For the last 100 years, due to its unintuitive nature, quantum physics has captured the imagination of physicists worldwide. Recently, there has been a new push by various companies, such as Google, Microsoft, and IBM, and the developed countries to use these bizarre effects of quantum mechanics for the development of a quantum mechanics based devices, e.g., a quantum computer. In a day-to-day classical computer, the information (e.g., picture of a birthday party) is stored and processed using transistors as “bits” that can have one of the two possible values: “0” (OFF state) or “1” (ON state). The quantum computer takes advantage of entanglement and massive parallelism via the superposition principle to solve problems unmanageable by classical computers. Quantum bits or “qubits” are different: in addition to “0” and “1,” a qubit can also exist in a superposition state. If a classical computer is tasked to figure its way out of a complex maze, it will try every single path sequentially, ruling them all out individually until it finds the right one. In contrast, a quantum computer can go down every branch of the maze at once. Hence a quantum computer reduces computational time by millions of times and at a lower energy cost than a classical computer.

The quantum information in a quantum computer can be materialized in different physical forms and converted from one to another without changing its content. The physical implementation choice is left to the “quantum engineer”: either natural microscopic systems such as atoms, ions, photons, electron, and nuclear spins, or more artificial systems such as superconducting qubits. Superconducting qubits are promising candidates for building a quantum computer; they couple very strongly to microwave fields, but exhibit coherence times to tens of microseconds. This limitation allows only a short time window to perform quantum calculations before the whole system decoheres. This time restriction has motivated researchers to look for hybrid quantum systems that increase the coherence time of superconducting qubits by combining them to other quantum systems better protected against decoherence. Researchers are trying to couple superconducting qubits, via a superconducting resonator, to ions, atoms, or spin ensemble.

Recently, magnons have been considered as a new candidate for coherent quantum information processing. Magnons are the collective excitation of spins in magnetic materials. Their frequency range lies from GHz to THz. In comparison to the paramagnetic spin ensembles, magnons can exchange information with a much faster speed and for more cycles before losing coherency, while keeping the device dimension small. To implement the high spin density magnetic materials into practical quantum devices, on-chip integration and miniaturization on a nanoscale are required. To achieve this goal, the following fundamental physics and technological issues must be addressed first: 1) Does the magnon-photon coupling scales as we systematically reduce the dimensions of the magnetic element into the nanoscale regime? 2) Are their critical dimensions (either in length, width, or height) of magnetic elements where magnon-photon coupling enhances or reduces non-linearly? 3) Can we tune the magnon-photon coupling via placing arrays of nanomagnets? Specifically, do arrays of nanomagnets on particular lattices or particular magnetic materials allow better magnon-photon coupling? 4) What is the effect on magnon-photon interaction as we vary the fundamental dipolar and exchange interactions among the nanobars? 5) Can we artificially tune the magnon-photon coupling by reprogramming magnetic arrays using a 2-D magnetic field protocol?

My goal is to address the above questions using a systematic approach that includes several state-of-the-art experimental and simulation techniques. We will miniaturize high spin density magnetic thin films using nanofabrication methods. These devices will be incorporated with superconducting microwave resonators to make an on-chip device. We will also construct a novel equipment package that will allow us to study the magnon-photon coupling in arrays of nanomagnets on periodic and quasicrystal lattices as a function of magnetic field, frequency, and temperature. We will utilize a two-dimensional magnetic field protocol to program the magnetic state of nanomagnets to tune the magnon-photon coupling. Furthermore, using the micro-focus Brillouin light scattering technique, we will image the spatial magnon profile. This will give unprecedent mesoscopic understanding of space dependent magnon profile as the magnetic material is miniaturized towards 100 nanometers length scale.