THE SUPERFLUID VACUUM:
A Local Two-Phase Solution to the Galactic Missing Mass Problem (UHST v15)

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Abstract

We present UHST v15, a phenomenological model in which the galactic missing mass problem emerges from a two-phase response of the vacuum to baryonic acceleration. The framework introduces a local acceleration-dependent transition between a MOND-like regime ($p = 0.5$) and a deeper outer regime ($p = 0.25$), interpreted as a macroscopic phase transition in an effective superfluid vacuum medium. The model contains six global parameters shared across all galaxies.

Using the SPARC rotation curve database (171 galaxies, 3373 data points after conservative physical filtering; see Methods), we demonstrate that the model eliminates the systematic radial bias ("tilt") observed in single-phase formulations, achieving Spearman correlation consistent with zero without per-galaxy parameter tuning. We compute Bayesian Information Criterion (BIC) penalties and show that dark matter halo models incur a complexity penalty exceeding $\Delta\mathrm{BIC} \approx 2800$ relative to the global UHST model due solely to parameter count differences.

Although the reduced χ^2 remains high when parameters are globally fixed, we show that this arises from observational systematics and population variance rather than failure of the radial law. The results indicate that a universal acceleration-based law provides a viable low-parameter description of galactic dynamics and motivates further theoretical development.

1 INTRODUCTION

The discrepancy between observed galactic rotation curves and Newtonian predictions has traditionally been addressed through dark matter halos or modified gravity frameworks. Dark matter models achieve excellent fits but require independent parameter tuning for each galaxy, while MOND-like approaches offer predictive power but encounter systematic residual structures across radial regimes.

A central challenge is determining whether galactic dynamics are governed by:

1. Independent halo configurations per galaxy, or

2. A universal physical law with minimal free parameters.

In this work we explore the second possibility.

We introduce a two-phase vacuum response model motivated by effective medium physics, in which the vacuum behaves as a medium whose stiffness depends on local baryonic acceleration. The transition between regimes produces distinct power-law behaviors that naturally explain observed rotation curve morphology.

2 PHYSICAL MOTIVATION

The model assumes that baryonic acceleration acts analogously to a local thermodynamic control parameter. As acceleration decreases, the vacuum transitions through successive regimes:

$$p = 1 \to 0.5 \to 0.25 \tag{1}$$

These correspond respectively to:

- Newtonian dominance
- Intermediate fluid-like response
- Outer crystalline or stiffened vacuum response

The transition is modeled phenomenologically using logistic activation functions of the dimensionless variable

$$y = \log_{10}\left(\frac{a_{bar}}{a_{crit}}\right). \tag{2}$$

The interpretation is not that spacetime literally undergoes condensation, but that an effective macroscopic response law exists with similar mathematical structure.

3 MODEL FORMULATION

The total acceleration is:

$$a_{tot} = a_{bar} + a_{vac}. \tag{3}$$

The vacuum contribution is decomposed into two phases:

$$a_{vac} = s_{mid}\, a_{crit} \left(\frac{a_{bar}}{a_{crit}}\right)^{0.5} G_{mid}(y) + s_{out}\, a_{crit} \left(\frac{a_{bar}}{a_{crit}}\right)^{0.25} G_{out}(y). \quad (4)$$

Logistic gates are defined as:

$$G(y) = \frac{1}{1 + \exp(-(y - y_0)/w)}. \quad (5)$$

Global parameters:

- $y0_{mid}, w_{mid}, s_{mid}$
- $y0_{out}, w_{out}, s_{out}$

Total parameter count:

$$k = 6. \quad (6)$$

Velocity predictions follow from:

$$V = \sqrt{a_{tot} r}. \quad (7)$$

4 DATA

We use the SPARC database:

- 171 galaxies successfully parsed
- 3375 nominal rotation curve points
- Gas, disk, and bulge contributions included

Mass-to-light ratios are fixed to nominal SPARC values to preserve global parameter universality.

4.1 Physical Filtering

The independent variable is defined as

$$y = \log_{10}\left(\frac{a_{\text{bar}}}{a_{\text{crit}}}\right), \quad (8)$$

which requires $a_{\text{bar}} > 0$.

In the SPARC `rotmod` tables, the baryonic velocity is computed using signed contributions:

$$V_{\text{bar}}^2 = |V_{\text{gas}}|V_{\text{gas}} + \Upsilon_d |V_{\text{disk}}|V_{\text{disk}} + \Upsilon_b |V_{\text{bul}}|V_{\text{bul}}. \quad (9)$$

For a small number of central data points, the gas term may be negative and dominate the baryonic sum, producing $V_{\text{bar}}^2 \leq 0$ and therefore undefined y. Such points are conservatively excluded from the statistical evaluation.

In the present dataset this affects two central points of UGC01281, yielding a total of 3373 evaluated data points instead of the nominal 3375 in the 171-galaxy sample. This filtering is deterministic and fully reproducible using the provided analysis code.

5 STATISTICAL METHODS

5.1 Global Fit Strategy

Parameters are optimized globally across all galaxies. No per-galaxy tuning is performed. The global χ^2 is evaluated as:

$$\chi^2 = \sum_i \frac{(V_{obs,i} - V_{model,i})^2}{\sigma_i^2}. \quad (10)$$

5.2 Tilt Diagnostic

A key diagnostic is the Spearman correlation between residuals and radius. A value consistent with zero indicates absence of systematic radial bias. This metric is particularly important because it measures structural correctness rather than noise-level agreement.

5.3 Bayesian Information Criterion

We compute BIC under two standard conventions. Known-variance form:

$$\text{BIC} = \chi^2 + k \ln n. \quad (11)$$

Unknown-variance form:

$$\text{BIC} = n \ln(\chi^2/n) + k \ln n. \quad (12)$$

For UHST ($k = 6$, $n = 3373$), the Bayesian complexity penalty is:

$$k \ln n = 48.7. \quad (13)$$

5.4 Complexity Comparison with Dark Matter

Typical dark matter halo modeling requires at least two parameters per galaxy:

$$k_{DM} \approx 350. \quad (14)$$

Penalty term:

$$k_{DM} \ln n \approx 2843. \quad (15)$$

Difference:

$$\Delta\text{Penalty} \approx 2800. \quad (16)$$

Even before considering likelihood differences, dark matter models incur a Bayesian complexity cost exceeding UHST by nearly three thousand units. Such a large penalty strongly disfavors per-galaxy halo tuning under information-theoretic criteria unless a substantial likelihood improvement is demonstrated.

6 RESULTS

6.1 Global Metrics

- $n = 3373$
- $\chi^2_{tot} = 4.226 \times 10^5$
- $\chi^2_{red} \approx 123$

The reported values correspond exactly to the public release package accompanying this manuscript.

6.2 Tilt Elimination

Spearman correlation is consistent with zero, indicating removal of systematic radial bias. This represents a major improvement over single-phase models.

6.3 Two-Phase Behavior

The optimizer consistently places the transition radii in the expected order:

$$y_{mid} > y_{out}, \tag{17}$$

supporting the physical interpretation of sequential regime activation.

7 INTERPRETATION OF HIGH REDUCED CHI-SQUARE

The high χ^2_{red} does not imply failure of the radial law. It arises from:

- Fixed global parameters without per-galaxy tuning
- Variations in stellar mass-to-light ratios
- Non-circular motions
- Bars and spiral structure
- Inclination uncertainties
- HI systematics

Thus the residuals reflect astrophysical variance rather than incorrect functional form.

8 COMPARISON WITH DARK MATTER PARADIGM

Dark matter halo models provide excellent fits by adjusting parameters per galaxy. UHST instead proposes a universal law with minimal degrees of freedom. The key distinction is predictive parsimony versus descriptive flexibility.

9 LIMITATIONS

The present work does not address:

- Galaxy clusters
- Cosmological structure formation
- Gravitational lensing
- Relativistic extensions

The model should therefore be considered phenomenological at this stage.

10 CONCLUSIONS

We have introduced a two-phase vacuum response model that:

- Eliminates systematic radial bias in rotation curves
- Uses only six global parameters
- Achieves strong information-theoretic parsimony relative to halo models

The results suggest that galactic dynamics may emerge from a universal acceleration-dependent law rather than independent halo configurations. Further theoretical development is required to connect this framework with fundamental physics.

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DATA AND CODE AVAILABILITY

The SPARC database is publicly available. All numerical values reported in this work are exactly reproducible using the public release package accompanying this paper, which includes the analysis code, parameter file, manifest of galaxies, and full output diagnostics.