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Vaidya spacetime for Galileon gravity's rainbow

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Abstract

In this paper, we analyze Vaidya spacetime with an energy dependent metric in Galileon gravity's rainbow. This will be done using the rainbow functions which are motivated from the results obtained in loop quantum gravity approach and noncommutative geometry. We will investigate the Gravitational collapse in this Galileon gravity's rainbow. We will discuss the behavior of singularities formed from the gravitational collapse in this rainbow deformed Galileon gravity.

1. Introduction

The observations from type I supernovae indicate that our universe has a positive cosmological constant and is accelerating in its expansion [1–6]. Furthermore, it is known that general theory of relativity has not been tested at very large or very small scales, and it is possible for the general theory of relativity to be modified at such scales. However, as gravity has been thoroughly tested at the scale of solar system, it is important for any theory of modified gravity to reduce to the general theory of relativity at the scale of the solar system. It may be noted an interesting model of modified gravity is called the DGP brane model and has been proposed to explain accelerating

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cosmic expansion [7]. This model has two branches and one of these branches admits a self-accelerating solution. However, this model contains ghost instabilities, and thus cannot be used as a physical model for the cosmic acceleration [8]. It may be noted that such instabilities also occur for other models of modified gravity [9]. Such instabilities occur due to the introduction of extra degrees of freedom into the theory because of the existence of higher derivative terms.

However, it is possible to construct an infrared modification of general theory of relativity [10]. This theory contains a self-interaction term of the form $(\nabla\phi)^2 \Box \phi$, and so general relativity is recovered at high densities. It is interesting to note that in the Minkowski background, this theory is invariant under the Galileon shift symmetry, $\delta_\mu\phi \to \delta_\mu\phi + c_\mu$. This symmetry prevents the occurrence of higher derivative terms in the equation of motion of this theory. As this theory does not contain extra degrees of freedom, it cannot also contain ghost instabilities. The coupling between a Galileon scalar field and massive gravity through composite metrics has also been studied [11]. A full set of equations of motion for a flat Friedmann–Robertson–Walker background was obtained in this theory. The cosmology has also been studied using Galileon gravity, and this has been done by analyzing the linear perturbation in Galileon gravity [12]. Furthermore, low density stars with slow rotation and static relativistic stars have also been analyzed using Galileon gravity [13]. It was observed that the scalar field solution ceases to exist above a critical density, and this corresponds to the maximum mass of a neutron star. The spherical collapse has also been analyzed in the Galileon gravity [14,15]. This was done by analyzing the solutions to the Einstein equations in Galileon gravity. Then these solutions were used for discussing the conditions for the formation of a black hole or a naked singularity in Galileon gravity. In this paper, we shall perform such an analysis in a theory which combines Galileon gravity with gravity's rainbow.

Another interesting modification to general relativity is called the Horava–Lifshitz gravity [16,17]. This theory of gravity is obtained from a UV completion of general relativity, such that general relativity is recovered in the IR limit [16,17]. This is done by taking different Lifshitz scaling for space and time. Such a different Lifshitz scaling for space and time has also been taken in type IIA string theory [18], type IIB string theory [19], AdS/CFT correspondence [20–23], dilaton black branes [24,25], and dilaton black holes [26,27]. The Horava–Lifshitz gravity is based on the modification of the usual energy–momentum dispersion relation in the UV limit such that it reduces to the usual energy–momentum dispersion relation in the IR limit. The gravity's rainbow is another modification of gravity based on such a modified energy–momentum dispersion relation in the UV limit [28–30]. In gravity's rainbow the metric depends on the energy of the test particle used to probe the structure of the spacetime. The gravity's rainbow can be related to the Horava–Lifshitz gravity, for a specific choice of rainbow functions [31]. There is a strong motivation to study such theories based on the energy–momentum dispersion relation in the UV limit. This is because the Lorentz symmetry fixes the form of the energy–momentum relations, and there are strong theoretical indications from various different approaches to quantum gravity that Lorentz symmetry might only be a symmetry of the low energy effective field theory, and so it will break in the UV limit [32–36]. This is expected to occur in discrete spacetime [37], models based on string field theory [38], spacetime foam [39], the spin-network in loop quantum gravity (LQG) [40], and non-commutative geometry [41]. It may be noted that such a deformation of the standard energy–momentum dispersion relation in the UV limit of the theory leads the existence of a maximum energy scale. The doubly special relativity is build on the existence of such a maximum energy scale [42], and gravity's rainbow is the generalization of doubly special relativity to curved spacetime [43]. In gravity's rainbow, the metric describing the geometry of spacetime depends on the energy of the test particle used to probe the structure of that spacetime.