

# CubeSat Handling of Multisystem Precision Time Transfer

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## Mission

### Overview

CHOMPTT is a precision timing satellite being developed at University of Florida's Precision Space Systems Laboratory in collaboration with NASA Ames Research Center and is equipped with atomic clocks to be synchronized with a ground clock via laser pulses. [1]

**"CHOMPTT will demonstrate technology for enhanced GPS and future disaggregated navigation systems."**

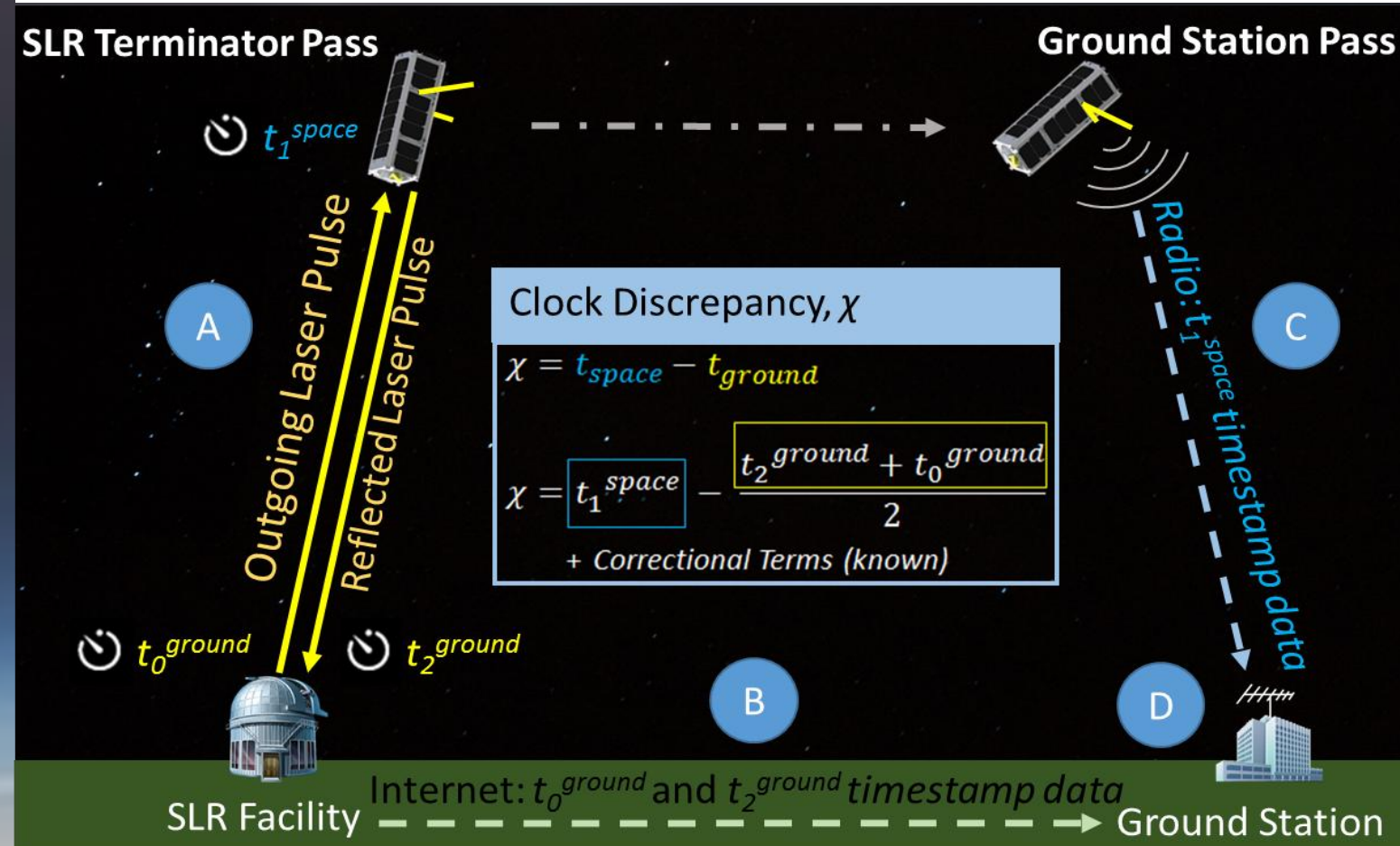


Fig. 1 CHOMPTT mission time transfer concept to calculate the clock discrepancy between a clock on the ground and a clock in space. A) Time transfer using satellite laser ranging (SLR) facility where  $t_0^{ground}$  and  $t_2^{ground}$  are timestamped with respect to a clock on the ground and  $t_1^{space}$  is timestamped with respect to the clock on the spacecraft. B)  $t_0^{ground}$  and  $t_2^{ground}$  are sent from the SLR facility to the radio ground station. C) Ground station pass, where  $t_1^{space}$  is transmitted to the ground station via radio. D) Clock discrepancy,  $\chi$  is calculated using received timestamps at the ground station.

### Objectives:

- 200 ps short term ground to space time transfer accuracy
- Real-time calculation of CubeSat clock discrepancy on-board
- 20 ns long term accuracy over 1 orbit

### Concept of Operations

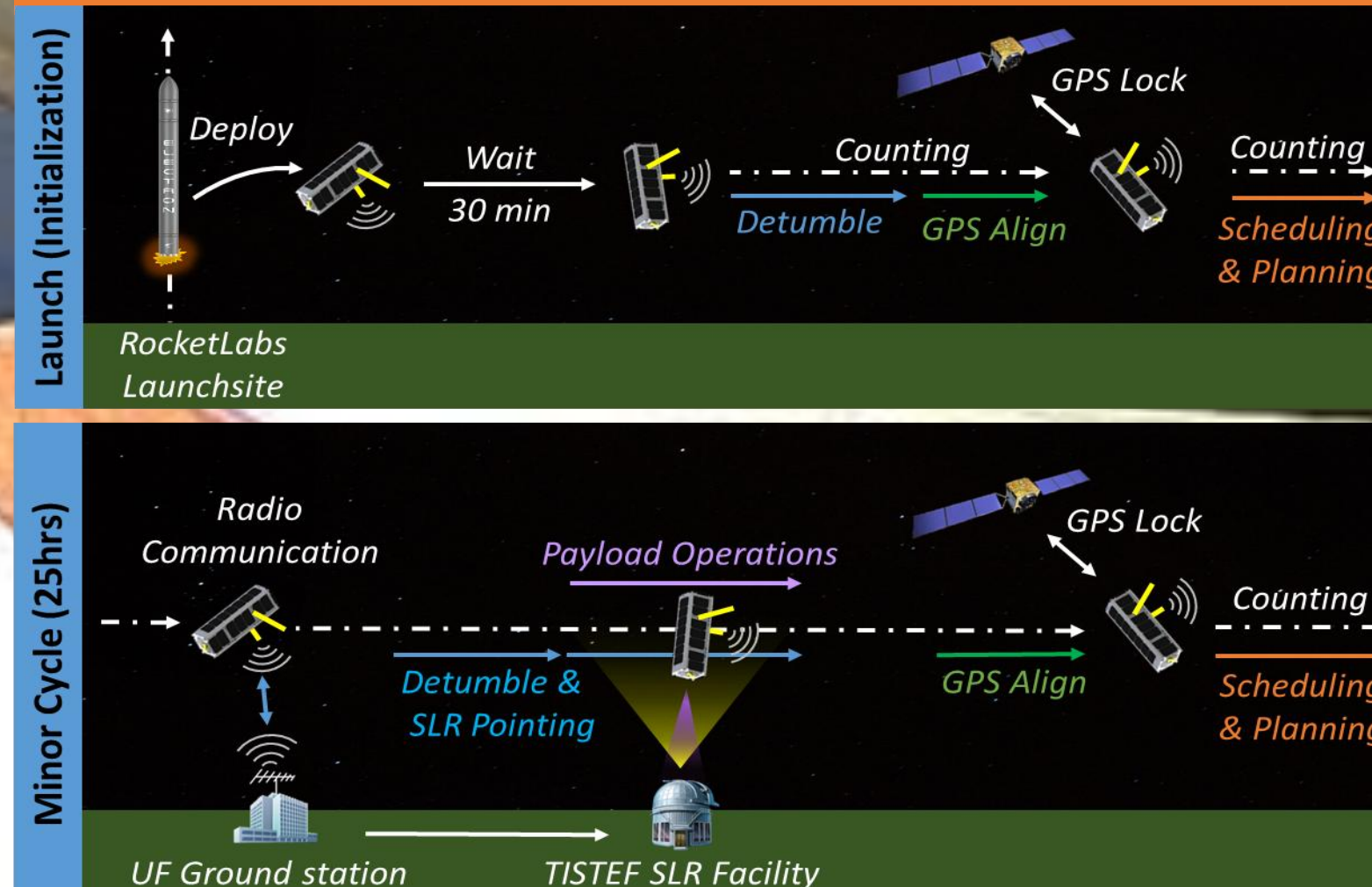


Fig. 2 CHOMPTT ConOps for the mission duration, keeping on-board time with reference to the space clock and determining clock discrepancy during time transfers with the SLR facility.

## Optical Precision Time-transfer Instrument (OPTI)

### Instrument Block Diagram

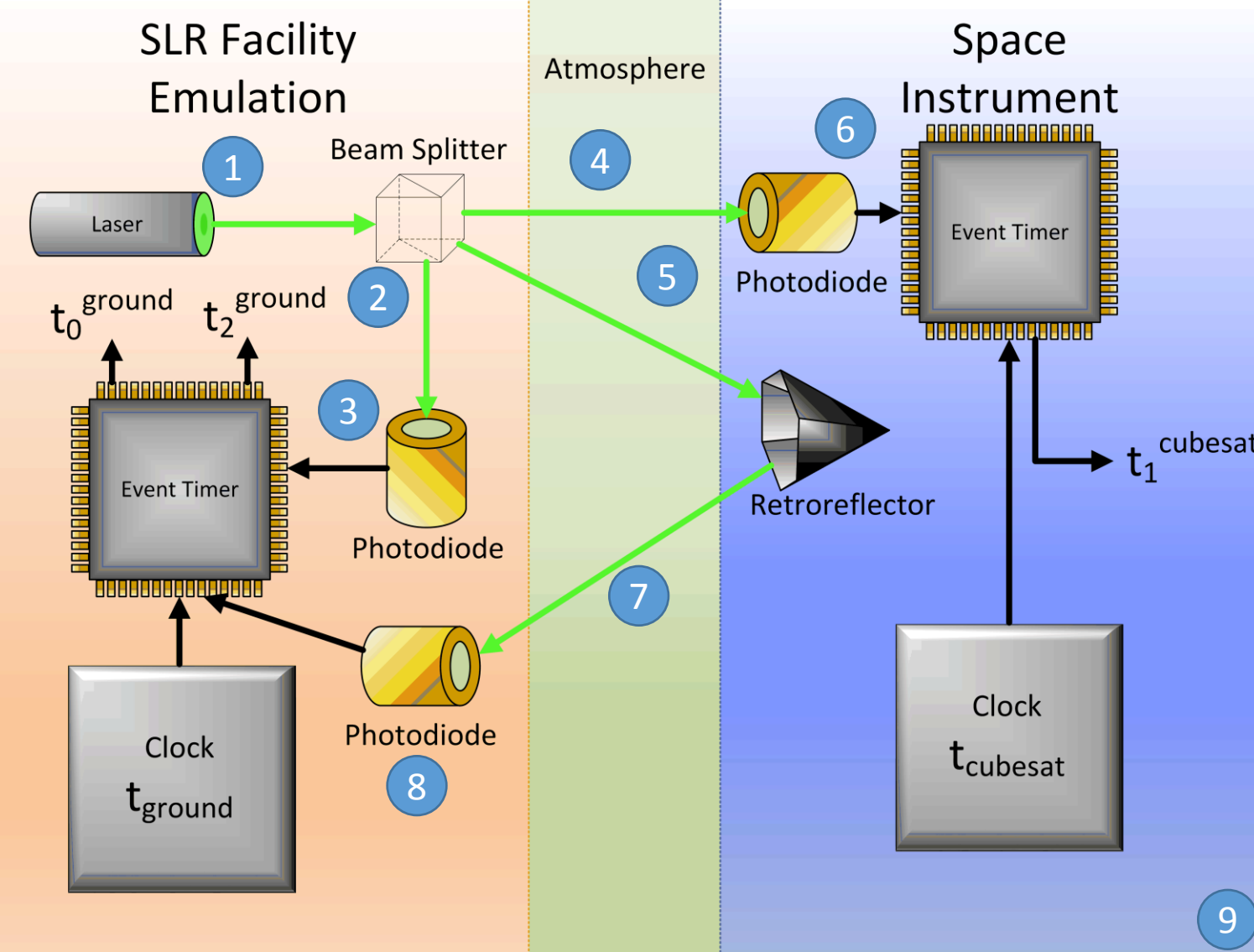


Fig. 3 Laboratory emulation of the time transfer between ground (left) and space (right): 1) SLR facility laser is emitted 2) Laser pulse is split by the beam splitter 3) The less intense portion of the laser pulse triggers the first ground photodiode and gets timestamped by the event timer as time  $t_0$  with respect to the ground clock 4) The more intense portion of the laser pulse is diffused as it travels through the atmosphere (via diffusing lens in a laboratory setting) 5) The pulse arrives at the retroreflector and space instrument photodiode simultaneously. 6) The space instrument photodetector is timestamped by the space event timer as time  $t_1$  with respect to the clock in space 7) The laser pulse is reflected to ground via the retroreflector 8) The second ground photodetector is triggered by the pulse and timestamped as time  $t_2$  with respect to the ground clock 9) Ground timestamps relayed to the space instrument and the discrepancy between the space and ground clocks is calculated on board the spacecraft.

### Laboratory Breadboard Demonstration

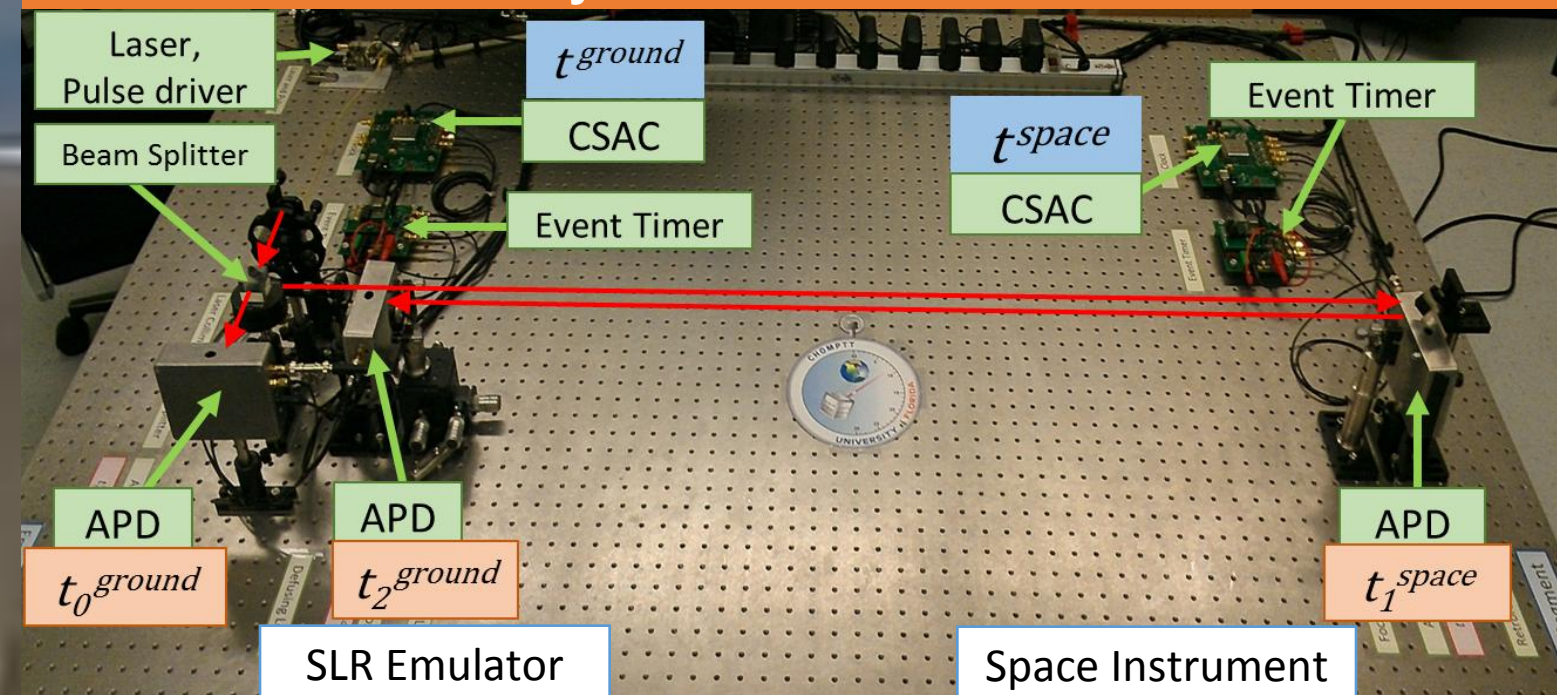


Fig. 4 Laboratory breadboard demonstration of the CHOMPTT mission, which validates time transfer functionality and performance characterization.

### Time to Digital Converter

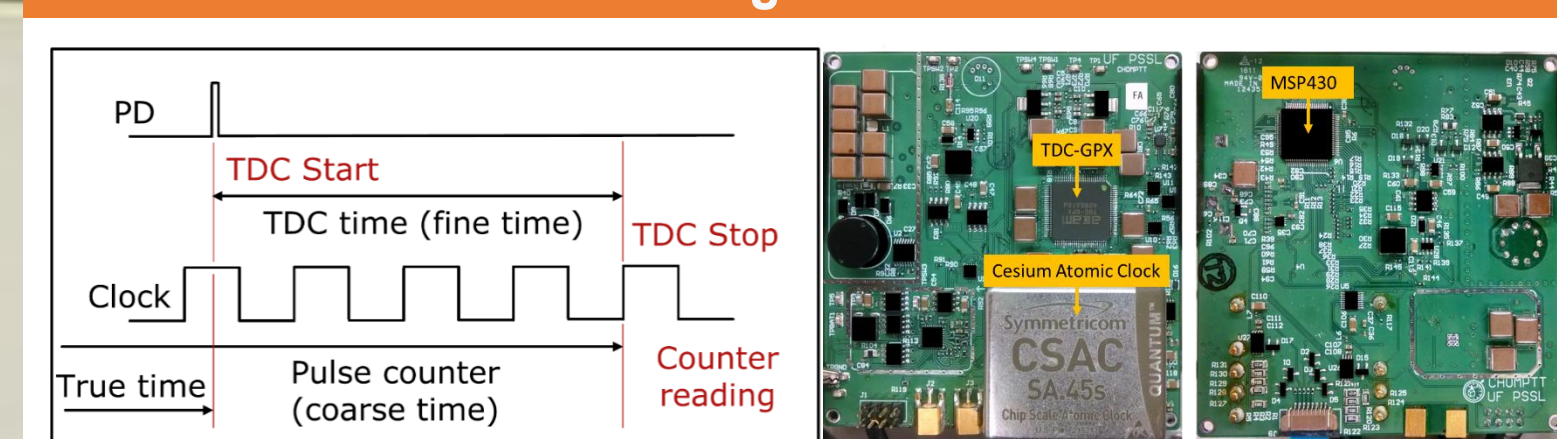


Fig. 5 Time stamping scheme (left) the engineering version channel board (middle and right) the CSAC (frequency source), MSP430 (coarse time), TDC-GPX (fine time).

100 ps measured short-term time transfer accuracy

### Laboratory Breadboard Timing Budget

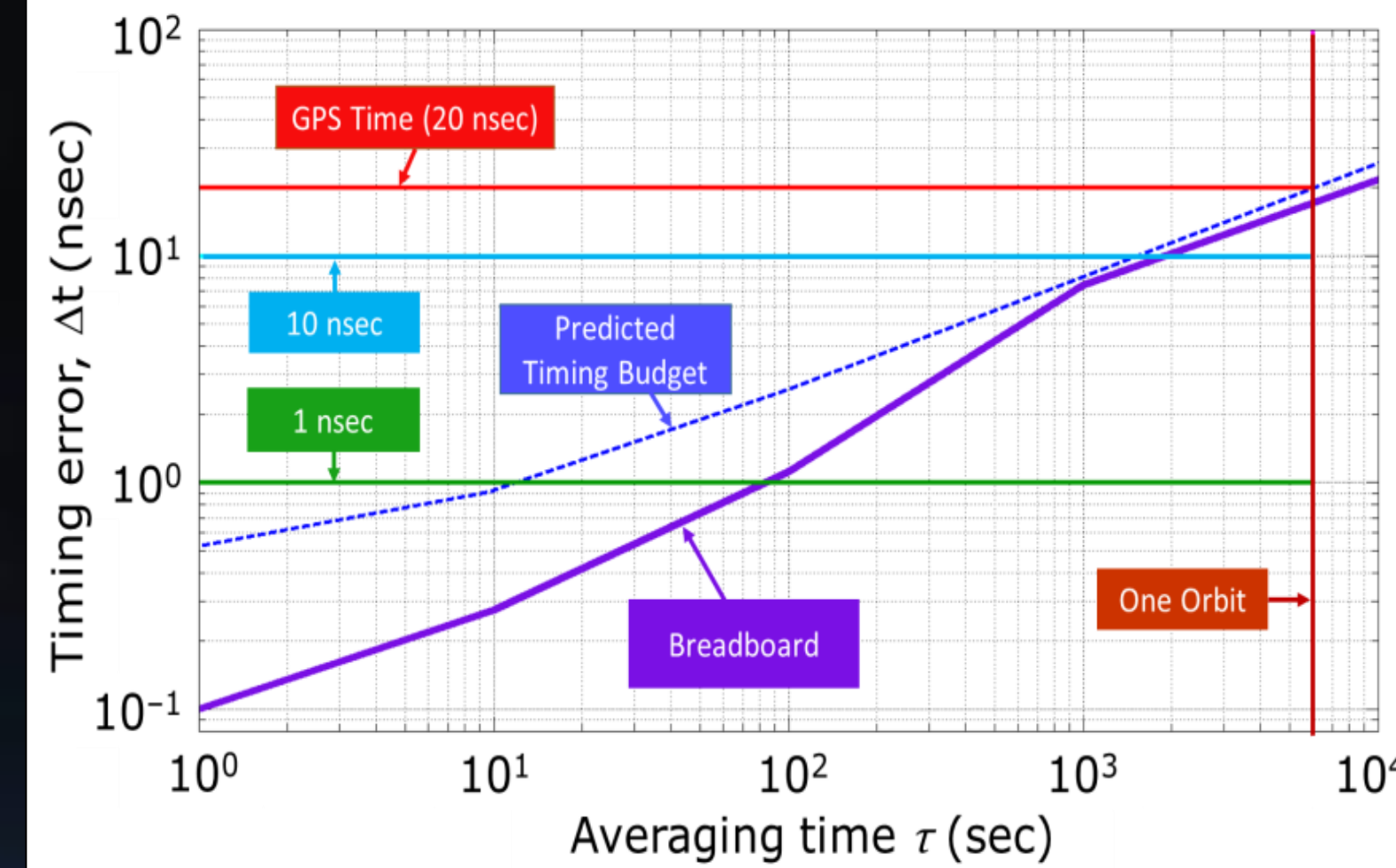


Fig. 6 Timing uncertainty of the entire breadboard experiment with 1 orbit (6000 s) between time transfers. OPTI has a better timing uncertainty than GPS (20 ns).

<20 ns of measured timing accuracy at 6000 s

### OPTI Design

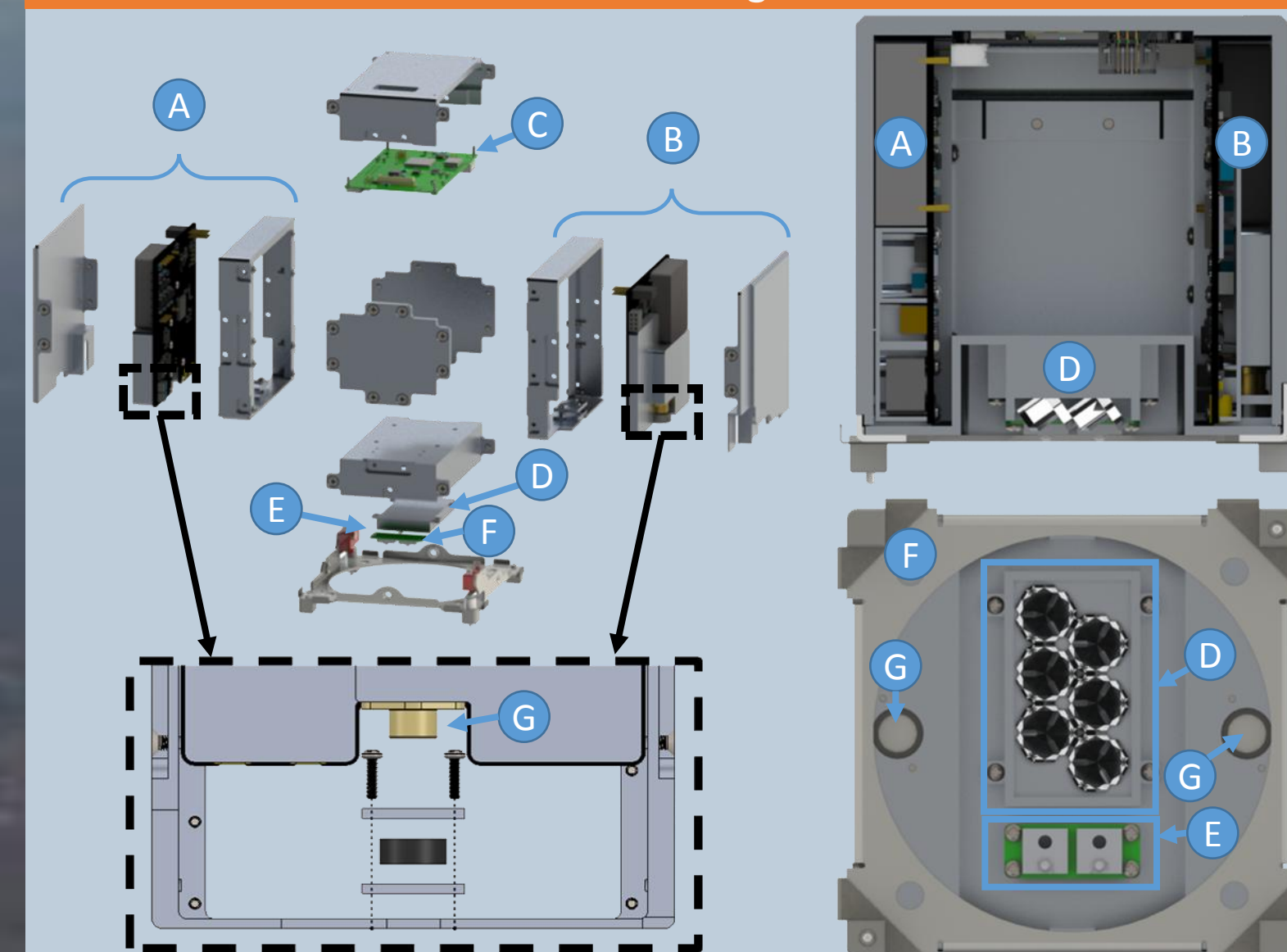


Fig. 7 OPTI 1U assembly: A) Channel Assembly A, performs time transfer B) Channel Assembly B, performs time transfer C) Supervisor Assembly, interfaces OPTI with spacecraft bus D) Retroreflector, returns timing laser pulse to the ground E) Laser Beacon, emits tracking laser pulse F) Pumpkin Large Aperture Cover Plate with foot switches G) Avalanche Photodiode (APD). The entire payload consumes ~5 W during time transfer and ~0.2 W during counting

### Optics and Supervisor Board

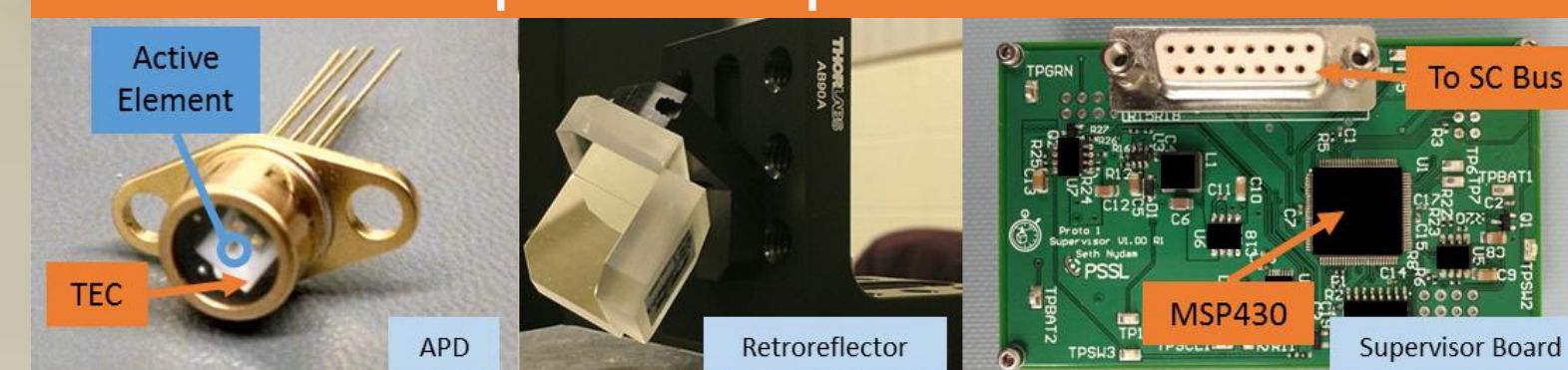


Fig. 8 APD with thermal electric cooler (TEC), Retroreflector, and the engineering version supervisor assembly with power and data interface to the spacecraft (SC) bus.

### High Altitude Balloon Testing



Fig. 9 Sage Cheshire high altitude balloon launch. Successful operation of OPTI in near space environment (no laser or time transfer test was performed, CSAC clock cycles counted).

### NASA ARC EDSN/NODEs Derived Bus Integration

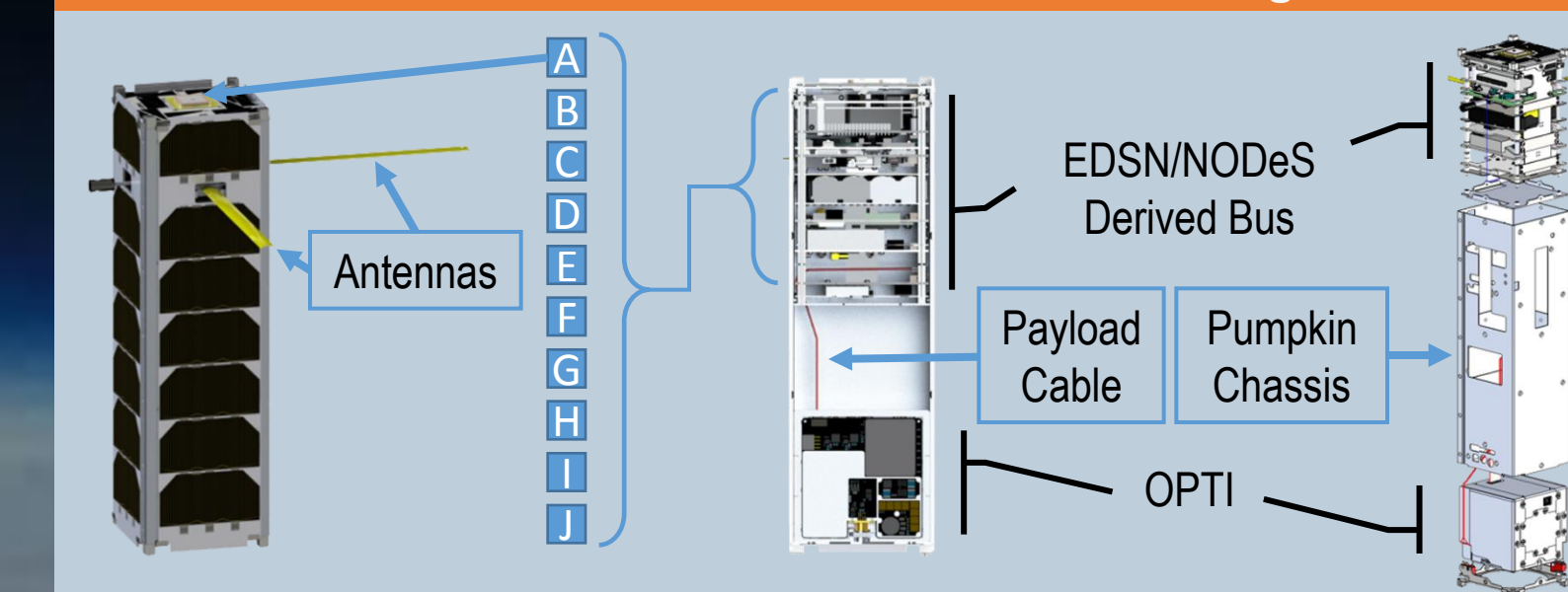


Fig. 10 OPTI is currently being integrated with the NASA ARC EDSN/NODEs Derived 1.5U bus (3U total). Spacecraft Bus (from top to bottom): A) GPS Patch Antenna, B) Router C) ADCS & Reaction Wheels D) Nexus S (CDH) E) EPS & UHF Antenna F) Batteries G) Stensat Beacon (radio beacon) H) Novatel OEMV-1 (GPS) I) Payload Cable Connection J) AstroDev Li-1 Radio (uplink/downlink radio). The entire bus consumes ~1 W orbit average power. [2]

### Satellite Laser Ranging Facility at TISTEF

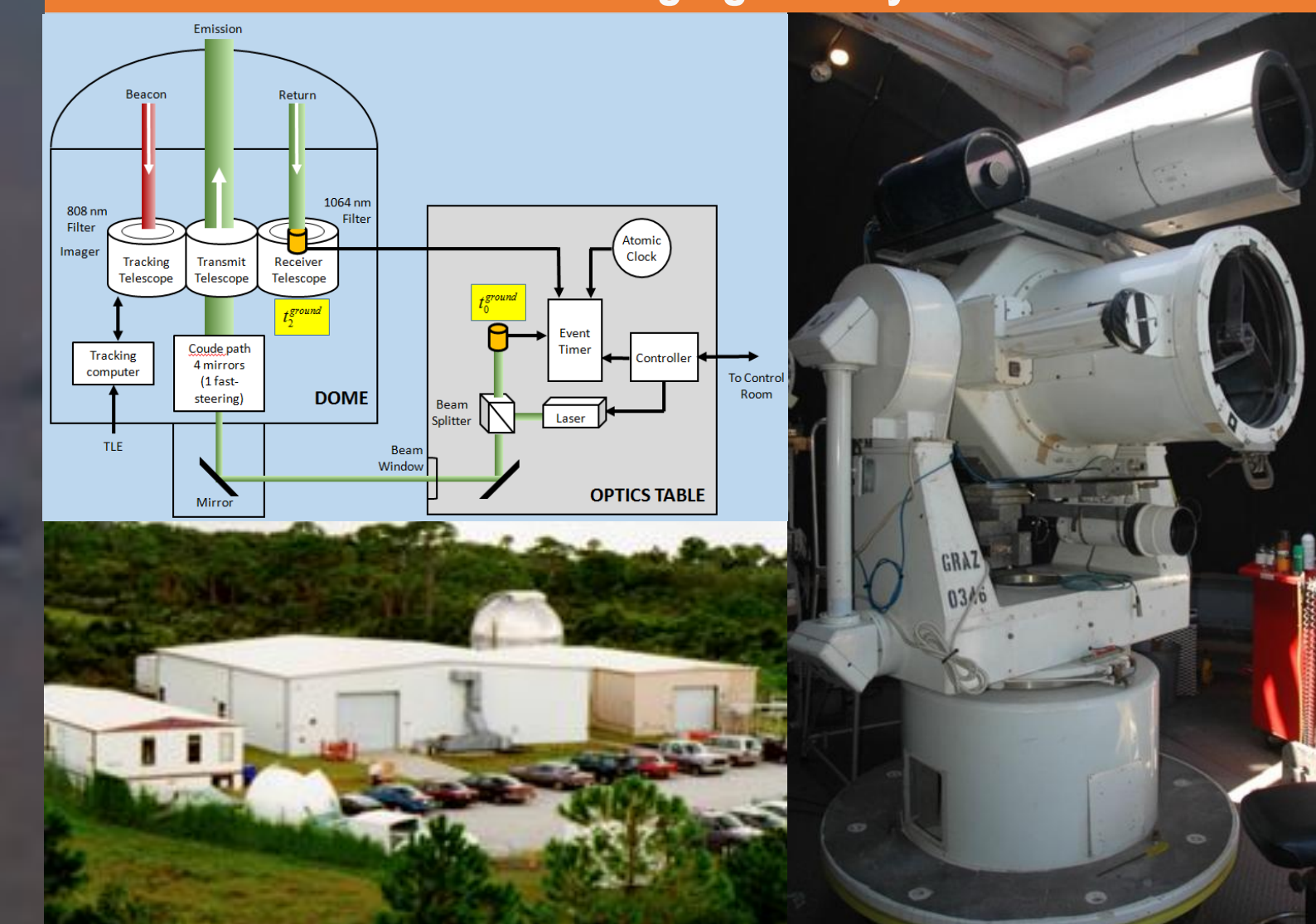


Fig. 11 Satellite Laser Ranging (SLR) facility operated by Townes Institute Science & Technology Experimentation Facility (TISTEF) managed by University of Central Florida at Kennedy Space Center. Collaboration includes a 1064 nm laser with 50 cm satellite tracking telescope and 1 km test range. [3] The block diagram is the configuration of the SLR facility for the CHOMPTT mission.

### References

- [1] Conklin, John, Barnwell, Nathan, et al. "Optical time transfer for future disaggregated small satellite navigation systems." (2014).
- [2] Chartres, James, Hugo Sanchez, and John Hanson. "EDSN Development Lessons Learned." (2014).
- [3] "The Townes Laser Institute." Townes Laser Institute. Web. 17 July 2015. <http://www.townes.ucf.edu/tistef.html>.