Primitive Volatile Explorer (PrOVE)

A CubeSat Mission Concept to Study Near Earth Comets

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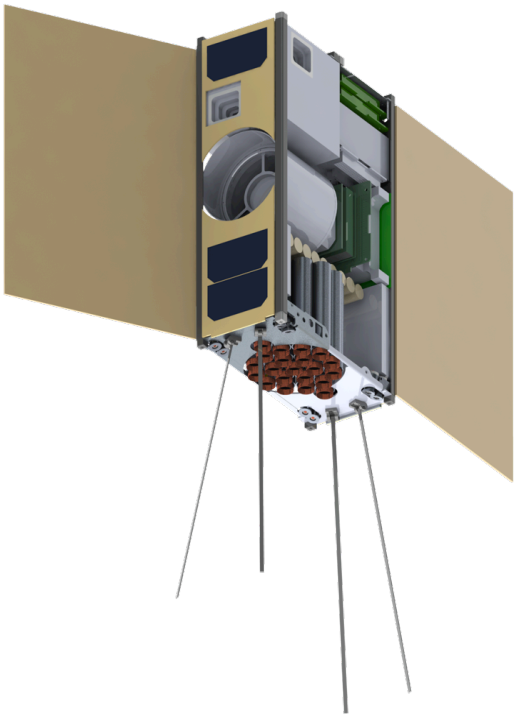


Back to the Future

Earth Science

JPSS (Suomi NPP) ($8B): VIIRS, CrIS, ATMS, OMPS, CERES

NASA Solar System Exploration Mission Programs

Flagship ($2-3 B): Cassini had 12 instruments
New Frontiers (<$1 B): OSIRIS-REx has 6 instruments
Discovery (<$450 M; without launch): Lucy has 3-4 instruments

Miniaturization

Earth Science

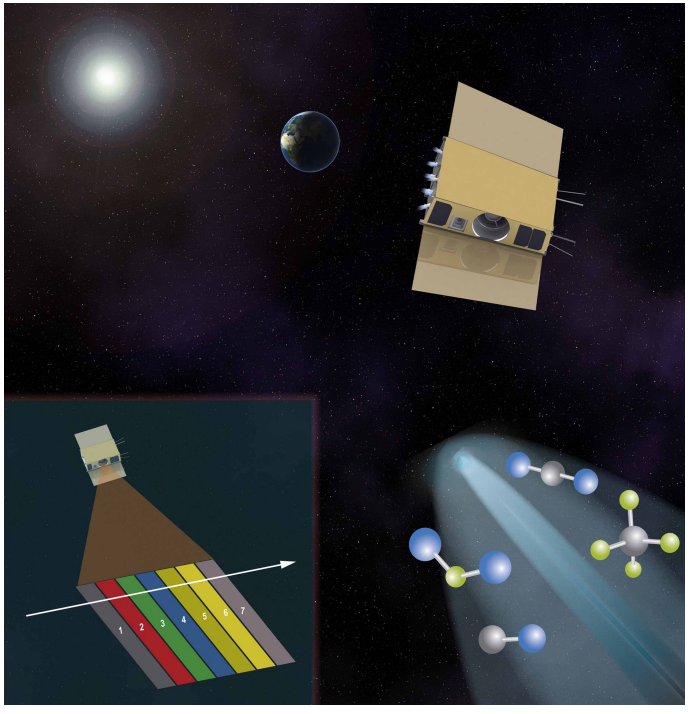
Multiple CubeSats deployed
Nominal cost ~$1M

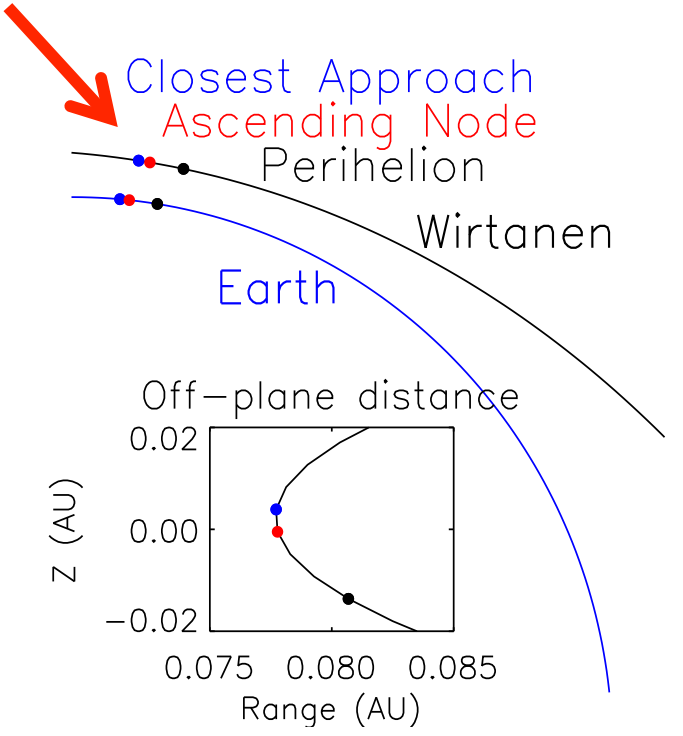
Frequent missions but with simpler instruments

Planetary Science

SIMPLEx (2015) – 22 proposals; 2 selections + 3 phase-1 funds
LunarH-map – SIMPLEx selection
BioSentinal; NEA Scout; Lunar Flashlight – Advanced Exploration Systems
Lunar Ice Cube – NextSTEP
MarCO – JPL ($20M)
Nominal cost for Deep Space (cis-lunar and beyond): >$6M (scales with range)
Can we get by on one planetary mission per year?

Primitive Object Volatile Explorer (PrOVE) and encounter trajectory

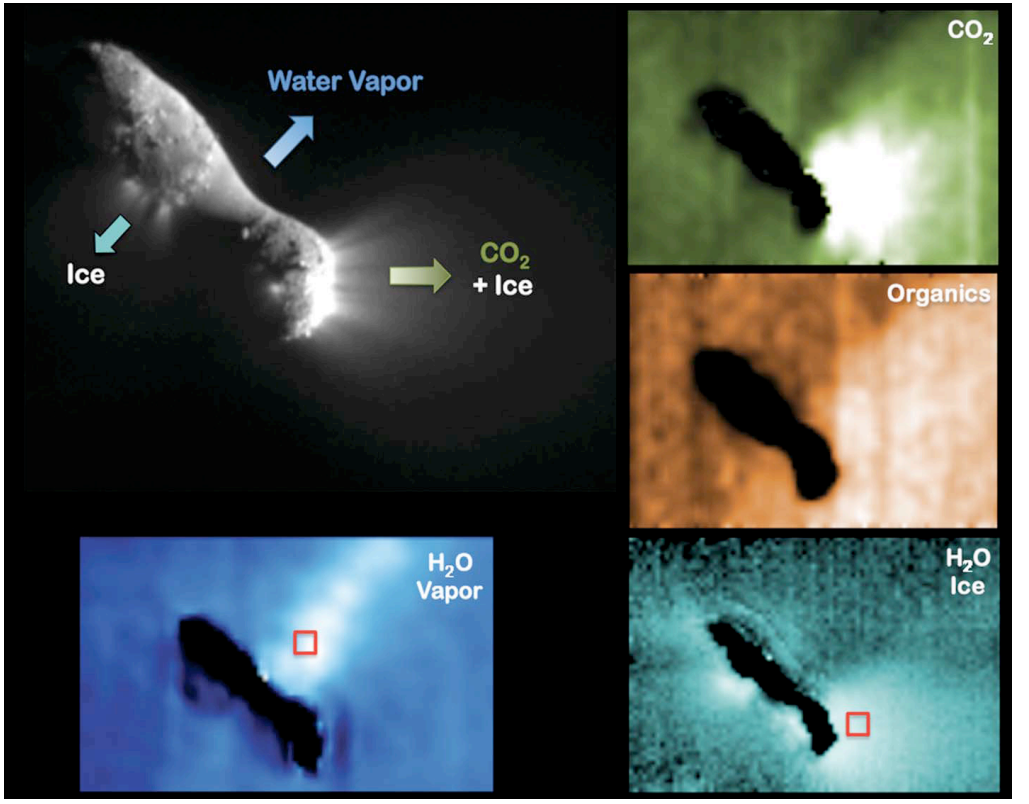




Chasing a Comet

- In December 2018, **Comet 46P/Wirtanen** presents a rare opportunity for a very near-Earth Jupiter Family Comet (**<0.1 AU**) with high CO_2 and H_2O production rates.
- Perihelion, closest encounter, ecliptic plane crossing nearly coincide for current apparition.
- **Abundant flight opportunities were found with Δv of ~1.3 km/s for deployment through 30-Sep-2018.** 
- A small 6-U spacecraft and 1.3-U science instrument will produce unique measurements, including gas outflows.
- Requisite CubeSat technology is currently available.
- Coordinated campaign with ground-based observations.
- **46P/Wirtanen was the original target of the ESA Rosetta mission.**

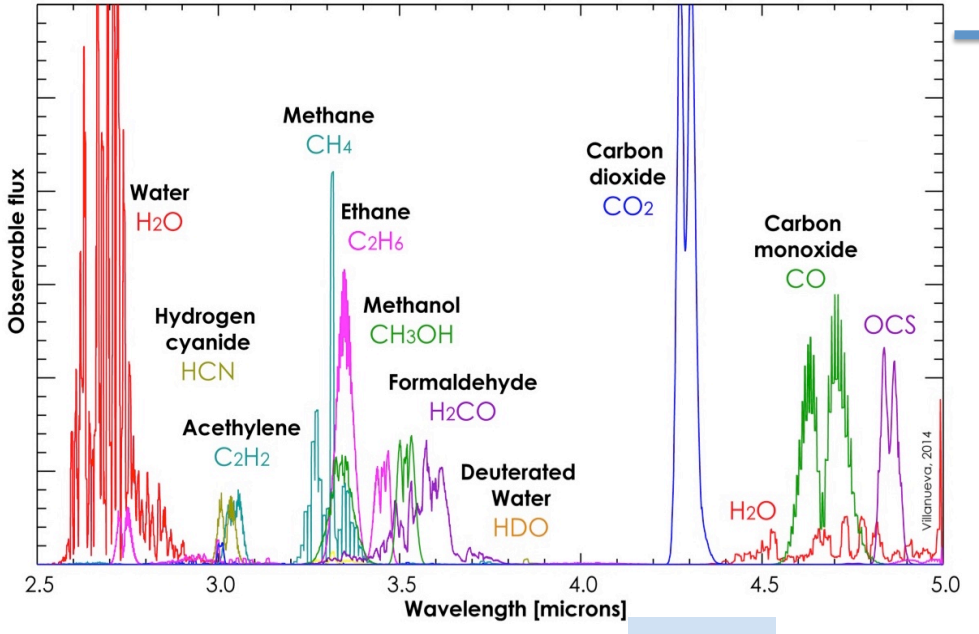
Expected Results: Comet Active Outgassing



- *Deep Impact* investigation of 103P/Hartley 2 showed CO_2 sublimation driving comet activity. The spatial scale shown in red boxes (275 m) can be matched by a CubeSat mission.

PrOVE Science Objectives

- Determine the chemical variability in the coma and determine what controls this variation.
- Determine the variations in the spatial distribution of CO2, CO, and organics with respect to H2O.
- Determine the frequency and distribution of outburst as measured by local enhancements and the endogenic mechanism that drives these events.



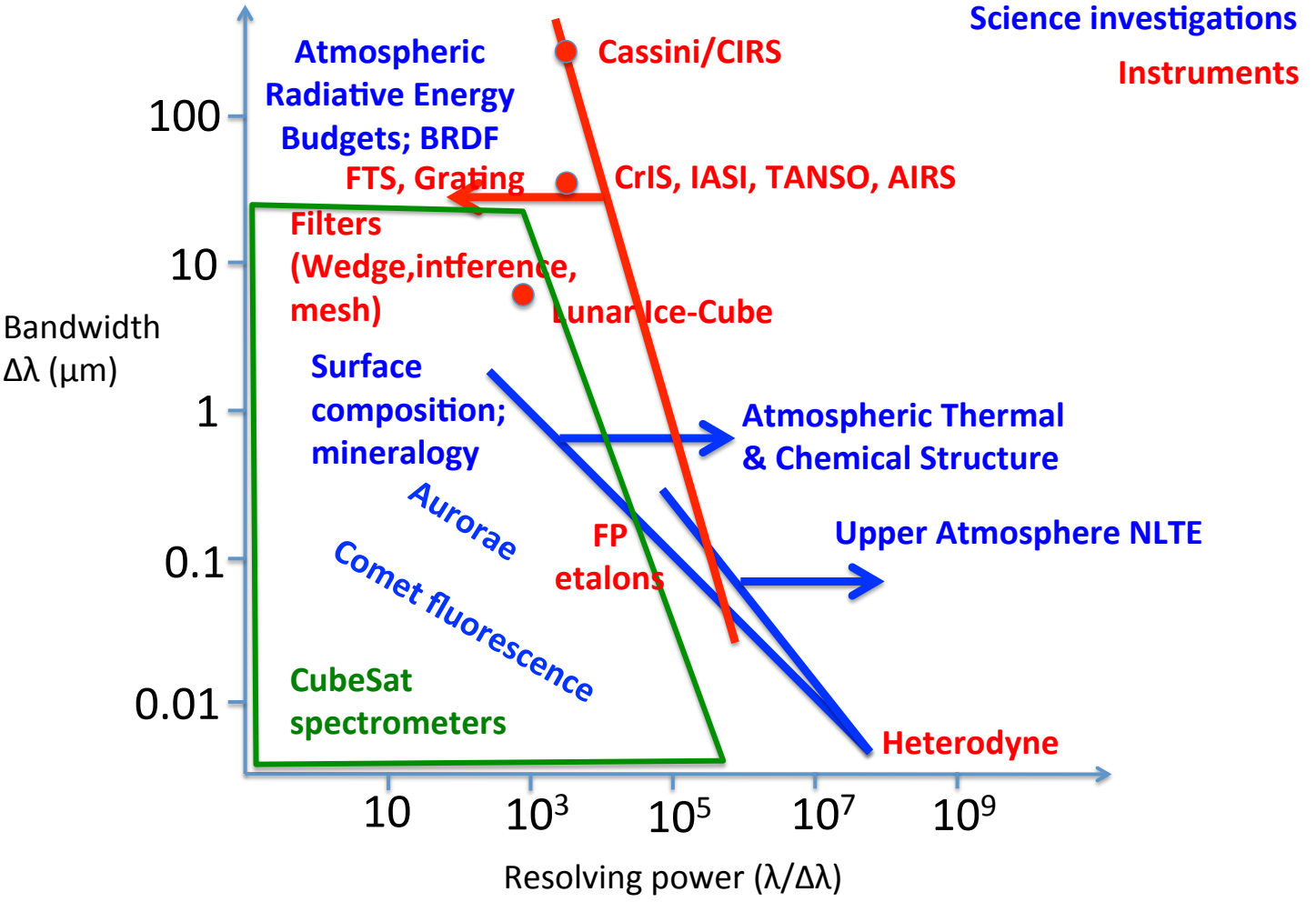
2.7 µm H_2O **3.3 µm Organics** **4.3 µm CO_2** **4.7 µm CO**

Comet Camera ComCAM

Thermal channels 7-10 µm 8-14 µm

- CO_2 measurements require a spacecraft due to strong telluric (Earth atmosphere) absorption.
- *JWST will not yet be launched. HST does not cover mid-infrared.*

CubeSat remote sensing instrument constraints



PrOVE mission profile

Spacecraft bus	**6U CubeSat**
Advantage	Cheaper ($5-10 M), faster to build, more launch opportunities.
Readiness	COTS instrument; spacecraft bus is available
Flight profile	Single flyby (11 km/s), attitude only
Instruments	Multispectral imager (microbolometer array) •MWIR (CO_2,H_2O,CO,Organics, control channel), •LWIR (7-10 µm and 8-14 µm) Visible camera or exploit navigation cameras
Measurements	Volatile production and distribution; frequency and distribution of outbursts; grain chemistry, surface structure, bow shock. Spatial resolution: 85 m/pixel at 200 km (mas from Earth at closest approach). Nadir pushbroom.

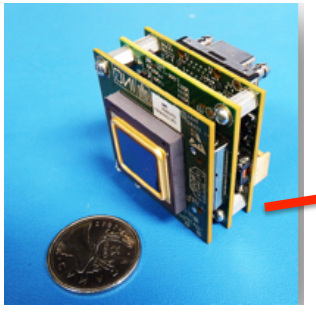
PrOVE Mission Summary

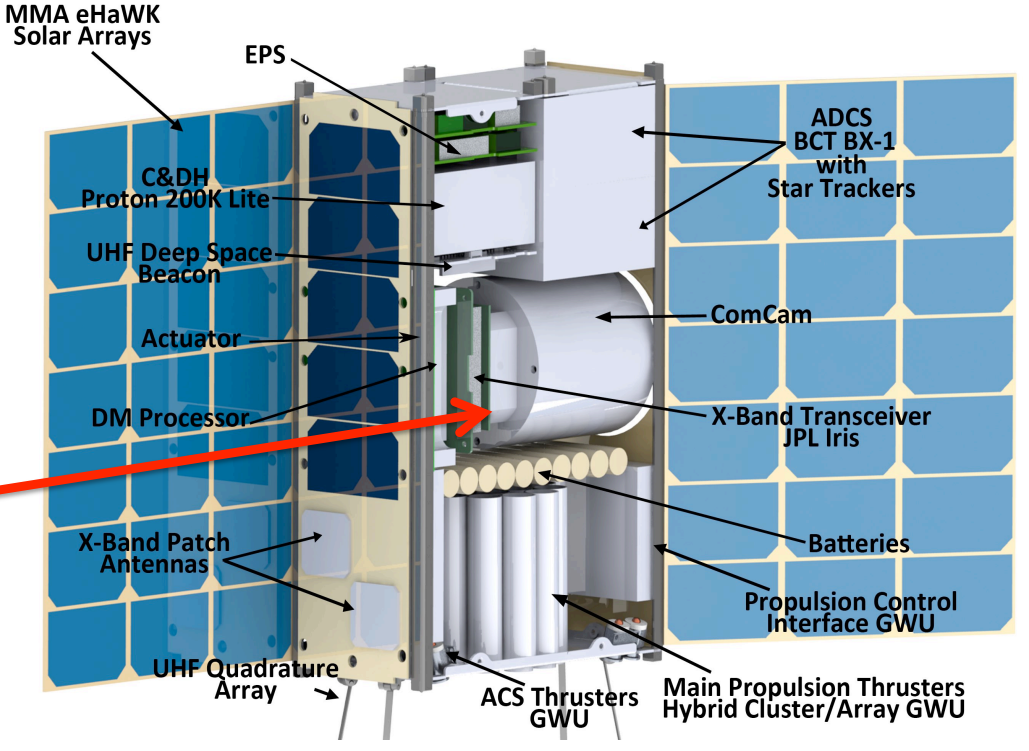
- Why the rush?
  - Historically close comet approach to Earth (0.08 AU, ~12 M km) that is accessible to a small spacecraft.
  - explore planetary science mission with very small s/c.
- What if we pass up on 46P/Wirtanen?
  - Lost high-value, low-cost scientific opportunity if a mission is not organized.
  - Chance to make up for original Rosetta science.
- Can we do it inside 2 years?
  - Time frame is sufficient for instrument and spacecraft build and launch given existing COTS s/c bus and instruments.
- **Mission concept is applicable to other JFC visiting in 2019+.**

PrOVE platform & ComCAM

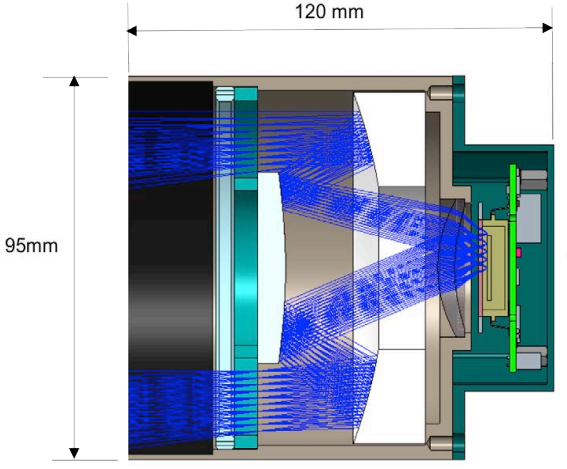
- The 6U bus developed by **Morehead State Univ**.
- **INO**'s ComCAM multispectral camera for targeted science.
- **Rapid development to launch is possible**.

INO camera
Microbolometer with integrated filters

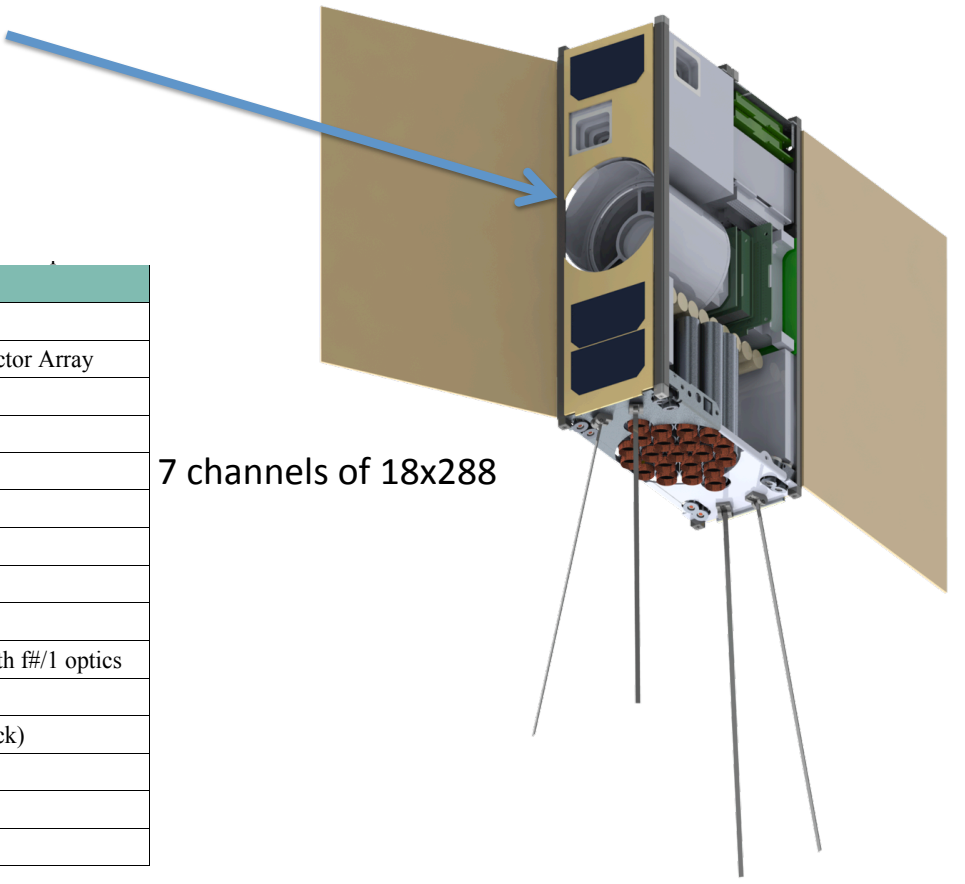




ComCAM sensor properties



Parameter	Value
Manufacturer	INO (Canada)
Detector Type	Microbolometer Detector Array
Detector Material	Vanadium Oxide
Design Waveband	2-to-14 µm
Pixel Count	384×288
Pixel Pitch	35 µm × 35 µm
Pixel Size	34 µm × 34 µm
Fill Factor	> 93 %
NEP	100 pW
NETD (8-14 µm band)	~125 mK @ 300K with f#/1 optics
Thermal Time Constant	11 ms (-3 dB cut-off)
Frame rate	50-60 Hz (6 MHz clock)
Absorber	Gold black
D* (33 Hz, 2-14 µm)	$>2\times10^{8}$ cm√Hz/W
Operating Environment	Vacuum



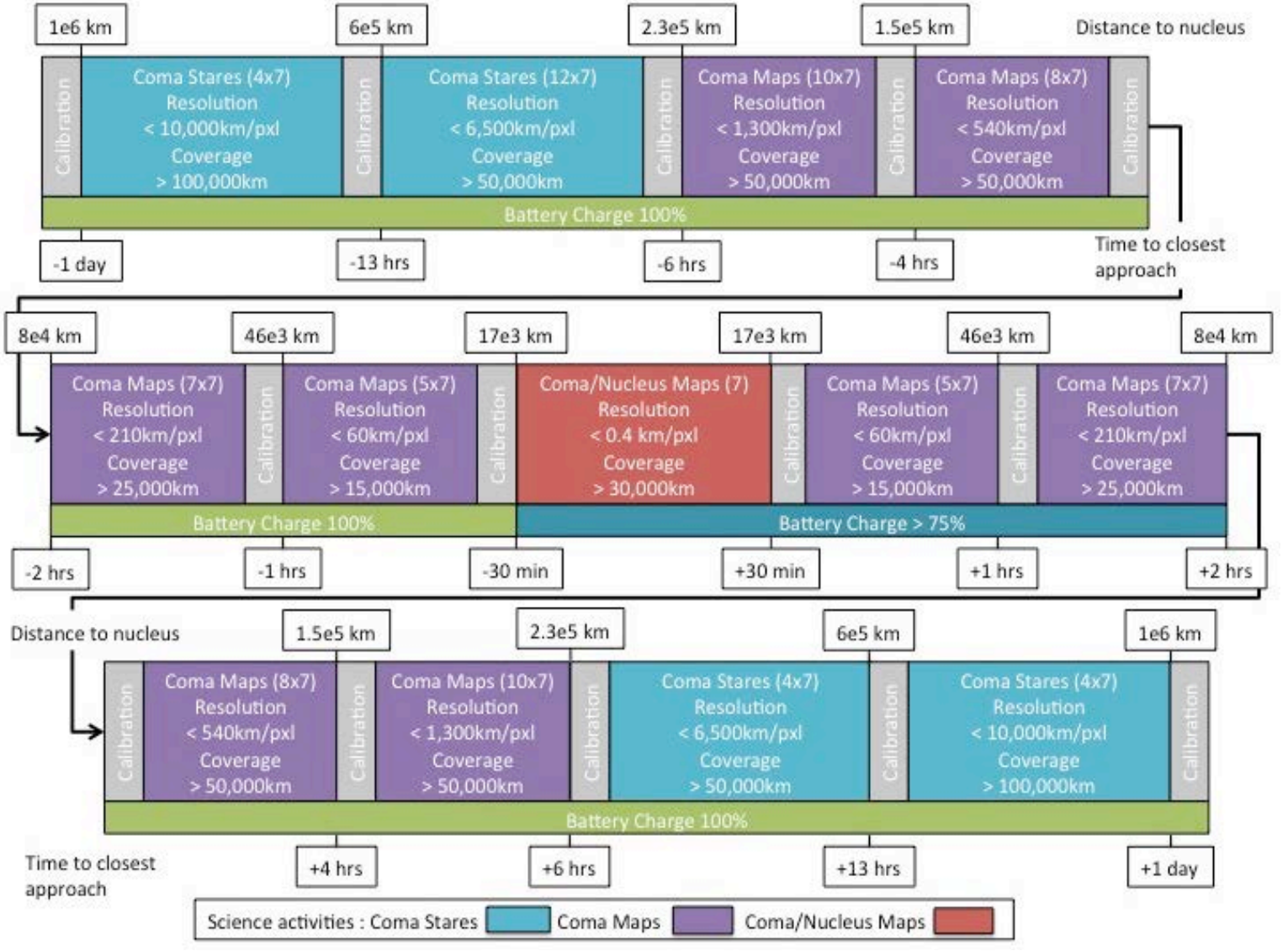
7 channels of 18x288

ComCAM properties

Parameter	Property
Instrument type	Filter radiometer
Spectral range	2.7 to 14 μm in seven distinct channels
Camera optics	80 mm aperture
Optics speed	F#/1.05 (equivalent considering central obscuration of secondary optic)
Étendue, $A\Omega$	9.08×10^{-6} cm^2 steradian
Detector type	Microbolometers
Detector format	(384×288) array
Pixel size	34 μm x 34 μm
Pixel IFOV	4.25×10^{-4} radians
Resolution @ 100,000 km	42.5 km
Resolution @ 200 km	85 m
Electrical interface	LVDS
Mass	~1.2 kg
Power	< 2.5 W
Mission data volume	~100 Mbits
Operating modes	0.011 to 10 s integration modes with nominal 11 ms detector time constant
Observation strategy	Nadir pushbroom mapping

ComCAM spectral channels

Channel #	Filter Band (μm)	Transmission	Science Goals
1	2.7 ± 0.2	>80%	H_2O
2	3.3 ± 0.2	>80%	$CH_3OH + C_2H_6 + CH_4$
3	4.0 ± 0.2	>80%	Control
4	4.3 ± 0.1	>80%	CO_2
5	4.7 ± 0.2	>80%	CO
6	7-10	>80%	Thermal Channel 1
7	8-14	>80%	Thermal Channel 2


1e6 km
6e5 km
2.3e5 km
1.5e5 km
Distance to nucleus
Calibration
Coma Stares (4x7)
Resolution
< 10,000km/pxl
Coverage
> 100,000km
Coma Stares (12x7)
Resolution
< 6,500km/pxl
Coverage
> 50,000km
Coma Maps (10x7)
Resolution
< 1,300km/pxl
Coverage
> 50,000km
Coma Maps (8x7)
Resolution
< 540km/pxl
Coverage
> 50,000km
Battery Charge 100%
-1 day
-13 hrs
-6 hrs
-4 hrs
Time to closest approach
8e4 km
46e3 km
17e3 km
17e3 km
46e3 km
8e4 km
Coma Maps (7x7)
Resolution
< 210km/pxl
Coverage
> 25,000km
Coma Maps (5x7)
Resolution
< 60km/pxl
Coverage
> 15,000km
Coma/Nucleus Maps (7)
Resolution
< 0.4 km/pxl
Coverage
> 30,000km
Battery Charge > 75%
-2 hrs
-1 hrs
-30 min
+30 min
+1 hrs
+2 hrs
Distance to nucleus
1.5e5 km
2.3e5 km
6e5 km
1e6 km
Coma Stares (4x7)
Resolution
< 10,000km/pxl
Coverage
> 100,000km
Coma Stares (4x7)
Resolution
< 6,500km/pxl
Coverage
> 50,000km
+4 hrs
+6 hrs
+13 hrs
+1 day
Time to closest approach
Science activities : Coma Stares
Coma Maps
Coma/Nucleus Maps

Start time rel. to closest approach	Start distance to nucleus (km)	Resolution (km/pxl)	Covered Height (km)	Covered Width	Est. Raw data volume (bits)	Uncompressed download time (h)
-1 day	1,000,000	10,000 to 6,500	100,000	9,000	44,000	0.2
-13 h	600,000	6,500 to 3,000	80,000 to 37,000	6,300 to 3,000	132,000	0.59
-6 h	230,000	1,300 to 840	31,000 to 21,000	> 50,000	1,600,000	7.17
-4 h	150,000	540 to 300	21,000 to 12,000	> 50,000	4,900,000	21.95
-2 h	80,000	210 to 130	10,000 to 6,700	> 25,000	6,800,000	30.47
-1 h	46,000	60 to 30	6,000 to 2,900	> 15,000	24,000,000	107.53
-30 min	17,000	0.4 to 0.3	70 to 40	> 30,000	18,000,000	80.65
+30 min	17,000	60 to 30	6,000 to 2,900	> 15,000	4,900,000	107.53
+1 h	46,000	210 to 130	10,000 to 6,700	> 25,000	1,600,000	30.47
+2 h	80,000	540 to 300	21,000 to 12,000	> 50,000	1,206,576	21.95
+4 h	150,000	1,300 to 840	31,000 to 21,000	> 50,000	399,840	7.17
+6 h	230,000	6,500 to 3,000	80,000 to 37,000	6,300 to 3,000	131,712	0.59
+13 h	600,000	10,000 to 6,500	100,000	9,000	43,904	0.2

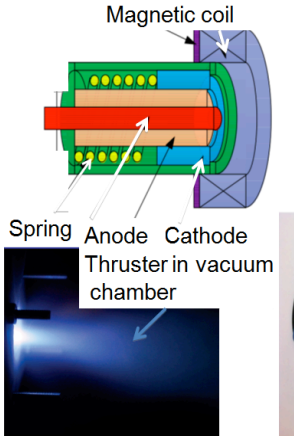
Science Activities	Est. Raw data volume (bits)	Uncompressed download time (h)
Coma/Nucleus Maps	18,000,000	80.65
Coma Maps	74,600,000	334.23
Coma Stares	352,000	1.58
Full Frame NavCam	1,500,000	6.72
Housekeeping (10s sampling)	2,300,000	10.3

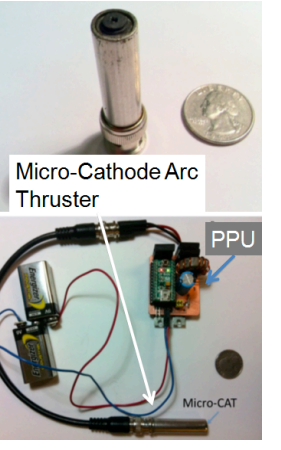
Deep Space Platforms (bus)

Morehead State
GSFC (Dellingr) – TOUR
Blue Canyon Technology (BCT)
Pumpkin, ISIS, Surrey Space, Clyde Space
Ragnarok Industries

Propulsion Systems

George Washington Univ (μCAT)
Busek (ElectroSpray)
MIT (S-iEPS)
Univ. Mich (Ambipolar)
JPL (MEP)
MicroSpace





Attitude Control Systems

BCT
Sinclair Interplanetary

Navigation & Trajectory

Command & Data Handling

Honeywell (Dependable Microprocessor)
CHREC Space Processor – TOUR
Space Micro (Proton)

Downlink

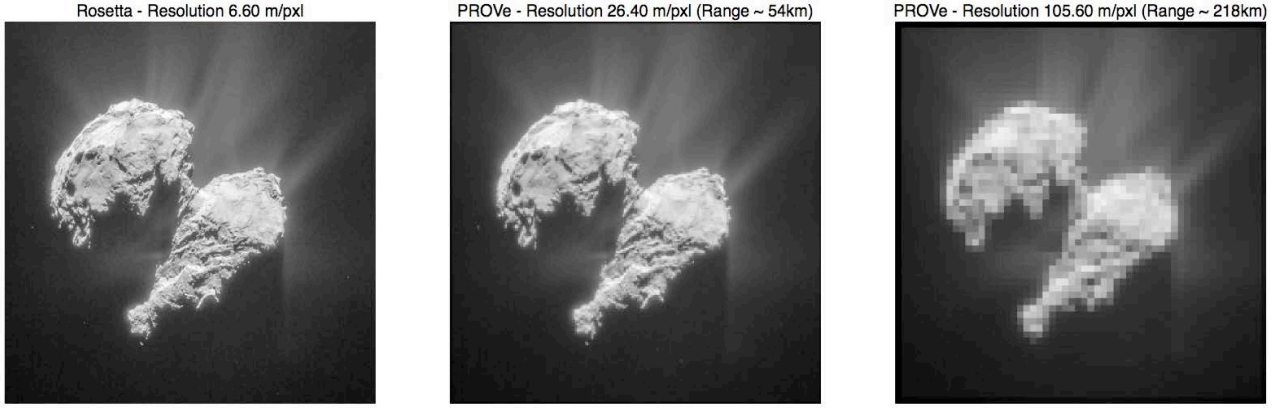
UHF (several vendors)
JPL IRIS X-band transceiver
Future : Ka band

Launch Systems

SLS/EM-1
RideShare opportunities
Falcon, Minotaur, Taurus, Vega
CubeSat Launch Initiative

Planning tool http://cubesatsforspace.com/

Dual purpose instruments
Simulation of NavCam Images



Rosetta Navigation Camera image at a distance of 77.8 km from the centre of Comet 67P/C-G. The image scale is 6.6 m/pixel and the 1024 x 1024 pixel image measures 6.8 km across. Although 67P is a much larger comet (3.5×4 km compared to an average diameter of ~1 km for Wirtanen), PrOVE will have the required spatial resolution on Wirtanen to study structure and jets at 50 km.

Thank you!

We acknowledge the support of Goddard Space Flight Center in this effort.

Backup slides

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 the chemical variability in the coma and determine what controls this variation	Determine thermophysical properties of the near nucleus inner coma	Determine the thermal inertia of the inner coma using daytime observations of surface thermal emission	Surface emission measured from 7-10 μm and 8-14 μm	Inner coma maps of temperature	Thermal models of comet response to insolation and its relationship to active outburst regions
	SO2 Determine the variations in the spatial distribution of CO2, CO, and organics with respect to H2O	Determine the distribution of compositions within the coma	Determine the relative abundances of CO2, CO, organics and H2O within the coma and active outbursts	Maps of the comet nucleus and coma at various spatial resolutions	Inner coma maps of compositions of CO2. CO, organics and H2O	Information about the relative abundances of CO2, CO, organics and H2O within the target
	SO3 Determine the frequency and distribution of outburst as measured by local enhancements and the endogenic mechanism that drives these events	Maps the comet's coma region to detect locations and number of outburst events	Maps 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

Other JFC targets

Potential opportunities for visiting comets near perihelion passage

Target	Perihelion	Closest Approach	Ecl. plane crossing
46P/Wirtanen	13-Dec-2018	17-Dec-2018	16-Dec-2018
	1.055 AU	0.078 AU (Z=–0.004)	†0.078 AU
P/2014 U2 (Kowalski)	12-Oct-2019	26-Sep-2019	04-Sep-2019
	1.116 AU	0.28 AU (Z=0.05)	†0.327 AU
P/2008 Y1 (Boattini)	10-Sep-2019	21-Jan-2020	30-Sep-2019
	1.27 AU	1.26 AU (Z=–0.29)	‡1.39 AU
P/2013 TL117 (Lemmon)	24-Dec-2020	14-Dec-2020	03-Jun-2020
	1.122 AU	0.469 AU (Z=0.18)	†3.07 AU

† Ascending node range from Earth

‡ Descending node range from Earth