Exploration Systems Mission Directorate

Lunar Architecture Update

AIAA Space 2007

September 20, 2007

NASA's Lunar Architecture

- Introduction to Session – Doug Stanley
- Current exploration strategy and status - Doug Cooke
  - Lunar Architecture update – Geoff Yoder
  - Lunar Science – Laurie Leshin
  - Pressurized Rover and EVA concepts - Mike Gernhardt

- **Session wrap-up and questions**

Exploration Systems Mission Directorate

Lunar Architecture Update

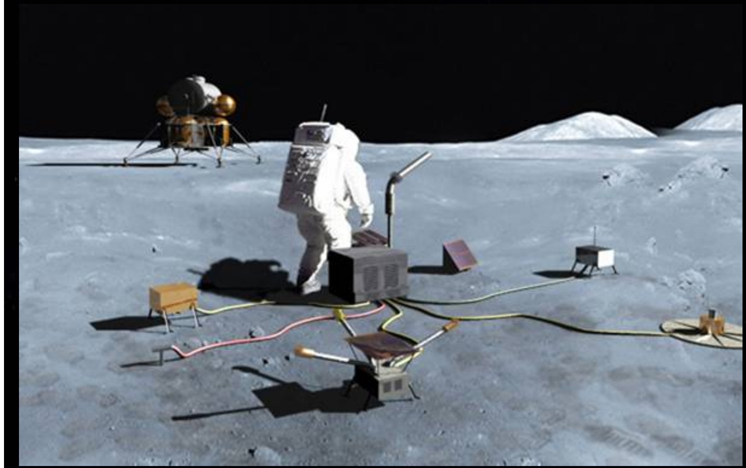
AIAA Space 2007

Doug Cooke
Deputy Associate Administrator
NASA Exploration Systems Mission Directorate

September 20, 2007

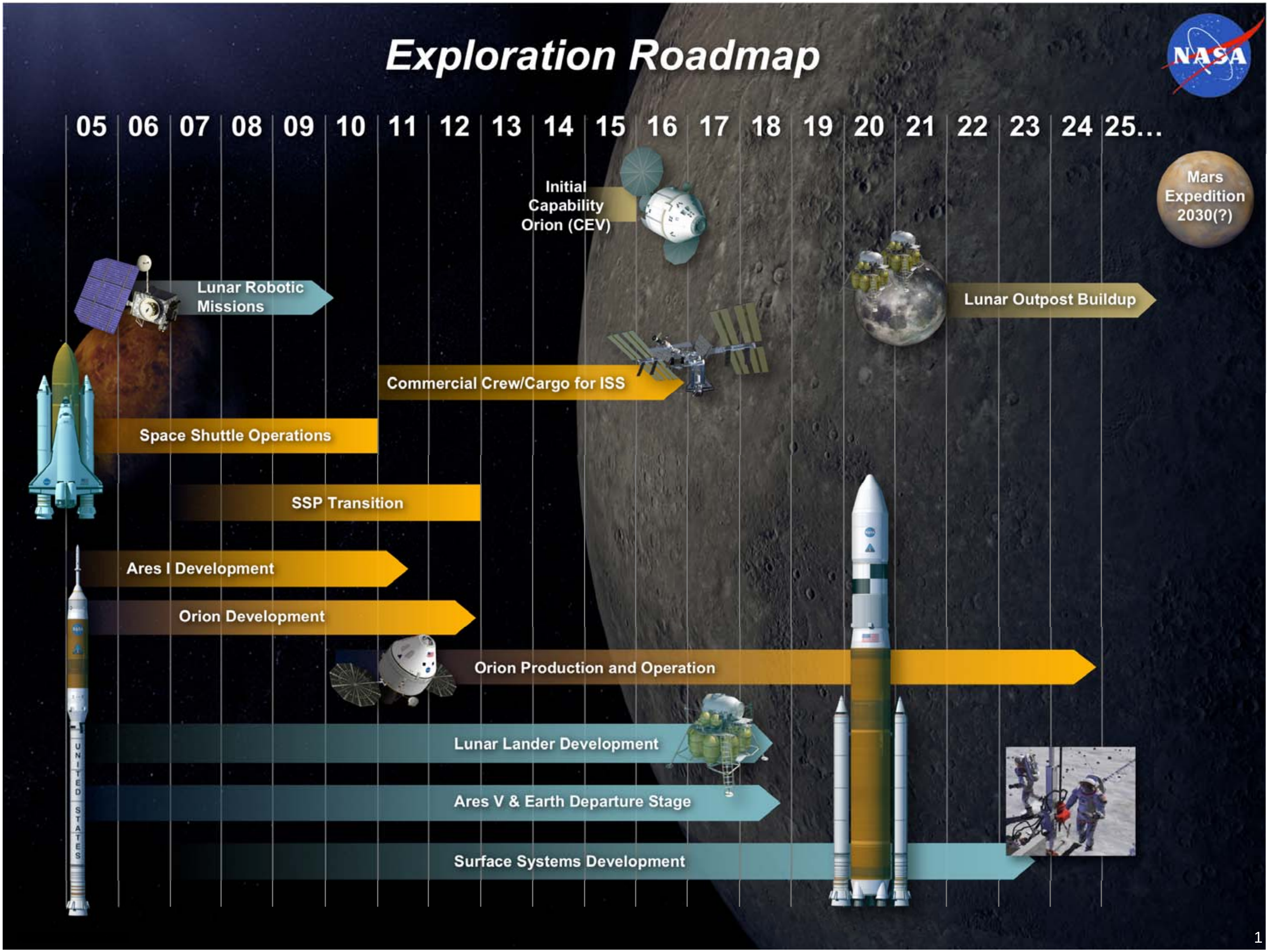
Space Exploration Direction, Authorized by Congress

- Complete the International Space Station
- Safely fly the Space Shuttle until 2010
- Develop and fly the Crew Exploration Vehicle no later than 2014
- Return to the Moon no later than 2020
- Extend human presence across the solar system and beyond
- Implement a sustained and affordable human and robotic program
- Develop supporting innovative technologies, knowledge, and infrastructures
- Promote international and commercial participation in exploration



NASA Authorization Act of 2005

The Administrator shall establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations.


Exploration Roadmap
NASA
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25…
Initial Capability Orion (CEV)
Mars Expedition 2030(?)
Lunar Robotic Missions
Lunar Outpost Buildup
Commercial Crew/Cargo for ISS
Space Shuttle Operations
SSP Transition
Ares I Development
Orion Development
Orion Production and Operation
Lunar Lander Development
Ares V & Earth Departure Stage
Surface Systems Development
1

Exploration Progress

- **In December 2006, we released**
  - **Exploration themes and objectives- Developed with together with**
    - **U.S. industry, academia, and science communities**
    - **13 other space agencies**
  - **Our initial Lunar architecture results- then shared with the broader community**
- **In 2007, our collective and individual communities have continued to make progress in defining what and how we will achieve our exploration objectives**
- **Here we will present results from latest studies**
  - **To be communicated and discussed with the broader community**
  - **Compared with architecture studies from these communities**

Architecture Development Driven By A Strategy

Global Exploration Strategy Development → Themes & Objectives

National Priorities Defined

LAT-1 — *Architecture Assessment* → Reference Architecture & Design Reference Mission

Outpost First at one of the Poles

Elements critical to US

Detailed Requirements Defined

LAT-2 — *Detailed Design* → Operations Concept, Technology Needs, Element Requirements

Maintain flexibility

Global Exploration Strategy - 6 Themes

Human Civilization

Global Partnerships

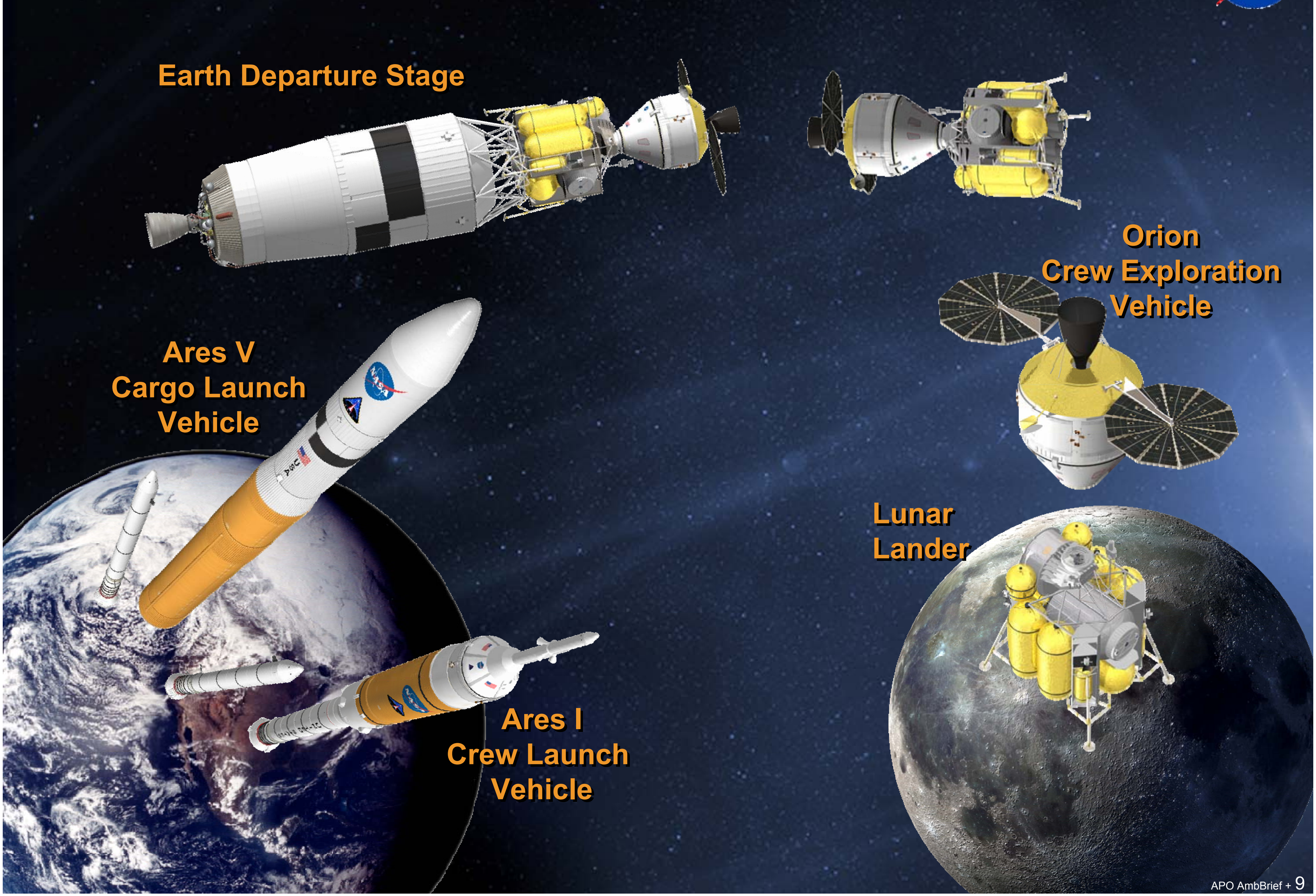
Scientific Knowledge

Economic Expansion

Exploration Preparation

Public Engagement

US Transportation Architecture



Lunar Architecture Framework — Point of Departure- December 2006

- **Human lunar missions will be used to build an outpost initially at a polar site**
- **The ability to fly human sorties and cargo missions with the human lander will be preserved**
- **Initial power architecture will be solar with the potential augmentation of nuclear power at a later time**

- **Robotic missions will be used to:**
  - Characterize critical environmental parameters and lunar resources
  - Test technical capabilities as needed
- **The ability to fly robotic missions from the outpost or from Earth will be a possible augmentation**

NASA Implementation Philosophy

- **The US will build the transportation infrastructure and initial communication & navigation and initial surface mobility**

- **Open Architecture: NASA will welcome external development of lunar surface infrastructure**

- **The US will perform early demonstrations to encourage subsequent development**
- **External parallel development of NASA developed capabilities will be welcomed**

Open Architecture: Infrastructure
Open for Potential External Cooperation

- **Lander and ascent vehicle**
- **EVA system**
  - CEV and Initial Surface capability
  - Long duration surface suit
- Power
  - Basic power
  - Augmented
- Habitation
- Mobility
  - Basic rover
  - Pressurized rover
  - Other; mules, regolith moving, module unloading
- Navigation and Communication
  - Basic mission support
  - Augmented
  - High bandwidth
- ISRU
  - Characterization
  - Demos
  - Production
- **Robotic Missions**
  - LRO- Remote sensing and map development
  - Basic environmental data
  - Flight system validation (Descent and landing)
  - Lander
  - Small sats
  - Rovers
  - Instrumentation
  - Materials identification and characterization for ISRU
  - ISRU demonstration
  - ISRU Production
  - Parallel missions
- Logistics Resupply
- Specific Capabilities
  - Drills, scoops, sample handling, arms
  - Logistics rover
  - Instrumentation
  - Components
  - Sample return

**** US/NASA Developed hardware**

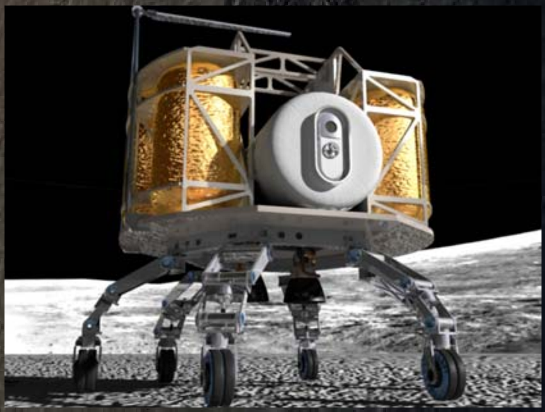
Second Phase of Lunar Architecture Studies

- **This phase of studies builds results presented in December**
  - **Significant NASA-wide effort**
  - **Responsive to more Themes and objectives**
    - Outpost decision addressed broad range of themes and objectives
    - Did not fully address objectives requiring travel to other lunar sites- primarily some science objectives
- **Assessed metrics**
  - **Merits and features**
  - **Relative risks**
  - **Crew time on the Moon**
  - **Time available for Exploration**
  - **Early return from missions**

Factors in latest Architecture Study Results

- **Six options studied**
- **Derived the best features from each option**
- **Based on better understanding of vehicle performance**
- **Better definition of concepts-**
  - Down to detailed components
  - To better understand capabilities and feasibility
- **Most effective use of crew**
- **Steps to better address objectives**

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

Lunar Architecture Update

Geoff Yoder
Director, Directorate Integration Office
Exploration Systems Mission Directorate

Outline

- Architecture
  - Guidelines and Attributes
  - Strategy
  - Options
- Communication and Navigation
- Figures of Merit
- Discriminators
- A Hybrid Approach

Architecture Guidelines

- **In addition to supporting the basic goals and objectives of the Vision, the Architecture must have the following:**
  - Programmatic Flexibility – The Architecture must be able to adapt to changes in national priorities and budgets over several election cycles
  - Participant Flexibility – The Architecture must be able to adapt to changes in external participation (Commercial or IP) and changes to their priorities
  - Exploration Flexibility – The Architecture must be able to adapt to changes in exploration priorities and changes in exploration methods

Architecture Desired Attributes

- Enable lunar sustained presence early
- Develop infrastructure while actively engaged in science and exploration
- Ensure architecture is flexible to redirection
- Ensure architecture supports Objectives
- Support the establishment of Mars analog
- Allow the earliest partnership opportunities for commerce and International Partners
- Continuous and measurable progress
- Continuous and focused public engagement

Architecture Strategy

- **Successful lunar exploration is not just about developing a Lander or a Habitat**
- **It will require development of a system of exploration elements**
  - Transportation Vehicles (Launch Vehicle, Landers)
  - Habitation
  - Rover
  - EVA Systems
  - Surface Power
  - Communication
- **The architecture challenge is to assemble the best mix of these elements so they work synergistically together to efficiently achieve the objectives**

Architectural Options Under Evaluation

Option 1: All elements delivered with crewed flights (LAT 1)

Option 2: Derivative of LAT 1 except uncrewed lander can deliver hardware to surface provided all elements must be sized to fit on a crewed lander.

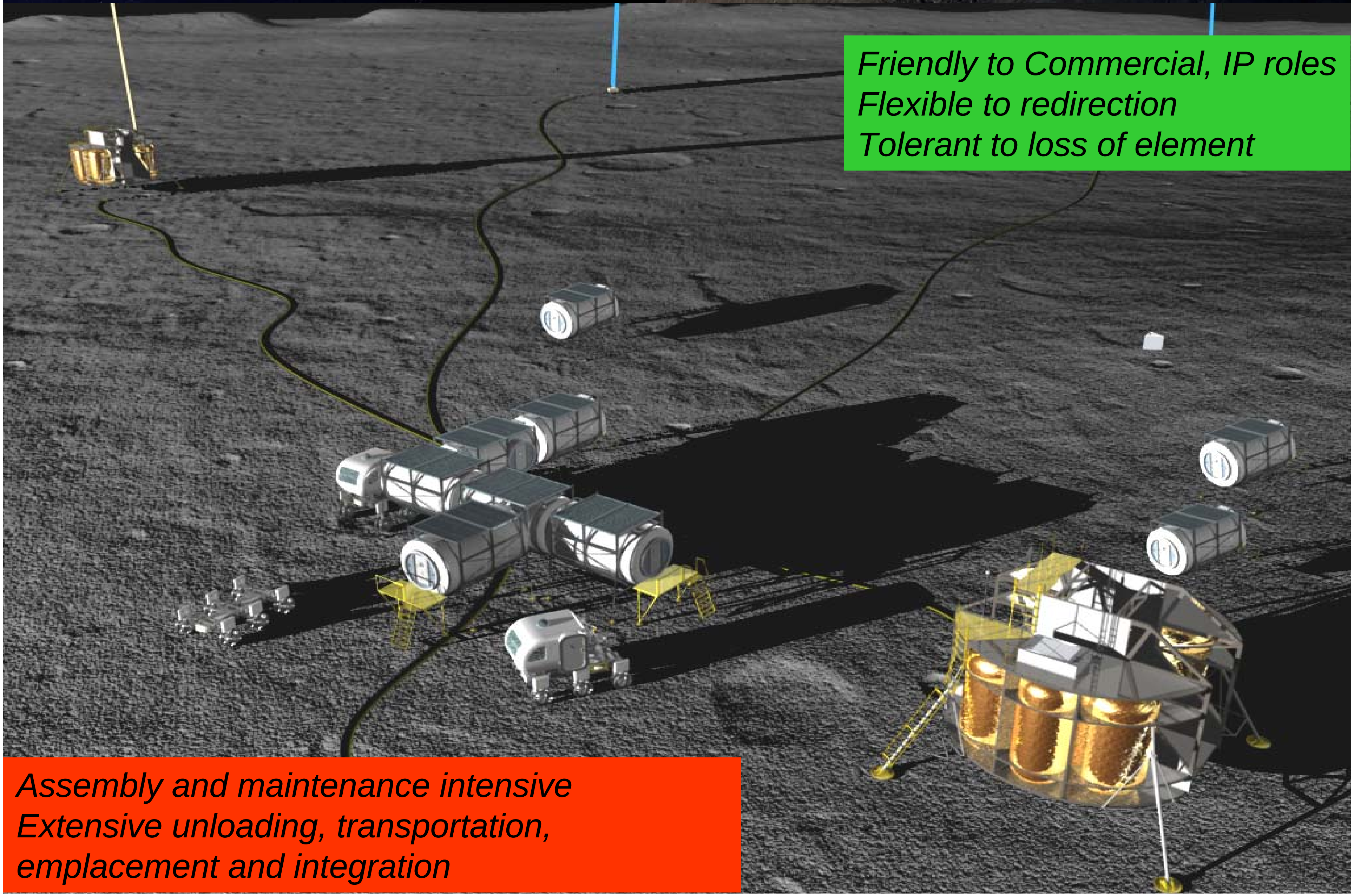
Option 3: A single large, fully outfitted and pre-integrated Habitation launched and landed on a single uncrewed mission

Option 4: The lander has integrated surface mobility (mobile lander)

~~Option 5: Long range, pressurized rover delivered as early in the sequence as possible~~ (Captured in each)

Option 6: Nuclear power used for the surface power in lieu of solar

Option 1 – Mini-habitat elements with Crew Lander (LAT-1)
Option 2 – Mini-habitat elements with Crew/Cargo Lander



Friendly to Commercial, IP roles
Flexible to redirection
Tolerant to loss of element

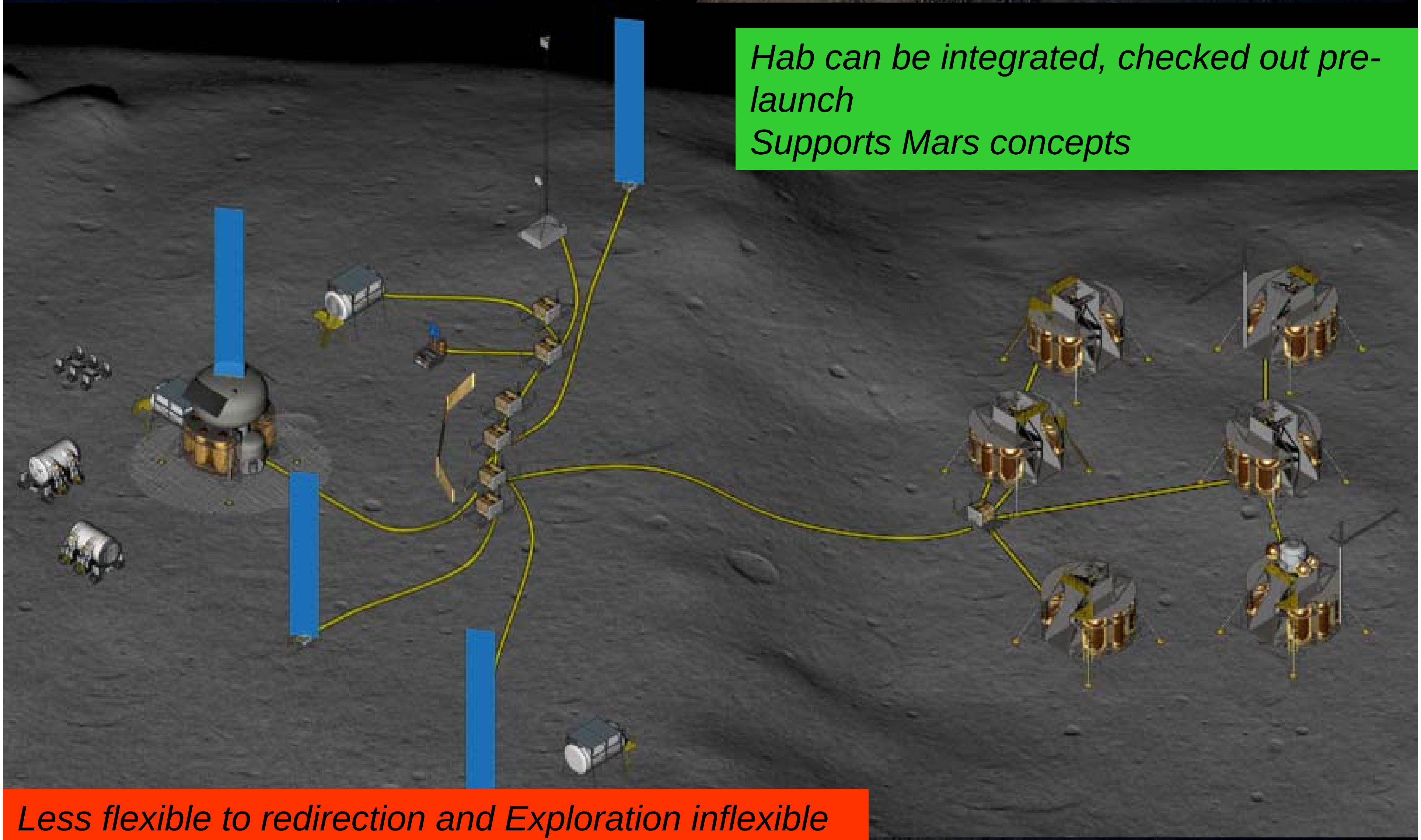
Assembly and maintenance intensive
Extensive unloading, transportation, emplacement and integration

Option 3 – Single Habitat Delivered in One Flight

MONOLITHIC

Option 3 – Single Delivery, Monolithic Habitat

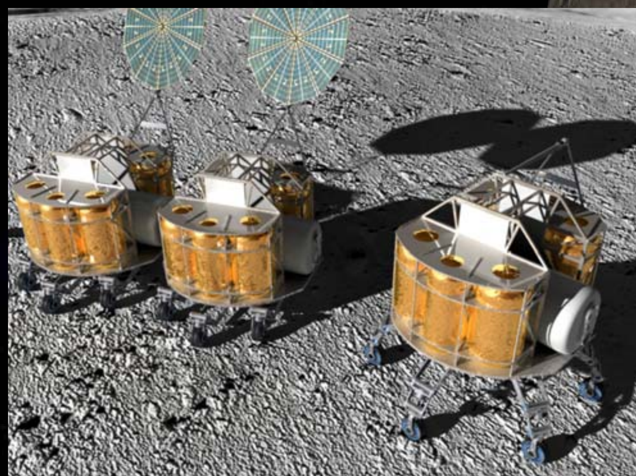
Hab can be integrated, checked out pre-launch
Supports Mars concepts

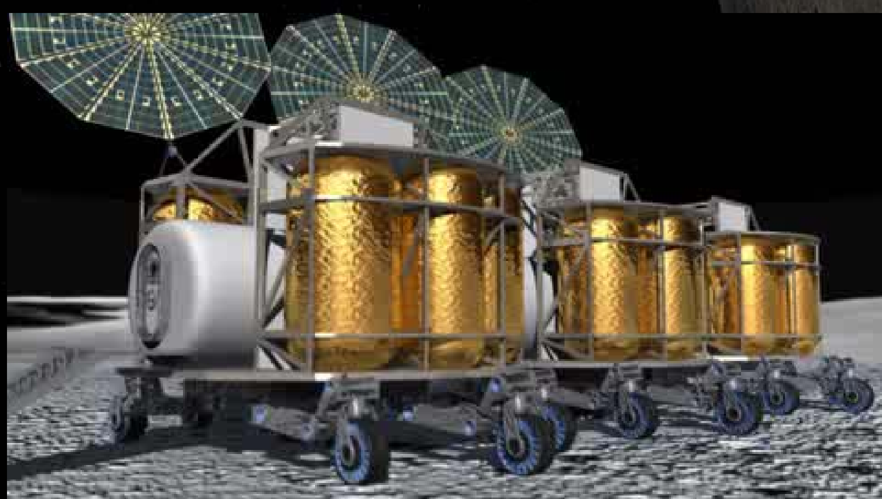


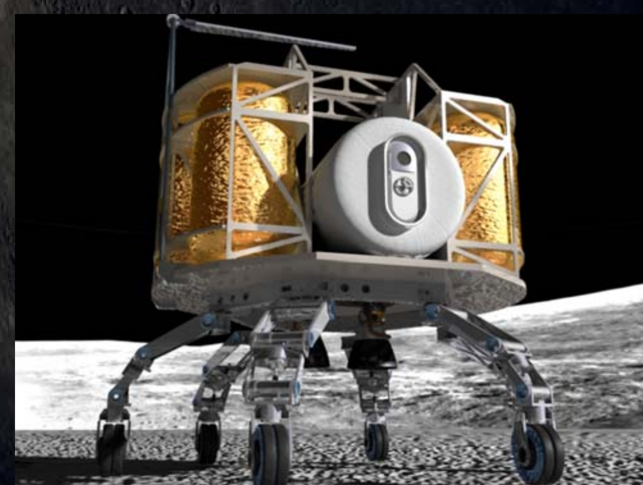
Less flexible to redirection and Exploration inflexible
Less tolerant to loss of element
Less adaptable to reduced transportation capability

Option 4 – Mobile Lander

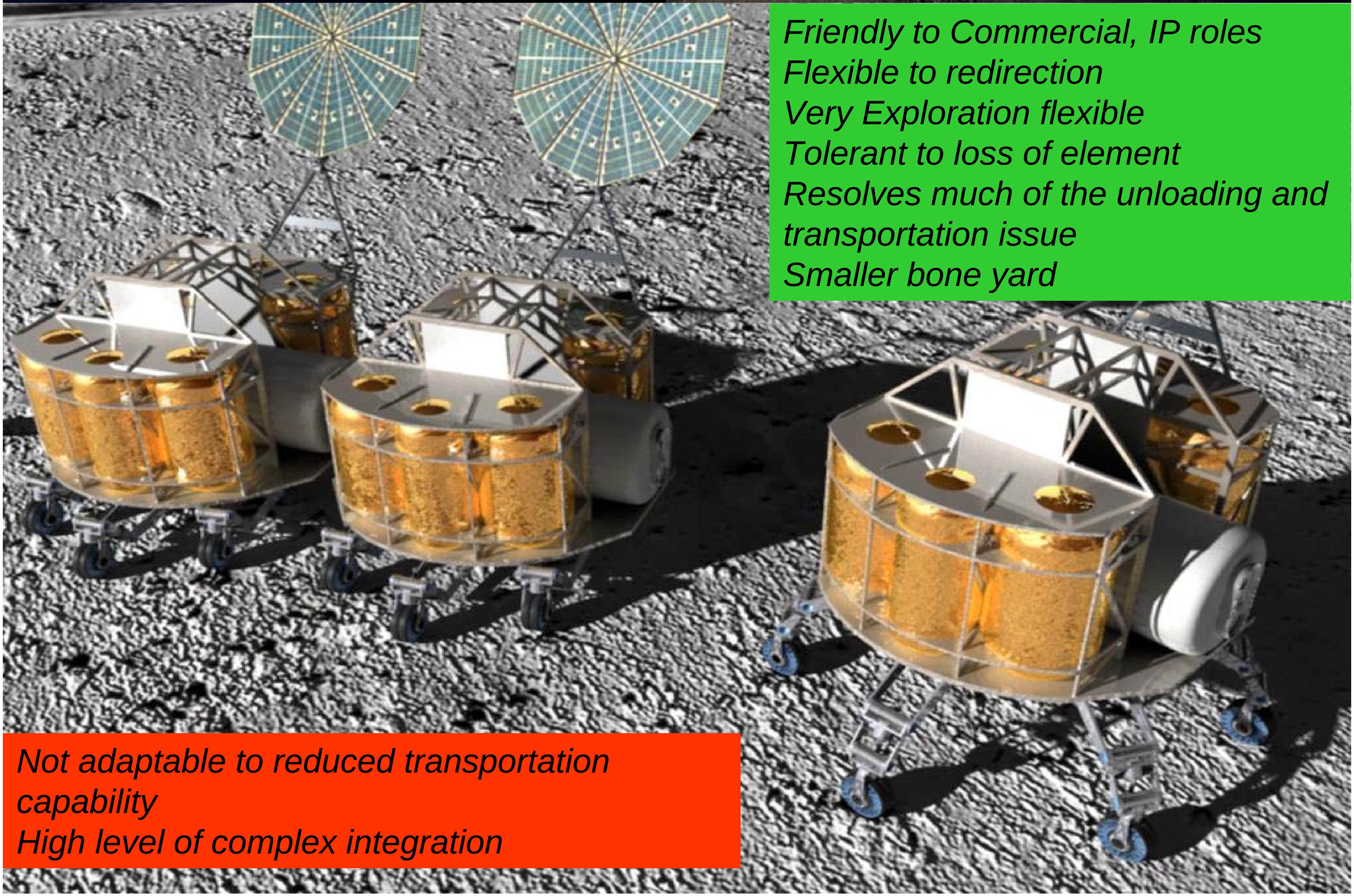
- ***Can use mobility to assemble outpost elements but carries a penalty***
- ***Challenge is to maximize benefit of lander mobility***







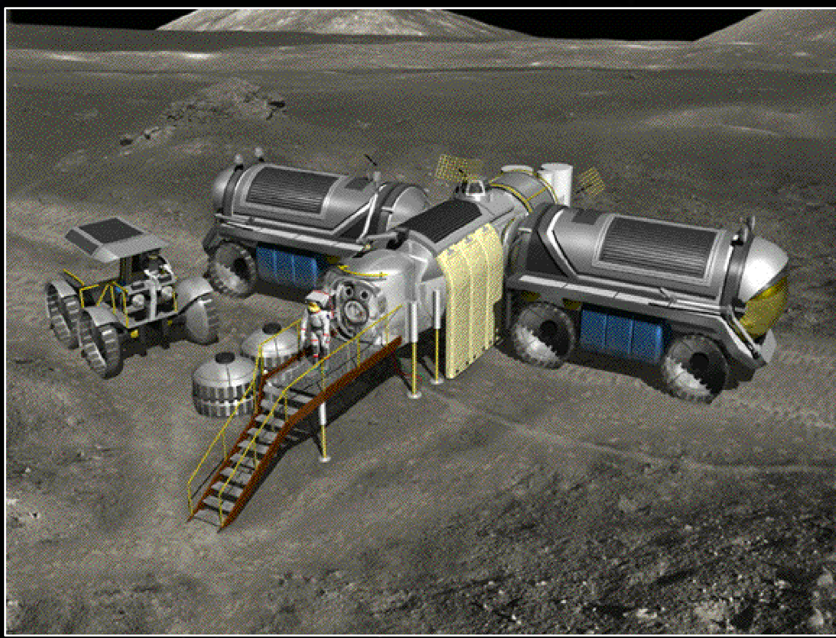
Option 4 – Mobile Lander Habitat System



Friendly to Commercial, IP roles
Flexible to redirection
Very Exploration flexible
Tolerant to loss of element
Resolves much of the unloading and transportation issue
Smaller bone yard

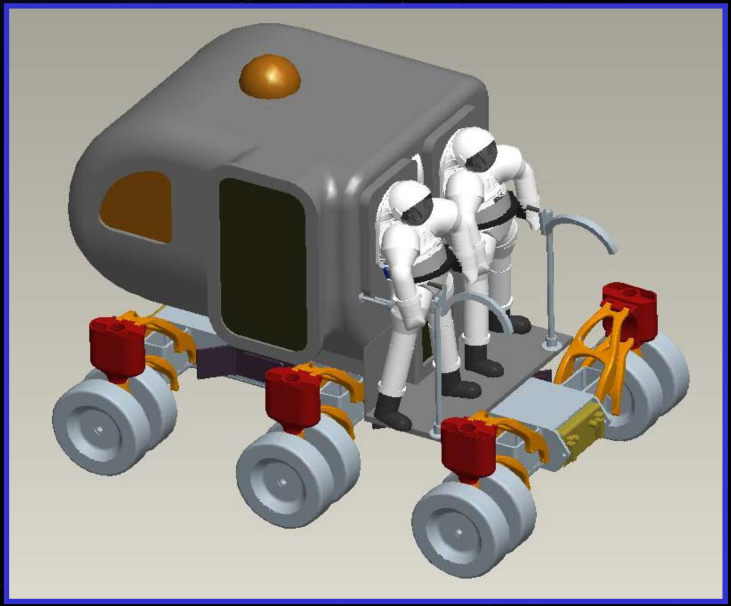
Not adaptable to reduced transportation capability
High level of complex integration

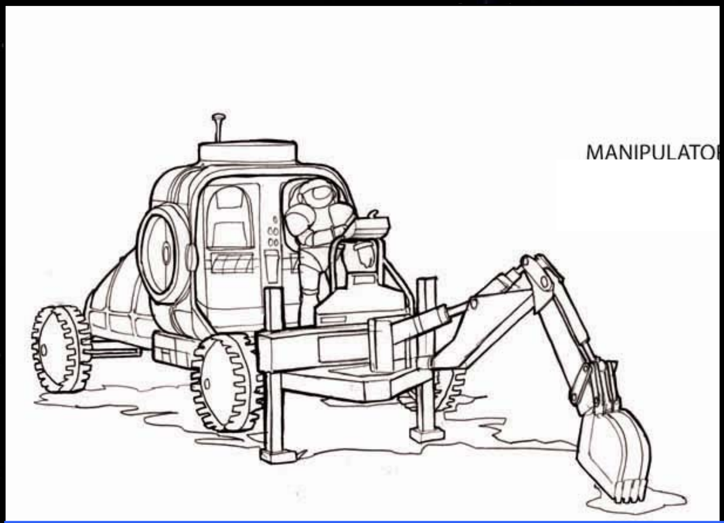
Option 5
Key Decision – Surface Mobility



- **Science in vicinity of Outpost can be quickly exhausted**
- **Extended range surface mobility is essential**
- **Unpressurized rovers limited because of crew suit time**
- **Drives need for long-distance pressurized rover capability**
- **Best trade is either very big rover (Winnebago), or small, agile rover**

New Approach to Surface Mobility
Pressurized Rovers



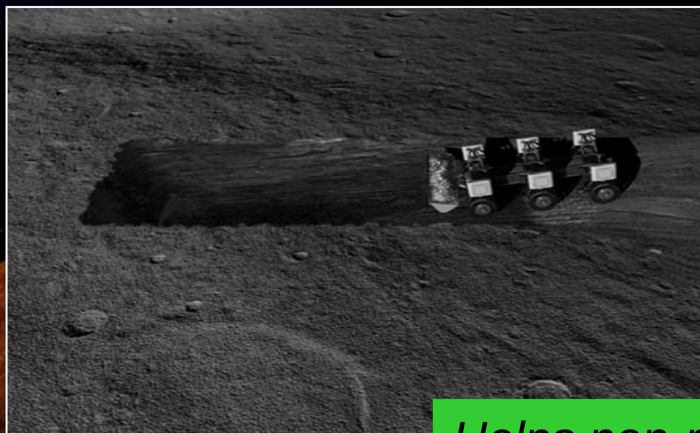


Vehicle Features –

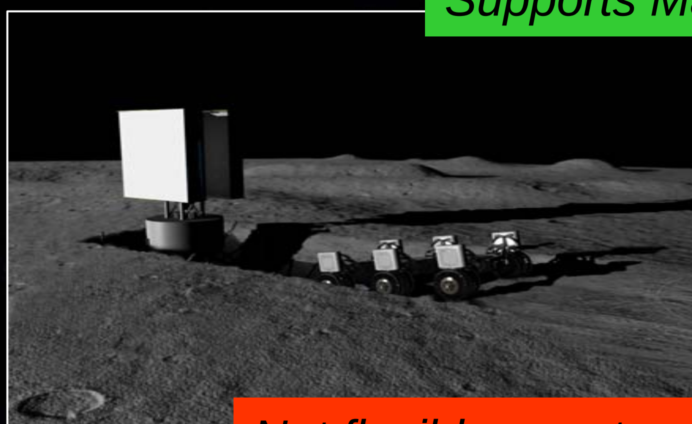
- Small vehicle, close to footprint of unpress rover
- Flexible to multiple uses, fore and aft drive stations
- Two-person suit lock for fast EVA access (~15 min)
- Environment Control Life Support System supported by suit Portable Life Support System elements
- Uses ice-shielded rear cabin to provide 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

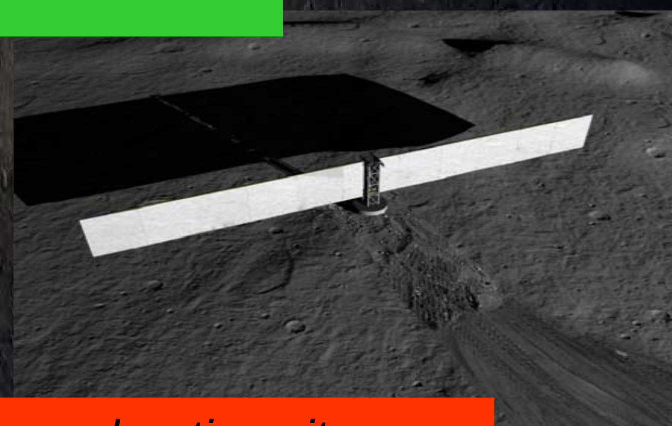
Impossible to consider long distance exploration without two rovers that are pressurized, have SPE protection, dust mitigation and ease of EVA access.

Option 6 – Nuclear Surface Fission Power



Helps non-polar Outpost sites
Good for ISRU
Supports Mars





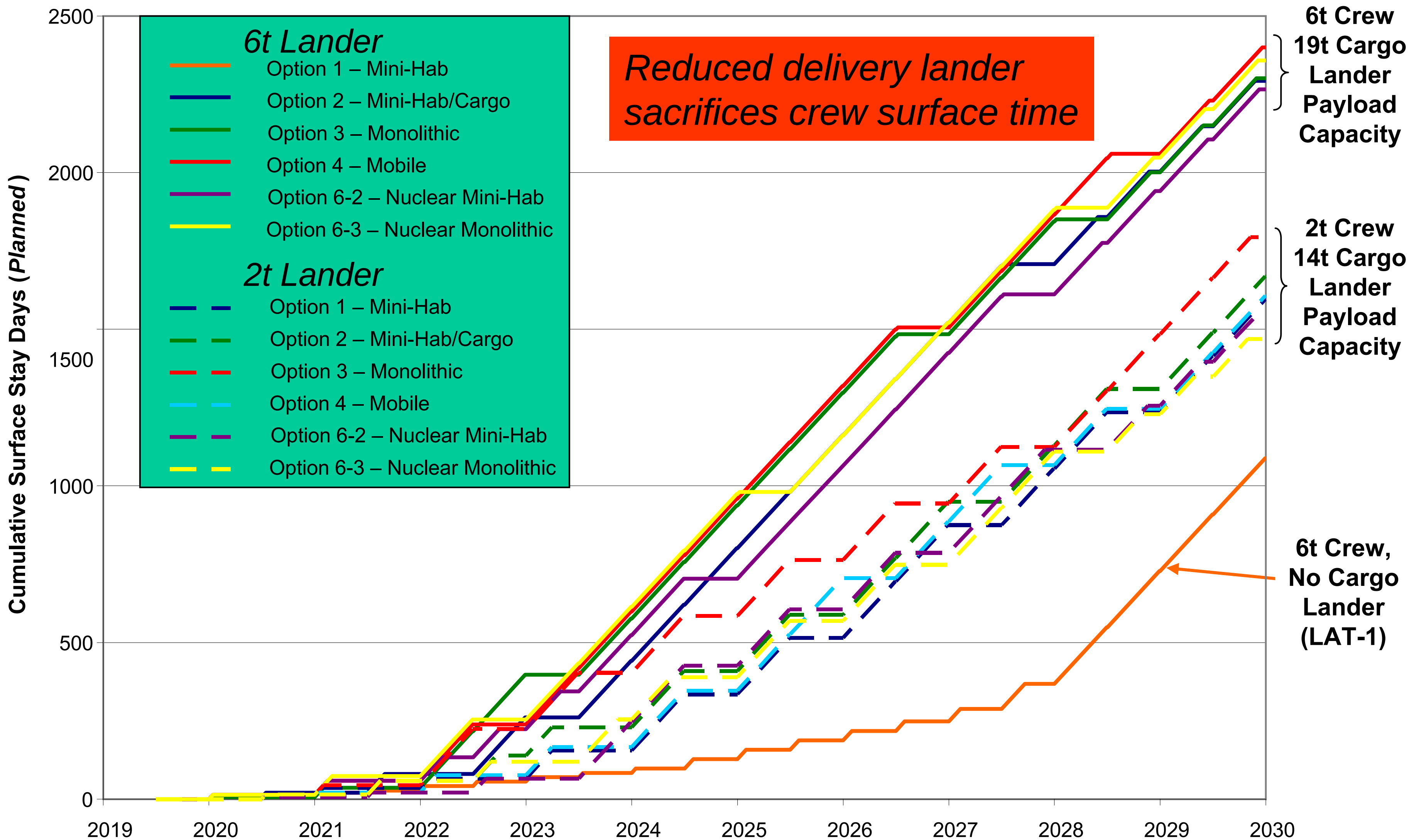
Not flexible, reactor anchors exploration site
Not failure tolerant, still need some solar initially
Emplacement is challenging
Carries political sensitivities

Option Discriminators

- Comprehensive set of Figures of Merit developed to cover key areas
  - Affordability
  - Benefit
  - Safety & Mission Assurance
  - Programmatic Risk
  - Sustainability

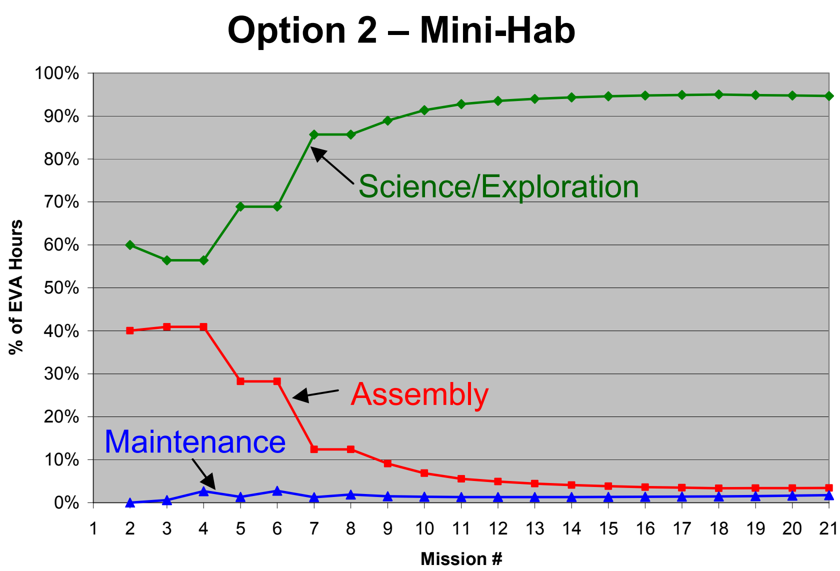
- Crew Surface Time
- Relative Costs
- Assembly, Maintenance and Exploration Time
- Unloading, transportation of large elements and enhanced exploration
- Capability for Sorties
- Lander Packaging and Ares V Shroud Size
- Technology Push
- Science Objectives
- Risks
- Exploration Benefits
- Public Interest

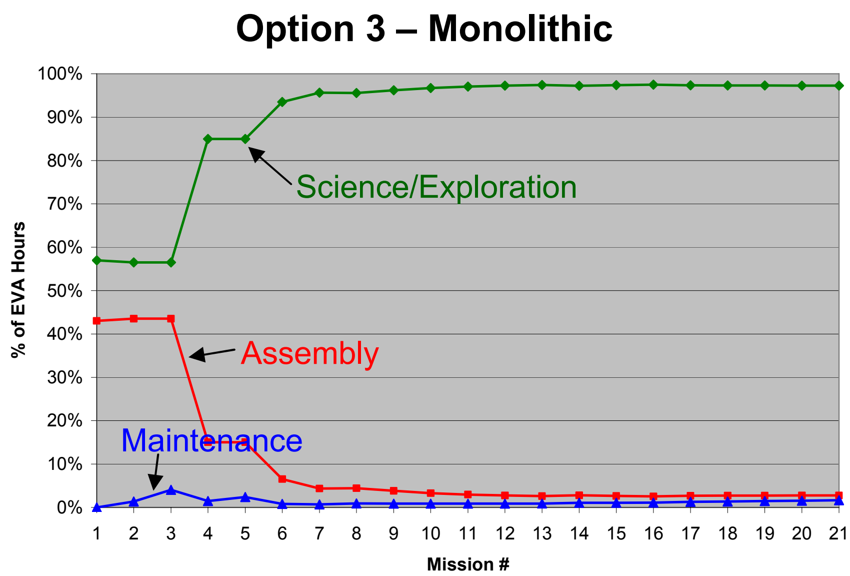
Cumulative Surface Stay Days (Planned)

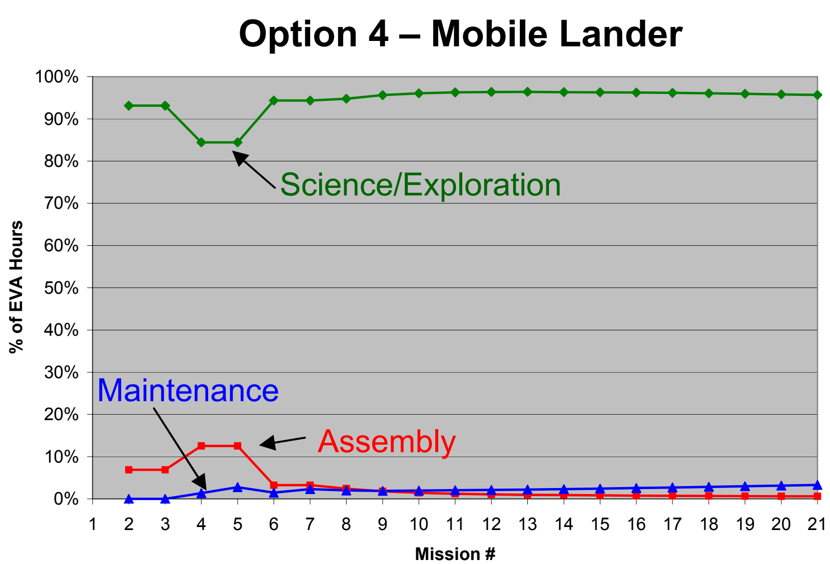


Crew surface time does not favor any one option over another

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





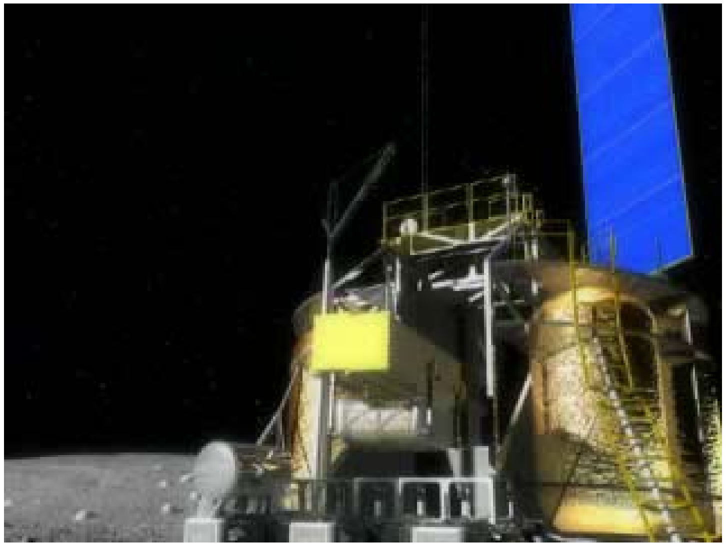


Early Assembly and Maintenance can be significant for construction of a mini-hab outpost

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……

Lunar Architecture Team Summary

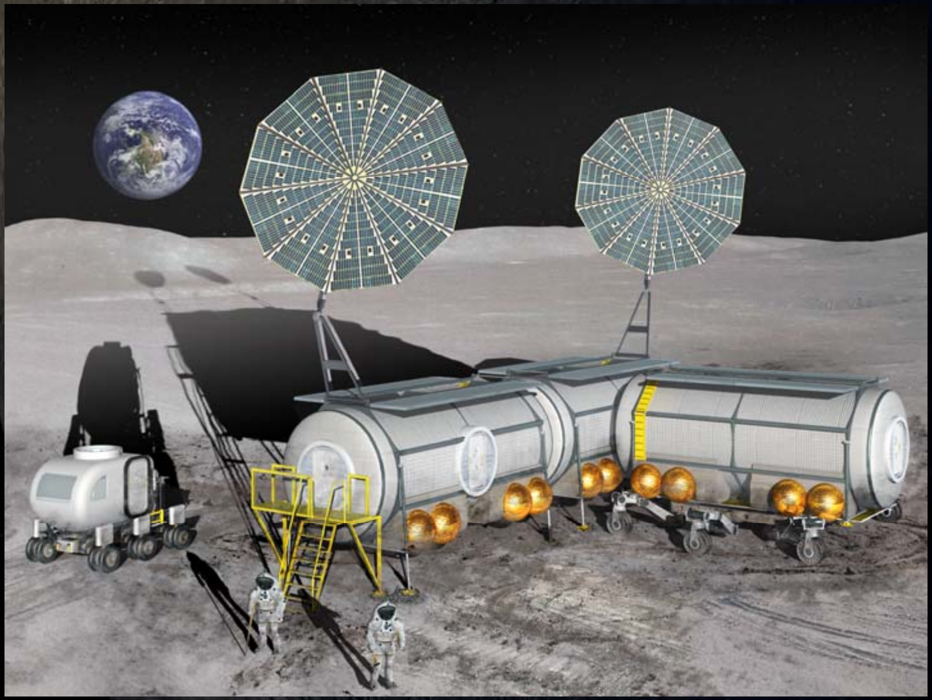
A Hybrid Approach to the Options

Hybrid Approach to Options

A flexible architecture incorporating best features and lessons learned from all the Lunar Architecture Team options

Surface Architecture - Discrete elements sized smaller than the monolithic unit, but larger than the mini-hab concept

- **Cargo lander needed for robustness**
- **Outpost built up from only 2 or 3 of these elements**
- **Assembly facilitated from separate surface mobility system**
- **Make maximum use of delivered hardware to minimize the bone yard**



Hybrid Approach to Options (cont.)

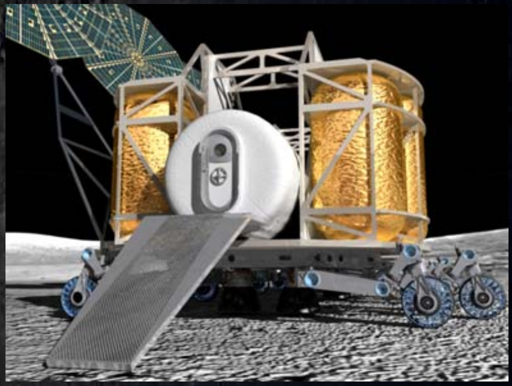
Capability for global access and extended range surface exploration is essential

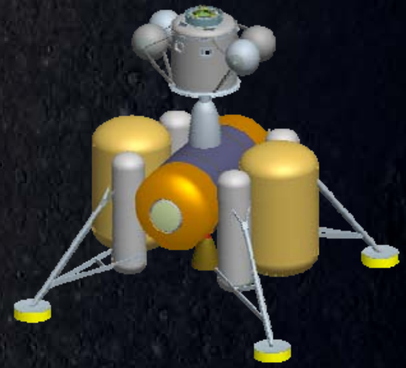
- **Surface Mobility**
  - Early delivery of small, agile pressurized rover that carries SPE protection, suit lock (not like Apollo)
  - Utilize common elements from surface carrier where possible (e.g. wheel/motor units)

Hybrid Approach to Options (cont.)

Lander packaging, Habitat Modules, and Surface Carrier must be worked as a system

- **Habitat Elements that:**
  – Are modular in design, with self-contained solar power, Communications and Environmental Closed Life Support System, etc.
  – Can be kitted to operate singly, or collectively
  – Provide full functionality with no more than 3 units
  – Can be delivered with cargo only lander





- **Lander packaging options that support surface operations (unloading, etc.) with these elements while minimizing the bone yard**

- **Surface Carrier concept that utilizes the Leg/Wheel concept for unloading, transportation and emplacement of elements**

Extended Surface Exploration

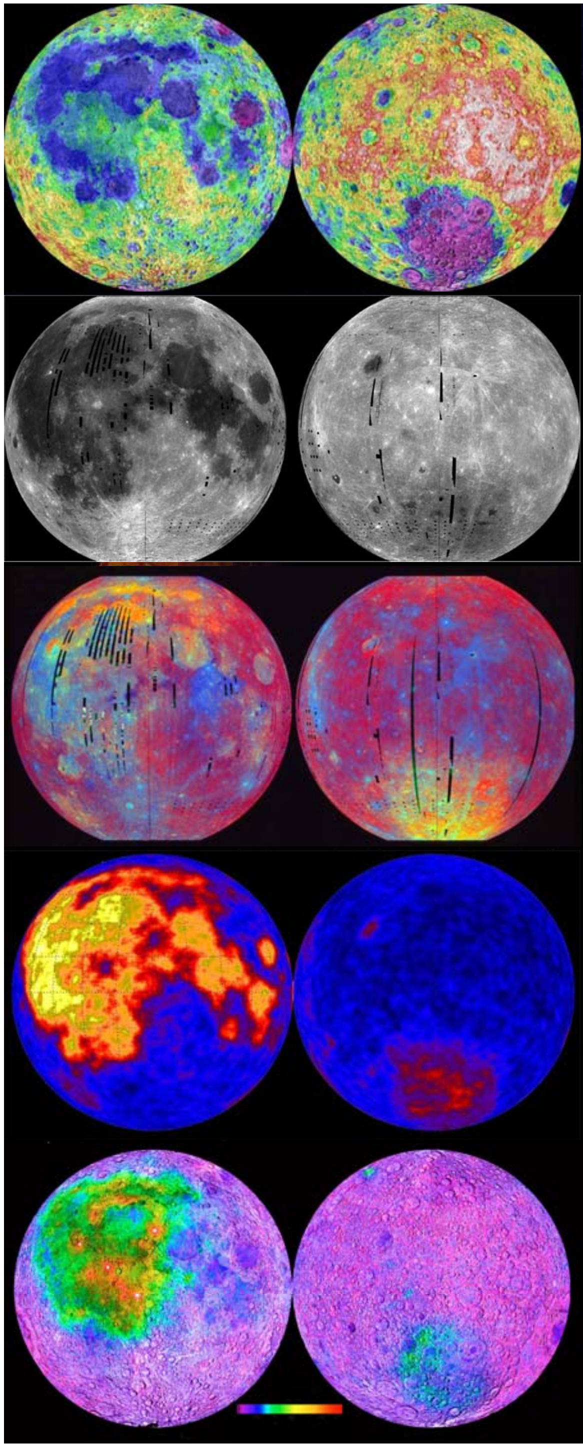
- **Wheel on leg surface carrier offers an additional possibility - a 'Winnebago' mode of exploration**
  - **Use carrier and habitat module to create fully equipped mobile habitat at Outpost**
  - **Re-use descent propellant tanks for storage of liquefied reactants (reduce bone yard)**
  - **Mobile habitat then drives robotically to new site of Interim Outpost**
  - **Crew drive with it, or to it in a rover, or land by it for an extended sortie ('Super Sortie' or 'Hosted Sortie')**
  - **After crew departure, mobile habitat drives to different site and awaits arrival of next crew**

Makes good use of spent landers and synergism with the pressurized rover, offering many 1000's of km's and possible reduction in number of Ares V launches.
This capability comes, as an added benefit of the mobility implementation, but not as a driver or constraint for everything else

Science Capability on the Moon

Laurie Leshin
NASA Goddard Space Flight Center
LAT Science Capability Focus Element
Constellation Program Science Office

September 20, 2007

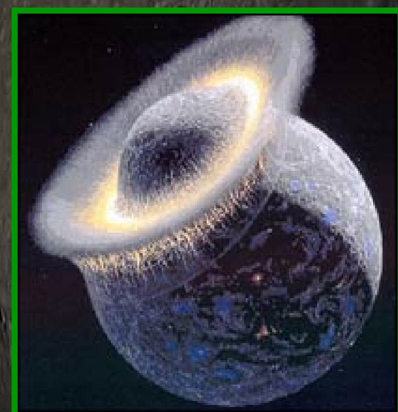


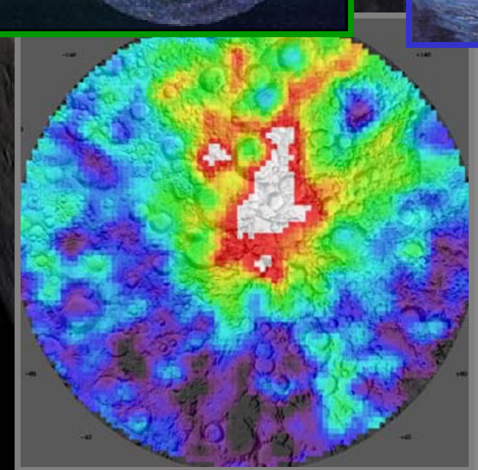
Outline

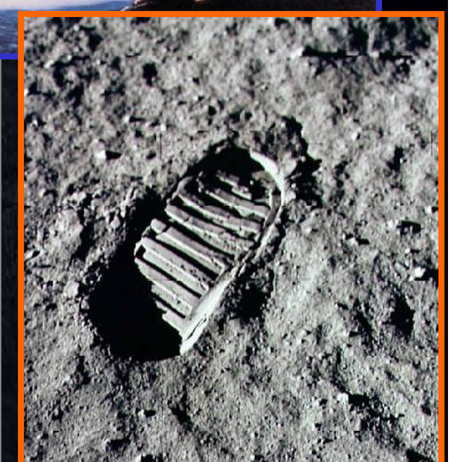
- Science Opportunities on the Moon
- LAT Science Focus Element Work Flow
- Design Reference Payloads
- Sorties in the Lunar Architecture
- National Academy SCEM recommendations – compatibility with LAT activities
- Next Steps

The Moon Presents Compelling Science Opportunities

- **Bombardment of the Earth-Moon system: Consequences for the emergence of life**
- **Lunar surface and interior processes and history**
- **Scientific treasure in the permanently shadowed polar environment**
- **Regolith as a recorder of the Sun's history**
- **The Moon as a Science Platform: Astronomy, Earth and Solar Activity Observations**
- **Testing Planetary Protection protocols**

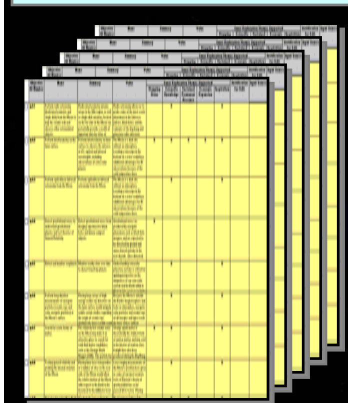




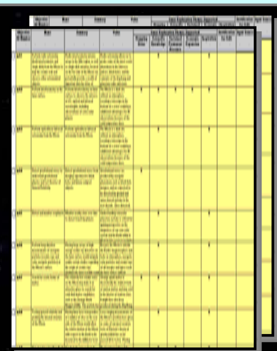


Lunar Architecture Team Science Capability Focus Element Work Flow

181 Objectives from Global Strategy Team



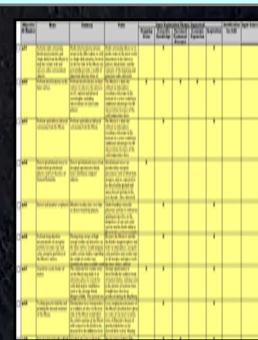
ALL Science Objectives (45 “SMD” Science objectives + some others…)



Each Objective Deconstructed to Define Needed Capabilities and Mapped to Architecture

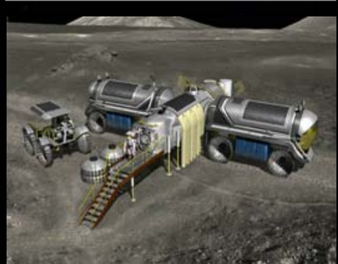
PRIORITIES from Tempe Workshop

Top Objectives



Grouped into key reference payloads

Mapped to Architecture options



Top Objectives Examples: Planetary Science Subcommittee Findings

- **INTERNAL STRUCTURE and DYNAMICS** - Geophysical/heat flow network - requires multiple sites, widely spaced ("global access")
- **COMPOSITION/EVOLUTION of LUNAR CRUST** - requires extensive sampling at both local and diverse sites
- **IMPACT FLUX** - requires access to impact basins and sample return for age dating
- **SOLAR EMISSIONS/GCR/ INTERSTELLAR** - requires drilling, regolith and core sample integrity, careful documentation
- **SAMPLE ANALYSIS INSTRUMENTS AND PROTOCOLS** - infrastructure for pristine sample collection, storage, documentation, and transport needed

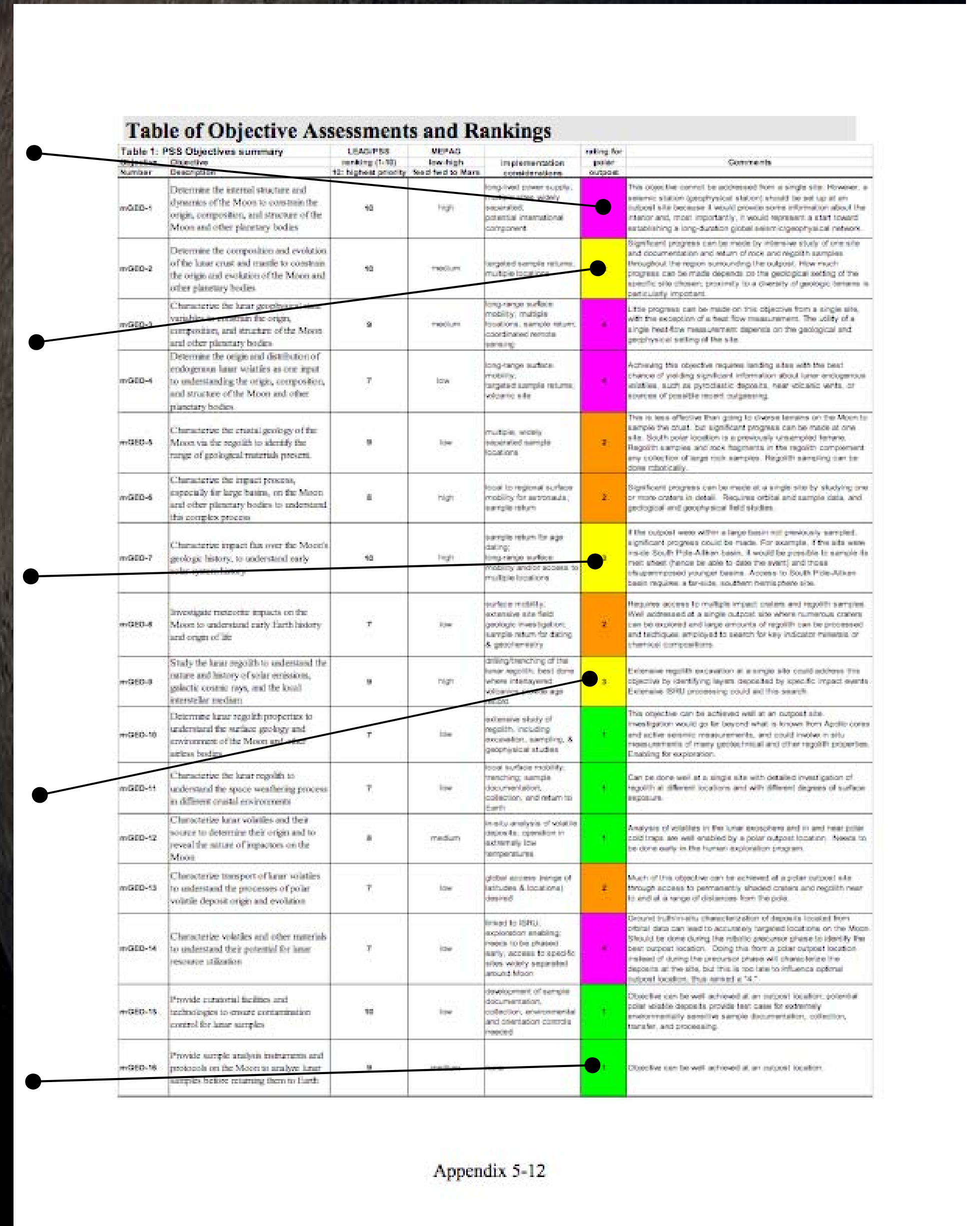


Table of Objective Assessments and Rankings

Table 1: PSS Objectives summary

Objective Number	Objective Description	LEAG/PSS ranking (1-10) 10: highest priority	MEPAG low-high feed fwd to Mars	Implementation considerations	rating for polar outpost	Comments
mGEO-1	Determine the internal structure and dynamics of the Moon to constrain the origin, composition, and structure of the Moon and other planetary bodies	10	high	long-lived power supply; multiple sites widely separated; potential international component	[illegible]	This objective cannot be addressed from a single site. However, a seismic station (geophysical station) should be set up at an outpost site because it would provide some information about the interior and, most importantly, it would represent a start toward establishing a long-duration global seismic/geophysical network.
mGEO-2	Determine the composition and evolution of the lunar crust and mantle to constrain the origin and evolution of the Moon and other planetary bodies	10	medium	targeted sample returns, multiple locations	[illegible]	Significant progress can be made by intensive study of one site and documentation and return of rock and regolith samples throughout the region surrounding the outpost. How much progress can be made depends on the geological setting of the specific site chosen; proximity to a diversity of geologic terrains is particularly important.
mGEO-3	Characterize the lunar geophysical state variables to constrain the origin, composition, and structure of the Moon and other planetary bodies	9	medium	long-range surface mobility; multiple locations, sample return, coordinated remote sensing	4	Little progress can be made on this objective from a single site, with the exception of a heat flow measurement. The utility of a single heat-flow measurement depends on the geological and geophysical setting of the site.
mGEO-4	Determine the origin and distribution of endogenous lunar volatiles as one input to understanding the origin, composition, and structure of the Moon and other planetary bodies	7	low	long-range surface mobility; targeted sample returns; volcanic site	4	Achieving this objective requires landing sites with the best chance of yielding significant information about lunar endogenous volatiles, such as pyroclastic deposits, near volcanic vents, or sources of possible recent outgassing.
mGEO-5	Characterize the crustal geology of the Moon via the regolith to identify the range of geological materials present.	9	low	multiple, widely separated sample locations	2	This is less effective than going to diverse terrains on the Moon to sample the crust, but significant progress can be made at one site. South polar location is a previously unsampled terrane. Regolith samples and rock fragments in the regolith complement any collection of large rock samples. Regolith sampling can be done robotically.
mGEO-6	Characterize the impact process, especially for large basins, on the Moon and other planetary bodies to understand this complex process	8	high	local to regional surface mobility for astronauts; sample return	2	Significant progress can be made at a single site by studying one or more craters in detail. Requires orbital and sample data, and geological and geophysical field studies.
mGEO-7	Characterize impact flux over the Moon's geologic history, to understand early solar system history	10	high	sample return for age dating; long-range surface mobility and/or access to multiple locations	3	If the outpost were within a large basin not previously sampled, significant progress could be made. For example, if the site were inside South Pole-Aitken basin, it would be possible to sample its melt sheet (hence be able to date the event) and those of superimposed younger basins. Access to South Pole-Aitken basin requires a far-side, southern hemisphere site.
mGEO-8	Investigate meteorite impacts on the Moon to understand early Earth history and origin of life	7	low	surface mobility; extensive site field geologic investigation; sample return for dating & geochemistry	2	Requires access to multiple impact craters and regolith samples. Well addressed at a single outpost site where numerous craters can be explored and large amounts of regolith can be processed and techniques employed to search for key indicator minerals or chemical compositions.
mGEO-9	Study the lunar regolith to understand the nature and history of solar emissions, galactic cosmic rays, and the local interstellar medium	9	high	drilling/trenching of the lunar regolith, best done where interlayered volcanics provide age control	3	Extensive regolith excavation at a single site could address this objective by identifying layers deposited by specific impact events. Extensive ISRU processing could aid this search.
mGEO-10	Determine lunar regolith properties to understand the surface geology and environment of the Moon and other airless bodies	7	low	extensive study of regolith, including excavation, sampling, & geophysical studies	1	This objective can be achieved well at an outpost site. Investigation would go far beyond what is known from Apollo cores and active seismic measurements, and could involve in situ measurements of many geotechnical and other regolith properties. Enabling for exploration.
mGEO-11	Characterize the lunar regolith to understand the space weathering process in different crustal environments	7	low	local surface mobility; trenching; sample documentation, collection, and return to Earth	1	Can be done well at a single site with detailed investigation of regolith at different locations and with different degrees of surface exposure.
mGEO-12	Characterize lunar volatiles and their source to determine their origin and to reveal the nature of impactors on the Moon	8	medium	in-situ analysis of volatile deposits; operation in extremely low temperatures	1	Analysis of volatiles in the lunar exosphere and in and near polar cold traps are well enabled by a polar outpost location. Needs to be done early in the human exploration program.
mGEO-13	Characterize transport of lunar volatiles to understand the processes of polar volatile deposit origin and evolution	7	low	global access (range of latitudes & locations) desired	2	Much of this objective can be achieved at a polar outpost site through access to permanently shaded craters and regolith near to and at a range of distances from the pole.
mGEO-14	Characterize volatiles and other materials to understand their potential for lunar resource utilization	7	low	linked to ISRU; exploration enabling; needs to be phased early; access to specific sites widely separated around Moon	4	Ground truth/in-situ characterization of deposits located from orbital data can lead to accurately targeted locations on the Moon. Should be done during the robotic precursor phase to identify the best outpost location. Doing this from a polar outpost location instead of during the precursor phase will characterize the deposits at the site, but this is too late to influence optimal outpost location, thus ranked a "4."
mGEO-15	Provide curatorial facilities and technologies to ensure contamination control for lunar samples	10	low	development of sample documentation, collection, environmental and orientation controls needed	1	Objective can be well achieved at an outpost location; potential polar volatile deposits provide test case for extremely environmentally sensitive sample documentation, collection, transfer, and processing.
mGEO-16	Provide sample analysis instruments and protocols on the Moon to analyze lunar samples before returning them to Earth	9	medium	[illegible]	1	Objective can be well achieved at an outpost location.

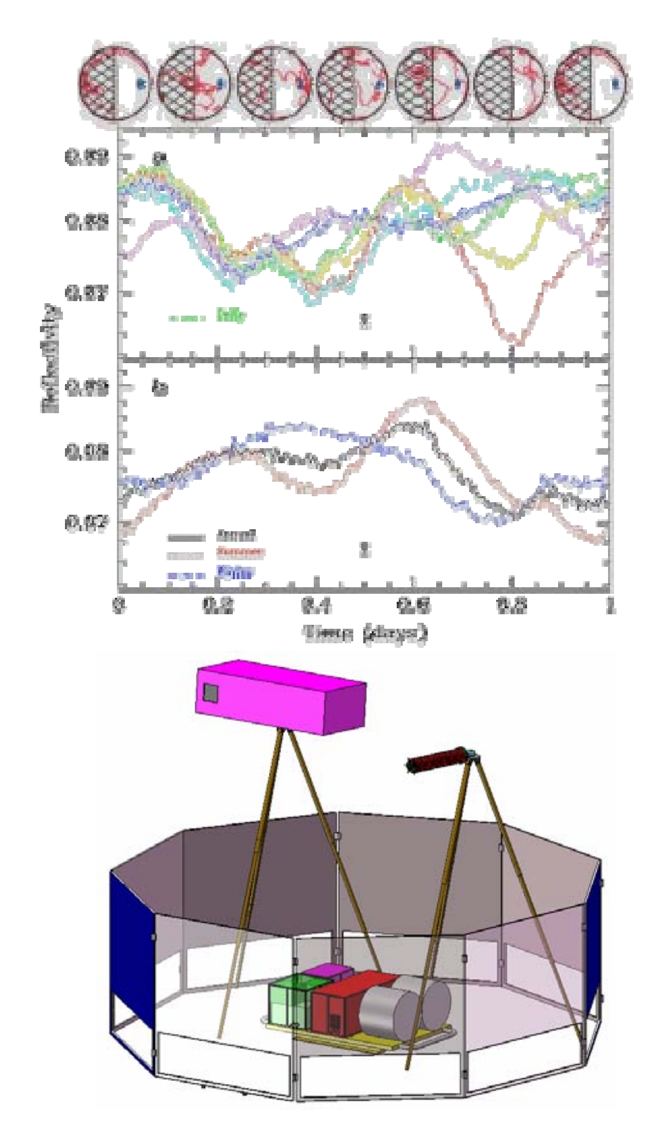
Appendix 5-12

Representative Science Payload Elements

Element Name	Description
Lunar Environmental Monitoring Station (LEMS)	Volatiles, plasma field, radiation monitoring, dust – should be deployed early to monitor site evolution
Traverse and Sampling Package (TSP)	Diverse kit including sampling tools and containers, rover-carried sample selection instruments, and traverse geophysics instruments
Sampling Resupply Kit (SRK)	Sample containers and tools to replace consumables in TSP
Lunar Interior Monitoring Station (LIMS)	Geophysics station – seismology, heat flow, etc.
Lab in Hab (LAB)	Instruments inside "lab" at outpost for sample screening
Automated Sample Handling System (SHED)	Automated sample handling equipment outside the hab-lab for handling samples in the "rock garden"
Telescope (OBS)	Small observatory for earth observation or astrophysics applications
Orbiter Packages (ORB)	Orbital science to be carried either in "SIM bay" or to be kicked out into lunar orbit – mostly heliophysics science

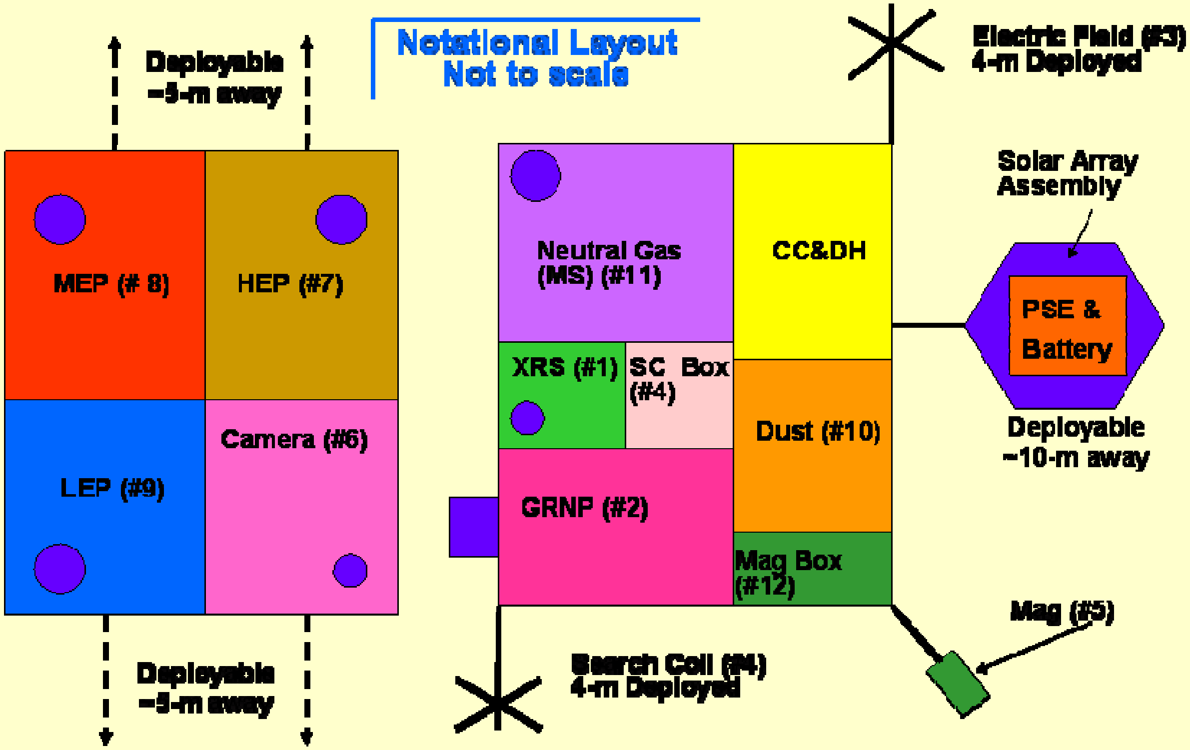
Lunar Telescope
Science Goals and Study Objectives

- ***Science Goals and Measurements***
  - A simple and autonomous Earth-observing system
  - A study of the light and chemical signatures of Earth can provide information on the planet's habitability and biology
  - The signature of the direct and spectroscopic light-curves of the Earth will be used to understand current and future observations of Earth-like exoplanets
  - Will measure variations in photometric, spectral, and polarization signatures over visible and near-infrared wavelengths
  - Provides near-simultaneous imaging, polarimetry, and spectral data of the full Earth disk
- ***Study Objectives***
  - Based on ALIVE Lunar Telescope proposal, develop a Lunar Telescope support system to be installed on the Lunar surface



Lunar Environmental Monitoring Station Science Goals and System Components

- ***Science Goals and Measurements***
  - Comprehensively characterize the Lunar environment
  - Measure coordinated multitude of lunar environmental parameters: high energy particles, imaging, solar flares, cosmic rays, plasma waves, magnetic fields, solar wind, volatiles, dust, etc.

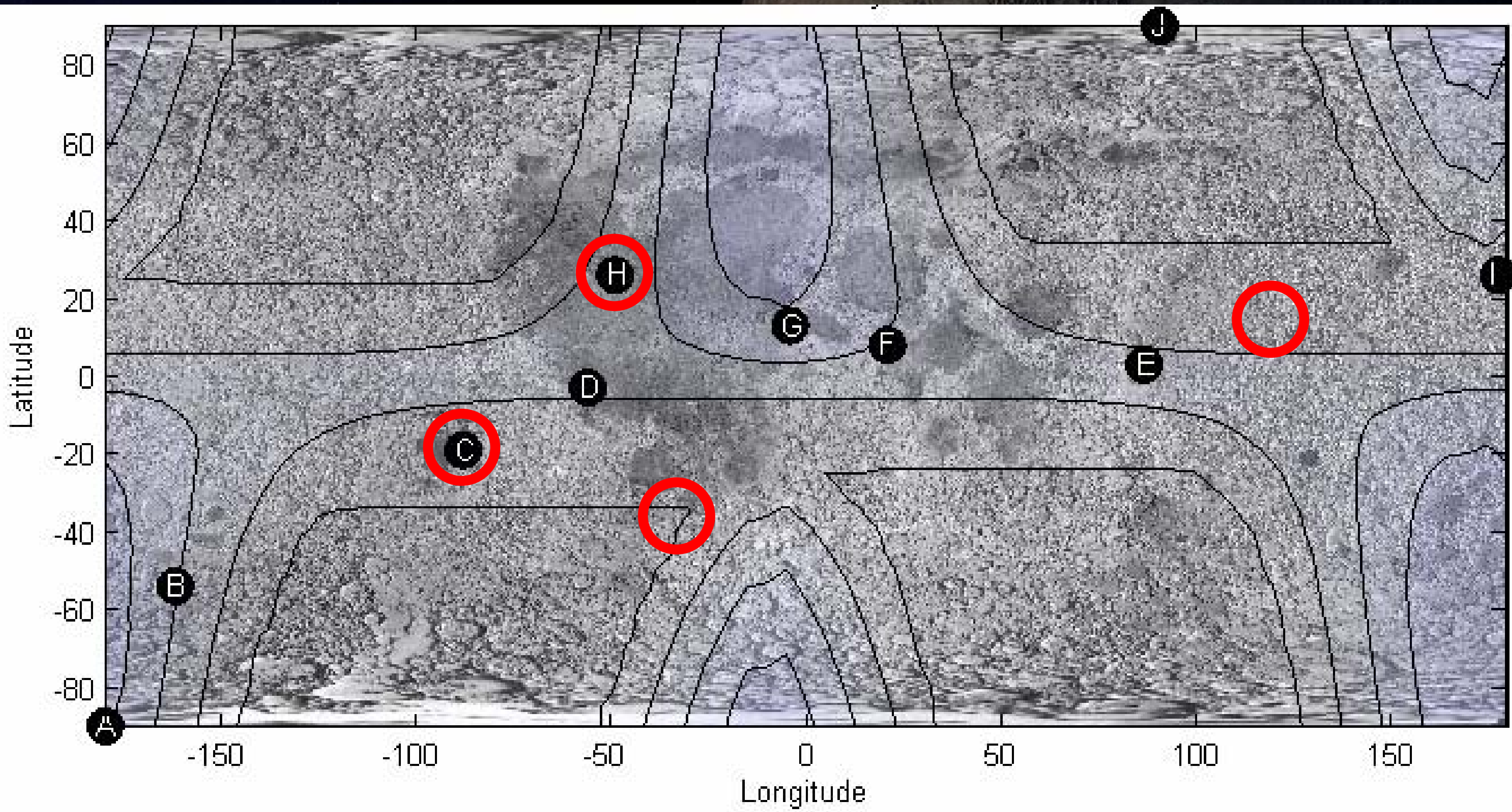


- ***System Components***
  - Multiple instruments
    - XRS X-ray Spectrometer (Solar Flares)
    - GRNP High Energy Protons and Neutrons, Gamma-rays
    - MS Mass Spectrometer
    - EF DC Electric Field/AC Electric Field (Plasma Waves)
    - MAG DC Magnetic Field
    - SC (Search Coil) AC Magnetic Field (Radio Waves)
    - LEP, MEP, HEP Energetic Particle Analyzers
    - DUST 3D Dust Detection
    - Camera Illumination, dust obscuration

Science Manifesting Guidelines

Element Name	Manifesting Guidance
Lunar Environmental Monitoring Station (LEMS)	HIGH PRIORITY -- Important to get this down as early as possible to monitor site evolution as humans come. 5 year life – replace after 5 yrs
Traverse and Sampling Package (TSP)	HIGH PRIORITY -- Need one of these for each rover. In absence of rover, at least need sample supplies up to available mass.
Sampling Resupply Kit (SRK)	HIGH PRIORITY -- Need one of these for each crewed mission – can stockpile ahead of time
Lunar Interior Monitoring Station (LIMS)	MEDIUM PRIORITY 1 – Bring 1 LIMS ASAP after LEMS and adequate sampling supplies. If mobility of ~500 km is possible, bring 2 more LIMS ASAP. 5 year life – replace after 5 years.
Lab in Hab (LAB)	This is most critical after stays get long (≥~a month), and assuming there is room to set it up in the hab
Automated Sample Handling System (SHED)	This is needed once the lab is functioning.
Telescope (OBS)	MEDIUM PRIORITY 2 – bring as soon as can be accommodated but after LIMS. Can bring more then 1 as this is a “generic” telescope
Orbiter Packages (ORB)	MEDIUM PRIORITY 3 – bring as soon as can be accommodated but after LIMS and OBS. Can bring more then 1 as this is a

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



	Site	Lat.	Long.
A	South Pole	89.9° S	180° W
B	Aitken Basin	54° S	162° W
C	Orientale Basin	19 S	88° W
D	Oceanus Procellarum	3° S	43° W
E	Mare Smythii	2.5° N	86.5° E

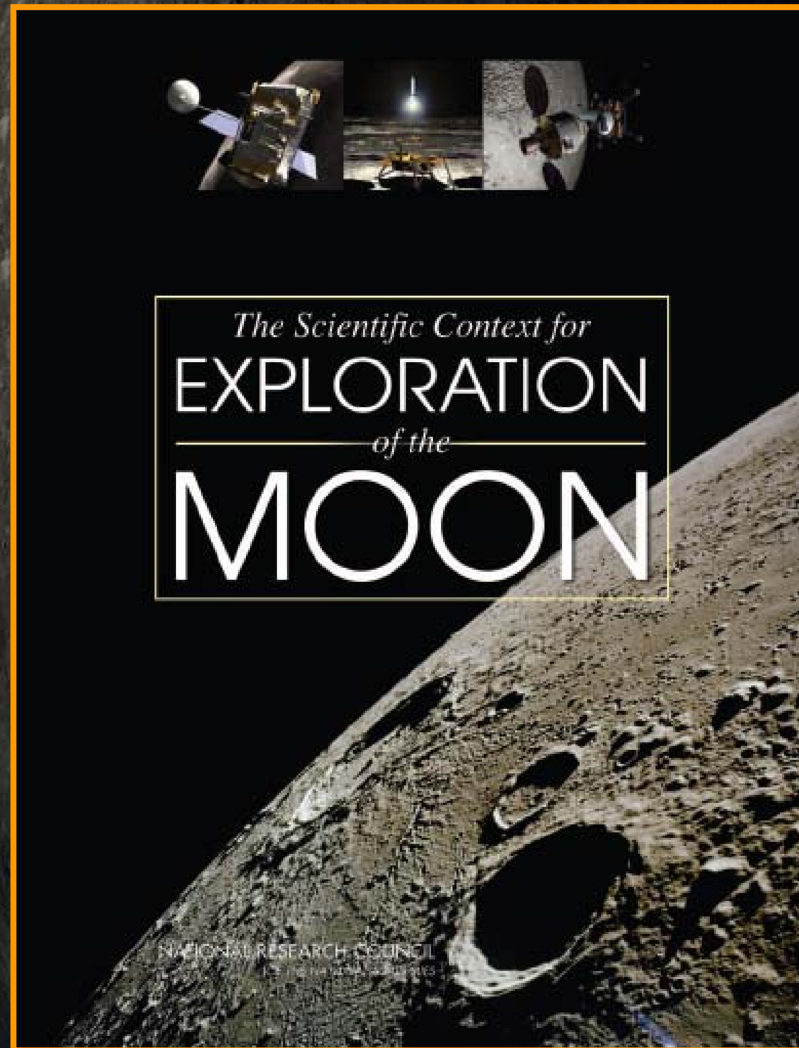
	Site	Lat.	Long.
F	Mare Tranquillitatis	8° N	21° E
G	Rima Bode	13° N	3.9° W
H	Aristarchus Plateau	26° N	49° W
I	Central Far Side Highlands	26° N	178° E
J	North Pole	89.5° N	91° E

National Research Council Report: “ Scientific Context for Exploration of the Moon”

- Asked by NASA SMD to provide guidance on the *scientific challenges and opportunities enabled by a sustained program of robotic and human exploration* of the Moon during the period 2008-2023 and beyond

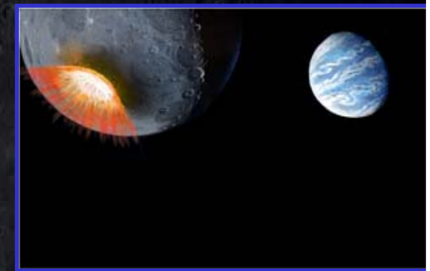
Key Science Findings:

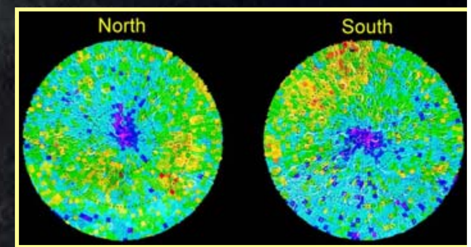
- *Enabling activities* are critical in the near term
- Strong ties with *international programs* are essential
- Exploration of the *South Pole-Aitken Basin* remains a priority
- *Diversity of lunar samples* is required for major advances
- The Moon may provide a *unique location for observation and study of Earth, near-Earth space, and the universe*

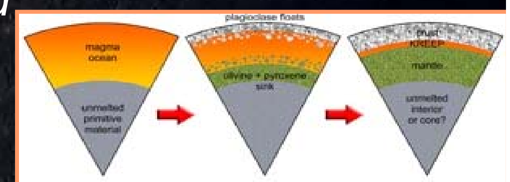


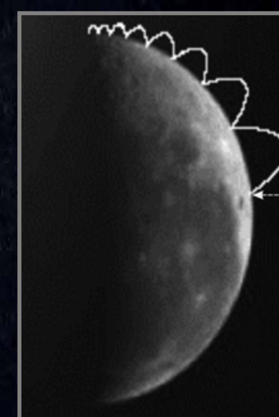
Scientific Context for Exploration of the Moon: Highest Priority Science Objectives

- *Test the cataclysm hypothesis by determining the **spacing in time of the creation of the lunar basins**.*
- *Anchor the early Earth-Moon impact flux curve by determining the **age of the oldest lunar basin** (South Pole-Aitken Basin).*
- *Establish a **precise absolute chronology**.*
- *Determine the compositional state (elemental, isotopic, mineralogic) and compositional distribution (lateral and depth) of the **volatile component in lunar polar regions**.*
- *Determine the extent and composition of the … feldspathic crust, KREEP layer, and other **products of planetary differentiation**.*
- *Determine the **thickness of the lunar crust** (upper and lower) and characterize its lateral variability on regional and global scales.*
- *Characterize the **chemical/physical stratification in the mantle**, particularly the nature of the putative 500-km discontinuity and the composition of the lower mantle.*
- *Determine the global density, composition, and time variability of the fragile **lunar atmosphere** before it is perturbed by … human activity.*
- *Determine the size, composition, and state (solid/liquid) of the **core of the Moon**.*
- *Inventory the variety, age, distribution, and origin of **lunar rock types**.*
- *Determine the size, charge, and spatial distribution of **electrostatically transported dust grains** and assess their likely effects on lunar exploration and lunar-based astronomy.*









Summary and Future Work

- **Science was an integral part of LAT 2 discussions**
- **The Lunar Architecture provides many opportunities for science**
- **Future studies will continue to our productive work with NASA's architecture process and the science community:**
  - Refine reference payload designs, deployment and power strategies in particular -- also look more seriously at deployment of small orbiters
  - Evaluate alternate sortie locations/science strategies
  - Work with surface and mobility teams on mobility options with and without crew
  - Help plan future workshops, e.g., Optimizing the human-robotic partnership in (1) traverses, (2) near-outpost environment and (3) when humans aren't there
- **NASA HQ is forming a joint SMD-ESMD Outpost Science and Exploration Working Group (OSEWG) that will consider these and other science issues within the evolving architecture**


NASA
The Moon as seen
from the Earth
~4.2 billion years ago
The Earth as seen
from the Moon
~15 years from now
After Pieters & Paulikas, SCEM Presentation

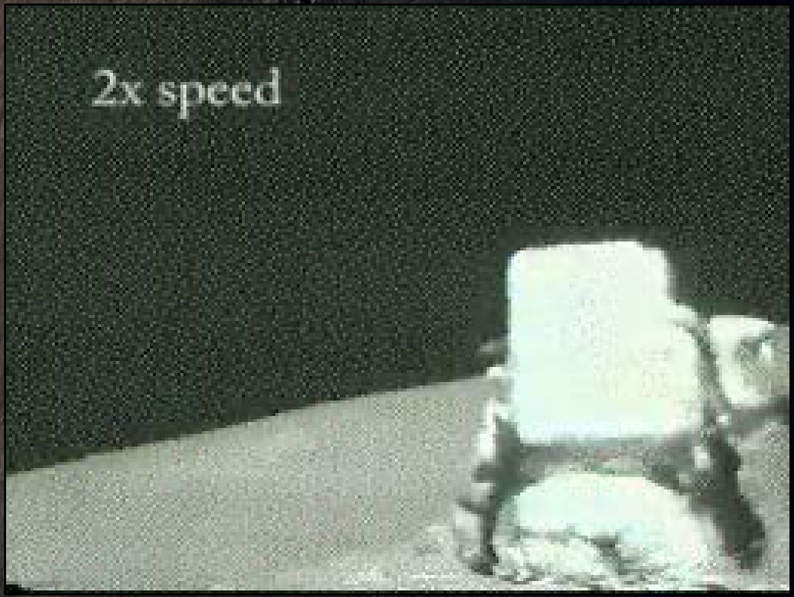
Extravehicular Activities (EVA) and Pressurized Rovers

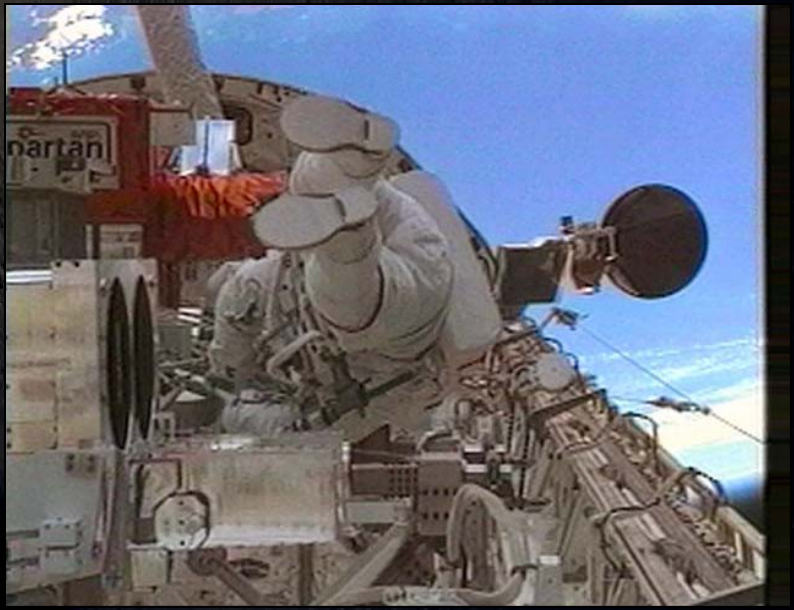
Mike Gernhardt
NASA Johnson Space Center

September 20, 2007

The Challenge of Moving Past Apollo

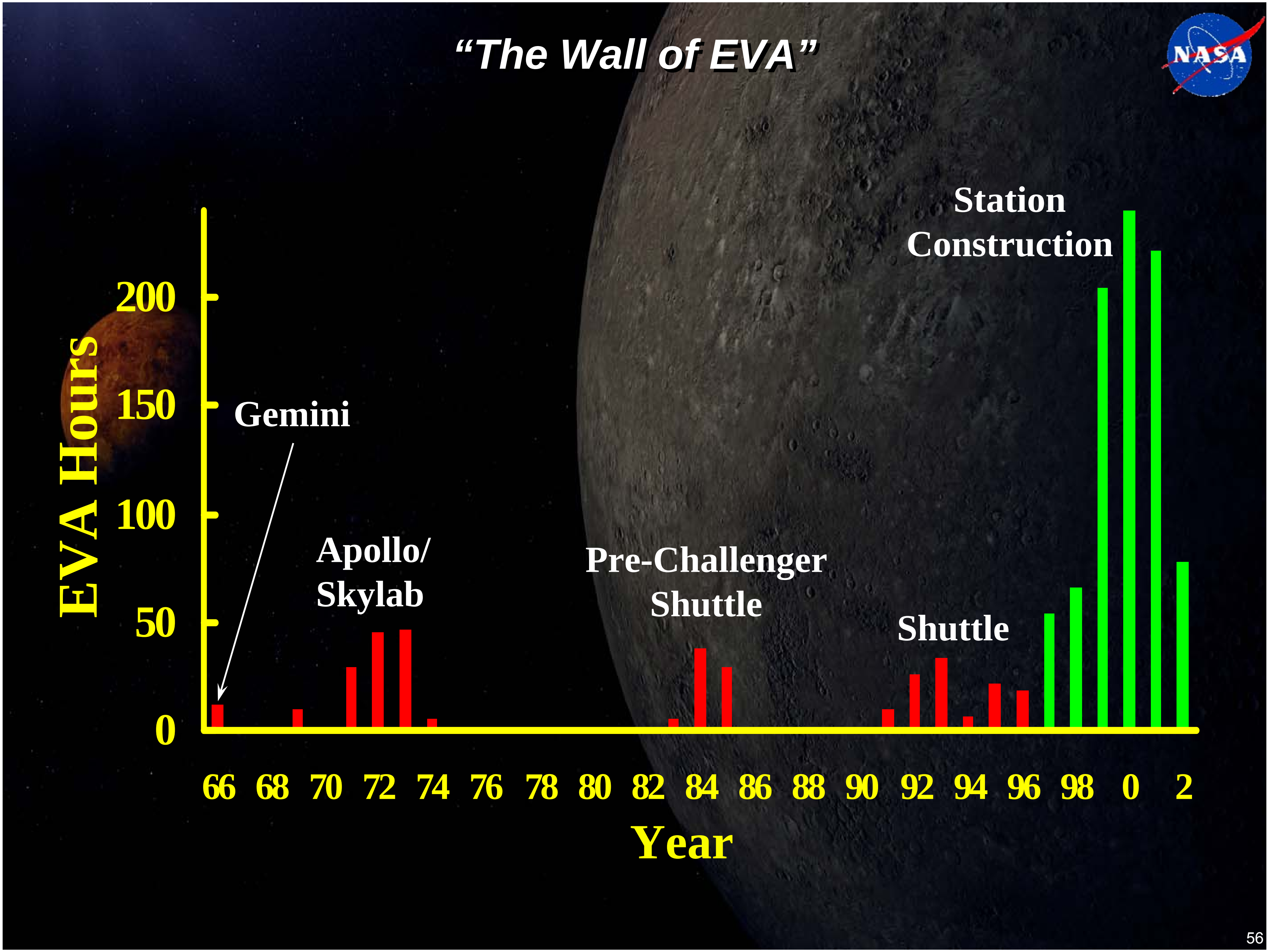
- Apollo was a remarkable human achievement
- Fewer than 20 EVAs, maximum of three per mission
- Constellation Program, up to 2000 EVAs over the 10 year Lunar program
- Limited mobility, dexterity, center of gravity and other features of the suit required significant crew compensation to accomplish the objectives. It would not be feasible to perform the constellation EVAs using Apollo vintage designs.
- The vision is to develop and EVA system that is low overhead and results in close to (or better than) one g shirt sleeve performance i.e. “A suit that is a pleasure to work in, one that you would want to go out and explore in on your day off.”
- Lunar EVA will be verey different from earth orbit EVA – a significant change in design and operational philosophies will be required to optimize suited human performance in lunar gravity.



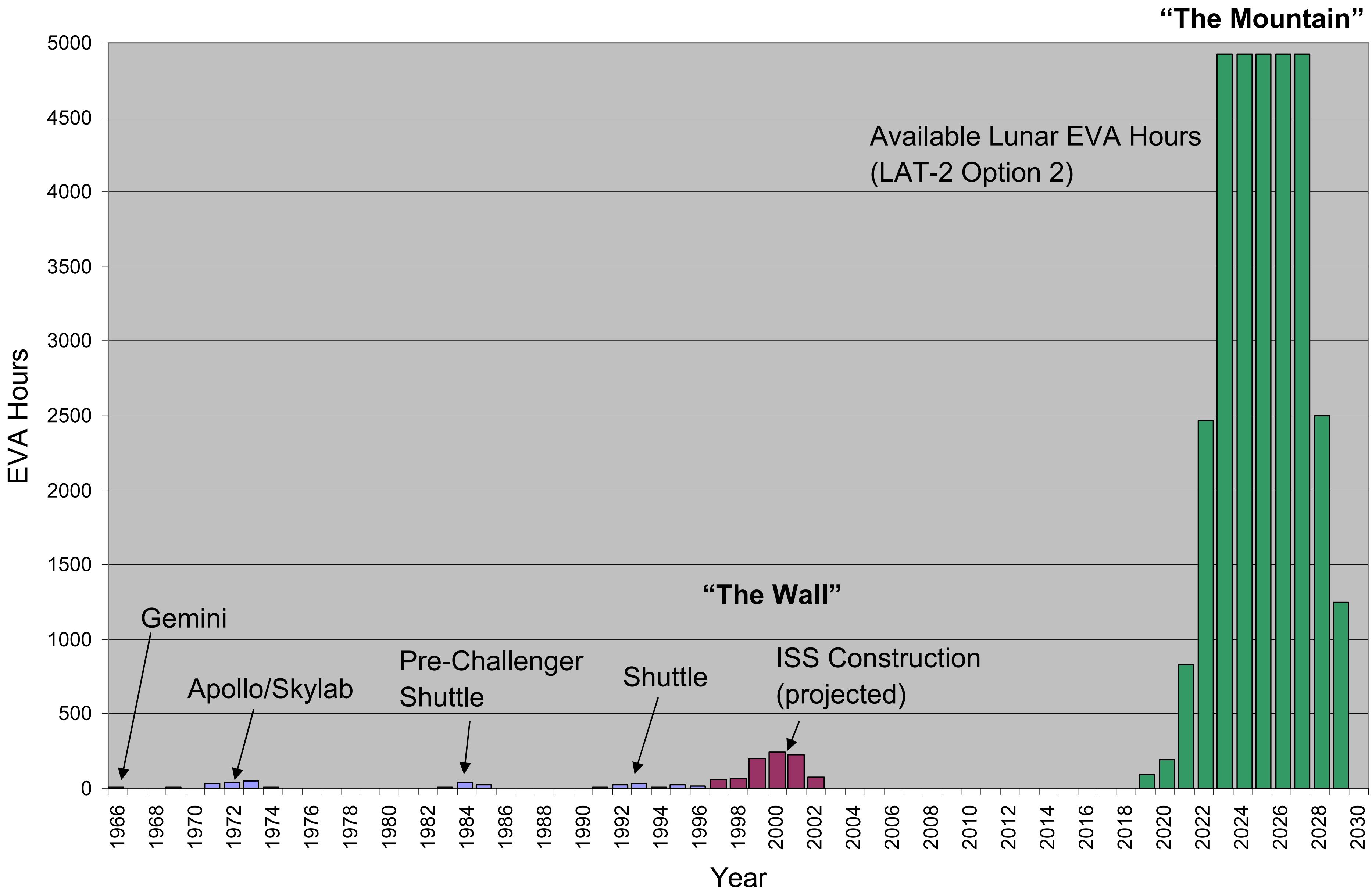


Challenges for EVA on the Moon

- **Dealing with risk and consequences of a significant Solar Particle Event (SPE)**
- **Long duration missions with three 8hr EVAs per person per week**
  - Apollo suits were used no more than 3 times
  - Individual crewmembers might perform up to 76 EVAs in a 6-month mission
  - Suit-induced trauma currently occurs with even minimal EVA time
- **With Apollo style unpressurized rover (UPR), exploration range is limited EVA sortie time and 10 km walkback constraint**
  - Science community believes that significantly greater range will be required for optimal science return
- **Apollo highlighted the importance of dust control for future long duration missions**
- **Increased Decompression Sickness (DCS) risk and prebreathe requirements associated with 8 psi 32% O_2 cabin pressure versus Apollo with 5 psi 100% O_2**
- **The high frequency EVA associated with the projected lunar architectures will require significant increases in EVA work efficiency (EVA prep time/EVA time)**


"The Wall of EVA"
NASA
Station
Construction
200
150
100
50
0
EVA Hours
Gemini
Apollo/
Skylab
Pre-Challenger
Shuttle
Shuttle
66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 0 2
Year
56

"The Mountain of EVA"



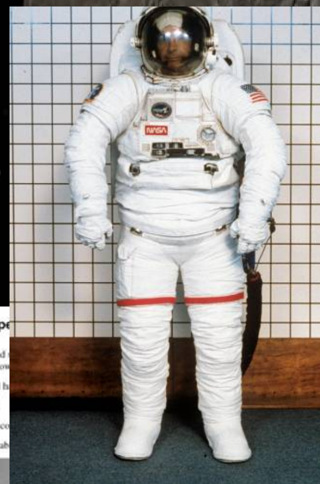
EVA Work Efficiency Index: Exploration EVA Should Target WEI >3.0

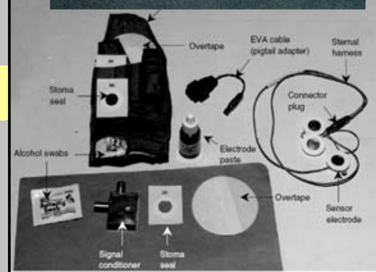
TOTAL EVA Work Efficiency Index =

$$\frac{\text{EVA Time}}{\text{(Total EMU/A/L Prep + Prebreathe + A/L Depress + A/L Repress + Total Post EVA)}}$$

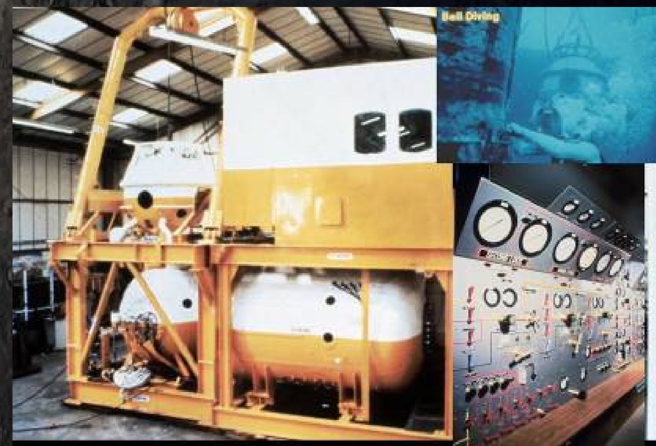
Total Suit/Airlock Overhead

PREBREATHE PROTOCOL	Shuttle 10.2 Staged Decompression (12 hrs at 10.2)	ISS: 4 hour In Suit	ISS CEVIS Exercise (Using ISS O2)
EVA Overhead Activities	TIME IN MINUTES	TIME IN MINUTES	TIME IN MINUTES
Suit checkout	115	185	185
REBA powered hardware checkout	25	25	25
SAFER checkout	30	30	30
Airlock config	95	90	90
Consumables Prep	60	120	120
EVA prep - prebreathe related	60	0	80
EVA prep - EMU related	30	30	30
Suit donning & leak check	60	60	60
SAFER donning	Completed during Prebreathe	Completed during Prebreathe	Completed during Prebreathe
Purge	8	12	12
Prebreathe	75	240	60
Airlock depress	15	30	40
Airlock egress	15	15	15
Airlock ingress	15	15	15
Airlock repress	15	15	15
Suit doffing	25	25	25
SAFER doffing & stow	10	10	10
Post EVA processing	105	90	90
TOTAL	758	992	902
EVA WORK EFFICIENCY INDEX	0.51	0.39	0.43





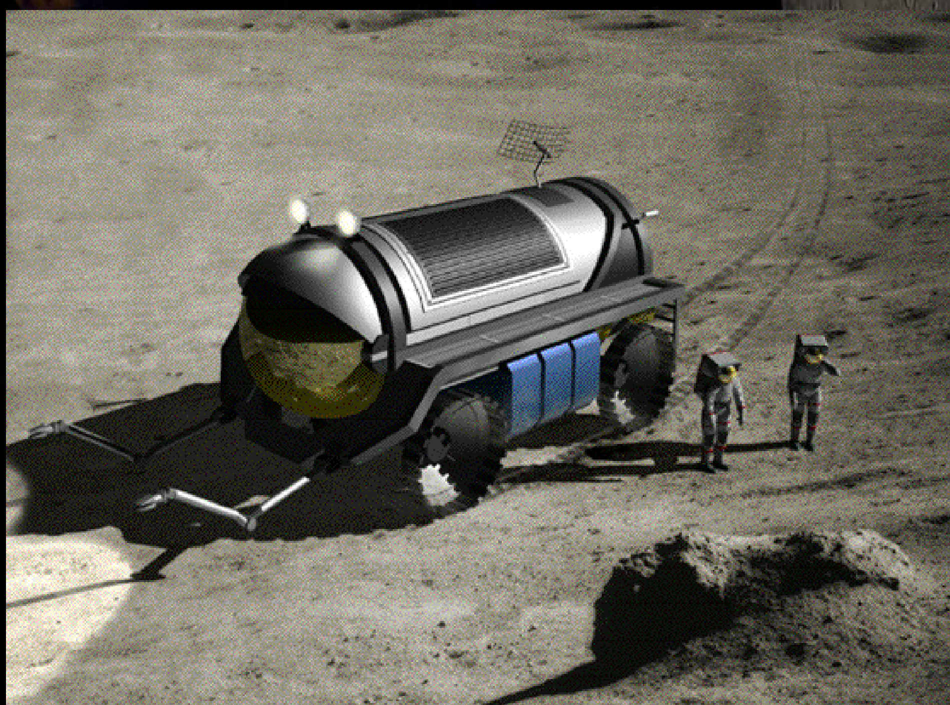
Commercial saturation diving has WEI of 3-10 depending on depth

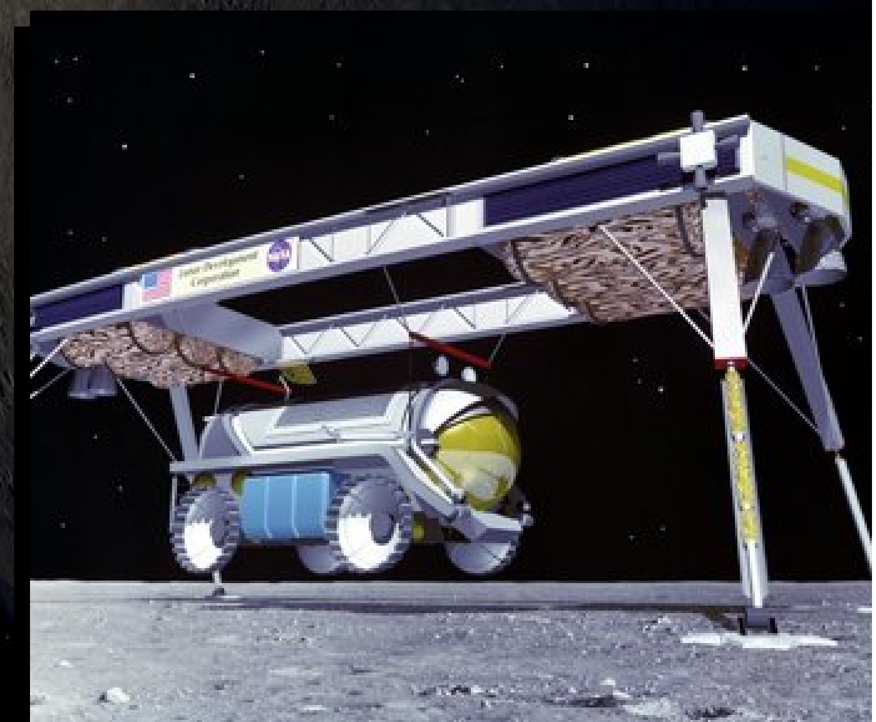


- **Life Science controls significant portion of EVA overhead:**
  - Prebreathe
  - Biomedical sensors
  - Nutrition and Hydration Systems
- **Additionally the EVA system needs:**
  - Suits with fewer distinct components
  - Automatic checkout and servicing
  - Lower volume airlock/suit lock
  - Improved Don/Doff etc.

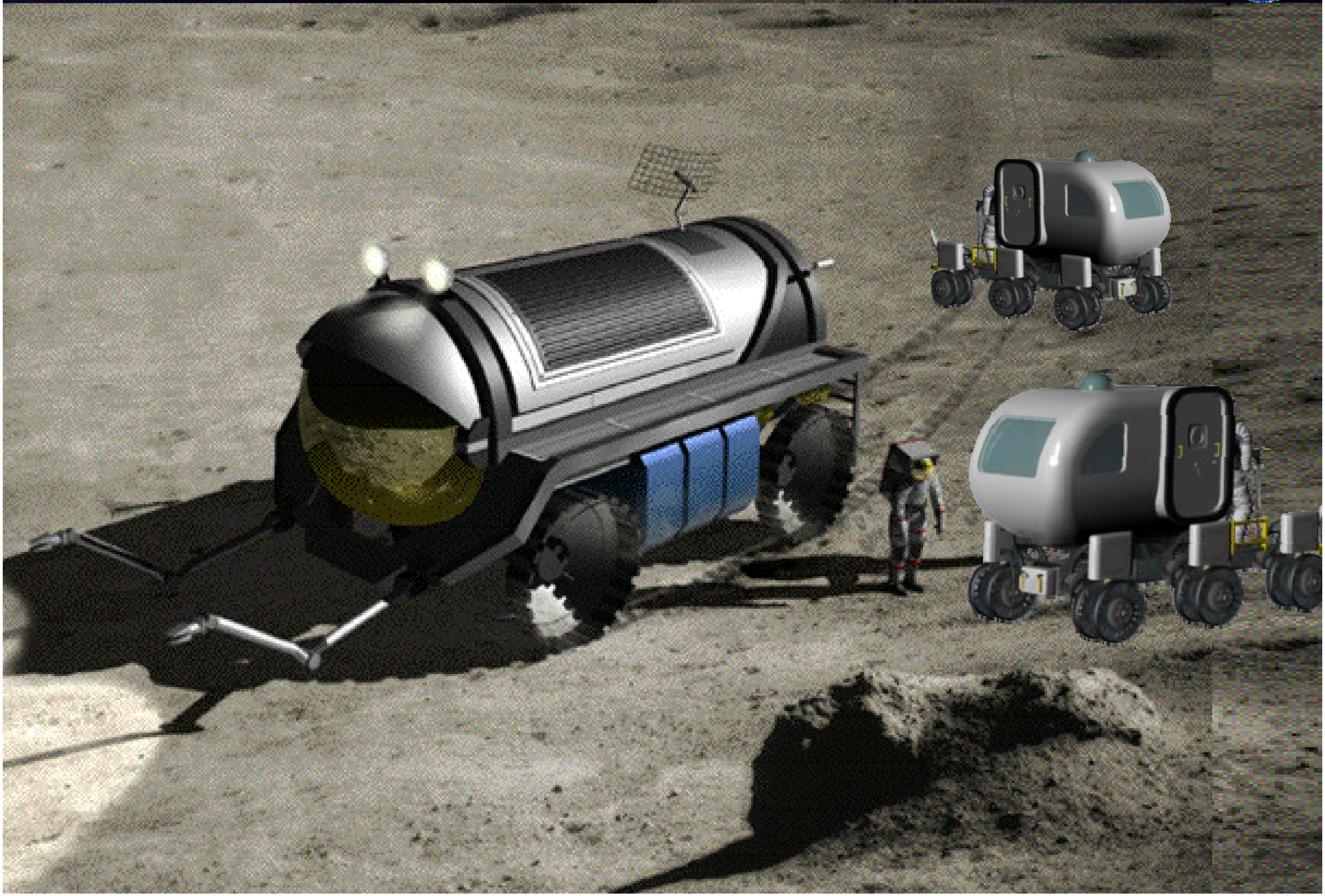
Large Pressurized Rovers

- **Previous Lunar / Mars studies have proposed a Large Pressurized Rover (LPR) to extend exploration range**
- **LPR designs complex and heavy, mass >8000kg**
- **Mobile landers may offer preferable solution to large scale pressurized mobility**
- **LAT-1 assumed only one LPR, delivered late in architecture**
- **Contingency Return Range: 240km**
  - UPR with 24hrs of energy and consumables (+ margin) on/behind the LPR provides 240km return capability
  - 24-hr unpressurized translation
    - No SPE protection
  - Limited by allowable in-suit translation time (24hrs)

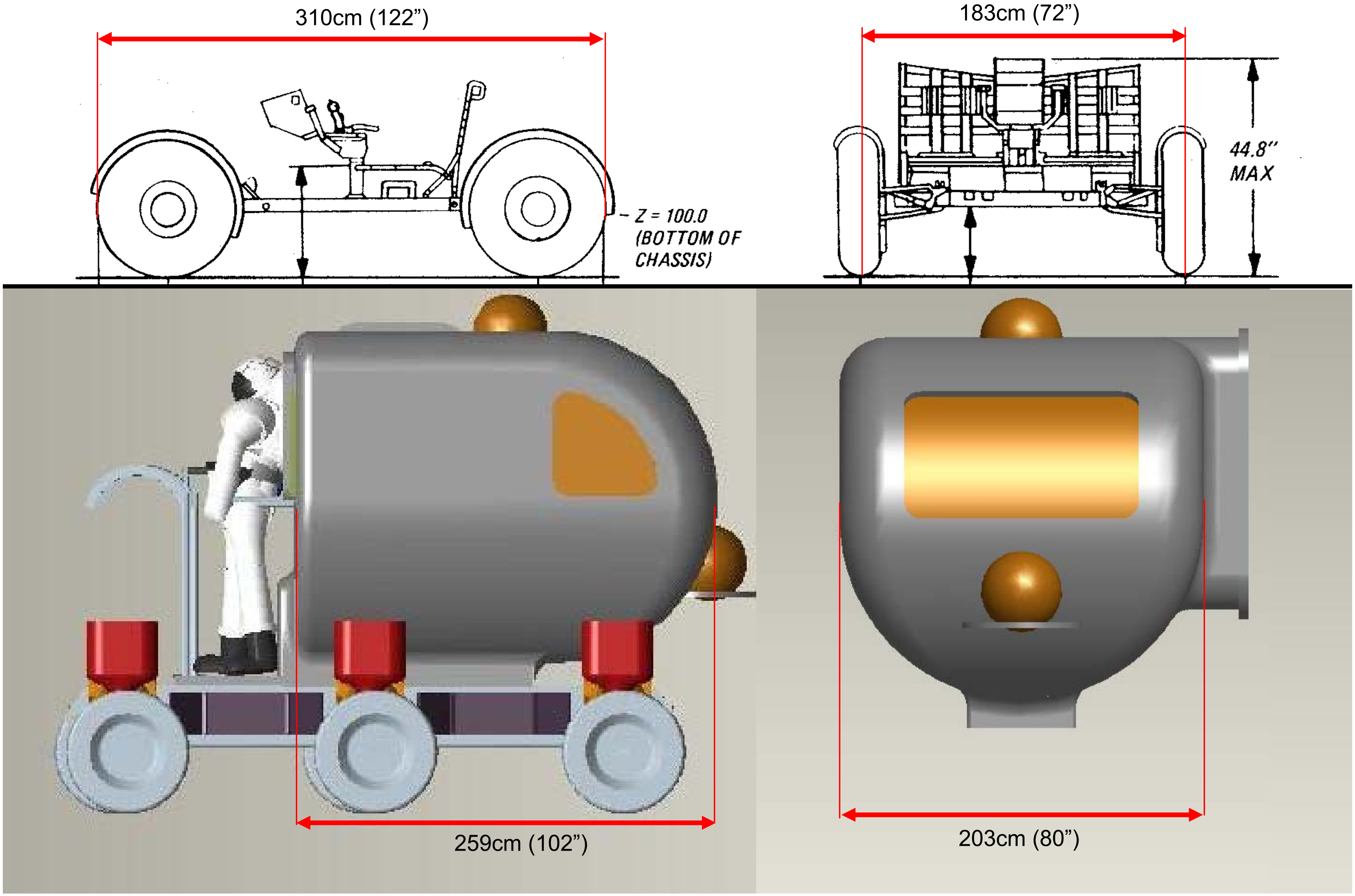




The New Lunar Architecture Drives Out The Need For A New Class Of EVA Surface Support Vehicles



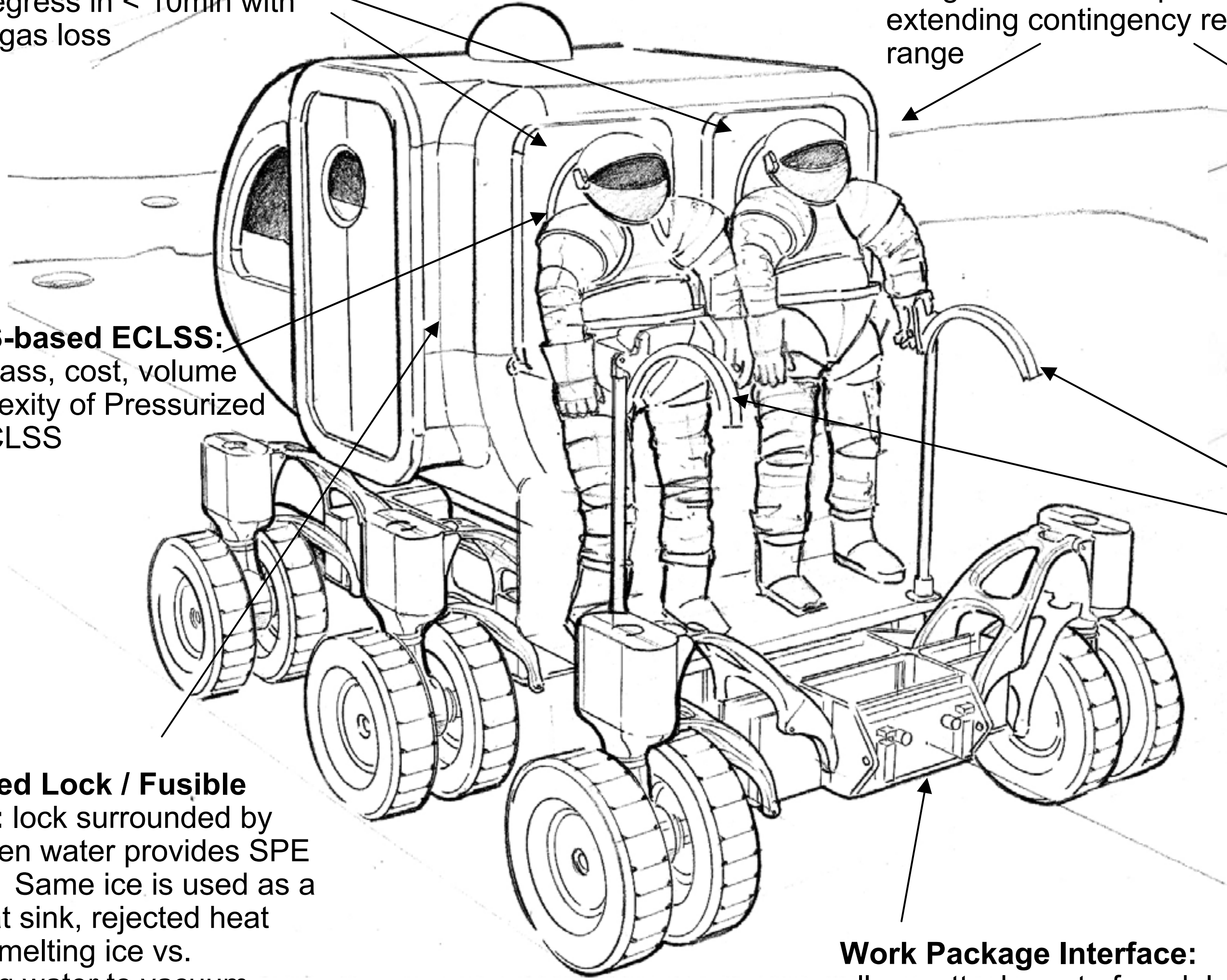
Apollo LRV vs. Small Pressurized Rover Dimensions

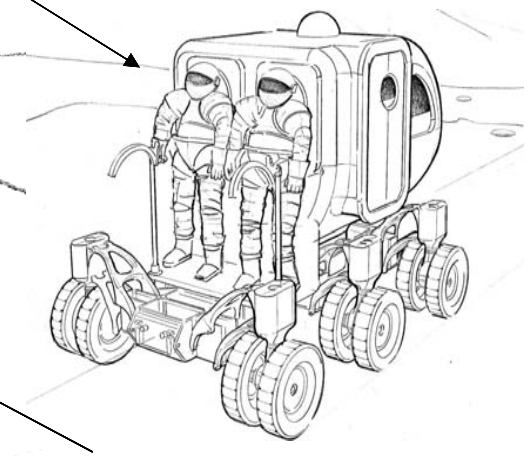


Small Pressurized Rover Design Features (Slide 1 of 2)

Suitports: allows suit donning and vehicle egress in < 10min with minimal gas loss

Two Pressurized Rovers: low mass, low volume design enables two pressurized vehicles, greatly extending contingency return (and thus exploration) range



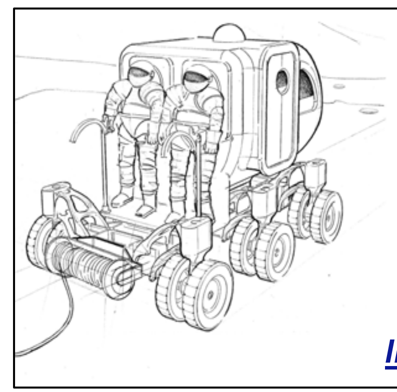


Suit PLSS-based ECLSS: reduces mass, cost, volume and complexity of Pressurized Rovers ECLSS

Chariot-Style Aft Driving Station: enables crew to drive rover while EVA, also part of suitport alignment

Ice-shielded Lock / Fusible Heat Sink: lock surrounded by 2.5cm frozen water provides SPE protection. Same ice is used as a fusible heat sink, rejected heat energy by melting ice vs. evaporating water to vacuum.

Work Package Interface: allows attachment of modular work packages e.g. winch, cable reel, backhoe, crane



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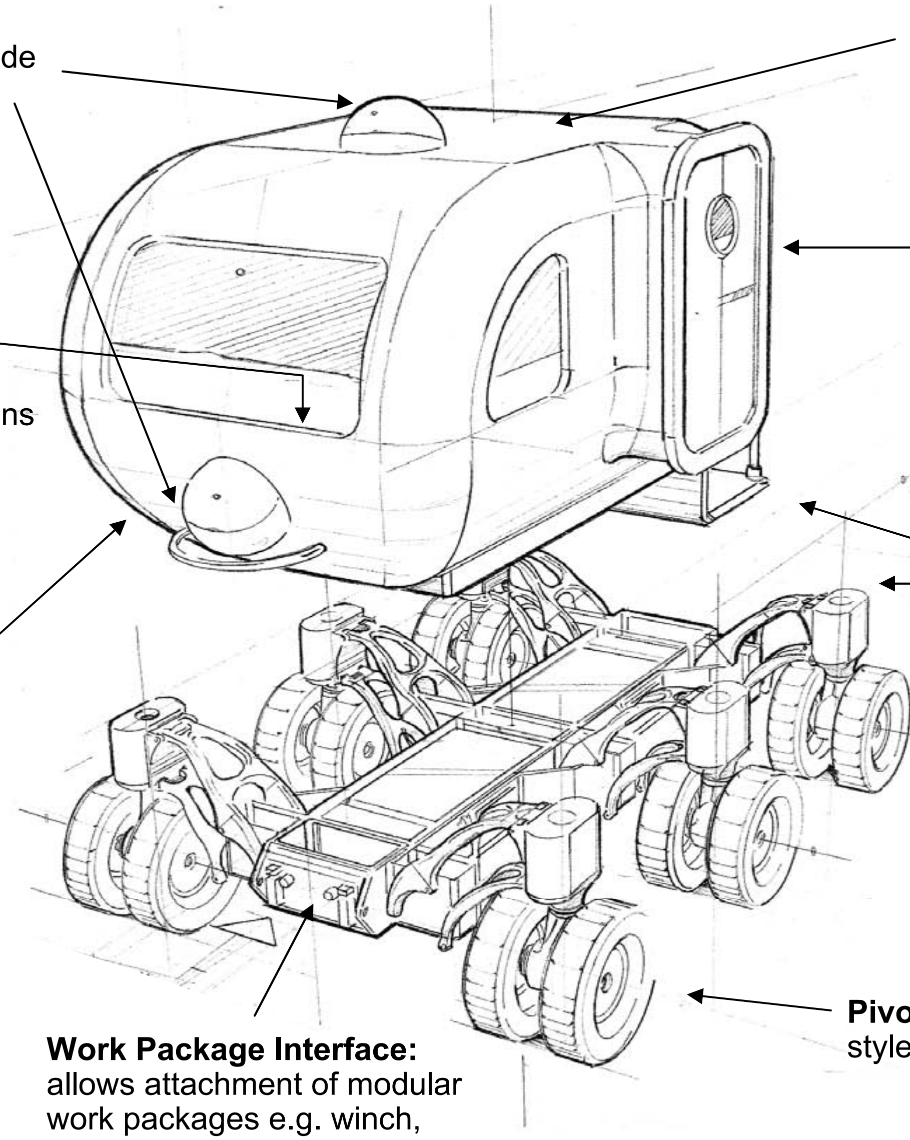
Small Pressurized Rover Design Features *(Slide 2 of 2)*



Dome windows: provide visibility as good, or better than, EVA suit visibility

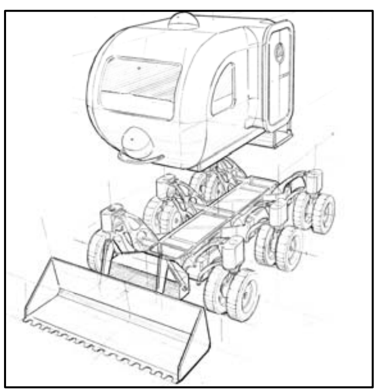
Radiator on Roof: allows refreezing of fusible heat sink water on extended sorties

Docking Hatch: allows pressurized crew transfer from Rover-to-Habitat, Rover-to-Ascent Module and/or Rover-to-Rover

Exercise ergometer (inside): allows crew to exercise during translations

Modular Design: pressurized module is transported using Mobility Chassis. Pressurized module and chassis may be delivered on separate landers or pre-integrated on same lander.

Cantilevered cockpit: Mobility Chassis does not obstruct visibility

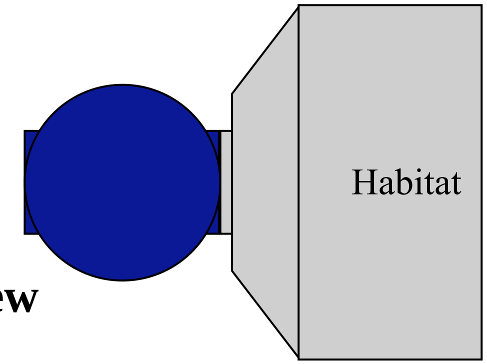


Work Package Interface: allows attachment of modular work packages e.g. winch, cable reel, backhoe, crane

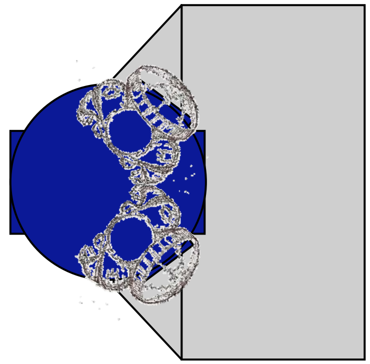
Pivoting Wheels: enables crab-style driving for docking

Airlock vs. Suitlock vs. Suitport

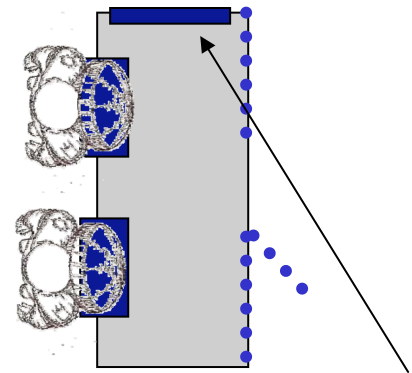
Airlock
STS Airlock with “submarine” hatches



Suitlock
Note: ARC Dimensions
Alternative configurations possible



Small Pressurized Rovers Suitport Configuration



Top View

- **Suitlock:**
  - Reclaim pump drops pressure to ~2psi in ~40mins (lose last 2psi to vacuum)
  - Standard submarine hatch for exit to lunar surface
  - Suitlock provides dust isolation and mitigation countermeasures
  - Interior hatch allows suits to be brought into the habitat
  - Outer hatch provides protection against hab depress through major suit **and** suit hatch leak
  - Option to add suitport feature to suitlock (requires donning suits at 8psi with relaxed man-loads)
- **Suitport:**
  - Suits are pressure/leak checked with both hatches closed, minimizing likelihood of catastrophic suit failure during donning
  - Interior hatch provides protection against depressurization of habitat/ forward cockpit of rover
  - Central lock can be depressed using reclaim pump e.g. from 8 to 6psi on high end of exponential depress curve in reasonable time. Final depress of volume between suit hatch and hab/ Small Pressurized Rover hatch. Allows suit-donning at lower pressure.

Suitports

	Option 2 Gas Loss (kg)	Option 2 Depress Time (hours)
LAT-2 Airlock/Suitlock	**16,299**	
LAT-2 Airlock/Suitlock with 90% Gas Save	**1,630**	**2,880**
Suitport (PLSS Hatch Volume)	**188**	**136**
2-Person Suitlock Cylinder	**14,338**	
2-Person Suitlock Cylinder with 90% Gas Save	**1,434**	**3,601**

Pros

- **Drastic reduction in cumulative depress time:**
  - 114 DAYS in Option 2 vs. LAT-2 Airlock/Suitlock w/ 90% gas save
  - 144 DAYS in Option 2 vs. Suitlock w/ 90% gas save
- **Significant reduction in gas losses:**
  - 1442kg in Option 2 vs. LAT-2 Airlock/Suitlock w/ 90% gas save
  - 1246kg in Option 2 vs. Suitlock w/ 90% gas save
- **No gas reclaim pumps**
- **No greater risk than suitlocks (if used with inner hatch)**

Cons

- **Lower Technology Readiness Level (TRL) than airlocks**
- **More difficult for incapacitated crewmember to ingress**
- **Possibly require suit-donning at 8psi w/ relaxed man-loads**
- **Would likely require some back-mounted PLSS components (challenges for optimal CG)**

Environmental Control and Life Support Systems (ECLSS) & Power

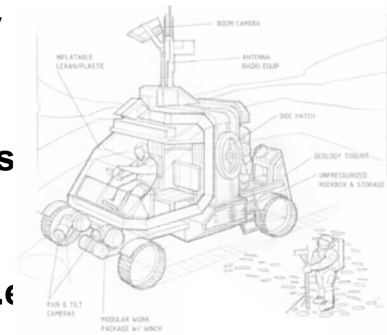
ECLSS:
- **ECLSS system based on the suit PLSS (assumes 2 PLSSs + 1 spare)**
- **Suit PLSSs provide O_2/pressure regulation, CO_2 removal (comm?)**
- **Additional components include**
  - N_2 tanks,
  - N_2/O_2 controller,
  - Cabin fan,
  - condensing heat exchanger,
  - WCS and waste water tanks,
  - O_2 and water supply tanks,
  - water heater
  - fusible heat sink/SPE protection with ~225kg (500lb) (TBR) water
  - top mounted radiator for freezing the water in the central lock

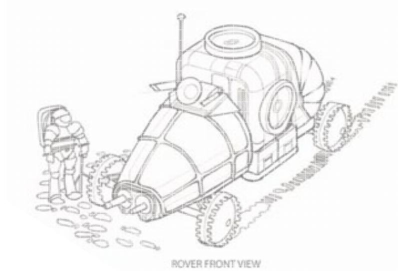
POWER:
- **415kg batteries = 83KWh (assumes 0.2KWh/kg by 2019)**
- **Recharged at outpost and/or at deployed Solar Power Units (SPU)**
- **Fuel cell options being investigated**

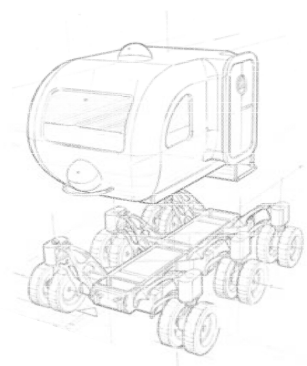
Subsystem	Power (Watts)
60W per PLSS x 2	**120W**
Cabin / CHX Fan	**100W**
Avionics / Lights / Cameras	**400W**
Total	620W

Small Pressurized Rovers: Functional Requirements

- **Power-up and Check-out including suit/PLSS power up and check-out: ≤1hr**
- **Mate/de-mate from Hab/Lander: ≤ 10mins and ≤ 0.03kg gas losses**
- **Nominal velocity: 10kph**
- **Driving naked-eye visibility should be comparable to walking in suit i.e. eyes at same level, similar Field-of-View**
  - Augmented by multi-spectral cameras/instruments
- **Visual accessibility to geological targets comparable to EVA observations i.e naked eyes ≤ 1m of targets**
  - Possibility of magnification optics providing superior capability than EVA observations
- **Suit don and Egress/Egress**
  - ≤ 10mins
  - ≤ 0.03kg gas losses per person
  - ≥ 2 independent methods of ingress/egress
- **Vehicle Mass (not incl. mobility chassis) ≤ 2400kg**
- **Habitable volume: ~8.4m^3**
- **12 2-person EVA hours at 200km range on batteries and nominal consumable load**
- **Ability to augment power and consumables range and duration to achieve ≥ 1000km**
- **PLSS recharge time ≤ 30mins**
- **Crewmembers ≤ 20mins from ice-shielded lock SPE protection (incl. translation to Small Pressurized Rovers and ingress)**
- **Heat and humidity rejection provided by airflow through ice-shielded lock and condensing heat exchanger**







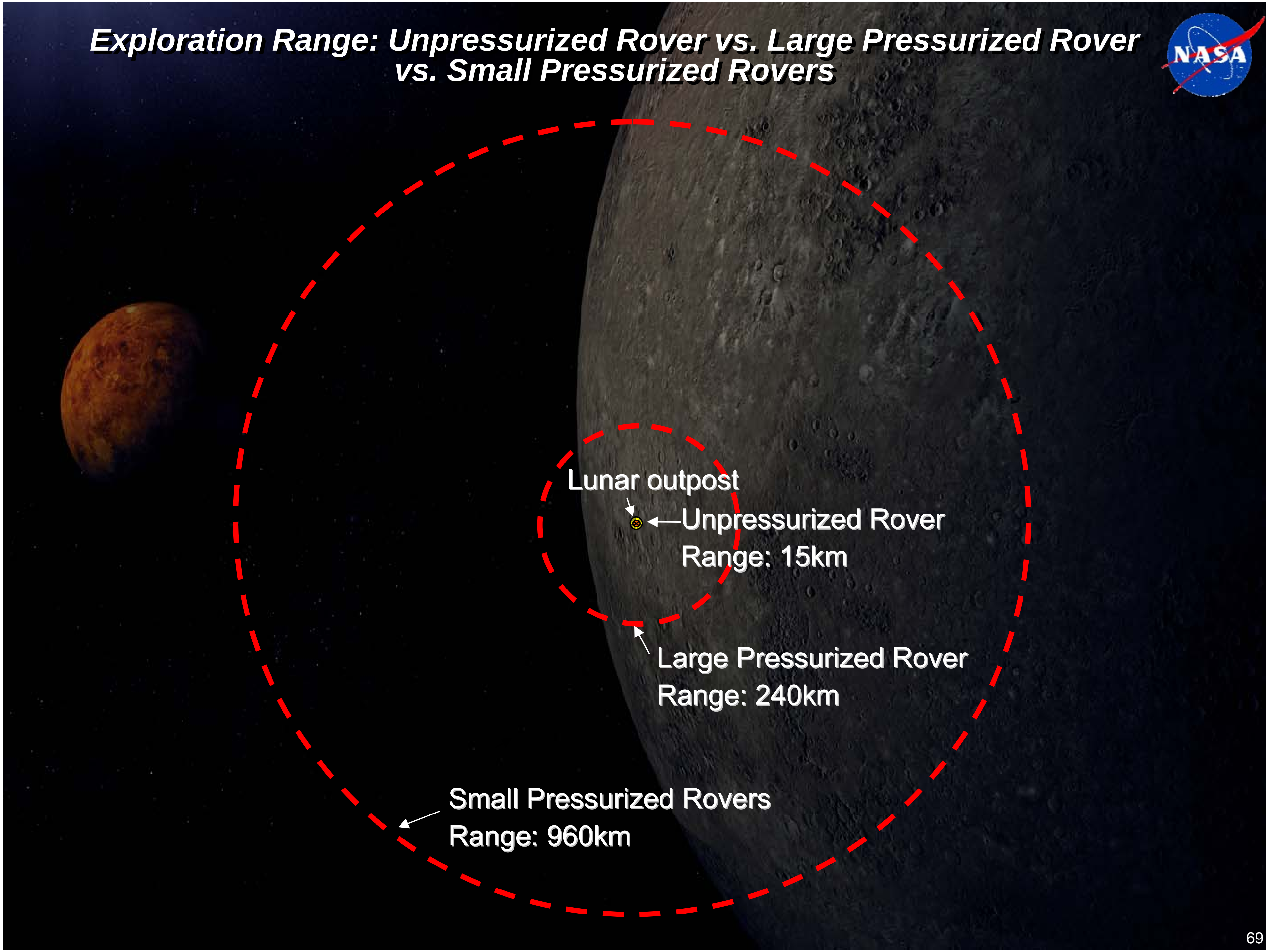
Comparison of Unpressurized vs. Small Pressurized Rovers (1-day, 1 site sorties)

			UPR		Pressurized Rover			
Range from Base (km)	Exploration Area (km2)	Boots-on-Surface EVA Time (hrs)	Total EVA Time (hrs)	Total Crew Time (hrs)	Total EVA Time (hrs)	Total Crew Time (hrs)	% Reduction in EVA Hours	% Increase in Exploration Area
1	3	3.3	5.2	7.9	3.6	7.1	**31%**	
10	314	3.3	7.0	9.7	3.6	8.9	**49%**	
15	707	3.3	8.0	10.7	3.6	9.9	**55%**	
20	1257	3.3			3.6	10.9	**Not possible w/ UPR**	**78%**
30	2827	3.3			3.6	12.9	**Not possible w/ UPR**	**300%**
40	5027	3.3			3.6	14.9	**Not possible w/ UPR**	**611%**

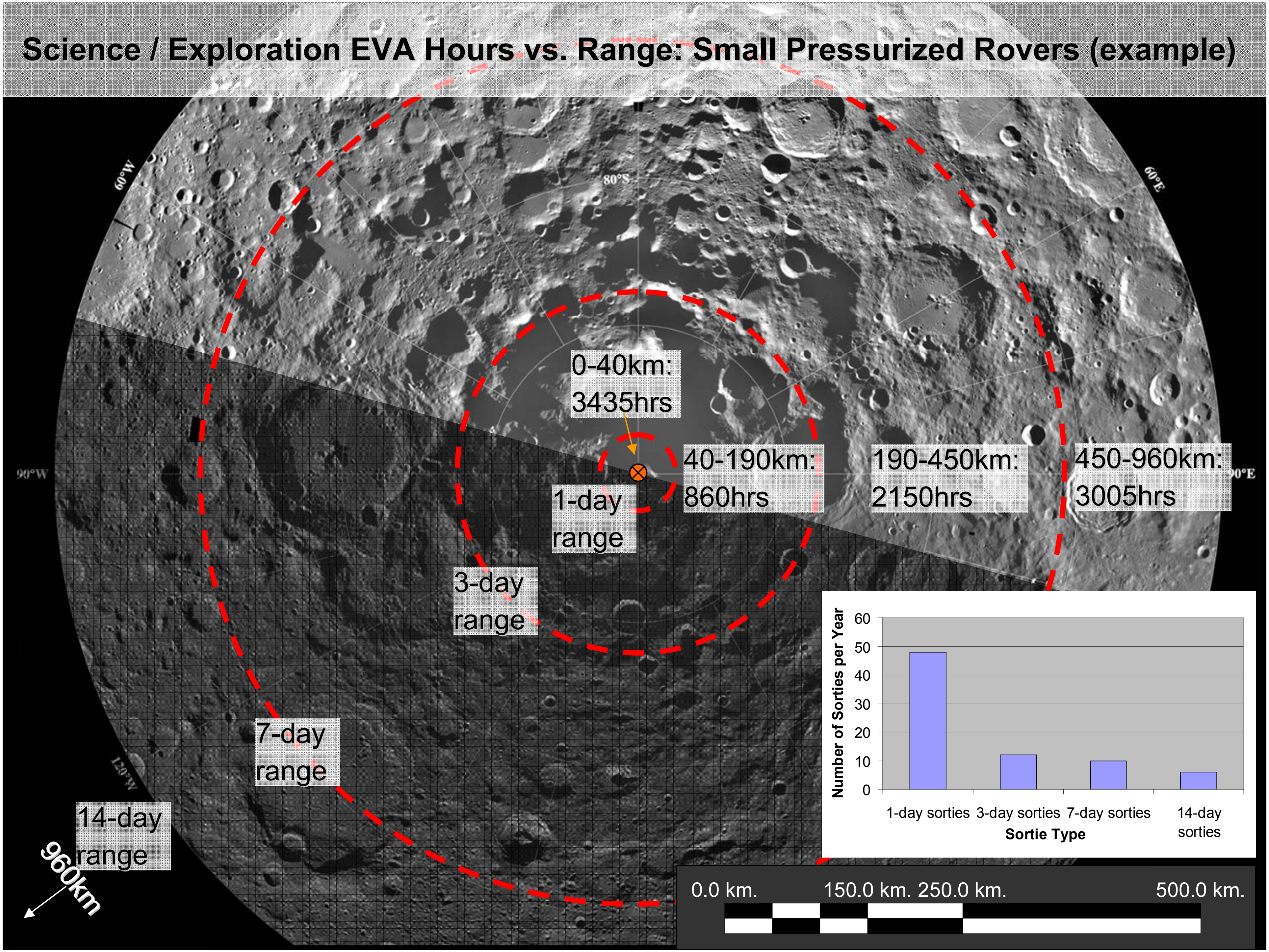
Constraints are 8hr EVA and 15hr crew day

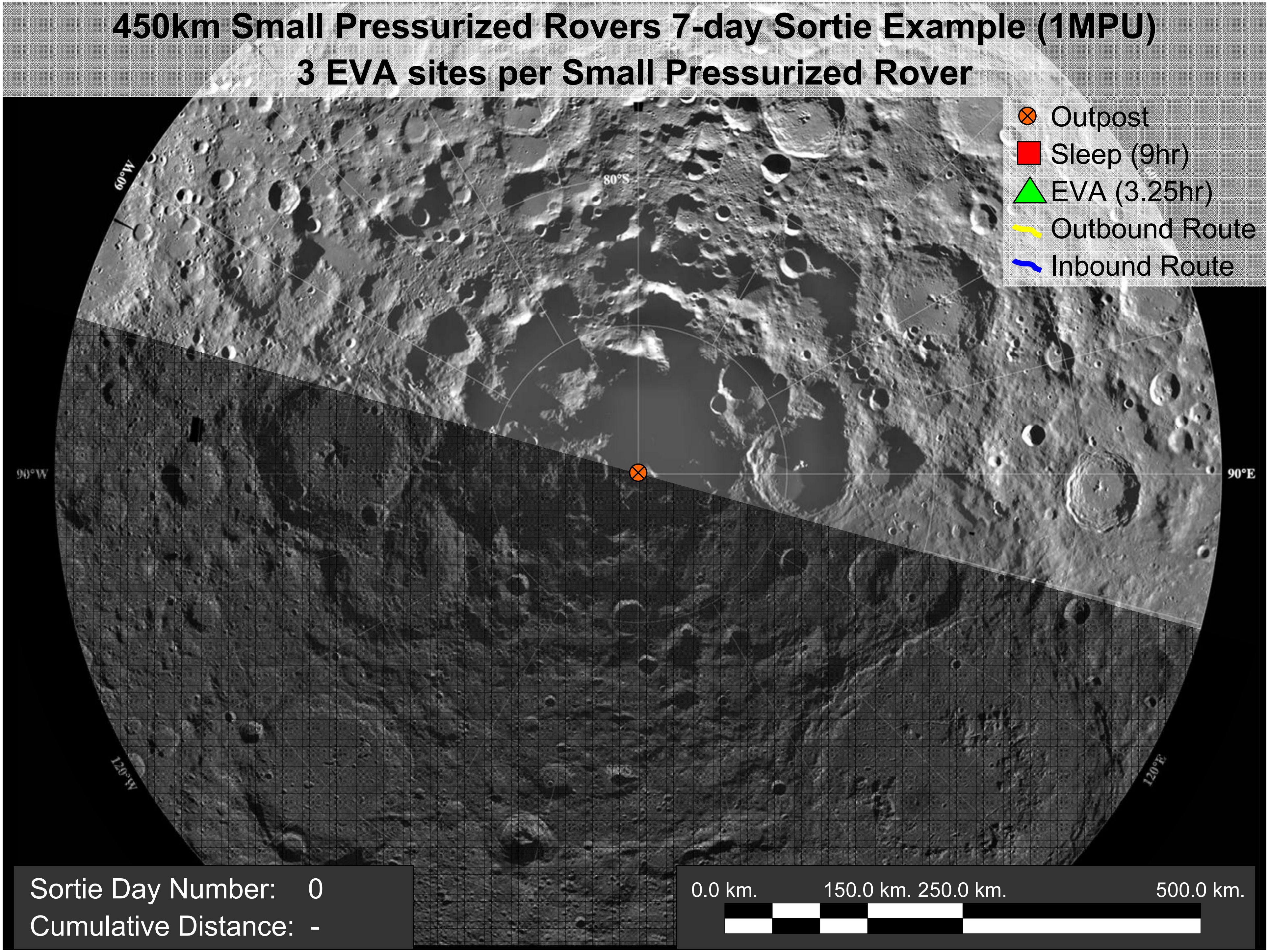
Greater total crew time required with UPR because of suitlock depress time

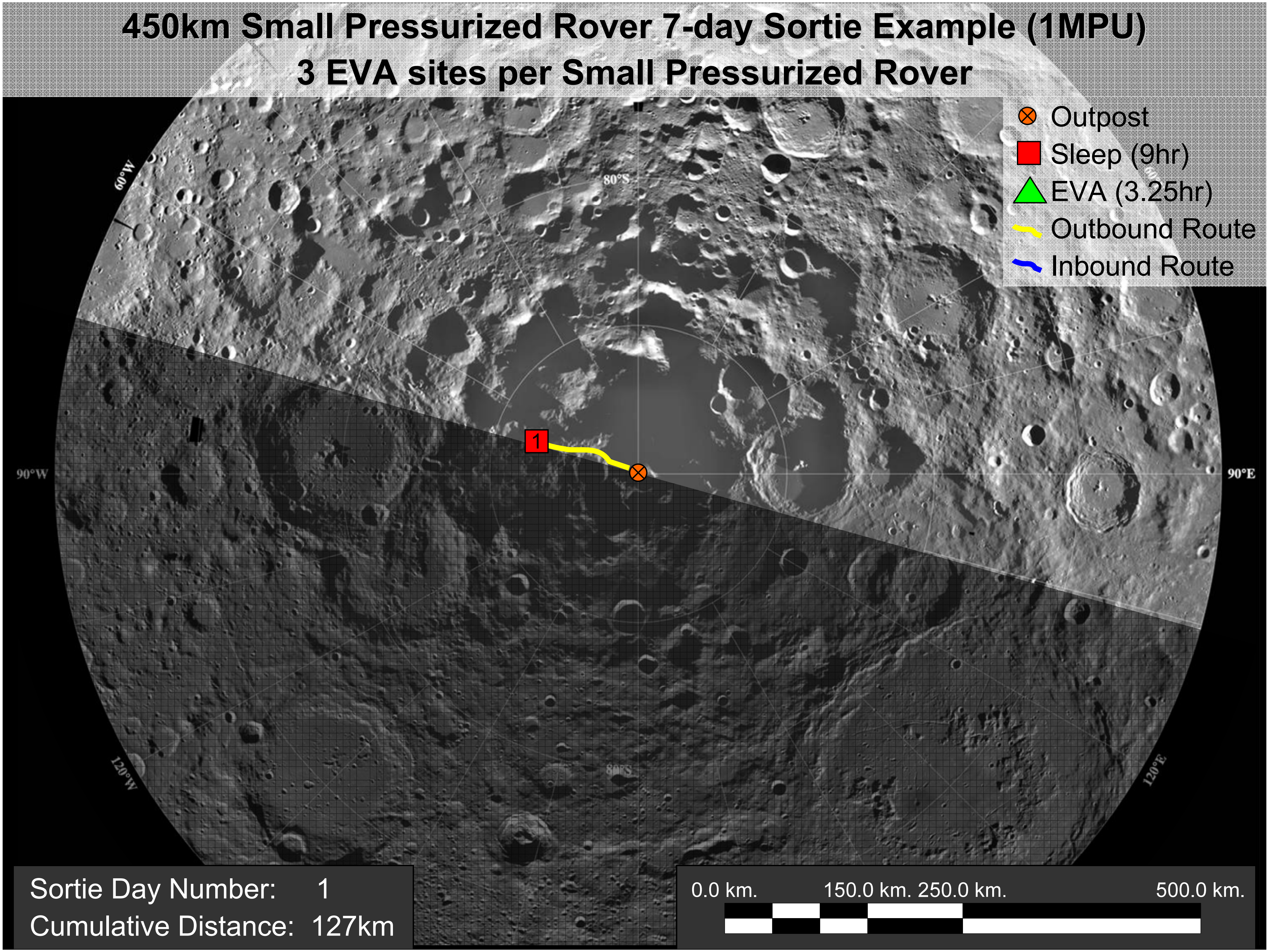
Link

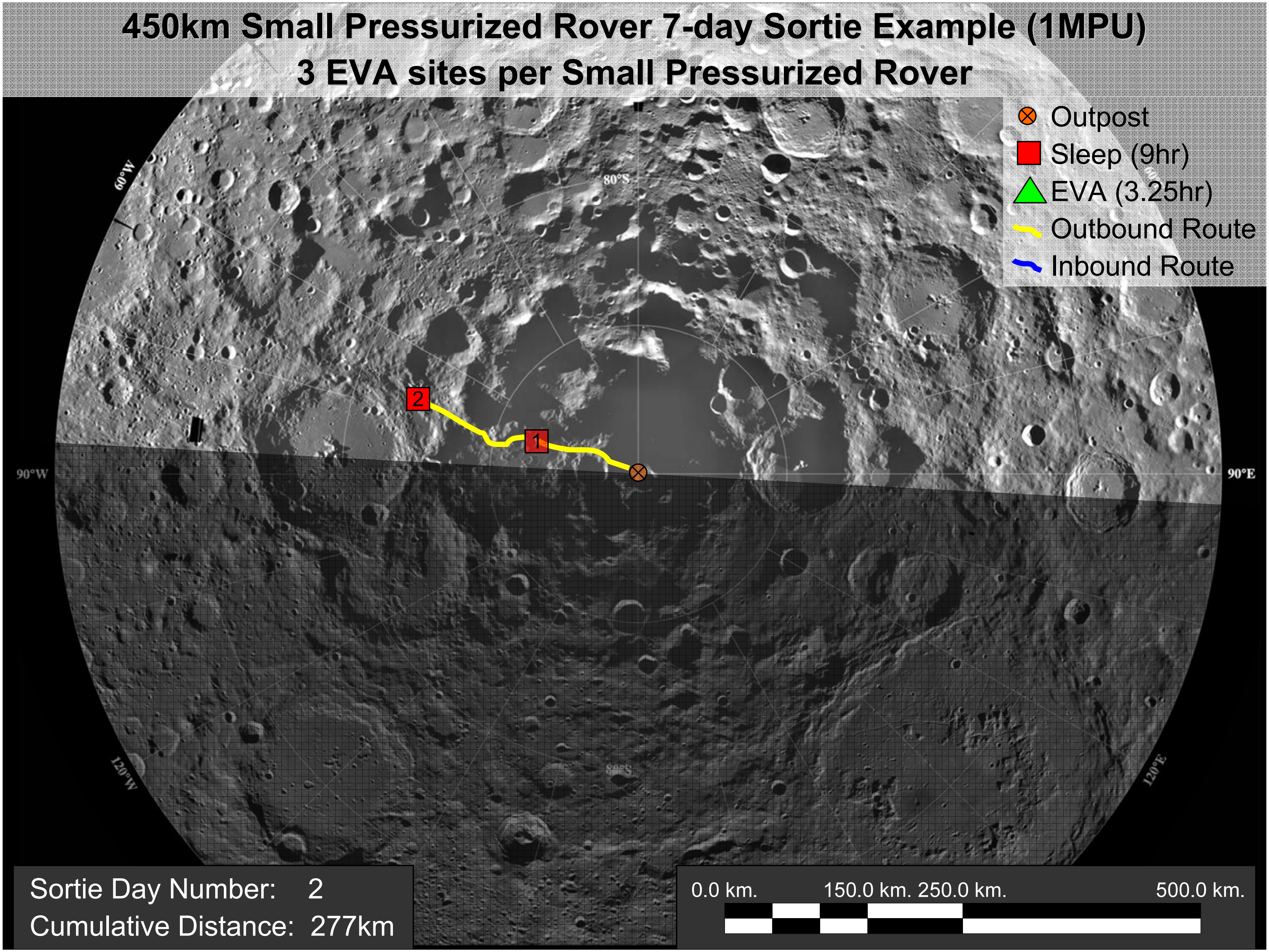

Exploration Range: Unpressurized Rover vs. Large Pressurized Rover vs. Small Pressurized Rovers
NASA
Lunar outpost
Unpressurized Rover
Range: 15km
Large Pressurized Rover
Range: 240km
Small Pressurized Rovers
Range: 960km
69

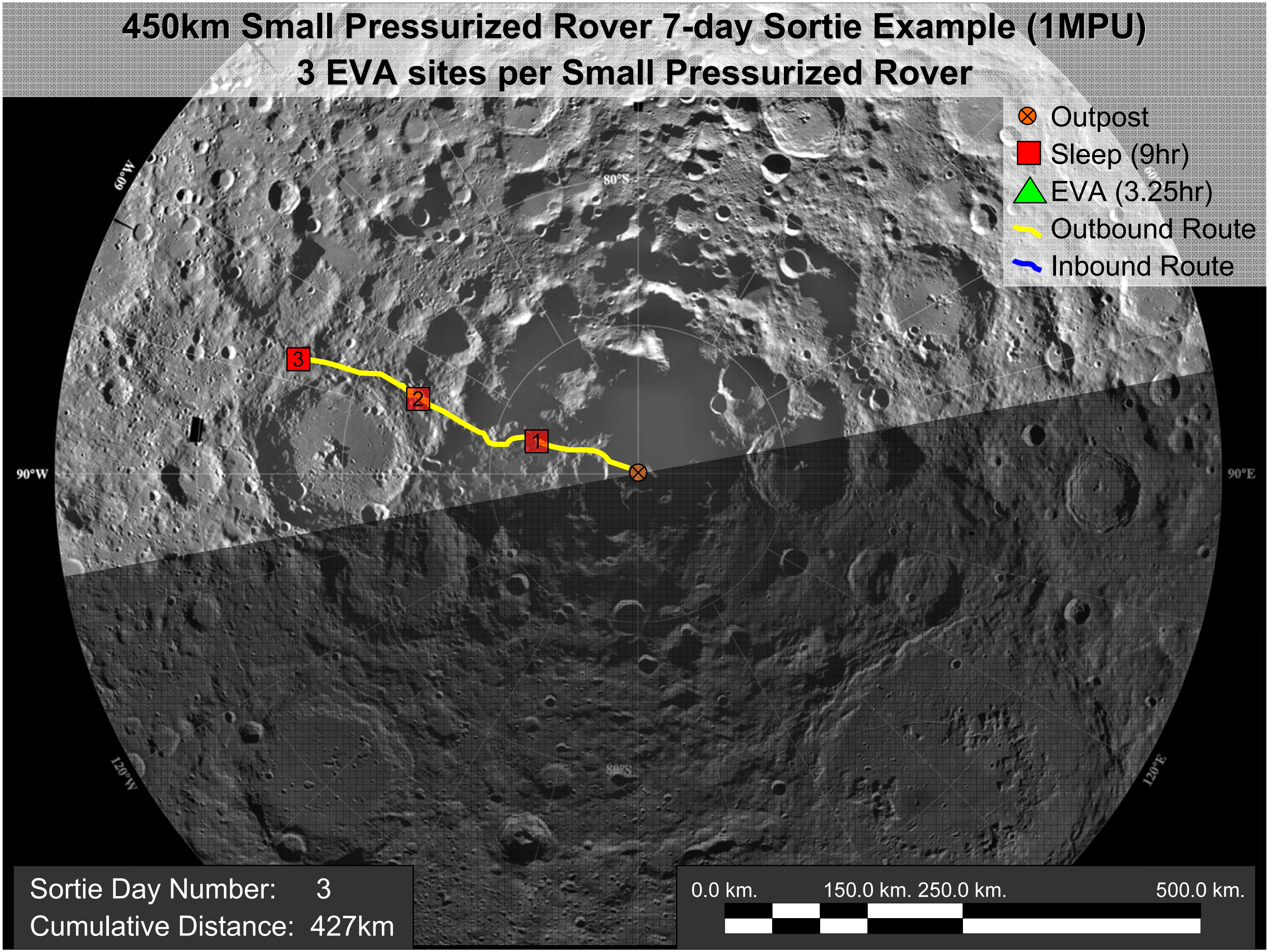
Science / Exploration EVA Hours vs. Range: Small Pressurized Rovers (example)

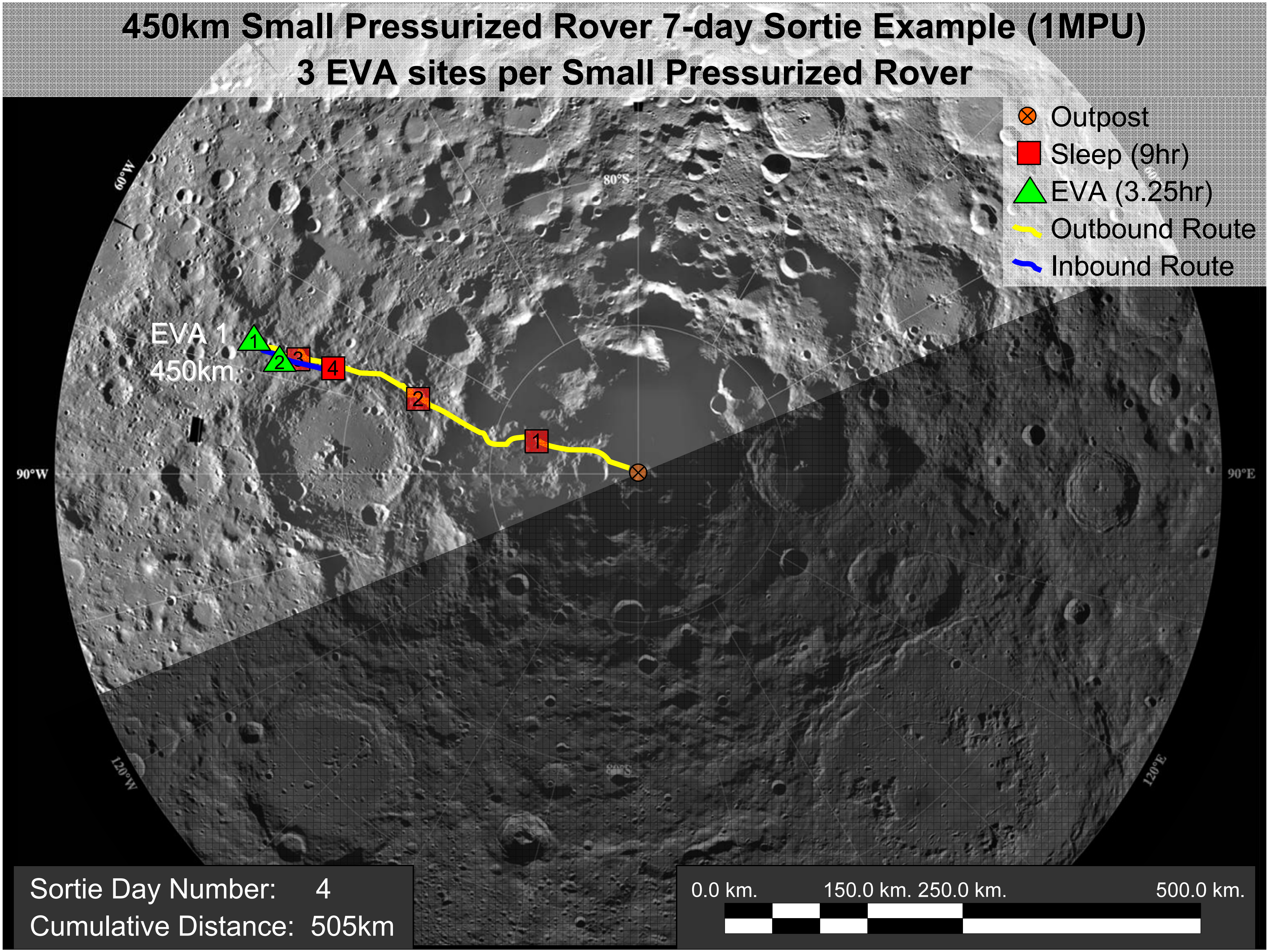


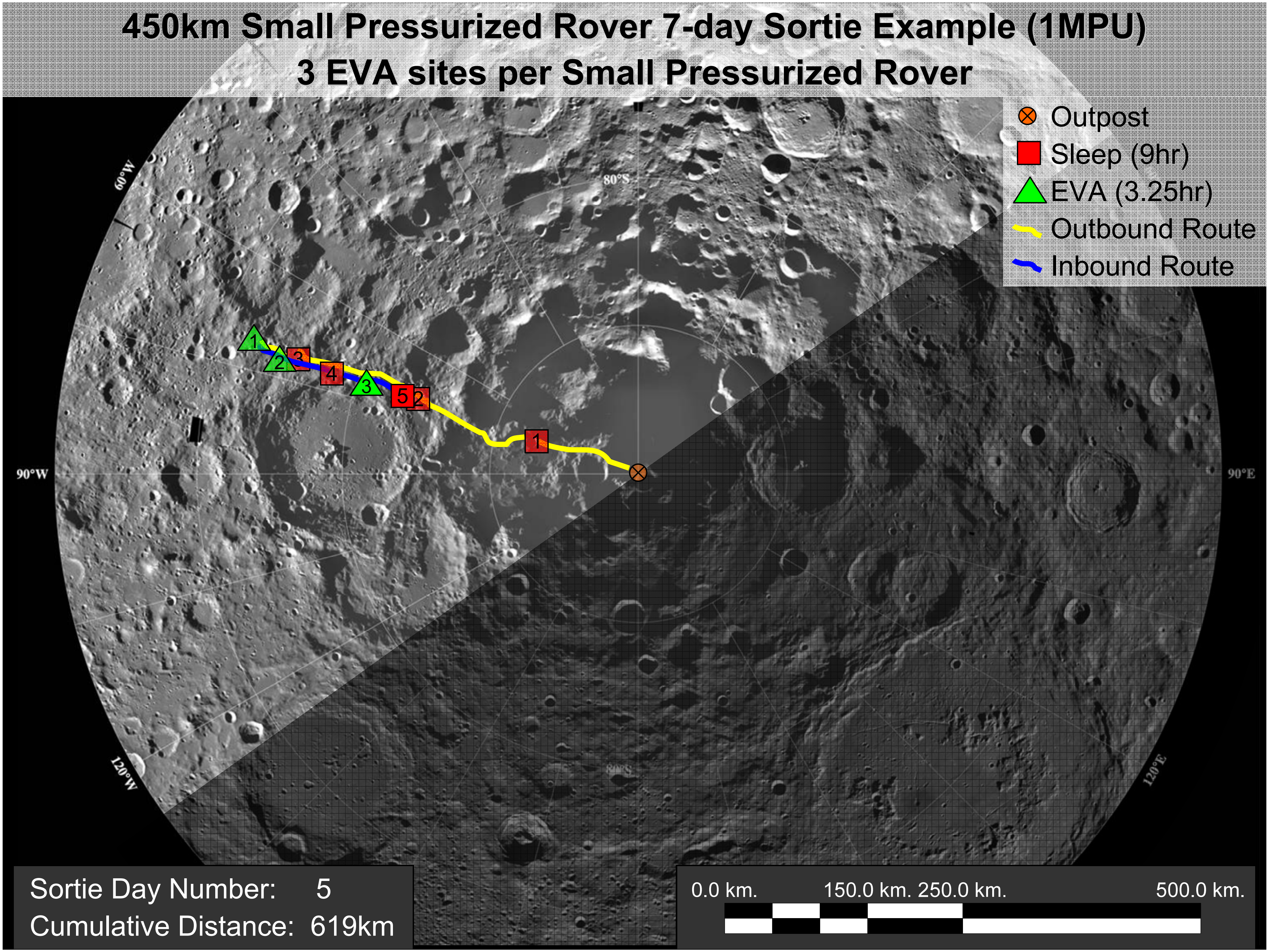

450km Small Pressurized Rovers 7-day Sortie Example (1MPU)
3 EVA sites per Small Pressurized Rover
Outpost
Sleep (9hr)
EVA (3.25hr)
Outbound Route
Inbound Route
60°W
80°S
90°W
90°E
120°W
120°E
Sortie Day Number: 0
Cumulative Distance: -
0.0 km.
150.0 km.
250.0 km.
500.0 km.


450km Small Pressurized Rover 7-day Sortie Example (1MPU)
3 EVA sites per Small Pressurized Rover
Outpost
Sleep (9hr)
EVA (3.25hr)
Outbound Route
Inbound Route
60°W
80°S
90°W
90°E
120°W
120°E
1
Sortie Day Number: 1
Cumulative Distance: 127km
0.0 km.
150.0 km.
250.0 km.
500.0 km.


450km Small Pressurized Rover 7-day Sortie Example (1MPU)
3 EVA sites per Small Pressurized Rover
Outpost
Sleep (9hr)
EVA (3.25hr)
Outbound Route
Inbound Route
60°W
80°S
90°W
90°E
120°W
120°E
2
1
Sortie Day Number: 2
Cumulative Distance: 277km
0.0 km.
150.0 km.
250.0 km.
500.0 km.

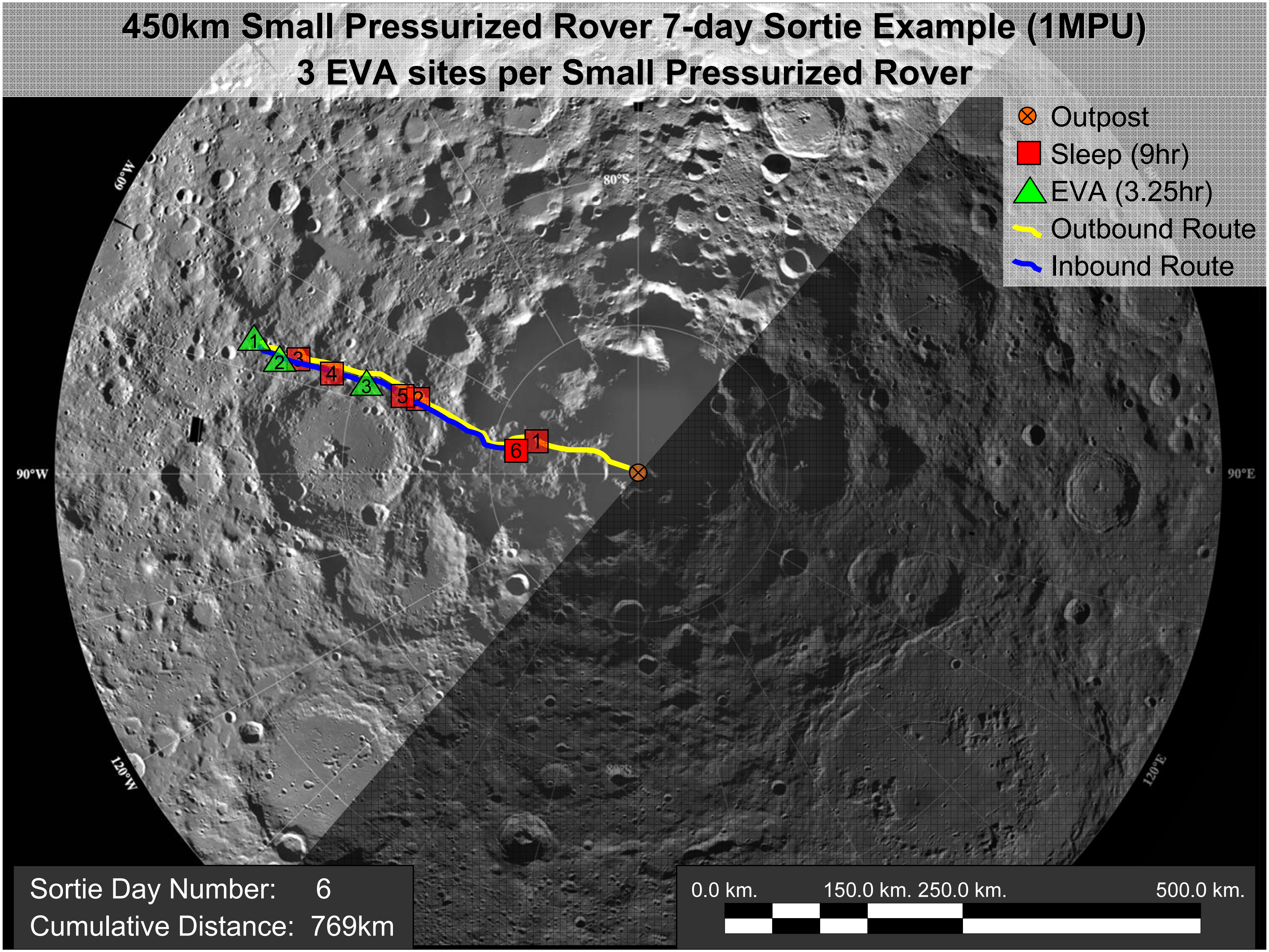

450km Small Pressurized Rover 7-day Sortie Example (1MPU)
3 EVA sites per Small Pressurized Rover
Outpost
Sleep (9hr)
EVA (3.25hr)
Outbound Route
Inbound Route
60°W
80°S
90°W
90°E
120°W
120°E
3
2
1
Sortie Day Number: 3
Cumulative Distance: 427km
0.0 km.
150.0 km. 250.0 km.
500.0 km.


450km Small Pressurized Rover 7-day Sortie Example (1MPU)
3 EVA sites per Small Pressurized Rover
Outpost
Sleep (9hr)
EVA (3.25hr)
Outbound Route
Inbound Route
EVA 1
450km
80°S
90°W
90°E
60°W
120°W
120°E
Sortie Day Number: 4
Cumulative Distance: 505km
0.0 km.
150.0 km.
250.0 km.
500.0 km.



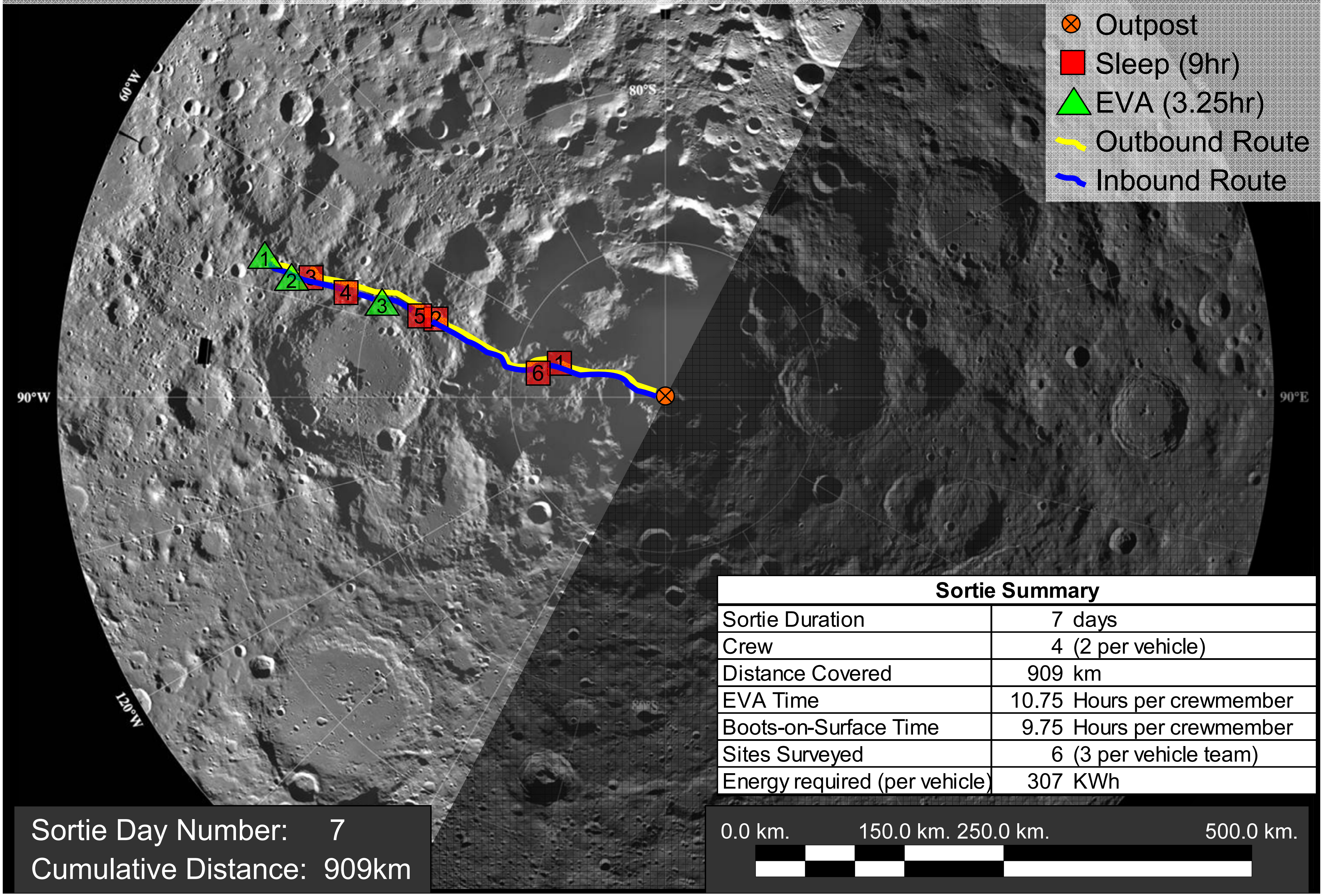
450km Small Pressurized Rover 7-day Sortie Example (1MPU)
3 EVA sites per Small Pressurized Rover
Outpost
Sleep (9hr)
EVA (3.25hr)
Outbound Route
Inbound Route
60°W
80°S
90°W
90°E
120°W
120°E
Sortie Day Number: 5
Cumulative Distance: 619km
0.0 km.
150.0 km.
250.0 km.
500.0 km.

WWW.NASAWATCH.COM



450km Small Pressurized Rover 7-day Sortie Example (1MPU)

3 EVA sites per Small Pressurized Rover



Sortie Summary	
Sortie Duration	7 days
Crew	4 (2 per vehicle)
Distance Covered	909 km
EVA Time	10.75 Hours per crewmember
Boots-on-Surface Time	9.75 Hours per crewmember
Sites Surveyed	6 (3 per vehicle team)
Energy required (per vehicle)	307 KWh

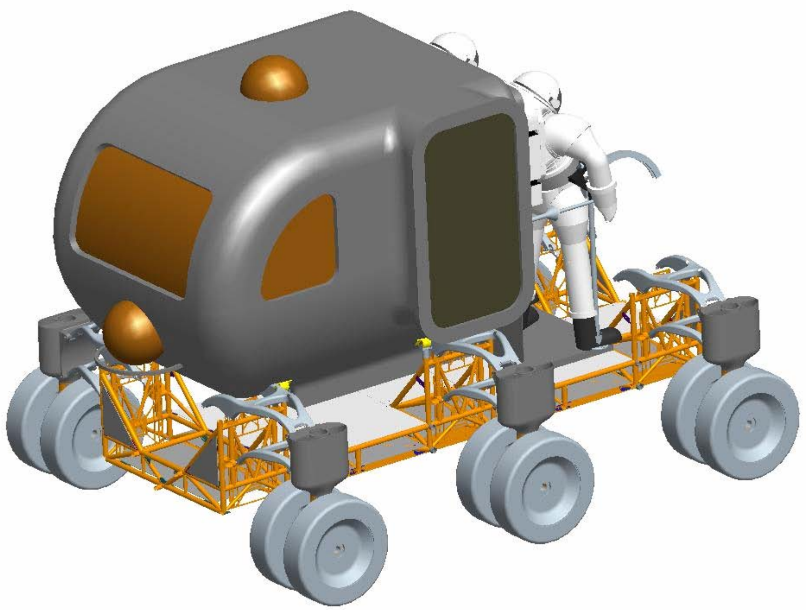
Small Pressurized Rovers vs. Large Pressurized Rover: Weight and Range Comparison

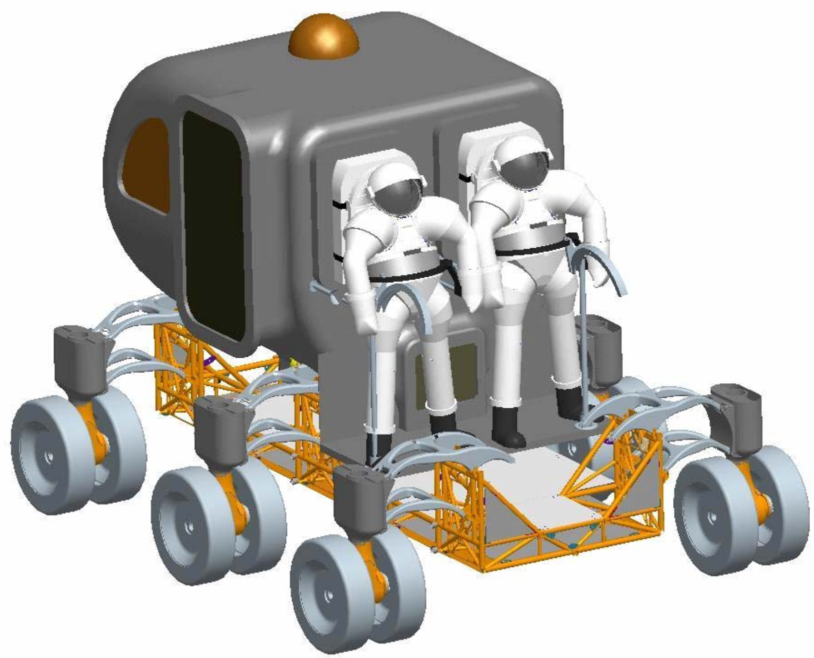
2 x MPRVs	2 x 2657	**5314 kg**
2 x Chassis C	2 x 1309	**2618 kg**
Total Mass		**7932 kg**
Max. Range (no MPUs)		**189 km**
Max. Range (2 MPUs)		**960 km**

1 x Large (LAT-1) Pressurized Rover	1 x 8006	**8006 kg**
1 x UPR (24hr capability assumed)	1 x 1180	**1180 kg**
Total Mass		**9186 kg**
Max. Range		**240 km**

Mass Difference: -1254kg (-13.7%)

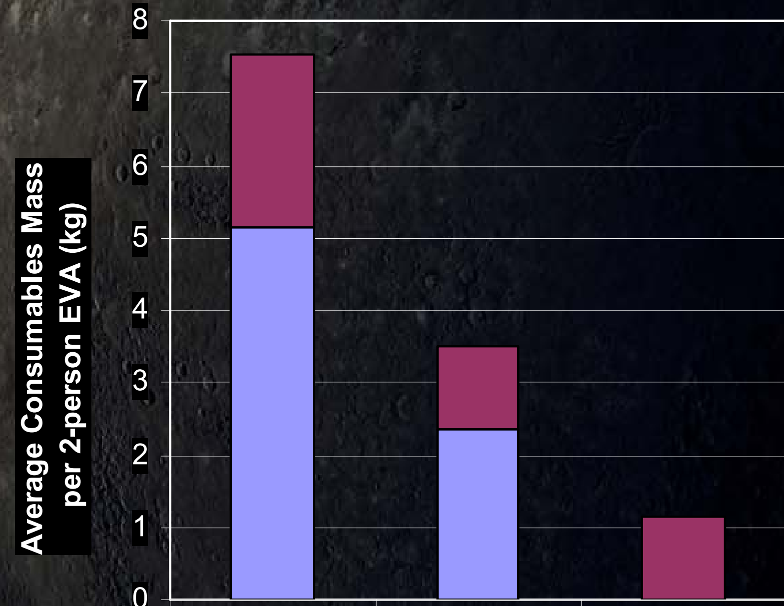
Range Difference: +720km (+400%)





Small Pressurized Rovers: Consumables Mass Savings

- The effect of Suitports and Fusible Heat Sinks on EVA water and gas consumption during EVAs was evaluated for the LAT-2 Option 2 architecture
  - Typical EVA timelines were developed by astronauts and Mission Operations Directorate (MOD) personnel using standard EVA planning techniques
  - Consumables usage rates were predicted from Apollo data and ongoing EVA suit testing being performed at Johnson Space Center
  - Mass savings over entire LAT-2 Option 2 architecture were estimated

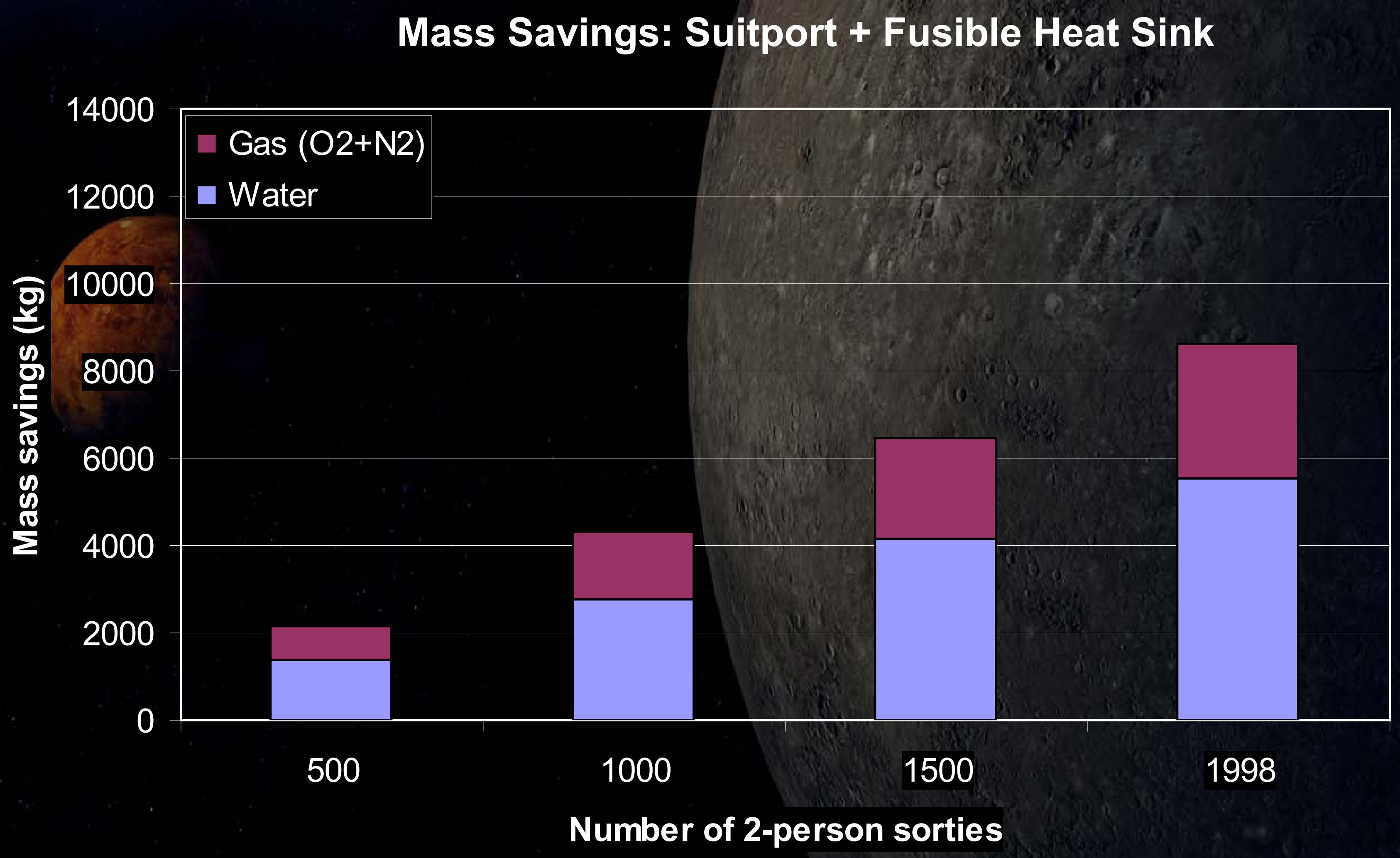


	Suit lock, with reclaim, evaporator	Suitports + Fusible Heat Sink in Rover	Suitports + Fus heatsink Rover+Suit
Gas (O2+ N2)	2.41	1.14	1.14
Water	5.14	2.36	0

Based on 15km 1-site sortie

Link to Suit Test Data

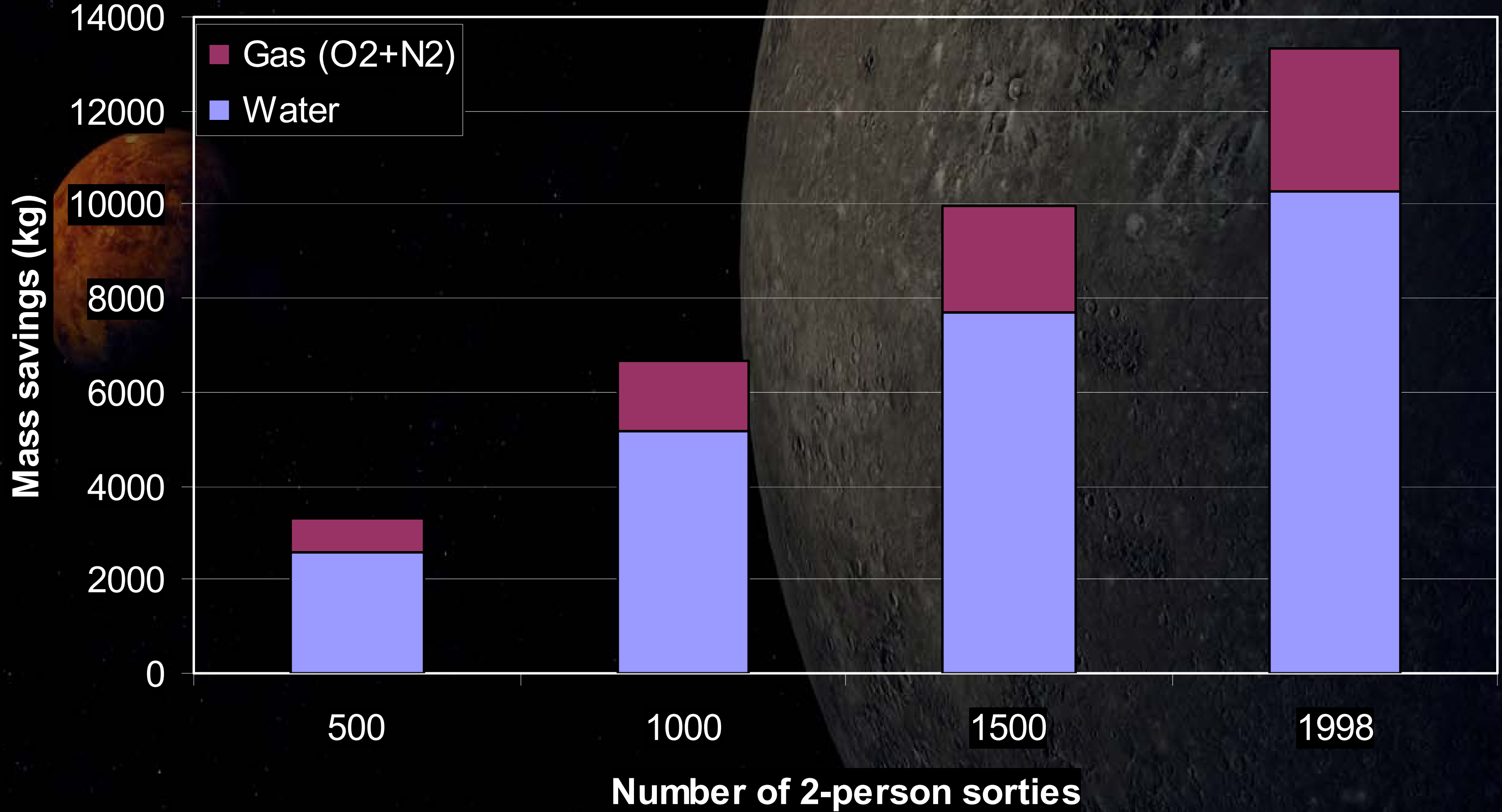
Small Pressurized Rovers: Consumables Mass Savings



- **1998 Total 2-person EVA sorties available in Option 2 architecture**
  - 124 Assembly and Maintenance (6.2%)
  - 1867 Science/Exploration (93.8%)

Small Pressurized Rovers: Consumables Mass Savings

Mass Savings: Suitport + Fusible Heat Sink in Rover <u>and</u> Suit PLSS



- **1998 Total 2-person EVA sorties available in Option 2 architecture**
  - 124 Assembly and Maintenance (6.2%)
  - 1867 Science/Exploration (93.8%)

Advantages of Small Pressurized Rovers

Health & Safety:

- SPE protection within 20mins
- Pressurized safe-haven within 20mins
- DCS treatment within 20mins
- Expedited on-site treatment and/or medication of injured crewmember
- Reduces suit induced trauma
- Better options for nutrition, hydration, waste management
- Increased DCS safety, decreased prebreathe reqts through intermittent recompression (would allow 3.5psi suit)
- Provides resistive and cardiovascular exercise (75% VO2 peak) during otherwise unproductive translation time
- Better background radiation shielding vs. EVA suit
- Dust control through use of suitport

Exploration:

- Exploration range of up to 1000km (vs. 240km w/ large pressurized rover)
- Shirt-sleeve envnmt with visibility as good as suited EVAs
- Multi-spectral sensors & instruments always available
- Single-person EVA capability

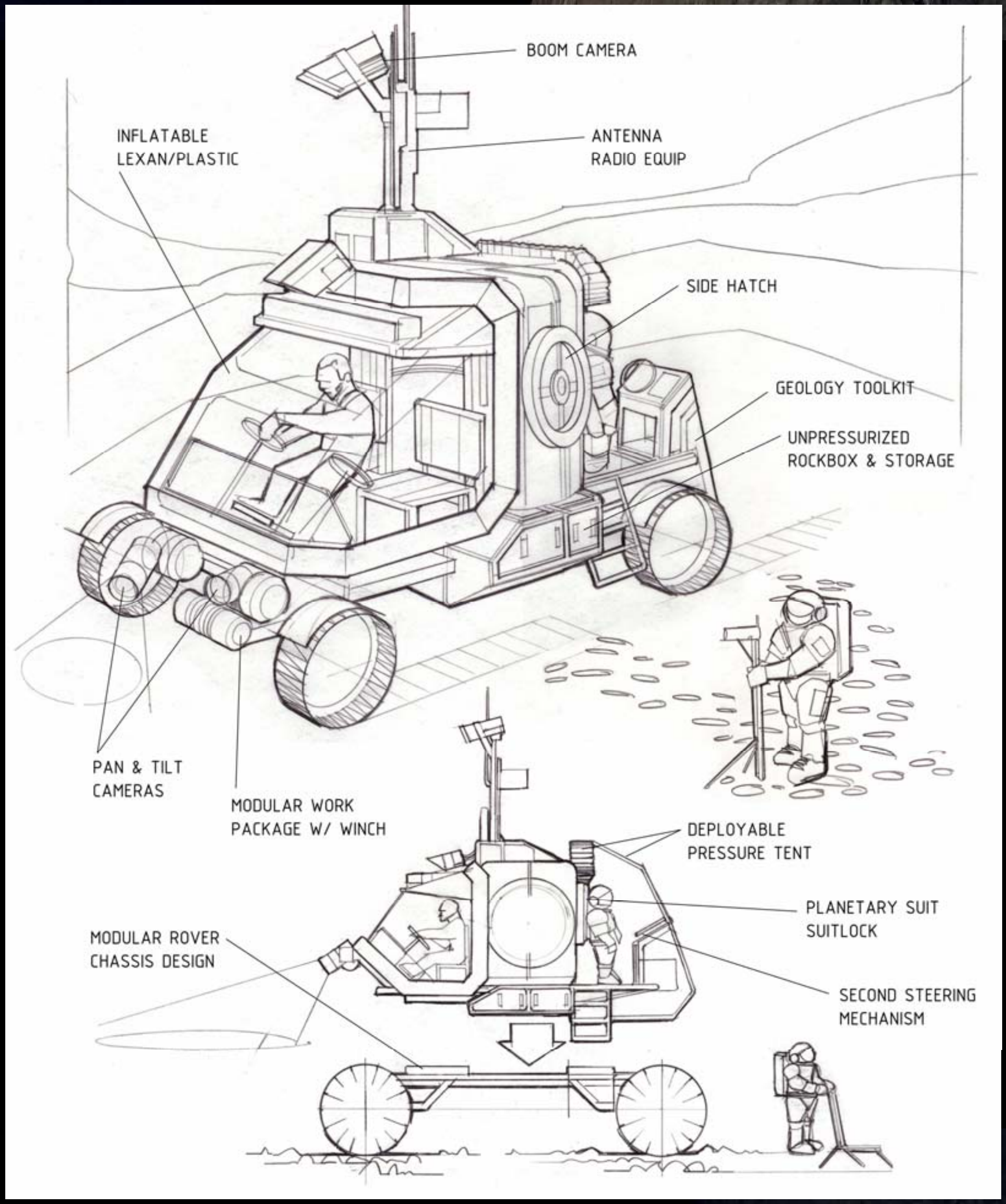
Operational / Engineering:

- Potential for transfer under pressure from Ascent Module and/or hab (PLSSs kept in controlled envnmnt for re-use)
- Reduced cycles on suit
- Uses suit PLSS for life support
- Potential for 4hr (lighter weight) PLSS- Mars forward *link*
- Potential to achieve Work Efficiency Index (WEI) of up to 9.0 for individual EVA excursions
- Reduces suit nutrition, hydration and waste mgmnt needs
- Eliminates need for contingency walkback, decreasing design reqts for suit
- >50% reduction in EVA time for equal or greater productivity and increased range

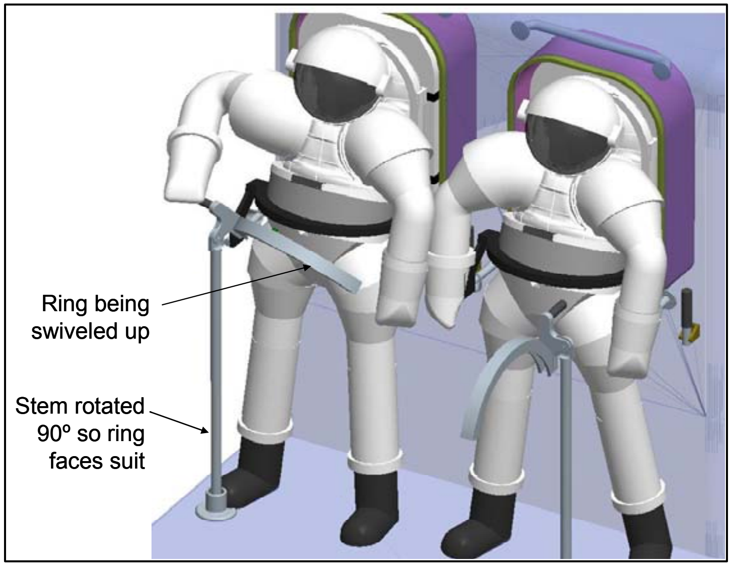
Architectural:

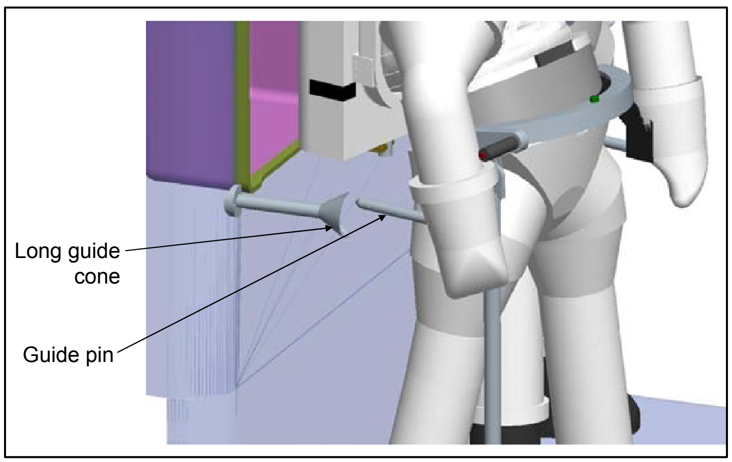
- 2 Pressurized Rovers weigh less than single large pressurized rover
  - Enables earlier delivery, possibly on crewed landers
- Up to 12,000 kg H_2O mass savings (with Rover and PLSS Heat Sink)
- 1000kg+ O_2 and N_2 mass savings and up to 144 days less depress time using suitport vs. suitlock
  - Earlier long-duration crew missions
  - Aggressive development of Hab ECLSS less important
- "Gods-eye view" capability (highly desirable for public outreach)
- Vehicle design and required technologies highly relevant to Mars missions

Small Pressurized Rovers Animation

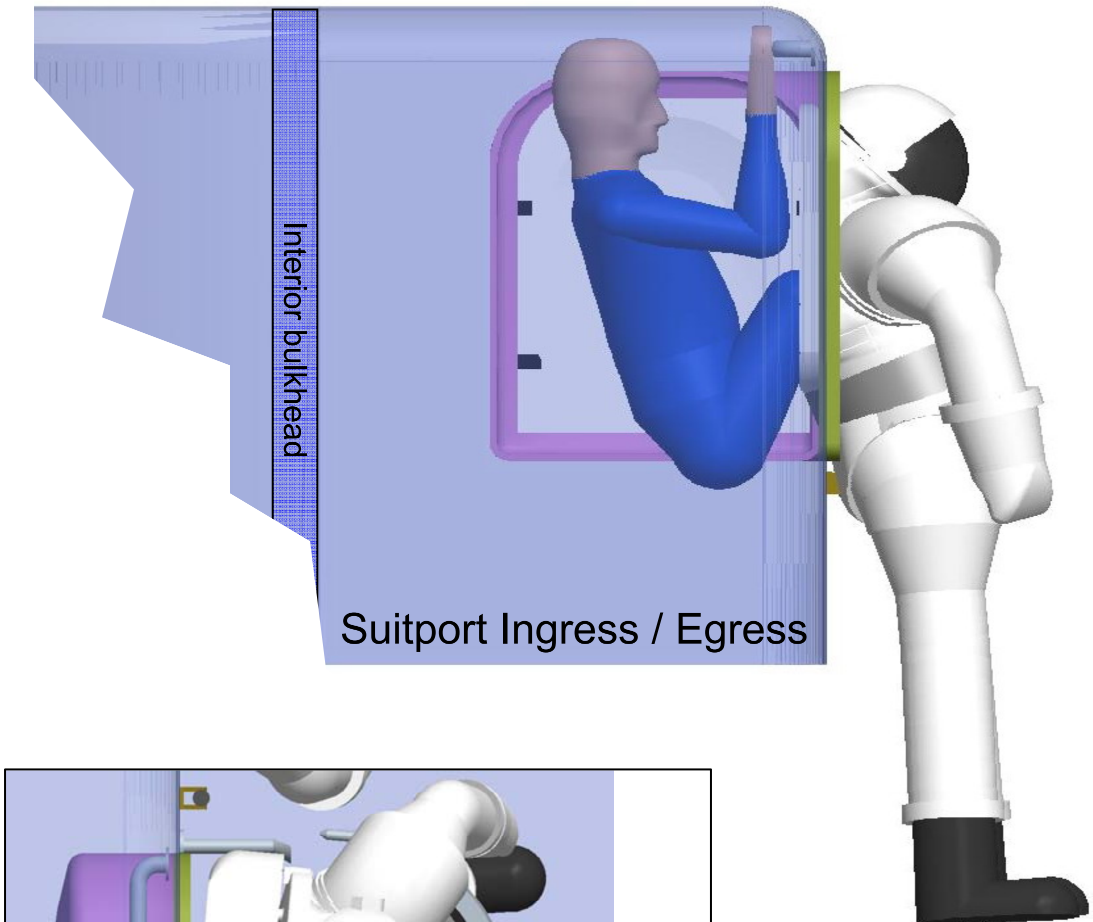


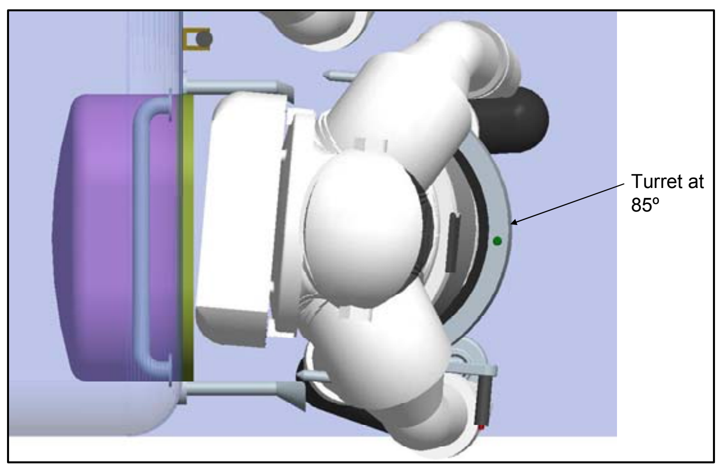
Suit Alignment Guides and Suitport Ingress/Egress





Suit Alignment Guides

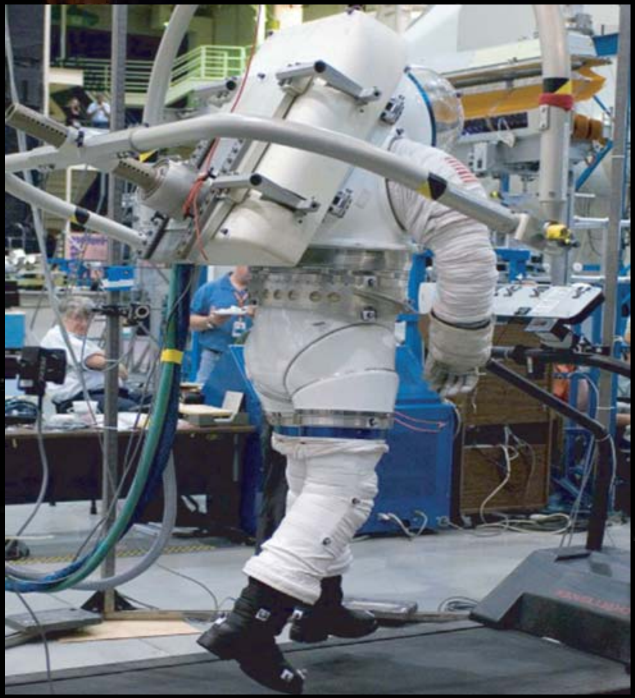


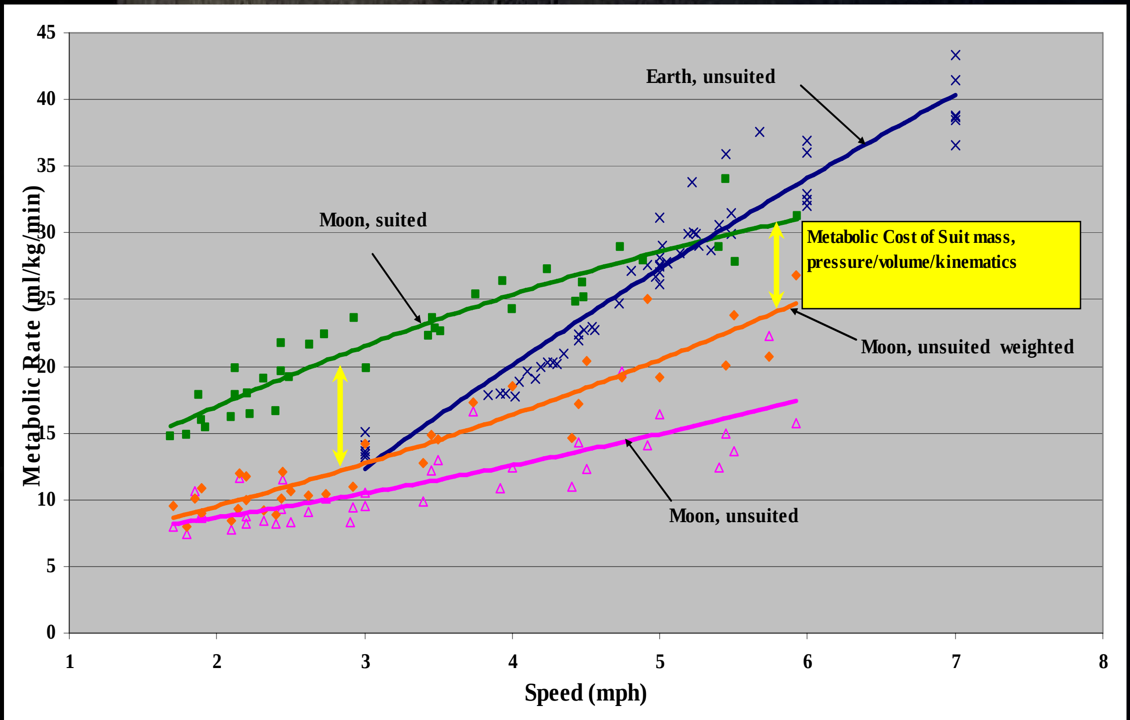


link

Consumables Assumptions

- Conservative metabolic rates assumed:
  - Light work = 10mL/kg/min,
  - Heavy work = 20mL/kg/min
  - Sitting in Pressurized Rovers = 3.9mL/kg/min
  - Sitting in suit on UPR = 6.8mL/kg/min
- Constant H_2O consumption rates assumed:
  - In suit = 0.329 kg/hr
  - In Pressurized Rovers = 0.0 kg/hr (fusible heat sink)
  - In suit with fusible heat sink = 0.0 kg/hr

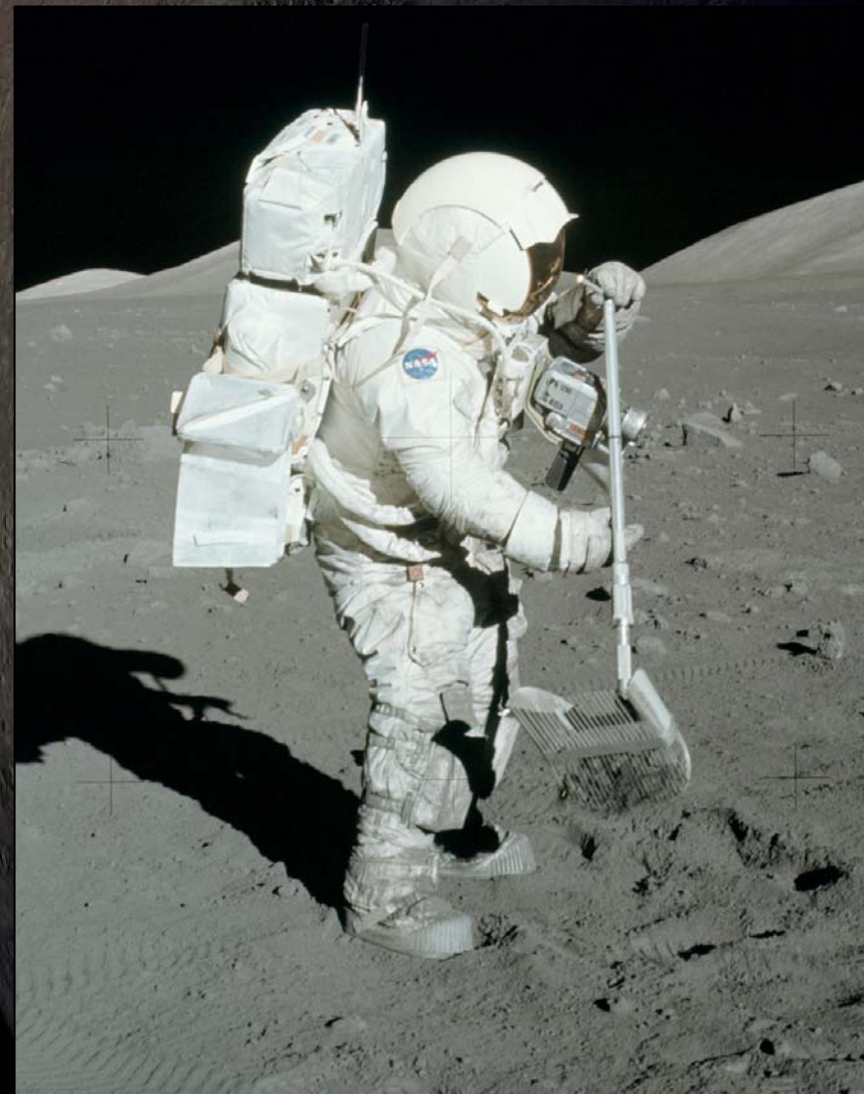




Typical Science/Exploration EVA

- **Boots-on-Surface EVA Time**
  - Geologic context determination (30mins)
  - Rock sample acquisition (15mins)
  - Soil sample acquisition (15mins)
  - Rake sample acquisition (15mins)
  - Drive tube acquisition (15mins)
  - Core sample acquisition (1h 45mins)

  = 3h 15mins per site



return

Summary

- These new ideas build on the results shown in December
- Better understanding of performance and capabilities
- Preserving an open architecture approach
- Capturing a broader range of Lunar objectives
- New features and concepts to be discussed and compared with ideas from broader community- Commercial, Industry, Science, International
- We are open to other new ideas for effective Exploration
- Responsibility for development of lunar infrastructure still to be determined through discussions with our partners in Exploration

[redacted]