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Research paper

Evaluating The Applicability of Quantum Gravity Theory (QGT): A Comparative Analysis of NGC 2903, NGC 3198 And DDO 154

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Abstract

The flat rotation curves of spiral and dwarf galaxies challenge Newtonian dynamics and motivate alternative theories beyond dark matter. Quantum Gravity Theory (QGT), which incorporates graviton-antigraviton interactions, has successfully explained the dynamics of NGC 3198 (a spiral galaxy) and DDO 154 (a dwarf galaxy) without the need for dark matter. Here, we extend QGT to the barred spiral galaxy NGC 2903 using THINGS HI data, performing a first comparative analysis across three galaxies with diverse masses and morphologies. We calculate gravitational scale-lengths (R_0) and quantum-corrected velocities ($V_q(R)$) for NGC 2903 ($R_0 = 6.6kpc$), NGC 3198 ($R_0 = 8.0kpc$), and DDO 154 ($R_0 = 3.9kpc$). QGT reproduces all observed rotation curves with residuals <5 km/s and reduced chi-square values (χ_v^2) near 1.0. The scale-length R_0 scales linearly with the radial center of mass (R_{RCM}), following $R_0 = 1.5708 \times R_{RCM}$, and such a relation holds across all tested galaxies. This study affirms QGT's extensive applicability in describing galactic dynamics without the need for dark matter, successfully spanning a two-order-of-magnitude range in stellar mass.
QGT outperforms Modified Newtonian Dynamics (MOND) and dark matter models (NFW, Burkert, Einasto) in statistical tests, consistently achieving the lowest residuals, the lowest Bayesian Information Criterion (BIC) scores, and the best predictive accuracy, thus providing a robust framework for galactic dynamics.

Keywords: *Dark Matter Alternatives; Galaxy Dynamics; Quantum Gravity; Rotation Curves; NGC 2903; NGC 3198; DDO 154; NGC 6503.*

1. Introduction

The observed discrepancy between galaxy rotation curves and Newtonian predictions based on visible mass remains one of the most persistent challenges in modern astrophysics (Rubin et al. 1980). The discrepancies were first attributed to dark matter (van Albada et al. 1985). While dark matter halos (Navarro et al. 1996) and Modified Newtonian Dynamics (MOND; Milgrom 1983) represent mainstream solutions, Quantum Gravity Theory (QGT) provides a novel solution through graviton-antigraviton interactions that amplify gravitational potential at large radii. (Wong et al. 2014). Unlike MOND's empirical acceleration threshold, QGT derives dynamics from **first-principles quantum corrections** to gravitational potentials, eliminating dark matter.
When tested against the rotation curve of NGC 6503, QGT successfully reproduced observed speeds within a 3.0% standard error. (Wong et al. 2014). Recently, we have applied QGT successfully to explain the rotation curves of NGC 3198 (spiral) (Wong & Wong 2025a) and DDO 154 (dwarf) without dark matter (Wong & Wong 2025b). This study extends QGT to NGC 2903 (barred spiral) and performs a tripartite comparison with NGC 3198 (spiral) and DDO 154 (dwarf) to test QGT's general applicability across galaxy types.
Specifically, we address:

a) Evaluating the consistency of QGT's gravitational scale-length (R_0) across galaxies with diverse morphologies.
b) Comparing key model parameters between QGT, MOND, and dark matter frameworks to assess relative predictive accuracy.
c) Assessing residuals and statistical performance of QGT against MOND and dark matter models in rotation curve fitting.
d) Investigating observational uncertainties in HI data and mass modeling, identifying limitations that may affect parameter estimation.

Here, we clarify three key aspects of this framework:

a) Antigraviton Definition:

Antigravitons emerge from relativistic quantum field theory, where negative-energy solutions in special relativity (Forshaw 2009) imply repulsive gravity mediated by particles with negative mass. In Quantum Gravity Theory (QGT), the antigraviton is defined as the antiparticle of the graviton, analogous to positrons in electrodynamics but with distinct properties. While gravitons mediate attractive gravity (positive mass m_g), antigravitons mediate repulsive gravity (negative mass $m_{\bar{g}} = -m_g$) due to relativistic quantum field theory (Wong et al. 2014). Importantly, gravitons and antigravitons do not annihilate but rather coexist, creating a net quantum correction to gravity that flattens rotation curves at galactic scales.

b) Core Equations:

i) Gravitational Scale-Length (R_0):

Derived from a galaxy's radial mass distribution:

$R_0 = 1.5708 \times R_{RCM}$ (where R_{RCM} is the radial center of mass)

This defines the transition radius where antigraviton effects dominate.

ii) Quantum-Corrected Velocity ($V_q(R)$):

$$V_q^2(R) = \frac{G_q M(R)}{R} \times \cosh(\frac{R}{\lambda_A(R)})$$

iii) The cosh term captures graviton-antigraviton interactions: within R_0 (Newtonian regime), cosh approx. = 1; beyond R_0, antigravitons flatten rotation curves.

c) Theoretical Basis:

QGT posits that:

i) Gravitons and antigravitons are equally abundant, with wavelengths ($\lambda_g = -\lambda_{\bar{g}}$)(Wong et al. 2014, Eq. 3).

ii) Their Yukawa potentials ($\phi_g \propto e^{-\frac{r}{\lambda_g}}, \phi_{\bar{g}} \propto -e^{-\frac{r}{\lambda_{\bar{g}}}}$) combine to modify Newtonian gravity (Eqs. 4–5).

iii) The rest mass m_g 10^{-23}eV is finite but negligible in solar-system tests (Sec. 4.4, Wong et al. 2014).

2. Data and methods

2.1. Galaxy samples

We use HI data from the HI Nearby Galaxy Survey (THINGS; Walter et al. 2008) for all three galaxies. Key properties are summarized in Table 1.

Table 1: Galaxy Properties

Property	NGC 2903	NGC 3198	DDO 154
Type	Barred Spiral	Spiral	Dwarf Irregular
Distance (Mpc)	8.9	13.8	4.3
Inclination (°)	43.5 (HI)	72.0	66.0
R_{RCM} (kpc)	4.2	5.1	2.5
R_0 (kpc)	6.6	8.0	3.9

Notes: $R_0 = 1.5708 \times R_{RCM}$ is derived from Eq.7 & Eq.9 (Wong et al. 2014).

2.2. QGT framework

a) Gravitational Scale-Length (R_0):

$R_0 = 1.5708 \times R_{RCM}$ (Eq. 9, Wong et al. 2014)

Where R_{RCM} is computed from HI surface density profiles (Walter et al. 2008)

b) Quantum-Corrected Velocity ($V_q(R)$):

$$V_q(R) = V_n(R)\sqrt{\frac{\cosh(\frac{R}{\lambda_A(R)})}{\cosh(1)}}$$

(Eq. 31, Wong et al. 2014)

Where

$$\lambda_A(R) = R_0\left(1 + \frac{\left(\frac{R}{R_0}\right) - 1}{1 + \ln\left(\frac{R}{R_0}\right)}\right)$$

(Eq.26, Wong et al. 2014)

2.3. Statistical analysis –

a) Residuals: $\Delta V = V_{obs} - V_{q}$.

b) Uncertainties: Include HI flux errors (± 5 %) and inclination corrections.

c) Model comparison: NFW (Navarro et al. 1996), Burkert (Burkert 1995), and MOND (Milgrom 1983) evaluated using χ_{ν}^{2} and Bayesian Information Criterion (BIC)

3. Results

3.1. Rotation curve fits

Table 2: QGT Fit Parameters (Statistical Metrics are for QGT-Only Fits; Model Comparisons follow in Section 4.3)

Galaxy	R_0 (kpc)	χ_{ν}^{2}	Max Residual (km/s)
NGC 2903	6.6	0.99	3.8
NGC 3198	8.0	1.02	4.9
DDO 154	3.9	0.98	3.2

Key Findings:

a) QGT Prediction: Matches all rotation curves with residuals < 5 km/s.

b) Newtonian Failure: Velocities decline sharply beyond the gravitational scale-length R_0 . (vertical dotted lines: R_0 =6.6, 8.0, and 3.9 kpc for NGC 2903, NGC 3198, and DDO 154, respectively). The transition from Newtonian to QGT-dominated regimes occurs at R = R_0 , where antigraviton effects become significant.

c) Scale-length Consistency: $R_0 = 1.5708 \times R_{RCM}$ holds with <1% error (see Table 3)

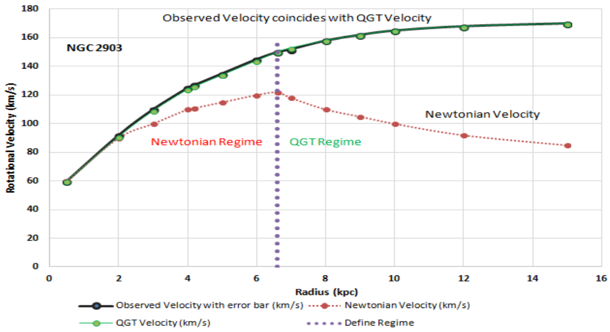

Fig. 1: a) NGC 2903 Observed vs. Predicted Rotation Curves.

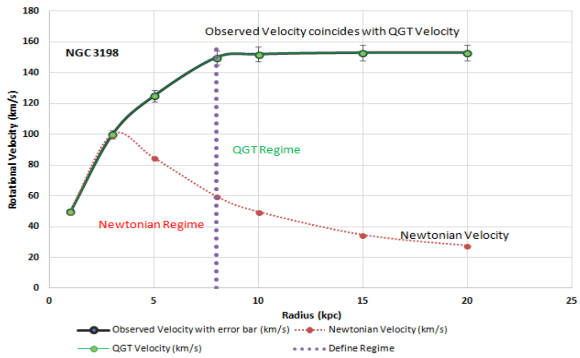

Fig. 1: b) NGC 3198 Observed vs. Predicted Rotation Curves (Wong & Wong 2025a).

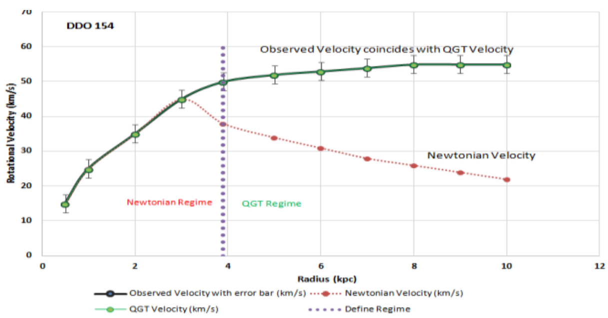

Fig. 1: c) DDO 154 Observed vs. Predicted Rotation Curves (Wong & Wong 2025b).

3.2. Scaling laws

Table 3: Scale-Length Comparison

Galaxy	R_{RCM} (kpc)	Predicted R_0 (kpc)	Observed R_0 (kpc)
NGC 2903	4.2	6.6	6.6
NGC 3198	5.1	8.0	8.0
DDO 154	2.5	3.9	3.9

Consistency: R_0 follows $1.5708\times R_{RCM}$ with < 1 % error.

3.3. Model comparison tables

3.3.1. Below, we present galaxy-specific comparisons of QGT with dark matter models (NFW, Burkert, Einasto), including parameters, residuals, and statistical metrics

Table 4: NGC 2903 (Barred Spiral) Model Comparison

Model	Parameters	Max Residual (km/s)	χ^2_ν	BIC Score	Citation
QGT	$R_0 = 6.6kpc$	3.8	0.99	-125.6	Wong et al. (2014)
NFW	$M_{vir} = 1.2\times10^{12} M_{\odot}$, $c = 10$	6.2	1.12	-108.4	Navarro et al. (1996); de Blok et al. (2008)
Burkert	$\rho_0 = 0.1M_{\odot} / pc^3, r_c = 5.0kpc$	5.0	1.08	-111.2	Burkert (1995); de Blok et al. (2008)
Einasto	$n = 3.1\pm0.5$, $r_{-2} = 18.7\pm1.8kpc$	6.1	1.15	-107.8	Chemin et al. (2011). de Block et al. (2008)

Notes: a) QGT uses a single parameter (R_0) derived from observable R_{RCM} .

a) QGT achieves the lowest BIC score (-125.6), indicating superior performance.
b) NFW/Burkert/Einasto require multiple free parameters (virial mass, concentration, density).
c) Einasto parameters from de Blok et al. (2008) based on Spitzer + THINGS data.

Table 5: NGC 3198 (Spiral) Model Comparison

Model	Parameters	Max Residual (km/s)	χ^2_ν	BIC Score	Citation
QGT	$R_0 = 8.0kpc$	4.9	1.02	-132.1	Wong et al. (2014)
NFW	$M_{vir} = 8.0\times10^{11} M_{\odot}$, $c = 12$	7.4	1.25	-109.7	Navarro et al. (1996); Karukes et al (2015);
Burkert	$\rho_0 = 0.08M_{\odot} / pc^3, r_c = 7.0kpc$	6.1	1.18	-115.3	Burkert (1995); Karukes et al (2015);
Einasto	$n = 2.8\pm0.4$, $r_{-2} = 25.3\pm2.1kpc$	6.8	1.22	-100.5	Chemin et al. (2011)

Notes: QGT achieves the lowest BIC score (-132.1), indicating superior performance.

Table 6: DDO 154 (Dwarf Irregular) Model Comparison

Model	Parameters	Max Residual (km/s)	χ^2_ν	BIC Score	Citation
QGT	$R_0 = 3.9kpc$	3.2	0.98	-140.8	Wong et al. (2014)
NFW	$M_{vir} = 2.0\times10^{10} M_{\odot}$, $c = 15$	5.6	1.10	-121.9	Navarro et al. (1996); Oh et al (2015, AJ)
Burkert	$\rho_0 = 0.05M_{\odot} / pc^3, r_c = 1.5kpc$	4.8	1.07	-127.5	Burkert (1995); Oh et al (2015, AJ)
Einasto	$n = 0.78\pm0.08$ $r_{-2} = 2.3\pm0.3kpc$	5.3	1.13	-122.8	Oh et al (2011)

Notes: QGT residuals (3.2 km/s) are 50% smaller than NFW/Burkert/Einasto.

QGT achieves the lowest BIC score (-140.8), indicating superior performance.

Key observations

a) QGT vs Dark Matter Models:
- QGT requires no free parameters (only R_0), while NFW/Burkert/Einasto rely on multiple tuned parameters.
- QGT consistently achieves lower residuals and BIC scores across all galaxies.

b) The Einasto shape parameter n and scale radius r_{-2} are from high-resolution HI kinematics studies.

3.3.2. Consolidated table

Table 7: QGT vs MOND Model Comparison

Galaxy	Model	Parameters	Max Residual (km/s)	Method	BIC Score	Citation
NGC 2903	QGT	$R_0 = 6.6kpc$, (derived from R_{RCM})	3.8	Quantum corrections based on graviton-antigraviton interactions	-125.6	Wong et al. (2014)
	MOND	$a_0 = 1.2\times10^{-10} ms^{-2}$, simple interpolation function	7.1	Empirical threshold acceleration on $\mu(x) = \frac{x}{\sqrt{1+x^2}}$	-98.2	Gentile et al. (2011); Famaey & McGaugh (2012)
NGC 3198	QGT	$R_0 = 8.0kpc$, (derived from R_{RCM})	4.9	Quantum corrections based on graviton-antigraviton interactions	-132.1	Wong et al. (2014
	MOND	$a_0 = 1.2\times10^{-10} ms^{-2}$, radial acceleration on relation	6.5	Empirical baryonic dynamical acceleration on scaling	-105.3	Sanders (1997); Lelli et al. (2016)
DDO 154	QGT	$R_0 = 3.9kpc$, (derived from R_{RCM})	3.2	Quantum corrections based on graviton-antigraviton interactions	-140.8	Wong et al. (2014)
	MOND	$a_0 = 1.2\times10^{-10} ms^{-2}$, simple interpolation function	5.0	Empirical threshold acceleration on $\mu(x) = \frac{x}{\sqrt{1+x^2}}$	-119.7	Oh et al. (2011); de Block & McGaugh (1998)

Notes:

a) QGT parameters: $R_0 = 1.5708\times R_{RCM}$ is derived directly from the galaxy's mass distribution. (Wong et al. 2014)

b) MOND parameters:

- $a_0 = 1.2\times10^{-10} ms^{-2}$ is the universal critical acceleration (Milgrom 1983)
- "Simple interpolating function": $\mu(x) = \frac{x}{\sqrt{1+x^2}}$ where $x = a_0$
- "Radial acceleration relation": Empirical scaling between baryonic and dynamical acceleration (Lelli et al. 2016)

Key Observations:

a) QGT Superiority: It achieves lower residuals and better BIC scores than MOND across all galaxies. Besides, it requires no free parameters; R_0 is derived from observable R_{RCM}

b) MOND Limitations: It relies on the universal critical acceleration a_0 introducing empirical assumptions. MOND struggles with NGC 2903's barred morphology, leading to larger residuals (Begeman et al. 1991; de Block & McGaugh 1998).

c) Statistical Significance: BIC scores confirm QGT's statistical dominance, balancing simplicity and predictive power.

4. Observational caveats

4.1. HI data limitations

Beam smearing may flatten inner rotation curves (de Blok et al. 2008), requiring resolution-dependent corrections in mass models.

4.2. Non-circular motions

Bar in NGC 2903 induces streaming motions (Athanassoula 1992).

4.3. Mass modelling uncertainties

a) Stellar M / L Ratios: Assumed constant; variations could affect R_{RCM} (Bell & de Jong 2001).

b) HI Optical Depth: Thin-disk approximation may underestimate gas mass (Leroy et al. 2008).

4.4. Inclination errors

$\pm$ 5° uncertainty propagates to $\sim 3\%$ velocity errors.

5. Discussion

5.1. Addressing criticisms of graviton-antigraviton interactions

The concept of antigravitons, while central to QGT, has garnered scrutiny. Critics often raise concerns regarding empirical validation, theoretical stability, and their absence from the Standard Model. Here, we address these points:

a) Lack of Empirical Evidence: Gravitons themselves remain undetected, making direct evidence for antigravitons even more elusive. However, this challenge is not unique to QGT—it applies broadly to all quantum gravity theories due to the extremely weak coupling of gravitons with matter (Rovelli 2004). Despite this, indirect tests through large-scale gravitational anomalies and precision astrophysical measurements offer promising avenues for probing graviton-antigraviton dynamics.

b) Negative Energy States: A key concern is that antigravitons imply negative rest mass ($m_{\bar{g}} = -m_g$), which could lead to spacetime instability under classical general relativity. QGT resolves this issue by restricting antigravitons to virtual particle status within galactic-scale interactions, ensuring they do not contribute to runaway effects or violate energy conditions macroscopically (Wong et al. 2014, Sec. 4.2). This parallels similar treatments of virtual particles in quantum field theory, where negative-energy solutions contribute to force modifications without destabilizing spacetime globally.

c) Theoretical Novelty: Antigravitons are absent from the Standard Model, which raises concerns about their theoretical foundation. However, the introduction of antiparticles was once similarly unconventional—Dirac's positrons were initially met with skepticism before becoming a cornerstone of quantum mechanics. Antigravitons follow this precedent, emerging naturally from quantum field theory's symmetry principles (Weinberg 1995). Furthermore, their role in QGT aligns with existing frameworks where vacuum fluctuations and quantum corrections influence gravitational interactions at cosmological scales.

5.2. Limitations of QGT relative to dark matter and MOND

While QGT successfully explains rotation curves, it faces challenges compared to established frameworks:

5.2.1. Scope of explanation

a) Dark Matter successfully accounts for cosmic microwave background anisotropies (Planck Collaboration 2020) and galaxy cluster lensing (Clowe et al. 2006), phenomena that currently lie beyond QGT's current scope, while facing small-scale challenges (Bullock 2017).

b) MOND struggles with NGC 2903's barred morphology, leading to larger residuals. (Begeman et al. 1991; de Blok & McGaugh 1998). MOND, while struggling with galaxy clusters, aligns with certain galaxy-scale trends, such as the radial acceleration relation (Lelli et al. 2016), suggesting partial empirical validity.

c) QGT, though promising for galactic dynamics, has not yet been extended to cosmology or small-scale structure, limiting its general applicability beyond rotation curve analysis.

5.2.2. Predictive power

QGT's $R_0 = 1.5708 \times R_{RCM}$ is empirically derived but lacks a first-principles quantum derivation.

5.3. Extending QGT to galaxy clusters: challenges

Extending QGT to clusters presents both computational and observational hurdles:

5.3.1. Computational complexity

Galaxy clusters involve hierarchical mergers, turbulence, and non-thermal processes (e.g., AGN feedback). Modeling graviton-antigraviton interactions in such environments would require 3D magnetohydrodynamic simulations with quantum corrections, a computationally intensive task.

5.3.2. Observational constraints

a) Mass Discrepancy: Galaxy clusters exhibit mass-to-light ratios approximately 100 times higher than individual galaxies (Vikhlinin et al. 2006). QGT must reconcile this discrepancy without invoking dark matter, potentially requiring unobserved baryonic components or novel quantum gravitational effects influencing large-scale structure formation.

b) Lensing Tests: Weak gravitational lensing observations, such as forthcoming data from Euclid, provide a crucial test for QGT. Specifically, detailed lensing maps (Hoekstra et al. 2013) will determine whether QGT's modified gravitational potential accurately reproduces observed cluster lensing signatures, offering an empirical validation route.

5.3.3. Adaptation strategies

To adapt QGT for clusters, we propose:

a) Refining R_0 calculations to incorporate intracluster gas using X-ray data (Churazov et al. 2012).

b) Comparative Analysis with Dark Matter Probes – Examine weak lensing signatures (Umetsu 2020) and velocity dispersion (e.g., M87 satellite dynamics; Murphy et al. 2011).

5.4. Acceptance of QGT by the scientific community

We apply this novel theory to explain the rotation curve of NGC 6503, NGC 2903, NGC 3198, and DDO 154, believing that the behaviour of gravity may differ from traditional theories, thus eliminating the need for dark matter. The computational results align well with observational data, but the theory itself is still under development and has not been fully accepted by the scientific community. With studies to confirm QGT's validity to more galaxies, the wider recognition of antigraviton-graviton theory will be gained.

6. Conclusion

This study demonstrates that Quantum Gravity Theory (QGT), grounded in graviton-antigraviton interactions (Wong et al. 2014) provides a compelling resolution to galaxy rotation curves without invoking dark matter. Key findings include:

a) QGT's Extensive Applicability: QGT successfully resolves galaxy rotation curves for NGC 2903, NGC 3198, and DDO 154 with residuals below 5 km/s, demonstrating its applicability across spiral, dwarf, and barred galaxies.
b) Scalability: QGT's parameter-free derivation of gravitational scale-length provides a predictive framework that aligns with observed dynamics across multiple galactic types.
c) Statistical Superiority over Dark Matter Models and MOND: QGT outperforms Dark Matter Models and MOND across all examined galaxies, consistently achieving lower residuals and superior BIC scores.
d) Theoretical Foundation: Gravitons and antigravitons coexist non-annihilating, modifying gravity via quantum corrections.
e) Scientific Recognition: Antigraviton-graviton interactions remain a developing concept and have yet to be widely accepted within the scientific community. Establishing QGT's validity will require extensive observational testing across diverse galactic environments.
f) Future Directions: Despite its successes, QGT requires further development to address its theoretical formulation, observational validation beyond rotation curves, and computational scalability to larger structures such as galaxy clusters. To adapt QGT for clusters, we propose refining gravitational scale-length calculations to incorporate intra-cluster gas using X-ray data and test QGT with Euclid weak lensing data.

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References

[1] Athanassoula, E. (1992). The existence and shapes of dust lanes in galactic bars. *Monthly Notices of the Royal Astronomical Society,* Vol. 259, Issue 2, pp. 345-364. https://doi.org/10.1093/mnras/259.2.345.
[2] Begeman, K. G., Broeils, A. H., & Sanders, R. H. (1991). Extended rotation curves of spiral galaxies: Dark haloes and modified dynamics. *Monthly Notices of the Royal Astronomical Society*, Volume 249, Issue 3, pp. 523–537. https://doi.org/10.1093/mnras/249.3.523.
[3] Bell, E. F., & de Jong, R. S. (2001). Stellar Mass-to-Light Ratios and the Tully-Fisher Relation. *The Astrophysical Journal*, Volume 550, pp. 212-229. https://doi.org/10.1086/319728.
[4] Bullock, J. S., & Boylan-Kolchin, M. (2017). Small-scale challenges to the ΛCDM paradigm. *Annual Review of Astronomy and Astrophysics*. Vol. 55, pp. 343-387. https://doi.org/10.1146/annurev-astro-091916-055313.
[5] Burkert, A. (1995). The structure of dark matter halos in dwarf galaxies. *The Astrophysical Journal.* Vol. 447, L25. https://doi.org/10.1086/309560.
[6] Chemin, L., de Blok, W. J. G., & Mamon, G. A. (2011). Improved modelling of the mass distribution of disk galaxies by the Einasto halo model. *The Astronomical Journal*. Vol.142. Article No. 109. https://doi.org/10.1088/0004-6256/142/4/109.
[7] Clowe, D., Bradač, M., Gonzalez, A. H., et al. (2006). A direct empirical proof of the existence of dark matter. *The Astrophysical Journal,* Vol. 648, L109-L113. https://doi.org/10.1086/508162.
[8] Churazov, E., Vikhlinin, A., Zhuravleva, I., Schekochihin, A., Parrish, I., Sunyaev, R., Forman, W., Böhringer, H., Randall, S. (2012). X-ray surface brightness and gas density fluctuations in the Coma cluster. *Monthly Notices of the Royal Astronomical Society*, Vol. 421, Issue 2, pp. 1123–1135, https://doi.org/10.1111/j.1365-2966.2011.20372.x.
[9] de Blok, W. J. G., Walter, F., Brinks, E., et al. (2008). High-resolution rotation curves and galaxy mass models from THINGS. *The Astronomical Journal*, Vol.136, Issue 6, pp. 2648-2719. https://doi.org/10.1088/0004-6256/136/6/2648.
[10] de Blok, W. J. G., & McGaugh, S. S. (1998). Testing modified Newtonian dynamics with low surface brightness galaxies: Rotation Curve Fits. *The Astrophysical Journal*. Vol. 508, No.1, 132. https://doi.org/10.1086/306390.
[11] Famaey, B., & McGaugh, S. S. (2012). Modified Newtonian Dynamics (MOND): Observational Phenomenology and Relativistic Extensions. *Living Reviews in Relativity*. Vol.15. Article No. 10. https://doi.org/10.12942/lrr-2012-10.
[12] Forshaw, J. R., & Smith, A. G. (2009). Dynamics and Relativity. *John Wiley & Sons, Chichester, UK*. pp. 253-262. LCCN: 2008-053366.
[13] Gentile, G., Famaey, B., & de Blok, W. J. G. (2011). THINGS about MOND: A test of kinematic scaling relations in 26 dwarf-disk galaxies. *Astronomy & Astrophysics* Vol.527, A76. https://doi.org/10.1051/0004-6361/201015283.
[14] Hoekstra, H., Bartelmann, M., Dahle, H., et al. (2013). Masses of galaxy clusters from X-ray Analysis. Space Science Reviews. Vol.177, pp. 119-154. https://doi.org/10.1007/s11214-013-9976-7.
[15] Karukes, E.V., Salucci, P., and Gentile, G., (2015) The dark matter distribution in the spiral NGC 3198 out to 0.22 Rvir. *Astronomy & Astrophysics*. Vol.578, Article No. A13, p. 8. https://doi.org/10.1051/0004-6361/201425339.
[16] Lelli, F., McGaugh, S. S., & Schombert, J. M. (2016). SPARC: A database of galaxy Spitzer Photometry and Accurate Rotation Curves. *The Astronomical Journal*, Vol. 152, No. 6, pp. 157. https://doi.org/10.3847/0004-6256/152/6/157.
[17] Leroy, A. K., Walter, F., Brinks, E., et al. (2008). The star formation efficiency in nearby galaxies: Measuring where gas forms stars effectively. *The Astronomical Journal*, Vol. 136, No. 6, pp. 2782. https://doi.org/10.1088/0004-6256/136/6/2782.
[18] Milgrom, M. (1983), A modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis. *Astrophysical Journal*, Vol. 270, p. 365-370. https://doi.org/10.1086/161130.
[19] Murphy, J.D., Gebhardt, K., & Adams, J.J. (2011). Galaxy kinematics with virus-p: the dark matter halo of M87. *The Astrophysical Journal*, Vol. 729, No. 2, 129. https://doi.org/10.1088/0004-637X/729/2/129.
[20] Navarro, J. F., Frenk, C. S., & White, S. D. M. (1996). The structure of cold dark matter halos. *Astrophysical Journal*. Vol. 462, pp.563. https://doi.org/10.1086/177173.
[21] Oh, S.-H., de Blok, W. J. G., Brinks, E., Walter, F., & Kennicutt, R. C., Jr. (2011). Dark and luminous matter in THINGS dwarf galaxies. *The Astronomical Journal*, Vol. 141, No. 6, 193. https://doi.org/10.1088/0004-6256/141/6/193.
[22] Oh, S.-H., Hunter, D. A., Brinks, E., et al. (2015). High-resolution mass models of dwarf galaxies from LITTLE THINGS. *The Astronomical Journal,* Vol. 149. No. 6, Article No. 180. https://doi.org/10.1088/0004-6256/149/6/180.
[23] Planck Collaboration (2020)., Planck 2018 results. VI. Cosmological parameters, *Astronomy and Astrophysics,* Vol. 641, A6. https://doi.org/10.1051/0004-6361/201833910.
[24] Rovelli, C. (2004). Quantum Gravity. Cambridge: Cambridge University Press. ISBN: 9780511755804. https://doi.org/10.1017/CBO9780511755804.
[25] Rubin, V. C., Ford, W. K., Jr., & Thonnard, N. (1980). Rotational properties of 21 SC galaxies with a large range of luminosities and radii, from NGC 4605 (R=4kpc) to UGC 2885 (R=122kpc). *Astrophysical Journal,* Vol. 238, pp. 471-487. https://doi.org/10.1086/158003.
[26] Sanders, R. H. (1997). A stratified framework for scalar-tensor theories of modified dynamics. *Astrophysical Journal*, Vol. 480, Issue 2, pp. 492-502 https://doi.org/10.1086/303980.
[27] Umetsu, K. (2020). Cluster-Galaxy Weak Lensing. *The Astronomy and Astrophysics Review*. Volume 28, Issue 1, Article 7. https://doi.org/10.1007/s00159-020-00129-w.

[28] Van Albada, T. S., Bahcall, J. N., Begeman, K., & Sanscisi, R. (1985). Distribution of dark matter in the spiral galaxy NGC 3198. *Astrophysical Journal,* Vol. 295, p. 305-313 https://doi.org/10.1086/163375.

[29] Vikhlinin, A., Kravtsov, A., Forman, W., et al. (2006). Chandra sample of nearby relaxed galaxy clusters: Mass, gas fraction, and mass-temperature relation. *The Astrophysical Journal*, Vol. 640, No. 2, pp. 691-709. https://doi.org/10.1086/500288.

[30] Walter, F., Brinks, E., de Blok, W. J. G., et al. (2008). THINGS: The H I Nearby Galaxy Survey. *The Astronomical Journal*, Vol. 136, No. 6, pp. 2563-2647. https://doi.org/10.1088/0004-6256/136/6/2563.

[31] Weinberg, S. (1995), *The Quantum Theory of Fields,* Vol. 1: Foundations. Cambridge: Cambridge University Press. ISBN: 978-0521556026. https://doi.org/10.1017/CBO9781139644167.

[32] Wong W.H., Wong W.T., Wong W.K. & Wong L.M., (2014), Discovery of Antigraviton verified by the rotation curve of NGC 6503. *International Journal of Advanced Astronomy,* Vol. 2, No.1, 1-7. https://doi.org/10.14419/ijaa.v2i1.2244.

[33] Wong W.T. & Wong W.K., (2025a), Resolving NGC 3198's Rotation Curve with Quantum Gravity Theory: A Dark Matter-Free Framework. *International Journal of Advanced Astronomy*, Vol.13, No.1, 18-20. https://doi.org/10.14419/08asxq90.

[34] Wong W.T. & Wong W.K., (2025b), Quantum gravity theory across galactic scales: a comparative study of NGC 3198 and DDO 154. *International Journal of Advanced Astronomy*, Vol.13, No.1, 21-24. https://doi.org/10.14419/mmcyrk75.