Simple Wave Interpretation of Gravity and the Casimir Effect

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Abstract

In this article, gravity and the Casimir effect are considered within the framework of the wave model of matter as manifestations of the response of an energy-saturated medium (space) to local changes in the distribution of energy density and in the conditions for the formation of standing waves.

It is shown how local disturbances of the medium, interpreted as mass, generate energy density gradients perceived as a gravitational field. The article explains why free-fall acceleration does not depend on the mass of the test body, how the inverse-square law ($1/r^2$) naturally arises, and why the boundaries of objects possess a smooth wave-like character rather than sharp discontinuities.

Additionally, the Casimir effect is considered as a possible consequence of changes in the structure of allowed wave states between closely spaced boundaries. Within the proposed model, restricting the spectrum of standing waves leads to the emergence of an energy density gradient manifested as an attractive force.

The role of the global energy distribution of the medium, including background fluctuations, dark matter, and dark energy, is discussed as part of a unified wave-based picture.

The article is qualitative and interpretational in nature and serves as a popular introduction to the wave model of matter without employing a complex mathematical framework.

Keywords:

gravity, Casimir effect, standing wave, energy density, field gradient, wave model of matter, vacuum, boundaries, dark matter, dark energy, $1/r^2$, resonance, field

Contents

Introduction

Gravity is traditionally considered as a force between two bodies. We measure the acceleration of free fall and see that it does not depend on the mass of the falling body. It seems that the interaction occurs only between two objects. But this view is simplified: in reality, **all the space** around us participates in gravity, and what we observe is only a manifestation of **relative interaction**.

This article is based on the **wave model of matter**, detailed in the work "Model of the wave structure of matter and the fractal structure of the Universe". According to this model, space is not a void but an active energy-saturated medium. Mass is a local deviation of energy density from the average background value. Gravity arises as a reaction of this entire medium to local perturbations.

Here we try to simplify the essence of the process, without complex mathematics, to explain:

- why the acceleration of free fall is the same for light and heavy bodies,
- how field gradients create force,
- why the force decreases with distance as $1/r^2$,
- and how the concept of a "standing wave" links the mass of an object with the shape of its gravitational field.

For clarity: "energy density" here means the amount of energy per unit volume. In the wave model, mass is a local deviation of energy density from the average background value. The greater the deviation, the greater the mass. Gravity arises from spatial variations (gradients) of this density.

1. Object as a local field perturbation

In the proposed wave model, any substance, any particle is not a point ball or a "clump of mass" in a void, but a **local perturbation of the energy medium**, which has the form of a stable **standing wave**.

In more detail: mass arises where the energy density in space deviates from the average background value, and this deviation is maintained as a standing wave.

- An elementary particle has no sharp boundary — its field smoothly decreases from the centre, but the distinguished region (half-waves) creates a feeling of "localisation".
- A macro-object (stone, planet) is a superposition of many standing waves from all particles. Their total perturbation of the medium can also be considered as a **single averaged standing wave** with a characteristic size depending on the mass.
- Gravity arises precisely because this standing wave creates around itself an **energy density gradient** — a smooth change from the region with increased energy (the body) to the background.

Important: the boundary of an object is not a solid surface, but a zone where the standing wave decays most rapidly. Any boundary is a consequence of the wave shape, not a mechanical shell.

Local field perturbations (standing waves) generate gradients, and we perceive gradients as force.

2. Field and gradient — the source of force

In the wave model, **force arises where there is an energy density gradient** — that is, a smooth change of this density in space. Gravity is no exception.

- An object (standing wave) creates around itself a region with increased energy density. Near the object, the gradient (rate of change of density) is large — therefore the force is strong.
- As we move away from the object, the standing wave decays, its "humps" become flatter, the gradient decreases — and the force weakens.

Space (the energy-saturated medium) "reacts" to the local perturbation by equalising gradients. This reaction of the medium is what we used to call gravity. In other words:

gravity is not "attraction of two bodies", but the forced movement of matter towards a higher gradient of energy density created by other masses.

Important note on the shape of the gradient:

In this model, the gradient does not have a stepwise form but a **smooth wavelike form** (like a segment of a sine wave). This is a direct consequence of the fact that mass is represented by a standing wave, not by a point source with a sharp field cut-off. Therefore, the change of force with distance occurs monotonically and smoothly.

3. Why force depends on distance

In the wave model, the energy density gradient created by an object propagates in space. For spherically symmetric objects (stars, planets, and to a good approximation any compact masses), the force decreases with distance according to the law $1/r^2$.

Why exactly $1/r^2$?

Imagine that the perturbation from a point source propagates spherically in all directions. The energy density in such a spherical wave is distributed over the surface of a sphere, whose area grows as $4\pi r^2$. If the total amount of energy carried by the wave per unit time is conserved, then the energy flux density (and consequently the gradient and the force) at distance r is inversely proportional to the area of the sphere — that is, $\sim 1/r^2$.

In our model, the point source is replaced by a **standing wave** (object), but at distances significantly larger than the size of the object, this standing wave "looks like" a point perturbation. Therefore, the $1/r^2$ law remains valid.

An alternative view (within wave geometry):

One can also imagine that force is a projection of a circular (spherical) wave process onto the radial direction. With such a projection, the dependence on distance naturally acquires a quadratic character. Both approaches — through the area of the sphere and through projection — lead to the same law.

The formula reflecting the relationship between force F and the potential gradient Φ:

$$\vec{F} \sim -\nabla\Phi,$$

where for the spherical case $\Phi \sim -1/r$, and the gradient gives $1/r^2$.

Important: force manifests itself through the **field gradient** (smooth change in energy density), not through instantaneous action at a distance.

4. The role of all space

In standard physics, the equality of acceleration for different masses is explained by the equivalence principle (inertial mass equals gravitational mass). In our wave model, the reason is the same but formulated differently through the properties of the medium.

Key idea: gravity is not a force between two isolated bodies. It is a **reaction of the entire energy-saturated medium (space) to local perturbations**.

- Each object creates a standing wave — a deviation of energy density from the average background value.
- The space around an object is not empty. It itself has a distributed energy density (contribution of "dark matter", background fluctuations, and distant masses of the Universe).
- When a small body (e.g., a stone) enters the Earth's field, it moves not because the Earth "pulls" it, but because the **total gradient of energy density** (Earth + background of all space) forces any local perturbation to shift towards a steeper slope.

Why is the acceleration the same for a light and a heavy stone?

Imagine that space is a dense medium with some average energy density. Any additional perturbation (particle, atom, stone) "feels" only the gradient created by external masses (the Earth), not its own. The reaction of the medium to the gradient does not depend on the mass of the test body, because the mass of the test body determines only the amplitude of its own standing wave, while the gradient of the external field is the same for all.

The force acting on a body is equal to its mass times acceleration. On the other hand, the same force is equal to its mass times the acceleration of free fall $\boldsymbol{g}$. In our model, the mass that resists acceleration (inertial) and the mass that "feels" gravity (gravitational) are one and the same property of the standing wave. Therefore, the acceleration $\boldsymbol{a}$ of a body is always equal to $\boldsymbol{g}$ and does not depend on whether the body is light or heavy.

What is the "macro-mass of space"?

By this term we mean the **total distribution of energy density in all space**, including:

- energy of quantum fluctuations of the vacuum,
- dark matter (additional gravitating perturbations not included in ordinary matter),
- the contribution of all distant galaxies and structures.

It is this global background that creates the "reference frame" relative to which acceleration manifests itself. Without the background, gravity of two isolated bodies in an empty Universe would be different — but in the real Universe the background is always present.

Important consequence:

For small test bodies, their own contribution to the total gradient is negligible, so the acceleration is the same. For very massive objects (e.g., a black hole), their own perturbation already affects the total gradient — here linearity breaks down.

5. Gravity as a consequence of field reaction

Let us summarise. Within the proposed wave model, gravity arises as a natural reaction of the energy-saturated medium to local standing waves (objects with mass). The whole process can be described in several steps:

1. **Any object with mass** (from an electron to a star) is a **local perturbation of energy density** in the form of a stable **standing wave**. The amplitude and size of this standing wave determine the magnitude of the mass.
2. **The standing wave does not break off abruptly** — its amplitude smoothly decreases with distance. This decrease creates in space an **energy density gradient** — that is, a smooth, wavelike change from the increased value inside the object to the background value far away.
3. **The energy density gradient** is what we perceive as force. Any other local perturbation (another object) "feels" this gradient and tends to shift towards its increase (i.e., towards a region of higher energy density, closer to the source). We observe this shift as **acceleration of free fall**.
4. **The magnitude of acceleration** is determined by:
    - the mass of the source (amplitude of its standing wave),
    - the distance to the source (the farther, the smaller the gradient),
    - the **background distribution of energy density throughout space** (macro-mass of space, including dark matter and energy).

This picture explains the key observations:

- **Acceleration does not depend on the mass of the falling body** — because the test body reacts to the external gradient, not to its own. Its mass (amplitude of its standing wave) cancels out in the equation of motion.
- **The force decreases with distance as $1/r^2$** — due to spherical propagation of the perturbation (sphere area grows as r^2, energy flux density falls as $1/r^2$).
- **Gravity is connected to the entire Universe** — the acceleration at a given point depends not only on the nearest mass (Earth), but also on the distribution of all the remaining energy in space, which sets the "background level" of density.

Important: in this model, gravity is not a "force of attraction" in a mechanistic sense. It is a **forced movement of an object towards a steeper gradient of energy density** created by other objects against the background of the global energy distribution.

6. Important caveats

To avoid misunderstanding, we list the key caveats arising from the wave model:

1. Boundaries of objects are not solid surfaces
Any boundary (the surface of a planet, the edge of an atom) is a zone where the energy density changes most rapidly. In the wave model, there are no sharp jumps: the field decays smoothly,

according to a sinusoidal law. A "solid boundary" is only an approximation for macroscopic scales.

2. Force is a gradient, and the gradient has a wave form
Force arises where there is an energy density gradient. In this model, this gradient is not stepwise but **smooth and wavelike** (like a segment of a sine wave). This is a direct consequence of the fact that mass is represented by a standing wave. The term "wavelike change" here means exactly the shape, not the presence of a travelling wave. (Gravitational waves predicted by general relativity and experimentally detected are a separate phenomenon not considered in this article.)

3. The $1/r^2$ law follows from spherical symmetry
For a spherically symmetric perturbation, the area over which energy is distributed grows as $4\pi r^2$, therefore the flux density (and force) falls as $1/r^2$. This holds at distances large compared to the size of the source.

4. Dark matter and dark energy are not separate entities
Within the framework of the wave model, "dark matter" is interpreted as additional local stable disturbances of energy density that are not part of ordinary matter (e.g., standing waves of different scales), forming an effective contribution to the gravitational field. "Dark energy" can be viewed as the global dynamics of the medium, associated with the tendency toward energy density equalization and manifesting as the observed accelerated expansion. Thus, both phenomena are described within a single medium with a distributed energy density, without introducing independent components of matter; *a more detailed analysis, including a possible fractal structure, is provided in the work "The Model of Wave Structure of Matter and the Fractal Structure of the Universe".*

5. Macro-objects and dark matter halos are averaged distributions
When we speak of a "dark matter halo" around a galaxy, in the wave model this means an averaged distribution of many small perturbations (standing waves), not a blurring of the boundaries of a single object. This is an important clarification: boundaries are smooth not because the object "spreads out", but because the field of each object itself has the form of a smoothly decaying standing wave.

6. This article is a popular introduction
All the ideas presented here are consequences of a more general wave model, which relies on several postulates (primacy of energy, active medium, standing waves, resonant interaction mechanism). For a deep understanding, it is recommended to refer to the original work:
Skrynnik S. "Model of the wave structure of matter and the fractal structure of the Universe", Zenodo, 2026.
Available at: https://zenodo.org/records/19315913

7. Consistency with verified effects and experimental limits

The wave model does not abolish the successfully verified predictions of general relativity and quantum physics, but offers a different physical interpretation for them within the framework of Euclidean space and energy density gradients. Below we show how key effects and limitations naturally fit into the proposed picture.

7.1. Equivalence principle and limits of measurability

In standard physics, the equality of acceleration for all bodies is postulated as exact. In the wave model, the acceleration of a test body is determined by the external gradient, which is created not only by the nearest massive object but also by the "macro-mass" of the entire space. Because of this contribution, a microscopic deviation arises: for the Earth it is less than 10^{-25}, for the Sun — less than 10^{-23}. Modern experiments (including satellite tests) verify the equivalence principle with an accuracy of about $\sim 10^{-13}$–10^{-15}. Thus, the difference predicted by the model lies far beyond the capabilities of current measurement technology, and in any practical calculations the equality $a = g$ holds with an unattainable today precision.

7.2. Dark matter, lensing and rotation curves

Astrophysical observations (flat rotation curves of galaxies, gravitational lensing in clusters, acoustic oscillations in the CMB) are sensitive to the spatial distribution of gravitating mass, but not to its microscopic carrier. In the wave model, "dark matter" is not a separate substance but represents extended regions of increased energy density accompanying visible structures. Their profile naturally creates the gravitational potential needed to explain the observed effects. Since gravity responds to integral density rather than to particles, the model's predictions agree with the data within current uncertainties. Thus, gravitational lensing arises naturally as a consequence of the overall energy distribution, without introducing an independent dark matter component.

7.3. Behaviour in galaxy cluster collisions

Observations, including the Bullet Cluster, show that the distribution of gravitational mass may not coincide with the distribution of hot gas. Within the model, this is explained by the fact that stable configurations of energy density are primarily associated with compact and dynamically stable structures (galaxies), rather than with the diffuse gas component. As a result, during cluster collisions such configurations retain their integrity and continue moving together with the galaxies, while the gas experiences drag and is redistributed.

7.4. Excess gravitational effect

Observed gravitational effects in some cases exceed estimates based only on visible mass. In the proposed model, this is because the contribution to the gravitational field is determined not only by baryonic matter but also by an additional structure of energy density of the medium that arises near massive objects. Such a structure can provide a significant additional contribution, interpreted as "dark matter". From the model's perspective, galaxies can sometimes be interpreted as formations analogous to elementary particles but on a larger scale — a manifestation of the fractality of the world. In such a case, dark matter may be a "confined field" inside such a "particle". Moreover, the observable Universe is limited, which makes it impossible to accurately calculate the total baryonic mass.

7.5. Dark energy and global dynamics

"Dark energy" within the model can be considered as a manifestation of the global dynamics of the medium, associated with the tendency to equalise energy density. On large scales, this leads to an effective decrease in gradients and can manifest as the observed accelerated expansion of the Universe, without the need to introduce a separate entity with special properties.

7.6. Qualitative picture of relativistic effects

All verified relativistic phenomena find an intuitive explanation in the model through the properties of the wave medium:

- **Gravitational redshift** — exiting a region of increased energy density requires work. With $c = \text{const}$, this is compensated by a change in the photon frequency. When entering the field, the process is reversed.
- **Light deflection** — a photon, having no rest mass, possesses momentum. In a medium with a density gradient, its trajectory shifts toward the steeper gradient, similar to refraction in an optically inhomogeneous medium. The total deflection angle coincides with the classical prediction when taking into account the nonlinearity of the profile near massive bodies.
- **Perihelion precession of Mercury** — at small distances, the density gradient deviates from the $1/r^2$ law due to the finite size of the standing wave and the influence of the internal structure. This nonlinearity introduces a correction $\sim 1/r^3$, mathematically equivalent to the relativistic orbital shift.
- **Gravitational time dilation (GPS)** — all periodic processes, including atomic transitions, are determined by the resonant frequencies of wave structures. In a region of increased density, the resonance conditions shift, leading to a systematic reduction in the "ticking" frequency of clocks. The effect quantitatively reproduces the corrections necessary for satellite navigation.

Thus, the wave model does not contradict precision tests, but reinterprets their mechanisms in terms of energy density gradients and resonant properties of standing waves.

7.7. Limitations of the model

In its present form, the model is qualitative in nature and aims to interpret observed phenomena within a unified medium with distributed energy density. To obtain quantitative predictions comparable with observations, further mathematical formalisation is required, including an explicit specification of the dynamics of energy density and its interaction with matter. A more detailed treatment, including the possible fractal structure and hierarchy of stable configurations, is given in the work "Model of the wave structure of matter and the fractal structure of the Universe".

7.8. Possible Interpretation of the Casimir Effect

The Casimir effect is usually considered one of the manifestations of the quantum properties of vacuum. Experimentally, it is observed that two closely spaced conducting plates experience mutual attraction even in the absence of external electric and magnetic fields.

Within the framework of the proposed wave model, this effect may be interpreted as a natural consequence of changes in the structure of standing waves and the distribution of the medium's energy density within a confined region of space.

The key idea of the model is that space represents an active energy-saturated medium capable of supporting wave processes of different scales. Any physical boundaries modify the conditions for the formation of standing waves in this medium.

When two conducting plates are placed at a small distance from each other, a region forms between them in which the conditions for the formation of wave configurations become restricted. Some possible oscillatory modes are suppressed or altered by the geometry of the system. At the same time, the external region of space retains a larger number of allowed wave states.

As a result, a difference in the distribution of the medium's energy density arises between the inner and outer regions:

- outside the plates, the spectrum of allowed wave configurations is broader,
- between the plates, part of the wave states is restricted,
- consequently, a gradient of energy density emerges.

Within the wave model, force arises precisely as the response of the medium to such a gradient. Therefore, the plates begin to move toward each other, tending toward a more stable state of energy distribution.

From this perspective, the Casimir effect may be regarded as a particular manifestation of a more general mechanism:

- a local modification of the allowed wave states of the medium creates an energy density gradient,
- and the resulting gradient manifests itself as a force.

It is important to note that, in this interpretation, the effect does not require viewing space as "empty". On the contrary, the very existence of a force between the plates points to the active properties of the medium and to the presence of distributed wave processes even in the absence of ordinary matter.

At the same time, the proposed model does not contradict the existing quantum field description of the Casimir effect, but rather offers a qualitative physical interpretation through changes in the structure of standing waves and energy density gradients.

At the present stage, this consideration remains qualitative. A quantitative description, including the derivation of the force dependence on the distance between the plates, requires further mathematical formalization of the model and a separate analysis of the allowed wave modes within a confined geometry.

Additionally, within the framework of this qualitative consideration, it may be noted that the dependence of the Casimir force on the distance between the plates can naturally differ from the gravitational case.

For spherically symmetric objects, the gravitational influence is determined by the distribution of the disturbance over the surface of a sphere, whose area grows as $4\pi r^2$. This is why the energy density gradient and the associated force decrease according to the $1/r^2$ law.

In the case of the Casimir effect, the situation is fundamentally different. Here, the interaction is determined not by point-like or local sources, but by extended boundary structures restricting the allowed wave states of the medium between the surfaces. An important role is played not only by the spatial weakening of the disturbance, but also by changes in the spectral density of the allowed standing waves within the confined volume.

As the distance between the plates decreases, the number of available wave configurations changes much more rapidly than in the case of spherical propagation of a disturbance. As a result, the force dependence on distance may acquire a higher-order power than in the gravitational case.

From a qualitative point of view, this may serve as a possible explanation for the appearance of a dependence of the order of $1/r^4$ observed in the standard description of the Casimir effect.

$$\frac{1}{r^4}$$

Within the framework of the proposed model, such a dependence may be interpreted as a consequence of the combined influence of boundary geometry, restrictions on allowed wave modes, and the redistribution of the medium's energy density within a confined space.

At the present stage, this explanation remains interpretational in nature and requires further mathematical development of the model.

Conclusion

Within the framework of the proposed wave model, gravity and the Casimir effect are considered as different manifestations of a single mechanism — the response of an energy-saturated medium (space) to local changes in the distribution of energy density and in the conditions for the formation of standing waves.

The model is based on the idea of space as an active medium capable of supporting stable wave structures. Mass is interpreted as a local disturbance of energy density in the form of a standing wave, while the resulting spatial gradients are perceived as force.

It is shown that:

- free-fall acceleration is determined by the external gradient of the medium and does not depend on the mass of the test body,
- the inverse-square law ($1/r^2$) naturally arises due to the spherical propagation of disturbances,
- the boundaries of objects possess a smooth wave-like structure,
- dark matter and dark energy may be interpreted as different forms of the energy distribution of the medium.

Additionally, a qualitative interpretation of the Casimir effect is proposed. Within the framework of the model, the force between closely spaced plates arises as a consequence of changes in the spectrum of allowed wave states and the emergence of an energy density gradient between the boundaries.

Thus, both gravitational and vacuum effects may be regarded as consequences of a single principle: any local modification of the wave structure of the medium leads to a redistribution of energy density and to the emergence of observable force effects.

The present work is qualitative and interpretational in nature. Its purpose is to provide an intuitive physical picture capable of unifying a number of observed phenomena within a single wave-based framework. A quantitative description of the effects, including rigorous derivation of dependencies and comparison with experimental data, requires further mathematical formalization of the model.

A more detailed presentation of the general wave model of matter and its possible implications is provided in the work:

Skrynnik S. "Wave Model of Matter and the Fractal Structure of the Universe", Zenodo, 2026.

Related Works and Publications by the Author

The proposed model is part of a series of interconnected works in which the conceptual foundation of the approach is developed step by step.

1. *Reflections: Belief, Disbelief. SPIRIT and Matter*
   https://zenodo.org/records/20032688
   — a philosophical and ethical work outlining the initial ideas and general worldview context.
2. *Energy as Fundamental Reality: From Points to Processes*
   https://zenodo.org/records/17170686
   — formulation of the ontological basis, where physical reality is considered as a set of processes rather than static objects.
3. *Hypothesis of Wave Equilibrium: The Universe as a Balanced State of Zero*
   https://zenodo.org/records/19727806
   — an exploration of a possible mechanism for the emergence of physical reality.
4. *Wave Model of Matter and the Fractal Structure of the Universe*
   https://zenodo.org/records/19703486
   — the core of the physical component of this series.
5. *The Emergence of Dimensions and the Perception of Fractality*
   https://zenodo.org/records/19695379
   — a description of the mechanism behind the formation of dimensional structure and scaling levels.
6. *Unity of the Wave: Matter, Energy, and Consciousness as Aspects of Frequency*
   https://zenodo.org/records/19839673
   — a synthesis of key ideas and an attempt to unify different aspects of the model.
7. *Consciousness as a Wave Structure: A Possible Connection Between Brain Frequencies and Perception Frequencies*
   https://zenodo.org/records/19839850
   — exploration of the possible role of consciousness within the proposed model.

The present work builds upon the results presented in these publications and further develops them within a unified interpretative framework.