1. **Abstract**

- For superconducting quantum computers to continue to scale, multiple processors will need to be networked.
- Optical channels provide a low-loss link capable of spanning long distances.
- Combining hot optical photons with milliKelvin superconducting circuits at microwave frequencies in a dilution refrigerator would appear incompatible.

**Question 1:** How do we connect the microwave and optical regimes quantum mechanically?

**Question 2:** What is the best way to use optical channels to entangle superconducting processor nodes?

**Question 3:** Will YOU be the first person in the world to experimentally demonstrate a “Quantum Internet” capable of distributing arbitrary quantum states?

2. **Microwave-Optical Transduction**

Collaborators at CU/JILA: Lehnert/Regal Lab

- Three coupled resonators (optical, mechanical, microwave): with “membrane in the middle” superconducting circuit

  - Efficiency: 47% (record)
  - Added noise: 9 photons
  - Target < 1 photon

Collaborators at NIST: Silverman/Mirin Lab

- Three coupled resonators (optical, acoustic, microwave): with quantum dot emitter

  - High generation rates
  - Integrated design
  - Low power

3. **Continuous Variables Approach**

- Based on measuring continuous field quadratures instead of discrete number states. This is an infinite Hilbert Space. It’s Analog!
- Optics: A quantized electromagnetic field => use squeezed light.

4. **Squeezed Light**

- **Uncertainty Principle:**
  \[
  \langle (\Delta E_1^2) \rangle \langle (\Delta E_2^2) \rangle \geq \frac{1}{4}
  \]
  The proportion is not fixed.
  Unequal is “squeezed.”
  Y1 quadrature noise is below vacuum fluctuations; Y2 is above.

- **Precision metrology:** LIGO

5. **Network Topology Study**

For imperfect transducers, lossy channel, Gaussian operations, is it better to:

- Distribute or swap entanglement?
- Squeeze in the optical, microwave, or combined optical/microwave domain?
- Introduce squeezing intrinsic or extrinsic to transducers?

**Distribute:**

- Optical Paths
- Electrical Paths

**Swap:**

- Optical measurement
- Electrical measurement

Modeling the Network Topologies:

- Transducer cooperativities, transmissivities, thermal noise (Temp. > 0).
- Optical channel loss.
- Calculate entanglement thresholds.

6. **Experimentally Making it Work**

7. **Future Research Topics**

- Demonstration of extrinsic optical distribution through transducers.
- Demonstration of short-distance entanglement of superconducting nodes.
- Demonstration of long-distance entanglement of superconducting nodes.
- Demonstration of entanglement across a free-space channel.
- Heterogenous quantum network demonstration between superconducting qubits and trapped ion nodes.
- Networking with exotic optical states with non-Gaussian processes.
- Networking with distillation of weak Gaussian states or coherent feedback control to overcome noise and loss.

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