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Locality of superposition principle is dictated by detection processes

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Abstract

Both classical and quantum physics thrive on the superposition principle (SP), yet the first one takes it as a local effect and the second one assumes it as a non-local phenomenon. We take SP as a tool to bridge the two worlds into one causal frame work by introducing extended interpretations on each one of the mathematical symbols and operators representing the photo detection equation for the case of various two-beam interferometer experiments. The experiments dramatize classical locality. The locality argument arises because the recorded energy re-distribution due to superposition of fields is due to real *energy exchange* through *field-dipole interaction*, and not due to field-field interaction. EM fields do not interact with each other in absence of material dipoles. All QM interactions are mediated through amplitude-amplitude stimulation, which is at the root of superposition principle. The detector dipoles attempt to respond to the sum of all the locally superposed EM fields, if allowed quantum mechanically, actualizing the principle of superposition. The energy exchange by the dipoles follow the standard prescription, ensemble average of the square modulus of all the superposed amplitudes, $\left\langle \sum_p \vec{\psi}_p^* \cdot \sum_q \vec{\psi}_q \right\rangle$ but for this paper, $\vec{\psi}_p$ represents the undulation of the detector dipoles induced by the p-th EM field rather than the field itself. The summation is carried out by the dipoles when allowed by their intrinsic quantum properties.

Key words: (i) locality of the superposition principle, (ii) locality of interference; (iii) reality of superposed fields; (iv) reality of energy exchange process; (v) detectors sum the effects of superposed fields; (vi) finite time of quantum interaction; (vii) quantum probability inherent in quantum interactions.

1. Introduction

Today's advanced physics is much closer than Einstein was in unifying a large number of interactions (forces) in nature [1,2] behind the emergence [3] of all the micro (e.g., single cells) and macro (e.g., galaxies) systems out of a basic set of elementary entities (particles and fields). It is apparent that the observable cosmic universe is a single continuum in spite of the apparent and staggering diversity, and space itself is a very rich "medium" [1]. That the space possesses important physical properties were appreciated since the foundation of Physics: (i) Newton's law of long range gravitational attraction remains effective through cosmic "emptiness", (ii) Coulomb, Ampere, Faraday's laws regarding short range electrical and magnetic attractions and repulsions led to the recognition of dielectric constant and magnetic permeability of vacuum, ϵ_0 & μ_0 , (iii) Maxwell's framing the EM wave equation led to $c = 1/\sqrt{\epsilon_0\mu_0}$, (iv) Einstein's Relativity led to bending of light by the "curved" cosmic medium in the neighborhood of stars by gravity, (v) Quantum Mechanics and its grand evolution led to the recognition that there are "background fluctuations" and "quantum foams", and (vi) astrophysicists have recently recognized that a very large portion of the cosmic energy is buried behind "dark energy" and "dark matter". The purpose of Physics is to organize our diverse observations due to different phenomena by enforcing *logical congruency and conceptual continuity* between them with the help of theories that guide us to visualize *the real physical processes* behind all interactions, including those that are successfully predicted by quantum mechanics. However, this vision has remained so elusive [4] over the last century that attempts to re-construct the processes behind the superposition phenomena as "causal" and "real" is considered mere illusion in the mainstream scientific thinking [5-9]. The subject of this paper is an attempt to assign such reality for the case of optical superposition phenomenon in classical and quantum optics. While "single photon interference" and the associated "non-locality" of the interference phenomenon appear to be an accepted fact in the established literature, Panarella has demonstrated with a very careful set of experiments that superposition ("interference") fringes become unobservable when the rate of propagation of the EM field energy on the detector is literally reduced to one unit of "hv" per second [10].

1.1. Readings of the detectors are our only hard knowledge. We "see" the world only through the "eyes" of the detectors (sensors) that we have discovered so far. All observables are essentially based on some measurable transformation in our detectors. The transformation can take place only when some energy exchange is allowed by the laws of nature, whether classical or quantum mechanical, between the entities when they are *physically superposed* within the range of their operating forces. Thus, physical superposition is universally behind any and all natural *processes* and all observations necessarily imply change (transformation) in both the detector and the observed entity through exchange of energy. Accordingly, we consider all transformations in nature are causal and local. Collectively, both the galactic evolution in the cosmo-sphere (using all the four forces) and the living cellular evolution (using dominantly the quantum mechanical electromagnetic force) in the biosphere, appear to be highly causal. We assume that the *emergence* [3] of a harmonious [1] and highly causal universe is founded on the causal behavior of all elementary interactions; probability (diverse possibilities) should not be interpreted as absence of causality. If self-interference were the general

behavior in nature, the universe would have been in a constant chaotic state, instead of being always in a state of change that appears orderly, systematic and causal as if always cyclically evolving from galactic gas to stars to intelligent cellular lives. Appearance of the orderly superposition fringes are a special case of the generalized superposition principle. It is an outcome of interactions between a set of simultaneously superposed fields and a detector array where the phases of the fields vary in an orderly and periodic manner.

We are forced to try to construct a model of the universe from a diverse set of apparently disjoint sensory perceptions; and some times the same phenomenon is reported to us differently by different sensors (detectors). Thus, we are prone to develop multiple theories to map different segments of the same universe. Further, on a fundamental level, we still do not completely know any of the elementary entities that constitute, photons, atoms and the molecules that constitute our perceptible material universe. Thus, all theories, by definition, are provisional, and must be repeatedly revisited and refined from the foundation up as our knowledge advances through ages. We cannot afford to accept any of these successful bodies of knowledge as final or complete or the ultimate model to be emulated. We still do not know how many more different “detectors” and “fields” are still there remaining to be discovered. With the success of every major new theories (driven by major paradoxes and a new paradigm), the scientific edifice has to be reconstructed anew from the foundation up to bring complete logical congruency and conceptual continuity between the new and the old. The construction of the scientific edifice is not like building a pyramid through the discovery of more and more similar stones based on the successes of the current theories, even though these successes are our only guide towards modeling a more complete universe. Thus, as in the allegorical story from ancient India, we are still effectively the same “blind men” who were asked to sense an elephant by touch and model it even though they have never “seen” its real shape!

1.2. Success of the amplitude driven Superposition Principle indicates a dominantly undulatory macro and micro universe. The causal Superposition Principle (SP) of “amplitudes” was long ago well developed in many branches of classical physics; quantum mechanics (QM) has just co-opted the concept with great success by amalgamating it with the concept of quantized energy exchange observed in the micro world. The classical world seems dominated by macro material bodies and the energy exchange is essentially kinetic and continuous. For a limited set of classical undulatory phenomena like water and sound waves, string vibrations, pendulum oscillations, electrical circuit oscillators, etc., the energy exchange precedes an interaction of the superposed amplitudes and phases and the energy exchange is always continuous, although the exact amount is dictated by the widths of the resonances. However, in the world of quantum physics, all interactions are driven by superposed complex amplitudes and energy exchanges are mostly discrete as if the entire QM world consists of undulatory entities. Thus, the SP plays a unique role in the microcosm whenever energy exchanges are strictly governed by quantization rules. However, we should recognize that it is not necessarily the size that invokes the rules of QM; rather, it is the energy exchange process. Thus, in simple scattering experiments, atoms and electrons can directly exchange kinetic energy by any amount, which can be analyzed by classical mechanics without the need of invoking SP and QM. Whereas, the molecular excitations and

transitions in a small DNA segment, attached to a huge chromosome, are governed by the SP and QM (electromagnetic interaction) together.

Undulatory behavior of QM entities does not necessarily imply that they have to be real waves like those in water, or need to be guided by some mysterious pilot waves. Undulating pendulums anchored on the same wall, undulating electrical oscillators within the range of each others EM fields, are all analyzed by superposition of harmonic functions. Their behavior is captured correctly by the harmonic “wave-like” functions and the classical SP; we do not assign “wave-particle duality” to these device interactions. Similarly, quantum entities have internal undulations which are appropriately represented by the complex amplitudes of Schrödinger’s “wave” functions. Like the pendulums or the LCR oscillators, their energy exchange processes are driven by wave-like mathematics of harmonic phases and resonances due to their internal undulations, except that the energy exchange is quantized. Thus, the enormous success of QM only begs for the development of future theories that can help us map the dynamical structures (internal *processes*) of the elementary particles, atoms and molecules, which will reveal their undulatory behavior more vividly [11, 12, 51]. We do not consider that the particles have associated “pilot waves” (de Broglie model) or that they are plane waves. Modern technology has learned to move these space-finite particles, one at a time, by appropriate nano-tip tools. Even at zero mean velocity when held by the nano tips, they do not show infinite spatial indeterminacy, as per $\delta x \delta p \geq 1$, or, $\lambda = h / p = \infty$. The locality of particle interference is the subject of a separate paper.

1.3. Our conceptual approach to bringing causal harmony, Reality Ontology.

The purpose of this paper is to demonstrate that the causal harmony between the experiential reality and the actual *processes* undergoing in nature can be brought within the framework of current QM formalism by staying focused on the following assumptions: (i) For any entity to “exist” in nature it must have space and time finite expanse rather than being a geometric point. (ii) For all observable transformations (detections), the *process* requires real physical superposition of the interacting entities within the physical range of the operating force between them (which defines our locality). (iii) For superposition of multiple entities of similar kind, the detecting entity must be able to sum all the simultaneous influences on it to make the “interference” effects manifested. And (iv) the mathematical representation of this superposition effects must map the actual physical interaction process. Our approach will be to demand conceptual continuity between the micro world depicted by the equations and the macro world of detectors. Accordingly, we will impose, what we call “Reality Ontology” (RO) on the QM formalism by demanding: (i) one-to-one correspondence between each mathematical symbol and an actual state of an entity in nature and (ii) one-to-one correspondence between each mathematical operator and the theory-allowed interaction processes between the states of the adjoining entities (mathematical symbols). We understand that RO is a stronger demand than EPR [13], but it is in the spirit of the very first sentence of this controversial, but highly stimulating paper: “In a complete theory there is an element corresponding to each element of reality”. By demanding such a *process driven interpretation* for each and every mathematical symbol and operator in a theory, we will be able to discover the power and the beauty behind its success, as well as its limits. Such an approach will then guide us to develop continuously evolving theories towards the grand unification in mapping every interaction in nature and visualizing

every entity and their interactions in the universe. Reductionism and synthesis (“emergence”) have to advance hand-in-hand [3].

1.4. Our observational premise, non-interaction of EM fields. This paper attempts to introduce locality, reality and causality to Schrödinger’s ψ using the observable phenomenon of optical superposition (“interference”) and its detection process based on an obvious but neglected fact that light beams do not interact with each other by themselves. Unlike material particles, the EM fields do not scatter or interact with (operate on) each other. In the absence of perturbations by any material medium, light beams propagate through each other without modifying each others energy distribution either in the space or in the time domain. In fact, on a fundamental level, this is true for all wave phenomena. If one carefully generates a pair of space-finite propagating beams of waves either in solids or liquids or gases and let them cross through each other, the two beams will appear unperturbed beyond their physical volume of superposition. However, within the volume of superposition, we can observe with our sensors (scattered light, etc.) that the medium sustaining the wave phenomenon exhibiting loci of stronger or weaker undulations, or “interference” fringes of superposition. Such fringes due to superposition of multiple material waves are a manifestation of the observable medium that sustains it. These observations usually do not destroy the waves since the energy dissipation due to scattering of the observing signal is usually minuscule compared to the medium’s inertial and kinetic energies due to their mass. Unfortunately, the cosmic medium that sustains the EM waves is not observable to us. Further, because of lack of inertial energy, the EM waves can be observed only “destructively” by inserting detectors within the physical volume of the beam and absorbing a part of the “wave” energy, and thereby perturbing it irrevocably, especially when the EM waves are weak. Our limitations, so far, in detecting the relative motion of the cosmic medium, can then be hypothesized by claiming that the undulation of the EM vectors do not require anything physical to move, as is required for water or sound waves. In fact, the grand success of Maxwell’s equation tells us so: it is only the gradient of the EM vector potential that transversely undulates periodically in time while moving on with a fixed velocity. The question is whether the particles can be successfully described as stable, energetically quantized and self-looped “material vector field potentials”, like some complex 3D vortices [11, 12, 51] in the same stationary cosmic medium. This hypothesis is logically encouraged by the facts that EM waves, being the simplest type of transverse field gradient undulations, have the highest possible velocity that cannot be attained by the self-looped vortices as their inertial mass prohibits them, which has been successfully captured by Special Relativity ($m = E / c^2 ; m = m_0 / \sqrt{1 - v^2 / c^2}$).

In section 2, we identify a series of paradoxes between the current interpretations and the detection processes behind the superposed light beams. These paradoxes strongly justify re-visiting the non-locality aspect of SP, which is generally accepted as a part of the Copenhagen interpretation [14]. Section 3 presents several experiments to underscore the critical roles played by the detectors. It is the detecting dipoles that facilitate the summation of the effects of the superposed multiple fields, and thereby make the effects of superposition become manifest to us. We have also underscored that different detectors report differently the effects of superposition of the same set of fields. But the conceptual harmony come together when we appreciate that light does not interfere with

light. In section 4, we introduces the Reality Ontology (RO) on the mathematical symbols and operators of QM formalism for the photo detection process and provide reality interpretations to (i) ψ , (ii) the conjugation operation $\psi^*\psi$ and (iii) the ensemble average on the conjugation operation $\langle \psi^*\psi \rangle$. These interpretations go beyond the Copenhagen School but are within the spirit of Born's and Schrödinger's original interpretations for ψ [14]. We come to the conclusion that while a quantum device can absorb only a discrete amount of energy during a particular transition ($\Delta E = h\nu$), this required total energy (ΔE) can be derived from interaction with multiple superposed EM fields of same frequency ν . Further, such interactions (state preparation) could be simultaneously influenced by the energy available from linear and nonlinear interactions with the fields due to background noises and vacuum fluctuations. Such “many body” interactions are clearly implied by the SP and are not negated by the QM formalism.

2. Conceptual Paradoxes

2.1. Paradox of unperturbed crossing of light beams and their “interference”:

For centuries, we have been using the expression, “interference of light”, in spite of the undeniable observations that light beams do not interact with (operate on) each other. They cross through each other unperturbed. Light is also forever invisible to us. We have not been able to infer anything about the nature of light through direct light-light interaction. We are still struggling to observe the extremely weak effects between light beams predicted by QED and Relativity (gravitational effect) [15]. We always “see” light through the “eyes” of some material detectors (atomic and molecular dipoles or their aggregate) that undergo some measurable transformation by absorbing energy from the EM fields. Accordingly, our understanding of the nature of the same light beam will always be differently “colored” by the different “QM-goggles” worn by the different atomic and molecular detectors.

The paradoxes abound further. In spite of the fact (i) that the time-frequency Fourier theorem implies the possibility of the synthesis of a light pulse by free-space superposition of multiple continuous wave optical frequencies and (ii) that the Maxwell's wave equation accepts any linear combination (superposition) of its sinusoidal solutions, EM fields do not operate on each other to redistribute their energy in space or in time. If light interacted with light, with light pouring in from trillions of stars from every directions, the visual universe, instead of appearing steady, would have always been full of glittering speckles in space and in time; and the instrumental spectroscopy could not have discerned the Doppler shifts of the individual star light and predict the “expanding universe”. Or, on our Earth, the wavelength domain multiplexed (WDM) communication, the back bone of our internet revolution, would not have worked; all the useful data would have evolved into random temporal pulses within the hair-thin fibers (which does happen if we fail to manage the nonlinear interactions over the very long length of the fiber conduit materials).

If superposed light beams do not create the “fringes”, then how do we routinely observe the bright and dark “interference” fringes on energy absorbing detector array and how do the beam splitters (passive dielectric boundary) succeed in redirecting the energies from two opposing beams into one or the other direction [16a] in various interferometers? It is the response characteristics of the dipoles of the material medium to the superposed EM fields. When two opposing electric vectors try to drive the same

dipole in a detector, it cannot undulate (get stimulated) and hence it cannot absorb energy from the superposed fields even though the fields are passing right through it; the location gets registered as a dark fringe! If we remove the detector array from the domain of superposed beams, the beams will propagate out as if they have never experienced each others presence.

For a typical beam splitter, an incident beam experiences a relative 180° phase shift at the boundary between the reflected and the transmitted beams. A second coherent beam (phase steady) arriving on the same spot, but from the opposite direction, can now dictate which way the resultant field energy will be directed from the beam splitter depending upon the relative phases and amplitudes of the two beams on the beam splitter [16a, 17]. The energy will be directed in the direction for which the phases of the two beams are matched. Thus, in the presence of two coherent but opposing beams, a 50% beam splitter could become a 100% reflector or a 100% transmitter! This effect is even more dramatic for the case of a Fabry-Perot interferometer (FP) consisting of a pair of plane parallel beam splitters separated by a distance. Irrespective of the finite reflectivity of each of the beam splitters and their spatial separation, the FP can also behave like a single 100% reflector or a 100% transmitter (as if the plates were absent). This classically obvious behavior becomes very instructive when one attempts to formulate the evolution of the response of a FP to a time finite pulse and tries to understand in terms of indivisible photons vs. classical wave packet [16b, c]. It is to be noted that the incident beams on the beam splitter(s) must be collinear with identical phase fronts for this kind of perfect energy re-direction to take place. If the Poynting vectors of the two beams are non-collinear, the beam splitter treats them as independent, sending the energies of each beam in both directions as if they were not superposed. However, the physical effect of the superposition of these beams can be observed on a detector array as spatial fringes after the beam splitter. This clearly implies that the dipoles on the beam splitter are capable of sensing the co-linearity and the phases of the Poynting vectors (direction of energy flow) of the incident beams [16a]. Thus, one can recognize that the coherence theory should be recast in terms of the correlation between the dipole undulations induced by the EM field to incorporate the physical properties of the detectors that dictate our observations. Coherence functions represented by simple field-field correlation are devoid of physics of real interactions [16a].

A careful investigation of the processes behind the spatial distribution of energy on a detector array (fringes), or the re-direction of beam energies in one specific direction from a beam splitter surface, clearly indicates that the superposition effects are *local*. This is because the material dipoles, responsible for summing the effects of multiple superposed beams, are physically very small and *must really experience the effects of the multiple fields simultaneously*. The mathematical expressions for all these effects are easily derived from Maxwell's classical expressions for the electromagnetic fields [17] without directly converting them to the actual dipole undulations, assuming it be always understood in classical physics. Unfortunately, the standard QM interpretation ignores this "understood" part, and effectively eliminates the real physical role played by the material dipoles, as if light beams interfere by themselves. Paradoxically, QED declares photons to be Bosons, and finds no measurable interactions between electromagnetic fields, and yet it promotes the concept of "single photon interference", requiring the unnecessary imposition of non-locality on the SP [5-10, 18-23].

2.2. Paradox of non-interaction of light and time-frequency Fourier theorem.

We have just underscored that light beams, when superposed on each other in free-space, do not modify each other. But, the time-frequency Fourier theorem paradoxically overrules this “non-interaction” and hence it is important to explore the consequences of this theorem in classical and quantum physics. The Fourier theorem claims that an arbitrary pulse $E(t) = e(t)\exp(-i2\pi\nu t)$ can be synthesized by free-space superposition of a set of infinitely long EM frequencies $\tilde{E}(f)$ spread over a band given by Eq.1a. The mathematically congruent inverse transform of Eq.1b implies that for given time-finite EM field amplitude $E(t)$, its spectral effects can be treated as consisting of a band of spectrum $\tilde{E}(f)$. We are deliberately using “ f ” for the mathematical Fourier frequencies to distinguish it from the actual carrier frequency ν of the EM field.

$$E(t) = \int_{-\infty}^{+\infty} \tilde{E}(f) \cdot e^{-i2\pi ft} df \quad (1a)$$

$$\tilde{E}(f) = \int_{-\infty}^{+\infty} E(t) e^{+i2\pi ft} dt \quad (1b)$$

Careful readers may raise the potential “counter” example that we do produce short pulses from lasers by superposing multiple longitudinal modes of a laser [24]. This is true, but one can do so only through the mediation of broad band saturable absorbers. The summation effect of the longitudinal modes is carried out by the complex molecules of the medium; their molecular relaxation time and the cavity round trip time must be chosen appropriately for “mode lock” to work [24]. Interestingly, the Eq.1a and b have been recognized as non-causal in the literature time and again and various mathematical manipulations have been developed to “contain” this non-causal infinite integral by “truncation” [25, 26].

How is Fourier theorem relevant to our discussions of “interference”, “locality” and SP? Eq.1 has a deep impact in the classical coherence and spectroscopy [25, 26]. Classical optics do not consider ν as the “spectrum” of the amplitude pulse, $E(t) = e(t)\exp(-i2\pi\nu t)$, with a single carrier frequency ν , even though it represents the actual physical undulation of the electric vector and is measurable by heterodyne technique (see section 3.1.3). The classical optics defines non-causal $\tilde{E}(f)$ as the “amplitude spectrum” of a time-finite EM wave packet $E(t)$ given by Eq.1b that removes the time parameter from the real signal without the support of any physical hypothesis or experimental justification. Parseval’s integral theorem showing the total energy content under $|E(t)|^2$ exactly equals that under $|\tilde{E}(f)|^2$ maintains conformity for those experiments where the measurements are carried out by integrating the spectrometer energy for the entire duration of the pulse propagation through the instrument. In fact, the author has shown that the time integrated “spectral” fringe $S(\nu)$ obtained by direct time-domain propagation of a short pulse $E(t) = e(t)\exp(-i2\pi\nu t)$ through a typical grating or a FP like spectrometers, is given by the convolution of the Fourier spectral intensity of the pulse $|\tilde{E}(\nu)|^2$ and the CW intensity impulse response of the spectrometer $G(\nu)$ [16a, c],

$$S(\nu) = \int_{-\infty}^{\infty} |i_{out}(t)|^2 dt = G(\nu) \otimes |\tilde{E}(\nu)|^2 \quad (2a)$$

$$|i_{out}(t, \nu)|^2 = \left| \frac{1}{N} \sum_{n=0}^{N-1} e(t - n\tau) \exp[i2\pi\nu(t - n\tau)] \right|^2 \quad (2b)$$

The mathematical equivalency of Eq.2a may have given the comfort in classical physics that $|\tilde{E}(f)|^2$ represents the “intensity spectrum” for the pulse $E(t)$. However, Eq.2b demonstrates the fallacy because the “spectral” fringe width, in reality, evolves with time since the effect is due to partial superposition of N-replicated and delayed pulses produced by the N-slit grating and propagating through the spectrometer, which should not be interpreted as a time varying “spectrum”; it is simply the fringe broadening, a combined artifact of the instrument and the finite duration of the light pulse [16]. For experimental appreciation of the time evolving fringes depicted by Eq.2b, see references 28 and 29. Even though the main stream literature does not recognize the limitations of the time-frequency theorem, the author has attempted to introduce the issue repeatedly in mid seventies and early eighties [16b, 27d & e].

Traditional spectrometers consisting of devices like mirrors, slits (grating) and lenses behave linearly at low intensities. The material dipoles in such devices, having femto second or shorter response times can experience only the carrier frequency ν as the pulse travels through them with a finite velocity. It is not possible for them to generate, or even anticipate the complete pulse shape of $E(t)$ and the consequent band of frequencies $\tilde{E}(f)$ demanded by the Fourier integral theorem. New frequency generation requires Raman or n-photon or nonlinear stimulation (polarization \vec{d}) of the dipoles of a material medium due to an incident field, expressed as real signal $\vec{E}_r = \vec{e}(r, t) \cos 2\pi\nu t$. The generalized linear and nonlinear dipole stimulation is given by [30], χ_p being the polarizability of order p for the detecting molecule:

$$\vec{d}_{real} = \chi_1 \vec{E}_r + \chi_2 \vec{E}_r^2 + \chi_3 \vec{E}_r^3 + \dots = \sum_p \chi_p \vec{E}_r^p \quad (3)$$

Under a linear stimulation (the first term only), the medium simply transmits, reflects and scatters the same incident carrier frequency of the field, but only at different strengths based on the boundary conditions. Accordingly, the linear time-frequency Fourier theorem cannot represent the process of new frequency generation by a medium during the linear propagation of a pulse.

Let us now connect this classical paradox to the concept of photon. Since the atoms and molecules follow the QM energy conservation rule $\Delta E = h\nu$ quite rigidly and they are usually well defined space-finite entities, we believe that the emitted pulse of EM energy that evolves into a photon $E_r(t) = e(r, t) \cos 2\pi\nu t$ must also be finite in its size, both in space and in time domain. We surmise that the classical concept of “monochromaticity” of ν imposed by the non-causal Fourier theorem and a uniquely single value for ν required by QM ($\Delta E = h\nu$), has encouraged the quantum definition of a photon as a Fourier “monochromatic” mode of undulation of the “vacuum” [31-33]. We believe that a photon carrying energy $\Delta E = h\nu$ could be adequately represented by $E_r(t) = e(r, t) \cos 2\pi\nu t$ [34, 52]. The unique value of the carrier frequency ν for a classical pulse can be measured by heterodyne spectrometry [35, 27a, b, c] and the shape of the photon wave packet $e(r, t)$ can be computed from the visibility function derived by

classical Fourier transform spectrometry of spontaneously emitted light (as in discharge lamps) [16a].

3. Experiments to underscore detectors' roles and locality of superposition effects.

Our premise is that understanding the physical processes behind the registration of the effects of superposition of multiple EM fields will help us appreciate that causality and locality are actually inherent in the detection process. Classical optics recognized that light beams of different frequencies or of orthogonal polarizations, did not “interfere” with each other and was explained as “incoherence” of light [25]. The generalized concept of non-interaction of light did not emerge because of lack of analysis of the actual detection *processes*. Perhaps, such enquiry was further dissuaded by some apparent successes of the Fourier’s time-frequency (synthesis/decomposition) theorem and mathematical acceptance by Maxwell’s wave equation of any linear combination (superposition) of its simple sinusoidal solutions. In this section we firmly establish the non-interaction of light in general by analyzing a series of experiments with two superposed light beams. We compare and contrast the responses by the energy absorbing dipoles of photo detectors with sharp and broad quantum energy levels that register “interference” fringes, and by the dipoles of energy non-absorbing (passive) dielectric boundary of beam splitters that re-directs the propagation of energies of the superposed fields.

3.1. Superposition of two frequencies: The invention of high speed photo detectors revealed that we can detect the effects of superposition of different frequencies [35]. Slow detectors and beam splitters in regular interferometers behave as though the different frequencies do not “interfere” and we generally “explain” this as due to “incoherence” [25]. This section will analyze several different experiments consisting of two superposed light beams of different frequencies using different detection conditions. In the process we will also underscore the limitations of the time-frequency Fourier theorem.

3.1.1. Superposition of two frequencies – response of photo detectors with sharp quantum levels vs. broad quantum bands. The simplest superposition of all is the combination of two steady continuous wave (CW) collimated beams, containing two distinctly different carrier frequencies. This is the simplest case of Fourier synthesis containing just two terms. The traditional mathematical equation for the linear superposition implies that the fields readjust themselves into a new mean frequency whose common amplitude undulates at half their difference frequency:

$$e_{total}(t) = e_0 \cos 2\pi\nu_1 t + e_0 \cos 2\pi\nu_2 t = 2e_0 \cos 2\pi \frac{\nu_1 - \nu_2}{2} t \cdot \cos 2\pi \frac{\nu_1 + \nu_2}{2} t \quad (4)$$

We are using real functions, instead of complex, to underscore the reality of the EM fields, whose significance will be apparent later. Neither of these new RHS mathematical frequencies is actually generated, nor are they experimentally observable. Consider two CW laser frequencies (ν_1, ν_2), approximately 2GHz apart and symmetrically straddling the Rb-atom’s resonance line (Fig.1). We are summarizing the results of our experiments here (see ref.36 for details): (i) When the superposed beams were passed through a Rb-vapor tube, the Rb-atoms did not fluoresce, demonstrating that the new frequency $\nu_{Rb} = (\nu_1 + \nu_2)/2$ was not generated, as per Eq.4. (ii) The superposed beams were then analyzed

by a high resolution Fabry-Perot spectrometer. It did not transmit a fringe resonant at $(\nu_1+\nu_2)/2$ with an amplitude undulation at the frequency $(\nu_1-\nu_2)/2$. It gave us back the two CW frequencies separately when tuned appropriately at high resolution mode. (iii) When the two beams were detected separately or as one superposed beam by a slow detector (power meter response time $<100\text{MHz}$), the meter always showed the appropriate CW power. (iv) However, when the superposed beams were detected by a 6-GHz fast detector, it generated a sinusoidal current at a frequency equal to $(\nu_1-\nu_2) = 2\text{GHz}$, and not $(\nu_1-\nu_2)/2 = 1\text{GHz}$, as per Eq.4. Perhaps, we should conclude that Eq.4 does not represent any physical processes in nature as they are not observable. The superposed EM fields had not modified each others intrinsic parameters. Since we can record only intensity of an EM field and Eq.4 represents only the amplitude, it is not fair to draw any final conclusions yet. So, let us now proceed to determine what is observable.

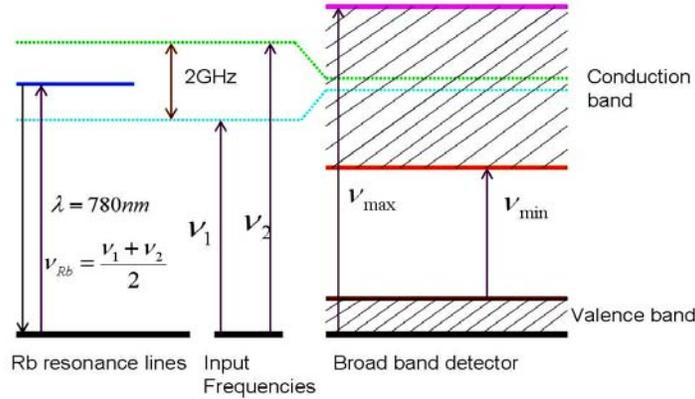


Figure 1. The diagram presents the comparative energy levels for (i) one pair of the Rb-resonance lines, (ii) one pair of input frequencies and (iii) the valance-conduction band pair for a photo conductor. When the input frequencies of the superposed light beams are above and below the Rb-excitation line, Rb-dipoles do not experience their presence in the linear domain and fails to respond to the superposed light beams. In contrast, the assembly of the dipole molecules of the photo conductors is quantum mechanically allowed to respond to both the frequencies simultaneously. As they do so, their amplitude of excitation undulates at the difference frequency (beat signal), creating undulatory transfer of electrons from the valence to the conduction band.

First, we need to recognize that the two E-fields in Eq.4 cannot be summed because they do not interact with each other to generate the summed effect. In the linear domain, each of the two E-fields induces real dipole undulations that are effectively summed by the detecting molecules before absorbing energy from the superposed fields:

$$\vec{d}_{total}(t) = \vec{d} \cos 2\pi\nu_1 t + \vec{d} \cos 2\pi\nu_2 t; \text{ where } \vec{d} = \chi_1 \vec{e}_0 \quad (5a)$$

We are assuming that the two E-fields are polarized parallel to each other and that the interaction strength for both the frequencies is of equal strength for the entire broad-band (Fig.1). In complex representation one can write:

$$\vec{\Psi}(t) = \vec{d} \exp(-i2\pi\nu_1 t) + \vec{d} \exp(-i2\pi\nu_2 t) \quad (5b)$$

The recipe for the energy exchange is to take the complex conjugate product $\vec{\Psi}^*(t)\vec{\Psi}(t)$ that yields the correct beat signal as an undulatory DC current, which is the rate of transfer of electrons from the valence to the conduction band:

$$I(t) = \left| \vec{d} \exp(-i2\pi\nu_1 t) + \vec{d} \exp(-i2\pi\nu_2 t) \right|^2 = 2d^2 [1 + \cos 2\pi(\nu_1 - \nu_2)t] \quad (6)$$

In classical physics, this same process of transfer of electrons from the valence to the conduction band is derived from the recipe that calls for taking a short time average of the square of the sum of the dipole undulations expressed as real functions, as in Eq.5a [see pp.295 & 379 of 17(b)]:

$$I(t) = \frac{1}{T} \int_t^{t+T} d_{total}^2(t) dt = \frac{d^2}{T} \int_t^{t+T} [\cos 2\pi\nu_1 t + \cos 2\pi\nu_2 t]^2 dt \approx 2d^2 [1 + \cos 2\pi(\nu_1 - \nu_2)t] \quad (7)$$

The integration period T is over only a few cycles of ν_1 or ν_2 , where $\nu_1 \approx \nu_2 \gg (\nu_1 - \nu_2)$. Accordingly, the slowly varying beat signal $\cos 2\pi(\nu_1 - \nu_2)t$ is essentially a constant during any interval of integration over the short period T. Please, note that the detector's electrical LCR integration time constant is a different issue that dictates the electronic speed of response. For example, in our case we used a 6GHz detector to detect an oscillatory current of $(\nu_1 - \nu_2) = 2\text{GHz}$. Apart from a small constant, the Eq.6 and 7 are identical. But the real representation of Eq.7 reveals more of the underlying physical processes than the complex representation of Eq.6 where the brief "time averaging" process remains buried. As the superposed fields pass through each detecting molecule, it experiences joint stimulation by both the fields over a very short period before absorbing energy from the two fields to excite its valence electron to a conduction electron. Then it recycles again. But, since the two E-fields go in and out of phase with each other periodically in time with a frequency $(\nu_1 - \nu_2)$, the strength of stimulation and the rate of transfer of electrons to the conduction band vary periodically as $\cos 2\pi(\nu_1 - \nu_2)t$. The energy exchange between sinusoidal undulators is always quadratic, $\bar{\Psi}^*(t)\bar{\Psi}(t)$ whether the stimulation is linear ($\vec{d} = \chi_1 \vec{e}_0$) or of higher order ($\vec{d} = \chi_p \vec{e}_0^p$). We are considering here only linear stimulation and linear superposition.

We can now appreciate why superposition effects ("interference") have to be local - *they are due to energy exchange processes driven by the field-dipole interaction process, and not by the field-field interactions*. It is the detector that sums the individual effects due to each of the superposed fields as undulating dipoles. The superposed beams did not modify themselves. The Rb-atoms with sharp quantum levels, which are quantum mechanically unmatched with the frequency of either of the superposed fields, could not respond to either of the fields (Fig.1). If all detectors were Rb-like atoms with sharp energy levels, we would have had difficulty discovering the superposition effects and the beat phenomenon. In contrast, fast detectors, with their excitable broad energy bands, were able to respond to both the frequencies simultaneously and there by reveal the superposition effect. The undulation of the rate of photo electron transfer from the valence to the conduction band followed the period $(\nu_1 - \nu_2)$ as per Eq.6 or 7. We believe that the confusion for assigning non-locality to the superposition effects arises because of the erroneous assumptions (i) that the fields themselves "interfere", or individual single photons interfere with themselves and (ii) that the quantum of energy absorbed by the detector must be supplied exclusively by the indivisible single quantum of photon. These two assumptions are neither experimentally justifiable [10], nor are required by the QM formalism. For the broad band detector to be able to transfer discrete electrons to the conduction band as an undulatory $(\nu_1 - \nu_2)$ but DC current, it had to absorb energy from both the fields simultaneously. Instead of hastily assigning non-locality to superposition

effects when the superposed intensities are extremely low, we should explore the quantitative and collective contributions (linear and non-linear amplitudes of excitations) on the detecting dipole due to various background noises and vacuum fluctuations, [37-40], in addition to the main superposed fields in the experiment under consideration. One should also contrast the undulatory DC current (one way electron transfer from valence to the conduction band) of the broad band photo detector from that what would be induced in a broad band LCR circuit responding to two radio frequencies within its resonance band width; the LCR circuit will produce AC currents in the circuit in response to both the radio frequencies. Electromagnetic waves behave the same way in the cosmic medium, but the responses of the sensors to these fields depend upon the *physical process* by which they absorb energy and display the observable effects.

3.1.2. Superposition of two frequencies - Michelson's Fourier transform spectrometry. It is quite instructive to analyze the above superposed fields with the help of the highly successful Michelson's Fourier Transform Spectrometer (FTS). FTS works because of "non-interference" of different optical frequencies on a passive dielectric beam splitter. Fig.2 shows the conceptual FTS set up. The output

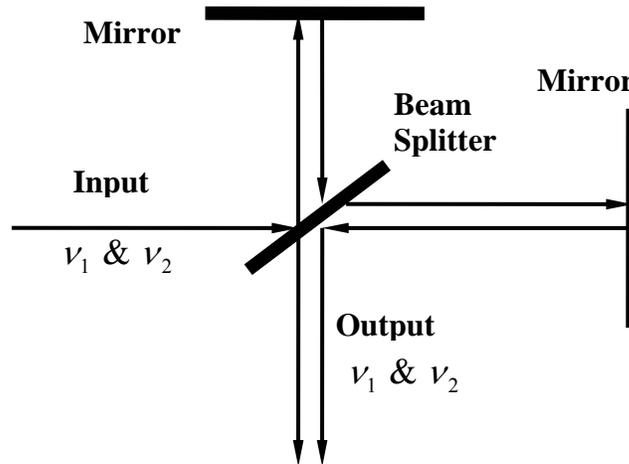


Figure 2. Michelson's Fourier transform spectrometer divides an input beam into two separate beams and then re-combines into one output beam with the help of one beam splitter and two mirrors, one of which is translated to introduce variable relative delay τ between the two recombined beams. The resultant transmitted intensity (fringe visibility) in the output direction is modulated by this delay separately for each frequency because of non-interference between the different frequencies on the beam splitter. The fringe visibility is then mathematically manipulated to conform to the 'delay'-'frequency' Fourier transform to extract the frequency information.

consists of two separate beams that are produced by a beam splitter with the help of a pair of mirrors that can introduce variable path delays. The material dipoles of the passive dielectric boundary surface of the beam splitter plays a very "active" role in re-directing the energy in the output direction for each frequency separately as explained in section 2.1. The success of FTS implies that energy non-absorbing dipoles of the dielectric boundary do not mix the amplitudes corresponding to different optical frequencies. This is why the superposition of the four dipole amplitude terms have been separated out into two separate "square modulus" terms in the second line of Eq.8 below; this mathematical transition is based on observation and is not a logical mathematical step. We have assumed that all light beams are polarized parallel to each other.

$$\begin{aligned}
I(\nu_1, \nu_2) &= \left| \left(\bar{d}e^{-i2\pi\nu_1 t} + \bar{d}e^{-i2\pi\nu_1(t+\tau)} \right) + \left(\bar{d}e^{-i2\pi\nu_2 t} + \bar{d}e^{-i2\pi\nu_2(t+\tau)} \right) \right|^2 \\
&= \left| \bar{d}e^{-i2\pi\nu_1 t} + \bar{d}e^{-i2\pi\nu_1(t+\tau)} \right|^2 + \left| \bar{d}e^{-i2\pi\nu_2 t} + \bar{d}e^{-i2\pi\nu_2(t+\tau)} \right|^2 \\
&= 4d^2 + 2d[\cos 2\pi\nu_1\tau + \cos 2\pi\nu_2\tau] \tag{8}
\end{aligned}$$

We can now manipulate the data of Eq.8 to remove the “dc” term and the constant multiplier to re-represent the “ac” fringe pattern as:

$$I_{osc}(\nu_1, \nu_2) = \cos 2\pi\nu_1\tau + \cos 2\pi\nu_2\tau \tag{9}$$

The Fourier inversion (transform) of the above equation yields the “normalized FTS spectrum”, which constitutes two sharp lines at ν_1 and ν_2 that we started out with [41]:

$$S(\nu) = \delta(\nu - \nu_1) + \delta(\nu - \nu_2) \tag{10}$$

The ‘delay’-‘frequency’ Fourier transform between the Eq.9 and 10 works because the conjugate variable pair (τ, ν) are actual physical parameters and the fringe *intensity* has been “linearized” from \cos^2 fringe intensity to a superposition of pure sinusoids by dropping the “dc” term by mathematical manipulation to make it adaptable to Fourier transformation. Further, Eq.9 and 10 do not represent EM fields, it is the modified energy pattern recorded by a detector. This is in contrast to the “time-frequency” Fourier transform of Eq.1 where the conjugate variables (t, f) supposed to represent real time undulation of field amplitudes, and yet f cannot be sensed or detected by any real dipoles in materials. Again, it is instructive to compare and contrast the roles of the various detectors we have discussed in this section that makes the same superposition effects become manifest differently because of their different types of response. Notice also that the energy absorbing photo detectors are quantized and can absorb energy in discrete units only, while the beam splitter behaves purely as a classical device and re-directs the incident energy, determined only by Maxwell’s boundary conditions and the superposed amplitudes and phases from the opposite directions.

3.1.3. Superposition of two frequencies - heterodyne spectrometry of AM pulses.

In the last two sections we underscored that Fourier synthesis is not a physical process for light beams. In this section, we test the inverse process, Fourier analysis – whether amplitude modulated light beams physically contains Fourier decomposable frequencies, as indicated by Eq.1b. We tried a variety of high resolution spectrometric experiments, but beat spectroscopy turned out to be the conceptually simplest [27, 42]. Fig.3 shows the set up and the results. We used two 1550nm semiconductor lasers. One laser had a fixed frequency, a DFB-type with about 20 MHz line width. The second one was a tunable external cavity laser (ECL) with less than 100 KHz line width. The DFB laser was used both as a CW source and as an amplitude modulated source (by using an external, 10 GHz Mach-Zehnder modulator). The two laser beams were combined by fiber coupler on to a very high speed, 25 GHz detector, connected parallel to a high speed scope and an electronic spectrum analyzer (ESA). The function of ESA is to present the undulating photo electric currents in terms of harmonics. [The ESA effectively carries out Fourier analysis of the undulatory input current with the help of its memory and software, which the atoms and molecules cannot do.] Out of a wide variety of experiments on the basic theme, we are presenting one set of data (two photographs of Fig.3) for two distinct cases: (i) both the lasers running in CW mode, and (ii) one of the lasers, the DFB,

undergoing AM at about 15 GHz. When the two lasers are running in CW mode, the beat spectrum is a narrow line as shown in the top photo of Fig.3. When the DFB laser is amplitude modulated with 2.5 GHz with pseudo random super Gaussian (almost square) data pulses of width 0.4 ns, the corresponding ESA beat signal is shown in the lower photo whose half-width (3dB down from the peak) is very similar to that for the CW case (note that the vertical scale is logarithmic). The mathematical representation of the detector current is very similar to Eq.7, but partially complicated by the fact that one of the superposed signals gets turned on and off intermittently. Here we are considering the photo current for a single pulse:

$$I(t) = \left| \vec{d}_{cw} e^{-i2\pi\nu_{cw}t} + \vec{d}_p(t) e^{-i2\pi\nu_p t} \right|^2 = d_{cw}^2 + d_p(t)^2 + 2\vec{d}_{cw} \cdot \vec{d}_p(t) \cos 2\pi(\nu_{cw} - \nu_p)t \quad (11)$$

Here, $\vec{d}_{cw}, \vec{d}_p(t)$ are the dipole undulations jointly induced by the CW reference signal (ν_{cw}) and the pulsed signal (ν_p). The Poynting vectors of the two beams must be collinear to obtain maximum beat current, which is naturally imposed by the single mode fiber combiner. In this case, one is able to discern the harmonic current, $2\vec{d}_{cw} \cdot \vec{d}_p(t) \cos 2\pi(\nu_{cw} - \nu_p)t$, at 15GHz even though its duration was intermittent for 0.4 ns (2.5 GHz) due to the modulation $\vec{d}_p(t)$. This interruption of the undulatory current at frequency $(\nu_{cw} - \nu_p)$ by $\vec{d}_p(t)$ was separately recognized by the ESA as a rectangle-like function and was separately displayed as a distribution of sinc²-like harmonics (Fourier transform of a square pulse) with first zero at 2.5 GHz (inverse of 0.4ns data pulses) centered on the origin.

If amplitude modulation were to actually generate new optical frequencies as per the Fourier theorem, then the narrow beat line would have been replaced by another broad sinc²-curve centered at the 15GHz position, exactly as wide as the sinc²-curve seen at the origin of the frequency scale. But the beat line is clearly far narrower than the traditional Fourier width $\delta f = 2.5\text{GHz}$. Thus, $\delta f \delta t \geq 1$, is not a fundamental limit in determining the actual carrier frequency distribution of an AM signal as our heterodyne experiment demonstrates. Determination of the absolute carrier frequency requires the knowledge of the reference frequency. The Fourier variable f is a mathematical parameter, not a physical variable. Classical spectrometers, like gratings and Fabry-Perot interferometers, does give extra fringe broadening that is mathematically exactly equal to $\delta\nu_f$ as would be given by Eq.2a. The corresponding fringe function (pulse impulse response) for traditional spectrometers has been derived by direct time domain propagation of the carrier frequency with a time-finite amplitude envelope [16a, c; also see Eq.2a, b above].

The key significance of this experiment is the deeper understanding that the Fourier theorem, which is a cornerstone of many branches of classical and quantum physics, is only an elegant mathematical tool, and not a principle of physics. Its successful application and consequent interpretation must be carefully secured in each separate case. We have directly demonstrated that a short optical pulse can carry a unique carrier frequency and is not burdened by the Fourier frequencies. Thus, when an excited atomic dipole spontaneously releases its discrete packet of energy ΔE in the cosmic medium, the classical model of the evolution of the photon as an EM wave packet $E(t) = e(r,t) \cos 2\pi\nu t$ with the unique frequency ν [16a], is congruent with the QM postulate, $\Delta E = h\nu$. Photon, as a CW Fourier mode of the vacuum, is a non-causal model

for a space and time finite packet of energy released by a space-finite atom in the free space. Conservation of energy demands that all physical entities be space and time finite; even a CW laser has to be turned on and off. However, we emphasize that when the atoms and EM fields are confined inside a micro cavity by enforced boundary conditions, the essential situation differs from free-space evolution [43] of a photon and the consequent interactions with atoms.

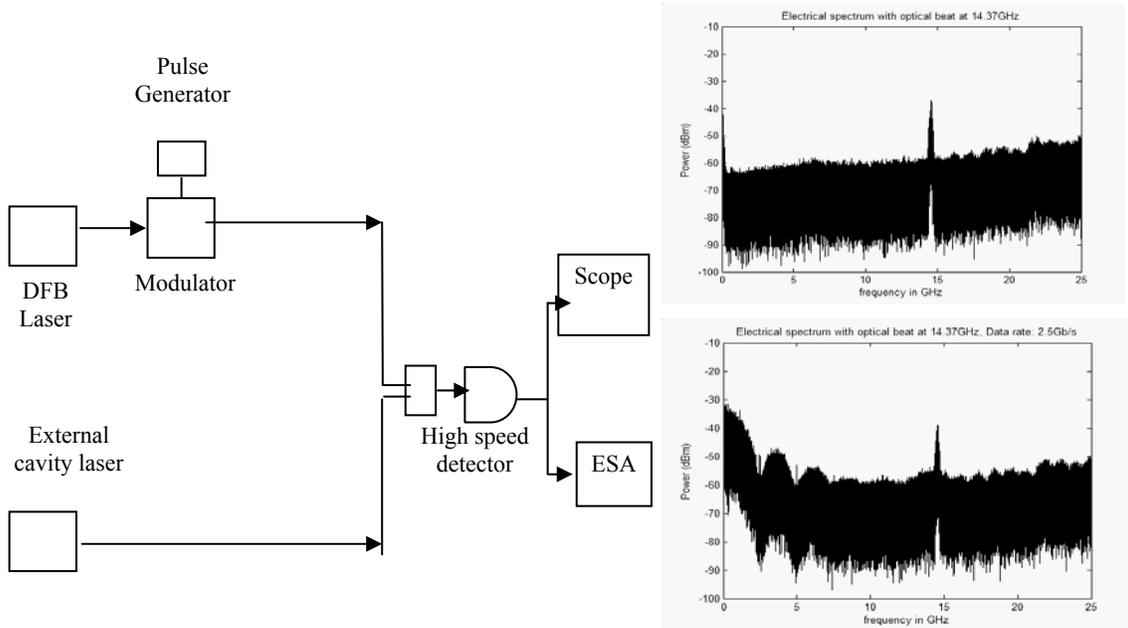


Figure 3. Left Top: Understanding the output from an electronic spectrum analyzer (ESA) fed by the photo current from a high speed detector illuminated by the superposed light beams of two different frequencies from two different lasers (ECL & DFB). ECL is always CW. The DFB laser is kept CW for the **right-top photo** and given a 2.5 GHz AM by an external modulator for the right-bottom photo. The right-top photo corresponds to an optical frequency difference of ~ 15 GHz, the beat frequency line. The **right-bottom photo** corresponds to the external amplitude modulation of the DFB laser by 0.4 ns super Gaussian (square-like) pulses (2.5 GHz pseudo random data). The carrier frequency of the modulated DFB laser remains essentially unchanged as is evidenced by essentially the same half-width (at the 3dB position) of the beat frequency lines in the two photos. It has not increased to 2.5 GHz as per Fourier theorem. The presence of AM is separately displayed by the ESA as the Fourier transform of the square-like pulses, sinc^2 -like harmonic distribution with the first zero close to 2.5 GHz location.

3.2. Superposition of two beams of same frequency: This section presents experiments with two-beam Mach-Zehnder interferometers (MZ) dealing with “coherent” light beams of same frequency but (i) by superposing the two beams with different polarizations, or (ii) by superposing two distinctly different temporal segments (pulses) from the original beam.

3.2.1. Non-interaction of orthogonally polarized light. In the last section, we underscored the summation capability of the material dipoles (active photo detectors and passive beam splitters). In this section we will justify the reasons behind concluding that active dipoles cannot simultaneously respond to, and hence sum the effects of, two orthogonally polarized EM fields, especially, when they are non-collinear to generate

spatial fringes. This will bring congruency in our explanation that the superposition effects are displayed differently by different detectors for the same superposed fields because of their uniquely different responses to them by the detectors.

Let us consider the MZ as shown in Fig.4, by mixing two beams with variable states of polarizations derived from a single frequency laser to further underscore the locality of SP. (The two side mirrors on the right in Fig.4, which introduces variable delays, will be considered in the section 3.2.2). The MZ system has four polarizers (P1– P4). When all of them are parallel to each other, one can observe two-beam fringes with perfect visibility as shown in the bottom-left picture of Fig.4. When P2 and P3 are rotated by $+45^\circ$ and -45° , respectively, to make the E-vectors of the two superposed beams orthogonal to each other on the detector plane, the superposition effect vanishes (Fig.4, bottom-middle picture), except immediately behind the centrally placed Polaroid (P4) just in front of the screen. The detection of fringe-free uniform energy is due to the fact that the isotropic detector dipoles can respond to all possible orientations of the E-vectors separately, one at a time, but not simultaneously to two orthogonal E-vectors ($\vec{d}_p \cdot \vec{d}_\sigma = 0$) incident on the dipoles at a small angle. Hence the effect of superposition is not manifesting here (Eq.12):

$$\begin{aligned} I(t) &= \left| \vec{d}_p \exp(-i2\pi\nu_1 t) + \vec{d}_\sigma \exp(-i2\pi\nu_2 t) \right|^2 \\ &= d_p^2 + d_\sigma^2 + 2\vec{d}_p \cdot \vec{d}_\sigma \cos 2\pi(\nu_1 - \nu_2)t = (d_p^2 + d_\sigma^2) \end{aligned} \quad (12)$$

When the polarizer P4 in front of the screen bisects the two polarizing vectors of the two incident beams, it transmits two modified beams with parallel polarizations but with equally reduced amplitudes. The two-beam superposition effect becomes manifest again because the dipoles can now sum the two stimulations as they can simultaneously undulate to both the parallel E-vectors. The absorbed energy becomes proportional to the square modulus of the sum of the resultant dipole stimulations (Eq.13). By rotating P4, one can continuously change the relative amplitudes of the two E-fields, and therefore the visibility of the observable fringes. For the case in which P4 is orientated at the symmetric bisecting angle, the time averaged spatial intensity variation with the relative path delay τ is given by:

$$\begin{aligned} I(t) &= \left| \vec{d} \exp(-i2\pi\nu t) + \vec{d} \exp(-i2\pi\nu(t + \tau)) \right|^2 = d^2 + d^2 + 2\vec{d} \cdot \vec{d} \cos 2\pi\nu\tau \\ &= 2d^2[1 + \cos 2\pi\nu\tau] = 4d^2 \cos^2 \pi\nu\tau \end{aligned} \quad (13)$$

Thus, once again we can see that effects from superposition can become manifest only through the response capabilities of detectors, constrained by their allowed quantum mechanical properties, as if they report the superposition effects by viewing the situation through their unique “QM goggles”! Statements like “orthogonally polarized light do not interfere”, while predicting the right observed results, hinders us from discovering the underlying *processes experienced by the detectors*. This is a simple example of extracting more physics by imposing Reality Ontology on mathematics. Further, the “locality of the interference effect” is dramatically obvious because “interference” fringes are visible only right behind the area of the small bisecting Polaroid, but not in the rest of the superposed screen area. The detector dipoles immediately behind this Polaroid can now sum the effect of the two superposed and parallel E-vectors, whose local in-phase and out-of-phase states dictate whether those local detectors can be stimulated (bright

fringes) or not (dark fringes). Explaining this complex registered energy pattern (uniform everywhere except right behind the small Polaroid) as arrival or non-arrival of “indivisible photons” dictated by the complex MZ system, will certainly require assignments of mystical properties like “non-locality” to the photons and the SP.

3.2.2. Superposition of two beams of same frequency – “interference” between photons belonging to different time pulses. The purpose of this illustration is to underscore the “temporal locality” of the superposition effect by superposing a distinctly different pair of pulses on a detector by manipulating the delay between them using the two-beam (two-path) MZ interferometer of Fig.4. Such experiments are routinely carried out in the field of holographic interferometry using pulsed lasers with different optical set up [44]; we are making a conceptual evaluation. Let us assume that the input pulse train generated from the DFB laser of section 3.1.3 can be represented by $\sum_p a(t - p\Delta t) \exp(-i2\pi\nu t)$, p being an integer. The laser cavity, the modulator, the lenses and other optical devices keep the photons well confined spatially and temporally within each pulse of this pulse train. Let us assume that the width of the pulse $a(t)$ is $\delta t = 0.1\text{ns}$ (3cm free space extension). The periodic pulse spacing is $\Delta t = 1\text{ns}$ (30cm free space separation). Since the exposure is exactly repetitive on the detector array (or a photographic plate), we are considering only one pulse from each arm of the MZ. The dipole stimulation by the two pulses can be written as (τ being the relative delay between the two wave fronts):

$$\left| \vec{d}(t)e^{-i2\pi\nu t} + \vec{d}(t+\tau)e^{-i2\pi\nu(t+\tau)} \right|^2 = d^2(t) + d^2(t+\tau) + 2\vec{d}(t)\cdot\vec{d}(t+\tau)\cos 2\pi\nu\tau \quad (14)$$

Let us now analyze two different conceptual experiments recorded photographically with two distinct delays: (i) Asynchronous case; for $\tau = \Delta t/2 = 0.5\text{ns}$, the pulse arrival on the detector is asynchronous. The pulse width being 0.1ns , they are never superposed on the detector at the same time and hence the “interference” cross-term of Eq.14 is always zero ($\vec{d}(t)\cdot\vec{d}(t+\tau) = 0$). There will be uniform intensity but no fringes. (ii) Synchronous case; for $\tau = p\Delta t = p\text{ns}$ (p -integer), the pulse arrival is synchronous. Two distinctly different pulses from the original train are now intermittently but simultaneously superposed on the detector and hence the cross-term now generates spatially stable fringes, with temporal undulation as the pair of pulses keep on arriving on the detector. Classical physics has no problem appreciating either the absence or the presence of the fringes. The amplitude modulated pulse train remains “coherent” (steady relative phase difference) to each other determined by the original coherence length (carrier frequency distribution width) of the CW laser. We do not need to complicate the interpretation with the use of Fourier transformed frequencies of the pulses.

Let us now use a 2D photo counting detector array to reveal the fringes. Again we are certain that the asynchronous case will give no-fringes, while the synchronous case will generate fringes. However, a careful analysis of the temporal records will reveal that for the asynchronous cases, the photo electrons will be registered only during the pulse duration intervals of $\delta t = 0.1\text{ns}$, periodically spaced by $\Delta t = p\text{ns}$ with intervals of no counts and uniform spatial distribution of the counts (no fringes). Again, the key point is that the photons are not “interfering” by themselves, or with each other, the detector elements are summing the effects of superposition of multiple photons from the two beams only during those time intervals when two pulses from the two MZ arms arrive on

the detector array simultaneously, establishing the hard causality of “temporal locality” requirement.

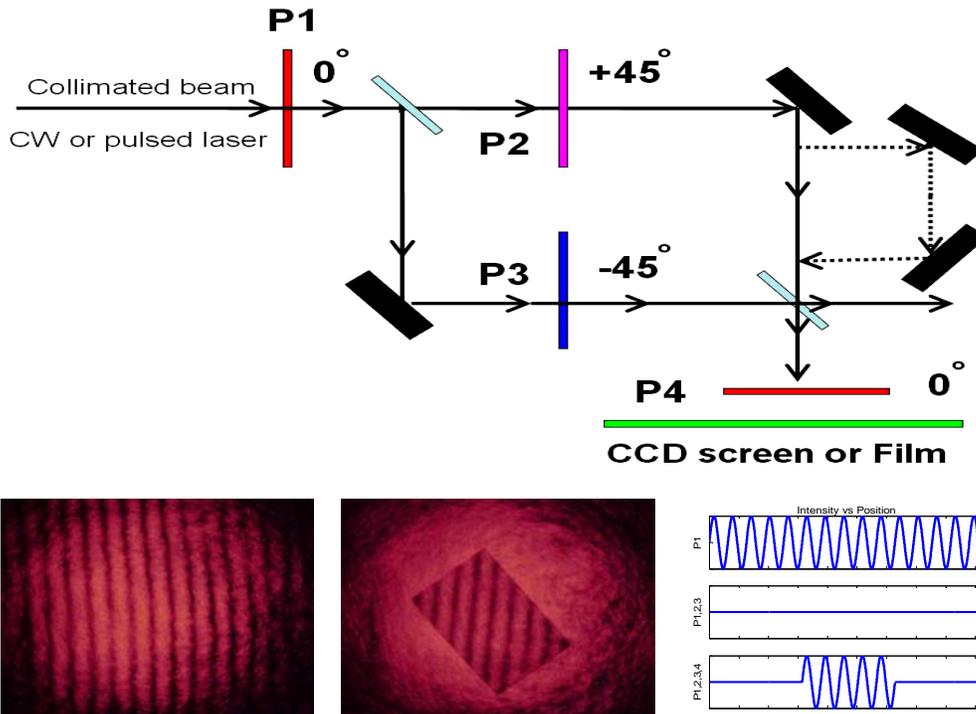


Figure 4. Top: the drawing shows a standard Mach-Zehnder interferometer with four polarizers (P1 –P4). **Bottom left:** When all of them are lined up one can observe perfect visibility two-beam fringes. **Bottom middle:** When P2 and P3 are rotated by +45° and -45° respectively to make the two superposed beams orthogonally polarized, the superposition effects vanish, except immediately behind the centrally situated Polaroid (P4) just in front of the screen, which bisects the two polarizing vectors of the two superposed beams. **Bottom right:** The sketch of the cosine fringes dramatizes the locality of the fringe positions for the two pictures on the left. This simple experiment demonstrates the central role played by the detector dipoles in making the superposition effects become observable, simultaneously underscoring the locality of superposition effects.

4. Imposing reality ontology on the equations and interpretations

So far, QM has been the best theory to facilitate mapping or constructing images of the interaction processes in the micro world. Since our measurement systems to explore the micro world appear to be classical, but the embedded “detectors” are dominantly quantum mechanical, natural confusions arise as to where the quantum-classical boundary lies in the measurement process. We believe, this is one of the root causes of confusion regarding causality and locality in interpreting QM equations. Interpreting (mapping) nature’s interaction processes by the words of our languages (based on individual scientist’s different types of imaginations and cultural biases) is the second natural source of controversies. Thus, explicit recognition and articulation of one’s epistemology is critical to avoid unnecessary controversies. The best way to maintain the objectivity in search of nature’s reality is to demand one-to-one correspondence between the mathematical entities and the interconnecting symbols with the actual processes (always imagined by us for the micro world), which are experienced by the interacting entities. We have defined such an approach as Reality Ontology (RO) in the introduction. We should distinguish between the subjective mental constructs by ourselves and the

strictly reproducible, causal and local responses by detectors in experiments. As we have mentioned earlier, this is in the spirit of EPR paper [13]. The phase driven (a) Schrödinger's QM wave equation, (b) Maxwell's EM wave equation, and the (c) Fourier theorem, all accept linear combinations of valid, individual solutions. This is the perceived "universality" behind the SP in both classical and QM physics. The mathematical correctness is not in question. *We must explicitly explore which entities actually carry out the "summation" process required for the manifestation of the SP* when the interacting entities are physically superposed within the physical domain of their force fields.

Suppose we have n-superposed EM vector fields. Then the equation below will be accepted as a natural solution by the Maxwell's wave equation and the Fourier theorem will claim that there is a new temporal re-distribution of the EM field energy:

$$\vec{e}_{total}(t) = \vec{e}_1(t) \cos 2\pi\nu_1 t + \vec{e}_2(t) \cos 2\pi\nu_2 t + \dots + \vec{e}_n(t) \cos 2\pi\nu_n t \quad (15)$$

To maintain conservation of energy, we are assuming that any and all natural signals must have finite time duration. So the vector $\vec{e}_n(t)$ represents a finite envelope function for the electric vectors. Let us now apply our reality ontology. Since light does not interact with light by themselves, the series of operators "+" in the above equation cannot represent any interaction between the superposed light beams. So, to represent a collection of non-interacting, but superposed EM fields within a non-interacting medium, we should introduce the convention [Eq.16], where the field entities are maintaining their self identities, separated by semicolons:

$$\vec{e}_{collection}(t) \subset [\vec{e}_1(t) \cos 2\pi\nu_1 t; \vec{e}_2(t) \cos 2\pi\nu_2 t; \dots; \vec{e}_n(t) \cos 2\pi\nu_n t] \quad (16)$$

We "see" light only when some material dipoles interact with the EM field and undergo some measurable transformation manifesting the presence of light. Thus, it is standard to introduce the expression $\vec{d}_n(t) \cos 2\pi\nu_n t$ as the actual dipolar undulations of the material particles under the influence of the EM field $\vec{e}_n \cos 2\pi\nu_n t$, where $\vec{d}_n(t) = \chi_1 \vec{e}_n$. The similarity of the mathematical structure is an educated guess and it appears to map nature very well as evidenced by a large array of light-material interaction experiments. Thus, the principle of superposition, as expressed by the Eq.17, to be operative, the detecting dipoles must be able to respond to, and absorb energy from, all the n-fields simultaneously,

$$\vec{d}_{total}(t) = \vec{d}_1(t) \cos 2\pi\nu_1 t + \vec{d}_2(t) \cos 2\pi\nu_2 t + \dots + \vec{d}_n(t) \cos 2\pi\nu_n t \quad (17)$$

If the quantum transition bands of the detector dipoles allow them to simultaneously respond only to a subset of the frequencies from ν_p to ν_{p+r} (same as ν_{min} and ν_{max} in Fig.1), then the effect of superposition will become manifest only for this subset of frequencies. So, the summation operators have been limited for only these terms in Eq.18 below, and segregated out by the curly brackets from the rest of the terms. We know that a silicon detector will not respond to either the high frequency (energy) X-ray or low frequency (energy) infra-red photons. Einstein's photo electric equation is valid for the cases of photo ionizations only.

$$\begin{aligned} \vec{d}_{total}(t) = & \vec{d}_1(\nu_1, t) \cos 2\pi\nu_1 t; \dots \left\{ \vec{d}_p(\nu_p, t) \cos 2\pi\nu_p t \right. \\ & \left. + \vec{d}_{p+1}(\nu_{p+1}, t) \cos 2\pi\nu_{p+1} t + \dots + \vec{d}_{p+r}(\nu_{p+r}, t) \cos 2\pi\nu_{p+r} t \right\}; \dots \vec{d}_n(\nu_n, t) \cos 2\pi\nu_n t \end{aligned} \quad (18)$$

The rest of the dipole undulations outside the curly bracket have been represented without the operator “+” because these undulations are normally too weak compared to the QM transition allowed terms within the curly bracket in the linear domain. See sections 4.4 and 4.5 for impact of the fields that are out of the quantum bands. The QM recipe for actual photo current is proportional to the ensemble average of the complex conjugate product of the collective stimulated amplitude when the field is expressed in complex form [25b, 31, 32]:

$$I(t) = \langle \bar{\Psi}^*(t) \cdot \bar{\Psi}(t) \rangle \quad (19)$$

$\bar{\Psi}(t)$ is the linear sum of all the linear amplitude stimulations induced by all the quantum compatible fields.

$$\bar{\Psi}(t) = \sum_n \bar{\psi}_n(t) = \sum_n \bar{d}_n(t) \exp[-i2\pi\nu_n t] = \sum_n \chi_n \bar{e}_n(t) \exp[-i2\pi\nu_n t] \quad (20)$$

Let us now try to introduce the Reality Ontology.

4.1. $\bar{\psi}$ is a vector and represents complex internal harmonic undulations, not wave-particle duality. The successful evolution of classical electromagnetism towards Maxwell’s coherent set of equations has been based on the observations that material media are *polarizable* as dipoles and have vectorial properties. Lorentz successfully derived a remarkably accurate form of optical dispersion theory of materials by assuming dipolar polarizability of atoms of the medium well before the atomic structure was understood. QM theory further confirmed this dipolar behavior of atoms and provided the most accurate formalism to calculate the rules of quantization and energy exchange. The semi-classical model by Jaynes and others [45-47] for the detection of photon wave packets through the induction of dipolar undulation on the quantized atoms and molecules by the “classical” E-field is also very successful. In this paper we have underscored that the summation of the effects of multiple superposed EM fields is also carried out by the detecting dipole as enhanced (bright fringe) or suppressed (dark fringe) dipolar undulations. Accordingly, it is not difficult to accept that this dipolar undulation of detecting atoms and molecules are real and physical under the influence of EM fields superposed on them. The question is, how do the particles display “interference” effects when they are sent through appropriately set up superposition experiments? This is the subject of a separate paper. However, we would like to refer the readers to recent references where “particles” are being modeled as some kind of undulating “vortex” in the cosmic medium [11] just as the EM field is a transverse undulation of the vector potential in the same medium. We have underscored this view also in section 1.2.

4.2. $\bar{\psi}^*(t) \cdot \bar{\psi}(t)$ or $\bar{\Psi}^*(t) \cdot \bar{\Psi}(t)$ implies QM-compatibility-sensing dipolar undulations for a short period before energy exchange. If we were to represent the dipolar stimulation as a real function, $\bar{\psi}_r(t, \nu) \sim \bar{d}(t) \cos 2\pi\nu t$, induced by the real electric field $\bar{e}(t) \cos 2\pi\nu t$, then the rate of emission of photo electron in individual interactions, $d^2(t)$, can be extracted only after taking short time average of the entire representative real expression, viz. $\psi_r^2(t, \nu) \sim d^2(t) \cos^2 2\pi\nu t$. However, complex representation only requires taking the complex conjugate of $\psi(t, \nu) \sim d(t) \exp[i2\pi\nu t]$, which is the recipe for photo electric detection by QM formalism. Thus, we have:

$$I(t) \sim (1/T) \int_t^{t+T} \psi_{\text{real}}^2(t, \nu) dt \equiv \psi * \psi \quad (21)$$

Our critical study of the more complex superposition effects of section 3.1 and the representative Eqns.6 and 7 do validate the need for this time averaging process. So, we assign the interpretation to this “conjugation operation” as follows. All the superposed QM entities actually and collectively carry out a short-time QM compatibility-frequency-sensing undulation under the influence of the EM fields before the eventual energy exchange can take place. Since light travels with a finite velocity, this undulation (dance) period is intuitively justifiable because the detecting dipole needs this time period of at least one cycle $t_0 = 1/\nu$ of the incident EM field to establish whether the field frequency is compatible with its internal quantum transition condition, $\nu = (\Delta E/h)$. The strength of this undulation becomes sensitive to the complex amplitudes of all the parties present and they evolve as the interactions proceed. Further, there is no necessity to introduce the concept of “sudden collapse of the wave function” because $\psi^*\psi$ represents a real QM compatibility-sensing, time-taking, conjugation operation before any quantum transition can take place. Schrödinger’s life-long insistence that ψ represents real oscillation of the atoms can now be easily appreciated.

4.4. Ensemble averaging $\langle \psi^*\psi \rangle$ is essential to accommodate uncontrollable influences during quantum compatibility undulation. During the brief moments of QM compatibility-sensing dance, the interacting entities become vulnerable to the “tapping on the shoulders” by the infinite number of ever-present (i) back-ground noise undulations, (ii) vacuum fluctuations, (iii) weak non-linear undulations induced by all the desired and undesired fields, (iv) potential Raman stimulations, (v) multi photon stimulations, etc. Since the detector dipole does not have any threshold limit against any of this infinite variety of stimulations, it is forced to respond to all these stimulations to different degrees [8, 37-40]. Since these undulations are statistically fluctuating, their collective contribution to the total energy ΔE required for the final transition is also a statistically variable parameter. The QM prescription of ensemble averaging, $\langle \psi^*\psi \rangle$ or $\langle \bar{\Psi}^*(t) \cdot \bar{\Psi}(t) \rangle$ is the only approach to reality. However, in our model ψ represents the actual strength of the undulating amplitude of the detector that fluctuates due to the influence of all the neighboring fields; it is not just an abstract mathematical probability amplitude. The origin of this statistical fluctuation in the transition is causal and real and is inherently indeterminable and uncontrollable; but they do not represent any mysterious uncertainty principle. These causal fluctuations do not represent causality violations either. The infinite number of stochastic background and vacuum undulations and the associated availability of energy exchange potential at every possible frequency, however weak, and the propensity for both the linear and the non-linear interactions between every entity make the deterministic modeling of the micro universe impossible in principle. A heuristic presentation of the complexity can be depicted by the Eq.22 where all the dipole oscillation inducing fields on the detector are real and sinusoidal; $\vec{E}_x, \vec{N}_y, \vec{V}_z$ are the various EM, noise and vacuum fluctuation fields, respectively, acting on the detector. Each curly bracket constitutes superposed effects of linear and various nonlinear interactions.

$$i(t) = \frac{1}{T} \int_t^{t+T} dt \left| \left\{ \sum_x (\chi_1 \vec{E}_x + \sum_p \chi_p \vec{E}_x^p) \right\} + \left\{ \sum_y (\xi_1 \vec{N}_y + \sum_q \xi_q \vec{N}_y^q) \right\} + \sum_z (\zeta_1 \vec{V}_z + \sum_r \zeta_r \vec{V}_z^r) \right|^2 \quad (22)$$

χ, ξ, ζ represent linear and nonlinear polarizabilities due to EM, noise and vacuum fluctuation fields, respectively, depicted by appropriate suffixes. One of the $\chi_1 E_x(\nu, t)$ fields, whose frequency ν is the most quantum compatible for the transition, will provide the dominant stimulation. But during this brief period of compatibility sensing undulations, all the other terms will be competing and will introduce statistical fluctuations at every transition requiring ensemble averaging. So the photo current will be the ensemble average of the individual transitions $I(t) = \langle i(t) \rangle$. Our attempts to seek out the real “picture” behind every process in the micro world should not be considered as “mere illusion”, even though practically it is daunting and elusive. Einstein was correct to underscore that “God does not play dice” and “Subtle is the Lord” (elusive). The trillions of electron wave functions, dictating the quantum mechanical molecular reactions in every human body cell, never compromise the locality and independence of the body’s individual organ or cell functions because of the “time evolving global electron wave functions”. Perhaps this inherent probabilistic nature of the molecular, multiple, alternate, transition potentials (due to very closely packed energy levels) allow the universe to be inherently creative, including genetic mutations, in spite of the rigid set of laws of nature! All undulating entities have a finite space and time extension that does not require violation of hard causality. In fact, this finiteness should be considered as a direct result of the Principle of Energy Conservation.

4.5. $\bar{\Psi}^*(t) \cdot \bar{\Psi}(t)$ preserves linearity of superposition principle even though energy exchange is quadratic. We want to underscore that even though the final energy exchange is “quadratic”, $\bar{\Psi}^*(t) \cdot \bar{\Psi}(t)$, the superposition principle remains linear via the initial process of field-dipole quantum-compatibility-sensing undulations and the follow-on *linear summation of all possible amplitude stimulations* before the quantum transition (quadratic energy exchange) takes place, even though the stimulation itself is always a combination of linear and non-linear stimulations induced by all the superposed EM fields and the uncontrollable and ever present noise and vacuum fluctuations. Eq.22 underscores this point and is compatible with our premise that photons, emitted by atoms as space and time finite energy, are divisible packets of EM fields during energy exchange. The required total energy for a quantum transition ΔE does not have to be provided by an indivisible photon. Thus, one could find *support in Planck’s life-long insistence* that while the atoms exchange EM energy always in discrete packets, the photons need not be indivisible “elementary particles” [14]. Electrons themselves are quantized and their binding energies in detectors are quantized. Accordingly, the photo electric effect will always consist of a discrete rate of “clicks” determined by the rate of arrival of the EM field energy, regardless of the actual nature of the photon, whether it is a classical divisible wave packet or an indivisible quantum. When the desired signal $\vec{E}_{\text{real}}(t, \nu)$ is drastically reduced for the so called “single photon” experiments; the contributions due to noise and vacuum fluctuations become significant under these circumstances [37-39, 10].

4.6. Reality ontology and mathematical theorems. All along this paper, our fundamental assumption has been that the universe is real and causal and we should be

able to understand and model it as such. However, our macro detection devices and systems, discovered so far, have failed to help us visualize the processes undergoing during each and every individual interaction. But we have several theoretical constructs with staggering successes within their own domains. While this proves that nature functions very logically, it is clear that not all of our mathematical logics are perfectly congruent with those of nature. Otherwise, we would have found the one “unified theory” by now. Our theories are our mental constructs that were developed based on our limited understanding of nature’s logics; we have not discovered “God’s Equations”. While our past and present successes strongly indicate that mathematics is *the tool* to explore nature, our failure to impose reality ontology on the successful theories based on our imaginations to map the real processes of nature can lead to blind alleys. The starting point of all of our major theories has been based on the mathematical representation of a hypothesis proposed after logical organization of diverse observed natural phenomena. Such a hypothesis (or a law) is not mathematically derivable. We have rarely assigned the stature of a principle or a hypothesis on a derivable mathematical theorem, except Heisenberg’s indeterminacy relation, which is a corollary, derived from Fourier’s theorem, emboldened by another theorem, called Schwartz’s inequality relation [53]. We should be careful in assigning the status of a nature’s principle to a mathematical theorem when it shows successful modeling to a number of experimentally observed data.

Fourier’s time-frequency theorem is one of those most successful mathematical inventions, which is a major discussion point of this paper. Based simply on our daily observations and the most sophisticated modern field theories [1, 4a], we know that the EM fields (light beams) do not operate on (interfere with) each other. That is why we cannot *synthesize* an optical pulse [section 3.1.1] simply by superposing a periodic array of CW frequencies without the mediation of saturable absorbers [36]. So the Fourier theorem “works” due to the intervention of a saturable absorber, provided we have chosen it with the right physical properties that cannot be prescribed by the Fourier’s theorem itself. We cannot *decompose* the Fourier frequencies either out of a simple amplitude pulse cut out from a CW laser. We have demonstrated that with the help of heterodyne interferometry [section 3.1.3]. This experiment also automatically implies that so-called time-frequency uncertainty upper bound $\delta f \delta t \geq 1$ does not represent any fundamental limit to all possible measurements.

With this supporting background, we present our view that, however mathematically cogent it may be, the Bell’s Inequality theorem [49, 21] cannot represent the ultimate word on “single photons interference”. Bell’s theorem does not accommodate the very basic fact that the superposition effect cannot become manifest by the fields alone; the superposed fields must be simultaneously present on the detector or on the beam splitter from the opposite sides. The physical processes behind fringe generation are different for different detectors and for different interferometric setup. As a specific example, the determination as to which port the photons will come out in an MZ interferometer is dictated by the dipole undulations of the molecules of the boundary of the re-combining beam splitter induced by the simultaneous presence of the photon wave packets from both sides. And the 180° relative phase shift of the photons experiencing the “external” vs. “internal” reflections is critical to the final result [16a]. Bell’s theorem does not capture any of these essential *physical processes*.

5. Summary and Discussions

Wilczek [1, 2] has aptly underscored that when one encounters a good number of conceptual paradoxes in a field, one should attempt to develop a better paradigm. The key conceptual contribution of this paper lies in illustrating a number of paradoxes related to optical superposition phenomena and then proposing two important concepts: (i) a paradigm shift that we have named Reality Ontology (RO), and (ii) the non-interaction between EM waves, which has been developed based on the observed fact that no wave phenomena, classical or quantum, interact with each other by themselves. Even well defined beams of waves sustained by classical material media emerge unperturbed after crossing through each other; and we observe daily that the same is true for light waves sustained by un-observable cosmic medium (vacuum). The two concepts together establish that the observed “fringes” of superposition of light beams have to be causal, real and local because the observational process is based on the capability of nanometric dipole-like molecules and their ability to *simultaneously* respond to all the superposed fields and then *sum* the induced stimulations followed by absorption of energy (detectors registering spatial fringes) or redirect the energy (beam splitters in interferometers with collimated beams). Our emphasis has been on a deliberate attempt to visualize the physical *processes* undergoing during the observation of superposition effects by demanding possible physical interpretations for the symbols and the operators in our successful equations that matches with the final observed results.

The joint application of these two proposed concepts (RO and non-interaction of EM fields) underscores that the time-frequency Fourier theorem cannot be a principle of physics, even though we tend to use it as such. Accordingly, photons should not be represented as infinite monochromatic Fourier modes in the vacuum, which also violates conservation energy. We have proposed that the photons should be represented by the causal, classical wave packets, $e(r,t)\cos 2\pi\nu t$ [16a, 34] with energy $\Delta E = h\nu$ carrying a unique frequency ν as prescribed by QM. Photons do not possess any mysterious “wave-particle duality”. They are simply space- and time-finite packets of sinusoidal undulations of the vector potential in the cosmic medium, which always propagate following Huygens-Fresnel diffraction principle. They have the dialectical property of always slowly diverging and yet grouping and regrouping themselves if the wave front is perturbed and then evolve into new sustainable beams. They can be broken up and re-assembled by diffractive processes and optical components and they can also be coalesced by the re-combining beam splitters in interferometers when they arrive with the right phases. These energy redistribution processes are continuous as predicted by classical E&M and optics. Conversely, many wave packets with the same carrier frequency can share their energy to provide the right amount of energy $\Delta E = h\nu$ for a quantum transition during photo detection processes (Eq.22). Acceptance of this many-body energy exchange, intrinsically sanctioned by QM, provides the elegant possibility to explain why quantum transitions must be inherently statistically probabilistic and yet causal.

The third important contribution of this paper is in the practical domain. RO has helped us to recognize that the “time-frequency” band-width barrier $\delta f \delta t \geq 1$, which is only a corollary of the time-frequency Fourier theorem, is not a fundamental limit in nature. So, we gathered the confidence to experimentally demonstrate that the carrier frequency content of a pure AM light pulse can be determined by heterodyne

spectrometry with an accuracy that is many orders of magnitude better than the bandwidth limit imposed by the corollary derived from the time-frequency Fourier theorem.

The staggering success of modern physics from diverse directions clearly indicates that the cosmic universe, from atto to macro domain, is a gigantic, orderly and logically evolving system but is an extremely complex one [1-4, 48]. Many of our logical and self-consistent theories have mapped some of the smaller segments of this gigantic cosmic system into separate segments of successful jig-saw-puzzles. In spite of almost a century long attempts, we have succeeded only partially to converge them into a single harmonious puzzle. Yet, we would rather sacrifice reality and causality in favor of non-local superposition effects and mysticism like teleportation through interference. The “Road to Reality” [4] lies in actively seeking to discover and model the *actual processes* behind all the individual interactions in the micro world giving rise to the “emergence of complex” [3] yet “harmonious” [1, 2] and cyclical cosmic evolution, from galaxies to cellular lives, through utilization of the lowest to the highest rate of energy utilization per unit mass per unit time [48]. We believe that our proposed principle of RO is an invaluable guide to explore these cosmic realities. Through the discussions of a small set of optical superposition experiments, we have demonstrated the need to broadly revisit all the fundamental hypotheses that helped us fit the individual sets of puzzle. We now need to modify them to impose logical congruence and conceptual continuity among them all and then reconstruct a whole new bigger puzzle piece. We have to continue such iterations indefinitely towards building a bigger and better but a single map for the single universe we experience. We are hoping to inspire the readers that the Bell’s inequality theorem [49, 21] and “single photon interference” experiments [7, 10] have not closed the debate on further exploring the quantum superposition principle. Similar critical thinking has been and is being promoted time and again by many authors [5, 6, 8-10, 12, 18-23, 27, 34, 36-40, 42, 45, 47, 50-53]. Copenhagen Philosophy is not the final answer since it does not guide us to reveal the *actual processes* undergoing in the micro world. The road to reality will be charted by those who are bold enough to climb and “ride on the shoulders of the giants” to increase their knowledge horizon a-la-Newton and at the same time recognize that all the past successful systems of knowledge are incomplete and provisional simply because they have been organized based on incomplete knowledge of our cosmic system. The road to reality lies in recognizing that the cosmic space is the final frontier; for everything appears to be manifest in it as if they are different kinds of undulations of their respective field gradients generated by induced perturbations on the corresponding built-in stresses under equilibrium!

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Résumé

Le principe de superposition joue un rôle important autant en physique classique qu'en physique quantique. Cependant dans le premier cas, il s'agit plutôt d'un effet local, alors que dans le second, on le considère comme non local. Nous utilisons ce principe comme outil pour fondre les deux mondes dans un seul ensemble causal, en élargissant les interprétations des symboles mathématiques et des opérateurs des équations de la photo détection pour le cas de certaines expériences avec des interféromètres à deux ondes avec des polariseurs multiples. L'expérience dramatise la localité classique. L'argument sur la localité vient du fait que la distribution d'énergie enregistrée liée à la superposition des champs est le résultat d'un réel échange d'énergie au moyen d'une interaction champ dipôle, et non à l'interaction champ. Les champs électromagnétiques n'interagissent pas entre eux dans le régime linéaire. Toute interaction quantique passe par une stimulation amplitude qui est à la source du principe de superposition. Les dipôles du détecteur tentent de répondre à tous les champs électromagnétiques locaux superposés selon ce que permet la mécanique quantique, réalisant ainsi la superposition de toutes les amplitudes superposées. L'échange d'énergie des dipôles suit la prescription standard, la moyenne d'ensemble du module au carré de toutes les amplitudes superposées $\left\langle \sum_p \vec{\psi}_p^* \cdot \sum_q \vec{\psi}_q \right\rangle$, où $\vec{\psi}_p$ représente dans cet article l'oscillation des dipôles du détecteur induites par le p-ième champ électromagnétique, plutôt que par le champ lui-même. La sommation est accomplie par les dipôles lorsque leurs propriétés intrinsèques le permettent.