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Using In-situ Cryogenic Radiometers to Measure the Performance of a Large Thermal Vacuum Chamber

Michael DiPirro[1], Edgar Canavan[1], James Tuttle[1], Keith Havey[2], Jesse Huguet[2], Wes Ousley[3], Peter Shirron[1], and Thomas Hait[1]

[1]Code 552, NASA/Goddard Space Flight Center, Greenbelt MD 20771
[2]Exelis Corporation, Rochester, NY
[3]Genesis Engineering, Lanham, MD

mike.dipirro@nasa.gov

Abstract. The James Webb Space Telescope will operate in space at temperatures lower than 50 K. To test the major parts of the telescope and instruments on the ground requires a very large thermal vacuum chamber with a helium-cooled shroud operating below 20 K. This chamber and shroud are being subjected to a series of 4 preliminary tests to characterize the chamber and the ground support equipment before the telescope and instruments are tested. We have made measurements in the first of these preliminary tests using simple radiometers, which are located in the chamber and are pointed at various locations and items of interest within the chamber. The radiometers, which have been previously described[1], consist of a Cernox thermometer attached to an absorber suspended behind a Winston cone with an acceptance half-angle of 11 degrees. 9 of these radiometers were anchored to the chamber at temperatures between 17 and 25 K and were able to resolve 2 mW over an area of one m^2. This level of sensitivity corresponds to a 60 K blackbody, which spans the radiometer field of view, changing in temperature by 0.04 K. The results of this test and plans for future tests will be described.

1. Introduction

The James Webb Space Telescope (JWST) is a very large and complex assembly of hardware, parts of which simultaneously operate at room temperature while others are at T< 50 K. Testing the thermal performance of JWST requires a large thermal vacuum chamber that does not allow significant reflections of stray thermal energy. Optical and structural tests are carried out at the same time, requiring ground support equipment (GSE) within the chamber. Some of this GSE runs warmer than the objects under test, requiring complex thermal mitigations to minimize ground test effects. To verify that the test set up and chamber provide the proper low thermal background, simple cryogenic radiometers were developed[1] to be used in situ. This paper briefly describes the design, describes the calibration techniques, and the results of the first test in the large Chamber A at Johnson Space Center (figure 1). This test is known as the Chamber Commissioning Test (CCT).

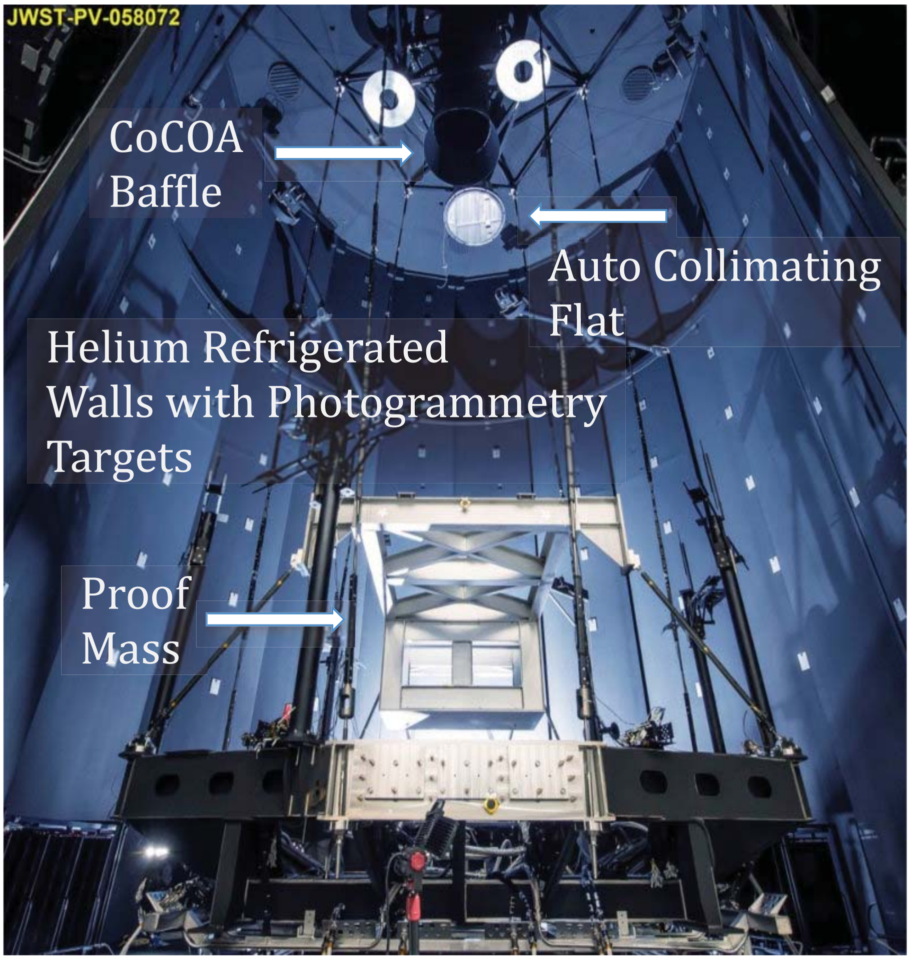


Figure 1. Set up for the Chamber A Commissioning Test.

The proof mass is the structure in the middle of the bottom of figure 1. The three objects near the top are the auto-collimating flats (ACFs) – one actual and two mass simulators. The dark object between the ACFs is the CoCOA baffle. The four "windmills" near the top of the chamber contain photogrammetry cameras. The chamber walls are black, but there are many photogrammetry targets attached in vertical columns.

The basic components of the radiometer are two thermometers – one suspended by fine stainless wires behind a Winston Cone optical concentrator, and one mounted to the base of the radiometer. The sensing thermometer is attached to an absorber made of copper foil and coated with Stycast 2850 GT loaded with fine stainless steel powder. This coating was selected because it has an absorptivity that is nearly independent of wavelength. The absorber and thermometer are suspended from the body of the radiometer by two 50 μm diameter stainless wires that are epoxied to the absorber with Stycast 2850 GT. The original Ph-Br thermometer leads are removed and replaced with a 13 mm coil of 50 μm diameter stainless steel wire. Thus the sensing thermometer assembly is connected to the radiometer body thermally only by stainless steel. The Winston cone and base are made of gold-coated Al 6061 alloy that provides good thermal performance while being readily machinable. The radiometers are suspended by a flexible, 1100 series Al strap from a cold mounting surface. The two thermometers are read out by an SRS resistance bridge, which is multiplexed among all the channels to provide good relative accuracy. In addition the two thermometers in each radiometer are matched for similar resistance at the operating temperature. Software then converts the individual resistances to temperature, subtracts the two temperatures and converts the result to an equivalent heat flux.

The Winston cone has the desirable property of concentrating (not focusing) incoming light within a certain acceptance angle of the cone axis, while rejecting all radiation outside of this axis. We have selected cones with an 11° half-angle which is a good compromise between area coverage and isolating individual sources.

Frequently, the radiometer may view a hot spot that does not fill its field of view. In that case the scene must be interpreted, factoring in the solid angle occupied by the hot sources, in order to determine the flux from the hot source.

2. Calibration

Two calibration techniques were used for the radiometers: a) optical calibration, which gives a direct measure of black body heat flux vs. temperature response, and b) electrically applied heat vs. temperature response which can be performed *in situ*. The calibration results show that the electrically applied heat and optically applied flux are consistent within a constant factor that is close to the expected absorptivity of the sensor element.

The optical calibration is performed by mounting 4 radiometers such that the input cones face a known temperature blackbody (figure 2a), which is formed from black painted aluminum honeycomb. The radiometer body is temperature-controlled independently. When the blackbody is held at the same temperature as the radiometer, the resulting signal represents the true zero for the radiometer. In this way, any offsets in the thermometer calibration or readout are nulled. The blackbody temperature is then raised to higher values and the differences between the base and sensor radiometer thermometers are measured. The temperature of the radiometer is also varied to determine the temperature dependence of the signal.

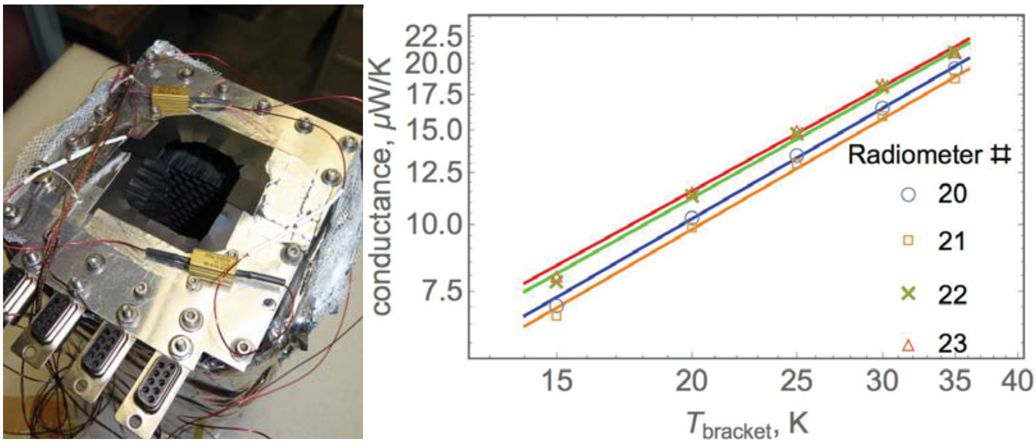
In addition to the optical calibration, an electrical calibration is performed. The black body and the radiometer are held at the same temperature and the sensor and base thermometer of each radiometer are raised in current so that they self heat. The differential heating of the thermometers provides an independent means of measuring the thermal isolation of the sense thermometer sensor compared to the base. The electrical calibration is convenient because it can be done in situ with the only drawback that there can be an offset of up to 10's of mW/m^2 due to systematic calibration or read out errors. Note that the 9 radiometers in the CCT did not have an optical calibration, but the proper magnitude, other than a small offset, can be determined from the *in situ* electrical calibration.

A summary of the electrical calibration results are shown in figure 2b.

In operation the radiometers are mounted to a heat sink that is not temperature controlled which leads to two considerations. Readings are made when the drift rate is low enough so that base and sensor of each radiometer are at thermal equilibrium (typically less than 0.1 mK drift over 10 minutes), and we must be able to interpolate readings between calibration points, which are done at fixed temperature. The latter is accomplished by noting that the radiometer gain (that is, dQ_{dot}/dT) is a constant times a power of temperature that itself has very little temperature dependence. That is, the radiometer reading can be written as:

$$Q_{dot}/Area = GTbase^{1.157}\,(T_{sense}-T_{base}).$$

Only the constant, G, is variable from radiometer to radiometer.



a) b)

Figure 2. a) The calibration apparatus uses a black painted honeycomb box. Four radiometers are mounted into the opening so that they are thermally isolated. b) Results of the electrical calibration. All data are fit by the same temperature exponent.

3. Results from Chamber Commissioning Test

The first test in a series of tests to characterize the thermal performance of Chamber A and the GSE within it was performed in November 2014. In that test the first 9 out of the full complement of 16 radiometers were installed and oriented to provide information summarized in table 1.

Some results of the tests are shown in figures 3-6. Analysis of these results shown in figure 3 shows that the shutter, which blocks room temperature radiation due to the CoCOA from entering the cold portion of the chamber, is very effective. Figure 3 also shows that the CoCOA baffle is very effective at limiting reflected radiation when the baffle is open. This baffle is made with the same material and techniques as the baffle used in the JWST instrument testing[3].

Table 1. Summary of the 9 Radiometers used in the Chamber Commissioning Test.

Radiometer Number	View	Result
1	CoCOA and CoCOA baffle, ceiling of chamber	Shutter and baffle have good performance, background is low
2	ACF, west ceiling	Some view of warm proof mass
3	West ceiling	No proof mass signal
4	CPM2, south wall	Some CPM signals
5	Door and floor	No stray heat visible
6	Door and floor	No stray heat visible
7	Warm cabling entry	Large signal associated with reflection of warm proof mass
8	Southeast door edge	No stray heat visible. Small oscillations of unknown origin.
9	CPM4, north wall	No stray heat visible

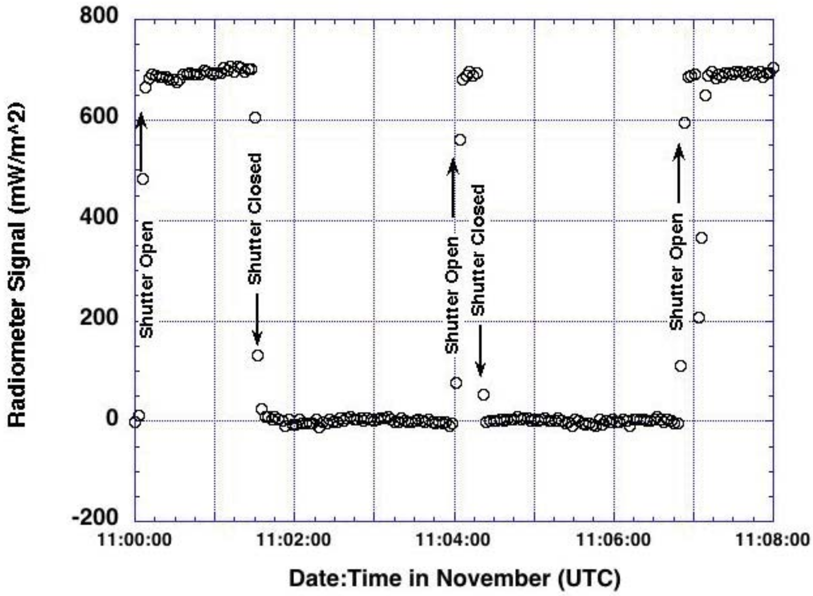


Figure 3. Results from Radiometer 1, measuring the effectiveness of the CoCOA shutter. Note that the date/time axis has the format of Day:Hour:Minute.

Figure 4 shows Radiometer 8 and its typical output. The magnitude of the signal is small and negative due to thermometer readout/calibration offsets. These 9 radiometers did not have an optical calibration which can remove this offset. The oscillations with about a 10 minute period seem to be too fast to be explained by the 90-120 minute oscillation period of the proof mass heaters. These oscillations are still of unknown origin.

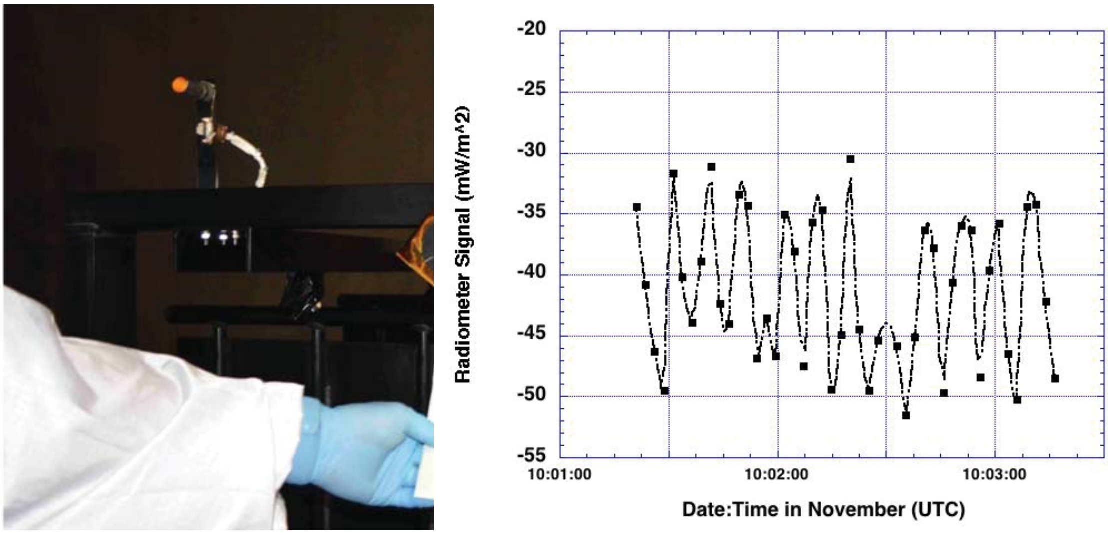


Figure 4. Radiometer 8's input cone can be seen near the top center of the left picture. A radiometer is about 17 mm in diameter and 70 mm long. The graph to the right shows typical data from this radiometer. The excursions are systematic so are real signals and not noise.

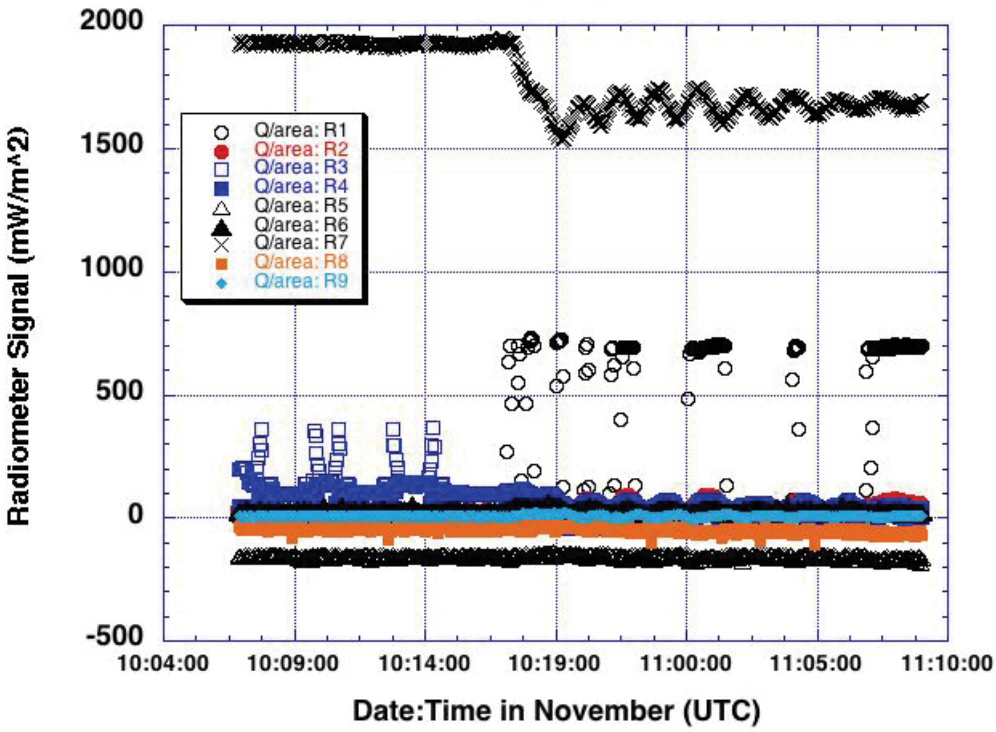


Figure 5. Typical signals from the 9 radiometers during 27 hours of testing. Note that Radiometer 7 has the highest reading and Radiometers 3 and 4 show responses to the use of the photogrammetry cameras. Note that time is expressed as Day:Hour:Minute.

Part of the CCT was to demonstrate the structural strength of the platform which will support the JWST telescope and instruments. For this purpose a dummy mass of twice the weight was used. This mass had such a long thermal time constant that it was prudent to keep the mass from cooling and warming to save time. The dummy mass was blanketed except for its upper surface. While the radiometers did not look directly at this warm surface, there was an auto-collimating flat near the ceiling of the chamber that potentially reflected this thermal energy back into the field of view of several of the radiometers. The data shown in figures 5 and 6 show periodic oscillations corresponding to the duty cycle of the heaters on the dummy mass. These data strongly point to the warm dummy mass as the source of the stray radiation.

4. Summary and Future Testing

These data show the usefulness of the cold radiometers in surveying possible heat sources inside a thermal vacuum chamber. The best sensitivities are a few mW/m^2.

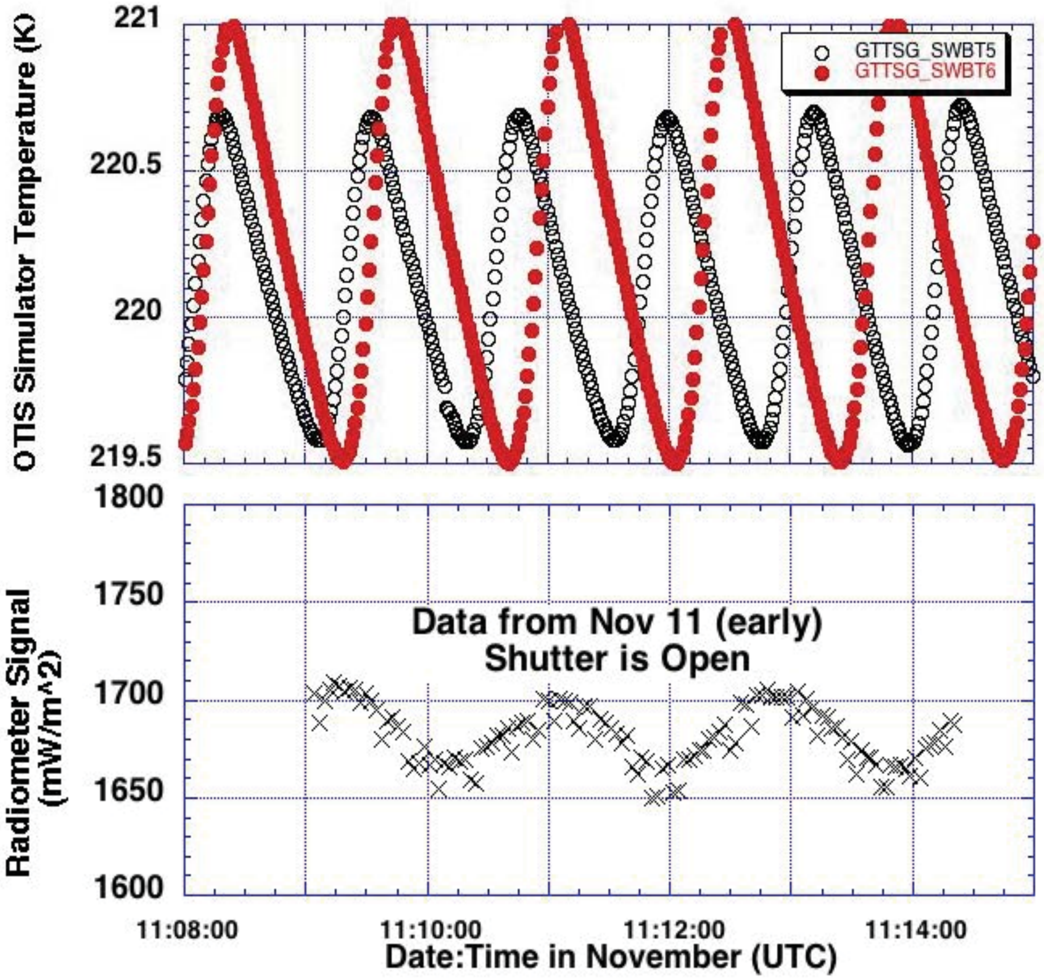


Figure 6. Detail of the Radiometer 7 signal (lower part of graph) with dummy mass temperature superimposed at the top. The magnitude and period of Radiometer 7's oscillations are consistent with the entire signal originating from the dummy mass and reaching radiometer 7 through reflections. Note that time is expressed as Day:Hour:Minute.

Over the next two years there are 4 more tests of the GSE and JWST hardware in Chamber A: Optical GSE-1, Optical GSE-2, Thermal Pathfinder, and finally OTIS itself will provide further opportunities to deploy the full 16 radiometers in different configurations. During Optical GSE-1 and -2, a Beam Image Analyzer (BIA) will be used that will look for GSE alignment and stray radiation, but which will itself be a radiation source since its in situ electronics operate at 170 K. 2 radiometers are pointed at the BIA to help understand this stray radiation. 2 radiometers will also be pointed at the back-side of the primary mirror segments. These mirrors are made of beryllium, which has been machined out on the back for light-weighting. Understanding the effective emissivity of the back of these mirrors is key to understanding the cool down time for the more elaborate upcoming tests. We will also measure the heat emitted from the photogrammetry cameras that are mounted on rotating booms. These cameras operate at room temperature but are thermally shielded by infrared-blocking windows. Several joints in the chamber walls that have potential for light leaks will also be examined during the next test.

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Figure 7. View of the pathfinder structure in the clean room from within Chamber A. This is the next thermal test, which will employ 16 cold radiometers for diagnostics.

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