Electromagnetic Synthesis of Four Fundamental Forces from Quantized Impedance Networks of Geometric Wavefunction Interactions

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Quantum Mechanics is all about wavefunctions and their interactions. If one seeks to understand QM, then a deep intuitive understanding of wavefunctions and wavefunction collapse would seem essential, indispensable. That's where it all starts, the causal origin of the quantum as manifested in the physical world. We introduce a wavefunction comprised of the geometric elements of the Pauli algebra of space - point, line, plane, and volume elements - endowed with quantized electromagnetic fields. Wavefunction interactions are described by the geometric product of geometric Clifford algebra, generating the Dirac algebra of flat Minkowski spacetime, the particle physicist's S-matrix.

Introduction

Ongoing proliferation of differing and often incompatible quantum interpretations[1–4] makes obvious ambiguity and confusion shrouding the wavefunction. Wavefunctions are not observable, but rather only their interactions. The canonical wavefunction is defined not in physical space, but rather in Dirac's infinite space of states, in Hilbert space.

What oscillates in the canonical wavefunction is not an observable field, but rather the square root of a probability. How does one gain a deep intuitive understanding of this thing and its interactions? Is it even possible?

"You know, it would be sufficient to really understand the electron."

So said Einstein, as quoted by Hans Dehmelt in his 1989 Nobel lecture[5].

To understand the 'electron', one must understand electron wavefunctions and their interactions. We examine the possibility of moving beyond Dirac spinors to complete geometric Clifford algebras[6–8], defining the vacuum wavefunction to be comprised of orientable elements of the 3D Pauli algebra of physical space - point (scalar), line (vector), plane (pseudovector), and volume (pseudoscalar) elements of Euclid. Wavefunction interactions, modeled by geometric products[9], yield the 4D Dirac algebra of flat Minkowski spacetime[10]. Time emerges from the interactions.

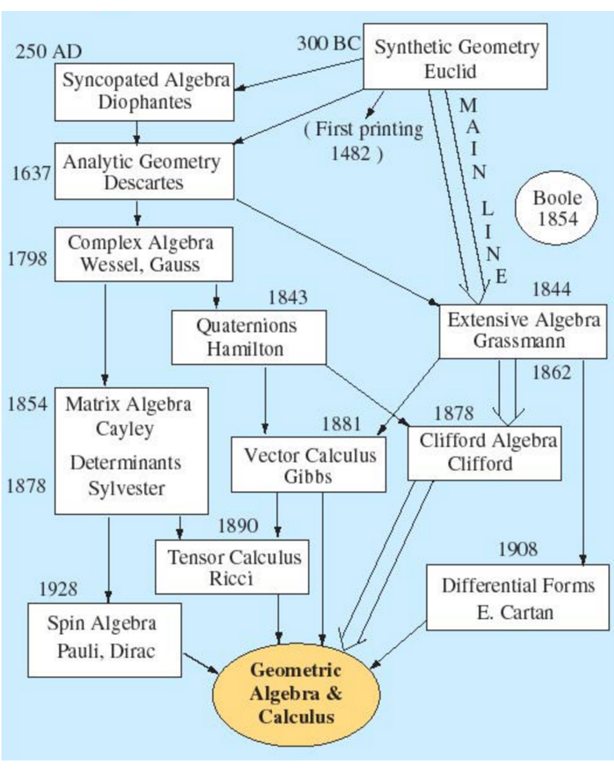

FIG. 1. Evolution of geometric Clifford algebra[17, 18]

This has been to some extent explored over the years. Early attempts were incomplete, ahead of their time[11, 12]. Seeds of the modern geometric wavefunction were sown by the Pauli and Dirac algebras of Hestenes' short and lucid seminal text[10]. Ensuing geometric approaches have gone astray, one reason being the accomodation of two or more fundamental forces[12–15]. The mix of multiple fields and geometric objects remains intractable today.

However, proceeding on the assumption of an electromagnetic conceptual synthesis requires nothing more than endowing geometric elements of the Pauli vacuum wavefunction with quantized EM fields. For this five fundamental constants are input by hand - speed of light, permittivity of the vacuum, electric charge, Planck's constant, and electron mass. There are no free parameters. This has proven to simplify the problem immensely. Defining the scale of space by the electron Compton wavelength yields an easily visualized electromagnetic geometric wavefunction model in physical 3D space[16]. Computationally, such a model must address three problems traditionally understood to be extraordinarily unwieldy.

Foremost is the core problem of electromagnetic models, the problem of **confinement**, not within Dehmelt's trap[5], but rather free space self-confinement at the Compton wavelength in the presence of Coulomb repulsion.

Flip side of confinement is **finiteness**. In the absence of confinement the model requires renormalization, has a finite probability to find the wavefunction at both the ultraviolet singularity (hidden behind the event horizon at the Planck length), and eventually at the essentially infinite infrared boundary of the universe.

A third consideration is **gauge invariance**. In the absence of confinement and presence of infinities how does one construct a geometric model that is gauge invariant? Pertinent to note that gauge invariance played almost no part in the implicitly confined point particle formulation of quantum electrodynamics, being "...largely regarded as a complication and a technical difficulty that had to be carefully handled,..."[19]

Wavefunction interactions via quantized impedance networks[20, 21] address these core questions.

Impedance governs amplitude and phase of the flow of energy. Like energy, the absolute value of impedances doesn't matter, but rather only differences - how well they're matched in amplitude and phase. Excepting the photon, which uniquely has both scale-dependent near-field and invariant far-field impedances[22], those of quantized electromagnetic interactions are apparently one or the other, invariant or not, never both.

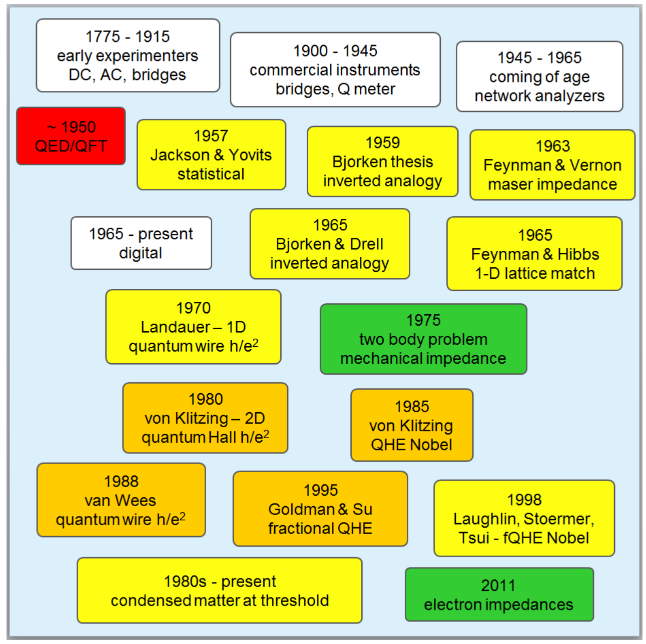

FIG. 2. Development of theory and technology of classical impedances highlighted in white, quantum impedances in yellow (theory) and gold (experiment), generalization of quantum impedances in green, and QED scaffolding in red.[23]

Scale-dependent (and therefore energy-dependent) slopes of the capacitive scalar Coulomb mode and inductive pseudovector dipole mode interaction impedances are of opposite sign, intersect and are matched at the Compton wavelength[20]. This, together with Maxwell's equations, opens the possibility of reflectionless energy transfer between all coupled modes of interacting Pauli wavefunctions, presenting essentially infinitely many modes of both self-interacting and two-body wavefunction elements[24].

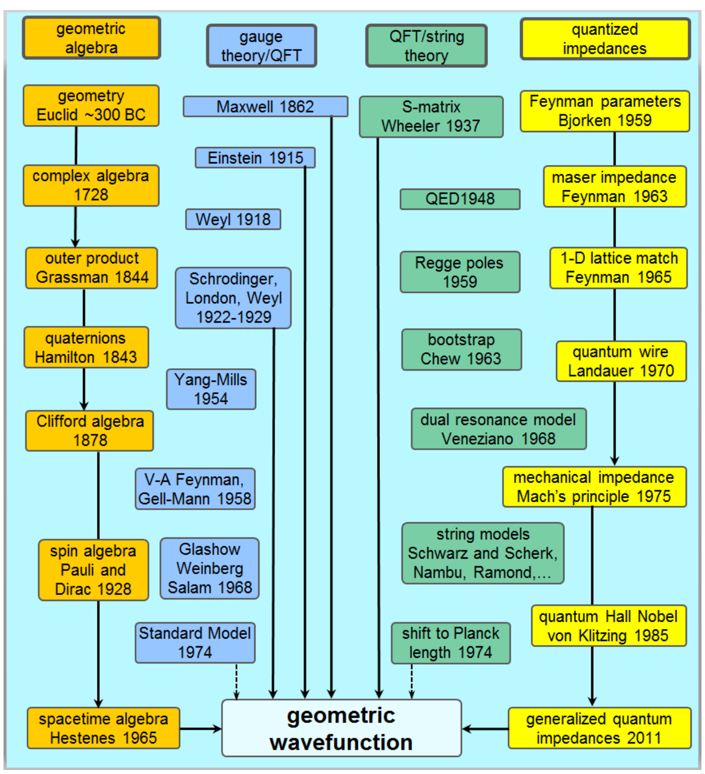

FIG. 3. Four Threads of the Geometric Wavefunction.

Mechanical impedance is a property shared by all massive particles[25]. Centrifugal impedances can be calculated by applying Mach's principle to the two body problem[26]. Equating centrifugal and Coulomb forces, for instance, permits calculating mechanical impedance of this electromechanical interaction, and to express it as the corresponding scale dependent electromagnetic impedance. Applying this to the Bohr atom yields the quantum Hall impedance[26]. More surprising is, absent the proton, quantum Hall appears an 'intrinsic' property of the free electron[27].

Such an approach applied to all interactions of Pauli wavefunction elements yields the impedance structure of the electron[16], the S-matrix of the particle physicist[28]. Exciting this impedance network generates the massive particle spectrum[29, 30]. By time symmetry, the same impedance network governs phase decoherence of unstable particles.[24]

Figure 3 shows concepts essential for the model linked by heavy black arrows. Possible connections between the model and the remaining concepts of gauge/QFT/string theory remain to be explored.

This completes a minimal introduction of ideas and methods employed in asserting the claims of the next sections, starting with the three computationally unwieldy problems. But first we present a few claims for innovation in geometric Clifford algeba.

Bold and Explicit Claims for Innovation

With wisdom of hindsight, in the preface to the 50th anniversary second edition[31] of the original text Professor Hestenes makes four "bold and explicit... claims for innovation" in SpaceTime Algebra:

- STA enables a unified, **co-ordinate free** formulation for all of relativistic physics, including the Dirac equation, Maxwell's equation, and General Relativity.
- Pauli and Dirac matrices are represented in STA as **basis vectors** in space and spacetime respectively, with no necessary connection to spin.
- STA reveals that the **unit imaginary** in quantum mechanics has its origin in spacetime geometry.
- STA reduces the mathematical divide between classical, quantum, and relativistic physics, especially in the use of **rotors** for rotational dynamics and gauge transformations.

The preface encourages making such claims, lest the innovations be overlooked. "Modestly presenting evidence and arguing a case is seldom sufficient." In this spirit, the following bold and explicit claims are made for the synthesis of geometric Clifford wavefunctions and quantized impedance networks:

- **gauge invariance** - Impedances shift phases. Quantum impedances shift quantum phases. In traditional gauge theories phase coherence is maintained by covariant derivatives. In the geometric wavefunction model coherent phase shifts are introduced by the interaction impedances. The model is *naturally gauge invariant.*
- **finiteness** - Low and high energy impedance mismatches appear in powers of the fine structure constant[20, 21], provide natural QED cutoffs as one moves away from the quantization scale, the Compton wavelength, are the model equivalent of QED renormalization coefficients. The model is *naturally finite.*
- **confinement** - Confinement is the flip side of finiteness. Reflections from impedance mismatches provide confinement to the vicinity of the quantization scale. The model is *naturally confined.*
- **background independence** - This fundamental connection with STA goes deep, to the co-ordinate free formulation essential for quantum gravity[32].

  In STA, motion is described with respect to the object in question rather than an external coordinate system.

  Similarly, impedances are calculated from Mach's principle applied to the two body problem[26]. Motion is described with respect to one of the two. There is no third body, no independent observer to reference rotations, only spin. The model is naturally *background independent.*
- **photon-electron interaction** - Dirac spoke to the core of the model in asserting that

  "Until we have a really satisfactory explanation of how electrons and photons interact with each other, it will hardly be possible to go on and explain the other particles."[33]

  Absence of impedances from mainstream models is due to a variety of historical accidents, among them the habit of particle physicists to set fundamental constants, including free space impedance, to dimensionless unity[34].

  Depth of the chasm into which this fundamental concept has fallen can be seen from omission of both near-field photon[35] and quantized electron impedances[16] from the physics textbooks and curriculum. What governs the flow of energy in photon-electron interactions is absent from formal education of the PhD physicist.
- **quantized impedance networks** - Why the quantum?

  There is no mystery about classical impedances. They're in everyday life of many engineers and technicians - electrical, mechanical, acoustic,... That impedances should be quantized in the model follows from composition of the wavefunction, from geometry and fields. It's all about the wavefunction.

  The first level of quantization is geometric. The vacuum wavefunction is comprised of geometric objects of the Pauli algebra of space[9]. They are individual, discrete; the point quantum of space, line quantum,...

  The second level of quantization is electromagnetic. To accomplish applications outlined in the next section, fields assigned to the geometry cannot have arbitrary values, must be quantized such that nodes of the impedance network describe particle properties. The empirical 'five fundamental constants input by hand' provide the needed ordering in powers of the fine structure constant.[20]

  "Why the quantum?" might better be phrased "Why the wavefunction?" For this we have no answer.

Applications of the Model

The synthesis presented here offers a radically different perspective on quantum field theory. Hamiltonian and Lagrangian approaches focus upon conservation of energy and the balance between potential and kinetic, rather than what governs the flow - the impedances. Differential equations that describe time evolution are replaced by simple algebra, the amplitudes and phase shifts of interaction impedances - the S-matrix. Multiplicity of 'fields', one for every particle, is replaced by the two fields of electromagnetism. The point particle quark and lepton model is replaced by the geometric wavefunction. There exist many new possibilities for particle physics insight, with a few shown here.

- **S-matrix** - The scattering matrix is the holy grail of particle physics. "...no matter which representation of field theory we work with, in the end we want to know the S-matrix elements."[36] In the present approach generation of the S-matrix is accomplished via the geometric products of wavefunctions.[28, 29, 37]
- **origin of mass** - is electromagnetic field energy of the geometric wavefunction[29, 38].
- **unstable particle lifetimes** - For unstable particles the causal limit, the boundary between local and nonlocal, is defined by their coherence lengths, the product of lightspeed and their lifetimes. It has long been known that particle lifetimes are ordered in powers of the electromagnetic fine structure constant[39–41], as is the quantized electron impedance network by virtue of the five fundamental constants input by hand. Decays take place at the α-spaced network nodes[20], where impedances are matched and energy can flow between modes[24].
- **proton structure and spin** - Distinguishing between unstable 'dark' and stable visible elements of the S-matrix permits identifying both transition and eigenmodes of the proton. Transition modes are those of topological mass generation via the muon. The resulting model contains three electric charge quanta 'quarks', two nuclear Bohr magnetons, and the phase pseudoscalar[29].

  The model is relatively simple. While running the simulation (it is just Maxwell's equations and the geometric wavefunction impedance network) presently appears beyond resources of independent researchers, it is surely within reach of modern university physics departments.
- **proton anomalous moment** - Distinction between near-field Bohr magneton and far-field anomalous moment[29] suggests the possibility of an *experimental test.*
- **chiral anomaly** - Anomalies are symmetries true classically but broken by regularization/renormalization. QFT treatment of chiral anomaly predicts wrong branching ratio for pizero. Geometric wavefunction model is naturally finite, gets branching ratios right to order $\alpha/2\pi$=.0012, and eta and etaprime within two per hundred, calculated from the impedance mismatches[42]. Neither chiral symmetry nor gauge invariance is broken.
- **time symmetry** - Time-symmetry measurements[44] suggest an impedance-based *experimental test*[45].
- **quantum gravity** - Matching quantized impedances at the Planck scale reveals an exact identity between electromagnetism and gravity[46].
- **black hole information paradox** - Nonlocal reduction of entangled states is clarified by considering the role of background independent scale-invariant quantum impedances, providing a possible resolution of the paradox[47].
- **gauge theory gravity** - Connection[48] of scale-dependent and scale-invariant impedances with translation and rotation gauge fields of gauge theory gravity[49–52] is easily seen. With scale-dependent impedances (monopole, dipole,...) resultant motion is parallel to applied force, whereas for invariant impedances (quantum Hall, centrifugal, chiral, Coriolis, three-body,...) it is perpendicular. Scalar and vector Lorentz forces are good examples.
- **LIGO/VIRGO quantum gravity** - Model predicts detector directionality orthogonal to that of GR, opens possibility of an *experimental test* of quantum gravity[53]
- **big bang/bounce** - Taking the singularity as origin of the big bang/bounce, the primordial photon first encounters the Planck particle wavefunction. The interaction impedance network as a template for the bang/bounce yields a plausible evolution of the first few zeptoseconds, including a possible inflationary scenario[21, 30].
- **quantum Hall impedance** - Detailed calculations [16] suggest the measured value of this fundamental constant is comprised of the sum of a high impedance series capacitive component and a low impedance (about 4 ohms) parallel inductive component, again suggesting the possibility of an *experimental test.*

The Geometric Interpretation

Quantum mechanics is all about wavefunctions and their interactions. Interpretations put flesh upon the bones of mathematical formalism, tell the story of QM in words we can understand, in images we can visualize.

Geometric Interpretation of the wavefunction and its interactions has, in addition to the traditional formalism shared by all interpretations, an easily visualized geometric wavefunction model. This permits unique and innovative resolution of ambiguity and apparent paradox.

Interpretations of the formalism and phenomenology address the distinction between knowledge and reality, between ontic and epistemic, between what we know and how we know. It's a pursuit that straddles the boundary between philosophy and physics.

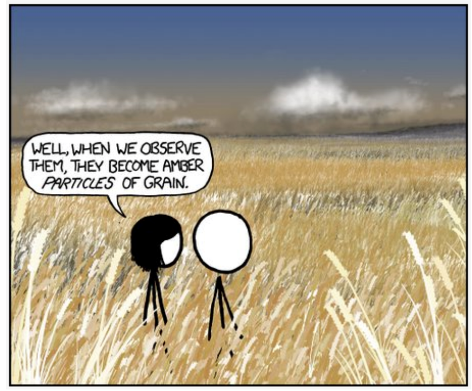

FIG. 4. Duality and wavefunction collapse

There are many areas of contention in the modern dialogue[4]. In each of these areas, interpretations seek to address the same basic question - how is one to understand the canonical measurement problem?[54, 55] How does one get rid of the shifty split [56] of the quantum jump [57], develop a smooth and continuous real-space visualization of state reduction dynamics?[58] What governs the flow of energy and information in collapse of the wave function?

- **Reality and Observability of the Wavefunction** - Wavefunctions are not observable. They're dynamic, coupled modes of geometric wavefunction elements, passing their electromagnetic rest mass energy between modes via Maxwell's equations as governed by interaction impedances. To 'observe' one must decouple modes, extract amplitude and lose the phase. What is 'seen' are not the dynamic coupled modes but rather a lump of energy. Wavefunction interactions generate the observable S-matrix of the elementary particle spectrum[29].

  Although unobservable, just because one can't see it doesn't mean it isn't there. To deny reality of the wavefunction breaks conservation of energy. The geometric wavefunction is unobservable and real.

- **Reality and Observability of Wavefunction Collapse** - Collapse follows from decoherence[59, 60], from differential phase shifts between the coupled modes of a given quantum system. The phase shifts are caused by impedances of wavefunction interactions[58]. This is what impedances do. They shift phases.

  To deny reality of wavefunction collapse breaks conservation of energy. Wave function collapse is real. The collapse itself, the transition mode structure, is not observable. What emerges from collapses are observables.

- **Determinism and Probabilistic Wave Function Collapse** - "...Schrodinger wave equation determines the wavefunction at any later time. If observers and their measuring apparatus are themselves described by a deterministic wavefunction, why can't we predict precise results for measurements, but only probabilities?" [61]

  Probabilistic character of quantum mechanics follows from the fact that phase is not a single measurement observable. Measurement extracts the amplitude. Internal phase information of the coherent quantum state is lost as the wave function decoheres. For quantum mechanics to be deterministic one would require phase to be a single measurement observable. Phase is relative, requires two measurements.

  Deterministic character of quantum mechanics follows from the fact that observable probabilities of branching ratios and particle lifetimes are *determined* by impedance mismatches of wavefunction interactions[24, 42]. This *unobservable* determinism removes some mystery from 'probabilistic' behavior.

- **Superposition of Quantum States** - Investigating newly discovered quantum states of Heisenberg and Schrodinger, Dirac led the way in introducing state space (later identified with Hilbert space) to the theory. "*The superposition that occurs in quantum mechanics is of an essentially different nature from any occurring in the classical theory*" (italics in original) [33]. What distinguishes quantum superposition from classical is superposition of *states*, of wave *functions*, as opposed to superpositions of waves. Waves are observable, wave functions are not. What determines the state into which the wavefunction collapses is phase relative to that of the wavefunction with which it interacts via Maxwell's equations as governed by the interaction impedances.

- **Entanglement** - "Entanglement is simply Schrodinger's name for superposition in a multiparticle system." [62] Modes of an entangled system are quantum phase coherent via phase shifts of the interaction impedance network, be they scale-dependent or invariant, local or non-local, causal or acausal.

- **Local and non-Local** - The model has both local and non-local modes.

  Non-local modes are those associated with scale invariant impedances (photon far-field, quantum Hall/vector Lorentz, centrifugal, chiral, Coriolis, three body,...). With the exception of the massless photon, which has both scale dependent near-field and invariant far-field impedances, invariant impedances cannot do work, cannot transmit energy/ information. Resulting direction of motion is perpendicular to applied force. Invariant impedances communicate phase only, not a single measurement observable. They are the channels linking the entangled eigenstates of non-local state reduction. They cannot be shielded[43–45]. The invariant impedances are topological. The associated potentials are inverse square.

  Local modes are defined by the light cone, the event horizon, the causal boundary. All wavefunction modes are local. Those associated with invariant impedances are non-local as well. Modes associated with scale dependent impedances (photon near-field, Coulomb/monopole, dipole, scalar Lorentz,...) are local only. They do the work, transmit energy/information. The scale dependent impedances are geometric.

- **Hidden Variables** - Early on in the development of quantum theory, the probabilistic character prompted Born[63, 64] to comment "...anybody dissatisfied with these ideas may feel free to assume that there are additional parameters not yet introduced into the theory which determine the individual event." Taking 'hidden' variables to be quantum phases (not single measurement observables!), it follows that the "...additional parameters not yet introduced into the theory..." are phase shifters, the quantum impedances.

- **Observer Role** - The model is background independent, which is to say there exist only the two interacting wavefunctions. For there to be an observer, it must be one of the two interacting wavefunctions. However, wavefunctions are not observable. It appears there is no place for an 'observer' in the quantum logic of the model, that the concept if useful must become emergent at some more complex level of interactions.

Timeline of interpretations is shown in figure 5. Green background corresponds to interpretations claiming the wavefunction is real, red to not real. Interestingly enough, Birkhoff's quantum logic claims to be agnostic.

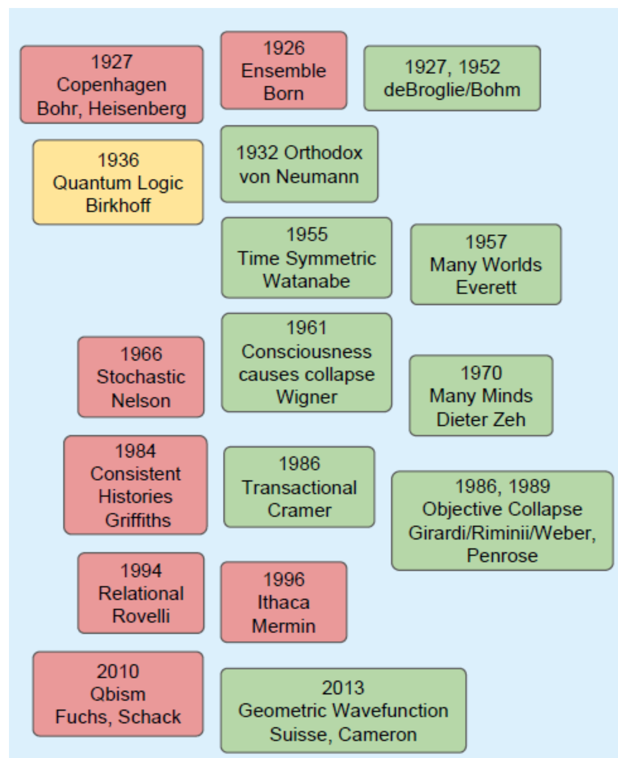

FIG. 5. Evolution of quantum interpretations.

Conclusion

It's all about the wavefunctions. That's the foundation. Observable physical reality emerges from their interactions, from the simple structure of space endowed with naught but the two fields of electromagnetism. From this we manifest, breathe, think, read, and write.

With the geometric wavefunction it seems possible to have a model that is naturally gauge invariant, finite, and confined. It seems possible to understand gravitation as impedance mismatched electromagnetism, and similarly weak and strong nuclear forces as confinement by reflections from impedance mismatches. It seems possible to have an intuitive, real world understanding of the measurement problem, to remove the ambiguities and resolve the outstanding quantum paradoxes.

Finally, one cannot help but feel excitement over what applications might arise in condensed matter.

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APPENDIX - SUPPLEMENTARY FIGURES

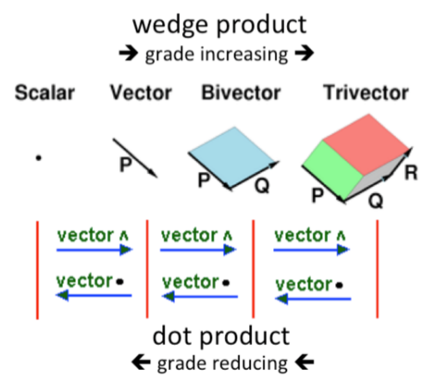

FIG. 6. Geometric product of the 3D Pauli algebra of space is the sum of dot and wedge products. Dot product reduces dimensionality/grade, wedge increases. The grade-increasing wedge product breaks topological symmetry (see fig.10). For instance, one can smoothy deform a vector to a scalar, but cannot smoothly construct a vector from scalars, due to presence of the singularities[65]. This symmetry breaking appears to play an essential role in topological mass generation of the nucleon.[29, 66]

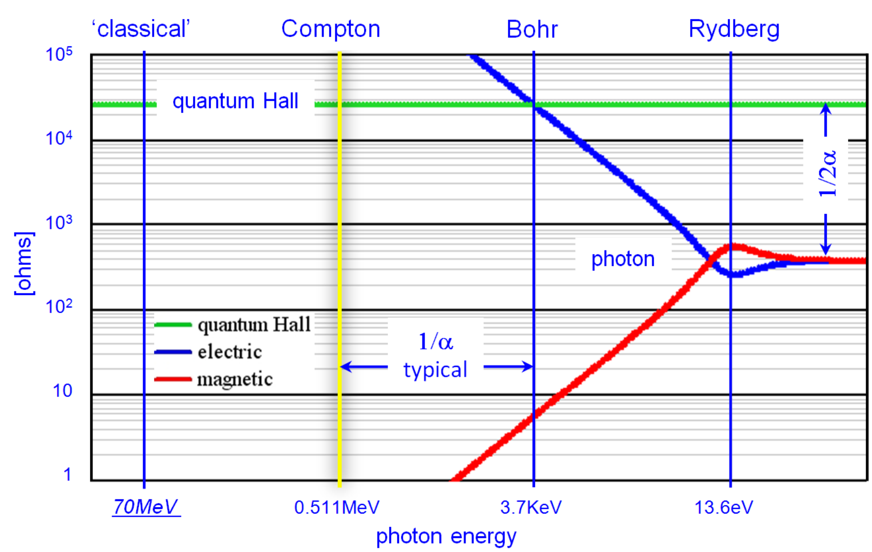

FIG. 7. Scale dependent near-field and invariant 377 ohm far-field impedances of a 13.6eV photon, showing near-field match to quantum Hall impedance at the Bohr radius[35]. Missing from figure (and Standard Model) is the matching quantized dipole impedance of the electron[16], essential for reflectionless energy transfer in dissociation of the H-atom. Both photon and electron near-field impedances - what governs the flow of energy in photon-electron interactions - are absent from the curriculim and textbooks, from the physics journals, from the formal education of the PhD physicist.

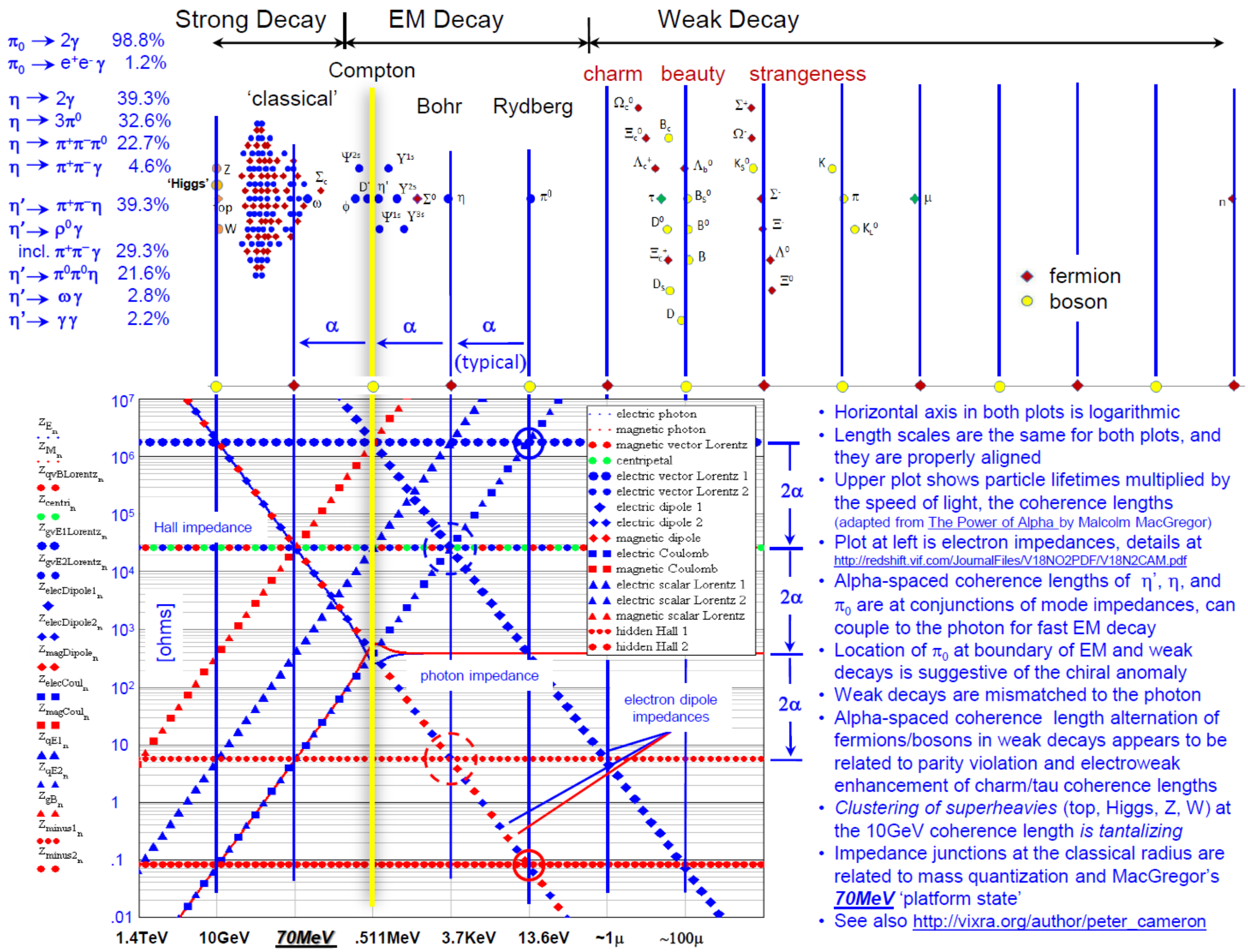

FIG. 8. In QFT one is permitted to define but one fundamental length, often taken to be the short wavelength cutoff. The geometric wavefunction model is finite, divergences being cut off by impedance mismatches as one moves away from the fundamental length of the model, the Compton wavelength. With elements of the wavefunction confined to that scale by reflections from the mismatches, interaction impedances can be calculated as a function of their separation, the 'impact parameter'. Strong correlation of the resulting network nodes with unstable particle coherence lengths (boundary of the light cone) follows from the requirement that impedances be matched for energy flow between modes during decays.

Modes shown here are a subset of the S-matrix of figure 10. Precise calculation of branching ratios shown at the upper left and resolution of the chiral anomaly follow from impedance matching considerations[42].

Lifetimes of the superheavies (top, Higgs, Z, W) cluster at intersection of the ~10GeV coherence length of the dominant bottomonium decay modes with the 377 ohm photon far-field impedance and the magnetic scalar Lorentz and Coulomb mode impedances, suggesting the superheavies are comprised of magnetic resonances.

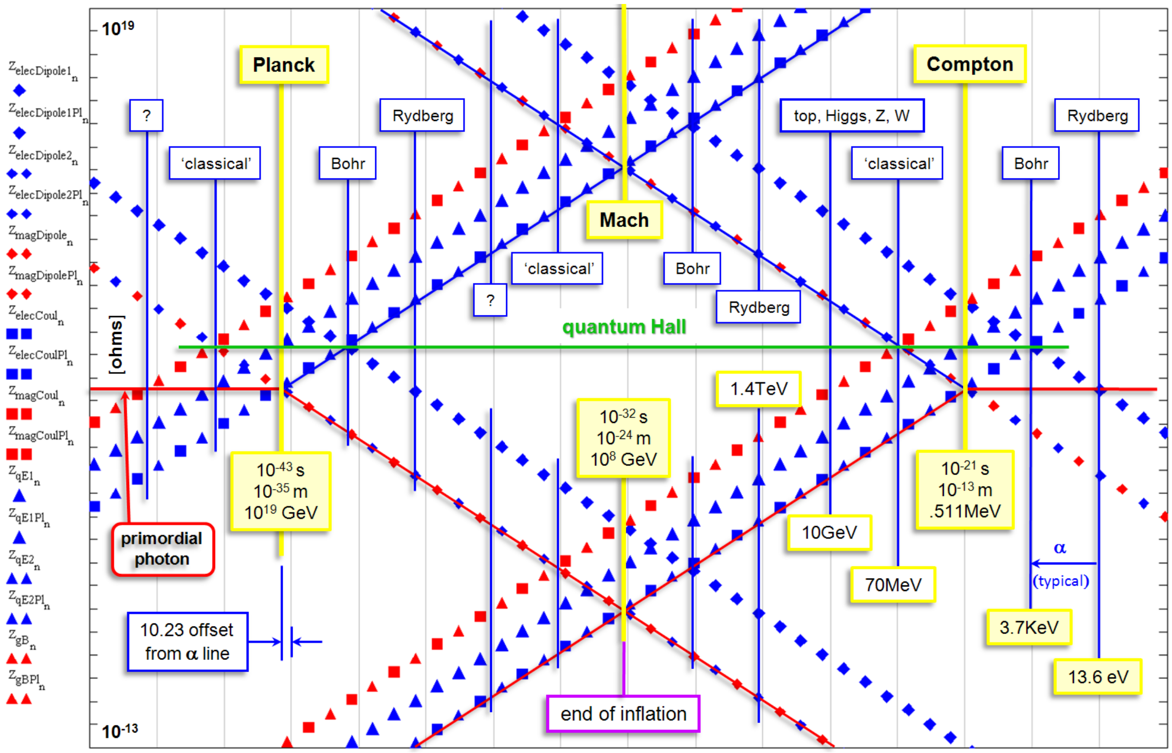

FIG. 9. A subset of impedance networks of the electron and Planck particle. Green line represents both quantum Hall and centrifugal impedances. Bringing gravity into the model requires introduction of Newton's gravitational constant G to establish a second length scale, the Planck length. The exact identity is revealed by examining the ratio of two ratios:

- ratio of gravitational and electromagnetic forces between the two particles
- ratio of scale-dependent impedances at the two particles

This ratio of ratios is unity. Big G, by far the most imprecise of the fundamental constants, cancels out in the ratio of ratios. Gravitation has entered, yet the model remains with just five fundamental constants input by hand.[46, 47]

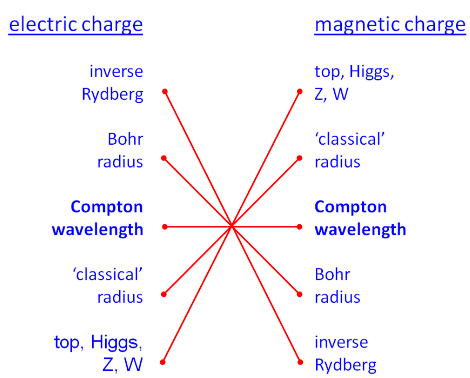

FIG. 10. **Inversion of fundamental lengths by magnetic charge** - The photon is our fiducial in measurements of the properties of space. Topological duality[67–69] arises from the difference in coupling to the photon of magnetic and electric charge[16, 23], and the related symmetry breaking induced by grade/dimension increasing wedge product. Progression from electric scalar to magnetic pseudoscalar at top of fig.11 illustrates the process.

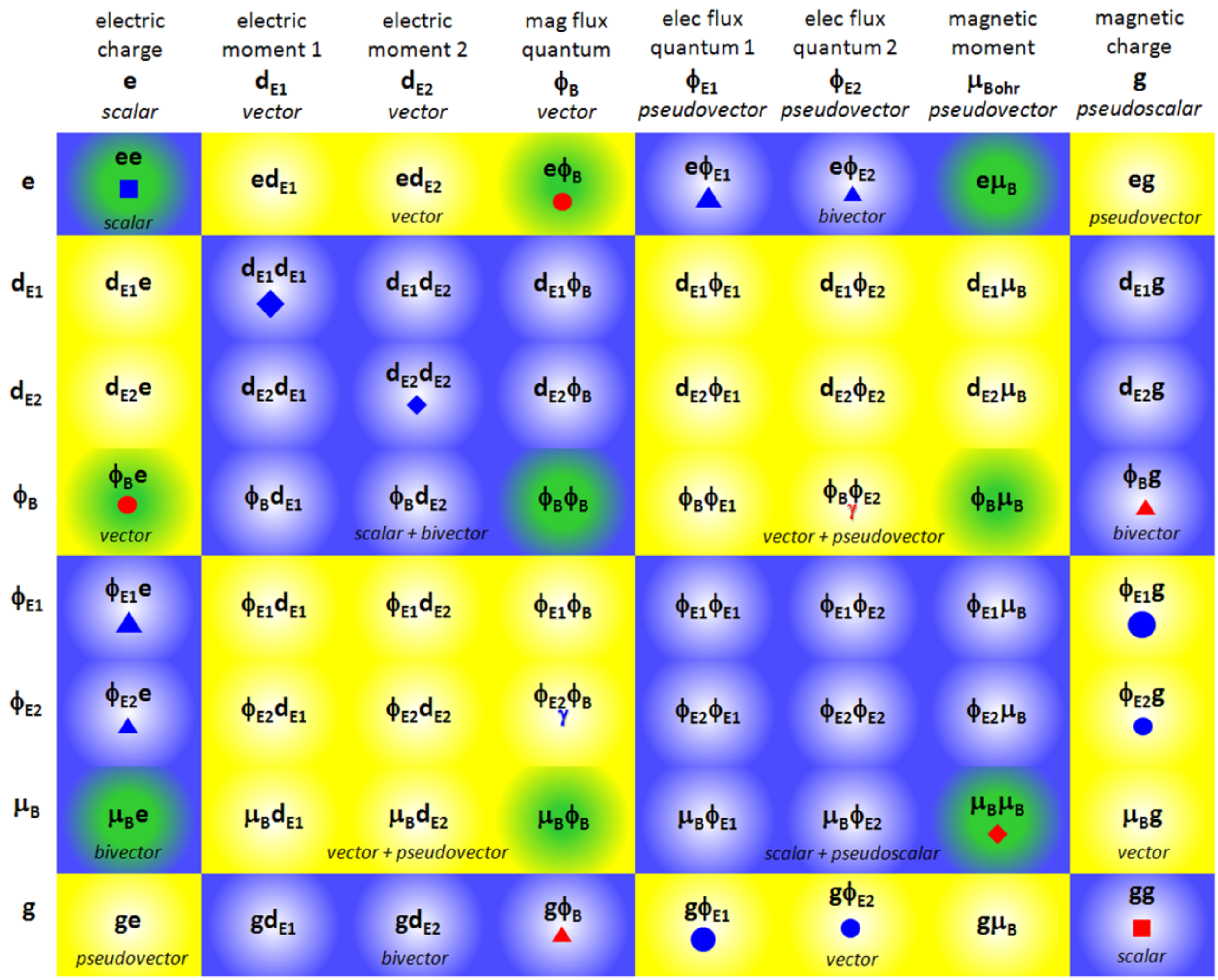

FIG. 11. **The S-matrix** As shown at top and left, a minimally complete Pauli algebra of 3D space is comprised of one scalar, three each vectors and bivectors (one for each of the three spatial degrees of freedom), and one trivector. These are the geometric elements of the vacuum wavefunction. Figure 10 illustrates the topological duality of electric scalar and magnetic pseudoscalar.

Attributing electric and magnetic fields to these elements yields the wavefunction model [16]. In the manner of the Dirac equation, taking those at top to be the electron wavefunction suggests those at left correspond to the positron. Their geometric product generates the background independent 4D Dirac algebra of flat Minkowski spacetime, arranged in odd transition modes (yellow) and even eigenmodes (blue) by geometric grade. Time (relative phase) emerges from the interactions.

The impedance network comprised of modes indicated by symbols (triangle, square, dot, diamond) is shown in figure 8. Modes lacking 'dark' wavefunction elements are highlighted in green, correspond to the transition (yellow) and eigenmodes (blue) of the stable proton[29]. A consequence of the topological symmetry breaking of the geometric product, unstable particles contain at least one dark wavefunction element, the proton none. The differing interactions of dark and visible elements as they excite the geometric vacuum wavefunction determines the differing impedances they see. This generates differential phase shifts, resulting in decoherence of unstable particles at impedance nodes of figure 8.

It also shifts one's concept of the gauge group. Standard model gauge particles maintain phase coherence between point particle quarks and leptons. Extending the wavefunction beyond point particles and gauge bosons to the full eight-component Pauli algebra of 3D space permits direct interparticle wavefunction interaction. The phase information is contained in the 4D pseudoscalars of the Dirac algebra S-matrix. The gauge bosons become elements in the S-matrix, as shown in the figure for the two polarization states of the photon by the symbol γ. Odd elements of the algebra, they populate the transition modes.