Small-Satellite Laser Communications

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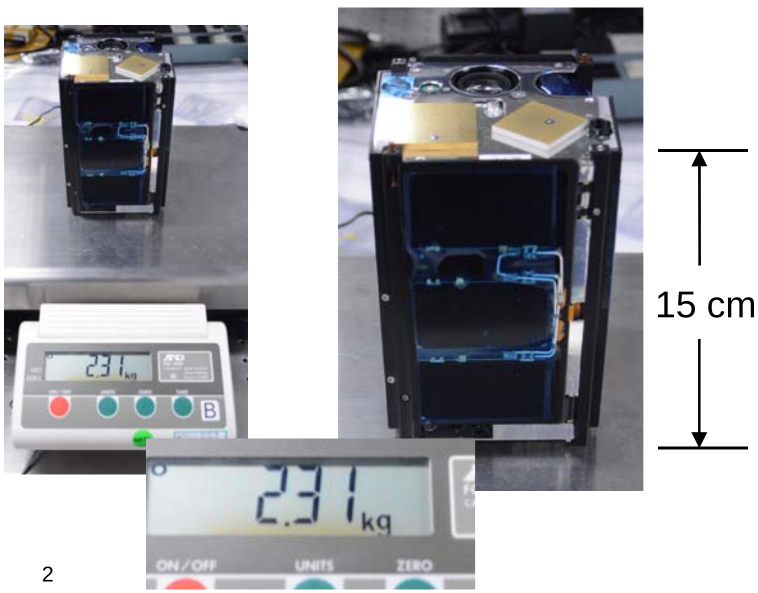
Why Small Satellites?

- 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

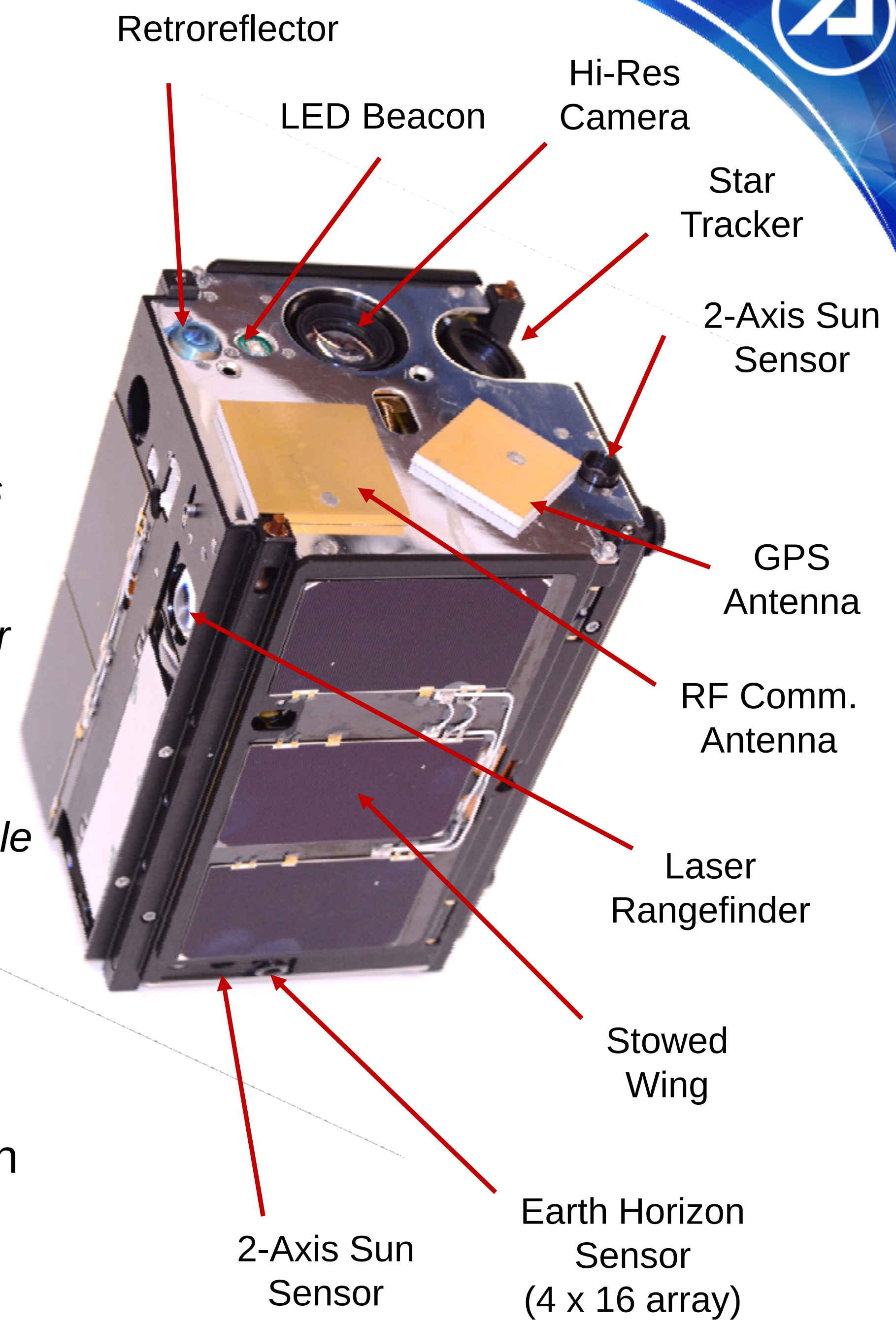


CubeSat laser terminal

OPAL laser terminal
NASA Photo

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

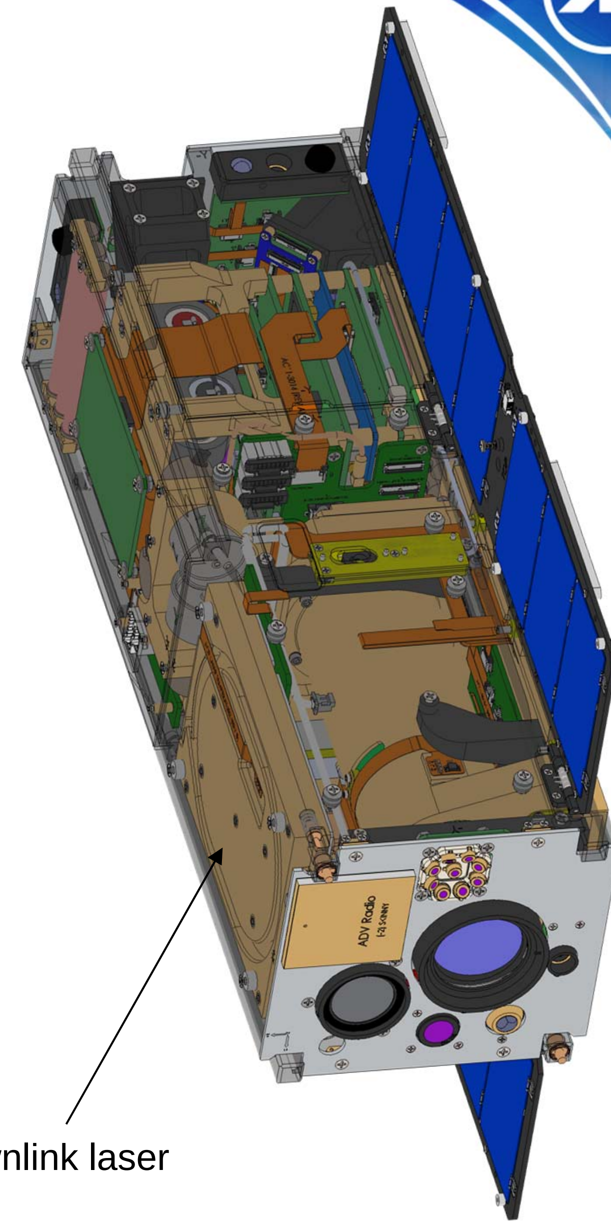


R-Cubed (AeroCube-11)

- 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*

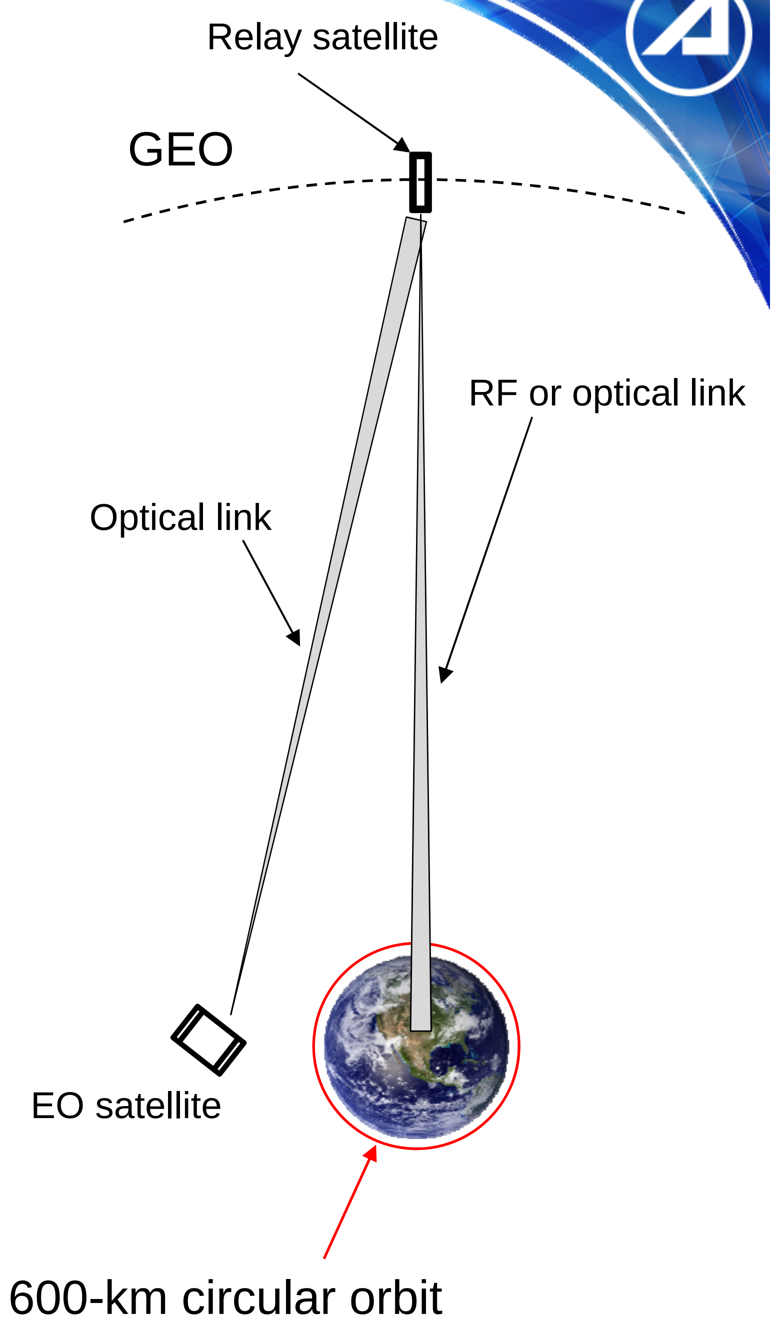
- R3 is expected to launch in early 2018

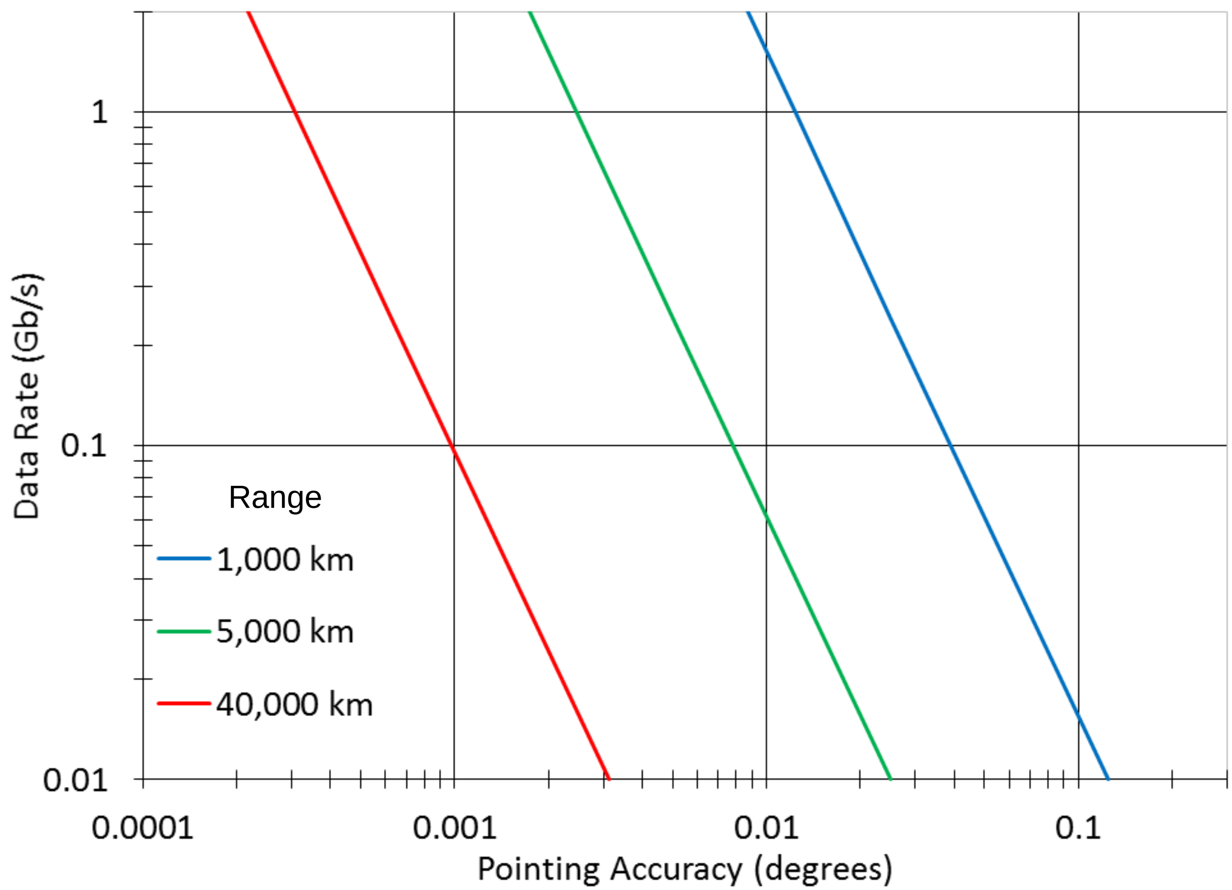
- Optical communications will provide the necessary data downlink capacity



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*



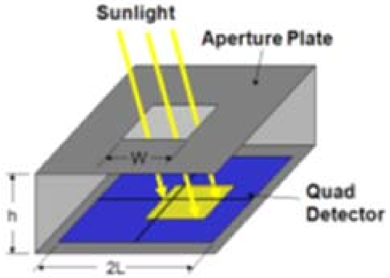


Data rate capacity of an optical link from a 4 W laser to a 10-cm-diameter receiver as a function of range and transmitter pointing accuracy.

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

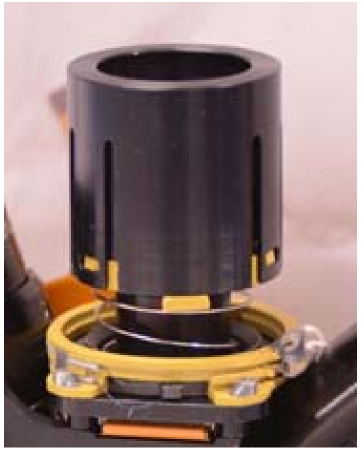
Sun Sensor
Quad Cell



OCSD minimum anticipated pointing performance

Error Sources	Pointing Error 3σ (Deg)
Real-time Clock Drift	0.002
Orbit Determination / Ephemeris Error	0.003
Attitude Determination Error	0.030
Attitude Control Error	0.054
Total	**0.062**

Star Tracker

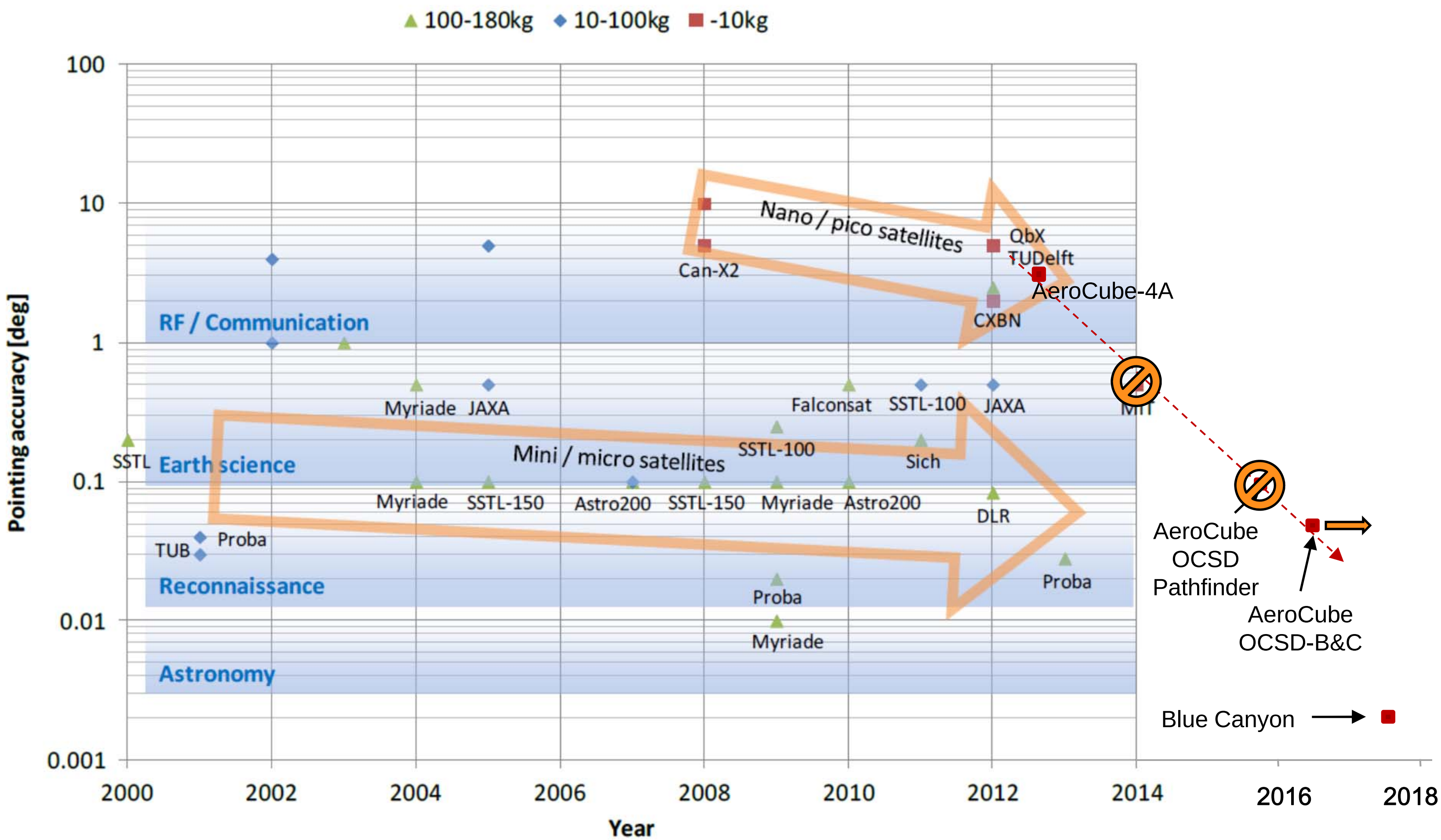


3 cm

Reaction Wheels

Small Satellite Pointing Accuracy

Status in 2017

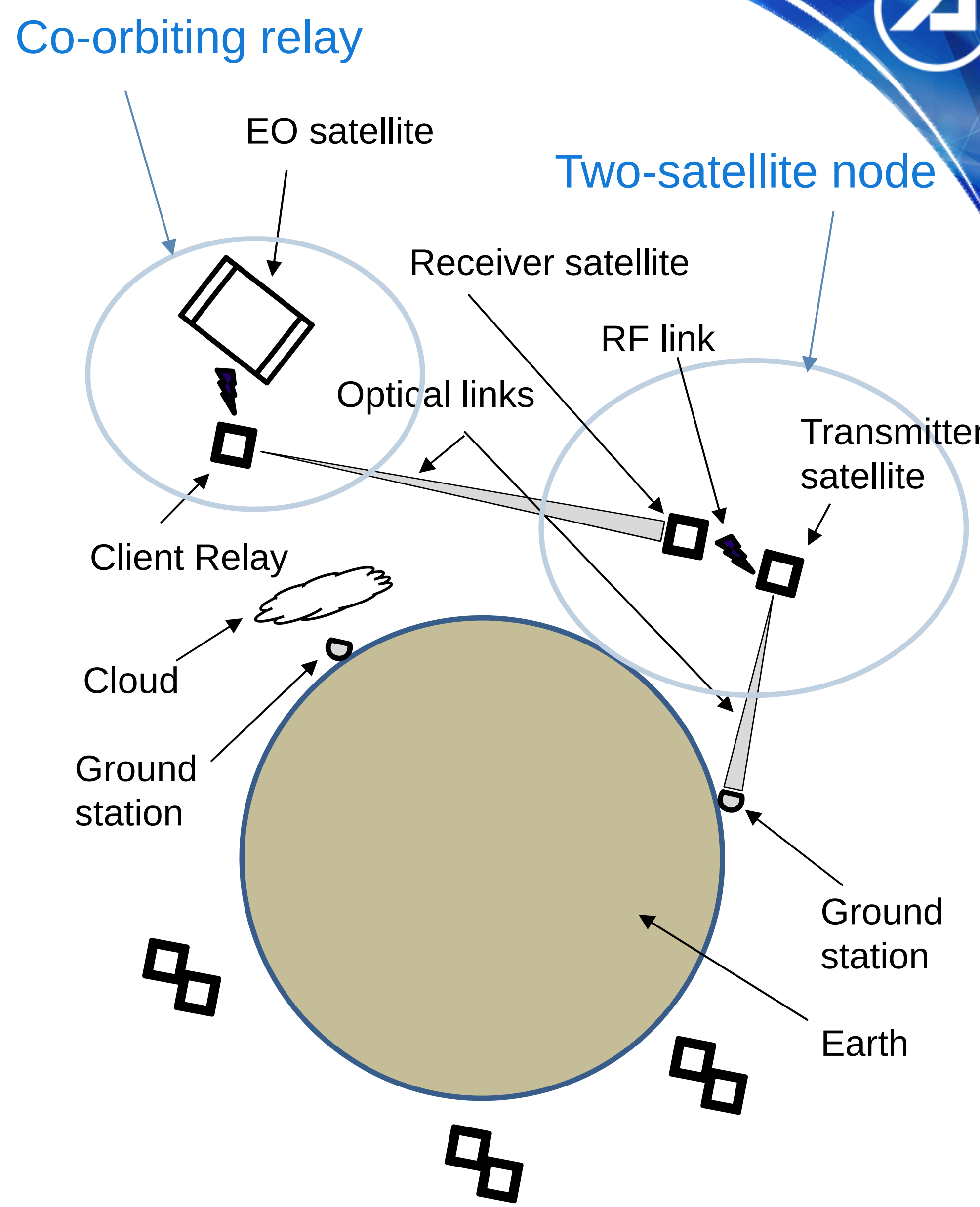


From: "Small Spacecraft Technology: State of the Art," by C. Frost, E. Agasid, et al., p.61, NASA Technical Report TP-2014-216648/REV1, NASA-Ames Research Center, 2014

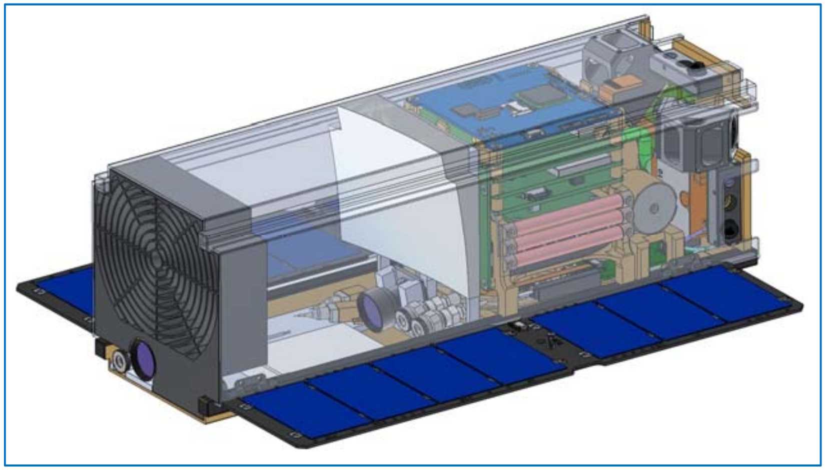
LEO Optical Nodes

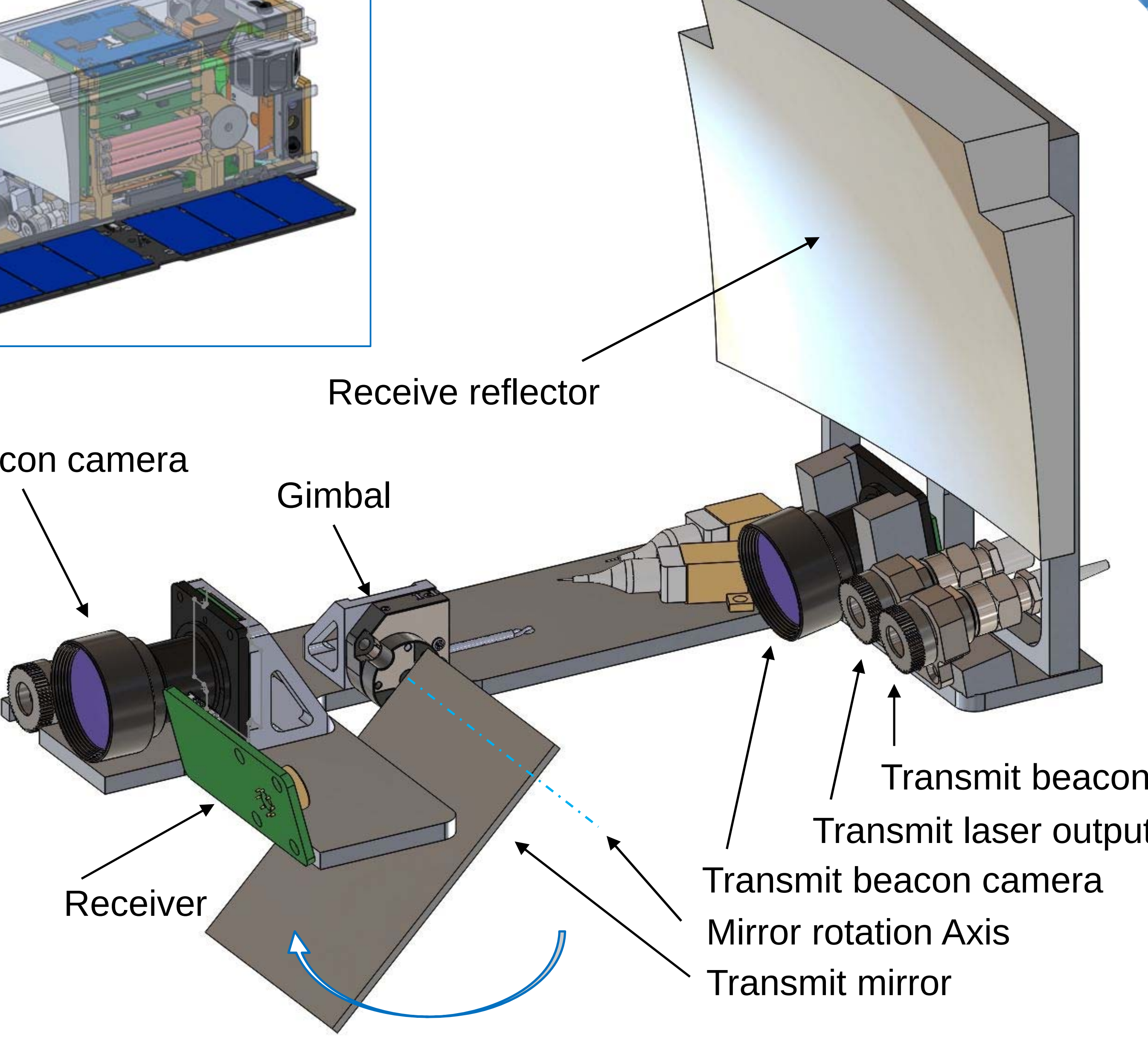
Options for optical nodes without two-axis gimbals:

- 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





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