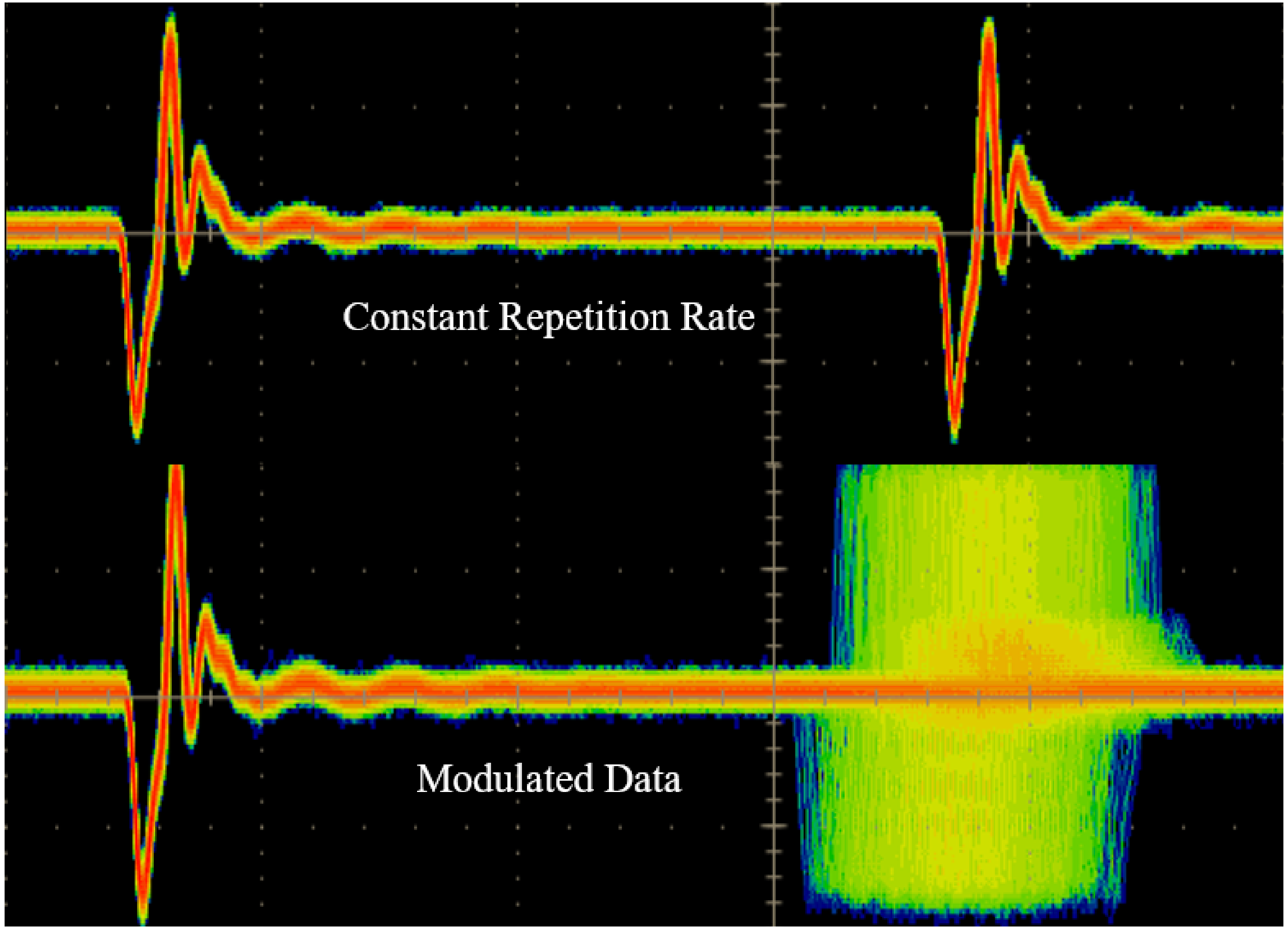

The Miniature Optical Communications Transceiver (MOCT)

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NASA Ames leads:
Anh N. Nguyen, Belgacem Jaroux

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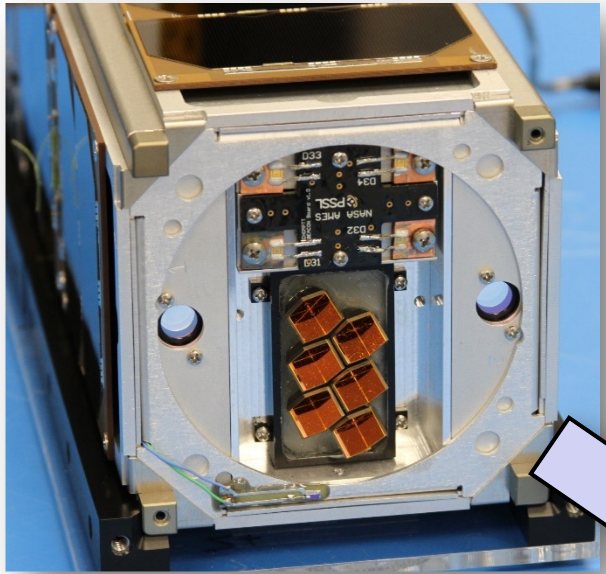
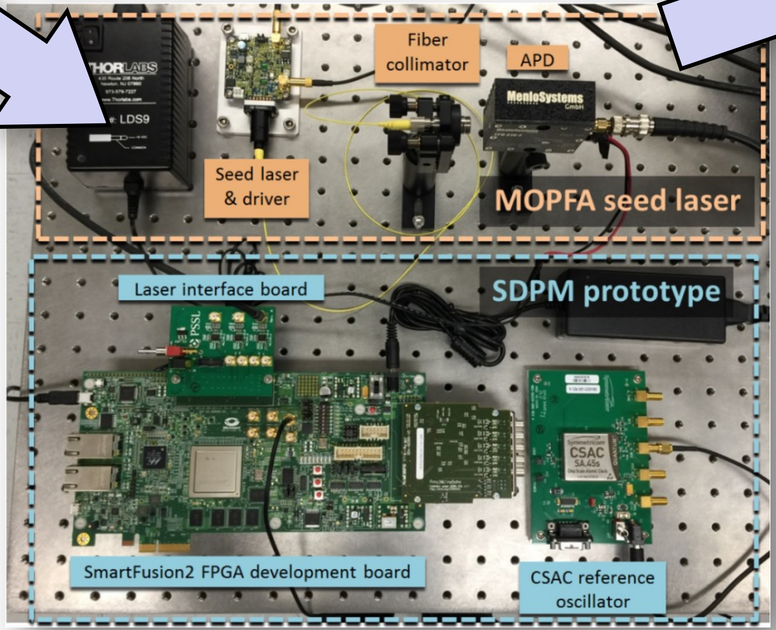
[This presentation contains no EAR- or ITAR-controlled information]

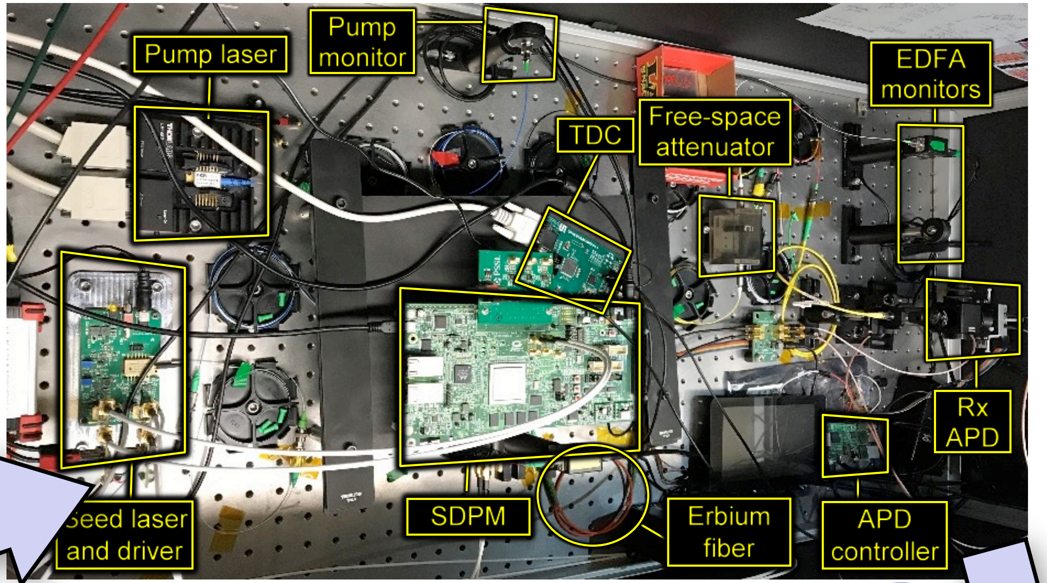
MOCT Development



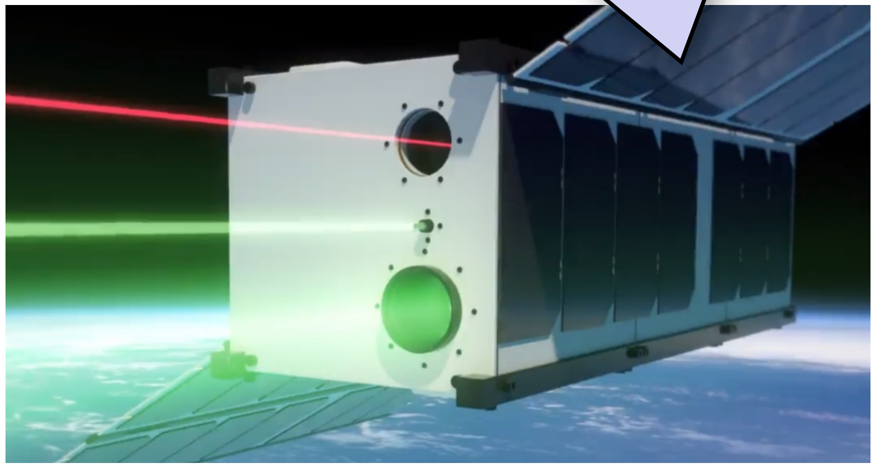
CHOMPTT (2013-2021)
Currently on orbit
AFRL, NASA, FSGC



NASA Early Career Faculty grant (2014-18), Low TRL development of MOCT



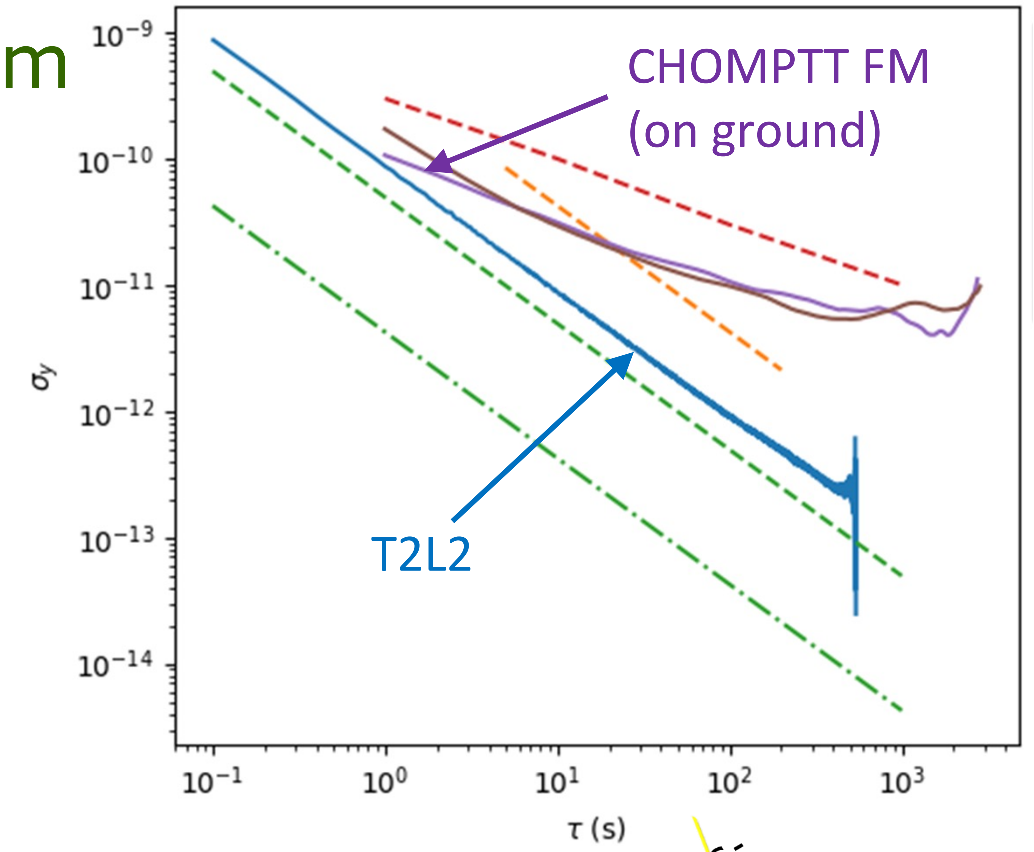
MOCT, NASA Tech Partnership (2017-19), Mid-TRL development

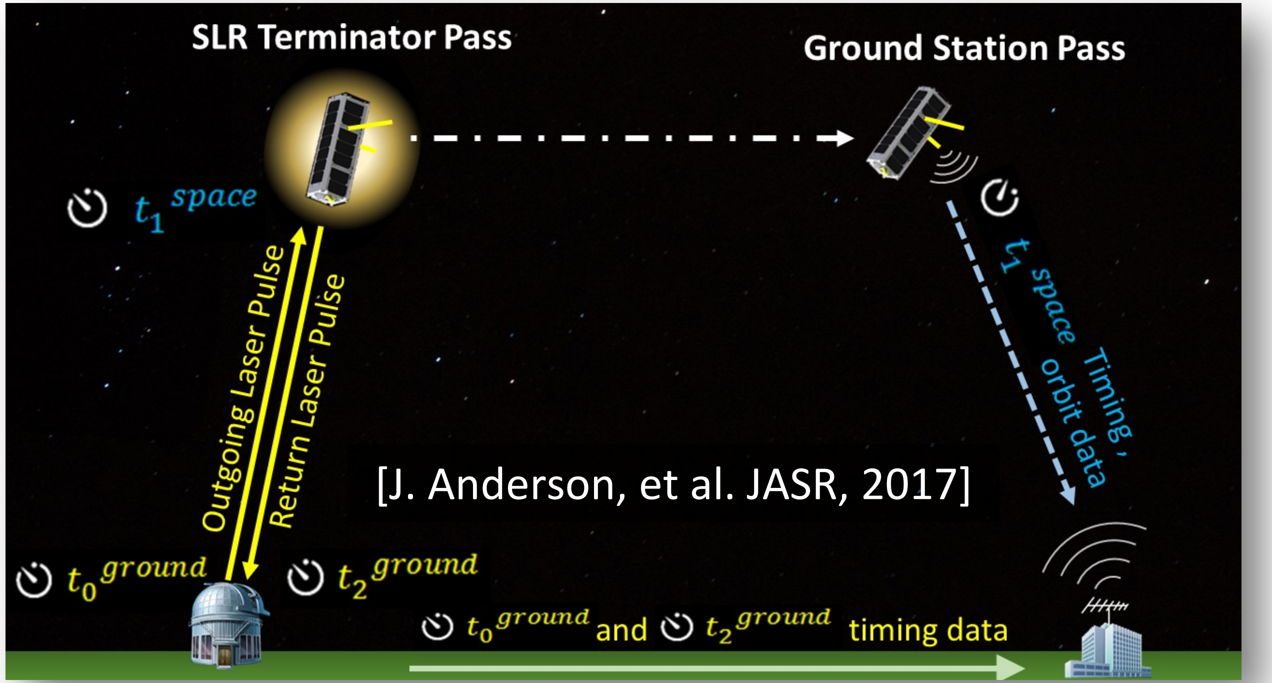


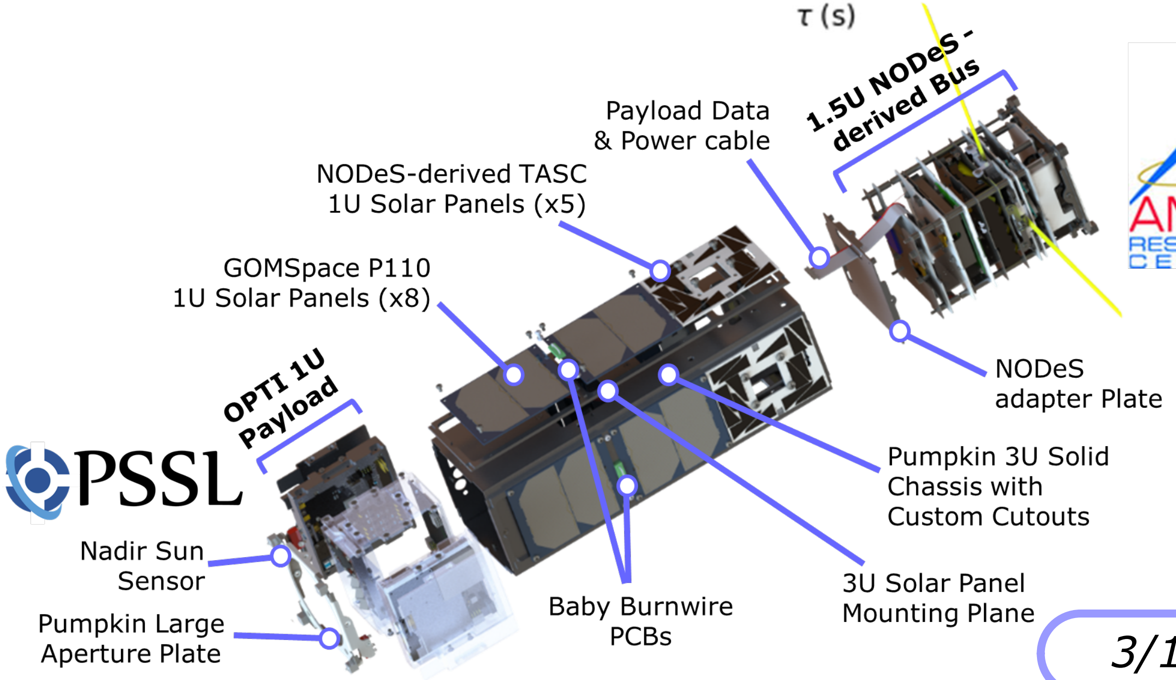
CLICK tech demo, (2017-23)
NASA SSTP

CHOMPTT: CubeSat Handling Of Multi-system Precision Time-Transfer

- Demo ground-to-space laser time transfer to 200 ps (6 cm) & long term performance of chip scale atomic clocks (CSAC) in space
- OPTI Payload:
  - CSAC, photoreceiver, precision timing electronics, and retroreflector array (used on MOCT)
- Launched in Dec 2018, still operating in LEO

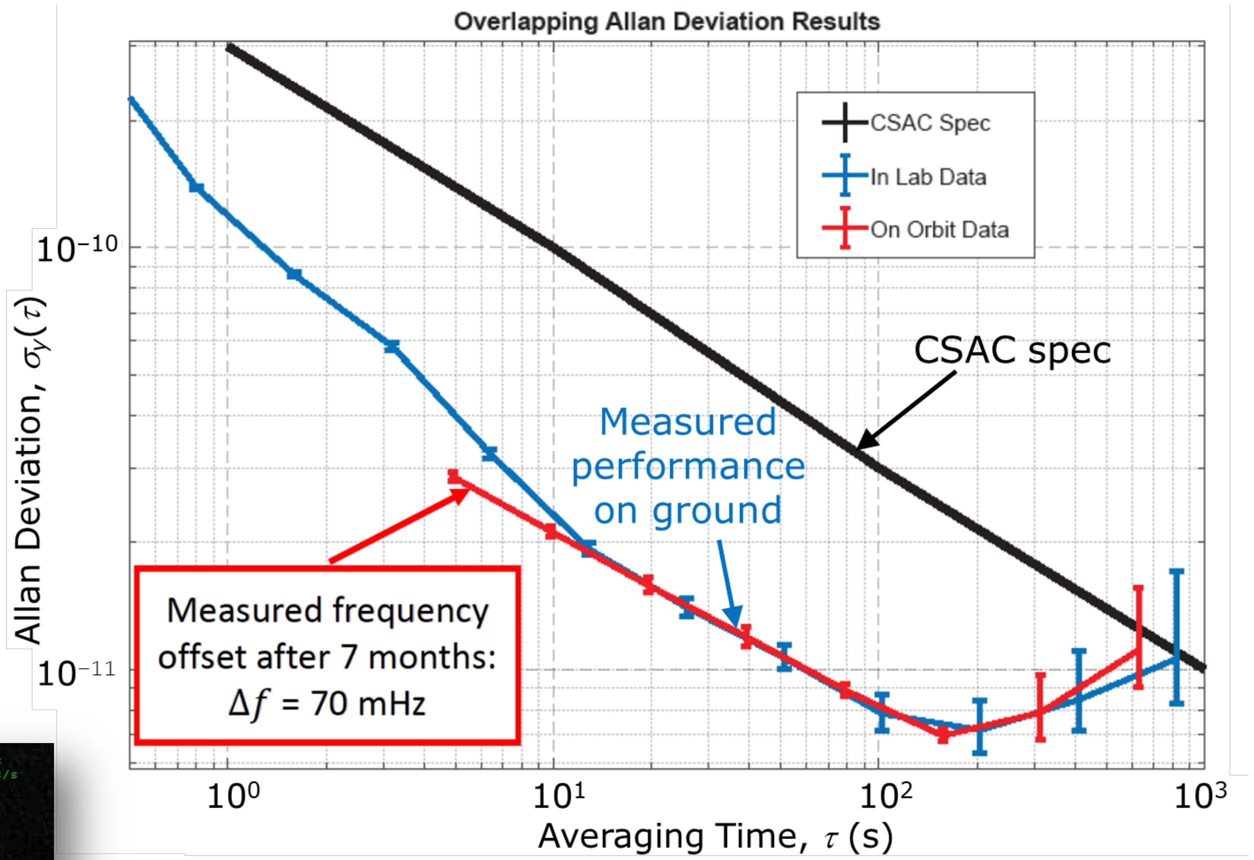


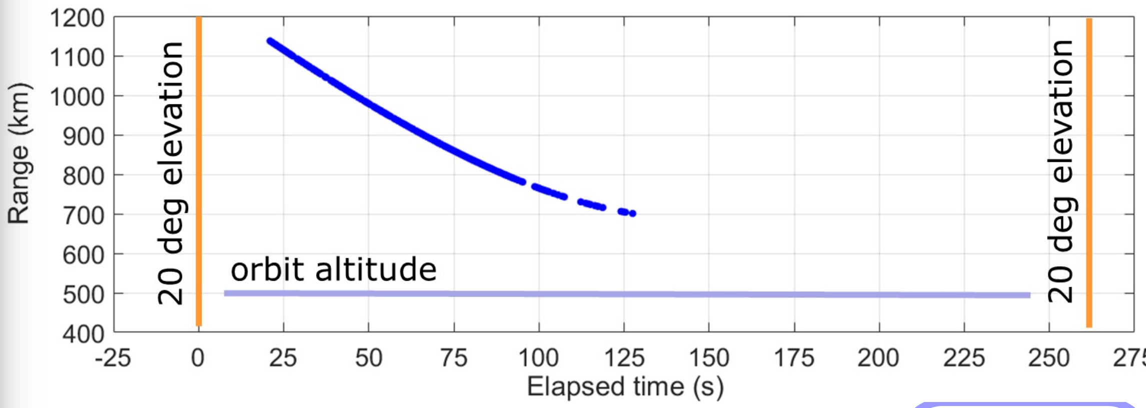




Some Results from CHOMPTT

- Despite S/C pointing (and other issues) preventing a successful time-transfer, CHOMPTT accomplished several things:
  - First ever measured performance of a CSAC in space (on any platform)
  - Optical tracking of CHOMPTT by an SLR facility via Sun reflections and CHOMPTT's laser beacons
  - Successful laser ranging to CHOMPTT
  - Demonstrated functionality and performance of all elements of the OPTI payload:
    - Photoreceivers
    - CSACs (two)
    - Timing electronics
    - Laser beacons
    - Thermal & Power performance

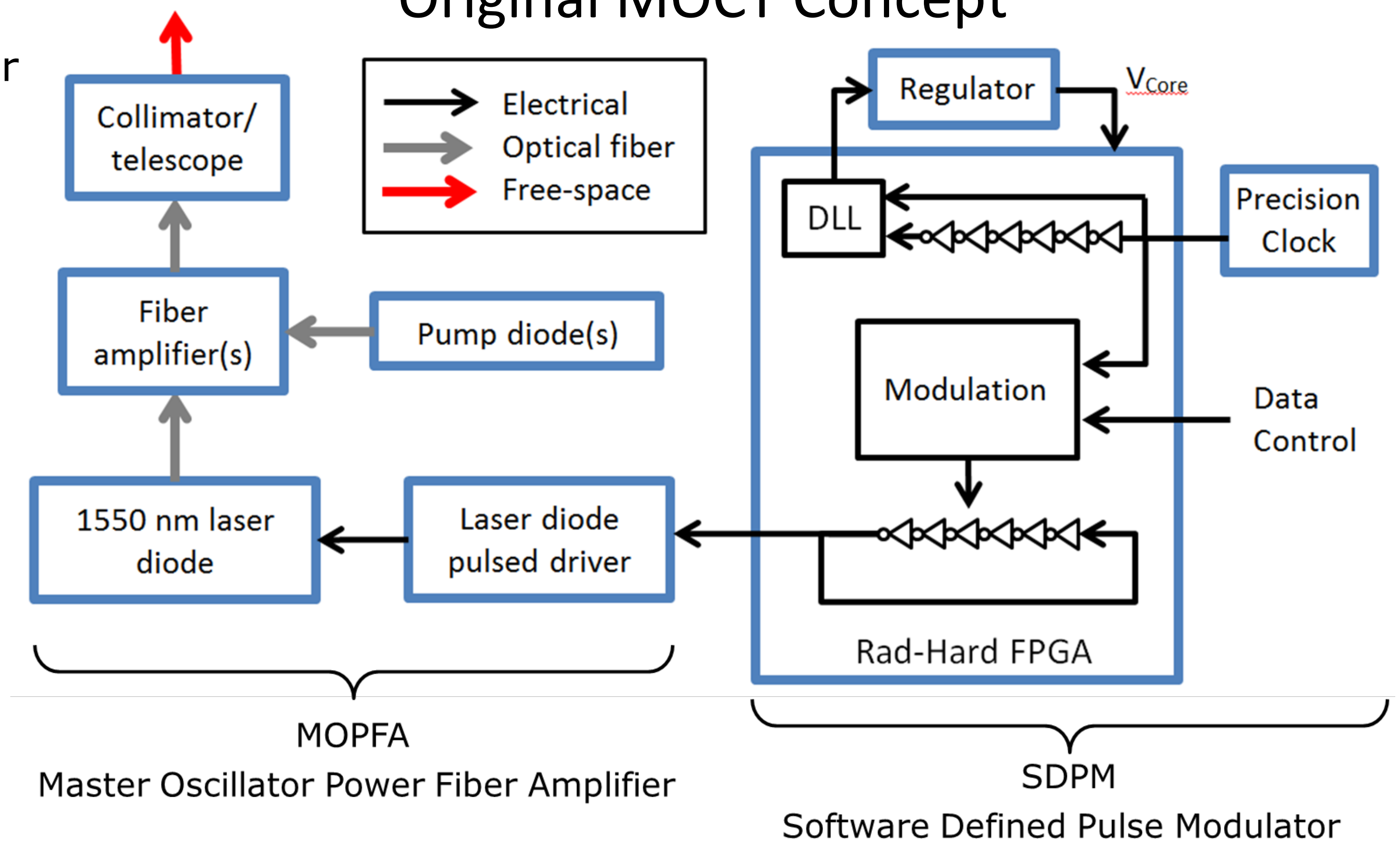




The Miniature Optical Communications Transceiver (MOCT)

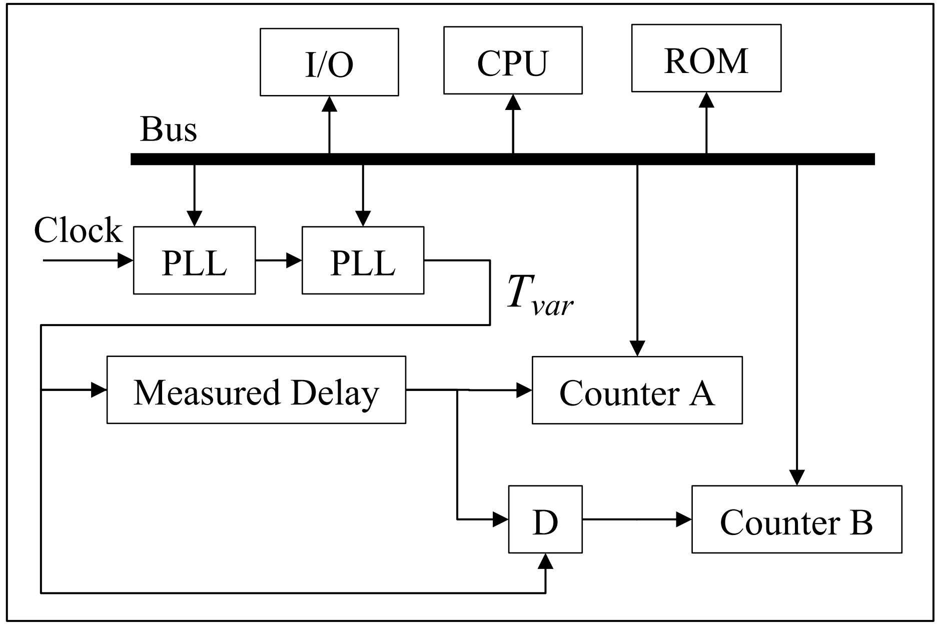
- Concept: Laser communications transceiver for small satellites and/or for long-haul comms based on pulse position modulation (PPM) consuming <15 W
- Innovations:
  - Replace GHz slot clock with low power precision oscillator: 100 mW CSAC
  - Laser pulse timing generated within an FPGA with <10 ps precision
  - Use feedback control to continuously correct timing errors due to PVT
  - Power efficient gain-switched seed laser diode driver
  - Master oscillator power fiber amp to achieve optical link
- Performance goals:
  - ~100 Mbps & <100 ps timing
- Project does not focus on optical font-end, acquisition, structural/thermal

Original MOCT Concept

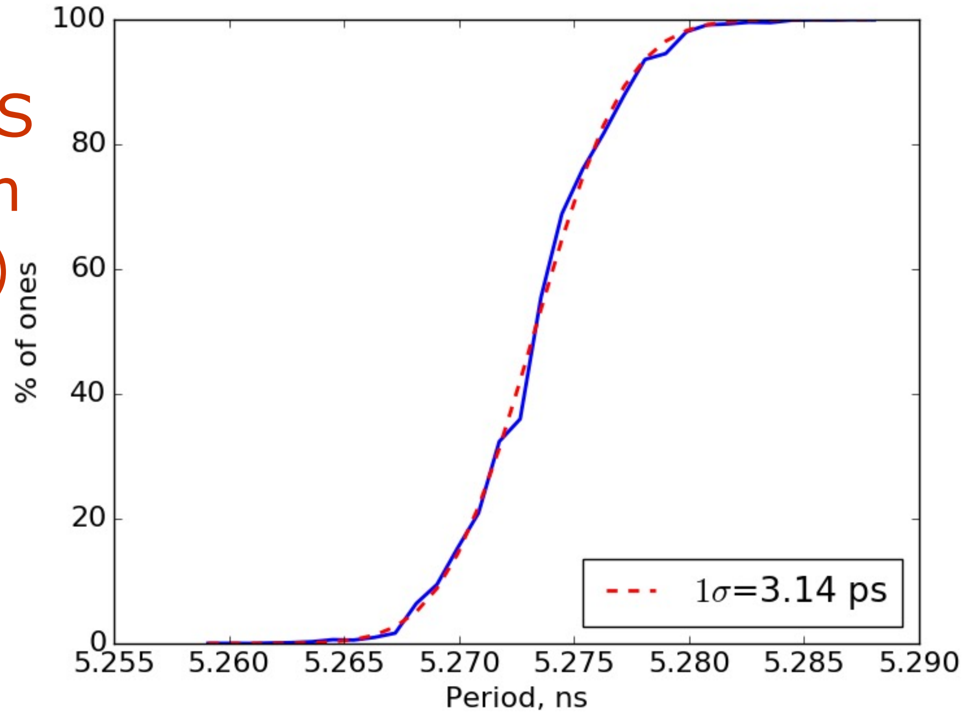


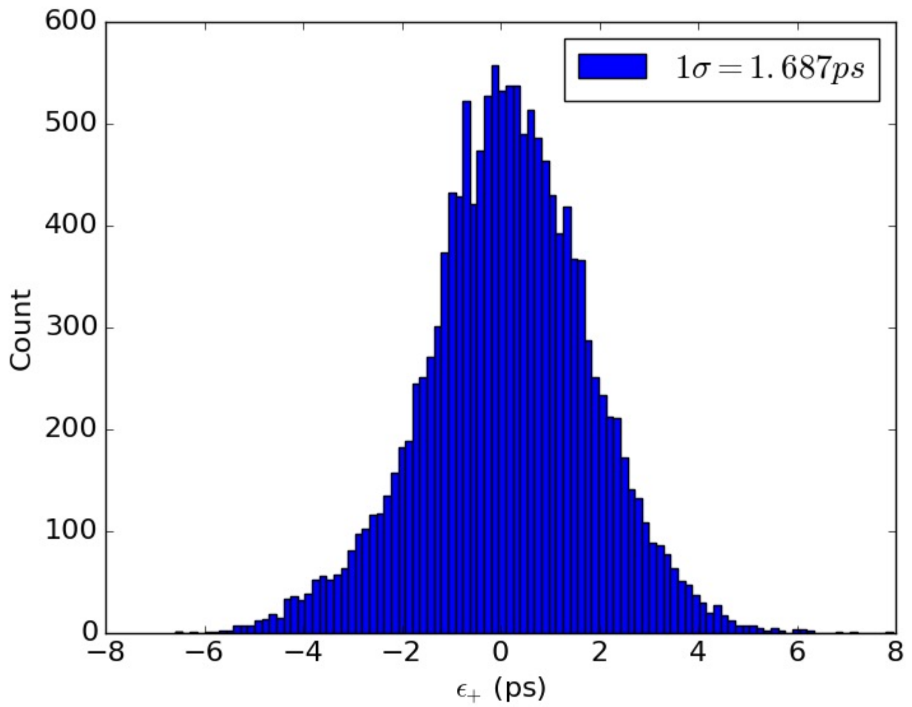
Software-Defined Pulse Modulator

- Generates electrical pulses with ~ps precision referenced to an external oscillator (CSAC)
- Pulse timing is based on a selectable signal propagation time through a delay chain within the FPGA
- Delay time is continually calibrated against the CSAC
  - U.S. patent (16/086,092) on this technology
  - See [Serra, Conklin, 2019]
- Demonstrated using COTS FPGA (Smartfusion2) with flight ~equivalent (RTG4)
- Measured performance in a lab environment
  - 2 ps timing precision
  - 10 ps timing accuracy
  - 14 ns range



Timing compensation circuit

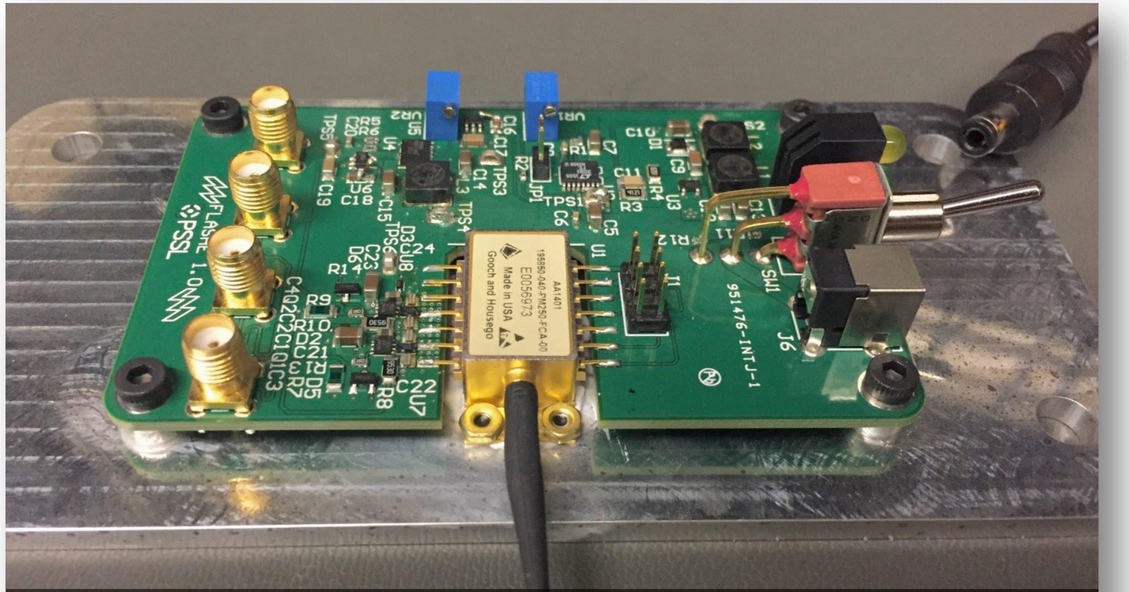




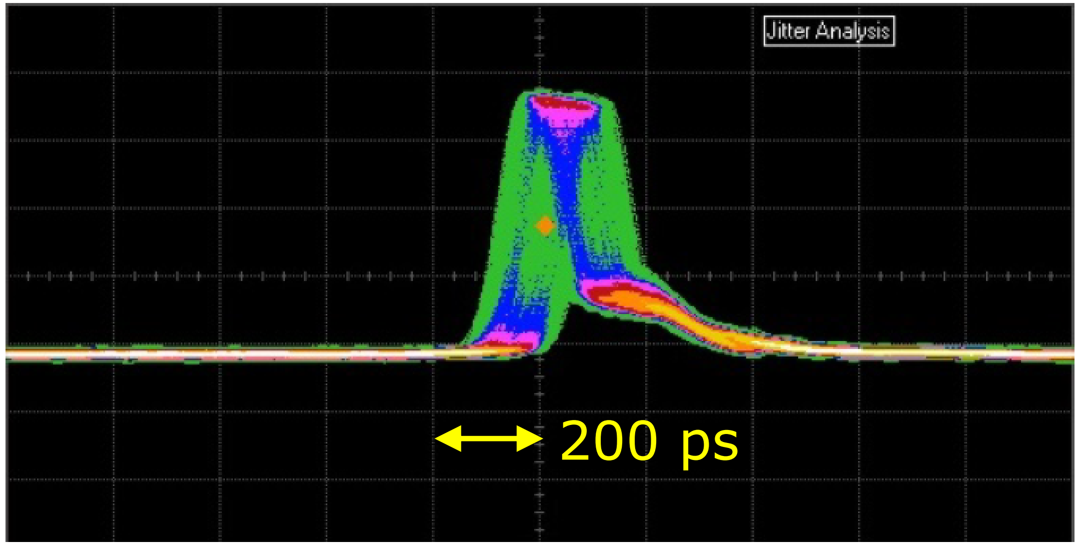
Timing error signal (left), generated pulse timing error (right)

100 ps Gain-switching Seed Laser Driver

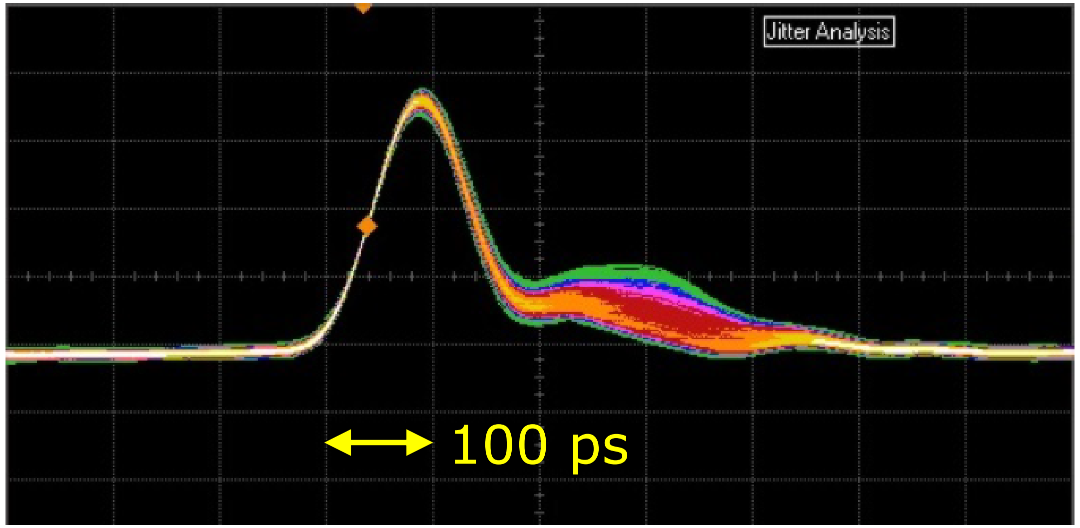
- Fast Laser Advanced Switching High-Frequency Emitter (FLASHE)
- Capable for generating 500 mA pulses at 50 MHz
- Uses double FET configuration
    - One for laser ON, one for laser OFF separated by 100 ps
    - Transistors are 'slow', operated in linear mode to conserve power and eliminate the need for an RF amp



FLASHE v1.0 with 1531 nm seed



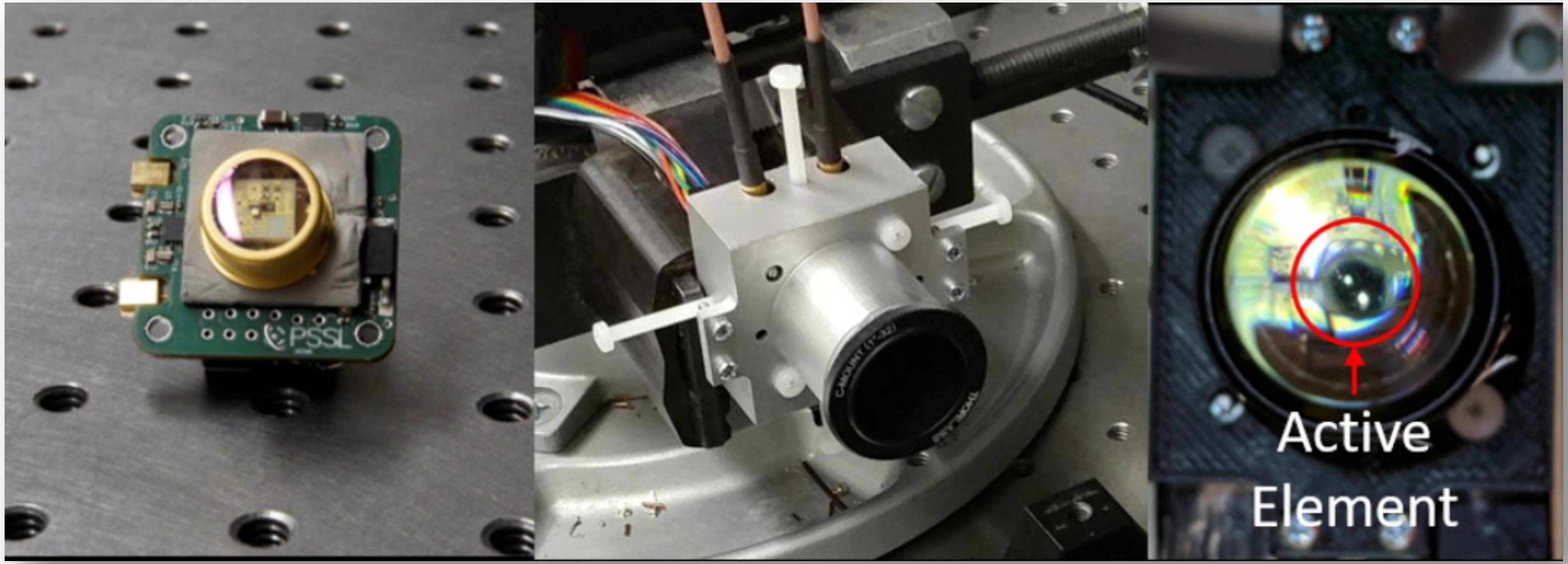
Triggered on CSAC reference oscillator



Triggered on measured rising edge

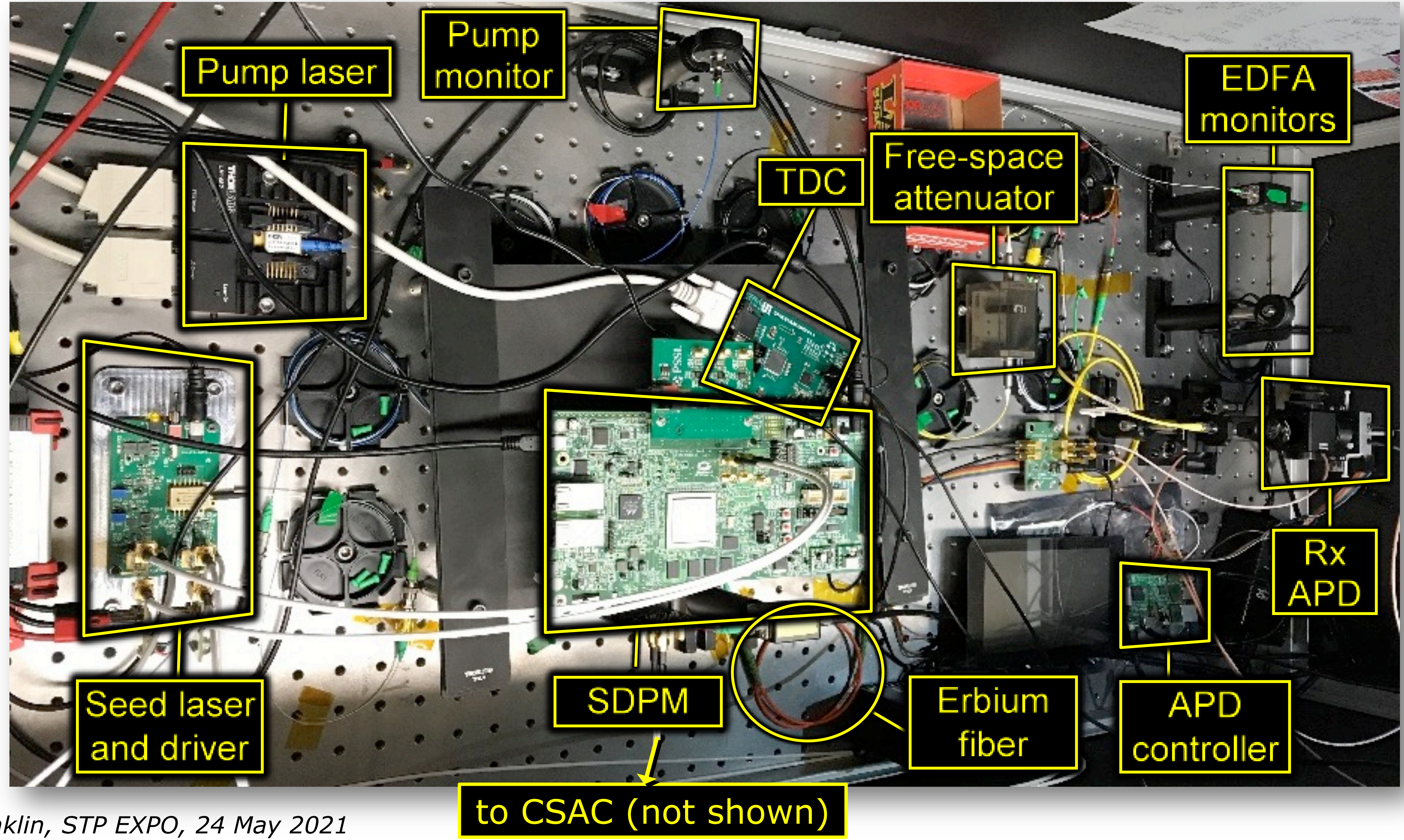
Pulse Detection and Timing

- Time-to-Digital Converter 2 (TDC-GPX2) used for time stamping
  - Measures rising and falling edges based on selected threshold
  - Consumes less power than a fast ADC, but ADC has better link margin with matched filtering
  - Data rate of 70 MS/s with 20 ps timing precision (<40 ps measured)
- Avalanche photodiode (APD) receiver
  - Selectable reverse bias for gain control
  - Active thermal control for stable breakdown voltage
  - Minimum received power: 100 nW
  - Measured timing jitter: 50 ps



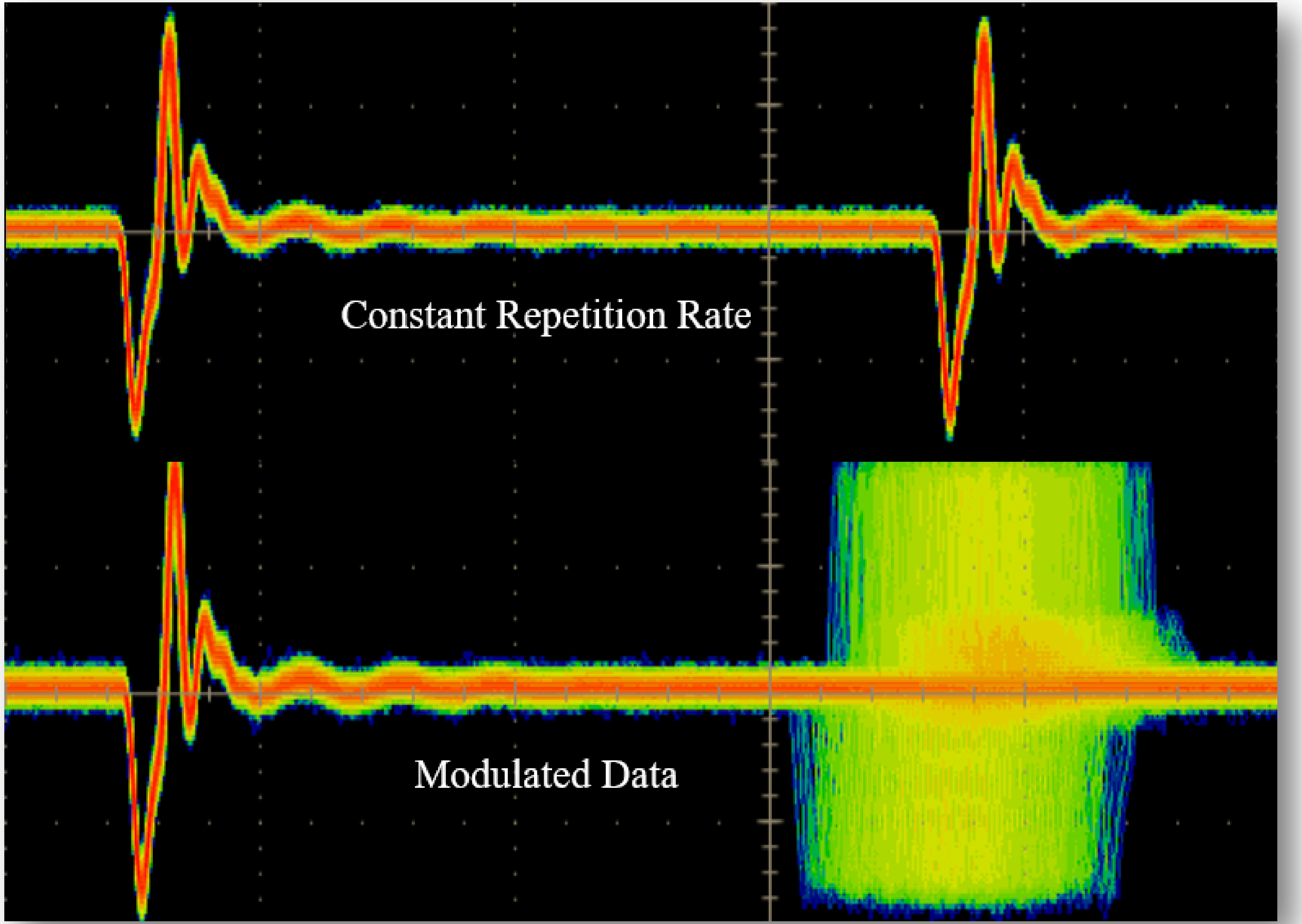
MOCT APD photo receiver (left) and mechanical enclosure (center)

MOCT Breadboard



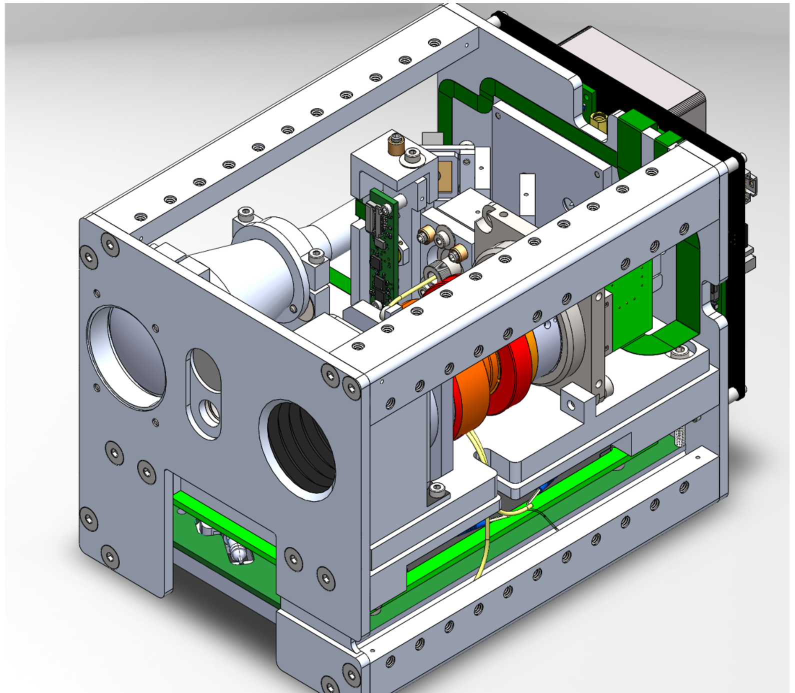
Measured Performance in the Lab

- EDFA output attenuated by an amount equivalent to LEO-to-Earth link
  - Tx peak power: 1.4 W
  - Rx peak power: 180 nW
- Pulse modulation scheme
  - 32 PMM
  - Pulse width: 2.5 ns
  - Guard time: 50 ns
  - Slot width 0.4 ns
- Uncorrected BER: $10^{-2.6}$
- Data rate: 78 Mbps
- See
  - [Barnwell et al. Aerospace, 2018]

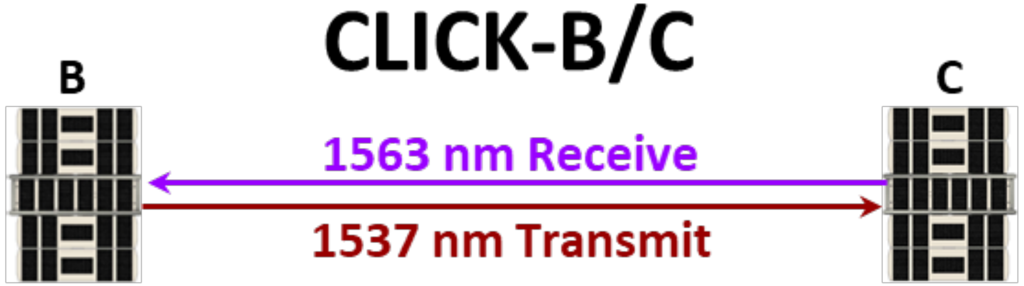


CLICK: CubeSat Laser Infrared CrosslinK

- NASA-MIT-UF CLICK B/C mission will demonstrate CubeSat space-to-space laser comms
  - CLICK A is a space-to-ground laser comm risk reduction mission for B/C, launching later this year
- Elements of MOCT will fly on CLICK B/C
  - FPGA modulator with CSAC frequency reference
    - Operated in a different way than the SDPM
  - APD photoreceiver
  - Time-to-digital converter
    - ADC-based receiver also flown for comparison
- B/C launch: 2022-23



Credit: P. Grenfell

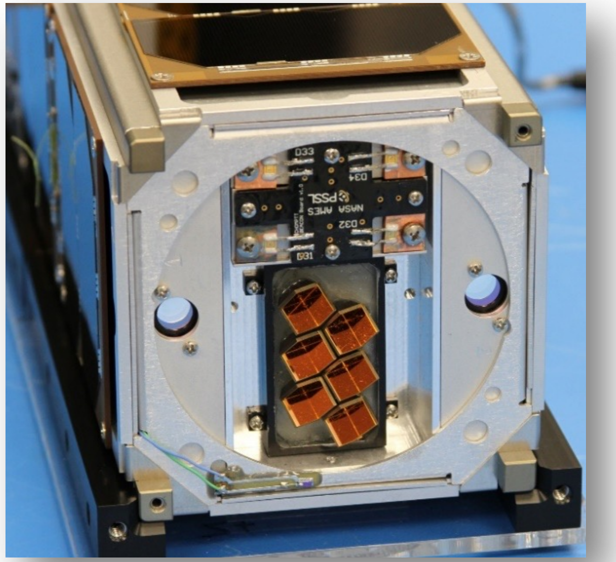


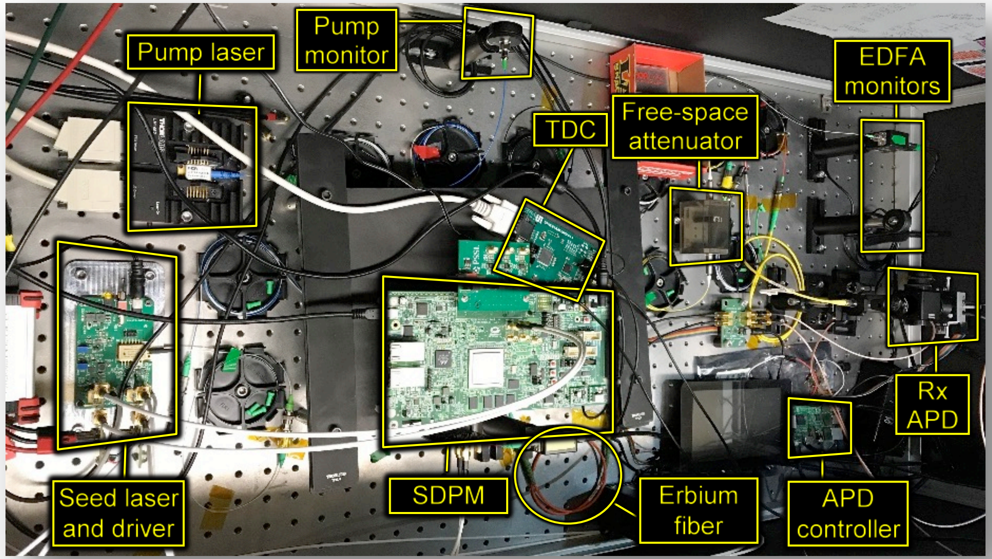
- Pair of **1.5 U, ~1700 g, <25 W** payloads
- **200 mW** avg. Tx, **70 µrad** divergence
- **2.5 cm** receive aperture
- **500 mW** beacon at 976 nm for PAT
- Full-duplex **PPM** crosslinks 1537/1565 nm
  - **50 Mbps**, 4-PPM, <450 km
  - **25 Mbps**, 16-PPM, <920 km
- **200** ps timing accuracy & time transfer
- Primary success criteria:
  - >20 Mbps full-duplex @ 580 km
  - <0.5 m ranging w/o GPS @ 580 km

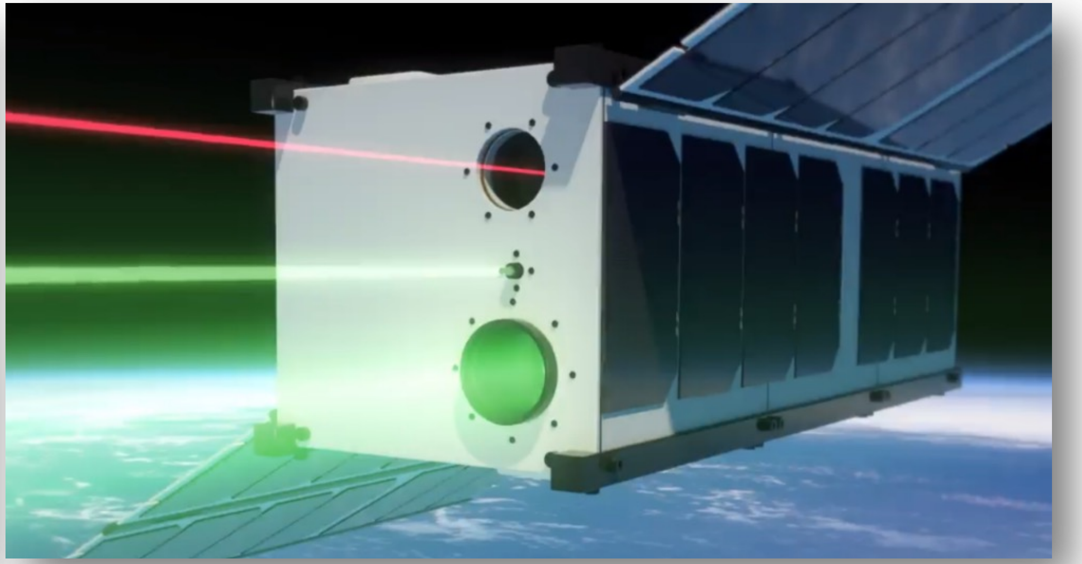
Credit: P. Serra

Conclusions

- CHOMPTT/OPTI
  - Ground → space time-transfer to <200 ps
  - <5 W
  - ~0.3U without redundancy
  - Partial flight demo; ongoing
- MOCT
  - ~10s Mbps laser comm
  - <200 ps time-transfer
  - Ideal for long haul or small sats
  - More easily scalable to longer links but not higher data rates
  - ~15 W, ~1.5U
  - Lab demo only
- CLICK B/C
  - ~10s Mbps laser comm
  - <200 ps time-transfer
  - More easily scalable to higher data rates
  - ~25 W, ~1.5U
  - Near future flight demo







PSSL

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