Quantization of Entropic Gravity

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Abstract

We present a model of gravity in which the gravitational interaction is interpreted as a consequence of changes in information regarding the mutual positions of Planckian masses on a holographic screen. This approach builds on the entropic interpretation of gravity and the holographic principle. We show that Newtons law of gravitation can be derived by considering entropy changes resulting from a small displacement of a mass. Furthermore, the minimal quantum of entropy, known from the quantization of black hole horizons, leads to the concept of a quantum of gravitational force. In addition, we introduce an uncertainty principle for mass. A prospective experimental test of these hypotheses, using highly sensitive torsion balances, is also proposed.

Keywords: entropic gravity; holography; quantum gravity; information; black holes; uncertainty principle; inertia; experiment

1 Introduction

Recent research has increasingly suggested a profound connection between gravity, entropy, and information. A series of works has shown that the equations of gravity can be derived from thermodynamic principles associated with the entropy of horizons [1]. The concept of entropic gravity, proposed by Erik Verlinde [2], interprets gravity as an entropic force arising from changes in the relative positions of masses with respect to a holographic screen.

In this work, we take the next step: we consider a black hole as a system composed of a large number of Planckian masses interacting in an

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informational-entropic sense. The black holes entropy is related to the number of pairwise interactions among these masses, which can be interpreted as information encoded on the holographic screen about their mutual distances. However, the distribution of these distances is highly non-uniform, with most pairwise separations clustering around a characteristic scale. By introducing a logarithmic dependence of information on distance, we derive Newtons law of gravitation directly from changes in entropy. Additionally, by taking into account the quantization of horizon entropy, we obtain a quantum of gravitational force. Extending this reasoning to the interpretation of inertia via gravity leads us to a quantization of inertial force and an uncertainty principle for mass.

2 Entropic Interpretation of Gravity

For a black hole of mass M, the Bekenstein entropy [3] is given by:

$$S = \frac{4\pi k G M^2}{\hbar c}. \tag{1}$$

Defining the Planck mass $m_p = \sqrt{\frac{\hbar c}{G}}$, we have $M = N m_p$, and substituting into (1) yields:

$$S = 4\pi k N^2. \tag{2}$$

The entropy scales as N^2, where N is the number of Planckian masses. Since entropy corresponds to the informational content of the system, we can think of it as 8π nats of information per pair, given that there are $N^2/2$ such pairs. This suggests that most pairwise distances concentrate around a certain characteristic scale R_0.

We assume the information about the distance R between two Planckian masses takes a logarithmic form:

$$I = 8\pi \ln\left(\frac{R}{R_0}\right). \tag{3}$$

The holographic screens entropy thus reflects the cumulative information about all pairwise distances. Changing the position of one mass alters these distances, thereby changing the information and entropy. This forms the basis for deriving the law of gravitation.

3 Derivation of Newtons Law

Consider a spherical holographic screen of radius R associated with a large mass $M = Nm_p$, and a small mass $m = nm_p$ at distance R. The number of pairwise interactions is proportional to $(Nn)/2$.

A small radial displacement Δx of the small mass changes the information. Differentiating (3) with respect to R:

$$\Delta I = \frac{\partial I}{\partial R}\Delta x = \frac{8\pi}{R}\Delta x. \tag{4}$$

The entropy change is then:

$$\Delta S = k\frac{Nn}{2}\Delta I = kNn\frac{4\pi\Delta x}{R}. \tag{5}$$

A holographic screen of radius R is associated with a Hawking temperature [4]:

$$T = \frac{\hbar c}{4\pi k R}. \tag{6}$$

Using Landauers principle, the force associated with the entropy change is:

$$F = \frac{\Delta S}{\Delta x}T = \left(\frac{4\pi k N n}{R}\right)\left(\frac{\hbar c}{4\pi k R}\right) = \frac{Nn\hbar c}{R^2}. \tag{7}$$

Substituting $Nm_p = M$ and $nm_p = m$, and using $m_p = \sqrt{\hbar c/G}$:

$$F = \frac{GMm}{R^2}. \tag{8}$$

Equation (8) recovers Newtons law of gravity from purely entropic and informational considerations.

4 Gravity Quantization through Minimal Entropy

Bekenstein and Mukhanov [5] showed that horizon entropy is quantized in units of:

$$\Delta S_{\min} = k\ln(2). \tag{9}$$

From the entropic relations (in particular, comparing 5 and 9), we have:

$$k \ln(2) = 4\pi k \frac{Nn\Delta x}{R}. \tag{10}$$

Combining (10) with the temperature relation (6) and the definition of F similar to (7), the minimal force quantum is:

$$F_{\min} = \frac{\hbar c \ln(2)}{4\pi \Delta x R}. \tag{11}$$

Hence, gravity acquires a fundamental discrete scalea quantum of gravitational force.

5 Quantization of Inertia

Consider now a body near a black hole horizon experiencing acceleration a. The Unruh temperature for an accelerated observer is given by:

$$T_U = \frac{\hbar a}{2\pi k c}. \tag{12}$$

Since the Unruh temperature corresponds to the Hawking temperature for an observer with acceleration a [1], we can draw an analogy to (11). By replacing T in the argument with T_U, we find that:

$$F_{\min} = \frac{\ln(2)\hbar a}{2\pi c \Delta x}. \tag{13}$$

Equating this minimal force to ma:

$$m_{\min} = \frac{\ln(2)\hbar}{2\pi c \Delta x}. \tag{14}$$

This can be expressed as an uncertainty relation for mass and position:

$$\Delta m \Delta x \geq \frac{\ln(2)\hbar}{2\pi c}. \tag{15}$$

Interpreting (15) as a mass uncertainty principle, if we take Δx as the Compton wavelength of the particle, we have:

$$\frac{\Delta m}{m} \geq \frac{\ln(2)}{2\pi}. \tag{16}$$

Thus, achieving maximum positional precision implies an irreducible uncertainty in mass.

6 Experimental Perspectives

For potentially achievable laboratory conditions, let $\Delta x = 10^{-11}\,\mathrm{m}$ and $R = 10^{-4}\,\mathrm{m}$. From (11), we find:

$$F_{\min} \approx 1.7 \times 10^{-12}\,\mathrm{N}.$$

Modern torsion balances can measure forces on the order of $10^{-12}\,\mathrm{N}$ [6, 7]. Although extremely challenging, such a test is not fundamentally impossible. It would require ultra-precise control, thermal stabilization, and picometer-scale positioning. A successful experiment would provide unique evidence for the quantum nature of gravity.

7 Conclusions

This approach provides a new interpretation of gravity as a phenomenon arising from changes in the information about the mutual arrangement of Planckian masses. Taking into account the quantization of holographic screen entropy leads to the concept of a quantum of gravitational force and implies a mass uncertainty principle, thereby opening a path toward rethinking the fundamental nature of inertia, gravity, and their potential experimental verification.

Beyond the proposed experiment to measure the minimal gravitational force, another promising direction would be to devise an experiment that simultaneously determines both the gravitational (or inertial) mass of a particle and its spatial localization. Such investigations could deepen our understanding of the relationship between mass and positional definiteness.

Future theoretical studies may focus on elucidating the physical significance of the characteristic scale R_0 inside black holes and deriving an analytical form for the distribution of pairwise distances among Planckian masses. This analysis could illuminate the informational patterns underlying the formation of cosmological structures in an expanding universe. Moreover, combining this new mass uncertainty principle with the well-known Heisenberg uncertainty principle might reveal deeper connections between space, time, and energy.

Finally, incorporating the quantization of gravitational force into cosmological models may prompt a reassessment of the role of dark matter in shaping the large-scale structure of the universe.

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