Hydrodynamics of the dark superfluid: II. photon-phonon analogy

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Abstract In "Hydrodynamics of the dark superfluid: I. genesis of fundamental particles" we have presented dark energy as an ubiquitous superfluid which fills the universe. Here we analyze light propagation through this "dark superfluid" (which also dark matter would be a hydrodynamic manifestation of) by considering a photon-phonon analogy, where photon is a quasi-particle which acoustically propagates through this dark superfluid as a transverse wave. The discussion is structured in four parts: (a) shared features and behavior photon-phonon according to current knowledge; (b) phonons in fluids and their role in expressing energy, along with the transient solid-like (quasi-lattice) structure arising in fluids and superfluids during relaxation time; (c) Gremaud's analogy of Maxwell's equations in a lattice applied to the quasi-lattice environment of a superfluid; (d) Lorentz factor as the rheogram of dark energy and a possible basis for a quantum interpretation of special relativity. Considering light as the acoustic excitation of the dark superfluid, in a subsequent investigation[1] we have been able to obtain the right redshift curve, also for distant supernovae, in function of the varying density of the cosmic superfluid, freeing modern cosmology from known critical issues: an important clue as regards the applicability of the present hypothesis.

Keywords Nature of light · Light propagation · Dark energy · Dark superfluid · Maxwell's equations · Special relativity

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Introduction

We know that light propagates through a *quantum* vacuum but also through dark energy, since according to recent measurings it constitutes 69.1% of the universe mass-energy, which along with dark matter reaches 95%. The remaining 5% baryon matter is in any case $>99\%$ vacuum. We have already discussed the possibility that quantum vacuum be a hydrodynamic manifestation of the dark superfluid (DS), [1] which may correspond to mainly dark energy with superfluid properties, as a cosmic Bose-Einstein condensate [3,2,5–9,15]. Dark energy would confer on space the features of a superfluid quantum space. Taking into account light propagation through the DS, a photon could be either a real particle behaving as a wave or a quasi-particle possessing wave-particle duality as a phonon. We opt for the second case and we discuss photon propagation through the DS via a transverse phonon-like dynamics (arguing that light is *the sound of the DS*) and we support this hypothesis in four steps. We reflect (Sect. 1) on an interestingly wide set of currently known analogies, also valid for fluids and superfluids, between phonons and photons and in Sect. 2, referring to Bolmatov [16], we discuss transversal wave propagation and heat transmission in fluids on acoustic basis (phonons), in analogy with thermal photons. From Gremaud (Sect. 3) [27] we resort to a complete analogy between Maxwell's equations for electromagnetism and non-divergent deformations of an isotropic lattice in Euler's coordinates, translated in our case into the quasi-lattice structure of fluids which manifests within their relaxation time, a structural property which has been discussed also for superfluid ^{4}He [41]. Finally (Sect. 4), arguing a possible dilatant behavior of some superfluids under shear stress in a relativistic regime, we present Lorentz factor as the rheogram of dark energy, opening a perspective onto the explanation of special relativity on a quantum basis and reinforcing the concept of transverse propagation of phonons in the DS. As a consequence, we understand that the main component of the DS, dark energy, would be undetectable only as long as it remains unperturbed, being light its most evident manifestation, along with its famous repulsive action which avoids the gravitational collapse of the universe, probably due to its internal pressure as a superfluid. Its energy density corresponds in fact to pressure ($\mathrm{J/m^3} \Rightarrow \mathrm{Pa}$).

1 Current photon-phonon analogies.

Let us start with listing all current analogies between photons and phonons (which can also manifest in superfluids [18,28]). Both are bosons [19], since identical excitations can be created by repeatedly applying the creation operator, $b^{\dagger}$; both possess wave-particle duality [20,21], indeed in a lattice, or quasi-lattice we expect that waves appear that behave like particles; they obey the doppler effect, $z = (f_{emit} - f_{obs})/f_{obs}$; are symmetric under exchange, $|\alpha,\beta\rangle = |\beta,\alpha\rangle$; possess a momentum, where that of a phonon[2] is $p_{ph} \equiv \hbar k = h/\lambda$, with $k = 2\pi/\lambda$ (hence the parallelism: radiation pressure $\Leftrightarrow$ sound pressure); are involved in photoelectric effect and Compton scattering thanks to their momentum; they can spin [22,23]. As far as spin is concerned, it would be realistic in our opinion that the higher degree of freedom of a phonon in the quasi-lattice of a fluid medium, may allow it to possess spin 1. For this reason we consider the photon as a special spin-1 phonon. Rotating phonons have been described also as regards the physics of nanotubes [24]). Moreover, we actually know that photon spin can have three different values (-1, 0, 1), so, at most, magnitude 1. Photon and phonon can form squeezed coherent states [25] and can interact via parametric down conversion [26]. For both, $\hbar\omega/2$ is vacuum's (we say dark energy's) contribution, since the harmonic oscillator eigenvalues for the mode ω_k (k is the wave number) are $E_n = (n+1/2)\hbar\omega_k$ with $n = 1,2,3,\ldots$ and (to confirm the presence of a "false vacuum") also for $n = 0$ the energy is not zero. This means that what we think to be the vacuum actually contains energy and according to $E = mc^2$, a certain density (ρ_0 in the cosmological constant $\lambda = k\rho_0$), where $c^2 = (\beta_d\rho_d)^{-1}$ would be precisely linked to dark energy's intrinsic parameters, as from Eq. (1). There is a medium throughout the universe owning density $\rho \neq 0$ which light propagates through and which can be described as a dark superfluid.

1.1 The formula for the speed of light.

It is worth recalling the fact that Maxwell derived the dielectric constant (ε_0) and the magnetic permeability (μ_0) of "vacuum", from which the formula $c = 1/\sqrt{\varepsilon_0\mu_0}$ follows, in terms of density and transverse elasticity of the ether (see Sect. 3, [27]). We excluded the existence of the ether but we still need a "quantum vacuum". Thus, if we now considered the old ether to be the modern dark energy, whose existence is on the contrary accepted, and we equate $\varepsilon_0\mu_0 = \beta_d\rho_d$, where ρ_d is the density of the DS and β_d its isentropic compressibility (expressed in Pa^{-1}), we may state that the speed of light is given as [6,11]

$$c = \frac{1}{\sqrt{\beta_d\rho_d}}. \tag{1}$$

Indeed, starting from the equation which defines the speed of sound in a fluid, $a = \sqrt{K/\rho}$, where K is the bulk modulus, and putting $\beta_S = \frac{1}{K}$ as isentropic compressibility (in the specific case of the DS we say β_d), we obtain (1). This acoustic analogy of the speed of light is also confirmed possible in [27], as discussed in Sect. 3.

Amendola and Tsujikawa [15], by introducing the speed of sound through a cosmological ultra-light scalar field ϕ, possibly coinciding with dark energy, state that it is the key parameter to understand the (background) dynamics of such a field. Starting from the ratio pressure/density, they define the speed of sound through this cosmic fluid as

$$c_{s,\phi} = \sqrt{\frac{\delta P_\phi}{\delta\rho_\phi}} = \sqrt{\frac{H^2(\phi'\varphi' - \phi'^2\Psi) - V_{,\phi}\varphi}{H^2(\phi'\varphi' - \phi'^2\Psi) + V_{,\phi}\varphi}}. \tag{2}$$

where we see that, when the potential of the field becomes flat, $V_{,\phi} \to 0$, we may have the speed of sound through the field coinciding with that of light (natural units are used by the authors, where the speed of light is $c = 1$). Since $\beta_d = (\rho_d(\partial P_d/\partial\rho_d))^{-1}$, Eq.(2) is equated to (1).

2 Thermal photons and phonons-driven energy propagation in fluids and superfluids.

We discuss now the possibility that photons-driven energy radiation be phonons-driven energy propagation when it occurs in the DS. We have remarked that phonons, which are typically associated to a solid state, also manifest in fluids and superfluids [16–18]. Particularly relevant for our case is the paper of Bolmatov, Brazhkin and Trachenko [16], about a phonon theory of heat diffusion in classical and quantum fluids where longitudinal and transversal phonons are described considering Frenkel [17], who first noticed that the density of liquids is much different from that of gases but only slightly different from the density of solids and who also defined the existence of transversal waves in liquids, as previously observed in solids, for frequencies larger than $1/\tau$, where τ is the relaxation time of the fluid, i.e. the time during which the structure of the liquid remains unaltered, similar to a solid lattice. After many years this has

[2] it is said that a phonon possesses a pseudo-momentum but following our reasoning this can be true also for a photon.

been observed and also for low-viscosity fluids [18]. The importance of what investigated in [16] is linked to the fact that we need to describe phonons through the DS as transverse waves (as light) and to the evidence that photons too transmit heat, energy (thermal photons). Indeed, any body whose temperature is not at absolute zero (i.e. any object, according to Nernst theorem) emits photons, whose frequency is in the infrared range for common objects around us, except higher frequencies of visible light sources. As a parallelism, it is interesting to notice that over the temperature of absolute zero (ground state) any solid or fluid also emits phonons, as energy fluctuations caused by random lattice (or quasi-lattice) vibrations and interpreted as heat. The relationship photon-phonon as far as heat/energy transmission is concerned is then noteworthy and we believe it may end up into the full identity photon-phonon if the propagation occurred in the scalar field of the DS. In fact, from the Bose-Einstein distribution function for the grand canonical ensemble $\rho \sim \exp\left[-(k_BT)^{-1}(\varepsilon-\mu N)\right]$ in the harmonic regime and with chemical potential $\mu = 0$ considering the lowest energy state at 0 K the probability of finding an average number of phonons *or photons* in a given state reads

$$\langle N(\omega_{k,s})\rangle = \frac{1}{\exp\left(\frac{\hbar\omega_{k,s}}{k_BT}\right)-1} \tag{3}$$

where k_B is Boltzmann's constant, T the absolute temperature, $\hbar\omega_{k,s} = \varepsilon$ the energy and $\omega_{k,s}$ the frequency of phonons or photons in the given state. Resorting to ladder operators, the Hamiltonian reads

$$\mathscr{H} = \sum_k \sum_{s=1}^{3} \hbar\omega_{k,s}\left(b^\dagger_{k,s}b_{k,s}+\frac{1}{2}\right) \tag{4}$$

in which we see again the contribution of the DS (quantum vacuum). We also reflect on the fact that the existence of optical phonons, i.e. phonons created via photon scattering, could represent, from our point of view, the passage of a phonon from the DS to a baryon lattice. We understand now that dark energy could be actually interacting with our baryon world in most common ways but we might not interpret its interactions in the right way yet, exclusively thinking of its repulsive action far into the cosmos.

In superfluids, energy is dissipated as heat at small scales by phonon radiation [29]. So let us analyze the issue of phonons carrying heat in fluids, useful to describe photons as transversal phonons in a superfluid. Brazhkin and collegues come to the result that there are two kinds of atomic motion in fluids: phonon motion, consisting in one longitudinal mode and two transverse modes with frequency $\omega > \omega_F$, where $\omega_F = 2\pi/\tau$ is Frenkel frequency, and diffusive motion. Both kinds of motion possess a kinetic (K) and a potential (P) component, so the energy of the fluid is expressed as

$$E = K_l + P_l + K_s(\omega > \omega_F) + P_s(\omega > \omega_F) + K_d + P_d \tag{5}$$

where the subscripts l and s refers to longitudinal and shear waves (transversal phonons) and d to diffusion. By applying several steps including the virial theorem, phonon free energy, Grüneisen approximation and Debye vibrational density of states, for the details of which we refer to [16], and neglecting the diffusive potential component since

$$P_d \ll P_s(\omega > \omega_F), \tag{6}$$

a final equation expressing a phonon theory of liquids is obtained in the form

$$E = NT\left(1+\frac{\alpha T}{2}\right)\left(3D\left(\frac{\hbar\omega_D}{T}\right) - \left(\frac{\omega_F}{\omega_D}\right)^3 D\left(\frac{\hbar\omega_F}{T}\right)\right) \tag{7}$$

where

$$D(x) = \frac{3}{x^3}\int_0^x \frac{z^3 dz}{\exp(z)-1} \tag{8}$$

is Debye function [30], ω_D is Debye frequency, α is the coefficient of thermal expansion of the fluid, $\hbar$ the reduced Planck constant coming from phonon free energy

$$F_{ph} = E_0 + T\sum_i \ln\left(1-\exp\left(-\frac{\hbar\omega_i}{T}\right)\right), \tag{9}$$

where E_0 is the temperature-dependent zero-point energy (that we can assume as the cosmic microwave background temperature in our case, i.e. as the intrinsic superfluidity temperature of dark energy, ~ 2.72K), and N the number of modes. In (7) the zero-point energy has been omitted. The authors conclude that as we have a good understanding of thermodynamics in solids based on phonons, despite their structural complexity, the same can apply for liquids. As regards the present investigation, this means that phonon-based transversal heat transmission through superfluid dark energy is possible. The thermal significance of a photon would then be comprised in phonon-based quasi-lattice vibrations of DS quanta (DSQ). Not only. Below, we discuss how Maxwell equations describing photon's electromagnetic field can equally express the lattice dynamics of the DS, theoretically completing the analogy phonon-photon.

3 Maxwell's equations express the transient quasi-lattice dynamics of the dark superfluid.

Important for our photon-phonon analogy in a DS is Gremaud's work at the Institute of Condensed Matter Physics of the Swiss Federal Institute of Technology, who discusses a complete analogy between the equations of a non-divergent deformation in an isotropic solid lattice in Euler's coordinates and Maxwell's equations of electromagnetism [27,31,32]. In his work he concludes that Maxwell's equations can be seen as a model for describing also different physical systems, not only electromagnetism. Simmetrically speaking, we go further and state that electromagnetism is the dynamic effect of a different physical system, the DS. This is fundamental if we want to define photon's electromagnetic field as acoustic perturbations of the DS, which, for excitation frequencies greater than the reciprocal of relaxation time ($1/\tau$), as discussed above, may behave as a solid-like lattice (quasi-lattice transient structure), despite possessing very low viscosity [41,18]. For radio waves of about 250MHz relaxation time should be for instance greater than $4\cdot 10^{-9}$ s while $>\sim 1.7\cdot 10^{-15}$ s for visible light.

Gremaud's analogy is complete since, along with Maxwell equations, it describes the dielectric polarization and magnetization of matter, as well as electrical charges and currents. The author introduces the concept of dislocation charges in the lattice [31], in analogy with the electrical charges, associated to plastic distortions. It is shown that the transversal waves of rotation and shear strain are associated with a propagation velocity given by

$$c_t = \sqrt{\frac{K_2+K_3}{nm}} \tag{10}$$

where the subscript on the left means transversal and K_2 and K_3 respectively represent shear stress modulus and rotation modulus. The dielectric permittivity of vacuum, ε_0, is given as $1/\left(2\left(K_2+K_3\right)\right)$, and this corresponds to $1/K=\beta_d$, to the isentropic compressibility of the DS used in Eq.(1), while $2nm$ corresponds to the mass density of the lattice and in our case to ρ_d.

In our superfluid approach to light, photon's electromagnetic field is therefore produced as transversal acoustic lattice oscillations, probably due to angular momentum transfer from the particle which emits the photon (see also the vortex-particle description in [1]).

Below we summarize the analogy between alterations of lattice geometry presenting homogeneous expansion in a mobile frame $O'x'y'z'$ and Maxwell's equations as argued in detail by Gremaud [27].

To do that, according to Frenkel [17] and Bolmatov [16], we treat the fluid medium as momentarily solid-like, assuming that electromagnetic waves have a frequency $\nu > 1/\tau$. This allows transversal waves propagation. Besides that concerning the speed of light, just discussed above, we also obtain the following analogies

$$\begin{cases} -\frac{\partial\omega}{\partial t}+\overrightarrow{rot}\,\frac{\phi^{rot}}{2}=\mathbf{J} & \Leftrightarrow -\frac{\partial\mathbf{D}}{\partial t}+\overrightarrow{rot}\mathbf{H}=\mathbf{j} \\ \operatorname{div}\omega=\lambda & \Leftrightarrow \operatorname{div}\mathbf{D}=\rho \end{cases} \tag{11}$$

where ω is the rotation field corresponding to the electric field of displacement, $\mathbf{D}$; $\mathbf{J}$ is the vector flow of rotation charges [31], equivalent to the density of electric current $\mathbf{j}$; λ is the density of rotation charges analogous to the density of electric charges ρ and $\mathbf{H}$ is the magnetic field.

$$\begin{cases} \frac{\partial n\mathbf{p}^{rot}}{\partial t}=-\overrightarrow{rot}\,\frac{\mathbf{m}'}{2} & \Leftrightarrow \frac{\partial\mathbf{B}}{\partial t}=\overrightarrow{rot}\mathbf{E} \\ \operatorname{div} n\mathbf{p}^{rot}=0 & \Leftrightarrow \operatorname{div}\mathbf{B}=0 \end{cases} \tag{12}$$

where $\mathbf{B}$ is the magnetic induction field, $\mathbf{E}$ the electric field, $n\mathbf{p}^{rot}$ the volume linear momentum of lattice (mass flow of lattice) and $\mathbf{m}'$ the generalized torque momentum.

$$\begin{cases} \omega=\left(\frac{1}{2(K_2+K_3)}\right)\frac{\mathbf{m}'}{2}+\omega^{an} \\ n\mathbf{p}^{rot}=2nm\left[\frac{\phi^{rot}}{2}+C\frac{\phi^{rot}}{2}+\frac{\left(\mathbf{J}_I^{rot}-\mathbf{J}_L^{rot}\right)}{2n}\right] \end{cases} \Leftrightarrow \tag{13}$$
$$\Leftrightarrow \begin{cases} \mathbf{D}=\varepsilon_0\mathbf{E}+\mathbf{P} \\ \mathbf{B}=\mu_0\left[\mathbf{H}+\chi\mathbf{H}+\mathbf{M}\right] \end{cases}$$

Being $1/\left(2\left(K_2+K_3\right)\right)\Leftrightarrow\varepsilon_0$ and analogous to $1/K=\beta_d$ in (1); ω^{an} the vector of anelastic shear and local rotation, analogous to the dielectric polarization of matter $\mathbf{P}$; $C=(C_I-C_L)$ the atomic concentrations of interstitials and vacancies, for which we take instead into consideration DSQ, analogous to the paramagnetic and diamagnetic susceptibility of matter $\chi=\left(\chi^{para}+\chi^{dia}\right)$; $(\mathbf{J}_I^{rot}-\mathbf{J}_L^{rot})$ is the surface flux of interstitials and vacancies; n the density of lattice sites and $\mathbf{M}$ the magnetization of matter. Finally we also obtain

$$\frac{\partial\lambda}{\partial t}=-\operatorname{div}\mathbf{J} \;\Leftrightarrow\; \frac{\partial\rho}{\partial t}=-\operatorname{div}\mathbf{j} \tag{14}$$

and

$$-\frac{\mathbf{m}'}{2}\mathbf{J}=\frac{\phi^{rot}}{2}\frac{\partial n\mathbf{p}^{rot}}{\partial t}+\frac{\mathbf{m}'}{2}\frac{\partial\omega}{\partial t}-\operatorname{div}\left(\frac{\phi^{rot}}{2}\wedge\frac{\mathbf{m}'}{2}\right)$$
$$\Updownarrow \tag{15}$$
$$-\mathbf{E}\mathbf{j}=\mathbf{H}\frac{\partial\mathbf{B}}{\partial t}+\mathbf{E}\frac{\partial\mathbf{D}}{\partial t}-\operatorname{div}\left(\mathbf{H}\wedge\mathbf{E}\right)$$

Superfluid behavior of light has been also observed in polaritons condensates from [33] up to recent experiences [34], even at room temperature [35]. The behavior of a photon gas produced in an electromagnetic cavity, wherein photons may be emitted or absorbed by the cavity walls is interestingly analogous to that of thermal phonons (Sect. 2) and this is not coincidental, as we know that the electromagnetic field may behave as a set of harmonic oscillators. The Bose-Einstein statistics applies in both cases. Another approach to the many body physics in fluids of light has been that of resorting to a bulk, non-linear medium with intensity-dependent refractive index, as showed by Carusotto [36], where, under the paraxial approximation, photon propagation can be described through a Gross-Pitaevskii equation for the order parameter, as the electric field amplitude of a monochromatic laser beam. Another noteworthy investigation on superfluid propagation of light is that of Leboeuf and Moulieras [37], although it has to be pointed out that these studies do not treat light itself as a hydrodynamic, acoustic phenomenon, as we do, but only analyze the superfluid behavior of light under the right circumstances.

4 Insurmountability of the speed of light: Lorentz factor as the rheogram of the dark superfluid.

DSQ which fill up the universe as a suspension in space, would cause a non-Newtonian, dilatant behavior of the DS. However, the dilatancy of this granular (see also recent positive statistical test from IceCube data and Fermi GLAST, [43] and the analogy with granular spacetime in Loop Quantum Gravity [47,46]) dark substance would be detectable only under relativistic shear stress, i.e. for accelerations occurring in relativistic regime, while for non-relativistic velocities, the cosmic scalar field with positive, near-zero viscosity behaves as a superfluid. Different behaviors of the same quantum fluid under different conditions are not new. Differences between relativistic and non-relativistic regime (see Fig. 1) would be then reduced to the apparent viscosity of the DS coming into play with the increase of acceleration (then of shear stress), as observed in synchrotrons, a phenomenon which is currently interpreted as relativistic mass increase and which would actually be the effect of apparent viscosity acting as a braking force in the opposite direction to motion ([44], Sect.7). In Lorentz factor, we can consider $\beta = v/c$ as the ratio v/v_{sds} of the velocity of a body through the DS to the speed of sound through it (we write v_{sds} instead of c to remark that we describe the speed of light as speed of sound in the DS). In short we see the β parameter of special relativity as the Mach number for bodies traveling through the DS, where Mach 1 is not possible due to the dilatancy of the medium: when it becomes solid only sound can still propagate through it. In this case nor a small electron can travel through the dilated DS, as a vortex [1] of DSQ cannot travel through a wall of DSQ. We therefore have to use the derivative of the arcsine to express this asymptote and we obtain Lorentz factor, revealed in its quantum hydrodynamic form

$$\gamma \equiv \arcsin' \frac{v}{v_{sds}} = \frac{1}{\sqrt{1-\left(\frac{v}{v_{sds}}\right)^2}} = \frac{1}{\sqrt{1-v^2\beta_d\rho_d}}, \quad (16)$$

where $\beta_d\rho_d = 1/c^2$ from (1). The derivative of the arcsine therefore specifies that it is not possible to exceed the speed of sound through a dilatant fluid unless to crack it, as easily verifiable, and this generates an asymptote to acceleration through dilatant fluids. Only sound can propagate when the fluid has transiently become solid under shear stress and this would be the reason for the insurmountability of the speed of light in a dilatant vacuum. Our reasoning would imply that also some among familiar superfluids could manifest a dilatant behavior under relativistic shear stress, a phenomenon for the verification of which we invoke specific tests. Accelerated particles could induce shear stress in the DS since in our picture they are not dimensionless points but vortices in the DS, whose radius is twice the healing distance [1]. What we call *dark energy*, the most part of DS, would therefore have a double face: superfluid within a non-relativistic regime [2], allowing stable orbits (in this regard see also [44]), and dilatant under relativistic regime, helping to explain the microscopic, quantum basis of special relativity, the upper physical limit to acceleration and the supposed mass increase observed in synchrotrons.

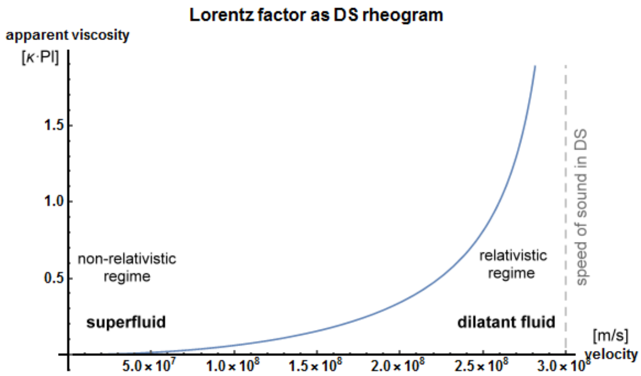

Fig. 1 Lorentz factor as the rheogram of the dark superfluid, by hypothesizing it exhibits a dilatant behavior under relativistic shear stress, when accelerated bodies approach the speed of sound through it. The asymptote represents the passage to a solid, impenetrable state, a situation in which only sound propagation is possible, which in the DS corresponds to light. Here k is an adimensional scale factor to be calculated from available data.

The increase of apparent viscosity (η_a) would be expressed as

$$\eta_a = \frac{\eta_0}{\sqrt{1-v^2\beta_d\rho_d}} \quad (17)$$

where we have used Eq. (1) and (16). Charges which are accelerated in a synchrotron toward the speed of light therefore press as against an impenetrable wall. The Nobel laureate R. B. Laughlin states [38]: “Studies with large particle accelerators have now led us to understand that space is more like a piece of window glass than ideal Newtonian emptiness. It is filled with ‘stuff ’that is normally transparent but can be made visible by hitting it sufficiently hard to knock out a part. The modern concept of the vacuum of space, confirmed every day by experiments, is a relativistic ether. But we do not call it this because it is taboo”. Indeed, we call it quantum vacuum. Or, in our case, DS, using a term closer to cosmology and to the need of general relativity itself of having a huge, invisible mass-energy exerting negative gravity (or more simply, in our opinion, exerting pressure from its energy density) present throughout the universe to impede a gravitational collapse. Eventually, it is important to point out that the dilatancy of the DS within a relativistic regime (then we can also include light propagation interpreted as sound through the DS traveling at a speed $c = 299792458\,\mathrm{m/s}$) would play a fundamental role in phonon propagation as a transverse wave, compared to standard, longitudinal sound propagation in other mediums, by producing a local, transient solid-like environment for the wave, making us remember Stoke's theory of light propagation, and this in addition to Frenkel's solid-like behavior of fluids for frequencies $\omega > \omega_F$.

5 Exact solution to the cosmological redshift from the equation of light through the DS

To substantiate the soundness of the assumption presented in this study (light as the acoustic excitation of the DS), in our subsequent investigation *Hydrodynamics of the dark superfluid: IV. Cosmological model* [45] we show how the simple equation defining the speed of light through the DS (1) is able to explain the complete observed redshift curve, including the redshift from distant supernovae, in function of density. Modern cosmology becomes in this way free of still critical complementary assumptions as the Big Bang, cosmic inflation and accelerated expansion, gaining simplicity and effectiveness, also in suggesting a solution to other unsolved issues, as baryon asymmetry. We refer to [45] for every detail and charts. There, it appears evident that we need to take a step back to the interpretation of the cosmological redshift, to abandon Lemaître's hypothesis of galaxy recession and start considering a superfluid static universe in which the redshift is due to the density of the DS decreasing with the radius of the universe ($1/r$), which reflects on the equation of light.

6 Conclusion

The propagation of light through a quantum vacuum for which there are good hints of superfluid features [1,44,45,8,4,5], and which probably corresponds to superfluid dark energy and dark matter, let us wonder whether a photon could be a transversal pulse through this dark medium [15,3,2,4,5]. The fact that photons and phonons virtually share all their features, including bosonic nature, wave-particle duality, doppler effect, symmetry under exchange, application of creation-annihilation operators, momentum, squeezed coherent states, photoelectric effect, interaction via parametric down conversion and the harmonic oscillator along with the "vacuum" contribution it expresses, as well as spin under certain conditions, has driven us to write a formula for the speed of light as that of sound through a fluid medium (using in our case density and isentropic compressibility of the DS) as originally done by Maxwell (calculating $c = 1/\sqrt{\varepsilon_0\mu_0}$), who considered vacuum's permittivity and magnetic permeability as, respectively, elasticity and density of the ether (see also [27]).

Transversal phonon propagation and heat transportation, as well as a transient solid-like behavior of fluids according to specific frequencies, were also necessary and have been analyzed through the work of Bolmatov and collegues [16], while a complete analogy between lattice deformations, useful for phonon propagation, and Maxwell's equations of electromagnetism has been reported from Gremaud [27,31,32]. Finally, by hypothesizing a dilatant behavior of the DS (and perhaps of some familiar superfluids too) if exposed to relativistic shear stress, we have justified the universally insurmountable limit of the speed of light (which in Einstein's theory of relativity is simply used as a matter of fact) as due to the increasing apparent viscosity of quantum vacuum, paving the way for a possible explanation of special relativity at a quantum level. From this investigation, light appears as the sound[3] of dark energy and a photon as a quasi-particle (exactly as a phonon) propagating through the DS. This framework would also explain why light has got a precise propagation speed in vacuum exactly as mechanical waves possess one for each different substance they propagate through. As regards light, this substance may be called dark energy in cosmology or quantum vacuum in QFT. Accordingly, if vacuum density were different in a distant part of the universe, light would travel at a different speed. To conclude, we know that the DS could be interpreted as a modern ether and one could wonder whether the Michelson-Morley test has once and for all expelled any sort of ether from modern physics. In our case, it should be noted that, if the ether wind corresponded to the gravitational field, as stated in Superfluid Quantum Gravity [44], then a Michelson-Morley interferometric test [39] could not detect any variation affecting light propagation due to the relative motion Earth-ether, as indeed happened. Light would be only influenced by the gravitational field, as also general relativity seems to confirm in the phenomenon of gravitational redshift (there the action of the field is however on clocks). Cosmological implications of the acoustic propagation of light through the cosmic superfluid, leading to a new superfluid cosmological model, free of known criticalities which are part of the standard model, as the big bang, cosmic inflation and accelerated expansion have been eventually discussed in [45], where an exact curve for the whole data set of cosmological redshift has been obtained. This can be in our opinion interpreted as an important clue in favor of light interpreted as the acoustic excitation of the DS.

[3] "*What? Is it the light I hear?*", R.Wagner, Tristan und Isolde, Act 3, Scene 2.

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