

The Hyparxis Field Model: A Covariant Scalar–Tensor Framework with an Informational Order Parameter and Screening

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Abstract

We present the Hyparxis Field Model (HFM), a covariant scalar–tensor framework in which a single ultralight scalar field $H(x)$ acts both as a dynamical degree of freedom and as a phenomenological order parameter responding to local spacetime structure. The field exhibits environment-dependent dynamics through a density-dependent effective mass, allowing it to remain screened in high-density regions while evolving cosmologically in underdense environments. The model reduces to General Relativity (GR) in appropriate limits and can drive late-time cosmic acceleration. The model builds upon prior works in scalar-field cosmology [1, 2, 3] and screening mechanisms [4, 5, 6].

1 Introduction

The observed late-time acceleration of the Universe remains a central problem in modern cosmology. While the cosmological constant Λ provides an excellent phenomenological description within Λ CDM, its small magnitude motivates the exploration of dynamical alternatives [3].

Scalar fields provide a natural framework for dynamical dark energy, including quintessence [3] and screened scalar–tensor models [4, 5]. These models must satisfy stringent Solar System and laboratory constraints, requiring mechanisms that suppress scalar-mediated forces in dense environments [6].

The Hyparxis Field Model introduces a single ultralight scalar field $H(x)$ with the following properties:

1. A canonical dynamical scalar degree of freedom.
2. Density-dependent screening via an effective mass.
3. A phenomenological informational interpretation based on local geometric and material structure.

2 Informational Order Parameter

We define a covariant scalar

$$I(x) = \alpha R(x) + \beta T(x) + \gamma \nabla_\mu u^\mu, \quad (1)$$

where R is the Ricci scalar, $T = g^{\mu\nu}T_{\mu\nu}$ is the trace of the stress–energy tensor, u^μ is the matter four-velocity, and α, β, γ are constants. This scalar encodes local curvature, matter density, and flow properties [4, 5].

3 Action

The covariant action is

$$S = \int d^4x \sqrt{-g} \left[\frac{M_{\text{Pl}}^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu H \partial_\nu H - V(H) \right] + S_m [\psi_i, A^2(H) g_{\mu\nu}], \quad (2)$$

where M_{Pl} is the reduced Planck mass, $V(H)$ is the potential, $A(H)$ encodes matter coupling, and ψ_i are matter fields [1, 3, 6].

4 Field Equations

Variation with respect to $g_{\mu\nu}$ gives

$$G_{\mu\nu} = \frac{1}{M_{\text{Pl}}^2} (T_{\mu\nu}^{(m)} + T_{\mu\nu}^{(H)}), \quad (3)$$

with

$$T_{\mu\nu}^{(H)} = \partial_\mu H \partial_\nu H - g_{\mu\nu} \left(\frac{1}{2} (\partial H)^2 + V(H) \right). \quad (4)$$

Variation with respect to H yields

$$\square H = \frac{dV}{dH} - \alpha_H T^{(m)}, \quad \alpha_H = \frac{d \ln A(H)}{dH} [4, 5]. \quad (5)$$

5 Effective Potential and Screening

The scalar experiences an effective potential

$$V_{\text{eff}}(H) = V(H) + A(H)\rho, \quad m_{\text{eff}}^2(H) = \frac{d^2 V_{\text{eff}}}{dH^2}. \quad (6)$$

High density increases m_{eff} , suppressing fifth forces. Low-density cosmological regions allow the field to evolve dynamically [4, 5].

6 Cosmology

For a flat FLRW metric

$$ds^2 = -dt^2 + a^2(t)d\vec{x}^2, \quad (7)$$

the Friedmann equations are

$$H_{\text{Hub}}^2 = \frac{1}{3M_{\text{Pl}}^2}(\rho_m + \rho_H), \quad \frac{\ddot{a}}{a} = -\frac{1}{6M_{\text{Pl}}^2}(\rho_m + \rho_H + 3p_H), \quad (8)$$

with

$$\rho_H = \frac{1}{2}\dot{H}^2 + V(H), \quad p_H = \frac{1}{2}\dot{H}^2 - V(H)[3]. \quad (9)$$

7 Observational Signatures

The model predicts:

1. Suppressed fifth forces in dense environments.
2. Modified growth of structure.
3. Deviations in cosmic void dynamics.
4. Small corrections to $f\sigma_8(z)$ [6].

8 Conclusion

The Hyparxis Field Model provides a mathematically consistent scalar–tensor framework incorporating screening and an informational interpretation. It reproduces GR locally while allowing dynamical dark energy behavior on cosmological scales.

References

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