Spacecraft/Rover Hybrids for the Exploration of Small Solar System Bodies

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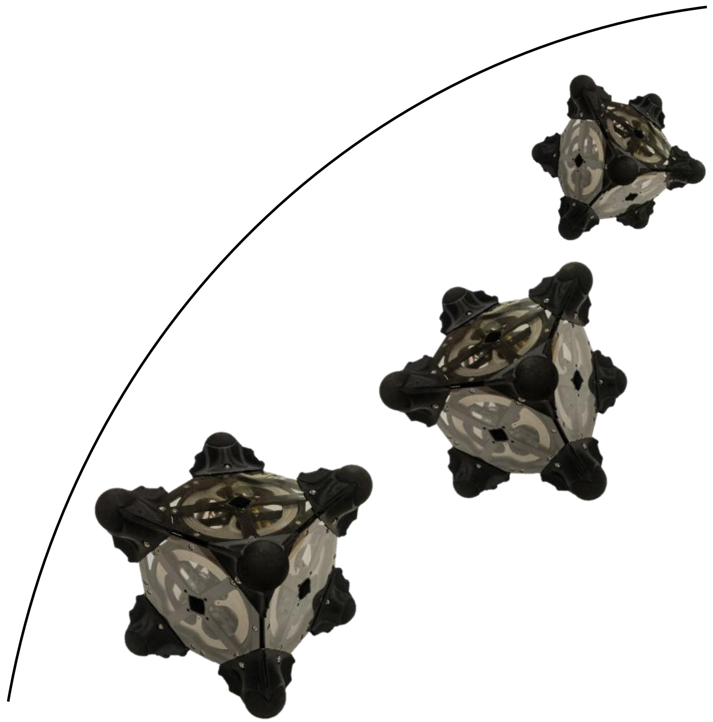
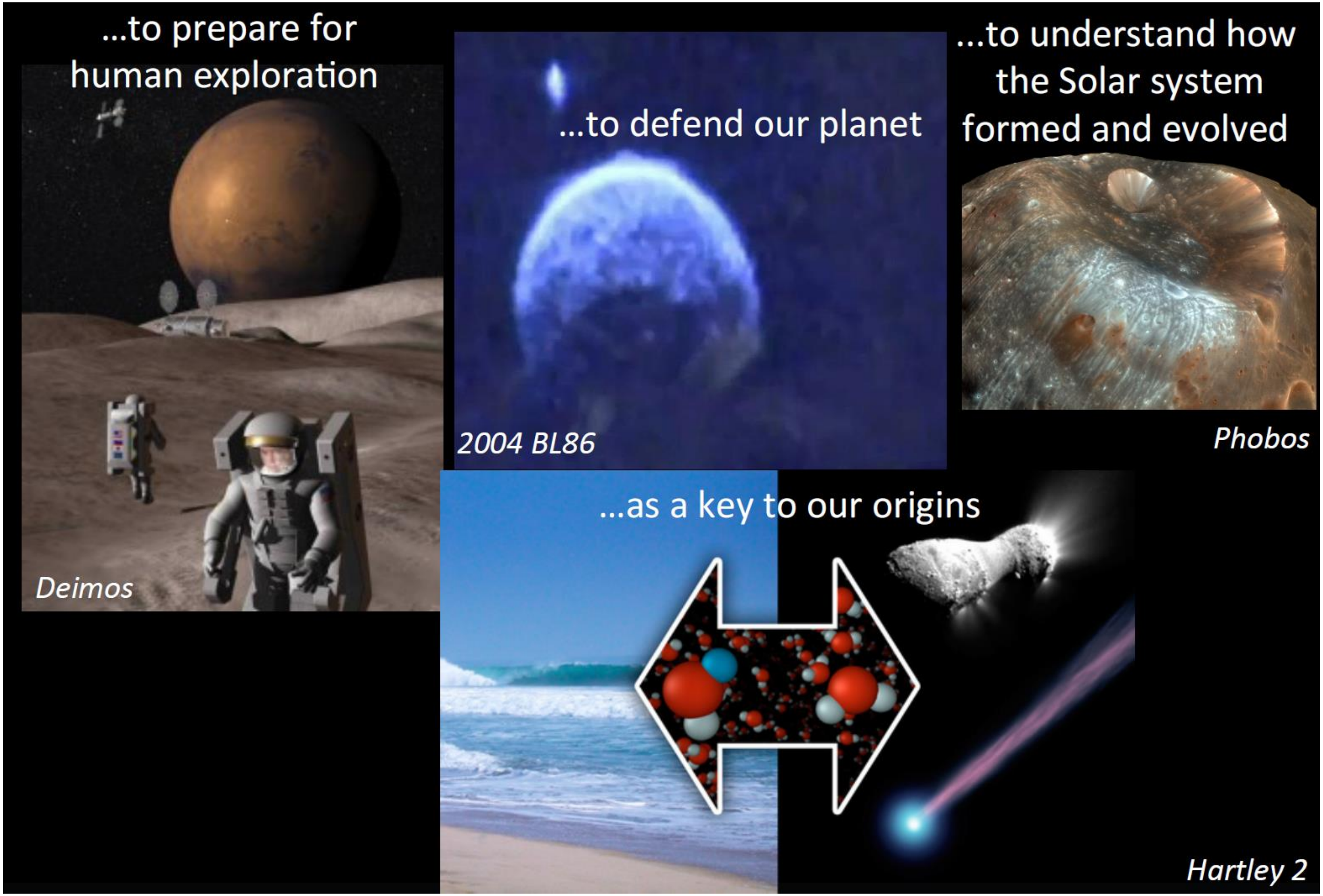
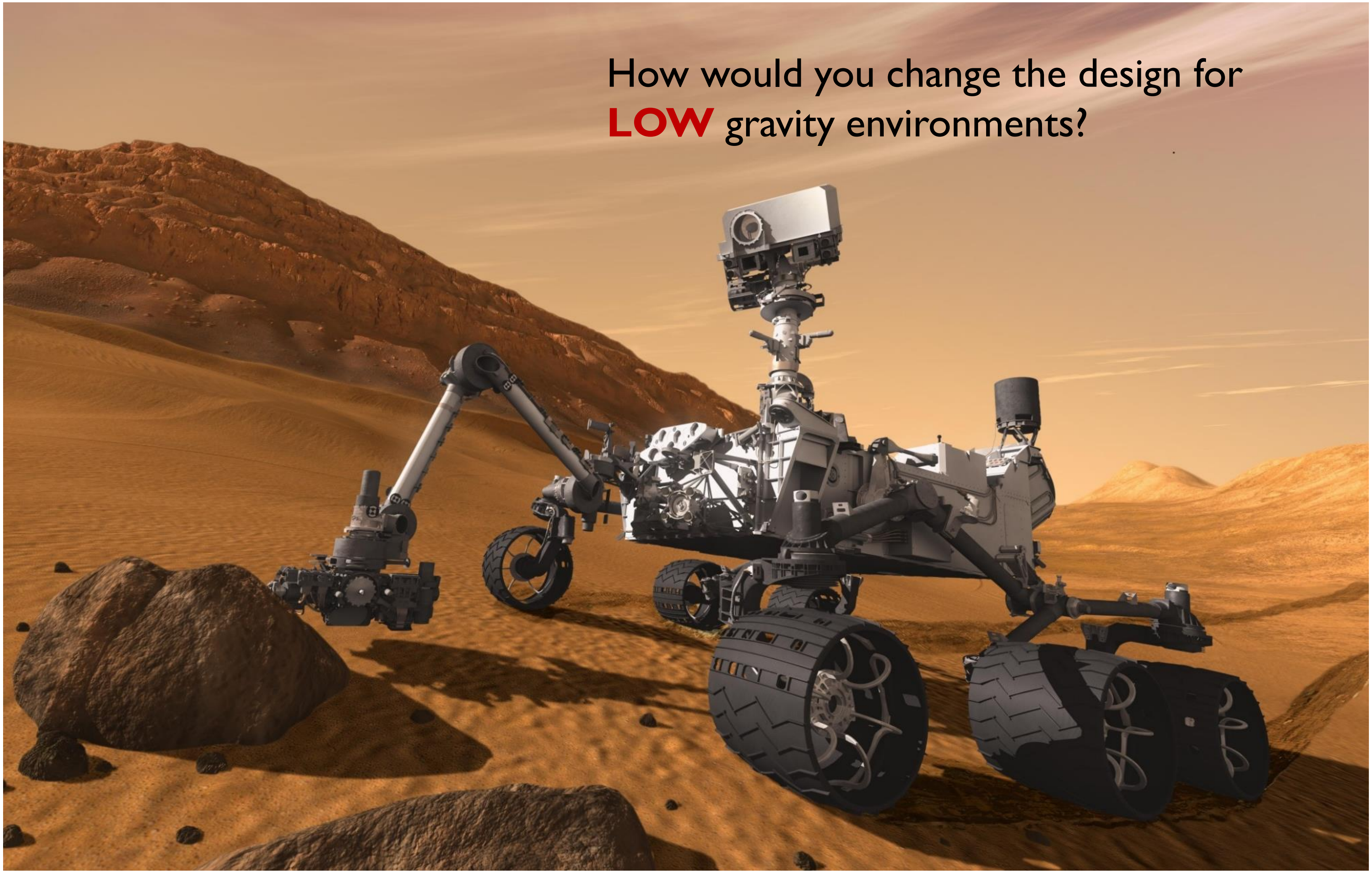
NIAC
NASA Innovative Advanced Concepts



Small Bodies Exploration



The Big Question



Motion in Low Gravity Worlds

	Surface Gravity (g's)	Escape Velocity (m/s)	Freefall time from 1 m (s)	Your weight Equivalent
Itokawa	10^{-5}	0.2	140	
Phobos	10^{-4}	11	20	

Itokawa Asteroid

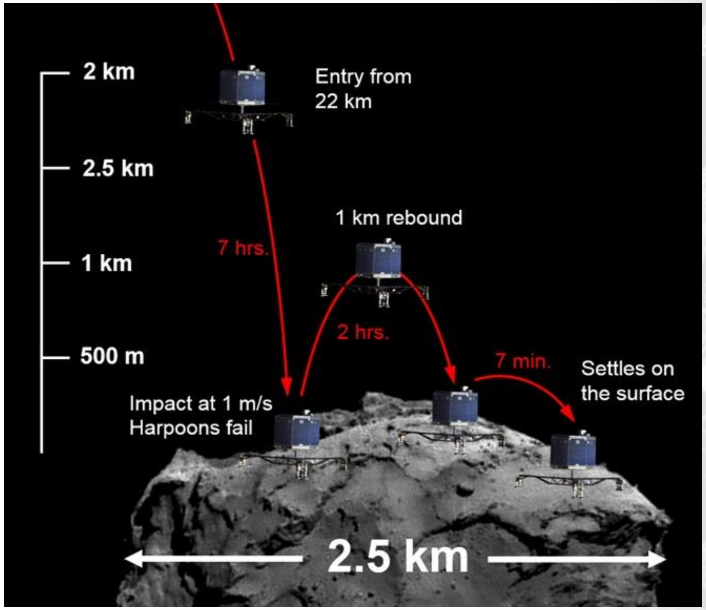
400 m

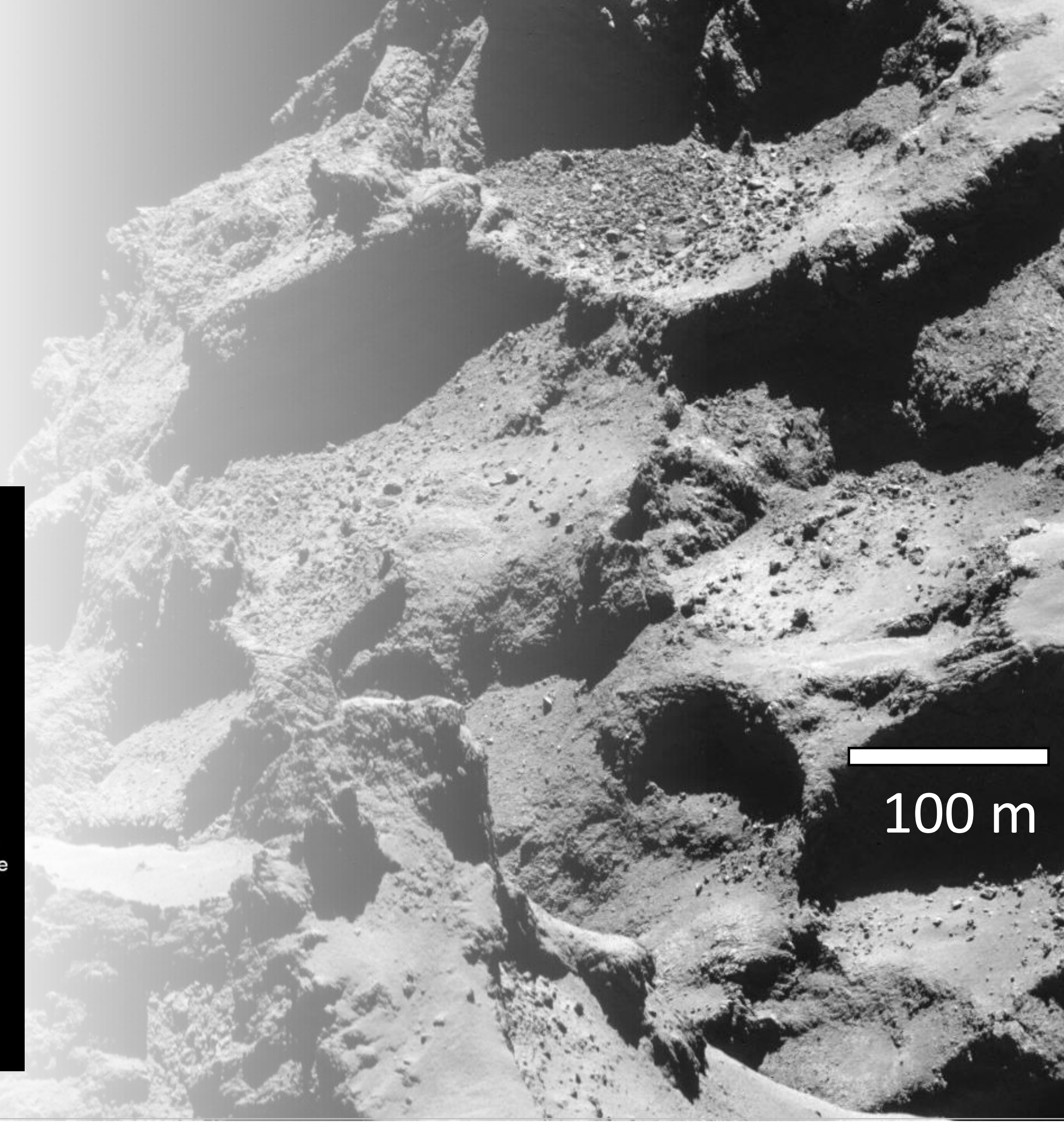
Phobos (Mars' moon)

20 km

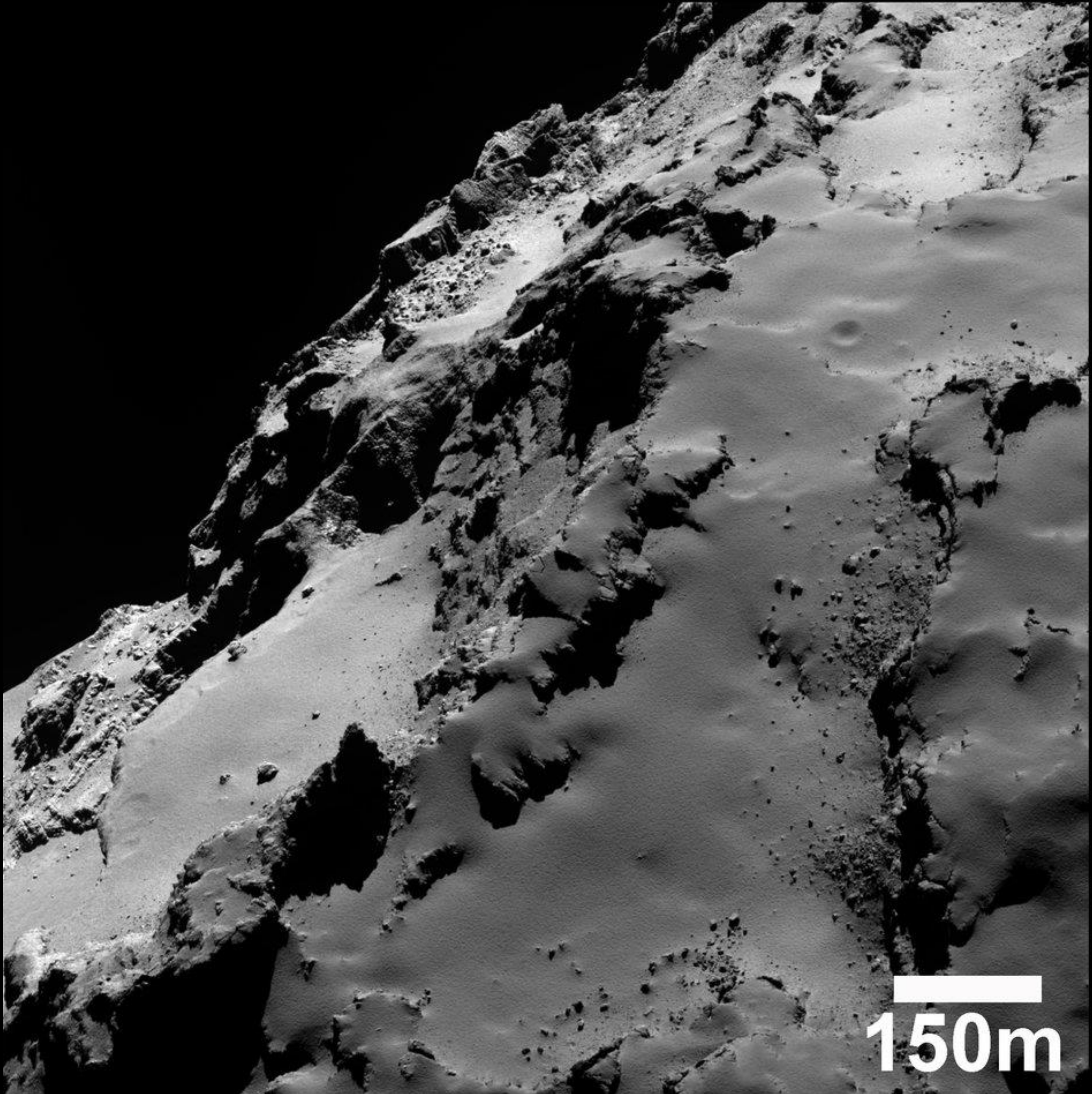
Mobility Challenges in Microgravity

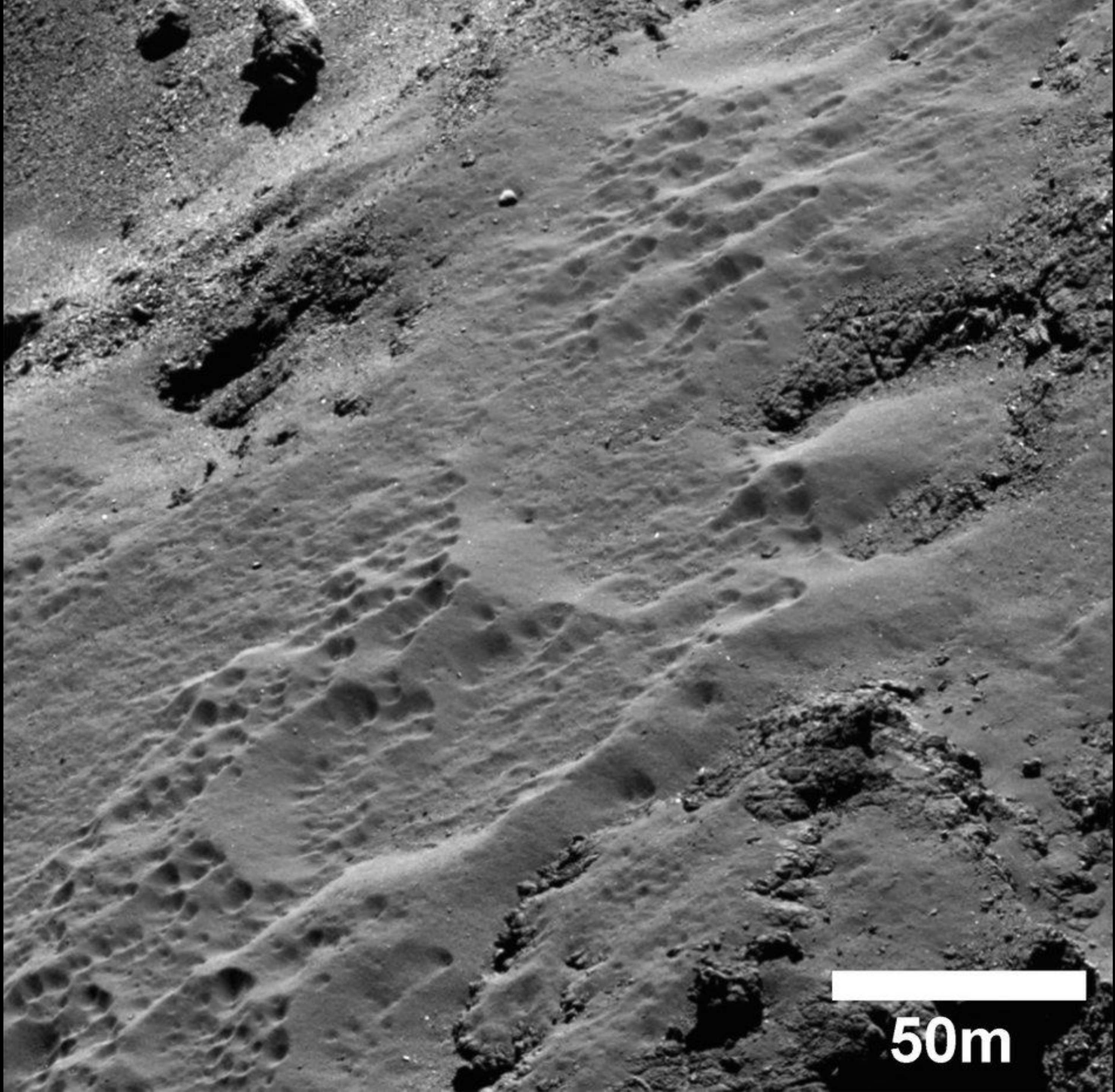
- Very limited traction
- Remaining "attached"
- Uneven/uncertain terrain






300m


150m

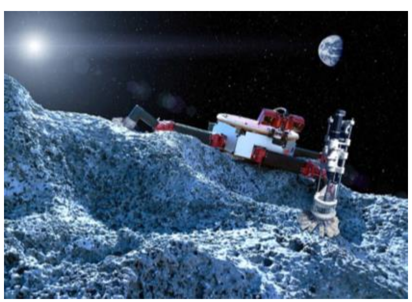

50m

Micro-Gravity Space Rovers

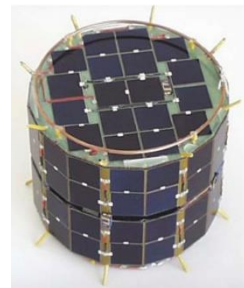
Four classes of mobility:

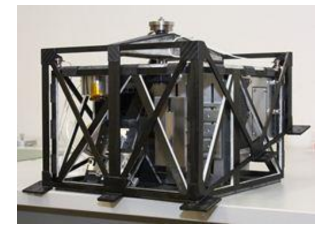
- Wheels

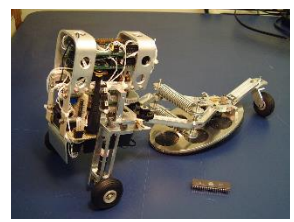
- Legs

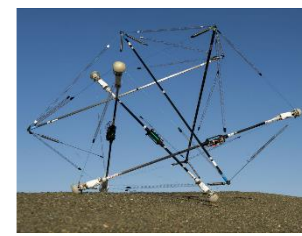


- Hopping

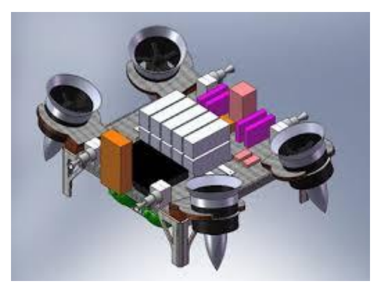






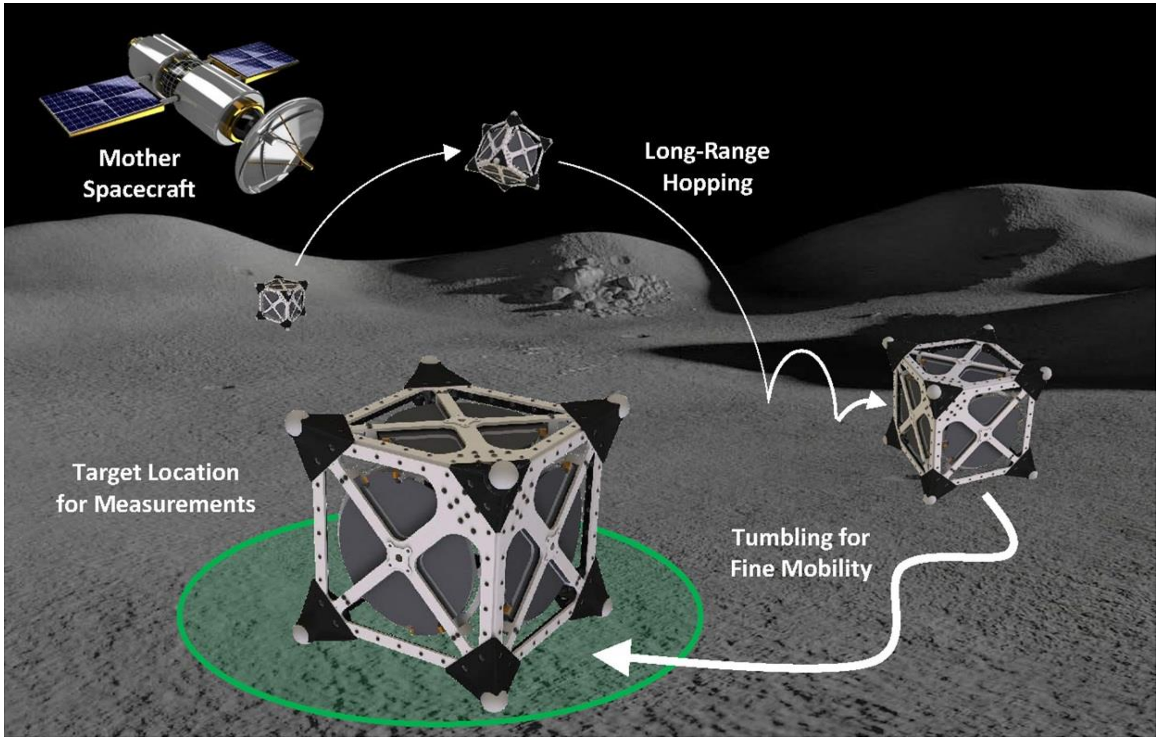


- Thrusters



Spacecraft/Rover Hybrids

A mission architecture that allows the systematic and affordable in-situ exploration of small Solar System bodies.



Key philosophy: Exploit low gravity

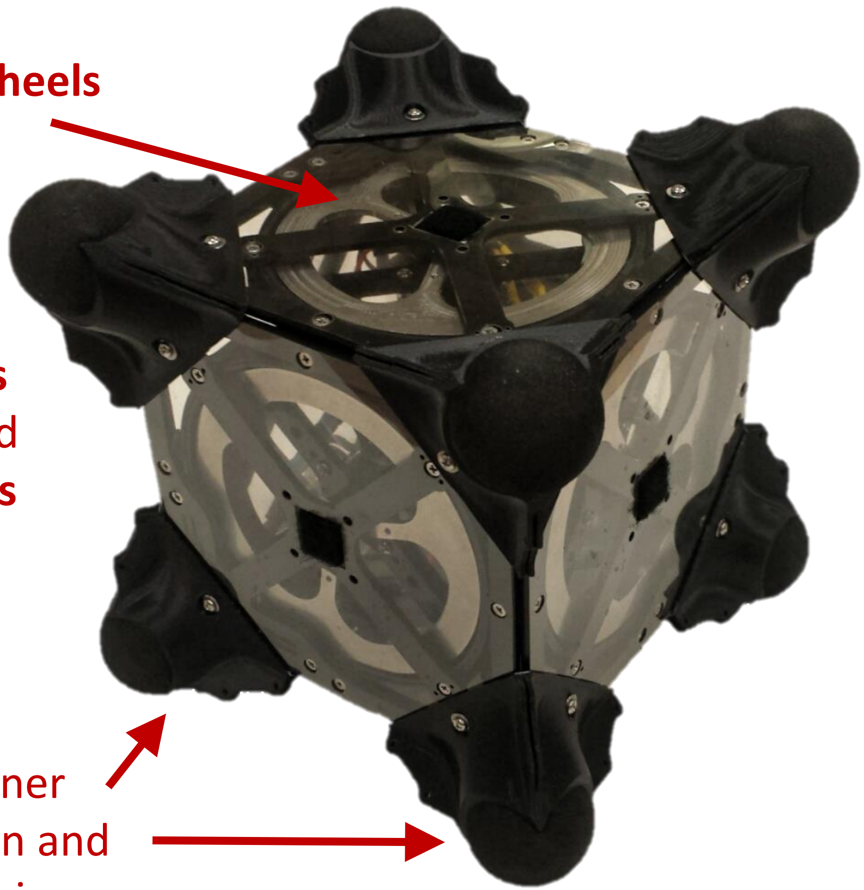
General Features

Mobility Components

Three internal **flywheels** for mobility

Motors and **brakes** generate controlled and abrupt **torques** on flywheels

Spikes on each corner protect from terrain and act as feet for hopping



Key Features

Mechanically and thermally **sealed** from environment

Symmetric design allows mobility in any configuration

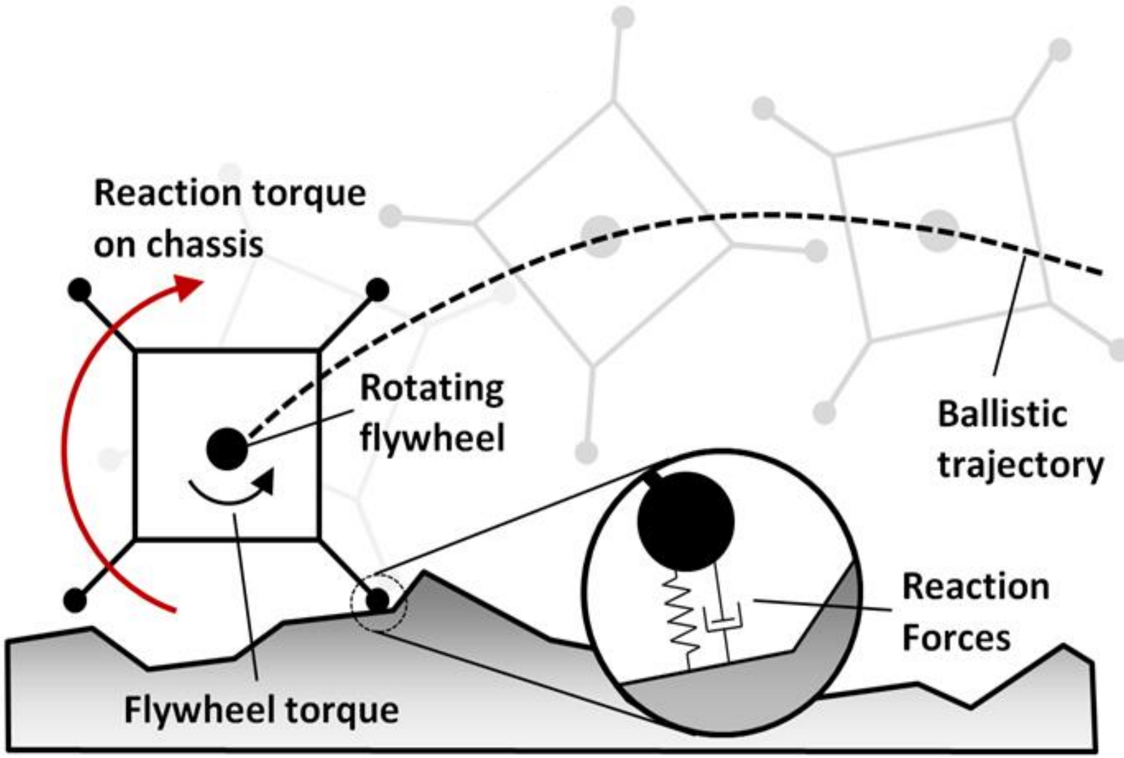
Large internal volume for **scientific payload**

Minimalistic

Scalable

Basic Concept

Key idea: Swapping angular momentum



Spin up flywheels to desired speed

⬇

Hit the brakes!
Generates large braking torque

⬇

Angular momentum transferred to chassis

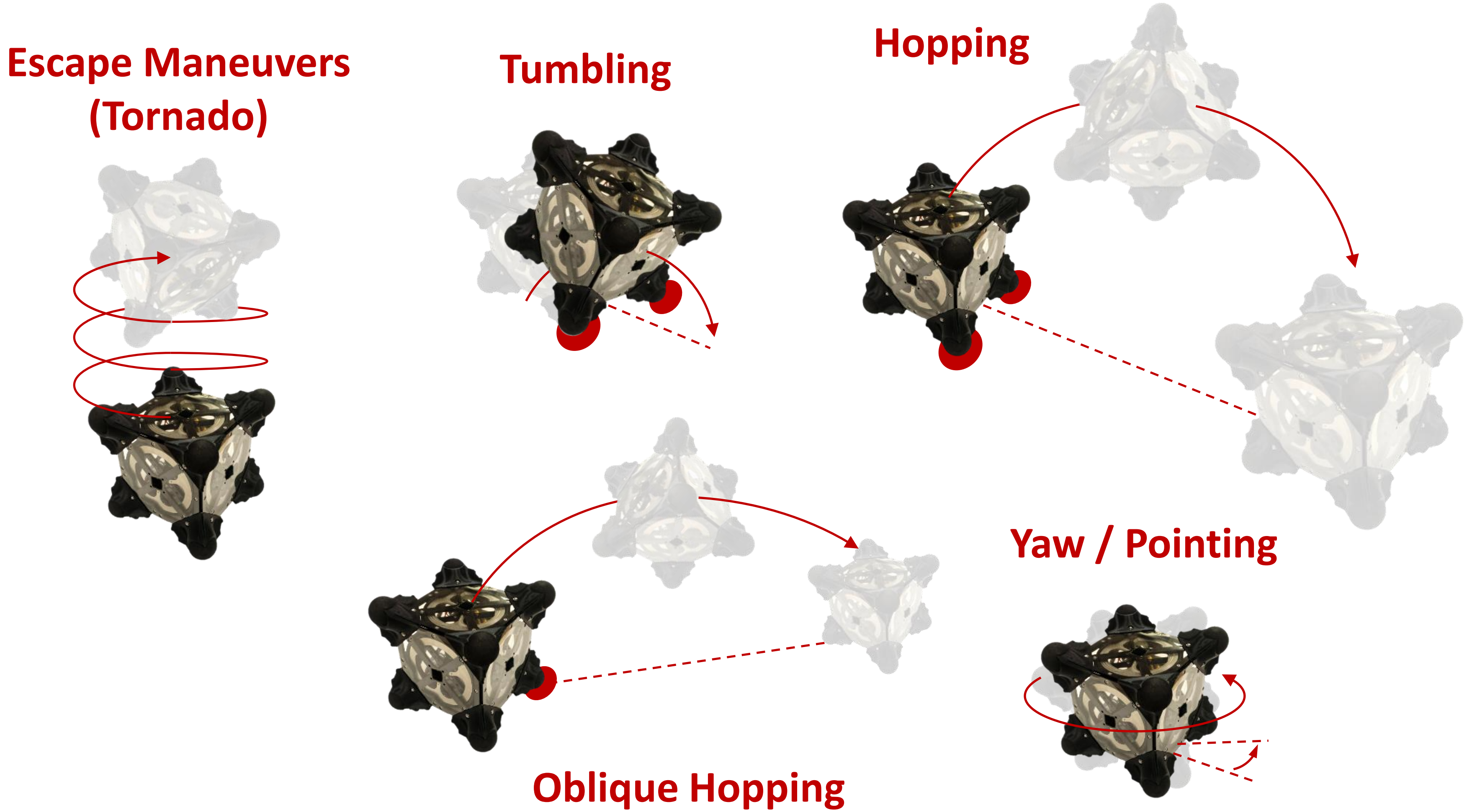
⬇

Reaction forces of spikes on the ground

⬇

Rover hops in a forward ballistic trajectory

Motion Primtives



There’s just one problem…

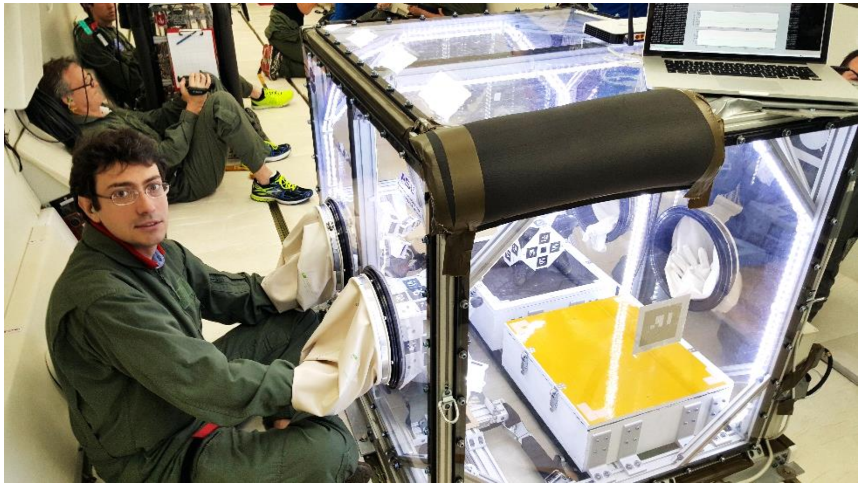
How do you test a microgravity rover on Earth?

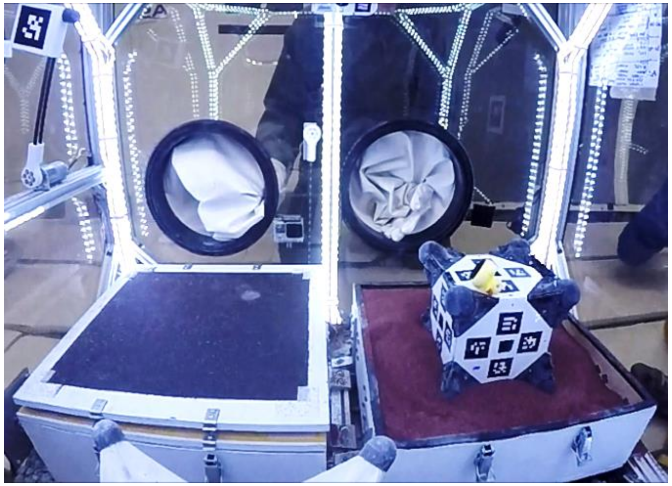
Overdesign it for Earth

Gravity offload test beds

Parabolic flights

Zero-g parabolic flight experiments

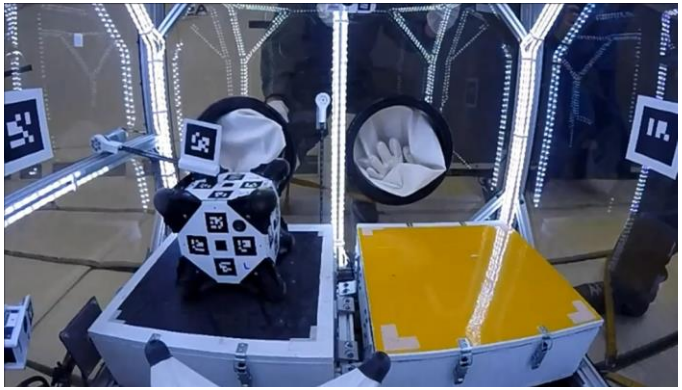




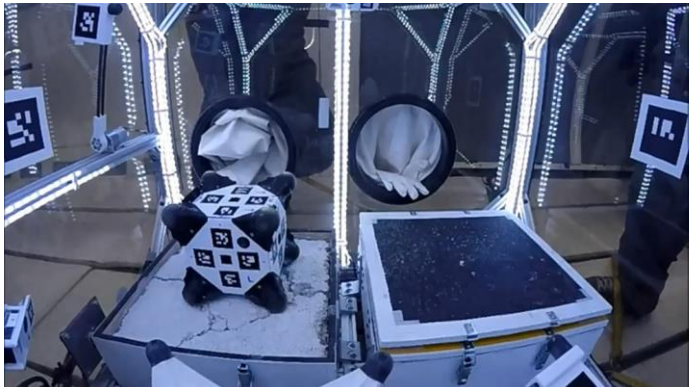
Zero-g parabolic flight experiments

Hopping on various surfaces …

Rough sand paper surface



Pumicite regolith simulant



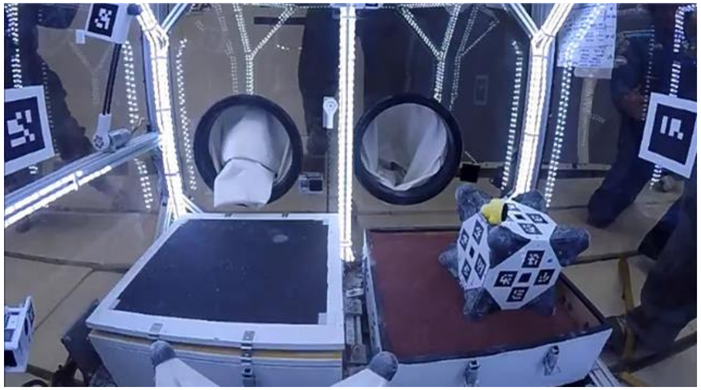
Hopping on uneven surfaces

Government sponsorship acknowledged

Zero-g parabolic flight experiments

Hopping on granular media …

Straight hop (single axis)



45^o hop (two axes)

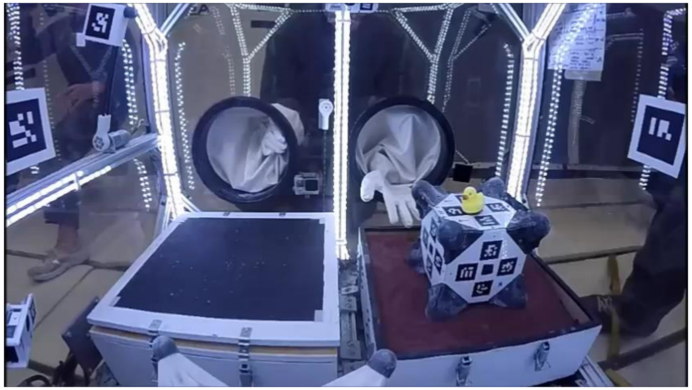
Even hopping on the moon!

Government sponsorship acknowledged

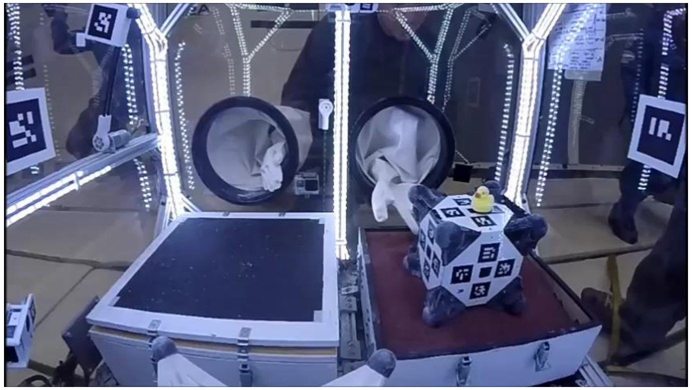
Zero-g parabolic flight experiments

Trying some more advanced maneuvers …

Tumbling



Yaw/Pointing



“Tornado” Escape Maneuver

Government sponsorship acknowledged

System Architecture

- Baselined for Phobos mission
- Leverages subsystems designed for JPL's interplanetary CubeSats
- 8U design, scalable from 1U to 27U

1. C&DH/Avionics

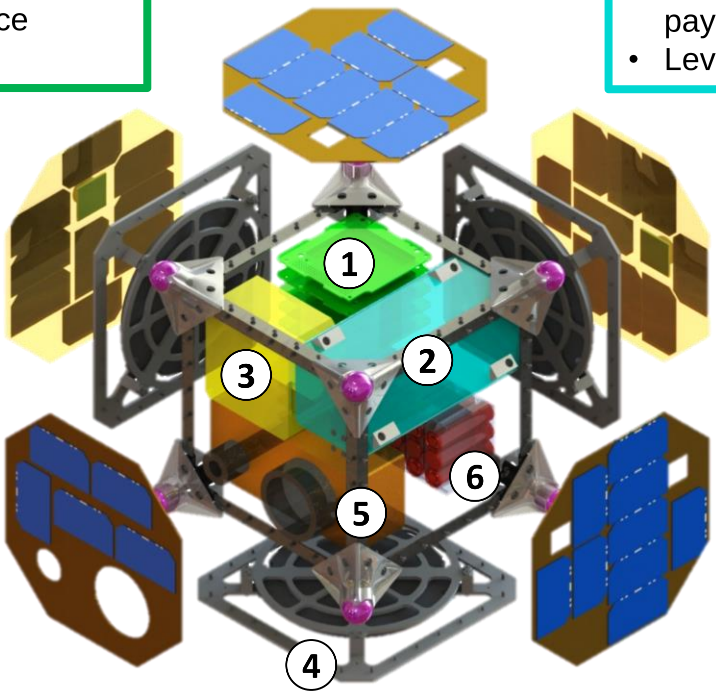
- JPL Interplanetary CubeSat C&DH Board
- Processing capability for semi-autonomous ops and agile science
- Leverages: NEA Scout

2. Cold Gas Propulsion (Optional)

- For soft landing from ~20m/s deployment
- Alternatively, volume can be used for payload or more batteries
- Leverages: INSPIRE, MarCO, NEAS

3. Telecom

- UHF or S band Relay to Mothership
- antennas embedded in frame
- Leverages: INSPIRE



4. GNC Sensors/Actuators

- 3 flywheels
- 3+ wide angle cameras
- Sun Sensors + IMU
- Star Tracker
- Leverages: JPL Visual Odometry frameworks & VSLAM algorithms

5. Science Instruments

- X-Ray Spectrometer
- Thermocouple
- Microscope
- Cameras + Accelerometers
- Leverages: APXS (Pathfinder/MER/MSL)

6. Electrical Power System

- Lithium primary and secondary batteries (>1000 W-h @12V)
- Optional solar panels
- Leverages: INSPIRE, MarCO, NEA Scout

Conclusions

Robotic Exploration of Small Bodies:

- Will be one of NASA's main focuses in years to come
- Requires disruptively new mobility approaches for microgravity environments

Spacecraft / Rover Hybrids:

- New paradigm for in-situ exploration of small bodies
- Technology to obtain new science at an affordable cost
- Proof of concept successfully demonstrated in simulations and experiments

Ongoing and Future Work:

- Planning and control for fine mobility on various surfaces
- (Synergistic) localization and navigation strategies for small body environments
- Mobility experiments in microgravity test bed and parabolic flights
- Mission formation trade studies

Questions

Publications

B. Hockman, A. Frick, I. Nesnas, and M. Pavone. Design, control, and experimentation of internally-actuated rovers for the exploration of low-gravity planetary bodies. In Conf. on Field and Service Robotics, Toronto, Canada, June 2015. **Best Student Paper Award**

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A. Koenig, M. Pavone, J. Castillo, and I. Nesnas. A dynamical characterization of internally-actuated microgravity mobility systems. In Proc. IEEE Int. Conf. Robotics and Automation, Hong Kong, China, June 2014.

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Current work funded by NSF and NASA under NIAC Phase II award
Previous work funded by NASA under JPL RTD, CIF, FOP, and NIAC Phase I award

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Instrument	IntelliCam	APXS	Microscope
Science Objective	Context imaging, surface navigation	Elemental composition	Regolith physical properties
Mass	500 gm	640 gm	500 gm
Power	2.5 W (peak)	1.5 W (peak)	2 W