PHD PROJECT DESCRIPTION

(4000 characters max., including the aims and work plan to de published online)

Project title: Ultrastable laser in metrology and fundamental physics

1.1. Project goals

- Experimental construction of ultrastable laser, with stability <1e-16

- Use of ultrastable lasers in optical atomic clocks

- Fundamental physics searches with ultrastable lasers and optical clocks

1.2. Outline

The proposed PhD project focuses on the development and investigation of ultrastable laser systems [Bar25, Mat17], with applications in optical atomic clocks and precision tests of fundamental physics. Ultrastable lasers are a cornerstone of modern experimental physics [Nar23, Wci18], enabling coherent interrogation of ultranarrow optical transitions and providing the frequency stability required for next-generation metrology and quantum technologies.

The objective of the project is to build, and optimize an ultrastable laser system based on high-finesse optical reference cavities. Particular attention will be given to minimizing thermal noise, mechanical vibrations, and environmental perturbations, which ultimately limit frequency instability. The developed laser system will be used on optical atomic clocks [Lud15] and for fibre dissemination of ultra stable signal. Ultrastable lasers are essential for probing narrow-linewidth transitions in ultracold atoms such as strontium. The project will involve interfacing the laser system with existing cold-atom setups and evaluating its performance in terms of clock stability and systematic uncertainty reduction. This includes studies of laser–atom coherence, interrogation schemes, and potential improvements in clock operation protocols.

The project will explore applications of ultrastable laser technology in fundamental physics searches. High-precision frequency measurements enable tests of possible variations of fundamental constants, searches for ultralight dark matter candidates, and constraints on physics beyond the Standard Model. The developed system may be used to compare optical transitions over time or between different atomic species, providing a sensitive probe for transient or spatial variations in physical laws.

The project will combine experimental work on laser stabilization with theoretical analysis of noise sources and measurement limits. It will also involve collaboration within a broader atomic, molecular, and optical physics environment, benefiting from access to ultracold atom platforms and optical frequency metrology infrastructure. Overall, the PhD aims to advance ultrastable laser technology while demonstrating its relevance for both applied quantum metrology and fundamental physics investigations.

The project will be realised in the National Laboratory for Atomic, Molecular and Optical Physics (KL FAMO), which is a national consortium established at the Nicolaus Copernicus University (UMK) in Toruń, Poland, for inter-university research. The main areas of research cover ultracold and degenerate matter, optical lattice atomic clocks, Bose–Einstein condensation, quantum state engineering, ion traps, ultracold molecules, cavity ring-down spectroscopy, and optical frequency combs. Hz-level laser frequency control is also implemented for spectroscopic and metrological applications, as well as for new concepts of optical atomic clocks. Other key activities in KL FAMO include both experimental and theoretical studies of new physics beyond the Standard Model, in particular the search for transient signatures of hypothetical dark matter in the form of scalar fields or stable topological defects.

1.3. Work plan

- Construction of an ultrastable laser system (or systems) and its optimization (M1–M24)
- Implementation of the ultrastable laser system with a strontium optical clock (M12–M36)
- Fundamental physics search using ultrastable lasers and optical clocks (M12–M40)
- Writing, submission, and defense of the thesis (M36–M48)

1.4. Literature (max. 7 listed as a suggestion for a PhD candidate preliminary study)

[Bar25] Barbarat J. et al., https://arxiv.org/abs/2504.06213 (2025),
[Mat17] Matei D.G et al., Phys. Rev. Lett. 118, 263202 (2017),
[Nar23] Narożnik M. et al., Physics Letters B, 846, 138260 (2023),
[Lud15] Ludlow A.D. et al., Rev. Mod. Phys. 87, 637 (2015),
[Wci18] Wcisło P. et al., Science. Advance 4(12) aau4869 (2018).

1.5. Required initial knowledge and skills of the PhD candidate

- The applicant has to have finished a master degree within the last 6 years prior to recruitment in physics or a closely related field
- An excellent academic record.
- Experience through coursework and/or a research project in atomic and molecular physics
- Experience through coursework and/or a research project in quantum mechanics up to the second quantization.
- It is highly beneficial if the master thesis has been done in experimental atomic, molecular or optical physic

1.6. Expected development of the PhD candidate's knowledge and skills

experience, knowledge and skills that are important in the high-tech industry and academia: experimental cold atoms, atom-light interaction, collective effects in quantum gases, high resolution spectroscopy, laser physics and optics, ultra-high vacuum systems, e¬lectronics, programming and other