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

1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020

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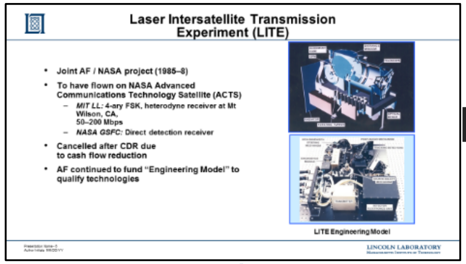

Laser Intersatellite Transmission Experiment

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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GeoLITE

First space lasercom success

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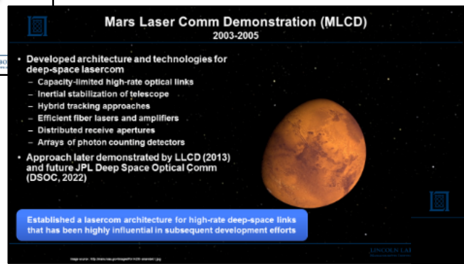

Mars Laser Comm Demonstration

Established architecture for deep space lasercom

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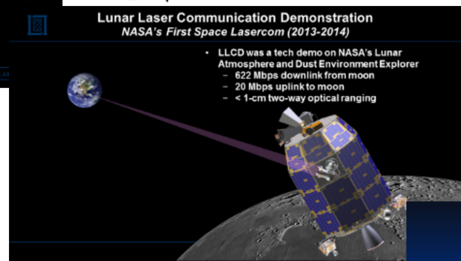

Lunar Laser Comm Demonstration

NASA's first space lasercom success

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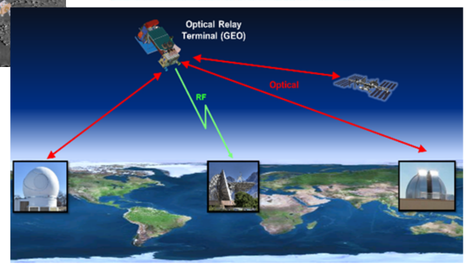
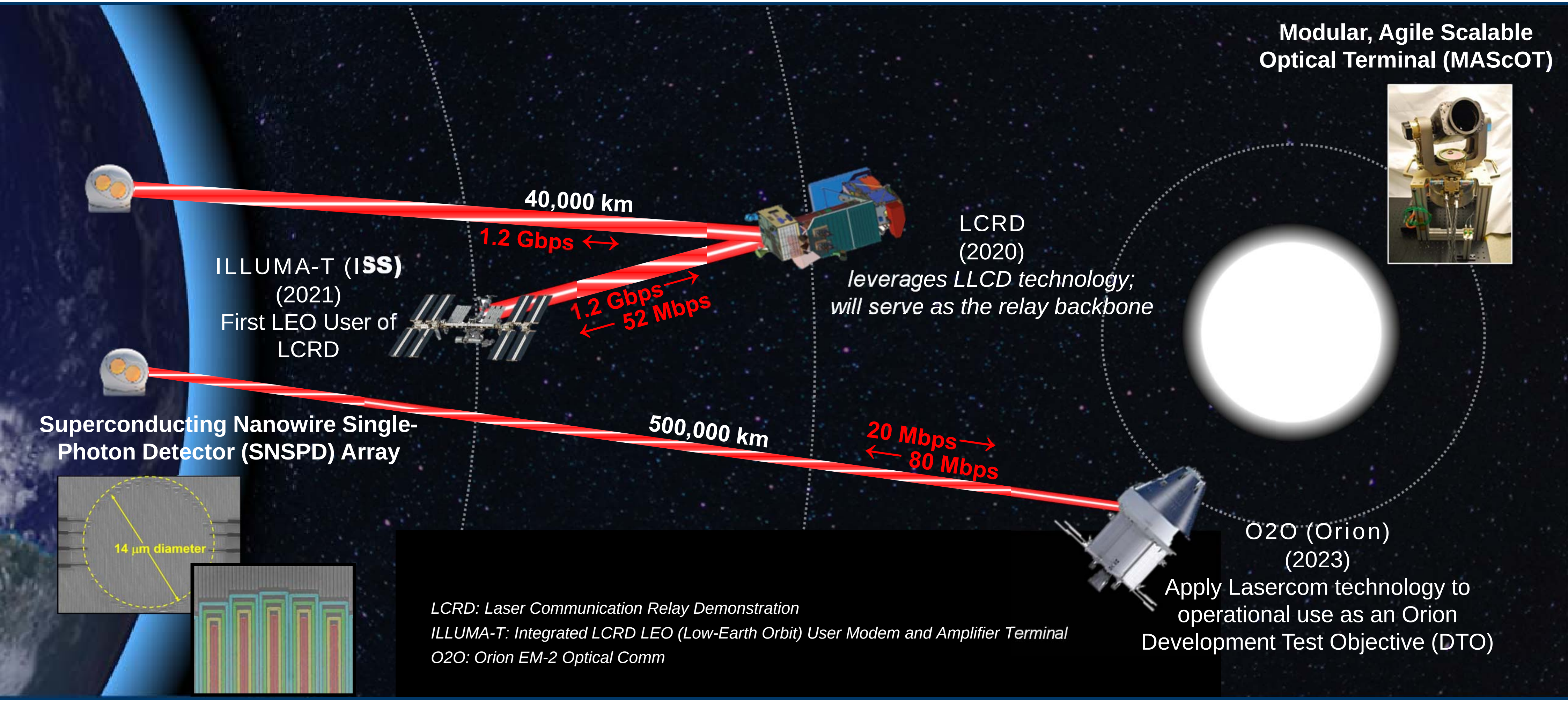


Laser Comm Relay Demonstration

Optical relay pathfinder

Based on MITLL risk reduction hardware designs

NASA's Near-Earth Lasercom Programs



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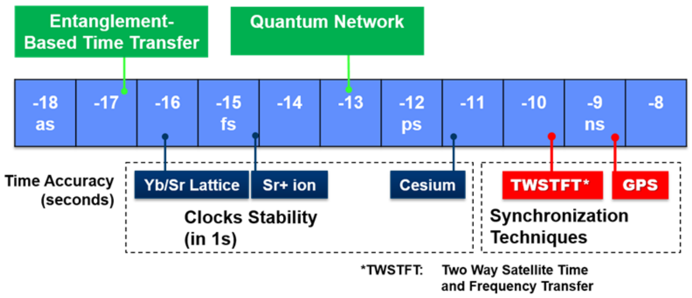
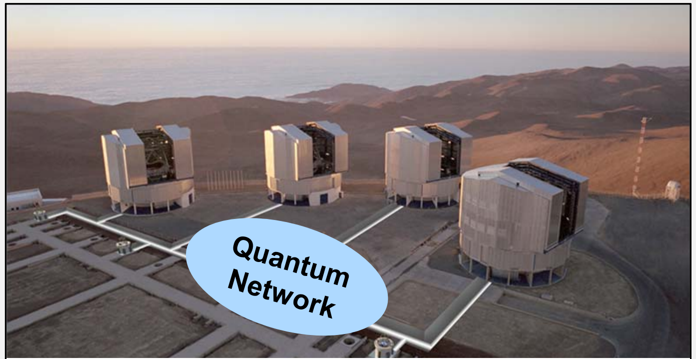
Entanglement-Based Quantum Communication Applications

Timing Application: Quantum Clocks and Synchronization



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

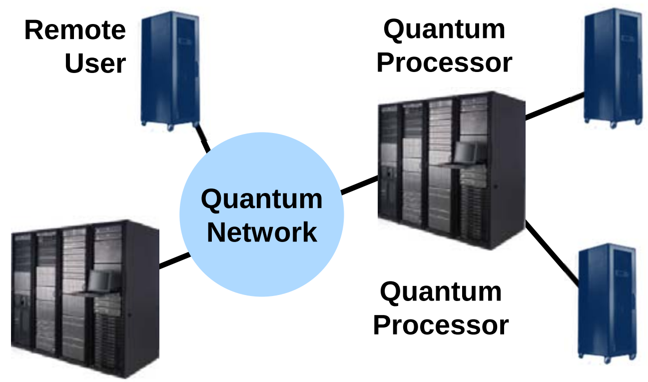
Sensing Application: Distributed Quantum Sensing



ESO Very Large Telescope Interferometer

- Enable increased baseline for enhanced resolution sensing

Computing Application: Networked Quantum Processors

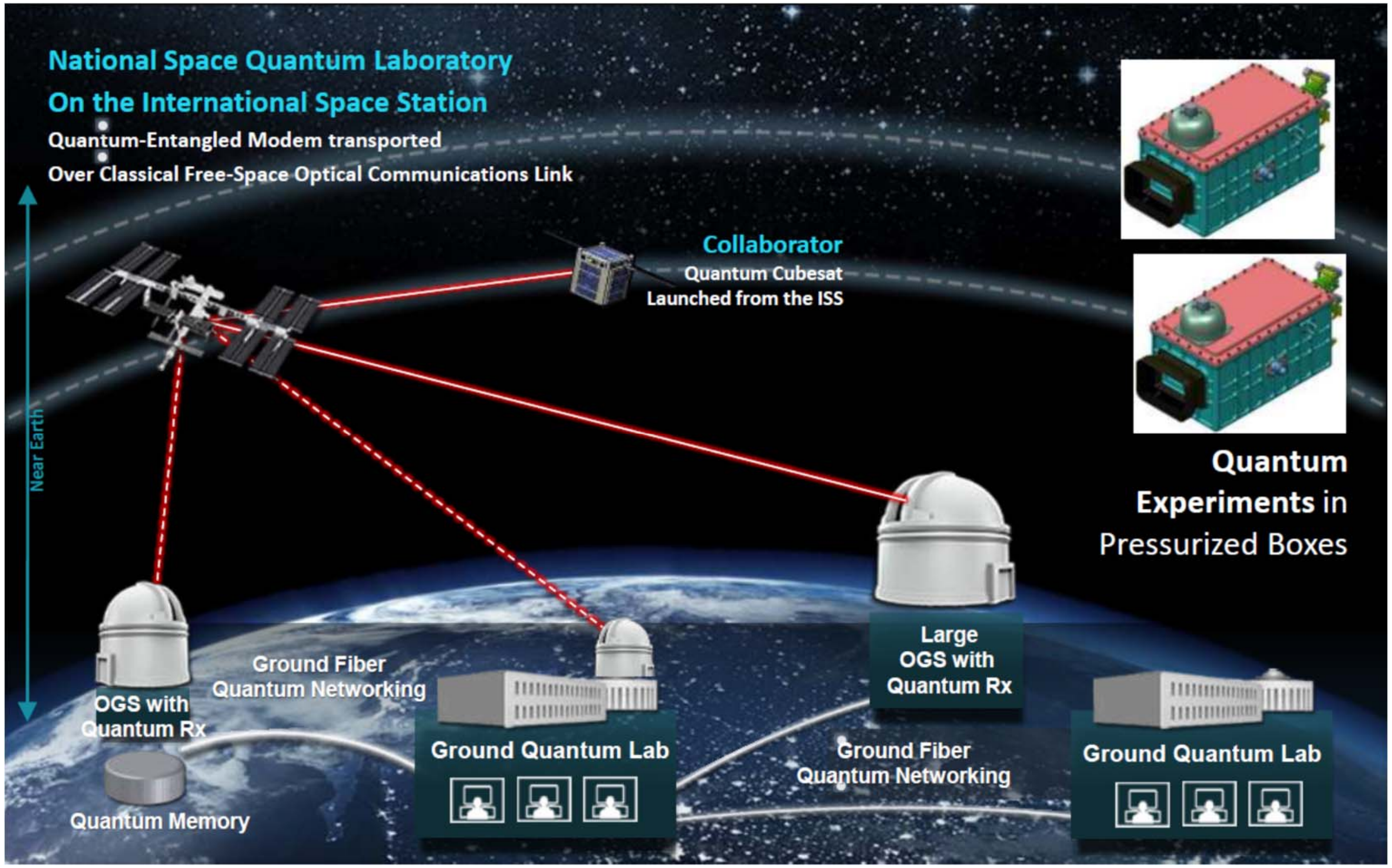


- Increase computing power
- Enable enhanced scaling architectures

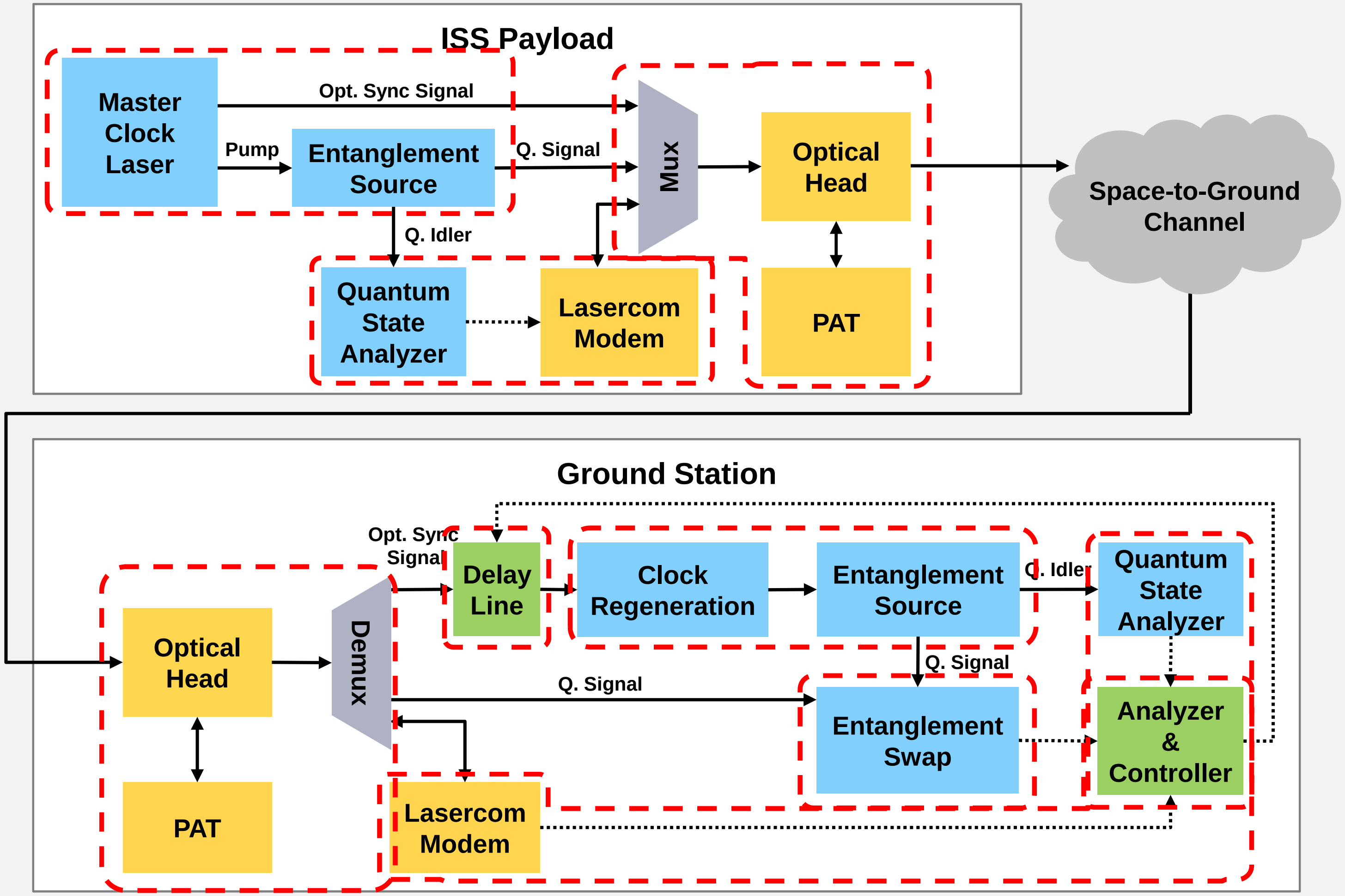
These applications rely upon interacting remote quantum systems using distributed entanglement

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

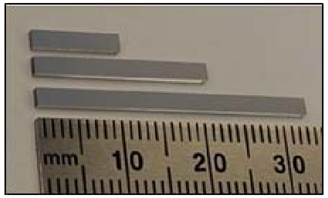


1. **Generate entangled pair of photons in the ISS payload**
2. **Track ground station and mux signals onto downlink**
3. **Track and demux optical signals**
4. **Generate a new signal / idler pair on the ground**
5. **Perform an entanglement swap**
6. **Path length stabilize receiver**
7. **Analyze idler photons, communicate measurement results, and verify swap**

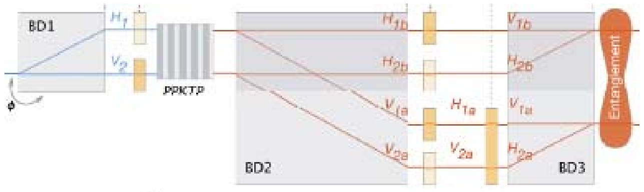
Quantum Modem Technology Development

Master Clock Laser and Entanglement Source

Pump Source

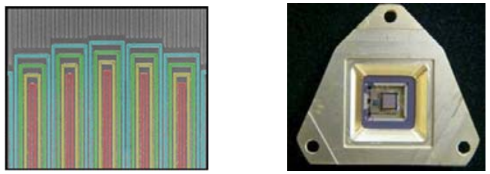


Nonlinear Crystal

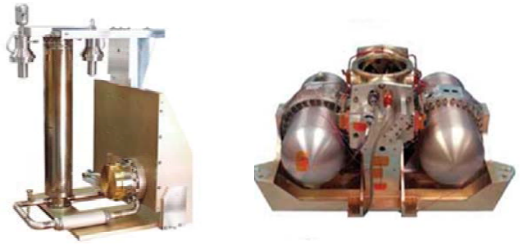


Entanglement Generation

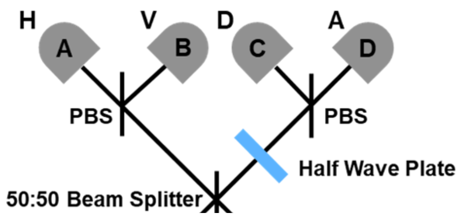
Quantum State Analyzer



Photon-Counting Detectors

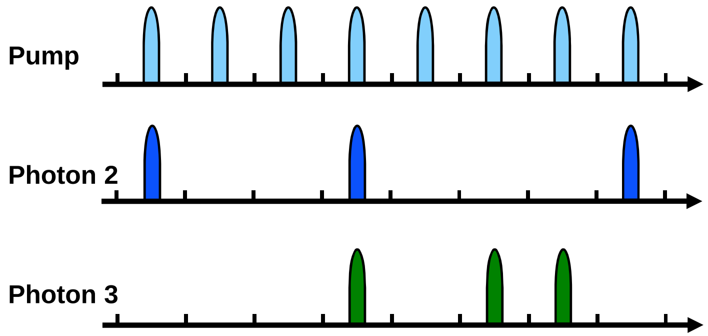


Space Cryocoolers



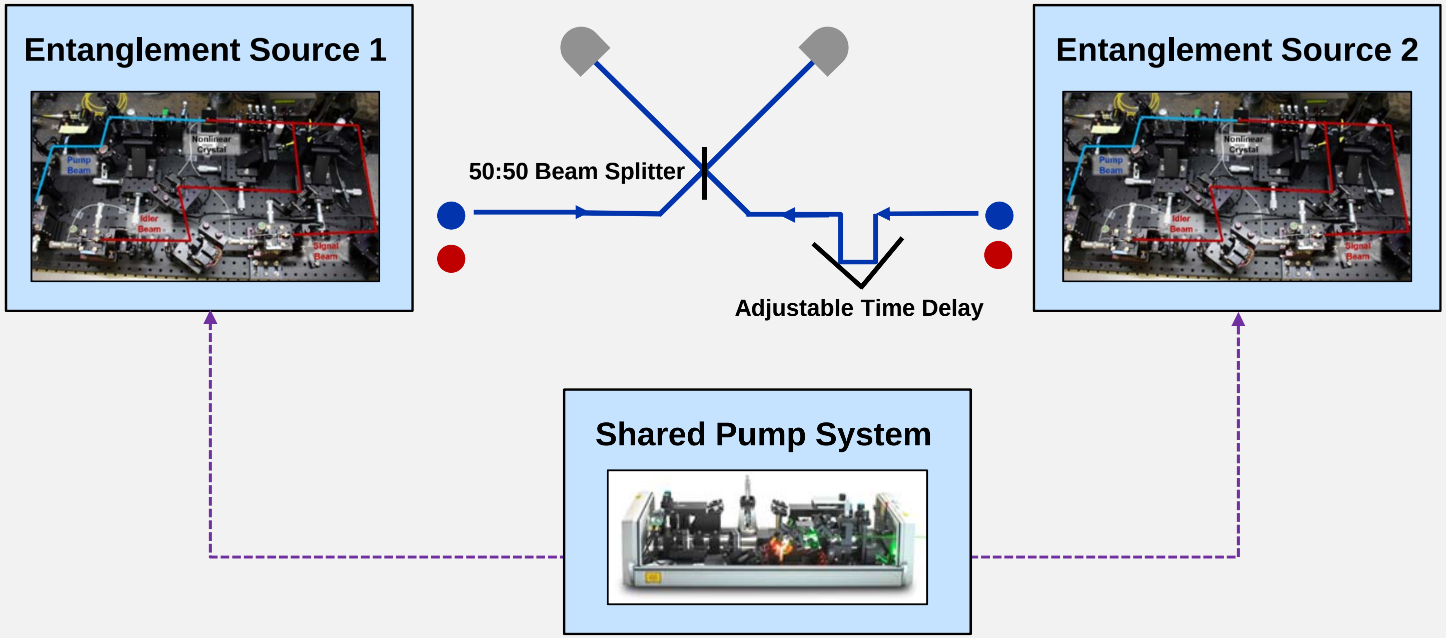
Entanglement Analyzer

Synchronization

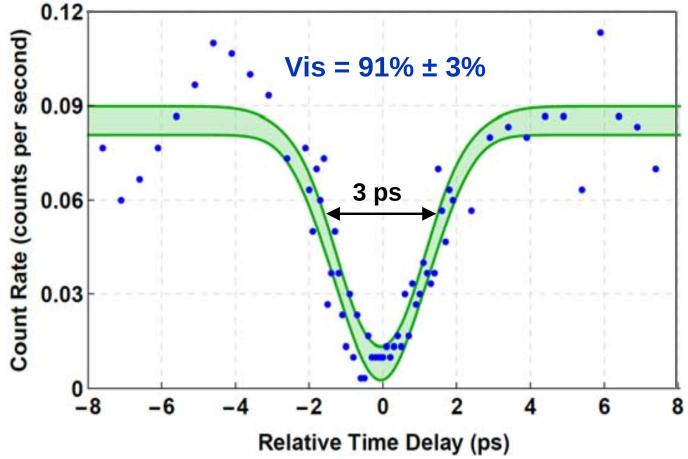


Free-Space Link

Two-Photon Interference Between Sources

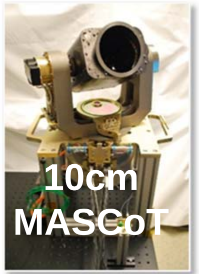
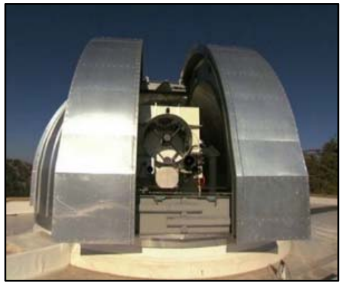
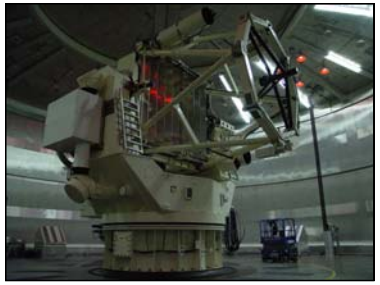


Hong-Ou-Mandel (HOM) Interference Between Sources



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 30º 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

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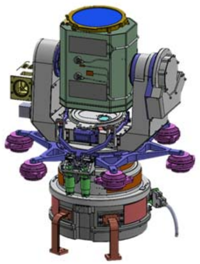
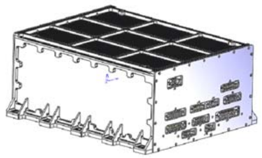
Quantum Terminal Subsystems and Payload

MAScOT Optical Module

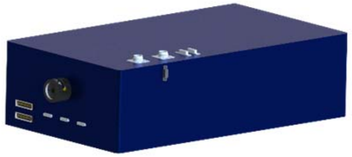


Controller Electronics

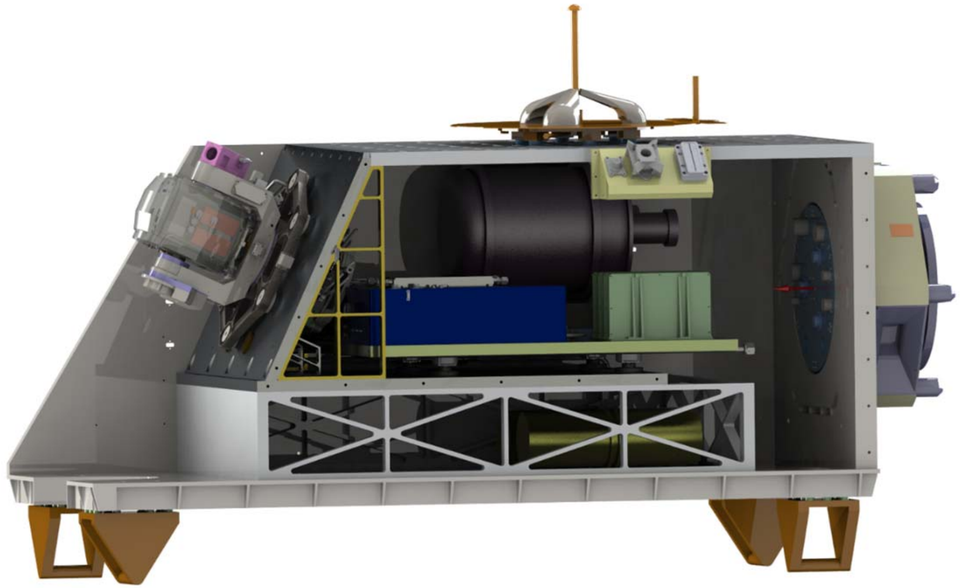


Power Conversion Unit

Quantum Modem



ISS Flight Payload



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

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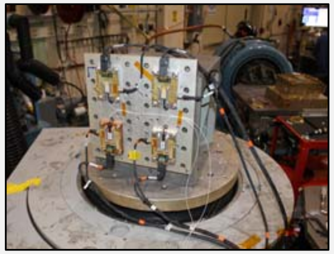
Quantum Modem Space Qualification

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

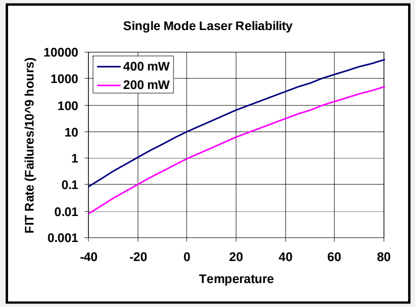


Radiation

- 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

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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