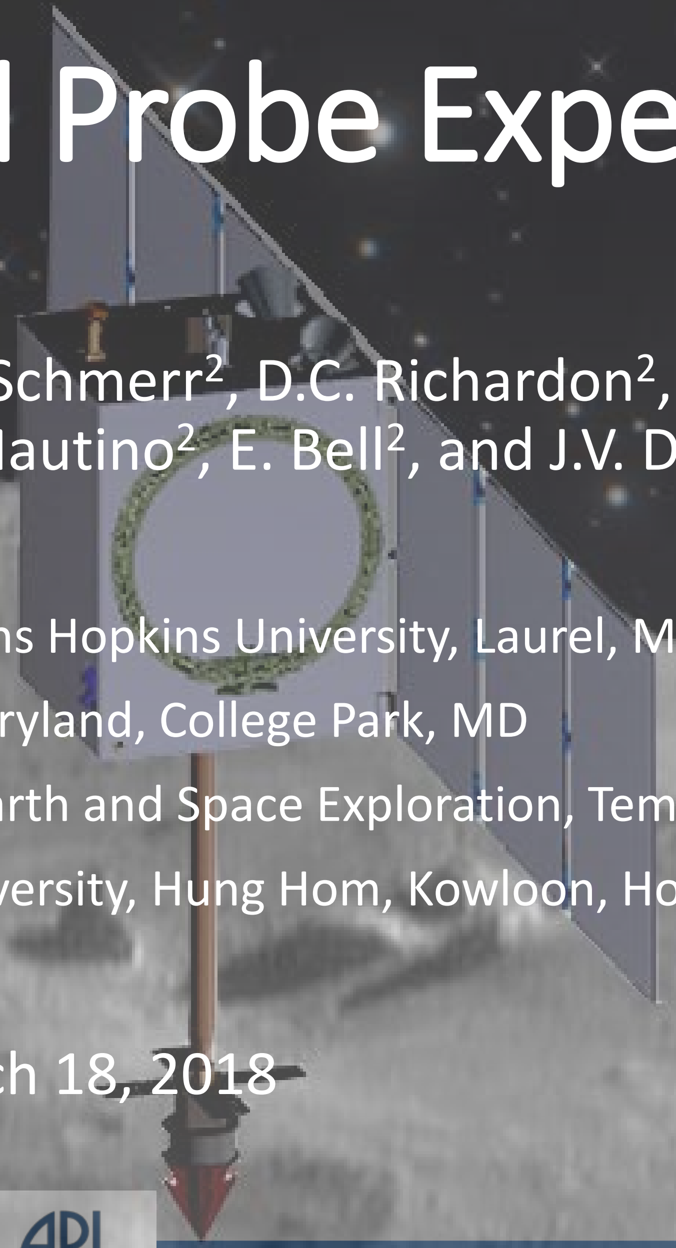
APEX – Asteroid Probe Experiment



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March 18, 2018

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

APL

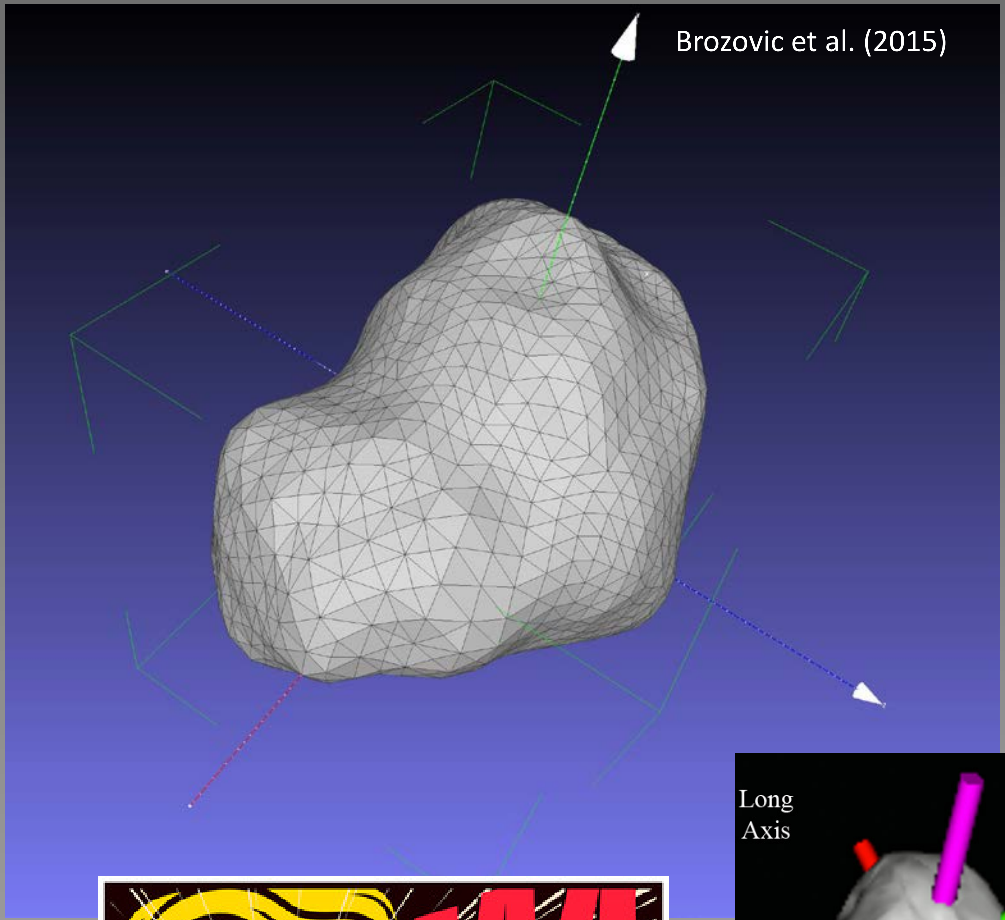
Outline

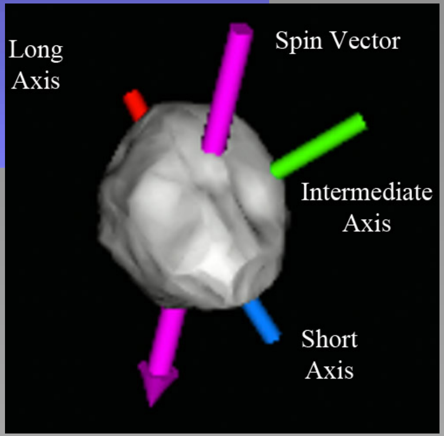
- Target
- Science Objectives
- Spacecraft – Mission
- Issues
- Alternative Approaches

- Conclusions:
    - APEX does not fit within the PSD SmallSat Study Constraints – 180 kg / $100M.
    - APEX fits a ESPA grande mass limit and larger (much larger) fiscal cap.
        - But, such a mission achieves only minimal science.
    - NASA better served by a Discovery class APEX mission – more science, less risk.

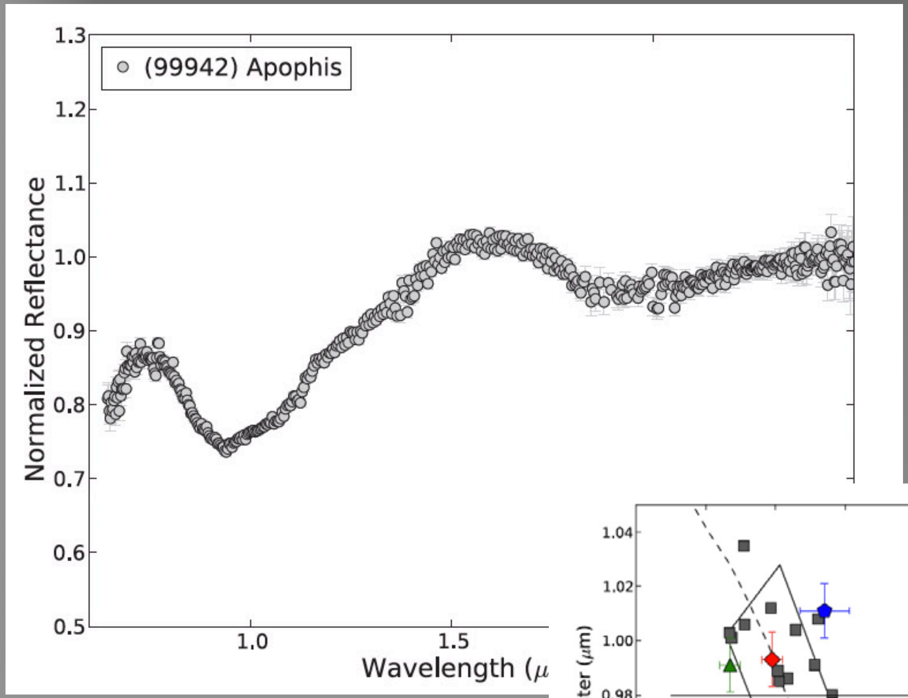
Apophis

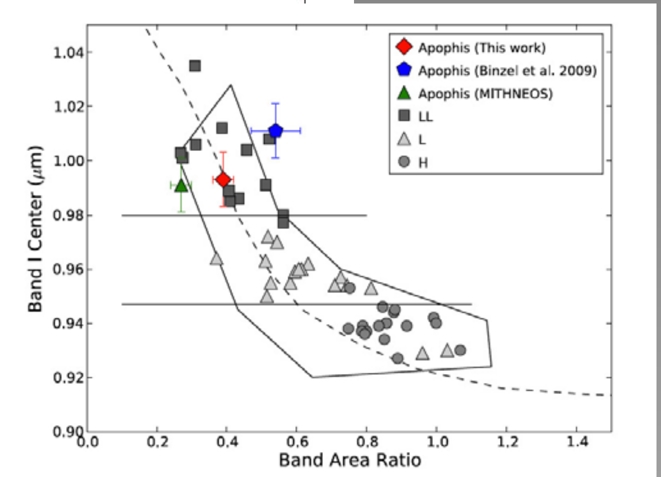
Table 1. (99942) Apophis Basic Information			
Parameter	Value	Units	Source
Dimensions	0.43 ± 0.04 0.30 ± 0.03 0.26 ± 0.03	km	Brozovic et al. (2015)
Volume	2.1×10^{7} 2.0×10^{7}	m^3	Brozovic et al. (2015) this analysis
Density	2.4	$kg\ m^{-3}$	assumed
Mass	4.9×10^{10}	kg	calculated from above
Surface gravity	0.00027	$m\ sec^{-2}$	calculated from above
Escape velocity	0.14	$m\ sec^{-1}$	
Rotation	27.38 ± 0.7 retrograde	hr.	Brozovic et al. (2015) Pravec et al. (2014)
Aphelion	1.099	AU	
Perihelion	0.747	AU	
Orbital period	323.6	day	
Inclination	3.331	deg	
Precession	6304.8	hr.	Brozovic et al. (2015) Pravec et al. (2014)
Radar albedo	0.25 ± 0.11		
Visible albedo	0.33 + 0.05 / -0.06		Müller et al. (2014)
Absolute magnitude	19.09 ± 0.19		Pravec et al. (2014)
Surface temperature	250	K	Müller et al. (2014)
Thermal inertia	600 + 200 / -350 50-500	$J\ m^{-2}\ s^{-0.5}\ K^{-1}$	Müller et al. (2014) Licandro et al. (2016)



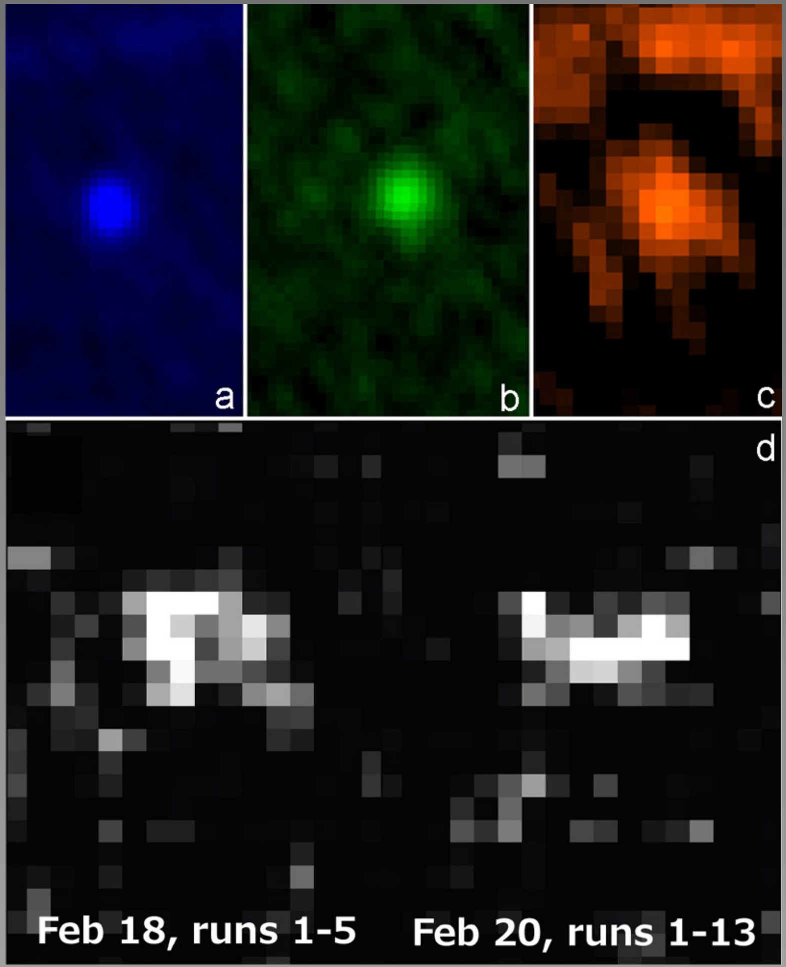


Apophis





Reedy et al., 2018 IRTF
Binzel et al., 2009



Herschel
70, 100, 160 μm

12.3 cm Radar
Goldstone

Müller et al., 2012; Brozovic et al., 2017

Science Objectives

- Level 1 objectives
  - Determine the rotational state and bulk properties of Apophis
  - Determine the interior structure
  - Determine the geology and geologic history of Apophis
  - Determine the tidal effects on surface morphology, interior structure, rotation.

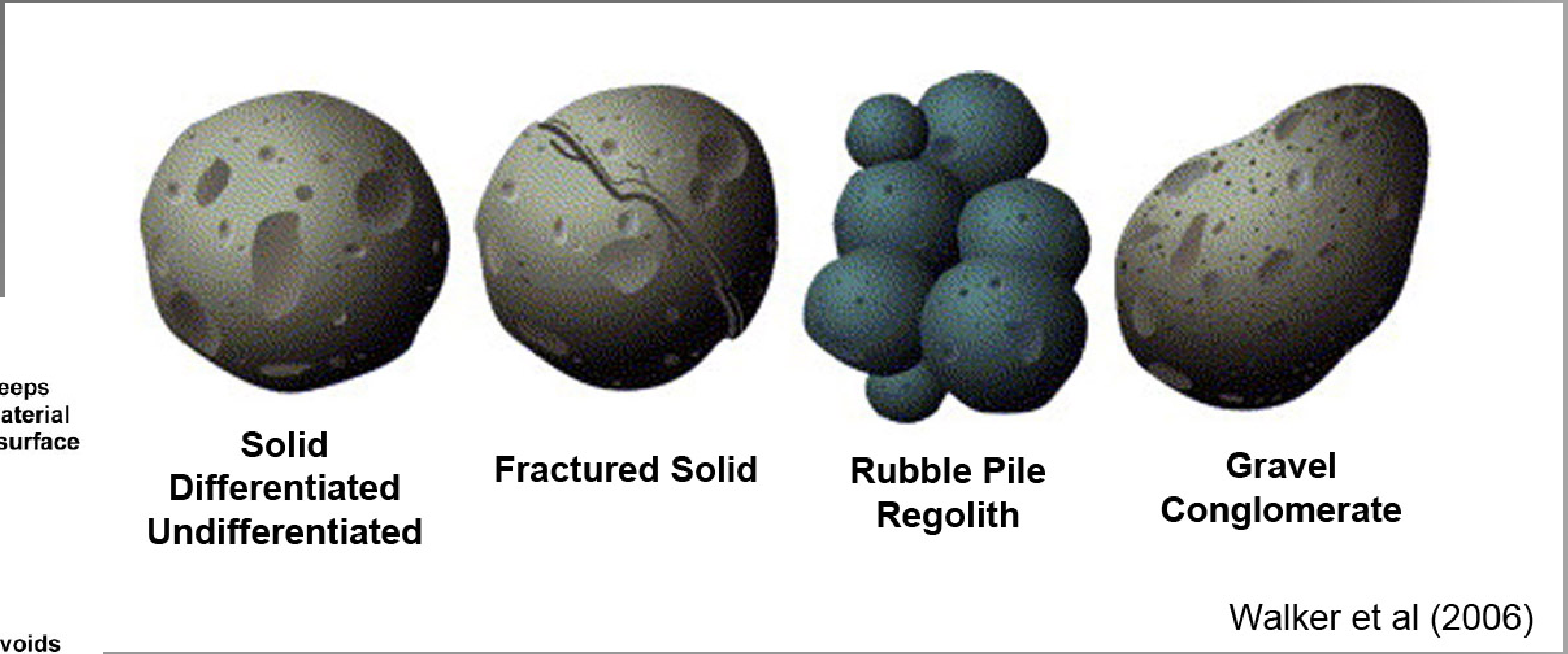
- Level 2 objectives
  - Rotation period and orientation
  - Shape and volume
  - Topography
  - Mass and density

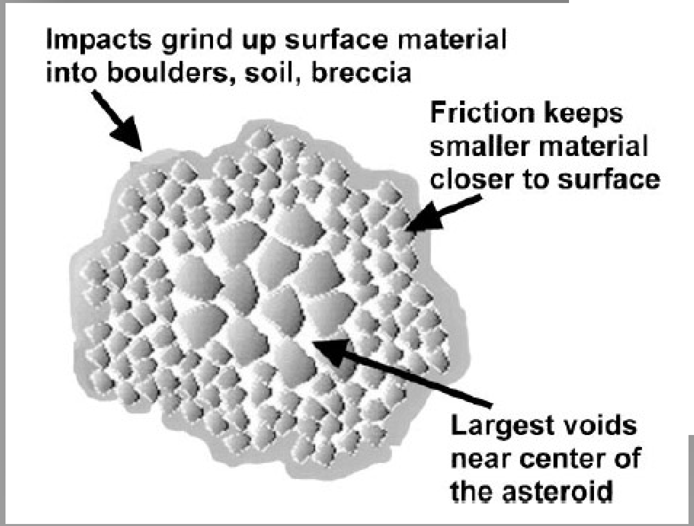
  - Internal tectonic stress seismicity
  - Surface thermal stress seismicity
  - Impact induced seismicity

  - Geologic history
  - Surface morphology
  - Physical properties
  - Calibration of remote sensing data

Friday the 13th April 2029

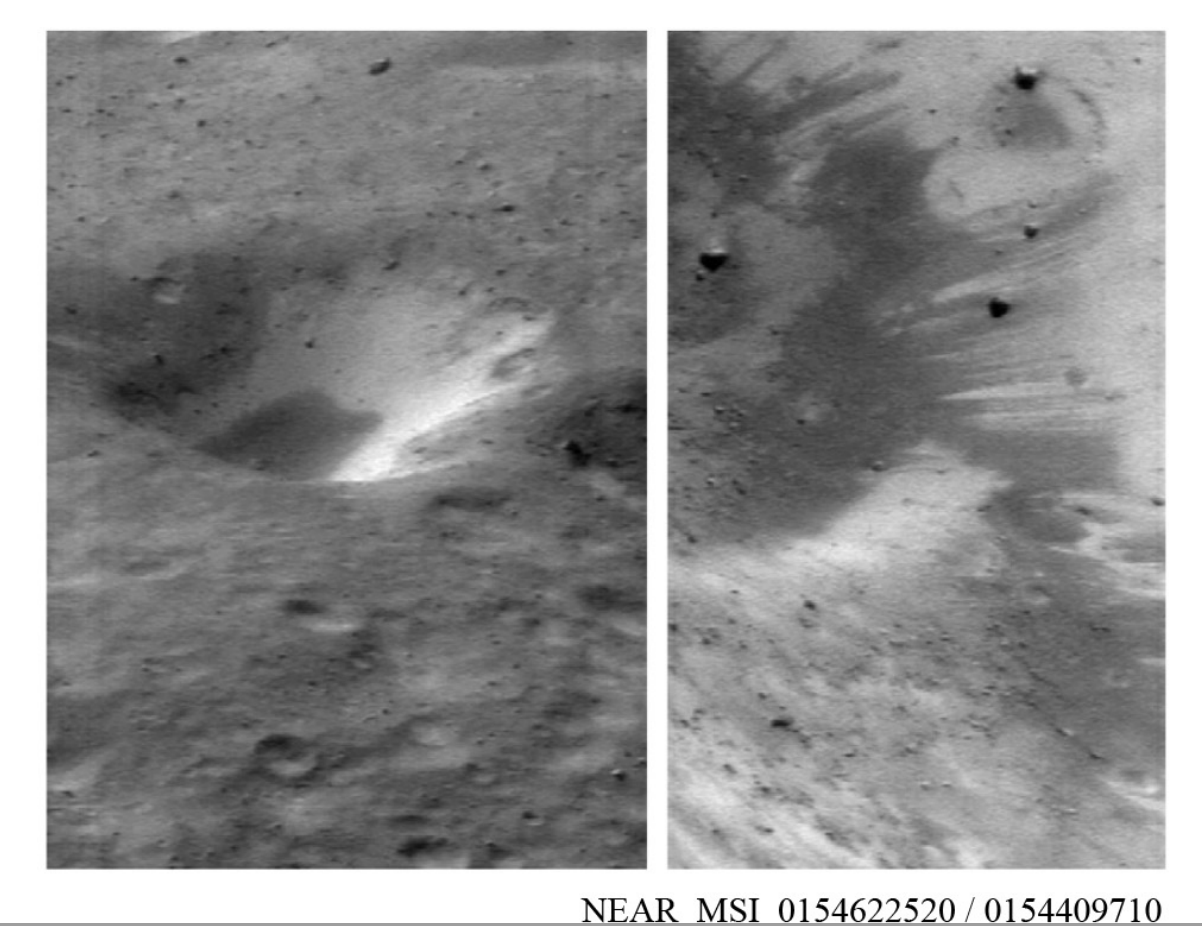
Internal Structure





Britt and Consolmagno, 2001
Perera et al., 2016

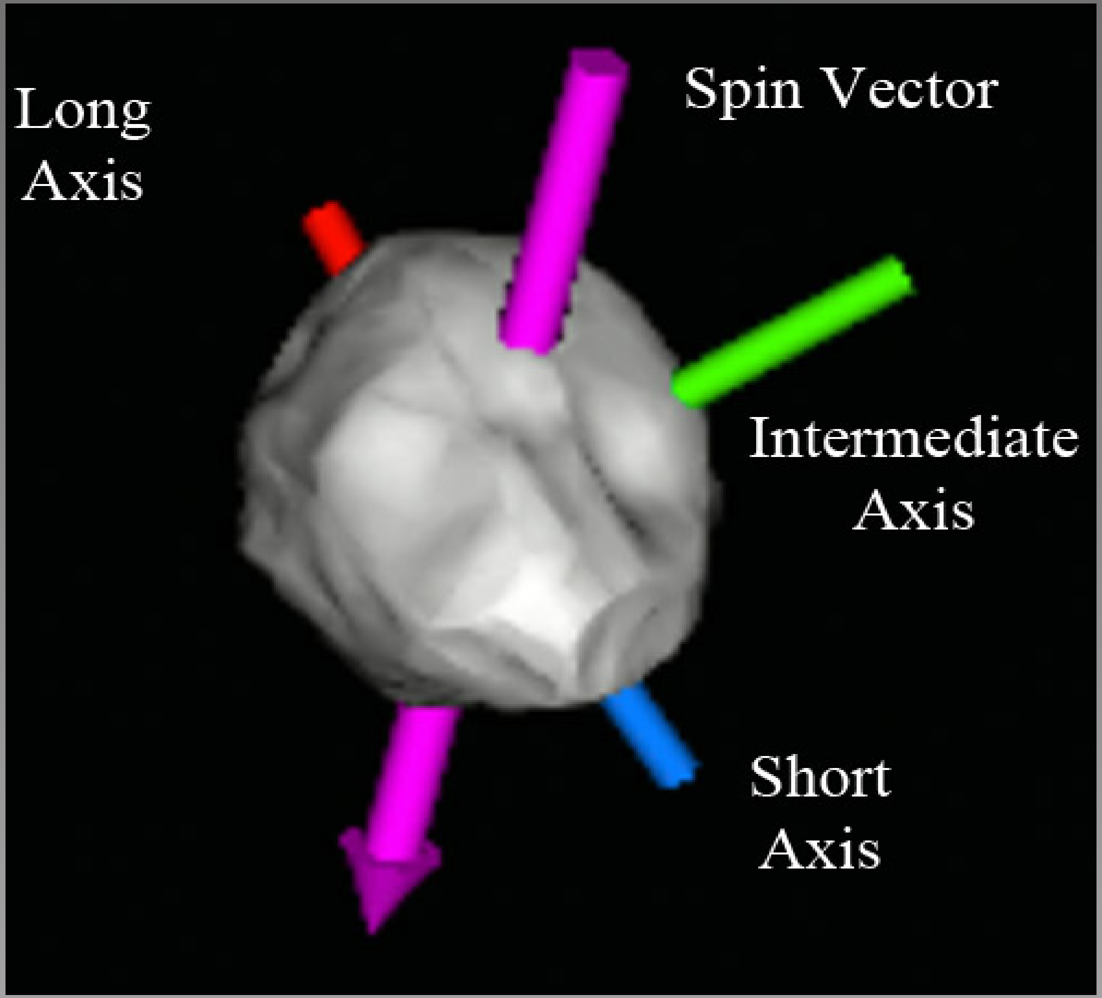
Surface Character and Modification

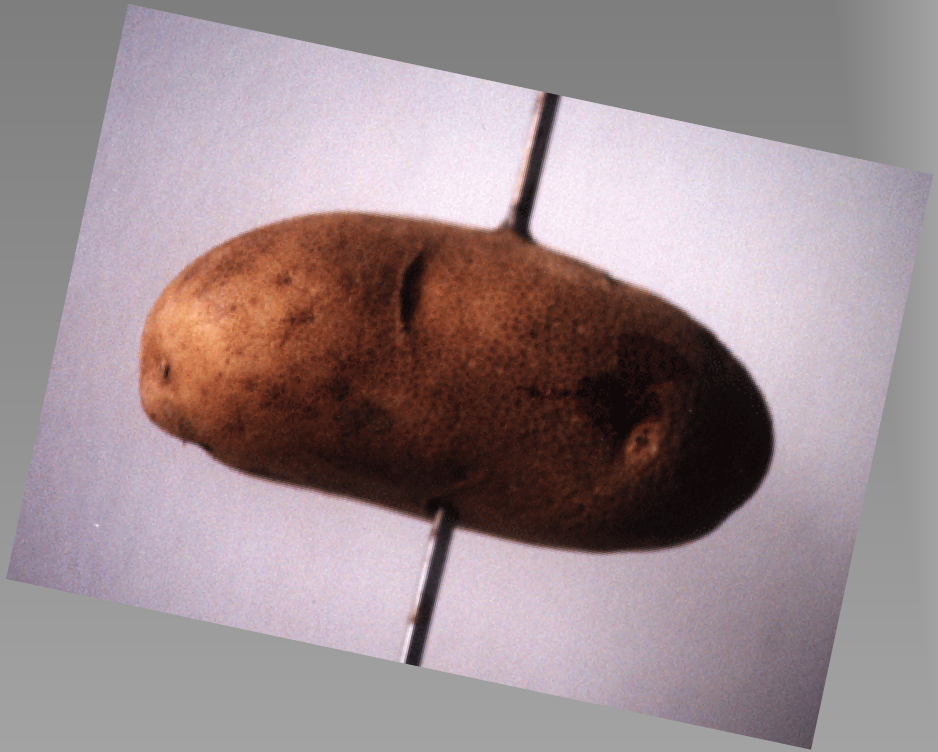


Richardson et al., 2004
Walsh et al., 2008
Binzel et al., 2010
Gaffey, 2010
Nesvorný et al., 2010;
DeMeo et al., 2014
Garcia et al., 2015
Keane and Matsuyama, 2015
Polishook et al., 2014a, 2014b

Expose fresh (unweathered) material
Movement downslope
Seismic motion

Rotational Dynamics





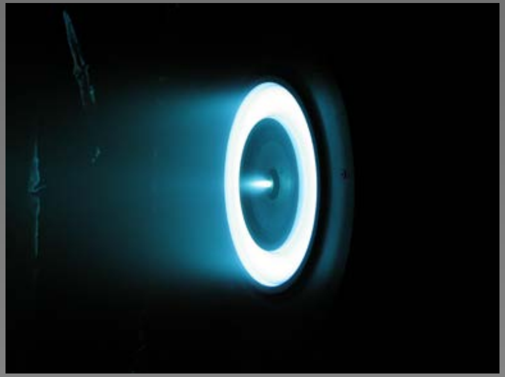
Trade Studies

- Propulsion: Chemical vs. **SEP**
- Propellant: Iodine vs. **Xenon**
- Trajectory Origin: LEO/GEO vs. **L1**
- Communication: Dish vs. **Radial Slot Array Antenna (RLSA)**
- Seismometer Deployment: Propulsive Impact vs. **Direct Emplacement**
- Boom: Stick vs. **Deployable**
- Payload: **Charlie Brown** vs. Rockefeller Center
  - Panchromatic imaging
  - Seismometer

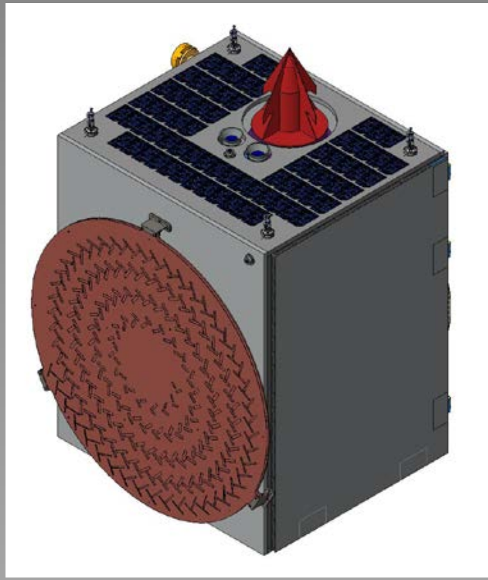
Scientist Perspective

Engineer / Program Manager Perspective

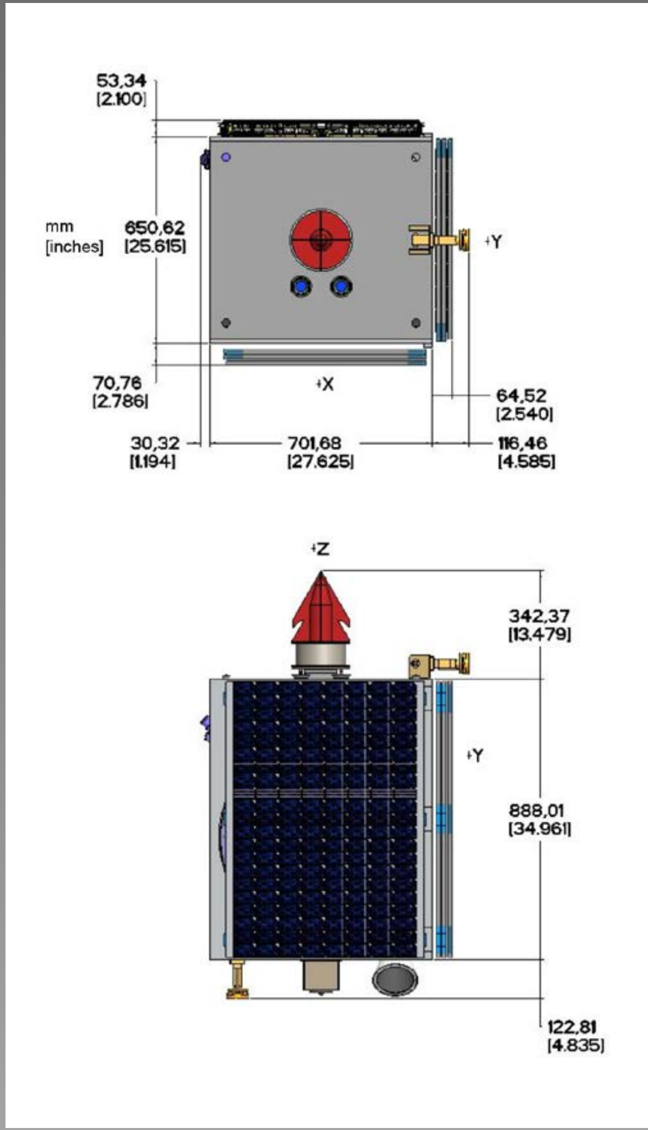
Spacecraft



SEP BHT-600 Busek

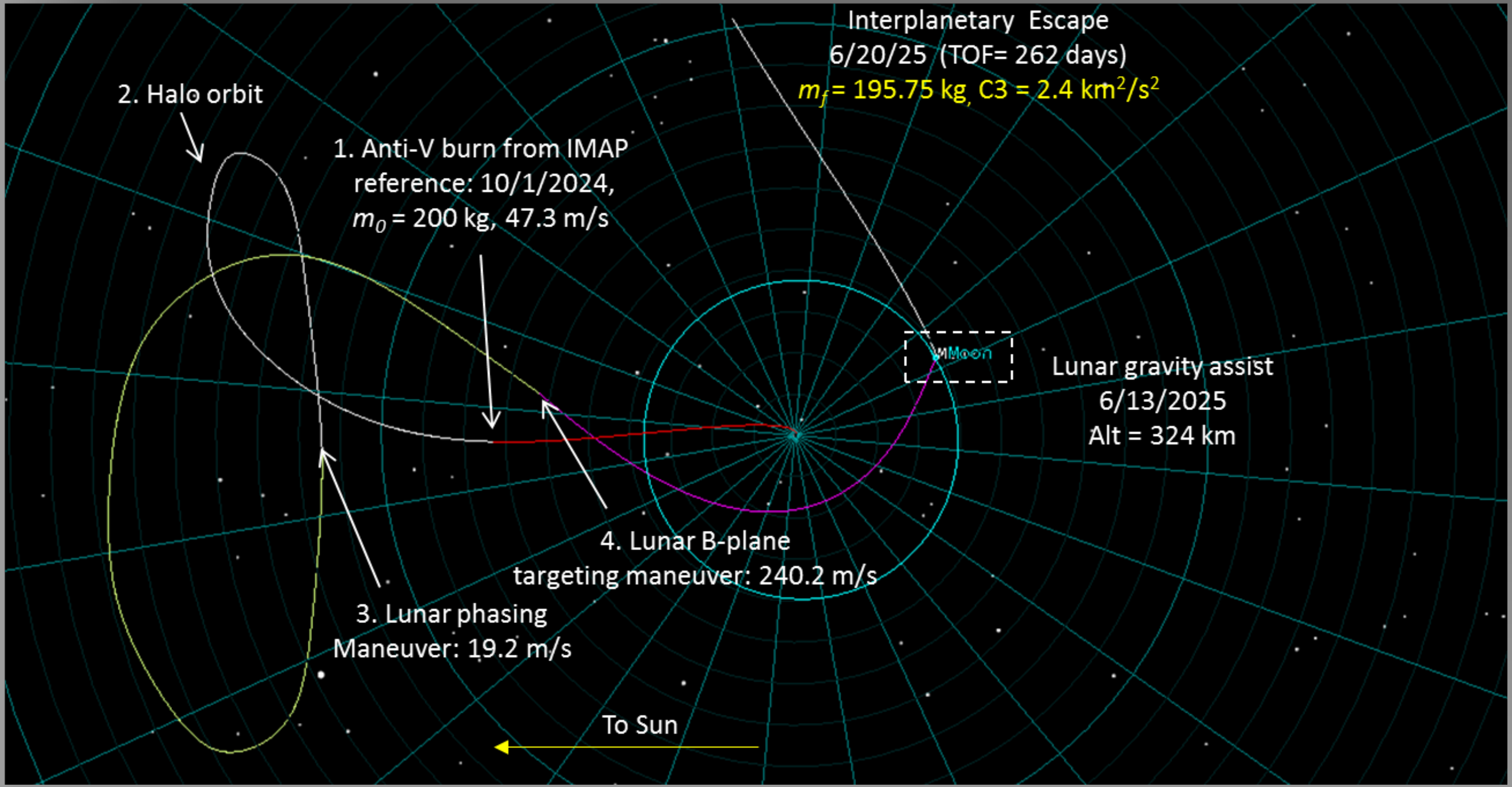


Antenna

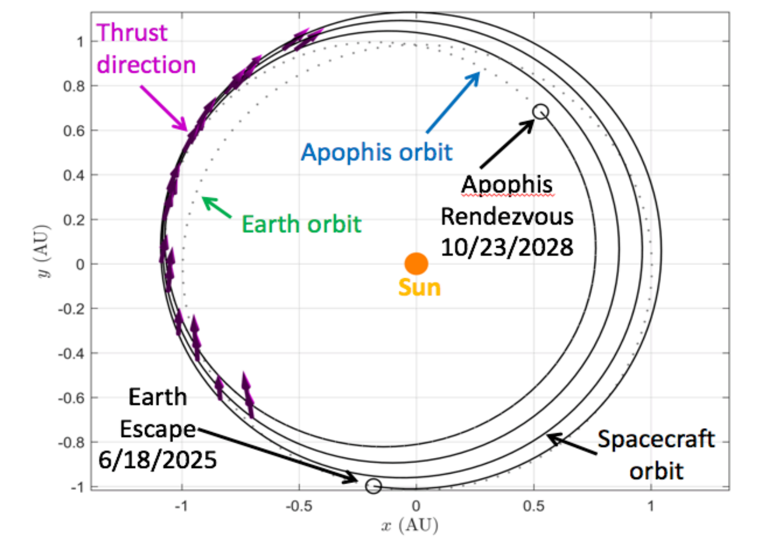


APEX Spacecraft Mass Summary	
Component	Unit Mass (kg)
Spacecraft Bus	159
Primary Structure	50
All other Structure	9
Propulsion Hardware	26
Avionics	6
Power Electronics	2
Solar Cells	24
Battery	2
Attitude Control (all sensors)	13
RF Communications	12
Harness	10
Thermal	5
Payload	7
Imaging System	1
Seismometer	6
Contingency (30%)	49
Dry Mass Total	166
Propellant	62
Total Mass	228
Total Mass vs. ESPA (180 kg)	-48
Total Mass vs. EPSA requalified (200 kg)	-28
Total Mass vs. ESPA Grande	72

Trajectory

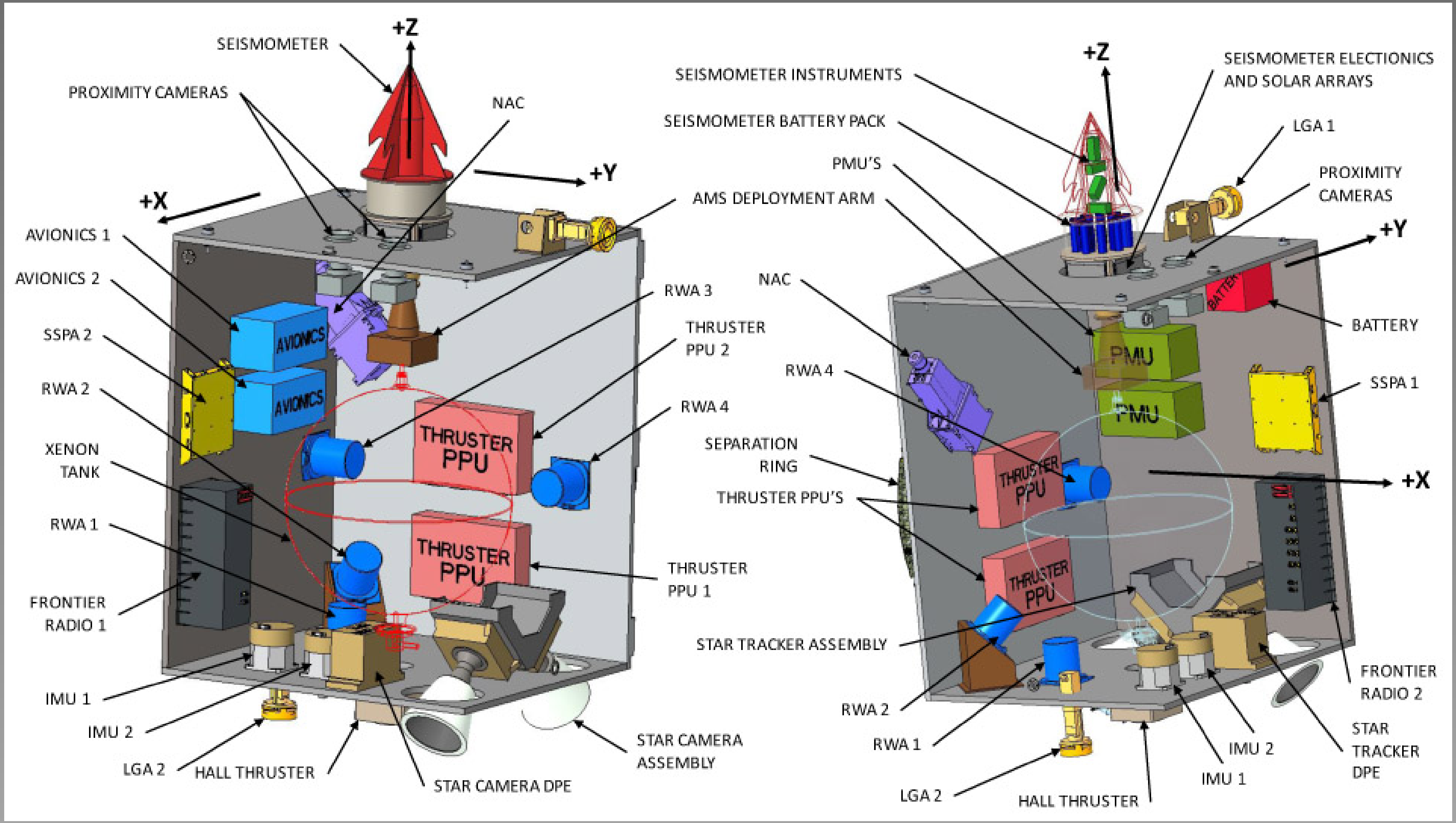


ΔV Budget	
Mission Phase	m s^{-1}
Early Ops through Earth Escape/Lunar Flyby	307
Heliocentric Cruise	3408
Station Keeping	50
Total	3765

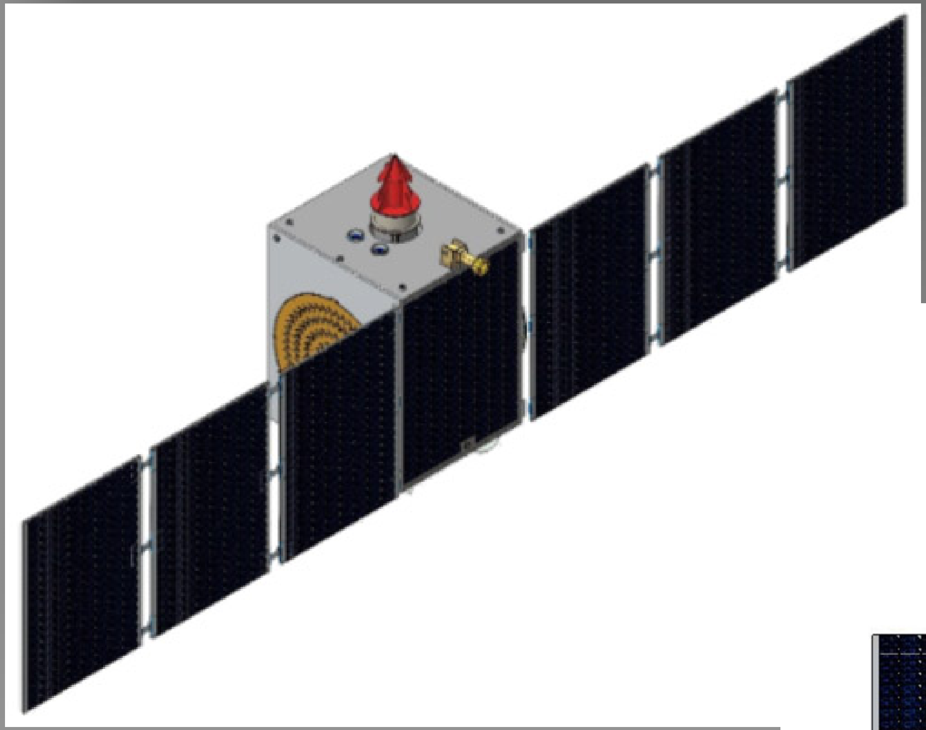


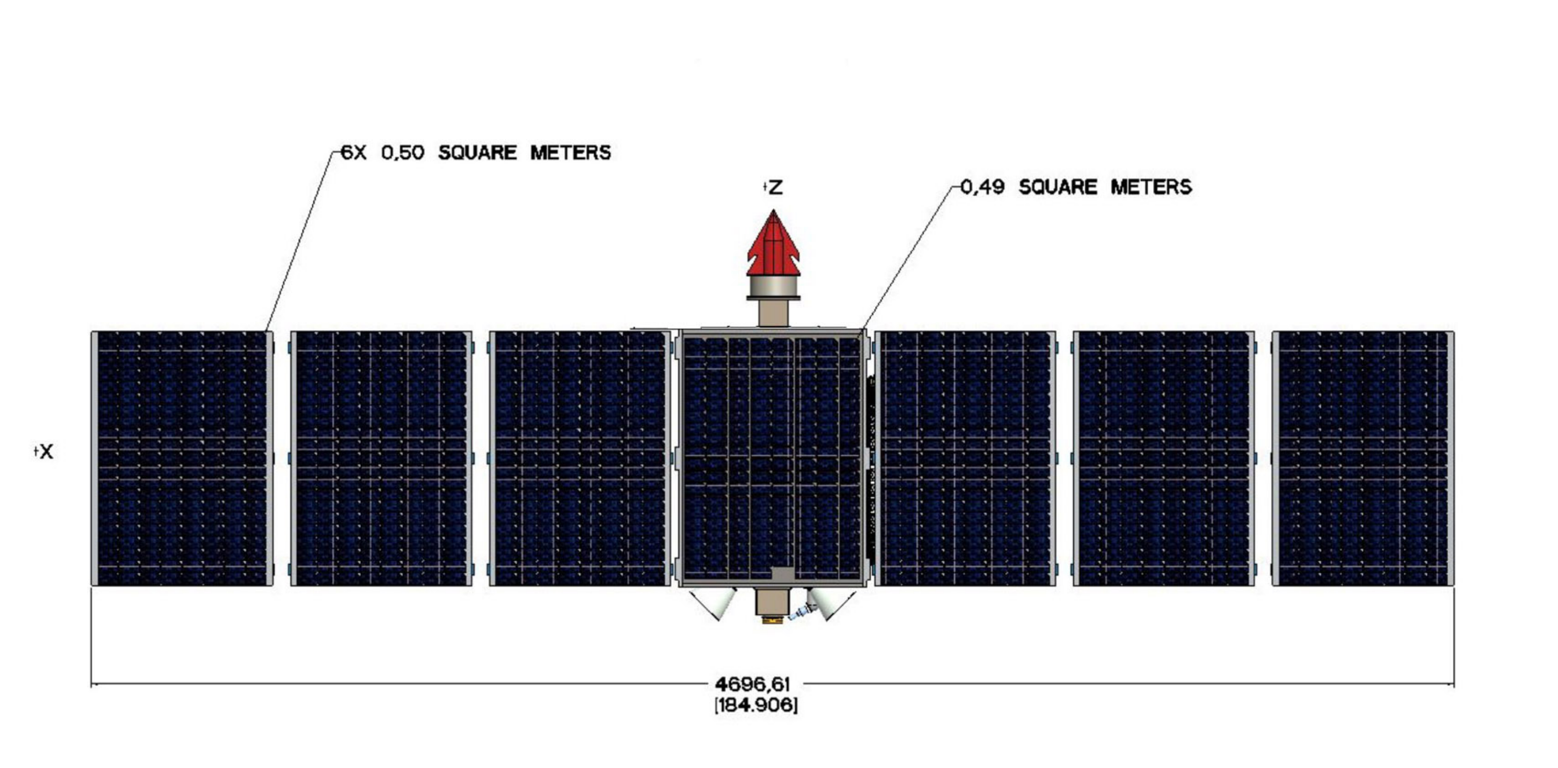
Launch data is flexible. Loiter in the Earth-Moon environment.
Departure of Earth-Moon environment is the real constraint 6/20/2025
Arrival at Apophis October 2028, Flight time is 3+ years.
Assume co-manifest with IMAP – launch by December 2024

Spacecraft


SEISMOMETER
+Z
PROXIMITY CAMERAS
NAC
+Y
+X
AVIONICS 1
AVIONICS 2
SSPA 2
RWA 2
XENON TANK
RWA 1
FRONTIER RADIO 1
IMU 1
IMU 2
LGA 2
HALL THRUSTER
STAR CAMERA DPE
STAR CAMERA ASSEMBLY
THRUSTER PPU 1
RWA 4
THRUSTER PPU 2
RWA 3
AMS DEPLOYMENT ARM
AVIONICS
AVIONICS
THRUSTER PPU
THRUSTER PPU
+Z
SEISMOMETER INSTRUMENTS
SEISMOMETER BATTERY PACK
PMU'S
AMS DEPLOYMENT ARM
NAC
RWA 4
SEPARATION RING
THRUSTER PPU'S
STAR TRACKER ASSEMBLY
RWA 2
RWA 1
LGA 2
HALL THRUSTER
IMU 1
IMU 2
STAR TRACKER DPE
FRONTIER RADIO 2
+X
SSPA 1
BATTERY
+Y
PROXIMITY CAMERAS
LGA 1
SEISMOMETER ELECTIONICS AND SOLAR ARRAYS
PMU
PMU
THRUSTER PPU
THRUSTER PPU

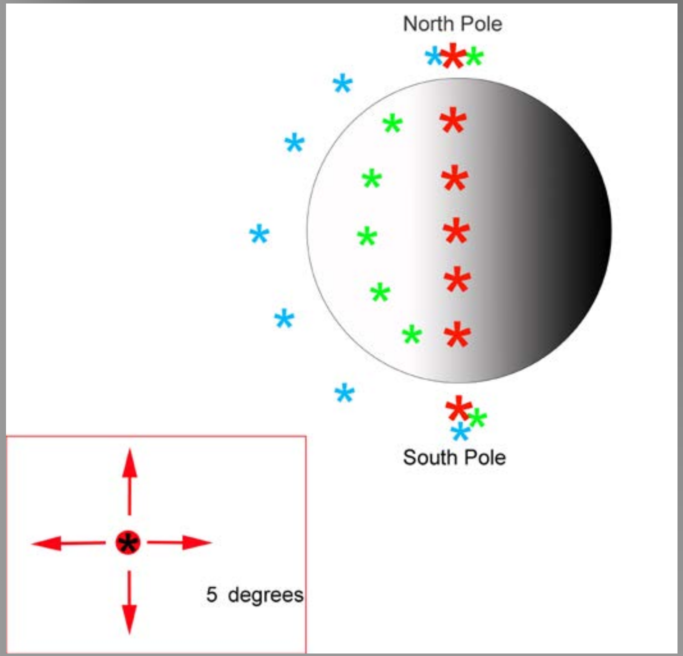
Spacecraft



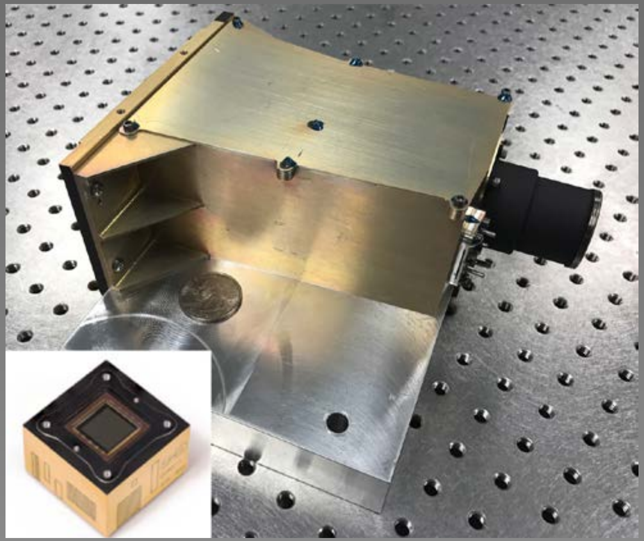


700 W power generation

Imaging

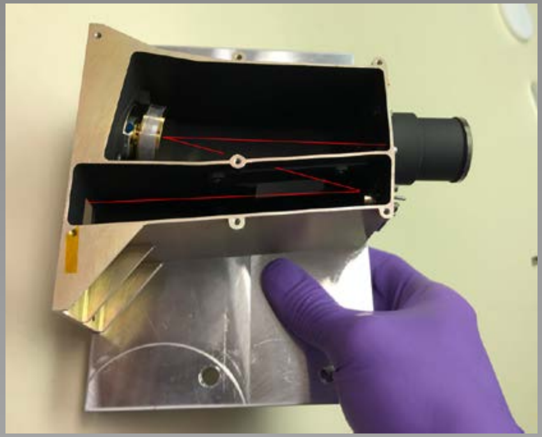


Imaging Strategy



3D Plus detector – Bayer RGB

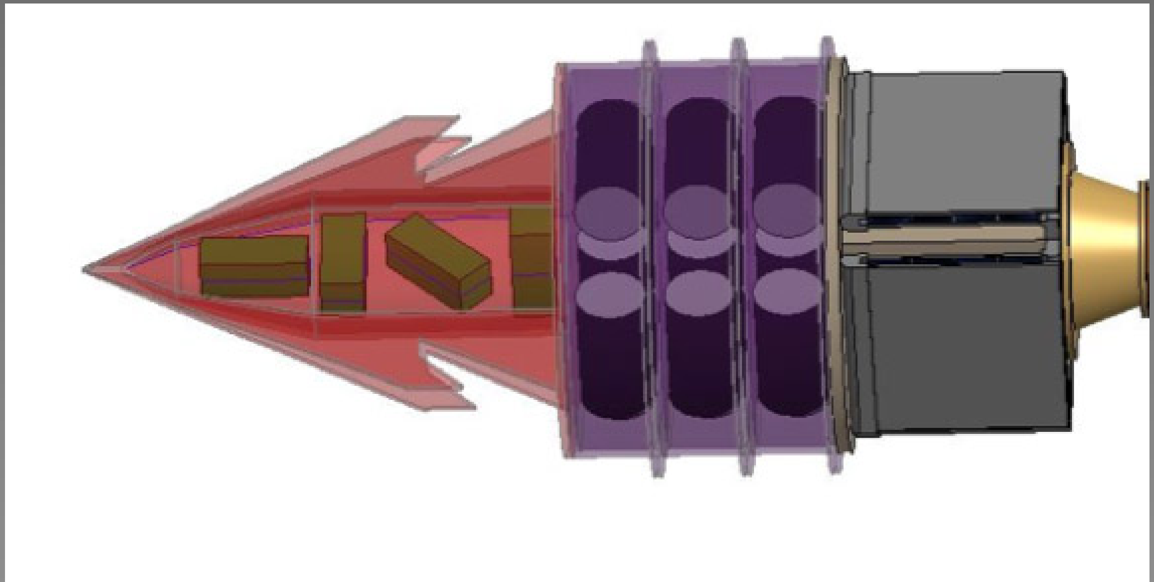
NAC

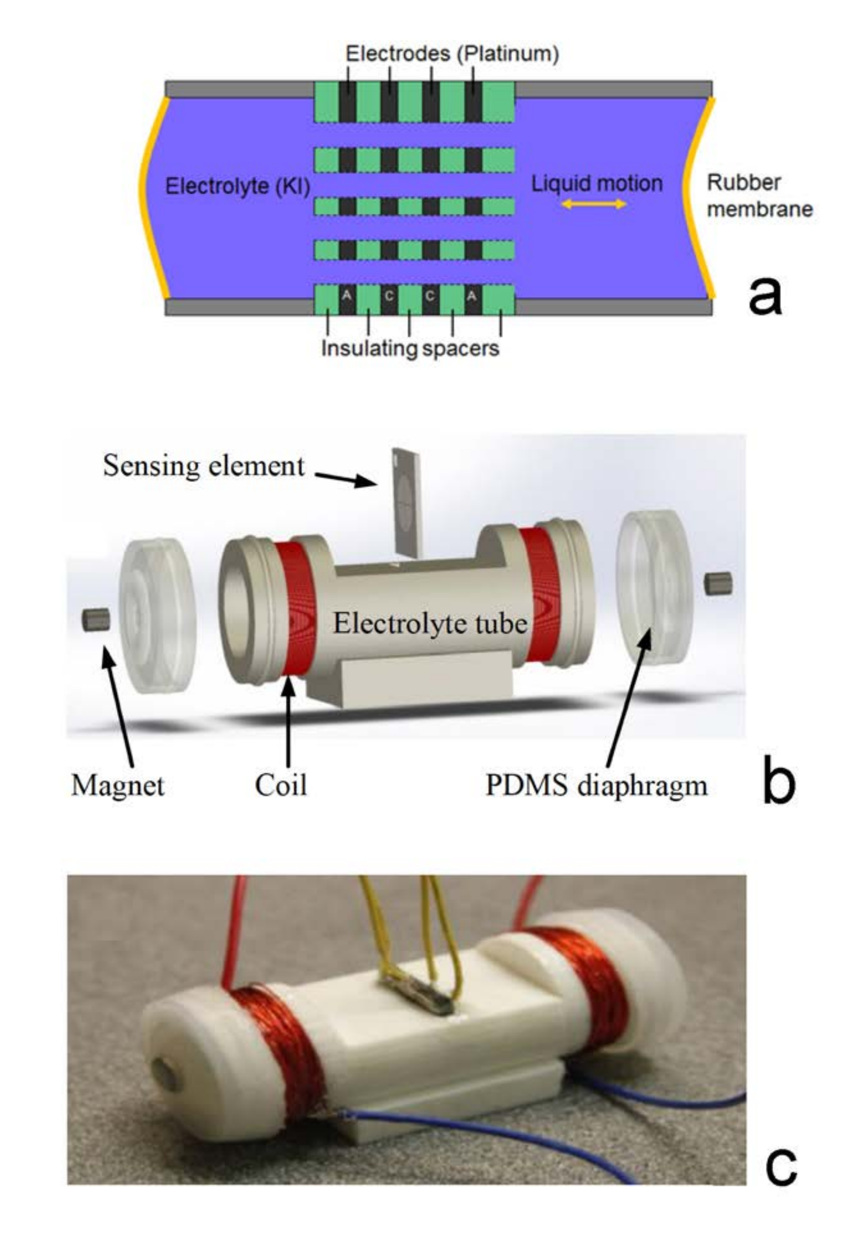


Proxops ECAM-C50
Malin Space Science

Imaging System Details		
Parameter	NAC	Proxops
Focal Length	550 mm	7 mm
Pupil Diameter	25 mm	2.3
Detector	3D Plus 3DCM681 2048 x 2048 pixels 5.5 μm pitch	2650 x 1944 pixels 2.2 μm pitch
F / number	22	3.5
FOV	1.17°	44° x 33°
IFOV	10 μrad	286 μrad
SNR	100	60-100
Spectral Bands	400-700 nm	400-700 nm
Mass (kg)		
Optics	0.45	0.6
Electronics	0.15	1.5
Structure	0.11	0.2
Total	0.71	2.8
Power (W)		
Average	2	17
Peak		19
Standby		8

Seismometer

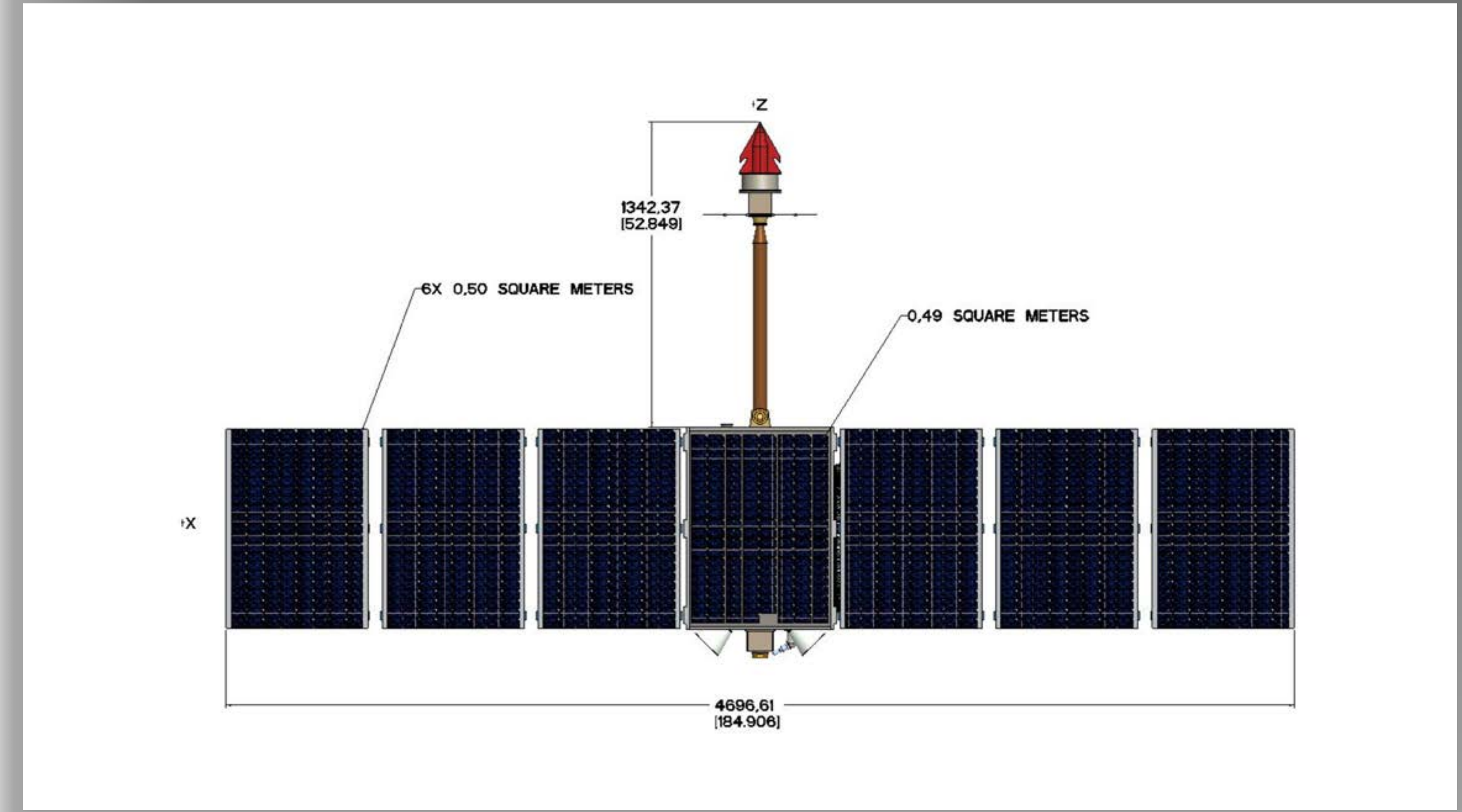


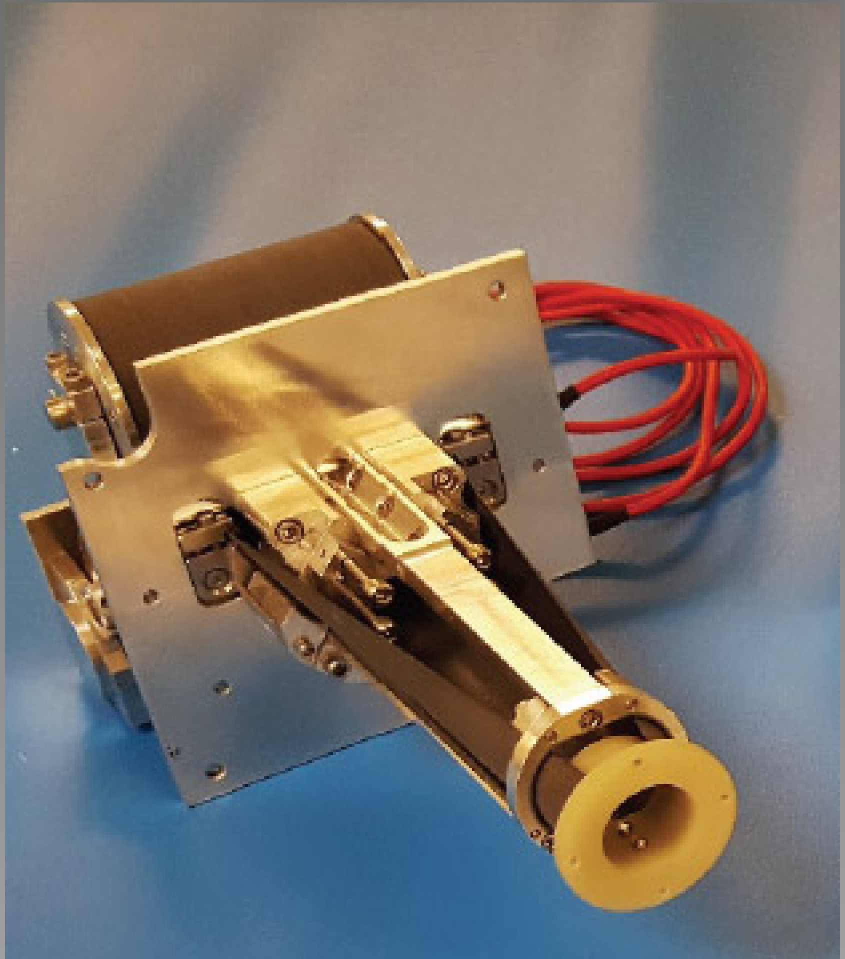


Fluid filled sensor. Motion detected by fluid flow / MEMs sensor. No moving part, orientation independent. High G tolerance.

Package needs to be self-contained: power, comm, data storage, long-lived.

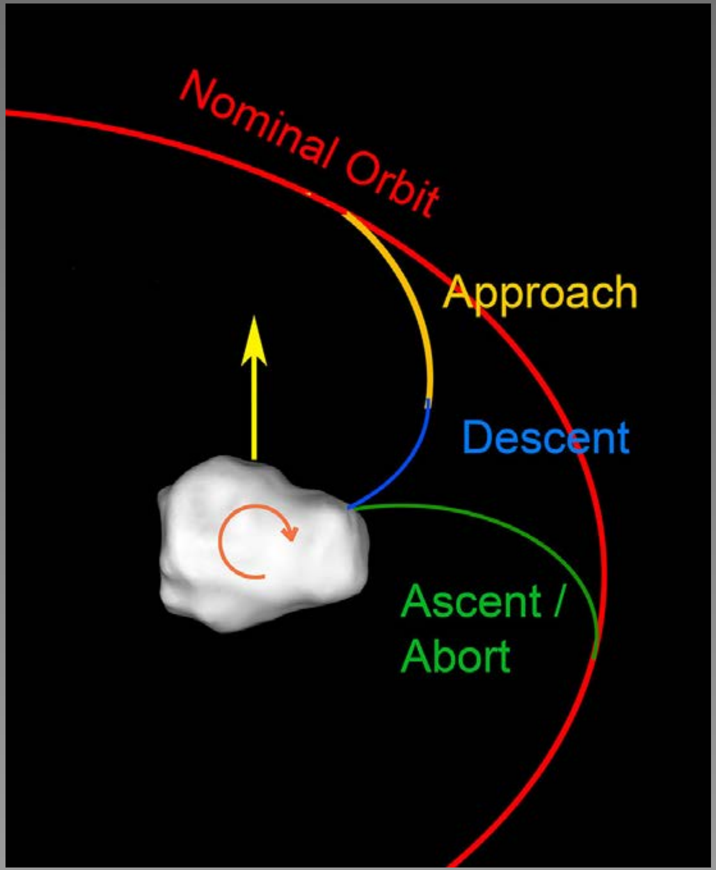
Seismometer Deployment

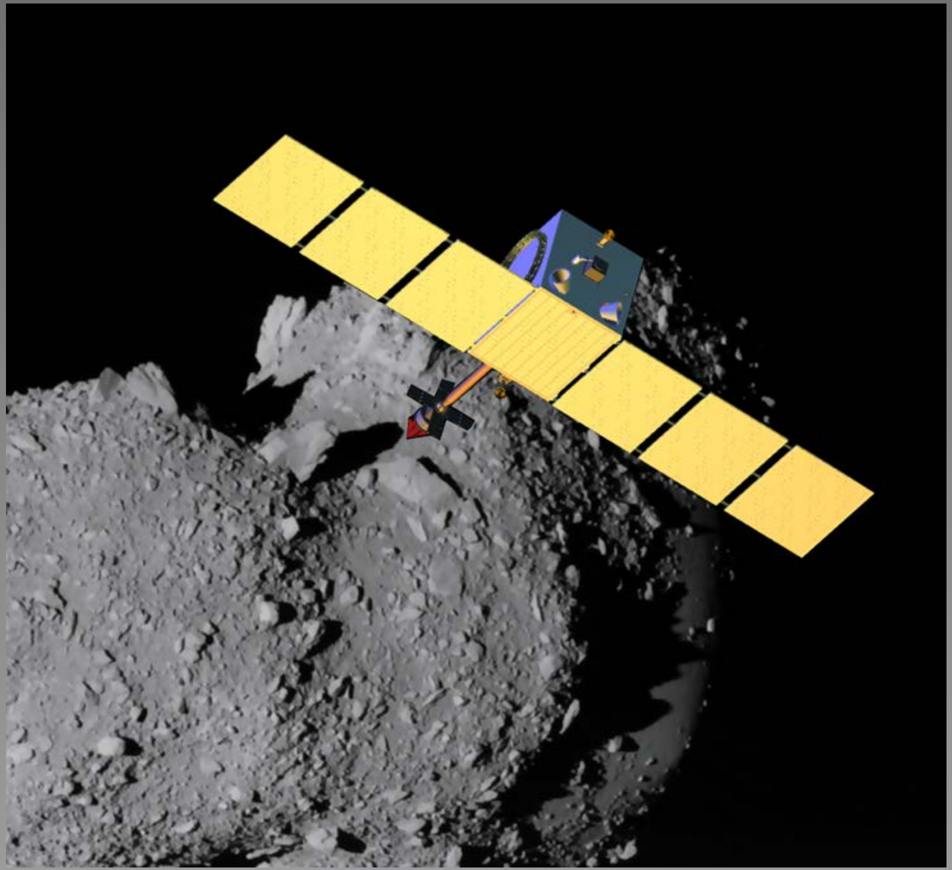




Roccor extendable tubular boom

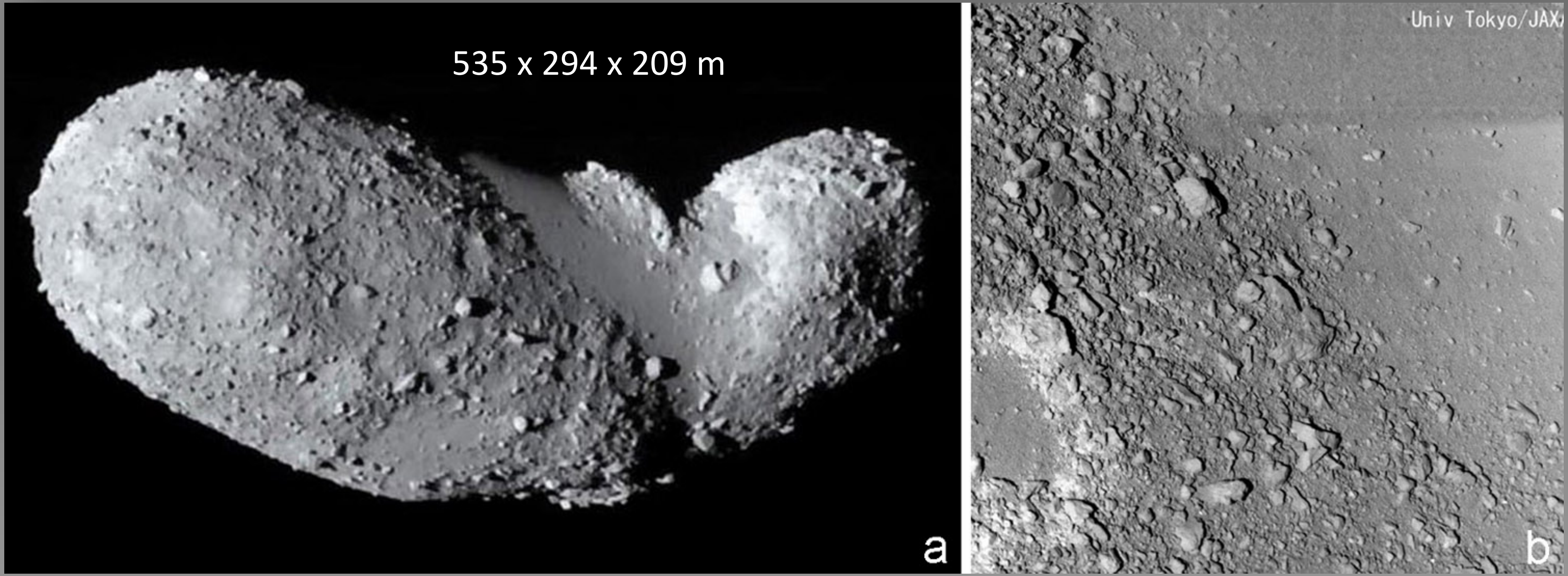
Seismometer Deployment





Descend to the surface, insert the seismometer, release, depart.
Allows for verification of deployment and failure recovery (back off and try again).
Similar to NEAR, Hayabusa, OSIRIS-REx trajectories.

Assumption: Apophis ≈ Itokawa



Thermal and radar properties consistent with collection of fine and coarse particles – regolith.

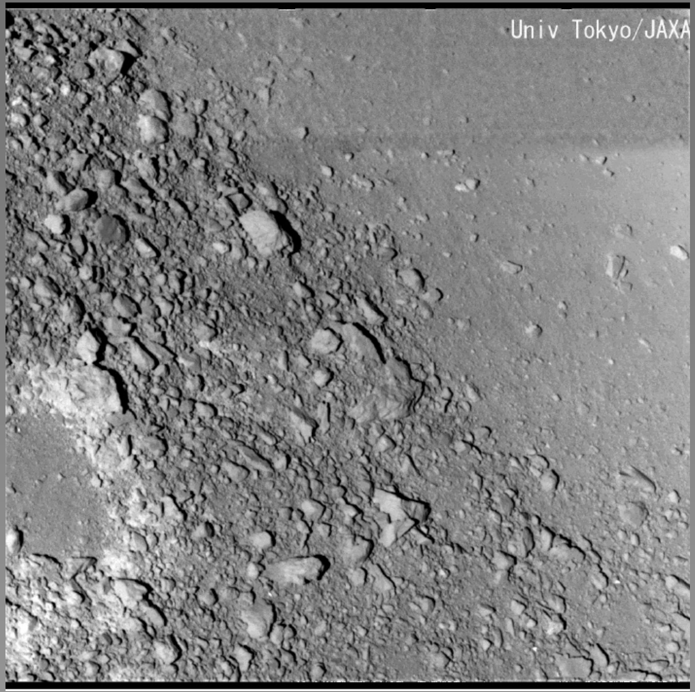
Thermal inertia of ~ 600 J m^{-2} $s^{-0.5}$ K^{-1}.

Radar SC/OC for Apophis is 0.33 ± 0.11

0.27 ± 0.04 for Itokawa

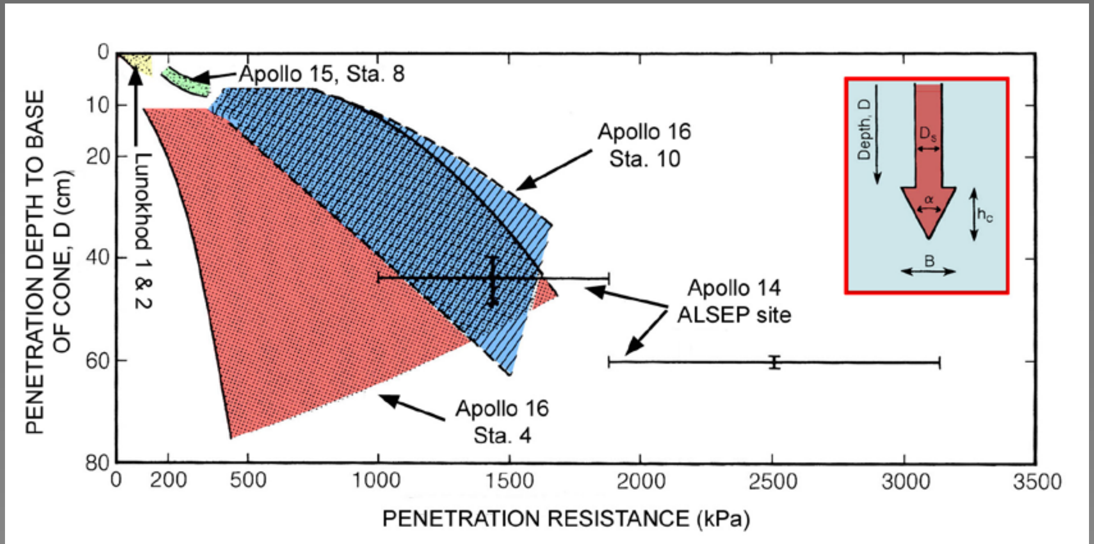
Surface Package Anchoring

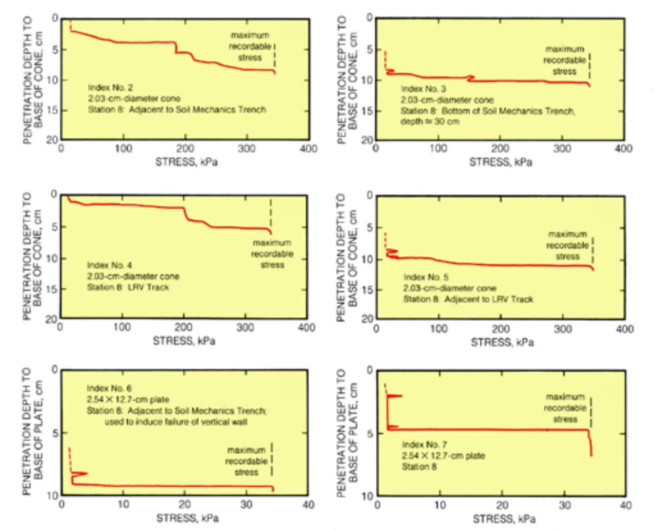
Itokawa



Assume fine-grained regolith occurs.
Thermal inertia suggests fine-grained material present.
Thickness unknown

Penetration Resistance Data

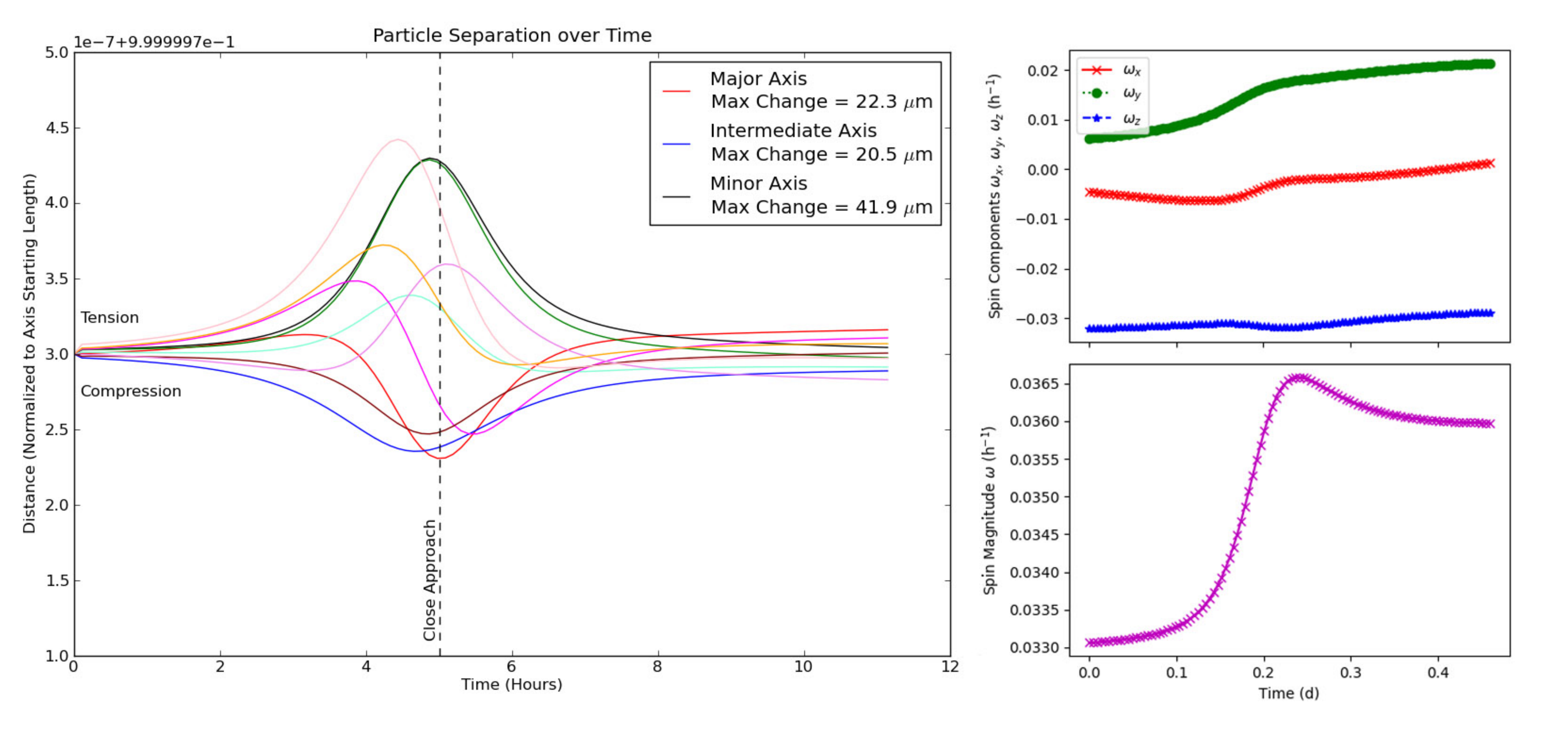




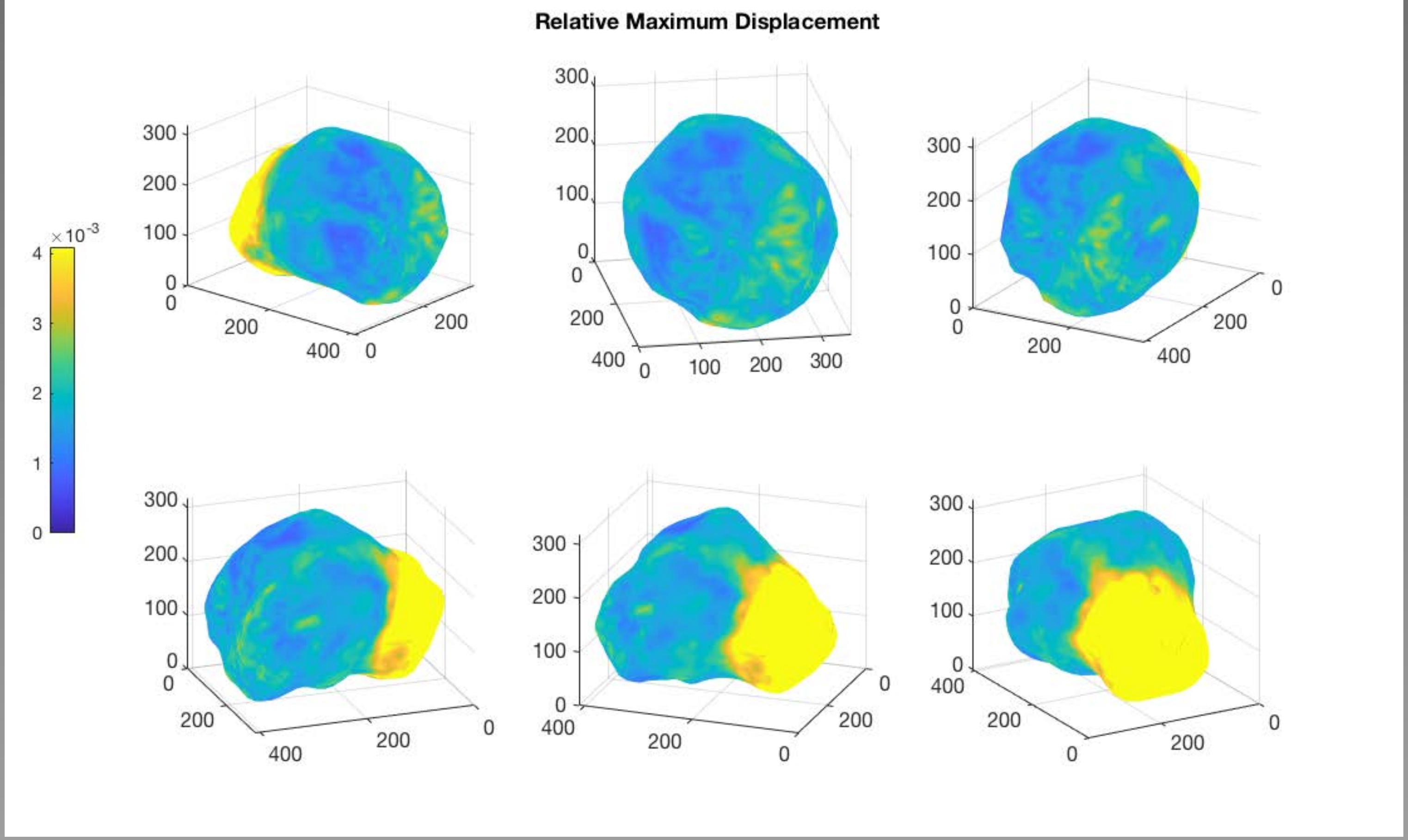
Apollo 15 Cone Penetrometer Data - mare

APL

Deformation



Seismology

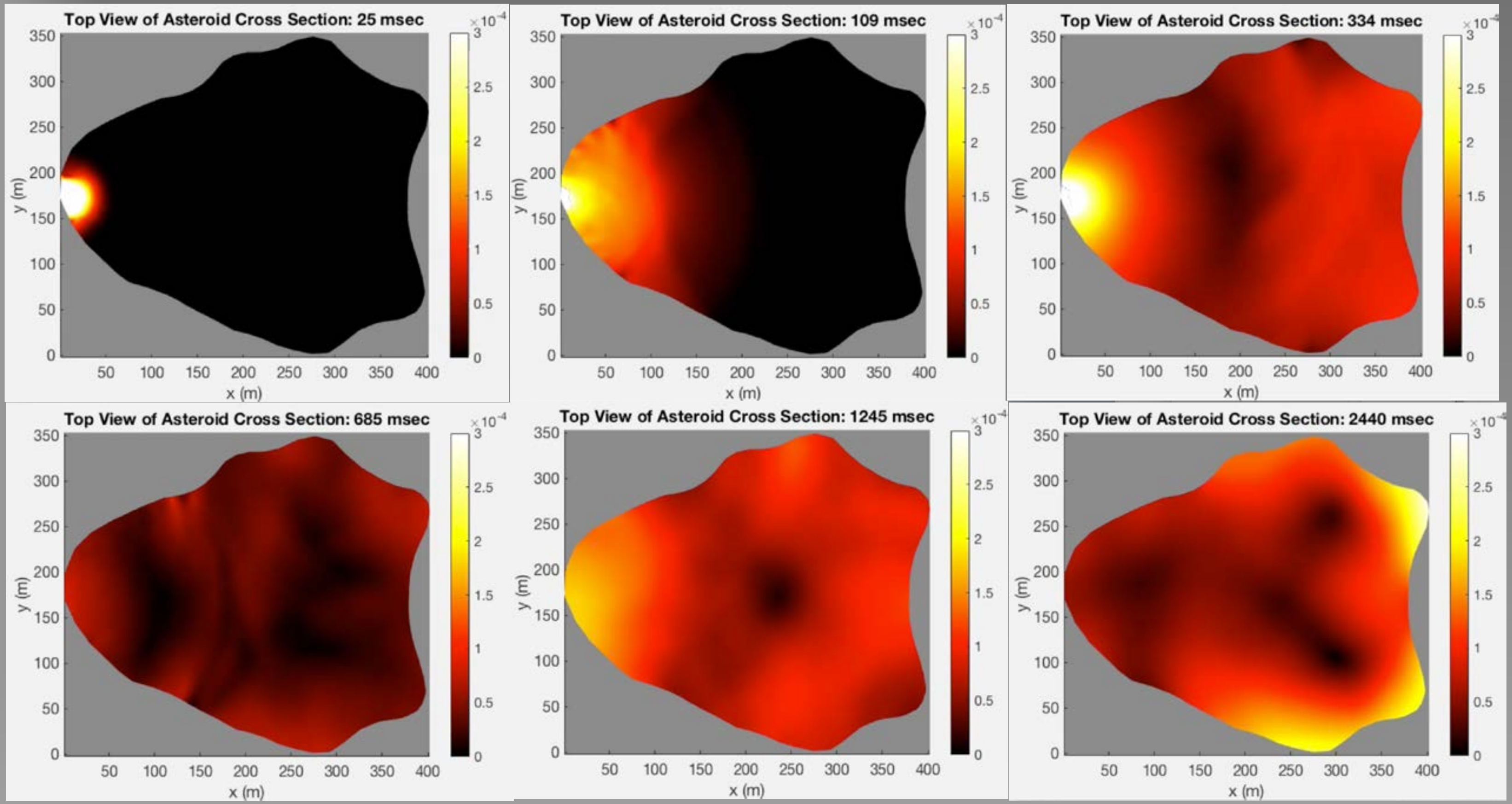


Peak ground motion (displacement) for a source situated at the surface of Apophis [0,150,150]. The source is located at the tip of the model in the lower right.

Seismic events:
- Interior stress relief
- Thermal cracking
- Impact
- Tidal deformation

Similar studies:
- Blanchette-Guertin et al., 2015
- Garcia et al., 2015
- Kharvroshkin and Tsyplakov, 2010
- Walker et al., 2009

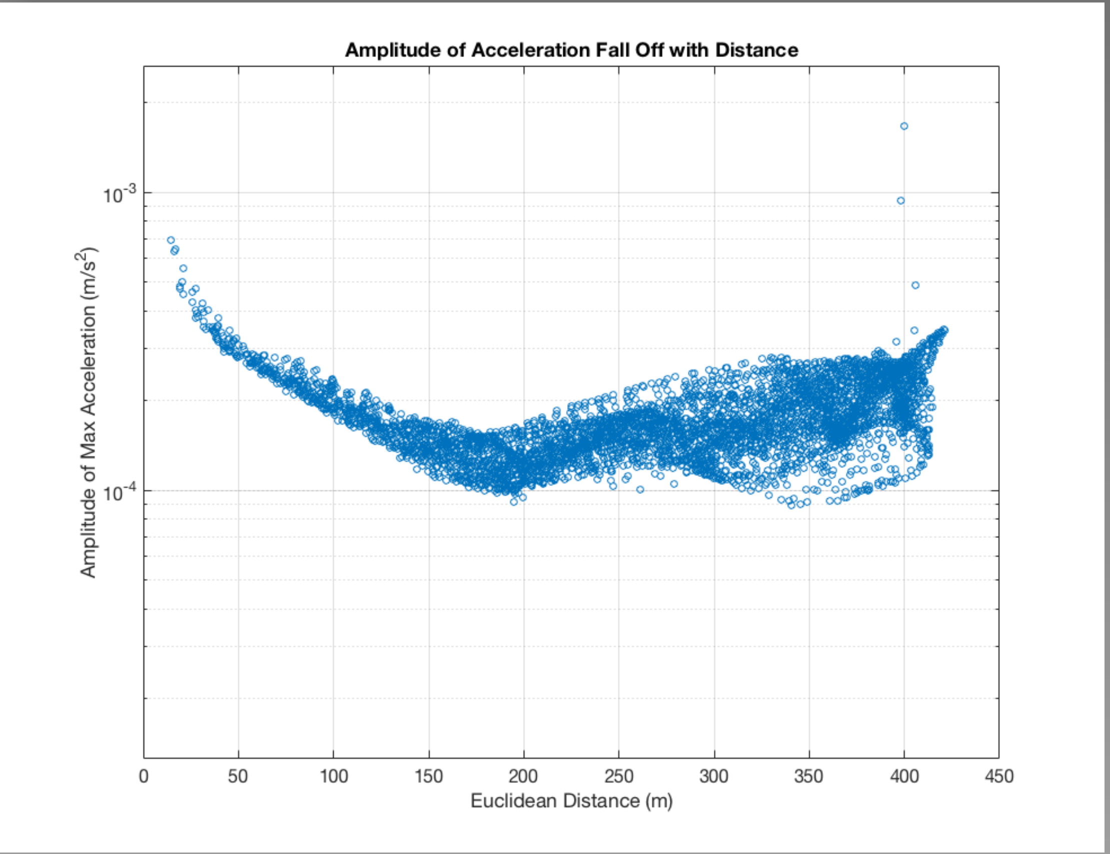
Seismology



Our 3-D simulation of seismic waves propagating within asteroid Apophis for a 5 N source at the surface. Each panel a snapshot of the evolution within the asteroid for ground motion in m/s^2. Note the strong antipodal focusing at the "peaks" in the asteroid cross-section.

Seismology

Seismology



Peak amplitudes of ground motion that would be recorded by a seismometer at Apophis for a 5 Newton, 1-second duration impact force at the surface.

Ground motion near the source (peak at 2 m/s^2) and antipode (peak at 3.5 m/s^2) are not shown.

Data points represent maximum amplitude of acceleration observed in Apophis for this force.

Issues – Good and Bad

- Mass Constraints – 228 kg wet
- No obvious technology changes to reduce mass

- Close to the Earth – 1 AU
  - Communications and power are not a problem

- Seismometer housing and deployment
- Lifetime of BHT-600
- Radial line slot array antenna

Summary - APEX

- Important science, unique opportunity – tidal interactions with a large planet
- Challenging mission within PSDS constraints
- CONOPS at a small no-g body – Autonomous operations
  - Rendezvous
  - Touch the surface
- Emplacement of seismometer (tiny self-contained "spacecraft") – ensure coupling
- Data downlink – high data volume from seismometer (40 Gb / Apophis day)
- Close to the Earth, close to the Sun

- *Acknowledgements*:
  - NASA Planetary Science Deep Space SmallSat Studies Program
  - NASA Innovative Advanced Concepts Program

APL