Decoherence in quantum gates based on ultracold molecules

Project Summary

We live in a new quantum revolution boosted by the prospective applications of quantum information and cryptography to society and industry. One possible experimental platform for realizing reliable quantum computers is ultracold polar molecules [1–3]. The idea is to use diatomic polar molecules at ultralow temperatures as qubits. Furthermore, quantum computers based on ultracold polar molecules are scalable, i.e., increasing the number of molecules (qubits) and the number of operations. The main idea is to use light-molecule interaction to control the outcome of a quantum gate via dipole-dipole interactions. However, as in many other quantum information platforms, decoherence, the unavoidable and ubiquitous coupling of a quantum system with the environment, causes a continuous loss of information and, with it, the malfunctioning of the computer [4]. Therefore, by controlling the decoherence of a quantum platform, it could be possible to improve a quantum computer's fidelity and operational performance.

Ultracold polar molecules are a unique testbed for simulating many-body Hamiltonians and exploring exotic and novel quantum many-body properties without the complexity and possible impurities of solid state systems [5–7]. In other words, using an array of ultracold polar molecules to simulate the dynamics that govern material science is possible. In this case, as in the quantum computer, light-matter interaction is used to control and tailor many-body Hamiltonians, for instance, through laser-induced alignment of molecules. However, in the case of a molecular array, if one of the molecules is aligned, the others should follow, causing a many-body excitation, the so-called excitons [8]. The dynamics of these excitons affect the properties of the array of ultracold molecules, including decoherence effects. Hence, it is necessary to understand the exciton dynamics to design quantum simulators and quantum computers better. Due to its impact on quantum information sciences, such as in quantum simulators, this proposal is well suited for funding programs from NSF, DOE, ARO, and AFOSR.

This proposal aims to study decoherence in quantum gates and arrays of ultracold polar molecules using laser-induced alignment of polar molecules in a sea of molecules. One of the molecules is excited via an ultra-short laser pulse, inducing its alignment toward the polarization axes of the laser pulse. In the presence of other molecules, the alignment will be hindered by dipole-dipole interactions. Therefore, looking into the dynamics of the excited molecule and how the expectator molecules (the bath) react will unravel the nature of decoherence in quantum systems based on ultracold polar molecules and find new avenues for quantum simulators based on an array of ultracold polar molecules.