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Probing the properties of dark matter particles with astrophysical observations

Magalich, A.

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Summary

Attempts to phenomenologically explain subatomic physics together with the well-rounded quantum theory of electrodynamics have culminated in the development of the most advanced description of particle physics to date. The Standard Model (SM) of particles unites the models of the electromagnetic, weak and strong interactions in a rigid and elegant theoretical framework. Nevertheless, today it is an established fact that the SM has to be extended to explain the so-called *Beyond the Standard Model* (BSM) phenomena: dark matter, matter-antimatter asymmetry of the Universe and neutrino flavour oscillations.

New particles and interactions necessary for BSM physics have so far evaded discovery in particle-physics experiments. The difficulty of direct detection lies in the huge parameter space of the possible candidates. Hence, data coming from the cosmological and astrophysical observation can provide invaluable directions for laboratory experiments.

In this thesis we explore two methods of constraining new-physics candidates: through their influence on the primordial nucleosynthesis and through observable differences in the matter distribution caused by free-streaming of the dark-matter particles. We concentrate our attention on the well-motivated extension of the SM that aims at explaining all 3 BSM problems at the same time: the *Neutrino Minimal Standard Model*. In this extension, there are 3 additional *heavy neutral leptons* (or *sterile neutrinos*), one of which plays the role of dark matter, while the other two are necessary for induction of matter-antimatter asymmetry and neutrino oscillations. The dark-matter candidate is an example of a Warm Dark Matter particle, the free-streaming of which might be detected in the Lyman- α forest spectra of distant quasars. The other two particles have lifetimes that make them relevant to the primordial nucleosynthesis.

Heavy sterile neutrinos are decaying particles with neutrino-like interactions that can influence the formation of light nuclei during primordial nucleosynthesis, both through their effect on the Hubble expansion rate and through the generation of particles that distort the spectra of SM neutrinos or interact directly with nucleons. Sterile neutrinos with masses above ~ 100 MeV also produce short-lived muons and mesons that can trigger complicated decay chains. We present a method for numerical modelling the primordial nucleosynthesis in the presence of sterile neutrinos in the mass range up to ~ 1 GeV, and we put constraints on their lifetime assuming various coupling patterns.

The observed Lyman- α flux power spectrum (FPS) is suppressed on scales below ~ 30 km/s. This cutoff could be due to the high temperature T_0 and pressure p_0 of the

absorbing gas or, alternatively, it could reflect the free streaming of dark-matter particles in the early universe. We perform a set of very high resolution cosmological hydrodynamic simulations in which we vary T_0 , p_0 and the amplitude of the free streaming of dark-matter, and compare the FPS of mock spectra to the data. We demonstrate that the FPS cutoff can be fitted assuming cold dark matter, but it can be equally well fitted assuming that the dark matter consists of ~ 7 keV sterile neutrinos in which case the cutoff is due primarily to the free-streaming dark matter. Consequently, the constraints on the dark-matter candidates depend on the detailed knowledge of the Epoch of Reionization. We demonstrate how to put robust constraints on general Warm Dark Matter by marginalizing over thermal histories consistent with observations.