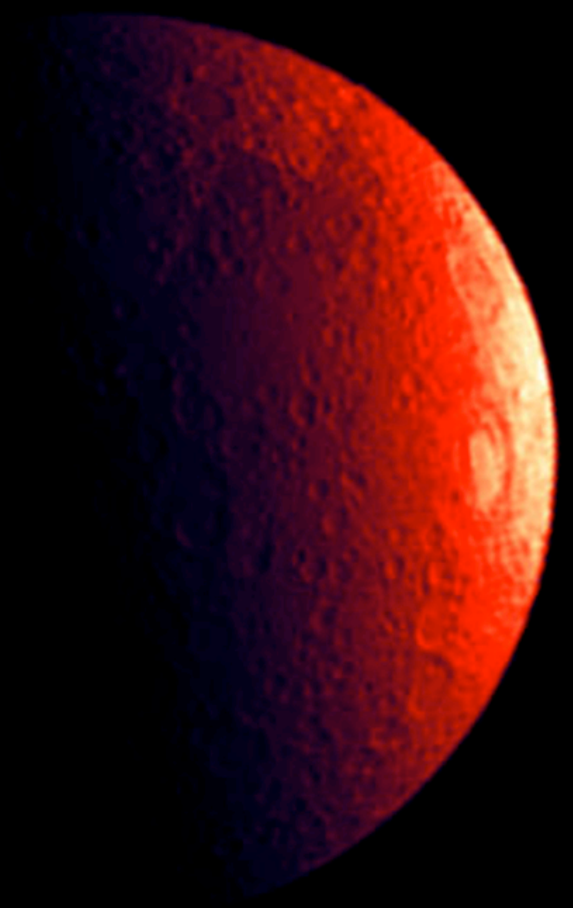
LCROSS Centaur Impact Site Recommendation

Presented for Consideration to the LCROSS Project

September 5, 2009

Prepared by Anthony Colaprete



LCROSS

This presentation is an abridged version of the original version presented to the LCROSS Project and Lunar Precursor Robotic Program adapted for presentation on the Web.

Data not released to the public by individual Projects and Principal Investigators has been removed.

Special thanks to the LRO Project, Project Science, and Instrument Teams, to the SELENE/Kaguya Project and Chandrayaan-1 Projects for use of data, data interpretation and discussion.

LCROSS Acronyms/Terms

- **LCROSS**: Lunar Crater Observation and Sensing Satellite
- **S-SC**: Shepherding Spacecraft- LCROSS guiding the Centaur to destination
- **LRO**: Lunar Reconnaissance Orbiter- Sister mission at launch and to the moon
- **LPRP**: Lunar Precursor Robotic Program- Umbrella program for LRO/LCROSS
- **LP:** Lunar Prospector- NASA/Ames Lunar mission (1999) that detected elevated hydrogen signatures at the moon's poles
- **TCM**: Trajectory Correction Maneuver
- **Ejecta**: Material thrown upwards as a result of an impact
- **SELENE/Kaguya:** Japanese Lunar Orbiter Mission
- **Chandrayaan-1**: Indian Lunar Orbiter Mission
- **Topo Mask**: Altitude of terrain the ejecta has to surpass before being exposed to sunlight
- **WEH**: Water Equivalent Hydrogen (percentage of water, by weight, in lunar regolith or soil
- **Pixon**: Mathematical process used to interpret water concentration
- **LOLA**: Lunar Orbiter Laser Altimieter (LRO instrument)
- **LEND**: Lunar Exploration Neutron Detector (LRO instrument)
- **LROC**: Lunar Reconnaissance Orbiter Camera (LRO instrument)
- **LAMP**: Lyman-Alpha Mapping Project (LRO instrument)
- **PSR**: Permanently Shadowed Region

Presentation Purpose and Organization

Purpose

- This presentation provides a recommendation to the LCROSS Project as to the Centaur impact point
- The Shepherding Spacecraft impact point will be provided later (by TCM 8)

Presentation Purpose and Organization

The presentation is organized as follows:

1. Summary of Criteria for Site Selection: Describes the basic criteria important to target selection
2. List of current candidate craters
3. Summary Table of key crater characteristics for list of candidates
4. Provides supporting data and description for each selection criteria
5. Concludes with recommendation

Centaur Target Selection Criteria

Criteria, in Priority Order

1. Solar illumination of ejecta cloud

- Topographic masks between impact site and sun **<3 km required (<1 km goal)**
- The ejecta must be illuminated for any observer to see it (note: some information will be taken during the impact flash period which does not require ejecta illumination but still does address the presence of volatiles)

2. Association with increased hydrogen concentrations

- [H] consistent with Water Equivalent Hydrogen (WEH) **levels of greater than 0.5%** (the LCROSS detection limit requirement)
- Additional requirement to impact within a permanently shadowed crater

Centaur Target Selection Criteria

Criteria, in Priority Order, Cont.

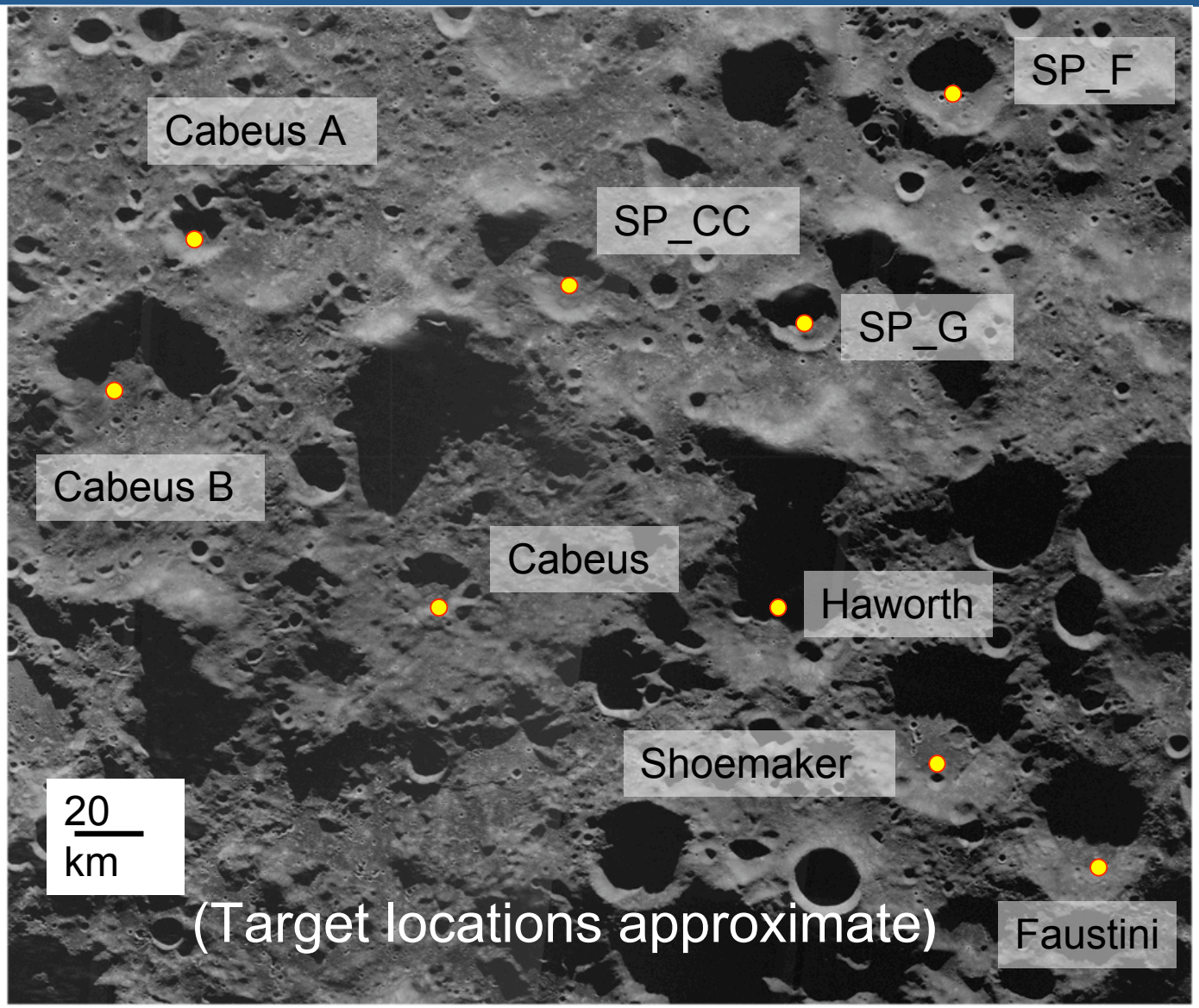
3. Observable by Earth assets

- Topographic masks between impact site and earth **<3 km required (<1 km goal)**
- Ability to observe from earth a minimum requirement and provides more than just backup data to the LCROSS Shepherding Spacecraft (S-SC) observations (e.g., water vapor from Keck)

4. Flat and Smooth terrain

- Slopes across 500 meters (100 meter goal) baseline **<20 deg req, <15 deg desired**
- Minimal Roughness (N<1 D=10 m rock per sqr km, N<300 D=5 m rock per sqr km)

List of Final Candidate Targets



Candidate Target Characteristics

Candidate Target Characteristics Summary and Ranking

- Table on the next slide gives a summary of each candidate target characteristics
- Targets are ranked in descending order
- Following slides support derivation of characteristics
- Color indicates viability: Green **GO**; Yellow **NO GO** (with red text indicating primary reason for exclusion)

Column Descriptions:

Rank: Final ranking number for each target
Target Designation: LCROSS Project target designation
Pole: Lunar North or South Pole
Crater Name: IAU Crater Name, if it exists
Slope (P/F): Pass (P) / Fail (F) evaluation for each target against target slope
Roughness: Pass (P) / Fail (F) evaluation for each target against target roughness
Pixon Mean WEH(%): Mean pixon WEH (see table note #2)
LEND $\Delta 2/\sigma$: LEND neutron depression from background - *Not for public release*
Topo Mask: Topographical line of sight mask to sun and to earth
Centaur Impact Location: Centaur impact lat/lon in Mean Earth Centric coordinates

Crater Summary Table

Current as of 9/03/09

Rank	Target Designation	Pole	Crater Name	Slope (P/F)	Roughness (P/F)	Pixon Mean WEH (%)**	LEND Δ2/σ	Topo Mask (km)		Centaur Target Location	
								To Sun	To Earth	Lat	Lon (East)
1	SP_CA	South	Cabeus A*	P	P	0.85		0.63	0.33	-81.55	316.90
2	SP_C	South	Cabeus	P	P	1.3		1.42	3.07	-85.50	307.70
3	SP_CB	South	Cabeus B	P	P	0.72		1.21	0.92	-81.95	305.00
4	SP_A	South	Faustini	P	P	0.31		3.00	1.50	-87.30	88.00
5	SP_B	South	Shoemaker	P	P	0.15		3.29	0.56	-88.40	50.00
6	SP_G	South	<no-name>	P	?	0.04		2.84	0.68	-84.70	2.20
7	SP_F	South	<no-name>	P	?	0.04		1.73	0.73	-82.40	11.50
8	SP_CC	South	<no-name>	P	P	0.29		1.54	0.24	-83.95	338.80
9	SP_D	South	Haworth	P	P	0.15		3.92	3.24	-87.75	355.00

* Note: The actual target site for Cabeus A is the somewhat smaller crater overlapping Cabeus A, sometimes referred to as Cabeus A1

** Note: Presented in this table is the Mean WEH derived from 100 noise realization simulations off of the original derived "truth"

Targeting Accuracy

- As part of target selection the accuracy at which the Centaur will be targeted was considered

- To be viable the targeting criteria rules had to be met within a **3.5 km diameter target circle**
    - The actual targeting performance is currently **expected to be better** and positional knowledge (map-tie errors) are now expected to be good to about 100 meters (horizontal position).

- Within each target crater a “sweet spot” is determined
    - Each “Sweet Spot” meets target criteria rules and was positioned to optimize impact ejecta solar illumination (while maintaining all other targeting rules)
    - In the Crater Summary Table, the latitude and longitude of the Centaur target location is for the “Sweet Spot” (see slide 19 for graphical representation of sweet spot locations)

Solar Illumination of Ejecta Cloud

- The amount of ejecta which comes into sunlight was analyzed using several separate modeling efforts, including analytical, empirical and semi-empirical

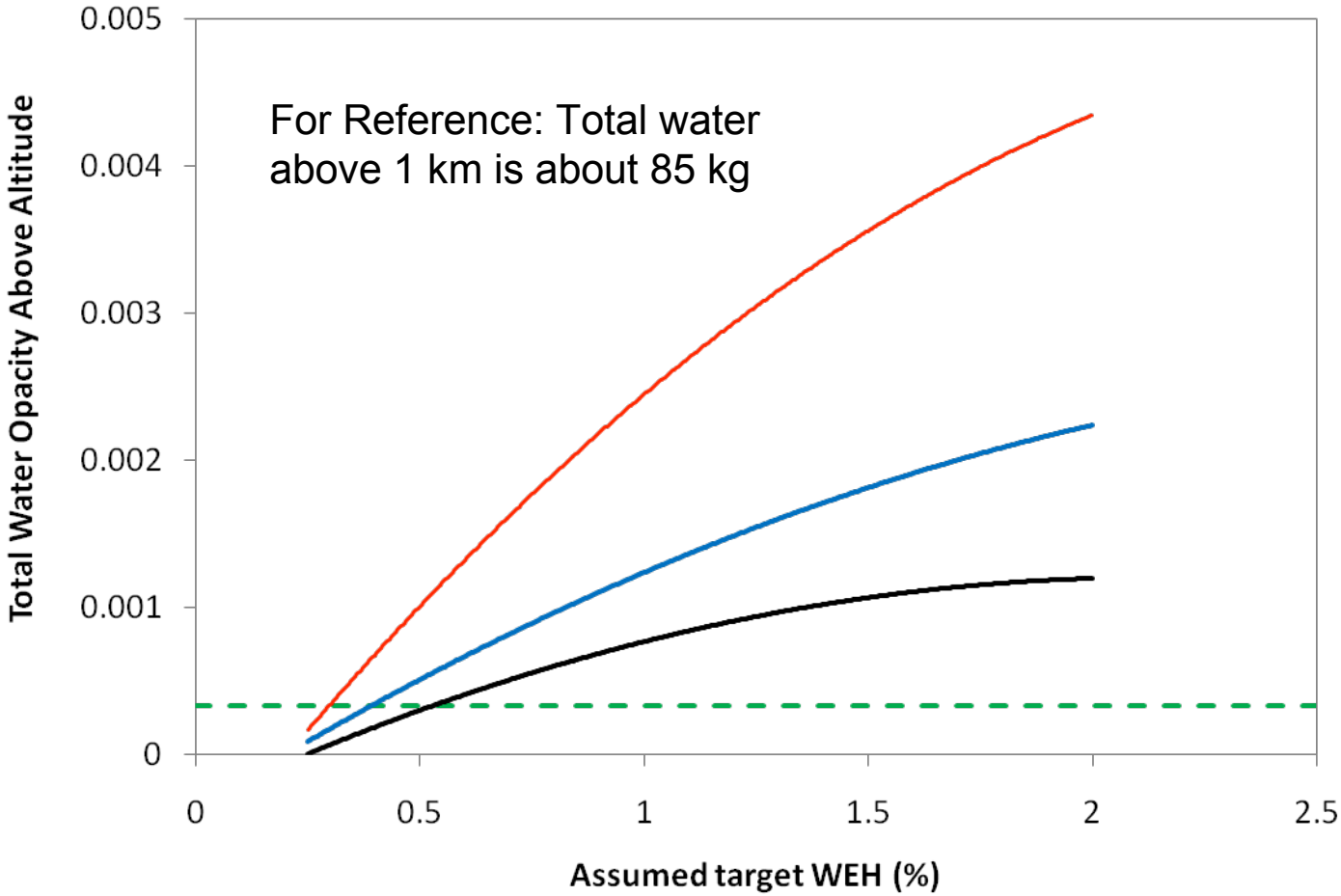
- Requirement driven by S-SC requirement to detect as little as 0.5% water ice in regolith

- Analysis has been updated with latest estimates from Schultz et al. (2009), with about 30% margin
  - Smooth Particle Hydrodynamic (SPH) modeled “dumbbell“ (Korycansky et al., 2009) and Ames Vertical Gun Range (AVGR) low-density models (Schultz et al., 2009) agree to within about 20%
  - Used lower limit of Schultz and added about 30% margin

- From ejecta trajectory analysis, total water and water opacity vs time we estimated as a function of material above an altitude (the altitude representing topographic mask height)

Solar Illumination of Ejecta Cloud

LCROSS S-SC Water Sensitivity vs Ejecta Altitude: From the S-SC observations, to meet 0.5% detection requirement solar topography mask must be < 3 km



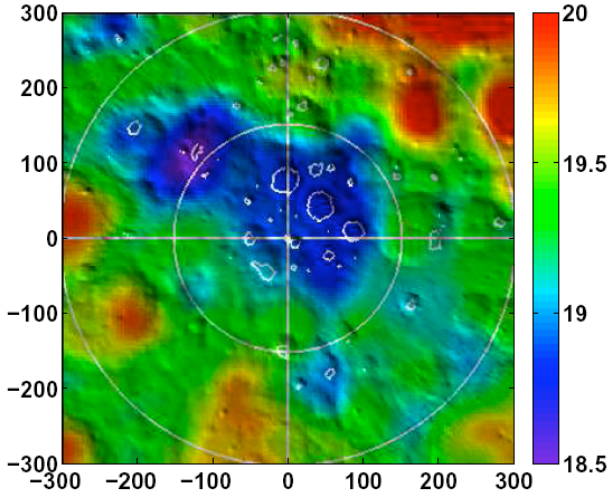
Association with Increased Hydrogen Concentrations

Two estimates for the local hydrogen association or concentration come from:

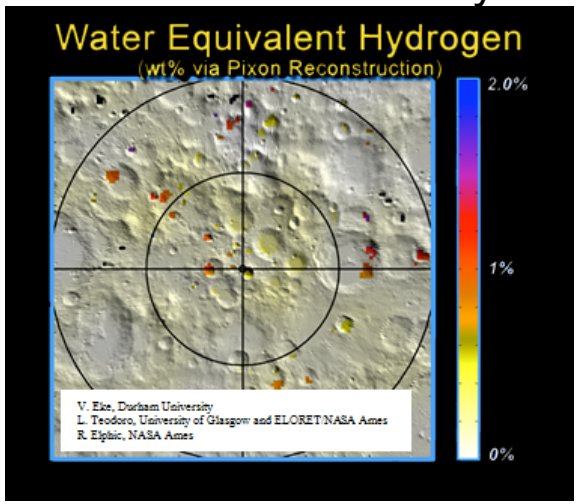
- Lunar Prospector neutron data and the Pixon Recovery analysis
- LRO LEND observations

Correlations and trends were used as a guide rather than just absolute values

LP Smoothed Epi. Neutron Counts

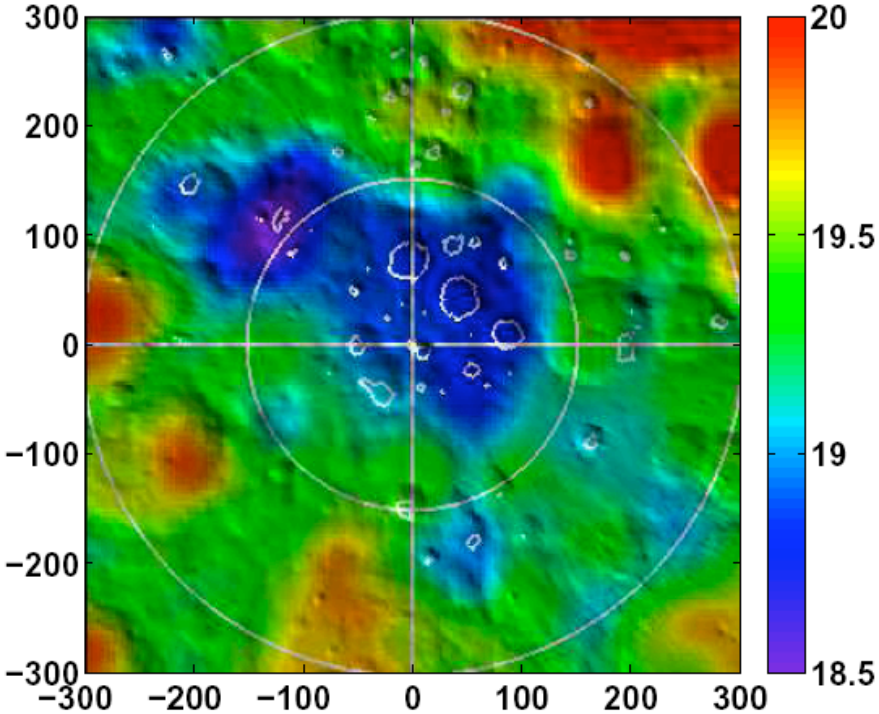


LP Pixon Recovery

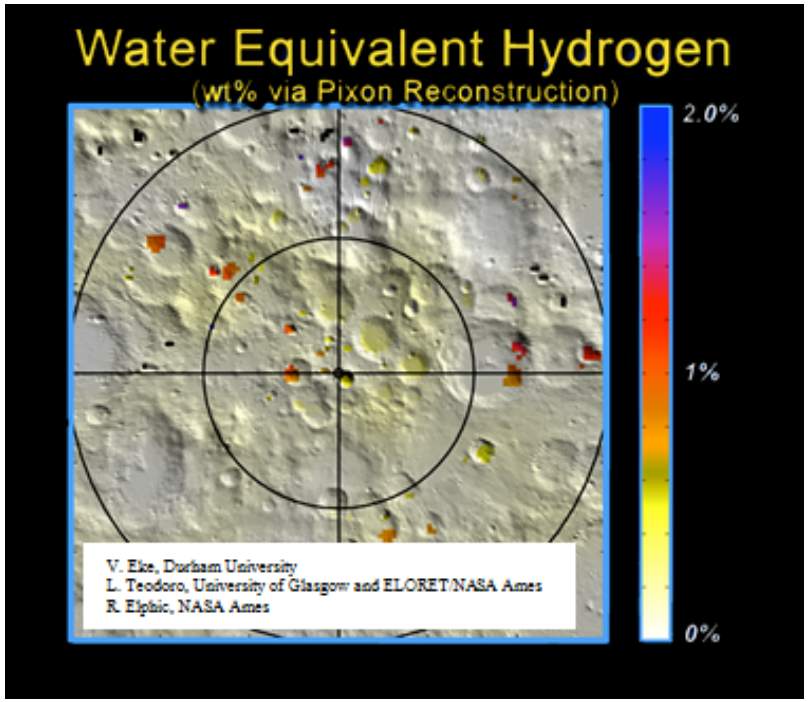


Association with Increased Hydrogen Concentrations

LP Smoothed Epithelial Neutron Counts

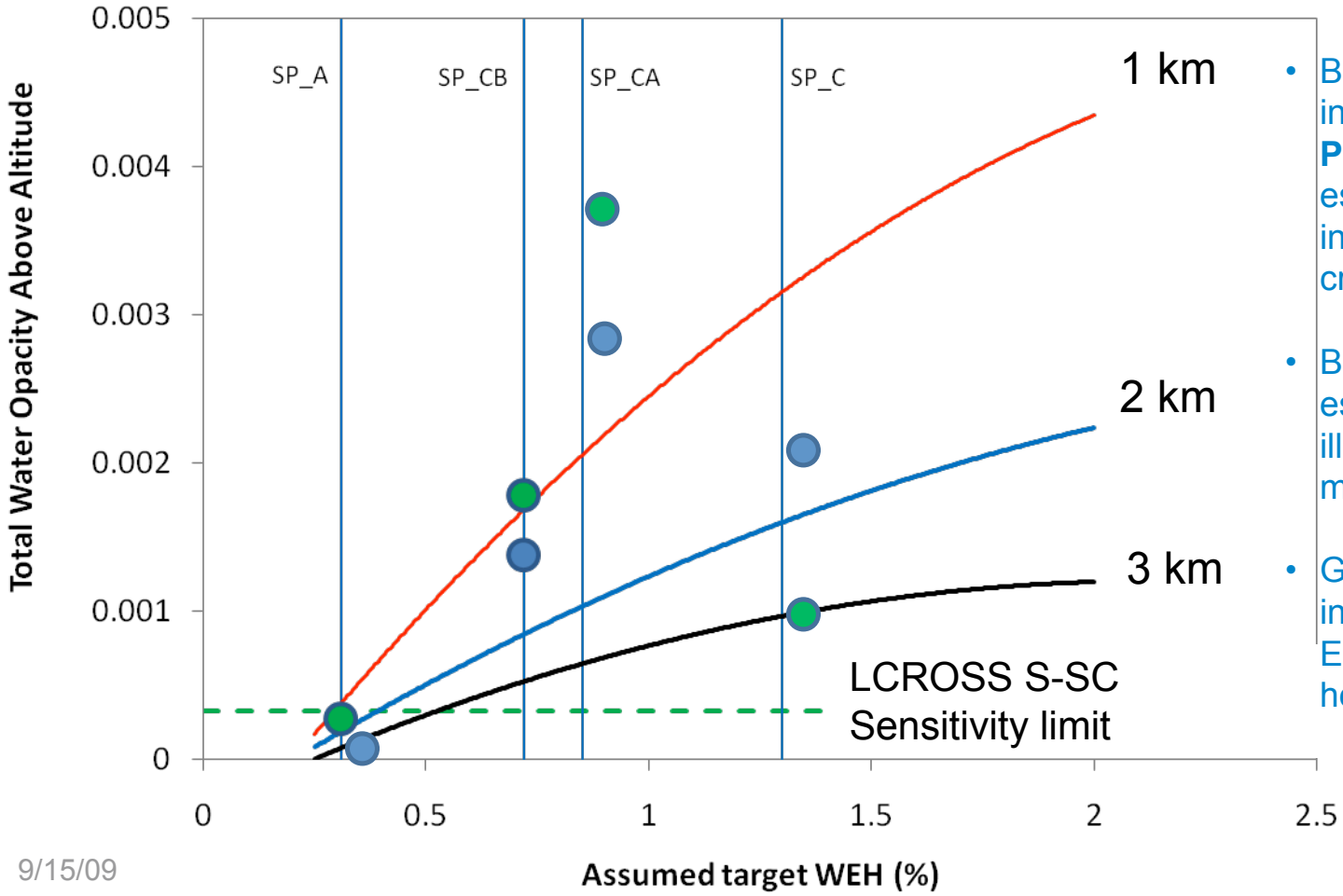


LP Pixon Recovery



Solar Illumination of Ejecta Cloud Convolved with [H]

LCROSS S-SC Water Sensitivity vs Ejecta Altitude: From the S-SC observations, to meet 0.5% detection requirement solar topography mask must be < 3 km



- Blue vertical lines indicate the **Mean Pixon Recovery** estimates for WEH in each of the top 4 craters
- Blue circles indicate estimate solar illumination topo mask height
- Green circles indicate estimated Earth topo mask height

Observable by Earth Assets

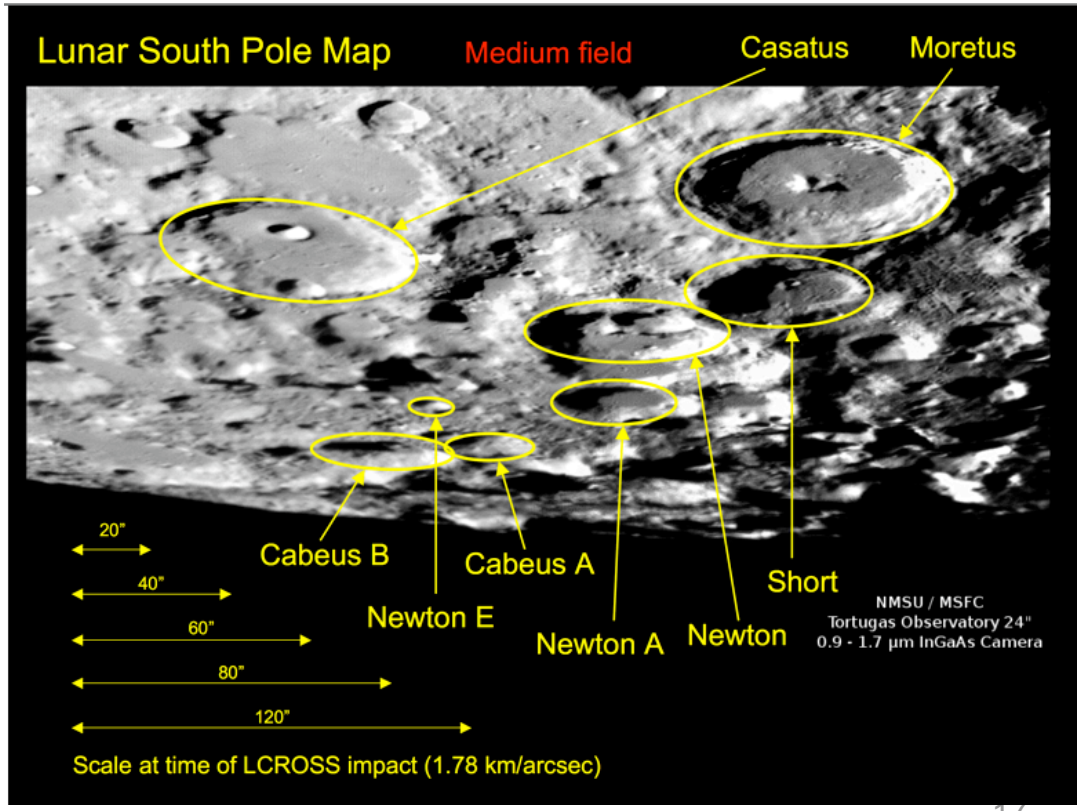
Mission Robustness insured by Earth observing assets

- Can detect water vapor and hydrated minerals
- Constrain total mass, mineralogical composition and grain sizes
- Project minimum success requirement to impact such that the event is visible to Earth

Primary concern is topographic masking (summarized in Summary Table)

Also consider:

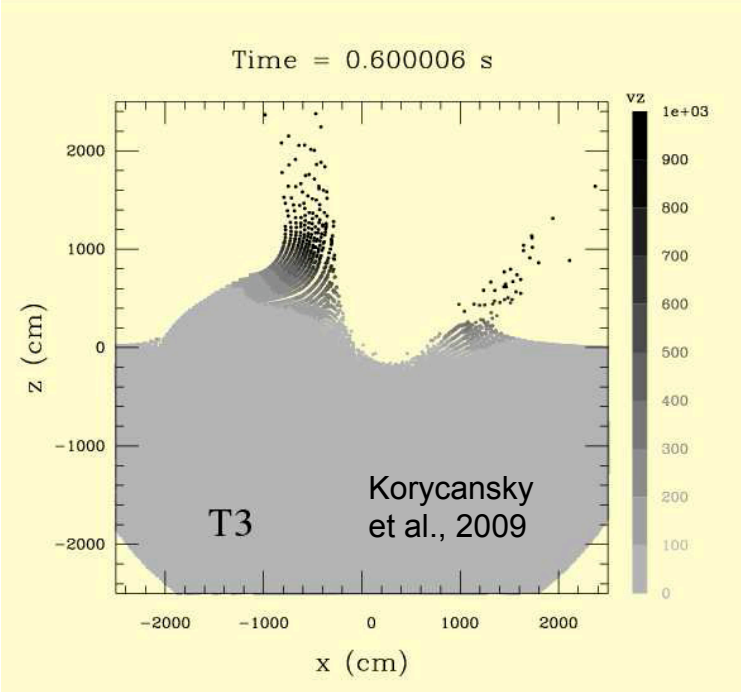
- Scene from Earth (expected ejecta contrast: against lit moon or shadow)
- Ability to find target
- Faustini may be difficult to find for Oct. 9 illumination



Flat and Smooth Terrain

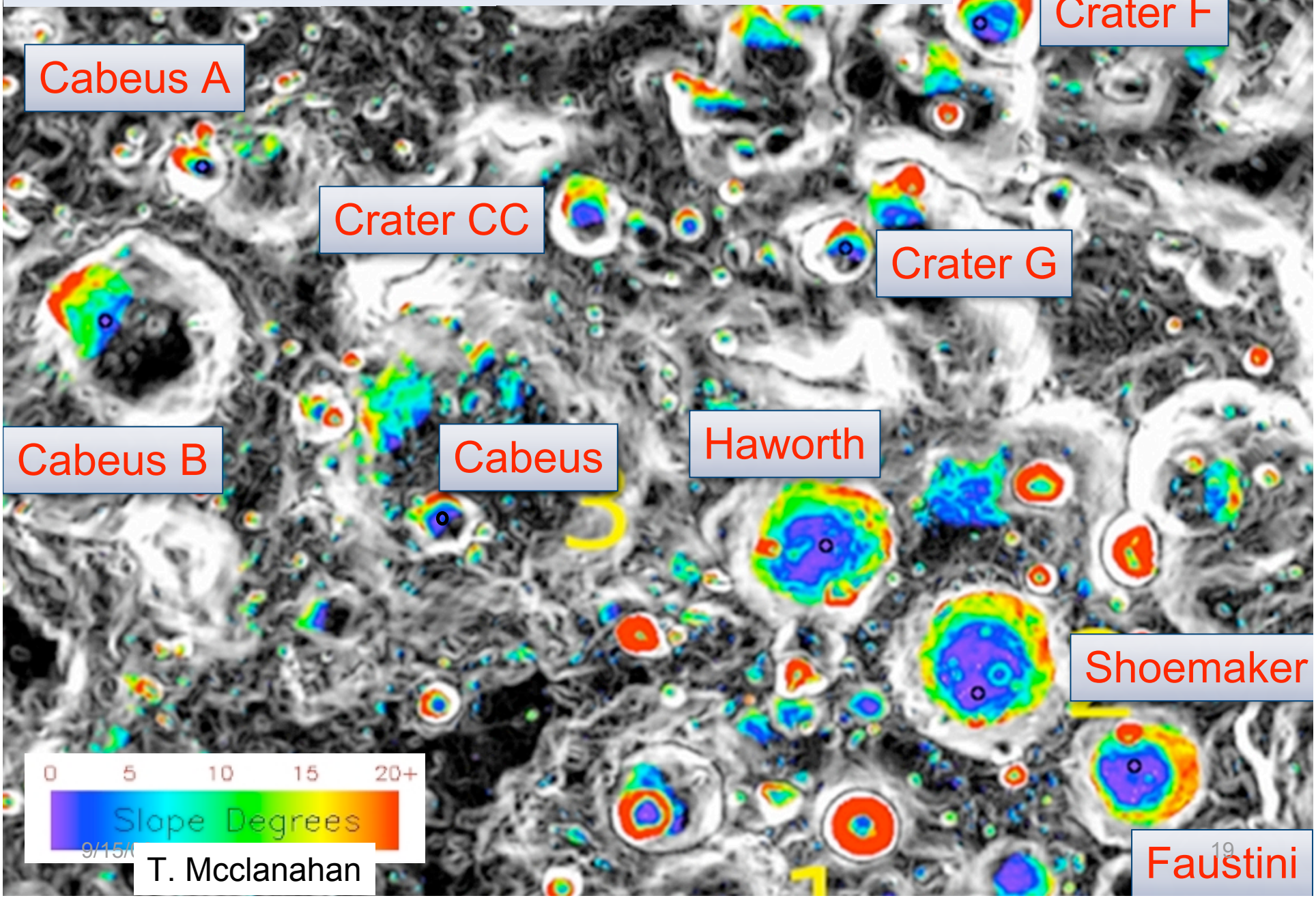
- Impact Ejecta “Productivity” dependent on slope and roughness effects
- Impacts into slopes greater than 20 deg across areas larger than about the crater scale can direct ejecta laterally (e.g., Korycansky et al., 2009), reducing the total ejecta at altitude
- Roughness (or Blockiness) can effect the total ejecta excavated and its velocity distribution
- Energy going into crushing of rock or inter-block slipping/compaction rather than “simple fluid” motion

Have used radar, altimetry, LOLA pulse width and imaging (Kaguya Terrain Camera (TC) and LRO LROC) to characterize slopes (quantitative) and roughness (qualitative)



Kaguya PSR and Slopes

- Black circles indicate LCROSS target planning accuracy limit



T. Mcclanahan

Conclusion

- Target characterization began even prior to LCROSS selection (part of proposal process)
- Both understanding of the impact processes, observation of the impact and the targets has matured considerably.
- Current list of candidate craters has continue to evolve with Kaguya, Chandrayaan-1 and LRO data sets.
- This presentation incorporated data from LRO as recently as Friday, Sept 4.

The accessibility of sites is greatly constrained by the criteria to have ejecta illuminated by sunlight and also be observable by Earth.

Conclusion

However several targets meet the basic criteria. These targets, in order of ranking, include Cabeus A, Cabeus, Cabeus B and Faustini.

Of these targets, Cabeus A is the most observable. Cabeus A also appears to have significant amount of hydrogen, however the actual amount is uncertain due to the low number of counts LEND has had over the region. The apparent correlation between LEND and Pixon Recovered WEH for Shadowed Regions does suggest that a general trend exists which would place Cabeus A as one of the wetter targets at the South Pole.

A considerable amount of data suggests both Cabeus (proper) and Faustini harbor significant amounts of hydrogen. However, in both cases the ejecta must travel to altitudes of at least 1.5 km (Cabeus) to 3 km (Faustini). Also, in the case of Cabeus the ejecta must travel at least 3 km before becoming visible to Earth, thus making Earth based observations much more difficult.

Recommendation

In discussions with the Project (including Maneuvering, Navigation, Systems Engineering, and Operations) it was agreed that there would ***very little impact to propellant or targeting margins to "come off" of any one of the Cabeus targets in favor of another Cabeus target.***

Thus, if further observations were to indicate Cabeus A is less attractive than current thinking, then the Project could retarget to Cabeus B or Cabeus, with little to no added risk. Any retargeting would only come after Project evaluation and Program concurrence.

- *LRO is currently approaching the Cabeus corridor again, and in two weeks, the time between now and TCM 7 (currently scheduled for September 25) LRO could have still another look at these craters.*
- *This additional LRO data will help reduce the total uncertainty of the LEND data, allow for LROC to image with higher solar angles, and allow for LAMP to further accumulate data for the Cabeus region. All of these extra data will further maximize the relevance of the LCROSS impact.*

Recommendation

Therefore, it is the recommendation of the LCROSS Science Team to target Cabeus A for the October 9, 2009 impact.

While Cabeus A is the current recommended target, the LCROSS science team will continue to evaluate Cabeus A against new data as it becomes available, with the understanding that the potential to re-target in favor of one of the other Cabeus candidates is an option prior to TCM 7 September 25, 2009).