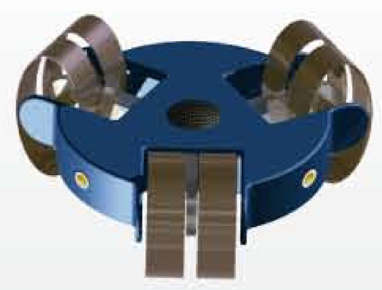
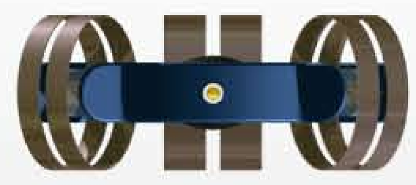
Scientific exploration of low-gravity planetary bodies using the Highland Terrain Hopper





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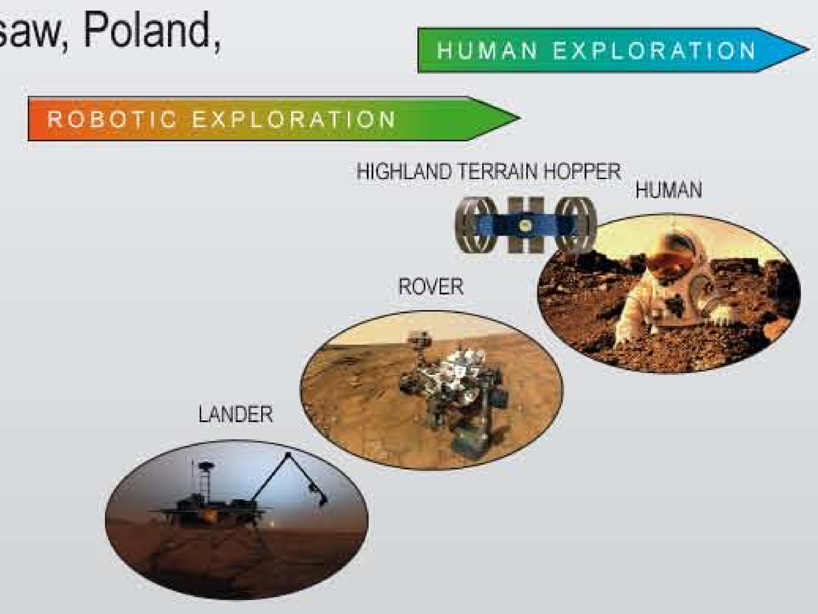


Access the inaccessible!

Highland Terrain Hopper: a cutting edge planetary locomotion system

Field geoscientists need to collect three-dimensional data in order to characterise the lithologic succession and structure of terrains, recontruct their evolution, and eventually reveal the history of a portion of the planet. This is achieved by walking up and down mountains and valleys, interpreting geological and geophysical traverses, and reading measures made at station located at key sites on mountain peaks or rocky promontories. These activities have been denied to conventional planetary exploration rovers because engineering constraints for landing are strong, especially in terms of allowed terrain roughness and slopes. The Highland Terrain Hopper, a new, light and robust locomotion system, addresses the challenge of accessing most areas on low-gravity planetary body for performing scientific observations and measurements, alone or as part of a hopper commando.

There are few limitations in the type of scientific payload conventional exploration rovers can carry, from geology and geophysics to geochemistry and exobiology. They lack two skills, however: the ability of working on uneven or unstable terrain, like in canyons and mountains, and on solid bodies having gravity too low for the friction between the wheels and the ground to generate robot displacement. ASTRONIKA Ltd. and the Polish Space Research Centre are designing the Highland Terrain Hopper, a small (diam 50-100 cm), light (5-10 kg), and low-cost jumping robot that may survey any type of landscape. It may assist other types of robots, or humans, in accessing difficult terrain, or even replace them for specific measurements or campaigning.

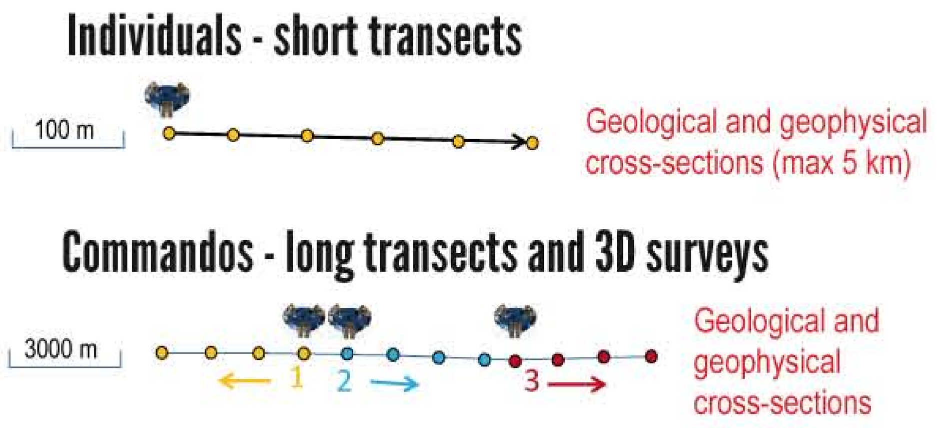
Hopper capabilities versus rover capabilities

	rover	Highland Terrain Hopper
Determination of study sites		
Select study sites on a scientific basis first, then fix engineering landing constraints	X (no)	● (yes)
Investigate any type of landscape	X (no)	● (yes)
Types of payloads		
Carry payload for observations	● (yes)	● (yes)
Carry payload for measurements	● (yes)	● (yes)
Carry payload for chemical analysis	○ (in general yes)	X (no)
Types of investigated geological surfaces		
Flat to shallow-dipping surfaces (0-30°)	● (yes)	● (yes)
Steep rocky surfaces (mountains) (>30°)	X (no)	● (yes)
Smooth terrain	● (yes)	● (yes)
Rocky terrain (fluvial, volcanic, periglacial, glacial, tectonic...)	X (in general no)	● (yes)
Unstable terrain (mass wasting processes, glacial processes etc.)	X (no)	● (yes)
Debris slopes	X (in general no)	● (yes)
Sandy areas	X (in general no)	● (yes)
Moving from one study site to another		
Study a succession of sites	● (yes)	● (yes)
Jump over topographic barriers (Mars, Moon)	X (no)	○ (in general yes)
Jump over topographic barriers (asteroids and small bodies)	X (no)	● (yes)
Move fast to in monotonous flat terrain to access remote outcrops behind	X (no)	● (yes)
Advanced scientific observation and measurement strategy		
Is robust enough to study seasonal changes	● (yes)	● (yes)
Perform continuous horizontal transects	● (yes)	● (yes)
Perform vertical traverses on stairstep topographic reliefs	X (no)	● (yes)
Perform horizontal transects of unlimited length for 2D underground probing	X (no)	● (yes) (1)
Perform geological and geophysical meshes for 3D underground probing	X (no)	● (yes) (2)

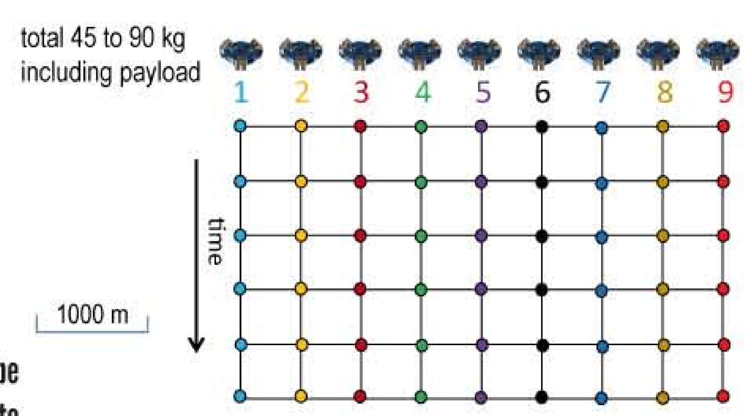
(1) single hopper or swarm deployment; (2) swarm deployment — yes ●; in general yes ○; in general no X (yellow); no X (red)

Individuals - short transects

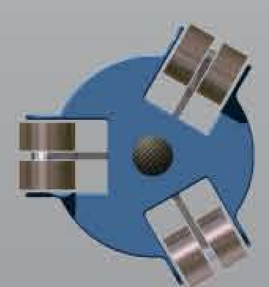
Displacement strategy



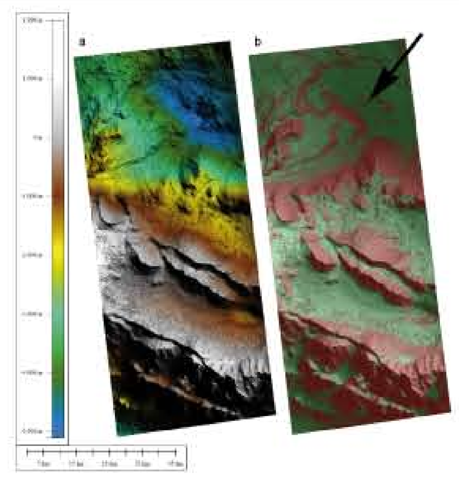
Vertical geological and geophysical profiles and 3-D views of the subsurface may be obtained from horizontal transects or grids, like for terrestrial surveys conducted to reveal crustal structures and investigate resources.



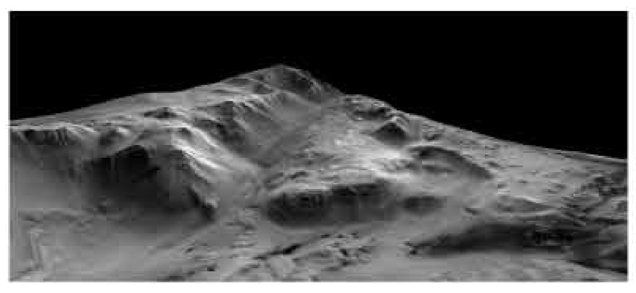
3D geometry and properties of subsurface



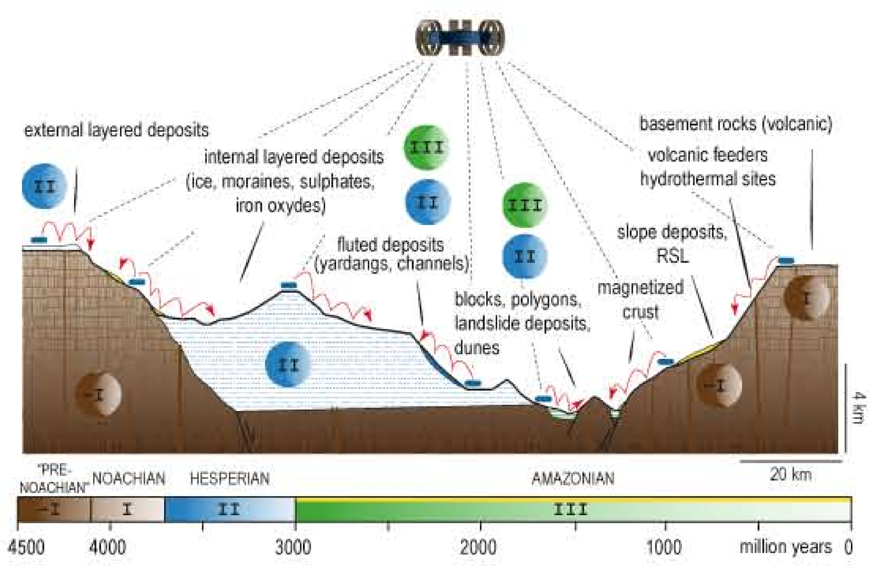
Exploring steep slopes



A Typical uneven Martian landscape: central Valles Marineris , Mars. Left: MRO/CTX Digital Elevation Model (calculated by A. Lucas, AIM Lab) and slope map. Slopes steeper than 30 deg., which are inaccessible to existing rovers, are displayed in red; the arrow indicates the viewing direction of the oblique view displayed on the right (MRO/CTX image G11 022567 1736 XI 06S074W).



Example of Martian investigations

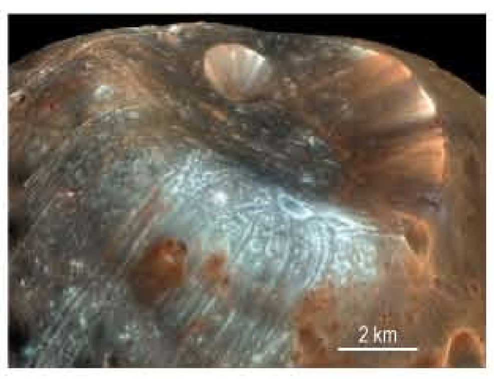


A Valles Marineris cross-section

The full stratigraphy of Mars, from the pre-Noachian [1] to some of the most recent deposits, may be obtained using a small swarm of hoppers dropped along a traverse going through one of the main Valles Marineris chasmata equipped with a payload including a visible-NIR multispectral camera and a clinometer. At the same time, data regarding rock fracturing, hydrogeologic and paleohydrologic conditions, paleogeography, paleoenvironments, soils and paleosoils, would be collected. Such measurements would provide helpful information as to early volatile delivery [2] and the very early climate, as well as assessment of past habitability. Hoppers carrying a ground-penetrating radar could probe the subsurface and look for buried ice; with geophones the present geologic activity and surface dynamics (slope processes, ice movement in rock- or dust-covered glaciers [3, 4], RSL [5] etc.) could be monitored and identified [6]; a magnetometer would provide the first in situ measurements of Martian rock magnetization induced by the early dynamo [7].

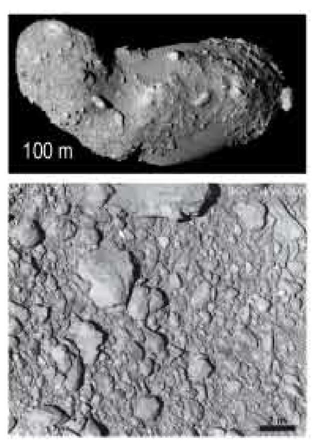
Natural satellites, asteroids, Near-Earth Objects

Jumping is the best locomotion method on these low-gravity bodies, where gravity is too low for friction to trigger displacement between the surface and wheels. Highland Terrain Hopper efficiency increases with decreasing gravity.



Phobos

Investigations of the rim and slopes of the Stickney crater, and the grooves and crater chains observed next to it in order to contribute to the debate as to their formation [8].



Asteroids and NEOs

Like for Phobos, rovers are not able to operate on such objects. In situ mobile exploration of asteroids both for scientific research and resource inventory [9] faces formidable challenges such as unpredicted terrain roughness and extremely low gravity. Hoppers capabilities are adapted to such harsh conditions.

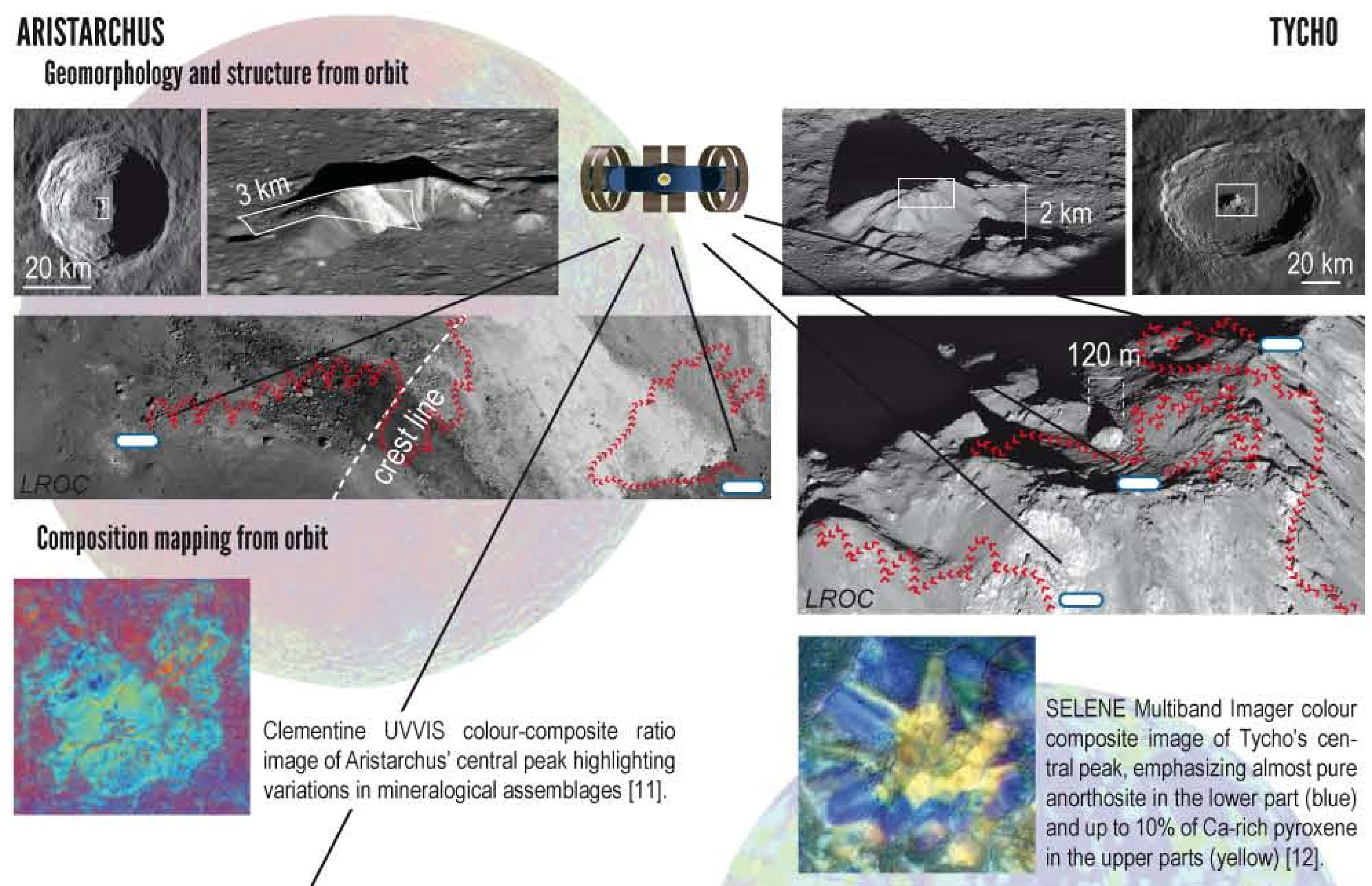
Asteroid 25143 Itokawa as viewed from Hayabusa in 2005. The surface is covered with boulders of various size.

Maximum jumping height and length is 1.5 m on Earth, corresponding to 4 m on Mars, 9 m on the Moon, and hundreds of meters or more on Phobos and asteroids.

Examples of lunar investigations

Two potential applications of Highland Terrain Hopper on the Moon: retrieving the structure and crustal rock succession from climbing lunar central peaks, and measuring the pristine orientation of lunar magnetic field in order to test for the first time if and when a dipolar lunar core dynamo was operating on the Moon [10].

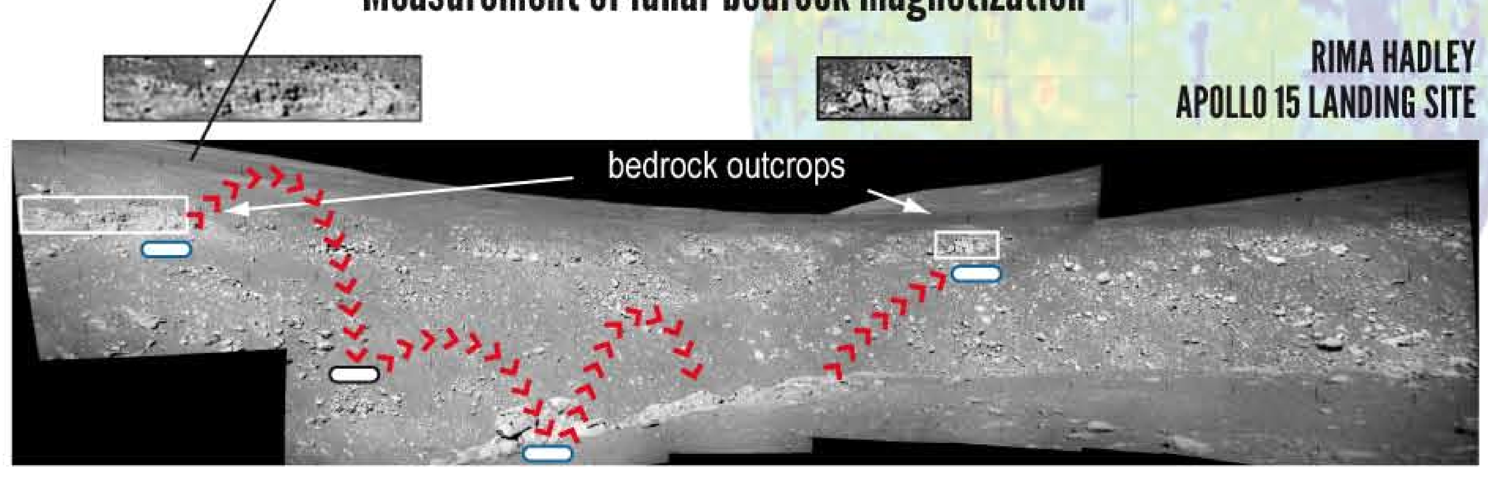
Geomorphology, structure and mineralogy of central peaks



Clementine UVVIS colour-composite ratio image of Aristarchus' central peak highlighting variations in mineralogical assemblages [11].

SELENE Multiband Imager colour composite image of Tycho's central peak, emphasizing almost pure anorthosite in the lower part (blue) and up to 10% of Ca-rich pyroxene in the upper parts (yellow) [12].

Measurement of lunar bedrock magnetization



Payload examples

Payload weight is limited to 3-5 kg per hopper. The payloads subsystems are integrated and miniaturized together with the main robot system in order to save weight; mobile parts are not allowed. A typical payload may consist, for instance in two to three of the following instruments: stereo visible and multispectral cameras, gamma-ray spectrometer, ground resistivity meter, and ground-penetrating radar; plus a clinometer, a SDT or AMR magnetometer, flashing LEDs, pressure, temperature, and humidity sensors.

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The Highland Terrain Hopper is at the stage of prototype development, laboratory testing and field testing (ESA Technology Readiness Levels 3 and 4)

ASTRONIKA CBK PAN ING PAN ASTC