Axion Dark Matter: Cosmological Production and Numerical Modeling

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1 Brief Description

Dark matter constitutes approximately 85% of the matter content of the Universe, yet its fundamental nature remains unknown. While weakly interacting massive particles (WIMPs) have historically been the leading dark matter candidates, increasingly stringent experimental constraints have motivated growing interest in alternative scenarios.

One of the alternatives is the axion, a hypothetical particle originally introduced to solve the strong CP problem in quantum chromodynamics (QCD). Remarkably, the same particle can naturally account for the observed dark matter abundance.

The goal of this project is to consider New Physics models predicting axion (or axion-like particles) and study the cosmological evolution of the corresponding field, understand the physics of the misalignment mechanism, and perform numerical calculations of the resulting dark matter abundance.

The project combines particle physics, cosmology, and computational physics while requiring only moderate numerical techniques.

2 Literature

Introductory Reviews

1. T.-T. Yu, *2024 TASI Lectures: A Dark Matter Primer* (2025)
   `https://arxiv.org/abs/2506.05234`
2. C. O'Hare, *The Cosmology of Axion Dark Matter* (2024)
   `https://arxiv.org/abs/2403.17697`
3. J. L. Feng, *Dark Matter Candidates from Particle Physics and Methods of Detection*
   `https://arxiv.org/abs/1003.0904`

Axion Theory

4. K. Choi and N. Righi, *Axion Theory and Model Building* (2024)
   `https://arxiv.org/abs/2401.17354`
5. R. D. Peccei, *The Strong CP Problem and Axions*
   `https://arxiv.org/abs/hep-ph/0607268`
6. D. J. E. Marsh, *Axion Cosmology*
   `https://arxiv.org/abs/1510.07633`

Experimental Searches

7. Y. K. Semertzidis and S. Youn, *Axion Dark Matter: How to See It?*
   `https://arxiv.org/abs/2104.14831`
8. P. Sikivie, *Invisible Axion Search Methods*
   `https://arxiv.org/abs/2003.02206`

3 Required Knowledge and Skills

Students should be familiar with:

Physics Background

- Introductory particle physics;
- Thermodynamics and statistical physics;
- Basic cosmology.

Mathematical Background

- Ordinary differential equations;
- Numerical integration methods;

Programming Skills

- Python;
- Scientific software packages.

4 Expected Results

At the end of the project, students will provide:

1. A short report (5–10 pages);
2. Figures illustrating axion field evolution and relic abundance calculations;
3. A discussion of theoretical assumptions and numerical uncertainties.