Spacetime Duality Principle Simulating Galactic Rotation Curves

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Abstract

Based on the spacetime duality principle, this paper proposes a theoretical model for galaxy rotation curves that does not require the dark matter hypothesis, replacing the traditional role of dark matter through quantum gravity correction terms. The core innovations are as follows: 1. Theoretical model orbital velocity formula: v(r) = $\sqrt{\frac{GM(r)}{r} + \frac{k(r)G_h M(r)^2 \ln r}{r}}$ where: Classical term: (G M(r))/r (Newtonian gravity) Quantum correction term: (k Gh M(r)2 ln r)/r (dark matter replacement mechanism) Dynamic parameters: Mass distribution: M(r) = Mbaryon,topo (1 - e-r/r0) (piecewise description of galactic bulge and disk regions) Entanglement factor: k(r) = k0 (rref/r)α (controls quantum gravity attenuation, α determines outer region flattening) 2. Observational verification Milky Way (α = 0.3): peak velocity 250 km/s (r=10 kpc), error < 10 km/s (maximum deviation of 13% at 5 kpc). Outer region flattening is dominated by quantum corrections, no dark matter halo required. Andromeda galaxy (α = 1.5): steep velocity rise in inner region (248.8 km/s) (r=2 kpc), rapid decay in outer region (error 4–15%). The difference in α values reflects its more concentrated mass distribution (high bulge proportion). 3. Advantages and significance Resolving the dark matter contradiction: the quantum correction term (k Gh M(r)2 ln r)/r naturally explains rotation curve flattening (e.g., v 212 km/s at 20 kpc for the Milky Way). Physical measurability: parameters k0, α are directly correlated with central black hole mass evolution (MBH,τ= MSgrA*/k(r)). Universality: only 4 adjustable parameters (Mbaryon,topo, r0, k0, α) are needed to fit different types of galaxies, substantially simplifying the number of parameter types required compared to mainstream dark matter models Conclusion: The spacetime duality principle, through black hole quantum gravity projection effects, replaces dark matter with a dynamic coupling term (k Gh M(r)2 ln r)/r, successfully reproducing the rotation curve characteristics of both the Milky Way and Andromeda galaxies (error <15%). This model provides a verifiable non-dark-matter explanation for galaxy structure formation.

Full Text

Simulating Galaxy Rotation Curves via the Spacetime Duality Principle
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Simulation of the Milky Way’s Rotation Curve

According to the theory, black holes create matter through extreme quantum gravitational potential energy; consequently, entire galaxies are created by their central black holes. The matter and black hole together constitute the galaxy’s topological structure (viewing the black hole and galaxy as an integrated whole). The circular orbital velocity formula comprises a classical Newtonian gravitational contribution and a correction term (quantum gravity term) that reflects the black hole’s non-local projection, producing a shadow effect analogous to the flattening role of “dark matter” at large distances.

Parameter Specifications

M: The topological structure mass corresponding to the computational target at the current light-cone time (excluding dark matter), with a value range of M_{BH},gal ≤ M ≤ M_{baryon},gal (the computational range may extend beyond the galaxy). By definition, M serves as the “mass of quantum-gravity radially curved spacetime.” Therefore, as a topological structure mass, M is a dynamic topological mass M(r) that varies with radial distance r from the black hole.

k(r) (Quantum Gravity Relative Entanglement Strength Factor): This parameter involves two black hole mass definitions. M_{BH},ref represents the reference black hole mass at current light-cone time, which can be viewed as the “reference mass for quantum gravitational phase oscillations” (typically selecting SgrA*, the Milky Way’s central black hole mass at current light-cone time). M_{BH},gal denotes the black hole mass corresponding to the galaxy’s topological structure at the target’s initial proper time. Within the galaxy, this corresponds to the mass of a single black hole; beyond the galaxy (e.g., in topological regions), it represents the total central black hole mass within that region, viewed as the “relative mass for quantum gravitational phase oscillations.” Thus, the black hole mass was larger in the early galaxy formation stage and gradually decreased to the current light-cone time through matter creation (M_{BH},gal(SgrA*) = 4.3 × 10^6 M_ = 8.5527 × 10^{36} kg). The function form k(r) serves as a dynamic indicator of black hole mass evolution.

1. Dynamic Topological Mass

The dynamic topological mass is defined through the relation) = M_{baryon},topo(1 − e^{-r/r_0}), where M_{baryon},topo represents the total baryonic mass within the topological region and r_0 is the characteristic scale controlling the growth rate of mass distribution. The model employs a piecewise configuration:

For the inner disk (r ≤ 4 kpc): M_{baryon},topo = M_{baryon},bulge = 4.5

× 10^{10} M_ = 8.9505 × 10^{40} kg, with r_0 = 3 kpc = 9.2571 × 10^{19} m. This represents the baryonic mass of the bulge topology, governing velocities in the inner region.

For the intermediate disk (4 kpc < r < 10 kpc): M_{baryon},topo = M_{baryon},mid = 9.0 × 10^{10} M_ = 1.7901 × 10^{41} kg, with r_0 = 6 kpc = 1.8514 × 10^{20} m. This transitional topological mass, intermediate between the bulge and the entire galactic disk, smooths the velocity profile between inner and outer regions.

For the outer disk (r ≥ 10 kpc): M_{baryon},topo = M_{baryon},MW = 1.5 × 10^{11} M_ = 2.9835 × 10^{41} kg, with r_0 = 10 kpc = 3.0857 × 10^{20} m. This represents the total baryonic mass of the Milky Way's topological structure, dominating the flat rotation curve in the outer region.

Typical parameter ranges are: M_{baryon},bulge = 4-6 × 10^{10} M_ (bulge characteristic range), M_{baryon},mid = 8-10 × 10^{10} M_ (transitional adjustment), and M_{baryon},MW = 1-2 × 10^{11} M_ (Milky Way baryonic mass). The inner, intermediate, and outer disks correspond to 2-4 kpc, 5-7 kpc, and 8-12 kpc respectively, optimized according to regional scales.

2. Dynamic Black Hole Evolution

The dynamic black hole evolution is defined by k(r) = k_0 (r/r_{ref})^{-α}, where r_0 represents the reference position (velocity peak location) and α is the power-law exponent controlling how k varies with distance. Parameter values are:

k_0 = 1.143 × 10^{-5} (derived from reverse calculation at r_{ref} = 10 kpc, v_{peak} = 250 km/s). r_{ref} = 10 kpc (peak position based on observations). α = 0.3 (optimized value ensuring the inner region is not excessively high and the outer region remains flat; this varies depending on the galaxy's topological evolution stage).

The parameter ranges are: k_0 = 1-2 × 10^{-5} (depending on peak velocity 225-250 km/s), r_{ref} = 8-10 kpc (possible peak range), and α = 0.2-0.5 (with 0.3 providing optimal balance). Calculated values yield: k(r=2 kpc) = 1.852 × 10^{-5}, k(r=8 kpc) = 1.297 × 10^{-5}, and k(r=20 kpc) = 0.928 × 10^{-5}.

3. Constants

- G = 6.6743 × 10^{-11} m$^{3 \cdot \mathrm{kg}}${-1} · s^{-2} (gravitational constant)
- Għ 3.5224 × 10^{-8} (quantum gravity constant, fixed value)
- M_{BH},gal(SgrA*) = 4.3 × 10^6 M_ = 8.5527 × 10^{36} kg (current black hole mass)

4. Black Hole Mass

The black hole mass is defined as M_{BH}(r) = M_{BH},gal / k(r). Examples:

At r = 2 kpc: M_{BH} = 8.5527$\times 10^{36} kg/1.852\times$10^{-5} 4.62 × 10^{41} kg = 2.32 × 10^5 M_ At r = 10 kpc: M_{BH} = 8.5527$\times 10^{36} kg/1.143\times$10^{-

5}   7.48 × 10^{41} kg = 3.76 × 10^5 M__ At r = 20 kpc: M__{BH} = 8.5527\$×$10^{36} kg/0.928$×\$10^{-5}   9.22 × 10^{41} kg = 4.64 × 10^5 M__

The range is 2-5 × 10^5 M__ , increasing slightly with r to reflect the early black hole mass.

Final Rotation Curve and Observational Comparison

r (kpc)	v(r) (km/s)	Observed (km/s)
...	...	...

Parameter Characteristics and Significance

The model features piecewise mass distribution: the inner disk is dominated by the bulge with lower mass producing rising velocities; the intermediate disk serves as a transition zone with moderate mass providing smooth connection; and the outer disk incorporates the full disk mass, producing a flat curve that slowly declines. The dynamic nature of k(r)—higher in the inner region (enhancing gravity) and lower in the outer region (maintaining flatness)—reflects black hole mass evolution. Error control shows maximum deviation at 5 kpc (~13-33 km/s), with other points within \$±\$10 km/s, demonstrating overall good agreement.

Simulation of the Andromeda Galaxy's Rotation Curve

For Andromeda (M31), the parameters are: k__0 = 4.911 × 10^{-5} (based on Andromeda's peak velocity) r__{ref} = 15 kpc (velocity peak region) $\alpha = 1.5$ (reflecting Andromeda's rapid outer disk decline)

Piecewise mass distribution: - Inner disk: M__{baryon},bulge = 5.0 × 10^{10} M__ , r__0 = 3 kpc - Intermediate disk: M__{baryon},mid = 6.0 × 10^{10} M__ , r__0 = 5 kpc - Outer disk: M__{baryon},M31 = 1.2 × 10^{11} M__ , r__0 = 15 kpc

Final Rotation Curve

r (kpc)	v(r) (km/s)	Observed (km/s)	Error
...	...	...	~1.2%

The intermediate disk shows velocities 11-36 km/s higher (5-14% deviation), while the outer disk matches perfectly when reverse-calculated.

Computational Details

The calculations show: M__{baryon},topo(r=2 kpc) = 5.0 × 10^{10} × (1 - e^{-2/3}) = 2.433 × 10^{10} M__ = 4.838 × 10^{40} kg M__{baryon},topo(r=8 kpc) = 6.0 × 10^{10} × (1 - e^{-8/5}) = 5.195 × 10^{10} M__ = 1.033 ×

10^{41} kg M_{baryon},topo(r=15 kpc) = 1.2 × 10^{11} × (1 - e^{-15/15}) = 7.584 × 10^{10} M_ = 1.508 × 10^{41} kg M_{baryon},topo(r=20 kpc) = 1.2 × 10^{11} × (1 - e^{-20/15}) = 9.842 × 10^{10} M_ = 1.957 × 10^{41} kg

Corresponding black hole masses are calculated accordingly.

Analysis and Conclusions

The model successfully reproduces Andromeda's rotation curve with distinct characteristics: the inner disk matches the Milky Way pattern, indicating universal topological structure features for galaxies as black-hole-created entities. The theoretical value at r=3 kpc (248.8 km/s) falls perfectly within the observed range (225-250 km/s). The intermediate disk shows slight overestimation (11-36 km/s, 5-14% error), reflecting reasonable model deviation considering other gravitational perturbations. The outer disk decline from peak velocity (250 km/s) to 234.8 km/s matches observations, consistent with Andromeda's concentrated mass and rapid disk scale decline.

Comparing with the Milky Way, Andromeda's α=1.5 is significantly higher than the Milky Way's α=0.3, indicating more concentrated mass distribution and stronger quantum gravitational effects in the inner region that decay faster outward. The model successfully explains Andromeda's rotation curve flattening without dark matter through dynamic k(r) and piecewise mass distribution. Errors of 5-15% in the intermediate and outer disks are reasonable given observational uncertainties and theoretical model expectations.

The large k_0 = 4.911 × 10^{-5} reflects Andromeda's early black hole mass, approximately 40 times larger than the Milky Way's SgrA* (M_{BH}   1.74 × 10^7 M_ at r=15 kpc), supporting Andromeda's compact structure and high stellar density.

Application of the Galaxy Rotation Curve Model

The circular orbital velocity formula v(r) = sqrt(GM(r)/r + Għk(r)/r^2) enables galaxy rotation curve simulation through four key parameters:

1. Characteristic Scale r_0

This parameter controls the growth rate of mass distribution M(r) = M_{baryon},topo(1 - e^{-r/r_0}), reflecting structural scales of different galactic regions (inner, intermediate, outer disk). The piecewise nature assigns independent r_0 values: Milky Way (3, 6, 10 kpc) and Andromeda (3, 5, 15 kpc). Physically, larger r_0 yields more gradual mass distribution and slower velocity growth, while smaller r_0 produces more concentrated distribution.

2. Quantum Gravity Correction Decay Factor α

This parameter regulates spacetime curvature in the quantum gravity term through k(r) = k_0(r/r_{ref})^{-α}, determining whether the velocity curve rises in the inner region and flattens or declines in the outer region. The Milky

Way's α=0.6 produces slow decay and a flat curve, while Andromeda's α=1.5 yields rapid decay and obvious outer disk decline. This reflects each galaxy's mass concentration and spatial distribution of black hole quantum gravitational effects.

3. Inner, Intermediate, and Outer Disk Mass Parameters

These parameters define the baryonic mass distribution of galactic topological structure, directly affecting both classical and quantum gravity terms. Examples include: - Milky Way: inner disk 1.0 × 10^{11} M_ , intermediate disk 1.5 × 10^{11} M_ , outer disk 1.5 × 10^{11} M_ - Andromeda: inner disk 5.0 × 10^{10} M_ , intermediate disk 6.0 × 10^{10} M_ , outer disk 1.2 × 10^{11} M_

These correspond to actual baryonic masses of bulge, transition zone, and outer disk topological structures, determining baseline velocity values typically calibrated at the velocity peak region.

4. Initial k_0

This parameter controls the overall strength of the quantum gravity term. Examples: Milky Way k_0 = 1.143 × 10^{-5} (r_{ref} = 10 kpc) and Andromeda k_0 = 4.911 × 10^{-5} (r_{ref} = 15 kpc). Physically, k_0 relates to black hole mass evolution M_{BH},gal/M_{BH},ref, reflecting the initial scale of quantum gravitational effects.

Universality and Advantages of the Model

1. Simplicity

Only four parameters—r_0 (piecewise), α, M_{baryon},topo, and k_0—are needed to generate rotation curves matching observations. This parametric approach greatly simplifies the modeling process.

2. Flexibility

The Milky Way, with lower α (0.3) and larger outer disk M_{baryon},topo, produces a flat, slowly declining curve. Andromeda, with higher α (1.5) and smaller inner disk M_{baryon},topo, generates a steeply rising inner region with rapid outer decline. By adjusting parameters, the model can adapt to different galaxy types (spiral, elliptical).

3. Physical Foundation

M_{baryon},topo corresponds to actual mass distribution of galactic topological structure, easily correlated with observational data such as stellar luminosity and gas distribution. The quantum gravity term introduces quantum gravitational effects, replacing dark matter to explain curve flattening while linking to central black hole mass evolution.

4. Error Control

Andromeda's errors (5-14% intermediate disk, 4-15% outer disk) and Milky Way's errors ($±$10 km/s) demonstrate that the model maintains theoretical consistency while allowing reasonable observational deviations.

Application Steps

To simulate any galaxy's rotation curve:

1. **Determine the velocity peak region** from observational data (e.g., Andromeda r_{peak} = 15 kpc, v_{peak} = 250 km/s).
2. **Estimate k_0** using k_0 = v_{peak}^2 r_{peak} / Gℏ.
3. **Estimate piecewise M_{baryon},topo** based on galactic topology (bulge, disk), referencing luminosity or gas mass distribution.
4. **Adjust** α according to outer disk velocity decline trends: smaller values (e.g., 0.3) for flat curves, larger values (e.g., 1.5) for rapid decline.
5. **Verify and fine-tune** by computing the complete curve and comparing with observations to optimize parameter agreement.

Note: Figure translations are in progress. See original paper for figures.

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