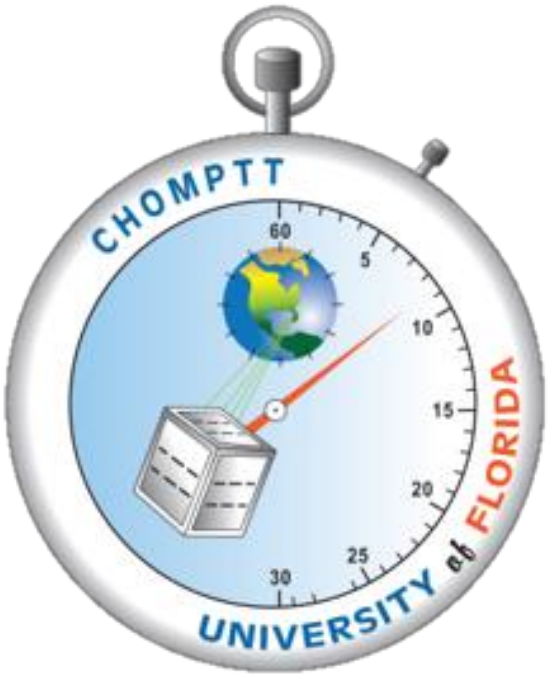
The CHOMPTT Precision Time Transfer CubeSat Mission

Nathan Barnwell, Lucas Bassett-Audain, Paul Buchman, Maria Carrasquilla, Leopoldo Caro, David Keister, Olivia Formoso, Seth Nydam, Blake Richards, Paul Serra, John W. Conklin



CubeSat **H**andling **O**f **M**ultisystem **P**recision **T**ime **T**ransfer

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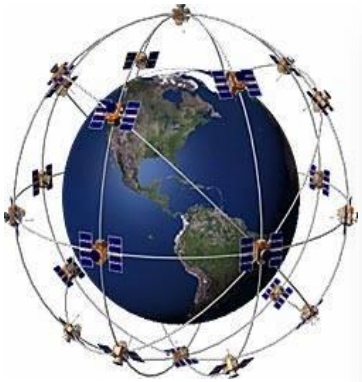
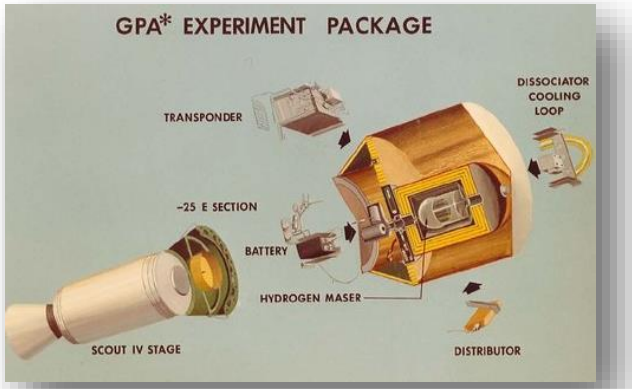
Background and Motivation

- 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

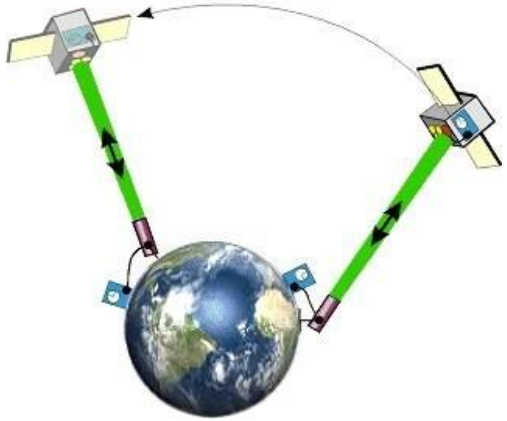


GPS Constellation



Gravity Probe A (1976)

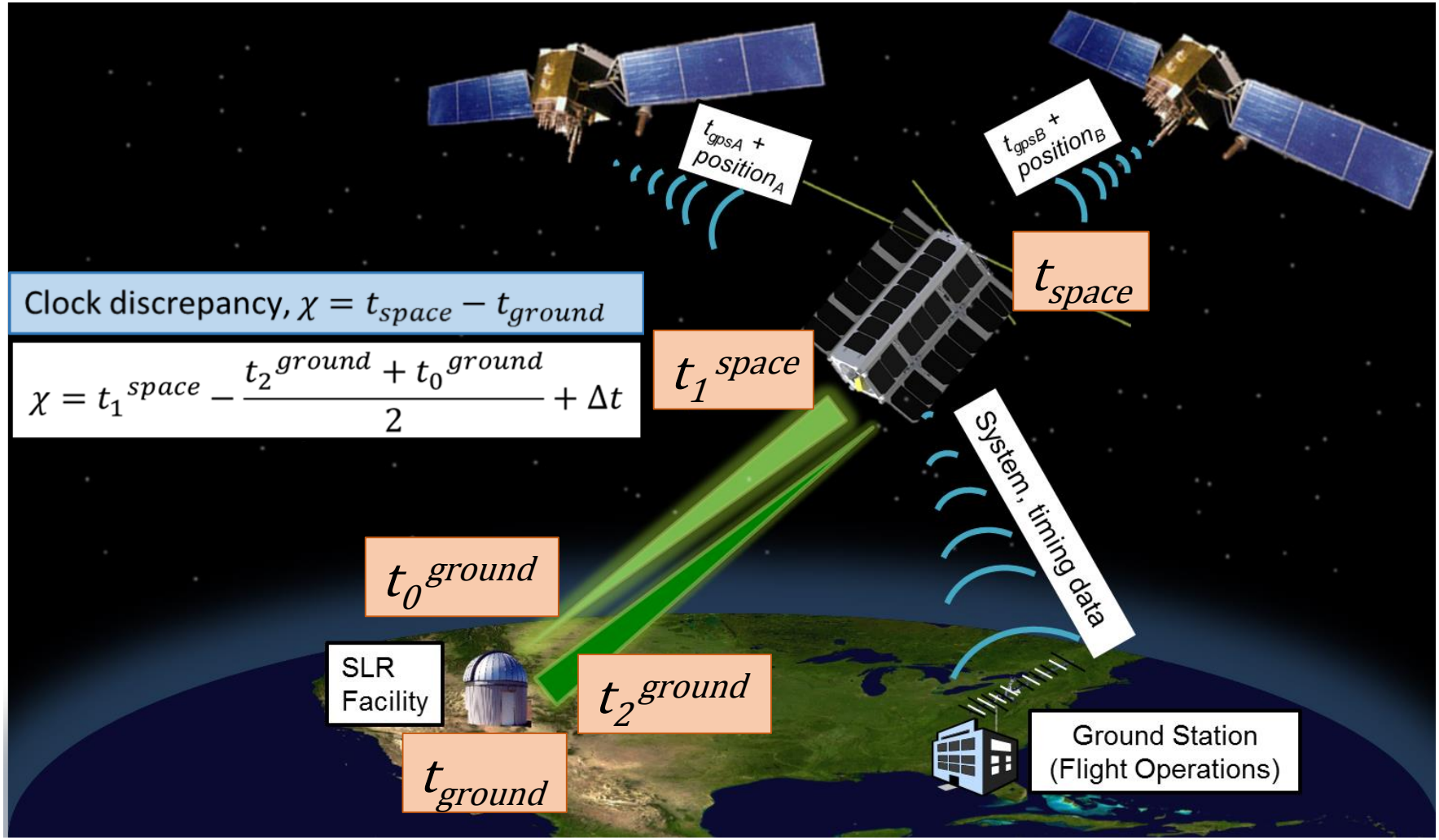
Common View



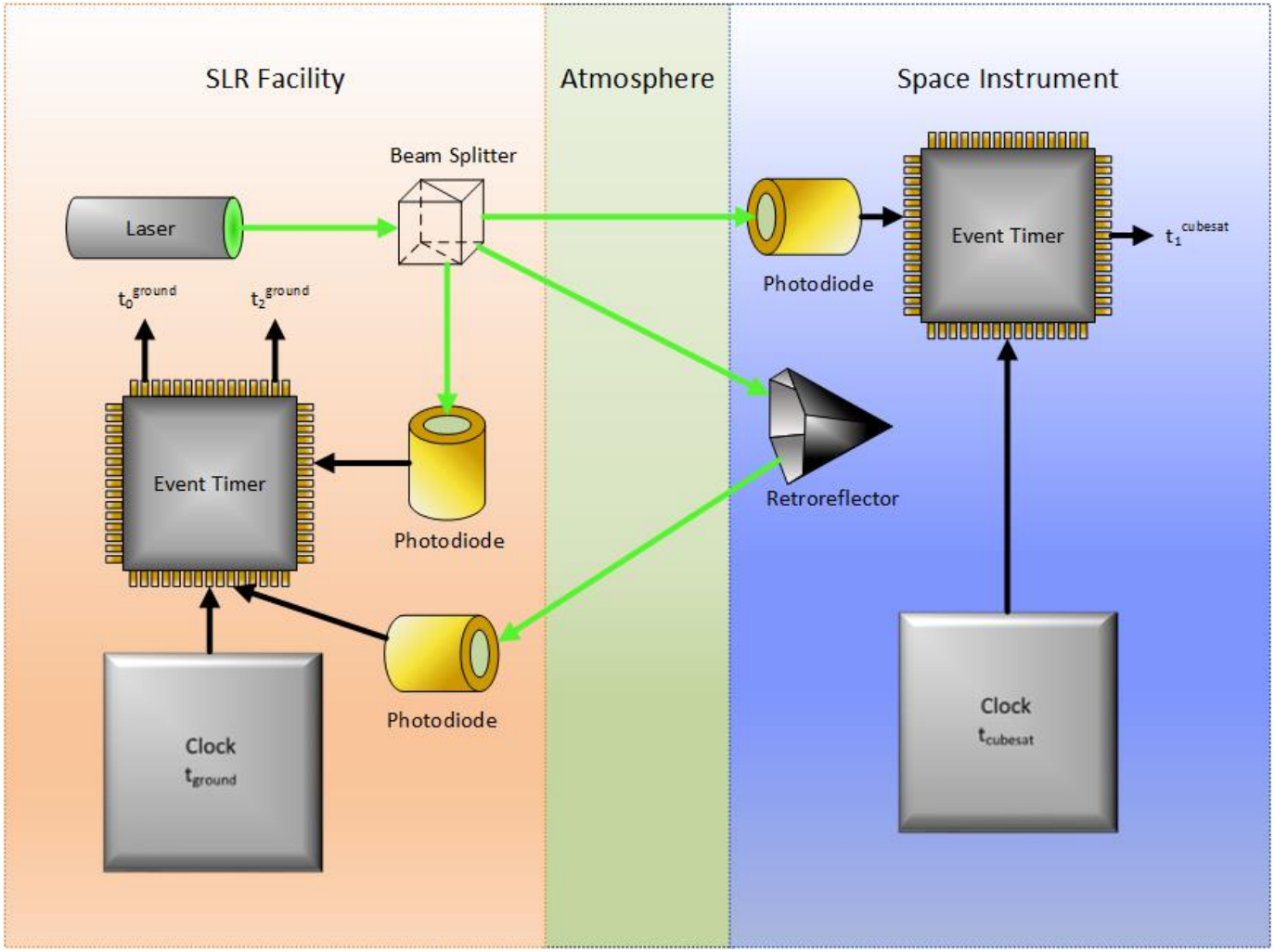
Non-common View

T2L2 mission [P. Guillemot et al 2006]

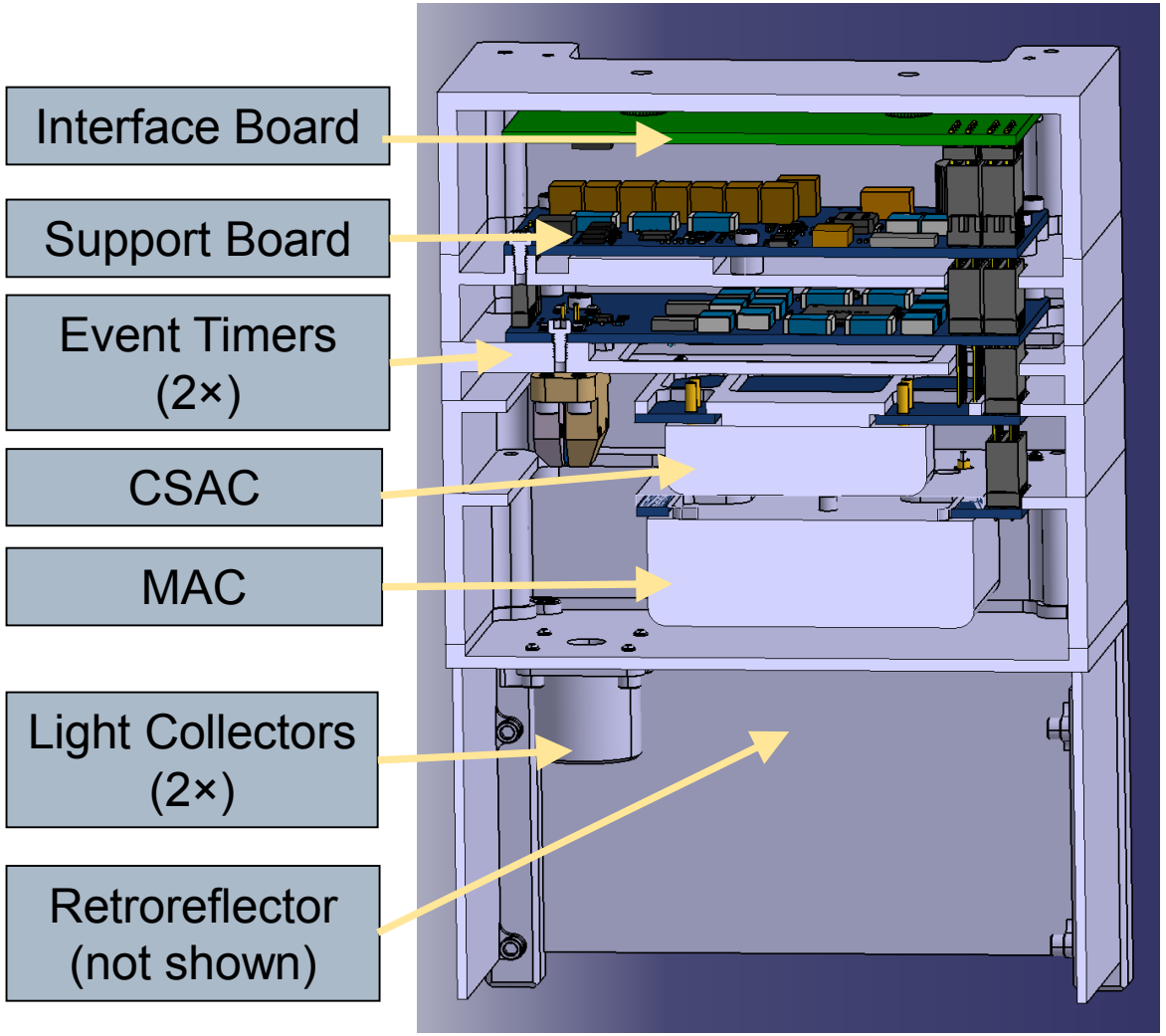
Time Transfer



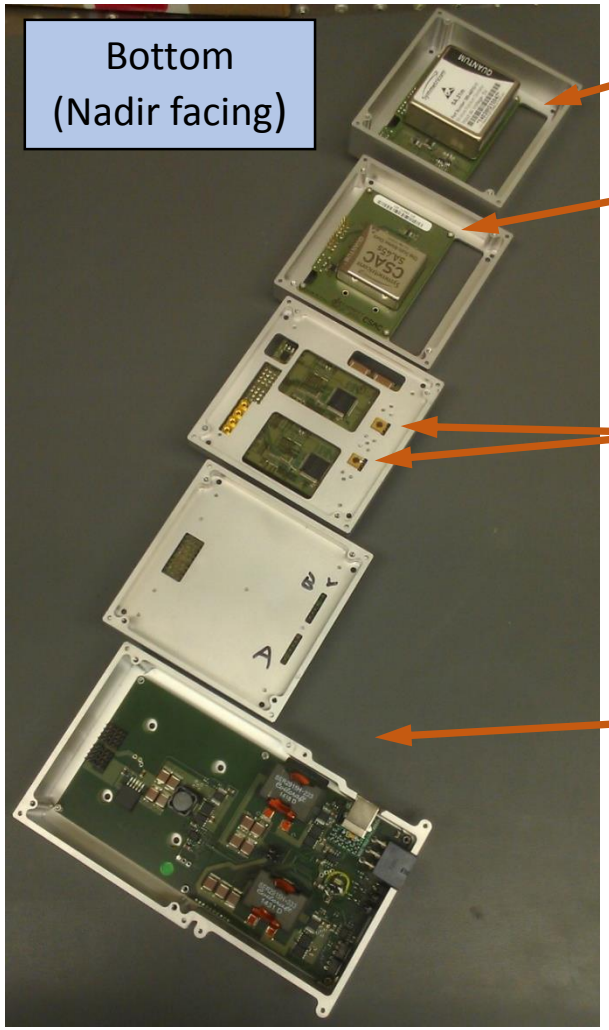
Optical Precision Time-transfer Instrument (OPTI)



OPTI Flight Configuration



OPTI Engineering Model



MAC

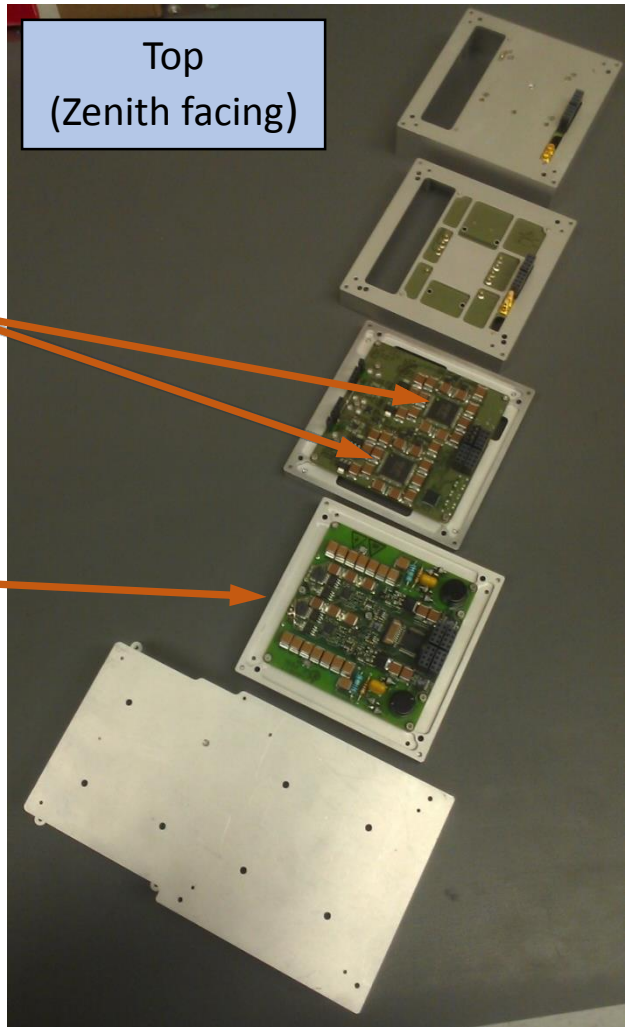
CSAC

Event Timers (2×)

Photodiodes (2×)

TEC controllers and reverse bias voltage

Interface & power regulator
(High altitude balloon configuration)

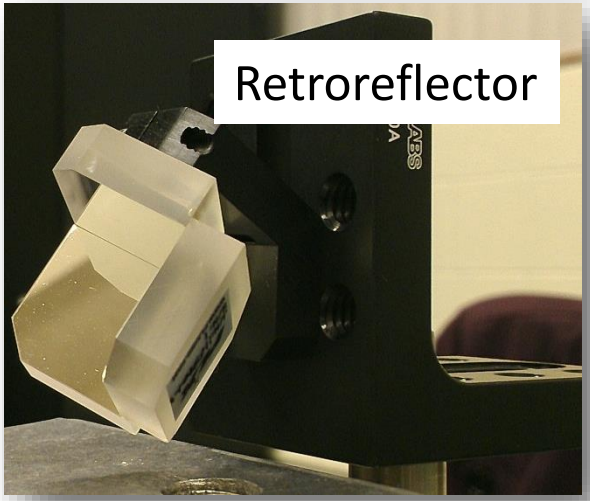


Clocks

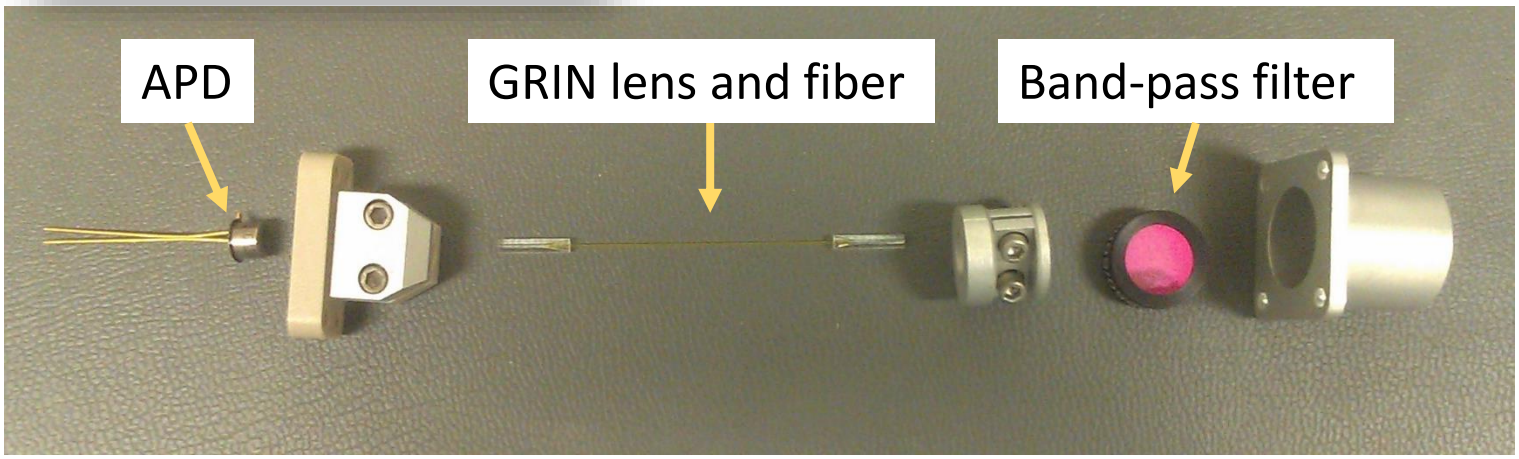
Characteristic	Chip Scale Atomic Clock (CSAC)	Miniature Atomic Clock (MAC)
Standard	Cesium	Rubidium
Allan Deviation (time error)	3.3×10^{-12} @ 6000 s (20 ns)	9.5×10^{-13} @ 6000 s (6 ns)
Power	0.12 W	5 W
Mass	35 g	85 g
Size (LxWxH)	40.64 x 35.31 x 11.42 mm	51 x 51 x 18 mm

Clocks from Microsemi

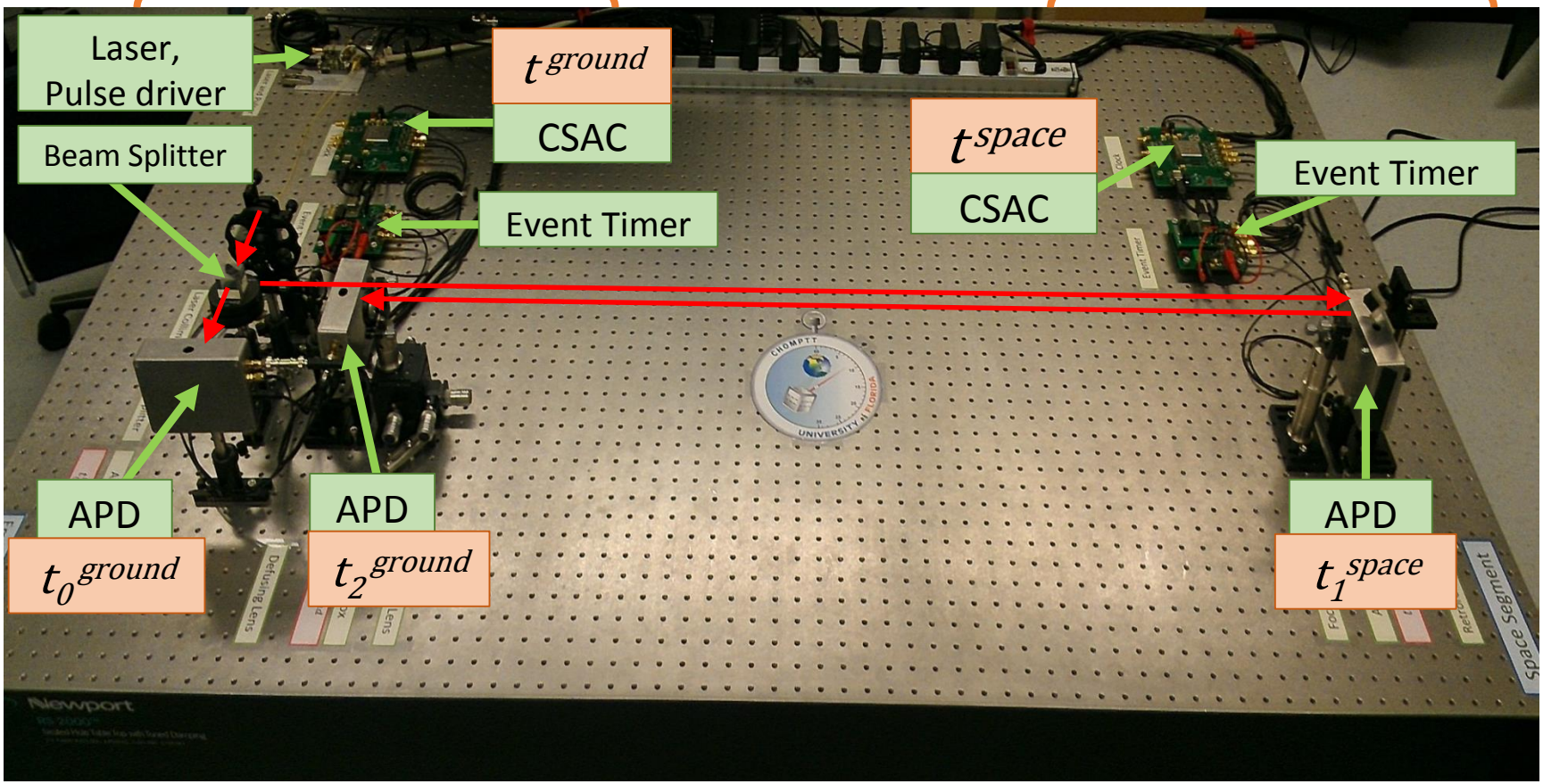
Optics


Retroreflector


GRIN lens and fiber

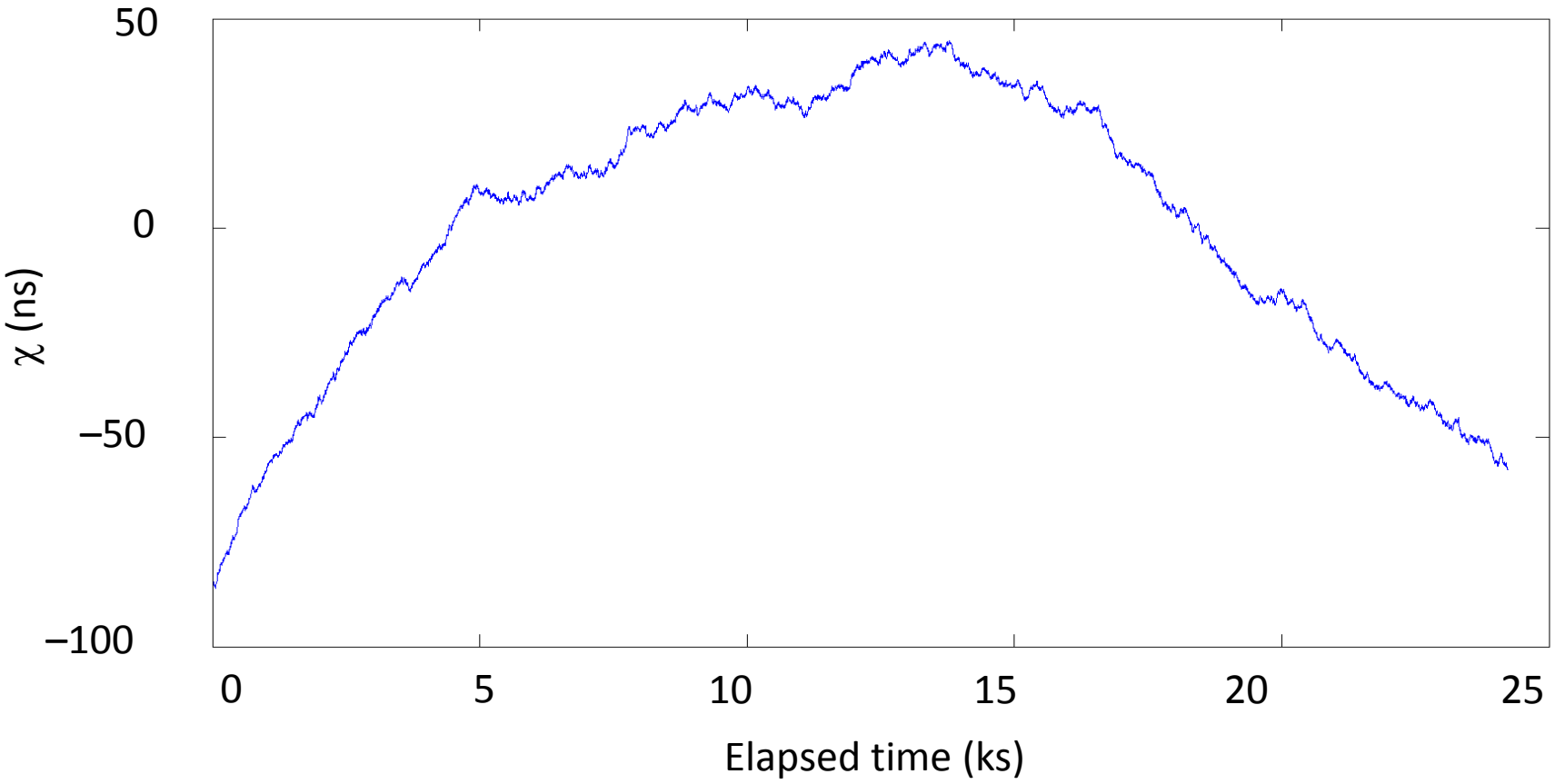

APD
GRIN lens and fiber
Band-pass filter

OPTI Time Transfer Demo

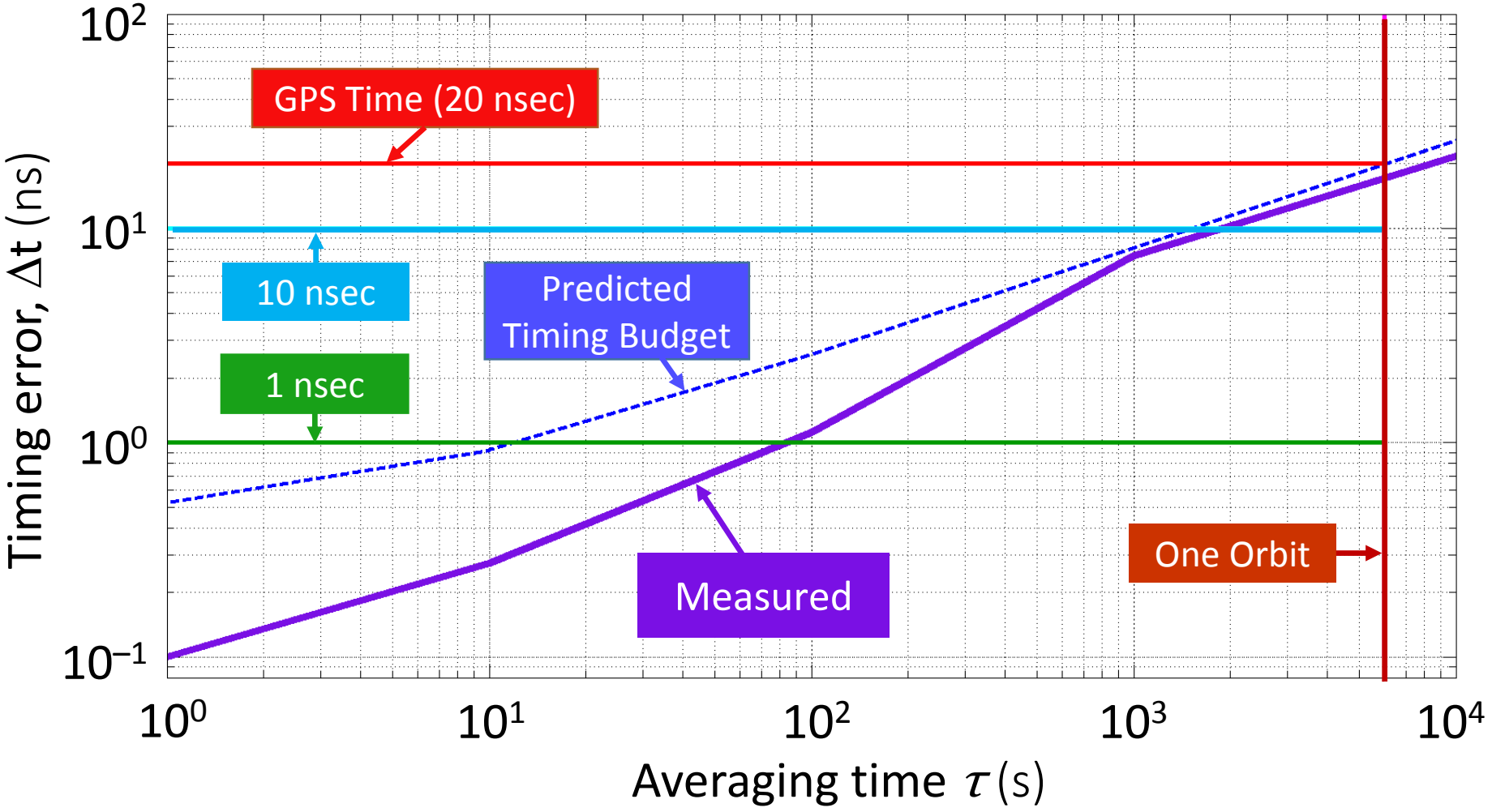


Measured Performance

Clock difference (2 CSACs) measured using OPTI breadboard

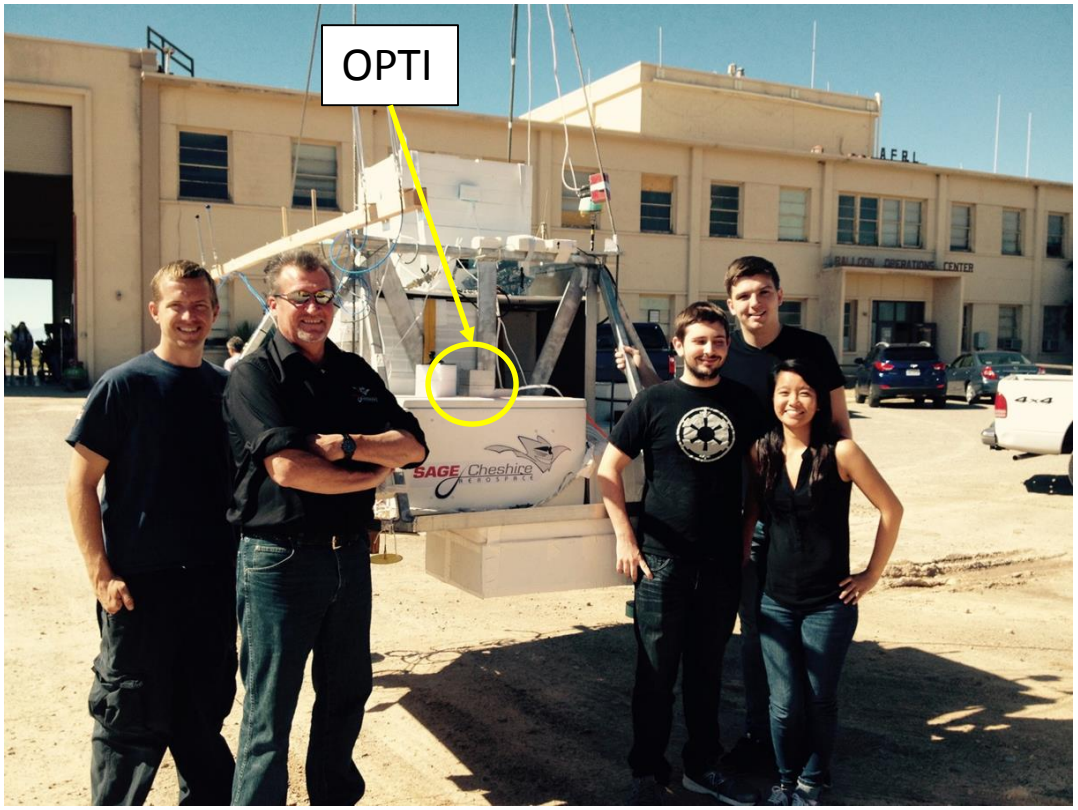


Timing Error Budget



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



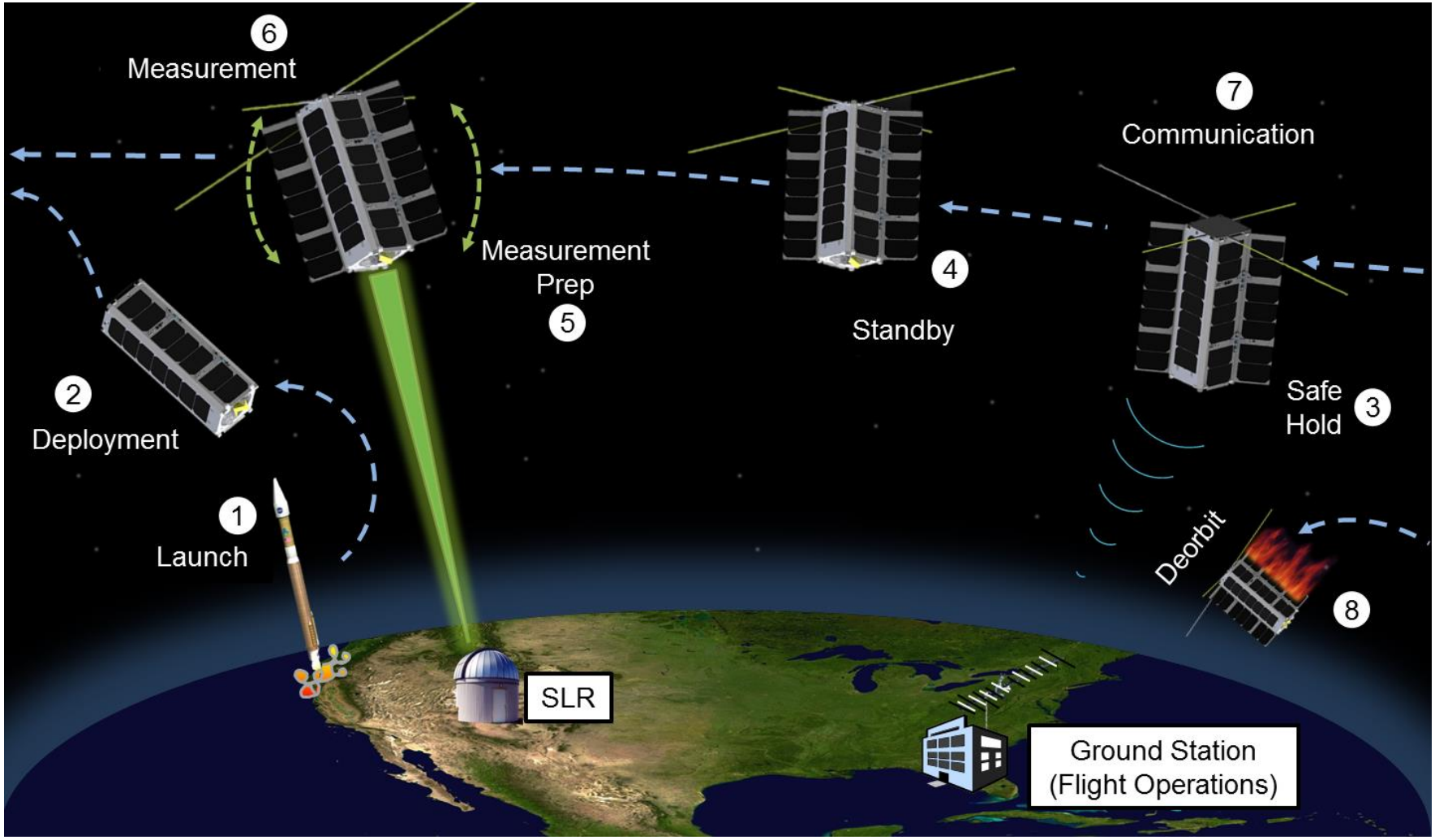
OPTI View in Space

Satellite Overview

UHF turnstile, GPS antennas
CDH (MSP430)
GPS receiver, UHF/VHF radio
Batteries
Power distribution system
ADACS interface electronics
ADACS

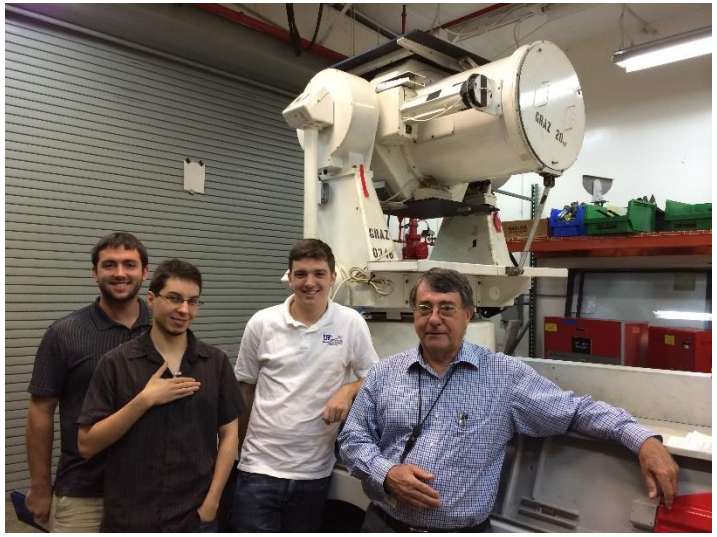
OPTI
Interface electronics
High voltage, TEC controllers
Event timers, clock counters
CSAC
MAC
Retroreflector and light collectors

Concept of Operations



Satellite Laser Ranging Facility

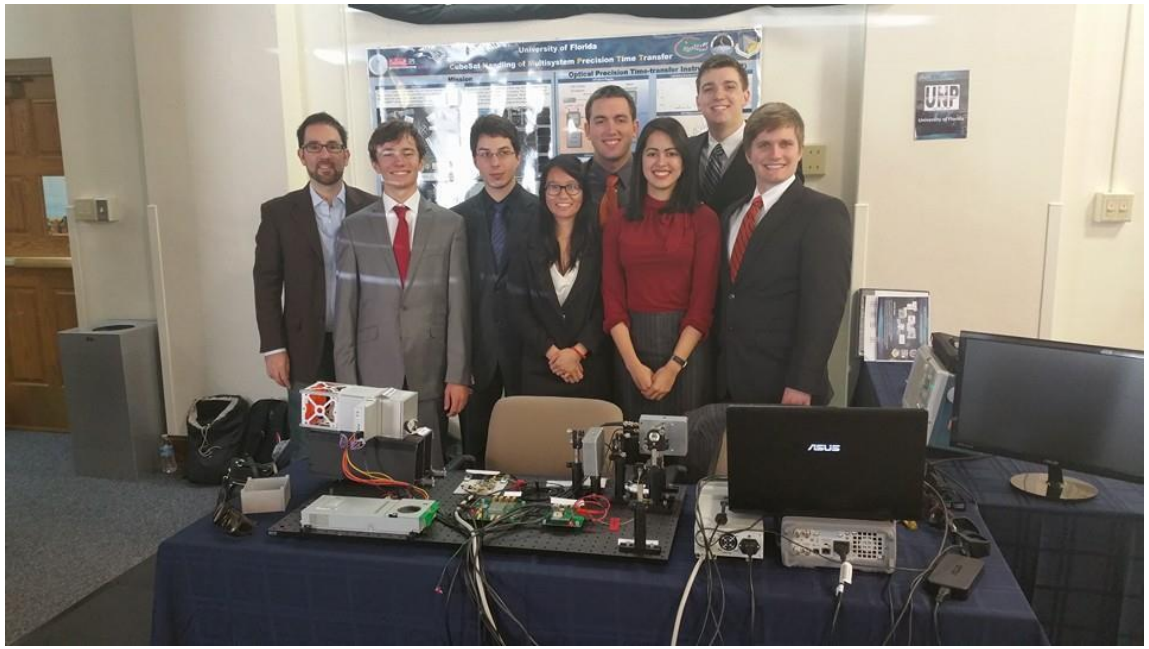
- Townes Institute Science & Technology Experimentation Facility (TISEF) managed by UCF
- 50 cm satellite tracking telescope
- 1 km testing range



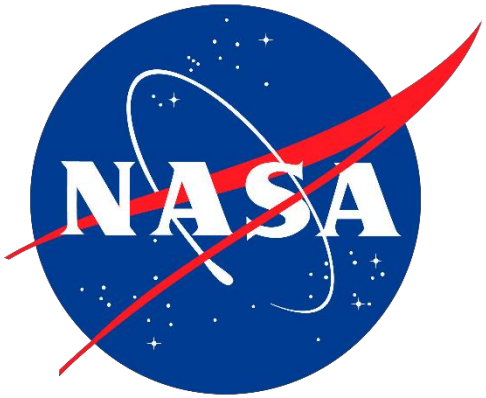
TISTEF (Kennedy Space Center)

Future Work

- Completion and testing of 2U bus
- Tailoring TISEF SLR facility for mission & OPTI testing
- ELaNA launch ~2017



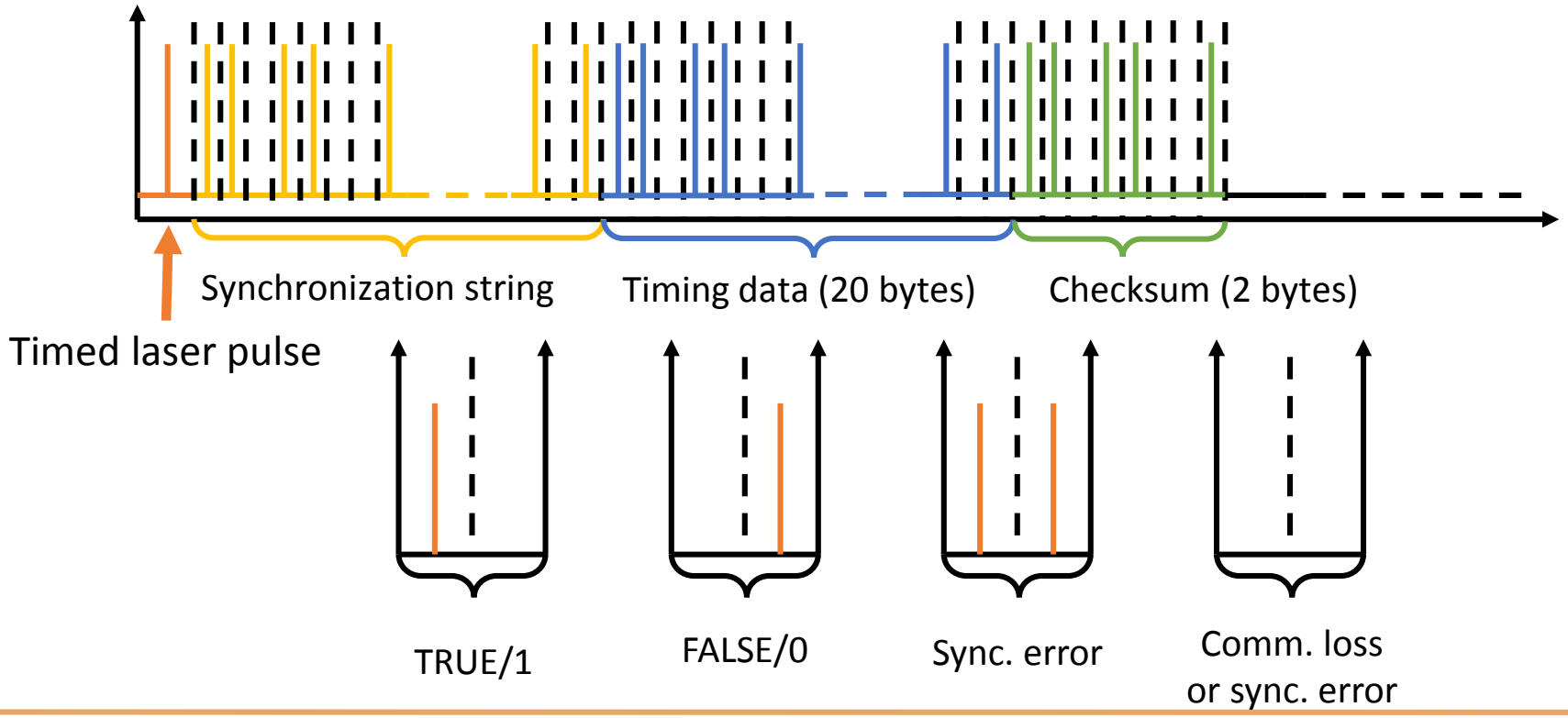
Sponsors and Collaborators



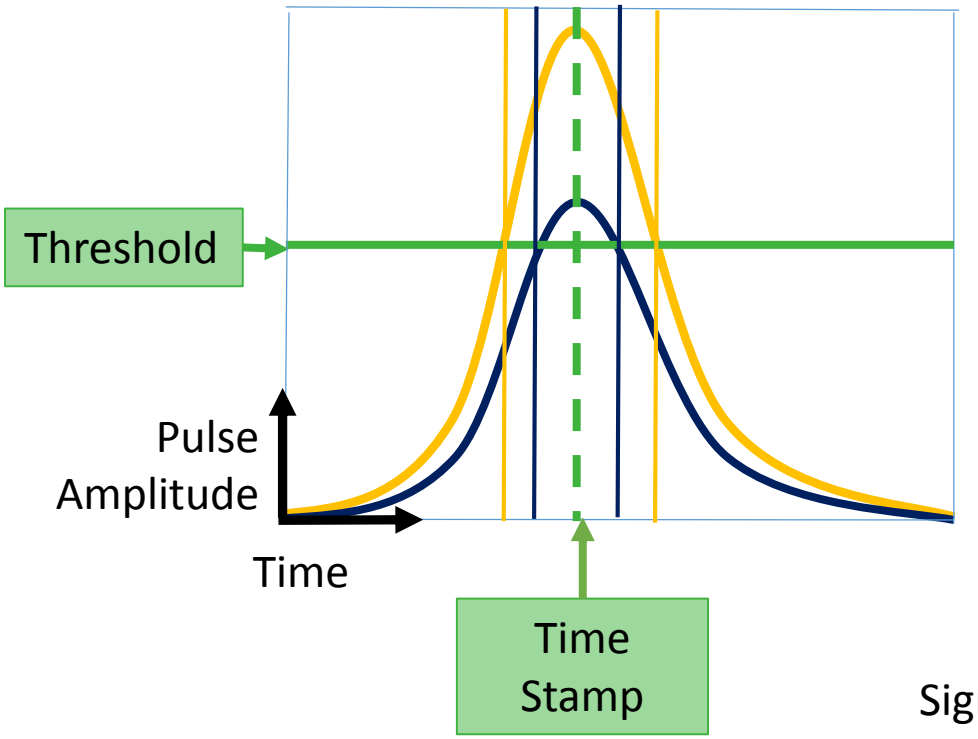
Backup Slides

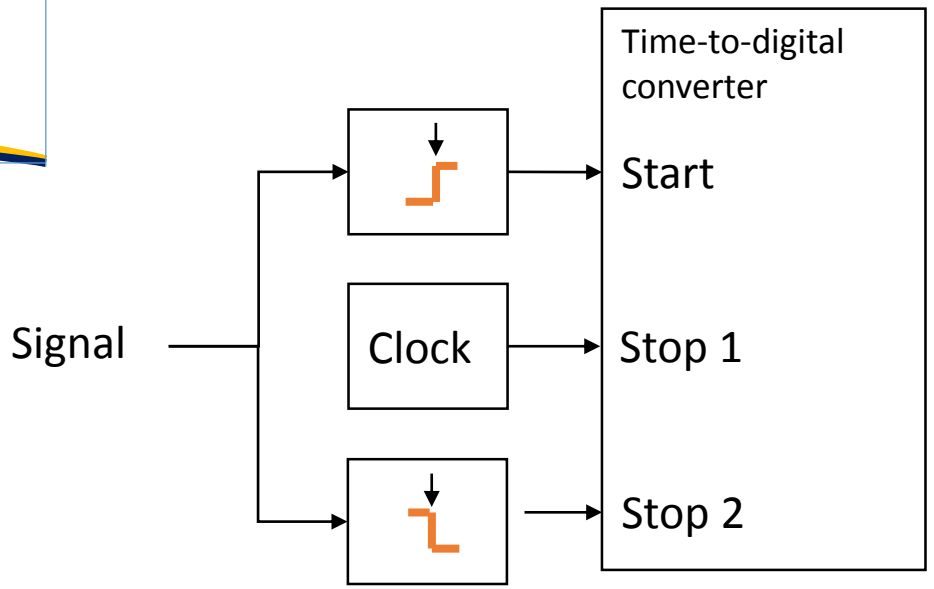
Laser Communication

- 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



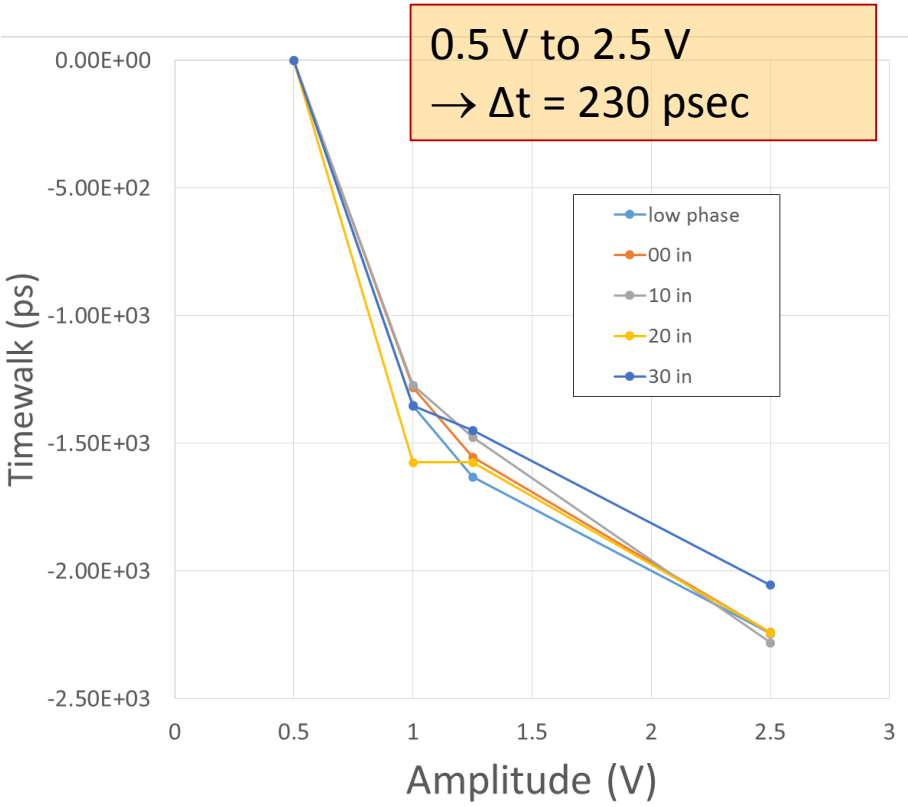
Timewalk Correction





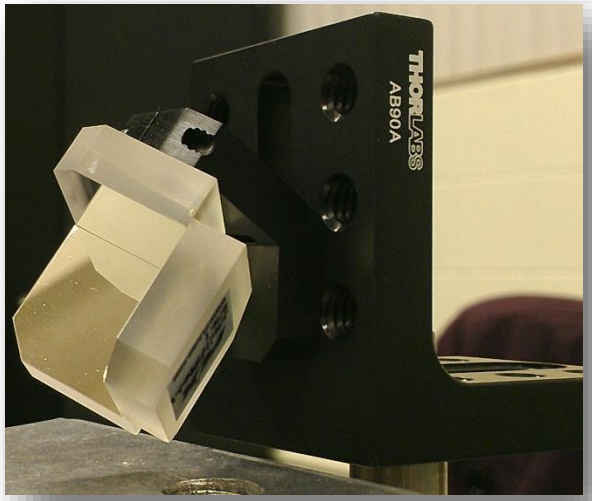
Timewalk Correction

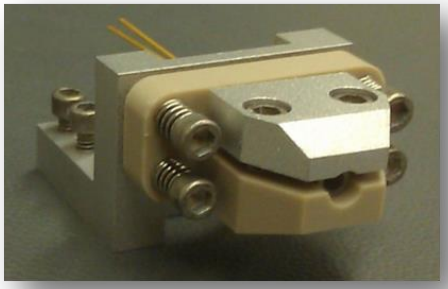
- Apparent timing variations due to pulse amplitude variations
  - Atmosphere, attitude, range, …
- Solution: Time both rising and falling edges of pulse



Photodetectors

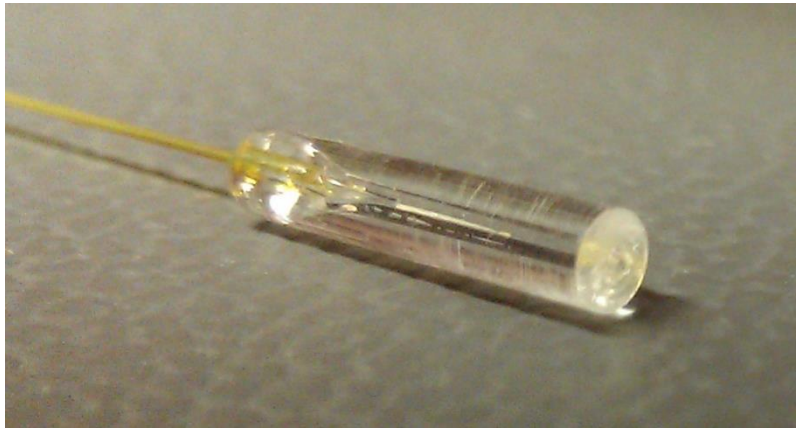
- 2 avalanche photodiodes:
  - InGaAs for 1064 nm, 150 ps rise time
  - Si for 532 nm ps rise time
- Photodetector in linear mode
- Temperature regulated by Thermal-Electric Coolers
- Photodetectors are fiber-coupled
- Pulse sent back by a PLX retroreflector
  - 25 mm diameter, 50° FOV
  - Space Capable

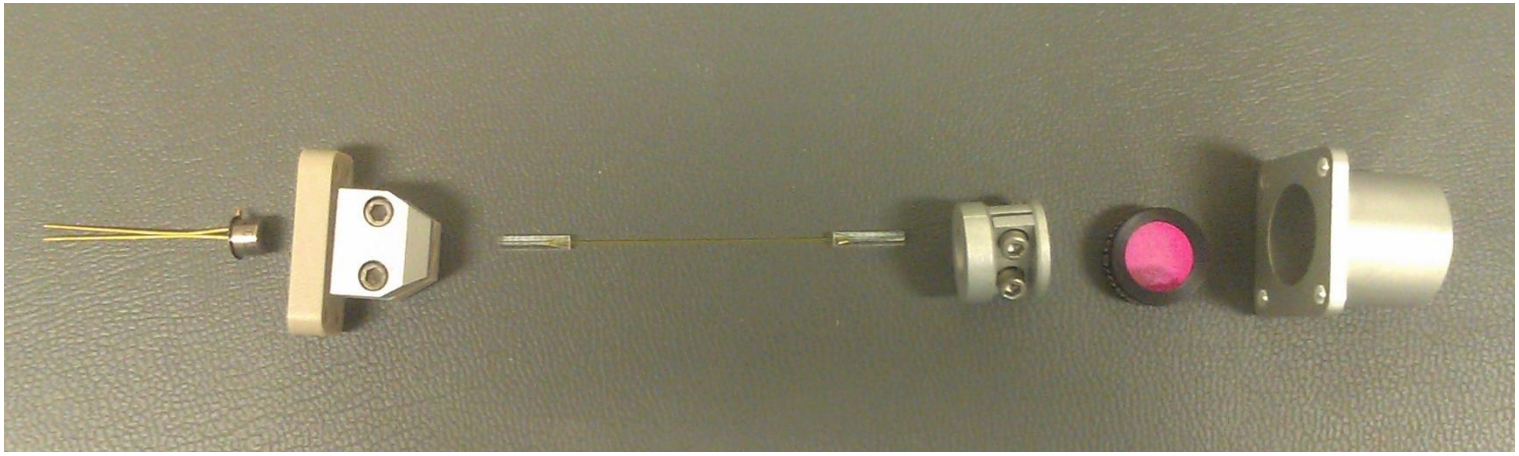




Optics

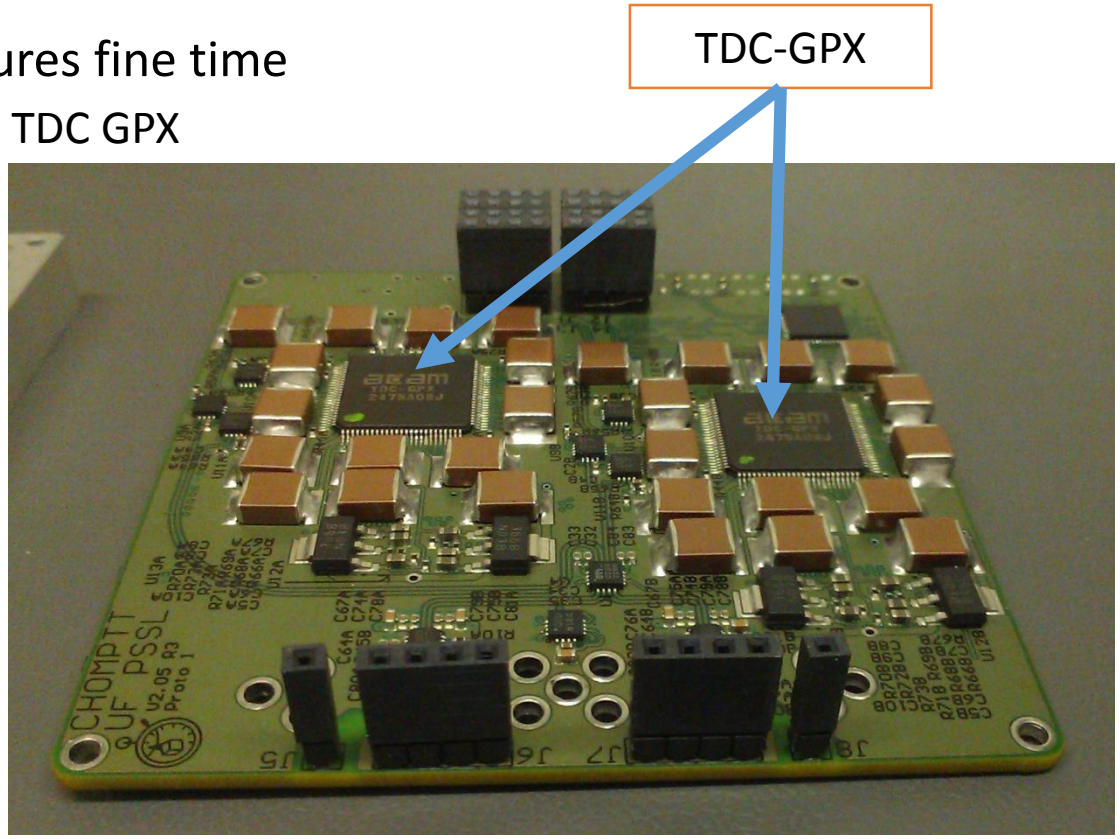
- Band-pass filters
  - Increase SNR
- Light collected by a multimode optical fiber on nadir face
  - 12° max incidence
  - 200 µm diameter
- GRIN Lens focuses light onto APD





10 ps Event Timers- Fine Time

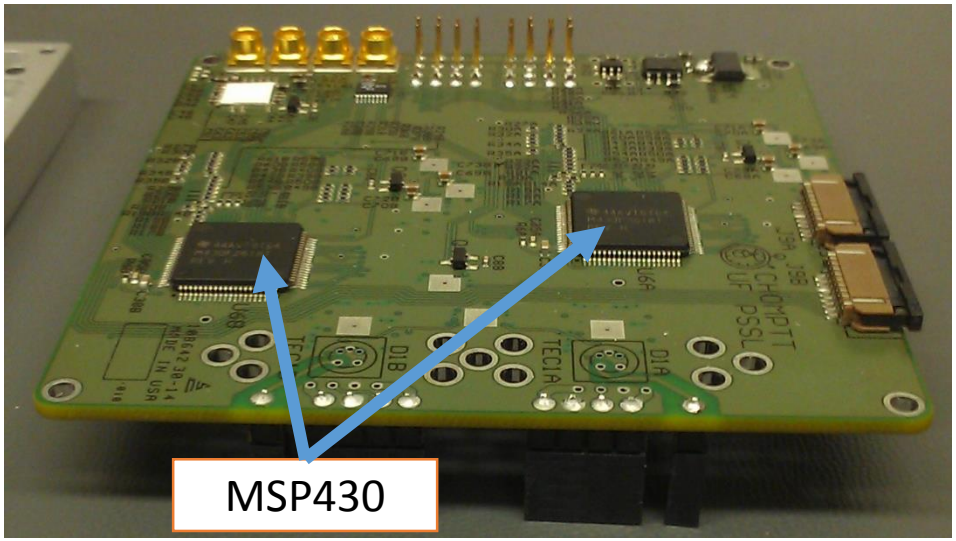
- 2 independent channels
- Fine time on short intervals, course time on long duration
- Time-to-digital converter- measures fine time
  - Integrated, off-the-shelf: Acam TDC GPX
  - Measurement based on propagation delays
  - Autonomous calibration using Delay Lock Loops
  - Low power (<150 mW)
  - 10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



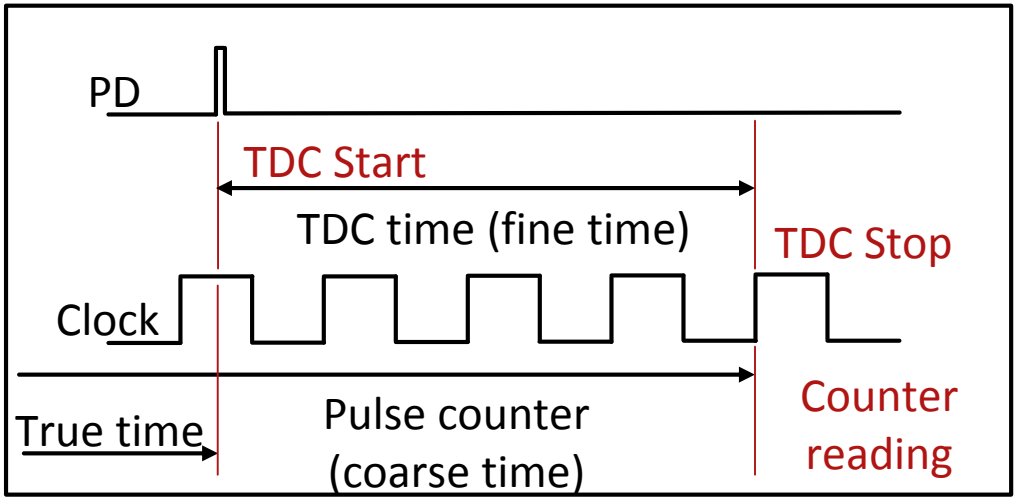
10 ps Event Timers- Fine Time

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