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

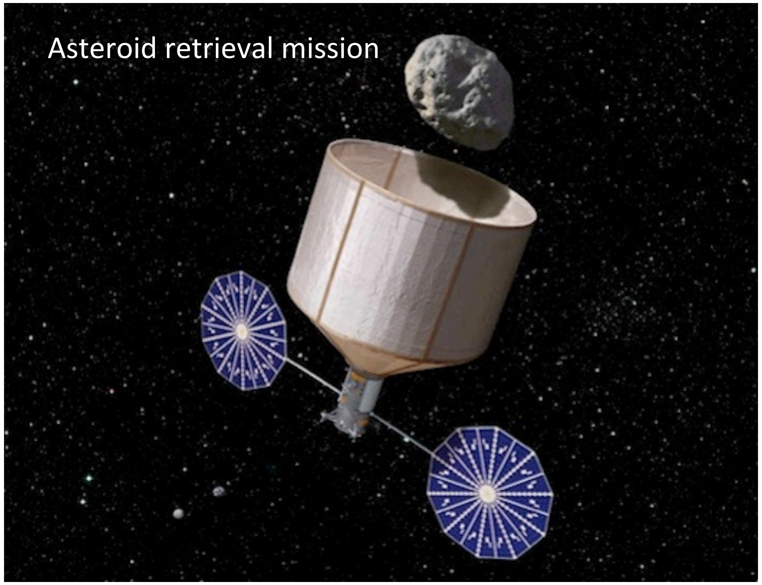
Paul Hayne[1], Andrew Ingersoll[2], David Paige[3], et al.
(30+ co-authors)

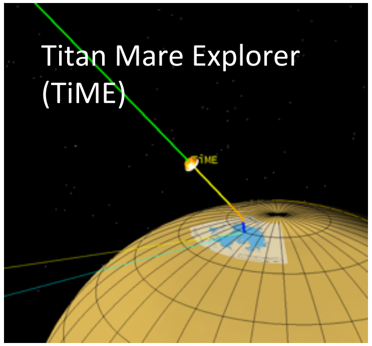
[1]Jet Propulsion Laboratory, California Institute of Technology
[2]Geological and Planetary Sciences Division, California Institute of Technology
[3]UCLA

Keck Institute of Space Studies, California Institute of Technology, Pasadena – November 2013

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)

Participants

California Institute of Technology — Geological and Planetary Sciences

NASA
MSFC
JSC
ARC
GSFC

JPL
Jet Propulsion Laboratory

UCLA

Bear Fight Institute

Department of Planetary Sciences
Lunar and Planetary Laboratory

מכון ויצמן למדע
Weizmann Institute of Science

University of Hawai'i

Georgia Institute of Technology

PSI

Morehead State University, Kentucky

Florida Institute of Technology

Keck Institute for Space Studies

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 Hermalyn - 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

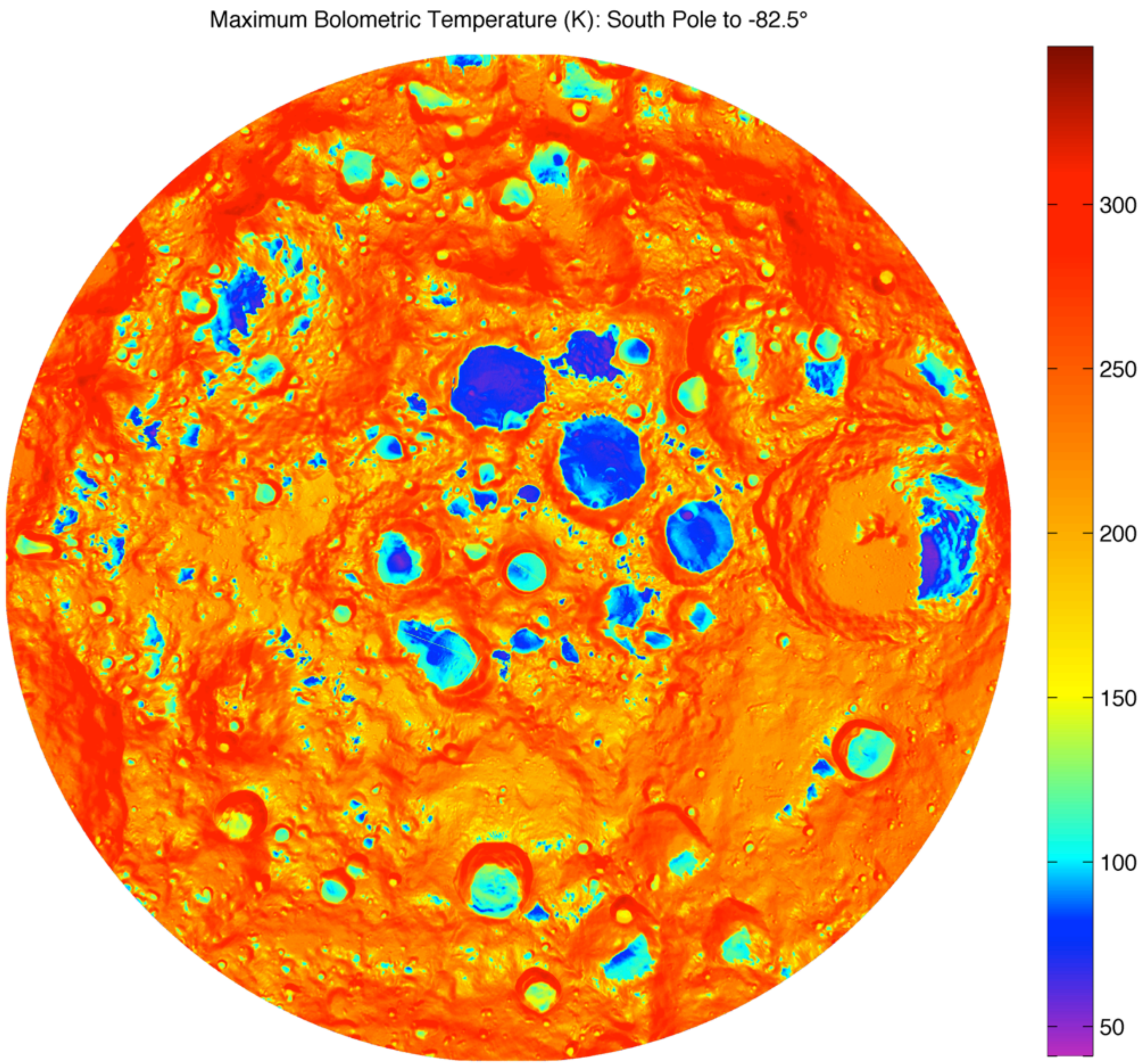
Low-cost mission leadership with the world's first CubeSat beyond Earth-orbit

PI: Dr. Andrew Klesh, Jet Propulsion Laboratory, California Institute of Technology
PM: Ms. Lauren Halatek, Jet Propulsion Laboratory, California Institute of Technology

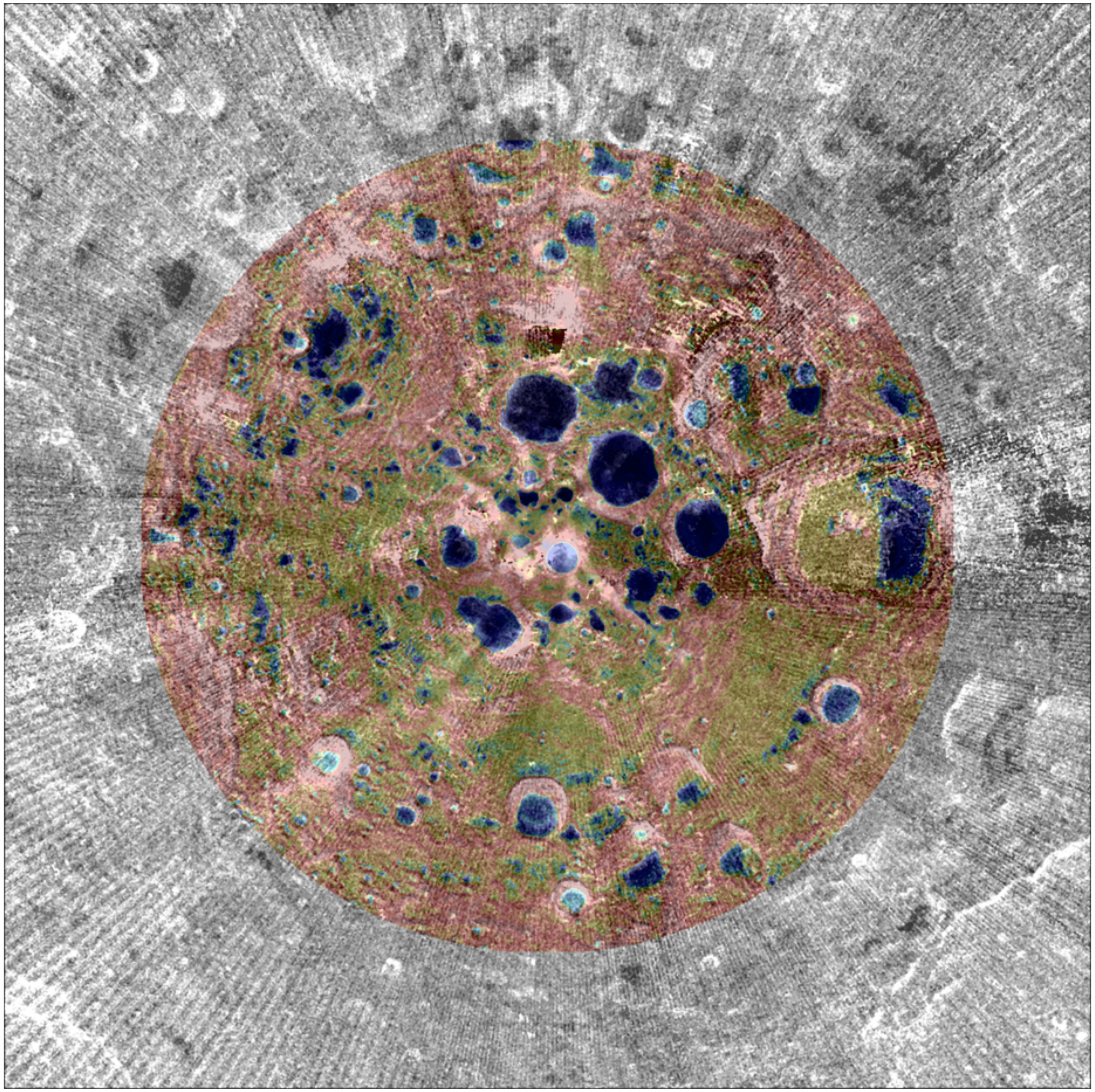
University Partners:
- *U. Michigan – Ann Arbor*
- *Cal Poly - San Luis Obispo*
- *U. Texas – Austin*

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

Jet Propulsion Laboratory
California Institute of Technology
CAL POLY GAVRT MICHIGAN THE UNIVERSITY OF TEXAS AT AUSTIN

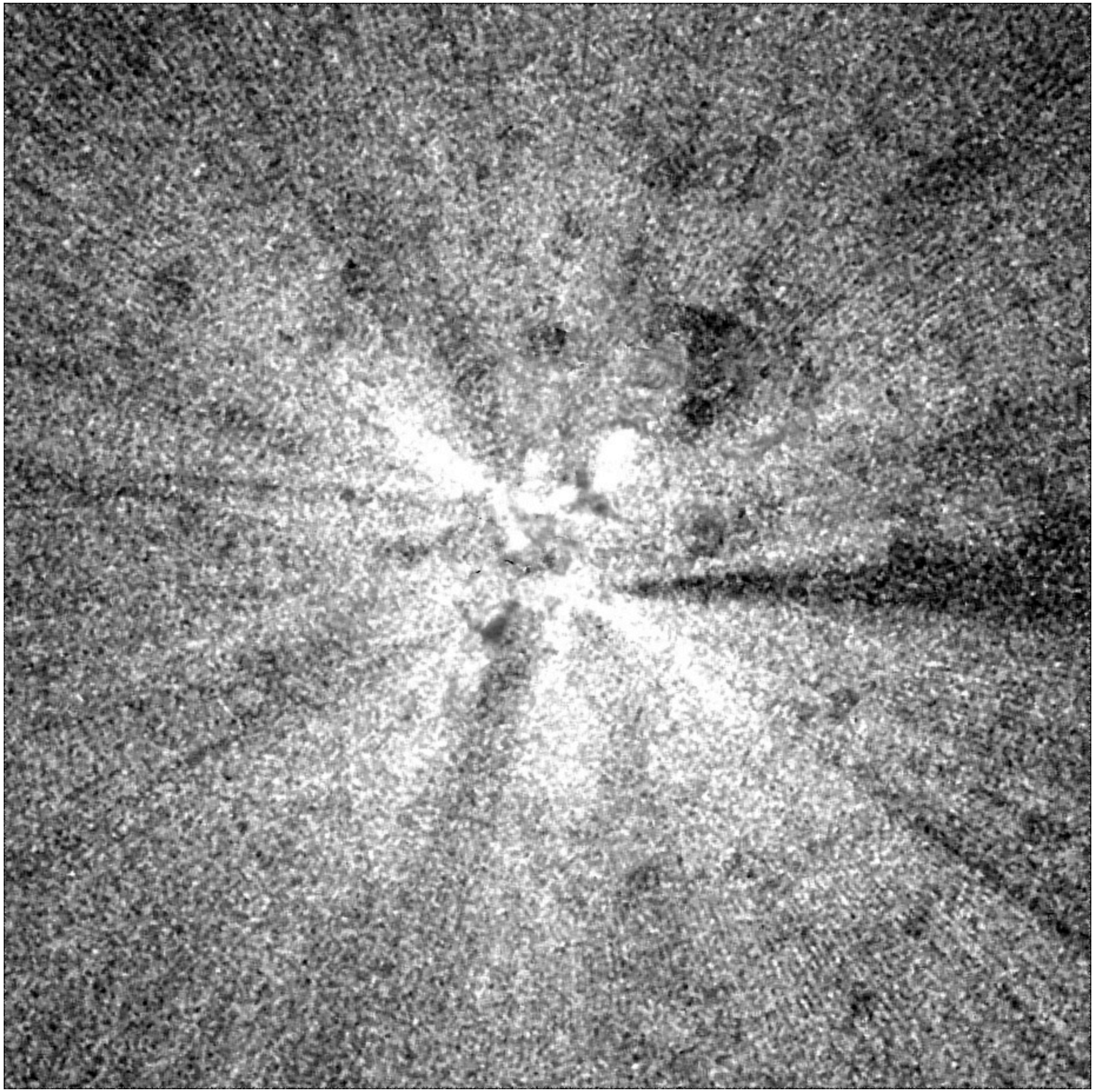


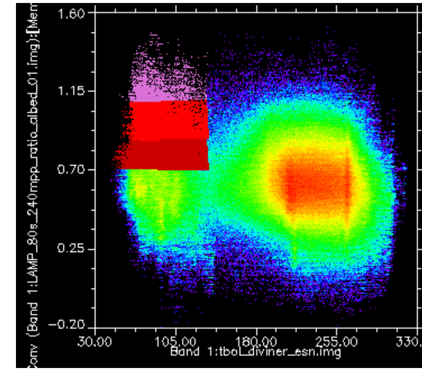
Maximum Bolometric Temperature (K): South Pole to -82.5°
300
250
200
150
100
50



Diviner maximum surface temperatures overlaid on LAMP Ly-α albedo

Strong correlation of low albedo with cold traps → consistent with either 1) water ice, or 2) highly porous regolith

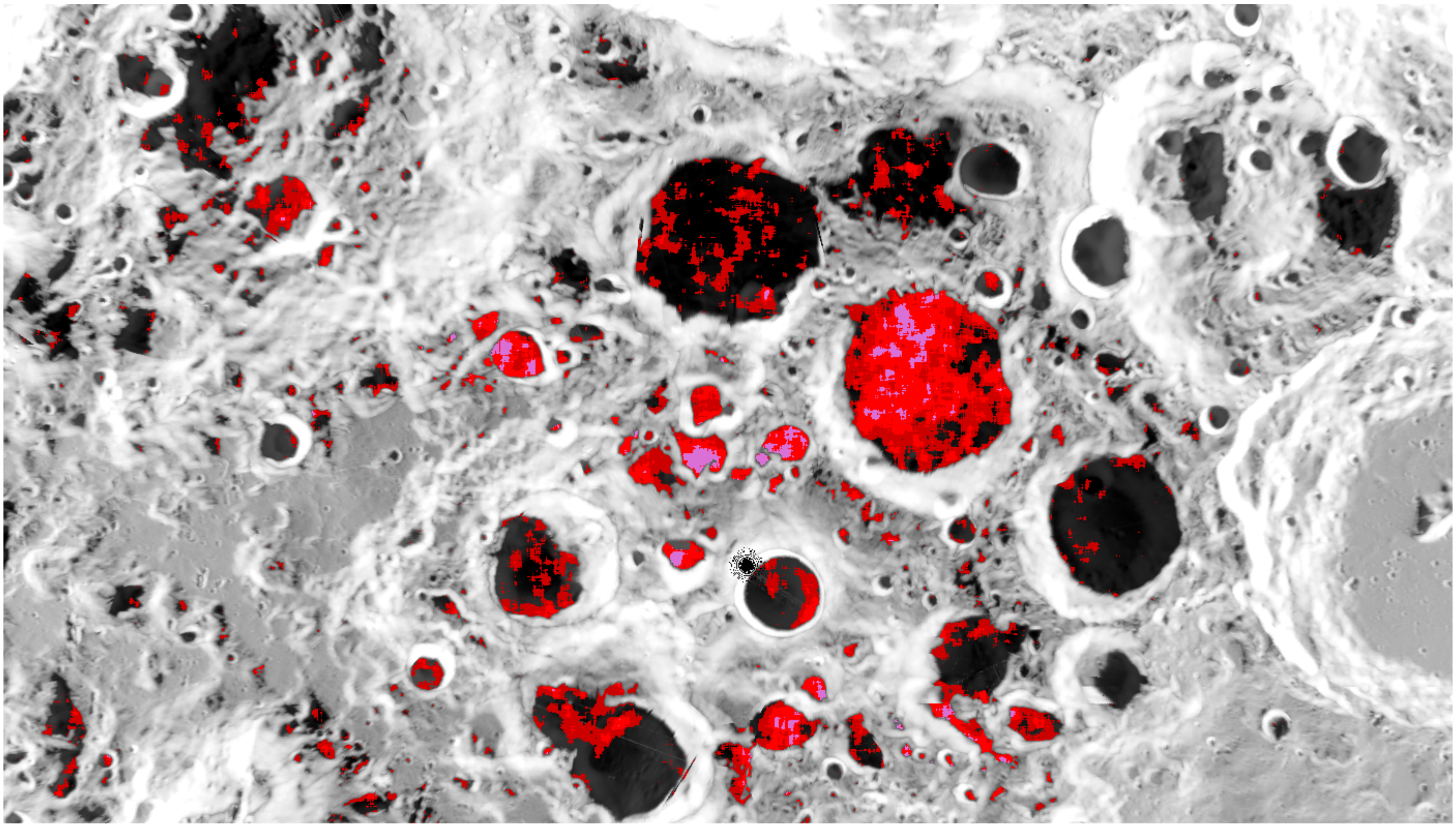




Map of LAMP water ratio, and histogram of water ratio vs. Diviner maximum temperature

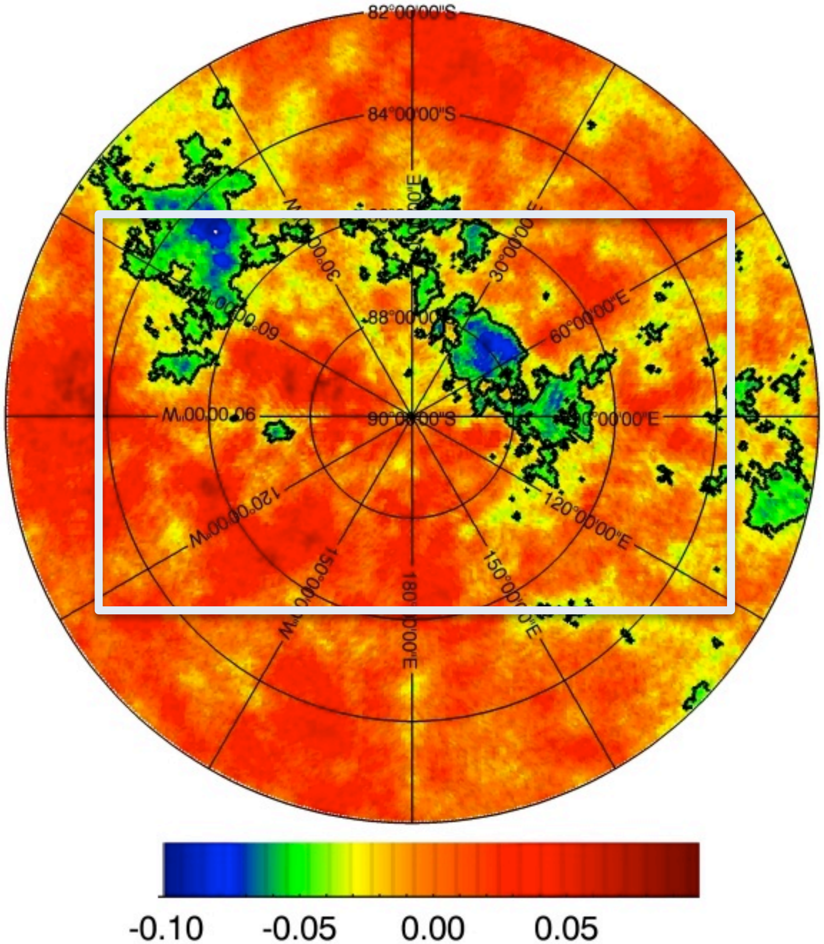
Colors indicate regions of interest mapped on next slide

Key Outcomes of First Workshop: Science

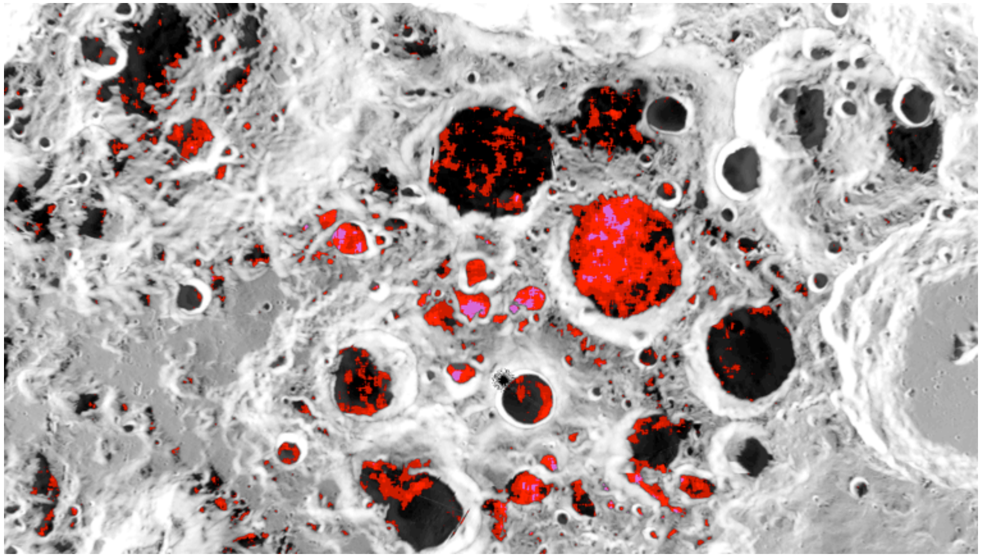


Comparison with (Collimated) Neutrons

LEND epithermal neutron counts



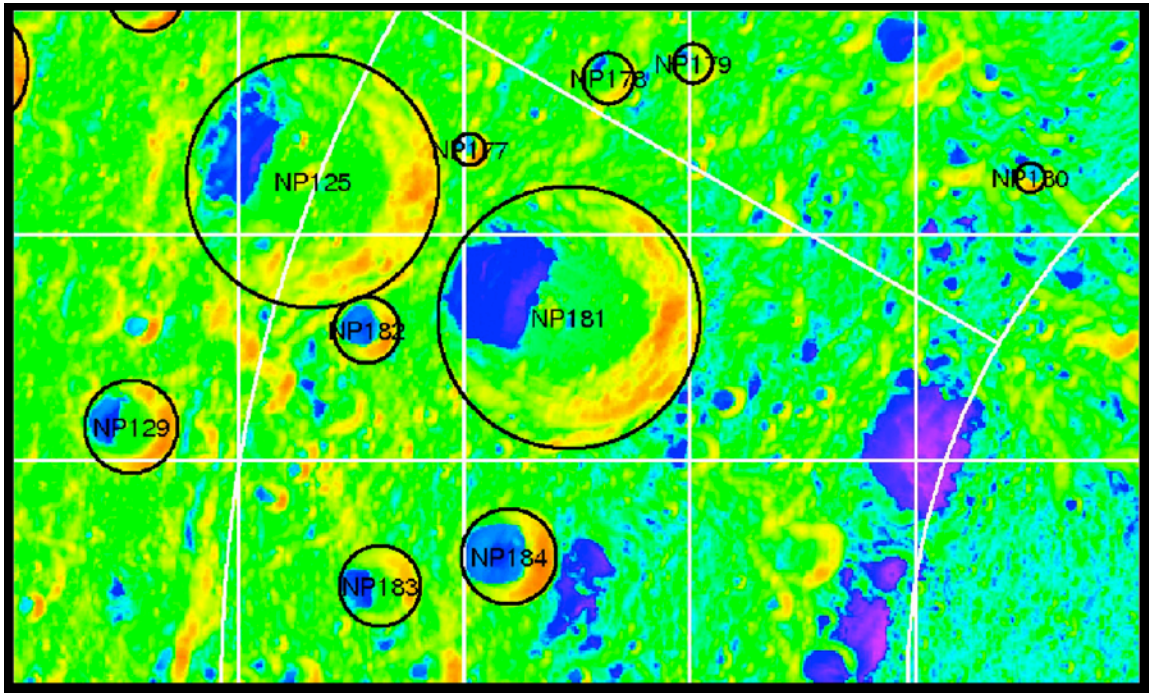
Diviner temperatures (grayscale)



LAMP water ice index (reds)

North pole:

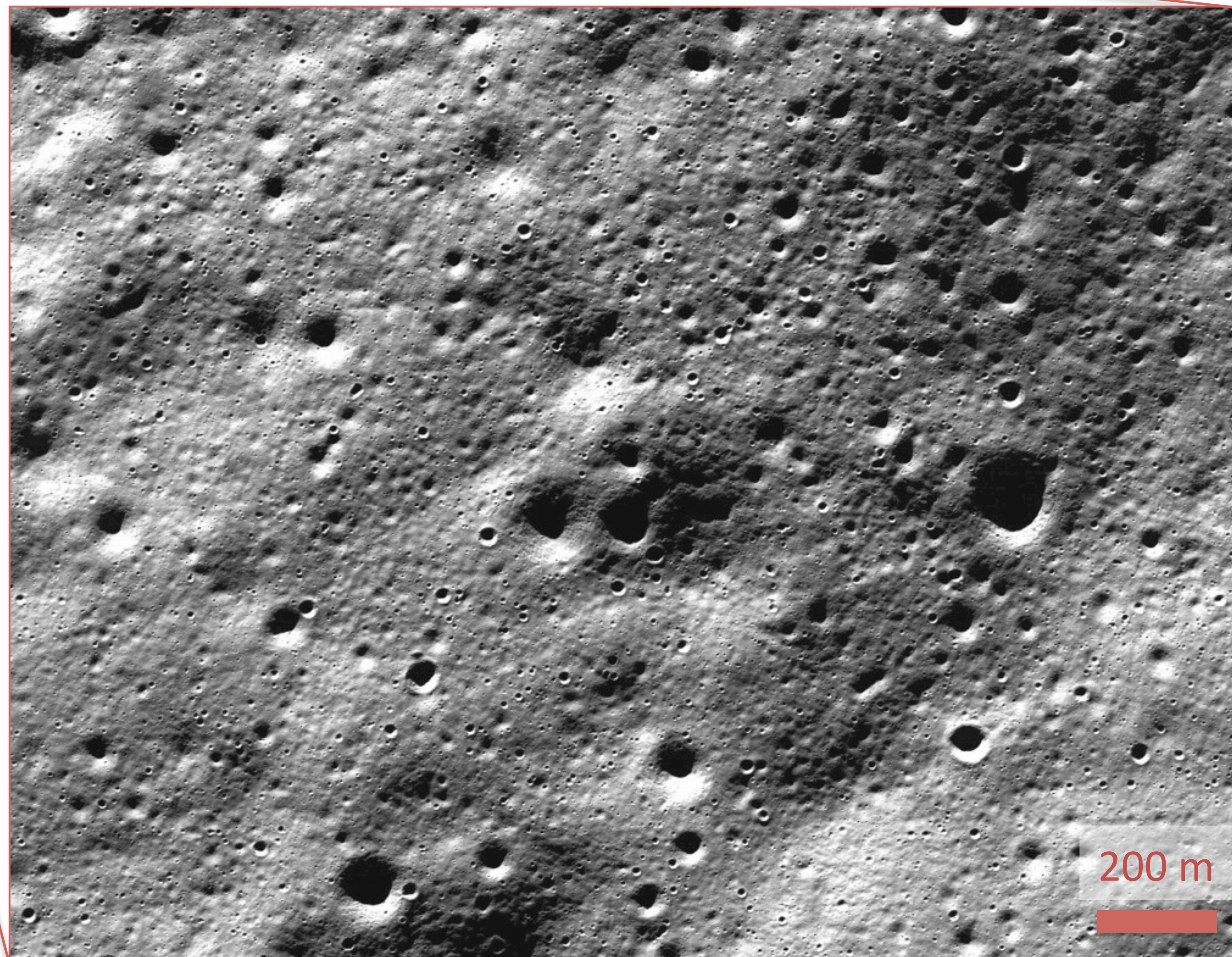
Diviner max. temperatures



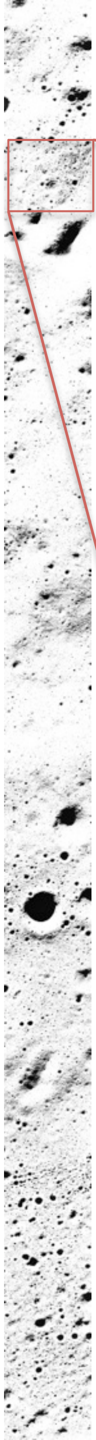
LOLA albedo

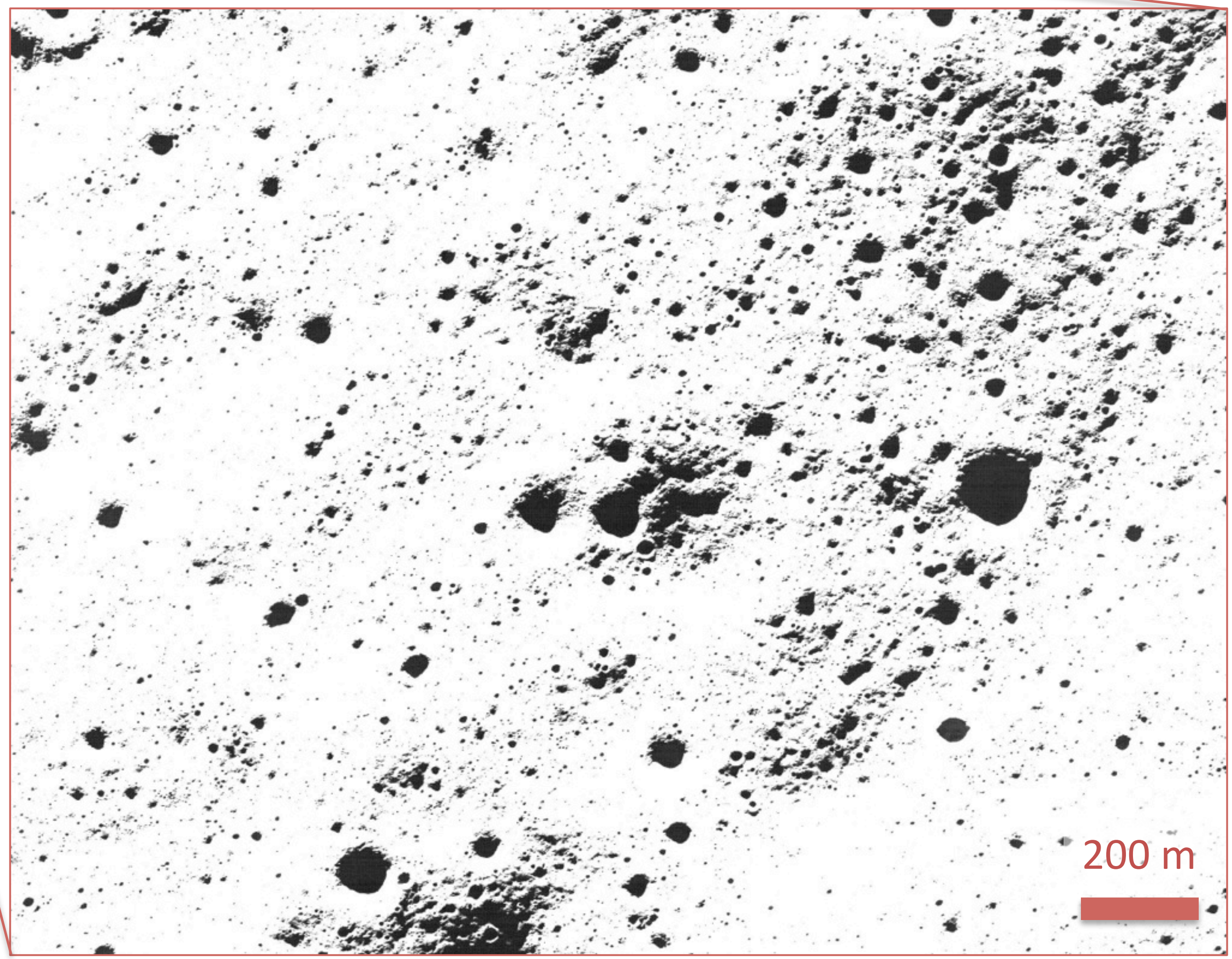
(Proprietary data / not for distribution)

Shadows in LROC Images

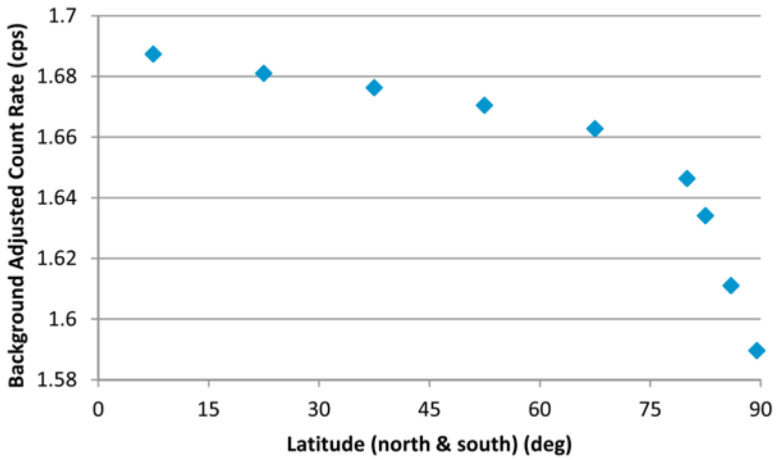


Shadows in LROC Images

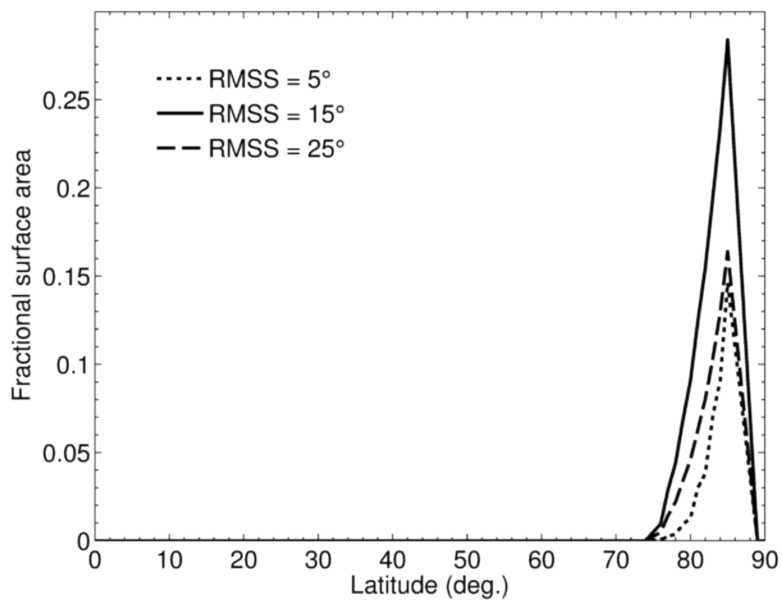




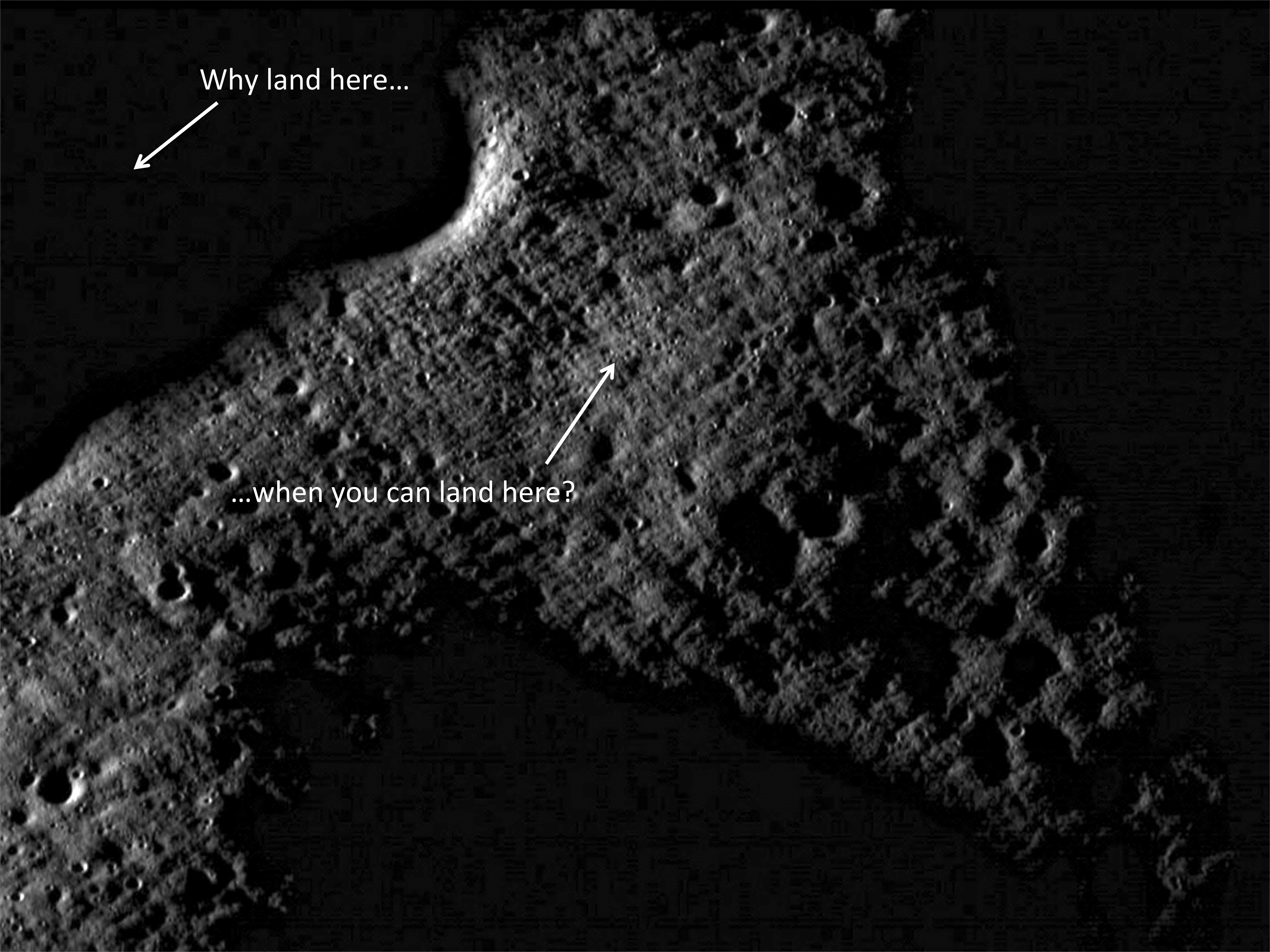
Comparison with "Background" Epithermal Neutron Suppression



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

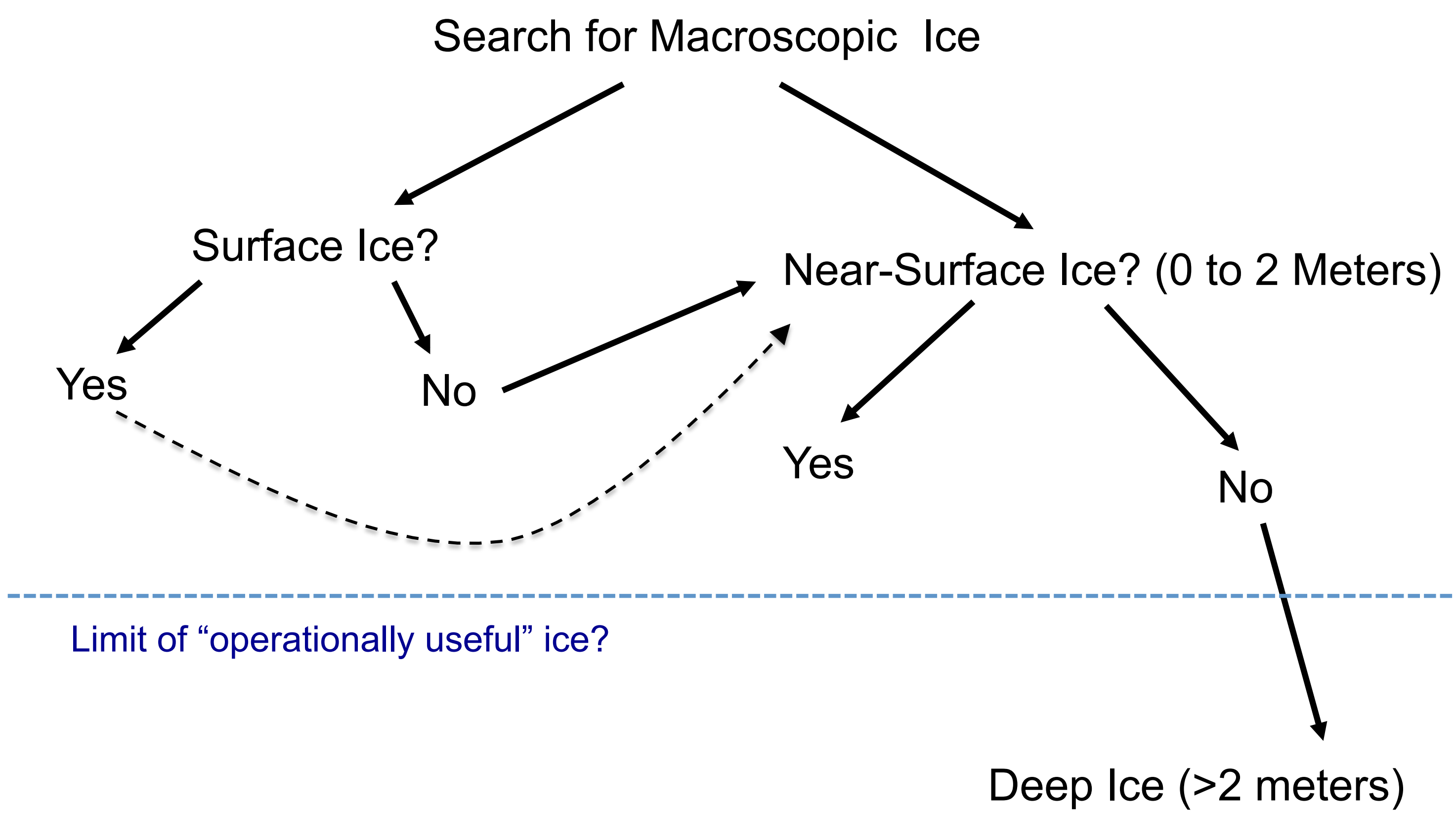


Fractional surface area with temperatures conducive to stable surface water ice



Why land here…
…when you can land here?

Key Outcomes of First Workshop: Science Strategy



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

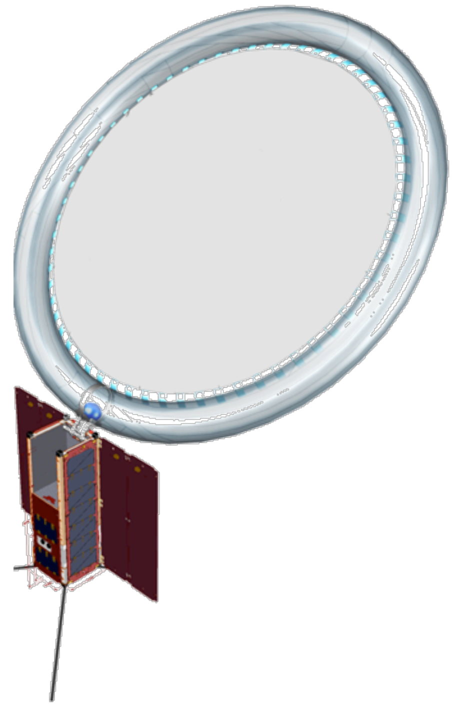
3. Assess the origins of lunar volatiles via their isotopic composition

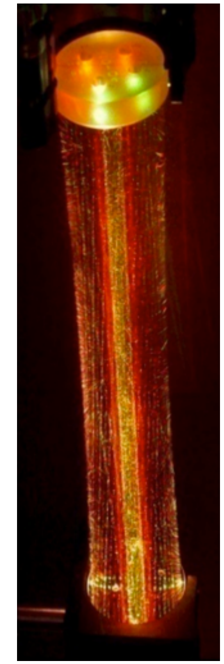
Requirement:

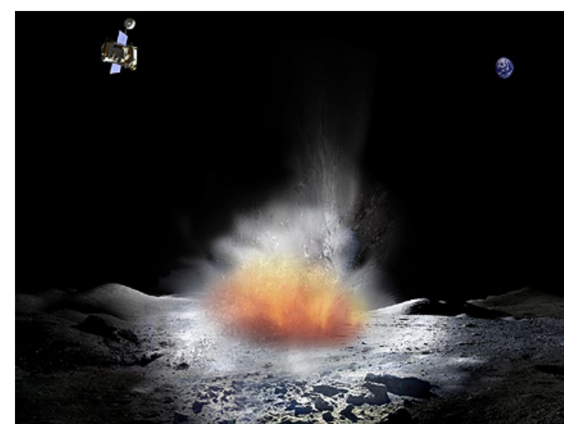
- Need "samples" from multiple locations (spaced > 100 m?)
- Need "samples" from multiple depths to ~1 meter
- Need time history of composition and abundance of volatiles for > 1 lunar day (i.e. 1 month)
- Need composition and high precision isotope ratios for each location sampled

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