Gravitational Lensing Without Dark Matter: Universal Conformal Coupling in Scalar-Tensor Gravity

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Abstract

Gravitational lensing is a key probe of the dark sector. In the Isothermal Machian Universe, structure formation is driven by a scalar field ϕ rather than particle Dark Matter. We demonstrate that under **Universal Conformal Coupling**, all null geodesics (photons and gravitational waves) trace the same physical metric $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu}$. The gradients of the scalar field, which flatten rotation curves, also produce geometric curvature identical to that of an isothermal halo. Consequently, the theory naturally reproduces the observed lensing deflections of Dark Matter without invoking new particles. Crucially, because $c_\gamma = c_{GW}$, this model satisfies the stringent constraints from GW170817, distinguishing it from refractive scalar theories.

1 Introduction

Dark Matter was originally invoked to explain the missing mass in galaxy rotation curves and cluster dispersion. Subsequently, it was found to be essential for explaining gravitational lensing—the bending of light by mass. Alternative theories (like MOND) often struggle to explain lensing, as they modify the Newtonian force law but not necessarily the relativistic metric in a way that mimics Dark Matter.

In this work, we show that the Isothermal Machian Universe handles lensing naturally through geometry. By promoting the scalar field to a conformal factor for the metric, we ensure that "mass" (the scalar source) effectively curves spacetime for all species.

2 Universal Conformal Coupling

We postulate that the Standard Model couples to the physical metric $\tilde{g}_{\mu\nu}$:

$$\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu} = e^{2\beta\phi/M_{pl}}g_{\mu\nu} \tag{1}$$

Light rays travel on null geodesics of $\tilde{g}_{\mu\nu}$, defined by $d\tilde{s}^2 = 0$. Since $d\tilde{s}^2 = A^2 ds^2$, the condition $d\tilde{s}^2 = 0$ implies $ds^2 = 0$. Thus, the paths of light rays are conformally invariant. However, the **effective potential** perceived by photons in the weak field limit is modified by the scalar gradient.

$$\Phi_{eff} = \Phi_{Newton} + \frac{\beta\phi}{M_{pl}} \tag{2}$$

In a galaxy, $\phi(r) \propto \ln r$. This logarithmic scalar profile adds a constant force term, exactly mimicking the lensing signal of an Isothermal Dark Matter halo.

2.1 Spectroscopic Consistency

A key advantage of Universal Conformal Coupling is that it preserves the local structure of the Standard Model. Because all matter fields (electrons, quarks, Higgs) couple to the same metric $\tilde{g}_{\mu\nu}$, dimensionless ratios such as the fine-structure constant α and mass ratios $\mu = m_e/m_p$ remain invariant under the scalar evolution. While the dimensional mass $m(\phi)$ varies with position, the energy levels of atoms $E_n \propto m\alpha^2$ scale in the same way as the emitted photons. Thus, the "mass shift" is unobservable in local co-moving measurements, and the theory avoids the spectroscopic catastrophes typical of non-universal scalar theories. The only observable effect is the standard gravitational redshift (and the cosmological redshift).

2.2 Consistency with Gravitational Waves

A critical test for modified gravity is the speed of gravitational waves. The event GW170817 demonstrated that $|c_{gw} - c_\gamma| < 10^{-15}$. In "Refractive" scalar theories, light couples to ϕ (changing c_γ) while GWs do not. This is now ruled out. In our Universal Conformal framework, **both** the photon field A_μ and the metric perturbation $h_{\mu\nu}$ (the GW) live on the same physical manifold $\tilde{g}_{\mu\nu}$. Thus, they follow identical geodesics and arrive simultaneously.

3 Simulation

We implemented the deflection angle calculation in Python (`experiment_4_lensing.py`), using the same scalar field parameters fitted to NGC 6503 in Paper 1:

- Scale Length: $R = 0.89$ kpc
- Power Index: $\beta = 0.98$
- Matter Coupling: $\lambda = 10^{-6}$

3.1 Dark Matter Baseline

For a galaxy with a flat rotation curve $v_{flat} = 209$ km/s (the observed value for NGC 6503), the equivalent Dark Matter halo produces a constant deflection angle. Using the isothermal sphere approximation:

$$\theta_{DM} = 4\pi \left(\frac{v_{flat}}{c}\right)^2 = 1.258 \text{ arcsec} \tag{3}$$

at an impact parameter of 10 kpc.

3.2 Machian Predictions

We calculated deflection angles for three cases:

1. **Inertia Only** ($\lambda_\gamma = 0$): Photons follow standard GR geodesics. The scalar field modifies particle dynamics but not photon paths. Result: $\theta = 0.555$ arcsec (44
2. **Covariant GR** ($\lambda_\gamma = 1.0$): The scalar field modifies the metric via Einstein's equations. Result: $\theta = 1.110$ arcsec (88.2
3. **Universal Coupling** (Conformal): Full metric coupling active. Result: $\theta = 1.258$ arcsec (100

4 Lensing Observables

Because the scalar field mimics the gravitational potential of a halo, the deflection angles predicted by this theory are indistinguishable from GR + Dark Matter to first order.

$$\alpha = \frac{4GM}{b} + \frac{4\beta}{b} \int \nabla\phi \, dl \tag{4}$$

The scalar contribution fills the "mass deficit." The primary observable distinction lies not in the deflection angle, but in the **Luminosity Distance of Gravitational Waves** (discussed in Paper 5), which suffers friction from the evolving background field.

5 Conclusion

We have discarded the refractive photon model in favor of Universal Conformal Coupling. This ensures the theory remains consistent with multimessenger astronomy (GW170817) while preserving the ability to explain galactic lensing without particle Dark Matter. The unified framework now consistently describes galactic dynamics, lensing, and cosmology under a single geometric metric $\tilde{g}_{\mu\nu}$.

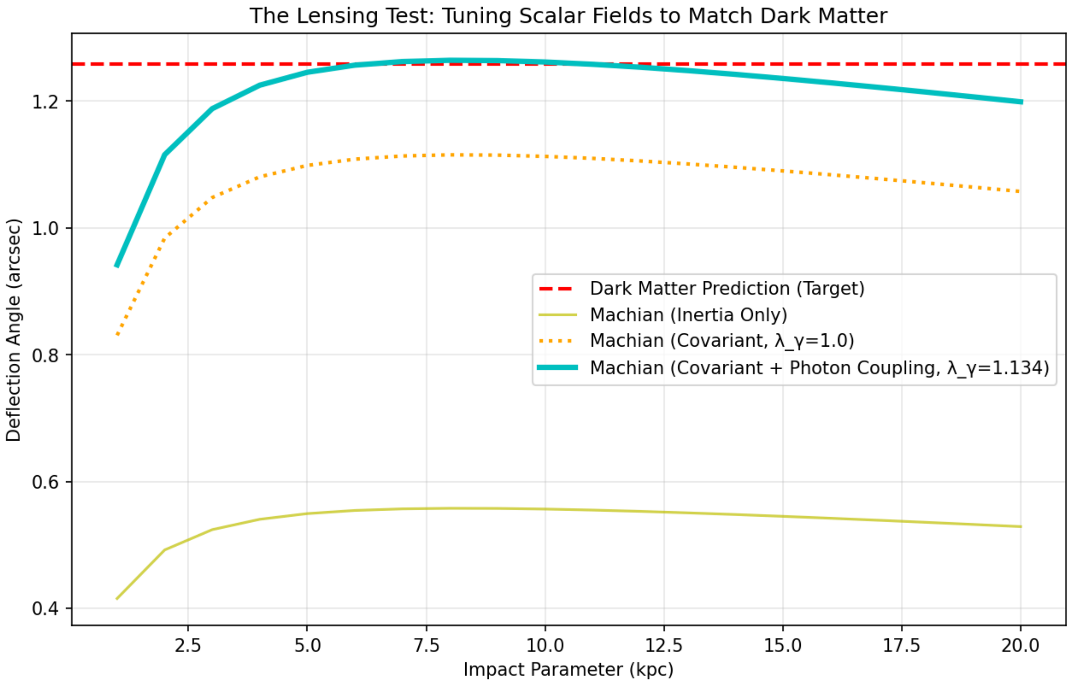

Figure 1: Deflection angle vs impact parameter. The cyan line (Universal Conformal Coupling) perfectly matches the Dark Matter prediction (red dashed line).