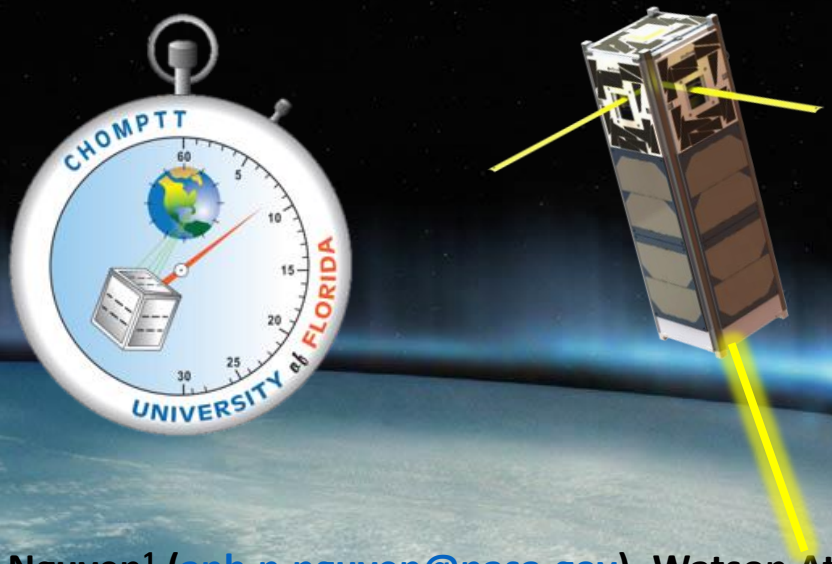
CubeSat Demonstration of Sub-nanosecond Optical Time Transfer



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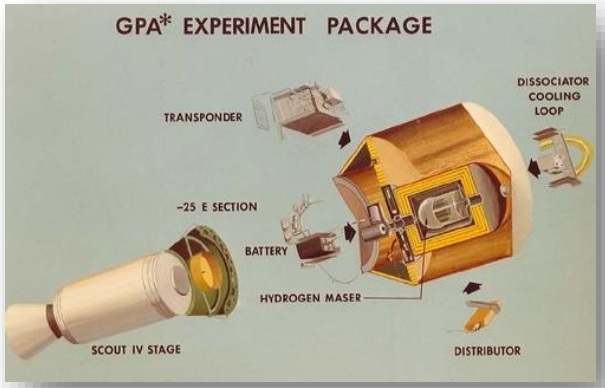
Background and Motivation

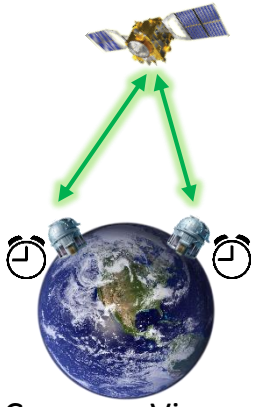
- Application of precision time transfer to space:
  - Satellite navigation system
    - **Beyond LEO** $(\Delta x = c\Delta t)$
  - Global time standards
  - Test of general relativity
  - Satellite encryption/authentication

GPS Constellation

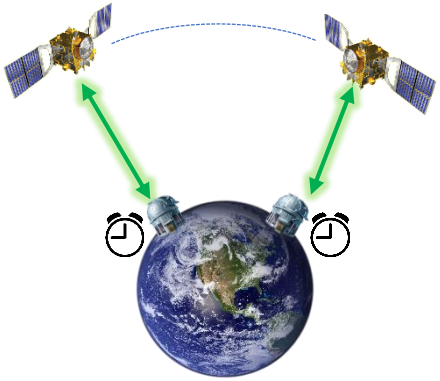


Gravity Probe A (1976)

- Optical time transfer
  - More resilient to ionospheric effects than RF (~$1/f^2$)
  - CNES T2L2 (2008), hosted payload on Jason-2



Common View

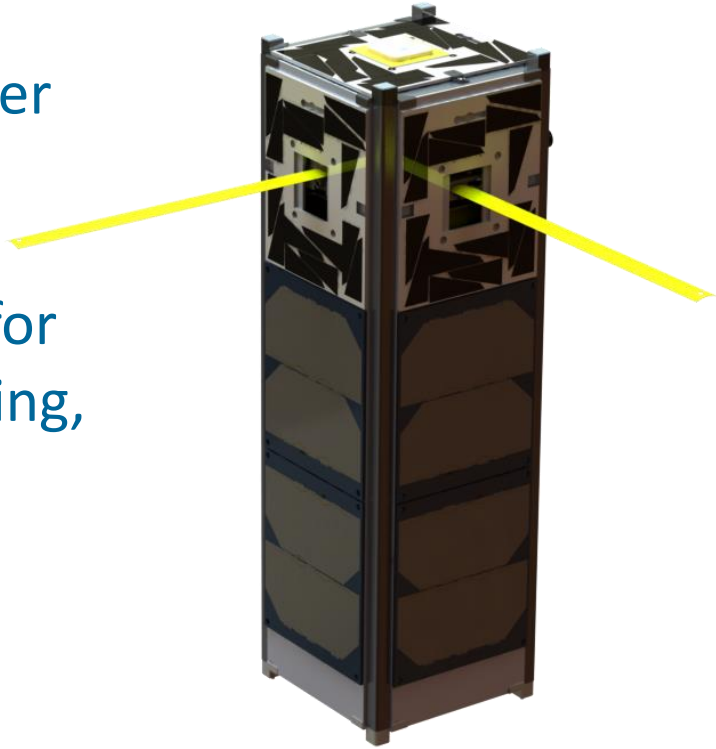


Non-common View

T2L2 mission [P. Guillemot et al 2006]

Spacecraft Overview

- CHOMPTT (CubeSat Handling of Multisystem Precision Time Transfer) is a precision timing satellite equipped with atomic clocks synchronized with a ground clock, via laser pulse

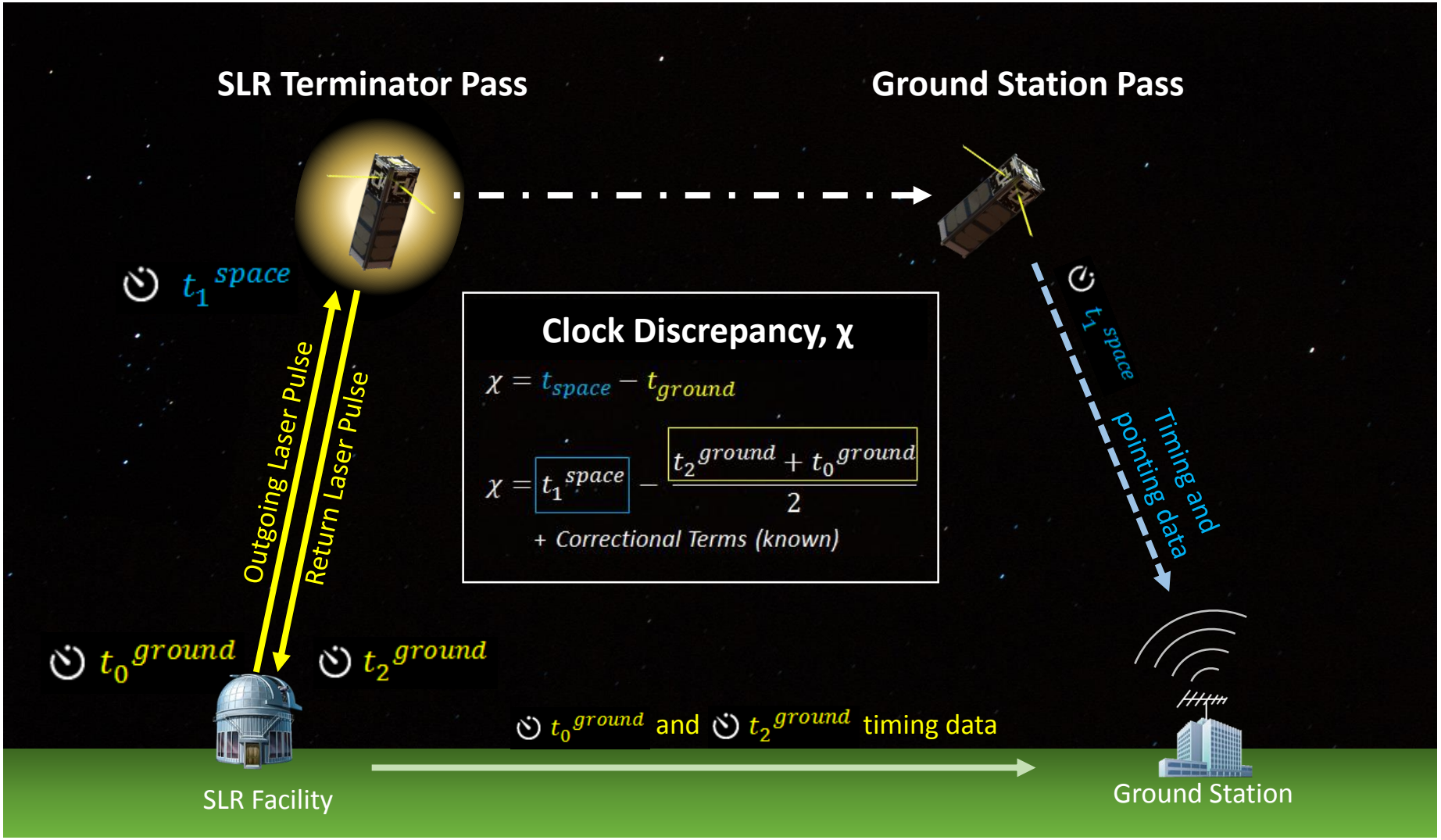


- CHOMPTT will demonstrate technology for deep space navigation, satellite networking, and distributed aperture telescopes

- CHOMPTT objectives:
  - <200 ps time transfer error (6 cm)
  - <20 ns clock drift after 1 orbit (6 m)
  - Real time clock update
  - Measure clock drift

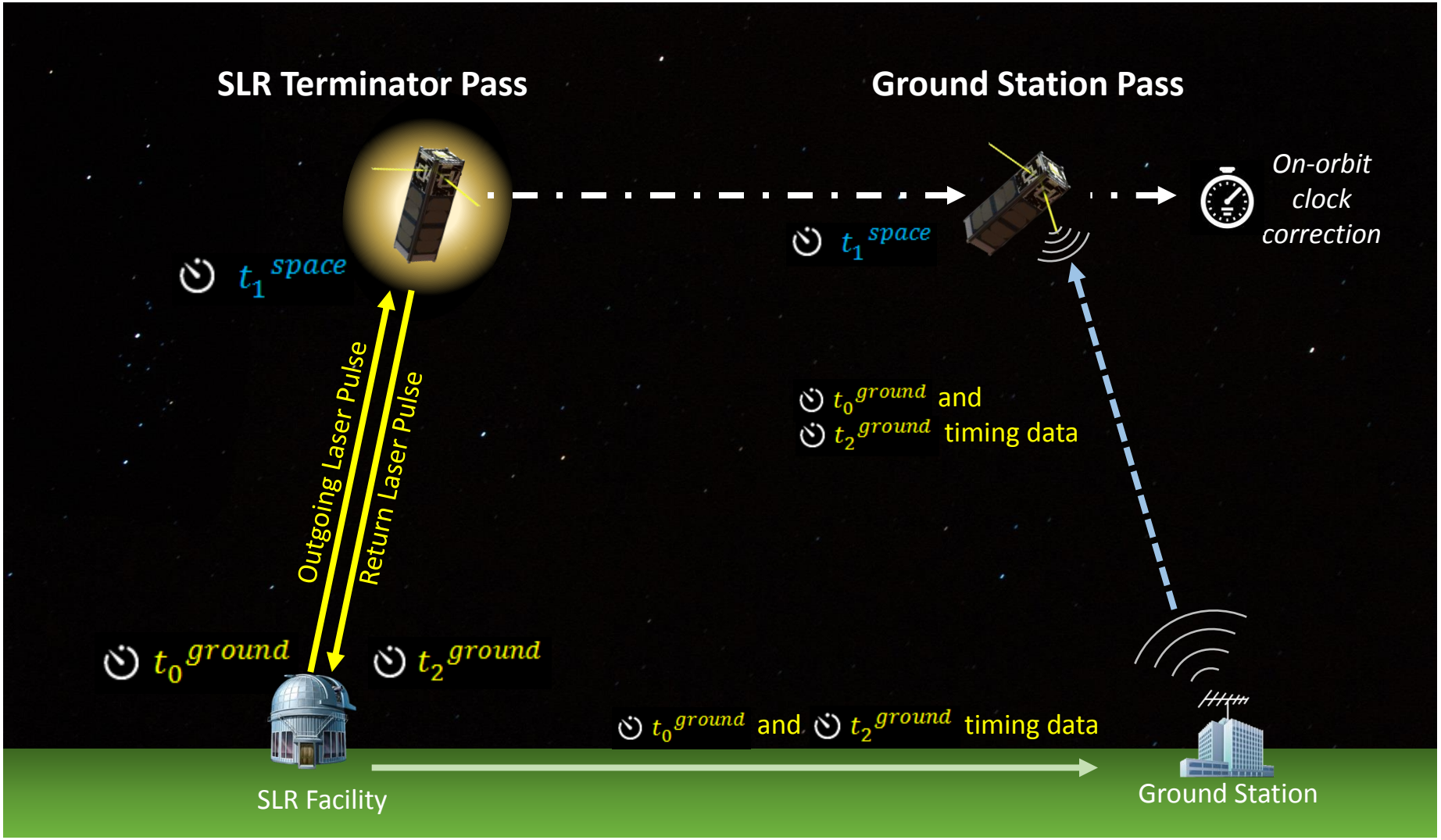
CHOMPTT Baseline Measurement

Single Time-Transfer <200 ps time transfer error, < 20 ns clock drift after 1 orbit



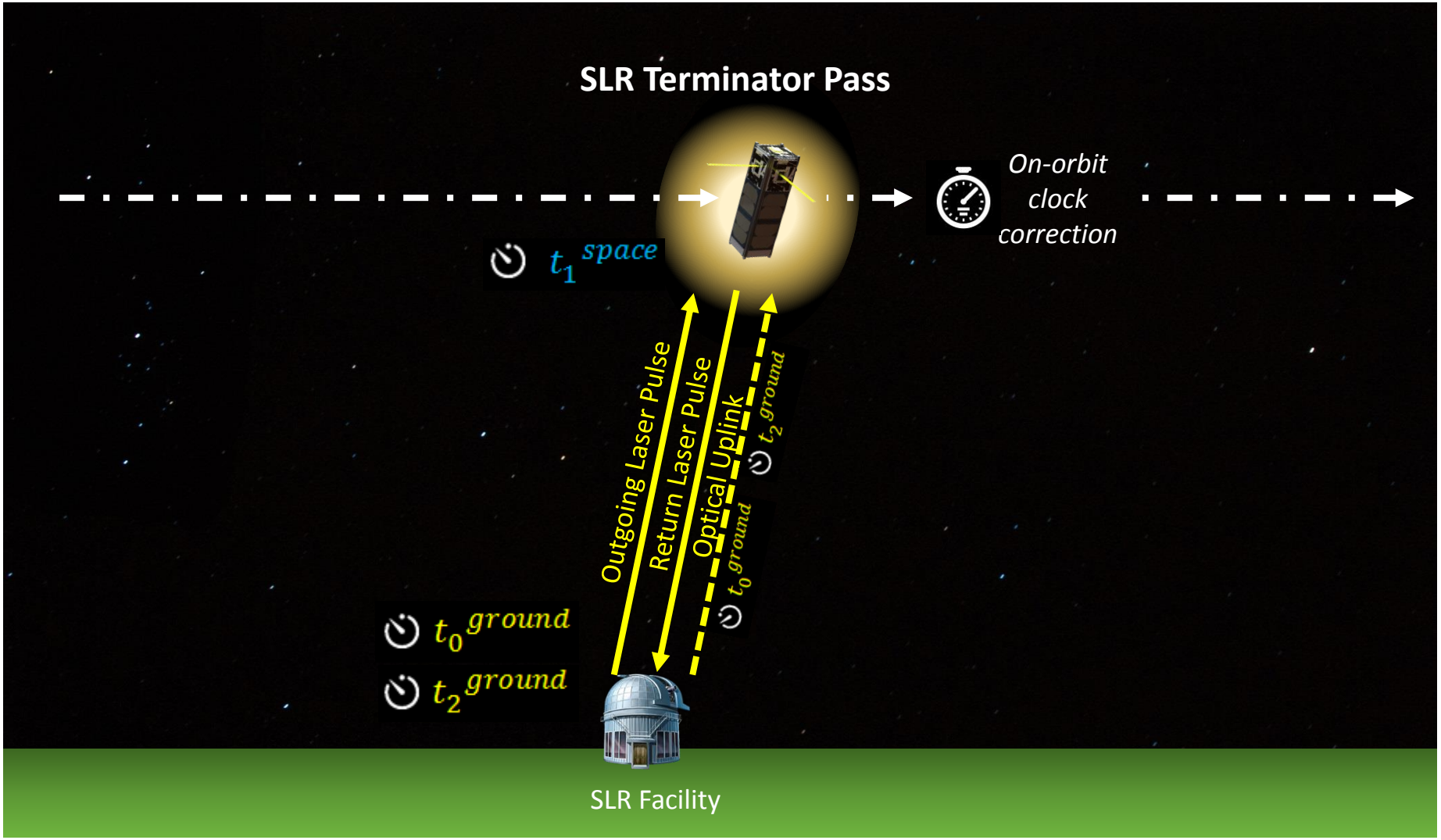
CHOMPTT Extended Measurement I

On-orbit clock correction



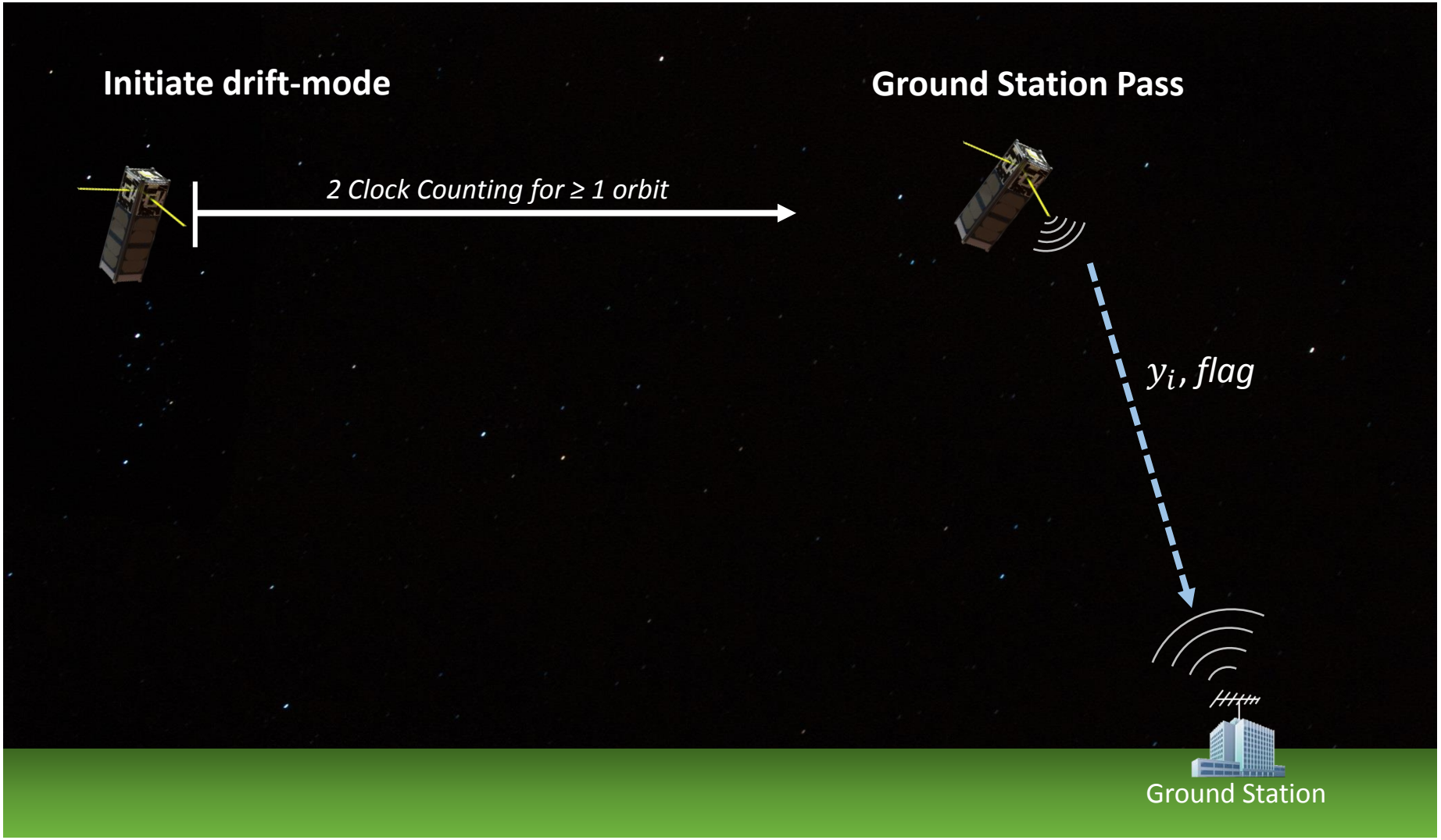
CHOMPTT Extended Measurement II

Time-Transfer with Optical Communications Uplink

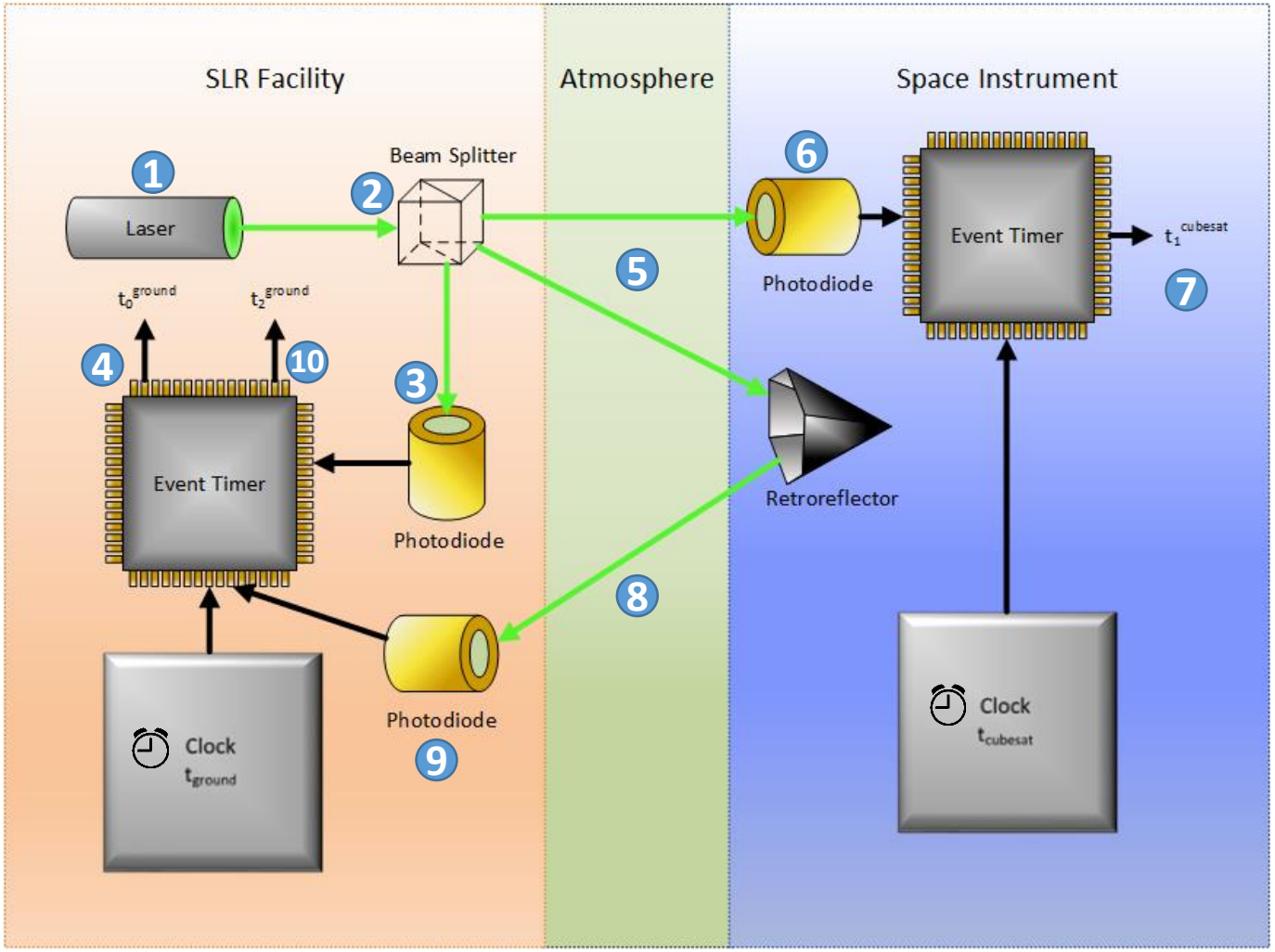


CHOMPTT Extended Measurement III

Drift-mode

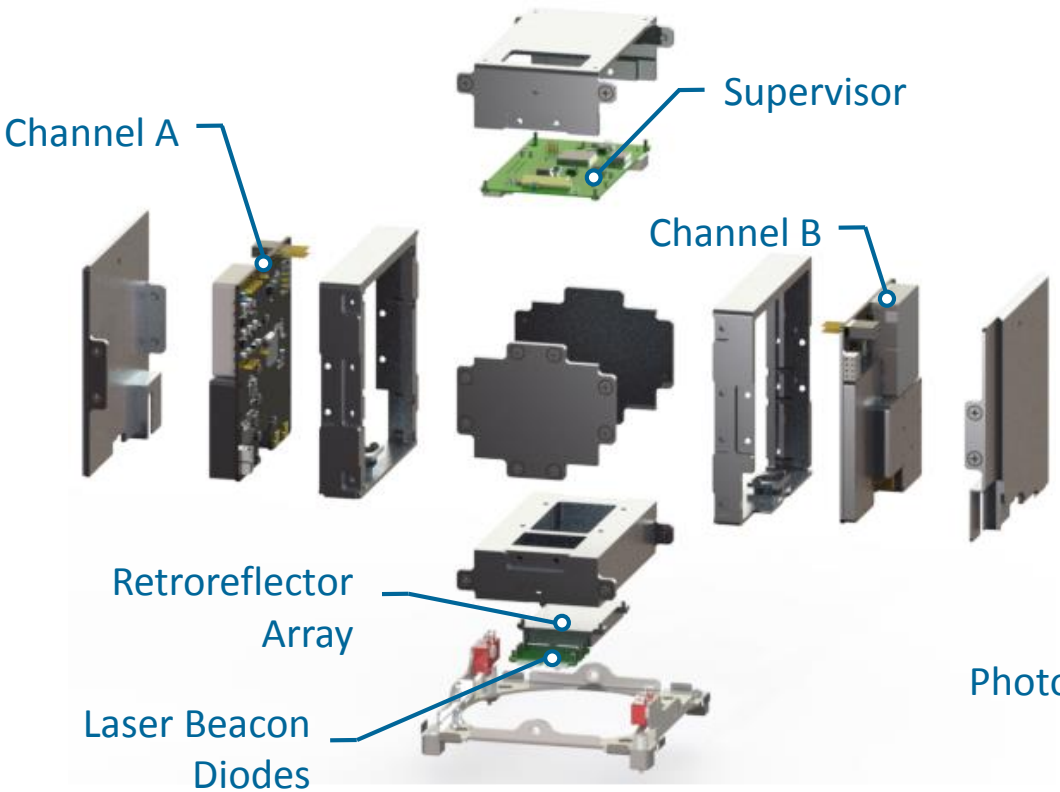


Optical Time Transfer Architecture

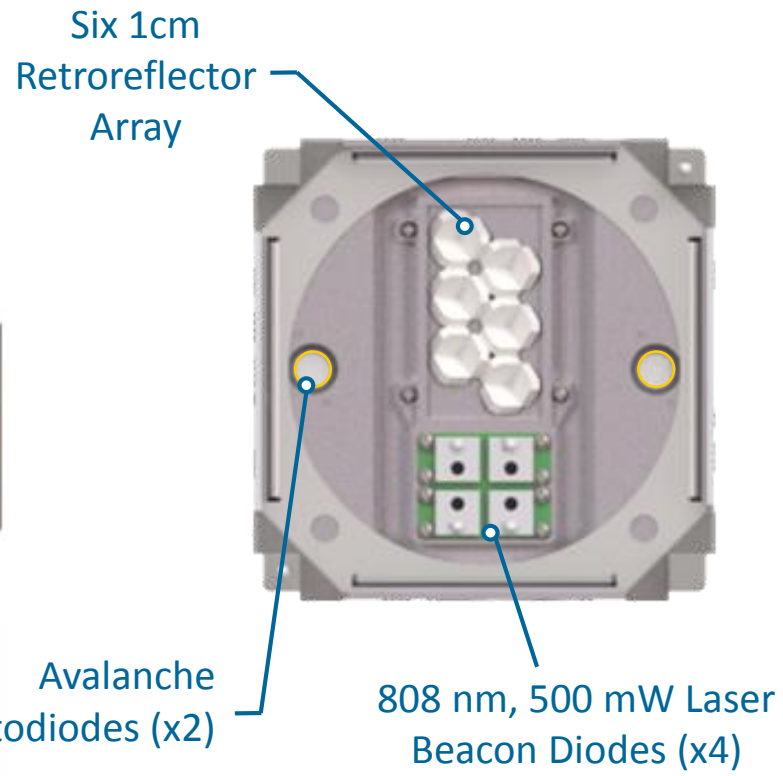


OPTI Payload

Expanded View



Nadir Optics Face



Timing

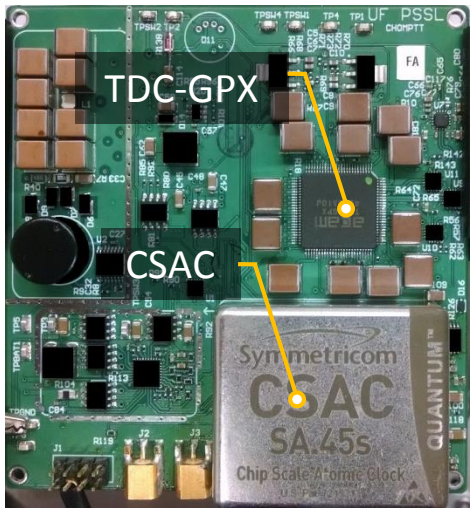
Coarse Time
MSP430 counter

- Chip Scale Atomic Clocks (CSACs) are used as clock reference
- TDC-GPX and MSP430 counter are synchronized on a chosen clock rising edge
  - Within 7 µs TDC-GPX range

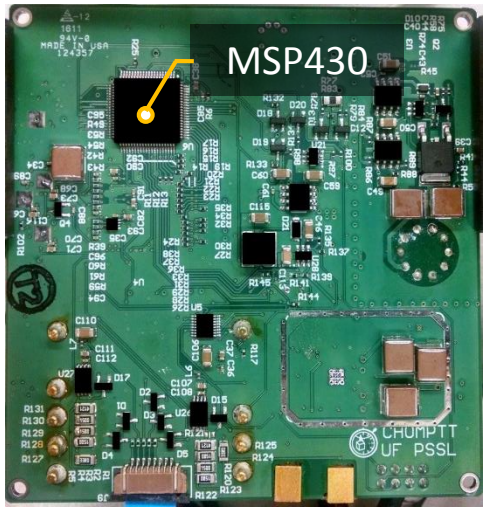
Fine Time
Time-to-digital converter (TDC-GPX)

- Integrated COTS 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)

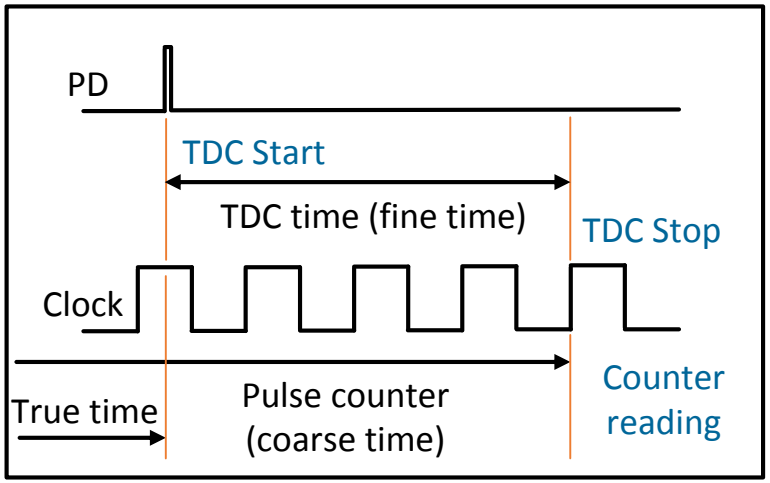
Channel Board



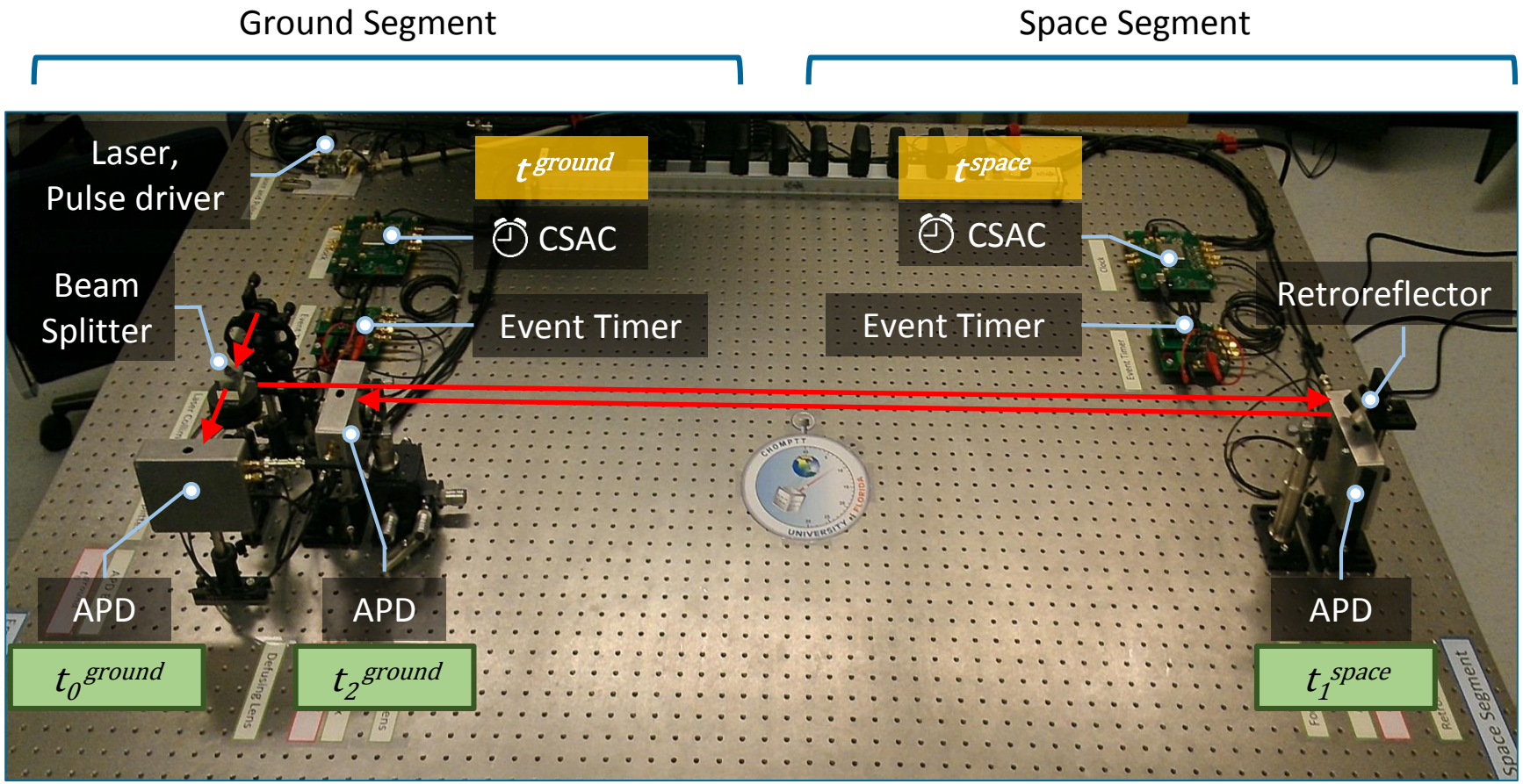
Top View



Bottom View



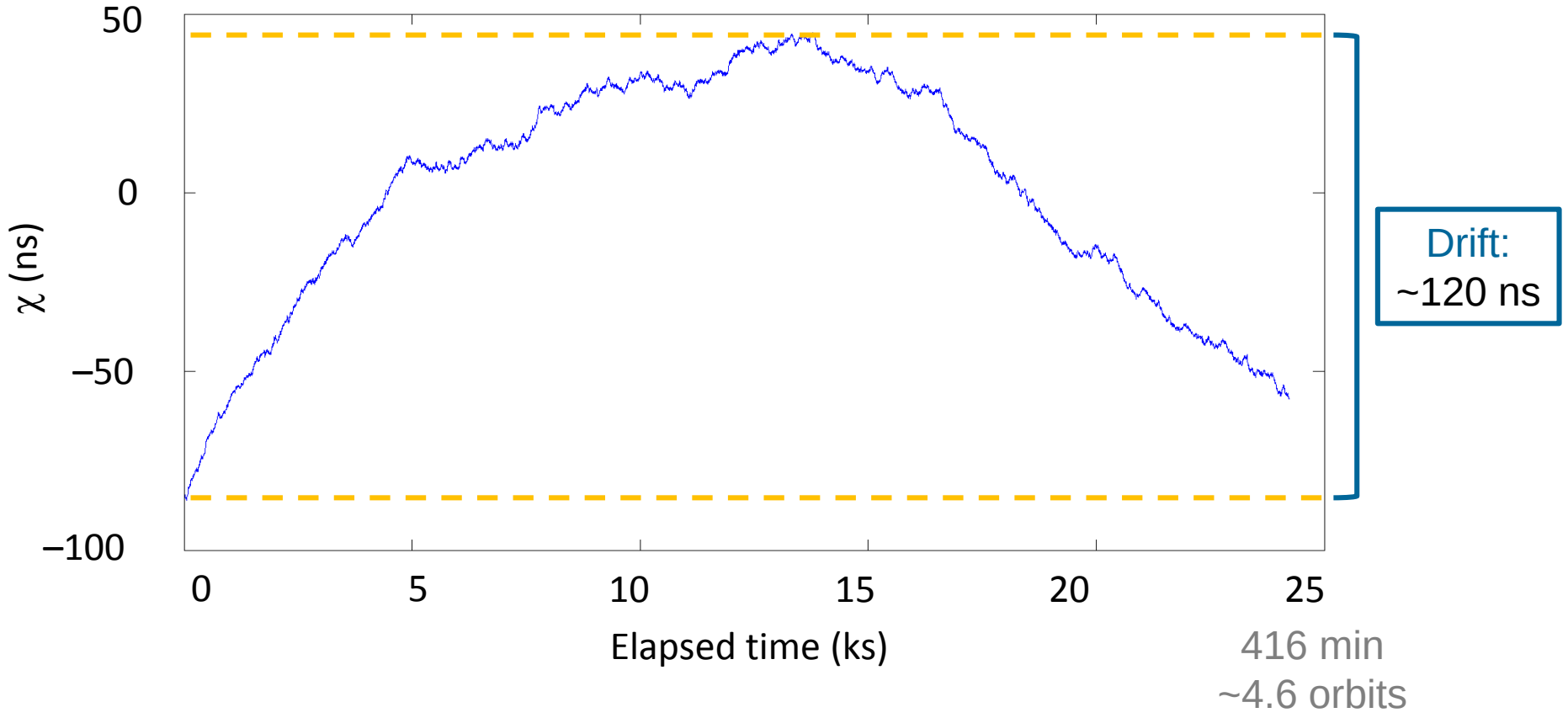
Bench Testing



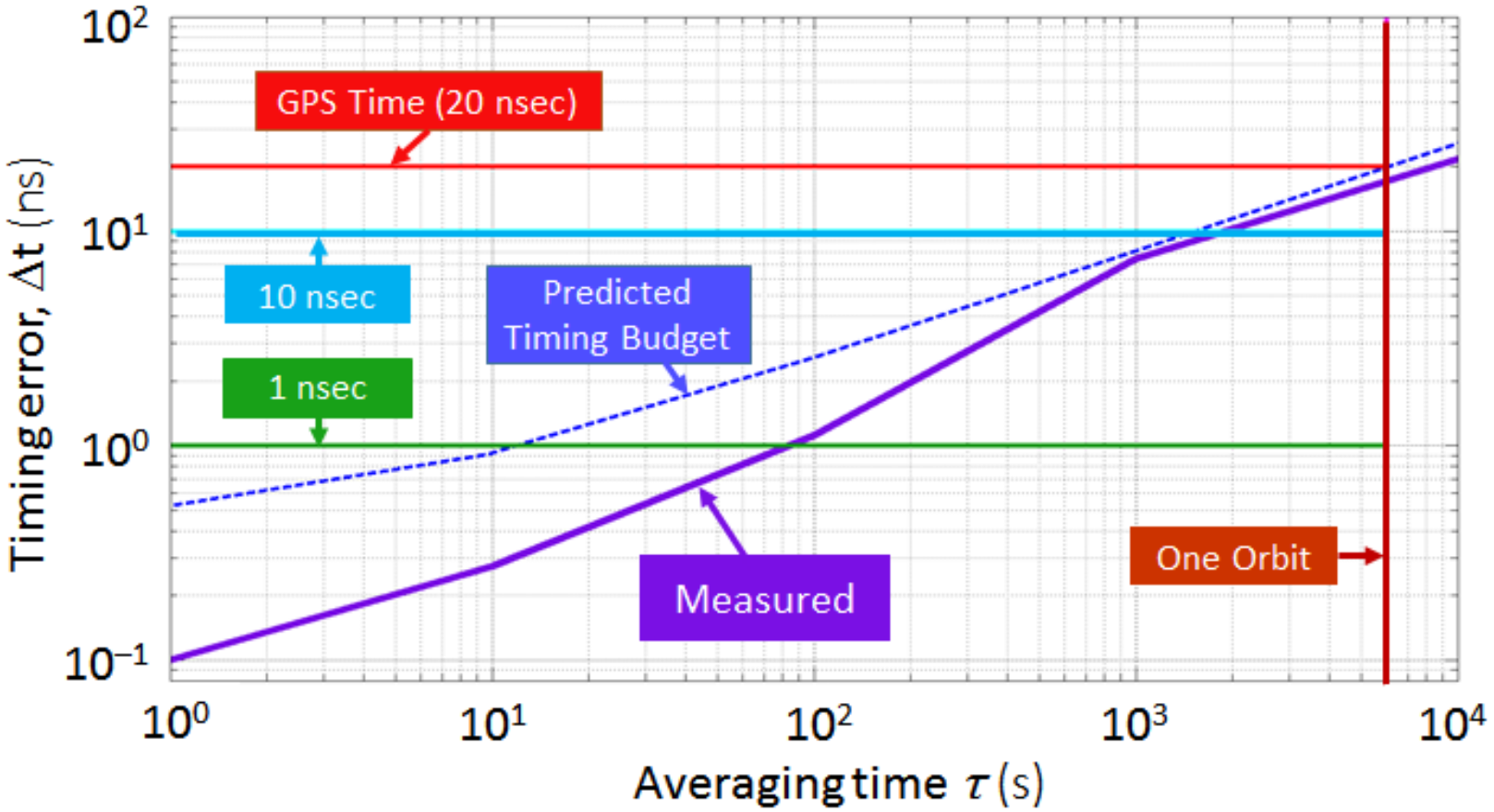
Measured timing error:
100 psec (3 cm) @ 1 sec
17 nsec (5 m) @ 6000 sec

Bench Testing

Clock difference (2 CSACs) measured using OPTI breadboard



Time-transfer Error Budget

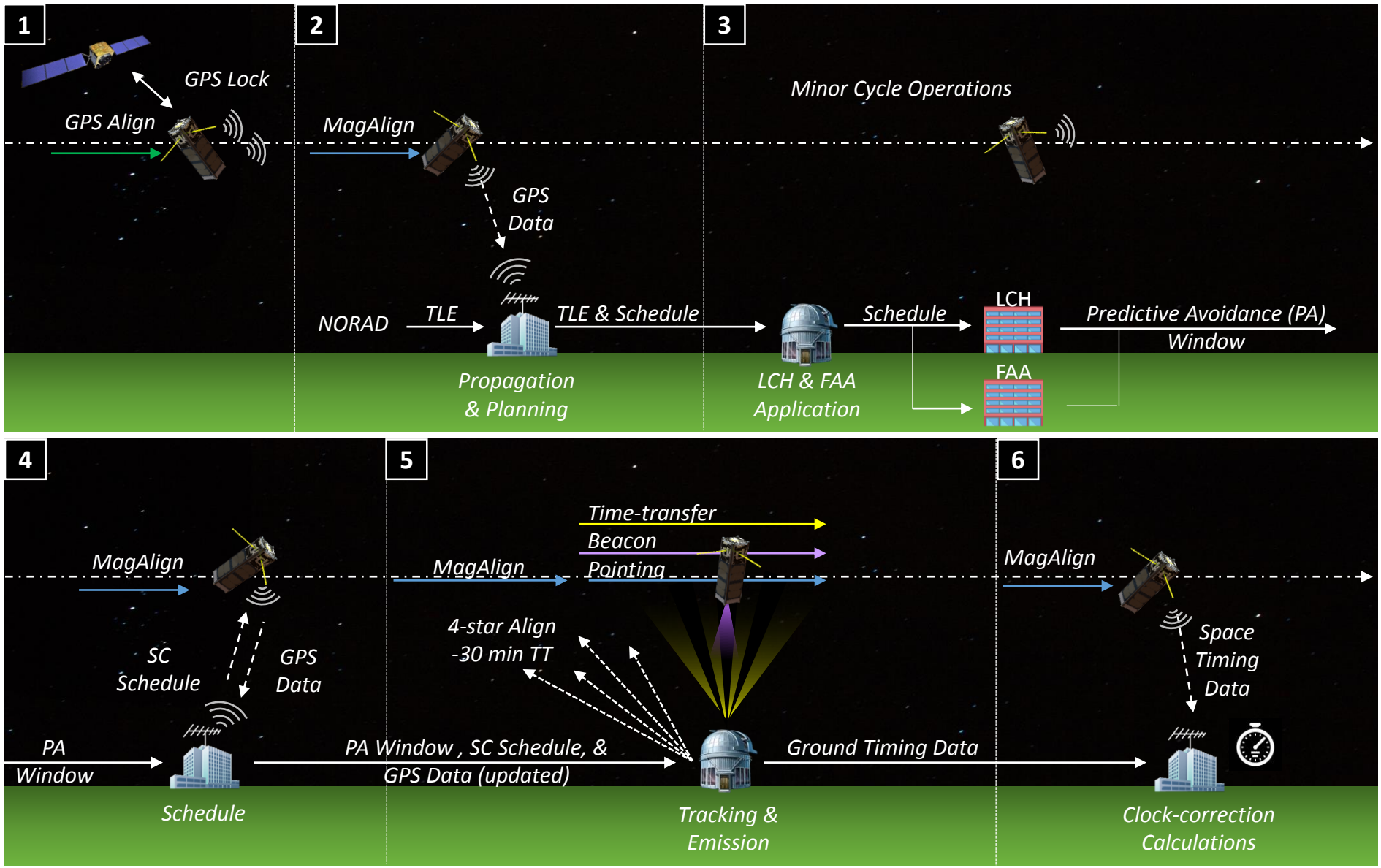


< 20 ns of measured timing accuracy at 6000 s (~1 orbit)

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

25 hr Minor Cycle Concept of Operations



Satellite Laser Ranging Facility

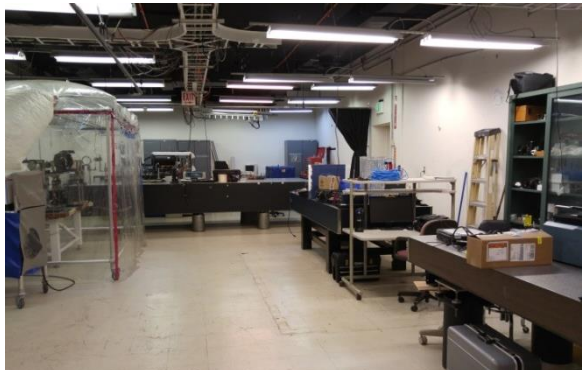
Townes Institute Science & Technology Experimentation Facility (TISTEF) managed by University of Central Florida (UCF) at Kennedy Space Center

TISTEF

1 km Testing Range

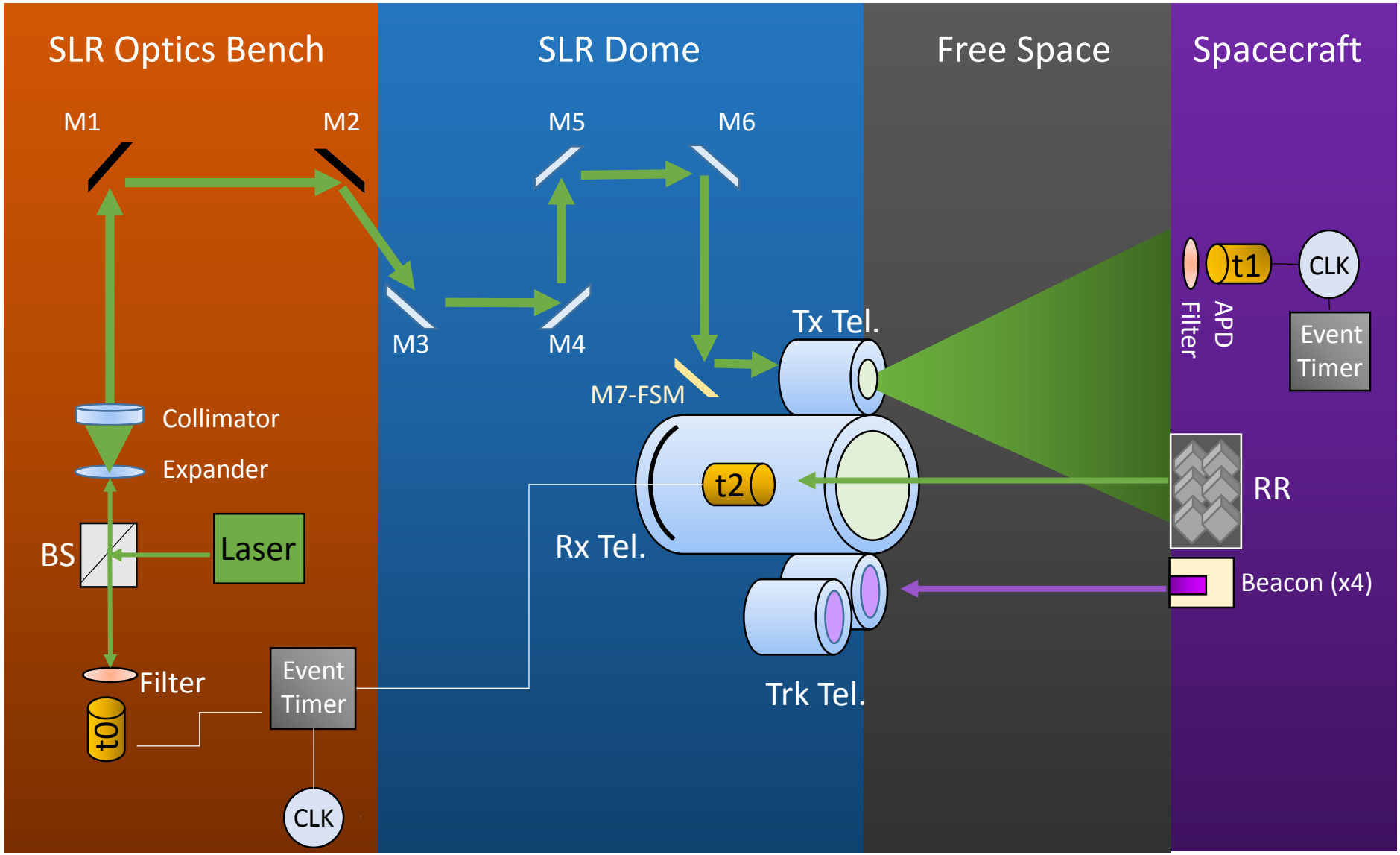
50 cm Tracking Telescope

Control Room



Optics Lab

Optical Links



Time Transfer Link Overview

Coherent Flare NX

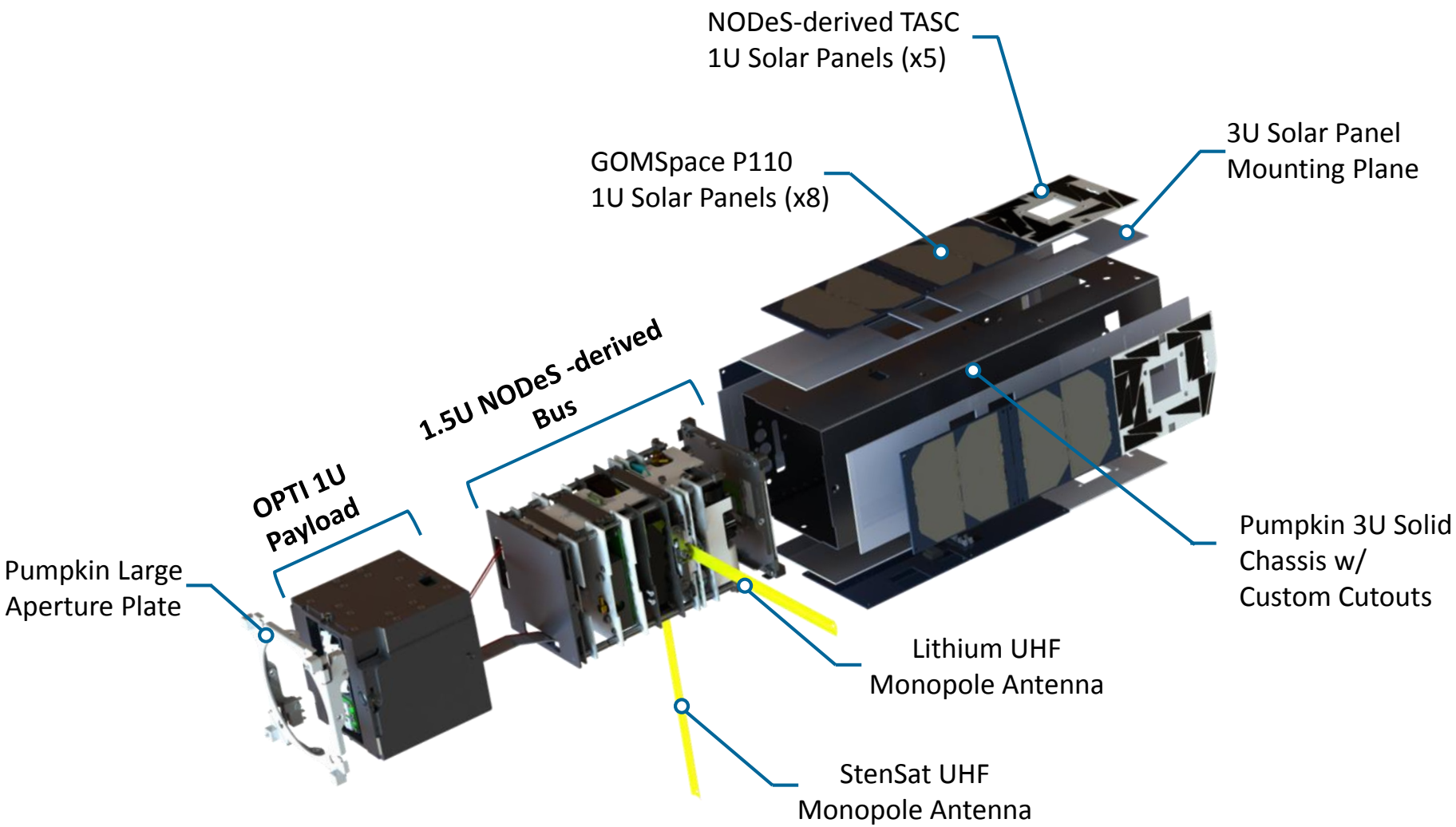
- 1064 nm
- 3mm Beam diameter
- Linear Polarized

Link Transmit Characteristics				
Altitude	**Laser Energy**	**Pulse Duration**	**Laser Power**	**Rep Rate**
500 km	1.1 mJ	2.6 ns	~423 kW	50 Hz

Link Detector Characteristics 30° Elevation	
Detector	**Power Received**
OPTI APD	180 nW
Ground APD	8 nW

Link Detector Characteristics 90° Elevation	
Detector	**Power Received**
OPTI APD	810 nW
Ground APD	140 nW

Spacecraft


NODeS-derived TASC
1U Solar Panels (x5)
3U Solar Panel
Mounting Plane
GOMSpace P110
1U Solar Panels (x8)
1.5U NODeS -derived
Bus
OPTI 1U
Payload
Pumpkin Large
Aperture Plate
Pumpkin 3U Solid
Chassis w/
Custom Cutouts
Lithium UHF
Monopole Antenna
StenSat UHF
Monopole Antenna

NODeS-Derived Bus

- Smartphone as main processor
- 13 Solar Panels
  - 8 identical 1U GOMSpace P110 panels
  - 5 identical 1U NODeS TASC panels with 15 cells
- Lithium UHF transceiver for uplink & downlink
- StenSat UHF transmitter for beacon
- 3 RF Antennas
  - GPS patch on 1U zenith face
  - Lithium and beacon monopoles off 3U faces
- 4 18650 Li-Ion Batteries
- ACS – 3 RW, magnetometer and torque coils
- Novatel OEMV-1 GPS receiver
- 8 PCB subassemblies electrically inter-connected through a single backplane PCB
- Single ribbon cable payload and bus interface for data and power

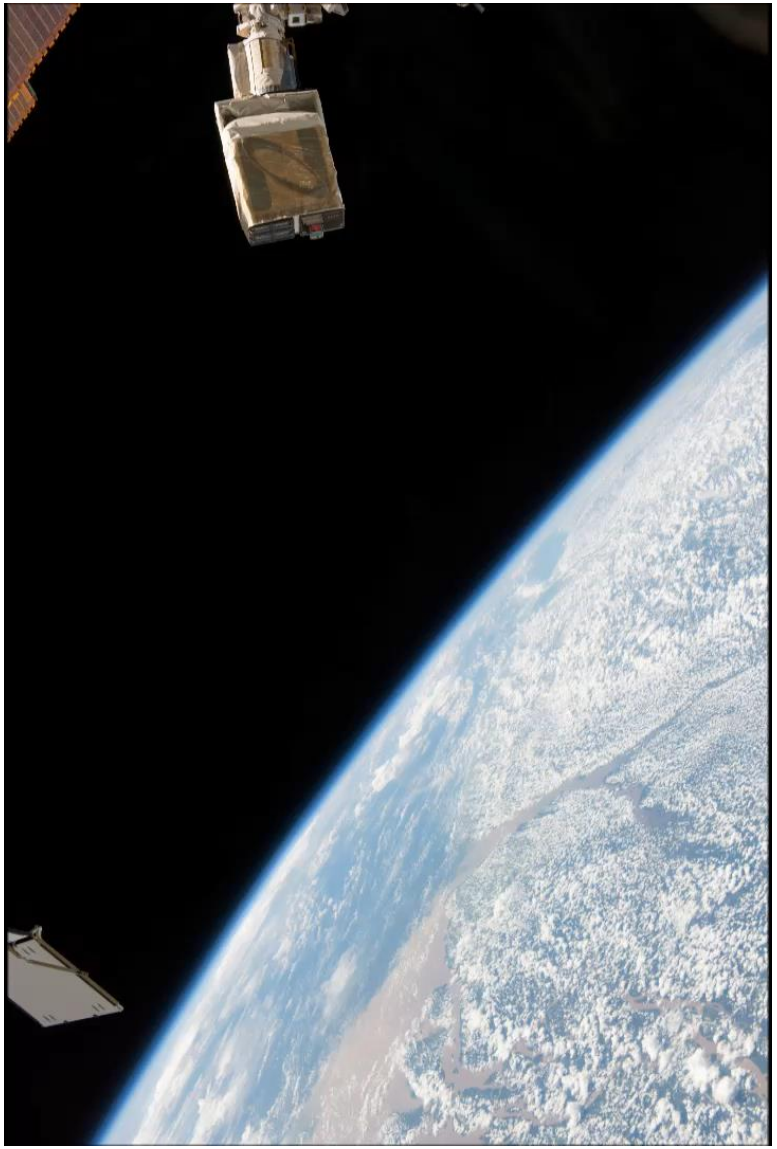
NODeS Assembly

NODeS Mission Objectives

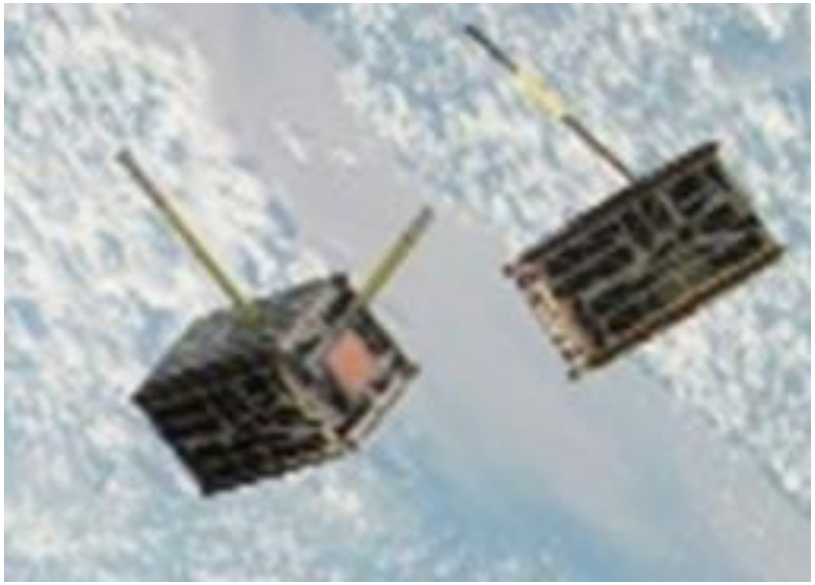
- Flight demonstrate the commanding of a satellite through a network of satellites by transferring a command from the ground through a relay satellite to a target satellite and having the target satellite execute the command.

- Flight demonstrate the ability of a swarm to autonomously negotiate which spacecraft shall take the role of leader (Captain) based on criteria dependent on the states of the two satellites.

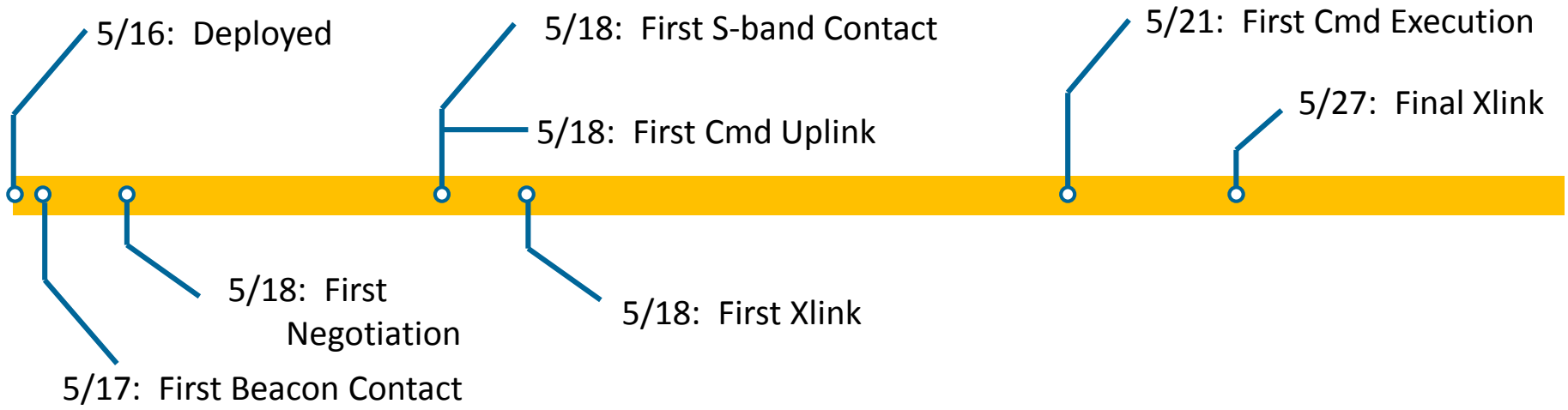
- Collect and downlink time synchronized multipoint science data using EPISEM instrument



NODeS Mission Summary

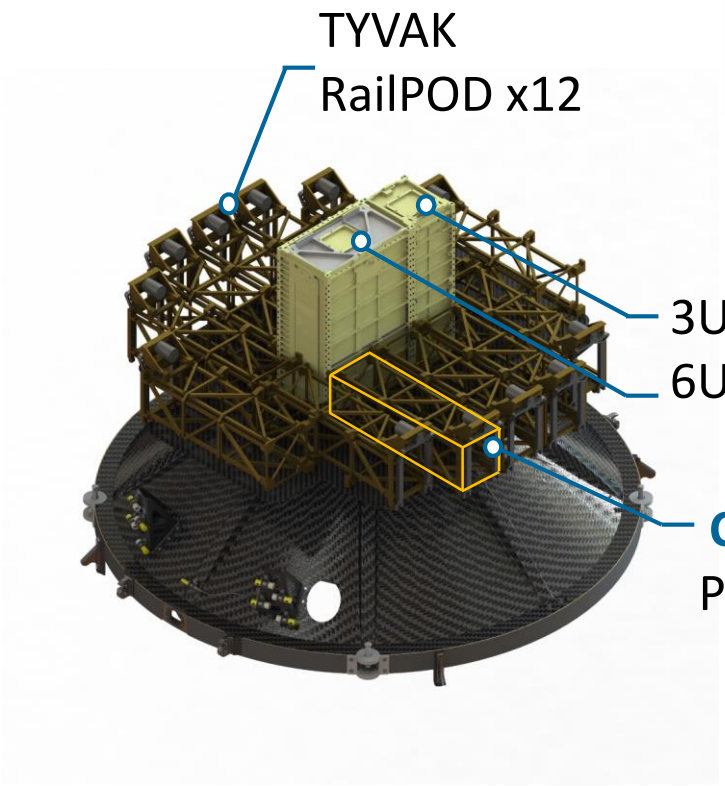


Mission Goal	Req'd	Ach'ved
Space-to-Ground Links	5	10+
Ground Command of S/C through Network	1	11
Perform Captaincy Negotiation	2	4
Collect Science Packets & Transfer to Ground	5	1,199 as of 7/27/16
Monitor S/C state-of-health	20 days	72 days +



ElaNa XIX Launch

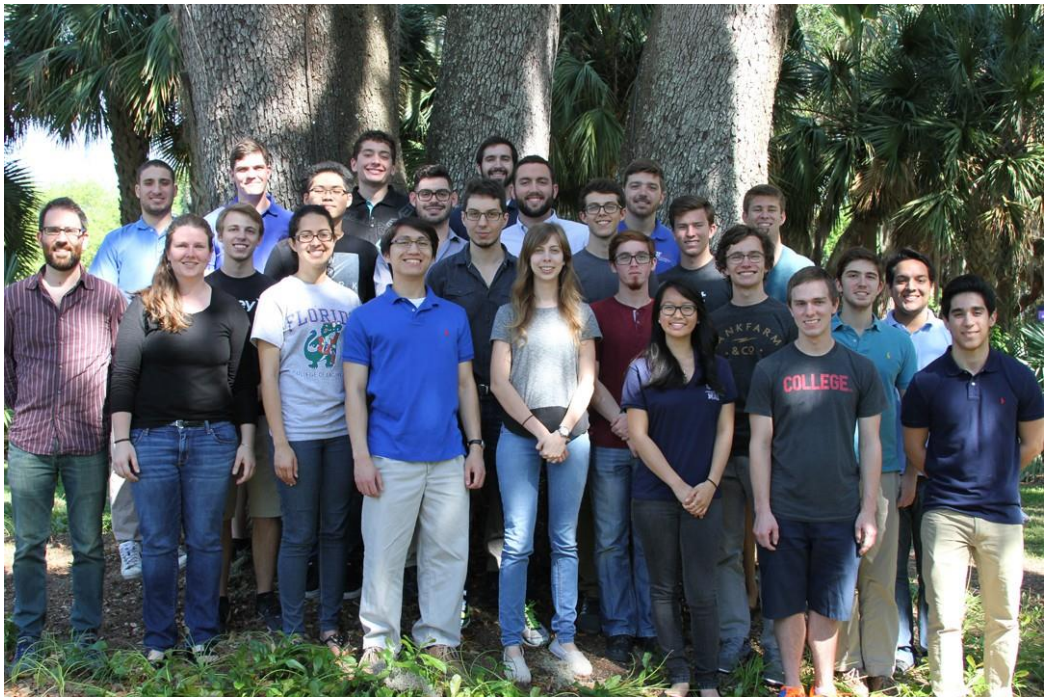
- RocketLab Electron, Mahia NZ
- Low Earth Orbit: 500 km x 85 deg
- Delivery: March 2017
- Launch: June 2017



TriSept Corporation
Integrity Expertise Innovation

Schedule

- PL + Bus FlatSat Interface testing and SLR Facility development
  - Fall 2016
- Build CHOMPTT FU
  - Dec 2016
- CubeSat Delivery
  - March 2017
- Elana XIX Launch
  - June 2017



University of Florida CHOMPTT Team

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