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

A Critical Scientific Assessment

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Abstract

This paper evaluates the thesis that supermassive black holes (SMBHs), rather than dark matter (DM), are the principal gravitational engines responsible for large-scale cosmic structure. We review observational evidence from galaxy rotation curves, gravitational lensing, the cosmic microwave background (CMB), large-scale structure, and black-hole astrophysics. We then test whether known SMBH populations, or plausible hidden black-hole populations (including primordial black holes), can reproduce the full set of constraints currently explained by the Lambda Cold Dark Matter (LambdaCDM) model. The core result is that SMBHs are unquestionably central to galaxy evolution and feedback, but they do not by themselves reproduce halo-scale mass distributions required by rotation curves and lensing. A black-hole-centric cosmology remains scientifically interesting in restricted mass windows (notably primordial black-hole scenarios), yet current data strongly constrain such models. The most rigorous position today is therefore: dark matter remains the best-supported explanation for large-scale gravitational aggregation, while SMBHs are dominant local/regional dynamical engines within galaxies.

Keywords: dark matter, supermassive black holes, primordial black holes, galaxy rotation curves, gravitational lensing, cosmology

1. Introduction

A central problem in modern cosmology is the persistent mismatch between the observed gravitational field and the gravity produced by visible baryonic matter. This mismatch appears across scales: in spiral galaxies, galaxy clusters, and the growth of large-scale structure. The standard interpretation introduces a non-luminous matter component (dark matter), whereas alternative programs seek to explain the same data through modified gravity, compact-object populations, or combinations thereof.

The present work addresses a concrete hypothesis: that black holes—particularly SMBHs at galactic centers—are the true global aggregators of the cosmos and may render dark matter unnecessary. This hypothesis is physically motivated by the extraordinary gravitational and energetic role of SMBHs and by ongoing uncertainty over the particle nature of dark matter.

2. Observational Pillars Supporting Dark Matter

2.1 Galaxy rotation curves

Observed circular velocities in disk galaxies remain approximately flat at large radii, while Newtonian expectations from luminous mass alone predict a declining profile $v(r) \sim r^{(-1/2)}$. This implies additional mass distributed in an extended halo.

2.2 Cluster dynamics and gravitational lensing

Galaxy clusters require substantially more gravitating mass than is visible in stars and gas. Lensing maps also reveal mass distributions offset from baryonic tracers in some merging systems, a key argument for a collisionless dark component.

2.3 Cosmic microwave background and structure growth

CMB anisotropy spectra and baryon acoustic oscillation measurements constrain cosmological parameters in a way that robustly supports a non-baryonic matter component. Planck-era parameter fits are broadly consistent with a universe containing approximately 26-27% total matter, dominated by a cold dark component.

3. Supermassive Black Holes as Proven Cosmic Engines

SMBHs are established astrophysical realities. Event Horizon Telescope imaging of M87* and Sgr A* confirms horizon-scale compactness and strong-gravity predictions. SMBHs power active galactic nuclei and relativistic jets, inject energy into interstellar and intracluster media, and regulate star formation via feedback.

Empirical scaling relations (e.g., M-sigma and bulge-mass correlations) indicate co-evolution between SMBHs and host galaxies. Thus, SMBHs are not incidental: they are fundamental to galaxy lifecycle physics.

4. Can SMBHs Replace Dark Matter as the Main Aggregator?

4.1 Radial-force limitation of a central mass

A central compact object produces a potential that declines steeply with radius. While dominant near the nucleus, its contribution at tens of kiloparsecs is insufficient to maintain flat rotation curves. Therefore, known SMBHs cannot replace distributed halo mass.

4.2 Population accounting

The integrated mass density in observed SMBHs is far below the cosmic matter budget attributed to dark matter. Even generous extrapolations do not naturally close the gap without violating other constraints.

4.3 Lensing morphology

Lensing reconstructions generally favor extended mass distributions. A scenario dominated by central compact masses cannot reproduce the full observed lensing phenomenology across clusters and cosmic filaments.

5. Primordial Black Holes: The Strongest Black-Hole Alternative

Primordial black holes (PBHs) remain the most serious black-hole-based dark matter candidate. If formed in the early universe, PBHs could contribute to or, in narrow mass intervals, potentially dominate dark matter. However, microlensing, CMB effects, dynamical heating limits, and gravitational-wave merger-rate constraints significantly restrict viable parameter space.

Recent LIGO-Virgo-KAGRA analyses continue to tighten constraints on PBH abundance in stellar-mass ranges. The current balance of evidence allows PBHs as a partial component in selected windows, but disfavors PBHs as a universal replacement for dark matter.

6. Modified Gravity and Hybrid Explanations

An SMBH-centric thesis can be reframed as a deeper statement: perhaps gravity is incomplete on galactic/cosmological scales. Modified-gravity frameworks (e.g., MOND and relativistic extensions) explain some galaxy-scale regularities, but matching cluster lensing, CMB peaks, and full structure formation remains challenging without additional unseen components.

Hybrid models—combining modified gravity, dark sectors, and compact-object populations—are active research frontiers.

7. Methodological Requirements for a Decisive Test

- Joint likelihood analyses across rotation curves, weak/strong lensing, CMB, BAO, and gravitational waves.
- Forward simulations comparing LambdaCDM halos versus BH-heavy alternatives under identical baryonic physics.
- Consistent priors on black-hole mass functions and merger histories.
- Model selection with information criteria and Bayesian evidence, not single-observable fits.
- Prediction-first strategy: define falsifiable signatures before tuning models.

8. Conclusion

The scientific verdict at present is nuanced but clear. SMBHs are indispensable engines of galaxy evolution and high-energy astrophysics. They shape star formation histories, gas thermodynamics, and central galactic dynamics. However, they do not currently account for the distributed gravitational mass inferred on halo and cosmological scales. Dark matter remains the most comprehensive explanation for large-scale aggregation.

A rigorous black-hole-first cosmology is still scientifically valuable, especially via PBH channels and precision tests of gravity. Its strongest contribution may be conceptual: forcing cosmology to tighten constraints, improve cross-scale modeling, and sharpen falsifiability. If future observations reveal systematic tensions in LambdaCDM, black-hole-rich or gravity-modified frameworks could become central. Until then, the evidence supports a dual picture: dark matter provides global scaffolding; black holes provide local dynamical power.

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