Developing Controlled Conductive Boundaries for JWST Cryogenic Testing

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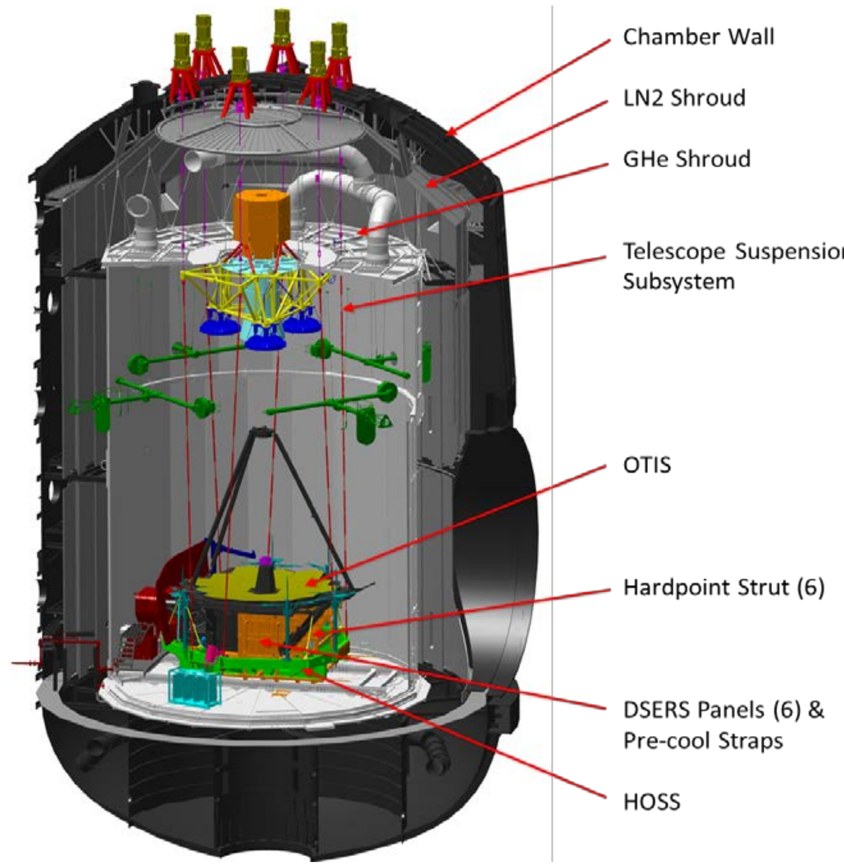
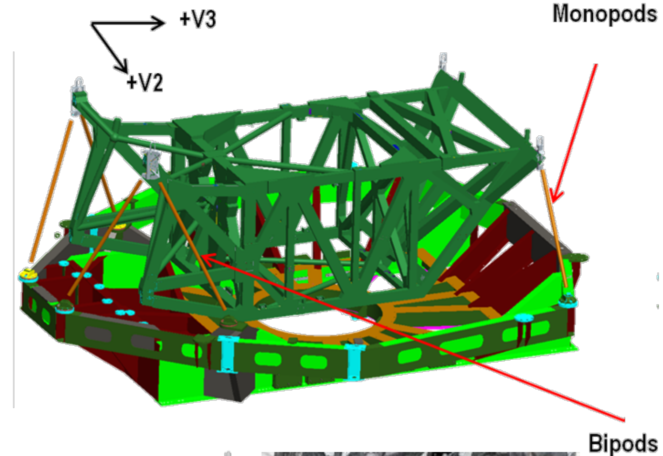
OTIS Test Configuration and Overview

- **The James Webb Space Telescope (JWST) completed cryogenic testing in the fall of 2017**
  - Final thermal test of Optical Telescope Element + Integrated Science Instruments Module (OTIS)
- **Thermal objectives for OTIS test:**
  - Verify system thermal workmanship
  - Validate thermal model with test data
  - Verify instrument heat loads within 10% of model predictions
- **Harris Thermal Role**
  - Thermal control of ground support equipment (GSE) boundary conditions
  - Keep OTIS heat loads and temperatures flight-like
  - Accelerate test schedule while obeying all limitations and constraints



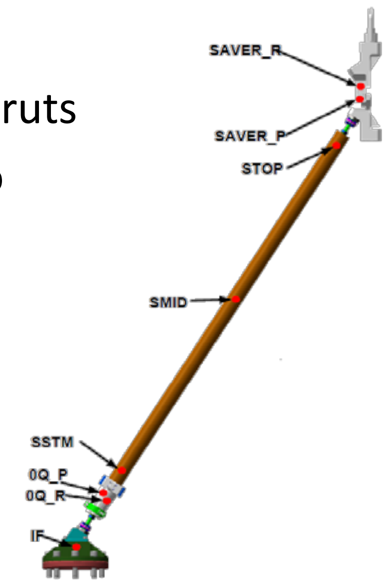
Hardpoint struts

- **6 carbon fiber composite struts with MP35N flexures**
  - Supports OTIS for the 1-G environment
    - Deviates from the flight condition
  - Bipod arrangement on –V3 end, Monopod at +V3
  - 25-layer MLI blankets on outside keep radiative effects low



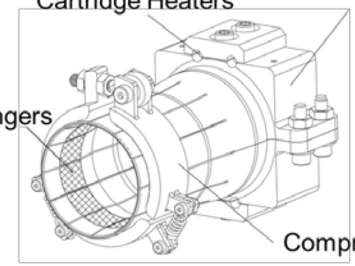
- **Heat leakage requirements**
  - 2 mW on monopod struts, 6 mW on bipod struts
  - More heat is acceptable at the bipods due to the warm Core Area on –V3 end of OTIS

Even with low conduction and insulated struts, active thermal control was required to meet heat leakage requirements



Hardpoint strut 0-Q heaters

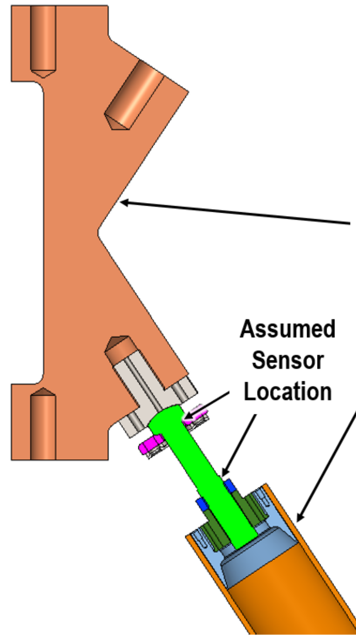
- **6 heaters were designed to mount at base of each strut**
  - Al-6063 heater block
  - Flexible fingers and compression ring maintain clamping loads at struts
    - As the aluminum shrinks, contact pressure is preserved



- **Calculating heat flow**
  - The difference in temperature across the flexure at the top of the strut is used

$$Q = \frac{kA}{L}(T_{Saver} - T_{STOP})$$

  - Discrete heat path
  - Small area limits errors from radiation
  - Conservatism in calculation based on actual sensor locations

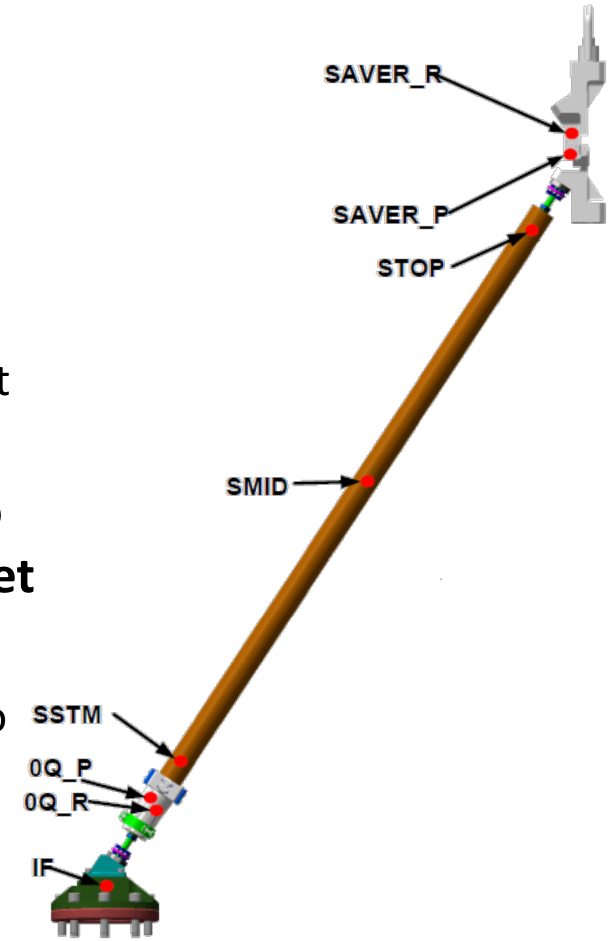


Heater Operation

- **A semi-automated routine was configured in the test set for changing setpoints during cooldown**
- **The 0-Q heater applies heat such that the temperature at**

  STOP = SAVER_P

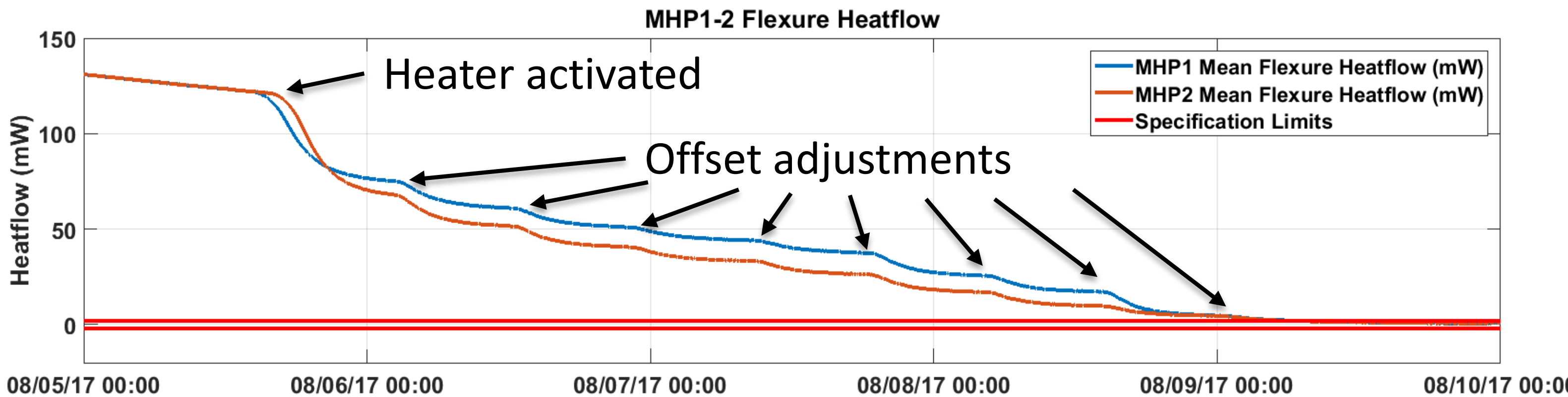
  – With zero gradient across the flexure, there is no heat transfer
- **The test set enabled the setpoint of the heater to be the current temperature of SAVER_P + an offset**
  – Heater setpoint gets updated every 2 minutes
  – User supplied offset modified to trim the heat flow to zero

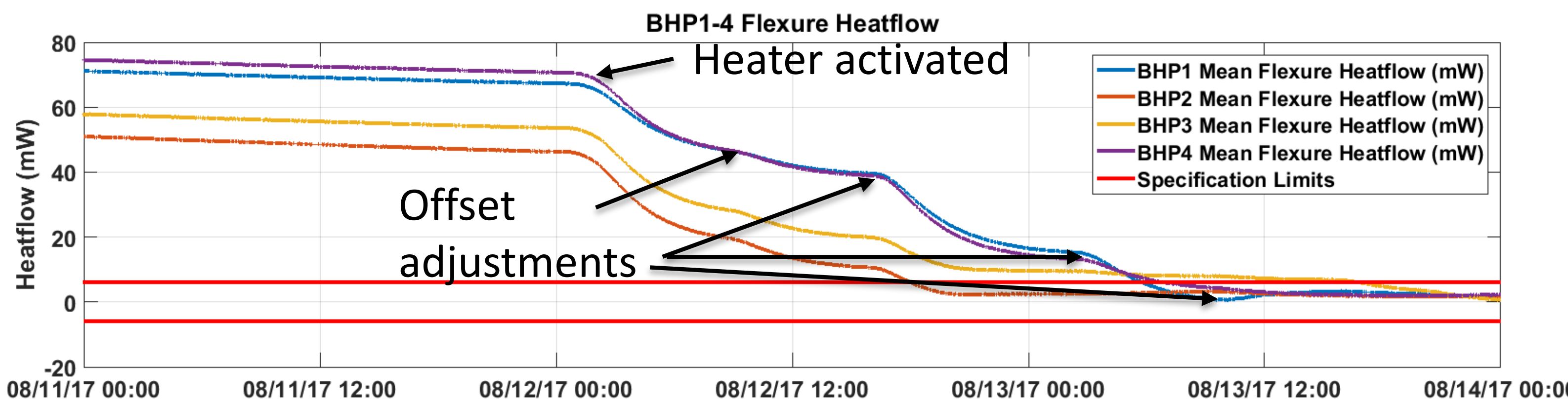


The updating setpoint was able to track the cooldown of OTIS while keeping heat leakage small

Hardpoint Strut

- Monopod 0-Q heaters activated 8/5 when saver plate reached 65K
- Bipod 0-Q heaters activated 8/12 after thermal distortion testing

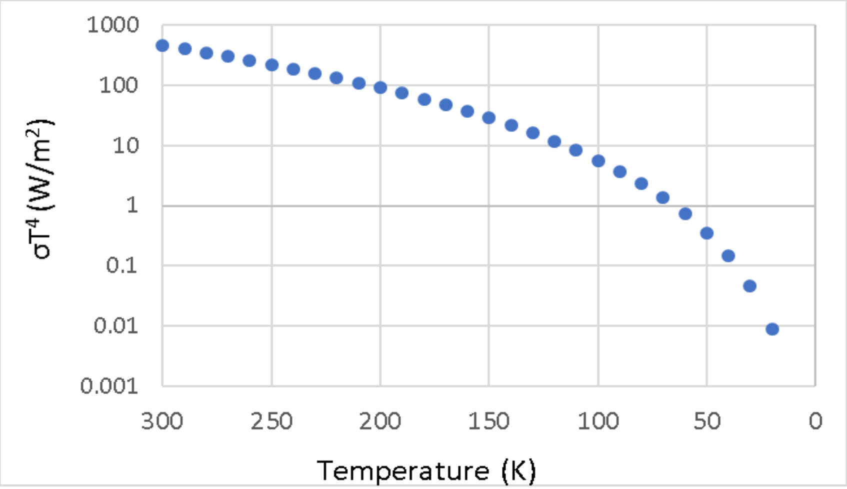


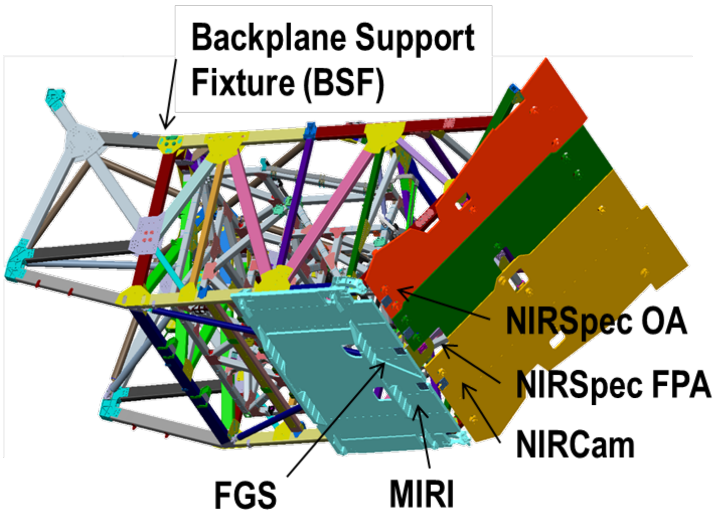


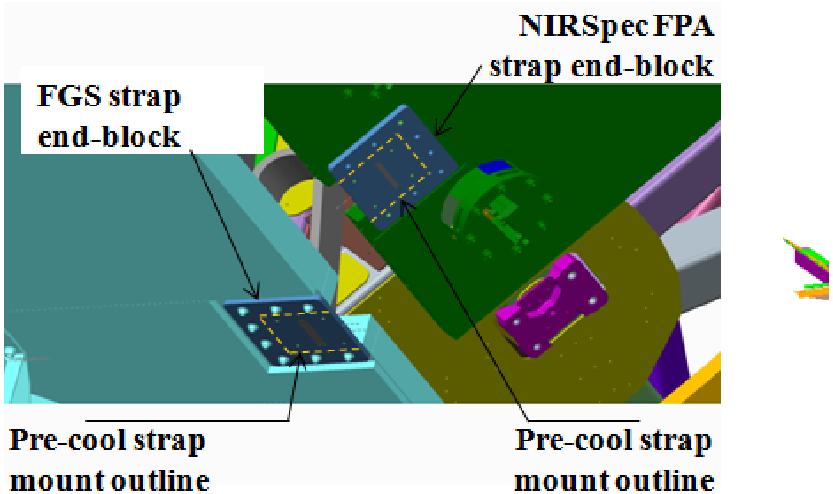
Pre-cool Straps

- **Critical functions**
  - Accelerate cooldown for science instruments with a link to a cold sink
    - Below 100K, radiation drops off
  - Stop conduction or “0-Q” the straps once at operating temp
- **5 Locations**
  - Mount to heat strap end blocks at radiators

Potential heat flux vs. temperature

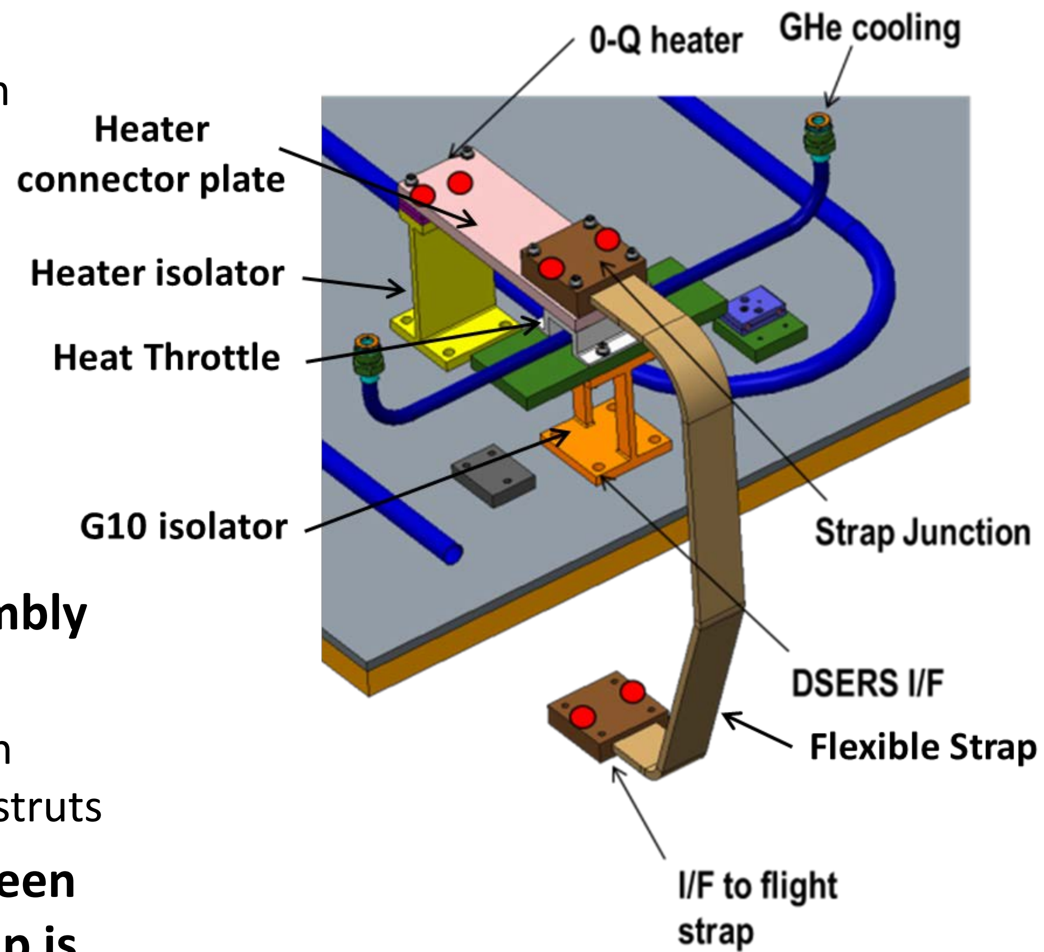




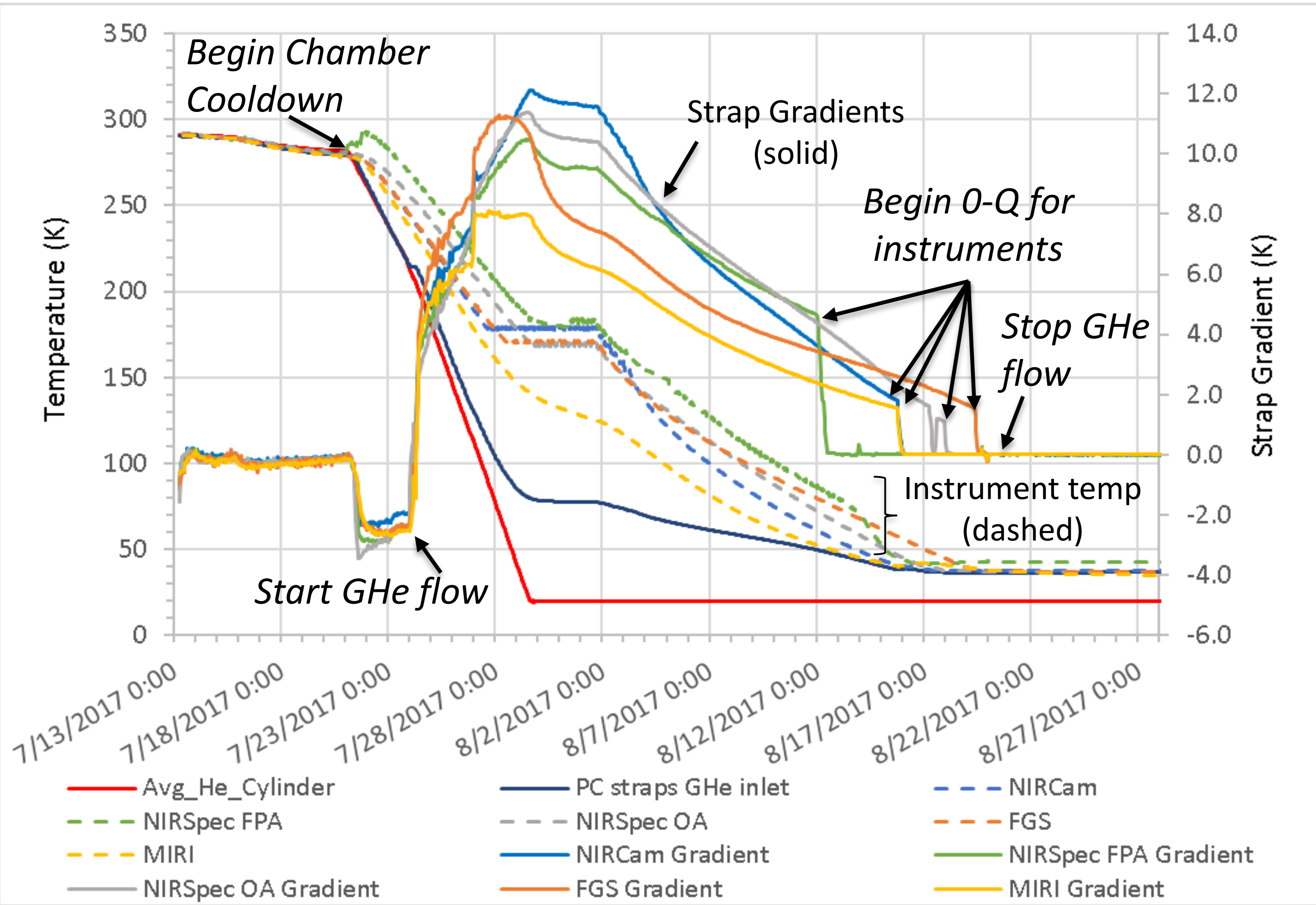


Detailed Design

- **High purity aluminum strap**
  - Accommodates relative motion from OTIS to support structure
- **GHe tube under the strap serves as a cold sink**
  - GHe flows during cooldown, shuts off for 0-Q phase
  - Conduction path optimized to throttle heat flow
- **0-Q heater located at end of assembly for precision control**
  - 0-Q heater designed to perform with automated setpoints like hardpoint struts
- **0-Q achieved when gradient between strap junction and I/F to flight strap is zero**



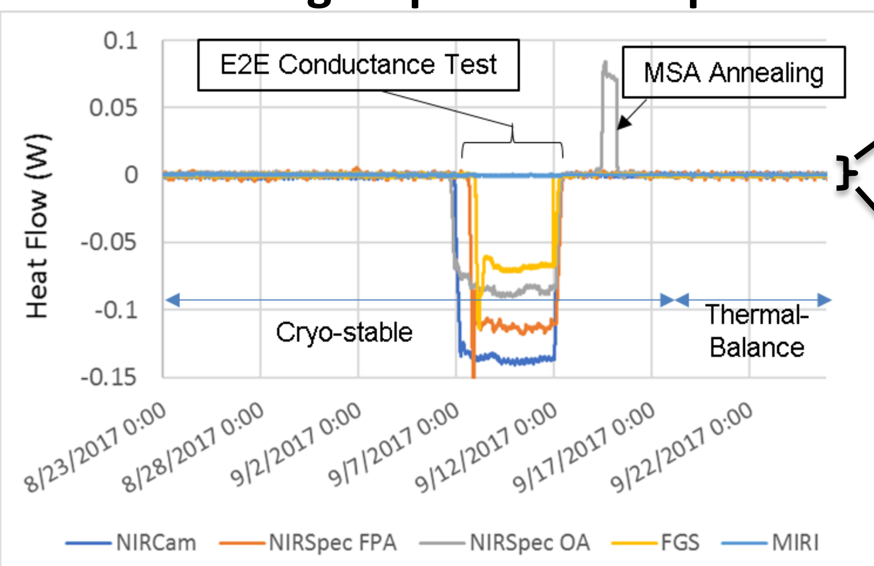
Cooldown Timeline

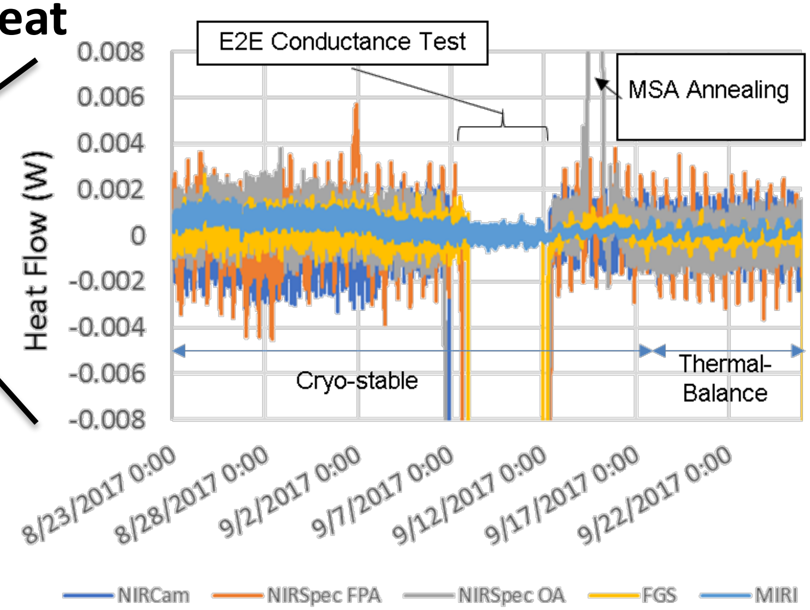


- **7/13 Chamber pumpdown**
- **7/21 Start of cooldown**
- **7/24 Start GHe flow to pre-cool straps**
- **8/11 NIRSpec FPA 0-Q started**
- **8/15 NIRCam and MIRI 0-Q started**
- **8/17 NIRSpec OA 0-Q started**
- **8/19 FGS 0-Q started**
- **8/19 GHe flow stopped to pre-cool straps**

Cryostability/Thermal Balance 0-Q

- **After the GHe flow was stopped, heater setpoint offsets were adjusted down to resolutions of 0.05K to 0.025K**
- **Heat flow variations were small, but from 9/7-9/12 was the E2E Conductance Test of the flight heat straps**
  - 0-Q heaters were used to push the strap interface up to 40K, driving heat out (negative value) of the strap
- **On 9/14 the planned microshutter annealing for NIRSpec OA took place, causing its pre-cool strap to remove heat**





0-Q Performance

- **All 5 pre-cool straps kept heat flows near 0 W**
  - Some spikes in heat flows, with largest on NIRSpec FPA
    - Corresponds with instrument system heater power/dissipation signature
    - Attempts to correct for the spikes were detrimental to the other direction of the oscillation
- **Heat leakages for 0-Q periods (excludes E2E Conduction and MSA Annealing tests) are shown in the table**
  - Negative values are heat flow out of OTIS, positive values are heat flow into OTIS
  - Heat from temperature uncertainty shows uncertainty from sensor calibration

	Average Heat Leak (mW)	Maximum Heat Leak (mW)	Minimum Heat Leak (mW)	Standard Deviation (mW)	Heat from temp. uncertainty (mW)
NIRCam	-0.39	1.95	-2.85	0.82	1.84
NIRSpec FPA	-0.08	5.70	-4.24	1.31	2.13
NIRSpec OA	0.29	2.75	-1.58	0.71	2.89
FGS	0.18	2.03	-0.84	0.45	1.68
MIRI	0.47	1.29	-0.22	0.33	3.02

Lessons Learned

- **Using engineering models and interface simulators can significantly burndown risk**
  - The Thermal Pathfinder Test before OTIS Testing helped to commission the systems and characterize responses
- **Communication between test teams and across organizations is crucial for a successful test**
  - Forewarnings can go a long way for anticipating future effects
- **Any time devoted for sensor calibrations or heater control parameters (PID) need to be scheduled into the test and planned for**
  - Calibrations or determining system settings can take time (and require specific environments)

Conclusion

- **In 2017, the hardpoint struts and pre-cool straps thermally managed OTIS interfaces in order to:**
  - Keep temperatures and heat flows flight-like
  - Accelerate test schedule
- **The hardpoint struts, the main structural offloading points to OTIS were used to manage heat flows**
  - Zeroed the gradient across flexure interface to < 6 mW for bipods and < 2 mW for monopods
- **The pre-cool straps interfaced to the end blocks of the flight heat straps and successfully**
  - Removed heat from the instruments when radiative heat transfer diminishes for cooldown
  - During the critical thermal balance period, heat flows were minimized to a few mW of heat leakage

Acknowledgments

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