

IAASS, 2023

**Identification of risks to EVA derived from lighting
conditions at the Lunar South Pole (LSP)**

Cynthia Null/NASA Engineering & Safety Center

Mary Kaiser/NASA Langley Research Center

Tom Wolters/NASA Langley Research Center

Jessica Marquez/NASA Ames Research Center

Miranda Cooter/NASA Goddard Space Flight Center

Charles Dischinger/NASA Marshall Space Flight Center

Lunar South Pole (LSP)

- NASA intends to go to the LSP, this decade, with partners
- Potential landing sites are south of 84° S latitude, so sun elevation in sky is never higher than about 7°
- This means sun is often in field of view during EVA, and even small objects cast long shadows
- The lighting at the LSP is very different than the Apollo experienced at mid-latitudes

Lunar Surface Safety at the South Pole- Illumination

- Clear vision is important to every task expected of Artemis Astronauts
 - Lack of visibility could cause a fall, or damage to the suit, resulting in permanent injury or death
 - Exploring the LSP region means that the human vision system will be put in the position of adapting to extremely bright light and very dark shadows
 - The ability to see clearly both close up (hands and feet) as well as the surrounding environment is essential to astronaut safety
- Artemis astronauts will be exploring the lunar south pole (LSP), a region only seen through cameras and robots
 - Representative simulations can aid in preparing crew for the expedition
- Illumination is influenced both by natural environments as well as any provided lighting equipment
- Natural illumination ranges from much darker than earth experience to much brighter; both cause hazards
- Providing integrated, adaptable tools and training mitigates the hazard to crew and can aid them in managing the LSP environment

LSP environment provides unique challenges to human vision

- Mission success requires accomplishment of vision-based tasks
- Ambient lighting is highly variable, from high brightness to deep shadow, and requires adaptable solutions in artificial lighting and glare protection
 - The extent to which the shadows are lit depends on the position of Earth and sun in the LSP sky and on the location of and distance to (and quality of) any source of reflected light
 - While deep shadows may be partially lit by Earthshine or reflections from terrain, they often will be so dark that the eye cannot discern large features (e.g., obstacles), especially in transition from lit areas to shadow
 - Low sun angle will result in the sun being in astronauts' field of view for tasks in its general direction
 - Astronauts working near LSP will experience potentially painful or disabling glare, high sunlight intensity, and deep shadows
 - Glare and intense light will make ambulation, driving, or near-field tasks in the direction of the sun difficult or even impossible

Vision-based EVA tasks likely needed for missions (determined by the authors, not programs)

Early missions

- Lander egress and ingress
- Lander system inspection and monitoring (contingency maintenance/repairs and abort decisions)
- Public affairs activities
- Ambulatory exploration
- Observation-based science: terrain, geology
- Deployment of instrument-based science payloads
- Tool access, use, and storage
- Sample collection and storage

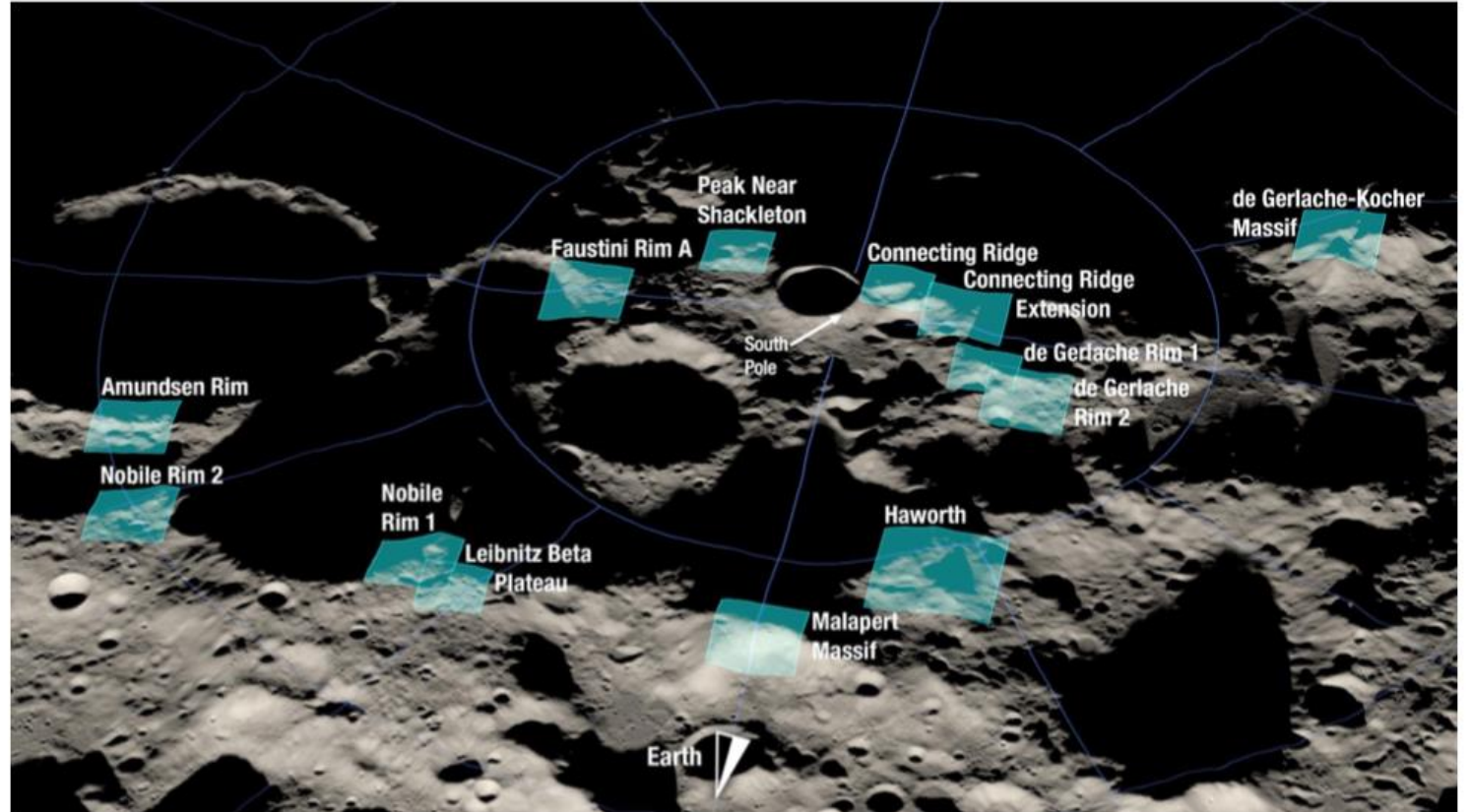
Later missions

Previous tasks, plus:

- Rover deployment and operation
- Science payload deployment and operation
- Logistics operations
 - Retrieval from delivery system
 - Deployment to appropriate locations
- Maintenance and repair of delivered systems
- Habitation infrastructure assembly and integration

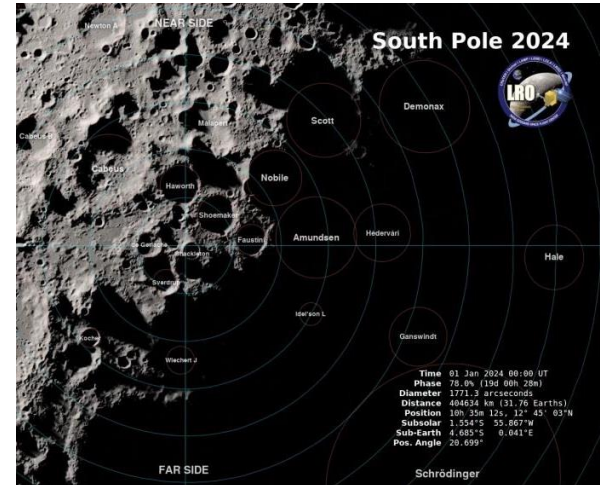
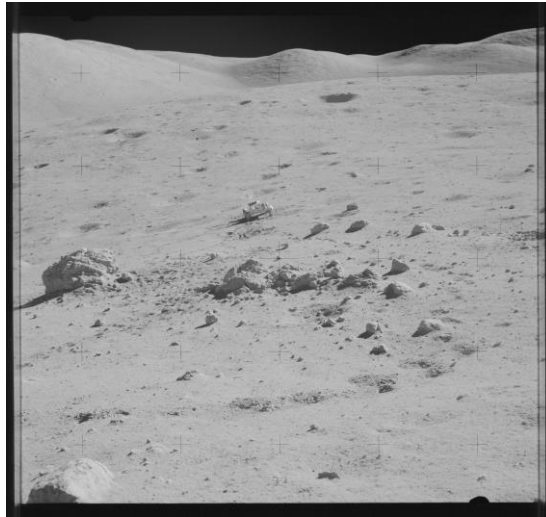
Natural Environments: Artemis Missions

- LSP surface features that might create hazards to ambulation, driving rovers, navigation, and other EVA tasks
- Lighting at LSP and its impact on human vision
- Likely effect on vision compared with Apollo



Candidate Landing Region for Artemis Missions (all within $\sim 6^\circ$ of LSP)

LSP Surface Features – Terrain and Geology

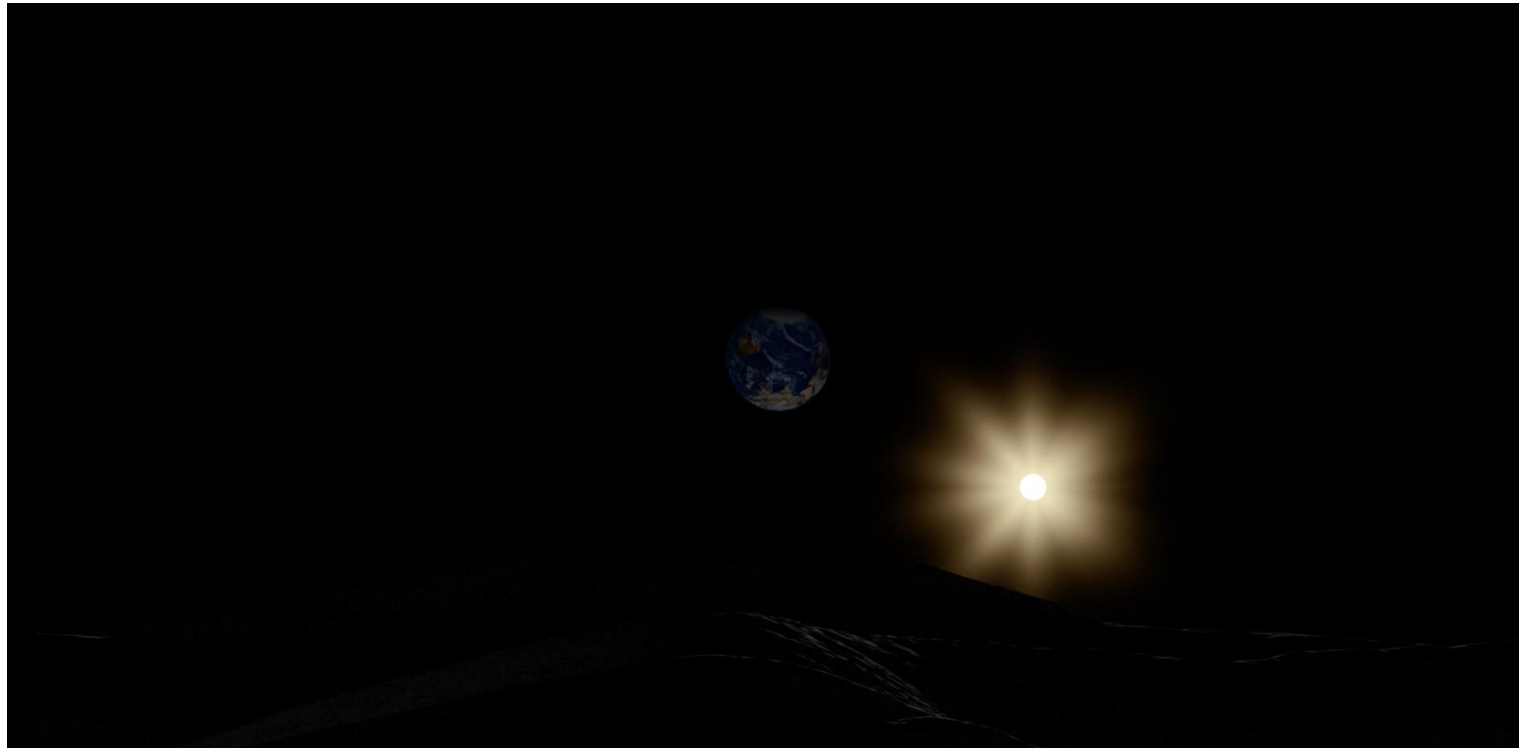


- Current knowledge of rock and crater distribution and size primarily from Lunar Reconnaissance Orbiter (LRO) (5m resolution)
- Rocks are relatively rare on the lunar surface
 - Mainly found around geologically newer craters and sloughed off from escarpments
 - Rocks are twice as reflective as regolith
- More craters at LSP than at most Apollo sites

Natural Environments: LSP Lighting

Position of sun in sky:

- Never higher than 7° at potential landing regions
- Sun moves across the sky at $12.86^\circ/24\text{h}$ (= 1 Earth day)
- Shadows are long and move extensively within a 6-day mission

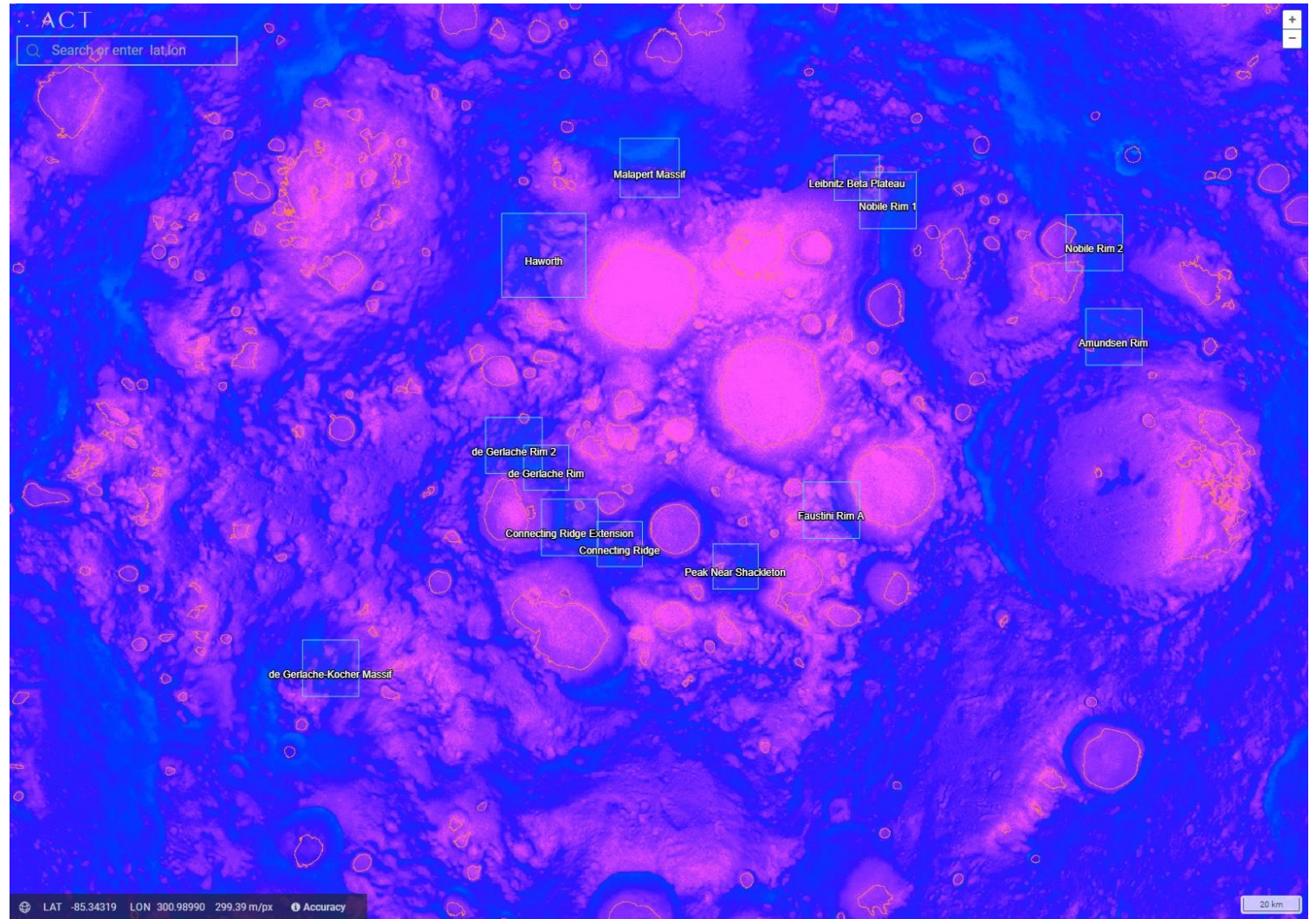


Safety consideration: temperatures

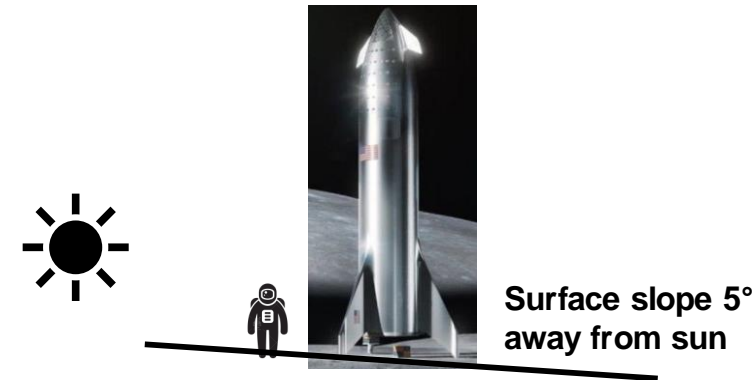
Low angle of incidence and extensive shadowing will result in much colder surface temperatures than Apollo experienced. These will create hazards:

Mean temperature at 85° latitude is ~60 K (-214 °C) at “3 AM equivalent” of lunar night. Permanently shadowed craters are colder. This will create risk if astronaut falls in a shadow and is in contact with the surface.*

* The time when one can safely be in contact with the lunar surface depends on location (permanently shadowed regions (PSRs) are coldest) and suit capabilities, such as heating. The existing suit requirement to maintain a stable thermal condition does not seem to address such anomalies as an astronaut being prone on the surface.



LSP Winter Minimum Temperature Map: light blue (90 K) through darker blues to dark pink, then light pink (18 K); 13 potential landing regions shown; lines inside craters indicate PSRs.



Sun at 2° above horizon

Sun elevation of 2° is a common situation, for sites and times

Level surface: 7' astronaut casts 201' shadow;
150' lander casts 4,298' shadow

Slope 5° toward sun: 7' astronaut casts 57'
shadow; 150' lander casts 1,231' shadow

Slope 5° away from sun: entire landscape in
shadow; lander top may cast some shadow,
depending on extent of slope

Sun at 7° above horizon

Sun will never be 7° above horizon, for many landing sites

Level surface: 7' astronaut casts 57' shadow;
150' lander casts 1,231' shadow

Slope 5° toward sun: 7' astronaut casts 201'
shadow; 150' lander casts 4,298' shadow

Slope 5° away from sun: 7' astronaut casts 29'
shadow; 150' lander casts 620' shadow

Apollo Program Experience



“Boy, that sun is bright... It’s just like somebody’s got a super-bright spotlight.”

-- Pete Conrad, Apollo 12’s EVA 1

Apollo missions landed at equatorial sites

- Fewer craters, boulders in terrain than in other lunar regions

Higher sun angles

- Sun angles during Apollo 12’s EVA-1 closest analog to Artemis missions
 - Apollo 12 EVA-1: 7.5° to 9.5° (over 4-hour duration)
 - Artemis missions: ~2° to ~6° (depending on “season” and landing location)

Low sun angle impacted Apollo 12 mission task performance

- Color camera disabled when its sensor was inadvertently pointed at the sun
- Sun’s brightness was commented upon five times in EVA-1 transcript; moved into a shadow several times to improve task visibility
 - “Wait until I get in this shadow. Because I can’t see what I’m doing looking right into the sun.” (*Pete Conrad, EVA-1 Transcript, p. 25*)
 - “Now, I can’t see it (camera he was lowering) on account of the sun, so tell me when it’s over the handrail.” (*Pete Conrad, EVA-1 Transcript, p. 29*)
 - “I think we need to modify the visor so that you have a center-top shield that you can pull down and blink (sic) the Sun out.” (*Pete Conrad, 1969 Technical Debrief, quoted in EVA-1 Transcript, p. 26*)

Human Visual System

Human vision provides *the primary* sensory input for situation awareness in most physical and many cognitive EVA tasks

This is especially true given that other senses have no (hearing, smell) or extremely limited (touch) environmental input during EVA

Human vision is highly capable (e.g., dynamic range greatly exceeds cameras') and reliable; however, it will be subject to:

Glare*, making it difficult to distinguish near-field objects (craters, rocks, designed systems)

Temporary blindness (2-30 min), when exposed to intense light

Light adaptation delays and limits (our system is tuned for terrestrial, not lunar, environment)

**glare reduces visual performance and visibility and often is accompanied by distracting discomfort*

Brightness Adaptation

On Earth, light intensities range across 9 orders of magnitude

A piece of pure white paper can be 1,000,000,000 times brighter in full sunlight than on a moonless night.

But for a given lighting condition, light ranges over 2-3 orders of magnitude



If we were sensitive to the entire range all the time, we'd be unable to discriminate lightness levels in the current scene.

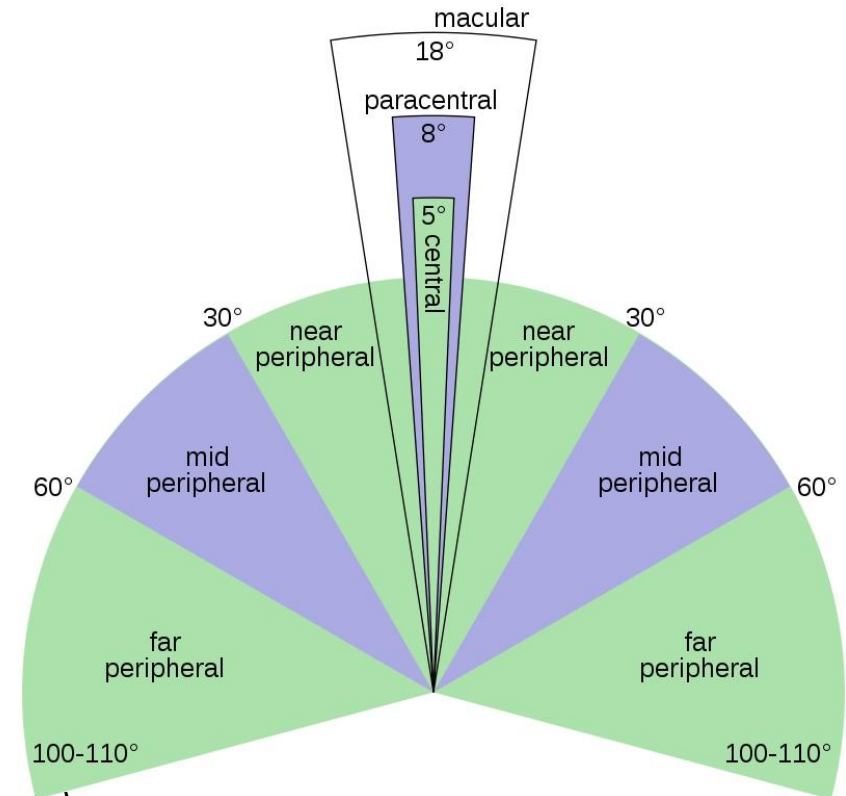
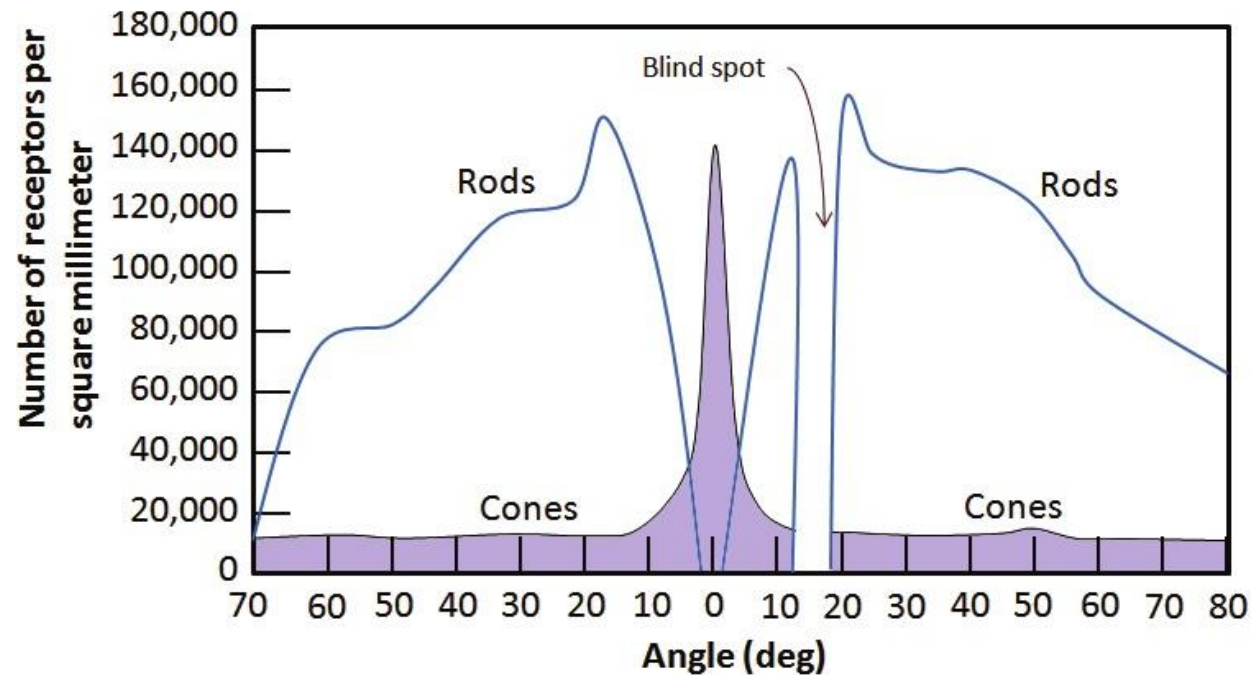
Instead, the human visual system calibrates its dynamic range to match ambient light levels:



A Quick Overview of Visual Receptors

Human retina contains rods (which supports monochromatic vision) and three* types of cones (which support chromatic vision)

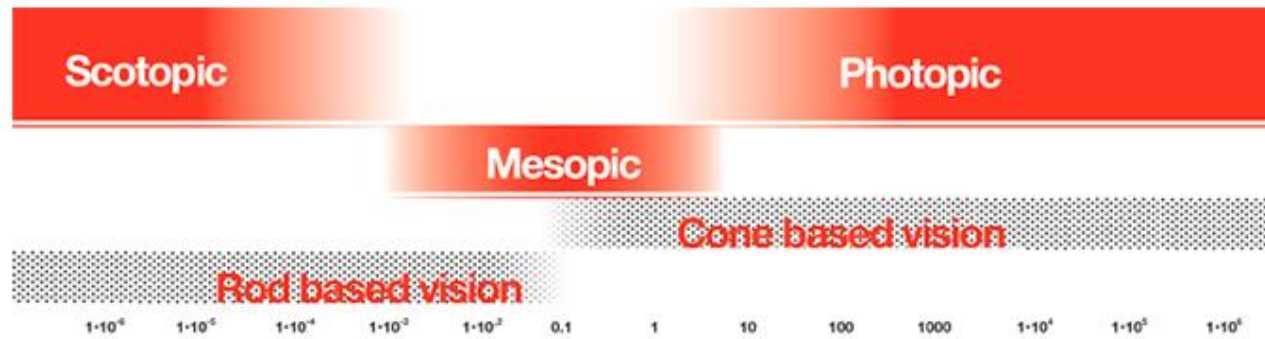
Cone density higher than rods in Macular region, with highest density in the Foveal and Parafoveal regions.



**Roughly 1% of the population have four types of cones (tetrachromats)*

Adaptation Mechanisms

First, the pupil can contract or expand in diameter (~2-8 mm range)
Accomplished in seconds (slightly longer to expand than contract)
This buys us about two orders of magnitude



Human eye luminance level range and types of vision: cd/m²

Second, our vision shifts its balance between photopic (cone-based) and scotopic (rod-based)

Third, both cones and rods adjust their sensitivity
Cones adjust more quickly (~10 minutes), but have smaller adjustment range
Rods have much larger adjustment range, but take longer (30 min for max)



Low Sun Angle: Moon vs. Earth (Desert)



Apollo 12, Ocean of Storms, EVA 1, 19 November 1969, frames A12-46-6738 to 6740 : Apollo 12 landing site

Extreme Glare Due to Lack of Atmospheric Attenuation and Scatter

Shadows Extremely Long

Shadows Extremely Dark

Shadows' Movement Changes Objects' Appearance



- Minimal Glare Due to Atmospheric Attenuation and Scatter
- Shadows Extremely Long
- Shadows Very Soft
- Shadows' Movement Minimally Affects Objects' Appearance

Takeaway: Apollo astronauts advised not looking at sun; this advice will be nearly impossible to follow at LSP

LSP Lighting – Likely Effects on Vision-Based Tasks

Intensity & Glare

- Will be a factor any time the sun (or reflective surface) is in the astronauts' field of view

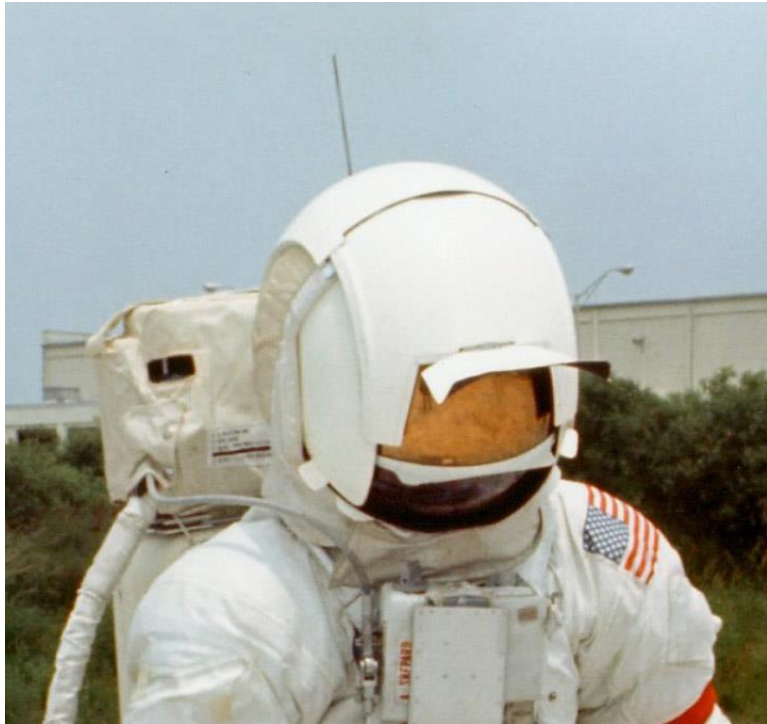
Shadow

- Sources:
 - Designed systems: self (suit), lander, and eventually rover and habitat
 - Natural systems: rocks, craters, slopes
 - Depth of shadows will be highly variable as there will often be reflected light

Changing light

- Over the course of a single surface mission, natural light will change dramatically; artificial lighting and other vision support will need to adapt to support tasks; e.g., translocation

Artemis illumination and vision protection will be more difficult to attain than in Apollo



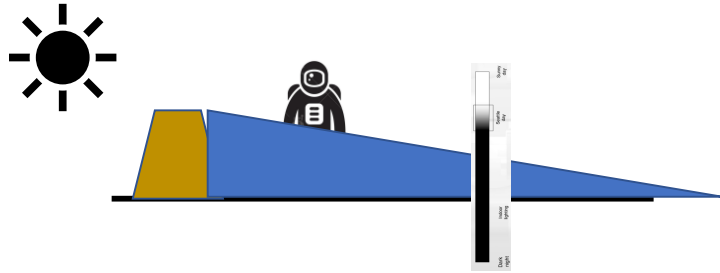
- Sun will *never* be higher than 7° elevation at Artemis landing sites (three fingers at arms length)
- Whenever the sun is in the astronauts' visual field, it **MUST** be occluded or otherwise attenuated (while avoiding complete visual blackout)
- Whenever the astronaut is working in shadow, additional illumination **MUST** be provided (lights, reflected/diffused sunlight, *etc.*)

Apollo LEVA suit with sun blocks fully deployed (but insufficient for LSP sun angles). Note lack of any suit lights.

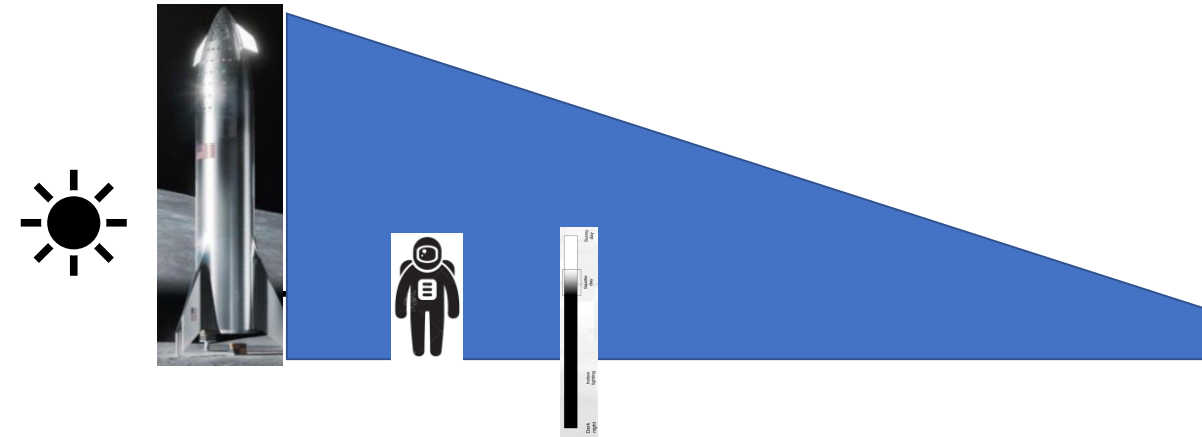
Apollo suit design did not deal with vision protection and illumination in ways that are sufficient for Artemis

The real problem:

The human eye, when adapted to one state - in light or darkness – cannot see outside its natural dynamic range range (box, in previous slides). The moon's extreme lighting/darkness exceeds earth-bound experience.



- Head above shadow: cannot see terrain in front of feet because of dynamic range of eye



- Head in shadow (*i.e.*, step into shadow): cannot see terrain in front of feet because of adaptation time, for visual range to shift to dark and be able to use artificial light

Conclusions

- Vision will be impaired during even the simplest of tasks, and all EVA tasks will rely on vision
- Artemis landing regions provide more challenging environments than Apollo landing sites; operational terrain is believed to be more rugged than even that at equatorial highlands (Apollo 16)
- The sun will always be near horizon, creating glare/bright light and extensive shadowing
- Lunar surface operations of 50 years ago were *never* conducted with sun angles as low as Artemis crews will encounter on all missions.
- While Apollo astronauts reported difficulty due to glare, they did not experience the dynamic lighting conditions of LSP; those astronauts were advised to not look at sun, but this advice will be nearly impossible to follow at LSP
- *Very* deep, persistent shadows will be created by terrain and human systems, and astronauts will need to be able to enter/exit them frequently
- Human vision is adapted to earth conditions and severely challenged by lighting conditions of LSP; the dynamic LSP lighting will create glare and shadow that will overwhelm the ability of astronauts' vision to adapt

What is needed

An integrated *designed* solution, addressing both vision protection (helmet) and lighting, is required; these solutions must address:

- Protection of human vision from being overwhelmed by sun's brightness and glare
- Highly-integrated lighting architecture to support all human tasks, through the dynamic natural environment