Thermal Assessment of OSIRIS-REx OVIRS Cryogenic Instrument During Flight System TVAC Test and in Flight

Michael K. Choi[1]
NASA Goddard Space Flight Center, Greenbelt, MD 20771

The Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) Visible and Infrared Spectrometer (OVIRS) is a cryogenic instrument. At the Outbound Cruise nominal spacecraft attitude, sunlight impinges on several multilayer insulation blankets on the forward deck. It is reflected or scattered to other components on the deck. This solar illumination adds heat load to the OVIRS, and causes its detector temperature to exceed the 105K maximum operating allowable flight temperature limit by 0.8K. During the flight system thermal vacuum test, the solar simulator beam reflected or scattered from the test fixtures to the OVIRS added non-flight heat load. The detector temperature was 9K warmer than that in flight. At those temperatures, the science data was acceptable, despite its quality was not as high as that of 105K or colder.

Nomenclature

AFT	=	allowable flight temperature
AU	=	astronomical unit
DTM	=	detailed thermal model
GBK	=	germanium coated black Kapton
HGA	=	high gain antenna
MEB	=	main electronics box
MLI	=	multilayer insulation
MST	=	Mountain Standard Time
OVIRS	=	OSIRIS-REx Visible and Infrared Spectrometer
$OvrBrk_T$	=	OVIRS Optics Box bracket temperature sensor
$OvrElBp_T$	=	OVIRS main electronics box baseplate temperature sensor
$OvrODe_T$	=	OVIRS detector assembly temperature sensor
RTM	=	reduced thermal model
SPE	=	Sun-Probe-Earth
$SUN_{NB}F$	=	Fraction of sun (on X, Y or Z axis)
TB	=	thermal balance
TM	=	thermal margined dwell
TVAC	=	thermal vacuum
UTC	=	Coordinated Universal Time

I. Introduction

THE NASA Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) spacecraft was successfully launched into orbit on September 8, 2016. It is traveling to a near-Earth asteroid (101955) Bennu, to study it in detail, and bring back a pristine sample of larger than 60 g to Earth for scientific analyses. Figure 1 presents the Mission Phases, including the sun range or solar distance in astronomical unit (AU), which affects the thermal environment. It also shows the Sun-Probe-Earth (SPE) angle in degrees, which is the solar incidence angle with the aft (–Z) deck.

The OSIRIS-REx Visible and Infrared Spectrometer (OVIRS) is a cryogenic temperature instrument on the OSIRIS-REx spacecraft. Its detector has a -168°C (105K) maximum operating allowable flight temperature (AFT) limit in the Environmental Requirements Document.[1] Figure 2 shows the OVIRS thermal design.[2] A two-stage aluminum radiator provides passive cooling to the detector. The radiator thermal coating is Z93C55 conductive white paint. Four flexures thermally isolate the second stage radiator from the Optics Box. A copper strap thermally couples the detector assembly to the second stage radiator. Three bipod flexures thermally isolate the first stage

[1] Senior Aerospace Engineer, Heat Transfer, Mechanical System Division

radiator from a support bracket on the spacecraft side of the interface. The Optics Box bracket is made of carbon composite, which has a very low thermal conductivity. It is mounted to the forward deck. Its operating AFT limits are -25°C minimum and 10°C maximum. From Fig. 3, the OVIRS Solar Calibrator and Optics Box +Z side are located at the -X edge of the forward (+Z) deck. The solar calibrator protrudes above the forward deck. Its interior is painted black. Both the solar calibrator and Optics Box have multilayer insulation (MLI) with germanium coated black Kapton (GBK) on the exterior. An electrical harness connects the Optics Box to the Main Electronics Box (MEB), which is mounted to a spacecraft panel under the forward deck. The MEB operating AFT limits are -15°C minimum and 40°C maximum. The Optics Box bracket and MEB are sources of parasitic heat load by conduction to the detector. In the OVIRS instrument level thermal vacuum (TVAC) and thermal balance (TB) test, a chamber shroud of -182°C (91.2K) average was used to simulate deep space. Additionally, a copper bar, which was cooled by a cryogenic refrigerator, was used to cool the radiator target plate by conduction. Its average temperature was -236°C (37.2K) in the hot case and -237.6°C (35.6K) in the cold case.[2] A detailed thermal model (DTM) with 7,971 nodes was developed and correlated to the instrument TB test by the OVIRS thermal team at Goddard Space Flight Center. Its pre-launch operating temperature prediction for the detector was 98.5K in the nominal Outbound Cruise phase, and 99.5K in the Reconnaissance 525 meter altitude case at Bennu.[3]

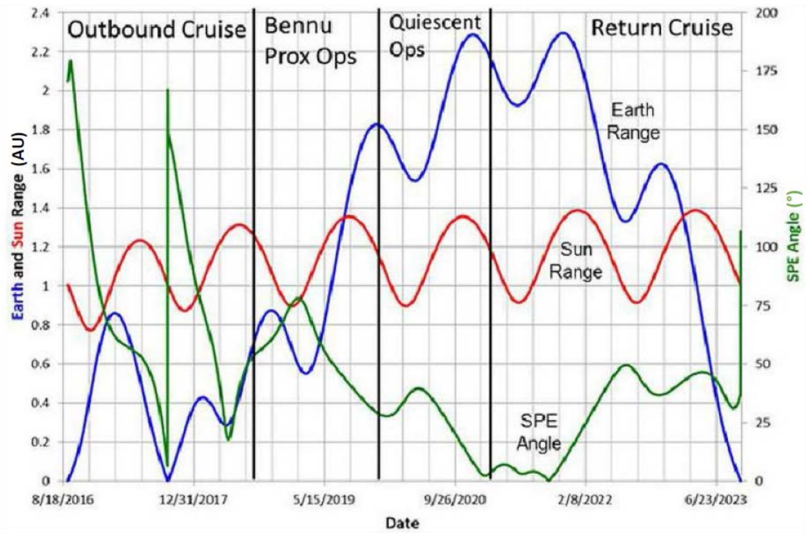

Figure 1. OSIRIS-REx Mission Phases (source: NASA, OSIRIS-REx Project).

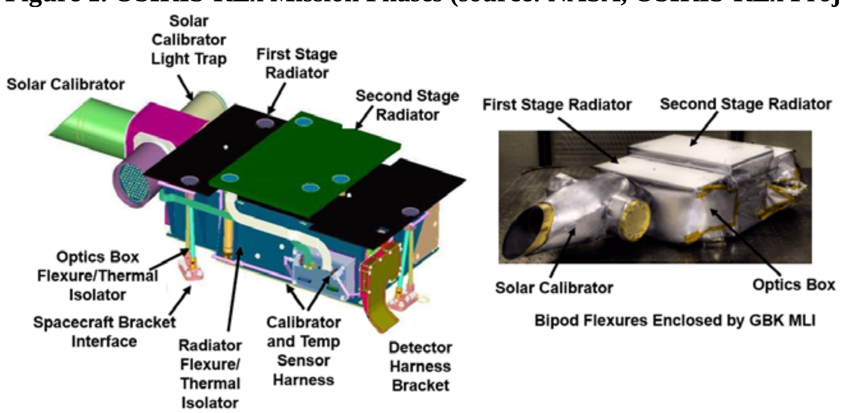

Figure 2. OVIRS with a Two-Stage Radiator, Flexures and MLI Blankets.[2,3]

At the Outbound Cruise nominal spacecraft sun-pointing attitude (i.e., sun on +X), sunlight is incident on the following components on the forward (+Z) deck:

•The OSIRIS-REx camera suite (OCAMS) PolyCam sunshade MLI with microporous black polytetrafluoroethylene (PTFE).

•A portion of the PolyCam optics support tube (MLI with GBK).

•A portion of the OSIRIS-REx Thermal Emission Spectrometer (OTES) sunshade (MLI with GBK).

•The spacecraft Inertia Measurement Unit (IMU)-sunshade (MLI with GBK).

•The spacecraft OSIRIS-REx Laser Altimeter (OLA)-sunshade (MLI with GBK).

Figures 3 through 5 illustrate the solar impingement, including reflection or scattering of the solar impingement.[4]

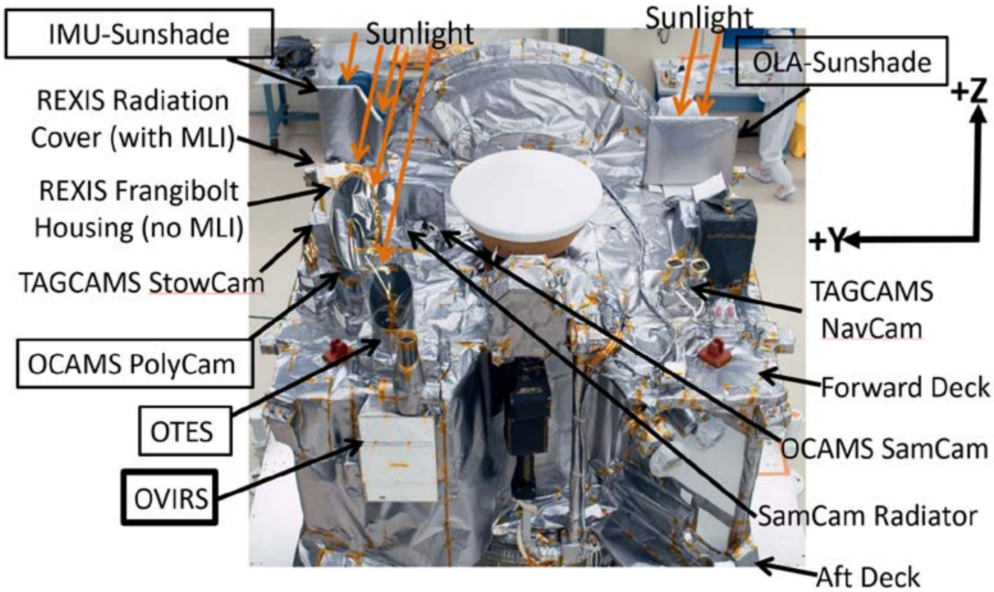

Figure 3. Solar Impingement on MLI Blankets (View from –X/+Z).

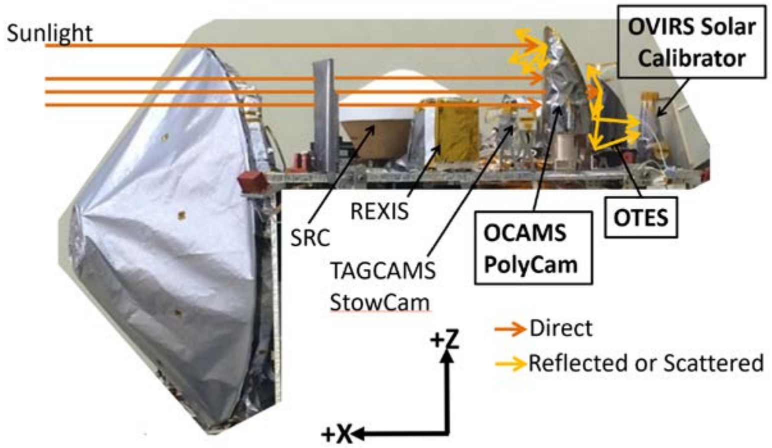

Figure 4. Reflection or Scattering of Sunlight Impinging on OCAMS PolyCam and OTES.

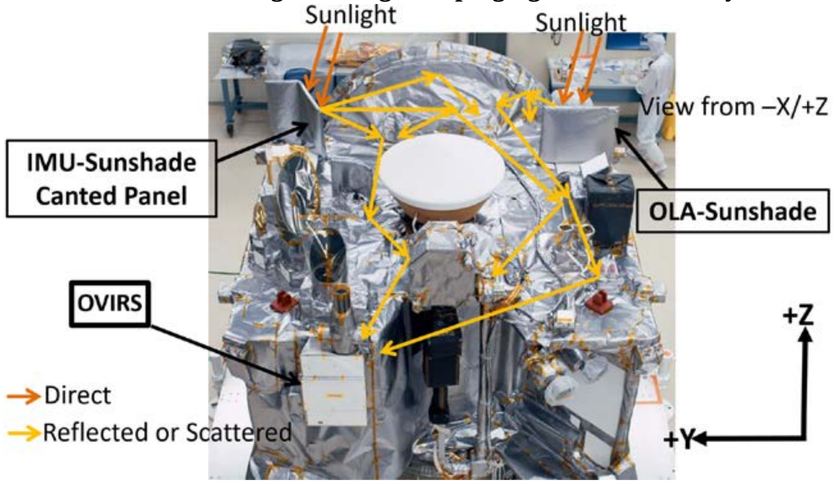

Figure 5. Reflection or Scattering of Sunlight Impinging on IMU-Sunshade and OLA-Sunshade.

Figure 6 shows an image taken by the Touch-and-Go Camera System (TAGCAMS) StowCam camera two weeks after launch. Stray light, which illuminates the Sample Return Capsule (SRC) and nearby components, is seen in the image. Reflection or scattering of solar impingement on the above MLI blankets is the source of stray light.

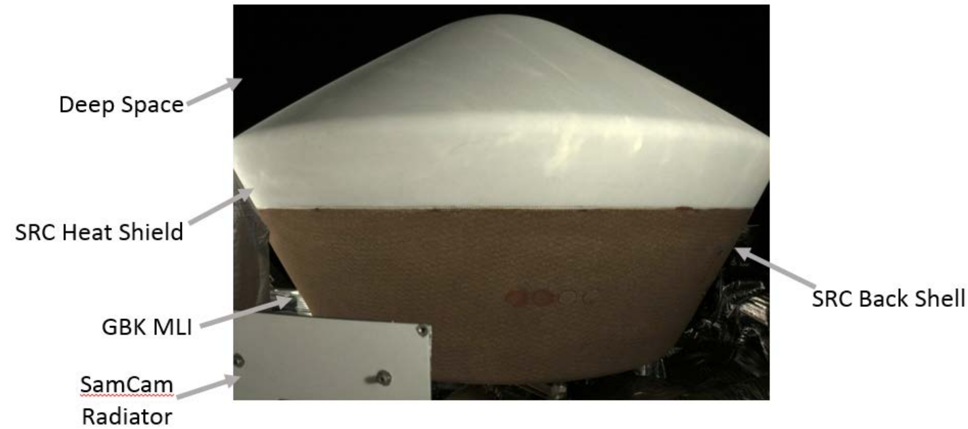

Figure 6. Image Taken by TAGCAMS StowCam (Source: OSIRIS-REx Project).

During the OSIRIS-REx flight system thermal vacuum (TVAC) test, a solar simulator beam was used to simulate the solar flux incident on the flight system. As a result, reflection or scattering of the solar simulator beam on the forward deck MLI blankets was simulated. The TVAC test included two thermal cycles and three thermal balance cases.

The objective of this paper is to present a thermal assessment of the OVIRS instrument during the OSIRIS-REx flight system TVAC test and in flight from the mission level thermal perspective, and to capture lessons learned.

II. Thermal Assessment of OVIRS during Flight System TVAC Test

The OSIRIS-REx flight system TVAC test began on February 18, 2016, and lasted for 21 days. Figure 7 shows the OSIRIS-REx spacecraft being lifted into the vacuum chamber in the Lockheed Martin Space Simulation Laboratory in Denver, Colorado.

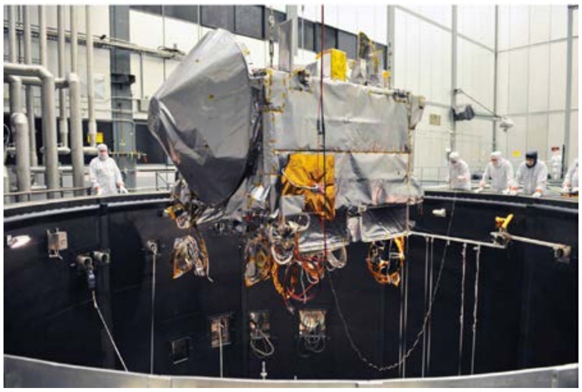

Figure 7. OSIRIS-REx Lifted Into Vacuum Chamber (Source: OSIRIS-REx Project).

A. OVIRS Radiator Heat Load

The heat load that was required to be removed from the OVIRS radiator in the flight system TVAC test was 0.577 W at 105K in the hot case and 0.343 W at 75K in the cold case in the OVIRS Interface Requirement Control Document (IRCD).[5]

B. Flight System TVAC Test Setup

The spacecraft marmon ring was attached to a large gimbaled test fixture, which could rotate up to 90° during the TVAC test.[6] After the fixture rotated the spacecraft 90°, the +X (sun) side of the spacecraft faced upward toward the top of the chamber. A solar simulator beam was used to simulate the solar flux.[6] The beam impinged on the +X side as shown in Fig. 8. This test configuration simulated the nominal Outbound Cruise sun-pointing attitude. Not only the solar simulator beam impinged on the spacecraft, but also it impinged on most of the gimbaled test fixture.

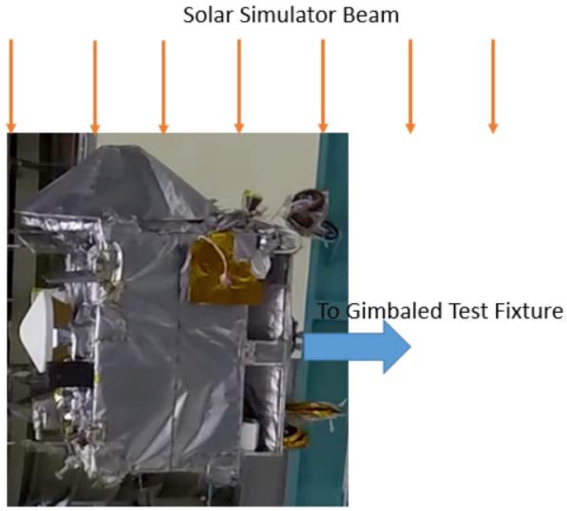

Figure 8. Illustration of Solar Simulator Beam Impinging +X Side of OSIRIS-REx in Vacuum Chamber.

A target plate was used to simulate the deep space heat sink for the OVIRS radiator. It consisted of an open cell aluminum honeycomb coated with Aeroglaze Z307 black paint. Its hemispherical emittance at 30K was about 0.95. The target plate was attached to the interior of the bottom side of a five-sided shallow box fixture. This target assembly was cooled to approximately 35K by a Stirling cycle gaseous helium system.[6] Since the gimbal test fixture rotated the spacecraft 45° to simulate the solar angle during the Detailed Survey mission phase, the target was designed in such a way that it had no interference with the OVIRS radiator during the rotation. That simulation occurred near the end of the TVAC test, which the OVIRS began to warm up to ambient and did not require cooling from the target assembly. A MLI blanket was used to close out the gap between the radiator and target assembly. It was attached to the target assembly only to ensure no interference with the spacecraft rotation.[6] The vacuum chamber shroud was cooled by gaseous nitrogen (GN2) to -170°C (103K) to simulate the deep space heat sink for the rest of the flight system.

C. Flight System TVAC Pre-Test OVIRS Detector Temperature Prediction

At the Critical Design Review (CDR), a 400-node OVIRS reduced thermal model (RTM) was delivered and was integrated to the flight system thermal model. It had eight times the number of nodes (50 maximum) specified in the IRCD.[5] Because it predicted the detector maximum operating flight temperature to be significantly colder than the 105K maximum AFT limit, the issue of warming caused by sunlight reflected or scattered by the forward deck MLI blankets to the OVIRS was not revealed. After the OVIRS instrument level TVAC and TB test, a 1,525 node correlated RTM was delivered. After it was integrated to the flight system thermal model, it increased the run time significantly. As a result, it was only used in special runs that required better accuracy for detector temperature prediction. Prior to the flight system TVAC test, the integrated thermal model, with the 1,525 node RTM, predicted the OVIRS detector operating temperature in cold margined dwell #2 (TM2) to be 109.1K, which exceeded the 105K maximum AFT limit by 4.1K. When all the GSE, chamber shroud and radiator target plate were deleted from the integrated thermal model, the OVIRS detector operating temperature prediction was 100.2K. The Project and OVIRS principal investigator understood that the vacuum chamber environment for the OVIRS was non-flight like. The main goal for the OVIRS in the flight system TVAC was to achieve an adequately cold detector temperature to check performance. Furthermore, the OVIRS principal investigator indicated that the OVIRS science data to be acceptable at 110K to 115K, but it can be harder to process and the quality is not as high as that of 105K or colder. Since the predicted OVIRS detector temperature in the vacuum chamber was 5.9K below 115K, the flight system TVAC test moved forward after the Pre-environmental Review.

D. OVIRS Detector Temperature in Flight System TVAC Test

Figure 9 presents the OVIRS detector temperature recorded during the OSIRIS-REx flight system TVAC test.

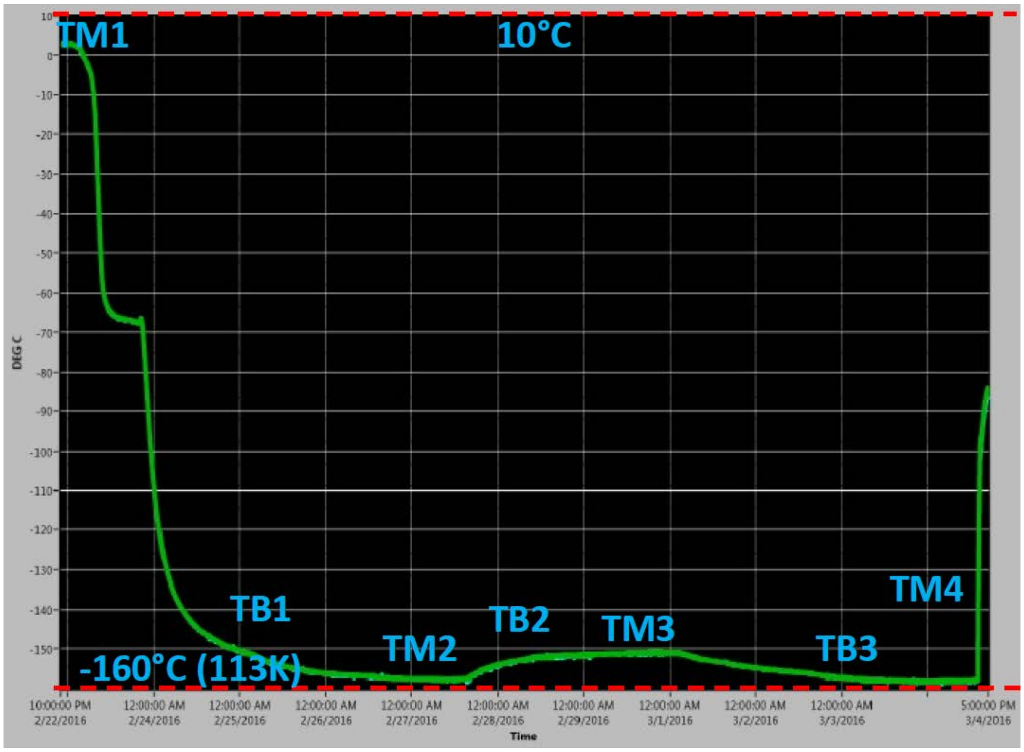

Figure 9. OVIRS Detector Flight Temperature Sensor Temperatures (°C) during Flight System TVAC.

Figures 10, 11 and 12 show the vacuum chamber shroud temperature, solar simulator beam intensity, and gaseous helium cooled target plate temperature, respectively.

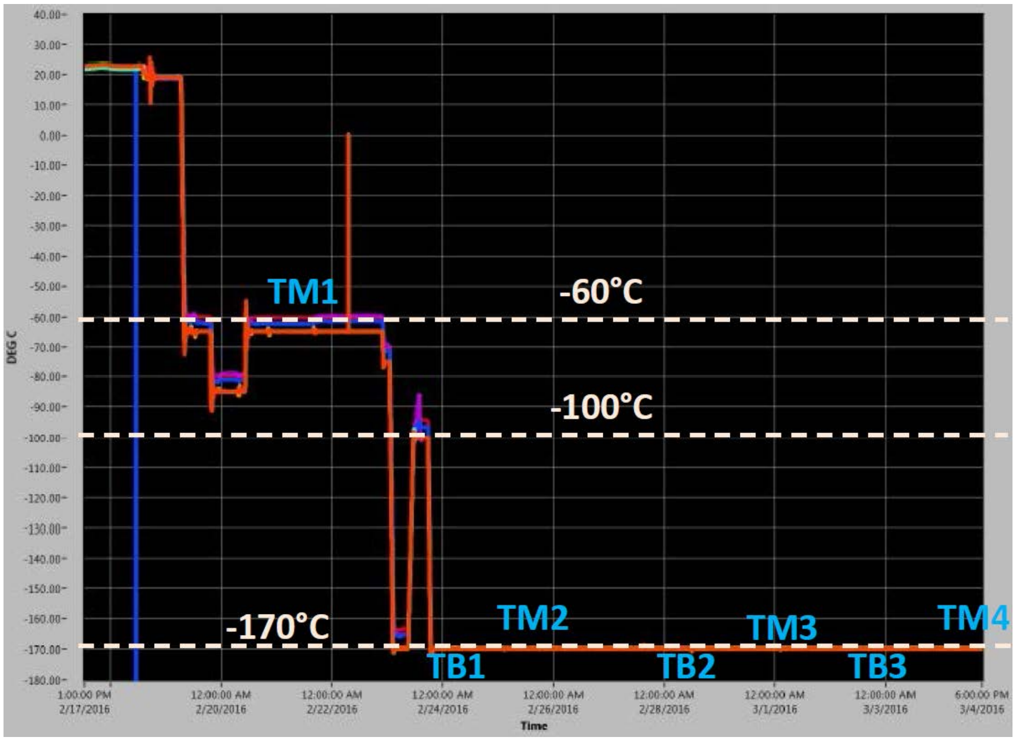

Figure 10. Chamber Shroud Temperature (°C).

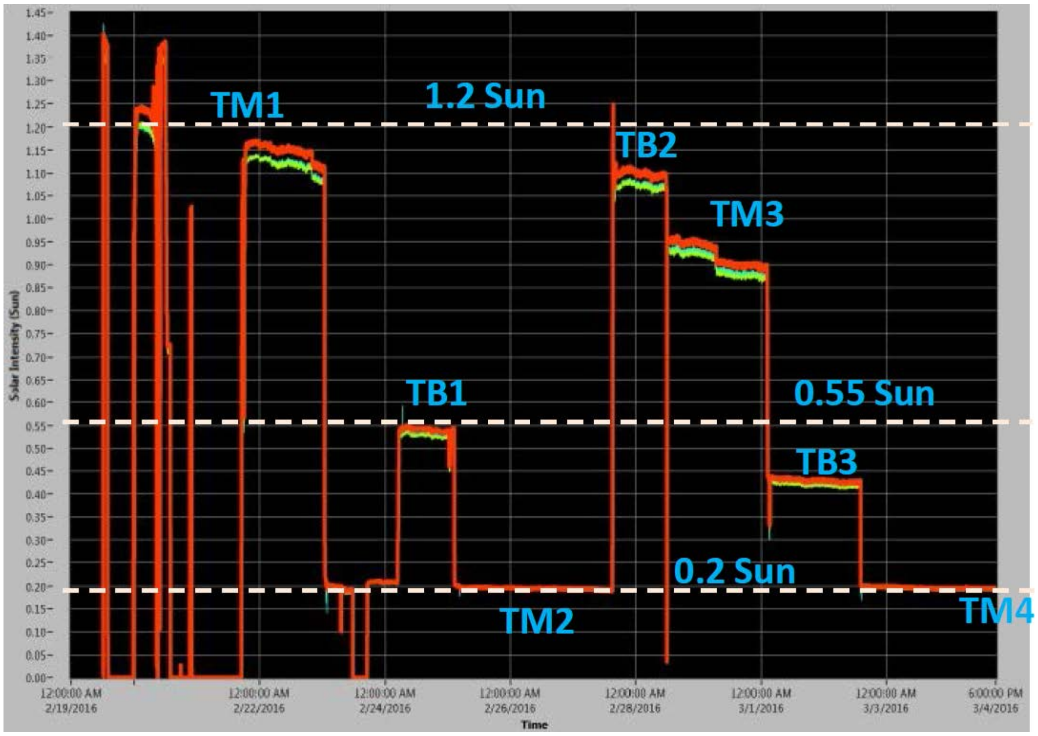

Figure 11. Solar Simulator Beam Intensity (Sun).

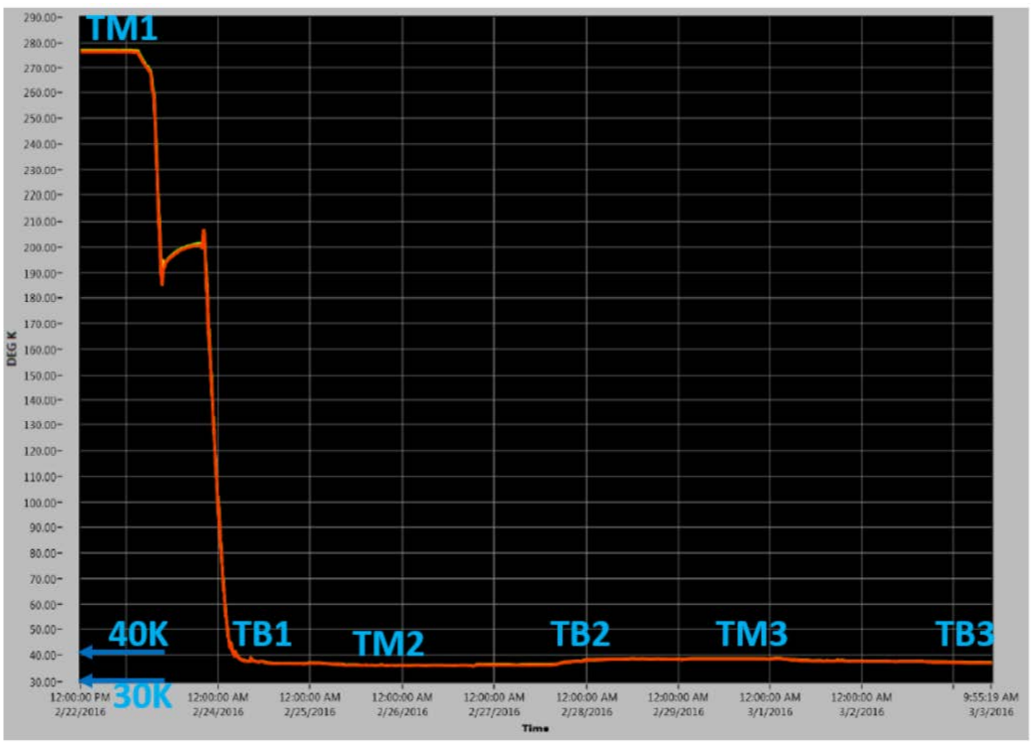

Figure 12. OVIRS Helium Cooled Target Cold Plate Temperature (K).

Cool down began at about 10 PM MST on February 22, 2016, with the chamber shroud temperature at -60°C (213K). The hot margined dwell and bakeout (TM1) was completed at 12 AM MST on February 23, 2016. The chamber shroud temperature was decreased to -170°C (103K). The gaseous helium cooling system was turned on to cool the target assembly to 35K. At 8 AM MST on February 23, the chamber shroud was increased to -100°C (173K) because the solar simulator had problems and repairs were performed. Without a solar simulator beam, the -100°C temperature was necessary to prevent the High Gain Antenna (HGA) from falling below its cold survival limit. At 4 PM MST on February 23, the chamber shroud temperature was decreased to -170°C (103K). The OVIRS cool down continued in the first cold margined dwell (TM2), with the solar simulator beam intensity maintained at 0.2 sun to keep the HGA temperature above -100°C. At 08:05 MST on February 27, the OVIRS detector temperature was -157.8°C (115.2K), which was 10.2K warmer than the 105K maximum operating AFT limit. It was 6.1K warmer the pre-TVAC 1,525-node OVIRS thermal model prediction. Additionally, the 4 days and 10 hours cool down time was nearly twice as long as that predicted by the thermal model for flight. It is evident that the thermal model under predicted the heat load on the OVIRS. A larger heat load not only increases the detector temperature, but also decreases the cooling rate.

At the end of TM2, the solar simulator beam intensity was increased to 1.1 sun to begin the hot case thermal balance (TB2). The OVIRS detector temperature began to increase. Because of solar simulator problems, the beam intensity in the first hot margined dwell (TM3) decreased to 0.95 sun and then to 0.9 sun. The OVIRS detector temperature continued to increase. It was at -153°C (120K) when TM3 ended. The thermal effect of the solar simulator beam on the OVIRS was obvious.

At the end of TM3, the solar simulator beam intensity was decreased to 0.43 sun to begin the cold case thermal balance (TB3). The OVIRS detector temperature began to decrease. When TB3 ended, the solar simulator beam intensity in the second cold dwell (TM4) was decreased to 0.2 sun. The OVIRS detector temperature continued to decrease. It was at -158.2°C (114.8K) when TM4 ended. It was the coldest OVIRS detector temperature achieved in the OSIRIS-REx flight system TVAC. It was 9.8K warmer than the 105K maximum operating AFT limit. Nevertheless, the OVIRS principal investigator reported the detector was not noise saturated and sufficient to check performance at 114.8K. The main goal for the OVIRS was achieved.

The OVIRS detector temperature was 9.8K to 10.2K warmer than the 105K maximum operating AFT limit and cool down time was much longer than that predicted by the OVIRS correlated detailed thermal model for flight. They were consistent with the flight system TVAC pre-test predictions, and were caused by the following test factors (not in a particular order):

- Non-flight like heat load caused by the solar simulator beam reflected or scattered by the gimbal test fixture to the OVIRS.
- The -170°C (103K) chamber shroud was 100K warmer than the deep space temperature.
- The approximately 35K gaseous helium cooled target for the radiator was approximately 32K warmer than deep space.
- The -170°C (103K) chamber shroud had a hemispherical emittance of less than 1.
- The gaseous helium cooled target for the radiator had a hemispherical emittance of less than 1.
- A very small and barely visible gap between the OVIRS radiator and target assembly, which could not be completely closed out, allowed a very small view from the radiator to the chamber shroud.

In TM2, the GBK coupon temperature near the OVIRS was -118°C (155K). It is an evidence of the thermal effect of the non-flight like reflected or scattered solar simulator beam and chamber shroud temperature on the OVIRS.

III. Thermal Assessment of OVIRS in Flight

A thermal assessment of the OVIRS instrument during the OSIRIS-REx Outbound Cruise mission phase is made.

A. Effect of Solar Irradiance on OVIRS Optics Box Bracket Temperature

Figure 13 shows the OVIRS Optics Box support bracket temperature versus days after launch when the spacecraft attitude was sun-pointing (i.e., sun on +X). It was within the AFT limits. Decontamination heaters maintained the OVIRS detector temperatures at -74°C (199K) and -76°C (197K), for silicon diode temperature sensors T-0226 and T-0426, respectively. Additionally, the relationship between solar distance and days after launch can be seen in Fig. 14. Solar irradiance is inversely proportional to the square of solar distance. The relationship between the solar irradiance and days after launch can be seen in Fig. 15. From these figures, during the nominal Outbound Cruise spacecraft sun-pointing attitude, the OVIRS Optics Box bracket temperature increased as the solar distance decreased, and vice versa. As the solar distance increases, the thermal effect of solar impingement on the

OVIRS decreases. It is an evidence that reflection or scattering of sunlight impinging on the PolyCam, OTES, IMU-sunshade and OLA-sunshade MLI blankets adds heat load to the OVIRS.

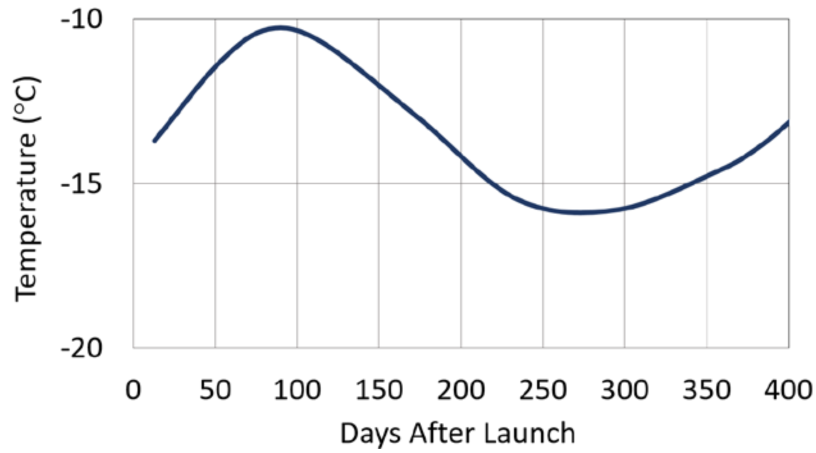

Figure 13. Flight Temperature of OVIRS Optics Box Bracket in Outbound Cruise with Sun on +X.

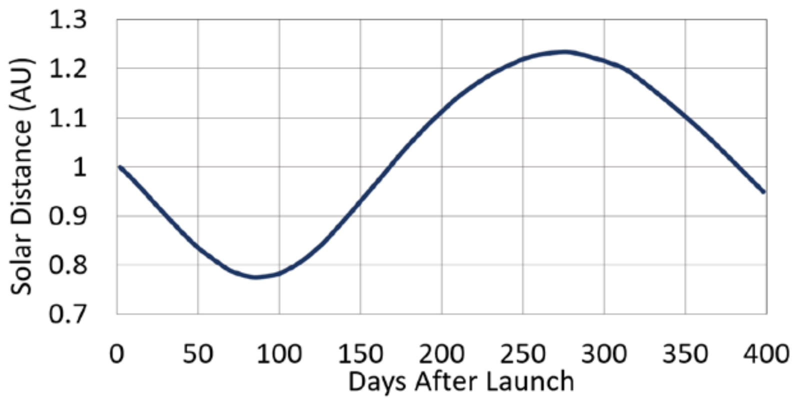

Figure 14. Solar Distance versus Days after Launch.

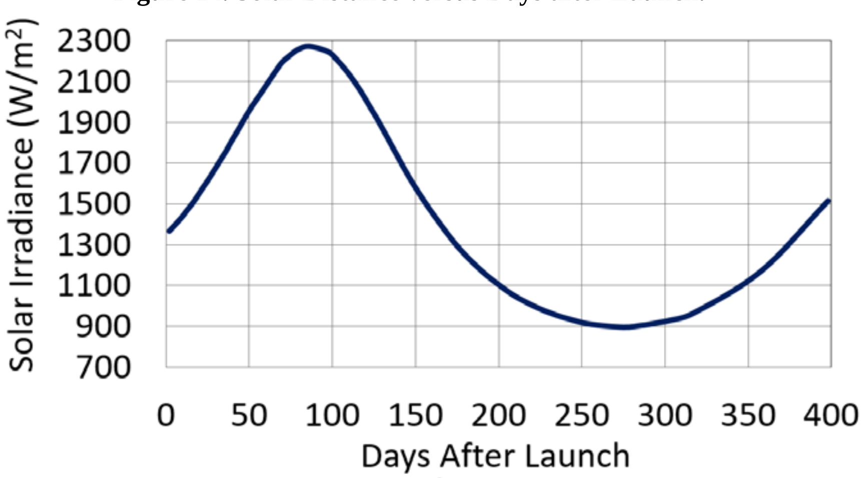

Figure 15. Solar Irradiance versus Days after Launch.

Figure 16 shows the OVIRS Optics Box bracket temperatures from Day 086 to Day 093 in 2017. It corresponds to sun on X, Y and Z in Fig. 17. When the spacecraft attitude is Earth-pointing, sun is on the aft (–Z) side of the spacecraft. When the spacecraft attitude changed from sun-pointing to Earth-pointing, the temperatures of the Optics Box bracket decreased, and vice versa. As a result, the temperatures of the Optics Box bracket oscillated. It is an evidence that reflection or scattering of sunlight impinging the PolyCam, OTES, IMU-sunshade, and OLA-sunshade MLI blankets adds heat load to the OVIRS.

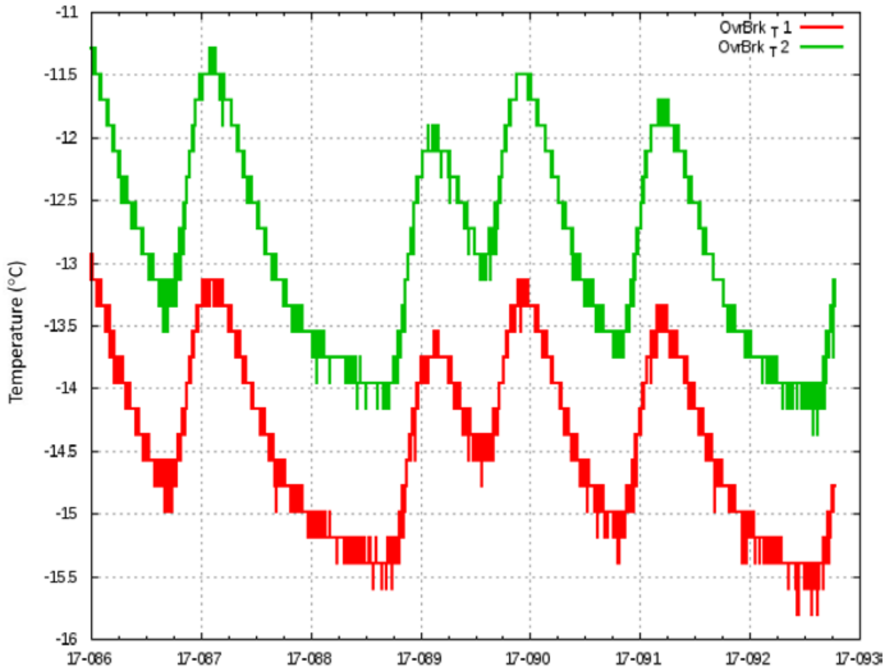

Figure 16. OVIRS Optics Box Bracket Temperature from Day 086 to Day 093 in 2017.

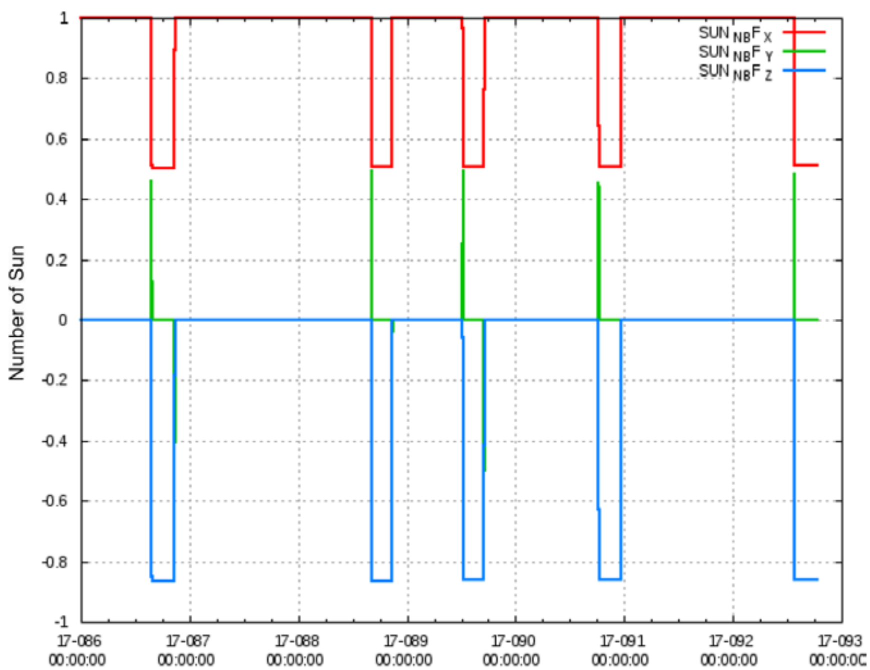

Figure 17. Fraction of Sun on X, Y and Z Axes from Day 086 to Day 093 in 2017.

B. OVIRS Cool Down from Day 284 to Day 288 in 2016

Figure 18 shows the OVIRS detector cool down from Day 284 to Day 287 in 2016. From Fig. 19 and Fig. 20, during the cool down, the Optics Box bracket and MEB temperatures were nominal. Figure 21 presents a plot of sun on the X, Y and Z axes. Sun was on +X during the entire OVIRS cool down. From Fig. 22, the solar distance was between 0.88 AU and 0.9 AU. The steady state temperature of the detector was 105.8K. It exceeded the maximum operating AFT limit by 0.8K. Additionally, it was significantly warmer than the 98.5K predicted by the OVIRS correlated detailed thermal model.[3] It is evident that sunlight impinging on the PolyCam, OTES, IMU-sunshade and

OLA-sunshade MLI blankets is reflected or scattered to the OVIRS and its neighboring MLI blankets. As a result, it increases the heat load to the OVIRS detector. Despite the OVIRS 7,971-node correlated detailed thermal model has the instrument modeled in great details, it did not include the reflected or scattered sunlight on the forward deck. In addition, it was not simulated in the instrument level TB test. The OVIRS principal investigator indicated that 105.8K is acceptable for science, despite it exceeds the maximum operating AFT limit. In flight, the detector cool down time from near room temperature to 105.8K was 3.4 days long. It was faster than that of 4.4 days in the flight system TVAC test. Additionally, the coldest detector temperature achieved during the first cool down in flight was 9K colder than that achieved in the flight system TVAC test. Non-flight like heat load in the flight system TVAC caused the difference.

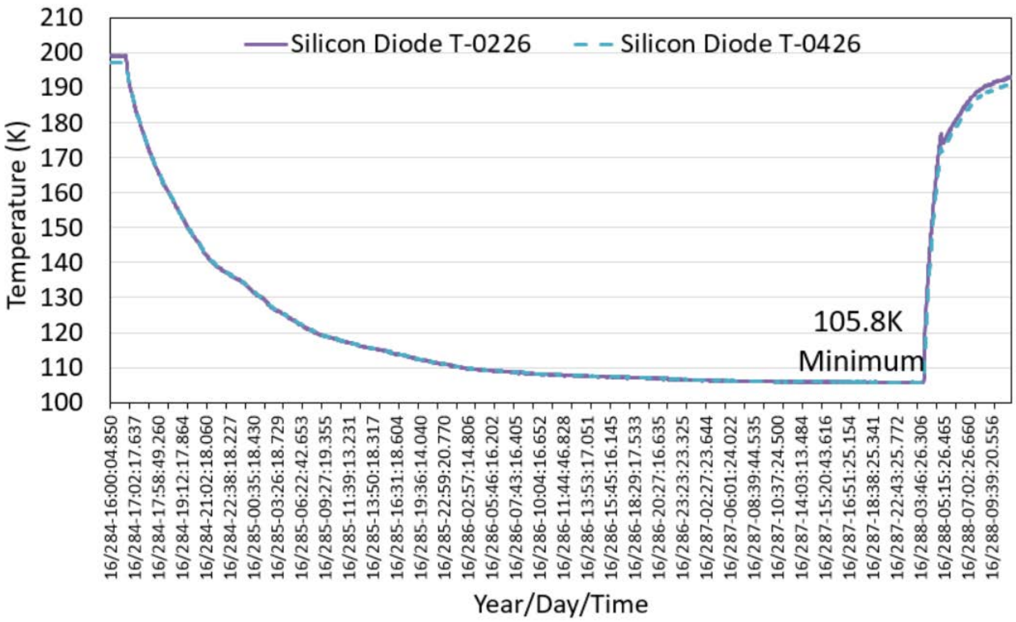

Figure 19. OVIRS Detector Cool Down from Day 284 to Day 288 in 2016.

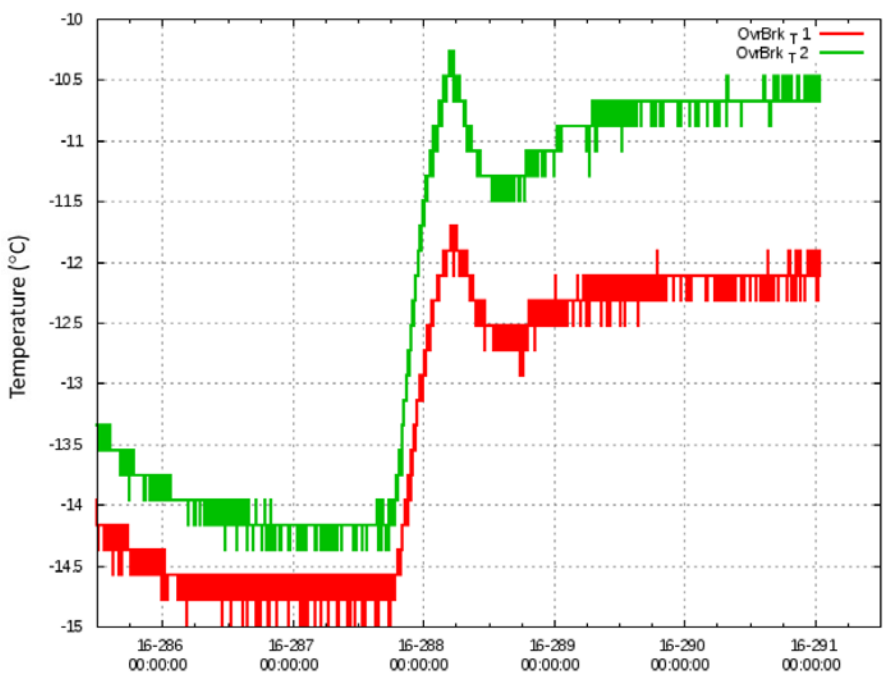

Figure 19. OVIRS Optics Box Bracket Temperature from Day 285 to Day 291 in 2016.

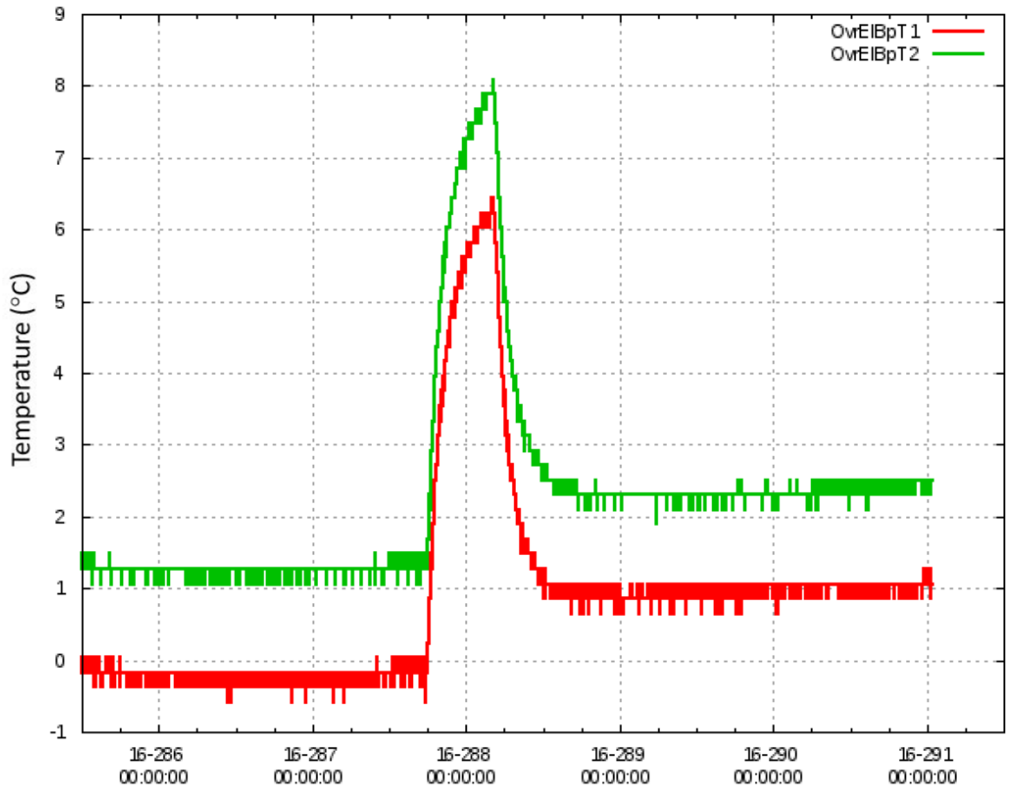

Figure 20. OVIRS MEB Temperature from Day 285 to Day 291 in 2016.

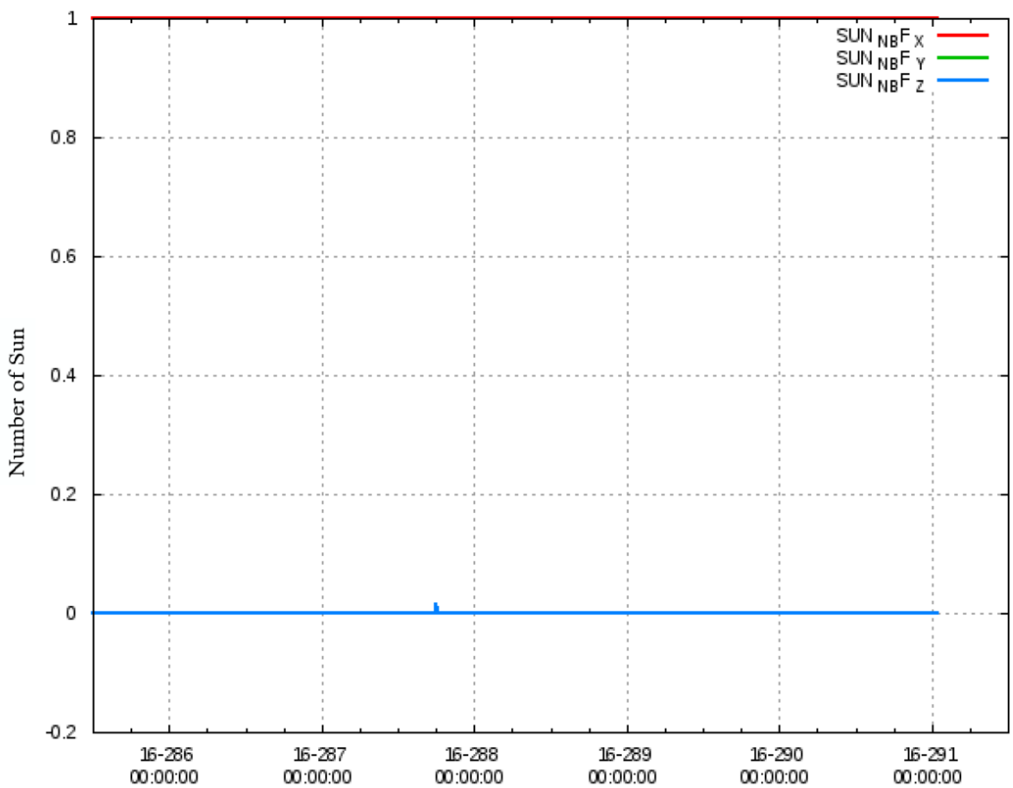

Figure 21. Sun on X, Y and Z Axes from Day 285 to Day 291 in 2016.

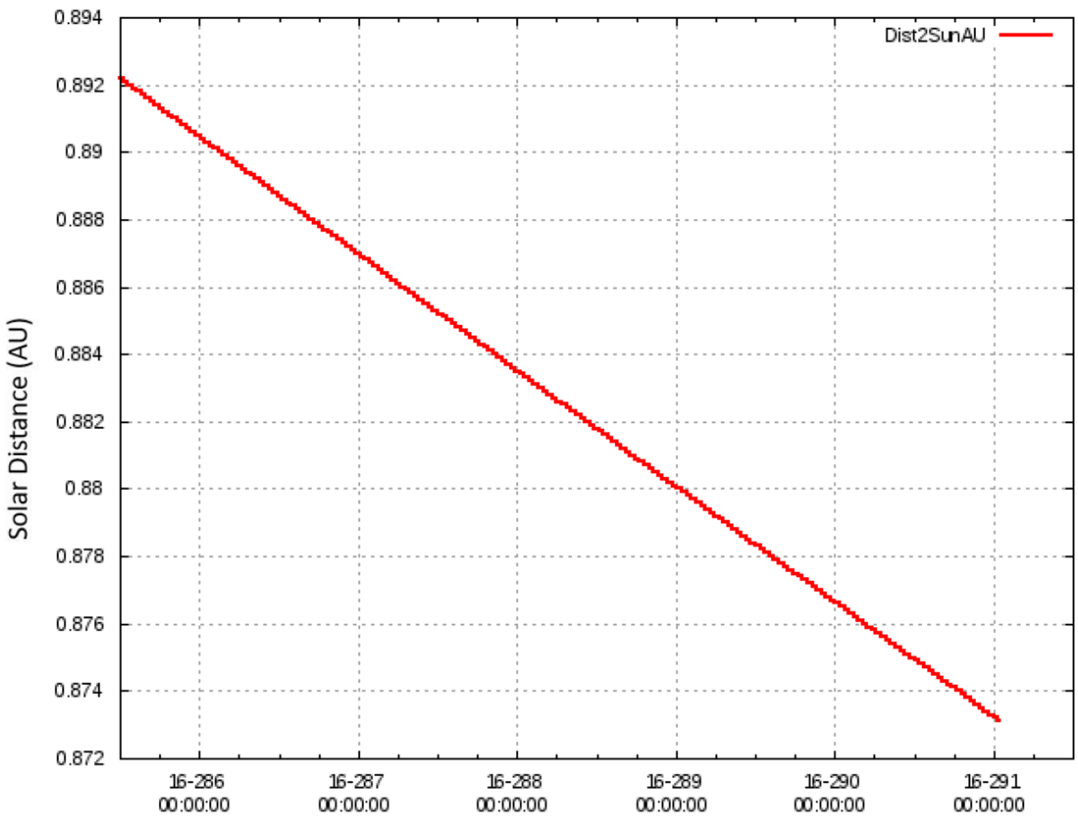

Figure 22. Solar Distance from Day 285-291 in 2016.

C. OVIRS Cool Down from Day 032 to Day 037 in 2017

From Fig. 23, the solar distance was 0.9065 AU at 00:00 UTC Day 030. It increased to 0.9345 AU at 22:00 UTC Day 036. From Day 030 to Day 037, there was a HGA pass each day. During the HGA passes, the spacecraft attitude was Earth-pointing and the sun was at an approximately 72° angle with the aft deck (i.e., 18° with the -Z axis). It can be seen on the plot of sun in the X, Y and Z axes in Fig. 24 that there was approximately 0.95 sun on the -Z deck during these passes. The plot of sun in the X, Y and Z axes also shows: a) each HGA pass had 0.53-0.59 sun on the +Y axis for a short time (30 minutes or less); b) the HGA passes on Day 030 and Day 036 had 0.55 sun and 0.04 sun, respectively, on the -Y axis for a short time (30 minutes or less). Additionally, an OVIRS +Y solar-cal boresight determination took place in the middle of the HGA pass on Day 036. It can be seen on the plot of sun in the X, Y and Z axes that there was one sun on the +Y axis for a short time (30 minutes or less) during this slew. Solar impingement on +Y or -Y caused warming on the payload deck, including the OVIRS.

From 00:00 UTC Day 030 to ~21:00 UTC Day 032, the OVIRS decontamination heaters continued to maintain its temperature above -77°C (196K). The OVIRS Conditioning Part 2 sequence began at ~21:00 UTC on Day 032. At that time, its decontamination heater was set from non-operating to operating and its MEB was powered on. The OVIRS detector began to cool down. Figure 25 presents a plot for the cool down. Figure 26 shows the Optics Box bracket temperature during the detector cool down. It was nominal. It oscillated due to the changes in the spacecraft attitude from sun-pointing to Earth-pointing. The maximum temperatures occurred when the spacecraft attitude was sun-pointing. The minimum temperatures occurred when the spacecraft attitude was Earth-pointing. The MEB temperature was also nominal. At ~11:00 UTC on Day 036, that is, after 3 days and 13 hours, the detector temperature reached a steady state value of 106.7K. It was 0.8K warmer than the 105.9 K temperature achieved during its first cool down on Day 287 in 2016. Direct solar flux, which impinged on the payload deck from the +Y and –Y sides during the HGA passes, had an impact on the heat load to the OVIRS detector. At ~11:00 UTC on Day 036, the OVIRS detector cool down ended. The decontamination heater was set to the non-operating set point and the MEB was powered off. The spacecraft slewed to put sun on the +Y side for ~30 minutes, so that the OVIRS solar-cal boresight could be precisely determined. This solar impingement on the OVIRS and its neighboring MLI blankets increased the detector by more than 10K.

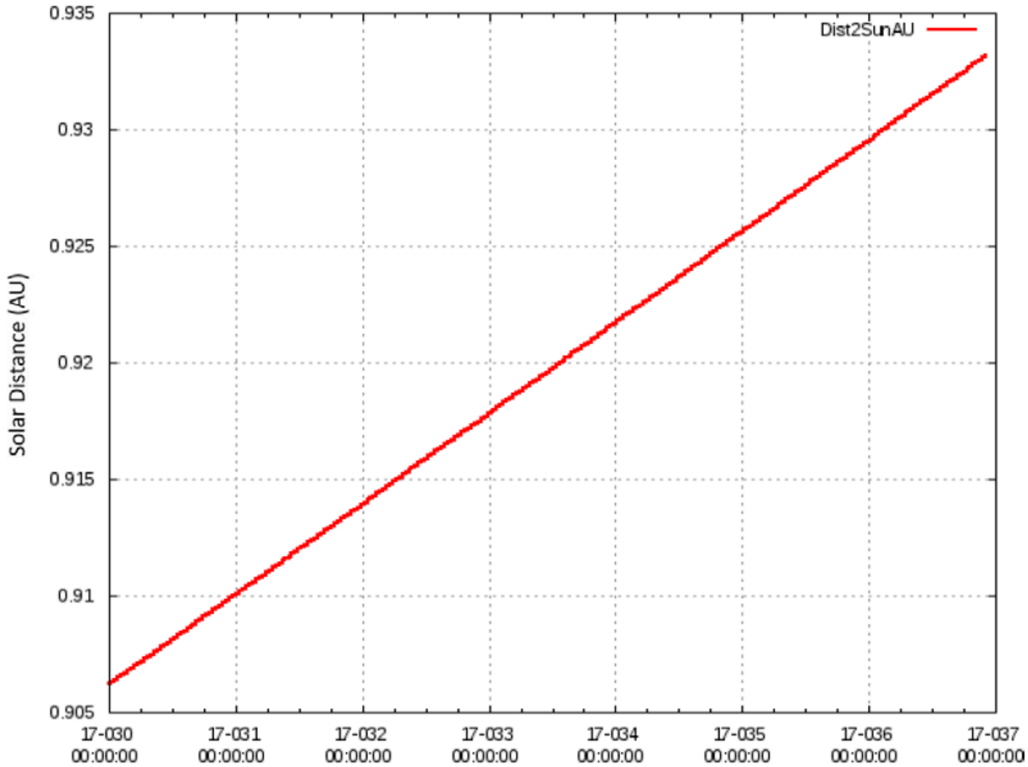

Figure 23. Solar Distance (AU) from Day 030 to Day 037 in 2017.

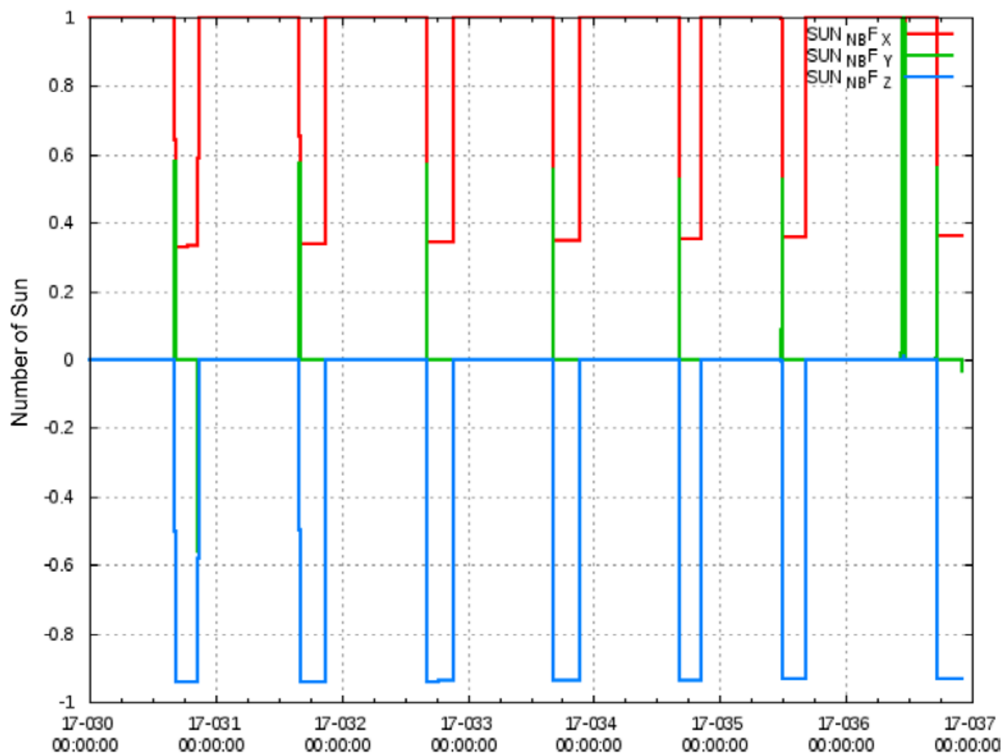

Figure 24. Sun in X, Y and Z from Day 030 to Day 037 in 2017.

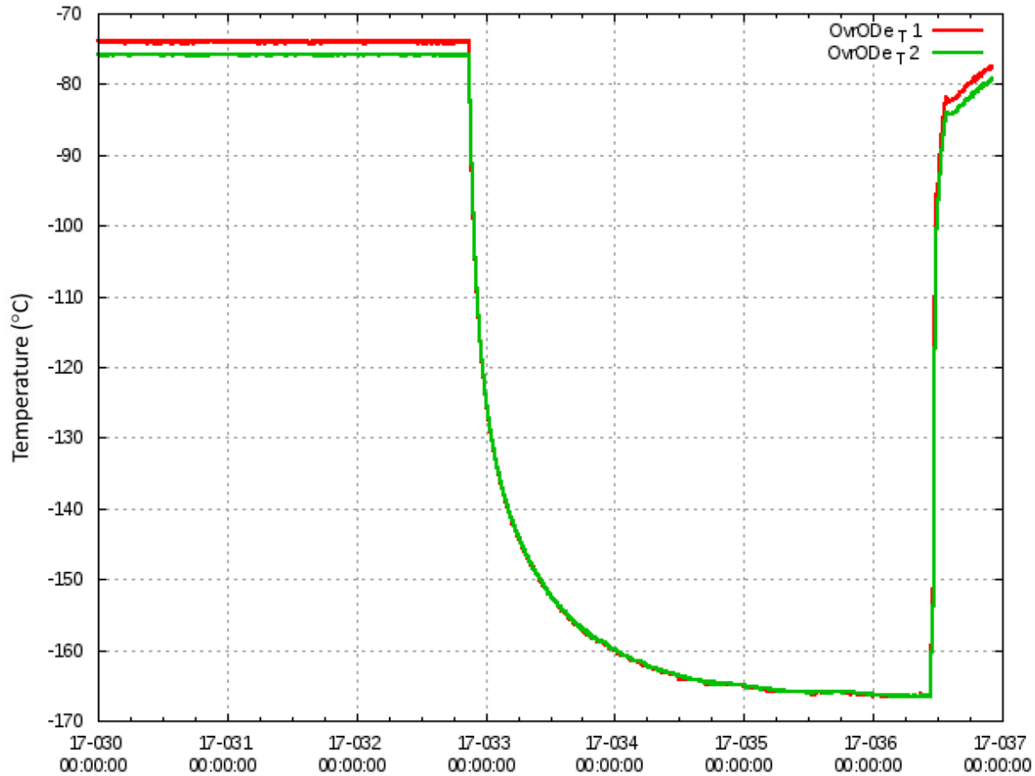

Figure 25. OVIRS Detector Temperature (°C) from Day 033 to Day 037 in 2017.

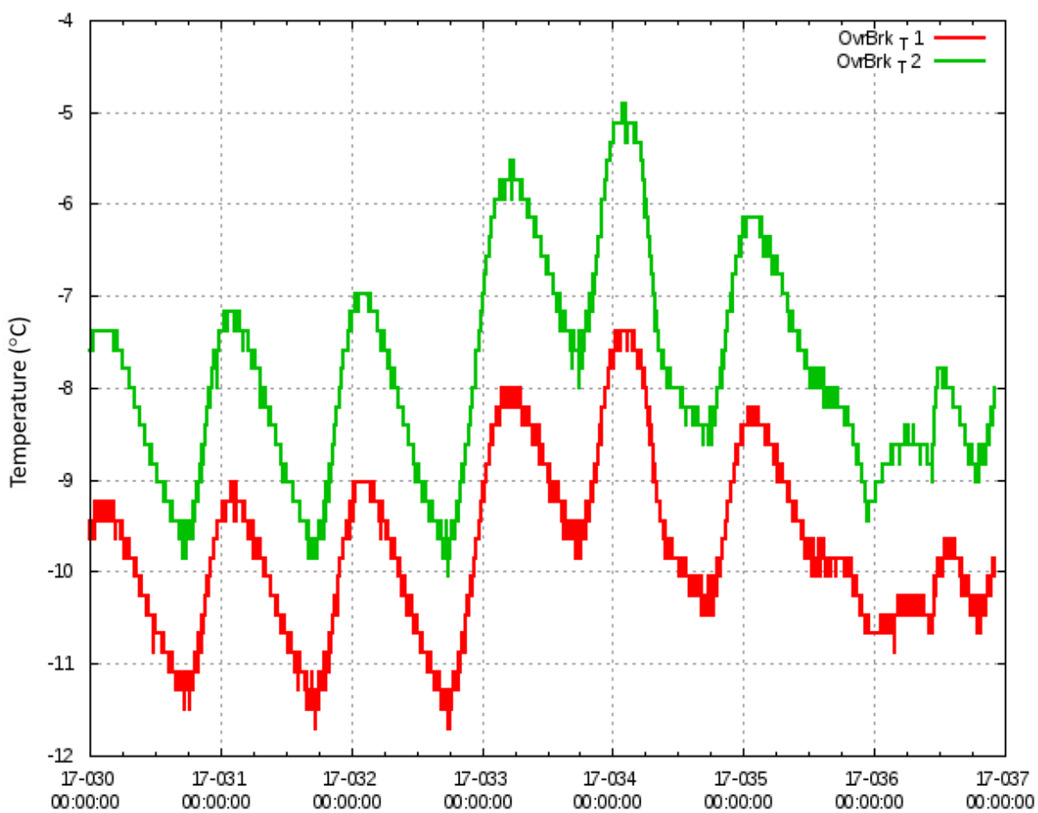

Figure 26. OVIRS Optics Box Bracket Temperature from Day 030 to Day 037 in 2017.

D. OVIRS Cool Down from Day 076 to Day 079 in 2017

From Fig. 27, the solar distance was 1.067 AU at 00:00 UTC Day 072 and it increased to 1.091 AU at 00:00 UTC Day 079. As the solar distance increases, the solar irradiance decreases. Figure 28 shows a plot of sun on the X, Y and Z axes. At 00:00 UTC Day 072, the OVIRS decontamination heater temperatures, T1 and T2, were -74.5°C and -76.2°C, respectively. At ~18:00 UTC Day 072, the first OVIRS checkout began. The set point of the decontamination heater was changed from non-operating to operating. The temperatures began to decrease. At ~19:00 UTC Day 072, T1 and T2 were -106°C and -107°C, respectively. At that time, the first checkout was completed, and the set point of the decontamination heater was changed from operating to non-operating. The temperatures began to increase, and reached -74.5°C and -76.2°C, respectively, at ~10:00 UTC Day 073. At ~16:00 UTC Day 076, the second OVIRS checkout began. The set point of the decontamination heater was changed from non-operating to operating. The temperatures began to decrease (Fig. 29). Figure 30 shows the OVIRS Optics Box bracket temperatures during the detector cool down. It was nominal. It oscillated due to the changes in the spacecraft attitude from sun-pointing to Earth-pointing. The maximum temperatures occurred when the spacecraft attitude was sun-pointing. The minimum temperatures occurred when the spacecraft attitude was Earth-pointing. The MEB temperature was also nominal. At 00:00 UTC Day 079, the detector temperature reached a steady state temperature of -167.5°C (105.6K). It was 1.1K colder than the 106.7K temperature achieved during its second cool down on Day 036 in 2017. <u>The reason is lower solar irradiance due to the larger solar distance, resulting in reduced solar flux reflected or scattered to the OVIRS.</u>

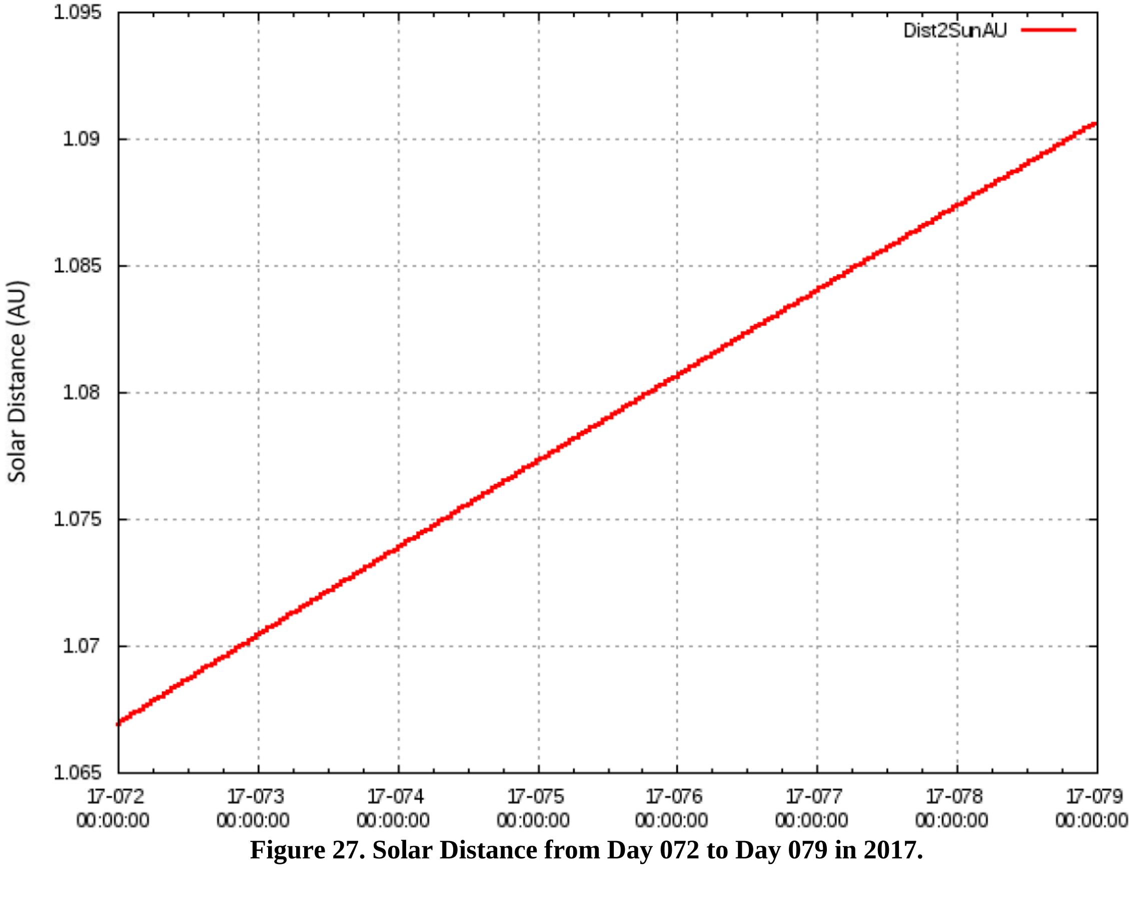

Figure 27. Solar Distance from Day 072 to Day 079 in 2017.

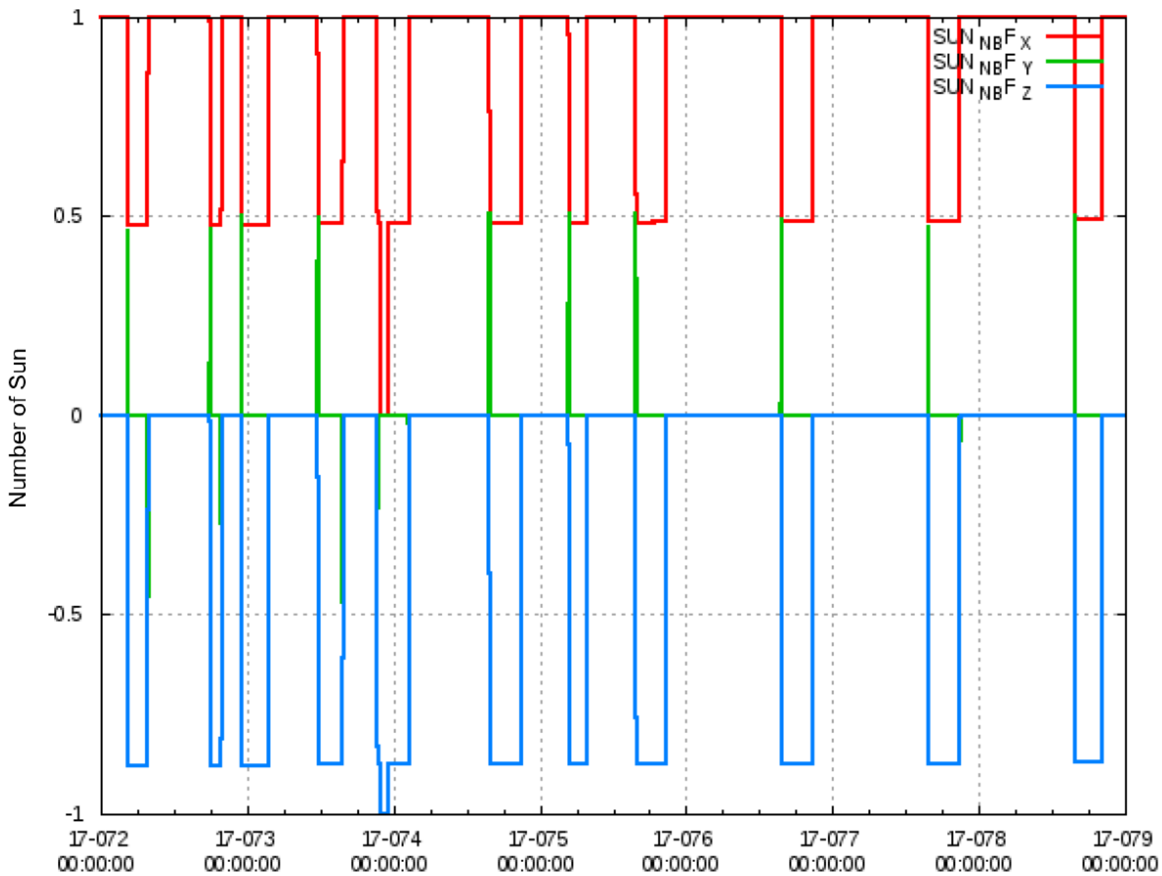

Figure 28. Sun in X, Y and Z from Day 072 to Day 079 in 2017.

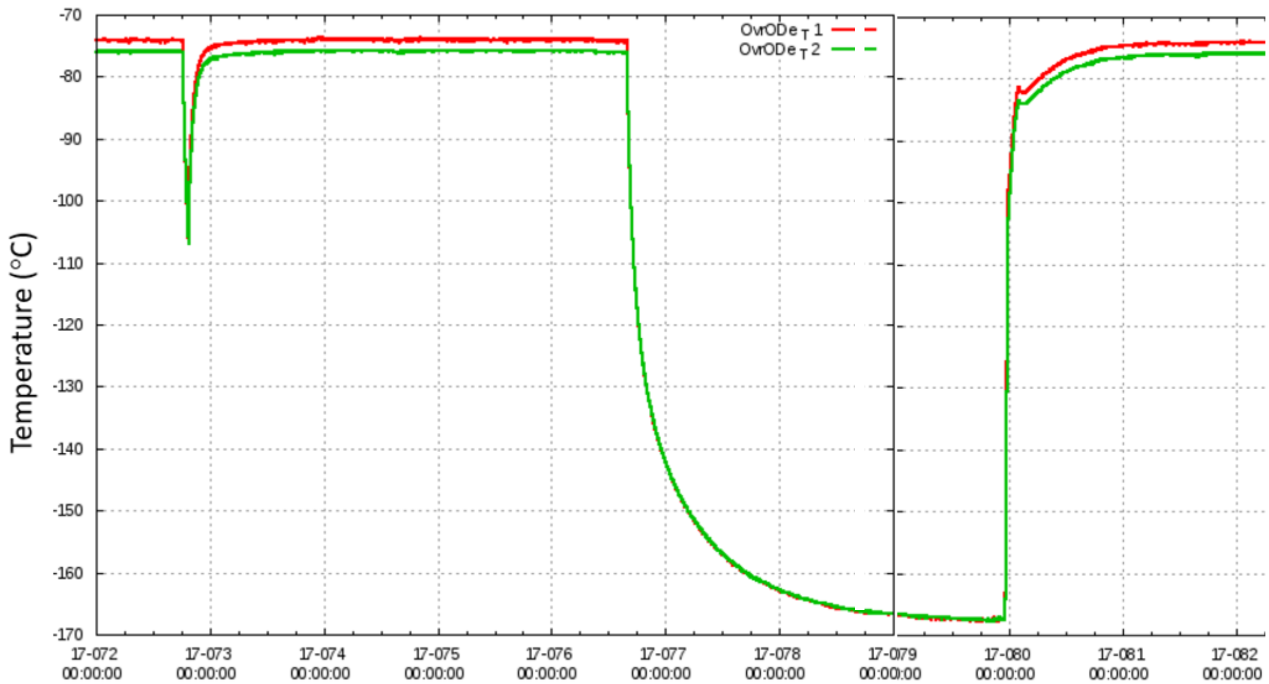

Figure 29. OVIRS Detector Temperature from Day 076 to Day 080 in 2017.

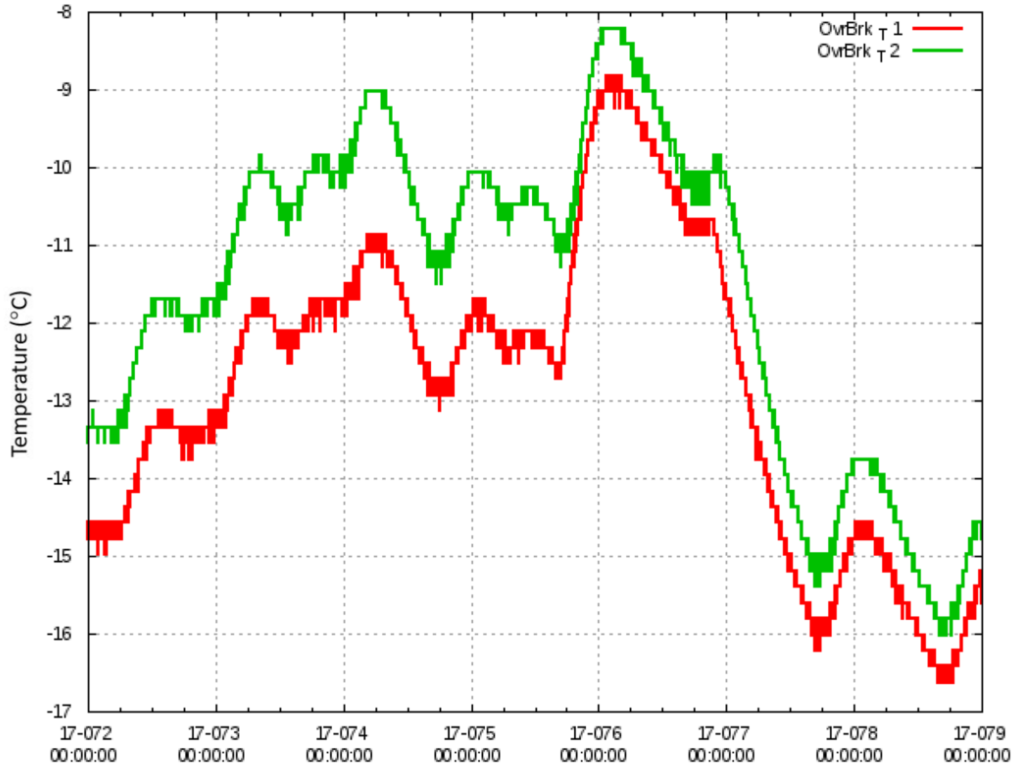

Figure 30. OVIRS Optics Box Bracket Temperature from Day 072 to Day 079 in 2017.

E. Thermal Effect of Earth Gravity Assist on Day 265 in 2017

On Day 265 (September 22), 2017, the OSIRIS-REx mission successfully completed its Earth Gravity Assist milestone. The closest Earth approach occurred at 16:52 UTC Day 265. The solar distance was 1.0075 AU at 18:00 UTC Day 264. It decreased to 1.0025 AU at 00:00 UTC Day 266, and to 0.9988 AU at 08:00 UTC Day 267. As the solar distance decreases, the solar irradiance increases.

At ~00:30 UTC Day 265, the spacecraft attitude was changed from sun-point to off-point. The solar flux in the +X, +Y and –Z axes at this off-point attitude was approximately 0.97 sun, 0.098 sun (very briefly) and 0.25 sun, respectively, until ~21:00 UTC Day 265. At that time, the spacecraft attitude was changed to Earth-point, with 1.0 sun on –Z. From ~00:30 to ~01:00 UTC Day 266, the solar flux in the +X, +Y and +Z axes was approximately 0.89 sun, 0.02 sun, and 0.47 sun, respectively. At ~01:00 UTC Day 266, the solar flux in the +X, +Y and –Z axes was approximately 0.97 sun, 0.049 sun (very briefly) and 0.25 sun, respectively. At ~03:00 UTC Day 266, the spacecraft attitude was changed back to the nominal Outbound Cruise sun-point.

From Fig. 31, prior to ~16:30 UTC Day 265, the OVIRS decontamination heater on the detector assembly was at the operating set point and its temperatures, T1 and T2, were -167.7°C (105.5K). The 400-node OVIRS RTM in the flight system thermal model predicted -188°C (85.2K), which is 20.3K colder than the flight telemetry data. The 1,525-node OVIRS RTM in the flight system thermal model predicted -175.5°C (97.7K), which is 7.8K colder than the flight telemetry data. Therefore, the 1,525-node OVIRS RTM has more accurate prediction for the detector temperature than the 400-node RTM. However, it is not accurate enough.

Shortly after 16:30 UTC Day 265, the temperatures began to increase and reached the maximum (-158.2°C (114.95K)) at ~19:00 UTC Day 265. Earth flux during Earth Gravity Assist caused the warming of the OVIRS detector. Then they began to decrease, and reached -164°C (109.15K) at 00:00 UTC Day 266. From ~00:30 to ~01:00 UTC Day 266, the spacecraft attitude change put sun on +Z, such that solar flux in the +Z axis was ~0.47 sun. It reduced the cooling rate of the OVIRS detector. At ~20:40 UTC Day 265, the OVIRS instrument was turned on. At that time, the OVIRS decontamination heater temperatures, T1 and T2, were both -160°C (113.15K). At ~02:00 UTC Day 266, the OVIRS was turned off. At that time, the decontamination heater temperatures, T1 and T2, were both -164.6°C (108.55K). They decreased to -166.5°C (106.65K) at 00:00 UTC Day 267.

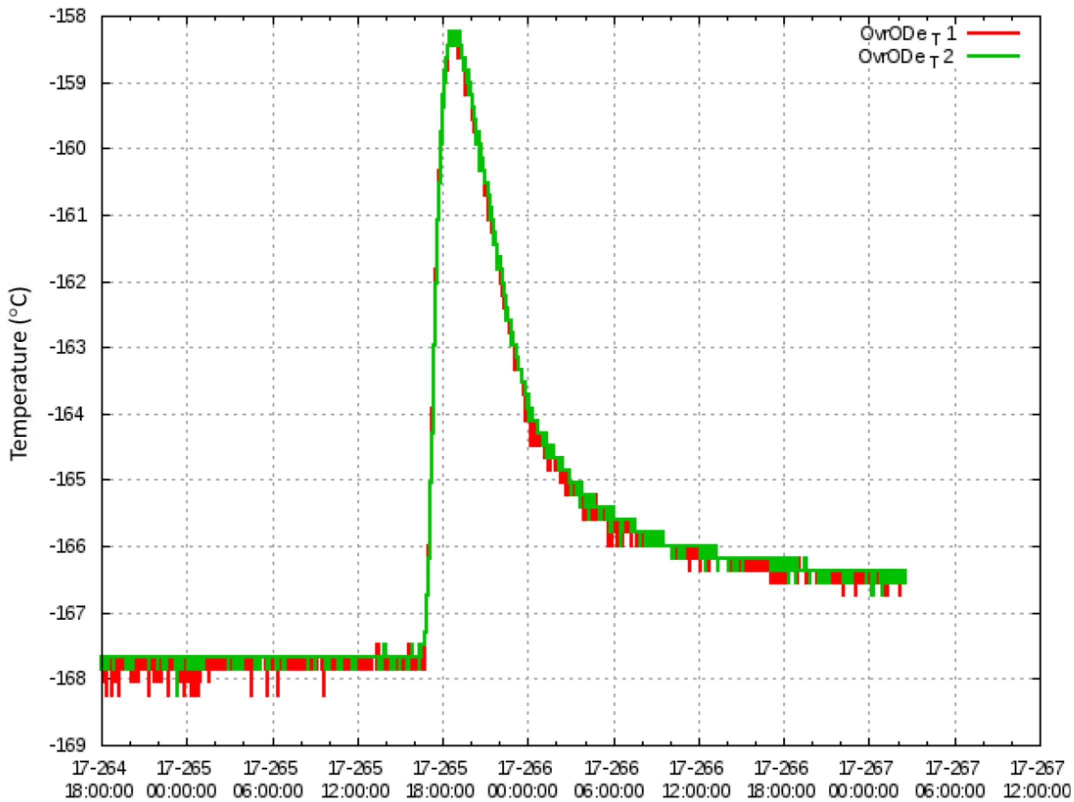

Figure 31. OVIRS Detector Temperature during Earth Gravity Assist.

IV. Conclusion

In the flight system TVAC test, non-flight like thermal environment factors limited the coldest OVIRS detector temperature in the TVAC test to 114.8K. It was expected prior to the flight system TVAC. The project determined that eliminating all non-flight like test factors for the OVIRS was not feasible given programmatic constraints. At 114.8K, the detector was not noise saturated and sufficient to check performance. In flight, during the Outbound Cruise phase with the sun-pointing attitude, sunlight impinges on the PolyCam, OTES, IMU-sunshade and OLA-sunshade MLI blankets. It is reflected or scattered to the OVIRS and its neighboring MLI blankets. Therefore, it adds heat load to the OVIRS detector. It was not included in the OVIRS thermal design or simulated in the OVIRS instrument level TB test. Generally, MLI blankets are assumed flat surfaces in thermal models. The MLI blankets on the OSIRIS-REx forward deck were not flat in the TVAC and are unlikely flat in flight. This adds uncertainty to the predicted sunlight reflected or scattered to the OVIRS and its neighboring MLI blankets. During the first OVIRS detector cool down in flight, the steady state temperature of the detector was 105.8K. It exceeded the maximum operating AFT limit by 0.8K. On Day 265 in 2017, Earth flux during Earth Gravity Assist caused the OVIRS detector temperature to increase from 105.5K to 114.95K. During the Proximity Op mission phase at asteroid Bennu, the thermal effect of the asteroid flux is expected to be less than that of the Earth flux. The OVIRS detector temperature is expected to be between 105.5K and 114.95K, and its science data is expected to be acceptable. In performing thermal design, modeling and TB test for a passively cooled cryogenic instrument, all heat loads need to be evaluated carefully. A simple spacecraft thermal model should be integrated to assure all the environmental heat fluxes are adequately captured. A correlated instrument DTM of several thousand nodes could predict the conduction paths and radiation couplings with good accuracies. However, it is also important to predict all the heat loads with good accuracies and simulate them in the instrument level TB test. If heat loads are uncertain, it is necessary to add thermal margin. The 400-node OVIRS RTM in the flight system thermal model under predicted the detector temperature by about 20K and the thermal issue was not revealed. A simple RTM that predicts cryogenic detector temperatures with good accuracies will help uncover thermal issues before the CDR. A spacecraft sunshield could have been installed to the forward deck to shield the OVIRS from sunlight reflected or scattered by the MLI blankets on the deck. For example, such a sunshield to shade the OCAMS SamCam from direct sunlight in the

Detailed Survey Phase was added after the CDR. A small RTM will help reduce the flight system integrated thermal model run time greatly. The access of the Project thermal lead on the government side to the test and on-orbit data has provided an opportunity to capture the lessons learned.

Acknowledgments

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