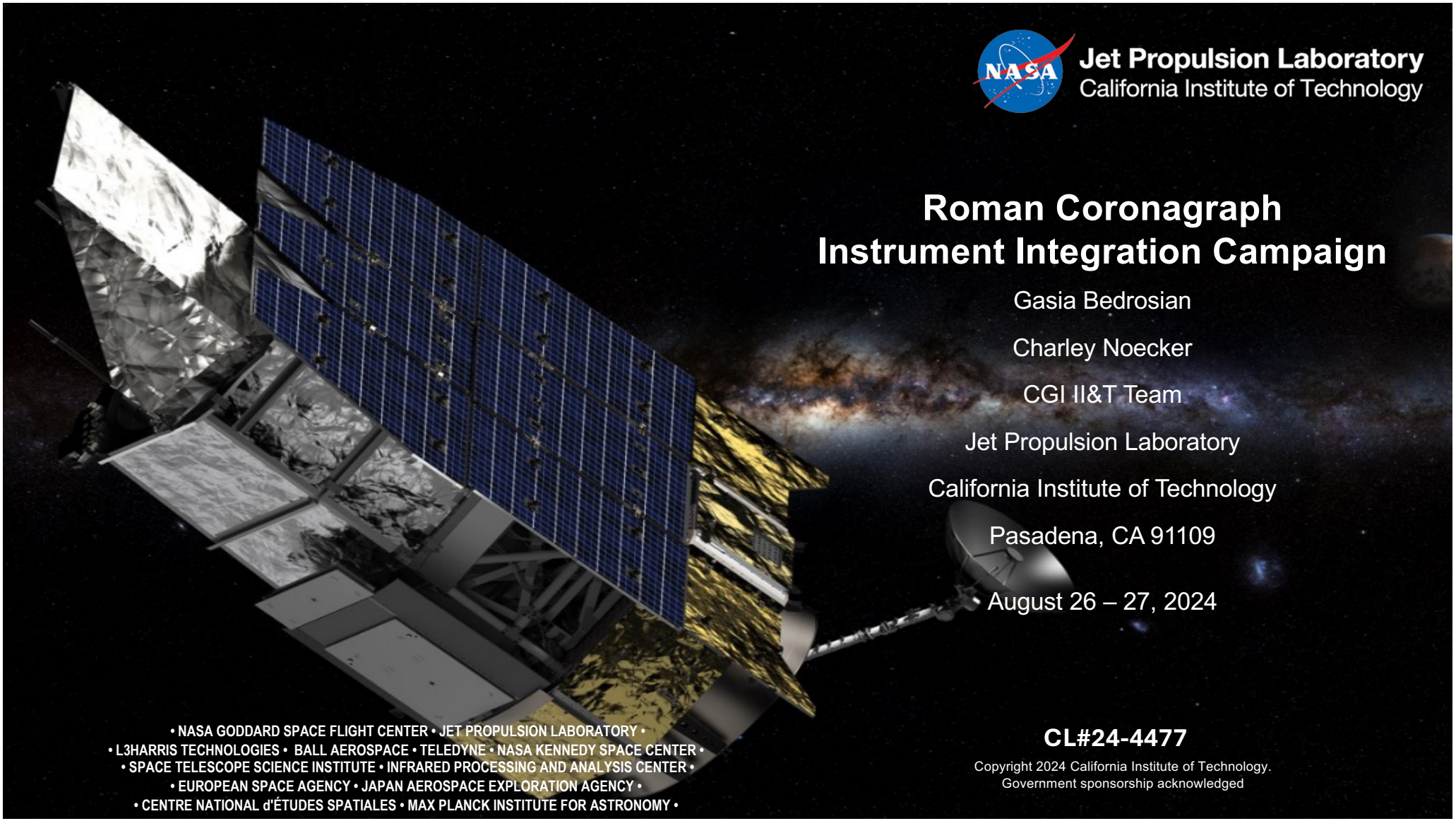

Jet Propulsion Laboratory
California Institute of Technology

Roman Coronagraph Instrument Integration Campaign

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California Institute of Technology

Pasadena, CA 91109

August 26 – 27, 2024

• NASA GODDARD SPACE FLIGHT CENTER • JET PROPULSION LABORATORY •
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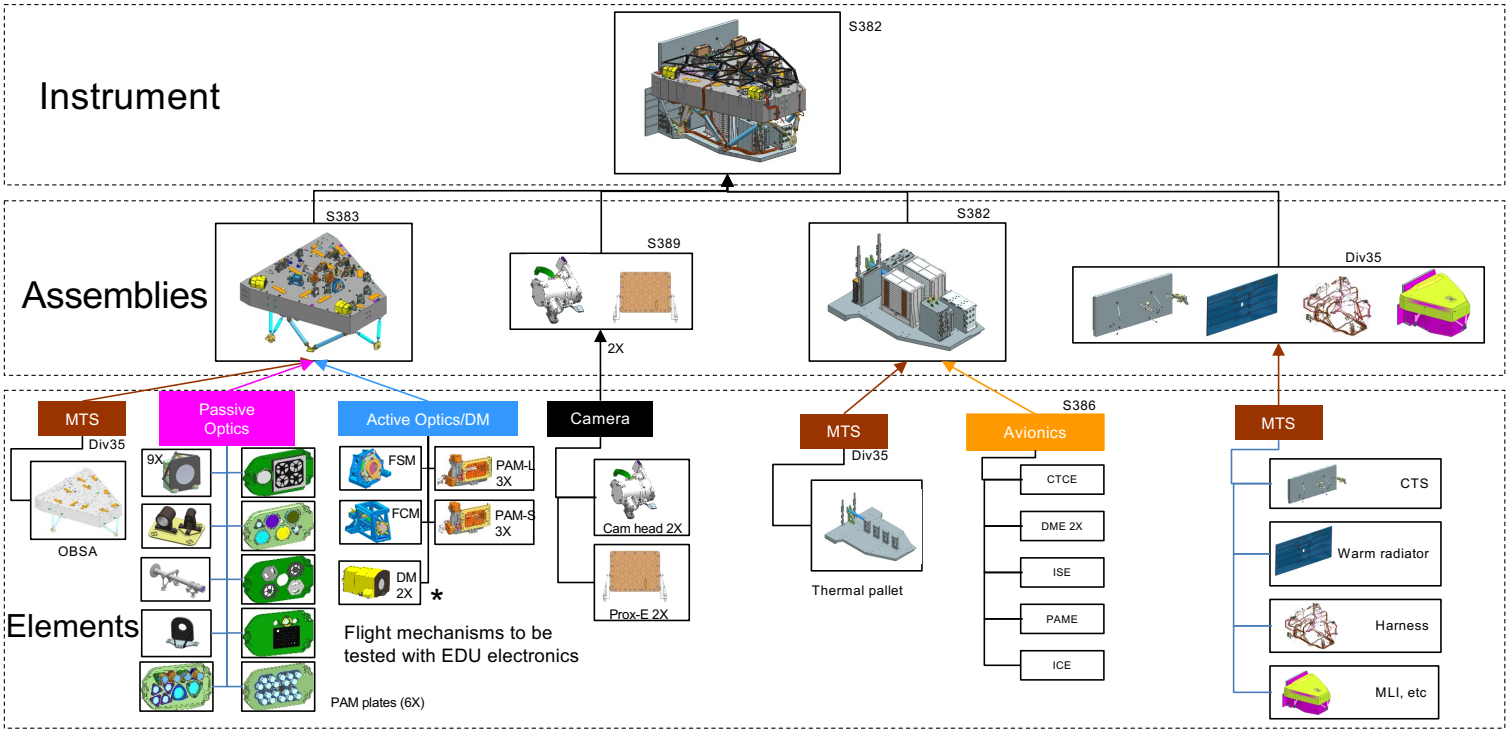
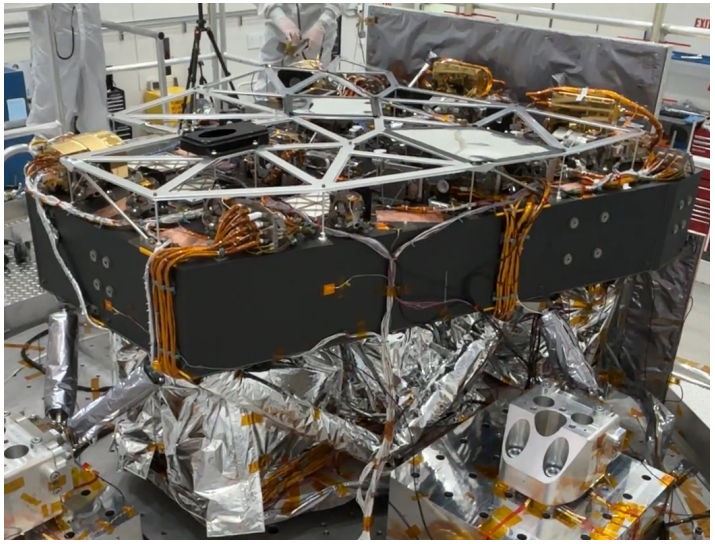
CL#24-4477

CGI FM Integration and Test Hierarchy



*Due to schedule, moved DM installation after delivery of OBSA to II&T

Special Challenges of Coronagraph II&T

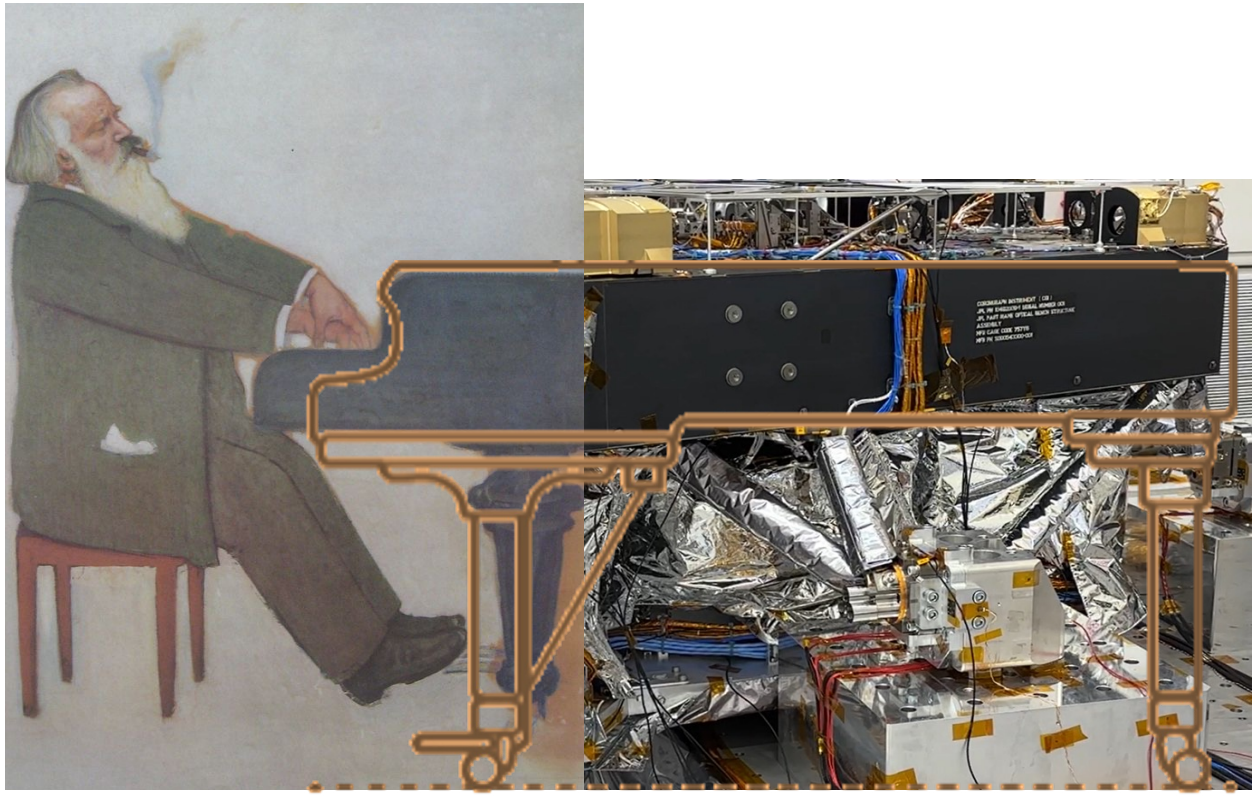


- High contrast broadband imaging with 3 nested closed loops
- Class D technology demonstration on a Class A observatory
- Stringent observatory interfaces managed through collaboration with GSFC
- The most complex optics, electronics, and software ever in a single JPL instrument
  - 22 optical elements in the path; six are mechanism-selectable; two are operated in closed loop
  - Advanced high-sensitivity electron-multiplying CCDs
  - Thermal control <0.5 K, in some places < 10 mK
  - 49 electronics slices with 9 unique FPGA designs
  - Two deformable mirrors (DMs) with >3000 actuators controlled by individual ultra-stable voltage sources
  - More than 260,000 lines of code (flight, ground, FPGA)

More typical of a JPL spacecraft than an instrument

- Challenging contamination and moisture adsorption requirements
- 54-day thermal-vacuum (TVAC) test including the final performance tests

Coronagraph and Grand Piano



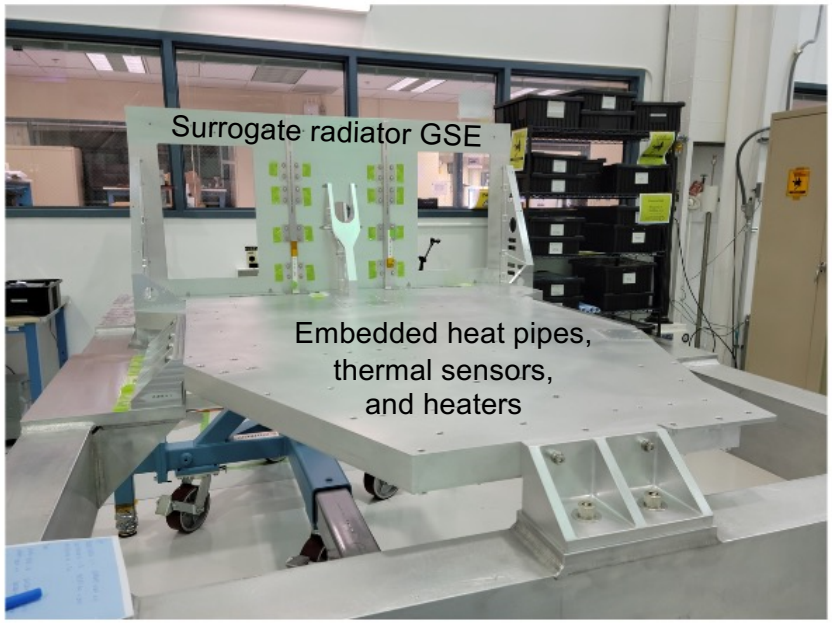
Johannes Brahms
Not cleanroom certified

The Roman Coronagraph is very close to the size and weight of a Steinway grand piano

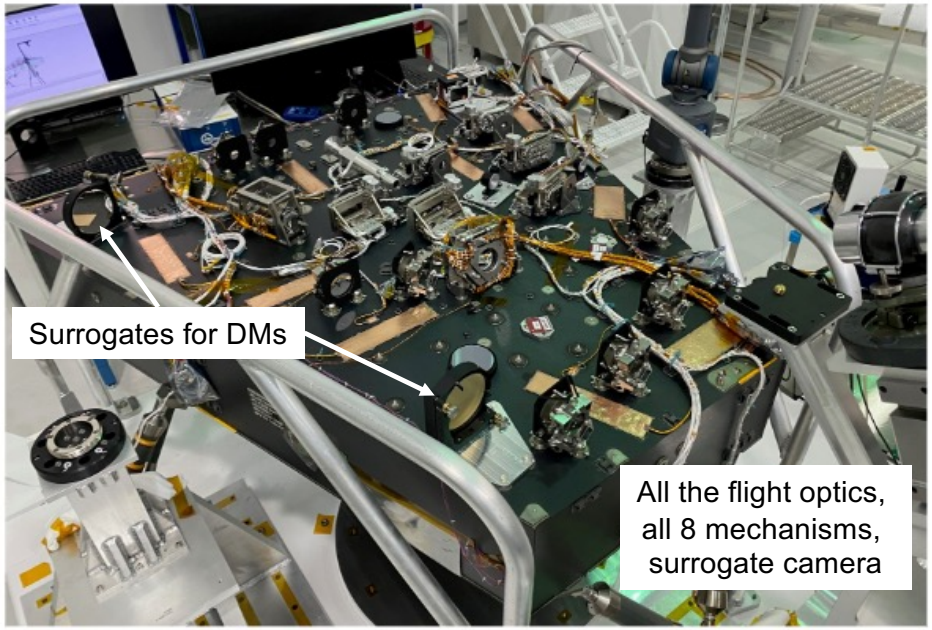
II&T Campaign

- The CGI II&T Campaign spanned from July 2022 to May 2024
- Where it all began…

Electronics pallet (EHTS) as Delivered to II&T

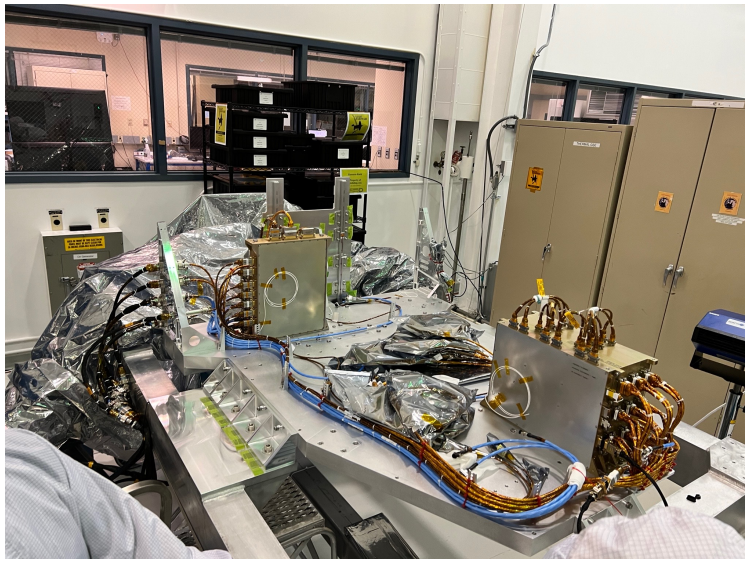


Optical instrument (OBSA) as Delivered to II&T

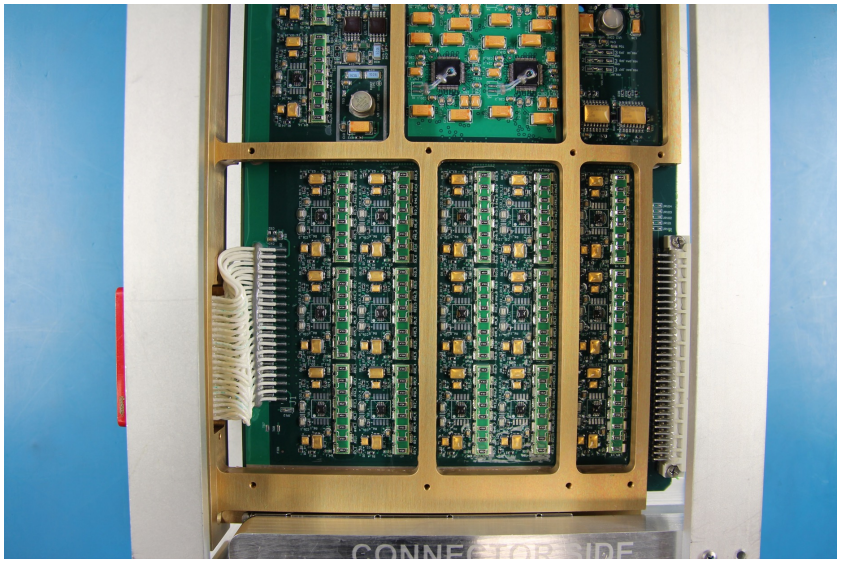


Where we Faced our Biggest Challenge

- Avionics team learned summer of 2022 that needed to replace 14,392 of resistors on their DME boards…



EHTS View for about six months post PAM DEL

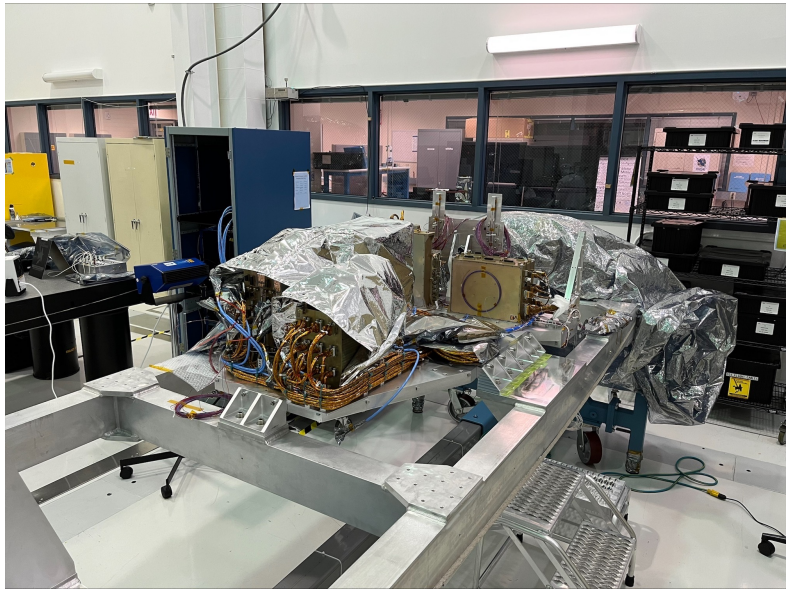


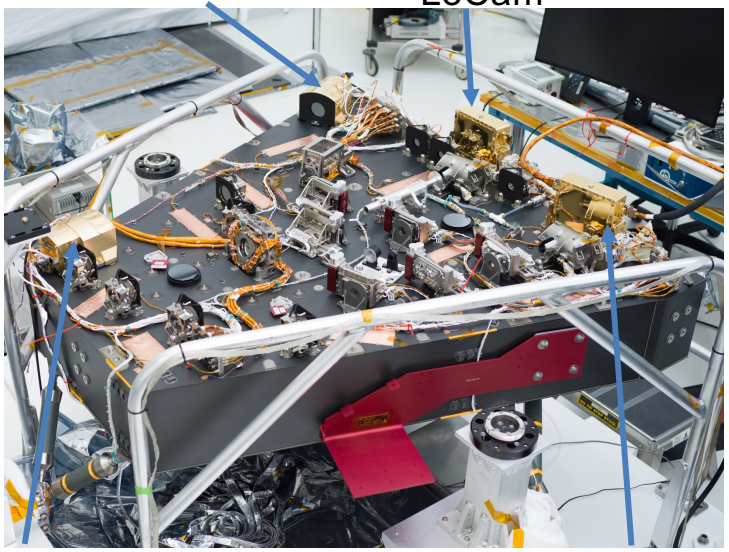
View of DME boards that needed resistor rework

- EHTS work stalled for six months while the Avionics team worked on the DMEs and the remaining Electronics to deliver to II&T

II&T Campaign

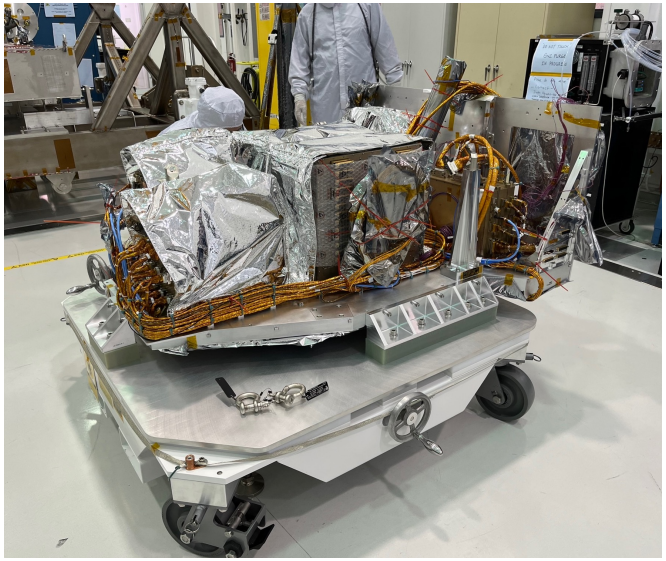
- The team worked together and with innovative approaches to swap the activity orders, made it through the hurdle of late Avionics deliveries and in August 2023…
- Achieved the milestone of EHTS and OBSA completion



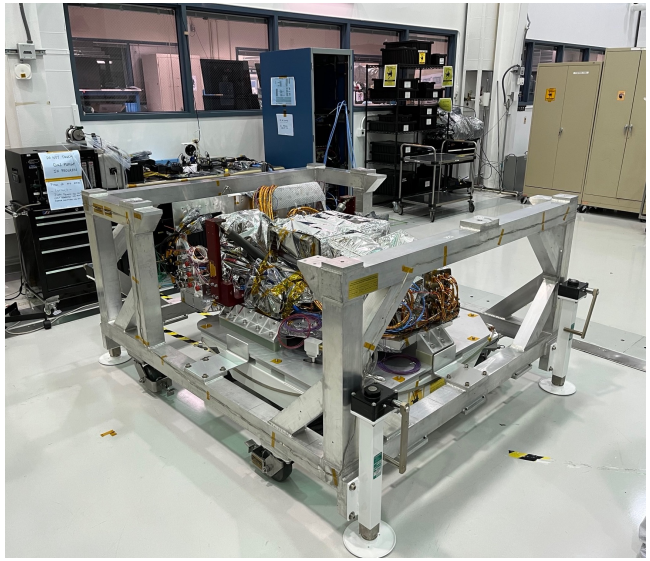


Camera installation was complicated as it required, the actual camera, it's Proximity Electronics and thermal straps. The Team used a combination of HoloLens, CAD, and fit checks to ensure smooth install. Overall Duration, with harnessing and test verification; Approximately 4 weeks.

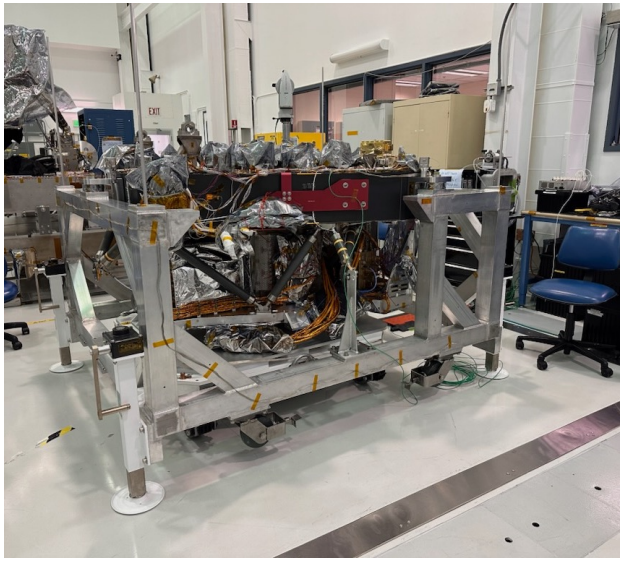
Instrument Integration was a Multi-Step Process



EHTS Lifted from Flotron to Integration Stand (Lift #1)



Offload Fixture Installed (Lift #2)



OBSA Lifted to Offload Fixture (on top of EHTS) (Lift #3)

Instrument Integration was a Multi-Step Process

4th and Final Lift of Instrument onto Assembly Platform

Challenge:

- During EHTS to OBSA integration, we lose hand access to the -X bipod attachment.
- It must be flight-installed on the EHTS prior to integration

Solution: metrology!

- Bipod was positioned/installed on EHTS using real-time metrology to be certain of its correct position

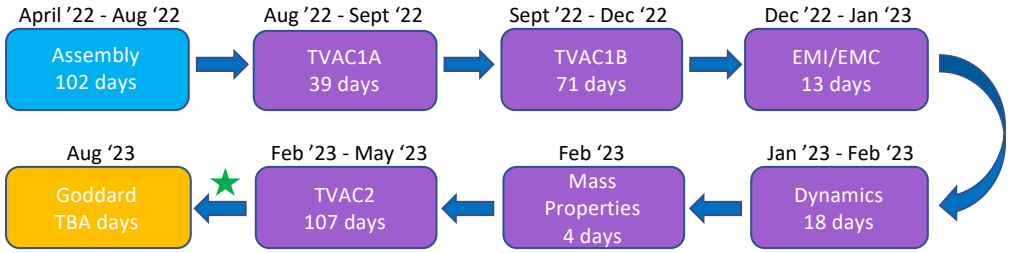
Team developed contingency plans
However, team was able to align all three bipods and meet our alignment requirements

Hololens rehearsal was helpful for this solution. Used often for checking access during the EHTS/OBSA integration

CGI Instrument-August 2023

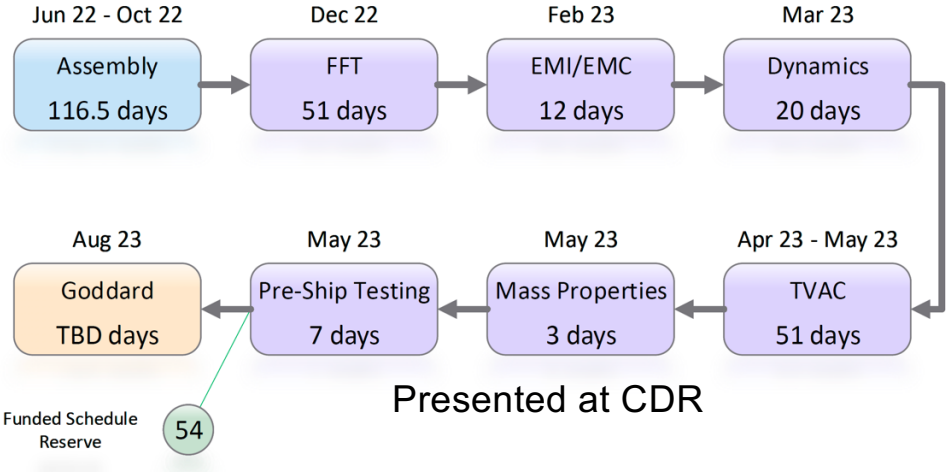
Completed Optical Bench alignment in May 2023, Electronics Pallet integration in July 2023
Optical Bench and Electronics Pallet integrated and cabled in August-Sept 2023

How we got from Start to Finish…II&T Flows



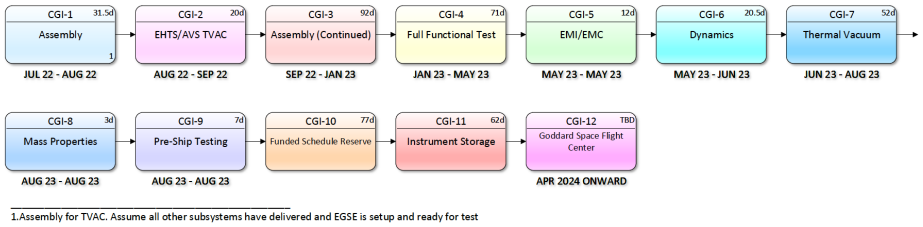
Blue = Instrument Integration, Purple = Testing Activities, Orange = Goddard (GSFC),
★ = Funded Schedule Reserve: 51 days

Presented at PDR



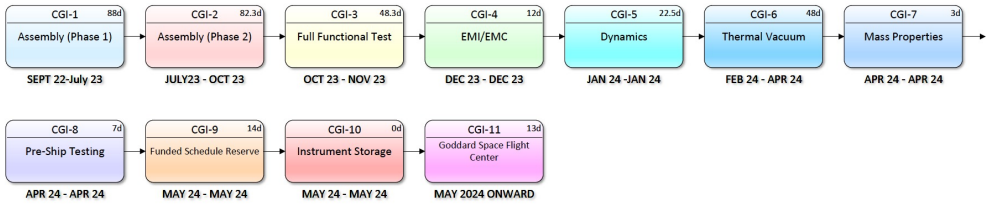
Presented at CDR

Team collaborated on innovate ideas…Changed course multiple times to change plans and shift/adjust/reduce/descope activities



1.Assembly for TVAC. Assume all other subsystems have delivered and EGSE is setup and ready for test

Presented at SIR



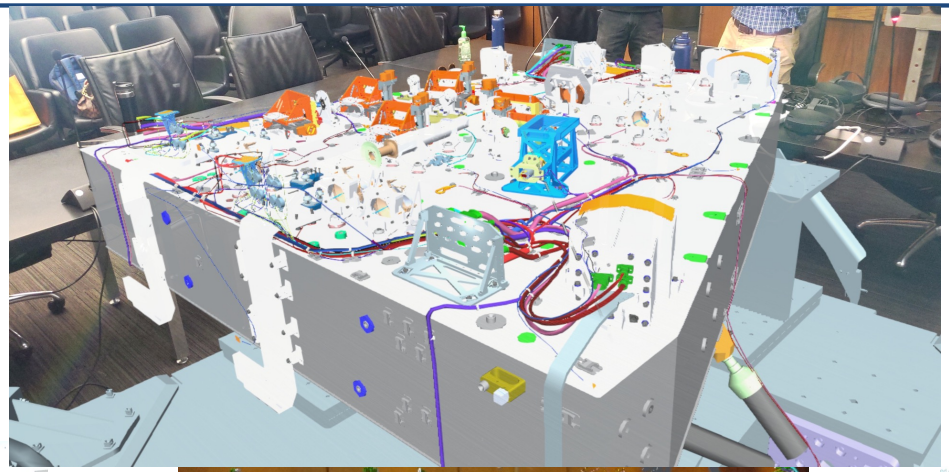
Actual Performed Plans

How we got from Start to Finish Despite Challenges

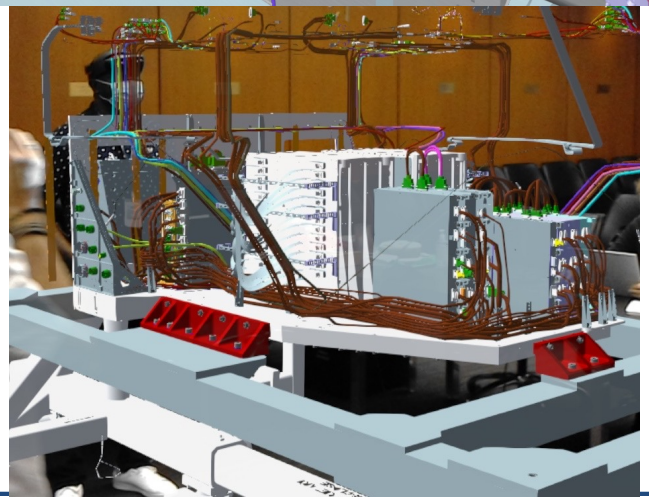
- Communication, Innovation, and TEAMWORK!
  - From post PDR through SIR faced challenges
  - COVID era: Regular meetings were essential with key stakeholders to ensure plans stayed accurate and on track
  - Descopes post PDR to Class D which led to test descopes and II&T scope changes
  - Daily II&T Meetings during II&T were crucial to talk through the schedule and shift plans to accommodate late deliveries
    - Avionics late deliveries (DME resistor change)
- Worked through reordering activities daily
  - Went from Full EHTS/AVS TVAC to bakeout of partial avionics pallet
  - Preparation of MGSE and EGSE
  - Early functional testing of software (“side-by-side” option)
  - DM and Camera Installation moved to post OBSA DEL to II&T.
    - DM realignment and optical testing/adjustments throughout II&T
- We heavily leaned on the use of Hololens to ensure we understood the nuances of our integration and test activities. This eased the integration process of EHTS and OBSA drastically.
- Harness Mockup became an asset and team went back to it regularly and even just before DM Flex Cable integration post Instrument Integration.
- Reshuffle project master schedule in collaboration with SE, QA, MA
  - Rewrite task flow and Daily Calendar as needed

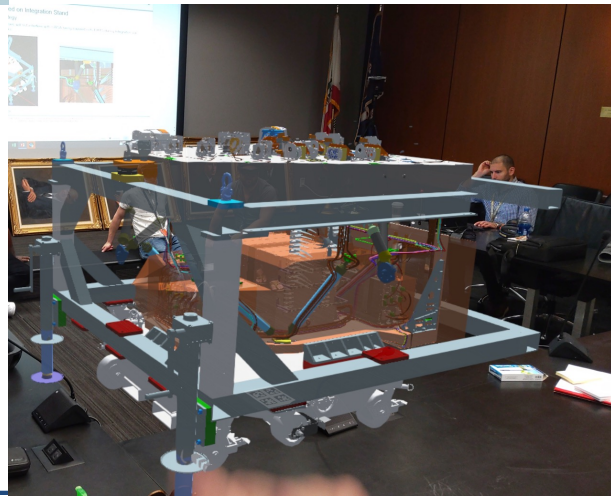
Hololens Activity Snapshots

Extremely useful years prior to II&T and during. Aided in planning for not only mechanical activities, but testing, such as Dynamics (ensuring access to Accel locations)



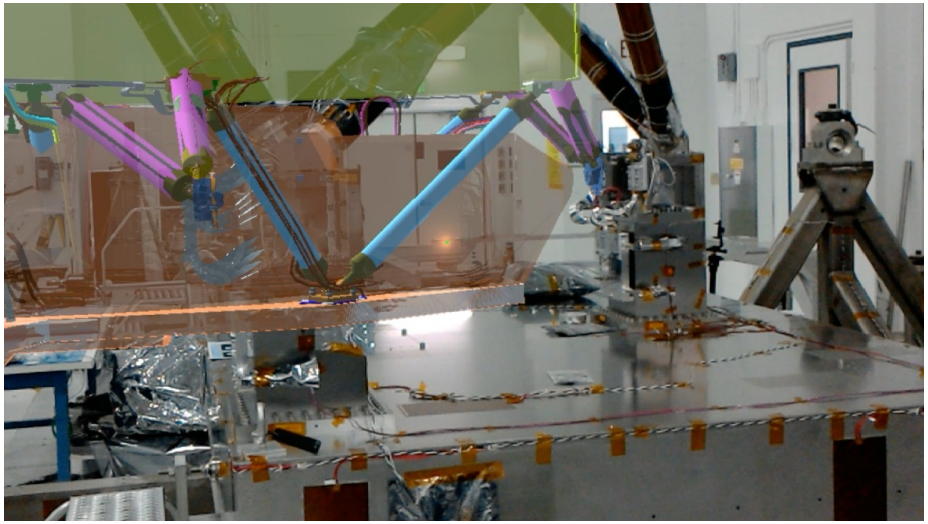
Also helped in planning for Camera Installation and what type of GSE would be best to design for safe and optimal integration





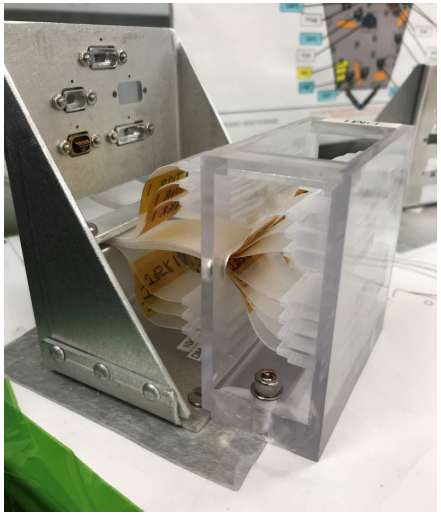
Hololens Activity Snapshots

Hololens was also used when planning for Full Functional and TVAC testing so the team could envision of size and scope of the configuration and determine if there were additional pieces of HW or GSE needed

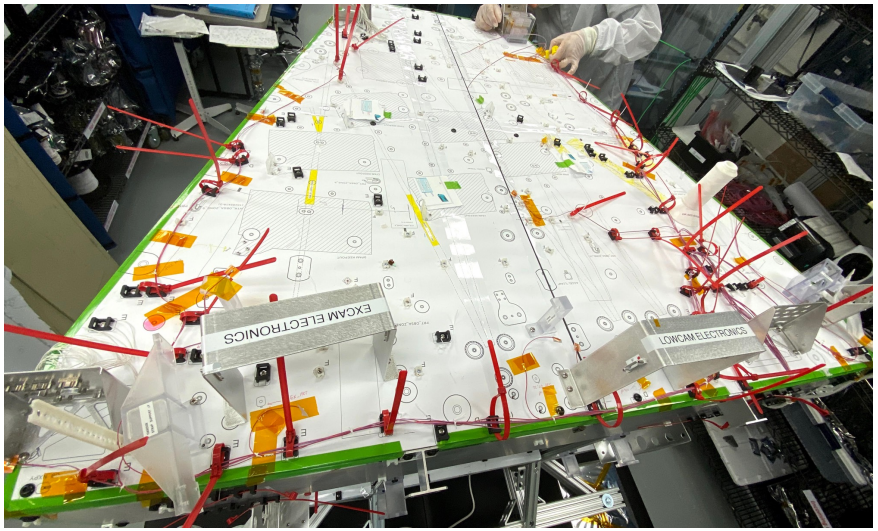


Harnessing and Use of Mockup

- Harness Mockup
- Used not only for fit checking, but for harness and thermal HW routing
- Learned through this process that needed a bracket or alternate way or routing



DM flex print mockup

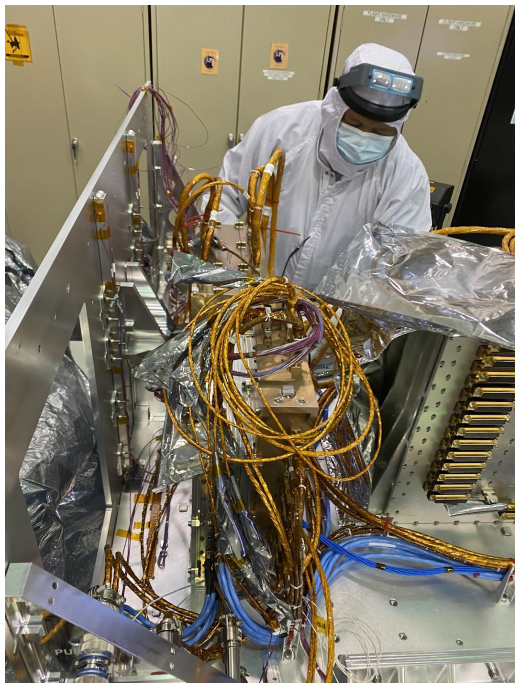


Test Fit/Routing of Heaters

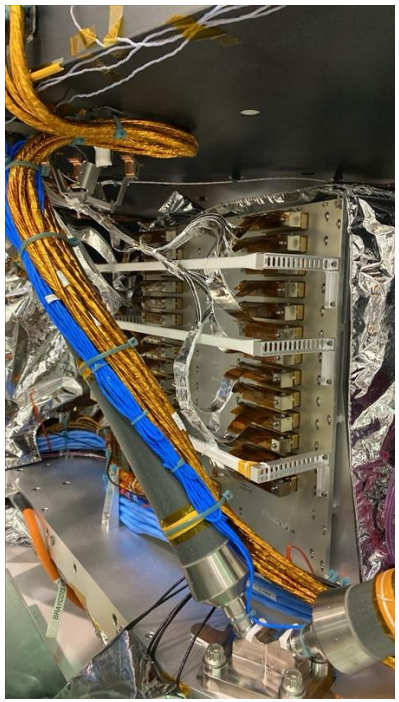
Instrument Mockup

Harnessing between Instrument and EHTS

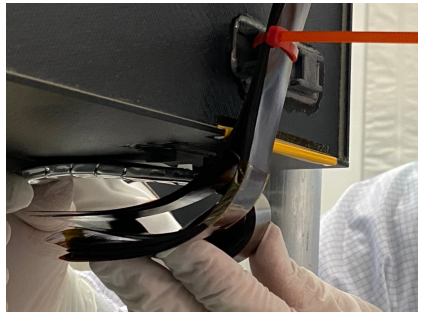
- Complex process to integrate EHTS and OBSA harnessing
  - Required use of mockup and pre-routing whenever possible
  - Overall, final instrument harnessing took about two weeks to complete

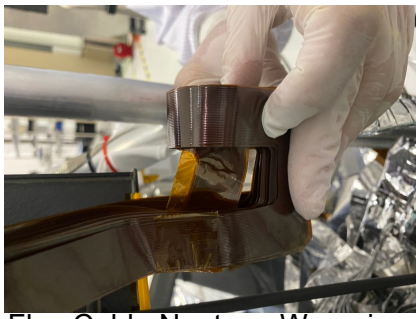


EHTS harness bundles prior to integration



DME Flex Cable harnessing from DM

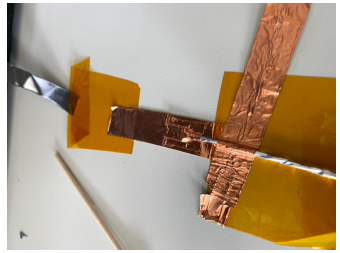




Flex Cable Neptape Wrapping

Methods Used:

- Team used innovative approach of wrapping the cables with Neptape for contamination and shielding
- Harness team spliced all the thermal HW at fabrication prior to arrival at II&T. (picture below)
  - Not conventional, but overall benefit for II&T(schedule) and minimized contamination during install

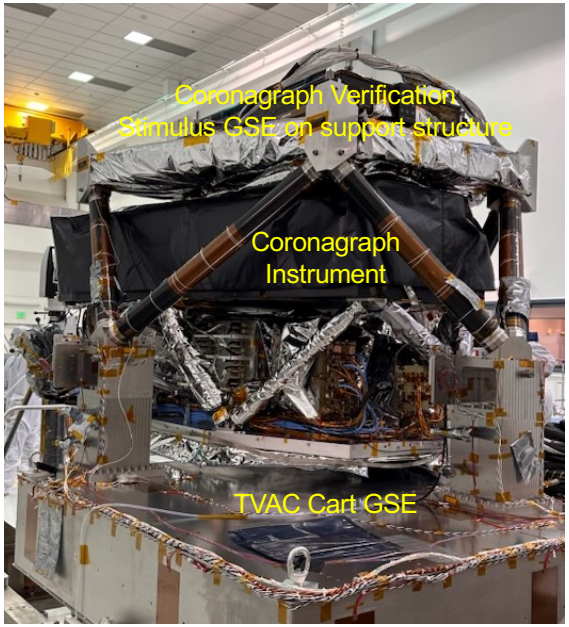


Wrapping of each PRT with copper wire after splicing

Full Functional Test (FFT): Oct-Nov 2023

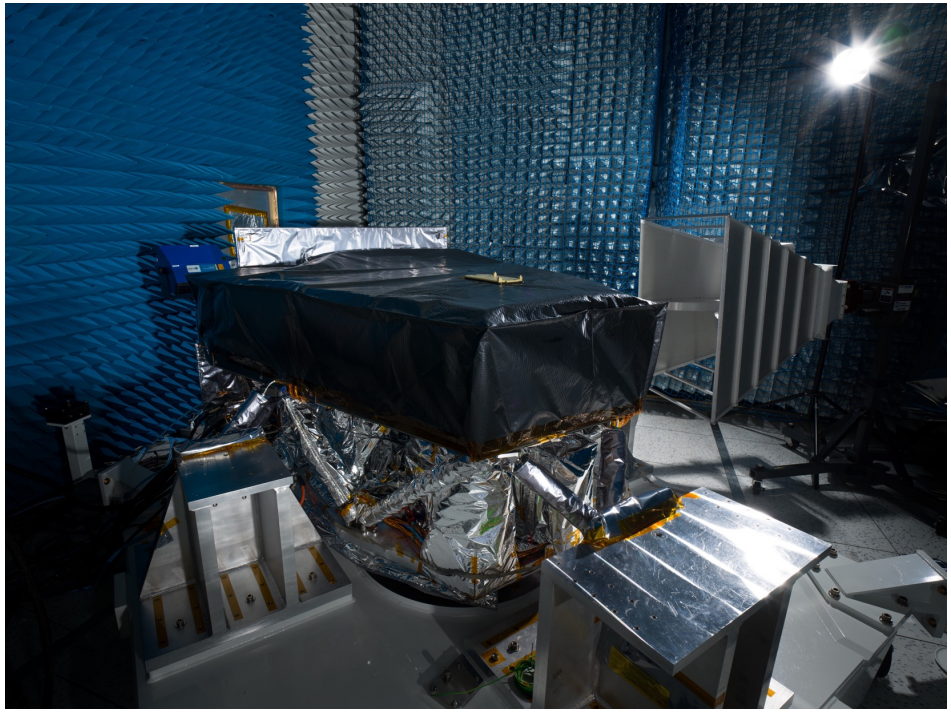
- First Coronagraph system-level test with flight hardware and software + flight-like optical stimulus
  - Coronagraph Instrument **in-air**, room temp cameras
  - Optical interface with Star and Telescope Simulator GSE (a.k.a. Coronagraph Verification Stimulus or CVS)
  - Power and data interface with Spacecraft Interface Simulator GSE

- Methods used during Planning and Prep
  - Utilized testbed for all dry runs of PBATs
  - Dry runs of GSE beforehand
  - Biggest lesson learned in FFT was to ensure a thorough walkthrough with all subsystem leads prior to final configuration declaration.
    - Reason: thermal wire in the beam path found during FFT.
      - Simple solution, but commotion and PFR could have been avoided
      - Also learned that we can determine where a problem blockage is located, by LOS parallax
  - Found several hardware, flight software, ground software issues related to system-level emerging behaviors
    - The objectives of the tests were met, and team learned a lot performing this test
    - Some issues fixed during FFT, others the team was to fix after the test once the



Full Functional Test met its objectives

EMI/EMC Test: Dec 2023



- Electromagnetic Interference (EMI) / Electromagnetic Compatibility (EMC) testing at JPL's anechoic chamber to Roman requirements
  - Radiated Emissions and Susceptibility
  - Conducted Emissions and Susceptibility
- No optical stimulus
  - Camera noise was the most sensitive susceptibility gauge
  - Electromagnetic self-compatibility verified in TVAC
- Methods used during planning and prep
  - EMI/EMC testing at lower level helped identify areas of focus for test
  - Dry run of test configuration and GSE to the chamber helped avoid issues when moving flight HW in
  - Maintaining purge was a critical factor so worked with Purge techs months in advance to ensure able to maintain purge on DMs throughout this test
  - Challenges faced:
    - Physical space of personnel in test area, limited number of team members.
    - Cooling the space with the portable A/C was quite a feat and proved to be critical in the success of the test. Limited durations of test as camera temps required close monitoring

Coronagraph Instrument successfully completed EMI / EMC testing

Dynamics Tests: Modal, Sine Vibe, Random Vibe – Jan 2024

- Performed at JPL's Environmental Test Lab (ETL)

- Modal Test:
  - Verified >35 Hz first mode frequency
  - Characterized instrument modes up to 100 Hz
  - Produced model correlation report

- Completed vibration tests in X/Y/Z orientations
  - Sine Vibe: 5-50 Hz
  - Random Vibe: 20-2000 Hz
  - Measured Optical Alignment before and after vibe with alignment scope; changes deemed acceptable

- Methods used and Challenges faced
  - Dry run performed Sept 2023
    - Good practice for team (i.e., lifts, GSE handling)
  - Challenges faced:
    - New SW used during Vibe (learning curve)
    - Full instrument dry run better option for one-to-one comparison to run for the record

Coronagraph Instrument successfully completed modal and vibe tests

Thermal Vacuum (TVAC) Test: Feb-Apr 2024

Thermal Verification and Validation (V&V):

- Hot Operational, Cold Operational, and Survival thermal balance
- Transient heater characterization test
- Thermal stability tests
- Collected data for thermal model correlation

- Dry run and bakeout were crucial
  - Fit check, clearances
  - Maneuvering challenges

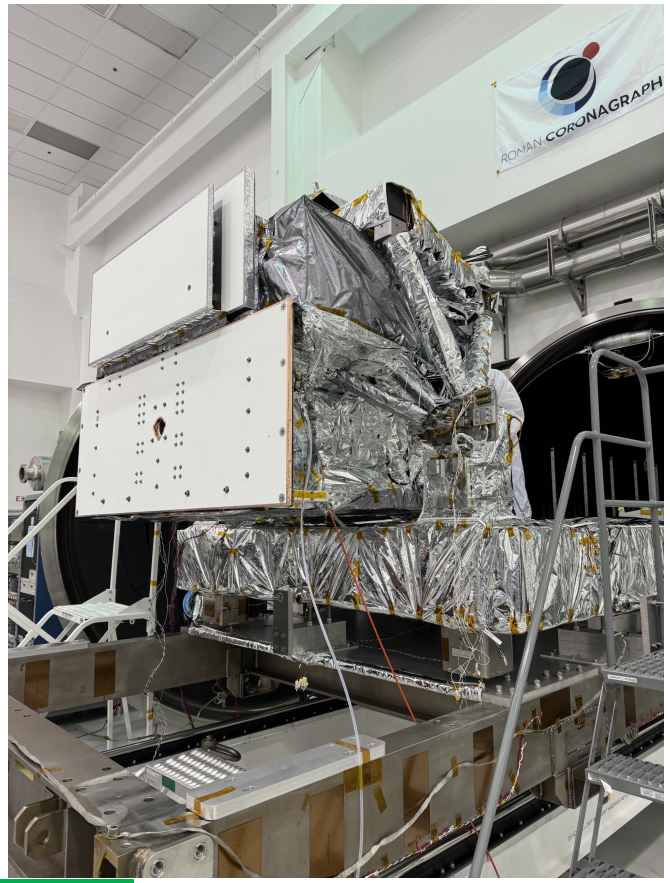
Challenges:

- MLI needed for sufficient thermal control was more than anticipated.
  Blanketing team to the rescue!
- Protecting light source optical fiber from low T in TVAC operations
  Last minute fix worked well

Thermal V&V (cont'd):

Challenges (cont'd):

- Daily challenges to test sequence based on fresh test results.
  Number and complexity of performance and functional requirements required PSE/II&T adjustments to test plans up to 3 times a day
- Prepared fallback options for vacuum ion gauges because of stray light.
  One of those was successful, and we also learned the stray light was tolerable
- New stray light path identified during test
  Team developed special tests to confirm hypothesis and mitigation.
  Post TVAC, II&T team implemented the change and results were successful



Coronagraph Instrument successfully completed TVAC

Pre/Post Ship Testing

- Optical Alignment testing plan developed by Optomechanical team utilizing optical fiducials existing on instrument that translated to what is used during payload integration.
- This led to a strong story at delivery since this test was developed prior to delivery and performed a few times before delivery.
- Also maintained same configuration for Pre and Post (IC-SIM to maintain consistency in results)
    - Prior to Dynamics
    - Post Dynamics
    - Pre-Ship
    - Post-Ship (GSFC)

Summary

- Flexible and Resilient Team that worked together for creative solutions when met with schedule and budget challenges
- Leaned in on technology to mitigate anticipated issues and worked through them in advance
- Utilized new approaches for integration (Neptape, Splicing HW Pre-II&T)
- Worked harmoniously throughout campaign
- Looked ahead for any ways to maximize integration and test plans
- Daily and open communication with the team as crucial to success

Teamwork Makes the Dream WORK!

GO TEAM!!!

Back-up charts