Dark Matter Relics

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Abstract

Dark matter particles' production, freeze-out, and relic abundance were examined and modeled. We found a solution for the Boltzmann equation, known as the Ricatti equation, for a dark matter particle. Using Mathematica, we numerically solved the differential Ricatti equation for several constant lambda values and created plots with the results. We solved for the dark matter density present today for several particle masses, and then related them to the freeze-out relic abundance of dark matter.

Introduction

We wanted to apply the Boltzmann equation to describe the production of dark matter particles. Then through numerically solving the differential equation for several particle masses, we planned to create a plot that models the abundance of dark matter particles and their freeze-out time. Lastly, we sought to link the relic abundance of dark matter with the dark matter density present in today's universe for different particle masses and scattering cross sections.

Methods and Research Design

We treated the dark matter particle as a weakly interacting massive particle (WIMP) and solved the Boltzmann equation for it. We assumed a radiation dominated universe to rewrite the Boltzmann equation into the Ricatti equation. We solved the equation numerically for many values of lambda using the computation software Mathematica. The plotted results can be seen in figure 1. We found an equation to give us the relic abundance for dark matter today and solved it for four particle masses: 10 GeV, 50 GeV, 100 GeV, and 100 GeV. Then they were plotted against Boltzmann equations with four separate scattering cross section values. The result for a particle mass of 10 GeV can be seen in figure 2.

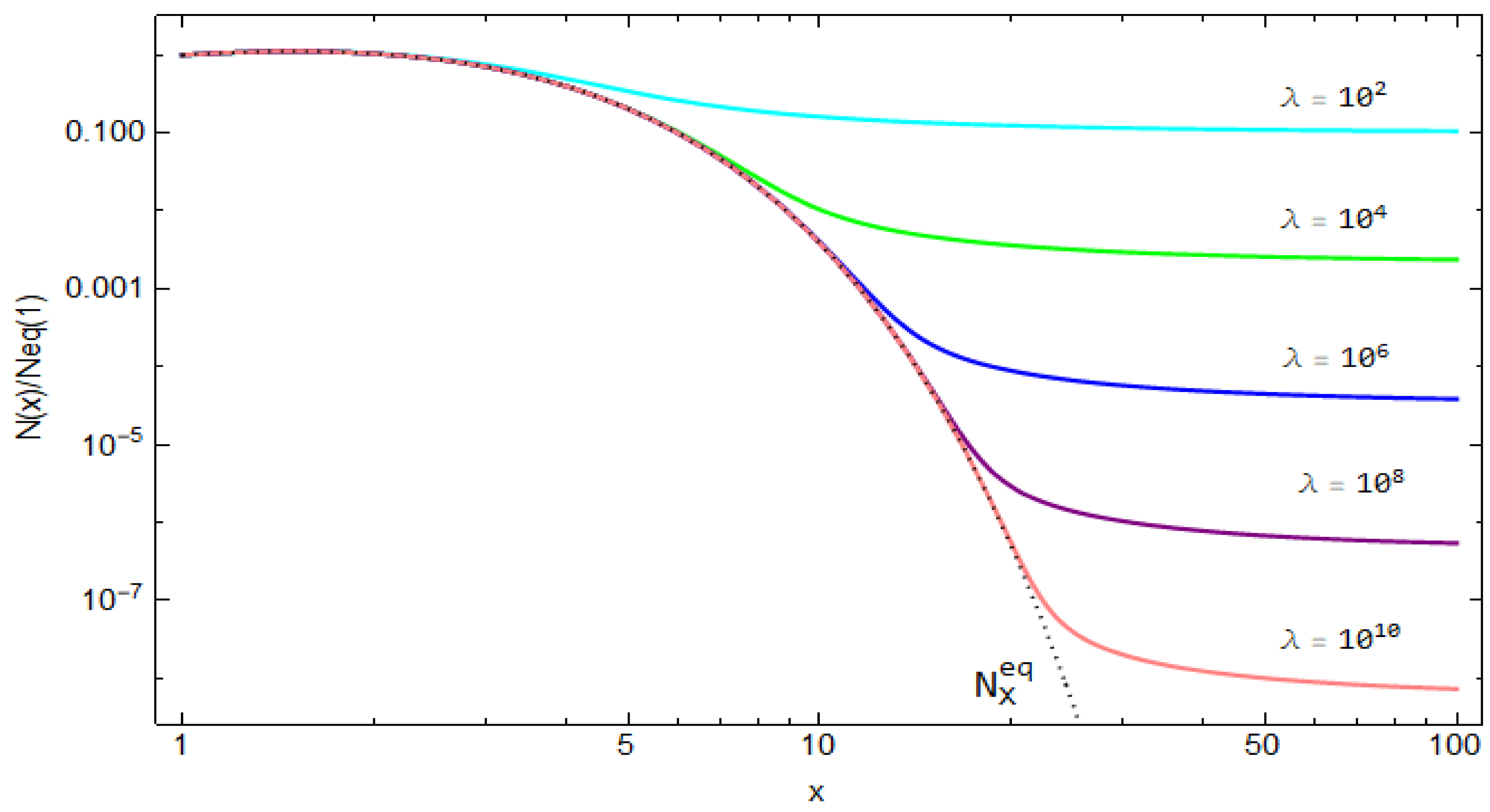

Figure 1: The relic abundance of dark matter particles as the temperature drops

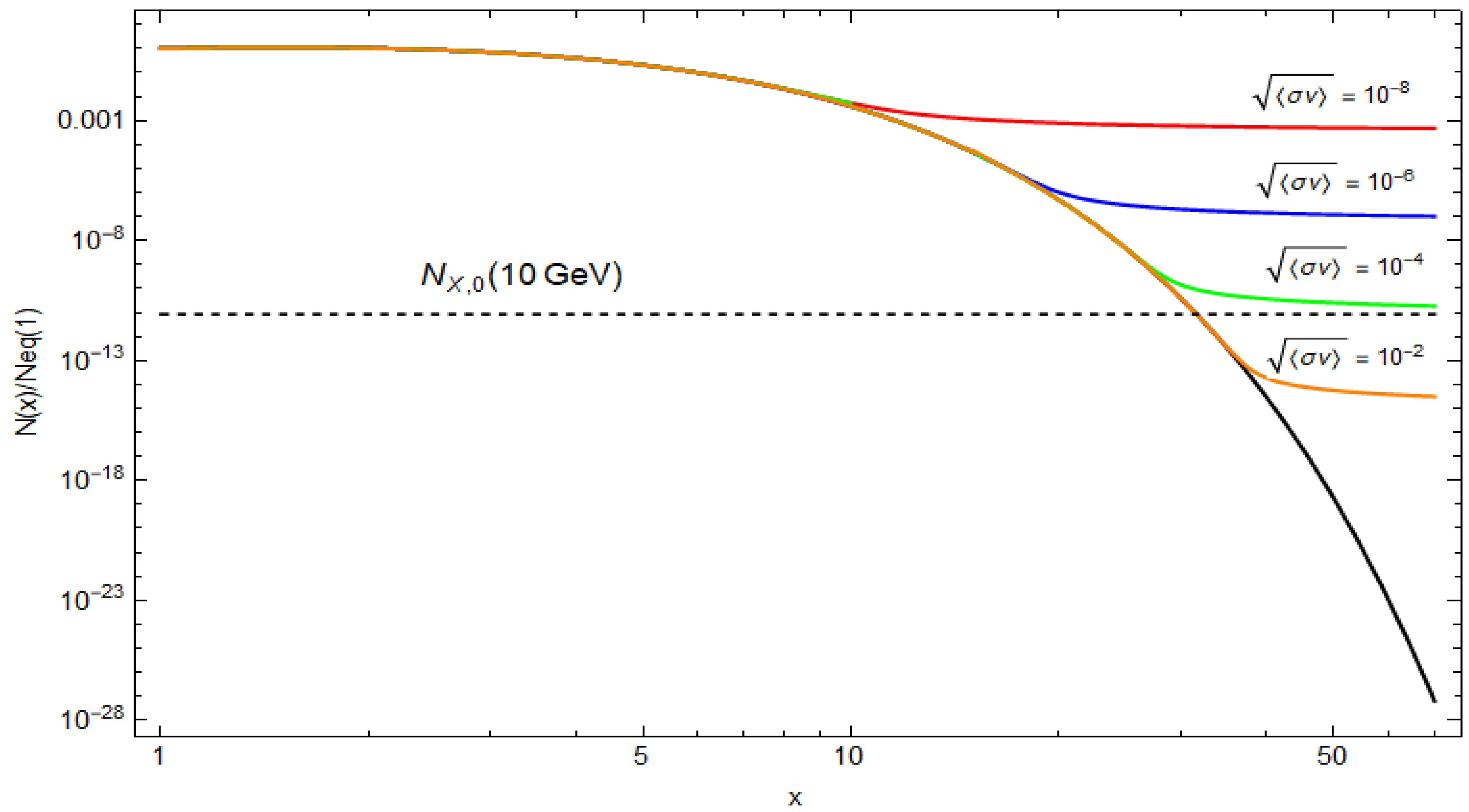

Figure 2: The relic abundance of 10 GeV dark matter particles as the temperature drops

Results

From figure 1 we found that freeze-out for dark matter particles occurs around the time $x_f = 10$. From figure 2 we concluded that for dark matter particles of mass 10 GeV, a scattering cross section of 10^{-4} would give the relic abundance of dark matter today. For the other three masses we found the relic abundance of dark matter would correspond to 10^{-4} for 50 GeV, 10^{-2} for 100 GeV, and 10^{-2} for 1000 GeV.

References: Baumann, Daniel. (2019) *Cosmology Part II Mathematical Tripos [Lecture Notes].* Retrieved from http://theory.uchicago.edu/~liantaow/my-teaching/dark-matter-472/lectures.pdf