<u>Using Cold Atom Lab (CAL) in the ISS for experiments with the quantum dots and spin qubits</u>

1. Creation of Cold Atoms: The first step in testing spin qubits in a cold atom lab involves creating ultra-cold atoms, typically using laser cooling techniques. This process involves reducing the atomic motion and lowering the temperature to fractions of a degree above absolute zero, creating a Bose-Einstein condensate (BEC) or a degenerate Fermi gas.
2. Generation and Manipulation of Spin Qubits: Spin qubits are quantum bits represented by the intrinsic spin of individual particles, such as electrons or ions. In the cold atom lab, researchers can engineer and control the spin properties of the trapped atoms or ions to act as qubits. This can involve manipulating external magnetic fields or using optical methods to control the spin states.
3. Quantum Information Processing: Once the spin qubits are prepared and controlled, researchers can perform quantum information processing tasks. This may include implementing quantum gates (e.g., single-qubit rotations and two-qubit entanglement operations) and running quantum algorithms.
4. Measurement and Readout: To analyze the quantum information stored in the spin qubits, appropriate measurements and readout procedures are essential. Cold atom labs typically have sophisticated detection systems to measure the quantum state of individual atoms or ions with high precision.
5. Noise and Error Characterization: One crucial aspect of testing spin qubits is to understand and mitigate noise and errors that affect the quantum information. In the cold atom lab, researchers can study various noise sources, such as environmental interactions and technical imperfections, and develop error-correction techniques to improve the qubit's coherence time.
6. Fundamental Quantum Studies: In addition to quantum information processing tasks, cold atom labs can also be used for fundamental studies in quantum mechanics. Researchers can explore quantum entanglement, quantum phase transitions, and exotic quantum states relevant to quantum computing and information science.

Below are some **potential experiment specifications** that could be considered for the CAL in the ISS with silicon quantum dots and spin qubits:

<u>Experiment 1: "Quantum Control of Silicon Spin Qubits in Microgravity"</u>

Objective: To investigate the behavior of silicon quantum dots and spin qubits in a microgravity environment, aiming to improve control and coherence times for potential quantum computing applications.

Experimental Setup:

- Generation of Cold Atoms: CAL's facilities can be used to create ultra-cold atomic gases, which act as a cooling mechanism for the silicon quantum dot system.
- Silicon Quantum Dot Array: Design and fabricate an array of silicon quantum dots on a semiconductor substrate, allowing precise control of electron spins within the dots.

- Optical Trapping and Manipulation: Utilize lasers or magnetic fields to optically trap and manipulate individual atoms or ions within the silicon quantum dots.
- Quantum Control and Manipulation: Develop experimental protocols to perform quantum control and manipulation on the spin qubits in the silicon dots. This might include single-qubit rotations, two-qubit gates, and measurements of quantum states.
- Coherence Time Measurements: Measure the coherence times of the spin qubits in the silicon quantum dots to understand the impact of the microgravity environment on quantum coherence.
- Quantum State Readout: Develop a scheme for non-destructive quantum state readout of the silicon qubits.

Safety and Containment:

Ensure that the experimental setup is safe and contained to prevent any hazards or contamination to the ISS environment.

Data Transmission and Remote Control:

As the experiments will be performed remotely from the ground, establish a reliable and efficient data transmission system for real-time control and monitoring of the experiments.

<u>Experiment 2: “Entanglement Generation and Preservation in Silicon Quantum Dot Arrays"</u>

Objective: Investigate the generation and preservation of entangled states in arrays of silicon quantum dots in microgravity conditions. Entanglement is a crucial resource for quantum information processing and communication.

Experimental Setup:

- Create an array of silicon quantum dots with well-defined quantum properties.
- Utilize lasers or magnetic fields for precise control of electron spins and to generate entangled states between neighboring quantum dots.
- Investigate the impact of microgravity on the coherence and entanglement times of the system.

<u>Experiment 3: "Quantum Communication with Spin Qubits in Silicon Quantum Dots"</u>

Objective: Demonstrate the feasibility of quantum communication using spin qubits in silicon quantum dots in a microgravity environment. Quantum communication offers enhanced security and information transfer capabilities.

Experimental Setup:

- Establish a communication link between two or more silicon quantum dots for quantum information transfer.

- Implement quantum key distribution protocols to ensure secure communication.
- Evaluate the effects of microgravity on the efficiency and fidelity of quantum communication protocols.

Experiment 4: "Exploring Topological Quantum Computation with Silicon Spin Qubits"

Objective: Investigate the potential of topological quantum computing using silicon quantum dots and their spin states. Topological quantum computing has the advantage of being more robust against certain types of errors.

Experimental Setup:

- Engineer the silicon quantum dots to exhibit topological properties suitable for protected quantum information storage and manipulation.
- Develop protocols for performing braiding operations on non-Abelian anyons (quasiparticles) in the system.
- Examine the impact of microgravity on the stability and coherence of topological quantum states.

Experiment 5: "Quantum Simulation of Complex Many-Body Systems with Silicon Quantum Dots"

Objective: Employ silicon quantum dots as a platform for quantum simulation of complex many-body systems, such as strongly correlated materials or condensed matter models.

Experimental Setup:

- Engineer the silicon quantum dot array to mimic the desired many-body Hamiltonian.
- Use quantum state tomography and other measurement techniques to characterize the quantum states of the system.
- Study the impact of microgravity on the accuracy and fidelity of quantum simulations.

I understand that the current design of CAL may not be suitable for these experiments. I am looking forward to adding capabilities to CAL to accommodate similar experiments as listed above. The above specifications are not accurate. The intention of the above specifications is to give an idea about how CAL could be used in this project. The experiment objectives, setup and specifications could change in the full proposal.