Interplanetary CubeSats: Opening the Solar System to a Broad Community at Lower Cost

Robert Staehle*
Diana Blaney
Hamid Hemmati
Martin Lo
Pantazis Mouroulis
Paula J. Pingree
Thor Wilson
Jet Propulsion Laboratory/
California Institute of Technology

Jordi Puig-Suari
Austin Williams
CalPoly San Luis Obispo

Bruce Betts
Louis Friedman
The Planetary Society

Tomas Svitek
Stellar Exploration

*robert.l.staehle@jpl.nasa.gov
+1 818 354-1176
MS 306-416
4800 Oak Grove Drive
Pasadena, California 91109 USA
Copyright 2011. All rights reserved.
6 New Technologies → 1 New Architecture

**CubeSat electronics and subsystems**
- extended to operate in the interplanetary environment
- radiation and duration of operation

**Optical telecommunications**
- very small, low power uplink/downlink over 2 AU distances

**Solar sail propulsion**
- rendezvous with multiple targets using no propellant

**Navigation of the Interplanetary Superhighway**
- multiple destinations over reasonable mission durations
- achievable ΔV

**Small, highly capable instrumentation**
- (miniature imaging spectrometer example)
- acquire high-quality scientific and exploration information

**Onboard storage and processing**
- maximum utility of uplink and downlink telecom capacity
- minimal operations staffing
?How does it fit?

6U Total (10 X 20 X 30 cm)

2U Miniature Imaging Spectrometer
visible/near-IR, $\Delta \lambda = 10$ nm
based on instruments currently being built at JPL

2U Solar sail: >6 X 6 m square $\rightarrow$ 5 m/sec/day @ 1 AU solar distance
based on Planetary Society/Stellar Exploration LightSail 1

1U Optical telecom flight terminal: 1 kbps @ 2 AU Earth-s/c distance
NIR transmitting to existing facility
based on JPL Laser Telecommunications development

1U Satellite housekeeping
(C&DH, power, attitude determination & stabilization)
based on CalPoly CP7 and JPL/Univ of Michigan COVE
Example Science Mission Application:

Exploring a series of Near-Earth Asteroids

Other Candidate Science Missions

Space- and Helio-physics
Planetary Orbiters
High Solar Orbit Inclination

[insert your idea here…]
Building an Image Cube: Moon Mineralogy Mapper Example
Example infrared spectra of the materials in the meteorite Allende from Sunshine et al. 2008.

False color images of the asteroid Eros from the NEAR spacecraft.

Image of the asteroid Vesta from the Dawn spacecraft.

True and False color images of the asteroid Gaspra from the Galileo spacecraft.
Mineral Map of the Moon

as in Carle Pieters/Brown Univ et al. (Moon Mineralogy Mapper Team), “Character and Spatial Distribution of OH/H₂O on the Surface of the Moon Seen by M³ on Chandrayaan-1,” Science 326, pp 568, 23 October 2009.
2U: Example Imaging Spectrometer

Representative Optical Layout:
Compact Dyson f/1.4 Imaging Spectrometer
33° Field of View

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength Range</td>
<td>450-1650 nm</td>
</tr>
<tr>
<td>Wavelength sampling</td>
<td>10 nm</td>
</tr>
<tr>
<td>Detector Type</td>
<td>Thinned InGaAs array</td>
</tr>
<tr>
<td>Pixel pitch</td>
<td>25 μm typ.</td>
</tr>
<tr>
<td>Angular Resolution</td>
<td>0.5 mrad</td>
</tr>
<tr>
<td>Field of View</td>
<td>14°</td>
</tr>
<tr>
<td>Detector Operating T</td>
<td>270 K</td>
</tr>
<tr>
<td>Response Uniformity</td>
<td>95%</td>
</tr>
</tbody>
</table>
2U: Grow a little from Lightsail 1
LightSail 1 Spacecraft
Interplanetary Superhighway
Genesis Return Trajectory’s Unstable Manifold: Many Different Orbital Motions

Halo Orbit Portal

Lunar Orbit

Earth Flyby & Capture

Genesis Earth Return Via L₂

Lunar Flyby

Escape to SPITZER Earth Trailer Orbits

Hitenn Lunar Capture

Earth
On the way to several asteroids...
1U: Laser Telecommunications Subsystem
Interplanetary Optical Communications Scheme
### Lasercom Link Analysis Summary for 2 AU downlink

**Assumptions/Input:**
- Average Laser Power: 0.5 W
- Transmit Aperture: 6 cm
- Pointing Accuracy: 10 $\mu$rad
- Detection Efficiency: 50%
- Effective Detector Diameter: 0.4 mm
- Link Margin: 4 dB
- Code: SCPPM
- Code Rate: 0.56
- Sky Radiance: 9E-4 W/cm$^2$/sr/$\mu$m
- Daytime SEP: 55°
- Zenith Angle: 60°
- $r_0$ (atmos. coherence length): 6 cm
- Ground Telescope: Hale/Palomar (5-m), or LBT (11.8m)

<table>
<thead>
<tr>
<th>PPM Order</th>
<th>Slot Width (ns)</th>
<th>Laser Peak Power (W)</th>
<th>Mean PRF (kHz)</th>
<th>Throughput (kb/s)</th>
<th>Condition</th>
<th>Ground Telescope</th>
</tr>
</thead>
<tbody>
<tr>
<td>256</td>
<td>263</td>
<td>160</td>
<td>11.042403</td>
<td>62.5</td>
<td>Night</td>
<td>LBT</td>
</tr>
<tr>
<td>256</td>
<td>263</td>
<td>160</td>
<td>11.042403</td>
<td>4</td>
<td>Night</td>
<td>Palomar</td>
</tr>
<tr>
<td>256</td>
<td>11601</td>
<td>160</td>
<td>11.042403</td>
<td>1.2</td>
<td>Day</td>
<td>LBT</td>
</tr>
<tr>
<td>256</td>
<td>11601</td>
<td>160</td>
<td>11.042403</td>
<td>0.2</td>
<td>Day</td>
<td>Palomar</td>
</tr>
<tr>
<td>128</td>
<td>789</td>
<td>80</td>
<td>10.38</td>
<td>56</td>
<td>Night</td>
<td>LBT</td>
</tr>
<tr>
<td>128</td>
<td>36926</td>
<td>80</td>
<td>10.38</td>
<td>0.7</td>
<td>Day</td>
<td>LBT</td>
</tr>
<tr>
<td>64</td>
<td>4905</td>
<td>40</td>
<td>2.6</td>
<td>44</td>
<td>Night</td>
<td>LBT</td>
</tr>
<tr>
<td>64</td>
<td>4905</td>
<td>40</td>
<td>2.6</td>
<td>0.4</td>
<td>Day</td>
<td>LBT</td>
</tr>
</tbody>
</table>
Optical Communications
Telescope Laboratory (OCTL)

- 1-meter diameter telescope
- Lasercom-dedicated Daytime/Nighttime Telescope
- Capable of precision tracking LEO & GEO spacecraft
- Equipped with Adaptive Optics system
- Located at JPL’s Table Mountain Facility (Wrightwood, CA)
- For deep-space comm, will be used to provide beacon/data to spacecraft
1U: evolve from Cal Poly CP7 Subsystem Electronics
...add COVE board evolved from UMich M-Cubed demo
...sail support components
...some instrument electronics
...and spot shielding
Biggest Challenges

- Laser telecomm flight terminal to fit 1U
- Electronics reliability beyond low Earth orbit
- Extending sail performance
  - 5 m/sec/day $\Rightarrow$ >1 km/sec/yr (@ 1 AU)
  - Can we get to 20 m/sec/day?
Interplanetary CubeSats: Opening the Solar System to a Broad Community at Lower Cost

Robert Staehle*
Diana Blaney
Hamid Hemmati
Martin Lo
Pantazis Mouroulis
Paula J. Pingree
Thor Wilson
Jet Propulsion Laboratory/
California Institute of Technology

Jordi Puig-Suari
Austin Williams
CalPoly San Luis Obispo

Bruce Betts
Louis Friedman
The Planetary Society

Tomas Svitek
Stellar Exploration

*robert.l.staehle@jpl.nasa.gov
+1 818 354-1176
MS 306-416
4800 Oak Grove Drive
Pasadena, California 91109 USA