation energy of the Higgs bosons, a constant energy term of the vacuum (HQS) that is absent in Einstein's original field equations. This energy term is equivalent to the cosmological term in Eq.(1) and will be seen to be responsible for the accelerating expansion of the universe. This vacuum energy density necessarily is highly uniform throughout the universe, because quantum condensates are ruled by an order parameter and hence intrinsically highly homogeneous.

If the Higgs mechanism gives mass to the elementary particles, it necessarily also is responsible for the gravitational dynamics, because it is mass that generates the gravitational fields. If the HQS gives mass to the elementary particles, it also necessarily governs their inertial motion and is the locally ultimate (locally absolute) reference for rest and for motions of matter-energy. Within this view, motions with respect to the local HQS and not relative motions are the true origin of all the effects of motions, the, so-called, relativistic effects.

Recent experimental observations have revealed that the gravitational slowing, predicted by GR due to the solar field, clearly is absent on the GPS clocks, moving with earth round the sun. Obviously the orbital motion of earth cannot cancel the solar gravitational potential. This observation demonstrates that the HQS is moving round the sun and that earth is very closely stationary with respect to the local moving HQS, which directly predicts the null results of the light anisotropy experiments on earth. The absence of this gravitational slowing on the GPS clocks and the null results of the light anisotropy experiments on earth are the obvious signature of the physical mechanism of gravity in action that historically has been missed.[14]

The Higgs theory pictures to us a universe in which macroscopic quantum mechanics effects are present throughout, giving mechanical properties to matter, governing the inertial motion of matter-energy and creating the gravitational dynamics. These assertions in no way can be seen as guess or speculation. They are genuine outcomes of the Higgs theory and this theory is giving evidence to be right.

2.2. The Bose-Einstein Phase Correlation Leading to the Quantum Condensation

Quantum condensates or Bose-Einstein (BE) condensates are bosons, condensed into a same macroscopic quantum state. This ground state however is created by the bosons themselves on spontaneously breaking their $U(1)$ symmetry and condensing all into the same and long-range phase coherent ground state, releasing the corresponding energy. It is important to note that this spontaneous breaking of the U (1) symmetry preserves the gauge symmetry of the Lagrangian of the boson system. Breaking of the U (1) symmetry suppresses the diffuse motion of the individual bosons. The bosons form an integrated and strongly correlated entity, analogous to an army troop, assuming collective ordered motion, coordinated by the order parameter. Breaking of the U (1) symmetry and BE condensation takes place because of the BE quantum phase correlation between the wave functions of the bosons, which, in the case of chargeless bosons is very strong. Particles in phase coherent states have lower energy than in incoherent states. This is also true in the case of fermions, however ruled by the Pauli Exclusion Principle.

At low temperatures, the frequency of decoherent scatterings of the particles decreases, the wave-packets or wave functions of the individual particles expand and overlapping of the particle wave functions becomes important. At sufficiently low temperatures the BE phase correlation eventually overcomes the thermal fluctuations, when the boson system can lower its energy by spontaneously breaking the $U(1)$ symmetry and condensing into a long-range phase coherent ground state, liberating the corresponding energy difference. In this coherence transition the wave-functions of the bosons assume all the same phase (θ_0 say), constituting a macroscopic quantum phase coherent state, in which however low energy (long wavelengths) phase fluctuations still are possible. On condensing, all the bosons become entangled and indistinguishable. The particles continuously tunnel throughout the volume of the condensate, which entails a high degree of spatial homogeneity throughout the volume of the condensate. In the case of the Higgs condensate, this homogeneity extends throughout the universe.

Bose-Einstein condensation is a second order phase transition. Second order phase transitions involve no latent heat. The condensation however liberates energy gradually down to absolute zero temperature. Nevertheless, the temperature can fall only in the measure the energy that is liberated by condensation, is removed by some dissipation mechanism. In the condensation of the usual superfluids and superconducting condensates, the small amounts of energy, liberated during the condensation, is removed by very efficient cryogenics. Insufficient dissipation of the condensation energy necessarily slows down the condensation rate.

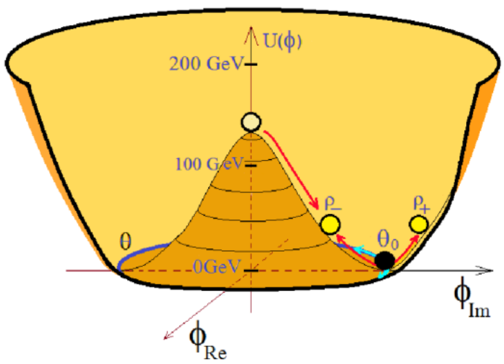
Many of the dynamical properties of the Higgs condensate are totally analogous to those of the superconducting condensate (SCC). Likewise the SCC, the Higgs condensate too can be described by a complex macroscopic Ginsburg-Landau like [15] order parameter $\Phi\ (\mathrm{r},\theta) = \phi(\boldsymbol{r})\mathrm{e}^{\mathrm{i}\theta}$ where $\phi(\mathbf{r})$ is the amplitude and $e^{\mathrm{i}\theta}$ is the phase factor. However, instead of the two components of the SCC, the Higgs condensate has four components, two have spin “1” and opposite electric charges, the other two components are chargeless, one of them has spin “1”, the other has spin “zero”. $\Phi\ (r, \theta_0) = \phi(\mathbf{r})e^{\mathrm{i}\theta 0}$ represents the resting condition (ground state) of the condensate and $\rho = \Phi^*\Phi$ is the local condensate density, where $\Phi^*\Phi\ \mathrm{d}V = \langle n_\mathrm{b}\rangle$ is the local volumetric particle density. In the case of the Higgs condensate, this condensate density distributes it very homogeneously throughout the volume of the condensate and $|\phi(\mathrm{r})|^2$ is essentially constant throughout the universe.

Analogously as in superconductivity, the BE phase correlation between the wave functions of the Higgs particles gives rise to a *negative* potential energy (bonding) term, the value of which increases linearly with the condensate density $\rho = \Phi^*\Phi$. Another positive potential energy (anti-bonding) term arises from repulsive core interaction between the bosons that increases with the squared density $\Phi^*\Phi^{\ 2}$ and prevents collapse of the system. The effective potential is:

$$V(\rho) = -n(\Phi^*\Phi) + m(\Phi^*\Phi)^2 \tag{5}$$

where however the negative coefficient (-*n*) of the bonding term is considerably larger than the positive coefficient (*m*) of the anti-bonding term. Therefore the minimum of the effective potential occurs not for $\Phi^*\Phi = 0$, as would be usual, however for a finite value $\Phi^*\Phi = n/m$. This value is known as a non-zero vacuum-expectation-value, which here is homogeneous throughout the volume of the condensate.

The first term in the right hand side of Eq. (5) is created by the BE phase correlation leading to the spontaneous breakdown of the *U* (1) symmetry of the bosons. This breakdown however preserves the gauge symmetry of the Lagrangian of the system. The deepness of the potential well depends on the strength of the BE correlation between the bosons and on the phase correlation length and hence on the density of particles. The second term in the right hand side of Eq. (5) is the usual parabolic potential energy of interacting particles. The fact that the phase of the condensate (θ_0) can take any value between zero and 2π, without changing the energy, proves that the gauge symmetry of the Lagrangian has been preserved during the spontaneous braking of the *U* (1) symmetry and condensation. The Higgs potential energy well is symmetric about Φ = 0 and thus has the form of a Mexican sombrero as a function of the complex components Φ_{Re} and Φ_{Im} (please see Fig. 1).



Caption: Characteristic Potential Well of Bose-Einstein Condensates: The figure depicts locally the form of the Mexican sombrero potential in terms of the Real and the Imaginary components of the order parameter, where the energy scale is for the Higgs condensate. Most importantly, the deepness of the energy well is exactly the same throughout the universe. A red arrow indicates the transition toward the lower energy phase coherent state with the well-defined phase θ_0. The figure also indicates the low volumetric density (ρ_-) and the high volumetric density (ρ_+) situations. While ρ_- drives accelerating contraction, ρ_+ drives accelerating expansion of the condensate. This is related with the Higgs mode. The global Goldstone mode is indicated along the blue bottom circle.

The deepness of the potential well in the case of the superconducting condensate (SCC) is in the order of only one meV. However, in the Glashow-Weinberg-Salam electroweak model, the energy gap between the unbroken and the spontaneously broken electroweak symmetry is in the order of 200 GeV. This is the deepness of the Higgs potential well. It is an enormous energy gap that strongly suppresses the local fluctuations and the zero-point energy of the vacuum (HQS). Because of this very strong suppression of quantum fluctuations and of the zero-point energy, conceiving empty space in terms of a perfect classical fluid and estimating the vacuum energy density in terms of the zero-point energy of independent oscillators certainly is inadequate. Due to this suppression, the contribution of the quantum fluctuations and of zero-point energies to the vacuum energy must be irrelevant. This will not say that local excitations in the HQS are impossible. They however involve very large energies, in the order of MeVs.

2.3. The Higgs Condensate and the Origin of the Inertial Mass

The physical properties of the HQS are closely analogous to those of the superconducting condensate (SCC). To every effect in superconductivity, there is an analog of the HQS. In particular, the Higgs mechanism is the perfect HQS analog of the Meissner effect [16] in superconductivity. By the

Meissner effect the SCC confines an applied magnetic field and gives inertial mass to the photons within superconductors. The first clue that coupling of a field to a quantum condensate results in confinement of the field and generates mass terms for that confined field was discovered in superconductivity by Anderson. [17] Gauge transformations of the superconducting order parameter, in the presence of an applied magnetic field, give rise to inertial mass terms. This is not at all magic, but the result of testing the mobility of the confined field. Changing the phase of the order parameter costs energy and means changing locally the velocity of the superconducting condensate (SCC). Uniform velocity of a photon, within a superconductor, involves only the persistent dynamics (propagation), which the superconducting order parameter naturally supports. However, acceleration depends on changes of the wave structure of the photons that involves increase (or decrease) of the local phase gradients and hence acceleration of the SCC. The superconducting order parameter offers resistance against such changes, because they involve local changes of momentum and of the energy of the SCC. The development of the Higgs theory and of the Higgs mechanism has extensively been guided by the Meissner effect in superconductivity. This is not a surprise. It is obvious from the fact that both the SCC and the HQS are quantum condensates of bosons, governed by analogous complex order parameters. The fact that these condensates are formed by different bosons has the consequence that they couple to different fields. While the SCC couples only to the electromagnetic field, the Higgs condensate couples only to the weak and strong nuclear fields.

As affirmed above, the electroweak symmetry break-down gave rise to four components, from which two have opposite charges "one" and opposite spins "one" and the other two are chargeless, one with spin "one", the other with spin "zero". The two charged components together with the chargeless component with spin one polarize the weak field giving mass to the W^+ W^- and Z^0 vector bosons of the weak interaction by the Higgs mechanism. The free chargeless and spin zero fourth component (Higgs condensate), present throughout the universe, confines the quarks and leptons, giving them mass by a Yukawa like coupling and thereby giving mass to the baryons, masons and leptons. Breaking of the electroweak symmetry and condensation of the Higgs field is believed to have initiated closely after the big-bang, as the temperature of the universe fell through 10^{15} K.

By giving mass to the elementary particles, the Higgs mechanism gives them mechanical properties. This lets clear that the HQS effectively governs the inertial motion of matter-energy and hence is locally their ultimate reference for rest and for motion. The HQS is an extremely powerful spatial medium in which the visible matter-energy is not more than foam of propagating perturbations. Without the Higgs mechanism, the particles would have no mechanical properties and the world, as we know it, would be completely impossible.

If the HQS itself moves in the ordinary space, matter, stationary with respect to the ordinary space coordinates, necessarily will be moving with respect to the local HQS. This motion is implicit, because it cannot be described in the ordinary space. If the HQS moves non-uniformly, it generates inertial dynamics, which, after Einstein's equivalence of gravitational and inertial effects, is gravitational dynamics. In Refs.[14] it is shown that motion of the HQS round earth and round the sun according to Keplerian velocity fields, consistent with the local astronomical motions, accurately creates the observed gravitational dynamics on earth, in the solar system, in the galaxy etc., as well as all the effects of the gravitational fields on the propagation of light and the rate of clocks.

2.4. The driving Force Accelerating the Expansion of the Universe

On condensing into the Higgs potential well, the Higgs particles liberate an enormous amount of energy. This however will not say that anything new is created from nothing during this condensation. As Stephen Hawking says, in order to create a mountain, it is enough to excavate a big hole. On condensing, the bosons fall into the negative energy ground state, liberating the corresponding energy difference. However, the condensation can go on only in the measure the energy density and the temperature of the universe fall.

As the Higgs condensate (HC) occupies the whole of space, there is no external world and no physical mechanism able to remove and absorb the very huge amount of condensation energy. Hence, the condensation necessarily is an adiabatic process, analogously as the condensation of clouds, during the ascension and adiabatic expansion of warm and humid air, however in the absence of an external pressure. In this free adiabatic expansion, the total energy must be conserved. The only way to lower the *energy density* and the temperature of the HC is by volumetric expansion. This expansion stretches the wavelengths λ of the particles and of radiation as a function of time, thereby reducing the energy of the particles and of radiation with respect to the local HQS. The particles lose momentum $\boldsymbol{p}$ according to the de Broglie equation ($\boldsymbol{p} = \mathbf{h}/\boldsymbol{\lambda}$) and the radiation lowers the frequency as is well known from the cosmic microwave background radiation. This energy must be stored in the form of macroscopic kinetic energy of the expanding universe.

However, besides this, the presence of the ordinary (fermion) matter in the universe represents a source of persistent phase perturbation and phase disorder of the Higgs order parameter that brake the advance of the HC toward the fully broken $U(1)$ symmetry and to the minimum of energy in the Higgs potential well Fig.1. The actual low temperature of the universe, of about 2.7 K, indicates that the universe lies deeply, near to the bottom of the Higgs potential well. On the other hand, the fact that the Higgs potential well in Fig.1 is created by an intrinsically homogeneous quantum condensate assures that the deepness of the energy well and the residual energy density and temperature of the condensate is closely the same throughout the universe. Stars and galaxies of fermion matter however represent local energy spikes in the uniform low temperature, where they hold back the condensation.

Current theories usually impute the accelerating expansion of the universe to dark energy, the nature of which is a mystery. They generically describe the vacuum in terms of the stress-energy tensor of a perfect fluid. This approach is not totally wrong. Quantum fluids too are frictionless and perfectly conservative. What is wrong is estimating vacuum energy from the perspective of particle physics in terms of the zero-point energy of local independent quantum fluctuations. From this perspective, the vacuum energy density does not fall with the expansion. Therefore, expansion of the universe creates energy, increasing the total energy of the universe, what leads to the odd negative pressure.

From the perspective of the Higgs Quantum Space (HQS), the procedure of particle physics certainly is inadequate, because the HQS, governing the motion of matter-energy and underlying the dynamics of the universe, is not simply a perfect classical fluid, however a quantum fluid. The properties of quantum fluids (quantum condensates) are fundamentally different from classical perfect fluids, as explained above. In the current theories, it usually is claimed that the observed Casimir effect and the Lamb shift of the Hydrogen energy levels, predicted by Quantum Electrodynamics corroborate the rightness of the method of estimating the vacuum energy density in terms of the zero-point energy. However, these effects are due to fluctuations of the electromagnetic (EM) field, that has its $U(1)$ symmetry preserved. The EM field is not a quantum condensate and is not ruled by an order parameter. Moreover, its contribution to the vacuum energy density is very low.

A quantum condensate is an integrated entity, with spontaneously broken U (1) symmetry and ruled by an order parameter that strongly suppresses diffuse motions of particles and local quantum fluctuations. Quantum fluids react collectively to an interacting field, which turns it able to confine and expel the interacting field, thereby reducing the energy of the condensate. A quantum condensate is like an army troop, where any attack will have the response of the whole troop. Moreover, in its ground state, *the quantum condensate behaves wholly as one unique oscillator*, which, in the case of the HQS (Higgs modes), means wave-lengths tending to the infinite and zero frequency. Only very high energies, in the order of MeV, can excite local (Goldstone) modes, which however automatically become real and persistent (non-virtual) and are not zero-point quantum fluctuations.

Any local displacement of the phase of the Higgs order parameter within a small spatial volume of the HQS, with respect to the overall phase θ_0 of the order parameter, costs large amounts of energy, because it must conquer with the local strong phase correlation and rise the energy of the Higgs condensate in the potential energy well. However, once excited, the excitations automatically become persistent, because the resistance of the quantum condensate against phase changes is transient. The quantum condensate is 100% conservative and resists to every new change of the phase.

3. DARK ENERGY, VACUUM ENERGY AND THE COSMOLOGICAL CONSTANT

Astrophysical observations demonstrate that actually the expansion of the universe is accelerating. Evidence of this accelerated expansion has been found independently from measurements of supernovae of type Ia [8,9] as well as from the cosmic microwave background radiation [10]. In the Robertson-Walker universe, empty spacetime usually is modeled in terms of the four-dimensional stress-energy-momentum tensor ($T_{\mu\nu}$) of a homogeneous isotropic perfect fluid, (please see Eq. (2)).

In the absence of ordinary mass-energy (empty space or vacuum), the stress-energy tensor reduces to the fourth component T_{00}, which is interpreted as a positive vacuum energy density ρ_V. From the perspective of particle physics, the energy density of this vacuum does not decrease with the expansion of the universe. Hence, the expansion of the universe creates energy, increasing the total energy of the universe. This leads to the odd negative pressure *p*. Usually, within this view, the energy density is assumed to obey the equation of state:

$$p = w\rho_V \tag{6}$$

in which $w \sim -1$. Estimates of the vacuum energy density from the perspective of particle physics come to the odd value that is 120 decimal orders of magnitude larger than shown by experimental observations. Now, after more than half a century of theoretical and experimental efforts, within this view, the nature of dark energy continues a true mystery.

The presence of a vacuum energy density, accelerating the expansion of the universe, is actually a well established observational fact. The consensus among the cosmologists is that this dark energy is not ordinary mass-energy, however is energy of space (vacuum) itself. It also is consensus that the energy of the vacuum distributes it very homogeneously throughout the universe and interacts with ordinary matter-energy only by gravity. These conclusions, although plausible from the viewpoint of the observations, are stated without indicating the physical background, able to give rise to these features. The goal of the present work is showing that all these features arise naturally and appropriately within the scenario of the global Higgs Quantum Space (HQS) dynamics.

3.1. The Accelerating Expansion of the Universe and the Accelerated Expansion of the HQS

Visibly the universe is self-contained and has no outside. The expansion of the universe necessarily is an adiabatic process, in which the total energy must be conserved. According to the Glashow-Weinberg-Salam electroweak model, the energy gap between the unbroken and the broken electroweak symmetry is in the order of 200 GeV. From the perspective of the Higgs theory, the total energy *U* of the universe is given by the equation:

$$U = \int_{V(t)} \rho_v(t)\,dV = \rho_v(t)\int_{V(t)} dV = \rho_v(t)V(t) = \text{Constant} \tag{7}$$

In Eq.(7), *V*(t) is the total volume of the universe as a function of time, ρ_V(t) is the time dependent vacuum energy density that is uniform over the volume of the universe and $200\times V_0$ GeV is the total initial energy of the universe at the epoch of the electroweak break-down, which must be conserved.

If the universe is an adiabatic system, the only way to it lower its energy density is by volumetric expansion. As far as observations show, the three-dimensional universe has no boundary and no barriers and thus the expansion is free and necessarily is accelerated (potential energy converts into kinetic energy). The process is analogous to the expansion of warm and humid air in the formation of clouds, however in the absence of an external pressure. Expansion of the HQS stretches the wave-lengths λ of the particles and of radiation. This expansion reduces the frequency of the radiation as is well known from the red-shifted cosmic microwave background radiation and also reduces the momentum of the particles according to de Broglie's equation $\boldsymbol{p} = h/\lambda$ and correspondingly their kinetic energy. This reduces the temperature of the universe. It also explains why all the astronomical bodies throughout the universe are actually very nearly stationary with respect to the local moving HQS as shown by the recent experimental observations, achieved with the help of the tightly synchronized atomic clocks in orbit [18,19] as well as by the null results of the light anisotropy experiments. Please see details in Ref.[14,20]. However, during the gravitational agglomeration into astronomical bodies, the averaging down of the velocity of the randomly moving particles, contributes importantly to the slowing down of the velocity and kinetic energy of matter with respect to the local HQS and thereby heating up these astronomical bodies.

Actually the Higgs condensate (HC) and the matter-energy universe lie deeply within the Higgs potential energy well Eq. (5) (see also Fig.1). The energy of the Higgs condensate (HC) is not usual mass-energy. It is energy of the HQS itself (space), energy of the vacuum. The energy of the HC, within the Higgs potential well, depends on the volumetric density $\rho = |\phi|^2$. If $\rho >$ n/m or $\rho <$ n/m, the energy of the HC is not minimum. If $\rho >$ n/m, it can lower its energy by accelerated adiabatic expansion. Actually, observations show that the expansion of the universe is accelerating. This indicates that ρ > n/m. However, if ρ < n/m, the HC also can lower its energy by contracting (please see Fig.1). This makes it possible to the universe to cycle between periods of expansion and of contraction. The Higgs potential well in Eq. (5) is generic to each point of space and its depths and, consequently, the energy density and temperature is the same throughout the universe, which can explain the flatness and the horizon problem of cosmology.

In the scenario of the HQS, modeling the vacuum energy in terms of the zero-point energy of independent local quantum fluctuations certainly is inadequate, because dynamically the HC is quite different from a perfect fluid. Superfluids and superconductors, as well as the HQS are strongly correlated systems with spontaneously broken *U* (1) symmetry. *The motion of such condensates is ruled by a complex order parameter* $\Phi = \phi\, e^{i\theta}$. The strong BE phase correlations, leading to condensation into a long-range phase coherent Higgs condensate and generating a large energy gap, strongly suppresses local quantum fluctuations and their corresponding zero-point energy. All excitations are intrinsically quantized and persistent. This enables a quantum fluid to confine a perturbing field, generating inertial mass terms for it or expelling it out from the quantum fluid. This reduces the energy of the condensate. *Due to the phase rigidity of the order parameter, a quantum condensate behaves wholly as one unique oscillator.* Quantum condensates constitute an integrated entity, where the particle wave functions are totally entangled and the particles are indistinguishable and act collectively by the order parameter. Any interaction with a quantum condensate always affects all the particles of the condensate through the order parameter. Quantum condensates are like an army troupe, where any attack always affects the whole group and will have the response of the whole troupe.

The potential well of the Higgs condensate in Fig.1 is represented in terms of the amplitudes of the real and imaginary components of the order parameter. The form of this potential well, in the case of the HQS, is generic to each point of space and its deepness necessarily is the same throughout the universe. It is analogous to the electrostatic potential well of an infinite homogeneous superconducting metal (*Nb*) piece at very low temperature, where the potential well extends and has the same depth throughout the whole piece. In the case of the Higgs condensate, the potential well has the size of the universe. This will say that only zero-point quantum oscillations with infinitely long wave-lengths are possible. This lets clear that the energy contribution of the zero-point oscillations (vacuum fluctuations) to the vacuum energy density in the HQS are irrelevant.

In the scenario of the HQS, the deepness of the Higgs potential well in the Glashow-Weinberg-Salam electroweak model is fixed (200 GeV). However, actually the HC together with the matter-energy universe, lies deeply within the Higgs potential well Eq. (5), though still not at the bottom. This is not effectively minimum energy density of the HC. The matter fields (weak and strong nuclear fields) perturbing the phase of the Higgs order parameter, hold back its advance toward the minimum of energy. The situation is analogous to that of the superconducting condensate (SCC) in a superconductor at very low temperature under an applied magnetic field. The phase perturbations of the superconducting order parameter by the magnetic field too hold back the advance of the SCC toward its true minimum of energy.

To parameterize the vacuum energy density (effective energy density of the HC) in terms of the volume of the universe is difficult, because the size of the universe in the epoch of the electroweak symmetry break-down is not well known. The temperature of the universe however is a better parameter. Cosmologists believe that the electroweak symmetry break-down initiated closely after the big-bang, between 10^{15} and 10^{12} K. On from this epoch, condensation of the HC was going on while the temperature lowered to the actual 2.7 K, which is well known from the cosmic-microwave-background radiation. However, taking into account the high temperatures within and in the neighborhood of the stars and galaxies, the actual average temperature of the universe certainly is somewhat higher than 2.7 K. Perhaps 100 K is a good guess. From this viewpoint, the energy density of the vacuum fell from the initial 200 GeV to the actual ~20 eV:

$$200 \text{ GeV} \times 10^{2}/10^{12} \sim 20 \text{ eV} \sim 10^{-10} \text{ ergs/cm}^3 \qquad (8)$$

This result is equivalent to about 10^{-29} g/cm^3. However, although this energy and mass density is very low, it distributes it uniformly over the entire universe, so that integrating it over the whole universe, the total vacuum energy (dark energy) is in the order of 14 times larger than that of the whole visible matter-energy in the universe concentrated in the astronomical bodies. On the other hand, the well known relation between the vacuum energy density ρ_v and the cosmological constant Λ is:

$$\Lambda = (8\pi G\rho_v)/c^2 \sim 10^{-35}\ \text{cm}^{-2} \qquad (9)$$

where G is the gravitational constant and c is the velocity of light.

It is important to emphasize the fundamental difference between the present approach of the HQS and the approach of particle physics. While, in the approach of the particle physics, expansion of the universe creates energy, in the present HQS approach expansion only lowers the energy density. The total energy of the universe is conserved. This eliminates the need of the odd negative pressure in the universe.

The actual small residual vacuum energy density consists of two parts: The condensation energy that still has not decayed, because the temperature of the universe is not absolute zero (bare cosmological constant) and the other major part, which is the energy density that is hold back by the phase perturbations of the Higgs order parameter, caused by the presence of the ordinary matter-energy in the universe. These phase perturbations are a macroscopic manifestation of the Higgs mechanism, underlying the gravitational dynamics and the confinement of the ordinary matter fields (please see Ref.14 for details).

The present estimate of the vacuum energy density, while giving values in close agreement with the observations, also solves the intriguing coincidence problem of cosmology. Why are actually the values of the vacuum energy and of the visible ordinary matter-energy so closely similar? According to the present work, the phase perturbation of the Higgs order parameter by the ordinary (visible) matter-energy in the universe is responsible for the major part of the residual vacuum energy density. This explains why actually the total vacuum energy and the total visible matter energy are so closely equal. On the other hand, the only relationship of the HQS, with ordinary matter-energy, is giving mass and ruling the inertial motion of the elementary particles. This will say that the only way of the HQS-dynamics (vacuum energy) to affect the motion of ordinary matter-energy is by inertial effects, which after Einstein's equivalence of gravitational and inertial effects are gravitational effects.

In conclusion, dark energy is not ordinary mass-energy, but is energy of the HQS itself, energy of the vacuum. The total vacuum energy is closely similar to the total visible matter-energy, because it is dominantly the visible matter-energy that holds back the Higgs condensate from its minimum of energy. As the HQS is a quantum fluid and pervades all of space, this energy necessarily distributes it very homogeneously throughout the universe. Moreover, the HQS, ruling the inertial motion of matter-energy, interacts with ordinary matter-energy only by inertial effects, which, according to Einstein's Equivalence Principle, are gravitational effects. This shows that the HQS-dynamics naturally meets all the characteristic properties of dark energy that are consensual among the cosmologists. It however entails a fundamental additional feature: The accelerating expansion of the universe perfectly keeps to the accelerated expansion of the HQS itself (please see below).

3.2. Experimental Evidence that the Accelerating Expansion of the Universe Keeps to the Accelerating Expansion of the HQS Itself

Clocks, stationary within gravitational fields, are well known to show exactly the gravitational slowing predicted by GR. However, the GPS clocks moving with earth round the sun show no sign of the gravitational slowing, predicted by GR due to the solar field,[18,19] which frontally contradicts GR. This observation, together with the null results of the Michelson light anisotropy experiments, demonstrates that the HQS, ruling the motion of matter-energy, is circulating round earth, round the sun and round every astronomical body throughout the universe, according to Keplerian velocity field, consistent with the local main astronomical motions. The Keplerian velocity field of the HQS is the quintessence of the gravitational fields and is shown in Refs.[14,20] to accurately create the observed gravitational dynamics on earth, in the solar system and within the galaxies, *without the need of dark matter*. It also produces correctly all the observed effects of the gravitational fields on light and on clocks. In the Keplerian velocity field of the sun, earth and all the other planets are closely stationary with respect to the local moving HQS. They are simply carried round the sun by the solar Keplerian velocity field of the HQS. Moreover, the solar system is stationary with respect to the local HQS and carried around by the velocity field of the HQS, creating the gravitational dynamics of the Milky Way galaxy. The observed absence of the gravitational slowing of the GPS clocks by the solar field and the isotropy of light with respect to earth are the obvious signature of the physical mechanism of gravity in action.

However, while the local HQS-dynamics round the sun and round the galactic center properly explains the isotropy of light with respect to earth, it cannot explain why the recession between the galaxies causes no light anisotropy. An appropriate explanation of the accelerated expansion of the universe can of course not run into conflict with the null results of the Michelson light anisotropy experiments. The fact that the velocity of light is isotropic with respect to earth, despite its motion in the solar system and despite the motion of the solar system in the Milky-Way galaxy and also in spite of the relative motion and recession between the galaxies, demonstrates that these relative motions as well as the accelerated recession between the galaxies too let earth stationary with respect to the local moving HQS. Despite the accelerated expansion of the universe, our Milky-Way galaxy remains stationary with respect to the local HQS. It certainly would not be reasonable to assume that our galaxy is in a privileged kinematic circumstance with respect to the HQS in detriment to all the remainder galaxies in the universe. All the galaxies must equally be closely stationary with respect to the local moving HQS. These facts inexorably entail the conclusion that the HQS, ruling the inertial motion of matter and propagating light, besides moving round earth, round the sun and round the Milky-Way galaxy, according to velocity fields, consistent with the local main astronomical motions and thereby creating the observed gravitational dynamics, also is expanding consistently with the recession between the galaxies.

Clearly the Hubble spectral red-shift of light from distant galaxies and the red-shift of the cosmic microwave background radiation, are not usual Doppler shifts, but are due to the time-rate of stretching of the wavelength, due to the expansion of the HQS, which is their medium of propagation and their ultimate reference for rest and for motions. It is easy to show that this stretching, as a function of time, causes exactly the same red-shift as the usual Doppler shift, due to conventional recession. It also stretches the wavelength of the particles, thereby reducing their velocity and kinetic energy with respect to the local HQS, according to the de Broglie equation ($\boldsymbol{p}$=h/$\boldsymbol{\lambda}$). The velocity of oppositely moving matter bodies is moreover averaged down and converted into heat during the gravitational agglomeration into the large astronomical bodies. These facts conclusively explain why the velocity of all the large astronomical bodies with respect to the local HQS is actually so small throughout the universe, as shown by the recent experimental observations.

In summary, the HQS, ruling the inertial motion of matter and the propagation of light, is circulating round earth, round the sun and round the galactic center, consistently with the local main astronomical motions. This is the quintessence of the gravitational fields. In the local HQS-dynamics round the sun and round the galactic center, earth is very closely stationary with respect to the local moving HQS, so that the orbital motion of earth and the motion of the solar system within the galaxy cause no relevant light anisotropy with respect to earth. The observed absence of the gravitational slowing of the GPS clocks by the solar field perfectly corroborates this conclusion. The null results of the light anisotropy experiments however demonstrate in addition that the accelerating expansion of the universe too lets earth, the solar system and the Milky-Way galaxy and all the other galaxies stationary with respect to the local HQS. This concomitant expansion of the HQS and of the matter universe ultimately explains the observed isotropy of light with respect to earth and shows that the accelerated expansion of the visible universe keeps to the accelerating expansion of the HQS itself. The fact that all the astronomical bodies throughout the universe are very closely stationary with respect to the local HQS, also predicts the universality of the laws of physics. Clocks, moving together with the natural astronomical bodies, run all very nearly synchronous and show all the universal proper time throughout the universe.

4. CONCLUSIONS

From the perspective of the Higgs Quantum Space (HQS) that forms the background of the universe, the vacuum energy density cannot be evaluated in terms of the usual zero-point energy of independent oscillators, because the Higgs quantum space is a very strongly correlated quantum fluid of condensed bosons with broken U (1) symmetry and *ruled by an order parameter*. This condensate has a large energy gap that strongly suppresses diffuse motions of individual particles as well as all local quantum fluctuations and zero-point energy. Therefore, the contribution of zero-point oscillations to the vacuum energy is completely irrelevant. The universe is an adiabatic system, which, on expanding, conserves its total energy. The only way of the universe reducing its energy density and temperature is by adiabatic expansion. Experimental observations demonstrate that, in this expansion, the visible universe keeps to the accelerated expansion of the HQS itself. The expansion of the HQS stretches the wave-lengths of the particles and of radiation, thereby reducing their energy and lowering the temperature from the initial $\sim10^{12}$ K to the final average temperature of about ~100 K. Parameterizing the energy density of the vacuum in terms of the temperature, gives very closely the actually observed vacuum energy density of about 10^{-10} erg/cm^3. The fact that this residual energy is mostly due to the phase disorder created by the presence of the ordinary mass-energy, holding back the advance of the Higgs condensate toward the minimum of energy, explains the actual coincidence between the total vacuum energy and of the total visible matter-energy.

REFERENCES

[1] M. v. Laue, Annalen der Physik, "Die Spezielle Relativitätstheorie", **68**, 1956.

[2] H. A. Lorentz, A. Einstein, H. Minkowski, and H. Weyl, "The Principle of Relativity", New York, Dover Publications (1923).

[3] A. Friedmann, "Über die Möglichkeit einer Welt mit konstanter negativer Krümmung des Raumes", Z. Phys. **21**, 326.(1924).

[4] H.P. Robertson, "Kinematics and World-Structure III", Astroph J. **83** 257, (1936).

[5] A.G. Walker, "On Milne's Theory of World-Structure", Proc. of the London Math. Soc. **42** (2), 90 (1937).

[6] S.M. Carrol, "Determination of Dark Energy and Dark Matter from the values of Redshift for the present time, Planck and Trans-Planck epochs of the Big-Bang model", arXiv: astro-ph/0004075v 28 Apr 2000.

[7] J. Solà, "Cosmological constant and vacuum energy: old and new ideas", arXiv:1306.1527v3 [gr-qc] 21 Jul 2013.

[8] A. Riess et al., "Observational evidence from supernovae for an accelerating universe and a cosmological constant", Astron Journal, **116**, 1009 (1998).

[9] S. Perlmutter et al., "Measurements of Ω and Λ from 42 high-redshift supernovae" Astroph. Jour., **517**, 565 (1999).

[10] F.S.N. Lobo, "Stable dark energy stars", Class. Quant. Grav., **23**, 1525 (2006).

[11] P. W. Higgs, "Broken Symmetries and the Masses of Gauge Bosons" Phys. Rev. Lett. **13** (16), 508 (1964).

[12] F. Englert and R. Brout, "Broken symmetry and the mass of gauge vector mesons." Phys. Rev. Lett. **13**, 321, (1964).

[13] T. W. B. Kibble, "Englert-Brout-Higgs-Guralnik-Hagen-Kibble mechanism", Scholarpedia, **4** (1), 8741, (2009).

[14] J. Schaf, "Gravitation, Dark Matter and Dark Energy: The Real Universe", Accepted for publication in the Journal of Modern Physics, February/2017 issue.

[15] L. Ginzburg and L. D. Landau, "To the Theory of Superconductivity" J. of Exp. and Th. Phys. (JETP), **20**, 1064 (1950).

[16] W. Meissner and R. Ochsenfeld, "Ein neuer effekt bei eintritt der supraleitfähigkeit", Naturwissenschaften **21** 787 (1933).

[17] P.W. Anderson, "Plasmons, gauge invariance, and mass", Phys. Rev. **130**, 439 (1963).

[18] R.R. Hatch, "Those Scandalous Clocks" GPS Solutions **8**, 67 (2004).

[19] R.R. Hatch, "Clocks and the Equivalence Principle" Found. of Phys., **34**, 1725 (2004).

[20] J. Schaf, "The Higgs Quantum Space Dynamnics Generating the Gravitational Dynamics in the Universe.", Universal Journal of Physics and Applications, **9**, 141, 2015.