My research direction includes study of quantum optical systems and cold atom physics, and their applications to quantum simulation and quantum information science. To be more specific, my interest lies in the BEC-BCS crossover theory of cold atoms in a trap or an optical lattice, quantum control and quantum gate with trapped ions, and “cooperative” effects such as superradiance.

Here I briefly sketch each category of my research:

(1) **Cold atom physics** deals with particles’ “unusual” behavior that can only be described quantum mechanically when their matter wave packets start to overlap (interfere). This usually requires very low temperature. Meanwhile, the interaction between these particles can further be engineered, which can make particles be paired like composite bosons or weakly interacting Cooper pairs. They lead to superfluidity when they condense at very low temperature. In the “quantum simulation” language, this system somewhat “simulates” a real superconductor. People believe that quantum simulation opens up a new way to study novel physics, including high-Tc superconductivity.

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(2) **Trapped ion quantum computation**: Quantum gates are building blocks of a quantum computer. It is generally believed that the trapped ion system is one of the best candidates to realize quantum gate devices. However, how to implement a large-scale quantum device with trapped ions has been a challenge. Up to date, the most convincing proposals to circumvent this difficulty include ion shuttling, transverse mode manipulation and pulsed control, and quantum network. (Figure 1)
(3) **Trapped ion quantum simulation**: Each ion in an ion trap corresponds to a “two-level” system (also called a qubit or a spin, depending on the context). When the whole “pool” of ions (can be a one-dimensional chain or a two-dimensional array) is illuminated by control laser beams, which induce the spin-spin interactions, we can simulate some interesting Hamiltonians such as spin models. Through study of such realization, we can build a bridge from a few to many-body phenomena such as phase transitions by directly observing and controlling the system in laboratory. (Figure 2)
(4) **Cooperative effects and superradiance:** Cooperative effects, which arise from the exchange interaction between particles, are interesting quantum many-body phenomena. A very important example is superradiance, which describes a drastic increase of radiation due to presence of identical particles, along with the build-up of collective dipoles. Cooperative effects strongly rely on high density and have strong connections to many interesting phenomena such as slow light and the collective Lamb shift. (Figure 3)

![Figure 3: Superradiance from different spin-\(j\) particles. Left: Emission profile; Right: Stimulated decay rate (in units of spontaneous rate \(\gamma\)).](image)

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