The CHOMPTT Precision Time Transfer CubeSat Mission

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CubeSat Handling Of Multisystem Precision Time Transfer

Background and Motivation

- Application of precision time transfer to space:
  - Satellite navigation systems ($\Delta x = c\,\Delta t$)
    - **Beyond LEO**
  - Global time standards
  - Test of general relativity
  - Satellite encryption/authentication
- Optical time transfer
  - More resilient to ionospheric effects than RF (~$1/f^2$)
  - CNES T2L2 (2008), hosted payload on Jason-2
- CHOMPTT objectives:
  - <200 ps time transfer error (6 cm)
  - <20 ns clock drift after 1 orbit (6 m)
  - Real time clock update

GPS Constellation

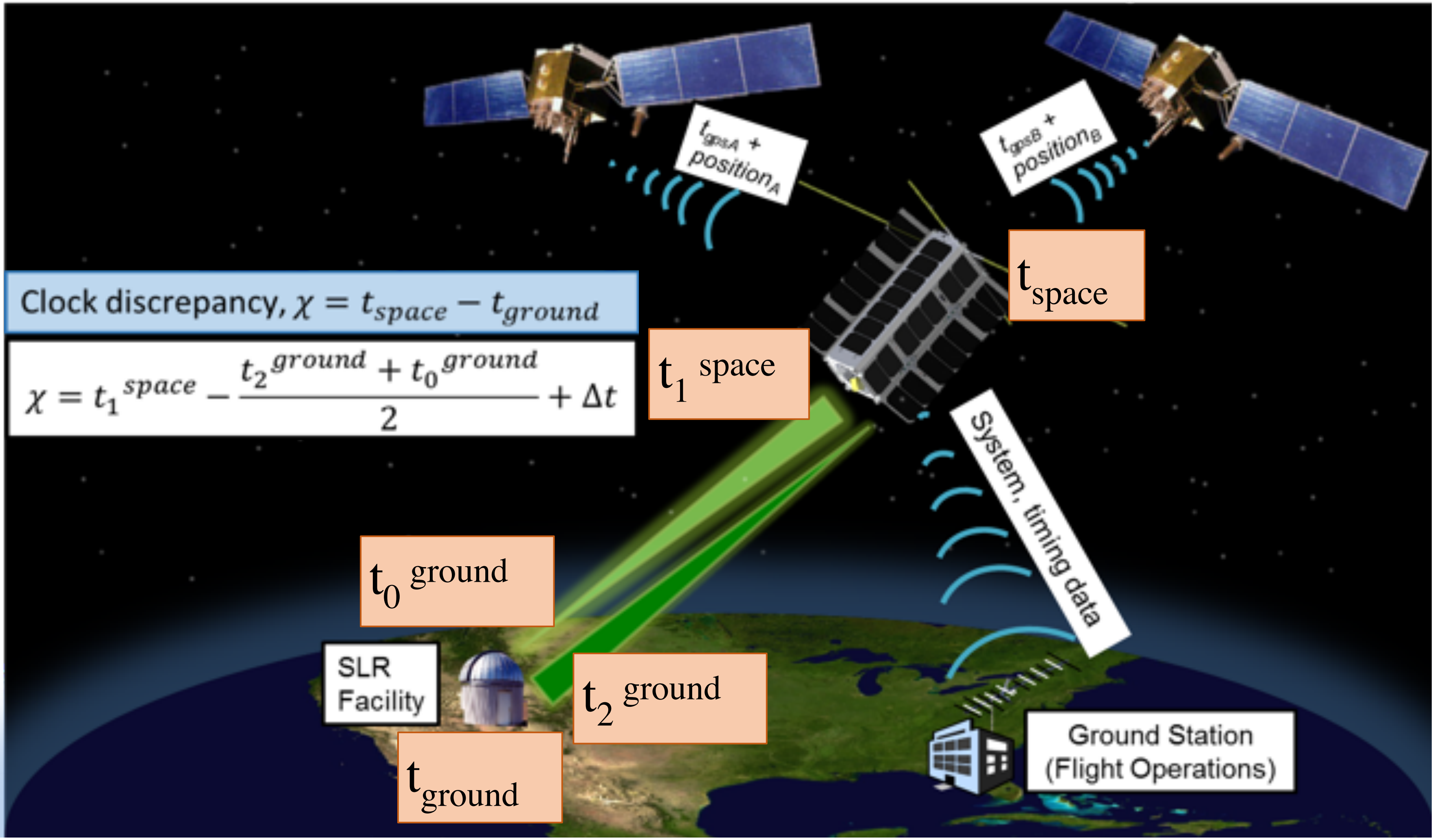
Gravity Probe A (1976)

Common View

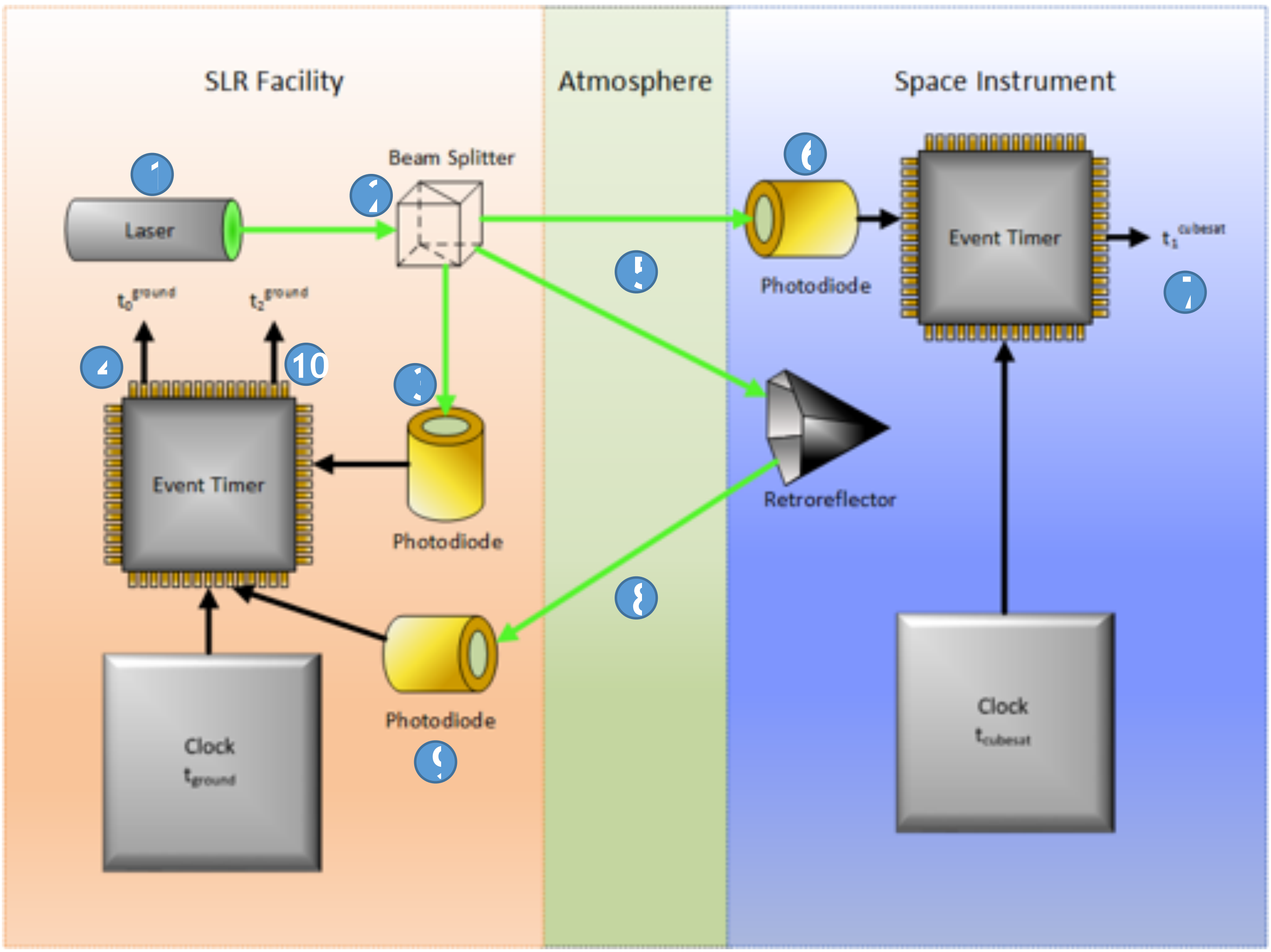
Non-common View

T2L2 mission [P. Guillemot et al 2006]

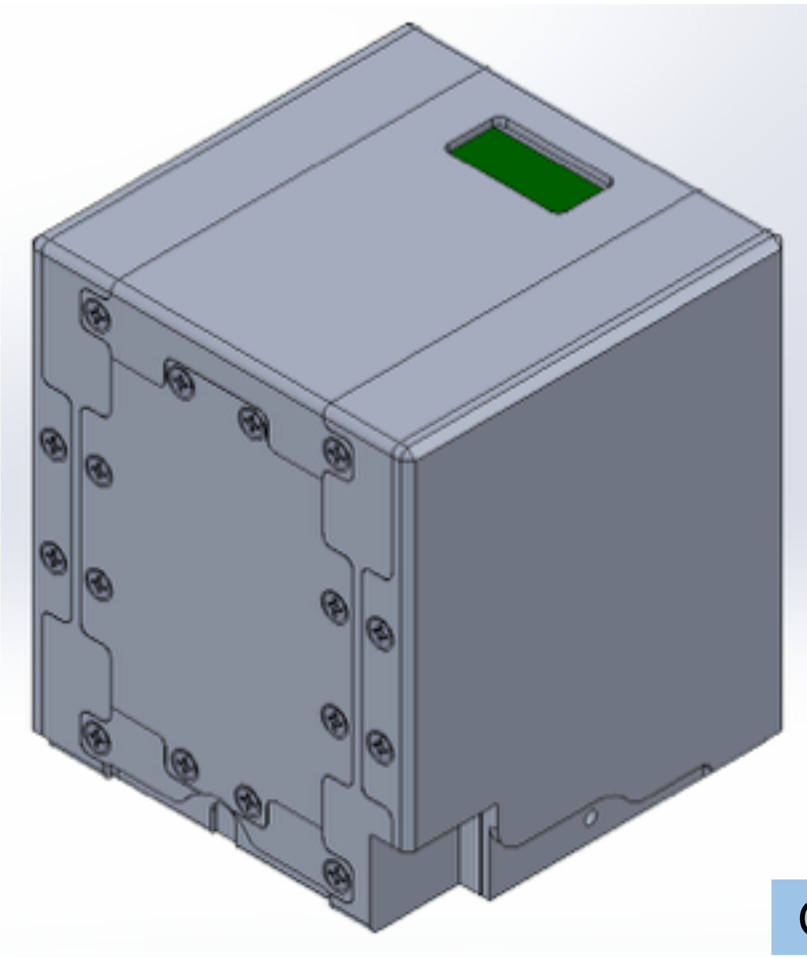
Time Transfer

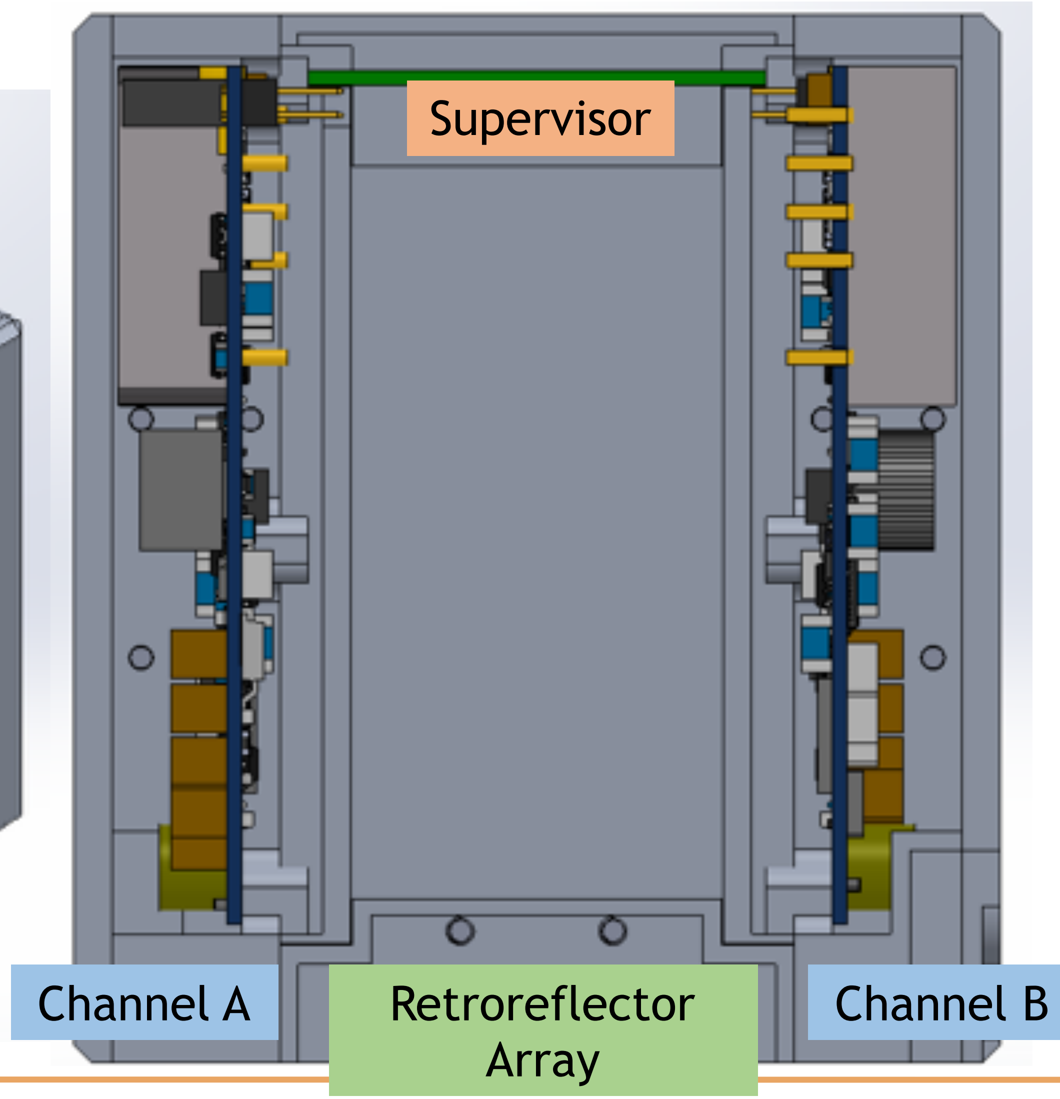


Optical Precision Time-transfer Instrument (OPTI)

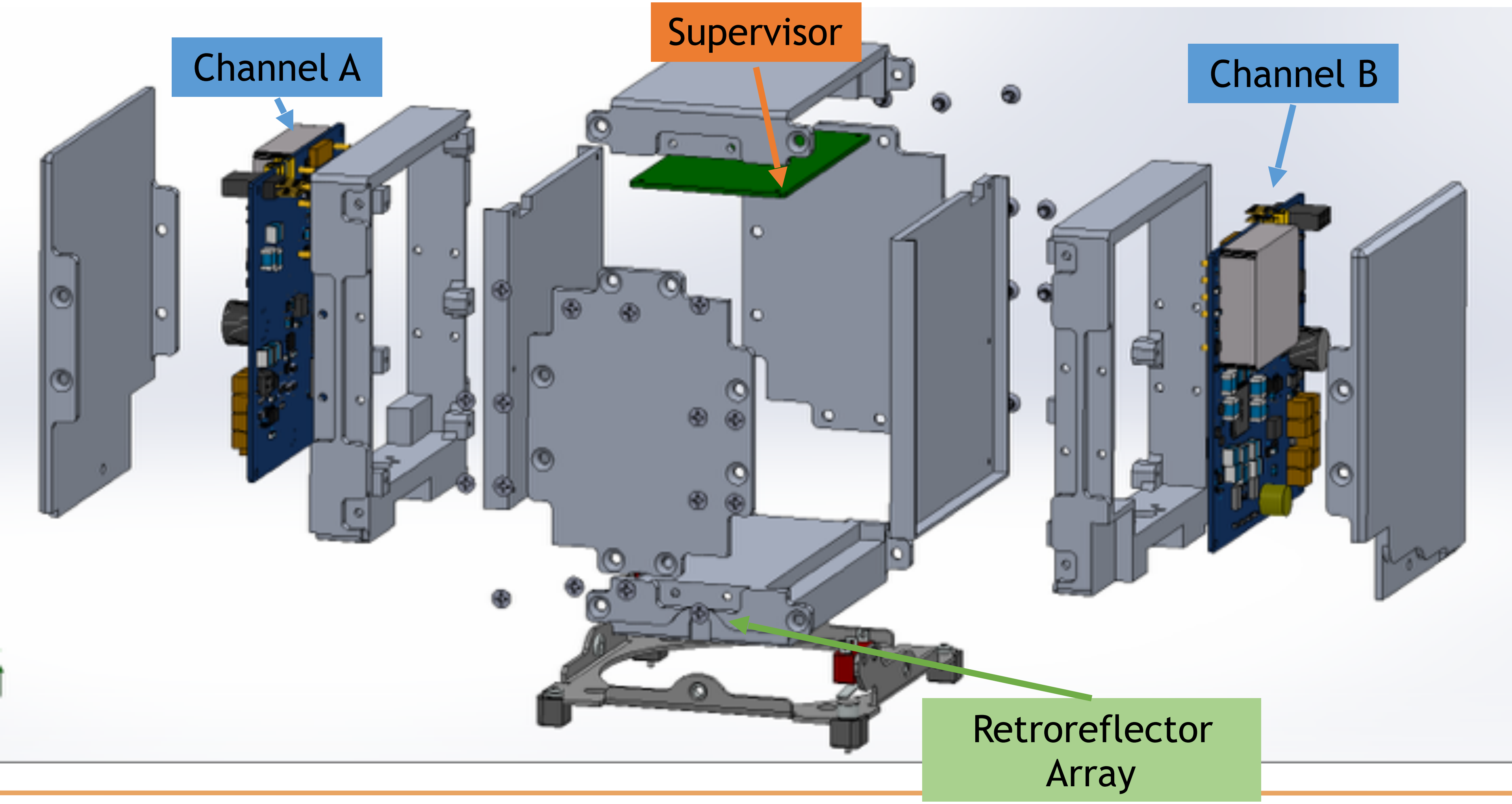


OPTI Flight Configuration

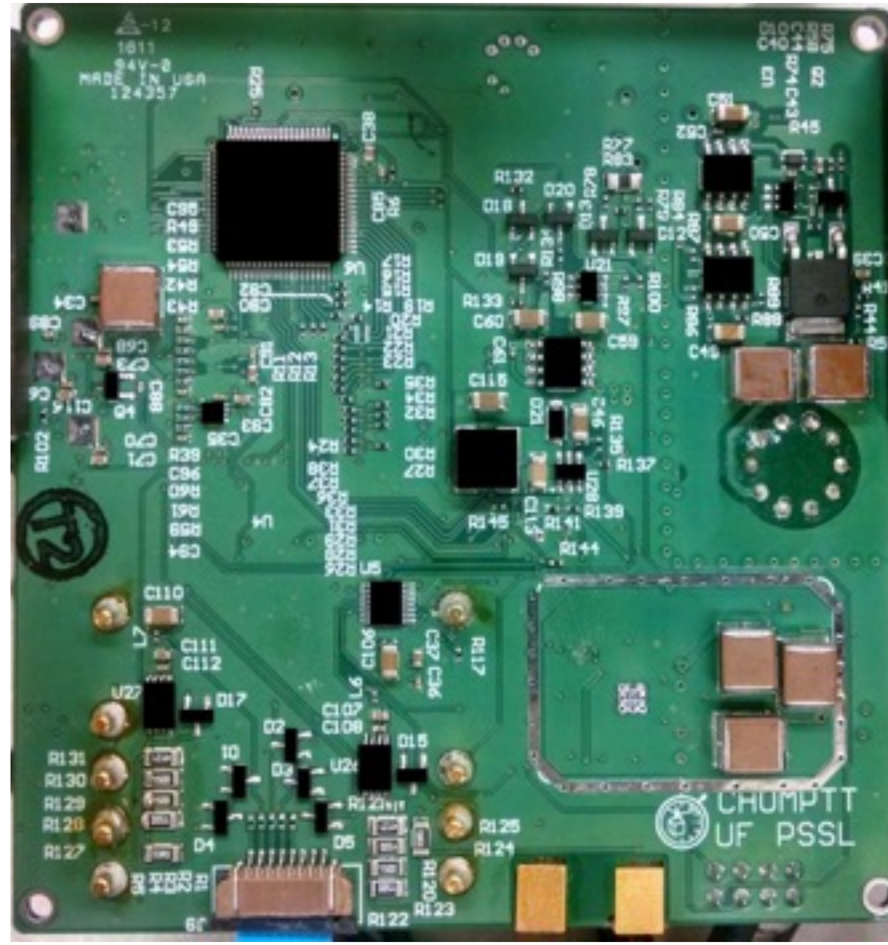




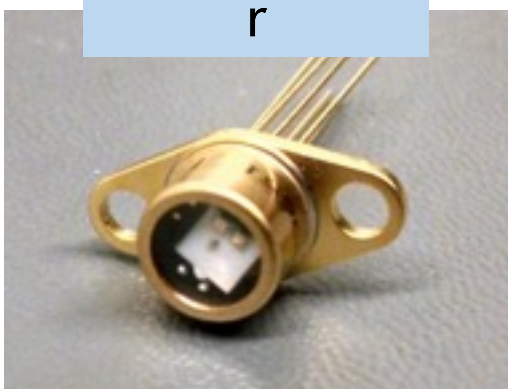
OPTI Flight Configuration

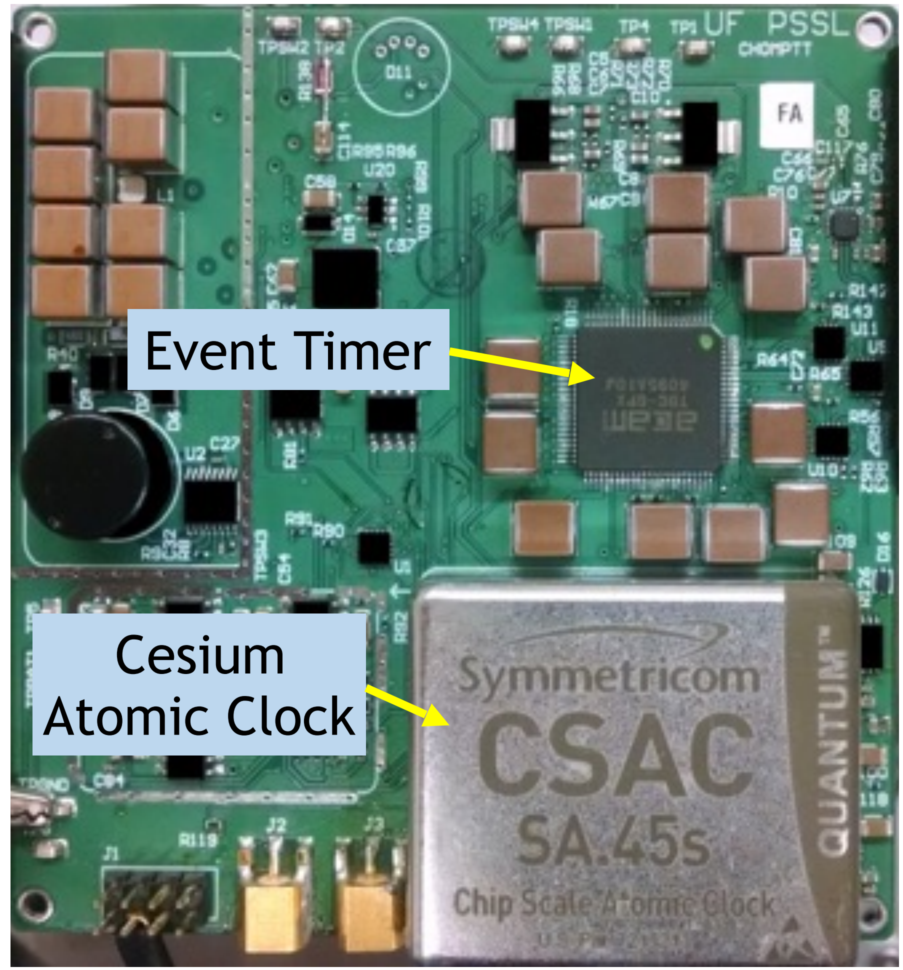


OPTI Engineering Model

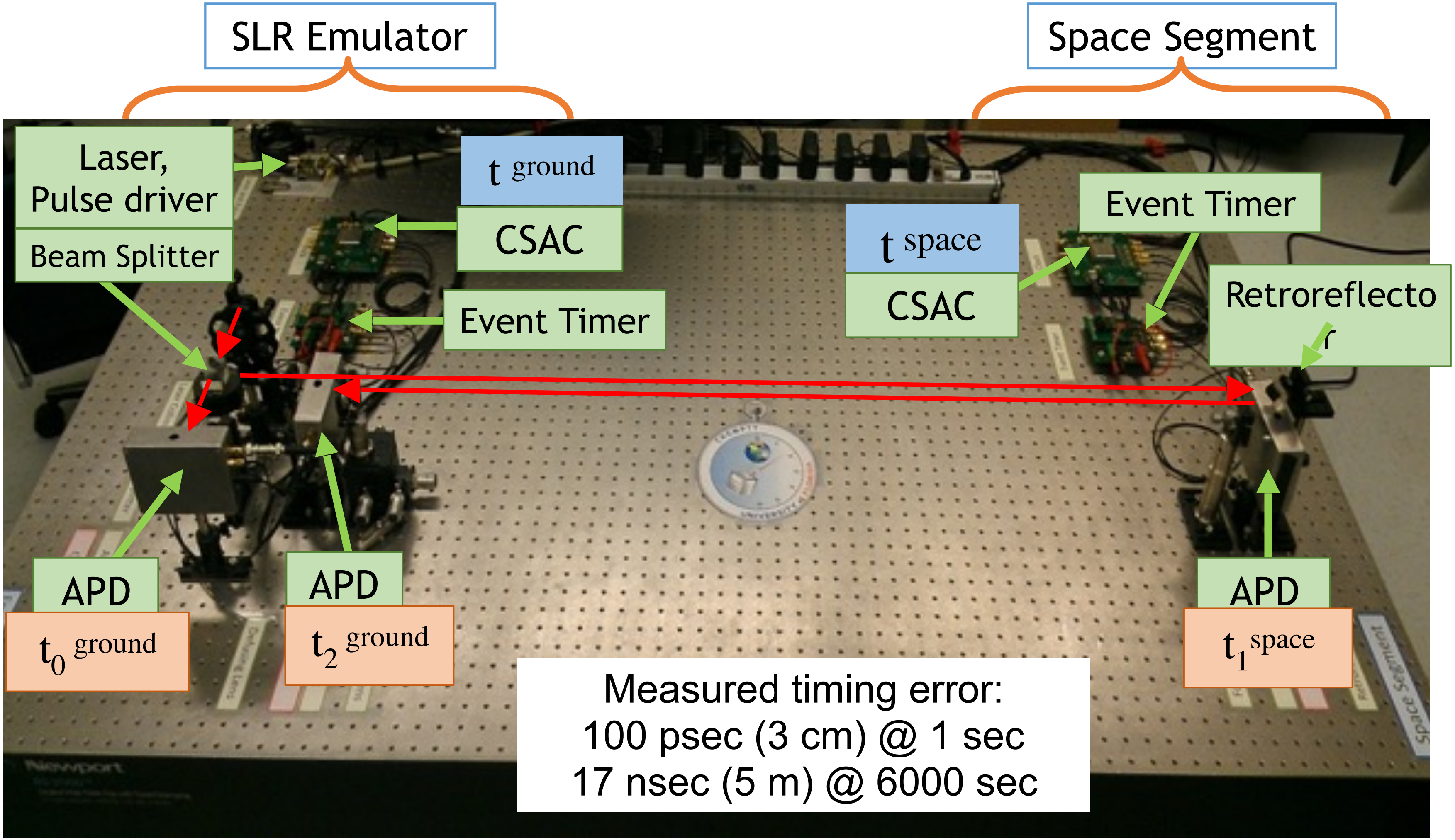


Key Hardware



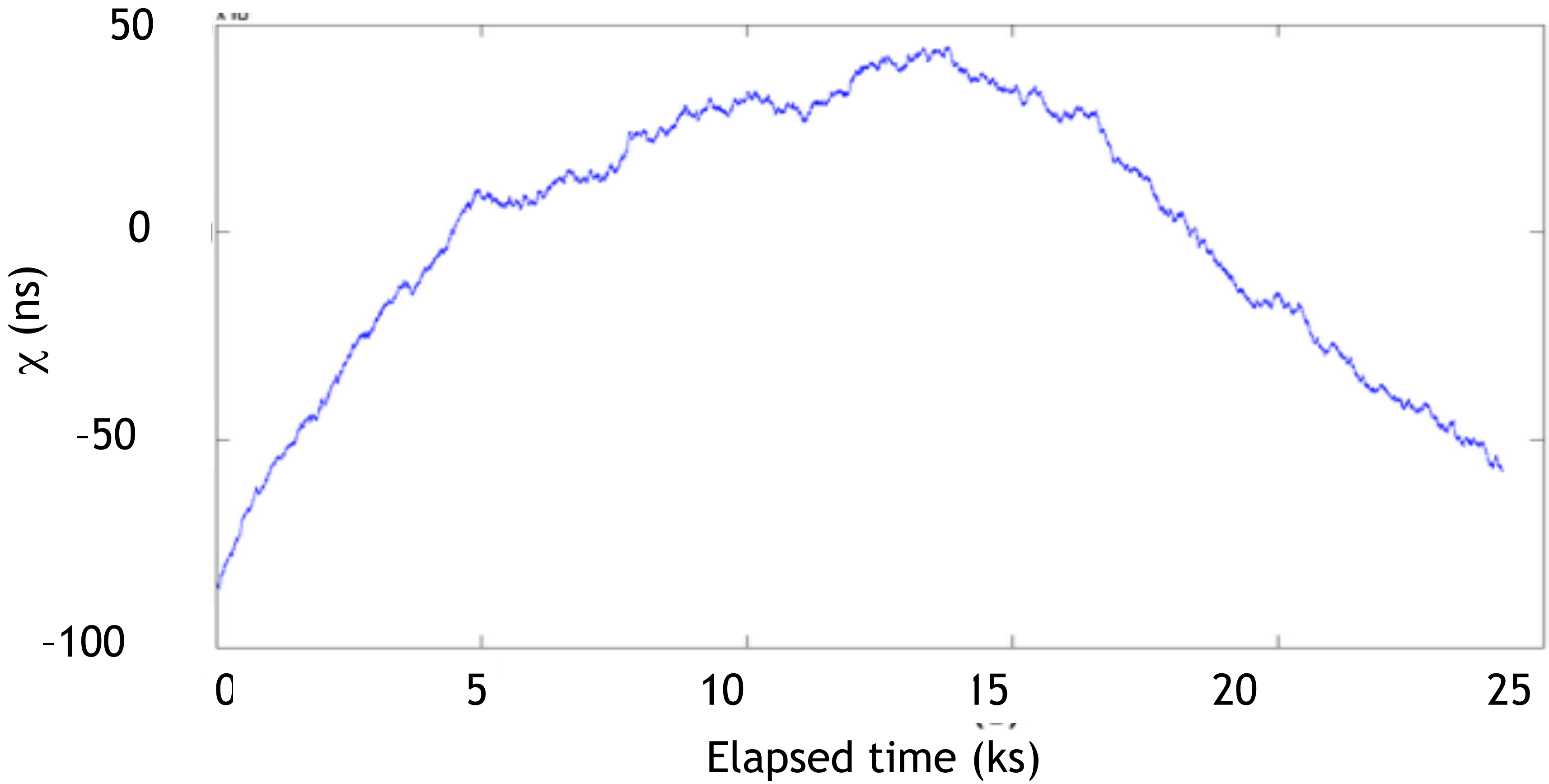


OPTI Time Transfer Demo

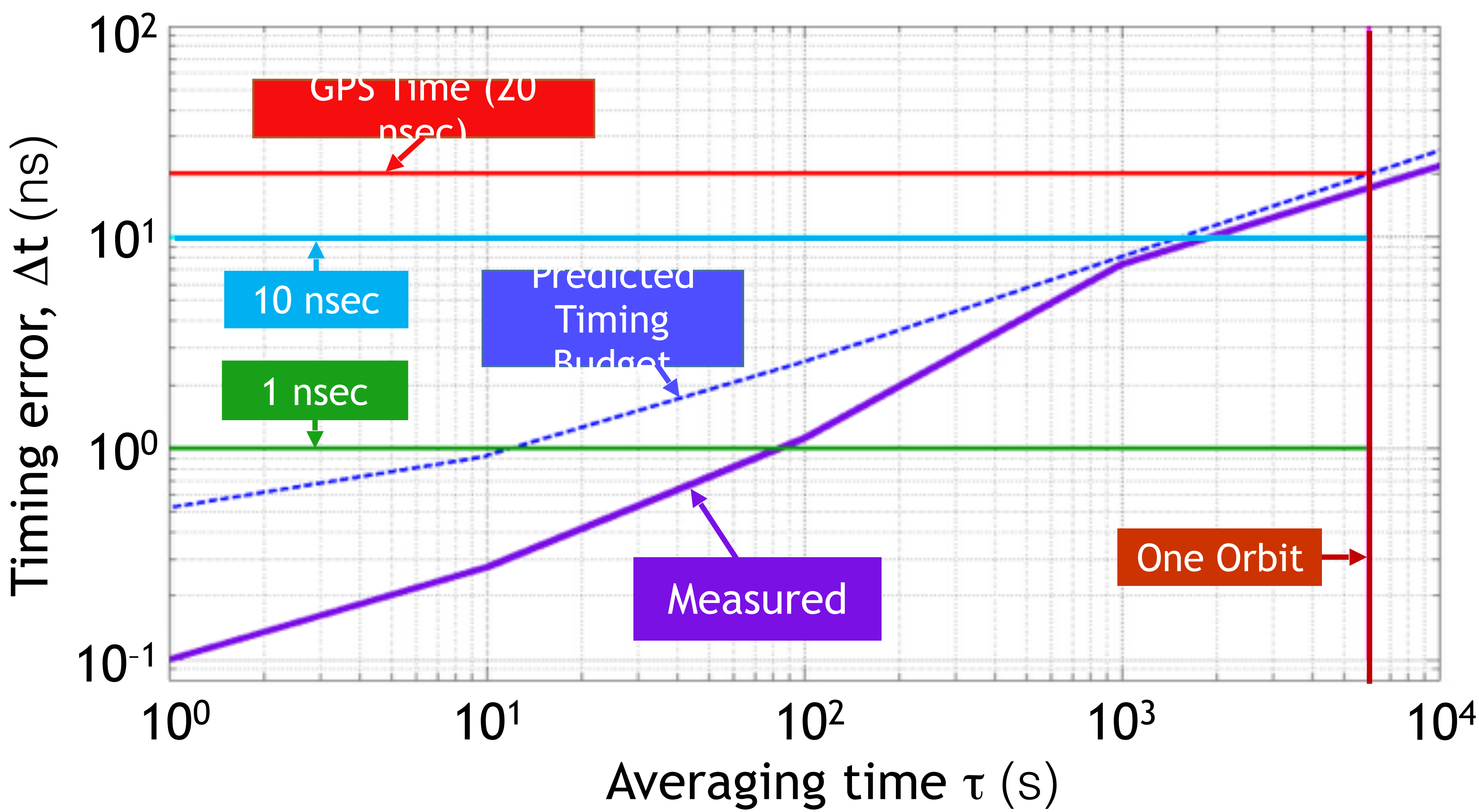


Measured Performance

Clock difference (2 CSACs) measured using OPTI breadboard



Timing Error Budget

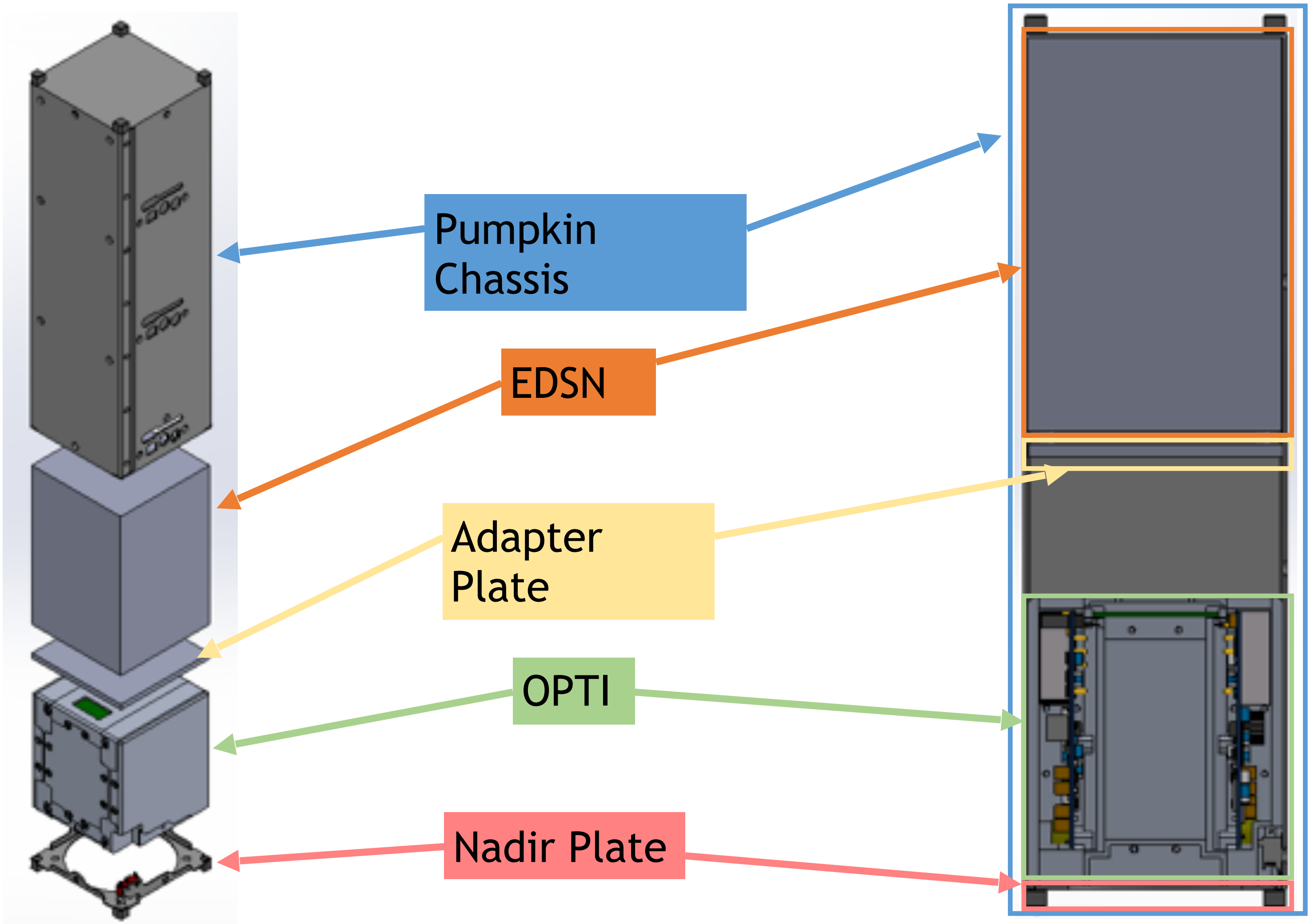


High Altitude Balloon Testing

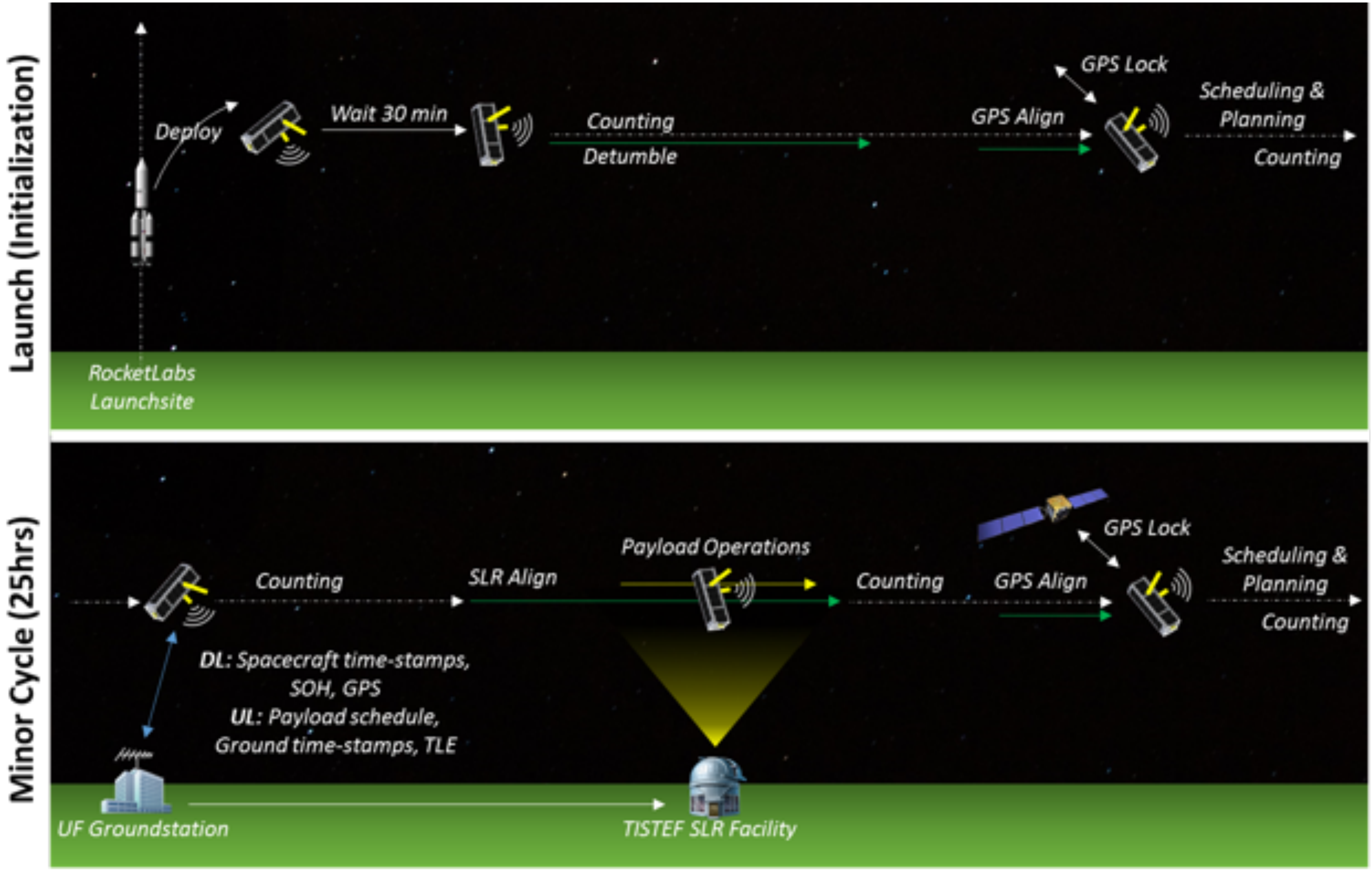
- ~100,000 ft. for 6+ hours
- Successful OPTI operations in near-space environment
- Obtained system health data
- Successful power cycle test

OPTI View in Space

Satellite Overview



Concept of Operations



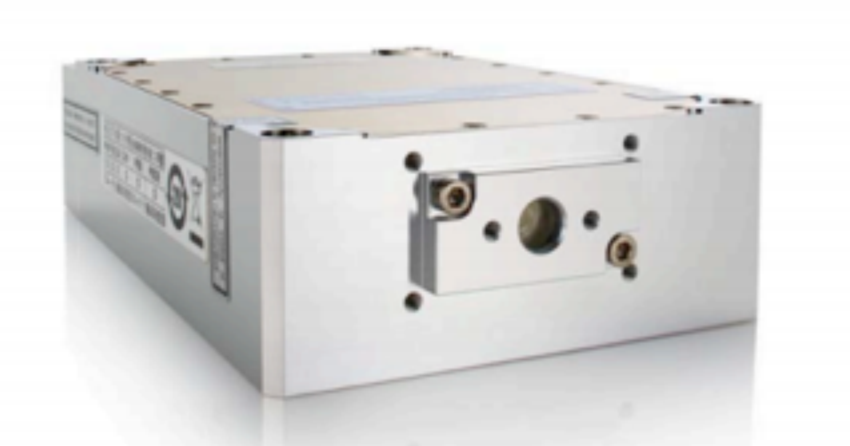
Satellite Laser Ranging Facility

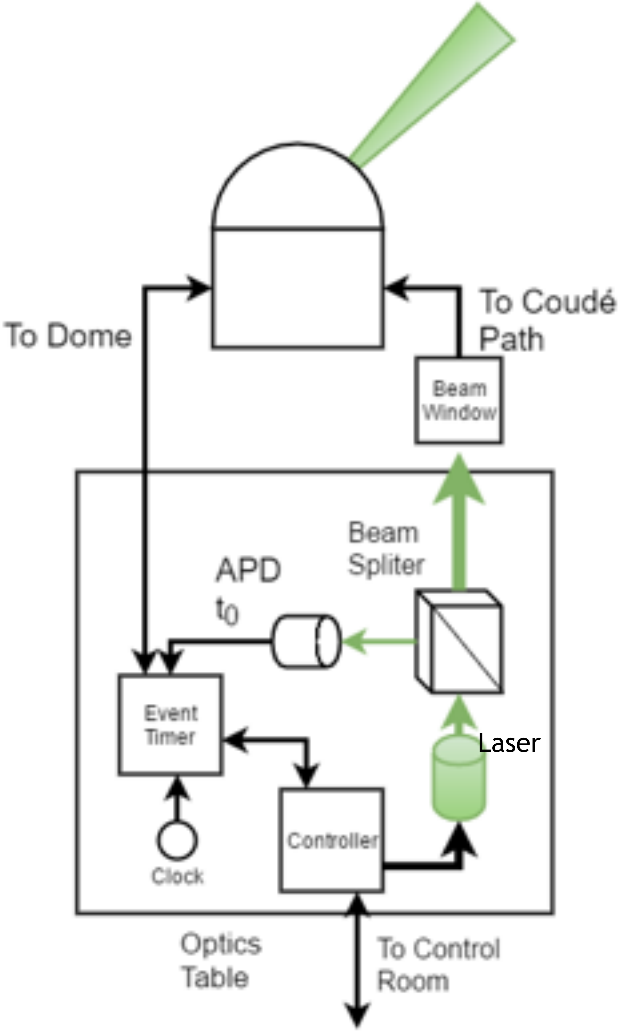
- Townes Institute Science & Technology Experimentation Facility (TISTEF) managed by UCF
- 50 cm satellite tracking telescope
  - Optical Beacon on CHOMPTT
- 1 km testing range

TISEF (Kennedy Space Center)

Satellite Laser Ranging Facility

- Laser: Coherent Flare NX
  - 1030 nm
  - 500 µJ
  - 1 ns pulses
  - 2 kHz repetition rate





Schedule

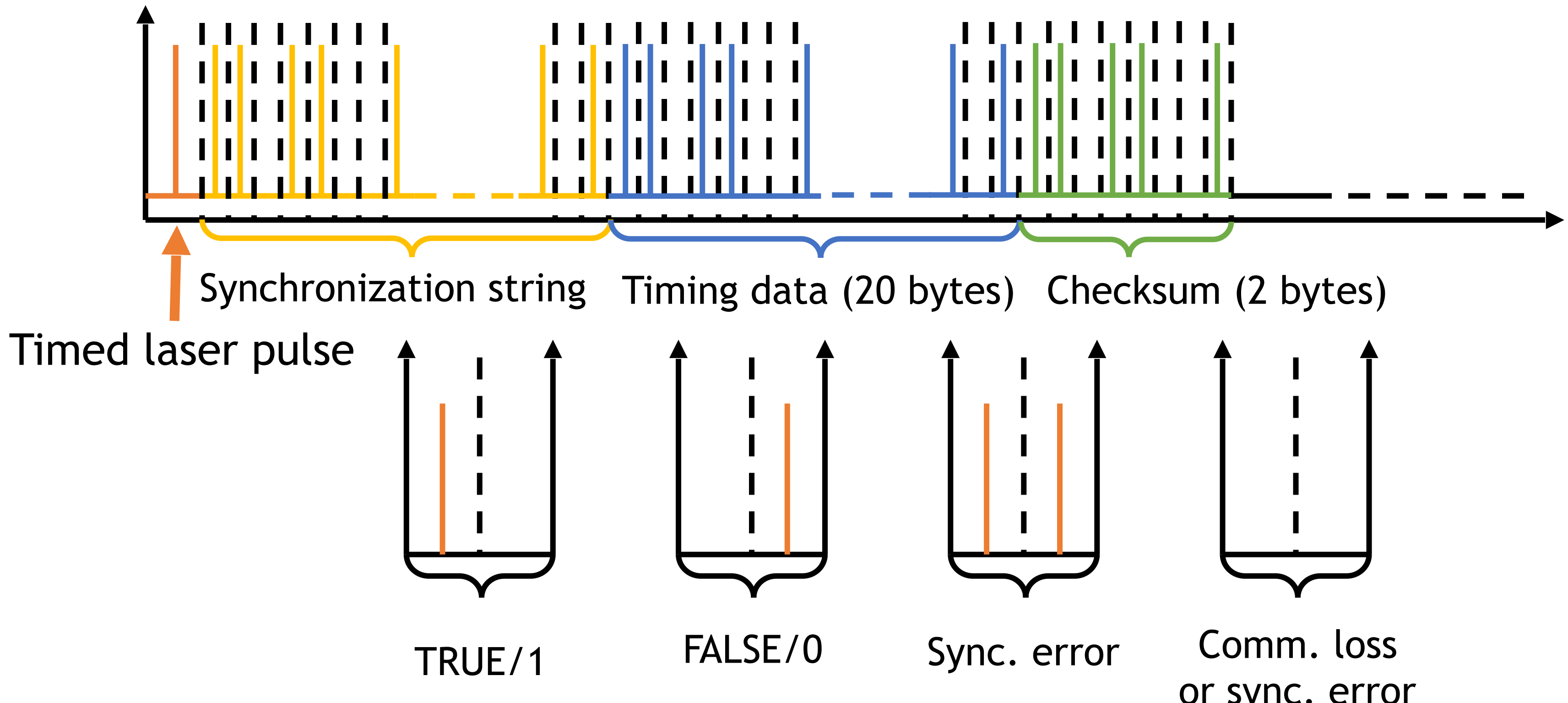
- Testing OPTI Engineering Model @ TISTEF
  - *Summer 2016*
- Integrate EDSN + OPTI
  - *Fall 2016*
- CubeSat delivery
  - *March 2017*
- ELaNA XIXlaunch
  - *June 2017*

Sponsors and Collaborators

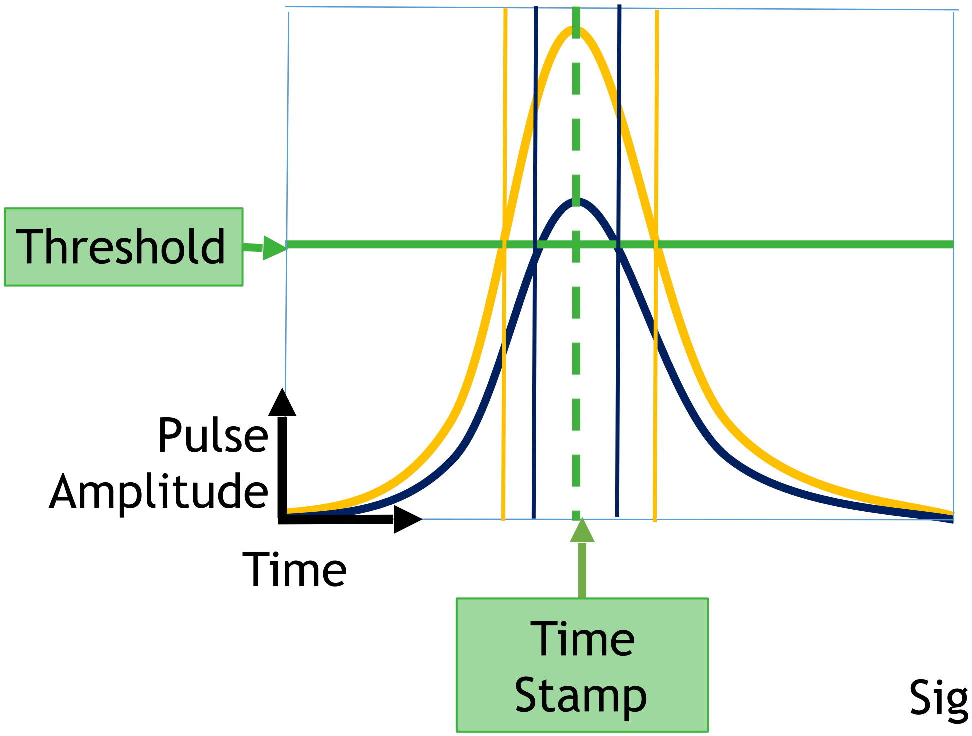
Backup Slides

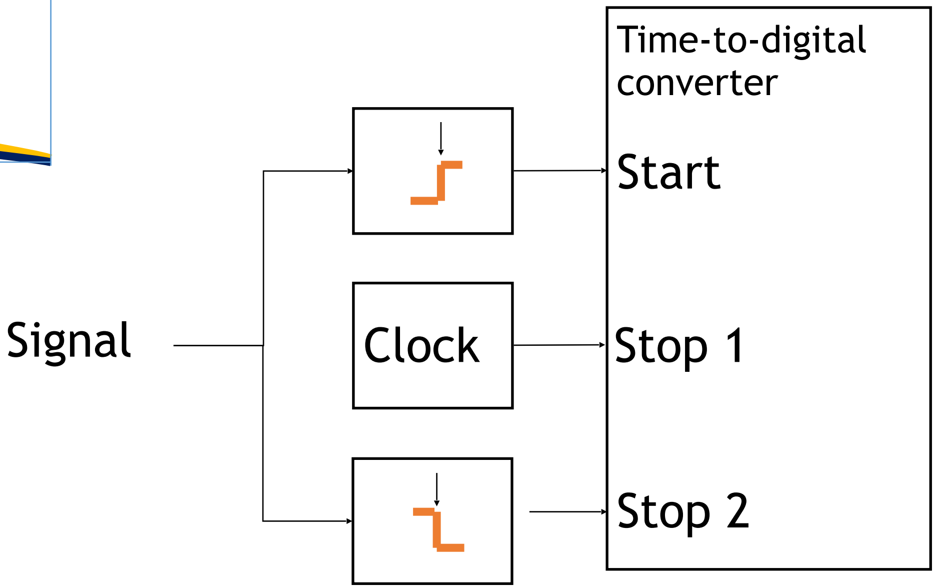
Laser Communication

- 2-Pulse Position Modulation (2 slots per pulse)
- High precision measurement only on the first pulse
- Synchronization string provides phase and rate for communication, masks SLR Delay



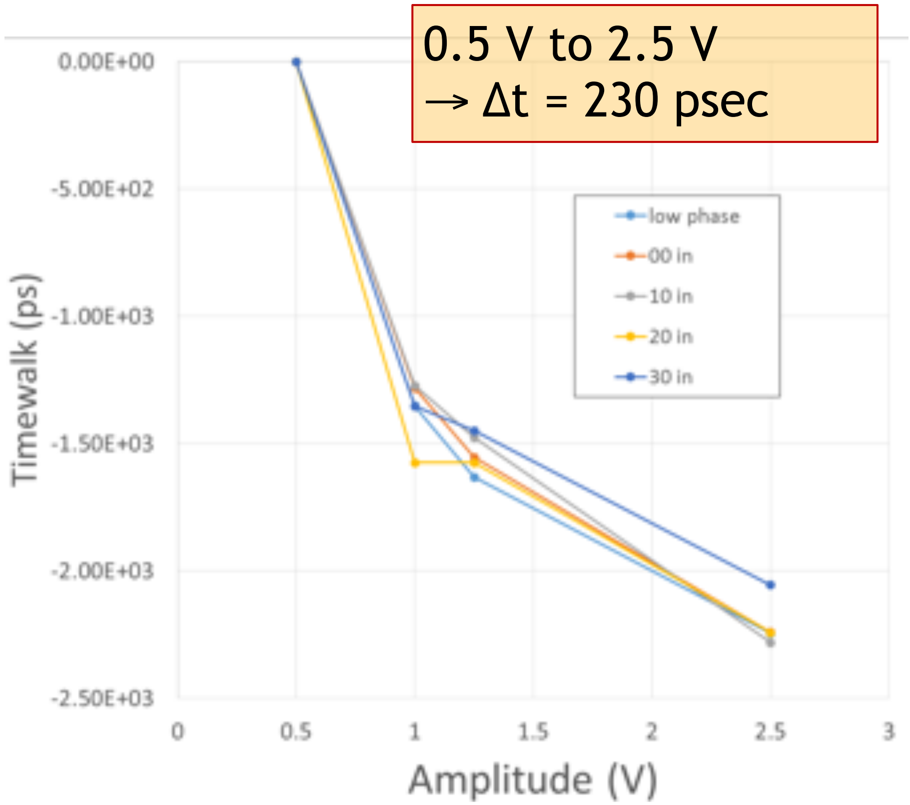
Timewalk Correction





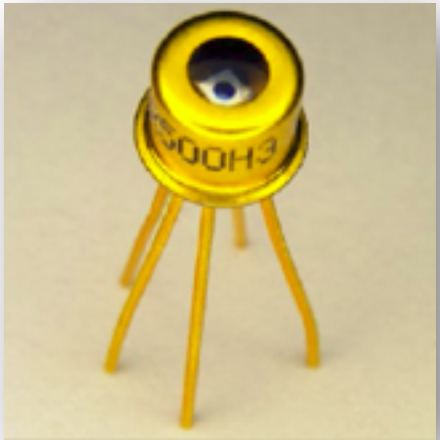
Timewalk Correction

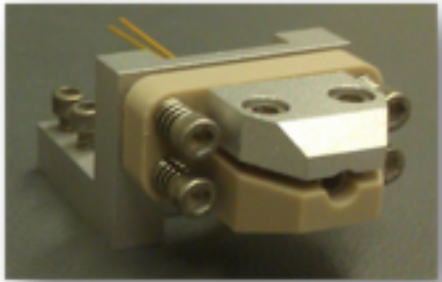
- Apparent timing variations due to pulse amplitude variations
  - Atmosphere, attitude, range, …
- Solution: Time both rising and falling edges of pulse

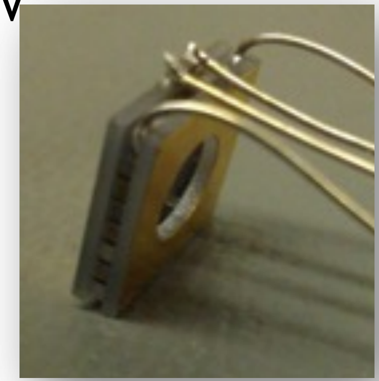


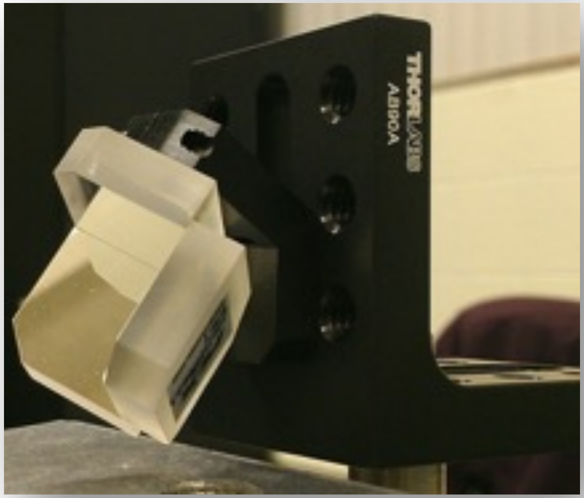
Photodetectors

- 2 avalanche photodiodes:
  - InGaAs for 1064 nm, 150 ps rise time
  - Si for 532 nm ps rise time
- Photodetector in linear mode
- Temperature regulated by Thermal-Electric Coolers
- Photodetectors are fiber-coupled
- Pulse sent back by a PLX retroreflector
  - 25 mm diameter, 50° FOV
  - Space Capable



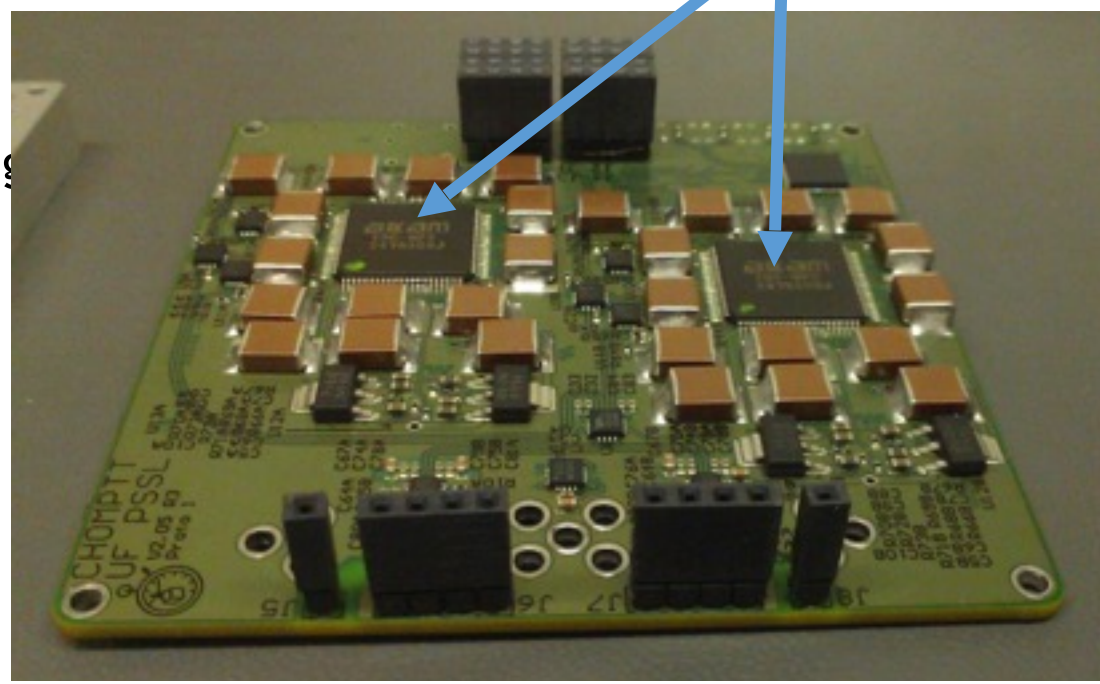






10 ps Event Timers- Fine Time

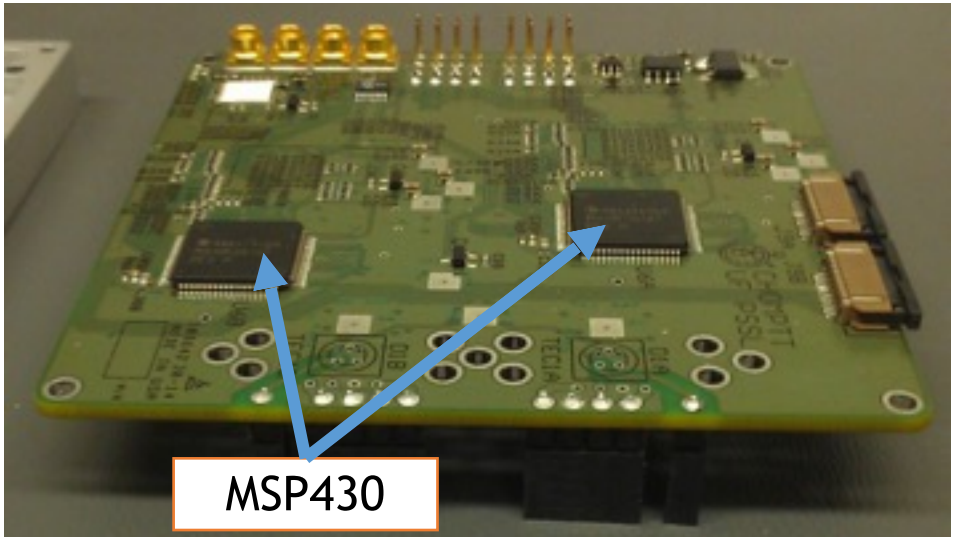
- 2 independent channels
- Fine time on short intervals, course time on long duration
- Time-to-digital converter- measures fine time
  - Integrated, off-the-shelf: Acam TDC GPX
  - Measurement based on propagation delays
  - Autonomous calibration using Delay Lock Loops
  - Low power (<150 mW)
  - 10 ps single shot accuracy (12 ps measured)



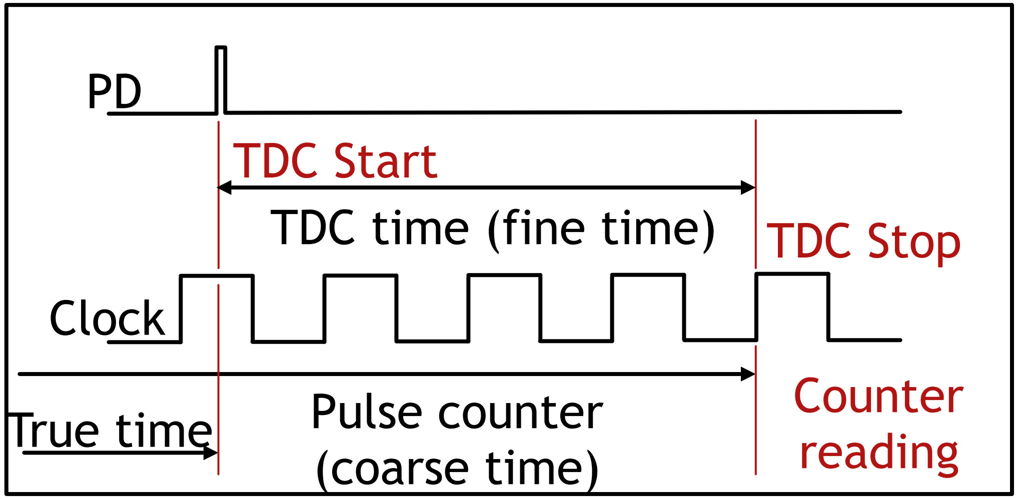
10 ps Event Timers- Fine Time

Counter-measures coarse time

- Ti MSP430 microcontroller used as counter



- TDC and counter are synchronized on a chosen clock rising edge
  - Within 7 μs TDC range



Mission Overview

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

- CHOMPTT is a precision timing satellite equipped with atomic clocks synchronized with a ground clock, via laser pulses
  - Optical frequencies reduce ionospheric time delay uncertainties relative to radio frequencies
  - Robust against signal interference / jamming
  - Payload with low size (1U), mass (1 kg), and power (7 W)
  - Real-time clock phase & frequency corrections via modulated laser pulses

Objectives

- Primary Objective
  - Demonstrate low cost, precision time transfer between an atomic clock on the ground and one on a CubeSat to 200 psec (short term)
- Secondary Objectives
  - Achieve timing accuracy of 1 ns over 1 orbit (long term)
  - Onboard real-time calculation of CubeSat clock discrepancy
  - Compare CubeSat's clock to GPS time
  - Utilize CubeSat to compare two spatially separated ground atomic clocks

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