Understanding Gravity on the Microscopic Level*

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Abstract:
Is there a consistent microscopic foundation for both general relativity and quantum mechanics? Both arose early in the 20th century from a background of classical mechanics and special relativity, but they took quite different turns, leading to seemingly incompatible worldviews. A simple picture is presented that may serve as a bridge between the microscopic quantum and macroscopic gravitational worlds. One may regard a relativistic quantum field as a real physical clock, which slows down as it enters a gravitational potential, providing a simple explanation for gravitational time dilation. This picture leads to a semi-classical Hamiltonian, with an orbital trajectory that is examined in the context of the Parameterized Post-Newtonian (PPN) Approximation. Remarkably, this avoids divergences and singularities, including black holes and event horizons.

Introduction

Classical mechanics has universal space and time coordinates, with real deterministic local trajectories that may be defined by constant total energy. Special relativity maintains the trajectories but introduces relative time and space and elevates the speed of light to a universal constant. Quantum mechanics (QM) has complex waves of constant frequency, related to energy by $E=\hbar\omega$, but also incorporates concepts of intrinsic indeterminacy, nonlocality, and entanglement on the microscopic level. In contrast, general relativity (GR) maintains real trajectories, but they follow non-Euclidian geometry with locally varying curved space-time that may be divergent. These theories represent mutually incompatible physical pictures.

An outline of a new consistent paradigm is presented[1,2,3], that extends from the microscopic to the macroscopic level, maintaining local continuous reality and deterministic trajectories. This enables one to define a local dynamical time, and also constructs gravity from microscopic quantum dynamics. The key picture is shown in Fig.1, which shows a localized coherently rotating real vector field with quantized spin. Fig.1a represents a localized electron wave with rotational frequency ω_0 given by $m_0c^2=E=\hbar\omega_0$, with all the rotators in phase. Since events that are simultaneous in one reference frame are non-simultaneous in others, this may be Lorentz-transformed to a moving electron as shown in Fig. 1b on the right, with $E' = mc^2 = \hbar\omega' =$

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$\sqrt{(pc)^2 + (m_0c^2)^2}$ and $\omega' = \sqrt{(kc)^2 + \omega_0{}^2}$. The phase gradient shows this to be a de Broglie wave with wavelength $\lambda = h/p$. This is similar to a circularly polarized electromagnetic wave, a rotating electric field vector which carries both energy E and angular momentum S, related (via Maxwell's equations) by $E = S\omega$. For the photon, $S = \hbar$, while for the electron, $S = \hbar/2$, but still yielding $E = \hbar\omega$. Quantization of spin is what turns a continuous relativistic field to a discrete quantum particle.

Note that Fig. 1 is drawn so that the vector rotation is clockwise, so that these look like clocks. These *are* local clocks, in a very real physical sense, as discussed below. Furthermore, this quantum rotation provides the basis for classical physics, as well as representing both the source and the detector of gravity. This provides new insight into the fundamental nature of gravity and mass.

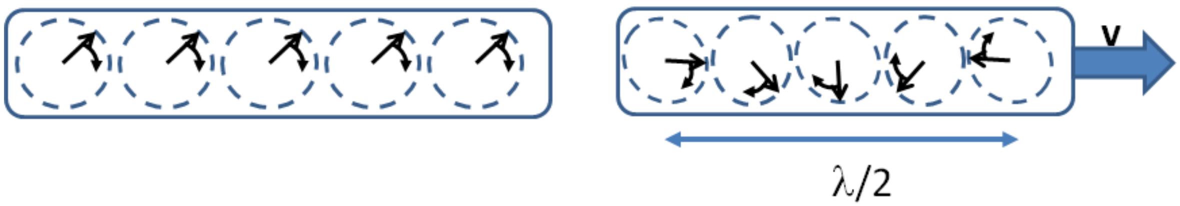

Fig. 1. Fundamental quantum particle as rotating vector fields, which also represent local clocks.[3] *(a) Particle at rest, with angles in phase. (b) Moving particle, with phase gradient corresponding to de Broglie wave.*

Trajectories and Gravitation

If a particle is free to move in a potential energy field $V(\mathbf{r})$, it will follow a trajectory $\mathbf{r}(t)$ such that the total energy E is constant along the trajectory, or equivalently that the rotational frequency ω is constant. This defines a quasi-classical Hamiltonian $H(\mathbf{r},\mathbf{p})$, or equivalently $\omega(\mathbf{r},\mathbf{k})$ in terms of wave properties. In the classical case, $\mathbf{v} = \frac{d\mathbf{r}}{dt} = \frac{\partial H}{\partial \mathbf{p}}$ and $\frac{d\mathbf{p}}{dt} = -\frac{\partial H}{\partial \mathbf{r}}$; in the equivalent quantum case, $\mathbf{v} = \frac{\partial \omega}{\partial \mathbf{k}}$ (also the group velocity of the wave) and $\frac{d\mathbf{k}}{dt} = -\frac{\partial \omega}{\partial \mathbf{r}}$.

Note that this is a completely deterministic relation, as long as the particle remains in a particular quantum state. Both position of the particle (defined by the center of the wave distribution) and its momentum are definite, as is its spin. There are no superpositions of quantum states of different ω or S, or entanglement between such states. Classical physics derives directly from the constant ω in a relativistic phase-coherent propagating wave packet.

Consider now that the particle is moving in a gravitational potential, e.g., falling into a gravitational potential well given by $V(\mathbf{r}) = -\frac{GmM}{R}$, for a small test particle m at a distance R from a large mass M. The negative gravitational potential will decrease the energy (frequency), while the moving particle will maintain its energy by increasing its kinetic energy (and momentum) as it falls. The dynamical equation from special relativity becomes

$$\hbar\omega = mc^2 = \sqrt{(pc)^2 + (m_0c^2)^2} - \frac{mMG}{R}. \quad (1)$$

Please note that *m* is now on both sides of the equation. This is a critical assertion, whereby the change in frequency $\Delta\omega$ is proportional to the frequency ω. Therefore ω can never change sign or go to zero, no matter how strong the potential. This makes sense physically, if ω is a real physical quantity on the microscopic level, corresponding to quantized spin. By combining *m* from both sides of the equation, one obtains

$$\hbar\omega = mc^2 = \frac{\sqrt{(pc)^2+(m_0c^2)^2}}{1-\phi}, \quad (2)$$

where $\phi = -\frac{MG}{Rc^2} = -2\frac{R}{R_s}$ is the normalized gravitational potential, and $R_s = \frac{2MG}{c^2}$ is the standard Schwarzschild radius. More generally, ϕ is always negative, so *m* and ω are always positive. Furthermore, rest mass $\frac{m_0}{1-\phi} \rightarrow 0$ as $R\rightarrow 0$, so that gravitational collapse saturates at a size ~R_s, rather than going all the way to zero. Within this picture, there should be no singularities such as black holes or event horizons (see also [4]). Compact high-mass astronomical objects have been observed, which according to standard theory should be black holes. But that is not the same as directly observing a non-emitting singular object.

Note also that all quantum rotators at a given location **r** are slowed by the same factor $\frac{1}{1-\phi}$, relative to the reference timebase in the absence of the gravitational potential. Therefore, any physical clock will be slowed by the same factor, which provides a simple physical basis for gravitational time dilation[5]. In GR, the slowing factor is $\sqrt{1+2\phi}$, which is the same to lowest order in ϕ.

The key test of time dilation is known as the gravitational red-shift, whereby a photon emitted inside a gravitational well (such as near a massive star) that travels away from the star (Fig. 2) undergoes a red shift, shifting to a longer wavelength and a lower energy. But from a quantum point of view, a quantum wave may not shift its frequency while remaining in the same quantum state. The resolution to this paradox is that the photon decreases its momentum as it moves away from the star, thus increasing its wavelength while its energy and frequency remains the same: $\lambda = \frac{2\pi c}{\omega}\frac{1}{1-\phi}$. Of course, this also requires that the speed of light is not a universal but changes: $v = \frac{c}{1-\phi}$. On the other hand, it changes by exactly the same factor as the local clocks, so that any local measurement of the speed of light will measure $v = c$ if one does not correct for the varying timebase.

This variation of particle mass and the speed of light may also have cosmological implications. The gravitational potential $\phi(\mathbf{r})$ may have a significant cosmological value due to distant galaxies, even in the present state of the universe, and was significantly larger in magnitude in the early universe, even away from localized gravitational wells. This may lead to variation in several cosmological parameters over time. A recent analysis[6] has suggested that the observational evidence for dark energy (the apparent accelerating expansion of the universe) may be an artifact of these changing parameters.

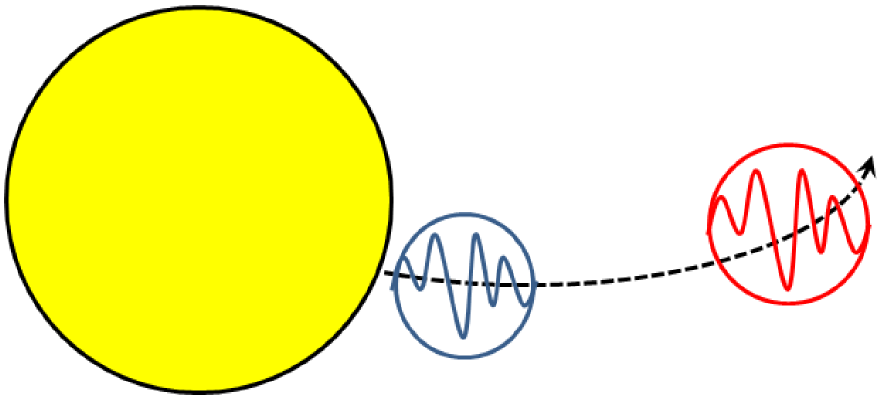

Fig. 2. In the gravitational red shift, a blue photon emitted close to a massive star becomes a red photon when observed far away. Here, the photon follows a constant-ω trajectory (referenced to a fixed timebase), losing momentum (and increasing $\lambda=h/p$) as it moves away from the star.

Quantitative Comparison to GR using PPN

There are three classic tests of GR,[7] which may be compared quantitatively to the predictions of Eq. (2). These are the gravitational red shift, the bending of light near a star, and the rotation of the perihelion of Mercury. The red shift matches that of GR to lowest order in ϕ. The other two tests are orbital trajectories around a star, which can be computed numerically using the Hamiltonian equations based on Eq. (2), and compared to the standard results of GR, using the Parameterized Post-Newtonian framework[8,9] (PPN). Direct simulations show that there are quantitative differences, even for $R \gg R_s$, for which the values are quite well established.

Specifically, the PPN expression for the angular bending of light (in radians) is given by

$$\Delta\theta = \frac{2R_S}{R_0}\frac{1+\gamma}{2}, \tag{3}$$

where R_0 is the distance of closest approach to the center of the star, and $\gamma=1$ in GR. The simulation (Fig. 3a) gives ~½ of the GR value, indicating that γ~0. Second, for the precession of the perihelion of Mercury, the PPN relation is:

$$\Delta\theta = \frac{3\pi R_S}{L}\frac{2-\beta+2\gamma}{3} \text{ radians per revolution,} \quad (4)$$

where L is a geometrical parameter of an ellipse known as the semilatus rectum, and β=1 in GR. The simulation also gives precession of the ellipse (Fig. 3b), but with an angular rotation that is ~1/6th of the GR result. That is also consistent with γ~0, while β>~1. Since the γ parameter represents the curvature of space, it makes sense that Eq. (2), which incorporates local time but not modification of space, would correspond to γ=0. It is not obvious how one could consistently incorporate such curvature of space into this picture.

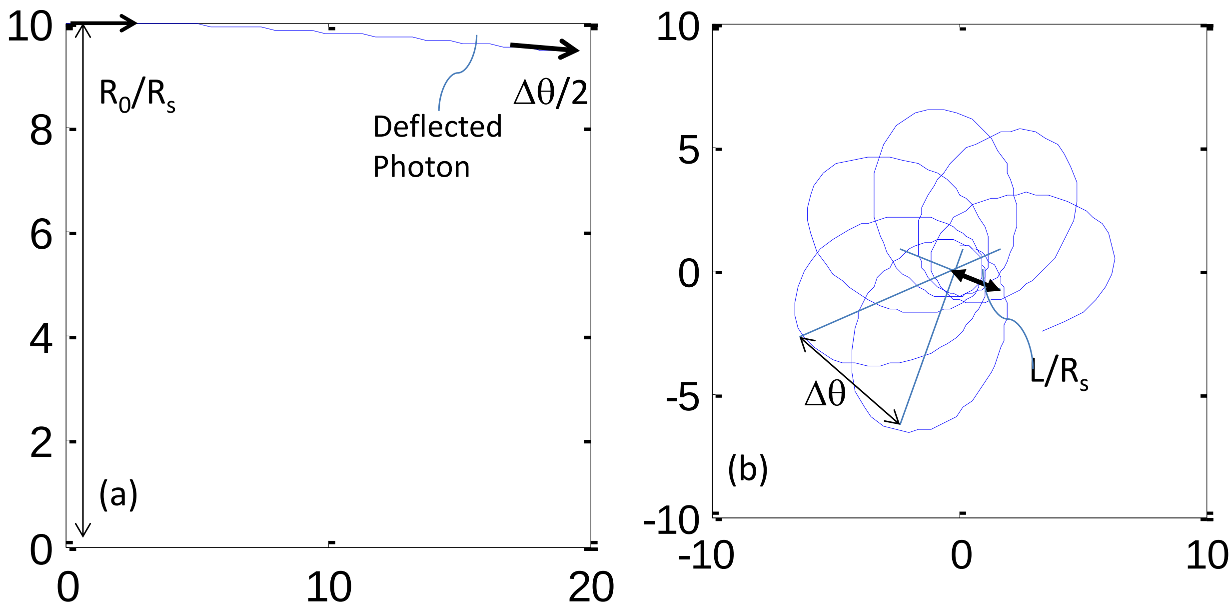

Fig. 3. Simulated trajectories for particle moving in central gravitational field, based on Eq. (2), using Matlab. (a) Deflection of photon trajectory by angle $\Delta\theta \sim 2R_s/R_0$. (b) Orbital precession by angle $\Delta\theta \sim \pi R_s/2L$ per revolution.

Conclusion

This essay presents a novel picture of the microscopic world wherein mass/energy has a simple dynamical meaning: it is just the rotational frequency of a fundamental quantum field (i.e., quantized particle), and represents a local clock. In addition to generating particle trajectories, ω for each particle contributes a proportional potential which acts to slow down the rotation rate of all other particles. This naturally avoids divergences (and black holes), but leads to rest masses that go asymptotically to zero in regions of large gravitational potential. This may have important implications for cosmology, dark energy, and the big bang. Finally, direct computation of trajectories has indicated quantitative differences from GR even to lowest order, in particular by not incorporating curvature of space. Still, this picture may help to provide a new start for a consistent foundation that could bridge both QM and GR.

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Dr. Alan M. Kadin is an applied physicist (Ph.D. in Physics, Harvard, 1979), specializing in superconducting devices, who has worked both in industry and academia, including at the University of Rochester and at Hypres, Inc. He is the author of a textbook, *Introduction to Superconducting Circuits*, Wiley, 1999, and more than 100 publications. He has also maintained an interest in the foundations of physics, going back to his senior thesis at Princeton on hidden variables in quantum mechanics. Dr. Kadin is now an independent consultant living in Princeton Junction, New Jersey.