LLCD Lunar Laser Communication Demonstration

Overview of the Lunar Laser Communications Demonstration

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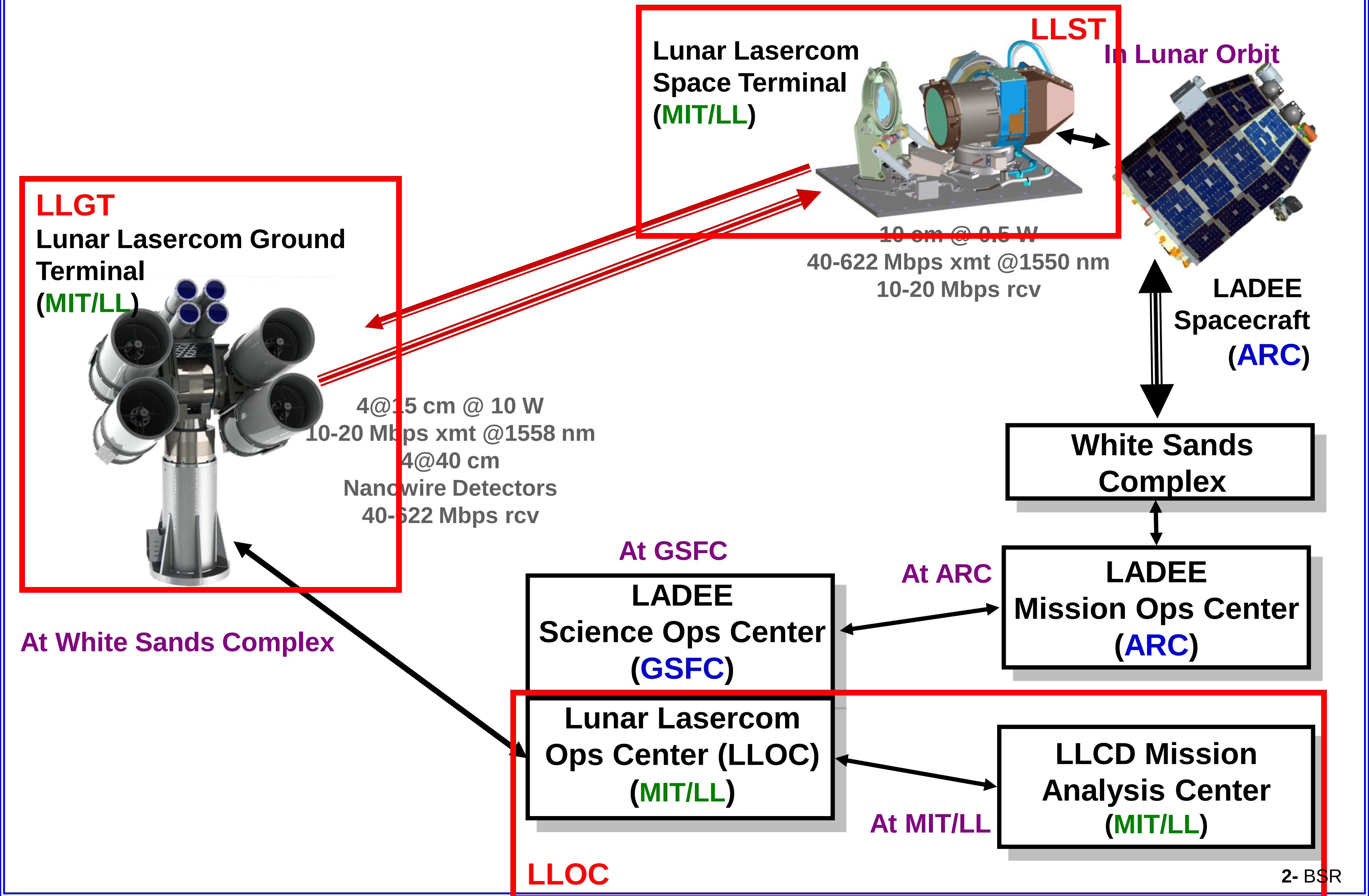
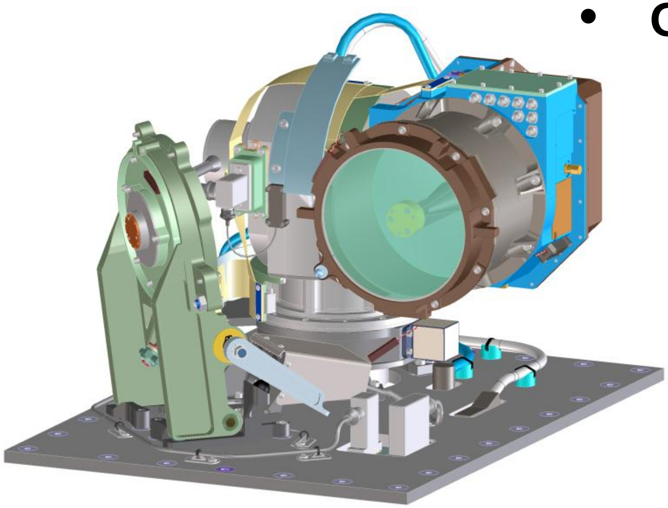
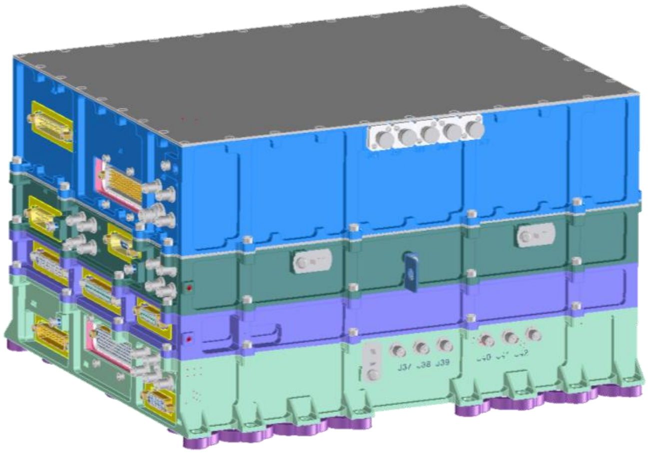
Lunar Laser Communication Demo System



LLST Overview

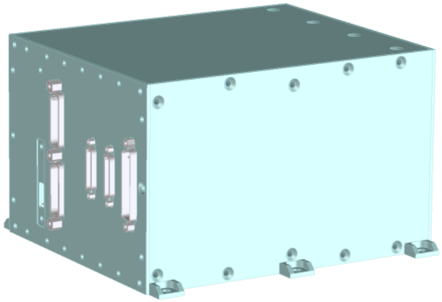


- **Optical Module (OM)**
  - **Inertially-stabilized**
  - **2-axis gimbal**
  - **Fiber coupled to modem transmit and receive**

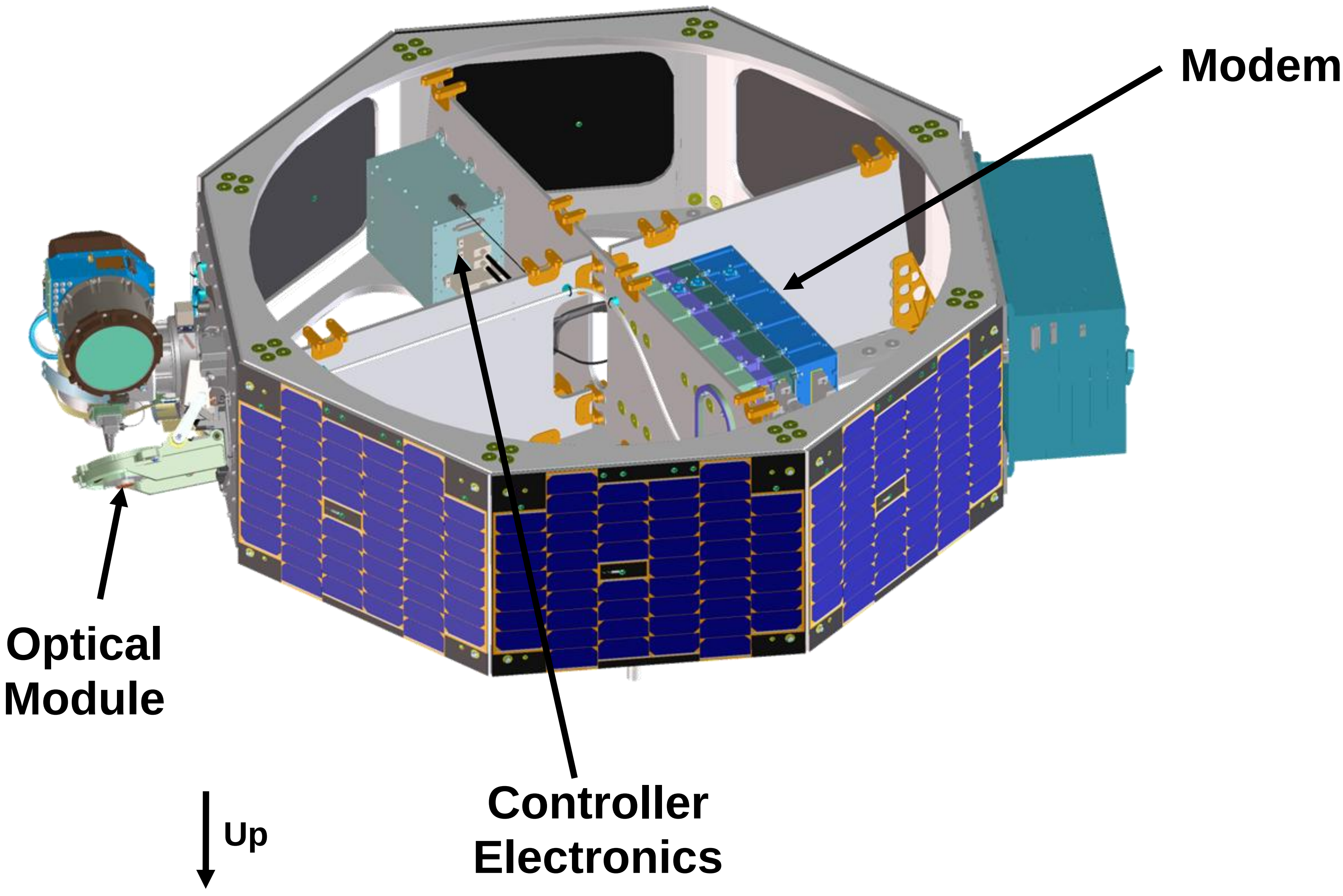


- **Modem Module (MM)**
  - **EDFA transmitter**
  - **Optically-preamplified receiver**
  - **CODECs and data interfaces**
  - **Data interface to spacecraft**

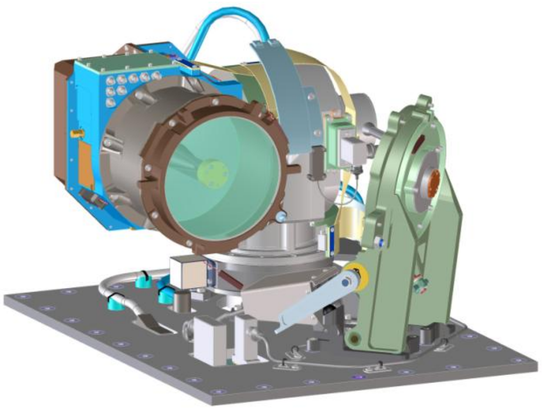
- **Controller Electronics (CE)**
  - **OM, MM control**
  - **CMD/TLM interface to S/C**

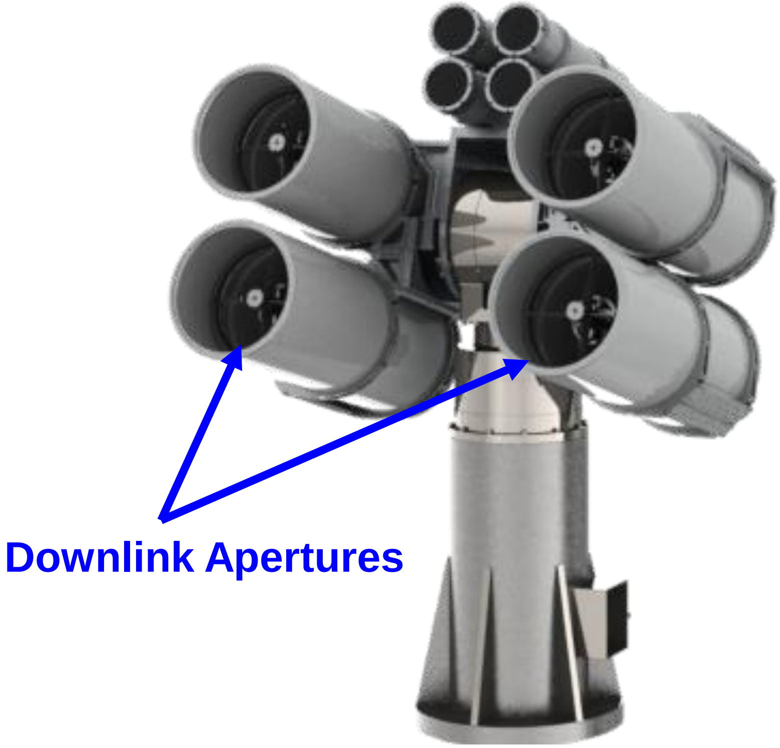


LLST on LADEE



LLCD Downlink Overview





* FIGURES NOT TO SCALE!

Space Terminal Transmitter

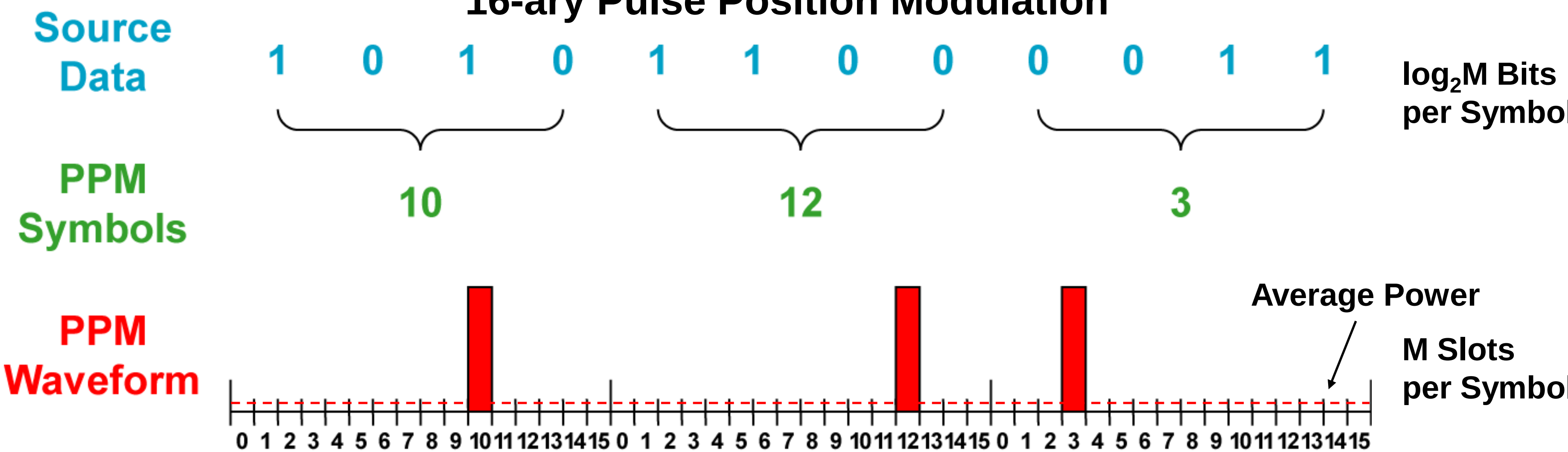
- 10-cm transmit aperture
- Fiber coupled to 0.5-W 1550-nm Master Oscillator Power Amplifier (MOPA) transmitter
- Data rates from 40-620 Mbit/s

Ground Terminal Receiver

- 4 x 40-cm collection aperture
- Each telescope fiber-coupled to photon-counting detector array

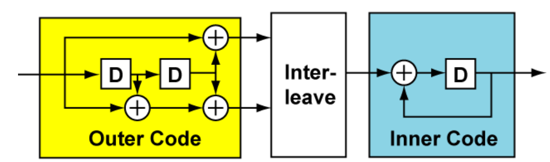
LLCD Downlink Signaling
Modulation and Coding

16-ary Pulse Position Modulation

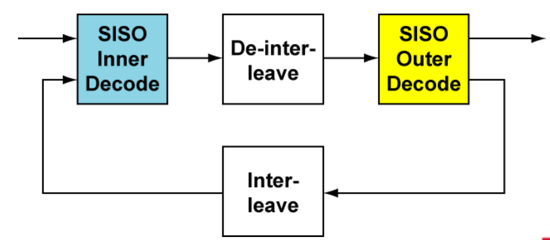


- **Pulse position modulation**
  - Orthogonal, power efficient
  - Well-suited for MOPA transmitter architecture
  - Well-suited to photon-counting detectors
    - Limited count rate (reset time)
    - High timing resolution
- **Data rate varied by changing slot frequency**
  - 311 MHz – 5 GHz
- **½-rate serially concatenated turbo code**
  - Simple encoder
  - Iterative decoder
  - Operates within 1 dB of theoretical channel capacity

Turbo Encoder



Turbo Decoder

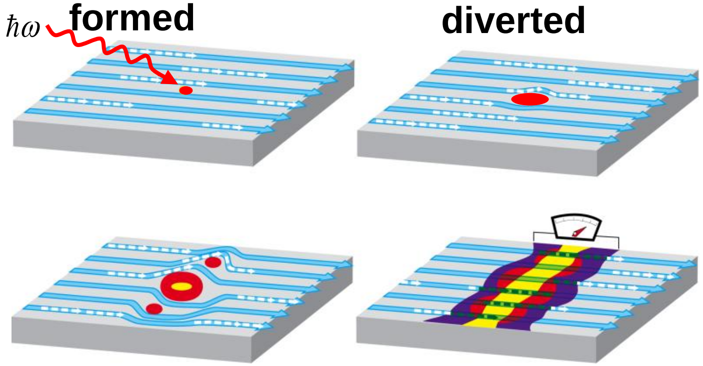


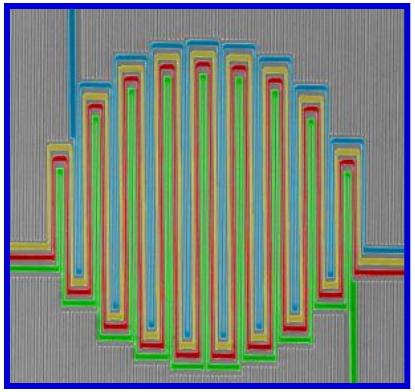
Serially Concatenated PPM Turbo Code

LLCD Superconducting Nanowire Detector Arrays (SNDA)

Principle of operation

Nanowire superconducting at T < 2 K

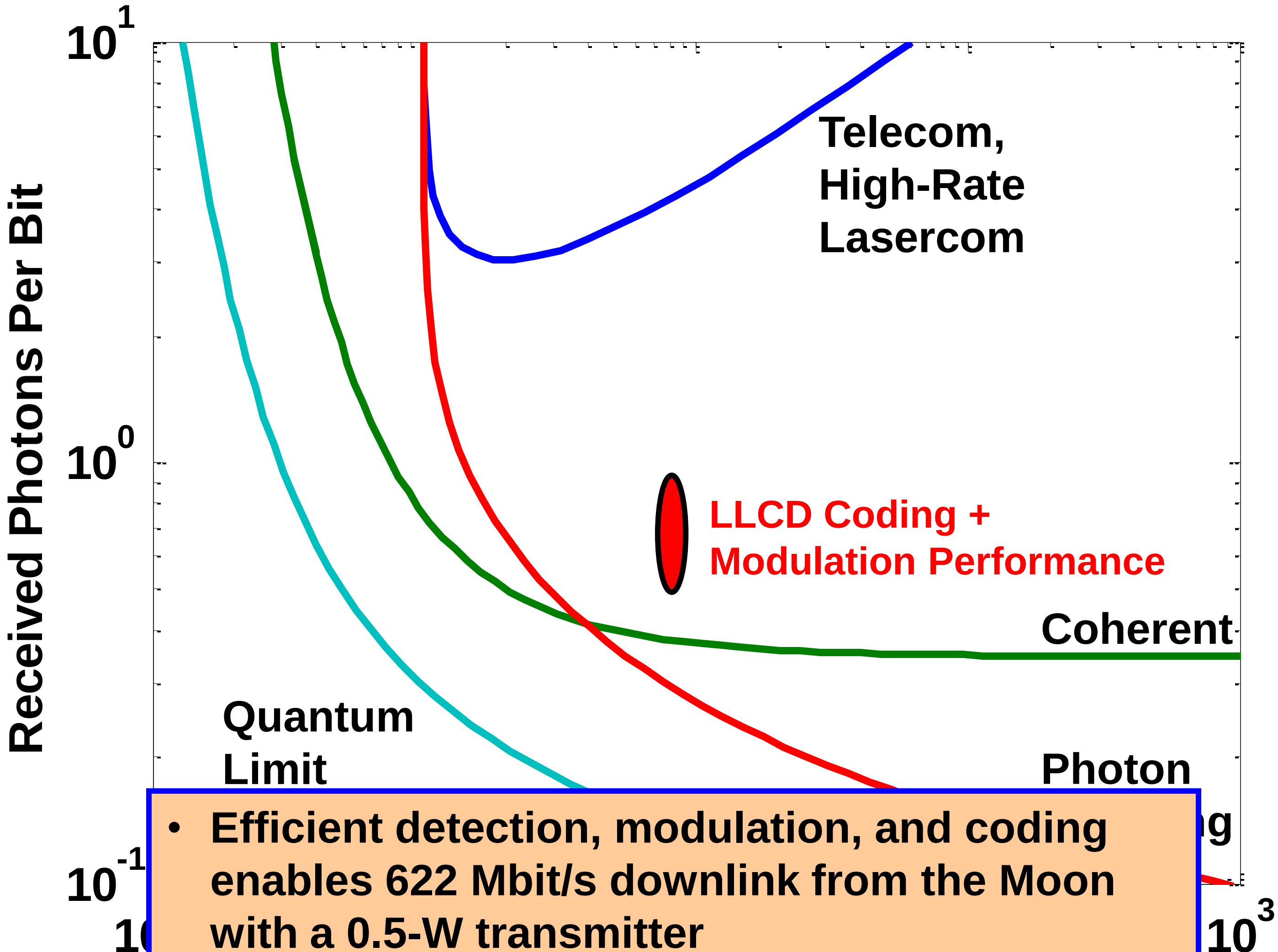




4-element LLCD SNDA

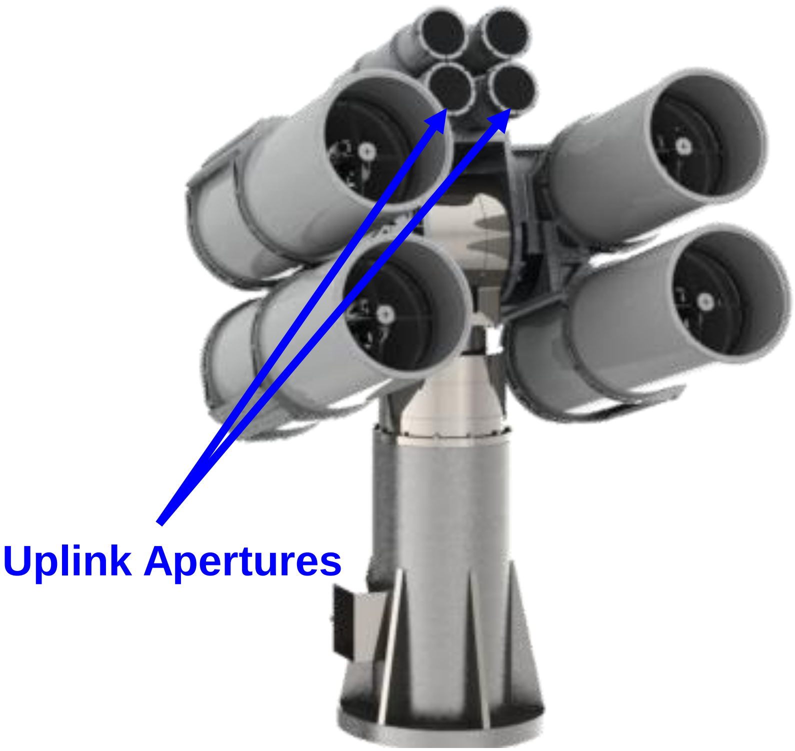
- **Superconducting nanowire detects individual photons**
  - **>60% detection efficiency**
  - **<15-ns reset time**
  - **<50-kHz dark count rate**
- **Detectors coupled to telescopes using custom multi-mode polarization maintaining fiber**
- **Detector array used to achieve large detection area and high count rates**
  - **4 detectors per telescope**
  - **4 telescopes**

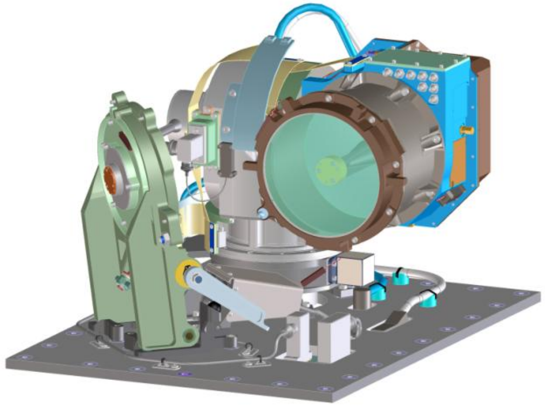
LLCD Downlink Power Efficiency



- Efficient detection, modulation, and coding enables 622 Mbit/s downlink from the Moon with a 0.5-W transmitter
- LLCD transmitter is 4000x more energy efficient (per bit) than LADEE RF transceiver

LLCD Uplink Overview





* FIGURES NOT TO SCALE!

Ground Terminal Transmitter

- **4 x 15-cm transmit aperture**
- **10-W per transmit aperture (40 W, total)**
- **Data rates from 10-20 Mbit/s**

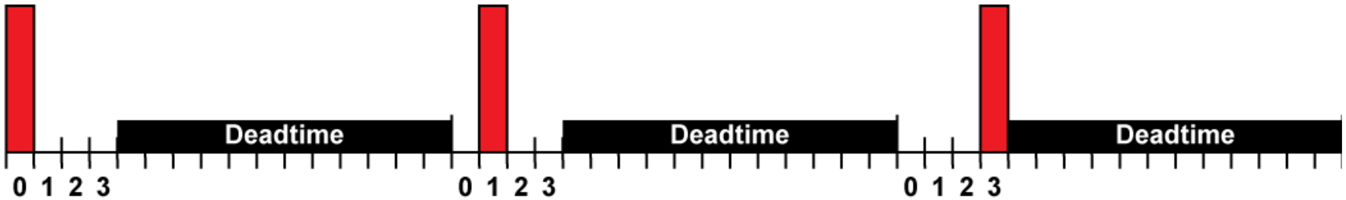
Space Terminal Receiver

- **10-cm receive aperture**
- **Non-coherent combining of uplink signals**
- **Fiber coupled to optically-preamplified direct detection receiver**

LLCD Uplink Signaling

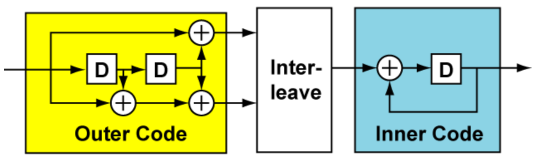
Modulation, Coding, Detection

PPM Waveform

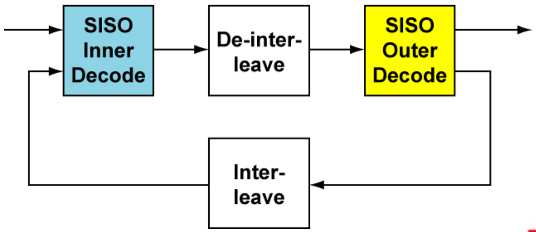


- **4-ary pulse position modulation with dead time**
  - **311-MHz slot rate**
  - **Deadtime provides better match with narrow-band optical filter**
  - **Data rate varied by changing dead time (10 or 20 Mbit/s)**
- **Pre-amplified direct-detection receiver**
- **Near-optimal hard-decision 4-PPM decoder**
- **½-rate serially concatenated turbo code**
  - **< 1 dB from theoretical channel capacity**

Turbo Encoder



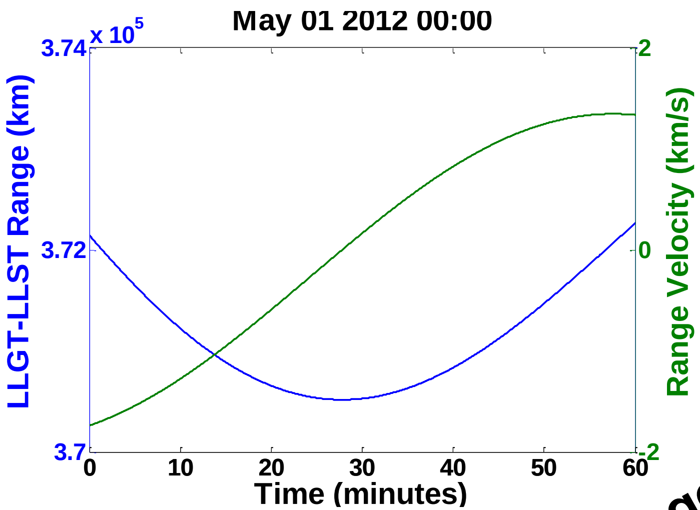
Turbo Decoder

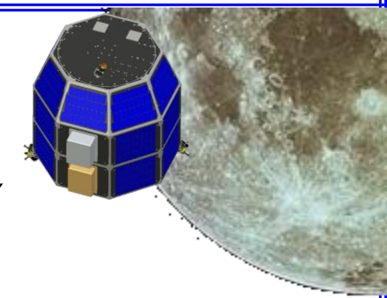


JPL

Serially Concatenated PPM Turbo Code

LLGT-LLST Ranging



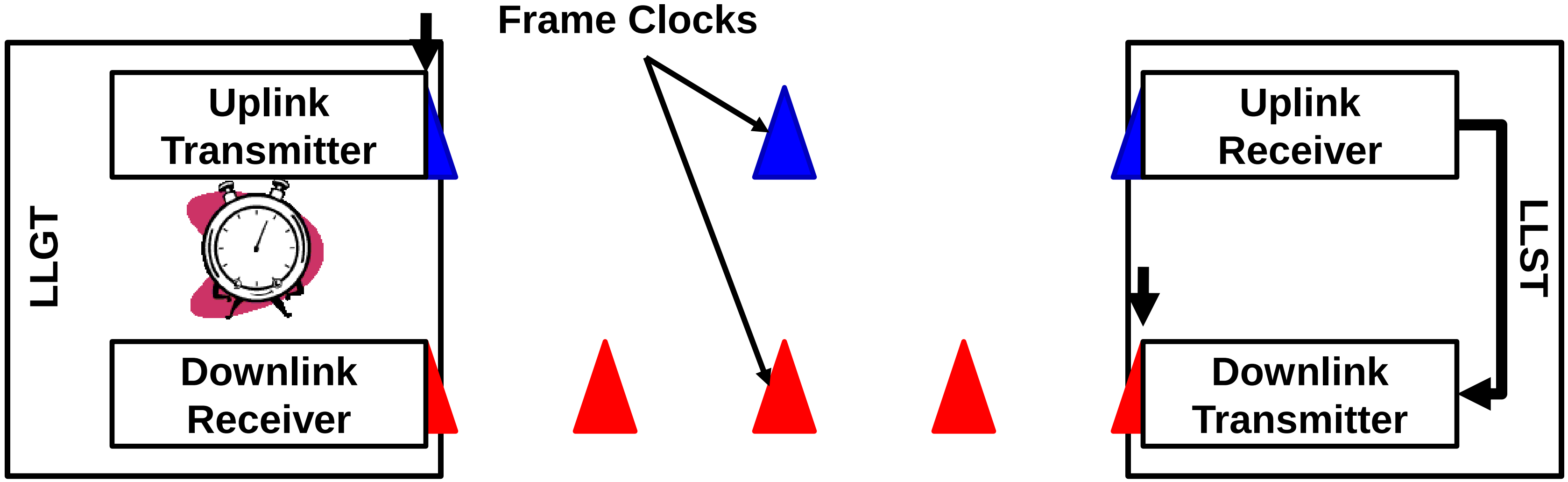


Range = 350,000 – 400,000 km

- **Ranging is critical for space navigation**
- **Fast optical clocks on uplink and downlink comm signals potentially enable high-resolution ranging**
  - **5-GHz downlink clock → <1-cm range resolution**
- **To demonstrate this potential, LLCD will measure two-way time-of-flight to sub-slot precision**

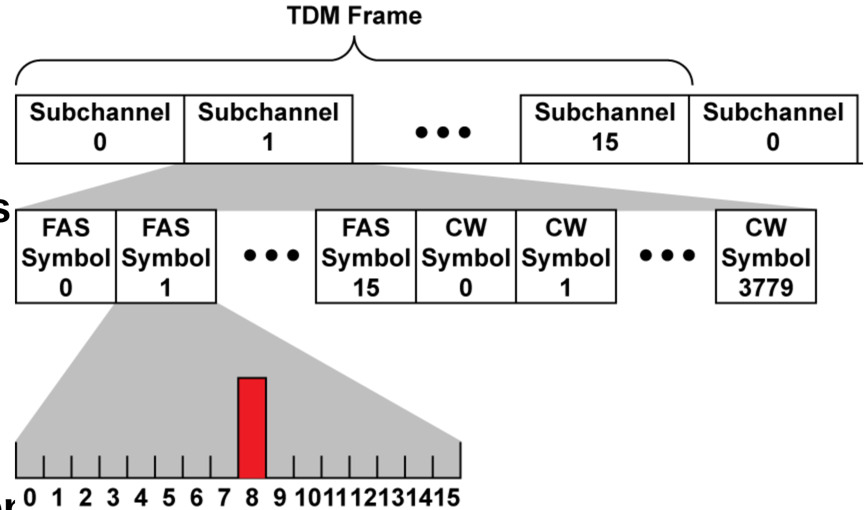
Two-Way Time-of-Flight Measurements

- **Duplex communications systems may be easily augmented to perform two-way time-of-flight measurements**
- **Additional requirements include**
  - **Common time reference on forward and return links**
    - **LLCD uplink frame duration = 32 x downlink frame duration**
  - **Phase-locked clocks in one of the terminals**
    - **Uplink phase-locked to downlink in LLST**
  - **High-stability time reference for measuring two-way time-of-flight**



LLCD Clocks for Two-Way Time-of-Flight Measurements

- **Numerous clocks embedded in uplink and downlink optical signals**
- **Successful optical communications requires precise synchronization of clocks**
  - **Slot**
  - **Symbol**
  - **Codeword**
  - **Frame**
- **High frequency clocks provide high-resolution common time reference between transmitter and receiver**
- **Low frequency frame clocks provide unambiguous measurements of long time scales**
  - **Downlink frame gives 58.5-km ambiguity**
  - **Can be improved to 1873-km ambiguity by observing loopback frame sequence**
  - **Could be further improved by inserting information in loopback data stream**
- **High-stability GPS-disciplined clock at LLGT used to generate uplink clocks and compare with received downlink clocks**

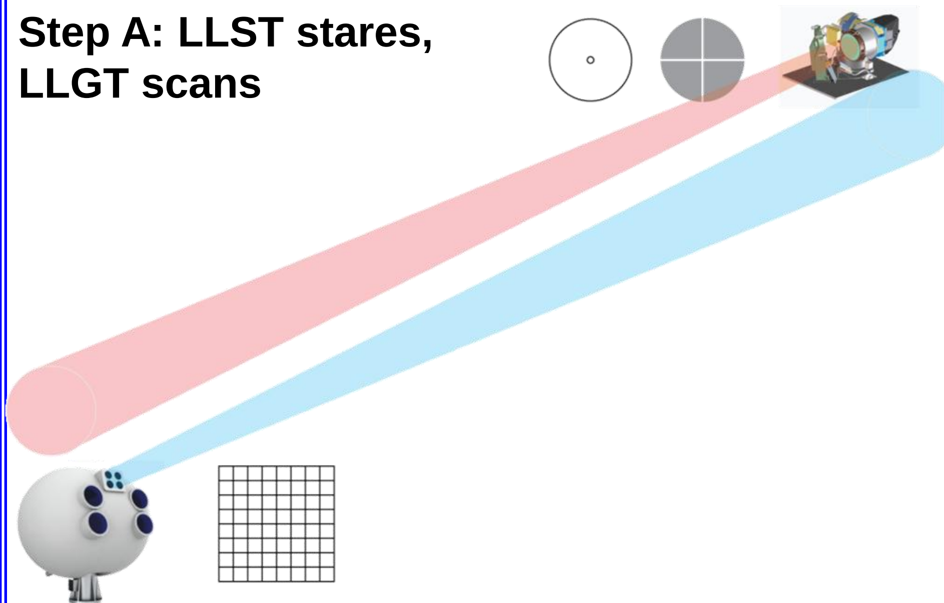


	Duration	Distance
Uplink		
Slot	3.2 ns	96 cm
Symbol	51.4 ns	15.4 m
Codeword	390 us	117 km
TDM Frame	6.25 ms	1873 km
Downlink		
Slot	200 ps	6 cm
Symbol	3.2 ns	96 cm
Codeword	12.2 us	3.7 km
		58.5 km

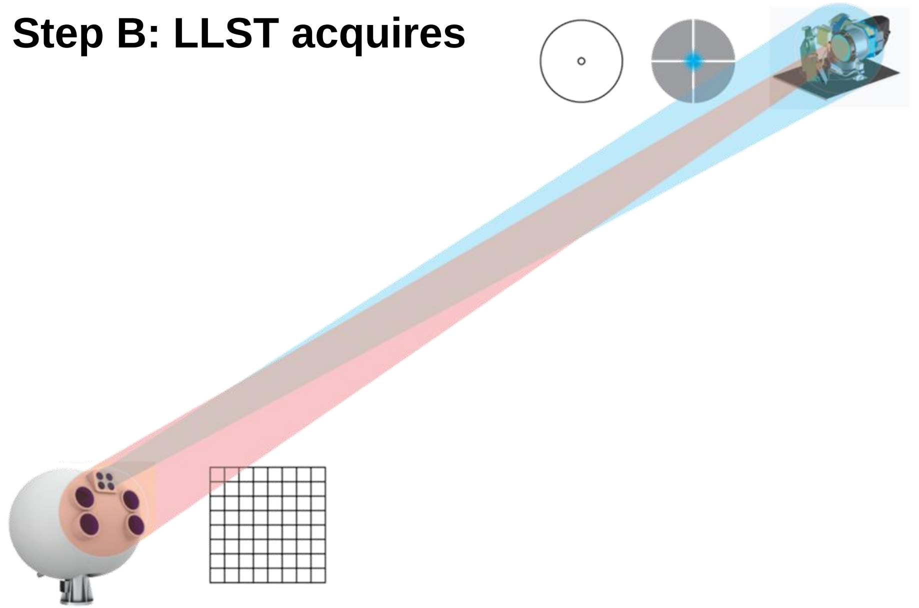
Combination of high-bandwidth modulation and low-frequency frame clocks enables unambiguous sub-cm ranging.

Acquisition Sequence Summary

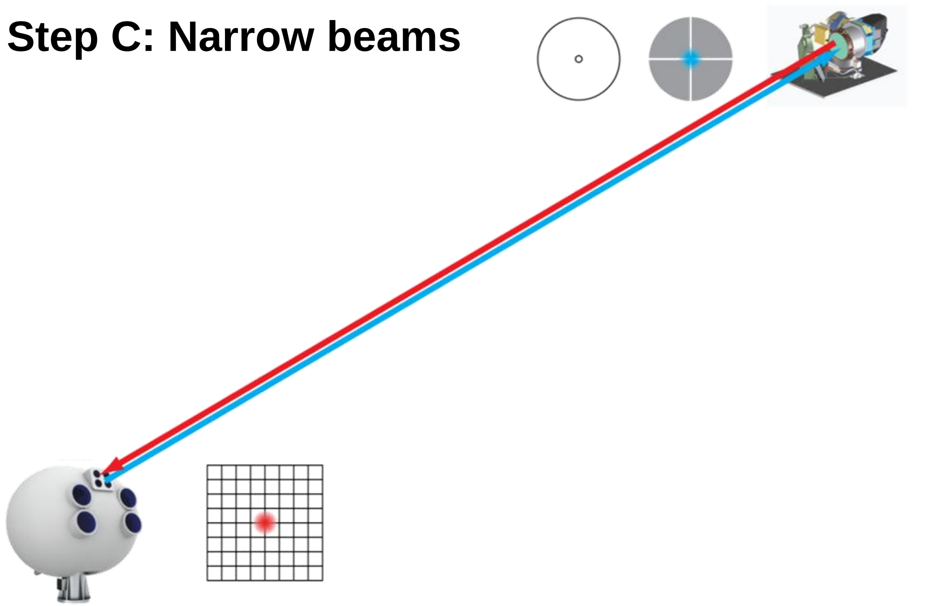
Step A: LLST stares, LLGT scans



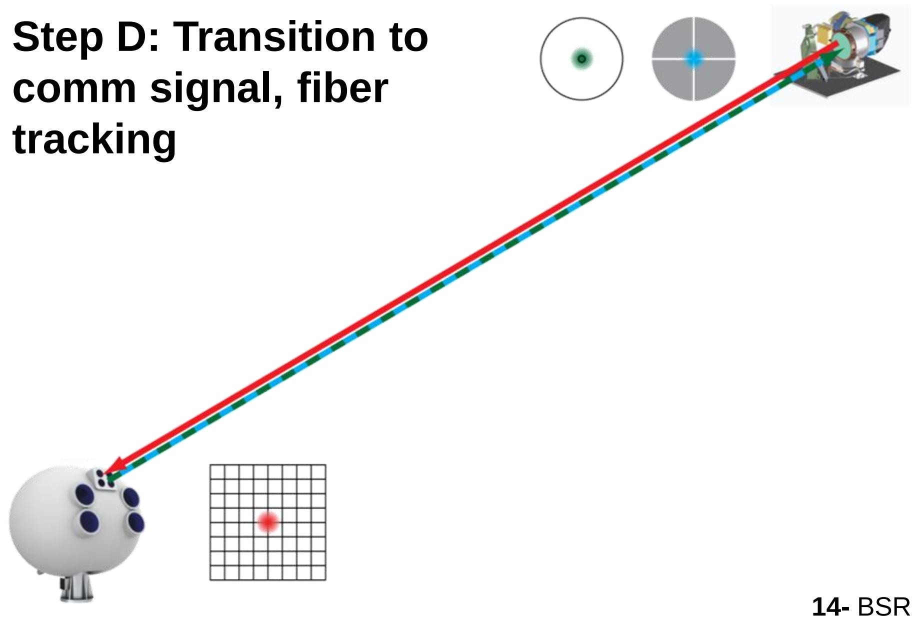
Step B: LLST acquires



Step C: Narrow beams



Step D: Transition to comm signal, fiber tracking



Some Conditions That Can Vary in Lasercom Links

- **Ground Terminal elevation – low / medium / high**
- **Time of day – dark night / dusk-dawn / bright sky**

- **Ground Terminal SEP – small / other**
- **Ground Terminal brightness behind Space Terminal – dark / light / terminator**
- **Space Terminal background – dark / medium / clouds-snow**
- **Space Terminal SPE – small / other**

- **Ground Terminal winds – low / medium / high**
- **Ground Terminal turbulence – low / medium / high**
- **Ground Terminal visibility – good / medium / poor**

- **Space Terminal temperature – near 0 / room temp / hot**
- **Time since last Ground Terminal calibration**
- **Time since last Space Terminal boresight**

- ***Hundreds of combinations***
- ***LLCD will try to sample as many of these as possible in its short mission***

Summary

- Optical communications offers the potential for substantial improvements in deep space communications capabilities while reducing burden on spacecraft

- LLCD will be NASA's first step in making lasercom a reality for future NASA missions