IWARA

From Quarks to Cosmos

6 to 12 September, 2020

Thermodynamic consequences for modified Rastall gravity

José Alberto Casto Nogales Vera and Karen Luz Burgoa Rosso

jnogales@ufla.br

Abstract

We studied thermodynamic aspects of modified Rastall gravity; recently, we proposed a modified Rastall gravity.

In this context, we research the non-conservation of the energy-momentum tensor; we develop a covariant formalism of the first and second laws of thermodynamics.

The second law implies a non-zero entropy flow and it is necessary to introduce particle production as part of the laws of thermodynamics, we show the consequences for the FLRW cosmological model.

karenluz@ufla.br

UNIVERSIDADE FEDERAL DE LAVRAS

Departamento de Física

Physics Department - DFI - UFLA

Lavras-Brazil

Considerations and proposal of the work

- Although General Relativity has been successfully tested, there are several observational data that it does not explain, such as the current phase of accelerating the expansion of the universe and the problem of dark matter, as examples. Furthermore, there is no completely consistent theory of quantum gravity.

- These problems lead to seeking modified theories of gravity, among these modified theories it is proposed that the condition of conservation of the covariant energy-moment tensor be relaxed. From this idea, P. Rastall in 1972 constructed a new theory of gravity where the usual conservation law is questioned.

- One criticism of this proposal corresponds to the fact that the field equations of Rastall's theory of gravitation were obtained adhoc by Rastall, and thus this theory of gravitation is not a theory based on a Lagrangean. Recently, however, there have been some attempts to obtain Rastall's field equations from a Lagrangian formalism.

- In this work, we present a Lagrangian formalism for a field equation similar to Rastall, having as an important characteristic that the energy-momentum tensor of matter may not be conserved covariantly.

- Then, we analyze, in this context, the non-conservation of the energy-moment tensor, developing a covariant formalism of the first and second laws of thermodynamics. The second law implies a non-zero entropy flow related to the production of particles as part of the laws of thermodynamics, we show the consequences for the FLRW cosmologies.

We start from the proposal of an action for a Rastall-type gravitation given by:

$$S = \int d^4x\sqrt{-g}(R + \beta\xi_\alpha\xi^\alpha R + \delta(\xi_\alpha\xi^\alpha - \frac{1}{\sqrt{-g}})$$

The field equations regimen by:

$$(1 + \frac{\beta}{\sqrt{-g}})(R_{ab} - \frac{1}{2}g_{ab}R) - \frac{1}{2}\delta g_{ab} - (\delta + \beta R)\xi_a\xi_b = \kappa T_{ab}$$

the conservation equation gives us:

$$\kappa\nabla^a T_{ab} = -\beta\xi_b\xi^a\nabla_a R$$

thus we develop the covariant thermodynamics for this model, with the production of entropy and particles given by:

$$\nabla_\mu S^\mu = \lambda\frac{\dot{R}}{T} \geq 0 \quad \text{and} \quad \nabla_\mu N^\mu = \alpha\lambda\dot{R}$$

finally, for the case of the LFRW model, we recover several stages of the standard cosmology model:

$$\rho = \rho_0\left(\frac{a_0}{a(t)}\right)^{(\frac{1}{3\Gamma(1+\omega)})} \quad a(t) \propto t^{\frac{1}{6\Gamma(1+\omega)}} \text{ or } a(t) \propto e^{\Gamma\omega t}$$

We recovered all thermodynamic quantities and analyzed them by contrasting them with current cosmological data.