The First Zeptoseconds: A Quantum 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 a current. Impedance is a fundamental concept, of universal validity. Impedances govern energy flow. 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[2] of exact impedance quantization in the scale invariant quantum Hall effect.

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 unstable 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.

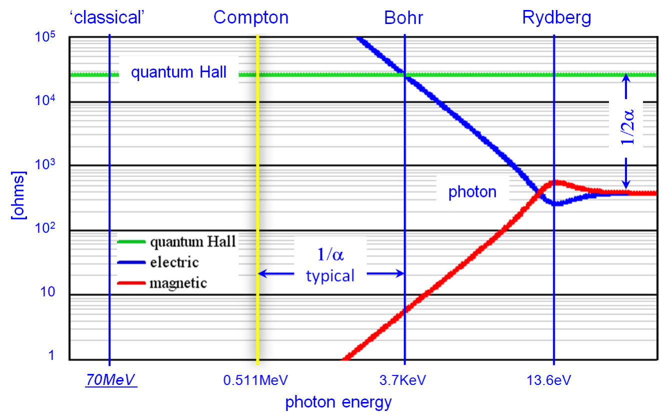

FIG. 1. Far and near field 13.6eV photon impedances[3] and scale invariant electron quantum Hall impedance as a function of spatial scale as defined by photon wavelength/energy, showing the decoupling of the magnetic and electric flux quanta that comprise the photon at the transition from far to near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

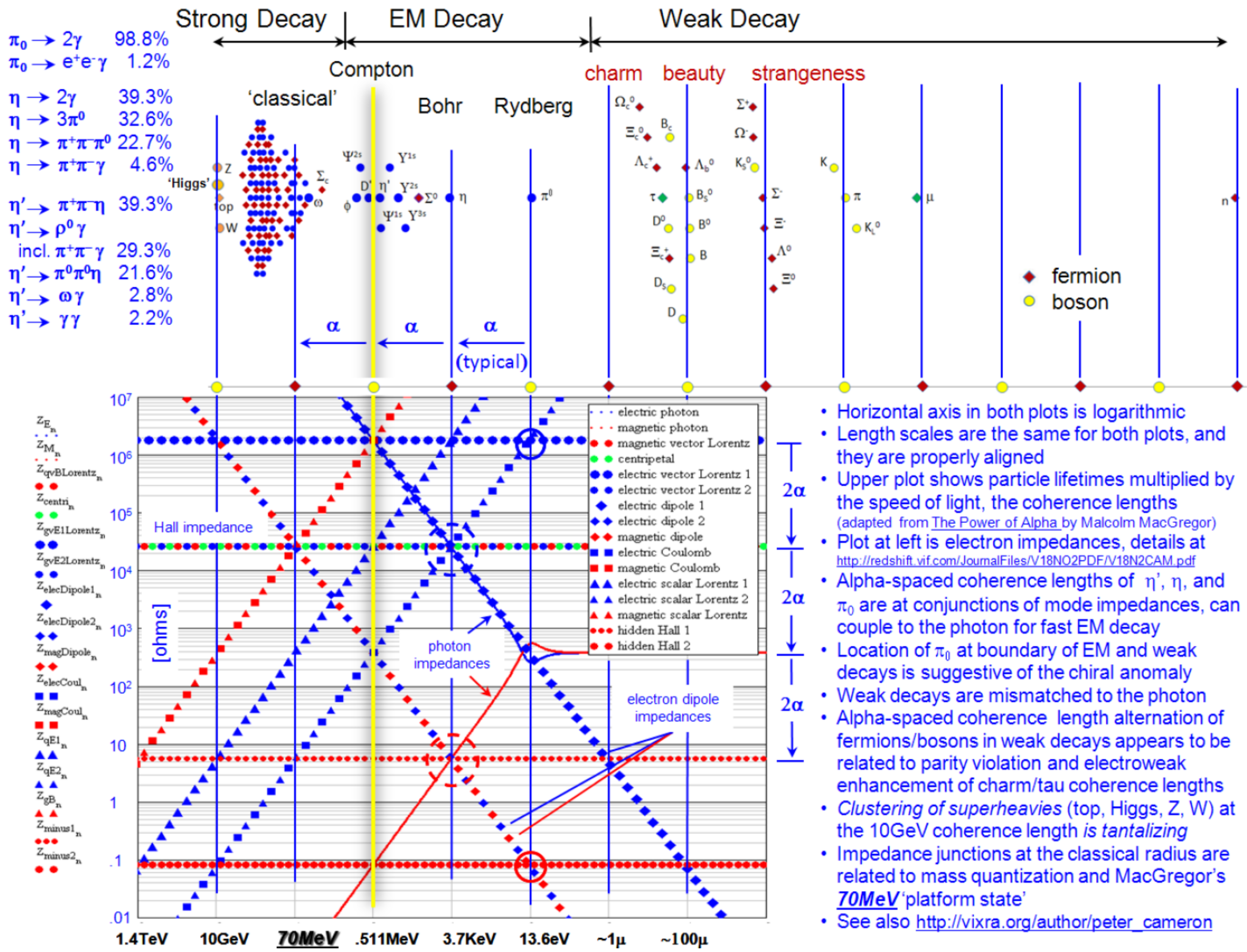

FIG. 2. A composite of 13.6eV photon impedances and a variety of background independent electron impedances[11], measured branching ratios of the π^0, η, and η'[12], the four fundamental quantum lengths shown in fig.1, and the coherence lengths of the unstable particles.[13–15]

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 cutoffs. 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.

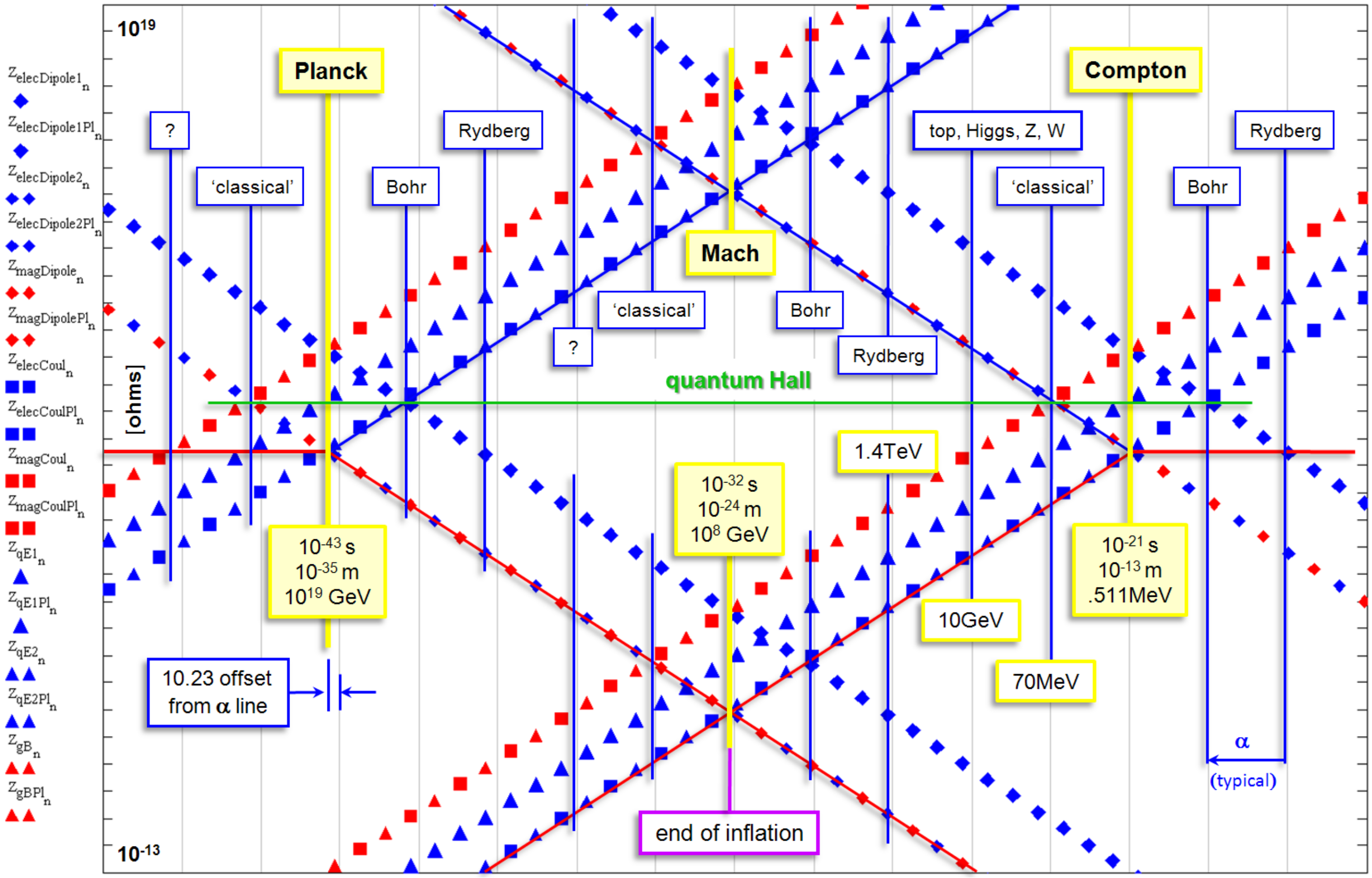

FIG. 3. A subset of the impedance networks of the Planck and Compton particles, showing both a .511 Mev photon entering from the right (included here not to imply relevance to the Big Bang but rather for illustrative purposes only), and the primordial photon entering from the left[16]. The end of inflation 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, and the one most 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.

The Planck Scale

As it propagates outward from the point of origin (presumably in all directions simultaneously, though depicted here in one dimension only), the 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 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 electric field of the photon does not couple energy to the magnetic impedances, at most couples only quantum phase.

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 resonant 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.

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 encounters and is perfectly matched to the Planck particle's electric Coulomb and scalar Lorentz impedances (blue triangles and squares), providing an additional path for energy flow.

Finally, after the absence of interaction at the Planck particle's Bohr radius (due to the impedance mismatch to the photon, interactions at this length 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 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.

In the first instant of the Big Bang only the photon is manifest. The Lorentz transforms of special relativity suggest at that instant space would be two dimensional and time stopped. Time and space start to emerge with the transfer of energy from the photon to the impedance network of the Planck particle.

It would seem (is there a proof?) that for space to have a scale, a metric, requires in addition to the photon 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 space and permitting localization of causality at the Mach length. The universe at this point in time consists of some unspecified number of Mach volumes, all existing within the three dimensional space of the now-inflated universe, each endowed with the $\sim 10^8$ GeV of the Mach particle. How one calculates the size the universe at the end of inflation in this scenario is not yet obvious.

It should be noted that 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 candidates.

The Compton Scale

While the behavior of the impedance network at the Compton scale has been discussed in detail in earlier notes, 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 Compton side of the network are not excited from the Planck side, and modes excited from the Planck side are not excited from the Compton side.

DISCUSSION

The availability of a detailed impedance model opens many possibilities for discussion. The simplicity of the model and the presence of only familar fields (electric and magnetic) offers hope that discussions might have a somewhat more intuitive appeal than what one most often encounters in the early Big Bang. Here we address only a few possibilities - time symmetry, antimatter and spin, and the inflaton.

Dark matter has been mentioned earlier in this note. More detail is available elsewhere[4, 20]. 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.

Time Symmetry

Phase is a measure of time correlation, time the conjugate variable to energy, and by the uncertainty principle both cannot be observed in a single measurement. An impedance analysis of the nested Mach-Zehnder interferometer[21] supports the view that quantum phase, being acausal (not a single measurement observable), propagates both forward and backward.

The backward propagation in time 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 appeat to be broken by the localization of causality to the individual 'Mach volumes'. 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 persist beyond that time[22, 23].

Antimatter and Spin

It was Feynman who brought forward the notion that antimatter is matter propagating backward in time. 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.

The two spin states of the photon correspond to the two possible relative phases of its electric and magnetic flux quanta, and in a larger sense one might take intrinsic spin to be a consequence of the modes, phases, and couplings of a given particle[12].

Taking seriously the notion that phase can be considered to be in some sense the quantum equivalent of 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 upon its first interaction with the Planck particle, and further that the handedness of the weak interaction might also follow from that first interaction.

The Inflaton

In the impedance model the superheavies (top, Higgs, Z, W) appear to be incredibly short-lived excitations of the magnetic modes. Their coherence lengths sit at the 9.59 GeV electromagnetic fine structure line, in the middle of the dominant bottomonium decay modes.

If the inflaton is a Higgs field, then it must couple to the magnetic modes at the Planck equivalent of that 9.59 GeV fine structure line, leftmost in figure 3. However, as pointed out earlier these magnetic modes of the Planck particle cannot be excited by the electric flux quantum of the primordial photon.

If may be that in the impedance approach there is no need for the inflaton, that the simple sequence in which the first two massive particles materialized in the very early universe was adequate to set the scale of space. It remains that how one calculates the size the universe at the end of inflation in this scenario is not yet obvious.

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[24], 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[25–28].

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