

The First Zeptoseconds: An Impedance Template for the Big Bang

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Impedance may be defined as a measure of the amplitude and phase of opposition to the flow of energy. Impedance is a fundamental concept, of universal validity. Classical or quantum impedances, geometric or topological, scale invariant or scale dependent, fermionic or bosonic, mechanical or electromagnetic or gravitational - impedance matching governs the flow of energy. This is a universal principle. As such, it is not surprising to find that quantized impedances provide an interesting sensibility when taken as a template for the Big Bang, presenting a detailed perspective on the first few zeptoseconds.

INTRODUCTION

The absence of quantized impedances from the foundation of quantum electrodynamics is a most peculiar and surprising historical accident[1], a consequence of the order in which the experimentalists revealed the essential relevant data. The foundation of QED was set in the first half of the twentieth century, over three decades before the concept of impedance quantization entered the world of the physicist with the Nobel-winning 1980 discovery of exact impedance quantization in the scale invariant quantum Hall effect[2].

The significance of that discovery can be seen by examining energy flow between a 13.6 eV photon[3] (whose wavelength is the inverse Rydberg) and the quantum Hall impedance of the electron, as shown in figure 1. It illustrates the scale-dependent impedance match that permits energy to flow without reflection between the Rydberg and the Bohr, between photon and hydrogen atom.

The force operative in the quantum Hall effect is the vector Lorentz force. Impedance quantization is a possibility for all forces, not just the Lorentz force[4]. Quantizing with electromagnetic forces only and taking the quantization length to be the electron Compton wavelength gives the impedance network of figure 2. The network nodes are strongly correlated with the unstable particle coherence lengths[5, 6], suggesting that, as in the hydrogen atom, energy flows to and from the particle spectrum via this network of electron impedances.

In the language of traditional network analysis[7–10], it suggests that high energy physics experiments are big network analyzers, and the unstable particle spectrum can be understood to be the result of transfer function measurements of this impedance network.

The horizontal scale of figure 2 can be regarded as an impact parameter, a measure of how deeply a photon entering from the right can penetrate and excite the network. To understand this network as a template for the Big Bang, one need only imagine an ‘infinite energy’ photon entering not from the right, but from the left, as shown in figure 3, entering from beyond the Planck scale.

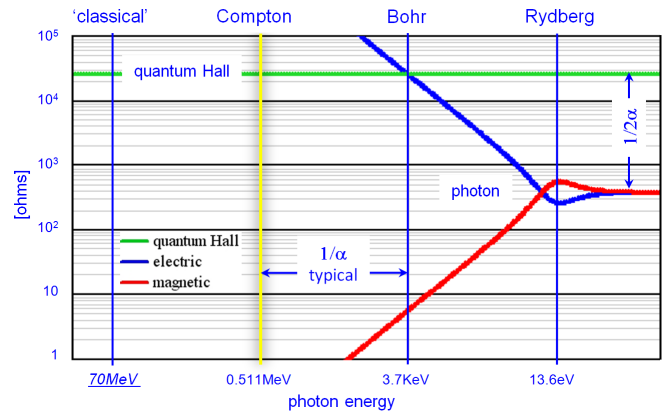


FIG. 1. Far and near field 13.6eV photon impedances[3] and scale invariant electron quantum Hall impedance as a function of spatial scale as defined by photon wavelength/energy, showing the decoupling of the magnetic and electric flux quanta that comprise the photon at the transition from far to near field. The role of the fine structure constant α is prominent in the figure.

THE ELECTRON IMPEDANCE NETWORK

Given a quantization length, what does one quantize? Restricting the possible fields to electromagnetic only, starting with full symmetry between electric and magnetic, and taking only the simplest topologies needed for an arguably realistic model, we have

- quantization of magnetic and electric flux, charge, and dipole moment
- three topologies - flux quantum (no singularity), monopole (one singularity), and dipole (two)
- confinement to a fundamental length
- the photon

What is shown in the impedance plot of figure 2 are calculated coupling impedances of the interactions between these three topologies[4, 11].

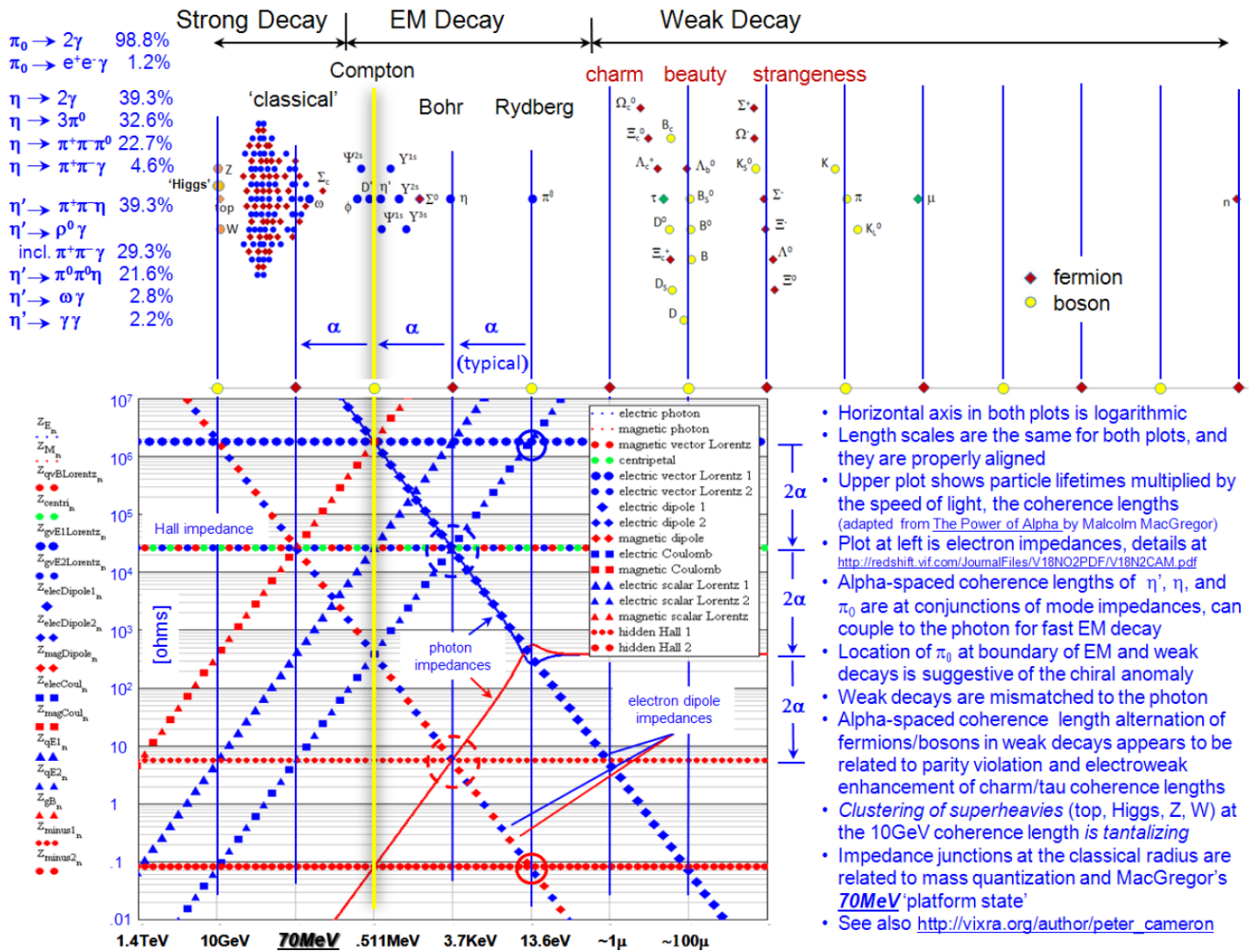


FIG. 2. A composite of 13.6eV photon impedances and a variety of background independent electron impedances[11], measured branching ratios of the π^0 , η , and η' (easily and accurately calculated from their impedance matches[12]), the four fundamental quantum lengths shown in fig.1, and the coherence lengths of the unstable particles.[13–15]

Defining a quantization length has significant consequences, as can be seen from figure 2.

- The low and high energy impedance mismatches of the scale dependent modes, here centered on the electron Compton wavelength, provide natural cut-offs. The impedance approach is finite in the absence of renormalization.
- Looking not at what is excluded by the cutoffs, but rather at what remains in the middle, the mismatches as one moves away from the quantization length provide a natural confinement mechanism for the coupled modes that define a given particle, in this case the electron.

The impedance approach is not only naturally finite and confined, but also naturally gauge invariant. Complex impedances - inductance and capacitance - shift

phases. Complex quantum impedance shifts quantum phase (not a single measurement observable). In the Standard Model the phase coherence that distinguishes quantum systems from classical (as required by gauge invariance) is maintained by the artifice of the covariant derivative. In the impedance approach one need only account for the phase shifts introduced by the impedances.

THE PLANCK PARTICLE

Just as the energy of a photon whose wavelength is the Compton wavelength of the electron is equal to the rest mass of the electron, the energy of a photon whose wavelength is the Compton wavelength of the Planck particle is the rest mass of the Planck particle and its associated event horizon. This is the 'electromagnetic black hole', the simplest eigenstate of the Planck particle.

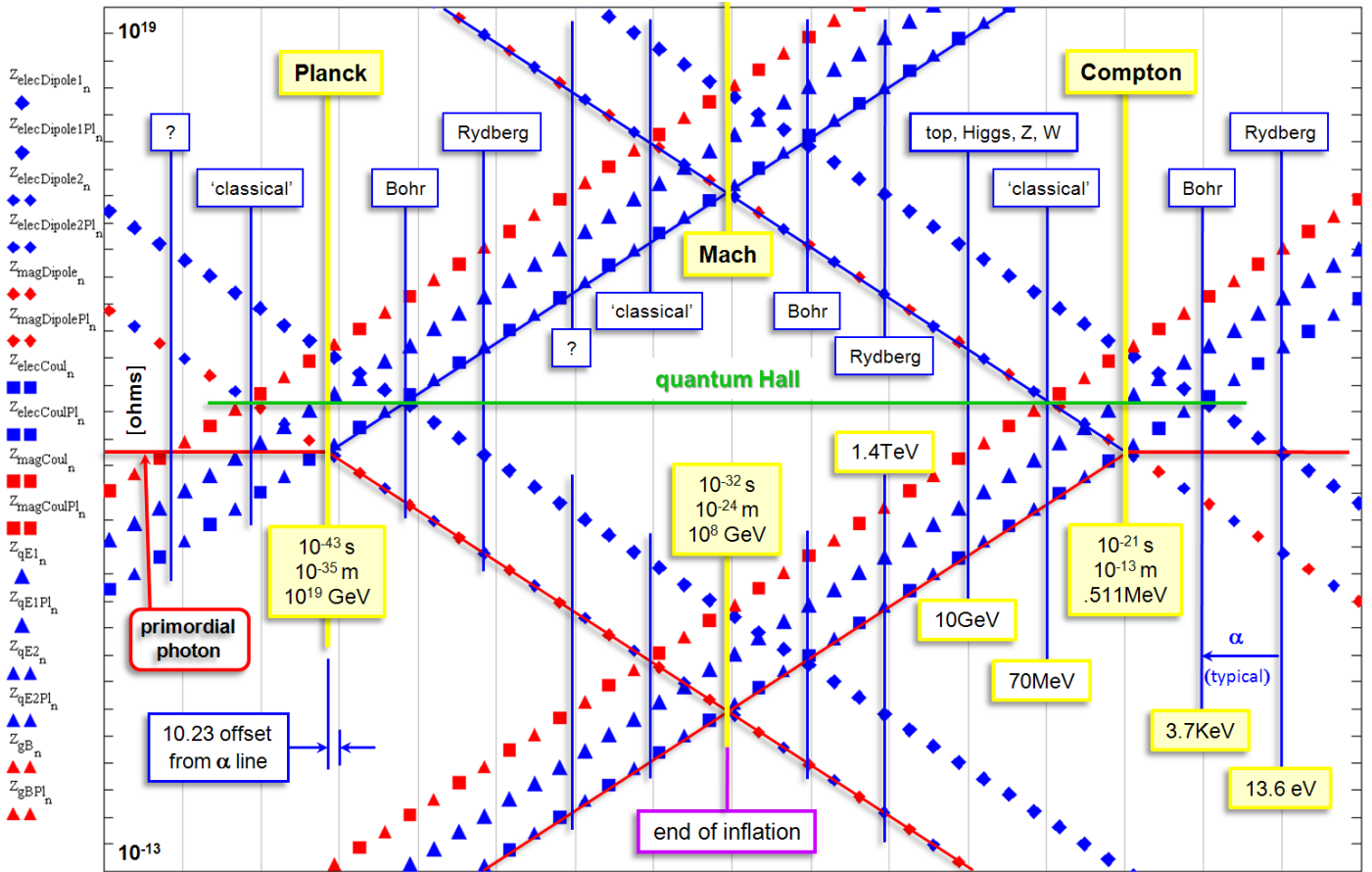


FIG. 3. A subset of the impedance networks of the electron and the Planck particle, showing both a .511 Mev photon entering from the right (included here not to imply relevance to the Big Bang but rather for illustrative purposes only), and the primordial photon entering from the left[16]. The end of inflation in the impedance approach (as in the Standard Model) comes at $\sim 10^{-32}$ seconds, at the intersection of the two impedance networks, referred to here as the ‘Mach scale’.

A more detailed model of the Planck particle can be had by taking the quantization length to be not the electron Compton wavelength, but rather the Planck length, resulting in the impedance network (shown together with that of the electron) of figure 3.

Calculating the impedance mismatch between electron and Planck particle gives an identity between electromagnetism and gravity[17]. The gravitational force between these two particles is identically equal to the impedance mismatched electromagnetic force they share. This result suggests that both gravity and rest mass might be thought to be of electromagnetic origin.

A possible resolution of the black hole information paradox[18] (presented at the 2013 Rochester Conference on Quantum Optics/Information) followed from a synthesis of that paper[17] with one other[6] and the holographic principle[19].

That the impedance approach delivers an exact result at the event horizon of the Planck particle (and perhaps beyond, to the singularity, which is completely decoupled by the infinite impedance mismatch at the dimensionless

point), in the presence of extreme relativistic distortion of time and space is quite surprising. One wonders what correspondence exists between this result and the dictates of general relativity near the event horizon, whether the two approaches can be found to be in agreement.

Of particular interest is the 10.23 offset of the Planck particle from the nearest electromagnetic fine structure line. Given the exact relationship between gravity and electromagnetism, and just as the unstable particle spectrum emerging from the excited electron impedance network is strongly correlated with the fine structure spacing of the impedance nodes, it is not unreasonable to expect that an electromagnetic-only model which yields exact relations between gravity and electromagnetism would have the Planck particle centered on a fine structure line.

The origin of this factor of 10.23 is a puzzle, as is the fact that the offset is so small, of the order of a part in $\sim 10^{22}$ when considered from the scale of the electron. Varying the fundamental constants used in the calculation by six times their uncertainty (as found in codata 2010) had essentially no effect on this factor of 10.23.

THE BIG BANG

To begin we require the ‘infinite energy’ primordial photon. The simplest assumption consistent with the first instant of the Big Bang is to take the initial excitation to be a delta function, with the characteristic flat spectrum that follows from the Fourier transform, the spectral power density being the same at all frequencies.

Shortly thereafter we require something with which the primordial photon might interact, some sort of structure of the vacuum. In the impedance approach, if one excites the network of figure 2 from the Rydberg side with sufficient energy the unstable particle spectrum appears. Given that, it seems reasonable to identify the impedance network of figure 3 with the structure of the vacuum.

The Singularity and Spacetime

For photons exciting the network from the Rydberg side, the singularity is not an issue. The infinite impedance mismatch to the point singularity guarantees that there can be no interaction, no sharing of energy.

Things are different when the excitation comes from the singularity side, from the infinite energy photon. The photon makes its appearance *inside* the yet virtual Planck particle. A consequence of the infinite energy, the event horizon is at infinity.

In that first instant only the photon is manifest. All the rest is virtual. The Lorentz transforms of special relativity suggest at that instant space would be two dimensional and time stopped. Four dimensional spacetime starts to emerge with the transfer of energy from the photon to the impedance network of the Planck particle.

What of the singularity? Can it be said to exist in that first instant? If spacetime is emergent the answer would seem to be no, that there is no issue with how the primordial photon escapes the singularity. The singularity does not yet exist. Four dimensional spacetime does not yet exist.

The Planck Scale

As it propagates outward from the point of origin (to the left at infinity on the log scale of figure 3), the primordial photon first encounters the Planck particle’s magnetic Coulomb and scalar Lorentz impedances (red triangles and squares in the upper left of figure 3), largest of the impedances associated with $1/r$ potentials. To effectively couple energy from photon to Planck particle requires that these impedances be matched to the near-field photon in both scale dependence and field (magnetic or electric). As can be seen from the figure, this is not the case. The photon’s electric field does not couple energy to the magnetic impedances.

However, the photon next encounters the electric scalar Lorentz impedance (large blue triangles) at the ‘classical’ wavelength of the Planck particle. Here we find an impedance match in both scale dependence and field, with the possibility of excitation of the Planck particle modes that are coupled to this impedance. This is the first transfer of energy from the photon to the Planck particle, and perhaps the best candidate for the initial impetus of inflation (if it proves needed).

The photon next encounters the electric and magnetic dipole impedances (the small blue and red diamonds) at the Planck length, where the perfect match to the latter permits energy flow from the photon’s magnetic flux quantum to the coupled modes of the Planck particle.

Also at the Planck length, the electric field of the photon is perfectly matched to the Planck particle’s electric Coulomb and scalar Lorentz impedances (blue triangles and squares), providing additional paths for energy flow.

Finally, after the absence of interaction at the Planck particle’s Bohr radius (another candidate for inflation - due to the impedance mismatch to the photon, interactions at this scale may be termed ‘dark’), the photon encounters the larger of the two electric dipole impedances, the ‘external’ dipole impedance, at the Planck particle’s inverse Rydberg, with no transfer of energy as a consequence of the magnetic/electric mismatch between the photon’s magnetic and dipole’s electric fields.

This completes the transfer of energy from the primordial photon to the Planck particle. The next opportunity for interaction comes at the Mach scale.

The Mach Scale and Inflation

Experience with the unstable particle coherence lengths shown in figure 2 and their strong correlation with nodes of the electron’s impedance network permits one to conclude with reasonable confidence that where one finds network nodes one will find particles. Unlike the Compton and Planck scales, nodes at the Mach scale result not from coupling of modes of a single particle, but from coupling of the Planck particle to the electron.

It would seem that for spacetime to have scale, a metric, requires at least two massive particles. The possibility of additional massive particles emerges at the $\sim 10^{-32}$ second Mach scale shown in figure 3, at the end of inflation in the Standard Model, at the impedance conjunctions of the Planck particle with the electron.

This can be taken to correspond to the initial coupling of the Planck particle to matter, setting the scale of spacetime and permitting localization of causality at the Mach length. A conjectured universe at this time might consist of some unspecified large number of Mach volumes, all existing within the four dimensional spacetime of the now-inflated universe, each endowed with the $\sim 10^8$ GeV of the ‘Mach particle’.

All of the impedance conjunctions in the vicinity of the Mach scale are mismatched to the photon. In that sense they are dark, and particles that might emerge at this scale could be considered dark matter/energy candidates.

The Compton Scale

While the behavior of the impedance network at the scale of the electron Compton wavelength has been discussed in detail in earlier notes[1], things are different when the excitation comes from the Planck scale. Rather than the initial excitation of the electron coming at the scale of the Rydberg via the ‘external’ electric dipole impedance (from the right in figure 3), it comes at the classical radius of the electron via the electric scalar Lorentz impedance (from the left).

This is one example of a more general complementary asymmetry - due to the electric/magnetic mismatches in the photon near field, modes excited from the Rydberg side of the network are not excited from the singularity side, and modes excited from the singularity side are not excited from the Rydberg side.

DISCUSSION

The discussion is focused on an epoch presently inaccessible in the Standard Model, the first few zeptoseconds. While the impedance approach might prove helpful in dealing with known Standard Model shortcomings (flatness, horizon, density fluctuation, exotics, thermal state, cosmological constant,...), that topic will not be addressed here.

The availability of a detailed model opens many possibilities for discussion. The simplicity of the model and the presence of only familiar fields (electric and magnetic) offers hope that this exploration might have an appeal both intuitive and explicitly detailed. Here we address a few possibilities - time symmetry, antimatter and spin, dark matter/energy, and the inflaton.

Time Symmetry

Phase is a measure of time correlation, time the variable conjugate to energy, and by the uncertainty principle both cannot be observed in a single quantum measurement. The phase information is lost as the wave function decoheres in the process of extracting an amplitude. An impedance analysis of the nested Mach-Zehnder interferometer[20] supports the view that quantum phase, being acausal, propagates both forward and backward in time.

The backward propagation of quantum phase lends support to the notion that the Big Bang is, in its entirety,

phase coherent at least until the end of inflation, when time symmetry would appear to be broken by the localization of causality to the individual ‘Mach volumes’. It brings to mind Wheeler and Feynman’s time symmetric electrodynamics[21, 22], suggests that in the first instant the retarded wave of the photon encounters the advanced wave of Planck particle impedances, that the quantum phase structure of the vacuum was present for the photon in that first instant.

The non-local character[6] of the scale invariant impedances (quantum Hall/vector Lorentz, centrifugal, Coriolis, three body,...) opens the possibility that at least some consequences of quantum phase coherence might persist beyond that time[23, 24].

Antimatter and Spin

If one assumes the primordial photon was in a superposition of spin states at the instant of creation, then it would have been projected into one of the two possible states upon the first interaction with the Planck particle.

Taking seriously the notion that phase can be considered to be in some sense the quantum equivalent of Wheeler’s and Feynman’s ‘time’, one might conjecture that the apparent absence of antimatter in our universe follows from the polarization of the photon that took place in that first interaction.

The two spin states of the photon correspond to the two possible relative phases of its electric and magnetic flux quanta. In a larger sense one might take intrinsic spin to follow from the phases of the modes and mode couplings of a given particle. The chiral anomaly provides an illustration[12].

Dark Matter/Energy

As explained elsewhere[4] the majority of the modes in figures 2 and 3 are dark, unable to couple to the photon.

As mentioned earlier in this note, there exist characteristic length scales at which the impedance networks are mismatched to the photon, namely the Bohr radii of both electron and Planck particle and all the characteristic lengths associated with the Mach scale.

Modes associated with the monopoles and dipoles contain singularities, and seem the best candidates for dark matter. Modes associated with flux quanta (the neutrinos can be included in this category) don’t contain singularities, and seem the best candidates for dark energy.

More detail is available elsewhere[4, 25]. A proper discussion of dark matter and energy requires one to solve the problem of the phases and couplings of the modes of the impedance networks. While an analytical approach seems possible for simple circumstances (for instance the decays of the pizero, eta, and eta’), some sort of iterative

variation of parameters seems necessary for a complete solution, optimized by the fit to the unstable particle spectrum of figure 2.

The Inflaton

The assumption here is that inflation is needed in the impedance approach to deal with the problems for which it was invented in the Standard Model, specifically the horizon and flatness problems. The monopole problem is absent from the impedance approach.

The suggestion here is that the inflaton is the DC component of the flat primordial photon spectrum. Inflation ends in the vicinity of the Mach scale. For wavelengths greater than that the inflationary epoch is in the the photon near field, which is understood to be longitudinal. Both the longitudinal and DC characteristics are likely relevant to the role of this inflaton.

SUMMARY

In keeping with the universal character of impedances, the quantum impedance approach has found direct and simple application to a variety of diverse topics[1] at the core of the Standard Model and beyond, application to the unstable particle spectrum, the chiral anomaly, state reduction, entanglement, non-locality, time asymmetry, gravitation, dark matter, electric dipole moments, paradoxes in our systems of units, and herein application to the first zeptoseconds of the Big Bang.

CONCLUSION

Just as having a model is helpful in interpretation of the formalism of quantum mechanics[26], it opens a window on the very early Big Bang. What is lacking is dynamics, the couplings and phases of the modes that comprise the impedance networks.

Of immediate interest is sorting out the dynamics of the electron impedance network, in the hope that this will give detailed insight into proton spin structure[27–30].

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