Thermal Considerations for Reducing the Cooldown and Warmup Duration of the James Webb Space Telescope OTIS Cryo-Vacuum Test

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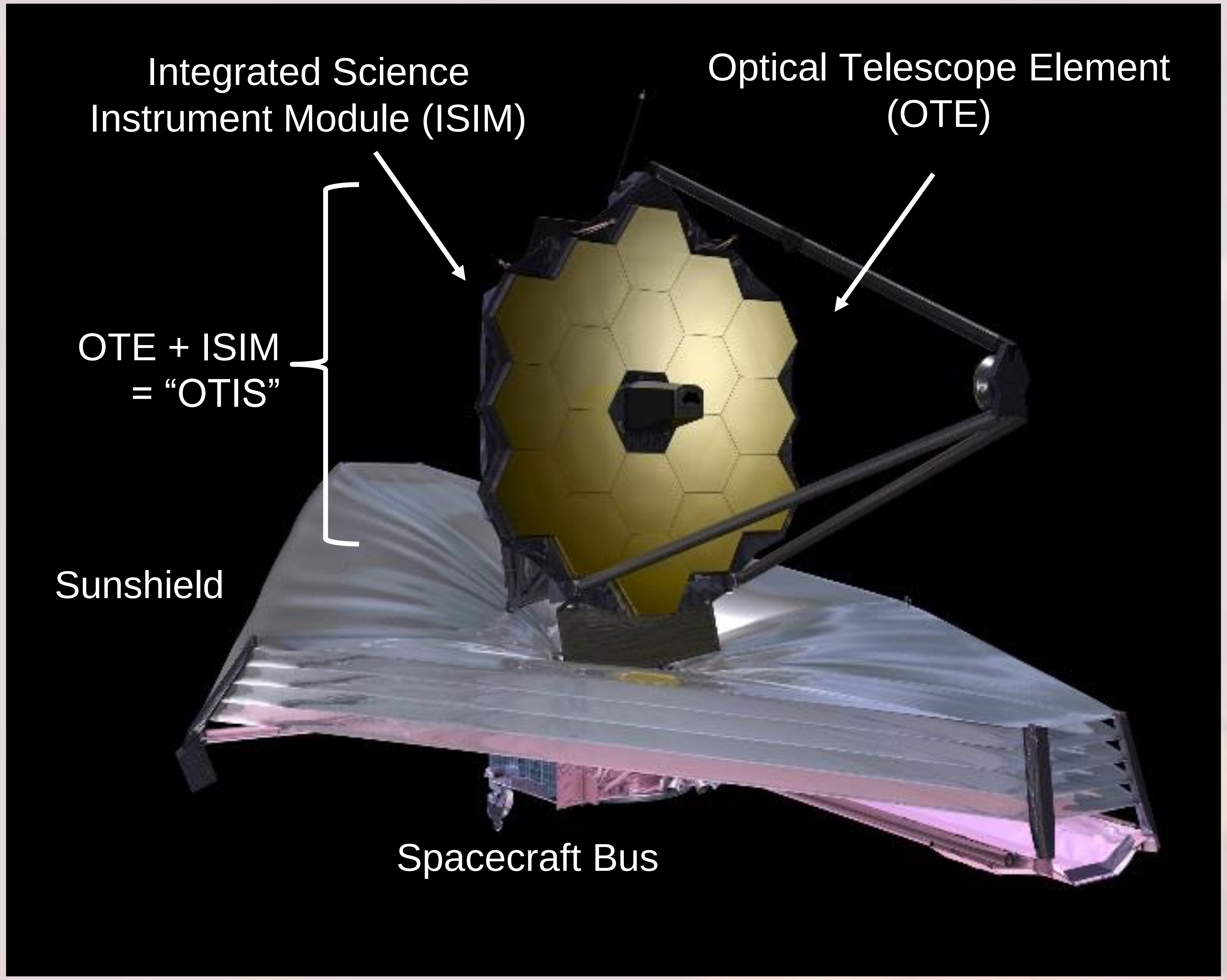
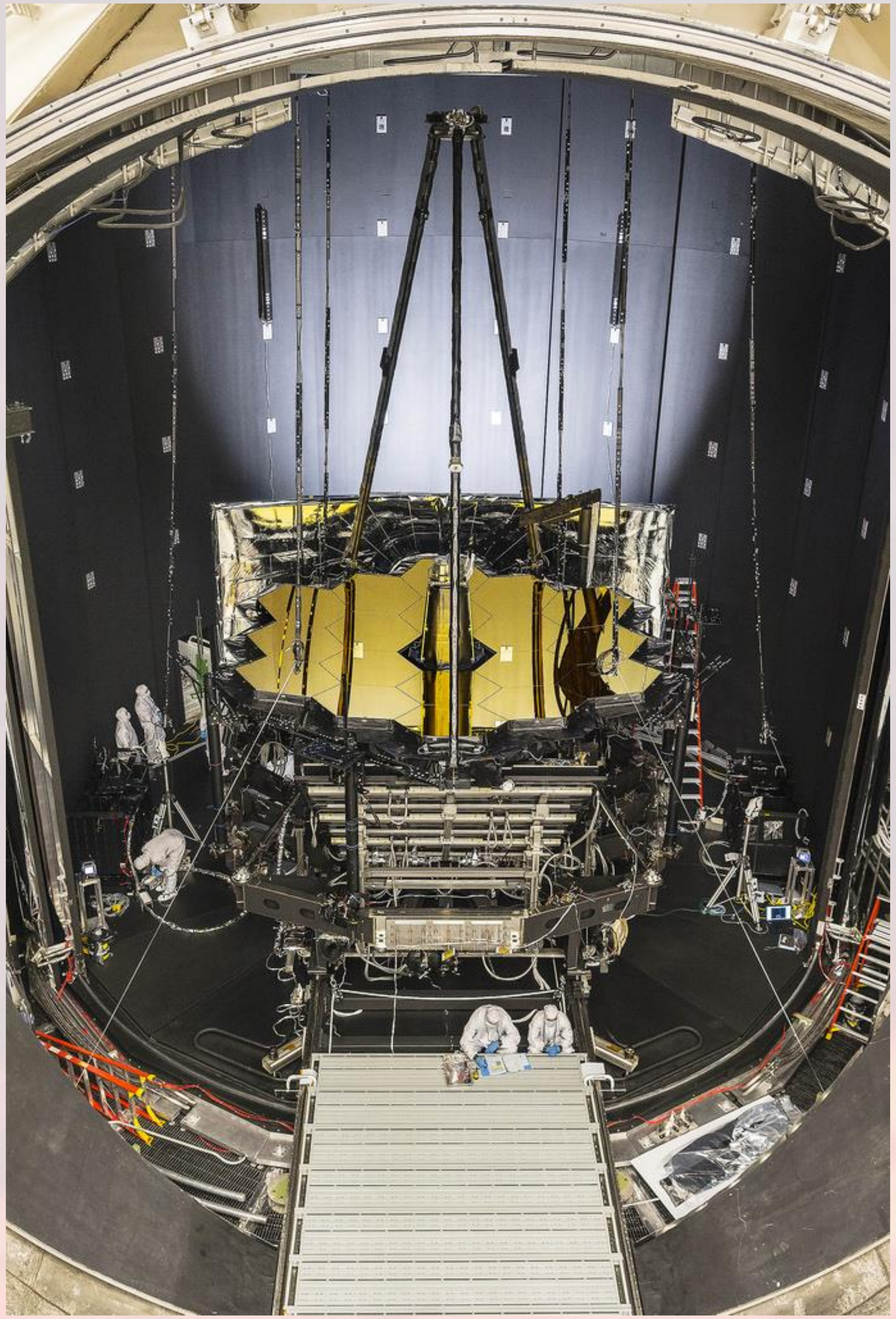
Introduction to JWST



- James Webb Space Telescope (JWST) is NASA's next-generation space telescope
  - Collaboration between NASA, ESA, European Consortium, CSA, and partners in industry and academia
- With four near-to-mid IR instruments, JWST will provide scientists with unprecedented resolution to study:
  - First light and reionization
  - Assembly of galaxies
  - Birth of stars and protoplanetary systems
  - Exoplanets and origins of life

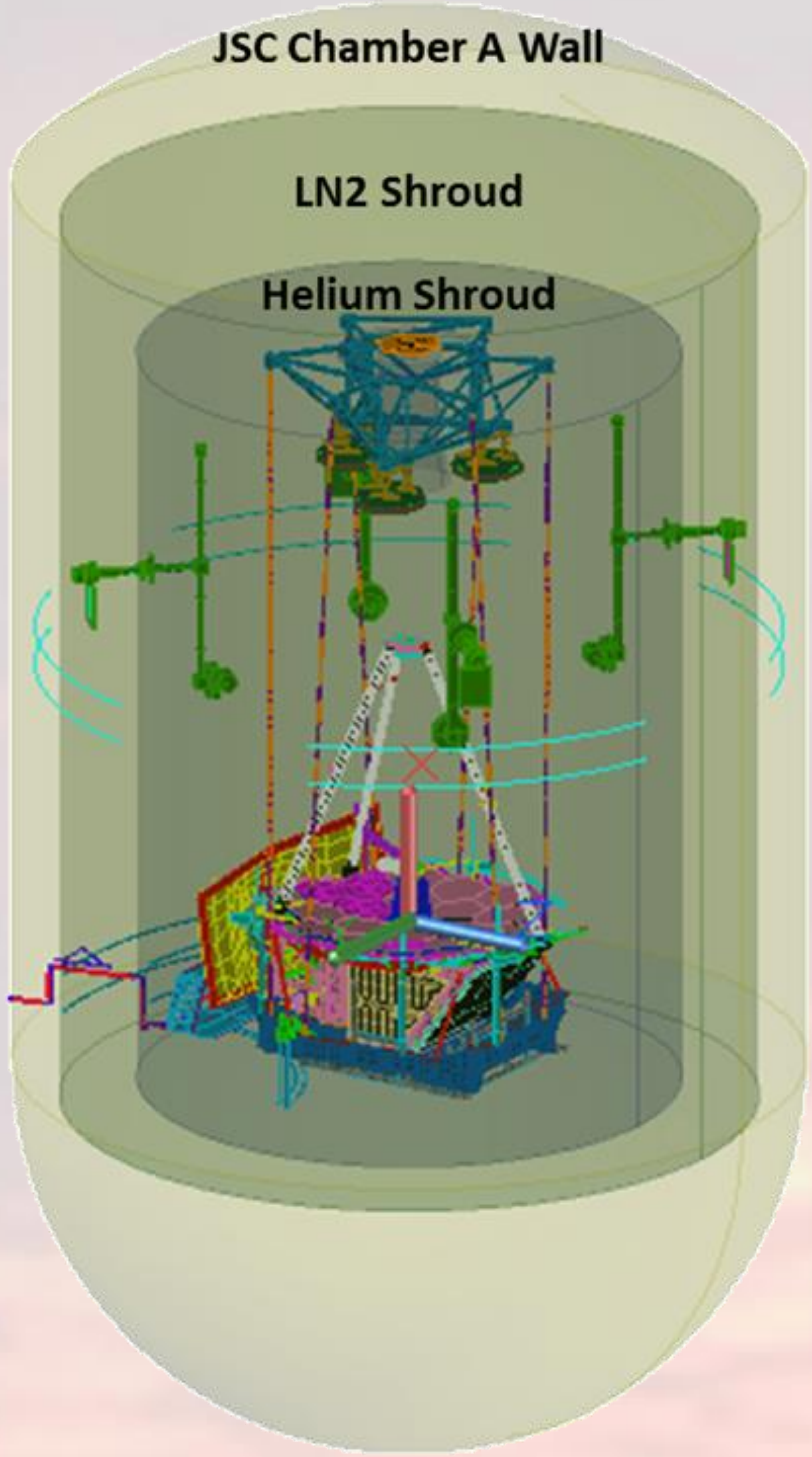
Introduction to the OTIS CV Test

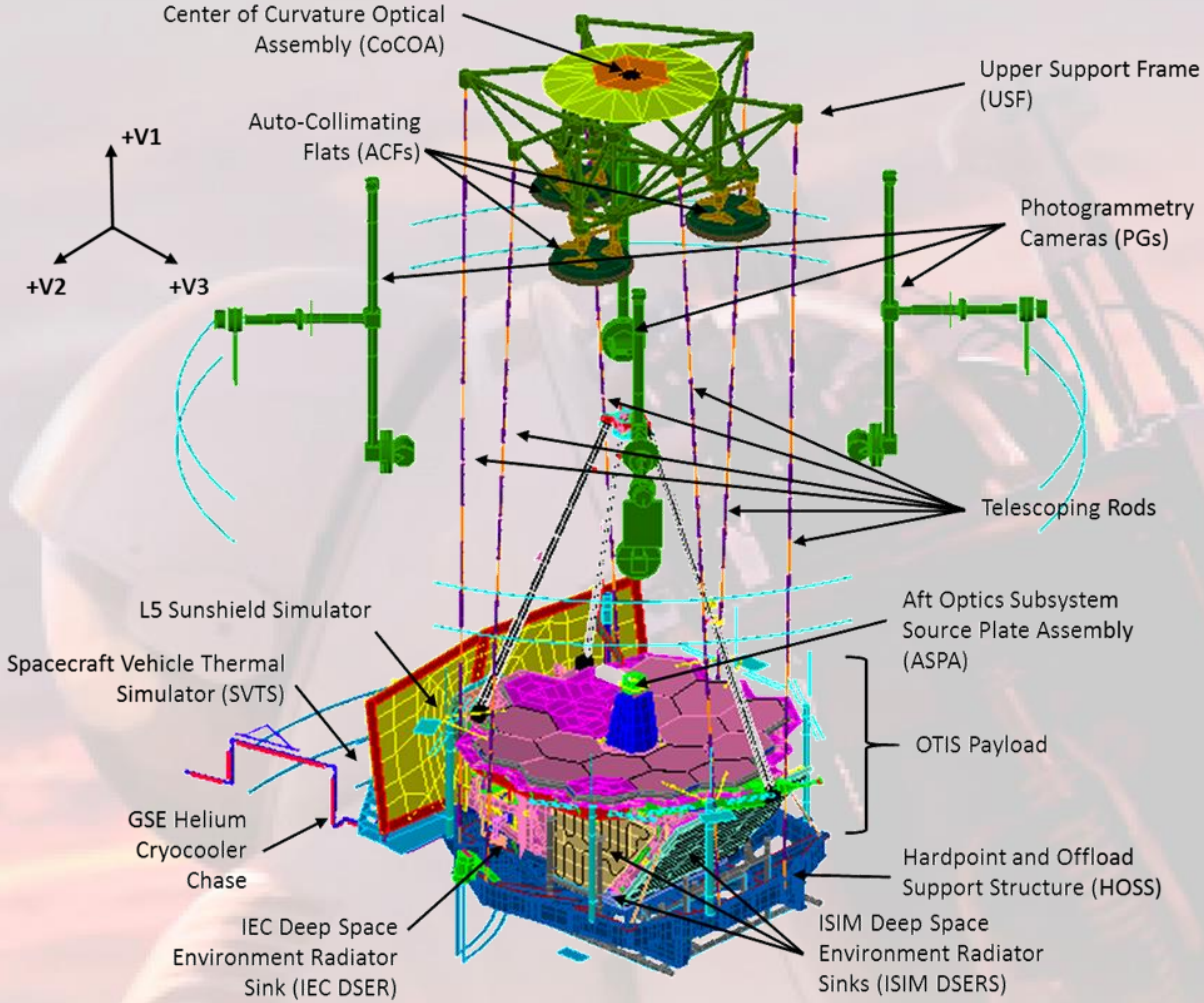


OTIS Payload at Chamber A, NASA JSC

- The Optical Telescope Element and Integrated Science Instrument Module (OTIS) Cryo-Vacuum (CV) Test is a critical part of the environmental test campaign for JWST
  - Due to the size of JWST, the entire observatory cannot be thermally balanced or optically tested in existing facilities
  - Two large subsystem-level thermal vacuum tests are planned (OTIS and Spacecraft Bus/Sunshield) for optical and cryo-vacuum verification
- The thermal control objectives of the OTIS CV test are to:
  - Achieve simulated on-orbit payload temperatures for optical, mechanical, and instrument tests
  - Predict and measure thermal balance data for model crosscheck
  - Preserve hardware integrity in temperature transitions i.e. meet all limits and constraints (L&Cs)
  - Assess thermal conductance of flight instrument heat straps
  - Achieve timeline optimization on payload cooldown and warmup

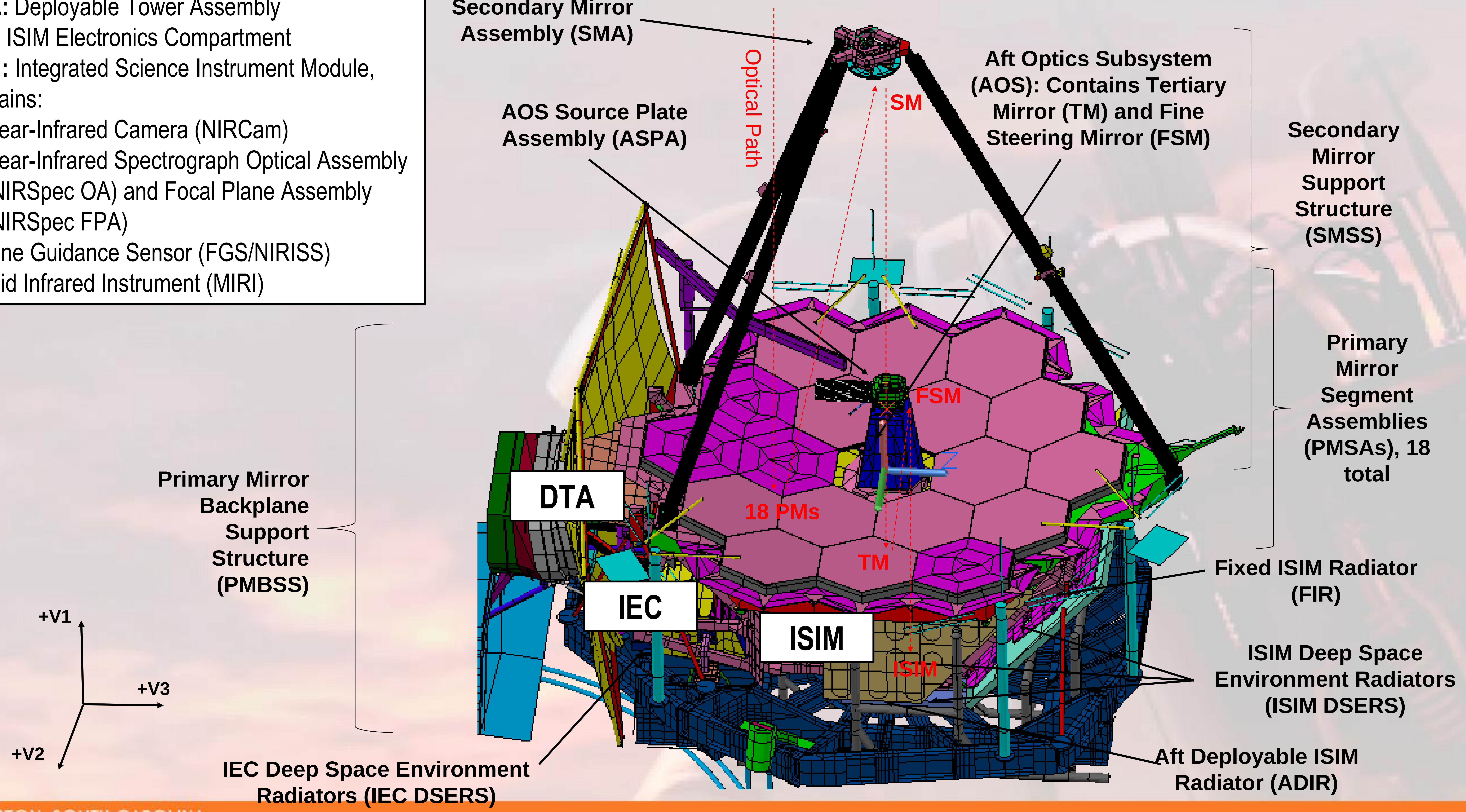
OTIS Test Configuration



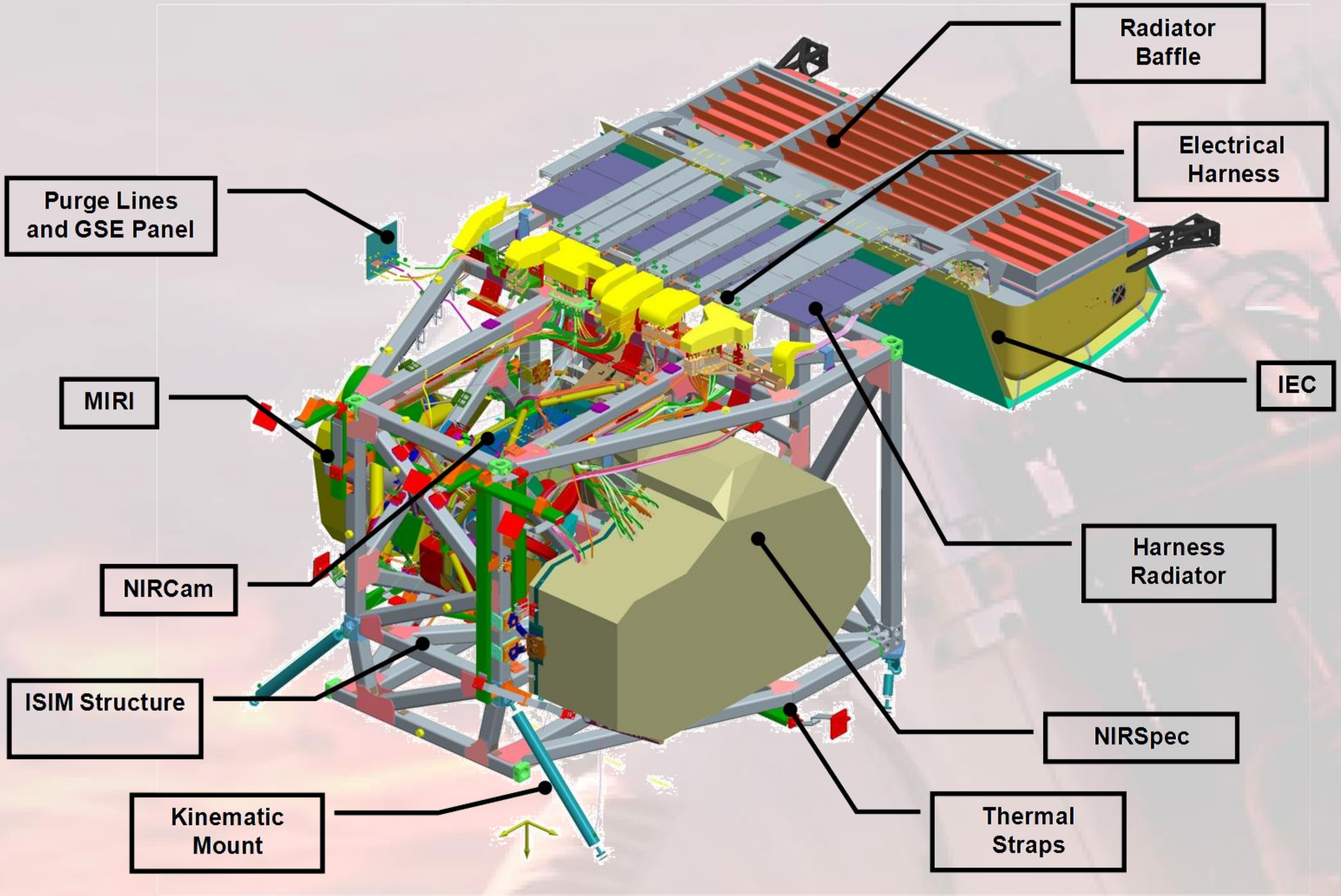


OTIS CV Critical Components: OTE

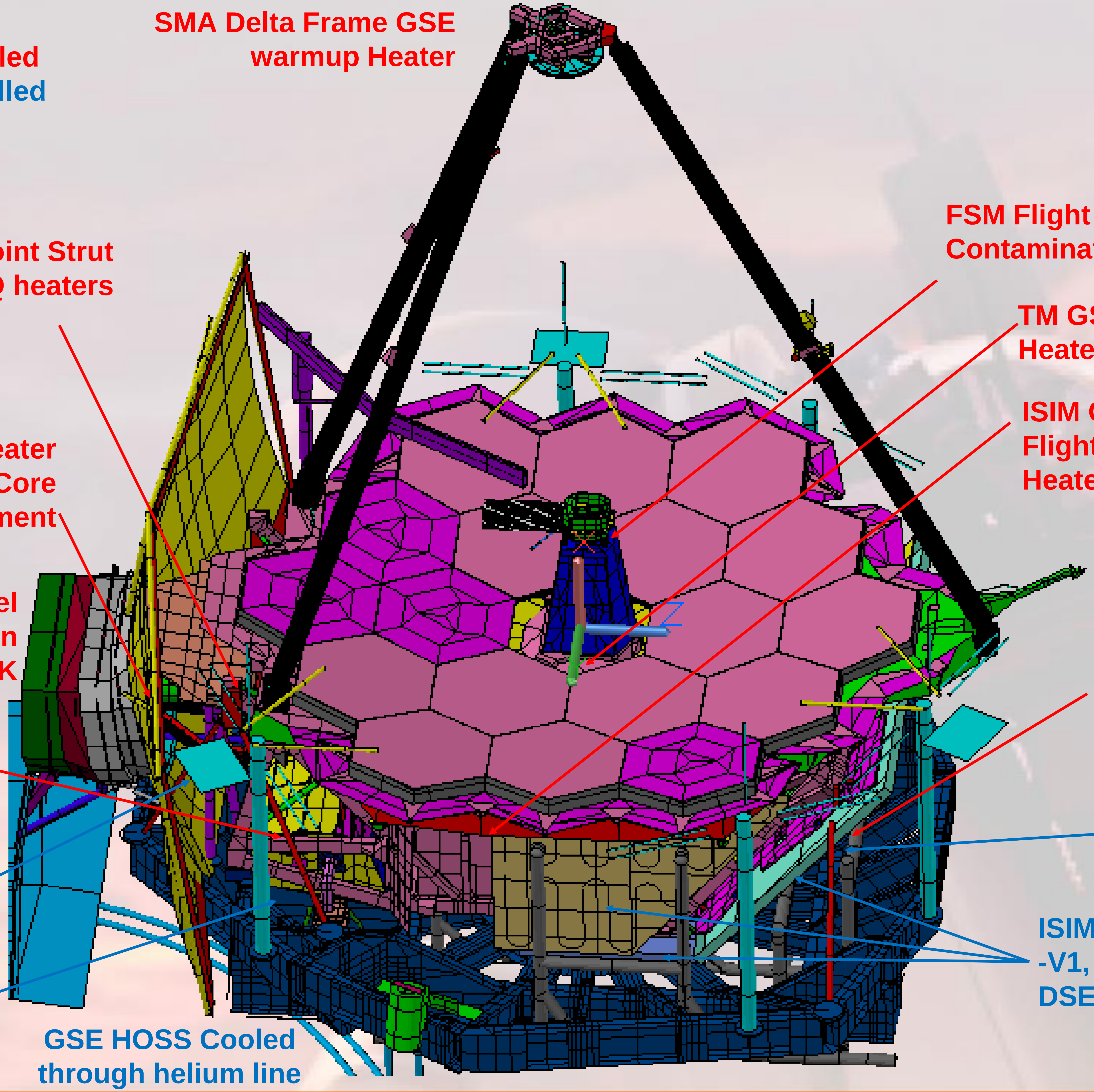
DTA: Deployable Tower Assembly
IEC: ISIM Electronics Compartment
ISIM: Integrated Science Instrument Module, contains:
- Near-Infrared Camera (NIRCam)
- Near-Infrared Spectrograph Optical Assembly (NIRSpec OA) and Focal Plane Assembly (NIRSpec FPA)
- Fine Guidance Sensor (FGS/NIRISS)
- Mid Infrared Instrument (MIRI)



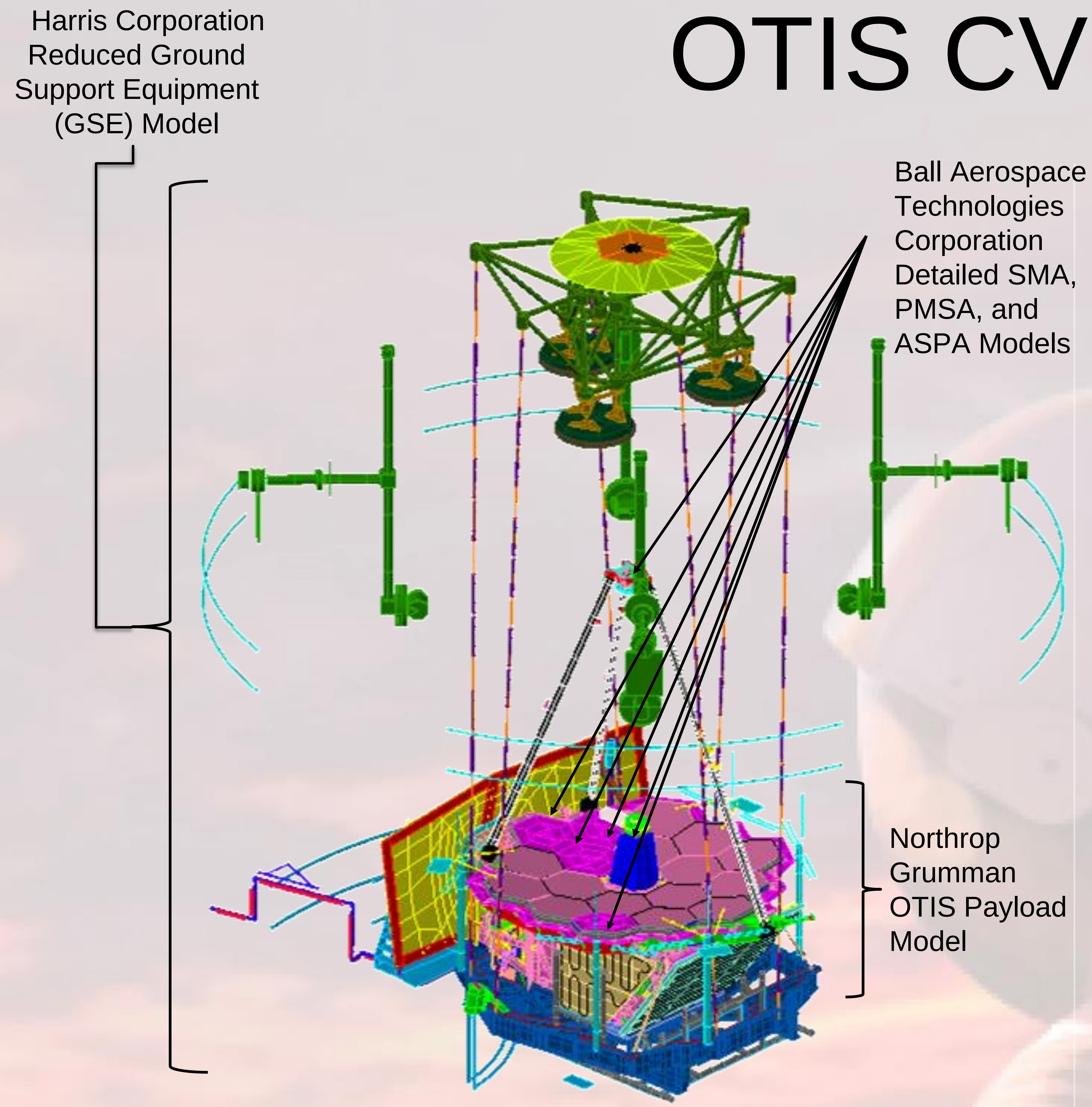
OTIS CV Critical Components: ISIM



OTIS Thermal Control Hardware



OTIS CV Test Model

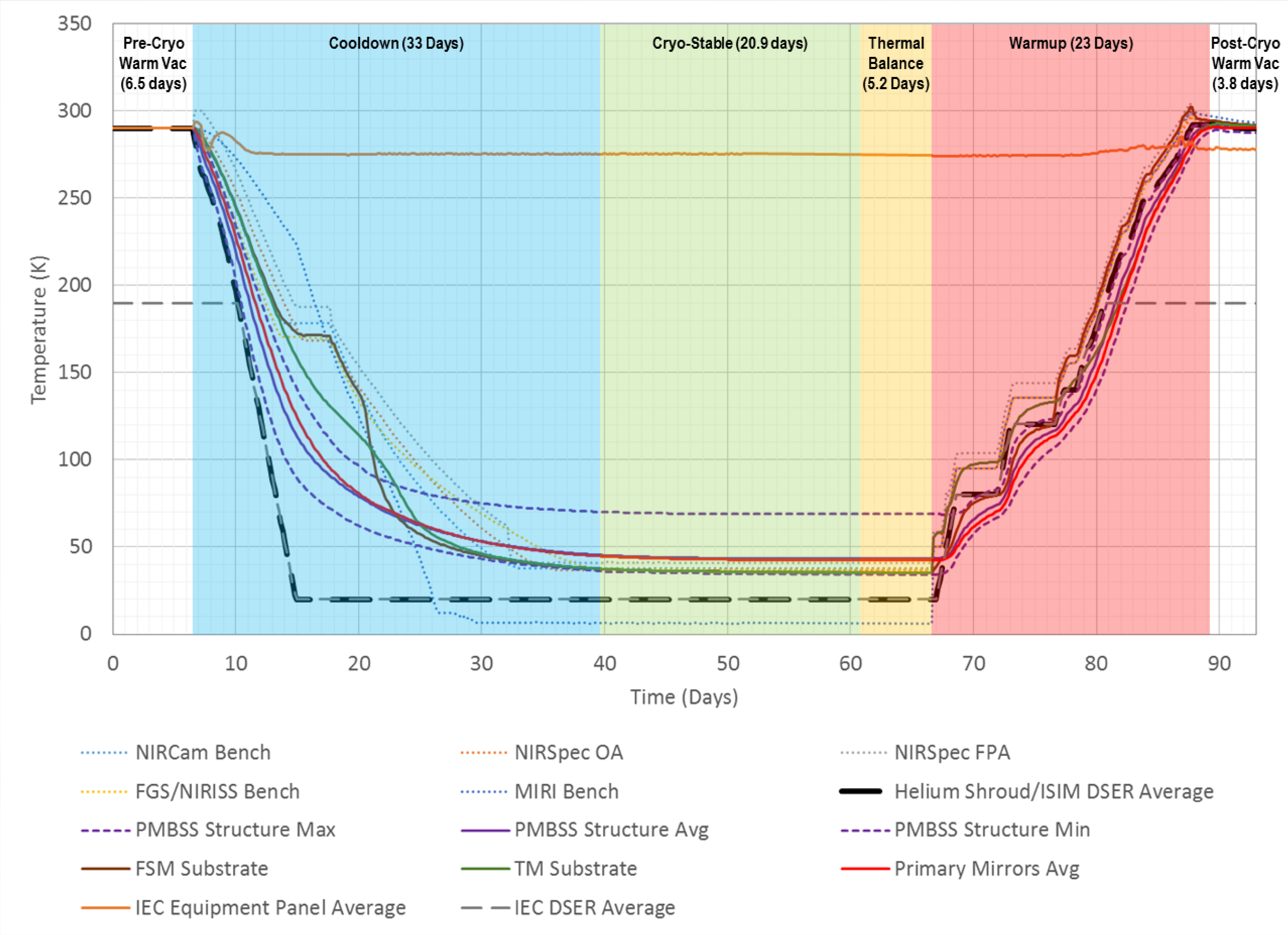


- The OTIS CV Test Thermal Model is a combination of four separate models
  - OTIS Payload Thermal Model from Northrop Grumman Aerospace Systems (NGAS)
  - Detailed Optical Component Thermal Models from Ball Aerospace Technologies Corporation (BATC)
  - GSE and Chamber Thermal Models from Harris Corporation
  - OTIS CV test-specific modifications from NASA Goddard Space Flight Center
- Thermal Desktop/SINDAF, ~84000 nodes, >1 week wall-clock time for transient run
- Used to develop appropriate cooldown and warmup procedures while keeping within L&Cs (over 90 Thermal-specific)

Drivers for OTIS CV Thermal Control in Transition Periods

- Structural Limitations and Constraints (L&Cs), as well as thermal mass of payload, are main driver for schedule in cooldown
  - Structural L&Cs consist of absolute temperature constraints, rate constraints, and gradient constraints
- Contamination Constraints are main driver for schedule in warmup
  - Component-to-component ΔT requirements in water (140K-170K) and molecular (220K-ambient) contamination bands, where composite OTIS structure is most likely to outgas water and organic molecules, which present contamination risk to optics
- Principal "knob to turn" to prevent violation of constraints is Helium Shroud and DSERs transition rate
  - Helium shroud provides effective control of gradients at beginning of cooldown, but past day 5, temperature difference between the helium shroud and bulk payload average is sufficiently large that larger ΔT causes little additional change to the rate of radiative heat transfer from the payload.
  - In warmup, slower helium shroud temperature transition rate allows for all contamination constraints to be met by maintaining appropriate ΔTs between components

Full Test Profile

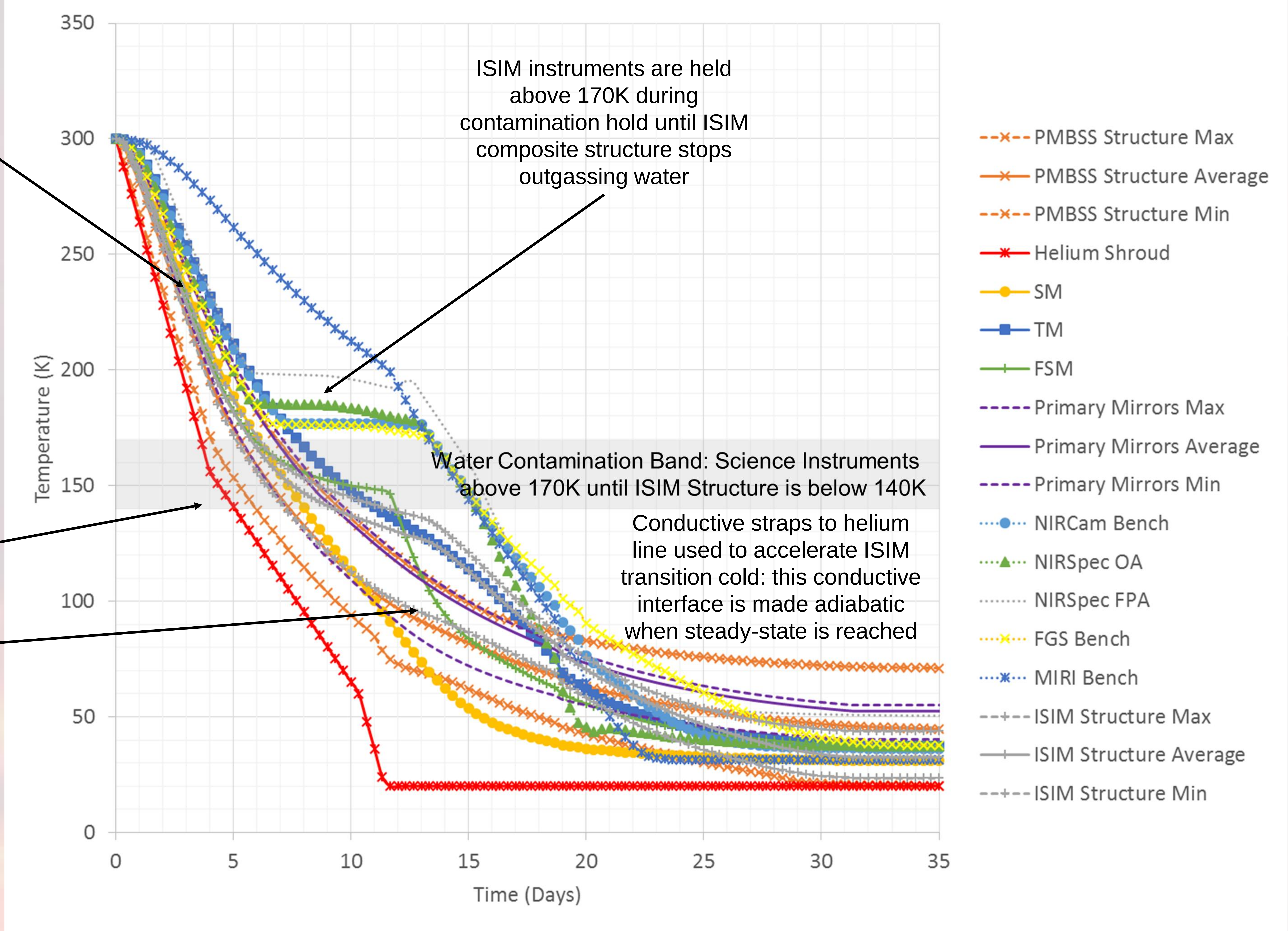


Baseline Cooldown Profile

Initial cooldown rate for most components determined by helium shroud profile

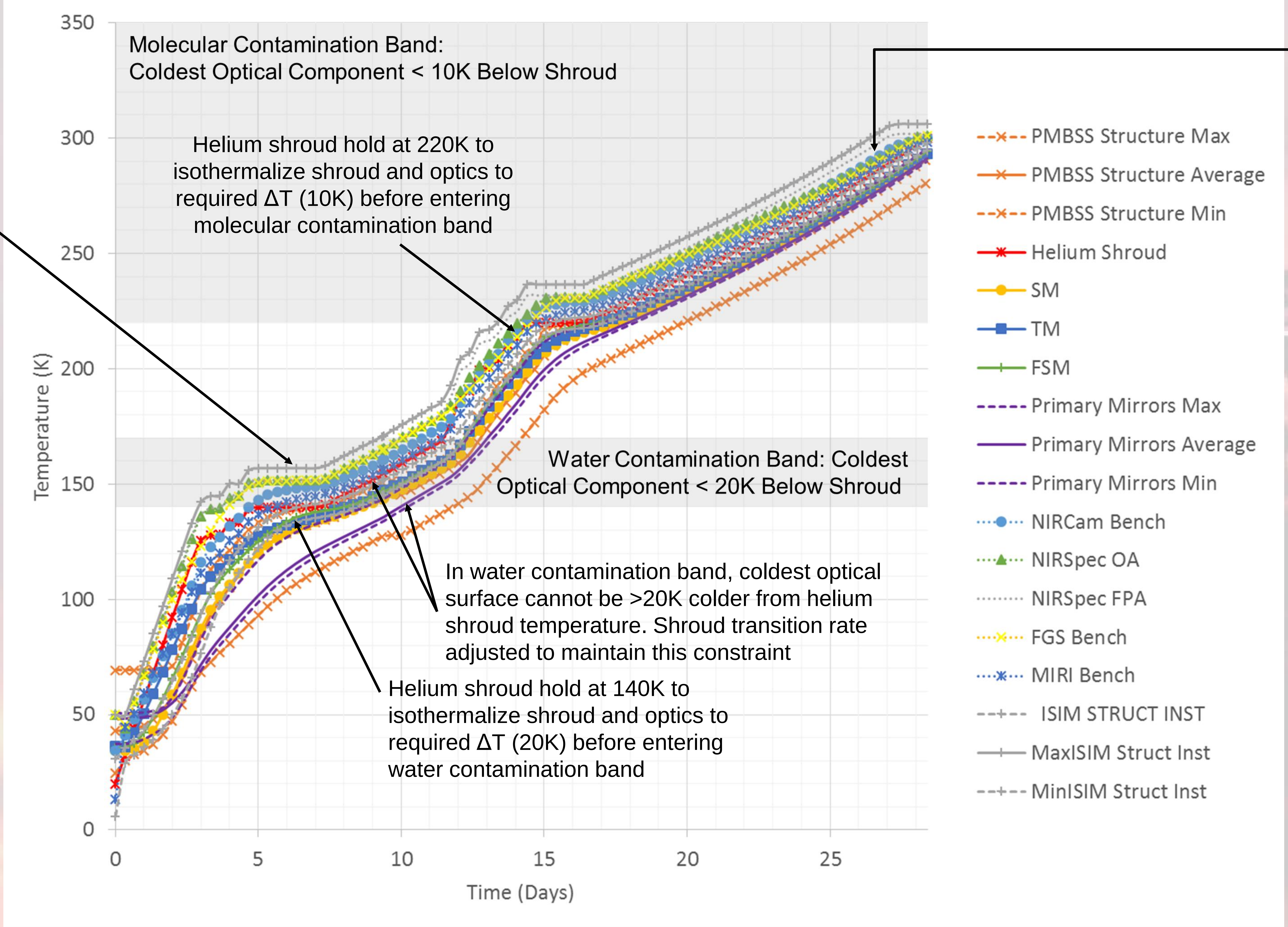
Lower shroud transition rate to control PMBSS structure gradients

Towards end of cooldown, payload cooldown profile does not mirror shroud cooldown profile (shroud is now an arbitrarily cold sink)



Baseline Warmup Profile

All ISIM instruments have contamination control heaters to accelerate their transition in warmup. These are powered to keep ISIM above helium shroud temperature in entirety of warmup

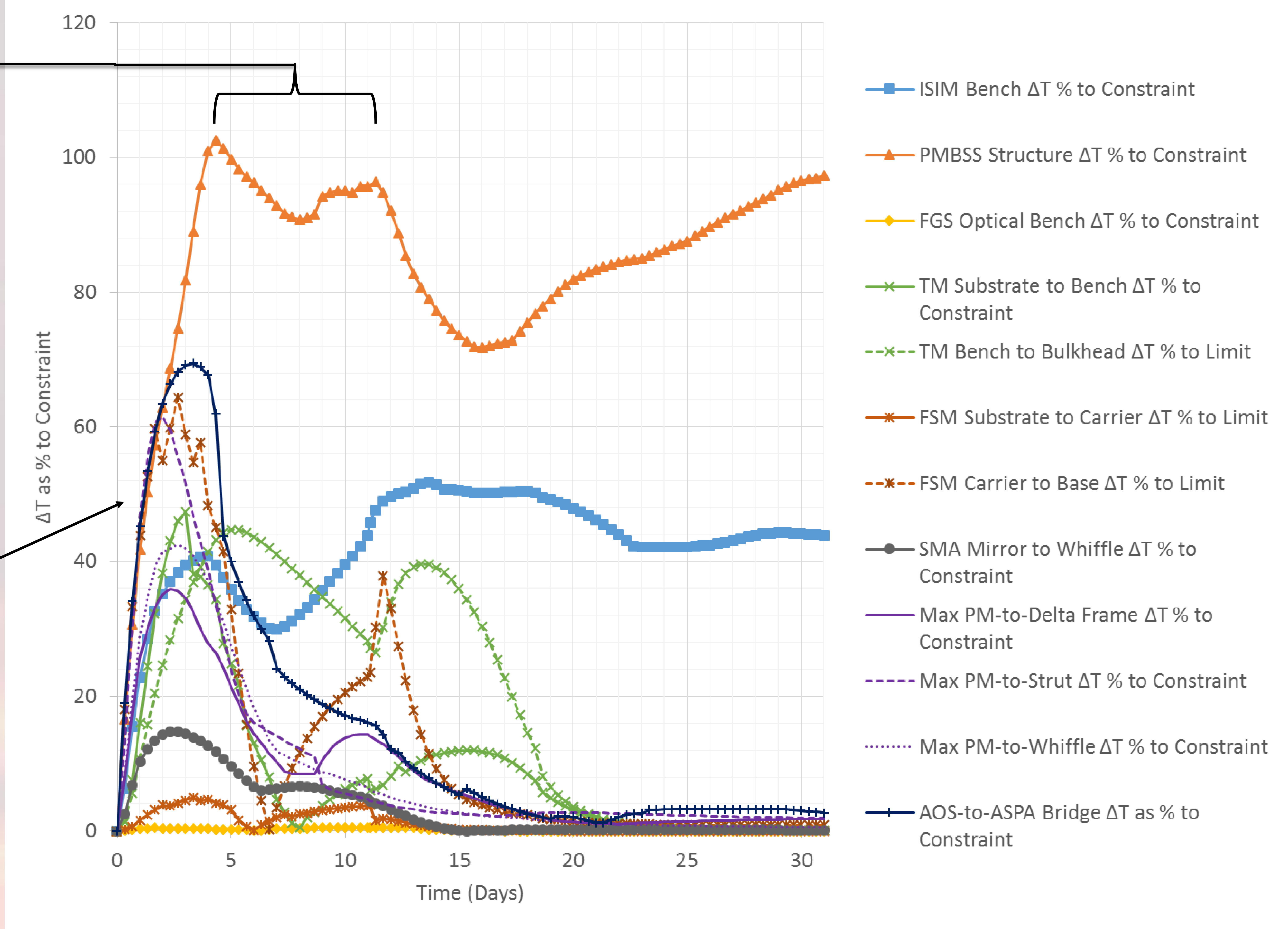


In molecular contamination band, coldest optical surface cannot be >10K colder from helium shroud temperature. Shroud transition rate adjusted to maintain this constraint

Baseline Cooldown ΔTs as % to Constraint

Slower shroud transition rate between days 4 and 10.3 of cooldown (1.5 K/hr to 0.63 K/hr) prevents exceedance of PMBSS structural constraint in cooldown

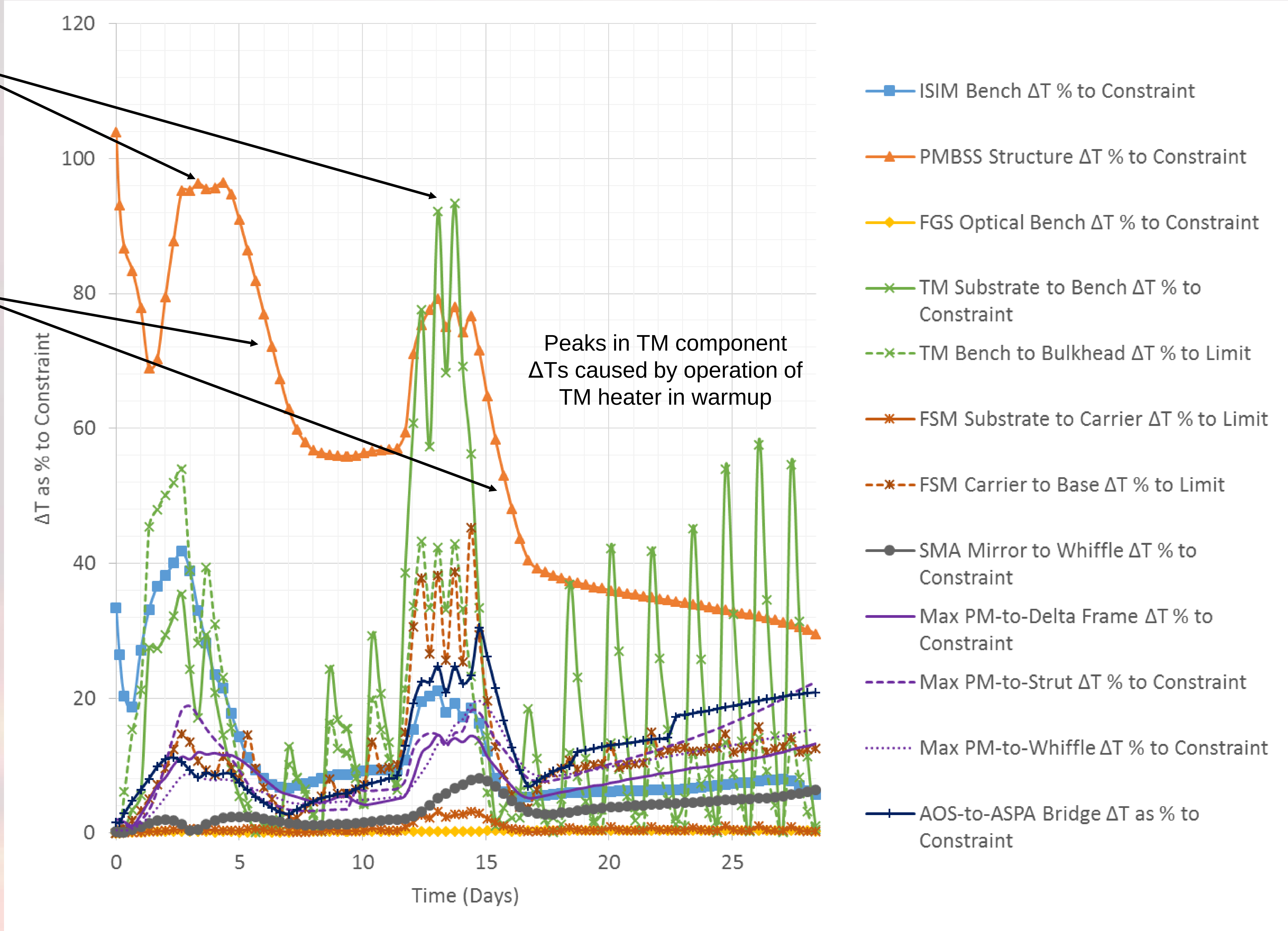
All other constraints are maintained by shroud rate required by gating schedule item (PMBSS structure gradient)



Baseline Warmup ΔTs as % to Constraint

Short shroud holds allow for control of PMBSS and Tertiary Mirror component structural ΔTs during warmup

Shroud contamination holds at 140K and 170K also allow for large reduction in PMBSS ΔTs as temperatures isothermalize

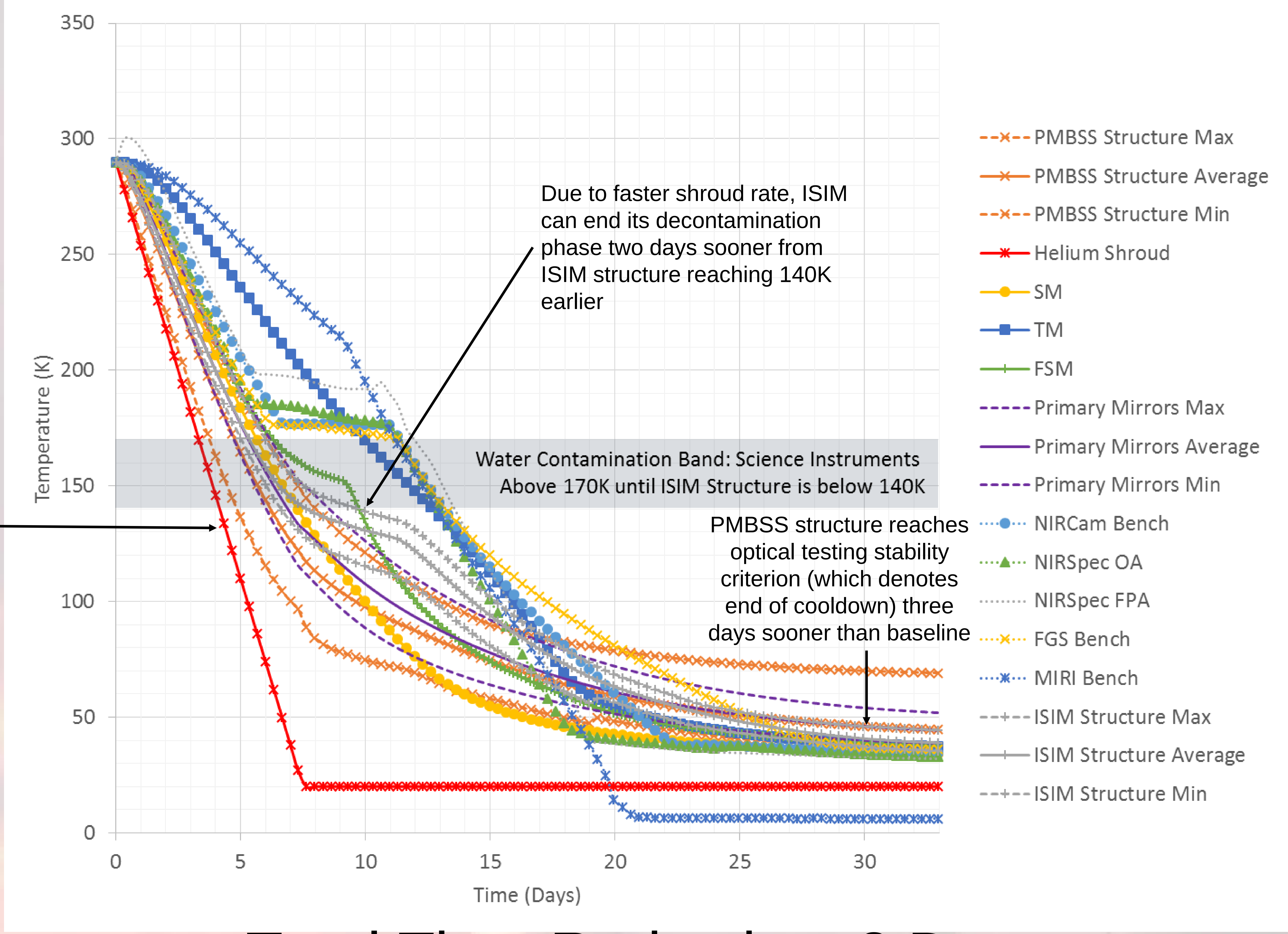


Schedule Optimization Study

- Due to high daily operational costs of OTIS CV test, a study was undertaken to reduce OTIS CV payload cooldown and warmup transition times
  - In purely radiative environment, schedule optimization can only be achieved with modulating helium shroud/DSER rates and heater usage, and reexamining all gating L&Cs
    - PMBSS structural constraint reviewed with mechanical team: new stress analysis showed that previous point-to-point structural ΔT constraint was too conservative. A new temperature-dependent constraint was developed which precluded need for helium shroud rate slowdown in baseline curve
    - Contamination constraint re-examined: previous constraint for optics-to-helium shroud ΔT was too conservative based on results from previous Pathfinder test. New allowables are 40K for both contam. bands
    - Overdriving of shroud temperatures and GSE boundaries also considered
- Optimization code was developed in the form of a feedback loop for helium shroud/DSER control in cooldown and warmup
  - Model calculates payload performance against all critical L&Cs per timestep, providing real-time monitoring of thermal behavior of components against allowable values
    - If no constraints exceeded, helium shroud/DSERs allowed to proceed at max. rate of 1.5 K/hr
    - If ΔT or rate of any component exceeded constraint + margin, the helium shroud/DSERs temperature will hold constant for that timestep
    - While this produces a stepwise shroud profile at a microscopic level, on a macroscopic level this produces the constant shroud rate needed to maintain this constraint

Modified Cooldown Profile

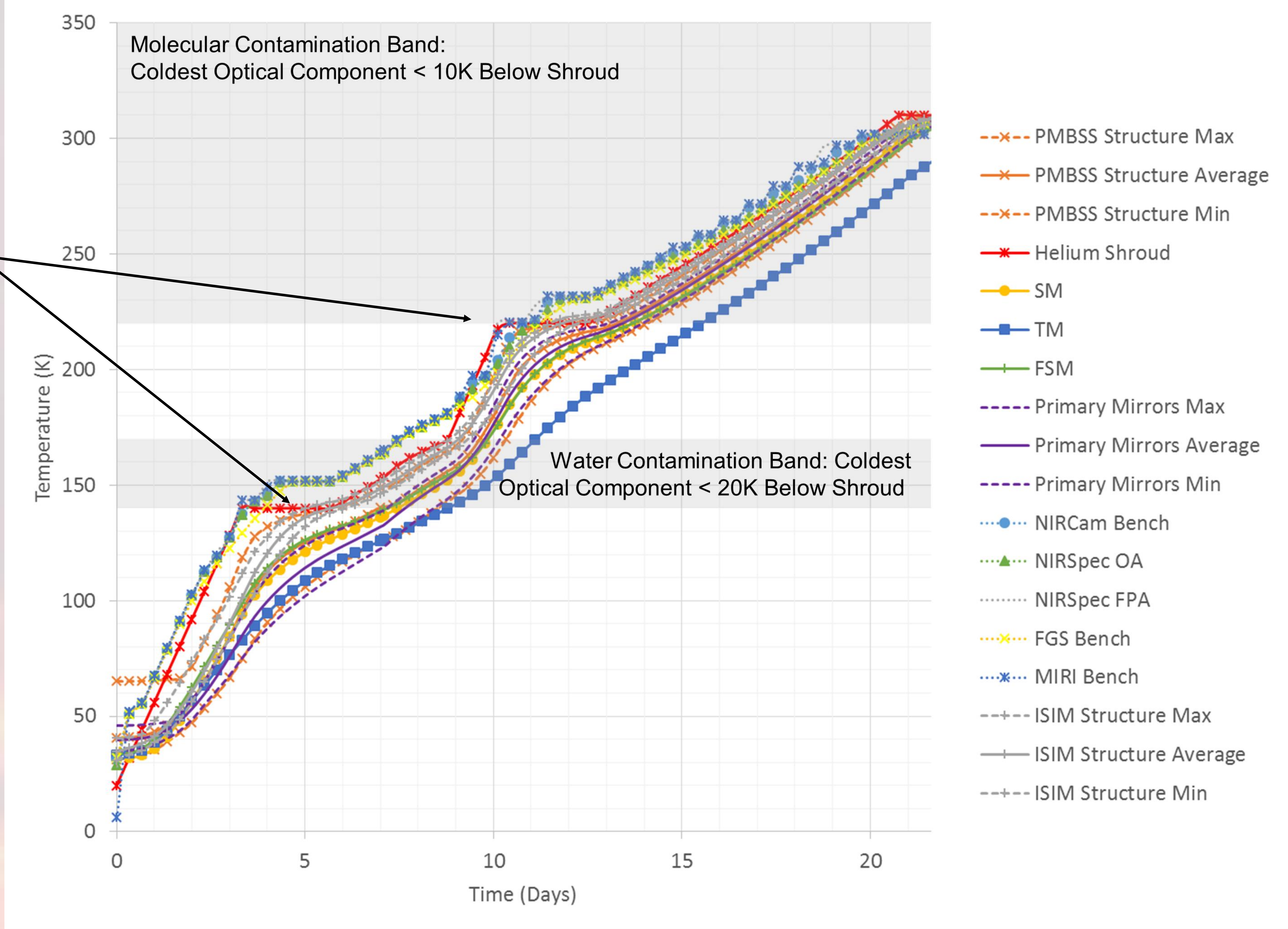
Expansion of PMBSS structural gradient allowable permits shroud to maintain constant 1.5 K/hr through entirety of cooldown: this allows payload to cool at fastest radiative rate possible



Total Time Reduction: 3 Days

Modified Warmup Profile

Due to relaxed ΔT requirements before entering water and molecular contamination bands, time needed to hold shroud and wait for components to isothermalize is now shorter

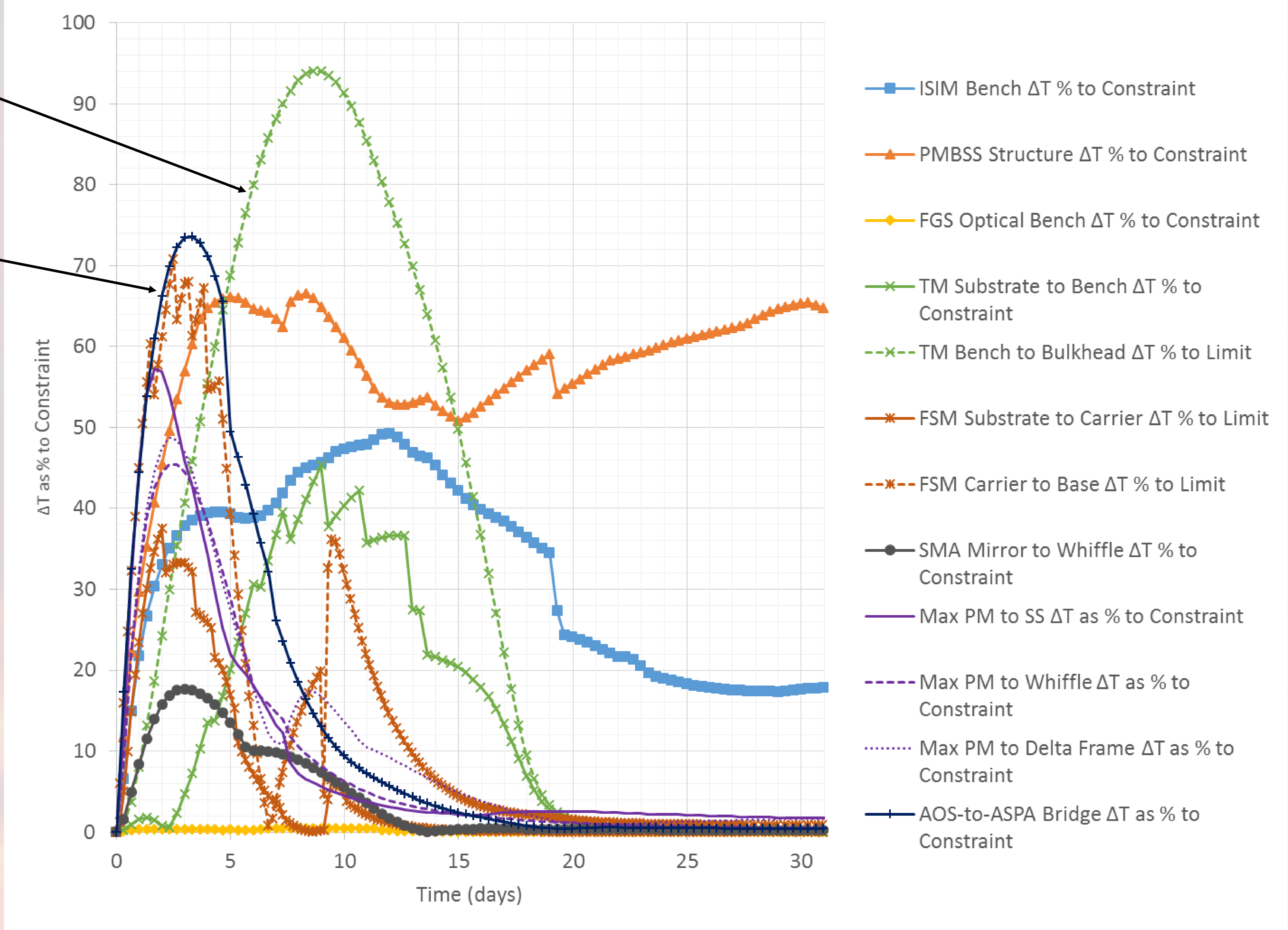


Total Time Reduction: 6.8 Days

Modified Cooldown ΔTs as % to Constraint

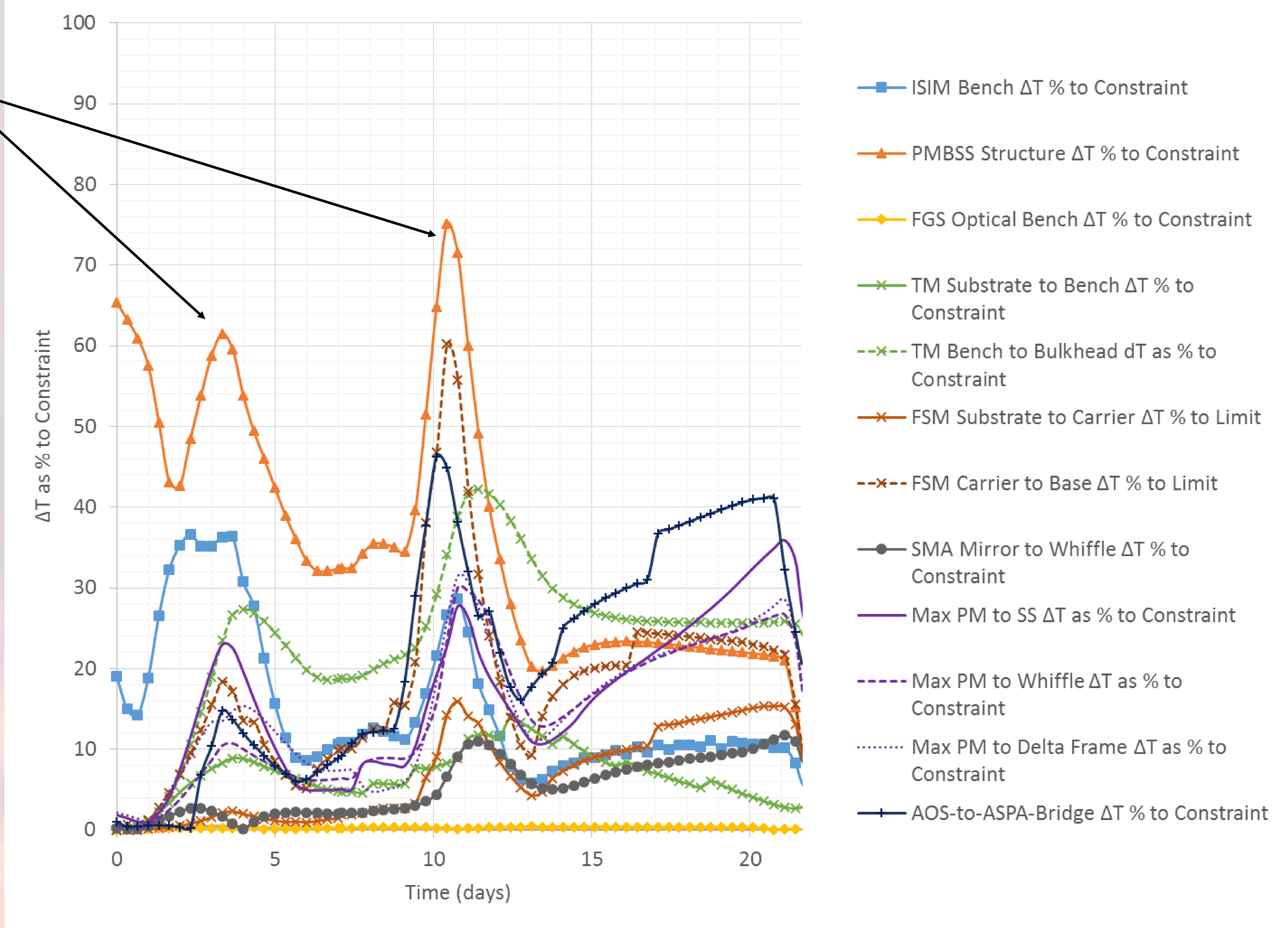
Faster shroud transition rate now exacerbates structural ΔTs over other components

Expansion of PMBSS structural gradient allowable permits PMBSS to maintain below constraints despite faster shroud transition rate



Modified Warmup ΔTs as % to Constraint

Expansion of PMBSS gradient allowables removes need for short shroud holds to control PMBSS gradient: shroud can move at 1.5 K/hr when outside contamination bands



Summary and Conclusions

- JWST OTIS CV Test is a workmanship test for the OTIS payload before its final integration with the spacecraft bus and sunshield
- A modeling study was undertaken to optimize the OTIS payload cooldown and warmup transition times for this test. The following table summarizes the major modifications made and their impacts on test schedule:

Major Modification to Baseline	Time Impact on Cooldown	Time Impact on Warmup
Expansion of PMBSS structural gradient constraint to a larger allowable ΔT via stress analysis	Reduction of Helium shroud cooldown time by 4 days, reduction of total cooldown time by 3 days	Removal of shroud plateau time spent to mitigate PMBSS gradient, savings of 0.6 days
Relaxation of Helium shroud-to-coldest optical surface allowable ΔT constraints in water and molecular contamination bands	--	Reduction of time in 140K shroud plateau and water contamination band by 1 day, reduction of time in 220K shroud plateau and water contamination band by 4 days
Other changes: Driving of Helium shroud to 310K at end-of-warmup, overdriving of GSE heater setpoints	--	Reduction of time spent at end-of-warmup by 1.2 days

- Baseline times: 33.3 Days cooldown, 28.4 days warmup. Modified transition times after optimization study: 30.3 days cooldown, 21.6 days warmup. Total time savings: **9.8 days**

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