Abstract

The theory of isolated horizons is considered in the context of generic black holes and gravitational radiation in spacetimes with cosmological constant Λ. Intrinsic geometry of such horizons consists of the induced degenerate metric tensor and covariant derivative. Assuming embeddability in Λ-vacuum Einstein's equations and imposing a condition on stationarity to the second order allow to generically determine the spacetime Weyl tensor on the horizon, and based on its property provide a complete classification of the Petrov types of isolated horizons. Condition distinguishing the type D horizon is derived and takes a form of a second order differential equation on a complex invariant constructed from a Gaussian curvature and rotation scalar. It is referred to as the Petrov type D equation with cosmological constant and its general properties as well as solutions considering various structures of the horizons constitute a significant part of this work.

To start with, axisymmetric horizons of the topology: $\mathcal{S}_2 \times \mathbb{R}$ are investigated. All the solutions to type D equation with cosmological constant are derived and found to be embeddable in the Schwarzschild/Kerr-(anti) de Sitter spacetimes or the near extremal horizon spacetimes obtained by the Horowitz limit form the extremal Schwarzschild/Kerr-(anti) de Sitter metric. The family of solutions may be parametrized by two parameters, the area and angular momentum, which provides the foundation for formulating the local version of the no-hair theorem. It is a generalization of the earlier result valid for the vanishing cosmological constant. Furthermore, the isolated horizons with spacelike cross-section of genus> 0 are considered. The only solutions are those with constant Gaussian curvature and no rotation. Consequently, a quasi-local argument is provided for the rotating black holes in 4-dimensional spacetimes to have a cross section of a topological 2-sphere. Finally, we consider the Petrov type D equation with cosmological constant on horizons generated by null curves that form nontrivial $U(1)$-bundles. The type D equation couples the $U(1)$ connection, 2-metric of the base manifold and surface gravity in a nontrivial form. We derive all axisymmetric solutions which set a 4-dimensional family of isolated horizons and discuss the issue of their embeddability.

The type D equation with cosmological constant is also satisfied by extremal isolated horizons regardless of the Petrov type of the Weyl tensor on the horizon. Therefore, our results may be applied to the near horizon geometry equation for the extremal horizons. Consequently, we found all solutions to the near horizon geometry equation on the 2-surfaces of genus> 0.

The notion of isolated horizons is also applied in context of gravitational radiation, where the isolated horizon serves as a generalization of the conformal boundary in Minkowski case for spacetimes with positive cosmological constant. We consider a time changing matter source in de Sitter spacetime emitting gravitational radiation. The formula for the energy flux passing through a cosmological horizon is derived and expressed in terms of the mass and pressure quadruple moments. It is written explicitly up to the first order in Hubble parameter $H := \sqrt{\Lambda/3}$. We found that the zeroth order term coincides with the Einstein's quadruple formula for the perturbed Minkowski spacetime, whereas the first order term is a new correction.