MSc project

Thermal production of feebly interacting dark matter

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Introduction

There is compelling evidence for the existence of dark matter (DM), where the only effects we observe are gravitational. We see these effects in the rotational curves of spiral galaxies, gravitational lensing and importantly in the cosmic microwave background (CMB), where the inferred cosmological DM abundance is about five times the abundance of ordinary matter [1]. The most popular scenario for the creation of DM is the so-called freeze-out mechanism, where DM was in thermal equilibrium with the visible sector heat bath at early times [2]; once its annihilation rate fell behind the expansion rate of the universe, DM would decouple and its comoving number density freeze to a constant value. A typical example for this are so-called weakly interacting massive particles (WIMPs) with mass around the electroweak scale. However there is no theoretical reason why the assumption that the DM was in thermal equilibrium with the visible heat bath must hold. Instead the present DM abundance may have been generated out of equilibrium, in a process known as freeze-in mechanism. In this scenario, DM couples very weakly, which means that it never reached thermal equilibrium. Instead, the DM particles were continuously produced by decay or annihilation processes from the visible sector – or a dark sector heat bath – until the production stopped once the heat bath temperature dropped below the relevant mass scale connecting the DM particle to the visible sector. Due to the small coupling strength, DM particles produced via the freeze-in mechanism have been called Feebly Interacting Massive Particles (FIMPs) [3].

Scope

The FORTRAN package DarkSUSY [4] was originally developed to numerically calculate properties of supersymmetric DM, which historically was the most popular DM candidate. The package has been upgraded to include other theories containing DM candidates as well [5], which also will be the focus of my MSc project. Its main scope will be to further develop DarkSUSY by adding the possibility to calculate the freeze-in abundance of FIMP DM candidates. As of today, the only publicly available code with this ability is micrOMEGAs5.0 [6]. An important task will thus be to independently verify the results presented there, and check the validity of the approximations entering in their derivation. In a second step, the newly written DarkSUSY routines will be used to study freeze-in production for a model where DM does not couple to standard model particles, but only to particles contained in a separate, 'dark' sector that is thermalized but with a temperature different from that of the photons.

Project tasks

(dates mark deadlines for the completion of the respective task)

- Thorough familiarization with the theoretical framework of how to calculate the DM relic density, both for freeze-out and freeze-in, as part of a special reading course in the curriculum. [***June 2020***]

- Familiarization with programming in FORTRAN, and the structure of DarkSUSY. Demonstrate basic usage of git (the version control system DarkSUSY is based on), the makefiles used in DarkSUSY, and DarkSUSY example programs that involve *i)* different particle modules and *ii)* 'replaceable functions'. [***July 2020***]

- Write a first version of subroutines to calculate the relic density, and a main program to test it, focussing on the simpler case of assuming Maxwell-Boltzmann statistics for all particles involved. Specifically, test the results obtained in Ref. [6] for a Z' portal. [***September 2020***]
- Update the routines to use the full Bose-Einstein statistics and Fermi-Dirac statistics, and compare the results with those reported for the Scalar portal in Ref. [6]. [***November 2020***]
- Tidy up and optimize existing code. Prepare a short written report of results obtained so far, including the theoretical tools necessary to obtain them. [***December 2020***]
- Implement dark sector model with changing number of degrees of freedom (and therefore dark sector temperature). Compute freeze-in production and discuss differences to models studied so far. [***February 2021***]
- Fully focus on thesis writing [**from** ***Februrary – March 2021***]

References

[1] P. A. R. Ade et al. Planck 2015 results. XIII. Cosmological parameters. *Astron. Astrophys.*, 594:A13, 2016.

[2] Paolo Gondolo and Graciela Gelmini. Cosmic abundances of stable particles: Improved analysis. *Nucl. Phys.*, B360:145–179, 1991.

[3] Nicolás Bernal, Matti Heikinheimo, Tommi Tenkanen, Kimmo Tuominen, and Ville Vaskonen. The Dawn of FIMP Dark Matter: A Review of Models and Constraints. *Int. J. Mod. Phys.*, A32(27):1730023, 2017.

[4] Darksusy. `http://darksusy.org`.

[5] Torsten Bringmann, Joakim Edsjö, Paolo Gondolo, Piero Ullio, and Lars Bergström. DarkSUSY 6 : An Advanced Tool to Compute Dark Matter Properties Numerically. *JCAP*, 1807(07):033, 2018.

[6] Geneviève Bélanger, Fawzi Boudjema, Andreas Goudelis, Alexander Pukhov, and Bryan Zaldivar. micrOMEGAs5.0 : Freeze-in. *Comput. Phys. Commun.*, 231:173–186, 2018.