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Dynamic Theory of Photons and Free Space the Fundamental Nature of Our Dynamic Universe

Wenzhong David Zhang

Independent Researcher, Hembury Avenue, Manchester, M19 1FH, UK

Abstract: Free space is a superfluid medium composed of dynamically polarizable dipoles. Photons are revealed as dynamically oscillating electromagnetic dipoles with quantized energies. Building on this premise, the interaction between photons and polarizable superfluid free space is examined, from which several phenomena are reinterpreted quantitatively. The Hubble constant is elucidated as the intrinsic relaxation frequency of the polarizable superfluid free space as an integrated medium. The energy dissipated per cycle by a single frequency electromagnetic wave of photon propagating through superfluid free space is shown to equal the product of Planck's constant and the Hubble constant. The analysis further derives the polarizability of superfluid free space quantitatively. A quantitative upper bound on the possible frequency of electromagnetic oscillations in superfluid free space is established correspondingly with the Schwinger critical field limit. This predicted upper frequency limit is shown to be slightly above the highest photon frequency of ultra-high energy photons observed experimentally to date. Conceptual tensions and logical inconsistencies within the standard cosmology model are analysed. These considerations point toward a fundamental paradigm shift to establish a logically consistent theoretical framework, which is capable of providing a coherent and interconnected understanding of our dynamic Universe's underlying physical nature.

Keywords: Hubble constant, relaxation frequency, dynamic dipole, superfluid free space, elementary super photon, wave–particle duality

INTRODUCTION

Photons, as the quantized excitations of free space electromagnetic field, have long been the primary carriers of information about our Universe. Observations of photons across the electromagnetic spectrum have revealed the structure of matter from electrons and atoms to galaxies and the cosmic web, shaping modern cosmology and fundamental physics, as emphasized in the Scientific Background to the 2017 Nobel Prize in Physics. Even small advances in the understanding of photons have historically generated major scientific and technological progresses.

Recent theoretical developments have revealed that photons are dynamically polarized dipoles propagating in free space, which are composed of spinning twin constituents with equal and opposite elementary charges. In this description, the centre of energy and equivalent mass of the polarized dipoles propagates rectilinearly at the speed of light, naturally giving rise to the oscillating electric and magnetic fields and the wave–particle duality of the electromagnetic radiation [1-4]. Within the same theoretical framework, free space is modelled as a superfluid medium populated by dynamically propagating dipoles with quantized energies, whose collective behaviour gives rise to the familiar properties of superfluid vacuum [1-8]. From this dynamic superfluid medium description, Planck's blackbody radiation law is derived quantitatively, and the Hubble

constant value of approximately 70.1 km s^{-1} Mpc^{-1} is theoretically derived from the peak frequency of the cosmic microwave background radiation (CMB) spectrum [1].

Electromagnetic dipoles are known to experience weak mutual attraction, and therefore, photons—dynamic electromagnetic dipoles must also attract one another with nonzero but tiny forces. These interactions, while negligible in most contexts, become relevant at sufficiently low temperatures and long wavelength, which play an important role in the formation of a coherent superfluid state [1-4]. Several theoretical investigations have indicated that low energy photons may undergo Bose–Einstein condensation and form a coherent superfluid state under appropriate conditions, which is analogous to helium [1-8]. Weak dipole–dipole interactions have also been proposed as a potential origin of the universal attractive gravitational force [9]. Superfluid free space contains two populations of photons: a pervasive low-energy and long wavelength superfluid photon component that permeates the observable Universe, and a higher-energy normal photon component that produced in Astro physically hot regions and emitting into the vast and cool superfluid free space. Hot environments partially transforming low energy superfluid photons to higher energy photon gases, reducing the local superfluid density and drawing additional superfluid photons toward these regions, while the excited normal photons with higher energy disperse outward to the vast and cool superfluid free space. This two-fluid system—the superfluid state of quantum liquid photons and higher energy normal photon gases—constitutes a dynamically polarizable free space in dynamic equilibrium. The polarizability of free space allows it to absorb and re-emit radiation efficiently, functioning effectively as an ideal blackbody on cosmological scales. This dynamic equilibrium offers a natural means of explaining the uniform CMB temperature of approximately 2.726 K and provides a dynamic medium-based context in which local and global physical processes are intrinsically coupled, which is consistent with ideas analogous to Mach's principle and nonlocal hidden variables in quantum mechanics [1-4].

Matter particles embedded within this dynamic medium of superfluid free space—electrons, protons, atoms, molecules, planets, stars, and galaxies—acts as both sinks and sources of dynamic energy and equivalent mass. These systems absorb dynamic mass–energy from superfluid free space to maintain their characteristic temperatures and dynamic motions and subsequently return mass–energy to the medium by emitting. As emitted normal photons propagate through superfluid free space, they experience extremely tiny energy loss per photon per cycle due to weak interacting and return their energy back to superfluid free space gradually [10-12].

This paper further develops the consequences of this framework in three steps. First, the tiny conductivity of superfluid free space is determined from the rigorous and unique solutions of the full set of Maxwell equations, establishing the character of superfluid free space as an extremely low-loss dynamic grand medium. Then the Hubble constant is elucidated as the intrinsic relaxation frequency of the dynamically polarizable superfluid free space as a grand medium. Afterwards, the polarizability of the superfluid free space is derived quantitatively, and the maximum electromagnetic frequency that the superfluid free space can sustain is obtained correspondingly with the Schwinger limit. Finally, several problems and internal inconsistencies in the standard model of cosmology are analysed, and it is argued that alternative physical mechanisms—built upon simple, coherent, and testable foundations—shall be admitted for advancing our understanding of the Hubble constant, various observing cosmology phenomena and the fundamental nature of our dynamic

Universe, without breaking the fundamental laws of physic, which shall be more friendly for the application of computer simulation and artificial Intelligence (AI) assisted analysis.

MAXWELL'S EQUATIONS FOR FREE SPACE AND THE HUBBLE CONSTANT

Interstellar space—representing a substantial portion of the Universe's free space—is far emptier than any laboratory vacuum and consists primarily of hydrogen atoms, electromagnetic and gravitational fields, cosmic rays, neutrinos, and sparse dust particles. Its mean density is approximately one hydrogen atom per cubic centimetre [13,14]. Even in regions of low ionization, the electrical conductivity is governed by interactions between oppositely charged particles mediated by Coulomb forces and is therefore largely independent of matter density or ionization fraction; instead, it depends primarily on temperature [15]. Because of the long rang nature of Coulomb forces, dynamically polarizable superfluid free space must exhibit an extremely small but nonzero electrical polarizing or so-called displacement current when subjected to oscillating electromagnetic fields. Consequently, the conductivity of the vast and cool polarizable superfluid free space at the nearly uniform temperature of approximately 2.726 K shall not be exactly zero.

A finite conductivity of free space implies that propagating electromagnetic waves (photons) will induce correspondingly tiny alternative polarizing displacement current densities through their oscillating electric fields. Local dynamic polarizing displacement currents are essential for the induction of magnetic fields. Therefore, when analysing electromagnetic wave propagation across astronomical distances, it is appropriate to treat free space as a dynamic polarizable superfluid medium that is linear, isotropic, and homogeneous, characterized by a very tiny constant conductivity σ together with the constant vacuum permittivity ε_0 and the constant vacuum permeability μ_0. While ε_0 and μ_0 are precisely determined in the SI system, the extremely tiny conductivity of free space has received comparatively little attention.

If the free charge density in superfluid free space is denoted by ρ_f, then, owing to the intrinsic neutrality of superfluid free space in average, and the fact that free charges appear only in oppositely charged pairs, the average free charge density must vanish over sufficiently large volumes, i.e. $\rho_f = 0$. However, the extremely tiny alternative current density locally induced by an oscillating electric field remains non-zero and shall obey the linear Ohm's law, $\vec{J_f} = \sigma\vec{E}$, where $\vec{E}$ is the electric field intensity. Combining this relation with the constitutive equations $\vec{D} = \varepsilon_0\vec{E}$ and $\vec{B} = \mu_0\vec{H}$, the full set of Maxwell's equations in averagely neutral superfluid free space can be written as follows:

$$\nabla \cdot \vec{E} = \frac{\rho_f}{\varepsilon_0} = 0 \qquad \nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \nabla \times \vec{B} = \mu_0\sigma\vec{E} + \mu_0\varepsilon_0\frac{\partial \vec{E}}{\partial t}$$

After some mathematical operations of the above Maxwell's equations for the dynamic polarizable superfluid free space, two damping electromagnetic field wave equations can be derived as:

$$\nabla^2\vec{E} - \mu_0\sigma\frac{\partial \vec{E}}{\partial t} - \frac{1}{c^2}\frac{\partial^2\vec{E}}{\partial t^2} = 0 \qquad (1)$$

$$\nabla^2\vec{B} - \mu_0\sigma\frac{\partial\vec{B}}{\partial t} - \frac{1}{c^2}\frac{\partial^2\vec{B}}{\partial t^2} = 0 \quad (2)$$

Equations 1 and 2 describe the damped harmonic oscillating and propagating of both the electric and magnetic fields in superfluid free space. Where c is the light speed in superfluid free space with $c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}$. Normally the conductivity of superfluid free space σ is assumed to be zero, thus the harmonic oscillating plane wave function $\vec{f} = \overrightarrow{f_0}exp[i(\vec{k}\vec{r} - \omega t)]$ becomes the approximated solutions for the electric field intensity $\vec{E}$ and the magnetic flux density $\vec{B}$ of the simplified Maxwell equations by assuming the conductivity of free space is zero. However, the ideal plane wave solutions have problems to fulfil the Sommerfeld and Silver-Müller radiation conditions.

By substituting the plane wave function $\vec{f} = \overrightarrow{f_0}exp[i(\vec{k}\vec{r} - \omega t)]$ as a trial solution into equations 1 and 2, the dispersion relation can be derived as:

$$k^2 = \omega^2\mu_0\,\varepsilon_0 + i\omega\mu_0\sigma \quad (3)$$

This dispersion relation refers to the relationship between the wave vector $\vec{k}$ and the angular frequency ω of the oscillating electromagnetic wave. From equation 3, $\vec{k}$ is a complex value and it can be written as $\vec{k} = \alpha + i\beta$, where α is the phase constant and ß is the attenuation factor. By substituting $\vec{k} = \alpha + i\beta$ into equation 3 and equating real and imaginary parts, it can be derived approximately [12, 16] as follows:

$$\alpha \approx \omega\sqrt{\mu_0\varepsilon_0} = \frac{\omega}{c} = \frac{2\pi}{\lambda} = |\vec{k}| \quad (4)$$

$$\beta \approx \frac{\sigma}{2}\sqrt{\frac{\mu_0}{\varepsilon_0}} \quad (5)$$

Where λ is the wavelength of the oscillating electromagnetic wave, because of the extremely tiny energy dispersion per cycle, λ, α, ω and $\vec{k}$ in equation 4 change extremely slowly with the propagating time and distance of the electromagnetic wave from emission point. For analyse the impact of the non-zero conductivity on the oscillating electromagnetic wave propagating in the one dimensional $\vec{r}$-direction in superfluid free space, let's first put aside the vector field direction and focus on the scalar value of the electric field intensity $\overrightarrow{E}$ as *E (r, t)* and the scalar value of the magnetic flux density $\overrightarrow{B}$ as *B(r, t)*, and with E_0 representing the initial scalar electric field intensity amplitude and B_0 representing the initial scalar magnetic flux density amplitude. The resulting solutions of the full set of Maxwell equations can be elicited as follows:

$$E(r,t) = E_0e^{-\beta r}exp[i(\alpha r - \omega t)] = E_r exp[i(\alpha r - \omega t)] \quad (6)$$

$$B(r,t) = (\frac{kE_0}{\omega})\,e^{-\beta r}\exp[\mathrm{i}(\alpha\mathrm{r} - \omega\mathrm{t})] = B_r\exp[\mathrm{i}(\alpha\mathrm{r} - \omega\mathrm{t})] \quad (7)$$

Interestingly, the solutions described in equations 6 and 7 describe a slowly decaying wave that approaching zero at the infinite boundary, which fulfil automatically the Sommerfeld and Silver-Müller radiation conditions with uniqueness.

A single photon may be viewed as the energy package of a single frequency electromagnetic wave per cycle. Based on equations 6 and 7, together with the Einstein-Planck energy equation for photons $U = hf$, the energy package of the single frequency electromagnetic wave per cycle (a photon) shall be equal to:

$$U(r) = hf \approx V_{eff}\varepsilon_0 E_r^2 = V_{eff}\varepsilon_0 E_0^2 e^{-2\beta r} = hf_0 e^{-2\beta r} \quad (8)$$

Where h is the Planck constant, f is the frequency of the monochromatic electromagnetic photon wave at the observation point r, and f_0 is the frequency of the monochromatic electromagnetic photon wave at the emission source point $(r = 0)$, V_{eff} is the effective interaction volume of the single frequency electromagnetic photon wave with superfluid free space. V_{eff} shall equal to the photon's effective interaction cross-section area multiplied by its wavelength λ. Because the effective interaction cross-section area of a single frequency photon is proportional to its energy, hence, the effective interaction volume of a photon with superfluid free space shall be proportional to $E\lambda = hf\lambda = hc$, which shall be a constant for any photon. Using equation 8 together with $f = \frac{c}{\lambda}$ and the definition of cosmic redshift $z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{f_0 - f}{f} = e^{\frac{H_0 r}{c}} - 1$ [11, 12,16-20], it can be elucidated as:

$$H_0 = 2\beta c \quad (9)$$

Where H_0 is the Hubble constant. The exponential relationship between the photon energy and the Hubble constant H_0, either from the best empirical fit of observational astronomical data or from theoretical derivations based on different cosmology models, is the same as following [11, 12,16-20]:

$$U(r) = U(0)e^{-H_0 t} = hf_0 e^{-H_0 t} = hf_0 e^{-\frac{H_0 r}{c}} \quad (10)$$

By comparing equation 10 with equation 8 and applying equations 5 and 9 altogether, it can be derived as:

$$H_0 = 2\beta c \approx \frac{\sigma}{\varepsilon_0} \quad (11)$$

If a modest value of the measured H_0 is taken approximately as $2.29 \times 10^{-18}\ s^{-1}$ [11,12,16-20], the estimation of the conductivity of superfluid free space can be elicited from equation 11 as

$$\sigma \approx H_0\varepsilon_0 \approx 2.0276 \times 10^{-29}\ S/m \quad (12)$$

Hence, the resistivity of superfluid free space shall be:

$$\rho_r = \frac{1}{\sigma} \approx 4.9319 \times 10^{28}\ \Omega m \quad (13)$$

From Equations 12 and 13, it is noteworthy to point out that the accuracy of the calculated conductivity and resistivity of superfluid free space is contingent upon the precision of the values of the measured Hubble constant and the permittivity of free space. Both the permittivity and the conductivity are intrinsic properties of the superfluid free space as a dynamically polarizable superfluid grand medium. Consequently, it can be inferred that the Hubble constant H_0 is also an intrinsic property of the dynamically polarizable superfluid free space grand medium. However, the accuracy of the Hubble constant measured is affected by measuring technologies and local contents within the propagating path of the propagating electromagnetic waves. Furthermore, from Equations 12 and 13, it can be derived as:

$$H_0 \approx \frac{1}{\varepsilon_0\rho_r} = \frac{1}{\tau_r} \quad (14)$$

Where τ_r is the intrinsic relaxation time constant of the superfluid free space as a dynamically polarizable grand medium, its value can be derived as approximately 1.3847×10^{10} *years*, which is quite similar with the well-known predicted age of the Universe by the Lambda cold dark matter (ΛCDM) cosmological model. It is interesting to point out that the reciprocal of the Hubble constant is usually called the Hubble time. Hence, it is apparent that the Hubble constant is essentially an intrinsic relaxation frequency of the superfluid free space as a dynamically polarizable grand medium.

The Hubble length is $L \approx c/H_0$, which is approximately 1.3091×10^{26} *m* if the H_0 is taken modestly as $2.29 \times 10^{-18}\ s^{-1}$. Assuming the observable Universe confined to the Hubble length as a cubic shape, its cross area is L^2. It is amazing to discover that the electrical resistance of the entire observable Universe confined to the Hubble length can be derived as:

$$R = \frac{\rho_r L}{L^2} \approx 376.73\ \Omega \approx Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} \tag{15}$$

It seems that every cycle of the oscillating electromagnetic wave is coupled with the entire observable Universe confined to the Hubble length, as may be inferred from the long-range nature of Coulomb forces. The relaxation of the dynamic polarizable superfluid free space following the disturb of every cycle of the oscillating electromagnetic wave is across the entire observable Universe.

POYNTING'S THEOREM, THE POLARIZATION OF SUPERFLUID FREE SPACE AND ITS UPPER FREQUENCY LIMIT

The entire observable Universe may be viewed as an integrated dynamic grand medium with a variety of different contents connecting together by polarizable superfluid free space. Photons travelling through this dynamically polarizable grand medium and interact with it, shall have mean and maximum free travel lengths, also mean and maximum free travel times. The free travel length and the free travel time of a certain spectrum of photons shall fall into a statistic distribution around a mean value. This is the reason why the Universe becomes opaque to observers beyond a certain distance [11, 21], depending on what spectrum of photons is observed and what kind of observational technologies is employed. Photons with a longer wavelength shall have a relatively longer free travel length, which is the reason why the observational depth by James Webb Space Telescope (JWST) is much deeper than the observational depth by the Hubble Telescope.

The differential form of the time-rate of energy changes due to oscillating electromagnetic wave field interacting with polarizable superfluid free space can be derived quantitatively from the full set of Maxwell's Equations as the Poynting's theorem:

$$\frac{\partial}{\partial t}\left(\frac{\varepsilon_0 E^2}{2} + \frac{B^2}{2\mu_0}\right) + \nabla \cdot \left(\frac{\vec{E} \times \vec{B}}{\mu_0}\right) + \sigma E^2 = 0 \tag{16}$$

Poynting's theorem in equation 16 states a differential form of the conservation of energy. The quantity $\left(\frac{\varepsilon_0 E^2}{2} + \frac{B^2}{2\mu_0}\right)$ is the energy-density stored in the electromagnetic wave field per cycle. The quantity $\left(\frac{\vec{E} \times \vec{B}}{\mu_0}\right)$ is Poynting's vector S , which defines the power flux, the energy-density crossing a unit area normal to the direction of the field propagation per unit

time. The quantity σE^2 is the time-rate at which the energy-density dissipated per unit time. Over one cycle period of time T, the dissipated energy of a photon within the effective interacting volume V_{eff} can be elucidated as:

$$\sigma E^2 V_{eff} T = \frac{\sigma \varepsilon_0 E^2 V_{eff} T}{\varepsilon_0} = \frac{\sigma h f T}{\varepsilon_0} = \frac{\sigma h}{\varepsilon_0} \approx h H_0 \tag{17}$$

Equations 8 and 11 are employed in the derivation of equation 17. It is notable that the derived energy dissipation for a monochromatic electromagnetic wave propagating through the integrated medium of dynamically polarizable superfluid free space per cycle equals to the product of the Planck constant and the Hubble constant. This result aligns precisely with the dissipated energy per cycle derived from a lightly damped oscillator model for photons, showing a photon particle propagating through the dynamically polarizable superfluid free space with an extremely low viscous frictional force [10-12, 21]. This consistency is a remarkable demonstration of the wave–particle duality of photons. The tiny portion of energy equalling the product of the Planck constant and the Hubble constant is named an elementary super photon by the author. There is another simpler way to derive the dissipated energy of a photon particle per cycle based on the physical meaning of Planck constant, Einstein mass-energy equation for photons and through simple mathematic manipulation, please reference to [10,11, 22].

For understanding the behaviour of normal photons having frequencies range from microwaves to γ rays, it is logical to treat the backstage superfluid free space as a linearly polarizable medium having dielectric displacement $\vec{D} = \varepsilon_0 \vec{E}$. If there is another linearly polarizable normal matter medium co-exists, the induced extra electric displacement (polarization) $\vec{P} = \chi_e \varepsilon_0 \vec{E}$ can be linearly added upon (superposition) the dielectric displacement of linearly polarizable superfluid free space directly as, $\vec{D} = \varepsilon_0 \vec{E} + \vec{P} = \varepsilon_0 (1 + \chi_e) \vec{E}$, where χ_e is the electric susceptibility of the polarizable normal matter medium. It has been revealed that superfluid free space is a dynamically polarizable medium, its electric polarizability tensor shall be able to be assigned as $\boldsymbol{\alpha}'(unit: Asm^2/V)$. When a disturbing electric field intensity $\vec{E}$ applied, an induced dipole moment shall be produced:

$$\mu_{ind} = \alpha' \vec{E} \tag{18}$$

This linear effect is sufficient for the consideration of the electric fields of normal photons propagating through dynamically polarizable superfluid free space. For simplicity, if only one space dimension of electric fields is considered, equation 18 can be simplified as $\mu_{ind} = \alpha' \vec{E}$, where α' becomes a scalar electric polarizability coefficient with the *SI* unit as Asm^2/V. It should be emphasized that the *SI* unit is not succeeded in driving out the so-called polarizability volume V_α originated from a modified *cgs* unit,

$$V_\alpha = \frac{\alpha'}{4\pi\varepsilon_0} \approx 10^{-24}\, cm^3 = 10^{-30} m^3 \tag{19}$$

It is well known that the approximate size of a ground state hydrogen atom is given by the Bohr radius, which is approximately $0.529 \times 10^{-10}\, m$; hence, the corresponding volume of a ground state hydrogen atom is approximately $0.621 \times 10^{-30} m^3$, which is close to the experimental value of approximately $0.67 \times 10^{-30} m^3$ [23]. For the polarization of a ground state hydrogen atom, the applied electric field displaces its electron cloud a small

distance away from its equilibrium position against the proton nucleus. For the polarization of superfluid free space, the applied electric field shall displace the charge cloud of a volume of superfluid free space a small distance away from its equilibrium position against its originally overlapped oppositely charged clouds. Superfluid free space is dynamically polarizable, and particle pairs with opposite charges can be created from superfluid free space, which are evidence that dynamically polarizable superfluid free space consists of dynamically overlapped opposite charge.

There shall be some interesting reason behind that the effective polarizable volume of superfluid free space V_α is approximately the same as the effective polarizable volume of a ground state hydrogen atom at approximately $0.621\times 10^{-30}m^3$, then the scalar electric polarizability coefficient of dynamically polarizable superfluid free space shall be able to be calculated as $\alpha' = 4\pi\varepsilon_0 V_\alpha \approx 6.91\times 10^{-41}\, Asm^2/V$. For the monochromatic electromagnetic wave per cycle, its total polarization energy shall be:

$$U = \mu_{ind}E = \alpha' E^2 = hf \tag{20}$$

It is exciting to notice that equation 20 is similar to equation 8, with $V_{eff}\varepsilon_0$ in equation 8 replaced by $\alpha' = 4\pi\varepsilon_0 V_\alpha$ in equation 20. How can the correctness of the equation 20 be verified based on different evidence? Let us try to calculate the highest possible frequency limit of photons that polarizable superfluid free space medium can withstand from equation 20. We know that the Schwinger limit for free space is $E_s \approx 1.32\times 10^{18}\, V/m$, substitute it into equation 20, the highest possible single photon frequency that superfluid free space medium can withstand is derived as $f \leq 1.82\times 10^{29} Hz$. Interestingly, the highest frequency of ultra-high energy photons has been detected experimentally is in the magnitude of approximately $10^{28} Hz$ to date (24), it is just slightly lower and quite close to the predicted upper limit frequency of superfluid free space from equation 20, which supply us an independent evidence of the correctness of equation 20. Coincidentally, hydrogen is the most abundant element in our Universe, and a dynamic equilibrium is established between ground-state hydrogen atoms and superfluid free space having zero-point fluctuations through ground-state hydrogen atom – vacuum (free space) interactions [25].

DISCUSSIONS

The electromagnetic plane-wave solutions to Maxwell's equations, derived under the idealized assumption of zero conductivity of free space, imply that electromagnetic waves in the absence of scattering or absorption of matter particles can propagate indefinitely in free space without energy dissipation. While this approximation is effective for engineering applications on terrestrial scales, it becomes unrealistic on astronomical scales. Free space as an integrated dynamically polarizable superfluid medium, its electrical conductivity cannot be strictly zero, as long-range Coulomb interactions between dynamic electromagnetic dipoles and appeared charge pairs with opposite charges prevent the conductivity from being zero. Superfluid free space medium is polarizable and particle pair with opposite charges can be exited from polarizable superfluid free space, which are evidence that free space consists of dynamically overlapped opposite charges. It is worth to point out that the displacement of opposite charge clouds while particles consist of dynamic electromagnetic dipoles moving through the polarizable superfluid free space medium will unavoidably create a tiny frictional force and a tiny displacement current, which may be

negligible small but strictly non-zero. Consequently, both normal photons and material particles must experience a finite—albeit extremely tiny frictional force as they traverse dynamically polarizable superfluid free space medium.

Within the prevailing cosmological paradigm, cosmic redshifts are mainly attributed to the stretching of photon wavelengths by an expanding space. This interpretation rests fundamentally on the assumption that electromagnetic waves propagate through free space without energy dissipation. However, if free space is experimentally demonstrated to possess a non-zero electrical conductivity and to exert a small nonzero frictional force on normal photons and matter particles propagating through it, then normal photons and matter particles must dissipate a minute amount of energy during propagation through free space. In that case, the physical basis of expanding-space and Big Bang cosmological models would require re-examination. Notably, recent work has reported experimental evidence for vacuum (free space) frictional forces for matter particles [26].

Analyses based on the full set of Maxwell equations and Poynting's theorem above show that a dynamically polarizable superfluid free space medium must indeed have a tiny but nonzero conductivity. The present work provides a theoretical determination of this conductivity quantitatively. Within this framework, the Hubble constant emerges as the intrinsic relaxation frequency of the dynamically polarizable superfluid free space as an integrated grand medium. Furthermore, the energy dissipated per cycle by an electromagnetic wave propagating through the dynamically polarizable superfluid free space medium—obtained directly from Poynting's theorem—matches exactly the energy dissipated by a photon particle modelled as a propagating lightly damped oscillator experiencing extremely low frictional force. This precise correspondence provides a striking demonstration of the wave–particle duality of photons.

The dynamic polarizability of superfluid free space is derived, and the maximum electromagnetic wave frequency that the dynamically polarizable superfluid medium can sustain is obtained correspondingly with the Schwinger limit. The predicted upper-frequency bound is slightly higher and approximately a magnitude above the highest photon frequencies observed experimentally to date.

Recent deep-field observations by the James Webb Space Telescope (JWST) further highlight potential limitations of the standard ΛCDM cosmological model. JWST has detected bright, massive galaxies at extremely high redshifts ($z \approx 14$), corresponding to an epoch roughly 300 million years after the hypothesized Big Bang event [27-33]. These galaxies appear comparably evolved to like much older nearby galaxies, raising the question of how such mature structures could form so rapidly in the early Universe. This discrepancy has become known as the "impossible early galaxy problem" or "Universe age crisis." Additional tensions challenging the standard ΛCDM model include the Hubble tension, the spatial curvature tension, the S_8 structure-growth tension, and the CMB lensing amplitude A_L tension [34-39]. Although Big Bang cosmology is claimed to be supported by four principal pillars—cosmic expansion, the origin of the cosmic background radiation, light-element nucleosynthesis, and the formation of galaxies and large-scale structure, there are major theoretical problems with every supporting pillar.

The primary observational evidence supporting the first pillar, the cosmic expansion, is the cosmic redshift z. According to the standard cosmology model, the observational evidence available for supporting space expansion is:

$$1 + z = \frac{R(t_0)}{R(t_e)} = e^{H_0(t_0 - t_e)} \quad (21)$$

where $R(t_0)$ is the scale factor at the present time, $R(t_e)$ is the scale factor at the photon emission time, H_0 is the Hubble constant. However, within the standard ΛCDM Big Bang cosmology model, the Universe is assumed to evolve through distinct eras with different scale-factor dependences, including a radiation-dominated epoch with $R(t) \propto \sqrt{t}$ and a matter-dominated epoch with $R(t) \propto t^{2/3}$. These predicted behaviours differ significantly from the empirical redshift relation expressed in equation 21, hence, there is no direct supporting evidence for these hypothetic expanding eras. The observational evidence implied by equation 21 instead points toward a free space (vacuum)-energy-dominated exponential expansion, $R(t) \propto e^{\sqrt{\Lambda/3}t}$, where Λ denotes the cosmological constant [40]. Yet the interpretation of Λ presents the longstanding cosmological constant problem: the value inferred from the vacuum (free space) energy density of the observable Universe is many orders of magnitude smaller than the vacuum zero-point energy predicted by quantum field fluctuations. Cosmological inflation theory based on quantum field fluctuations, introduced to resolve early-Universe problems such as homogeneity, isotropy, and flatness, faces several major theoretical challenges, including fine-tuning requirements, a proliferation of model variants, unknown nature and origin of the inflation field, unknown pre-inflation period, graceful exit and multiverse implication problems [41]. Without the hypothesis of inflation, the Big Bang cosmology model cannot account for the large-scale homogeneity and isotropy that form the basis of the cosmological principle. In contrast, dynamically polarizable superfluid free space model automatically fulfils the basis of the cosmological principle.

If the hypothesis of the undergoing expansion of the Universe is acceptable, then spatial and temporal translation symmetries must be broken continuously. Such symmetry breaking would undermine the foundational conservation laws of energy and momentum. Additionally, gravitational, thermodynamic and electromagnetic laws valid under present-day conditions would not necessarily apply to earlier epochs of the proposed continuously expanding Universe, because of the breaking of the foundational conservation laws of energy and momentum. This raises important questions: would the binding energy of the hydrogen atom remain approximately 13.6 eV during recombination and decoupling? Would the electron rest energy $(0.511\ \text{MeV})$, proton rest energy $(938.27\ \text{MeV})$, and neutron-proton mass-energy difference $(1.29\ \text{MeV})$ remain unchanged during nucleosynthesis and early galaxy formation?

Applying present-day physical laws, physical constants and parameter values across multiple evolutionary stages of the hypothesized accelerating expansion of the Universe — as is standard practice in the Big Bang cosmology—becomes problematic while spatial and temporal translation symmetries are continuously broken. Matter particles are excited states of free space fields, free space and matter particles co-exist with each other to form an integrated and interconnected physical system, they cannot be isolated completely, they shall obey the same set of fundamental laws of physics as an integrated system. It is unreasonable to allow only local parts of the observable Universe for example galaxies to obey the foundational conservation laws of energy and momentum, meanwhile, allowing free space and the observable Universe as a whole to violate the foundational conservation laws of energy and momentum.

Another interesting feature often noted in standard Big Bang cosmology models is that the product of the scale factor *R(t)* and the temperature *T(t)* of free space remains constant throughout stages of cosmological evolution.

$$R(t)T(t) = constant \tag{22}$$

Equation 22is a thermodynamic equation, it has nothing to do with Einstein's general relativity; however, it is essential for the fulfilment of Wien's displacement law of black-body radiation. Thermodynamically, it holds only under the condition that the dominant cosmic components behave as an ideal blackbody radiation field in quasi thermodynamic equilibrium state, for example, the adiabatic expansion is a quasi-static process that occurs infinitely slow, so the system can be always infinitesimally close to thermodynamic equilibrium. This allows us to define state functions like pressure and temperature meaningfully at each point of time along the expanding path. From a purely thermodynamic standpoint, firstly, the state functions of the system undergoing a quasi-static process are path independent, it is impossible to figure out how many stages the process has experienced from an initial stage to current stage because of the memory lost effect. Secondly, the existence of stages of the epoch of inflation or exponentially accelerating expansion becomes impossible, as such rapid expansion would preclude the quasi-thermodynamic equilibrium state demanded by equation 22. Basically, equations 21 and 22 cannot be both correct at the same time for the hypothesized rapid space expansion. These considerations underscore the numerous conceptual difficulties and internal inconsistencies within the standard Big Bang cosmology models.

There are more challenging problems within the standard Big Bang cosmology models, for example, what is there outside the surface boundary of the entire expanding space volume? When the space expanding speed is much less than the light speed, will the light energy escape across the expanding boundary surface? When the space expanding speed is higher than the light speed, what will be inside the newly increased volume of space because of the fast space expanding? It is either completely empty because even lights are unable to catch up, or pre-existing electromagnetic and gravitational fields will be overstretched to something with unknown behaviours, even electromagnetic and gravitational forces can only transmit at light speed through electromagnetic and gravitational fields. If we have already lived in an era of space expansion at a rate faster than the light speed according to the Big Bang cosmology models, every galaxy will be in isolation without gravitational and electromagnetic interactions already.

If instead, sufficiently large as the observable Universe is, the net energy exchanging across its remote and approximately static surface boundary with outside will be able to be balanced out, hence, the total energy of the observable Universe would be approximately conserved. Even a small net gain or loss of energy for the entire observable Universe across its remote boundary surface, which either is negligible small in comparison with the total energy of the entire observable Universe or could be treated as a small transient perturbation. The observed cosmic microwave background radiation exhibits an almost perfect blackbody spectrum at a temperature of approximately 2.726 K, with a peak wavelength near 1.9 mm, which fulfil Planck blackbody radiation law and Wien's displacement law, this isotropy and blackbody character strongly suggests that the observable Universe behaves as a cavity in dynamic global thermodynamic equilibrium dominated by photons. Given these considerations, it is scientifically valuable to explore

alternative physical mechanisms rather than the mainstream Big Bang paradigm for understanding the true origin of cosmic redshifts, the Hubble constant, and other cosmological phenomena. There is an urgent need for a fundamental paradigm shift to establish a logically consistent theoretical framework capable of providing a coherent and interconnected understanding of the Universe's underlying physical nature without breaking the fundamental laws of physic, which will be better for the application of computer simulation and AI assisted analysis.

CONCLUSIONS

The weakly damped electromagnetic wave equation and the associated dispersion relation for electromagnetic waves traveling through superfluid free space—treated as an extremely low-loss, dynamically polarizable grand medium—were rigorously derived from the full set of Maxwell equations and Poynting's theorem with unique solutions. The relationship between the attenuation coefficient and the minute electrical conductivity of dynamically polarizable superfluid free space was established quantitatively. When combined with the standard definition of cosmological redshift and its exponential dependence on the Hubble constant, this analysis revealed a direct link between the Hubble constant and the conductivity of dynamically polarizable superfluid free space as an integrated grand medium. Within this framework, the Hubble constant is identified as the intrinsic relaxation frequency of the dynamically polarizable superfluid free space as an integrated grand medium.

The electrical conductivity and electrical resistivity of dynamically polarizable superfluid free space were calculated quantitatively from the Hubble constant and the vacuum permittivity. A striking result is that the electrical resistance of the observable Universe, idealized as a cubic domain bounded by the Hubble length, is equivalent to the well-known free space impedance of approximately 377 Ω. This correspondence suggests that fundamental constants such as ε_0, μ_0, the vacuum impedance Z_0, the Hubble constant H_0, and the speed of light c are intrinsic parameters governed by the electromagnetic properties of the dynamically polarizable superfluid free space as an integrated grand medium.

Employing Poynting's theorem, the energy dissipated per cycle by an electromagnetic wave propagating through dynamically polarizable superfluid free space as an integrated grand medium was shown to equal to the product of Planck's constant and the Hubble constant. This rate of energy dissipation matches precisely the energy loss per cycle experienced by a photon particle modelled mechanically as a lightly damped propagating harmonic oscillator. The exact correspondence between these electromagnetic and mechanical models provides a compelling demonstration of photon wave–particle duality within this theoretical framework. The dynamically polarizable superfluid free space model automatically fulfils the basis of the cosmological principle and the fundamental conservation laws of physics, which shall be a better model for the application of computer simulation and AI assisted analysis.

However, mainstream Big Bang cosmologies, including the advanced ΛCDM model, rest on the foundational assumption that electromagnetic waves propagate indefinitely through a perfectly lossless free space, with cosmic redshift interpreted as wavelength stretching due to free space expansion. If free space is experimentally confirmed to possess

a non-zero electrical conductivity and a finite frictional coefficient, then energy dissipation during photon propagation becomes unavoidable, and the foundational assumption underlying expanding-space cosmology models would be no longer valid. Recent experimental reports of non-zero vacuum friction of matter particles lend support to this possibility. Analysing results based on the full set of Maxwell equations and Poynting's theorem reinforce the conclusion that polarizable superfluid free space, viewed as an integrated dynamic grand medium, must exhibit a nonzero electrical conductivity—an effect that should become experimentally accessible with future experimental measurements.

Tiny attractive forces between dynamic electromagnetic dipoles imply that photons as dynamic dipoles also attract each other weakly. These interactions are crucial for understanding the distinctive properties of photons, including the existence of superfluid state and the extremely low friction force experienced by particles moving through superfluid free space. Tiny attractive forces between dynamic electromagnetic dipoles may help to unify the understanding of gravitational force and electromagnetic force as well. Low energy superfluid liquid photons tend to flow freely and permeate uniformly throughout the observable Universe. However, in astrophysical hot spots, low-energy superfluid liquid photons are excited into higher-energy normal photons, reducing local superfluid liquid photon density and drawing additional superfluid liquid photons inward, while the excited higher-energy normal photons disperse outward into the vast and cool superfluid free space at the light speed. This two-fluid photon system constitutes a dynamically polarizable superfluid free space as an integrated grand medium whose dynamic polarizability suggests that, the observable Universe behaves as an effective blackbody cavity, consistent with the fluctuation-dissipation theorem.

Treating free space as a linearly polarizable superfluid medium provides a natural approach to describing the behaviour of normal photons from microwave to gamma-ray frequencies. By assigning the equivalent effective polarizable volume of superfluid free space as the same as the ground-state hydrogen atom while free space interacting with a single electromagnetic wave oscillation, the maximum electromagnetic frequency sustainable by the dynamically polarizable superfluid free space as a grand medium was quantified. Combining this analysis with the Schwinger limit yields a predicted upper bound frequency for superfluid free space, which is slightly higher and remarkably close to the highest photon frequency observed experimentally to date.

The discussion also highlighted conceptual tensions and logical inconsistencies within standard Big Bang cosmological models, including issues in the origin of the cosmic background radiation, light element nucleosynthesis, the formation of galaxies and large scale structure, especially the reliance on present-day physical laws, physical constants and parameter values across widely different and hypothetical expanding cosmic epochs while the fundamental conservation laws of physic are violated due to the breaking of spatial and temporal translation symmetries. Matter particles are excited states of free space fields, free space and matter particles co-exist with each other to form an integrated and interconnected physical system, they cannot be isolated completely, they shall obey the same set of fundamental laws of physics as an integrated system. If the hypothesis of the exponential expanding of the Universe is acceptable, then every galaxy in the Universe will be in isolation without gravitational and electromagnetic interactions already. These considerations point toward the need for a fundamental paradigm shift to establish a logically consistent theoretical framework capable of providing a coherent and

interconnected understanding of the Universe's underlying dynamic physical nature without breaking the fundamental laws of physic, which will be more suitable for the application of computer simulation and AI assisted analysis.

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