Primitive Object Volatile Explorer (PrOVE) – Waypoints and Opportunistic Deep Space Missions to Comets.

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Introduction: Primitive Object Volatile Explorer (*PrOVE*) is a CubeSat mission concept to study the surface structure and volatile inventory of comets in their perihelion passage phase when volatile activity is near peak (Fig. 1). CubeSat infrastructure imposes limits on propulsion systems, which are compounded by sensitivity to the spacecraft disposal state from the launch platform and potential launch delays.

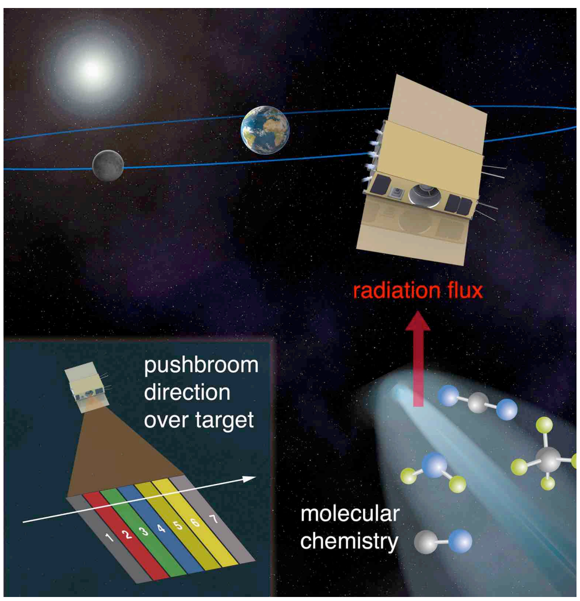

Fig. 1. PrOVE will accomplish important science investigations and measurements of the nucleus and coma of comets. Solar heating causes volatile outgassing, lofting dust from the nucleus. A close flyby will obtain unique and unprecedented mapping of inner coma molecular species and nucleus temperatures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

We propose circumventing launch platform complications by using waypoints in space to park a deep space SmallSat or CubeSat while awaiting the opportunity to enter a trajectory to flyby a suitable target. Waypoints are a novel solution to enable exploring *new comets*, since a fully functional spacecraft can be directed to an encounter with reasonable lead time following discovery – otherwise infeasible with conventional spacecraft, which have only been able to visit short-period comets on well-known orbits. In our Planetary Science Deep Space SmallSat Studies (PSDS3) program, we investigated scientific goals, waypoint options, potential concept of operations (ConOps) for periodic and new comets, spacecraft bus infrastructure requirements, launch platforms, and mission operations and phases.

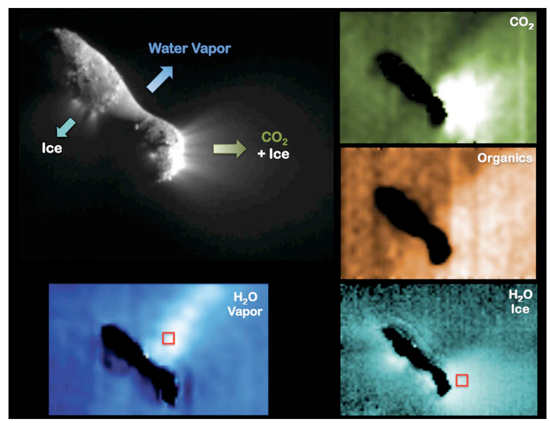

Fig. 2. PrOVE will establish the abundance and distribution of volatile species in the volatile-rich inner coma, building on the *Deep Impact* investigation of 103P/Hartley 2 that showed CO_2 sublimation driving comet activity [1]. Red boxes show a 275 m scale, which matches ComCAM's resolution at 200 km range.

Scientific Context: Volatiles in new comets and in periodic comets (e.g., Jupiter family) are optically active near 1 AU. A CubeSat deployed from a parked orbit can yield high-quality science by traveling to any comet that passes through the accessible range, rather than a dedicated mission that could not be prepared in time to investigate a new comet in the brief period between discovery and the comet's return to deep space. New or dynamically young comets present a pristine volatile distribution, uneroded by volatile sublimation. A mission to such an object is of significant scientific interest to investigate the nature of the early solar system. We have designed a CubeSat science payload to return unique data not obtainable from ground-based telescopes and to complement data from Earth-orbiting observatories. The PrOVE mission will (1) acquire 5-10 m resolution surface maps, (2) investigate chemical heterogeneity of a comet nucleus by quantifying volatile species abundance and changes with solar insolation, (3) map the spatial distribution of volatiles and determine any variations, and (4) determine the frequency and distribution of outbursts.

Such measurements probe the origin of the nucleus and the formation and evolution of our Solar System. Cost profiles for CubeSat infrastructure permit Class-D missions not otherwise practical with conventional missions, such as waiting for targets of opportunity. The low-risk and highly versatile multispectral Comet CAMera (ComCAM) on PrOVE targets the most important cometary volatiles: H_2O, CO_2, CO, and organics; CO_2 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 μm in the inner coma, which enables PrOVE to map the inner coma temperature distribution by measuring 7-10 and 8-14 μm Long-Wave InfraRed (LWIR) emission. At closest approach, the flyby will discriminate measured quantities at a spatial resolution of ~0.3 km, comparable to 0.005" angular resolution for a ground-based observatory on a comet $\sim 10^7$ km from Earth.

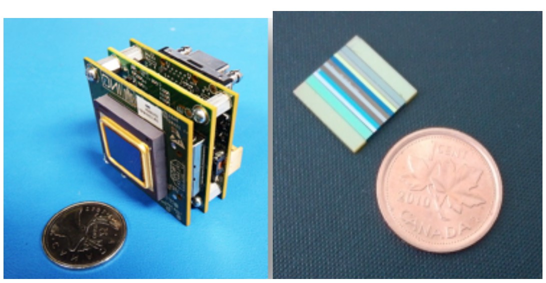

Fig. 3. (*left*) ComCAM will be built around the INO μXCAM OEM sensor. (*right*) Example of Multi-Zone filters manufactured by Iridian. These filters will be integrated onto the sensor focal plane. The optical assemblies are not shown.

Payload: Our PSDS3 study investigated using a Malin Space Science Systems (MSSS) ECAM-50 imaging camera with optics to produce broadband visible images of the nucleus at 5-10 m resolution. A microbolometer-based multispectral camera will accomplish ComCAM science goals. ComCAM will span MWIR and LWIR spectral regions with integrated filters and 80 mm aperture imaging optics (Fig. 3). The filters bracket the molecular fluorescence spectral bands (2.7 μm, H_2O; 3.3 μm, organics; 4.3 μm, CO_2; and 4.7 μm, CO) and mid-infrared channels to study thermal radiation. ComCAM is compact and designed to fit neatly into a 1.5U volume.

Waypoints: An impediment for a mission to a comet approaching perihelion is uncertainty 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 new comets reaching the inner solar system for the first apparition and asteroids; hence, the concept of *waypoints*.

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. A series of lunar and/or Earth flybys can increase apogee to permit a comet flyby. While rideshare manifesting on a specific planetary mission is a good opportunity, we believe seeking and exploiting excess capacity on more frequent mission launches provides a viable and mission enabling prospect, provided that waypoints can be identified as an intermediate mission phase for the target. Waypoints can also be used to store groups of spacecraft for mass deployment as a constellation to a single target or individually to explore different targets.

References:

[1] A'Hearn *et al.* (2011) Science 332, 1396-1400.