On-Orbit Planetary Science Laboratories for Simulating Surface Conditions of Planets and Small Bodies

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Motivation

In the next 35 years, we aspire to send human and robotic explorers to every corner of our solar system using flyby spacecraft, orbiters, landers and subsurface robots (Figure 1), with two major objectives:

Explore and catalog *the diverse surface environments, physical and chemical processes, and geologic structures of planets, satellites and small bodies.*

Answer fundamental science *about the origin and evolution of the solar system, conditions to sustain life, and prospects for resource utilization and off-world human settlement.*

This will require accessing extreme environments with unfamiliar and dynamic gravity, pressure, and temperature conditions, the most rugged geology, and ice-ocean interfaces.

Figure 1: Artistic view of a comet (top left), Europa surface (top right), Mars canyon (bottom left) and skylight (bottom left).

Challenges

While some of these extreme conditions (temperature, pressure) can be reproduced in testbeds on Earth, for most solar system exploration targets -- even those that have been explored by flybys and orbiters -- we lack fundamental knowledge of their surface material properties, geologic structures, and chemical processes. And to simulate operations on bodies much smaller than the Earth and Moon, we need to reproduce low-gravity off-world conditions -- a major challenge. These great uncertainties cause dangers that may prematurely end a mission (Figure 2).

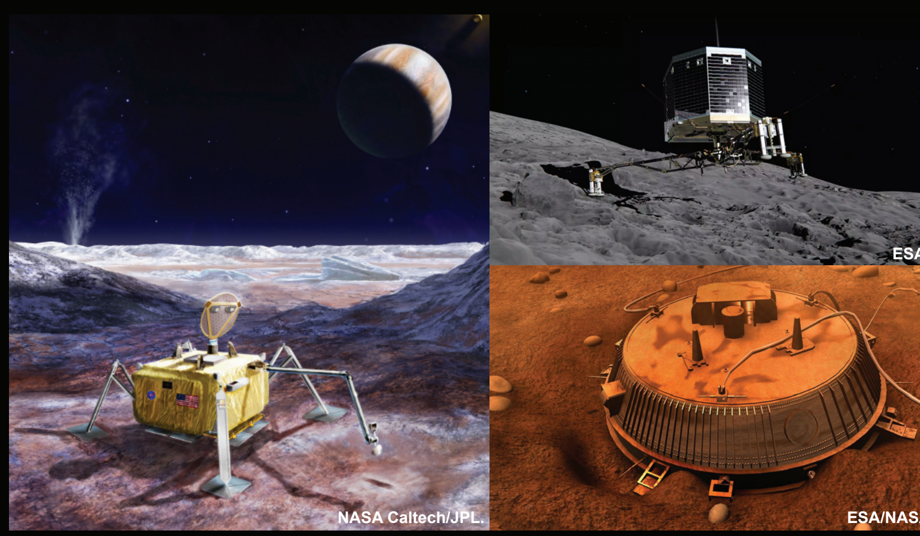
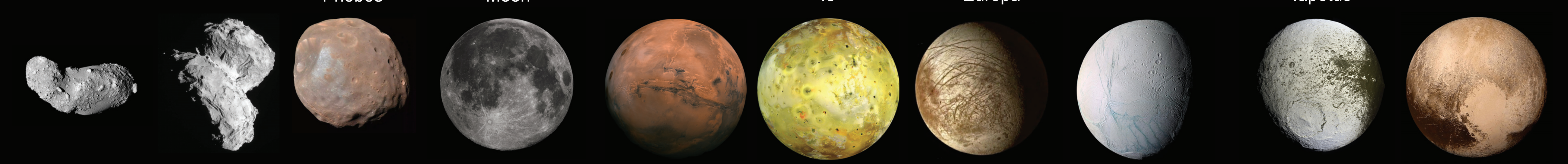


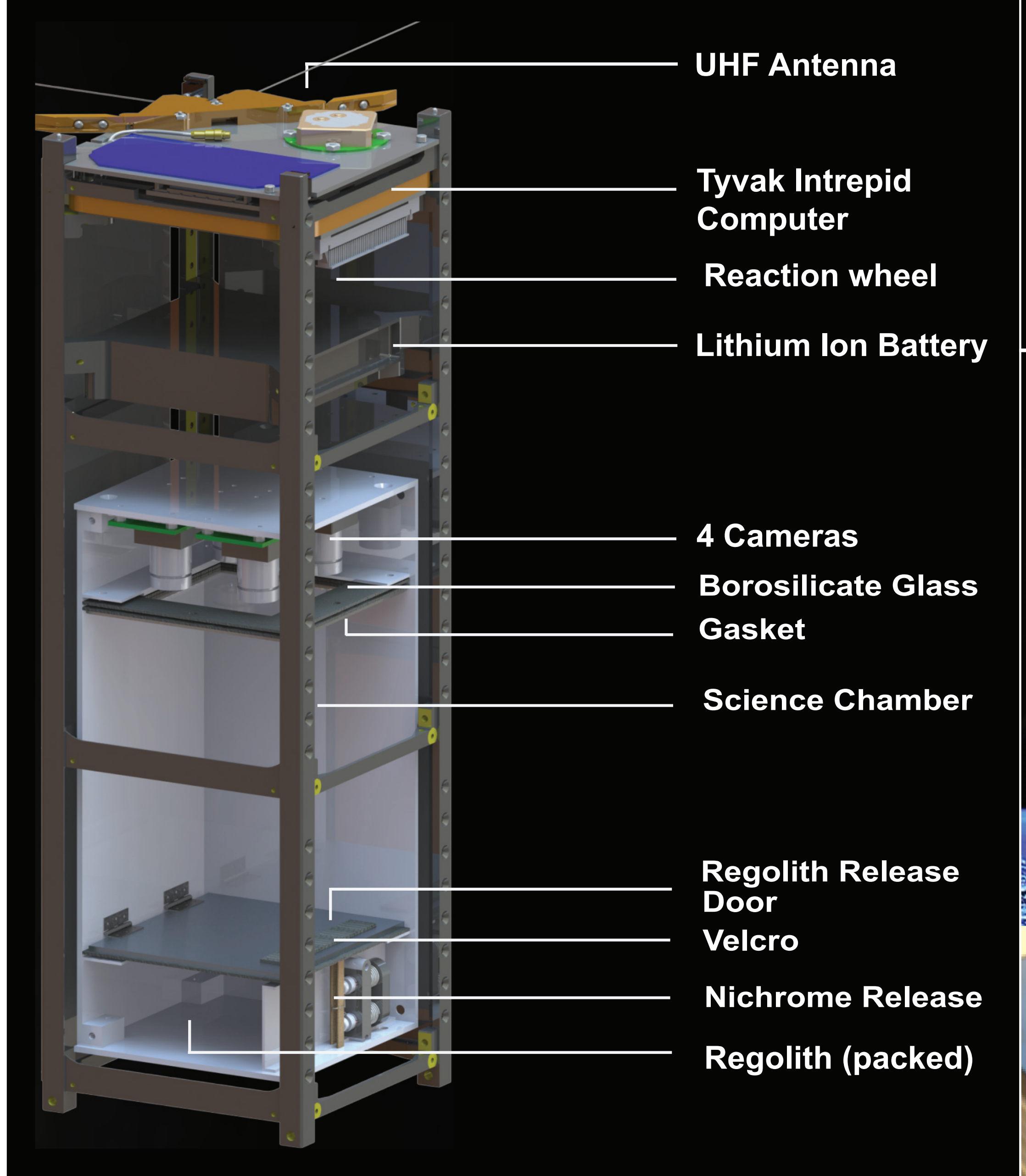
Figure 2: Surface explorers face major challenges in determining implications of the planetary material properties due to low-gravity, temperature and pressure extremes. A Europa Lander concept (left), Philae landing on Comet 67P (top right), Huygens on the surface of Titan (bottom right).

Extreme Surface Conditions throughout the Solar System



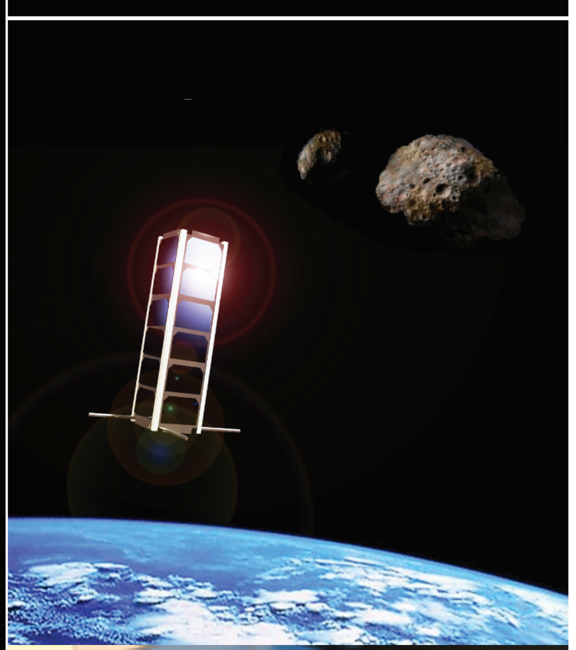
	Itokawa	67P	Phobos	Moon	Mars	Io	Europa	Enceladus	Iapetus	Pluto
Type	Asteroid	Comet	Moon of Mars	Moon of Earth	Planet	Moon of Jupiter	Moon of Jupiter	Moon of Saturn	Moon of Saturn	Minor Planet
Gravity	**~1.0x10e-4 g**	**~1.0x10e-4 g**	**5.8x10e-4 g**	**0.16 g**	**0.39 g**	**0.18 g**	**0.13 g**	**0.01 g**	**0.02 g**	**0.06 g**
Temperature	~210 K	180 to 330 K	160 to 270 K	26 to 390 K	140 to 300 K	140 to 3,000 K	50 to 110 K	75 to 90 K	90 to 130 K	33 to 70 K

Asteroid Origins Satellite I - (AOSAT I)



Specifications

System: 3U Cubesat Centrifuge spinning at up to 4 rpm
Simulates: ~10^{-4}g
Instruments: Stereo Camera, Force-Moment Sensors, IMUs
Mass: 4 kg
Volume: 3,000 cm^3
Power: 4 W (avg)
Comms: 128 Kbps (UHF)
Life: 1 Year
Orbit: LEO



1. CubeSat Centrifuge Demonstrator

2. On-Orbit Laboratory

3. On-Orbit Permanent Facility

"Blue Sky" exploratory science missions are not possible in this current paradigm, because of the *mission death spiral*. Inherent lack of knowledge, operational uncertainty, and lack of technology advancement leads to increasingly complex spacecraft and missions, unexpected high cost, delayed schedules, and reduced political confidence, often resulting in cancellation.

On-Orbit Centrifuge

A on-orbit centrifuge science laboratory can be used to simulate the unique, low-gravity conditions of asteroids, comets, planets and moons. A large laboratory can house entire spacecraft, landers and astronauts. We have been developing a proof-of-concept centrifuge demonstrator called the Asteroid Origins Satellite 1 (AOSAT 1), a CubeSat the size of a loaf of bread that wil be on-orbit (see above).

Achieving More with Less

A centrifuge science laboratory can fulfill the following goals:

1. A realistic simulation environment where fundamental planetary science experiments maybe performed and processes understood for low-cost.

2. Methods to train and demonstrate in off-world conditions without having to go there, accumulate experience, better assess capabilities, derisk and address science and technology knowledge gaps for low-cost.

3. Maintain a persistent link to planetary environments, attain and maintain readiness, demonstrate confidence in missions operations to the public at low-cost.

Long Duration Exploration

Long duration exploration will require living off the land (In Situ Resource Utilization), for fuel, supplies and the ability to repair systems and components (Figure 3). Many chemical, biological and physical processes depend on or benefit from gravity. Thorough testing is required to prove these techniques work before deployment on a mission.

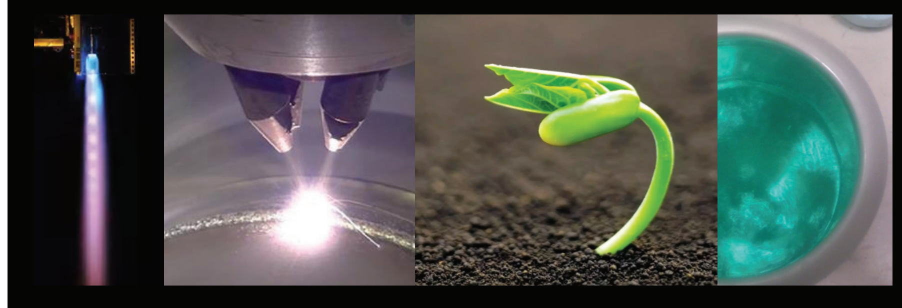


Figure 3: Low-gravity has significant impact on most chemical and biological processes needed to sustain long duration missions. This includes combustion technologies (left), manufacturing/repair (center left), food-production (center right) and propellant generation (right).

Path Forward

On-orbit centrifuge science laboratories offer a compelling path forward towards a new field, experimental planetary science. These facilities will be needed for testing a new generation of exploration technologies. Importantly, the proposed approach will provide a persistent link to off-world environments and facilitate mission experimentation, the ability to suceed and fail at low-cost and low-cadence.