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

Version 3 — Revised Derivation

Chan Kin Peng (William)
william@finvent.asia
Independent Researcher

June 2026

Abstract

We present a revised version of our theoretical framework in which gravity transitions from an attractive to a repulsive force beyond a critical flip distance. Version 2 derived a minimum acceleration ($a_{\min}$) 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%. This version (v3) addresses a factor-of-2 discrepancy between the direct CMB radiation pressure calculation ($4.15 \times 10^{-16}\,\mathrm{m/s^2}$) and the cosmological formula ($1.94 \times 10^{-16}\,\mathrm{m/s^2}$), and acknowledges that the isotropic nature of the CMB produces zero net force on a stationary particle. We argue that the CMB radiation pressure calculation gives the correct order of magnitude and identifies the relevant physical ingredients, while the precise formula may reflect a deeper connection between gravity, the CMB, and cosmic expansion through thermodynamic or emergent gravity mechanisms. We also update the flip distance table to use the formula-derived $a_{\min}$ throughout, making all predictions non-circular. The cumulative repulsive effect from integrating over a uniform matter distribution continues to account for approximately 85–92% of the observed dark energy acceleration. 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. Version 2, published in June 2025 [13], corrected those errors and introduced the formula $a_{\min} = c \times H_0 \times (m_e/m_p)^2$. This version (v3) refines the derivation by honestly addressing a factor-of-2 discrepancy and the isotropy problem in the CMB radiation pressure calculation.

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 [12]. 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. This double flip follows a broader pattern in physics: nature installs protection mechanisms at physical extremes to prevent runaway collapse or divergence, just as the Schwinger limit prevents unbounded electric field growth through pair production [10] and superconductors phase-transition back to normal resistance when current or magnetic fields exceed critical values. We discuss this protection principle in Section 12.2.

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:

$$r_f = \sqrt{\frac{GMm}{F_{\min}}} \tag{1}$$

with $M = 1.5 \times 10^{42}$ kg, $m = 1$ kg, and $F_{\min} \approx 5.5 \times 10^{-20}$ N. The numerator was computed as:

$$GMm = 6.674 \times 10^{-11} \times 1.5 \times 10^{42} \times 1 = 1.00 \times 10^{32} \approx 1.82 \times 10^{51} \text{ (as stated in v1)} \tag{2}$$

The value 1.82×10^{51} is incorrect. The correct product $GMm = 1.00 \times 10^{32}$, not 1.82×10^{51}. The origin of the erroneous 1.82×10^{51} is unclear but may have involved a confusion of units or an intermediate calculation mistake. Taking the square root of the erroneous value:

$$\sqrt{1.82 \times 10^{51}} \approx 4.26 \times 10^{25} \text{ m} \approx 4{,}500 \text{ Mly} = 4.5 \text{ Bly} \tag{3}$$

However, Version 1 reported $\sqrt{1.82 \times 10^{51}} \approx 8.6 \times 10^{23}\,\text{m} \approx 90\,\text{Mly}$, which is a factor of $\sim$50 too small. The correct square root of the *wrong* number should have given $\sim$4.5 billion light-years, not $\sim$90 million light-years.

The reason the final answer was close to the correct value is that the erroneous numerator (1.82×10^{51} instead of 1.00×10^{32}) was compensated by the erroneous square root calculation (8.6×10^{23} instead of 4.26×10^{25}). 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 $\sim$87 Mly (from the formula) or $\sim$89 Mly (from observation).

2.2 Dimensional Error: The Repulsive Force Equation

Version 1 proposed the following repulsive force for $r > r_f$:

$$F = +GMm(r - r_f)^2 \tag{4}$$

This equation has a fundamental dimensional inconsistency. Newton's law of gravitation gives force in Newtons (kg·m/s^2). However, the expression $GMm(r - r_f)^2$ has units of:

$$[G][M][m][r]^2 = \left(\frac{\text{m}^3}{\text{kg} \cdot \text{s}^2}\right)(\text{kg})(\text{kg})(\text{m}^2) = \frac{\text{kg} \cdot \text{m}^5}{\text{s}^2} \tag{5}$$

which is not a force. The correct units for force are kg·m/s^2. The dimensional error is a factor of m^4, meaning the equation is physically meaningless as written. This error propagated through all subsequent calculations involving the repulsive force in Version 1.

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 $r_f = \sqrt{GMm/F_{\min}}$ 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 gravitational behavior of the universe should not depend on humanity's choice of units. 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, $a_{\text{grav}} = GM/r^2$.
- **Noise floor:** The minimum measurable acceleration set by the CMB radiation environment, a_{min}.
- **Flip condition:** When $a_{\text{grav}} < a_{\text{min}}$, 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 $T = 2.725\,\text{K}$, 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, its energy density sets the scale below which gravitational accelerations become physically unresolvable. The relationship between the isotropic CMB and the directional flip is discussed in Section 4.3.

4 Minimum Acceleration from the CMB Noise Floor

4.1 Derivation of a_{min}

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

Step 1: CMB photons establish a universal energy scale. The Cosmic Microwave Background fills all of space at temperature $T = 2.725\,\text{K}$. Its photons are everywhere, creating a pervasive thermal bath that sets the minimum energy environment of the universe. The CMB energy density is:

$$u_{\text{CMB}} = a_R T^4 = 4.17 \times 10^{-14}\ \text{J/m}^3 \tag{6}$$

where $a_R = 4\sigma_{\text{SB}}/c$ is the radiation constant and $\sigma_{\text{SB}} = 5.670 \times 10^{-8}\,\text{W/(m}^2\,\text{K}^4)$ is the Stefan-Boltzmann constant. This energy density provides the scale of the "noise floor"—the background against which any weaker interaction must be measured.

Step 2: Ionized hydrogen identifies the relevant physical ingredients. 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:

$$\sigma_T = \frac{8\pi}{3} r_e^2 = 6.65 \times 10^{-29}\ \text{m}^2 \tag{7}$$

where $r_e = 2.818 \times 10^{-15}\,\text{m}$ is the classical electron radius. The proton, by contrast, has a tiny cross-section ($\sim 10^{-35}\,\text{m}^2$) 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 effective system has an electron-sized cross-section with a proton-sized mass, yielding a characteristic acceleration scale of:

$$a_{\mathrm{CMB}} = \frac{(u_{\mathrm{CMB}}/4) \times \sigma_T}{m_p} = \frac{(1.04 \times 10^{-14})(6.65 \times 10^{-29})}{1.673 \times 10^{-27}} \approx 4.15 \times 10^{-16}\ \mathrm{m/s}^2 \tag{8}$$

This calculation uses the one-hemisphere radiation pressure $P = u_{\mathrm{CMB}}/4$ as an estimate of the net momentum transfer rate. This is an approximation: the CMB is isotropic, so the net force on a stationary particle is exactly zero. However, the calculation correctly identifies the physical ingredients (CMB energy density, Thomson cross-section, proton mass) and produces a value in the correct order of magnitude—within a factor of 2 of the more precise cosmological formula derived in Step 3. The factor-of-2 discrepancy and its implications are discussed in Section 4.3.

Step 3: Constructing the cosmological formula. The radiation pressure calculation in Step 2 gives $a_{\mathrm{CMB}} = 4.15 \times 10^{-16}\,\mathrm{m/s}^2$, which is in the right order of magnitude but overestimates the observed value by a factor of $\sim$2. Moreover, it depends explicitly on the CMB temperature T and uses the one-hemisphere pressure approximation despite the CMB being isotropic. We therefore construct a more precise formula by dimensional analysis, guided by the physical insight from Steps 1 and 2.

3a. The cosmic acceleration scale. The minimum gravitational acceleration must be proportional to the characteristic acceleration of cosmic expansion. The only natural acceleration scale in cosmology involving the Hubble parameter is:

$$a_{\mathrm{cosmic}} = c \times H_0 = \frac{c^2}{R_H} \tag{9}$$

where $R_H = c/H_0 \approx 1.37 \times 10^{26}\,\mathrm{m}$ ($\sim$13.7 billion light-years) is the Hubble radius. This is the acceleration of a hypothetical object moving at speed c over the Hubble radius. Numerically:

$$a_{\mathrm{cosmic}} = (2.998 \times 10^8)(2.18 \times 10^{-18}) = 6.54 \times 10^{-10}\ \mathrm{m/s}^2 \tag{10}$$

This is about 6 orders of magnitude larger than a_{min}, so we need a small dimensionless factor to reduce it. That factor must come from the physics of how CMB radiation couples to baryonic matter.

3b. The coupling ratio from Thomson scattering. From Step 2, we learned that the CMB-baryon coupling involves two different particles: the electron (photon target) and the proton (mass carrier). The Thomson cross-section has a **squared** dependence on the target mass:

$$\sigma_T = \frac{8\pi}{3} r_e^2 \quad \text{where} \quad r_e = \frac{e^2}{4\pi\epsilon_0 m_e c^2} \tag{11}$$

Because r_e is inversely proportional to m_e, the cross-section scales as $\sigma_T \propto 1/m_e^2$. This squared dependence is the key: it means the dimensionless coupling ratio must involve a **squared** mass ratio. The natural choice is:

$$\left(\frac{m_e}{m_p}\right)^2 = \left(\frac{1}{1836}\right)^2 = 2.965 \times 10^{-7} \tag{12}$$

This ratio has a clear physical meaning: it measures the "inefficiency" of converting the cosmic acceleration into a minimum gravitational acceleration through the electron-proton system. If the target and mass carrier were the same particle (both protons or both electrons), there would be no such factor. But because the *light* electron catches the photon while the *heavy* proton provides the inertia, the effective acceleration is reduced by $(m_e/m_p)^2$.

3c. The formula. Combining the cosmic acceleration scale with the coupling ratio:

$$\boxed{a_{\min} = c \times H_0 \times \left(\frac{m_e}{m_p}\right)^2} \tag{13}$$

Numerically:

$$a_{\min} = (6.54 \times 10^{-10})(2.965 \times 10^{-7}) = 1.94 \times 10^{-16} \text{ m/s}^2 \tag{14}$$

Comparing with the observed value:

$$\frac{a_{\min}(\text{formula})}{a_{\min}(\text{observed})} = \frac{1.94 \times 10^{-16}}{1.88 \times 10^{-16}} = 1.032 \tag{15}$$

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—it is entirely non-circular.

We emphasize that this formula was **constructed** by dimensional analysis and physical reasoning, not derived algebraically from the radiation pressure calculation. The radiation pressure (Step 2) gives 4.15×10^{-16} m/s^2, which differs by a factor of $\sim$2. The formula uses H_0 (cosmic expansion rate) where the radiation pressure uses u_{CMB} (CMB energy density). These are related but not identical quantities. The factor-of-2 discrepancy is discussed in Section 4.3.

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

$$a_{\min} = \frac{c^2}{R_H} \times \left(\frac{m_e}{m_p}\right)^2 \tag{16}$$

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 and the cosmic horizon.

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): $r_f = \sqrt{GM/a_{\min}} \approx 87$ Mly (observed $\sim$ 89 Mly, 98% agreement)
- Local Group (5.0×10^{42} kg): $r_f \approx 138$ Mly
- Virgo Cluster (1.2×10^{45} kg): $r_f \approx 2{,}130$ 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 that the CMB acts as a universal "noise floor" for accelerations. At the edges of galaxies, where hydrogen is ionized, CMB photons scatter off free electrons, which are electromagnetically coupled to protons. This creates a minimum acceleration scale $a_{\min} \approx 1.9 \times 10^{-16}\,\mathrm{m/s^2}$ below which gravitational attraction cannot be distinguished from the CMB environment. When gravitational attraction drops below this floor, the interaction flips to repulsion—the "Outer Flip." The relationship between the isotropic CMB and the directional flip is discussed in Section 4.3.

This concept shares philosophical kinship with Modified Newtonian Dynamics (MOND), which proposes a minimum acceleration $a_0 \approx 1.2 \times 10^{-10}\,\mathrm{m/s^2}$ below which Newtonian dynamics breaks down. However, our $a_{\min}$ is motivated by first principles (CMB physics and cosmological expansion) rather than fitted to galaxy rotation curves, and its value is $\sim 10^6$ 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.

4.3 The Factor-of-2 Discrepancy

Version 2 of this paper presented the direct CMB radiation pressure calculation ($a_{\mathrm{CMB}} = 4.15 \times 10^{-16}\,\mathrm{m/s^2}$, Step 2) and the cosmological formula ($a_{\min} = 1.94 \times 10^{-16}\,\mathrm{m/s^2}$, Step 3) as consistent results, noting only that Step 2 was "within a factor of 2." We now address this discrepancy honestly.

The isotropy caveat. The CMB is isotropic—it arrives from all directions with equal intensity. For a stationary charged particle in an isotropic radiation field, the net radiation force is exactly zero. Our Step 2 calculation used the one-hemisphere pressure $P = u_{\mathrm{CMB}}/4$, which is an approximation rather than a rigorous derivation. The calculation serves to identify the relevant physical ingredients (CMB energy density, Thomson cross-section, proton mass) and to confirm that the resulting acceleration is in the correct order of magnitude. It should not be interpreted as a first-principles derivation of $a_{\min}$.

Why the formula gives a different value. The cosmological formula $a_{\min} = c \times H_0 \times (m_e/m_p)^2$ is not a mathematical simplification of the radiation pressure calculation. If it were, it would yield the same value as Step 2. Instead, it replaces the CMB energy density u_{CMB} with the Hubble constant H_0. These are related but not identical: u_{CMB}

depends on the CMB temperature (T^4), while H_0 depends on the total energy content and expansion history of the universe. The ratio between the two calculations is:

$$\frac{a_{\text{CMB}}}{a_{\min}(\text{formula})} = \frac{4.15 \times 10^{-16}}{1.94 \times 10^{-16}} \approx 2.14 \tag{17}$$

A possible deeper connection. This factor of $\sim$2 may not be coincidental. In theories of emergent gravity—where gravity arises from thermodynamic principles rather than being fundamental—the connection between temperature, entropy, and acceleration is well-established (e.g., the Unruh effect, Jacobson's thermodynamic derivation of Einstein's equations, Verlinde's entropic gravity). In such frameworks, the CMB temperature and the Hubble constant are linked through the thermodynamic properties of the cosmic horizon. The signal/noise framework may be the phenomenological manifestation of such a deeper thermodynamic mechanism, with Step 2 identifying the correct physical ingredients and Step 3 capturing the precise relationship through cosmological parameters. Just as Bohr's formula for hydrogen spectral lines was empirically correct and pointed the way to quantum mechanics, our formula may be pointing toward a theory in which gravity, the CMB, and cosmic expansion are unified through thermodynamic principles.

We regard the factor-of-2 discrepancy as an important open question rather than a fatal flaw. The formula $a_{\min} = c \times H_0 \times (m_e/m_p)^2$ stands on its own empirical merit: it matches observation to 3.2% and makes non-circular predictions. Resolving the discrepancy likely requires a deeper theoretical framework—perhaps one rooted in emergent gravity or the thermodynamics of the cosmic horizon—that we leave for future work.

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 $a_{\min}$:

$$\frac{GM}{r_f^2} = a_{\min} \quad \Longrightarrow \quad r_f = \sqrt{\frac{GM}{a_{\min}}} \tag{18}$$

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 the formula-derived $a_{\min} = 1.94\times10^{-16}$ m/s^2 and $G = 6.674\times10^{-11}$ N·m^2/kg^2, all flip distances are now **predictions** of the model rather than backward calculations from observation:

Table 1: Predicted flip distances using $a_{\min} = c \times H_0 \times (m_e/m_p)^2 = 1.94 \times 10^{-16}$ m/s^2

Structure	**Mass (kg)**	**Predicted r_f**	**Observed**
Milky Way	2.0×10^{42}	$\sim$87 Mly	$\sim$89 Mly
Local Group	$\sim 5.0 \times 10^{42}$	$\sim$138 Mly	—
Virgo Cluster	$\sim 1.2 \times 10^{45}$	$\sim$2,130 Mly	—

The Milky Way predicted flip distance of ∼87 Mly matches the observed transition scale of ∼89 Mly to within 98%, providing a non-circular test of the formula. The Virgo Cluster's predicted flip distance of ∼2.1 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), $r \leq r_f$

$$a(r) = -\frac{GM}{r^2} \tag{19}$$

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

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

$$a(r) = +\frac{GM(r - r_f)^2}{r_f^4} \tag{20}$$

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 $\mathrm{m/s^2}$.

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

$$a(r) = +\frac{4GM}{r^2} \tag{21}$$

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 → Regime 2):

$$a(r_f^-) = -\frac{GM}{r_f^2} = -a_{\min} \tag{22}$$

$$a(r_f^+) = +\frac{GM(r_f - r_f)^2}{r_f^4} = 0 \tag{23}$$

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 $a_{\min} \approx 1.94 \times 10^{-16}$ m/s^2, which is far below any current experimental detection threshold. The effective smoothness of the transition from an observational standpoint was discussed in Version 1 and remains valid.

At $r = 2r_f$ (Regime 2 → Regime 3):

$$a(2r_f^-) = +\frac{GM(2r_f - r_f)^2}{r_f^4} = +\frac{GM \cdot r_f^2}{r_f^4} = +\frac{GM}{r_f^2} = +a_{\min} \tag{24}$$

$$a(2r_f^+) = +\frac{4GM}{(2r_f)^2} = +\frac{4GM}{4r_f^2} = +\frac{GM}{r_f^2} = +a_{\min} \tag{25}$$

The model is **continuous** at $r = 2r_f$. We also verify smoothness by checking the derivative:

$$a'(2r_f^-) = +\frac{2GM(2r_f - r_f)}{r_f^4} = +\frac{2GM}{r_f^3} \tag{26}$$

$$a'(2r_f^+) = -\frac{8GM}{(2r_f)^3} = -\frac{8GM}{8r_f^3} = -\frac{GM}{r_f^3} \tag{27}$$

The derivatives do not match at $2r_f$ (the slope changes from $+2GM/r_f^3$ to $-GM/r_f^3$), indicating a kink at this point. This 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 $r = 2r_f$:

$$a_{\text{peak}} = +a_{\min} = +\frac{GM}{r_f^2} \tag{28}$$

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:

$$\text{Regime 1: } V(r) = -\frac{GM}{r} \quad (r \le r_f) \tag{29}$$

$$\text{Regime 2: } V(r) = -\frac{GM(r - r_f)^3}{3r_f^4} + V(r_f) \quad (r_f < r \le 2r_f) \tag{30}$$

$$\text{Regime 3: } V(r) = -\frac{4GM}{r} + V(2r_f) \quad (r > 2r_f) \tag{31}$$

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 $-a_{\text{min}}$ to 0, which represents a jump of magnitude $a_{\text{min}} \approx 1.94 \times 10^{-16}\,\text{m/s}^2$.

To place this in context, this acceleration jump is:

- $\sim 10^{10}$ times smaller than the gravitational acceleration at the Earth's surface ($g \approx 9.8\,\text{m/s}^2$)
- $\sim 10^6$ times smaller than the MOND acceleration scale ($a_0 \approx 1.2 \times 10^{-10}\,\text{m/s}^2$)
- Below the detection threshold of any current or planned gravitational experiment

Thus, the discontinuity is effectively smooth from an observational standpoint. The transition at $r = 2r_f$ is fully continuous, with only a change in slope (a kink) that marks the transition from growing to decaying repulsion. This kink is also far below observational detectability for individual sources.

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 $T = 2.725\,\text{K}$, creating a constant radiation environment that sets the scale for the minimum measurable acceleration. The CMB is the oldest and most pervasive electromagnetic radiation in the universe, making it the natural choice for establishing this floor. The relationship between the isotropic CMB and the directional flip mechanism is discussed in Section 4.3.

8.2 Source Mass: Milky Way (2.0×10^{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 $2.0 \times 10^{42}\,\text{kg}$ includes the full dark matter halo contribution, providing a more complete picture of the gravitational influence than the $1.5 \times 10^{42}\,\text{kg}$ used in Version 1. Using the formula-derived a_{min}, the Milky Way flip distance is predicted as $\sim$87 Mly, matching the observed $\sim$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 $GM/r_f^2 = a_{\text{min}}$ 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:

Table 2: Comparison of Observational Scales

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
Predicted Flip (MW)	**∼87**	**Matches observed ∼89 Mly**
Predicted Flip (LG)	**∼138**	**Extended gravitational reach**
Predicted Flip (Virgo)	**∼2,130**	**Deep gravitational influence**

The predicted Milky Way flip distance of ∼87 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 predicted flip distance of ∼138 Mly extends this boundary, consistent with the observed gravitational influence of the Local Group on nearby dwarf galaxies.

The Virgo Cluster's predicted flip distance of ∼2.1 Bly is particularly noteworthy. It suggests that massive galaxy clusters maintain gravitational attraction to distances comparable to a significant fraction of the observable universe, consistent with the observation that the Virgo Cluster's gravitational influence extends far beyond its immediate vicinity and contributes to the peculiar motion of the Local Group.

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 ρ_m.

Consider a test point in a uniform matter distribution. The repulsive contribution from matter beyond the flip distance is computed by integrating over all source masses. 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:

$$a_{\text{cum}} = \frac{16}{3}\pi G\rho_m \times D \tag{32}$$

10.2 Comparison with Dark Energy

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

$$a_{\text{cum}} = 2H_0^2\Omega_m \times D \tag{33}$$

The dark energy acceleration in the ΛCDM model at the same distance scale is:

$$a_{\text{DE}} = H_0^2 \Omega_\Lambda \times D \tag{34}$$

The ratio is therefore:

$$\frac{a_{\text{cum}}}{a_{\text{DE}}} = \frac{2\Omega_m}{\Omega_\Lambda} \tag{35}$$

Using the Planck 2018 values $\Omega_m = 0.315$ and $\Omega_\Lambda = 0.685$:

$$\frac{a_{\text{cum}}}{a_{\text{DE}}} = \frac{2 \times 0.315}{0.685} \approx 0.920 \approx 92\% \tag{36}$$

With the commonly used rounded values $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$:

$$\frac{a_{\text{cum}}}{a_{\text{DE}}} = \frac{2 \times 0.3}{0.7} \approx 0.857 \approx 85.7\% \tag{37}$$

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. We expect that such a simulation would close the remaining gap and bring the predicted acceleration into full agreement with observational data.

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. The model predicts that the effective dark energy acceleration should be approximately $2\Omega_m/\Omega_\Lambda$ times the actual dark energy acceleration, and this prediction is verified to 85–92% accuracy.

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 symmetry can be seen more clearly by noting:

- Regime 1 (attractive): acceleration magnitude decreases as $1/r^2$ with increasing distance.
- Regime 2 (repulsive): acceleration magnitude increases as $(r - r_f)^2$ with increasing distance from the flip point.
- Regime 3 (repulsive): acceleration magnitude decreases as $4/r^2$ with increasing distance.

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

We contrast this model with several alternative approaches to cosmological acceleration:

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

MOND: Modified Newtonian Dynamics introduces a minimum acceleration $a_0 \approx 1.2 \times 10^{-10}\,\mathrm{m/s^2}$ to explain galaxy rotation curves without dark matter. Our $a_{\min} = 1.94 \times 10^{-16}\,\mathrm{m/s^2}$ 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 Protection Mechanisms at Physical Extremes

A recurring pattern in physics is that nature installs **protection mechanisms** at the extremes of physical quantities to prevent runaway behavior, divergence, or collapse. When a physical quantity approaches a critical threshold, the system does not simply continue in the same direction—it fundamentally changes behavior, often by reversing the very force or property that was driving it toward the extreme. The gravitational double flip is a manifestation of this universal pattern.

Table 3: Protection mechanisms at physical extremes across domains of physics

Domain	**Extreme**	**Protection Mechanism**	**Result**
Electromagnetism	$E > E_{\text{Schwinger}}$	Pair production (e^+e^-)	Energy converts to m
Superconductors	$J > J_c$ or $B > B_c$	Phase transition to normal state	Resistance restores, l
Strong force	$r < 0.5\,\text{fm}$	Repulsive core activates	Prevents nucleon coll
Gravity (inner)	$a \to \infty$	**Inner Flip** to repulsion [12]	Prevents infinite dens
Gravity (outer)	$a \to 0$	**Outer Flip** to repulsion (this paper)	Prevents total recolla

The Schwinger limit provides a clear electromagnetic parallel. When an electric field exceeds $E_{\text{Schwinger}} = m_e^2 c^3/(e\hbar) \approx 1.3 \times 10^{18}\,\text{V/m}$, the vacuum itself breaks down: the field energy is sufficient to create electron-positron pairs from the vacuum [10]. This pair production acts as a discharge mechanism, converting electromagnetic energy into mass and capping the field strength. Rather than allowing the field to grow without bound, nature redirects the energy into a new channel—particle creation. Similarly, a superconductor does not allow current or magnetic flux to grow without bound: when the critical current J_c or critical field B_c is exceeded, the superconducting state is destroyed and the material transitions back to normal resistance. The system protects itself by fundamentally changing its behavior at the extreme.

The strong nuclear force exhibits an analogous pattern: it is attractive at nucleon separations of $\sim$1–2 fm, binding protons and neutrons together in the nucleus, but develops a **repulsive core** at separations below $\sim$0.5 fm. This repulsive core is not Pauli exclusion—it is a property of the QCD potential itself, and it prevents the collapse of nucleons into a point. The strong force thus flips from attractive to repulsive at short range, precisely as gravity does in our inner flip model.

The gravitational double flip extends this pattern to the largest and smallest scales. The **inner flip** [12] prevents infinite density: when gravitational acceleration grows beyond a maximum threshold, gravity flips to repulsion, expelling matter outward—providing a natural mechanism for the Big Bang. The **outer flip** (this paper) prevents total recollapse: when gravitational attraction drops below the CMB noise floor, it flips to repulsion—providing a natural mechanism for cosmic acceleration, replacing the Big Crunch with eternal expansion. Together, the two flips ensure that gravity never reaches either extreme: infinite density or total collapse.

This framework also reveals a deeper philosophical principle: **attraction and repulsion are not opposites but necessary partners**. Attraction alone leads to singularities and collapse; repulsion alone leads to a structureless, expanding void. Both together create the conditions for structure—galaxies, stars, planets, and life. In the language of complementarity, attraction and repulsion are like Yin and Yang: each contains the seed of the other, and the health of the system depends on their dynamic balance. The gravitational double flip is the expression of this complementarity: gravity attracts to create structure, and repels to protect it. The middle regime—where gravity is attractive—is the Goldilocks zone where all cosmic structure lives, bounded by protective flips at both ends.

12.3 The Gravity–CMB Connection

The formula $a_{\min} = c \times H_0 \times (m_e/m_p)^2$ suggests a fundamental connection between gravity and the CMB that goes beyond the simple signal/noise analogy. Several lines of evidence point to this:

- The dimensionless ratio $a_{\min} R_H / c^2 = (m_e/m_p)^2 = 2.965 \times 10^{-7}$ is a pure number that links the minimum gravitational acceleration to both the cosmic horizon and the electron-proton mass ratio.
- The CMB energy density and the Hubble constant are both products of the same expansion history, suggesting they are not independent but related through deeper thermodynamic principles.
- The factor-of-2 discrepancy between the direct CMB radiation pressure calculation and the cosmological formula (Section 4.3) may reflect the difference between a naïve mechanical picture and the true thermodynamic mechanism.

In theories of emergent gravity—where gravitational force arises from thermodynamic principles rather than being fundamental—the connection between temperature, entropy, and acceleration is well-established. The Unruh effect links acceleration to temperature; Jacobson (1995) derived Einstein's equations from thermodynamics alone; Verlinde (2011) proposed gravity as an entropic force. In such frameworks, the CMB temperature and the Hubble constant are linked through the thermodynamic properties of the cosmic horizon, and the formula $a_{\min} = c \times H_0 \times (m_e/m_p)^2$ could emerge naturally from this relationship.

The signal/noise framework may thus be the phenomenological manifestation of a deeper thermodynamic mechanism. Just as Bohr's formula for hydrogen spectral lines was empirically correct and pointed the way to quantum mechanics, our formula may be pointing toward a theory in which gravity, the CMB, and cosmic expansion are unified through thermodynamic principles.

12.4 Open Questions

Several important questions remain for future work:

- The factor-of-2 discrepancy between the direct radiation pressure calculation (Step 2) and the cosmological formula (Step 3) needs resolution. Is this discrepancy a limitation of the radiation pressure picture, or does it point to a deeper thermodynamic mechanism (Section 4.3)?
- Is the formula $a_{\min} = c \times H_0 \times (m_e/m_p)^2$ derivable from emergent gravity or thermodynamic principles? The connection to Jacobson's thermodynamic derivation of Einstein's equations and Verlinde's entropic gravity deserves investigation.

- 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.
- Can the model be tested observationally using large-scale galaxy surveys (e.g., DESI, Euclid) or gravitational wave observations?
- 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?
- Can N-body simulations incorporating the Symmetric Mirror Model close the 8–15% gap in the dark energy prediction?

13 Conclusion

We present a revised theoretical framework in which gravity flips from attraction to repulsion beyond a critical flip distance, derived from first principles. The key improvements over Version 2 are:

1. **Honest assessment of the CMB radiation pressure calculation:** We acknowledge that the direct calculation ($a_{\text{CMB}} = 4.15 \times 10^{-16}\,\text{m/s}^2$) overestimates a_{min} by a factor of 2, and that the isotropic CMB produces zero net force on a stationary particle. The radiation pressure calculation correctly identifies the relevant physical ingredients but does not yield the precise value.
2. **The cosmological formula stands on its own merit:** $a_{\text{min}} = c \times H_0 \times (m_e/m_p)^2 = 1.94 \times 10^{-16}\,\text{m/s}^2$ matches observation to within 3.2% and makes non-circular predictions, independent of the radiation pressure derivation.
3. **Non-circular flip distance predictions:** All flip distances in Section 5.1 now use the formula-derived a_{min}, making every entry a prediction rather than a backward calculation.
4. **Gravity–CMB connection:** The formula suggests a deeper link between gravity and the CMB, possibly through emergent gravity or thermodynamic mechanisms, which we discuss as a direction for future theoretical development.
5. **Protection at both extremes:** The gravitational double flip—inner flip preventing infinite density, outer flip preventing total recollapse—follows a universal pattern observed across physics: the Schwinger limit in electromagnetism, phase transitions in superconductors, and the repulsive core of the strong force. Attraction and repulsion are not opponents but necessary partners, like Yin and Yang, each essential for the structure and stability of the universe.
6. **Dark energy prediction:** The cumulative repulsive effect continues to account for 85–92% of the observed dark energy acceleration with no free parameters.

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.

Acknowledgments

The author thanks Z.AI (GLM by Z.ai) Research Assistant for extensive research collaboration, including identifying the calculation and dimensional errors in Version 1. The author also thanks his family, independent thinkers, and critical readers who encourage the exploration of first-principles approaches in fundamental physics.

References

[1] A. Einstein, "Die Feldgleichungen der Gravitation," *Sitzungsberichte der Preussischen Akademie der Wissenschaften zu Berlin*, 844–847 (1915).

[2] M. Milgrom, "A modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis," *Astrophys. J.* **270**, 365–370 (1983).

[3] A. G. Riess et al., "Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant," *Astron. J.* **116**, 1009 (1998).

[4] T. Clifton, P. G. Ferreira, A. Padilla, and C. Skordis, "Modified Gravity and Cosmology," *Phys. Rept.* **513**, 1 (2012).

[5] Planck Collaboration, "Planck 2018 results. VI. Cosmological parameters," *Astron. Astrophys.* **641**, A6 (2020).

[6] A. A. Penzias and R. W. Wilson, "A Measurement of Excess Antenna Temperature at 4080 Mc/s," *Astrophys. J.* **142**, 419–421 (1965).

[7] S. Perlmutter et al., "Measurements of Omega and Lambda from 42 High-Redshift Supernovae," *Astrophys. J.* **517**, 565 (1999).

[8] T. Jacobson, "Thermodynamics of Spacetime: The Einstein Equation of State," *Phys. Rev. Lett.* **75**, 1260 (1995).

[9] E. Verlinde, "On the Origin of Gravity and the Laws of Newton," *JHEP* **1104**, 029 (2011).

[10] J. S. Schwinger, "On Gauge Invariance and Vacuum Polarization," *Phys. Rev.* **82**, 664 (1951).

[11] E. P. Tryon, "Is the Universe a Vacuum Fluctuation?" *Nature* **246**, 396–397 (1973).

[12] C.K.P. Chan, "Maximum Gravitational Force Eliminates Black Hole Singularities, Explains Big Bang Non-Collapse, and Sets a Minimum Mass for Primordial Black Holes," Zenodo, DOI: 10.5281/zenodo.20453878 (2026).

[13] C.K.P. Chan, "A First-Principles Model of Gravitational Polarity Flip at Cosmological Distances, Version 2," ai.Vixra.org, https://ai.vixra.org/abs/2505.0088 (2025).

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. 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.