The Nobel Prize winner in Physics, Arthur Shawlow used to say to his students at Stanford University: “Never measure anything but frequency!”. Indeed, in the story of mankind the frequency measurements were always those measurements that where the most accurate. One of the reason is that digital, discrete and finite counting the number of cycles during a given time unit is immune to most of the uncertainty sources seen in other measurements.

Optical atomic clocks still are the most precise scientific instrument available to humanity. They accuracy and stability reached eighteen significant digits. Therefore, the optical atomic clocks are one of those experiments that pushes the boundaries of knowledge. They are used, e.g., for search for variation of fundamental constants, validating the assumption of the Standard Model, and, as we show recently, even in detection of Dark Matter. The cost of their construction and maintenance, however, is many times lower and the needed research team is smaller in comparison to other, great experiments that enlarge our knowledge on structure and history of our Universe.

In our project we plan to exploit the precision of the Polish Optical Atomic Clock, the most accurate scientific instrument in Poland, to study fundamental interactions between atoms and electromagnetic field, e.g. polarizability and photoionization. The so-called magic and magic-zero wavelengths that also will be determined during the project are crucial for the next generation of the optical lattice atomic clocks.

The most important component of an optical frequency standard is a sample of cold atoms or a single ion trapped in a coherence-preserving electromagnetic trap. Neutral atoms in an optical lattice are trapped in an optical lattice potential, which relies on spatially inhomogeneous Stark shift that depends on the relevant electronic state. For a given atomic species, a special narrow optical transition (the so-called clock transition) is selected to ensure that its frequency is hardly sensitive to external fields. Nevertheless, the intense trapping light affects the clock transition frequency by the ac-Stark shift effect. The so-called “magic” wavelength is a trap laser wavelength, where scalar polarizabilities of both ground and excited states of the clock transition are identical and the light shift of the clock transition is largely suppressed, at least in the first order of approximation. However, all practical realizations of the optical lattice atomic clock to date are based on the red-detuned optical trap, which confine atoms in the intensity maxima and to achieve a high accuracy, the residual polarization-dependent and higher-order light shifts still have to be evaluated.

In the blue-detuned lattice atoms are trapped in the intensity minima of a lattice field and experience negligible light-induced perturbation. Optical lattice clock with blue detuned trap combines benefits of ion clock where influence of external fields is minimized as well as optical lattice clocks which allows probing simultaneously large number of atoms.

Our fist experimental task will be the measurement of the blue magic wavelength around 389.9 nm for the ^{88}Sr isotope. The second task will be the measurement of the absolute photoionization cross sections of the states in strontium that are used in the actual atomic clock experiment by the blue magic wavelength photons. This enable creation of new, effective procedures and protocols in the next generation of optical lattice atomic clocks.

Recently, it was predicted that in the proximity of the blue magic wavelength in strontium there are several so-called magic-zero wavelengths (also called tune-out wavelengths) for the excited clock state, where the frequency-dependent polarizability of this state vanishes. The atom in such a state does not interact with the magic-zero wavelength light at all. This feature can be applied for state-selective atom manipulation for implementation of quantum logic operations. The magic-zero wavelengths have been used in experiments to study entropy exchange between ultra-cold quantum gases and diffraction of matter waves on an ultra-cold atom crystal. But most of all, they can be used as the benchmarks of theory. They can verify such physical parameters as static polarizabilities, lifetimes of the states, transitions’ oscillator strengths, van der Walls potentials, or last but not least, magic wavelengths. The exact knowledge of the oscillator strengths is essential in many areas of research, e.g., studies of fundamental symmetries, quantum degenerate gases, quantum information, plasma physics, and astrophysics. Therefore, our third, last, experimental task will be the spectroscopy of the magic-zero wavelengths for the strontium excited clock state.