Lunar Exploration Analysis Group - International Space Exploration Coordination Group Volatiles Special Action Team 2

LEAG-ISECG V-SAT-2

Gilruth Center

NASA Lyndon B. Johnson Space Center, Houston, Texas

14-16 August 2017

LEAG-ISECG V-SAT-2

Dana Hurley (co-chair)	Johns Hopkins University Applied Physics Lab, USA
Sam Lawrence (co-chair)	NASA Johnson Space Center, USA
Simeon Barber	Open University, United Kingdom
Wenzhe Fa	Peking University, China
Leslie Gertsch	Missouri University of Science & Technology, USA
John Gruener	NASA Johnson Space Center, USA
Ralf Jaumann	DLR, Germany
Myriam Lemelin	York University, Canada
Clive Neal	University of Notre Dame, USA
Jerry Sanders	NASA Johnson Space Center, USA
Menelaos Sarantos	NASA Goddard Space Flight Center, USA

LEAG-ISECG V-SAT-2 Observers/Ex Officio

James Carpenter	European Space Agency
Sungchul Hong	KICT, Korea
Hyu Shin	KICT, Korea
Gwanghyeok Ju	KARI, Korea
Kyeong Ja Kim	KIGAM, Korea
Markus Landgraf	European Space Agency
Sarah Noble	NASA SMD, Planetary Science Division
Makiko Ohtake	JAXA, Japan
Victoria Friedensen	NASA HEOMD
Nantel Suzuki	NASA HEOMD, Advanced Exploration Systems

Specific Action Team (SAT) on Lunar Polar Volatiles Charter

- The LEAG SAT will bring together an international team of experts and those nominated by ISECG space agencies to review the different lunar mission plans that have been identified by ISECG.
- The Mission Coordination Dialogue (MCD) team, created by ISECG, will provide a detailed set of mission goals and parameters that are candidates for review and are potentially open to adjustment.
- After reviewing the designated mission goals and parameters, the LEAG SAT will participate in a discussion and/or workshop with the MCD team within ISECG, which will provide input on the lunar mission plans under development.
- This input should focus on options for these missions to answer science and exploration questions related to the resource potential of lunar polar volatiles.

Specific Action Team (SAT) on Lunar Polar Volatiles Charter

The LEAG SAT could provide input or suggestions related to:

- Landing sites.
- Orbital plans.
- Payload complement or instrumentation.
- Measurement objectives.
- Communications architectures.
- Sample return or analysis efforts.
- Instrumentation calibration and/or validation.
- Data sharing and the potential for joint or multilateral science investigator teams.

Specific Action Team (SAT) on Lunar Polar Volatiles Charter

- The LEAG SAT will build upon the results of the LEAG Volatile Specific Action Team report of 2014 and the subsequent European response to the study and reference the lunar NASA and ISECG Strategic Knowledge Gaps as guidance in their review.
- The LEAG SAT should constrain its review and input to the mission parameters defined by ISECG space agencies.
- While individual space agencies and lunar project managers ultimately will necessarily focus mission plans and resources to meet space agency objectives, this review will provide suggestions and insight that may assist these leaders in the space community with strategic, tactical, and coordinated lunar mission planning.

V-SAT-2 Agenda

Monday 14 August 2017

08:30	Welcome and Introduction	Neal & Suzuki
08:45	Structure of the Agenda	Hurley & Lawrence
09:00	Overview of Missions under consideration and ISECG Volatiles Working Group	Gruener
09:15	Overview of V-SAT-1	Lemelin
09:15	European Response to V-SAT-1	Carpenter
09:30	Lunar SKGs related to Polar Volatiles	Lawrence

Mission Details:

09:45	HLEPP Discussion	Carpenter/Landgraf
10:15	BREAK	
10:30	JAXA	Ohtake
11:00	Noon -13:30	LUNCH

V-SAT-2 Agenda

Monday 14 August 2017

13:30	Resource Prospector	Friedensen
14:00	Chinese missions	Shin/ Fa
14:30	Russian missions	TBD

Integration of Information:

15:00	BREAK	
15:15	ISECG Polar Volatiles Goals	All – ISECG members
15:30	Discussion – V-SAT-2 Charter and Product	All – Neal to lead
16:00	Measurement Objectives discussion	All – Gruener to lead
16:45	Orbital plans discussion	All – to lead
17:30	ADJOURN	

V-SAT-2 Agenda

Tuesday 15 August 2017

Integration of Information (continued):

08:30	Recap of Day 1 - Discussion	Hurley & Lawrence
08:45	Mission Instrumentation (inc. Calibration)	All – Barber to lead
09:30	Orbital plans discussion3	All
10:15	BREAK	
10:30	Landing Sites	All – Lawrence to lead
11:15	Sample Return, handling, analysis	All – Neal to lead
Noon -13:30	LUNCH	

V-SAT-2 Agenda

Tuesday 15 August 2017

14:00	Orbital plans discussion	All
14:30	Landing Sites	All – Lawrence to lead
15:00	Sample Return, handling, analysis	All – Neal to lead
15:30	BREAK	
15:45	Joint and Multilateral Investigations	All – Hurley to lead
16:15	Data sharing	All – Hurley & Lawrence to lead
16:45	General Discussion of Findings	
	Writing Assignments	All – Hurley & Lawrence to lead
17:15	ADJOURN	

Wednesday 16 August 2017

09:00	Review of findings - discussion	Hurley & Lawrence to lead
Noon	ADJOURN	

Focusing Questions for V-SAT-2

The missions we will consider potentially form the Prospecting Stage for ISRU at the poles and the three-stage LEAG Implementation Plan (Prospecting, Mining and Pilot Production, Full Production).

Assuming the next stage after these missions is Pilot ISRU Production Plant, we will need to consider the following:

Can the resources at lunar poles support such an ISRU Pilot Plant that could in turn be scaled up to support human exploration?

Therefore:

- What are the knowledge gaps that prevent a decision being taken now?
- What would be an ideal strategy to address these specific gaps using robotic precursor missions?
- How can the proposed missions from the international partners best be applied to approximate this strategy?
- After doing this what would still be missing?

Missions Under Consideration

	2017		2019		2021		2023		2025		2027		2029
CNSA	Chang'E-5* (Nearside, Sample Return)	Chang'E-4 (Farside, +rover)			Chang'E-P1 South Pole		Chang'E-6 (TBD South Pole, Sample Return)		Chang'E-P2 South Pole				
CSA ASC									Participation w/HLEPP				
esa					Participation w/Luna 27				Participation w/HLEPP				
इसरो isro		Chandrayaan 2 Chandrayaan 2 (Nearside, +rover)											
JAXA				SLIM		SELENE-R (TBD)			Participation w/HLEPP				
KARI				KPLO									
NASA		Lunar Flashlight Lunar Ice Cube LunaH-Map Skyfire (flyby)				Resource Prospector (+rover)							
ROSCOSMOS			Luna 25 Glob (nearside)	Luna 26 Ressurs-1	Luna 27 Ressurs-1 South Pole			Luna 28 Grunt (Sample Return) South Pole					

= Orbiting Missions

= Non-polar Landed Missions, (≤ 85° lat)

= Polar Landed Missions, (> 85° lat)

* Chang'E-5 will likely be delayed

V-SAT-2 Findings Summary

Finding #1 – V-SAT-1 Report: The V-SAT-2 endorses the findings from the V-SAT-1 and the European Response to the V-SAT-1 report.

Finding #2 - Orbital Data: Neutron measurements to ≤5 km/pixel; Contemporaneous orbital data supports interpretation of landed mission data.

Finding #3 – the KPLO mission: The V-SAT-2 endorses the Korean KPLO mission as it will add important new data to our understanding of polar volatiles.

Finding #4 Mission Coordination Dialogue: The ongoing ISECG Mission Coordination Dialogue (MCD) has great value and should continue.

Finding #5 – Mission Distribution: The set of missions specified for consideration by the V-SAT-2 should visit multiple sites.

Finding #6 – Communication Relay Satellite: Enabling for farside polar missions, enhancing for polar missions in line-of-sight of Earth, and a potential commercial on ramp.

Finding #7 – Coordinated Resource Prospecting: Prospecting for lunar polar volatiles should be executed as a coordinated two-phase approach: (1) a preliminary characterization followed by (2) a comprehensive characterization.

Finding #8 – Phase 2 Missions: A variety of architectures should be considered for Phase 2 to explore large (several km scale) PSRs.

Finding #9 – Essential Measurements to evaluate a site for ISRU development potential.

Finding #10 - Complementary Measurements to evaluate a site for ISRU development potential.

V-SAT-2 Findings Summary (continued)

Finding #11 - Technology Development. Technology development is required to enable rover systems with the capability to enter, survive, and operate for extended periods in PSRs for Phase 2 missions.

Finding #12 – Data Sharing 1: Data from missions should be made available and accessible to the international community and archived in a documented format.

Finding #13 – Data Sharing 2: Sharing data from missions enables comparison of observations at multiple sites and environments.

Finding #14 – Data Sharing 3: Development and application of data fusion techniques can integrate data from multiple landing sites.

Finding #15 – Sample Return and Analysis: Discussions regarding international sample allocations should be initiated at the appropriate time.

Finding #16 – Multilateral Investigation Teams 1: Inclusion of co-investigators or participating scientists from multiple nations enhances the knowledge (science, exploration, and engineering) return from the missions.

Finding #17 – Multilateral Investigation Teams 2: An openness to international payload contribution enables comparable instruments on multiple missions, providing consistent data sets.

Finding #18 – Multilateral Investigation Teams 3: Interactions between the various international polar volatile mission teams would facilitate coordination efforts.

LEAG-ISECG V-SAT-2 Findings

<u>Finding #1 – V-SAT-1 Report</u>: The V-SAT-2 endorses the findings from the V-SAT-1 and the European Response to the V-SAT-1 report, including that both the North and South polar regions of the Moon have potentially significant volatile deposits that should be explored. VSAT-2 notes that Orbital Finding #6 from V-SAT-1 has been addressed.

Background Information:

V-SAT-1 Orbital Finding #6**:** Restarting the LRO bistatic radar capability should be a priority

LEAG-ISECG V-SAT-2 Findings

<u>Finding #2 - Orbital Data</u>:

- Neutron measurements where individual PSRs could be resolved (≤5 km/pixel) were identified as desirable, consistent with V-SAT-1 Orbital Finding #2 (LunaH-map cubesat mission, in principle, could address this finding at least to some degree).
- Contemporaneous orbital data supports interpretation of landed mission data.

Background Information:

- Current neutron data (Lunar Prospector, LEND) have a spatial resolution coarser than the mobility ranges of planned rover missions. Obtaining data at a finer/higher spatial resolution would reduce risks for future rover and landed missions;
- Contemporaneous orbital assets can track environmental changes induced at the landing site by the landed craft;
- Orbital assets can provide context of the evolving environment at the lunar polar regions and to the data provided by any environmental monitoring stations on the surface;
- Orbital data provides context for landed mission data and landed mission data provides ground truth for orbital remote sensing data.
- LunaH-map is a cubesat mission and necessarily involves a higher level of risk.

LEAG-ISECG V-SAT-2 Findings

Finding #3 – the KPLO mission: The V-SAT-2 endorses the Korean KPLO mission as it will add important new data to our understanding of polar volatiles.

Background Information:

- The inclusion of ShadowCam on the KPLO mission will yield important exploration and science information about the interior of PSRs that will be important for surface exploration scenarios.
- ShadowCam will also help in the interpretation of orbital radar data interpretation.

LEAG-ISECG V-SAT-2 Findings

Finding #4 Mission Coordination Dialogue: The ongoing ISECG Mission Coordination Dialogue (MCD) has great value and should continue.

Background Information:

The MCD provided a consolidated list of lunar missions that is

- Relevant for understanding lunar polar volatiles
- Consistent with the Global Exploration Roadmap

Considering the major application case of lunar polar volatiles as an enabler for sustained human lunar exploration, the MCD provides a key interface to globally coordinated human lunar exploration scenarios and thus helps to formulate the objectives for lunar polar volatile missions and research

LEAG-ISECG V-SAT-2 Findings

Finding #5 – Mission Distribution: The set of missions specified for consideration by the V-SAT-2 should visit multiple sites rather than concentrate on one site in order to broadly assess the resource potential of the lunar poles.

Background Information:

- Orbital neutron data are consistent with H deposits extending outside PSRs (e.g., Sanin et al., 2017. Hydrogen distribution in the lunar polar regions. *Icarus* **283**, 20-30);
- Orbital data have been interpreted to suggest a change in polar axis, so not all volatile deposits exist in the extreme PSR environment (e.g., Siegler et al., 2016. Lunar true polar wander inferred from polar hydrogen. *Nature* **531**, 480-484);
- Landed missions at multiple destinations will provide much-needed groundtruth information for existing and planned orbital datasets to enable significant advances in predictive modeling of volatile deposit locations;
- Hypotheses/model-based investigation goals are best tested at multiple locations with multiple data sets:
  - In order to translate the observations into a physical understanding of the processes modulating the distribution and abundance of volatiles, sharing of data between missions diversifies the conditions under which to test the models.

LEAG-ISECG V-SAT-2 Findings

Finding #6 – Communication Relay Satellite: While a communications relay* capability may not be strictly needed for all missions to the lunar poles, they are essential for far side areas.

** This could be a potential commercial opportunity.*

Background Information:

- This capability would be enhancing for polar missions where Earth is low to the horizon or not visible that would ensure that data are transmitted back to Earth and would reduce risk for each mission.
- We note that the proposed orbital Gateway could provide communication relay capabilities for future missions beyond 2025.
- Need to ensure that sufficient data rates can be achieved to support download of measurement data sets and images – emerging laser communications technologies enhance mission capabilities.

LEAG-ISECG V-SAT-2 Findings

Finding #7 – Coordinated Resource Prospecting: Prospecting for lunar polar volatiles should be executed as a coordinated two-phase approach:

- Common and comparable measurements at diverse sites across the region would find the best locations and develop good models for distribution. Preliminary characterization of the deposit and ore grade at several regions of high interest with the missions currently planned[1] within ISECG agencies allows completion of Phase 1.
- Phase 2 requires follow up missions to comprehensively characterize the ore grade and distribution and to enable future development at a narrow set of promising sites, including PSRs identified from orbit or from the surface in Phase 1.

Background Information:
Results from Phase 1 missions will guide Phase 2 mission site selection and implementation. Access to kilometer-scale PSRs in terms of ISRU potential with the current roster of planned Phase 1 missions is not currently contemplated.

LEAG-ISECG V-SAT-2 Findings

<u>Finding #8 – Phase 2 Missions</u>: A variety of architectures should be considered for Phase 2 to explore large PSRs to obtain at least some of the core measurements. For example, such missions could include:

- New L-CROSS-type missions (facilitated by ride-sharing to get to the Moon) to examine the bulk volatile content of a PSR;
- Distributed penetrators within a PSR containing instrumentation to measure volatile species;
- Distributed hard landers (e.g., crushable material to absorb impact) within a PSR to measure volatile species;
- Soft landers and capable rovers (e.g., long-lived for multiple lunar day-night cycles, rover several 10s of km).

LEAG-ISECG V-SAT-2 Findings

Finding #8 Background Information:

- The LCROSS mission gave one point of groundtruth for volatiles with the PSR Cabeus. Similar missions could be used to explore other potential targets for surface explorations, but are not necessary given the wealth of orbital data (V-SAT-1 report - https://www.lpi.usra.edu/leag/reports/vsat_report_123114x.pdf - that shows likeness of other PSRs to Cabeus).
- Penetrator technology has developed to the point were they can be targeted and use mass spectrometers to measure the liberated volatile species at several points within a given PSR.
- Hard landers could be used to explore PSRs in a manner similar to penetrators but shorter-lived is another way to target volatile distribution within a given PSR.
- The most expensive type of Phase 2 mission would be the instrumented rover that could survive the low temperatures within a PSR. The previous three mission architectures are cheaper and more could be flown.
- It is likely that a combination of these different mission architectures could be used for Phase 2 missions.

LEAG-ISECG V-SAT-2 Findings

<u>Finding #9 – Essential Measurements to evaluate a site for ISRU development potential</u>:

***IMPORTANT NOTE: Not all missions need to execute the full complement of core measurements; significant progress can be made by performing a subset of these measurements*.**

Bulk H within at least 1 meter of the surface:

- Multiple Implementation Options:
  - At one location with static lander;
  - Determine lateral distribution with < 10m distribution using mobility systems;
  - Establish ground truth measurement baseline of 100 m to 1 km using longer-lived mobility systems.

Volatile inventory - species present and abundance at the site:

- Resolved over depth to at least 1m - deeper if possible;
- Discrete sampling laterally and associated with bulk hydrogen;
- Determine physical and chemical form of volatile deposit (e.g., adsorbed OH-, water ice, frost)

Geological context where measurements are performed:

- Panoramic/stereo images;
- Close up images;
- Microscopic images;
- Bulk mineralogical information.

Geotechnical and physical properties of the regolith (potentially integrated with drilling, sampling, etc.) that allow an evaluation of trafficability and resource extraction (e.g., particle size distribution, density, permittivity, thermal/electrical conductivity).

LEAG-ISECG V-SAT-2 Findings

Finding #9 – Background Information:

- Mobility is certainly enhancing and potentially enabling so measurements can be made at multiple locations.
- Understanding the Hydrogen composition with the top meter of regolith with give groundtruth to orbital neutron datasets. This could be done with neutron spectrometers on rovers, but direct access to the subsurface is needed to identify the volatiles present. If drilling is used, geotechnical and physical properties of the regolith can be evaluated against depth.
- Understanding the abundance, form, compositions and distribution of volatiles in the upper 1 m of regolith is critical for understanding the resource potential in terms of extraction, purity, and refining options.
- Geologic context is critical for understanding how volatiles are distributed within PSRs, which could lead to better informed prospecting missions that follow.
- Our current understanding of geotechnical and physical properties of regolith are based on measurements at normal temperature, whereas the extremely low temperatures in PSRs could result in very different regolith properties.

LEAG-ISECG V-SAT-2 Findings

Finding #10 - Complementary Measurements to evaluate a site for ISRU development potential (These are measurements that support the understanding of polar volatiles as a resource):

- Exospheric fluxes and changing plasma/electrical environments (monitoring stations):
  - species, fluxes, incident angles, energies, temporal variation on short (~hours to weeks) to long (~year) timescales in different locations.
- Elemental composition of regolith;
- Trace Mineralogy of regolith components, including products and effects of space weathering processes;
- Subsurface structure and stratigraphy;
- Volatile Stable Isotopes to establish origins and emplacement processes (e.g., CHON).

Sample return is not required to address essential and complementary measurements, but could be a mechanism to acquire the information needed to understand polar ISRU potential.

LEAG-ISECG V-SAT-2 Findings

Finding #10 – Background Information:

- The environment in and around PSRs will be very different both in terms of exospheric composition and electrostatic properties (Farrell et al. (2010) J. Geophys Res. 115, E03004, doi:10.1029/2009JE003464). Understanding species, fluxes, incident angles, energies, temporal variation on short (~hours to weeks) to long (~year) timescales in different locations will enhance knowledge of resource extraction and transport
- Elemental composition, mineralogy, and subsurface structure and stratigraphy of the regolith is needed for context and to understand the nature of the volatile deposits.
- Isotopic composition is critical science data, although it complementary to exploration objectives.

LEAG-ISECG V-SAT-2 Findings

Finding #11 - Technology Development. Technology development is required to enable rover systems with the capability to enter, survive, and operate for extended periods in PSRs for Phase 2 missions.

Background Information:

- The SAT notes the importance of power systems and heating unit development to enable longer mission durations in PSRs (e.g., Radioisotope Thermoelectric Generators, power beaming, fuel cells, etc., taking into account technology readiness);
- Continued discussions should be carried out by the MCD to coordinate enabling technology developments.

LEAG-ISECG V-SAT-2 Findings

<u>Finding #12 – Data Sharing 1</u>: Data from missions should be made available and accessible to the international community and archived in a documented format, including calibration information, to facilitate sharing of data between missions and with the greater community.

Background Information:

- PDS-like standards have been applied in many countries already;
- Necessary documentation that goes along with the data should be preserved in English and the native language of the mission (if different);
- Data portals should be designed to promote accessibility through utilization of existing standards (e.g., WMS);
- Assistance from entities with relevant planetary dataset archiving experience should be made available for creating these archives.

LEAG-ISECG V-SAT-2 Findings

Finding #13 – Data Sharing 2: Sharing data from missions enables comparison of observations at multiple sites and environments. To increase the fidelity of the comparison, instrument cross-calibrations should be done using common standard reference materials.

Background Information:

- Use the same standard materials for calibrations when the material is not consumed in the analysis;
- Use reproducible standard derivatives when the material is consumed in the analysis
- Common calibration facilities can aid in this process;
- If samples are returned, they should be shared along with details of how each sample was collected;
- This should remain an ongoing topic of discussion for the MCD.

LEAG-ISECG V-SAT-2 Findings

Finding #14 – Data Sharing 3: Development and application of data fusion techniques can integrate data from multiple landing sites.

Background Information:

This is important for looking at intersections of different datasets. The V-SAT-1 report (https://www.lpi.usra.edu/leag/reports/vsat_report_123114x.pdf - pages 25 & 30) did this to compare Cabeus Crater with other PSRs to show similarities with the one PSR from which we have ground truth information.

LEAG-ISECG V-SAT-2 Findings

Finding #15 – Sample Return and Analysis: Discussions regarding international sample allocations should be initiated at the appropriate time.

Background Information:

- For returned samples, sharing of samples increases methods available to assay sample properties.
- The details of how each sample was collected should also be shared.
- This should remain an ongoing topic of discussion for the MCD.

LEAG-ISECG V-SAT-2 Findings

Finding #16 – Multilateral Investigation Teams 1: Inclusion of co-investigators or participating scientists from multiple nations enhances the knowledge (science, exploration, and engineering) return from the missions.

Background Information:

- Subject Matter Experts exist throughout the world with knowledge to contribute to the project;
- Sharing expertise in analysis and interpretation among missions facilitates integration of results from different sites;
- Resources need to be made available to support multilateral participation.

LEAG-ISECG V-SAT-2 Findings

<u>Finding #17 – Multilateral Investigation Teams 2</u>: An openness to international payload contributions enables comparable instruments on multiple missions, providing consistent data sets.

Background Information:

- See Finding #9 - Essential Measurements;
- Example: similar instrument to one flown on previous mission to allow direct comparison of data at target of this mission to previous mission;
- Reduces the cost for individual sponsor for the total science return and increases return on investment

LEAG-ISECG V-SAT-2 Findings

Finding #18 – Multilateral Investigation Teams 3: Interactions between the various international polar volatile mission teams would facilitate coordination efforts.

Background Information:

- Regular shared meetings at mission management and science team levels to update plans and progress;
  - e.g., Chandrayaan-1 + LRO, Hayabusa-2 and OSIRIS-Rex joint meetings.
- Participation in science and/or investigation team meetings increases ability for subsequent missions to adapt and plan to recent results.