**Interplanetary CubeSats: Small, low cost missions beyond low Earth Orbit.** D. L. Blaney[1], R. L. Staehle[1], B. Betts[2], L. Friedman[2], H. Hemmati[1], M. Lo[1], P. Mouroulis[1], P. Pingree[1], J. Puig-Sauri[3], T Svítek[4], and T Wilson[1], A. Williams[3]. [1]Jet Propulsion Laboratory / California Institute of Technology (4800 Oak Grove Drive, MS 264-527, Pasadena CA 91101, Diana.L.Blaney@jpl.nasa.gov ), [2]The Planetary Society (85 S. Grand Ave. Pasadena, CA 91105) [3]Cal Poly (Aerospace Engineering Department, Building 41A, Room 134, 1 Grand Avenue San Luis Obispo, CA 93407) [4]Stellar Exploration Inc. (174 Suburban St. Suite 120, San Luis Obispo, CA 93401).

**What is an Interplanetary CubeSat?** The NASA Innovative Advanced Concepts (NIAC) recently selected Interplanetary CubeSats for further investigation as a new technology/architecture that could enable a new class of missions beyond low Earth orbit.

Interplanetary CubeSats are small low-cost missions beyond low Earth orbit. This class is defined by mass < 10 kg, cost < $30M (and maybe << $30M), and durations up to 5 years. Over the coming decade, a stretch of each of six distinct technology areas, plus one overarching architecture, can enable comparatively low-cost Solar System exploration missions with capabilities far beyond those demonstrated in small satellites to date.

**Technologies:** The six technologies required to be developed and combined to enable planetary CubeSats are:

1. *CubeSat electronics* and subsystems extended to operate in the interplanetary environment (esp. radiation and duration of operation).
2. *Optical telecommunications* to enable very small, low power uplink/downlink over interplanetary distances.
3. *Solar sail propulsion* to enable rendezvous with multiple targets using no propellant.
4. *Navigation of the Interplanetary Superhighway* to enable multiple destinations over reasonable mission durations and achievable deltaV.
5. *Small, highly capable instrumentation* (with a miniature imaging spectrometer example) enabling acquisition of high-quality scientific and exploration information.
6. *Onboard storage and processing* of raw instrument data and navigation information to enable maximum utility of uplink and downlink telecom capacity, and minimal operations staffing.

When Integrated, these technologies form the Interplanetary CubeSat Architecture.

**Interplanetary CubeSat Architecture.** The Interplanetary CubeSat builds on the existing terrestrial CubeSat architecture. The spacecraft has a volume of 10 cm x 20 cm x 30 cm (6 U in CubeSat parlance where 1 U equals a 10 cm x 10 cm x 10 cm volume). Two U are reserved for the payload which is mission specific. The solar sail takes 2U and deploys to form a 6 x 6 m square. The solar sail is based on the Planetary Society/Stellar Exploration LightSail™ 1 [1]. Optical communication is based on JPL Laser Telecommunications Development with a bandwidth of 1 kbps @ 2 AU Earth-s/c distance [2]. It takes up 1 U bay. The final 1 U bay is used for satellite housekeeping (C&DH, power, attitude determination & stabilization) and based on CalPoly CP7 and JPL CubeSat On-board processing Validation Experiment (COVE) avionics [3].

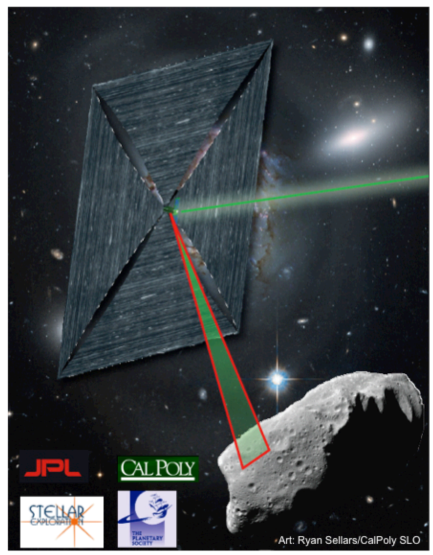
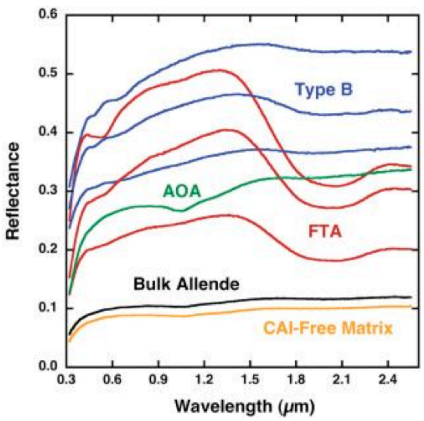



Figure 1: Artist concept of the Interplanetary CubeSat Asteroid Flyby (R. Sellars, personal communication).

**Asteroid Flyby Mission: An Example Interplanetary CubeSat.** Example missions have been studied in detail in order to find technology gaps and develop requirements for future technology development. The first concept that has been investigated is a multiple near earth asteroid flyby (Figure 1).

*Why Asteroids?* The 2011 Planetary Science Decadal Survey by the National Research Council that identified a large number of asteroids as important targets to understand presolar processes recorded in the materials of primitive bodies; to study condensation, accretion, and other formative processes in the solar nebula; to determine the effects and timing of secondary processes on the evolution of primitive bodies; and to assess the nature and chronology of planetesimal differentiation [4]. Additionally, near earth asteroids are targets of interest for future human exploration. We know of >~7500 near Earth asteroids ranging in size from 10s of meters to > 1 km. There are >800 with diameters > 1 km. This large number of potential targets would greatly benefit from a capability to conduct science in a low cost manner at multiple targets.

Figure 2. Example infrared spectra of the materials in the meteorite Allende from Sunshine et al. 2008 [5].




*Science Measurements*. Surface composition is an important parameter for asteroid science. It can be used to understand their evolution and formation, and to identify potential resources and hazards for future human missions. Visible to short wavelength infrared spectroscopy is a proven technique to study composition and has been used successfully to study asteroids from *Galileo*, *NEAR*, *Cassini*, and *Rosetta*. Key minerals have diagnostic features in the 450-1600 nm wavelength region. Mafic minerals (e.g. olivine and pyroxene) have strong bands around 1 um which are related to iron minerals. In the 1400 nm region, water bands can be used to determine if hydrated minerals are present. These features can be used to investigate asteroidal differentiation and evolution. (Figure 2).

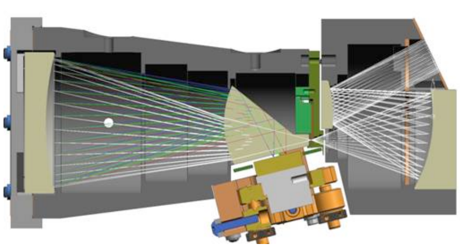


Figure 3: Optomechanical design of a compact Dyson F/1.4, $33^o$ imaging spectrometer.

*Payload.* The spectrometer is a miniaturized version of the compact Dyson design form that is currently under development at JPL [e.g. 6,7]. Our example spectrometer (Figure 3) has a spatial IFOV of 0.5 mrad and would provide spatial sampling of the surface ranging from 0.5 m to 10 m depending on the encounter range. The data volume for a range of asteroid sizes from 10-1000 m and flyby distances in a range of 1-20 km is estimated to be 0.66-5299 Mbits (uncompressed). The size of the image is assumed to have 115 wavelengths with 250 rows times the number of spatial elements needed to completely sample the asteroid. If the asteroid fills more than 250 rows, additional rows are included to reach complete coverage.

*Technology Challenges.* In studying the CubeSat Asteroid Flyby mission, the key technical challenges for achieving the mission are:

1. Making the laser telecommunication system compact enough to be accommodated on the spacecraft.
2. Ensuring that the electronics are reliable from both a mission duration and radiation perspective.
3. Extending the solar sail performance from the 5 m/ sec /day (~6 μg) (@ 1 AU) for LightSail™ 1, to 2 or more times this level to keep mission lifetime reasonable and encounter multiple asteroids. Much higher performance appears possible in the 2020s, perhaps to 30 m/ sec/ day (~35 μg).

**Other Planetary Mission Concepts Under Study:** Other planetary mission concepts are also under study ranging from small body sample return to solar monitoring. If you have an idea for an Interplanetary CubeSat mission please contact the authors for more information.

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