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

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Abstract

We introduce the *Hyparxis Field Model*, a fully covariant scalar–tensor framework in which a single ultralight scalar field $H(x)$ plays a dual role: it acts as a physical scalar degree of freedom mediating a long-range interaction, and simultaneously serves as a phenomenological covariant order parameter responding to local spacetime structure. The field exhibits environment-dependent dynamics, remaining effectively frozen in high-density regions—thereby reproducing General Relativity locally—while evolving slowly in underdense regions, where it can drive late-time cosmic acceleration. The model admits canonical kinetic terms, screened matter couplings, and self-interaction potentials motivated by quartic or pseudo–Nambu–Goldstone boson forms. We derive the covariant field equations, discuss screening via a density-dependent effective mass, and outline observable consequences, including modified growth of structure and lensing–dynamics discrepancies in cosmic voids. The Hyparxis Field Model provides a mathematically consistent and predictive platform for studying dark energy phenomenology with a clear informational interpretation.

1 Introduction

The observed late-time acceleration of the Universe remains one of the central open problems in modern cosmology. While a cosmological constant provides an excellent phenomenological fit to current observations, its small observed value and apparent fine-tuning motivate the exploration of dynamical alternatives. Scalar fields have long been studied as candidates for dynamical dark energy, including quintessence models, pseudo–Nambu–Goldstone boson (PNGB) fields, and scalar–tensor theories with screening mechanisms [1–4].

A central challenge for such models is reconciling cosmological dynamics with stringent local tests of gravity. Screening mechanisms—such as the chameleon, symmetron, and Vainshtein effects—address this tension by suppressing scalar-mediated forces in high-density environments while allowing significant cosmological influence on large scales [5, 6].

The Hyparxis Field Model is built around a single ultralight scalar field $H(x)$ with the following defining features:

1. A physical scalar degree of freedom mediating a long-range interaction that is dynamically screened in dense environments.

2. A covariant informational interpretation, in which the scalar responds to local geometric and material structure.

3. Predictive late-time cosmology compatible with Solar System and laboratory constraints.

The informational interpretation introduced here is phenomenological and does not modify the underlying covariant dynamics. Rather, it provides a unifying conceptual perspective linking scalar-field dynamics to spacetime structure.

2 Informational Order Parameter

We define a covariant scalar quantity $\mathcal{I}(x)$ constructed from local geometric and material variables:

$$\mathcal{I}(x) = \alpha R(x) + \beta T(x) + \gamma \nabla_\mu u^\mu, \tag{1}$$

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 local four-velocity of matter, and α, β, and γ are constant couplings.

The Hyparxis field is taken to be a monotonic functional of this scalar:

$$H(x) = \mathcal{F}(\mathcal{I}(x)), \tag{2}$$

where $\mathcal{F}$ may take logarithmic, power-law, or PNGB-inspired forms.

From a phenomenological perspective, $\mathcal{I}(x)$ acts as a coarse-grained covariant order parameter encoding aspects of local spacetime curvature, matter density, and flow. The scalar field $H(x)$ dynamically adjusts in response to this local structure while remaining governed by a standard covariant action.

3 Action and Field Equations

The covariant action for the Hyparxis Field Model is

$$S = \int d^4x \sqrt{-g} \left[\frac{M_{\rm Pl}^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu H \partial_\nu H - V(H) - \frac{H}{M_b} T_b - \frac{H}{M_{\rm dm}} T_{\rm dm} - \frac{c^4}{8\pi G} \Lambda(H) \right]. \tag{3}$$

Variation with respect to the metric yields modified Einstein equations:

$$G_{\mu\nu} + \Lambda(H) g_{\mu\nu} = \frac{8\pi G}{c^4} \left(T_{\mu\nu}^{(b)} + T_{\mu\nu}^{(\rm dm)} + T_{\mu\nu}^{(H)} \right), \tag{4}$$

with the scalar stress–energy tensor:

$$T_{\mu\nu}^{(H)} = \partial_\mu H \partial_\nu H - \frac{1}{2} g_{\mu\nu} (\partial H)^2 - g_{\mu\nu} V(H). \tag{5}$$

Variation with respect to H yields the scalar field equation:

$$\Box H - \frac{dV}{dH} - \frac{c^4}{8\pi G} \frac{d\Lambda}{dH} - \frac{T_b}{M_b} - \frac{T_{\rm dm}}{M_{\rm dm}} = 0. \tag{6}$$

The effective mass governing screening is

$$m_{\rm eff}^2(H, \rho) = \frac{d^2 V}{dH^2} + \frac{\rho_b}{M_b^2} + \frac{\rho_{\rm dm}}{M_{\rm dm}^2}. \tag{7}$$

4 Cosmological Dynamics

For a spatially flat FLRW metric:

$$ds^2 = -c^2 dt^2 + a^2(t) d\vec{x}^2, \tag{8}$$

the Friedmann equations are

$$H_{\rm Hub}^2 = \frac{8\pi G}{3}(\rho_b + \rho_{\rm dm} + \rho_H) + \frac{\Lambda(H)}{3}, \tag{9}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) + \frac{\Lambda(H)}{3}, \tag{10}$$

with

$$\rho_H = \frac{1}{2c^2}\dot{H}^2 + V(H), \quad p_H = \frac{1}{2c^2}\dot{H}^2 - V(H). \tag{11}$$

5 Observational Signatures

The Hyparxis Field Model predicts:

- Late-time cosmic acceleration emerging in underdense environments.
- Environment-dependent deviations in the growth rate $f\sigma_8(z)$.
- Lensing–dynamics mass discrepancies in cosmic voids.
- Suppressed fifth forces in the Solar System due to screening.

6 Conclusion

We have presented the Hyparxis Field Model, a mathematically consistent scalar–tensor framework that unifies screened scalar-field dynamics with a phenomenological informational interpretation. The model recovers General Relativity in high-density environments while naturally producing late-time cosmic acceleration in underdense regions. It provides a predictive and testable platform for exploring dark energy phenomenology within a covariant theoretical structure.

References

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