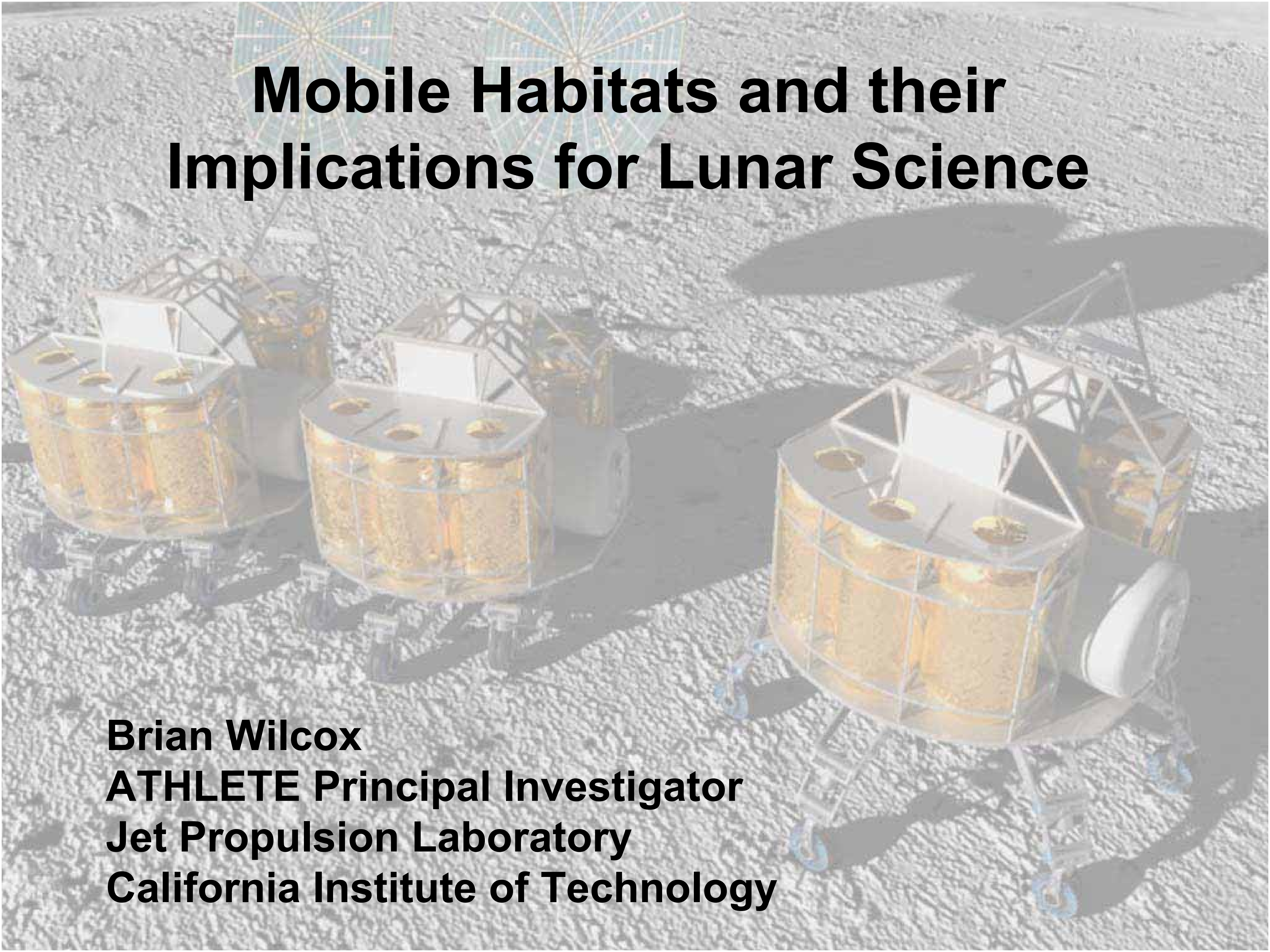

Mobile Habitats and their Implications for Lunar Science

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Why Mobility on Habitats?

- Landing debris ejecta moves at km/s, in every direction from the lander, sandblasting anything within “ballistic- line-of-sight”.
- Thus landing needs to occur beyond ballistic-line-of-sight from any valuable assets. Making berms or other structures that allow nearby landing is challenging.
- Assets need to move to the lander, or visa-versa.
- If assets are mobile, then landing can happen in a safe zone km distant from other assets, and then move to link up outside landing zone. Eliminates complex handing of heavy/bulky assets, cabling on surface, & outpost assembly.
- Almost “for free” this mobility enables global-scale scientific exploration of the moon.

Why Wheels-on-Limbs are a less massive way to achieve mobility...

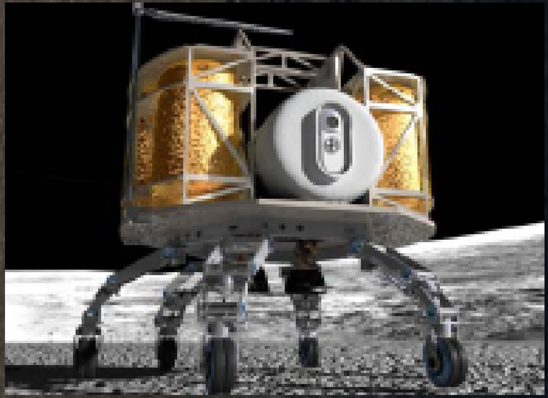
Design Parameter	Conventional Vehicle (that doesn't get stuck in 4σ terrain)	Wheel-on-Limb Vehicle (rolls in 2-σ terrain; walks in extreme terrain)
Ground pressure	~1 PSI (e.g. Apollo LRV, MER)	~4 PSI (saves 2x each in radius and thickness; 8x mass)
Stall Rim Thrust	Each wheel needs rim thrust=50% of total vehicle weight	All wheels combined = 50% of vehicle weight (~12x mass savings for actuators, since radius is less)
Suspension	Each wheel may need to bear up to 50% of total vehicle weight	No wheel needs to bear more than 20% of the total weight, and each can be lifted whenever necessary

- Mass savings for wheels, wheel actuators, and suspension components more than "pays" for all limb actuators – allowing general-purpose manipulation and mobility >4-σ for "free".

Of course you would have mobility, if it were free...

- Current estimates are that, using a conventional (e.g. Mars Exploration Rover) mobility system, making a 20-ton vehicle mobile on the moon requires 10.9% of the vehicle mass for mobility.
- Using ATHLETE to make the same system mobile requires 7.4% of the total mass.
- A lander that can shed mass before full-performance mobility is needed (e.g. rocket engines, tanks, etc.) might use as little as 5% of the landed mass for the mobility system.
- The deployed landing gear on Apollo was 2.7% of landed mass. Some or all might overlap with mobility.

Latest Developments in Architecture Features



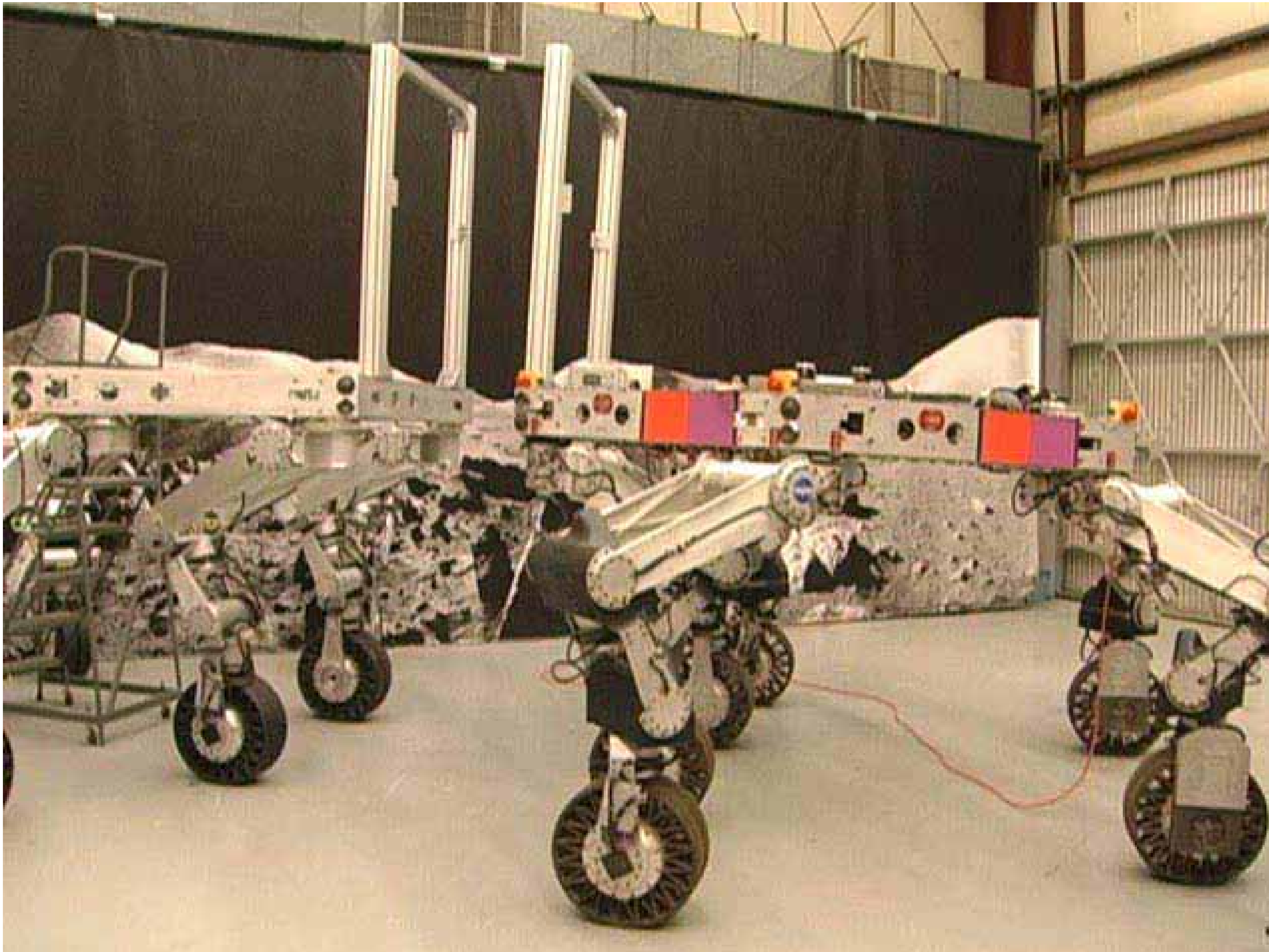
- **Habitat(s) on cargo lander (2-3)**
  - **Earlier operations**
  - **Less assembly**
- **Early Pressurized rovers-**
  - **More effective and productive crew**

- **Mobility to move landers/habs**
  - **Concentrates used landers for scavenging**
  - **Provide for placement of large surface elements**
- **Super sortie mode-** Land crew at other locations and provide enhanced capability
  - **Mobile hab- traverse to other sites - long distances**
  - **Pressurized rover**

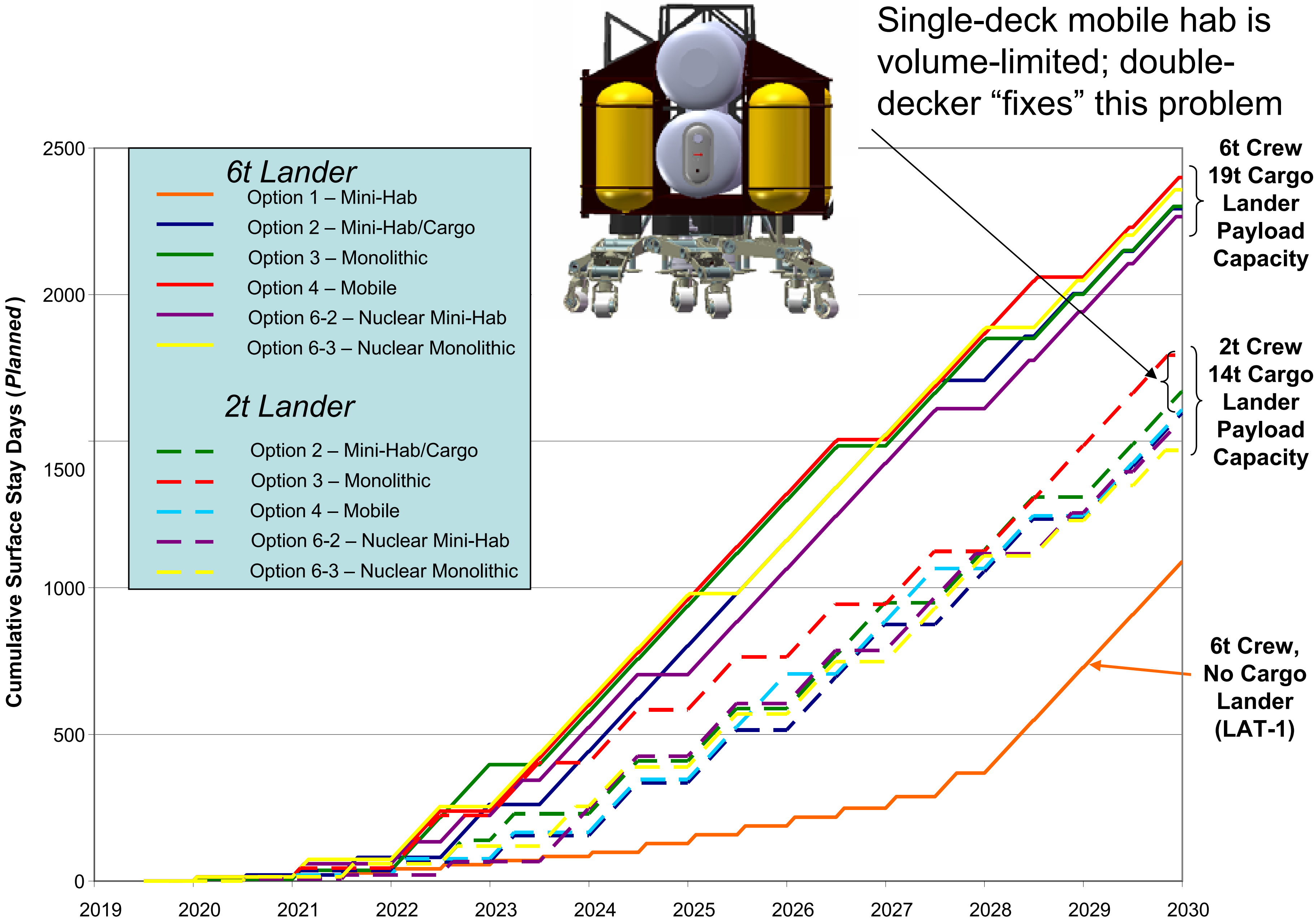
  - **10 Meter Shroud for ARES V-** Better Lander configurations

Option 4 – Mobile Lander

- *Can use mobility to assemble outpost elements but carries a penalty*
- *Challenge is to maximize benefit of lander mobility*



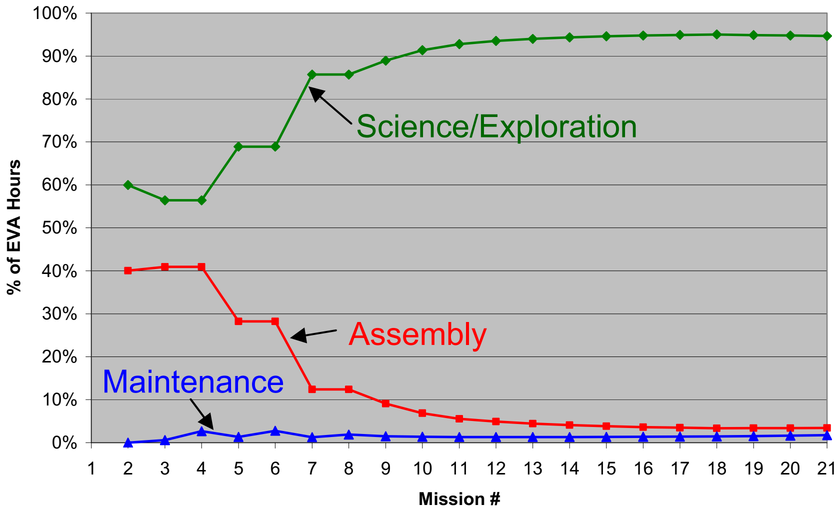
Single-deck mobile hab is volume-limited; double-decker “fixes” this problem



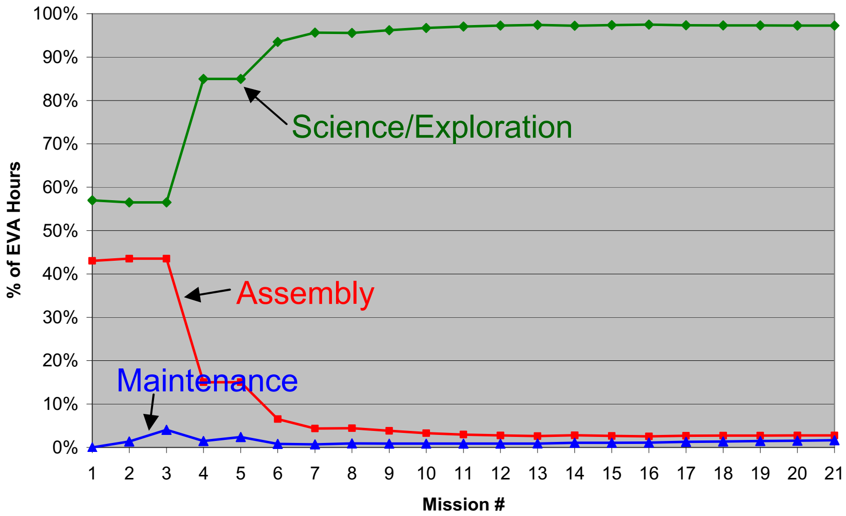
Crew surface time does not favor any one option over another but cargo lander greatly facilitates build up

Crew Time Utilization, Mini-Hab vs. Monolithic vs. Mobile

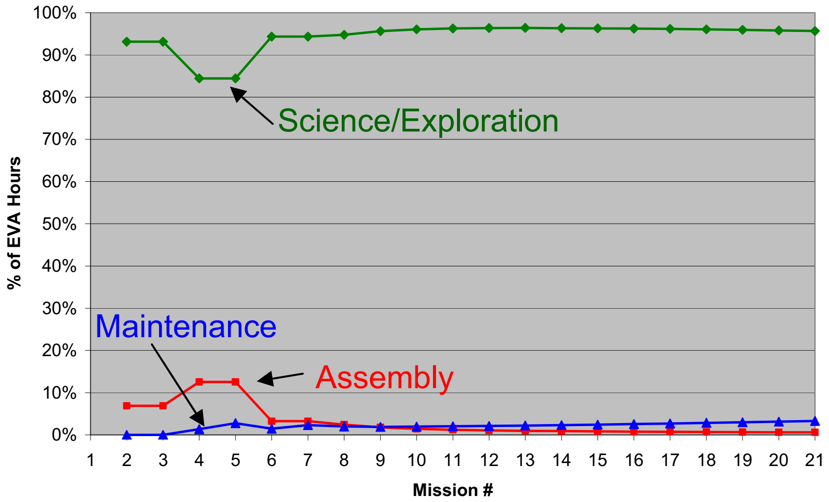
Option 2 – Mini-Hab



Option 3 – Monolithic



Option 4 – Mobile Lander

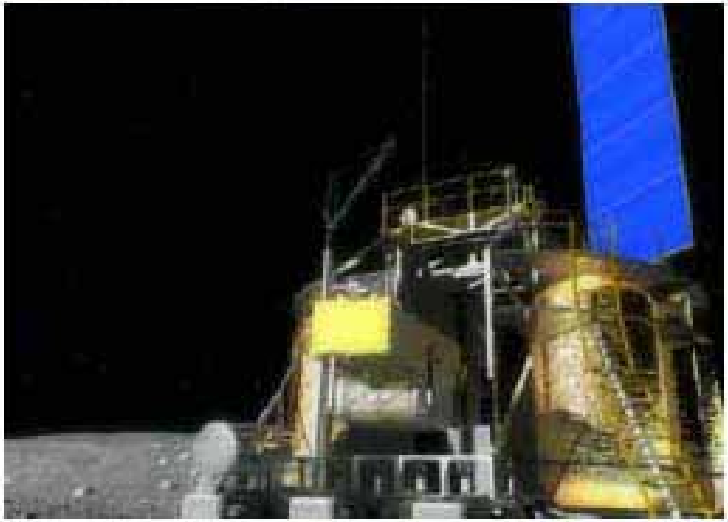


Early Assembly and Maintenance can be significant for construction of a mini-hab outpost

A large proportion of time is still available for exploration

Unloading and Transportation of Large Elements

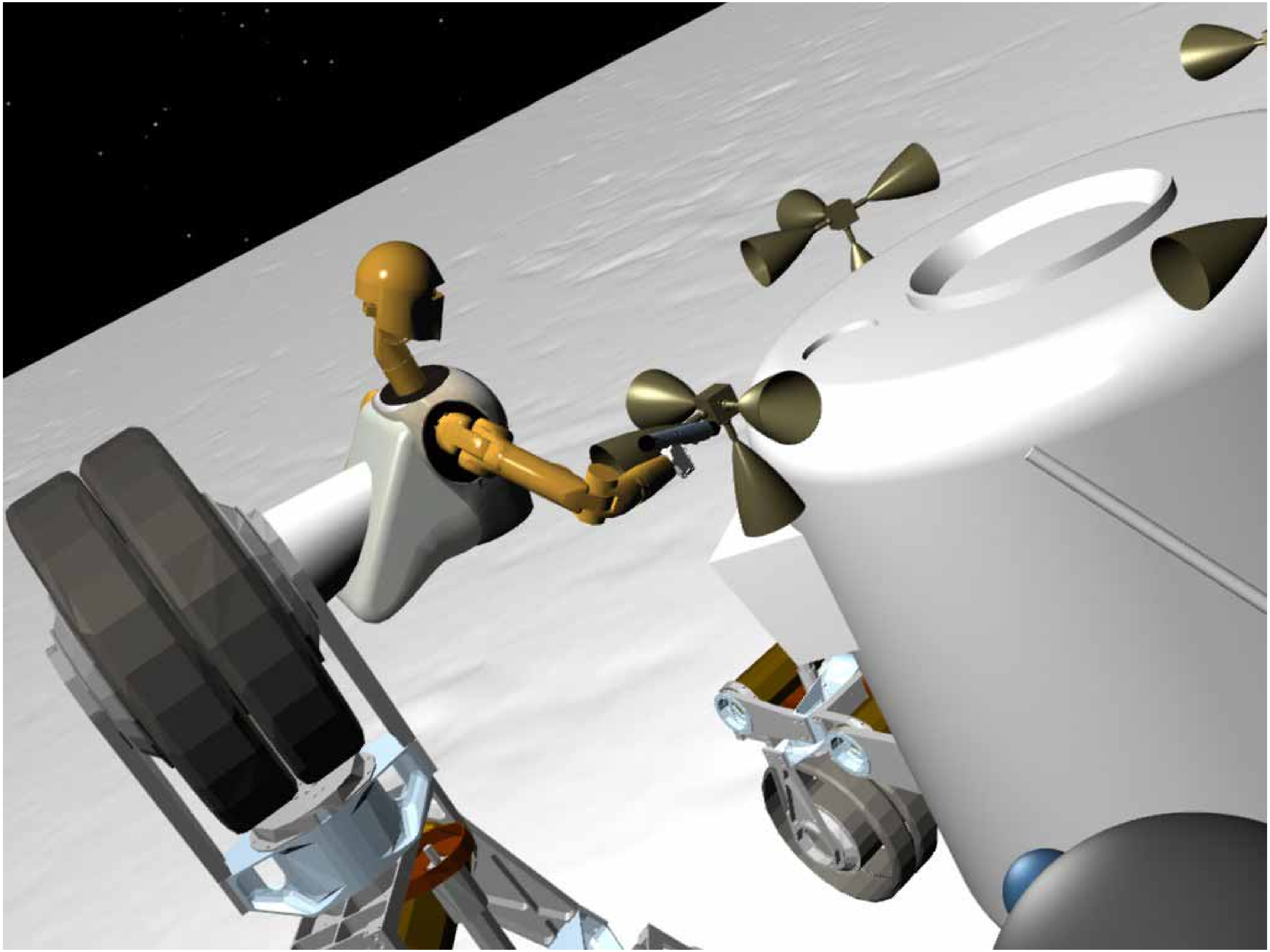
- Any outpost build up requires unloading and transportation of large elements, usually pressurized
- Davits, cranes, flatbeds are the traditional approach – these are labor intensive (either by crew or ground)
- Dedicated carrier that provides lifting, mobility and manipulation capability, such as ATHLETE, offers same functionality, lower crew work load and better terrain tolerance
- Same device, with proper tool can drag, dig, scrape, scoop, drill, tow, grasp, lift (robotically, or human tended)

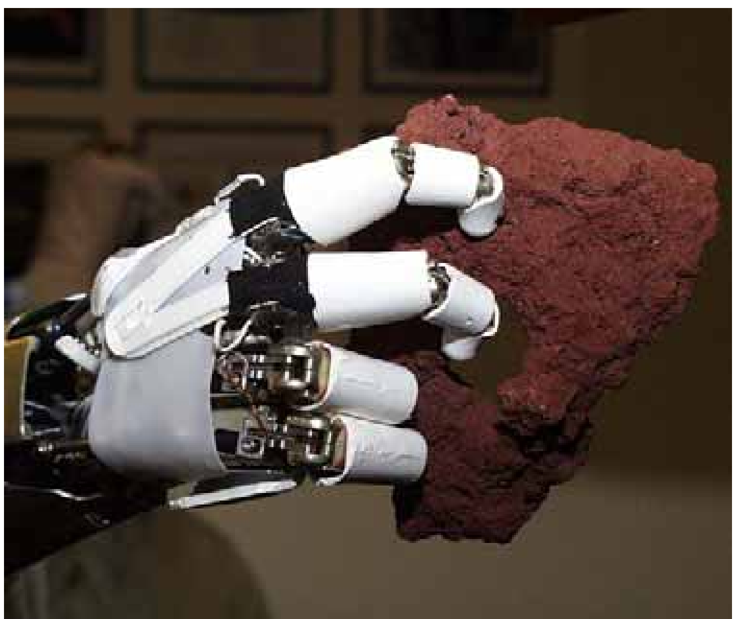


Wheel on leg carrier facilitates unloading and assembly of surface assets, AND repair and maintenance tasks, AND can be a tool for scientific investigations (e.g. coring), AND……

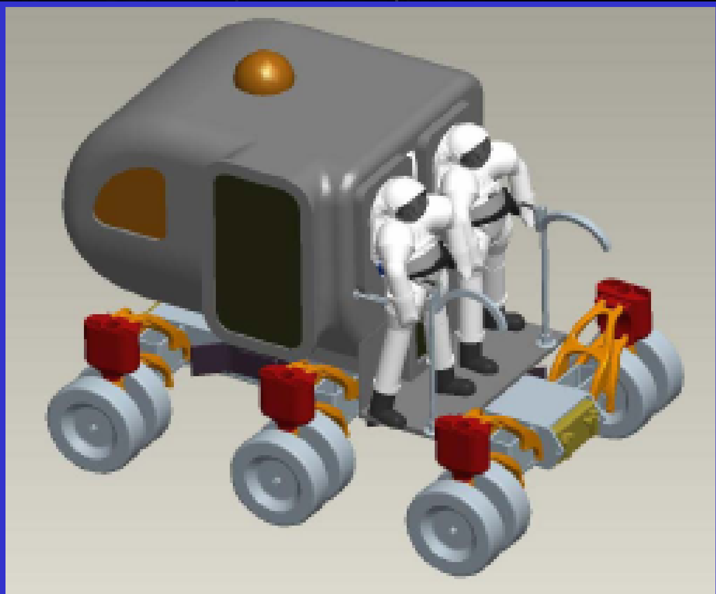
Some output from LPI Workshop 25-26 June 2007

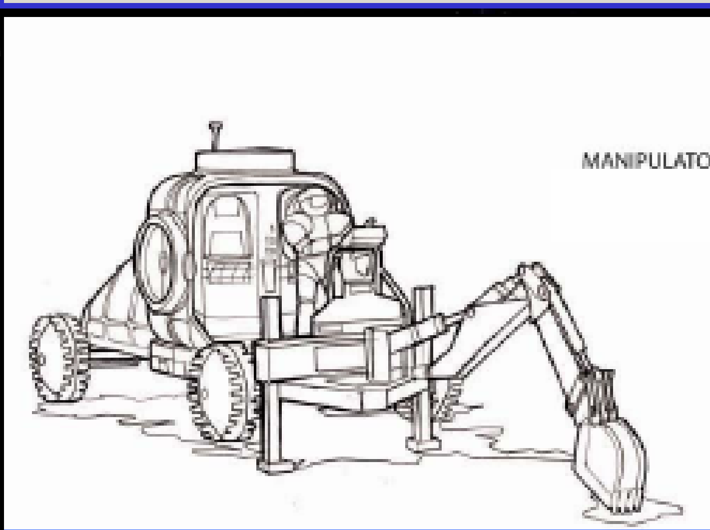
- A very large fraction of participants felt that samples should not go into the habitat for reasons of contamination.
- Instead, there should be an external “robotic workbench” where high-grading can be performed. As the campaign progresses, at least 10X more samples will be collected than can be returned.
- When astronauts are on the moon, “telepresence” technology can be used to link IVA astronauts with the robotic workbench. When astronauts are not on the moon, the workbench can still be used via supervisory control from Earth.
- Clive Neal and I formulated a LASER proposal to trench, explore the walls of the trench with instruments, and subsample with core bits.
- JPL and JSC have formulated a robotic workbench over-guideline proposal for ETDP FY ’08 funding that will probably be in-guideline in FY ’09.





New Approach to Surface Mobility
Pressurized Rovers



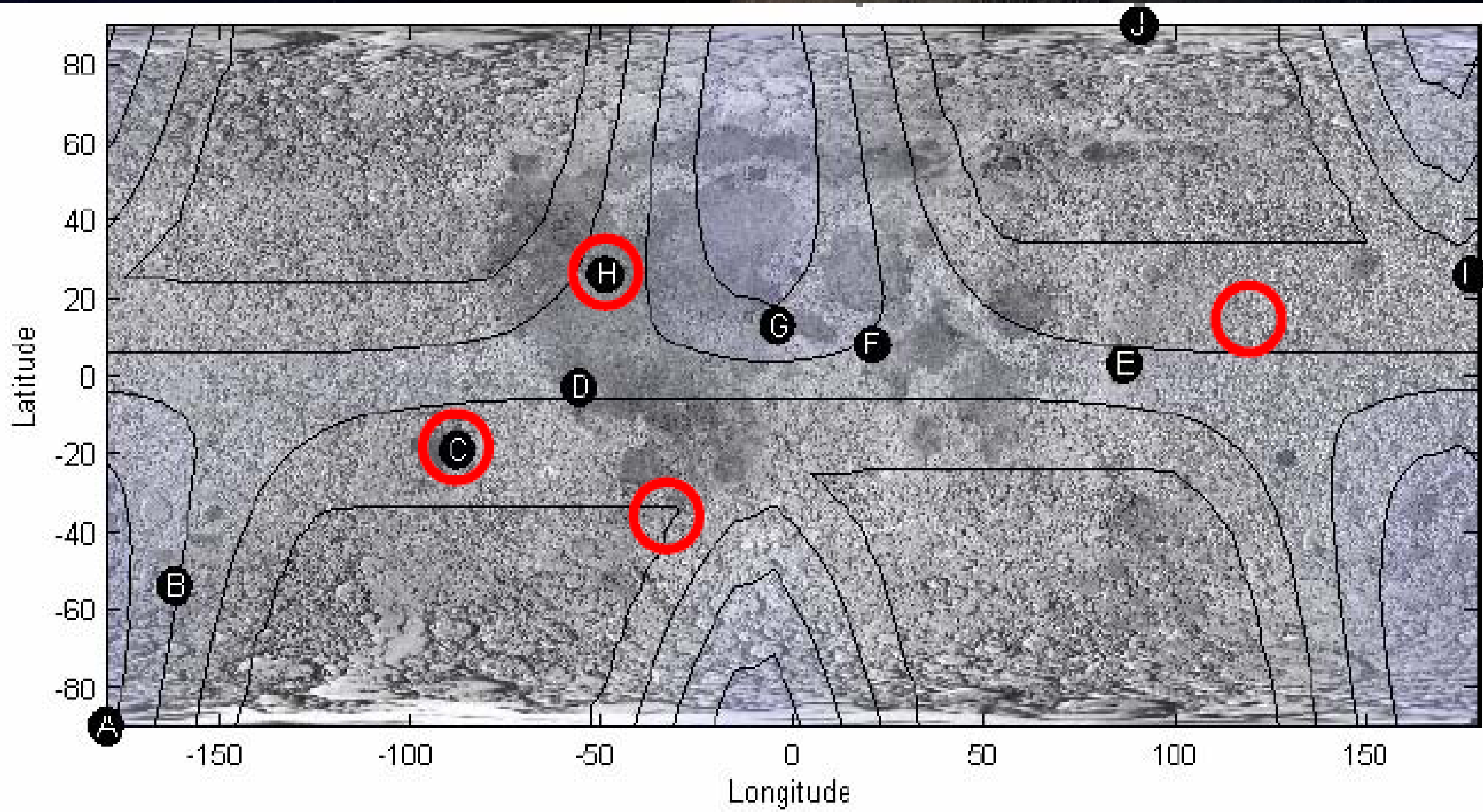


Vehicle Features –

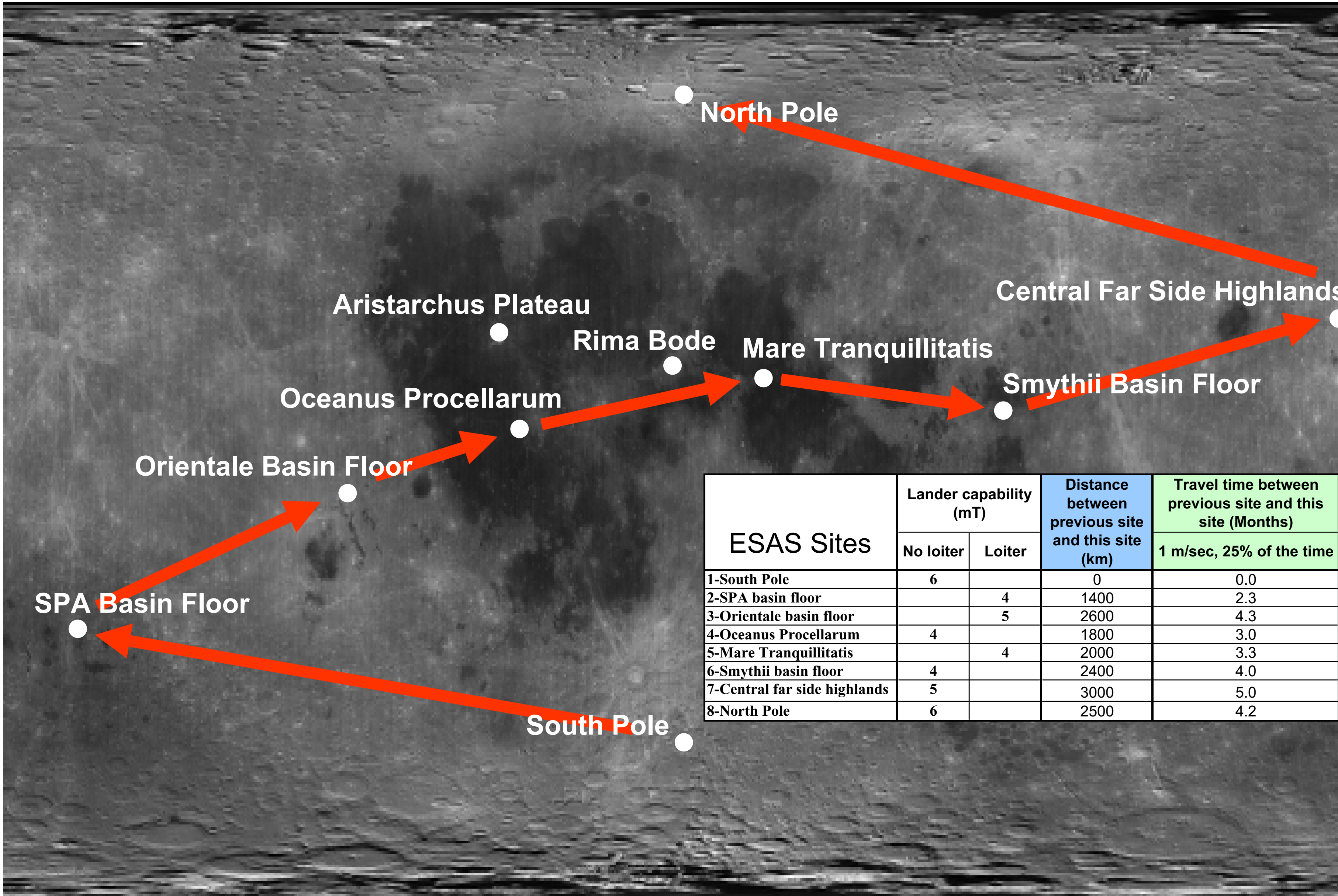
- Small vehicle, close to footprint of unpress rover
- Flexible to multiple uses, fore and aft drive stations
- Two-person suit lock for fast EVA access (~15 min)
- Environment Control Life Support System supported by suit Portable Life Support System elements
- Uses ice-shielded rear cabin to provide Solar Particle Event (SPE) protection as well as vehicle thermal control via ice-water phase change.
- Pressurized transfer to hab greatly reduces EVA burden
- **200km** distance on batteries and nominal consumable load

Impossible to consider long distance exploration without two rovers that are pressurized, have SPE protection, dust mitigation and ease of EVA access.

The Architecture Maintains Sortie Capability: Possible Sortie Locations to Optimize for Geophysics



	Site	Lat.	Long.		Site	Lat.	Long.
A	South Pole	89.9° S	180° W	F	Mare Tranquillitatis	8° N	21° E
B	Aitken Basin	54° S	162° W	G	Rima Bode	13° N	3.9° W
C	Orientale Basin	19 S	88° W	H	Aristarchus Plateau	26° N	49° W
D	Oceanus Procellarum	3° S	43° W	I	Central Far Side Highlands	26° N	178° E
E	Mare Smythii	2.5° N	86.5° E	J	North Pole	89.5° N	91° E



ESAS Sites	Lander capability (mT)		Distance between previous site and this site (km)	Travel time between previous site and this site (Months)
	No loiter	Loiter		1 m/sec, 25% of the time
1-South Pole	6		0	0.0
2-SPA basin floor		4	1400	2.3
3-Orientale basin floor		5	2600	4.3
4-Oceanus Procellarum	4		1800	3.0
5-Mare Tranquillitatis		4	2000	3.3
6-Smythii basin floor	4		2400	4.0
7-Central far side highlands	5		3000	5.0
8-North Pole	6		2500	4.2

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"Winnebagos and Jeeps" for Global-scale Lunar Exploration

- Global-scale exploration is enabled by mobile habitats ("Winnebagos")
- Small Pressurized Rovers ("Jeeps") allow astronauts to quickly and easily reach sites of scientific interest, to bring human senses as close to the samples as a field geologist on Earth.
- Mobile habitats can perform excavation, drilling, and other sample and resource gathering functions without excessive need for short segments of EVA.
- It has been stated that "continuous presence" and "global exploration" are in conflict, because the explorers must always return to the ascent stage (and the next crew must come down to the nearby habitats). A solution is to make the ascent stage lander mobile and bring it in the caravan of mobile habitats.