Why Small Satellites?

- Reduce complexity and mass of space-based laser communication systems
- Enable deployment of low-cost, high-density LEO optical relay network
  - Target CubeSat scale
- Previous demonstrations of space-based laser communication used terminals with a mass of ~30 kg and cost in excess of $20M per terminal
  - Much of the cost is in the two-axis pointing system
  - Far too massive and expensive for high-density LEO constellation
- Current systems rely on GEO relay to get signal to ground
  - Requires massive/expensive terminal on LEO satellites to reach GEO
OCSD (AeroCube-7)

- Funded by NASA’s Small Satellite Technology Program
- Goals:
  - Demonstrate optical communications from a CubeSat to a 30-cm diameter ground station from low Earth orbit (LEO) at rates between 5 and 50 Mb/s
  - Demonstrate tracking of a nearby cooperative spacecraft using a commercial, off-the-shelf (COTS) laser rangefinder
  - Demonstrate attitude determination using a sub-cubic-inch star tracker.
  - Demonstrate orbit control using variable drag
  - Demonstrate propulsive orbit control using a steam thruster
- Pathfinder spacecraft, OCSD-A, launched October 8, 2015
- Two flight units scheduled for launch in October 2017
R-Cubed (AeroCube-11)

- R3 will demonstrate CubeSat-based remote sensing activities analogous to Landsat 8’s Operational Land Imager (OLI) instrument
  - Custom-designed refractive telescope
  - High-framerate commercial CMOS focal plane
  - pushbroom mode imager
    - filter block identical to those flown on Landsat 8
    - Six of the nine Landsat 8 OLI bands will be read
    - individual frames will be downlinked
    - time-delay integration will be performed on the ground
  - Space-based vicarious calibration will be tied to OLI

- R3 is expected to launch in early 2018

- Optical communications will provide the necessary data downlink capacity
Relay Networks

• Space-based relay network can provide continuous downlink capability

• GEO-based relays
  – Three relay satellites can cover all of LEO space
  – Typical link range is 40,000 km
  – RF link to ground avoids cloud issues

• All-LEO network
  – Fifty to 100 satellites required to cover all of LEO space
  – Typical link range is under 5,000 km
  – Multiple paths to ground for optical downlink
Data rate capacity of an optical link from a 4 W laser to a 10-cm-diameter receiver as a function of range and transmitter pointing accuracy.
Attitude Determination and Control System

- The Attitude Control System is designed to point the downlink laser to within 0.07 Degrees (3σ) of the optical ground station.

- A combination of custom-designed attitude sensors (sun and earth) and star trackers are used to meet stringent power, size and performance requirements.

- Miniature Reaction Wheels and Torque Rods are used for actuation and momentum control.

### OCSD minimum anticipated pointing performance

<table>
<thead>
<tr>
<th>Error Sources</th>
<th>Pointing Error 3σ (Deg)</th>
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<tbody>
<tr>
<td>Real-time Clock Drift</td>
<td>0.002</td>
</tr>
<tr>
<td>Orbit Determination / Ephemeris Error</td>
<td>0.003</td>
</tr>
<tr>
<td>Attitude Determination Error</td>
<td>0.030</td>
</tr>
<tr>
<td>Attitude Control Error</td>
<td>0.054</td>
</tr>
<tr>
<td>Total</td>
<td>0.062</td>
</tr>
</tbody>
</table>
Small Satellite Pointing Accuracy

Status in 2017

LEO Optical Nodes

Options for optical nodes without two-axis gimbals:

• Operate in store-and-forward mode
  – *Point first at source, then at destination*

• Two-satellite node
  – *Dedicated receive and transmit satellites point respectively at source and destination*
  – *Communication between them through short-range omnidirectional link*

• Single-axis gimbal combined with body rotation of satellite about receive axis (next slide)
Relay Node with single-axis gimbal

Receive reflector

Receive beacon camera

Receive beacon

Gimbal

Receiver

Transmit beacon

Transmit laser output

Transmit beacon camera

Mirror rotation Axis

Transmit mirror
Summary

- Small-satellite laser communication is entering operational service
- There are no unmanageable technical barriers to small-satellite LEO optical networks
- If small satellites are to be interoperable with larger satellites, then standards should accommodate the limitations of small satellites
- Standards should also allow for rapid technology evolution
Basic Standards
Should be amenable to large and small sat platforms

• Wavelength
  – Coarse selection: 1060 or 1550 nm
  – Fine selection: specific wavelengths (channels) with wavelength tolerance

• Waveform
  – Amplitude Modulation
    • OOK, PPM: better for small satellites since detectors are simpler, Rx pointing less critical since supported by non-fiber based detectors
  – Phase Modulation
    • BPSK, DPSK, QPSK: better performance but more complicated receiver
  – Other modulation schemes: polarization, frequency
  – Channel and data rate; bit shape/envelope

• Data format
  – Frame structure, FEC, etc.

• Acquisition and tracking
  – Sequence for making and breaking links

• Max/min irradiance for acquisition/tracking/com

Small-satellite compatible May be challenging for small satellites