ON-ORBIT THERMAL PERFORMANCE OF THE BIGELOW EXPANDABLE ACTIVITY MODULE

Presented By:

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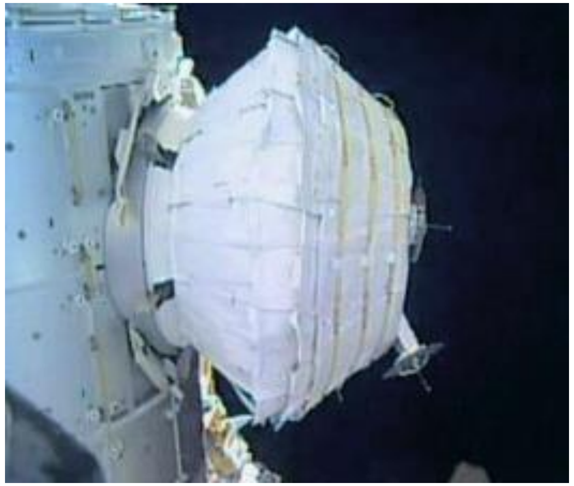
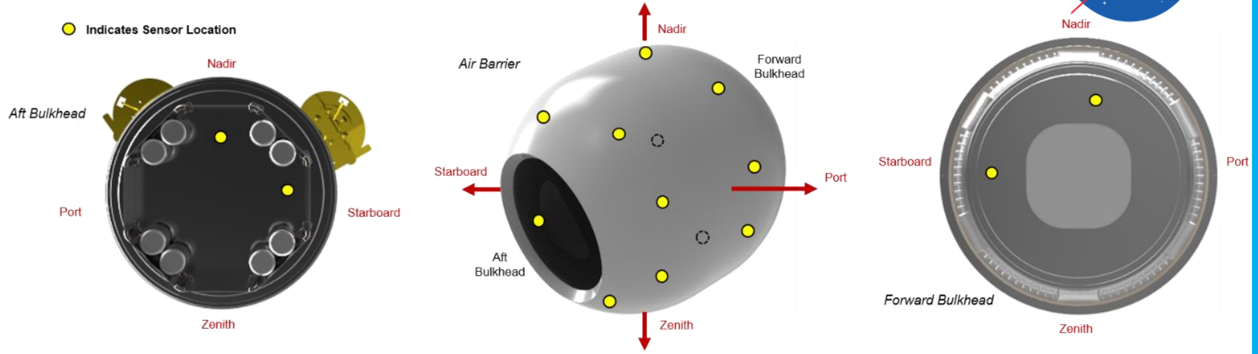
The Bigelow Expandable Activity Module (BEAM) project is co-sponsored by National Aeronautics and Space Administration (NASA) and Bigelow Aerospace (BA)

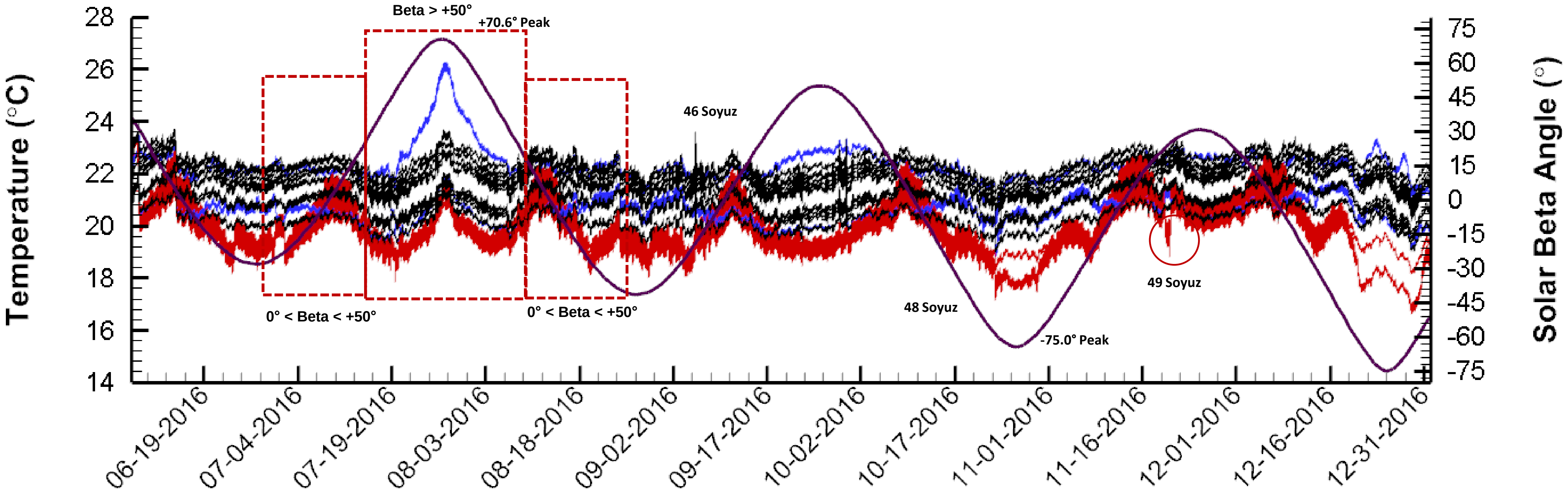
- BEAM supports the development of deep space habitats and expandable structures for human missions beyond Earth orbit.
- It was launched on the eighth SpaceX Commercial Resupply Service Mission (CRS-8) and was berthed to the Node 3, aft port, of the International Space Station (ISS) on April 18, 2016. Expansion of the module began May 26, 2016 and ended on May 28, 2016.
- The mission duration was a two-year test period in which astronauts aboard the space station conducted a series of tests to validate overall performance and capability of expandable habitats.

2016 WTS RESULTS (ALL SENSORS)

- Temperatures are recorded by the wireless temperature sensors (WTS) in sixteen locations
- Data below represents the first year of the BEAM mission
  - Data points are recorded every minute at each location and data sets are downloaded from ISS on monthly increments

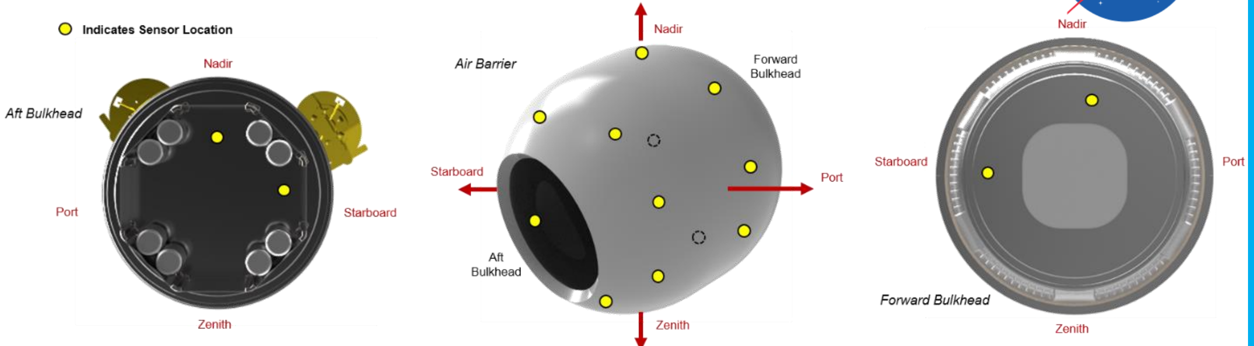


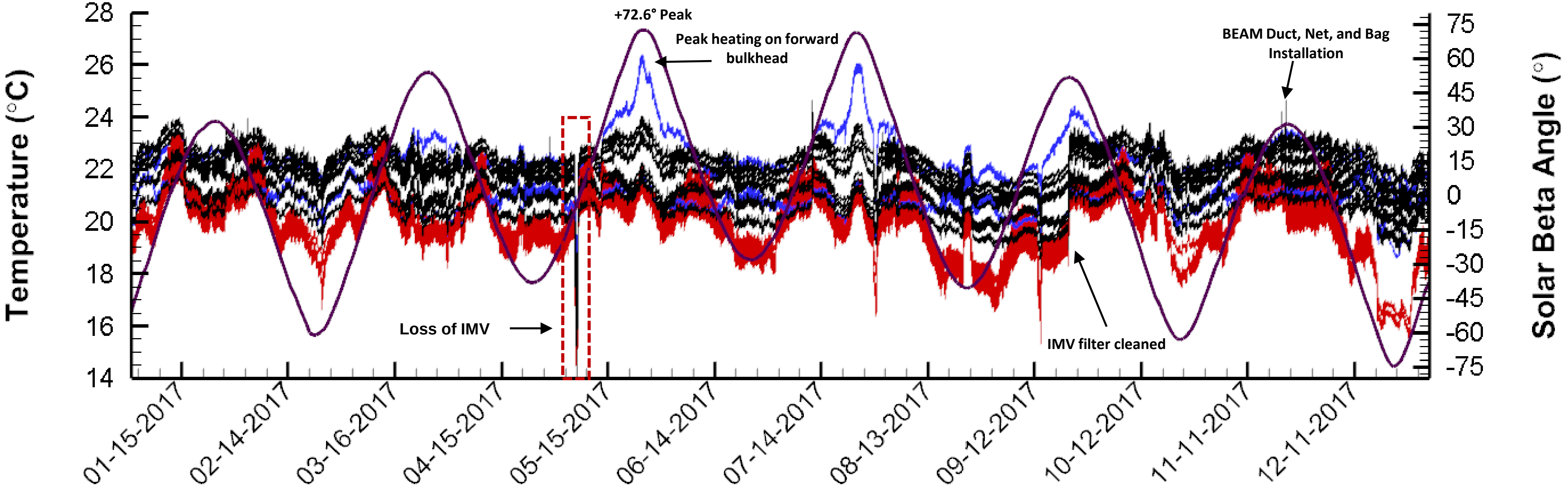


AFT BULKHEAD WTS | FWD BULKHEAD WTS | AIR BARRIER WTS | SOLAR BETA ANGLE

2017 WTS RESULTS (ALL SENSORS)

- Data below represents BEAM mission in 2017

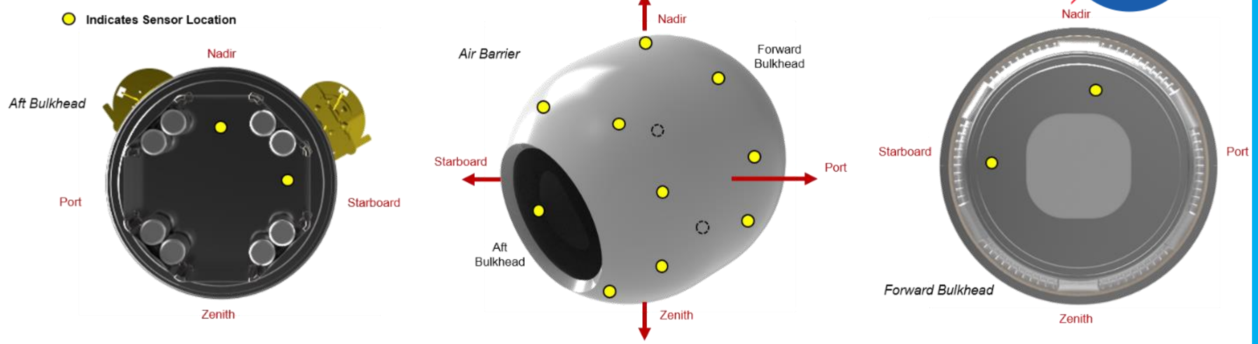


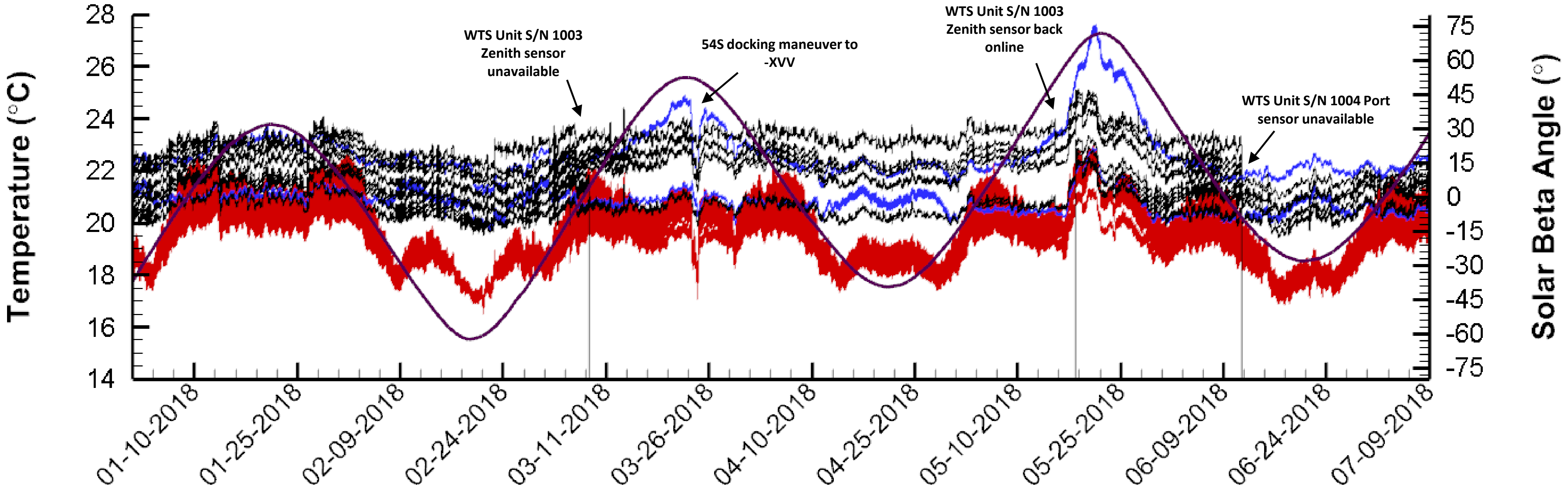


AFT BULKHEAD WTS | FWD BULKHEAD WTS | AIR BARRIER WTS | SOLAR BETA ANGLE

2018 WTS RESULTS (ALL SENSORS)

- Data below represents the BEAM mission in 2018 (with life extension)

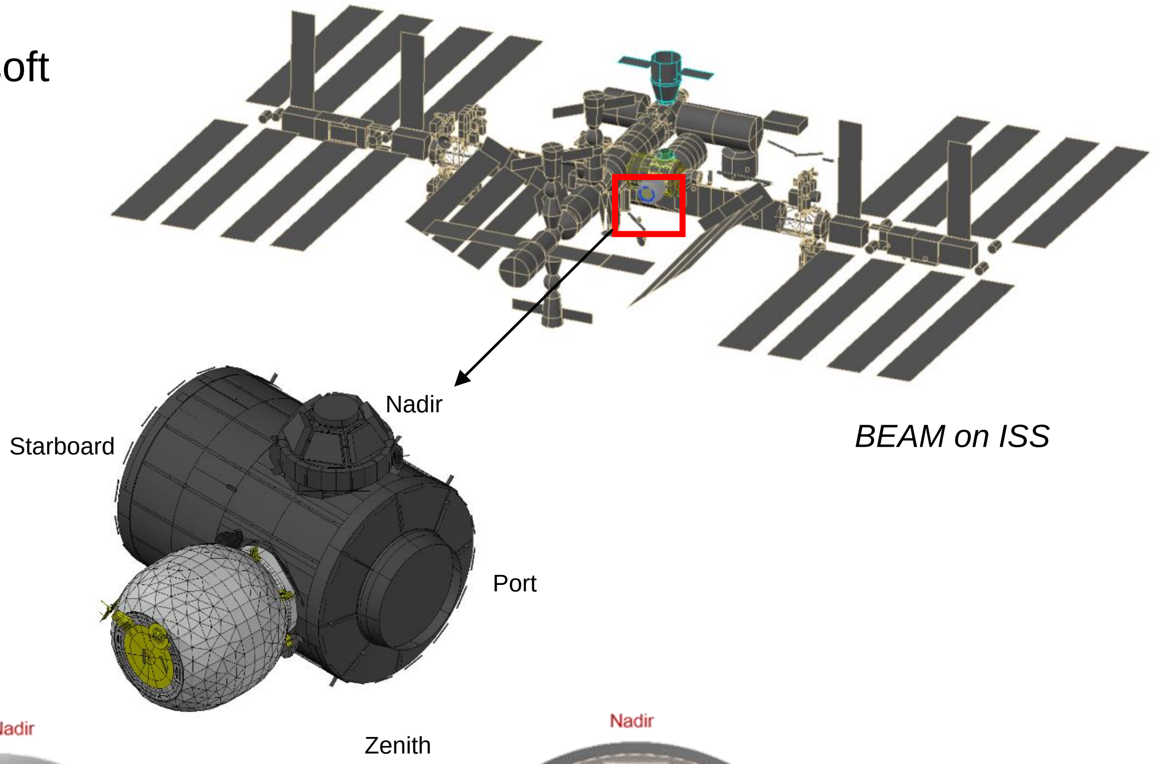




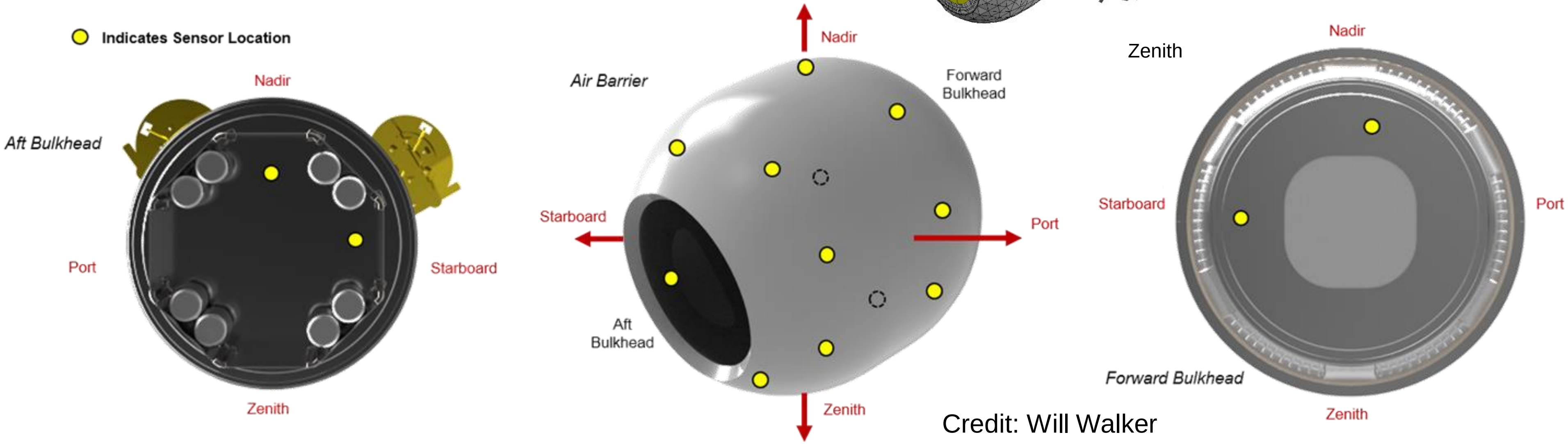
AFT BULKHEAD WTS | FWD BULKHEAD WTS | AIR BARRIER WTS | SOLAR BETA ANGLE

Expanded BEAM Assembly

- Two metal bulkheads, an aluminum structure, and layers of soft fabric with spacing between layers
- Internal restraint and bladder system
- Expanded volume ~13.16 ft and 10.5 ft in diameter: 565 ft^3
- Mass ~3,000 lbs
- Configured with various sensors/monitors
    - Dynamic Deployment Sensors (DDS)
    - Radiation Environment Monitor (REM) sensors
    - Radiation Area Monitor (RAM) sensors
    - Distributed Impact Detection System (DIDS) sensors
    - **Wireless Temperature Sensors (WTS) (shown below)**
    - Resistance Temperature Detectors (RTD)



BEAM on ISS



Credit: Will Walker

Background:

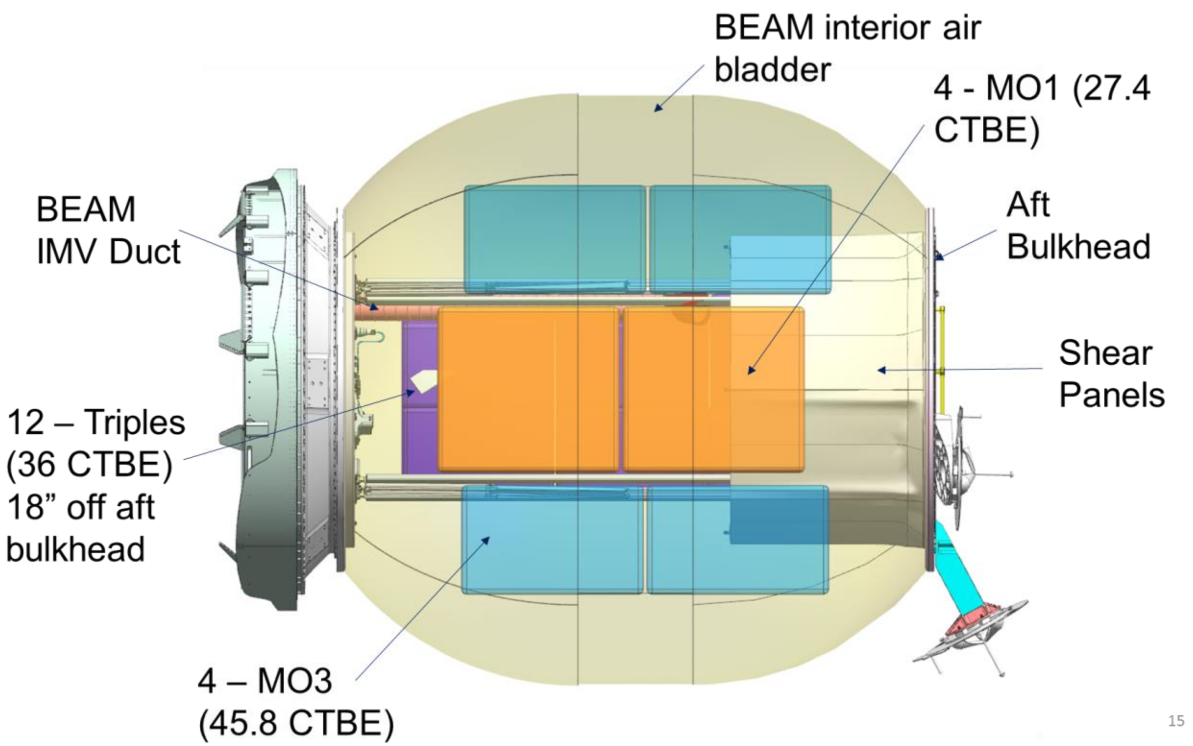
- ISS program extended BEAM life (from original 2 year certification) to help alleviate some of the stowage issues onboard
- Current BEAM Thermal Desktop model (integrated with ISS v7r1) was updated to reflect stowage configuration
    - 20 “boxes” were added to represent the 109 Cargo Transfer Bag Equivalent (CTBE)

Objective:

- Compare date specific thermal analysis results of BEAM with stowage against dew point temperature limit (~11 °C)
- Assess the impacts of IMV loss on stowed items

Methodology:

- Model preparation on SpaceClaim
- Changes to the Original BEAM TD Model

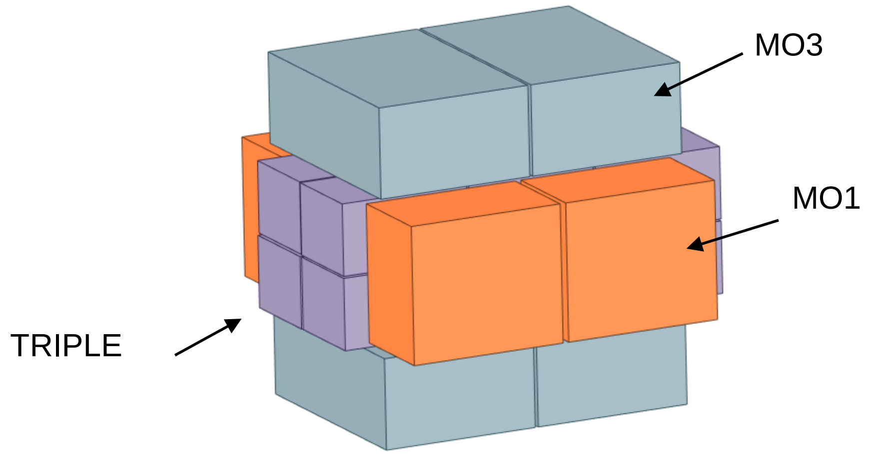


Part 1:

- Create detailed Thermal Desktop model developed to predict transient on-orbit temperature profile for all component

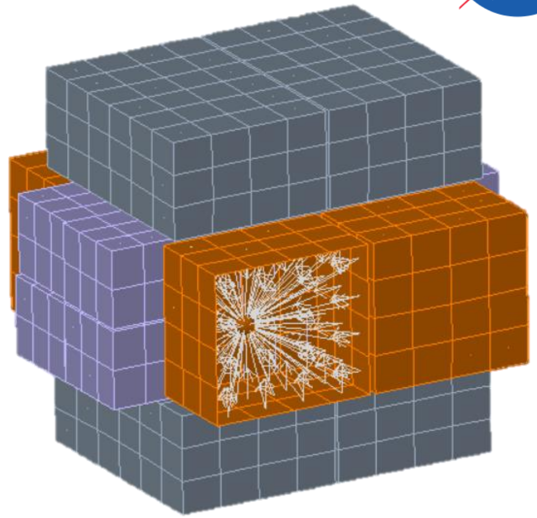
SpaceClaim Model Preparation

Submodels	Domain Tag Sets	Radiation Analysis Groups	Meshing Parameters	Properties
• CAD of CTBE surfaces prepared in SpaceClaim • Geometry defeaturing • Submodels created • Domain Tag Sets for internal/external surfaces	• Inside surfaces of boxes connected to mass nodes • External surfaces of boxes connected to the flow network	• External box surfaces identified for inclusion with BEAM internal radiation analysis group	• Created structured meshes in SpaceClaim	• Thermophysical and Optical Properties of the bags

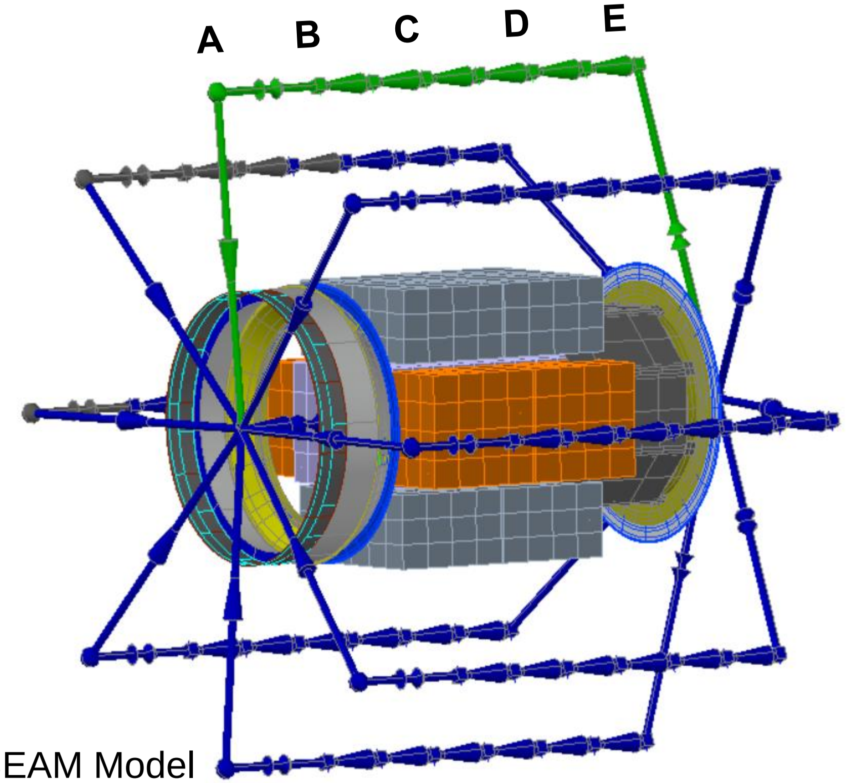


Part 2:

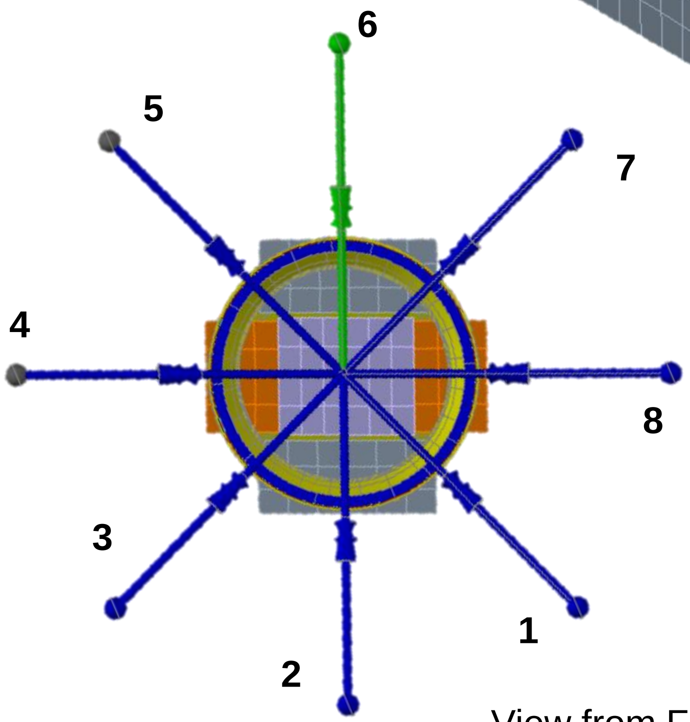
- Deleted Submodels representing removed hardware
- Imported stowage model from SpaceClaim via TD Direct
- Added Internal Mass Node for each CTBE
- Connected diffusion nodes to the internal surfaces (see image) with conductor
- Connected to the airflow network



Bag Properties
Conductivity = 0.103 W/mK
Density = 44.9481
Specific Heat = 0.92 J/gK

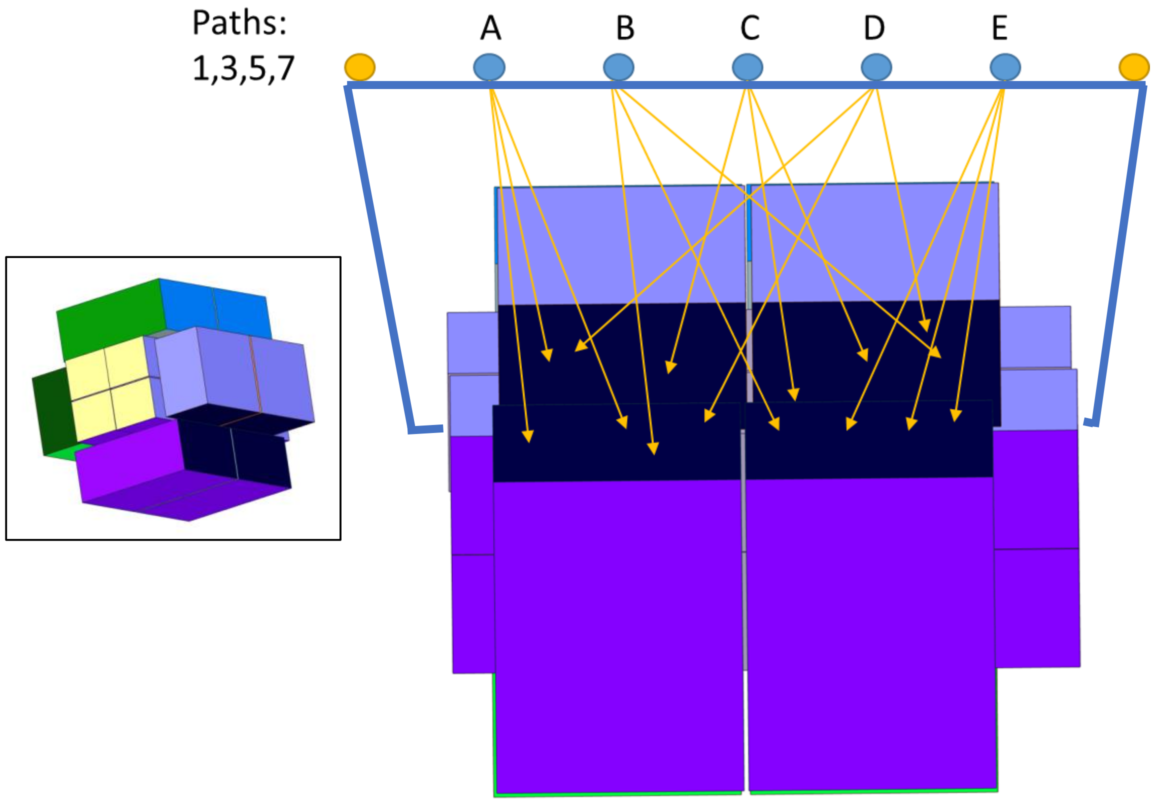


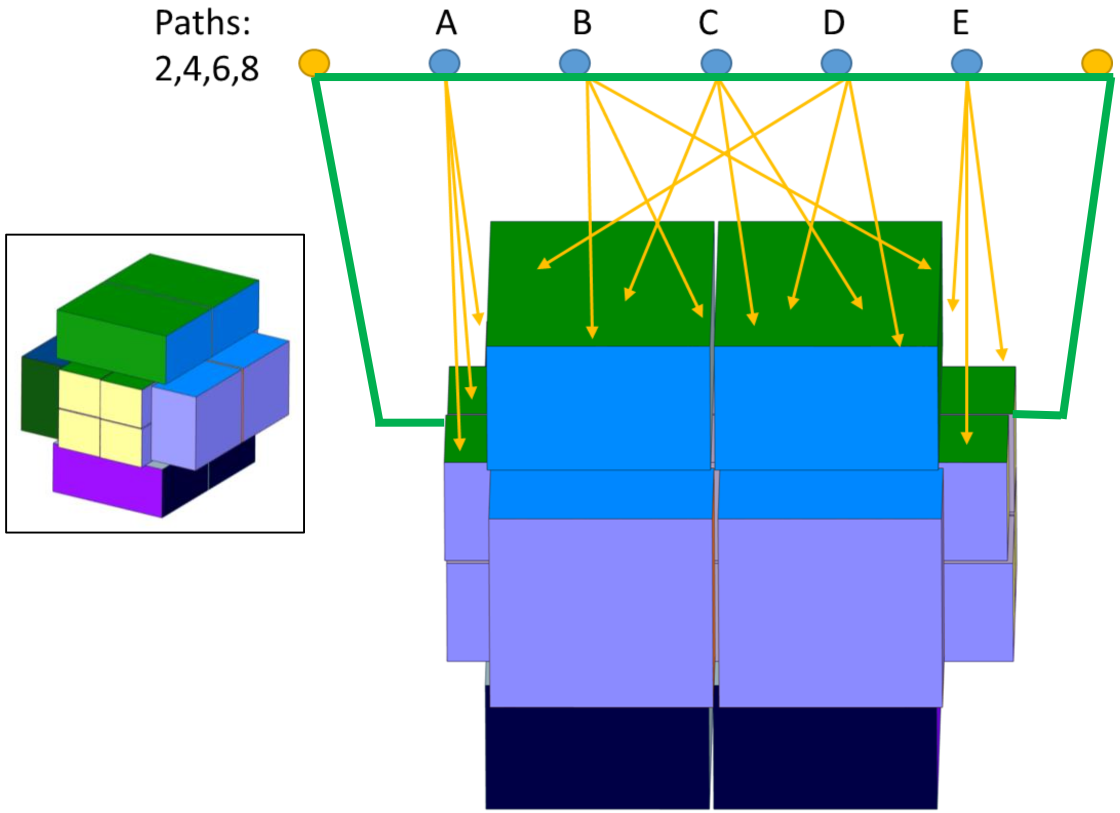
Stowage in BEAM Model
with Flow Paths shown



View from Forward
Bulkhead

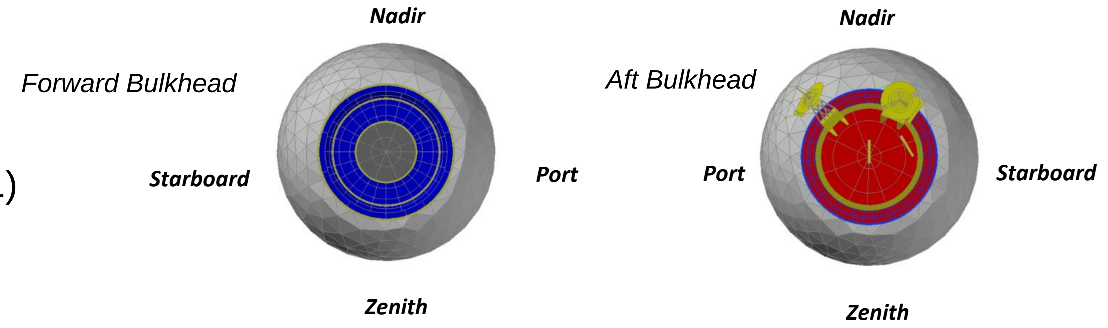
Integration:
- Created ties to connect CTBE external surfaces to existing flow network
- Value of the tie to the box surfaces matches the value of the tie to the BEAM internal surfaces – place holder until CFD values become available

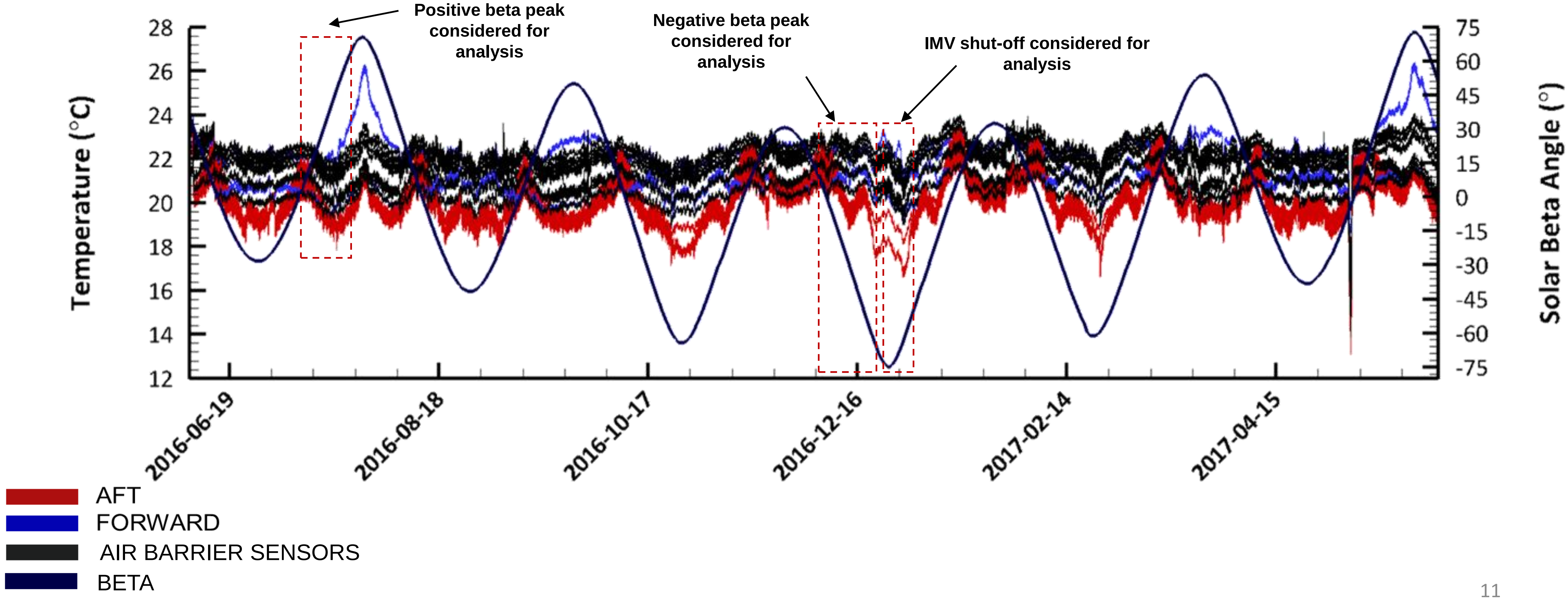




DATE SPECIFIC ANALYSIS PARAMETERS

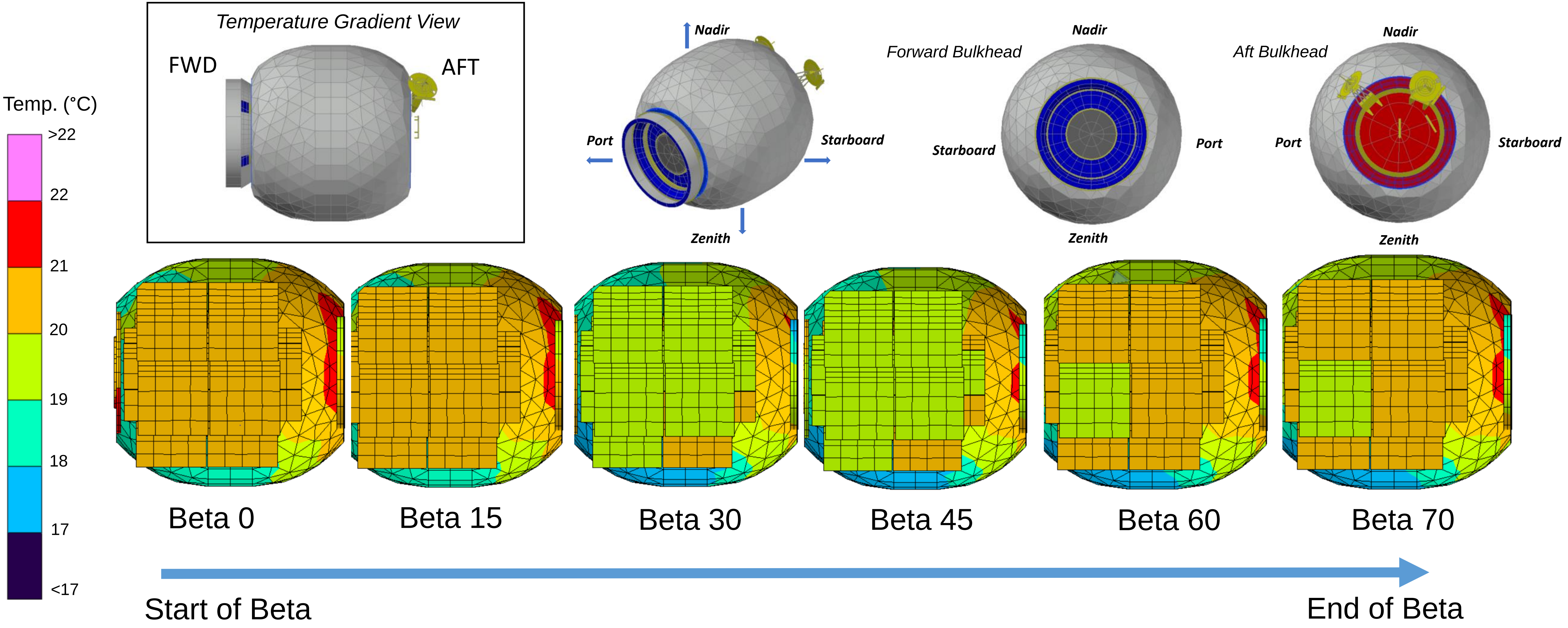
- Date specific thermal analysis was conducted with an integrated Thermal Desktop (TD) model of the BEAM and the NASA Passive Thermal Control Systems (PTCS) International Space Station (ISS) simplified TD model (Version 7 Revision 1)
  - The integrated model also employs a TASI provided detailed N3 model
  - Mean IR: 65 BTU/hr/ft2 and Albedo: 0.2
  - Date specific direct solar radiation
  - EOL ISS optical properties





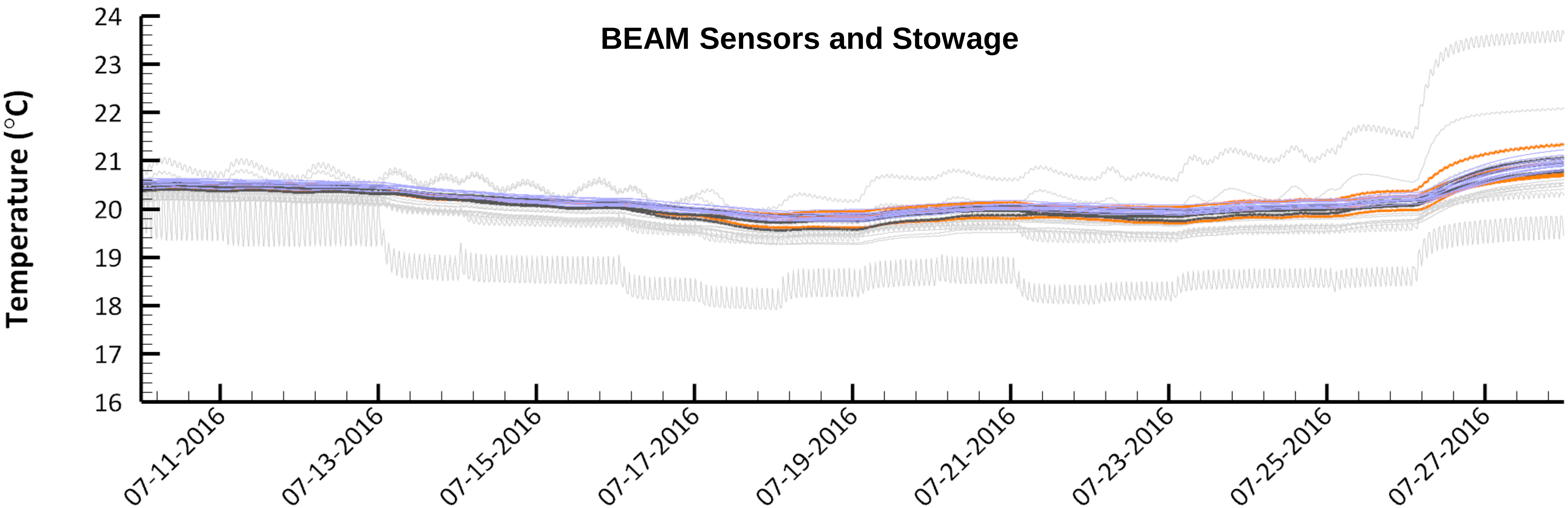
STOWAGE TEMPERATURE GRADIENT: POSITIVE BETAS

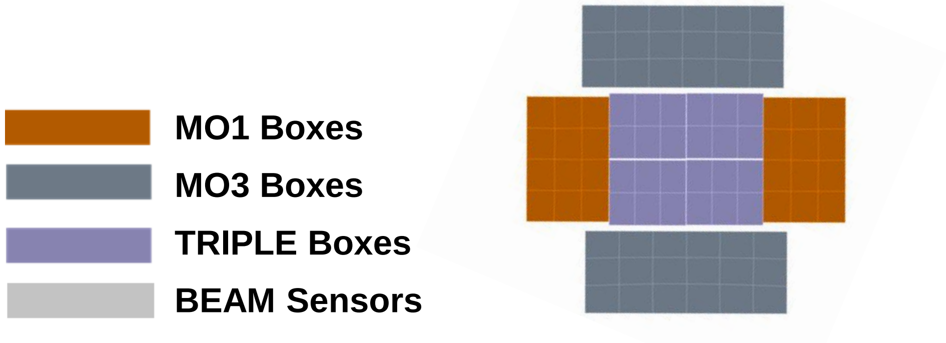
- Dew point in BEAM is 11 °C



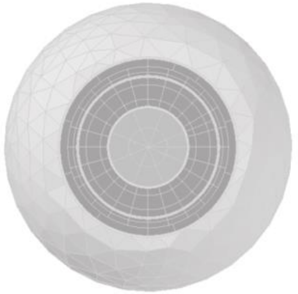
DATE SPECIFIC ANALYSIS: POSITIVE BETAS

- 07-09-2016 to 07-28-2016 (GMT 191 to GMT 210) with a solar beta range from 0° to +70.6° (positive beta peak analysis)





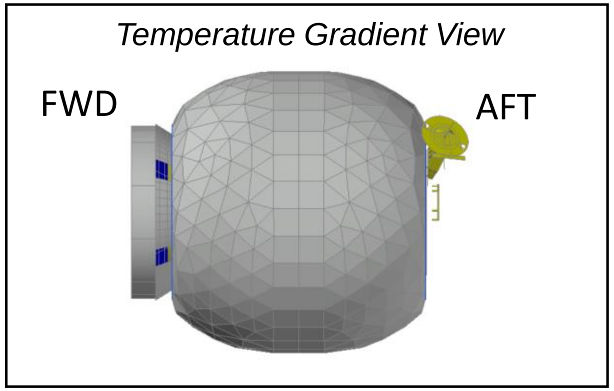
CTBE Boxes

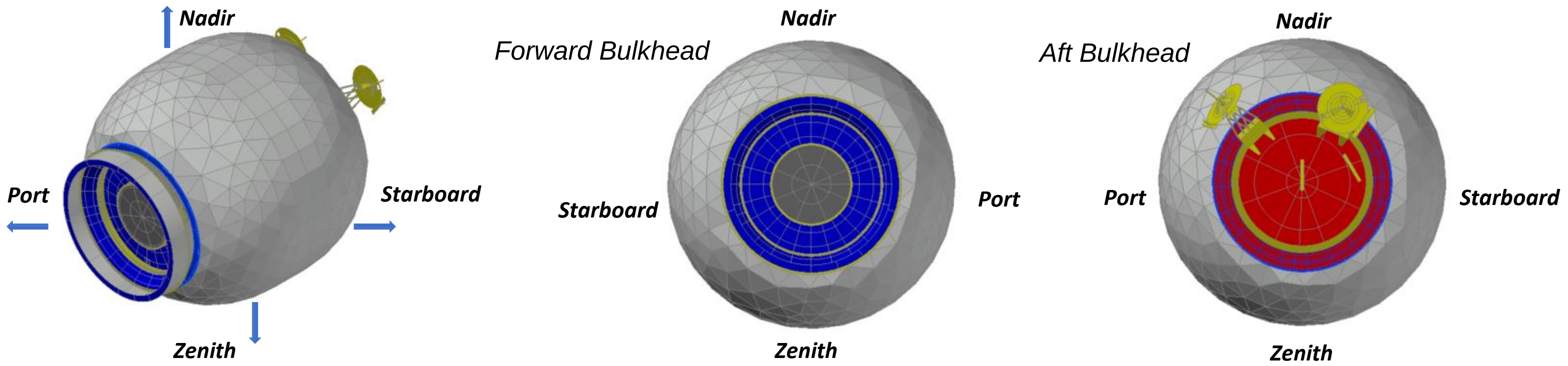


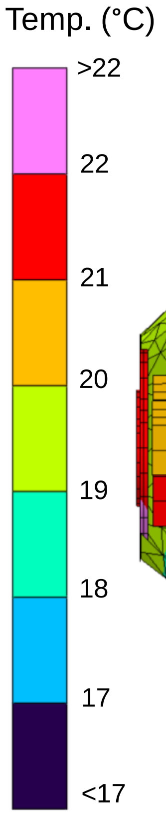
Forward Bulkhead

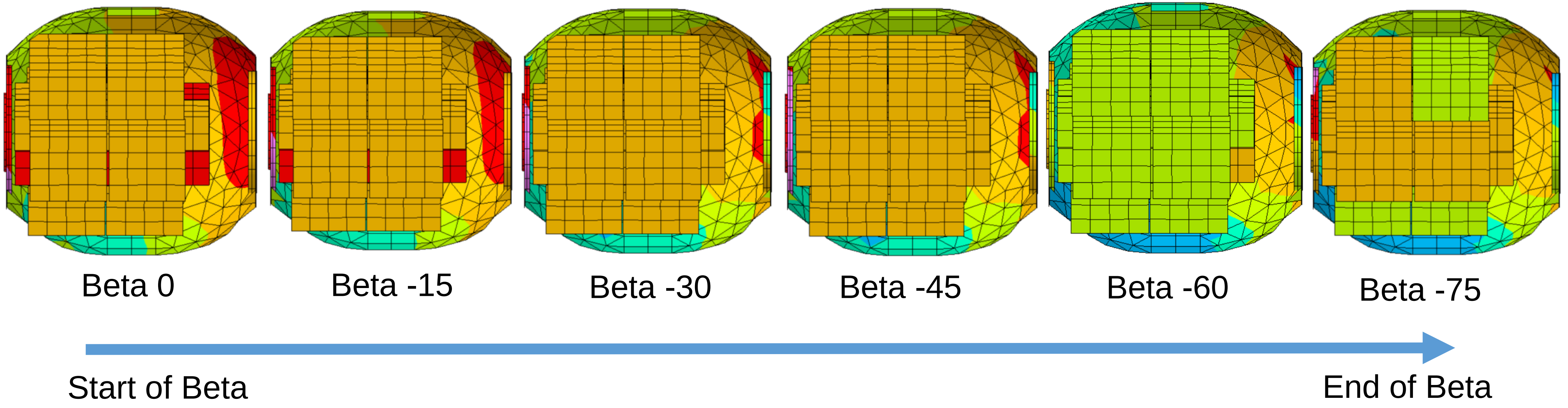
Aft Bulkhead

- Dew point in BEAM is 11 °C

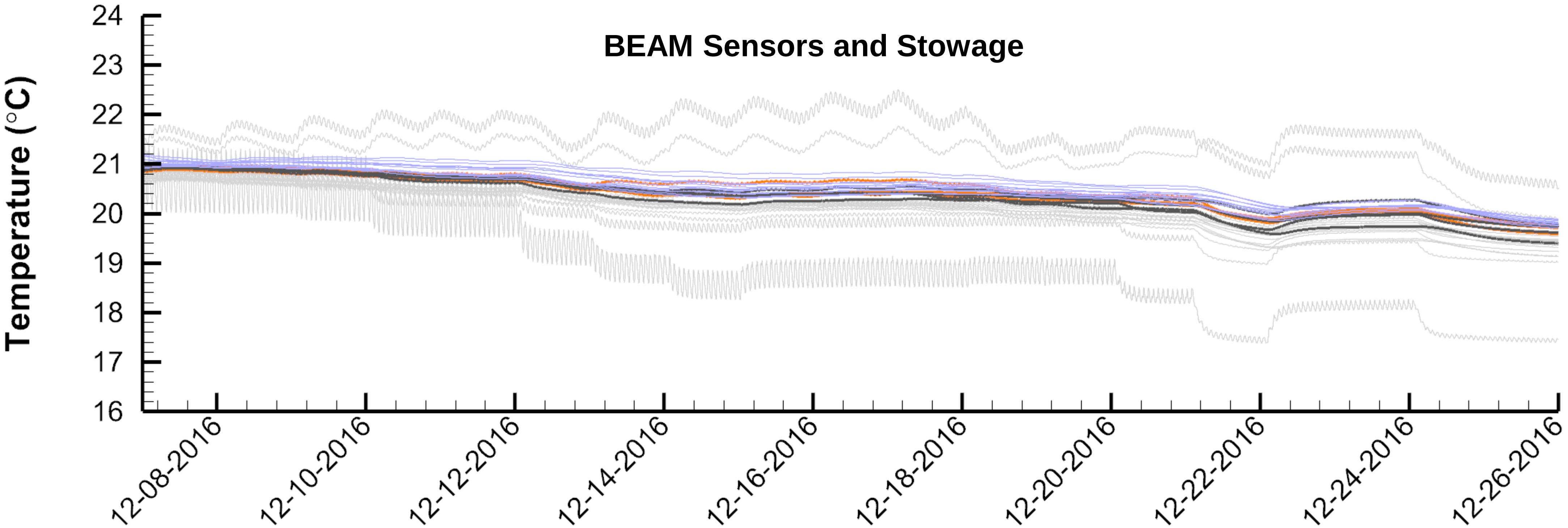


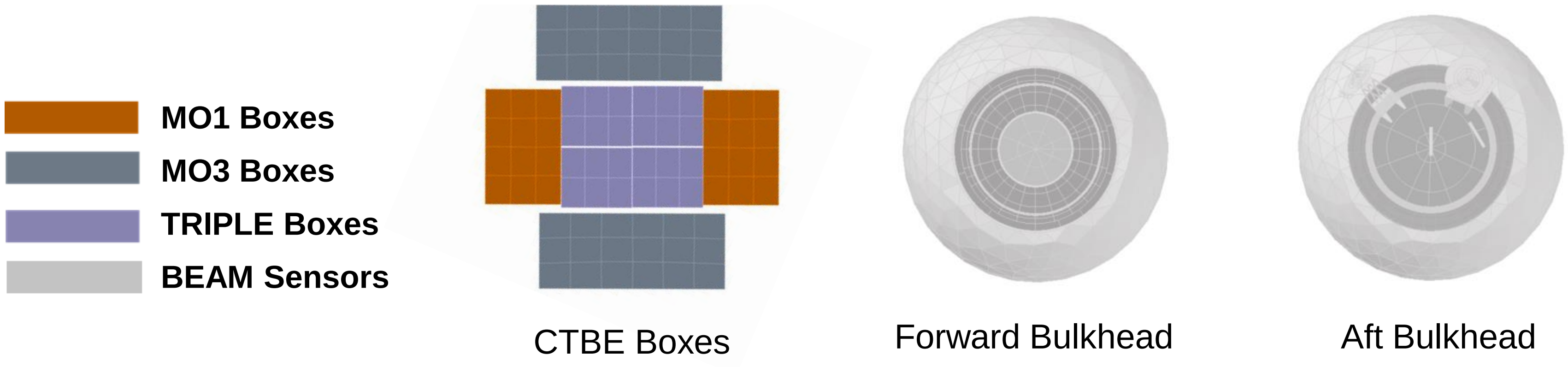






- 12-07-2016 to 12-25-2016 (GMT 342 to GMT 360) with a solar beta range from 0° to -75.0° (negative beta peak analysis)



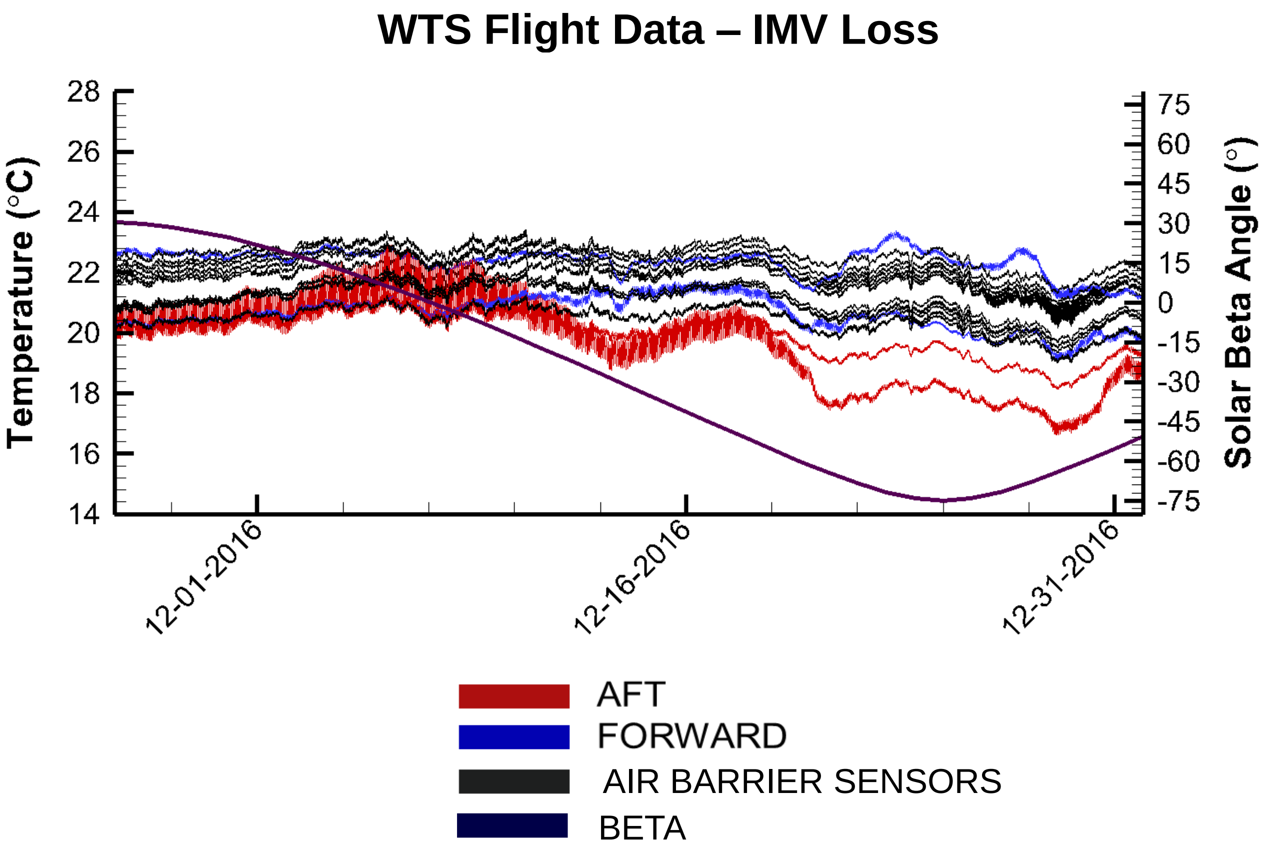


Impacts

- IMV shutdown can be caused by Rapid Depress, Node 3 fire, manual fire or Tox alarm, flow blocked due to clogged filter or EVA powerdowns
- Low temperatures start at the aft bulkhead and some locations on the port wall. Heat transfers through radiation and conduction across the air gap, through the bags
- BEAM contains between 3 to 5 oz of moisture. Anywhere the temperature drops below the dew point, condensation will form.
- There is an unknown impact of condensation on electronics. Moisture can wick into tight spaces and isn't guaranteed to evaporate when IMV is returned.

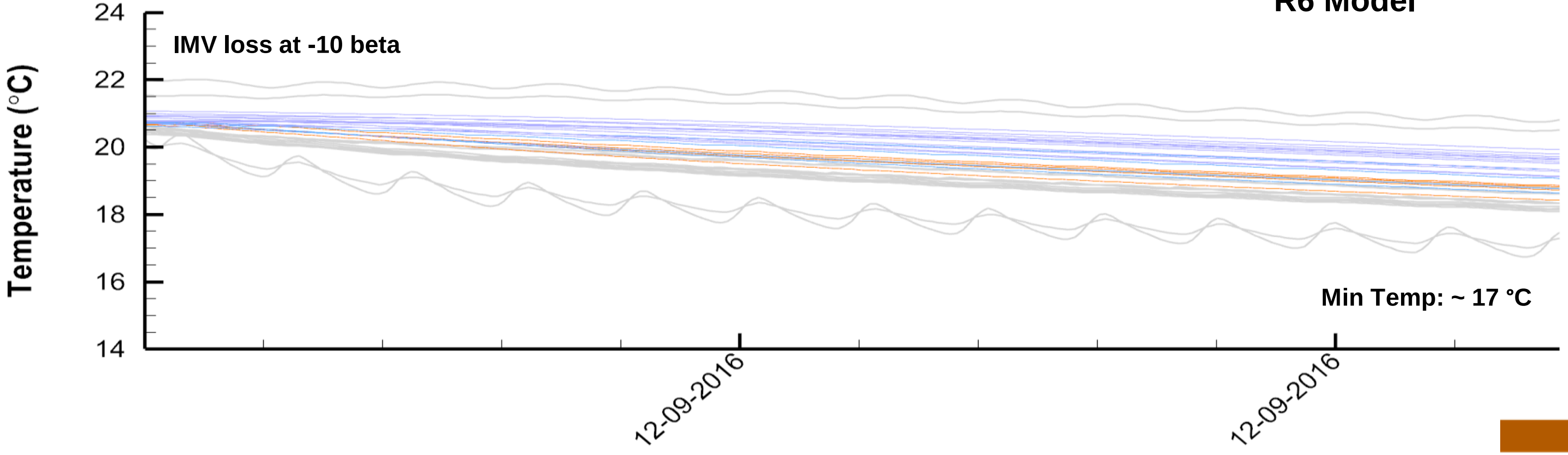
Modeling Approach

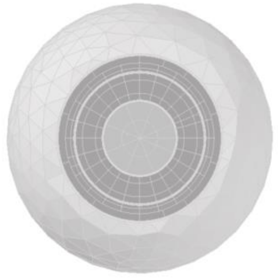
- Shut down nominal 120 cfm air flow to 0
  - Selected case, Beta -10
  - Selected worst case, Beta -75



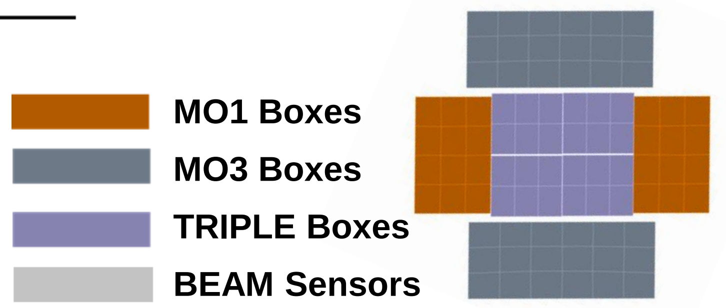
IMV Loss with CTBE Boxes

R6 Model





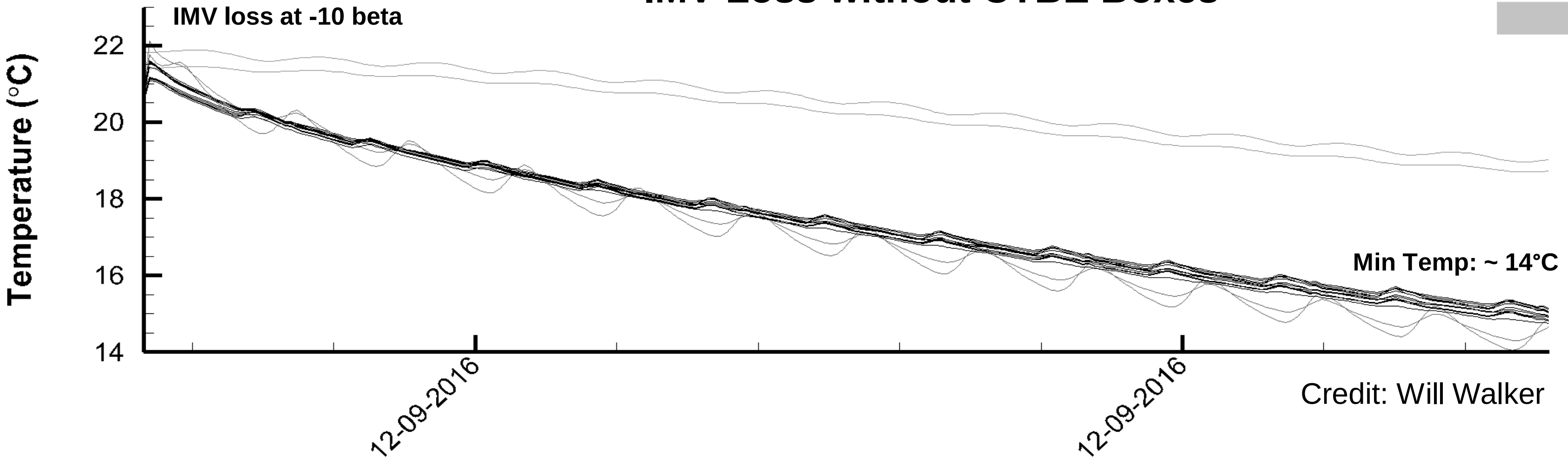
Forward Bulkhead



CTBE Boxes

IMV Loss without CTBE Boxes

R4 Model

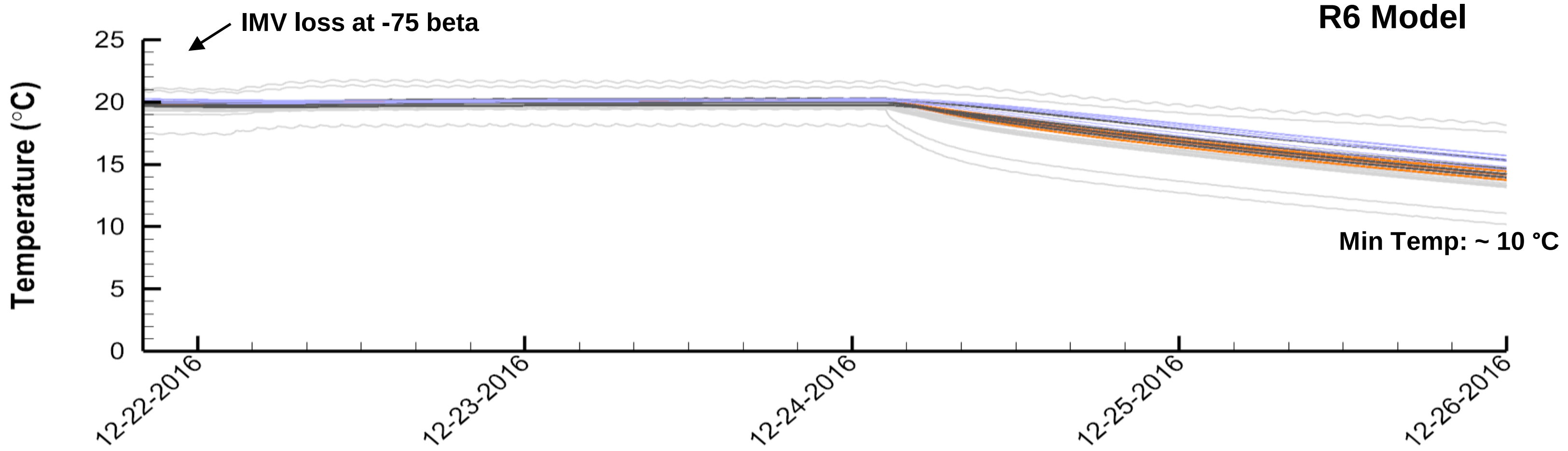


Credit: Will Walker

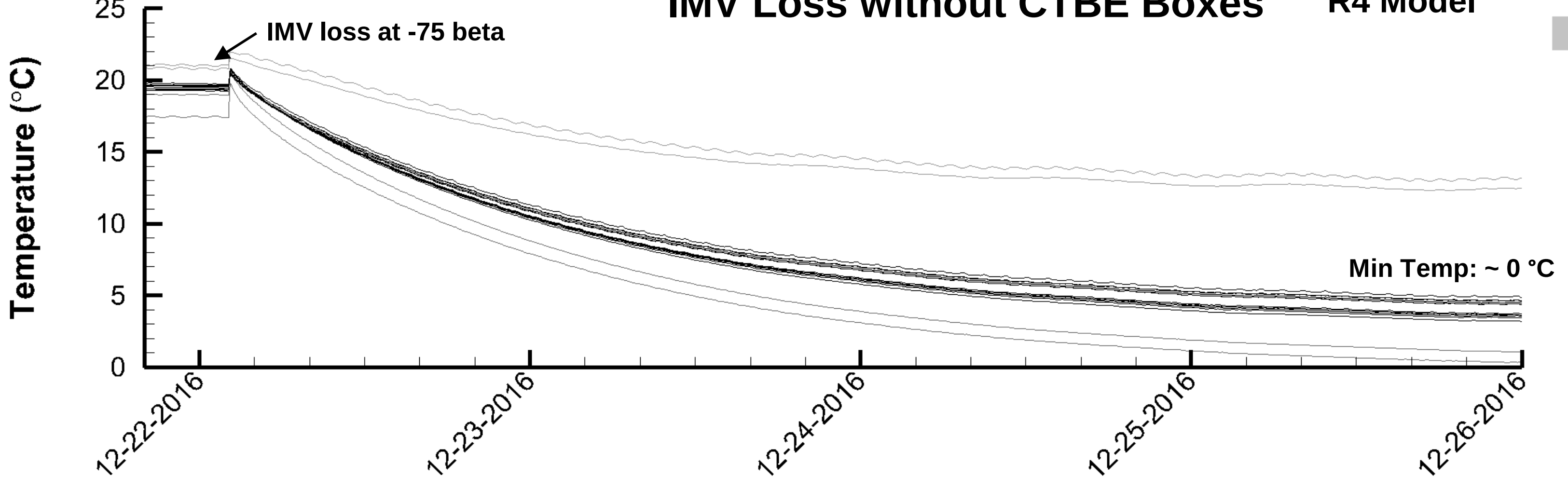
Aft Bulkhead

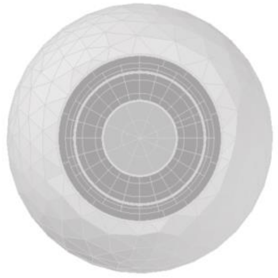
WORST CASE IMV LOSS COMPARISON

IMV Loss with CTBE Boxes



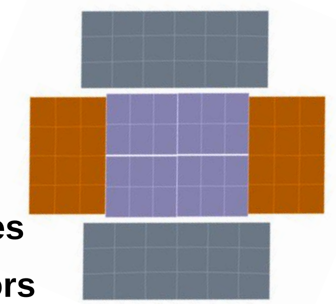
IMV Loss without CTBE Boxes





Forward Bulkhead

MO1 Boxes
MO3 Boxes
TRIPLE Boxes
BEAM Sensors



CTBE Boxes

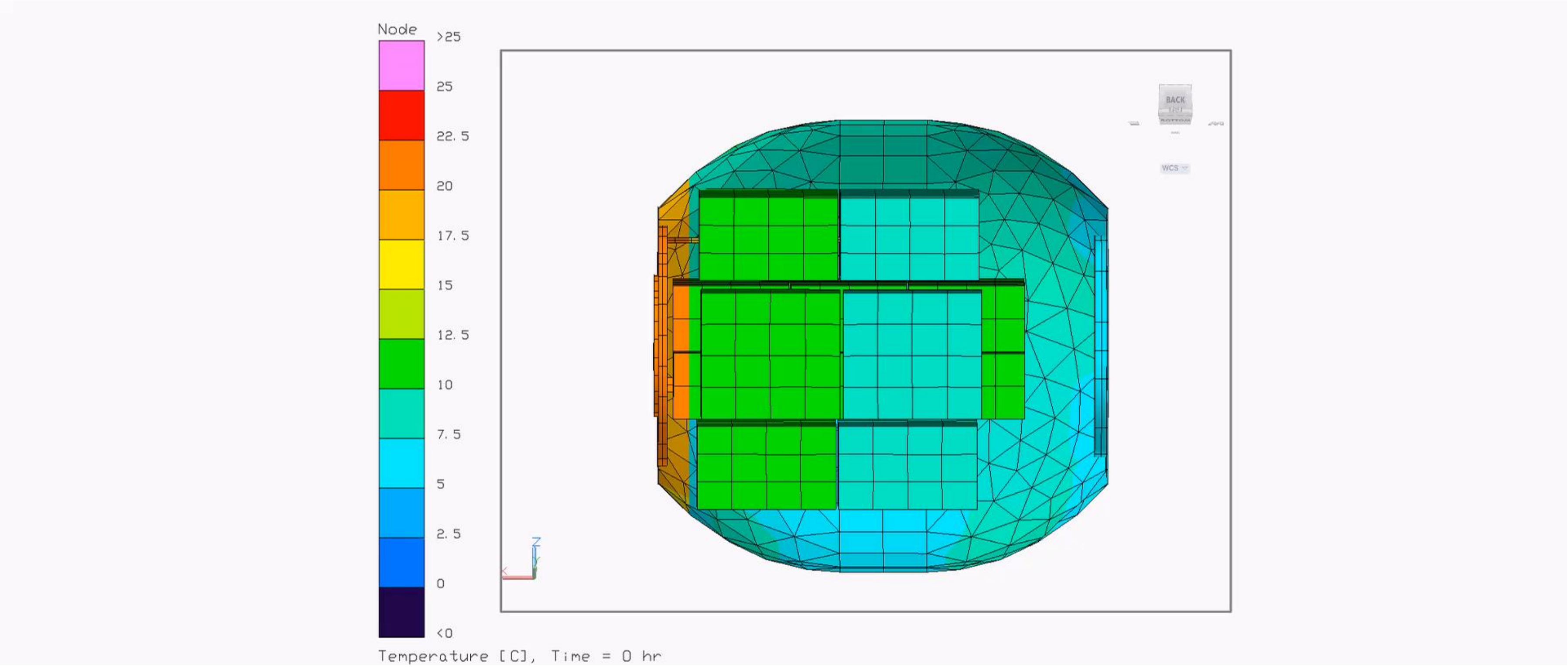
Aft Bulkhead

Credit: Will Walker

IMV LOSS CONCLUSION

- Flight data suggests temperatures could have dropped to low as 17°C had the IMV flow remained off indefinitely with a solar beta of -10°
- Temperatures could have dropped as low as 10-11°C had the IMV flow remained off indefinitely with a solar beta of -75°

Time Lapse of Worst Case IMV Loss

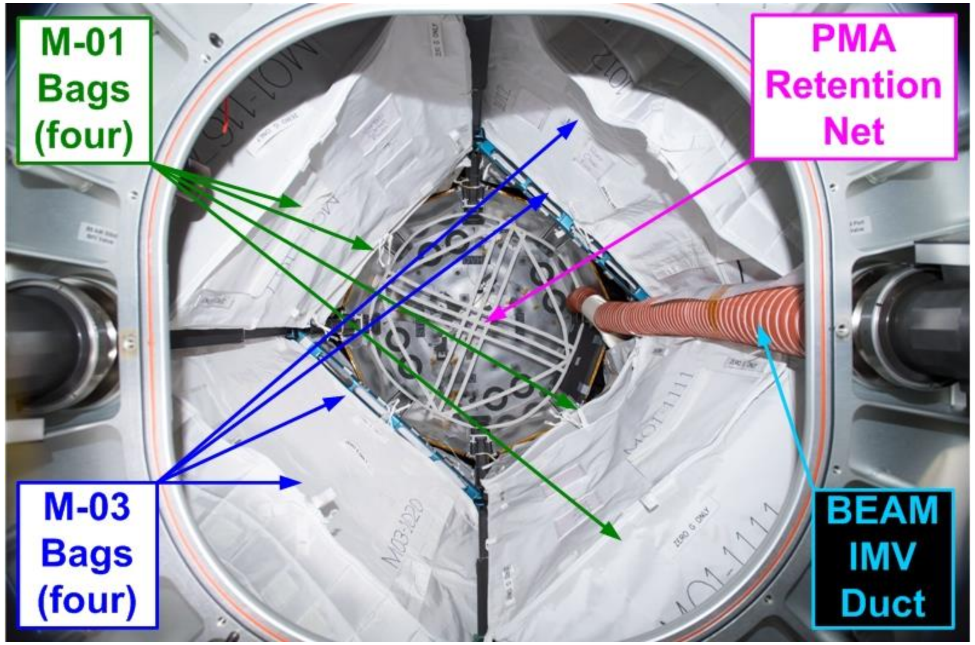


Conclusion

- All thermal environments the BEAM will experience are shown with these results
- We do not expect condensation to form on the bags
- Use of BEAM for stowage will free an equivalent space of about 3.7 to 4.4 International Standard Payload Racks, enabling more space in the ISS for research
- BEAM Stowage begins September 2018

Future Work

- Determine whether the ventilation through the BEAM provides adequate thermal control for the 109 CTBE configuration
  - Find the lowest allowable airflow for condensation control
  - Ensure that the cargo temperature limits are maintained
- Define new cleaning schedule for IMV ducts
- Incorporate CFD heat transfer coefficients from stowage to model



BEAM Stowage – BEAM Hatch Removed

THANK YOU

NASA Johnson Space Center

Bigelow Aerospace

BEAM Team

- **Will Walker**
- **John Iovine**

Thermal Design Branch/ES3

TFAWS Committee

thank you!

DATE SPECIFIC ANALYSIS (PARAMETERS)

	Date	Beta Angle (°)	Transient (hrs)	Analysis Time (hrs)	YPR (°)	Solar Constant (W m^{-2})
Positive Beta Peak	2016 GMT 191	0	24	0-24	-4, -2 +1	1324.9
	2016 GMT 192	5	24	24-48	-4, -2, +1	1324.9
	2016 GMT 193	10	24	48-72	-4, -2, +1	1324.9
	2016 GMT 194	15	24	72-96	-4, -2, +1	1324.9
	2016 GMT 195-196	20	48	96-144	-4, -2, +1	1324.9
	2016 GMT 197	25	24	144-168	-4, -2, +1	1324.9
	2016 GMT 198	30	24	168-192	-4, -2, +1	1324.9
	2016 GMT 199	35	24	192-216	-4, -2, +1	1324.9
	2016 GMT 200	40	24	216-240	-4, -2, +1	1324.9
	2016 GMT 201	45	24	240-264	-4, -2, +1	1324.9
	2016 GMT 202	50	24	264-288	-4, -2, +1	1324.9
	2016 GMT 203	55	24	288-312	-4, -2, +1	1324.9
	2016 GMT 204-205	60	48	312-360	-4, -2, +1	1324.9
	2016 GMT 206	65	24	360-384	-4, -2, +1	1324.9
	2016 GMT 207-210	70	72	384-456	-4, -2, +1	1324.9
Negative Beta Peak	2016 GMT 342	0	24	0-24	-4, 0, +1	1410.1
	2016 GMT 343	-5	24	24-48	-4, 0, +1	1410.1
	2016 GMT 344	-10	24	48-72	-4, 0, +1	1410.1
	2016 GMT 345-346	-15	48	72-120	-4, 0, +1	1410.1
	2016 GMT 347	-20	24	120-144	-4, 0, +1	1410.1
	2016 GMT 348	-25	24	144-168	-4, 0, +1	1410.1
	2016 GMT 349	-30	24	168-192	-4, 0, +1	1410.1
	2016 GMT 350	35	24	192-216	-4, 0, +1	1410.1
	2016 GMT 351	40	24	216-240	-4, 0, +1	1410.1
	2016 GMT 352	45	24	240-264	-4, 0, +1	1410.1
	2016 GMT 353	50	24	264-288	-4, 0, +1	1410.1
	2016 GMT 354	55	24	288-312	-4, 0, +1	1410.1
	2016 GMT 355	-60	24	312-336	+4, -1, +1	1410.1
	2016 GMT 356	-65	24	336-360	+4, -1, +1	1410.1
	2016 GMT 357-358	-70	48	360-408	+4, -1, +1	1410.1
	2016 GMT 359-360	-75	48	408-456	+4, -1, +1	1410.1
IMV Shut-Off	2017 GMT 125-126	-10	24	0-24	-4, -2, +1	1343.5