Lunar Polar Volatiles: Compelling Science at the Lunar Poles

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Lunar Polar Volatiles: Compelling Science at the Lunar Poles

- What is known about lunar polar volatiles.
- Science questions about volatiles at the lunar poles.
- New information from lunar poles.
  - Orbital and Landed Measurements.

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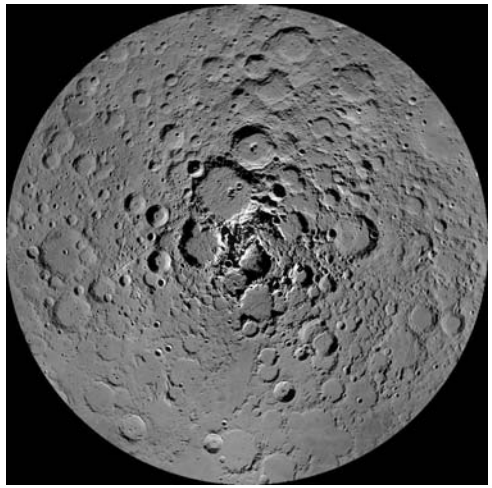
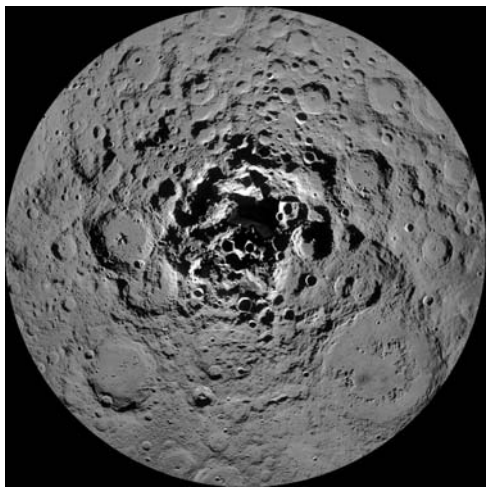
History of lunar polar volatiles

North Pole (>70°)



South Pole (<-70°)



images from the Clementine mission

- Permanently shaded craters at the poles of the Moon act as cold traps for hydrogen and other volatile elements.
- Cold temperatures + billions of years of accumulation
  → Significant deposits of volatiles.
- *Watson et al*., [1961] and *Arnold*, [1976] predicted significant amounts water ice may exist at the lunar poles.

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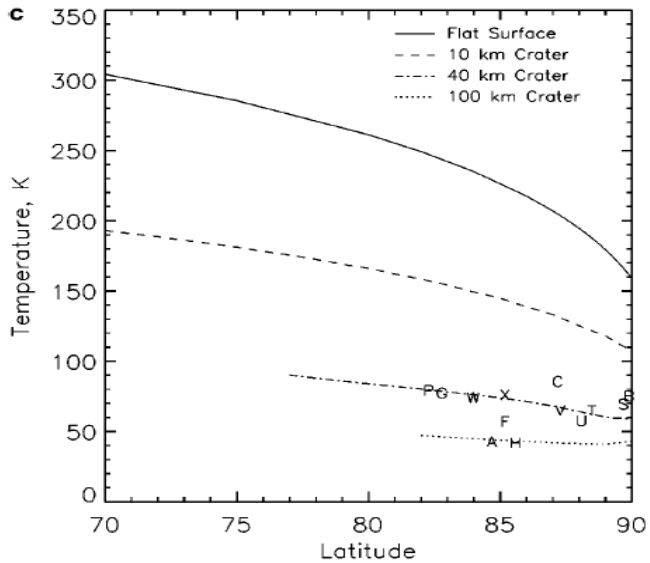
What is Known: Environment of lunar poles



Maximum diurnal temperatures for various sized craters (from *Vasavada et al.*, [1999]).

Locations of simple craters containing some permanent shadow (from *Bussey et al.*, [2002])

- Temperature in lunar polar craters
  - Modeled temperatures for craters < 40 km dia. are less than 70 K near poles [***Vasavada et al.***, 1999].
- Area of permanent shade
  - Estimated permanent shade from simple craters is ≤7500 km^2 (north) and ≤ 6500 km^2 (south) [*Bussey et al.*, 2002].
- There is more shadowed area in complex craters and inter-crater topography.

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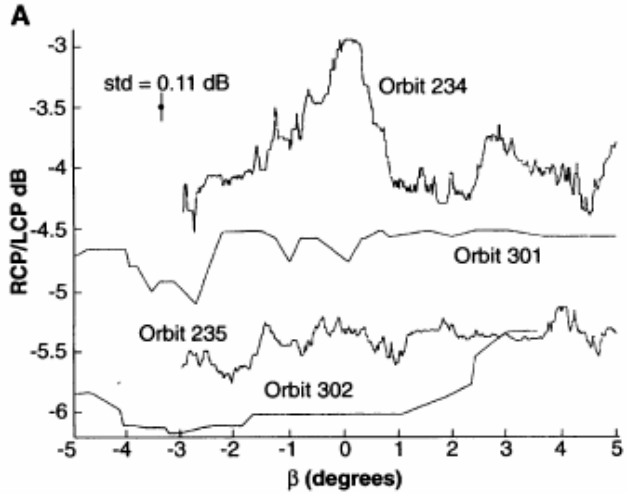
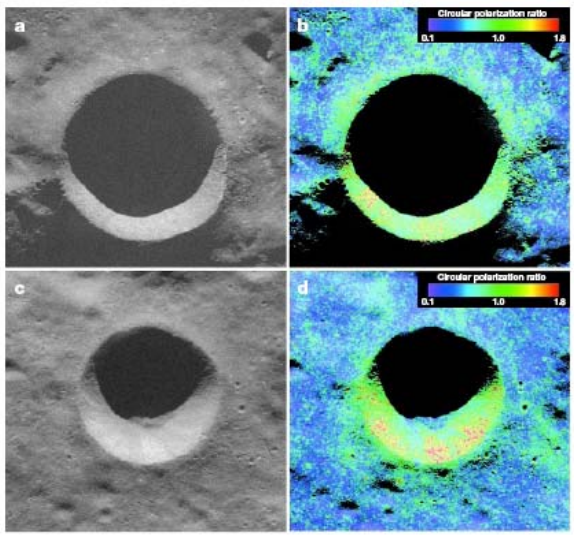
What is Known: Volatile Measurements



Radar circular polarization ratios near the Moon's south pole (from *Nozette et al*., [1996]).



Radar (left) and circular polarization ratio (right) for Shackleton (top) and Schomberger (bottom) craters [from *Campbell et al*., 2006].

Orbital and Earth-based Radar Data

- Bi-static radar from Clementine.
  - Hints of H_2O at lunar south pole [*Nozette et al*., 1996]
  - H_2O interpretation controversal [*Simpson and Tyler*, 1999]
- Earth-based radar.
  - No clear evidence for large amounts of water ice [*Campbell et al*., 2006].
  - Radar data consistent with up to 10s wt.% H_2O in lunar regolith [Campbell, pers. comm].
- Mercury shows significant polar deposits compared to the Moon [*Harmon et al*., 2001].

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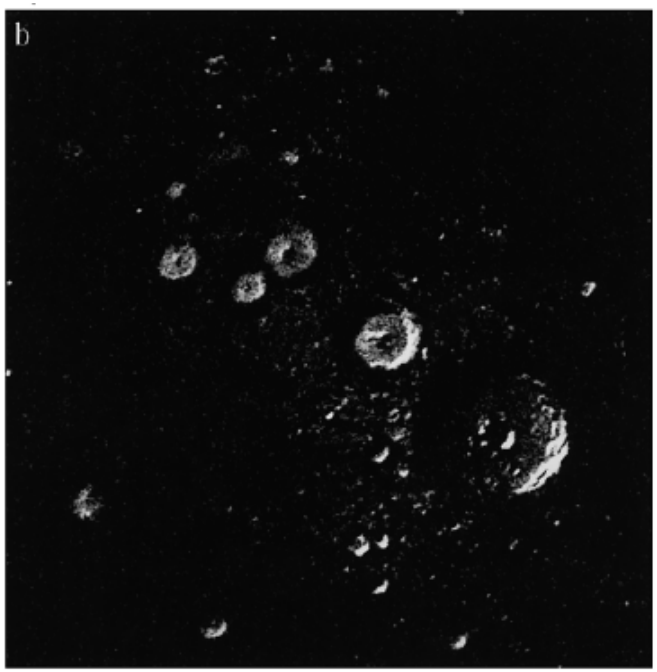

Radar image of craters near Mercury's north pole [*Harmon et al*., 2001].

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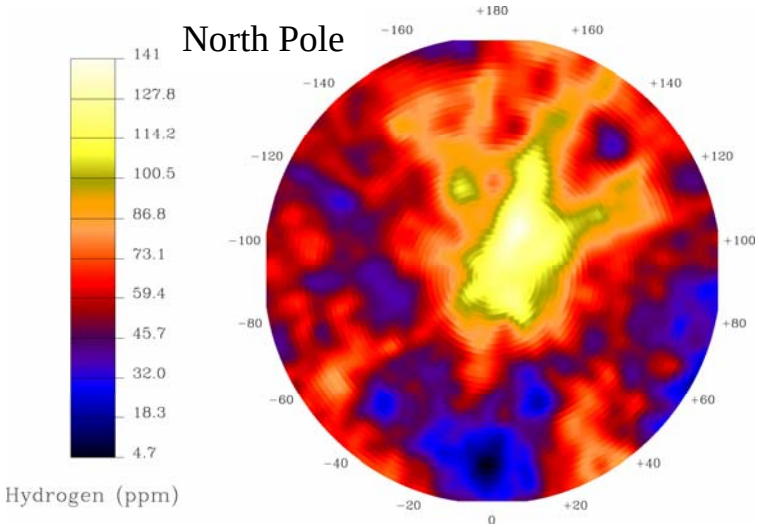

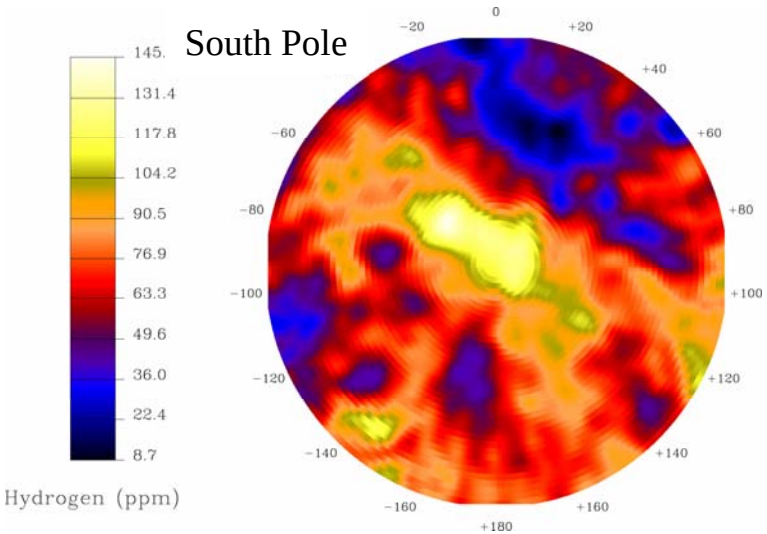

(from *Lawrence et al.*, [2006])

Orbital Neutrons and Gamma-rays

- Neutron signal shows 100 – 150 ppm H over 45 km^2 footprint [*Feldman et al.*, 2000, 2001; *Lawrence et al.*, 2006].
- Combine with estimate of permanent shade to derive surface H content.
  - *Feldman et al.*, [2001] estimate 1700±900 ppm H (1.5 wt.% H_2O)
  - *Elphic et al.*, [2007] use deconvolution to show [H] = 1100 ppm H in some locations.
  - Uncertainties derive from knowledge of permanent shade.
- Fast and thermal neutrons indicate H is buried by 10 – 30 cm of dry lunar soil [*Feldman et al.*, 2000; *Lawrence et al.*, 2006].
- Gamma-rays consistent with <1.5 wt.% H_2O over large regions [*Feldman et al.*, 2000].

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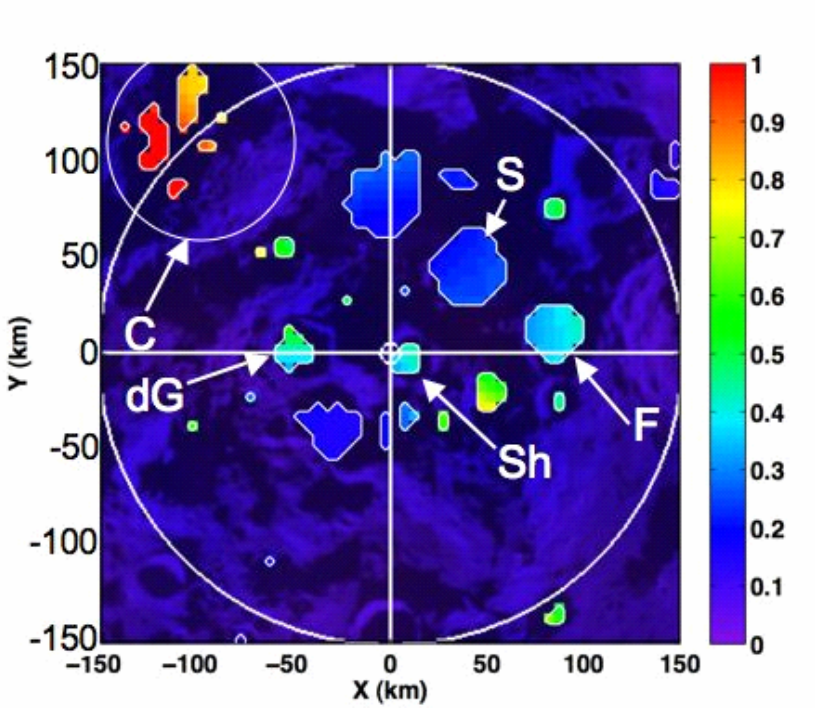

Spatially Deconvolved Hydrogen Abundances at South Pole (from *Elphic et al*., [2007])

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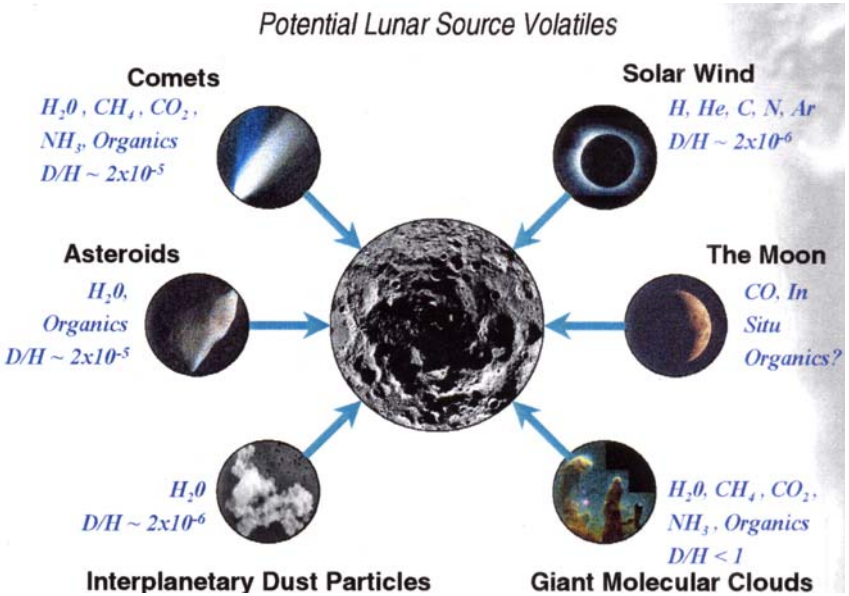
Scientific Questions Related to the Lunar Poles



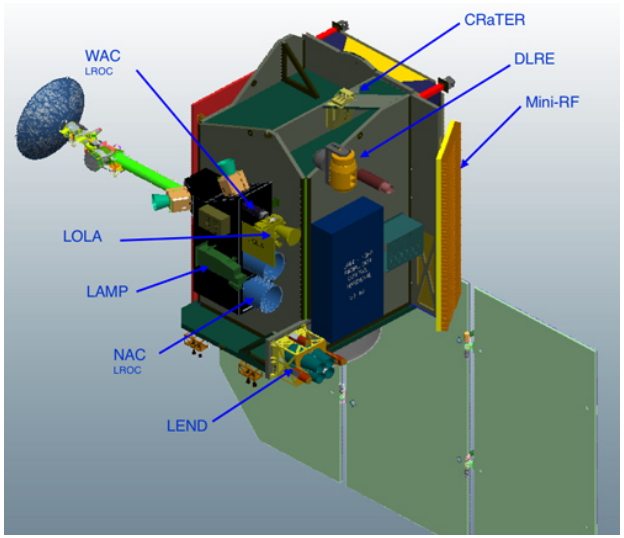
(from *Lucey*, SPIE, [2000])

- What is the compositional distribution – laterally and in depth – of polar volatiles?
- What is the molecular form of hydrogen at the lunar poles?
  - Solar wind hydrogen or water ice?
- What are the dominant sources of polar volatiles?
  - Variety of sources range from solar wind, comets, asteroids, to giant molecular clouds.
  - Is there a potential for pre-biotic chemistry at lunar poles? (*Lucey* [2000])
- What retention/loss/transport processes operate on polar volatiles?
  - Why is the Moon apparently different from Mercury?
- What is the regolith structure in a very cold and possibly volatile rich environment?

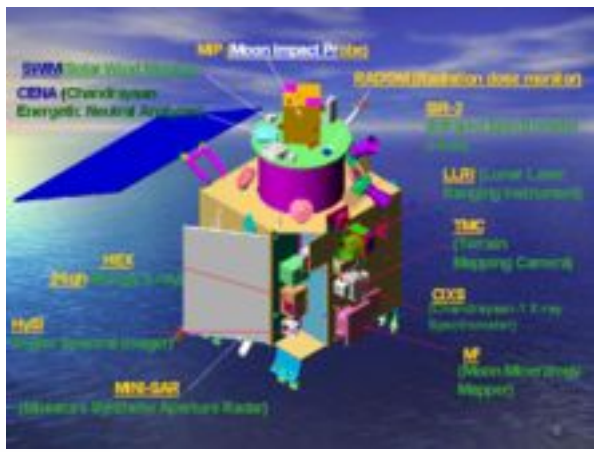
Compelling Science at the Lunar Poles

- The study of lunar polar volatiles provides insight into the volatile distribution within the solar system.
- The Moon is the nearest, accessible reservoir of solar system volatiles.
  - The lunar poles collect volatiles in an analogous manner to how Antarctica collects solar system refractory materials (i.e., meteorites).
  - The lunar poles may retain a unique record of solar system environment.
- Lunar polar science has strong synergy with NASA human exploration.
  - Polar volatiles represent possible resource for humans on the Moon.
  - New data will greatly benefit both the science and exploration enterprises.

New Information From Lunar Poles: Orbital



Lunar Reconnaissance Orbiter



Chandrayaan

- New international spacecraft will provide significant new information about lunar poles.
  - SELENE (Japan)
  - Lunar Reconnaissance Orbiter (USA)
  - Chandrayaan (India)
  - Chang'E (China)
- Better knowledge of permanent shade, including topography, crater morphology.
- Better knowledge of temperature.
- Better knowledge of volatile distribution.
  - There may be limitations with polar hydrogen measurements on LRO.

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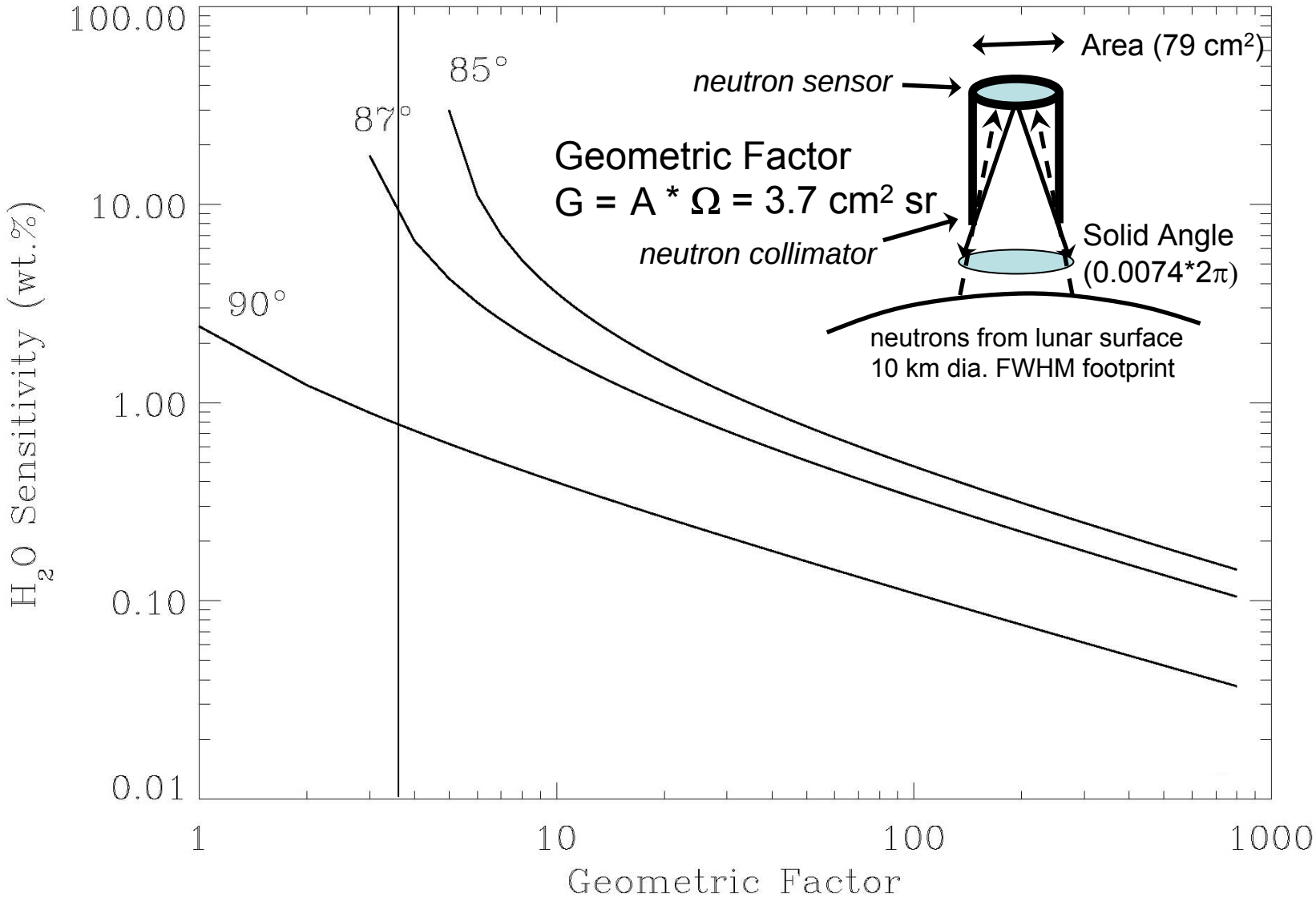
Limitations of Hydrogen Measurements



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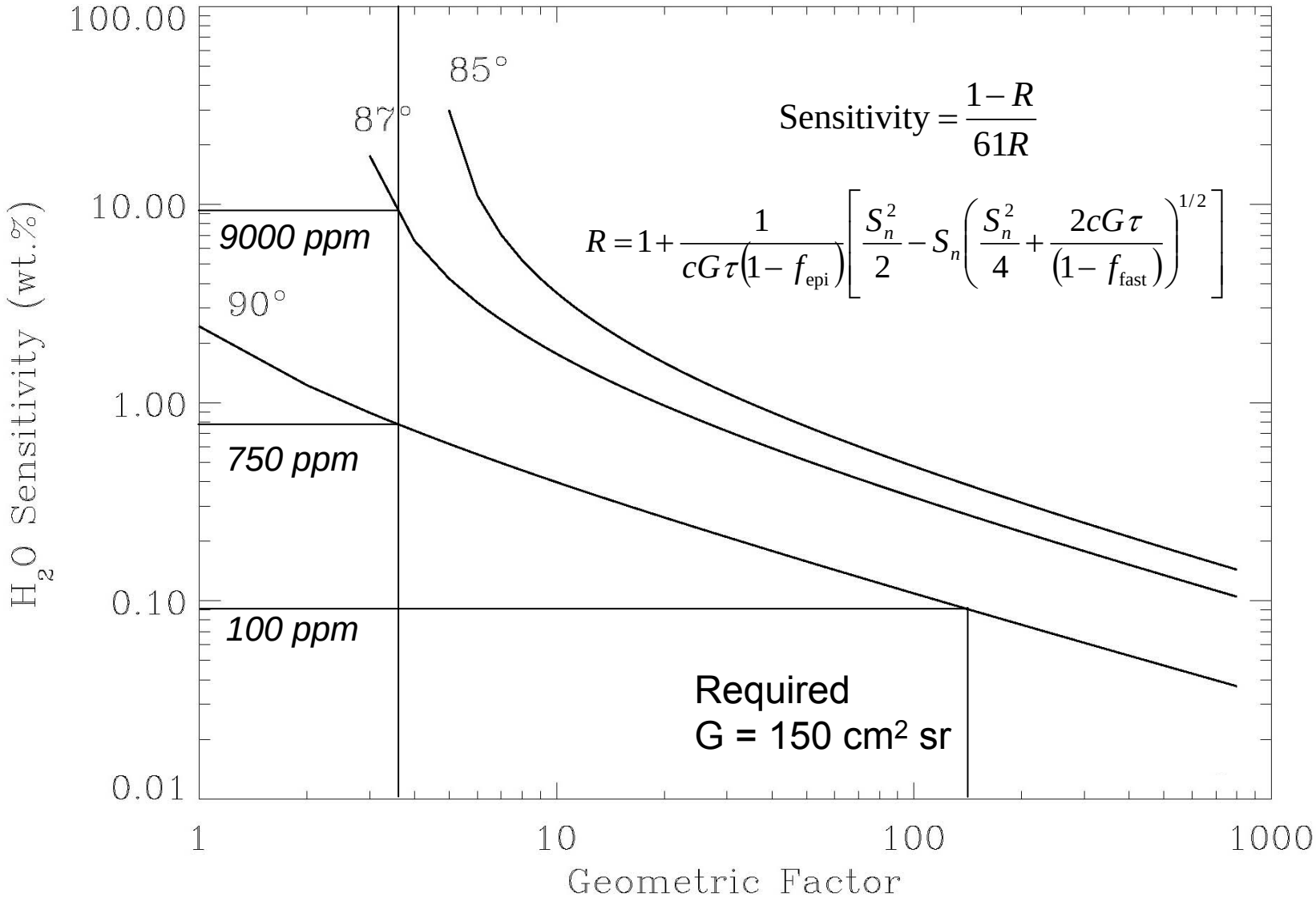

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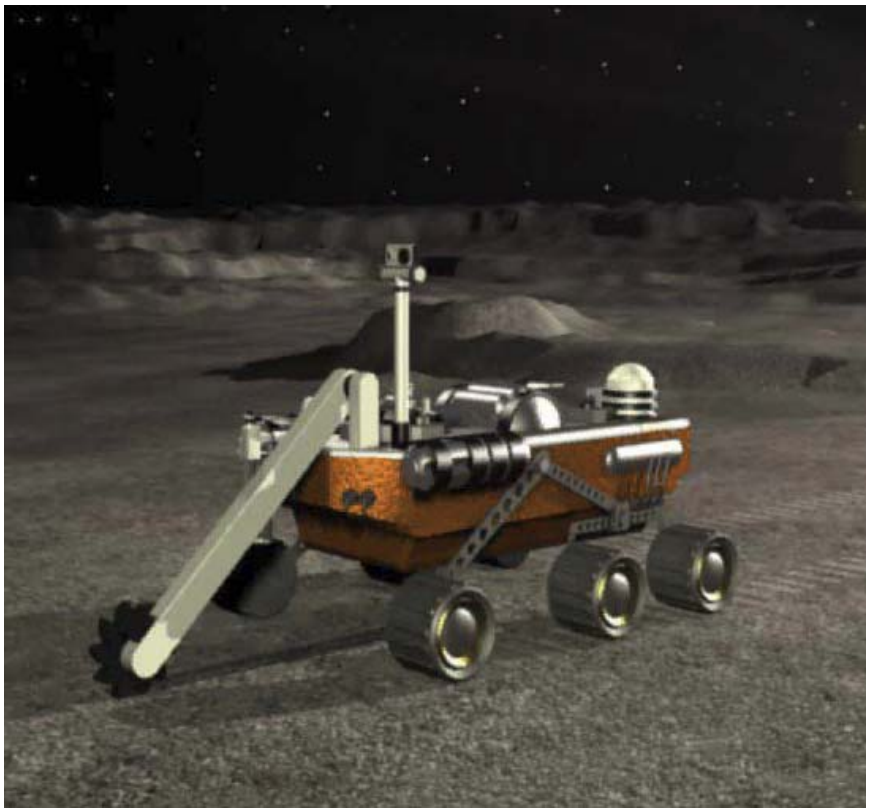
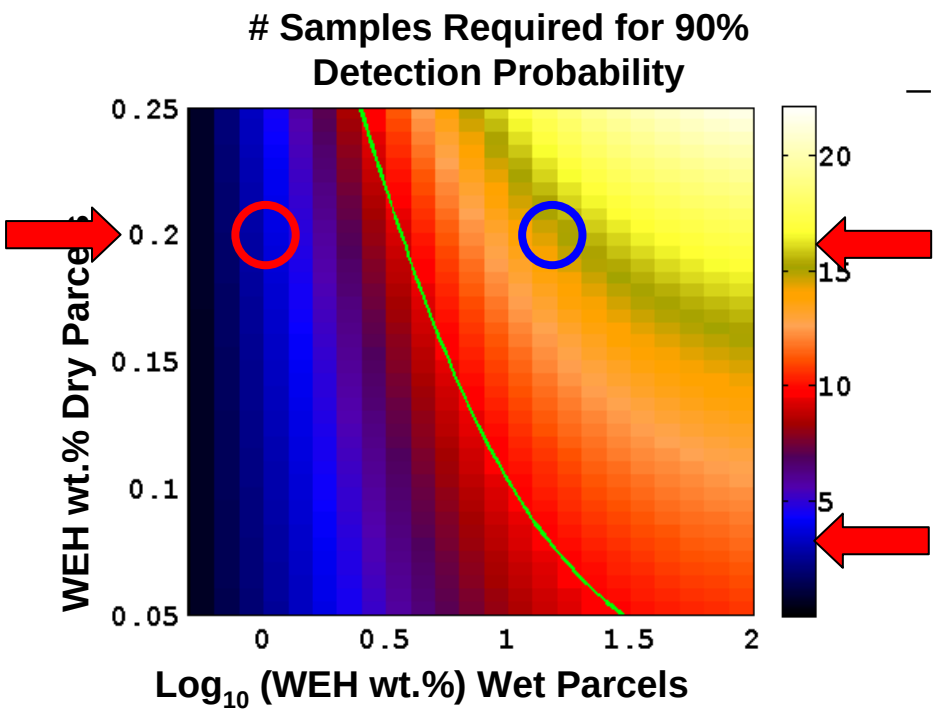
New Information From Lunar Poles: Landed



- Landed measurements are required to fully understand lunar polar regions.
- Lateral and depth dependent volatile composition measurements.
  - Evaluate spatial inhomogeneities and stratigraphy.
- Isotopic composition
  - Use D/H ratio to investigate sources of cometary material.
- Atmospheric measurements to understand retention/loss/transport processes.

Sampling Requirements for Polar Volatiles



- Statistically estimate required sampling sites for locating wet parcel within dry parcel.
  - If wet area has 1 wt.% WEH, then less than 5 sample sites are needed.
  - If wet area has 20 wt.% WEH, then greater than 15 sample sites are needed.

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Conclusions

- The lunar poles are an exciting and unique environment at the lunar surface.
- Near-term, future measurements will reveal much new information about the structure and history of the lunar poles and the polar environment.
- Lunar polar scientific exploration is well suited for the polar outpost architecture.