

Research Proposal

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1. Research Objectives

This research aims to establish a fully analytical framework for black hole perturbation theory based on exact WKB analysis. By deriving exact expressions for quasinormal modes (QNMs), excitation factors, and greybody factors, the project provides a unified understanding of scattering phenomena in black hole spacetimes. In addition to applications to gravitational-wave physics, this framework will be extended to explore broader theoretical contexts such as holography and non-Hermitian physics, where similar structures—resonances, Stokes geometry, and non-perturbative corrections—play central roles. The final goal of the project is to expand the physical reach of exact WKB analysis beyond black hole physics and shed light on universal structures governing resonant spectra in strongly coupled and open quantum systems.

2. Research Plan

The project proceeds in several phases:

(i) Establishing Mathematical Framework and QNM Application

- *Developing Low-Damped Mode Calculation methods:* I am currently developing a method for calculating low-damped QNMs, which are crucial for observations. Preliminary results show excellent agreement with existing numerical methods (e.g., Leaver's method).
- *Performing Exact Calculation for Rotating Black Holes:* Based on my prior research, I will apply exact WKB analysis to the more realistic case of rotating black holes to precisely calculate their QNMs.

(ii) Extension to Excitation Factors and Greybody Factors, and Application to Modified Gravity Theories

- *Deriving Exact WKB Analysis of Excitation and Greybody Factors:* I will derive analytical formulas for excitation factors (amplitudes of each QNM) and greybody factors (transmittance of gravitational wave) using exact WKB analysis, exploring the contributions of Voros coefficients from both mathematical and physical perspectives.
- *Applying to Modified Gravity:* The established methods will be applied to modified theories of gravity (e.g., $f(R)$ gravity, Hořava-Lifshitz gravity) to elucidate their differences from general relativity.

(iii) Extension to Holography and Non-Hermitian Physics

- *Application to Holographic Models and Strongly Coupled Field Theories:* Using the analytical results, I will apply the exact WKB framework to holographic models, where quasinormal modes determine transport coefficients.
- *Application to Non-Hermitian Physics and Resonant Spectra:* Since black hole QNMs mathematically correspond to resonance spectra in open quantum systems, I will extend the formalism to non-Hermitian models. This includes examining how Stokes geometry encodes exceptional points and topological transitions.