
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**



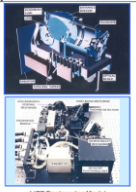
A History of High-Impact Lasercom Collaborations



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Laser Intersatellite Transmission Experiment (LITE)

- Joint AF / NASA project (1985-9)
- To have flown on NASA Advanced Communications Technology Satellite (ACTS)
 - MIT LL 4-ay FBK heterodyne receiver at Mt Wilson, CA
 - 50-200 Mbps
 - NASA GSFC Direct detection receiver
- Cancelled after CDR due to cash flow reduction
- AF continued to fund "Engineering Model" to qualify technologies



LITE Engineering Model

Laser Intersatellite Transmission Experiment

Early lasercom partnership between MITLL and GSFC

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

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The First Space Lasercom Successes: GeoLITE and ALEX (1997-2002)



GeoLITE
Lasercom Experiment
• Launch (18 May 2001)
• World's first successful demo of high-rate, space-based laser communications (12 June 2001)

Airborne Laser Experiment (ALEX) Demonstrations (2002)
• World's first successful demo of air-space duplex laser communications


GeoLITE

First space lasercom success

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Mars Laser Comm Demonstration (MLCD) 2003-2005

- Developed architecture and technologies for deep-space lasercom
 - Capacity-limited high-rate optical links
 - Inertial stabilization of telescope
 - Hybrid tracking approaches
 - Efficient fiber lasers and amplifiers
 - Distributed receive apertures
 - Arrays of photon counting detectors
- Approach later demonstrated by LLCD (2013) and future JPL Deep Space Optical Comm (DSOC, 2022)



Established a lasercom architecture for high-rate deep-space links that has been highly influential in subsequent development efforts

Mars Laser Comm Demonstration

Established architecture for deep space lasercom

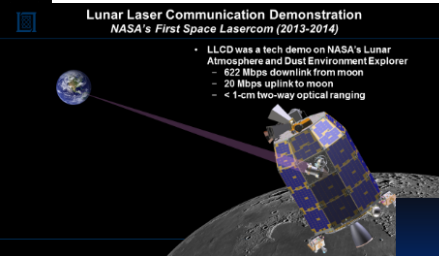
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Lunar Laser Comm Demonstration

NASA's first space lasercom success

Lunar Laser Communication Demonstration
NASA's First Space Lasercom (2013-2014)

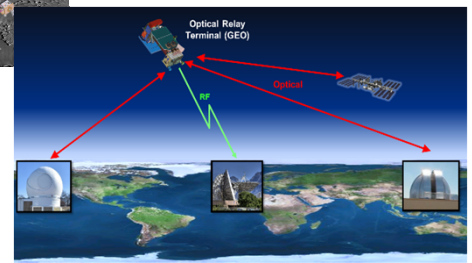
- LLCD was a tech demo on NASA's Lunar Atmosphere and Dust Environment Explorer
 - 622 Mbps downlink from moon
 - 20 Mbps uplink to moon
 - < 1-cm two-way optical ranging



Laser Comm Relay Demonstration

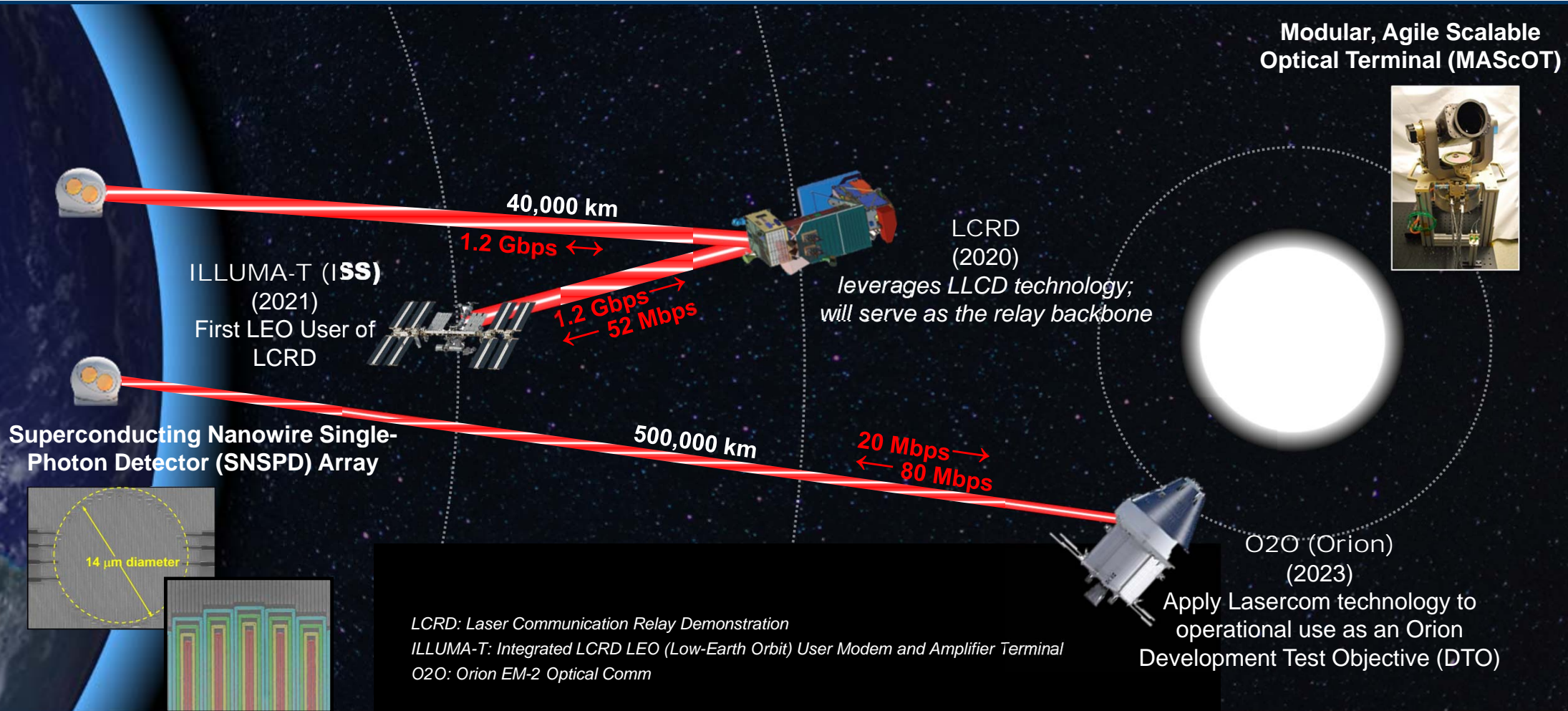
Optical relay pathfinder

Based on MITLL risk reduction hardware designs





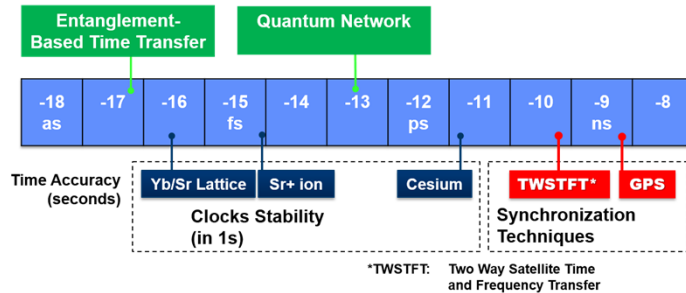
NASA's Near-Earth Lasercom Programs





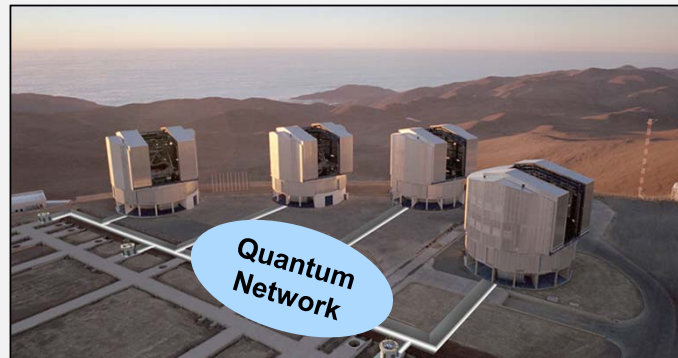
Entanglement-Based Quantum Communication Applications

Timing Application: Quantum Clocks and Synchronization



- Develop laser comb-based synchronization
- Demonstrate entanglement-based time-transfer protocols

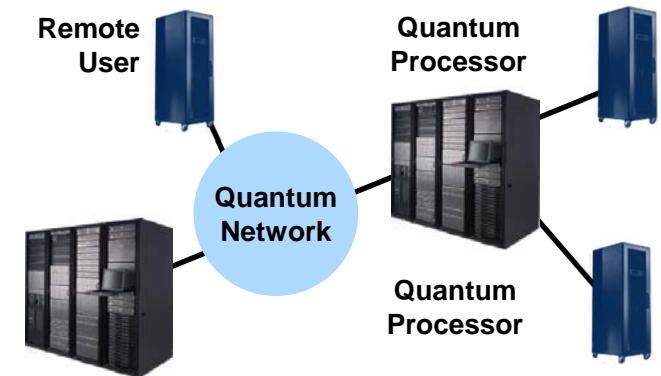
Sensing Application: Distributed Quantum Sensing



ESO Very Large Telescope Interferometer

- Enable increased baseline for enhanced resolution sensing

Computing Application: Networked Quantum Processors



- Increase computing power
- Enable enhanced scaling architectures

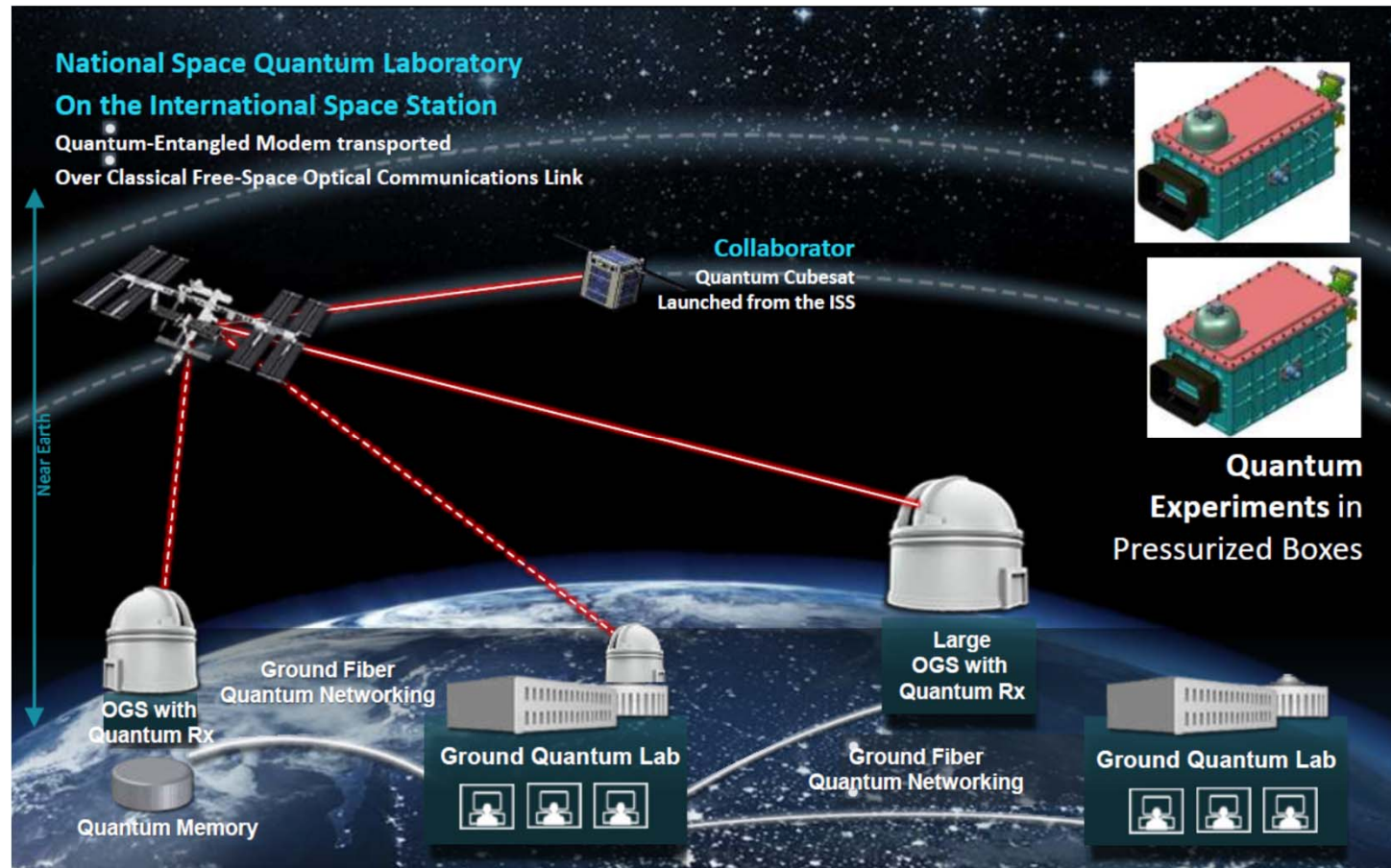
These applications rely upon interacting remote quantum systems using distributed entanglement



National Space Quantum Laboratory (NSQL)

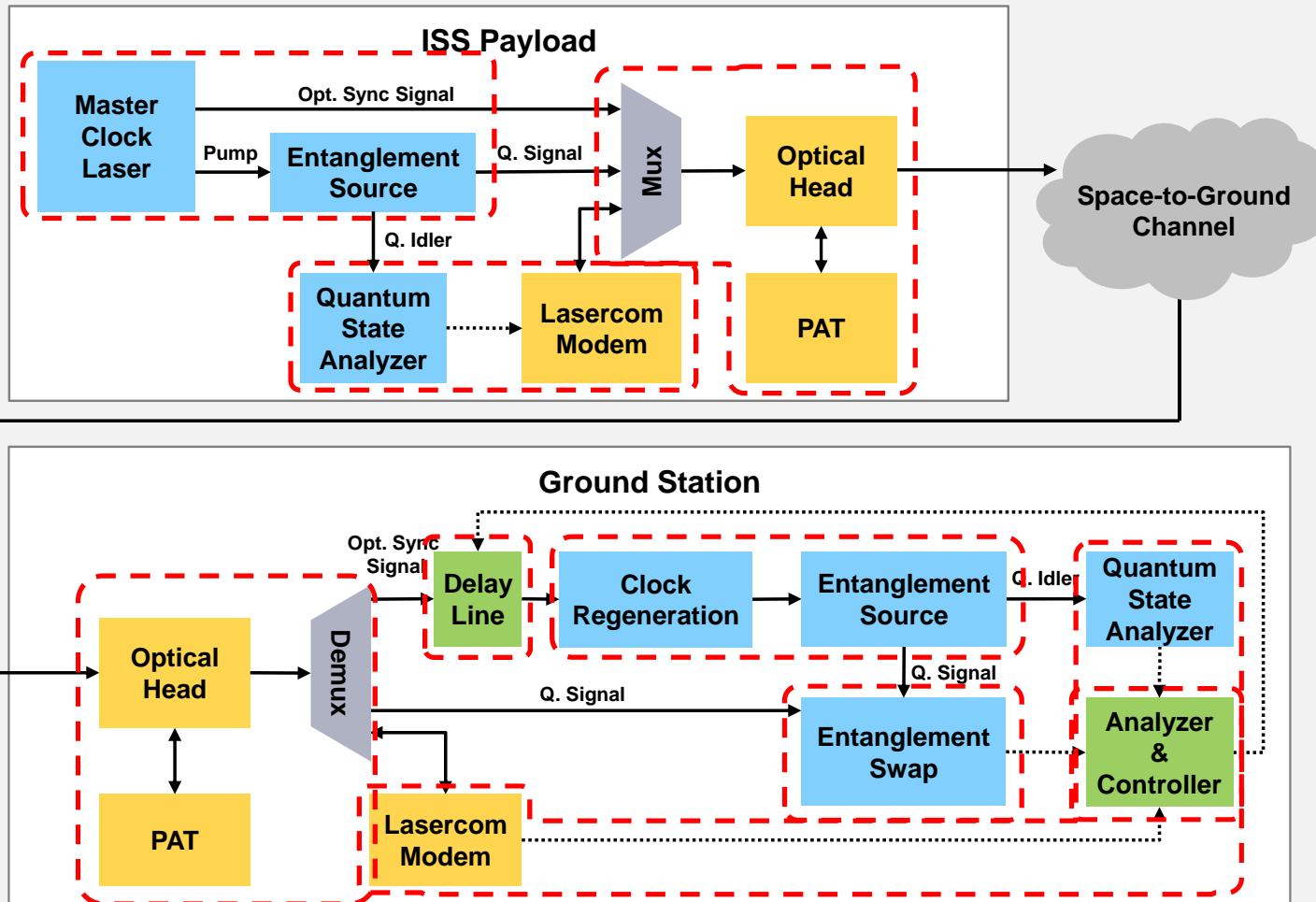


- **Integrated space and ground quantum network**
 - Quantum downlinks, uplinks and crosslinks
 - NASA's International Space Station (ISS) will provide flexible access to space
 - A free-flyer option can be utilized to complement the ISS
- **High-rate entanglement distribution for quantum-enabled sensing and timing applications**
- **Supports incorporation of future technology**
 - Supports hybrid space/terrestrial quantum network architectures
 - Complementary to fiber-based quantum network effort





Single-Span Entanglement Swap System Architecture



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

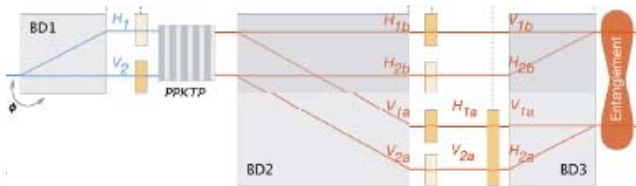
Master Clock Laser and Entanglement Source



Pump Source

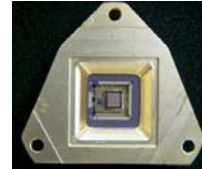
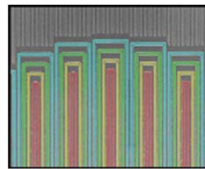


Nonlinear Crystal



Entanglement Generation

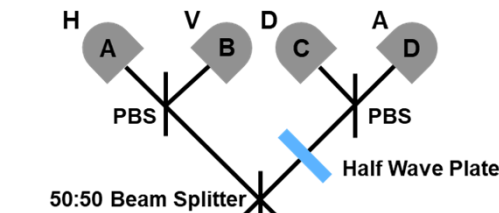
Quantum State Analyzer



Photon-Counting Detectors

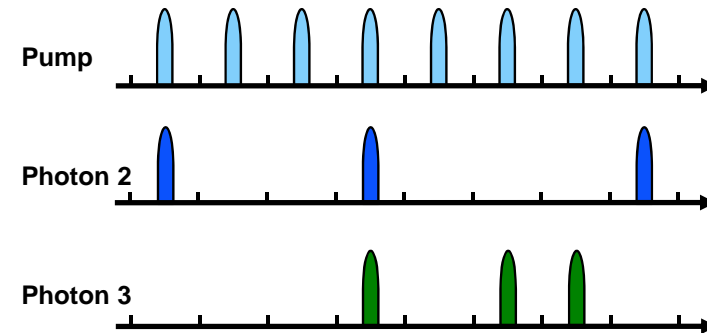


Space Cryocoolers

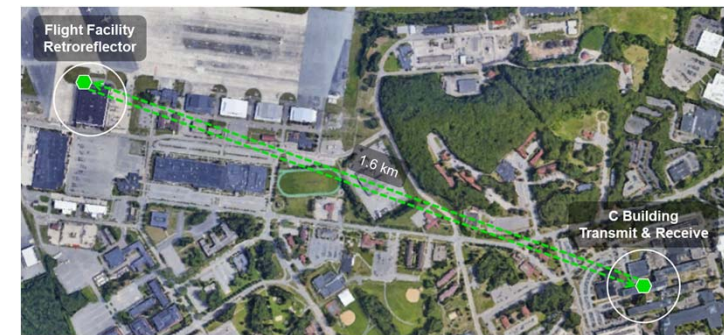


Entanglement Analyzer

Synchronization

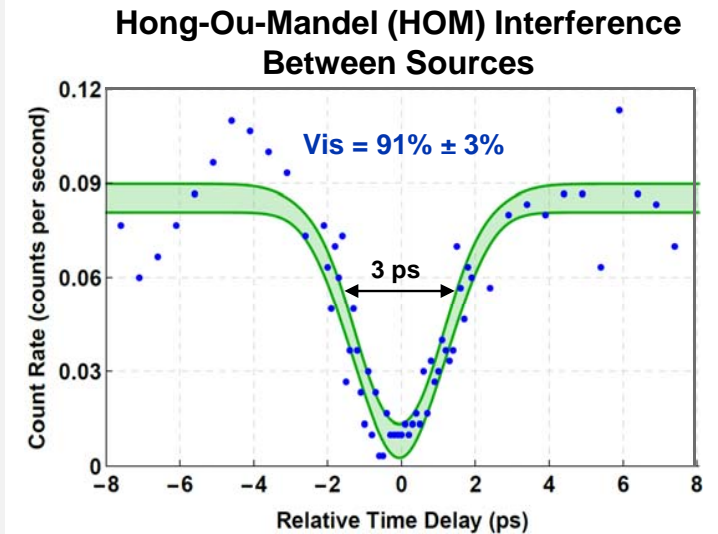
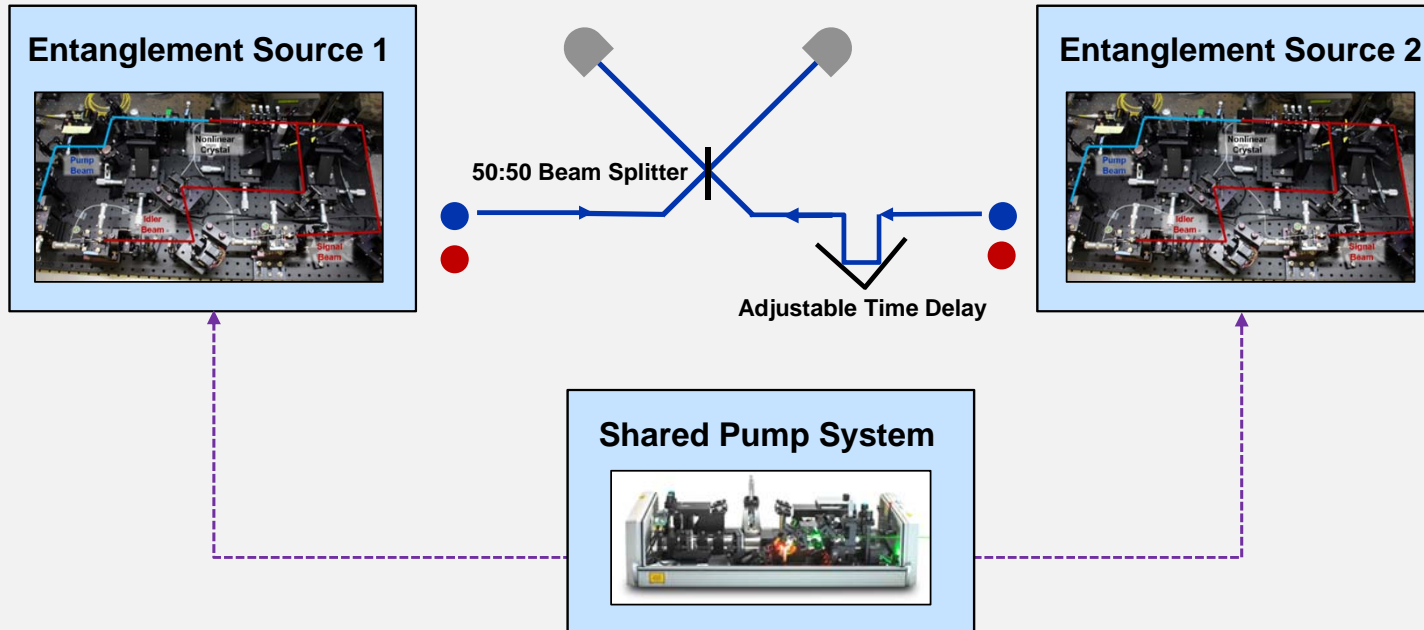


Free-Space Link





Two-Photon Interference Between Sources

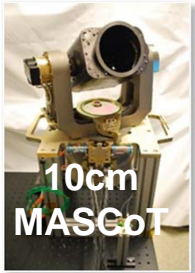


Laboratory demonstration of high-visibility two-photon interference, which is needed for high-fidelity entanglement swapping



QTS Quantum Downlink Terminal Trades

ISS Terminal



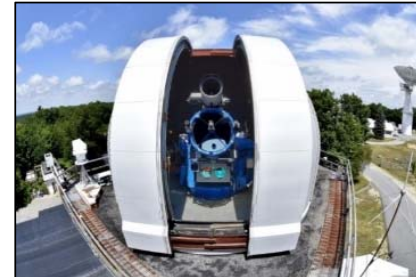
MIT-LL GS2



JPL OCTL



MIT-LL Firepond



AFRL AEOS



ISS Terminal	Ground Station			
	GS2 (0.6m)	OCTL (1m)	Firepond (1.2m)	AFRL AEOS (3.7m)
10 cm	-38 dB	-33.5 dB	-32 dB	-22.5 dB
30 cm	-28.5 dB	-24 dB	-22.5 dB	-13 dB

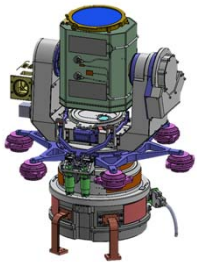
Link Assumption	
Range	1000 km (~ISS at 30° el.)
Atmosphere	-2.7 dB
Turbulence	-5.2 dB
Tx & Rx optics	-4.4 dB each

Entanglement distribution at 20 kHz – 1.5 MHz,
swaps at 300 Hz – 25 kHz

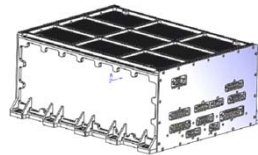


Quantum Terminal Subsystems and Payload

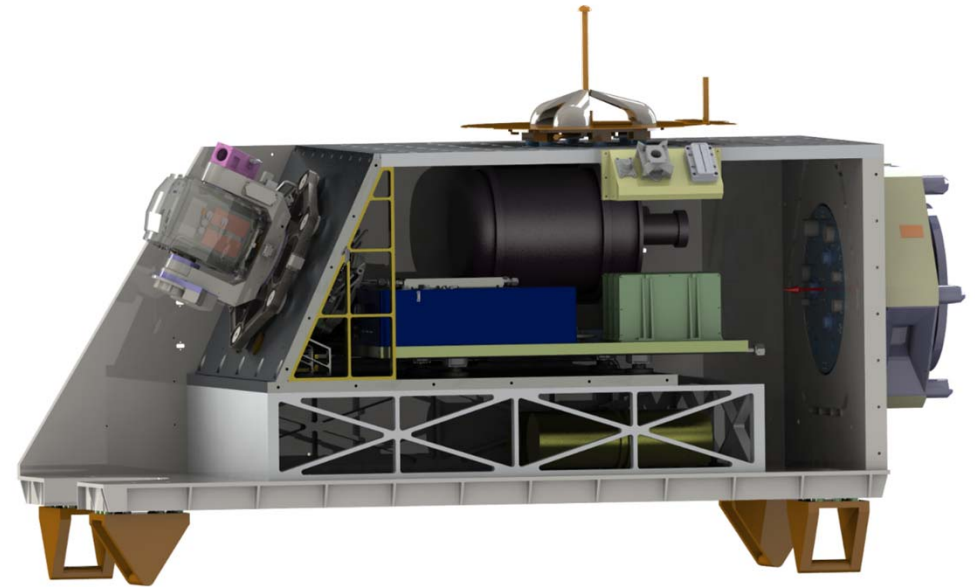
MAScOT Optical Module



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

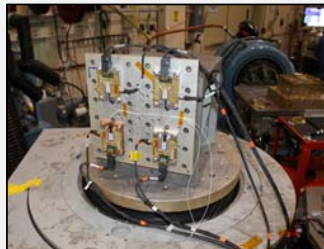
Thermal-Vacuum

- 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



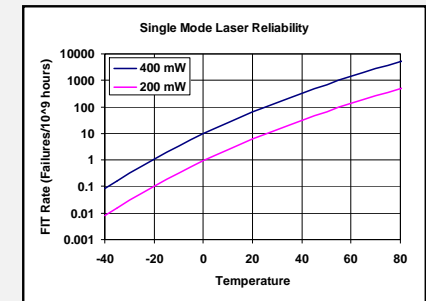
Radiation

- 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



Summary

- **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**