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Early Universe production of dark matter

A great deal of indirect evidence for dark matter has accumulated, but so far, its exact nature and production mechanism remain as mysteries. Consequently, several different models have been created to try and explain the observed phenomena, such as particle dark matter and modified gravity. We will consider the former.

In our work, we cover two possible mechanisms by which the relic abundance (i.e. the amount in the Universe today) has come to be: freeze-out and freeze-in, which can be seen as opposites of each other.

Freeze-out is the so-called thermal production mechanism, in which the particle, which had a nonzero initial abundance, would've been in thermal equilibrium with the early Universe plasma. But, as the Universe kept expanding, the interactions maintaining said equilibrium fail to keep it up, and the particles subsequently decouple from the plasma, asymptotically approaching a constant relic abundance.

Freeze-in, on the other hand, is the so-called non-thermal production mechanism. In this case, the particle species in question would not have been in thermal equilibrium with the plasma. Instead, the production mechanisms themselves (e.g. through scatterings) would have become Boltzmann-suppressed with the expansion and cooling of the Universe. So, starting from (near) zero initial abundance, dark matter particles would've kept accumulating until the process became suppressed, while the relic density again approaches a constant value asymptotically.

The main machinery in our work is the covariant relativistic version of the Boltzmann equation, with which we can describe non-equilibrium dynamics. This equation is then numerically integrated to obtain the relic density, and this value is then compared to the estimated abundance based on observations. The calculated value is dependent on a so-called thermally averaged cross section, which can further be parameterized in terms of the particle's mass and coupling strength. Thus, for example, if we are given these values from a specific candidate model, we can check the compatibility with observations (assuming our model is sufficiently valid).

The freeze-in part is still work-in-progress.