**Graviton Superluminal Propagation Theory Based on Negative-Mass Dark Matter Field Dynamics and Its Cosmological Verification**

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**Abstract:**Within the framework of Li Zhijun’s field-composition theory, this paper proposes a complete dynamical model for the superluminal propagation of gravitons in a negative-mass dark matter field. The core argument is: The negative-mass dark matter permeating the universe constitutes a special background field, which exerts a “repulsive resistance” on particles propagating within it, inversely proportional to the particle’s rest mass. Chinese scientists have measured the upper limit of the photon’s dynamic mass to be , confirming that the photon’s rest mass is extremely small but non-zero; thus, the speed of a photon with non-zero dynamic mass under the repulsive resistance in the negative-mass dark matter particle “soup” is defined as the speed of light . Due to its even smaller rest mass compared to the photon, the graviton experiences minimal resistance, enabling it to propagate at speeds exceeding the vacuum speed of light. This paper first constructs the effective Lagrangian for the negative-mass dark matter field and derives the modified dispersion relation for particles within this field:

This relation indicates that when the background field density exceeds a critical value , the phase velocity of the particle can surpass . We further calculate the propagation speed of the graviton as and use this model to provide a unified explanation for the horizon problem in early universe structure formation, the black hole information paradox, and high-energy astrophysical phenomena. This theory offers a new, falsifiable paradigm for quantum gravity research.

**Keywords:** Graviton superluminal speed; Negative-mass dark matter; Modified dispersion relation; Quantum gravity; Cosmology; Li Zhijun field-composition theory

1. **Introduction**

Einstein’s general relativity posits the speed of light as the ultimate speed limit in the universe. However, quantum gravity theory suggests that spacetime itself may possess microscopic fluctuations, challenging the constancy of the speed of light. In particular, if the graviton (the quantum propagator of gravity) has a non-zero but extremely small rest mass (), its propagation behavior may deviate from the predictions of special relativity under specific conditions.

Li Zhijun’s field-composition theory introduces a key hypothesis: the existence of negative-mass dark matter in the universe, whose formed background field interacts with propagating particles. This paper aims, within this framework, to establish a rigorous mathematical model proving that the repulsive effect of the negative-mass field on particles can lead to superluminal propagation of gravitons and explore its profound cosmological implications.

1. **Theoretical Framework: Particle Dynamics in the Negative-Mass Dark Matter Field**

**2.1 Effective Field Theory Description of the Negative-Mass Dark Matter Field**

We assume the negative-mass dark matter field is described by a scalar field with a negative mass term. Its free Lagrangian density is:

where indicates an imaginary mass for the field, leading to its instability. However, its average effect on cosmological scales can be a stable background energy density .

The interaction between a propagating particle (e.g., a graviton) and this background field can be described by an effective metric :

where is the metric perturbation induced by the background field. In a homogeneous and isotropic background, it can be approximated as , where is a critical density scale.

**2.2 Modified Dispersion Relation and Superluminal Condition**

In the effective metric , the action for a free particle becomes . The derived modified dispersion relation is:

where is a critical density determined by the fundamental scale of the theory.

The phase velocity of the particle is:

For high-energy particles (), the phase velocity approximates to:

This shows that when the background negative-mass field density is sufficiently significant, the denominator becomes less than 1, resulting in . Particularly for gravitons with an extremely small rest mass , their group velocity (i.e., signal propagation speed) also approximates the phase velocity, thus enabling superluminal propagation.

**2.3 Critical Condition for Graviton Superluminality**

The graviton’s rest mass is extremely small. Its superluminal condition simplifies to:

where is the Planck energy. Due to the minuscule , this critical density condition can be easily met in many regions of the universe.

1. **Cosmological Implications and Observational Verification**

**3.1 Resolving the Cosmological Horizon Problem**

In the very early universe, the scale was small, and the relative density of negative-mass dark matter might have been very high. This allowed gravitons in the early universe to propagate superluminally, their causal horizon being much larger than the photon horizon. This naturally explains the high uniformity of the cosmic microwave background radiation in different directions, solving the horizon problem without invoking inflation theory.

**3.2 Time Difference Between Gravitational Waves and Electromagnetic Signals**

When binary compact objects (e.g., neutron stars) merge, they emit both gravitational waves (primarily propagated by gravitons) and electromagnetic waves. In our model, the propagation speed of gravitational waves in the current cosmic negative-mass background field is , while the speed of electromagnetic waves remains . Therefore, for the same cosmological event, the gravitational wave signal should arrive on Earth earlier than the electromagnetic signal. Observations of the GW170817 event constrain , imposing a strong constraint on our model, requiring the current cosmic to be very close to zero. However, this effect might be detectable in the early universe or in special regions (e.g., centers of dark matter halos).

**3.3 Implications for the Black Hole Information Paradox**

If gravitons can propagate superluminally, information might traverse or bypass the event horizon via gravitational degrees of freedom. This offers a potential solution to the black hole information paradox: information is not lost but is encoded and released from within the black hole through superluminal gravitational radiation.

1. **Theoretical Self-Consistency and Extended Discussion**

1.Relation to Causality: Superluminal propagation does not necessarily violate causality. If superluminally moving particles cannot transfer energy and information in a reference frame moving at sub-light speeds (i.e., tachyon behavior), time travel paradoxes can be avoided. In our model, what is superluminal is the excitation of spacetime itself (the graviton), not ordinary matter particles.

2.Compatibility with Quantum Field Theory (QFT): In QFT, superluminal propagation may conflict with microcausality. This may require placing the theory within a broader framework, such as string theory or loop quantum gravity, where spacetime non-locality is more natural.

3.Falsifiability: The key prediction of this theory is that gravitational waves arrive before electromagnetic waves. Future more precise multi-messenger astronomical observations, particularly for high-redshift events or events located within massive dark matter halos, will directly test this theory.

1. **Conclusion**

Based on the Li field-composition theory, this paper has constructed a mathematically self-consistent model for the superluminal propagation of gravitons in a negative-mass dark matter field. By introducing an effective metric and a modified dispersion relation, the condition for superluminal propagation was derived from first principles. This model not only provides new insights into cosmological puzzles but, more importantly, presents a clear prediction that can be tested by the next generation of astronomical observations. If confirmed, it would fundamentally change our understanding of the nature of spacetime and gravity.

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