A Focused Path to Extend Human Presence Beyond Low Earth Orbit

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Focused Path

Developing a sustainable long-term architecture to move humans out of low Earth orbit and into the Solar System requires a *focused path* built around a *series of achievable goals and objectives* within a *structured time frame*.

Early milestones can be accomplished through a series of robotic and crewed missions culminating in human activities on the Moon (***Stage 1***). While learning to live and work on another world (the Moon) development can then begin on the next set of tasks focused on initiating human activities on Mars (***Stage 2***), and beyond.

Stage 1 Objectives (1/2)

1. Test and perfect automated pinpoint landing (*first robotic, then crewed*)
2. Test and perfect automated hazard avoidance (*first robotic, then crewed*)
3. Test and perfect autonomous roving (*robotic*)
4. Characterize surface radiation environment and test efficacy of mitigation strategies (*robotic*)
5. Characterize deep space radiation environment and test efficacy of mitigation strategies (*robotic*)
6. Investigate time sequence of key lunar events (*robotic then crewed*)
7. Determine presence and location of lunar resources (*robotic*)

Stage 1 Objectives (2/2)

8. Determine grade and tonnage of lunar resources (*robotic then crewed*)
9. Test ISRU hardware (*robotic*)
10. Test advanced ISRU and utilize generated product for surface exploration (*robotic and crewed*)
11. Test human support systems on lunar surface (*crewed*)
12. Initiate sustained human presence to learn to live and work on another world: exploit resources, explore, undertake scientific activities (*crewed and robotic*)
13. Collect and transport materials from one point on the Moon to another point (*robotic and crewed*)
14. Transport materials off the Moon (*robotic and crewed*)

Focused Path Example Tasks

(short list)

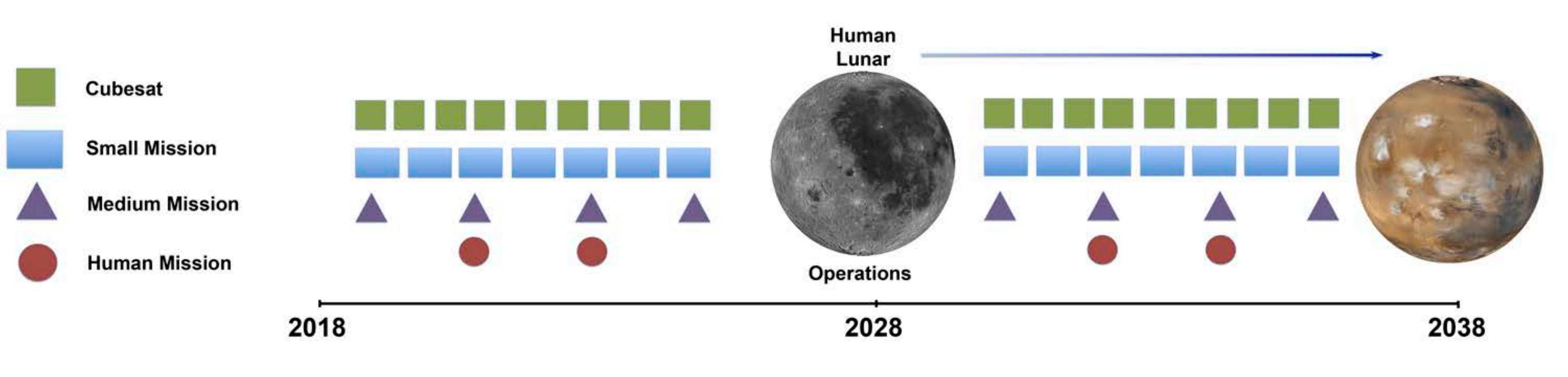
- Precision landing and hazard avoidance
- Develop and test surface exploration strategies
- Resources (grade, tonnage, accessibility, extraction methods)
- Radiation mitigation (primary, secondary: GCR, nominal solar, solar flare events)
- Overarching science questions
  - Early Solar System bombardment history
    - SPA – when?
    - Imbrium, Serenitatis, Crisium - or rather Imbrium, Crisium, Serenitatis???
  - History of volcanism (window to interior)
  - Magnetic fields
  - Volatile transport and sequestration

Mix of Mission Types
To Meet Focused Path Objectives

- Very small missions (<$10M)
- Small Missions($50M – $150M)
- Medium missions ($300M - $600M)
- Large Missions (>$1000M)

Serial and parallel objectives met through mix of mission types

Retire goals and objectives frequently



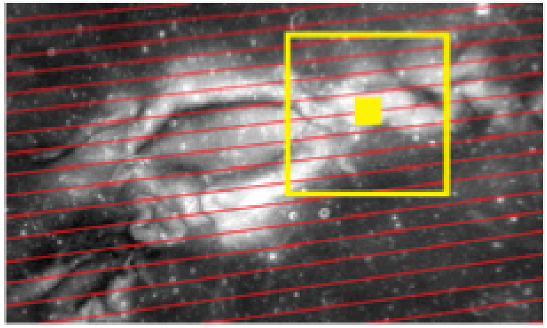
Swirl ($10M)

Determine Nature of Reiner Gamma Magnetic Field

What *Swirl* Will Measure
Field strength (FS) and polarity (P) at 5 km scale
Variation of FS and P at 100 Hz (200 m) sampling
Ten closely spaced (4 km) orbits over core RGS

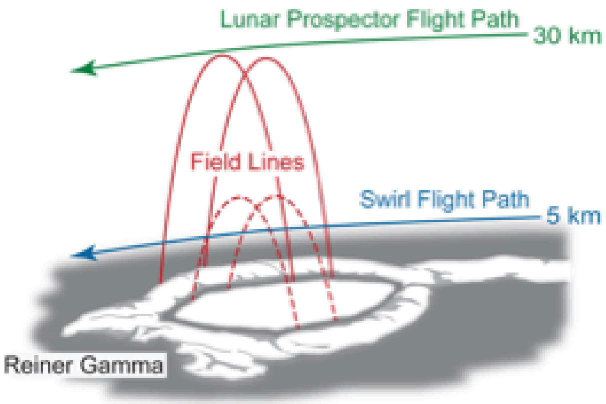
What We Will Learn	
Magnetic Source Regions	Spatially resolved FS and P, and depth to anomaly
Swirl Relation to Magnetic Anomaly	Magnetic signature (FS and P) association with swirl albedo patterns
	Where magnetic properties are able to hold off solar wind

Test Magnetic Source Formation Models	
Dike	Linear to meandering, constant P, strong, deep
Basin Ejecta	Surficial, randomized polarity, weak, shallow
Buried Ni,Fe Asteroid	Discrete, polarity varies per locale, constant at a given locale, strong to weak, shallow
Cometary	Surficial, uniform polarity, weak, shallow



Orbit tracks, 4 km spacing, large box is 30 km wide, small box 5 km wide

Test Swirl Formation Models	
Shielding	Field orientation vertical at dark lanes
Deposition	Field orientation vertical above bright swirl



Swirl path through RGS magnetic field

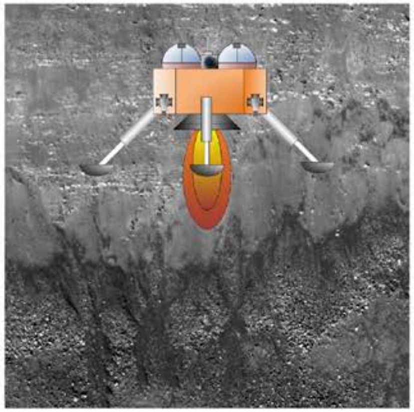
Arne ($100M)

Explore Mare Tranquillitatis Pit

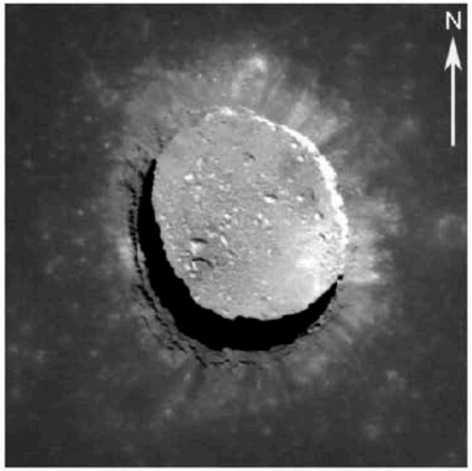
What *Arne* Will Measure
Morphology of MTP walls and floor
Extent and topology of void
Environment of void

What We Will Learn	
Pit	Thickness of mare flows, floor roughness, origin of pit
Void	Extent and roughness
	Environmental conditions

Test Key Technologies	
Pinpoint landing	Real time landmark identification and guidance feedback loop
Hazard avoidance	Real time hazard identification/avoidance
Flying bot	Autonomous navigation and hazard avoidance
Wireless communication	Bot-to-bot and bot-to-lander



Exploitation Potential	
Engineering	Utility for habitat
Science	Mare volcanism processes



Intrepid: Roving Explorer ($500M)

What *Intrepid* Will Measure
Chemistry and mineralogy
Magnetics, radiation, temperature
Topography, color, albedo

What We Will Learn
Variability of magmatic source regions over time
Nature of local magnetic sources
Secondary radiation risks
Formation and evolution of regolith

Enabling Future Exploration
Measurements in key geological terrains
Ground truth to orbital measurements
Sample cache for future collection

Test Key Technologies
Autonomous pinpoint landing
Laser communication
Highly mobile - 2000 km baseline traverse
Autonomous driving for sustained periods (>4 hrs) at > 1 kph
Advanced thermal mitigation
Two-year nominal mission timeline

Focused Path Sustainability

The focused path invites international cooperation by laying out a set of key objectives achievable with focused mission scenarios; interested nations can negotiate a logical division of responsibility to divide costs and increase the political payoff (critical to sustainability).

Along the focused path, mission returns will in many cases directly address key NSF decadal goals further strengthening science community, lawmaker, and public support (*Science Enables Exploration, Exploration Enables Science*).

Possibly the most difficult aspect is starting on a focused path – a process that requires political vision and leadership. Perhaps kick started from a bottom up approach. Write your Senators and Representatives!

The Moon is in the critical point to any sustained human exploration of the Solar System.