APEX
Asteroid Probe Experiment

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Small Satellite Conference

Technical Session VI: Science Mission Payloads 1

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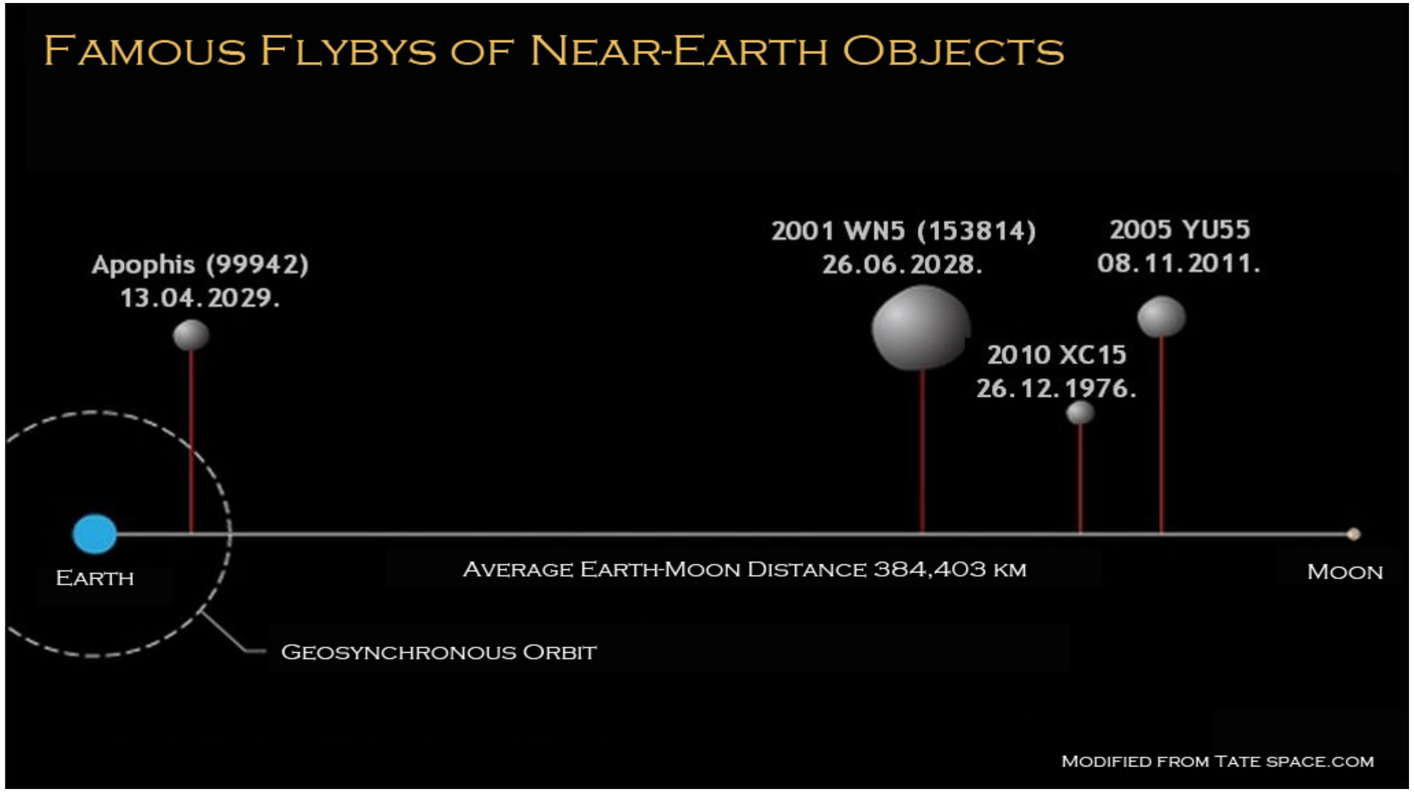
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

APL

Outline

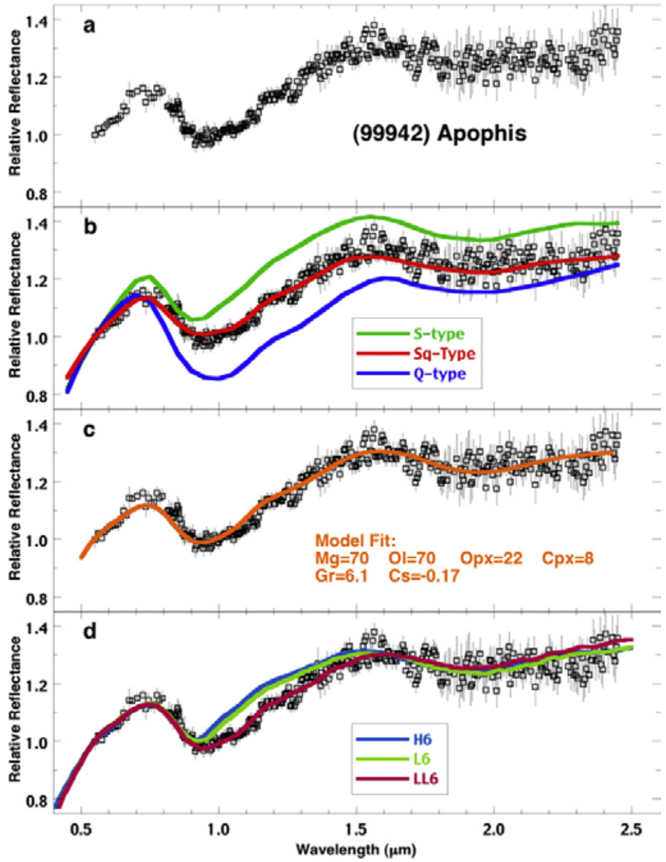
- Apophis
- Science Requirements
- Mission Requirements / Challenges
- Conops
- Spacecraft
- Summary

Apophis Encounter – Friday the 13th April 2029



Utah Sate University, Logan, UT

Apophis



65-75% olivine (70%)
17-27% orthopyroxene (22%)
3-13 % clinopyroxene (8%)

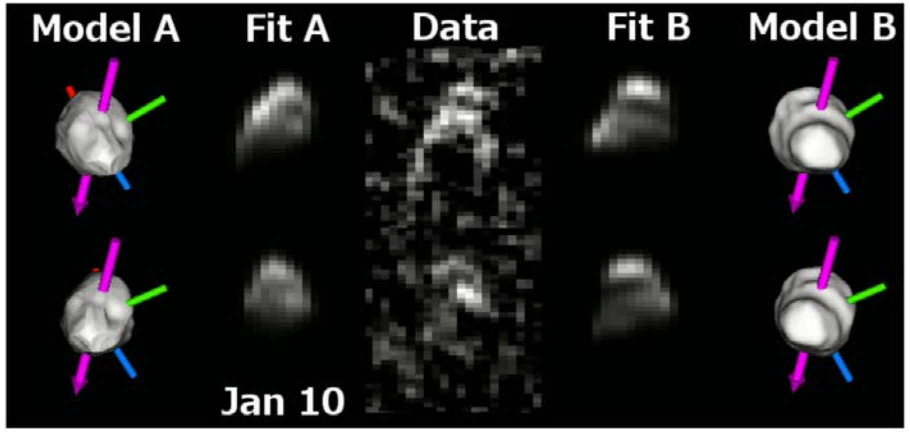
Sq type asteroid

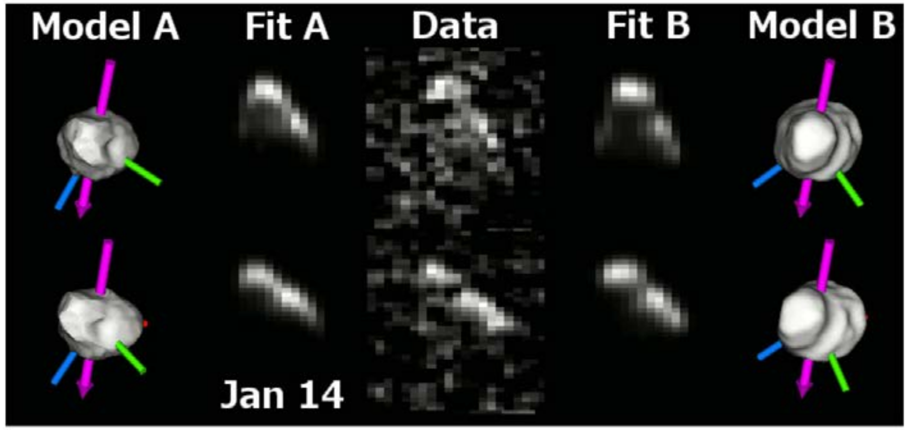
Uncommon spectrally immature inner belt asteroid with olivine and pyroxene bands
Surface possibly refreshed and rotational period and axis altered by close passage to Earth

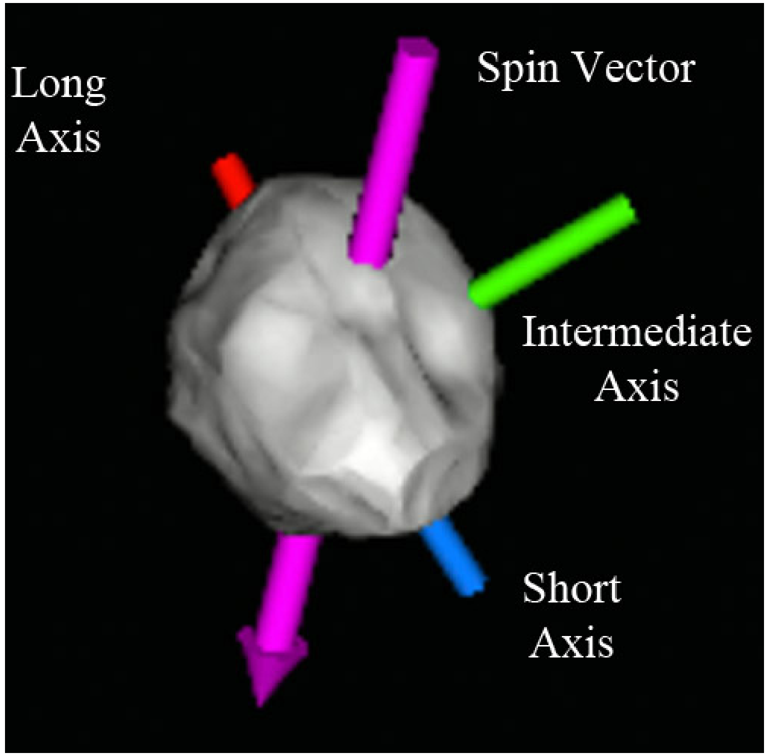
Properties

Dimensions:	410 x 350 x 317 m
Equivalent Diameter:	340 m
Surface Area:	0.39 km^2
Volume:	0.02 km^3
Rotation:	30.4 hr (retrograde) tumbling
Precession:	262.7 days
Gravity:	0.00027 m s^{-2}
Orbital period:	324 days
Eccentricity:	0.19
Inclination:	3.33

Apophis Shape - Radar

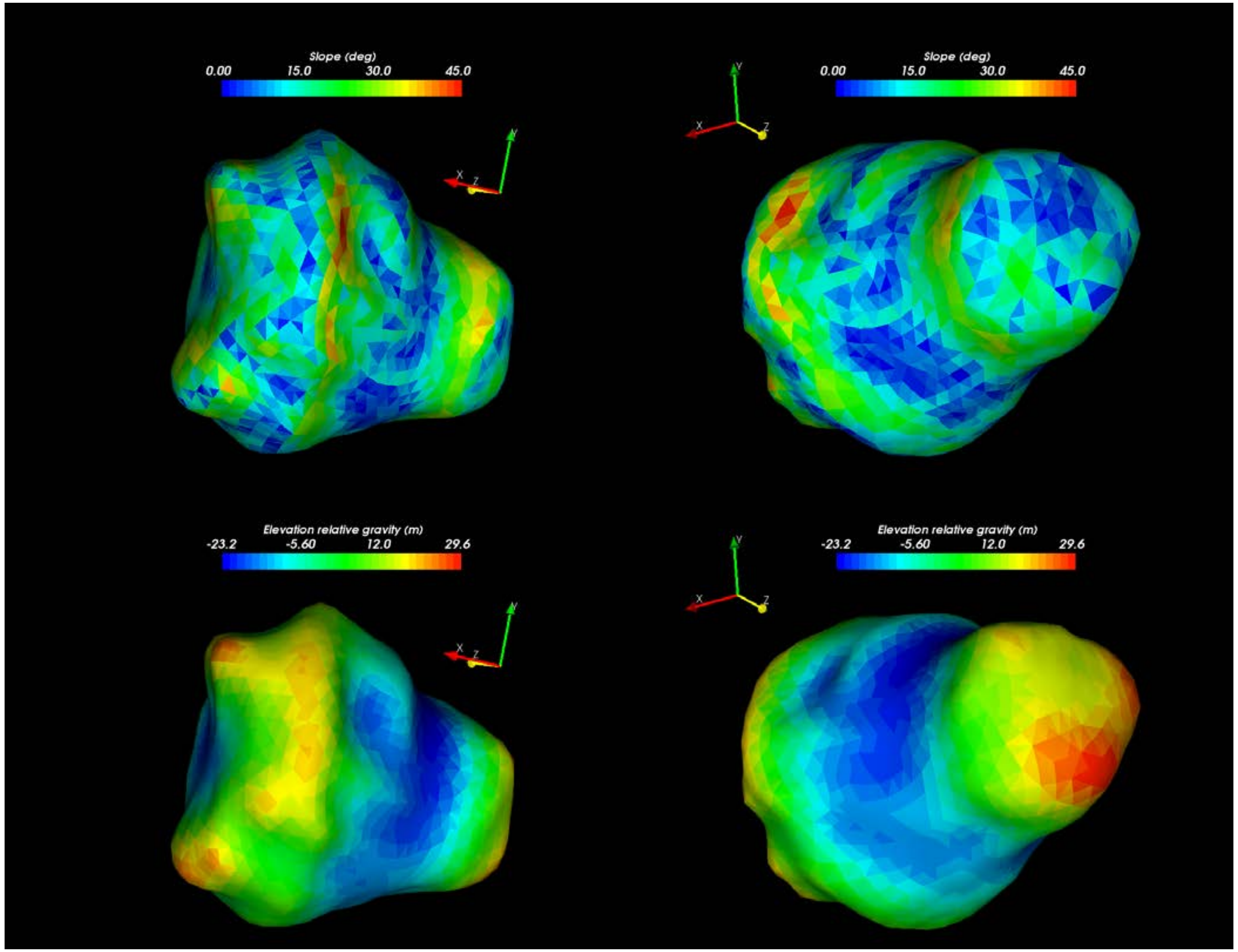






Non-Principal Axis Rotation
Period: 30.56 hr
Oscillation Long Axis: 262.7 Days
Brozović et al. 2017

Apophis Shape / Gravity

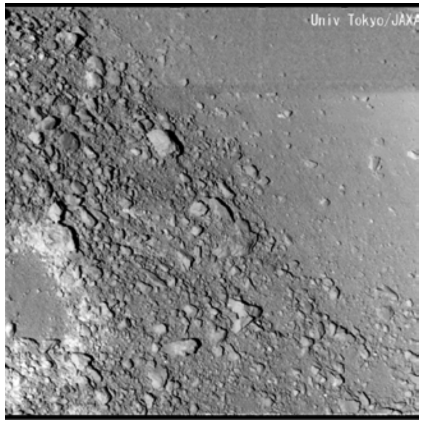


Assumes bulk density 2400 kg m^3

Expectations

Lutetia 121000 x 101000 x 75000 m

Itokawa: 535 x 294 x 209 m

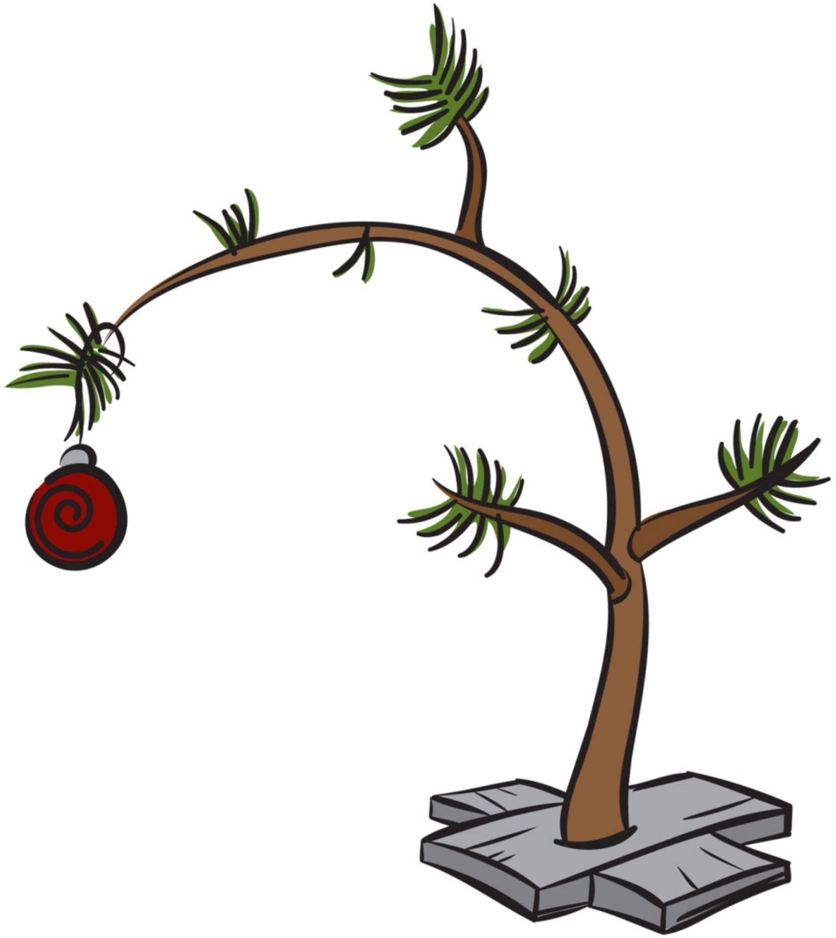


Steins: 6670 x 5810 x 4470 m

Eros: 34400 x 11200 x 11200 m

Science Requirements

Engineer / Program Manager Perspective



Scientist Perspective

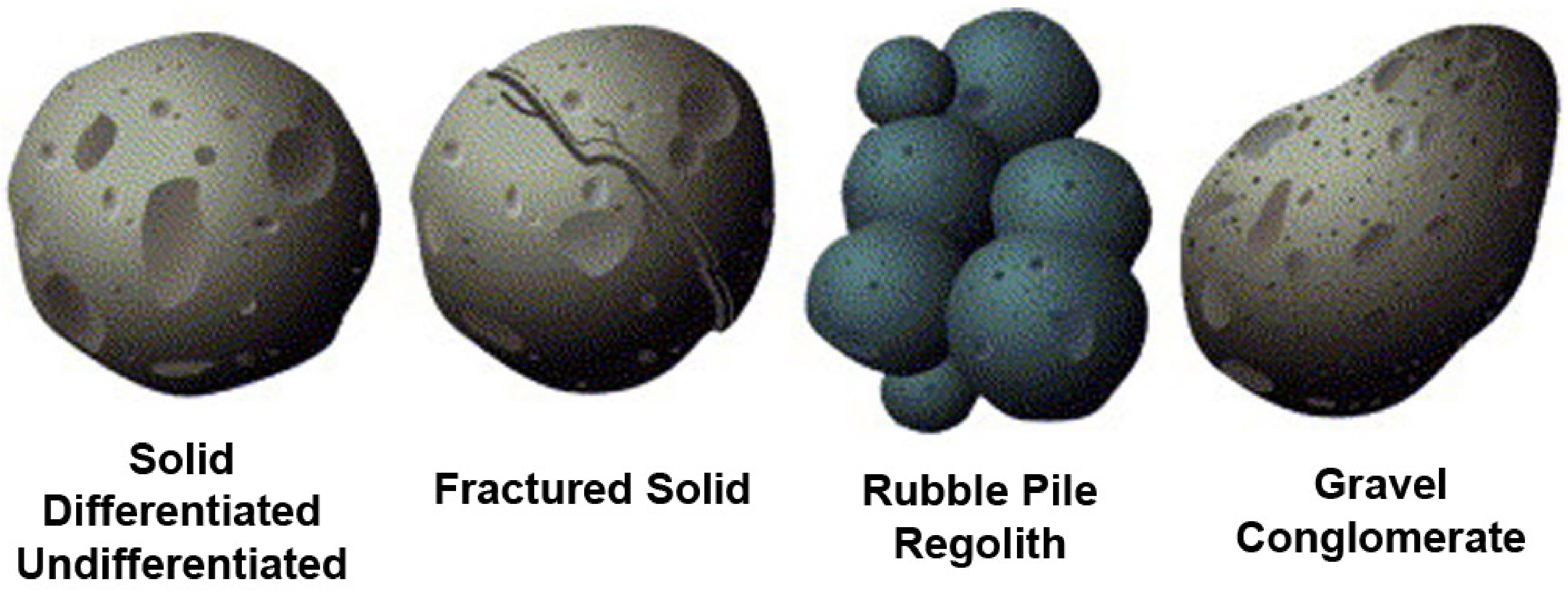
Science Requirements

Examine the tidal distortion effects of a close encounter with the Earth in April 2029 to understand the structure – implications for history and planetary protection.

- Determine the rotational dynamics
- Establish the physical dimensions
- Determine the shape / topography
- Determine the interior structure
- Define the surface morphology
- Define the mass

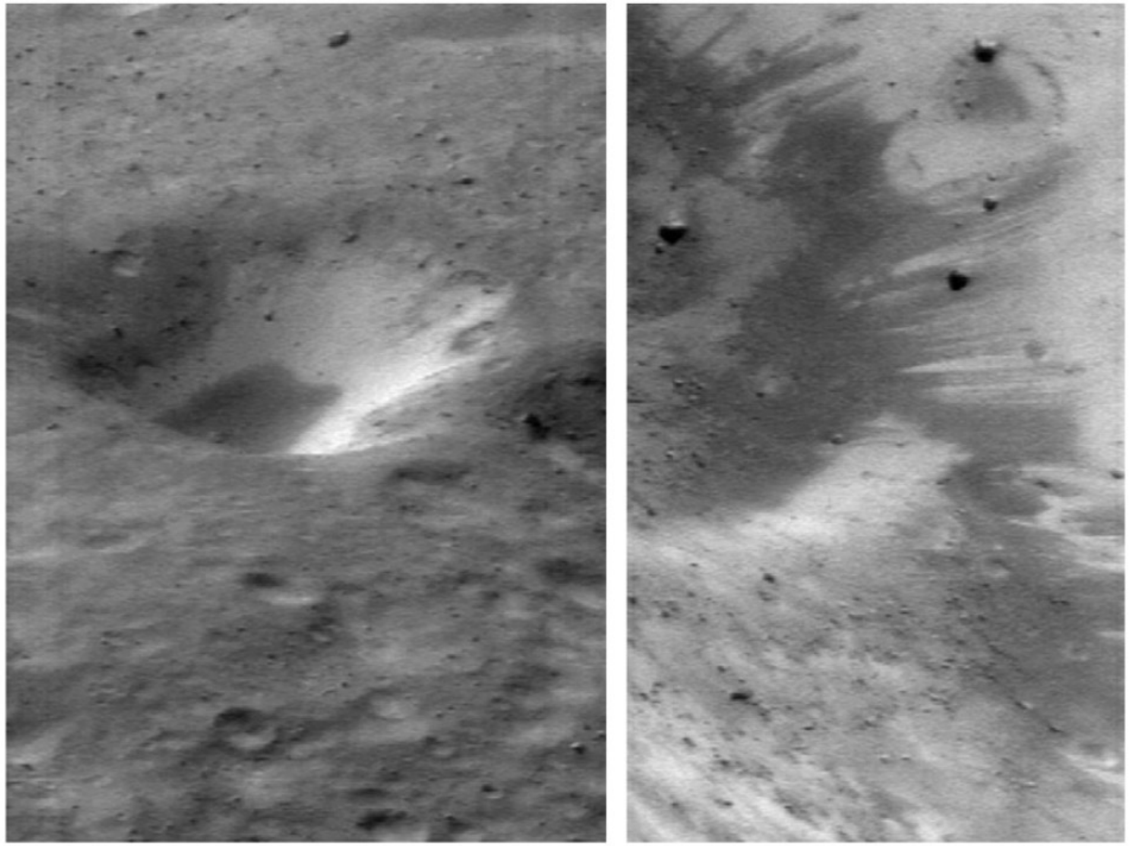
- Orbital change: semi-major axis 0.92 to 1.1 AU Aten to Apollo Family

Internal Structure

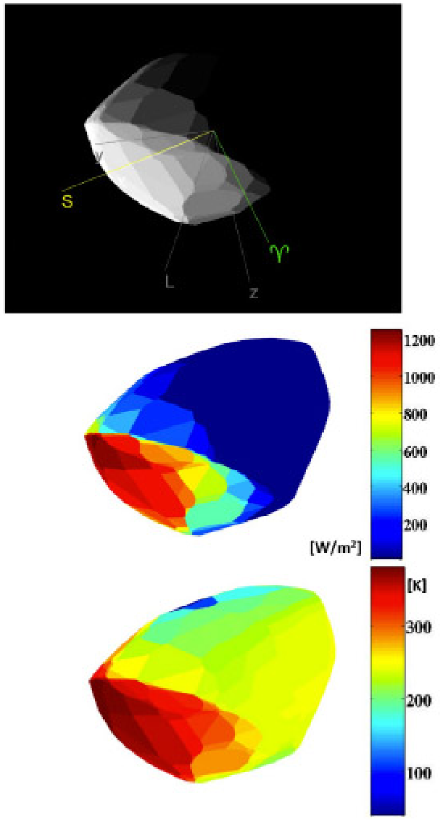


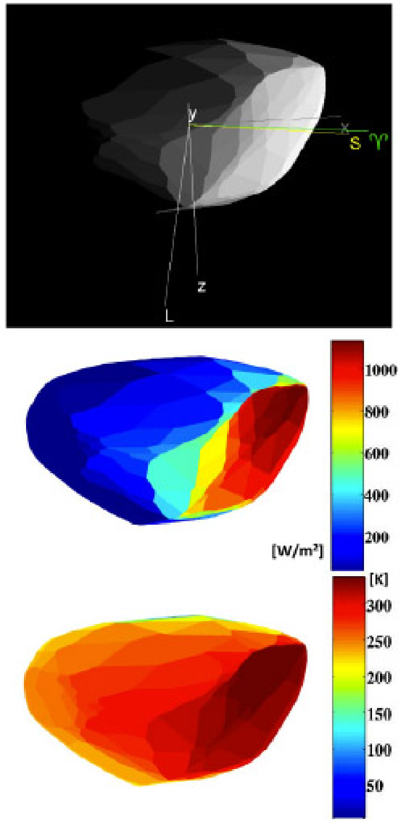
Walker et al (2006)

Surface Character and Modification



NEAR MSI 0154622520 / 0154409710





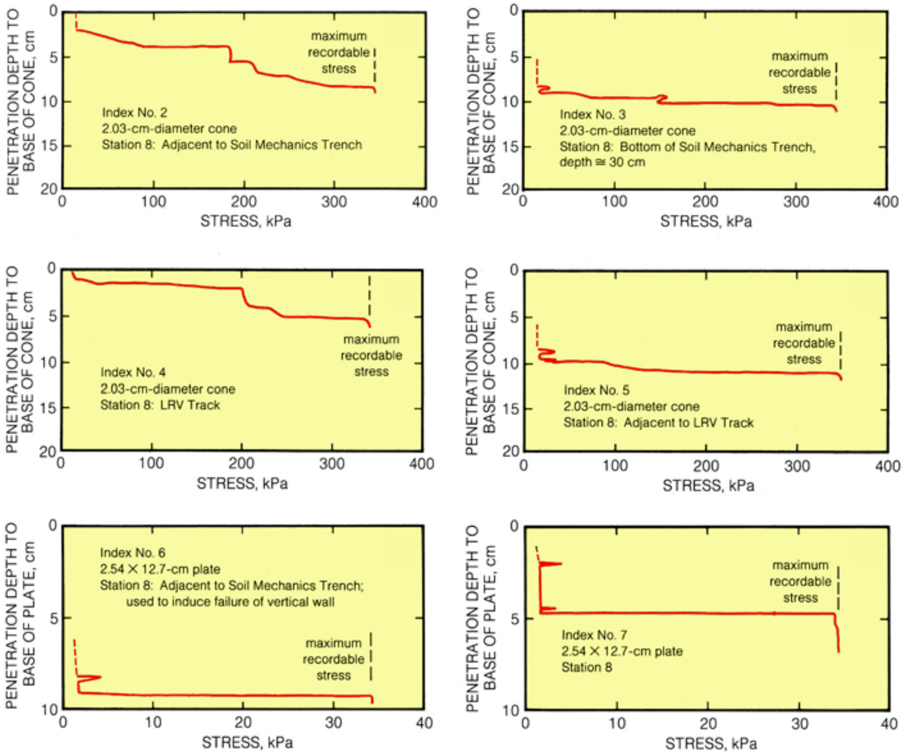
Mission Requirements / Challenges

- Rendezvous with Apophis sufficiently before Earth-encounter to map the surface and emplace a seismometer on the surface.
- Image the entire surface, in stereo, such that a DTM can be produced and the rotational dynamics established.
- Deploy seismometer on the surface to detect seismic signals induced by thermal, rotational and tidal deformation forces. Monitor baseline seismic signal and encounter signal.
- Baseline payload:
    - panchromatic imager
    - seismometer
- Additional possibilities:
    - multiband imager
    - thermal imager
    - gamma ray spectrometer

Mission Requirements / Challenges

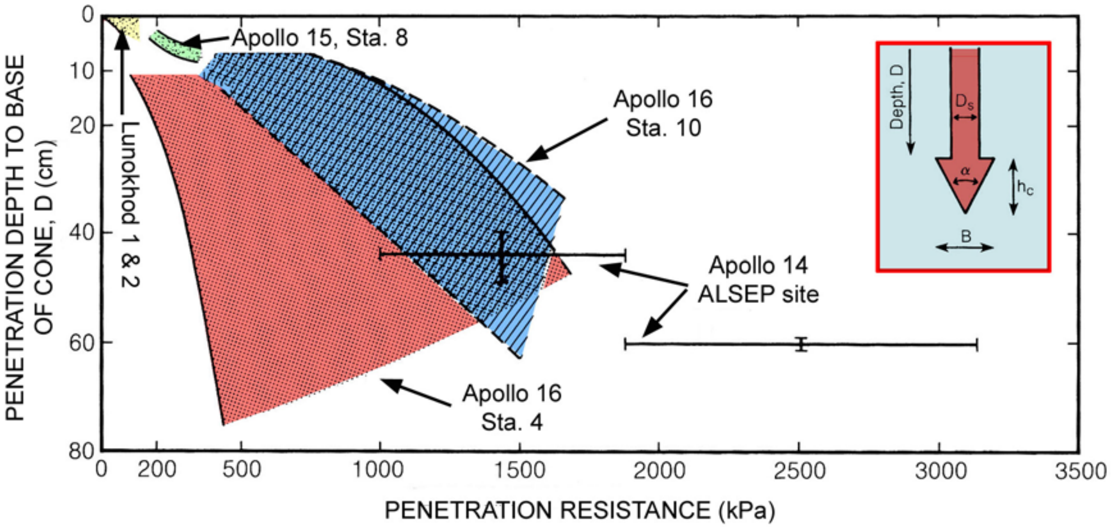
- Rendezvous and station-keep / orbit with a small body ~375 m diameter, at 1 AU, at close range (1 km). Solar forces > gravity
- CONOPS
  - “Orbit” Apophis to map the surface
  - Deploy a seismometer on the surface, ensure instrument is coupled to the surface. Touch the surface.
  - Autonomous operations
  - PROXOPS – terrain recognition
- Deployment mechanism
  - Space qualified stick - Use spacecraft to anchor the surface package
  - Launched penetrator
- Seismometer must be an independent instrument – power (solar cells and batteries), communications, electronics. Must survive for multiple months.
- Communications: Apophis to s/c, s/c to Earth
  - Data volume: Seismometer 40 Gb / Apophis day (30.4 hrs)
  - RF vs. Optical comm. for data
- PSDS spacecraft – <180 kg, low solar cell area – low power, small structure – small antenna
  - ESPA ring mount

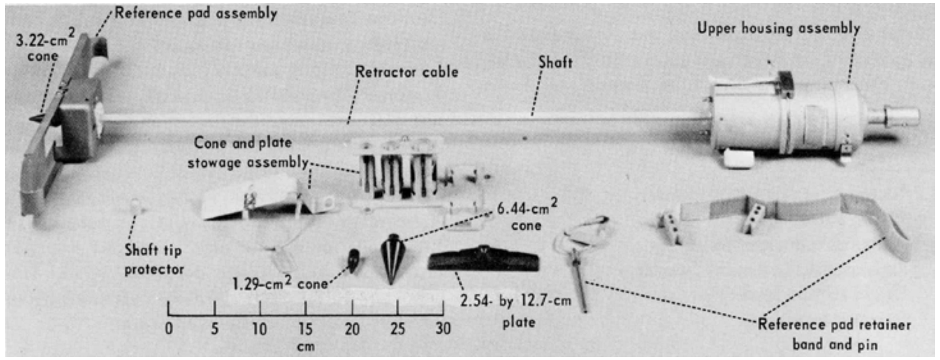
Surface Package Anchor



Apollo 15 Cone Penetrometer Data - mare

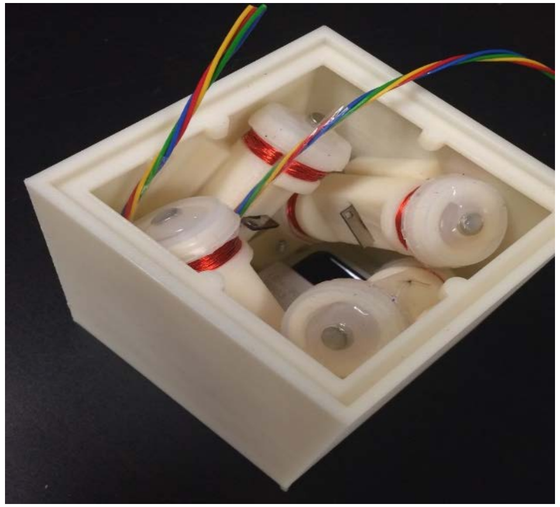
Penetration Resistance Data





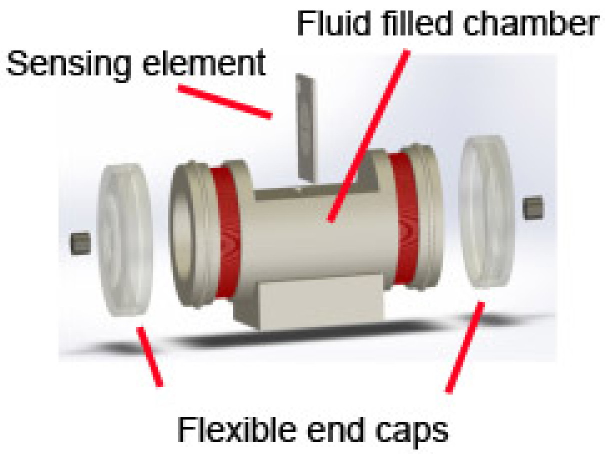
Seismometer

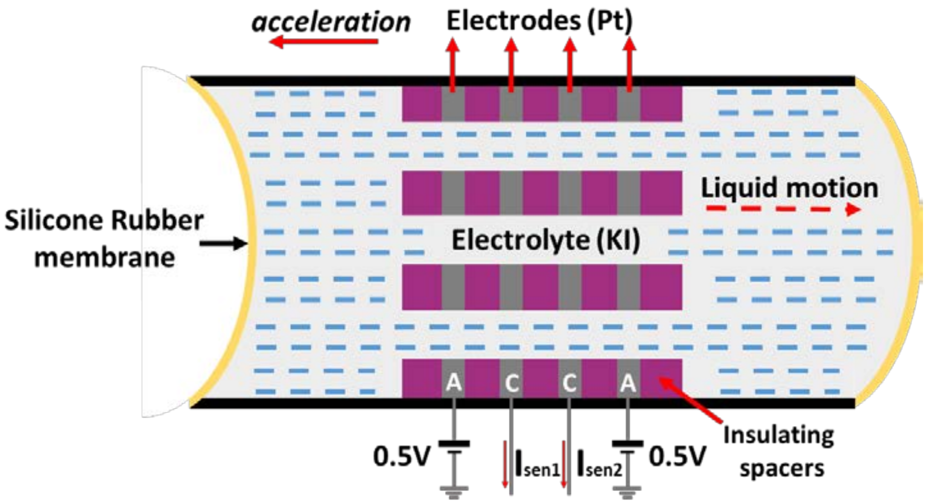
Molecular Electric Transducers work as a novel motion sensing mechanism by integrating mass-spring system and electro-chemical reaction.



Molecular electronic transducer

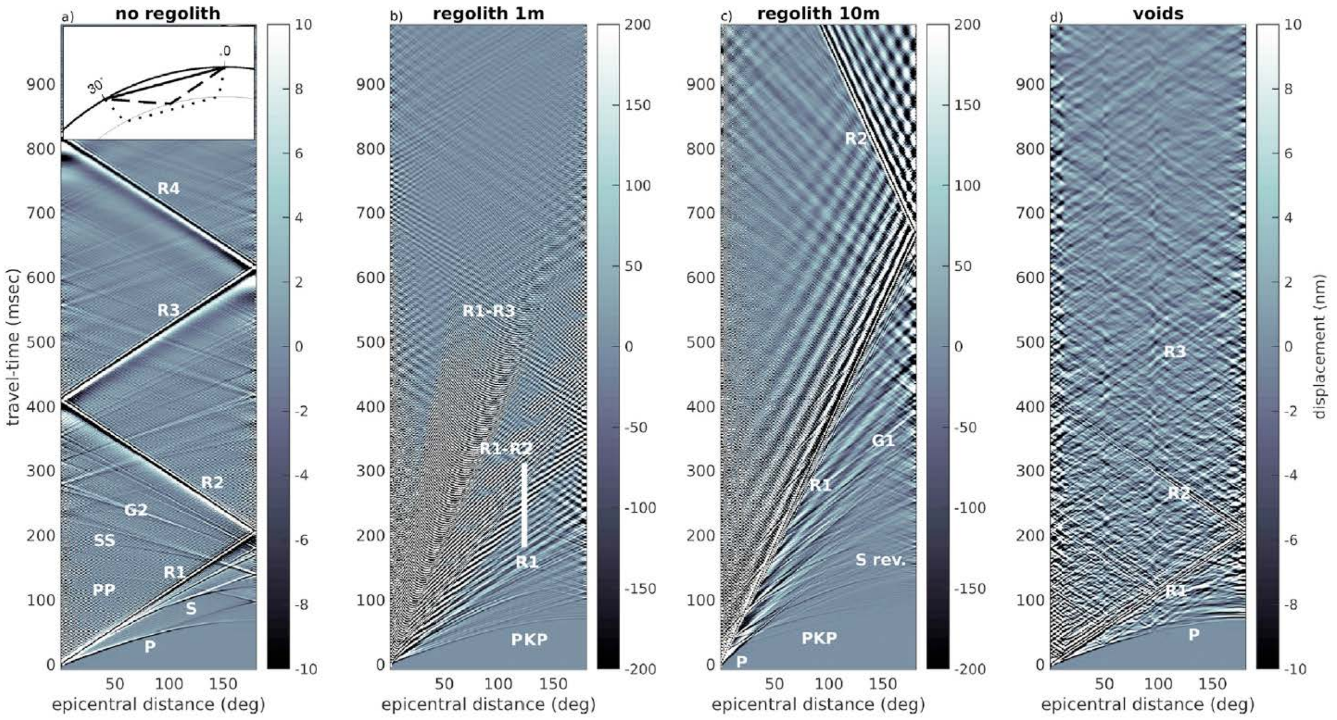
- 4 electrodes (Pt)
- Inter-electrode spacers
- Channels
- Iodine ion solution
- Flexible diaphragm



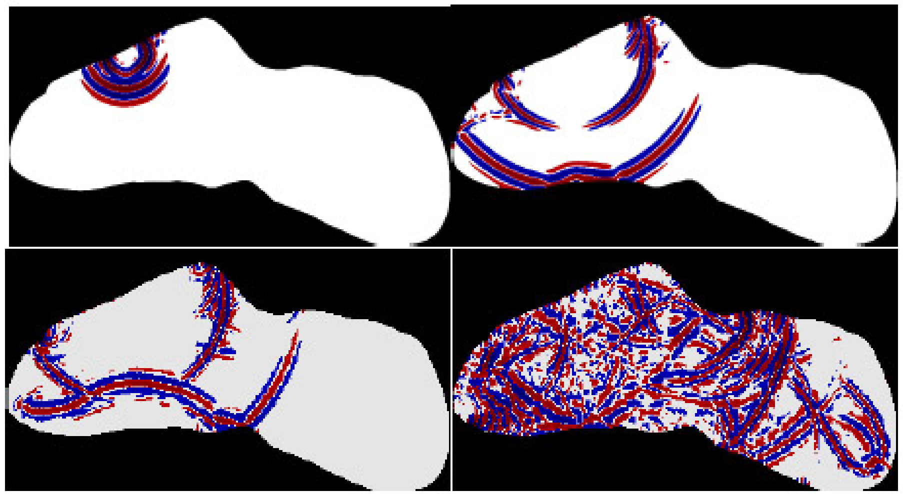


Arizona State University

Seismology

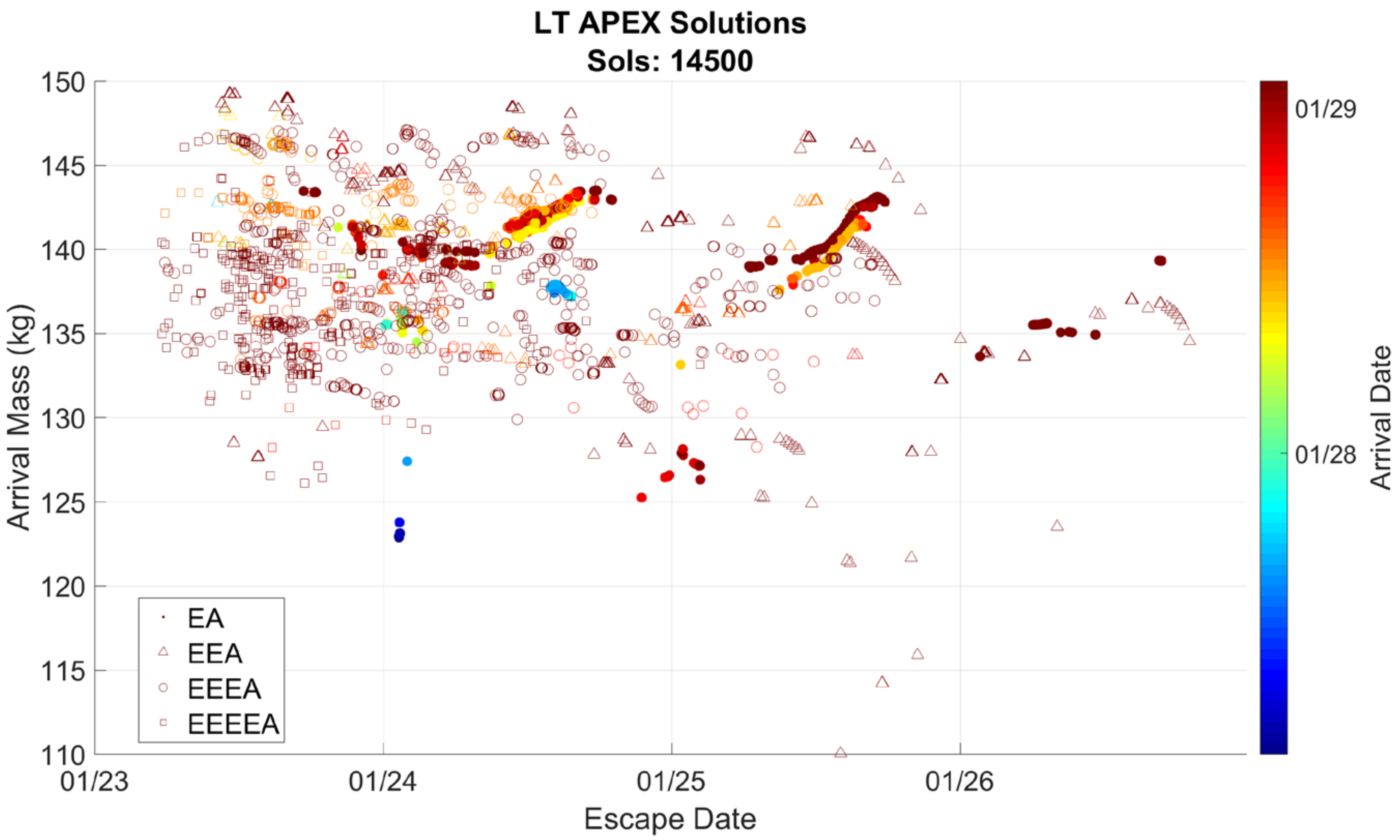


Murdoch et al. 2017



Martin et al. (2008) 60 sec propagation

Trajectory Analysis



APL

Trajectory Down-Select

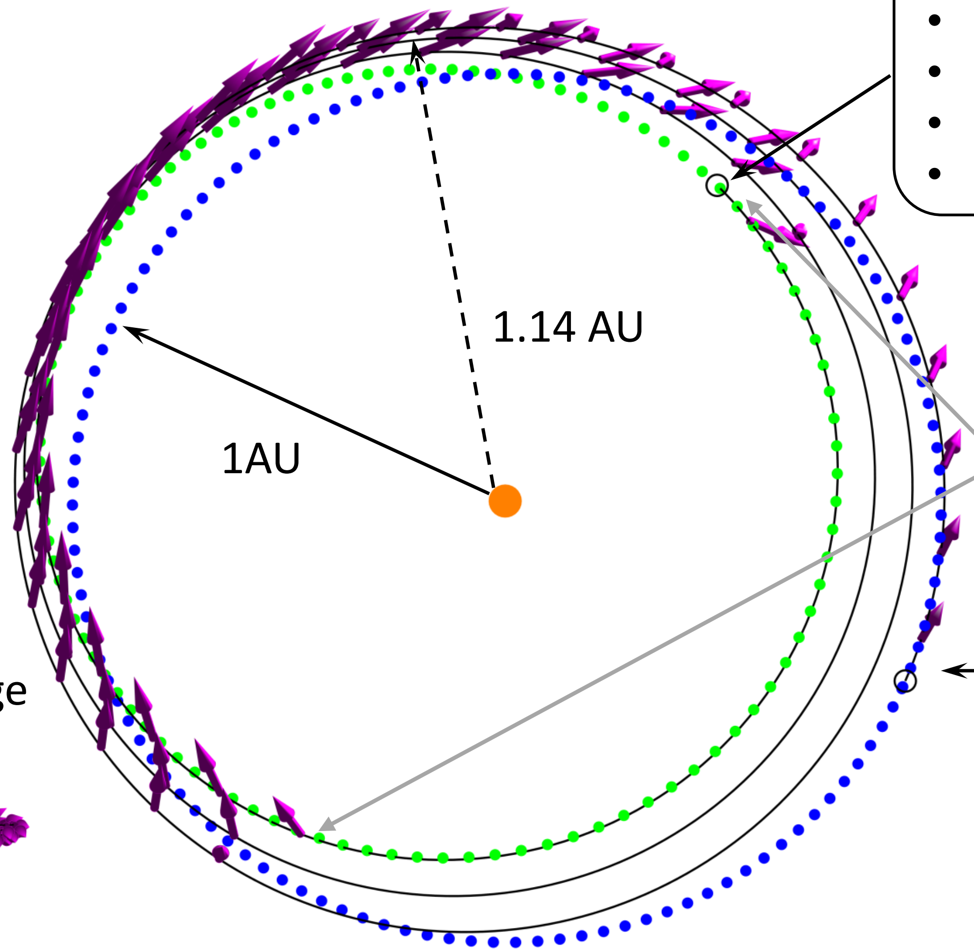
Solution	Sequence	Departure Date	Arrival Date	Time of Flight (years)	Final Mass (kg)
7105	[E]L[A]	9/3/2024	10/18/2028	4.1	143.3
8120	[E]L[A]	8/27/2025	10/23/2028	3.2	141.8
398	[E]LE[A]	6/10/2024	8/12/2028	4.2	146.8
1152	[E]LE[A]	8/26/2024	2/1/2029	4.4	148.0
670	[E]LE[A]	6/21/2025	2/1/2029	3.6	146.7
446	[E]LE[A]	7/4/2025	8/5/2028	3.1	142.9

Highlighted trajectories are mass optimal for mid-2025 launch with arrival dates several months prior to Earth close approach

Trajectory Solution 8120 [E]L[A]

Baseline for parameter engine studies

Apophis Orbit = Green
Earth's Orbit = Blue
S/C Orbit = Black
Thrust Vectors = Magenta

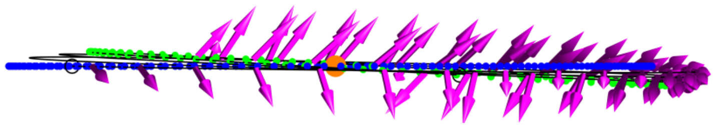


2. Apophis Rendezvous
- 10/26/2028
- TOF = 1,154.5 Days
- Mass = 141.5 kg
- V_∞ = 0.0 km/s

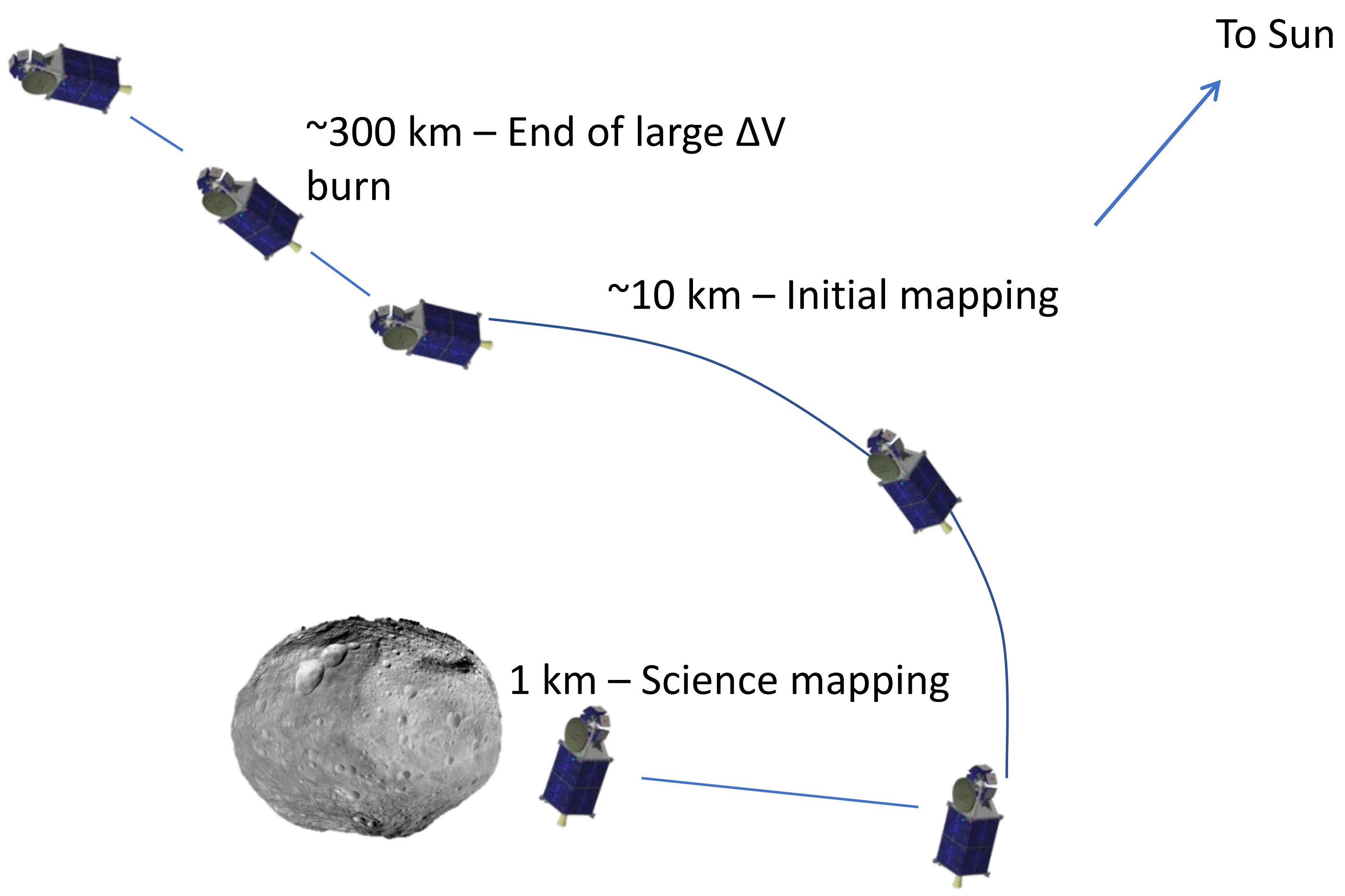
Arrival Date easily floats along this long coast duration

1. Earth Escape via LGA
- 8/29/2025
- TOF = 0.0 Days
- Mass = 180.0 kg
- C3 = 1.0 km^2/s^2

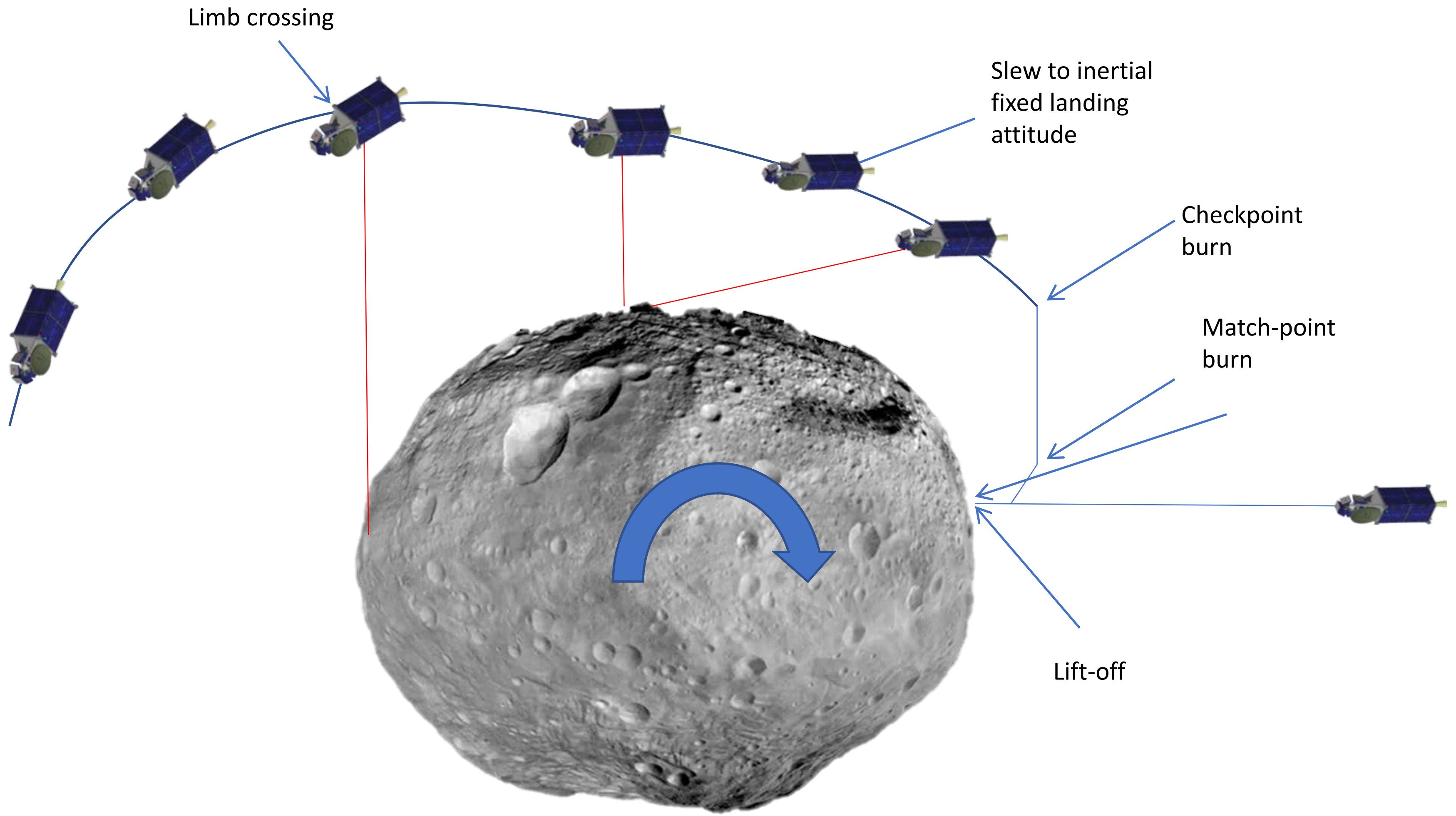
SEP system provides plane change



CONOPS - Approach and Rendezvous

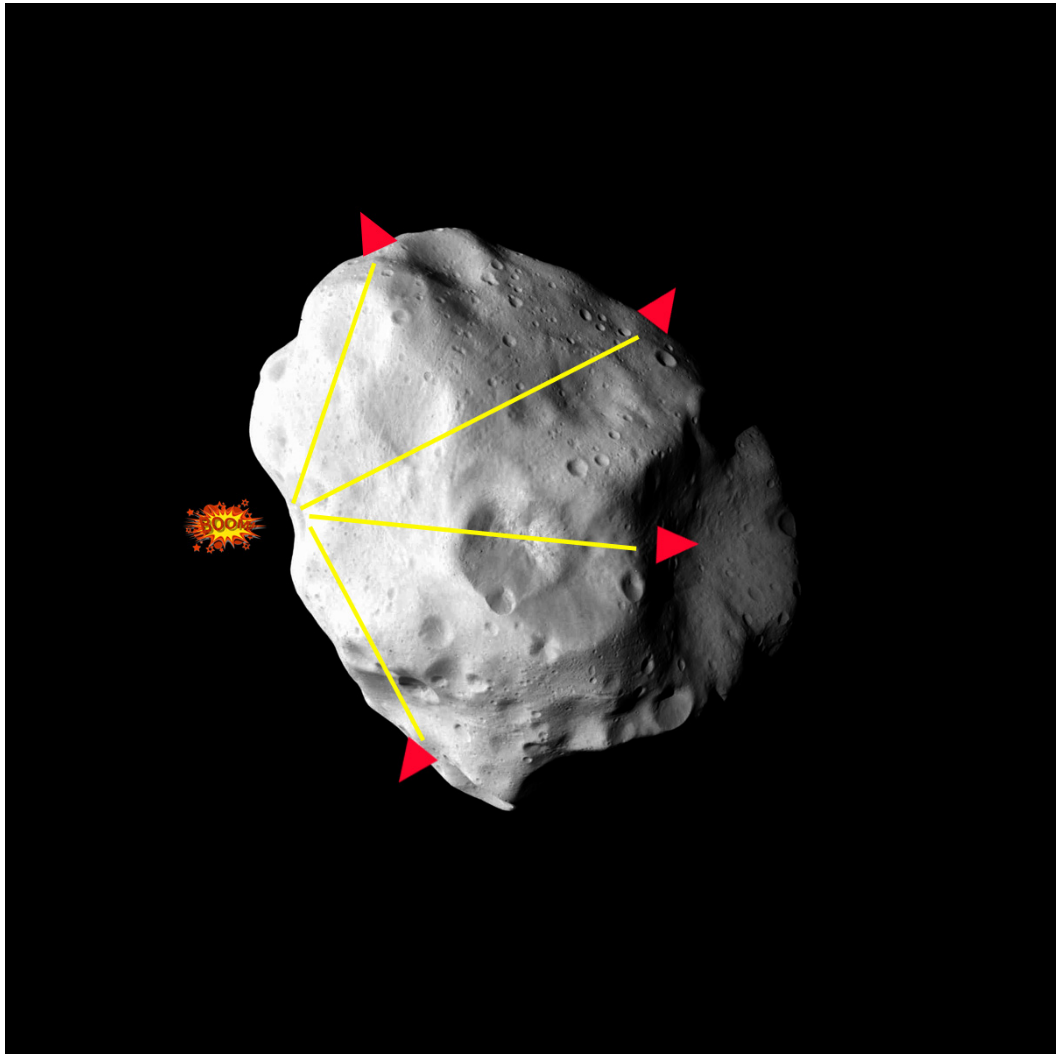


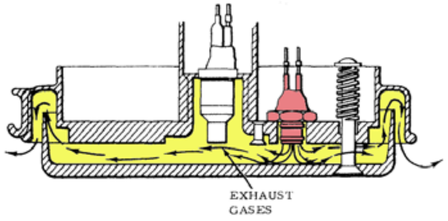
CONOPS - Surface Package Deployment

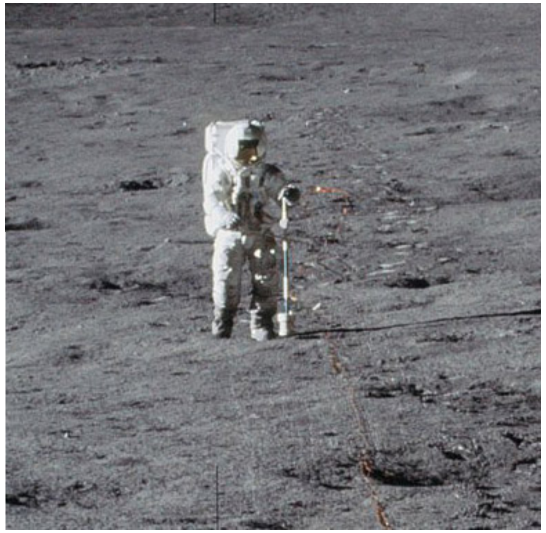


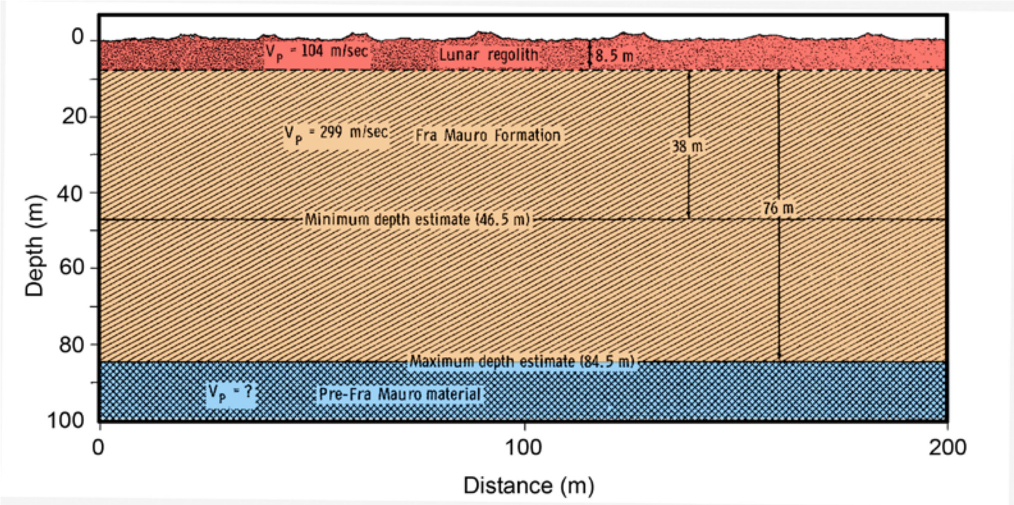
(OSIRIX-REX concept - Not to scale)

Active Seismic Experiment





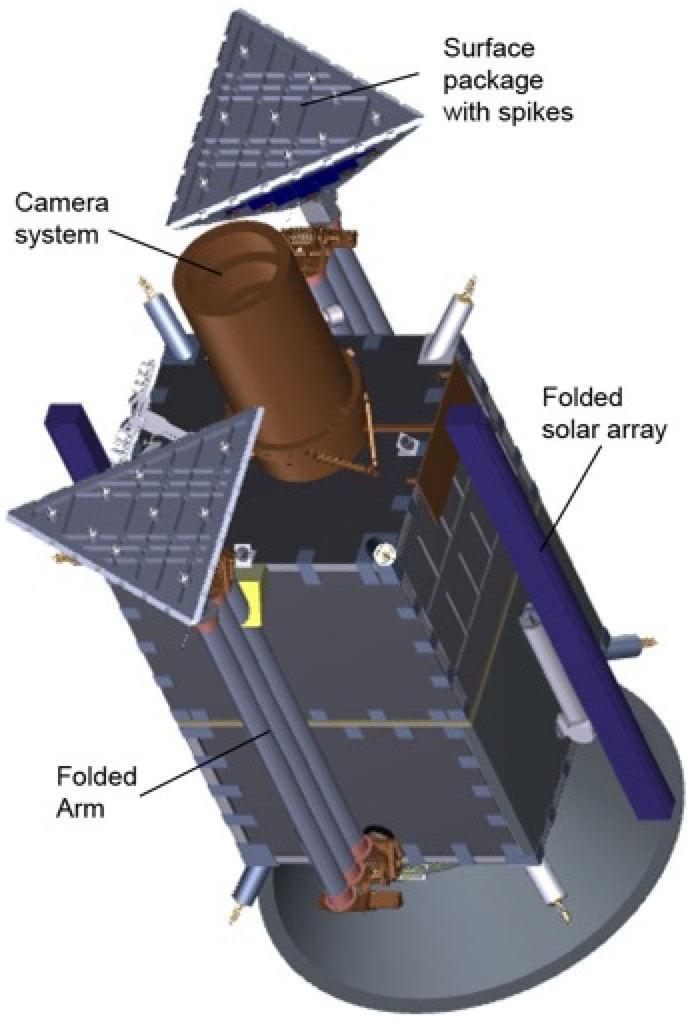


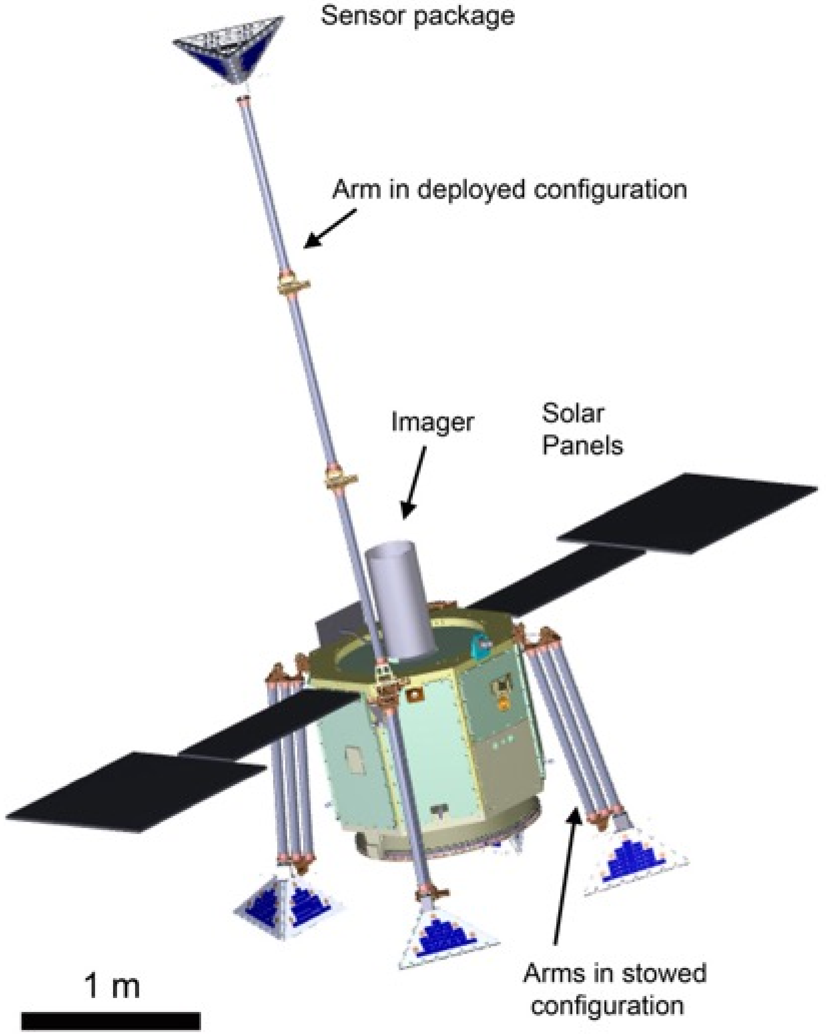


NIAC

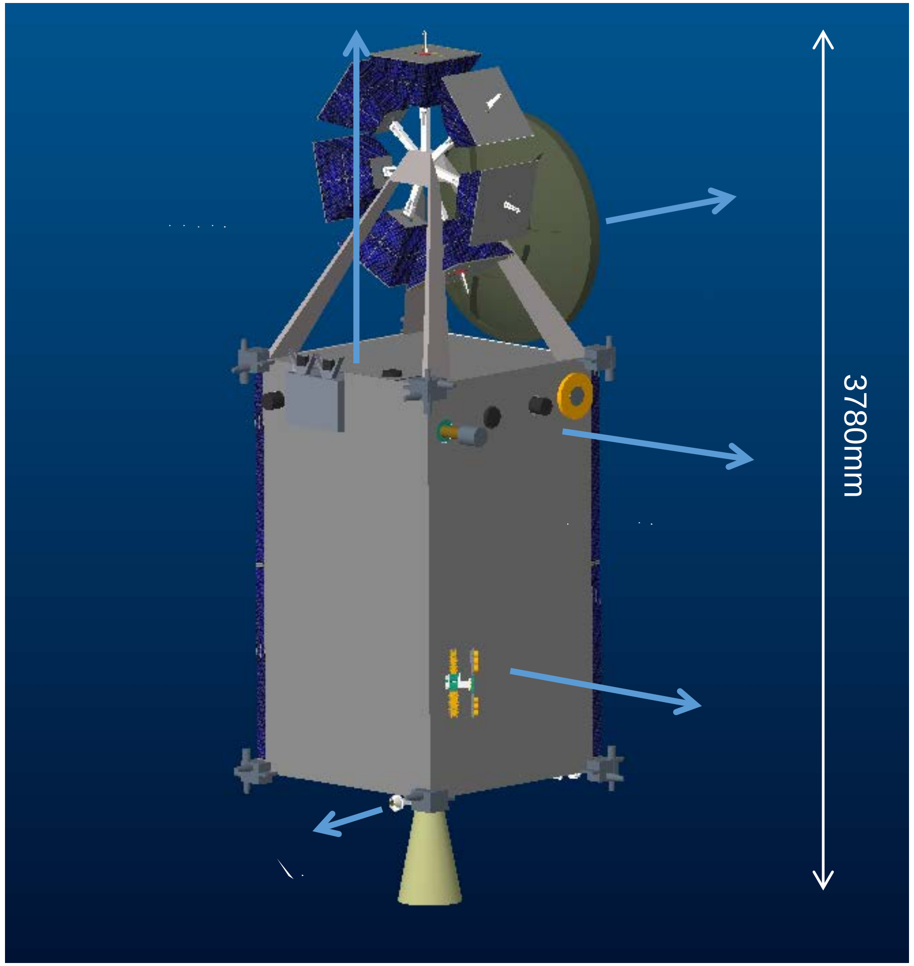
Table 1. Flight System Mass Summary			
Subsystem	**CBE (kg)**	**Cont. (%)**	**MERV (kg)**
Structures	52	10	57
Integrated Propulsion	16	3	17
Avionics	11	4	11
Electrical Power	27	7	29
Attitude Determination Control	12	7	12
Thermal Control	4	15	4
RF Communications	4	6	4
Harness	11	10	12
Spacecraft Bus	136	8	146
Instrument packages	42	15	49
Total Dry Mass	**174**	**10**	**195**
Usable Hydrazine Propellant*			109
Propellant Residual & Pressurant			5
Total Mass*			**309**
Launch Capability*			**358**

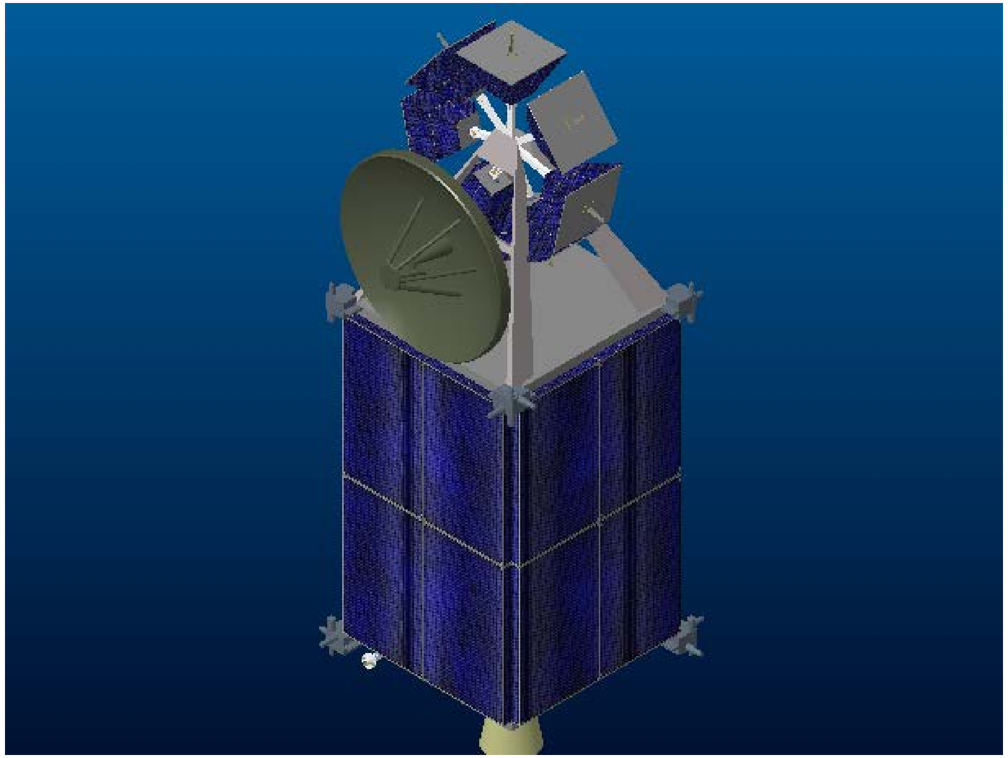
* These values are for target 1991VG.
Maximum expected resource value: MERV
Contingency = Maximum expected resource value - current estimate of resource value
% Contingency = [Contingency / (MERV-Contingency)] *100





Discovery



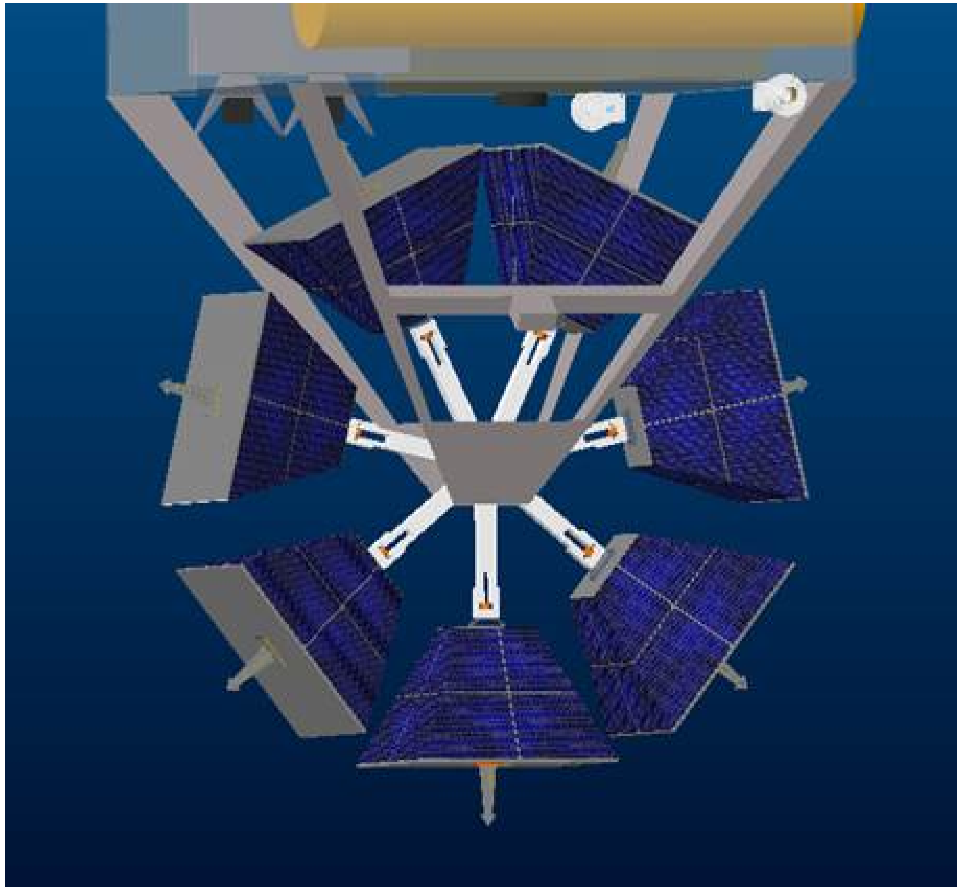


Discovery - MEL

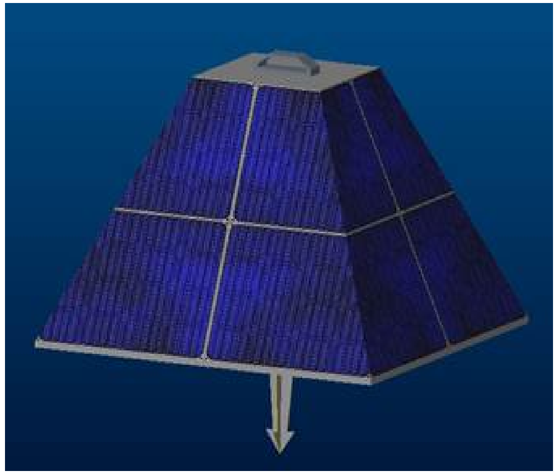
FATE Flight System Mass Summary			
Subsystem	**CBE (kg)**	**Cont.**	**MEV (kg)**
Structures	**281.3**	**11%**	**313.5**
Propulsion	**56.9**	**6%**	**60.5**
Avionics	**28.4**	**6%**	**30.2**
Electrical Power	**30.3**	**6%**	**32.1**
Attitude Determination and Control	**57.5**	**3%**	**59.2**
Thermal Control	**17.9**	**5%**	**18.8**
RF Communications	**58.8**	**9%**	**64.1**
Harness	**42.4**	**3%**	**43.6**
Spacecraft Bus Total	**573 kg**	**8%**	**622 kg**
Wide Angle Camera	**5.5**	**15%**	**6.3**
Narrow Angle Camera	**8.0**	**15%**	**9.2**
Seismometer	**39.6**	**4%**	**41.3**
Laser Altimeter	**21.4**	**15%**	**24.6**
Payload	**75 kg**	**9%**	**81 kg**
Total Dry Mass	**648 kg**	**9%**	**704 kg**
Maximum Possible Dry Mass (used to size propulsion)			**850 kg**
Consumables			**513 kg**
Apophis Observatory Total Wet Mass			**1360.0 kg**

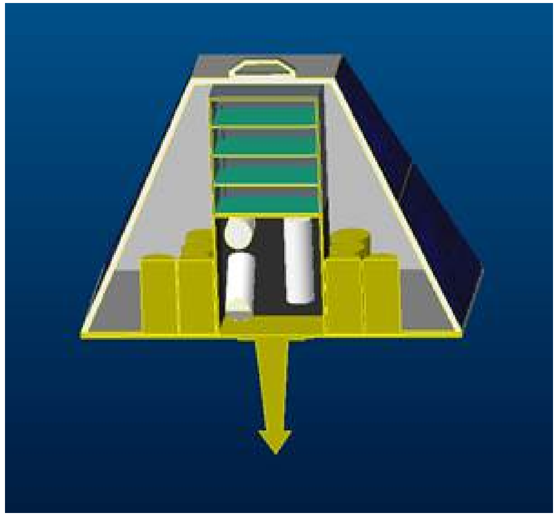
<u>Launch Vehicle Capability</u>
(C3 of -0.7 km2/s2; Antares 232)
1805kg

Discovery - Deployment



Ferris Wheel – Sensors and Sources





Surface package

Summary - APEX

- Challenging mission
- PSDS – low mass, small budget
- CONOPS at a small no-g body – Autonomous ops
  - Rendezvous
  - Touch the surface
- Emplacement of seismometer (tiny self-contained “spacecraft”) – ensure coupling
- Data downlink – high data volume from seismometer
- Close to the Earth, close to the sun
- Looking for suggestions

- *Acknowledgements*: NASA Planetary Science Deep Space SmallSat Studies Program, NASA Innovative Advanced Concepts Program, Applied Physics Laboratory, Cast of Summer Interns

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