PHD PROJECT DESCRIPTION

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

Project title: Fundamental research with optical lattice clocks based on ultra-cold strontium atoms in fibre

1.1. Project goals

- probing new physics with ultra precise clock spectrscopy
- development of methods for transfer atoms in hollow-core fibre
- atom-light interaction studies
- advanced studies on cooling of ultra-cold atoms in hollow-core fibres

1.2. Outline

The project's main objective is to study new physics by using ultra-cold atoms. The project will be conducted at KL FAMO in two parallel and complementary ways: work with already existing optical lattice clocks based on ultra-cold Sr atoms, development a new setup for study efficient transfer of ultra-cold Sr atoms by using hollow core photonic crystal fibres.

Optical clocks (OC) are based on the highly precise interrogation of an optical transition, where instabilities and inaccuracies in the 10-18 range can now be reached [1,2]. These transitions, however, are susceptible to a range of perturbations, including magnetic fields, the black-body radiation field of the environment and collisions with the background gas. Most OC realizations includes an oven at over 500 K and strong dynamic magnetic fields. Disentangling the production region from the measurement region by spatial separation would be a great improvement. One of the biggest limitations of the present generation OC comes from the need of a macroscopic frequency reference, which preserves the frequency while a new sample of ultracold atoms is prepared and loaded into the atomic standard. This frequency reference is a laser pre-stabilized to the length of an ultrastable high-Q cavity. The cavity must be exceptionally well isolated from the environment, requiring extensive thermal insulation and vibration isolation systems. At the same time, the linewidth provided even by the best reference lasers is much broader than the atomic clock transition. One of the proposed and actively developed solutions is the system with continuous superradiant lasing of an ensemble of atoms on the clock transition, producing light directly at the clock frequency [3, 4, 5]. If superradiant lasing is sustained continuously, e.g. by replenishing the lasing ensemble from an external reservoir, there is no longer any need for bridging dead-time by an external reference oscillator. The single mode of a hollow core fiber can be an essential element to continuously load the ultra-cold atom reservoir [6]. Using new types of source for optical clocks opens new perspectives in terms of improvement of accuracy and stability by investigating and quantifying systematic frequency shifts in clock and searching of new physics [7].

The main goal of the PhD thesis is to get experience in research that includes broad range of work like design, simulations, theoretical and experimental work with optical clocks and strontium ultra-cold atoms. Experimental work will be focused on studying atom-light interaction, methods for atom cooling, fundamental physics research and ultra-precise metrology. The excellence and skills aquired at KL FAMO will make that PhD student will actively participate in development of the atom transfer setup, dark matter searches and optical clock comparisons within the intercontinental optical atomic clock network with the leading quantum metrology groups like NIST (USA), LNE-SYRTE (France), PTB (Germany), NICT (Japan), INRIM (Italy), NPL (Great Britain).

1.3. Work plan

- Upgrading the Sr optical lattice clock (new laser system for operation with fermionic isotope) and improve the accuracy budget
- Development of the atom transfer setup
- Dark matter searches within the intercontinental optical atomic clock network
- Designing and testing Sr source for continuous operation of optical clocks and quantum computers
- International atomic clock comparisons of European frequency standards to establish the new types of international timescale
- Advanced study on atom-light interaction and atom cooling methods in HCF fibre
- Performing spectroscopy measurements of the clock transition

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

[1] AD Ludlow, MM Boyd, J Ye, E Peik, PO Schmidt, Optical atomic clocks, Reviews of Modern Physics 87 (2), 637

[2] Masao Takamoto, Feng-Lei Hong, Ryoichi Higashi & Hidetoshi Katori, An optical lattice clock, Nature volume 435, pages321–324 (2005)

[3] M. A. Norcia, M. N. Winchester, J. R. K. Cline, J. K. Thompson, Superradiance on themillihertz linewidth strontium clock transition. Sci. Adv.2, e1601231 (2016)

[4] M. A. Norcia, M. N. Winchester, J. R. K. Cline, J. K. Thompson, Superradiance on themillihertz linewidth strontium clock transition. Sci. Adv.2, e1601231 (2016)

[5] Georgy A. Kazakov, Swadheen Dubey, Anna Bychek, Uwe Sterr, Marcin Bober, and Michał Zawada, Ultimate stability of active optical frequency standards, Phys. Rev. A 106, 053114

[6] Okaba, S., Yu, D., Vincetti, L. et al. Superradiance from lattice-confined atoms inside hollow core fibre. Commun Phys 2, 136 (2019)

[7] Piotr Wcisło et al. New bounds on dark matter coupling from a global network of optical atomic clocks, Sci. Adv.4, eaau4869 (2018)

1.5. Required initial knowledge and skills of the PhD candidate

- an excellent academic record
- good knowledge of quantum mechanics, atomic, molecular and optical physics
- computer and experimental skills
- team work
- highly demanded: master thesis related with atomic, molecular or optical physics

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

Within the PhD course student will get experience, knowledge and skills that are important in the high-tech academia and industry:

- cold atomic physics
- atom-light interaction
- collective effects in quantum gases
- high resolution spectroscopy
- laser physics and optics
- ultra-high vacuum physics