GEORGE MASON UNIVERSITY

# The NASA Landolt mission

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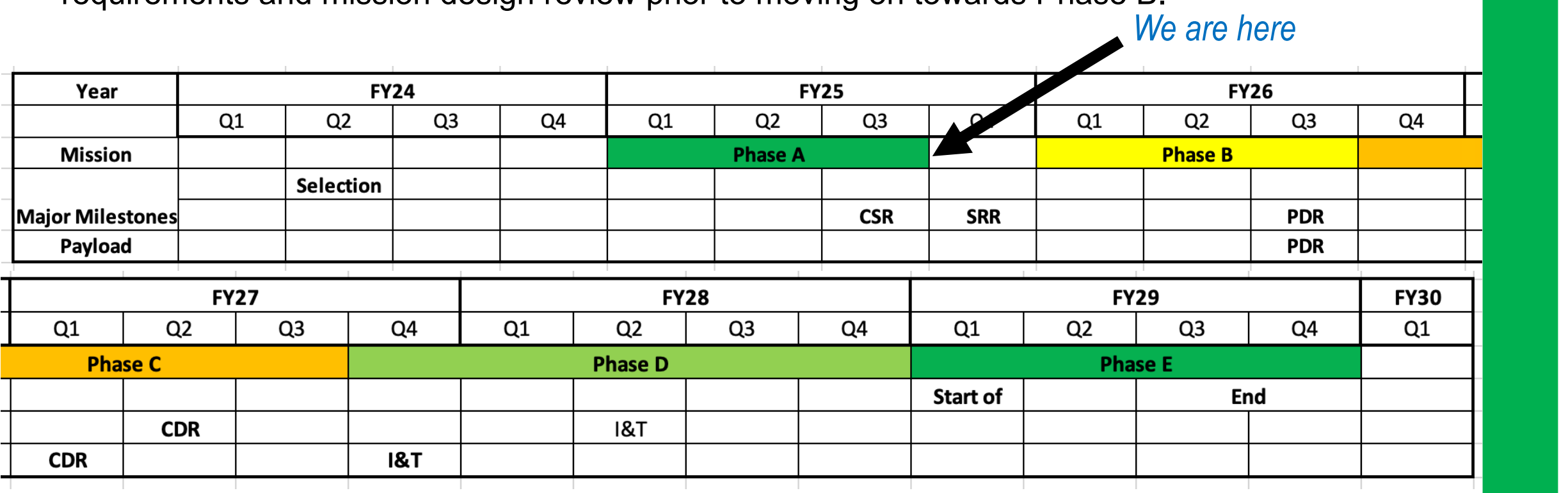
## Summary

The NASA Landolt astrophysics PIONEERS mission led by George Mason University is a SmallSat (16U) project designed to provide significant improvements in the accuracy of absolute flux measurements of stars, enabling the refinement of dark energy parameters, improve our ability to assess the habitability of terrestrial worlds, and advance fundamental constraints on stellar astrophysics and evolution. These measurements require a space-based artificial "star" with a precisely characterized photon flux, achievable through a NIST-calibrated, SI-traceable suite of six single-mode fiber-fed laser beacons at visible and near-infrared wavelengths forming the primary payload. The mission also includes a technology demonstration element, consisting of a calibrated solar reflector element wheel, in-beam photodiode and electron substitution radiometer samplers, and a tunable supercontinuum monochromator.

## Timeline

The mission is currently in Phase A, or mission formulation, with a combined system requirements and mission design review prior to moving on towards Phase B.

*We are here*



| Year | FY24 | | | | FY25 | | | | FY26 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| Mission | | | | | Phase A | | | | Phase B | | | |
| | | Selection | | | | | | | | | | |
| Major Milestones | | | | | | | CSR | SRR | | | PDR | |
| Payload | | | | | | | | | | | PDR | |

| FY27 | | | | FY28 | | | | FY29 | | | | FY30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 |
| Phase C | | | Phase D | | | | | Phase E | | | | |
| | | | | | | | | Start of | | End | | |
| | CDR | | | | I&T | | | | | | | |
| CDR | | | I&T | | | | | | | | | |

| Kick-off | Concept Study Report | System Requirements / Mission Definition | Preliminary Design Review | Critical Design Review | Flight Instrument Delivery | Pre-Ship Review | Operations Readiness Review | Launch Readiness | Commissioning | End of Mission |
|---|---|---|---|---|---|---|---|---|---|---|
| 10/1/2024 | 4/4/2025 | 09/15/2025 | 08/15/2026 | 04/15/2027 | 01/15/2028 | 6/13/2028 | 7/31/2028 | 09/30/2028 | Launch + 2 months | Launch + 12 months |

## Science Cases

The NASA Landolt mission has three main science areas of investigation:

### Dark Energy:

***Does the dark energy content in the Universe evolve?***

- Our knowledge of the accelerating Universe is currently limited by systematic errors in the VIS/NIR absolute flux ratios in measuring distances to Type Ia supernova.
- Along with the NASA Roman mission, Rubin Observatory, and other dark energy experiments, the NASA Landolt mission will advance our current understanding of the ΛCDM model of our Universe by placing SN Ia flux measurements on an experimentally-based, SI-tracable spectral irradiance ratio system.

### Exoplanets:

***What are the radii of exoplanets and their orbital locations and how do they compare to theories of planetary evolution?***

- In the post-*Gaia* era, our knowledge of exoplanet radii, and, by extension, exoplanet bulk compositions, as well as the host star properties driving insolation and habitability, are currently limited by systematic errors in the VIS/NIR absolute flux zero points.
- The NASA Landolt mission will improve exoplanet stellar host radii accuracy by at least a factor of 3 compared to current knowledge to further refine our understanding of exoplanet bulk composition, demographics, evolution and habitability.

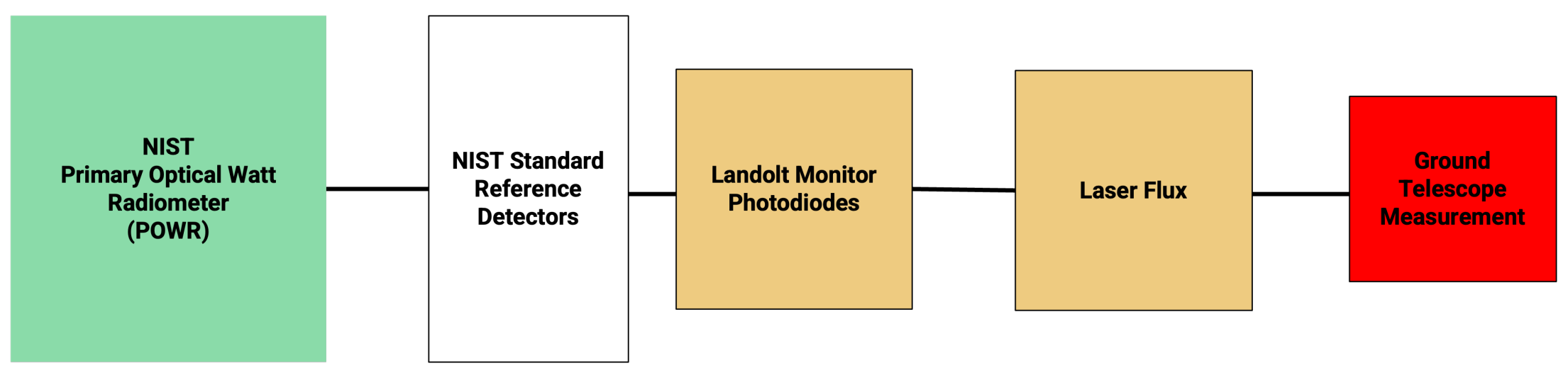
### Stellar astrophysics:

***What are the radii of stars across a range of ages and evolutionary state, spectral types, rotation periods, viewing inclinations, and other properties, and how do they compare to our theoretical models of stellar evolution?***

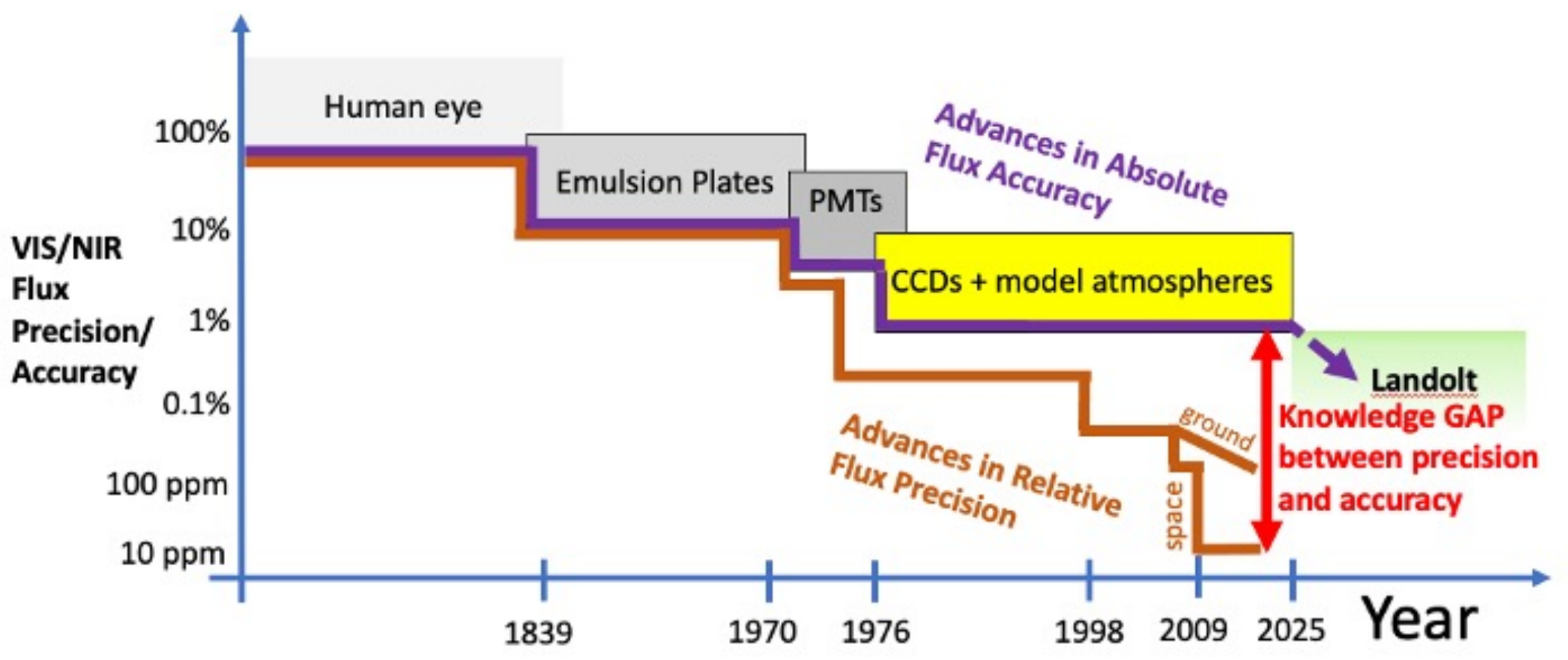
- Our measurements of stellar fluxes limit our current knowledge of stellar bolometric fluxes, and by extension, stellar radii, effective temperatures, stellar masses and stellar evolution and ages.
- The NASA Landolt mission will improve stellar radii and mass accuracy by at least a factor of 4 compared to current knowledge, and enable the determination of Sun-like main sequence star ages to the nearest ~Gyr to advance our understanding stellar evolution.

### SI-Traceable Fluxes

The absolute calibration of stellar fluxes is ripe for disruption. While we can measure stellar brightness to ~10 ppm relative precision, we now need absolute accuracy to catch up. The true uncertainty is ~2.5% in deriving physical photon flux rates from observations. Existing networks of photometric standard stars are daisy-chained to three white dwarf stars and their atmospheric models, or decades-old measurements of Vega fluxes with systematic uncertainties >1%. These absolute measurements dominate photometric error budgets, resulting in a cascade of systematic uncertainty that spreads across all areas of observational VIS/NIR astronomy. Modern analyses need a flux calibration covariance matrix, which is not available even assuming blackbody and lamp calibrations are accurate.



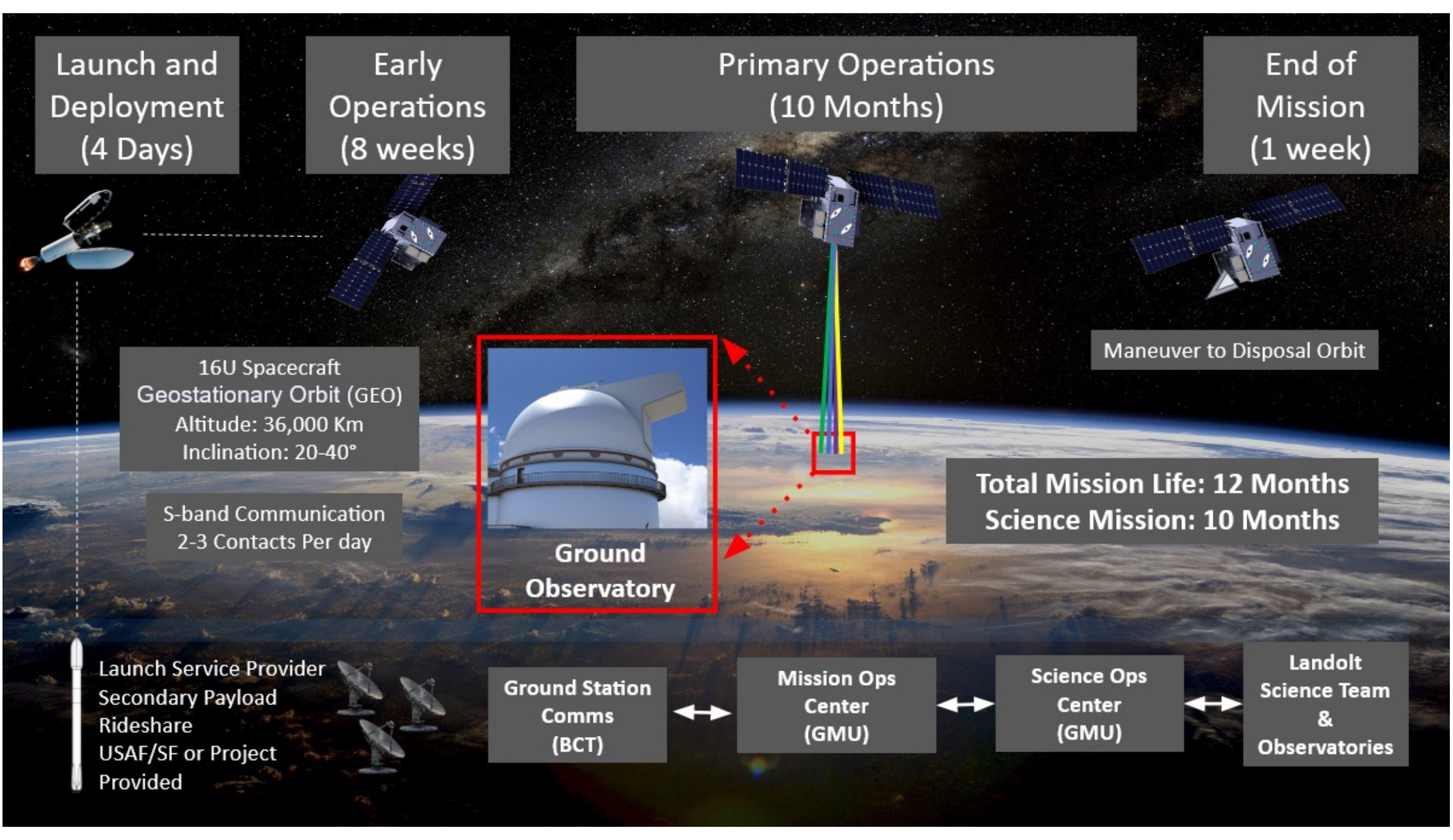
*Above: The SI Traceable path for the Landolt mission measurements*



*Above: A qualitative history of advances in flux measurement accuracy and precision.*

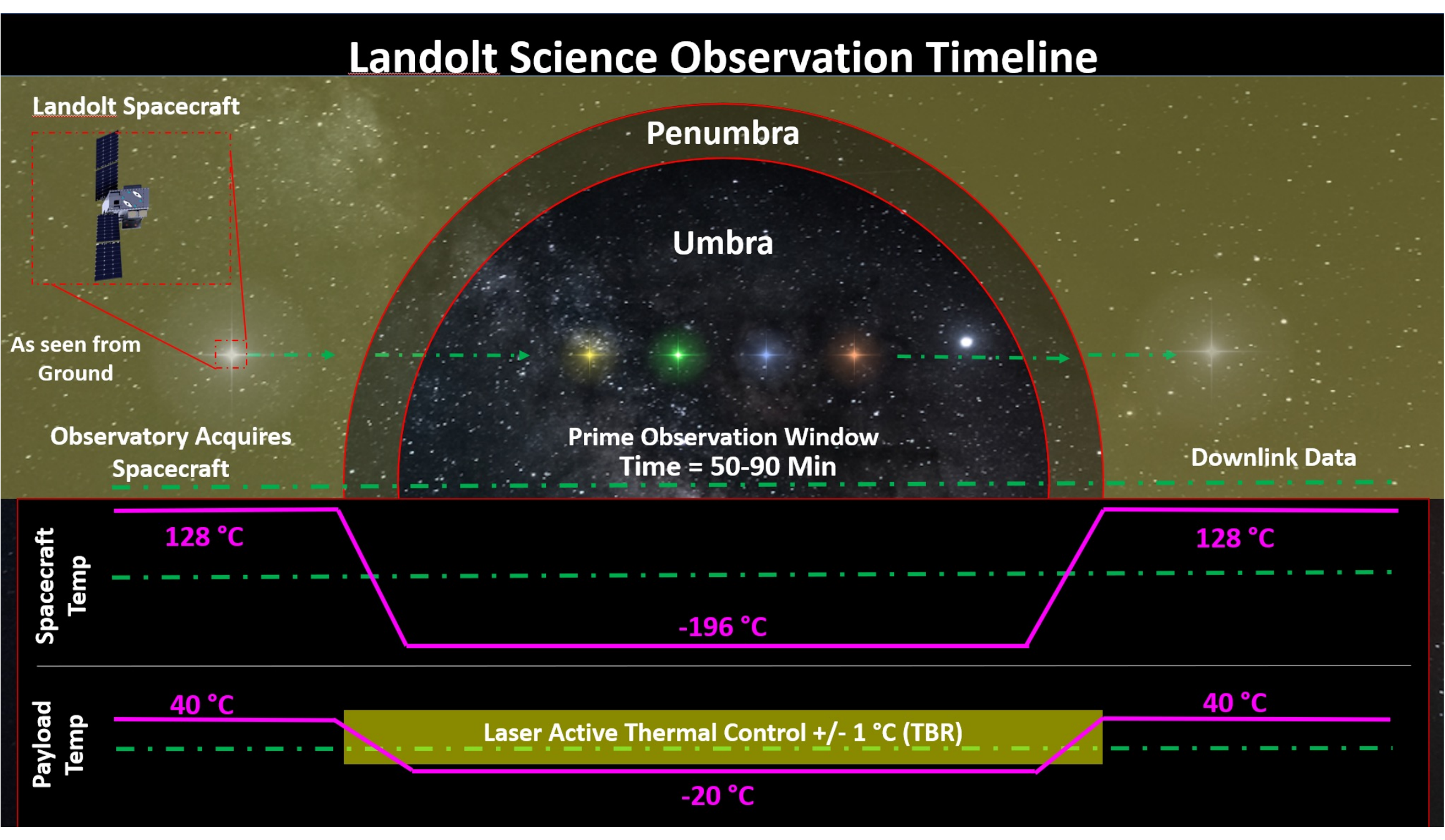
## Concept of Operations

Landolt baselines deploying a satellite bus provided by a commercial vendor to a near-geosynchronous orbit with a primary mission duration of one year and a launch readiness date of October 2028. After commissioning with the mission operations center, the Landolt science operations center will execute coordinated pointing campaigns to partner ground-based observatories to collect calibration and science data across scheduled observing sessions that will be processed and shared via a data archive, key publications and catalogs.

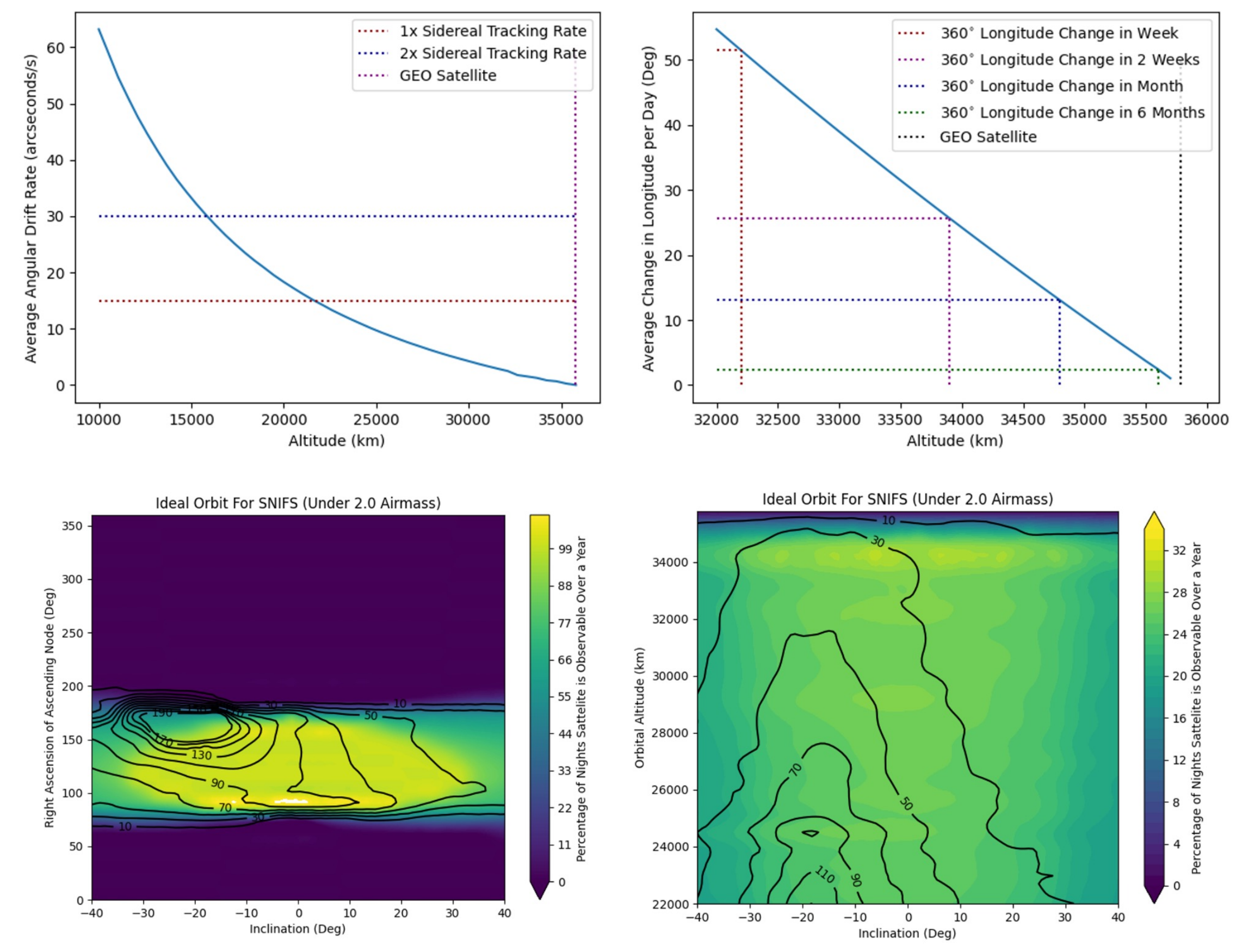


*Above: This mission operations overview illustrates the integrated space and ground system concept, including the mission timeline and the roles of the MOC, SOC, and participating observatories.*

*Above: Current mission ground-based telescope partners*



*Above: Timeline of a typical umbral crossing for the Landolt mission. Time progresses left-to-right illustrating the modulation of the spacecraft lasers while in umbra and an approximate thermal profile for the eclipse. The shaded area of the payload temperature timeline is intended to show the time where active thermal control will be used to thermally stabilize the Laser Instrument to +/-~1C.*

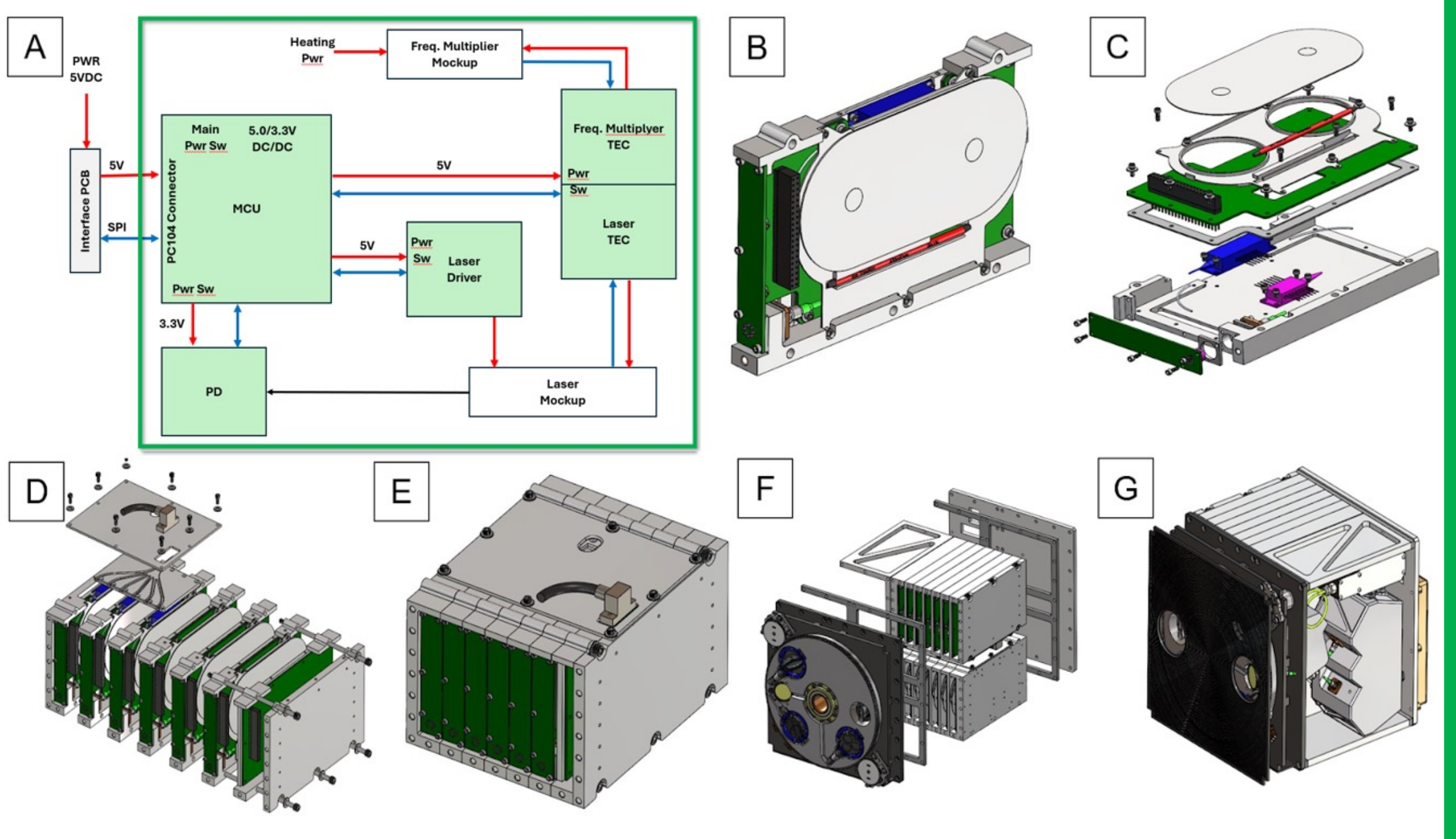


*Above: Orbital Altitude Requirements. Top Left: Average tracking rates of ground observatories as a function of orbital altitude, in horizon coordinates - e.g. a geostationary satellite requires zero telescope motion. Below orbital altitudes of 22,000 km, telescope tracking rates exceed typical professional telescope tracking rates. Top Right: Projected Longitude drift rate as a function of orbital altitude, with geosynchronous marked, as well as drift rates corresponding to Earth circum-navigation times of one week, two weeks, one month and six months. Bottom Left: Percentage (colorbar) of nighttime Landolt will be visible by the UH 2.2m telescope and SNIFS instrument as a function of orbital inclination and initial right ascension of ascending node (RAAN, akin to the Earth longitude the spacecraft will hover over) for a geo-synchronous orbit, which is our first family of orbits that meet our baseline science requirements. The black contours do not align with the color intensities, as they correspond to the number of nights during the primary mission during which umbral crossings will occur. Bottom Right: Similar plot to the bottom left, except for Landolt visibility as a function of orbital inclination and orbital altitude for a fixed initial RAAN. The top of the plot is just below a geosynchronous orbital altitude, and demonstrates the dark "dead zone" where the spacecraft drifts too little to be visible from our ground observatories. At an altitude of ~34,000 km, we see the spacecraft drifts fast enough that we can observe it for up to 35% of our Phase E primary mission to achieve our threshold science requirements. We have conducted similar analyses for all of our ground observatories to identify orbit requirements and thus assess available launch opportunities.*

## Payload

The Landolt Laser Instrument is the core payload element to enable establishing a space-based, SI-traceable artificial star. The instrument generates precisely calibrated laser beams (0.5% baseline and 0.75% threshold) (Stability, knowledge, etc,) at different wavelengths (6 baseline 4 Threshold, spanning 488-1550nm) with powers up to 500 milliwatts, which are then pointed via the spacecraft at a Geo like orbit, towards ground-based observatories. Each laser is fiber-coupled using single-mode fibers (NA = 0.05) to ensure spatial coherence and Gaussian beam profiles (~f/10) suitable for simulating a point-source "star" as seen by ground-based observatories. The lasers meet the STM driven requirements to deliver >440,000 photo-electrons to ground-based observatory detectors with cumulative exposure times of up to several minutes for the smallest telescopes, sufficient to achieve the required 0.15% shot noise and absolute flux and color accuracy requirements. Continuous in-flight monitoring via onboard calibration hardware ensures the laser outputs remain traceable to NIST standards throughout the mission, providing the reliable absolute flux measurements necessary to achieve Landolt's science goal of reducing photometric calibration uncertainties to sub-percent levels. To minimize risks to the mission and demonstrate robust science measurement repeatability, the Landolt spacecraft carries two redundant Laser Instruments that can be alternatively used in the event of component or other system failure.

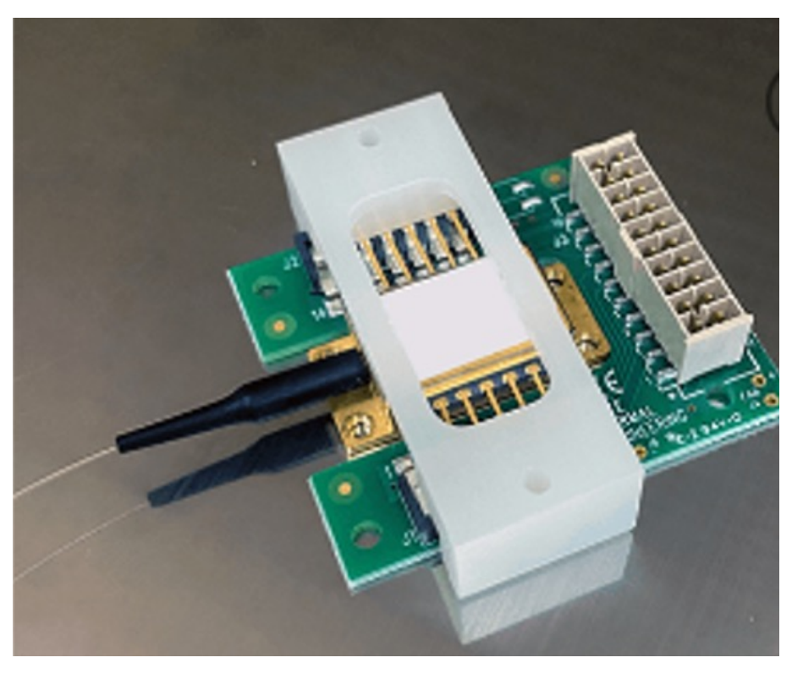
To maintain absolute calibration throughout the mission, each laser's output is split by a 99:1 fused fiber splitter, where 99% of the power forms the artificial star beam, while the remaining 1% is directed to an on-board radiation-hardened photodiode array. NIST will calibrate the 99% output of the Laser Instrument, the relationships between the 1% and 99% fiber channels, and each laser diode's internal power readings prior to launch. These calibrated relationships, and constant in-situ monitoring via photodiodes, maintain NIST-traceability of the laser output throughout flight. In addition to photodiode monitoring, the thermal environment (stabilized by internal Thermoelectric Coolers), accumulated radiation dose monitoring, and laser source power draw will be continuously monitored throughout flight. These measurements will be used in conjunction with periodic beam-profile calibrations using the ground-based observatories to identify and account for potential drifts or perturbations in the laser output, further preserving the integrity of the NIST-traceable calibration.



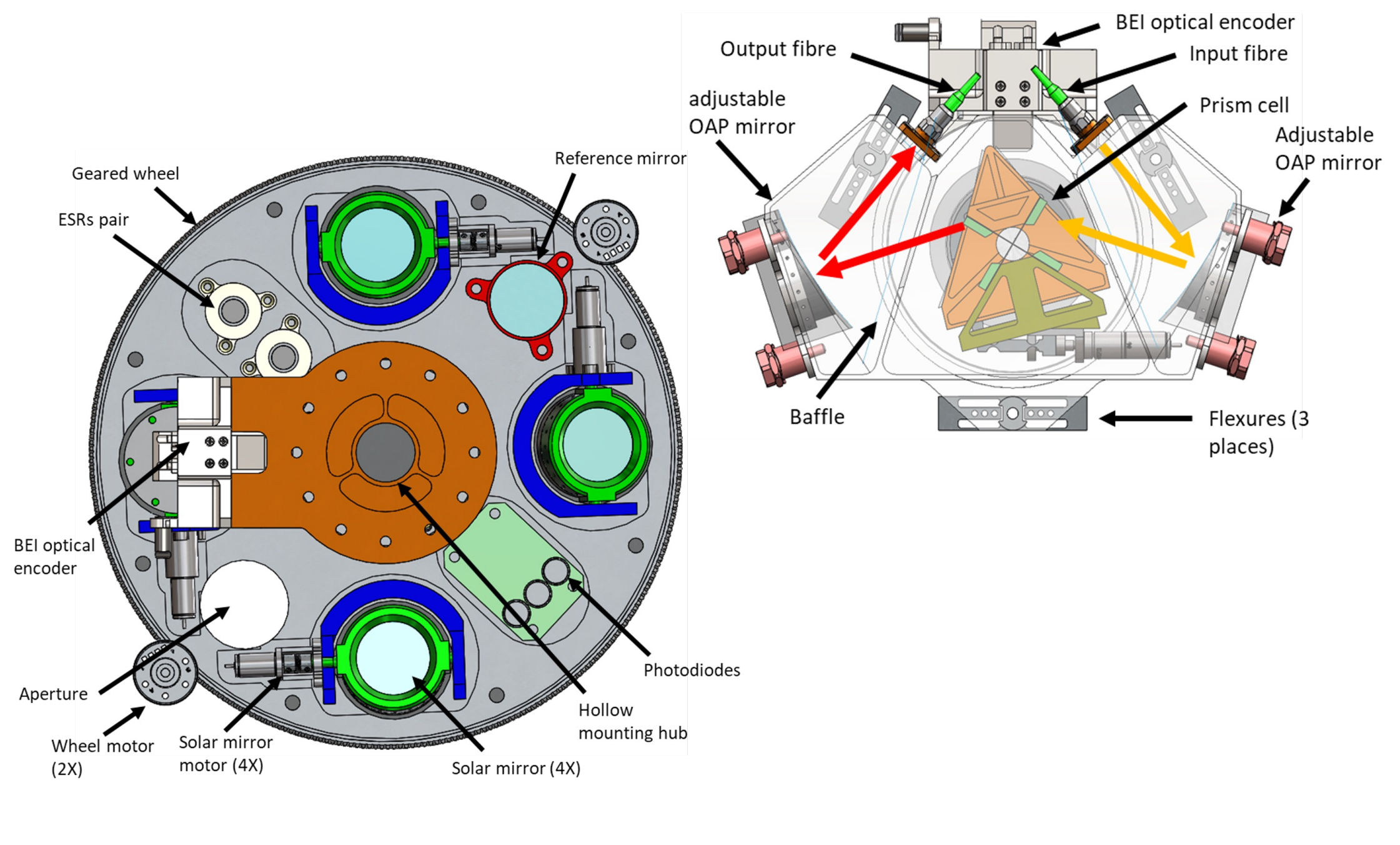
*Above: . [A] Block diagram for a single laser tray. [B,C] Assembled view and exploded view of a single laser tray model. [D,E] Exploded and assembled view of a single Laser Instrument (Landolt has two identical instruments, each with six laser trays). [F,G] Exploded and assembled view of the Landolt science payload including the two technology demonstrations and the black-coated thermo-optical shield mounted to the Earth-facing side of the payload (shown in [G]).*

The Earth-facing side of the Landolt spacecraft will be equipped with a thermo-optical shield to provide thermal, radiation, and stray light control for the spacecraft. The shield is designed with black-coated 45-degree concentric baffle rings to minimize sunlight and other contaminating illumination in the science field of view, while enhancing the thermal regulation of the shield by radiating absorbed solar heat to space, both properties are critical to enable science observations while the spacecraft is sunlit as well as eclipsed by Earth's umbra. The solar panels are also "knife-edged" during science operations w/r/t to the ground observatories to eliminate solar reflections.

Landolt is baselining two technology demonstration payloads from the CANDLE project, an element wheel and fiber output monochromator system, The element wheel and monochromator provide additional SI traceable calibration paths for absolute flux measurements, using sunlight and a controllable monochromatic source that complement and substantially expand the Landolt mission calibration capabilities. These payloads will be operated opportunistically after baseline science objectives are expected to be met within the first ~6 months, to complement and expand on the Landolt science capabilities within the planned primary mission duration schedule margin (~4 months).



*Above: A single laser butterfly package prototype with single mode fiber.*



*Above: Optomechanical designs for the tech demo modules*

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