Solar Power for Lunar Pole Missions

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- Advantages of lunar pole sites
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- Electrostatic dust lifting and adhesion
- Technology challenges

- Backup charts…

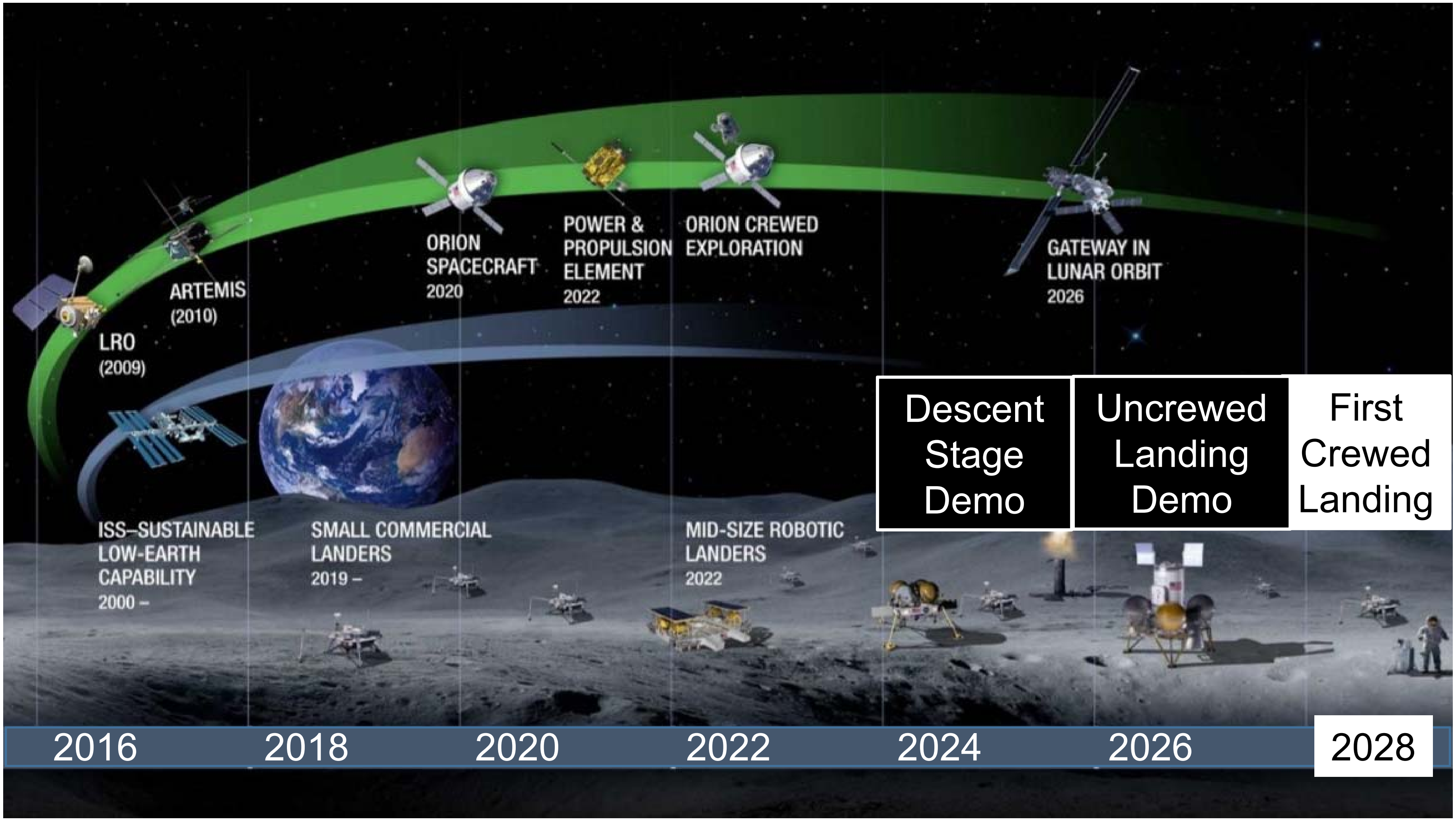
8 charts

8 charts

Administrator Bridenstine's Vision

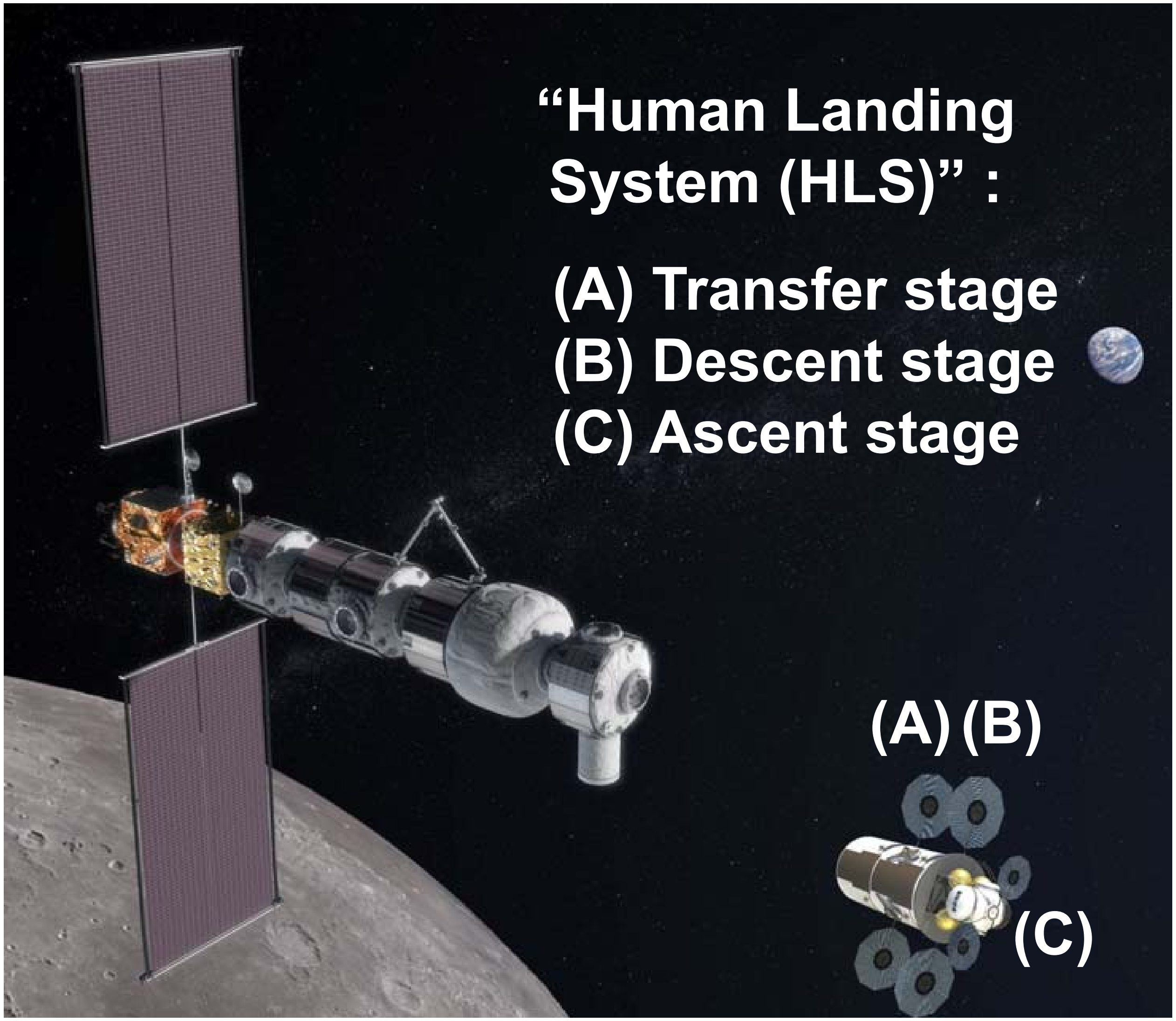
- "This time we're going to stay. We're not going to leave flags and footprints and then come home."
- "We're making it **sustainable** so you can go back and forth regularly with humans."
- "We want the entire architecture between here and the Moon to be **reusable**."
- "We want access to the entire Moon."

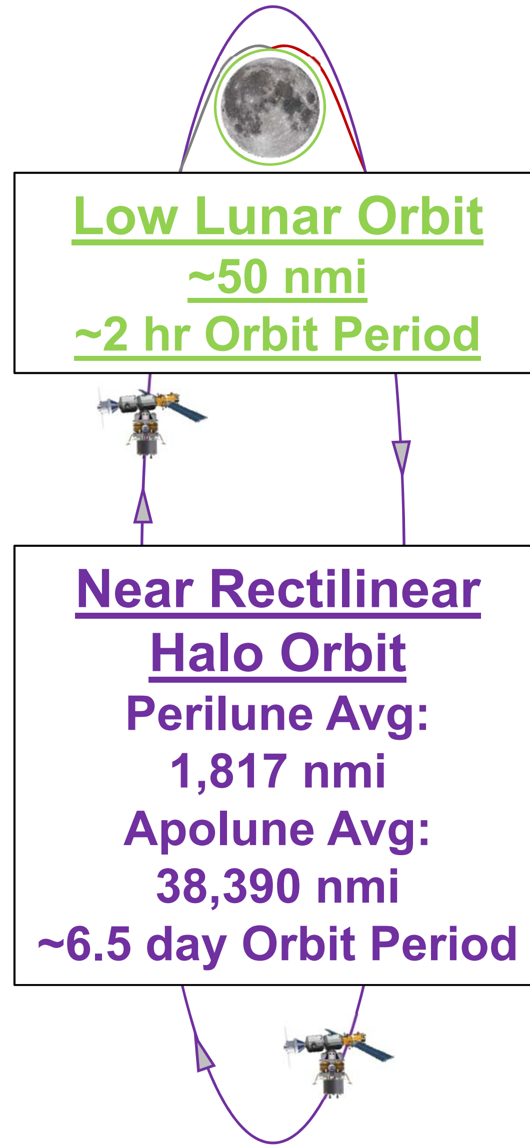
NASA's Return to the Moon



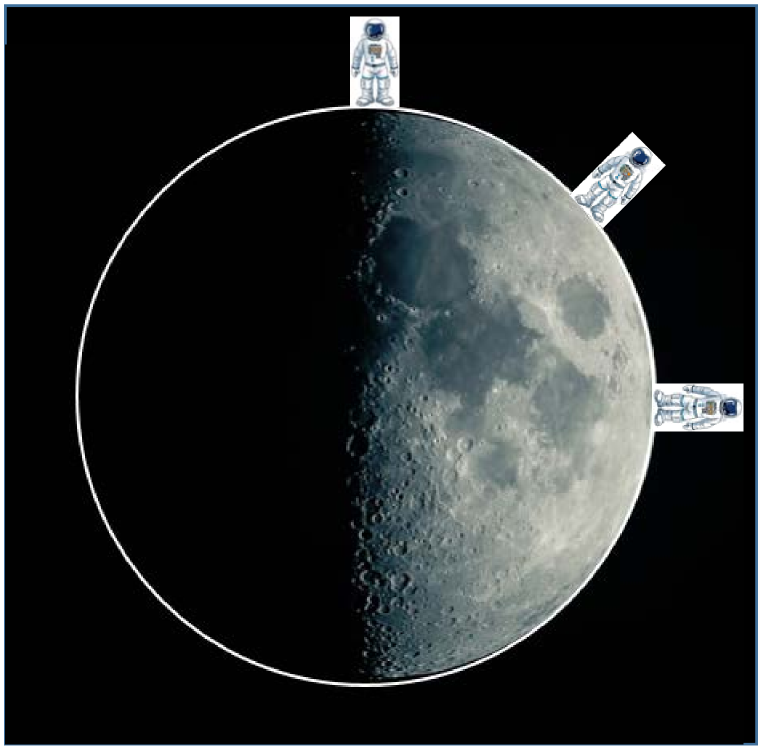
For now, NASA's focus is sustainable exploration and preparation for Mars, not settlement.

Notional Configuration of Lunar Gateway and 3-Stage Lander

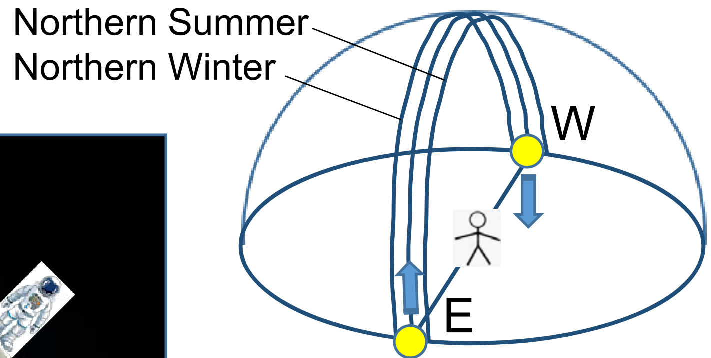




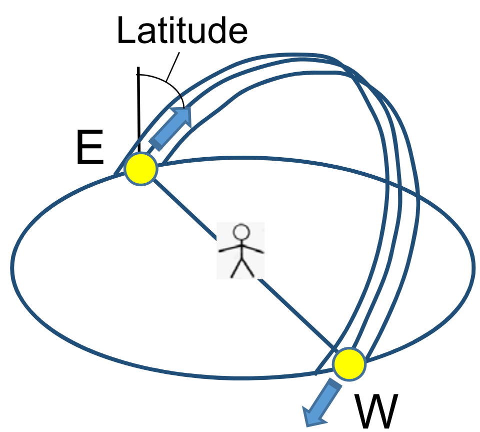
Sun Paths on the Moon



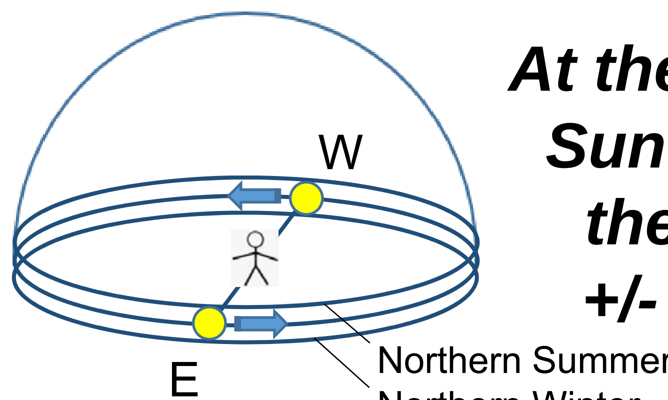
On the Moon, the Sun moves westward just 0.5° per hour (1 Lunar day = 29.5 Earth days)



At the equator, the Sun passes directly overhead +/- 1.5 degs



At mid-latitudes, the Sun's path is tilted by latitude degrees +/- 1.5 degs



At the poles, the Sun traverses the horizon +/- 1.5 degs

Pros/Cons of Lunar Pole Sites

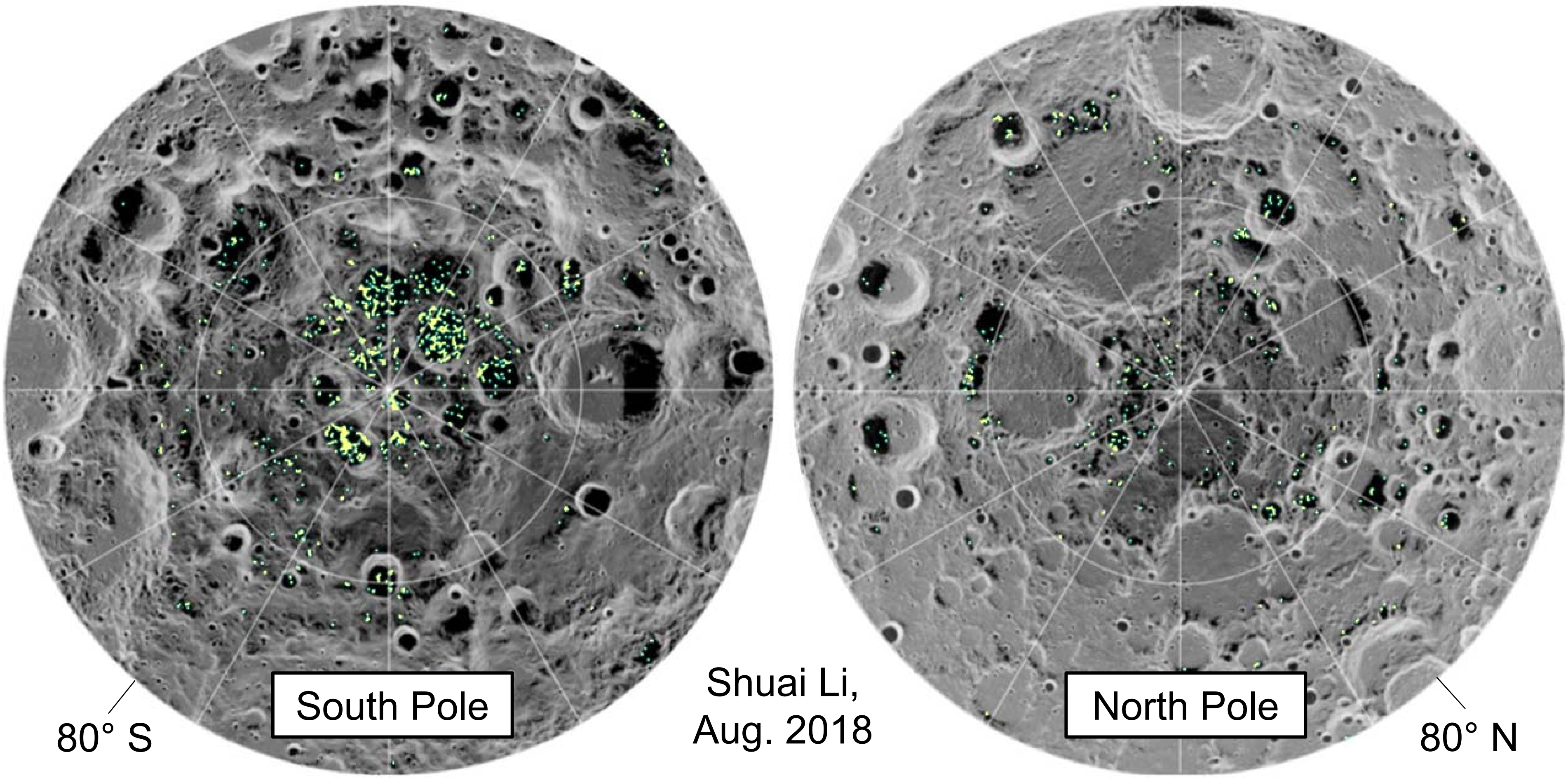
Pros:

- Water ice for life and fuel (H_2, O_2) is plentiful in polar craters, especially at the South Pole.
- 74 km^2 near the North Pole is illuminated >80% of the time in the summer, where power can be provided primarily by solar arrays. The South Pole has 26 km^2 with >80% illumination.
- Solar-powered landers, surface operations, and ISRU with minimal energy storage are feasible and sustainable there.
- Probable site for multi-national "Moon Village" (near South Pole).

Cons:

- Rugged terrain (especially near South Pole) with patches of steep slopes, boulders, craters, long shadows.
- Sun shading *and Earth visibility* can change dramatically from the best case "summer" lunation to the worst case "winter" lunation depending on local elevation and terrain.

Water Confirmed at Both Poles

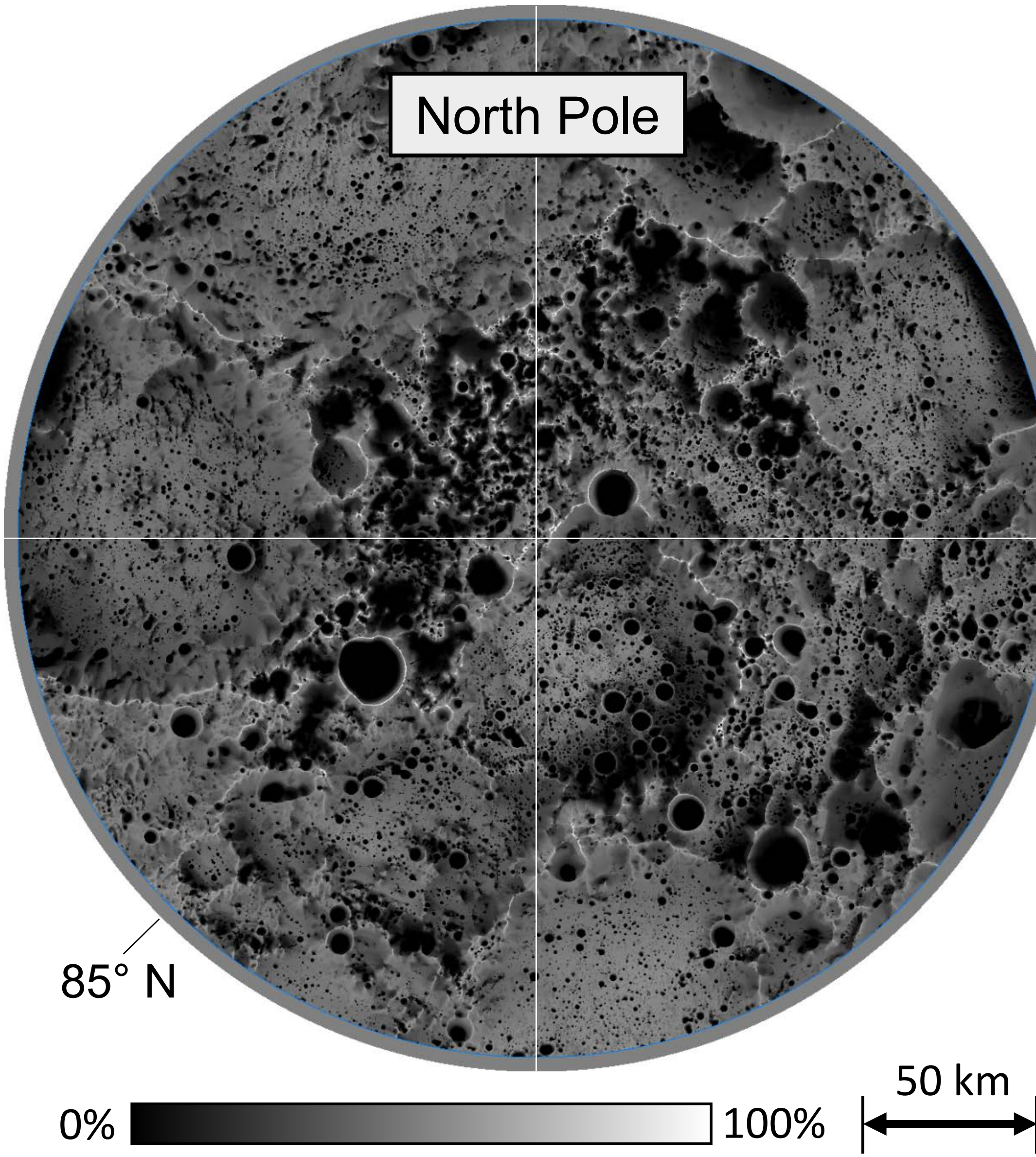


- Water ice (yellow) in permanently shadowed craters (cold traps)
- Temperature: Darker gray = colder, Lighter gray = warmer
- “Billions of tons of water ice on the Moon at the poles” – J. Bridenstine

Illumination Near the Poles is Highly Variable because of the Rugged Terrain and Low Sun Angle

The best sites for sustained illumination are the highest points in an area that are not near other high points.

Example Illumination Prediction for Mission Planning

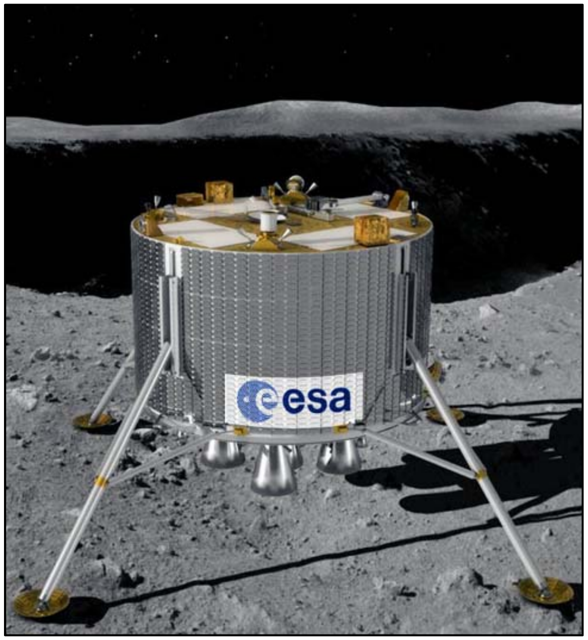


Summer Quarter Average Illumination using 240 m/pixel LRO Digital Elevation Map

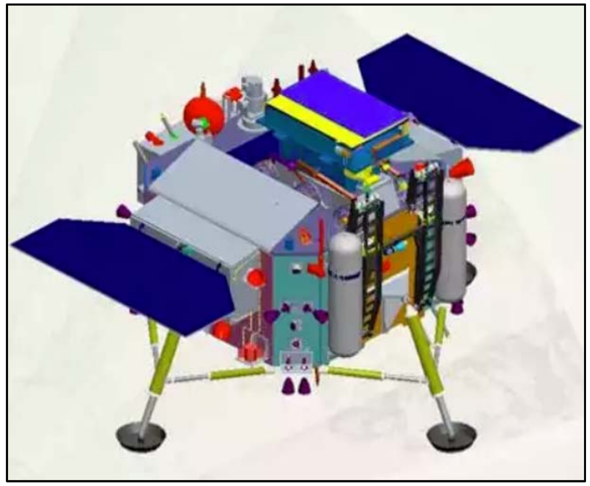
- 209 km^2: >70%
- 74 km^2: >80%
- 24 km^2: >90%
- 1.5 km^2: ~100%

Additional predictions in the Backup charts.

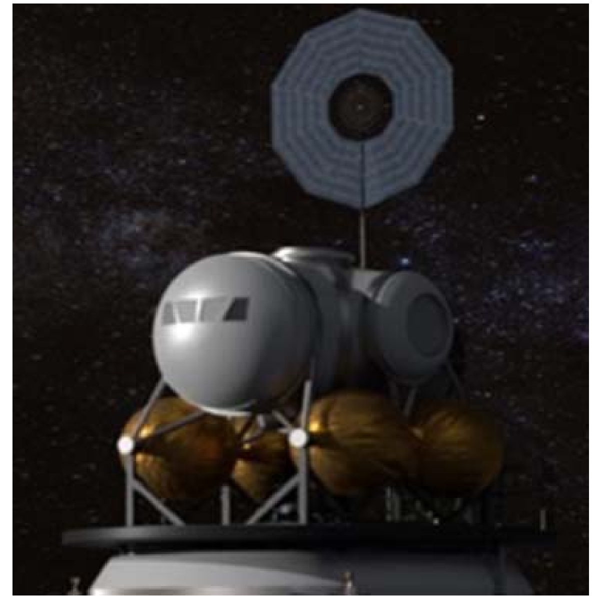
Solar Array Options for Landers



Body Mounted



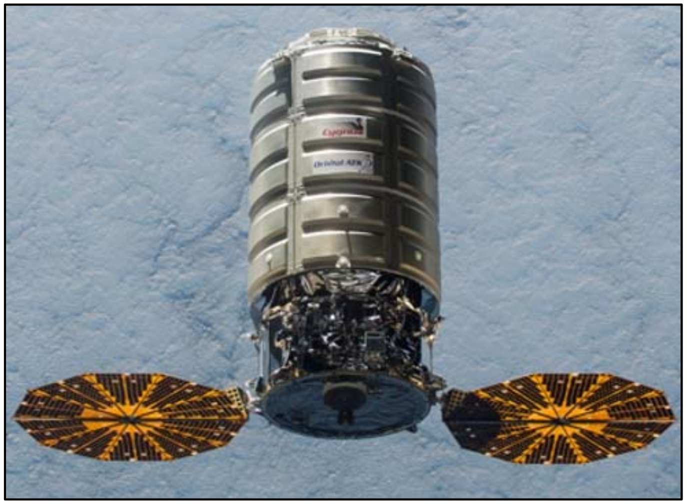
Rotating Rigid Panels



Lightweight Deployables

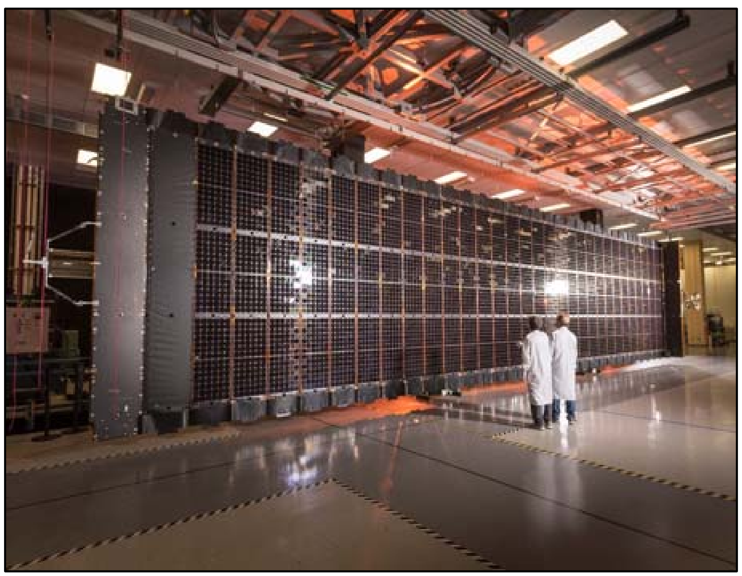
	Body Mounted	Rotating Rigid Panels	Lightweight Deployables
Pros	• Simplest • Low Risk	• Used Successfully on Previous Moon Missions	• Maximum Power Output • Possibly >100 W/kg
Cons	• >3x Cells Required • Operates Hotter	• No Azimuth Tracking • Probably <50 W/kg	• Adv. Structures/Mech • Retraction has Low TRL

Lightweight Deployable Arrays



UltraFlex (NGIS)

ROSA (DSS)

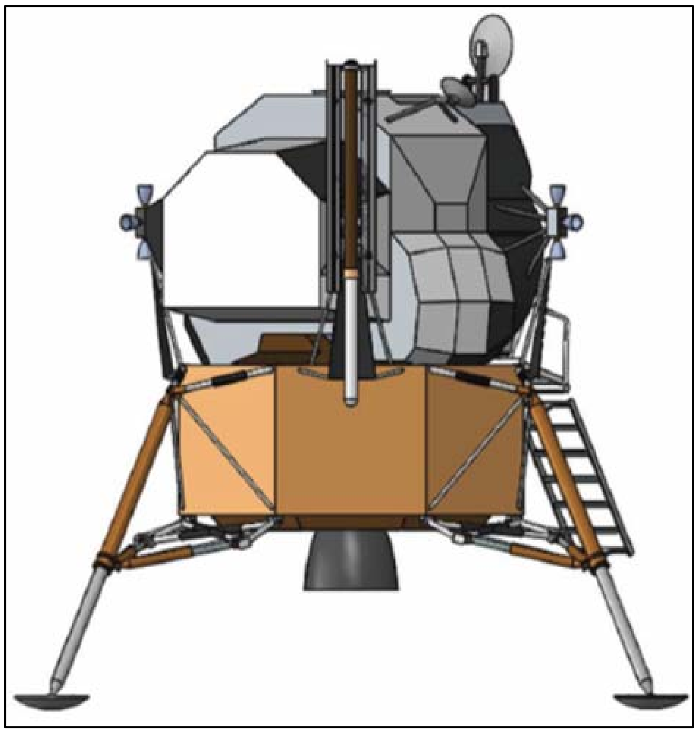


MMSA (LM)

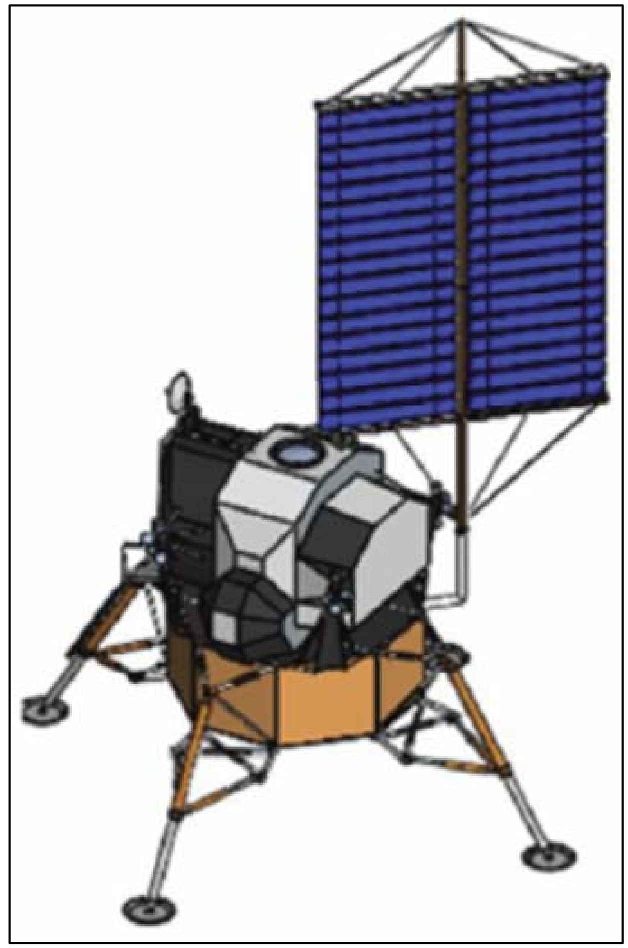
CTA (NGIS)

Notional Lander with a Compact Telescoping Array (CTA)

Stowed



Deployed



Notional Lander with an UltraFlex Solar Array

Locked Down for Landing and Launch

Rotated up after Landing

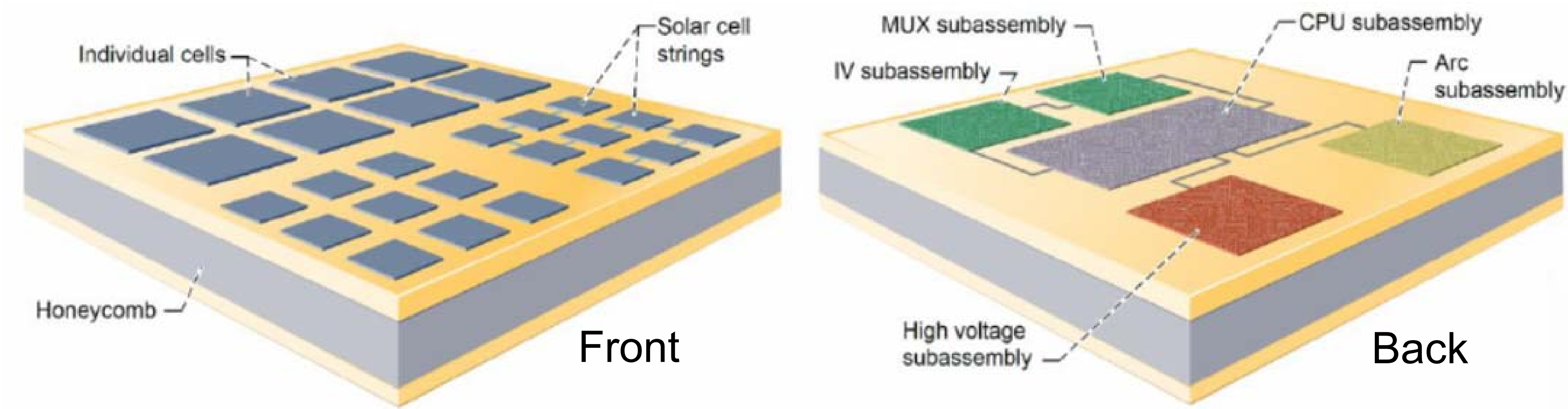
Dust Considerations

- **Impact:**
  - Covers solar cells: Reduces power and operates hotter
  - Degrades motors, gimbals, hinges, retraction
  - On Apollo, caused some failures after just 75 hrs.
- **Sources:**
  - Electrostatic attraction (primary) and friction (secondary)
    - *Sticks to even smooth vertical surfaces…*
  - Electrostatic dust lofting at terminator/polar regions
    - Detected by Surveyors 5, 6, 7, Apollo 17, but not LADEE?
    - *Complicated near poles by variable terrain shadows*
  - Landing, launching, surface ops will cause the most
    - Surveyor 3 got dusty from Apollo 12 landing 155 m away!

Photovoltaics Demo on CLPS Lander

Advanced photovoltaics and high voltage strings with arc detection and mitigation circuitry.

PIs: Jeremiah McNatt and Timothy Peshek (GRC)



<u>Objectives</u>:

- Qualify existing technology solar cells on the lunar surface.
- Also test next-generation and low-cost cells.
- Quantify plasma environment to improve environmental models.
- Test high voltage ops in ambient plasma to understand & avoid arcing.

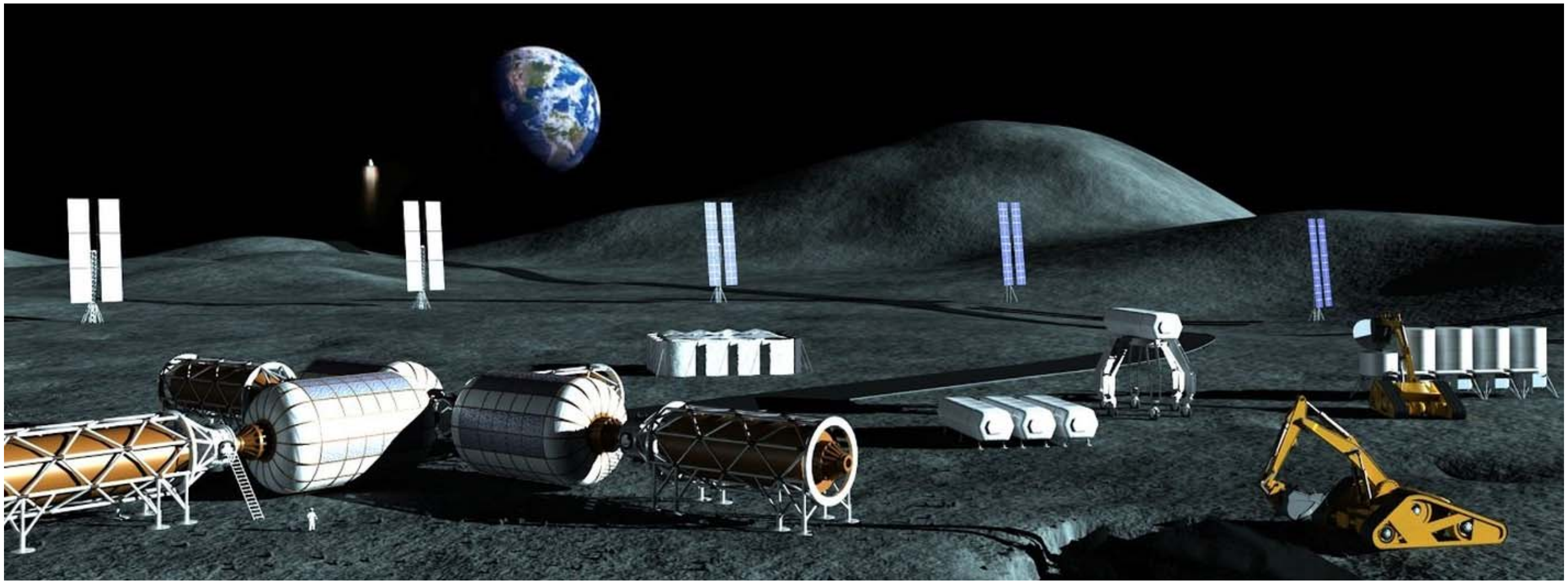
Selected for development to potentially be flown as a payload on a commercial lander as early as 2020.

Technology Challenges for Deployable Arrays on Landers

- **Adaptable**
  - Adaptable to multiple landing sites (latitudes) and landers.
- **Reusable**
  - Multiple partial or full retractions on reusable lander.
- **Dust**
  - Protection from tenacious, highly abrasive dust.
- **Thermal**
  - Survivable through temperature extremes.
- **Shadowing**
  - Optimal string layout for uncertain terrain shadowing.

Conclusions

- Water for life and fuel (H_2, O_2) is plentiful in polar craters, especially at the South Pole.
- 74 km^2 near the North Pole is illuminated >80% of the time in the summer, where power can be provided primarily by solar arrays. The South Pole has 26 km^2 with >80% illumination.
- ***NASA is studying solar power options for reusable landers.***
- A grid of vertical-axis tracking solar arrays could eventually power a large polar settlement, e.g.:



Acknowledgments

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NASA Johnson Space Center:

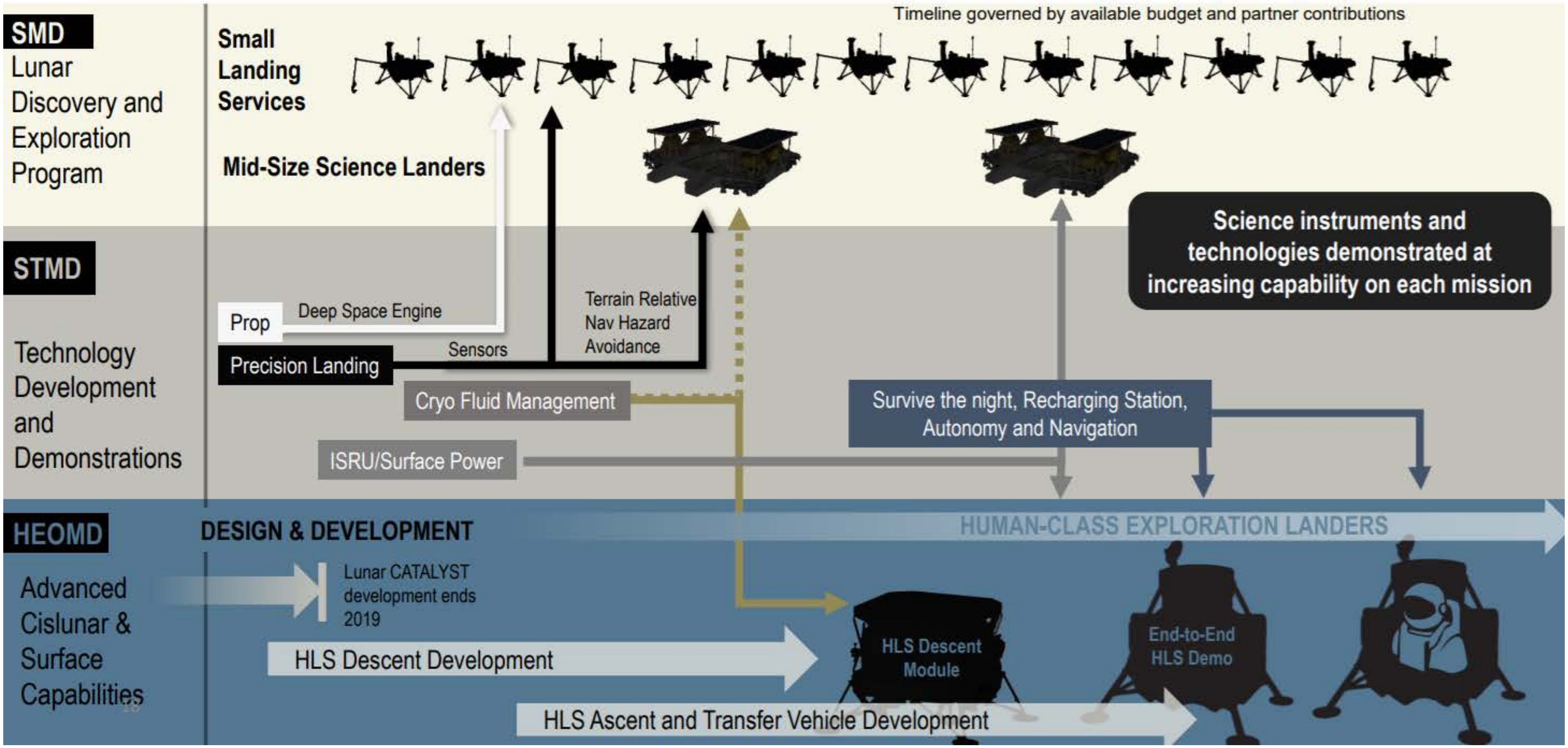
Tim Lawrence

NASA Langley Research Center:

Dan Mazanek, Gabe Merrill

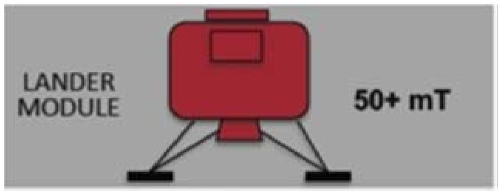
Backup

Lunar Transportation Technology Development

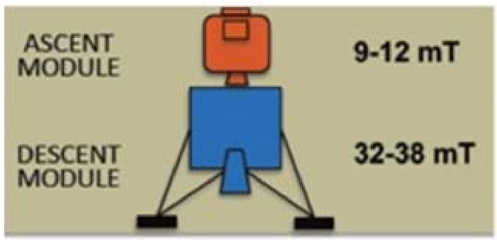


Crewed Lander Options

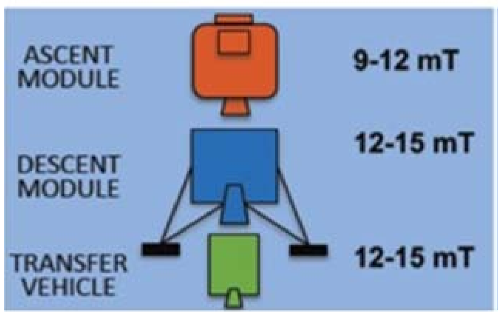
NASA Administrator Bridenstine: "We want the entire architecture between here and the Moon to all be reusable."



- **Single-stage human lander**
  - Does not fit on any launch vehicle, including SLS Block 1B Cargo



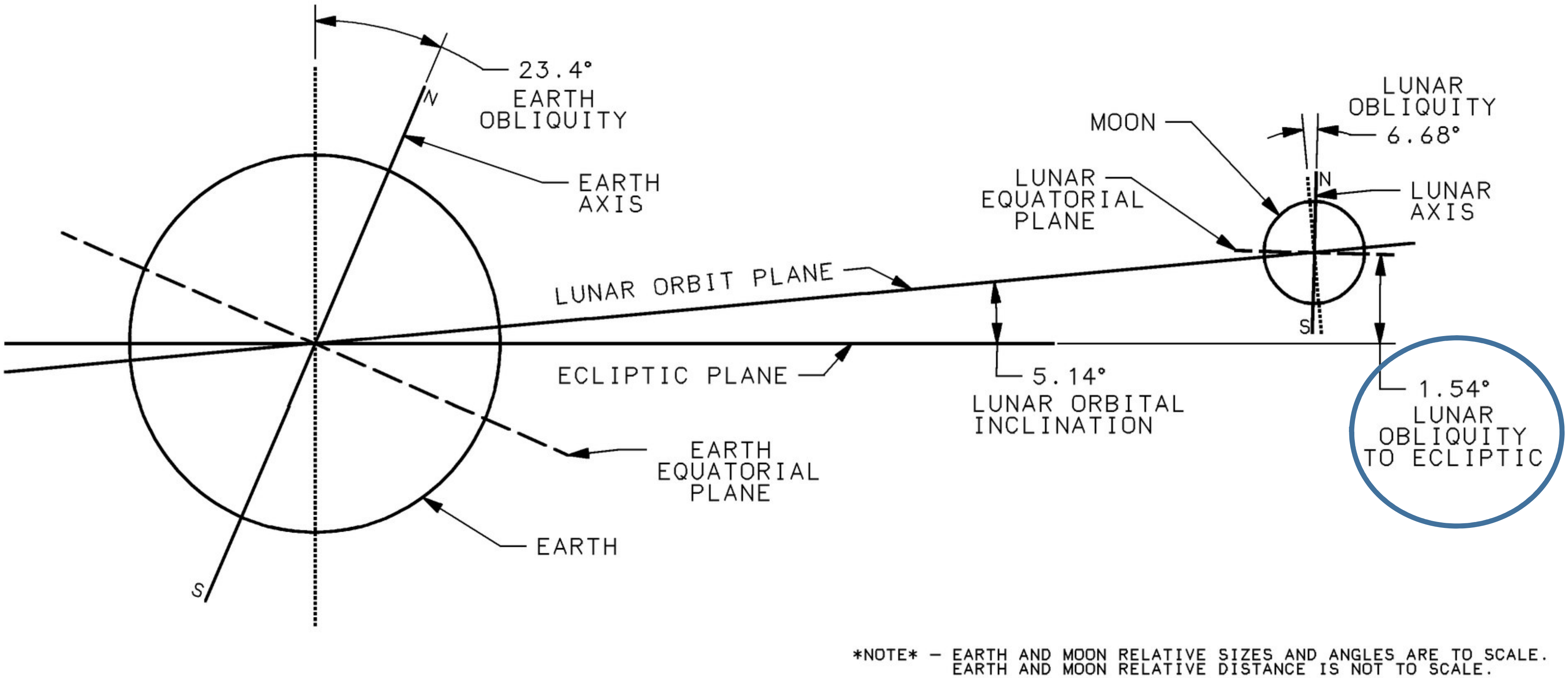
- **Two-stage options**
  - Ascent Module fits on commercial launch vehicles expected to be available
  - Descent Module does not fit on commercial launch vehicles



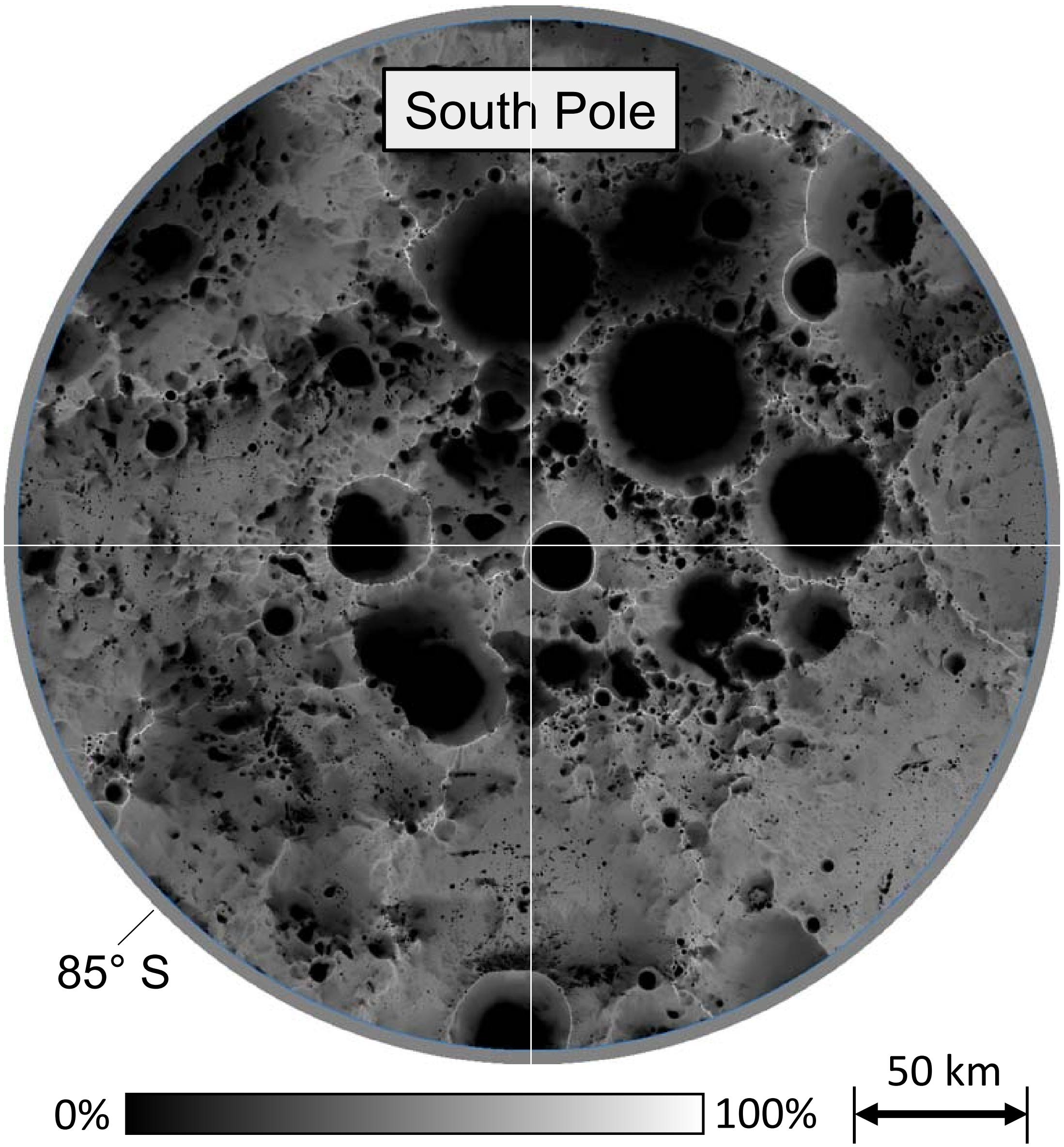
- **Three-stage options**
  - Fits on commercial launch vehicles expected to be available
  - Single elements potentially can be co-manifested payload on SLS
  - Allows increased partnering opportunities

NASA expects the Crewed Landers will shuttle between the Lunar Gateway and the surface

Moon is Tilted Just 1.5° from Ecliptic
(Negligible Seasonal Effects *Except* Near Poles)



Example Illumination Prediction for Mission Planning



Summer Quarter Average Illumination using 240 m/pixel LRO Digital Elevation Map

- **101 km²: >70%**
- **26 km²: >80%**
- **9 km²: >90%**
- **1.1 km²: ~100%**

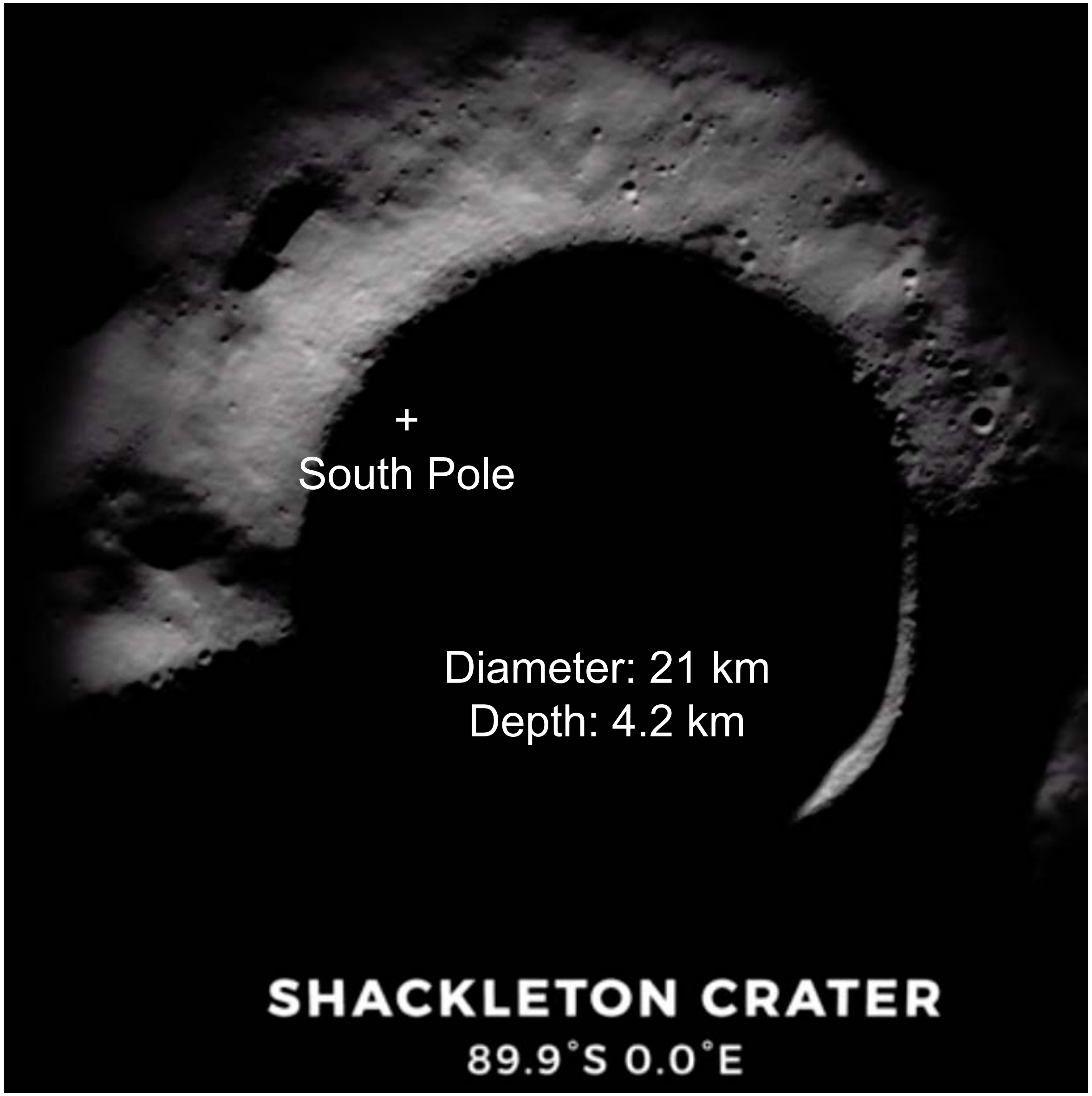
Illumination Predictions

South Pole
Annual Average
Illumination

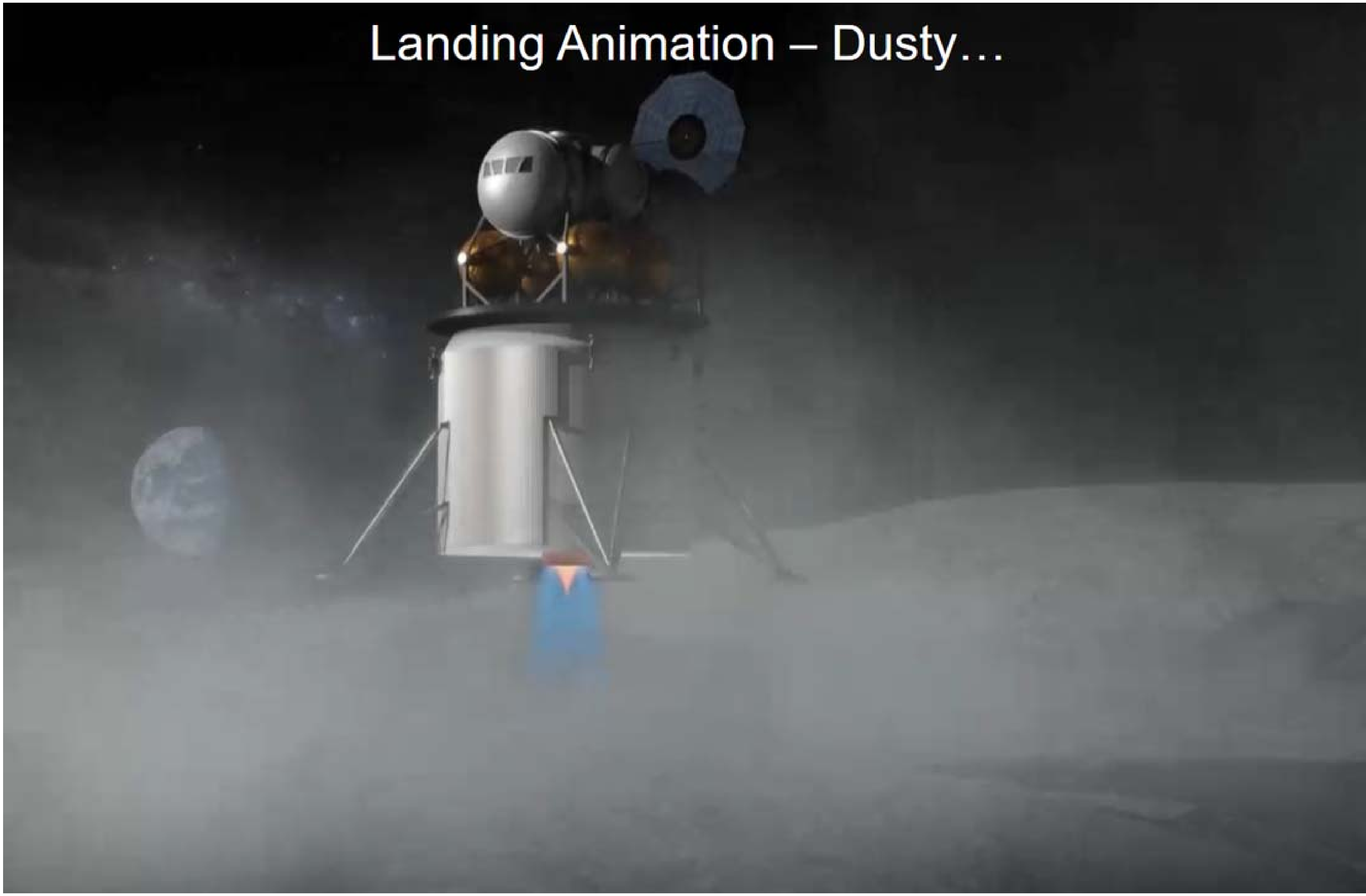
Using 240 m/pixel LRO Digital Elevation Map

- **Best 3 pixels (Total ~0.2 km^2): ~84%**
- **Best 46 pixels (Total ~3 km^2): > ~70%**

Rim of the Shackleton Crater – Best Place for a Moon Base?

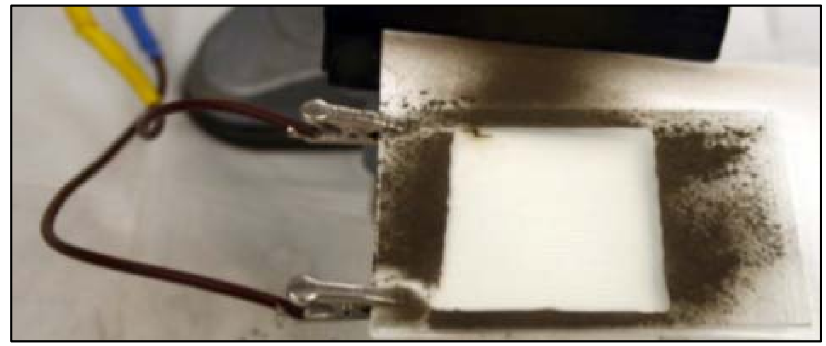


Notional Lander with an UltraFlex Solar Array



Lunar Dust is Powdery, Sticky, & Abrasive…

Dealing with Lunar Dust



- **Prevention methods:**
  - Retract or feather the array prior to landings, launches, and other ops
  - Sinter or treat lunar surface?
  - Shield the array w/ curtains?
- **Removal methods:**
  - Electrodynamic Dust Shield (good for large surfaces such as solar arrays, radiators)
  - Other piezoelectric/electromechanical devices, coatings
- **These methods are not perfect:**
  - Dust will probably not come completely off the blanket!
  - *Removing dust from mechanisms/joints is harder and the effects on lubricants and coatings is a concern. Requires robust initial design & development.*

Impact of Dust on Retraction

- Space arrays are not retracted unless absolutely necessary.
- Reusing expensive lunar solar arrays is desirable and feasible.
- "Land, deploy, use, retract, launch, and repeat" raises concerns about dust on all moving parts, lubricants, and coatings.

- ➢ Retracted solar array must be locked under force to survive launch and landing loads, stresses, vibrations and must tolerate some dust in their mechanisms and contacting surfaces.
- ➢ Reusable Hold Down and Release Mechanisms (HDRMs), actuation motors or mechanisms, and springs and hinges must be robustly designed to achieve reuse.

Photovoltaics

- **Environmental considerations:**
  - Temperature extremes: -175 C to +125 C, thermal cycling profiles are mission and location dependent.
  - Radiation environment: cosmic rays, solar wind, solar flares; degradation expected to be similar to GEO.
- **Cell technologies:**
  - Surface spectrum assumed to be ~AM0 (no atmosphere).
  - SOA technologies (MJ, III-V based) being considered for most near-term missions.
  - Lower-cost technologies could work for short-duration missions (Si, CIGS, perovskites, single/dual junction cells)

Solar cells planned for the lunar surface are high TRL but largely unproven in this specific environment.