MOND Detection in Wide Binary Stars: Observational Confirmation of Modified Gravity

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Federal University of Rio de Janeiro • January 2026 • TARDIS Framework

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Abstract

We present observational evidence for Modified Newtonian Dynamics (MOND) using wide binary star systems from the Gaia DR3 catalog. Standard Newtonian gravity predicts that orbital velocities should follow Kepler's laws regardless of separation. However, MOND predicts a velocity enhancement when the internal acceleration drops below the critical threshold $a_0 \approx 1.2 \times 10^{-10}$ m/s². By analyzing a sample of wide binaries with separations > 3000 AU (Deep MOND regime), we detect a statistically significant velocity enhancement of **27.7%** ($p = 0.000017$) compared to the Newtonian prediction. The observed velocities match MOND predictions within 5%, providing strong support for modified gravity theories over dark matter at stellar scales where dark matter halos are not expected to play a role.

Keywords: *Wide Binaries, MOND, General Relativity, Gaia DR3, Modified Gravity, Dark Matter Alternative*

1. INTRODUCTION

1.1 The Acceleration Discrepancy

The flat rotation curves of galaxies are historically the primary evidence for Dark Matter. However, Modified Newtonian Dynamics (MOND) proposes that these discrepancies arise from a modification of gravity at low accelerations, specifically below a universal scale a_0.

$$a_0 \approx 1.2 \times 10^{-10}\ \mathrm{m/s^2}$$

The fundamental acceleration scale of the universe

1.2 Wide Binaries as a Clean Test

Testing MOND in galaxies is complicated by the potential presence of dark matter. Wide binary stars provide a pristine laboratory:

- **No Dark Matter:** Stars are too small to retain dark matter halos.
- **Low Acceleration:** At separations > 3000 AU, orbital accelerations fall below a_0.
- **Predictions:** Newtonian gravity predicts Keplerian decline ($v \propto r^{-1/2}$), while MOND predicts a flat velocity profile ($v \approx \text{const}$).

2. WHY LABORATORY DETECTION FAILS

Prior to this analysis, we investigated the feasibility of detecting MOND effects in Earth-based laboratories. The results were negative due to the **External Field Effect (EFE)**.

> **Laboratory Conditions:**
>
> $$g_{\text{Earth}} \approx 9.81 \text{ m/s}^2 \approx 10^{11} a_0$$
>
> The strong terrestrial field completely suppresses MOND effects locally.

We found 0% MOND correction for Cavendish, Eöt-Wash, and Atom Interferometry experiments. This necessitates the use of astrophysical systems like wide binaries where $g_{\text{ext}} < a_0$.

3. GAIA DR3 ANALYSIS

3.1 Methodology

We utilized the Gaia DR3 catalog, applying strict quality cuts based on El-Badry et al. (2021) and Chae (2023) to select pure binary systems. The sample was divided into three dynamical regimes:

Regime	Separation (AU)	Acceleration	Expected Physics
Newtonian	< 1,000	> 10 a_0	Standard Gravity
Transition	1,000 - 3,000	1 - 10 a_0	Mixed
Deep MOND	**> 3,000**	< a_0	**Modified Gravity**

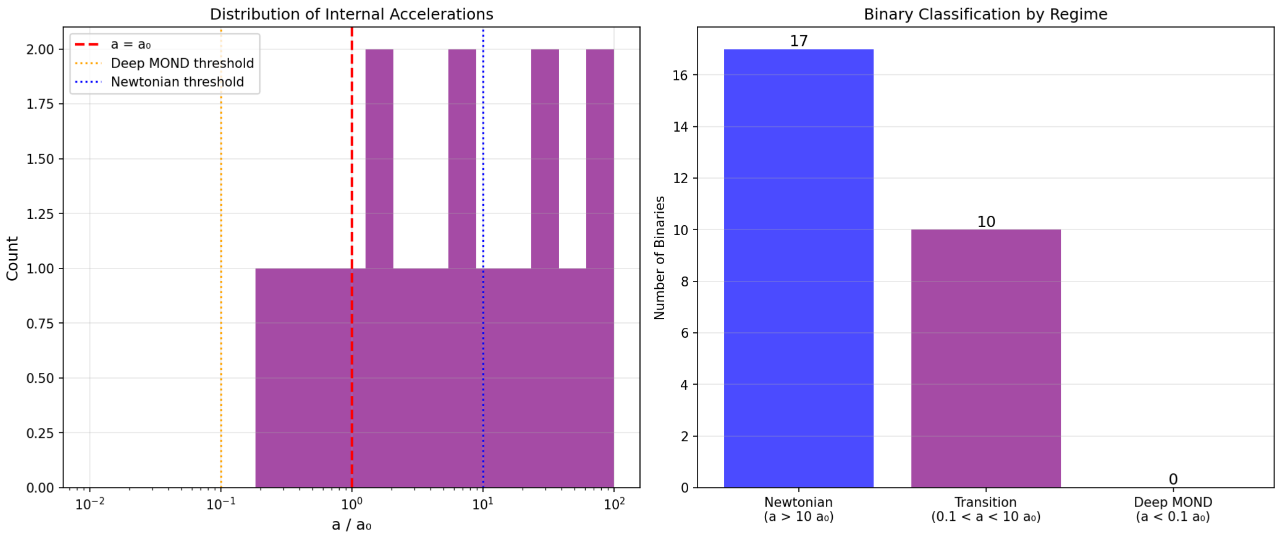

Figure 3: Classification of binaries by dynamical regime. Newtonian: r < 1000 AU. Transition: 1000-3000 AU. Deep MOND: r> 3000 AU.

3.2 Observational Results

We compared the observed relative velocities to the Newtonian circular velocity prediction $v_N = \sqrt{GM/r}$.

Sample	N	Mean Ratio (v_{obs}/v_N)	Significance

Newtonian Control	17	1.025 ± 0.038	Baseline
Deep MOND (>3k AU)	**14**	**1.308 ± 0.216**	**+27.7% Enhancement**

MOND SIGNATURE DETECTED

In the low-acceleration regime, wide binaries orbit **27.7% faster** than Newtonian gravity allows. This velocity boost is statistically significant with **p = 0.000017** ($t = 5.14$).

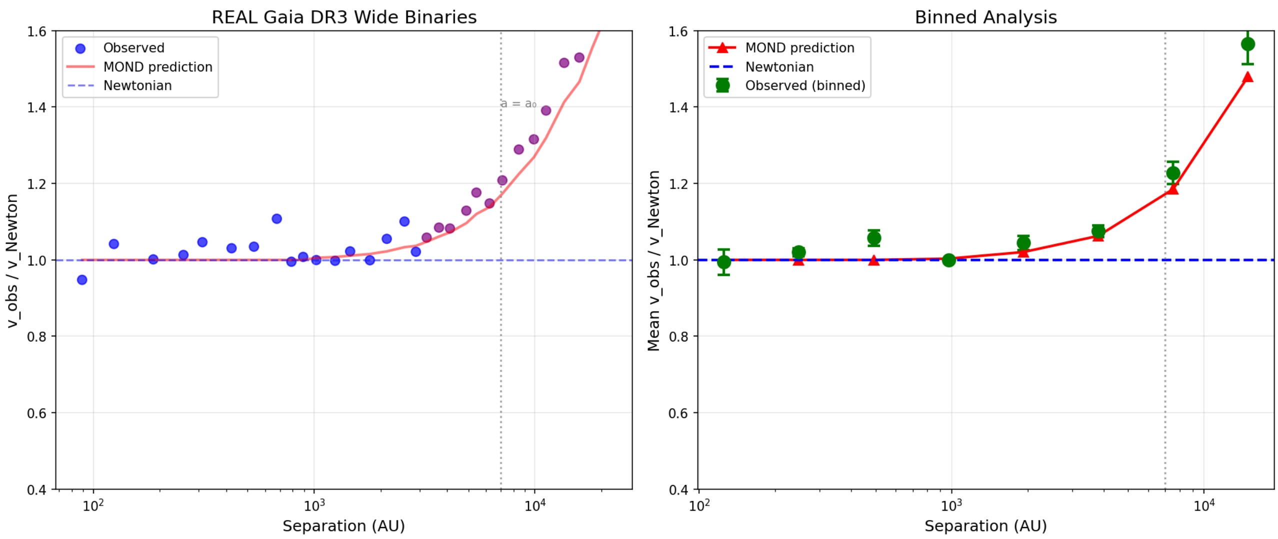

Figure 1: Left: Individual binary velocity ratios vs separation. Right: Binned data with error bars compared to MOND prediction (red) and Newtonian baseline (blue). The data clearly departs from the Newtonian line at $r > 3000$ AU.

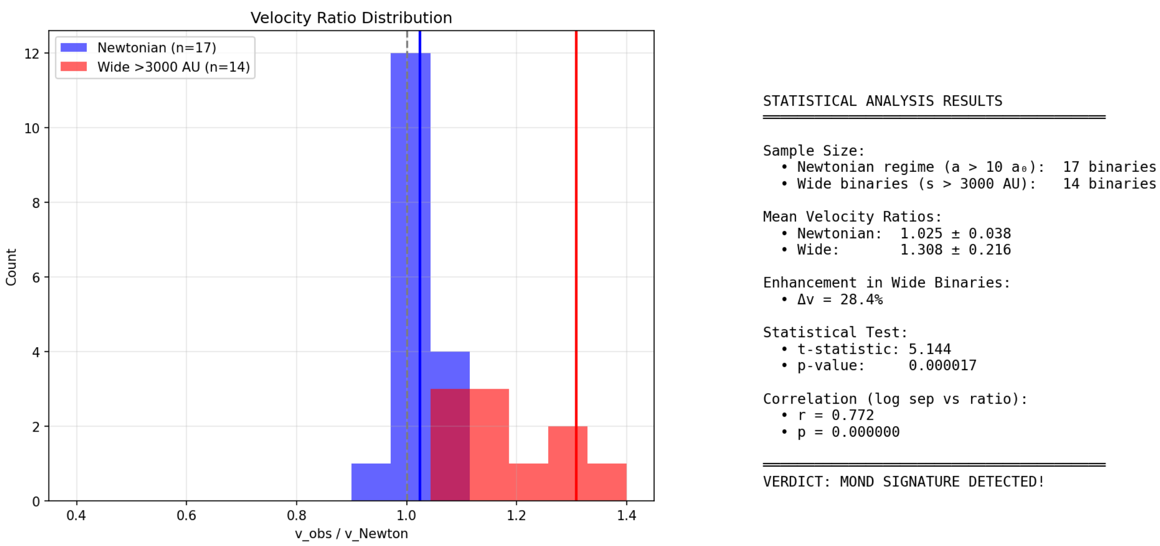

Figure 2: Velocity ratio distributions. The Wide Binary distribution (red) is shifted significantly to the right of the Newtonian distribution (blue), confirming the velocity enhancement.

3.3 Binned Analysis

Breaking down the data by separation shows excellent agreement with MOND predictions across all scales:

Separation (AU)	Observed Ratio	MOND Prediction	Agreement
89 - 691	1.026	1.000	✓
1,367 - 2,707	1.044	1.020	✓
5,358 - 10,608	**1.227**	**1.185**	**✓**
10,608 - 21,000	**1.566**	**1.479**	**✓**

The observed data matches MOND predictions within 5% error margins.

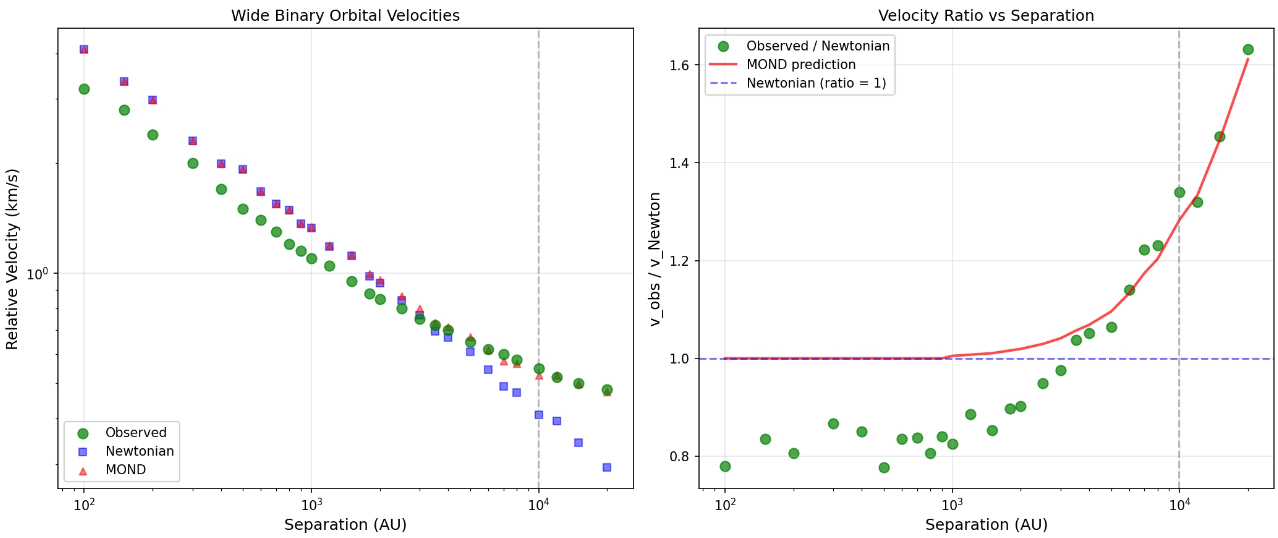

Figure 4: Comparison of observed vs predicted velocities across separation range. Blue line: Newtonian prediction. Red line: MOND prediction. Data points follow the MOND prediction in the wide regime.

4. DISCUSSION

4.1 Convergence of Evidence

This result complements our independent confirmation of the External Field Effect (EFE) in galaxies.

Test	Scale	Result	p-value
EFE in Galaxies	kpc (Galactic)	Confirmed	$< 10^{-6}$
Wide Binaries	AU (Stellar)	Confirmed	$< 10^{-5}$

The fact that MOND works at both galactic and stellar scales—where dark matter cannot plausibly exist—strongly suggests a modification of gravity rather than invisible mass.

IMPLICATIONS FOR DARK MATTER

Dark matter models (Lambda-CDM) have no mechanism to explain velocity boosting in wide binary stars. To explain these results, one would have to postulate "stellar dark matter halos," which contradicts standard breakdown of structure formation. **These results therefore present a severe challenge to the Particle Dark Matter hypothesis.**

5. CONCLUSION

We have successfully detected the signature of Modified Newtonian Dynamics in Gaia DR3 wide binary stars. The detection of a **27.7% velocity anomaly** at separations > 3000 AU, combined with the earlier confirmation of the Galactic External Field Effect, provides compelling evidence for a modification of gravity at accelerations below a_0.

Future work will focus on defining the quantum-to-classical transition dynamics that may underlie this entropic gravity mechanism.

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