

# On-Orbit Measurements of Solar Exclusion Angle for Modular Agile Scalable Optical Terminal (MAScOT) on the ILLUMA-T Mission

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# Outline



- **Introduction and Payload Description**
- **Design for Stray Light Mitigation**
- **Stray Light Testing**
- **Summary**

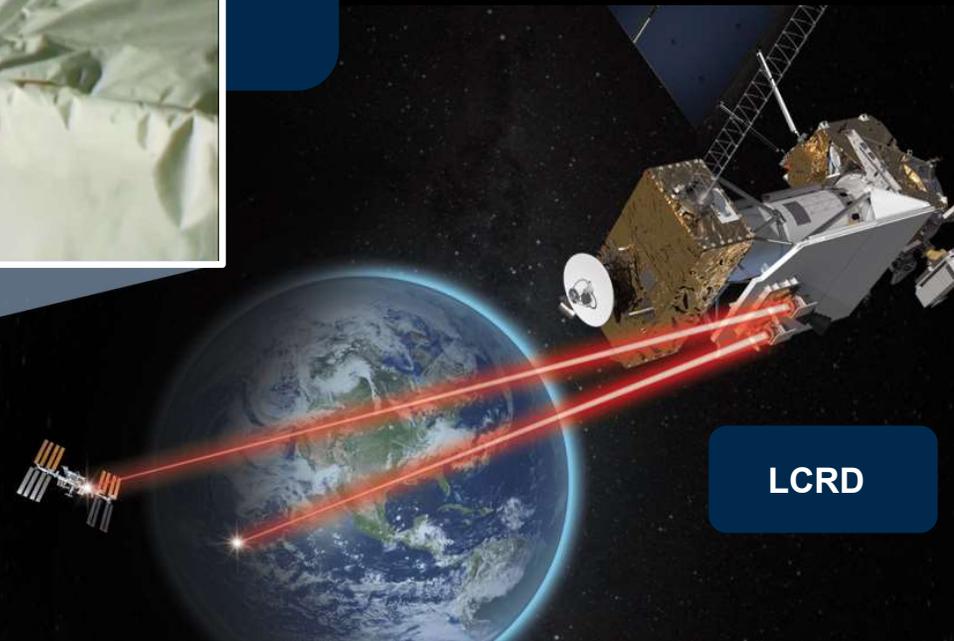
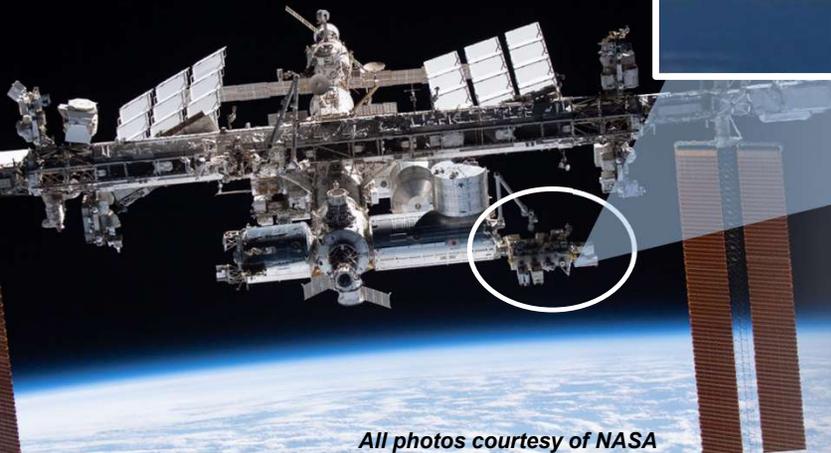
Launched November 2023  
successful operation  
Duration: 8 months

Design for stray light  
mitigation critical  
to mission success

Demonstrate through  
on-orbit straylight  
measurements that the solar  
exclusion zone meets  
operational requirements

## ILLUMA-T: First lasercom user terminal for human exploration

ILLUMA-T: Integrated LCRD LEO User Modem and Amplifier Terminal



LCRD

*All photos courtesy of NASA*



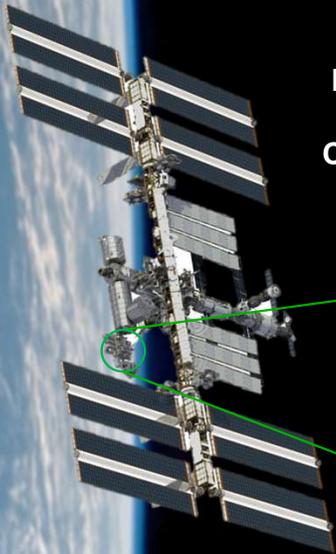
# Modular Agile Scalable Optical Terminal (MAScOT) Missions



## ILLUMA-T

(Integrated LCRD LEO User Modem and Amplifier Terminal)

Launched to ISS\* on SpaceX Dragon:  
Nov. 2023  
Comm demonstrated with LCRD\* relay  
Mission completed: June 2024



\* Internal Space Station and Laser Communications Relay Demonstration,



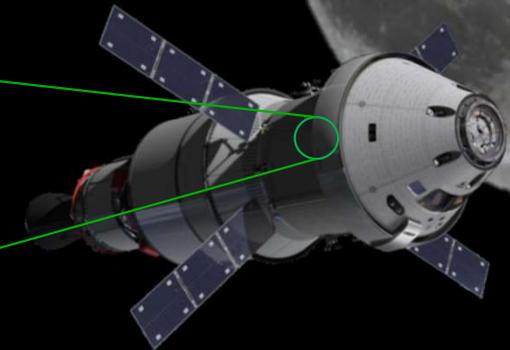
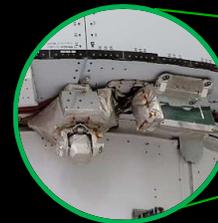
宇宙航空研究開発機構  
Japan Aerospace Exploration Agency



## O2O

(Orion AM-2 Optical Comm)

Direct to ground (WSC, TMF\*\*)  
Launch on Orion/SLS: April 2026  
10 day mission

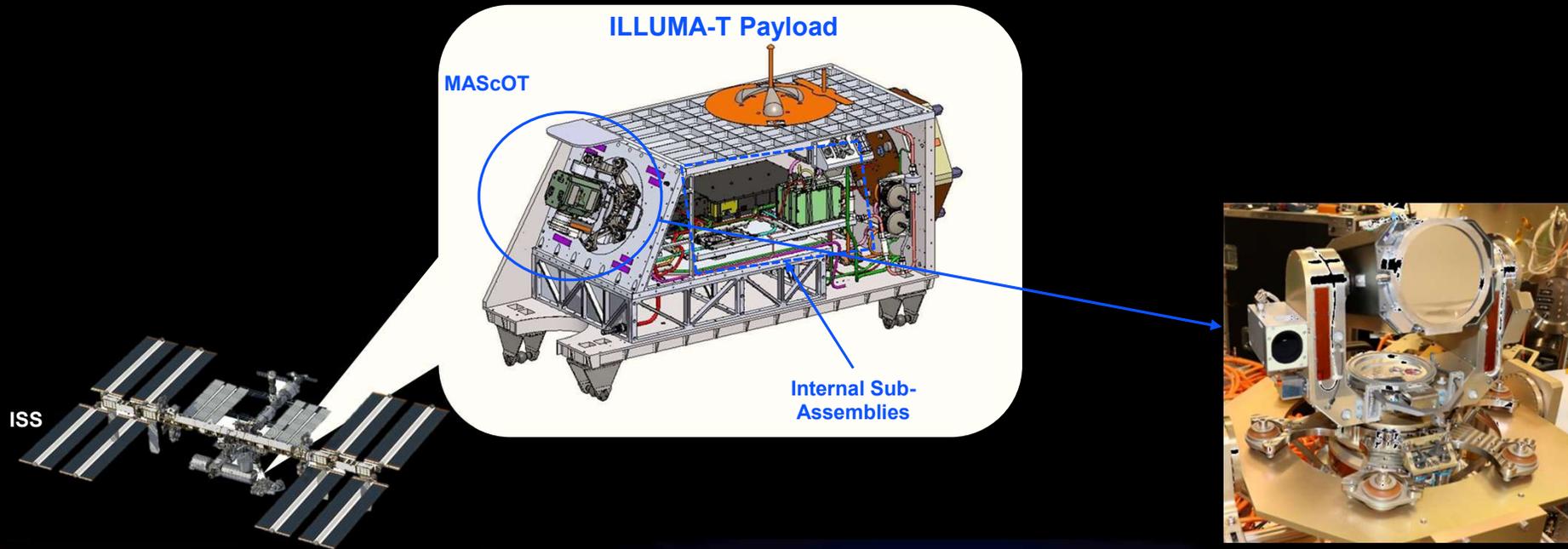


\* White Sands Complex & Table Mountain Facility



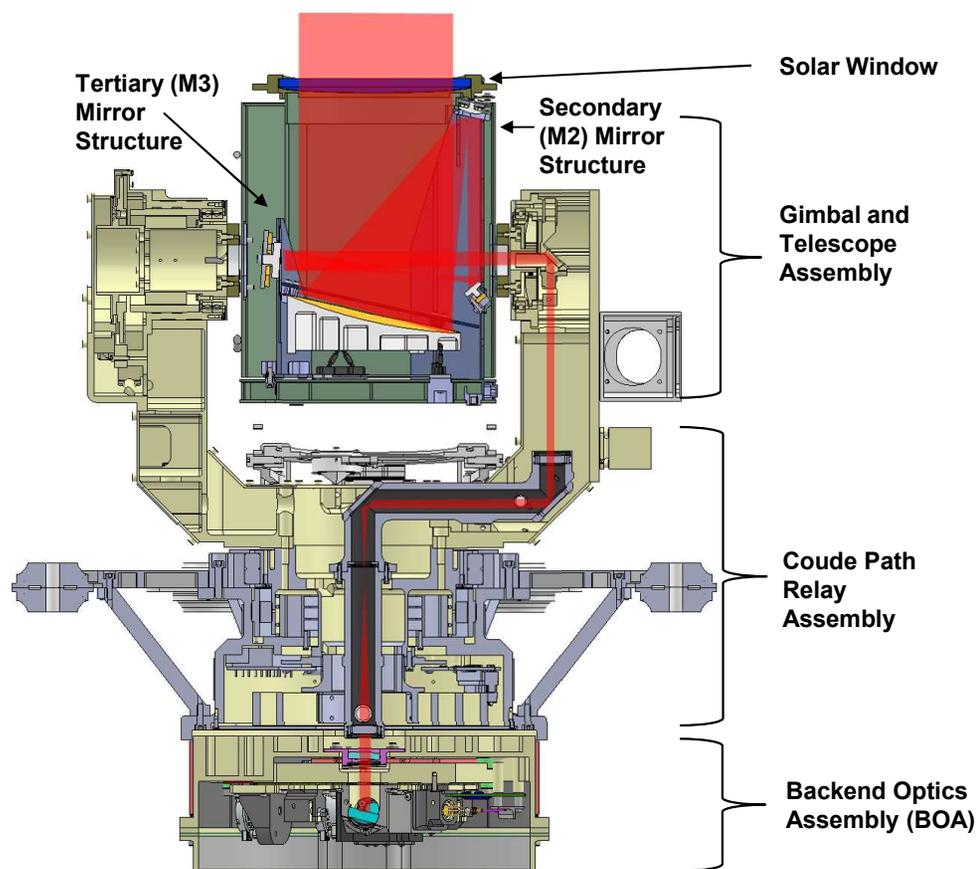


# MAScOT on ILLUMA-T Payload





# Optical Schematic



## • Optical Module Description

- Solar window provides thermal and optical solar isolation
- 2-axis gimbal with  $\pm 175^\circ$  azimuth and  $\pm 120$  elevation field of regard
- 43.25X magnification (off-axis reflective telescope and refractive relay)
- Backend optical assembly (BOA)
  - Transmit comm, receive comm and receive acquisition beam paths
  - Steering mirrors provide tracking stabilization
  - Pointing, acquisition, and tracking (PAT) quadrant detector

- OM design common to both ILLUMA-T and O2O with minor PAT differences



# Stray Light Mitigation: Design



## Solar Window

- Cleanliness: CL 300 exterior; CL 200 interior
- Spectral Filtering

## Quality Mirror Surfaces: $\leq 8\text{\AA}$ RMS Roughness

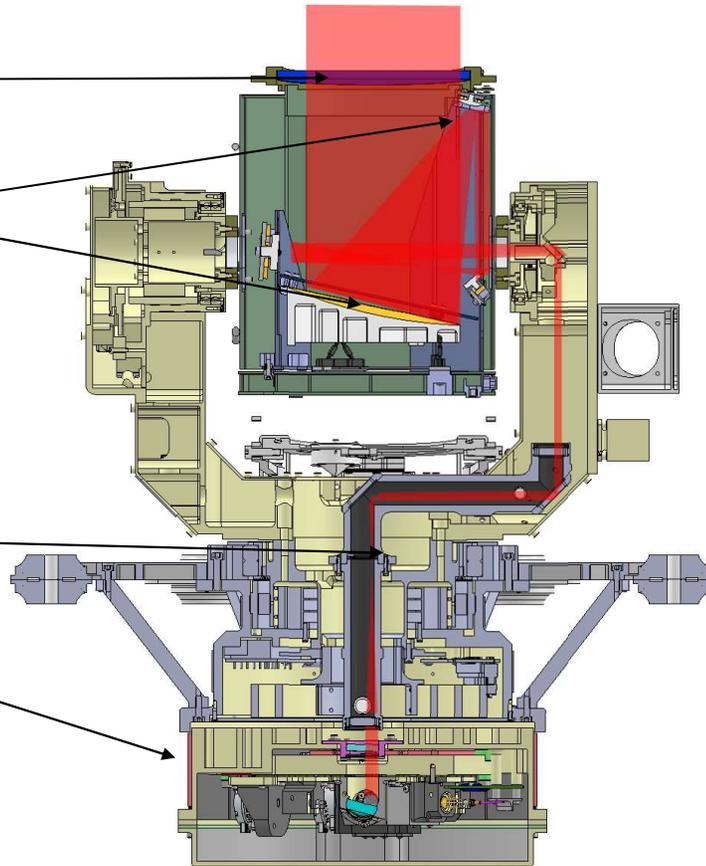
## Best Practices

- Low reflectivity interior surface treatments
- Clean/high quality optical surfaces

## Field Stop at Relay focus: $\pm 0.5\text{mrad}$ (ILLUMA-T)

## Backend Optics Assembly (BOA)

- Lyot stop at system pupil
- 1.7nm narrow bandpass spectral filtering



**Requirement: Minimize stray light at the PAT detector**

**Requirement: Establish solar exclusion zone, a radial operational keep-out zone where solar stray light will not impact mission performance**



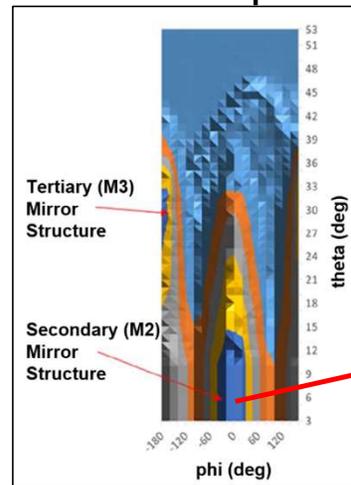
# Stray Light Mitigation: Analysis



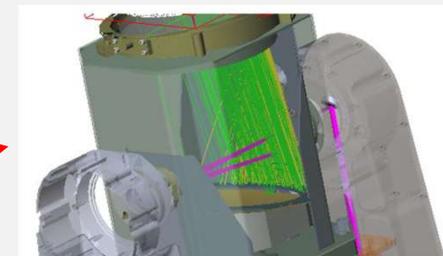
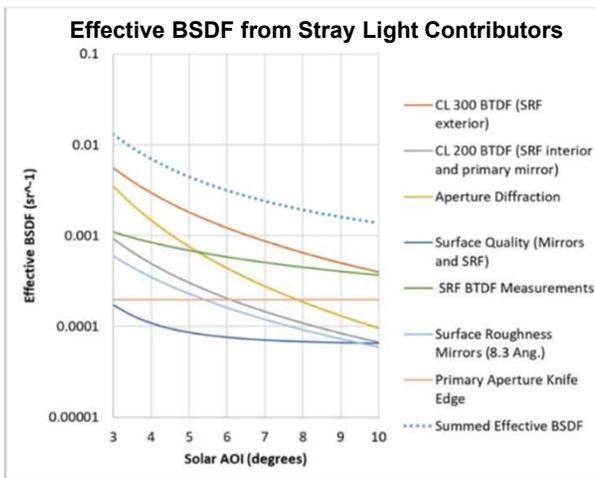
- **Stray light FRED (optical scattering software, Photon Engineering) model is a hybrid of CAD models and primitive solid elements**
  - **BSDF (bidirectional scattering distribution function) properties assigned to all internal surface**
  - **Scatter map generated**



### Solar Stray Light Scatter Map



**Solar Exclusion Zone set to 10° for ILLUMA-T**



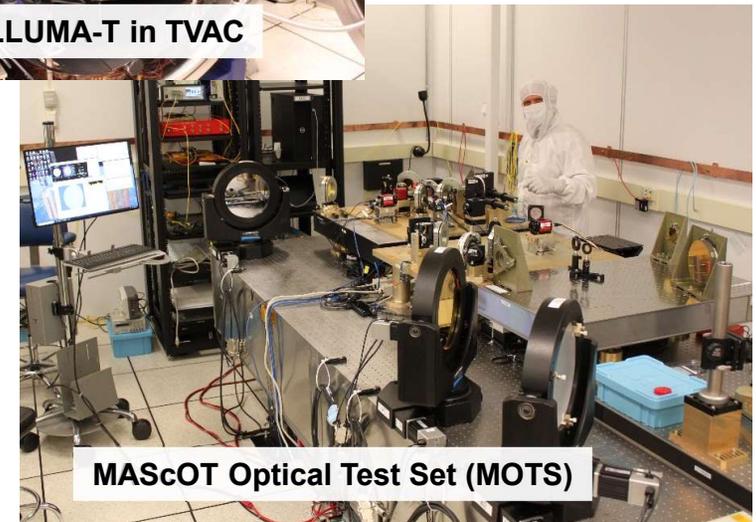
- Scatter from secondary (M2) mirror structure:**
- **Green rays incident at angle on mirror structure**
  - **Pink rays illustrate scatter that propagates within the system field-of-view**



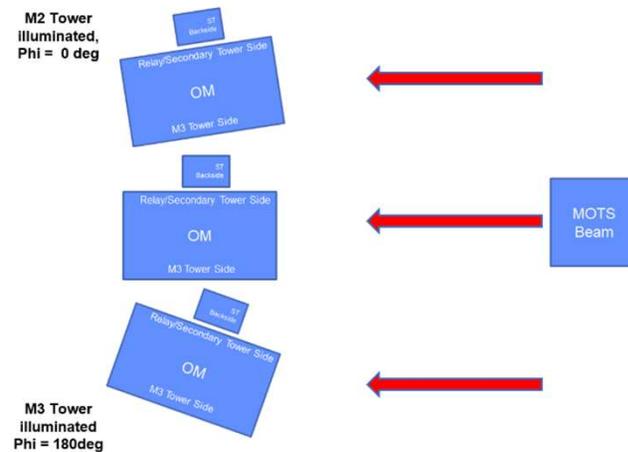
# Laboratory Testing



- An opportunity was available to perform limited laboratory testing, using the MAScOT Optical Test Set (MOTS)
  - MOTS laid collimated, 6" diameter, in-band, "solar simulation" beam on Optical Module (OM)
  - OM tilted along primary axes to simulate solar off-axis illumination

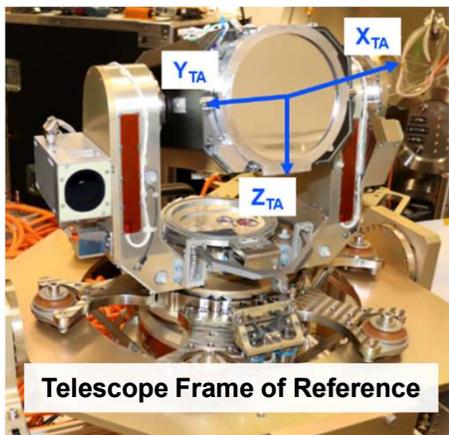


Equivalent in-band solar power, blackbody model, 3.7mW, scanned along OM primary axes

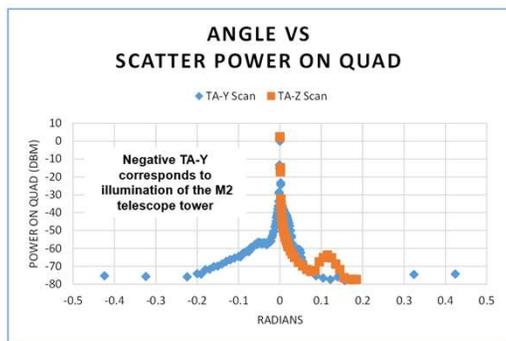




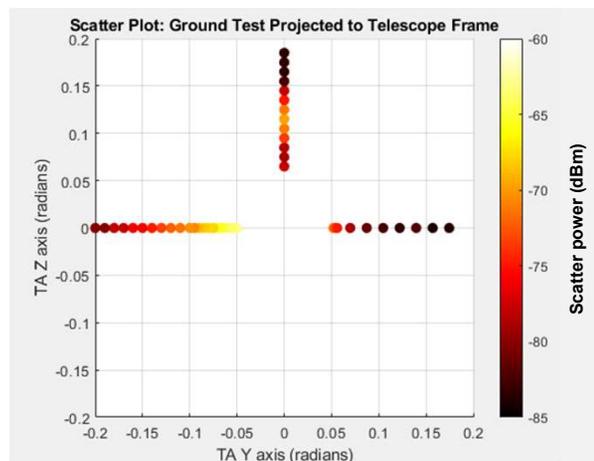
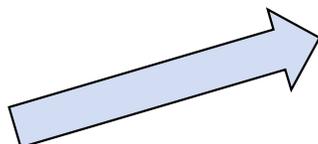
# Laboratory Testing Results



- Laboratory test performed using O2O Optical Module\* simulating ILLUMA-T operating conditions
  - O2O field of view 2x larger, thus expect ~ 6dB more stray light



O2O laboratory stray light results



O2O laboratory stray light results, shown in telescope frame of reference. 6dB correction factor for ILLUMA-T equivalency.

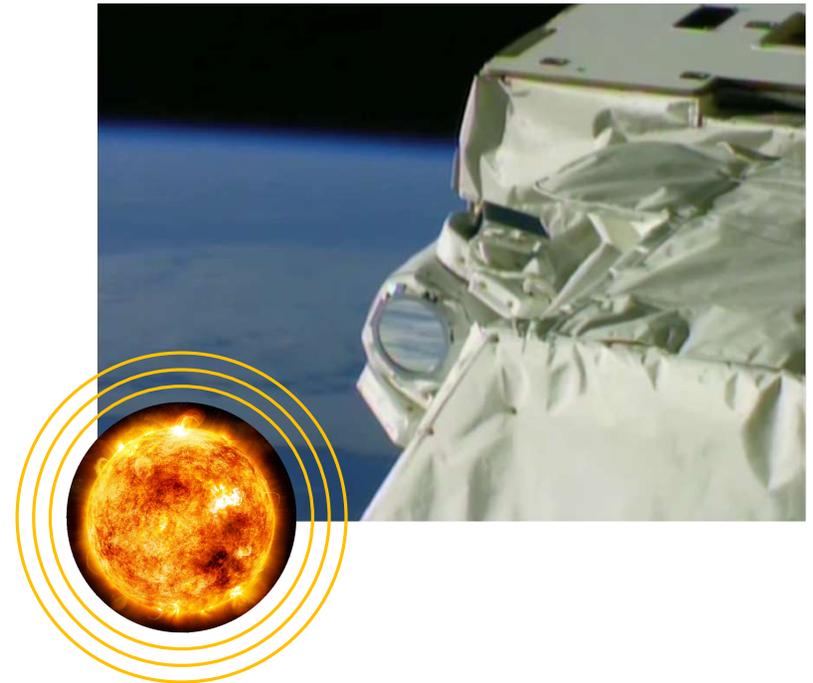
\* ILLUMA-T had limited availability while still at MITLL



# On-Orbit Testing



- **Unique opportunities became available, during primary mission outages, to perform on-orbit measurements of solar stray light on ILLUMA-T**
- **MITLL and NASA Goddard team worked together to develop a stray light testing approach**
- **3 time blocks (one each April, May and June 2024)**
  - **First block: conservative start, refined scan design, data collect and analysis; confidence in the process was established though results were generally inconclusive**
  - **Second & third blocks: successful spirals around the sun**



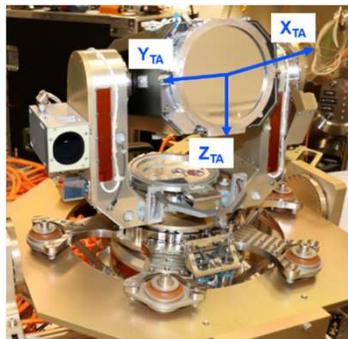
*Photos courtesy of NASA*



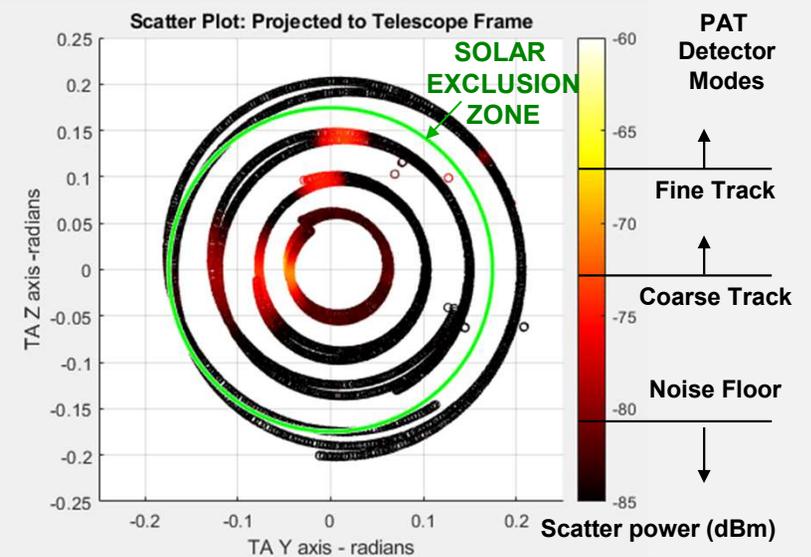
# On-Orbit Testing Results: 2<sup>nd</sup> Block



- **Second block in May, four successful passes**
  - Gimbal encoder readouts, system calibrations, ECI pointing, and PAT detector counts mapped to measured scatter in the telescope reference frame



**Model validated: no scatter observed outside the 10° solar exclusion zone**



**May data block: radial rings  
3deg, 6deg, 9deg, and 12 deg**

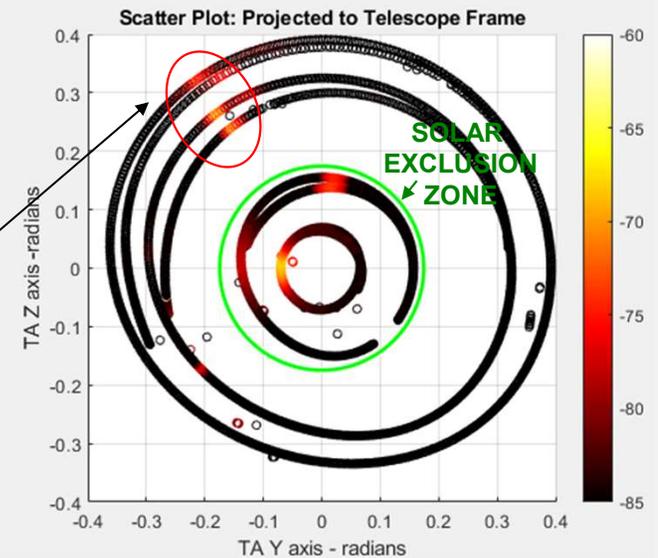


# On-Orbit Testing Results: 3<sup>rd</sup> Block



- Third block in June, four successful passes were performed
- Unexpected stray light at 30degrees from telescope TA-Z axis observed in the large rings

Believe this scatter results from ISS structure rather than a scattering telescope feature



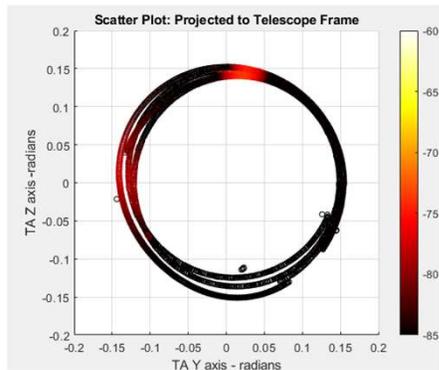
June data block: radial rings  
4.5deg, 9deg (repeat of May), 20deg, and 25 deg



# On-orbit Testing Summary



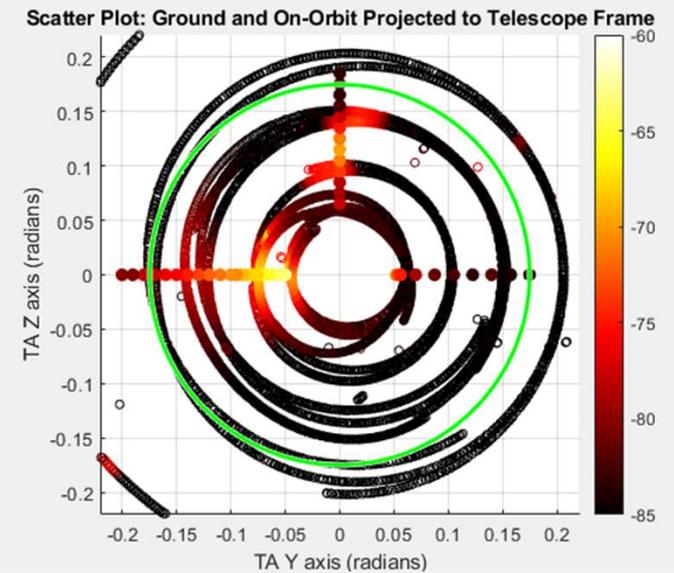
- Passes are repeatable:



May and June 9deg scans overlaid

- While limited to 8 passes, the two blocks of on-orbit data were sufficient to demonstrate successful validation of the MAScOT stray light mitigation design

## Laboratory and On-Orbit Data Correlate



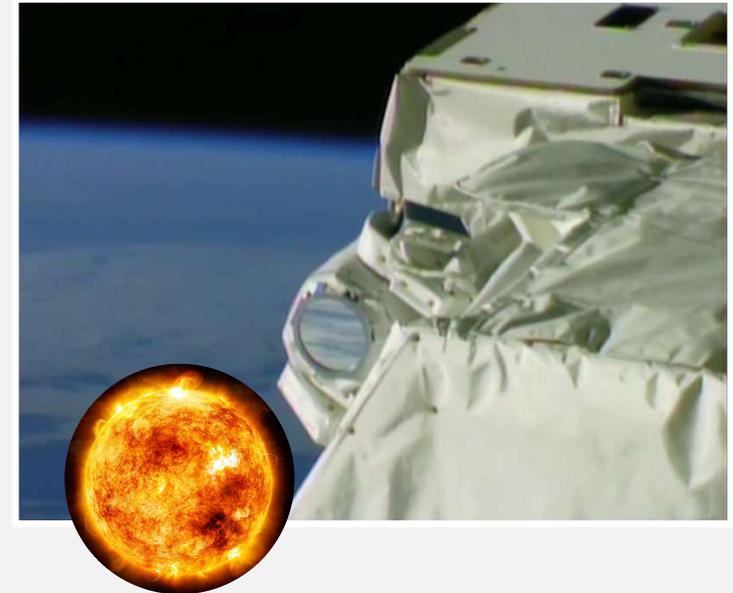
Laboratory data overlaid on inner rings of on-orbit May and June data



## Final On-Orbit Testing: Direct Solar Exposure



- Upon completion of all the primary mission experiments, on the last pass before decommissioning, there was an opportunity to directly command ILLUMA-T to stare at the sun
  - The MAScOT payloads, optics and detectors, were designed to survive all sun illumination angles
- Last experimental pass of ILLUMA-T
  - A standard pre-pass optical health test was performed (CCT, closed cover test)
  - ILLUMA-T was commanded to point towards the sun and to attempt to coarse track
    - Six minute window, intermittent tracking was achieved even with a saturated PAT quad sensor
  - Gimbal and telescope were stowed and CCT optical health check was repeated



CCT post exposure optical health check showed  
**NO OBSERVABLE IMPACT**

*Photos courtesy of NASA*



## Summary



- **Optical scattering modeling predictions, pre-launch laboratory testing, and on-orbit measurements of solar scatter combined to demonstrate that the MAScOT design on ILLUMA-T provided sufficient stray light mitigation for the mission to meet its laser communications performance objectives.**
- **On-orbit testing validated the 10 degree radial solar exclusion zone**
- **Last day direct solar exposure experiments further demonstrated the robustness of the MAScOT design, causing no damage and even demonstrating capability for limited tracking on the sun.**

**The successful demonstration of the MAScOT design on ILLUMA-T paves the path for a successful upcoming O2O mission on Artemis II**