Ultra-accurate spectroscopy of simple molecules for fundamental studies - cryogenic cavity-enhanced spectrometer

The main goal of this project is to study the structure of the simplest molecules (molecular hydrogen) at the unprecedented level of accuracy. The simplest molecules are of particular interest for fundamental studies mainly because their structure can be calculated from first principles, and hence they can be used to test not only the quantum mechanics but also the quantum electrodynamics for molecules. Furthermore, for the same reasons, the simple molecules can serve as unique sensors of new hypothetical forces or additional special dimensions.

To reach this goal we will develop a high-power laser source coupled with an optical spectrometer that operates at cryogenic conditions (down to 10 K). The high power of the laser source is necessary to saturate the weak transitions in the HD isotopologue of molecular hydrogen and, hence, observe a narrow sub-Doppler spectroscopic structures. The low temperature is crucial since lower molecules speed allows the spectroscopic features to be probed much more accurately. The spectrometer will be based on ultra-high-finesse optical cavity (also cooled down to cryogenic conditions), which will increase the effective light-molecules interaction distance up to hundreds of kilometers, hence, incredibly increasing the sensitivity of the method.

Besides the aforementioned goal, we will also benefit from the cryogenic cavity-enhanced spectrometer to study the phenomena at the interface of quantum chemistry and molecular physics. We will study low-temperature molecular collisions and structure of molecular van der Waals complexes (i.e. very weakly bound states of two molecules/atoms). These studies are essential for understanding basic processes that relates calculations from first principles with actual experimental chemistry.

On the theoretical side of our project, we will use computer workstations to numerically solve the quantum-mechanics equations for the molecular collisions (which in quantum picture are really considered as scattering of matter waves). We will use these theoretical results to interpret the structure of the measured spectra.