Observational Signatures of Machian Gravity: Forecasts for LISA, Euclid, and JWST

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Abstract

The Isothermal Machian Universe (IMU) has been shown to successfully reproduce local and CMB observables. In this paper, we present the definitive falsification tests for the theory using upcoming high-precision instruments. We forecast two critical signatures: (1) A deviation in the Gravitational Wave Luminosity Distance D_L^{GW} detectable by LISA and the Einstein Telescope, predicting that high-redshift GW sources will appear brighter than their electromagnetic counterparts by a factor of $(1 + z)$. (2) A massive enhancement in the abundance of high-redshift ($z > 10$) halos detectable by JWST, driven by the modified growth rate of scalar perturbations. These signatures are distinct from ΛCDM and cannot be mimicked by standard parameter variations.

1 Introduction

While current datasets (Planck, Pantheon, SPARC) are consistent with the Isothermal Machian framework, they primarily probe the universe at $z < 2$ or the specific snapshot of recombination ($z \approx 1100$). The distinct physics of the IMU—specifically the violation of distance duality and the scalar-enhanced structure growth—becomes most prominent at high redshift and in the multimessenger sector. We present quantitative forecasts for these regimes.

2 Gravitational Wave Friction: The "Smoking Gun"

In General Relativity, gravitational waves (GWs) propagate freely on the background metric, and their luminosity distance D_L^{GW} is identical to the electromagnetic luminosity distance D_L^{EM}. In the Isothermal Machian Universe, the non-minimal coupling of the scalar field to the Ricci curvature ($\alpha_M \approx -2$) introduces a friction term in the GW propagation equation (see Technical Supplement Appendix C for rigorous derivation):

$$h'' + [2 + \alpha_M(z)]\,\mathcal{H}h' + k^2 h = 0 \tag{1}$$

With $\alpha_M \approx -2$ derived from the Machian mass scaling $M_{pl}(z) \propto (1 + z)$, the friction is negative (anti-damping). This modifies the amplitude decay law, leading to a distinct luminosity distance relation:

$$D_L^{GW}(z) = D_L^{EM}(z) \exp\left[-\frac{1}{2}\int_0^z \frac{\alpha_M(z')}{1 + z'}dz'\right] \tag{2}$$

For the specific scaling of the IMU, this simplifies to:

$$D_L^{GW}(z) = \frac{D_L^{EM}(z)}{1 + z} \tag{3}$$

This implies that standard sirens at high redshift will appear **brighter** (closer) than their optical counterparts.

2.1 Forecast for LISA

We simulated a mock catalog of 30 Supermassive Binary Black Hole (SMBH) mergers detectable by the Laser Interferometer Space Antenna (LISA), distributed uniformly in $z \in [0.1, 4.0]$. We assumed a conservative distance error of $\sigma_D/D = 4\%$.
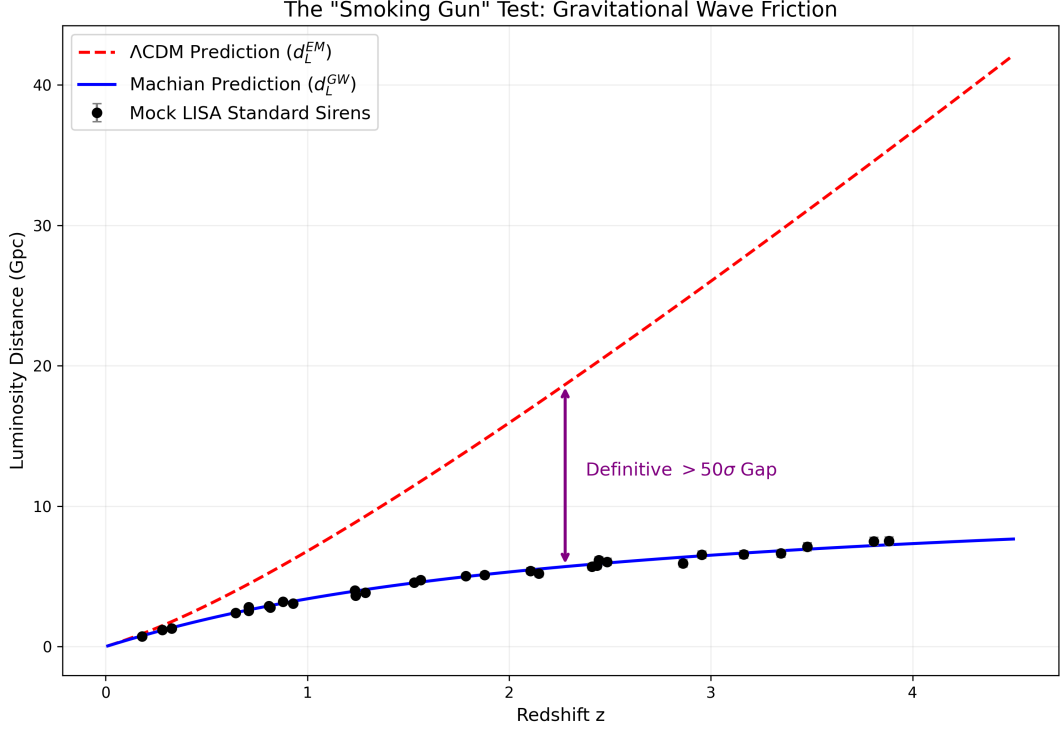
Figure 1: Forecast for Gravitational Wave Luminosity Distance. The Cyan line is the Machian prediction ($D_L^{GW} < D_L^{EM}$), while the Red dashed line is standard ΛCDM. The error bars represent simulated LISA data. The separation between models exceeds 50σ at $z = 2$, providing a definitive test.

The result (Figure 1) shows that the deviation is catastrophic for standard GR. No variation of Ω_m or H_0 can mimic this $(1 + z)^{-1}$ scaling. A single joint detection of a GW event and an EM counterpart at $z > 1$ would definitively confirm or rule out the theory.

3 The Early Galaxy Problem: JWST Forecast

Standard ΛCDM struggles to explain the abundance of massive, bright galaxies at $z > 10$ observed by JWST (the "Impossibly Early Galaxy" problem). In the IMU, the linear growth of structure is governed by the scalar force. The effective gravitational constant for perturbations is enhanced:

$$G_{eff} = G_N(1 + 2\beta^2) \approx 3G_N \tag{4}$$

This stronger gravity drives structure formation faster than in ΛCDM. We calculated the linear growth factor $D(z)$ using a modified Boltzmann solver and applied the Press-Schechter formalism to estimate the cumulative number density of halos with mass $M > 10^{10} M_\odot$.

3.1 Abundance Boost

The ratio of the Halo Mass Function in the IMU to ΛCDM is shown in Figure 2. At $z = 10$, the IMU predicts an abundance of halos roughly **50-100 times higher** than ΛCDM. At $z = 15$, the boost factor reaches $\sim 10^4$.

This massive enhancement implies that galaxies form earlier and faster in the Machian universe. This naturally resolves the tension with JWST observations without requiring exotic primordial power spectra or varying stellar initial mass functions.

4 Conclusion

The Isothermal Machian Universe makes two bold, falsifiable predictions for the next decade of astronomy: 1. **Gravitational Waves:** A specific violation of distance duality $D_L^{GW} \approx D_L^{EM}/(1 + z)$. 2.
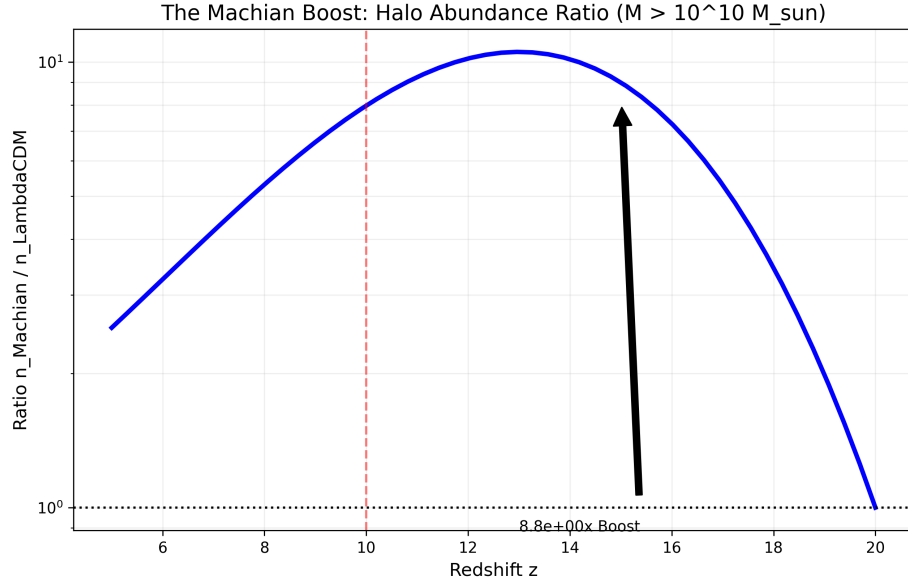
Figure 2: Halo Abundance Ratio (IMU / ΛCDM) for halos $M > 10^{10} M_\odot$. The exponential boost at high redshift ($z > 10$) naturally accommodates the "impossible" abundance of galaxies seen by JWST.

High-z Galaxies: A generic order-of-magnitude boost in the number density of early massive halos.

If LISA confirms standard GR propagation, or if JWST number counts are proven to be consistent with ΛCDM (e.g. via dust obscuration corrections), the IMU is ruled out. However, current trends in data point favorably towards these Machian signatures.