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

Project title: Superradiance with ultra-cold strontium atoms in high finesse caviy

1.1. Project goals

- experimental study of superradiance phenomena on ultra-narrow clock transition with ultra-cold strontium atoms
- take a step towards active optical atomic clock, in particular go towards sustained superradiance and extremely narrow linewidth
- fundamental physics research, in particular investigate cavity QED and search for new physics with optical clocks.

1.2. Outline

Only once superradiance was experimentally demonstrated on ultra-narrow clock transition [Nor16] a few years ago. With our theoretical model we were able to simulate experimental results [Gog20]. Based on superradiance phenomena an active optical atomic clock can be constructed. This is a very high gain, high risk project. In this project we propose research towards the very first active optical clock.

Optical atomic clocks [Lud15] are currently widely used in fundamental physics research i.e. for dark matter search [Wci18], changes of fundamental constants, state-of-the-art King-plot-based measurements and many others. With all benefits of optical atomic clocks, their current design sets a hard limit with their performance, where orders of magnitude better results seem impossible. Active optical atomic clock based on superrdiance phenomena could be a solution, allowing for orders of magnitudes better sensitivity in fundamental physics search.

The experimental setup for superradiance investigation will be an excellent platform for cavity QED and atomic quantum systems research, advanced in quantum metrology, many-body physics and for a quantum computer development. Additionally, the with the use of passive optical atomic clocks and the superradiant setup we can probe fundamental physics.

1.3. Work plan

- installation of high-Q cavity inside a vacuum setup, trapping atoms in crossed optical lattice (M1-M12)
- investigation on superradiance pulses, research with cold atoms strongly coupled with optical cavity mode (M12-M36)
- improvement of the setup with the goal towards sustained radiation and narrower linewidth (M12-40)

- use of the optical clocks and superrdaint setup for fundamnetal physics search (M6-M36)
- writing, submitting and defending the thesis (M36-M48)

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

[Bob22a] Bober M. and Bennetts S., Design of continuous mHz-line clock apparatus (2022), https://cordis.europa.eu/project/id/820404/results

[Bob22b] Bober M. and Bennetts S., Continuous mHez-line clock apparatus (2022), https://cordis.europa.eu/project/id/820404/results

[Che22] Chen C.-C. et al., Nature 606, 683 (2022),

[Gog20] Gogyan et al., Optics Express 28(5), 6881 (2020),

[Lud15] Ludlow A.D. et al., Rev. Mod. Phys. 87, 637 (2015),

[Nar23] Narożnik M. et al., Physics Letters B, 846, 138260 (2023),

[Nor16] Norcia M.A. et al., Sciectific Advaces 2, e1601231 (2016),

[Nor18] Norcia M.A. et al., Phys. Rev. X, 8 021036 (2018),

[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 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

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, electronics, programming and other