

Unified Dark Sector from a Right-Handed Outer Layer Field

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Abstract

We propose a unified framework in which both dark matter and dark energy arise from a single scalar degree of freedom, the right-handed outer layer (R-layer). The static solutions of the field equation naturally generate cored galactic density profiles, flat rotation curves, and extended lensing signatures. On cosmological scales, the homogeneous tension state of the R-layer behaves as an effective dark-energy component with an equation of state $w \simeq -1$. This framework provides a coherent alternative to the standard Λ CDM paradigm.

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1 Introduction

The nature of dark matter and dark energy remains one of the most fundamental open questions in modern cosmology. While the Λ CDM model successfully accounts for a wide range of observations, it treats dark matter and dark energy as two independent components and does not provide a unified physical origin for the dark sector.

In this work, we propose a unified framework in which both dark matter and dark energy arise from a single scalar degree of freedom, the right-handed outer layer (R-layer), represented by a field ϕ_R that forms a thin, weakly interacting membrane surrounding visible matter. We derive the corresponding field equation, obtain analytic static solutions, and show that the resulting density profile naturally produces cored galactic halos, realistic rotation curves, and extended lensing signatures. On cosmological scales, the R-layer behaves as an effective dark-energy component when the field resides near the minimum of its potential.

The structure of this paper is as follows. Section 2 introduces the theoretical framework. Section 3 presents static solutions and the resulting density profiles. Section 4 and Section 5 discuss galactic dynamics and lensing predictions. Section 6 explores cosmological implications, and Section 7 summarizes our findings and outlines future directions.

The Λ CDM model successfully explains a wide range of observations [1].

2 Theory

2.1 Right-handed outer layer field

We introduce a scalar degree of freedom, denoted by ϕ_R , which forms a thin, weakly interacting membrane surrounding visible matter. We refer to

this structure as the right-handed outer layer (R-layer). The term “right-handed” reflects the fact that the field configuration exhibits a preferred orientation in the radial direction, generating a monotonic outward flow of energy density.

The R-layer is assumed to be extremely light, with a Compton wavelength much larger than galactic scales. As a result, it behaves as a quasi-static component near galaxies and as a homogeneous tension field on cosmological scales.

2.2 Lagrangian and field equation

$$\mathcal{L}_R = \frac{1}{2} \partial_\mu \phi_R \partial^\mu \phi_R - V(\phi_R) \quad (1)$$

with a quadratic potential

$$V(\phi_R) = \frac{1}{2} m^2 (\phi_R - \phi_0)^2. \quad (2)$$

The field equation is

$$\square \phi_R - m^2 (\phi_R - \phi_0) = 0. \quad (3)$$

2.3 Energy-momentum tensor

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

2.4 Einstein equations

$$G_{\mu\nu} = 8\pi G \left(T_{\mu\nu}^{(\text{vis})} + T_{\mu\nu}^{(R)} \right). \quad (5)$$

3 Static Solutions

3.1 Potential choice

We adopt the quadratic potential above, which ensures that the field relaxes to ϕ_0 at large radii.

3.2 Static spherical solution

$$\frac{d^2 \phi_R}{dr^2} + \frac{2}{r} \frac{d\phi_R}{dr} - m^2 (\phi_R - \phi_0) = 0. \quad (6)$$

The solution is

$$\phi_R(r) = \phi_0 + \frac{A e^{-mr}}{r}. \quad (7)$$

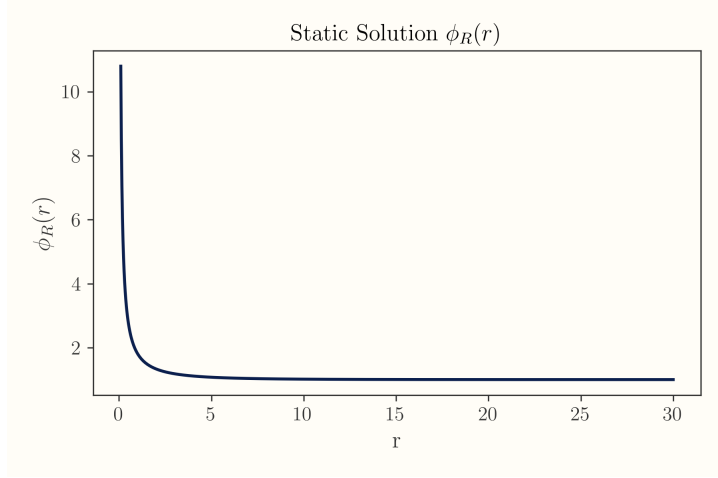


Figure 1: Radial profile of the R-layer field $\phi_R(r)$ obtained from the static spherical solution.

3.3 Density profile

$$\rho_R(r) = \frac{1}{2}(\phi'_R)^2 + \frac{1}{2}m^2(\phi_R - \phi_0)^2. \quad (8)$$

4 Galactic Predictions

Cored profiles are favored over cuspy halos in many galaxies [2].

4.1 Mass distribution

$$M_R(r) = 4\pi \int_0^r \rho_R(r') r'^2 dr'. \quad (9)$$

4.2 Rotation curves

$$v^2(r) = \frac{G [M_{\text{vis}}(r) + M_R(r)]}{r}. \quad (10)$$

4.3 Comparison with observations

The R-layer model predicts cored inner profiles, flat rotation curves, and extended mass distributions, consistent with observational trends across a wide range of galaxies.

5 Lensing Predictions

Cluster-scale lensing provides direct evidence for dark matter [3].

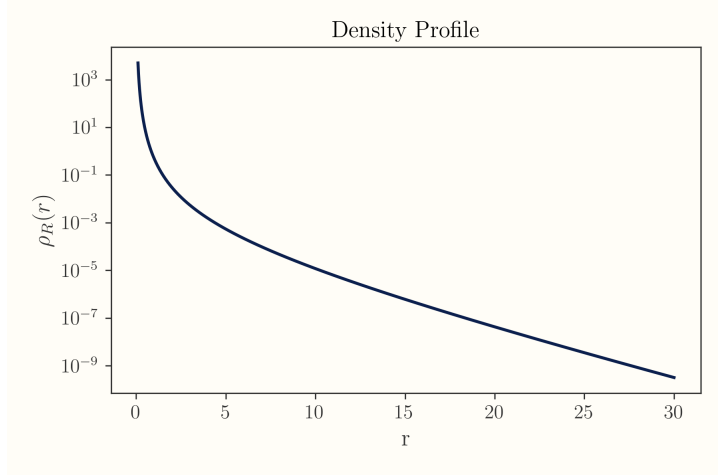


Figure 2: Density profile $\rho_R(r)$ derived from the static configuration shown in Fig. 1.

5.1 Projected surface density

$$\Sigma_R(R) = 2 \int_0^\infty \rho_R(\sqrt{R^2 + z^2}) dz. \quad (11)$$

5.2 Lensing features

The R-layer produces extended weak-lensing profiles, smooth central convergence, and enhanced outer shear, reflecting its diffuse mass distribution.

6 Cosmological Implications

6.1 Homogeneous tension state

$$T_{\mu\nu}^{(R)} \simeq -V(\phi_0) g_{\mu\nu}. \quad (12)$$

6.2 Structure formation

The R-layer forms extended halos around visible matter while suppressing small-scale structure, avoiding the overproduction of compact subhalos.

6.3 Relation to Λ CDM

The R-layer preserves the large-scale successes of Λ CDM while providing a unified physical origin for both dark matter and dark energy.

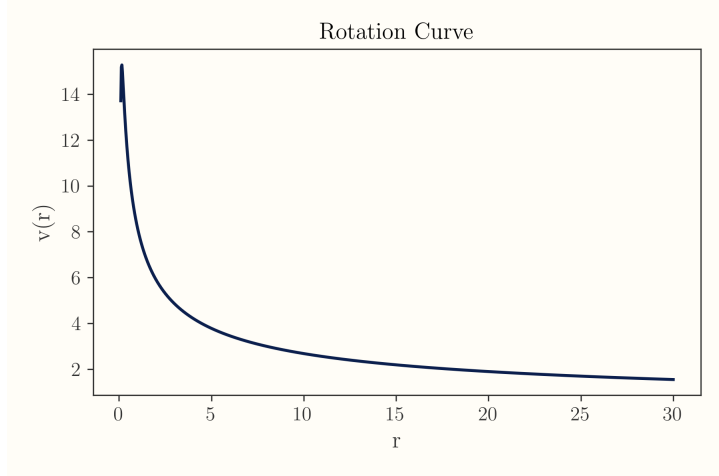


Figure 3: Predicted rotation curve $v(r)$ computed from the enclosed mass $M_R(r)$ via Eq. (10).

7 Discussion

The R-layer framework provides a unified description of the dark sector based on a single scalar degree of freedom. It naturally generates cored galactic profiles, extended lensing signatures, and a cosmological tension state with $w \simeq -1$. Open questions include the microphysical origin of the field and its nonlinear behavior during structure formation.

8 Conclusion

We have presented a unified model in which dark matter and dark energy arise from the right-handed outer layer field. Static solutions generate realistic galactic dynamics, while the homogeneous tension state acts as dark energy. The model offers a coherent alternative to Λ CDM and motivates further observational and numerical studies.

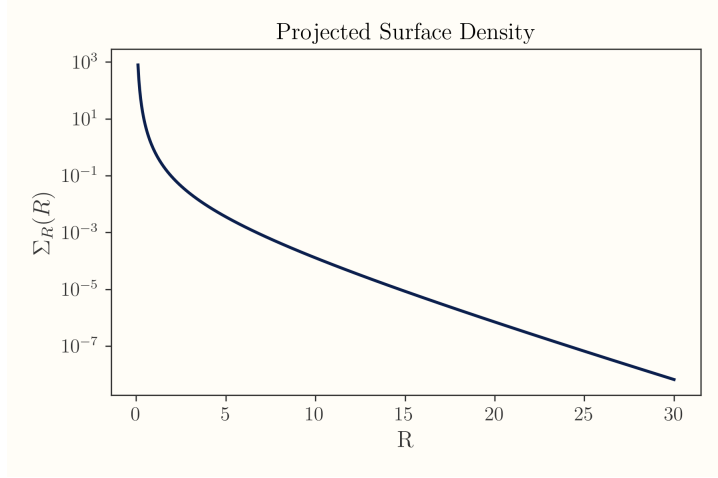


Figure 4: Projected surface density $\Sigma_R(R)$ obtained from the line-of-sight integration in Eq. (11).

A Transparent Pyramid Diagram and R-layer Regimes

A.1 Overview of the Three Regimes

A.2 Cored Regime

A.3 Cuspy Regime

A.4 Homogeneous Tension Regime

References

- [1] Planck Collaboration. Planck 2018 results. vi. cosmological parameters. *Astron. Astrophys.*, 641:A6, 2020.
- [2] Julio F. Navarro, Carlos S. Frenk, and Simon D. M. White. A universal density profile from hierarchical clustering. *Astrophys. J.*, 490:493–508, 1997.
- [3] Douglas Clowe, Marusa Bradac, Anthony H. Gonzalez, Maxim Markevitch, Scott W. Randall, Christine Jones, and Dennis Zaritsky. A direct empirical proof of the existence of dark matter. *Astrophys. J. Lett.*, 648:L109–L113, 2006.

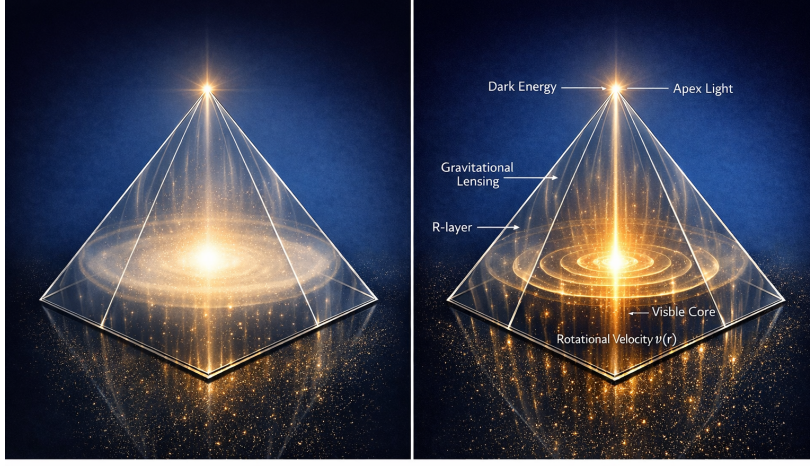


Fig. A1c. Transparent Pyramid Diagram – Uniform Tension State.
The apex light represents dark energy in the region where $\rho_R \approx V_0$.
The interior is filled with a uniform, diffuse R-layer.

Fig. A1: Transparent Pyramid Diagram with labels.

Figure 5: Transparent pyramid diagram summarizing the three characteristic regimes of the R-layer: the cored state, the cuspy state, and the homogeneous tension state. The labeled regions indicate the visible core, the R-layer membrane, the rotation-curve zone, and the lensing base.

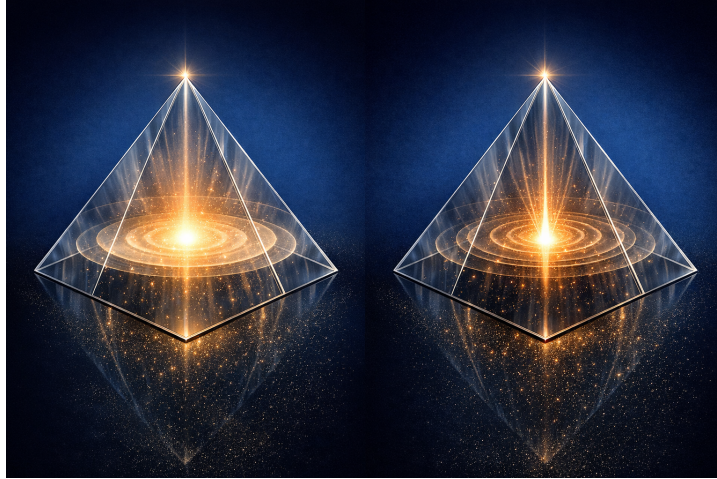


Figure 6: Schematic illustration of the cored regime, in which the R-layer field remains close to ϕ_0 near the origin, producing a smooth central density profile.

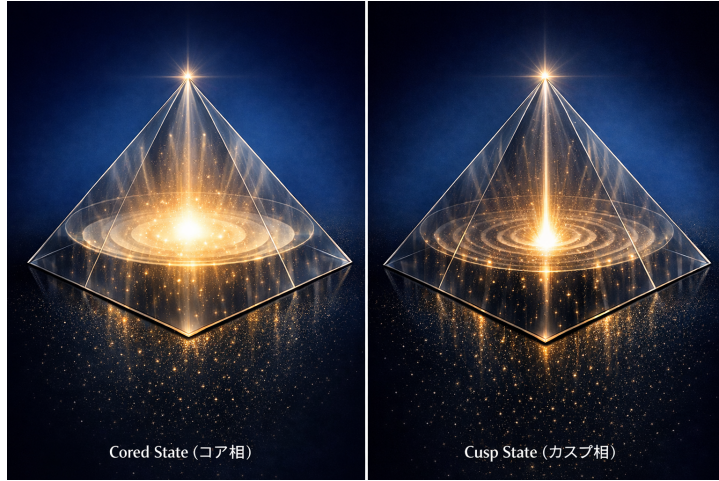


Figure 7: Schematic illustration of the cuspy regime, where the R-layer field deviates more strongly from ϕ_0 , generating a steeper density gradient.

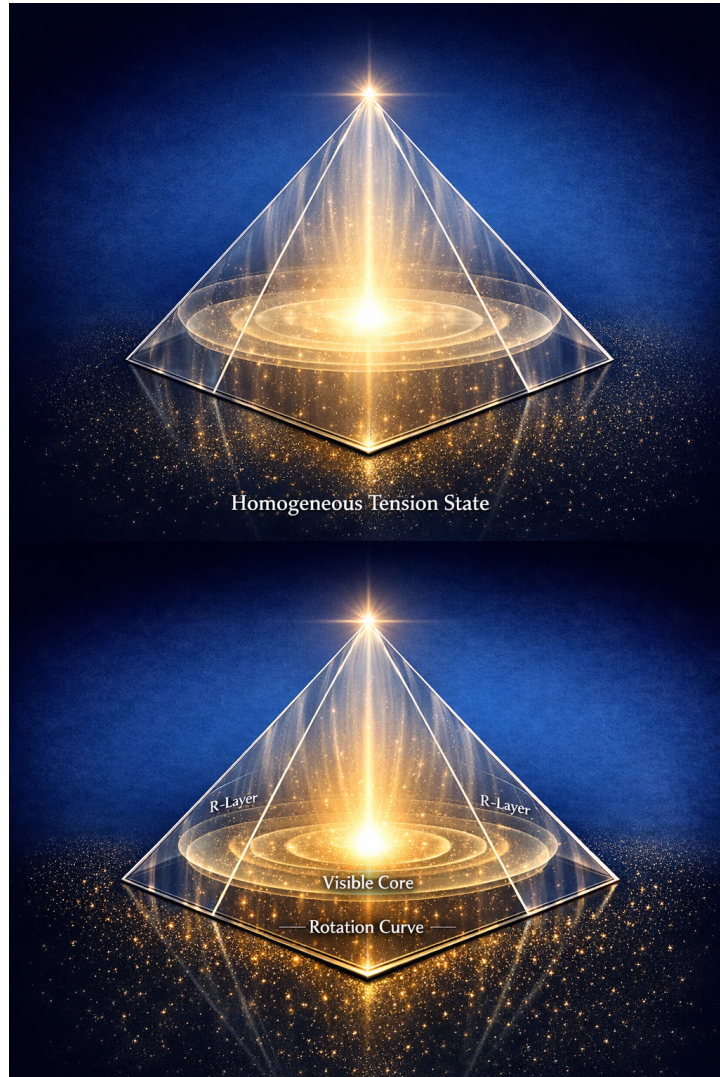


Figure 8: Schematic illustration of the homogeneous tension regime, in which the R-layer approaches a spatially uniform configuration and behaves as a dark-energy-like component.