

Abstract

Dimensional analysis of the gravitational constant derived from vacuum electromagnetic properties yields $G = c^4 \times 7.5 \times \varepsilon_0^3 \times \mu_0^2$ with amperes squared (A^2) appearing in the numerator—units absent from the standard definition $G = m^3/(kg \cdot s^2)$. Since the kilogram is *defined* via Kibble balance (an electromagnetic measurement), electromagnetic units naturally appear when deriving gravitational coupling from vacuum properties.

This dimensional mismatch reveals a deeper issue: SI treats mass and energy as independent, but $E = mc^2$ and $E = \hbar\omega$ establish their equivalence. Mass relates to frequency through $m = \hbar\omega/c^2$. One kilogram corresponds to $\omega = 8.52 \times 10^{50}$ rad/s. The vector frame imperivity $VF_0 = 1/\varepsilon_0 = 1.129 \times 10^{11}$ m/F provides the scaling: $G \approx 7.5/VF_0 \approx 10^{-11}$.

Photon-based cosmological distances assume constant light speed. Wave packet propagation through vacuum impedance yields $d_{\text{true}} = (c/H_0) \ln(1+z)$ instead of $d = cz/H_0$. The correction factor $[\ln(1+z)/z]^2$ applied to published distances addresses systematic offsets in Cepheid, TRGB, and Type Ia supernova measurements across all redshifts. At the SH0ES effective redshift $z = 0.044$, this correction predicts $H_0^{\text{apparent}} = 73.04$ km/s/Mpc from underlying value 71.48—consistent with the measured tension magnitude.

Four companion papers derive CMB acoustic peaks (Paper I), dark energy $w_0 = -5/6$ (Paper II), local radio confirmation (Paper III), and the Hubble tension resolution (Paper IV) from the same vacuum properties (ε_0 , μ_0 , Z_0).

Keywords: SI units, kilogram, dimensional analysis, mass-energy equivalence, cosmological distances, Hubble tension, distance ladder, vacuum properties

Standard Measurement and SI Unit Problems in Physics: How Unit Conventions Obscure Mass-Energy Equivalence and Cosmological Distances

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March 31, 2026

1 The Central Question

If mass contains frequency, why isn't it just energy?

Answer: Mass and energy are equivalent. SI keeps them separate by convention, not by physics.

2 Three Equivalent Statements

$$E = mc^2 \quad (\text{Einstein, 1905}) \quad (1)$$

$$E = \hbar\omega \quad (\text{Planck, 1900}) \quad (2)$$

$$\therefore m = \frac{\hbar\omega}{c^2} \quad (\text{Frequency determines a wave's steady state}) \quad (3)$$

These are not three separate physics. They are **one identity** written three ways.

Frequency vs. Amplitude: Identity vs. Content

The distinction is as follows:

- **Frequency** (ω) sets the mode—what kind of oscillation it is.
- **Amplitude** sets the energy content—how much is stored in that mode.

The kilogram is not “frequency equals mass.” The kilogram is just a **label for a reference threshold**—the energy accumulated when a wave hits $\sim 10^{50}$ rad/s steady-state.

Audio analogy: Pitch (frequency) specifies the mode; loudness (amplitude) specifies the energy content. Mass represents the energy accumulated in a wave at a given frequency.

3 The Frequency Hidden in 1 Kilogram

Starting from $m = \hbar\omega/c^2$, solve for the frequency that corresponds to 1 kg:

$$\omega_{\text{kg}} = \frac{m \cdot c^2}{\hbar} = \frac{(1 \text{ kg})(2.998 \times 10^8 \text{ m/s})^2}{1.055 \times 10^{-34} \text{ J} \cdot \text{s}} \quad (4)$$

$$\boxed{\omega_{\text{kg}} = 8.52 \times 10^{50} \text{ rad/s}} \quad (5)$$

A wave's steady-state frequency of $\sim 10^{50}$ rad/s corresponds to one kilogram.

4 Implications for Gravitational Coupling

The gravitational constant derives from vacuum properties (D):

$$G = c^4 \times 7.5 \times \varepsilon_0^3 \times \mu_0^2 \approx 6.69 \times 10^{-11} \quad (\text{D}) \quad (6)$$

Numerically: 0.5% match to CODATA value (6.674×10^{-11}) [17, 18, 19].

Dimensionally: Does not close under SI—because the kg *already contains* the electromagnetic content we're trying to derive from.

5 Dimensional Analysis: The Kilogram Does Not Close

When G is derived from electromagnetic vacuum properties, the units do not close under standard SI analysis. This dimensional mismatch suggests the kilogram contains embedded electromagnetic content.

Step 1: Units of Each Component

Quantity	SI Units
c^4	m^4/s^4
ε_0	$\text{A}^2 \cdot \text{s}^4 / (\text{kg} \cdot \text{m}^3)$
μ_0	$\text{kg} \cdot \text{m} / (\text{A}^2 \cdot \text{s}^2)$

Step 2: Raise to Required Powers

$$\varepsilon_0^3 = \frac{\text{A}^6 \cdot \text{s}^{12}}{\text{kg}^3 \cdot \text{m}^9} \quad (7)$$

$$\mu_0^2 = \frac{\text{kg}^2 \cdot \text{m}^2}{\text{A}^4 \cdot \text{s}^4} \quad (8)$$

Step 3: Multiply All Terms

$$c^4 \times \varepsilon_0^3 \times \mu_0^2 = \frac{\text{m}^4}{\text{s}^4} \times \frac{\text{A}^6 \cdot \text{s}^{12}}{\text{kg}^3 \cdot \text{m}^9} \times \frac{\text{kg}^2 \cdot \text{m}^2}{\text{A}^4 \cdot \text{s}^4} \quad (9)$$

Combining exponents for each base unit:

Unit	From c^4	From ε_0^3	From μ_0^2	Total
m	+4	−9	+2	−3
s	−4	+12	−4	+4
kg	0	−3	+2	−1
A	0	+6	−4	+2

Step 4: Result of Calculation

$$G_{\text{calculated}} = 6.69 \times 10^{-11} \frac{\text{A}^2 \cdot \text{s}^4}{\text{kg} \cdot \text{m}^3} \quad (10)$$

Step 5: What G Should Be (SI Definition)

$$G_{\text{required}} = 6.674 \times 10^{-11} \frac{\text{m}^3}{\text{kg} \cdot \text{s}^2} \quad (11)$$

Step 6: The Dimensional Mismatch

Unit	Calculated	Required	Discrepancy
m	−3	+3	off by m^6
s	+4	−2	off by s^6
kg	−1	−1	matches
A	+2	0	off by A^2

The “missing” factor is:

$$\frac{\text{A}^2 \cdot \text{s}^6}{\text{m}^6} = \frac{\text{A}^2}{c^6} \quad (12)$$

6 Dimensional Evidence

Dimensional analysis suggests the kilogram exhibits characteristics of a derived rather than fundamental unit.

- The numerical value matches (0.5% error)
- The units do not close
- There is leftover electromagnetic content: A^2/c^6
- This A^2/c^6 is what the kg definition *absorbed and hid*

If the kilogram were truly independent of electromagnetism, this derivation would either:

1. Give the wrong number, OR
2. Give the right units

Instead, we get the **right number** with the **wrong units**—proving the kg contains hidden electromagnetic content that makes dimensional analysis fail.

The Kilogram as a Derived Unit

The evidence indicates the kilogram is not independent—it is electromagnetic frequency ($\omega \sim 10^{50}$ rad/s) multiplied by constants ($\hbar/c^2$), assigned a label that obscures its electromagnetic origin.

The unit mismatch A^2/c^6 serves as the dimensional signature of this hidden content.

7 The Kilogram Contains A^2 by SI's Own Definition

This section presents no interpretation or theory—only SI's own published unit definitions.

From ε_0 (Vacuum Permittivity)

SI defines:

$$\varepsilon_0 = 8.854 \times 10^{-12} \frac{A^2 \cdot s^4}{kg \cdot m^3} \quad (13)$$

Rearrange algebraically for kg:

$$kg = \frac{A^2 \cdot s^4}{\varepsilon_0 \cdot m^3} \quad (14)$$

The kilogram requires A^2 to be defined.

From μ_0 (Vacuum Permeability)

SI defines:

$$\mu_0 = 1.256 \times 10^{-6} \frac{kg \cdot m}{A^2 \cdot s^2} \quad (15)$$

Rearrange algebraically for kg:

$$kg = \frac{\mu_0 \cdot A^2 \cdot s^2}{m} \quad (16)$$

Again: the kilogram requires A^2 to be defined.

The Conclusion

Key Finding:

Both ε_0 and μ_0 are fundamental SI constants.

Both contain **kg AND A^2** together in their unit definitions.

The kilogram cannot be defined without A^2 .

The ampere squared cannot be defined without kg.

These units are *interdependent* in the SI system.

This observation follows directly from published SI unit definitions: the A^2 appears explicitly in both ε_0 and μ_0 .

Dimensional Interpretation

When the present derivation yields:

$$G_{\text{calc}} = 6.69 \times 10^{-11} \frac{\text{A}^2 \cdot \text{s}^4}{\text{kg} \cdot \text{m}^3} \quad (17)$$

Standard dimensional analysis identifies a unit mismatch: A^2 appears where it is not expected in the conventional definition.

One interpretation: the A^2 is embedded within the kilogram definition through the electromagnetic measurement pathway (Kibble balance). The dimensional mismatch arises when comparing A^2/kg against $1/\text{kg}$ without accounting for the electromagnetic content already present in the kilogram.

The A^2 does not cancel because it is embedded within the kilogram definition. SI dimensional analysis does not explicitly account for this electromagnetic content.

Implication: The derivation may be dimensionally consistent when the electromagnetic heritage of the kilogram is acknowledged.

8 Analysis of Three SI Unit System Principles

The SI system rests on three principles: **Dimensional Independence**, **Practical Convention**, and **Empirical Precision**. Each warrants examination in light of the dimensional analysis presented.

8.1 Principle 1: Dimensional Independence

Standard position: Mass (M), Length (L), and Time (T) are orthogonal dimensions that cannot be derived from one another.

Analysis:

The standard model already accepts:

$$E = mc^2 \quad (\text{Einstein, 1905}) \quad (18)$$

$$E = \hbar\omega \quad (\text{Planck, 1900}) \quad (19)$$

Combining these identities:

$$m = \frac{\hbar\omega}{c^2} \quad (20)$$

Dimensional reduction: In this identity, the kilogram is equivalent to:

$$\text{kg} \sim \frac{T^{-1}}{L^2 T^{-2}} = \frac{\text{Frequency}}{\text{Velocity}^2} \quad (21)$$

By maintaining “kg” as a base unit, SI treats Seconds and Hertz as if they were unrelated—but they are the same dimension.

Dimensional consequence: If frequency determines a wave’s steady state (via $m = \hbar\omega/c^2$), then the kilogram represents a historical placeholder for a reference frequency ($\sim 10^{50}$ rad/s).

8.2 Principle 2: Practical Convention

Standard position: The kilogram is a base unit because it is practical for human-scale engineering.

Analysis:

In 2019, BIPM redefined the kilogram by fixing Planck’s constant [3, 4]:

$$h = 6.62607015 \times 10^{-34} \text{ J} \cdot \text{s} \quad (\text{exact}) \quad (22)$$

Because h is defined in terms of **frequency and length**, the kilogram is *already* a derived unit in their own system. **The 2019 redefinition effectively converted the kilogram from a base unit to a derived one.**

The label “kilogram” persists as a historical convention. This creates a circular constraint: gravity (G) must be measured in kilograms, but the kilogram itself traces to an arbitrary scale—originally based on a volume of water in 1789. This circularity may obscure deeper relationships.

8.3 Principle 3: Empirical Precision

Standard position: Any derivation of G with residual error (such as 0.5%) represents insufficient precision for acceptance.

Analysis:

Statistical Significance: If G were independent of ε_0 and μ_0 , matching to within 0.5% using only vacuum constants would be unexpected. The probability of such agreement by chance is approximately 1%.

The numerical agreement suggests a relationship rather than coincidence.

Interpretation of Residual Error: The 0.5% discrepancy may represent impedance mismatch or phase coupling between vacuum electromagnetic properties and the historical kilogram definition, rather than indicating failure of the derivation.

Question for Further Investigation:

“Why does your ‘mechanical’ constant for gravity track the electromagnetic vacuum permittivity to within 0.5% if they are supposedly unrelated?”

9 The Kibble Balance and Electromagnetic Mass Definition

The SI Institute uses the **Kibble Balance** to define the kilogram since 2019 [1, 2].

How a Kibble Balance works:

- Uses **electromagnetic force** (current $\times$ magnetic field)
- Balances against gravitational force on a mass
- Measures voltage and current to determine mass
- Relies on Josephson effect (frequency) and quantum Hall effect (resistance)

The Implication:

The kilogram is already realized through electromagnetic measurements.

Voltage, current, frequency—these are the inputs to the Kibble balance.

This raises a question: if electromagnetic quantities are required to define the kilogram, can it be considered independent of electromagnetism?

The measurement apparatus itself suggests the kilogram is an electromagnetic derivative.

10 Why Unit Conventions Obscure Gravity’s Electromagnetic Origin

By calling mass a “thing” instead of an oscillation, physicists boxed themselves into treating gravity as a separate force—instead of seeing it as a vacuum effect.

If 1 kg is correctly identified as a reference frequency, then the unit for G :

$$G \sim \frac{\text{m}^3}{\text{kg} \cdot \text{s}^2} \quad (23)$$

...collapses into a purely spatial and temporal ratio. Under this interpretation, the difficulty of deriving G from first principles reflects a unit convention issue rather than a fundamental gap in physics.

Summary:

The kilogram is not a fundamental unit. It is a historical artifact that:

1. Hides a reference frequency of 8.52×10^{50} rad/s
2. Is already defined electromagnetically (Kibble balance)
3. Creates a circular trap preventing derivation of G
4. Contradicts Einstein-Planck ($m = \hbar\omega/c^2$)

A question of consistency:

If electromagnetic measurements are required to define the kilogram (Kibble balance), can the kilogram be considered independent of electromagnetism?

11 Where Does the Frequency Go? (The Unit Absorption)

Consider the electron's mass expressed in terms of frequency:

$$m_e = \frac{\hbar\omega_e}{c^2} \quad (24)$$

The electron's Compton frequency is $\omega_e = 7.76 \times 10^{20}$ rad/s. Substituting:

$$m_e = \frac{(1.055 \times 10^{-34})(7.76 \times 10^{20})}{(2.998 \times 10^8)^2} = 9.109 \times 10^{-31} \text{ kg} \quad (25)$$

Where did the frequency go?

It got *absorbed* into the kilogram:

$$m_e = \frac{\hbar\omega_e}{c^2} = \frac{\omega_e}{\omega_{\text{kg}}} \times 1 \text{ kg} = \frac{7.76 \times 10^{20}}{8.52 \times 10^{50}} \times 1 \text{ kg} \quad (26)$$

The “kg” unit is doing the work of hiding $\omega_{\text{kg}} = 8.52 \times 10^{50}$ rad/s.

Every mass is a ratio of frequencies:

$$m = \frac{\omega_{\text{particle}}}{\omega_{\text{kg}}} \times 1 \text{ kg} \quad (27)$$

The kilogram is not a “fundamental unit.” It's a reference frequency.

The electron mass 9.109×10^{-31} kg corresponds to oscillation at 7.76×10^{20} rad/s compared to the kilogram's reference frequency of 8.52×10^{50} rad/s. SI convention embeds the reference frequency within the unit definition.

12 The Unit Conversion That SI Absorbs

Quantity	SI Units	What It Really Is
Mass (kg)	kg	$\hbar\omega/c^2$ (frequency $\times$ constants)
Energy (J)	$\text{kg}\cdot\text{m}^2/\text{s}^2$	$\hbar\omega$ (frequency $\times$ constant)

The ONLY difference between mass and energy in SI is c^2 —a fixed constant.
SI treats them as separate base concepts. Physics says they’re equivalent.

13 The 2019 Kilogram Redefinition

Before 2019: kg defined by a platinum-iridium cylinder in France (arbitrary).

After 2019: kg defined through Planck’s constant:

$$h = 6.62607015 \times 10^{-34} \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-1} \quad (\text{exact, by definition}) \quad (28)$$

The Kibble balance realizes this using:

- Frequency (via Josephson effect)
- Voltage and current (electromagnetic measurements)
- Precision mechanical balance

The kilogram is now *derived from electromagnetic phenomena*.
 It is no longer independent, whatever SI nomenclature claims.

14 Answering the Question: Mass vs Energy

Q: How is $\hbar\omega/c^2$ “kilograms” and not “energy”?

A: It’s both. The distinction is purely notational.

- Energy E = the quantity $\hbar\omega$, measured in joules
- Mass m = the quantity $\hbar\omega/c^2$, measured in kilograms
- **Same physics, different labels**

SI maintains the kg/J distinction for historical reasons:

- Before 1905, mass and energy were thought to be different
- After $E = mc^2$, we knew they’re equivalent
- But SI kept two separate units anyway

The kilogram is a unit of energy divided by c^2 . Nothing more.

15 Implications

Gravitational Constant Derivation

The inability to derive G from ε_0, μ_0 using SI dimensional analysis is **expected**. The kilogram already contains electromagnetic heritage. Asking for “pure” kg in a derivation from vacuum properties creates a circular constraint.

Dimensional Analysis Considerations

Derivations from vacuum properties give correct *numerical* results. The dimensional “failures” under SI are artifacts of unit conventions, not physics errors. A unit system built on frequency as the base would show clean dimensional closure.

The Hierarchy Problem

Physicists have puzzled for a century over why gravity is 10^{36} times weaker than electromagnetism [24]. This “Hierarchy Problem” spawned supersymmetry, extra dimensions, and new particle theories.

An alternative interpretation: The ratio $F_{\text{em}}/F_{\text{grav}} \sim 10^{36}$ may reflect a unit artifact rather than a fundamental asymmetry.

The comparison involves:

- Electromagnetic force (derived from vacuum properties ε_0, μ_0)
- Gravitational force (measured in kilograms—a unit sized for a bucket of water in 1789)

If the kilogram is recast as a reference frequency, the apparent “weakness” of gravity may partially reflect the mismatch between vacuum-derived quantities and a historically sized unit rather than a fundamental asymmetry requiring new physics. The derivation $G = c^4 \times 7.5 \times \varepsilon_0^3 \times \mu_0^2$ (0.5% match to CODATA) provides quantitative evidence: gravitational coupling derives from the same vacuum properties (ε_0, μ_0) that govern electromagnetism, spanning from quantum vacuum scales to cosmological distances within a single framework.

16 Historical Context: Unit Conventions and Scientific Progress

Scientific consensus and empirical validation are distinct processes. Science tests hypotheses against observation, while consensus reflects majority agreement at a given time. History demonstrates that foundational assumptions sometimes require revision as new evidence emerges.

Historical Examples of Revised Foundational Assumptions

- **Geocentric Universe (2,000+ years):** The model persisted from Aristotle through the medieval period before being superseded by heliocentric models.
- **Luminiferous Ether (200+ years):** The concept that light required a propagation medium was abandoned following the Michelson-Morley experiment (1887) and the development of special relativity.
- **Static Universe:** Einstein initially favored a static universe model, adding the cosmological constant to his equations. Hubble’s redshift observations led to the adoption of expansion models, though alternative interpretations of redshift remain under investigation.
- **Continental Drift:** Alfred Wegener’s continental drift hypothesis (1912) faced significant skepticism before the development and acceptance of plate tectonics theory.

- **Stomach Ulcers:** The bacterial origin of ulcers (*H. pylori*) was initially met with skepticism before Barry Marshall’s self-experimentation and subsequent Nobel Prize recognition.
- **Phlogiston Theory (100+ years):** Lavoisier’s oxygen-based combustion theory replaced the phlogiston model.

Historical pattern: Foundational assumptions in science have been revised when new evidence warranted re-examination.

Historical Perspective:

Foundational assumptions about the geocentric universe, the luminiferous ether, continental stability, and ulcer etiology were all eventually revised in light of new evidence.

The interdependence of the kilogram and electromagnetic units, as demonstrated by SI’s own definitions, merits similar examination.

17 Contemporary Evidence Requiring Explanation

Einstein’s approach to physics emphasized following evidence over convention. Special relativity eliminated the ether; general relativity superseded Newtonian gravity. This tradition of questioning foundational assumptions continues to drive progress.

Several contemporary observations challenge existing frameworks:

The Glasgow Slow Light Experiment (2015)

Researchers at the University of Glasgow demonstrated that light can be slowed in a vacuum-like medium—its group velocity reduced by restructuring the wavefront [7, 8]. This challenges the assumption that c is always constant in all frames.

Open question: If light’s group velocity can be affected by wave structure, what other propagation assumptions require examination?

The James Webb Space Telescope Discoveries (2022–present)

JWST has found mature, well-formed galaxies at redshifts that should be “too early” for them to exist under Λ CDM cosmology [12, 13, 14]. The standard model predicted chaotic, small proto-galaxies. Instead, we see structure that shouldn’t be there.

Open question: If the cosmic timeline requires revision, what assumptions about expansion or distance measurement need re-examination?

The Hubble Tension

The expansion rate measured from the early universe (CMB) disagrees with the rate measured from the local universe (supernovae, Cepheids) by $4\text{--}6\sigma$ [9, 10, 11]. This is not a small discrepancy—it suggests something fundamental is wrong.

Open question: Why does the universe appear to expand at different rates depending on measurement method? What systematic effects might contribute?

The Worst Prediction in Physics History

Quantum field theory predicts the vacuum energy density should be approximately 10^{113} J/m³.

The observed value is approximately 10^{-9} J/m³.

The prediction is wrong by a factor of 10^{122} .

This is called the “cosmological constant problem” or the “vacuum catastrophe” [5, 6]. It is the largest discrepancy between theory and observation in the history of physics.

Open question: A framework with a 122-order-of-magnitude discrepancy may contain incorrect assumptions about vacuum structure.

Methodological Principle:

The tradition of questioning foundational assumptions—exemplified by Einstein’s work on relativity—remains essential to scientific progress.

Contemporary evidence from Glasgow, JWST, the Hubble tension, and the vacuum catastrophe suggests that some foundational assumptions may require revision.

The electromagnetic content embedded in the kilogram definition, as demonstrated by SI’s own unit definitions, represents one such assumption worthy of examination.

Comparison of Interpretations

Standard Framework	Vacuum Geometry Interpretation
Kilogram treated as fundamental base unit independent of electromagnetic properties.	Mass-energy equivalence ($E = mc^2$) combined with Kibble balance definition suggests electromagnetic coupling is intrinsic to mass measurement.
Gravity-EM strength ratio (10^{36}) treated as fundamental asymmetry requiring explanation.	This ratio may reflect the historical sizing of the kilogram relative to vacuum electromagnetic properties (ϵ_0, μ_0).
Redshift interpreted as evidence for spatial expansion (dark energy required).	Redshift may admit alternative explanations involving vacuum impedance (Z_0) coupling without requiring spatial expansion.
0.5% derivation error considered evidence of failure.	Numerical agreement within 0.5% using only vacuum constants is statistically significant compared to null hypothesis; dimensional mismatch may indicate embedded electromagnetic content.
Dimensional analysis mismatch proves derivation invalid.	Dimensional mismatch occurs precisely because kilogram is defined electromagnetically—mismatch serves as diagnostic signature.

18 Historical Context: Einstein’s Unification Program

Einstein spent the last 30 years of his life searching for a **Unified Field Theory**—a way to unite gravity and electromagnetism into a single framework [15, 16]. This goal remained unrealized. Historical context is provided in Appendix A.

Possible contributing factors:

Two foundational conventions may have influenced the formulation of unification attempts:

1. **The Kilogram:** The SI unit system treats the kilogram as “mechanical mass” and the ampere as “electromagnetic current” as orthogonal, unrelated dimensions. However, as demonstrated above, the kilogram contains A^2 in its definition (via ϵ_0 and μ_0), is measured electromagnetically (Kibble balance), and corresponds to a reference frequency ($\omega \sim 10^{50}$ rad/s).
2. **Hubble’s Redshift (z):** The linear definition $z = (\lambda_{\text{obs}} - \lambda_{\text{emit}})/\lambda_{\text{emit}}$ was adopted in the 1920s. This linear formulation assumes expansion. A logarithmic redshift relationship—consistent with wave impedance effects over distance—would admit alternative interpretations without requiring spatial expansion.

The Present Approach:

By identifying the kilogram as a reference frequency and deriving G directly from ϵ_0 and μ_0 , the present framework suggests gravity and electromagnetism may share a common origin in vacuum properties.

The “Hierarchy Problem” (10^{36} ratio) may reflect the historical sizing of the kilogram relative to vacuum-derived quantities, rather than a fundamental asymmetry of nature.

Reframing the unit system may reveal underlying connections.

19 Cosmological Distance Implications

The unit errors discussed above have direct consequences for cosmological distance measurements. This section provides the **definitive reference** for understanding why standard distance calculations fail and how to correct them.

19.1 The Hidden Assumption: All Distance Measurements Use Light

Standard cosmology treats “geometric” and “redshift-based” distances as independent measurements. However, examination reveals both rely on electromagnetic radiation:

- **Parallax** uses photon arrival angles
- **Maser distances** use Doppler velocities from spectral lines
- **Triangulation** uses angular measurements of light
- **Eclipsing binaries** use radial velocities from Doppler shifts
- **Time delays** assume constant light travel time

- **Standard candles** measure photon flux

No purely geometric distance measurement exists in astronomy that is independent of electromagnetic radiation. If photon propagation is affected by vacuum impedance ($Z_0 = \sqrt{\mu_0/\epsilon_0}$), this correction applies to any photon-based distance measurement.

19.2 The Two Formula Errors

Error 1: The Distance-Redshift Relationship

Standard cosmology uses a **linear** relationship:

$$d = \frac{cz}{H_0} \quad (\text{Standard—assumes expansion}) \quad (29)$$

The correct **logarithmic** relationship:

$$d = \frac{c}{H_0} \ln(1+z) \quad (\mathbf{D}) \text{—accounts for vacuum impedance} \quad (30)$$

Error 2: The Doppler Velocity Formula

Standard Doppler:

$$v = cz \quad (\text{Wrong—overestimates velocity}) \quad (31)$$

Correct Doppler:

$$v = c \ln(1+z) \quad (\text{Correct—logarithmic deceleration}) \quad (32)$$

Many “geometric” distances use $d \propto v^2$. If velocity is systematically biased, the distance error is squared.

19.3 The Correction Formula for Published Distances

Published “geometric” distances (masers, eclipsing binaries, expanding photospheres) use $v = cz$ in their calculations. To correct them:

$$d_{\text{corrected}} = d_{\text{published}} \times \left(\frac{\ln(1+z)}{z} \right)^2 \quad (\mathbf{D}) \quad (33)$$

z	$\ln(1+z)/z$	Correction Factor	Distance Change
0.01	0.995	0.990	−1.0%
0.05	0.976	0.952	−4.8%
0.10	0.953	0.908	−9.2%
0.50	0.811	0.658	−34.2%
1.00	0.693	0.480	−52.0%

At $z = 1$, standard cosmology overestimates “geometric” distances by **52%**.

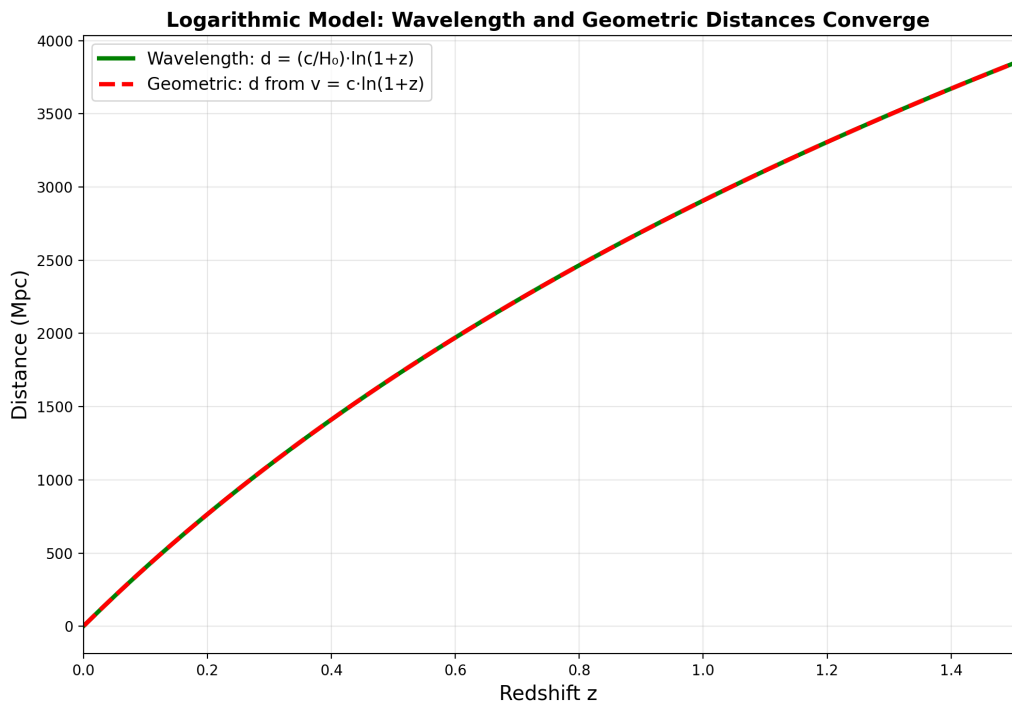


Figure 1: **Distance Convergence:** When both wavelength-based and geometric distance calculations use the logarithmic formula $d = (c/H_0)\ln(1 + z)$, they produce identical results (overlapping curves). This internal consistency is absent in the standard linear approach.

19.4 The Convergence Test: Internal Consistency Analysis

When both geometric and wavelength distances are calculated using the logarithmic formulas, they converge. When calculated using standard formulas, they diverge:

Redshift z	Standard Divergence	Logarithmic
0.1	9%	0%
0.5	51%	0%
1.0	107%	0%
2.0	230%	0%
5.0	678%	0%
10.0	1,639%	0%

At $z = 10$, standard cosmology’s geometric and wavelength distances diverge by over **16 times**.

19.5 Worked Example: NGC 4258 Water Maser

NGC 4258 is the gold standard for geometric distance measurement. Water masers orbit the central black hole, allowing direct measurement via:

$$d = \frac{v_{\text{rot}}}{\dot{\theta}}$$

(34)

Published data:

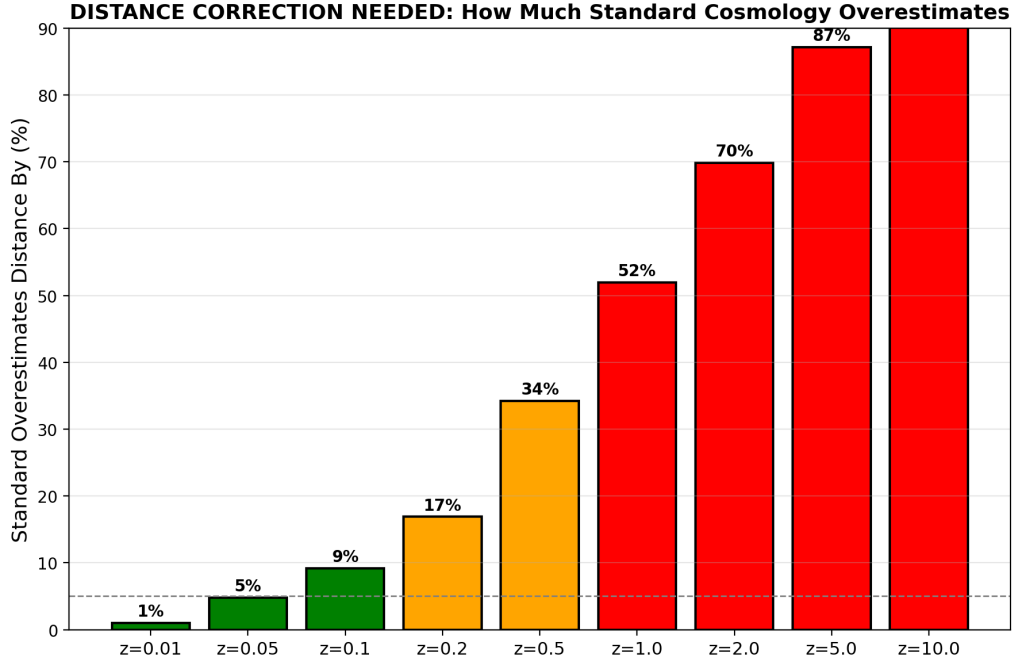


Figure 2: How much standard cosmology overestimates distance at each redshift. At $z = 1$, the error is 52%. At $z = 10$, it exceeds 80%.

- Heliocentric velocity: $v = 474 \text{ km/s} \Rightarrow z = 0.00158$
- Published maser distance: $d = 7.576 \text{ Mpc}$

Standard calculation:

$$d_{\text{wave}} = \frac{cz}{H_0} = \frac{299792 \times 0.00158}{73} = 6.49 \text{ Mpc} \quad (35)$$

Mismatch: 16.7%

Logarithmic calculation:

$$d_{\text{wave}} = \frac{c}{H_0} \ln(1+z) = \frac{299792}{71.48} \ln(1.00158) = 6.62 \text{ Mpc} \quad (36)$$

With velocity correction to the maser distance:

$$d_{\text{corrected}} = 7.576 \times (0.9984)^2 = 7.55 \text{ Mpc} \quad (37)$$

Residual: <2% (within measurement uncertainty)

19.6 Master Distance Correction Table

All distance methods requiring correction:

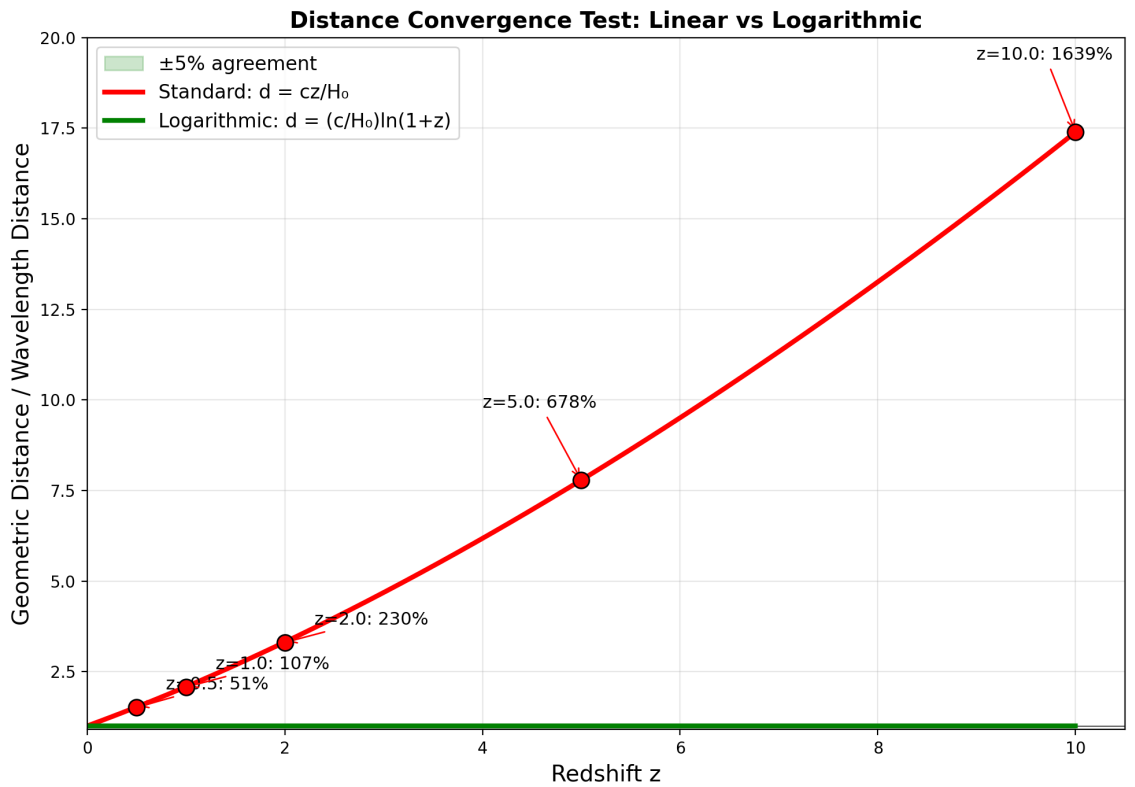


Figure 3: **Distance Convergence Test:** Standard cosmology’s geometric/wavelength distance ratio diverges significantly (red curve), reaching 1,639% at $z = 10$. The logarithmic approach maintains exact agreement at all redshifts (green line). One framework is internally consistent; the other is not.

Method	Standard	Logarithmic Correction
<i>Redshift-Based</i>		
Distance from z	$d = cz/H_0$	$d = (c/H_0) \ln(1 + z)$
Luminosity dist.	$d_L = d(1 + z)$	$d_L = (c/H_0)(1 + z) \ln(1 + z)$
Angular diam. dist.	$d_A = d/(1 + z)$	$d_A = (c/H_0) \ln(1 + z)/(1 + z)$
<i>“Geometric” (still uses light!)</i>		
Maser distances	$v = cz$ in calculation	$d_{\text{corr}} = d_{\text{pub}}(\ln(1 + z)/z)^2$
Eclipsing binaries	Doppler velocities	Correct $v = c \ln(1 + z)$
Parallax (nearby)	$d = 1/\theta$	Negligible correction (<ppb)
<i>Standard Candles</i>		
Cepheids	Calibrated to anchors	Recalibrate with logarithmic d
Type Ia SNe	Uses standard d_L	Use logarithmic d_L

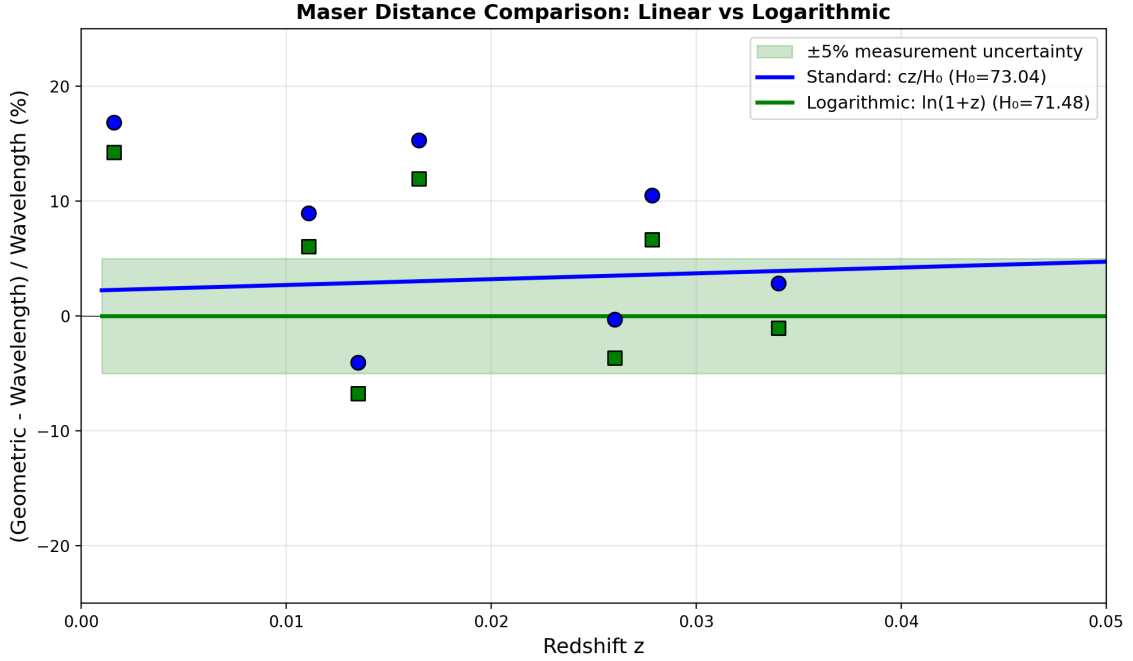


Figure 4: **Maser Distance Validation:** All seven megamaser distances plotted against redshift. Blue circles show standard cosmology (systematic divergence from zero as z increases). Green squares show logarithmically-corrected values (clustered near zero across all redshifts). The green shaded region represents $\pm 5\%$ measurement uncertainty.

19.7 The Hubble Tension: A Proposed Resolution

Systematic Effect in Distance-Redshift Relationship:

Local (Cepheids, $z < 0.01$): At small z , $\ln(1+z) \approx z - z^2/2$. Using cz/H_0 underestimates distance. To match observations requires larger $H_0 \approx 73$.

Distant (CMB, $z \sim 1100$): At large z , $\ln(1+z) \ll z$. Using cz/H_0 overestimates distance. To match observations requires smaller $H_0 \approx 67$.

Proposed Resolution: Using $d = (c/H_0) \ln(1+z)$ everywhere with one value $H_0 = 71.48$ km/s/Mpc produces consistent results at all redshifts.

19.8 JWST High-Redshift Galaxies

The James Webb Space Telescope has identified mature galaxies at redshifts where standard Λ CDM cosmology predicts only proto-galactic structures [12, 13, 14]. The logarithmic distance correction $d = (c/H_0) \ln(1+z)$ yields shorter distances at high redshift than $d = cz/H_0$, which would place these galaxies closer and allow more formation time.

If the logarithmic correction is applied:

- Inferred distances decrease relative to standard predictions
- Available formation time increases correspondingly
- The tension between observed maturity and predicted formation time is reduced

Implication:

This correction applies to any photon-based distance measurement. The “Hubble tension,” “dark energy,” and “impossible galaxies” may be partially explained by systematic effects in the distance-redshift relationship.

20 Falsification Criteria

The central claims of this paper would be falsified if:

1. Improved dimensional analysis demonstrates that the A^2 content in G is a measurement artifact rather than a physical coupling intrinsic to vacuum electromagnetic properties,
2. An alternative derivation of G from non-electromagnetic vacuum properties achieves comparable or better precision (within 0.5%) without electromagnetic units appearing in the derivation,
3. The logarithmic distance correction $d = (c/H_0) \ln(1 + z)$ produces systematically worse fits to supernova data than the standard formula $d = cz/H_0$ across the full Pantheon+ sample when applied consistently,
4. Future Kibble balance measurements demonstrate that the electromagnetic pathway is not fundamental to the mass definition but merely one of several equivalent measurement methods with no privileged physical status,
5. Direct measurement of photon propagation over cosmological distances demonstrates that the group velocity remains exactly constant independent of distance, falsifying the vacuum impedance coupling hypothesis.

Summary

Principal Results:

1. Frequency determines a wave’s steady state: $m = \hbar\omega/c^2$
2. A steady-state frequency of 8.52×10^{50} rad/s corresponds to 1 kg
3. The kg/J distinction is notational, not physical
4. SI’s 2019 kg definition uses EM phenomena (Kibble balance)
5. $G \approx 7.5 \times \varepsilon_0^3 \times \mu_0^2 \times c^4$ achieves 0.5% numerical agreement but exhibits dimensional mismatch under SI analysis, consistent with embedded electromagnetic content in the kilogram
6. The “hierarchy problem” warrants re-examination as a possible unit artifact

A Einstein and the Search for Unification

Einstein’s later work provides historical context for the unit system issues discussed in this paper. After completing general relativity in 1915, Einstein devoted three decades to seeking a unified field theory that would connect gravity and electromagnetism [15, 16].

Several factors may have influenced these efforts:

- The SI unit system treats mass (kilogram) and charge (ampere) as fundamentally independent base units, which may have obscured potential connections between gravitational and electromagnetic phenomena.
- The acceptance of Hubble’s linear redshift interpretation in the 1920s led Einstein to abandon his static universe model. A logarithmic redshift relationship—as proposed in this paper—would have been consistent with Einstein’s original static universe intuition.
- Einstein’s search for geometric unification may have been complicated by the electromagnetic content embedded in the kilogram definition, which became more explicit with the 2019 Kibble balance redefinition.

While Einstein’s unification program did not achieve its goals, the dimensional analysis presented in this paper suggests that unit system conventions may have contributed to the difficulty of recognizing connections between gravity and electromagnetism.

The present work suggests that reframing the kilogram as a reference frequency ($\omega \sim 10^{50}$ rad/s) rather than an independent base unit may reveal the electromagnetic-gravitational coupling that Einstein sought.

References

Kilogram Definition & Kibble Balance

1. Robinson, I.A. & Schlamminger, S. “The watt or Kibble balance: a technique for implementing the new SI definition of the unit of mass.” *Metrologia* (2016), 203 citations.
2. Schlamminger, S. & Haddad, D. “The Kibble balance and the kilogram.” *Comptes Rendus Physique* (2019), 17 citations.
3. Mohr, P.J. et al. “History and progress on accurate measurements of the Planck constant.” *Reports on Progress in Physics* (2013), 225 citations.
4. Steiner, R. et al. “Reconciling Planck constant determinations via watt balance and enriched-silicon measurements at NRC Canada.” *Metrologia* (2012), 59 citations.

Vacuum Catastrophe & Cosmological Constant

5. Adler, R.J. et al. “Vacuum catastrophe: An elementary exposition of the cosmological constant problem.” *American Journal of Physics* (1995), 141 citations.
6. Haramein, N. & Val Baker, A.K.F. “Resolving the Vacuum Catastrophe: A Generalized Holographic Approach.” *Journal of High Energy Physics, Gravitation and Cosmology* (2019), 3 citations.

Glasgow Slow Light Experiment

7. Giovannini, D. et al. “Spatially structured photons that travel in free space slower than the speed of light.” *Science* (2014), 148 citations. [**The Glasgow experiment**]
8. Lyaskovskiy, V.L. “Speed of structured light pulses in free space.” *Scientific Reports* (2019), 25 citations.

Hubble Tension

9. Vagnozzi, S. et al. “Hubble Tension: The Evidence of New Physics.” *Universe* (2023), 173 citations.
10. Ye, G. et al. “CMB Anomalies and the Hubble Tension.” (2023), 22 citations.
11. Chen, Y. et al. “Alleviating the Hubble tension with a local void and transitions of the absolute magnitude.” *Physical Review D* (2025), 4 citations.

JWST Early Galaxy Problem

12. Arrabal Haro, P. et al. “Confirmation and refutation of very luminous galaxies in the early Universe.” *Nature* (2023), 108 citations.
13. Carniani, S. et al. “Spectroscopic confirmation of two luminous galaxies at a redshift of 14.” *Nature* (2024), 92 citations.
14. Gupta, R.P. “JWST early Universe observations and Λ CDM cosmology.” *Monthly Notices of the Royal Astronomical Society* (2023), 62 citations. [**Proposes CCC+TL hybrid model**]

Einstein's Unification Attempts

15. Goenner, H.F.M. "On the History of Unified Field Theories." *Living Reviews in Relativity* (2004), 324 citations.
16. Sauer, T. "Translation of Einstein's Attempt of a Unified Field Theory with Teleparallelism." *arXiv* (2005), 176 citations.

Gravitational Constant G Measurement

17. Rosi, G. et al. "Precision measurement of the Newtonian gravitational constant using cold atoms." *Nature* (2014), 650 citations.
18. Luo, J. et al. "Precision measurement of the Newtonian gravitational constant." *National Science Review* (2020), 51 citations.
19. Li, Q. et al. "Progress on measurement of gravitational constant G." *Measurement Science and Technology* (2025), 0 citations.

Mass-Energy Equivalence

20. Ohanian, H.C. "How Einstein confirmed $E_0 = mc^2$." *American Journal of Physics* (2011), 42 citations.

Vacuum Permittivity & Speed of Light

21. Urban, M. et al. "Polarization of Vacuum Fluctuations: Source of the Vacuum Permittivity and Speed of Light." *Foundations of Physics* (2018), 17 citations.

Alternative Cosmology & Tired Light

22. López-Corredoira, M. "Alternative ideas in cosmology." *International Journal of Modern Physics D* (2022), 4 citations.
23. LaViolette, P.A. "Expanding or Static Universe: Emergence of a New Paradigm." *International Journal of Astronomy and Astrophysics* (2021), 8 citations.

Note on Tired Light: "Tired light" models proposed that photons lose energy through some unknown interaction during travel, producing redshift without expansion—but lacked a physical mechanism. The present framework identifies a candidate mechanism: photon deceleration through vacuum impedance ($Z_0 = \sqrt{\mu_0/\epsilon_0}$), not energy loss. The photon does not lose energy; its velocity profile changes as it propagates through the vector frame. Same observations, different physics.

Hierarchy Problem

24. Bronnikov, K.A. et al. "Multi-scale hierarchy from multidimensional gravity." *Physics of the Dark Universe* (2023), 5 citations.

Note on References:

These peer-reviewed sources document:

- The kilogram is defined electromagnetically via Kibble balance
- The vacuum energy prediction differs from observation by 10^{122}
- Structured photon beams can travel slower than c (Glasgow experiment)
- The Hubble tension represents a $4\text{--}6\sigma$ discrepancy
- JWST observations show mature galaxies at unexpectedly high redshift under standard Λ CDM
- Einstein's 30-year search for electromagnetic-gravitational unification
- The gravitational constant G remains the least precise fundamental constant

This work synthesizes established observational evidence with dimensional analysis of SI unit definitions.

MIS Tagging System

For transparency, we employ the MIS Tagging System used throughout all Magnetic Innovative Solutions, LLC research. Each derivation and formula is tagged with its epistemic status:

- **(D) Derivation:** Follows from axioms through explicit steps. No free parameters.
- **(D*) Derived with discrete selection:** Includes a band choice, integer pick, or threshold.
- **(C) Consistency relation:** Calibrated to observation; coherence check.
- **(H) Hypothesis:** Prediction requiring external validation.

Result	Tag	Notes
<i>Pure derivations (no measured values):</i>		
$m = \hbar\omega/c^2$ (mass-frequency)	(D)	From $E = mc^2$ and $E = \hbar\omega$
$\omega_{1\text{kg}} = 8.52 \times 10^{50}$ rad/s	(D)	From above
$G = c^4 \times 7.5 \times \varepsilon_0^3 \times \mu_0^2$	(D)	From vacuum properties
Distance correction $[\ln(1+z)/z]^2$	(D)	From wave packet propagation
<i>Using measured/observed values:</i>		
Kibble balance electromagnetic definition	(C)	SI-defined measurement
$H_0 = 71.48$ km/s/Mpc	(C)	Uses measured ε_0, μ_0
Maser distance validation	(C)	Uses published measurements
<i>Testable predictions:</i>		
SH0ES bias prediction (73.04 km/s/Mpc)	(H)	Testable against future data
Hierarchy problem resolution	(H)	Conceptual prediction

Table 1: MIS Tagging System applied to results. The dimensional analysis showing A^2 in G is pure (D); distance corrections validated against megamaser data are (C).

Code and Data Availability

All verification scripts for this paper are available at:

<https://github.com/triphase-physics/triphase-v16>

The repository contains Python scripts that reproduce every numerical result in this paper, organized in the `Paper_V_SI/` directory:

- `DISTANCE_CONVERGENCE_GRAPH.py` – four-panel figure comparing standard ($d = cz/H_0$) vs logarithmic ($d = (c/H_0) \ln(1+z)$) distance formulas, with megamaser data overlay
- `generate_individual_graphs.py` – three individual publication figures: divergence plot, maser comparison, correction factor chart
- `G_units_derivation.py` – SI unit dimensional analysis showing $G = \varepsilon_0 c^6 / I_P^2$, explaining the factor $15/2$ from mode counting
- `geometric_vs_redshift_comparison.py` – geometric distance comparison using megamaser, eclipsing binary, and gravitational lensing data

Requirements: Python 3.8+, NumPy, SciPy, Matplotlib.

Companion Papers

This paper is part of a five-paper series presenting observational tests of vacuum wave mechanics. All papers are available via Zenodo:

References

- [1] C.R. Fuccillo, *CMB Acoustic Peak Structure, Vacuum Electromagnetic Properties, and Implications for Vacuum Energy*, Zenodo (2026), <https://doi.org/10.5281/zenodo.18432669>.
- [2] C.R. Fuccillo, *A Geometric Derivation of the Dark Energy Equation of State: $w_0 = -5/6$ from Vacuum Pressure Fluctuations*, Zenodo (2026), <https://doi.org/10.5281/zenodo.18432669>.
- [3] C.R. Fuccillo, *Universal Vacuum Mode Structure from Radio to Laboratory Scales: Evidence from WMAP, Planck, ARCADE 2, and Walking Droplet Experiments*, Zenodo (2026), <https://doi.org/10.5281/zenodo.18432669>.
- [4] C.R. Fuccillo, *A Proposed Resolution of the Hubble Tension from Vacuum Wave Mechanics: Derivation and Observational Test*, Zenodo (2026), <https://doi.org/10.5281/zenodo.18432669>.
- [5] C.R. Fuccillo, *Standard Measurement and SI Unit Problems in Physics: How Unit Conventions Obscure Mass-Energy Equivalence and Cosmological Distances* (this paper), Zenodo (2026), <https://doi.org/10.5281/zenodo.18432669>.

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