INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
PhD-17 SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

This thesis investigates well-motivated beyond the Standard Model scenarios whose signatures are challenging to probe in laboratory experiments but can be explored through cosmological and astrophysical observations. It focuses on the imprints of dark sector physics on the cosmic microwave background, the role of primordial black holes in generating dark radiation and stochastic gravitational waves, and high-energy astrophysical messengers. Together, these observables provide complementary probes of new physics in the early Universe.

A central theme is the study of light relics, including right-handed Dirac neutrinos and Goldstone bosons, within well-motivated extensions of the Standard Model. In the framework of light Dirac-neutrino portal dark matter, both thermal and non-thermal production mechanisms are investigated, along with the associated dark radiation component and its impact on the effective number of relativistic species and structure formation. The analysis is performed first in a minimal phenomenological framework and then extended to an ultraviolet-complete model.

The thesis also explores the cosmological implications of ultra-light primordial black holes, including the production of thermalised dark radiation and the cogenesis of axion dark matter and the baryon asymmetry via leptogenesis. Their associated gravitational-wave signatures provide promising observational tests. Finally, the thesis examines the interpretation of two recently observed ultra-high-energy events as decays of superheavy dark matter. A multimessenger analysis combining cosmic-ray, neutrino, and gamma-ray constraints yields updated limits on the model parameter space, with the absence of corresponding gamma-ray signals placing dark matter decay interpretation under significant tension.

Overall, the results demonstrate the power of cosmological and astrophysical observations to constrain beyond the Standard Model physics and highlight the discovery potential of next-generation cosmic microwave background experiments, gravitational-wave detectors, and high-energy observatories.