

Chapter 11: Analytical Study of Gravitational Baryogenesis within a selected Modified $f(R)$ Gravity Model

Rajdeep Majumdar¹, Niki Gogoi¹, Kalyan Malakar²

¹Department of Physics, Dibrugarh University, Assam, India.

²Department of Physics, Silapathar College, Assam, India.

Abstract: This work investigates the matter–antimatter imbalance within the framework of gravitational baryogenesis and generalized gravitational baryogenesis, employing a specific modified gravity model characterized by: $f(R) = R + \alpha R^2(1 + \gamma R)$. The baryon asymmetry is quantified by the net baryon-to-entropy ratio, $\eta_B = \frac{n_B - n_{\bar{B}}}{s}$, where n_B and $n_{\bar{B}}$ denote baryon and anti-baryon densities, respectively, while s is the entropy density of the primordial plasma. In this scenario, a CP-violating interaction of the form $\partial_\mu f(R)J^\mu$ replaces the conventional $\partial_\mu R$ coupling, introducing an effective chemical potential that biases baryon production over anti-baryons in the early universe. Our results show that the generalized coupling involving CP-violation interaction term enhances the generated baryon asymmetry compared to minimal models and provides additional flexibility through the model parameters α and γ . By appropriately tuning these parameters, we obtain a baryon-to-entropy ratio consistent with the observed value $\eta_B \cong 9.42 \times 10^{-11}$, in agreement with constraints from CMB observations and established cosmological data. This study demonstrates that the modified gravity model: $f(R) = R + \alpha R^2(1 + \gamma R)$, offers a viable and self-contained framework for addressing both the origin of baryon asymmetry without invoking additional scalar fields or exotic matter components.

Keywords: *General Relativity, Modified $f(R)$ gravity, Gravitational baryogenesis.*

Introduction

The striking cosmic imbalance, where matter vastly outweighs antimatter, constitutes a foundational puzzle at the heart of modern cosmology. This asymmetry is not merely theoretical; it is robustly confirmed by empirical data from the cosmic microwave background (CMB) [1] and the established framework of Big Bang nucleosynthesis (BBN) [2]. The prevailing narrative suggests that in the universe's earliest instants, a slight preference for matter emerged. This led to a process where a residual amount of antimatter was transformed into matter, followed by a near-total annihilation that left behind the small, surviving surplus of matter we observe today [3]. Pinpointing the physical origin of this initial preference, however, remains a central challenge.

Theoretical efforts to resolve this mystery are grouped under the concept of baryogenesis - the study of processes that could generate a baryon asymmetry in the early universe. Several prominent mechanisms have been proposed, including electroweak baryogenesis [4], grand unified theories (GUTs) [5], the Affleck-Dine scenario [6], spontaneous baryogenesis [7, 8], and models involving black hole evaporation [9]. Among these, gravitational baryogenesis presents a particularly intriguing avenue, as it directly ties the genesis of the matter-antimatter imbalance to the fundamental properties of gravity and spacetime [3]. This approach posits that baryon asymmetry is a natural consequence of spacetime curvature dynamics [10]. It typically introduces a CP-violating interaction that couples the derivative