TIRS II Cryocooler System Performance and Initial On-Orbit Data

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ABSTRACT

The Thermal Infrared Sensor II (TIRS II) is the next generation of the original TIRS instrument on Landsat 8, launched in February 2013. TIRS and the Ball TIRS two-stage Stirling cryocooler has been successfully operating on orbit for over nine years. Recently the TIRS II instrument and TIRS II cryocooler successfully completed all ground testing and was launched in September 2021. The TIRS II infrared focal plane is cooled by the second stage of a two-stage Ball Aerospace Stirling cycle cryocooler, operating at 36K. The first stage of this cryocooler provides shield cooling at 95K. This paper describes the TIRS II Cryocooler System, performance test results of two flight cryocoolers, and initial on-orbit performance.

INTRODUCTION

The Landsat 9 Mission continues the USGS/NASA Landsat Program's 50+year heritage of providing the global community with earth facing scientific data for making informed decisions about Earth's resources and environment. Landsat 9 consists of two science instruments – Operational Land Imager 2 (OLI-2) and the Thermal Infrared Sensor II (TIRS II). The focus of this paper is the TIRS II instrument and the mechanical cryocooler system that provides cooling for the Focal Plane Assembly (FPA) at 38.6K for Infrared imaging of the earth.

The TIRS II instrument builds upon the success of the original TIRS I instrument with noted improvements in stray light, upgrade of electrical system reliability to NASA Class B, and upgrade of thermal control system reliability to NASA Class B. The mission class upgrade was performed so the TIRS II payload would have the same design/reliability as the OLI-2 payload (5.25 years). A high-level system architecture is shown in Figure 1.

Flight Cryocooler System

Ball Aerospace delivered the TIRS II Flight Cryocooler System to NASA Goddard Space Flight Center (GSFC) in December 2018. The flight deliverable system (shown in Figure 2) includes a Thermo-Mechanical Unit (TMU), primary and redundant Cryocooler Control Electronics (CCE)

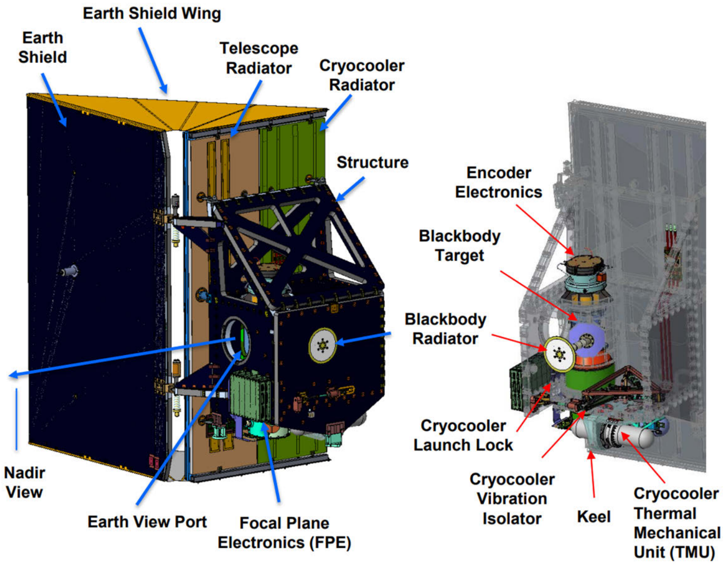

Figure 1. TIRS II instrument high-level architecture with details of the cryocooler sub-system.

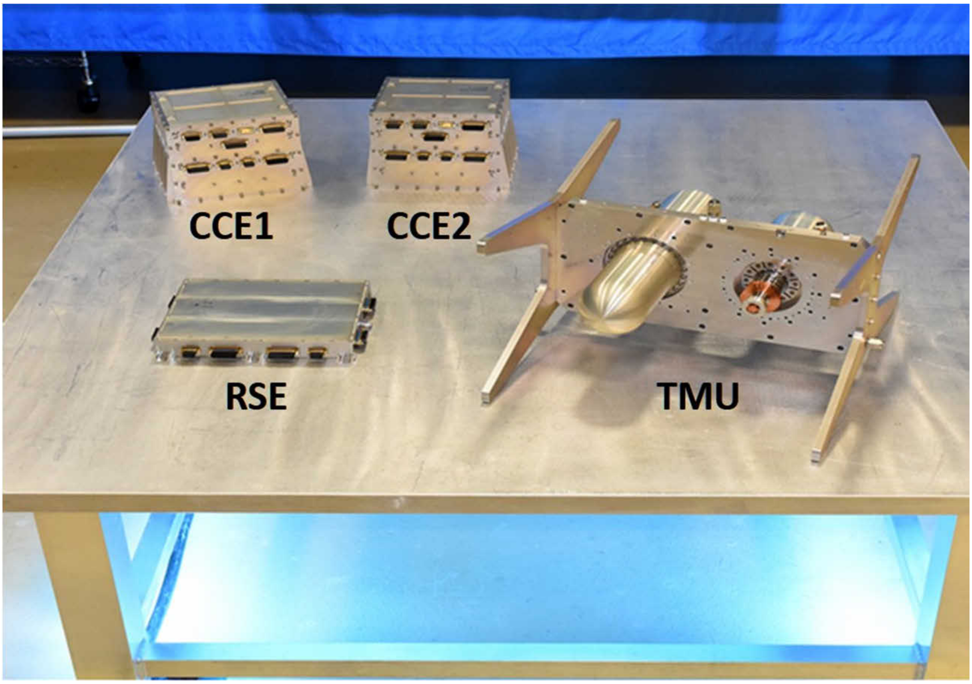

Figure 2. TIRS II Flight deliverable hardware that includes a Flight TMU, two Flight CCE's and a Flight RSE. Note the TMU is mounted in a GSE configuration prior to integration to the flight keel.

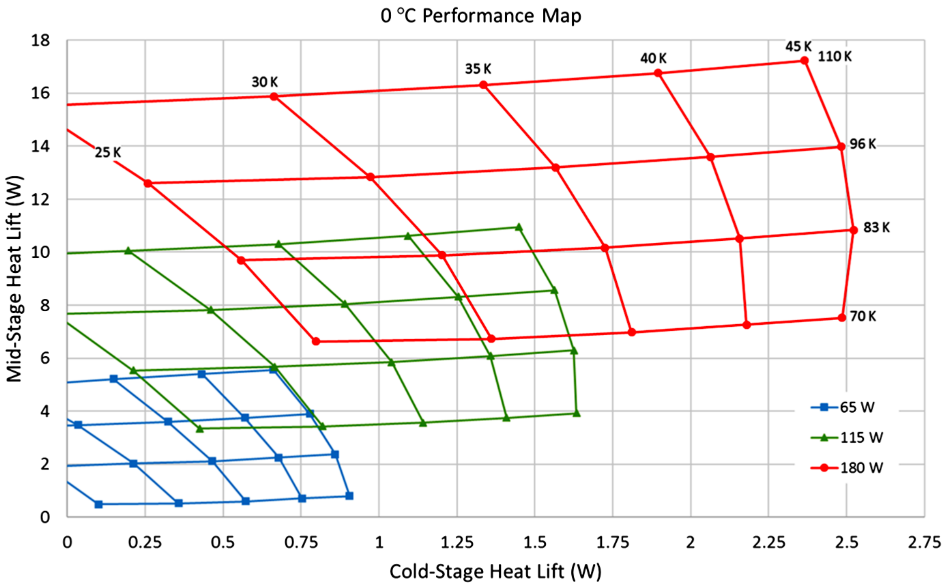

Figure 3. TIRS II Flight deliverable TMU Thermodynamic performance map.

boxes, and a Redundant Switching Electronics (RSE) box. Thermodynamic performance of the flight deliverable system is shown in Figure 3. Based on the requirements of Class B electrical reliability, the TIRS II Cryocooler system uses a single TMU that is connected to dual flight CCE boxes through the RSE box. Details of the qualified and deliverable flight system are discussed by Marquardt, et al.[1].

Flight Spare TMU

In addition to the flight deliverable system, a spare flight TMU and Engineering Model (EM) CCE were built, tested and delivered to NASA GSFC on the TIRS II cryocooler subcontract; see Figure 4.

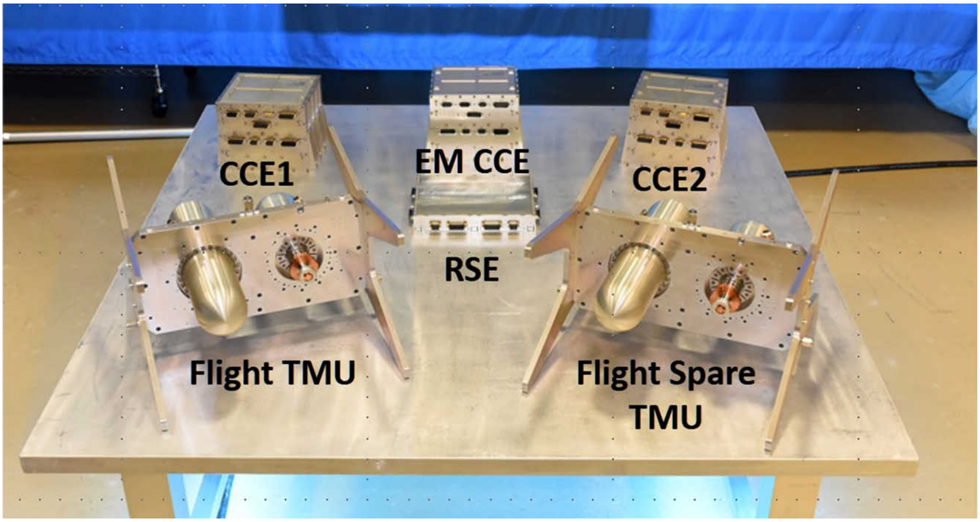

Figure 4. TIRS II Flight deliverable hardware that includes a Flight TMU, two Flight CCE's and a Flight RSE. Note that both TMU's are mounted in the flight keel assembly for flight integration.

Table 1. Thermodynamic performance comparison of the Flight and Flight Spare TMU's.

TMU	Tc (K)	Qc (W)	Tm (K)	Qm (W)	PTMU (W)
Flight	38	1.62	85	8.82	150
Flight Spare		1.89		8.44	

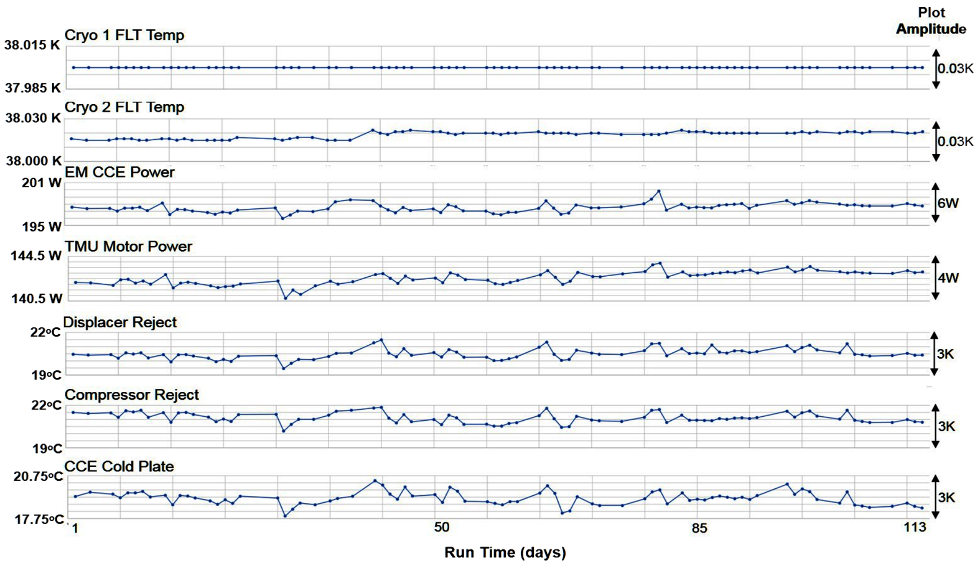

Figure 5. TIRS II Flight Spare TMU extended run-in data trending. TMU was energized using the EM CCE for all run-in testing.

The performance of the Flight Spare TMU was very similar to the delivered Flight TMU, and the thermodynamic performance is summarized in Table 1. Ball Aerospace delivered the TIRS II Flight Cryocooler System to NASA Goddard Space Flight Center (GSFC) in December 2018.

In addition to normal Flight hardware processing and test, the Flight Spare TMU was subjected to an extended run-in test of 5% of mission life to verify no performance degradation or anomalies for extended operation of the TMU. The extended run-in test was a cumulative run time of 110 days+ at flight-like cold tip operational temperatures and heat loads. The results of this accelerated life test are shown in Figure 5. The outputs of this extended run-in test were no performance degradation of the Flight Spare TMU and cold stage temperature drift of <10mK (excluding environmental factors related to temperature changes in the test environment). Note that all excursions directly track across all monitored values and were attributed to the less than ideal thermal conditions of the lab space housing the run-in test setup.

Thermodynamic performance comparison between the Flight and Flight Spare TMU's are summarized in Table 1. Differences in performance are attributed to unit-to-unit variation and differences in charge pressure between the Flight and Flight Spare TMU's.

SPACECRAFT INTEGRATION AND TEST

EMI/EMC Testing

During EMI/EMC testing (shown in Figure 6), the entire spacecraft was kept at ambient conditions, with only brief low-power operation of the cryocooler in an air environment. Issues

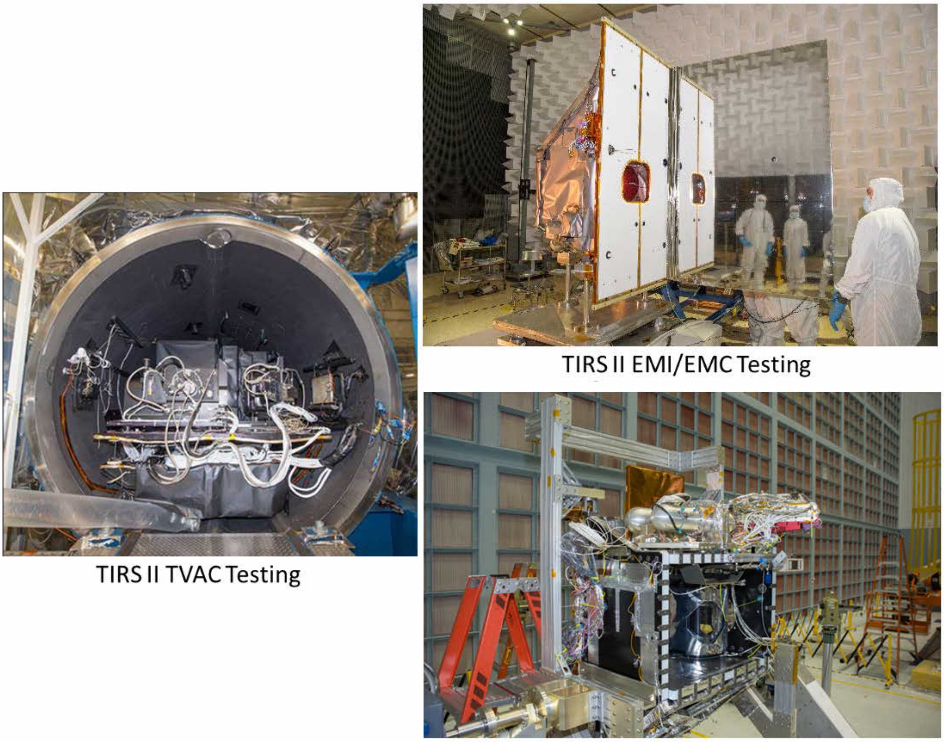

Figure 6. (Left) TVAC testing of the TIRS II instrument, (Upper Right) TIRS II Instrument EMI/EMC testing, and (Lower Right) TIRS II Cryocooler integration to the TIRS II instrument.

noted with the TIRS I Cryocooler Cryogenic Temperature Diodes were resolved on TIRS II using Cernox Temperature Sensors that are not susceptible to excitation in the same manner as Cryogenic Silicon Diodes.

Random Vibration Testing

During vibration and shock testing, the cryocooler was kept in its "caged" mode and the NASA GSFC launch lock assembly for the TMU remained in the "Locked State" for all testing. Closed motor relays in the CEE provide low-impedance paths across each of the motor coils resulting in high level electrodynamic damping for the moving masses in each motor. This damping limits the piston displacement and subsequent potential for damage or overstroke during random vibration testing.

TVAC Testing

Thermal/vacuum (TVAC) testing at the instrument level in early 2019 allowed the first opportunity to operate the delivered cryocooler at full power (illustrated in Figure 6). With some differences related to the operation of the instrument heaters, this cooldown was very similar to the TIRS-I instrument-level cooldown in December 2011 and matched closely with cryocooler performance prior to integration with the instrument. During TVAC testing at the observatory level in 2021, the cryocooler experienced overstroke trips during startup with the cryocooler axis oriented vertically. Cooldown in a reduced power mode was successful, with operation closely matching performance at instrument level TVAC.

Figure 7. (Top) Spacecraft installation to the Atlas V fairing and final encapsulation, (Lower Left) Landsat 9 Spacecraft to Launch Vehicle stack in preparation for launch, and (Lower Right) Landsat 9 launch on 9/27/2021.

LAUNCH

The Landsat 9 spacecraft was shipped to Vandenburg AFB in July of 2021 to begin preparation for launch. Checkout at the launch site included low-power cooldown of the cryocooler, showing similar performance with operation before shipping. The spacecraft was encapsulated and stacked at the end of August 2021, and on September 21, 2021 was launched into a 98.2deg sun synchronous orbit. High level illustration of launch preparation to the Landsat 9 launch is illustrated in Figure 7.

ON-ORBIT COOLDOWN PERFORMANCE

After successful initial in-orbit operations, the cryocooler control electronics were enabled a few weeks after orbital insertion to verify functionality and health. One month into the mission, the TIRS II instrument cooldown commenced on October 27th, 2021. Initial cooldown (OBS1) overlaid on the last instrument TVAC cooldown (TVAC) is shown in Figure 8. Comparison of these two cooldowns, while they start at slightly different temperatures, is comparable, demonstrating no adverse performance impact from launch.

In late February 2022 there was a CCE reset that resulted in a minor CCE Flight Software update. As part of this process, the instrument was warmed for contamination mitigation and a second cooldown was initiated on March 17th, 2022. This second on-orbit cooldown (OBS2) is shown and compared to the last TVAC (TVAC) and the initial on-orbit cooldown (OBS1). Comparison of these three cooldown curves for Cold Tip Temperature and TMU Input Power show almost identical performance and no degradation due to launch or multiple cooldown processes on-orbit.

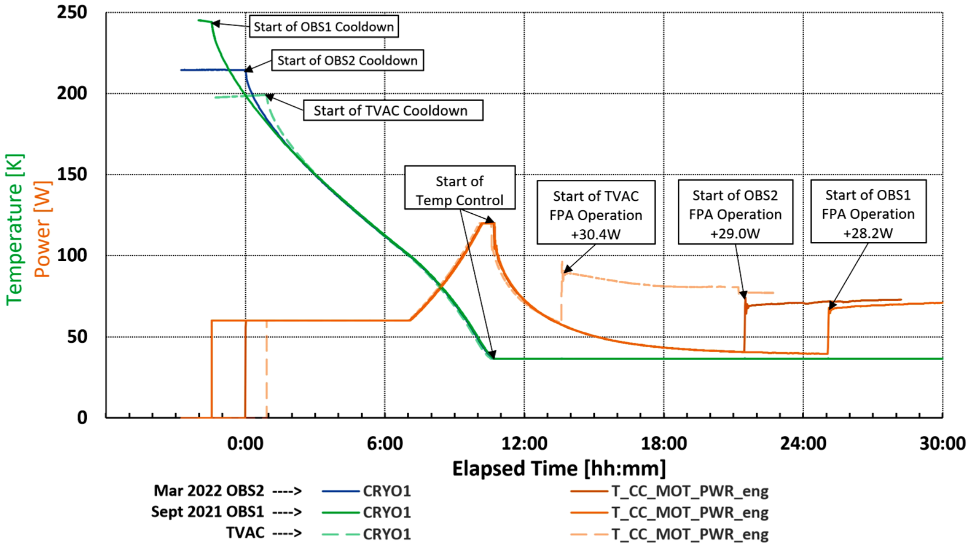

Figure 8. TIRS II Flight Spare TMU life-test data trending. TMU was energized using the EM CCE for all life testing.

ON-ORBIT STEADY STATE OPERATION

The TIRS II cryocooler has been in continuous operation since the most recent cool down that occurred on March 17th, 2022. Data trending for TMU Power, motor stroke and critical temperatures are summarized in Figures 9a through 9c for 1.5 months after nominal steady-state operations commenced following cooldown. Observation of the data shows excellent temperature stability for

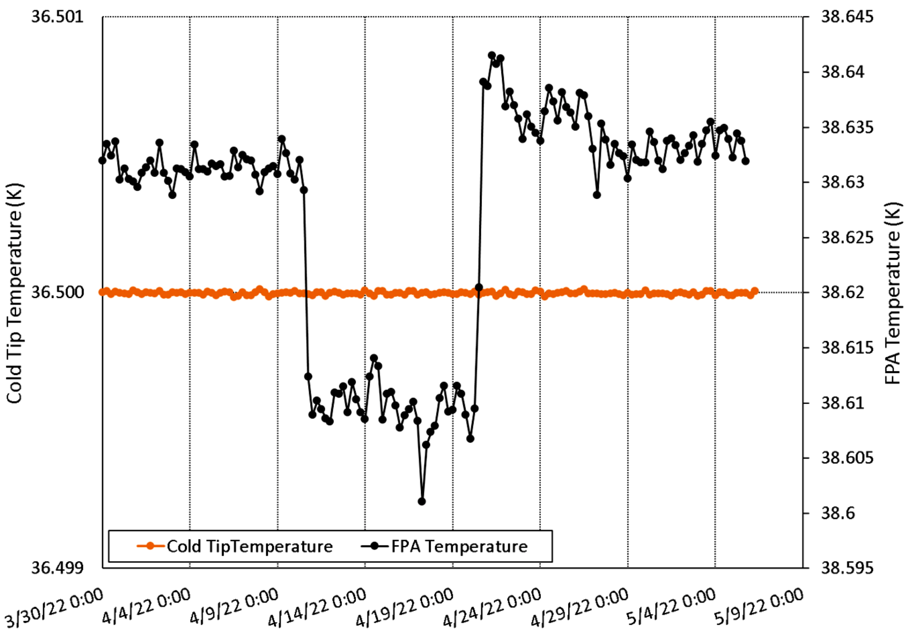

Figure 9a. On-orbit cold-tip temperature trending for the TIRS II Cryocooler System and after the latest cooldown.

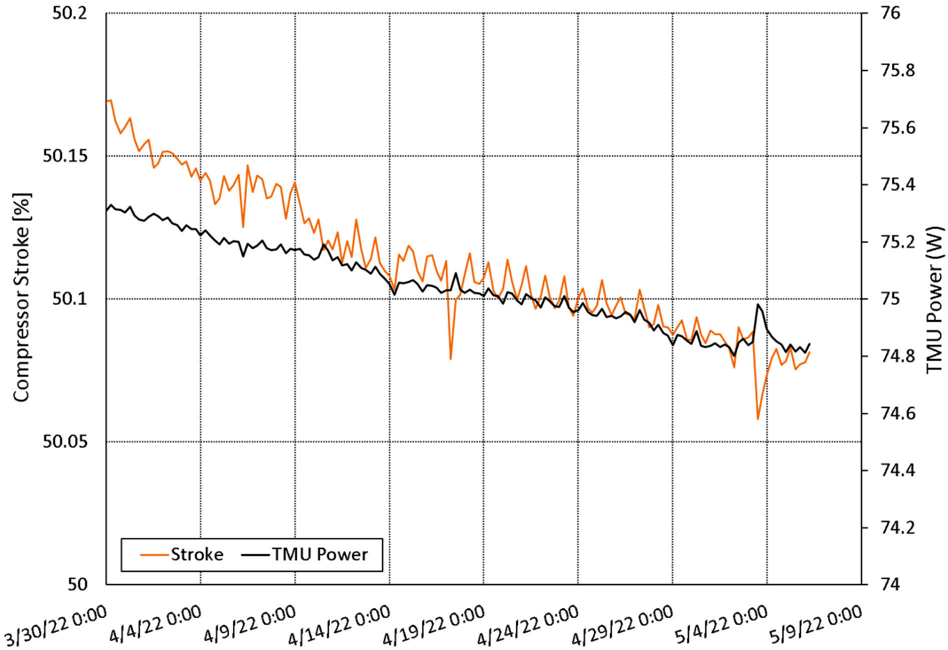

Figure 9b. On-orbit compressor stroke trending for the TIRS II Cryocooler System and after the latest cooldown.

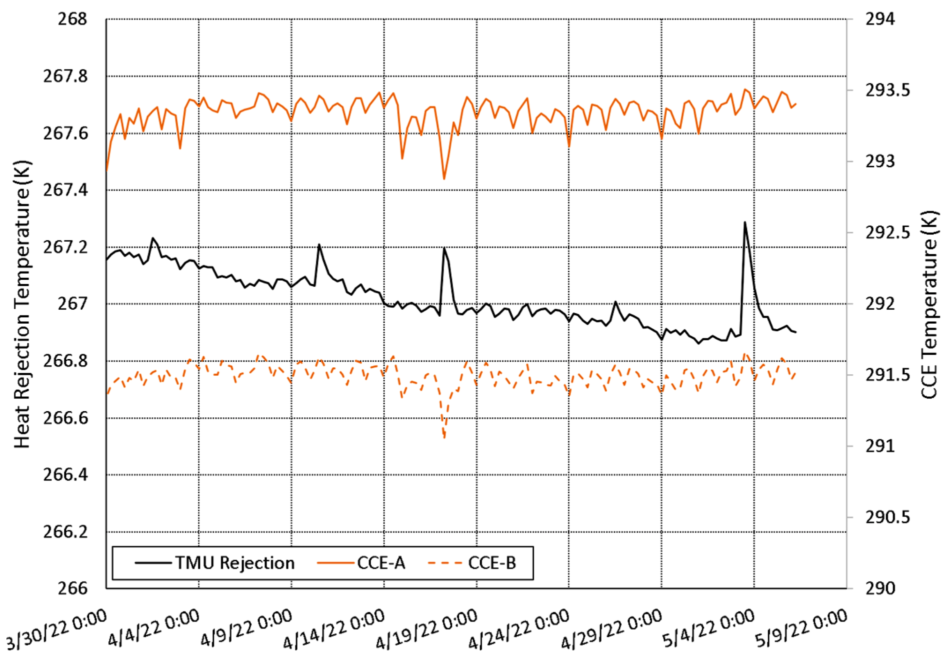

Figure 9c. On-orbit heat rejection temperature trending for the TIRS II Cryocooler System and after the latest cooldown.

the cold tip and FPA. The CCE-A and CCE-B rejection temperatures have remained very stable during steady-state condition with minor variances due to normal orbital variation. After each cooldown, TMU heat reject, power and stroke have decreased slowly as the cryocooler and its radiator equilibrate, with a time constant of over two months.

SUMMARY

The Ball TIRS II cryocooler system, delivered in 2018 was successfully integrated to the payload and launched on September 21, 2021. The cryocooler is now in orbit on Landsat 9 and operating as expected with stable performance.

ACKNOWLEDGMENT

The authors would like to acknowledge the tremendous work by the NASA GSFC TIRS II Instrument team and the Ball TIRS II Cryocooler Team. The technical excellence, one team effort, and mission first focus have led to a successful TIRS II mission.

REFERENCES

1. Marquardt, E., Taylor. R., Marquardt, J., and Muench, T., "Qualification Test Results for the TIRS-2 Cryocooler," *Cryocoolers 20,* ICC Press, Boulder, Colorado (2018), pp. 49-55.