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Hartle-Hawking v.s. Vilenkin saddle points in quantum cosmology by the generalized Lefschetz thimble method

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Quantum cosmology investigates the origins of our Universe, including the concept of "tunneling from nothing" proposed by Vilenkin and Hartle-Hawking. Recent advancements have renewed interest in this field, employing the Picard-Lefschetz theory in Lorentzian quantum gravity. In this study, we address crucial challenges using the generalized Lefschetz thimble method, overcoming the sign problem in Monte Carlo techniques. By the mini-superspace model, we perform first-principle calculations to shed light on fundamental issues. We tackle concerns regarding the integration domain of the lapse function and explore the Robin boundary condition at the initial time, incorporating aspects of Dirichlet and Neumann boundary conditions. Our findings reveal the Stokes phenomenon, where the dominant saddle point transitions from Vilenkin to Hartle-Hawking, aligning with expectations from the Picard-Lefschetz theory. Notably, we focus on the intricate simulation of the Hartle-Hawking proposal for a minute final size of the universe, which is highly nontrivial.

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