WAYFARER: On Demand Small Body Exploration with a Common Architecture CubeSat Probe

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Science/Technical Justification: Small Body Exploration

Relevance: Primordial remnants of solar system formation

Asteroids:

- Building blocks of the inner solar system
- Planetesimal to protoplanetary scales, with remnant families
- Compositional diversity and source of terrestrial volatiles
- Dynamical organization

Science/Technical Justification: Small Body Exploration

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Comets:

- Building blocks of the outer solar system
- Record of composition, temperature, density, and mixing in the protoplanetary disk
- Reservoir distribution a legacy of late stage planetary migration
- Potential source of volatiles on terrestrial planets

Science/Technical Justification: Small Body Exploration

Relevance: Interaction with civilization

Planetary Protection:

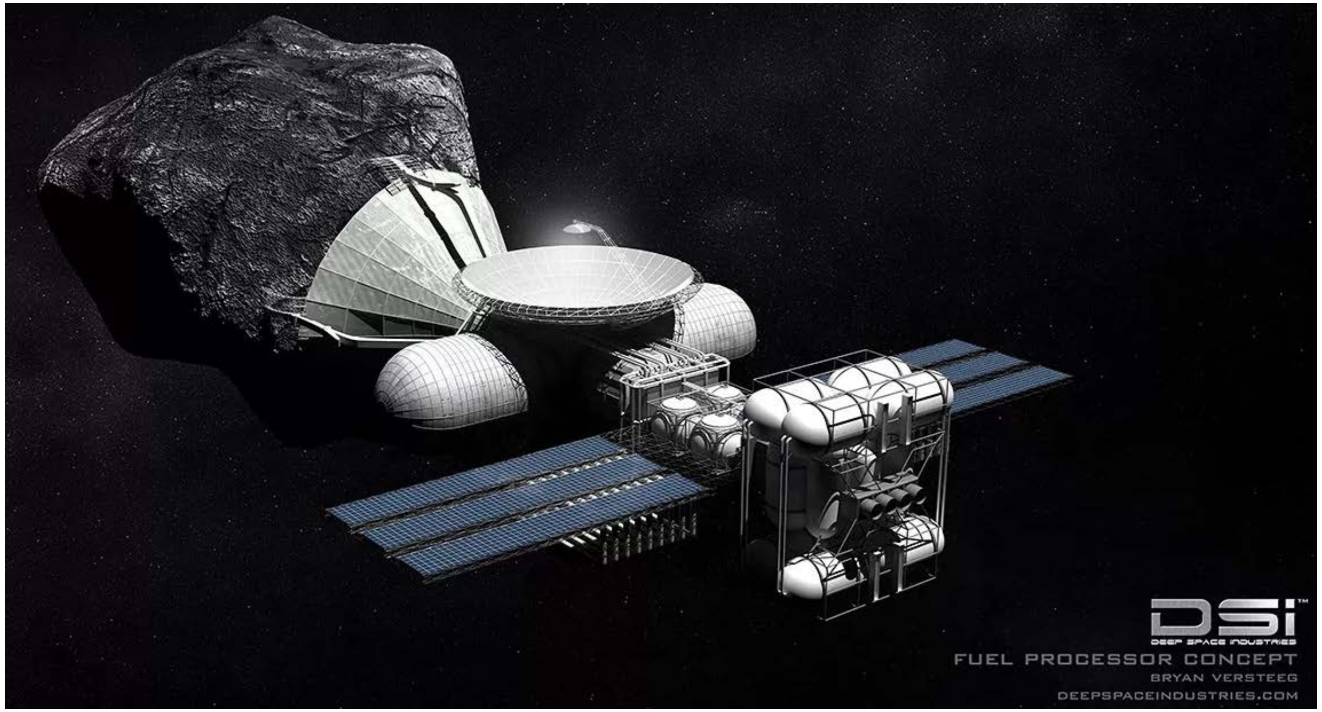
- Impact hazards
- Non-gravitational forcing
- Mitigation strategies

Science/Technical Justification: Small Body Exploration

Relevance: Interaction with civilization

Resource Utilization:

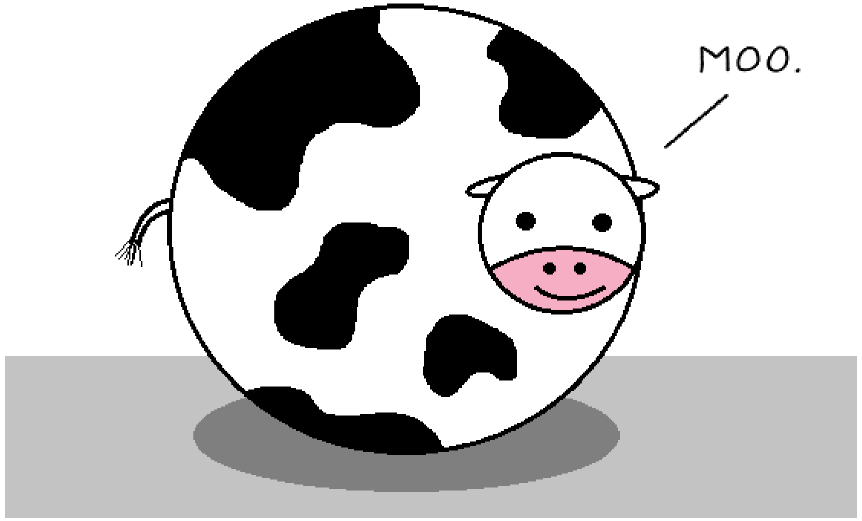
- Metals, Rare Earth elements
- Volatiles
- Fuel
- Trillions in economic value



Small Body Exploration: Ground Based Remote Sensing

’Spherical Cow’ Era of Exploration: Prior to mid-1980’s

Assume a spherical cow of uniform density.



Small Body Exploration: Ground Based Remote Sensing

’Spherical Cow’ Era of Exploration: Differences were assumed to apply globally and be limited to composition.

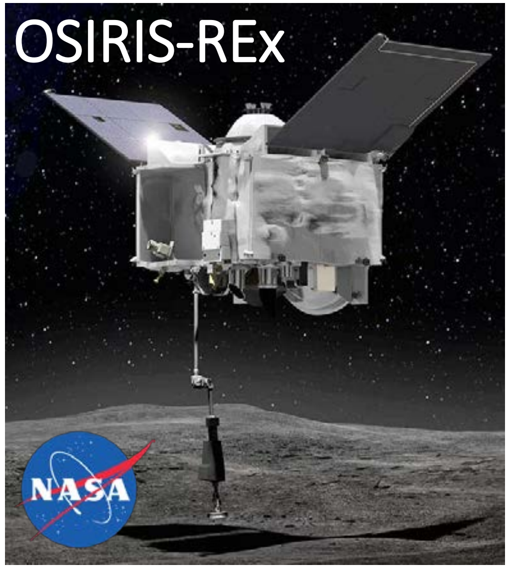
Chondritic (C) Metallic (X) Silicaceous (X) Family Comet

Small Body Exploration: The “One-off” Method

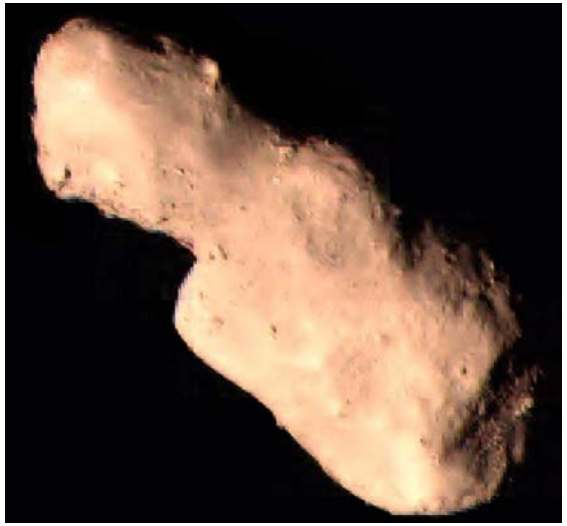
In situ study is the best method for characterizing individual bodies and has formed the basis for our current set of questions.

Customized exploration maximizes scientific return:

- Highly capable
- Multi-faceted sampling
- Incorporated redundancy
- Reliable



Visits to a Number of Asteroids and Comets Show a Tremendous Diversity of Characteristics: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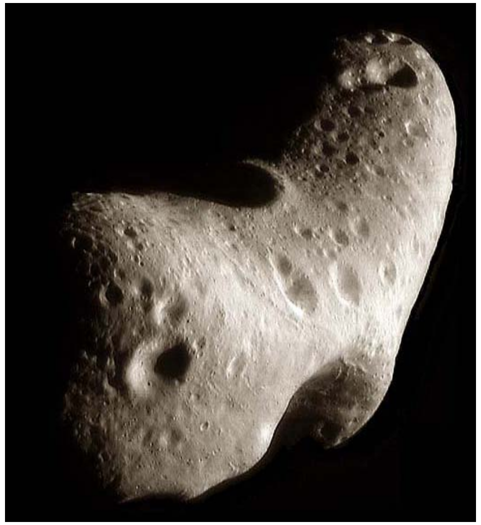
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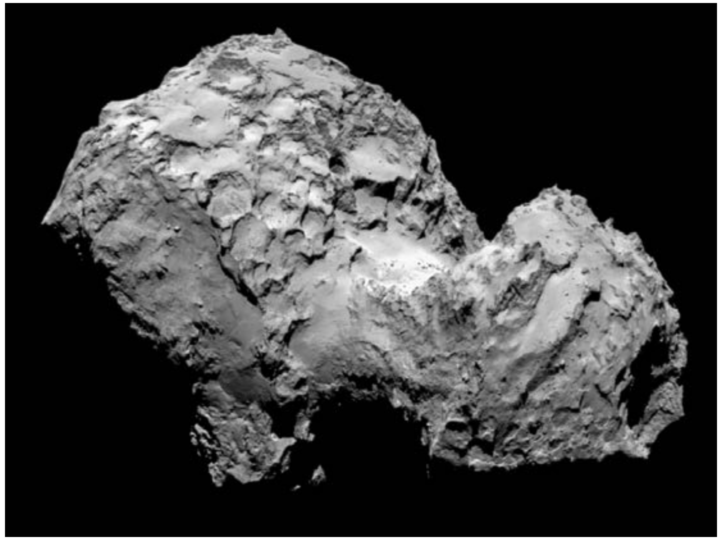
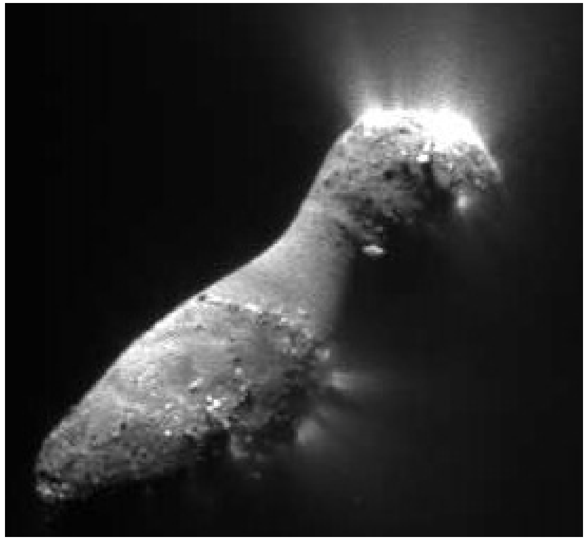
Visits to a Number of Asteroids and Comets Show a Tremendous Diversity of Characteristics:

9P/Tempel



67P/Churyumov-Gerasimenko



103P/Hartley 2

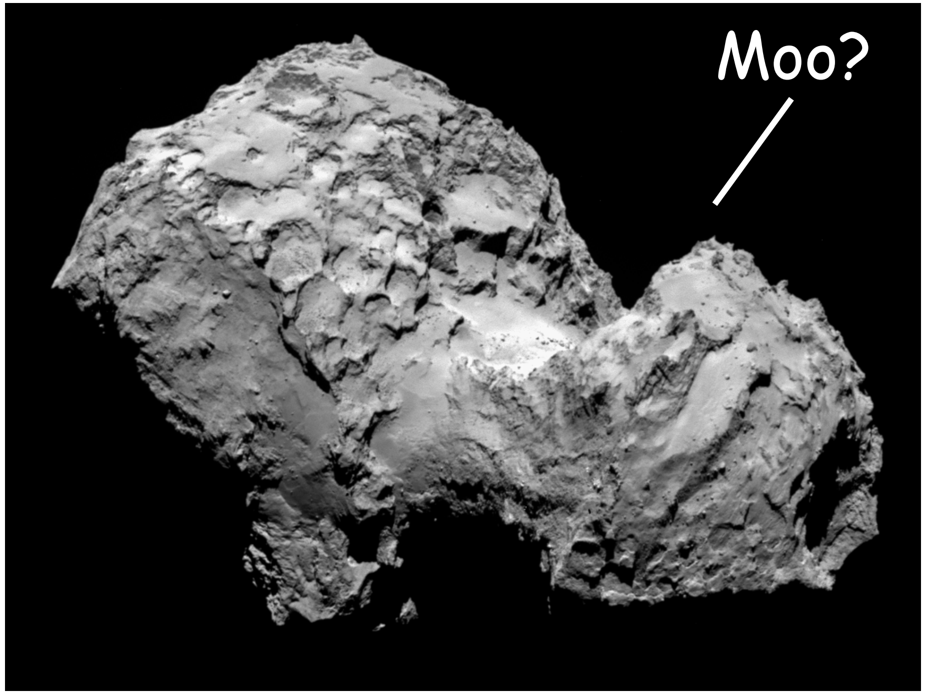
81P/Wild

Small Body Exploration: The “One-off” Method

Our limited sample has generated as many new questions as it has answered!

Diversity:

- Surface characteristics
- Composition, cohesion, and density
- Internal uniformity
- Rotational state (rate & axis)
- Non-gravitational forcing
- Short term physical evolution
- Operational environment

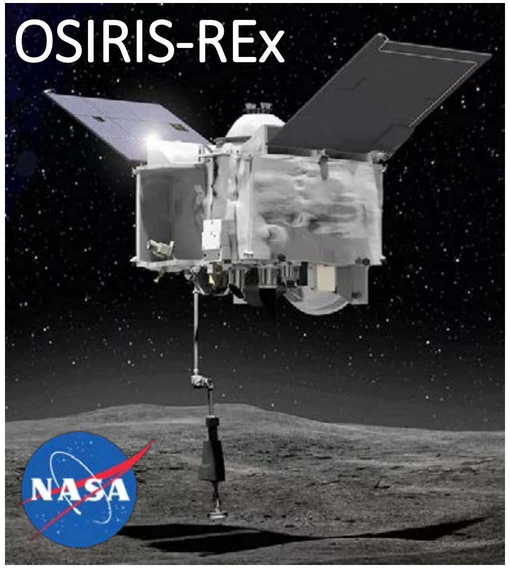


Small Body Exploration: The "One-off" Method

In situ study is the best method for characterizing individual bodies and has formed the basis for our current set of questions.

One-off missions have ***significant limitations***.

- Expensive ($300M-$1B)
- Schedule driven
- Highly customized
- Risk averse
- Small target list



Small Body Exploration: Next Steps

The “One-Off” model falls short in multiple ways:

Phenomenological Coverage:

- The number of compositional and dynamical planetesimal classes exceeds the number of missions.
- *Targets of Opportunity* are not possible
- Long period comets have never been visited
- Outbursting and fragmented bodies have not been explored
- ’Challenging’ environments are off limits

Small Body Exploration: Next Steps

The “One-Off” model falls short in multiple ways:

Statistical Coverage:

- Body driven (rotation, internal structure)
- Surface diversity (cohesion, roughness, debris)
- Shape (bi-lobate, oblate)
- Composition (isotopes, volatile ratios, hetero vs. homogeneous)

Small Body Exploration: The New World Analogy

Exploration of small bodies near Earth is equivalent to early exploration of North America.

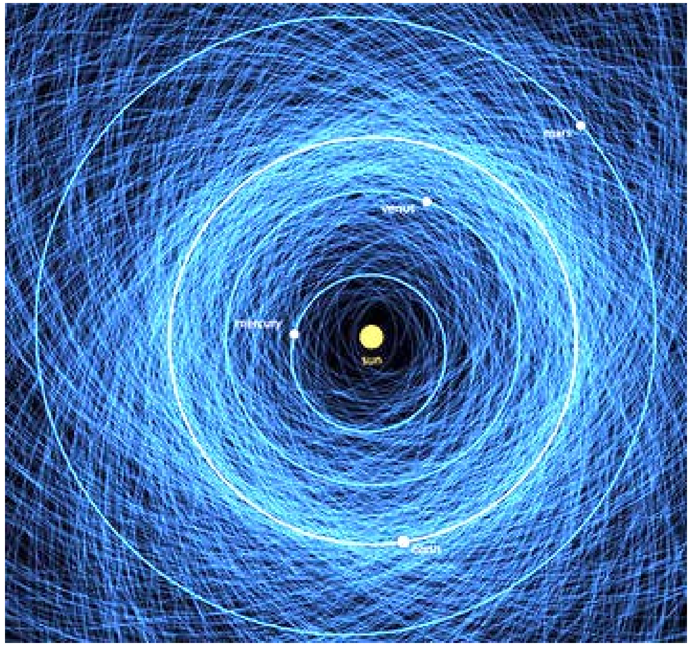
We extrapolate understanding of the continent based on a few landing sites.

Future Exploration: The Challenge

To expand our phenomenological and statistical coverage we must address

Numbers:

- ~1000 NEOs more than 1 km in diameter
- ~10000 NEOs between 0.14 and 1 km in diameter
- >250 Periodic comets



Timing:

- Development-launch vs. stochastic events (outbursts, breakups, late identification)
- Long period comets (1-3 year lead times)

Future Exploration: The Requirements

Proper sampling of the near Earth small body population requires several spacecraft characteristics

- Independent operation (*not* a daughter spacecraft)
- On-demand deployment (rapid response)
- Large numbers of individual probes (statistical survey)
- Low data cost ($/byte) at high volume (perhaps not high rate)
- Large ΔV (4 km/s) to maximize mission options
- Modest reliability (losses acceptable)
- Modular instrument suite

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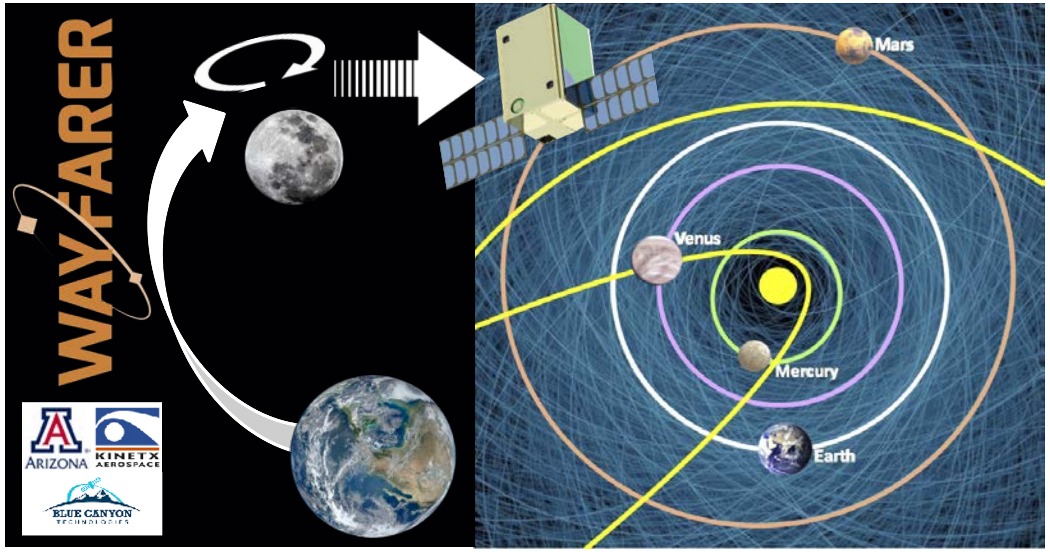
A *Fleet*, not a swarm!

Future Exploration: The Wayfarer Concept

Wayfarer is a common architecture spacecraft with uniform interfaces for science instrumentation.



Operating Range	0.8-1.2 AU
Deployment	Orbital storage at Lunar L2 from LEO-GEO
Format	12 U
Drive System	Solar electric with ~4 km/s ΔV
Attitude Control	Blue Canyon XACT
Power	120 W (1 AU)
Communication	X, Ka, S band, Low bandwidth approach

Joint project of the University of Arizona, Arizona Space Grant Consortium, Blue Canyon Technologies, Kinetx Aerospace.

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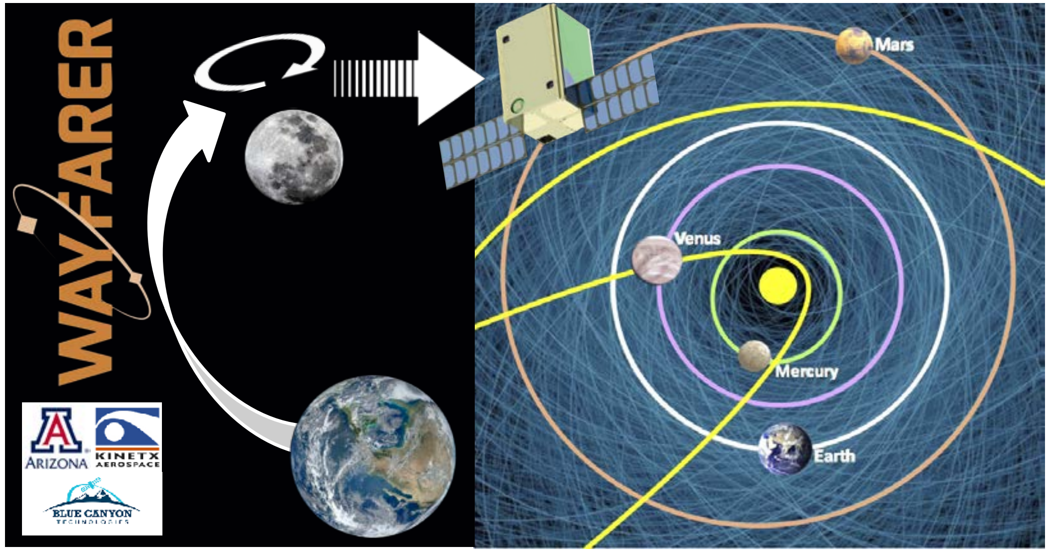
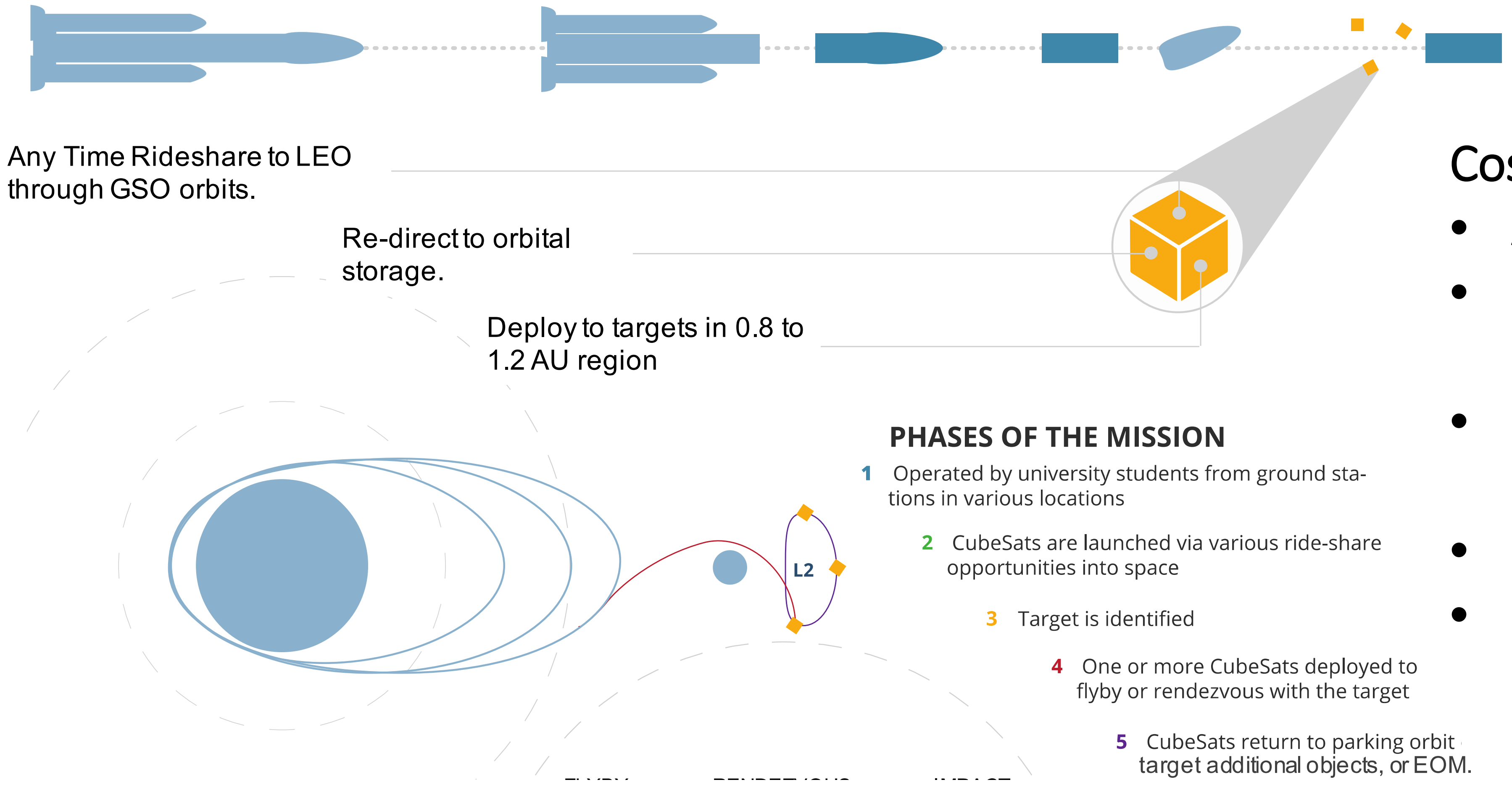


Target based instrument suites (Package driven) (up to 3/spacecraft) drawn from existing hardware.

- Visible imaging
- Vis/NIR hyperspectral, Push-frame sensor
- Mass Spectrometer
- Penetrating Radar
- Neutron Spectrometer
- Altimeter

Mix and match for a small number of mission profiles.

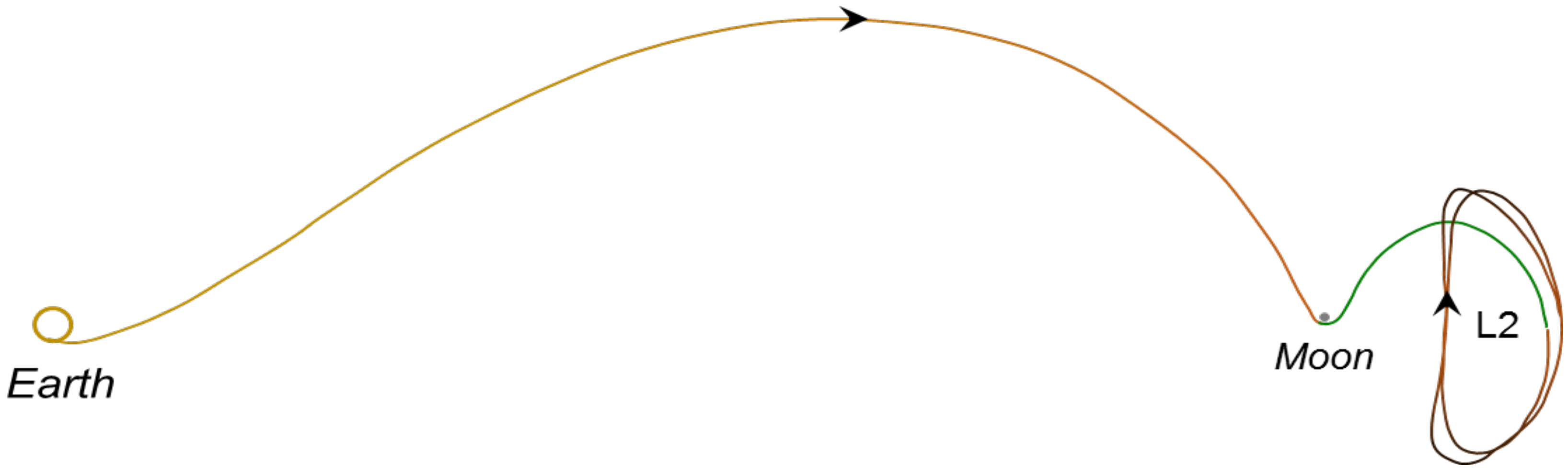
Wayfarer: Basic Mission Profile



Cost/Schedule Reduction:

- Assembly Line Construction
- Consistent Flight Implementation Profiles
- Common Communication architecture
- Failure Tolerant
- Use of orbital storage

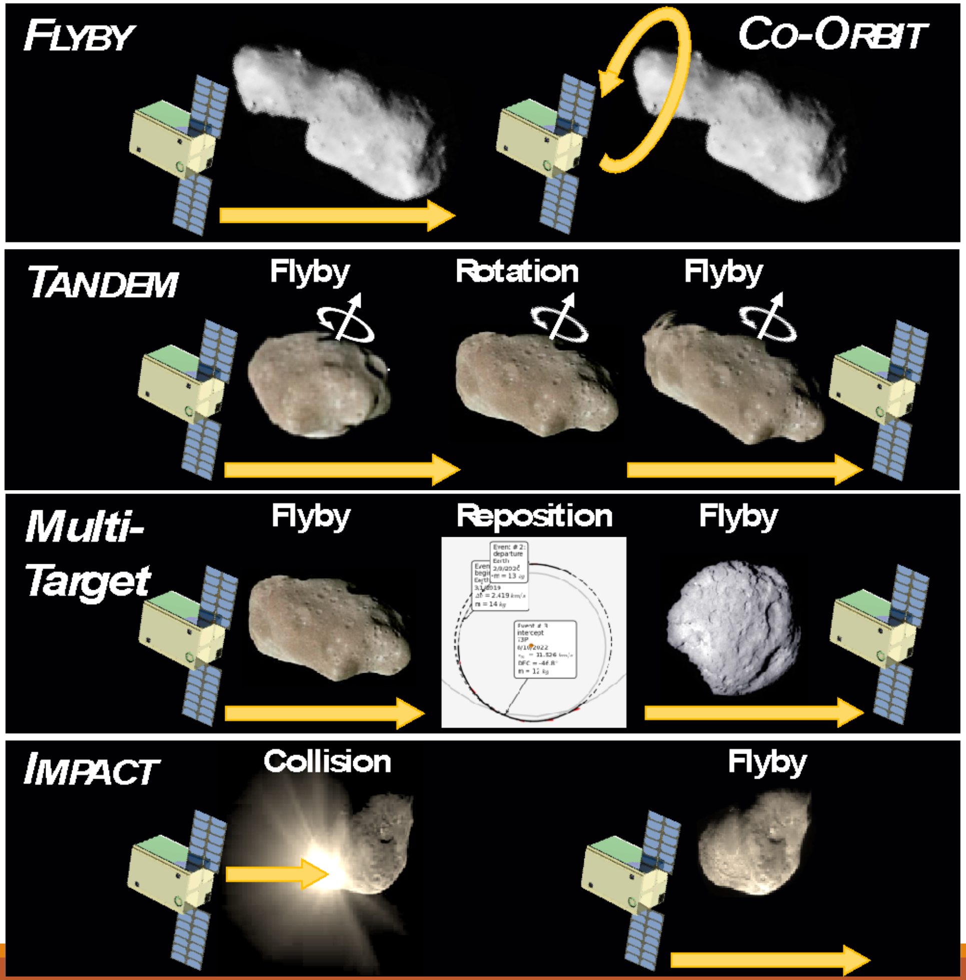
Wayfarer: Orbital Deployment



Transfer Type: Transfer Trajectory Insertion (TTI)	Transfer Time (Days)	Required ΔV (km/s)	Propulsion ΔV (km/s)
Powered Lunar Swingby	12	3.132	2.796
Ballistic v WSB	140	3.212	3.197
WSB w Unpowered Lunar Flyby	173	3.156	3.126

LEO permits low cost launch options from rideshare to dedicated flights.
(e.g. Vector Space = 4 Wayfarers to 400 km for $2M)

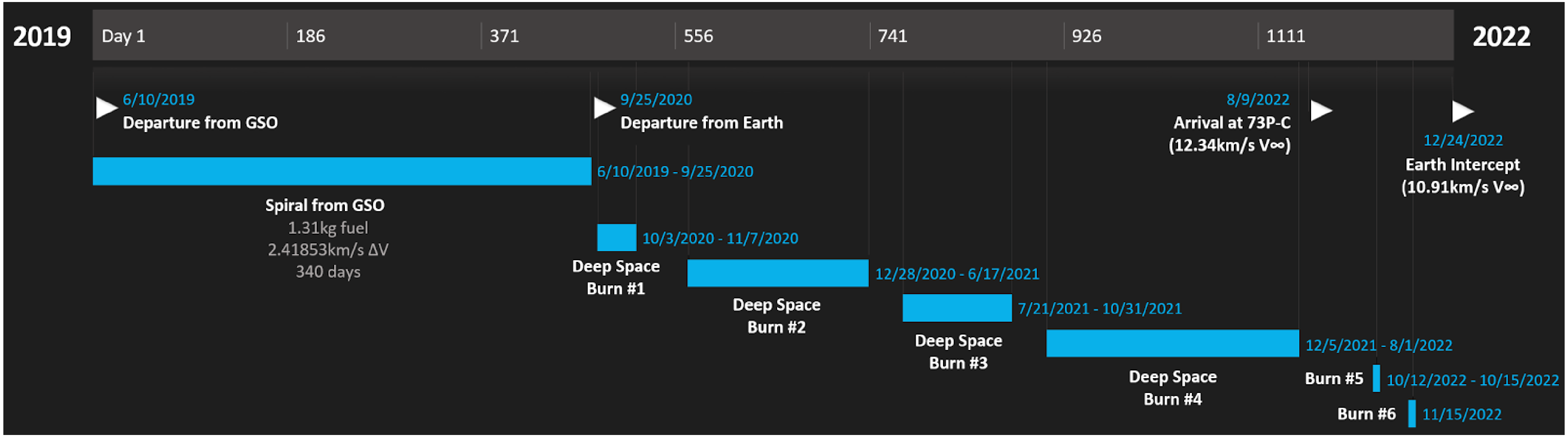
Wayfarer: Mission Flexibility



Wayfarer can be used in multiple mission designs as a stand-alone instrument or group.

Target	Class	Q (AU)	q (AU)	P (yr)	i (deg)	Diameter (km)	DV
107P Wilson-Harrington	JFC	4.293	0.991	4.29	2.8	4.0	2
79P du Toit-Hartley	JFC	4.756	1.124	5.06	3.1	3.0	4
73P SW 3 - C	JFC	0.943	5.183	5.36	11.4	2.0	5
99942 Apophis	Aten	1.098	0.748	0.89	1.1	0.3	2
2003 UC20	Aten	1.040	0.518	0.70	3.8	1.0	3
3122 Florence	Amor	2.516	1.021	2.35	22.1	4.0	3
1998 HG49	Amor	1.337	1.066	1.32	1.3	0.2	1
4183 Cuno	Apollo	3.22	0.743	2.79	6.7	5.0	3
4179 Toutatis	Apollo	4.145	0.955	4.03	0.44	1.7 x 2 x 2	2
202X Comet	LPC	inf	~1AU	inf	any	any	5

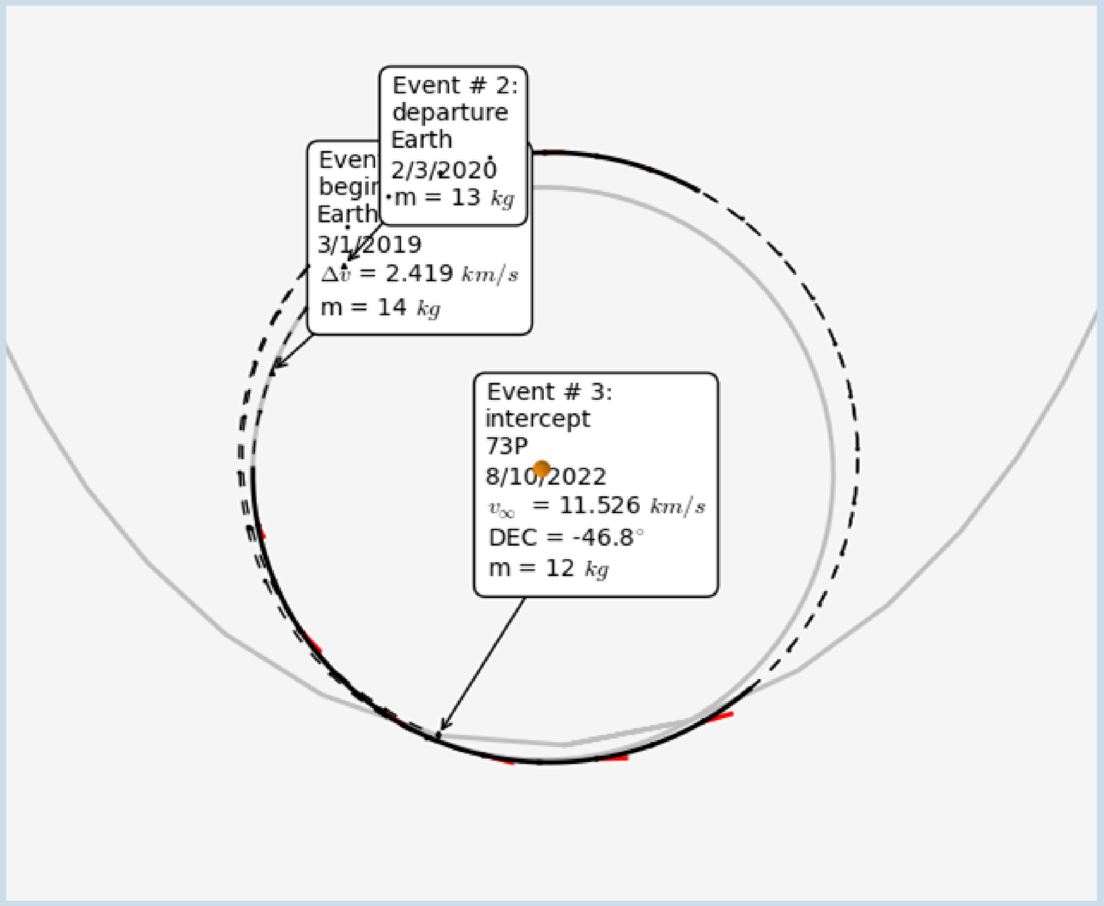
Wayfarer: Schwassmann-Wachmann 3



A sample mission was developed for a launch to SW3, a fragmented comet, in 2019.

Wayfarer: Schwassmann-Wachmann 3

The trajectory begins at GEO, reaches SW3 in 2022, and ends with *reinsertion* into the Lunar L2 parking orbit with a total ΔV = 4.25 km/s.



Summary:

- Wayfarer-class spacecraft can provide necessary statistical & phenomenological studies of Near-Earth small bodies.
- Use of rideshare and low-end boosters along with a Lunar L2 parking orbit provide frequent ‘on-demand’ capabilities at low cost.
- Application of an assembly-line model and a limited orbital zone decreases cost/spacecraft and increases the number of possible missions.
- Adopting a failure tolerant model where spacecraft loss is factored in reduces complexity and enables use of Wayfarer in more extreme environments and as a technology pathfinder.

Summary:

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