New Approaches to Lunar Ice Detection and Mapping: Study Overview and Results of the First Workshop

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(30+ co-authors)

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Introduction to KISS

• Keck Institute for Space Studies (KISS) established 2008 at Caltech
• Funded by the W. M. Keck Foundation, with support from Caltech/JPL
• “Think and do tank”: bring together scientists and engineers for sustained technical interaction for developing new space mission concepts and technology
• Tom Prince (Director), Michele Judd (Managing Director)
Study and Workshop Format

• Two invitation-only 4-day workshops (July and November, 2013), ~35 participants
• One-day “short course” at start of first workshop – open to community
• First workshop: science discussions, interpretation of existing datasets, identification of key measurements needed
• Inter-workshop period: sub-team analyses of instrument/mission concepts
• Second workshop: down selection of 2-3 mission concepts, Team-X type studies
• Final Report + Proposal for tech development funds ($750k/yr available)
Workshop Attendees

New Approaches to Lunar Ice Detection and Mapping

| study page | overview | schedule | list of attendees | restricted wiki |

July 22-25, 2013
California Institute of Technology
Pasadena, CA 91125

- Oded Aharonson - Weizmann Institute of Science Israel
- Leon Alkalai - JPL
- Shane Byrne - Lunar and Planetary Laboratory
- Barbara Cohen - NASA Marshall Space Flight Center
- Anthony Colaprete - NASA Ames Research Center
- Jean-Philippe Combe - Bear Fight Institute
- Christopher S. Edwards - Caltech
- Bethany Ehlmann - Caltech
- William C. Feldman - Planetary Science Institute
- Emily Foote - UCLA
- Benjamin T. Greenhagen - JPL
- Paul O. Hayne - JPL
- Brendan Hermaly - University of Hawaii SOEST
- Andrew P. Ingersoll - Caltech
- Yang Liu - JPL
- Paul G. Lucey - University of Hawaii
- Benjamin K. Malphrus - Morehead State University
- Timothy P. McClanahan - NASA/GSFC
- Daniel J. McCleese - JPL
- Thomas B. McCord - Bear Fight Institute
- Catherine D. Neish - ORAU at NASA/GSFC
- David A. Paige - UCLA
- Michael J. Poston - Georgia Institute of Technology
- Gerald B. Sanders - NASA/JSC
- Norbert Schörghofer - University of Hawaii at Manoa
- Robert Glenn Sellar - JPL
- Matthew A. Siegler - JPL
- Robert L. Staehle - JPL

+ Several additional participants for the second workshop and beyond
Motivation: Science and Exploration

1. Significant uncertainty still remains about the nature, abundance, and distribution of lunar volatiles (in spite of fantastic discoveries by LRO, Chandrayaan-1, and predecessors)

2. Small satellite technologies such as CubeSats have matured to the point that revolutionary low-cost missions could enable real science and exploration
**INSPIRE**

*Interplanetary NanoSpacecraft Pathfinder In a Relevant Environment*

Low-cost mission leadership with the world’s first CubeSat beyond Earth-orbit

**PI:** Dr. Andrew Klesh, Jet Propulsion Laboratory, California Institute of Technology

**PM:** Ms. Lauren Halatek, Jet Propulsion Laboratory, California Institute of Technology

**University Partners:**
- U. Michigan – Ann Arbor
- Cal Poly - San Luis Obispo
- U. Texas – Austin

**Collaborator:**
- Goldstone-Apple Valley Radio Telescope (GAVRT)

Pre-Decisional -- For Planning and Discussion Purposes
Diviner maximum surface temperatures overlaid on LAMP Ly-α albedo

Strong correlation of low albedo with cold traps \( \rightarrow \) consistent with either 1) water ice, or 2) highly porous regolith
Map of LAMP water ratio, and histogram of water ratio vs. Diviner maximum temperature

Colors indicate regions of interest mapped on next slide
Key Outcomes of First Workshop: Science
Comparison with (Collimated) Neutrons

LEND epithermal neutron counts

Diviner temperatures (grayscale)

LAMP water ice index (reds)
North pole:

Diviner max. temperatures

LOLA albedo

(Proprietary data / not for distribution)
Shadows in LROC Images
Shadows in LROC Images

200 m
Comparison with “Background” Epithermal Neutron Suppression

LEND background neutron suppression (Boynton et al., 2012)

Fractional surface area with temperatures conducive to stable surface water ice
Why land here...

...when you can land here?
Key Outcomes of First Workshop: Science Strategy

Search for Macroscopic Ice

Surface Ice? (Yes/No)

Near-Surface Ice? (0 to 2 Meters)

Yes

No

Deep Ice (>2 meters)

Limit of “operationally useful” ice?
Example Science Objectives

Objective:

1. Determine the volatile inventory of the lunar polar cold traps

2. Determine the temporal behavior and mobility of lunar volatiles

3. Assess the origins of lunar volatiles via their isotopic composition

Requirement:

- Need “samples” from multiple locations (spaced > 100 m?)
- Need “samples” from multiple depths to ~1 meter
- Need time history of composition and abundance of volatiles for > 1 lunar day (i.e. 1 month)
- Need composition and high precision isotope ratios for each location sampled
Key Outcomes of First Workshop: Mission Concepts

- Active reflectance spectroscopy of the surface:
  - Broadband lamp + multispectral detector(s)
  - Solar sail reflector + multispectral detector(s)
  - Tunable near-IR lasers + receivers
- Impactor probes
- Penetrator probes
- Landers, rovers
- Others
Mission Concepts: Orbital

• Gamma ray and neutron spectrometry:
  – Very low altitude orbital/descent stage
  – Penetrators at multiple sites (distinct thermal environments)
• Active Spectroscopy
  – Tunable lasers, LiDAR reflectance (LOLA, MOLA, MLA, etc)
  – Incandescent broadband w/ near-IR spectrometer
  – Solar sail (Lunar Flashlight, AES)
• Impactors/chasers (e.g. LCROSS)
  – Orbital UV emission spectroscopy and IR reflectance spectroscopy
  – Lander based spectroscopy + gas phase sampling
  – Earth-based spectroscopy
• Radar
  – P-band from orbit
  – Bi-static at many more phase angles
• UV Spectroscopy
  – Emission spectra from volatile species in lunar atmosphere
  – Impact plume dynamics
Mission Concepts: Landed

- Lander with subsurface sampling and isotopic composition measurements (e.g. TLS, GCMS, etc)
- Rover with surface reflectance spectra and subsurface isotopic composition (RESOLVE/Resource Prospector)
- Lander with small “excavator” rover (Ben Greenhagen)
- Crazy: “beach ball” filled with sensors, etc.
(WHITEBOARD PICTURES FROM FIRST WORKSHOP)
Goals for Second Workshop

• Select 2-3 mission concepts for further study, based on sub-team studies
• Generate mature mission concepts w/ estimates of cost, power, mass, etc. (Team-X)
• Identify key technology gaps where KISS funding could be used to advance TRL
• Begin drafting final report
Major Milestones and Expected Products

• July 2013 – first workshop
• August – October, 2013 – sub-team studies
• November 2013 – second workshop
• December 2013 – application deadline for KISS postdoc fellowship
• February 2014 – final report published on KISS web site
• Early 2014 – proposal to KISS for follow-on technology funding

Also: review article on lunar polar volatiles
Summary

• KISS studies bring together experts to identify new technologies that will advance space science and exploration

• Sometimes KISS studies lead to new missions and/or instrumentation (e.g. InSight)

• Significant uncertainty still remains w.r.t. lunar ice, motivating the present study

• The study final report will be a freely-available resource for this community

• Follow-on technology development funding may lead to real advancements in lunar ice detection and mapping