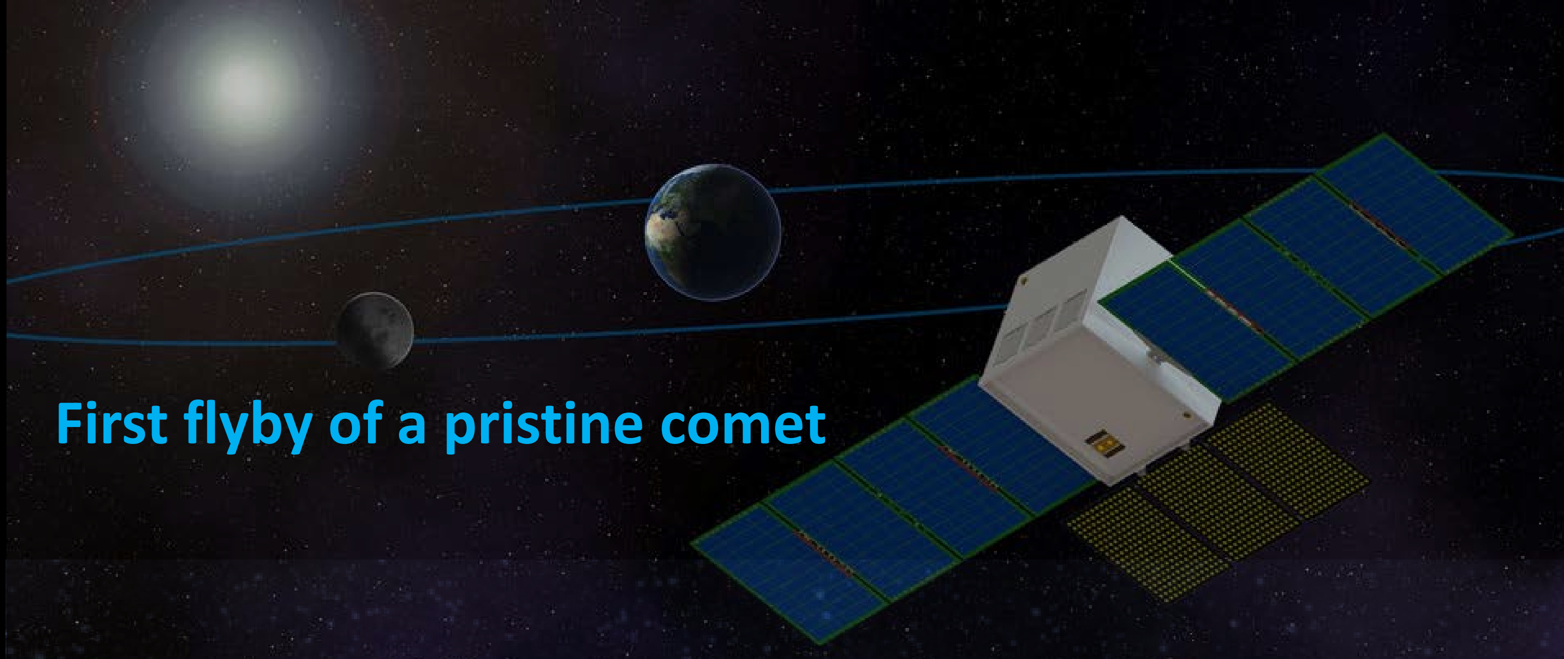
Primitive Object Volatile Explorer (PrOVE) – Waypoints and Opportunistic Deep Space Missions to Comets

PSDS3 meeting – LPSC – March 18, 2018



First flyby of a pristine comet

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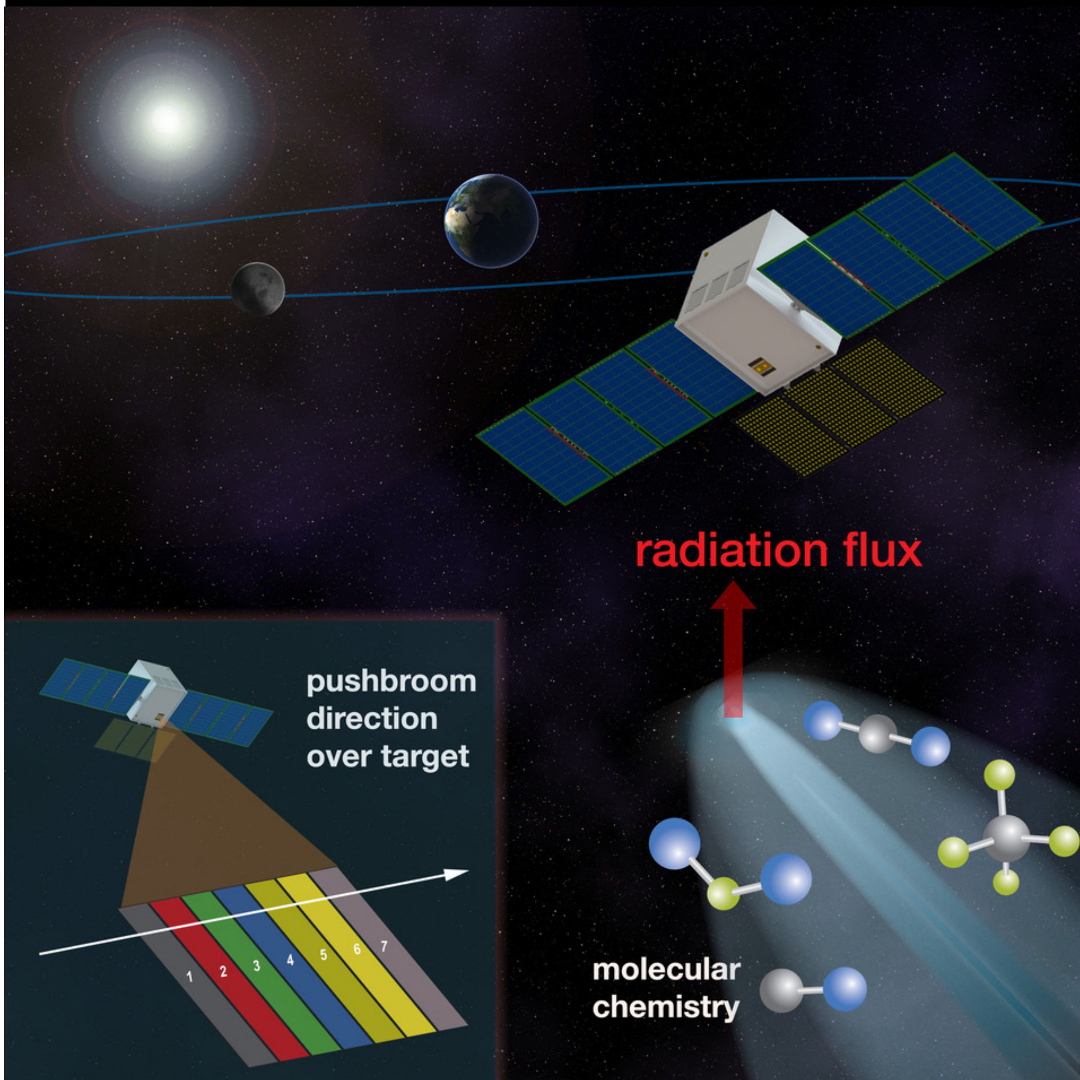
Lead Institution: University of Maryland

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



- A **new** or long period comet flyby will yield unprecedented science.
  - New comet missions: limited time to develop/launch a spacecraft after discovery.
  - Periodic comet missions: potentially involves mission risk with launch platform delays.

- Solution: Waypoints in space.

- CubeSats/SmallSats are a cost efficient pathway for parking a spacecraft pending a new comet.

- *PrOVE* payload goal is to acquire 8-m spatial resolution images of nucleus, volatile inventory and temperatures of a **new** or periodic comet.

Primitive Object Volatile Explorer (PrOVE)

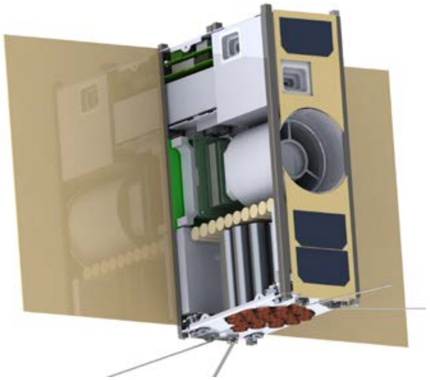
Background

History:

UMD/GSFC/MSU/CUA/JPL team proposed Primitive Object Volatile Explorer (*PrOVE*) to the SIMPLEx-1 program.

- Mission was to a volatile rich Jupiter-family comet 46P/Wirtanen with an ecliptic plane crossing within **0.09 AU** of Earth.
- Launch platform delays were an identified risk.
- **Spacecraft and Propulsion were not investigated for more remote missions.**

Morehead State University 6U bus



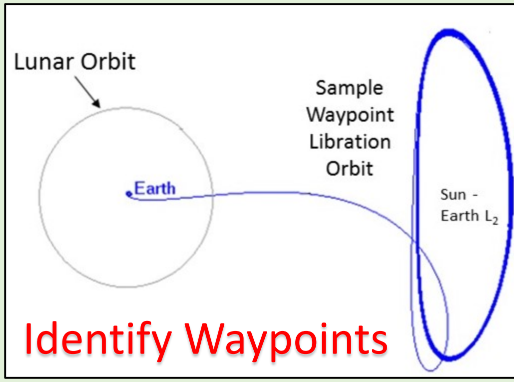
Compact 2-12 μm camera

PSDS3 award allowed the opportunity to:

- **Study waypoints**
- **Investigate Cruise and Ops for high-inclination, high-energy new comets**
- **Spacecraft systems**

Solution:

- Retire risk associated with launch platform delays – investigate Waypoints in space.
- Change science scope to observing a new comet



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MSSS
Visible Camera

Subsystems
Management
Science - Volatiles
Science – Imaging
Science - Thermal
Payload 1 - Infrared Camera
Payload 2 - Visible Camera
Spacecraft
Systems
Radiation
Thermal
Navigation
Communications
Data, PDS

Why Study Comets?

- Are among the most enigmatic and spectacular objects in the sky
  - indelibly recorded throughout human history
- Formed at the beginning of the Solar System (4.6 billion years ago)
  - record conditions, compositional variability, and processes in the protoplanetary disk
  - preserve record of volatiles in the early solar nebula
  - building blocks of the planets
  - bearers of volatiles to inner solar system
- “Stored” in outer Solar System freezer
  - relatively unchanged since formation
- Contain dust, organics, and ices
  - contribute ingredients for life to Earth
- Potentially hazardous to life on Earth

Comet Lovejoy, Dec 2011

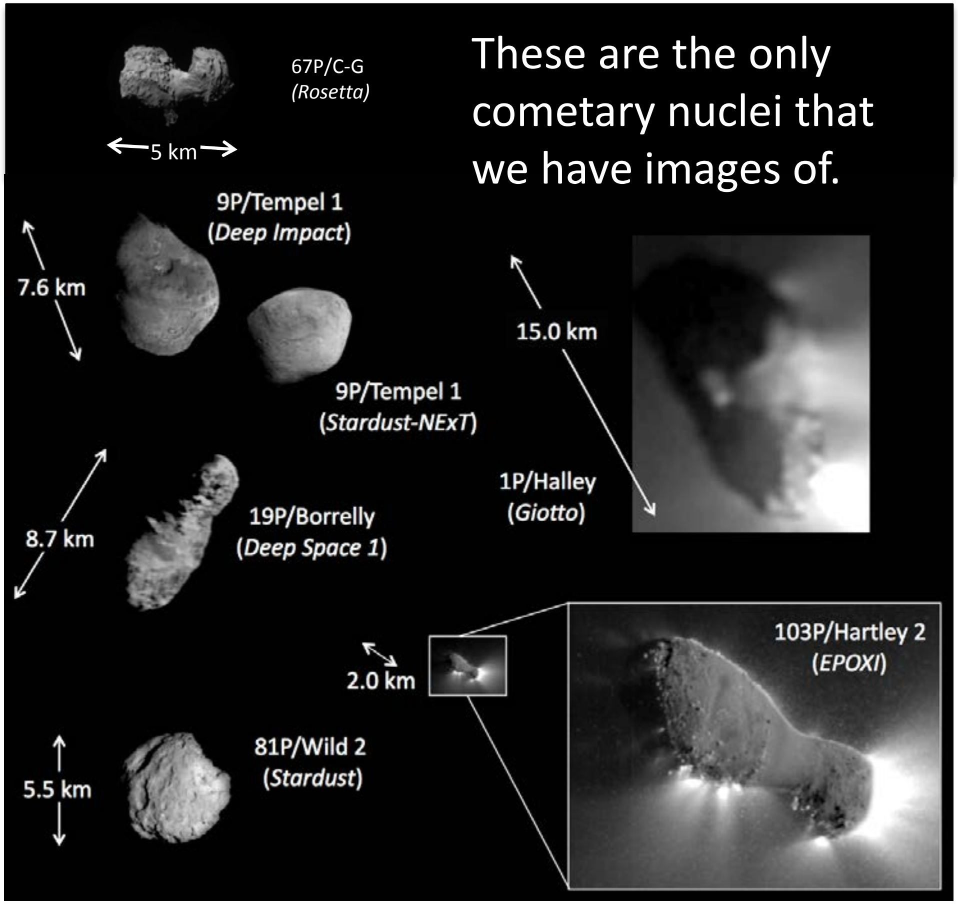
Bayeux Tapestry: Battle Hastings 1066

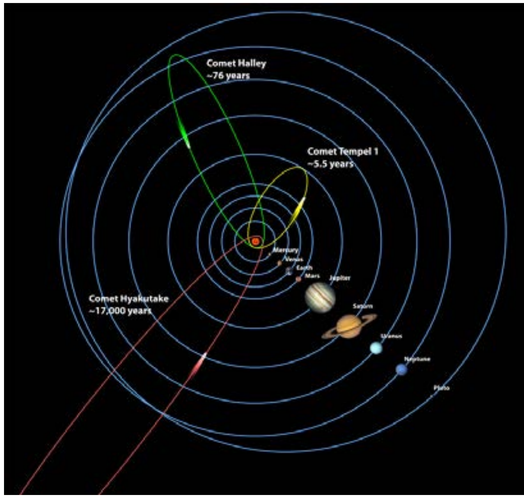
Shoemaker-Levy 9, 1994

Image Credit: HST Comet Team & NASA

When beggars die, there are no comets seen….
Calpurnia in Shakespeare’s Julius Caesar

Types of Comets





- Short period (Jupiter-family)
  - Orbit between Jupiter and the Sun
  - Disturbed by the gravity of the planets
  - Spacecraft have imaged 5
- Halley type (every 50-200 years)
  - Orbit between Pluto and the Sun
  - Spacecraft have imaged 1
- Long period (>> 200 years)
  - "New" and "young" come from the Oort cloud when disturbed by a passing star
  - **None observed up close**

Potential for high science return

Why Waypoints

New comets:

Hale-Bopp discovery was 2 years prior to perihelion.

Many long-period comets are discovered with even shorter times.

Insufficient lead time for a mission

Proposed solution:

Park a spacecraft in space.

Technology advances in CubeSats/SmallSats enable cost-efficient opportunities

Statistics of Oort cloud comets:

Statistics over past 10 years indicate 1 detected every 2 years. Hughes (2001) estimates the historical long-period comet flux as ~1 per year.

Spacecraft lifetime of ~4 years

Close flyby to study nucleus of a long-period comet:

Surface maps of ~8-m resolution and volatile inventory will yield compelling scientific results.

CubeSat/SmallSat missions can risk close flyby operations

The PSDS3 effort showed that a mission to a new comet is within contemporary CubeSat/SmallSat technology!

Primitive Object Volatile Explorer (PrOVE)

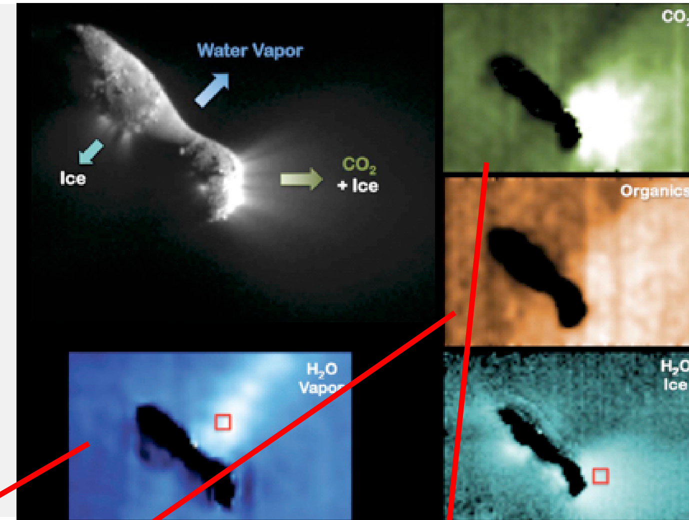
Planetary Science Deep Space SmallSat Studies (PSDS3)

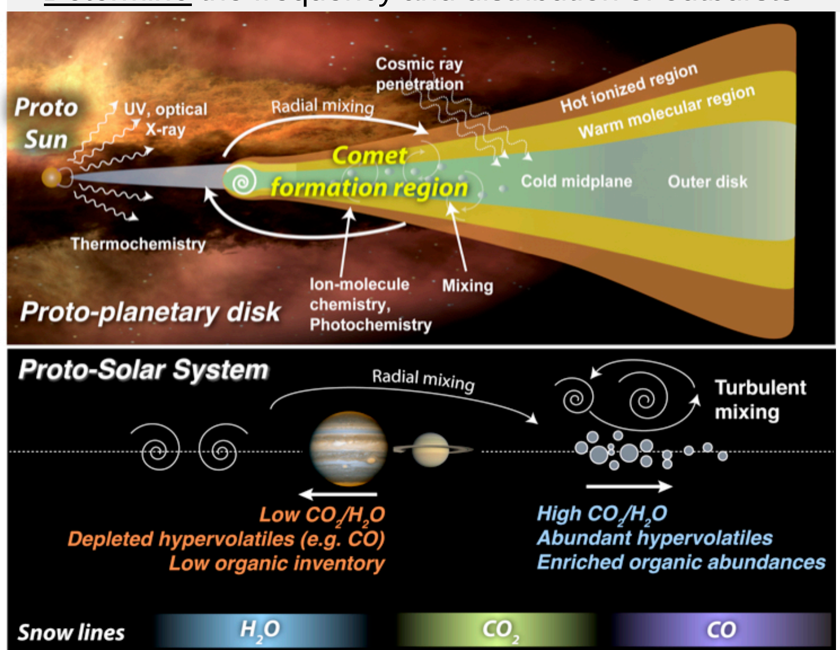
Mission Concept and Science Deliverables

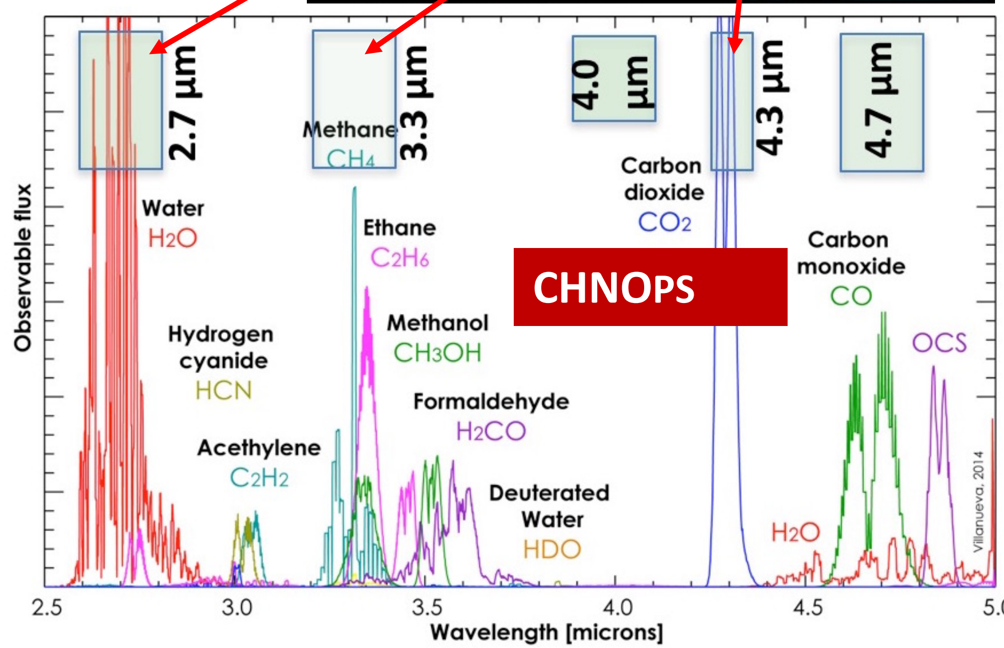
Science Objectives:

PrOVE will perform a close flyby of a *new or Jupiter-family* comet near perihelion when surface processes and volatile activity are maximum, to probe the origin of the nucleus and the formation and evolution of our Solar System.

- *Investigate* morphological and chemical heterogeneity of nucleus by quantifying surface fine structure and volatile species abundances, and how these depend on solar insolation;
- *Map* surface relief and spatial distribution of volatiles, especially CO_2 (which cannot be measured from ground based telescopes), and determine any variations;
- *Determine* the frequency and distribution of outbursts.







Primitive Object Volatile Explorer (PrOVE)

Planetary Science Deep Space SmallSat Studies (PSDS3)

Science Traceability Matrix

	Science Objectives	Investigations	Measurement	Products	Result	Requirements
Understand the Role of Primitive Bodies as Building Blocks for Planets and Life	**SO1** Determine surface morphology and thermal structure	Determine surface fine structure and thermophysical properties of the near nucleus inner coma	Measure dayside surface reflectance at high spatial resolution, and thermal inertia of the inner coma observations of surface thermal emission	Surface reflected broadband visible at <8-m pixel resolution and thermal emission measured from 7-10 µm and 8-14 µm	Maps of the surface topography and temperature in the inner coma	Surface relief and thermal models of comet response to insolation and its relationship to active outburst regions
	SO2 Determine the coma chemical composition, and variations in the spatial distribution of CO_2, CO, and organics with respect to H_2O	Determine the distribution of volatiles within the coma	Determine the relative abundances of CO_2, CO, organics and H_2O within the coma and active outbursts	Maps of the comet nucleus and coma at various spatial resolutions	Inner coma maps of compositions of CO_2. CO, organics and H_2O	Information about the relative abundances of CO_2, CO, organics and H_2O within the target
	SO3 Determine the frequency and distribution of outburst as measured by local enhancements and the endogenic mechanism that drives these events	Map the comet's coma region to detect locations and number of outburst events	Maps of the comet's coma region	Maps of the comet coma regions allowing the ejected material to be detected	Maps of the comet nucleus and coma at various spatial resolutions	Information on the number of outburst events observed and the source locations for this events from the comet nucleus

PrOVE can address Priority Comet Science!

Ideal Criteria:

Flyby of a dynamically new (Oort cloud) or long period comet. Identify a waypoint/parking orbit in space, launch from an arbitrary platform and disposal above Earth's gravity well, navigate to waypoint with on-board propulsion, indefinite residence with minimal station keeping, design a cruise trajectory to a newly acquired target or a known long period comet, navigate to a new target with on-board propulsion, flyby encounter with 5m optimum spatial resolution (visible imaging).

Minimum Criteria:

Flyby of a Jupiter Family comet and Near-Earth comet (q<1.3 AU, P<200 years).

SKG: https://www.nasa.gov/exploration/library/skg.html

SBAG report on venues/contexts for addressing SKGs "Space-based robotic missions which can be telescopic or precursor mission to a small body target" includes high priority for NEO albedos, size, rotation state, dust environment, resource identification.

Recent Comets listed on JPL/SBDB as Hyperbolic/Parabolic

H/P comets close to Earth

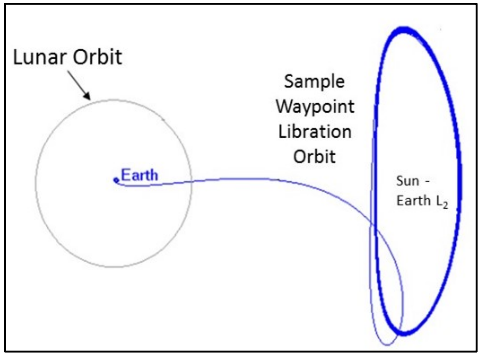
- 28 in 10 years, MOID<0.6 AU
- 21 in 10 years, MOID<0.4 AU
- ~2 comets/year

- Low inclination comet apparition interval ~2.5 years
- Can we reach high-inclination comets?

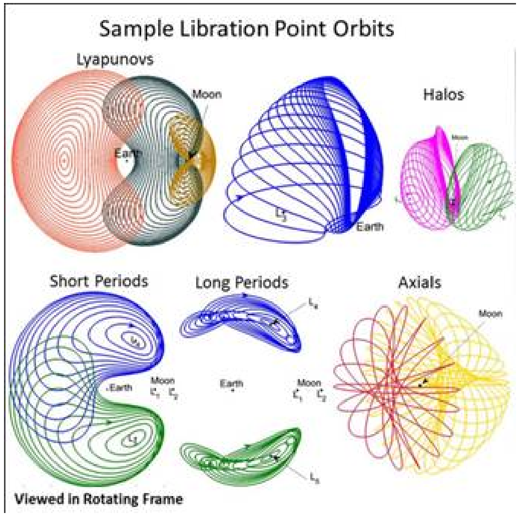
High perihelion velocity is important!

Comet ID	Inclination	Perihelion passage (ET)	Orbit Class
C/2017 T1 (Heinze)	96.96	2018-Feb-21.5	PAR
C/2015 E61-B(PANSTARR)	6.35	2017-May-09.9	HYP
C/2017 E1 (Borisov)	14.55	2017-Apr-10.1	HYP
C/2016 U1 (NEOWISE)	46.43	2017-Jan-14.0	HYP
C/2013 X1 (PANSTARRS)	163.23	2016-Apr-20.7	HYP
C/2013 US10 (Catalina)	148.88	2015-Nov-15.7	HYP
C/2015 G2 (MASTER)	147.56	2015-May-23.8	HYP
C/2013 A1 (SidingSpri)	129.03	2014-Oct-25.2	HYP
C/2012 K1 (PANSTARRS)	142.43	2014-Aug-27.7	HYP
C/2014 C2 (STEREO)	135.5	2014-Feb-18.2	PAR
C/2012 S1 (ISON)	62.4	2013-Nov-28.8	HYP
C/2012 T5 (Bressi)	72.1	2013-Feb-24.1	HYP
C/2011 U3 (PANSTARRS)	116.78	2012-Jun-03.9	HYP
C/2012 E2 (SWAN)	144.24	2012-Mar-15.0	PAR
C/2012 C2 (Bruenjes)	162.79	2012-Mar-12.6	HYP
C/2011 Q2 (McNaught)	36.87	2012-Jan-19.8	HYP
C/2010 X1 (Elenin)	1.84	2011-Sep-10.7	HYP
C/2011 M1 (LINEAR)	70.18	2011-Sep-07.6	HYP
C/2009 R1 (McNaught)	77.03	2010-Jul-02.7	HYP
C/2010 J4 (WISE)	162.3	2010-May-03.2	PAR
C/2008 T2 (Cardinal)	56.3	2009-Jun-13.2	HYP
C/2009 G1 (STEREO)	108.32	2009-Apr-16.6	PAR
C/2008 A1 (McNaught)	82.55	2008-Sep-29.1	HYP
C/2007 W1 (Boattini)	9.89	2008-Jun-24.9	HYP
C/2008 J4 (McNaught)	87.37	2008-Jun-19.1	HYP
C/2007 F1 (LONEOS)	116.08	2007-Oct-28.8	HYP
C/2006 VZ13 (LINEAR)	134.79	2007-Aug-10.9	HYP
C/2007 P1 (McNaught)	119.21	2007-Apr-03.2	PAR

Waypoint examples examined in PSDS3



Sun-Earth Libration orbit



Other Libration orbit examples

Sun-Earth L1/L2 are good solutions
Station keeping is minimal

Primitive Object Volatile Explorer (PrOVE)

Payloads

Infrared Imager/radiometer

ComCAM: IR microbolometer (with TEC) has broad spectral response (1-100 µm) which includes science requirements of 2-5 µm for molecular species and 8-12 µm for thermal.

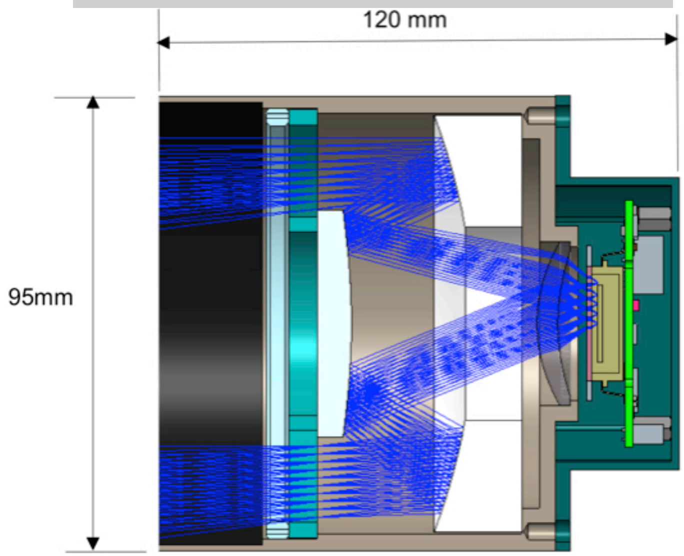
- 384x288 pixels
- IFOV = 120 m @300 km
- 1.2 kg, 2.5 W

Visible Imager

VisCAM: High spatial resolution mapping of a Jupiter-family comet surface is optimum. Mapping of a new comet would be unprecedented.

- 2592x1944 pixels
- IFOV= 8 m @ 300 km
- 0.4 kg, -30C<T_{oper}<40C
- 2.5 W imaging, 1.3 W idle

Compact 2-12 µm camera



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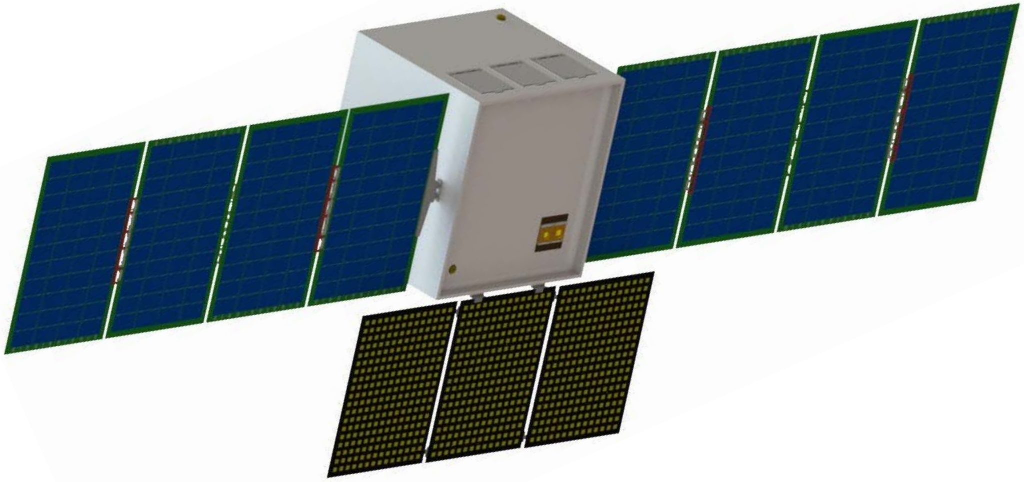
Based on TAGCAMS instrument on OSIRIS—Rex

Spacecraft Concept
ABC/ESPA Bus Assembly

Stowed volume ~100-U

Low mass



PSDS3 study at Wallops Flight Facility, including GSFC engineers

Conclusions

- *Methodology has the best chance to produce ground breaking science by visiting a new comet*
- *Mission is within current technological capabilities*
- *Spacecraft bus: ~100 U*
- *Developed ConOps for operations at comet*
- *Mission time ~4 years from waypoint residency to data telemetry*

Thank you!

We gratefully acknowledge
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