Volume 3, Issue 2, 2026

Intuitions & Insights

An Interdisciplinary Peer Reviewed Research Journal

ISSN: 3048-6793

A Note on Euclidean Wormhole

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Abstract: The Big Bang theory is one of the most successful models for describing the evolution of the universe. However, this theory fails to describe phenomena of the very early universe, precisely near the Planck epoch. It cannot avoid initial singularity. To describe phenomena of the very early universe, quantum gravity must be evoked. The Wheeler-DeWitt (WDW) equation is the quantum counterpart of the classical gravitation field equation. To solve the WDW equation, we need some specific boundary condition. The Hartle-Hawking no boundary proposal is widely used for this purpose. It insists that the time near and beyond the Planck epoch is Euclidean in nature. Classical Euclidean wormholes are solutions of the field equation with Euclidean time, and quantum Euclidean wormholes are solutions of the WDW equation in the Euclidean regime. Euclidean wormholes provide a compelling theoretical tool for probing the deep structure of space-time and quantum gravity. Studying Euclidean wormholes is crucial in theoretical physics because they act as non-perturbative gravitational instantons that provide essential insights into quantum gravity, black hole information, and the structure of space-time at the Planck scale. These geometries, which connect disconnected boundaries or distant regions of space, are instrumental in addressing the black hole information paradox by preserving the unitarity of quantum mechanics. Thus, the study of quantum Euclidean wormholes will help us to understand the very early universe in a better way. In this review, I have discussed both the classical and quantum Euclidean wormholes in a simplified way. The results are quite fascinating. In the case of quantum Euclidean wormholes, some authors have shown that the universe has evolved from Euclidean space-time in the very early universe to late-stage Lorentzian space-time.

Key-words: Early Universe, Wheeler DeWitt Equation, Hawking-Page boundary conditions, Classical and Quantum Euclidean wormholes.

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Received: 03.03.2026; **Accepted**: 15.07.2026; **August 2026**

1. Introduction

Wormholes are theoretical solutions arising from Einstein's General Theory of Relativity (GTR). In GTR, mass and energy curve spacetime. Under certain extreme conditions, space-time might bend so much that it forms a “tunnel” between two regions. Such a type of tunnel is known as a wormhole. It acts like a shortcut, connecting two distant points of the universe. This concept was first explored by Einstein and Rosen in 1935, leading to the idea of the Einstein–Rosen bridge (Einstein et al. 1935). Since its inception, the concept of wormholes has attracted both scientists and the general public, because of its relation with time travel. Instead of travelling through ordinary spacetime, an object could pass through a wormhole and emerge