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Photon-phonon analogy in a superfluid vacuum.

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Abstract

We discuss clues to consider quantum vacuum as a superfluid, probably superfluid dark energy, in which we analyze a photon-phonon analogy. The discussion is structured in four parts: (a) shared features and behavior photon-phonon; (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 Frenkel relaxation time; (c) Gremaud's analogy of Maxwell's equations in a lattice; (d) Lorentz factor as the rheogram of dark energy and a possible basis for a quantum interpretation of 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, comes to 95%. We show that quantum vacuum fluctuations possess a hydrodynamic nature appearing as quantized vortices, so we can interpret quantum vacuum as the spontaneous hydrodynamic perturbation of an ubiquitous cosmic superfluid, which may correspond to dark energy with superfluid characteristics, as a cosmic Bose-Einstein condensate [1, 2, 3, 4, 5, 6, 7, 13]. Thus, dark energy would confer on space the features of a superfluid quantum space (SQS). According to our considerations, here a photon might propagate as a transverse phonon (arguing that light is *the sound of dark energy*) and we support this thesis in four steps. We reflect (§2) on an interestingly wide set of currently known analogies, also valid

for fluids and superfluids, between phonons and photons and (§3) referring to Bolmatov [14], we discuss transversal wave propagation and heat transmission in fluids on acoustic basis (phonons). From Gremaud (§4) [25] 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 ^4He [38]. Finally (§5), 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 hydrodynamic basis and reinforcing transverse propagation of phonons in superfluid dark energy due its dilatancy within a relativistic regime. As a consequence, we understand that dark energy would be undetectable only as long as it remains unperturbed, being light its most evident manifestation, along with its (at the moment more known) repulsive action which avoids the gravitational collapse of the universe, probably due to its internal pressure as a superfluid.

1 Light propagates through a quantum vacuum, corresponding to superfluid dark energy.

The existence of a false vacuum with non-zero energy content is definitively accepted and proven in a lot of physical phenomena: the Lamb shift, the Casimir effect, the Unruh effect, the anomalous magnetic moment, vacuum birefringence [12]etc. From the point of view of quantum physics, light travels through such a *quantum vacuum*. This environment is known for the continuous appearance and annihilation of virtual particle-antiparticle pairs, as initially formulated by Dirac. The relationship for these

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fluctuations is

$$\Delta E \Delta t \geq \frac{h}{2\pi} = \hbar. \quad (1)$$

The Bohr-Sommerfeld quantization condition, expressing mass circulation in a quantized vortex

$$\oint_C \mathbf{p} \cdot dx = nh \quad (2)$$

for $n = 1$ tells us that the quantum of action, h , actually refers to a complete turn along a circular path of a quantum whose momentum is \mathbf{p} . In (1) 2π also refers to a 360° turn and we can therefore interpret vacuum fluctuations as quantized vortices. The sign \geq states that we consider $n \geq 1$ complete rotations of the vortex during a time Δt as the vacuum fluctuation.

Quantum vortices are known to manifest in superfluids, as in ^4He [8, 37]. We also observe vortex-antivortex pairs, which form and annihilate [39, 8, 37], exactly as particles-antiparticles pairs in quantum vacuum. In our opinion, these are therefore clues for considering quantum vacuum as a superfluid. The analogy particles-quantized vortices is reinforced by the fact that fermions spin- $\frac{1}{2}$ may be described in hydrodynamic terms as the circulation of quanta in a torus vortex (see [4], §3.1). Thus, if vacuum fluctuations are superfluid vortices, what is the underlying superfluid in which they arise?

The possible answers are the Higgs field or dark energy, both observed as “dark” scalar fields. Being the Higgs boson the fundamental excitation of the Higgs field and very massive, it is probably a vortex itself, so we opt for dark energy, as a cosmic fundamental superfluid. After all, we know it constitutes $\sim 69\%$ of the mass-energy of the universe, also expressed in the cosmological constant, $\Lambda = k\rho_0$, where ρ_0 (T^{00} , as regards the stress-energy tensor) indicates the density of dark energy. Along with dark matter, which can be interpreted as condensed dark energy [1, 2, 3, 4] and whose existence is for instance evident in the dark halos of spiral galaxies which the flat profiles of orbital velocities are believed to be due to, we arrive at $\sim 95\%$.

As for any form of energy, also dark energy has to be quantized. We speak of dark energy quanta (DEQ). The hydrodynamical perturbation of these quanta would produce the known picture of quantum vacuum as well as the Higgs boson itself.

The temperature of the cosmic microwaves background radiation (CMB), ~ 2.72 K, would be in agreement with the temperature of other superfluids such as ^4He . Fig. 1 shows dark matter distribution in the universe in analogy

with the structure of a vortex web arising in a familiar superfluid such as ^4He . In this analogy all the space among the filaments is occupied by liquid helium in (a) and by superfluid dark energy (SDE) in (b).

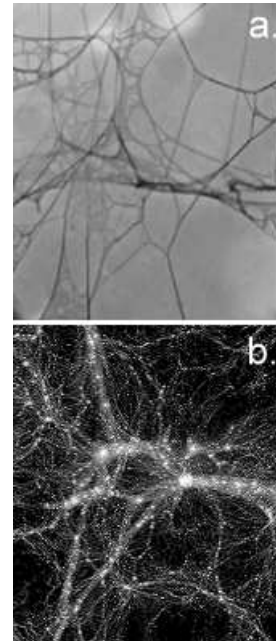


Figure 1: Left [10]: (a) Metal atoms trapped in superfluid helium vortices highlight a structure of vortex filaments; (b) galactic filaments of dark matter which galaxies aggregate on [11]. Here the relationship between dark energy and dark matter is the same existing between superfluid helium and the vortex filaments which manifest in it, i.e. dark matter is a hydrodynamic manifestation of dark energy [1].

The internal pressure of SDE would be responsible [9] for the repulsive force traditionally attributed to dark energy in cosmology. Moreover, the equation of state of cosmology for a single-fluid model can be referred to SDE, where P_d and ρ_d are respectively the pressure and the density of dark energy [13]

$$w = \frac{P_d}{\rho_d} \quad (3)$$

As far as the propagation of light through this ubiquitous superfluid is concerned, we can still believe that photon is a real particle whose energy is not affected by any minimal friction while traveling through this superfluid or we can analyze, as below, the possibility that a photon is actually a transverse phonon (a quasi-particle) propagating in superfluid dark energy. According to this view, dark energy does not interact with baryon matter *unless it is hydrodynamically perturbed* and the most evident perturbation might coincide with light itself.

2 Current photon-phonon analogies.

Let us start with listing all current analogies between photons and phonons (which can also manifest in superfluids [16, 26]). Both are bosons [17]; have wave-particle duality [18, 19]; obey the doppler effect, $z = (f_{emit} - f_{obs})/f_{obs}$; are symmetric under exchange, $|\alpha, \beta\rangle = |\beta, \alpha\rangle$; can be created by repeatedly applying the creation operator, a^\dagger ; possess a momentum, where that of a phonon¹ 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 [20, 21] (rotating phonons has been also described as regards the physics of nanotubes [22]); can form squeezed coherent states [23]; can interact via parametric down conversion [24]. Both for photons and phonons, $\hbar\omega/2$ is vacuum's (we say dark energy's) contribution, where the harmonic oscillator eigenvalues for the mode ω_k (k is the wave number) are $E_n = (n + 1/2)\hbar\omega_k$ $n = 1, 2, 3, \dots$ and to confirm the presence of a "false vacuum" we see that 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 $E = mc^2$, energy implies a certain mass density (ρ_0 in the cosmological constant), where $c^2 = (\beta_d \rho_d)^{-1}$ would be precisely linked to dark energy's intrinsic parameters, as from Eq. (4). There is a medium throughout the universe owning density $\rho \neq 0$ which light propagates through. In other words and according to quantum physics, light *does not* propagate in a vacuum but in a "quantum" vacuum, which, from a cosmological point of view, may be identified as dark energy with superfluid features.

2.1 The formula for the speed of light.

It is worth recalling that Maxwell derived the dielectric constant (ϵ_0) and the magnetic permeability (μ_0) of "vacuum", from which the formula $c = 1/\sqrt{\epsilon_0\mu_0}$ follows, in terms of density and transverse elasticity of the ether (see §4, [25]). We excluded the existence of the ether but we still need "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 $\epsilon_0\mu_0 = \beta_d\rho_d$, where ρ_d is the density of SDE and β_d its isentropic compressibility, we may state that the speed

¹it is said that a phonon possesses a pseudo-momentum but following our reasoning this can be true also for a photon.

of light is given as [4, 9]

$$c = \frac{1}{\sqrt{\beta_d \rho_d}}. \quad (4)$$

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 SDE we say β_d), we obtain (4). This acoustic analogy of the speed of light is also confirmed possible in [25], as discussed in §4.

Amendola and Tsujikawa [13], by introducing the speed of sound through a ultra-light scalar field ϕ , state that it is the key parameter to understand the (background) dynamics of such a field. Using the ratio pressure/density under root as the the speed of sound through this cosmic fluid, they define such a speed as

$$c_{s,\phi} = \sqrt{\frac{\delta P_\phi}{\delta \rho_\phi}} = \sqrt{\frac{H^2(\phi'\phi' - \phi'^2\Psi) - V_{,\phi}\phi}{H^2(\phi'\phi' - \phi'^2\Psi) + V_{,\phi}\phi}}. \quad (5)$$

where we see that, when the potential of the field becomes flat, $V_{,\phi} \rightarrow 0$, 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 $c = 1$).

3 Phonons-driven thermal energy transmission in fluids.

We have remarked that phonons, which are typically associated to a solid state, also manifest in fluids and superfluids [14, 15, 16]. Particularly relevant for our case is the paper of Bolmatov, Brazhkin and Trachenko [14], about a phonon theory of heat diffusion in classical and quantum fluids where longitudinal and transversal phonons are described considering Frenkel's work [15], 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 been observed and also for low-viscosity fluids [16]. The importance of what investigated in [14] is linked to the fact that we need to describe phonons through SDE as transverse waves (as light is) and to the evidence that photons too transmit heat, energy. Indeed, any body whose temperature is not at ab-

solute 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. The relationship photon-phonon as far as heat/energy transmission is concerned is interesting and we believe it may end up into the coincidence photon-phonon if the propagation occurs in the scalar field of SDE. It is interesting to also reflect 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 SDE to a baryon lattice. We understand now that dark energy could be actually interacting with our baryon world in most common ways but still we do not interpret its interactions in the right way, exclusively thinking of its mere repulsive action far into the cosmos.

In superfluids, energy is dissipated as heat at small scales by phonon radiation [27]. So let us analyze the issue of phonons carrying heat in fluids, useful to describe photons as transversal phonons in a superfluid. Brazhkin and colleagues 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

$$E = K_l + P_l + K_s(\omega > \omega_F) + P_s(\omega > \omega_F) + K_d + P_d \quad (6)$$

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 [14], and neglecting the diffusive potential component since $P_d \ll P_s(\omega > \omega_F)$, a final equation expressing a phonon theory of liquids is obtained in the form

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

where

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

is Debye function [28], 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

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

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, $\sim 2.72\text{K}$), 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. For 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 dark energy quanta. Not only. Below, we discuss how Maxwell equations describing photon's electromagnetic field can equally express the lattice dynamics of SDE, theoretically completing the analogy phonon-photon.

4 Maxwell's equations express SDE quasi-lattice dynamics.

Important for our photon-phonon analogy in SDE is Gremaud's work at the Institute of Condensed Matter Physics of the Swiss Federal Institute of Technology in Lausanne, who discusses a complete analogy between the equations of a non-divergent deformation of an isotropic solid lattice in Euler's coordinates and Maxwell's equations of electromagnetism [25, 29, 30]. In his work he concludes that Maxwell's equations can be seen as a model for describing also different physical systems, not only electromagnetism. Symmetrically speaking, we go further and state that electromagnetism is the dynamic effect of a different physical system. This is fundamental if we want to define photon's electromagnetic field as acoustic perturbations of SDE, which, for excitation frequencies greater than the reciprocal of Frenkel's relaxation time ($1/\tau$), as discussed above, may behave as a solid-like lattice (quasi-lattice transient structure), despite possessing very low viscosity [38, 16]. For radio waves of about 250MHz relaxation time should be for instance greater than $4 \cdot 10^{-9}\text{s}$ while $> \sim 1.7 \cdot 10^{-15}\text{s}$ 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 [29], 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

$$c_t = \sqrt{\frac{K_2 + K_3}{nm}} \quad (10)$$

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 $1/(2(K_2 + K_3))$, and this corresponds to $1/K = \beta_d$, the isentropic compressibility of SDE used in (4), while $2nm$ corresponds to the mass density of the lattice and in our case to ρ_d .

In this fluid approach to light, photon's electromagnetic field is produced as transversal acoustic lattice oscillations (Fig. 2), probably due to angular momentum transfer from the particle which emits the photon.

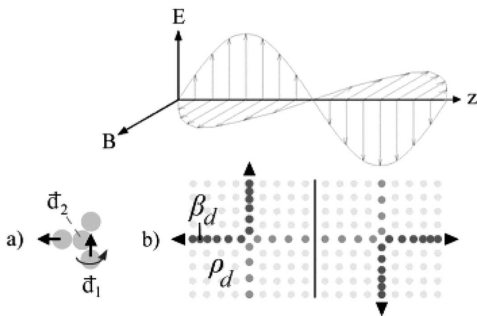


Figure 2: Density (ρ_d) and compressibility (β_d) of dark energy at the origin of photon's transverse EM field (b), whose oscillations are due to harmonic, orthogonal compressions of dark energy quanta occurring within the relaxation time, while the main pulse propagates along the z -axis. On the left (a), the probable quantum mechanism at the origin of $B \perp E$, due to compression and intrinsic angular momentum of DEQ (here \vec{d}_1 and \vec{d}_2 are two exemplifying quanta) arising from that of the emitting particle (e.g. of an electron).

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 in [25].

To do that, according to Frenkel [15] and Bolmatov [14], we treat the fluid medium as momentarily solid-like, assuming that electromagnetic waves have a frequency $\nu > 1/\tau$, being τ Frenkel relaxation time. This allows transversal waves propagation. Besides that concerning the speed of light, just discussed above, we also obtain the following analogies

$$\begin{cases} -\frac{\partial \vec{\omega}}{\partial t} + r \vec{\text{rot}} \frac{\vec{\phi}^{\text{rot}}}{2} = \vec{J} & \Leftrightarrow -\frac{\partial \vec{D}}{\partial t} + r \vec{\text{rot}} \vec{H} = \vec{j} \\ \text{div} \vec{\omega} = \lambda & \Leftrightarrow \text{div} \vec{D} = \rho \end{cases} \quad (11)$$

where $\vec{\omega}$ is the rotation field corresponding to the electric field of displacement, \vec{D} ; \vec{J} is the vector flow of rotation charges [29], equivalent to the density of electric current \vec{j} ; λ is the density of rotation charges analogous to the density of electric charges ρ and \vec{H} is the magnetic field.

$$\begin{cases} \frac{\partial n \vec{p}^{\text{rot}}}{\partial t} = -r \vec{\text{rot}} \frac{\vec{m}'}{2} & \Leftrightarrow \frac{\partial \vec{B}}{\partial t} = r \vec{\text{rot}} \vec{E} \\ \text{div} n \vec{p}^{\text{rot}} = 0 & \Leftrightarrow \text{div} \vec{B} = 0 \end{cases} \quad (12)$$

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

$$\begin{cases} \vec{\omega} = \left(\frac{1}{2(K_2 + K_3)} \right) \frac{\vec{m}'}{2} + \vec{\omega}^{\text{an}} \\ n \vec{p}^{\text{rot}} = 2nm \left[\frac{\vec{\phi}^{\text{rot}}}{2} + C \frac{\vec{\phi}^{\text{rot}}}{2} + \frac{(\vec{J}_I^{\text{rot}} - \vec{J}_L^{\text{rot}})}{2n} \right] \end{cases} \quad (13)$$

$$\begin{cases} \vec{D} = \varepsilon_0 \vec{E} + \vec{P} \\ \vec{B} = \mu_0 [\vec{H} + \chi \vec{H} + \vec{M}] \end{cases}$$

being $1/(2(K_2 + K_3)) \Leftrightarrow \varepsilon_0$ and analogous to $1/K = \beta_d$ in (4); $\vec{\omega}^{\text{an}}$ the vector of anelastic shear and local rotation, analogous to the dielectric polarization of matter \vec{P} ; $C = (C_I - C_L)$ as the atomic concentrations of interstitials and vacancies (for which we take instead into consideration DEQ), analogous to the paramagnetic and diamagnetic susceptibility of matter $\chi = (\chi^{\text{para}} + \chi^{\text{dia}})$; $(\vec{J}_I^{\text{rot}} - \vec{J}_L^{\text{rot}})$ is the surface flux of interstitials and vacancies; n the density of lattice sites and \vec{M} the magnetization of matter.

And finally

$$\frac{\partial \lambda}{\partial t} = -\text{div} \vec{J} \Leftrightarrow \frac{\partial \rho}{\partial t} = -\text{div} \vec{j} \quad (14)$$

and

$$-\frac{\vec{m}'}{2}\vec{J} = \frac{\vec{\phi}^{rot}}{2}\frac{\partial n\vec{p}^{rot}}{\partial t} + \frac{\vec{m}'}{2}\frac{\partial \vec{\omega}}{\partial t} - \text{div}\left(\frac{\vec{\phi}^{rot}}{2}\wedge\frac{\vec{m}'}{2}\right)$$

$$\Downarrow \quad (15)$$

$$-\vec{E}\vec{j} = \vec{H}\frac{\partial \vec{B}}{\partial t} + \vec{E}\frac{\partial \vec{D}}{\partial t} - \text{div}\left(\vec{H}\wedge\vec{E}\right)$$

Superfluid behavior of light has been also observed in polaritons condensates from 2007 [31] up to recent experiences [32]. Another approach to the many body physics in fluids of light has been resorting to a bulk non-linear medium with intensity-dependent refractive index, as showed by Carusotto [33], 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 [34], 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.

5 Insurmountability of the speed of light: Lorentz factor as the rheogram of SDE.

Dark energy's quanta which fill up the universe as a suspension in space, would cause a non-Newtonian, dilatant behavior of dark energy. However, the dilatancy of this granular, dark substance would be detectable only under relativistic shear stress, i.e. for accelerations occurring in relativistic regime, while for non-relativistic speeds, the cosmic scalar field with positive, near-zero viscosity called dark energy behaves as a superfluid. The difference between a relativistic and non-relativistic regime (see Fig. 3) would be then reduced to the apparent viscosity of SDE coming into play with the increasing of acceleration, as observed in synchrotrons, a phenomenon which is currently interpreted as relativistic mass increase. In Lorentz factor, we can consider $\beta = v/c$ as the ratio v/v_{sd} of the velocity of a body through SDE to the speed of sound in dark energy (we write v_{sd} instead of c to remark that we describe the speed of light as speed of

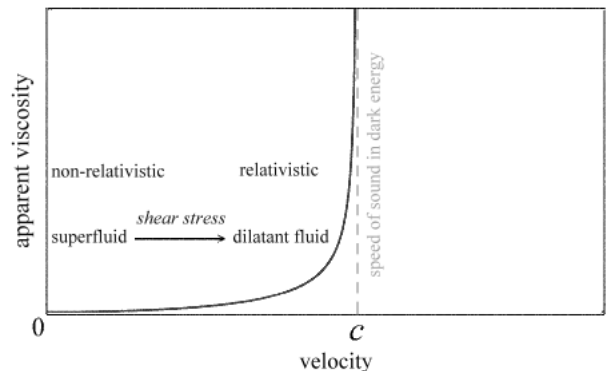


Figure 3: Lorentz factor as the rheogram of dark energy. Because of its quantum, granular nature, superfluid dark energy should behave as a dilatant fluid when shear stress enters into a relativistic regime, that is when the body velocity approaches the speed of sound in dark energy. This would imply that the so-called relativistic mass increase is actually the effect of apparent viscosity, which acts as a force in the opposite direction to acceleration). Assumed that the speed of sound in a dilatant fluid can't be exceeded without cracking it, this would explain the upper limit to acceleration experienced in synchrotrons.

sound in dark energy)

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

where $\beta_d\rho_d = 1/c^2$ from (4) and the derivative of the arcsine specifies that it is not possible to exceed the speed of sound through a dilatant fluid unless to crack it, as experimentally verifiable, generating an asymptote to shear stress (and to acceleration). 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. Dark energy would therefore show a double side: superfluid within a non-relativistic regime and dilatant inside a relativistic regime, helping to explain the microscopic, quantum basis of special relativity.

As far as the hypothesized dilatancy of space (filled of quantized dark energy) is concerned, we can cite the words of the Nobel laureate for the quantum Hall effect R. B. Laughlin [35]: "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, SDE, using a term closer to cosmology and to the need of general relativity itself of having a huge, invisible mass-energy present throughout the universe to impede a gravitational collapse. Finally, it is important to point out that dark energy dilatancy at relativistic regime (then we can also include light propagation interpreted as sound through SDE traveling at a speed $c = 299792458 \text{ m/s}$) 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 the Frenkel's solid-like behavior at frequency $\omega > \omega_F$.

6 Conclusion

The propagation of light through a quantum vacuum for which there are strong hints of superfluid features, let us wonder whether a photon could be a transversal pulse through this dark medium, identified as superfluid dark energy [4, 2, 13, 1]. The fact that photons and phonons share virtually 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, 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 an isentropic compressibility of superfluid dark energy) as originally done by Maxwell, in $c = 1/\sqrt{\varepsilon_0\mu_0}$, who considered vacuum's permittivity and magnetic permeability as, respectively, elasticity and density of the ether (see also [25]).

Transversal phonon propagation and heat transportation, as well as transient solid-like behavior of fluids according to specific frequencies, were necessary and have been analyzed through the work of Bolmatov and colleagues [14], while a complete analogy between lattice deformations, useful for phonon propagation, and Maxwell's equations of electromagnetism has been reported from Gremaud [25, 29, 30]. Finally, by hypothesizing a dilatant behavior of SDE (and perhaps of some familiar superfluids) 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 used as a matter of fact) as due to the increas-

ing apparent viscosity of dark energy, paving the way for a possible explanation of special relativity at a quantum level. From this investigation, light appears as the sound² of dark energy and a photon as a quasi-particle (just like a phonon) propagating through dark energy. This framework would also explain why light possesses 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 the density of dark energy should be different in a distant part of the universe, light would travel at a different speed. To conclude, it should be noted that if the gravitational field corresponded to an ether wind (or better SDE wind), as theorized in the theory of Superfluid Quantum Gravity ([4], §4), then a Michelson-Morley interferometric test [36] could not detect any variation in light propagation due to the relative motion Earth-ether, as indeed happened, but light would be only influenced by the gravitational field, as general relativity confirms. Cosmological implications of acoustic propagation of light through the cosmic superfluid have been discussed in [9].

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

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