International Lunar Polar Volatiles Strategy

Addressing Science and Exploration Knowledge Gaps

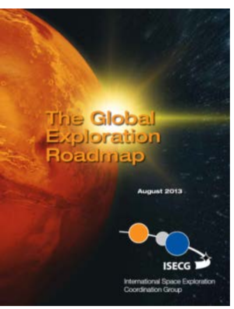
Proposal to the International Space Exploration Coordination Group (ISECG)

LEAG Annual Meeting
Laurel, Maryland
22 October 2014

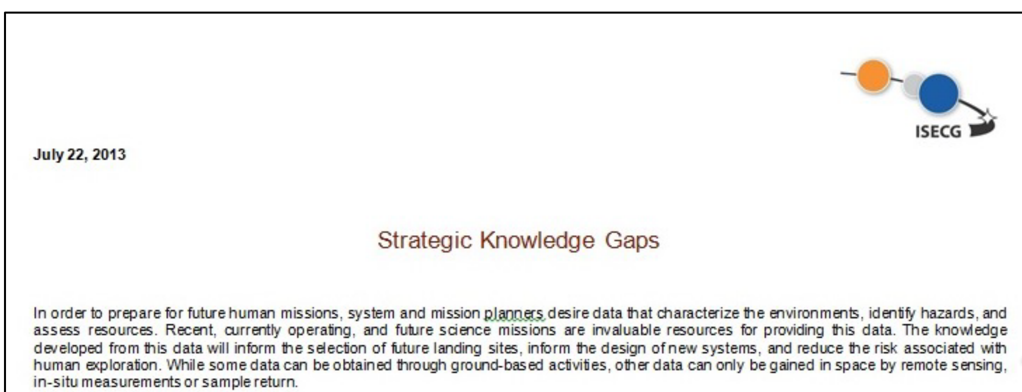
Background

- **Formed small team of ISECG participating agency representatives to develop a proposal for an international strategy to assess lunar polar volatiles and make recommendations**
  - CSA (Vicky Hipkin, Martin Picard)
  - DLR (Norbert Henn, Oliver Angerer)
  - ESA (Bernhard Hufenbach, James Carpenter)
  - JAXA (Naoki Sato, Takeshi Hoshino)
  - NASA (Nantel Suzuki, John Gruener)
  - Roscosmos (Georgy Karabadzhak)
- **Key Lunar Volatiles Challenges and Questions are traceable to ISECG Common Exploration Goals/Objectives and Strategic Knowledge Gaps (SKGs)**

Global Exploration Roadmap



Common Goals	Objectives
Perform Science to Enable Human Exploration	Characterize available resources at exploration destinations (e.g. Moon, asteroids, Mars)
Develop Exploration Technologies &Capabilities	Develop and validate tools, technologies, and systems that extract, process, and utilize resources to enable exploration missions.


ISECG

July 22, 2013

Strategic Knowledge Gaps

In order to prepare for future human missions, system and mission planners desire data that characterize the environments, identify hazards, and assess resources. Recent, currently operating, and future science missions are invaluable resources for providing this data. The knowledge developed from this data will inform the selection of future landing sites, inform the design of new systems, and reduce the risk associated with human exploration. While some data can be obtained through ground-based activities, other data can only be gained in space by remote sensing, in-situ measurements or sample return.

Lunar Cold Trap Volatiles:
Composition/ quantity/ distribution/ form of water/ H species and other volatiles associated with lunar cold traps.

Background

- **Many agencies are planning Lunar missions and related spacecraft/payloads**
- **Coordination can maximize value of existing agency plans and create new opportunities**
  - **CNSA**
    -- Chang'e 4; Chang'e 5; Chang'e 6
  - **CSA**
    -- Rover (in formulation)
  - **ESA**
    -- Lunar South Pole Mission (put on hold at the 2012 ESA Ministerial Council)
  - **ISRO**
    -- Chandrayaan-2
  - **JAXA**
    -- Lander (in formulation)
  - **KARI**
    -- Lunar Orbiter Pathfinder; Lunar Orbiter; Lunar Lander
  - **NASA**
    -- Resource Prospector (rover & payload for polar lander); Lunar Flashlight (cubesat mission); Space Launch System, Orion (can support lunar surface missions from cis-lunar space); Deep Space Habitat (with partners)
  - **Roscosmos and ESA**
    -- Luna 25 (polar lander); Luna 26 (orbiter); Luna 27 (polar lander)

Goal

Establish an internationally-coordinated effort to address exploration and scientific knowledge gaps related to lunar water ice and other polar volatiles.

Developing the International Strategy

Objectives

- Leverage space agency and private sector interest in lunar polar volatiles to advance the overall state of knowledge
    - Seek answers regarding the quantity, distribution and form of volatiles and address the "Lunar Cold Trap Volatiles" Strategic Knowledge Gap, as detailed in the Global Exploration Roadmap
    - Identify initial, affordable small-scale ISRU demonstrations and experiments to understand whether water ice could be economically extracted and utilized as a resource, in a fashion consistent with maintaining the scientific value of polar volatile deposits
    - Pursue science questions regarding the delivery, transport, accretion, and composition of lunar polar volatiles
- Stimulate collaboration and coordination of relevant capability development and lunar mission planning
- Identify the means of exploiting lunar polar volatiles as a resource for further scientific exploration and discovery

Benefits of Investigating Lunar Polar Volatiles

- Use of lunar volatiles for propellant and life support will improve the sustainability of human space exploration
- Technologies and methods for accessing lunar volatiles are relevant to potential future Mars resource utilization
- Ground truth measurements on the lunar surface will improve our understanding of lunar polar volatiles, increasing the scientific knowledge on the bombardment history of comets and asteroids in the inner solar system, the evolution of planetary bodies in the inner solar system, and the Sun's output over time
- Affordable, small-scale ISRU demonstrations will show the feasibility of ISRU
- The public, governments, and the exploration community may be inspired and provide support for using the moon as a testbed and proving ground for the exploration of Mars

Developing the International Strategy (cont'd)

- **Scope**

  Assumptions

  - Include missions and activities over the next ~10 years, using primarily robotic systems, but also available human-deployed assets in cis-lunar space
  - Assume realistic budget projections and technology advancements in describing what would be required, programmatically, to implement the strategy

  Activities

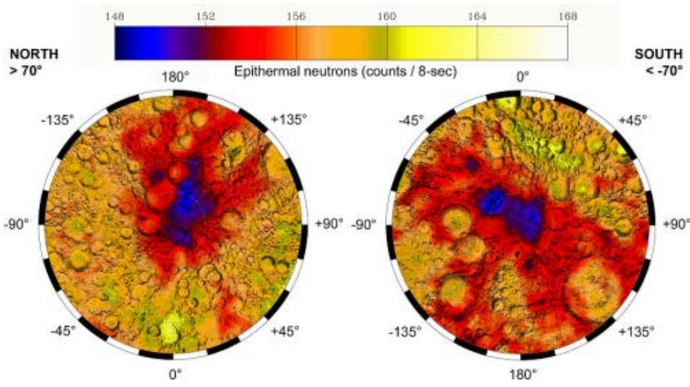
  - Confirm a common understanding of the current state or knowledge and the questions to be answered regarding lunar polar volatiles
  - Identify common lunar regions of potential interest for investigation, and the means to coordinate landing site selection
  - Identify approaches to lower the cost of lunar missions and potentially enable new missions (i.e. lower entrance barriers for organizations that wish to explore the moon)
  - Identify areas where standards could be applied, and the benefits of doing so
  - Evaluate whether there are valuable common approaches and technologies to prospecting measurements and investigations, and to coordinating common instrumentation, measurements, methodologies and analysis, so to ensure a common interpretation and maximum science return

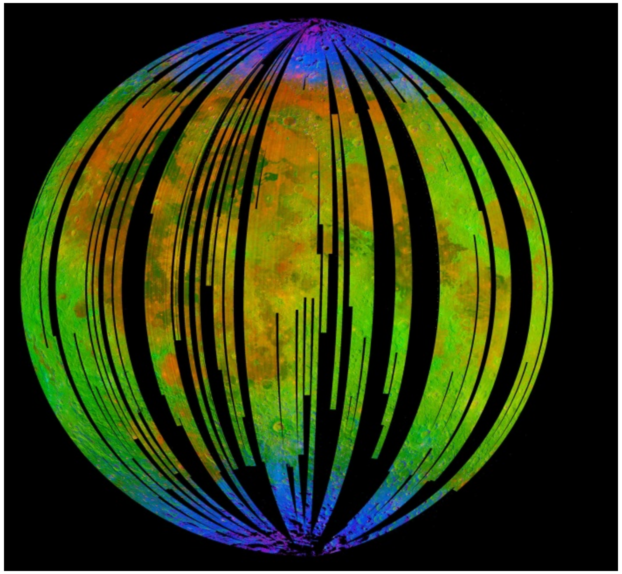
- **Expected Outcomes and Measures of Success**

  - Coordination of lunar volatile prospecting/ISRU-related capability development and missions among space agencies and private entities
  - GER "Lunar Cold Trap Volatiles" Strategic Knowledge Gaps are addressed, resulting in scientific gain
  - Nature and usability of polar volatiles well-characterized in a common region of interest
  - New missions are enabled

Which Lunar Volatiles should the strategy address?

- **Begin by finding polar water ice**
  - Data from Lunar Crater Observation and Sensing Satellite (LCROSS) indicates water is the most abundant compound in lunar south pole crater Cabeus
  - Water ice is likely easier to detect than other ices because of its higher abundance, and possibly exists co-mingled with other ices
  - Water ice has many potential uses and implications for human spaceflight (e.g., rocket propellants, life support, electricity generation)
- **Continue investigating other polar volatiles for scientific purposes**
  - LCROSS data include many other volatile species exist in Cabeus (i.e., H_2S, NH_3, SO_2, C_2H_4, CO_2, CH_3,OH, CH_4, OH) – origin?
  - Data from Chandrayaan-1, Deep Impact, and Cassini missions indicates surface-bound hydroxyl and/or water
  - Hydrocarbons and sulfur-containing volatiles may have potential uses for longer-term lunar surface operations
- **Do not focus on 'classical' volatile elements associated with geochemical-aspects of the Moon's origin and evolution**
  - "Vapor-mobilized elements", those that tend to be transferred from solid materials into a coexisting vapor phase at relatively moderate temperatures, (e.g., Cu, Zn, As, Se, Ag, Cd, In, etc.)
  - Volatile coatings on particle/mineral grains due to volcanism or micro-meteorite impacts (e.g. S, nano-phase Fe)





Elements of the Strategy

Core Elements:

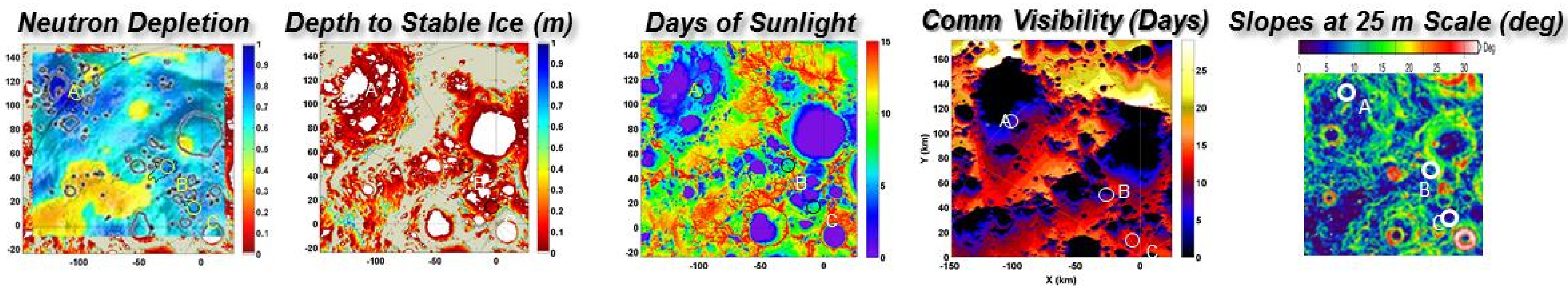
- Common Lunar Regions of Interest
- Low-Cost Lunar Architectural Approaches
- Standards for Interoperability

Possible additional elements:

- Robotic Systems for Lunar Volatiles Missions
- Lunar Volatiles Legal Framework

Common Lunar Regions of Interest

Global Data Provided by Orbital Instruments



Core Element to Coordinated Lunar Polar Volatiles Strategy

- Build consensus among broad community for common "Regions" on the lunar surface to be collectively explored by a variety of sequential, coordinated missions. "Regions" are larger than a lunar site for a single mission, perhaps including distances up to a few 10s of km

Desirable Attributes

- Access to surface and/or subsurface enhanced hydrogen deposits as measured from lunar orbit
- Access to sites of high solar illumination
- Access to permanently shadowed regions (PSRs) and/or partially sunlit areas
- Reasonable terrain for multiple landing locations
- Reasonable terrain for conducting traverses (i.e., low slope angles, low boulder count)
- Direct view of Earth for communications

Possible Coordination Activities

- Prospecting and mapping of volatile deposits over a larger area in same region
- Communication/navigation relay between multiple landed systems (may require line-of-sight)
- Missions of opportunity for individual science instruments/sensors, or excavation systems

Common Lunar Regions of Interest (cont'd)

- **Issue: Whether volatiles strategy should focus on one region, or several regions**
  - Possible reservations from scientific community. A science goal may be to understand extent and variability, hence going to very different regions may be desired as a science strategy
  - Measurements made at a single location may not represent the broader distribution in the polar region, or may be insufficient to answer questions relating to prospecting polar volatiles
  - Should strategy first acquire comparable surface measurements from different locations?
- **Current Activities**
  - NASA – Lunar Exploration and Analysis Group (LEAG) study to recommend polar locations (report in Dec 2014); Resource Prospector (RP) landing site analyses
- **Proposed Activities over next 1 year/ 5 years**
  - Share data and analysis to help identify candidate regions of interest
  - Apply results to exploration and science missions by engaging mission managers/stakeholders
- **Agency experts for detailed analyses**
  - TBD

Low-cost Lunar Architectural Approaches

Core Element of International Strategy

Facilitate broad participation by space agencies, commercial entities, and universities by enabling simpler, lower-cost missions

- Deployment of common infrastructure
  - -- Surface utility services supporting rovers within a common region (i.e., power generation, thermal protection, communication relays)
  - -- Orbiting communication relays (including nanosats)
  - -- Navigation beacons
- Multi-purpose systems
  - -- Use of an orbiter as a comm relay after science/mapping lifetime
  - -- Lunar Secondary payload / ride-sharing opportunities

Current Activities

- NASA – Glenn Research Center study of robotic lunar exploration scenario with surface utility stations and low-cost rovers

Proposed Activities over next 1 year/ 5 years

- Architecture definition: develop common mission scenarios & operations concepts , and identify opportunities for mission collaboration/coordination

Agency experts for detailed analyses

- TBD

Standards for Interoperability

Core Element of International Strategy

- Standard interfaces (mechanical, electrical, communication) and standard propellants to optimize use of surface utility services, permit interchangeability of vehicle payload complements, and maximize interoperability

Current Activities

- ISECG International System Maturation Teams (I-SMTs)

Proposed Activities over next 1 year/ 5 years

- TBD

Agency experts for detailed analyses

- TBD

Lunar Volatiles Workflow – Overview of Proposed 1-year Effort

- **Phase 1:**
  - Confirm common understanding and relevance of Strategic Knowledge Gaps (SKGs) to lunar polar volatiles and frame SKGs as basic questions that need to be answered.
    - Notional references: ISECG SKG Report (July 22 2013); Lunar Exploration Analysis Group (LEAG) SKG-SAT (Mar 2012)
- **Phase 2:**
  - Engage mission owners and system/science instrument developers to answer basic SKG-related questions about currently-planned missions.
    - Mission questions: e.g., landing site?; static or mobile?; instruments & measurements?; ISRU demos?
    - System/Instrument questions: e.g., lander payload capability; rover size and traverse capability; instrument size and measurement capability; mechanical, communication et al. interfaces
- **Phase 3:**
  - Gap analysis - Assess whether/how planned missions will address SKGs, and determine which SKGs are not being addressed.
- **Phase 4:**
  - Engaging space agency and private experts to develop and implement core elements of the lunar volatiles strategy
    - Common regions of interest; low-cost architectural approaches; standards for interoperability
    - ISECG System Maturation teams (I-SMTs): e.g., ISRU; Comm/Nav; Human-Robot Mission Operations
    - External Communities/Stakeholders: Lunar Exploration Analysis Group (LEAG); ; Lunar and Planetary Science Conference (LPSC); Space Resources Roundtable (SRR); Planetary & Terrestrial Mining Sciences Symposium (PTMSS); ISECG-sponsored workshops
- **October 2015 - Report back to full ISECG**

Possible legal issues with finding/using lunar volatiles

- Legal and policy concerns may or may not be an issue, with respect to data collected and potential future exploration and use, depending on a variety of circumstances
- There is an international legal framework (1967 Outer Space Treaty) binding on most nations, including all ISECG members' governments
- National laws, regulations, and policies are also important
- As the need arises, future arrangements may include: bilateral and multilateral government arrangements; government to private sector arrangements; and/or private sector to private sector contracts
- It is not productive to try to develop a legal regime before its time

The Lunar Polar Regions Today