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# *Inevitable Incompleteness of All Theories: An Epistemology to Continuously Refine Human Logics Towards Cosmic Logics*

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## Abstract

This article proposes a methodology of thinking (epistemology) to assist scientific exploration of real physical processes in nature (ontology). Our first assumption is that whatever we sense (experimentally or observationally), always represents real interactions between physical entities nature. Our second assumption is that nature evolves through causal (logical) interactions between different entities, which are validated by the very successes of our logical mathematical theories. So, our objective is to understand and visualize all the processes taking place in nature, which are at the root of cosmic and biospheric evolution. Unfortunately, we do not know any of the natural entities completely. Further, the transformations (change) that we measure or observe do not provide us with the complete information regarding neither all the forces that the interactants are experiencing, nor can they relay to us through our measuring device(s) all the information regarding any particular transformation they experience in any experiment. Thus we are forever challenged to create a causal theory about nature without inventing (imaginary) human logics to fill in the gap of incomplete information to construct a theory that hopefully will map the cosmic logics behind the interactions we are studying. To overcome this "incompleteness paradigm", we need a scientific epistemology to iteratively keep on refining our human logics in all theories and move them closer and closer to our goal of mapping the cosmic logics. This "incompleteness paradigm" underscores the inevitability of paradoxes, contradictions and confusions in our conceptual interpretations of any theory. In this article, we explore these paradoxes regarding wave-particle duality of photons and suggest possible resolutions of such paradoxes.

## Introduction

The purpose of this article is to generate sufficient doubt in the minds of the readers regarding the current definition of photon by proposing a new paradigm of thinking for doing science. Hopefully, this will entice the readers to explore the out-of-box proposals regarding what photons are presented in section III.

But, do we really need another paradigm change in thinking for doing science? We think so because some of the leading thinkers like Smolin [1] Laughlin [2] and Penrose [3] are expressing doubt about the direction of physics research. Conferences for out-of-box thinkers are being created [4,5], although these are miniscule in size compared to main stream conferences. And this book itself is an attempt to inspire thinking about photons beyond the currently accepted definition—a monochromatic Fourier mode of the vacuum. We want to underscore that our approach is that of reverse engineers by accepting nature as a creative system engineer. Everything in the micro and macro domains of nature, single cells or galaxies, are all very

complex systems constantly undergoing orderly and creative transformations through assembly, dis-assembly and re-assembly.

Today we have over half a dozen or more "solved puzzles" or theories that are logically congruent and self consistent in mapping the behavior of different domains of nature: (i) classical theory, (ii) special relativity, (iii) general relativity, (iv) quantum mechanics, (v) quantum field theories, (vi) cosmology, (vii) string theory, etc. But we have been failing to merge these separate "solved puzzle" pieces into one harmonious bigger puzzle even though the number of operating forces behind all possible transformations are only four, so far. It is important to appreciate that mathematics being pure logic, an equation "working" in modeling nature represents causally connected terms (states of interactants) by appropriate symbols (interacting force between the interactants and outcome). Physical meaning, the reality, or visualization of the interaction processes behind the equation, is a matter of human interpretation, and not a mathematically derivable set of statements. Hence, interpretations of any equation should not be considered as either unique or final. Thus, we must maintain serious scientific doubts on the imposition of interpretations like non-causality on causal mathematical relations and the underlying interactions as non-local when they represent interactions between physical interactants through forces, which are always of finite range. Therefore, our interpretation process requires a well structured methodology of thinking, or an epistemology to sort out the difference and connectivity between different *human logics* (epistemology) that have organized the theories and the *cosmic logics* (ontology) that run all the real *interaction processes* in our universe. If we treat all the "working" theories as inviolable, we will never succeed advancing science very much further. Almost thirty years of failure to find anything fundamentally new in physics clearly tells us that we need to reassess all the hypotheses that are behind all these different "successful" theories [1-3] and revisit the purpose of physics. We believe that the motto of classical physics, understanding and visualizing the physical processes undergoing in nature, should be our key guidance.

It is generally acknowledged that framing a question determines the answer we create by developing a theory around various observations. The frame of our enquiring mind, or the model of our thinking, which is varied and quite complex, determines how we frame our questions. This makes debating different interpretations of the same theory sometimes confusing, the best example being the unresolved [6] "Bohr-Einstein debate" over *reality* about quantum mechanics [7]. Another good example is our insistence on the same questions like, "what are light quanta?" [8], which has yielded very little new information about the deeper nature of light for over a century. Semi classical analysis yields most of the light-matter interactions [9]. Formalism of quantum mechanics (QM) "works" very well and Schrödinger's equation has opened up a flood gate of accurate predictions about the quantum world of micro universe. Obviously, QM must have captured a good amount of fundamental *realities* regarding interaction *processes* behind atoms, molecules and their interactions. Instead of accepting conceptual problems of QM as a guide to discover better or newer theories [10], we are mystifying nature to be non-causal whenever

our attempt to visualize the micro world becomes unsuccessful. Logically it is more self consistent to accept emergence of a chaotic and non-causal macro system out of constituent entities interacting causally but randomly. But, it is difficult to accept the emergence of our causally evolving macro universe to be built out of fundamentally non-causal micro interactions between elementary particles. Culturally we have become so accustomed to accept "nobody understands quantum mechanics" that we do not question the current interpretations and accept that QM is "complete". We are still engaged in creating wide ranges of non-causal, non-local interpretations leading to accept teleportation, delayed superposition, etc., to accommodate Dirac's statement, "photon interferes only with itself", which perhaps appeared logical in 1930.

We ought to urge the students with proactive encouragements that there must be something seriously wrong with the current interpretations of QM and initiate efforts towards finding better interpretations and eventually frame a better theory to supersede QM, just as QM superseded classical mechanics. A broadly accepted simple and rational epistemology could facilitate our understanding how we have become more inclined to invent many mathematical realities for nature rather than staying focused on discovering actual realities in action. These realities, however elusive they may be to visualize, they are manifest through incessant interaction *processes* between diverse entities, both in the macro and micro domains of the entire universe.

We need to develop a better methodology of thinking, debating and scrutinizing information gathered from new and old experiments and theories and learn to re-phrase our exploratory questions and re-evaluate the current state of understanding. In this article we propose an epistemology that will encourage the next generation to carry out such re-evaluation to advance physics [11]. We must also acknowledge at the outset that the proposed epistemology itself being a product of *human logics*, it must be scrutinized, modified, changed as we progress farther towards mapping *cosmic logics* with increasing accuracy.

## Classical Physics Nurtured the Emergence of Quantum Physics by Seeking Reality in Nature

Maxwell presented his comprehensive equations on electromagnetism in 1864 by synthesizing the already discovered rules of electricity and magnetism developed by Coulomb, Ampere, Gauss and Faraday, all of whom contributed between during the period 1736 and 1867. Lorentz utilized this knowledge to correctly attribute the generation of light by atoms as due to dipole like undulations of electrons in atoms validated by observation of Zeeman effect in 1896 in which magnetic field splits the spectral lines. This dipole model with multiple absorption lines led to the development of a quite accurate model of dispersion theory with distinct "oscillator strengths" for

the different absorption lines, which was corroborated many decades later after quantum theory was fully developed.

Before the end of the 19th century, the Rydberg-Ritz formula:

$$\nu_{mn} = cR_y\left(\frac{1}{n^2} - \frac{1}{m^2}\right) \tag{1}$$

was correctly mapping the discrete spectroscopic frequencies found from gas discharge lamps, where $R_y$ is the Rydberg constant and $n \& m$ are integers that turned out to be the "principal quantum numbers" by both Bohr's early heuristic quantum theory and later formal Quantum Mechanics. By 1900 Planck also captured another very important quantum nature of light regarding its emission and absorption through his heuristic representation of the classical experimental energy density curve for "blackbody" radiation:

$$u(\nu, T) = \frac{8\pi h\nu^3}{c^3}\frac{1}{\exp(h\nu/kT) - 1} \tag{2}$$

Some 25 years later, quantum theory did find that all light-matter interactions do correspond to quantized energy exchange of $\Delta E_{mn} = h\nu_{mn}$, establishing also the logical congruence between the Eqns.1 and 2. Noteworthy also was the derivation of "A and B coefficients" by Einstein for stimulated absorption and emission from atoms, which gave birth to lasers much later during 1960's. In view of Jaynes' [9] successes in showing that most light-matter interactions can be analyzed by semi classical approach, Dirac's $a, a^+$ do not appear to help any better understanding of the realities than Einstein's "A and B coefficients" regarding light-matter interactions. After all, photon wave packets are always "created" and "annihilated" by atoms and molecules, not by the "vacuum" that only sustains their propagations. It is important to note that the classical motto of visualizing the physical entities was at the root of Einstein's 1905 hypothesis of photon as a quantum and Bose's derivation of Planck's black body relation in 1922 using statistics of indistinguishable particles, which became the quantum mechanical foundation of Bose-Einstein statistics for spin integral particles. Several recent Nobel prizes went to people in recent years demonstrating applications of BE statistics.

Our point in summarizing these elementary classical achievements of various observed phenomena is to underscore that the platform for the birth of Quantum Mechanics (QM) and the necessary structure for formulating it were already embedded in classical physics. *Classical physics, by staying focused on how to figure out the actual processes behind various interactions in nature, succeeded in nurturing the minds of the scientists for the next revolutionary changes in our theories.* In contrast, QM, based on its rapid successes beyond expectations in computing the observable results with extreme accuracy, marginalized (and even opposed) the concept of seeking *reality* in the micro world. It taught us not to waste our energy in imagining and visualizing the actual processes going on in nature. Even after more than 80 years of maturity, QM has failed in

its leadership role to facilitate the next revolution in constructing new concepts to map processes of the micro world with further depth. We believe that this has been due to the belief system established by some of the key founders and developers of QM. For generations, we have been systematically pushed to believe that: (i) QM is a *complete* theory of the micro world; (ii) visualizing the actual processes in the micro world is beyond QM and hence beyond human capability of imaginations; (iii) the "lack of knowledge" of humans as to which way light or particle beams travel to the detector is essential to the emergence of interference patterns, etc. Heisenberg's indeterminacy relation for measurements [6,12,13], essentially a corollary of the Fourier theorem, which itself is not a principle of nature [14]. But it has been re-interpreted as incessant violation of causality in the micro world. Do we really need to, or do we measure more than one physical parameter of the same entity in any one experiment? Is the progress of physics really fundamentally limited by our lack of simultaneous measurement of two related parameters of a single entity, whether they commute or not? It is generally agreed upon in the scientific culture that all organized bodies of knowledge in use to day are necessarily provisional and incomplete because they have been constructed based on the incomplete knowledge of the universe. Yet, our enquiring mind has been trained to ask only those questions which are congruent within the logical bounds of the accepted "working" theories and their interpretations, effectively ensuring that we will never find our way out beyond the current framework of QM.

All the startup classical physics rules ("laws") were firmly rooted on seeking reality, or the deeper cosmic logics in operation in nature. The mathematical relationships were such that all the symbols represented some dynamic and/or static parameter of the state of a physical entity and the operating symbols implied some actual interaction (force law) or evolving process constrained by some conservation rule. Unfortunately, rapidly accelerating successes of the mathematical QM formalism and the concomitant exuberance diverted us from keeping ourselves anchored to repeated refinement of our starting human logics towards actual cosmic logics. We misplaced our objective of doing science as figuring out and visualizing the actual processes behind all the magnificent cosmic evolutionary events to become mere data gatherers and data correlators. We have become equation-crunchers as computers are our number crunchers. By demeaning our visualization and imagination faculties, we have made our enquiring mind subservient to a belief system that elegance, esthetic beauty and symmetry of mathematical relationships give us the power over nature and tell her how she ought to behave in carrying out physical processes.

## Accepting a Higher Order Challenge to Seek Cosmic Realities

The *purpose* of science needs to be redefined as incrementally becoming wiser and wiser towards understanding the *purpose* of the orderly evolving universe, which will then help us define our *purpose* as humans in this

universe. Irrespective of our divergent belief systems as to whether there is a pre-ordained *purpose*, we will evolve to define one for ourselves simply because of our innate desire to keep on evolving. Our sciences, so far, have wisely stayed focused on understanding and/or predicting the outcomes of interaction *processes* going on in the material universe, which are the causation behind the cosmic and biospheric evolution and appears objective (reproducible). Here we are addressing the issue of refining the methodology of studying physical *processes* in nature and leave the subjective issue of defining our "*purpose*" for social scientists.

Nonetheless, we believe that a deeper understanding of the inter-related cosmic *processes*, when sufficiently well organized by human logics (*working rules*) and refined towards cosmic logics (*laws of the universe*), our wisdom will be capable of defining and slowly refining our *purpose* hypothesis congruent with our desire for sustainable evolution and the laws of cosmic evolution. As of now, none of our organized set of human knowledge system, however successful they are, can claim to have reached the level of refinement as to have become identical with the pure cosmic logics. Accordingly, any attempt to define our "*purpose*" in the cosmic universe is bound to produce many different subjective interpretations developed by human logics belonging to different epistemological groups. Let us leave the reader with the following question. Is it possible to enlighten ourselves in understanding the *cosmic purpose* by understanding the *cosmic processes* [15], *the domain of scientific studies*?

## "Incompleteness Paradigm" or Fundamental Limits in Information Accessible Through Observations

We have created impediments towards our scientific progress by ignoring the roots of unavoidable limitations in gathering information about nature (interaction processes) from even the best organized experimental apparatus. We can "see" (or sense, or measure) incidents in the universe only indirectly through the "eyes" of the various sensors (detectors or interactants). First, none of these interactants are completely known to us. We still do not know what an electron is. Second, all interactants have inherently limited capabilities to "see" (or, respond to) all the input signals (forces or potential gradients) around it and generate discernable and measurable transformations (change) in a particular experiment. Third, all interactants have limited capabilities to relay all that it experiences through the various parts of any practical detecting system, which constitute, at a minimum, a "classical" device as the final measuring meter. We may characterize the situation this way. All sensors (interactants) "see" through vision-limiting "goggles" and "speak" to us through band-limited "channels" that are characteristically unique for each of them and not quite known to us.

We need to appreciate the deep consequences of this "incompleteness paradigm" thrust upon us by nature. We are forced to develop our logically

complete "working" equation by using incomplete experimental information by inserting innovative human logics (hypotheses) to fill the information gap, which may not be exactly mapping the cosmic logics (cosmic laws) that we are seeking to map. Thus all theories are necessarily provisional and incomplete since they are predicting only correctly measured but limited reports gathered about the interactants. Such a theory automatically limits our progress in integrating new behaviors of nature that are not logically congruent with those limited set of human logics that has already constructed the "working" equation! New parameters may not be "plugged" in arbitrarily. The fact that decades' of attempts of introducing "hidden variables" to aid the visualization of the invisible micro world phenomena could not be accommodated within the framework of QM implies that QM, inspite of its successes, is logically closed to logics behind "hidden variables". They are logically incongruent. Instead of declaring that nature is not visualizable, we should be building a new theory that can accommodate causality and locality within its framework.

A working equation needs to be almost logically "complete" (hence "closed") for it to be successful. Such an equation (theory) to work for a small segment of the undivided universe, by necessity, it must have ignored many other potential interactions due to other forces and/or under logically very different contexts. Thus, the only way to integrate multiple successful theories, akin to partially solved jig-saw-puzzles of the universe, is to break them apart and try to re-assemble them as one bigger jig-saw-puzzle by selectively rejecting and/or modifying some of the human logics towards mapping infallible cosmic logics. Therefore, we should be careful not to jump into conclusion with any working theory that we have correctly captured all the necessary cosmic logics behind the set of interactions represented by the theory.

## Identifying Logical Process Steps Behind All Observations as Semt

### SEMT and Locality of Interactions Defined

SEMT stands for ***S****uperposition* ***E****ffects as* ***M****easured* ***T****ransformations*. We are implying that all scientific measurements, classical or quantum, arise out of interaction between our chosen interactants. Since all of our validate-able information about any phenomenon comes through experimental observations and the gathered information is always incomplete, it is necessary for us to identify all the logical process steps behind all measurements. This would help the process of applying human logics to construct the best possible mathematical equation to map the observations under consideration while filling the missing gaps of information that cannot be provided by the experiments. When a working theory is already well matured, we can re-assess the human logics behind its construction by re-visiting the related

experimental process steps while being cognizant that there was missing information that is essential to refine our theory towards mapping cosmic logics more accurately.

- We can scientifically measure only re-producible quantitative *transformations* (changes in states) that are experienced by our interactants (or detector-detectee, or sensor-sensee interaction).
- Any transformation in a measurable physical parameter requires *energy exchange* between the interactants.
- The energy exchange must be guided by at least one *force of interaction* between the interactants and it must be strong enough to facilitate the exchange of energy, which are usually constrained by unique characteristics of each interactant.
- All force rules being range (distance) dependent, energy exchange between the interactants requires that they must experience each other as *local* or *physically superposed* entities (experience each other within their sphere of influence).

In summary, the interactants in an experiment must be physically *superposed* (present) within the range of the *interacting force* that will allow for some *energy exchange* followed by some t*ransformations* that is measurable for us through some classical meter. Superposition effect is thus an *active causal and local process*, and not a passive mathematical principle only! Interpretations of successful mathematical formulation must recognize this *reality*. Operationally, real physical superposition, as implied by our dissection of all interaction processes, is a concept of high physical significance both in classical and quantum mechanics because it implies *locality* for all interaction processes. This understanding also provides a path to reduce the epistemological gap between the classical mechanics and quantum mechanics. Purpose of physics is to map, visualize and articulate the physical interaction *processes* that facilitate the energy exchange leading to change and evolution.

## Generalized Validity of SEMT Reality

We have claimed *locality* for all physical interactions, classical or quantum mechanical. In view of the dominant role of currently accepted interpretation of QM, we feel that following explanations will be useful to accept our broad proposition behind SEMT.

*(i). Gravitational force (GF):* GF is weak; its range is long. Our planets within our solar system constitute, of course, a strongly bound *local* and superposed system. Air molecules in our lower atmosphere are tethered by Earth's gravity, but cannot effectively display the influence of the significantly weaker Sun's gravity. Yet, all cosmic entities, from galaxies, stars, planets, atoms and elementary particles, the entire observable material universes is effectively superposed on each other or *local* as far as GF

is concerned; however, the degree of influence on each other is dictated by their mass and distance.

*(ii). Electromagnetic force (EMF):* EMF is relatively stronger than GF, but the range is generally shorter. Atoms within a molecule are superposed and *local* to each other by EMF. Stability of atoms, molecules and their all possible transformations, including their interactions with electromagnetic waves are all dictated by this force. The dominant part of the biospheric evolution is driven by this force. The superposition effects due to the EMF from the molecules within a biological cell may or may not be effective depending upon the type of molecule and their physical separations.

*(iii). Weak Nuclear force (WNF):* Radioactivity and related isotopic nuclear transmutations are a by product of this force. The range of WNF is of the order of the size of the atomic nuclei. The superposition effects due to two radioactive atomic nuclei within the same bound molecule are negligible within the first order analysis.

*(iv). Strong nuclear force (SNF):* Our slow physical evolution relies on the stability of an array of nuclei held together by this SNF, built into stable atoms and molecules by the EMF and held on to the surface of the Earth under the atmosphere by the GF. Different atoms within the same molecule are superposed as far as electromagnetic force is concerned, but their nuclei are not superposed as far as SNF is concerned within the first order analysis.

Thus, *locality* as we have defined in the context of SEMT is unique and force dependent. Even though the physical range varies from the size of a nucleon to almost "infinity" (for galaxies under mutual gravitational influence), it is logically self consistent for any interaction process to generate the measurable transformation. Physical entanglement (measurable influence) between different entities can be operative only within the range of the operating force. Interaction free energy exchange or measurable transformation is not allowed by our SEMT platform. We understand that our reality epistemology is a stronger demand than EPR [7], 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* we will be able to check and re-check our assumptions behind all theories as our knowledge evolves and expands.

## Proposed Epistemology for Refining Human Logics Toward Unknown Cosmic Logics

### Defining CC-LC-(ER)1,2 Epistemology

We believe that the "trouble" is not with physics [1], but lies with the lack of application of a well articulated epistemology. All organized human bodies of knowledge in general and physics in particular has evolved by applying the CC-LC epistemology. We seek out *Conceptual Continuity* (CC) among

a group of diverse but related set of observations. We iteratively and creatively impose *Logical Congruence* (LC) among the entire set to find a higher level of organization leading to a coherent map or a theory. Human *belief* in this CC-LC epistemology and intuitive *faith* in one continuous and logically functioning universe have been paying off enormously. Our cumulative successes in physics indicate that nature's evolutionary processes do consist of logical patterns & organizations. Otherwise, our mathematical theories based on pure logic, would not been so successful. Thus far, the CC-LC-epistemology has helped us "solve" several separate little pieces out of the giant cosmic jig-saw-puzzle. But we are having trouble in integrating them into one coherent puzzle.

We should also recognize that mathematics is a secondary by product of our rational thinking and imaginations. Mathematics must be subordinate to our thinking and imaginations, not the other way around. Newton invented differential calculus because he needed a tool that has the built-in capability of enforcing *logical congruence* (LC) among apparently very different kinds of observations (those of Brahe and Keppler; Galileo's "stone and feather" falling, his own "apple falling", acceleration of objects, etc.) under one conceptually continuous (CC) or a harmonious model of nature.

As articulated earlier, all of our "successful" theories are constructed based on limited information gatherable from experiments. But however limited, the very success implies that the theory has captured some cosmic truth in some form. Accordingly, it is time for further attempts in *Extracting and Extrapolating Reality* $(ER)_1$ from the working theory. There are two great benefits. First, *extraction* of reality aids visualization of some correctly predicted phenomenon that was not originally anticipated. Second, *extrapolation* of potential reality either to visualize some processes deeper than before or an attempt to integrate a different phenomenon within this theory will help us understand the limits and "bottle necks" of the theory. This step of reality epistemology will help refine a theory and may also help find the limits of its validity in accommodating new observation, which will then pave the way for a new logical frame work to construct a higher level theory.

The state of classical physics went through this $(ER)_1$ epistemology phase during the last quarter of 19$^{th}$ century and the first quarter of the 20$^{th}$ century, which paved the way for the discovery of quantum theory, as articulated in section 2. However, we have been neglecting the power of this $(ER)_1$ epistemic process by not applying them on the quantum theory, which could have paved the way for discovering next generation of higher level theories.

Current physics has been developed based essentially on reductionism—matter into elementary particles and radiations into photons. We have neglected to develop a formal methodology of thinking that would help appreciate the emergence of new complex properties and rules when a complex system is formed out of very many simpler elements or sub-systems. We now need to add another iterative feed back loop of $(ER)_2$—*E*mergentism *and R*eductionism on to CC-LC-$(ER)_1$ and create a higher level of methodology, CC-LC-$(ER)_{1,2}$ epistemology. We need to understand the real physical

is very orderly. Validation of light as discrete quanta will require carrying out very careful experiments with isolated single atom emitter and single atom detector [17]. Careful experiments with extremely reduced intensity from a laser do demonstrate that expected diffraction pattern rings cannot be recorded simply by increasing the recording time [18]. Recognition that *interference* is as an emergent phenomenon as detectors' behavior has enormous consequences both in the classical and quantum optics that we have been neglecting at the cost of progress in physics! After centuries of unresolved struggles with wave-particle (or corpuscular) duality of light, if we keep on framing our enquiring question as "what are light quanta?", we cannot get any better answer than already given by Copenhagen Interpretation of quantum mechanics. However, the readers are advised to consult the articles summarizing the dominant main stream views [8,19,20].

## The Purpose of CC-LC-$(ER)_{1,2}$ Epistemology

This reality seeking epistemology will help us iteratively refine, reject and re-define some of the founding human logics behind our current "successful" puzzle pieces (theories) and let them evolve closer and closer to the actual operating cosmic logics. Thereby, make the various theories more congruent (amenable) to each other towards possible unification, through CC-LC epistemology but at a higher level. As we have underscored earlier, logically closed equations, mapping successfully different subsets of cosmic phenomena based on incomplete knowledge of the universe, will necessarily require modifications on their original fundamental premises (hypotheses) before they can accommodate, or amalgamate into one coherent model. We do not have any other options but to start with human logics, organize related observations into small solved puzzles and then reorganize and or break them to create a bigger puzzle, and so on, to move closer towards solving the cosmic puzzle. Application of such iterative feedback loop is akin to successful biological evolutionary intelligence.

Four molecules GACT (Guanine, Adenine, Cytosine and Thiamine) in all possible permutations in the DNA-helix, starting with the simple combinations of GC and AT, have been gathering and processing feed back information from the real world into intelligence and wisdom allowing our sustainable evolution. CC-LC-$(ER)_{1,2}$ epistemology explicitly calls for utilization of all possible feed back loops within and between theories to refine, enhance and integrate them to higher level theories while facilitating the visualization of the real physical processes behind all interactions that we are modeling [Fig.1]. The key goal of real genes (or their genetic algorithm) is sustainable evolution of all biological specie collectively. Accordingly, if CC-LC-$(ER)_{1,2}$ epistemology succeeds in understanding and emulating real genetic algorithm, it will be applicable not only in science, but also in developing and advancing all organized bodies of human knowledge, which are deeply connected to our sustainable evolution. After all, from biospheric processes to human thinking, they are all physical processes bound by the

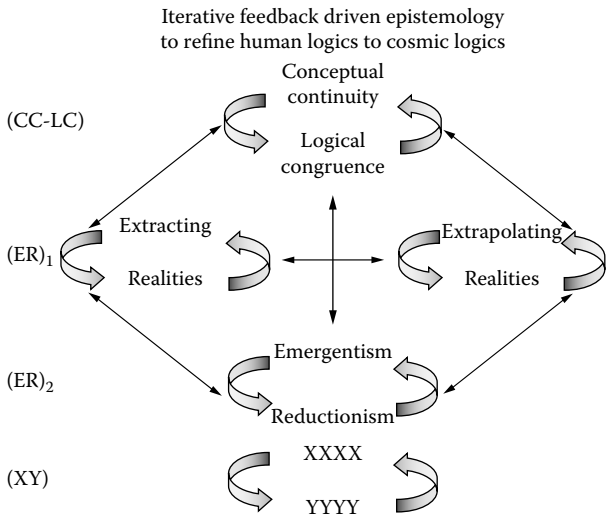


**FIGURE 1**
Logical flow-diagram for CC-LC-$(ER)_{1,2}$ epistemology. The lower (XY) segment is undefined to underscore that all of our epistemology must remain flexible and open to radical revision as our understanding of the universe advances. Our proposal attempts to emulate our biological genetic algorithm, which is at the root of intelligence, derived from the desire to assimilate all possible feed back information applied proactively towards a specific goal of sustainable evolution even though the actual path of the evolution is not known. Similarly, we do not know the path that will take us from the starting platform of human logics to the final goal of understanding the cosmic logics, yet we must attempt to create one. We still do not fully understand how our genetic system creates the intelligence. Our fundamental premise is that we are starting from ignorance; we are deprived from gathering complete information about anything and hence we must remain open to ever refining epistemology for advancing our science. Yet, the proposed epistemology, attempting to emulate biological genetic algorithm, is very generic. Accordingly, it is applicable to developing and advancing all organized bodies of human knowledge that are deeply connected to our sustainable evolution.

same set of basic laws of nature we are trying to understand. Understanding nature's evolutionary processes has a deeper pragmatic value for us. Our successful and sustainable evolution clearly demands better and better technologies over uncontrollable natural calamities by developing newer technologies to protect ourselves. That is the teaching of our DNA.

### *Ancient Example of* CC-LC-$(ER)_{1,2}$ *Epistemology*

Some 2500 years ago Gautama Buddha of India gave the best allegorical story on how to apply CC-LC-$(ER)_{1,2}$ to visualize and understand the subtle and elusive "material" universe. How would a group of people, blind from birth, describe and visualize an elephant? It applies equally well to us today as we are trying to describe and visualize the cosmic elephant. First we need to recognize that as far as scientific vision is concerned, we are literally blind.

We never see or sense the world directly. Even our human vision is essentially a set of interpretations created by our brains that is convenient for our evolution, not what the actual image is on the retina. We see vivid colors in bright light and we recognize the same colors even in faint light, even though the photons do not have any colors at all. The images we "see" are erect, even though the actual image on the retina is always inverted! We do not see anything! We only interpret the patterns registered by the rods and cones, congruent with our biological evolutionary needs, dictated collectively by the molecules GACT, which are behind the intelligence of our DNA!

In seeking reality about the elephant, the blind people have to search for conceptual continuity (CC) among all their individual sensory inputs by iteratively applying all possible logical congruence (LC) among them. [Diversity of input is critically important.] Even then they will only get the outer shape of the elephant. A deeper level of understanding about how such a shape can be a conscious living being requires the blind people to iteratively refine the model of elephant by first applying $(ER)_1$—extracting and extrapolating their perceived realities to become commensurate with models of other living species they are aware of. Then they need to apply $(ER)_2$ – *emergentism and reductionism*, to delve deeper into understanding the emergence of elephant's living behavior out of many parts and organs. Today, we "scientifically" understand the *emergence* (E) of any living being out of molecules and DNA's that are highly *reduced* (R) constituents, but we still do not fully understand the emergence of consciousness. Buddha's story also underscores that the existence of the elephant is real, irrespective of whether the blind people sensed it at all or understood its existence in the strict sense. So, philosophies giving serious credence to questions like, "did the tree fall if nobody heard of it?" is a useless diversion if we want to seriously explore the realities of the emergent cosmic universe. The bacteria in the woods are fully cognizant of the availability of lots of food from the fallen tree! Human philosophy cannot hinder their evolutionary physical drives.

We can learn to visualize the invisible interaction processes in the domains of atoms and elementary particles only when we gather the wisdom to acknowledge that we are literally blind. We do not see anything; we only interpret using incomplete information!

## Why Elegant Mathematics and Visualizations are not Enough

Although it is obvious from the prolonged stagnant state of physics that elegance and symmetry of mathematics is not complete guide to explore nature, we present two simple examples to underscore the necessity of constantly applying CC-LC-$(ER)_{1,2}$ epistemology. First, let us revisit why we have rejected Ptolemy's geocentric model. It required several free parameters to allow Ptolemy to construct "epicycles" for each planet separately to accommodate relative "wiggle" motion relative to our Earth. Keppler, based on Copernicus' suggestion, showed that Helio-centric model fits the observations more coherently and logically without many free parameters except a central force

of attraction by the Sun. Over the following centuries, Newton formalized the "central force" as gravity, Einstein generalized it to "curvature of space" and we are still at dilemmas as to how to accommodate the measured velocity discrepancy of the stars in the outer periphery of the galaxies. The point is we need continuous refinements in our modeling based on discovering actual realities rather than inventing mathematically elegant ones. But, if we take the example of today's "successes" of various String Theories using many dozens of free parameters, Ptolemy's geocentric model can be revived with many fewer free parameters than the String Theories require.

Let us look at another example with elementary mathematics. Pythagoras' relation can be replaced by a pair of relations that I discovered in my 7th grade school from a particular example of a right angled triangle with sides 5, 4 and 3, as many other students must have:

$$[c^2 = a^2 + b^2] \quad \text{vs.} \quad [c = 2a - b \text{ where } (\text{b}/\text{a}) = (3/4)] \tag{3}$$

Even though Pythagoras' quadratic relation can be derived from the pair of linear relations suggested above, which makes the two relations mathematically equivalent, my teacher favored the visualizing power of the geometric construct proposed by Pythagoras. Because, one can literally construct the unit squares on each side of a right angled triangle and see for himself why Pythagoras' relation makes sense, which is not so obvious from the other approach based on a particular geometric ratio of the sides. Advanced physics is replete with many such examples like (i) the equivalency of Heisenberg's matrix formulation vs. Schrödinger's "wave" equation and (ii) equivalency of Feynman's "path-integral" vs. Tomonaga-Schwinger's "variational method". (iii) Sudarshan showed that Wolf's classical coherence formulation is equivalent to Glauber's QM representation. Can one of the mathematical constructs guide us better than the other in seeking and visualizing the actual interaction processes in nature? This is a relevant question from the stand point of the epistemology we are proposing. The key point is to recognize that not all "working" human logic has a unique one-to-one relation to the cosmic logic. Thus we must develop a methodology of rational iteration process that can help us keep on refining our working human logic towards the "nirvana", the cosmic logic. Continuous debate and rational doubt over even the most successful theory is at the core of doing science. No human organized theory is ever complete!

## Fourier Theorem in Optics and Interference as an Emergent Phenomenon

The Fourier theorem that effectively represents superposition principle in mathematical form is quite enigmatic [14]. It has never been declared as a principle of nature but it plays a principal role in all sciences, especially, in physics. Its pervasive success in physics and optics derives from its foundation. It represents linear superposition of harmonic functions. Physics deals

with fields and particles that are all based on different kinds of harmonic undulations (may or may not be waves). Because of its diverse successes, we have started pretending that it is equivalent to the superposition principle of nature, creating epistemological problems of enormous magnitude. This section will demonstrate that inspite of mathematical correctness of the Fourier transform (FT), we have been using it incorrectly in a number of places. This recognition will strengthen our view point that quantization of EM field as a Fourier monochromatic mode of the vacuum may not be sound physics.

### *Space-Space Transform; Optical Signal Processing*

This is the only FT-formalism that is in a sound platform because the Huygens-Fresnel Integral, a proposed principle of nature, morphs into a FT integral under the far field condition because the quadratic curvatures of the secondary wavelets drop off. Optical signal processing is a highly matured field based on this FT-formalism. However, one should be aware of pitfalls of modeling higher order diffracted intensity distribution due to an ultra short light pulse; it is not a serious problem for imaging applications since the relative delays in the image plane is essentially zero [21–24].

### *Delay-Frequency Transform; Fourier Transform Spectroscopy* (*FTS*)

FTS is on a sound platform as long as one does not use (i) fast detector and (ii) the maximum interferometer delay is smaller than the pulse width. Otherwise, differential amplitude induced visibility reduction would artificially broaden the recovered spectrum [25, 26]. One should be aware of the built-in contradiction behind FTS. The key assumption is that different optical frequencies are *incoherent* to each other. This is a wrong assumption but correct observation as long as the photo detector has a long time constant for integrating photo electric current. During the days of slow retinal observations followed by photographic recordings, this signal integration requirement was built-in. But, after the discovery of fast photo detectors [**27**] we have developed heterodyne or light beating spectroscopy, which is quite common these days. Light beams of different optical frequencies are really not *incoherent* to each other.

### *Time-Frequency Transform, Classical Spectrometry*

Classical spectrometry also gives numerically correct results but only for light pulses that are definitely longer than the instrument's characteristic time constant, $\tau_0 = R\lambda/c$, R being the classical resolving power. For some unknown reasons, this time constant is not explicitly recognized in classical spectrometry [28]. We have shown that the true spectrometer impulse response must be derived by time domain propagation of a pulse, which converges to the classical CW formulation for signal duration longer than this time constant. *Time integrated fringe broadening* due to a pulse do correspond to the convolution of the CW intensity impulse response with the Fourier

intensity spectrum by virtue of conservation of energy (Parseval's theorem) [29]. Recognition of this subtlety has two important consequences.

The first consequence relates to classical spectrometry. It tells us that the traditionally accepted time-frequency bandwidth limit $\delta t \delta \nu \geq 1$ is observationally correct because $\delta \nu$ represents the *time integrated* physical fringe broadening, but not the physical generation of a new set of frequencies by a linear diffraction grating (or a pair of Fabry-Perot beam splitters). New frequency generation generally requires nonlinear, Raman or n-photon stimulations of a material medium by the incident field. In other words, $\delta t \delta \nu \geq 1$ does not represent physical presence of new frequencies. This opens up the door to designing algorithm and instruments to achieve spectral super resolution. The summary of the necessary derivation and some experimental results can be found in these references [29, 30].

The second consequence relates to the demand of QED for a photon to be a Fourier monochromatic mode of the vacuum [31–33], as if required by the combination of QM requirement that the frequency of the spontaneously emitted "photon" has to be uniquely defined through the relation $\Delta E = h\nu$ while classical observation $\delta t \delta \nu \geq 1$ apparently claims that it cannot be a space and time finite wave packet, which is a conceptual mistake perpetuated by classical physics and co-opted by QM. Accordingly, we have proposed [34] that a spontaneously emitted photon is a "mode of the vacuum" but as a space and time finite wave packet with a unique carrier frequency $\nu$ as demanded by $\Delta E = h\nu$. The envelope function is dominantly an exponential function with a very sharp rise time to accommodate the observation that the time integrated line width of spontaneous emission is approximately Lorentzian.

### *Time-Frequency Transform, Coherence Theory*

First let us appreciate that all light signals must necessarily be time and space finite pulse dictated by the principle of conservation of energy. Even a CW laser has to be turned on and off in the real world. The physical spectrum of a pulse is its actual carrier frequencies (undulations of the E & B field vectors) contained in it, and not the FT of the amplitude envelope. This position is validated by the observations made in the last section. Measurable fringe visibility (modulus of autocorrelation function) can be degraded (i) by unequal amplitudes of same frequency light pulse, (ii) by displaced fringe locations due to variable phase delays produced by the same path delay, $\nu_x \tau = m_x$ (order of interference), or (iii) due to presence of light with nonparallel states of polarizations. Today, we do not distinguish between temporal coherence (due to a time finite pulse with a single carrier frequency) and the spectral coherence (due to CW light containing multiple carrier frequencies). Pitfalls of traditional Wiener-Khintchine theorem can be compared from these references [25, 33]. These understandings will provide the platform for better characterization of ultra short light pulses whose spectral content (distribution of E-vector undulation frequencies) may be different

even for the same intensity envelopes. We mentioned in section 6.5.2 that FTS works using slow detectors under the assumption that beams of light containing different optical frequencies are *incoherent*. In reality, different optical frequencies are coherent and they do produce oscillatory beat or heterodyne currents in fast detectors. The concept of coherence needs to be revisited through the "eyes" of photo detectors.

This last point can be appreciated further by exploring why orthogonally polarized light beams produced from the same single mode laser do not produce superposition fringes. Obviously, the two beams from the same laser mode cannot suddenly become *incoherent* (phase random or multi frequency) by inserting orthogonal polarizers. Our proposed hypothesis is that it is the quantum property of the detecting dipoles (see section 7 and Eqns.5–9) embedded in the susceptibility property $\chi$ that dictates the observed results. The energy absorption is not modulated by the "cross term" when the two beams are orthogonally polarized. Orthogonality of the inducing dipolar stimulation makes this term zero [see Eqns. 6–11 below]. In effect, the complex amplitudes due to simultaneous but orthogonal stimulations cannot be summed by detecting dipoles. This limiting quantum property of detecting dipoles should not be assigned to orthogonal EM fields as being *incoherent*. EM fields are never *incoherent.* Integration time and the dipolar properties of detectors determine the degree of fringe visibility, mathematically equivalent to the modulus of the autocorrelation of the superposed fields. Any wave group by definition consists of a collective *coherent* set of undulations.

If indivisible single photon really "interferes only with itself", all thermal sources could be converted into *coherent* sources simply by putting a narrow band spectral filter followed by an absorber to allow only single photons to emerge out!

### *Time-Frequency Transform, Laser Mode Locking*

It is standard to express mode locked laser pulses as the summation of periodic longitudinal modes of a laser cavity, irrespective of whether the characteristics of the laser gain media are homogeneously or inhomogeneously broadened. But we know from discussions in the previous sections that light beams by themselves do not re-group their energy. We also know from the key requirements for designing actual mode locked lasers that it is the insertion of devices like a saturable absorber (or, its equivalent, a nonlinear Kerr medium) that really generates the short pulses by behaving as a temporal on-off switch. Interactions between the cavity fields and the dipoles of the devices jointly create the temporal on and off durations of these mode locking devices. So, the ultra short pulse generation community has correctly kept their engineering focus more on the material properties of the gain media, saturable absorber, Kerr medium, etc., rather than on just the phases of the longitudinal modes. Besides, we doubt that simple intra-cavity insertion of a mode locking device can make a homogeneous gain medium to oscillate in multiple longitudinal modes. We believe that truly transform limited pulses contain a single carrier frequency [35–37].

### *Time-Frequency Transform, Pulse Dispersion*

Based on the correctness of the diffraction theory and our success in reformulating classical spectroscopy [29-30], we believe that "pulse dispersion" is actually pulse stretching [38] due to time diffraction. This is the counter part of diffractive spatial spreading of a beam when it is cut off by a small aperture. When people use FDTD (finite difference time domain) method of computation to propagate short pulses using directly Maxwell's wave equation, they are computing time diffraction [39]. Molecules in media usually respond in the femto second domain to the local amplitude and carrier frequency (-ies) at the moment of their exposure. They do not have memory and they cannot wait to determine the Fourier frequencies due to pulses of long durations and shapes. Thus, as in classical spectrometry, propagating Fourier transformed frequencies may give "correct" *time integrated* pulse broadening in limiting cases, but that is not the correct physical modeling. Counter examples to establish our point can be found in these references [37, 40].

## BELL'S Theorem and Interference as an Emergent Phenomenon

Our proposed reality epistemology, CC-LC-$(ER)_{1,2}$, requires imposing real physical meaning to the symbols and mathematical operators of key working equations. Even in pure mathematics, equations to be correct, the meaning and operation of all the symbols and the connecting operators must be clearly defined. This is an essential component of the reality epistemology we are promoting [10]. Superposition effects emerge as measurable transitions in photo detectors. Thus the detector's first-order susceptibility $^{(1)}\chi$ to polarization induced by the superposed E-vectors is an important physical parameter that is not normally taken into account when writing equations for interferometry when the basic superposition process is linear, but we need to:

$$\text{Field}: E(t) = a(t)e^{i2\pi\nu t};\ \text{Stimulation}: \psi(t) = {}^{(1)}\chi a(t)e^{i2\pi\nu t};\ \text{Transformation}: D(t) = <\psi^{*}\psi> \tag{4}$$

Ensemble averaged photo current $D(t)$ is the measurable transformation due to real physical superposition of the EM field on the detecting molecules. QM prescription to compute has two built in steps, taking square modulus of the dipole stimulation and the ensemble average. The susceptibility to polarization of the dipole $^{(1)}\chi$ contains all the classical and quantum response properties of the detecting molecules. Note that while normally we use only the linear (first order susceptibility), in reality all EM fields induce all possible linear and non-linear susceptibilities all the time. We normally neglect these higher order effects until we encounter molecules with strong nonlinear

polarizability that is becoming more and more common with time. In reality, the total dipole stimulation due to an EM field should be written as:

$$\text{Stimulation:}\Psi(t) = \sum\nolimits_n {}^{(n)}\chi E^n(t);\ \text{Transformation: } D(t) = <\Psi^*(t)\Psi(t)> \quad (5)$$

While Eq.5 already looks complex for general situations, it is even more complex in reality, because both the susceptibility and the EM field should be treated as vectors to accommodate the angle between them in anisotropic media as is done by the specialists in nonlinear optics. Consider the simple case of a two beam Mach-Zehnder interferometer containing two rotate-able linear polarizers in the two arms and illuminated by a linearly polarized single mode laser beam. Neglecting the possible phase and polarization changes that can be introduced by the beam splitters and mirrors, the output beams can be represented as $\vec{a}_1 \exp(i2\pi\nu t - t_1)$ & $\vec{a}_2 \exp[i2\pi\nu(t - t_2)]$ where $\tau = (t_1 - t_2)$ is the propagation induced relative time delay between the two beams. When these two superposed output beams are received by a detector, the sum of the induced dipolar undulation amplitudes experienced by the detector is:

$$\begin{aligned}\Psi(t) = \psi_1(t) + \psi_2(t) = {}^{(1)}\chi\vec{a}_1 e^{i2\pi\nu(t-t_1)} + {}^{(1)}\chi\vec{a}_2 e^{i2\pi\nu(t-t_2)} \equiv {}^{(1)}\hat{\chi}_1\,{}^{(1)}\chi a_1 e^{i2\pi\nu(t-t_1)} \\ + {}^{(1)}\hat{\chi}_2\,{}^{(1)}\chi a_2 e^{i2\pi\nu(t-t_2)}\end{aligned} \quad (6)$$

The unit vectors ${}^{(1)}\hat{\chi}_{1,2}$ in Eq.6 represent the two physical directions of undulations induced on the detecting molecule (or cluster). The detectable transition $d$ can be written as; assuming $\theta$ is the angle between the induced dipole stimulations:

$$\begin{aligned}d = \Psi^*\Psi = \left|{}^{(1)}\hat{\chi}_1\,{}^{(1)}\chi a_1 e^{i\phi_1} + {}^{(1)}\hat{\chi}_2\,{}^{(1)}\chi a_2 e^{i\phi_2}\right|^2 = |\vec{\psi}_1 + \vec{\psi}_2|^2 = \vec{\psi}_1^* \cdot \vec{\psi}_1 + \vec{\psi}_2^* \cdot \vec{\psi}_2 \\ + \vec{\psi}_1^* \cdot \vec{\psi}_2 + \vec{\psi}_2^* \cdot \vec{\psi}_1 = {}^{(1)}\chi^2\left[a_1^2 + a_2^2 + 2a_1a_2({}^{(1)}\hat{\chi}_1 \cdot {}^{(1)}\hat{\chi}_2)\cos 2\pi\nu\tau\right] \\ = {}^{(1)}\chi^2\left[a_1^2 + a_2^2 + 2a_1a_2\cos\theta\cos 2\pi\nu\tau\right]\end{aligned} \quad (7)$$

When the polarizers within the interferometers are lined up with the incident vertically polarized beam, $\theta = 0$, and we can recover from the Eq.7 the traditional intensity pattern multiplied by a constant ${}^{(1)}\chi^2$ that we routinely neglect and yet contains most of the details behind the ongoing real physical processes:

$$d = {}^{(1)}\chi^2\left[a_1^2 + a_2^2 + 2a_1a_2\cos 2\pi\nu\tau\right] = a_0[1 + \gamma\cos 2\pi\nu\tau] \quad (8)$$

Here $\gamma \equiv 2a_1a_2/(a_1^2 + a_2^2)$ represents the fringe visibility quotient and $a_0 \equiv {}^{(1)}\chi^2 \times (a_1^2 + a_2^2)$. When the two beams within the MZ are deliberately made

orthogonally polarized, $\theta = 90^0$, then the detectable transition becomes simply proportional to the sum of the two intensities multiplied by ${}^{(1)}\chi^2$; the interference term drops out:

$$d = {}^{(1)}\chi^2 \left[ a_1^2 + a_2^2 \right] \tag{9}$$

Photodetecting molecular complexes cannot respond to the different phase information brought by the EM fields if they are orthogonally polarized, ${}^{(1)}\hat{\chi}_1 \cdot {}^{(1)}\hat{\chi}_2 = 0$. Since EM fields do not interfere with each other by themselves, we should not attribute the absence of fringes because "orthogonally polarized light beams do not interfere". Again, we must recognize that we "see" light through the "eyes" of dipoles. Further, any time light passes through any material and/or reflected or scattered by some material surface, some of their intrinsic physical properties (frequency, phase, amplitude, and polarization) very likely will change. This is built into Maxwell's wave equation when one applies the "boundary conditions". Thus, if we think in terms of propagating photons, most of the time the "re-directed" photon is no longer the same photon that originally impinged on the surface of the medium.

Accordingly, the Bell's theorem [41] to be relevant at all for superposition (*interference*) experiments, it has to be re-derived for each interferometer in terms of physical dipole undulations of not only the detector molecules but also of those of dielectric or metal coating boundary molecules of beam splitters and mirrors that introduce differential phase shifts for "internal" vs. "external" reflections and the states of polarizations [25], etc. Our point should be obvious from the Eqns. 5–9 even though they consider the very simple case where no relative phase or polarization changes are introduced by the two separate arms of the MZ mirrors and beam splitters. We have demonstrated the consequences in the fringe intensity and location changes produced by an MZ illuminated by a beam containing two orthogonally polarized lights having an asymmetric case of gold and a dielectric mirror [see section III-20 of this book]. Simple sum of the EM fields with two different phases, as represented by the Bell's theorem, is not what we measure or what emerges as transformations in detectors.

Equations 5 through 9 essentially represent classical relation for energy absorption. Let us now apply $(ER)_1$-epistemology on the Eq.8 and take a deeper look at the significance behind the QM prescription of taking ensemble average of $\Psi^*\Psi$. The fringes represented by Eq.8 is re-written below with the reminder that all photo detectors are quantized and that each individual transition (photo counting "clicks") needs to absorb a unique "quantum cup" of energy given by $(\Delta E)_{m-n} = h\nu_{m-n}$, where the suffix "m-n" refers to quantum transition between levels (or bands) m and n.

$$d \equiv (\Delta E)_{m-n} = h\nu_{m-n} \stackrel{?}{=} a_0[1 + \gamma \cos 2\pi\nu\tau] \tag{10}$$

If $d$ represents a single quantum transition event in a detector that always requires the absorption of a fixed quantity of energy $(\Delta E)_{m-n}$ to be delivered by a radiation of well defined frequency $\nu_{m-n}$, then can it be equated to a quantity that varies sinusoidally with the delay $\tau$ by an interferometer? Obviously, the absorbed energy cannot vary for any individual transition even when we vary $\tau$ (as long as the frequency remains fixed). An individual count at any value of $\tau$ cannot provide very useful information regarding the superposition effect we are studying. The right hand side of Eq. 10 must now be re-interpreted as the rate of discrete transitions in the photo detector; *it is no longer a simple energy balance equation*. We just wanted to underscore the conceptual shift from "discrete photons" to discrete detector transition. The energy equation has become a rate equation determined by the flux of the propagating light energy, which is uniquely quantum mechanical. Accordingly the founders of QM have wisely developed the necessity of ensemble average that completes the picture:

$$D = \; < \Psi^{*}\Psi > \; = \; < a_0[1+\gamma\cos 2\pi\nu\tau] > \tag{11}$$

However, $\Psi$ to us, is not an abstract "probability amplitude". It represents the strength of the resultant physical amplitude of the dipole undulation induced by all the simultaneously present EM fields provided their frequencies and polarizations conform to the QM allowed stimulation rules. Superposition principle naturally allows a quantum detector to collect the necessary quantum of energy $(\Delta E)_{m-n}$ for any single transition by gathering energy from multiple fields as long as they are congruent with the QM rules. We do not need to hypothesize that only an "indivisible single photon" can trigger a detector transition. We should not unnecessarily assign the quantum behavior of detectors to the EM fields. Further, if $\Psi$ represents actual dipole amplitude induced by the EM field, then it can be characterized as a joint "quantum compatibility dance" jointly carried out by the field and the detector before the dipole can undergo an allowed transition. There is no arbitrary "collapse of wave function"; a finite number of dipole undulation before the allowed transition takes place. Quantum processes are visualizable.

From the perspective of communication theory, the relative phase delay $\tau = (t_1 - t_2)$ is derived from two pieces of separate information that has to evolve as propagational delays experienced by the two separate light beams in the two arms of the MZ, which must be jointly delivered on to the detectors for taking action. This is part of the same causality in nature that we are underscoring. We agree that information is "physical", as is now claimed in literature [42], but it does not have separate existence outside of physical entities that we can detect and manipulate. In general, physical information is manifest as changes in values of some dynamic physical parameters of some naturally manifest entity that are accessible to control by other physical means.

## Applying CC-LC-$(ER)_{1,2}$ to Model a Photon

We believe that in **section 6** it was justified that an attempt to re-define the photon is called for inspite of the current state of very broad acceptance of photons as indivisible quanta propagating as various Fourier modes of the vacuum, which "interferes only with itself" [43], perhaps, because they are Bosons. A summary of the main stream views and related references can be found from these review articles [8, 19-20], which accepts non-causality, non-locality and the consequent teleportation, etc. Our position is that the interactions between elementary particles are causal, albeit probabilistic. So we should try to model a causal "photon" to bring back *reality* in physics.

A Fourier monochromatic mode of the vacuum is not a starting causal model for a photon since Fourier modes are physically non-causal, existing over all time that violates conservation of energy. So, the "CC-LC" component of our epistemology demands a causal model for the photon and when we press to also apply $(ER)_1$ (*extract and extrapolate reality*) out of various classical and quantum optics theories and observations, we find the following model. Our proposed photon is a mode of the vacuum as QED claims, but with two caveats. First, it is a space and time finite packet of EM wave evolving and propagating out following Maxwell's classical wave equation from the moment the emitting molecule releasing the quantum of energy $(\Delta E)_{m-n} = h\nu_{m-n}$ and undulating the "vacuum" with a carrier frequency $\nu_{m-n}$. This "perturbation" then evolves (diffracts) out, following Maxwell's equation, under the space and time finite 3D exponential-like amplitude envelope [34]. This far, our model is congruent with the correct demand of QM, $(\Delta E)_{m-n} = h\nu_{m-n}$. The next issue is to reconcile with the measured natural line width of spontaneous emission to be a Lorentzian. Classical physics (Lorentz) has solved the problem by proposing the emission envelope to be exponential whose Fourier transform is Lorentzian. We have analytically shown that the *time integrated* fringe broadening observed in classical spectrometers due to time-finite pulses does mathematically appear to be equivalent to the presence of a broad spectrum given by the Fourier spectral intensity of the amplitude envelope [29–30].

Let us now apply again $(ER)_1$ along with $(ER)_2$ (*emergentism and reductionism*). The HF diffraction model, also supported by Maxwell's wave equation, is holding out as a remarkably accurate model for light propagation from all the macro to nano photonic devices. So, it must have captured some cosmic logic in it. Its key proposition is that every single point on the wave front behaves as a new source point. We are proposing to accept this point to be literally true. This implies that the cosmic "vacuum" holds a stationary and uniform electromagnetic tension field (EMTF) everywhere in a state of equilibrium [44-45]. The light wave (photon) is simply a propagating wave group that is an undulation of the EMTF induced by the released energy $\Delta E$ by an excited molecule while undulating as a dipole at a frequency $\nu$. The photon wave packet is an emergent phenomenon out of the stationary EMTF.

The model is quite congruent with all classical material-based undulations that inherently propagate out with diffraction. The wave on the water surface is simply an undulation of the surface against the surface tension when displaced by an external energy source out of its state of equilibrium. Same is true for sound wave where the tension in equilibrium is the air pressure due to Earth's gravitational attraction on the air molecules. The similarity between the Maxwell's wave equation and the material based wave equation is remarkable. The displaced point out of the state of equilibrium, whether EMTF or water surface under tension, wants to comeback to its original state of equilibrium and delivers its "displacement energy" to the next domain making it the next ("secondary") source of wave while generating propagating wave and also validating Huygens' hypothesis over Newton's "corpuscular" model, although a space and time finite wave packet (energy conservation) do imply the "corpuscular" existence of light! Propagating wave is an emergent and collective phenomenon. By applying CC-LC on all the material based wave phenomena (water wave, sound, string and percussion instrument vibrations, etc.) we find that the root of the generation and propagation of the waves lay with the respective "tension field" in equilibrium held by the material media over extended domain.

"Do photons have mass?" may be the wrong question to ask. In reality, all wave propagation is effectively a perpetual motion of some "form", not of matter, which is energetically supported by the tension energy of the medium that wants to stay in its state of equilibrium! Mass-less energy transfer from one point to another through the manifestation of propagating waves is obvious in classical physics in any medium under uniform tension. In classical medium, the wave energy propagates out leveraging local kinetic movement but without transfer of any mass to the distant places where the wave arrives. Considering the similarity in the structure of various wave equations, it is logical to extend the EMTF-like tension concept on the cosmic medium. After all, Maxwell's wave equation does find that the velocity of light, $c = 1/\sqrt{\varepsilon_0 \mu_0}$, which is actually a manifestation of the properties of the vacuum, $\varepsilon_0$ (dielectric constant) and $\mu_0$ (magnetic permeability). If EMTF-hypothesis is correct, then the cosmic space holds an enormous amount of un-manifest potential energy. Only a tiny fraction of this EMTF energy is manifest as propagating photon wave packets whirling in every direction of the universe carrying the messages from one set of atoms and molecules to another distant set. Could possibly this EMTF energy be the "Dark Energy" the astrophysicists have been looking for? No cosmic or local communication waves would have been possible without the existence of such an EMTF in a state of quiet equilibrium! This concept is very different from "luminiferous ether" of the nineteenth century because such a field cannot possess traditional matter like properties. The point is obvious from the considerations that light of wave length 500nm can be easily transported or collected by 10nm guides and a mega watt laser beam can be focused and passed through a pinhole of diameter no bigger than two wavelengths without any distortion in any of its fundamental properties. The energy is transported

locally by a very steep gradient of the field, EMTF. The important question may be: What holds, or has generates, this cosmic EMTF?

This model raises another question. How to construct the stable particles out of this tension filed? May be they are some form of vortex [46-47]. Or, more likely as a self-looped wave train propagating forever in resonance with itself, leveraging EMTF and giving rise to the key properties of *matter* like rigidity and inertial opposition (*mass*) to any of the 3D lateral translation. Schrödinger's "wave equation" already contains the time varying internal harmonic undulation factor, $\exp(i2\pi Et/h)$ [44-45]. We already know from $E = mc^2$ that mass is definitely not an immutable property of nature; Relativity validates that mass is some form of inertia. After all, the key premise of Huygens-Fresnel principle, that wave energy at every point becomes the source of wave energy for the next point, is possible only when the wave is manifest as an undulation of a uniform tension filed existing in a state of equilibrium.

## Summary and Discussions

All theories have to start with human logics that help organize a selected set of measurements into a logically congruent group with the implied dream of refining the theory to eventually map the actual cosmic logics behind the physical processes making the measured transformation happen.

The core contribution of this paper is to underscore that we are forever challenged in gathering complete information about any phenomenon through experiments alone because the measurable transformations relayed by our instruments are rarely all that they have experienced. Thus working theories (equations) have to be made logically closed as an equation and self consistent by filling in the information gaps with imagined (*invented*) human logics some of which may not be correctly mapping the cosmic logics (*realities*), which we are trying to *discover*. Nature being fundamentally logical and causal, as evidenced by the very successes of our logical mathematical theories, we should be able to develop a rational epistemology to move towards the reality ontology that lies behind the evolving universe. However, several centuries' of successes demonstrated by our mathematical modeling, we have developed the tendency to *invent* realities and impose that on nature whenever our elegant theories are falling short of making a causal and visualizable model of the very *processes* we are trying to model. This paper is an attempt to overcome this troubling trap [1].

We have accepted that all experimental observations, classical and quantum mechanical, as *causal and "local"* superposition effects as measured transformation (SEMT). Dissection of SEMT informs us of the eternal information gap or the "incompleteness paradigm" of all experimental observations that we are forced to accept. This awareness creates the opportunity for us to appreciate that our *human logics* behind "working" theories need continuous refinements to move them closer to the *cosmic logics* that are

driving the cosmic evolutionary *processes*, which are undeniably real irrespective of whether humans had evolved to observe them or not.

Then we have proposed a model methodology of thinking, CC-LC-$(ER)_{1,2}$ epistemology [Fig.1]. The utility and power of this epistemology has been demonstrated by summarizing the successes and hidden failures in the field of optics that uses ubiquitous Fourier theorem. We have used our epistemology to argue that superposition effects are necessarily local and that "photons" may be space and time finite undulation of a hitherto undiscovered electromagnetic tension field (EMTF) filling the entire volume of cosmic space. We have also presented our view that superposition effects being local interactions with detecting molecules, Bell's theorem is not the right guide to over throw causality in nature. It's ineffectiveness may also lie with the faulty derivation of the joint probability distribution, as has been claimed by some [48].

The proposed epistemology can guide us to continuously refine our human logics towards correctly mapping cosmic logics. The model attempts to emulate our biological genetic algorithm, the stuff out of which we are built. From the very early stages of evolution the GACT's (Guanine, Adenine, Cytosine, and Thiamin) moved to create the DNA molecules, and then the viruses and the living cells. They all function as little creative engineers, effectively following the interaction processes allowed by nature's limited set of laws. As very complex systems, as conscious humans, we will be better off by being humble and honest creative reverse engineers. This is not a philosophy. This is emulating successful evolutionary engineering of nature for our own sustainability. However, neither the path to sustainability is defined for us, nor can we acquire complete information from any observation or experiment. Perhaps, this is a deliberate design to keep our mind challenged towards choosing a better evolutionary direction!

By virtue of "incompleteness paradigm", our proposed CC-LC-$(ER)_{1,2}$ epistemology must remain as a "work in progress" for ever. Then only can we assure ourselves that one dominant epistemology cannot slow down the progress of scientific investigations and thinking [1–3]. All "correct" scientific theories must be superseded and/or invalidated by new theories! Therefore, the younger generation should be constantly asking: How can we stay focused on *discovering* actual *realities* in nature driven by *cosmic logics* rather than stay limited to *inventing* realities that are esthetically pleasing to our *human logics*?

We hope this article will inspire our readers to give serious attention to the various out-of-box proposals for photons presented in the next section.

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