Jet Propulsion Laboratory
California Institute of Technology

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GlobeTrotter

A Concept Airbag Hopper for Lunar Surface & Pit/Cave Exploration

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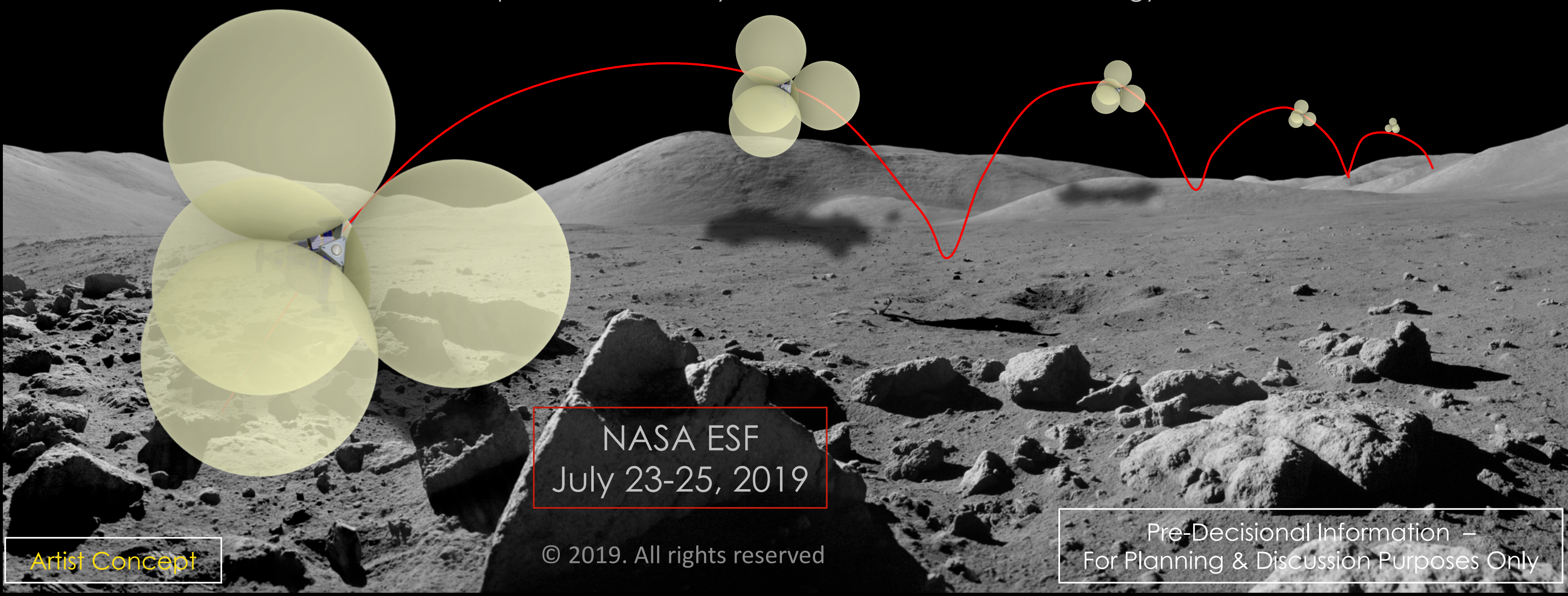


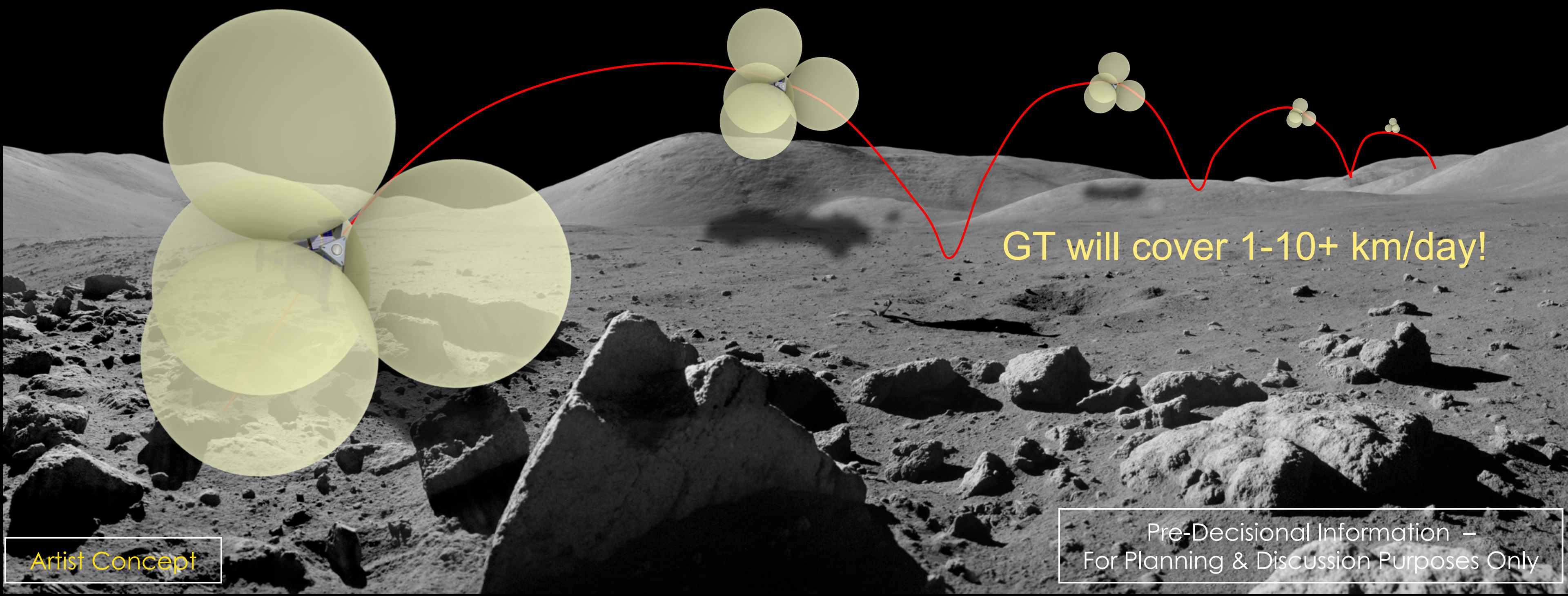
NASA ESF
July 23-25, 2019

Return to The Moon: The Challenge

- Moon Areas Visited: < 0.002%
- Highest Priority Science Sites = Difficult Terrain
  Basins, Craters, Volcanoes, Rilles, Pits/Caves, PSRs, ...
- Artemis: Astronauts at Lunar South Pole by 2024
- Precursors: Fill SKGs, Scout Landing Sites, Assess H_2O
- Need Rapid, Robust, Low-Risk, Low-Cost, All-Terrain Scouts

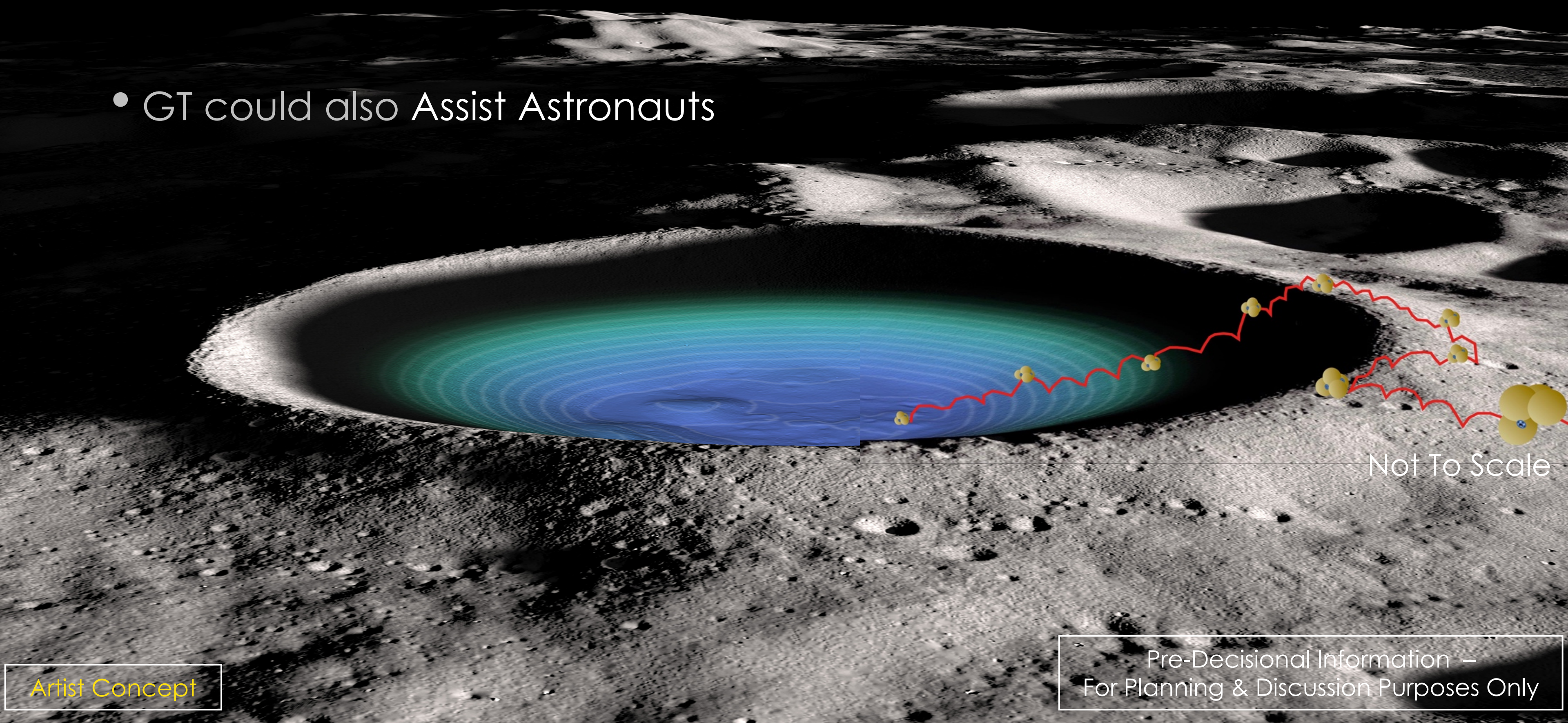
GlobeTrotter Concept

- GlobeTrotter: Concept for All-terrain Inflatable Airbag Hopper/Rover for Lunar (+ Other) Surface + Subsurface Exploration
- GT Roves by Leaps & Bounds via Cold-Gas Thrusters + Pop-n-Pounce
- GT can Fly w/ Directional Control, Fall, Roll, Tumble, Settle, Right itself
- GT: Fast, Robust, Low-Risk, Low-Cost, Versatile, Scalable, Networkable



GlobeTrotter To Shackleton

- Shackleton Crater at Lunar South Pole: D~20km, Z~4km, Slopes~25-33°
  PSR w/ Extensive H_2O Signature
- GT could Scout Shackleton's Rim + Interior + South Polar Landing Sites
- GT could Be to Artemis What Ranger & Surveyor Were to Apollo
- GT could also Assist Astronauts



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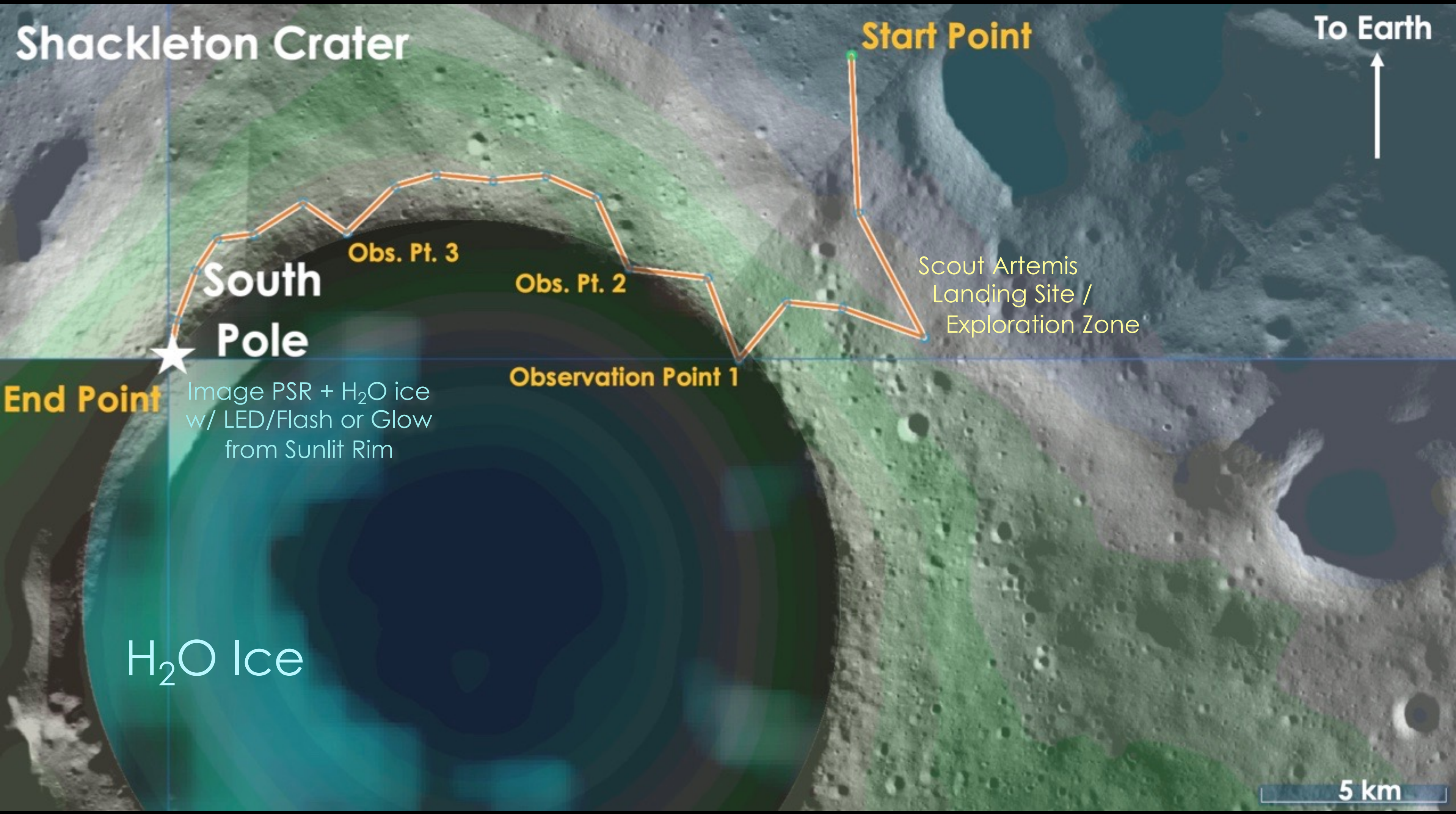
GlobeTrotter To Shackleton Rim



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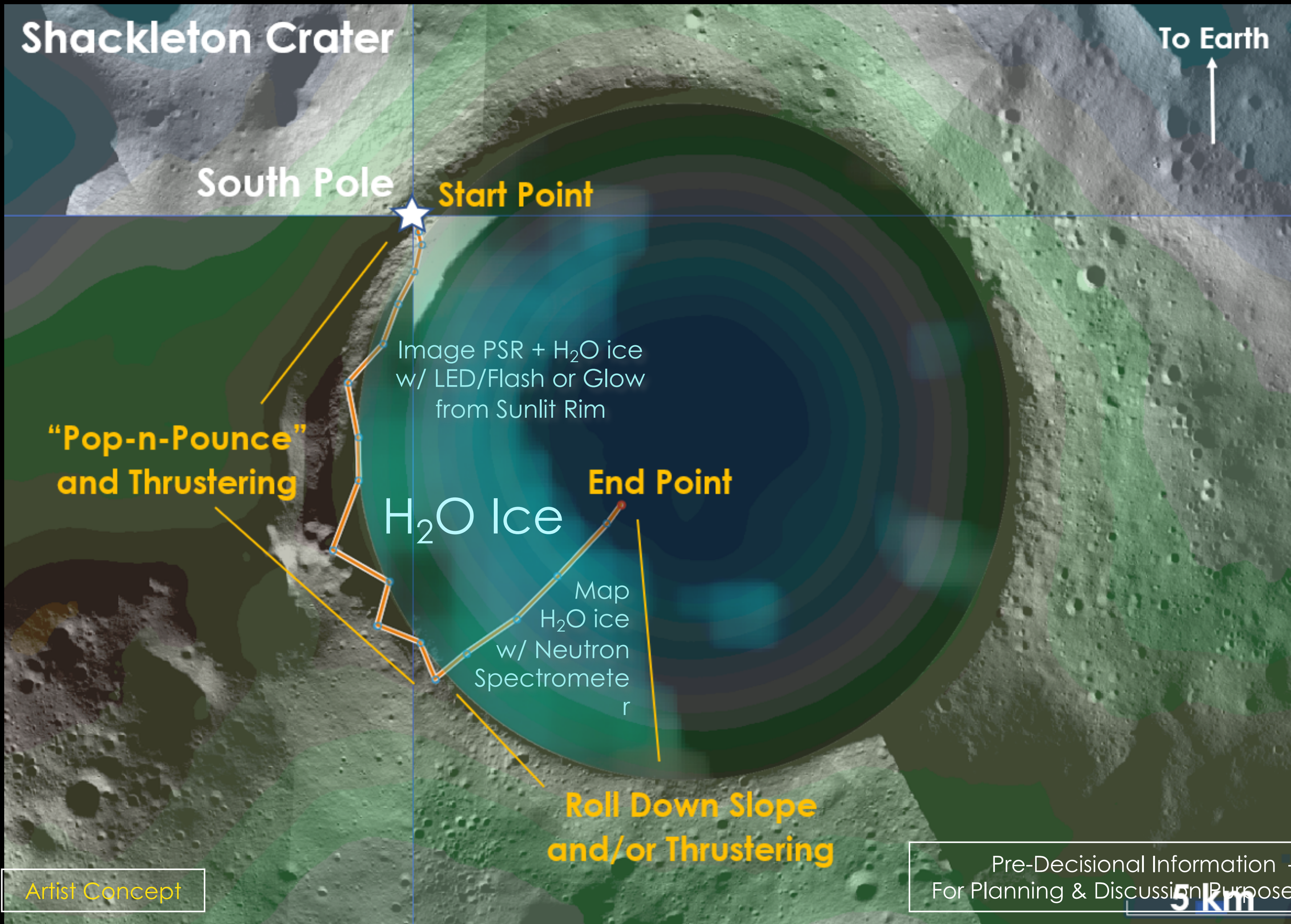
GlobeTrotter To Shackleton PSR



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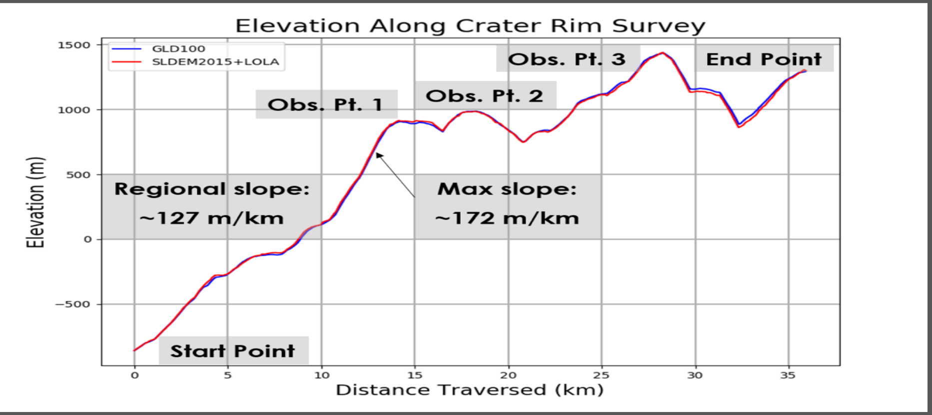
GlobeTrotter To Shackleton

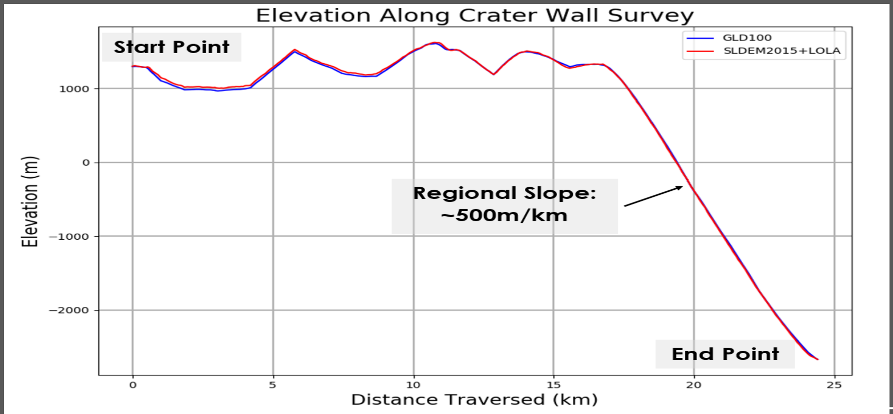
GT Specs & Performance Assumptions
- GT Mass: 50 kg, N2 tank: 10 kg, 4.5 kg N2
- 25% Energy Loss per Bounce
- PnP Max Range: (level ground): 400 m/hop
- PnP Max Height: 60 airbag diams ~ 120 m
- PnP Max Speed (level ground): 1 km/hr
- Max Range: indefinite with PnP; 2 km with thrusters only

GT Science Ops Assumptions
- Imaging, Neutron Spectrometry, Accelerometry
- Imaging (RGB Color) both In-Flight and at Stops
- Imaging LEDs allow Imaging inside PSRs
- Imaging for Geology + Charged Dust Transport Phenom.
- Neutron Spectrometry requires 30 min+ per Stop
- Direct To Earth (DTE) Comms and/or Relay (Other GT or Sat)

GT To Shackleton Rim
- Start Point in Safe Landing Area
- Recons Safe Human Landing Site(s) in Vicinity
- Observation Points are along PSR boundary on Crater Rim
- End Point at South Pole
- Distance Traversed: 35.9 km
- Duration: 7 days



GT To Shackleton PSR
- Survey of Crater Wall in and out of PSR
- Descent along Wall Section w/ Max Water Equivalent Hydrogen (WEH) to Maximize Ice Encounter Probability
- Descent along Earth-Facing Slope to Max DTE Comms.
- Distance Traversed: 24.4 km
- Duration: 5-6 days. (Final Descent: 1-2 days).



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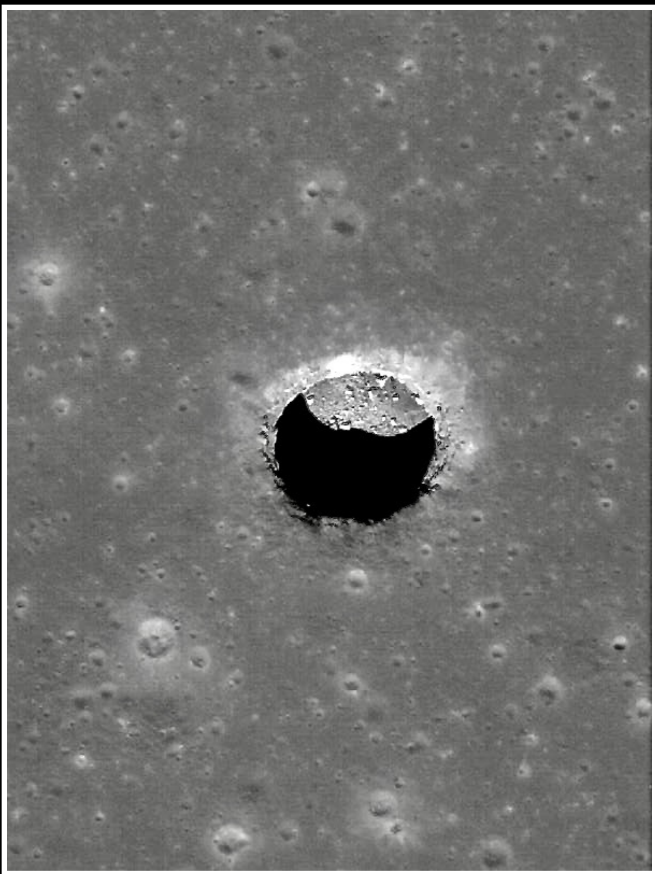
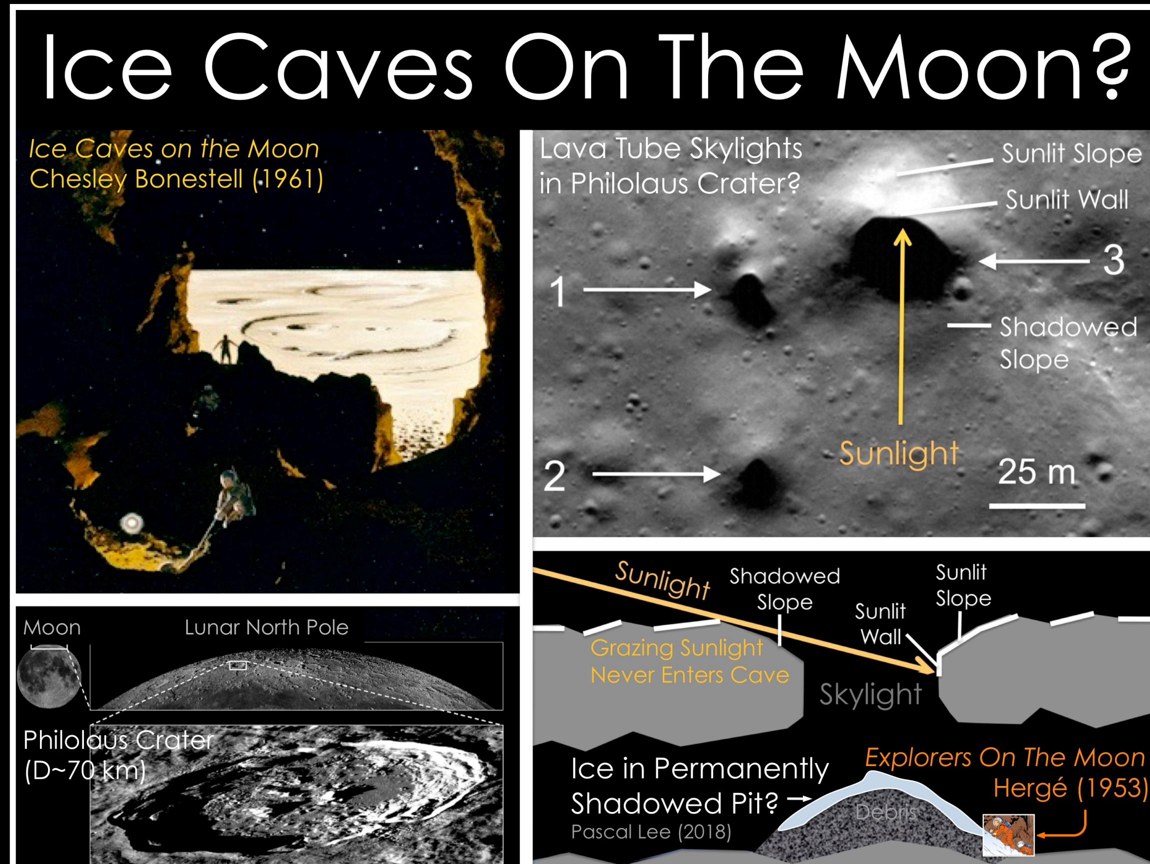
Pits/Caves on the Moon

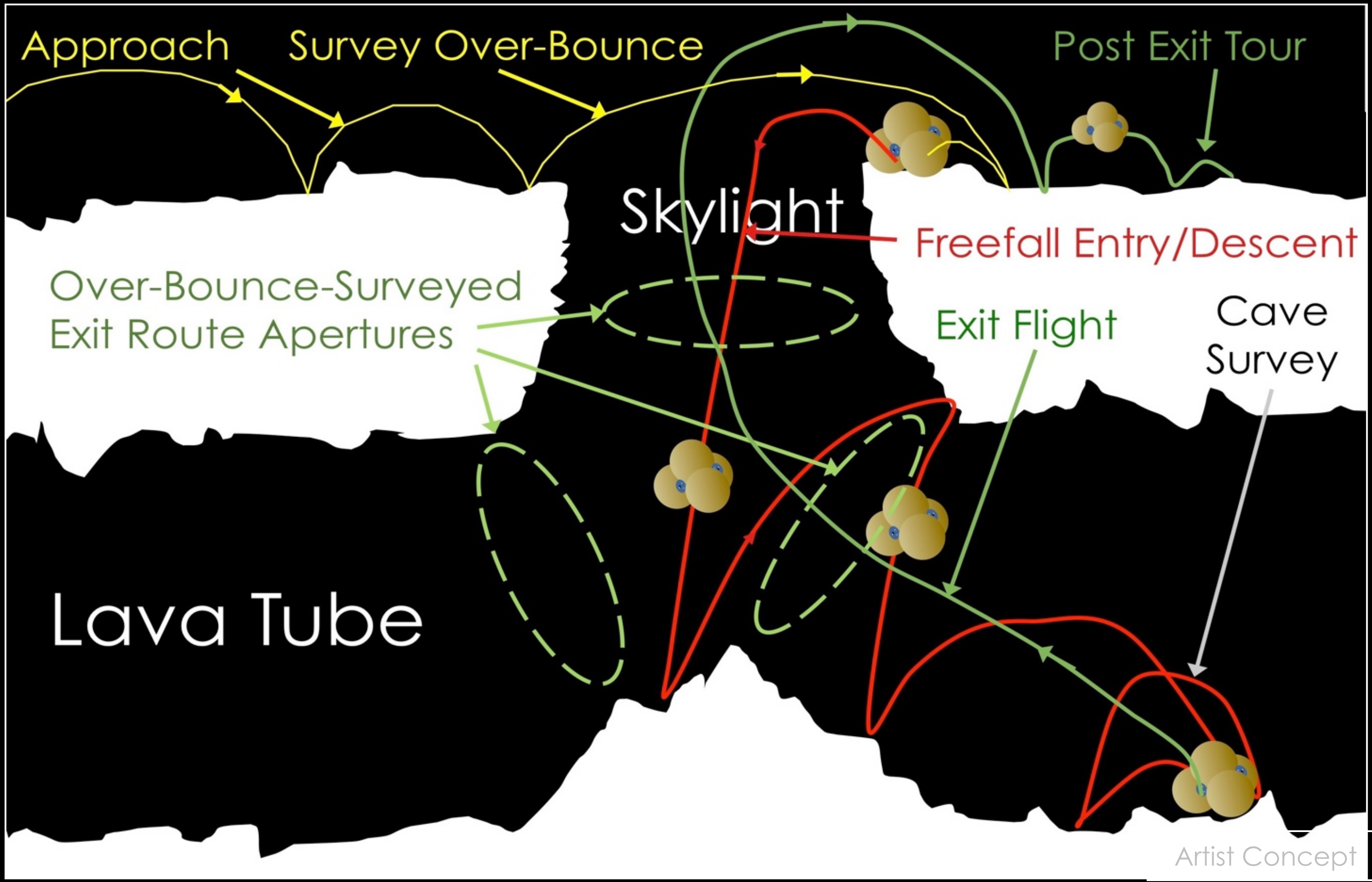
- Several Hundred Pits known on Moon. Many are Lava Tube Skylights.
- Caves = Shelters from Wide ΔT, Micrometeorites, Radiation, Sandblasting.
- Candidate Pits/Caves at 72°N = Mini PSRs? Might Cold-Trap H_2O Ice.





GlobeTrotter Into Pits/Caves

- Cave Challenges: No Sunlight, Low T, No Direct Comm, Unknown Rough Terrain
- GlobeTrotter: Robust "EDL", Brief Stay, Rapid Survey, Post Exit Tour Continuation



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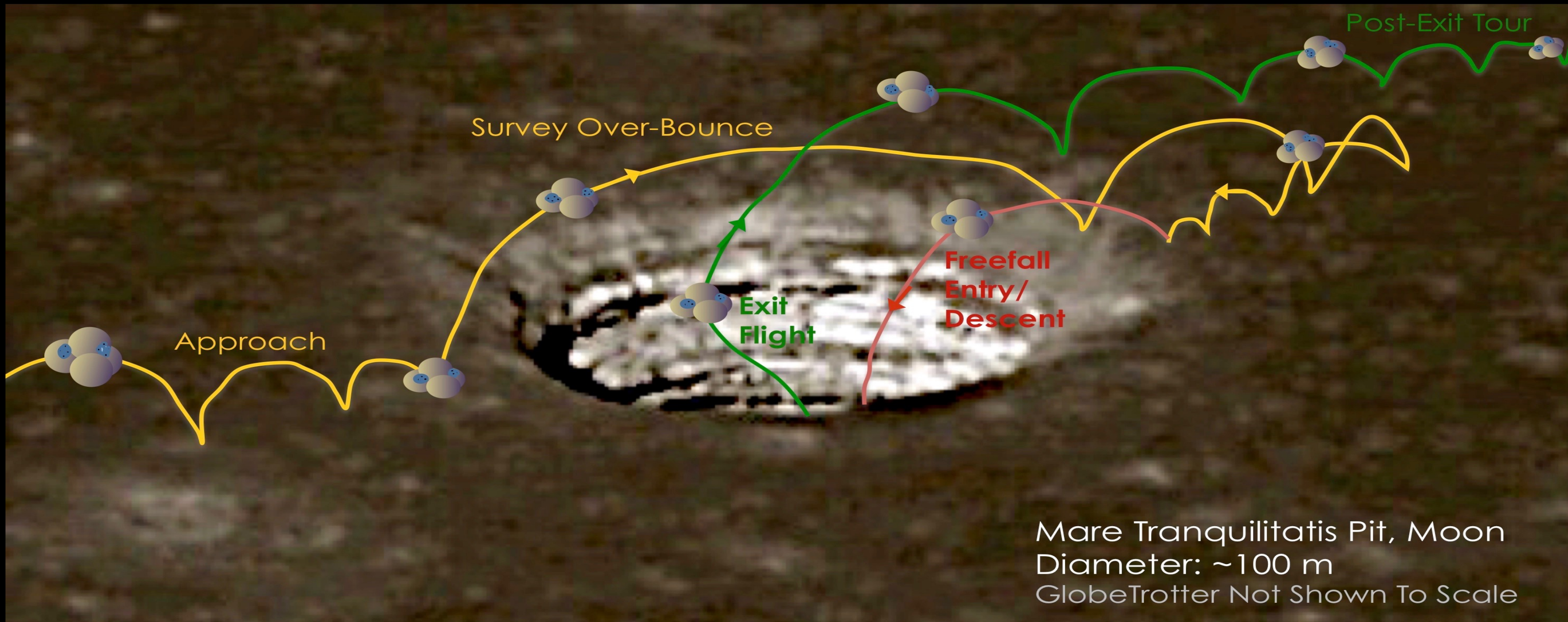
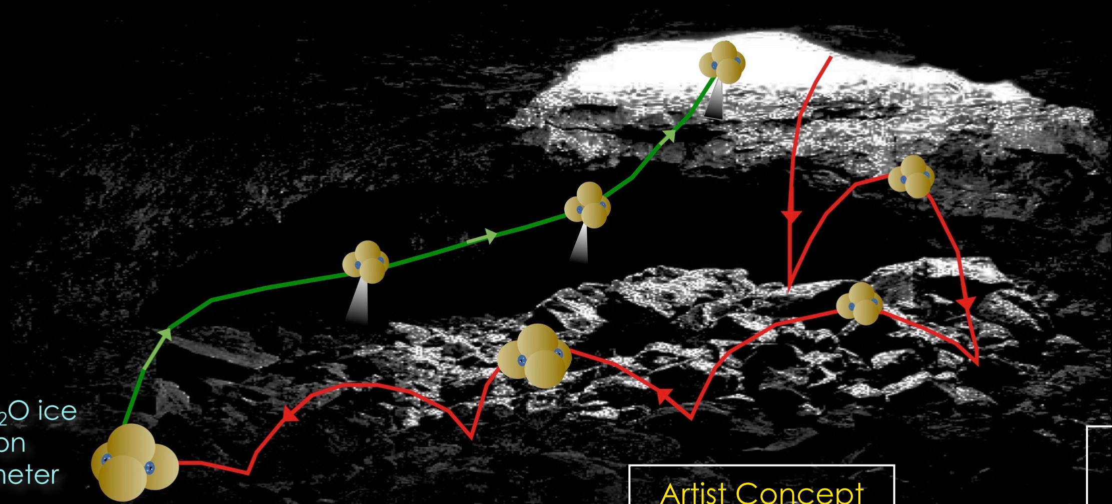
GlobeTrotter Into Pits/Caves





Image/Model Pit/Cave During "Entry/Descent/Landing"

Detect H_2O ice w/ Neutron Spectrometer

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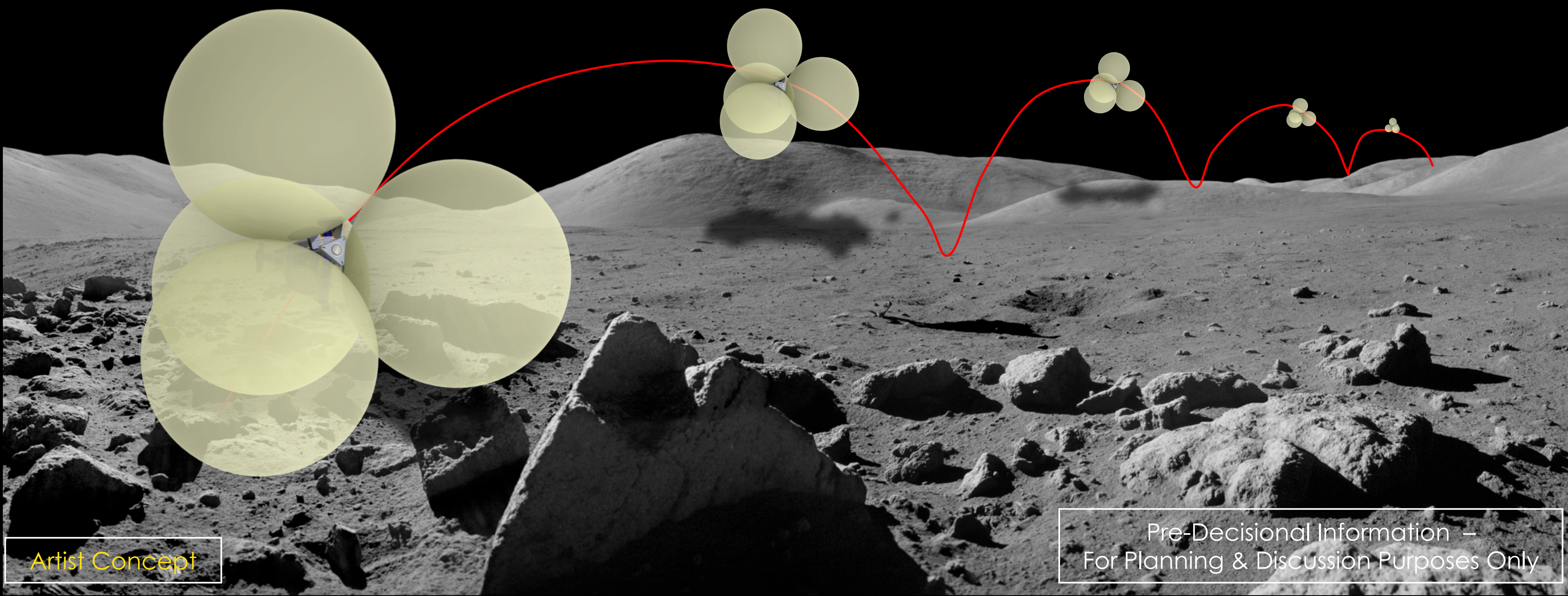
Science & Exploration Payload

- **Color Imaging** — Geology, Surface Physics, Atmosphere
  Wide-angle RGB Color (Bayer pattern) w/ LED Lighting + Long Exp.
  FOV 80+°, <28 mm, 10+ Mpxl, CMOS – Many COTS Options.
- **Neutron Spectrometry** — Hydrogen (H_2O, OH) + Regolith Bulk Composition + Radiation
  Two NASA-Provided Lunar Payloads are neutron spectrometers:
  NSS (1.89 kg, 2W) + NS (2 kg, 10W) – Avail March 2020.
- **Accelerometry** — Slopes, Topography, Gravity, Gravity anomalies
  Part of spacecraft systems payload.



Exploration Science Traceability

Goal	Category	Objectives	Visible Camera		Neutron Spectrometer		Bolometric Radiometer	Accelerometer
			Color Imaging	Surface Albedo	Epi-thermal	Thermal		
Evaluate Potential Human Exploration Targets	Local Surface Geology	Characterize Surface Features	●	●				
		Characterize the Dynamics of Surface Materials in the Terminator Zone	●	●				
		Determine the Composition of Surface and Near-Surface Materials			●	●		
		Establish Local Gravimetry						●
	Permanently Shadowed Regions at Lunar Pole	Characterize the Geology and any Surface Exposures of H_2O ice	●	●				
		Characterize the Physical Environment	●	●			●	
		Determine the Composition of Surface and Near-Surface Materials, and the distribution of any H_2O			●	●		
		Characterize the topography (slopes, terrain roughness)	●	●				●
	Pits/Caves	Characterize the Geology and any Exposures of H_2O	●	●				
		Characterize the Physical Environment/ Topography Inside of Pits/Caves	●	●			●	●
		Determine the Composition of Materials, and the distribution of any H_2O			●	●		

GlobeTrotter – Moon

GT Relevance to LEAG SKGs

SKG Theme	SKG Cat.	GT Contributions
I. Lunar Resource Potential	C. Regolith 2	Quality/quantity/ distribution/form of H species and other volatiles in mare and highlands regolith
		Preservation of volatiles & organic components during robotic & human sampling, handling, storage, curation
	D. Polar	Geotechnical characteristics of cold traps
		Physiography and accessibility of cold traps
		Charging and plasma environment within and near PSR
		Composition, form, and distribution of polar volatiles
		Temporal variability and movement dynamics of surface-correlated OH & H2O deposits towards PSR retention
	E. Pyroclastic Deposits	Composition/ volume/ distribution/ form of pyroclastic/dark mantle deposits & characteristics of associated volatiles
II. Lunar Env. & Effects on Human Life	B. Radiation at Lunar Surface	Radiation environment at lunar surface (measurement)
		Radiation shielding effects of lunar materials (measurement)

SKG Theme	SKG Cat.	GT Contributions
III. How to Work & Live on Lunar Surface	A. Resource Production	Tech. for excavation of lunar resources
		Tech. for transporting lunar resources
		Tech. for comminution of lunar resources
		Tech. for beneficiation of lunar resources
	B. Geodetic Grid & Nav.	Lunar geodetic control
		Lunar topography control
		Autonomous surface navigation
		Autonomous landing and hazard avoidance
	C. Surface Trafficability	Lunar surface trafficability- in-situ measurements
	D. Dust and Blast Ejecta	Lunar dust remediation
		Regolith adhesion to human systems and associated mechanical degradation
	E. Plasma Environment & Charging	Near-surface plasma environment and nature of differential electrical charging
		Energy storage – non-polar missions
	F. Energy Production & Storage	Energy storage – polar missions
		Power generation – non-polar missions
		Power generation – polar missions
		Lander propellant scavenging
	G. Radiation Shielding	Test radiation shielding technologies
	H. Micrometeorite Shielding	Test micrometeorite protection tech
	J. Habitat, Life Support, & Mobility	Fixed habitat
		Mobile habitat
		Semi-closed life support
		Human mobility

a — Key GT Contribution (May fill SKG)

a — Enhancing GT Contribution (May contribute to components of SKG)

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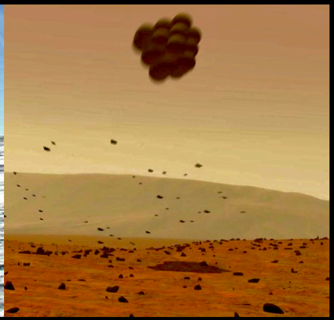
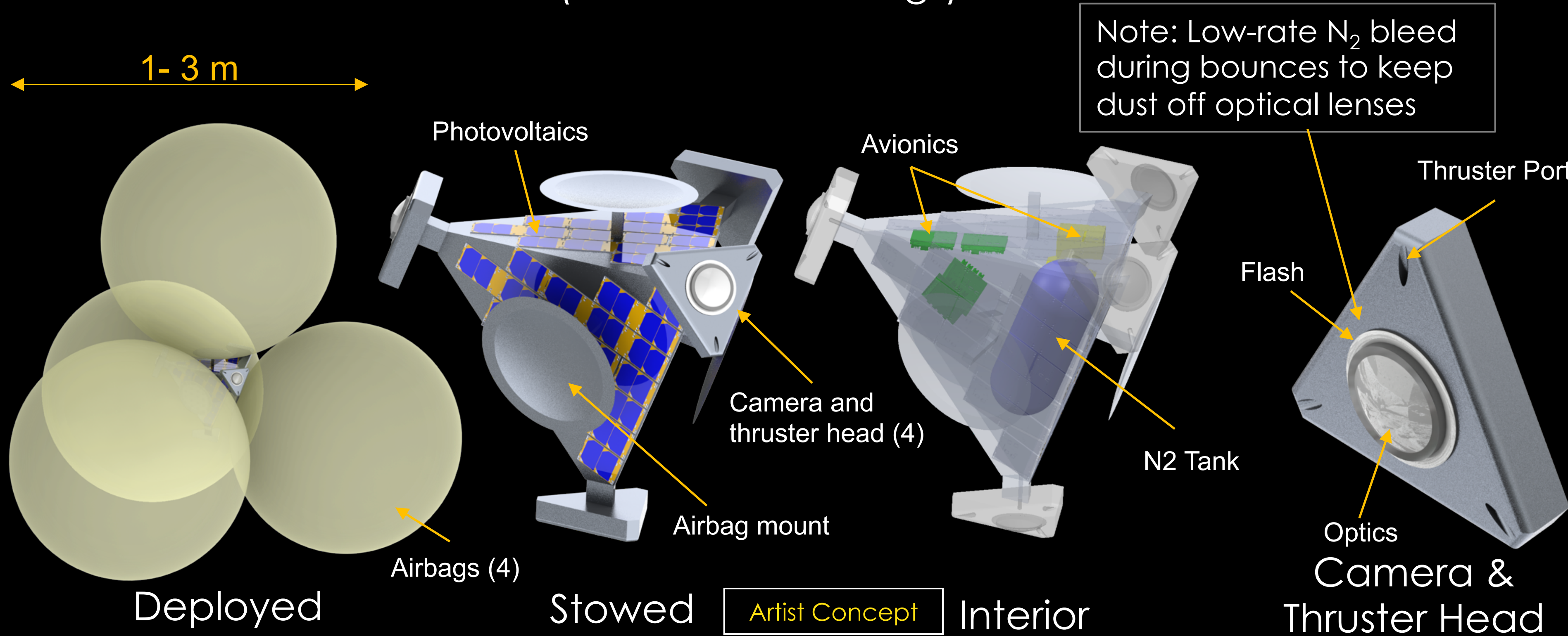
Pre-Decisional Information – For Planning & Discussion Purposes Only

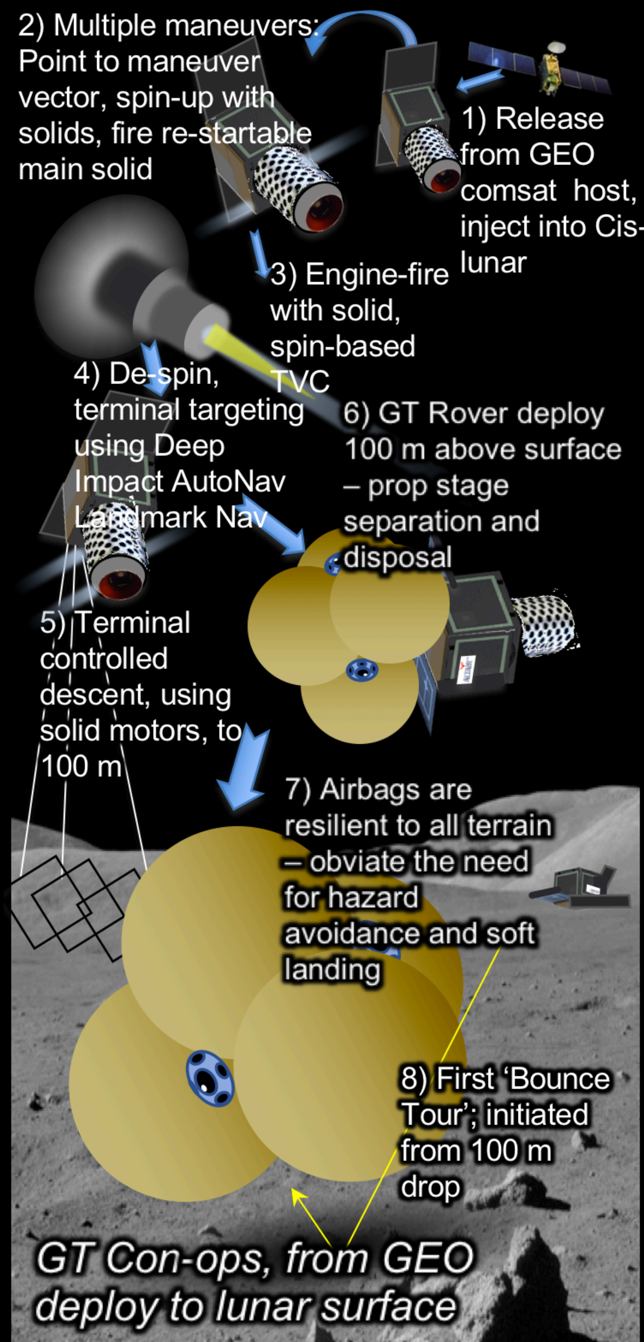
Lander System: Design Concept

- Heritage: NASA/JPL Inflatable Rover Studies
  Airbags: MPF, MER
  Avionics: COTS Space Micro/MarCO
- Propulsion: Cold-Gas Thrusters or ‘Pop-n-Pounce’
- Baseline Power Sys: Photovoltaics – (Translucent Airbags)





GT Con-Ops: GEO to Moon



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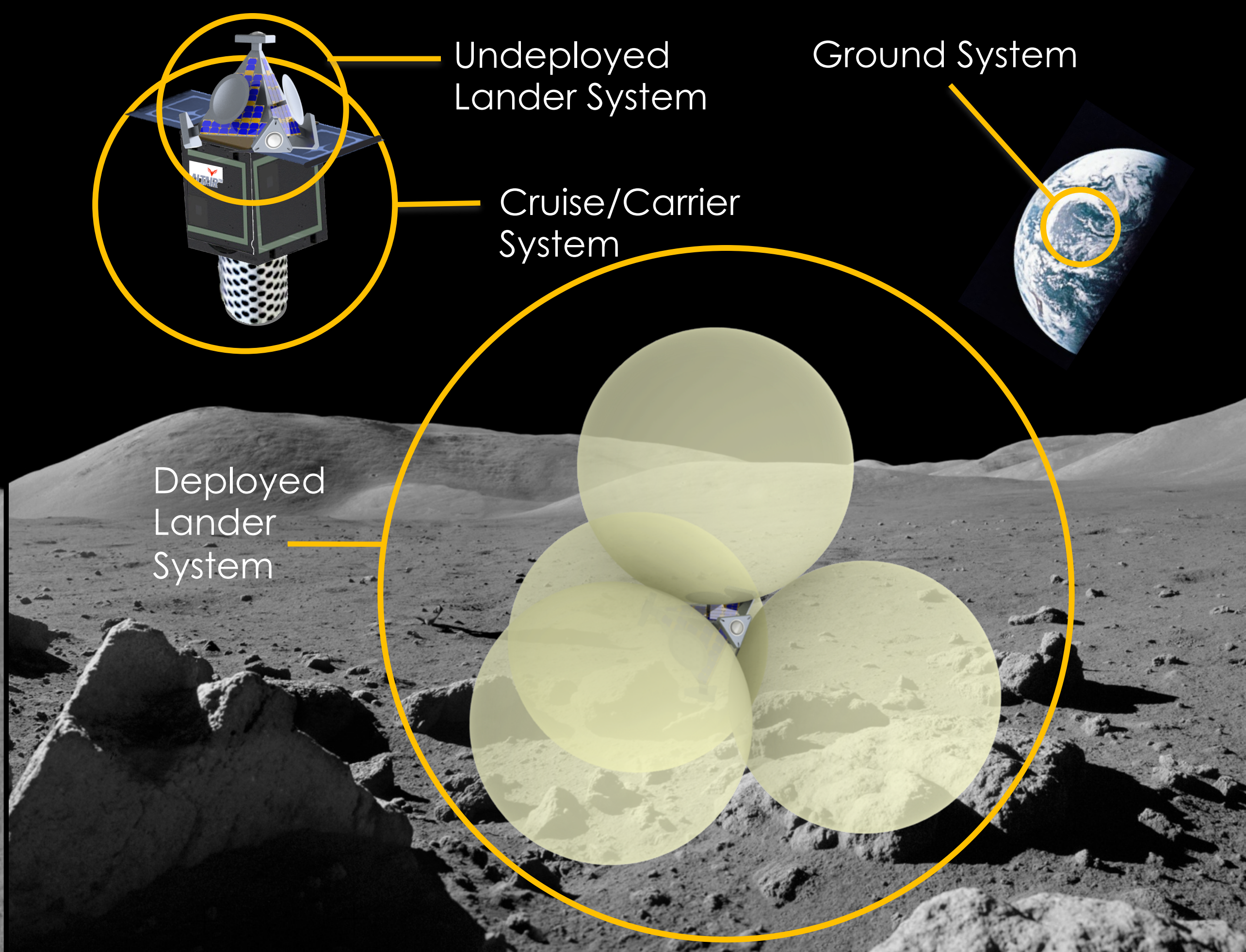
GT System

- GT System Elements are COTS or High TRL



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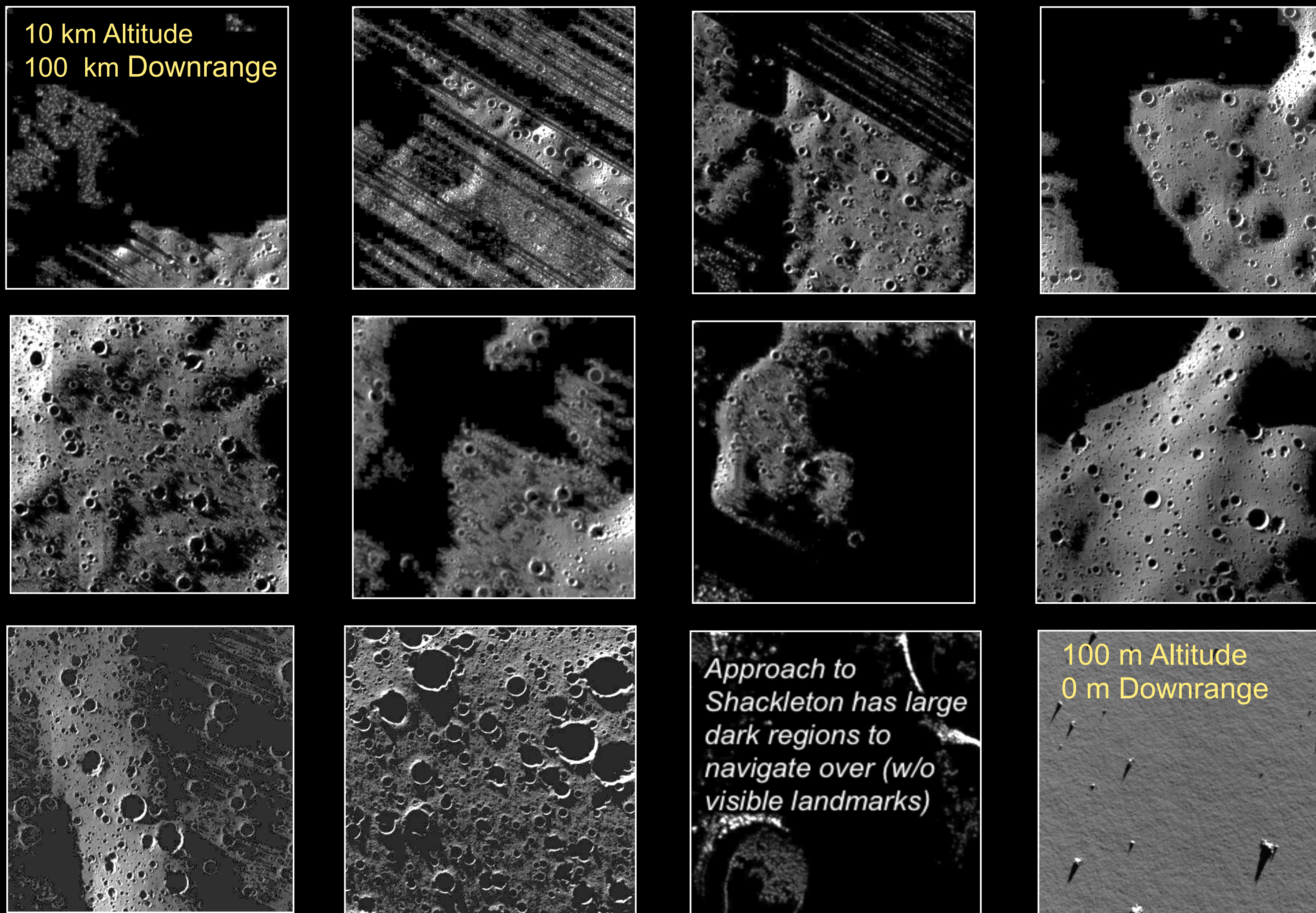
Shackleton AutoNav Landing Sim

- GT Landing Accuracy Sim: Meter-class Landing, Even in WInter

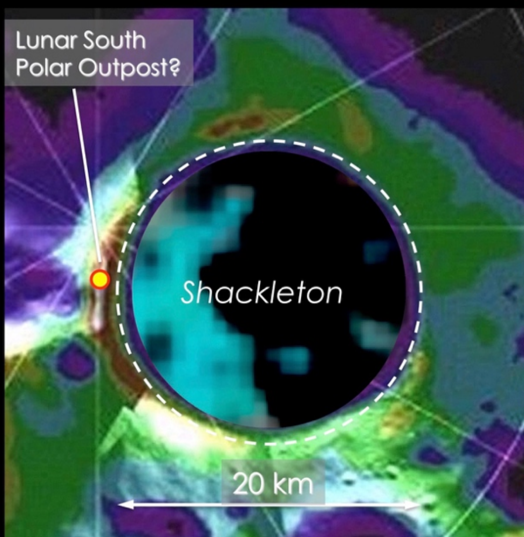


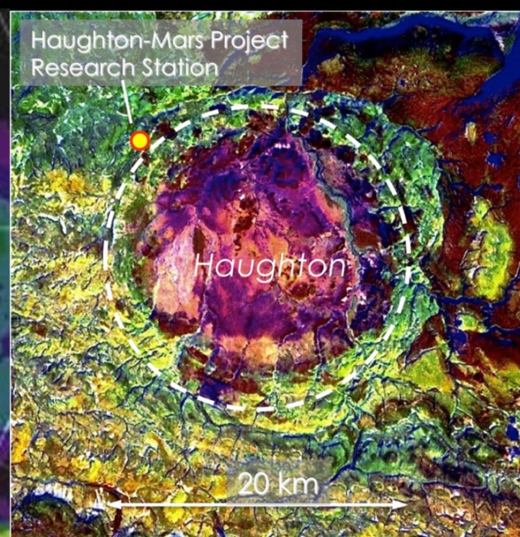
Analog Field Tests

- GT development might include field tests at relevant lunar analog sites, *e.g.* NASA HMP where infrastructure for Moon/Mars field tests already exists (used by Constellation).

Shackleton Crater vs Haughton Crater

South Pole, Moon — Devon Island, Arctic





	Shackleton	Haughton
Geologic Feature	Impact Crater	Impact Crater
Diameter	20 km	20 km
Terrain	Impact Rubble	Impact Rubble
Solar Power	Permanent (Rim)	Permanent (Summer)
H_2O Ground Ice	Yes	Yes
Comms Direction	Horizontal	Horizontal
Research Outpost	Yes (?)	Yes

Pascal Lee 2019

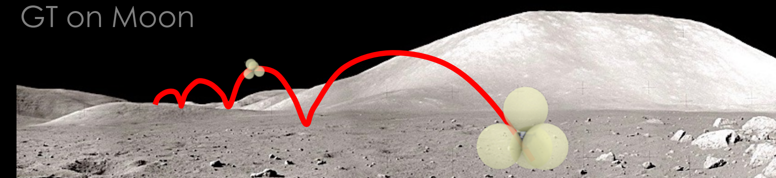
- Not just useful. Also engages public.

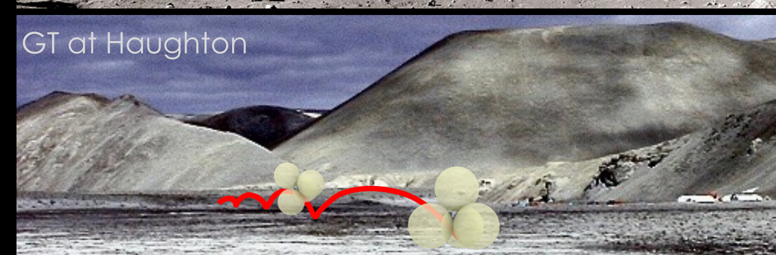
Moon

Moon
Apollo 17 – Taurus Littrow Valley

Haughton Crater, Devon Island
Valley of the Moon

GT on Moon





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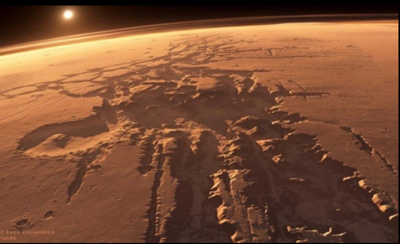
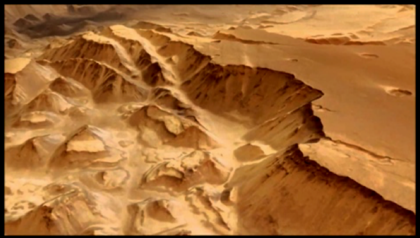
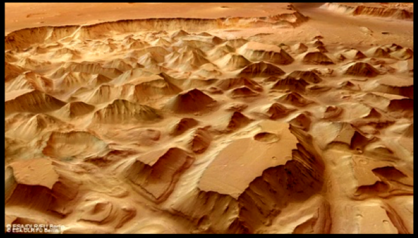
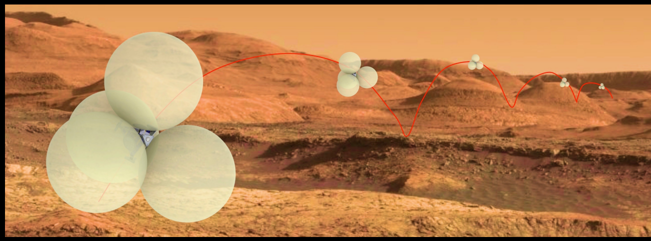
GlobeTrotter – Moon To Mars

GlobeTrotter On Mars

Extreme Terrain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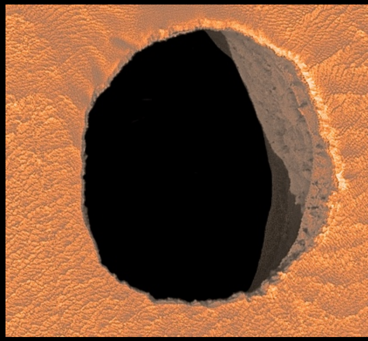
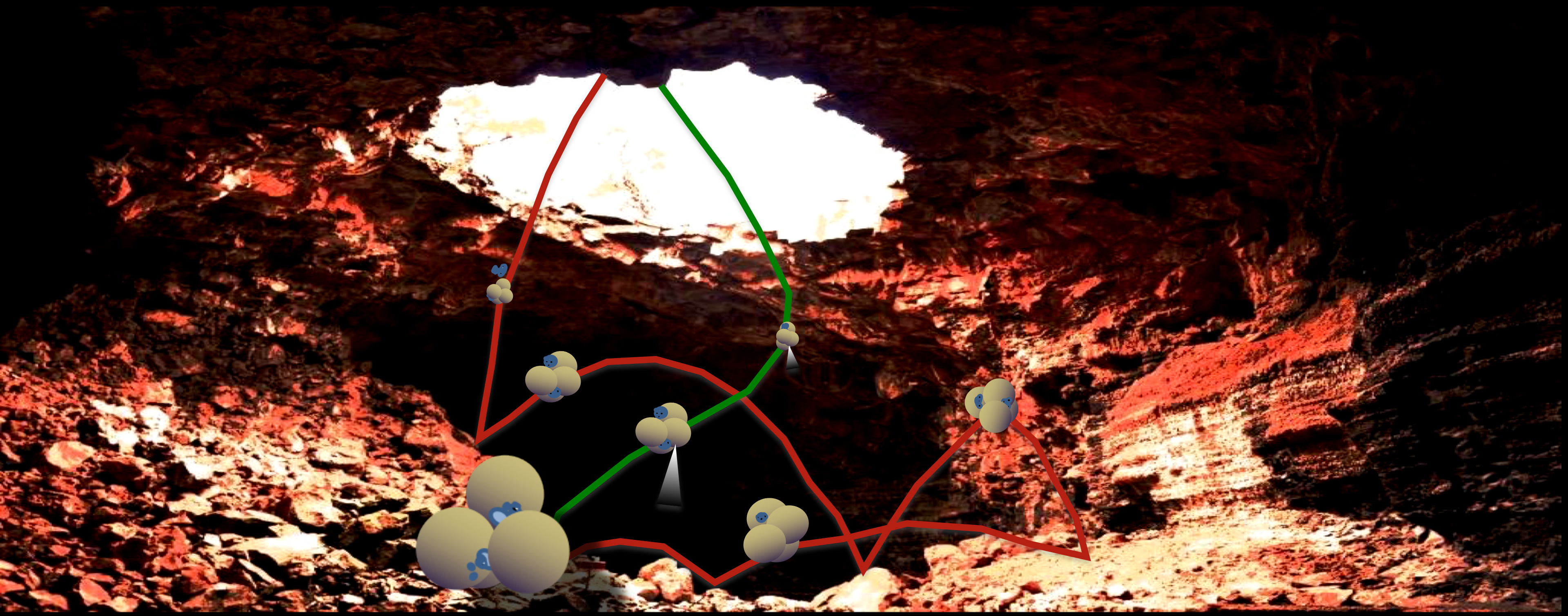
GlobeTrotter On Mars

Pit/Cave Exploration



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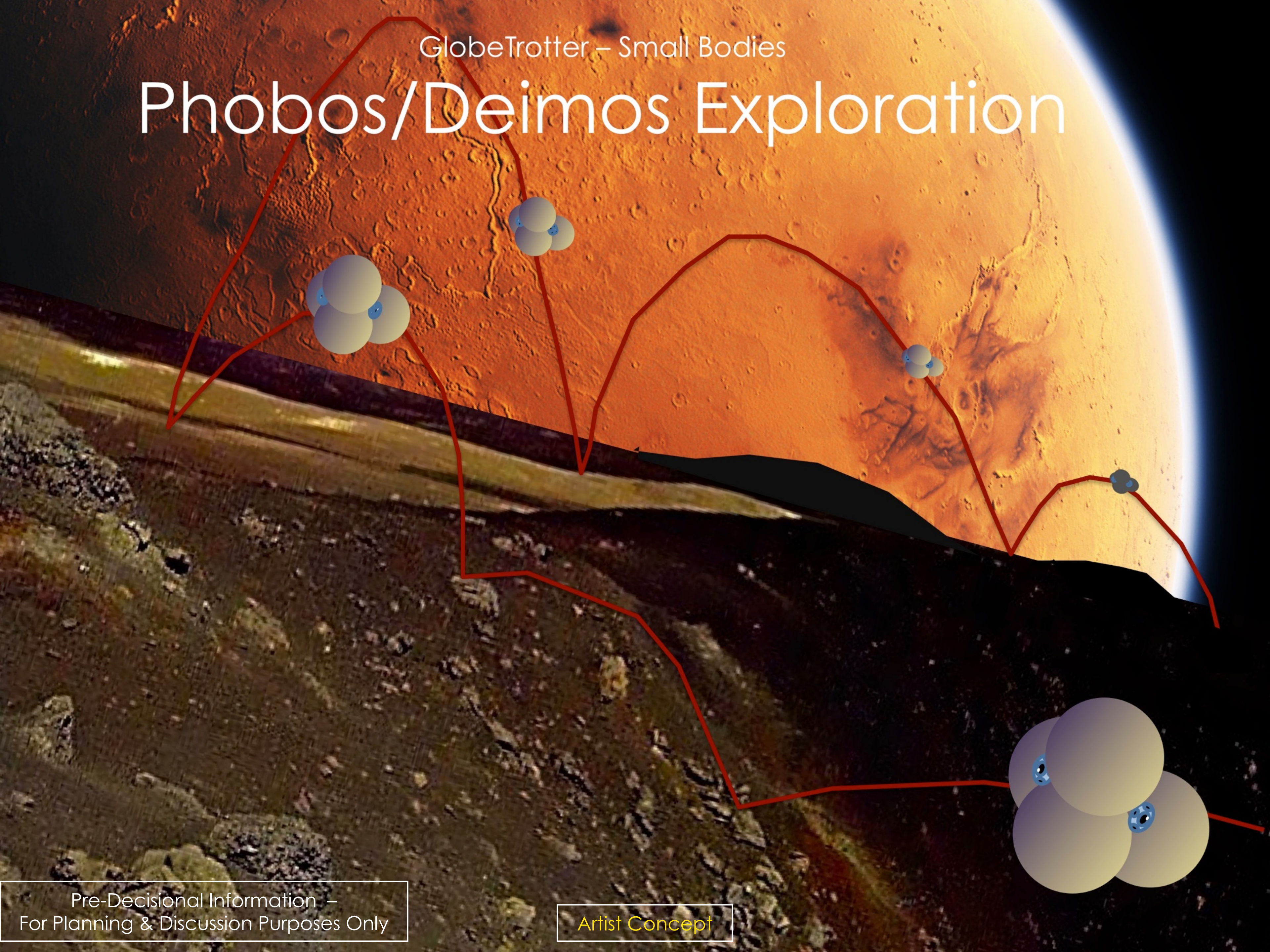
GlobeTrotter – Small Bodies

Phobos/Deimos Exploration



GlobeTrotter

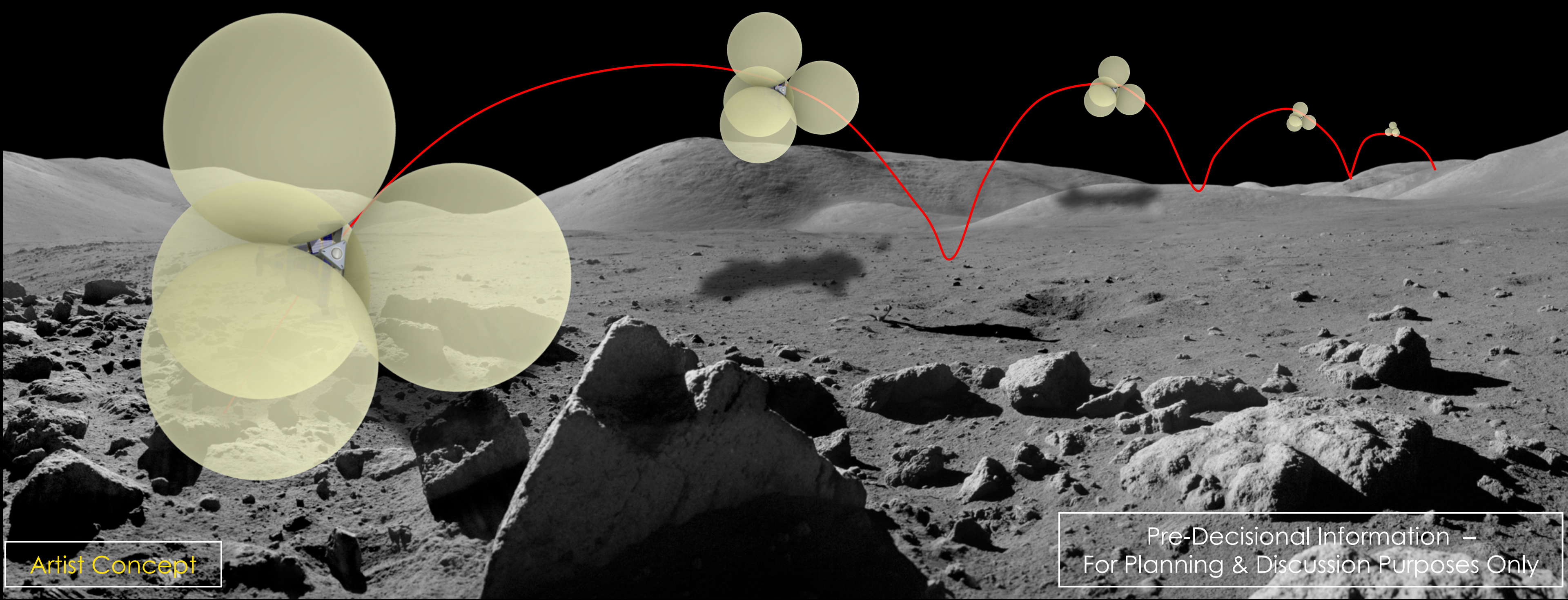
Conclusion

- GlobeTrotter: A "Universal" Lunar and Planetary Exploration Concept
- GT could begin Scouting for Artemis by 2021

- Fast
- Robust
- Simple
- Versatile
- Efficient

- Low Risk
- Low Mass
- Low Volume*
  * at launch
- Networkable

- Uniquely Capable
- Scientifically Far-Reaching
- Wide-Ranging (Surface)
- Deep-Probing (Subsurface)
- Engaging & Fun!



For More Information

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Publications

Lee, P., J. E. Riedel, L. L. Jones-Wilson, E. J. Brandeau, C. O'Farrell, J. C. Gallon, & R. S. Park (2019). GlobeTrotter: An airbag hopper for lunar surface and pit/cave exploration. *NASA Exploration Science Forum 2019*, NASA Ames Research Center, Moffett Field, CA, Jul 23-25, 2019. *Accepted*.

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GlobeTrotter

Next ~~Step~~ Leap