The Lunar Polar Environment

Ben Bussey
JHU/APL
ben.bussey@jhuapl.edu

Moon 101
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- Ice at the Poles?
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Lunar Poles

- Interesting for both operational and scientific reasons
- Spin axis 1.5° from the perpendicular to the ecliptic plane results in special illumination conditions
- Sun always close to the horizon during the 708 hour lunar day
- Permanently shadowed regions are cold traps (< 100K) and are possible locations of ice deposits
- Poles offer abundant solar power and relatively benign operational environment (220 K)
Location! Location! Location!

- South pole inside SPA basin rim.
- 2800 km diameter
- Mantle deposits?
- Quiet far side
The Search for Ice

• Ice is a resource: Oxygen, water, fuel
  – Two orders of magnitude less to extract H$_2$ from ice than equatorial regolith

• Lowers cost, learn to live off the land

• Clementine and Lunar Prospector both detected evidence of ice at the lunar poles

• The search continues…
Clementine Bistatic Radar Experiment
Lunar Prospector

Water Ice Signature

Medium Energy Neutrons

Latitude (degrees)

North Pole

South Pole
But what if there is no ice?

- Ice is a major resource
- We are NOT going to the poles because of the ice
  - i.e. Ice is not a requirement
  - Enhanced hydrogen *is* present in any event
- We are going to the poles because of the unique lighting conditions.
  - Light is a resource too!
NP Orbit Movie
Crater Simulations

- Current illumination coverage is limited.
- Simulations permit investigations of all lighting conditions.
- Lunar topography data exist (Margot et al., 2000; Cook et al., 2000).
- Lunar crater profiles are known (Pike, 1977).
Topography Simulation Results

• Both topography datasets produce reasonably accurate results.
• Radar topography produces more accurate simulations but are constrained to nearside illumination direction due to the spatial coverage of DEM.
• Stereo topography permits equally accurate simulations for all illumination directions.
Simulated Simulations

- Crater profiles for lunar craters are known (e.g. Pike, 1977).
- Investigate amount of permanent shadow as a function of size, latitude and season.
- Craters in the range 2.5 to 20 km were studied
- Craters placed every 1° latitude from 70° to 90°
- A series of runs are conducted to calculate the extent of permanent shadow
- $S = (0.9465 \cdot D) + (0.0202 \cdot q^2) - (0.009258 \cdot q \cdot D) - 78.06$
Permanent Shadow

- 1000’s km² of permanent shadow in simple craters at both poles
- Permanent shadow exists in simple craters at long distances from the pole
- Represent possible locations of volatile deposits
Clementine’s View of the Poles

- Imaged each pole every 10 hours for 71 days
- Data collected during winter in the southern hemisphere
- High resolution data collected at 15 m/pixel
Quantitative Illumination Map

- No constant illumination
- A, B, C lit more than 70% of a winter day
- A & B collectively lit > 98%
Illumination Profiles

- No constant illumination
- A, B, C lit more than 70% of a winter day
- A & B collectively lit > 98%
High Resolution Data
High Resolution Image of the Rim of Shackleton Crater + Illumination
North-Pole Illumination Map

- Four places on the rim of Peary crater were constantly illuminated during a lunar summer day.

- All are in close proximity with permanently shadowed regions.
Conclusions

• No continuously illuminated areas at the south pole. Possibly at the north.

• Extensive dark regions at both poles, potential locations for ice deposits.

• Widely distributed highly illuminated areas.

• Potential for constant solar power
SMART-1
AMIE’s View of the Poles
Spatial & Temporal Coverage Vastly Improved

• Covered a whole year
  – Both summer and winter, ∴ illumination extremes

• South Pole
  – 50 m/pixel (~Clementine hi-res)
  – 50 km x 50 km FOV

• North Pole
  – 500 m/pixel (~Clementine UVVIS)
  – 500 km x 500 km FOV
AMIE Conclusions

- AMIE images complement existing Clementine polar coverage
- Initial results support earlier findings that zones of extended illumination exist near the south pole
- Have found an area near the south pole that appears to be it for an entire day in summer
- Future work will produce refined quantitative illumination maps for both poles
Kaguya (SELENE) HDTV images

Malapert peak

De Gerlache

Shackleton

Confirms inferences from Clementine and SMART-1 images on sunlit peaks in region
Malapert peak appears to be in sunlight during lunar night
Surface Operations

- Relatively short eclipse durations increase useable operations time
- But....
  - Best locations are very localized
  - Still get long eclipse periods (~10’s of hours) from an engineering point of view
- Vertical structures encounter full solar thermal conditions (up to 400 K)
- Low Sun means long shadows
- Direct Earth communication, 14 days on, 14 days off
Chandrayaan-1

- Launch Autumn 2008, 525 kg dry mass
- 2 year duration, 100 km circular orbit
- 11 Instruments
  - 5 Indian, 6 International contributions
  - High resolution remote sensing in the visible, near infrared and X-ray
  - Global high resolution topography
  - Global low resolution mapping of key elements (including Mg, Al, Si)
  - Mini-SAR
1. Terrain mapping camera (TMC);
2. Lunar laser ranging instrument (LLRI).
3. Moon mineralogy mapper (MMM);
4. Chandrayaan Imaging X-ray Spectrometer (CIXS);
5. High energy X-ray spectrometer (HEX);
6. Miniature synthetic aperture radar (mini-SAR) antenna
7. Hyper spectral imager (HySI);
8. Infrared Spectrometer (SIR-2);
9. Sub-keV atom reflecting analyzer [SARA]
10. Radiation dose monitor (RADOM);

The blue panel is the canted solar array.
Lunar Reconnaissance Orbiter

- Launch spring 2009
- 1 year mission in 50 km polar orbit
- Six instruments
  - LROC
  - LOLA
  - LEND
  - LAMP
  - Diviner
  - Crater
- One Tech demo
  - Mini-RF
The LCROSS Mission is a Lunar Kinetic Impactor employed to reveal the presence & nature of water ice on the Moon

- LCROSS Shepherding S/C (S-S/C) directs the 2000 kg Centaur into a permanently-shadowed crater at 2.5 km/s
- ~200 metric tons minimum of regolith will be excavated, leaving a crater the size of ~1/3 of a football field, ~15 feet deep.
- The S-S/C decelerates, observing the Centaur ejecta cloud, and then enters the cloud using several instruments looking for water
- The S-S/C itself then becomes a 700 kg 'impactor' as well
- Lunar-orbital and Earth-based assets will also be able to study both clouds, (which may include LRO, Chandrayaan-1, HST, etc)
Mini-RF

- The case for water-ice can be resolved only if robust and repeatable data of the lunar polar regions support that conclusion. This rigorous standard can be met only by a dedicated polar-orbiting radar.

- Mini-RF will use a unique hybrid polarity architecture to look for ice deposits

- Transmit circular polarization (e.g. right-circular polarization RCP)

- Receive coherent orthogonal polarizations

- Derive Stokes parameters of the received signal

- Use Stokes parameters to reconstruct and investigate the nature of the backscatter field. Distinguish between surface (roughness) and volume (ice) scattering
## Mini-RF Overview

<table>
<thead>
<tr>
<th>Parameter</th>
<th>S-band</th>
<th>S-band and X-band</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Polarization</strong></td>
<td>$T_x$</td>
<td>$R_x$</td>
</tr>
<tr>
<td></td>
<td>Right Circular Polarization</td>
<td>H- and V- linear orthogonal polarizations</td>
</tr>
<tr>
<td><strong>Scatterometry</strong></td>
<td>S-band</td>
<td>(none)</td>
</tr>
<tr>
<td><strong>Imager</strong></td>
<td>Regional maps</td>
<td>Site-specific selections</td>
</tr>
<tr>
<td><strong>Resolution (m/pixel)</strong></td>
<td>75</td>
<td>75, 7.5 azimuth x 15 range</td>
</tr>
<tr>
<td><strong>Looks</strong></td>
<td>16</td>
<td>16 or 8</td>
</tr>
<tr>
<td><strong>Swath (km)</strong></td>
<td>8</td>
<td>6 or 4</td>
</tr>
<tr>
<td><strong>Altitude (km)</strong></td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td><strong>Incidence</strong></td>
<td>33°</td>
<td>45°</td>
</tr>
<tr>
<td><strong>Interferometry</strong></td>
<td>No</td>
<td>Yes: experimental</td>
</tr>
</tbody>
</table>
Conclusions

- The Lunar Poles ARE the ideal lunar outpost site
- Easiest place to establish permanent, sustainable human presence
- Best areas of illumination are likely small and dispersed
- Constant solar energy likely requires multiple sites to generate power
- Ice is a significant resource, but not a requirement, and will be a challenge to extract
- Still a large number of unknowns, but key data will be available soon