

UDC 53.01

Elucidating the Dark Energy and Dark Matter Phenomena within the Scale-Invariant Vacuum (SIV) Paradigm

Gueorguiev Vesselin G.^{1,2(*)}

Vesselin.Gueorguiev@iaps.institute

Andre Maeder³

Andre.Maeder@unige.ch

¹Institute for Advanced Physical Studies, Sofia, Bulgaria²National Coalition of Independent Scholars, Battleboro, USA³Geneva Observatory, University of Geneva, Geneva, Saubervy, Switzerland

Abstract. The enigmatic phenomenon of dark energy (DE) is the elusive entity driving the accelerated expansion of our Universe. A plausible candidate for DE is the non-zero Einstein Cosmological Constant Λ_E manifested as a constant energy density of the vacuum, yet it seemingly defies gravitational effects. In this work, we interpret the non-zero Λ_E through the lens of scale-invariant cosmology. We revisit the conformal scale factor λ and its defining equations within the Scale-Invariant Vacuum (SIV) paradigm. Furthermore, we address the profound problem of the missing mass across galactic and extragalactic scales by deriving an MOND-like relation, $g \sim (a_0 g_N)^{1/2}$, within the SIV context. Remarkably, the values obtained for Λ_E and the MOND fundamental acceleration, a_0 , align with observed magnitudes, specifically, $a_0 \approx 10^{-10} \text{ m/s}^2$ and $\Lambda_E \approx 1.8 \cdot 10^{-52} \text{ m}^{-2}$ propose a novel early dark energy term, $T_{\mu\nu} \sim \kappa H$, within the SIV paradigm, which holds potential relevance for addressing the Hubble tension.

Keywords: cosmology, theory, dark energy, dark matter, MOND, Weyl integrable geometry

Introduction. In modern cosmology, the Lambda Cold Dark Matter (Λ CDM) model is the prevailing framework for explaining cosmic acceleration and galaxy rotation curves. However, this model relies on two hypothetical components — dark matter and dark energy — which remain undetected despite extensive observational efforts. The Scale-Invariant Vacuum (SIV) paradigm presents an alternative, modifying general relativity by allowing the properties of vacuum to define a conformal scaling factor. This approach introduces scale invariance of the vacuum as a fundamental symmetry, providing an innovative perspective on cosmic expansion and large-scale structure formation.

This work examines how the SIV paradigm naturally accounts for the observed value of the cosmological constant and the MOND like fundamental acceleration related to phenomena that traditionally require dark matter and dark energy, offering a theoretically consistent and observationally testable framework.

Methods and materials; results. Our analysis builds upon the extended Einstein field equations incorporating scale-invariant vacuum paradigm. The key modifications include:

- A time-dependent conformal factor that changes over the cosmic evolution.

- Adjusted geodesic equations leading to alternative interpretations of galactic rotation curves.

- A reformulated evolution equation that eliminates the need for a cosmological constant.

These theoretical developments are validated against observational data, including Type Ia supernovae luminosity distances, galaxy rotation curves, and large-scale structure distributions. The mathematical framework adheres to a well defined Lagrangian formulation, ensuring consistency with fundamental physical principles.

We apply the SIV framework to key cosmological datasets and find:

- **Cosmic Acceleration:** The SIV approach reproduces the late-time accelerated expansion observed in supernovae data without requiring a separate dark energy component.

- **Galaxy Rotation Curves:** The modified geodesic equations under SIV naturally yield flat rotation curves, eliminating the need for dark matter halos.

- The framework naturally introduces an early dark energy term in the FLRW equations.

These results suggest that the SIV paradigm can successfully account for key cosmological observations, providing a compelling alternative to the Λ CDM model.

Conclusion. The Scale-Invariant Vacuum paradigm offers a novel approach to understanding dark energy and dark matter phenomena by extending Einstein's equations to incorporate vacuum scale invariance. This framework provides a consistent explanation for cosmic acceleration, galaxy rotation curves, and structure formation without invoking undetected particles based on a new understanding of the Einstein Cosmological Constant and the origin of the MOND like behavior. Future work will focus on refining observational tests and exploring potential extensions to quantum gravity theories. The SIV paradigm represents a promising avenue for rethinking fundamental physics in cosmology.

References

- [1] Gueorguiev V.G., Maeder A. Elucidating the Dark Energy and Dark Matter Phenomena Within the Scale-Invariant Vacuum (SIV) Paradigm. MDPI Journal Universe, 2025, vol. 11 (2), no. 48. <https://doi.org/10.48550/arXiv.2502.02282>