Optical Time Transfer for Future Disaggregated Small Satellite Navigation Systems

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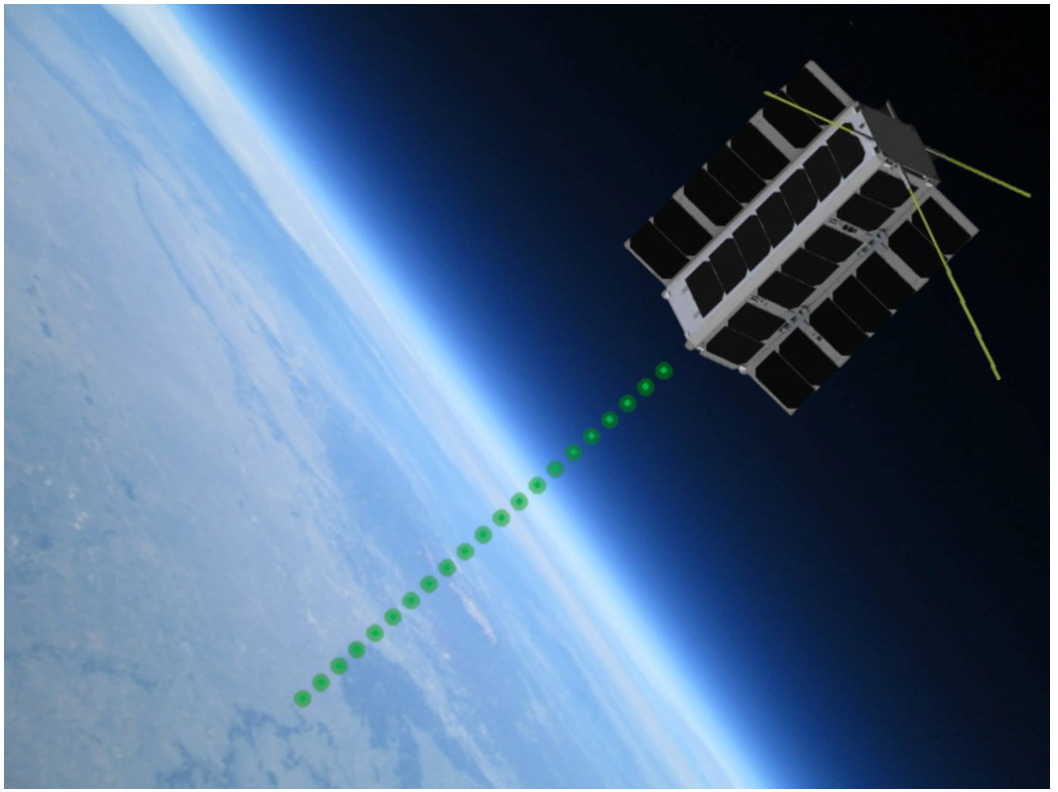

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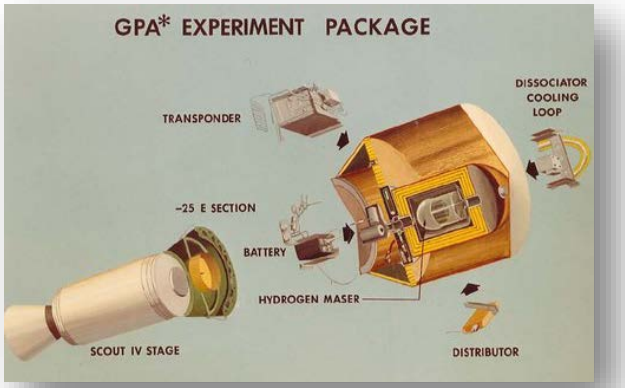
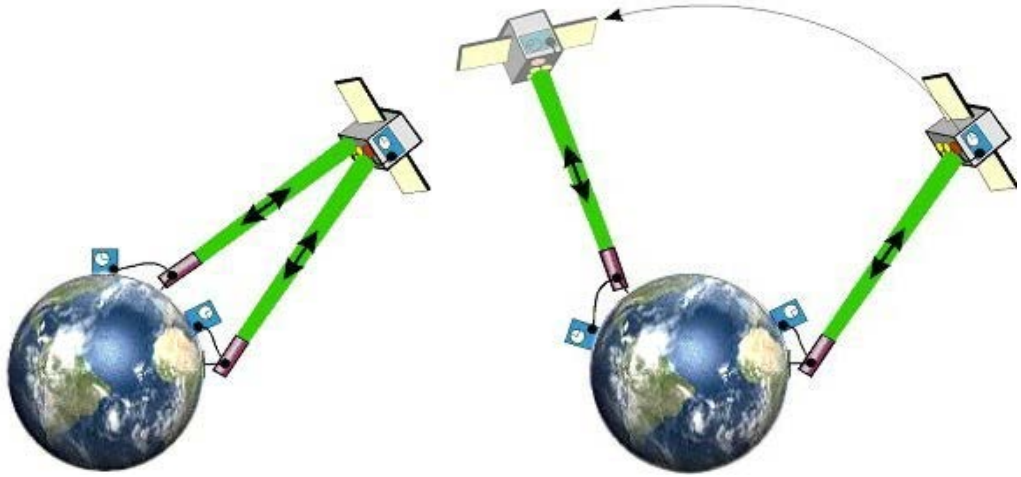
Background and Motivation

- Precision time transfer to space important for:
  - Satellite nav systems, e.g. GPS ($\Delta x = c\,\Delta t$)
  - International time standards
  - Test of general relativity
  - Satellite encryption/authentication
- Technique: exchange of light pulses
  - Optical frequencies less affected by ionosphere relative to RF (~ $1/f^2$)
  - European T2L2 (2008) was hosted payload
- CHOMPTT Objectives:
  - <200 psec time transfer error
  - <20 nsec clock drift after 1 orbit
  - Real time clock update

GPS constellation



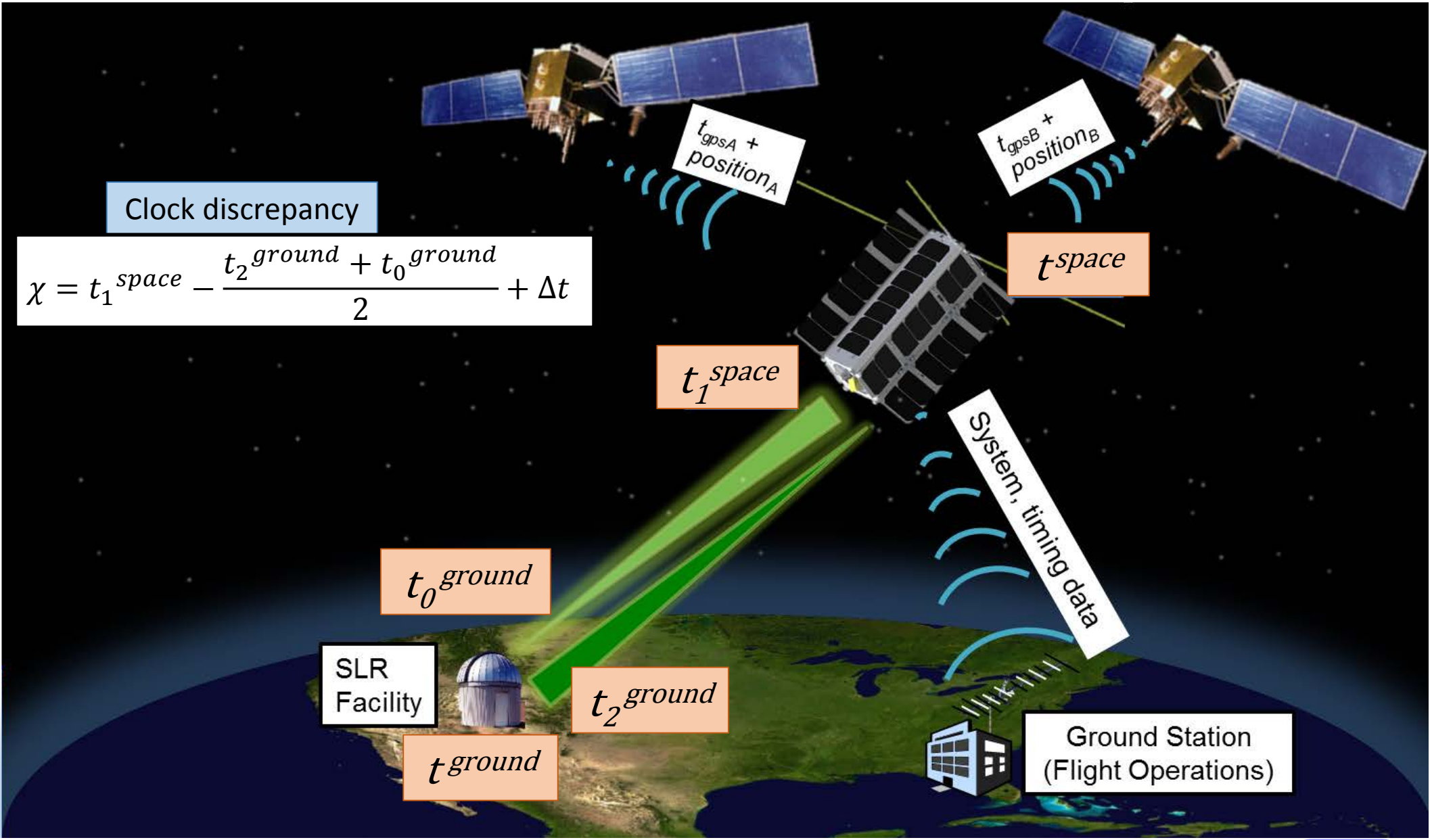
Gravity Probe A (1976)



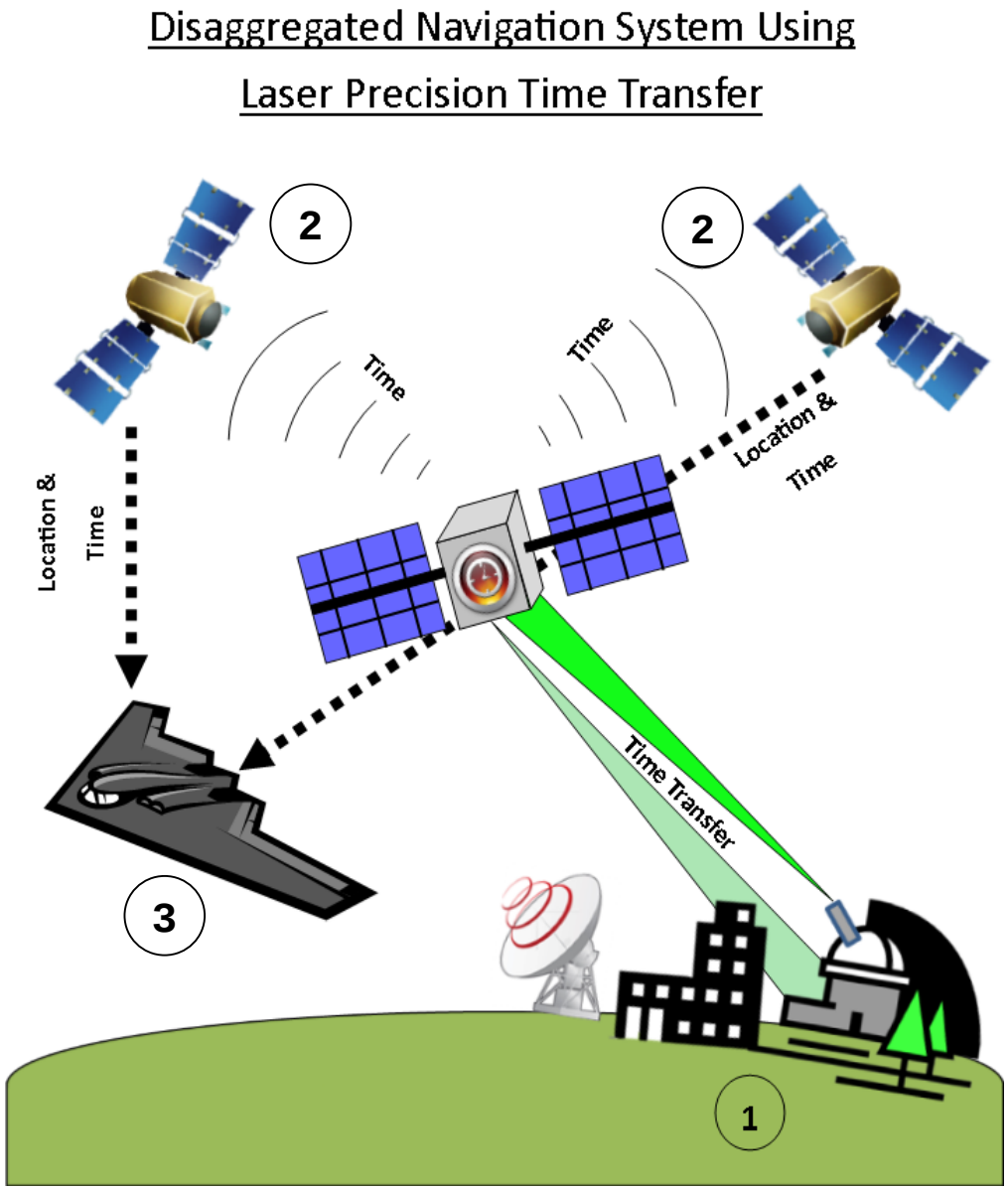
Common View | Non-common View

T2L2 mission [P. Guillemot et al 2006]

CHOMPTT: CubeSat Handling Of Multisystem Precision Time Transfer (NS-8)

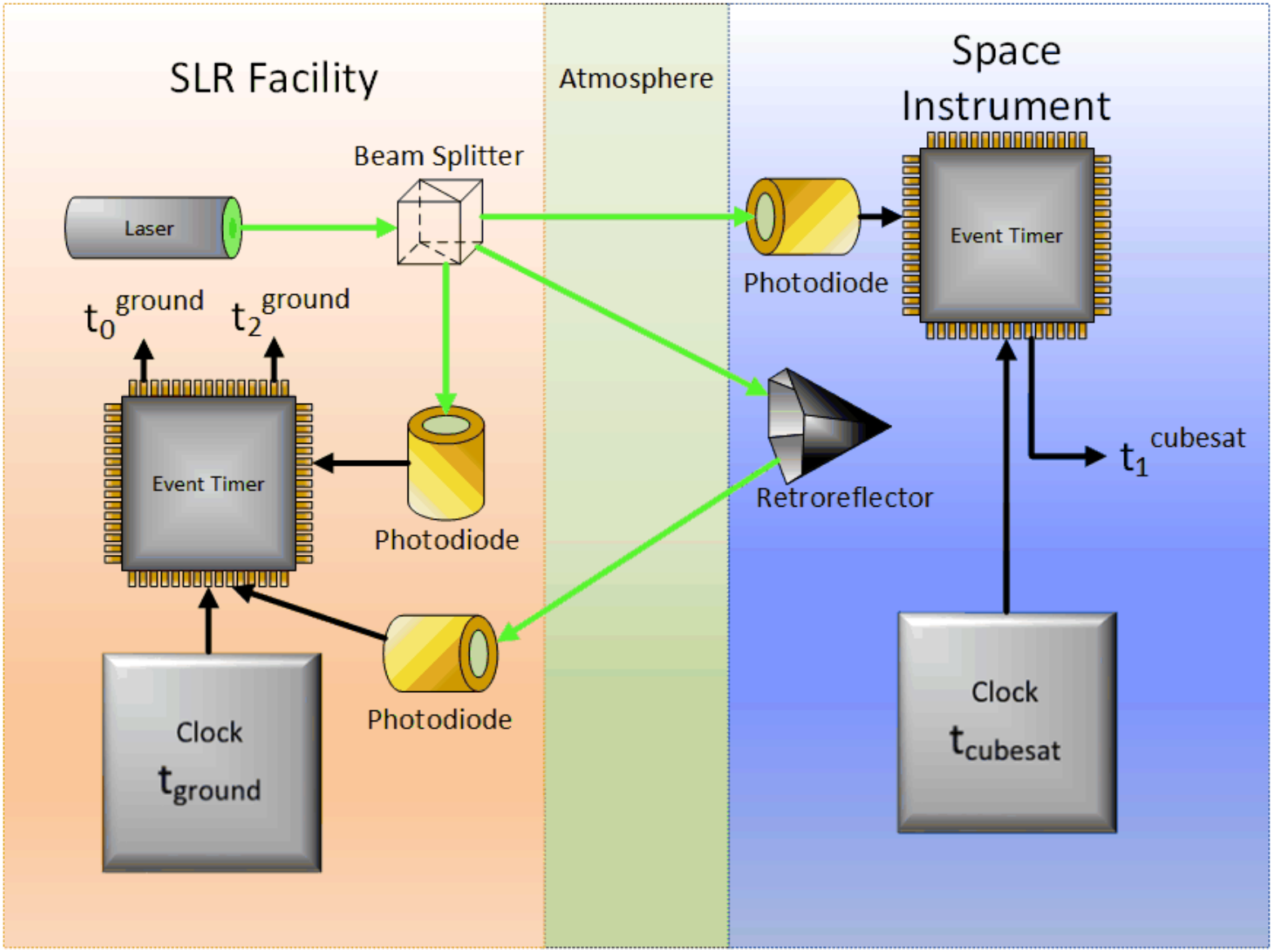


Application to Navigation



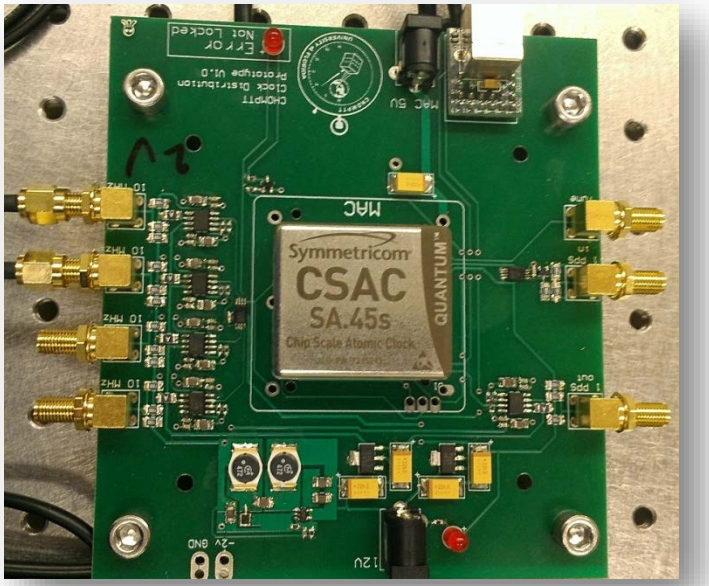
- Improved time transfer accuracy
- Robust against signal interference/jamming
- Disaggregated Nav System:
  1. Command station performs time transfer to timing satellite
  2. Navigation satellites synced to timing satellite using RF
  3. End-users determine location and time from navigation satellites

Optical Precision Time-transfer (OPTI) Overview



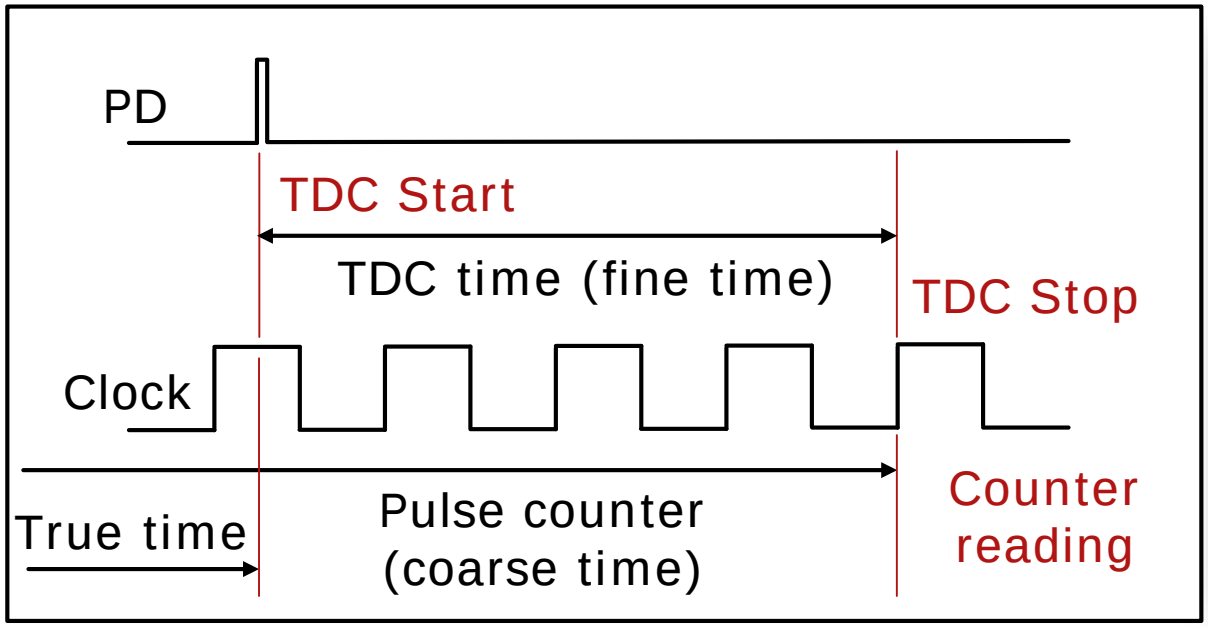
Atomic Clocks (Microsemi)

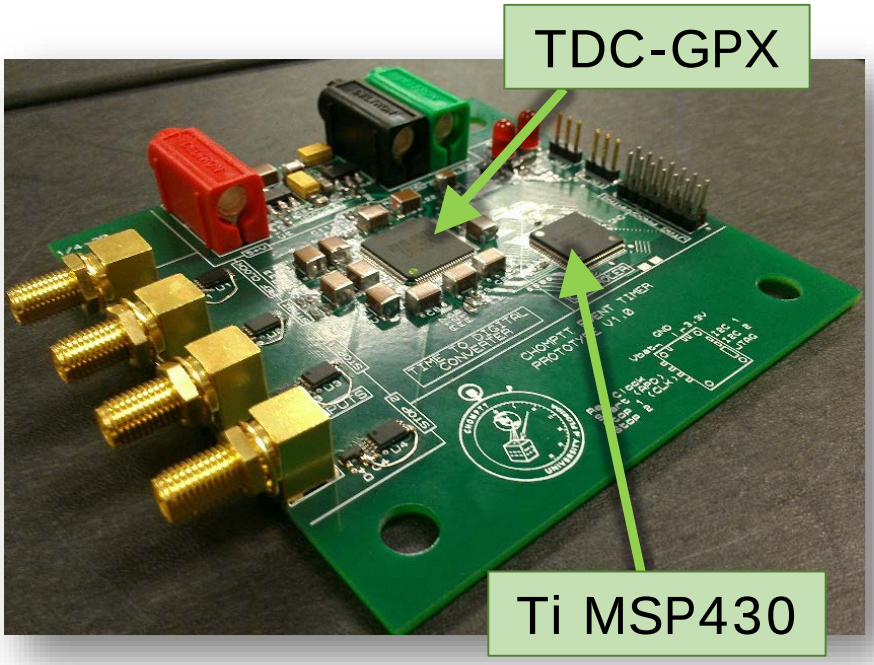
Characteristic	Chip Scale Atomic Clock (CSAC)	Miniature Atomic Clock (MAC)
Standard	Cesium	Rubidium
Allan Deviation (time error)	3.3×10^{-12} @ 6000 sec (20 nsec)	9.5×10^{-13} @ 6000 sec (6 nsec)
Power	0.12 W	5 W
Mass	35 g	85 g
Size (LxWxH)	40.64 x 35.31 x 11.42 mm	51 x 51 x 18 mm



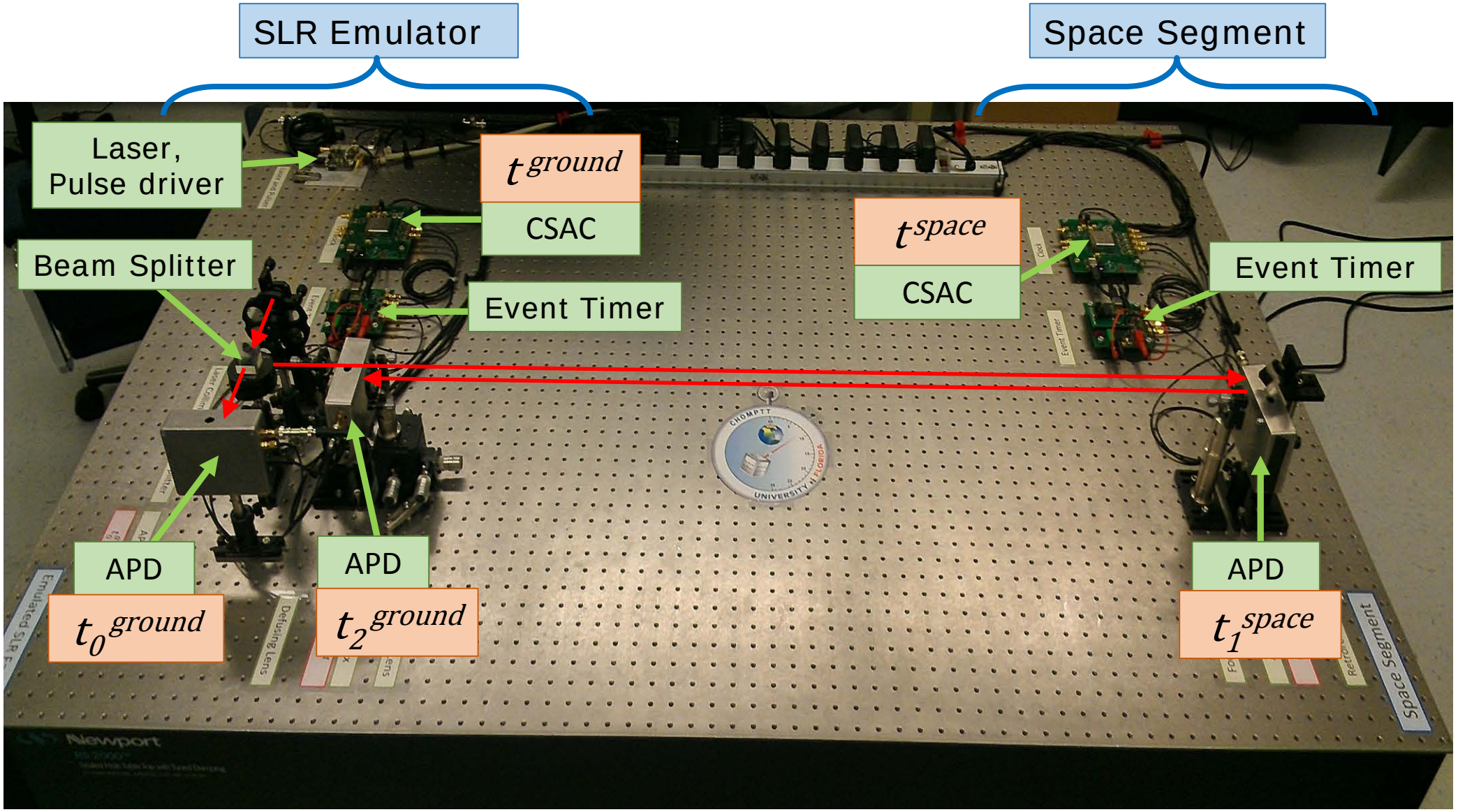
10 psec Event Timer

- Time-to-digital converter – measures fine time
  - Measurement based on propagation delay
  - Autonomous temperature compensation using DLL
  - Low power (132 mW)
  - 10 ps single shot accuracy (12 ps measured)
- MSP430 microcontroller - course time



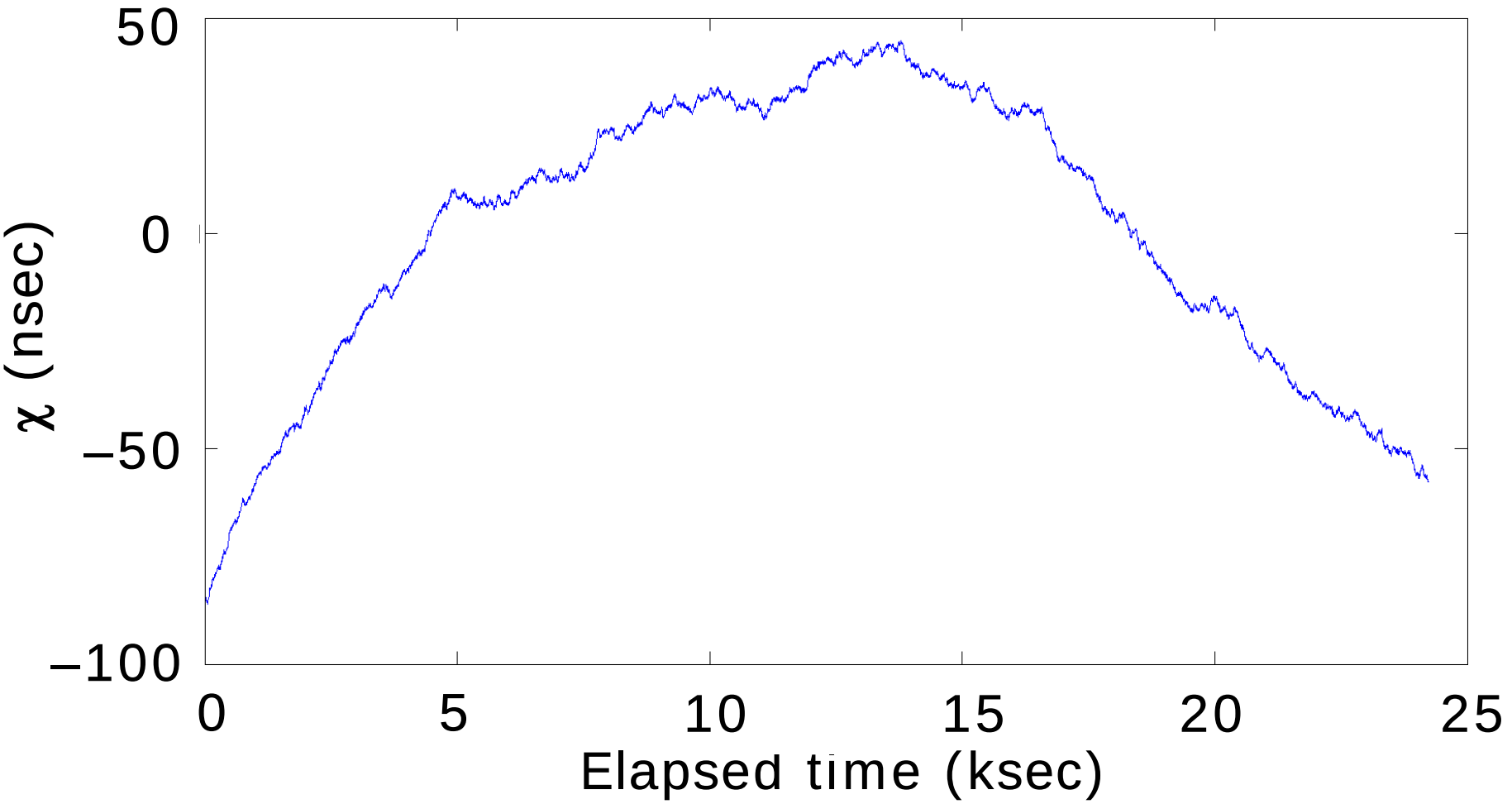


OPTI Laboratory Demonstration

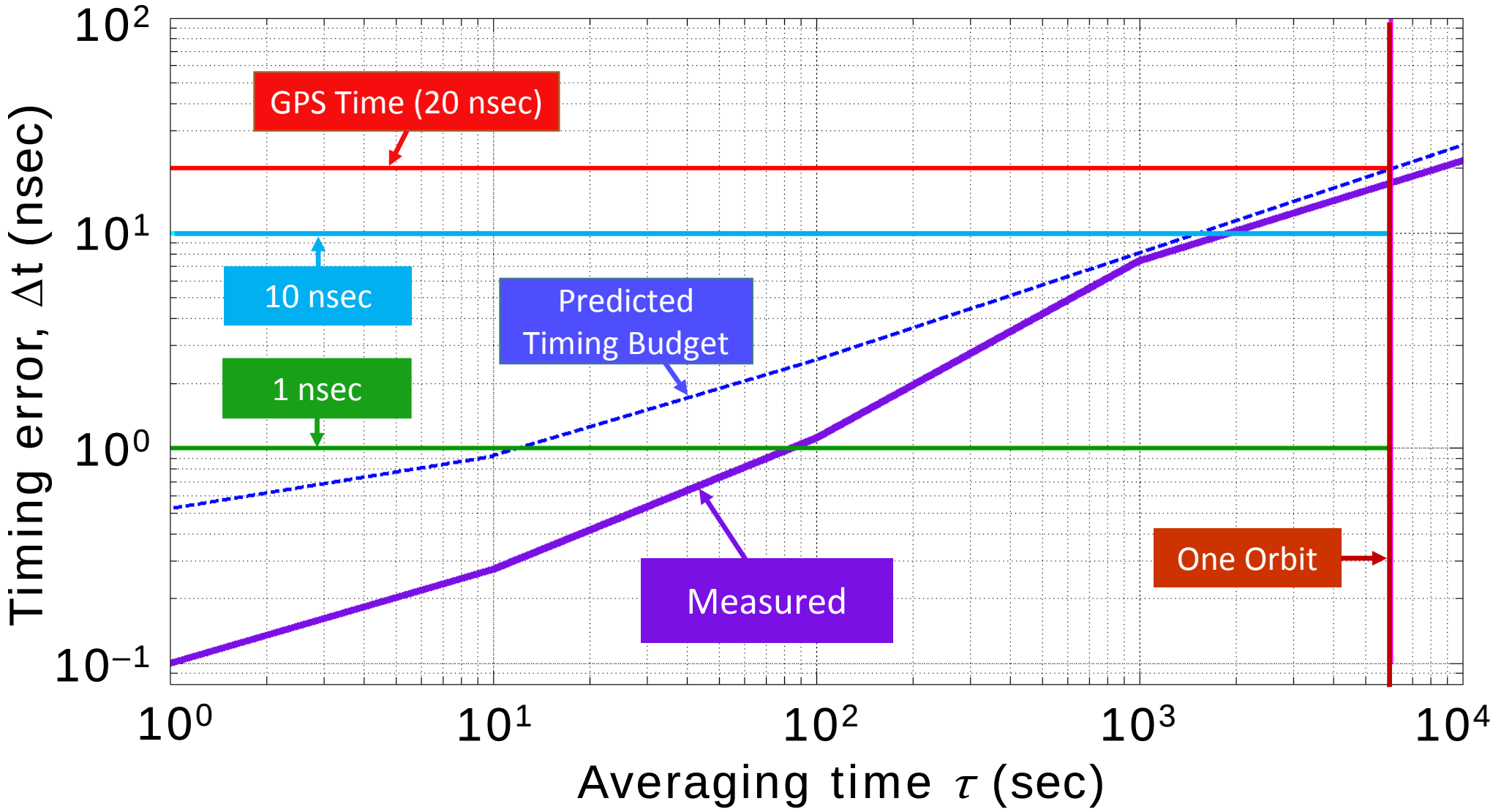


Measured Performance

- Clock difference (2 CSACs) measured using OPTI breadboard



Timing Error Budget

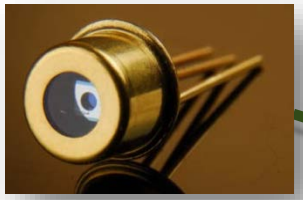


OPTI Flight Instrument

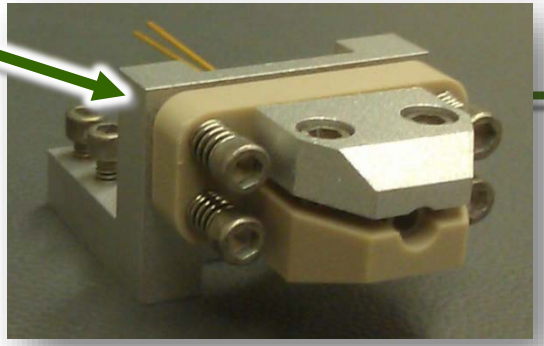
TEC controllers,
reverse bias voltage

Time-to-digital converters,
clock counters

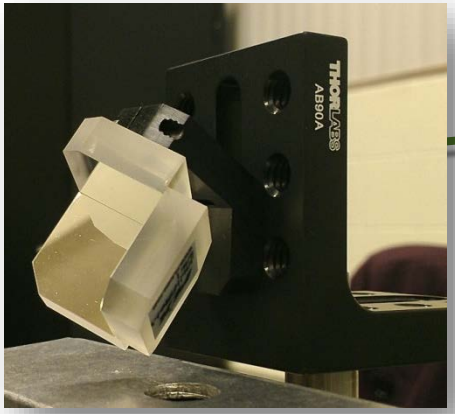
APDs



1. Si: 532 nm, 500 ps
2. InGaAs: 1064 nm,
   140 psec

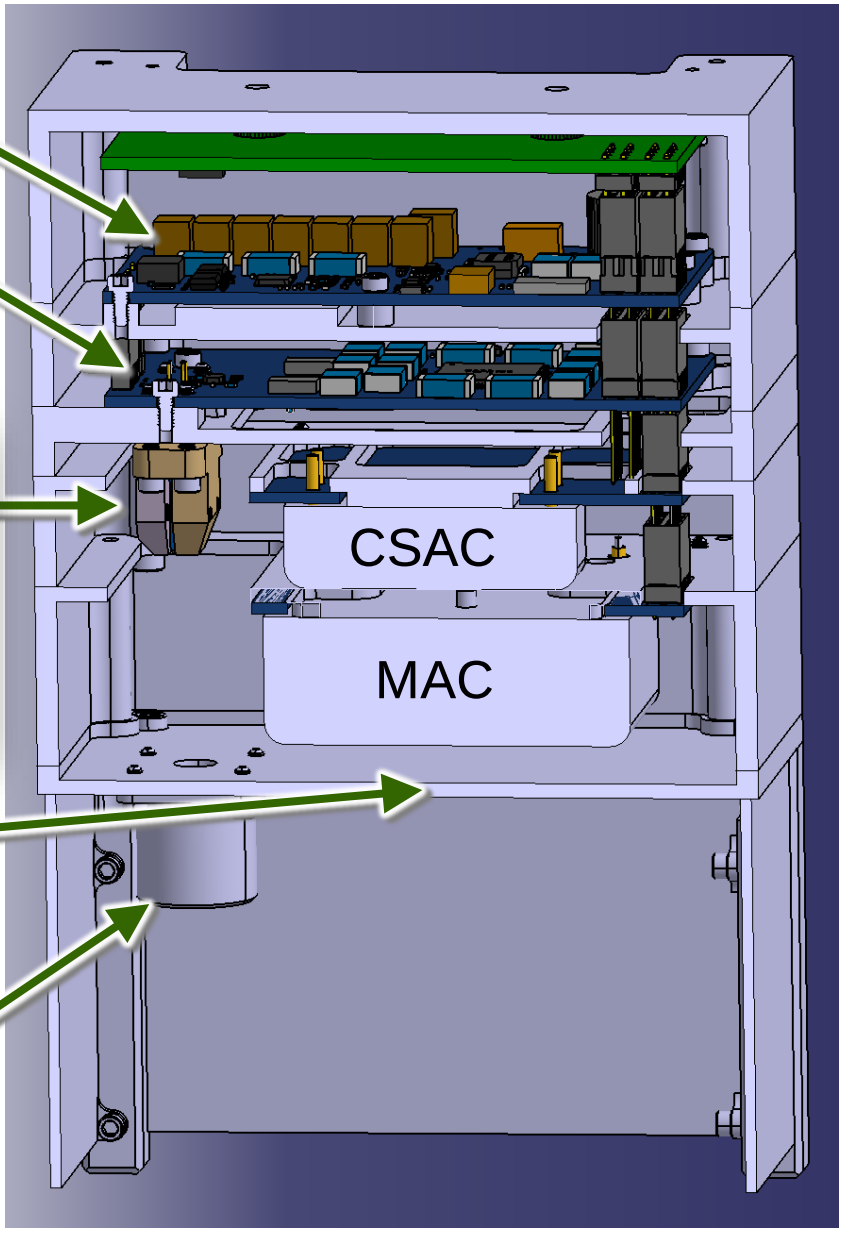


Fiber coupler / TEC



PLX Retroreflector

Light collectors,
filters



The CHOMPTT 3U CubeSat

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

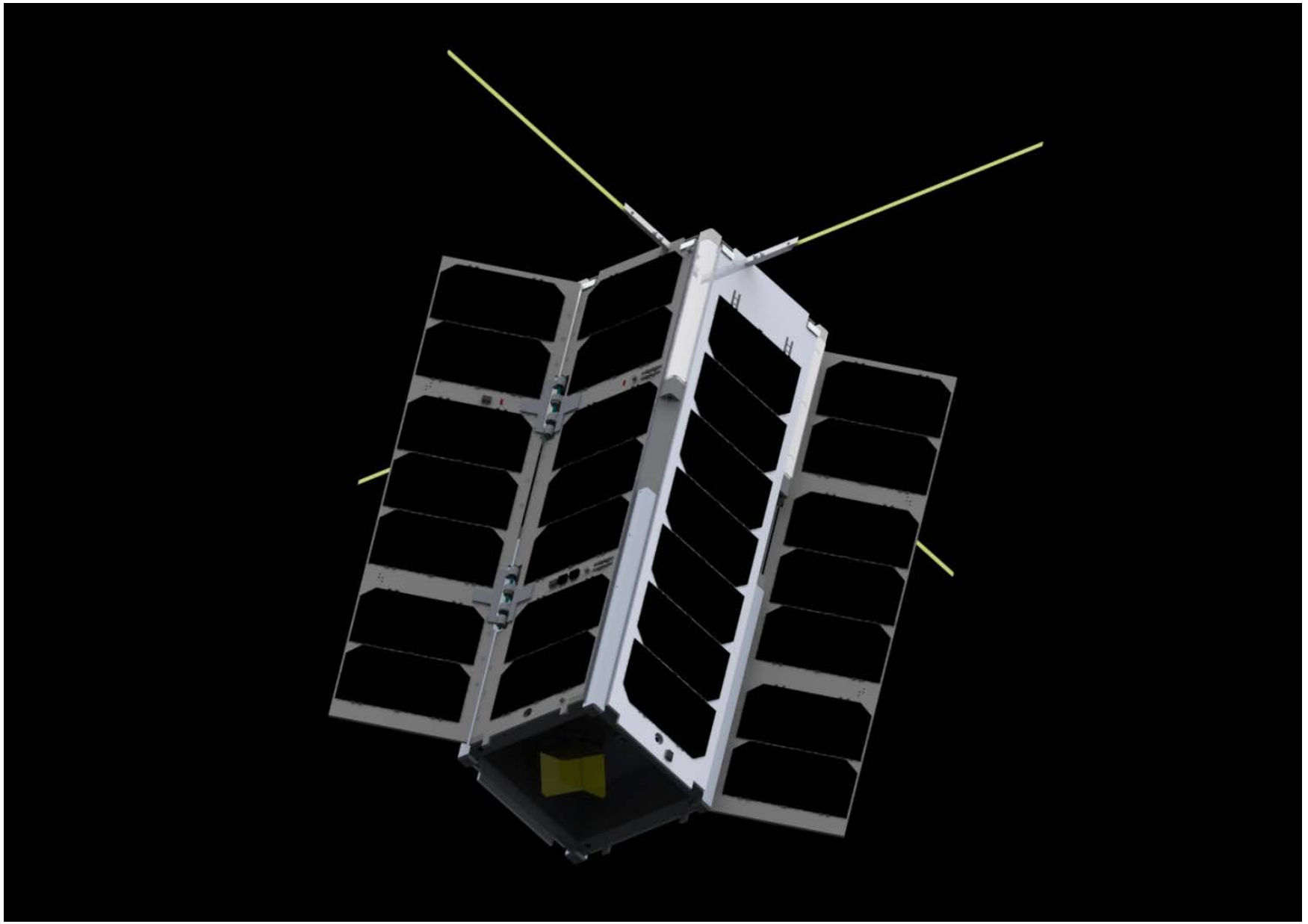
Event timers, clock counters

CSAC

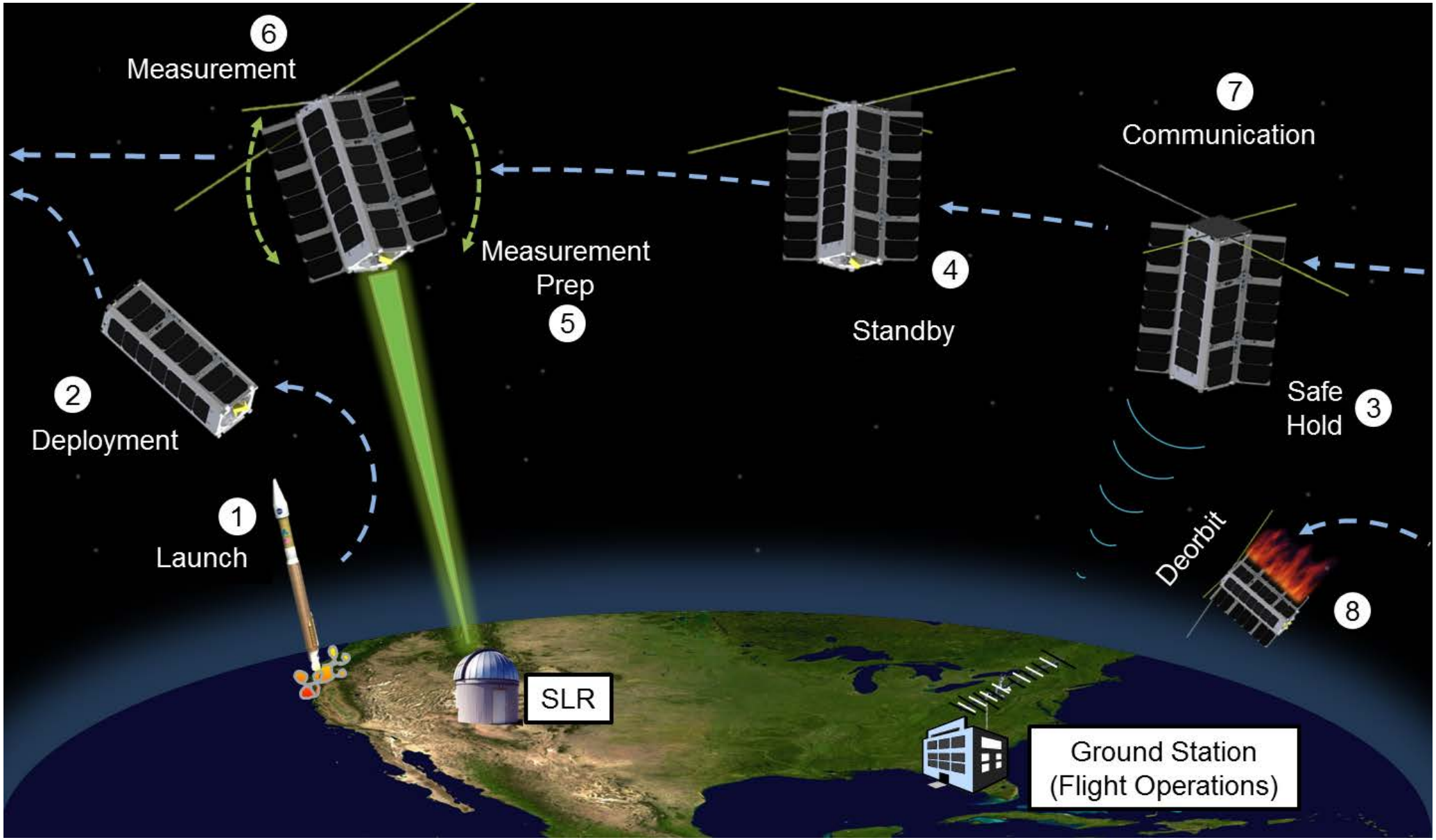
MAC

Retroreflector and light collectors

Rendered View of the CHOMPTT Satellite

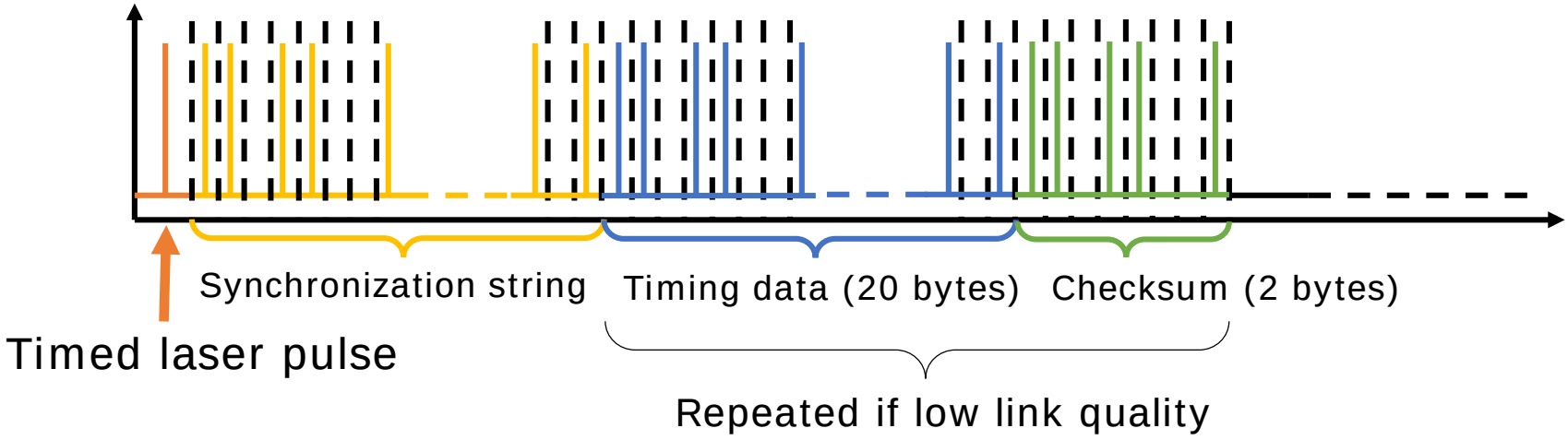


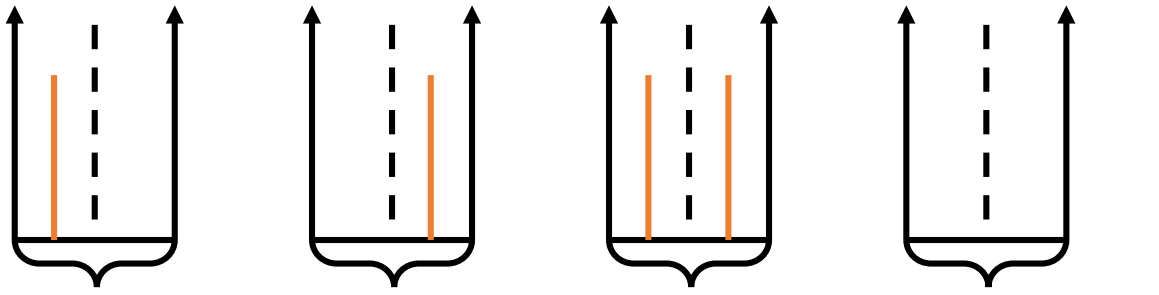
Concept of Operations



Laser Communication

- 2-Pulse Position Modulation (2 slots per pulse)
- Synchronization string provides phase, rate, & masks SLR delays
- Fine time required only for first ‘timing’ pulse





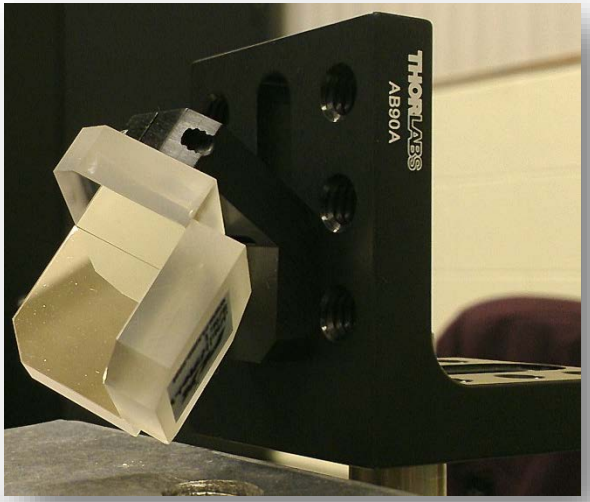
Status and Future

- EM of OPTI fabricated, currently under test
- High altitude balloon launch, Sept. 2014 (Sage Cheshire)
- OPTI integrated into CHOMPTT satellite bus, 2015
- Qualification testing at NASA KSC
- ELaNA launch
  - 2016-2017
- SLR collaborators
  - NGSLR managed by NASA GSFC, MD
  - Starfire optical range at Kirtland AFB, NM

Backup slides ...

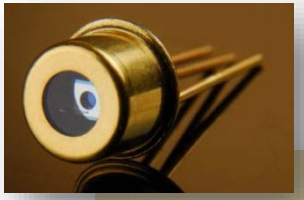
Optics & Light Detection

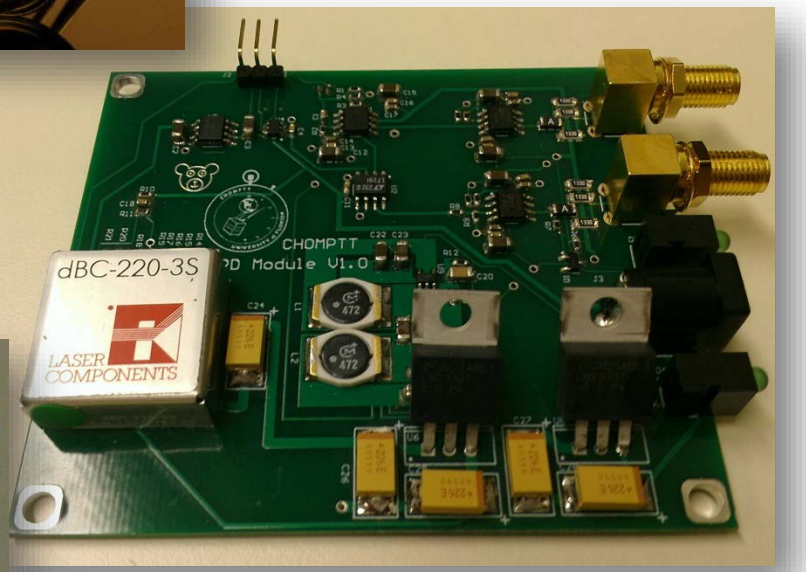
- PLX retroreflector
  - 25 mm diam, 50° FOV
  - Space capable
- Avalanche photodetectors (2)
  - Si (532 nm, 1064 nm): 500 ps rise
  - InGaAs (1064 nm): 140 ps rise
- Light collection
  - Light collected by optical fiber terminating on nadir face
    - 12° max incidence
  - GRIN lens focuses light onto APD



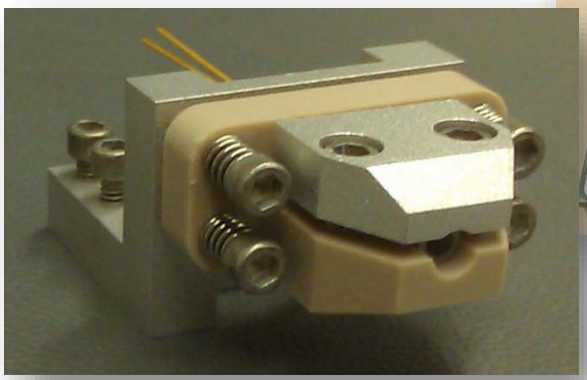
PLX Retroreflector

APD



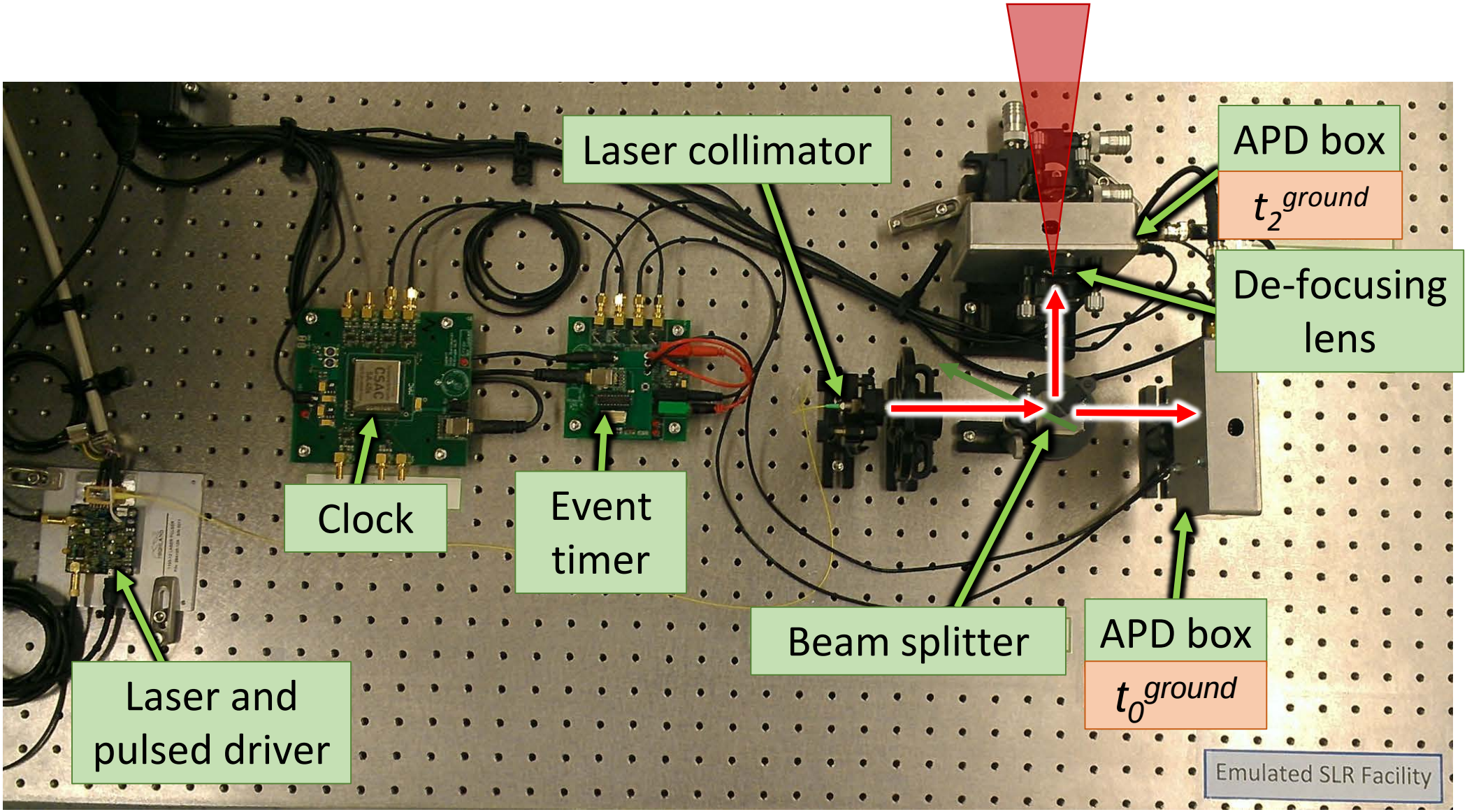


APD electronics

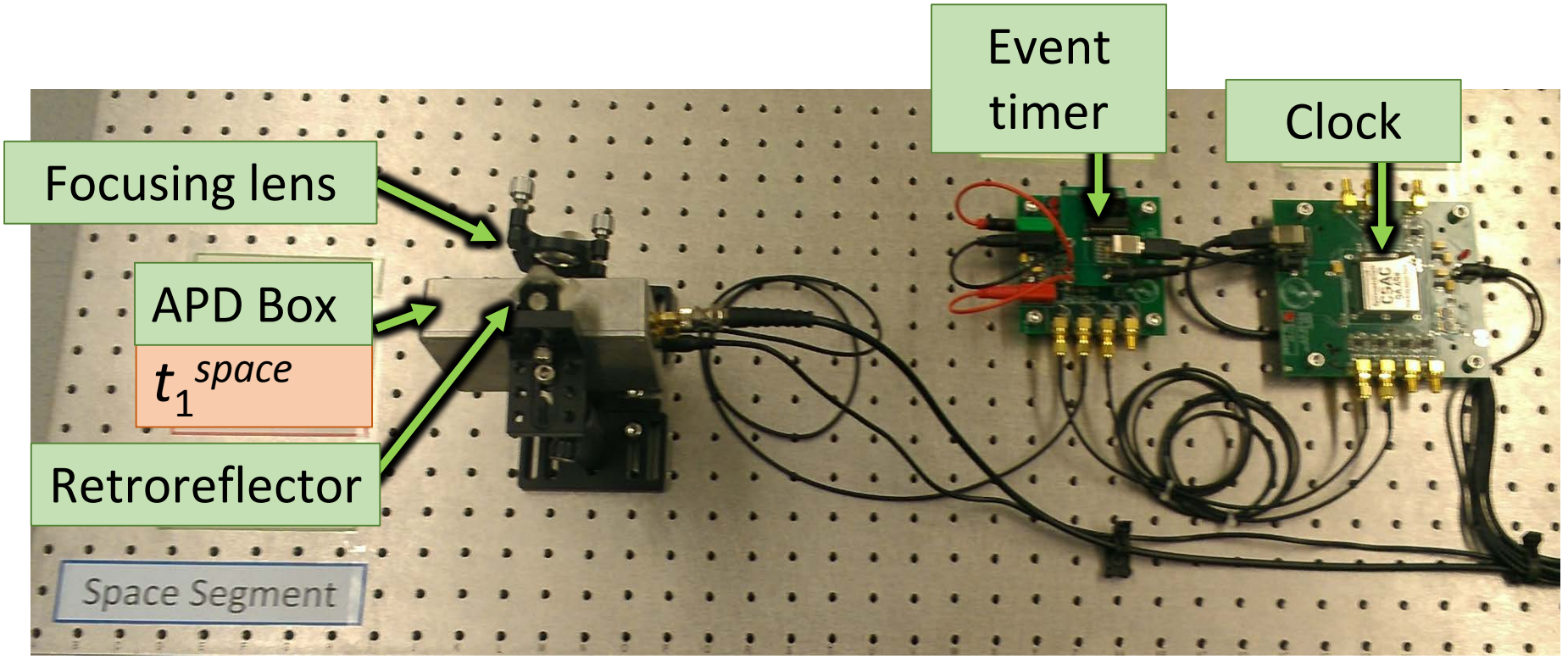


Fiber coupler / TEC

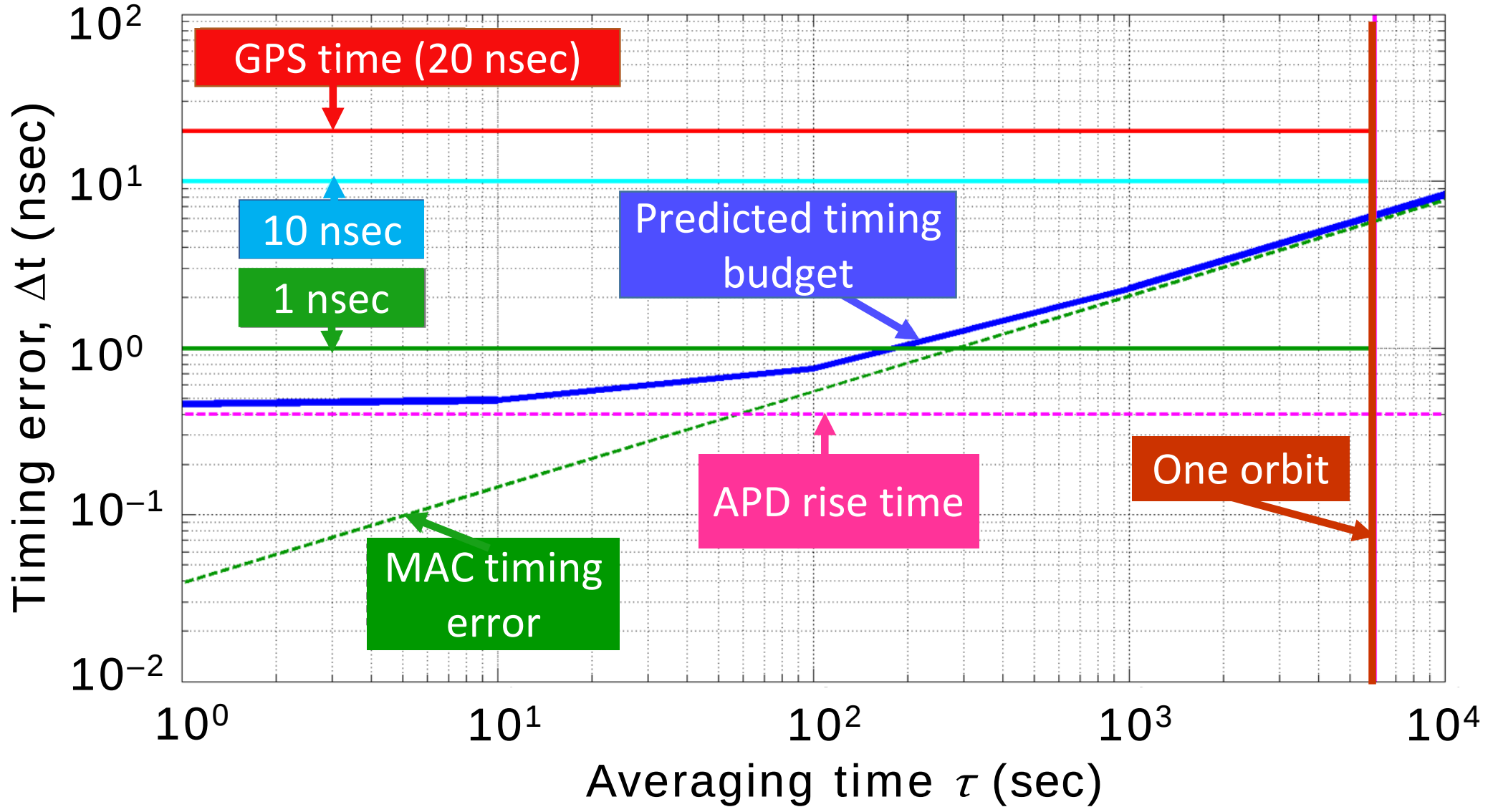
SLR Emulator



Space Segment



Timing Error Budget (MAC)



Timewalk Correction

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