Free Space Optical Communications with Nanosatellites

K. Cahoy, MIT

CubeSats can enable persistent global imaging

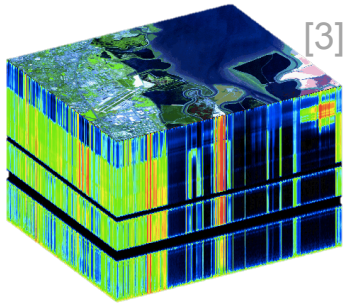
100 Gb =

[1]

80,000 images
~ 1 every second for a day

[2]

2 hours of GoPro video



[3]

120 Hyperspectral Image Cubes

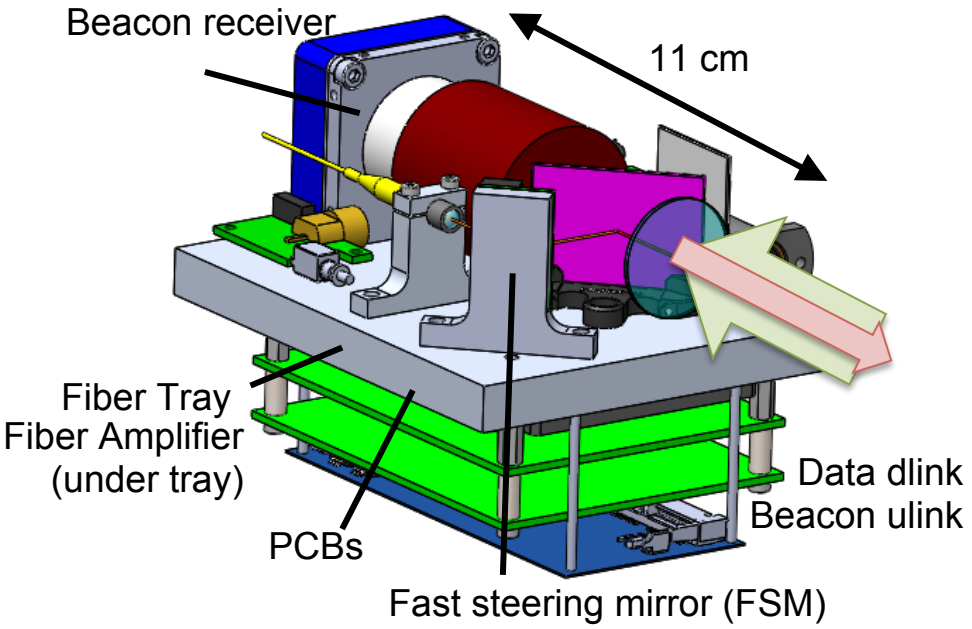
E. Clements, MIT

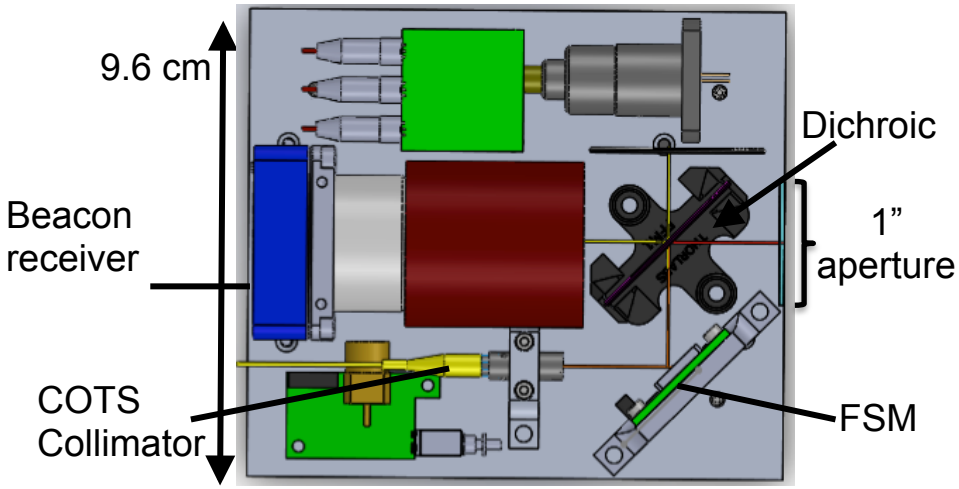
Low-cost spacecraft and access to space, but…
resource constraints limit data transfer

Downlink: NODE Space Terminal

NODE: Nanosatellite Optical Downlink Experiment

Scope	Low-cost CubeSat payload
Architecture	Direct detection MOPA COTS telecom parts (1550 nm)
Downlink data rates	10 Mbps (amateur telescope) 100 Mbps (OCTL)
Power	200 mW Tx < 15 W during Tx
Beamwidth	1.3 mrad HPBW (initial experiment)
Modulation	PPM
Coding	RS(255,239)
Mass, volume	1.0 kg, 1 U
Control architecture	• Bus coarse pointing (<0.5°) • FSM throw (+/- 3°) • Beacon receiver (976 nm) for pointing knowledge (20 arcsec)





Downlink: NODE Ground Terminal

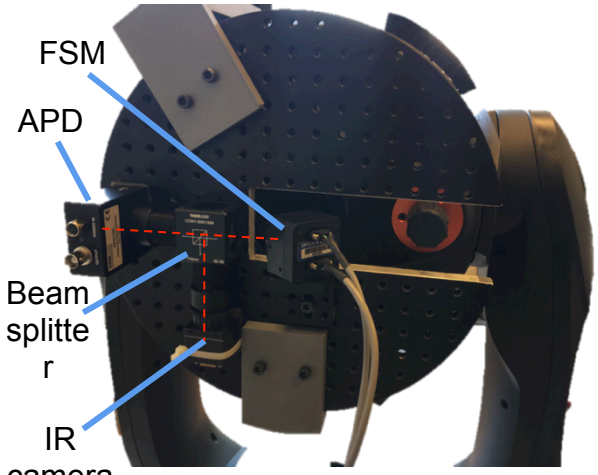
Downlink with NODE amateur telescope:

Data rate	10 - 50 Mbps
Rx Diameter	30 cm
Detector	Direct detection w/ COTS Voxtel APD
Receiver electronics	Custom data acquisition system
Pointing	COTS IR camera and star tracker [19] FSM to keep spot on APD (no AO)
Uplink beacon	976 nm (OCTL) beacon[20]

E. Clements, K. Riesing

Downlink with JPL OCTL telescope:

Data rate	50 - 100 Mbps
Rx Diameter	1 m
Detector	Direct detection w/ COTS Voxtel APD
Receiver electronics	Custom data acquisition system
Uplink beacon	976 nm, 10 W tx power, 1 mrad beam

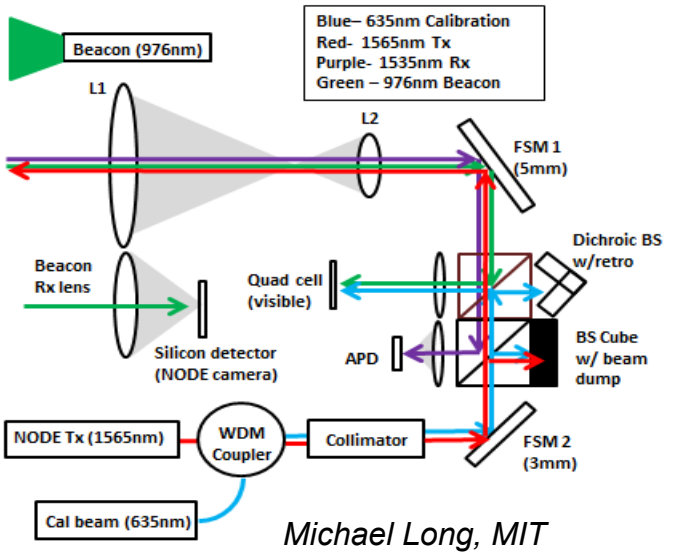


[4] Yoon, H., K. Riesing, and K. Cahoy. "*Satellite Tracking System using Amateur Telescope and Star Camera for Portable Optical Ground Station.*" SmallSat 2016.

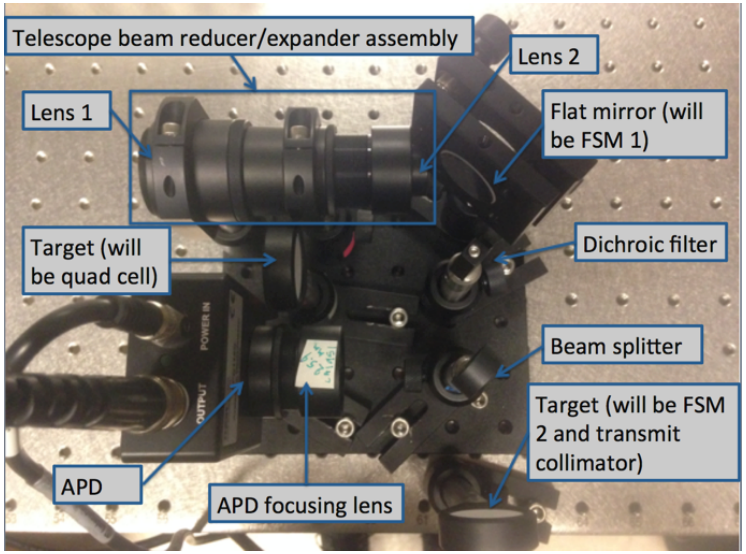
Crosslink: CLICK Space Terminal

CLICK: Cubesat Laser Intersatellite CrosslinK

Scope	Monostatic, full-duplex
Architecture	Direct detection MOPA 1565 nm, 1535 nm tx/rx 976 nm beacon, 635 nm cal
Transmit divergence **Transmit beam size**	+/-0.07 mrad (FWHM) 16 mm (1/e^2 Gaussian diam.)
Power	200 mW Tx , 500 mW beacon
Acq/Rx entrance aperture	20 mm
Telescope magnification	10.5x
Tx small beam size **Acq/rx small beam size**	1.6 mm 2.0 mm
Max dimension	106 mm
Quad cell FOV (acquisition) **Quad cell linear range (acq)**	+/-0.5° +/-0.15°
Beacon spot size on quad cell	1 mm
Data rate, range	20 Mbps at > 1000 km



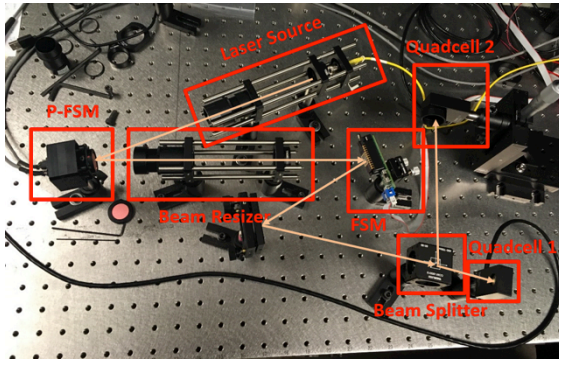
Michael Long, MIT

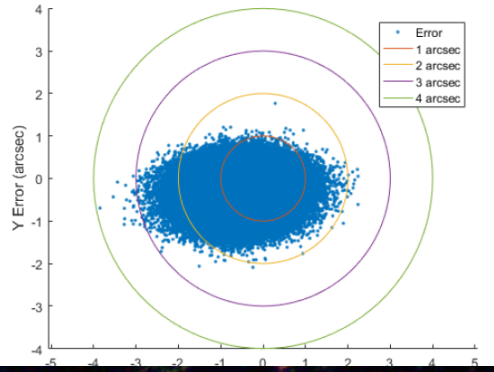


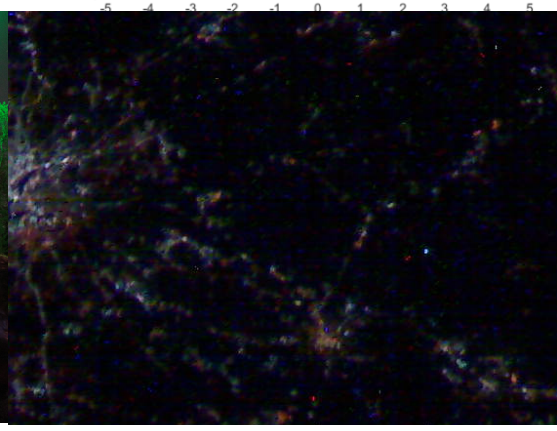
Rachel Morgan, MIT

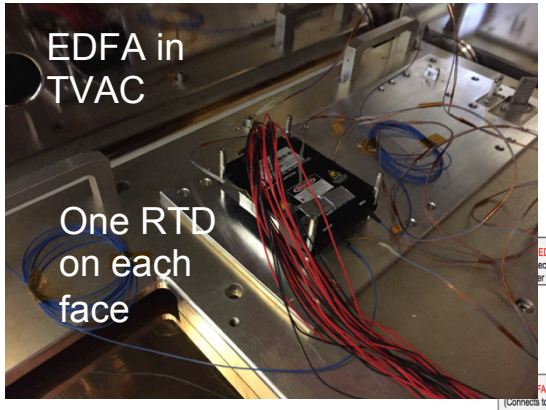
Recent MIT Accomplishments

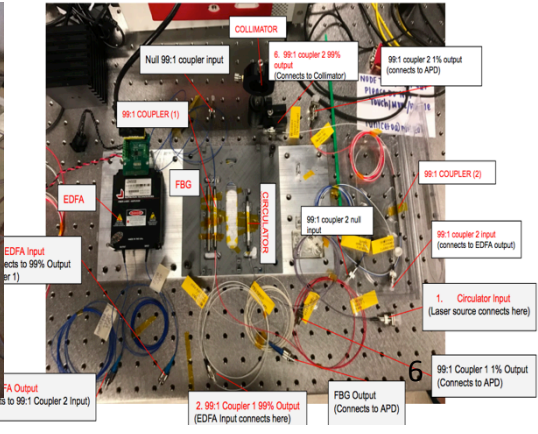
- < 1arcsec, 1-sigma pointing control w/ MEMS FSM vs. 40” 1-sigma CubeSat disturbances (H. Yoon, Ph.D. 2017)
- Internal MEMS FSM feedback calibration laser tracking beacon (O. Cierny, visiting MS 2017)
- TVac and radiation testing of EDFA
- Flight electronics boards and structures for downlink module
- Control software for alignment of and LEO tracking with COTS telescope
- Over the air testing of modulation, coding, and interleaving and clock recovery; also GS peak power tracking (Ziegler, SM 2017, Riesing Ph.D. 2018)
- Detailed design and simulation of monostatic crosslink terminal (Long, SM 2018, Morgan SB 2018)











Citations & Other Compact Space Lasercom

Citations:

[1] https://www.planet.com/gallery/

[2] http://www.businessinsider.com/long-lost-gopro-footage-from-the-edge-of-space-2015-9

[3] https://aviris.jpl.nasa.gov/data/image_cube.html, https://www.nasa.gov/centers/dryden/research/AirSci/ER-2/aviris.html

[4] Yoon, Hyosang, Kathleen Riesing, and Kerri Cahoy. "Satellite Tracking System using Amateur Telescope and Star Camera for Portable Optical Ground Station." (2016).

Other Compact Space Lasercom

Clements, Emily, et al. "Nanosatellite optical downlink experiment: design, simulation, and prototyping." Optical Engineering 55.11 (2016): 111610-111610.

Rose, Todd S., et al. "LEO to ground optical communications from a small satellite platform." SPIE LASE. International Society for Optics and Photonics, 2015. OCSD manifest on Cygnus OA-8E, Oct. 2017

Sinclair, D. http://www.sinclairinterplanetary.com/opticalcomms

Shubert, P., et al. "Design of low SWaP optical terminals for free space optical communications (FSOC)." *SPIE LASE*. International Society for Optics and Photonics, 2017. ATA.

Serra, Paul, et al. "Deep Space Laser Communication Transmitter and High Precision Timing System for Small Satellites." Small Satellite Conference, Logan, UT (2016). University of Florida MOCT.

Schmidt, Christopher, et al. "OSIRIS Payload for DLR's BiROS Satellite." *International Conference on Space Optical Systems and Applications 2014*. 2014.

Walz, S., M. Lengowski, and Mv Schoenermark. "Payload and Scientific Investigation of the Flying Laptop." *International Symposium on Small Satellite for Earth Observation Selected Proceedings*. 2005.

Takenaka, Hideki, et al. "In-orbit verification of small optical transponder (SOTA): evaluation of satellite-to-ground laser communication links." SPIE LASE. International Society for Optics and Photonics, 2016.

C. Metz, “Google laser-beams the film real genius 60 miles between balloons.” http://www.wired.com/2016/02/google-shot-laser-60-milesjust-send-copy-real-genius/ (24 February 2016).

D. Gershgorn, “Facebook will use these lasers to beam internet from the sky,” http://www.popsci.com/facebook-will-use-these-lasers-beaminternet-sky (2 July 2015).

SA Photonics, http://www.businesswire.com/news/home/20160526005244/en/SA-Photonics-Completes-2015-2016-Navy-SBIRSTTR-Transition

Fibertek, https://www.sbir.gov/sbirsearch/detail/888145

BridgeSat, SSTL, http://www.bridgesatinc.com/surrey-satellite-bridgesat-develop-free-space-satellite-optical-communications-solution/

Analytical Space, https://www.analyticalspace.com/