A review on the construction, constraining and falsification of asymmetric dark matter models

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The existence of dark matter (DM) is inferred from discrepancies between observed gravitational dynamics and the predictions of Newtonian gravity. Precision fits of the ΛCDM cosmological evolution model to observations of the cosmic microwave background (CMB) indicate that the dark matter density is approximately five times larger than that of visible matter. To reach this abundance symmetric DM models rely on tuning the annihilation cross-section of DM such that the expansion of space slows the reaction to a halt at just the right time for the correct abundance to ”freeze-out”. Asymmetric DM models instead have the ratio between visible and dark matter arise dynamically from the asymmetric components of the two sectors being linked, which makes them particularly interesting for further study. The purpose of this review is to teach the model building methodology, inspiring more research into asymmetric DM.

The process of building an asymmetric DM model is discussed by first defining the characteristic traits of the theory, such as the addition of a new particle, which doesn't interact with photons, and the demands on its abundance. Then a few key problems are tackled: the deposition of energy from annihilation and the creation of the asymmetric component. For the latter, the Sakharov conditions for asymmetry are first mentioned. The heavy progenitor particle decay and first order phase transition scenarios are introduced, followed by an explanation of how they satisfy the requirements.

The recombination and big bang nucleosynthesis (BBN) are introduced. Their sensitivity to electromagnetic energy injections would lead to changes in the observed CMB or helium abundance, the lack of which induces constraints. Furthermore, the BBN sensitivity to relativistic degrees of freedom, such as the addition of new radiation, is constrained. Collider experiments searching for either the production of invisible particles or the backwards decay of an unknown boosted heavy mediator set constraints on processes of interaction between the visible and dark sectors. Direct detection experiments, expecting DM collisions with nuclei via the weak force, set tight constraints on interaction cross-sections.

Finally, a toy model is introduced and used as an example on how to get from phenomenological constraints to constraints in the parameter space of the model. An annihilation, scattering and creation channel are discussed along with how the constraints on cross-sections reflect on the permitted parameter space regions. If the permitted regions have overlap, the parameter space is constrained. In case there is no overlap, the model is falsified instead.