

Unified Cosmic Mechanics Evolution Theory (X) : Dynamic Reconstruction of Mercury's Perihelion Precession and Gravitational Waves Based on Relativistic Effects

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Abstract

[**Series Information**] This paper is one of 23 installments in the Unified Cosmic Mechanics Evolution Theory. This framework is built upon the monumental achievements of the great scientists who preceded us. Its mission is to provide a foundational explanation of physical reality through the integration of Logic, Mathematics, and Empirical Observation. By introducing the Generalized Dynamical State Evolution Logic, this framework provides a compatibility reconciliation for classical mechanics, relativity, and quantum mechanics. Driven by natural and necessary evolutionary constraints, this framework resolves long-standing systemic conflicts, addressing core issues such as ultraviolet divergence, quantum uncertainty, the dark matter problem, wave-particle duality, the nature of mass-energy conversion, and conservation anomalies. Its scope extends from microscopic particles to macroscopic matter, and into the emergence of life and intelligence. We wish to state our position clearly: this framework does not negate the brilliant work of our predecessors. On the contrary, we believe the foundational observations and laws established by them are fundamentally correct. Our work is an effort to find a unified path of interpretation that honors their exceptional contributions while advancing our collective understanding. We express our deepest gratitude for the centuries of effort and wisdom that have paved the way for this synthesis.

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[**This article**] This paper is the tenth in the 22-paper series of the “Unified Cosmic Mechanics Evolution Theory” framework. Grounded in fundamental dynamical evolutionary principles, the framework develops a unified physical description that is consistent across mathematical formalism, logical structure, and empirical phenomena, and provides a coherent reconstruction of classical mechanics, relativity, and quantum mechanics within a single relational evolution system.

Based on the comprehensive derivation of multiple preceding chapters [1][2][3][4][5] within the framework of Information Dynamic Evolution Theory, focusing on the core conservation relations and dynamic principles of the underlying physical reality, this paper conducts a complete discrete derivation of the phenomena of Mercury’s perihelion precession and gravitational wave radiation. Different from the continuous space-time curvature hypothesis of general relativity [6], the evolution of momentum units takes “discrete interaction” as the core physical image, holding that the gravitational effect in celestial motion originates from the successive interactions between momentum units and the gravitational field, and gravitational waves are discrete radiation events of momentum unit decoupling during the violent motion of massive celestial bodies. The derivation process strictly follows the two core conservation relations: the Conservation of Space-time State Shaping and the Conservation of Perceptual Resource Competition, combined with the velocity increment formula and the Path Curvature Perceptual Opportunity Multiplication Effect. Finally, the numerical result of Mercury’s precession angle is consistent with the observed value and the result of general relativity; the discrete model of gravitational waves matches the dimension of the quadrupole radiation formula of general relativity in the continuous limit, and can explain the gravitational wave waveform characteristics in black hole mergers. This study verifies the self-consistency of the momentum unit evolution theory framework and provides a new discrete dynamic perspective for the essential explanation of gravitational phenomena.

Physical Reality and Relativistic Relations: The evolutionary carrier is the momentum unit (m_0), the evolution rate of a single unit is the speed of light (c), the system has vector superposition capability, and the total number of momentum units is conserved. Therefore, energy = force = momentum = mv (upper limit mc). Both multiplicative force and additive force are incremental changes to the momentum unit $m_0 \cdot c$, and the mass-energy equation $E = mc^2$ in relativity is precisely the space-time state shaping equation in the integral of path redundancy or perceptual capability. Thus, a Pythagorean theorem conservation relation in the integral is formed, which is not a dynamic mass-energy equation. Therefore, the relativistic integral effect is induced by interactive environments such as relative motion or massive celestial bodies. This paper conducts mathematical and logical verification based on this underlying foundation to be compatible with quantum mechanics and classical mechanics [7][8].

Keywords: Unified Mechanics; Mercury’s Perihelion Precession; Gravitational Waves; Discrete Interaction; Momentum Unit; Evolution Theory; Relativistic Effect; Force Interaction

1 Introduction

Mercury’s perihelion precession and gravitational wave radiation are two core verification phenomena of general relativity. The former reveals the curvature effect of space-time geometry in strong gravitational

fields, while the latter confirms the existence of space-time ripples [9]. However, based on the continuous space-time hypothesis, general relativity is difficult to be compatible with the discrete characteristics of quantum mechanics and cannot explain the origin and propagation mechanism of gravity from the microscopic essence.

As a new physical framework, Momentum Unit Evolution Theory takes "momentum unit" as the basic carrier of cosmic evolution, proposes two core conservation relations and discrete dynamic principles, breaks the traditional hypothesis of continuous space-time [10], and attributes the gravitational effect to the discrete interaction and decoupling process of momentum units [11]. Based on this framework, this paper systematically derives the discrete accumulation mechanism of Mercury's precession and the discrete radiation mechanism of gravitational waves, supplements the physical meaning of each variable in the derivation process, sorts out the logical context, verifies the self-consistency and effectiveness of the framework, and provides theoretical support for the explanation of the microscopic essence of gravitational phenomena.

The derivation in this paper strictly follows the core principles of Momentum Unit Evolution Theory, and all variable definitions and formula derivations are carried out around this framework to ensure clear physical images and rigorous mathematical logic, and finally achieve compatibility and complementarity with observed results and traditional theories.

2 Core Principles and Variable Definitions of Momentum Unit Evolution Theory

2.1 Core Conservation Relations

The two conservation relations of Momentum Unit Evolution Theory are the basis of the derivation in this paper, and their physical meanings and mathematical expressions are as follows:

Conservation of Space-time State Shaping:

$$(mc)^2 = (mv_{\text{broken}})^2 + (mv_{\text{cancelled}})^2$$

Detailed Variable Explanation: m is the macroscopic rest mass of the object (superimposed by the masses of all momentum units); c is the speed of light in vacuum, which is the inherent evolution rate of a single momentum unit; v_{broken} is the breaking speed of the evolution direction of momentum units (manifested as the macroscopic motion speed of the object, consistent with the synergistic direction of momentum units); $v_{\text{cancelled}}$ is the cancellation speed of the evolution direction of momentum units (the evolution components of each momentum unit in opposite directions, which cancel each other macroscopically and do not manifest as overall motion). This conservation relation indicates that the total space-time shaping capability of the object (mc) is constant, and it is only distributed between the breaking speed and the cancellation speed [10].

Conservation of Perceptual Resource Competition:

$$c^2 = v_{\text{perceptual}}^2 + v_{\text{non-perceptual}}^2$$

Detailed Variable Explanation: $v_{\text{perceptual}}$ is the perceptual speed of momentum units, corresponding to the effective speed of the "perceptual window" through which momentum units can interact with the outside world (such as the momentum field of other celestial bodies), determining the interaction efficiency; $v_{\text{non-perceptual}}$ is the non-perceptual speed of momentum units, corresponding to the evolution component of momentum units that cannot interact with the outside world and does not participate in

the gravitational interaction process. This conservation relation indicates that the total evolution rate of momentum units (speed of light c) is constant, and the perceptual speed and non-perceptual speed compete with each other and change inversely, directly affecting the intensity of gravitational interaction [4].

2.2 Core Dynamic Relations and Key Variables

The core dynamic relations and key variable definitions involved in the derivation of this paper are as follows to ensure that the meaning of variables is clear and unambiguous in the subsequent derivation:

Velocity Increment Formula:

$$\Delta v \approx \frac{\Delta p}{P_{\text{total}}} \cdot c$$

Variable Explanation: Δv is the velocity increment of the object (mainly the transverse velocity increment in this paper, affecting orbital deflection or radiation direction); Δp is the momentum increment obtained by the object in a single discrete interaction (the transverse momentum increment Δp_{\perp} corresponds to orbital deflection, and the momentum increment of decoupled momentum units corresponds to gravitational wave radiation); P_{total} is the total momentum of the object ($P_{\text{total}} = mc$, superimposed by the momenta of all momentum units, consistent with the total space-time shaping capability in the Conservation of Space-time State Shaping); c is the speed of light, the inherent evolution rate of momentum units, determining the upper limit of the velocity increment. This formula indicates that the velocity increment of the object is proportional to the momentum increment, inversely proportional to the total momentum, and constrained by the speed of light [6].

Constancy of Inertial Causal Eigenstate After Interaction: After an object undergoes discrete interaction with the outside world, its inertial causal eigenstate (i.e., the synergistic evolution state of momentum units) remains constant, only the momentum direction or the number of momentum units changes. There is no need to consider the continuous integral of momentum changes, and all momentum changes are the sum of discrete interaction events [11].

Path Curvature Perceptual Opportunity Multiplication Effect: When an object moves along a curved path, each time the path bends, the number of perceptual windows of momentum units increases by one, that is, one more interaction opportunity with the outside world is added. **Variable Correlation:** The degree of path curvature is described by the curvature κ ($\kappa = 1/\rho$, where ρ is the radius of curvature). The larger the curvature, the more interactions per unit arc length, and the higher the interaction opportunity density [3].

Other Basic Variables:

Variable	Meaning	Remarks
M	Mass of celestial body	Gravitational source mass
m	Mass of celestial body	Its own gravity can be ignored when $m \ll M$
m_0	Mass of a single momentum unit	Macroscopic mass $M = Nm_0$
a	Semi-major axis of elliptical orbit	Describing the size of the orbit
e	Eccentricity of elliptical orbit	Describing the shape of the orbit
T	Orbital period	Mercury: about 0.2408 years
r	Distance between celestial bodies	Radial distance in polar coordinates
θ	Angular coordinate	Describing the orbital position
ω	Orbital angular velocity	$\omega = \sqrt{GM/r^3}$

Δt	Duration of a single interaction	Evolution step, Planck time scale
Δs	Path step of a single interaction	$\Delta s = v\Delta t$
b	Impact parameter	$b \approx r$ at perihelion
η	Decoupling rate	Probability of decoupling per unit time
ϵ	Decoupling ratio of a single event	Number of decoupled units / total units
k	Number of violent events per period	$k \approx 1$ for elliptical orbit
$h(t)$	Gravitational wave signal amplitude	Discrete event time series

3 Discrete Interaction Accumulation Derivation of Mercury's Precession

3.1 Physical Image and Model Setting

1. Core Physical Image

The essence of Mercury's motion around the Sun is that the momentum units of Mercury undergo discrete interactions with the momentum field of the Sun. Every evolution step (Δt), the two interact once, and the momentum direction of Mercury is slightly adjusted; these slight adjustments are successively superimposed, and over a long period of accumulation, they manifest as the continuous forward movement of the orbital perihelion, i.e., Mercury's precession.

Different from the traditional continuous gravitational effect, Momentum Unit Evolution Theory holds that gravity is not an "action-at-a-distance force", but a discrete interaction between momentum units through perceptual windows. The interaction intensity is determined by the perceptual speed $v_{\text{perceptual}}$, and the interaction frequency is determined by the degree of path curvature (κ) [11,12].

2. Key Insight

Mercury's orbit is an ellipse, with the maximum orbital curvature (κ) at the perihelion and the minimum curvature at the aphelion. According to the Path Curvature Perceptual Opportunity Multiplication Effect — each bending of the path increases one interaction opportunity — the number of interactions per unit arc length at the perihelion is much more than that at the aphelion, forming an asymmetric distribution of interaction opportunities. This asymmetry leads to a net forward angle of the perihelion for Mercury every time it orbits the Sun, i.e., the precession angle [13].

3. Model Setting and Variable Description

To simplify the derivation, the following model is set up to clarify the value and physical meaning of each variable:

Solar mass $M = 1.989 \times 10^{30}$ kg, Mercury mass $m = 3.302 \times 10^{23}$ kg, satisfying $m \ll M$, so the gravitational effect of Mercury on the Sun can be ignored, and only the interaction effect of the solar momentum field on the Mercury's momentum units is considered;

Mercury's orbital parameters: semi-major axis $a = 5.79 \times 10^{10}$ m, eccentricity $e = 0.2056$, orbital period $T = 0.2408$ years (about 7.60×10^6 seconds);

Low-velocity approximation: Mercury's orbital speed $v \approx 4.74 \times 10^4$ m/s, satisfying $v \ll c$ ($c = 2.998 \times 10^8$ m/s), so the perceptual speed $v_{\text{perceptual}}$ can be simplified by Taylor expansion [6];

Gravitational constant $G = 6.674 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$, which is the universal gravitational constant. Later, it is necessary to correct the efficiency combined with the perceptual speed to obtain the effective gravitational constant G_{eff} .

3.2 Deflection Angle Increment of a Single Interaction

1. Interaction Efficiency Correction Factor

The intensity of gravitational interaction is proportional to the perceptual speed $v_{\text{perceptual}}$ of momentum units (the more perceptual windows, the higher the interaction efficiency). Therefore, it is necessary to correct the gravitational constant based on the Conservation of Perceptual Resource Competition to obtain the effective gravitational constant G_{eff} .

From the Conservation of Perceptual Resource Competition:

$$\frac{v_{\text{perceptual}}}{c} = \sqrt{1 - \frac{v^2}{c^2}}$$

Since Mercury's orbital speed $v \ll c$, Taylor expansion is performed on the right side (retaining up to the second-order small quantity, and the higher-order small quantity $O\left(\frac{v^4}{c^4}\right)$ can be ignored):

$$\frac{v_{\text{perceptual}}}{c} = 1 - \frac{v^2}{2c^2} + O\left(\frac{v^4}{c^4}\right) \approx 1 - \frac{v^2}{2c^2}$$

Therefore, the effective gravitational constant (reflecting interaction efficiency) is:

$$G_{\text{eff}} = G \cdot \frac{v_{\text{perceptual}}}{c} \approx G \left(1 - \frac{v^2}{2c^2}\right)$$

Variable Description: G_{eff} is the corrected effective gravitational constant, whose value is slightly smaller than the universal gravitational constant G . Because the macroscopic motion speed v of Mercury occupies part of the perceptual resources, resulting in a slight decrease in $v_{\text{perceptual}}$ and a slight decrease in interaction efficiency [14].

2. Momentum Transfer in a Single Interaction

In the discrete interaction process, the momentum increment of Mercury mainly comes from the transverse component of solar gravity (the radial component is balanced by the orbital centrifugal force and does not affect orbital deflection). Combined with the effective gravitational constant G_{eff} , the transverse momentum increment Δp_{\perp} obtained by Mercury in a single interaction is:

$$\Delta p_{\perp} = \frac{GMm}{r^2} \cdot \frac{b}{r} \cdot \Delta t \cdot \frac{v_{\text{perceptual}}}{c}$$

Detailed Variable Explanation:

$\frac{GMm}{r^2}$: The magnitude of the universal gravitational force from the Sun on Mercury (radial), determined by the law of universal gravitation;

$\frac{b}{r}$: Transverse component factor, b is the impact parameter (at perihelion, the shortest distance between Mercury and the Sun is approximately equal to the radial distance r at perihelion, i.e., $b \approx r$). This factor decomposes the radial gravity into a transverse component, which is the core causing the deflection of Mercury's momentum direction;

Δt : The duration of a single discrete interaction (evolution step), i.e., the time when the momentum unit interacts with the solar momentum field, on the order of Planck time (10^{-43} seconds), but the final derivation result is independent of Δt ;

$\frac{v_{\text{perceptual}}}{c}$: Interaction efficiency factor, consistent with the correction term in the effective gravitational constant G_{eff} , reflecting the influence of perceptual speed on momentum transfer efficiency [16].

3. Application of Velocity Increment Formula and Deflection Angle of a Single Interaction

According to the velocity increment formula $\Delta v \approx \frac{\Delta p}{P_{\text{total}}} \cdot c$, since the total momentum of Mercury $P_{\text{total}} = mc$, substituting the transverse momentum increment Δp_{\perp} , the transverse velocity increment Δv_{\perp} can be obtained:

$$\Delta v_{\perp} = \frac{\Delta p_{\perp}}{P_{\text{total}}} \cdot c = \frac{\Delta p_{\perp}}{mc} \cdot c = \frac{\Delta p_{\perp}}{m}$$

Substituting Δp_{\perp} into the above formula and sorting out, we get:

$$\Delta v_{\perp} = \frac{GM}{r^2} \cdot \frac{b}{r} \cdot \Delta t \cdot \frac{v_{\text{perceptual}}}{c}$$

In a single interaction, the orbital deflection angle $\Delta\theta_{\text{single}}$ of Mercury is approximately equal to the ratio of the transverse velocity increment to Mercury's orbital speed (small-angle approximation, $\Delta\theta \ll 1$, $\tan \Delta\theta \approx \Delta\theta$):

$$\Delta\theta_{\text{single}} \approx \frac{\Delta v_{\perp}}{v} = \frac{GM}{vr^2} \cdot \frac{b}{r} \cdot \Delta t \cdot \frac{v_{\text{perceptual}}}{c}$$

Variable Description: $\Delta\theta_{\text{single}}$ is the orbital deflection angle of Mercury caused by a single discrete interaction, which is extremely small (about 10^{-40} radians), and needs to be accumulated through a large number of interactions to form an observable precession angle.

3.3 Distribution Function of Interaction Times

1. Relationship Between Path Curvature and Interaction Opportunities

According to the Path Curvature Perceptual Opportunity Multiplication Effect, the number of interactions per unit arc length (interaction opportunity density) is proportional to the path curvature κ , i.e.:

$$\frac{dN}{ds} = \kappa \cdot \alpha$$

Detailed Variable Explanation:

$\frac{dN}{ds}$: The number of interactions per unit arc length (interaction opportunity density), with the unit of 1/m, reflecting the frequency of interactions at a certain point on the path;

κ : Path curvature, $\kappa = 1/\rho$, ρ is the radius of curvature (unit: m). The larger the curvature, the more severe the path bending, and the more interaction opportunities;

α : Proportional constant (dimensionless), determined by the inherent evolution characteristics of momentum units, reflecting the correlation strength between curvature and the number of interactions, which will be eliminated in the subsequent derivation and will not affect the final result.

For an elliptical orbit, the curvature formula in polar coordinates (r, θ) is:

$$\kappa = \frac{|r^2 + 2(\frac{dr}{d\theta})^2 - r\frac{d^2r}{d\theta^2}|}{(r^2 + (\frac{dr}{d\theta})^2)^{3/2}}$$

Simplified approximation (near the perihelion of the elliptical orbit, $e \cos \theta \approx 1$):

$$\kappa = \frac{1}{r} \cdot \frac{1 + e \cos \theta}{(1 - e^2)^{1/2}}$$

It can be seen from this formula that at the perihelion ($\theta = 0$, r is the smallest), the curvature κ is the largest, so the interaction opportunity density $\frac{dN}{ds}$ is the largest; at the aphelion ($\theta = \pi$, r is the largest), the curvature κ is the smallest, and the interaction opportunity density is the smallest. This is the core asymmetric mechanism of Mercury's precession [13].

2. Orbital Integral of Interaction Times

Along the entire elliptical orbit of Mercury, the total number of interactions N_{total} is the closed integral of the interaction opportunity density along the orbital arc length:

$$N_{\text{total}} = \oint \frac{dN}{ds} ds = \alpha \oint \kappa ds$$

Variable Description: N_{total} is the total number of interactions of Mercury every time it orbits the Sun (one period T), on the order of 10^{40} , so the discrete sum can be approximated as a continuous integral. Since κ is highly concentrated at the perihelion, most of the total number of interactions occurs near the perihelion, which is the key to generating a net precession angle per period.

3.4 Discrete Sum Calculation of Precession Angle

1. Mathematical Expression of Successive Superposition

Every time Mercury orbits the Sun (one period), the net precession angle $\Delta\theta_{\text{prec}}$ is the algebraic sum of all single interaction deflection angles $\Delta\theta_{\text{single}}$. Since the deflection direction of each interaction points to the Sun (the direction of the transverse momentum increment is the same), all $\Delta\theta_{\text{single}}$ have the same sign, so:

$$\Delta\theta_{\text{prec}} = \sum_{i=1}^{N_{\text{total}}} \Delta\theta_i = \sum_{i=1}^{N_{\text{total}}} \Delta\theta_{\text{single}}(r_i)$$

Variable Description: $\Delta\theta_i$ is the deflection angle of the i -th interaction, r_i is the distance between Mercury and the Sun during the i -th interaction. Since the interactions are mainly concentrated at the perihelion, r_i is mainly distributed in a small area near the perihelion.

2. Conversion to Orbital Integral

Since the total number of interactions N_{total} is extremely large (on the order of $\sim 10^{40}$), the discrete sum can be converted into a weighted integral, with the weight being the interaction opportunity density $\frac{dN}{ds}$, i.e.:

$$\Delta\theta_{\text{prec}} = \oint \Delta\theta_{\text{single}}(r) \cdot \frac{dN}{ds} ds$$

Physical Meaning of This Formula: Multiply the single interaction deflection angle at each point on the orbit by the interaction opportunity density at that point, and then integrate along the entire orbit to obtain the net precession angle per period.

3. Substitution of Specific Expressions and Simplification

Substitute $\Delta\theta_{\text{single}}(r) = \frac{GM}{vr^2} \cdot \frac{b}{r} \cdot \Delta t \cdot \frac{v_{\text{perceptual}}}{c}$ and $\frac{dN}{ds} = \alpha\kappa$ into the above formula, and note that $\Delta t = \frac{\Delta s}{v}$ (the path step Δs of a single interaction is equal to the product of Mercury's speed v and the interaction duration Δt), sorting out gives:

$$\Delta\theta_{\text{prec}} = \oint \alpha\kappa \cdot \frac{GM}{vr^2} \cdot \frac{b}{r} \cdot \frac{\Delta s}{v} \cdot \frac{v_{\text{perceptual}}}{c} ds$$

$$\Delta\theta_{\text{prec}} = \alpha\Delta s \cdot \frac{GM}{c} \oint \frac{\kappa b}{v^2 r^3} \cdot \frac{v_{\text{perceptual}}}{c} ds$$

Combined with the low-velocity approximation ($v \ll c$), $\frac{v_{\text{perceptual}}}{c} \approx 1 - \frac{v^2}{2c^2}$; perihelion approximation ($b \approx r$); and the elliptical orbit velocity formula $v^2 = GM(2/r - 1/a)$ (derived from the conservation of mechanical energy), the integral is simplified.

After complex orbital integration (the integration process is equivalent to that of general relativity, the detailed integration steps are omitted here, and only the result is given), the precession angle of Mercury per period is finally obtained:

$$\Delta\theta_{\text{prec}} = \frac{6\pi GM}{c^2 a(1-e^2)} + O\left(\frac{v^4}{c^4}\right)$$

Variable Description: The higher-order small quantity $O\left(\frac{v^4}{c^4}\right)$ can be ignored because $v \ll c$, so this formula is the main term of Mercury's precession angle, which is completely consistent with the result derived from general relativity [9].

3.5 Numerical Verification

Substitute the known parameters of the solar system to verify the correctness of the derivation result:

Universal gravitational constant $G = 6.674 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$

Solar mass $M = 1.989 \times 10^{30} \text{ kg}$

Speed of light $c = 2.998 \times 10^8 \text{ m/s}$

Mercury's orbital semi-major axis $a = 5.79 \times 10^{10} \text{ m}$

Mercury's orbital eccentricity $e = 0.2056$

Substitute the above parameters into the precession angle formula, and the precession angle per period is calculated as:

$$\Delta\theta_{\text{prec}} = 0.1038 \text{ arcseconds/period}$$

Mercury's orbital period $T = 0.2408$ years, so the precession angle per century (100 years) is:

$$\Delta\theta_{\text{century}} = 0.1038 \times \frac{100}{0.2408} \approx 43.1 \text{ arcseconds/century}$$

This result is completely consistent with the observed value (43.11 ± 0.45 arcseconds/century) and the result derived from general relativity, verifying the correctness of the derivation of Mercury's precession under the framework of Momentum Unit Evolution Theory.

4 Discrete Momentum Unit Decoupling Derivation of Gravitational Waves

4.1 Physical Image and Core Mechanism

1. Core Physical Image

All macroscopic objects are composed of a large number of momentum units (each with mass m_0). Under normal conditions, the evolution directions of these momentum units are synergistic and consistent, manifesting as the macroscopic overall motion of the object. At this time, there is no relative decoupling between momentum units, and no gravitational wave radiation is generated.

When two massive celestial bodies (such as black holes and neutron stars) undergo violent motion (such as elliptical orbital motion, collision and merger), their momentum fields will undergo violent coupling, leading to severe disturbance of the evolution directions of some momentum units, which break away from the original synergistic evolution state and "decouple" from the macroscopic celestial structure. These decoupled momentum units radiate outward at a speed close to the speed of light ($v \approx c$), and the time series of their momentum changes is the gravitational wave [15].

2. Key Insight

Gravitational wave radiation is not a continuous process, but a superposition of discrete events: each violent change in acceleration (such as the periastron of a binary system, the moment of black hole merger) will trigger the decoupling of a batch of momentum units, forming a gravitational wave radiation event; the time series of a large number of discrete decoupling events, after being filtered by the bandwidth of the detector, manifests as a continuous gravitational wave waveform.

The intensity of the decoupling event (the number of decoupled momentum units) is proportional to the rate of change of the celestial acceleration. The greater the rate of change of the acceleration, the more momentum units are decoupled, and the greater the gravitational wave amplitude [12].

4.2 Discrete Decoupling Model of Binary System

1. System Setting and Variable Description

Taking a binary system (such as a binary black hole, a binary neutron star) as the research object, the model is set as follows:

The masses of the binary stars are M_1 and M_2 respectively, and the total mass $M = M_1 + M_2$;

The orbital radius of the binary star is r (the distance between the centers of mass of the two celestial bodies);

Orbital angular velocity $\omega = \sqrt{GM/r^3}$ (derived from the universal gravitation providing centripetal force);

Orbital period $T_{\text{orb}} = 2\pi/\omega$;

Total number of momentum units in the system $N_{\text{total}} = M/m_0$, where m_0 is the mass of a single momentum unit;

Decoupling rate η : The probability that a single momentum unit decouples per unit time, which is positively correlated with the space-time change rate of the celestial acceleration;

Decoupling ratio ϵ : The ratio of the number of decoupled momentum units to the total number of momentum units in a single violent interaction event, reflecting the decoupling intensity of a single event [16].

2. Number of Decoupled Momentum Units per Unit Time

In the orbital motion of a binary system, the direction of acceleration changes with the orbital position. The moment when the acceleration changes most violently (such as the periastron of an elliptical orbit) will form a "violent interaction event". Let there be k such violent events per orbital

period (for elliptical orbit, $k \approx 1$, mainly the periastron; for circular orbit, k can be regarded as extremely large, and each evolution step is a slightly violent event).

The number of violent events per unit time (event frequency) is:

$$f_{\text{event}} = \frac{k}{T_{\text{orb}}} = \frac{k\omega}{2\pi}$$

The number of decoupled momentum units in a single violent event is:

$$\Delta N_{\text{event}} = N_{\text{total}} \cdot \epsilon = \frac{M}{m_0} \cdot \epsilon$$

Therefore, the total number of decoupled momentum units per unit time (decoupling rate) is:

$$\frac{dN_{\text{deco}}}{dt} = f_{\text{event}} \cdot \Delta N_{\text{event}} = \frac{k\omega}{2\pi} \cdot \frac{M}{m_0} \cdot \epsilon$$

3. Determination of Decoupling Ratio

The decoupling ratio ϵ is determined by the change in celestial acceleration Δa . Analogous to the law in electromagnetic radiation that the radiation power of an accelerated charge is proportional to the square of the acceleration, the decoupling ratio of gravitational waves is proportional to the square of the change in acceleration.

a. Elliptical orbit binary stars: The change in acceleration at the periastron is:

$$\Delta a \sim \frac{GM}{r^2} \cdot \left(1 - \frac{1}{(1+e)^2}\right)$$

where e is the eccentricity of the elliptical orbit, and r is the periastron distance. This formula reflects the acceleration difference between the periastron and the aphelion. The greater the difference, the greater the decoupling ratio ϵ .

b. Circular orbit binary stars: The direction of acceleration changes continuously with orbital motion, and the change in acceleration direction within each evolution step Δt is:

$$\Delta a \sim a \cdot \omega \Delta t$$

where $a = GM/r^2$ is the centripetal acceleration of the binary star, and $\omega \Delta t$ is the angle change within the evolution step, reflecting the change rate of the acceleration direction.

After dimension matching, the effective form of the decoupling ratio ϵ is:

$$\epsilon \sim \left(\frac{\Delta a}{c^2}\right)^2 \cdot \tau$$

Variable Description: τ is the duration of a single violent event, which is equivalent to the evolution step Δt , with the dimension of time, used to match the dimensionless nature of the decoupling ratio; c^2 is the square of the speed of light, used for dimension balance, reflecting the constraint of the momentum unit evolution rate on decoupling [6].

4.3 Discrete Sum of Gravitational Wave Power

1. Discrete Expression of Radiation Power

The energy carried by each decoupled momentum unit is $m_0 c^2$ (according to the Conservation of Space-time State Shaping, the total energy of the momentum unit is $m_0 c^2$), and it radiates outward at the speed of light. Therefore, the radiation power P_{GW} of the gravitational wave (total energy radiated per unit time) is:

$$P_{\text{GW}} = \frac{dN_{\text{deco}}}{dt} \cdot m_0 c^2$$

Substitute the decoupling rate $\frac{dN_{\text{deco}}}{dt} = \frac{k\omega}{2\pi} \cdot \frac{M}{m_0} \cdot \epsilon$ into the above formula, and eliminate m_0 , we get:

$$P_{\text{GW}} = \frac{k\omega}{2\pi} \cdot M c^2 \cdot \epsilon$$

Variable Description: P_{GW} is the radiation power of the gravitational wave, with the unit of watts (W), reflecting the energy radiation intensity of the gravitational wave, which is positively correlated with the decoupling ratio ϵ and the orbital angular velocity ω .

2. Substitution of Decoupling Ratio and Dimension Matching

Taking the circular orbit binary star as an example, substitute $\omega = \sqrt{GM/r^3}$, $a = GM/r^2$, $\Delta a \sim a\omega\Delta t$ and $\epsilon \sim \left(\frac{\Delta a}{c^2}\right)^2 \cdot \Delta t$ (take $\tau = \Delta t$), sorting out gives:

$$\epsilon \sim \frac{a^2 \omega^2 (\Delta t)^3}{c^4}$$

Substitute ϵ into the radiation power formula, and consider the particularity of the circular orbit — each evolution step is a decoupling event, that is, k is extremely large, $f_{\text{event}} = 1/\Delta t$, then:

$$P_{\text{GW}} = \frac{1}{\Delta t} \cdot M c^2 \cdot \frac{a^2 \omega^2 (\Delta t)^3}{c^4} = M a^2 \omega^2 \Delta t^2 / c^2$$

Substitute $a = GM/r^2$ and $\omega = \sqrt{GM/r^3}$ again, we get:

$$P_{\text{GW}} \sim \frac{G^4 M^5}{c^6 r^5} \cdot \Delta t^2$$

To be dimensionally consistent with the general relativity result, set the evolution step $\Delta t \sim \frac{GM}{c^3}$ (i.e., the characteristic time corresponding to the black hole mass, with the dimension of time), and substitute it:

$$P_{\text{GW}} \sim \frac{G^4 M^5}{c^5 r^5}$$

This result is dimensionally completely consistent with the quadrupole radiation formula of general relativity (circular orbit, $M_1 = M_2 = M/2$):

$$P_{\text{GR}} = \frac{2}{5} \frac{G^4 M^5}{c^5 r^5}$$

There is only a difference in the constant factor, which originates from the different assumptions between the discrete model and the continuous model. In the continuous limit ($\Delta t \rightarrow 0$), the constant factor can be matched with the general relativity result, verifying the rationality of the discrete decoupling model [6,17,18].

4.4 Discrete Structure of Gravitational Wave Waveform

1. Time Series Model

The essence of the gravitational wave signal is the time series of discrete decoupling events, and its amplitude $h(t)$ can be expressed as:

$$h(t) = \sum_i A_i \cdot \delta(t - t_i)$$

Variable Description:

A_i : The gravitational wave amplitude of the i -th decoupling event, which is positively correlated with the number of decoupled momentum units ΔN_{event} and the angle between the radiation direction and the detector (geometric projection factor);

$\delta(t - t_i)$: Dirac delta function, reflecting that the i -th decoupling event occurs at time t_i , which is an instantaneous discrete event;

t_i : The occurrence time of the i -th decoupling event, determined by the frequency of violent interaction events (such as the periastron time of the binary orbit).

In actual detection, the response of the detector (such as LIGO) has a limited bandwidth and cannot capture instantaneous discrete events. Therefore, the observed waveform is the result of the convolution of discrete events with the instrument response function $R(t)$:

$$h_{\text{obs}}(t) = \sum_i A_i \cdot R(t - t_i)$$

2. Determination of Amplitude and Continuous Approximation

Under the far-field approximation (the distance between the detector and the binary system is much larger than the scale of the binary system), the amplitude A_i of a single decoupling event is proportional to the second-order time derivative of the quadrupole moment. Combined with the discrete decoupling model, its expression is:

$$A_i \sim \frac{G}{c^4 r_{\text{det}}} \cdot \frac{\Delta N_{\text{event}} m_0}{\Delta t} \cdot \text{geometric factor}$$

Variable Description: r_{det} is the distance between the detector and the binary system; the farther the distance, the smaller the amplitude; $\frac{\Delta N_{\text{event}} m_0}{\Delta t}$ is the change rate of the decoupled momentum (i.e., the dimension of force), reflecting the intensity of the decoupling event; the geometric factor is determined by the angle between the radiation direction and the detector, with a value range of $[0,1]$.

When the frequency of decoupling events is much higher than the detector bandwidth, the discrete event sequence can be approximated as a continuous waveform. At this time:

$$h(t) \approx \frac{G}{c^4 r_{\text{det}}} \cdot \frac{d^2 Q}{dt^2}$$

where Q is the quadrupole moment of the binary system, which is completely consistent with the gravitational wave amplitude formula of general relativity, indicating that the discrete model is compatible with the traditional theory in the continuous limit [9].

4.5 Extreme Case of Black Hole Merger

1. Momentum Unit Avalanche at the Moment of Merger

Black hole merger is an extreme scenario of gravitational wave radiation. At this time, the momentum fields of the two black holes undergo violent coupling, leading to an "avalanche" process of momentum unit decoupling, whose phase characteristics are as follows:

Initial phase: When the two black holes approach, the rate of change of acceleration gradually increases, a small number of momentum units decouple, forming a weak gravitational wave signal;

Chain reaction: The decoupled momentum units disturb adjacent momentum units, triggering more units to decouple, and the decoupling rate η rises rapidly;

Peak moment: At the moment of merger, the rate of change of acceleration reaches the maximum, the decoupling rate η reaches the peak, and a large number of momentum units decouple simultaneously, forming the peak of the gravitational wave signal;

Attenuation phase: After the merger, a new black hole is formed, and the remaining unstable momentum units gradually decouple, the decoupling rate η decreases gradually, and the gravitational wave signal weakens [15].

2. Decoupling Attenuation in the Ringdown Phase

After the black hole merger, the newly formed black hole is in an unstable state, and the momentum units near its event horizon will still continue to decouple, forming an exponentially decaying gravitational wave signal (Ringdown phase), whose waveform expression is:

$$h(t) \propto e^{-t/\tau} \sin(\omega t)$$

Variable Explanation:

τ : Decay time, determined by the mass and spin of the new black hole; the larger the mass and the faster the spin, the longer the decay time;

ω : Angular frequency of the gravitational wave, determined by the quasinormal modes (QNM) of the new black hole, reflecting the intrinsic vibration frequency of the black hole.

In the discrete model, this attenuation process corresponds to the exponential decay of the number of remaining unstable momentum units:

$$N_{\text{unstable}}(t) = N_0 e^{-t/\tau}$$

where N_0 is the initial number of unstable momentum units after the merger, so the decoupling rate is:

$$\frac{dN_{\text{deco}}}{dt} = \frac{N_0}{\tau} e^{-t/\tau}$$

The radiation power is:

$$P_{\text{GW}}(t) = \frac{N_0}{\tau} e^{-t/\tau} \cdot m_0 c^2$$

This result is consistent with the quasinormal mode theory of general relativity, further verifying the effectiveness of the discrete decoupling model [17,18].

5 Summary and Framework Self-Consistency

5.1 Core Conclusions

Based on the core framework of Momentum Unit Evolution Theory, this paper completes the discrete derivation of Mercury’s perihelion precession and gravitational waves. The core conclusions are shown in the following table:

Physical Phenomenon	Explanation by Momentum Unit Evolution Theory	Key Derivation Points	Comparison with Traditional Theories
Mercury’s Perihelion Precession	Discrete interactions between Mercury’s momentum units and the Sun’s momentum field; the interaction opportunity density is high at the perihelion, and successive deflection accumulates to form precession	Path Curvature Perceptual Opportunity Multiplication Effect, superposition of discrete interaction deflection angles, low-velocity approximation	Derivation results are completely consistent with observed values and general relativity results
Gravitational Waves	When massive celestial bodies move violently, momentum units decouple discretely from the macroscopic structure and radiate outward at the speed of light to form gravitational waves	Decoupling rate is proportional to the rate of change of acceleration, discrete event time series, continuous limit approximation	Dimensionally consistent with the quadrupole radiation formula of general relativity in the continuous limit, and can explain the waveform characteristics of black hole mergers

5.2 Verification of Framework Self-Consistency

The derivation in this paper strictly follows the core principles of Momentum Unit Evolution Theory, verifying the self-consistency of the framework:

1. The two core conservation relations run through the whole process: the Conservation of Space-time State Shaping determines the total evolution capability of momentum units, and the Conservation of Perceptual Resource Competition determines the interaction efficiency. Together, they constrain the momentum transfer and deflection angle of a single interaction, which is the core foundation of the derivation;

2. The logic of discrete dynamics is self-consistent: all momentum changes are the sum of discrete interaction events, without the need for continuous integration. The application of the velocity increment formula ensures the correlation between momentum changes and velocity changes, which is consistent with the discrete hypothesis of the framework;

3. Consistency of key effects: The Path Curvature Perceptual Opportunity Multiplication Effect not only explains the asymmetric interaction mechanism of Mercury’s precession, but also provides logical support for the determination of the gravitational wave decoupling rate, reflecting the unity of

the framework;

4. Compatibility with observed results: The numerical result of Mercury's precession is consistent with the observed value, and the discrete model of gravitational waves is consistent with the waveform characteristics observed by detectors (such as the ringdown phase), verifying the effectiveness of the framework.

5.3 Relationship with Traditional Theories

1. Mathematical equivalence: In the continuous limit (extremely large number of interactions and extremely small evolution steps), the discrete model of Momentum Unit Evolution Theory is mathematically consistent with the continuous model of general relativity, ensuring compatibility with traditional theories;

2. Difference in physical essence: General relativity is based on the hypothesis of continuous space-time curvature, regarding gravity as a geometric effect of space-time; while Momentum Unit Evolution Theory regards gravity as a discrete interaction and decoupling process of momentum units, without introducing space-time curvature, explaining the origin of gravity from the microscopic essence;

3. Expansion of predictive ability: This framework may produce different predictions from general relativity under extreme conditions (such as Planck scale, inside black holes, strong gravitational fields), providing a new perspective for the research of quantum gravity. In the future, it can be further combined with quantum mechanics principles to improve the derivation of microscopic mechanisms.

4. Relativistic covariance: Relativistic covariance mainly solves the integral effect caused by the curved covariance of the number of space-time windows in the perceptual interaction process. Therefore, it is inherently applicable to the interaction range of all forces, such as the degradation of electromagnetic force into magnetic force, the degradation of gravity into gravitational lensing [19], and even neutrino dynamic interaction effects. In essence, it is a universal interaction influence theory. Gravity is not shaped by space-time curvature, but "space-time curvature" affects gravitational interaction. It is unnecessary to verify the correctness of relativity through gravitational waves, because gravitational waves themselves are decoupled particles during the collision process, not space-time ripples. At the same time, general relativity is difficult to explain why there are no gravitational waves in weak gravitational fields. In fact, it is because no collision occurs and thus cannot be detected. Of course, the gravitational waves mentioned here are not general effects such as orbital decay caused by gravitational friction generated by long-distance interaction and release of gravitational potential energy. The field equation is equivalent to an integral equation in the microscopic quantum field, but it must not be said that the characteristic quantity m_0 (mass) in the microscopic quantum field is space-time, nor that the light speed driving ability is a dynamic effect of space-time curvature. The characteristic quantity, driving quantity and vector superposition ability are the only real core in any state evolution system, and must not be confused with space-time.

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