Goals & Strategies

for the Human Lunar Reference Architecture

11 May 2010

The First Step: Common Goals & Strategies

- Common Goals for Human Lunar Exploration
  - Independent of Architecture; precede its development
  - Could drive multiple architectural approaches
  - Used to evaluate GPoD approach
  - Cross-cutting and compelling; linked to GES themes
- Strategic Guidance
  - Applied to drive an architectural approach
  - Emphasis on particular goals
  - Used to evaluate GPoD approach

Process and Product

Process

Collection of Agency's Draft Objectives → Assessment of Commonalities → Development of Common Goals → Mapping of Common Goals to GES Themes → Mapping of individual Agency objectives to common Goals (an ongoing activity within each agency)

Product

Theme 1: New Knowledge in Science and Technology

Theme 2: A Sustained Presence - Extending Human Frontiers

Theme 3: Economic Expansion

Theme 4: A Global Partnership

Theme 5: Inspiration and Education

Common Goals for Human Lunar Exploration

(Traced to "GES: The Framework for Coordination")

Theme 1	Theme 2	Theme 3	Theme 4	Theme 5	Common Goals for Human Lunar Exploration
	■		■		Embrace a long-term strategic view for enhancing and expanding global partnerships for sustainable exploration of the Moon and beyond.
	◣		■		Maximize early international partnership opportunities for lunar exploration.
■	■		◣		Use lunar exploration as a stepping stone for the demonstration of technologies, operational concepts, and cooperation approaches for Mars and other destinations.
■	■		■		Take maximum advantage of ISS assets and other opportunities in LEO to advance technologies and capabilities for exploration beyond LEO.
■	■	◣		◣	Develop, demonstrate and apply innovative capabilities, technologies and processes for improving resource and energy management and environmental protection, driven by the challenge of sustaining human life and operations in the hostile environment of space and the lunar surface.
◣	■		■		Develop a flexible, robust and reliable architecture that allows humans to safely explore the moon.
	◣	■		◣	Stimulate economic development and industrial innovation to enhance global economic prosperity via exploration of the Moon.
■			◣	◣	Understand the origin and evolution of the Moon
■			◣	◣	Interpret the uniquely preserved record of solar system evolution on the Moon and its relation to the origin and evolution of life
■	■		◣	◣	Extend human presence in the solar system and improve the health of humans on Earth, by understanding and mitigating the risks to astronaut health in the lunar environment.
■	◣		◣	◣	Maximize science return by leveraging human presence on the Moon and/or capabilities developed for lunar exploration
◣		◣		■	Develop innovative tools, means and methods to enable the public to engage interactively in human exploration.
◣				■	Inspire the next generation to embrace the tools of exploration: science, technology, engineering, mathematics and a sense of curiosity.
	■			■	Engage the public on the broader rationale and benefits of exploration.
	◣		■	■	Achieve early, frequent and inspiring milestones relevant to the partnership, and to the public.

Some Illustrative Example Goals

Strategic View of Partnerships

New Knowledge in Science & Technology

A Sustained Presence

Economic Expansion

Global Partnership

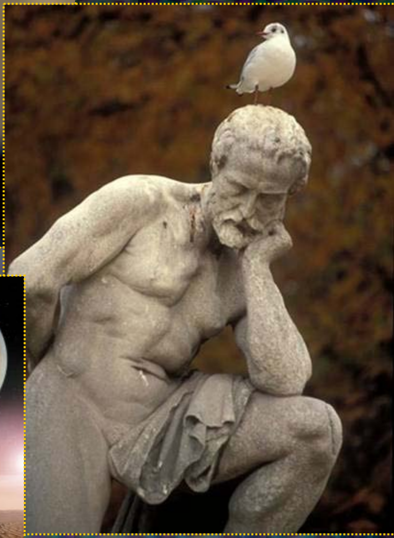
Inspiration & Education

Embrace a long-term strategic view for enhancing and expanding global partnerships for sustainable exploration of the Moon and beyond.

Example Objective:

Establish a global and sustainable partnership framework to enable all interested parties to participate in lunar exploration and beyond (Mars and/or NEO).

Expand global partnership to non-space faring nations and private companies.



Stepping Stone

New Knowledge in Science & Technology

A Sustained Presence

Economic Expansion

Global Partnership

Inspiration & Education

Use lunar exploration as a stepping stone for the demon-stration of technologies, operational concepts, and cooperation approaches for Mars and other destinations.

Example Objective:

Perform possible system and operational rehearsal of a safe human mission to Mars scenario.

Maximise extensibility of lunar architecture to other destinations.

Develop and demonstrate cooperation models/ frameworks required for human mission to Mars and other destinations.

Uniquely Preserved Record

New Knowledge in Science & Technology

A Sustained Presence

Economic Expansion

Global Partnership

Inspiration & Education

Interpret the uniquely preserved record of solar system evolution on the Moon and its relation to the origin and evolution of life.

Example Objective:

Investigate the lunar palaeoregolith (history recorded in the lunar soil).

Understand the meteoritic impact history of the inner Solar System as recorded on the Moon.

Human-Robotic Partnership

- New Knowledge in Science & Technology
- A Sustained Presence
- Economic Expansion
- Global Partnership
- Inspiration & Education

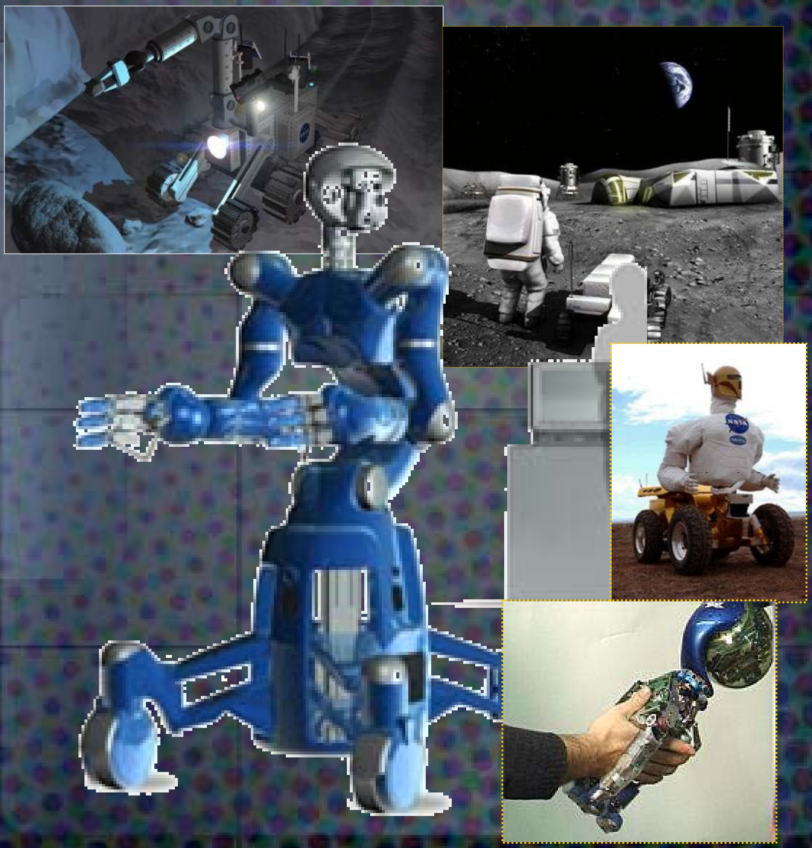
Maximize science return by leveraging human-robotic partnership for lunar exploration and/or capabilities developed for lunar exploration.

Example Objective:

Evaluate human-robotic partnership operational scenarios for the future human exploration of Mars.

Demonstrate the use of robots to supplement astronaut's surface activities, including the human/robot interface.

Maximise scientific opportunities/return from the Moon and on the Moon.



Innovative Engagement

- New Knowledge in Science & Technology
- A Sustained Presence
- Economic Expansion
- Global Partnership
- Inspiration & Education

Develop innovative tools, means and methods to enable the public to engage interactively in human exploration.

Example Objective:

Provide opportunities for public tele-operations and tele-presence in the exploration of the Moon and beyond.

Utilise the latest interactive technologies to maintain a fresh and innovative view of human presence on the Moon and beyond.

Strategic Considerations

- Advance the principles of programmatic and technical sustainability and ensure their early incorporation in the architecture
  - Apply a phased approach to exploration with interim milestones to accommodate evolution of mission objectives and changes in programmatic priorities
  - Include a phase that captures robotic missions to the moon in preparation for human lunar surface operations
  - Consider affordability in laying out campaign approaches
  - Maximize the synergies between human and robotic activities
- Balance compelling science and Mars Forward objectives, understanding that specific Mars Forward and science priorities will evolve.
- Take due consideration of ISS Lessons Learned including the importance of dissimilar redundancy in critical systems.

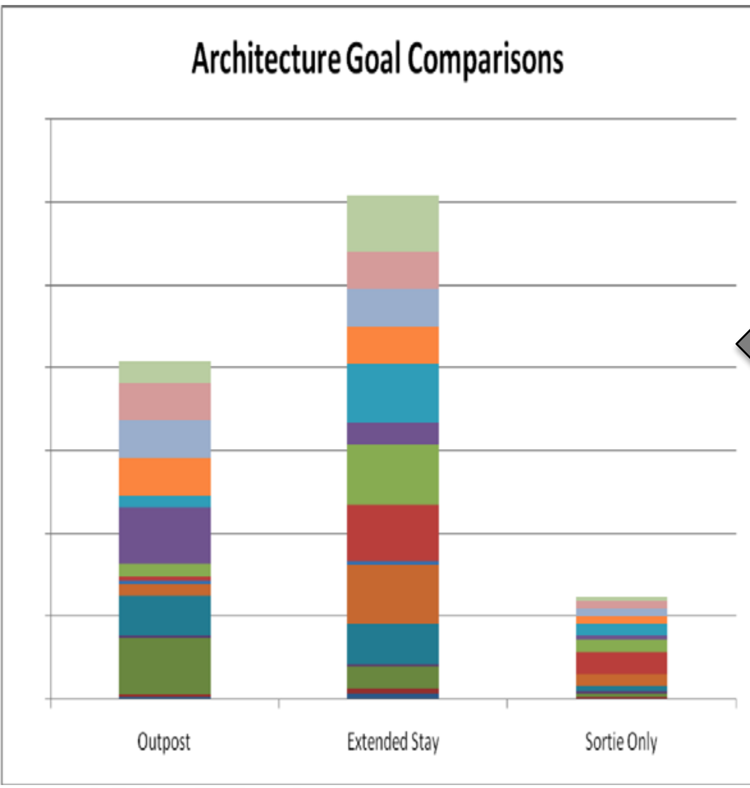
Evaluation of Campaigns against Common Goals

Extended Stay	1- Strongly Prefer	2 - Prefer	3 - Neutral	**4 - Prefer**	5 – Strongly Prefer	*Outpost*
Sortie-Only	1- Strongly Prefer	2 - Prefer	3 - Neutral	4 - Prefer	**5 – Strongly Prefer**	*Outpost*
Sortie-Only	1- Strongly Prefer	2 - Prefer	3 - Neutral	4 - Prefer	**5 – Strongly Prefer**	*Extended Stay*

Example:

Goal #3

Using the Moon as a stepping stone to Mars



① Pair-wise comparative evaluation of each Goal:

– Inputs: Metrics and other strategic considerations.

– Output: Group consensus on a scaled evaluation of preference, for each pair of campaigns.

② Extraction of quantitative data for entire set of 15 Goals

③ Total score identifies preferred campaign

IAWG evaluated all 15 Goals against all 3 campaign variants during the January 2010 workshop in Houston

Summary

- The IOWG has developed a Common set of Human Lunar Exploration Goals
  - Traceable to GES themes and agency specific objectives
  - Extremely well-received across ISECG working groups and by participating agencies
  - Used to drive the GPoD along with strategic considerations
- The methodology for gathering and extracting goals & objectives is extensible to any destination
  - Provided agencies participate having considered/developed their national objectives
  - Should precede architecture studies

Introduction to the GPoD Campaign

Campaigns Considered

- Outpost centric campaign (NASA)
  - Address most Mars forward objectives thanks to large amount of available surface time, delivery of key hardware tested over extended period of time
  - Science objectives are only partially addressed because of low number of site visited
  - Resources intensive: Requires upfront delivery of large hardware to sustain long duration stays
- Sortie Only campaign (NASA)
  - High diversity of sites visited to meet science objectives but with reduced available mass for utilization (tools, instruments)
  - Scarcely addresses Mars forward objectives
  - Poor sustainability from technical and programmatic point of view
  - Lowest level of resources required

GPoD Campaign

- Phased approach with mixture of dedicated sortie mission and extended stays of increasing duration
- Ability to relocate assets become key to re-use support infrastructure at different sites
- There is a minimum set of capabilities and thus resources required to deploy an infrastructure capable of mobility and surviving the lunar environment over several day/night cycles

Philosophy of GPoD

- Phased approach with ability to incrementally assess science and Mars risk reduction needs
- Extensive use of robotics and human-robotic interactions
- Early robotic phase is integral part of human mission campaign/DRM
- Science objectives are equal priority to Mars forward
  - Surface science itself is very Mars forward
- Leverages reusable and relocatable surface assets to maximize exploration and participatory exploration opportunities while minimizing the need to deliver cargo to the moon.
  - Extensive action on lunar surface between crewed visits
- Flexibility to accommodate changes in technologies, international partner priorities and programmatic constraints.
- Sustainability

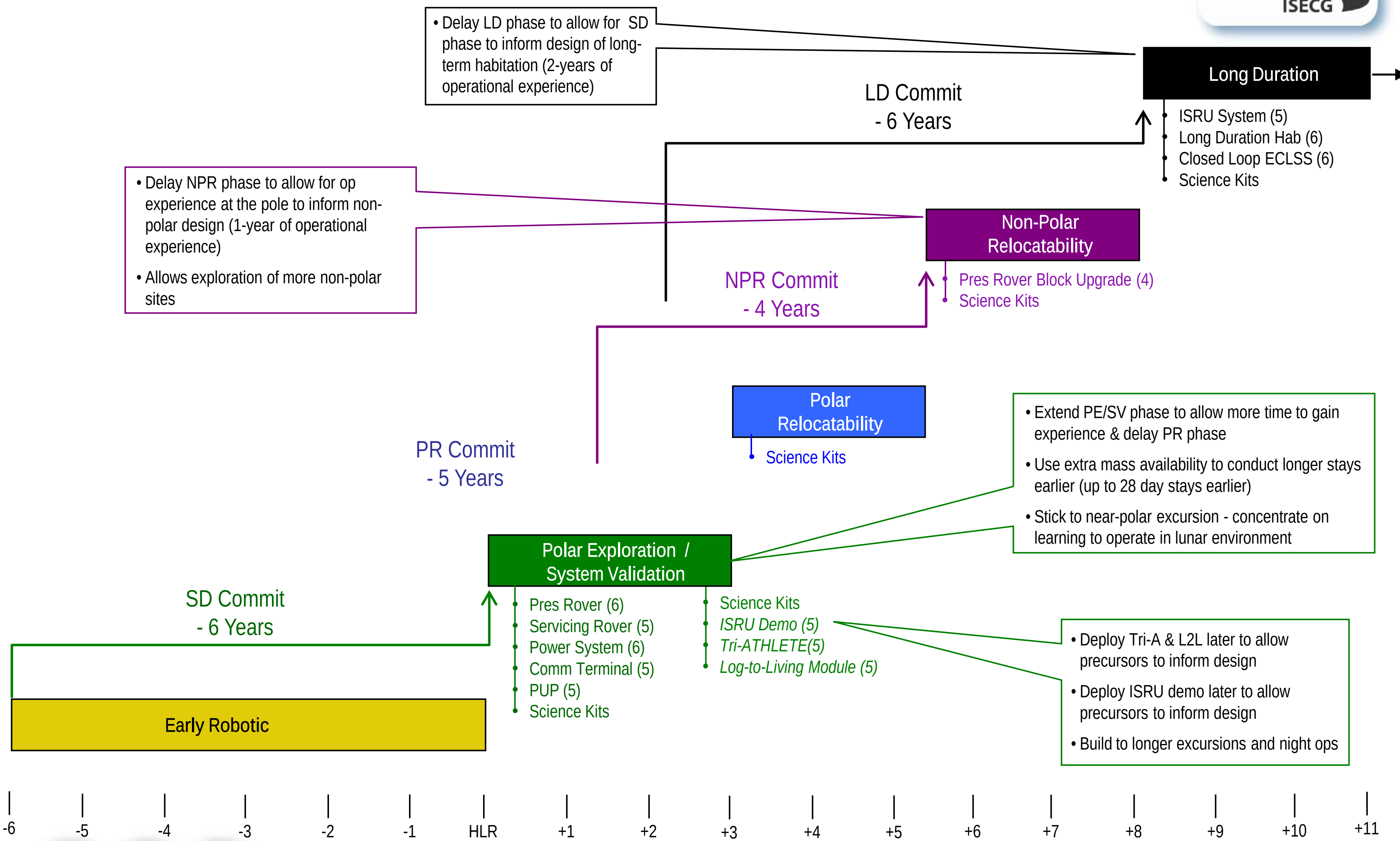
GPoD Campaign Phase Definitions

The following phases of the architecture have been defined. The phases could be implemented in different step/order:


- **Early Robotic Phase** – Robotic missions to increase knowledge, reduce risk and understand required margins. Participatory exploration.
- **Polar Exploration / System Validation Phase** – Validation & verification at pole of mobility and power infrastructure
- **Polar Relocatability Phase** – Use relocatability to enable extended crew missions to “near polar locations”
- **Non-Polar Relocatability Phase** – Utilize evolved assets to enable exploration via extended crew missions (at least 14 days) at non-polar regions
- **Long Duration Phase** – Long duration extended stay capability (at least 60 days)

- Ability to add targeted Sortie missions to meet science objectives as needed

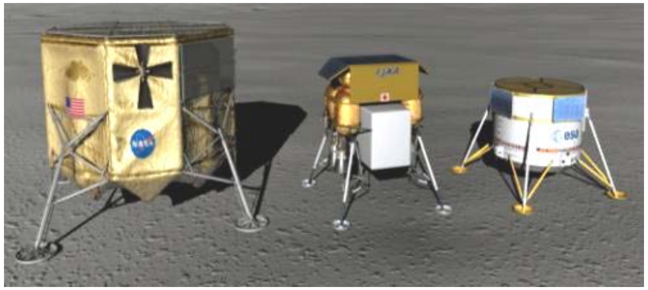
GPoD Design Decision Points



GPoD Overview

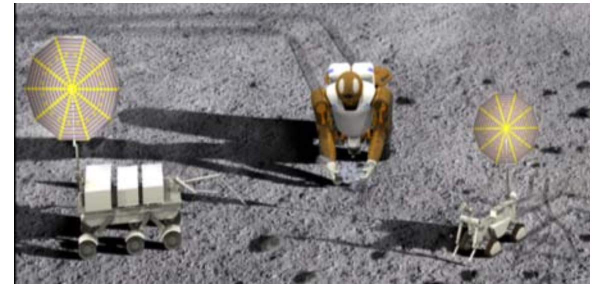
Lunar Exploration Capabilities

Surface Access



Heavy Lift Mobility

Robotic Explorers

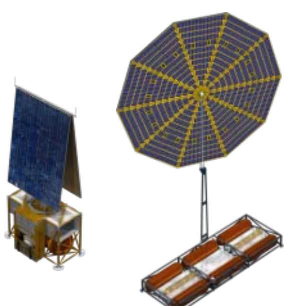


Human Explorers

Pressurized Mobility

Science, ISRU and Support Systems

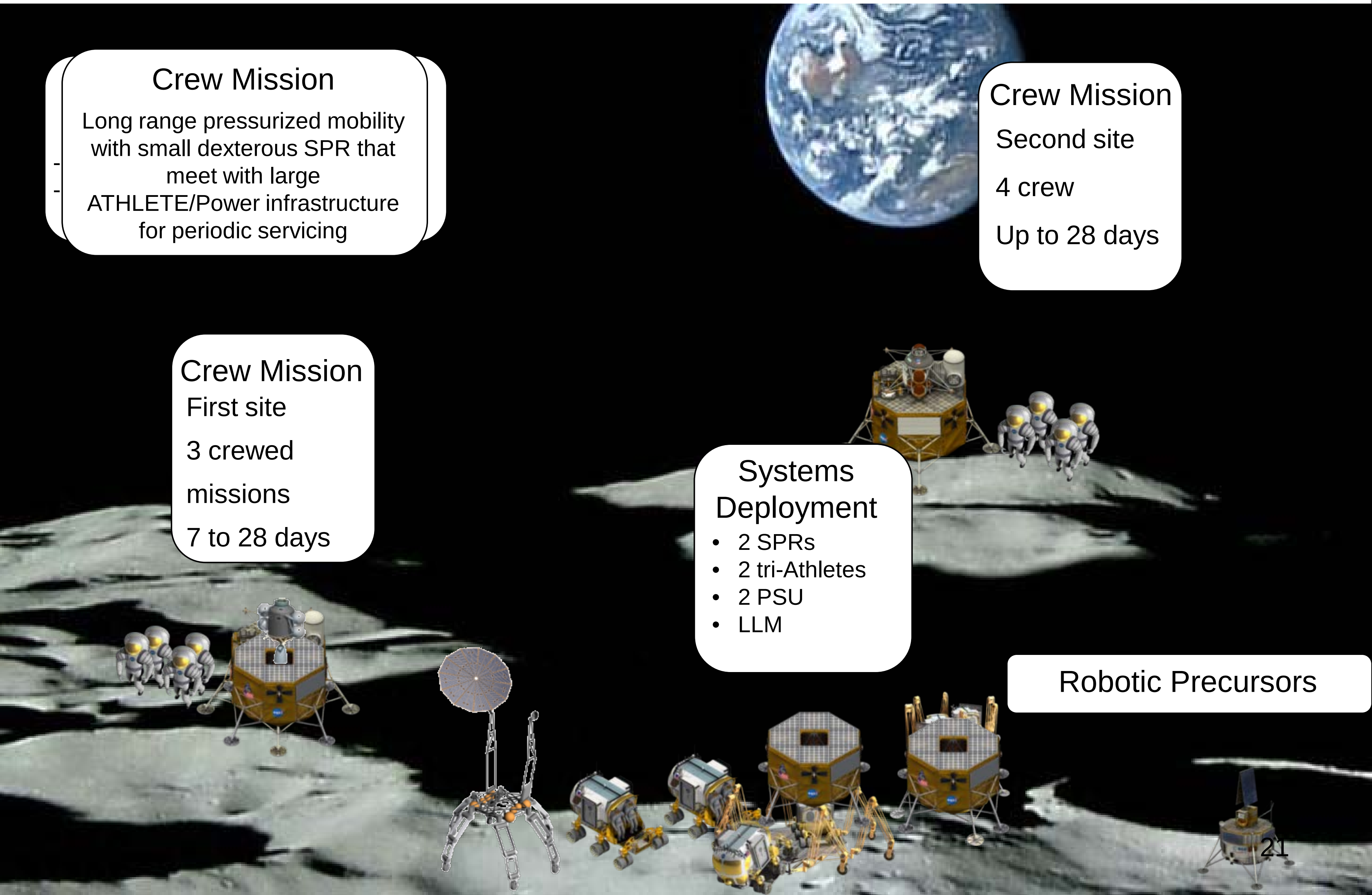
Power Infrastructure



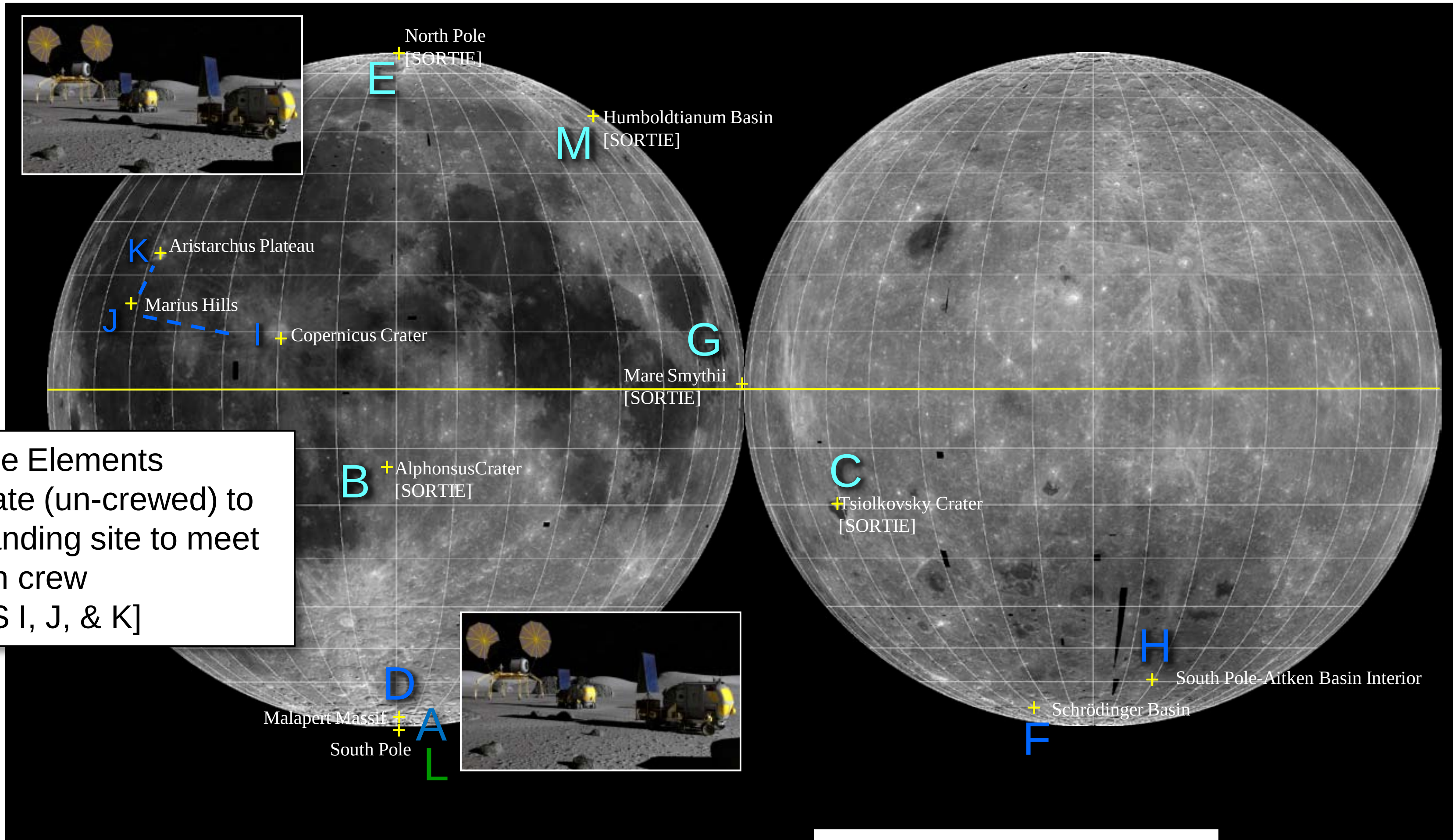
Communications

Habitation & Logistics

Extended Stay - Relocation Exploration Mode



Notional Campaign Destinations for GPoD



Surface Elements Relocate (un-crewed) to next landing site to meet up with crew [SITES I, J, & K]

Surface Elements Relocate (un-crewed) to next landing site to meet up with crew [SITES A, D, F, & H]

Light Blue = Sortie (7 day)

Blue = Extended Stay (≤28 day)

Green = Long Duration (70 day)

Notional Campaign Destinations for GPoD

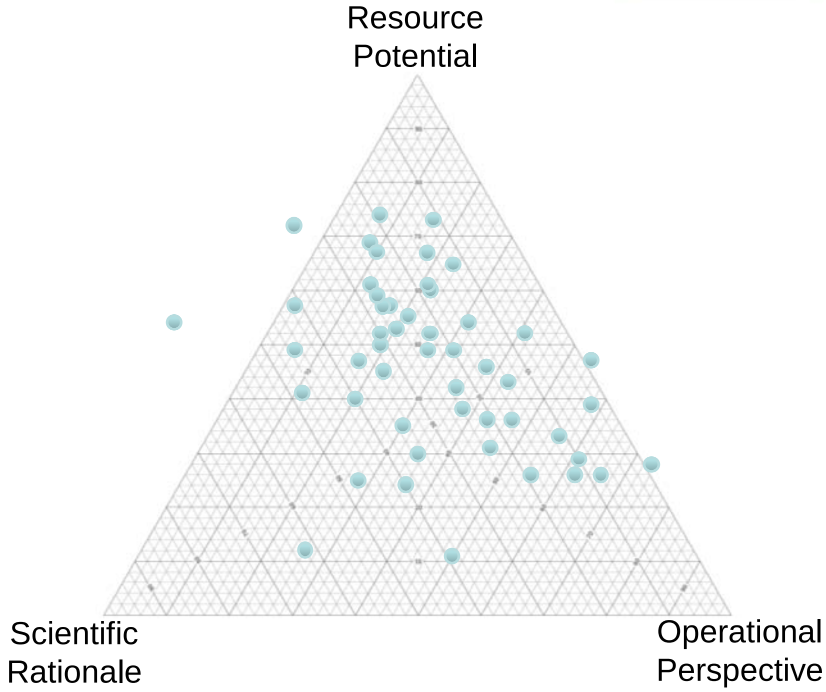
Constellation identified 50 high priority regions of interest for human exploration of the Moon, based on results from the Clementine and Lunar Prospector missions, and three NASA reports:

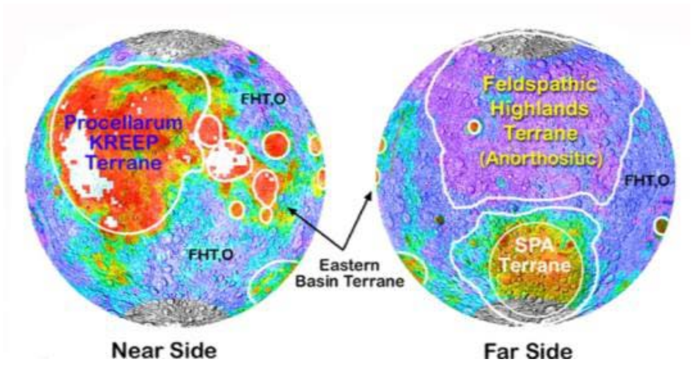
1. NASA's Exploration Systems Architecture Study (ESAS), 2005.
2. A Site Selection Strategy for a Lunar Outpost, Science and Operational Parameters, 1990.
3. Geoscience and a Lunar Base, A Comprehensive Plan for Lunar Exploration, NASA Conference Publication 3070, 1990.

The regions of interest identified by Constellation are not intended to be, and are not to be interpreted as, a site selection activity for actual landing sites. Rather, they illustrate the diversity of scientific and resource opportunities, and geographic terrains and locations, that together form a representative basis for scientific exploration, resource development, and mission operations.

A Lunar Exploration Analysis Group (LEAG) specific action team reviewed and modified Constellation's initial set of regions of interest to the current set.

Notional campaign destinations for GPoD are a subset of the Constellation regions of interest to illustrate polar, equatorial, nearside, and farside exploration of the major terrain types on the Moon (i.e., South Pole-Aitken basin, Procellarum KREEP terrain, and the Feldspathic Highlands terrain)





Notional Campaign Destinations for GPoD

A (also L). South Pole
Possibly on South Pole-Aitken (SPA) basin inner ring
SPA basin geology and basin formation process
Polar volatiles (e.g., water ice)
Enhance sun illumination

B. Alphonsus Crater
Pyroclastic vents and materials, possibly mantle xenoliths
Associated with lunar transient events
Rim massifs and possible impact melts

C. Mare Smythii
Young basaltic lavas high in iron and titanium
Near mare-highland contact
Floor fractured crater (crater formation process)
Possible location for observatories (e.g., limb site)

D. Malapert Massif
Likely part of South Pole-Aitken basin rim
Impact process, large basin formation, possibly basin impact melt
Possible location for earth observatories and communication assets (relay for South Pole)

E. North Pole
Polar volatiles (e.g. water ice)
Enhanced sun illumination

F. Schrödinger Basin
Second youngest basin on Moon
Pyroclastic vent and materials, possibly mantle xenoliths
Far side mare
Basin age and formation

G. Tsiolkovsky Crater
Far side mare
Central peak complex
Impact melt
Impact and crater formation processes

H. South Pole-Aitken Basin Interior
SPA floor materials and possibly impact melt
SPA basin geology and basin formation process

I. Copernicus Crater
Major stratigraphic horizon
Crater floor materials, central peak, impact melts
Impact process and crater formation

J. Marius Hills
Largest volcanic dome complex on the Moon
Many different styles of eruption and lava flows present
Chemistry/mineralogy variations suggests multiple source regions
Possible intact lava tubes with skylight entrances

K. Aristarchus Plateau
Geologically complex
Plateau likely associated with Imbrium basin formation
Pyroclastic materials and lava flows
Vallis Schröteri and other sinuous rilles
Aristarchus crater ejecta, Herodotus crater

M. Humboldtianum Basin
Mare-highland contact
Mare age and composition
Basin melt sheet
Basin geology and formation process

Early Robotics Phase

- Intent was to develop an integrated set of early robotic missions consistent with GPoD campaign needs while attempting to balance sustainability and affordability
  - Number and type of mission opportunities provided as top down guidance from IAWG (Montreal, March 2010)
  - Mission content, scheduling and location derived through bottoms up analysis from inputs provided by Function Teams, Science Community, Public Engagement representatives, IPs, etc.
- Current manifest represents a *preliminary scoping* of functions and tasks that provide substantial benefit if performed early on prior to humans
  - Product is *not* intended to be taken as a final detailed manifest of missions and payloads
  - Mission definition is extremely preliminary in nature (i.e. think “back of the envelope”) and needs to be verified through a more rigorous concept definition process
  - Should be used as a first step in a highly iterative process to derive requirements for actual mission content
- Key Lessons Learned
  - Significant opportunities exist for early international coordination on robotic missions
  - When planned in conjunction with a human exploration campaign, considerable value can be added by the robotic campaign and robotic activities can provide significant risk deduction for eventual human missions.

Development of the GPoD Early Robotics Phase

Identified GPoD Functions to be Supported - Element Design, Operations Support, Stand-Alone GPoD Goal (Science/Public Eng.)

Mapped Critical Precursor Tasks For each Function & Identified Required Sites & Mode (Mobile/Fixed)

Identified Specific Instruments/Packages for Each Task & Estimated Mass

Developed Rough Required Timing for Each Task and Package

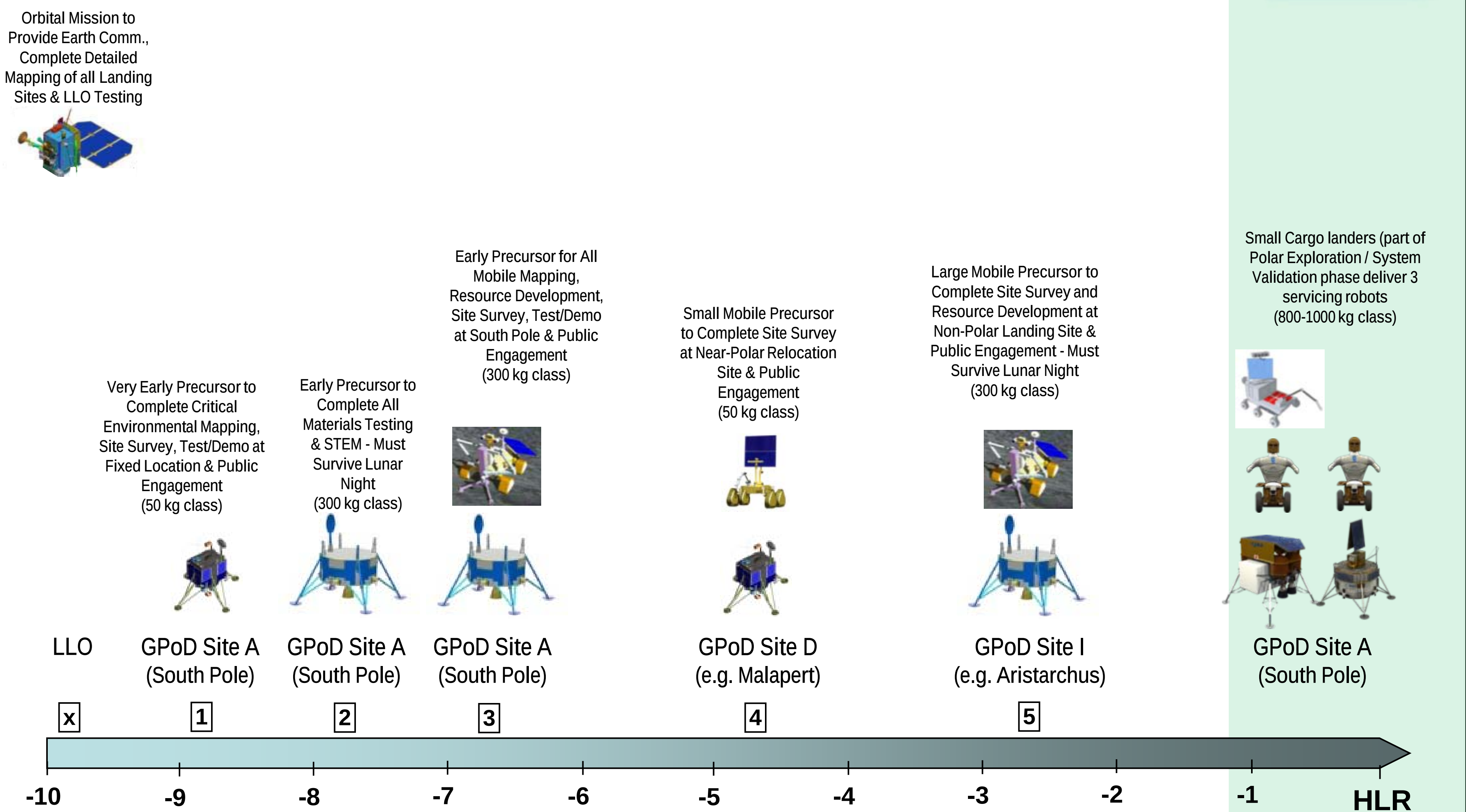
Grouped Packages by Synergies, Sites, Mode, & Timing

Allocated Packages to Missions

GPoD Early Robotic Missions: a shopping list of interesting and important preparatory activities directly tied to success of the human campaign

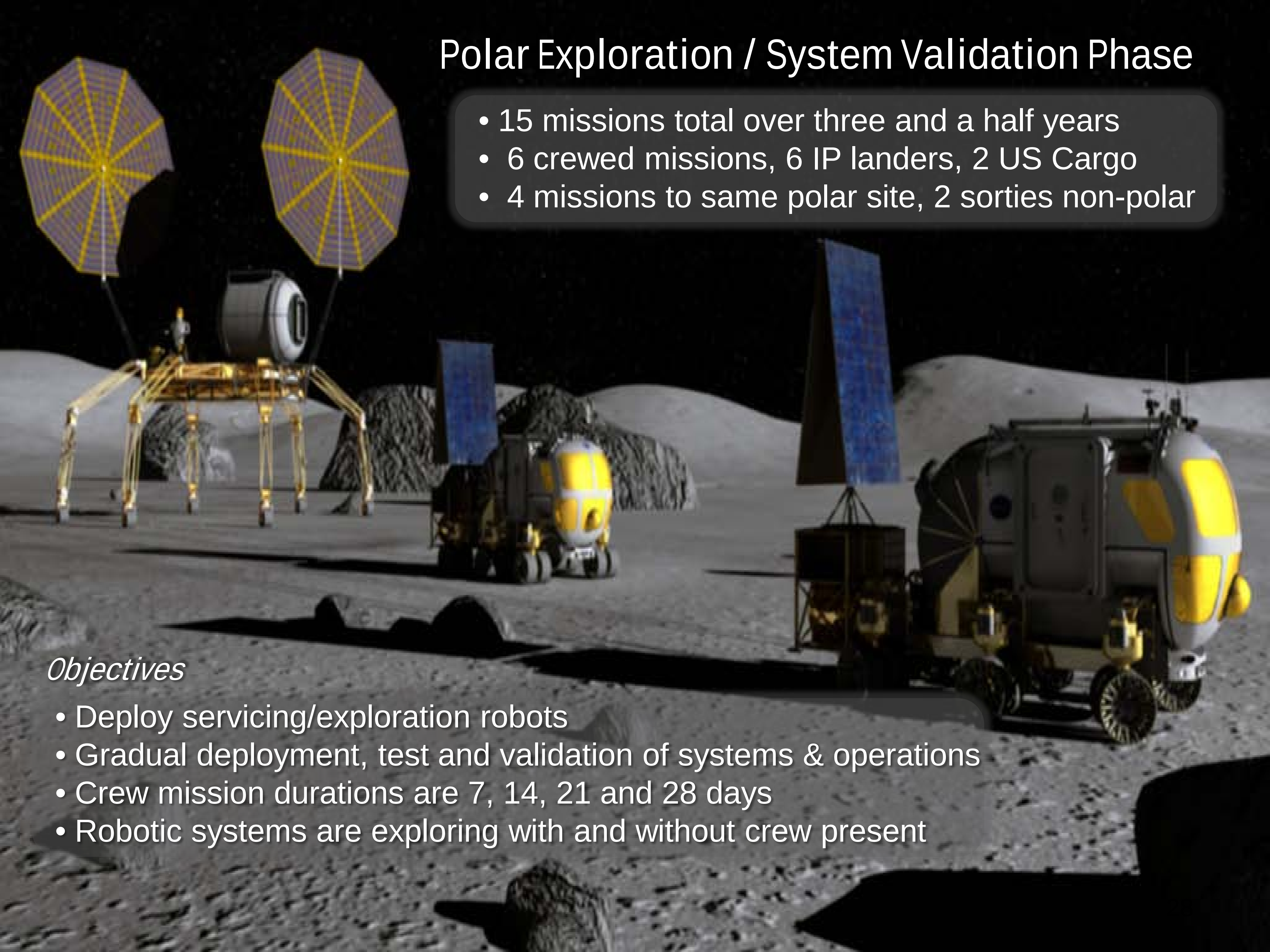
- Green: Inputs from Function Teams, Science Community, IPs, etc.
- Purple: Driven by Element DD&TE and production schedules, derived by NASA cost community
- Dark blue: Early Robotics Integration Team

GPoD Early Robotics Phase



Polar Exploration / System Validation Phase

- 15 missions total over three and a half years
- 6 crewed missions, 6 IP landers, 2 US Cargo
- 4 missions to same polar site, 2 sorties non-polar



Objectives

- Deploy servicing/exploration robots
- Gradual deployment, test and validation of systems & operations
- Crew mission durations are 7, 14, 21 and 28 days
- Robotic systems are exploring with and without crew present

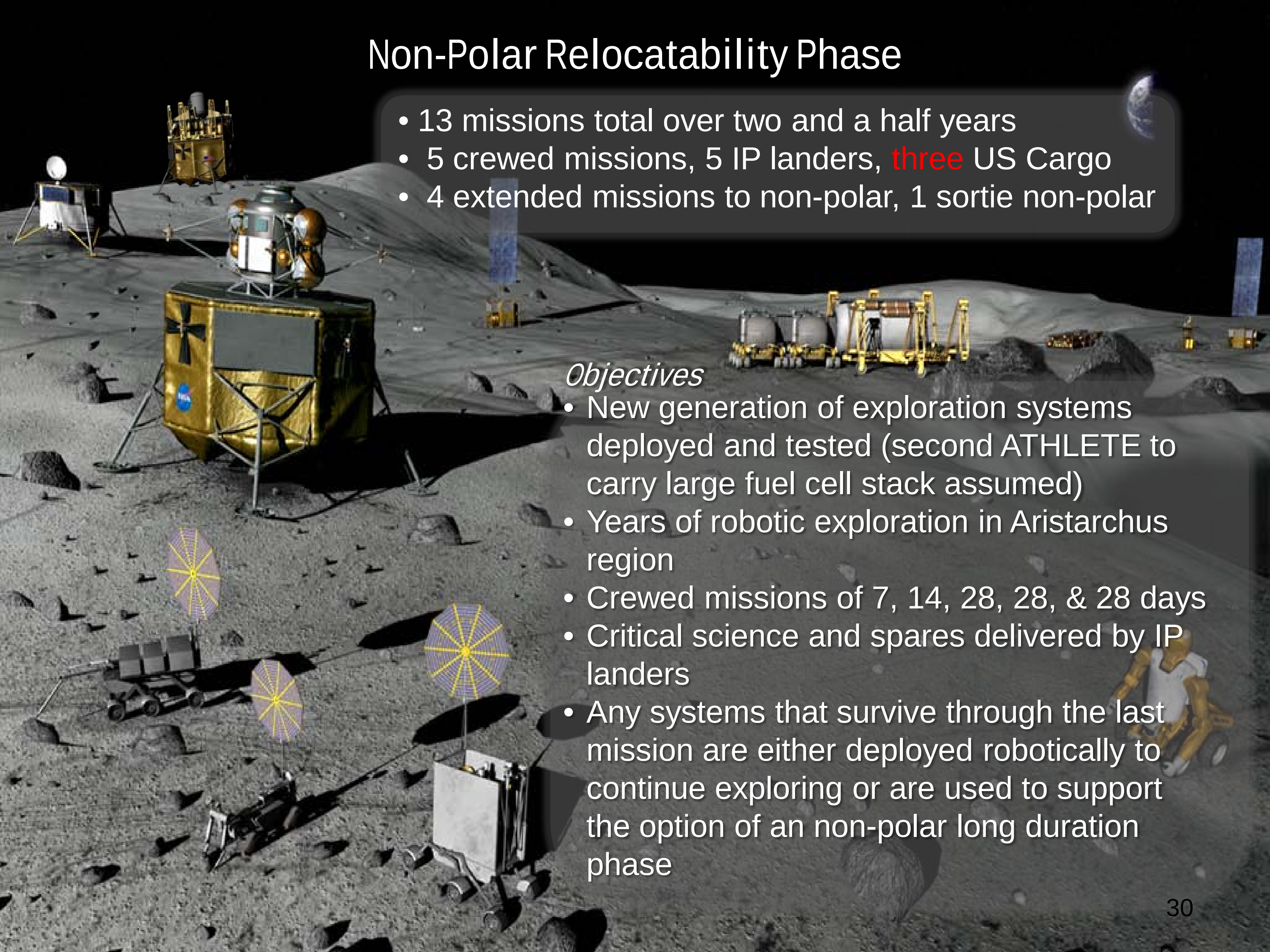
Polar Relocatability Phase

- 10 missions total over two and a half years
- 5 crewed missions, 5 IP landers, Zero US Cargo
- 3 extended missions to near-polar sites, 2 sorties non-polar

Objectives

- Months of robotic exploration at Malapert
- 28 days of crewed exploration at Malapert
- Critical science and spares delivered by IP landers
- Months of robotic exploration at and in between Schrödinger Basin and South Pole-Aitken Basin Interior
- 14 days of crewed exploration at Schrödinger Basin and South Pole-Aitken Basin Interior
- Any systems that survive through the last mission are driven back to the South polar site for future use

Non-Polar Relocatability Phase



- 13 missions total over two and a half years
- 5 crewed missions, 5 IP landers, three US Cargo
- 4 extended missions to non-polar, 1 sortie non-polar

Objectives

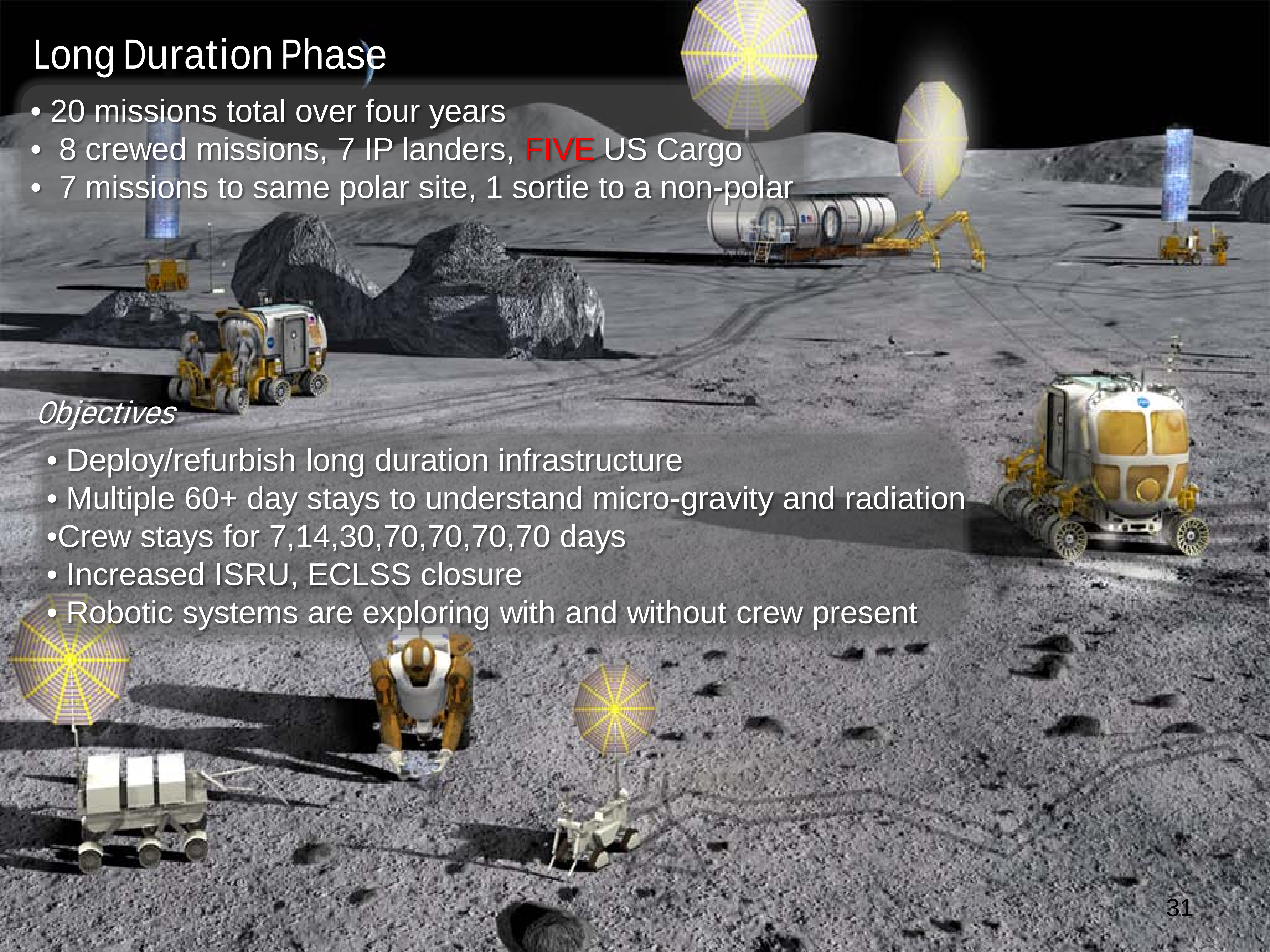
- New generation of exploration systems deployed and tested (second ATHLETE to carry large fuel cell stack assumed)
- Years of robotic exploration in Aristarchus region
- Crewed missions of 7, 14, 28, 28, & 28 days
- Critical science and spares delivered by IP landers
- Any systems that survive through the last mission are either deployed robotically to continue exploring or are used to support the option of an non-polar long duration phase

Long Duration Phase

- 20 missions total over four years
- 8 crewed missions, 7 IP landers, FIVE US Cargo
- 7 missions to same polar site, 1 sortie to a non-polar

Objectives

- Deploy/refurbish long duration infrastructure
- Multiple 60+ day stays to understand micro-gravity and radiation
- Crew stays for 7,14,30,70,70,70,70 days
- Increased ISRU, ECLSS closure
- Robotic systems are exploring with and without crew present



Return to Evaluation of Campaigns

Extended Stay	1- Strongly Prefer	2 - Prefer	3 - Neutral	4 - Prefer	5 – Strongly Prefer	*Outpost*
Sortie-Only	1- Strongly Prefer	2 - Prefer	3 - Neutral	4 - Prefer	5 – Strongly Prefer	*Outpost*
Sortie-Only	1- Strongly Prefer	2 - Prefer	3 - Neutral	4 - Prefer	5 – Strongly Prefer	*Extended Stay*

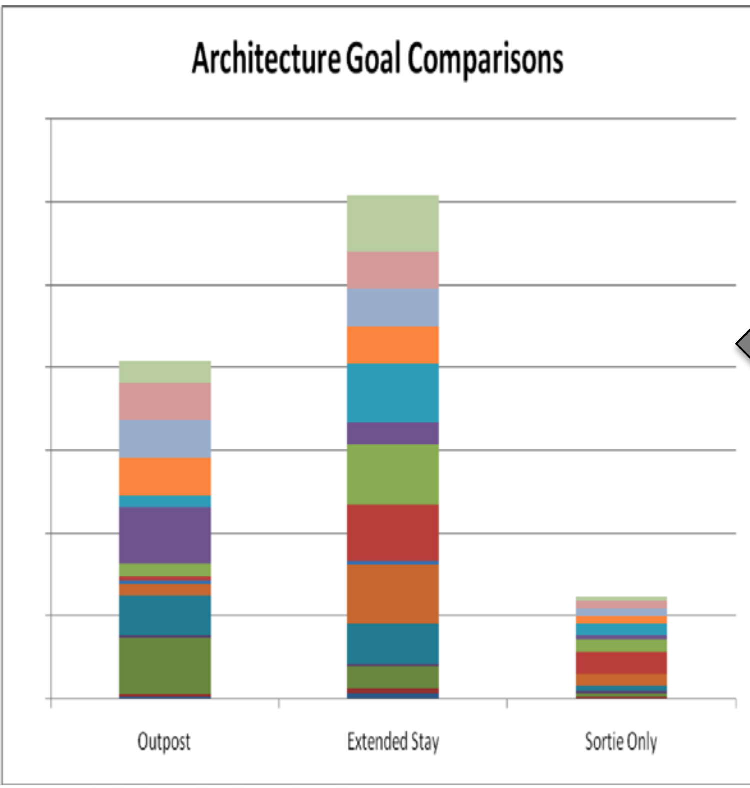
Example:

Goal #3

Using the Moon as a stepping stone to Mars

① Pair-wise comparative evaluation of each Goal:

- Inputs: Metrics and other strategic considerations.
- Output: Group consensus on a scaled evaluation of preference, for each pair of campaigns.



② Extraction of quantitative data for entire set of 15 Goals

③ Total score identifies preferred campaign

IAWG evaluated all 15 Goals against all 3 campaign variants during the January 2010 workshop in Houston

Summary

- The GPoD establishes an architectural framework that enables significant scientific and exploration risk reduction goals to be addressed by multiple partners through use of a phased approach to exploration.
- The GPoD architecture's flexible approach to lunar exploration can accommodate changes in technologies, international partner priorities and programmatic constraints as necessary.
- The GPoD maximizes use of mobile and relocatable assets to drive down costs and enhance opportunities for scientific discovery.