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**Towards Hybrid Quantum Information Processing with Polar Molecules**[1]

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With the ongoing miniaturization of on-chip traps for atoms and ions it is timely to think about coherent interfaces between AMO and solid state systems with potential applications for new hybrid implementations for quantum computers. In this talk I will discuss a potential scenario, where ensembles of polar molecules serve as long-lived quantum memories for superconducting qubits and quantum information is transmitted via a high-Q microwave cavity. Polar molecules combine the exceptional features of a large electric dipole moment and long-lived rotational states with level splittings in the GHz regime. When trapped close to the surface of a chip this combination allows strong interactions with coherent solid state devices, e.g., superconducting microwave cavities or Josephson qubits. I will first introduce the system consisting of a single polar molecule coupled to a stripline cavity which realizes a cavity QED system in the microwave regime and discuss applications for quantum information processing, state detection and new cavity-assisted cooling schemes for polar molecules. I will then switch to molecular ensemble qubits where quantum information is encoded in collective spin or rotational excitations of an ensemble of $N$ molecules. Ensemble qubits benefit from a collectively enhanced coupling $\sim \sqrt{N}$ which allows quantum state transfer between the molecules and, e.g., a charge qubit on a timescale that is compatible with typical coherence times in a solid state environment. With the goal to protect ensemble qubits from collisions, I will finally discuss a scenario, where molecules are prepared in a crystalline phase under 1D trapping conditions and dipole moments aligned by an external field.

[1]The work presented in this talk was performed at the University of Innsbruck, Austria, and the Institute for Quantum Optics and Quantum Information of the Austrian Academy of Science under the supervision of Prof. Peter Zoller.