Building on the Cornerstone Mission: Focused LRO Workshops to Support Science Team Synergies

- The LRO Mission has undertaken a series of science workshops to focus on specific topics that LRO can address with current data or data that we will collect
- Outside expertise is solicited to broaden discussion.
- Goals of the workshops include
  - Develop new collaborations
  - New targets and measurement strategies

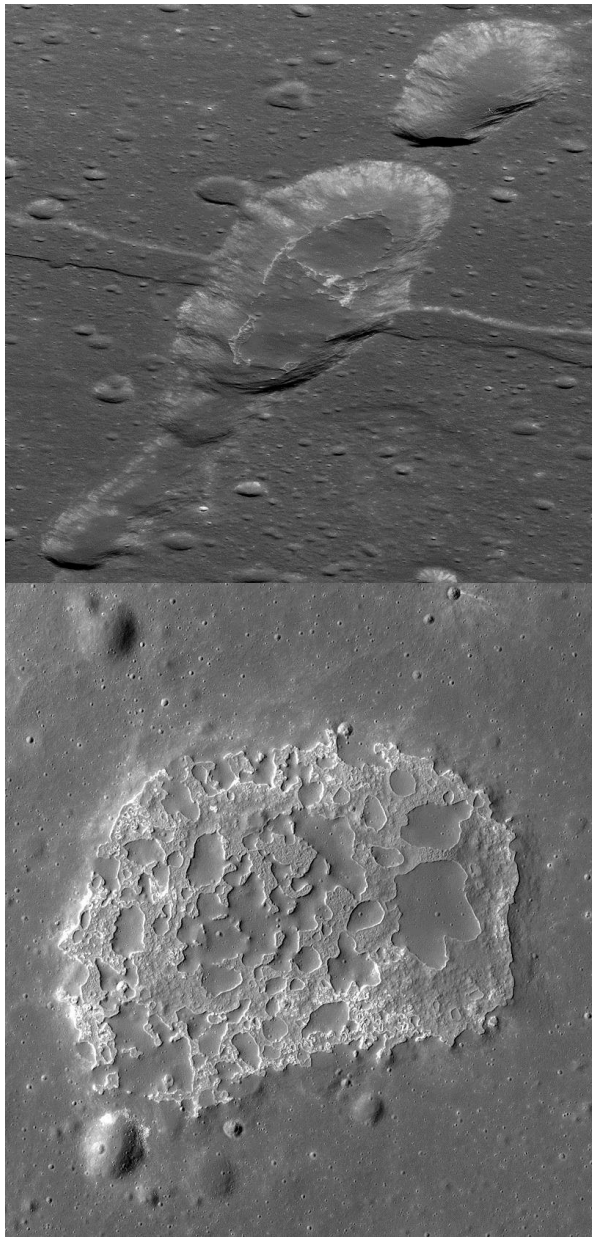
Four Workshops… So far

- Young Lunar Volcanism
  - Held at LPI in Houston Feb 9, 2017
  - Organized by Julie Stopar
- Impact Cratering
  - Held at the Weizmann Institute in Israel, April 19
  - Hosted by Oded Aharonson
- Lunar Basin Chronology
  - Held at Institut für Planetologie, Münster, May 6 2017
  - Organized by Carolyn H. van der Bogert
- Diurnally Varying Surface Hydrogen
  - Held at UNH, Durham, June 6-8, 2017
  - Organized by Andrew Jordan

Young Lunar Volcanism Workshop

LPI Feb 9, 2017

- When did volcanism on the Moon cease?
  - Emerging topic of scientific interest since Braden et al. (2014) analysis of Irregular Mare Patches (IMPs) indicate relatively recent formation (~100 Myr)
  - Alternative explanation is that highly porous regolith (magmatic foams) in the IMPs skews apparent crater counting ages younger (Qiao et al, 2017).



Young Lunar Volcanism Workshop

LPI Feb 9, 2017

- ~30 in attendance representing LROC, LOLA, LAMP, MRF, Diviner, M^3, GRAIL, and lunar sample experts
- Key goals
  - assess our current understanding of volcanism in the last 1.2 Ga;
  - assess future measurement needs;
  - assess potential future collaborative and inter-instrument studies

Agenda

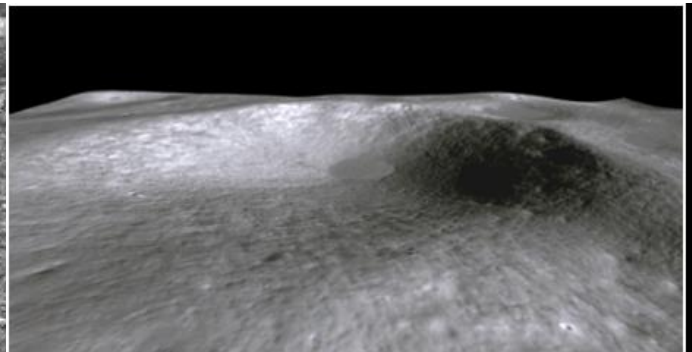
- Abundance and Distribution of Young Volcanism
  - van der Bogert – youngest mare basalts and issues in young chronologies
  - Jolliff – Procellarum P60 mare basalts
  - Stopar – IMP geomorphologies
  - Elder – IMP thermal properties
  - Donaldson-Hanna – IMP spectral and thermal properties
- Are there key geochemical tracers of young volcanism?
  - Sato – Ti evolution and young volcanism
- Geophysical properties
  - Watters – Copernican-era global contraction/tectonics
  - Patterson – Radar perspectives
  - Neumann – GRAIL/LOLA perspectives
- Models of interior evolution – how does young volcanism fit into global models derived from sample analyses?
  - Elardo – Young mare basalt petrogenesis
  - Barnes – Evolution of magmatic volatiles

Key Outcomes

- Identified some follow-up observations and measurements – including:
  - Collect regolith information (thickness, rock abundance) across instruments to better constrain CSFDs at key sites
  - Consider following up on small-scale (10's km) density anomalies discovered by GRAIL (Jansen et al. 2017)
  - Investigate gravity anomalies and sites of possible recent intrusions, particularly with NAC stereo images of graben
  - IMP observations with MRF bistatic
  - Improve temporal coverage with Diviner, particularly daytime coverage with Diviner of Cauchy IMP needs improvement
  - Diviner eclipse measurements may reveal additional information
  - Need more samples to fully integrate observations with models of the lunar interior, LRO should consider keeping possible sampling sites as high-priority observation types

Impact Cratering Sessions

- Impact Cratering I
  - Can we date very young lunar surfaces from crater statistics (Williams)
  - LROC surface changes (Speyerer)
  - Copernican age crater topographic roughness and age correlations (Neumann)
  - Topographic degradation of lunar impact craters (Du)
- Impact Cratering II
  - Cold spot formation models (Hayne)
  - Tycho antipode modeling update (Paige)
  - Tycho antipode deposits: New analysis of rocky deposits and flow features (Curren)



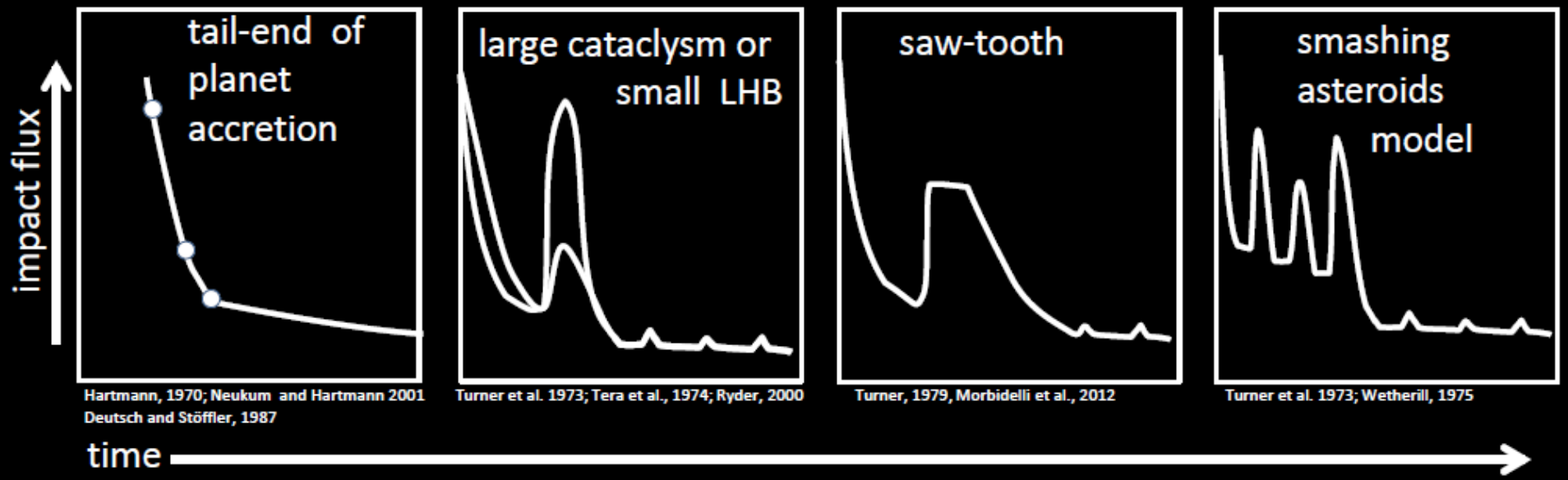
Lunar Basin Chronology

Institut für Planetologie, Münster, May 6 2017

- Participants included
  - LRO team members,
  - Members from German science foundation-funded regional collaborative project TRR170 Late Accretion onto Terrestrial Planets
  - Invited speakers
- Presentations from David Minton, Csilla Orgel, Paul Spudis, and Katie Joy, Christian Riedel, Tiantian Lui
- Themes from the meeting
  - Multiple scenarios beyond LHB must be considered.
  - Age determination of ancient surfaces is difficult due to saturation
  - Impact rate models can help distinguish source populations

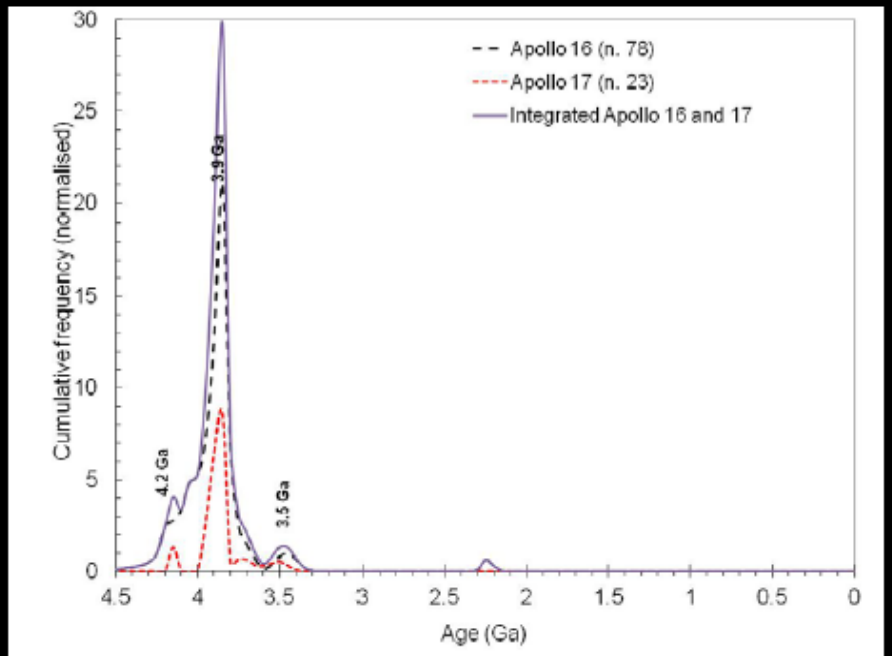
Timing and Extent of Lunar Bombardment

Thanks to: Jörg Fritz and Vera Fernades for graphics



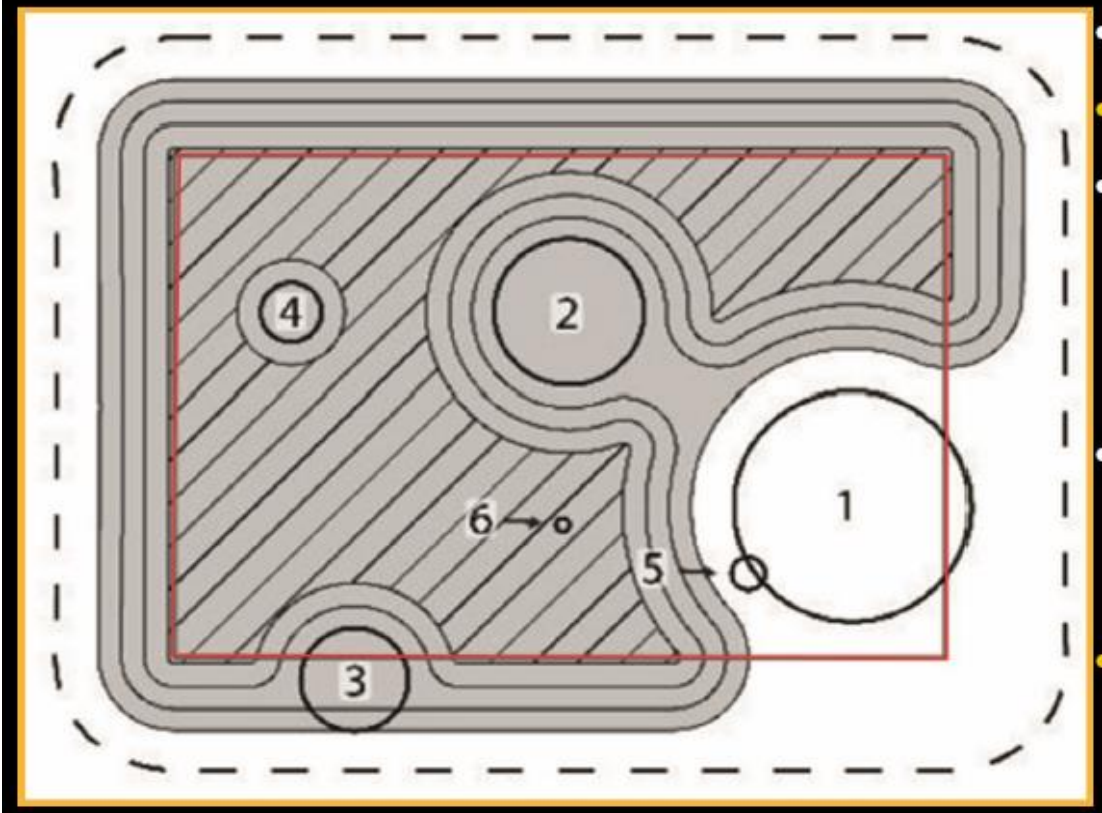
Vast literature, debate and theories…

- Sample perspective
  - Evidence from isotopic resetting of rocks and impact melt crystallisation events
  - Evidence from added meteoritic material
- Imaging and remote sensing perspective
  - Physical disruption of crust (number and size of basins and craters, relative ages)



K. Joy chart

Method: Buffered Non-Sparseness Correction (BNSC)



Kneissl et al., 2016

- Talk from Riedel et al.
- Combination of 2 techniques
- Correct accounting of smaller craters on highly cratered surfaces--|Non-Sparseness Correction (NSC)
- Include all craters with a buffer (Buffered Crater Counting, BCC Fassett and Head, 2008)
- Each crater has a reference area by excluding the larger craters and their buffer
- Effect is the increased measured frequencies of smaller craters

C. Orgel chart

Conclusions

P. Spudis chart

New LROC images allow us to reconstruct basin stratigraphic relations and determine relative ages

New remote sensing data permits analysis of basin ejecta and melt compositions; new identification of promising sites for future sample return missions (composition, absolute age)

Impact melt ejected from the basin has been identified at two basins (Orientale, Imbrium); *in situ* melt sheets identified at two basins (Orientale, Crisium)

South Pole-Aitken basin is largest, oldest basin on Moon; determination of its absolute age would help clarify nature and magnitude of late heavy bombardment

Complexity and age of SPA deposits make unambiguous recognition of basin impact melt difficult; will likely require extended human field study to correctly identify and analyze

Proposed to Investigate

1. Investigate different types of equilibrium surfaces (e.g., mare/highlands) with known surface ages derived from crater size-frequency distribution (CSFD) measurements of larger diameter craters
2. Investigate degradation of rays and other radial features (or sculpture) from both recent craters and major basins
3. Smallest counting areas could be targeted for LRO measurements as representative of areas least affected by non-sparse cratering and most representative of ancient highland materials.
4. GRAIL and LOLA data indicate the presence of additional outer rings at some basins, which have not been documented visually. It is proposed to use these data to define LRO measurement locations in an effort to identify these features in additional data sets.
5. Additional targets could be defined at the intersections of gravity gradients that are documented in GRAIL data.
6. In support of a campaign to gain additional stratigraphic information about lunar basins it is necessary to continue imaging basin impact melt sheet exposures, basin ejecta deposits, and possible ejected melt blobs (e.g., Airy).
7. Obliques across basin ejecta and melt units at low sun can help to confirm and problem solve basin stratigraphic relationships.

Diurnally Varying Surface Hydrogen

UNH, Durham, June 6-8, 2017

- ~15 in attendance representing LRO, LADEE NMS, Chandrayaan M3 , SSERVI
- Oct. 2009 Science issue that reported the observations in the IR of a surface veneer of H2O or OH
  - Chandrayaan M3 Pieters et al.
  - Cassini VIMS, Clark
  - Deep Impact HRI-IR, Sunshine
- LRO team has found diurnal signatures of hydrogen or water in its data sets.
- The Clark/Sunshine divergent interpretations of the diurnal observations remains a central consideration in the interpretation if IR data and we must be sensitive to alternative interpretation of other data sets.
- Evidence of transport or photometric effects?

Diurnal Variability of Hydrogen.
What do we agree on?

Topic	Agree on	Note
Water on the Moon	There is a surficial layer of OH or H_2O on the Moon	As observed in the IR and UV. More likely OH over water. May be in the rims of grains
Water on the Moon	There is a H signature in neutron measurements that increases with latitude. Proton albedo modified by H in the upper 1-10 cm.	
Hydrogen in Apollo core samples	Order 50 µg/g (0.005 wt.%)	Weakly attached Hydrogen was lost prior to measurements? New lab measurements needed.
Diurnal observations	Diurnal signatures seen in multiple data sets on multiple missions	Translation to quantities is uncertain. Some but not all show dawn terminator enhancement over dusk.
Solar Wind H	H_2 observations account for 10-50% of SW, ~20% backscattered as ions and ENAs	As measured by LAMP, Artemis, Chandrayaan-1, IBEX
LADEE measurements	H_2O observed episodically-instrumental upper limit of H_2O not associated with impact 17 /cm^3	Observations correlated with meteor streams. Equatorial orbit.
Lunar temperatures	Lunar surface temperatures known and thermal wave models are reliable at relevant scales	Longitudinal temperature variation is asymmetric with respect to the terminators.
Exospheric transport of water	Sources of water must replace losses	On equivalent time scales.

Summary – LROs Role

- The transport of volatiles is a focus of the current extended mission with new operating modes that address diurnal cycle.
- Interdisciplinary, inter-instrument approaches. This meeting is an outcome of this approach (SSERVI DREAM also gets credit!)
- The LRO team is open to suggestions for targeted measurements and collaborations.
- LRO has compiled an extensive data set in the PDS that the community can take advantage.

LRO Focused Workshops

- The LRO Mission has undertaken a series of science workshops to focus on specific topics that LRO can address with current data or data that we will collect
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  - Develop new collaborations
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LRO Focused Workshops

- Four Workshops completed over the past 8 months.
- New targets and measurement strategies identified.
- New collaborations formed
  - Gestation period for new papers?
- What's next?
  - Polar Volatiles Meeting organized by LRO/SSERVI
  - Follow on meetings?
  - Other suggestions?