This project is devoted to the development of a new molecular sensor to allow the study of fundamental interactions. The energetic structure of molecules is determined by the interaction between their components and the surrounding space. Therefore molecules can be used to test quantum electrodynamics in systems more complex than a single atom and look for more exotic interactions like: fifth force additional to four already known ones, short-range non-Newtonian gravitation or perturbations by dark matter fields. We will use isotopologues of the heavy Hg_2 molecule to look for signatures of additional interactions beyond the Standard Model at the nano-scale or at least to give new bounds for their possible magnitude. Our approach relies on the confrontation of accurate spectroscopic measurements with theoretical calculations. If it reveals any statistically meaningful discrepancies, we will look for signatures of exotic hadron-hadron interactions. We will approach this problem by measuring the bound states of the Hg_2 molecule near the dissociation threshold. In this case, we will take advantage of a relatively simple form of interaction at the large separation between atoms.

Accurate determination of energies of Hg_2 bound states needs other approach in which atoms are trapped and cooled by forces generated with high intensity laser light. Such colliding ultraslow Hg atoms are next converted by two light pulses into Hg_2 Molecule. The energy of bound states can be found with great accuracy just by looking on the loss of atoms from the trap depending on the frequency difference between two light pulses. Thanks to technology developed for optical atomic clocks and the fact that the frequency is a physical quantity which can be measured best, the molecular structure of Hg_2 will be determined and compared with theory with accuracy not reached before. This sensor will be used to check if we can see new forces between massive particles at the nanometer scale.

The experimental observation of signatures of new interaction would have a huge impact on physics and understanding of our Universe. However, even without such an observation our project will establish new methodologies and experimental bounds on possible magnitudes of interactions beyond the Standard Model helping to eliminate some theoretical models. Moreover, our spectroscopic technique and theoretical approaches to data analysis will push forward optical metrology. For example, spectroscopy of thermal gases already is one of the main techniques of ultra-accurate temperature measurements called Doppler width thermometry. The developed techniques will improve the possibilities of gas composition metrology. This is crucial for remote sensing of pollution in the Earth's atmosphere and isotope ratio determination in environmental applications. On the other hand in case of ultraslow colliding atoms in the presence of light, the interaction between them can quickly change. Repulsive interaction can be switched to an attractive one and vice versa. This opens new possibilities for quantum engineering. The experience gained within this project will help to construct an Hg_2 optical molecular clock