Thermal Model Performance for the James Webb Space Telescope OTIS Cryo-Vacuum Test

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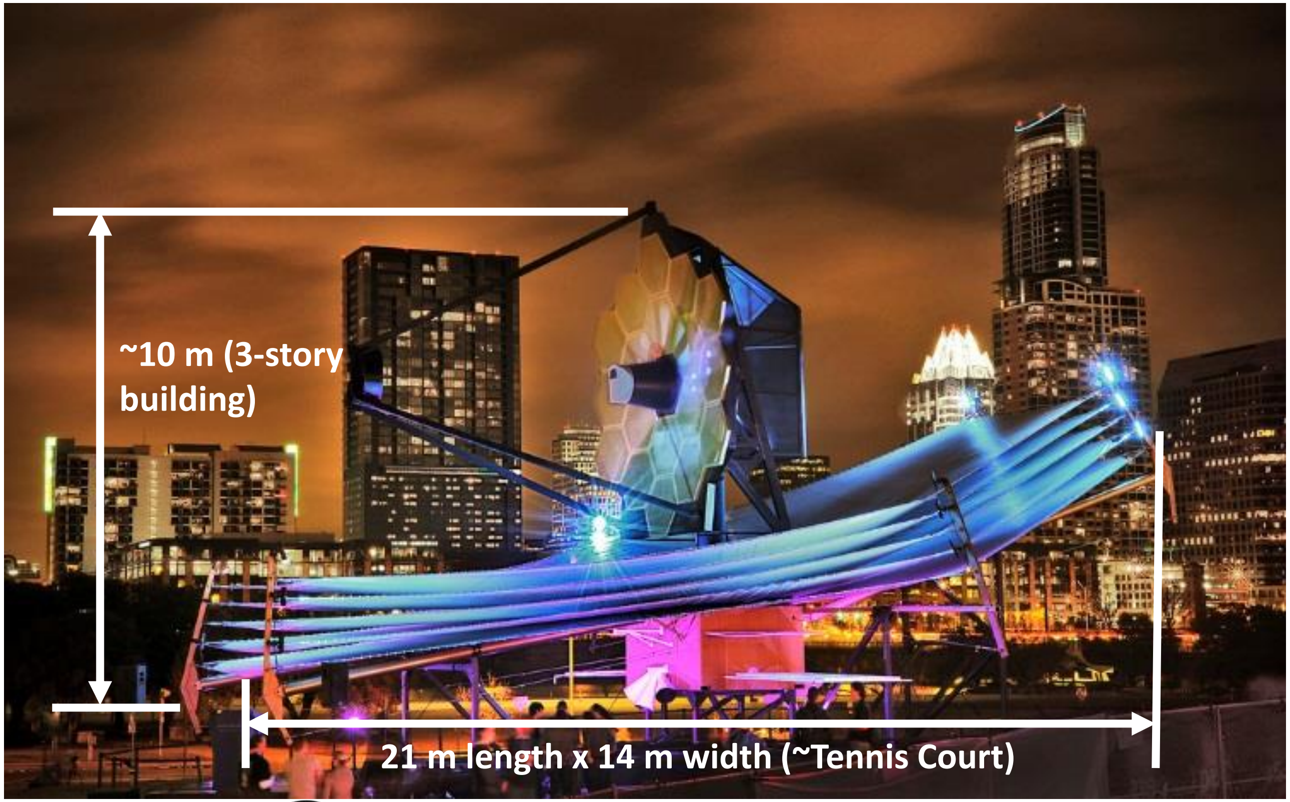
The James Webb Space Telescope

Upon launch, the James Webb Space Telescope (JWST) will become the world's most powerful general-purpose space observatory

- Scientific successor to the Hubble Space Telescope
- Optimized to observe in near-to-mid infrared wavelengths (0.6 – 28 µm)



JWST Full-scale model at SXSW in Austin, TX, 2013. Image source: www.jwst.nasa.gov

Major System-Level Assemblies of JWST

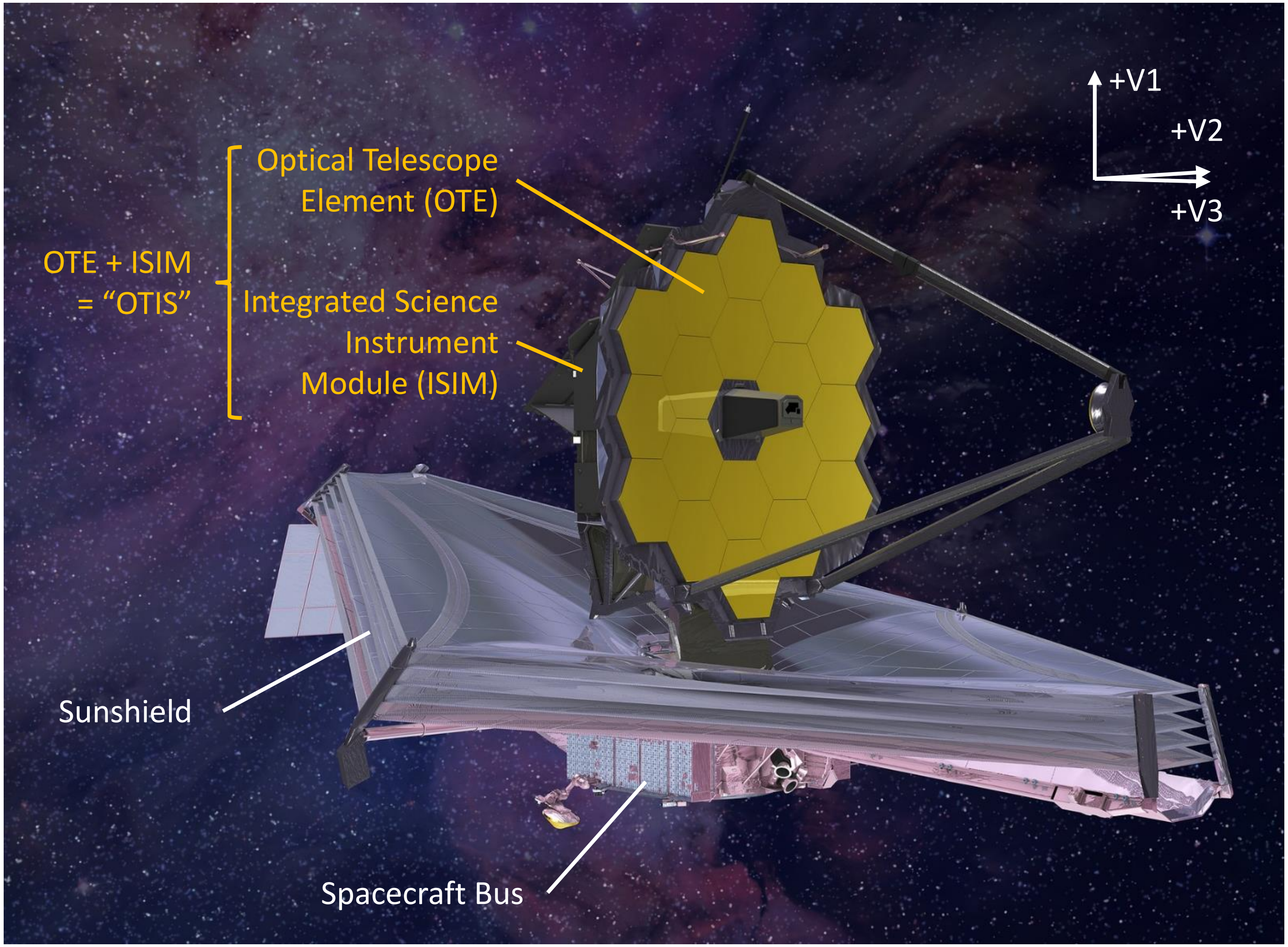
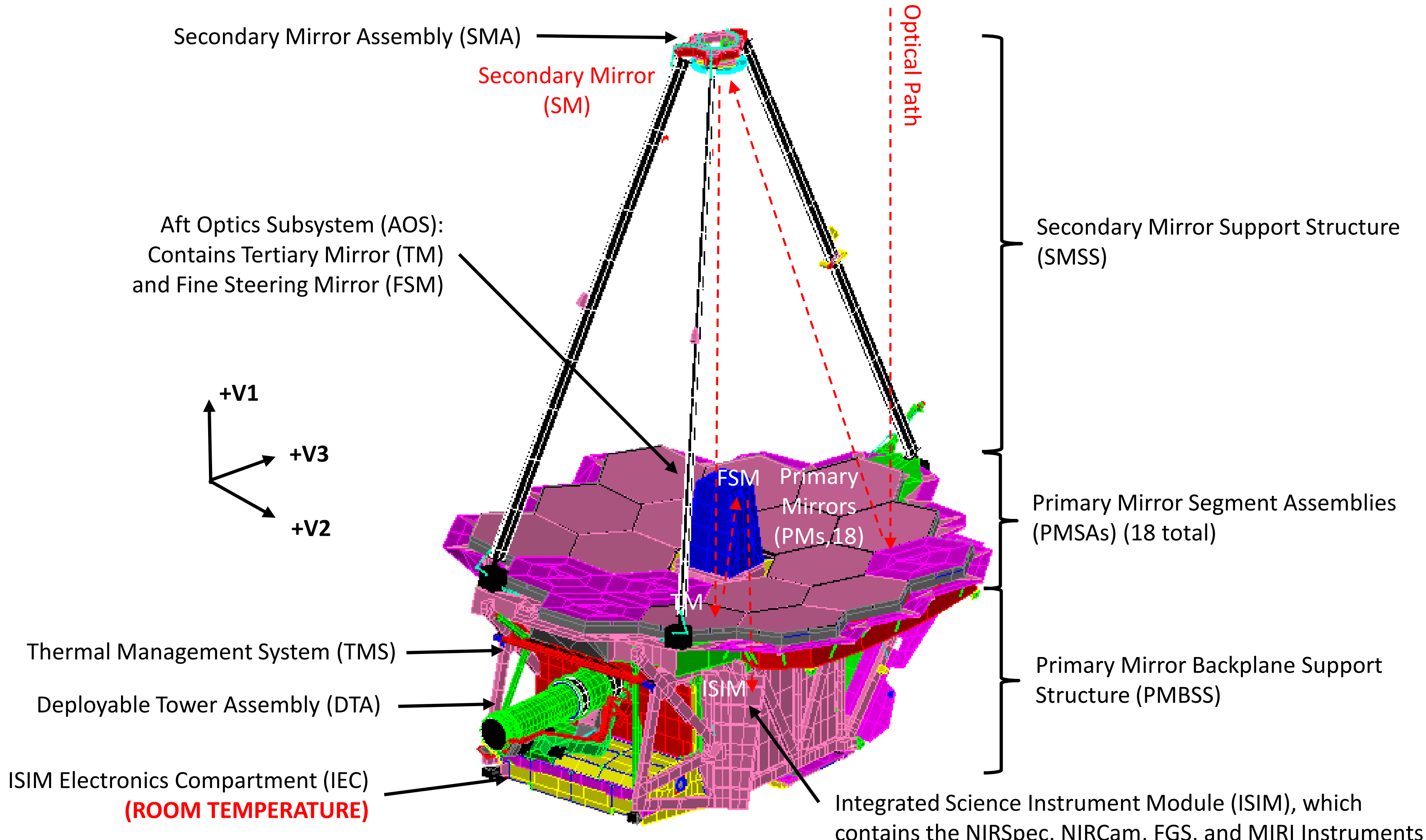


Image source: www.jwst.nasa.gov

JWST OTIS Payload Major Components

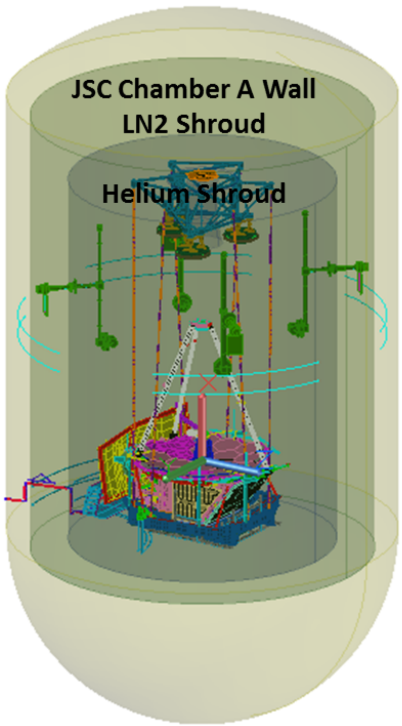


OTIS CV Thermal Test Objectives

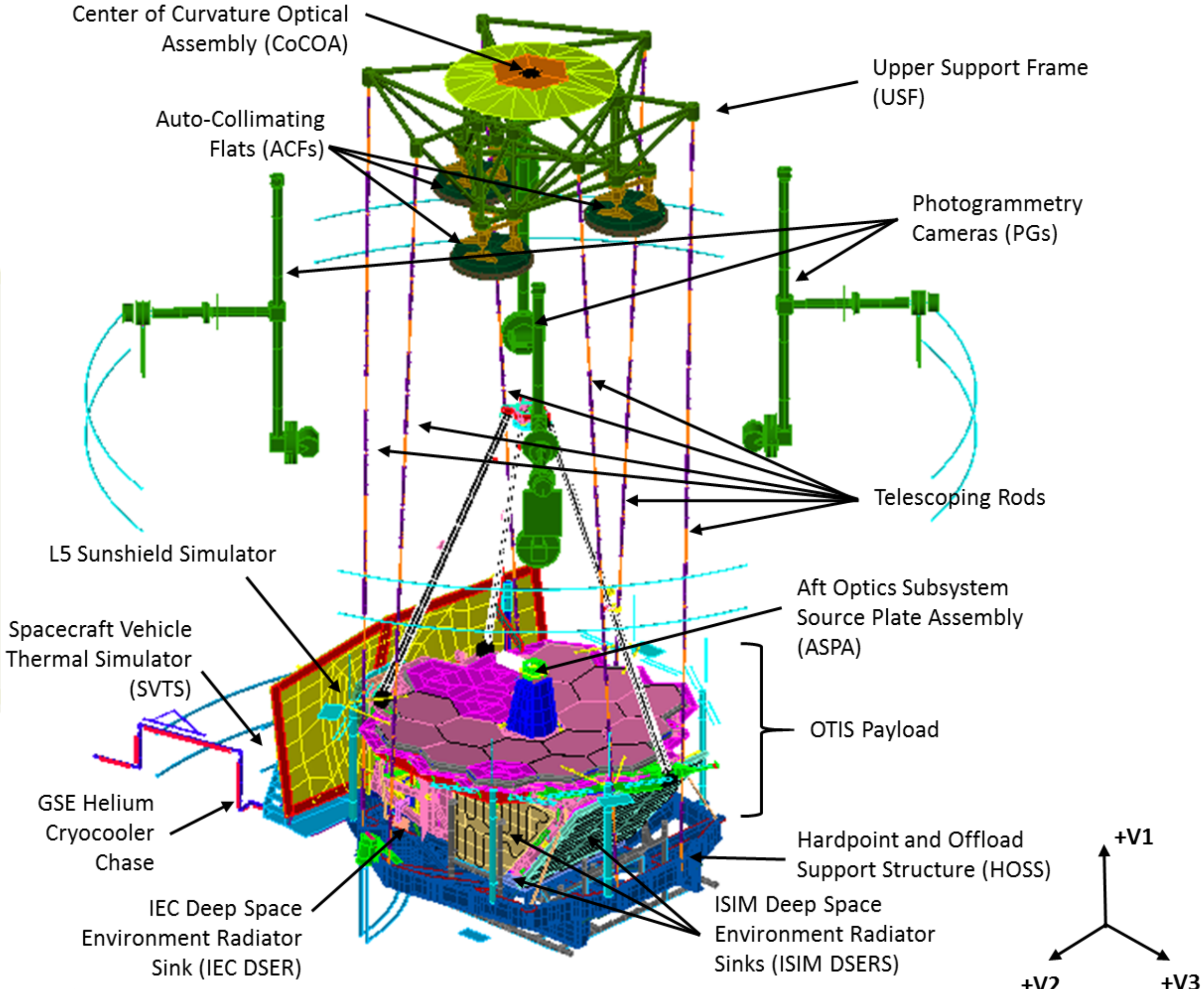
1. To preserve hardware integrity upon transition to cryogenic thermal balance (cryo-balance) conditions and transition back to ambient temperatures by respecting all imposed limits and constraints (L&Cs, 92 total)
2. To achieve the simulated on-orbit payload temperature levels and stability for optical, mechanical, and instrument tests
3. To predict and measure thermal balance test data for model crosscheck, both on ISIM and OTE components
4. To achieve a workmanship thermal conductance assessment of the flight instrument heat straps which for the first time would be connecting all the payload flight instruments and radiators
5. To achieve test timeline optimization by executing the OTIS CV cooldown and warmup in a time-efficient manner

OTIS CV Test Configuration

With Chamber and Shrouds



Without Chamber and Shrouds



OTIS CV Test Thermal Control Hardware

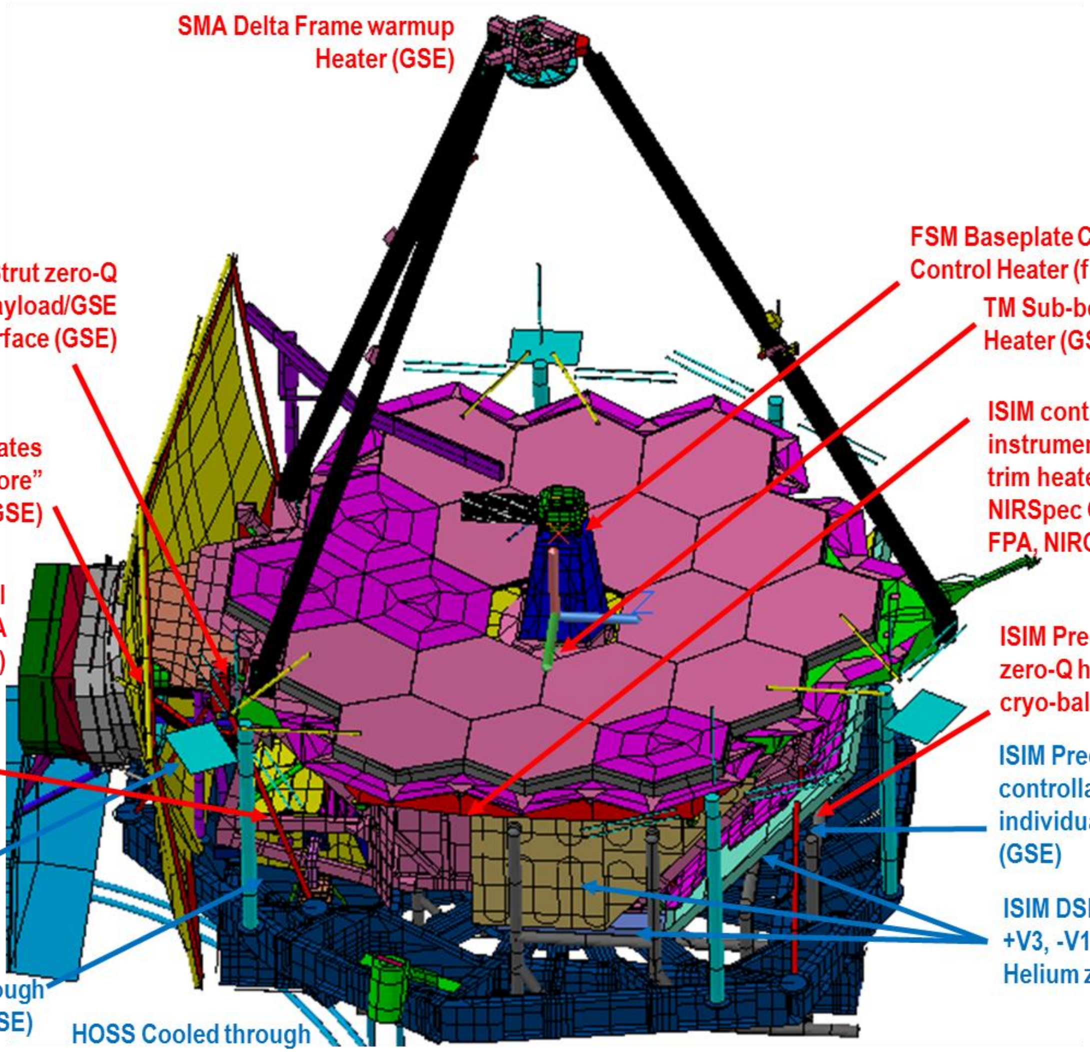


Photo of OTIS CV Test Configuration inside NASA JSC Chamber A

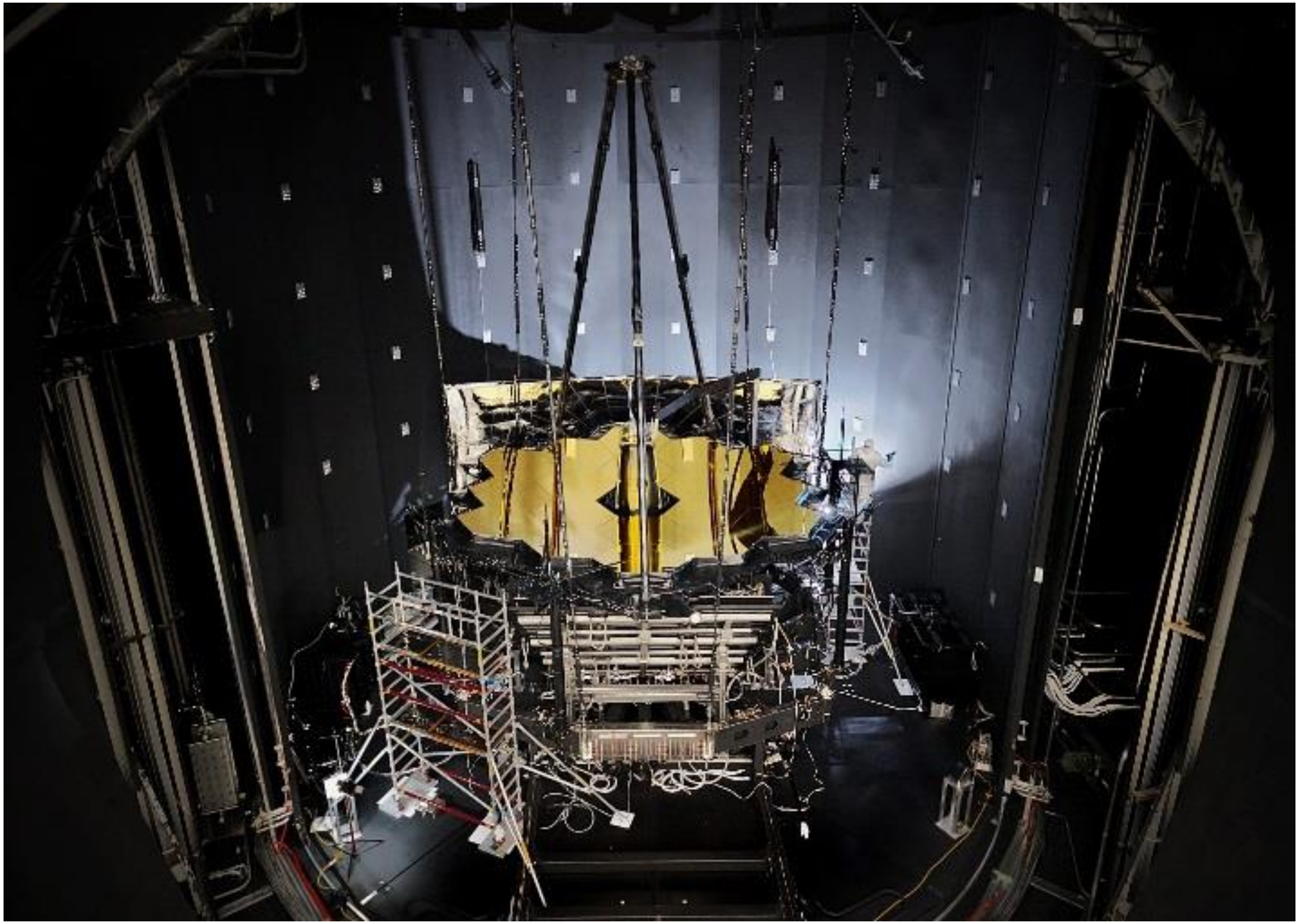
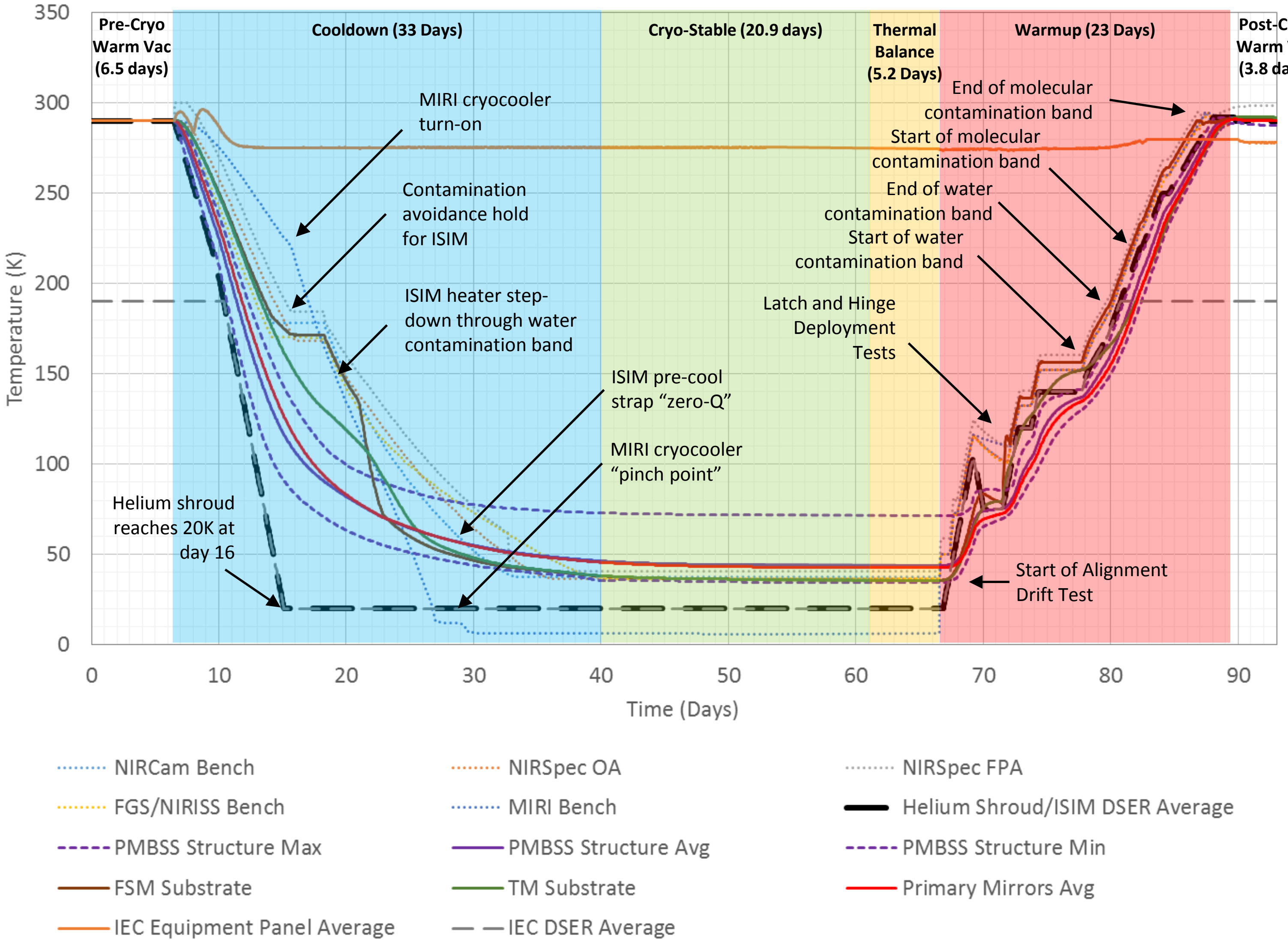
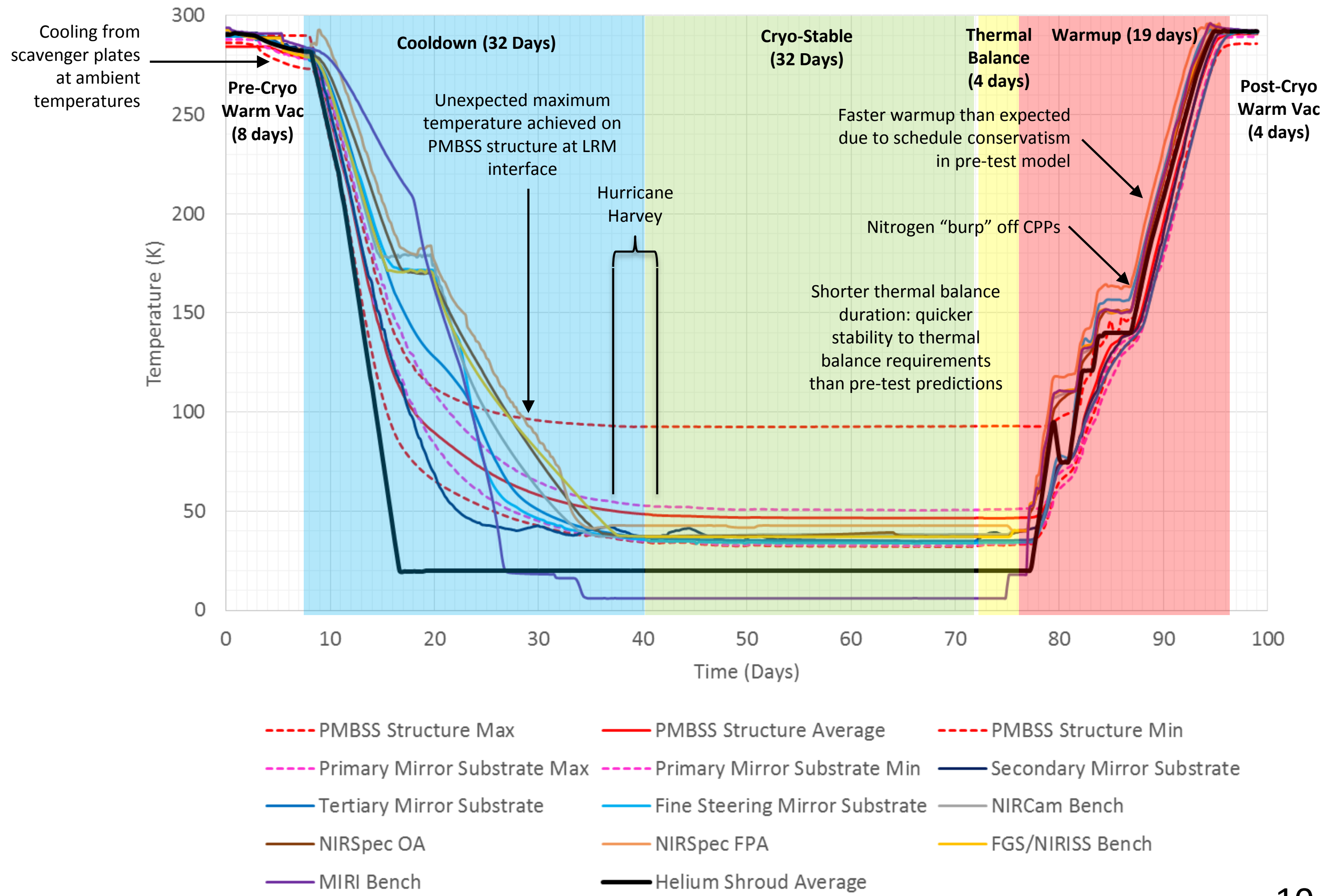


Image source: www.jwst.nasa.gov

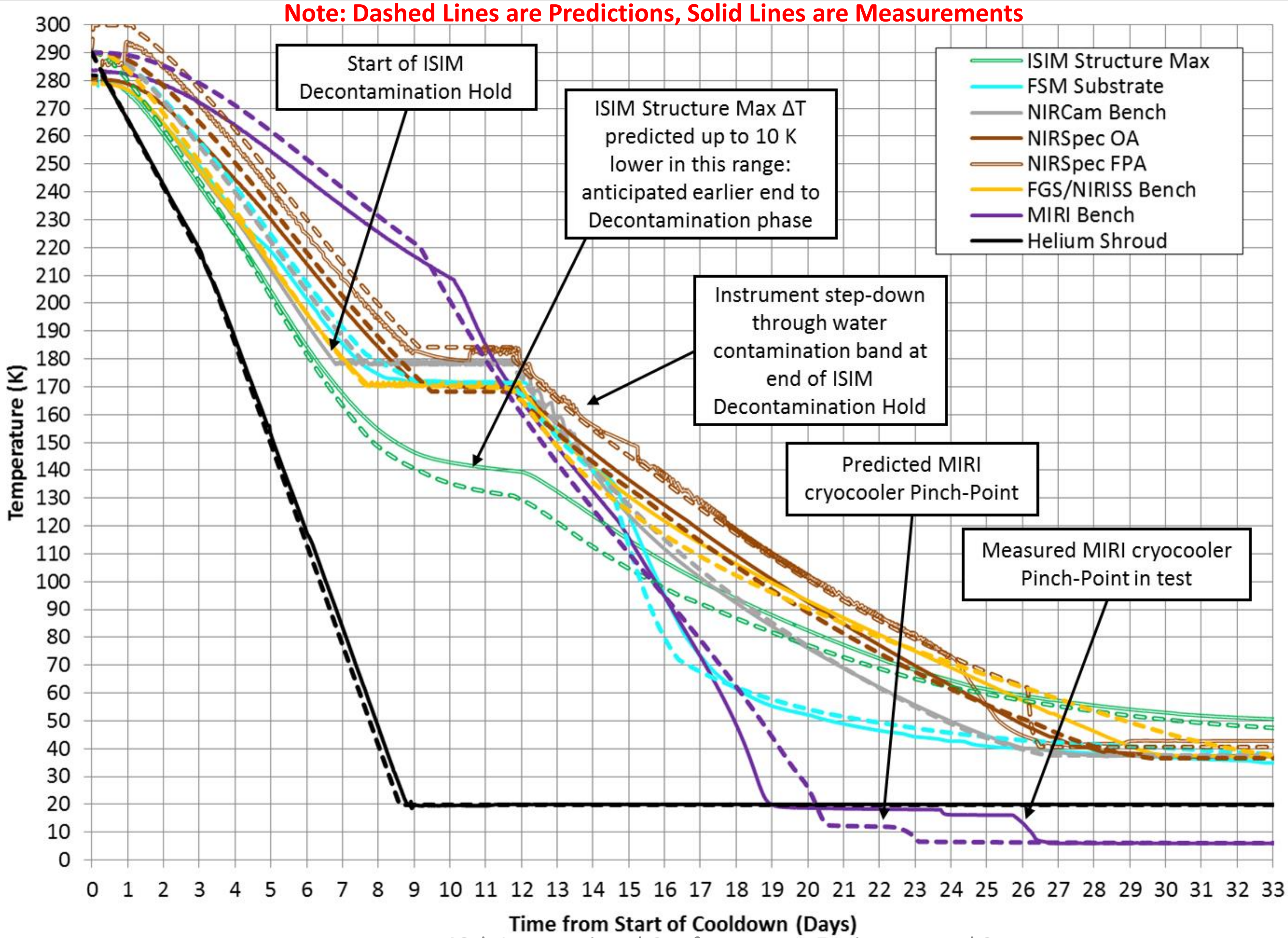
Pre-Test Predictions (shown at ICES 2017 Conference)



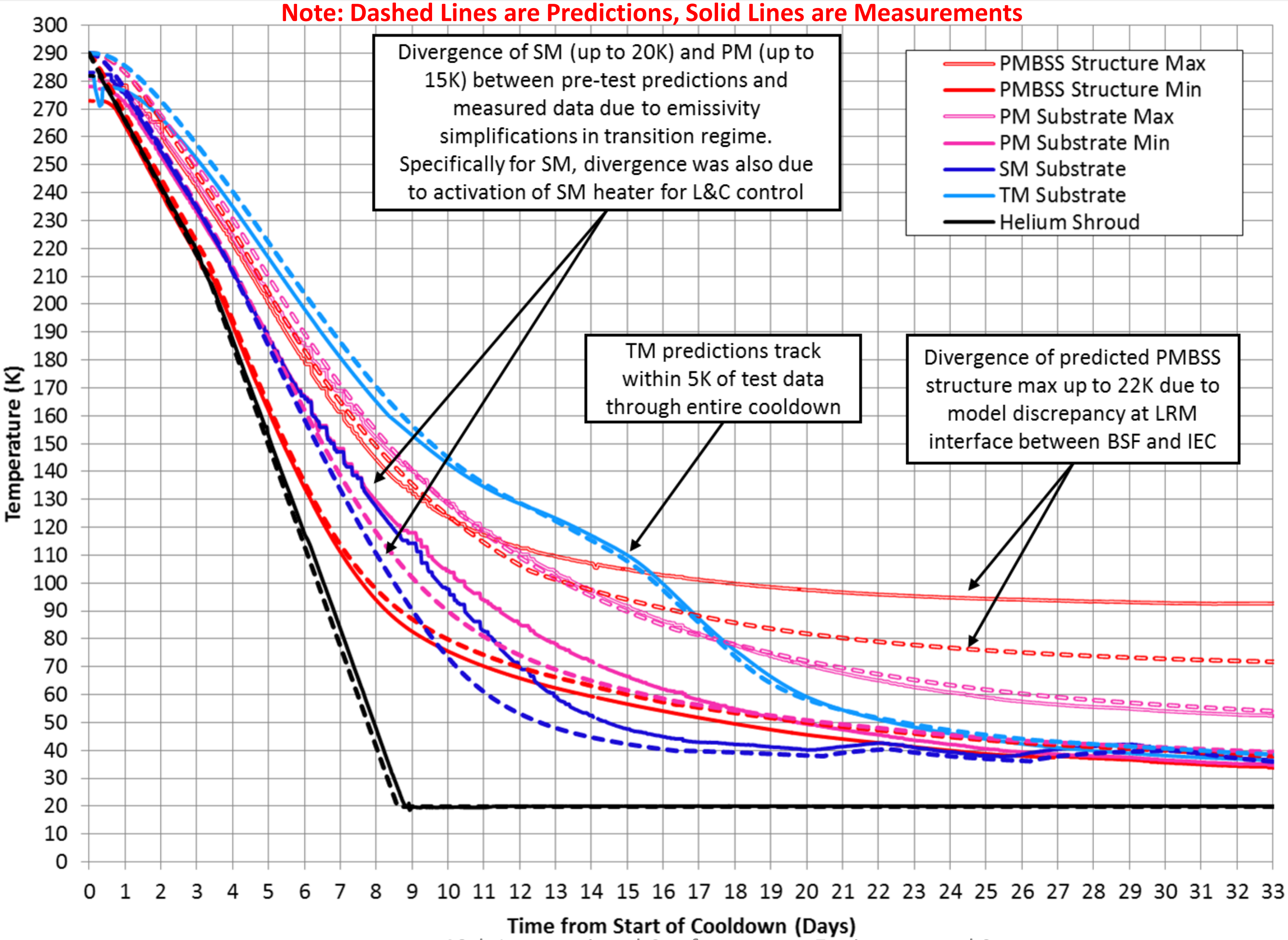
As-Tested Full OTIS CV Profile



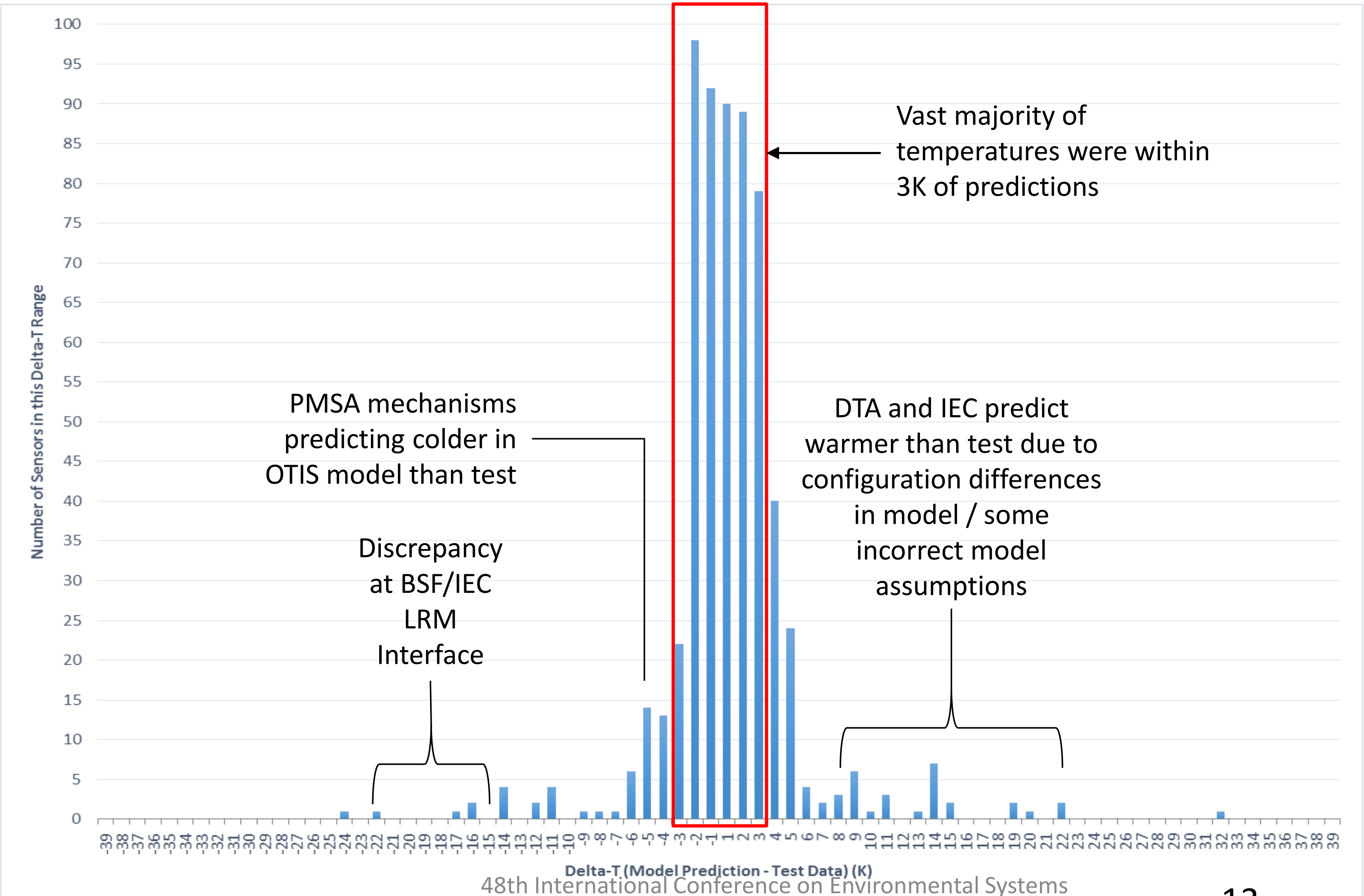
OTIS CV Pre-Test Model Predictions vs. Test Measurements: ISIM Cooldown



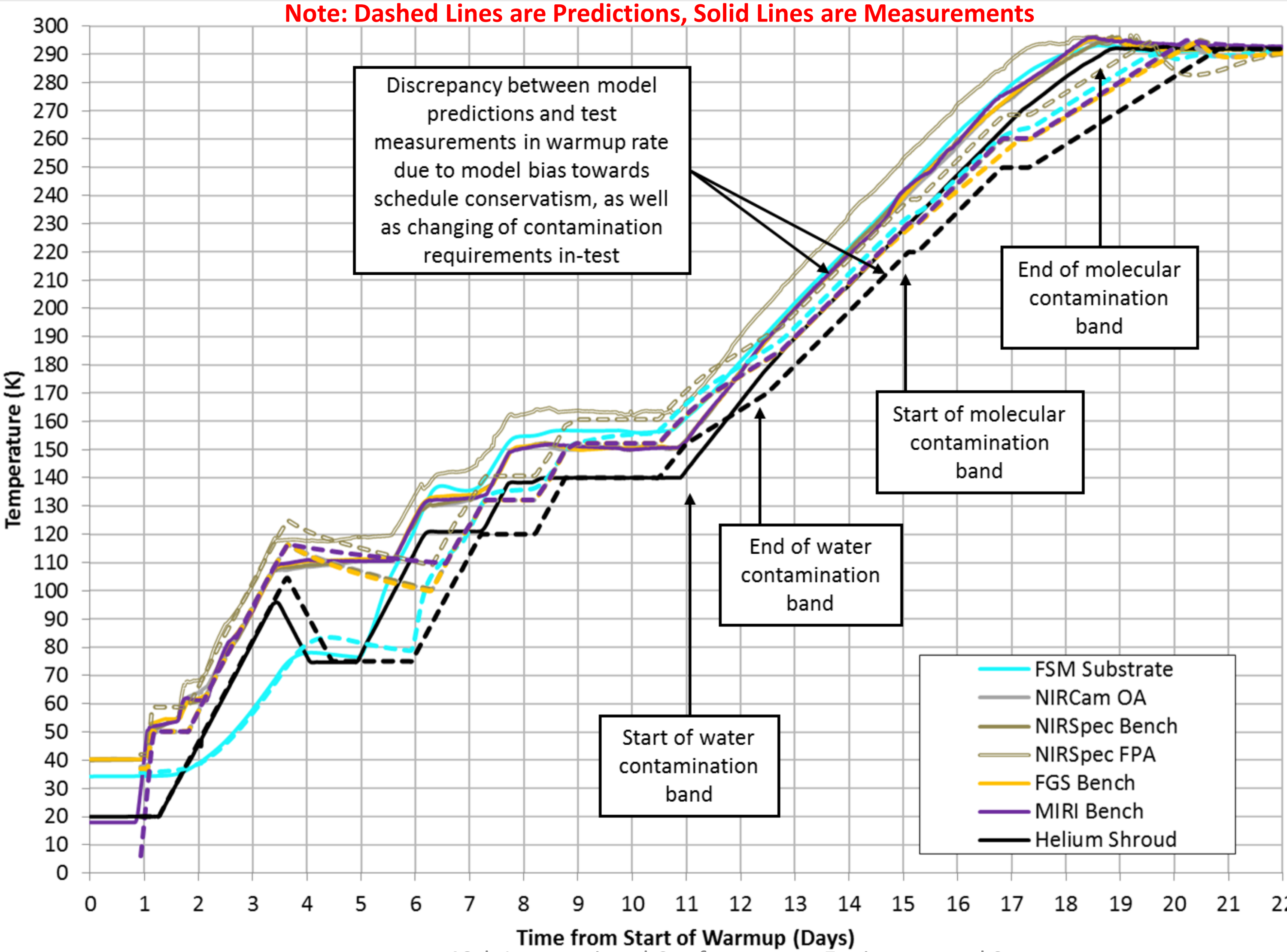
OTIS CV Pre-Test Model Predictions vs. Test Measurements: OTE Cooldown



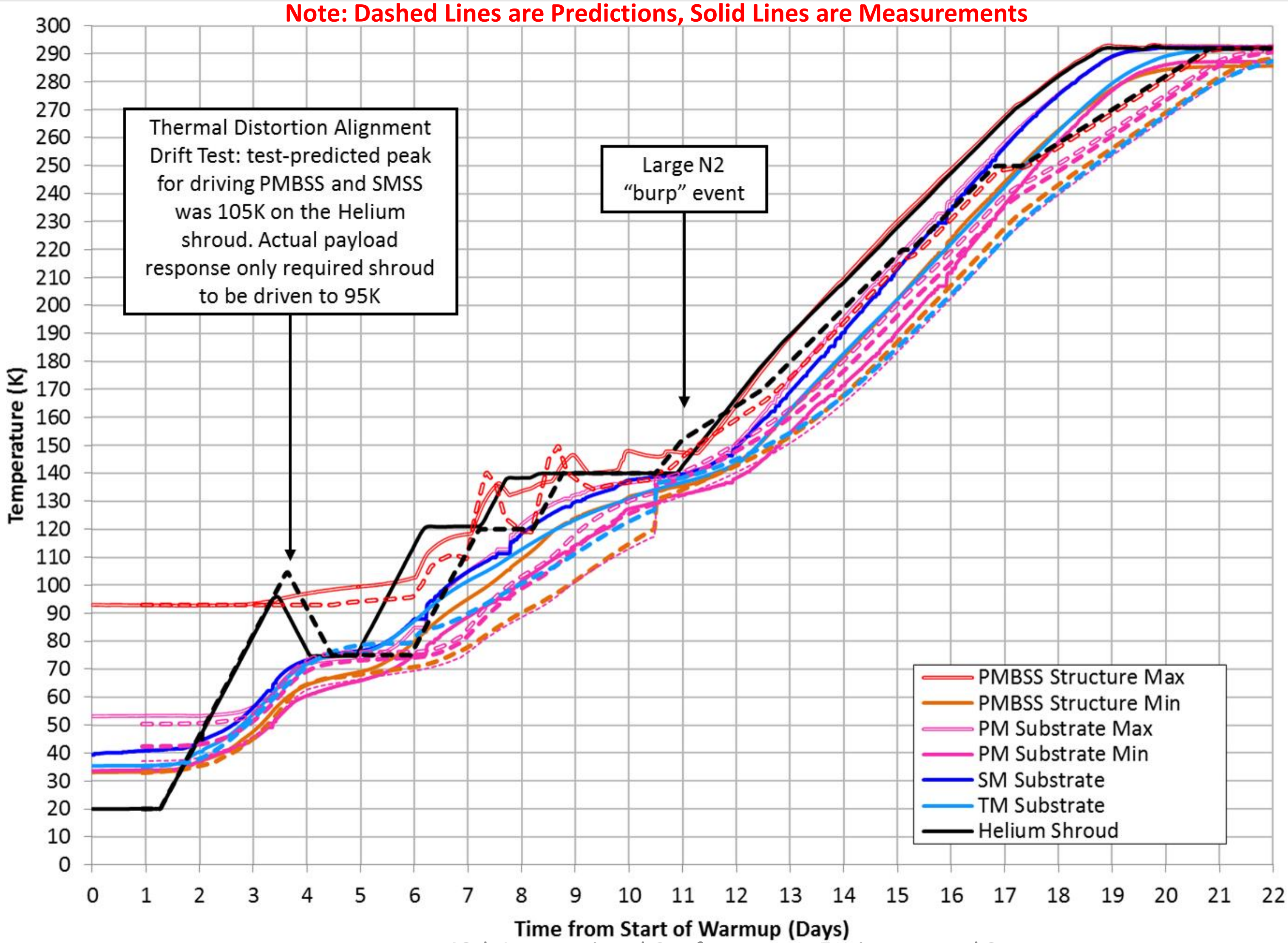
OTIS CV Pre-Test Model Predictions vs. Test Measurements: Thermal Balance



OTIS CV Pre-Test Model Predictions vs. Test Measurements: ISIM Warmup



OTIS CV Pre-Test Model Predictions vs. Test Measurements: OTE Warmup

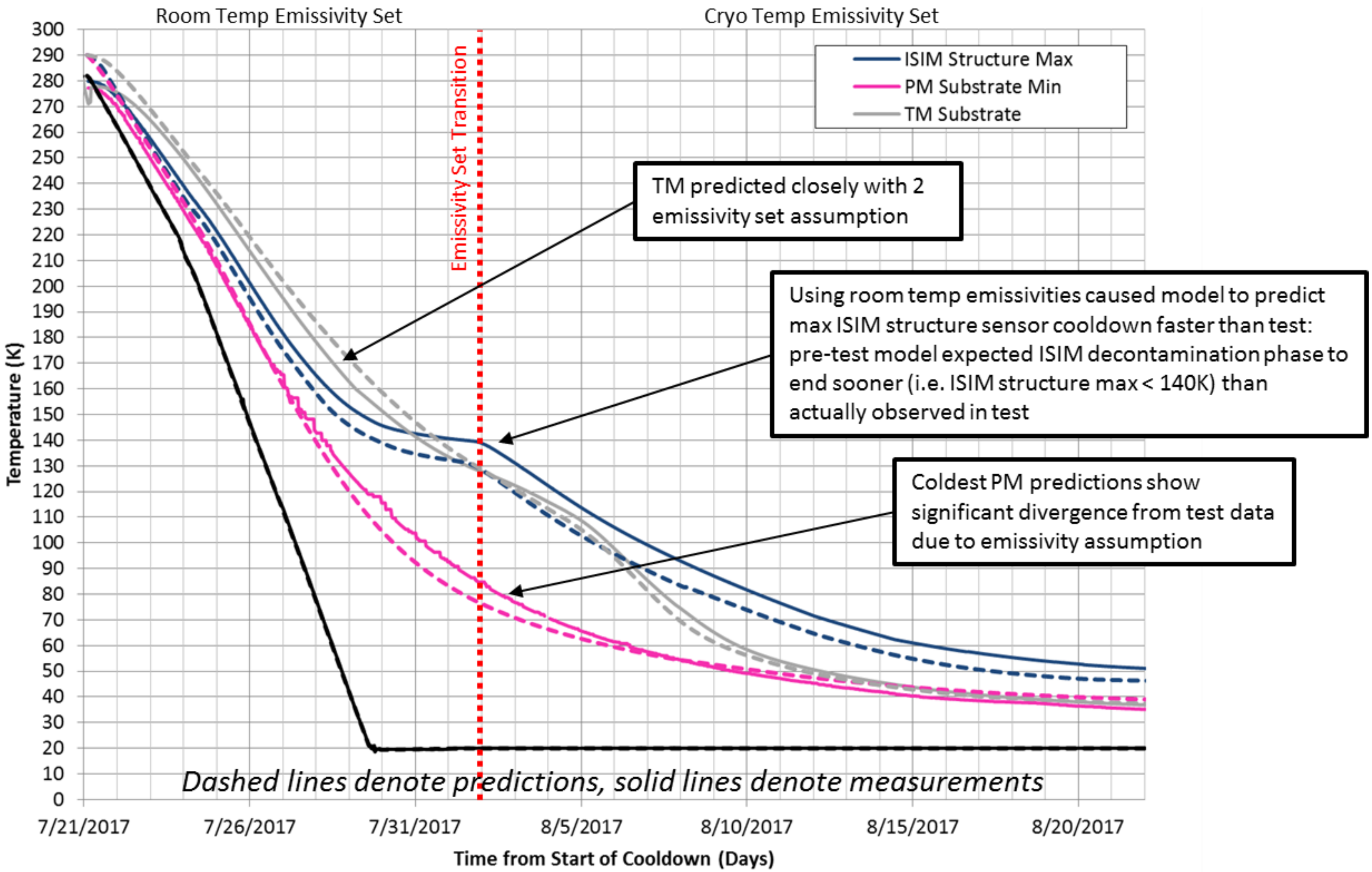


Discussion of Discrepancies between Model and Test: Cooldown

At Thermal Balance:

- IEC and DTA region predicted warmer in model than test
  - Blanket high ε* assumption resulted in more heat escaping from IEC warm electronics components via MLI: background sink temperature of modeled test environment was warmer than observed
  - Conservatively high copper conductance through harnesses caused more heat to flow into the IEC than assumed
- For faster runtimes in transient analysis, only two discrete emissivity sets (room temperature and cryogenic) were used, with an abrupt transition between emissivity sets when PMBSS average reaches 90K
  - However, temperature-dependent emissivity is a large driver of model accuracy in the transition regime between 60K and 170K
  - Generally, assumption of room temperature emissivities when PMBSS Avg > 90K cause model predictions to cool more rapidly than test, while assumption of cryogenic emissivities after PMBSS Avg < 90K cause predictions to transition slower than test (shown in plot on next page)

In-Depth Look at Emissivity Effects on OTIS CV Predictions



Discussion of Discrepancies between Model and Test: Thermal Balance and Warmup

At Thermal Balance:

- Max PMBSS temperatures diverged from as-predicted results due to LRM interface between BSF and IEC
  - Since IEC was 270K and BSF at interface was 80-90K, even small differences in conductance/material properties between model and actual hardware were enough to cause large temperature differences between model predictions and test measurements
  - The resultant model discrepancy was attributed to errors in assumed conductances across LRM joints and conservatively high composite conductance in BSF

On Warmup:

- Payload response was faster on hardware than in model predictions
  - Original pre-test analysis stacked worst-case conditions for schedule conservatism, and placed large margins on performance with respect to structural and contamination constraints to ensure hardware safety
  - In test, it was observed that components could maintain faster rate without violating constraints: overall warmup rate was accelerated

Conclusions and Recommendations from OTIS CV Modeling

- The extensive thermal modeling effort ensured that schedule was met and the payload was kept safe during the 100-day OTIS CV test
  - The model gave OTIS thermal engineers insight into payload behavior during transitions between ambient and cryogenic temperatures and understanding as to the driving L&Cs for each phase of test
  - Most of the discrepancies between model and test were due to conservative modeling assumptions and simplifications in the interest of runtime and test schedule
- From this effort, the following recommendations are made improving future system-level accuracy of test cryogenic thermal models:
  - For large-scale cryogenic systems, a modeling and analysis plan which trades analysis speed and geometric fidelity against accuracy should be developed
  - Use of more temperature-dependent emissivity sets between 60K and 170K greatly increases prediction accuracy this transition regime
  - Conservatism built into payload models consistently results in longer predicted transition times than observed
  - For interfaces with large gradients or temperature change vs. time, a greater number of test sensors is critical to understanding physical phenomena in case trends observed do not match pre-test predictions

Acknowledgments

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The OTIS CV Test Thermal Team

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