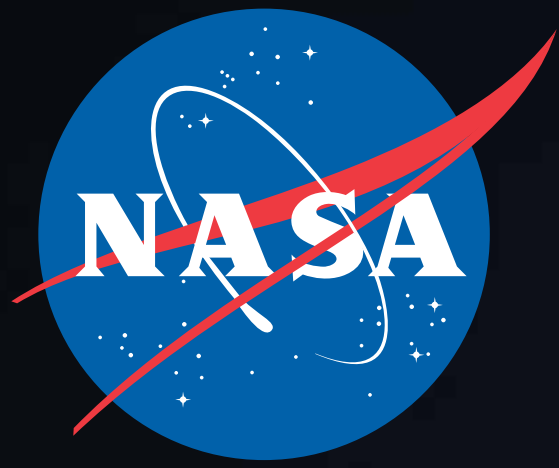




National Aeronautics and
Space Administration

Ad Astra **Per Lunam**

A TDAMM Observatory at the Lunar South Pole

August 1, 2026
Ad ASTRA Workshop
Pasadena, CA, USA

Leo P. Singer, S. Bradley Cenko, Elisa Quintana, Tom Barclay, Alex Kuttyrev, Carolyn Kierans (NASA Goddard)
Nick Law, Igor Andreoni (University of North Carolina)
Noel Klinger (University of Maryland Baltimore County)

image: NASA

One-Slide Summary

- **Current policy prioritizes Moon-to-Mars (M2M)** and dual-use missions. NASA is actively creating a demand signal to **radically alter lunar transport economics**.
- Economics and **reusable Artemis infrastructure** make the Moon highly competitive for missions we would otherwise assign to free-flying space telescopes.
- The Moon shares the dark, cold advantages of space while introducing new operational challenges. However, its definitive advantage is a **solid surface capable of supporting large, precise, fast-slewing mounts** without the failure modes of reaction wheels.
- This makes the Moon the ideal platform for a **powerful, nimble, and era-defining TDAMM observatory**.
- Lunar radio arrays, optical interferometers, and gravitational wave concepts are already well-studied; **they do not require an ASTRA incubator study**.

At least one selected Ad ASTRA study must be a ground-based observatory on the Lunar surface.

Beyond Astro2020

By the late 2020s, the Rubin Observatory (LSST) and the Roman Space Telescope will have revolutionized our baseline understanding of the time-domain universe.

To justify a 2030s flagship, we must look past the transients we already know how to catch. The 2030s belong to:

- **Multi-Messenger 2.0 (The LISA Era):** Catching prompt UV/X-ray flares from Supermassive Black Hole mergers requires staring continuously at massive error boxes for weeks.
- **The Ultra-Fast Universe:** Ground surveys miss sub-minute astrophysics. We must capture prompt flashes from Fast Radio Bursts (FRBs), magnetar flares, and supernova shock breakouts.
- **The Dark Universe:** Discovering "rogue" planets and primordial black holes requires pristine, uninterrupted microlensing light curves over dense star fields.

Beyond TDAMM: The Ultimate Static-Sky Observatory

- **Ultra-Deep, Ultra-Wide Frontier:** Current deep fields (e.g., JWST) are narrow. Staring uninterrupted for weeks, a lunar array can execute massive, ultra-deep IR surveys to map the Epoch of Reionization and Population III stars.
- **Extreme Low Surface Brightness:** Deep space (L2) avoids Earth-shine, but free-flyer reaction wheels create high-frequency micro-vibrations (jitter) that smear images. The Moon's solid surface eliminates this, providing the absolute stability needed to map faint intra-cluster light.
- **Far-UV Circumgalactic Medium:** The Moon's pristine vacuum avoids Earth's glowing exosphere, enabling direct UV imaging of the cosmic web.
- **Decadal-Baseline Astrometry:** Free from orbital decay and gyro degradation, a fixed lunar array yields a multi-decade baseline for cosmic expansion.

Anchored to a stable, thermally invariant, slowly rotating surface, the Moon provides the ultimate pristine optical bench.

Bottlenecks of free-flying spacecraft

- **The Slew-Rate Limit:** If a transient lasts 5 seconds, a telescope cannot slew fast enough. We must already be looking when it detonates.
- **Interrupted Light Curves:** Microlensing and flare monitoring require perfect, continuous observation. Missing even an hour of data corrupts the measurement.
- **The Free-Flyer Wall:** Space observatories are severely bottlenecked by narrow fields of view, mechanical slewing, orbital occultations, and thermal settling.

2030s science demands a platform that never blinks, is never blocked by the Earth, and can either stare continuously or slew rapidly without the penalty of reaction wheels.

Destination: Moon

- The Commercial Lunar Payload Services (CLPS) program aims to provide soft landings on the lunar surface at a *near monthly cadence*.
- Artemis IV will put *humans back to explore & deploy experiments*.
- Both CLPS and Artemis are targeting the *lunar south pole* and its *permanently shadowed regions (PSRs)*.
- There is a lot of interest in building *infrastructure to support long-term presence and operations* at the lunar poles (e.g. nuclear reactors, comms infrastructure, ISRU, etc.).

The Agency and the Administration have been clear that they will *prioritize missions that further the Moon To Mars (M2M) objective or that have dual use for science and for human exploration.*

Timeline of Past and Future CLPS Deliveries



Astrobotic Technology
Peregrine Mission One

*Launched Jan. 8, 2024
No lunar landing*



Firefly Aerospace
Blue Ghost Mission 1

*Launched Jan. 15, 2025
Landed Mar. 2, 2025*



Blue Origin*
Blue Moon Mark 1 Mission



Intuitive Machines*
IM-3 Mission



Draper*
Draper Mission 1



Firefly Aerospace*
Blue Ghost Mission 3

2024

2025

2026

2027

2028

*Launched Feb. 15, 2024
Landed Feb. 22, 2024*

Intuitive Machines
IM-1 Mission



*Launched Feb. 27, 2025
Landed Mar. 6, 2025*

Intuitive Machines
IM-2 Mission



Astrobotic Technology*
Griffin Mission One



Firefly Aerospace*
Blue Ghost Mission 2

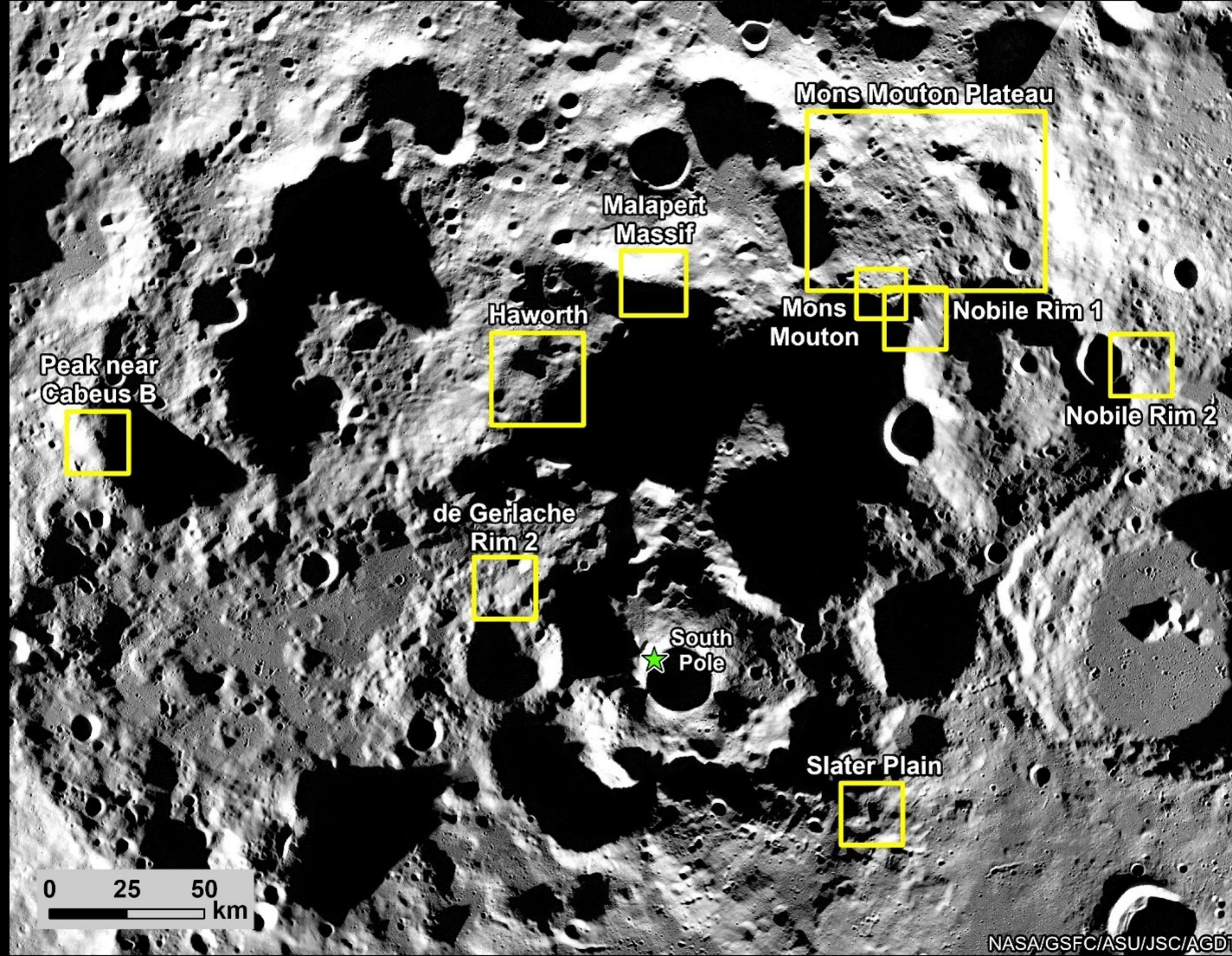


Intuitive Machines*
IM-4 Mission



* Future planned deliveries are placed on the timeline by year only, and their order within each year is not exact.

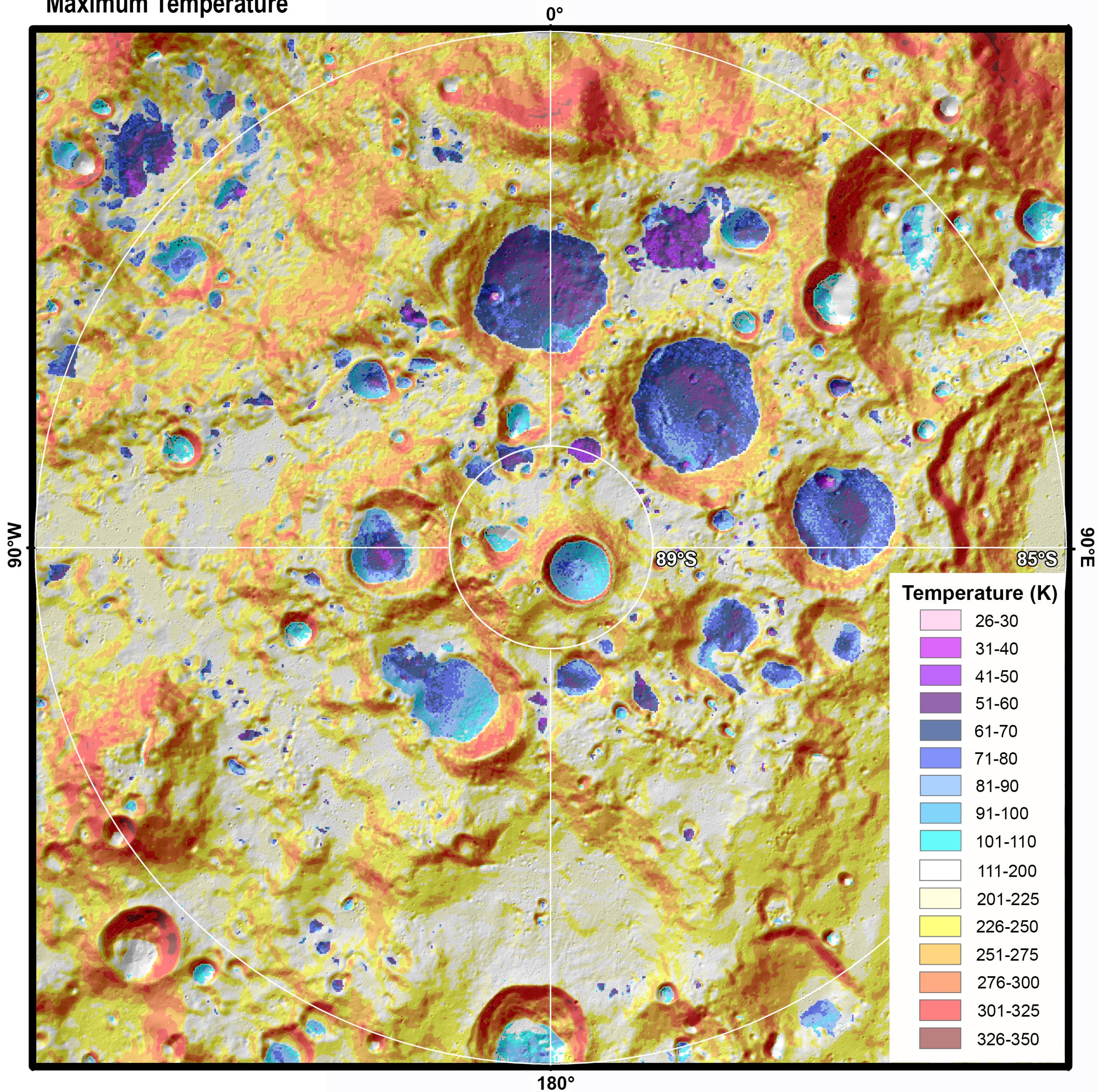
Artemis IV Landing Sites



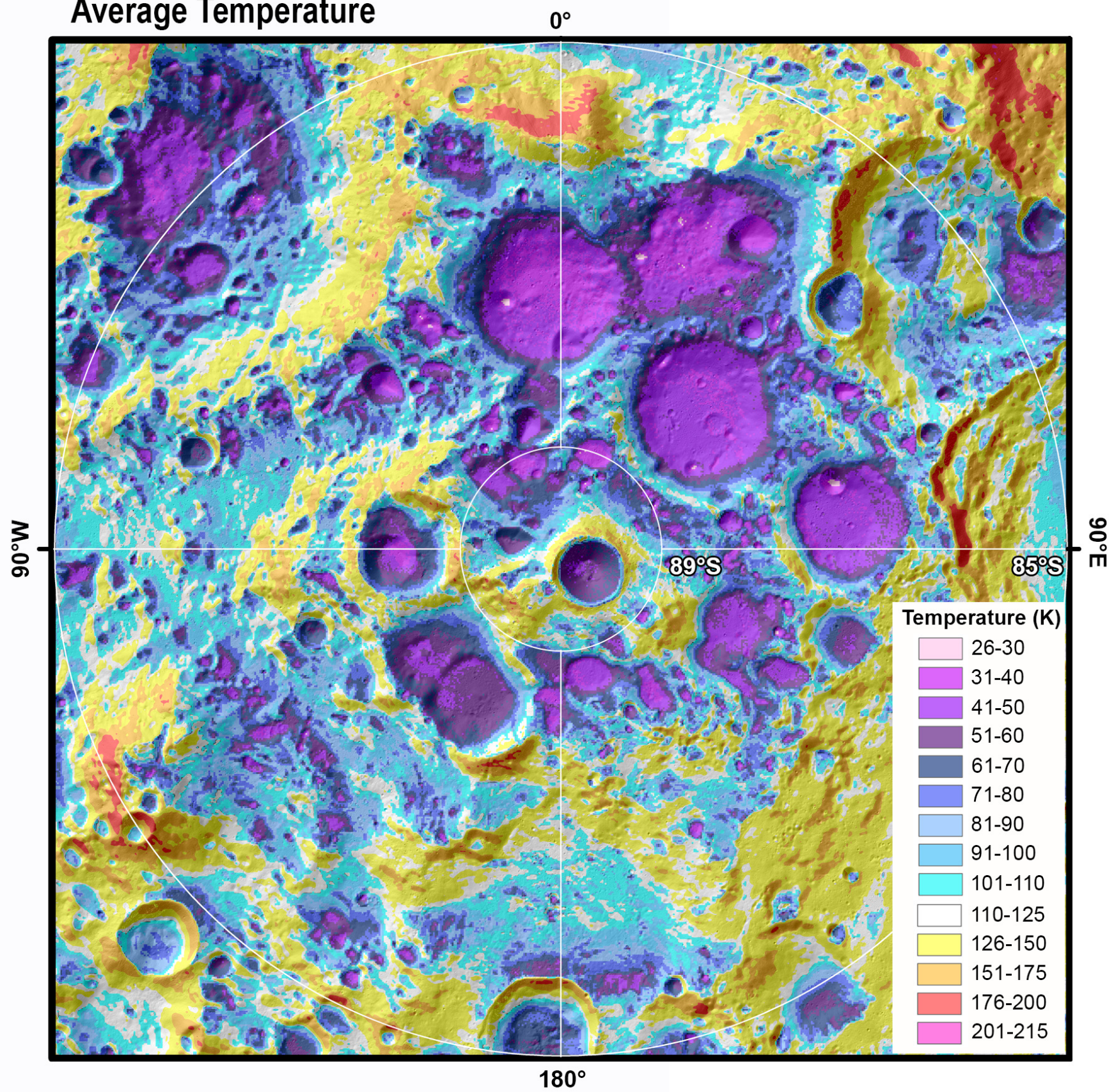
Near-Surface Temperatures Modeled for the Moon's South Pole (85°S to Pole)

Polarstereographic Projection (Scale 1:1,250,000)

Maximum Temperature



Average Temperature



Data sources:

Lunar Reconnaissance Orbiter Diviner instrument modeled temperature data at 2-cm depth for the lunar south pole (model of *Paige et al., 2010*) [NASA Goddard Space Flight Center (GSFC); University of California Los Angeles]. Colors denote quantized modeled temperatures; these are not actual measurements of surface temperature and discrepancies exist between the model and actual measurements. Modeled temperatures are shown overlain on a hillshaded relief map (with solar azimuth 45°W and solar elevation 45°) derived from the Lunar Reconnaissance Orbiter Laser Altimeter (LOLA) 20-m elevation data [NASA Goddard Space Flight Center (GSFC)].

Advantages of the lunar south pole

- **Very cold (40-60 K)** → good environment for infrared and sub-millimeter
- **Reduced geocoronoal emission** → good for far UV, low background
- **Practically no human-made RFI** → good for radio (well covered by other talks)
- **Huge, perpetually dark, slowly turning sky** → *excellent for time domain*
- **Solid surface** → *no need for reaction wheels if pointing is required*

Some of these advantages are common to L2 or high Earth orbit, which have been more economical than the lunar surface. However, ***economics are changing with increased lunar surface opportunities.***

A lunar permanently shadowed region may be an ideal site of opportunity for a flagship TDAMM observatory.

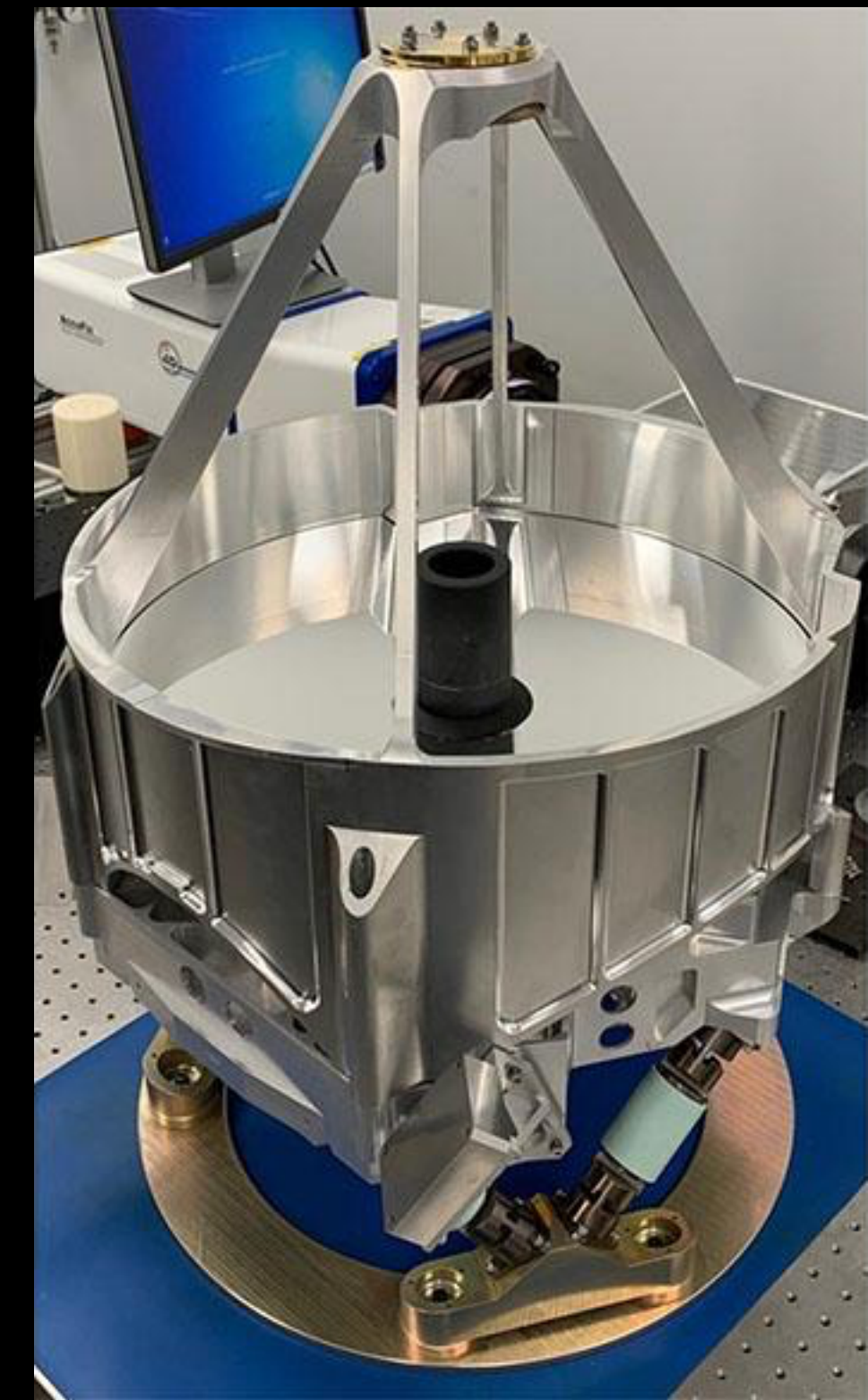
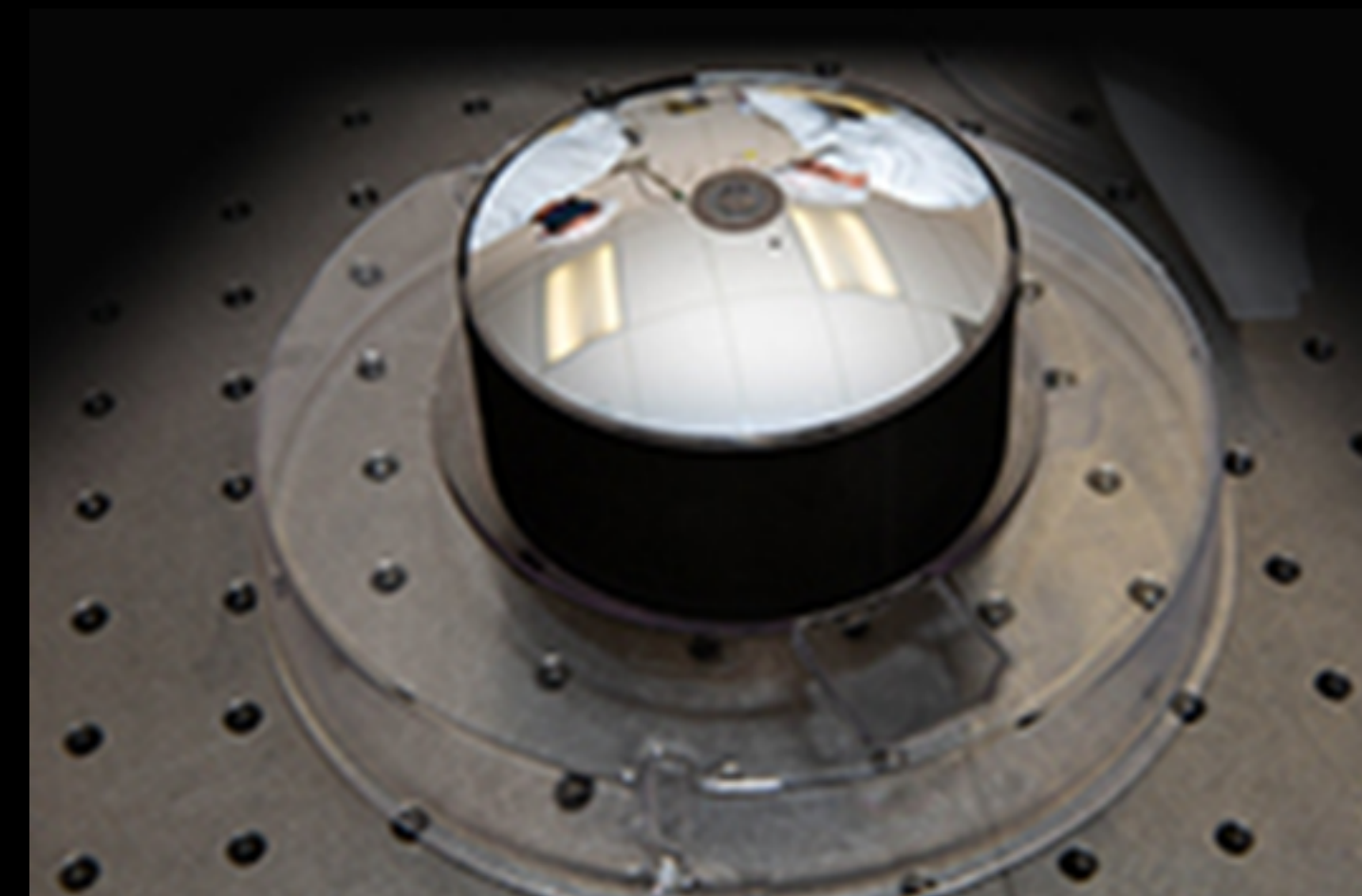
But the moon is a harsh mistress, so I'll go there first

- At GSFC we (Cenko, Kierans, Kutylev, Quintana, Singer) are developing a concept for a *quick turnaround dual use astrophysics mission* on a *CLPS lander pallet* called *LSTEP (Lunar Surface Transient Explorer Pathfinder)*.
- The concept currently consists of:
 - Solid-state gamma-ray monitor
 - Wide-field monolithic IR and UV telescopes (Pandora heritage)
- It will test shake out edge computing, thermal management, comms, and dust management strategies for operating an astronomical facility on the moon.

Images:

<https://ipo.llnl.gov/ipo-technologies/lasers-and-optics/monolithic-space-telescopes-and-mounting-system>

<https://space-science.llnl.gov/research/smallsat-capabilities>

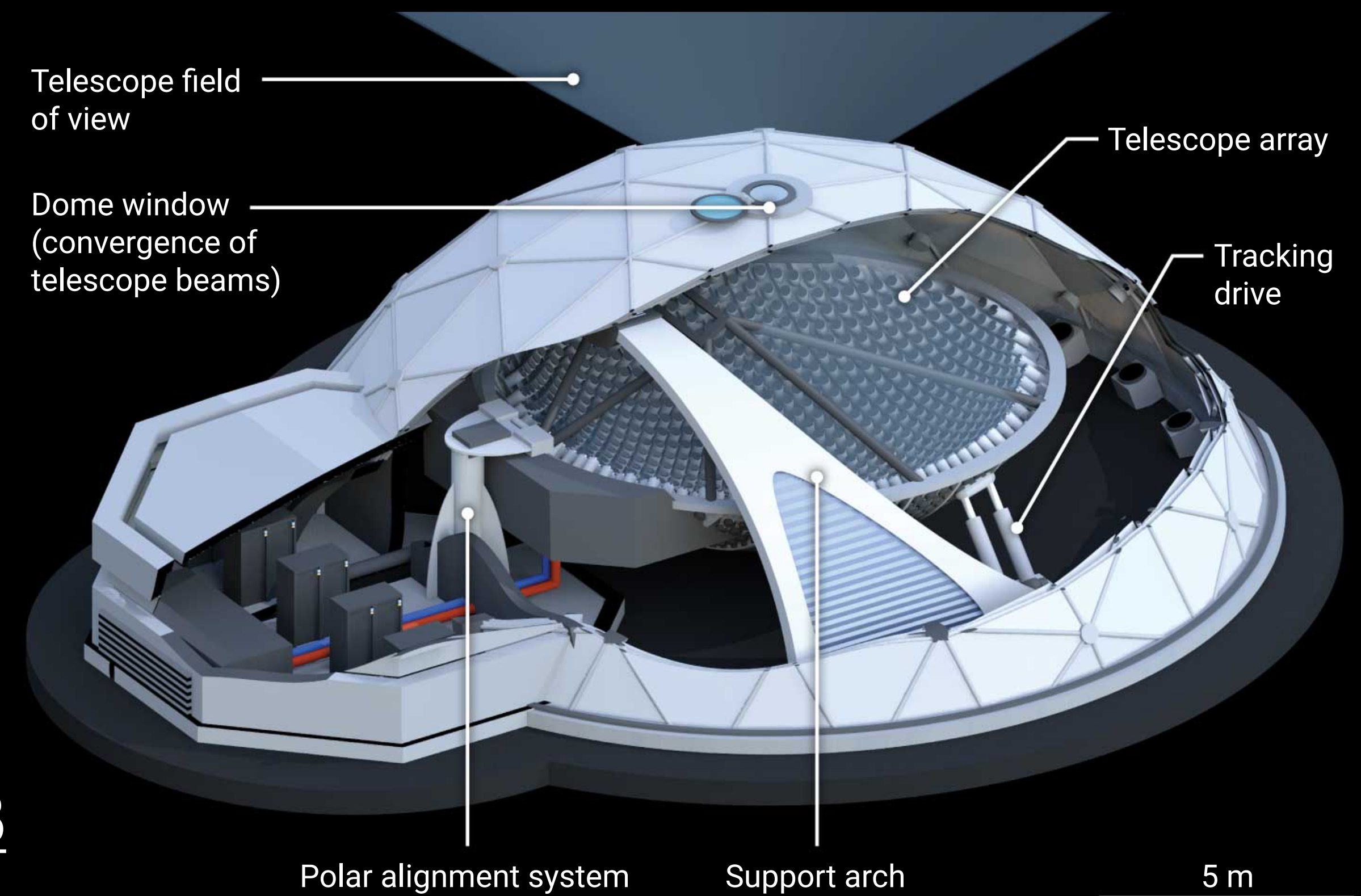


We need to develop CLPS pathfinders now to pave the way for flagship lunar observatory.

Compelling architectures for a flagship mission

Configuration A: "Argus Array on the moon."

An all-sky gamma-ray monitor plus a deep, super wide field IR/UV transient surveyor. Hundreds of small telescopes look through one optical window. With zero moving parts and a minimal surface area to keep clear of dust, this concept emphasizes hardness and survivability.

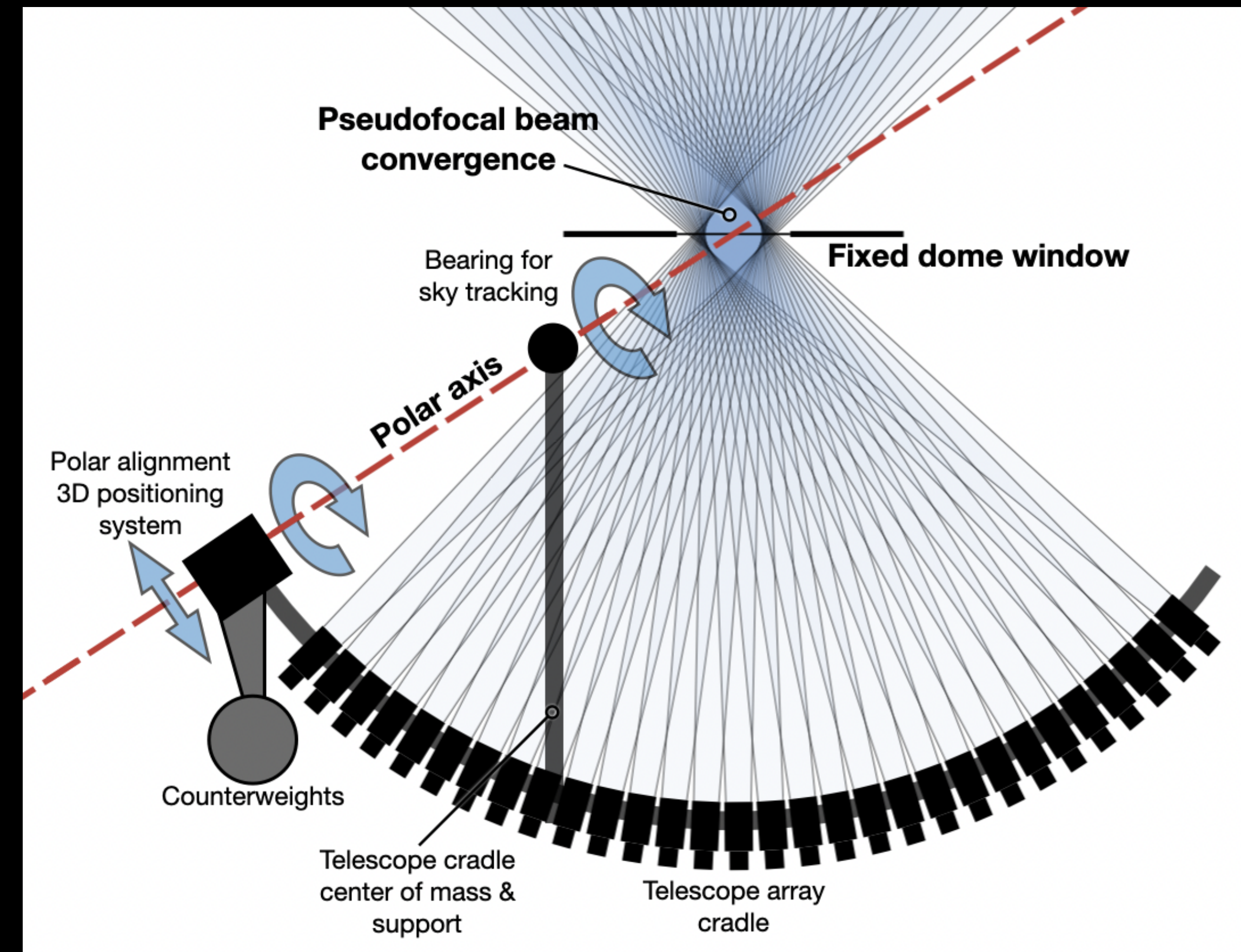


Law+ 2022, arXiv:2207.14318

Compelling architectures for a flagship mission

Configuration A: "Argus Array on the moon."

An all-sky gamma-ray monitor plus a deep, super wide field IR/UV transient surveyor. Hundreds of small telescopes look through one optical window. With zero moving parts and a minimal surface area to keep clear of dust, this concept emphasizes hardness and survivability.



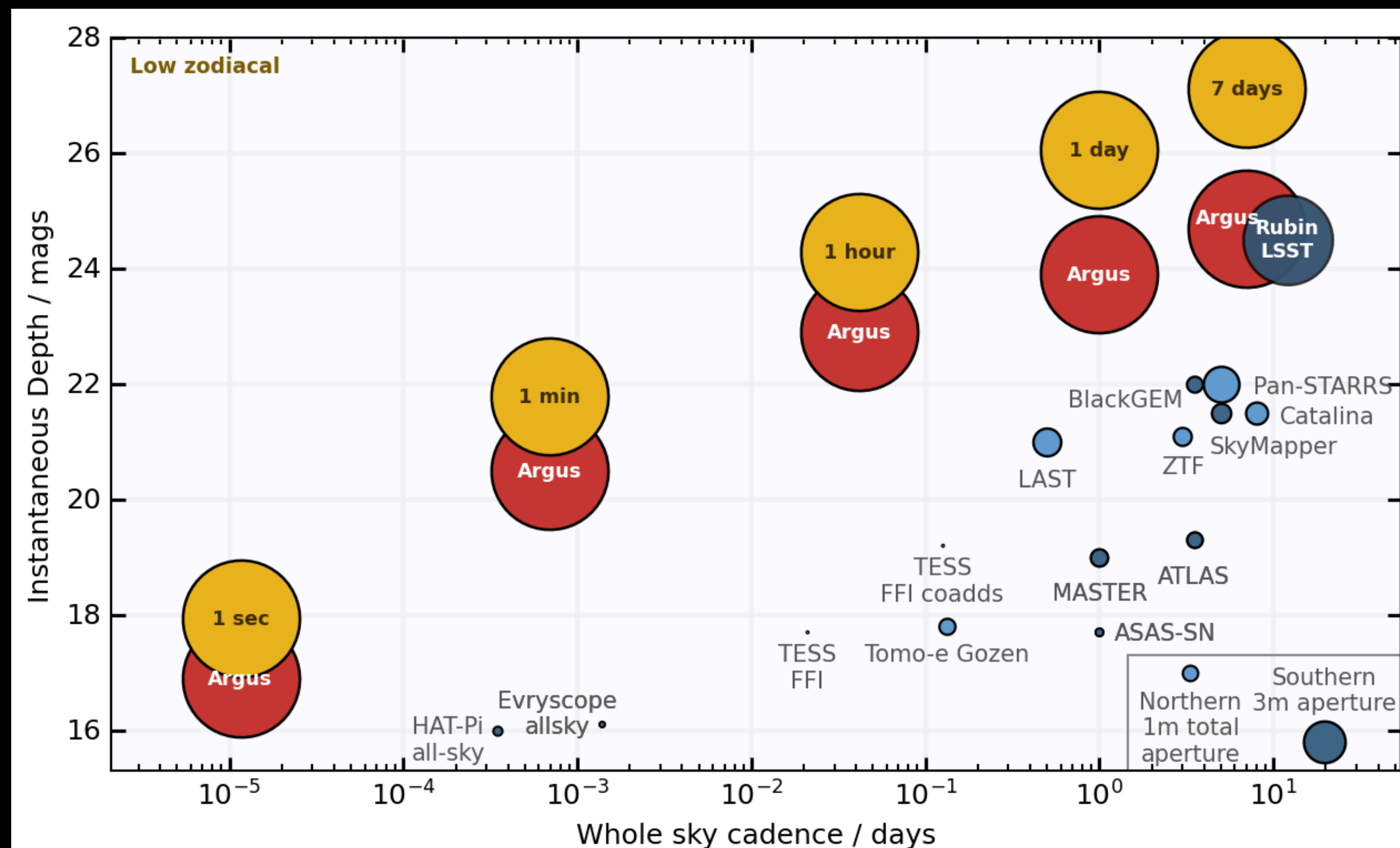
Law+ 2022, arXiv:2207.14318

Compelling architectures for a flagship mission

Configuration A: "Argus Array on the moon."

An all-sky gamma-ray monitor plus a deep, super wide field IR/UV transient surveyor. Hundreds of small telescopes look through one optical window. With zero moving parts and a minimal surface area to keep clear of dust, this concept emphasizes hardness and survivability.

N. Law & H. Corbett (Argus Array Science Collaboration),
adapted from Law+2022



Compelling architectures for a flagship mission

Configuration A: "Argus Array on the moon."

An all-sky gamma-ray monitor plus a deep, super wide field IR/UV transient surveyor. Hundreds of small telescopes look through one optical window. With zero moving parts and a minimal surface area to keep clear of dust, this concept emphasizes hardness and survivability.

Configuration B: "Zwicky Transient Facility on the moon."

A wide-field IR or UV survey telescope and an IR or UV spectrograph on gimbals similar to conventional ground-based telescope mounts. Combines sensitivity that is only possible in deep space with nimble slewing that is only possible on the ground.

Configuration C: "Keck on the moon."

A massive, multi-meter class reflecting telescope with a modular suite of instruments, and designed to be serviced by astronauts, refreshed and improved for decades to come. Capitalizes on and gives rich meaning to a lasting human presence on the Moon.

Dual-Use Imperative: SSA & Crew Safety

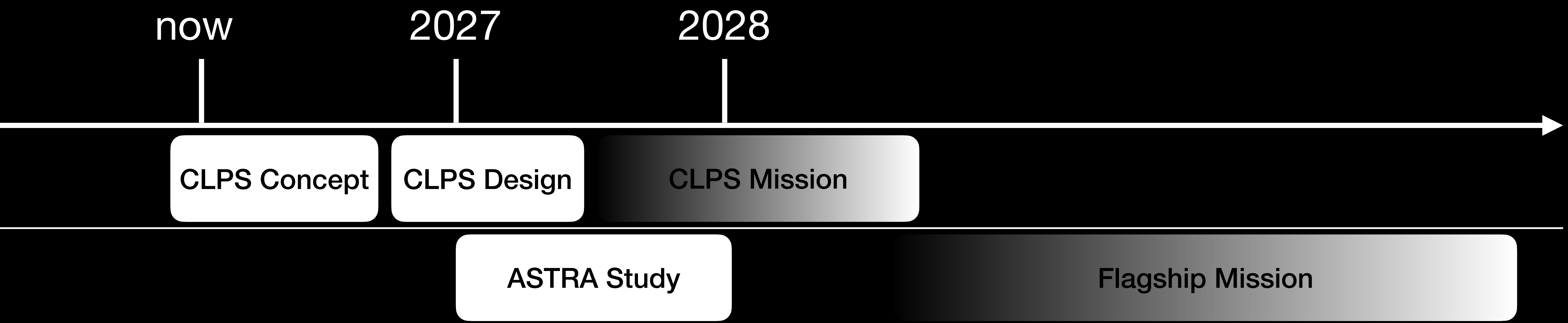
A wide-field UV/IR and high-energy facility is critical human spaceflight and cislunar security infrastructure.

- **The Cislunar SSA Gap:** Earth-based telescopes cannot reliably track cislunar traffic due to extreme distance and blinding lunar glare.
- **The Lunar Vantage Point:** A lunar observatory looks outward into a pitch-black sky, easily tracking faint, fast-moving cislunar satellites and debris.
- **Hardware Match:** Space Situational Awareness (SSA) demands the exact hardware we propose: continuous fields of view (Config A) or fast-slewing gimbals (Config B & C).
- **Protecting Explorers:** Detecting prompt solar gamma-ray flashes provides astronauts crucial early warning before slower, hazardous Solar Energetic Particle (SEP) storms.

A lunar observatory delivers Decadal-class astrophysics using the exact same hardware required to secure and protect the Artemis frontier.

Conclusions

- The current national space policy and the Agency's messaging is clear that everything (including science) **must be in service of Moon to Mars**.
- Let's treat this for the opportunity that it is: a permanently shadowed region on the Moon is an **extremely compelling site for a TDAMM observatory**.
- In my opinion, **at least one ASTRA study must be of a ground-based Lunar astronomical observatory**.



One-Slide Summary

- **Current policy prioritizes Moon-to-Mars (M2M)** and dual-use missions. NASA is actively creating a demand signal to **radically alter lunar transport economics**.
- Economics and **reusable Artemis infrastructure** make the Moon highly competitive for missions we would otherwise assign to free-flying space telescopes.
- The Moon shares the dark, cold advantages of space while introducing new operational challenges. However, its definitive advantage is a **solid surface capable of supporting large, precise, fast-slewing mounts** without the failure modes of reaction wheels.
- This makes the Moon the ideal platform for a **powerful, nimble, and era-defining TDAMM observatory**.
- Lunar radio arrays, optical interferometers, and gravitational wave concepts are already well-studied; **they do not require an ASTRA incubator study**.

At least one selected Ad ASTRA study must be a ground-based observatory on the Lunar surface.