Waypoints for Opportunistic SmallSat/CubeSat Missions to Comets & Asteroids.

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Introduction: Waypoints to indefinitely park a deep space SmallSat or CubeSat is a novel solution for opportunistic missions to explore new comets and circumvents mission risk due to launch system delays. Comet apparitions into the inner solar system (<0.4 AU from Earth) are accessible to CubeSat class missions that can return unique data not obtainable from ground-based telescopes. Primitive bodies such as comets are key to understanding Solar System formation.

Fig. 1. PrOVE will accomplish important science investigations and measurements of the nucleus and coma of comets. Solar insolation causes volatile outgassing, lofting dust from the nucleus. A close flyby will obtain unique and unprecedented mapping of inner coma molecular species and nucleus temperatures with high spatial resolution in seven filter bands.

For example, our mission concept Primitive Object Volatile Explorer (PrOVE, [1]) utilizes a 6U CubeSat mission, to perform a close flyby of a Jupiter-family or new comet near perihelion with maximum volatile activity (Fig. 1). We judiciously designed a CubeSat science payload to return unique data not obtainable from ground-based telescopes and to complement data from orbiting observatories. The PrOVE mission will (1) investigate chemical heterogeneity of a comet nucleus by quantifying abundances of volatile species and how these change with solar insolation, (2) map the spatial distribution of volatiles and determine any variations, and (3) determine the frequency and distribution of outbursts.

Such measurements uniquely probe the origin of the nucleus, and the formation and evolution of our Solar System. Cost profiles of CubeSat infrastructure permits Class-D missions not otherwise practical with conventional missions such as waiting for opportunistic targets. The low-risk and highly versatile multispectral Comet CAMera (ComCAM) on PrOVE targets the most important cometary volatiles: H2O, CO2, CO, and organics; CO2 is observable only from space due to telluric extinction. These molecules are best probed by their non-thermal fluorescence signatures (Fig. 2) in the 2–5 µm Mid-Wave InfraRed (MWIR) spectral region, which PrOVE will use to map all four species simultaneously.

Thermal emission dominates spectral wavelengths
>5 \mu m in the inner coma, which enables PrOVE to map the inner coma temperature distribution by measuring 7-10 and 8-14 \mu m Long-Wave InfraRed (LWIR) emission. The flyby will discriminate measured quantities at high spatial resolution of ~0.3 km, comparable to 0.005" angular resolution for a ground-based observatory for a comet ~10^7 km from Earth.

A microbolometer based multispectral camera will be used to accomplish ComCAM science goals. ComCAM will span MWIR and LWIR spectral regions with integrated filters and 80 mm aperture imaging optics (Fig. 3). ComCAM, propulsion, and infrastructure will fit neatly into a 6U spacecraft bus (Fig. 4).

A number of propulsion system are now available for deep space CubeSat missions. For example, the a multi-channel Micro-Cathode Arc Thruster (\mu CAT) micromodel propulsion subsystem which is an outgrowth of GWU Micropropulsion and Nanotechnology Laboratory (MpNL) research in scalable small spacecraft electric propulsion. The \mu CAT is an electric propulsion device, based on the well-researched ablative vacuum arc process, enhanced by an external magnetic field that uses its own thruster cathode as propellant. The cathode terminal can be any conductive material. The applied magnetic field extends operation lifetime while reliance on a thruster element for propellant reduces system mass for micropropulsion compatible with 1-50 kg class satellites, including all CubeSat forms.

**Waypoints – Mission Architectures for 2050:** A potential impediment to a mission to a comet approaching perihelion are uncertainties due to launch delays. We believe a solution that eliminates the impact of launch delays is ideal for spacecraft missions to study transient celestial events such as short period comets near perihelion, but especially of new comets and asteroids reaching the inner solar system for the first apparition; hence, the concept of *waypoints*. Our recent studies of trajectories to comets such as Wirtanen. However, mission goals can be compromised by extended launch delay.

**Pathways to Waypoints:** Missions such as PrOVE can be launched aboard a NASA, DoD, or NOAA LEO, MEO, or GTO EELV rideshare mission and use the launch vehicle’s excess capacity to reach escape, or near escape, velocities and then use a series of lunar and/or earth flybys to increase apogee to permit a comet flyby (private communication and analysis, D. Folta and P. Spidaliere). While rideshare manifesting on a specific planetary mission is a good opportunity, we believe seeking and exploiting excess capacity on more frequent mission (likely with significantly greater excess capacity) launches provides a viable and mission enabling prospects provided waypoints can be identified as an intermediate mission phase for the target. Waypoints can also be used to store spacecraft for mass deployment as a constellation to a single target or individualistically to different targets.