Overview of NASA’s National Space Quantum Laboratory Program

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Outline

• NASA-MIT-LL Lasercom Collaboration
• National Space Quantum Laboratory (NSQL)
• Quantum Technology Development
A History of High-Impact Lasercom Collaborations


**Laser Intersatellite Transmission Experiment (LITE)**
Early lasercom partnership between MITLL and GSFC
LITE EM demonstrated all key lasercom subsystems in space-qualified form—also revealed engineering challenges

**GeoLITE**
First space lasercom success

**GeoLITE**

**Mars Laser Comm Demonstration (MLCD)**
Established architecture for deep space lasercom

**Lunar Laser Comm Demonstration**
NASA’s first space lasercom success

**Laser Comm Relay Demonstration**
Optical relay pathfinder
Based on MITLL risk reduction hardware designs

**GeoLITE**
First space lasercom success

**LITE EM**
 Demonstrated all key lasercom subsystems in space-qualified form—also revealed engineering challenges

**Laser Intersatellite Transmission Experiment (LITE)**
Early lasercom partnership between MITLL and GSFC
NASA’s Near-Earth Lasercom Programs

**ILLUMA-T** (ISS) (2021)
First LEO User of LCRD

**LCRD** (2020)
leverages LLCD technology; will serve as the relay backbone

**O2O** (Orion) (2023)
Apply Lasercom technology to operational use as an Orion Development Test Objective (DTO)

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**Superconducting Nanowire Single-Photon Detector (SNSPD) Array**

**ILLUMA-T** (ISS) (2021) First LEO User of LCRD

**LCRD** (2020) Leverages LLCD technology; will serve as the relay backbone

**O2O** (Orion) (2023) Apply Lasercom technology to operational use as an Orion Development Test Objective (DTO)

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**LCRD**: Laser Communication Relay Demonstration
**ILLUMA-T**: Integrated LCRD LEO (Low-Earth Orbit) User Modem and Amplifier Terminal
**O2O**: Orion EM-2 Optical Comm
Entanglement-Based Quantum Communication Applications

Timing Application: Quantum Clocks and Synchronization
- Develop laser comb-based synchronization
- Demonstrate entanglement-based time-transfer protocols

Sensing Application: Distributed Quantum Sensing
- Enable increased baseline for enhanced resolution sensing

Computing Application: Networked Quantum Processors
- Increase computing power
- Enable enhanced scaling architectures

These applications rely upon interacting remote quantum systems using distributed entanglement
National Space Quantum Laboratory (NSQL)

- Integrated space and ground quantum network
  - Quantum downlinks, uplinks and crosslinks
  - NASA’s International Space Station (ISS) will provide flexible access to space
  - A free-flyer option can be utilized to complement the ISS
- High-rate entanglement distribution for quantum-enabled sensing and timing applications
- Supports incorporation of future technology
  - Supports hybrid space/terrestrial quantum network architectures
  - Complementary to fiber-based quantum network effort
1. Generate entangled pair of photons in the ISS payload
2. Track ground station and mux signals onto downlink
3. Track and demux optical signals
4. Generate a new signal / idler pair on the ground
5. Perform an entanglement swap
6. Path length stabilize receiver
7. Analyze idler photons, communicate measurement results, and verify swap
Quantum Modem Technology Development

Master Clock Laser and Entanglement Source
- Pump Source
- Nonlinear Crystal
- Entanglement Generation

Quantum State Analyzer
- Photon-Counting Detectors
- Space Cryocoolers
- Entanglement Analyzer

Synchronization
- Pump
- Photon 2
- Photon 3

Free-Space Link

Two-Photon Interference Between Sources

Laboratory demonstration of high-visibility two-photon interference, which is needed for high-fidelity entanglement swapping.

Hong-Ou-Mandel (HOM) Interference Between Sources

<table>
<thead>
<tr>
<th>Entanglement Source 1</th>
<th>50:50 Beam Splitter</th>
<th>Adjustable Time Delay</th>
<th>Entanglement Source 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shared Pump System</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Vis = 91% ± 3%

3 ps
## QTS Quantum Downlink Terminal Trades

<table>
<thead>
<tr>
<th>ISS Terminal</th>
<th>MIT-LL GS2</th>
<th>JPL OCTL</th>
<th>MIT-LL Firepond</th>
<th>AFRL AEOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 cm</td>
<td>-38 dB</td>
<td>-33.5 dB</td>
<td>-32 dB</td>
<td>-22.5 dB</td>
</tr>
<tr>
<td>30 cm</td>
<td>-28.5 dB</td>
<td>-24 dB</td>
<td>-22.5 dB</td>
<td>-13 dB</td>
</tr>
</tbody>
</table>

### Link Assumption
- **Range**: 1000 km (~ISS at 30° el.)
- **Atmosphere**: -2.7 dB
- **Turbulence**: -5.2 dB
- **Tx & Rx optics**: -4.4 dB each

Entanglement distribution at 20 kHz – 1.5 MHz, swaps at 300 Hz – 25 kHz
Quantum Terminal Subsystems and Payload

MAScOT Optical Module  Controller Electronics  ISS Flight Payload

Power Conversion Unit  Quantum Modem

Near-term NSQL flight demonstration enabled by leveraging NASA lasercom technology development and ISS payload integration experience
Quantum Modem Space Qualification

**Thermal-Vacuum**
- ISS thermal interfaces may be well controlled
- Pressurized environment might be possible
- Mode-locked laser performance in vacuum TBD

**Shock & Vibration**
- Telcordia heritage of many QM parts reduces risk
- Detectors may have greatest design risk
- Use conventional electronic designs

**Radiation**
- ISS radiation environment is benign
- Short mission pass duration compatible with simple reboot approach to single-event-effects
- Relatively simple data and control needs expected to allow use of mature space qualified electronics

**Reliability and Redundancy**
- Experimental mission nature compatible with risk tolerance
- Will consider selected redundancy and use of cold spares

Lasercom heritage experience will be leveraged to space qualify quantum modem technology
• Much hype and much promise surround the international race to develop quantum systems and technology today

• Base technologies have matured to the point where it makes sense to begin engineering quantum systems

• NSQL will enable entanglement-based quantum network demonstrations over satellite-based downlinks and crosslinks

• ISS deployment enables collaborative use by the quantum research community to characterize new technologies and emerging applications
  – Improved timing and synchronization systems
  – Distributed sensing
  – Quantum computation