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Naked Singularity Formation in Higher Curvature Gravity

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Abstract. We find an exact solution in dimensionally continued gravity in arbitrary dimensions which describes the gravitational collapse of a null dust fluid [1]. Considering the situation that a null dust fluid injects into the initially anti-de Sitter spacetime, we show that a naked singularity can be formed. In even dimensions, a massless ingoing null naked singularity emerges. In odd dimensions, meanwhile, a massive timelike naked singularity forms. These naked singularities can be globally naked if the ingoing null dust fluid is switched off at a finite time; the resulting spacetime is static and asymptotically anti-de Sitter spacetime. The curvature strength of the massive timelike naked singularity in odd dimensions is independent of the spacetime dimensions or the power of the mass function. This is a characteristic feature in Lovelock gravity.

1. Introduction

It has been of great importance to consider higher-dimensional spacetimes. There exists a natural extension of general relativity in higher dimensions: Lovelock gravity [2]. We will restrict our attention to the special case of the Lovelock gravity, called dimensionally continued gravity (DC gravity) [4]. The purpose of the present work is to analyze how higher-order Lovelock terms modify the final fate of gravitational collapse in comparison to the Gauss-Bonnet [3] or general relativistic cases. A detailed analysis is reported in [1].

2. Null Dust Solution in DC gravity

We find an exact solution of DC gravity in D -dimensional spacetimes representing a radially ingoing null dust fluid:

$$ds^2 = -f(v, r)dv^2 + 2dvdr + r^2 d\Sigma_{k, D-2}^2 \quad (1)$$

with

$$f(v, r) = \begin{cases} k - (2M(v)/r)^{1/(n-1)} + l^{-2}r^2, & \text{for } D = 2n, \\ k - M(v)^{1/(n-1)} + l^{-2}r^2, & \text{for } D = 2n - 1. \end{cases} \quad (2)$$

The energy density of the null dust fluid is given by $\rho(v, r) \propto \dot{M}/r^{D-2}$ both in odd and even dimensions. $\dot{M} \geq 0$ is required due to the weak energy condition. We shall call the solution (1) DC-Vaidya solution.

3. Formations of Naked Singularities and Their Strength

We consider the situation in which a null dust fluid radially falls into the initial AdS spacetime ($M(v) = 0$) at $v = 0$ in even dimensions at first. We set $M(v) = M_0 v^q$ for simplicity, where $M_0 (> 0)$ and $q (\geq 1)$. Then a central singularity appears at $r = 0$ for $v > 0$ both in odd and even dimensions. We can find the radial null geodesics emanating from the singularity. Along these null geodesics, the energy density for the null dust fluid and the Kretschmann scalar $I_1 = R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma}$ diverge as $r \rightarrow 0$ for particular ranges of q and D . Thus, the spacetime represents the formation of a naked singularity. In order to see whether the singularity is globally naked, we consider the situation in which the null dust fluid is switched off at $v = v_f > 0$. The possible Penrose diagrams of the gravitational collapse are drawn in Fig. 1 for the globally naked singularity formation.

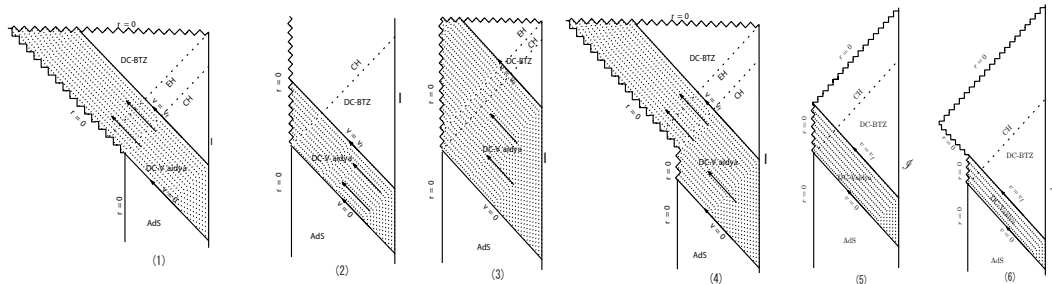


Figure 1. Possible Penrose diagrams

Calculating $\psi \equiv R_{\mu\nu}k^\mu k^\nu$, where $k^\mu = dx^\mu/d\lambda$, we evaluate the strength of naked singularities along the radial null geodesics by the divergent behavior of ψ . In four dimensions, the strong curvature condition and the limiting focusing condition are satisfied along an affinely parametrized geodesic if $\lim_{\lambda \rightarrow 0} \lambda^2 \psi > 0$ and $\lim_{\lambda \rightarrow 0} \lambda \psi > 0$, respectively [5, 6]. We find that the divergent behavior depends both on the spacetime dimensions and the power of the mass function, except for the singularity $r = 0$ and $0 < v < M^{-q}$ in odd dimensions.

4. Conclusions and Discussions

We analyzed the $D (\geq 3)$ -dimensional gravitational collapse of a null dust fluid in DC gravity. We found that globally naked singularities can be formed in DC gravity. Furthermore, the final states of the gravitational collapse differ substantially depending on whether the spacetime dimensions are odd or even. These naked singularities can be globally naked. The strength of the naked singularity at $v = r = 0$ depends on D and q both in odd and even dimensions. In contrast, around the massive timelike singularity portion in odd dimensions, ψ diverges as λ^{-1} , independent of D or q , which might be salient features in Lovelock gravity.

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