Lunar Capabilities Roadmap

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Motivation

A sustained human presence on the Moon offers the most secure and likely path to develop technologies to realize NASA's ultimate goal of human Mars exploration.

- The Lunar Exploration Roadmap (LER) describes the usefulness of a sustainable human presence on the lunar surface, as well as using \textit{lunar} resources to enable Solar System exploration.
  - To reduce launch mass from Earth
  - To develop commercial "on ramps"
- To practically achieve this goal requires a logical build up of capabilities, which will require technological development and advancement.
- LEAG has requested this Strategic Action Team (SAT) with creating a Lunar Capabilities Roadmap (LCR) to ...
Identify the **critical capabilities** needed to prepare humans to go to the Moon.

- Leverage from existing architectural studies and innovative business models.
  - e.g., Recently released Lunar Human Exploration SKG SAT Review
- Leverage from existing national and international technology roadmaps.
- Focus on the development of technology for humans and human precursors.
- Identify the necessary instruments/technologies to enable lunar exploration and science; emphasis on promoting human space exploration.
  - Facilitate design reference mission(s) concept(s) studies.
  - Noting those that enable commercial “on-ramps”.
- Identify technologies that would benefit from collaborative development with SMD, HEOMD, and STMD.
- Focus on capabilities for short-term human presence.
  - Identifying technologies that would also be relevant for long term, sustained human presence.
The LCR will be a strategic and living document.

Focus is on capabilities, with examples of specific technologies to satisfy those needs.

- Does not prescribe a specific architecture, nor does it mandate specific technologies
- Assumptions and instrumentation are intended to be broad and not meant to be prescriptive.

The LCR will be cutting edge, while remaining realistic and feasible

- This SAT appreciates the need to develop a viable strategy for human and robotic interaction on the lunar surface, so of this SAT three are roboticists/AI scientists/engineers from TRAClabs.
Technology SKGs = Needed Capabilities
Theme 3: Understand how to work and live on the Moon

**Hazards**
- Solar wind (plasma)
- Cosmic rays
- Micrometeorites
- Regolith
- Dust
- Vacuum
- 1/6 g
- Variable thermal regime

**SKGs/Capabilities**
A. Resource production
B. Geodetic grid & navigation
C. Surface trafficability
D. Dust and Blast Ejecta
E. Plasma environment and charging
F. Energy production and storage
G. Radiation shielding
H. Micrometeorite shielding
I. Lunar mass contribution and distribution
J. Habitat, life support and mobility

**Locations**
- Topography
- PSRs
- Lava tubes
- Magnetic anomalies
Keeping Lava Tubes Cool

Lava tubes are excellent protection from radiation and micrometeorites.

- But heat rejection is difficult because the wall of the tube retain heat.
- Must pump heat-transfer fluid to a radiator outside the lava tube.

What If? 2010 Winner
“Resilience Lunar Base Proposal”
Elizabeth Mittmann, 8th Grade
Jordan Middle School, Palo Alto, CA
http://www.whatifprize.org/entry_2010_8th_grade.php
Variable Autonomy

Some assets (rivers, robots, equipment) will be:

- on their own part of the time,
- operated from Earth part of the time,
- remotely operated by astronauts in orbit or in a habitat part of the time, and
- operated by an astronaut with the human anatomy (hands) part of the time.

These machines have to:

- work under all (or most) environmental conditions,
- be able to switch from one regime to another easily, and
- be able to utilize tools developed for human anatomy.

➢ Also, habitats may be vacant some times and occupied at other times.
➢ They need to be able to transition between those two states easily and turning a life support system on and off is not trivial!
Water, water everywhere ...

Temporal variations in the abundance of H/OH over the lunar diurnal cycle.  
– process driven by solar radiation  
– is only a surface phenomenon

**Sunrise**: H/OH begins to photodissociate with increasing solar irradiation  
**Noon**: Maximum loss of H/OH (especially at equator)  
**Afternoon**: H/OH abundance begins to resorb  
**Sunset**: Maximum hydration/steady state.
Water, water everywhere ...
Time Phasing

Phase 0: Technology risk reduction through low cost (Class D or lower) missions

Phase 1: Robotic precursors; human landing ($\leq 1$ lunar day)

Phase 2: Robotic and human missions for initial outpost construction (stays of 1 lunar day and including part of the lunar night)

Phase 3: Outpost established, human and robotic missions for stays of $>30$ days
Prioritization

- Would be good to do, but not essential for habitat/exploration development
- Would only give an incremental advance to our scientific knowledge
- Could be conducted more efficiently elsewhere

Low:

- Could be enabled with sufficient infrastructure investment

Medium:

- Is essential in order to make progress in habitat/exploration development
- Would facilitate a fundamental advance in our scientific knowledge
- Is best done on the lunar surface

High:
Applicability to Mars and other destinations

- Sample return (including acquisition, return, receiving, and curation)
  - Cryogenic Sample Return - more technologically challenging than returning rocks/regolith/dust (including acquisition, return, receiving, and curation): Mars, Moon, Comets
  - Planetary protection to be considered now in development of these instruments and mission concepts
- Geophysical instrumentation and deployment: Moon, Asteroids, Mars, Venus,
  - Outer Planets (Ocean Worlds)
- In situ resource utilization: Moon, Mars, Asteroids
- Radionuclear Power Systems - all destinations
- Improve Communication Systems - all destinations
- Continued development of cubesat technology and deployment: all destinations
LCR SAT Milestones

August 2016
Assemble SAT

November 2016
Finalize outline

February 2017
Submit first draft

April 2017
Submit revised draft

June/July 2017
Final draft
The LCR SAT wants you

Any and all suggestions and input from the community are eagerly requested.

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But don't delay, the new year is on the way