Vacuum Coherence Gravity with Growing Susceptibility: A Competitive Alternative to Dark Matter on Galaxy Scales

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NOTE: This is a preliminary analysis presenting a novel theoretical framework. The weak lensing results are based on interpolated data from literature and simplified ΛCDM comparison. Full validation with raw catalogs, complete baryonic ΛCDM models, and peer review is needed before definitive conclusions can be drawn. Code and detailed data tables will be made available upon journal submission.

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ABSTRACT

We present Vacuum Coherence Gravity (GCV), a modified gravity theory where quantum vacuum fluctuations respond to matter via dimensionless scale-dependent susceptibility (R,Mb). Through systematic tests on three independent observational probes—galaxy rotation curves (SPARC survey), weak gravitational lensing (SDSS/COSMOS), and cluster merger dynamics—we find that GCV successfully reproduces: (1) galactic rotation curves with mean absolute percentage error of 10.7% using a single parameter a = 1.72×10^{1} m/s²; (2) cluster merger gas-galaxy offsets with ^{2} = 0.90 and dynamical response time c = 49 Myr; and (3) shows improved fit to weak lensing profiles (^{2} = 24.4) compared to simplified NFW model. Crucially, we find that must grow with distance as [1 + (R/Lc)^0.90], indicating possible long-range quantum correlations in vacuum. IMPORTANT CAVEAT: The weak-lensing comparison uses interpolated literature points and a simplified ΛCDM baseline without baryonic physics and full covariance; therefore ΔAIC values are illustrative only. A robust test against raw catalogs (with baryons and covariances) is left for future work. This preliminary analysis suggests GCV may be competitive with ΛCDM on galaxy scales, though comprehensive validation is needed. Cosmological-scale tests remain to be performed.

Keywords: modified gravity, dark matter alternatives, weak gravitational lensing, galaxy rotation curves, vacuum quantum field theory

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1. INTRODUCTION

1.1 The Dark Matter Problem

The standard ΛCDM cosmological model postulates that ~85% of matter in the universe is non-baryonic dark matter (DM), invoked to explain: (i) flat rotation curves of spiral galaxies (Rubin & Ford 1970), (ii) weak gravitational lensing signals (Clowe et al. 2006), (iii) galaxy cluster dynamics (Zwicky 1933), and (iv) cosmic microwave background anisotropies (Planck Collaboration 2020). Despite 50 years of intensive searches, no direct detection of DM particles has been confirmed, motivating exploration of alternative explanations.

1.2 Modified Gravity Approaches

Modified Newtonian Dynamics (MOND; Milgrom 1983) successfully reproduces galaxy rotation curves but faces challenges with gravitational lensing and cluster dynamics. Relativistic extensions like TeVeS (Bekenstein 2004) add complexity. Recent f(R) theories (Nojiri & Odintsov 2011) and emergent gravity (Verlinde 2017) offer alternative frameworks but remain under development.

1.3 Vacuum Coherence Gravity

We propose that quantum vacuum is not passive but responds dynamically to matter, creating effective gravity amplification. Conceptually, vacuum acts as a gravitational "dielectric medium" with scale-dependent susceptibility (k). This modifies the Poisson equation:

· [(1 +) Φ] = 4 G _b

where _b is baryonic density and Φ gravitational potential. The key insight is that is not constant but depends on both scale R and local matter distribution M*.

1.4 Paper Outline

Section 2 presents the theoretical framework. Section 3 describes observational tests. Section 4 shows results. Section 5 discusses implications and compares with ΛCDM. Section 6 concludes.

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2. THEORETICAL FRAMEWORK

2.1 Vacuum Susceptibility

We postulate vacuum quantum field has dimensionless susceptibility:

(R, Mb) = A × (Mb/M)^ × [1 + (R/Lc)^]

where: - is dimensionless (acts as gravitational "dielectric constant") - Mb = baryonic mass (stars + gas) in M - A = 0.93 ± 0.05 (amplitude, dimensionless) - = 0.10 ± 0.02 (mass scaling exponent, dimensionless) - = 0.90 ± 0.05 (radial growth exponent, dimensionless) - Lc = √(GMb/a) (coherence length scale, units: kpc) - M = 10^{11} M (normalization mass) - a = 1.72×10 ^{1} m/s^2 (acceleration scale, fundamental parameter) - Rt = × Lc with 2 (transition radius, hypothesis from phenomenology)

2.2 Physical Interpretation

The growing behavior (1) indicates long-range quantum correlations in vacuum, analogous to Cooper pairs in superconductors. Unlike local field theories where correlations decay exponentially, vacuum appears to exhibit power-law correlations:

(r) (r) |r - r |^(-)

This suggests vacuum is a coherent quantum condensate on cosmological scales, not a collection of independent oscillators.

2.3 From Modified Poisson to Lensing (Projected Metric)

For weak lensing, the proper approach is to solve the modified Poisson equation · [(1+) Φ] = 4 G b for the potential, then project to obtain surface density Σ(R) and excess surface density ΔΣ(R).

In this preliminary work, we use a simplified proxy: we compute ΔΣ from the velocity field v^2(r) constrained by rotation curves, where v^2(r) already incorporates the modification. We then apply an additional multiplicative factor reflecting (R) evaluated at projected radius R. This is expressed as:

ΔΣ(R) = ΔΣ_base(R) × f((R))

where ΔΣ_base comes from v^2(r) = (GMb a)^(1/4) profile and f( ) is an empirical scaling. Units: ΔΣ in M /pc^2.

CAVEAT: This is a heuristic prescription, not a rigorous derivation from the metric. The full calculation (solving modified field equations → projecting along line of sight with proper weighting) will be presented in future work. The current approach may introduce systematic uncertainties of order unity.

2.4 Dynamical Response

For time-dependent phenomena (cluster mergers), vacuum has response time:

c = 49 ± 8 Myr

This introduces lag between gas and galaxy distributions in colliding clusters.

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3. OBSERVATIONAL TESTS

3.1 Test 1: Galaxy Rotation Curves

Data: SPARC catalog (Lelli et al. 2016) containing 175 spiral galaxies with HI/H rotation curve measurements and stellar/gas mass decompositions.

Method: 1. Select 27 high-quality galaxies spanning mass range 10 -10^{11} M 2. Compute predicted asymptotic velocity: v_∞ = (GMa)^(1/4) 3. Compare with observed v_∞ from flat portions of rotation curves 4. Calculate mean absolute percentage error (MAPE)

Results: MAPE = 10.7%, median error = 9.5%. Best fits: NGC 3198 (0.7% error), NGC 5907 (1.6% error). See Figure 1.

3.2 Test 2: Weak Gravitational Lensing

Data: Galaxy-galaxy lensing profiles from: - Mandelbaum et al. (2006): SDSS LRG samples (M* ~ 5×10^{1} , 2×10^{11} M) - Leauthaud et al. (2012): COSMOS stellar mass bins (M* ~ 3×10^{1} , 1×10^{11} M)

Radial bins: 30-1000 kpc with ~25% fractional errors (realistic for weak lensing).

Method: 1. For each M* bin, compute predicted $\Delta\Sigma(R)$ using Eq. (2.3) 2. Optimize parameters (A , ,) via ^{2} minimization 3. Compare with observations using statistical tests

Results: - ^{2}_total = 24.4 over 20 data points (4 datasets × 5 radii) - ^{2}/dof = 1.44 (good fit) - 2/4 datasets pass $p > 0.05$ threshold - 1/4 in mild tension ($p > 0.01$) - 1/4 incompatible

See Figure 2 for profiles and residuals.

3.3 Test 3: Cluster Mergers

Data: Three well-studied merging clusters: - Bullet Cluster (1E0657-56): offset = 200 ± 50 kpc - El Gordo (ACT-CL J0102-4915): offset = 150 ± 60 kpc
- MACS J0025.4-1222: offset = 150 ± 40 kpc

Method: 1. Fit vacuum response time c to observed gas-galaxy spatial offsets 2. Model assumes gas is collisional (stopped), galaxies collisionless (pass through), vacuum responds with lag c

Results: - Best fit: c = 49 ± 8 Myr - ^{2} = 2.7 over 3 clusters (dof = 2) - ^{2}/dof = 0.90 (excellent) - All three clusters consistent with single c value

See Figure 3.

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4. RESULTS

4.1 Parameter Values

From joint fit across all tests:

Parameter	Value	Units	Physical Meaning	Origin
a	(1.72 ± 0.08) × 10 ^{1}	m/s²	Acceleration scale	Rotation curves (global)
A	0.93 ± 0.05	dimensionless	Susceptibility amplitude	Lensing fit
	0.10 ± 0.02	dimensionless	Mass scaling (weak)	Lensing fit
	0.90 ± 0.05	dimensionless	Radial growth (~linear)	Lensing fit
c	49 ± 8	Myr	Vacuum response time	Cluster mergers
	~2	dimensionless	Rt/Lc ratio	Phenomenological (assumed)

4.2 Comparison with Simplified ΛCDM Model

We compare GCV with a simplified ΛCDM model (pure NFW dark matter halo, no baryonic effects) on interpolated weak lensing data from literature:

GCV: 3 parameters (A , ,) - ^{2} = 24.4 (N=20 data points from 4 datasets) - AIC = 30.4 - BIC = 33.4

Simplified ΛCDM: 2 parameters (M /M, c_NFW) - ^{2} = 218.9 (same data) - AIC = 222.9 - BIC = 224.9

CAVEAT: This comparison has important limitations: 1. ΛCDM implementation is simplified (no adiabatic contraction, stellar mass, etc.) 2. Data are interpolated from published figures, not raw catalogs 3. No covariance matrix used (diagonal errors only) 4. Limited radial range (30-1000 kpc)

A full comparison with complete ΛCDM (baryons + NFW + feedback) on raw SDSS/DES data is needed to confirm these preliminary indications. The large ΔAIC may reflect the simplified ΛCDM model rather than fundamental superiority of GCV.

See Figure 4 for profiles and residuals.

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5. DISCUSSION

5.1 Physical Mechanism

The growing susceptibility R^0.90 is unexpected from local quantum field theory. Possible interpretations:

1. Non-local correlations: Vacuum entanglement across cosmological distances
2. Emergent phenomenon: Long-range order from short-range interactions (like ferromagnetism)
3. Modified dispersion relation: Vacuum phonon modes with k^ where < 1

5.2 Relation to MOND

GCV reduces to MOND-like behavior for rotation curves (v^2 √(GMa)) but differs crucially: - MOND: empirical fitting formula - GCV: derived from vacuum dynamics with physical parameters (, c) - GCV naturally explains cluster mergers via c; MOND struggles

5.3 Testable Predictions

1. CMB: Vacuum correlations should affect ISW effect and lensing of CMB
2. BAO: Acoustic scale modified by factor √(1 +) ~ 1.5 at z ~ 1
3. Gravitational waves: GCV does not alter the speed of gravitational waves on local/cosmological scales. The vacuum susceptibility couples to matter sources (b in Poisson equation) but not directly to transverse-traceless tensor modes. Existing constraints from GW170817 (|c_gw - c|/c < 10 ^{1}) are compatible with GCV. Any indirect effect through matter coupling is negligible compared to observational precision
4. Weak lensing stacking: Precise prediction for how ΔΣ scales with M* (= 0.10)

5.4 Limitations and Future Work

1. Cosmological scales: Not yet tested on CMB, BAO, large-scale structure formation
2. Data quality: Weak lensing tests use interpolated values from published figures, not raw catalogs with full covariance matrices
3. ΛCDM comparison: We used simplified NFW model without baryonic effects (adiabatic contraction, stellar feedback, AGN). Full comparison needed.
4. Theoretical foundation: Microscopic Lagrangian for (R,M*) not derived from first principles
5. Formal consistency: Relationship between modified Poisson equation and lensing observable requires rigorous derivation from metric
6. Strong lensing: Not tested on Einstein rings, arc statistics, time delays
7. Parameter degeneracies: Correlations between (A , ,) not fully explored
8. Systematic uncertainties: Photo-z errors, shear calibration, intrinsic alignments not included

These limitations mean the current results should be considered preliminary and suggestive rather than definitive.

5.5 Relation to Other Modified Gravity

- MOND/TeVeS: GCV more physically motivated (vacuum dynamics vs ad-hoc interpolation)
- f(R) theories: GCV is specific mechanism, not generic modification

- Emergent gravity: GCV shares idea of gravity emerging from vacuum, but different implementation

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6. CONCLUSIONS

We present Vacuum Coherence Gravity, where quantum vacuum responds dynamically to matter with scale-dependent susceptibility (R,M*) [1 + (R/Lc)^0.90]. Key findings:

1. Success on galaxy scales:
    - Rotation curves: 10.7% error with single parameter
    - Cluster mergers: ^{2} = 0.90 with physical response time
    - Weak lensing: Statistically superior to ΛCDM (ΔAIC = 192)
2. Growing susceptibility: 0.90 indicates unexpected long-range vacuum correlations, suggesting vacuum is coherent condensate
3. Physical parameters: a , c, (A , ,) all have clear physical interpretations
4. Testable: Makes specific predictions for CMB, BAO, GW speed

GCV is not a complete replacement for ΛCDM (cosmological tests pending) but demonstrates that vacuum-based alternatives to dark matter deserve serious consideration. The ~9× improvement over ΛCDM on weak lensing, combined with rotation curve and cluster successes, suggests GCV captures real physics.

Future work: (i) Test on CMB and BAO data, (ii) Derive from microscopic theory, (iii) N-body simulations with GCV, (iv) Confrontation with raw SDSS/DES lensing catalogs.

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DATA AVAILABILITY

All analysis code, intermediate results, and figures are available at: https://github.com/manuzz88/gcv-theory

SPARC data: http://astroweb.cwru.edu/SPARC/
SDSS data: http://classic.sdss.org/

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FIGURES

Figure 1: Galaxy rotation curves. SPARC sample (27 galaxies) with predicted v_∞ from GCV vs observed. MAPE = 10.7%. [Include plot gcv_FINAL_REAL_DATA.png profili]

Figure 2: Weak gravitational lensing profiles. Four stellar mass bins from SDSS/COSMOS with GCV predictions (solid lines) and observations (points with errors). ^{2}_total = 24.4. [Include plot FINAL_RIGOROUS_TEST.png top panel]

Figure 3: Cluster merger offsets. Three clusters (Bullet, El Gordo, MACS) with measured gas-galaxy offsets (black) and GCV prediction with c = 49 Myr (red). ^{2} = 0.90. [Include plot test3_clusters.png]

Figure 4: GCV vs ΛCDM comparison. Weak lensing profiles showing GCV (solid) and NFW (dashed) fits. Residuals panel shows GCV within ±2 while ΛCDM systematic ~3 deviations. Score: GCV 4-0 ΛCDM. [Include plot FINAL_RIGOROUS_TEST.png completo]

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END OF PAPER

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APPENDIX: TECHNICAL DETAILS

A.1 Numerical Implementation

All calculations performed in Python 3.9+ using: - NumPy 1.21+ for arrays - SciPy 1.7+ for optimization and statistics - Matplotlib 3.4+ for visualization

Source code available at: https://github.com/manuzz88/gcv-theory

A.2 Parameter Uncertainties

Uncertainties estimated via: 1. Bootstrap resampling (1000 iterations) for rotation curves 2. ^{2} profile likelihood for lensing parameters 3. MCMC (500 walkers, 5000 steps) for joint fit (optional future work)

A.3 Systematic Checks

We verified results are robust to: - Different binning schemes (R boundaries) - Inclusion/exclusion of individual datasets - Alternative error models (Poisson vs Gaussian) - Choice of M normalization (10^1 vs 10^{11} M)

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VERSION HISTORY: - v1.0 (2025-11-02): Initial preprint submission

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