SETH Technology Demonstration of Small Satellite Deep Space Optical Communications to aid Heliophysics Science and Space Weather Forecasting

Marta Shelton
NASA Wallops Flight Facility
Wallops Island, VA 23337; (757) 824-2134
marta.b.shelton@nasa.gov

Antti Pulkkinen, Errol J. Summerlin
NASA Goddard Space Flight Center
Greenbelt, MD 20771; (301) 286-0652
antti.a.pulkkinen@nasa.gov

Mark Storm
Fibertek, Inc.
Herndon, VA 20171; (703) 471-7671
mstorm@fibertek.com

ABSTRACT

Diversified, and high data rate communications are critical for the growing number of current and future small satellites providing the next generation of high-resolution science observations. Science Enabling Technologies for Heliophysics (SETH) is a small satellite mission concept[1] that will utilize Fibertek's low cost, Compact Laser Communication Terminal (CLCT) to demonstrate high rate optical communications from deep space. This cutting-edge technology will support the Helio Energetic Neutral Atom (HELENA) heliophysics instrument that demonstrates solar energetic neutral atom (ENA) and space weather observation capabilities, in alignment with NASA's Moon to Mars exploration initiative. SETH will demonstrate data rates of at least 10 Mbps from 0.1 AU. The CLCT includes a telescope, Pointing, Acquisition and Tracking sensor, vibration isolation mounts, and a fine steering mirror, all fitting in a 2U commercially available stack. SETH will prove that deep space optical communications are now available also for small satellite missions. The mission utilizes public-private partnerships and multi-center NASA collaboration. Compatibility between ground and space segments is established by adopting the emerging Consultative Committee for Space Data Systems (CCSDS) High Photon Efficiency (HPE) standard.

BACKGROUND

According to the United Nations Office for Outer Space Affairs, there were 4,857 satellites orbiting Earth in 2018, with a 4.79% increase over 2017[2]. Another 3,000 satellites of 50 kg or greater are forecasted to launch between 2017 and 2026[3]. As part of this exponential growth, there is a shift in the market for smaller, more inexpensive satellites, which will fly not just in Erath orbits, but into deep space as well. This also means that an ever-increasing number of satellites from varied distances from the Earth will need to communicate with ground communication networks. Optical Communications is a disruptive technology which will allow data rates and volumes of two orders of magnitude higher than Radio Frequency (RF), and will play an important role in future satellite communications.

As humanity expands its quest in human space exploration, space weather prediction is becoming increasingly important. We cannot hope to understand, model and predict the system as a whole without observing and modeling the dynamics across the full range of relevant scales, which span across 1 m structures in the ionosphere to 10^8 m large-scale interplanetary plasma structures with varied time scale emissions, subject to cross-scale coupling due to plasma turbulence and magnetic reconnection. Heliophysics thus has a need to observe the environment at higher and higher spatiotemporal rates. These multi-point observations can only be accomplished by harnessing data from Small satellite constellations, equipped with miniaturized high bandwidth communicationsystems penetrating deep space, like the one SETH has to offer.

SETH MISSION DESCRIPTION

The SETH bus is an EELV Secondary Payload Adapter (ESPA) class ~100 kg, ~130 W small satellite with mature bus subsystems including the Goddard Space Flight Center's (GSFC) MUSTANG avionics, Blue Canyon Technologies' attitude control system, and the IRIS RF system for ranging and commanding. An Aerojet 6U green propulsion system provides propulsion for maneuvering to an optimized drift away orbit. After its release from the ESPA Grande ring, SETH maneuvers into an Earth-leading heliospheric trajectory with a drift rate placing it ~0.25 AU from the Earth within 12 months. During the 12-month mission, SETH demonstrates 10 Mbps deep space small satellite optical communications at distances of 0.1 AU and greater from the Earth.

NASA Goddard Space Flight Center (GSFC) and Jet Propulsion Laboratory (JPL) are building on expertise in optical communications from the Lunar Laser Communication Demonstration (LLCD) and Laser Communications Relay Demonstration (LCRD), but in SETH at a fraction of the size and cost of the earlier missions. SETH will re-use the JPL high-efficiency photon counting ground receiver and high power ground Uplink Laser Assembly currently under development for the Deep Space Optical Communications (DSOC) payload to be flown on the Psyche mission. A comparison of the range, data rate and flight terminal mass of these missions is found in Figure 1.

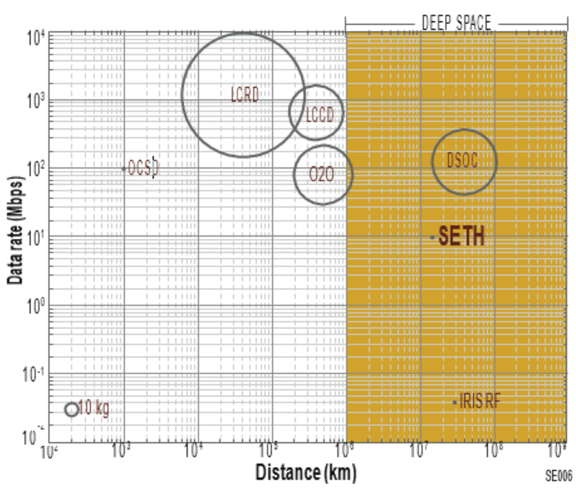

Figure 1: Comparison of SETH capability with that of the other NASA optical communication activities and IRIS Radio Frequency (RF) system. Circle size indicates flight terminal mass.

OPTICAL COMMUNICATION APPROACH

The SETH optical communication system (OCS) is comprised of 4 elements. First is Fibertek's Compact Laser Communication Terminal (CLCT) flight terminal (Figure 2). This unit receives an uplink beacon from the JPL ground laser beacon used to lock onto, and improve flight terminal pointing accuracy. CLCT then transmits to the 4.3m Lowell Observatory Discovery Channel Telescope (DCT), which will house the JPL optical ground receiver assembly. The cryostat equipped ground receiver detects and decodes the optical signal into data.

CLCT SPECIFICATIONS

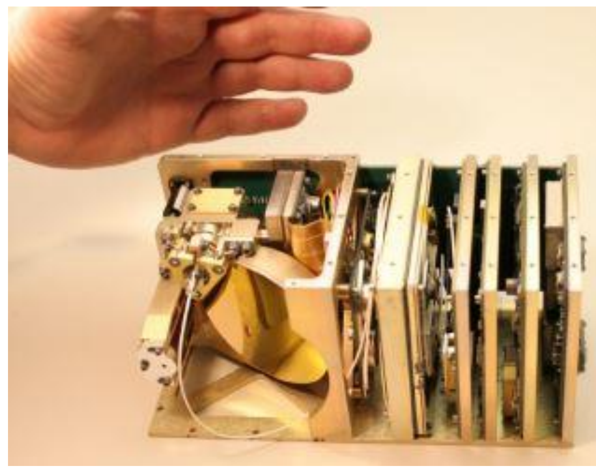

Figure 2: Fibertek's Compact Laser Communications Terminal.

A key aspect of the optical flight terminal is scaling. Its telescope is optimized at 6.5 cm for size, while fitting a low size, weight, power envelope, and its power output needs to be maximized (2W) while not exceeding the power duty-cycle of a small satellite. A 45 µrad telescope divergence, point ahead capability (which accounts for the motion of the target relative to the spacecraft during the optical signal travel time), up-link beacon detection camera, fast steering mirror, and state-of-the-art pointing capability of the SETH bus and ground assets provide generous pointing margins and precision locking to 8 µrad residual jitter. Pointing accuracy requirement for the CLCT is 11 µrad, exceeded by the pointing capability at 8 µrad.

OPTICAL GROUND STATION

We present a Bring-Your-Own-Terminal approach for overcoming limited large telescope availability. Since the coveted use time by astronomers are the night hours, and SETH can still communicate in the dawn hours, at the 10Mbps data rate only couple hours of scheduled telescope time is needed accomplish the downlink of all the data required for the demonstration. The use of optical communications will not only deliver higher data rates than RF transmissions, but will also free up use on the NASA Deep Space Network (DSN).

SETH's approach is capitalizing on JPL's 1064-nm, multi-beam ground laser beacon assembly at the Table Mountain Facility, for which a power upgrade is currently planned to facilitate the DSOC demonstration launching in 2022. SETH will be able to re-use this asset without any further modification. Building on JPL's core expertise in deep space communications, SETH will employ a copy of the 1550 nm ground photon counting receiver (PCR) also designed for DSOC, conforming to the emerging CCSDS High Photon Efficiency (HPE) standard. The PCR will be retrofitted to the DCT at the Lowell Observatory. Flagstaff, AZ (Figure 3).

Figure 3: Lowell Observatory's DCT, ports inside DCT interfaced at the back of the telescope, and customer instrument boxes.

DISCUSSION

The past heliophysics small satellite missions have been confined to near-Earth environment and low-Earth orbit (LEO) in particular. However, the heliophysics system that extends from the Sun to the outer edges of the solar system has to be sampled also in the deep space environment. This creates a "perfect storm" of multiple linked factors needed for the next-generation heliophysics: i) Need to sample the environment in high spatiotemporal resolution, ii) Need to fly constellations, iii) Need to use small satellites, and iv) Need to ultimately fly small satellites also in deep space. This perfect storm necessitates technology development that allows the coexistence of all four factors. Perhaps the most pressing technology development need pertains to communication systems that allow high science data return rates from small satellites and reduced reliance on DSN.

All future ambitious deep space small satellite missions can baseline their communications to the high TRL optical system demonstrated by SETH. Importantly, the communication system developed in SETH is also directly applicable for CubeSat form factors.

Acknowledgments

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