Unveiling the Quantum Nature of Black Holes: A First Proof of Hawking Radiation through Gamma-Ray Observations

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Abstract

Hawking's groundbreaking prediction that black holes emit thermal radiation and ultimately evaporate remains unverified due to the extreme faintness of this radiation for stellar-mass or larger black holes. In this study, we propose a novel observational strategy to detect Hawking radiation from asteroid-mass black hole morsels—hypothetical small black holes formed and ejected during catastrophic events like binary black hole mergers. These black hole morsels may account for the missing mass in merger events and are predicted to emit gamma rays across the GeV to TeV energy range on observable timescales. We analyse data from the Fermi-Large Area Telescope coinciding with the binary black hole merger GW170814, searching for gamma-ray signatures delayed relative to the gravitational wave signal—indicative of radiation from such black hole morsels. Additionally, we assess the detectability of this phenomenon with both existing and future telescopes and explore its implications for fundamental physics.

Introduction

- In 1974, Stephen Hawking predicted that black holes emit faint radiation and eventually evaporate. But this Hawking radiation is far too weak to detect from typical black holes—until now.
- When two black holes merge, they might not just form a larger black hole—but also create tiny, low-mass black holes with asteroid-like masses [1]. These black hole morsels would evaporate rapidly, releasing a brief burst of high-energy gamma rays.
- This provides a golden opportunity to test quantum predictions using the most extreme events in the universe. Confirming this would prove that black holes obey quantum mechanics—a key step toward unifying gravity and quantum theory.

The Challenge

- Stellar-mass black holes emit Hawking radiation that's colder than the cosmic microwave background—far too faint to detect.
- Tiny black holes (~10^8 kg), potentially formed during mergers, could evaporate rapidly, emitting gamma rays detectable by Fermi-LAT.

The Search

- As first observed by the LIGO and Virgo detectors on 14 September 2015, the merger also emits gravitational waves, wiggles in spacetime that travel outward [2].
- We use Fermi-LAT gamma-ray data, aligned with LIGO/Virgo gravitational wave events, to look for these short-lived, high-energy signals.

- It would be the first-ever experimental evidence of Hawking radiation. Even null results constrain exotic merger outcomes and guide future gamma-ray missions.
- Why GW170814? Relatively nearby (Ld =540 Mpc, z = 0.11). Pretty well constrained (90% credible area <100 deg²)

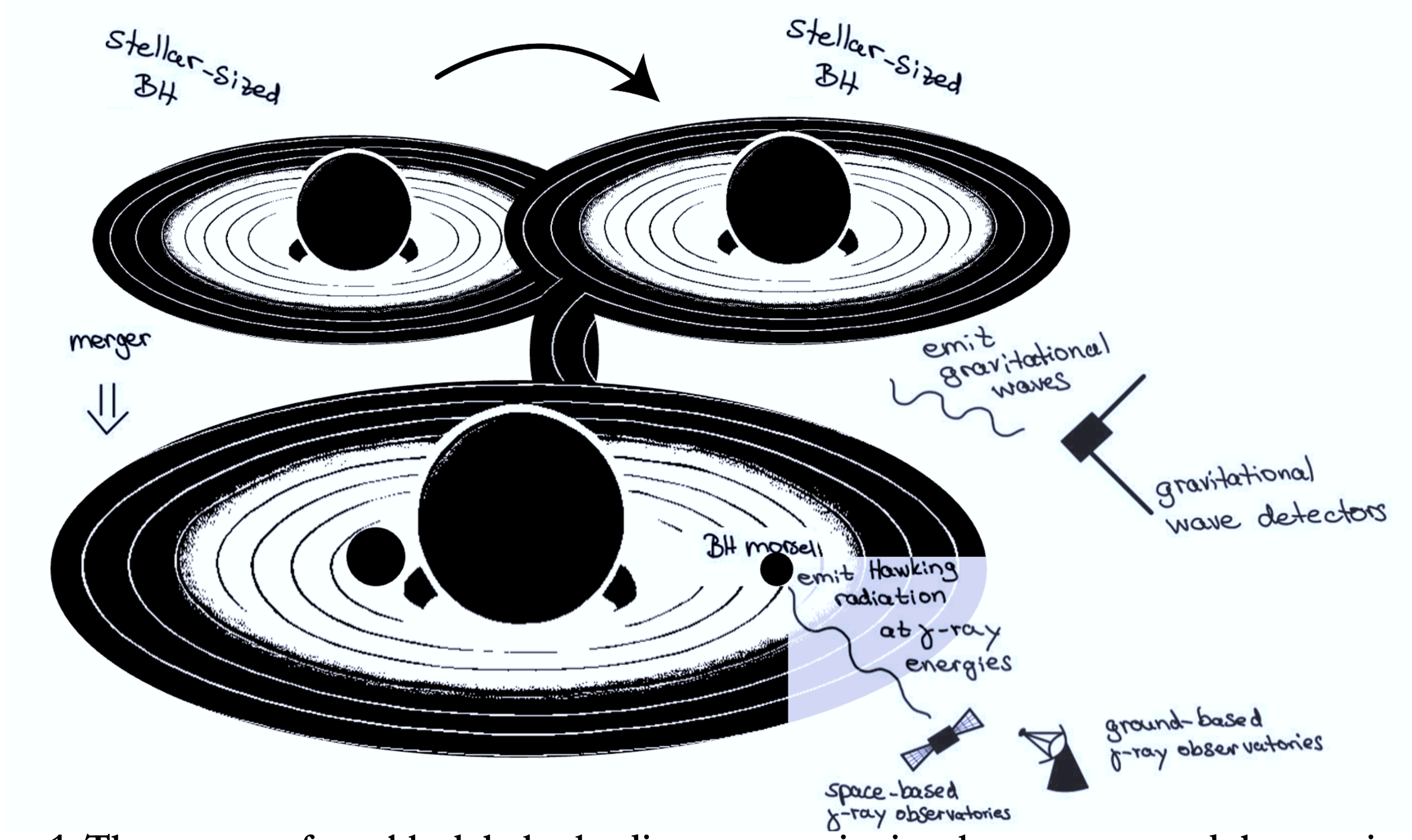

Figure 1: The merger of two black holes leading to a gravitational wave event and the creation of a larger black hole, as well as smaller black hole morsels. The black hole morsels are predicted to emit gamma rays which can be observed with current instruments.

Analysis

- Source added at most probable pixel from sky map: R.A = 47.283°, Dec = –44.59°
- Spectrum modeled using input spectra generated with BlackHawk [3]

Model Assumptions

- Total emitted mass: 1 solar mass (in black hole morsels)
- Morsel masses: 1.8–4.0 × 10^8 kg
- Evaporation times: 29–339 days
- We assume all emitted black holes morsels have the same mass and normalize the total emitted mass to 1 solar mass

Spectral Treatment

- Spectra analyzed month by month until evaporation
- Before evaporation, spectra were scaled by:
  (days until evaporation) ÷ 30. Example: GW on Jan 1, evaporation time = 79 days.
  →Use Jan and Feb spectra directly. For March: apply scaling factor (e.g., 19 ÷ 30)

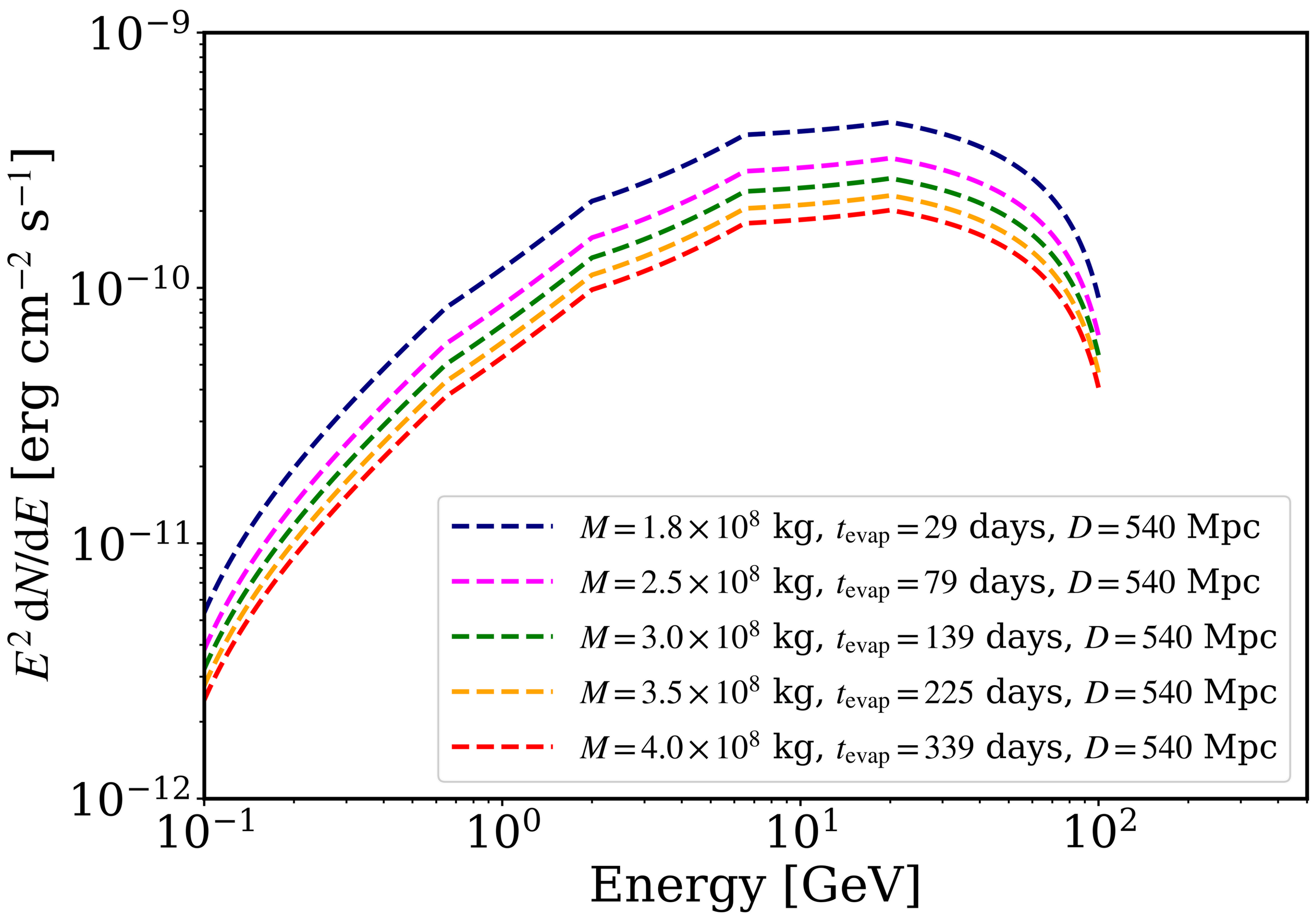

Figure 2: Simulated differential flux spectra from 1 solar mass of black hole morsels of masses 1.8 to 4.0 × 10^8 kg., located at a distance of 540 Mpc. These spectra are used to model a possible new source at the location of the highest probability pixel of GW170814. The spectrum is averaged over the entire lifetime.

Results

- The significance of gamma-ray emission was evaluated using the likelihood ratio test:
  $TS = -2 \ln(L_0 / L_1)$
  where L_1 and L_0 are the maximum likelihoods with and without an added source.
- Monthly TS values are consistently negative for all considered black hole morsel masses. No significant gamma-ray counterpart was detected at the GW event location in Fermi-LAT data.
- Nevertheless, the obtained upper limits can be used to provide exclusion limits on black hole mass. Taking the least negative TS value as a reference and computing ΔTS for other cases suggests the 4×10^8 kg scenario can be excluded at 95% confidence.
- Further exclusion limits require extending the mass grid on both sides and incorporating the late-time gamma-ray spike near evaporation.

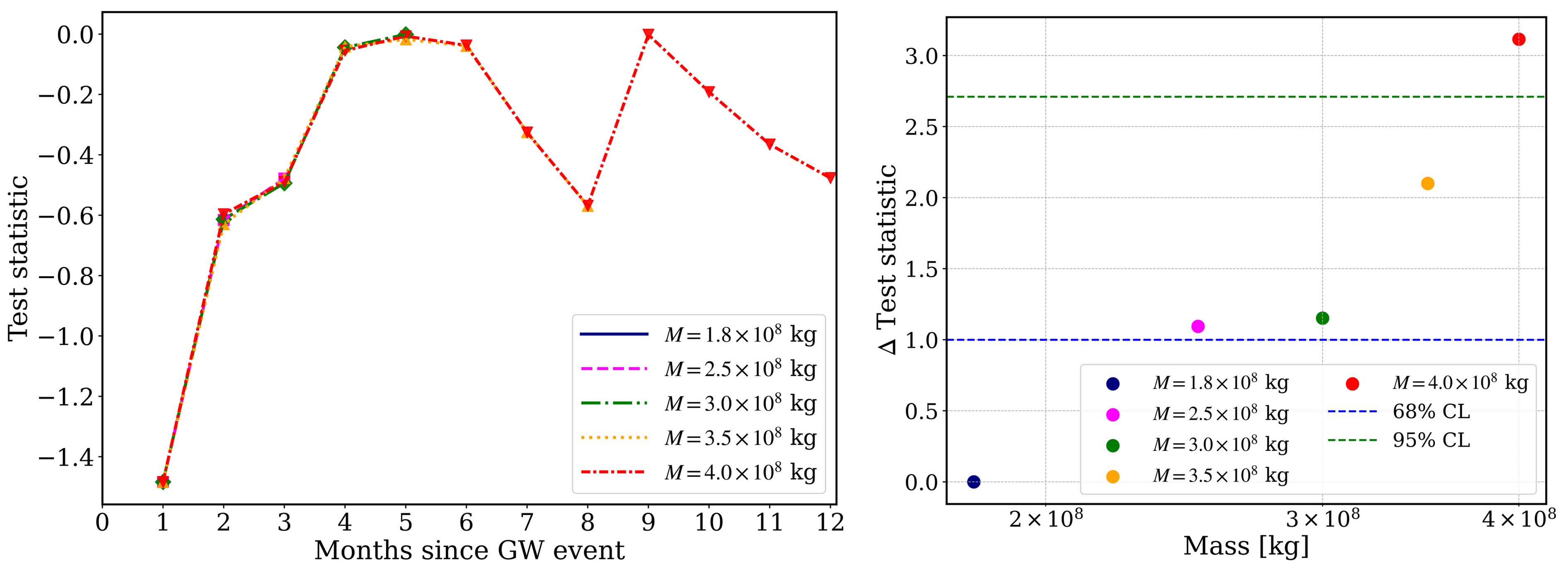

Figure 3. (a) Monthly test statistic (TS) values from Fermi-LAT data at the GW event location for black hole morsel models of different masses. All curves show negative TS across the 12-month window, indicating no significant gamma-ray counterpart. The total summed TS for each mass scenario is listed in the legend. (b) ΔTS as a function of black hole mass, computed relative to the least negative TS case (1.8×10^8 kg). The horizontal dashed lines indicate exclusion thresholds at 68.3% (ΔTS = 1) and 95% (ΔTS = 2.71) confidence levels. The 4×10^8 kg scenario exceeds the 95% threshold and is therefore excluded at this level.

References

[1] G. Cacciapaglia, S. Hohenegger, F. Sannino, Nuclear Physics B 1018:117021 (2025)
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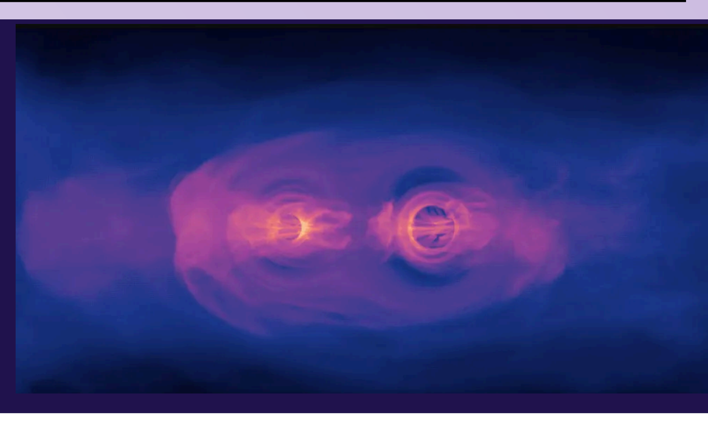

Read more on Phys.org: Detecting 'Hawking radiation' with today's telescopes (scan QR code).

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