How Time, Space, and Gravity Emerge From Microscopic Quantum Waves:

A New Interpretation of Relativity[*]

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Abstract:

Einstein explained special and general relativity in terms of abstract four-dimensional space-time, and that interpretation remains universally accepted. I suggest that on the microscopic level, both relativity and gravity can be understood as emerging from oscillating quantum wave-packets of elementary particles. These localized quantum oscillators act as clocks and rulers, reproducing the standard relations for time dilation and length contraction due to both speed and gravity. Gravity can be regarded as a frequency-modulation of quantum oscillators by every other quantum oscillator in the universe. Gravitational trajectories can be computed using a quasi-classical Hamiltonian formalism. This interpretation suggests a simple unified picture of relativity and quantum mechanics, which has been missing for the past 100 years. This also has implications for the structure of black holes and the early universe.

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I. Introduction

Recall how thermodynamics emerges from microscopic degrees of freedom to create macroscopic quantities of temperature, entropy, and free energy. Similarly, microscopic quantum waves constitute all matter, and I argue that these generate mass, energy, and gravity on the macroscopic scale, as well as the four-dimensional space-time of special and general relativity. This provides a simple, natural picture which unifies physics in all regimes.

Section II shows how de Broglie waves give rise to special relativity, as well as clocks and rulers that define time and space. Frequency and wave-vector are the fundamental microscopic quantities, which enable macroscopic quantities such as energy, momentum, and angular momentum.

Section III shows how these quantum waves modulate other quantum waves, generating gravity and permitting the calculation of gravitational trajectories using a simple quasi-classical Hamiltonian, corresponding to frequency as the constant of motion.

Section IV suggests that in large gravitational potentials, the standard formulas indicating mathematical divergence at event horizons may be mathematical artifacts, and an alternative non-divergent gravity for very large fields has important implications for the theory of black holes and the early universe.

Section V argues that this simple unifying picture could have been developed in the 1930s, but that a combination of history and politics may have prevented this.

Finally, the conclusions of this essay are summarized in Section VI, and a set of references given at the end in Section VII.

II. De Broglie Waves and Special Relativity

100 years ago, de Broglie derived matter waves from special relativity, and Einstein approved. Specifically, de Broglie showed that applying the Lorentz transformation to a localized coherent oscillation with frequency $\omega = mc^2/\hbar$ leads directly to a wave with $k = p/\hbar$, where p is the momentum and $\hbar$ is Planck's constant. This led to the Schrödinger equation, and to modern quantum mechanics. But the fundamental relativistic nature of quantum waves was generally obscured, especially for the non-relativistic limit with $v \ll c$.

I suggest that this relationship between de Broglie waves and relativity should be inverted: special relativity can be derived directly from the existence of de Broglie waves. This differs from the historical development of special relativity, based on the constancy of the speed of light c. Within the alternative picture presented here [1,2], de Broglie waves in their rest frame provide the clocks and rulers which define time and space, and these clocks and rulers change with speed (and gravity, as described in Section III). Empty space does not have an intrinsic time reference. Further, photons cannot provide such clocks and rulers, since they are never at rest. The same is true of gravitational fields.

The fundamental equation is the dispersion relation for a de Broglie wave, usually written

$$\omega^2 = (mc^2)^2 + (kc)^2, \qquad (1)$$

which can be rewritten

$$(\omega\tau)^2 = 1 + (k\Lambda)^2, \qquad (2)$$

where $\tau = \hbar/mc^2 = 1/\omega_0$, and $\Lambda = \hbar/mc$ are the characteristic time and length. Consider, for example, $m = 9 \times 10^{-31}$ kg, the mass of the electron. Then $\tau = 1.3 \times 10^{-21}$ s and $\Lambda = 0.4 \times 10^{-12}$ m. The electron wave itself is a natural clock and ruler, for anything composed of electrons, including all atomic matter. While most of the mass is composed of quarks with different values of m, they are also localized quantum oscillators, and behave in a similar way.

For a localized wave-packet, this leads to a group velocity $v_g = \partial\omega/\partial k = kc^2/\omega$. For $\omega >> \omega_0$, v_g goes asymptotically to c, while in the non-relativistic limit $v_g = kc^2/\omega_0 = \hbar k/m = p/m$, as it must for the velocity of a quantum "particle". From this point of view, $c = \Lambda/\tau$ is not primarily the speed of light, rather it is the maximum speed of all matter waves.

Because de Broglie waves are true vacuum waves with no preferred reference frame, Eqs. (1) and (2) must be the same in all reference frames, requiring the Lorentz transformation to ω' and k' in a reference frame moving with velocity v:

$$\omega' = \gamma(\omega - \mathbf{k.v}), \text{ where } \gamma = (1-v^2/c^2)^{-1/2} \tag{3}$$

$$\mathbf{k}' = \gamma(\mathbf{k} - \omega\mathbf{v}/c^2) \tag{4}$$

This gives rise to the standard relativistic time-dilation and length-contraction associated with a moving reference frame: $\tau' = \gamma\tau$; $\Lambda' = \Lambda/\gamma$. From this point of view, it is not abstract time and space that are changing, but rather the matter-based clocks and rulers that define them. Furthermore, energy, momentum, and angular momentum are macroscopic quantities derived from the fundamental quantum waves.

That means that there is no intrinsic time reference and spatial grid. Instead, there is always a local reference associated with a particular quantum wave, or set of quantum waves. The orthodox interpretation of the Lorentz transformation as a rotation of four-dimensional space-time is a derived mathematical construction applicable to the macroscopic scale. Only in the special case of low velocities (and low gravity) do all of the microscopic clocks behave similarly, allowing one to recover classical universal time and space.

This is in accord with the modern functional view of time: what our atomic clocks (based on electronic states in atoms) say it is. For example, the Global Positioning System (GPS) consists of atomic clocks on the ground and on satellites in orbits. Relativistic corrections are required for the orbiting atomic clocks, both for satellite speed and gravitational potential. Without these corrections, GPS locations would be off by kilometers. This is true even though satellite velocities are not large, and the gravitational fields are quite weak.

III. Quantum Waves and Gravity

These same fundamental quantum oscillators also provide a unified picture of gravity [3]. Every oscillator has a fundamental rest energy $E = \hbar\omega_0 = m_0c^2$, but this is decreased in a gravitational potential due to the influence of all other quantum oscillators in the universe. The potential is given by $\Phi = -G\Sigma\, m_i/R_i$ where the sum is over all other masses, and G is the gravitational constant. But since all masses are made of quantum oscillators, this can also be written $\Phi = -(\hbar G/c^2)\Sigma\, \omega_i/R_i$, where the sum is now over all oscillators, or in terms of the normalized dimensionless potential $\phi = \Phi/c^2$,

$$\phi = -(\hbar G/c^4)\Sigma\, \omega_i/R_i \qquad (5)$$

Since the energy becomes $E = m_0c^2 + m_0\Phi = mc^2 = \hbar\omega$, one has $\omega = \omega_0(1+ \phi)$, which leads to the results for gravitational time-dilations and length-contraction:

$$\tau = \tau_0/(1+ \phi) \text{ and } \Lambda = \Lambda_0(1+ \phi). \qquad (6)$$

This appears different from the standard metric results from general relativity theory, which are equivalent to $\tau = \tau_0/(1+ 2\phi)^{0.5}$ and $\Lambda = \Lambda_0(1+ 2\phi)^{0.5}$. However, these standard results were derived (and confirmed) only for $\phi<<1$ (typically ~ 10^{-6}), where the expressions are indistinguishable. This is the regime that is examined here, although implications for larger ϕ are discussed in Section IV.

Note also that $c = \Lambda/\tau = c_0(1+\phi)^2 \approx c_0(1+2\phi)$, for the low-$\phi$ limit discussed here. This picture predicts that the speed of light c is NOT constant, but rather decreases in gravitational fields. This would seem to contradict what everyone believes about Einstein's general relativity, but it is actually only special relativity where c is a universal constant. In standard general relativity, the variation in c is implicit, but hidden in the concept of curved space-time. Indeed, the curvature of the trajectory of light near a star can be explained by a spatially-varying index of refraction and classical wave optics, and this is the viewpoint presented here.

To calculate the gravitational trajectory of a quantum wave-packet, consider for example an electron confined within an atom, described by a position $\mathbf{r}(t)$, moving in a static gravitational potential $\phi(\mathbf{r})$. As the atom moves, its electron quantum frequency $\omega(\mathbf{k},\mathbf{r})$ should remain constant (as long as it remains in the same quantum state).. So

$$d\omega(\mathbf{k},\mathbf{r})/dt = 0 = \partial\omega/\partial\mathbf{r} \,.\, dr/dt + \partial\omega/\partial\mathbf{k} \,.\, d\mathbf{k}/dt \qquad (7)$$

Then in the same way as for a classical Hamiltonian,

$$d\mathbf{r}/dt = \partial\omega/\partial\mathbf{k} = \mathbf{v} \text{ for any wave-packet, and so } d\mathbf{k}/dt = -\partial\omega/\partial\mathbf{r}. \qquad (8)$$

Given Eqs. (2) and (6), and a spatial dependence of $\phi(\mathbf{r})$, this can be solved numerically to obtain trajectories and orbits fully consistent with general relativity.

For example, given a central potential $\phi(\mathbf{r}) = -GM/rc^2$ corresponding to the sun, a numerical solution using Matlab reproduces quantitatively both the curvature of light and the rotation of the perihelion of Mercury, the two standard tests of general relativity. Note that this solution has no mention of four-dimensional space-time or curved space.

IV. Large Gravitational Potential in Black Holes and Early Universe

The normalized gravitational potential ϕ is quite small even close to the sun, $\sim 10^{-6}$. But from Eq. (5), the major contributions to the potential are actually from distant galaxies. That is because $\phi \propto 1/R$, but the area increases as R^2. The largest contributions should be from the early universe, billions of light-years away. Although an accurate accounting of the total potential for the universe may be lacking, estimated values $\sim 0.1 – 1$ have been suggested. Can this uniform potential really be neglected? Yes, but this implies that the local value of c is significantly smaller than the "true" value c_0. However, since all our instruments are also embedded in this large uniform background, we cannot measure this. The trajectories are determined by potential gradients, and those are exclusively due to nearby masses.

The dependences of τ and Λ for small ϕ have been accurately confirmed, but not for larger values close to 1. Despite the universally accepted theory of black holes, with event horizons corresponding to $\phi = -0.5$, this regime has never actually been accurately measured. The evidence for gravitational condensed objects in the centers of many galaxies is clear, but I would suggest that any divergent event horizon may be a mathematical artifact of an expression outside its regime of validity [4]. If everything is based on local quantum oscillators, the physical frequency should never go to zero for a finite value of ϕ. If such an event horizon does not exist, most of the theoretical analysis of black holes is invalid.

For example, consider an alternative expression $\tau = \tau_0 (1- \phi)$, which has the same low-ϕ limit. This increases continuously as $|\phi|$ becomes large, as the oscillation frequency goes smoothly to zero. Or consider $\tau = \tau_0 \exp(-\phi)$ (referred to as "exponential gravity" [5]). For small ϕ, this becomes $\tau = \tau_0 (1- \phi)$, matching what has been measured. This grows rapidly for $|\phi|>1$, but never diverges. Many other expressions have this same low-ϕ limit, and careful observations near regions with very large gravitational fields would be required to determine the most accurate expression.

Consider a gravitationally dense object similar to a black hole, but without an event horizon. For a spherically symmetrical object, a photon could escape, but only for a very narrow angle around the vertical. All other photons would be trapped. This is not quite a black hole, but rather a "dim star" with an enormous red shift. Unlike the orthodox theory of black holes, the interior of this dim star is NOT cut off from the rest of the universe, and its internal structure might be accessible from outside observation.

More detailed models would be necessary to determine whether the interior of such a dim star would collapse into a singularity, or instead remain some sort of dense quark-lepton plasma.

Most models of the early universe incorporate a dense quark-lepton plasma, which might be similar to the interior of this gravitationally condensed star or galactic core, without an event horizon. Perhaps such a not-quite-black-hole could provide a laboratory for the exploration of the early universe. For example, a very rapid expansion of the early universe, similar to cosmic inflation, might follow from a particularly strong (exponential?) dependence of ϕ in the large-ϕ regime.

V. Past and Future Reunification of Physics

This picture unifying relativity and quantum waves could have been presented 100 years ago, after deBroglie's relativistic derivation of matter waves, but the geometrical picture of relativity had already been well established. Furthermore, Einstein's relativity was a politically dangerous subject in Nazi Germany in the 1930s and 1940s, blocking any talk of unifying quantum mechanics and relativity [6]. The only way that the new quantum theory could even be taught was by deliberately obscuring its relativistic foundation, and this is how the field developed. This apparent split between relativity and quantum mechanics was enhanced by Einstein's own objections to quantum entanglement and randomness. In the absence of this common foundation, relativity became associated with abstract space-time, and quantum theory with abstract multi-dimensional Hilbert space, incompatible mathematical frameworks. This fundamental split was maintained after the defeat of the Nazis, and has continued to the present.

I have proposed a picture of fundamental quantum waves which are real vector fields, rotating in real space with quantized spin [1]. This represents a locally real, deterministic picture of quantum waves, which is closer to Einstein's vision, and which helped to inspire the new interpretation of relativity discussed here. But this is incompatible with abstract concepts of massive quantum entanglement, which are part of the established quantum theory. Recently, quantum entanglement has been applied to develop a technology of quantum computers, with billions of dollars being invested. If quantum computing turns out to be a conspicuous failure [7], there may be an opportunity for re-examination of the foundations of modern physics. Only time will tell!

VI. Conclusions

Most physical theories build up from microscopic foundations to macroscopic variables, but that is missing for relativity, where an abstract 4-dimensional space-time is imposed from above. In contrast, quantum waves represent a microscopic foundation in search of a macroscopic theory. Putting these together results in a more complete theory which looks quite different, but is really an alternative interpretation of Einstein's theories of special and general relativity. By building this on microscopic physical clocks and rulers, this seems more in accord with Einstein's vision of local physical reality.

I further suggest that this approach reunifies a fundamental split in the foundations of physics, between relativity on one hand and quantum mechanics on the other. It should have been obvious in the 1930s that these two were closely related, but this was likely suppressed due to political pressures in Nazi Germany. Once the orthodox theories became established, it became virtually impossible to question them. I suggest that near-future problems with quantum entanglement and quantum computing may enable these questions to be re-examined.

Another important implication of this picture is that the physical frequency should not go to zero for any finite value of the gravitational potential, suggesting that event horizons around black holes may be a mathematical artifact rather than a physical reality. This, in turn, suggests consideration of non-divergent models for strong gravity, which may enable observational access to the internal structure of not-so-black holes. These may even represent laboratories for dense quark-lepton plasmas in the early universe.

The picture presented here focuses on unifying relativity and quantum theory on the pm and fm scales, and does not in any way address issues of grand unification of forces on much smaller scales. But only by resolving and clarifying existing paradoxes can physics then proceed to the next level of reality.

VII. References

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