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Classical vs Quantum Black Hole Mergers

Visual and Mathematical Comparison

This report presents a visual and mathematical comparison between **classical black hole mergers** (as predicted by general relativity) and speculative **quantum-scale black hole mergers**. The classical system follows well-established physics and produces observable gravitational waves. The quantum system explores Planck-scale dynamics, beyond current physical theories.

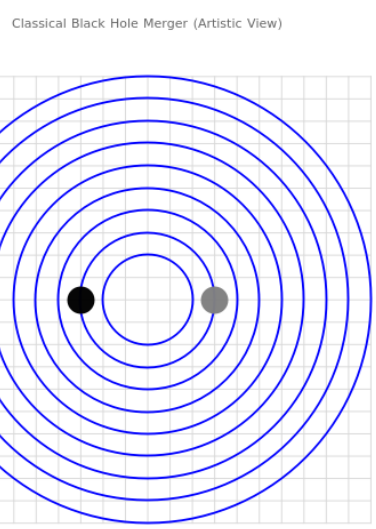
1. Classical Merger (GR-based Quadrupole Emission):

$$P = \frac{32}{5}\frac{G^4}{c^5}\frac{(m_1 m_2)^2(m_1+m_2)}{r^5}, \quad h(t) \approx \frac{4G}{c^4}\frac{\mu}{R}(GM\omega(t))^{2/3}\cos[2\phi(t)]$$

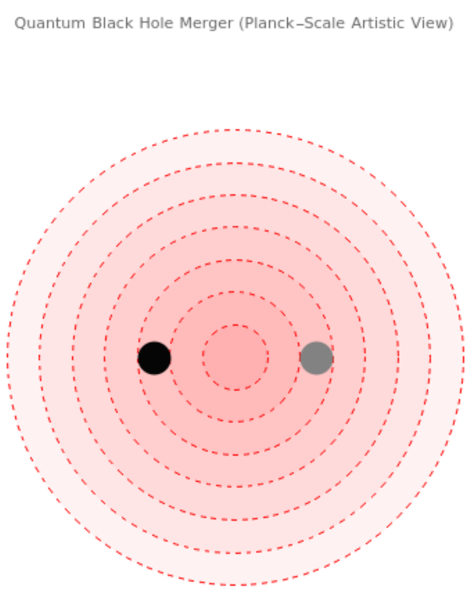
2. Quantum Merger (Planck-scale Model – Hypothetical):

$$h_q(t) = \epsilon \cdot \sin\left(2\pi f_q(t) t\right) \cdot e^{-\alpha t}, \quad f_q(t) \sim \frac{1}{2\pi}\sqrt{\frac{2Gm_p}{r(t)^3}}$$

Classical Merger



Quantum Merger



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Classical black hole mergers involve two massive black holes spiraling inward due to gravitational wave emission, culminating in a merger and ringdown. The radiated energy can be approximated using the **quadrupole formula** from general relativity.

At scales near the **Planck length** (~10^{-35} m) and **Planck mass** (~2.18×10^{-8} kg) black holes may behave according to quantum gravitational rules. Although no empirical quantum gravity theory exists, we can model a speculative waveform.

🔵 Classical Black Hole Merger (Quadrupole Radiation)

For a binary system of black holes with masses m_1 and m_2, the **power emitted as gravitational waves** is given by:

$$P = \frac{32}{5}\frac{G^4}{c^5}\frac{(m_1 m_2)^2(m_1+m_2)}{r^5}$$

The **chirp waveform** strain at a distance R from the merger is approximately:

$$h(t) \approx \frac{4G}{c^4}\frac{\mu}{R}(GM\omega(t))^{2/3}\cos[2\phi(t)]$$

Where:

- $\mu = \frac{m_1 m_2}{m_1+m_2}$ is the reduced mass
- $M = m_1 + m_2$ is the total mass
- $\omega(t)$ is the orbital frequency increasing over time (chirp)

🔴 Quantum Black Hole Merger (Speculative Model)

At Planck-scale, quantum gravity is expected to dominate. A **toy model** for quantum gravitational radiation (non-standard) might use:

$$h_q(t) = \epsilon \cdot \sin\left(2\pi f_q(t)t\right) \cdot e^{-\alpha t}$$

Where:

- $\epsilon \ll 10^{-22}$ is a very small amplitude
- $f_q(t) \sim \frac{1}{2\pi}\sqrt{\frac{2Gm_p}{r(t)^3}}$ (Planck-scale frequency)
- α is a damping coefficient from quantum effects (e.g. Hawking evaporation)

This is speculative, as quantum gravity is not yet experimentally confirmed.

Feature	Classical Merger	Quantum Merger (Speculative)
Scale	Astrophysical (Solar mass)	Planck-scale
Radiation	Gravitational waves (LIGO-confirmed)	Hypothetical quantum gravity waves
Modeling Framework	General Relativity	Quantum Gravity (unknown)
Detectability	Observable with current detectors	Undetectable today

Note: LLM AI models + Wolfram used to assist in generating equations and illustrations for the thought experiment