1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

Project title: Ultra-cold atoms in an optical conveyor belt

1.1. **Project goals**:

- to load ultracold Sr atoms into a moving optical lattice potential
- check the feasibility of using trapped atoms either in a hollow core photonic fibres or in a free space for continuous reloading an atomic system, for instance a magneto-optical trap or an optical cavity of an active superradiant optical clock
- study systematic effects in an optical atomic clock originating from the loading of an optical cavity from an optical conveyor belt and acting on atoms trapped in an optical conveyor belt potential inside the hollow core fibre

1.2. Outline

The main goal of the project is to demonstrate application of engineered and movable optical potentials for dead-time free optical clocks and active superradiant optical clocks, using novel techniques (e.g. cold atoms in hollow core fibres, continuous loading of cold atoms, and conveyor belt potentials). The PhD student will develop and study trapping potentials that can be moved during an optical clock sequence, providing new features such as the ability to (repeatedly) load atoms into optical fibres, or optical resonators, and to provide zero dead-time operation. The key step is extending moving optical lattice or "optical conveyor belts" technology from alkali atoms to Sr in an optical clock context. The project will be realized in two experimental set-ups, the first aimed for atoms trapped a hollow core photonic fibre, the second for atoms trapped in a free space. The first setup will be available for the student in the first months of the school, The second setup should be assembled by the student during the first year of the school.

The project will be performed in cooperation with Universiteit van Amsterdam and NPL Management Limited, partners of UMK within JRP 23FUN02 CoCoRICO "Controlled confinement to reduce the inaccuracy of clocks based on optical lattices" collaboration.

1.3. Work plan

- M1-M6 creating the moving optical potential in a hollow-core fibre
- M6-M12 loading the Sr atoms into the moving optical potential in a hollow-core fibre
- M1-M12 assembling from existing components the experimental system for studying atoms in a conveyor belt in a free space
- M12-M18 creating the moving optical potential in a free space
- M18-M24 loading the Sr atoms into the moving optical potential in a free space
- M24-M36 check the feasibility of using trapped atoms either in a hollow core photonic fibres or in a free space for continuous reloading an atomic system
- M30-M36 study systematic effects in an optical atomic clock originating from the loading of an optical cavity from an optical conveyor belt and acting on atoms trapped in an optical conveyor belt potential inside the hollow core fibre
- M36-M48 writing, submitting and defending the thesis

1.4. Literature *(max. 10 listed, as a suggestion for a PhD candidate)*

- *M. Abdel-Hafiz et al., Guidelines for Developing Optical Clocks with 10^{-18} Fractional Frequency Uncertainty, arXiv:1906.11495 (2019)*
- *A. D. Ludlow et al., Optical atomic clocks, Rev. Mod. Phys, 87, 637 (2015).*

- *H. Katori "Longitudinal Ramsey spectroscopy of atoms for continuous operation of optical clocks" Appl. Phys. Express 14 072006 (2021)*
- *S. L. Kristensen, et al. "Subnatural Linewidth Superradiant Lasing with Cold 88Sr Atoms" Phys. Rev. Lett. 130, 223402 (2023)*
- *D. Meiser, Jun Ye, D. R. Carlson, and M. J. Holland, Prospects for a Millihertz-Linewidth Laser, Phys. Rev. Lett. 102, 163601 – Published 20 April 2009*
- *R. Takeuchi et al Continuous outcoupling of ultracold strontium atoms combining three different trap Appl. Phys. Express 16 042003 (2023)*
- *M. J. Renn et al., Laser-Guided Atoms in Hollow-Core Optical Fibers, Phys. Rev. Lett. 7, 3253 (1995).*
- *P. Russell et al., Photonic Crystal Fibers, Nature 299, 358 (2003).*
- *S. Okaba et al., Lamb-Dicke spectroscopy of atoms in a hollow-core photonic crystal fibre, Nature Commun. 5, 4096 (2014).*

1.5. Required initial knowledge and skills of the PhD candidate

- The applicant has to have finished a master degree within the last 4 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.
- Computer programming skills or electronic engineering skills.

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

- Expertise in experimental cold atomic physics.
- Expertise in optical atomic clocks,
- Improving experience in atomic, molecular, and optics physics.
- Communication skills: presenting posters, seminars, and reporting progress.