NESC Webinar

The Visual Experience at the Lunar South Pole

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This work was conducted under an NESC assessment titled:

Exploration Systems Exterior Lighting Design Guidance

Assessment Team

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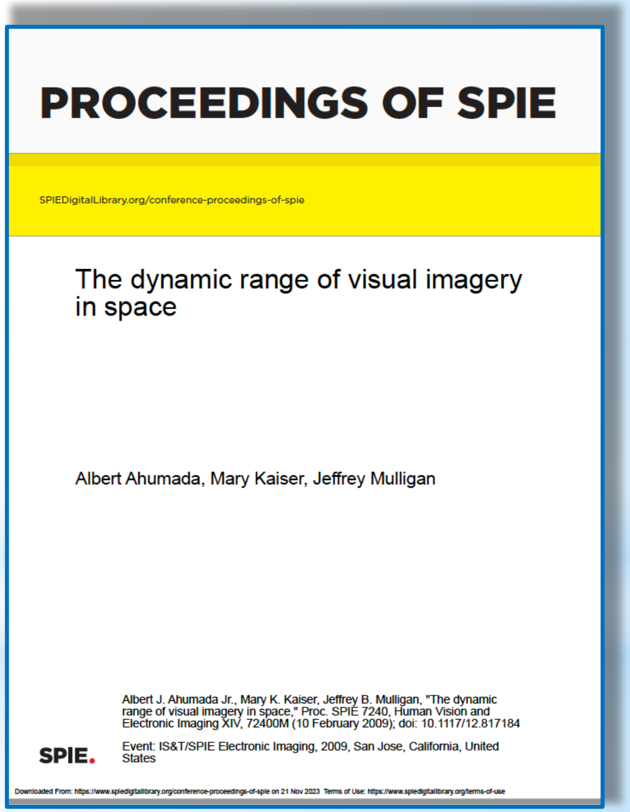
Lunar South Pole (LSP) Environment Presents Unique Challenges to Human Vision

- 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



PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

The dynamic range of visual imagery in space

Albert Ahumada, Mary Kaiser, Jeffrey Mulligan

Albert J. Ahumada Jr., Mary K. Kaiser, Jeffrey B. Mulligan, "The dynamic range of visual imagery in space," Proc. SPIE 7240, Human Vision and Electronic Imaging XIV, 72400M (10 February 2009); doi: 10.1117/12.817184

SPIE.

Event: IS&T/SPIE Electronic Imaging, 2009, San Jose, California, United States

Vision-based EVA Tasks Likely Needed for Missions (determined by NESC assessment team, not programs)

Early Missions

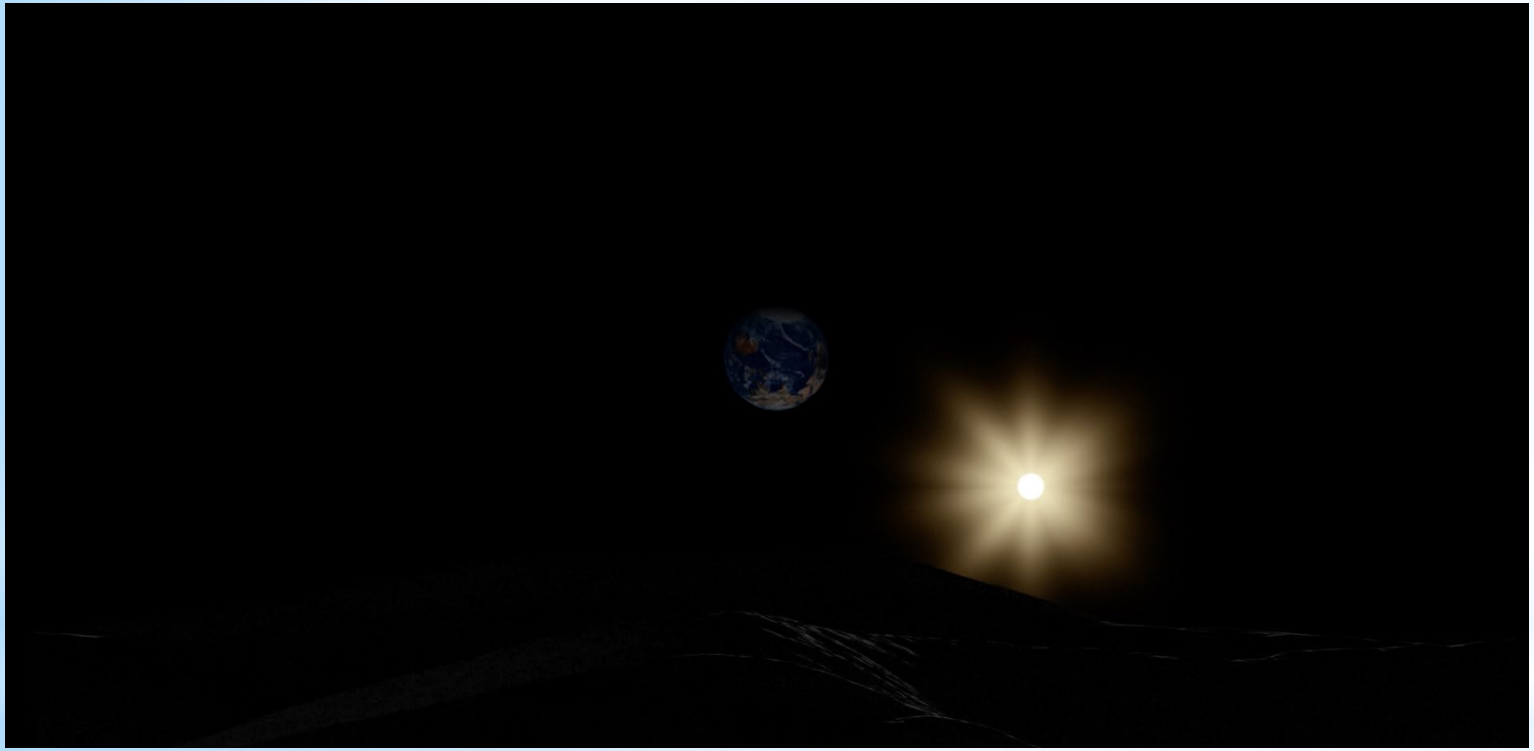
- Lander egress and ingress
- Lander system inspection and monitoring (contingency maintenance/repairs and abort decisions)
- Public affairs activities
- Ambulatory exploration
- Observation-based science: terrain, geology
- Deployment of instrument-based science payloads
- Tool access, use, and storage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

Later Missions

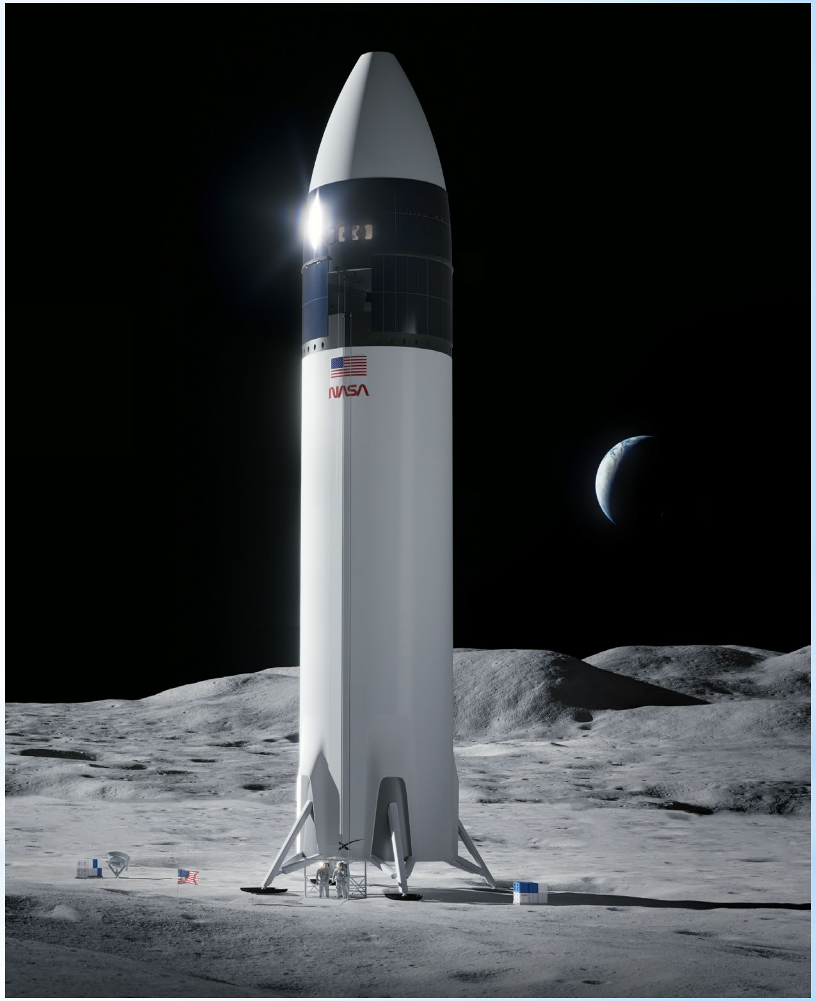
Previous tasks, plus:

- 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

One Concern for Understanding the Challenges to Vision is Representation (Simulation) of the Environment



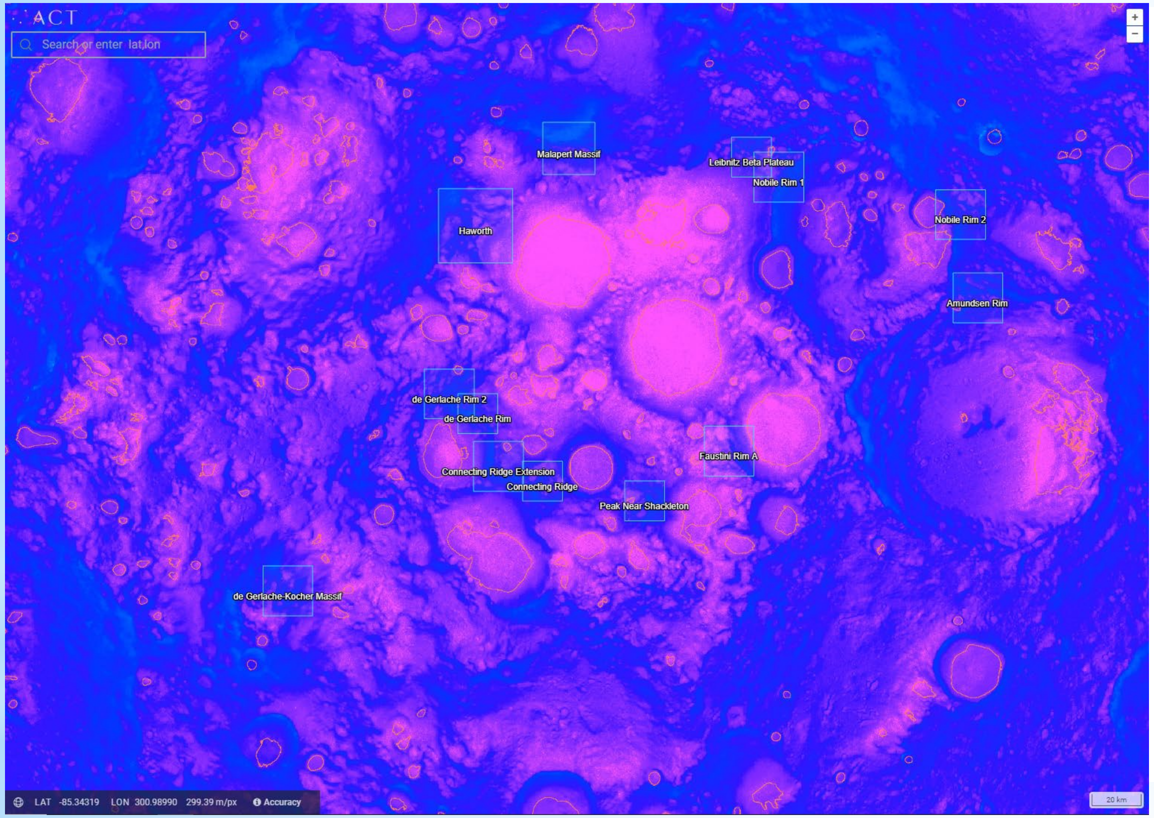
Scientifically-accurate representation of relative positions of Earth, Moon, & Sun



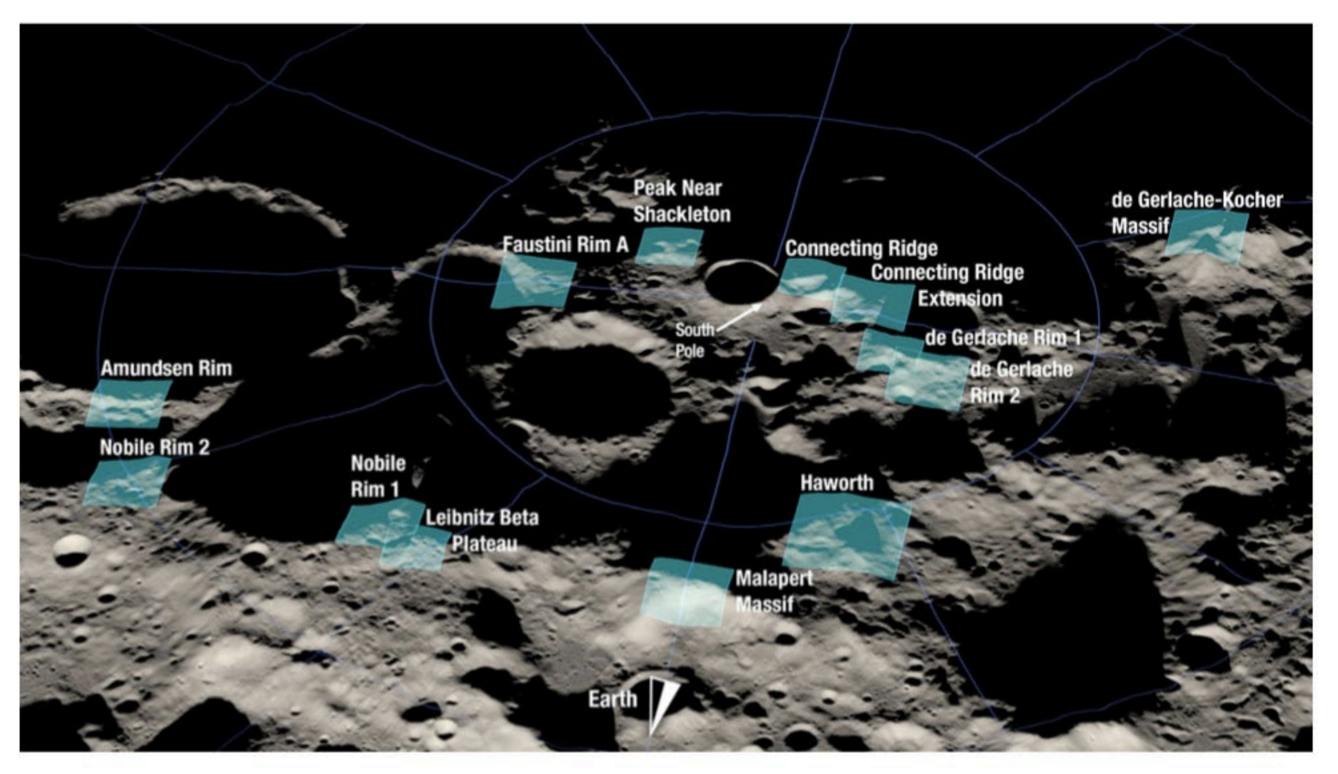
Inaccurate representation, for public affairs purposes; intent is to demonstrate scale of lander to humans

Natural Environments: Artemis Missions

Artemis landing regions provide more challenging environments than Apollo landing sites

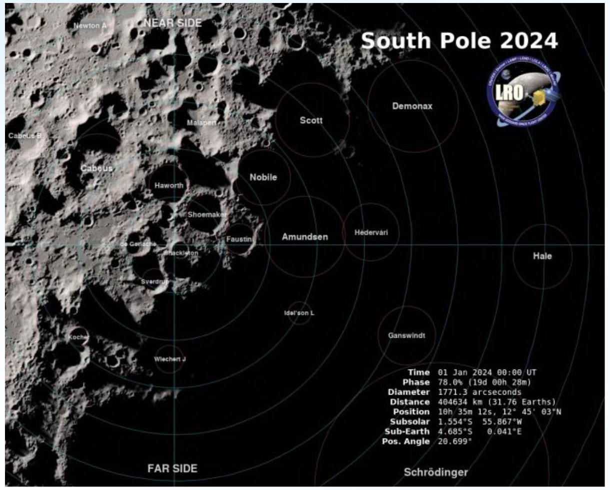


LSP Winter Minimum Temperature Map: light blue (90 K) through darker blues to dark pink, then light pink (18 K); 13 potential landing regions shown; lines inside craters indicate PSRs.



Candidate Landing Region for Artemis Missions (all within ~6° of LSP)

LSP Surface Features – Terrain and Geology



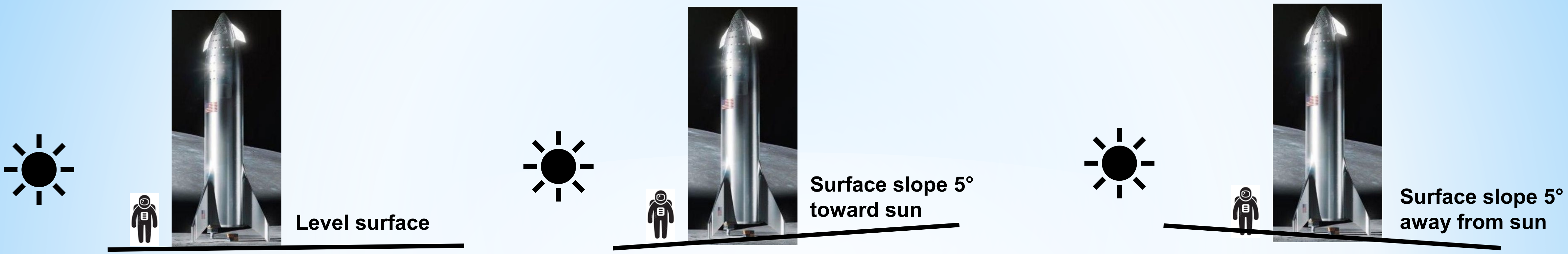
- Current knowledge of rock and crater distribution and size primarily from Lunar Reconnaissance Orbiter (LRO) (5m resolution)
- Rocks are relatively rare on the lunar surface
  - Mainly found around geologically newer craters and sloughed off from escarpments
  - Rocks are twice as reflective as regolith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

Operational terrain is believed to be more rugged than even that at equatorial highlands (Apollo 16)

Natural Environments:
LSP Lighting

- **Position of sun in sky:**
- Never higher than 7° at potential landing regions, resulting in the Sun's being in EVA crew field of view, during many operations
- Sun moves across the sky at 12.86°/24h (= 1 Earth day)
- Shadows are long and move extensively within a 6-day mission
- Shadows near-black; very little light reflected into them (unlike in Apollo)

Explorers will need to move into and out of bright sun frequently, in accomplishment of mission objectives



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

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

Sun at 7° above horizon

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

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

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

Very **deep, persistent shadows will be created by terrain and human systems, and astronauts will need to be able to enter/exit them frequently**

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

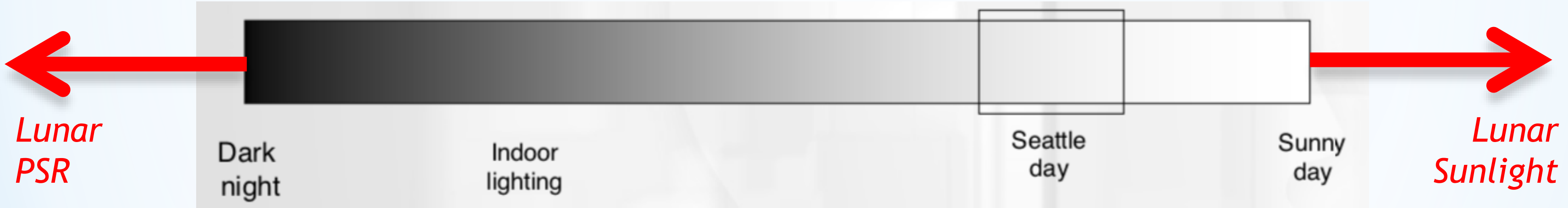
- Human vision provides *the primary* sensory input for situation awareness in most physical and many cognitive EVA tasks
  - This is especially true given that other senses have no (hearing, smell) or extremely limited (touch) environmental input during EVA
- Human vision is highly capable (*e.g.*, 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

Human vision is well-adapted to earth conditions and will be severely challenged by lighting conditions of LSP

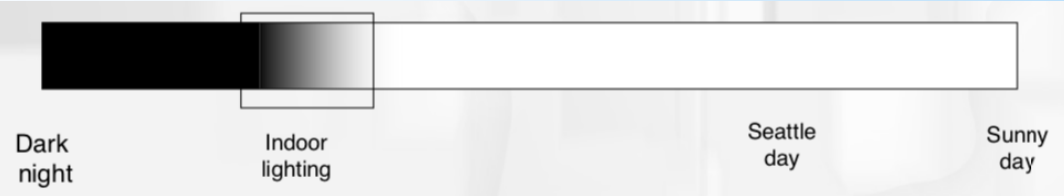
**glare reduces visual performance and visibility and often is accompanied by distracting discomfort*

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

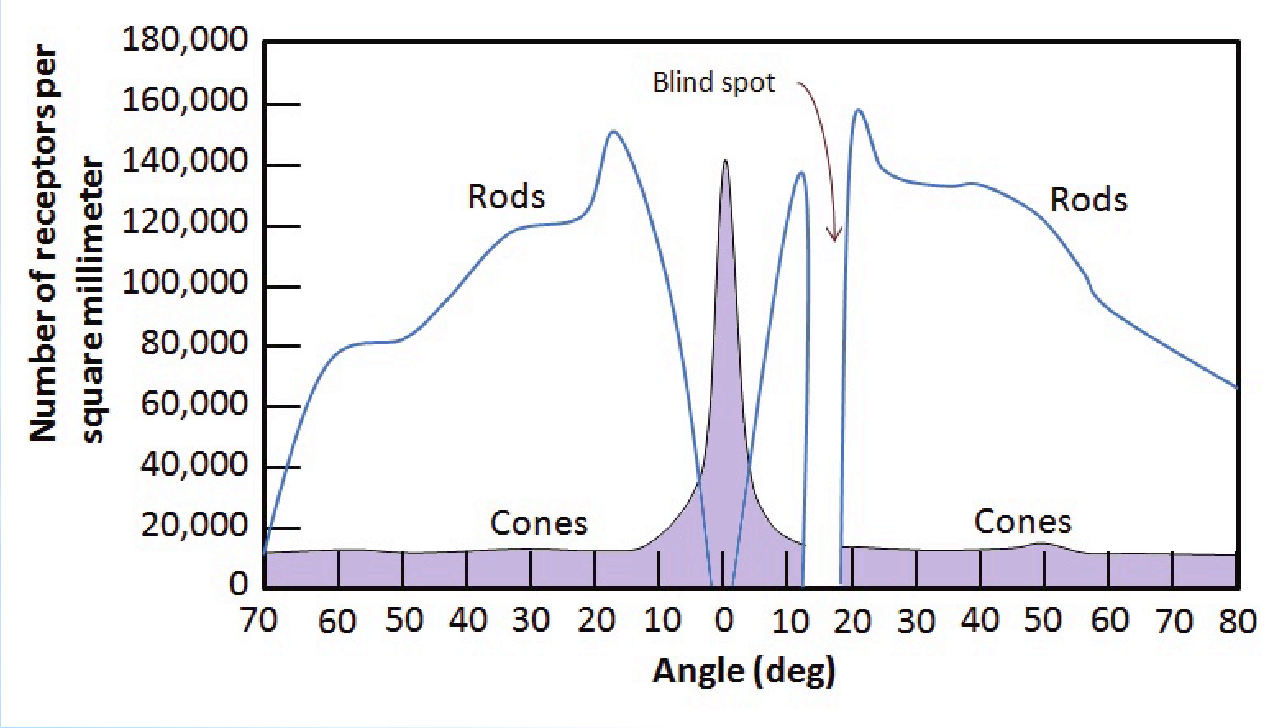


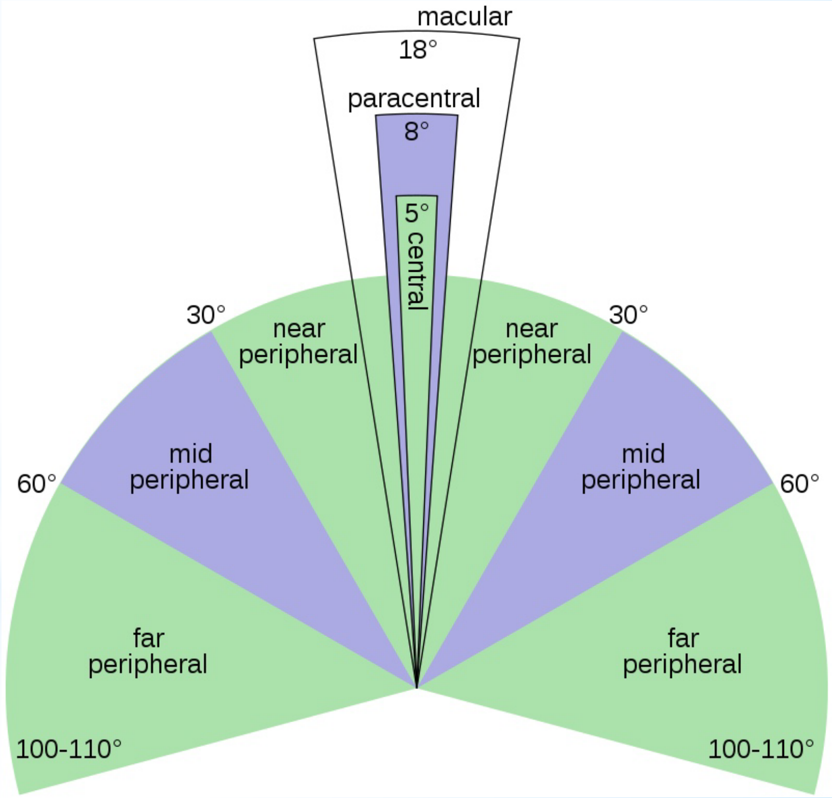
  - If we were sensitive to the entire range all the time, we'd be unable to discriminate lightness levels in the current scene.
- Instead, the human visual system calibrates its dynamic range to match ambient light levels:



A Quick Overview of Visual Receptors

- Human retina contains rods (which supports monochromic 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.

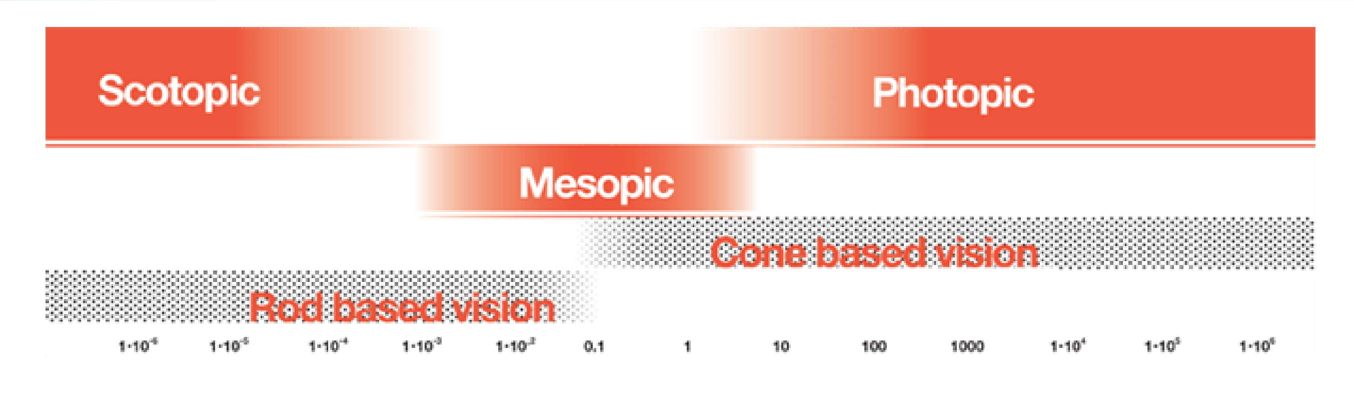




**Roughly 1% of the population have four types of cones (tetrachromats)*

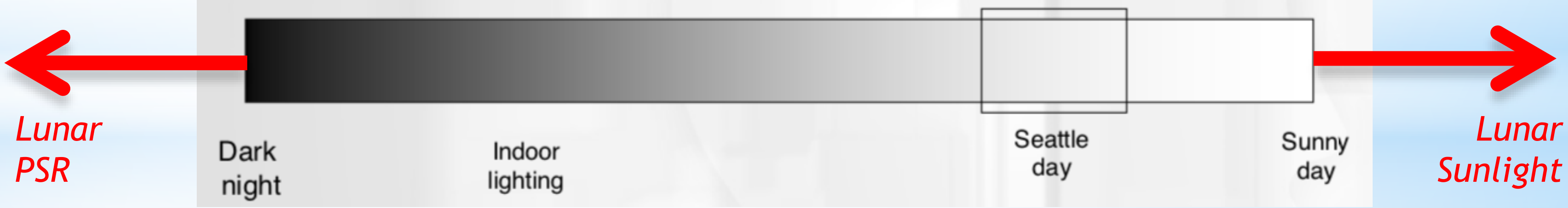
Adaptation Mechanisms

- 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 sotopic (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

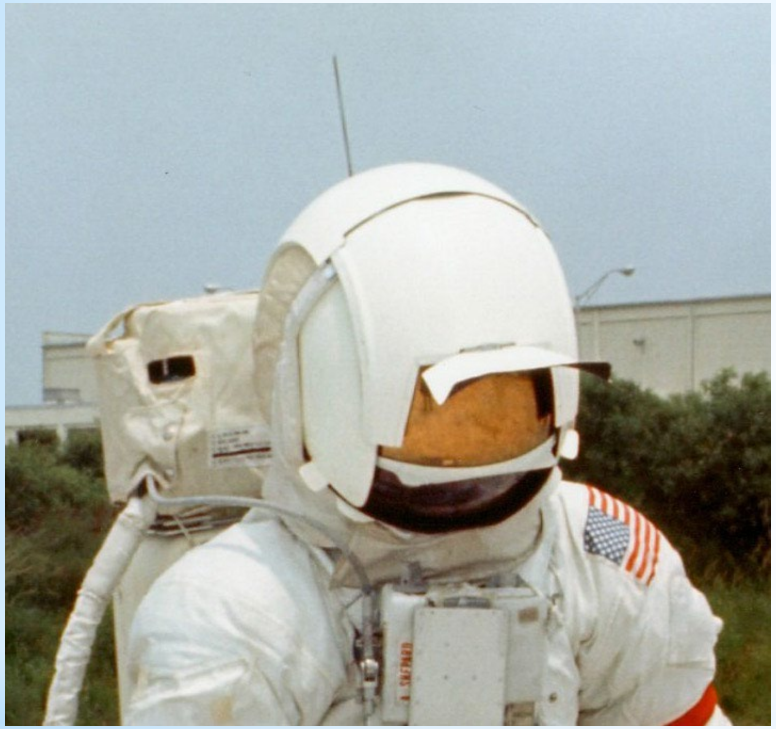
- Minimal Glare Due to Atmospheric Attenuation and Scatter
- Shadows Extremely Long
- Shadows Very Soft
- Shadows' Movement Minimally Affects Objects' Appearance

Apollo astronauts were advised to not look at sun; at the LSP, the sun will be in field of view much of the time

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

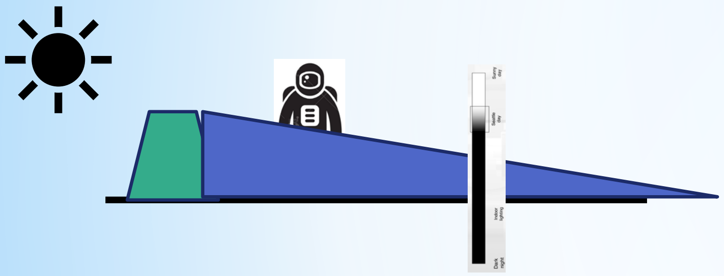


Apollo LEVA suit with sun blocks fully deployed (but not sufficient for LSP sun angles). Note lack of any suit lights.

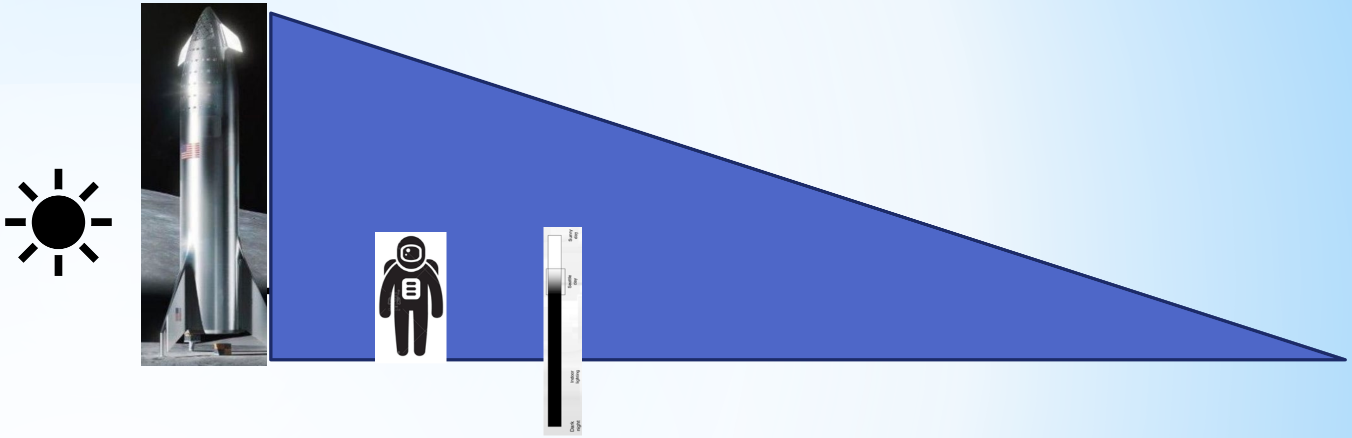
- Sun will *never* be higher than 7° elevation at Artemis landing sites (three fingers at arms length)
- Whenever the sun is in the astronauts' visual field, it MUST be occluded or otherwise attenuated (while avoiding complete visual blackout)
- Whenever the astronaut is working in shadow, additional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

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

The Real Problem



- 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

An integrated solution, addressing both vision protection (helmet) and lighting, is required

Considerations

- 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; this solution cannot simply cut off solar intensity (*e.g.,* as in static welding helmet), because that would make even brightly-lit surface features difficult or impossible to see
- Highly-integrated lighting architecture to support all human tasks, through the dynamic natural environment
- Designed lighting solutions that are integrated with helmet (or other?) solutions that protect vision; these must work in concert, to support "seeing"
- Adequate lighting & eye protection for all tasks (including locomotion and based on mission-level task analyses); this process should define EVA timelines, understanding impacts of setup & disassembly of lighting systems
- Integrated (cross-program) volume, power, and mass budgets

The integrated solution will affect all programs; not just suits (xEVAS)

Agency Status

- While the Agency currently employs a SME in lighting analysis and lighting system design, there is no SME in human vision to support the integrated design
- Cross-program integration not yet achieved
- Solutions for shielding vision from solar glare are low-TRL