

# **Solar Power for Lunar Pole Missions**

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8  
charts

8  
charts



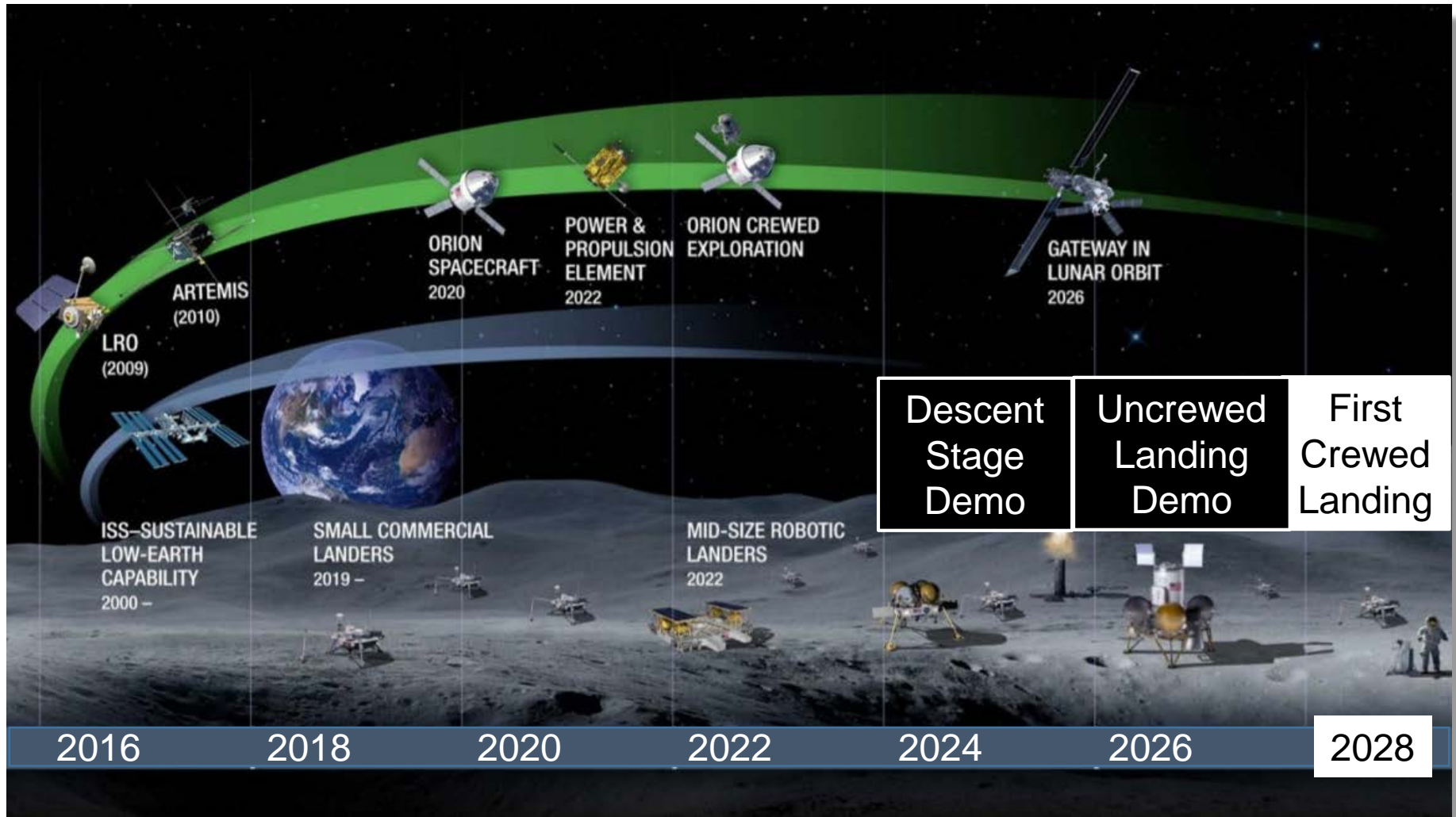
# Administrator Bridenstine's Vision



- “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.”



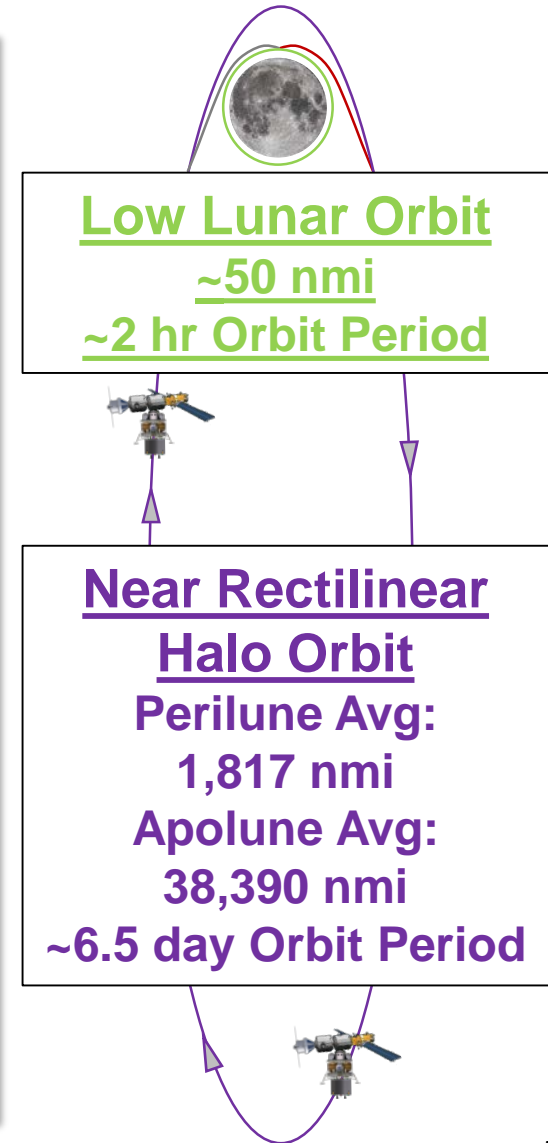
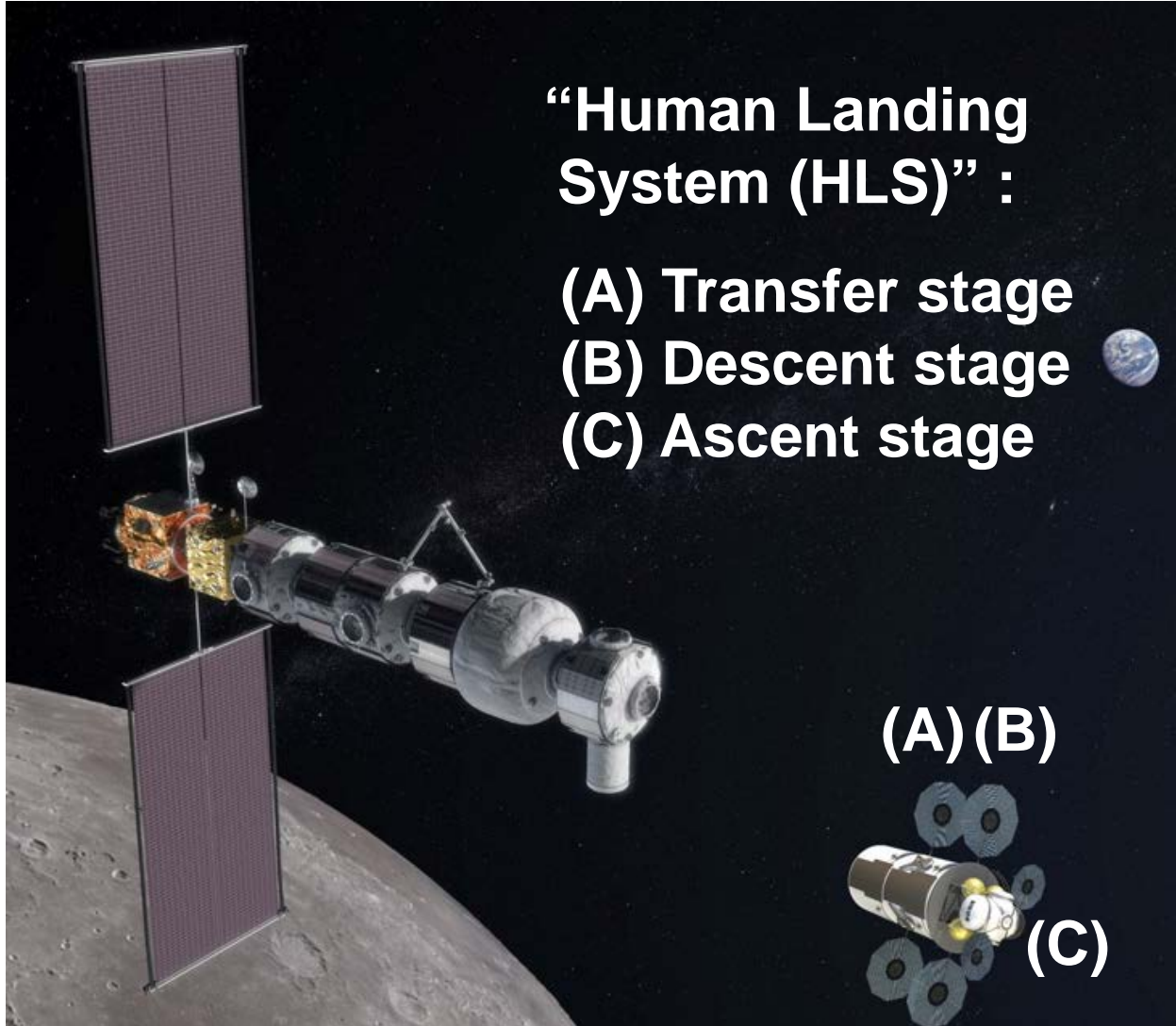
# NASA's Return to the Moon



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



# Notional Configuration of Lunar Gateway and 3-Stage Lander

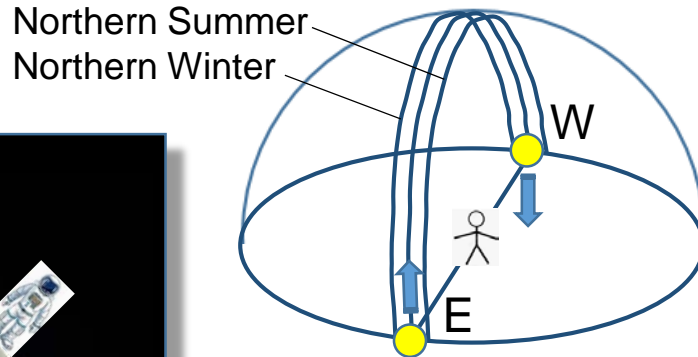




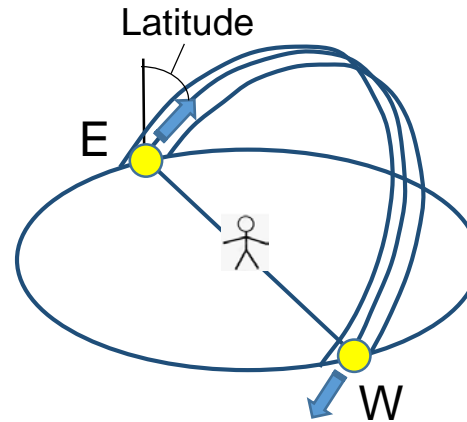
# Sun Paths on the Moon



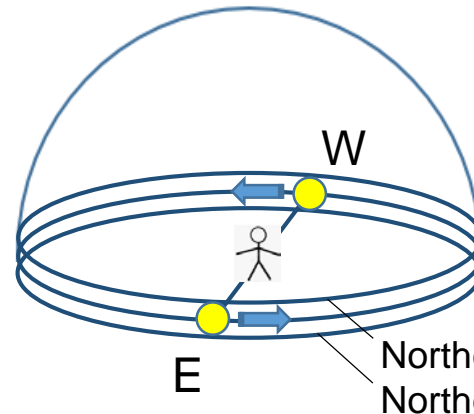
On the Moon, the Sun moves westward just  $0.5^\circ$  per hour (1 Lunar day = 29.5 Earth days)



At the equator, the Sun passes directly overhead  $\pm 1.5$  degs



At mid-latitudes, the Sun's path is tilted by latitude degrees  $\pm 1.5$  degs



**At the poles, the Sun traverses the horizon  $\pm 1.5$  degs**



# Pros/Cons of Lunar Pole Sites

## Pros:

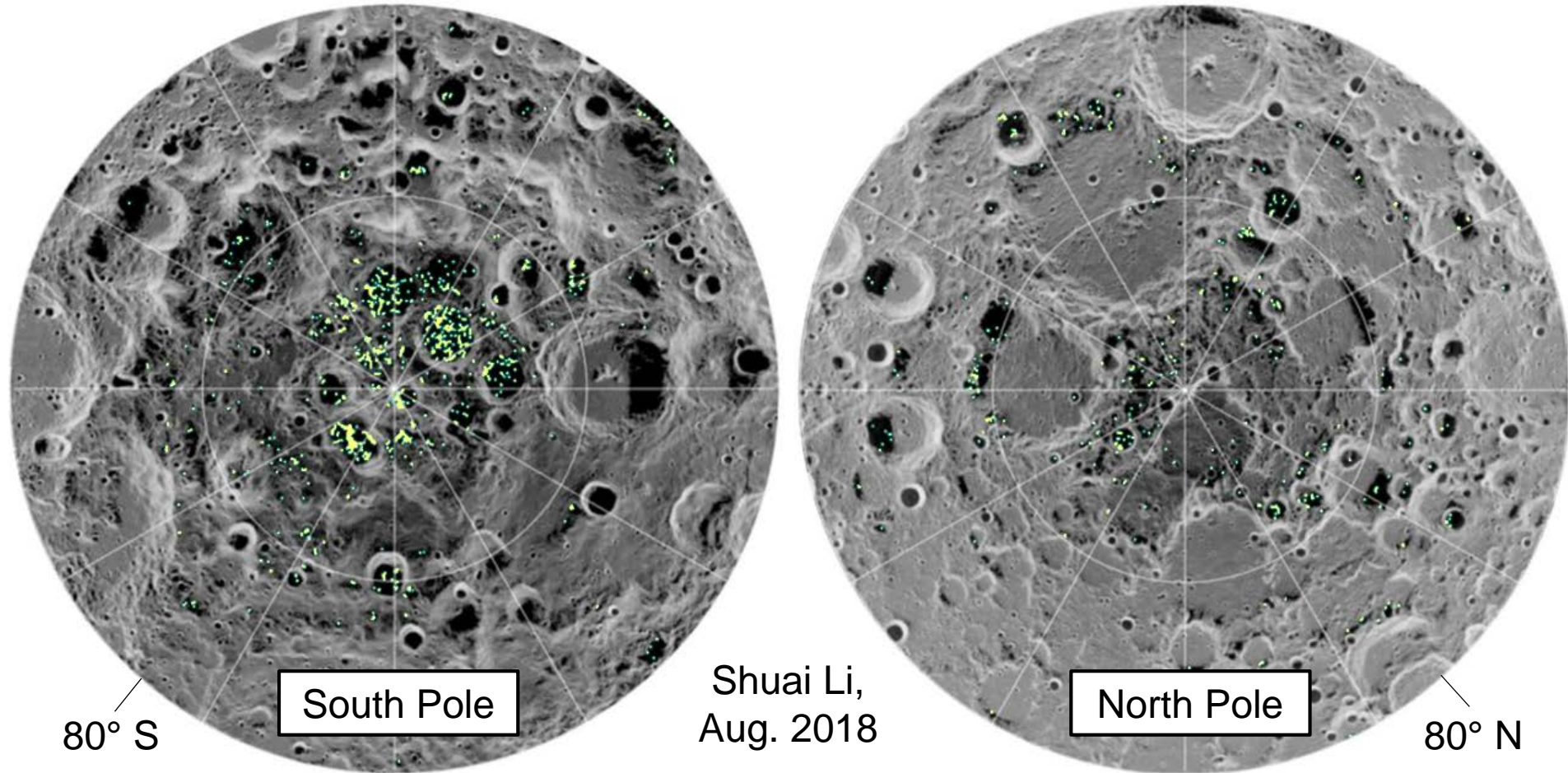
- Water ice for life and fuel ( $H_2$ ,  $O_2$ ) is plentiful in polar craters, especially at the South Pole.
- 74 km<sup>2</sup> near the North Pole is illuminated >80% of the time in the summer, where power can be provided primarily by solar arrays. The South Pole has 26 km<sup>2</sup> with >80% illumination.
- 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





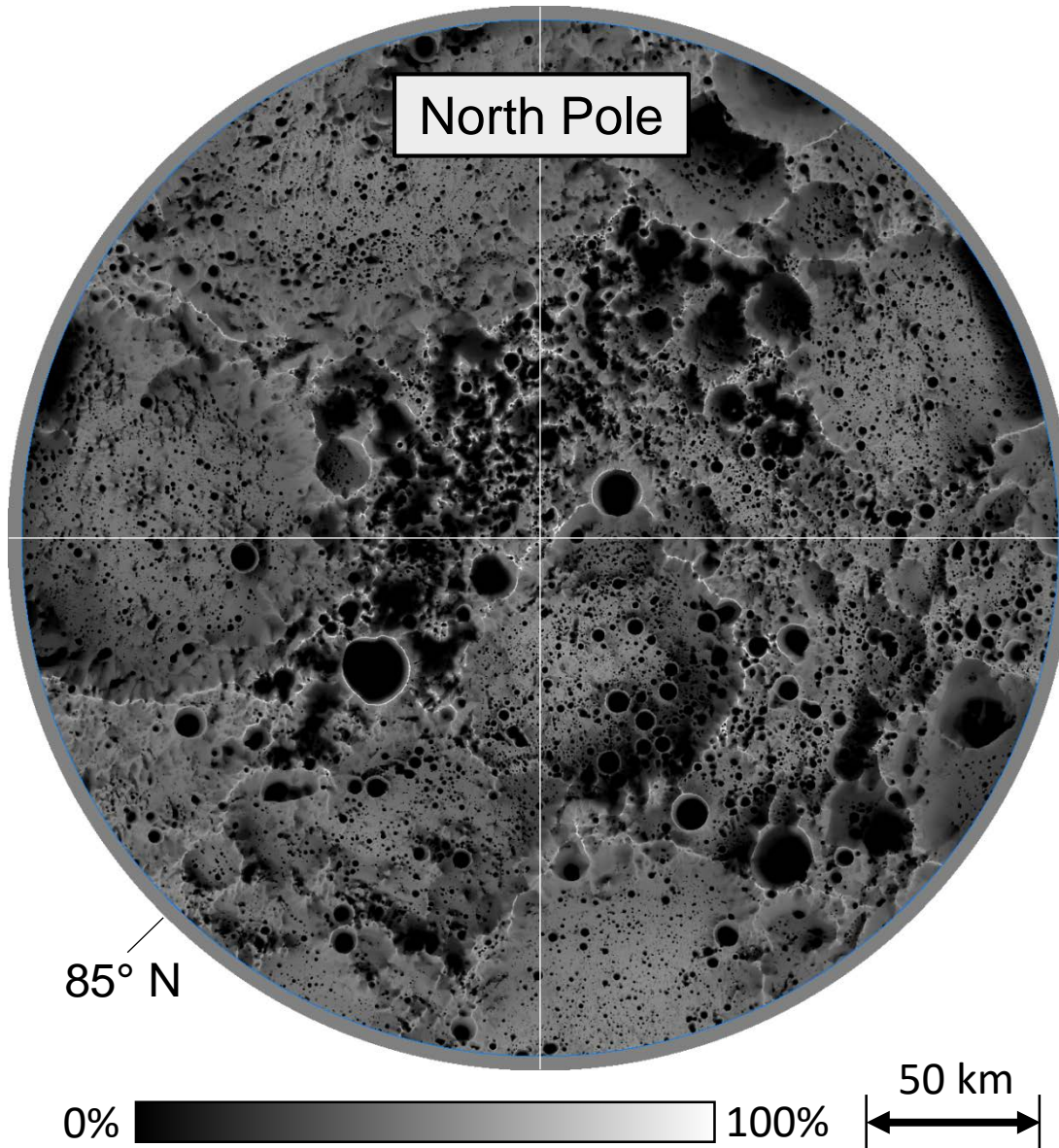
# **Illumination Near the Poles is Highly Variable because of the Rugged Terrain and Low Sun Angle**



***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



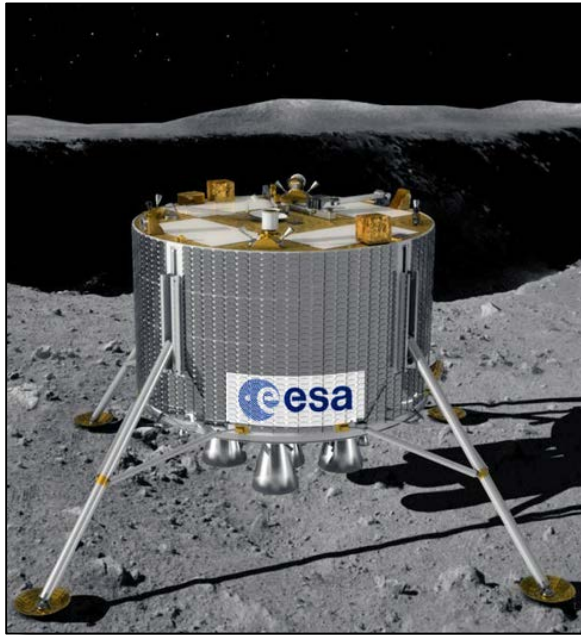
**Summer Quarter  
Average  
Illumination  
using 240 m/pixel  
LRO Digital  
Elevation Map**

- 209 km<sup>2</sup>: >70%
- 74 km<sup>2</sup>: >80%
- 24 km<sup>2</sup>: >90%
- 1.5 km<sup>2</sup>: ~100%

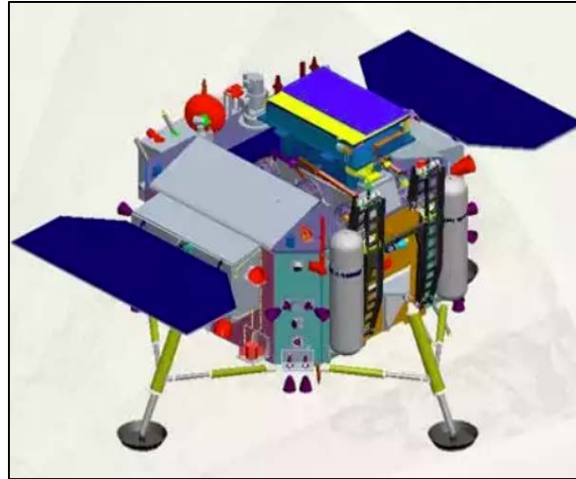
Additional predictions in  
the Backup charts.



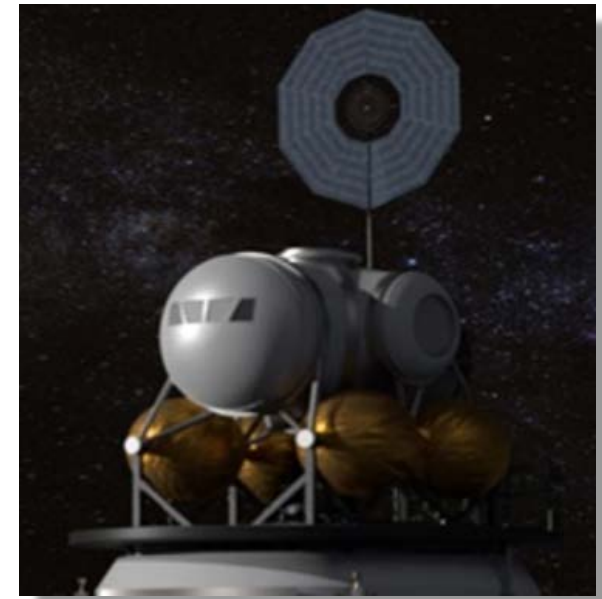
# Solar Array Options for Landers



## Body Mounted



## Rotating Rigid Panels

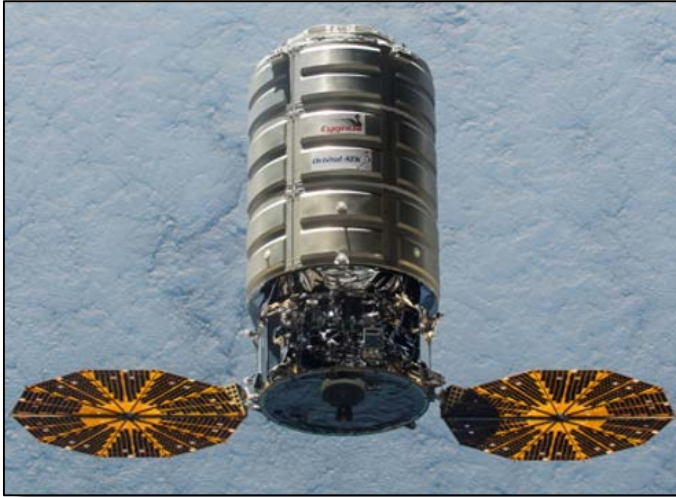


## Lightweight Deployables

|             |  |   |  |
|-------------|--|---|--|
| <b>Pros</b> | <ul style="list-style-type: none"> <li>• Simplest</li> <li>• Low Risk</li> </ul>                     | <ul style="list-style-type: none"> <li>• Used Successfully on Previous Moon Missions</li> </ul>         | <ul style="list-style-type: none"> <li>• Maximum Power Output</li> <li>• Possibly &gt;100 W/kg</li> </ul>  |
| <b>Cons</b> | <ul style="list-style-type: none"> <li>• &gt;3x Cells Required</li> <li>• Operates Hotter</li> </ul> | <ul style="list-style-type: none"> <li>• No Azimuth Tracking</li> <li>• Probably &lt;50 W/kg</li> </ul> | <ul style="list-style-type: none"> <li>• Adv. Structures/Mech</li> <li>• Retraction has Low TRL</li> </ul> |



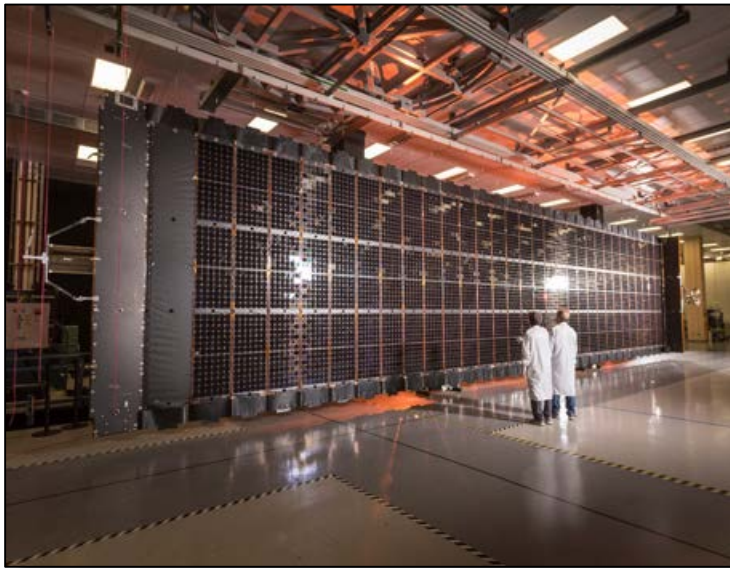
# Lightweight Deployable Arrays



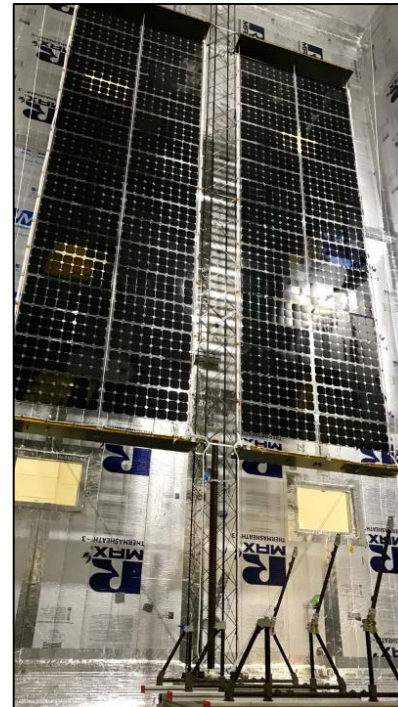
**UltraFlex (NGIS)**



**ROSA  
(DSS)**



**MMSA (LM)**

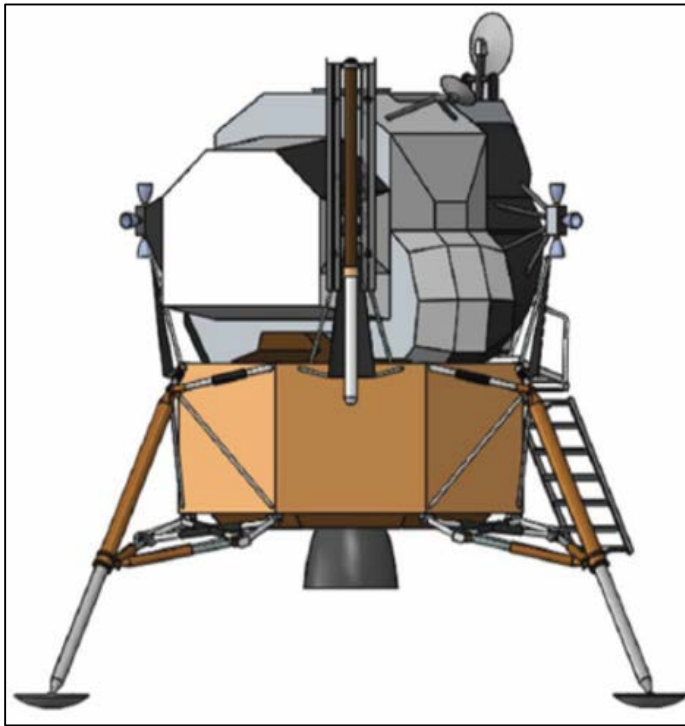


**CTA  
(NGIS)**

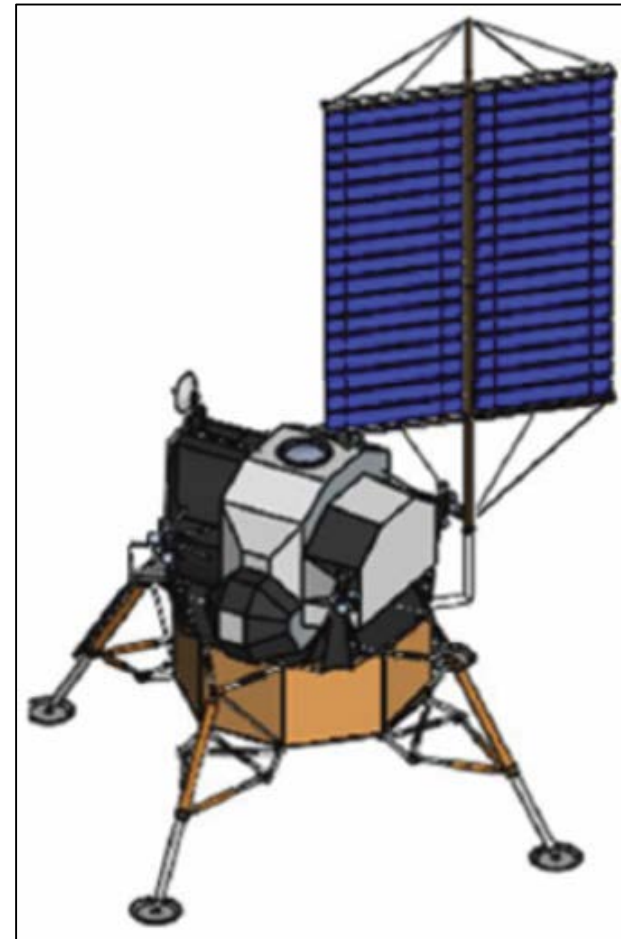


# Notional Lander with a Compact Telescoping Array (CTA)

Stowed



Deployed

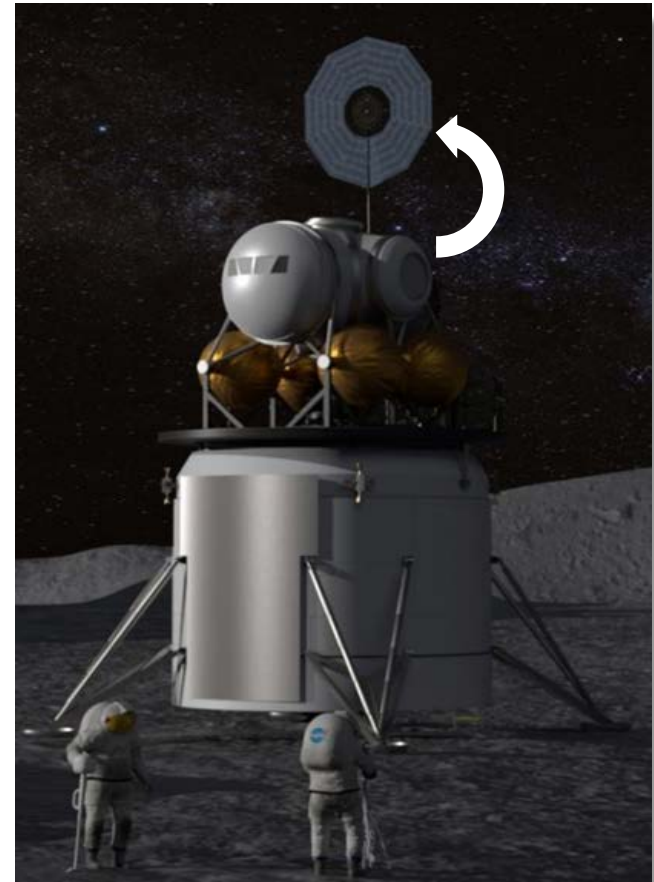




# Notional Lander with an UltraFlex Solar Array



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:**

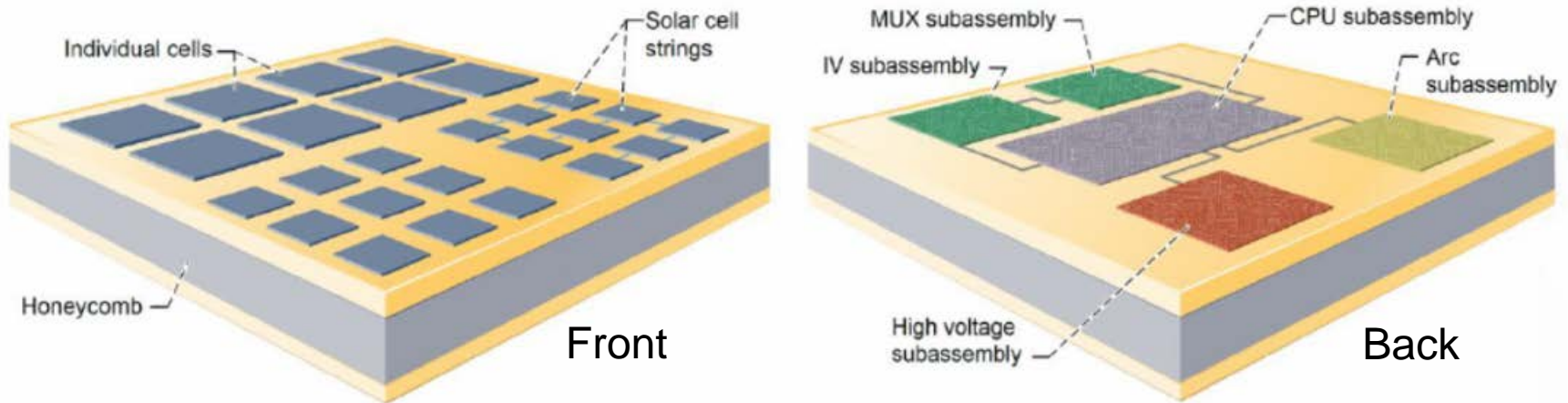
- Electrostatic attraction (primary) and friction (secondary)
  - *Sticks to even smooth vertical surfaces...*
- Electrostatic dust lofting at terminator/polar regions
  - Detected by Surveyors 5, 6, 7, Apollo 17, but not LADEE?
  - *Complicated near poles by variable terrain shadows*
- Landing, launching, 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)*



## Objectives:

- 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.

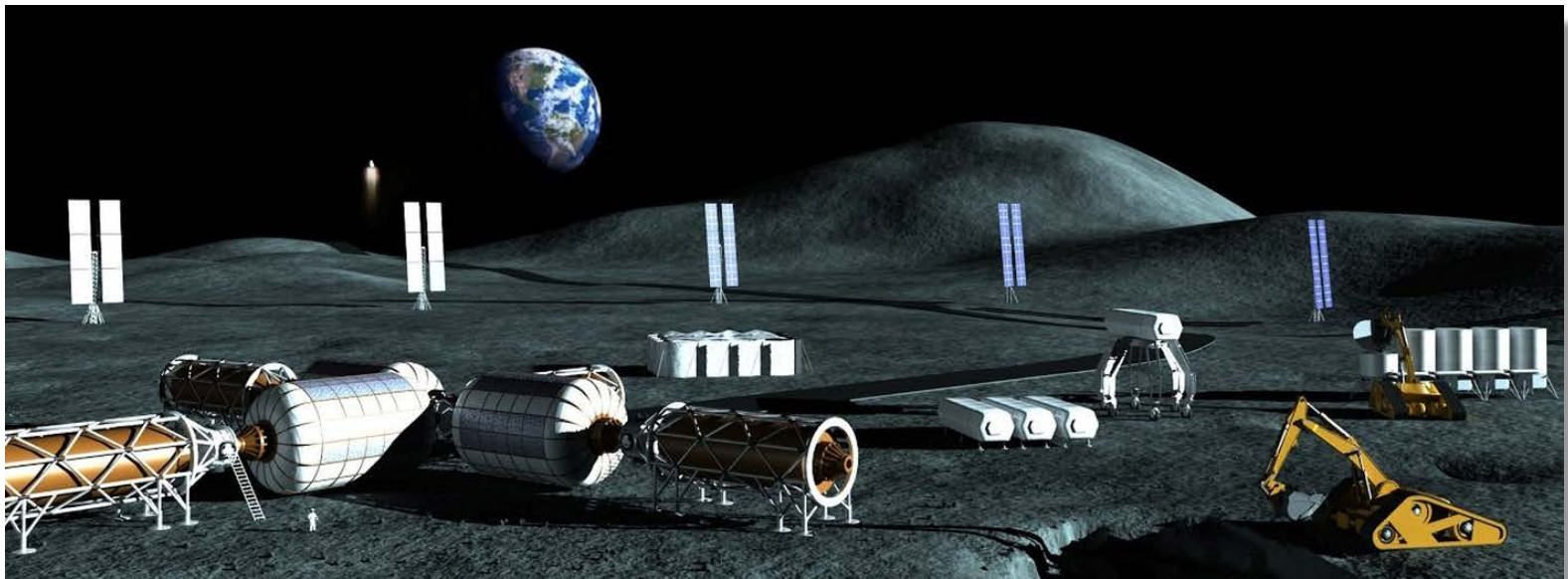
- **Shadowing**

- 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<sup>2</sup> 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<sup>2</sup> 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

## **NASA Glenn Research Center:**

**Tom Kerslake, Fred Elliott, Karin Bozak,  
Lee Mason, Bob Cataldo**

## **NASA Johnson Space Center:**

**Tim Lawrence**

## **NASA Langley Research Center:**

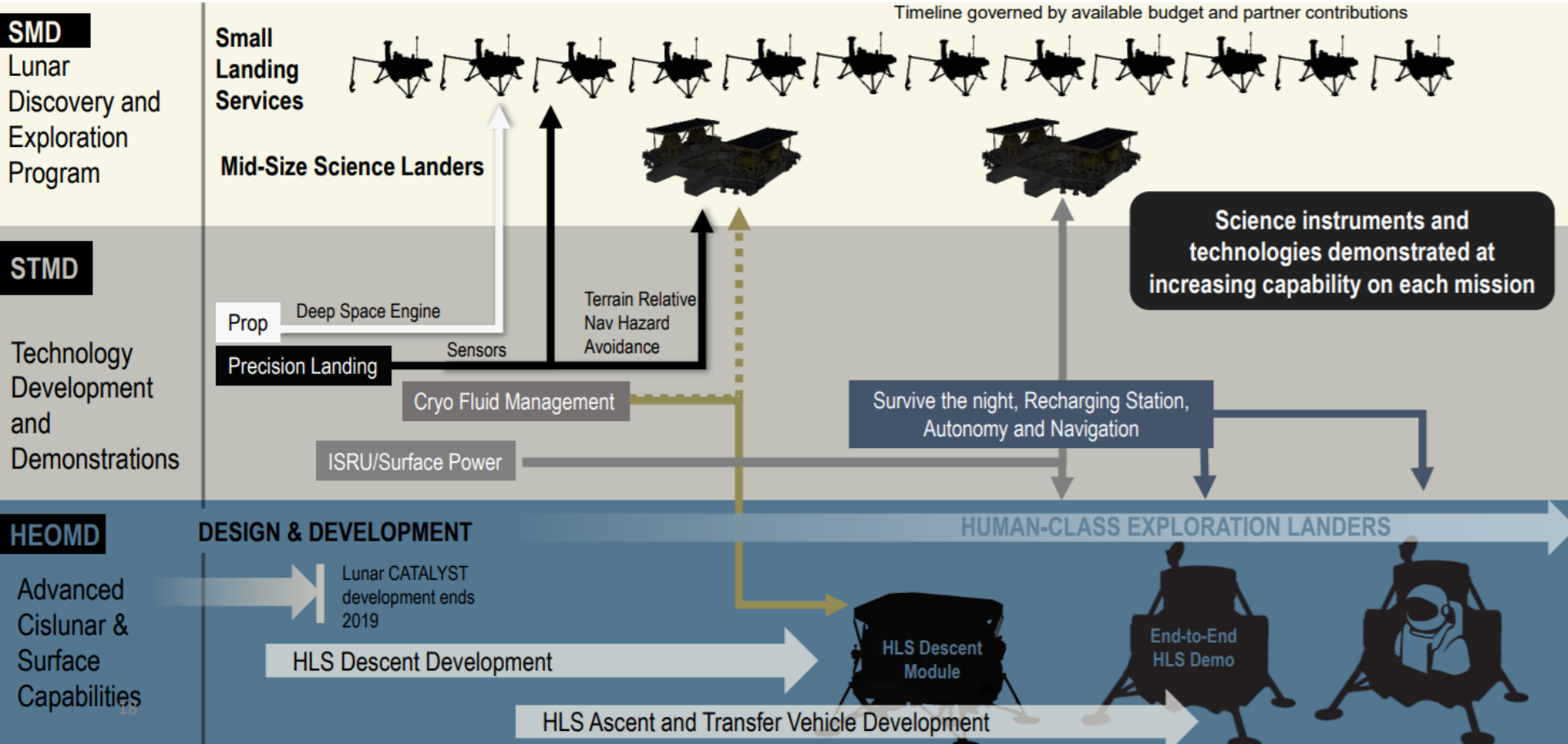
**Dan Mazanek, Gabe Merrill**



# Backup




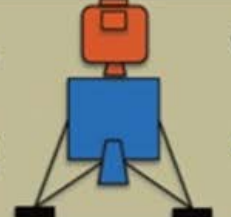
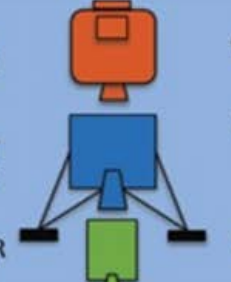
# Lunar Transportation Technology Development





# Crewed Lander Options

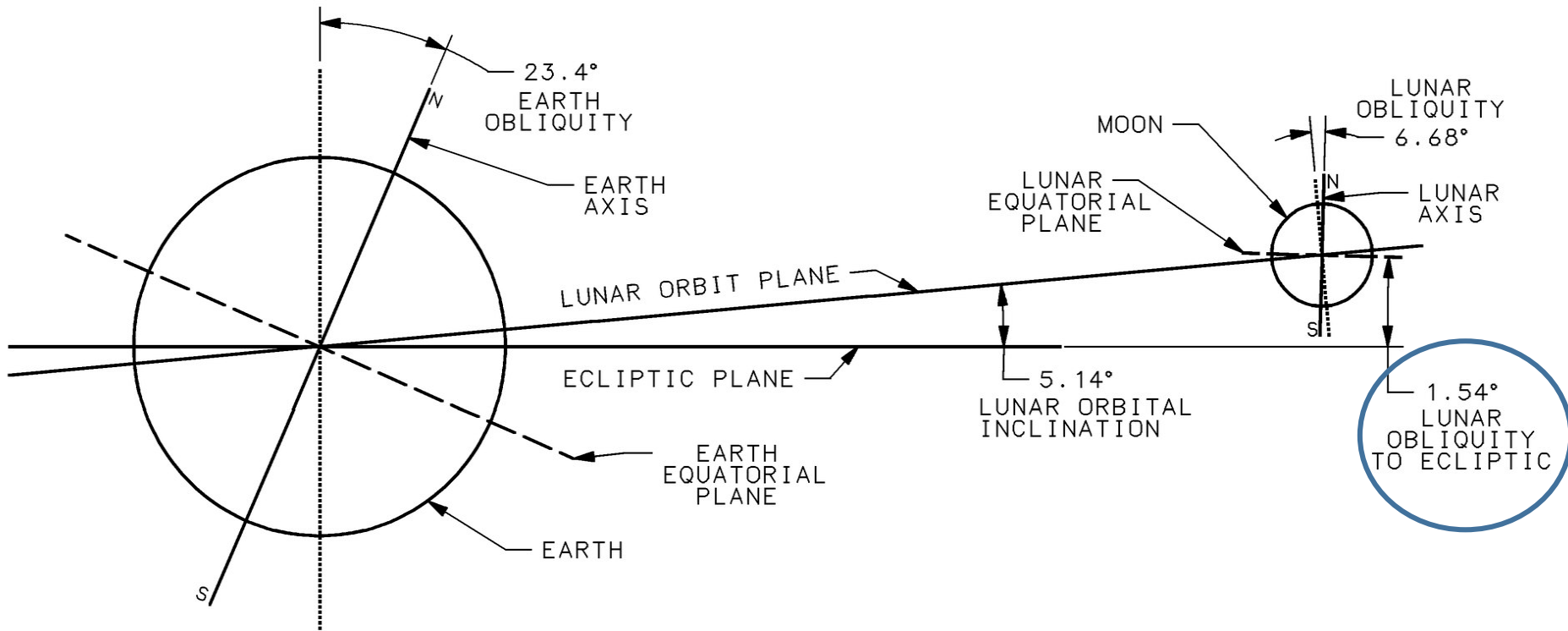
NASA Administrator Bridenstine: "We want the entire architecture between here and the Moon to all be reusable."

|  |   |
|--|---|
|  <p>LANDER MODULE</p> <p>50+ mT</p>   | <ul style="list-style-type: none"><li>• <b>Single-stage human lander</b><ul style="list-style-type: none"><li>– Does not fit on any launch vehicle, including SLS Block 1B Cargo</li></ul></li></ul>  |
|  <p>ASCENT MODULE</p> <p>9-12 mT</p> <p>DESCENT MODULE</p> <p>32-38 mT</p>  | <ul style="list-style-type: none"><li>• <b>Two-stage options</b><ul style="list-style-type: none"><li>– Ascent Module fits on commercial launch vehicles expected to be available</li><li>– Descent Module does not fit on commercial launch vehicles</li></ul></li></ul>   |
|  <p>ASCENT MODULE</p> <p>9-12 mT</p> <p>DESCENT MODULE</p> <p>12-15 mT</p> <p>TRANSFER VEHICLE</p> <p>12-15 mT</p> | <ul style="list-style-type: none"><li>• <b>Three-stage options</b><ul style="list-style-type: none"><li>– Fits on commercial launch vehicles expected to be available</li><li>– Single elements potentially can be co-manifested payload on SLS</li><li>– Allows increased partnering opportunities</li></ul></li></ul> |

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



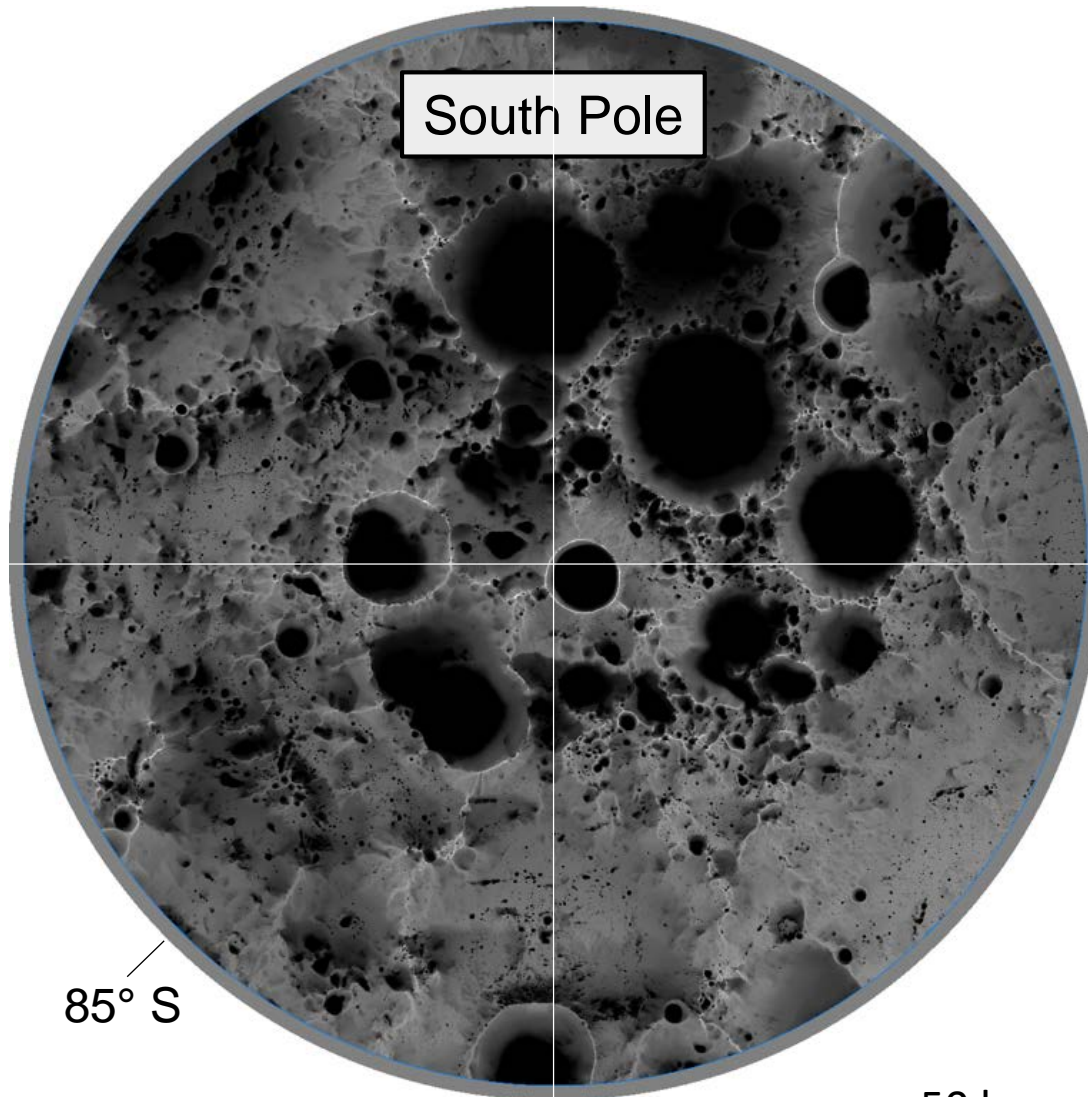
# Moon is Tilted Just $1.5^\circ$ from Ecliptic (Negligible Seasonal Effects *Except* Near Poles)



\*NOTE\* - EARTH AND MOON RELATIVE SIZES AND ANGLES ARE TO SCALE.  
EARTH AND MOON RELATIVE DISTANCE IS NOT TO SCALE.



# Example Illumination Prediction for Mission Planning



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

- 101 km<sup>2</sup>: >70%
- **26 km<sup>2</sup>: >80%**
- 9 km<sup>2</sup>: >90%
- 1.1 km<sup>2</sup>: ~100%







# Illumination Predictions



## South Pole Annual Average Illumination

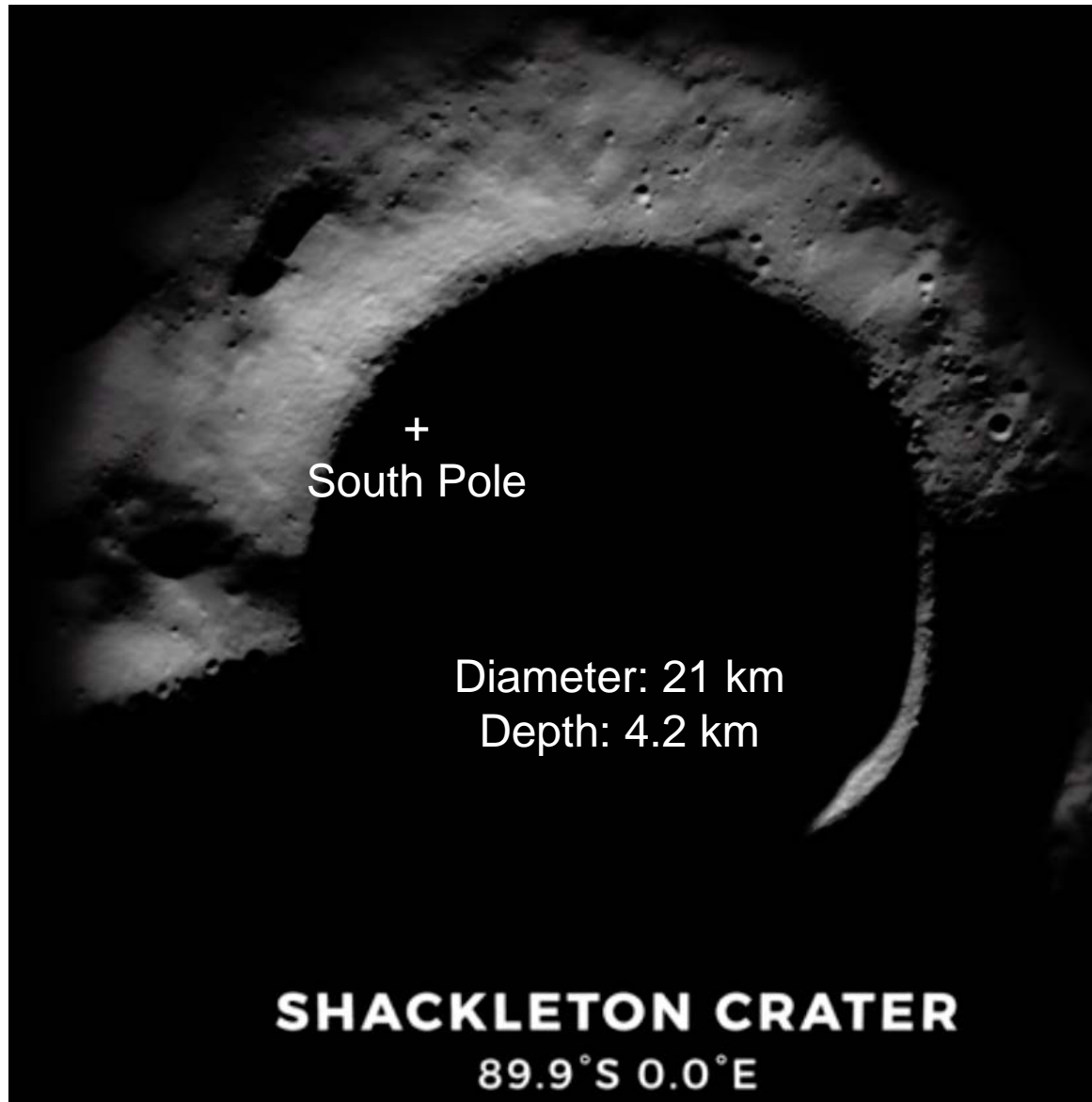
*Using 240 m/pixel  
LRO Digital  
Elevation Map*

- **Best 3 pixels**  
(Total  $\sim 0.2 \text{ km}^2$ ):  
 $\sim 84\%$
- **Best 46 pixels**  
(Total  $\sim 3 \text{ km}^2$ ):  
 $> \sim 70\%$





# 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:**

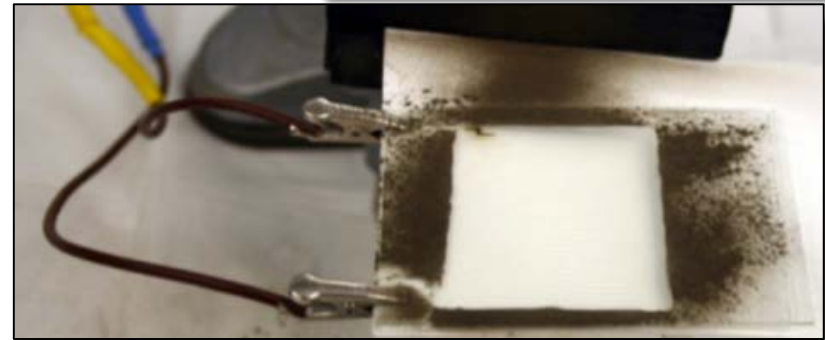
- Retract or feather the array prior to landings, launches, and other ops
- Sinter or treat lunar surface?
- Shield the array w/ curtains?

- **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.***