Lockheed Martin's Systems-of-Systems Lunar Architecture Point-of-Departure Concept

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CE&R BAA Open Forum

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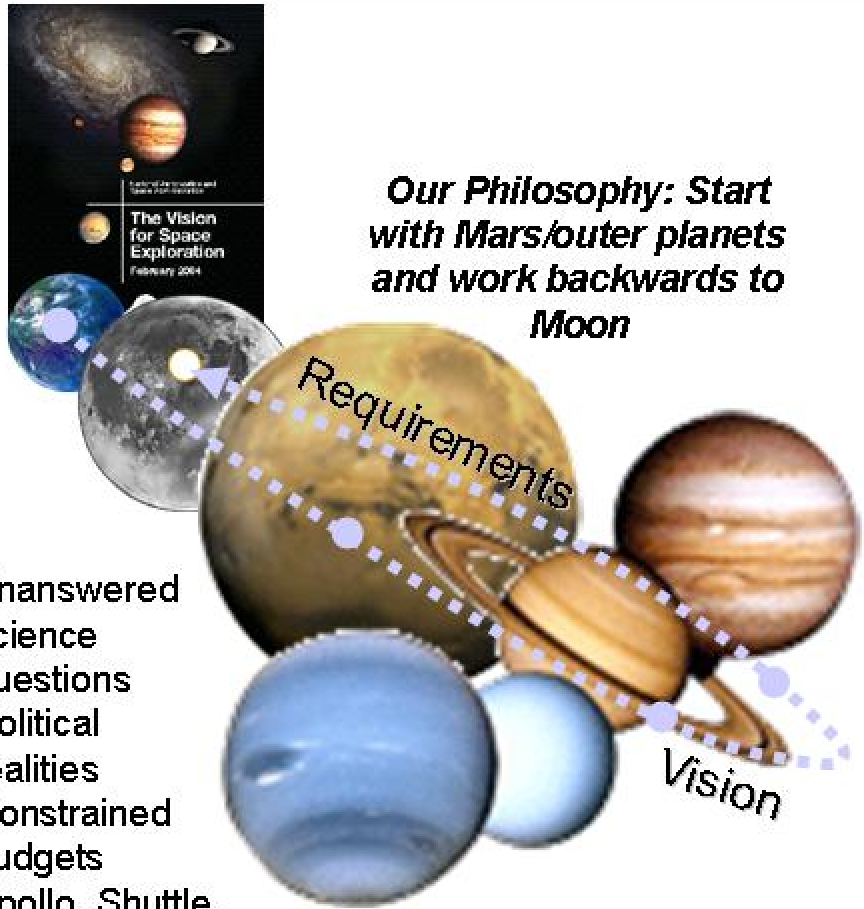
Mars/Moon Exploration Approach Considerations



Our Philosophy: Start with Mars/outer planets and work backwards to Moon

- Unanswered science questions
- Political realities
- Constrained budgets
- Apollo, Shuttle, and ISS legacies
- Emerging commercial space industry
- Expanding international space capabilities

- **Human exploration/Science missions;**
  - Use same exploration approach for both Moon & Mars
  - Mars is big and multiple sites are of interest while missions are 2 years apart
  - Need an approach that samples multiple sites each mission
  - Approach must provide global access to Mars/Moon surface
  - Use robots to augment effectiveness of human explorers
- **ISRU missions;**
  - Mars LOX/CH4 or LOX/H2 ISRU propellant plant will be pre-deployed and verified prior to human missions
  - Need to deploy lunar ISRU robotically as test of approach required for Mars

Additional Derived Requirements

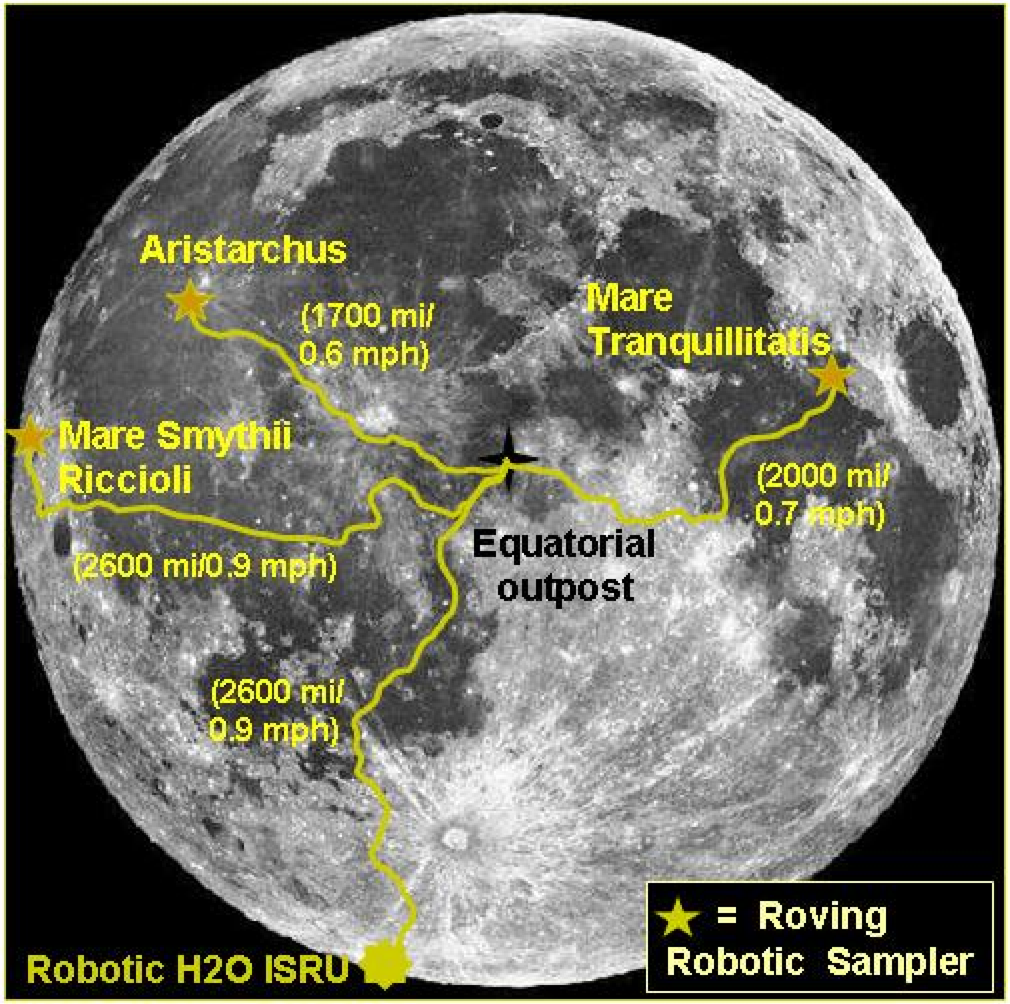
- Safety/Reliability
  - ✓ ***Ensure safe havens/abort modes exist** during all phases of human exploration*
    - *Need to provide a safe haven in case of solar flares*
  - ✓ ***Provide abort options that are not dependent on return to Earth***
    - *Abort to Earth is not an option for Mars missions*
    - *Abort to Earth is an option for Lunar missions but requires > 3-5 days*
- Affordability
  - – ***Utilize CAIV-driven approach to match scope, schedule, and risk to available budget and budget profile***
  - – ***Minimize initial investments** required for first missions*
  - ✓ ***Avoid throwaway elements** in the surface infrastructure wherever possible*
  - – ***Address total life cycle** by significantly reducing operations costs*
- Effectiveness
  - ✓ ***Minimize the number of missions** required to sample all areas of interest on Moon/Mars*
  - – ***Design Moon missions to test all relevant aspects of Mars mission***
  - ✓ ***Use Moon ISRU missions to develop ISRU technology expertise and experience base** and to demonstrate feasibility of "living off the land"*

Additional Derived Requirements

- Sustainability
  - *<u>Avoid simply repeating Apollo</u>*
  - ✓ *Plan architectural elements that <u>involve the public</u> in the lunar exploration*
- Extensibility/Evolvability
  - *<u>Provide open solutions to accommodate certain changes</u>*
  - ✓ *<u>Design for incremental extensions/improvements</u>*
  - *Allow for <u>reusable space elements in later stages</u> of architecture evolution*
- Development Risk/Schedule Realism
  - ✓ *<u>Minimize the up-front technology development</u> needed before the first lunar missions*
  - *<u>Leverage spiral developments</u> to provide early answers to key questions prior to taking next steps*
  - *<u>Invest in innovative, beneficial technologies</u>*

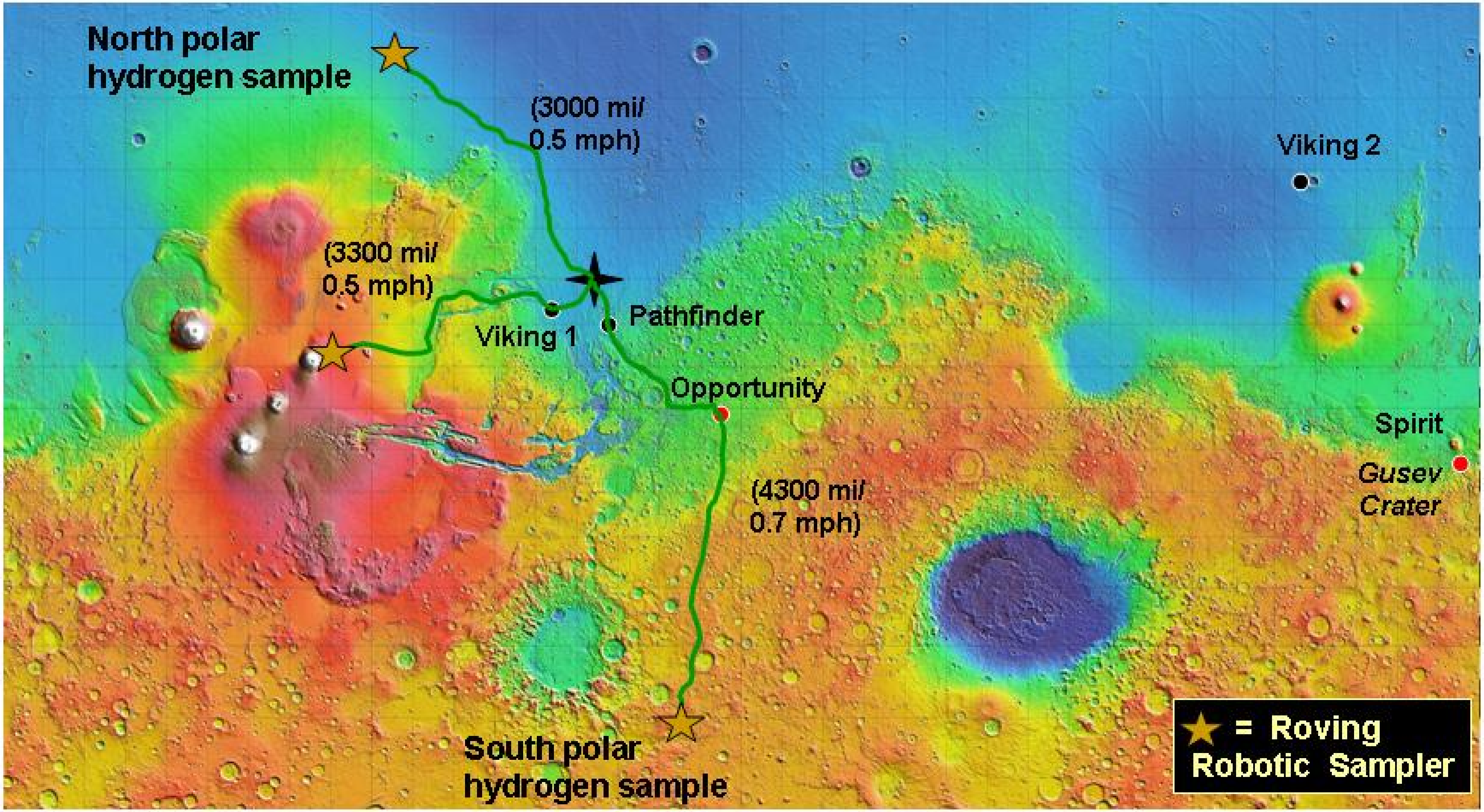
Integrated Robotic/Human Exploration Approach

- Multiple roving robotic samplers;
  - Pre-deployed 1-2 years before human mission
  - Autonomous navigation/ Teleoperated from Earth
  - Average speed < 1 mph
  - Collect samples along route to equatorial outpost
  - Samples waiting for astronauts on arrival
- Human surface infrastructure pre-deployed robotically before human mission
- Humans explore outpost site and examine samples from many sites selecting best to return to Earth
- Robotic ISRU exploration at South Pole as test of Mars approach with samples delivered to fixed base



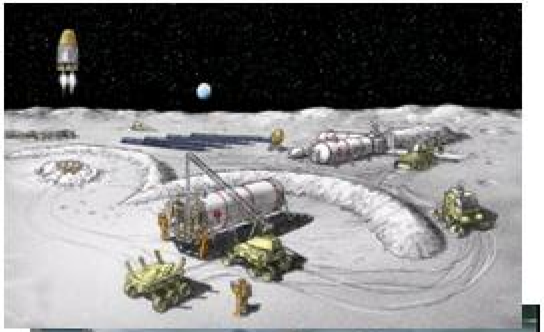
More science accomplished in first mission than in all of Apollo

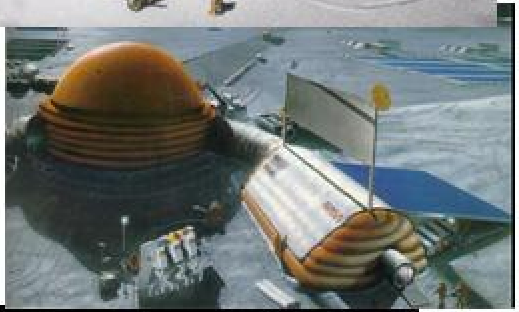
Integrated Robotic/Human Exploration Approach - Mars Mission Example



First mission examines samples from both poles, from three previous visited sites, and from highlands and "riverbeds"

Fixed Equatorial Lunar Outpost

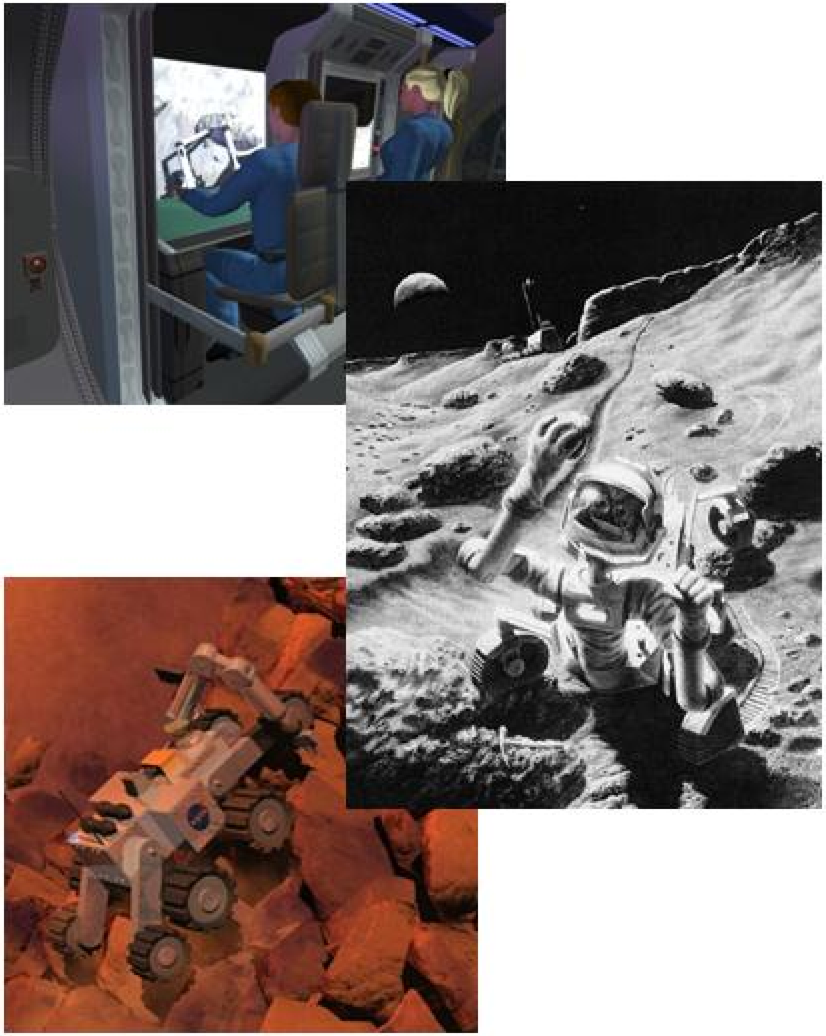




- Fixed near-equatorial site allows;
  - More mass to be landed relative to polar site (going through L1) for given ETO launch capability
  - Incremental expansion of capabilities with each mission
  - More capable science laboratories and sample warehousing
  - Anytime abort to Earth with no additional delta-V
  - Continual connectivity to Earth
  - Effective base location for astronomical investigations (e.g. Mare Smythii)
  - Mare/highland contact for geological exploration
  - Regolith shielded safe haven for solar flare events
  - Safe haven for aborts from higher latitude missions
  - Site for O_2 ISRU testbed and pilot production plant
- Evolves to become effective testbed for all relevant aspects of Mars mission including long duration reliability, operations, maintenance, and logistics

Fixed outpost improves safety and can become basis for long term settlement

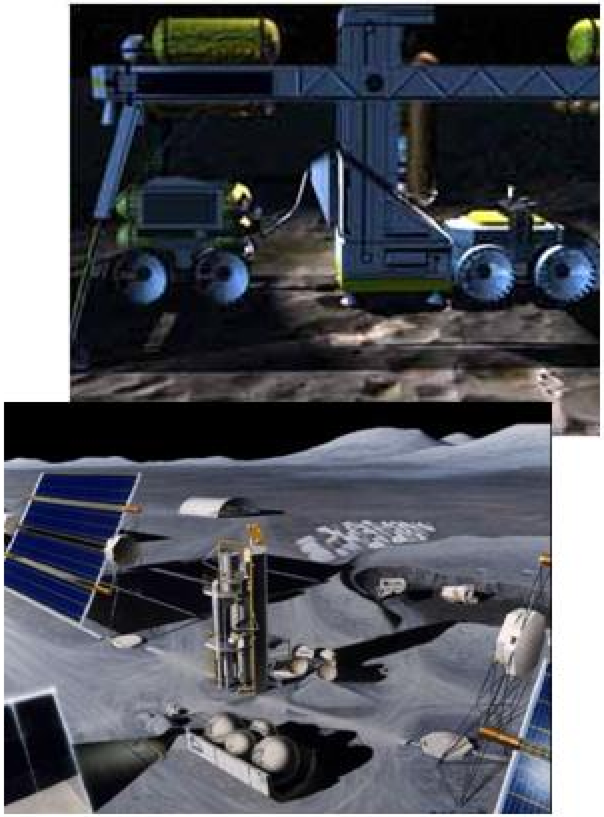
Robotic Precursors Augment Human Missions



- Offer opportunity to get public “involved” prior to human missions
- Critical exploration methods and systems demonstrated prior to human arrival
- Enhances effectiveness and safety of human missions by:
  - Pre-sampling sites enabling informed decision to send humans to best sites
  - Allowing humans to focus on tasks they do best (e.g. laboratory analyses of samples)
  - Reducing time pressures during missions
  - Off-loading repetitive or high-risk tasks
- Astronauts can teleoperate robotic samplers for improved sample collection efficiency and reduced numbers of EVAs
- Minimizes crew size needed for mission

Builds upon success of Spirit and Opportunity MERs

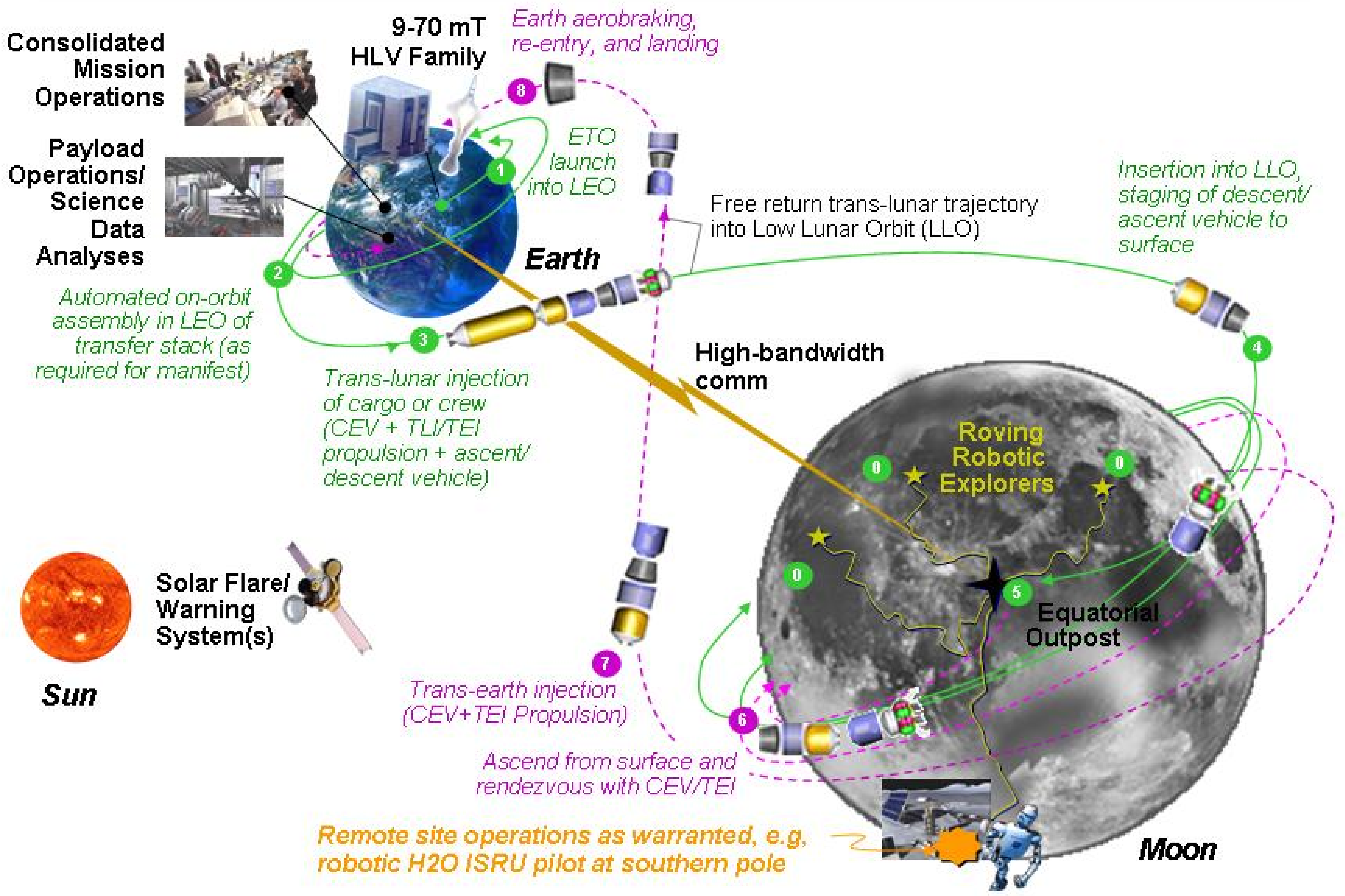
ISRU Missions



- Robotic setup and execution of ISRU missions on Moon in accordance with approach required for Mars missions
  - Initially robotic testbed to sample materials and test extraction approaches
  - Followed by pilot-production scale robotic regolith processor capable of processing its own weight each hour (produces useful quantities of O_2 or H_2O)
  - Full-scale production initiated after verification of pilot-scale production
- Avoids need to establish fixed human outpost in unfavorable location at pole (Moon & Mars)
- O_2 production near fixed equatorial site
- H_2O production at pole (will require storage and transport to fixed site similar to Mars missions)

Common robotic approach makes science and ISRU missions synergistic

POD (2015-2020) Lunar Architecture



Mission Effectiveness

Feature	Benefits
Robotic precursor missions integrated with human missions	• Critical exploration methods and systems demonstrated prior to crew arrival
Predeployed robotics explore surface/collect science samples	• Crew examines samples from many sites each mission • More science accomplished in one mission than all of Apollo • Synergistic science and ISRU investigations
Robotic ISRU emplacement and demonstrations	• Demonstrates abilities for self-sustaining operations • Essential for remote sites where crew is unlikely to be (e.g., Martian ice cap); required prior to crewed missions to Mars • Minimizes labor intensive/risky EVAs
Equatorial fixed outpost enables incremental expansion of capabilities over time	• More capable science laboratories and sample warehousing • Effective base location for astronomical investigations • Mare/highland contact for geological exploration • Continuous high-bandwidth communications
Equatorial fixed outpost test all relevant aspects of Mars mission	• Systems reuse bases for expansion of mission duration • Long duration effects on crew realistically studied • Long duration reliability, operations, maintenance, and logistics considerations developed and demonstrated
Robust human surface transportation including rovers and hoppers	• Affordable global access vs orbital platform/gateway • Provides exploration along the way vs 'touch and go' sites • Supports crew safety/abort/rescue objectives

Safety/Reliability

Feature	Benefits
Fixed equatorial outpost	• Abort to equatorial outpost from high latitude/polar missions avoids 3-5 day trips to Earth • Abort to earth at any time during mission with no additional delta-V required • Single safe haven for solar particle events (deployed once) • Incremental build-up increases reliability through build-a-little/test-a-little • Crew returns to familiar location avoiding initial 'burn in' time for each mission • Continuous communications without need for Orbiter
Extensive use of intelligent systems/robotics	• Enables minimum crew size missions • Reduces high-risk EVA requirements • Robots off-load requirements for repetitive or high-risk tasks letting crew focus on what they are best at • Predeployed robotics reduce time pressures during missions • Enables 'man-tended' mode of operational concept where exploration continues with or without crew on the surface
Human-rated design across architecture consistent with 8075.2	• Abort/safe haven during all mission phases • Two-failure tolerant solutions
Free return trajectory	• Consistent with near-equatorial outpost location • Provides safe abort in event of LOI engine failure

Affordability

Feature	Benefits
Fixed equatorial outpost	• No throw away systems (each system deployed once) • More capabilities built up faster then alternate mobile or orbital basing • More usable mass delivered to lunar surface per mission
Extensive use of intelligent systems/robotics	• Maximizes science return for given investment • Minimizes expensive crew systems and operations • Reduces overall cost impact of human rating requirements
Capable of deploying with a family of launch vehicles	• Applies human rating requirements to minimum systems • Optimizes manifest to required cargo • Leverages advantages of HLV developments if available but delays need for heaviest systems until Mars
Modernized operations and support processes	• Reduced standing armies • Synergistic with ISRU and closed resource strategies • Integrated maintenance and logistics strategies optimize deployment/resupply costs
Spiral development at lunar architecture level	• Answers key questions relating to future ISRU and mission models prior to making significant, long-term investments in permanent lunar base/systems • Defers (while not precluding) propellant stage reusability until mission model and ISRU propellant production warrants necessary investments • Defers need for on-orbit telecommunication and navigation systems to future consistent with decision to stay or not

Sustainability

Feature	Benefits
Integrated robotic/human exploration starting in 2008	• Robotics and human programs focused on single goal • Robotics visit more sights and fill gaps in between crewed missions • Near continuous science/engineering test returns; 50% of objectives accomplished prior to arrival of crew in 2015
Exploration strategy goes beyond simply repeating Apollo	• Science objectives drive human-robotic collaboration on a new level • Extended stays and incremental build up at fixed Outpost ensures continual new results (vs repeating same things at multiple sights) • Overall greater breadth and depth of lunar science • Expansion of scope to exploration testbed and ISRU investigations that are key to Mars and Beyond
Teleoperated robotic samplers	• Extensive educational opportunities for continuous mission operations and data analyses
No dependence on large in-space infrastructure	• Avoids perceptions that this is Shuttle or ISS all over again • Mission returns begin immediately without need for extended deployment timeframes • Systems/technologies developed/deployed in manageable-sized pieces that more readily accommodate programmatic changes
Significant technology insertion opportunities	• Opportunities to leverage international and academia capabilities • ISRU demonstrations enable commercial development of more-permanent lunar-based manufacturing, propellant production, tourism, and settlement as part of future architecture spirals

Extensibility/Evolvability/Flexibility

Feature	Benefits
Lunar solutions designed with Mars application in mind	• Common exploration strategies • Common design and interface standards • Modular systems, subsystems, and components reduce life cycle cost • Common science and ISRU systems to greatest extent possible given environment differences • Reduces risk and non-recurring cost of Mars exploration
Open design solutions	• Enables changes in design, technology, and programmatics with minimal risk, cost, and schedule impacts • Solutions readily reconfigured for various missions • Systems that accommodate the range of potential launch vehicles • Solutions supports contingency in-space operations/maintenance • Proven solutions may be reused in future spirals or alternative campaigns
Incremental mission deployment model	• Architecture systems 'right sized' to provide flexibility to change funding profiles/schedules • Mission sequences may be stretched out to fit further constricted funding profile

Summary

- Integrated robotic/human exploration approach:
  - Efficiently satisfies a balanced set of exploration objectives within defined cost, schedule, and risk constraints
  - Effectively demonstrates exploration approach prior to Mars missions
  - Takes next step (2008-2020) in human exploration with maximum crew safety/effectiveness
  - Provides opportunity to involve larger community to promote public interest and improve sustainability
  - Contains no "throwaway" surface elements, can be incrementally improved/extended with each mission
- Lunar architecture extensible to a more permanent lunar presence based on the same concepts or one of several more ambitious alternatives in the next architecture spiral