

# Mid Infrared Instrument cooler subsystem test facility overview

**B Moore, J Zan, B Hannah, T Chui, K Penanen, M Weilert**

Jet Propulsion Laboratory, California Institute of Technology  
4800 Oak Grove Dr, Pasadena, CA 91109

Bradley.D.Moore@jpl.nasa.gov

**Abstract.** The Cryocooler for the Mid Infrared Instrument (MIRI) on the James Webb Space Telescope (JWST) provides cooling at 6.2K on the instrument interface. The cooler system design has been incrementally documented in previous publications [1][2][3][4][5]. It has components that traverse three primary thermal regions on JWST: Region 1, approximated by 40K; Region 2, approximated by 100K; and Region 3, which is at the allowable flight temperatures for the spacecraft bus. However, there are several sub-regions that exist in the transition between primary regions and at the heat reject interfaces of the Cooler Compressor Assembly (CCA) and Cooler Control Electronics Assembly (CCEA). The design and performance of the test facility to provide a flight representative thermal environment for acceptance testing and characterization of the complete MIRI cooler subsystem are presented.

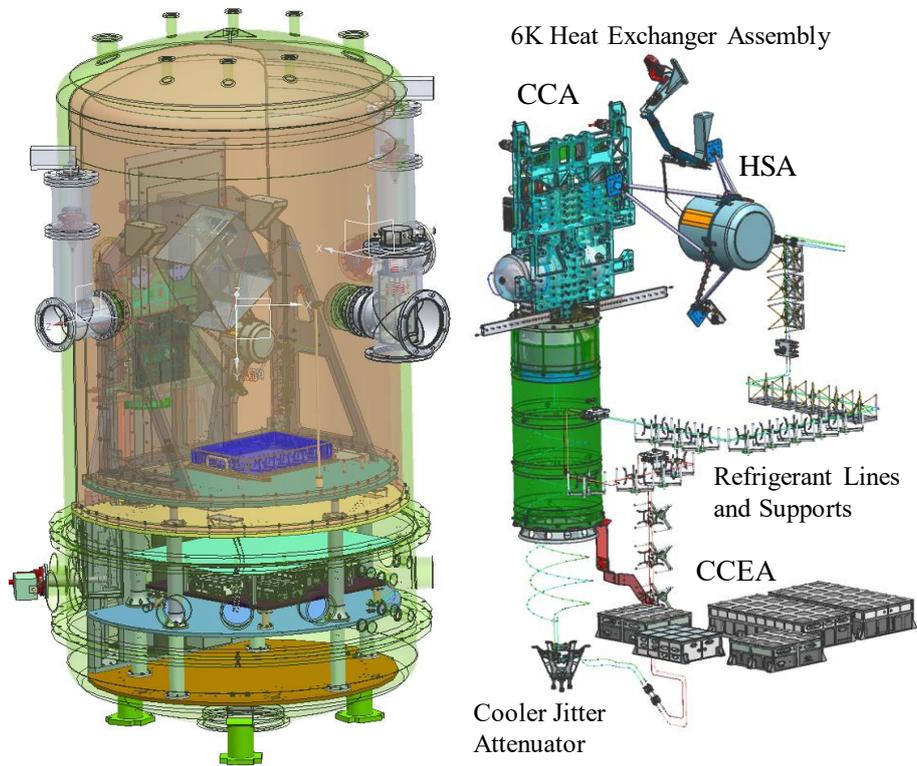
## 1. Introduction

The test campaign to verify and characterize the performance of the MIRI Cryocooler subsystem spanned across several system and subsystem test. This paper will focus on the configuration used for the thermal vacuum test used to verify the performance requirements of both the flight model (FM) and flight spare (FS) CCA, C2 (cool down 2). For this test, the FM/FS CCA, FM/FS CCEA, FS 6K heat exchanger (6K HX), FS Heat Exchanger Stage Assembly (HSA), FS/flight-like GSE stand-ins for the refrigerant lines and supports and an engineering model (EM) of the Cooler Jitter Attenuator (CJA) were used to represent a complete cooler subsystem. As such, the full capability of the chamber is utilized to provide the requisite thermal zones to represent a flight-like environment.

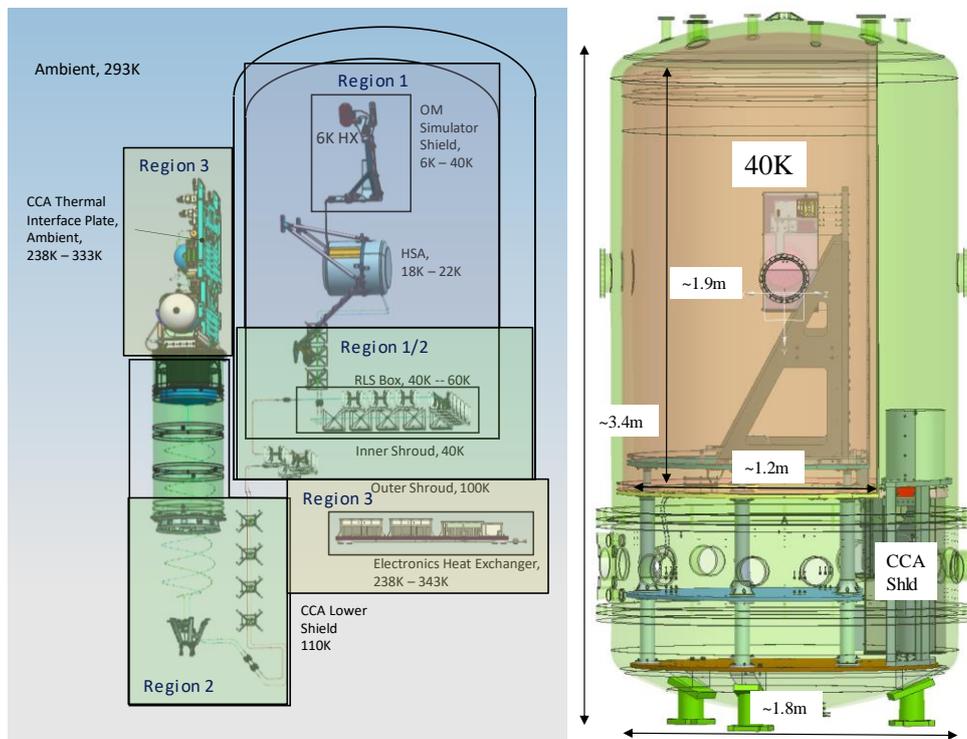
## 2. Chamber design and configuration

### 2.1. Overall chamber configuration

The overall chamber configuration and flight and flight-like GSE hardware for the test campaign is shown in Figure 1. Figure 2 shows the mapping of the chamber thermal regions to the three primary flight thermal regions on JWST: Region 1, approximated by 40K; Region 2, approximated by 100K; and Region 3, which is at the appropriately margined allowable flight temperatures for the spacecraft bus. The chamber is internally ~1.8 m in diameter with a height of ~3.4 m, with ~3.4 m<sup>2</sup> in the 40K thermal region and ~.15 m<sup>2</sup> in the CCA shield region. In later sections the various thermal zones that are used to create these regions will be described.



**Figure 1.** Overall ATP3/4 and E2E test chamber configuration (left) and flight and flight-like GSE under test (right).



**Figure 2.** Chamber thermal regions.

## 2.2. Thermal system design

To achieve the thermal regions outlined above several different GSE systems are implemented to provide 7 different thermal zones inside the chamber:

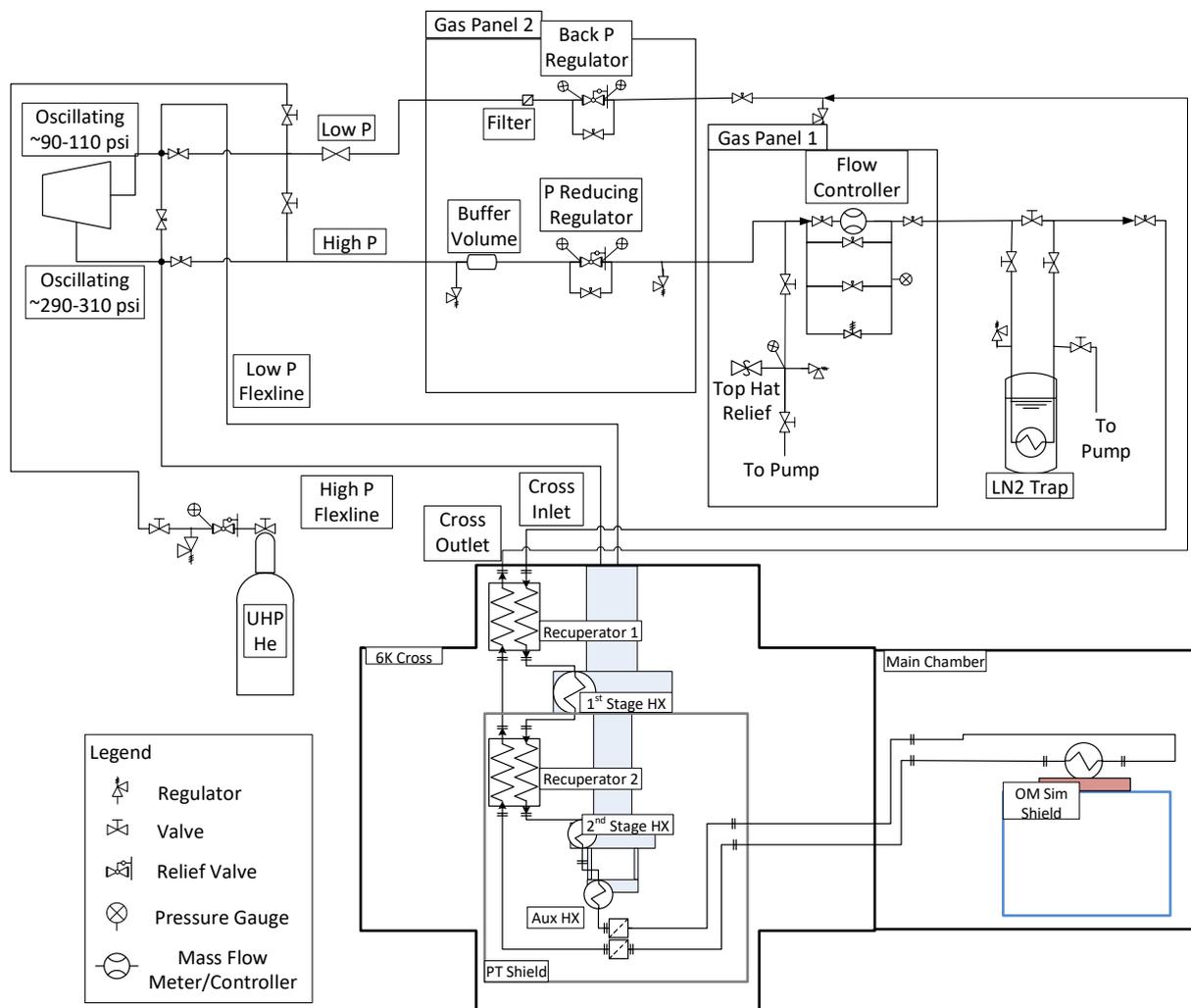
- Zone 1 (Ambient): Vacuum chamber and CCA Scaffold.
- Zone 2 (100K): Outer Shroud shielded with MLI on the outside and SLI on the inside. This is cooled by two single stage Gifford-McMahon cryocoolers (GM1 and GM2) via gravity fed N2 heat pipes, and the CCA shield cooled by the 1st stage of a two stage cryocooler (GM3) via a thermal strap. A liquid nitrogen (LN2) system is used to precool this region from room temperature to ~110K.
- Zone 3 (40K): Inner Shroud shielded with SLI on the outside and black Kapton on the inside. This is cooled by the 2nd stage of cryocooler GM3 via a thermal strap. The LN2 system is also used to precool this region from room temperature to ~110K.
- Zone 4: OM (Optical Module) Simulator Shield (6-40K) is cooled by a recirculating helium loop from a GSE PT cooler
- Zone 5: RLS (Refrigerant Line Support) box is a 40-80K heater controlled region surrounding a subset of the GSE refrigerant lines and line supports.
- Zone 6 (CCEA Chiller Plate): Recirculating chiller cooled/heated plate on which the flight electronics are mounted
- Zone 7 (CCA Chiller Plate): Recirculating chiller cooled/heated plate on which the flight CCA is mounted. This zone is controlled by two separate chillers, one for each compressor, to provide consistent temperature across the CCA thermal interface

*2.2.1. Liquid nitrogen precooling.* Heat exchanger plates on the base plates for the 40K and 100K regions are initially cooled by liquid nitrogen from the building supply (~30psig). The system utilizes a monitoring temperature sensor and external bypass to ensure that liquid is flowing to the two plates. In operation, it was discovered that if the bypass is not left cracked slightly, the flow will begin pulsating and the bulk temperature of the supply will increase to ~120K rather than the nominal ~90K. Valves on the outlet of the 40K and 100K heat exchanger loops allow the flow to be preferentially throttled to prevent the temperature difference between the 40K and 100K plate from becoming too great. Optimized support struts for the 100K and 40K plate were designed to minimize conduction while still supporting the heavy shrouds and test articles. If the difference in temperature becomes too great, differential thermal contraction in the plates can induce yielding stresses in the support struts. This limit changes with cool down as the contraction is a function of temperature. Once the chamber has cooled below ~120K, the LN2 precooling is disabled and the remainder of the cooldown is completed with cryocoolers. The steady state operation is cryogen free.

*2.2.2. GM cryocoolers.* Three GM cryocoolers are utilized to provide cooling after the liquid nitrogen precooling has completed. Two of the GM coolers, Cryodyne model 1050 single stage coolers are supplemented by a novel nitrogen heat pipe system to cool the 100K shroud. Both coolers are powered by a single compressor with a “y” manifold on the high and low pressure Aeroquip lines to split the flow. A third cryocooler, Cryodyne model 1020, provides cooling to the CCA shield with the first stage and the 40K region with the second stage.

*2.2.3. GSE PT cooler for OM simulator shield.* The OM simulator shield is held at the temperature of the OM simulator to serve as both a radiative and conductive intercept. Applied electrical power at the OM simulator is lifted by the 6K heat exchanger and provides a direct measurement of the performance of the flight cooler. Any additional parasitic load from the environment could lead to perceived reduced cooler performance. Thus, to achieve the temperature of the OM at various operating condition ranging from 5.9-20K, a powerful GSE cooler is required. Given geometric constraints, the cold head of a conventional cryocooler cannot be tied directly to the OM simulator shield with a thermal strap so a cooling loop is required. A novel custom manifold produced by

Cryomech is connected in-line with a CP2800 compressor unit and PT407 cold head. A JPL designed and built gas handling system and fluid loop provides remote cooling at the OM simulator shield shown in Figure 3. The manifold bleeds the flow from the high pressure side of the system and stabilizes it using a buffer volume and pressure reducing regulator. An omega digital thermal mass flow meter/controller allows the flow to be set to a level to either optimize for low temperature operation (4-10K) or high temperature operation (10-30K). The gas is passed through a liquid nitrogen trap to ensure no contaminants circulate in the system. The flow is then fed into the chamber through set of recuperators and heat exchangers on the PT407 cold head to precool it to the set point of the second stage. An auxiliary heat exchanger thermally isolated from the second stage allows tighter control of the gas temperature before it is fed to the OM simulator shield. At the shield a heat exchanger with a temperature control heater provides the required cooling. The return gas exchanges heat in the PT 407 recuperators before exiting the chamber. A back pressure regulator is used to further stabilize the flow and the loop is closed at the low pressure side of the compressor.



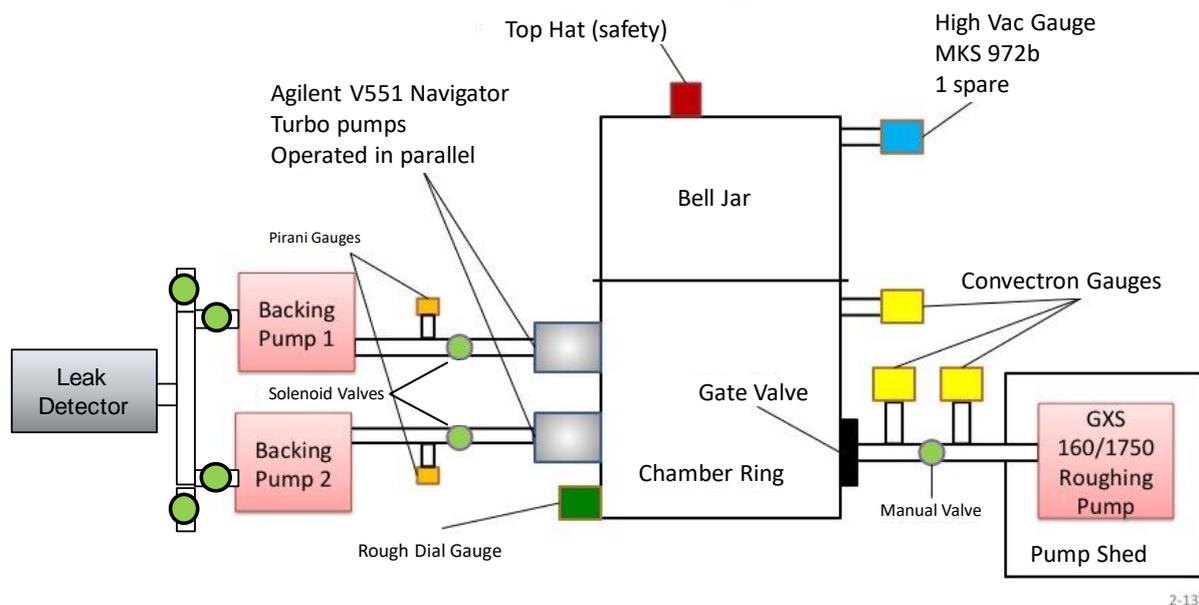
**Figure 3** Valve diagram for OM Simulator PT cooling system

**2.2.4. Chiller systems** The chillers serve to hold the CCA and CCEA heat reject interfaces at the required temperatures for test. The CCEA chiller is a standard SP scientific RC-211 using Galden HT-110 as a working fluid with 550W of lift at -70C and a 1500W heater. The RC-211 has a centrifugal pump with 2-3 gpm flow at 22psi. A second RC-211 was also used as a stand by replacement spare.

On the CCA interface, the required temperature range was wide (-35C to 65C at non-operation limits) with the operational heat rejection on the order of 500W. Two SP scientific RC-311 chillers with the positive displacement pump option capable of lifting 1200W at -70C using Galden HT-110 with a flow of ~4 gal/min at a pressure difference of 120 psi provide a heat rejection sink. The PD pump requires a specialized manifold to filter particles generated and ensure long term pump reliability. Two additional Lytron Kodiak XT (RC50222) chillers prove hot swap replacements for the RC-311 chillers. Though the Lytron chiller lower temperature limit is higher (2kW at -40C limit) and use a turbine pump, which provides slightly less flow (~3 gpm at 70 psi), this is determined to be adequate given the CCA limits. A manifold allows a hot swap of these chillers in less than 30 min such that the test is not interrupted.

### 2.3. Pneumatic design

2.3.1. *Vacuum system.* The configuration of the vacuum system is shown in Figure 4. It includes a large Edwards GXS 160/1750 roughing pump to initially pump the chamber to  $10^{-4}$  torr, after which it is isolated with a gate valve. For redundancy against failure, two Agilent V551 Navigator Turbomolecular pumps (TMP) backed by dry scroll pumps bring the chamber below  $1E-5$  torr. Either pump can be isolated at its vent to allow the chamber to continue to function in the event of one TMP failure. Vacuum gauges connected to solenoid valves coupled with a low pressure relief top hat valve safe the chamber in the event of natural disaster, power outage, or equipment failure.



**Figure 4.** Test chamber vacuum system.

2.3.2. *Flight Pneumatic System.* The helium fill of the Joule Thompson (JT) loop of the flight cooler is handled by a fill cart external to the chamber. See reference [2] for a description of the JT loop. Standard feedthroughs penetrate the chamber and connect the fill and vent ports of the fill cart to the inlet and outlet of the CCA respectively. Since the performance of the closed JT loop is affected by the volume and mass, additional volume could not be added by isolating the system outside the chamber. In flight the system will be filled then isolated with manual valves at the inlet and outlet of the CCA. However, this operation would prevent any adjustment of the fill pressure without warming up, venting the chamber and removing the bell jar to access the valves. As a result, two pneumatically actuated valves are installed directly at the CCA inlet and outlet to allow the system to be isolated

during test, but allow a contingency fill pressure adjustment external to the chamber. The proximity to the CCA avoids adding significant volume to the JT system. The actuation volumes of these valves leak at a significantly higher rate than the flight cooler or chamber, so a vacuum tight can hermetically seals a volume around the valves and is vented outside the chamber. The valve “cans” and one of the pneumatically actuated valves connected to the feedthroughs are shown in Figure 5.

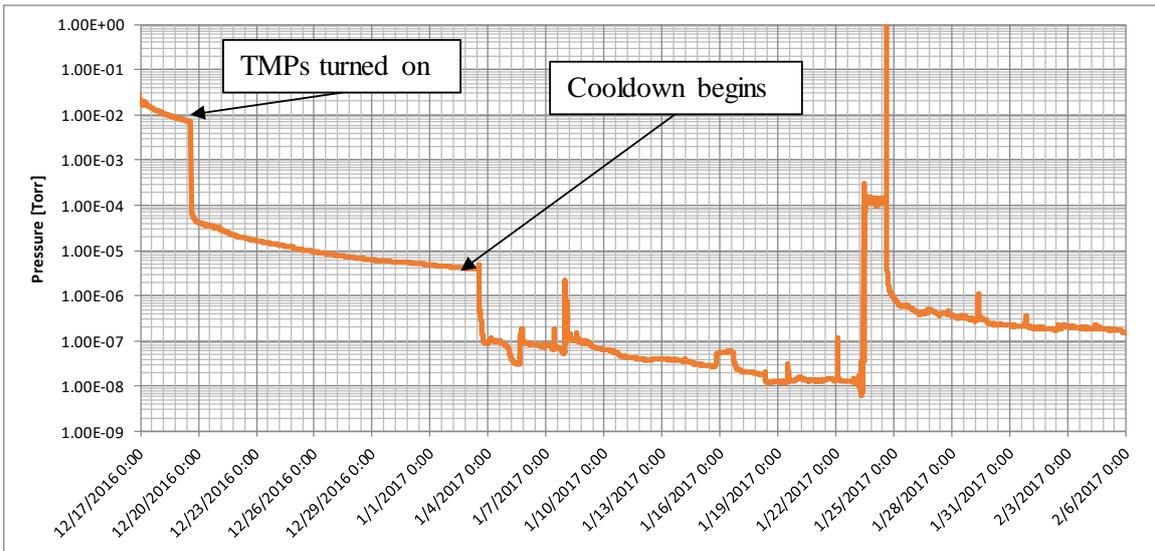


**Figure 5.** Sealed valve “cans” in close proximity to CCA (left) and a pneumatic valve (right)

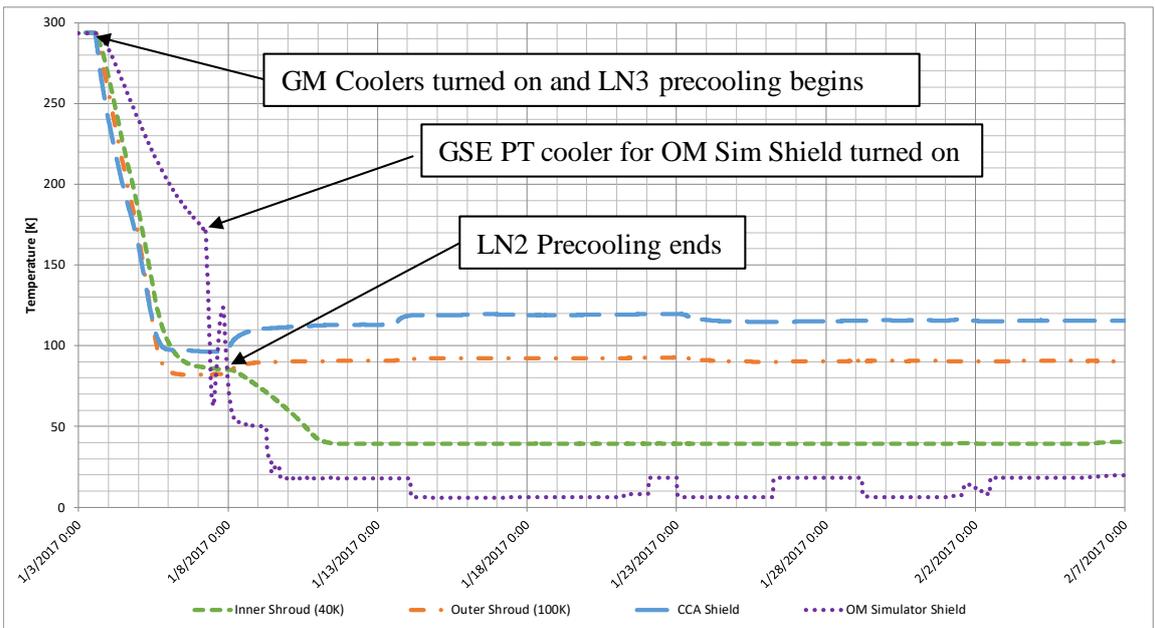
### 3. Results

The pump down for the C2 functional test of the flight spare cryocooler is shown in Figure 6. This is a sample of the pump down and cool down of the chamber. Previous tests had similar profiles, though pumping time on TMPs varied, when the cool down begins the pressure drops dramatically due to cryopumping. A true chamber background was not measureable during cooler acceptance and characterization testing due to the leak rate of the cooler hardware. However, the chamber check out tests found a leak rate on the order of  $1\text{E-}9$  to  $1\text{E-}8$  mbar-l/s, depending on the specific feedthroughs mounted.”

A typical cool down, also taken from the flight spare C2, with annotations for the activation of various components is shown in Figure 7. The 40K shroud was the final region to reach temperature after  $\sim 7$  days of cool down. The chamber has held a stable temperature similar to that shown without significant failures through numerous test campaigns.



**Figure 6.** Representative chamber pump down, taken from the functional test, C2, of the flight spare MIRI cryocooler compressor assembly



**Figure 7.** Representative chamber cool down, taken from the functional test, C2, of the flight spare MIRI cryocooler compressor assembly

#### 4. Conclusion

In conclusion, the test facility can successfully provide a flight representative thermal and vacuum environment for the acceptance testing of both the flight and flight spare CCA and CCEA. Accurately representing the flight thermal environment and characterizing the performance of a large and complex 6K cooler provides many challenges requiring novel solutions. The resulting facility continues to be used in extended characterization of the Cooler Subsystem as of June 2017 and will be used in future test bed activities in support of the MIRI cooler operations on orbit.

## 5. References

- [1] Durand D, Colbert R, Jaco C, Michaelian M, Nguyen T, Petach M and Raab J 2008 Mid InfraRed Instrument (MIRI) cooler subsystem prototype demonstration *Advances in Cryogenic Engineering: Transactions of the Cryogenic Engineering Conference – CEC* **53** pp 807-814
- [2] Durand D, Adachi D, Harvey D, Jaco C, Michaelian M, Nguyen T, Petach M and Raab J 2009 Mid InfraRed Instrument (MIRI) cooler subsystem design *Cryocoolers* **15** pp 7-12
- [3] Petach M, Durand D, Michaelian M, Raab J and Tward E 2011 MIRI cooler system design update *Cryocoolers* **16** pp 9-12
- [4] Petach M and Michaelian M 2014 Mid InfraRed Instrument (MIRI) Cooler Cold Head Assembly Acceptance Testing and Characterization *Cryocoolers* **18** pp 11-17
- [5] Petach M, Michaelian M, Nguyen T, Colbert R and Mullin J 2016 Mid InfraRed Instrument (MIRI) Cooler Compressor Assembly Characterization *Cryocoolers* **19** pp 1-8

## Acknowledgement

The research is supported by the National Aeronautics and Space Administration and was carried out at the Jet Propulsion Laboratory, California Institute of Technology.