MSFC Thermal Testing Lessons Learned Course

Section 3: Lessons Learned from Protoflight StarBurst Instrument Thermal Vacuum Test

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Outline StarBurst Instrument Lessons Learned

StarBurst Instrument Protoflight Thermal Vacuum Test

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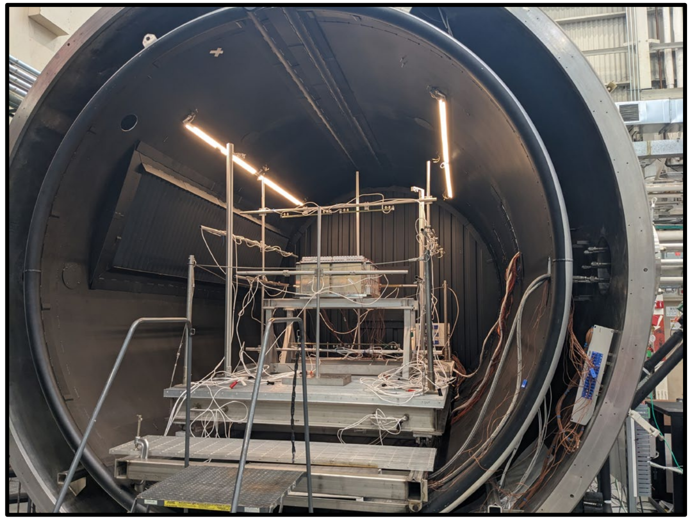
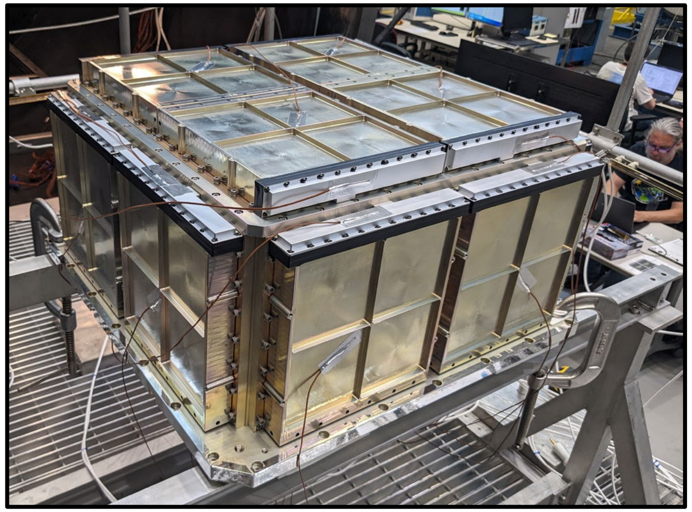
- Tailoring requirements
  - Parent document
  - Revised requirements
  - Justification
- Thermal Vacuum Test Overview
  - Planned thermal vacuum profile
  - As-run thermal vacuum profile
- Lessons learned
- Best practices summary

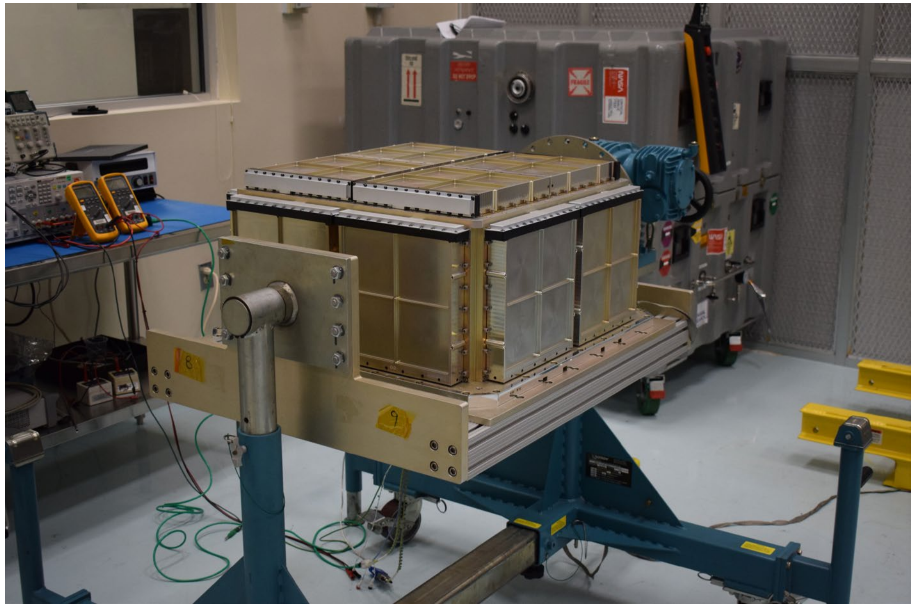




About StarBurst

- **The StarBurst Multimessenger Pioneer** is a small satellite with a highly sensitive and wide field gamma-ray monitor designed to detect the prompt emission of short gamma-ray bursts (SGRBs), a key electromagnetic signature of neutron star mergers.
  - Marshall Space Flight Center (MSFC) is the Principal Investigator (PI) institution and provides overall project management.
- **The StarBurst Spacecraft Bus** provides essential spacecraft operations including power, communication, guidance, and navigation.
  - The University of Toronto Institute for Aerospace Studies (UTIAS) Space Flight Lab (SFL) designed and built the spacecraft bus.
- **The StarBurst Instrument** mounts to the spacecraft bus and collects the science data using 12 Crystal Detector Units (CDUs) and associated electronics.
  - The Naval Research Lab (NRL) designed and fabricated the CDUs.
  - MSFC designed and fabricated the instrument electronics, performed the instrument integration and test, and provided instrument level thermal design and analysis.

https://science.nasa.gov/mission/starburst/

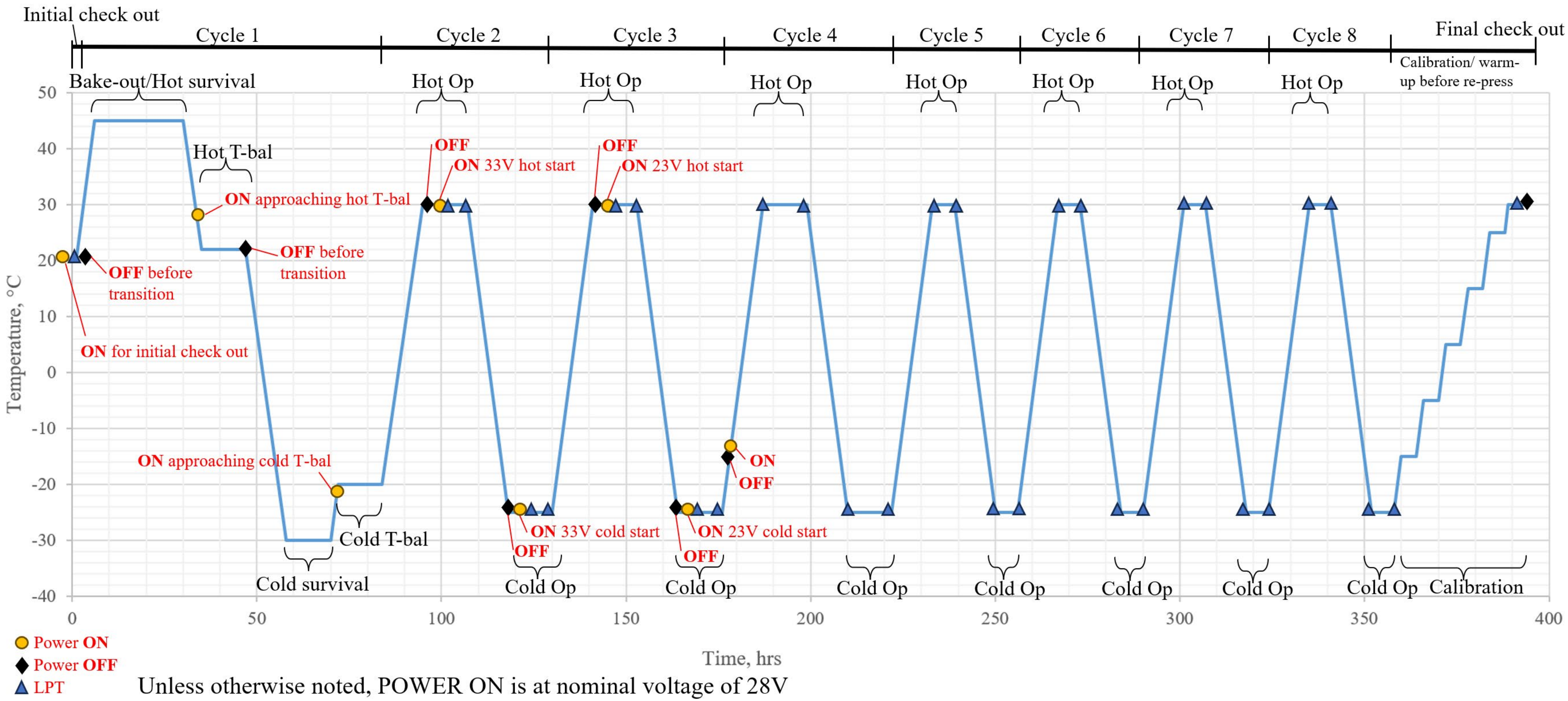


StarBurst Instrument at MSFC/4487/SLTF.

Tailoring of StarBurst Instrument Thermal Vacuum Test Plan

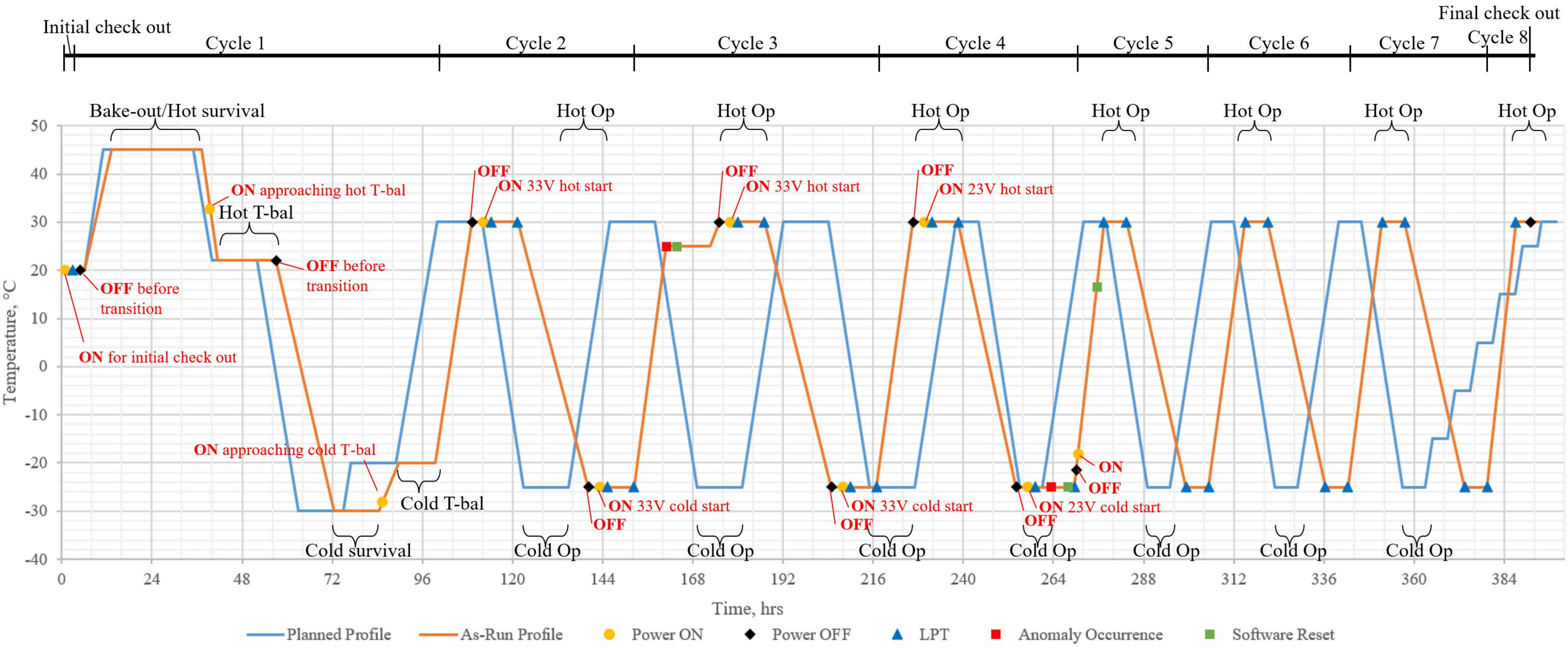
- Requirement parent document: General Environmental Verification Standard (GEVS)
  - Section 2.6: Vacuum, Thermal, and Humidity Verification Requirements
  - Protoflight test temperature range: maximum expected temperature range (including contingency required by design rules) +/- 10°C
  - Number of cycles for Subsystem/Instrument: A minimum of 4 thermal-vacuum temperature cycles
  - Duration of plateaus for Subsystem/Instrument: minimum of 12 hours at each extreme of each temperature cycle
  - Pressure: < 1 x 10^{-5} torr
  - Test demonstrations
    - Bakeout
    - Survival hot and cold
    - Temperature cycling
    - Thermal balance
    - Functional tests at each plateau
    - Operation over range of possible voltages
    - Hot and cold turn-on
    - 200 failure-free hours in vacuum
      - 100 trouble free hours of functional operations at the hot conditions in vacuum
      - 100 trouble free hours of functional operations at the cold conditions in vacuum
- Tailoring changes from parent document
  - Protoflight test temperature range: maximum expected temperature range (including contingency required by design rules) +8°C/ -10°C
    - **Justification**: reduces hot margin to prevent exceeding hot operational limit of CDUs
  - Number of cycles for Subsystem/Instrument: 8 total thermal-vacuum cycles: 4 full cycles (1 survival, 3 operational), 4 risk reduction cycles (all operational)
    - **Justification**: Survival cycle is counted toward number of instrument cycles to reduce cost and schedule impact. Cycles were increased because GEVS also recommends 4 cycles at the payload/spacecraft level of assembly and 8 cycles at the component/unit level of assembly. For StarBurst, 0 were performed at the component/unit level on the CDUs, and 1 cycle is planned at the payload/spacecraft level.
  - Duration of plateaus for Subsystem/Instrument: 12 hours for each full cycle, 6 hours for each risk reduction cycle
    - **Justification**: risk reduction cycles reduced to minimize cost and schedule impact. GEVS recommends 4 hours for component/unit level and 24 hours for payload/spacecraft level.
  - Failure free hours planned in instrument thermal-vacuum: > 200 hours total, hot plateaus = 60 hrs, cold plateaus = 60 hrs
    - **Justification**: Additional hours at thermal balance temperatures and during transitions of instrument level testing, additional hours at spacecraft level testing, Class D mission.

Planned T-Vac Profile



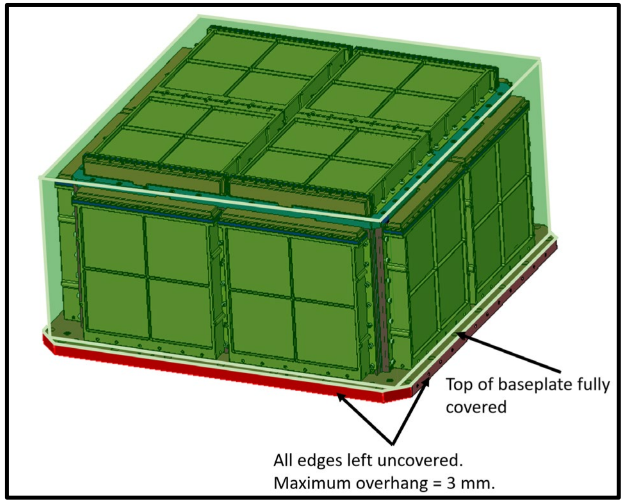
Unless otherwise noted, POWER ON is at nominal voltage of 28V

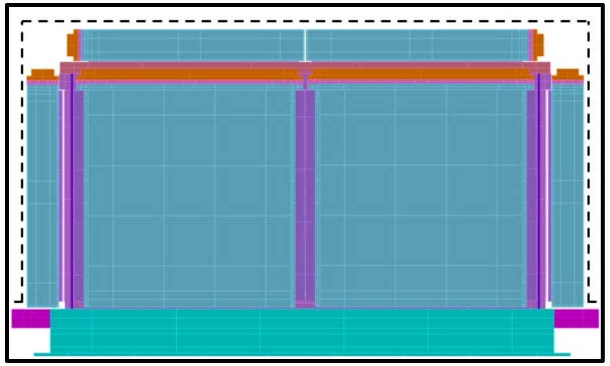
As-Run T-Vac Profile



Unless otherwise noted, POWER ON is at nominal voltage of 28V

- **Lesson Learned:** Understand rationale of temperature limit requirements.
  - The maximum temperature limit of the CDU was initially lower in requirements until asked if the equipment could operate at hotter temperatures.
  - Some temperature limits are perceived design solutions.
  - Questions to ask:
    - What is rationale of temperature limits?
    - Are temperature limits based on efficiency and/or performance or temperatures at which components will break?
    - Can components operate outside recorded temperature range for short periods of time and/or when science data is not being collected?
    - Can components operate outside recorded temperature range and still achieve the goals of the mission?
    - What does "operational" mean? (ex: when data is collected, when unit is powered on)
    - Have components been tested outside of recorded temperature limits?
- **Lesson Learned:** Changes to requirements or Interface Control Document (ICD) should be changed "officially" before assuming true.
  - Changes to the instrument keep-out-zone verbally agreed to could not be implemented after further review.
  - Changes to official documentation requires proper review and concurrence.



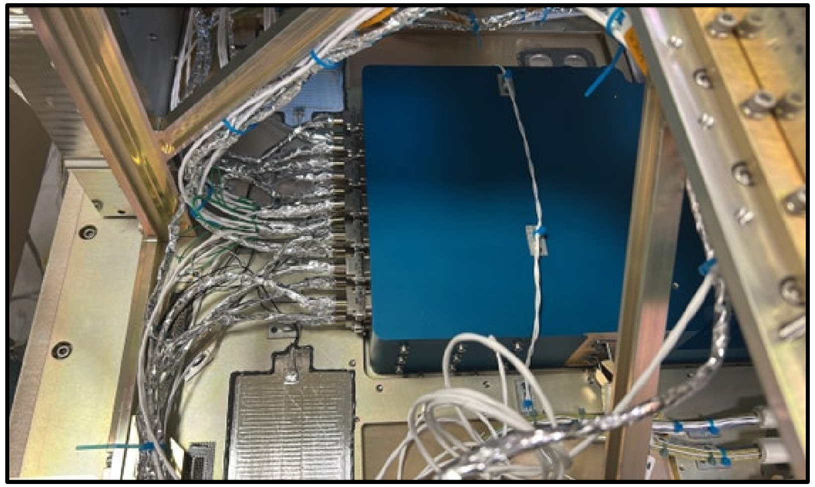


MLI Coverage Diagrams.

StarBurst Instrument Lessons Learned from Testing - Hardware

- **Lesson Learned:** Use flight hardware to measure and make templates when possible.
  - The thermal control tape templates were made based on CAD. One mistake was corrected by adjusting the tape pattern during assembly; however, the templates could have easily been checked against the flight hardware before cutting tape for assembly.
  - MLI final design was adjusted based on fit check observations.
- **Lesson Learned:** Compare hardware to documentation.
  - Pictures taken during assembly process revealed baseplate heaters to be in different locations than indicated in ICD.
  - Lay eyes on hardware as much as possible and request pictures when not possible.
- **Lesson Learned:** Some thermal contact assumptions are better than others.
  - Contacts through wedgelock calculations based on datasheets were higher than adjusted values correlated with test data.
    - Conduct developmental testing on mounting methods in critical areas.
  - Contact assumptions for bolted connections based on GE Handbook method did not require adjustment based on correlation to test data.

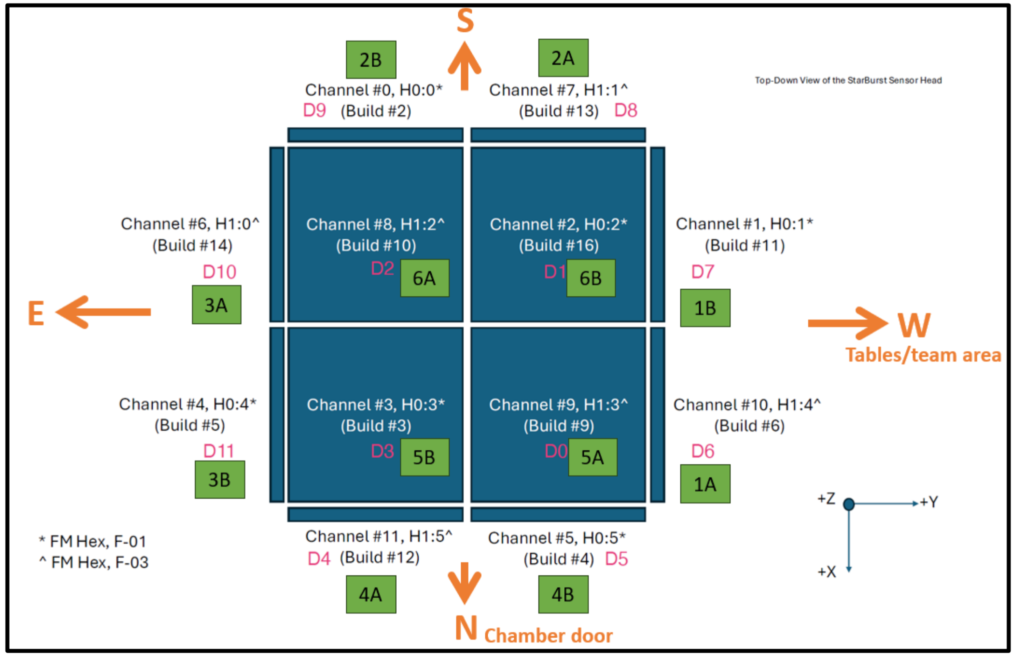
Tape applied to baseplate with patch circled.



Assembly mid harness install.

StarBurst Instrument Lessons Learned from Testing - Preparation

- **Lesson Learned:** Ensure consistent labeling of components between teams early on.
  - The instrument CDUs were labeled different by the fabrication team, science team, and thermal analysis model.
  - A consistent naming convention is easy to establish early to save time and confusion later.
- **Lesson Learned:** Ensure full test team is aware of operational needs and plans during thermal vacuum testing.
  - Instrument restarts were being performed to troubleshoot software during thermal balance because it was thought it wouldn't make a big difference.
  - Even if this is information provided to everyone beforehand, check with personnel operating equipment before critical test operations and each phase of test to ensure the team knows the expected procedure.



CDU labels key.

StarBurst Instrument Lessons Learned from Testing - Preparation

- **Lesson Learned:** Change as little as possible in environment outside of thermal vacuum chamber.
  - Changes to the instrument temperature were observed when facility high bay doors were opened.
  - Coordinate with facilities to change as little as possible and to alert test team to unavoidable changes to make as little impact as possible on the test.
- **Lesson Learned:** Prepare guidelines for on-shift personnel for off-nominal situations as much as possible.
  - Non-thermal related software anomalies occurred during StarBurst thermal vacuum testing.
  - At minimum provide instructions to safe hardware in holding pattern until further guidance can be provided and provide instructions on who to call if anomalies occur.
- **Lesson Learned:** Review and understand previous testing done on components or similar hardware.
  - Will inform test plans and priorities.
  - May reveal updates to previously assumed limitations.

StarBurst Instrument in test facility prior to t-vac test.

Best Practices Summary

- Understand temperature limits and thermal requirements. Ask questions!
- Changes to requirements or design assumptions should be tracked and updated in project-controlled documentation.
- Reference the actual hardware when possible.
  - When making templates and checking fit of thermal control hardware.
  - Compare to design documentation that models are based on and design assumptions.
  - If not able to view hardware in person, request pictures throughout assembly.
- Verify thermal contact assumptions
  - Adjust thermal model contacts when correlating analysis to test data.
  - Perform developmental testing on crucial interfaces early on.
- Establish consistent naming convention early in project.
- Ensure full test team is aware of planned test operations.
  - Remind personnel before critical operations.
- Change as little as possible in external test environment and coordinate with test facility if changes are unavoidable.
- Prepare off-nominal guidelines for support personnel.
- Review and understand previous relevant thermal testing.