A Gravidade Invisível ou o Fogo dos Abismos?

Dark Matter versus Supermassive Black Holes as the Primary Gravitational Aggregators of the Universe

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A Critical Multi-Scale Scientific Assessment

Resumo (Português)

Este artigo avalia a tese de que os buracos negros supermassivos (SMBHs), e não a matéria escura, são os principais aglutinadores gravitacionais do Universo. O estudo integra evidência de curvas de rotação galácticas, lentes gravitacionais, anisotropias da radiação cósmica de fundo (CMB), formação de estrutura em grande escala e astrofísica observacional de buracos negros. A análise mostra que os SMBHs são centrais na evolução das galáxias, mas não reproduzem, por si só, a distribuição de massa em halo exigida pelos dados dinâmicos e de lensing. Cenários com buracos negros primordiais permanecem de interesse científico, embora fortemente limitados por observações actuais. A conclusão robusta é dual: a matéria escura continua a explicação mais abrangente para a agregação em grande escala; os buracos negros são motores energéticos e dinâmicos dominantes em escalas galácticas e sub-galácticas.

Abstract (English)

This paper evaluates the hypothesis that supermassive black holes (SMBHs), rather than dark matter, are the primary gravitational aggregators of the Universe. We synthesize evidence from galaxy rotation curves, gravitational lensing, cosmic microwave background (CMB) anisotropies, large-scale structure growth, and black-hole astrophysics. The analysis shows that SMBHs are central to galaxy evolution but cannot, by themselves, reproduce the halo-like mass distributions required by rotation and lensing data. Primordial black-hole scenarios remain scientifically relevant, yet current observations impose strong constraints. The most robust conclusion is a dual framework: dark matter remains the most comprehensive explanation for large-scale aggregation, while black holes are dominant energetic and dynamical engines on galactic and sub-galactic scales.

Keywords: dark matter; supermassive black holes; primordial black holes; rotation curves; gravitational lensing; CMB; cosmology

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1. Introduction

A foundational tension in modern cosmology is the mismatch between visible baryonic matter and the observed gravitational field. Across scales—from galaxies to clusters to cosmic-web growth—the measured dynamics exceed luminous-mass predictions. The standard interpretation introduces non-baryonic dark matter (DM), while alternative approaches invoke compact-object populations or modified gravity.

This paper examines a specific, controversial thesis: that black holes—especially SMBHs—are the true gravitational engines of cosmic aggregation and may reduce or remove the need for dark matter.

2. Observational Basis of the Dark Matter Paradigm

2.1 Galaxy rotation curves

Disk-galaxy rotation profiles remain approximately flat at large radii where luminous mass predicts decline.

$$v(r) = \sqrt{G\, M(<r)/r} \tag{1}$$

If $M(<r)$ stops growing with radius, $v(r)$ should decline as $r^{-1/2}$. Empirically, many systems do not.

2.2 Gravitational lensing and cluster dynamics

Weak and strong lensing maps indicate mass distributions extending beyond baryonic components. Cluster velocity dispersions and X-ray gas hydrostatics also imply additional gravitating mass.

2.3 CMB and large-scale structure

CMB acoustic-peak structure and BAO constraints jointly support a cold, non-relativistic matter component that seeds structure growth prior to significant baryonic collapse.

3. Supermassive Black Holes: Established Physics and Astrophysical Role

SMBHs are observationally established through stellar/gas dynamics, AGN energetics, and horizon-scale imaging (M87*, Sgr A*). Feedback from accretion and jets regulates star formation, gas thermodynamics, and galaxy-core evolution.

$$L = \eta \dot{M} c^2 \tag{2}$$

Accretion efficiency (η) enables extreme luminosities, making SMBHs major local/regional energy engines.

4. Core Falsification Test: Can SMBHs Replace Dark Matter?

4.1 Radial force limitation

A central mass dominates near the nucleus but cannot sustain flat rotation profiles at large galactocentric radii.

$$g(r) = G\, M_{BH} / r^2 \tag{3}$$

Thus, known SMBHs cannot substitute distributed halo mass in standard galaxies.

4.2 Cosmic mass-density accounting

Observed SMBH mass density is far below the cosmological dark-matter budget inferred from CMB+LSS constraints.

4.3 Lensing morphology mismatch

Central compact objects do not generally reproduce extended lensing convergence fields observed in clusters and filaments.

5. Primordial Black Holes as a Dark-Matter Alternative

PBHs remain the most credible black-hole-based DM candidate. However, microlensing, dynamical-heating bounds, CMB-accretion effects, and gravitational-wave merger-rate constraints strongly limit viable PBH abundance across most mass ranges.

6. Modified Gravity and Hybrid Frameworks

If compact objects are insufficient, one may question gravity itself at galactic/cosmological scales. MOND-like paradigms reproduce some galaxy phenomenology but face challenges on cluster and CMB observables. Hybrid frameworks remain active research domains.

7. Methods and Statistical Standards for Decisive Comparison

- Use unified likelihoods across rotation curves, lensing, CMB, BAO, and GW catalogs.
- Apply forward simulations with identical baryonic subgrid physics for all competing models.
- Perform Bayesian model comparison (evidence ratios), not only best-fit residuals.
- Publish pre-registered falsifiable signatures for each framework.

8. Results Synthesis

Current evidence does not support replacing dark matter with observed SMBHs alone. PBH scenarios remain partially open in restricted windows but are increasingly constrained. The strongest evidence-supported framework remains dual: global DM scaffolding plus BH-driven energetic/dynamical regulation.

9. Discussion

The black-hole-first thesis retains epistemic value by sharpening falsifiability and forcing tighter constraints. Its scientific merit lies less in immediate replacement of DM and more in advancing discriminative tests that can expose hidden tensions in LambdaCDM or reveal new gravitational sectors.

10. Conclusion

At present, dark matter remains the most comprehensive explanation for large-scale cosmic aggregation. Supermassive black holes are indispensable, but primarily as local/regional engines of galaxy evolution and high-energy feedback. Future decisive progress will come from cross-probe inference, next-generation lensing surveys, CMB-S4, and precision GW population studies.

Appendix A. Compact Equation Set

A1. Circular velocity relation:

$$v(r)^2 = G\, M(<r) \,/\, r \tag{A1}$$

A2. Point-mass gravitational field:

$$g(r) = G\, M \,/\, r^2 \tag{A2}$$

A3. Accretion luminosity:

$$L = \eta\, \dot{M}\, c^2 \tag{A3}$$

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