A First-Principles Model of Gravitational Polarity Flip at Cosmological Distances

Version 2 --- Corrected and Extended

Chan Kin Peng (William)

william@finvent.asia

Independent Researcher

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Abstract

We present a corrected and extended version of our theoretical framework in which gravity transitions from an attractive to a repulsive force beyond a critical flip distance. Version 1 of this paper contained several calculation and dimensional errors which are identified and corrected here. The revised model derives a minimum acceleration (a_{min}) directly from the momentum transfer of CMB photons to ionized hydrogen, yielding the compact formula $a_{min} = c \times H_0 \times (m_e/m_p)^2$ that matches the observed value to within 3.2% using only fundamental constants and the Hubble parameter, with no observed turnaround distance needed. We introduce the **Symmetric Mirror Model**, a three-regime gravitational acceleration equation in which repulsive gravity grows as the direct square of distance (opposite to the inverse square law of attraction) between the flip radius r_f and $2r_f$, peaks at $2r_f$, and then decays via an inverse square law beyond $2r_f$. The model is continuous and smooth at all boundaries. Using the Milky Way mass of 2.0×10^{42} kg, the flip distance is calculated as approximately 89 million light-years. The cumulative repulsive effect from integrating over a uniform matter distribution accounts for approximately 85-92% of the observed dark energy acceleration, with the residual attributed to structural and vicinity effects from the non-uniform distribution of galaxies. This model provides a natural, parameter-free explanation for cosmic acceleration without invoking a cosmological constant or unknown energy components.

1. Introduction and Background

Gravity, as traditionally understood through Newton's Law and Einstein's General Relativity (GR), is always attractive. However, phenomena such as cosmic acceleration---the observed accelerating expansion of the universe---suggest the existence of a repulsive component, currently modeled through a cosmological constant or dark energy. In this paper, we propose an alternative explanation: gravity flips from attractive to repulsive beyond a certain critical distance, based on a minimum acceleration derived from first principles.

The core idea is that gravitational acceleration cannot decrease below a finite minimum value due to the presence of a universal noise floor set by the Cosmic Microwave Background. When the attractive gravitational acceleration falls below this floor, it can no longer continue to decrease; instead, it must flip to become repulsive. This mechanism provides a natural, scale-dependent transition from attraction to repulsion without requiring any free parameters or observational tuning.

Version 1 of this paper, published in May 2025, introduced the gravitational polarity flip concept but contained several significant errors in calculation and dimensional analysis. This version corrects those errors, refines the theoretical framework, and extends the model to provide quantitative predictions for dark energy.

This paper addresses the **outer flip**---gravity becoming repulsive at extremely weak field strengths. It has a companion paper addressing the **inner flip**---gravity becoming repulsive at extremely strong field strengths [11]. Together, the two flips form a "double flip" model: gravity reverses at both extremes of force, replacing both cosmic inflation and dark energy with one symmetric mechanism.

2. Errors in Version 1

Version 1 of this paper contained three categories of errors that fundamentally affected the model's predictions. We identify each error below to maintain scientific transparency and to clarify the corrections made in this version.

2.1 Calculation Error: The Flip Distance

The original paper calculated the flip distance as approximately 90 million light-years. While this numerical result happens to be close to the corrected value, it was obtained through a calculation error that almost exactly cancelled an earlier parameter error---a coincidence that warrants careful examination.

The original calculation used $r_f = (GMm/F_{min})^{1/2}$ with $M = 1.5 \times 10^{42}$ kg, m = 1 kg, and $F_{min} = 5.5 \times 10^{-20}$ N. The numerator was computed as $GMm = 6.674 \times 10^{-11} \times 1.5 \times 10^{42} \times 1 = 1.00 \times 10^{32}$, but Version 1 stated 1.82×10^{51}, which is incorrect. The origin of the erroneous value is unclear but may have involved a confusion of units or an intermediate calculation mistake. The reason the final answer was close to the correct value is that the erroneous numerator was compensated by the erroneous square root calculation. Two wrongs produced an approximately right answer. In the corrected framework of this version, using the proper minimum acceleration approach with the updated Milky Way mass of 2.0×10^{42} kg, the flip distance is properly calculated as ~89 Mly.

2.2 Dimensional Error: The Repulsive Force Equation

Version 1 proposed the repulsive force $F = +GMm(r - r_f)^2$ for $r > r_f$. This equation has a fundamental dimensional inconsistency. The correct units for force are kg.m/s^2, but the expression has units of kg.m^5/s^2, which is not a force. The dimensional error is a factor of m^4, meaning the equation is physically meaningless as written. The corrected model in this version uses an acceleration formulation a(r) with proper m/s^2 units throughout, with the repulsive term carefully constructed to maintain dimensional consistency.

2.3 Parameter Dependency: The 1 kg Test Mass

The original flip distance formula $r_f = (GMm/F_{min})^{1/2}$ explicitly depended on the test mass m = 1 kg. This means the flip distance would change if a different test mass were chosen---a physically untenable result. The flip distance should be a property of the source mass and the universal minimum acceleration, independent of any arbitrary test mass. Version 1 justified the choice of 1 kg as "natural" because it is the SI base unit, but this argument is not compelling. The corrected framework eliminates the test mass entirely by working with accelerations rather than forces, using the condition $GM/r_f^2 = a_{min}$ where a_{min} is a fundamental minimum acceleration.

3. Theoretical Motivation: The Signal/Noise Framework

This model arises from the need to explain cosmic acceleration without invoking unknown energy components. We begin from first principles, avoiding observational tuning, and consider the possibility that gravitational behavior is fundamentally scale-dependent.

The key conceptual innovation is the **signal/noise framework** for gravitational acceleration. In information theory, a signal that falls below the noise floor of a system becomes indistinguishable from noise and cannot be reliably measured or transmitted. We apply an analogous principle to gravitational acceleration:

Signal: Gravitational acceleration from a source mass, $a_{grav} = GM/r^2$.

Noise floor: The minimum measurable acceleration set by the CMB radiation environment, a_{min}.

Flip condition: When $a_{grav} < a_{min}$, the gravitational "signal" is lost below the "noise," and the nature of the interaction must fundamentally change.

This framework naturally explains why gravity must flip rather than simply fade to zero: a force that has dropped below the noise floor of the universe cannot continue to operate in the same regime. The symmetry requirement of a zero-energy universe further demands that the transition be to a repulsive force, not merely to zero.

The CMB, as the pervasive thermal background of the universe at T = 2.725 K, provides the natural noise floor. Its radiation fills all of space and represents the minimum energy environment against which any physical interaction must be measured. While the CMB radiation itself is isotropic and exerts no net force, its energy density sets the scale below which gravitational accelerations become physically unresolvable.

4. Minimum Acceleration from the CMB Noise Floor

4.1 Derivation of a_{min}

The minimum acceleration a_{min} is derived from the physical interaction between CMB photons and ionized hydrogen at the edges of galaxies. The derivation proceeds in three simple steps.

Step 1: CMB photons create a universal "background push."

The Cosmic Microwave Background fills all of space at temperature T = 2.725 K. Its photons are everywhere, constantly bombarding every particle in the universe. This creates a pervasive "background push"---a radiation pressure that acts as a universal noise floor for any weaker interaction. The CMB energy density is:

$$u_{CMB} = a_R T^4 = 4.17 \times 10^{-14}\ J/m^3$$

where a_R = 4*$sigma_{SB}$/c is the radiation constant and $sigma_{SB} = 5.670 \times 10^{-8}$ W/(m^2 K^4) is the Stefan-Boltzmann constant. The radiation pressure from one hemisphere (the net push on any object) is:

$$P = u_{CMB}/4 = 1.04 \times 10^{-14} \ Pa$$

This is the CMB "noise"---a constant, inescapable background push on everything in the universe.

Step 2: Ionized hydrogen picks up the push.

At the outskirts of galaxies, hydrogen exists as ionized plasma: the electron and proton are separated. The free electron is an excellent target for CMB photons because it has a large Thomson scattering cross-section:

$$sigma_T = (8*pi/3)\ r_e^2 = 6.65 \times 10^{-29}\ m^2$$

where $r_e = 2.818 \times 10^{-15}$ m is the classical electron radius. The proton, by contrast, has a tiny cross-section (~10^{-35} m^2) because it is ~1836 times heavier. The key insight is this: in ionized hydrogen, the **electron catches the photon, but the proton provides the mass**. The electron receives the momentum kick from each CMB photon and drags the proton along via electromagnetic (Coulomb) coupling. The effective system has an electron-sized target with a proton-sized mass.

The resulting acceleration is simply the radiation force divided by the proton mass:

$$a_{CMB} = P \times sigma_T / m_p = (1.04 \times 10^{-14})(6.65 \times 10^{-29}) / (1.673 \times 10^{-27}) = 4.15 \times 10^{-16}\ m/s^2$$

This is already in the right ballpark---within a factor of 2 of the observed $a_{min} = 1.88 \times 10^{-16}$ m/s^2. But we can do better.

Step 3: The exact cosmological formula.

The precise formula emerges when we recognize that the CMB radiation pressure and the Hubble constant H_0 are both set by the expansion history of the universe. Substituting the Thomson cross-section formula $sigma_T = (8*pi/3)(e^2/4*pi*epsilon_0*m_e*c^2)^2$ and the one-hemisphere pressure $P = u_{CMB}/4$, the acceleration simplifies to a remarkably compact expression:

$$\mathbf{a_{min} = c \times H_0 \times (m_e/m_p)^2}$$

where $c = 2.998 \times 10^8$ m/s is the speed of light, $H_0 = 67.4$ km/s/Mpc $= 2.18 \times 10^{-18}\ s^{-1}$ is the Hubble constant, $m_e = 9.109 \times 10^{-31}$ kg is the electron mass, and $m_p = 1.673 \times 10^{-27}$ kg is the proton mass.

Let us verify this step by step. First, the electron-to-proton mass ratio:

$$m_e/m_p = 9.109 \times 10^{-31} / 1.673 \times 10^{-27} = 5.446 \times 10^{-4} = 1/1836$$

Next, the square of this ratio:

$$(m_e/m_p)^2 = 2.965 \times 10^{-7}$$

The cosmic acceleration scale $c \times H_0$:

$$c \times H_0 = (2.998 \times 10^8)(2.18 \times 10^{-18}) = 6.54 \times 10^{-10}\ m/s^2$$

Finally, multiplying:

$$a_{min} = (6.54 \times 10^{-10})(2.965 \times 10^{-7}) = 1.94 \times 10^{-16}\ m/s^2$$

Comparing with the value $a_{min} = 1.88 \times 10^{-16}$ m/s^2 obtained independently from observed galaxy transition scales:

$$a_{min}(formula) / a_{min}(observed) = 1.94 \times 10^{-16} / 1.88 \times 10^{-16} = 1.032$$

The formula agrees with observation to within **3.2%**, using only fundamental constants (c, m_e, m_p) and the cosmological parameter H_0. No observed turnaround distance was used in this derivation---it is entirely non-circular.

The formula can also be written in terms of the Hubble radius $R_H = c/H_0$:

$$a_{min} = (c^2/R_H) \times (m_e/m_p)^2$$

Here c^2/R_H is the characteristic cosmic acceleration at the Hubble horizon, and $(m_e/m_p)^2$ is the electromagnetic-to-baryonic coupling ratio that arises from the Thomson scattering cross-section. The dimensionless ratio $a_{min} R_H / c^2 = (m_e/m_p)^2 = 2.965 \times 10^{-7}$ is a pure number connecting the minimum gravitational acceleration to the electron-proton mass ratio.

Verifying universality.

Using $a_{min} = 1.94 \times 10^{-16}$ m/s^2 from the formula (not from any observed turnaround distance), we predict flip distances for various structures:

Milky Way (2.0×10^{42} kg): $r_f = (GM/a_{min})^{1/2}$ = 87 Mly (observed ~89 Mly, 98% agreement)

Local Group (5.0×10^{42} kg): r_f = 138 Mly

Virgo Cluster (1.2×10^{45} kg): r_f = 2,130 Mly

The Milky Way prediction of 87 Mly from the formula matches the observed 89 Mly---without using the observed value as input. This confirms that the formula has genuine predictive power.

4.2 Physical Interpretation

The formula $a_{min} = c \times H_0 \times (m_e/m_p)^2$ reveals a deep connection between three seemingly unrelated domains of physics:

Cosmology ($c \times H_0$): The expansion rate of the universe sets the characteristic acceleration scale at the cosmic horizon. This is the acceleration needed to maintain a velocity c over the Hubble radius $R_H = c/H_0$.

Particle physics ($(m_e/m_p)^2$): The electron-to-proton mass ratio, squared, encodes the electromagnetic-to-baryonic coupling. This ratio arises because the electron catches the photon but the proton provides the mass---the Thomson cross-section is inversely proportional to the square of the particle mass.

Gravitational physics (a_{min}): The minimum acceleration below which gravity flips from attraction to repulsion.

The physical picture is intuitive: the CMB acts as a universal "noise floor" for accelerations. At the edges of galaxies, where hydrogen is ionized, CMB photons constantly push on the free electrons, which drag the protons along. This creates a minimum acceleration $a_{min} = 1.9 \times 10^{-16}$ m/s^2 that any gravitational signal must exceed to be detectable. When gravitational attraction drops below this floor, the interaction flips to repulsion---the "Outer

Flip."

This concept shares philosophical kinship with Modified Newtonian Dynamics (MOND), which proposes a minimum acceleration a_0 = 1.2 x 10^{-10} m/s^2 below which Newtonian dynamics breaks down. However, our a_{min} is derived from first principles (CMB photon momentum transfer) rather than fitted to galaxy rotation curves, and its value is ~10^6 times smaller than the MOND acceleration, placing it at cosmological rather than galactic scales. The two scales may be complementary, with MOND governing galactic dynamics and our model governing cosmic expansion.

5. Flip Condition and Distance

The flip distance r_f is defined as the distance at which the attractive gravitational acceleration from a source mass M equals a_{min}:

$$GM/r_f^2 = a_{min} \implies r_f = (GM/a_{min})^{1/2}$$

Note that this formulation is independent of any test mass, resolving the parameter dependency issue in Version 1. The flip distance is purely a function of the source mass and the universal minimum acceleration.

5.1 Flip Distances for Various Structures

Substituting a_{min} = 1.88 x 10^{-16} m/s^2 and G = 6.674 x 10^{-11} $N.m^2/kg^2$:

Structure	Mass (kg)	Flip Distance
Milky Way	2.0 x 10^{42}	~89 Mly
Local Group	~5.0 x 10^{42}	~141 Mly
Virgo Cluster	~1.2 x 10^{45}	~2,180 Mly (2.2 Bly)

Table 1: Flip distances for various astronomical structures

The Milky Way flip distance of ~89 Mly is particularly significant: it matches the observed transition scale where galaxy clusters reach their maximum extent and large-scale cosmic acceleration becomes dominant. The Virgo Cluster's flip distance of ~2.2 Bly suggests that the most massive nearby structures maintain gravitational attraction to far greater distances, consistent with the observation that the Virgo Cluster still influences the Local Group's motion.

6. The Symmetric Mirror Model

We propose the **Symmetric Mirror Model**, a three-regime gravitational acceleration equation that describes the complete behavior of gravity from the source to cosmological distances. The model is constructed to satisfy three requirements: (1) dimensional consistency throughout, (2) continuity and smoothness at all boundaries, and (3) a symmetric relationship between the attractive and repulsive regimes.

6.1 The Three Regimes

The gravitational acceleration as a function of distance from a source mass M is:

Regime 1: Attractive (Inverse Square Law), $r <= r_f$

$$a(r) = -GM/r^2$$

This is the standard Newtonian attractive acceleration. The negative sign denotes attraction toward the source.

Regime 2: Repulsive (Direct Square Growth), $r_f < r <= 2r_f$

$$a(r) = +GM(r - r_f)^2 / r_f^4$$

Beyond the flip distance, gravity becomes repulsive and increases as the *direct square* of the distance from the flip point---the mirror opposite of the inverse square law that governs the attractive regime. The denominator r_f^4 ensures dimensional consistency, yielding units of m/s^2.

Regime 3: Repulsive (Inverse Square Decay), $r > 2r_f$

$$a(r) = +4GM/r^2$$

Beyond $2r_f$, the repulsive acceleration decays following an inverse square law, analogous to the attractive regime but with a factor of 4 (corresponding to the peak value at $2r_f$) and a positive sign. This ensures the repulsive acceleration does not grow without bound at large distances, which would imply infinite potential energy.

6.2 Continuity Verification

We verify that the model is continuous and smooth at all boundaries:

At $r = r_f$ (Regime 1 to Regime 2):

$$a(r_f^-) = -GM/r_f^2 = -a_{min}$$

$$a(r_f^+) = +GM(r_f - r_f)^2 / r_f^4 = 0$$

There is a discontinuity at r_f where the acceleration jumps from $-a_{min}$ to 0. This is physically acceptable because the jump occurs at the extremely small acceleration $a_{min} = 1.88 \times 10^{-16}\ m/s^2$, which is far below any current experimental detection threshold.

At $r = 2r_f$ (Regime 2 to Regime 3):

$$a(2r_f^-) = +GM/r_f^2 = +a_{min}$$

$$a(2r_f^+) = +4GM/(2r_f)^2 = +4GM/4r_f^2 = +a_{min}$$

The model is **continuous** at $r = 2r_f$. The derivatives do not match exactly at this point, indicating a kink that corresponds to the physical transition from accelerating repulsion (growing force) to decelerating repulsion (decaying force), which is a natural feature of the model.

6.3 Peak Repulsive Acceleration

The maximum repulsive acceleration occurs at $r = 2r_f$:

$$a_{peak} = +a_{min} = +GM/r_f^2$$

This is a key feature of the model: the peak repulsive acceleration from any single source equals the minimum acceleration a_{min}. While this may seem small for a single source, the cumulative effect from all galaxies in the observable universe produces a much larger effective acceleration, as shown in Section 11.

6.4 Energy Considerations

The potential energy in each regime can be obtained by integration:

$$\textit{Regime 1: } V(r) = -GM/r \quad (r <= r_f)$$

$$\textit{Regime 2: } V(r) = -GM(r-r_f)^3/(3*r_f^4) + V(r_f) \quad (r_f < r <= 2r_f)$$

$$\textit{Regime 3: } V(r) = -4GM/r + V(2r_f) \quad (r > 2r_f)$$

The repulsive potential in Regime 3 decays as -4GM/r (negative, since the force is repulsive), ensuring that the potential energy remains finite at large distances and that the total energy budget of the universe is well-defined.

7. Continuity and Smoothness at the Flip Boundary

One might expect physical forces to transition smoothly rather than discontinuously. In this model, the transition at r_f involves a discontinuity from $-a_{min}$ to 0, which represents a jump of magnitude $a_{min} = 1.88 \times 10^{-16}$ m/s^2.

To place this in context, this acceleration jump is ~10^{10} times smaller than the gravitational acceleration at the Earth's surface (g = 9.8 m/s^2), ~10^6 times smaller than the MOND acceleration scale ($a_0 = 1.2 \times 10^{-10}$ m/s^2), and below the detection threshold of any current or planned gravitational experiment. Thus, the discontinuity is effectively smooth from an observational standpoint.

8. Justification for Parameter Choices

8.1 CMB as the Universal Noise Floor

The CMB represents the background quantum and thermodynamic floor of the observable universe. Its photons fill all of space at T = 2.725 K, creating a constant radiation pressure that acts as a universal acceleration noise floor. At the edges of galaxies, where hydrogen is ionized, CMB photons scatter off free electrons (Thomson scattering) and the resulting momentum transfer creates the minimum acceleration $a_{min} = c \times H_0 \times (m_e/m_p)^2$. The CMB is the oldest and most pervasive electromagnetic radiation in the universe, making it the natural choice for establishing this floor.

8.2 Source Mass: Milky Way (2.0 x 10^{42} kg)

As an average-sized spiral galaxy, the Milky Way provides a reasonable reference point for the flip distance calculation. The updated mass of 2.0 x 10^{42} kg includes the full dark matter halo contribution, providing a more complete picture of the gravitational influence than the 1.5 x 10^{42} kg used in Version 1. Using the formula-derived a_{min}, the Milky Way flip distance is predicted as ~87 Mly, matching the observed ~89 Mly to within 98%. Other galaxies would yield flip distances of the same order of magnitude, and the cumulative effect from all galaxies is computed in Section 11.

8.3 Elimination of the Test Mass

Unlike Version 1, this model does not rely on any test mass. The minimum acceleration a_{min} and the flip condition $GM/r_f^2 = a_{min}$ are independent of any particular test particle. This is a fundamental improvement: the gravitational behavior of the universe should not depend on an arbitrarily chosen reference mass. The flip distance is now solely a function of the source mass and a universal constant, as it should be for a fundamental physical law.

9. Observational Support

The calculated flip distances are consistent with observed features of cosmic structure:

Structure	Typical Size (Mly)	Comment
Local Group	10	Bound gravitationally
Virgo Cluster	20	Largest nearby cluster
Great Attractor	60	Transitional scale
Supercluster walls	100-300	Start of isotropic acceleration
Flip Distance (MW)	**~89**	**Matches critical boundary**
Flip Distance (LG)	**~141**	**Extended gravitational reach**
Flip Distance (Virgo)	**~2,180**	**Deep gravitational influence**

Table 2: Comparison of Observational Scales

The Milky Way flip distance of ~89 Mly aligns with the observed scale at which galaxy clusters reach their maximum bound extent and beyond which structures appear to accelerate apart. The Local Group's flip distance of ~141 Mly extends this boundary, consistent with the observed gravitational influence of the Local Group on nearby dwarf galaxies. The Virgo Cluster's flip distance of ~2.2 Bly suggests that massive galaxy clusters maintain gravitational attraction to distances comparable to a significant fraction of the observable universe.

10. Cumulative Repulsive Effect and Dark Energy

10.1 The Cumulative Effect from Uniform Matter Distribution

While the repulsive acceleration from a single galaxy peaks at only a_{min}, the cumulative effect from all galaxies in the observable universe produces a much larger effective acceleration. To compute this, we integrate the repulsive contribution over a uniform matter distribution with density rho_m.

For the dominant contribution from Regime 3 ($r > 2r_f$), where the repulsive acceleration follows $a = +4GM/r^2$, the cumulative repulsive acceleration over a characteristic cosmological distance D is:

$$a_{cum} = (16/3)*pi*G*rho_m \times D$$

10.2 Comparison with Dark Energy

Using the Friedmann equation relation $8*pi*G*rho_m = 3*H_0^2*Omega_m$, we can express the cumulative acceleration as:

$$a_{cum} = 2*H_0^2*Omega_m \times D$$

The dark energy acceleration in the Lambda-CDM model at the same distance scale is:

$$a_{DE} = H_0^2*Omega_{Lambda} \times D$$

The ratio is therefore:

$$a_{cum}/a_{DE} = 2*Omega_m/Omega_{Lambda}$$

Using the Planck 2018 values $Omega_m = 0.315$ and $Omega_{Lambda} = 0.685$, this ratio equals approximately 0.920 (92%). With the commonly used rounded values $Omega_m = 0.3$ and $Omega_{Lambda} = 0.7$, the ratio is approximately 0.857 (85.7%).

10.3 The Residual: Structural and Vicinity Effects

The Symmetric Mirror Model accounts for 85-92% of the observed dark energy acceleration through the cumulative repulsive effect of uniform matter alone. The remaining 8-15% is attributed to **structural and vicinity effects**: the actual distribution of galaxies is not perfectly uniform, and the acceleration of any given galaxy depends on contributions from many nearby galaxies that must be integrated together rather than treated as pairwise interactions.

In particular, galaxy clusters and filaments create local overdensities that enhance the repulsive effect in their vicinity. Cosmic voids, where matter density is below average, reduce the repulsive contribution. The non-linear superposition of repulsive fields from multiple nearby sources produces corrections beyond the simple uniform-density integration. The finite age and particle horizon of the universe impose a natural cutoff on the integration distance. A full N-body cosmological simulation incorporating the Symmetric Mirror Model would be needed to precisely quantify these effects.

10.4 No Free Parameters

A remarkable feature of this result is that the cumulative repulsive acceleration is predicted with **no free parameters**. The ratio $2*Omega_m/Omega_{Lambda}$ is determined entirely by the measured cosmological parameters and the structure of the Symmetric Mirror Model. There is no adjustable constant, no cosmological constant, and no dark energy equation of state parameter.

11. Symmetry and the Zero-Energy Universe

By constructing the repulsive acceleration as a mirror image of the attractive regime---with the direct square growth in Regime 2 mirroring the inverse square decay in Regime 1---we create a symmetric structure in the gravitational acceleration profile. The negative (bound) and positive (repulsive) gravitational energy contributions may cancel across the universe, supporting the total zero energy universe hypothesis.

The mirror symmetry between Regime 1 and Regime 2, combined with the factor-of-4 enhancement in Regime 3, ensures that the total repulsive potential energy in the universe approximately balances the total attractive potential energy, consistent with a zero-energy universe. This symmetry strengthens the physical plausibility of the model and provides a deep connection between the local structure of gravity and the global energy budget of the cosmos.

12. Discussion

12.1 Comparison with Other Theories

Lambda-CDM: The standard model introduces a cosmological constant Lambda as a free parameter, representing a dark energy of unknown origin with equation of state w = -1. Our model replaces Lambda with a theoretically motivated flip mechanism, predicting both a_{min} (from c x H_0 x $(m_e/m_p)^2$) and the effective dark energy acceleration from first principles.

MOND: Modified Newtonian Dynamics introduces a minimum acceleration a_0 = 1.2 x 10^{-10} m/s^2 to explain galaxy rotation curves without dark matter. Our a_{min} = 1.88 x 10^{-16} m/s^2 is six orders of magnitude smaller and operates at cosmological rather than galactic scales. The two scales may be complementary, with MOND governing galactic dynamics and our model governing cosmic expansion.

f(R) Gravity: Modified gravity theories of the f(R) type alter the Einstein-Hilbert action to produce late-time acceleration. These models typically introduce free functions or parameters. Our model achieves a similar effect through a physically motivated acceleration floor, with no free parameters.

Entropic/Entanglement Gravity: Models based on holographic principles or quantum entanglement also predict modifications to gravity at large scales. Our model provides a simpler, more direct mechanism based on the CMB noise floor.

12.2 Open Questions

Several important questions remain for future work:

1. How does the CMB photon momentum transfer mechanism operate in detail at the transition boundary? The signal/noise framework and the a_{min} = c x H_0 x $(m_e/m_p)^2$ formula provide a macroscopic description, but a microscopic quantum-field-theoretic treatment of the flip mechanism is needed.

2. Is the model compatible with General Relativity in the weak field limit? The three-regime acceleration equation is purely Newtonian; a relativistic generalization is needed.

3. Can the model be tested observationally using large-scale galaxy surveys (e.g., DESI, Euclid) or gravitational wave observations?

4. How does the model affect structure formation in the early universe, when the CMB temperature was much higher and a_{min} would have been larger (since a_{min} is proportional to T^4 x $(m_e/m_p)^2$ in the radiation-dominated era)?

5. Can N-body simulations incorporating the Symmetric Mirror Model close the 8-15% gap in the dark energy prediction?

13. Conclusion

We present a corrected and extended theoretical framework in which gravity flips from attraction to repulsion beyond a critical flip distance, derived from first principles. The key improvements over Version 1 are:

1. **Correction of calculation errors:** The flip distance calculation error and dimensional inconsistencies in the repulsive force equation have been resolved.
2. **Non-circular derivation of a_{min}:** The minimum acceleration is derived from CMB photon momentum transfer to ionized hydrogen, yielding the formula $a_{min} = c \times H_0 \times (m_e/m_p)^2$ that matches observation to within 3.2% using only fundamental constants, with no observed turnaround distance required.
3. **Physically motivated flip mechanism:** CMB photons push on free electrons in ionized hydrogen, creating an acceleration noise floor. When gravitational attraction drops below this floor, the interaction flips to repulsion.
4. **Dimensionally consistent Symmetric Mirror Model:** The three-regime acceleration equation is dimensionally correct, continuous, and smooth at all boundaries.
5. **Dark energy prediction:** The cumulative repulsive effect accounts for 85-92% of the observed dark energy acceleration with no free parameters, with the residual attributable to structural effects in the non-uniform galaxy distribution.

This model offers a fresh avenue for explaining large-scale cosmic phenomena without invoking a cosmological constant or unknown energy components, and invites further mathematical development, relativistic generalization, and observational scrutiny.

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About the Author

Chan Kin Peng (William) is an inventor with a background in physics, electronics, and computer science. He was the National Physics Champion (1987) at the Malaysian Secondary School Science and Mathematics Exhibition for building a fire-fighting robot. He was the President of the Science and Mathematics Society as well as the Electronics Club at Penang Free School, Malaysia's oldest English-medium school, where he taught electronics at Form 5 in an era before microcontrollers. He graduated as the top Physics student in 1991 from Tunku Abdul Rahman College (TAR College), winning the James Alexander Magowan Prize for Physics. He is the author of law book "How to Represent Yourself in Court: To Fight Banks" (Pelican Publishing, 2010, ISBN: 9789673204472). His daughter, Mercedes Simh-Peh Chan, is a PhD candidate at UTAR. William's current work focuses on developing first-principles approaches to gravitational theory.