Role of gravitational interactions during reheating and dark matter production

Abstract

This work focuses on the minimal model of dark matter, assuming it consists of particles interacting solely through gravity. The considered scenario involves massive vector particles as candidates for dark matter. Such a hypothesis is quite restrictive and, in this sense, extreme, but on the other hand, it captivates with its simplicity and universality. What makes this scenario so compelling is its inevitability and complementarity with cosmological models of the early Universe. Its attractiveness is also evidenced by the rich phenomenology considered in this work. The origin of purely gravitational dark matter is related to gravitational effects occurring in the very early Universe. Hence, its genesis and dynamics are attributable to how the primordial Universe transformed from an inflationary to a radiation-dominated phase.

This thesis aims to shed some light on the unknown physics of the early Universe. We explore the possibility of a non-standard cosmological history by postulating the existence of a non-instantaneous reheating phase. In particular, we focus on the perturbative reheating model induced by direct inflaton coupling to the visible sector or as a result of indirect interactions of gravitational origin. The production of the Standard Model radiation is discussed by considering a time-varying inflaton decay rate, which exhibits a power-law dependence on the scale factor. Such behavior could reflect the non-standard form of the inflaton potential during reheating and/or might be generated by the kinematic effects. The time-dependent inflaton decay width, in general, meaningfully affects the production of the visible sector and thus alters the thermal bath's evolution. In addition, it might also change the duration of the reheating phase. We also study the implications of the non-standard reheating scenario for primordial gravitational waves, showing that the presence of a stiff epoch before the Big Bang nucleosynthesis era might enhance their spectrum. Finally, we use this effect to explore the possibility of probing inflaton-matter couplings in future gravitational wave detectors.

Three different mechanisms of dark matter creation are considered in this work. Namely, we investigate purely gravitational particle production in the expanding Universe, gravitational scattering through graviton exchange in the inflaton background, and the gravitational freeze-in from the thermal bath. Limitations and necessary conditions for their occurrence are discussed. We also determine the parameter space in which each of these mechanisms, individually, as well as all of them combined, saturate the observed amount of dark matter. The presented analysis justifies gravitational production as a viable mechanism for the vector dark matter in a wide range of dark matter mass. Moreover, our results apply to various possible models of the early Universe with non-standard cosmology, demonstrating that reheating dynamics play a crucial role in the gravitational production of dark vectors and cannot be neglected in calculations of their present abundance.