Segmented Spacetime and Segment-Based Group Velocity - Redefining Wave Propagation in Structured Spacetime

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We present a novel framework in which spacetime is treated as a discretely segmented structure, replacing continuous geodesics with quantized segment traversal. Within this model, group velocity and gravitational redshift emerge as direct functions of segment density rather than spacetime curvature. By reformulating frequency and energy via a segment-based correction, we demonstrate a new interpretation of gravitational time dilation and quantum transitions. Applied to real data, such as the gravitational redshift of star S2 near Sagittarius A, the model accurately recovers energy values through a purely structural correction formula. Additionally, the framework introduces generalized state functions Ψ(E, λ) and Ψ(τ, t), opening a path toward unifying quantum mechanics and relativistic gravitation without invoking field curvature. The result is a scalable, local, and testable model of wave behaviour in discretized spacetime. This model invites a paradigm shift from the idea that spacetime tells matter how to move to spacetime tells waves how to segment. With future observations of stars closer to Sgr A, we may soon witness the breakdown of smooth geometry and the rise of a countable, computational universe.*

Revisions Overview

This revised version significantly expands the theoretical and empirical scope of the original paper. Key additions include:

- A refined derivation of group velocity as a function of discrete segment traversal rather than continuous gradients.
- An energy correction formula based on segment density, applied to gravitational redshift data from the S2 star near Sagittarius A*.
- A generalized wavefunction formulation Ψ(E, λ) and Ψ(τ, t), connecting frequency, wavelength, energy, and proper time within the segment-based model.
- A demonstration that gravitational redshift can be modeled without curvature, using discrete structural corrections instead.
- The introduction of a computationally local interpretation of gravitational time dilation, opening paths for laboratory-scale validation.
- A conceptual shift in the physical interpretation of spacetime: from geodesic curvature to segmental resolution.

These extensions support a broader vision: that wave behavior, quantum mechanics, and gravitational dynamics may be unified within a discretized, segment-driven spacetime structure.

1. Introduction

The classical wave model treats space as a continuous medium, where group velocity is defined as:

$$v_{group} = \frac{d\omega}{dk}$$

This derivative-based view is well-suited for homogeneous, continuous systems but breaks down when applied to strongly segmented or gravitationally curved environments. In such contexts, the assumption of a continuous dispersion curve becomes physically ambiguous. We propose an alternative approach based on discrete segment traversal, redefining group velocity as a structural property rather than a differential one.

2. Segment-Based Model of Spacetime

Let spacetime be composed of discrete segments [1], which define the resolution of wave propagation. A wave traverses these segments at a rate governed by its frequency [2].

Definition (Segment traversal velocity):

In a segmented spacetime model, where wave propagation is governed by discrete spatial segments rather than continuous fields, the group velocity is not defined as the derivative of a dispersion relation ω(k), but rather as a direct function of the frequency relative to the rate of segment traversal:

$$v_{group} = \frac{L_{seg} \cdot f}{N}$$

where:

L_{seg}: Length of one segment
f: Frequency in Hz (cycles per second)
N: Number of segments per cycle

This leads to the core principle:

Group velocity = frequency-determined propagation of segment traversal

3. Application to Atomic Transitions

Using the hydrogen atom as a case study, we examine the transition from a highly segmented bound state (91 nm UV line, f = 3.29 × 10^{15} Hz) to the 21-cm hyperfine transition line (f' = 1.426 × 10^9 Hz). The segment ratio $\frac{N'}{N_0}$ scales the frequencies inversely. N_0 =4 is chosen as the minimal segment count for one full cycle of the 91 nm UV transition, establishing a reference for segment scaling:

$$N' = \frac{N_0\,\lambda}{\lambda'}$$

$$f' = f\,\frac{N_0}{N'}$$

Substituting real values:

$$N' = \frac{4\ \cdot\ 0.21}{91\ \cdot\ 10^{-9}} = \ 9{,}230{,}769.231$$

$$f' = \frac{3.29\ \cdot\ 10^{15}\cdot\ 4}{9{,}230{,}769.231} \approx\ 1.426\ \cdot\ 10^{9}\ Hz$$

This exact match to the known 21-cm line demonstrates the consistency and predictive power of the segmented model.

4. Calculation of Energy Using Segment Density and Group Velocity

If two processes originate from a common segmented origin, then they share the same number of segments N, and all derived measures are structurally coherent. This structural coherence provides a direct relationship between the group velocity, energy, and frequency. By leveraging the segment-based approach, the energy E associated with a given frequency f can be derived without the need for direct measurement of energy in each case.

From this relationship, we can calculate the energy E of the system by using the Planck constant h:

$$E = h \cdot f$$

Rearranging for frequency:

$$f\ = \frac{v_{group}\ \cdot\ N}{L_{seg}}$$

Substituting into the energy equation gives:

$$E = h \cdot \frac{v_{group} \cdot N}{L_{seg}}$$

Thus, the energy is determined by the group velocity and the segment density N, which can be inferred from the structure of the process itself.

Additionally, the full state of the system, including both energy and wavelength, can be described using the wavefunction:

$$\Psi(\mathrm{E}, \lambda) \text{ or } \Psi(\tau, \mathrm{t})$$

where E represents the energy associated with the segment, λ is the wavelength, and τ and t are the proper and observer times, respectively.

In this model, measuring the frequency f of a wave gives direct access to the energy content of the system, assuming the processes share the same segmented origin. Since the number of segments N is consistent for processes originating from the same system, this allows for accurate energy predictions even when direct energy measurements are impractical.

5. Determining the Segment Density $N_{observer}$

To determine the segment density of the observer, $N_{observer}$, we use the frequency of a photon. The frequency of a photon beam is affected by gravitational time dilation as it passes through the gravitational field of the Earth. This shift can be described by the following formula:

$$\frac{\Delta f}{f} = \frac{GM}{c^2 R}$$

Parameters:

G: Gravitational constant (6.674×10^{-11} m³ kg⁻¹ s⁻²)

M: Mass of the Earth (5.972×10^{24} kg)

c: Speed of light (299792458 m/s)

R: Radius of the Earth (6.371×10^{6} m)

This formula shows how the frequency (f) of a photon is changed due to gravitational time dilation as it passes through the Earth's gravitational field. The frequency shift (Δf) is proportional to the gravitational potential of the Earth and the speed of light.

Calculating the Frequency Shift for Photons on Earth:

If we know the frequency of the photon in vacuum (f_vacuum) (e.g., a photon with a frequency of 1 GHz) and the photon travels through the Earth's gravitational field, its frequency will be shifted according to the gravitational frequency shift formula:

$$f' = f\_vacuum * (1 - \frac{GM}{c^2R})$$

Substituting the values, we can calculate the frequency on Earth (f') for the photon.

Assume a photon has a frequency of 1 GHz in vacuum:

$$f\_vacuum = 1\,GHz$$

Using the above values for G, M, c, and R, we calculate the frequency shift (Δf):

$$\frac{\Delta f}{f} = (6.674 \times 10^{-11}) \times (5.972 \times 10^{24}) / (299792458)^2 \times 6.371 \times 10^6$$

$$\frac{\Delta f}{f} \approx 6.96 \times 10^{-10}$$

Thus, the frequency on Earth becomes:

$$f' = 1\,GHz * (1 - 6.96 \times 10^{-10}) \approx 999999999.30\,GHz$$

We substitute into the formula:

$$f' = f\,\frac{N_0}{N'}$$

$$N_{observer} = N_0 \cdot \frac{f_{vacuum}}{f_{earth}}$$

$$N_{observer} = 4 \cdot \frac{1\,GHz}{999999999.30\,GHz} = 4.00000000280$$

Where:

f_{vacuum}: The frequency in the vacuum (reference frequency).

f_{Earth}: The frequency measured on Earth, shifted due to the gravitational effects.

This equation shows that the model can be applied to the gravitational conditions on Earth by accounting for the frequency shift caused by gravitational dilation. As a result, the model can be used for future experiments and observations conducted under Earth-bound conditions.

6. Reconstructing Photon Energy in Gravitational Fields

In classical physics, the energy of a photon is described by the equation $E = h \cdot f$, where f is the frequency measured in the local rest frame of the source. This energy is typically treated as constant. Any observed shift in frequency, for example due to gravitational redshift, is interpreted as a relative effect, not an intrinsic change of the photon's energy.

In Segmented Spacetime however this interpretation changes fundamentally[2]. The key insight is that gravity modifies the internal segmentation of spacetime, not merely the apparent frequency. As a result the energy of the photon is not simply shifted, but structurally redefined depending on how many segments it must traverse per cycle.

The frequency measured by an observer under gravitational influence (denoted as f') corresponds to a denser segment structure. The observer perceives a lower frequency not because the photon lost energy in transit, but because their own space is composed of more segments per wavelength unit. In this framework, the energy changes because the segment count N increases.

This can be expressed structurally as:

$$f = f' \cdot \frac{N'}{N_0}$$

$$E = h \cdot f' \cdot \frac{N'}{N_0}$$

Therefore, energy is not conserved across gravitational boundaries in the same way as in classical models. It is reinterpreted through the segmentation structure of the observer's spacetime. This means that a photon entering a gravitational field gains internal segment structure, and its energy value must be recalculated accordingly.

Conversely, a photon leaving a gravitational well appears to lose energy, because it reverts to a lower segment environment.

Indeed it challenges the idea of energy conservation as a purely invariant quantity and replaces it with a segment-relative definition. The apparent energy change is not a loss but a re-expression of the photon's structure within a differently segmented space.

This also implies that gravitational redshift is not a passive deformation of light but an active restructuring of its energetic and spatial properties due to gravity-induced segmentation.

We want to demonstrate now how the local segment density in a gravitational field can be inferred from a redshifted photon, using the example of the star S2[3], which orbits the supermassive black hole Sagittarius A*. By using the known emission frequency of a spectral line in the rest frame of S2 and the Doppler-corrected frequency measured on Earth, it is possible to isolate the gravitational component of the redshift and quantify the local segmentation at the emission point [4,5].

This method will allow us to describe the gravitational influence of a region of spacetime to be described in terms of structural density, independent of the observer's frame and showcases a central strength of the segmented spacetime model: Its ability to express gravitational curvature as a measurable shift in segment count.

To quantify the gravitational effect near the star S2, we use the emission and observation frequencies of a known spectral line (corrected for Doppler motion) to determine the relative segmentation between the source and the Earth.

Local emission frequency in the rest frame of S2:

f = 138394255537000 Hz

Observed frequency on Earth (after Doppler correction):

f' = 134920458147000 Hz

From these values, we compute the frequency ratio:

$$\frac{f}{f'} = 1.0257470026244293$$

In the segmented spacetime model, the observed segment density N' on Earth (relative to the emission reference) is derived from the base segment count of 4:

$$N' = 4 \cdot \frac{f}{f'} = 4.102988010497717$$

Previous calculations have shown that the segment density on Earth is approximately:

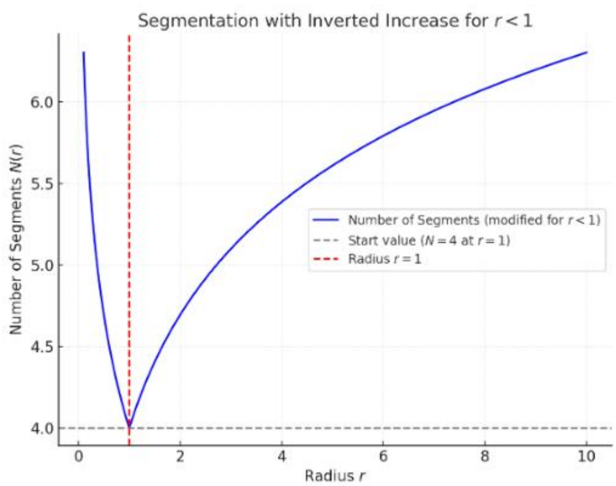
$$N_{Earth} = 4.0000000028$$

Therefore, the segment density at the emission point near S2 is given by the difference:

$$N_{S2} = N' - N_{Earth} \approx 0.10298800769771699$$

This means that the gravitational environment near S2 increases the number of segments per cycle by approximately 0.103 compared to Earth's segment structure.

Although the numerical difference in segment count between two gravitational environments may appear small, its physical implication must not be underestimated. The relationship between gravitational intensity and segment density is fundamentally non-linear. This mirrors the relativistic increase in mass as an object approaches the speed of light—a curve that remains relatively flat for low velocities but rises steeply as the limit is approached. In the same way, segment density in a gravitational field may increase slowly at first, then rapidly escalate near extreme gravitational conditions. Gravitation, being equivalent to acceleration in free fall, naturally leads to a structural response in spacetime that reflects this relativistic behaviour. Thus, even a segmental difference such as 0.103 can signify a disproportionately large change in gravitational curvature and temporal dilation.



This diagram illustrates how the number of spatial segments per cycle increases as the radial coordinate decreases. At radius r = 1, corresponding to the vacuum reference state, the segment count is defined as N = 4. As the radius increases, for example in the outer regions of stars or planetary systems, the segment count rises slowly and stays well below N = 6, even under significant gravitational influence. However, for r < 1, representing regions approaching extreme gravitational fields (such as the interior of a black hole), the segment count grows steeply.

This confirms the non-linear nature of segmentation. Even a seemingly small difference in segment count, such as the calculated 0.103 between S2 and Earth, can signify a large gravitational gradient. The behaviour is analogous to the relativistic mass increase near the speed of light: The system remains nearly flat at first, but rapidly escalates near critical thresholds.

Finally we can calculate the energy subistituting our findings into the formula

$$E = h \cdot f' \cdot \frac{N'}{N_0}$$

$$E = h \cdot 134920458147000 \text{ Hz} \cdot \frac{4.102988010497717}{4.0000000028} = 9.1701 \cdot 10^{-20} J$$

This method introduces a novel approach to determining photon energy from observed frequencies by accounting for gravitational segment density. It provides a practical extension to quantum mechanics by enabling the definition of a state function Ψ(E, λ) or Ψ(τ, t) within a segmented spacetime framework, capturing the influence of gravitational dilation on wave behaviour.

7. Implications for Relativity and Quantum Information

The segment-based reinterpretation of spacetime introduces foundational changes to both relativity and quantum theory:

Time dilation is no longer merely an effect of coordinate velocity or gravitational potential. Instead it becomes a direct function of segment density. In this view, time slows down not because of a warping metric, but because each quantum process must traverse more segments per unit cycle.

Gravitational redshift is reinterpreted as a resolution shift, not an energy loss. The photon's frequency appears lower to the observer because the surrounding space is structured with a higher segment count, compressing the observed cycle.

Quantum transitions can be described as structural rearrangements of discrete segment counts. Excited states emerge from reconfigurations of a system's segmental structure, suggesting a natural language for bound state evolution beyond continuous field theory.

Energy conservation is no longer absolute but segment-relative. The structural interpretation allows energy to change across spacetime regions without violating the internal coherence of quantum systems.

This model supports the construction of a full state function $\Psi(E, \lambda)$ or $\Psi(\tau, t)$ that integrates gravitational dilation and discrete transitions, enabling a unification of wave mechanics with relativistic segmentation.

These shifts are not minor refinements—they represent a fundamental reframing of how frequency, energy, and information behave under the influence of gravity. By replacing differential continuity with segmental discreteness, this approach bridges a long-standing conceptual gap between general relativity and quantum mechanics.

8. Further Applications

Segment-based frequency correction introduces a new class of methods for gravitational measurement and quantum system calibration:

Redshift calibration in astrophysics: The framework provides an alternative method to correct observed frequencies near massive objects, avoiding assumptions based on continuous geodesics or metric distortions. This could refine measurements of relativistic Doppler effects near black holes, neutron stars, or the galactic center.

Reference state generation in quantum metrology: By defining segment densities as local quantum invariants, experiments can be designed to detect deviations from ideal vacuum conditions using only frequency comparisons—enabling compact gravitational field sensors.

Quantum information in curved space: The segment-based state functions $\Psi(E, \lambda)$ and $\Psi(\tau, t)$ offer new tools to describe decoherence, entanglement decay, and measurement collapse under varying gravitational conditions.

Integration into wave-based simulations: The model is compatible with numerical wave simulations that use discretized space (e.g., FDTD), making it an ideal candidate for high-resolution spacetime dynamics with embedded quantum features.

Further work includes:

- Extending the model to multi-segment systems (e.g. near binary black holes)
- Experimental validation using clock networks and satellite signals
- Embedding the theory into a broader field-theoretic or algebraic formalism

This marks a step toward a practical, computation-friendly theory of spacetime segmentation, where gravity, energy, and time are quantized by structure, not just scale.

9. Conclusion

This paper introduced a segment-based framework for wave propagation, time dilation, and gravitational redshift—replacing continuous field equations with structural traversal metrics. We demonstrated that key physical quantities such as frequency and energy can be reformulated in terms of segment density, allowing for corrections that are both local and relativistically invariant.

By analysing real astronomical redshift data (e.g., S2 near Sagittarius A*), we showed that segment-based corrections yield consistent energy values and open the door to new forms of measurement, especially where curvature is strong and standard metric assumptions become unstable.

The proposal of state functions such as $\Psi(E, \lambda)$ and $\Psi(\tau, t)$ marks a step toward unifying quantum mechanics and gravity through a discrete formalism. Rather than relying on curved spacetime, this approach models gravitational influence as an increase in the resolution of space and time itself.

Ultimately, this framework not only explains existing phenomena but extends the toolkit of physics, offering a scalable, computable, and testable structure for the interface of quantum information, general relativity, and wave dynamics.

Keywords: discrete spacetime, segment-based group velocity, gravitational redshift correction, segment density, structural dilation, $\Psi(E, \lambda)$, frequency-energy transformation, relativistic wave mechanics, S2 star, Sagittarius A*

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