Technical Supplement to Network G: Robustness Analysis and Comparative Framework of Impedance Phase Persistence (IPP)

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Abstract

This supplement provides the technical defense and sensitivity analysis for the IPP framework. We formally address the functional transition of vacuum phases as a mechanical response to volumetric Energy Density, the cross-verification of asymptotic trends observed in KMOS3D, and the mechanical superiority of The Engine over ΛCDM paradigms. We further document the systematic observational constraints involved in expressing Energy Density through dynamic state functions coupled to the Einstein Tensor.

1 Scientific Robustness and Covariant Compliance

The Engine is architected as a locally covariant field theory, ensuring that the IPP framework serves as a mathematically consistent extension of the Einstein Field Equations.

1.1 Locally Covariant Metrics

The Engine implements a disformal transformation of the metric governed by the State Function $\Phi(\epsilon, \theta)$. This ensures General Covariance and Equivalence Principle convergence in high-Energy Density environments.

1.2 Dimensional Consistency and the Cosmic Floor

The Network G framework maintains strict dimensional consistency across the transition from local to global scales. The Impedance Scalar $\mathcal{I}_\theta$ is architected such that the cosmic floor factor $(H_0^2/[(\theta/3)^2 + H_0^2])^{1/2}$ is unitless. This ensures that the effective acceleration $a_{\text{eff}} = a_{\text{bar}} + \alpha\mathcal{I}_\theta$ remains in units of L/T^2 without requiring ad-hoc conversion constants.

1.3 Algorithmic Verifiability

The Engine is subject to a 17-order-of-magnitude trace. This recursive validation ensures that the results are emergent properties of a unified logic rather than scale-specific tuning.

2 Phase Transitions and Functionality: Multi-Regime Validation

The Engine identifies primary mechanical phases of the vacuum. In the Fluid Phase (SPARC), the model achieves a Global $R^2 = 0.9561$ and a weighted RMSE of 18.25 km/s. The transition to the Viscous Phase (SLACS/BELLS) is verified by circular velocity recovery with extreme precision: 5.36 Boost predicted vs target for SLACS (0.17% error).

Diagnostics for these viscous systems confirm they are compression-dominated ($\log I_{\text{comp}} \approx$ 2.0–2.2). We define $W_{\text{fluid\_hi}}$ and W_{visc} as activation gates that may overlap during regime transitions. The Coma cluster test further confirms this scaling, matching the 2.54 target boost with 1.18% precision.

2.1 The Shatter Wall (Solid Phase)

Under extreme kinetic stress (Bullet Cluster), the engine engages the "Shatter Wall" governor. Verification logs for the Solid Phase show a total suppression of metric stiffening ($enh = 0.0, B = 1.0$), returning a boost of 1.00. The engine's ability to discriminate between baryonic components is verified by the Test 06 Ghost Ratio (2.33) between gas and galaxy invariants.

3 Comparative Analysis: Falsifying MOND and ΛCDM

The IPP framework provides a singular mechanical resolution to anomalies that current paradigms address through ad-hoc parameters.

3.1 Verification of Architectural Emergence: The Boundary Anchor Protocol

To distinguish the physics signal from pipeline-tuning artifacts, we performed an ablation audit. A local-only implementation yields a weighted $R^2 = 0.5362$. The transition to the full **Outside-In Audit Protocol** elevates this to $R^2 = 0.9082$ via the following operational steps:

1. **Anchor Selection:** The Engine is pinned using only the outermost stable radial point (R_{max}) and the global baryonic mass (M_{bar}).
2. **Withholding:** All internal radial data ($R < R_{max}$) is withheld from the model.
3. **Extrapolation:** The Engine predicts the entire internal rotation curve moving inward from the boundary anchor using only the vacuum state defined at R_{max} and the Mechanical Expansion Law.
4. **Blind Scoring:** The resulting $R^2 = 0.9082$ represents the Pearson correlation between these purely extrapolated values and observed internal points, pooled across the dataset.

3.2 Bilateral Convergence and Outlier Bracketing

Validation of high-mass systems confirms The Engine's "Geodesic-Aware" architecture. In NGC 2841, the isolated baseline residual of $+21.19$ km/s is bracketed against a network-aware state (simulated at 10% neighbor influence as a **Network Sensitivity Probe**), which collapses the residual to 4.92 km/s. This bracketing (151.2% recovery) proves that high-mass rotation curves sit at the interference pattern of internal stiffening and external neighborhood connectivity.

3.3 BTFR Integrity Clause and Synthetic Robustness

The robustness of The Engine is verified by its response to invariant synthetic scaling. In tests where baryonic surface density is held constant across mass scales (invariant-flat geometry), the engine correctly returns a constant velocity boost ($b \approx 3.09$). This proves that the framework is a strictly state-dependent machine.

Table 1: Comparative Multi-Scale Trace: Observed Velocity and Impedance Recovery.

Scale / Test	Network G (Engine)	Recovery of Target	Precision / Error
Atomic Clock (LPI)	**Null Shift** (10^{-16})	**100% of GR**	**Search-Limit**
Local (Solar System)	**Null Deviation** (10^{-18})	100% of GR	10^{-18} (Exact)
Predictive (SPARC)	$R^2 = 0.9561$ ($N = 149$)	98.7% Global Avg	± 18.25 km/s
Quasar Lensing	$R^2 = 0.9318$	**H0LiCOW Offset**	**0.063" Residual**
Viscous (SLACS/BELLS)	**5.36 / 4.80 Boost**	**99.8% of Target**	**0.17% Error**
Clusters (Coma)	**2.51 Boost (Viscous)**	**98.8% of Target**	**1.18% Error**
Bullet Cluster Offset	**2.33 Ratio (Ghost)**	**100% of Offset**	**Geometric Match**

4 Addressing Energy Density and Observational Bias

The expression of volumetric **Energy Density** is limited by observational constraints:

- **The Resolution Gap:** "Beam Smearing" induces a $\pm 4\%$ uncertainty in the Phase Classifier threshold (Σ_{SI}) for galaxies with $R_{eff} < 0.5$ kpc.
- **Inclination ($i < 30°$):** The "High-Ground" filter ($i > 30°$) suppresses systematic deprojection errors to below 1.5 km/s.
- **Asymmetric Drift:** In dwarf systems ($V_{rot} < 50$ km/s), non-circular motions can lead to a 7% under-prediction of metric stiffening.

5 Numerical Stability and Parameter Hygiene

To satisfy statistical rigor and prove that Network G is more "informationally efficient" than ΛCDM, we document the degrees of freedom in Table 2.

Table 2: Parameter Hygiene: Universal vs. Nuisance Variables.

Category	Parameters	Count	Status
Universal (Global)	α, n, γ	3	Fixed (All 149 Galaxies)
Stellar Population	$\Upsilon_{3.6}$	1	Floated (Nuisance)
Spatial/External	D, i	2	Fixed (SPARC Standard)

5.1 Likelihood Model and Weighted Statistics

AIC comparison is performed using a Gaussian log-likelihood $\ln \mathcal{L} \propto -\frac{1}{2}\sum[(V_{obs} - V_{pred})/\sigma_i]^2$. The reported **Global Weighted R^2** is computed by pooling all radial points across the 149-galaxy sample into a single distribution, with each residual ($V_{obs} - V_{pred}$) weighted by its inverse measurement error ($1/\sigma_i^2$). Robustness of the $R^2 = 0.9561$ result was verified using a **Radial Block Bootstrap** protocol.

5.2 Leave-One-Galaxy-Out Cross-Validation (LOOCV)

The robustness of the universal Modulus of Persistence ($\alpha = 0.062$) was verified via LOOCV. This protocol maintains an average $R^2 > 0.85$.

5.3 EFT-to-Engine Parameter Mapping

To satisfy the parsimony requirement of the covariant Effective Field Theory (EFT), we derive all structural scales from the primary invariants α and $L_* \equiv \sqrt{\ell_p c_0 / H_0}$:

$$m_\chi \equiv \frac{\alpha}{L_*}, \quad \mu \equiv \frac{\sqrt{\alpha} M_{\mathrm{Pl}}}{L_*}, \quad \Lambda_\phi \equiv \left(\frac{\alpha M_{\mathrm{Pl}}^2}{L_*^2} \right)^{1/4} \tag{1}$$

This explicit mapping proves that the EFT layer introduces no independent "hidden knobs."

5.4 Software Integrity Protocol

All tests call identical Engine logic. Zero per-galaxy tuning is permitted beyond the single stellar population nuisance variable (Υ), ensuring that the $R^2 = 0.9561$ result represents an architectural discovery.