Abstract

Few exact solutions to the Einstein Equations have posed more difficulty in their physics interpretation than spacetimes containing the NUT parameter. Charles Misner famously said that the Taub-NUT spacetime, the simplest spacetime with the NUT parameter, is a counterexample to almost everything[1]. It is a direct and vacuum generalization of the Schwarzschild spacetime and yet is not asymptotically flat. It contains closed time-like curves close to the axis, is not geodesically complete, and contains two equivalent maximal analytic extensions[2]. All of those problems are tightly connected with the existence of a singular axis of rotation in spacetime. Usually, this singularity is associated with a conical singularity and subsequently with the existence of a cosmic (sometimes called Misner) string. Coincidently it was Misner, who proposed a non-singular interpretation, which changes the topology of the spacetime to the product of a 3-sphere and a real line. A crucial element of this interpretation is the introduction of a periodic time-like (in certain regions) coordinate. Consequently through every point of the so-called NUT region of spacetime passes a closed timelike curve, further inhibiting physical interpretation.

In this thesis, I seek to extend the Misner interpretation to a broad class of NUT solutions contained in the Plebański-Demiański solution. In particular, non-singular Misner-like spacetimes are constructed for generic spherical Type D black hole solutions, including the Kerr parameter, acceleration, the cosmological constant, and electromagnetic charges. It turns out that there always exist Killing Vector fields giving rise to a smooth space of the orbits and the $U(1)-$ PFB structure, from which the non-singular spacetime may be constructed. An immediate possible application is the construction of singularity-free non-homogeneous cosmological models.

NUT spacetimes are intrinsically connected with black hole horizons of the S^3 topology. Interestingly they split into two cases, depending on whether the $U(1)$ symmetry coincides with the horizon-generating Killing vector field. The Petrov Type D equation is a recently obtained tool in mathematical relativity allowing for obtaining the geometry of Isolated Horizon, a local generalization of the Killing horizon. In this work, a novel type of IH horizon, such that the $U(1)-$ symmetry is transversal to the null symmetry is proposed and its geometry is studied. Then the solutions to the Petrov Type D Equation on the Hopf bundle, corresponding to both of the above cases, are compared with the embedded horizon in non-singular (accelerated) Kerr-NUT-(anti-) de Sitter.

NUT spacetimes also include a generalization admitting a family of two-surface of vanish-

ing and negative curvature. Upon compactification to a Riemann surface with a genus higher than 0, the spacetimes naturally admit a non-trivial bundle topology. A full family of Isolated Horizons of $U(1)-$ PFB structure over a compact Riemann surface will be constructed and studied via the Petrov Type D equation. Their embedding spacetimes have been found to be locally isometric to the generalized Taub-NUT-(anti-) de Sitter.