Thermal Control System of the ECOsystem Spaceborne Thermal Radiometer Experiment in Space Station (ECOSTRESS)

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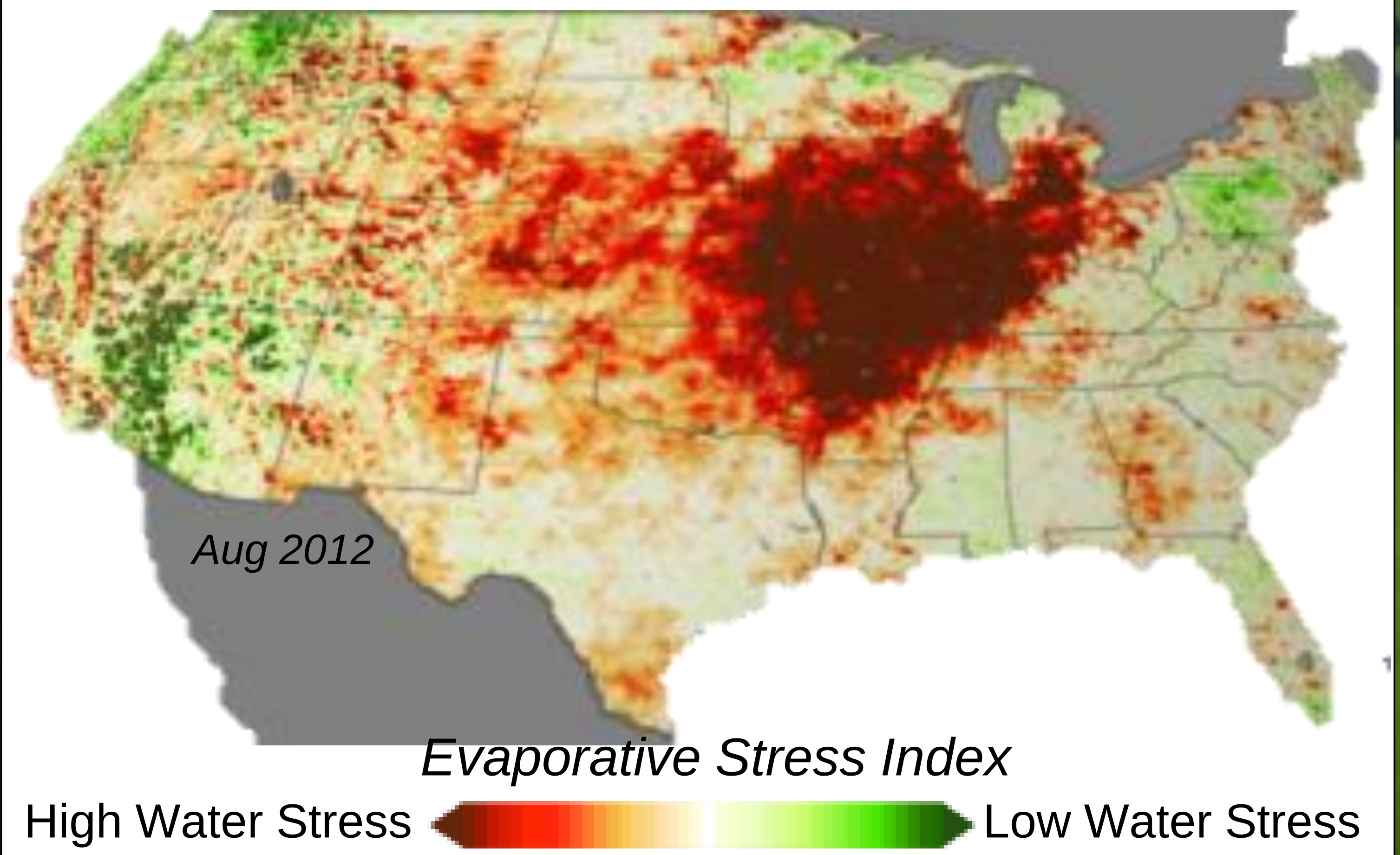
Science Overview

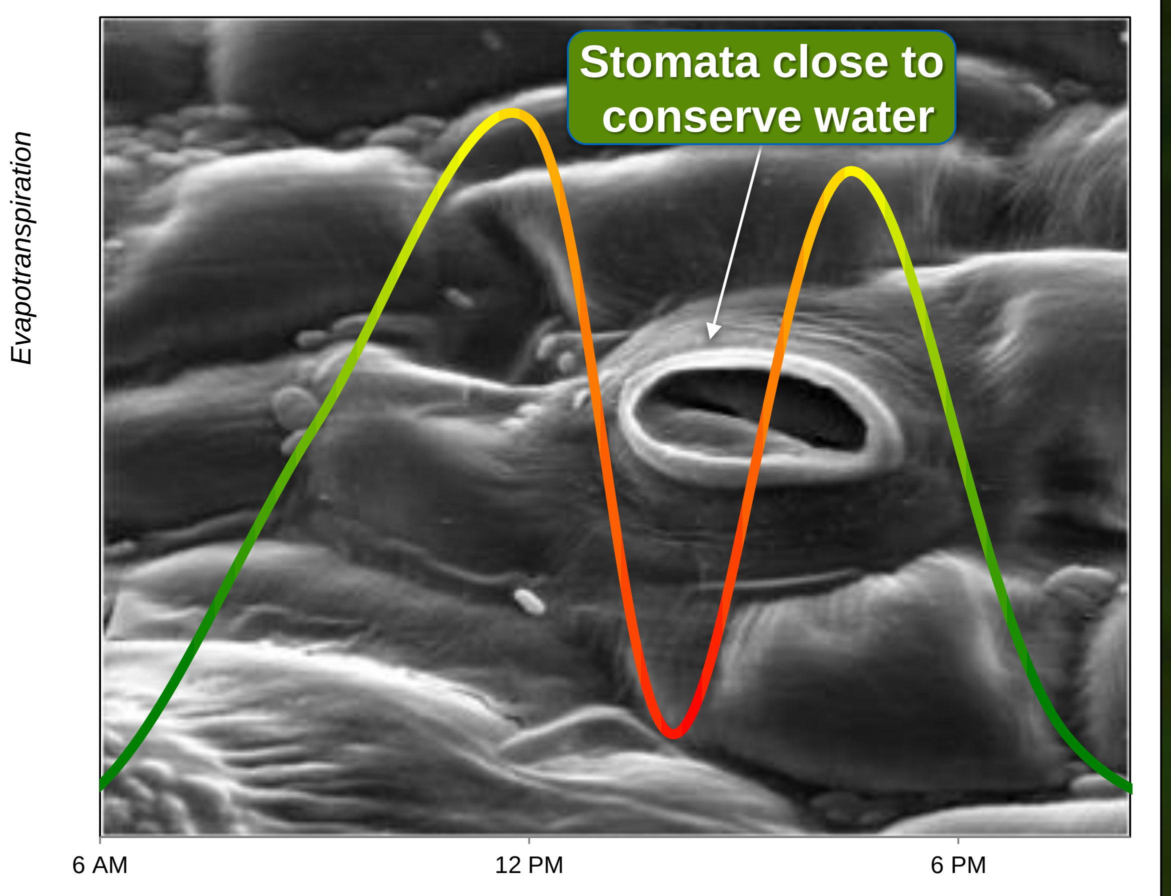
*ECOSTRESS will provide critical insight into **plant-water dynamics** and how **ecosystems change with climate** via **high spatiotemporal** resolution thermal infrared radiometer measurements of evapotranspiration (ET) from the International Space Station (ISS).*

Water Stress Threatens Ecosystem Productivity



Water stress is quantified by the Evaporative Stress Index, which relies on evapotranspiration measurements.

Water Stress Drives Plant Behavior



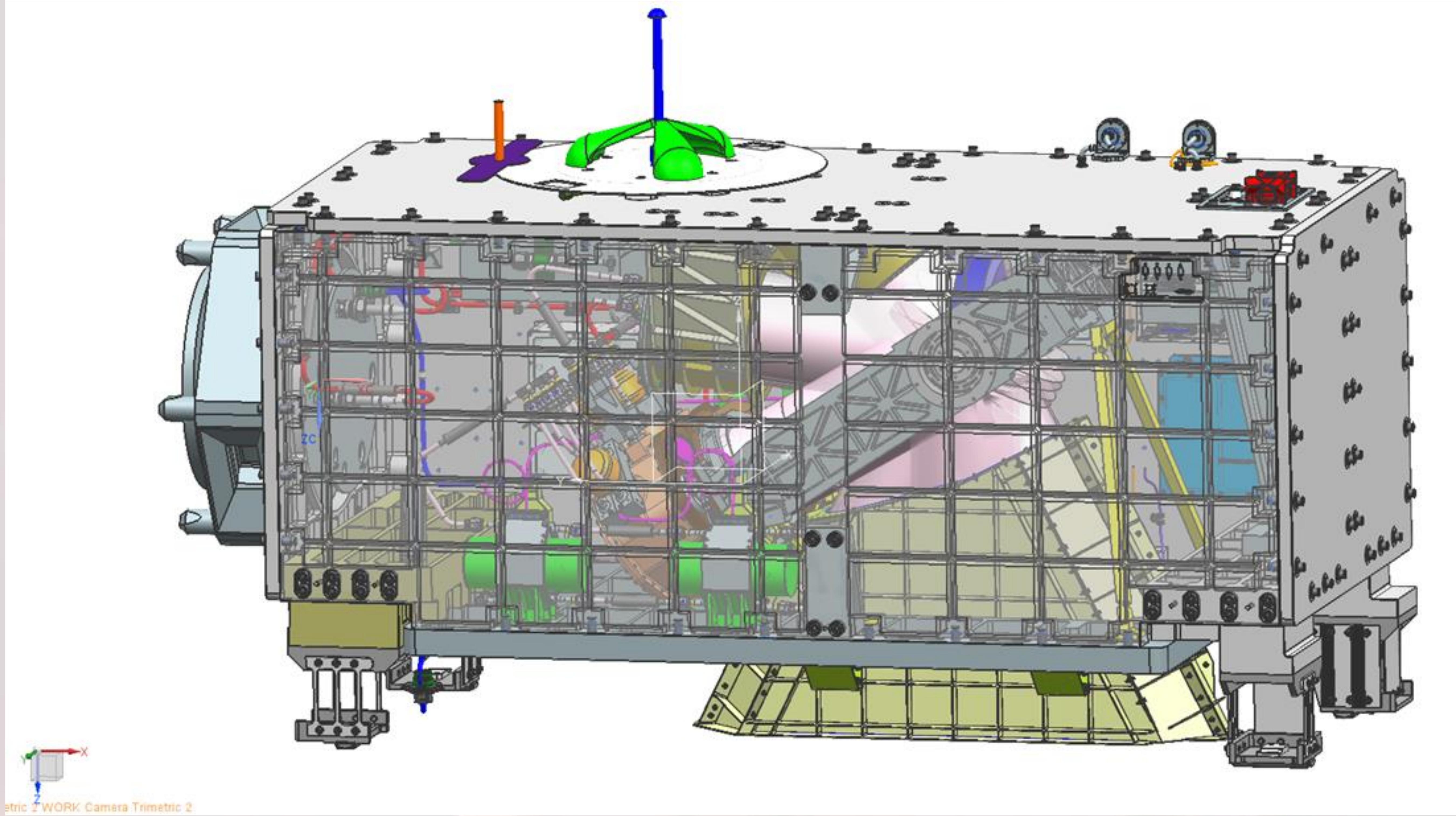
When stomata close, CO_2 uptake and evapotranspiration are halted and plants risk starvation, overheating and death.

Science Objectives

- Identify **critical thresholds of water use and water stress** in key climate-sensitive biomes
- Detect the timing, location, and predictive factors leading to plant **water uptake decline** and/or cessation over the **diurnal cycle**
- Measure **agricultural water consumptive use** over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy

Courtesy of S. Hook

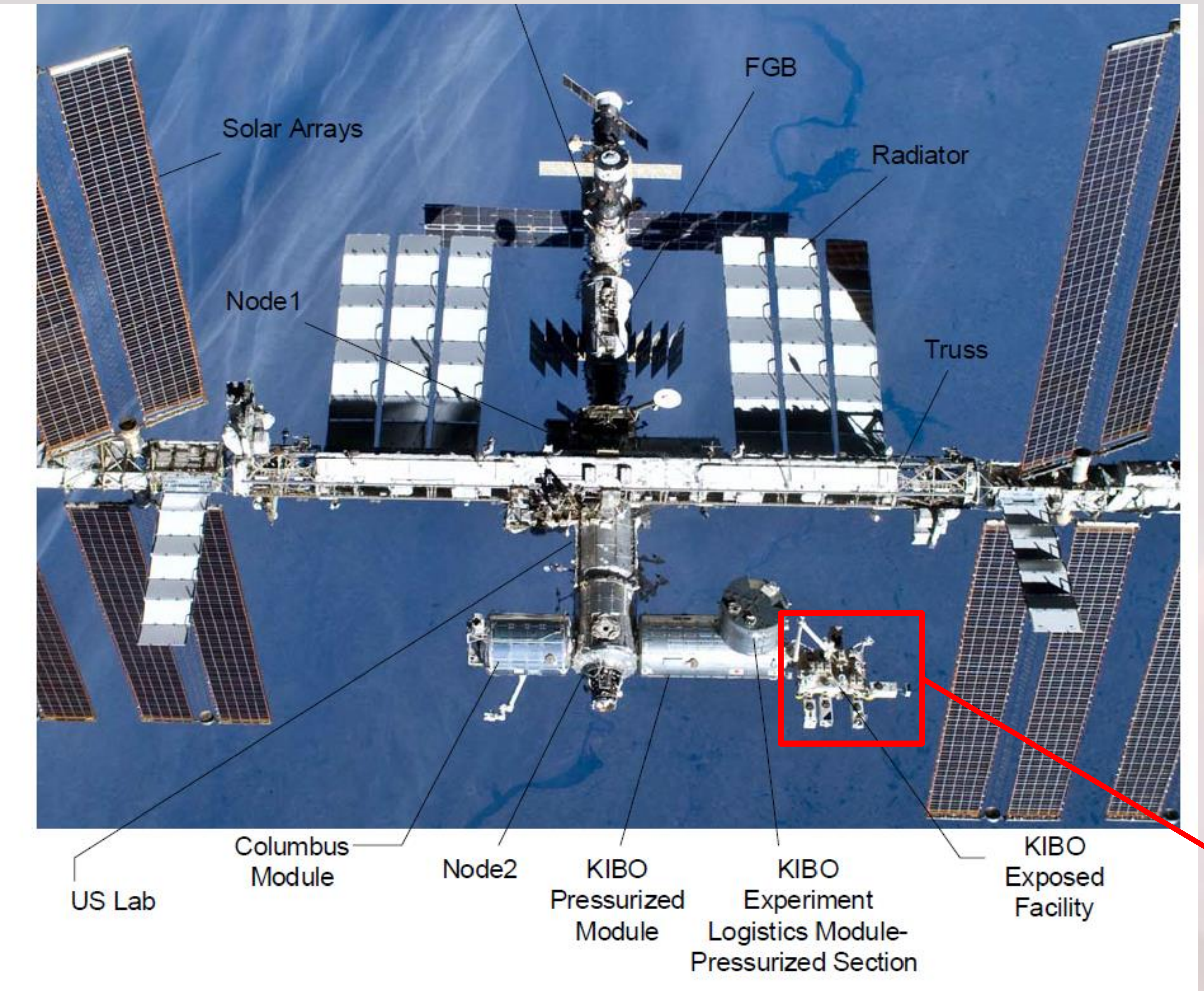
ECOSTRESS Instrument Overview



ECOSTRESS is an Earth Venture Instrument-2 on the ISS

- 8–12.5 μm Radiometer with a 400km swath, 60-m resolution
- Measure brightness temperatures of Earth at selected locations
- Launch April 2018 on SpaceX-15
- Deployed on the ISS on JEM-EFU 10
- Mission Operational life: 1 year

ECOSTRESS Thermal Environment

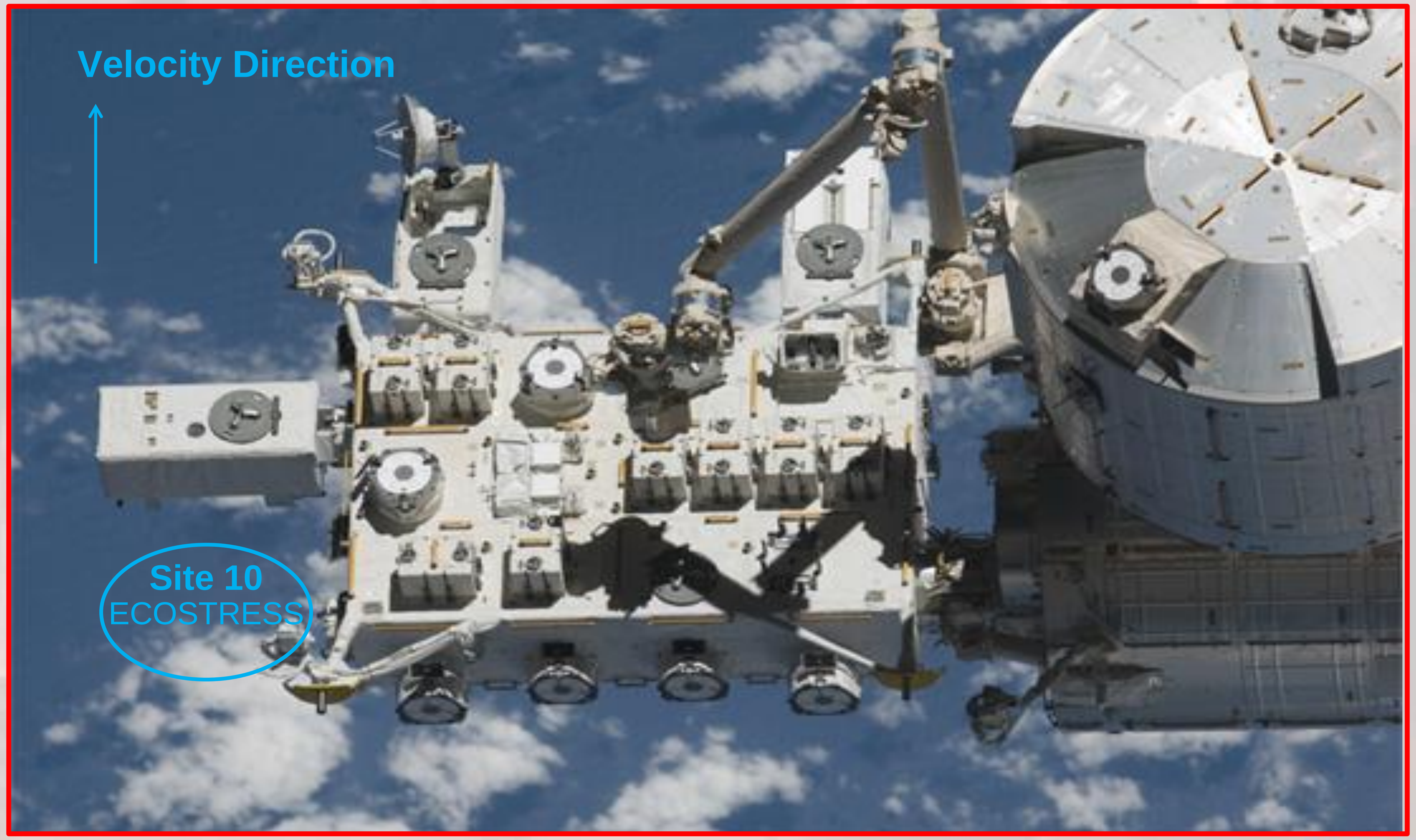


- ECOSTRESS will fly on the ISS and will be integrated with Japanese Experimental Module (JEM) Exposed Facility (EF) at site #10
- ISS orbital parameters
  - 278 km < altitude < 500km (150 nmi to 250 nmi)
  - 51.6° inclination orbit
  - -75° < β < 75°
- The payload is fully enclosed in an aluminum structure except
  - Grapple and H-Fixture
  - Payload Interface Unit (PIU)
  - Instrument Nadir baffle and WIFI Antennae (Nadir and Zenith)

- The payload enclosure is covered in MLI
  Required by JAXA
  Beta cloth outer layer
  $\varepsilon^* < 0.04$, $0.31 < \alpha < 0.6$, $0.85 < \varepsilon < .96$

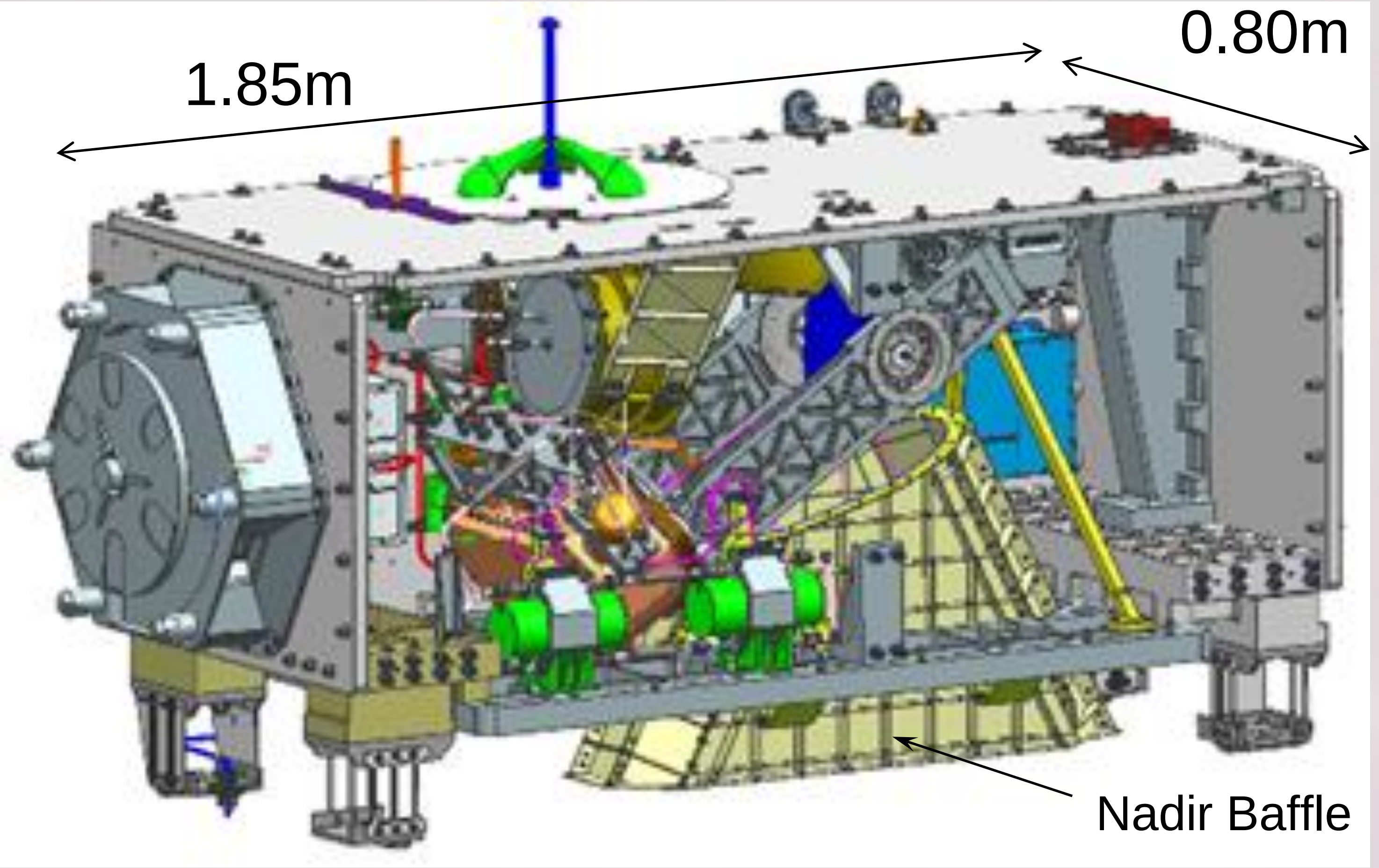
- JEM-EF provides a pumped fluid for heat rejection

  Fluorinert liquid FC-72
  Flow rate: 155kg/hr +18%/-0%
  Supply fluid temp range: 16°C to 24°C
  Return fluid temp range:16°C to 50°C



ECOSTRESS Instrument Overview

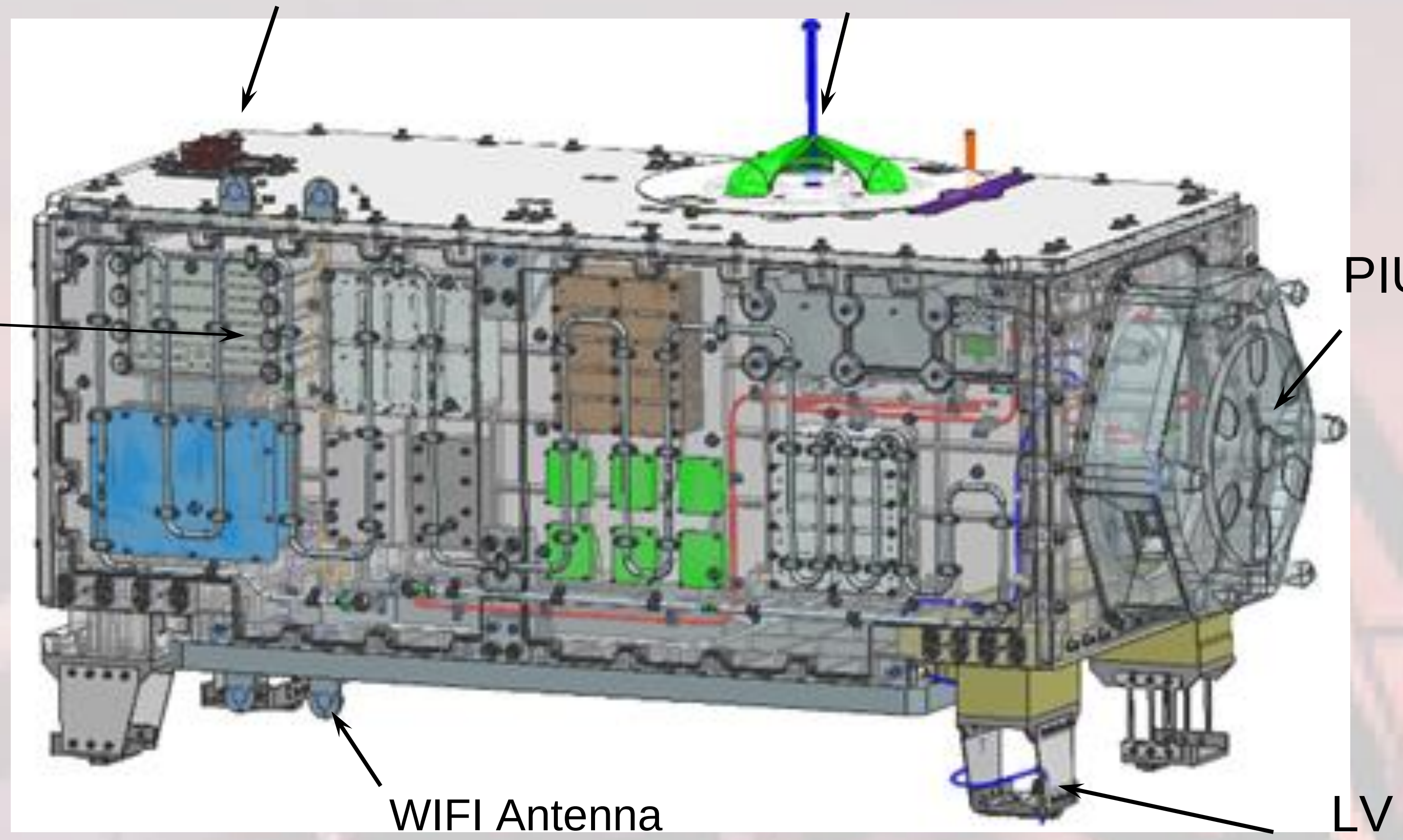
ECOSTRESS Instrument



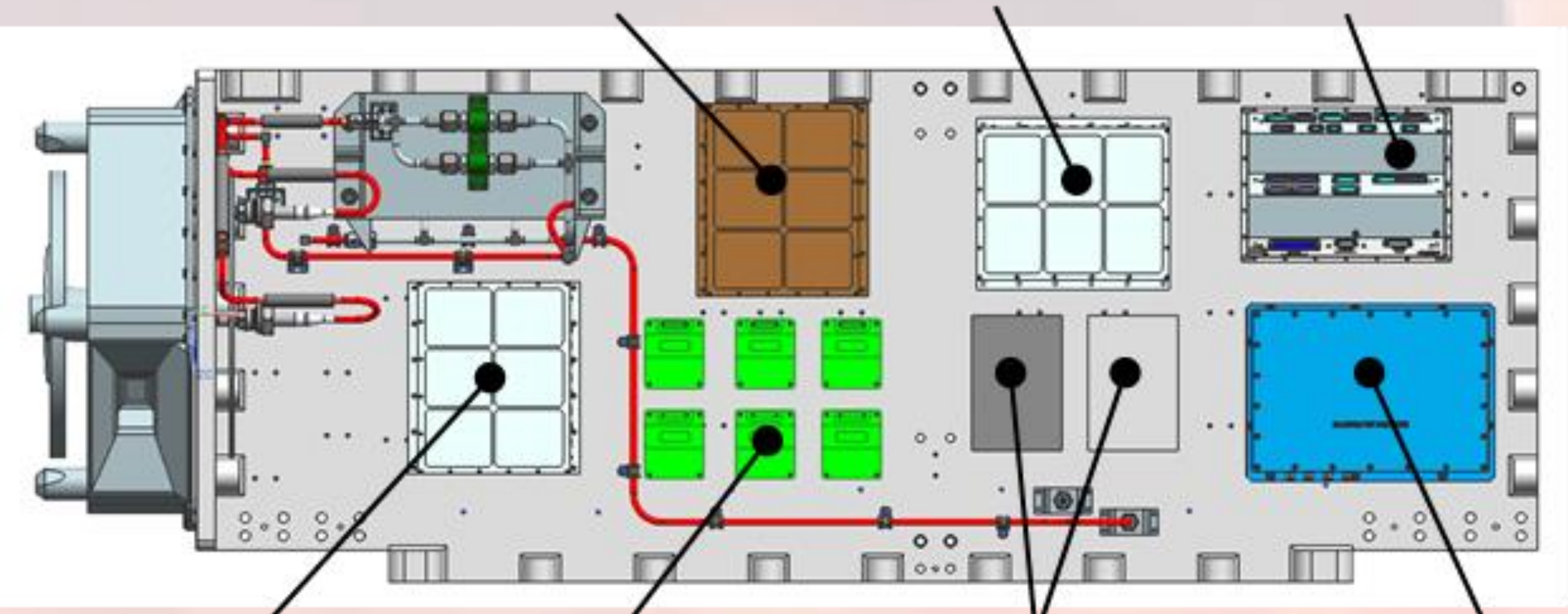
* Includes contingency

ECOSTRESS Resources	
Power	*782W **
Mass	*529kg **

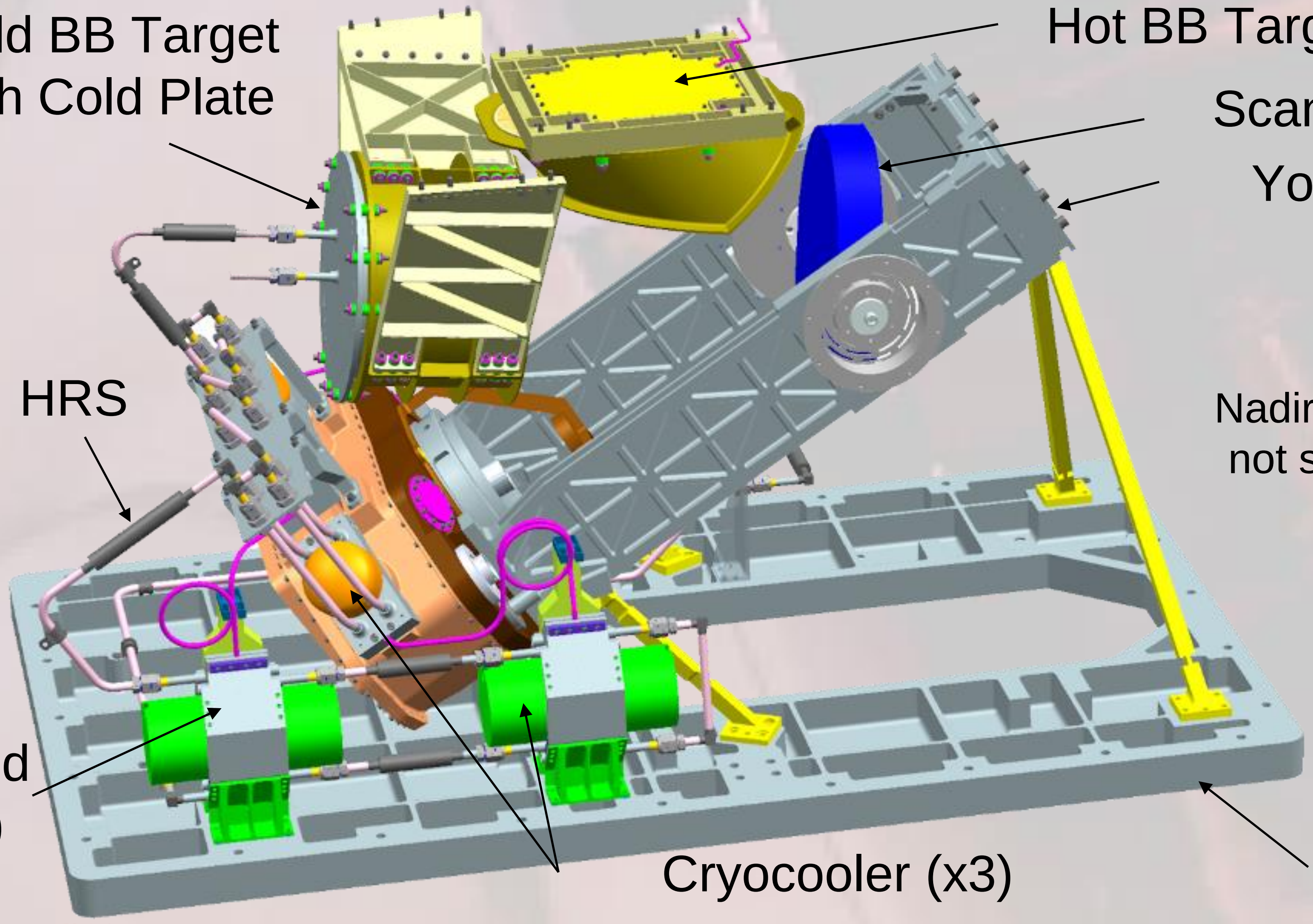
** Government Furnished Equipment (GFE)



Cold Panel with Support Hardware



Radiometer Instrument



ECOSTRESS Temperature Requirements

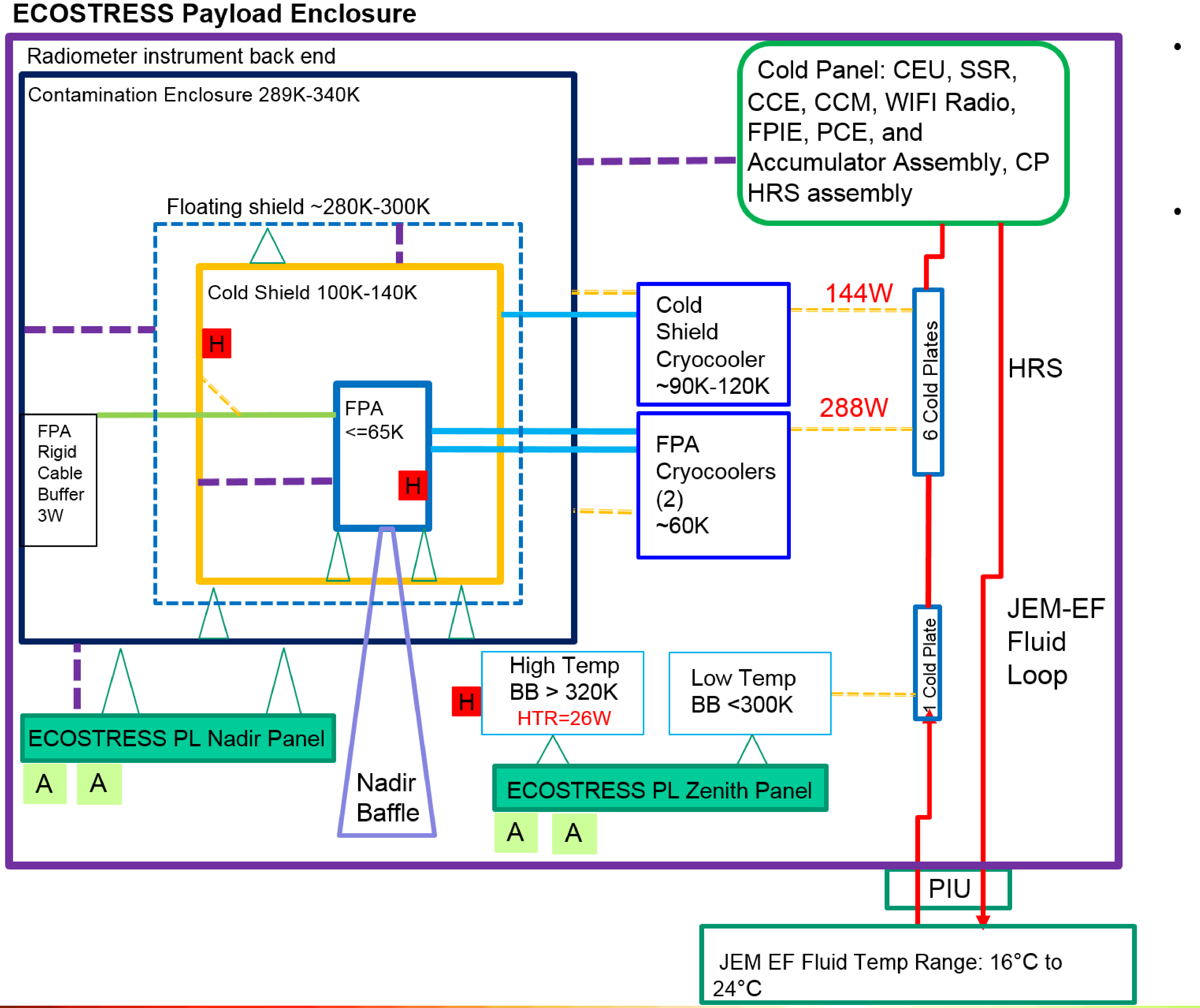
ECOSTRESS	Allowable Flight Temperature	
Radiometer	Operating	Non-Operating
FPA	-208°C (65K)	-218°C (55K) to 35°C (308K)
Telescope (M1, M2, M3, Scan Mirror)	10°C to 50°C	-15°C to 50°C
Warm Blackbody Target	16°C to 24°C	-15°C to 50°C
Cold Blackbody Target	40°C	-15°C to 50°C
Support Hardware		
CCM	10°C to 50°C	-15°C to 50°C
CCE	10°C to 50°C	-15°C to 50°C
FPIE	10°C to 50°C	-15°C to 50°C
PCE	10°C to 50°C	-15°C to 50°C
CEU	10°C to 50°C	-15°C to 50°C
WEBA	10°C to 50°C	-15°C to 50°C
MSU	10°C to 50°C	-15°C to 50°C
WIFI Antenna	-20°C to 55°C	-20°C to 55°C

Description	Key Driving Requirements
FPA Operating Temp and Temporal Stability	< 65K, +/- 100 mK over 2.4 sec
Heat Rejection Method	JEM-EF ATCS
Cryocooler Heat Rejection skin temperature	< 40°C
Instrument Cooldown Time	< 24 hrs
Dragon/JEM-EF Transfer Operation Survival Time	>7 hrs
Fluid Pressure Drop	55.7 kPa < DP < 58.4 kPa
MLI	Beta Cloth, e* < 0.04
Blackbody Target Temperature and Spatial Gradient	16°C to 24°C (cold)/40°C (warm), <1°C gradient over entire surface
Failure Tolerance	Two fault tolerant
Mass Flow rate	155 kg/hr
Temporary storage Survival	Survive indefinitely at site #12
Cryocooler power allocation	432W
Survival Power	<120W

Additional requirements

1. Maintain all component temperatures within the non-operating allowable flight temperature ranges during launch, Dragon trunk to JEM-EF transfer, berthing, and operations on JEM-EF until end of life disposal
2. Comply to ISS/JAXA JEM-EF ATCS Usage Requirements: Coolant compatibility, Cleaniless, leakeage, coolant pressure, two fault tolerant
3. Comply to ISS fracture control requirements: pressure vessel, leak before burst, burst, proof, and NDE tests

Thermal Subsystem Architecture Overview

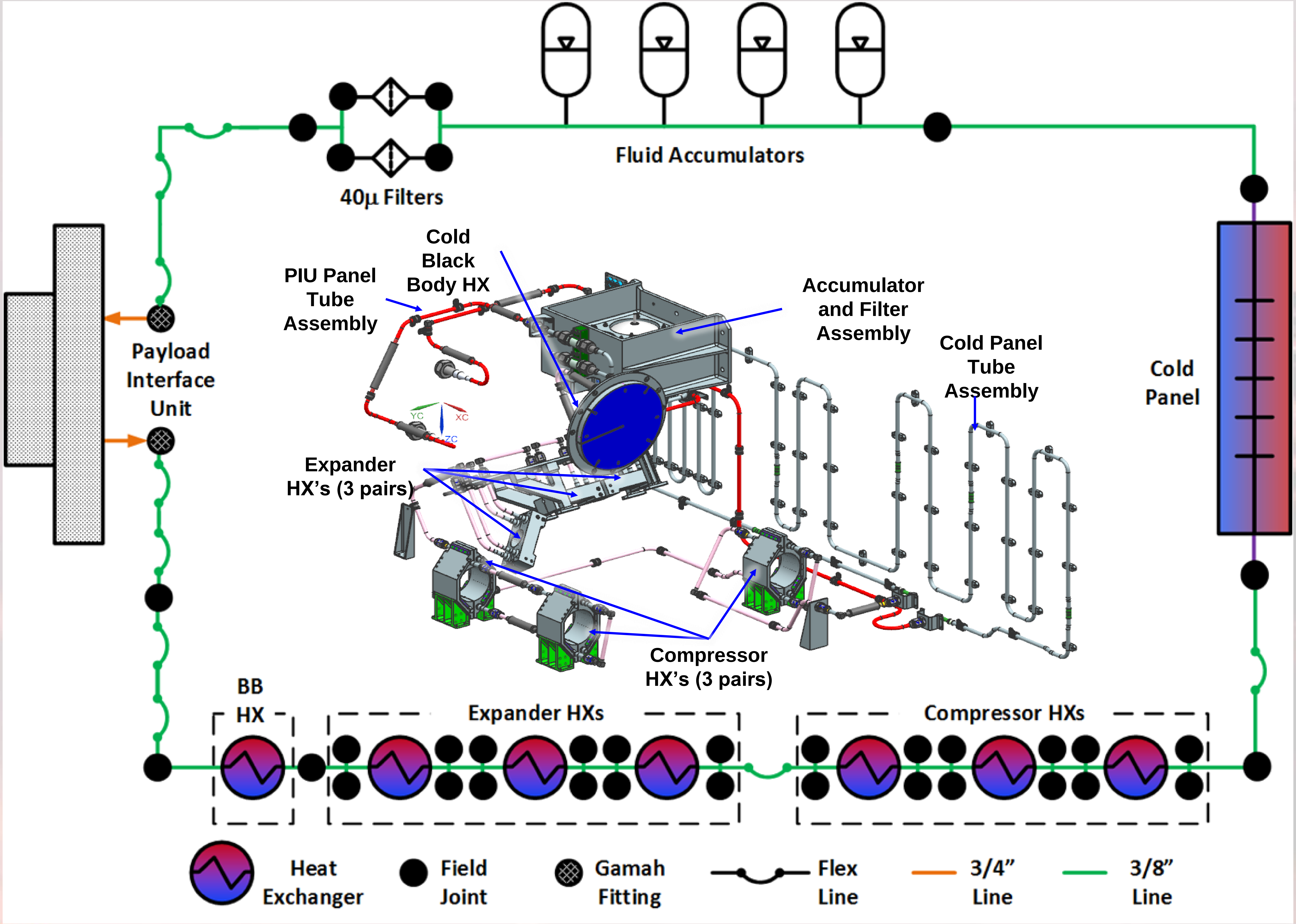


- Active Thermal Control: Three split-stirling Pulse Tube coolers are used to cool the FPA to <=65K and instrument cold shield to 100K-140K.
- Cryogenic staging: Cold shield and floating shield are used to minimize the radiation and conduction parasitic loads onto the FPA assembly

- The TCS is based on a pumped fluid loop with the fluid circulation provided by JEM-EF
- Radiometer FPA is cooled and temperature controlled by means of pulse tube cryocoolers
- Dedicated cold plate heat exchangers (HX) remove waste heat from cryocooler compressors (3), expanders (3), and low temp black body target (1)
- A “Cold Panel” is used to remove waste heat from ECOSTRESS payload bus components/units
- The fluid loop heritage of MSL and experience of CATS and OCO-3 is used in this TCS

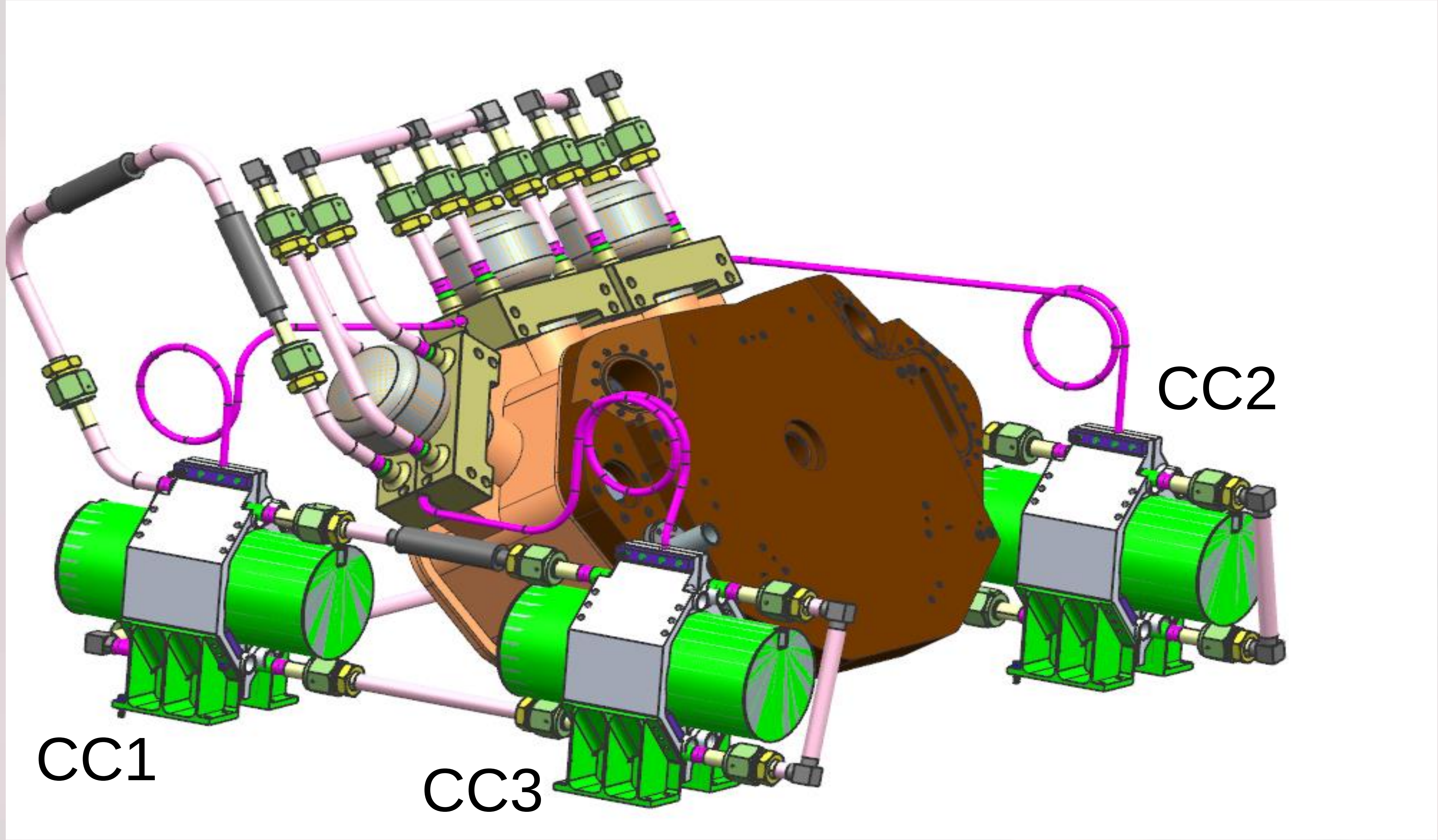
TCS is designed to handle Payload CBE power plus contingency of 782W and maintain payload within AFT limits using a fluid loop with JEM-EF supplied flow circulation

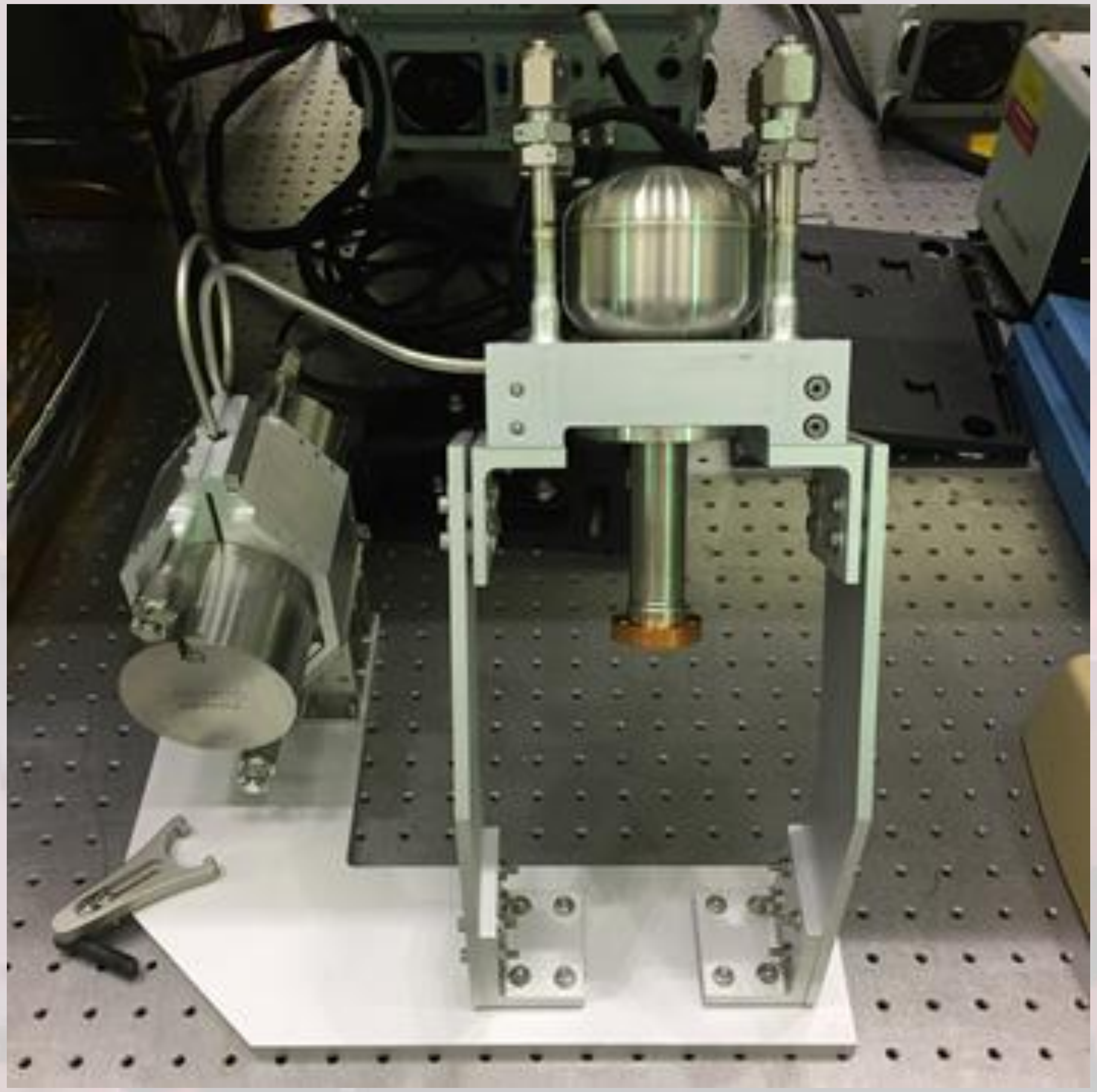
Heat Rejection System Overview



Cryocooler

ECOSTRESS Cryocooler Configuration





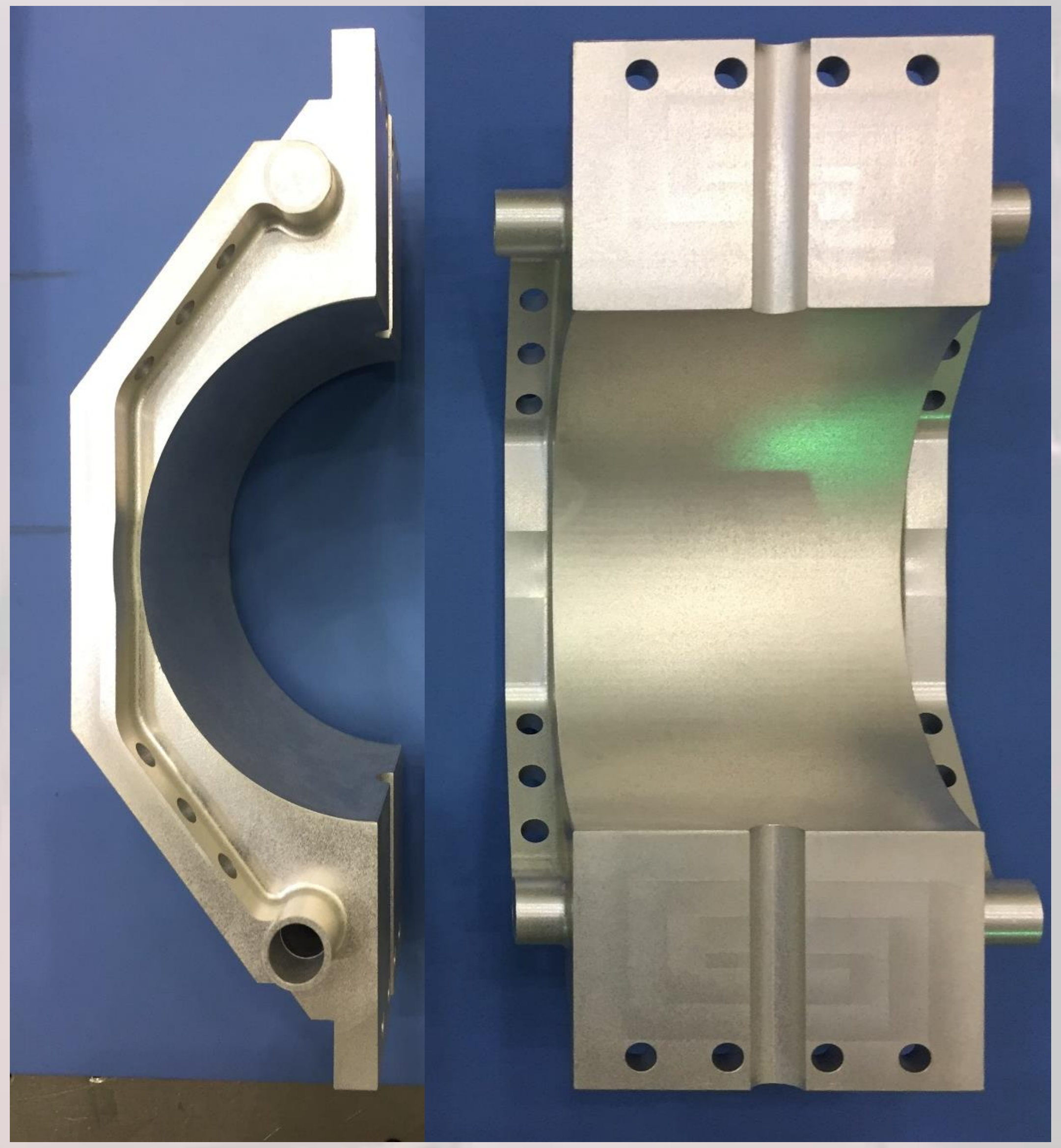
Enhanced Performance High Efficiency (EPHE) LPT9310 cooler shown with MaxQ Cold Plates.

- Three LPT 9310 coolers from Thales Cryogenics provide cooling and maintain FPA temperature at or below 65K
- Two cryocoolers provide cooling for FPA and one cryocooler provide cooling for cold shield

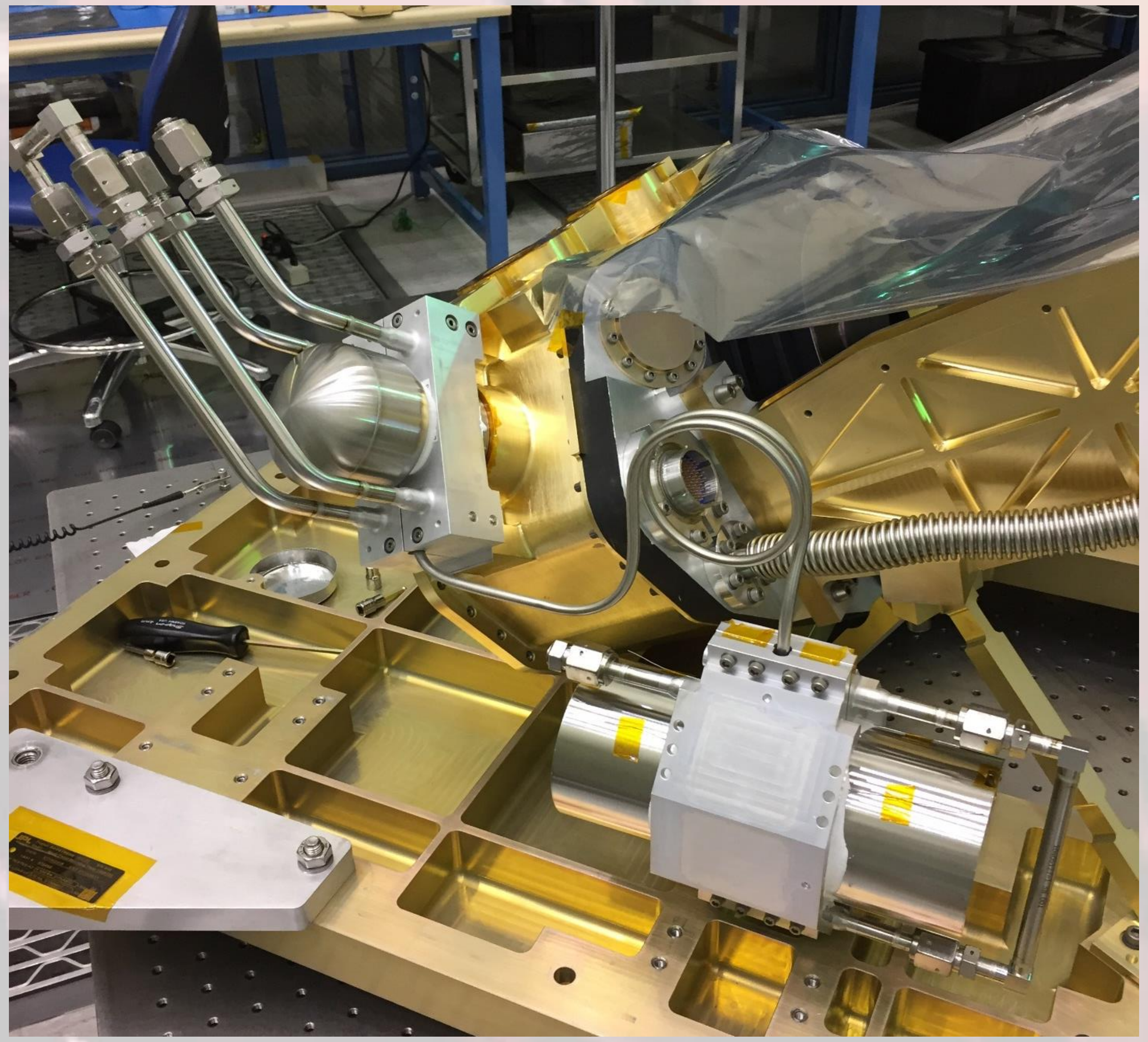
Cryocooler Heat Rejection

- Non-Planar Liquid Cooled Cold Plate heat exchanger provided by MAXQ Technology (MQT)
- MQT's internal fin technology offers
- high heat transfer surface area per volume
- more uniform surface temperatures at heat rejection surface
- low pressure drop
- low cost proven aluminum solution with performance comparable to copper based solutions
- compatible with FC-72 (JEM-EF fluid)
- cold plates manufactured using Friction Stir Welding (FSW) process

Performance requirements at 155 kg/hr:
Power dissipation: 90W per HX
Thermal : <0.09 C/W per HX
Hydraulic : <0.2 psi per HX

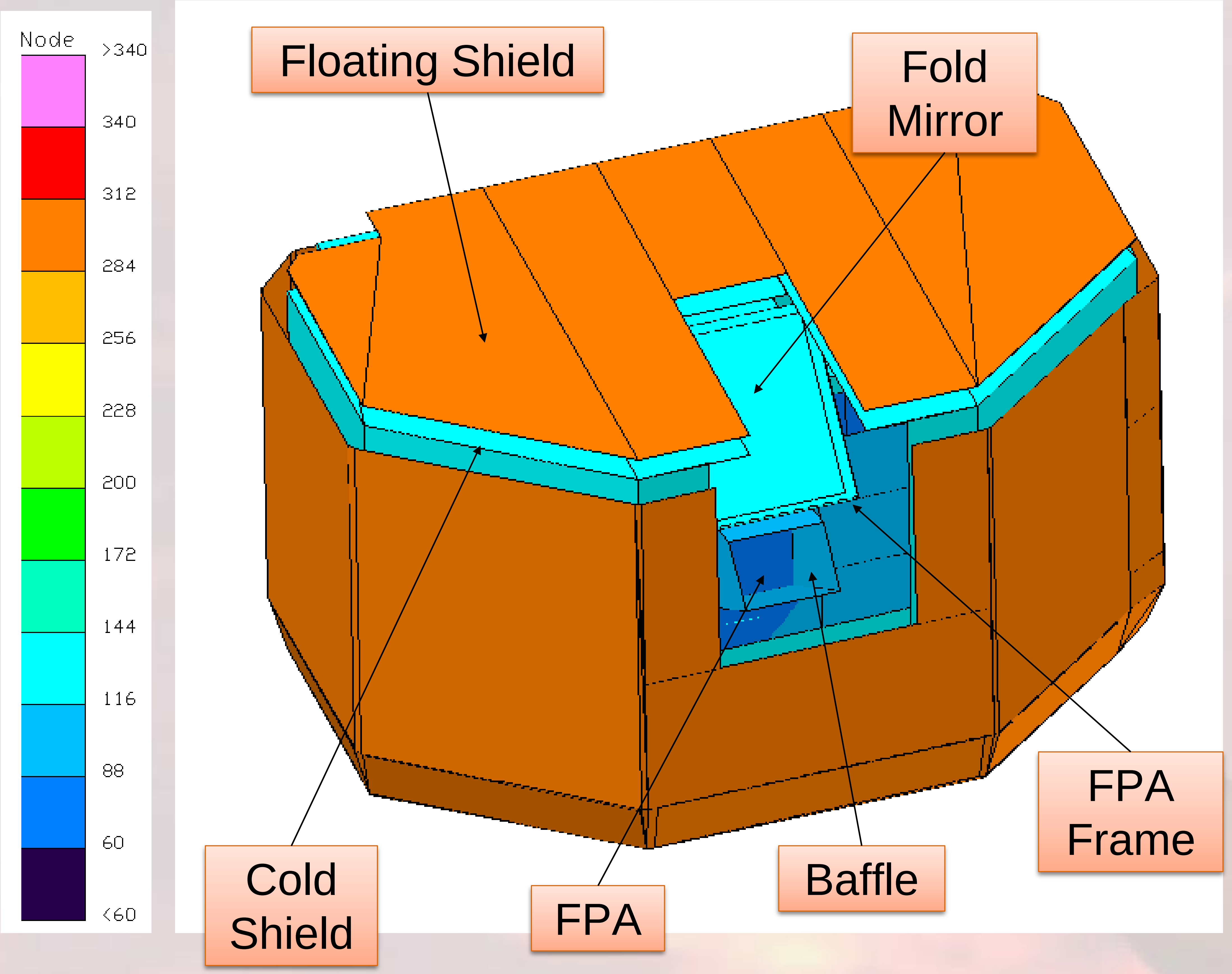


Compressor LCCP HX



Radiometer Telescope shown with EPHE LPT9310 coolers and non-planar MaxQ Cold Plates

Hot Operational Optics Temperature Contour



	Power (W)
FPA Cooler 1 Heat Load	-1.302
FPA Cooler 2 Heat Load	-1.302
Cold Shield Cooler Heat Load	-6.10

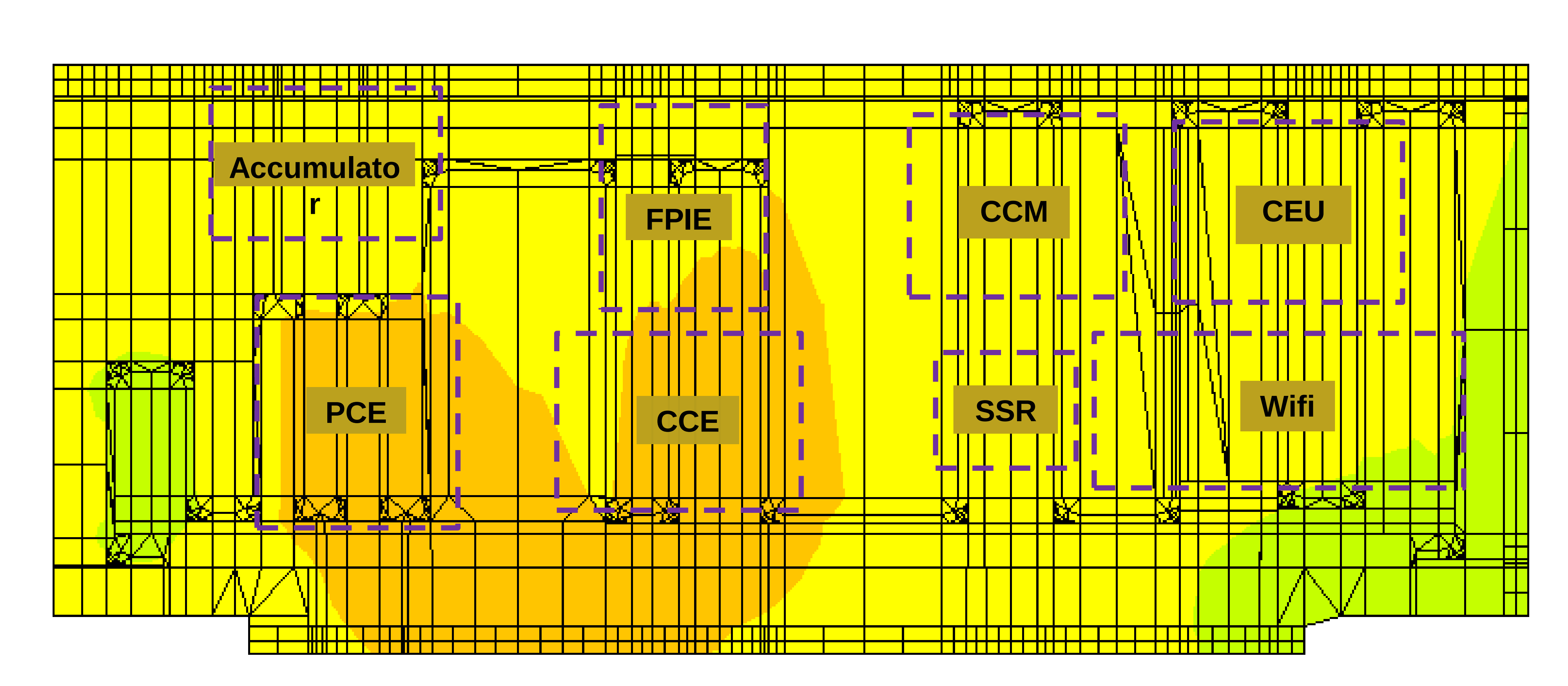
	Hot Operational (K)	
	Min	Max
Contamination Enclosure	314.4	314.6
Contamination Enclosure Top	313.8	314.2
Yoke	315.0	315.4
Floating Shield	299.6	299.9
FPA Frame	131.1	131.6
Nadir Baffle	300.4	314.6
FPA Cooler 1 Cold Tip	60.7	60.9
FPA Cooler 2 Cold Tip	60.8	60.9
Cold Shield Tube	127.3	127.6

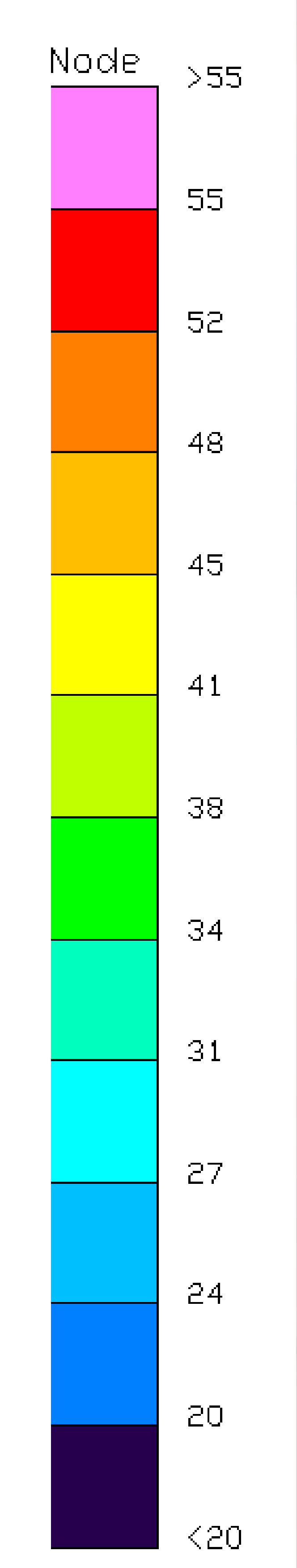
	AFT Limits Operational		Hot Operational (K)			
	Min	Max	Min	Margin	Max	Margin
FPA Temp	60	75	64.6	4.6	64.7	10.3
Baffle	65	100	93.0	28.0	94.2	5.8
M1	283.15	323.15	312.7	29.6	313.5	9.7
M2	283.15	323.15	313.0	29.9	313.8	9.3
M3	283.15	323.15	313.3	30.2	313.5	9.6
Scan Mirror	283.15	323.15	314.6	31.5	314.8	8.3

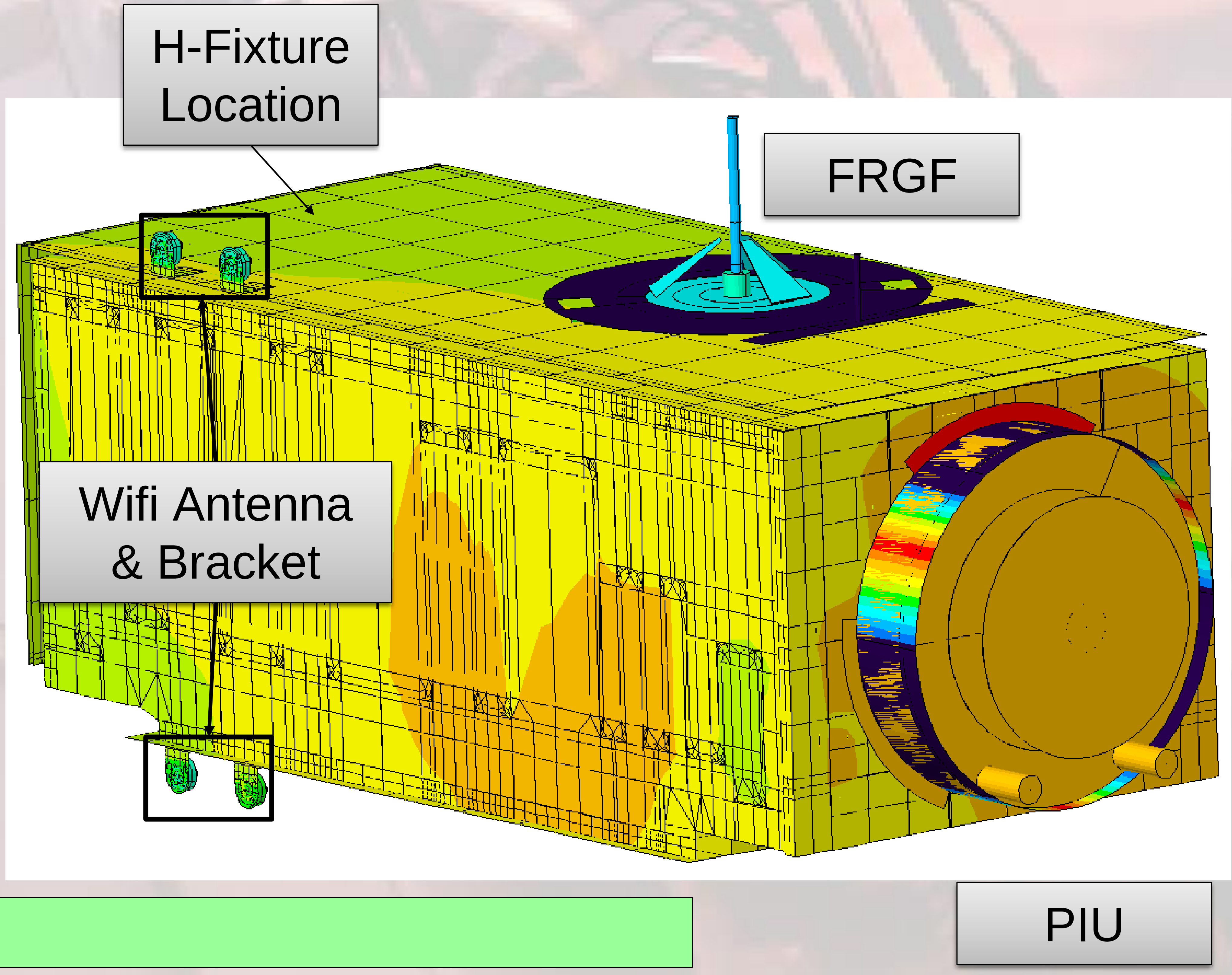
Hot Operational Temperature Contour

	AFT Limits Operational		Hot Operational (°C)			
	Min	Max	Min	Margin	Max	Margin
Cryocooler Electronics (CCE)	10	55	45.8	35.8	46.5	8.5
Cryocooler Module (CCM)	10	50	42.9	32.9	43.7	6.3
FPIE	10	50	43.8	33.8	44.5	5.5
PCE	10	50	45.1	35.1	45.5	4.5
CEU	10	50	43.1	33.1	43.9	6.1
Wireless Radio (Wifi)	10	50	40.9	30.9	41.6	8.4
SSR	10	50	41.8	31.8	42.5	7.5
Accumulator	10	50	42.9	32.9	43.6	6.4

	AFT Limits Operational		Hot Operational (°C)			
	Min	Max	Min	Margin	Max	Margin
H-Fixture	-101.11	121.11	38.7	139.8	40.8	80.3
FRGF	-156.67	121.11	9.4	166.1	55.2	65.9
Wifi Antenna	-20	55	33.2	53.2	47.1	7.9
Wifi Bracket	-20	55	37.6	57.6	44.5	10.5
PIU	-45	65	59.9	104.9	62.7	2.3



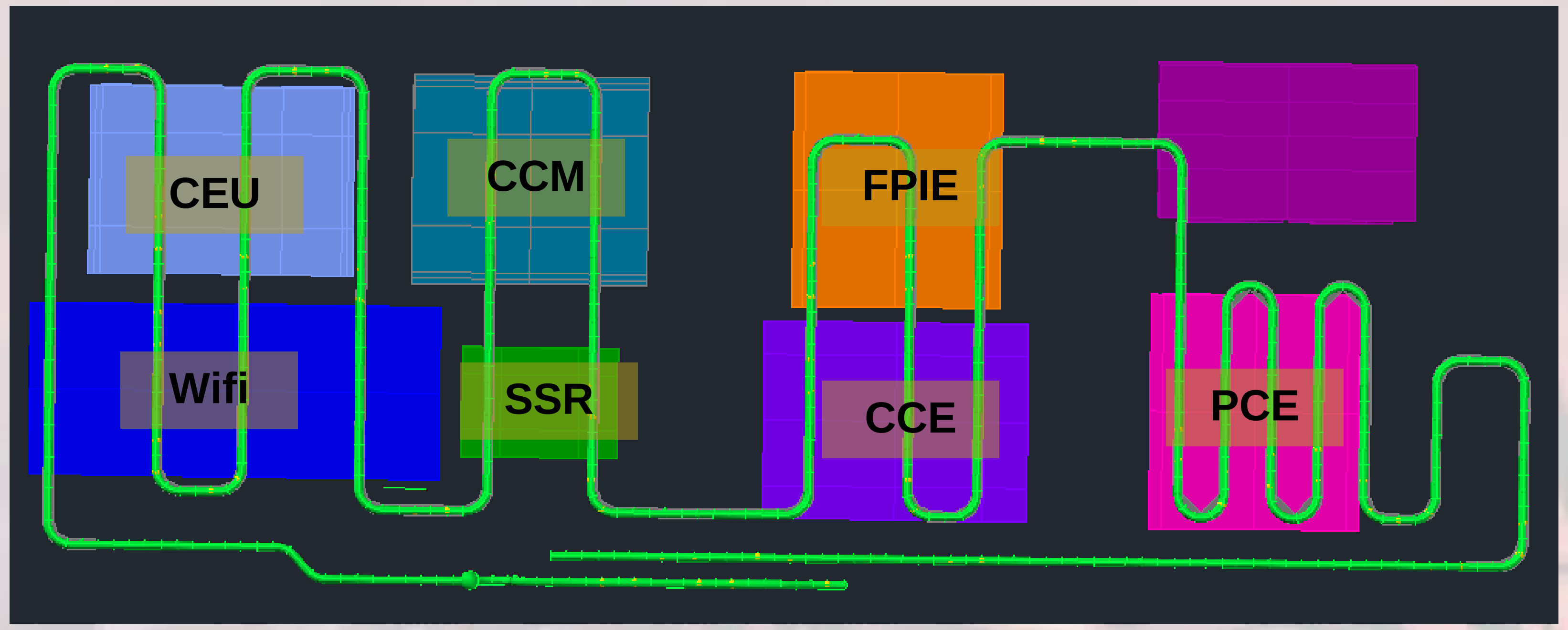


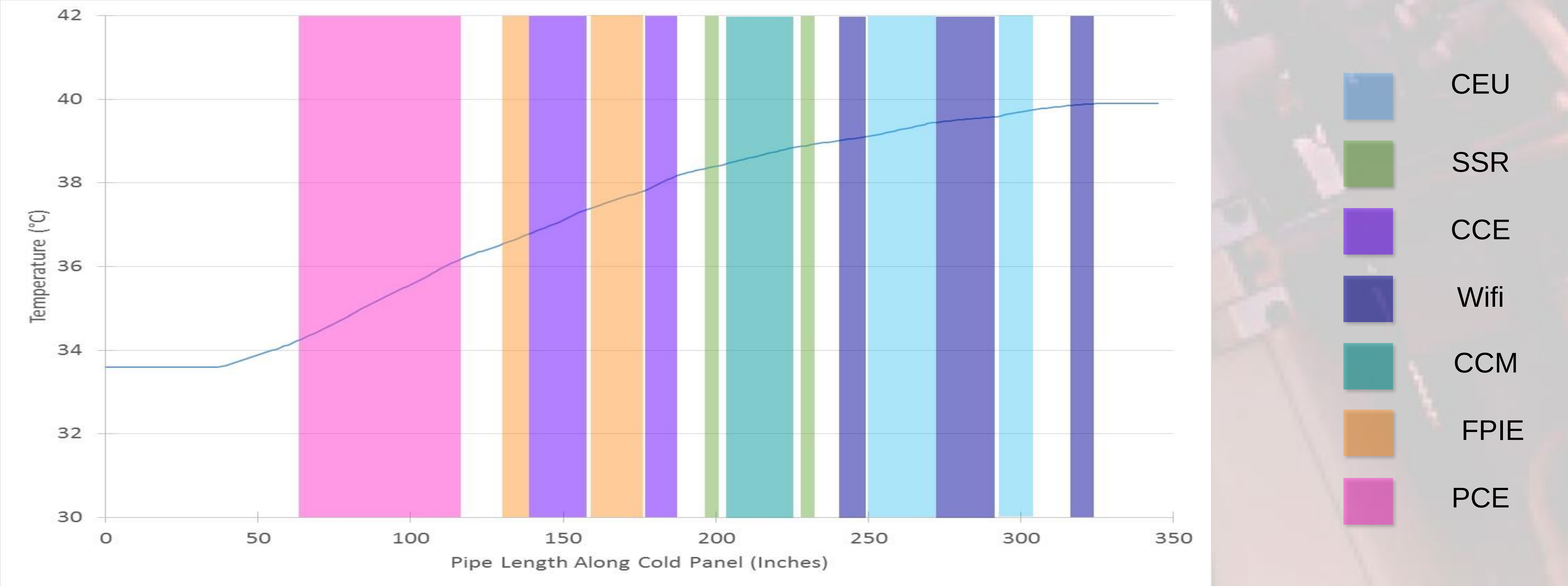


All components within AFT limits

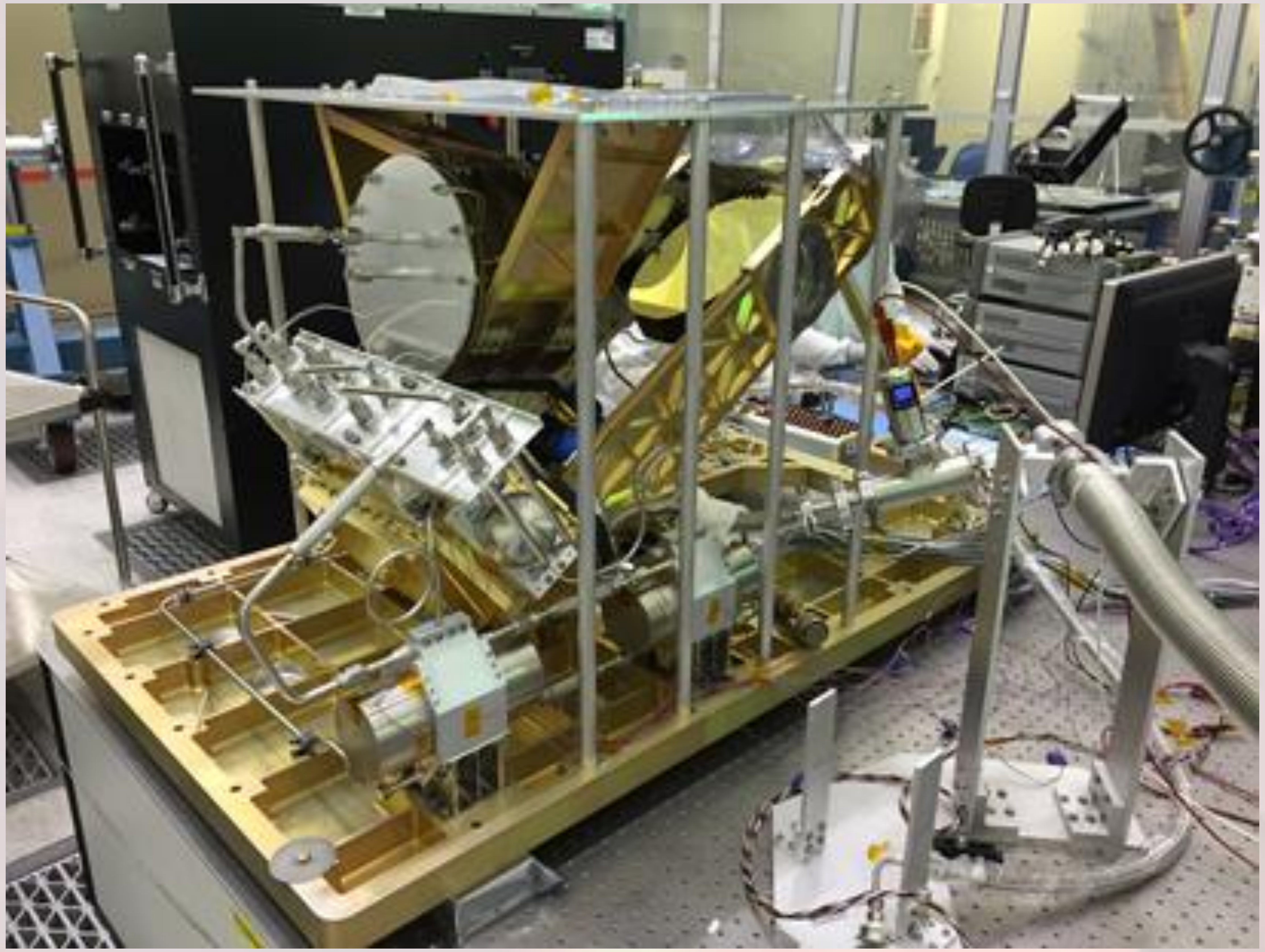
Hot Operational Fluid Loop Temperatures

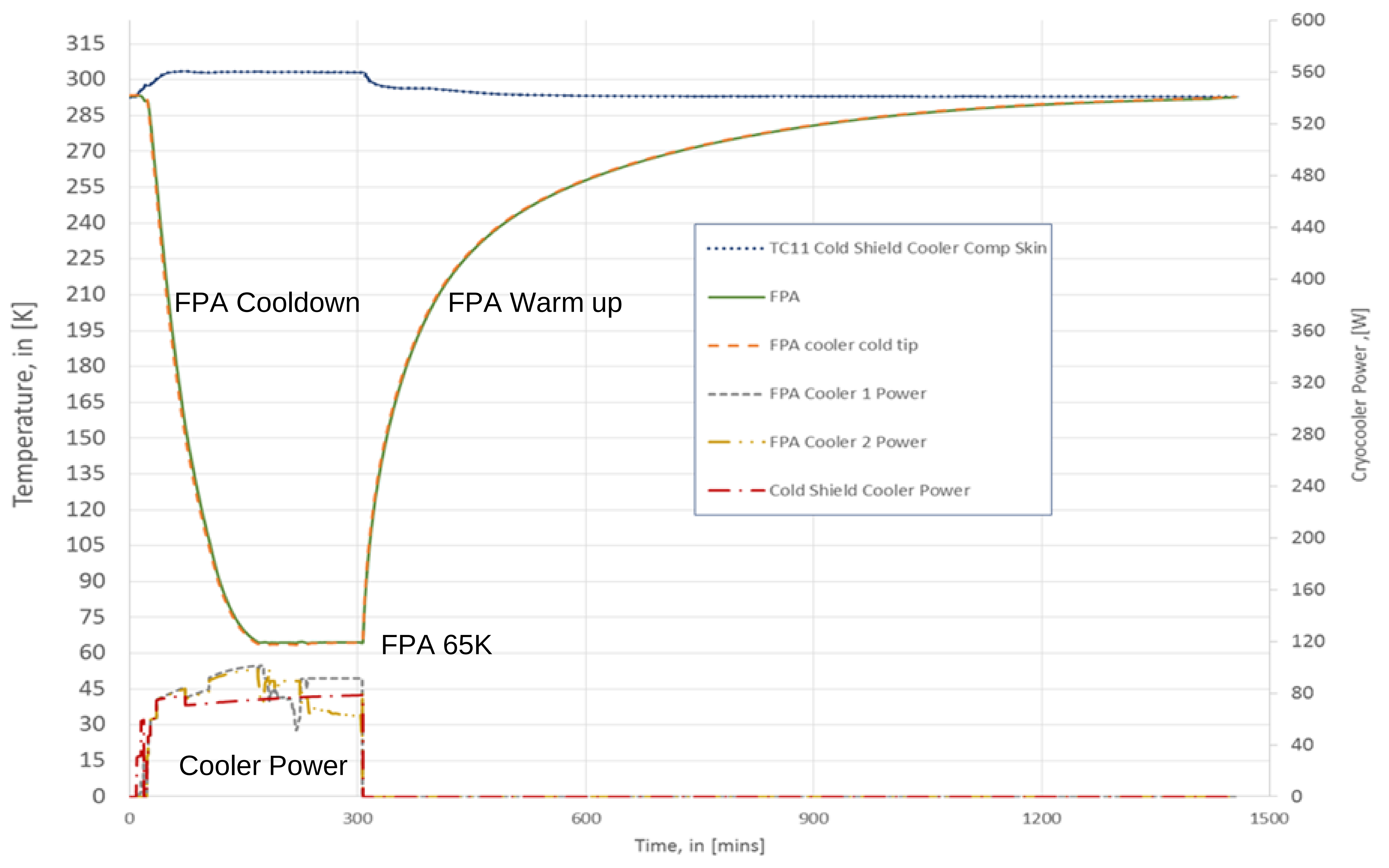
Location	Temperature (°C)
PIU Inlet	24.0
Cold Panel Inlet	33.6
Cold Panel Exit	39.9





Radiometer Thermal Test





Radiometer Telescope Assembly Thermal Test Configuration.

65K FPA temperature requirement met with less than 300W (432W requirement) cooler input power

Conclusions

- A thermal control system has been successfully designed to meet the challenging ECOSTRESS thermal requirements.
- A combination of active and passive thermal control systems was employed to maintain the components within the AFT limits.
- TCS design has positive technical margin on all requirements
- The radiometer thermal performance test results were excellent and repeated performance was demonstrated over a range of FC-72 fluid temperatures (16°C to 24°C).
- The cryocoolers and cold plates operated better than anticipated and no temperature limits were exceeded.
- The flight temperature sensors and heaters operated nominally. The implementation of EPHE cooler and coldplates minimized the TCS power consumption.
- The system level thermal control system design will be verified in Payload TVAC which is planned for summer 2017.

Acknowledgements

- ECOSTRESS Project team members and JPL.
- Memo Romero and MAXQ Technology.
- Thales team and Thales Cryogenics.

Backup

Blackbody Calibration Target Thermal Design