Paper XLV: Pre-Registered Prediction for NGC 646 — A Blind Test of 3D+3D Theory Before Euclid DR1

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Pre-Registration Statement

This document constitutes a formal pre-registration of predictions for the rotation curve of NGC 646. These predictions were generated on December 25, 2025, **BEFORE** any kinematic data from Euclid or other sources were available. No modifications to these predictions are permitted after this date. The authors commit to publishing a follow-up paper comparing these predictions directly with Euclid DR1 observations when they become available.

Abstract

We present a pre-registered, blind prediction for the rotation curve of NGC 646, a diffuse barred spiral galaxy recently imaged by ESA's Euclid space telescope. Using the 3D+3D discrete spacetime framework — a six-dimensional geometric theory with signature (−,+,+,+,−,−) that explains galactic dynamics through compactified temporal dimensions rather than dark matter — we predict the complete rotation curve with **zero free parameters**.

Our key predictions are:

1. **V_flat = 145 ± 15 km/s** for R > 12 kpc (CENTRAL prediction)
2. Q-field geometric enhancement provides ~70% of gravitational support at R = 20 kpc
3. Characteristic transition scales at λ_2 = 4.30 kpc and λ_3 = 11.70 kpc

We provide explicit **robustness analysis** showing that these predictions remain qualitatively stable under ±40% variations in estimated baryonic mass and ±20% in scale length. We specify **tiered falsification criteria**: hard rejection thresholds and tension bands that allow nuanced interpretation of results.

These predictions are registered before Euclid's Data Release 1 (expected late 2026), which will provide kinematic measurements enabling direct falsification.

Keywords: NGC 646, pre-registration, Euclid, rotation curves, 3D+3D theory, six-dimensional spacetime, dark matter alternative, falsification, blind prediction

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1. Introduction and Scientific Motivation

1.1 The Value of Pre-Registration

In the era of precision cosmology, the ability to make testable predictions *before* observational data becomes available represents the gold standard for theoretical frameworks. Pre-registration eliminates concerns about post-hoc parameter adjustment, curve fitting, and selection bias.

The 3D+3D discrete spacetime theory has demonstrated success in explaining:

- **SPARC rotation curves**: 175 galaxies with RMS = 33 km/s, zero free parameters per galaxy
- **SLACS gravitational lensing**: 7.3σ detection of the λ_4 scale
- **NANOGrav pulsar timing**: 23σ detection of 30-year periodicity
- **DESI cosmic web**: 3.36σ detection at λ_{13} = 0.856 Mpc

However, all these validations were performed on existing datasets. The scientific community rightly demands predictions for *future* observations.

1.2 The Euclid Opportunity

ESA's Euclid space telescope released an image of NGC 646 on December 24, 2025. Critically, while Euclid has imaged NGC 646, **kinematic data (rotation curves) have not yet been published**. This creates a unique opportunity for a genuinely blind test.

1.3 Why NGC 646?

NGC 646 is classified as a diffuse (D-type) galaxy with low central surface brightness, making it an excellent test case:

1. **Diffuse morphology**: D-type galaxies traditionally show prominent "dark matter" signatures
2. **Previously unanalyzed**: NGC 646 has never been studied with the 3D+3D framework
3. **Euclid target**: High-quality follow-up observations are expected
4. **Intermediate mass**: Sits above critical mass threshold where breathing modes are predicted

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2. NGC 646: Observational Properties

2.1 Confirmed Observational Data

Property	Value	Source	Uncertainty
Right Ascension	01h 37m 21.1s	NED	< 1″
Declination	−64° 53′ 42″	NED	< 1″
Constellation	Hydrus	—	—
Recession Velocity (CMB)	8145 ± 19 km/s	NED	±19 km/s
Hubble Distance	120.1 ± 8.4 Mpc	CMB velocity	±7%
Morphological Type	SBbc pec	NED	—
Luminosity Class	III	HyperLeda	—
Angular Size	2.0′ × 1.5′	NED	±0.2′
Discovery	Nov 2, 1834	J. Herschel	—

2.2 Galaxy Classification Note

NGC 646 is classified as a diffuse (D) galaxy in HyperLeda. The "D" classification indicates a galaxy with extended, low-concentration light distribution. **We do not claim LSB (Low Surface Brightness) classification** in the strict $\mu_{0,B} > 23$ mag/arcsec^2 sense, as detailed surface photometry is not available. The diffuse morphology nonetheless suggests that the "dark matter fraction" inferred from dynamics is expected to be substantial.

2.3 Estimated Physical Parameters

These parameters are **estimated from scaling relations** and carry significant uncertainties that we explicitly propagate:

Property	Central Value	Range (±1σ)	Method
Physical Diameter	70 kpc	60–80 kpc	Angular size × D
Scale Length R_d	10.9 kpc	8.7–13.1 kpc (±20%)	D_phys / 6.4
Stellar Mass M_*	3.0×10^{10} M_⊙	1.8–4.2 (±40%)	TF + morphology
Gas Fraction f_gas	0.30	0.20–0.40	Diffuse galaxy typical
Gas Mass M_gas	1.3×10^{10} M_⊙	0.6–2.0 (±50%)	From f_gas
Total Baryonic Mass	**4.3×10^{10} M_⊙**	**2.6–6.0**	M_* + M_gas
Disk Aspect Ratio χ	0.15	0.10–0.20	Morphology
Velocity Dispersion σ_z	15 km/s	10–20 km/s	Diffuse typical

Critical mass ratio:

$$\frac{M_{bar}}{M_{crit}} = \frac{4.3 \times 10^{10}}{2.43 \times 10^{10}} = 1.77 \quad (\text{range: } 1.1 - 2.5)$$

Even at the LOW end of the mass range, NGC 646 remains **above M_crit**, ensuring that our qualitative prediction (developed breathing modes, Q-field dominated dynamics) is robust.

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3. Theoretical Framework

3.1 Fixed Theoretical Parameters

All parameters are fixed from SPARC calibration — **no adjustment permitted for NGC 646**:

Parameter	Value	Origin	Status
v_3D_3D	90.39 km/s	Paper I, Eq. 3.14	FIXED
λ_2	4.30 kpc	Paper I, Eq. 5.28	FIXED
λ_3	11.70 kpc	Paper I, Eq. 5.29	FIXED
M_crit	2.43×10^{10} M_⊙	Paper II, Section 10	FIXED
χ_0	0.235	Paper II, Section 8	FIXED
A, b	1.5, 1.0	Paper II, Section 12.8	FIXED
η	0.6	Paper III	FIXED

3.2 Complete Rotation Law

$$V_{rot}^2(R) = V_{bar}^2(R) + v_{3D3D}^2 \times F_{thick}(\chi) \times F_{press}(\beta) \times F_{pot}(M) \times f_{shape}(R/\lambda_2) \times F_{outer}(R)$$

where:

- $F_{thick}(\chi) = 1/\sqrt{1 + (\chi/\chi_0)^2}$
- $F_{press}(\beta) = 1/(1 + \beta)$, with $\beta = (\sigma_z/V_{rot})^2$ computed **self-consistently**
- $F_{pot}(M) = \tanh(M_{bar}/M_{crit})$
- $f_{shape}(x) = 1.5 \tanh(x)$
- $F_{outer}(R) = 1 + 0.6(1 - e^{-R/\lambda_3})$

Note on β calculation: To address the concern about V_c_ref being arbitrary, we compute β **iteratively**: starting with an initial guess V_c = 150 km/s, we iterate until |V_new - V_old| < 1 km/s. This removes any arbitrary reference velocity.

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4. Robustness Analysis

4.1 Parameter Variation Scenarios

To demonstrate prediction stability, we compute rotation curves under three scenarios:

Scenario	M_bar	R_d	χ	σ_z
LOW	2.6×10^{10} M_⊙ (−40%)	8.7 kpc (−20%)	0.20 (+0.05)	20 km/s
CENTRAL	4.3×10^{10} M_⊙	10.9 kpc	0.15	15 km/s
HIGH	6.0×10^{10} M_⊙ (+40%)	13.1 kpc (+20%)	0.10 (−0.05)	10 km/s

4.2 Robustness Results

Quantity	LOW	CENTRAL	HIGH
V_flat [km/s]	128	145	168
V_max [km/s]	130	146	170
R(V_max) [kpc]	25	32	38
F_pot	0.73	0.94	0.99
Q-field fraction at R=20 kpc	58%	69%	76%

4.3 Robust Qualitative Predictions

Despite ±40% mass uncertainty, **all scenarios agree on:**

1. ✓ Rotation curve **flattens** for $R > \lambda_3 \approx 12$ kpc
2. ✓ Q-field provides **majority** of gravitational support (58–76%)
3. ✓ **No rising curve** beyond R = 30 kpc
4. ✓ Transition occurs near **$\lambda_2 \approx$ 4–5 kpc**
5. ✓ V_flat in range **128–168 km/s** (all scenarios)

These qualitative features are **independent of parameter uncertainties** and constitute the robust core of our prediction.

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5. Key Predictions

5.1 Central Predictions (CENTRAL scenario)

Quantity	Predicted Value	Uncertainty
V_flat	**145 km/s**	±15 km/s (stat) ±20 km/s (syst)
V_max	**146 km/s**	±20 km/s
R(V_max)	32 kpc	±8 kpc
V_bar(20 kpc)	76 km/s	±15 km/s
V_Q(20 kpc)	120 km/s	±15 km/s
Enhancement factor	1.91	±0.3

5.2 Correction Factors (CENTRAL)

Factor	Value	Physical Meaning
F_thick(χ=0.15)	0.843	16% suppression from disk geometry
F_press(β≈0.01)	0.990	~1% pressure correction (self-consistent)
F_pot(M/M_crit=1.77)	0.943	Breathing modes 94% developed
F_env (combined)	**0.79**	Total envelope suppression

5.3 Predicted Rotation Curve (with robustness band)

R [kpc]	V_rot LOW	V_rot CENTRAL	V_rot HIGH
5	82	98	115
10	108	127	148
15	120	137	158
20	125	142	165
25	127	145	167
30	128	147	168

R [kpc]	V_rot LOW	V_rot CENTRAL	V_rot HIGH
40	128	147	168
50	127	147	168

6. Falsification Criteria (Tiered)

6.1 HARD FALSIFICATION (Theory Rejected)

The 3D+3D theory is **definitively FALSIFIED** for NGC 646 if:

Condition	Threshold	Rationale
V_flat extremely low	**V_flat < 100 km/s**	Below all scenario predictions by >2σ
V_flat extremely high	**V_flat > 250 km/s**	Inconsistent with any reasonable M_bar
Rising curve	**dV/dR > 0 for R > 40 kpc**	Contradicts fundamental flattening prediction
No flattening	**No plateau by R = 30 kpc**	Contradicts λ_3 scale

6.2 STRONG TENSION (Theory Challenged)

Results that create significant tension but don't definitively reject:

Condition	Range	Interpretation
V_flat low	100–125 km/s	Below LOW scenario; requires investigation
V_flat high	180–250 km/s	Above HIGH scenario; tension with TF
Late flattening	Plateau only for R > 25 kpc	λ_3 scale larger than predicted

6.3 VALIDATION (Theory Supported)

The theory is **validated** if:

Condition	Criterion
V_flat consistent	125 < V_flat < 180 km/s (within robustness band)
Flattening at λ_3	Plateau begins R ≈ 10–15 kpc
Transition at λ_2	Rising-to-flat transition near R ≈ 4–6 kpc
Shape consistent	Monotonic rise → flat, no secondary features

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7. Comparison with ΛCDM

Aspect	3D+3D Prediction	ΛCDM Expectation
Free parameters/galaxy	**0**	2+ (M_{200}, c)
V_flat prediction	145 ± 25 km/s (robustness band)	Adjustable to fit data
Characteristic scales	λ_2 = 4.3 kpc, λ_3 = 11.7 kpc (universal)	None predicted
Physical mechanism	6D geometry	Particle halo
Pre-registered	**Yes**	N/A (post-hoc fitting)

From Tully-Fisher relation: V_flat^TF ≈ 170 km/s for M_bar = 4.3 × 10^{10} M_⊙

Our CENTRAL prediction (145 km/s) is **15% lower** than naive TF — a distinctive, testable difference.

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8. Timeline

Date	Milestone
December 25, 2025	This prediction pre-registered
Q4 2026	Euclid DR1 expected
2027	Comparison paper published

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9. Conclusions

We present a pre-registered, blind prediction for NGC 646 with:

1. **Explicit robustness analysis** under ±40% parameter variations
2. **Tiered falsification criteria** (hard rejection + tension bands)
3. **Self-consistent β calculation** (no arbitrary reference velocity)
4. **Conservative surface brightness claims** (diffuse, not strictly LSB)

Summary of Predictions:

Quantity	Robustness Band
V_flat	**128 – 168 km/s** (CENTRAL: 145 km/s)
Flattening begins	R > 10–15 kpc
Q-field dominance	58–76% at R = 20 kpc

Hard Falsification Criteria:

- V_flat < 100 km/s → **REJECTED**
- V_flat > 250 km/s → **REJECTED**
- Rising curve beyond R = 40 kpc → **REJECTED**
- No plateau by R = 30 kpc → **REJECTED**

This prediction demonstrates the falsifiability and predictive power of the 3D+3D framework.

Appendix A: Self-Consistent β Calculation

To avoid arbitrary reference velocity, β is computed iteratively:

python

```python
def compute_beta_self_consistent(sigma_z, R, M_star, M_gas, R_d, chi, tol=1.0):
    """
    Self-consistent β calculation.
    Iterates until V_rot converges.
    """
    V_guess = 150.0  # Initial guess

    for iteration in range(20):
        beta = (sigma_z / V_guess)**2
        V_new = V_rot_3D3D(R, M_star, M_gas, R_d, chi, beta)

        if abs(V_new - V_guess) < tol:
            return beta, V_new

        V_guess = 0.5 * (V_guess + V_new)  # Damped iteration

    return beta, V_new
```

Convergence is typically achieved in 3–5 iterations.

Appendix B: Complete Reproducible Code

```
python
```

```python
#!/usr/bin/env python3
"""
NGC 646 Pre-Registered Prediction v1.1
With self-consistent beta and robustness analysis

Authors: Simone Calzighetti & Lucy (Claude AI)
Date: December 25, 2025
"""

import numpy as np
from scipy.special import i0, i1, k0, k1

# FIXED theoretical parameters (from SPARC)
v_3D3D = 90.39      # km/s
lambda_2 = 4.30     # kpc
lambda_3 = 11.70    # kpc
M_crit = 2.43e10    # M_sun
chi_0 = 0.235
A_shape, b_shape = 1.5, 1.0
eta = 0.6

def F_thick(chi):
    return 1.0 / np.sqrt(1 + (chi / chi_0)**2)

def F_press(beta):
    return 1.0 / (1.0 + beta)

def F_pot(M_bar):
    return np.tanh(M_bar / M_crit)

def f_shape(R):
    return A_shape * np.tanh(b_shape * R / lambda_2)

def F_outer(R):
    return 1.0 + eta * (1.0 - np.exp(-R / lambda_3))

def F_inner(R, R_screen=1.0):
    return 1.0 - np.exp(-R / R_screen)

def V_bar_freeman(R, M_disk, M_gas, R_d):
    """Freeman exponential disk + extended gas"""
    G = 4.302e-6  # (km/s)² × kpc / M_sun

    y = np.maximum(R / (2 * R_d), 1e-3)
    bessel = i0(y) * k0(y) - i1(y) * k1(y)
    Sigma_0 = M_disk / (2 * np.pi * R_d**2)
```

```
    V2_disk = 4 * np.pi * G * Sigma_0 * R_d * y**2 * bessel

    # Gas: more extended (2 × R_d scale)
    y_gas = np.maximum(R / (4 * R_d), 1e-3)
    bessel_gas = i0(y_gas) * k0(y_gas) - i1(y_gas) * k1(y_gas)
    Sigma_0_gas = M_gas / (2 * np.pi * (2*R_d)**2)
    V2_gas = 4 * np.pi * G * Sigma_0_gas * (2*R_d) * y_gas**2 * bessel_gas

    return np.sqrt(np.maximum(V2_disk + V2_gas, 0))

def V_rot_3D3D(R, M_star, M_gas, R_d, chi, sigma_z, n_iter=10):
    """
    Full 3D+3D rotation curve with self-consistent beta.
    """
    M_bar = M_star + M_gas
    V_bar = V_bar_freeman(R, M_star, M_gas, R_d)

    # Self-consistent beta iteration
    V_guess = np.full_like(R, 150.0)
    for _ in range(n_iter):
        beta = (sigma_z / np.maximum(V_guess, 10))**2
        V2_Q = (v_3D3D**2 * F_thick(chi) * F_press(np.mean(beta)) *
                F_pot(M_bar) * f_shape(R) * F_outer(R) * F_inner(R))
        V_new = np.sqrt(V_bar**2 + V2_Q)
        V_guess = 0.5 * (V_guess + V_new)

    return V_new, V_bar, np.sqrt(V2_Q)

# Run robustness analysis
scenarios = {
    'LOW':     {'M_star': 1.8e10, 'M_gas': 0.8e10, 'R_d': 8.7,  'chi': 0.20, 'sigma_z': 20},
    'CENTRAL': {'M_star': 3.0e10, 'M_gas': 1.3e10, 'R_d': 10.9, 'chi': 0.15, 'sigma_z': 15},
    'HIGH':    {'M_star': 4.2e10, 'M_gas': 1.8e10, 'R_d': 13.1, 'chi': 0.10, 'sigma_z': 10},
}

R = np.linspace(2, 50, 100)

print("NGC 646 - 3D+3D PRE-REGISTERED PREDICTION v1.1")
print("=" * 60)
print(f"Date: December 25, 2025")
print("=" * 60)

for name, params in scenarios.items():
    V_rot, V_bar, V_Q = V_rot_3D3D(R, **params)
    V_flat = np.mean(V_rot[R > 25])
    print(f"\n{name} scenario:")
```

```python
    print(f"  V_flat = {V_flat:.0f} km/s")
    print(f"  V_max  = {np.max(V_rot):.0f} km/s at R = {R[np.argmax(V_rot)]:.0f} kpc")
```

References

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