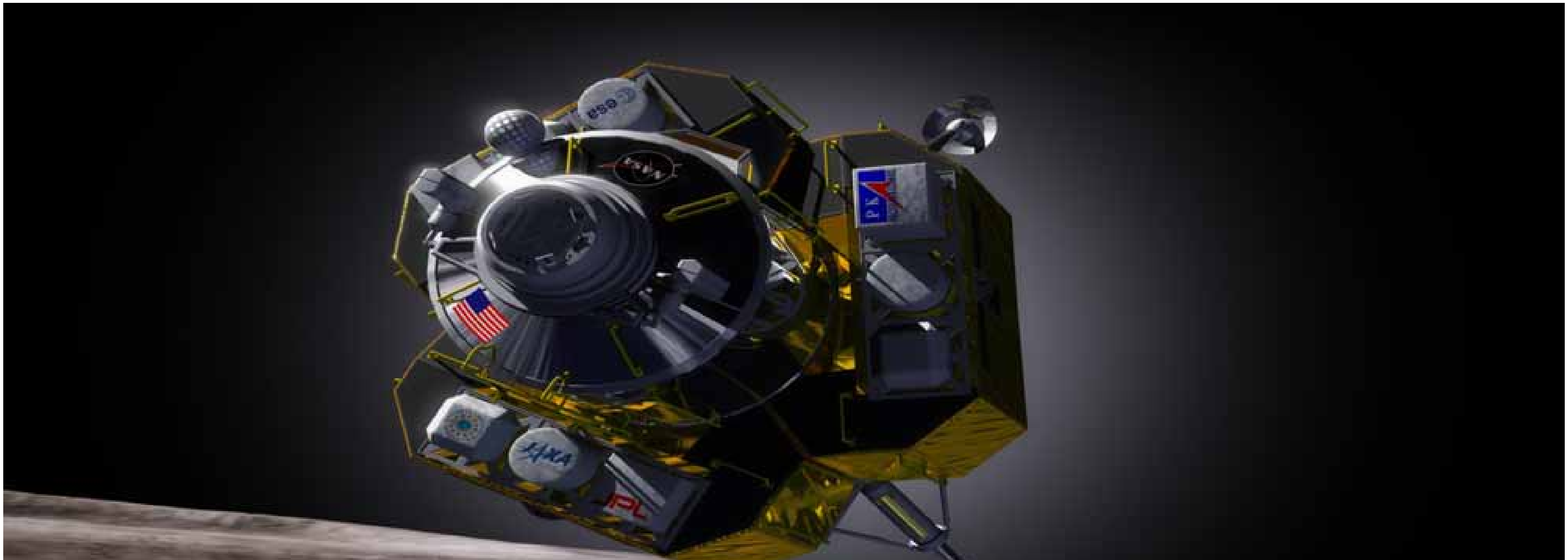


A Day in the Life of the Constellation Arcitecture Team-lunar (CxAT-lunar) Science Team

John E. Gruener
Lunar Surface Systems Project Office/Constellation Program
Johnson Space Center

CxAT-lunar Science Team

Goddard Space Flight Center

Jake Bleacher
Pam Clark
Laurie Leshin
Ruthan Lewis
Scott Mest
Noah Petro

Johnson Space Center

Dean Eppler
John Gruener
Wendell Mendell

Langley Research Center

Julie Williams-Byrd

The 'Theoretical' Systems Engineering Approach

Users
Science
Resource dev
Tech demos

→

Operators
Astronauts
Robots
Mission control

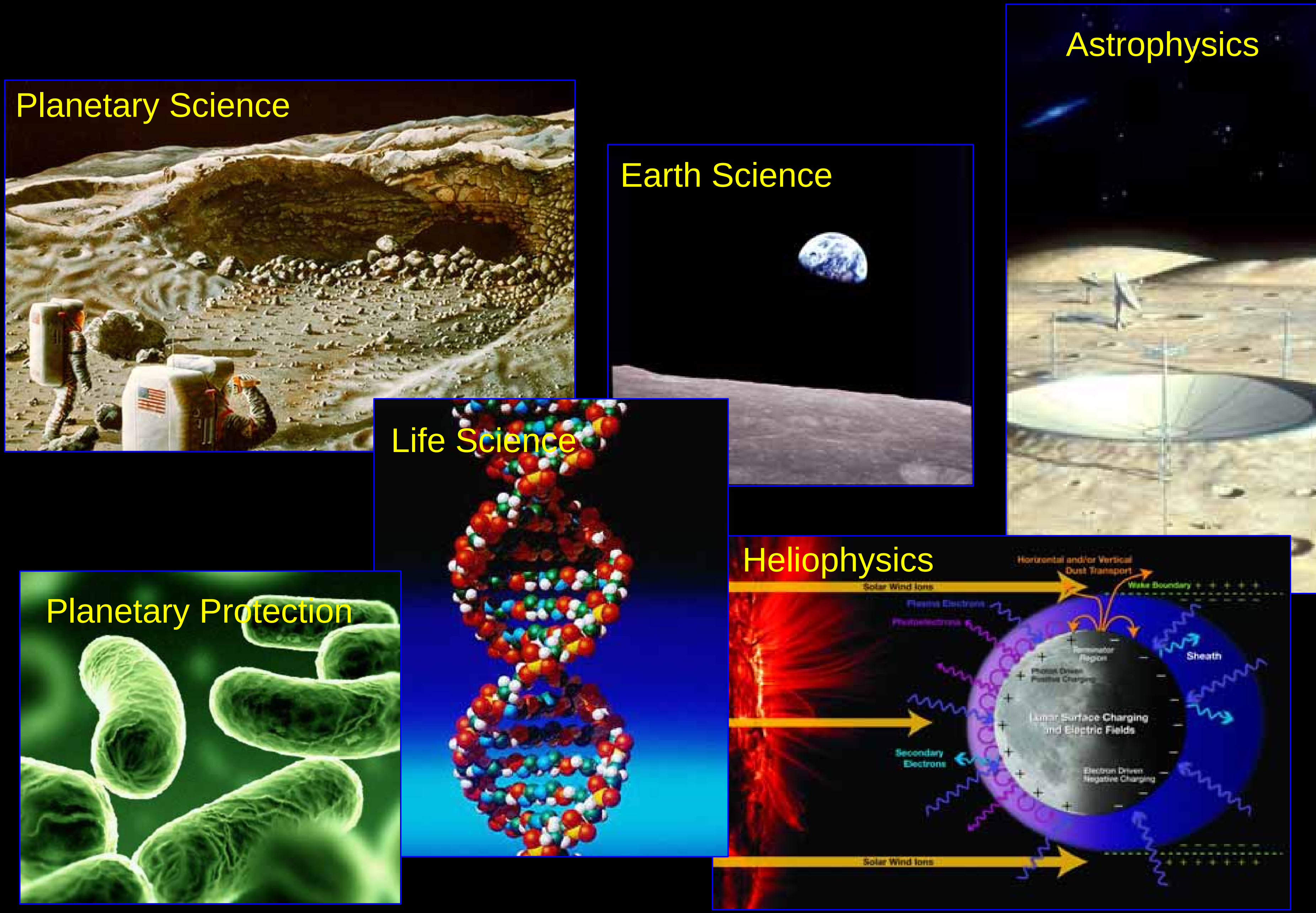
→

Developers
System designers
Payload designers

User needs drive Concept of Operations development

Concept of Operations drives system/payload definition

Science on the Moon



Guiding Documents for the Scientific Exploration of the Moon

Planetary Science
NRC “The Scientific Context for Exploration of the Moon” (2007)
NAC “Workshop on Science Associated with the Lunar Exploration Architecture” (2007)

Heliophyiscs
NASA “Heliophysics Science and the Moon” (2007)
NAC “Workshop on Science Associated with the Lunar Exploration Architecture” (2007)
NRC “The Sun to the Earth – and Beyond: A Decadal Research Strategy in Solar and Space Physics”(2003)

Astrophysics
NAC “Workshop on Science Associated with the Lunar Exploration Architecture” (2007)
NRC “Astronomy and Astrophysics in the New Millennium” (2001)

Earth Science
NRC “Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond” (2007)
NAC “Workshop on Science Associated with the Lunar Exploration Architecture” (2007)

Life Science
NAC “Lunar Biomedical Workshop” (2007)
NASA Astrobiology Institute “Astrobiology Science Goals and Lunar Exploration” (2004)

Planetary Protection
NAC “Workshop on Science Associated with the Lunar Exploration Architecture” (2007)

NASA
Global Exploration Strategy (2006)

Basic Needs of the Scientific Communities

Planetary Science
Global access (e.g., crustal diversity)
Remote stations (e.g., control from earth)
Crew operations (e.g., field work, emplacement and maintenance)
Robotic operations (e.g., teleoperation)

Astrophysics
Far side (e.g., radio telescope)
Remote observatories (e.g., control from earth)
Crew operations (e.g., emplacememt and maintenance)

Earth Science
Earth view (e.g., ideally near side)
Remote observatories (e.g., control from earth)
Crew operations (e.g., emplacememt and maintenance)

Heliophyiscs
Sun and Earth view
Instruments in lunar orbit and on lunar surface
Remote observatories (e.g., control from earth)
Crew operations (e.g., emplacememt and maintenance)

Life Science
Anywhere
Crew operations (e.g., research)

Planetary Protection
Anywhere
Crew operations (e.g., research)

Basic Needs of the Scientific Communities
Lunar South Pole- an example

Planetary Science
Shackleton crater possibly on South Pole-Aitken (SPA) basin inner ring (Spudis et al, 2008)
Malapert and Leibniz β possibly SPA basin rim (Spudis et al, 2008)
SPA terrane distinct from Apollo samples (e.g., Procellarum KREEP terrane)

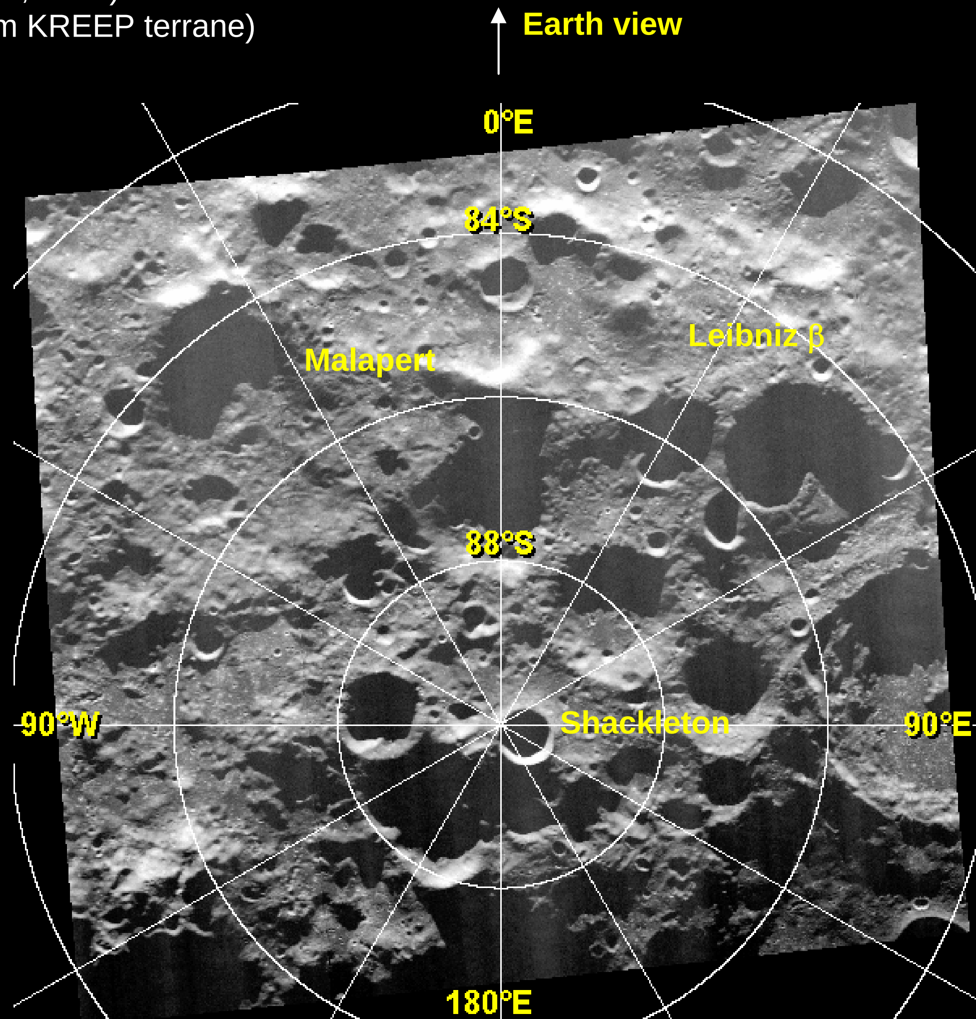
Astrophysics
Far side is accessible
Requires long range traverse, continuous power, and communications

Earth Science
Malapert peak-continuous earth view
Requires long range traverse, continuous power, and communications
Shackleton Outpost partial earth view

Heliophyiscs
Malapert peak-continuous sun view likely
Requires long range traverse, continuous power, and communications
Shackleton Outpost partial sun view

Life Science
At Outpost

Planetary Protection
At Outpost



(from Margo et al, 1999 and Bussey)

NASA Lunar Architecture Studies

Exploration Systems Architecture Study (ESAS) - 2005

Lunar transportation system concepts and functionality
Human sortie and outpost missions

Lunar Architecture Team 1 (LAT 1) - 2006

Outpost first strategy
Polar location (e.g., Shackleton crater)
lighting, thermal, anytime return, hydrogen, water?
Surface system concepts functionality

Lunar Architecture Team 2 (LAT 2) - 2007

Opened trade space for surface system concepts
Reference outpost scenarios at South Pole (e.g., Shackleton crater)

Constellation Architecture Team - lunar (CxAT-lunar) - 2008

Refined surface system concepts
Reference outpost scenarios at South Pole (e.g., Shackleton crater)

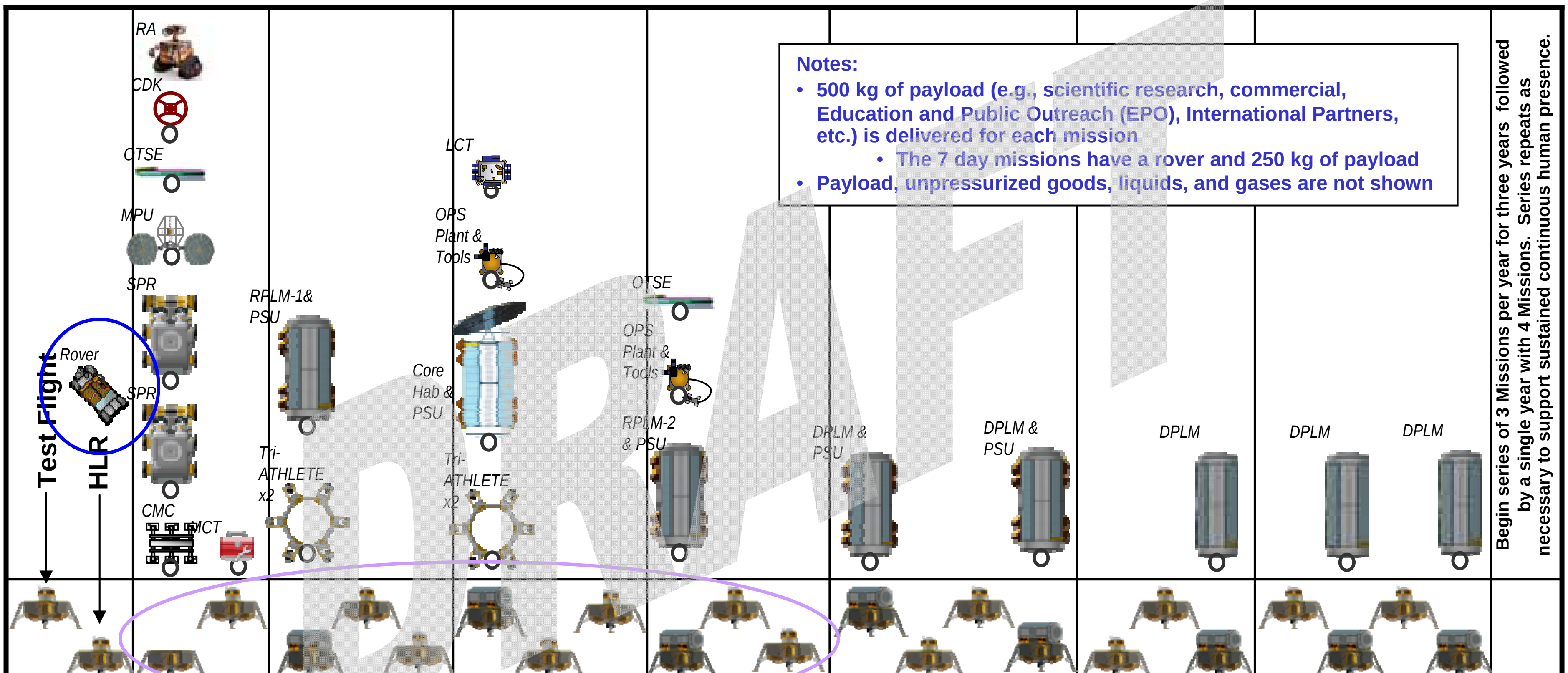
1.0 Full Capability
2.0 Mobility Emphasis
3.0 Habitation Emphasis
4.0 Increased Flight Rate
5.0 Nuclear Power

Reference outpost scenarios at South Pole plus limited human-sortie capability to other locations

Scenario 4.2.0 Manifest

Added a rover as part of payload

Reordered Cargo flights and crew flights to support longer duration crewed missions

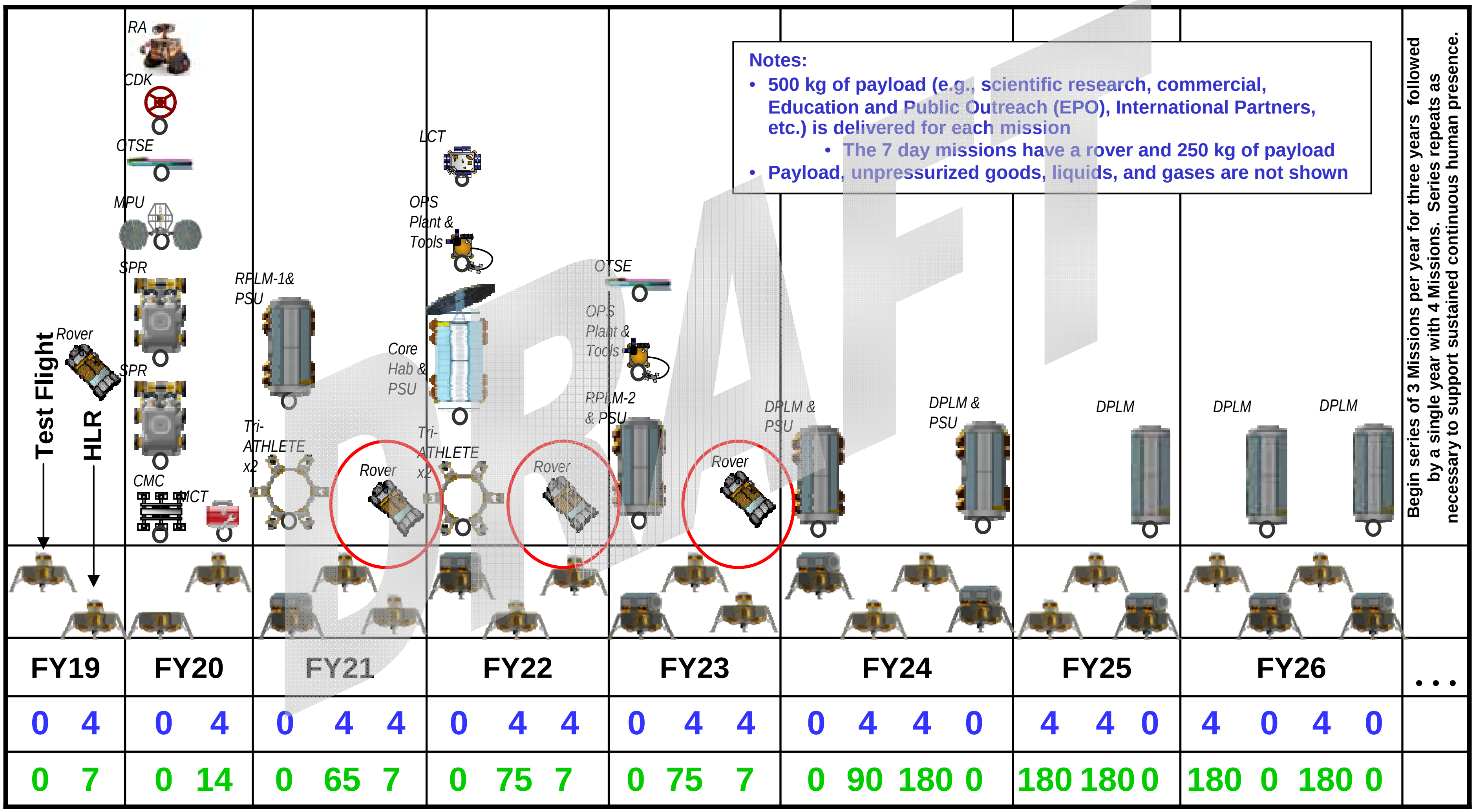


FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	. . .
0 4	0 4	0 4 4	0 4 4	0 4 4	0 4 4 0	4 4 0	4 0 4 0	
0 7	0 14	0 21 21	0 30 45	0 50 75	0 75 180 0	180 180 0	180 0 180 0	

 # - Crew Size **# - Surface Duration**

Scenario 4.2.3 Manifest – Addition of 3 Sorties During Outpost Buildup

With 3 Sorties, will not impact continued human presence (CHP) after the buildup phase
Can also repeat one sortie every three years, starting in FY26, without impacting CHP



 # - Crew Size **# - Surface Duration**

Scenario 4.2.0 Manifest
(South Pole Outpost)

Crew mission date	Crew size/ Surface duration	New capability on lunar surface that enables science	Science objectives	Relevant goals and recommendations
FY2019	4 crew 7 days	Small unpressurized rover	Lunar environment monitoring station Reconnaissance of Shackleton rim Initial bio data collection (continues on every mission)	Lunar environment Impact process Bombardment History
FY2020	4 crew 14 days	2 small pressurized rovers Unpressurized chariot Robotic assistant	Lunar geophysical station Traverse geophysics Reconnaissance of Shackleton ridge (SPA inner ring?) Revisits based on prior discoveries/research (continues on every mission)	Lunar interior Bombardment history
FY2021	4 crew 21 days	Pressurized logistics module	Initial earth observatory Reconnaissance of de Gerlache crater,unnamed young crater on De Gerlache rim	Bombardment history Impact process Earth science
FY2021	4 crew 21 days		Reconnaissance of Sverdrup crater/far side, secondary craters (Orientale?), SPA terra Regolith stratigraphy Shackleton permanently shadowed area	Bombardment history Crustal diversity Regolith processes Polar environment
FY2022	4 crew 30 days	Core habitat Communictions tower	Initial geo/bio laboratories Initial solar observatory Reconnaissance of Shoemaker crater, SPA terra, unnamed crater south of Malapert	Bombardment history Impact process
FY2022	4 crew 45 days		Reconnaissance of Faustini crater, farside Initial radio telescope observatory Continue geo/bio research (occurs on every mission)	History of Universe

Scenario 4.2.0 (South Pole Outpost)

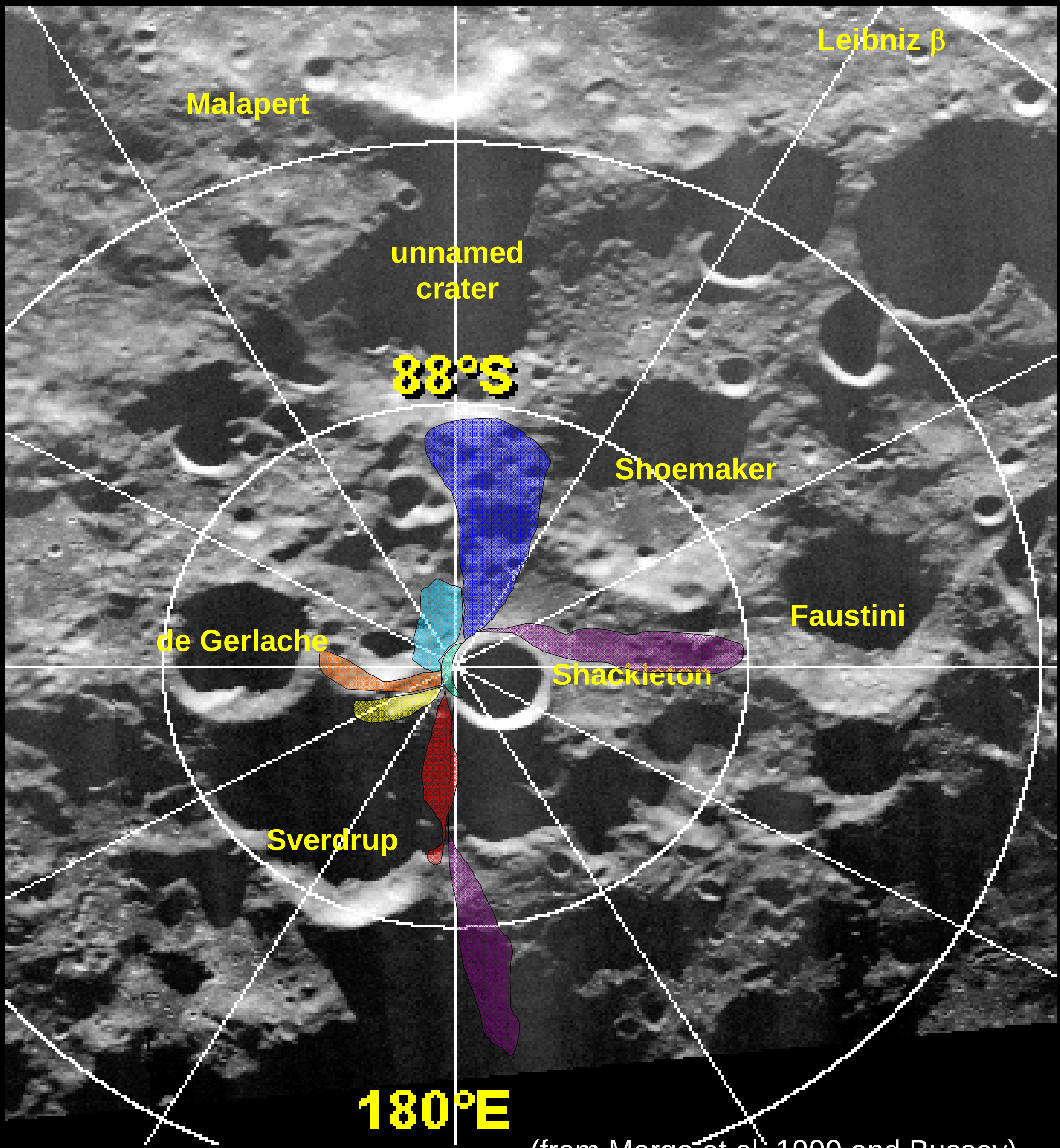
Mission Scenario Example

- 2019, 7 day mission
- 2020, 14 day mission
- 2021, 21 day mission
- 2021, 21 day mission
- 2022, 30 day mission
- 2022, 45 day mission

Each mission builds on previous missions and expands explored area

Every mission should plan time for revisits to prior sites

Missions beyond 2022 not shown



(from Margo et al, 1999 and Bussey)

The Art of Evaluating Lunar Exploration Scenarios

Traditionally, the merit of a lunar surface scenario has been measured and evaluated by engineering and cost parameters

Mass accumulated on the lunar surface
Human hours spent on the lunar surface
Life Cycle Cost
Range of exploration
Power Available

However, how well a particular scenario addresses scientific goals and objectives is also an important metric to consider

Planetary Science
Astrophysics
Heliophysiscs
Earth Science
Life Science
Planetary Protection

This is difficult to accomplish

Engineering parameters are based on known quantities generated during concept development

The effectiveness of a scenario to address science goals and objectives can only be truly judged after the fact, based on discoveries made

The best we can do is measure "how likely is it" that a scenario will address important science goals and objectives

The Art of Evaluating Lunar Exploration Scenarios

NRC Goal 1a: Test the cataclysm hypothesis by determining the spacing in time of the creation of lunar basins

Shackleton Outpost-Good

Shackleton crater sits on a ridge that may be SPA inner ring, and Malapert and Leibniz β massiffs maybe part of SPA rim (Spudis et al, 2008)
Possible Orientale secondary craters near Shackleton (Spudis et al, 2008)

Shackleton Outpost + Robotic Missions - Better

Robotic Sample Return missions to Nectaris, Orientale, etc. (Geoscience and a Lunar Base, 1990)

Shackleton Outpost + Robotic Missions + Human Sorties - Best

Human sortie missions to Nectaris, inner SPA, etc.

NRC Goal 3b: Inventory the variety, age, distribution, and origin of lunar rock types

Shackleton Outpost-Good

Shackleton crater is located in South Pole-Aitken Terrane (as defined by Joliff et al, 2006), whereas Apollo samples came from Procellarum KREEP Terrane

Shackleton Outpost + Robotic Missions - Better

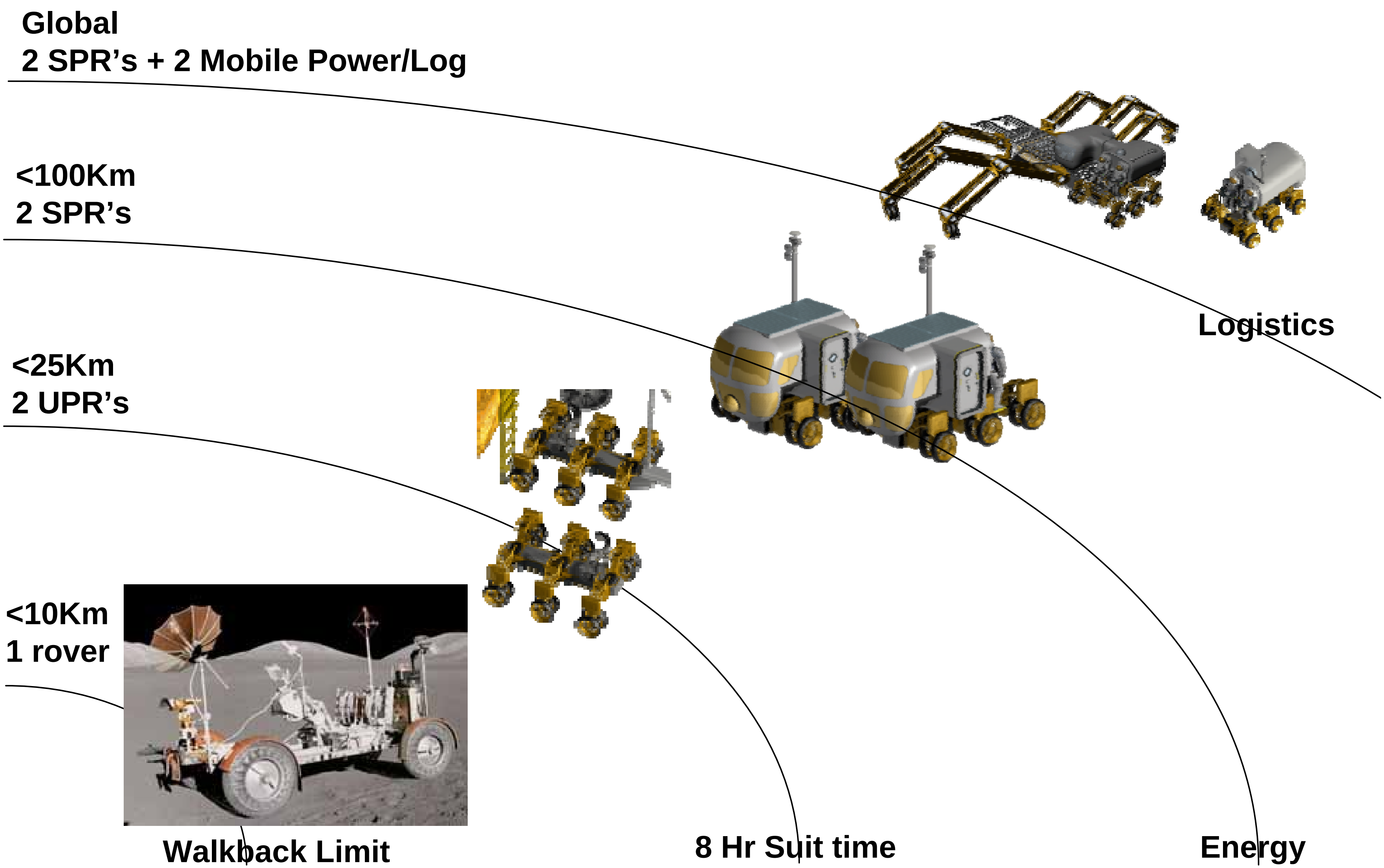
Robotic Sample Return missions to Feldspathic Highlands Terrane, or Eastern basin Terrane

Shackleton Outpost + Robotic Missions + Human Sorties - Best

Human sortie missions to Feldspathic Highlands Terrane, Eastern basin Terrane , or inner SPA

Surface Mobility Functional Range

(Data Rob Ambrose/JSC)



Science Influencing the Small Pressurized Rover

Range

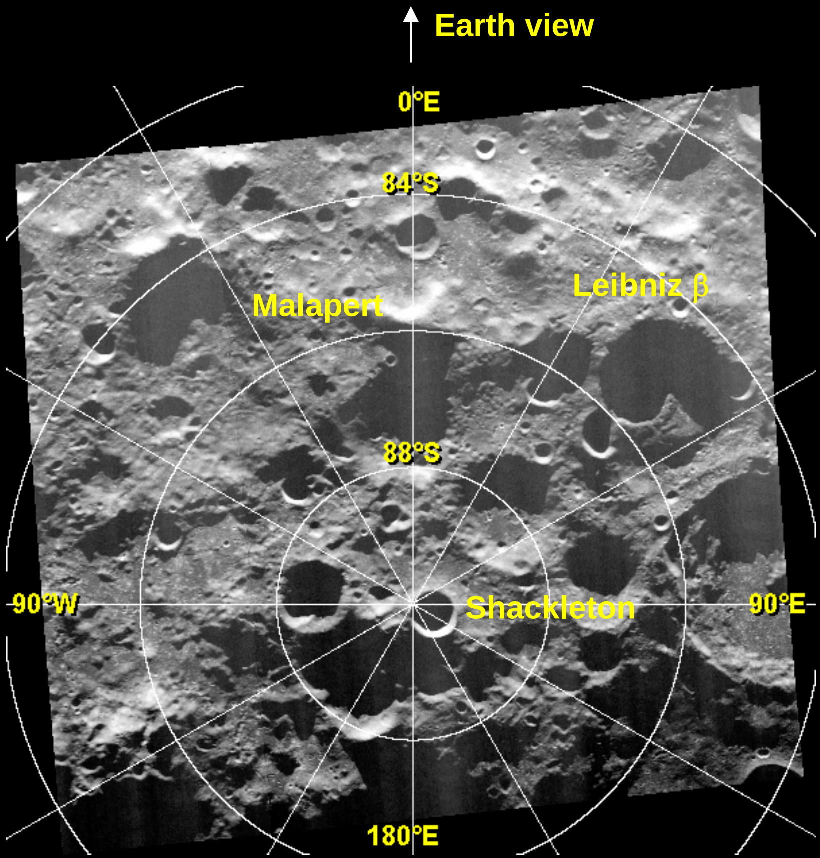
Current concept: < 100 km from Outpost
Malapert (~150 km) and Leibniz β (~200 km), possibly SPA basin rim, are beyond current concept.
Schrödinger basin and other important features within SPA are even further

More energy storage needed:
Modify concept
Add power cart (e.g., caravan or tow)

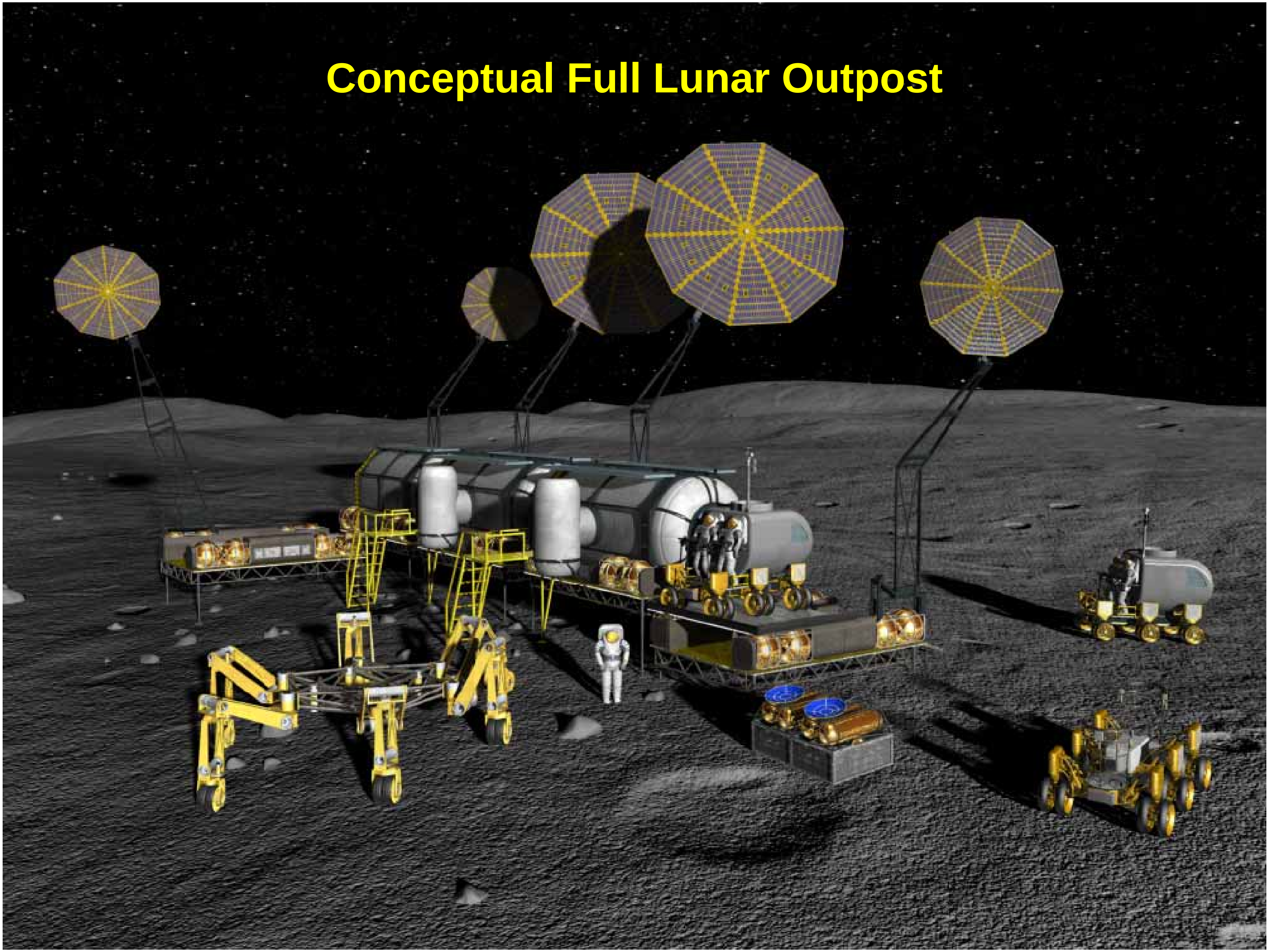
Science Payload Possibilities

Geophysical instruments
- ground penetrating radar
- traverse gravimeter

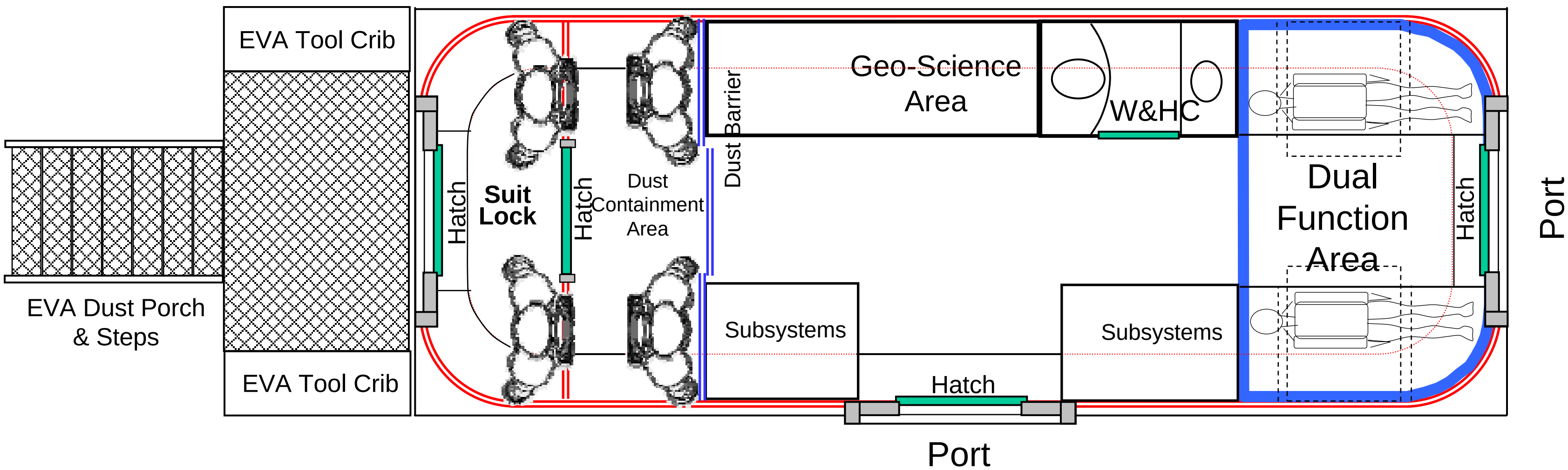
Remote sensing instruments (mineralogy, chemistry)
- MER mini-TES
- MSL ChemCam
- Surface version of Chandrayaan-1 M3



(from Margo et al, 1999 and Bussey)


Conceptual Full Lunar Outpost

3-Port 'Core' Hab Unit
(data from Larry Toups/JSC)



Science Influencing the Habitat

Mass, volume, and power allocation for geo-science and bio-science have been established

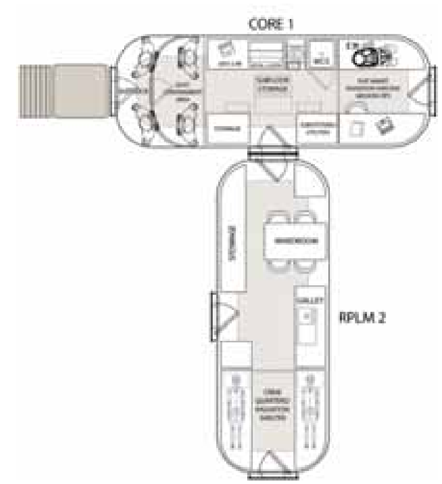
Larger laboratory floor space and volume as part of reusable presuurized logistics module

Geo-science details still in work

- sample analysis in glove-box?
- telerobotic workstation?
- planning/maintenance bench?

Bio-science details still in work

- medical operations/life science research synergy?
- glovebox?



CxAT-lunar Science Team
Future Work

The work done by the CxAT-lunar science team will transition to a much broader team, the Surface Science Scenario Team, which will support the Optimizing Science and Exploration Working Group (OSEWG)

Communicate-coordinate-cooperate with science communities to stay up to date on latest needs, goals, and objectives

- National Research Council (e.g., decadal survey, workshops, etc.)
- NASA Advisory Council (e.g., Science Committee and sub-committees)
- Lunar Exploration Analysis Group (e.g., Lunar Exploration Roadmap)
- International Groups (e.g., ICEUM/ILEWG)

Continue working with Constellation Architecture Team in assessing lunar architectures with respect to science needs, goals , and objectives

- human outpost missions
- human sortie missions
- robotic missions

Continue working with Lunar Surface System Project Office to influence surface system concepts to be science and user friendly

- habitat (e.g., laboratory, work stations)
- surface mobility (e.g., range, duration, field measurements/sampling)
- power and communications (e.g., remote science stations)