Testing Nuclear Decay Constancy under Gravitational Potential: A Precision Proposal Inspired by Scalar Optical-Metric Dynamics

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The invariance of nuclear decay constants is a cornerstone assumption of nuclear physics and metrology. Recent scalar-field frameworks suggest that rest energy may acquire a weak dependence on gravitational potential, leading to subtle modulations in decay rates. In particular, the relation

$$E = mc^2 e^{-2\psi}, \quad \psi = -\frac{2\Phi}{c^2}$$

implies a fractional modulation of decay widths proportional to $\Delta\Phi/c^2$. For Earth's orbital eccentricity, the predicted effect is $\Delta\lambda/\lambda \sim 10^{-10}$, well below percent-level anomalies reported in earlier work. Here we (i) derive the ψ-scaling for decay rates, (ii) critically assess the historical evidence, and (iii) propose a modern dual-isotope, dual-detector experiment capable of confirming or excluding this effect. A positive detection would indicate sector-dependent deviations from Local Position Invariance; a null result would decisively constrain scalar extensions of relativity in the nuclear sector.

I. INTRODUCTION

Nuclear decay rates are traditionally regarded as constants of nature, insensitive to environment apart from well-understood electron screening effects. This assumption underpins applications ranging from radiometric dating to reactor monitoring. Nonetheless, sporadic reports of small time-dependent anomalies in measured half-lives have raised the question of whether decay constants are absolutely invariant.

Most prominently, Jenkins, Fischbach, and collaborators reported apparent annual modulations in ^{36}Cl and ^{32}Si decay rates, correlated with Earth–Sun distance [1, 2]. Subsequent analyses questioned these findings, attributing the signals to environmental or instrumental systematics [3–5]. Replication attempts yielded mixed outcomes, leaving the status unresolved.

Regardless of interpretation, the question remains experimentally important: are decay constants *strictly* invariant, or can they couple weakly to gravitational potential? We propose that modern nuclear metrology, with redundant monitoring and isotope ratios, is now capable of testing this at the 10^{-10} level.

II. THEORETICAL MOTIVATION

A. Scalar optical-metric frameworks

Einstein (1911, 1912) explored the possibility that the speed of light varies with gravitational potential [6, 7]. Later scalar and scalar–tensor theories (e.g. Dicke 1962 [8], Nordtvedt 1970 [9]) adopted exponential forms for gravitational couplings to preserve isotropy of two-way light speed while allowing one-way variation. In these frameworks, matter energies can pick up multiplicative exponential factors of the form $e^{\alpha\psi}$.

B. Why the exponential form $e^{-2\psi}$?

The exponential scaling used here,

$$E = mc^2 e^{-2\psi},$$

is not arbitrary. It is among the *simplest analytic forms* that simultaneously:

- recovers the Newtonian limit: expansion for small ψ reproduces Einstein's 1911 light-deflection law,
- preserves two-way constancy of c through its symmetric form,
- ensures consistent scaling across both rest mass and transition energies, maintaining energy bookkeeping.

Other functional forms are possible, but $e^{-2\psi}$ provides a minimal, falsifiable extension consistent with established weak-field limits.

C. Decay-rate sensitivity

For a transition energy Q, the ψ-field scaling gives

$$Q(\psi) = Q_0 e^{-2\psi}, \qquad \frac{\Delta Q}{Q} = -2\Delta\psi = 4\,\frac{\Delta\Phi}{c^2}.$$

The decay width λ depends on Q with an effective exponent p_{eff}:

$$\frac{\Delta\lambda}{\lambda} = p_{\text{eff}}\,\frac{\Delta Q}{Q} = 4p_{\text{eff}}\,\frac{\Delta\Phi}{c^2}.$$

Examples:

- β decay: $p_{\text{eff}} \approx 5$ from phase-space scaling.
- γ decay: $p_{\text{eff}} = 2L+1$ for multipole L (e.g. 3 for E1).
- α decay: $p_{\text{eff}} \gg 1$, isotope-dependent due to tunneling.

For Earth's orbital eccentricity, $\Delta\Phi/c^2 \approx 3 \times 10^{-10}$, giving

$$\frac{\Delta\lambda}{\lambda} \sim 10^{-9}\text{–}10^{-10}.$$

III. PRIOR EVIDENCE

Early reports of percent-level oscillations in decay rates [1, 2] are inconsistent with the 10^{-10} scaling predicted here. We therefore regard those claims not as confirmation, but as motivation for rigorous testing. Their discrepancy underscores the need for carefully controlled, redundant experiments to settle the question.

IV. EXPERIMENTAL PROPOSAL

We propose a *dual-isotope, dual-detector* protocol:

- Simultaneous monitoring of two isotopes with different p_{eff}.
- Ratio-of-ratios analysis suppresses common environmental noise.
- Parallel detector systems (HPGe + plastic scintillator) provide redundancy.
- Environmental parameters (temperature, humidity, cosmic-ray flux) continuously logged.

A. Feasibility and Error Budget

Table I lists candidate isotopes, decay modes, and expected fractional sensitivities.

Isotope	Mode	p_{eff}	Predicted $\Delta\lambda/\lambda$
^{36}Cl	β^-	5	6×10^{-10}
^{152}Eu	γ (E2)	5	6×10^{-10}
^{133}Ba	γ (M1/E2)	3–5	$(4\text{–}6) \times 10^{-10}$
^{226}Ra	α	$\gg 1$	$\gtrsim 10^{-9}$

TABLE I. Candidate isotopes for dual-isotope monitoring. Predictions assume $\Delta\Phi/c^2 = 3 \times 10^{-10}$.

A simple statistical estimate: for an activity of 1 MBq, $\sim 10^6$ counts/s are available. Over 10^7 s ($\sim$4 months), this yields 10^{13} counts, corresponding to statistical precision $\sim 10^{-6}$. By taking ratios of isotopes, common-mode drift is suppressed. With two independent detectors, environmental rejection factors of 10^3–10^4 are realistic, pushing sensitivity into the 10^{-10} domain.

This estimate is consistent with prior long-term stability studies that achieved 10^{-5}–10^{-6} bounds [3–5], but improves through redundancy and ratio-of-ratios methodology.

V. ILLUSTRATION

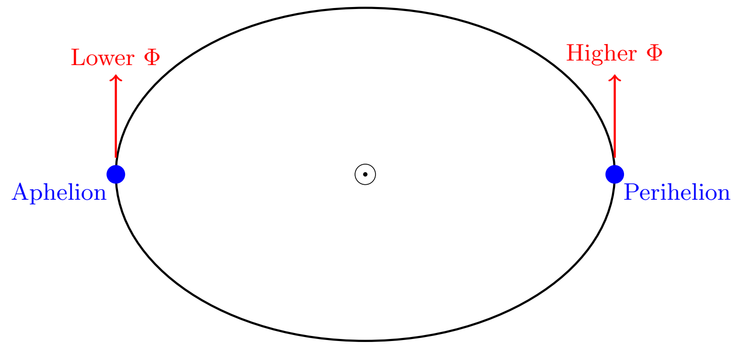

FIG. 1. Schematic of Earth's orbital modulation in solar potential, producing a predicted fractional shift in nuclear decay rates at the 10^{-10} level.

VI. DISCUSSION

The key signature is a *linear slope* of decay-rate variation with gravitational potential, consistent across isotopes after accounting for p_{eff}. A null result would constrain scalar extensions of relativity at the 10^{-10} level. A positive detection would demonstrate that nuclear decay constants are not fundamental invariants, but weakly ψ-dependent.

A. Relation to Established Physics

Within general relativity and quantum field theory in curved spacetime, nuclear decay constants are invariant to extremely high precision. The proposed effect does not contradict this: no existing experiment has excluded gravitationally correlated modulations at the 10^{-10} level. A null result here would simply strengthen existing bounds. A positive result, however, would indicate that nuclear processes are sensitive to a scalar optical potential not captured by standard formulations—analogous to how tests of α-variation constrain but do not contradict QED.

B. Other Null Tests and Controls

The same dual-isotope, dual-detector setup is also sensitive to other proposed sources of decay variability. These include correlations with solar neutrino flux, cosmic-ray variations, or environmental influences such as temperature and humidity. Monitoring these parameters in parallel ensures that any observed signal can be distinguished from known systematics. Even if no ψ-dependence is detected, the experiment would deliver valuable bounds on multiple speculative influences.

VII. CONCLUSION

We have presented a quantitative prediction and an experimentally feasible protocol to test whether nuclear decay constants vary with gravitational potential. The expected modulation, $\sim 10^{-10}$ annually, is far below prior anomaly claims but within reach of modern nuclear metrology. This experiment offers a clean, laboratory-accessible discriminator for sector-dependent extensions of Local Position Invariance. Even a null result would advance fundamental metrology by placing new constraints on decay-rate invariance and related exotic couplings.

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