

Hubble's Law and the Interpretative Choice: Does the Standard Model's Spatial Ontology Conflict with Electromagnetism?

S. M. H. Emamifar^{1,†}

Z. Derakhshani²

¹Independent Researcher

²Independent Research Collaboration on Black Hole & Cosmology Concepts (IRCBHC)

†Corresponding author: s.m.h.emamifar@researcher.org

ORCID: 0009-0007-6257-0163

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Abstract

The apparent superluminal recession of distant galaxies, inferred from Hubble's law, presents a well-known challenge to special relativity. The standard cosmological model resolves this by interpreting the recession as a consequence of the expansion of space itself, rather than motion through space. This paper examines the ontological implications of this resolution. We argue that while the expanding space interpretation is mathematically consistent within general relativity, it implicitly commits to a substantialist view of spacetime that stands in tension with the treatment of the vacuum in classical electromagnetism. We do not claim that this tension amounts to a logical inconsistency, but rather that it represents an interpretative choice with philosophical consequences that deserve scrutiny. By exploring how the constants μ_0 and ϵ_0 are understood in different theoretical contexts, we highlight that the nature of space—whether a void or a dynamic structure—remains an open question. We then survey several alternative interpretations of cosmological redshift, noting both their motivations and their challenges, to emphasize that the current paradigm is not the only logically possible one. The aim is not to advocate for a specific alternative, but to encourage critical reflection on the ontological commitments embedded in our most successful theories.

1 Introduction

Special relativity, born from the consistency of Maxwell's equations, establishes the constancy of the speed of light $c = 1/\sqrt{\mu_0\epsilon_0}$ as a fundamental postulate [1]. A direct consequence is that no physical signal can exceed c , a principle that underpins our understanding of causality.

Edwin Hubble's 1929 discovery [2] of a linear relation between the recession velocity of galaxies and their distance,

$$v = H_0 d, \quad (1)$$

introduced an apparent conflict: for sufficiently large d , the inferred velocity exceeds c . This tension has been resolved within general relativity by interpreting the recession not as motion through space, but as a consequence of the expansion of space itself [3].

This resolution is mathematically elegant and empirically successful. However, like all theoretical interpretations, it carries ontological commitments. This paper examines those commitments and asks whether they are compatible with the conception of space implied by classical electromagnetism. Our goal is not to challenge the validity of general relativity or the expanding universe model, but to highlight that the choice between competing interpretations of spacetime structure involves philosophical as well as empirical considerations.

We proceed as follows: Section 2 revisits the Hubble-relativity conflict. Section 3 analyzes the standard resolution and its ontological implications. Section 4 examines the status of the electromagnetic vacuum and the constants μ_0 and ϵ_0 . Section 5 discusses the interpretative tension between the two domains. Section 6 surveys alternative approaches to cosmological redshift, noting their challenges. Section 8 concludes with a call for reflexivity regarding the metaphysical assumptions embedded in our theories.

2 The Conflict: Hubble's Law vs. Special Relativity

Special relativity's prohibition of superluminal motion is among the most robust principles in physics. Hubble's law, however, appears to demand recession velocities that exceed c for galaxies beyond a distance $d > c/H_0 \approx 4.2$ Gpc. Such galaxies are routinely observed.

This presents a dilemma: either the interpretation of redshift as a Doppler-like velocity is incorrect, or special relativity is not applicable on cosmological scales. Both options have been explored in the literature, but the consensus has favored a third path: the reinterpretation of recession within the framework of general relativity.

3 The Standard Solution: Expanding Space and Its Ontological Implications

In the Friedmann–Lemaître–Robertson–Walker (FLRW) metric, the proper distance D between comoving observers

evolves as

$$D(t) = a(t) \chi, \quad (2)$$

where $a(t)$ is the scale factor and χ the comoving distance. The recession velocity is then

$$v = \dot{a}(t) D, \quad (3)$$

which can exceed c for large D without violating special relativity, because the motion is not through space but of space.

This resolution is mathematically sound and has become the standard interpretation. However, it implicitly treats space as a dynamical entity with degrees of freedom—it expands, curves, and even supports wave propagation [4]. This substantialist reading of spacetime, while not forced by the formalism, is the most natural interpretation in the context of general relativity [5, 6].

The question we wish to raise is whether this substantialist view coheres with the conception of space found in another pillar of modern physics: classical electromagnetism.

4 The Status of the Electromagnetic Vacuum

Maxwell’s equations in vacuum contain the constants μ_0 and ϵ_0 , which combine to give the speed of light $c = 1/\sqrt{\mu_0\epsilon_0}$. Pedagogical presentations sometimes refer to these as “properties of the vacuum,” a phrasing that can suggest space itself possesses electromagnetic attributes.

A closer examination reveals a more nuanced picture. In SI units, μ_0 and ϵ_0 are defined constants, not measured properties; in Gaussian units they do not appear at all, with c entering explicitly. This unit-dependence indicates that μ_0 and ϵ_0 are not intrinsic features of space, but conversion factors that reflect the choice of measurement system [7].

From a philosophical standpoint, the constants can be interpreted in two ways:

- As **properties of spacetime itself**, in which case space is endowed with a structure that determines the speed of causal influences.
- As **properties of the electromagnetic interaction**, in which case space remains a void, and c is a contingent feature of how fields propagate.

Neither interpretation is forced by the mathematics; both are compatible with the empirical success of Maxwell’s theory. This underdetermination is characteristic of fundamental physics and invites philosophical reflection.

5 Interpretative Tension: Two Conceptions of Space

We now have two conceptions of space at play:

1. **Cosmological conception:** Space is a dynamical structure that expands, curves, and supports waves. This aligns with a substantialist ontology.

2. **Electromagnetic conception:** Space may be viewed either as a void or as possessing causal structure, but it lacks the kind of dynamical agency attributed to it in cosmology.

These conceptions are not logically contradictory; one could consistently maintain that space has geometric properties (as in general relativity) while lacking electromagnetic properties. However, the tension becomes apparent when we ask: **what is the ontological status of the constants μ_0 and ϵ_0 ?**

If they are properties of space, then the cosmological and electromagnetic conceptions converge—space is a structure with both geometric and electromagnetic attributes. If they are properties of the interaction, then space in electromagnetism is a void, while space in cosmology is a dynamical entity. This asymmetry is not an inconsistency, but it is an interpretative choice that has been made largely without explicit acknowledgment.

The choice has consequences. Adopting a substantialist view of spacetime (as in the standard cosmological interpretation) opens questions about the nature of this substance, its relation to matter, and its quantum properties. Adopting a relational or void-based view preserves the simplicity of the electromagnetic vacuum but must then explain how cosmic expansion can be understood without treating space as a fabric.

Our aim is not to resolve this tension, but to highlight that it exists and that the scientific community has, perhaps inadvertently, adopted one interpretative stance without fully examining the alternatives.

6 Alternative Interpretations of Cosmological Redshift

If the interpretative tension warrants concern, it is natural to ask whether other interpretations of cosmological redshift might circumvent it. Several alternatives have been proposed over the decades, each with its own motivations and challenges.

- **Modified gravity theories:** Models such as $f(R)$ gravity or scalar-tensor theories modify Einstein’s equations on large scales, potentially explaining apparent acceleration without invoking dark energy or spatial expansion [8, 9]. These theories face the challenge of matching the full suite of cosmological observations, from the cosmic microwave background to baryon acoustic oscillations.
- **Tired light hypotheses:** First proposed by Zwicky [10], these models suggest that photons lose energy gradually over cosmic distances due to interactions with intervening matter or fields. While early versions encountered difficulties with time dilation in supernova light curves and the blackbody spectrum of the CMB, some modern variants attempt to address these issues [11]. The primary challenge remains consistency with all available data.
- **Geometric and hierarchical frame models:** Some approaches explore the possibility that redshift arises from a nested structure of reference frames rather

than from expansion. These models preserve local relativity while generating a global redshift-distance relation through cumulative frame shifts [14]. They remain underdeveloped compared to Λ CDM and face the burden of making precise predictions.

- **Plasma cosmology and alternative cosmologies:** Proposals such as Alfvén’s plasma universe [12] or the steady-state model [13] offer non-expanding frameworks. These have largely been set aside due to their inability to explain the CMB and light element abundances without additional assumptions.

None of these alternatives currently matches the empirical success of Λ CDM. Their mention here is not to advocate for any of them, but to demonstrate that the conceptual space of possibilities is larger than often acknowledged. The dominance of the expanding space paradigm owes much to its empirical success, but also to the interpretative choices made decades ago.

7 Discussion: The Role of Interpretative Choices in Science

Science advances through a combination of empirical testing and conceptual interpretation. The history of physics is replete with examples where the same equations admitted multiple interpretations—the debate over action-at-a-distance versus field theory, the interpretations of quantum mechanics, and the substantialist-relationalist debate about spacetime are prominent cases.

The case of Hubble’s law is no exception. The FLRW equations can be interpreted in ways that emphasize either the dynamical nature of spacetime or its relational structure. The choice between these interpretations is underdetermined by the data; it depends on broader philosophical commitments.

What we have sought to show is that the standard interpretation—space as a dynamic fabric—sits in some tension with the way space is often conceived in electromagnetism. This tension does not invalidate either theory, but it invites us to reflect on whether our interpretative choices are consistent across domains.

The existence of alternative interpretations, however speculative or incomplete, serves as a reminder that our current framework is not inevitable. Future empirical discoveries, or deeper theoretical insights, may eventually favor one interpretation over others. Until then, a degree of epistemic humility is warranted.

8 Conclusion

We have examined the interpretative dimensions of Hubble’s law and its resolution within the expanding universe model. The standard interpretation, while empirically successful, commits to a substantialist view of spacetime that contrasts with the more minimalist conception of space found in classical electromagnetism. This contrast is not a logical contradiction, but it is an ontological tension that merits attention.

By surveying alternative interpretations of cosmological redshift, we have emphasized that the current paradigm is

one among several logical possibilities. The choice among them involves not only empirical fit but also philosophical considerations about the nature of space, time, and causation.

We do not advocate for any specific alternative. Rather, we invite the community to engage more explicitly with the interpretative choices embedded in our theories. Recognizing that these choices exist is the first step toward a more reflective and ultimately more robust understanding of the universe.

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