

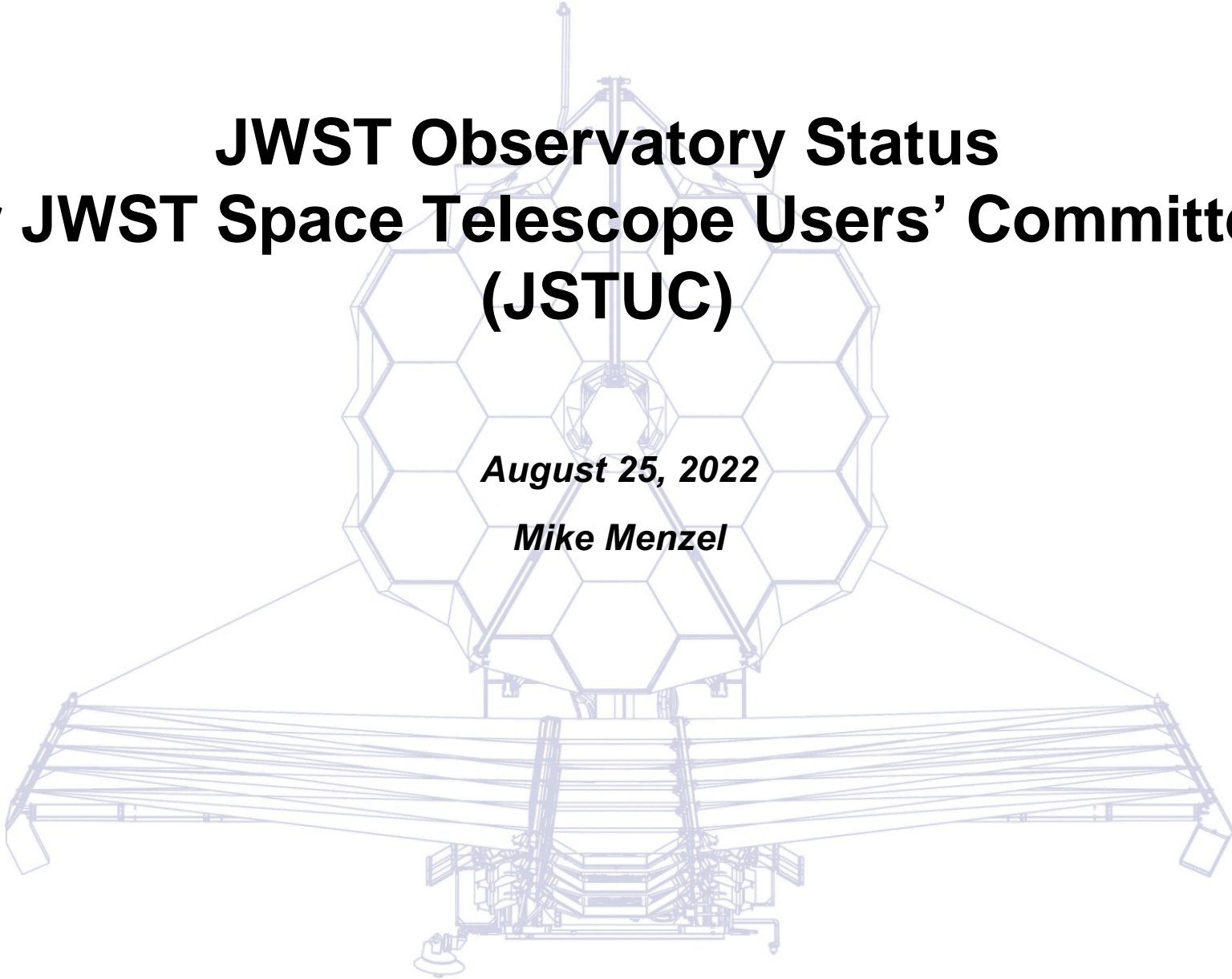


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# **JWST Observatory Status for JWST Space Telescope Users' Committee (JSTUC)**

*August 25, 2022*

*Mike Menzel*





# Introduction and Topics

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- **This section will provide a summary of the top level performance metrics and observatory and systems following the successful completion of observatory commissioning.**
  - Observatory Status and Environments
  - Technical Performance Metrics
    - Image Quality
    - Thermal / Cryogenic / Thermal Performance
    - Stray Light
    - Momentum Management and Propellant Life
    - RF Link Margins
  - Issues
    - Micro-Meteors
    - CFDP Latency
    - Artemis Launch “EM-1” Impacts on DSN coverage
  - Summary



# Observatory Status Summary (1 of 2)

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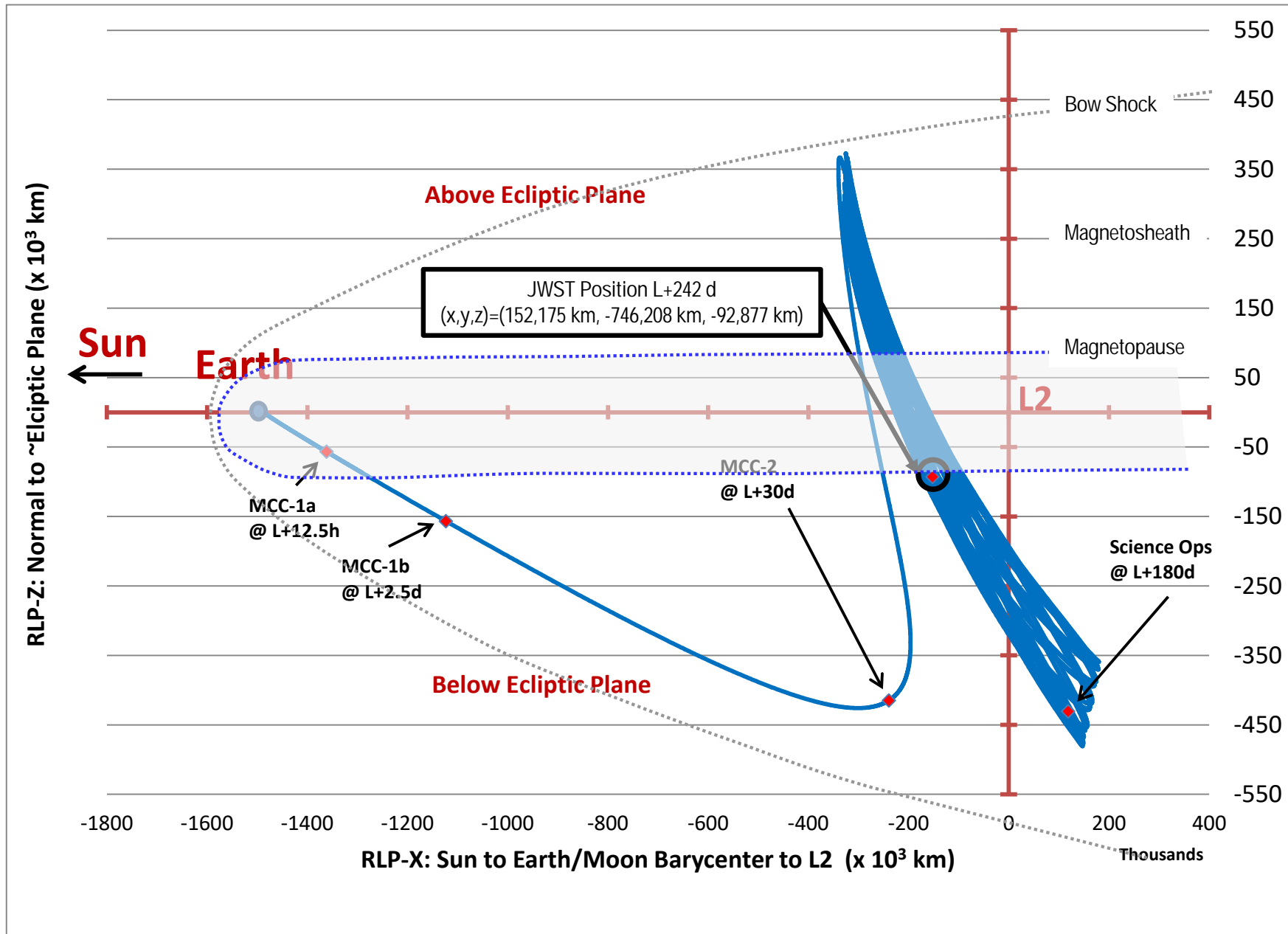


- **The observatory was successfully launched on 12-25-22, 12:20:07 UTC.**
- **Successfully completed all Mid-Course Corrections, and 5 station-keeping maneuvers. The observatory continues to follow its nominal trajectory. (See following charts)**
- **All major deployments were successfully completed by 1-8-22.**
  - Deployment completion retired 295 of the 344 Single Point Failures
- **Successfully achieved all cryogenic operational temperatures.**
- **Completed all OTE alignment and phasing activities.**
- **There were 152 recorded anomalies through Commissioning. None have had any lasting impact on performance or estimated life.**
- **Has experienced several solar proton events, flares and Coronal Mass Ejections (CMEs) with no lasting effects.**
- **Has experienced up to 7 measurable impacts from micro-meteors.**
  - Six events were in family with predicts.
  - One event was not in family with expectations, however optical performance still exceeds requirements by almost a factor of 2.



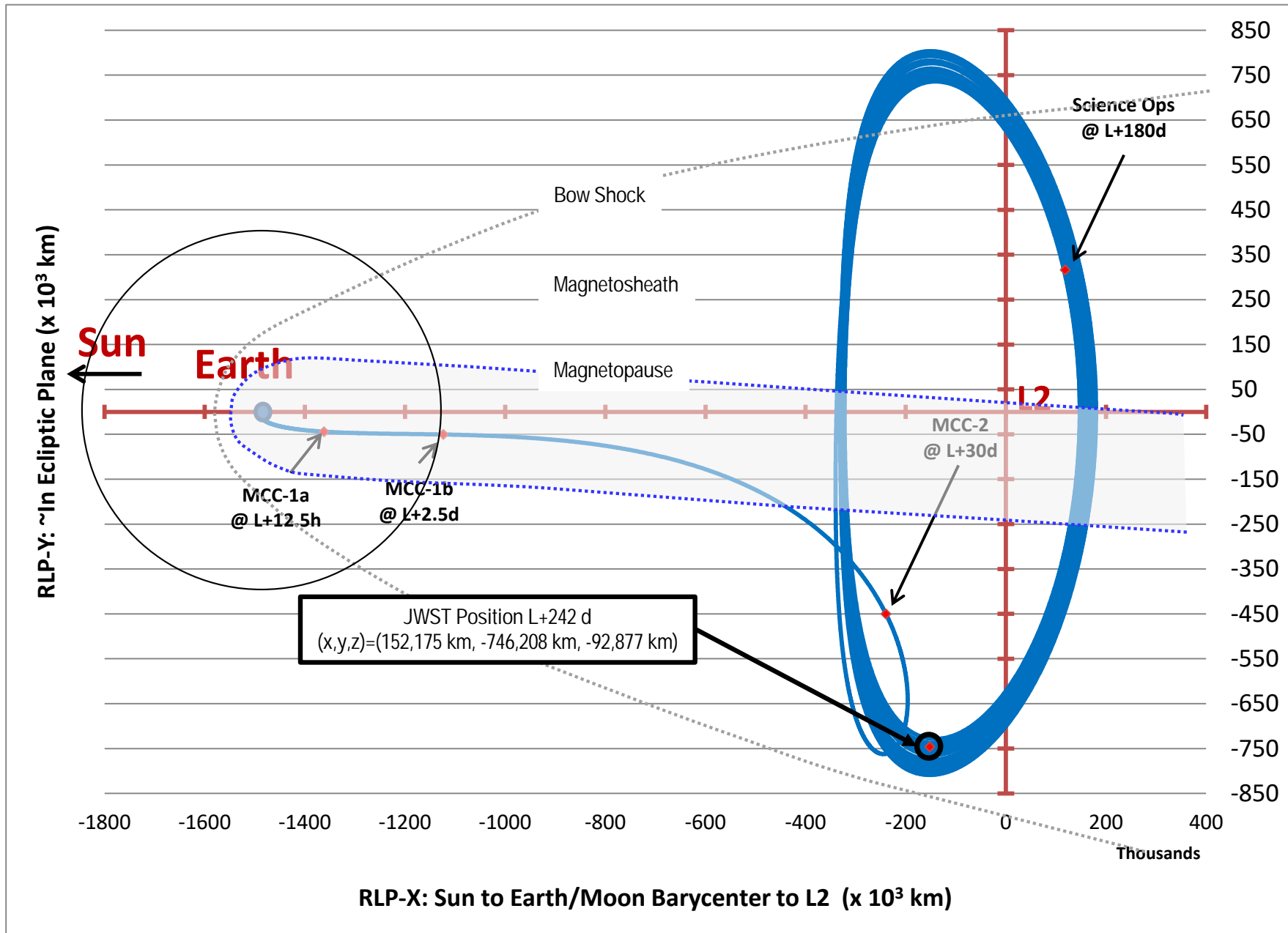


# Location in Trajectory as of L+242 d (1 of 2)





# Location in Trajectory as of L+242 d (2 of 2)





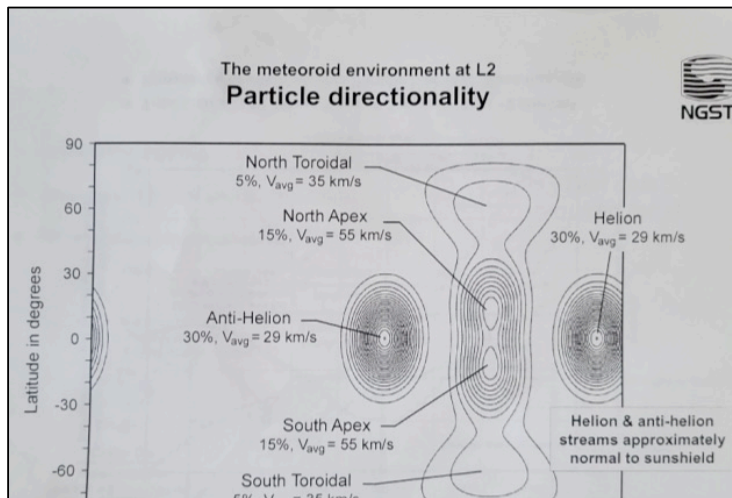
# JWST Environments



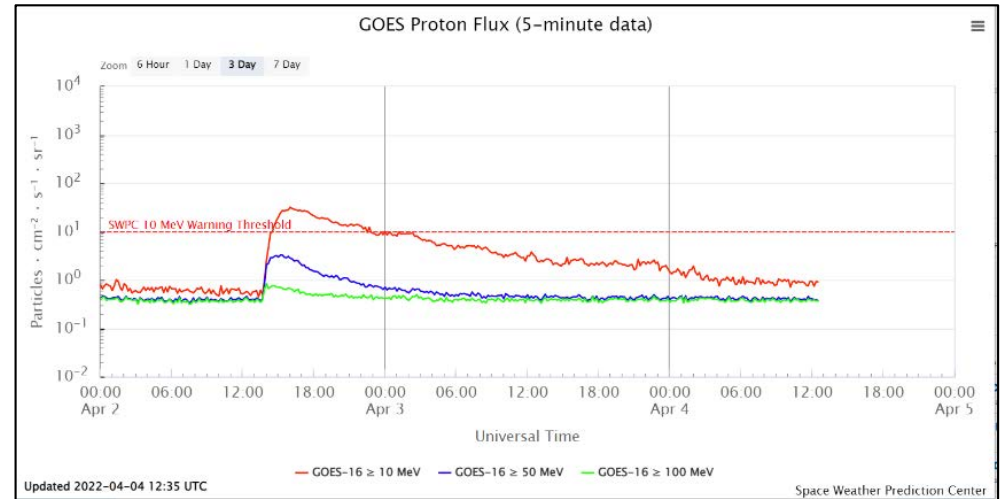
● JWST has experienced the full variety of anticipated “typical” operational environments during commissioning:

- Solar Proton Events
- Coronal Mass Ejections
- Solar Flares
- Sporadic Micro-Meteoroids (Velocity Distribution shown below) and five minor showers.
  - Lyrids
  - Aquariids
  - Herculids
  - Southern Delta Aquariids
  - Perseids

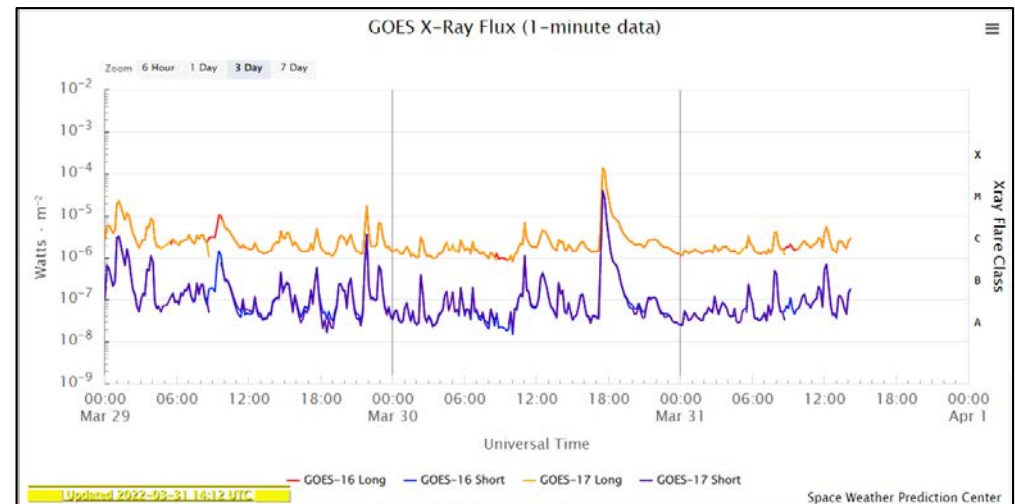
Sporadic Meteor Velocity Distribution



High Proton Flux on 4-2-22



X1 Flare on 3-31-22





# Technical Performance Metrics



Performance / Resource Parameters	Capability / Requirement	Estimate or Predict 10-21	Post Commissioning 7-2022
<b>Sensitivity Parameters</b>			
NIRCam SI Sensitivity @ 2 microns (nJy)	11.4	9.56	7.30
MIRI SI Sensitivity @ 10 microns (nJy)	700	513	462
Straylight (MJy/ster @ NIR 2 microns)	0.091	0.080	0.060
Straylight (MJy/ster @ NIR 3 microns)	0.07	0.065	0.040
Straylight (MJy/ster @ MIR 10 microns)	3.9	1.66	1.66
Straylight (MJy/ster @ MIR 20 microns)	200	178	178
OTE Transimission* Ap m2 Revised (TBR)	21.5	21.286	22.507
<b>Image Quality Parameters</b>			
Strehl (NIR 2 microns)	0.80	0.856	0.820
Strehl (MIR 5.6 microns)	0.80	0.962	0.962
NIRCam Channel Wavefront Error (nm)	150	126	96
NIRSpec Channel Wavefront Error (nm)	238	168	115
NIRISS Channel Wavefront Error (nm)	180	139	96
MIRI Channel Wavefront Error (nm)	421	174	140
EE Stability at 2 microns Over 24 hours	2.30%	0.41%	0.20%
EE Stability at 2 microns Over 14 days	3.00%	2.40%	0.53%
Image Motion rms for 15 sec Sliding Window for NIRCam (mas)	6.6	5.7	1.0
<b>Operations Parameters</b>			
Observing Efficiency	70%	78.0%	78.0%
Slew Time for 90 Degree Slew with 5 RWAs (min)	60.0	59.6	50.0
Momentum Accumulation LV1 (Nms/d)	22	16.16	4.30
Momentum Accumulation LV4 (Nms/d)	23	16.44	4.90
<b>Thermal Parameters</b>			
Cryo Parasitic Margin (NIRCam)	60%	79.7%	79.7%
Cryo Parasitic Margin (NIRSpec FPA)	60%	76.1%	76.1%
Cryo Parasitic Margin (FGS/NIRISS)	60%	80.4%	80.4%
Cryo-Cooler Line Load Margin (Pinch Point / Steady State)	83%	260%/288%	260%/288%
Cryo-Cooler OM Load Margin (Pinch Point / Steady State)	83%	245%/154%	245%/154%
<b>Data and Link Parameters</b>			
S-Band Uplink Margin (dB)	3.00	6.90	26.30
S-Band Downlink Margin (dB)	3.00	4.40	6.26
Ka-Band Downlink Margin (dB)	3.00	6.41	8.60
<b>Observatory Resources</b>			
Observatory Wet Mass (kg) as of 7-2016	6310	6161	6161
Observatory CG Offset (mm)	Area in DCI	38.0	38.0
Propellant Budget (kg)	300	251	251
Observatory Power Load (W)	1808	1802	1802
Observatory Power Generation (W)		2073	2073
Max Battery Discharge Time (Min)		458	458

**All Technical Performance Metrics Predicted to be GREEN**

**Sensitivity Metrics**

**Image Quality Metrics. These predictions assume periodic Wave Front Sensing and Control (WFSC) Operations**

**Key Operational Metrics are those associated with efficiency.**

**Thermal Performance Metrics**

**RF Link Margins**

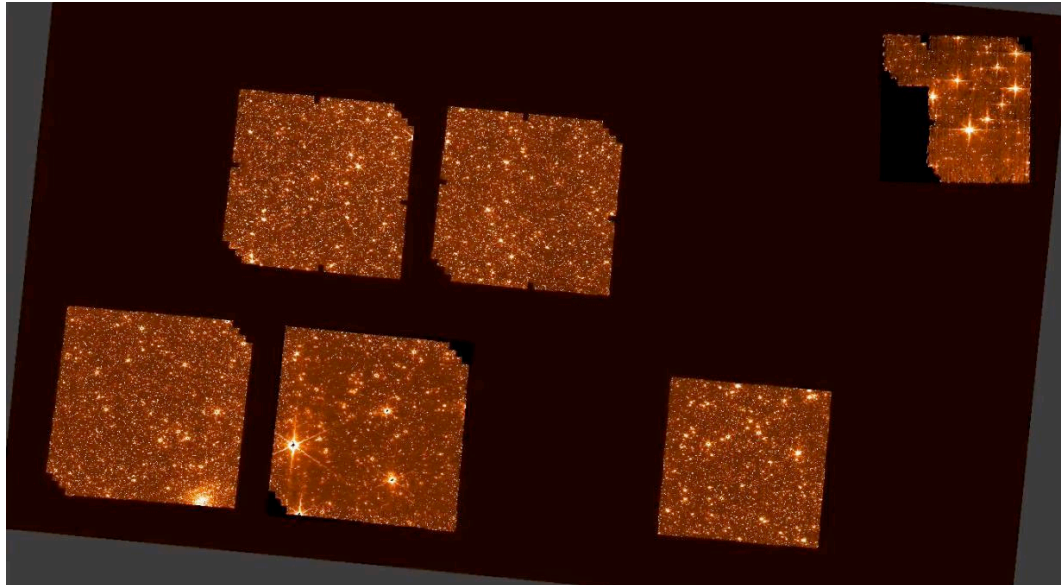
**Observatory Mass and Power Margins**



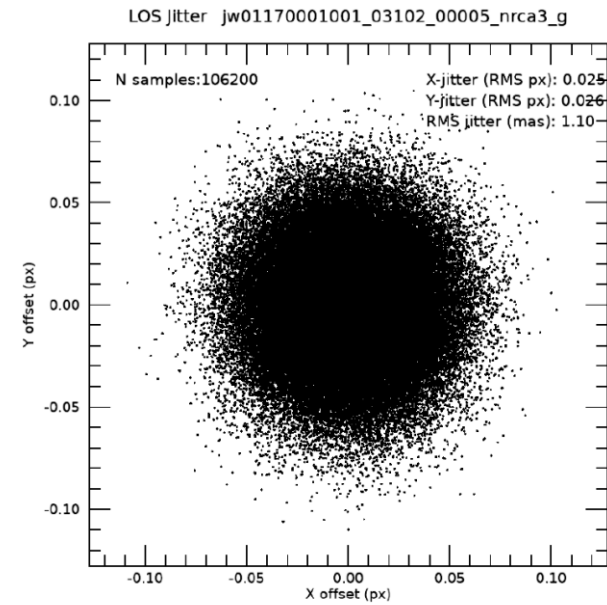
# Image Quality (1 of 2)



- **Key Level 2 optical metrics are specified in terms of:**
  - OTE Aperture x Transmission (MR-211)
  - Strehl Ratio (MR-110 and MR-116)
  - Encircled Energy (EE) Stability ((MR-113, MR-114 and MR-115)
- **Detailed descriptions of the optical metrics will be presented in the OTE, Science Performance and Science Instrument Sections.**
- **Optical Throughput:**
  - Unobstructed area measured from pupil image  $25.44 \text{ m}^2 > 25.431 \text{ m}^2$
  - Table at the upper right gives the EOL predictions for Aperture X Transmission based on contamination levels measured at the launch site:
    - Minimum margin of 5% at wavelength of 3.1 microns
- **Strehl Ratio:**
  - Strehl at 2 microns required to be 0.80
  - Current BOL estimate for NIRCам B Short Wave channel at 2 microns Strehl is 0.84.
  - EOL estimate for NIRCам B Short Wave channel at 2 microns is 0.82.
  - Currently the Observatory is Diffraction Limited at a wavelength of 1.1 microns
- **Encircled Energy (EE) Stability:**
  - EE Stability is required to be less than 2.3% in 24 hours and less than 3% for 14 days following a hot to cold slew.
  - EE stability has been measured to be less than 0.2% for 24 hours and less than 0.53% for 14 days.



Post Phasing Engineering Images



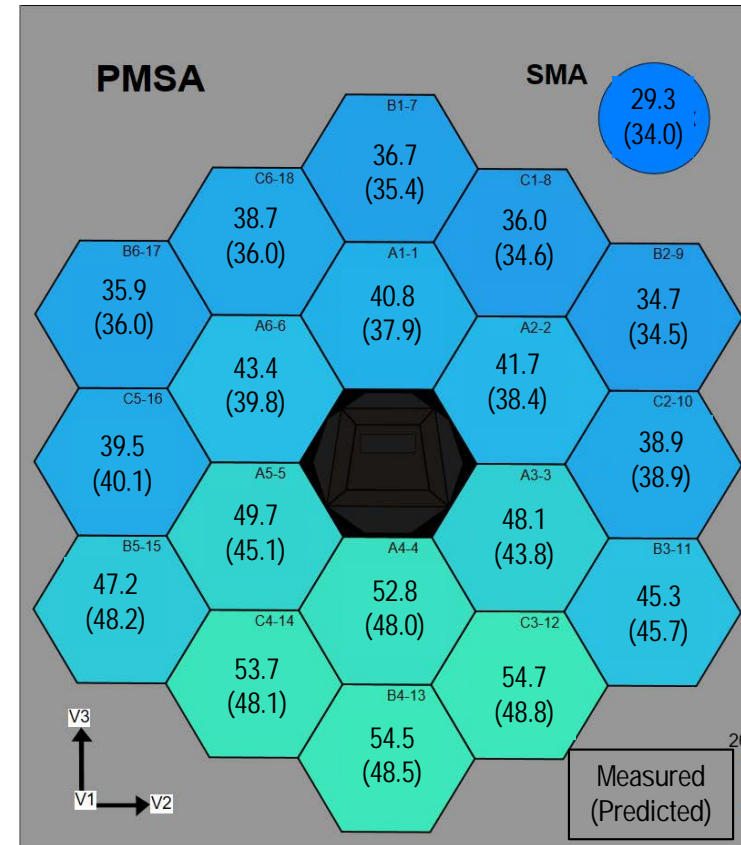
Measured LOS Stability



# Cryogenic Performance



- The observatory telescope has successfully reached all its operational temperatures.
  - Thermal Health is Green (all systems on Side-A)
  - Only 1 sensor lost (SMSS IB-Hinge Pin)
- Primary Mirror (PM) and Secondary Mirror (SM) temperatures shown on the upper right.
  - Secondary mirror 5K colder than expected
  - Center section warmer than predicted (1-6K)
  - Wings close to predicted (slightly cooler)
- All Science Instrument (SI) instruments are within operational temperature ranges and tuned to SI Team requested Targets within those ranges, as shown in the table on the lower right.
  - Stability is also with requirements < 25mK/day (Req 50mK/day)
- The MIRI has been cooled to its operating temperatures via the MIRI cryo-cooler.
  - Measured cooler load vs Predicted at measured interface temperatures is extremely close. (124mW predicted prelaunch)



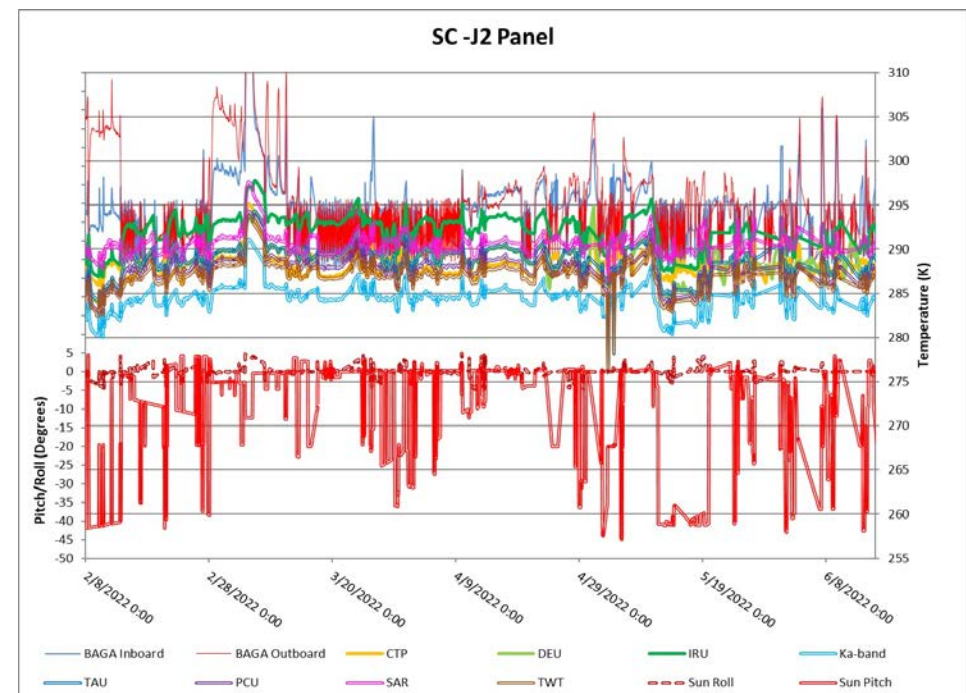
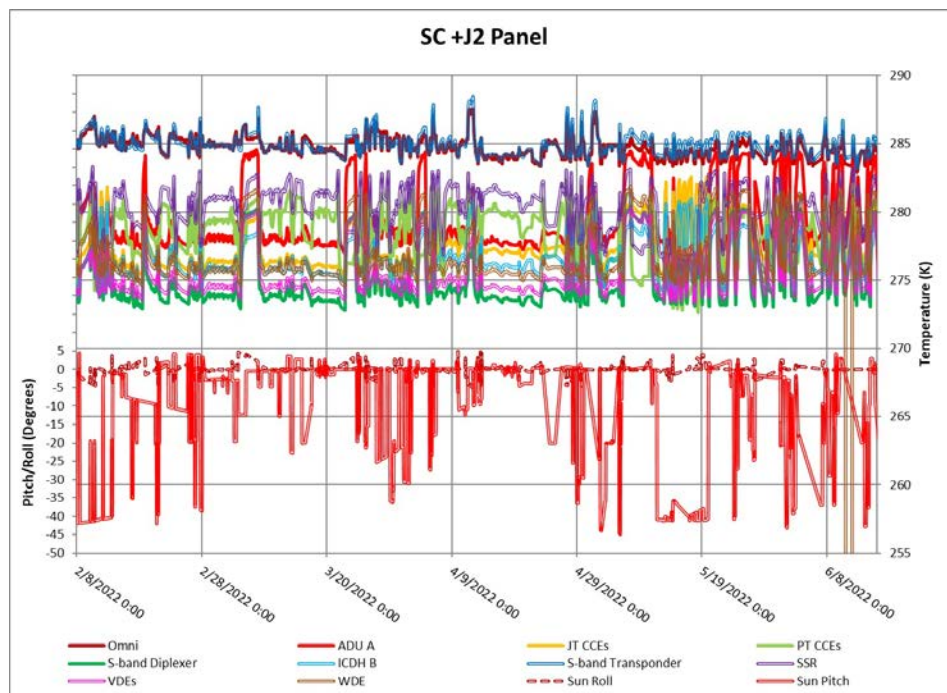
Instrument	Flight (K)	Target (K)
NIRSpec OA	35.57	35.5
NIRSpec FPA	42.80	42.8
FGS	38.48	38.5
NIRCam	38.52	38.5
MIRI	6.03	6.0
Cooler Load	Measured 119 mW	Predicted 118 mW



# Spacecraft Bus Thermal Performance



- **The Observatory Bus is operating within required temperature ranges.**
  - Thermal Health is Green (all thermal control systems on Side-A)
  - Observatory has experienced Roll and Pitch solar aspect angles across entire FOR and TCS has demonstrated proper heater & temperature control throughout.
  - No sensors or heaters lost



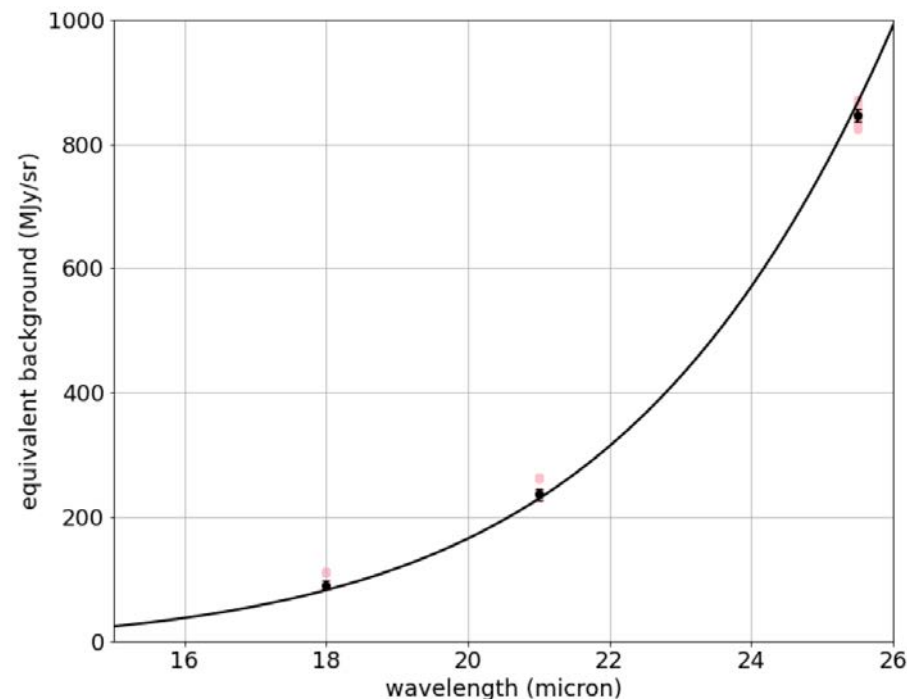
- **STA heater control parameters tweaked on-orbit as planned (CAR-747) to improve temperature stability over entire FOR.**



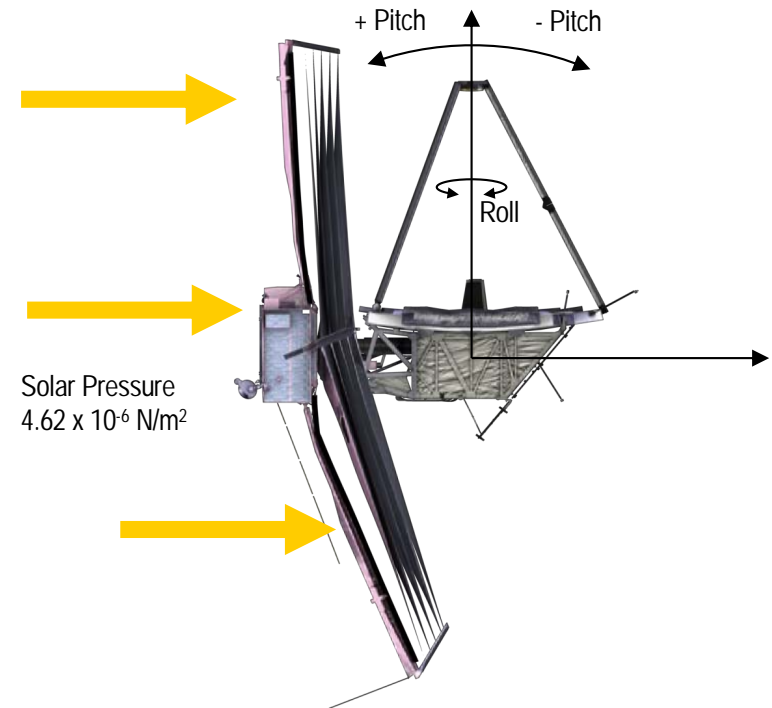
# Stray Light Performance



- **NIR Stray light performance is driven by scattering. Estimates for NIR stray light are:**
  - 0.06 MJy/SR at  $\lambda = 2$  microns
  - 0.04 MJy/SR at  $\lambda = 3$  microns
  - Well below requirements of 0.091 MJy/SR at  $\lambda = 2$  microns and 0.070 MJy/SR at  $\lambda = 3$  microns.
- **Stray light path from Sky to Instruments found to arrive at NIRCam and NIRISS detectors after glancing reflections on internal hardware**
  - This is mitigated by small “keep out zones” for bright objects and calibrations.
- **MIR Stray Light levels are driven by observatory temperatures.**
  - Plot to the right shows measured MIR Stray Light levels against predicts
  - In flight measurements show excellent agreement with predictions



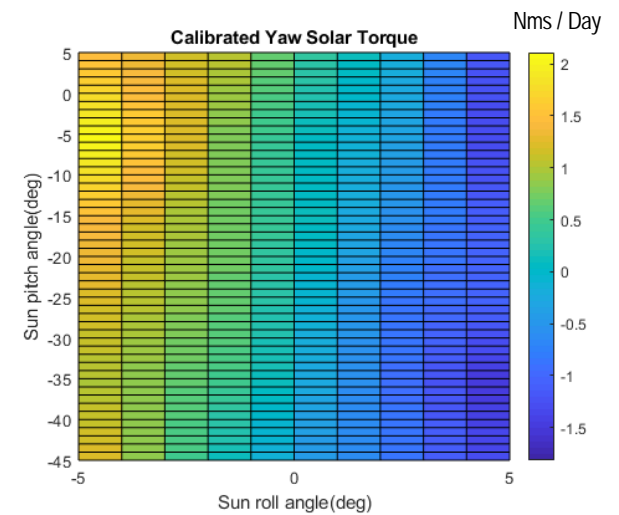
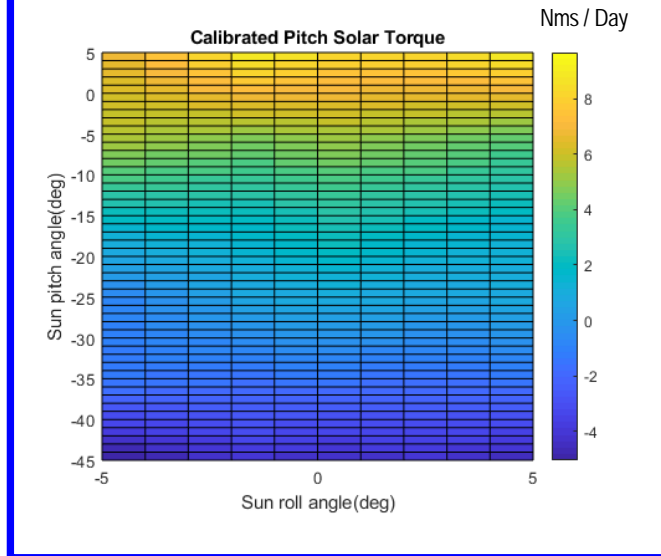
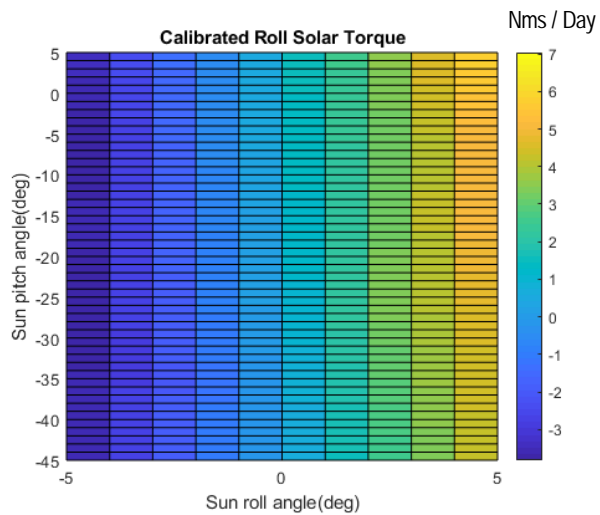
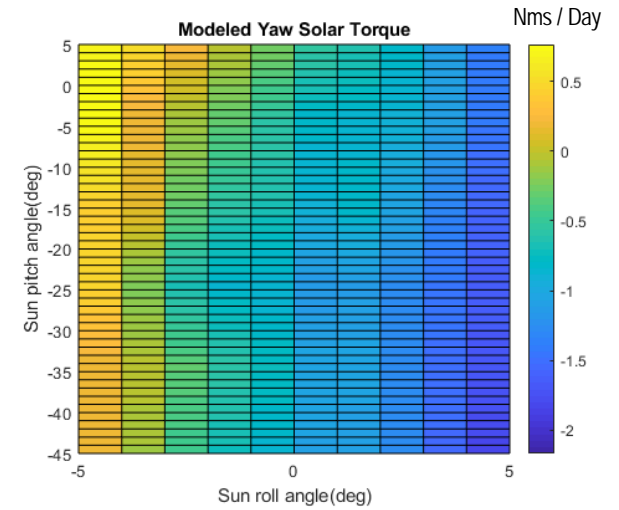
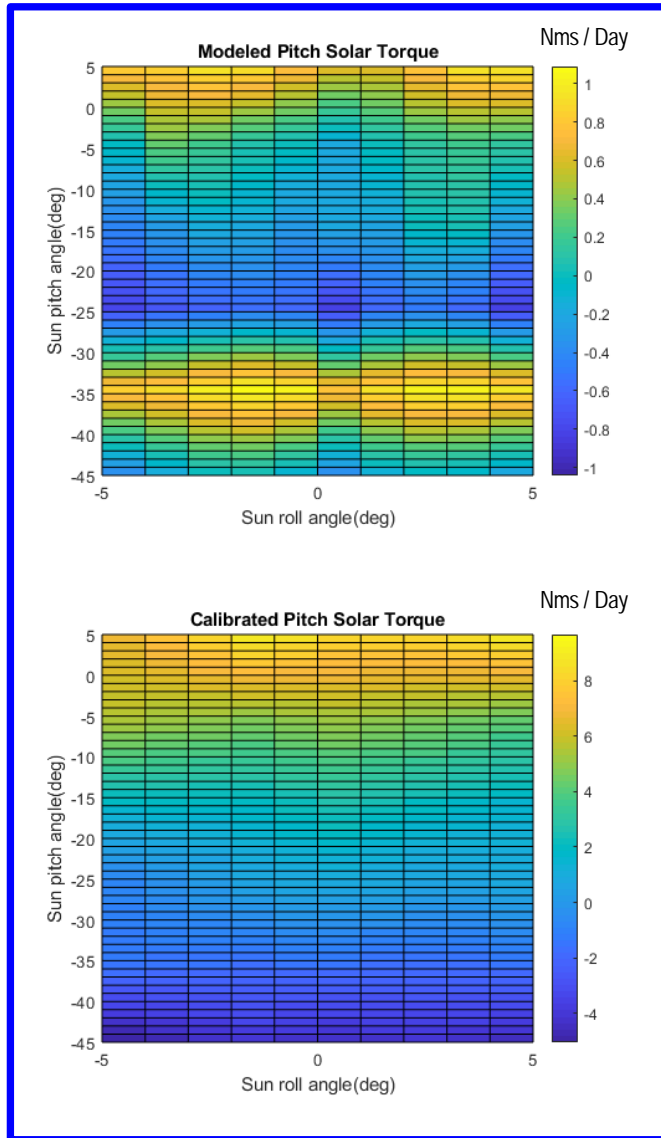
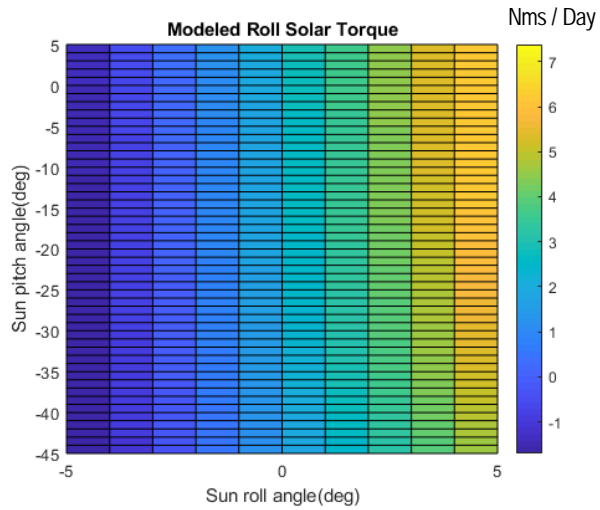
- **The large sunshield, observatory attitude changes, and shadowing effects conspire to produce unbalanced torques resulting in significant momentum accumulation in the Reaction Wheels Assemblies (RWAs).**
  - Sunshield geometry is designed to minimize momentum accumulation.
  - Momentum accumulation (Nms / day) is plotted as a function of Roll and Pitch attitude as shown on the following chart. (Torque Tables).
  
- **Momentum accumulation can be managed via observation scheduling. The Ground Segment defined LV1 and LV4 metrics such that if Torque Tables have values lower than these, there is a high probability that momentum can be effectively managed via scheduling:**
  - LV1 = The mean momentum buildup per day within a roll band of  $\pm 1^\circ$ .
  - LV4 = The mean momentum buildup per day within a roll band of  $\pm 4^\circ$ .
  
- **Required LV1 and 4 metrics as well as measured on-orbit values shown in table on lower right.**



	Requirement (FG-2308)	Calibrated	Nominal (Modeled, 2018)	Worst-case* (Modeled, 2018)
<b>LV1</b>	22	4.3	3.2	16.2
<b>LV4</b>	23	4.9	3.5	16.4



# Momentum Management (2 of 2)



Pitch Torque Table Shows values higher than predicted but Well within the +/- 12 Nms/day error band for the model predict



# Propellant Life



- Because of the injection accuracy of the Ariane LV, and the timely execution of the Mid Course Correction Maneuvers, JWST has excellent propellant margins.

- Propellant life currently exceeds 20 years.

- **Current propellant levels:**

- Hydrazine: 144.89 kg
- Oxidizer: 104.63 kg

- **Projected Propellant Life:**

- Table to the right shows the pre-launch DV and propellant allocations
- Predicted rates from the budget:
  - 5.36 kg Fuel per year (see blue boxes)
  - 2.94 kg Ox per year (see green boxes)
- Subtract fuel and Ox for EOL maneuver from current propellant levels
  - Hydrazine: 144.17 kg
  - Oxidizer: 103.78 kg
- Remaining propellant life limited by Hydrazine to 26.9 years.

Function	Delta-V Update	9/2020 Budget	
		Fuel (kg)	Ox (kg)
Post-sep rate damp		0.37	
MCC-1a	49.4	50.03	57.32
		(5.54)	
MCC Contingencies	12.6	12.81	14.47
		(1.29)	
MCC-1b	5.4	5.49	6.19
		(0.55)	
MCC-2	3.1	3.29	3.48
		(0.55)	
Stationkeeping (10.5 yrs)	23.6	24.70	27.98
		(3.41)	
Post-SK rate damp	-	(6.10)	
Stationkeeping contingencies	2.4	2.47	2.91
		(0.33)	
Momentum Unloading	-	28.40	
Safe Mode	-	0.75	
EOL Maneuver	0.7	0.72	0.85
		(0.10)	
Residuals	-	4.50	4.75
Propellant Margin	N/A	33.96	14.56
<b>Totals</b>	<b>97.2</b>	<b>167.49</b>	<b>132.51</b>
<b>Fuel/Ox Total</b>			<b>300.00</b>
<b>GHe Pressurant (Fuel &amp; Ox)</b>			<b>0.59</b>
<b>Propellant + GHe</b>			<b>300.59</b>



# RF Link Margins



- All Rf link margins remain at very healthy levels.
  - See tables on the right show pre-launch RF margin estimates.
- Measured RF Link margins have exceeded these pre-launch estimates:
  - Ka-band downlink margin at 28 Mbps: 8.6 dB (Average)
  - S-Band downlink margin at 40 Kbps thru the MGA: 6.23 dB (Average)
  - S-Band uplink margin at 16 kbps: 11.58 dB

S-band Downlink Rate* [bps]	Max Range	DSN adverse Margin † [dB]	Transmit antenna & power/pointing configuration
200	L2	5.0/ 8.4	SC/OTE (Split 75%/25%)
1000	L2	5.2	SC Omni alone (full power)
40,000	L2	4.5	MGA (BAGA pointed)
20,000	L2	7.5	MGA (BAGA pointed)
2,000	700,000	10.4	SC Omni alone (full power)
4,000	400,000	12.2	SC Omni alone (full power)
8,000	300,000	14.8	SC Omni alone (full power)

S-band Uplink Rate* [bps]	Max Range	DSN adverse Margin † [dB]	Receive path
250	L2	15.9/ 18.3	SC/OTE path
2,000	L2	6.9/ 9.3	SC/OTE path
16,000	L2	11.1	MGA path

Ka-band downlink Rate* [Mbps]	Max Range	DSN adverse Margin † (dB)
28	L2	6.43
14	L2	9.43
7	L2	12.43



## Micro-Meteoroids (1 of 2)

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- **The primary mirror has experienced 7 measurable micro-meteor hits on our primary mirror and are averaging about 1 per month as expected based on our analysis.**
- **The resulting optical errors from 6 of these were well within our expectations and within what we had budgeted for optical wavefront error (WFE).**
- **One of the seven had WFE considerably higher than our expectations. However even after this event our optical performance is still twice as good as our requirements.**
- **This event could well be a rare statistical anomaly but out of an abundance of caution we have been investigating possible mitigation strategies.**
  - **Since we have over 20 years of fuel, it is wise to consider methods that could ensure all parts of the observatory perform at their best for that long.**



## Micro-Meteoroids (2 of 2)

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- **The Project has assembled a team that has been investigating a balanced approach of restricting certain pointing directions, that have the highest likelihood of the most energetic micro-meteors without putting undue restrictions on science efficiency and targets of opportunity.**
  - The team consists of experts from Project, mirror manufacturer and the NASA Meteoroid Environment Office (MEO) at the Marshall Space Flight Center (MSFC).
  - The team has been investigating potential mitigation methods such as pointing restrictions to quantify their benefit and weigh that against their impact to science and operational efficiency.
  - These methods will be in addition to the defensive maneuvers that were already anticipated as a mitigation for the known periodic meteor showers.
    - Such maneuvers are currently implemented for previous mission such as HST.
  
- **Project engineering will be making their recommendations in September.**



# DSN CFDP Latency Anomaly (1 of 4)

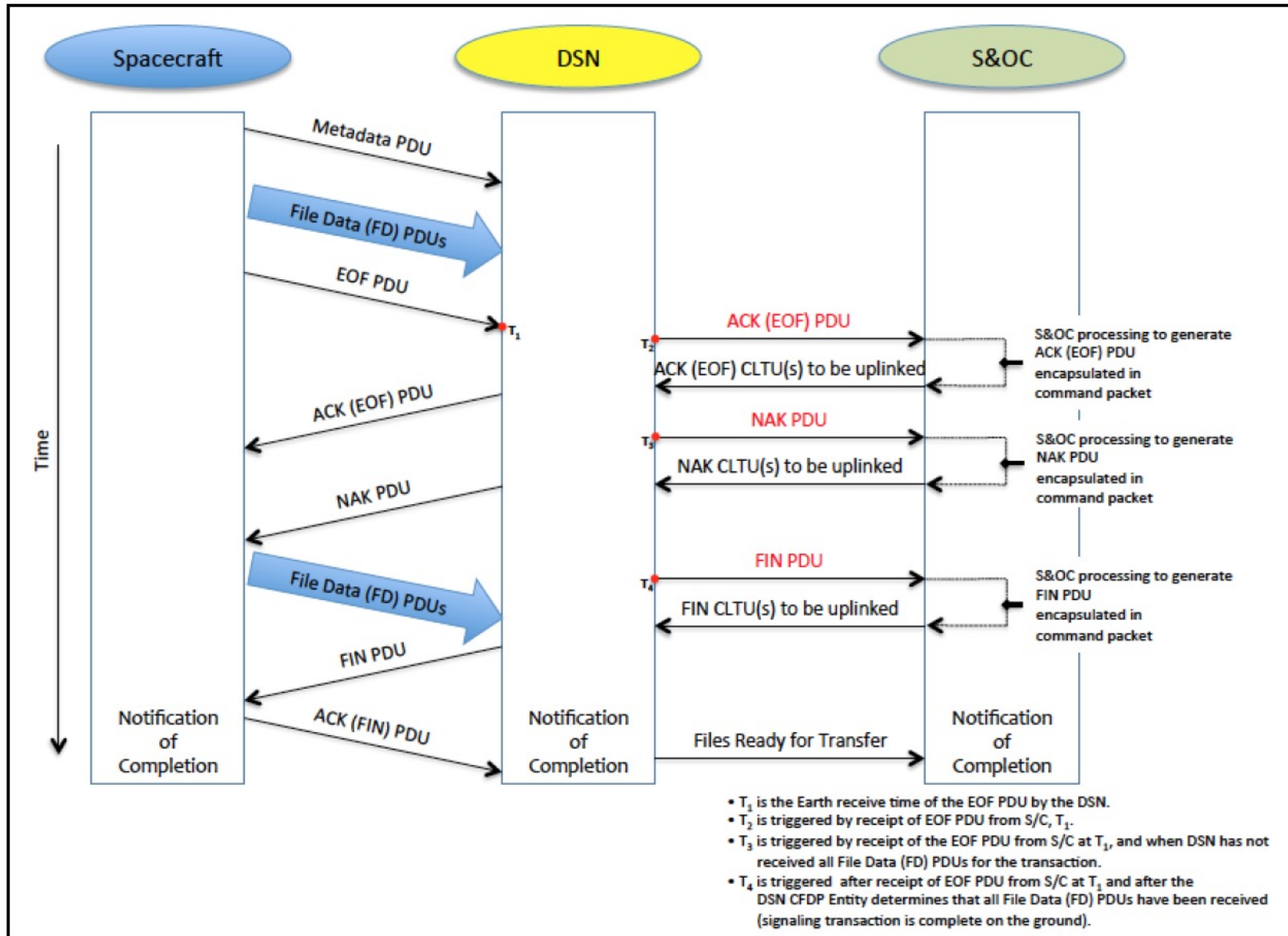
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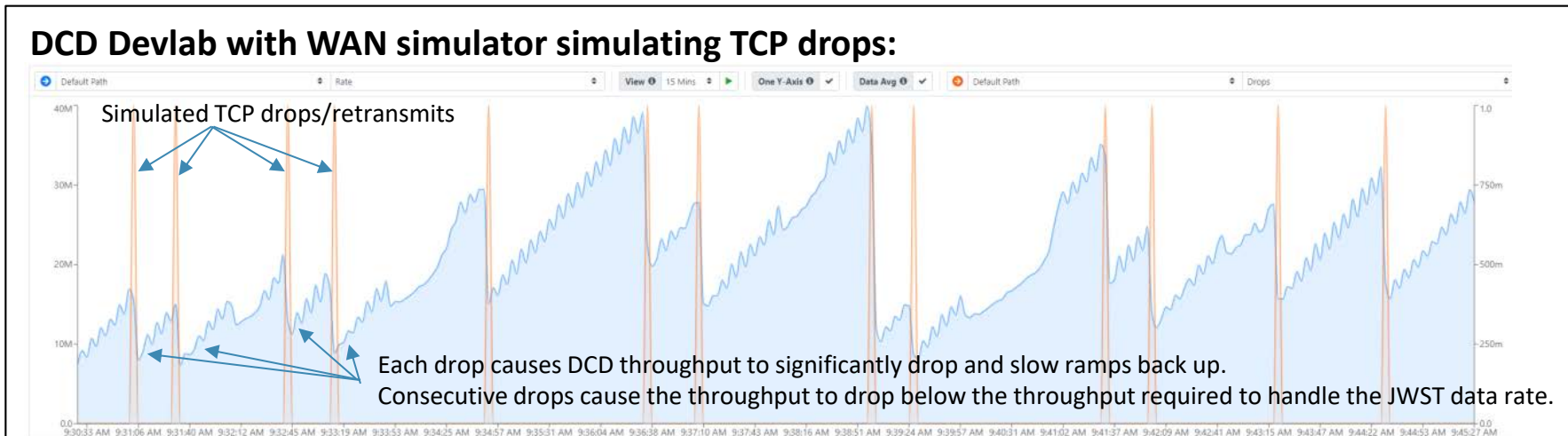
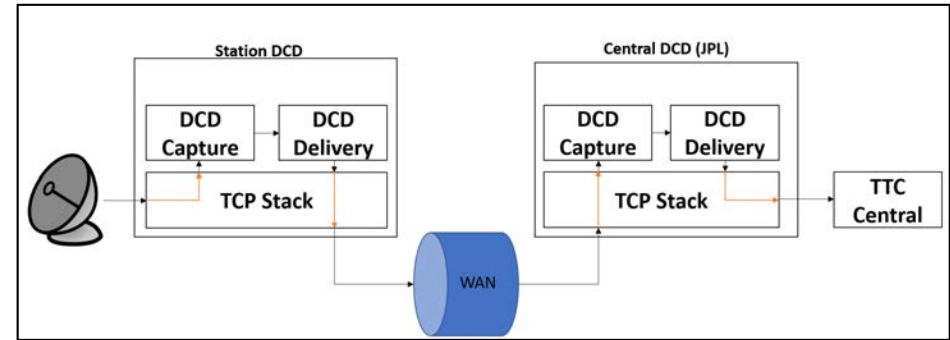
- **The Ka-Band downlink of science data uses a high reliability Class 2 Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol (CFDP).**
  - CFDP Class 2 uses an acknowledged protocol:
    - Receiving system detects errors or missing data and declares fault
    - Missing or erroneous data re-transmitted
  
- **Time delays (latency) in the ground system Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol (CFDP) processing during Ka-Band Solid State Recorder playbacks can result in on-board timers running out resulting in:**
  - Accumulation of on-board faults that may mask other faults that occur simultaneously
  - Extended time duration to close downlink transactions:
    - Cannot use full contact time for playback
    - Lower playback availability → less science data can be collected

# DSN CFDP Latency Anomaly (2 of 4)

CFDP Transaction Overview



- DSN engineering generated a fish-bone diagram with potential root causes, and have isolated the most probable causes in the TCP congestion control software within the Data Collection and Distribution (DCD) systems.
  - Dropped packets in the Wide Area Network (WAN) can cause this congestion control software to reset resulting in ramp-up in throughput. Results in data back-ups.
    - See diagram on the upper right
  - Depending on the frequency and distribution of packet drop-outs significant latencies can develop.
    - Simulation result below.





# DSN CFDP Latency Anomaly (4 of 4)

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- **The issue is under Anomaly Management Board (AMB) control.**
  - The last AMB meeting was held on 6-18-22
  - The approved path forward from this meeting:
    1. Continue implementing DSN troubleshooting recommendations as needed with MOM approval (see previous slide 18)
    2. Continue root cause investigation
    3. Flight control room has discretion to halt PB at first instance and contact DSN for further coordination, as needed
    4. Move DCD to low latency queue with voice (120Kbps) on CBWFQ [Proposed for THIS WEEK (Week June 13th)]
    5. Complete testing of updated DCD TCP congestion algorithm
    6. Continue testing to explore IBM Aspera solution to maximize WAN bandwidth
- **While investigations continue DSN contact time will remain at 12 hours per day for normal operations (buffer to ensure adequate SSR playback time)**



# Artemis EM-1 Impacts

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- **Artemis's EM-1 will require a significant amount of DSN antenna resources.**
- **JWST will have significantly decreased ground station coverage with some prolonged outages.**
  - Exact DSN coverage depends on EM-1's launch date, but instead of the normal 12 hours of DSN coverage per day, there are days of 2-4 hours or even 0 hours
  - Some launch contingency scenarios include multiple 40-50 hour outages.
- **Without at least 8 hours of DSN coverage per day, JWST must reschedule science as planned.**
  - Time critical science can be accommodated
- **Significant DSN outages also cause undesirable reconfigurations onboard**
  - The Engineering team has evaluated options to minimize the impact of these reconfigurations
- **In all cases, the first two weeks of the EM-1 mission have the most pain.**
- **In general, the earlier EM-1 launches, the less impactful it is for JWST.**



# Summary

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- **JWST has been successfully launched and deployed on-orbit.**
- **It has completed the majority of its major observatory level tests and performed its observatory level functions.**
- **It's measured observatory level performance has met all specifications with healthy margins.**
- **We have experienced anomalies, but so far the majority have been addressed and or have not had significant impacts to mission safety or performance.**
  - Mission Systems Engineering is participating in efforts to address DSN ground system issues associated with CFDP latency.
  - MSE and the Flight Ops Team will trend meteoroid impacts and assess performance degradation.