From Straight Beams to Curved Paths: A Unified Perspective on Energy, Fields, and Spacetime

Marco Maccarrone

6-12-24

Abstract

This paper proposes a conceptual and mathematical framework that replaces the straight-line propagation of energy and fields, as traditionally assumed in quantum field theory (QFT), with a curved-wavefront perspective that aligns with the geometry of spacetime in general relativity (GR). By redefining straight beams as curved paths where the length of any beam equals the radius of a spherical wavefront at a given instant we achieve a unified description of energy propagation, reconciling wave-particle duality with spacetime curvature. This approach resolves inconsistencies between QFT and GR, offering a new lens for understanding phenomena like redshift, gravitational lensing, and wave-particle interactions in curved spacetime.

1 Introduction

The discord between Quantum Mechanics and General Relativity has long been a central challenge in physics. While QFT assumes a flat spacetime background and straight-line propagation of energy and fields, GR describes a universe fundamentally curved by mass-energy.

This paper introduces a new perspective:

1. **Straight-line propagation**: A convenient but limiting abstraction in flat spacetime.
2. **Curved wavefronts**: A more natural descriptor, aligning with the reality of curved spacetime.

By treating wavefronts as expanding spheres or ellipsoids whose geometry adapts to spacetime curvature, we propose a unified framework that respects both the local and global nature of energy propagation.

2 Straight lines vs. curved reality

2.1 The straight-line approximation

In QFT:

- Energy is typically modeled as traveling in straight-line trajectories (e.g., plane waves, beams).
- This works well in flat spacetime but becomes less accurate in curved geometries.

2.2 The reality of curved paths

Light and energy naturally propagate along curved paths (e.g., null geodesics in GR). Wavefronts are inherently spherical or elliptical, spreading energy across a growing surface area.

2.3 The proposal: replace lines with curves

Redefine straight beams as *spherical or elliptical wavefronts.* The length of any "beam" at a given instant is the radius r of the wavefront, consistent with the inverse-square law.

3 Mathematical framework

3.1 The geometry of wavefronts

$$\text{Spherical wavefronts in flat spacetime:} \quad A = 4\pi r^2, \quad I = \frac{E_{\text{total}}}{4\pi r^2}, \tag{1}$$

$$\text{Elliptical wavefronts in curved spacetime:} \quad A = 4\pi ab, \quad I = \frac{E_{\text{total}}}{4\pi ab}, \tag{2}$$

where A is the surface area, I is intensity, and a, b are the semi-major and semi-minor axes.

3.2 Adapting QFT to curved wavefronts

Replace plane wave solutions with spherical harmonics:

$$\psi(r, \theta, \phi) = R(r) Y_\ell^m(\theta, \phi), \tag{3}$$

where $R(r)$ encodes the radial dependence and Y_ℓ^m captures angular variation.

3.3 Unifying GR and QFT

Energy propagation respects both the local spacetime curvature (GR) and the quantum wavefunction (QFT):

$$\Box\psi + V(\psi, g_{\mu\nu}) = 0, \tag{4}$$

where $\Box$ is the dAlembert operator in curved spacetime.

4 Implications

4.1 Redshift and energy dilution

The inverse-square law arises naturally from spherical wavefronts, even in expanding or curved spacetimes. Redshift is understood as the stretching of wavefronts as they propagate through expanding space.

4.2 Gravitational lensing

Gravitational fields distort spherical wavefronts into elliptical shapes. The curvature of spacetime guides the photons path while preserving the wavefront geometry.

4.3 Wave-particle unity

The photon exists as a localized packet on the wavefront, guided by the curvature of spacetime. This resolves inconsistencies in describing wave-particle duality in curved geometries.

5 Predictions and testability

5.1 Polarization in gravitational lensing

Predict subtle polarization shifts in lensed light due to the elliptical distortion of wavefronts.

5.2 Energy distribution in high-energy events

High-energy photons in curved spacetimes should show directional anisotropies in energy distribution.

5.3 Experimental simulations

Laboratory experiments with curved wavefronts (e.g., optical traps, metamaterials) could mimic spacetime curvature effects.

6 Conclusion

By rethinking straight-line propagation as curved wavefront expansion, we unify quantum mechanics and general relativity within a single geometric framework. This approach not only resolves inconsistencies but also offers new predictions, bridging the gap between the microscopic and macroscopic descriptions of reality. As science spirals forward, this model underscores the elegance of curved paths in a fundamentally curved universe.

References

- Einstein, A. (1915). The field equations of gravitation. Annalen der Physik.
- Planck Collaboration. (2020). Planck 2018 results. Astronomy and Astrophysics.
- Dirac, P. A. M. (1930). Principles of Quantum Mechanics.
- Hawking, S. (1974). Black hole explosions?. Nature.
- Maxwell, J. C. (1865). A dynamical theory of the electromagnetic field.

A Appendix A: The Inverse-Square Law and Spherical Wavefronts

The inverse-square law, a foundational concept in physics, naturally arises from the expansion of spherical wavefronts. Consider a point source emitting energy E_{total} uniformly in all directions. The energy spreads out across the surface of a sphere as the wavefront expands:

$$A = 4\pi r^2. \tag{5}$$

The intensity, defined as energy per unit area, is then given by:

$$I = \frac{E_{\text{total}}}{A} = \frac{E_{\text{total}}}{4\pi r^2}. \tag{6}$$

This relationship underpins phenomena such as the propagation of light, sound, and gravitational fields, demonstrating that energy conservation and spherical symmetry inherently produce the inverse-square law.

B Appendix B: Gravitational Lensing as Curved Wavefront Distortion

Gravitational lensing occurs when massive objects distort the spacetime around them, bending the paths of light. While traditionally described as the bending of straight rays, this phenomenon is better understood as the distortion of spherical wavefronts into elliptical or otherwise asymmetric shapes. This reinterpretation aligns the behavior of light with the curvature of spacetime and the helical wave model's framework. Polarization effects observed in gravitational lensing events provide additional evidence for the interaction between wavefront geometry and spacetime.

C Appendix C: Redshift and Expanding Spherical Wavefronts

Cosmological redshift is commonly attributed to the stretching of light waves as the universe expands. From the perspective of the helical wave model, this can be interpreted as the progressive expansion of spherical wavefronts. As the wavefront grows, the energy density decreases, and the wavelength elongates, consistent with observations. This geometric understanding complements the standard metric-based explanation from general relativity.

D Appendix D: Fast Radio Bursts (FRBs) and High-Energy Wavefront Compression

Fast Radio Bursts (FRBs) are intense, millisecond-long radio signals from extragalactic sources. The helical wave model offers an intuitive interpretation: during high-energy events, or in high energy environments, wavefronts become compressed due to intense gravitational fields. This compression concentrates energy into directional bursts, aligning with the observed characteristics of FRBs.

E Appendix E: double-slit experiment and curved paths

The double-slit experiment demonstrates interference patterns arising from the superposition of wavefronts. By modeling light as curved wavefronts rather than linear rays, the interference fringes can be understood as the result of overlapping spherical or elliptical wavefronts. This perspective naturally integrates the wave-particle duality of light into the curvature of spacetime.