Developing An Optical Ground Station For The CHOMPTT CubeSat Mission

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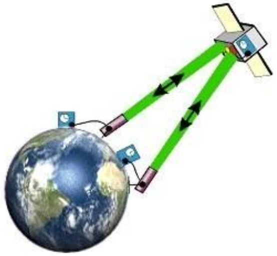
Background and Motivation

PSSL

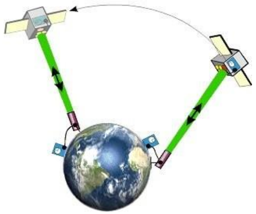
- Application of precision time transfer to space
  - Satellite navigation systems ($\Delta x = c\,\Delta t$)
    - Beyond LEO
  - Global time standards
  - Test of general relativity
  - Satellite encryption/authentication
- Optical time transfer
  - More resilient to Ionospheric effects than RF (~$1/f^2$)
  - CNES T2L2 (2008), hosted payload on Jason-2

GPS Constellation

Gravity Probe A (1976)



Common View



Non-common View

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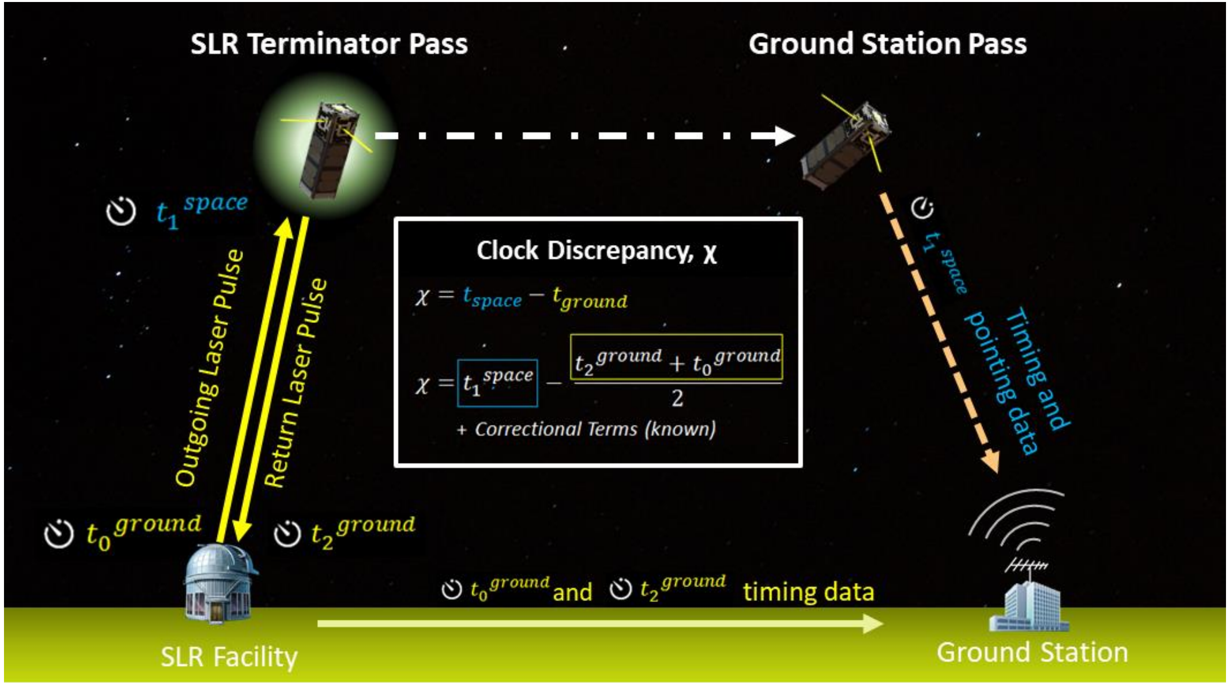
CHOMPTT Mission

Single Time-Transfer < 200 ps time transfer error (6 cm), < 20 ns clock drift after 1 orbit (6 m)



CHOMPTT CubeSat Status

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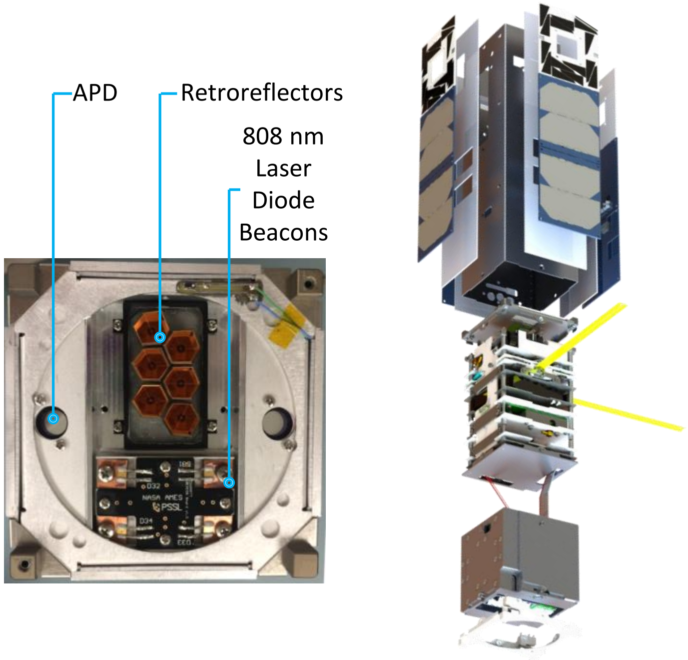
- Mission Simulation Testing performed at the University of Florida
  - All systems operating as desired
  - APD response characterized
- CHOMPTT spacecraft has been delivered to the Rocket Lab headquarters in Huntington Beach
  - Integrated into dispenser 11:30 am 4/12/18
- Current launch window begins May 30th 2018



CHOMPTT CubeSat (2018)

Satellite Laser Ranging (SLR) Facilities

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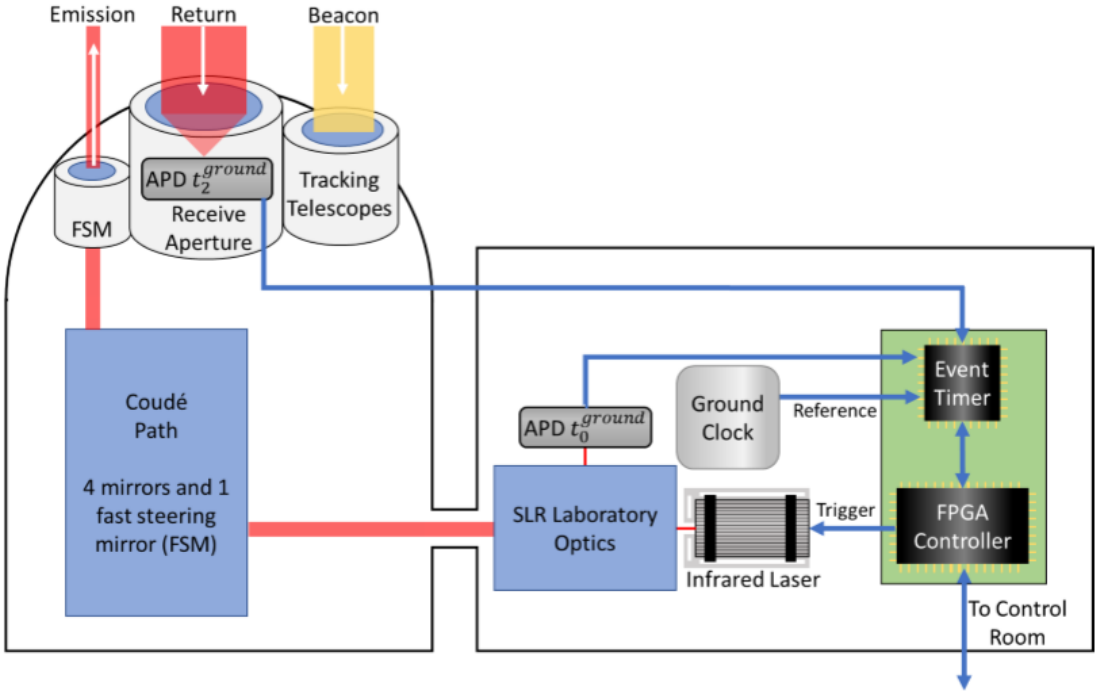
- Townes Institute Science and Technology Experimentation Facility (TISTEF)
  - Primary SLR Facility
- Electro Optic Systems (EOS) Australia

EOS (Australia)

SLR Facility Overview



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SLR Components

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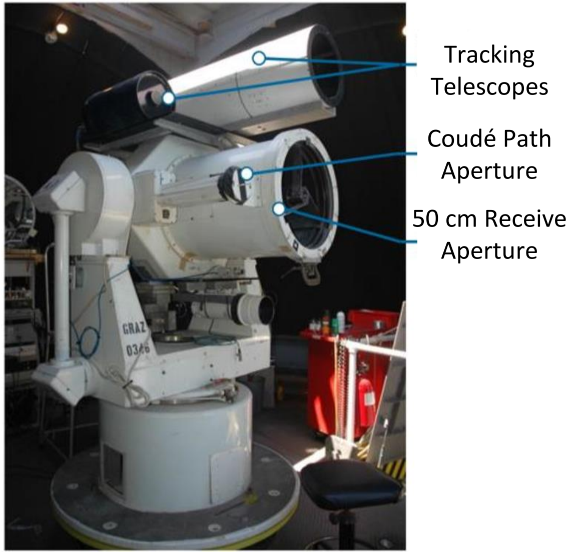
TISTEF

- Emitted pulse travels through coudé path and out the aperture
- Return pulse is captured by 50cm receive telescope and focused onto APD at t_2^{ground}
- Laser and time-to-digital converter (TDC-GPX2, RMS error < 30 picoseconds) use Rubidium-based miniature atomic clock (MAC) as reference (clock accuracy < 50 picoseconds)
- Tracking telescopes
  - Infrared imagers for 808 nm beacon
  - Different field of view for each

EOS

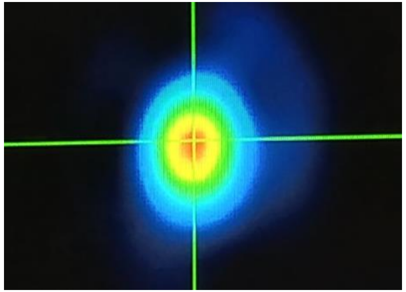
- Automated or remote controlled
- Ranging to high and low satellites with millimeter resolution
- Picosecond timing systems
- Standard systems of 1 m aperture



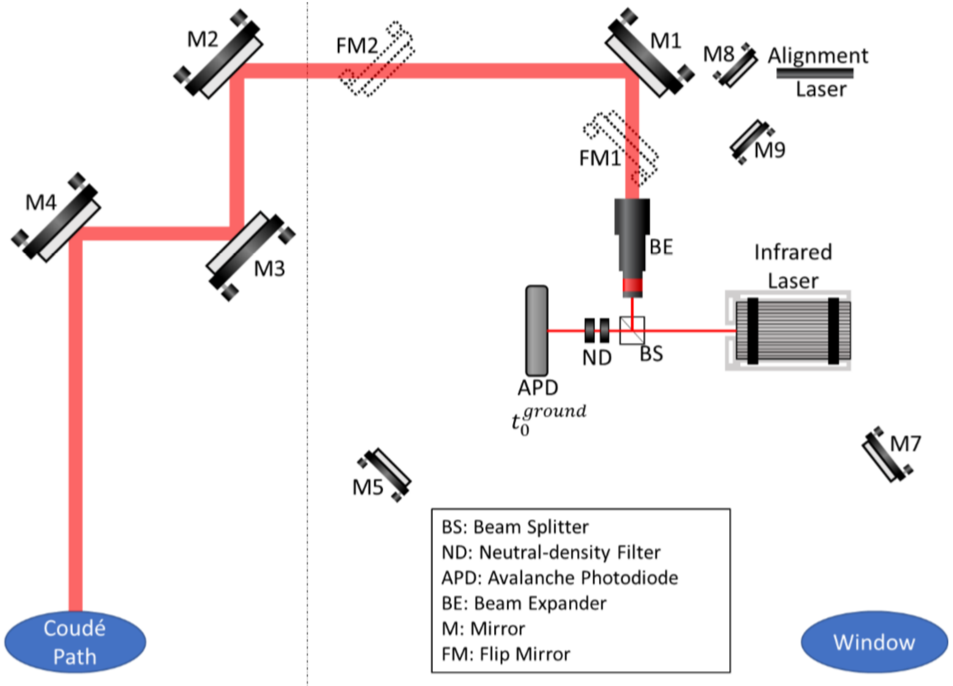
[2]

SLR Laser

- Coherent FLARE 1064 50-50
  - Pulse energy verified at 1.22 mJ
  - Pulse width 2.62 ns
    - Corresponding to ~465 kW peak power
  - Beam Diameter measured with Coherent LaserCam
    - 1.13 mm x 0.72 mm



Laser/Mirror Setup



Optical Link Budget

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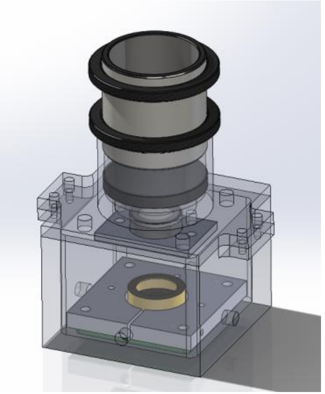
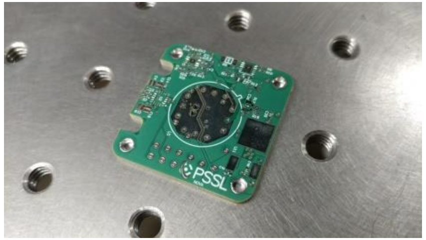
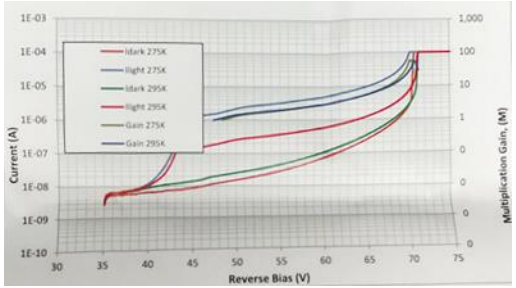
Initial Peak Laser Power	465 kW
Beam Expander Magnification	30x
Expected Power on t_0	45.7 mW
Expected Power on spacecraft APD (t_1)	2.17 µW
Expected Power on t_2	355 nW

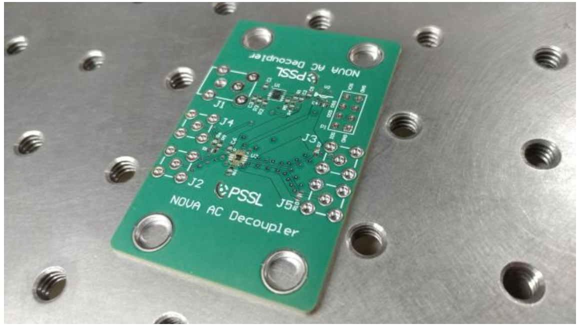
Detection Setup

- Near-IR Optical detector with Variable Amplification (NOVA)
  - Detector boards used at the TISTEF facility for t_0 and t_2
  - Voxtel InGaAs avalanche photodetectors (>1GHz bandwidth) paired with high speed amplifiers send AC coupled signal into AC decoupler
  - AC decoupler uses high speed comparator to send digital signal to a TDC-GPX2 referenced to a Rubidium based Miniature Atomic Clock (MAC)









Scintillation

- Scintillation is defined as fluctuations in intensity of light
  - *Gracheva and Gurvich, (1965)* showed a leveling off of the scintillation magnitude with increasing range beyond 1 km
  - *Johnson et al., (1970)* showed scintillation magnitude actually decreases with increasing range beyond this level
- The images show that scintillation is not heavily wavelength dependent
  - Beam power and divergence are also less affected by range at higher altitudes

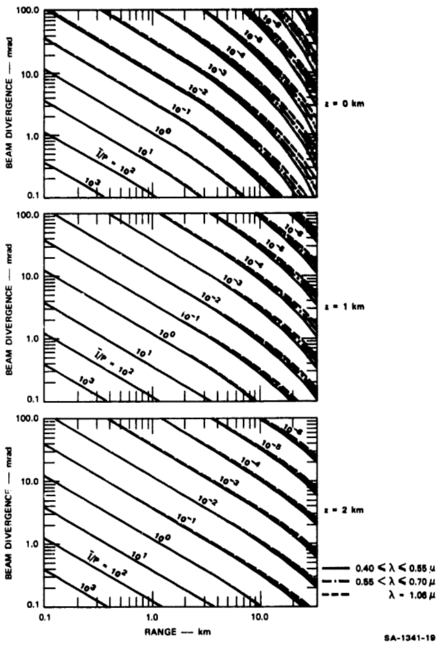
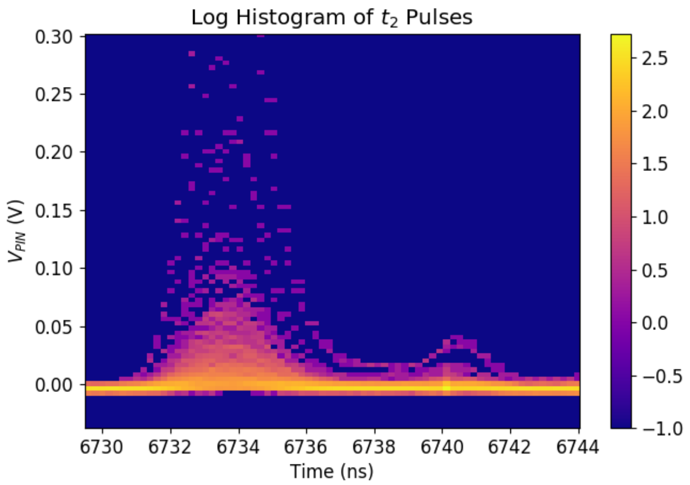


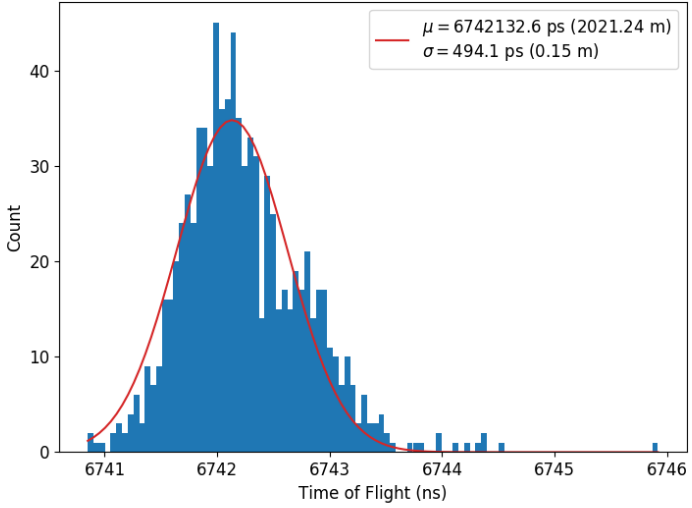
FIGURE A-2 NORMALIZED MEAN POWER DENSITY (I/P,m^{-2}) AS A FUNCTION OF LASER BEAM DIVERGENCE (β) AND RANGE (R) FOR VARIOUS WAVELENGTHS (λ) AND HEIGHTS (z) IN A CLEAR STANDARD ATMOSPHERE [3]

Ranging Results

- Pulse peak amplitude greatly varied due to scintillation, which also varied throughout the day
  - Proximity to large body of water added higher than normal turbulent air flow, though there was lower than average humidity due to a cold front



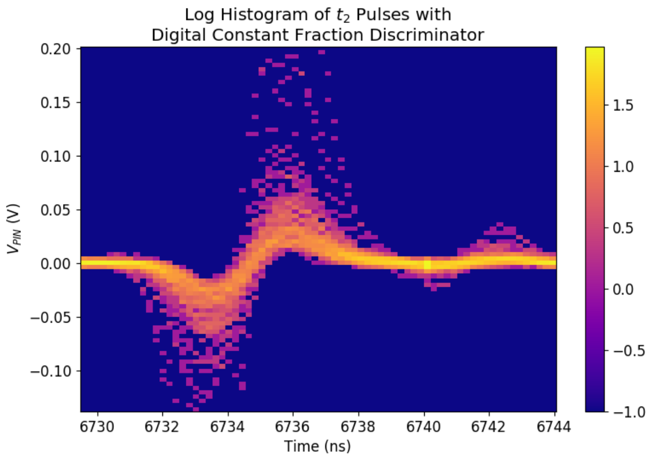
Peak amplitude variation, afternoon testing



Time of Flight timestamps, morning testing (less scintillation).
Corresponds to 1010.62 meters, one way, with a 494.1 ps standard deviation

Ranging Results

- Jitter in time of flight can be corrected via constant fraction descrimination (CFD)



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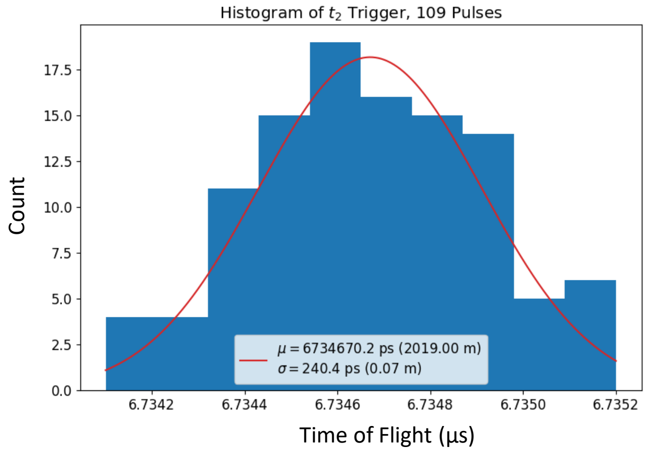

Time of Flight timestamps, morning testing (less scintillation).
Corresponds to 1009.5 meters, one way, with a 240.4 ps standard deviation

PSSL

@Precisionspace

References

[1] *T2L2 mission [P. Guillemot et al 2006]*

[2] *N. Barnwell, Oral Qualification Presentation, 2017*

[3] *Dabberdt, SRI, 1972*

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