Gravity in Modified Theories

Abstract
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Abstract

Einstein's general relativity has been the most celebrated theory of gravity that successfully explains the dynamics of gravitating bodies, from free-falling of apples to the cosmological evolution of the Universe. However, in recent years, both theoretical and observational studies suggests a need for modifying the theory. Like all other physically meaningful theories in nature, we expect Einstein's general relativity to be well posed theory. In other words, we expect the theory to determine the future of a gravitating body uniquely through Einstein's Field equations and physically reasonable initial conditions. This deterministic nature of the theory is guaranteed by Penrose's *strong cosmic censorship conjecture*. However, in recent years, several counter-example of this conjecture have been found, in particular, in case of charged de Sitter black holes under the influence of different fundamental fields. More importantly, the study suggests that even contribution from non-linear perturbation can not save the conjecture. This failure of determinism forces us to closely inspect the assumptions that goes into the calculation and overall, the formulation of the theory itself. However, the biggest objection to theory come from a remarkable observation nearly two decades ago which suggests that the Universe is expanding with an accelerated pace. This observation demands the presence of repulsive gravity at Cosmological scale, which standard general relativity can not explain. There have been several

attempts to explain the phenomena, however, a satisfactory explanation is yet to be found.

Part of the Chapter 1 is dedicated to explain some predictions of general relativity and the correct formulation of strong cosmic censorship conjecture. We briefly discuss different black hole solutions in the framework of general relativity. We extensively discuss the mass inflation phenomena and the formulation of the modern version of the conjecture. Moreover, in this chapter, we briefly describe two modified theories of gravity, which are the brane-world model and generalized Proca theories.

In Chapter 2, we discuss on the validity of strong cosmic censorship conjecture in presence of higher dimensions. For this purpose, we mainly focus on two possibilities. The first one concerns with a spacetime in which the black hole itself lives on higher dimension whereas the second possibility deals with a spacetime where the black hole resides on a slice (which we call brane) of a higher dimensional spacetime. In these scenarios, we check the validity of the conjecture for both charged and rotating black holes when the spacetime gets perturbed by scalar fields.

The Chapter 3 tells fermionic side of the story. Previous studies showed that strong cosmic censorship conjecture holds true in astrophysical Kerr-de Sitter black holes in presence of scalar field perturbations. In this chapter, we check whether the same is also true in presence Dirac fields.

In continuation of the work done in Chapter 2 and Chapter 3, we study the response of Kerr-Newman -NUT-de Sitter black holes against ex-

ternal scalar perturbations and its effect on strong cosmic censorship conjecture in Chapter 4. In this work, we are concerned about Plebański class of black holes which are stationary, axially symmetric, Petrov D type solutions of Einstein-Maxwell equation. Here, we discuss the separability of Klein-Gordon equation in presence of NUT charge and conformal coupling and check the validity of strong cosmic censorship conjecture in this scenario.

Chapter 5 deals with different astrophysical aspects for a black hole in second order generalized Proca theories with derivative vector field interactions coupled to gravity. These black hole solutions are hairy and hence give us a perfect opportunity to observationally verify the "No-Hair theorem". We considered the super massive black hole in the center of galaxy is given by these generalized Proca theories and numerically estimated the values of different observables in strong field limit for two separate lensing configuration namely a) when the source, lens and the observer is highly aligned with both the source and the observer is at infinity and b) taking the star S2 as a source. We also analyse the shadow of this black hole.

Finally, we end the thesis with some concluding remarks in Chapter 6.

List of Publications

The thesis is based on the following publications:

1. **"Astrophysical Signatures of Black holes in Generalized Proca Theories"**, **Mostafizur Rahman**, Anjan Ananda Sen,
   Phys.Rev. D99 (2019) no.2, 024052.

2. **"Fate of Strong Cosmic Censorship Conjecture in Presence of Higher Spacetime Dimensions"**,
   Mostafizur Rahman, Sumanta Chakraborty, Soumitra SenGupta, Anjan Ananda Sen,
   JHEP 1903 (2019) 178.

3. **"On the validity of Strong Cosmic Censorship Conjecture in presence of Dirac fields"**,
   Mostafizur Rahman,
   Eur. Phys. J. C **80**, no.5, 360 (2020).

4. **"Strong cosmic censorship conjecture with NUT charge and conformal coupling"**,

Mostafizur Rahman, Soumodeep Mitra, Sumanta Chakraborty,

Accepted in Classical and Quantum Gravity, arXiv:2001.00599 [gr-qc].