

Swift BAT Thermal Recovery After Loop Heat Pipe #0 Secondary Heater Controller Failure in October 2015

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The *Swift* BAT LHP #0 primary heater controller failed on March 31, 2010. It has been disabled. On October 31, 2015, the secondary heater controller of this LHP failed. On November 1, 2015, the LHP #0 CC temperature increased to as 18.6°C, despite that the secondary heater controller set point was 8.8°C. It caused the average DM XA1 temperature to increase to 25.9°C, which was 5°C warmer than nominal. As a result, the detectors became noisy. To solve this problem, the LHP #1 secondary heater controller set point was decreased in 0.5°C decrements to 2.2°C. The set-point decrease restored the average DM XA1 temperature to a nominal value of 19.7°C on November 21.

Nomenclature

<i>BAT</i>	=	Burst Alert Telescope
<i>Block</i>	=	BAT detector array Block
<i>CC</i>	=	compensation chamber
<i>CCHP</i>	=	constant conductance heat pipe
<i>DAP</i>	=	Detector Array Plate
<i>DM</i>	=	Detector Module
<i>GRB</i>	=	Gamma Ray Burst
<i>I&T</i>	=	integration and testing
<i>LHP</i>	=	loop heat pipe
<i>P</i>	=	primary
<i>PCB</i>	=	Power Converter Box
<i>R</i>	=	secondary
<i>S/C</i>	=	spacecraft
<i>TH</i>	=	thermistor
<i>UVOT</i>	=	Ultraviolet Optical Telescope
<i>VCHP</i>	=	variable conductance heat pipe
<i>XA1</i>	=	analog signal processing ASIC
<i>XRT</i>	=	X-ray Telescope

I. Introduction

Swift is a National Aeronautics and Space Administration (NASA) Medium-Size Explorer (MIDEX) mission. The mission objective is to study the origin and evolution of Gamma Ray Burst (GRB). It was launched successfully from Cape Canaveral Air Force Station, Florida into an orbit of 600-km altitude and 20.69° inclination on November 20, 2004. Fig. 1 shows the *Swift* observatory. The Burst Alert Telescope (BAT) Detector Array Blocks are thermally well coupled to eight constant conductance heat pipes (CCHPs) embedded in the detector array plate (DAP). The CCHPs have ammonia as the working fluid. Two loop heat pipes (LHPs), numbered #0 and #1, transport heat from the CCHPs to a radiator, which is located on the shaded side of the observatory. They provide redundancy. LHP #0 is located on the +Y side of the DAP. LHP #1 is located on the -Y side of the DAP. The LHPs have propylene as the working fluid. Fig. 2 shows the LHP thermal system.¹

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Figure 1. *Swift* Observatory.

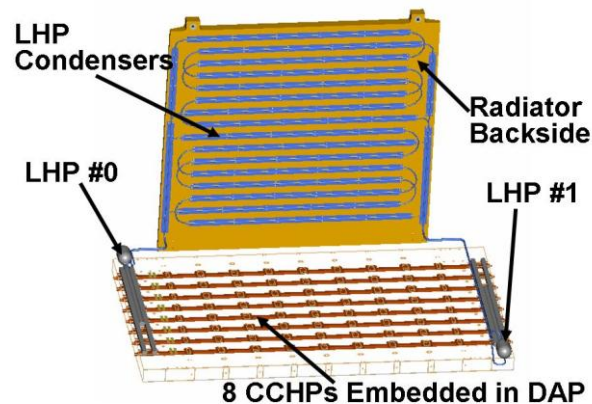


Figure 2. BAT LHP Thermal System.

The *Swift* observatory is required to slew to targets within 50° in 75 seconds, and to targets from 50° to 270° in 75 to 270 seconds. The allowable sun angle, which is the angle between the optical axis (+X axis) and solar vector, is in the 45° to 180° range. The reason is that if the sun angle is less than 45° , direct sunlight enters the x-ray Telescope (XRT) and Ultraviolet Optical Telescope (UVOT) through the apertures. The spacecraft is also allowed to rotate up to $\pm 10^\circ$ about the +X axis. This limit on the roll angle prevents direct sunlight from reaching the BAT LHPs. Because of frequent slewing, the thermal environment for the *Swift* observatory changes constantly. Another factor that also affects the *Swift* thermal environment is the beta (β) angle, which is in the -44.14° to $+44.14^\circ$ range, and changes at about 2° per day (Fig. 3). Direct sunlight is not permitted on the shaded side of the observatory because cold biased radiators for the nickel-hydrogen batteries, BAT Detector Array and XRT focal plane camera assembly heat rejection system are located there.^{2,3}

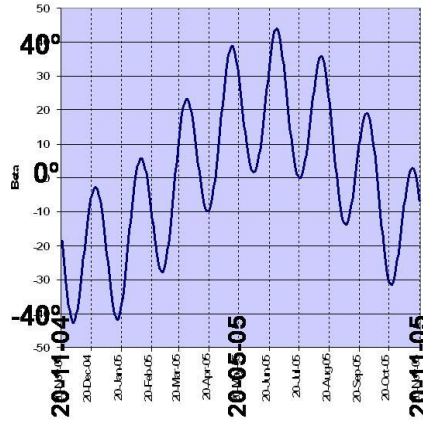


Figure 3. Swift Beta Angle (°).

On April 1, 2005, the LHP #1 primary heater controller failed and was disabled. The use of the secondary heater controller for controlling LHP #1 began. On March 31, 2010, the BAT LHP #0 primary heater controller failed and was disabled. The use of the secondary heater controller for controlling LHP #0 began. Therefore, prior to the LHP #0 secondary heater controller failure on October 31, 2015, only the secondary heater controller on either LHP was functional.

II. Objective

The objective of this paper is to present a thermal assessment of the *Swift* BAT thermal control system and recovery as a result of the LHP #0 secondary heater controller failure on October 31, 2015.

III. Novel VCHP Feature for BAT LHP

A novel feature of the BAT LHP is the variable conductance heat pipe (VCHP). The VCHP evaporator is thermally coupled to the LHP evaporator. A heat exchanger is swaged over the VCHP condenser to allow heat exchange between the VCHP condenser and LHP liquid return line (Fig. 4). The CCHPs embedded in the DAP transfer heat from the Blocks (208 W power dissipation) to the LHP evaporator. A small fraction of this heat transfers from the LHP evaporator to the VCHP evaporator. As a result, this provides pre-conditioning of the propylene liquid before it returns to the LHP compensation chamber (CC). The VCHP was intended to reduce the LHP CC heater power to meet the BAT power budget.^{2,3,4}

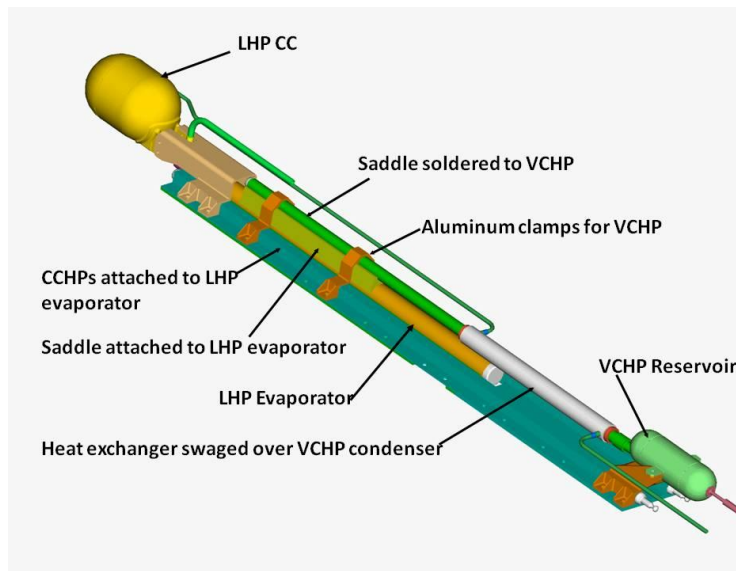


Figure 4. BAT LHP with Novel VCHP.

IV. BAT LHP Heater Controllers

The BAT LHP CCs require heater controllers with adjustable set points in flight. Fig. 5 shows the locations of the heaters and thermistors for the LHP CC primary (P) and secondary (R) heater controllers. As part of the LHP thermal system, the VCHP reservoirs also require a heater controller with adjustable set points in flight. In the operational mode, the set point of the VCHP reservoir heater controller is required to be 5°C colder than the LHP CC heater controller set point when the CC set point is 5°C. For colder set points, a larger offset is required, and for warmer set points a smaller offset is required (Fig. 6). Also the VCHP heater controller is required to work “in reverse” (i.e., off when the VCHP thermistor temperature feedback to the controller is below the set point, and on when it is above the set point).⁵ The VCHP thermistor is located at the LHP liquid return line just after it exits the heat exchanger (Fig. 7). If the VCHP reservoir thermistor feedback to the controller is larger than the VCHP heater controller set point, the reservoir heater is powered on and the non-condensable gas expands. This reduces the VCHP condenser area and decreases the heat transfer from the VCHP to the LHP liquid return line. The BAT Power Converter Box (PCB) supplies power and adjustable set point signals to the heater controllers. Due to the limit on the number of PCB power switches, the same heater controller is used to control the LHP CC and VCHP reservoir. To make it possible, a heater controller with three control units or channels was developed for the BAT LHPs. One of the channels is used for temperature control of the VCHP reservoir (Fig. 8). The offset and work-in-reverse capabilities were integrated into the heater controller.⁶ Fig. 9 shows a flight heater controller. Its Side A and Side B control the primary heater circuits and secondary heater circuits respectively.⁶

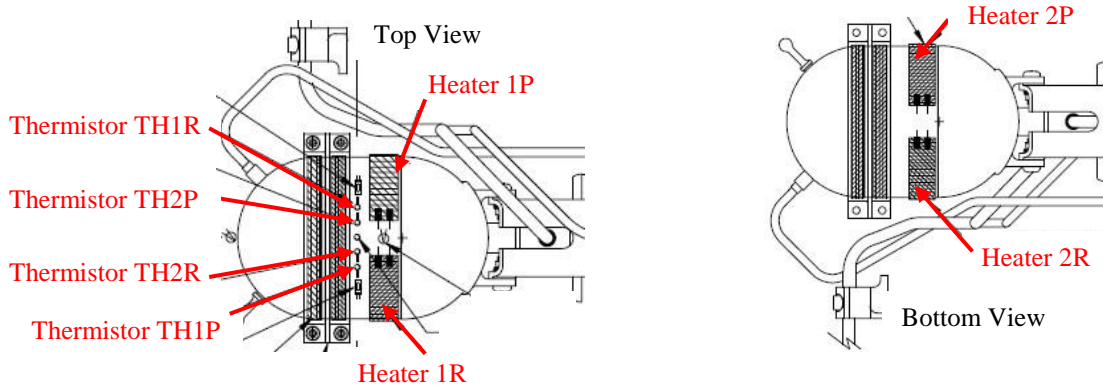


Figure 5. LHP Heater and Heater Controller Thermistor Locations.

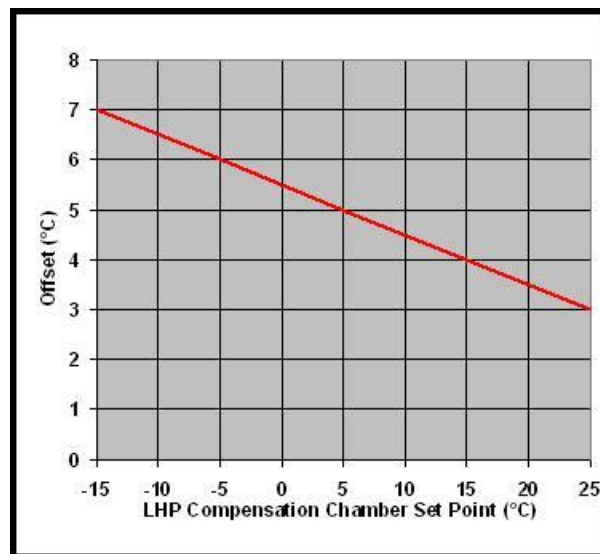


Figure 6. Offset for VCHP.

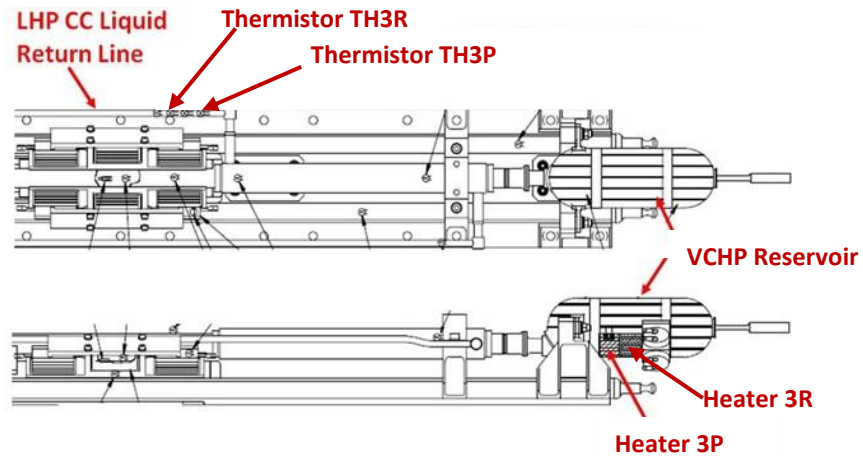


Figure 7. VCHP Heater and Heater Controller Thermistor Locations.

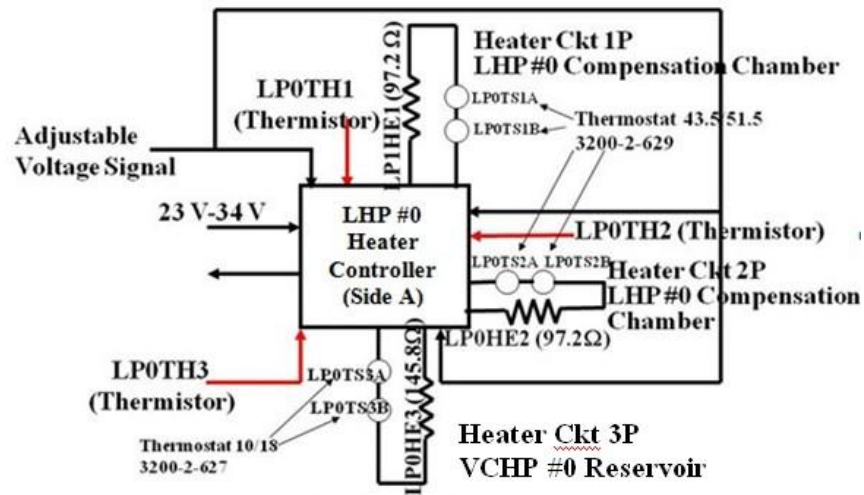


Figure 8. LHP CC and VCHP Heater Controller Circuits (LHP #0).



Figure 9. Flight Heater Controller.

V. Flight Telemetry During LHP #0 Secondary Heater Controller Failure

On October 31, 2015, the secondary heater controller of LHP #0 failed. Fig. 10 shows the LHP #0 CC flight temperature telemetry during the failure. From October 30-31, the LHP #0 CC temperature became unstable and oscillated between 8°C and 22°C for about 24 hours. Note that prior to the failure, the heater controller maintained the LHP #0 CC temperature at the 8.8°C set point. At 14:00 Universal Time (UT) on October 31, the LHP #0 CC temperature had a temperature droop. It decreased to 1°C first and settled at approximately 18°C. Fig. 11 through 13 show the flight temperature telemetry of the LHP #0 evaporator, liquid line/vapor line, and condenser respectively. At 20:00 UT on October 31, the Detector Module (DM) Block temperature increased to 21°C (Fig. 14), which led to an increase in the average DM XA1 temperature to 25.9°C. It also led to noisy detectors and high triggering rates. Therefore the detector high voltage was reduced from 200 V to 100 V.

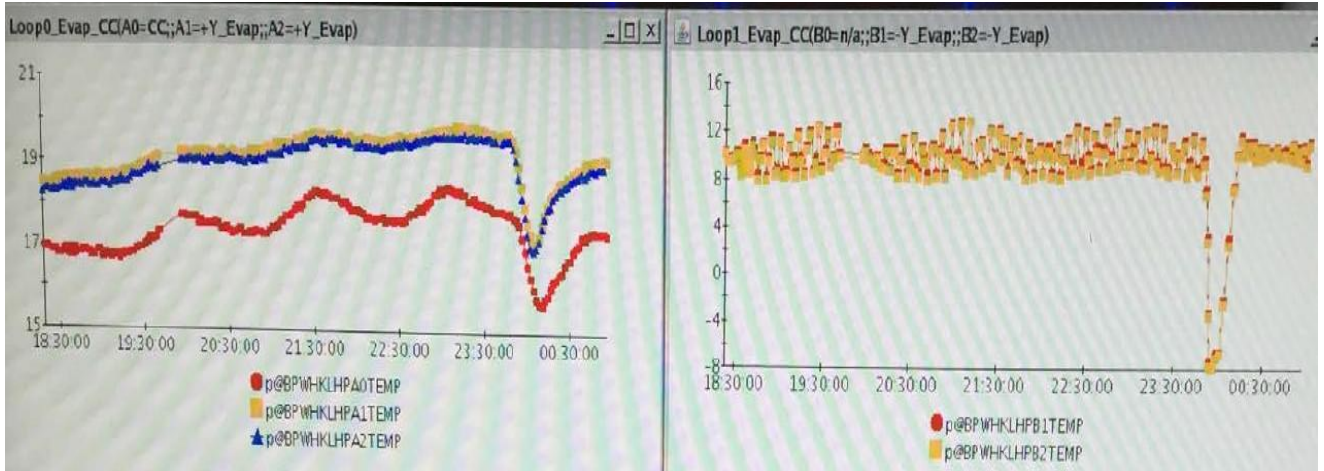


Figure 10. CC and Evaporator Temperatures of LHP #0 and LHP #1 on November 1, 2015.

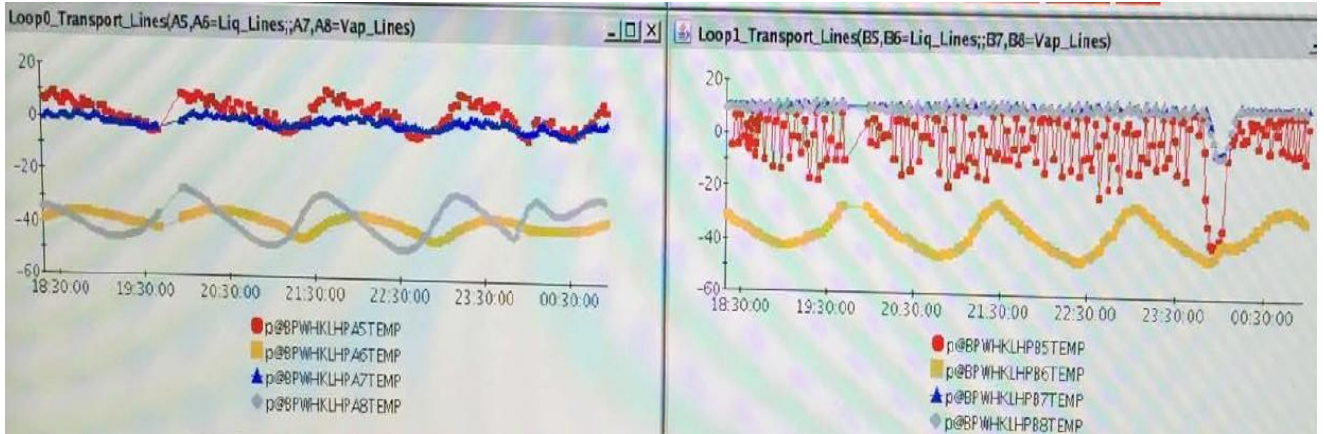


Figure 11. Transport Line Temperatures of LHP #0 and LHP #1 on November 1, 2015.

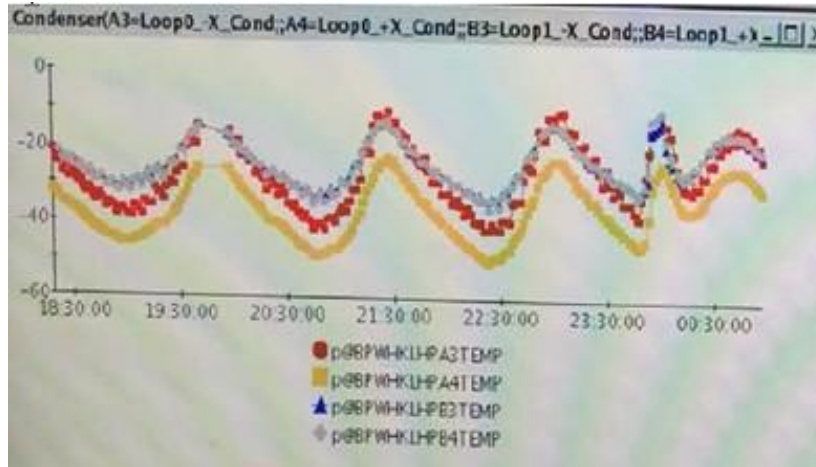


Figure 12. Condenser Temperatures of LHP #0 and LHP #1 on November 1, 2015.

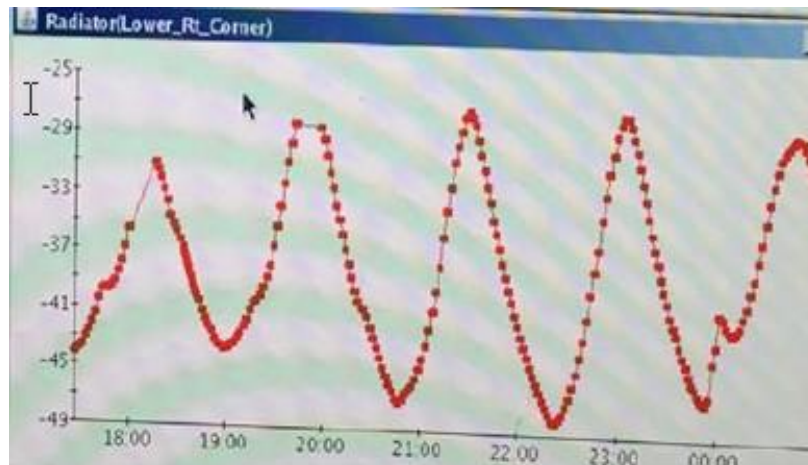


Figure 13. Radiator Temperature on November 1, 2015.

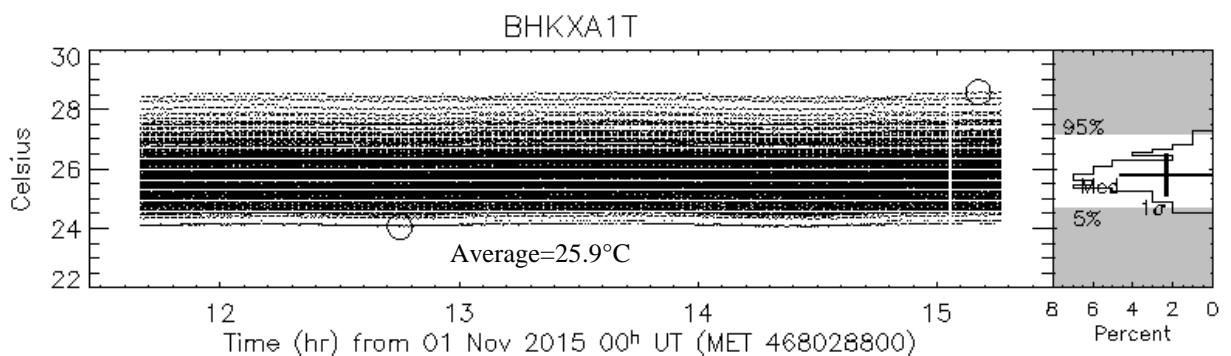


Figure 14. DM XA1 Temperature on November 1, 2015.

Fig. 15 through Fig. 21 show the flight temperature telemetry of LHP #0 on October 31, 2015. The LHP #0 CC temperature (about 18.6°C) is much higher than the LHP #0 secondary heater controller set point (8.8°C). After the LHP #0 secondary heater controller failed, it was unable to control the LHP #0 CC temperature. It possibly failed on (i.e., operating at 100% duty cycle). As a result, the LHP #0 evaporator temperature increased to 20°C. To verify this hypothesis, the set point of this heater controller was decreased in 0.5°C decrements by sending commands

during command passes, such as Tracking and Data Relay Satellite System (TDRSS). The temperatures of LHP #0 CC and evaporator did not respond to the commands.

The LHP #1 CC and evaporator temperatures were not affected by the LHP #0 secondary heater controller failure. Therefore the LHP #1 secondary heater controller was nominal. With LHP #0 operating at temperatures nearly 10°C warmer than nominal, and LHP #1 operating at nominal temperatures, the conductive heat sink temperature for the DM XA1 was basically the average of the two LHP evaporator temperatures. As a result, the average DM XA1 temperatures was nearly 5°C warmer than nominal. Fig. 22 presents the DM Block flight temperature telemetry on October 31, 2015. The DM Block temperature increased from 16.7 at 20:00 UT on October 30, 2015 to 21.2°C at 20:00 UT on October 31, 2015.

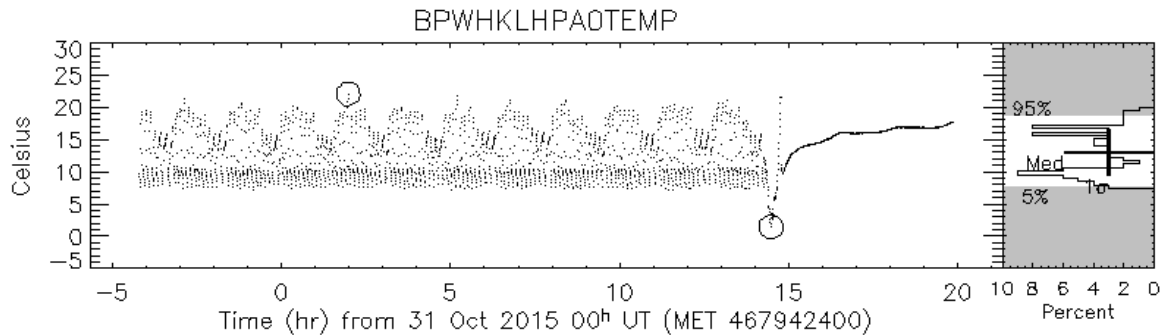


Figure 15. LHP #0 CC Temperature on October 31, 2015.

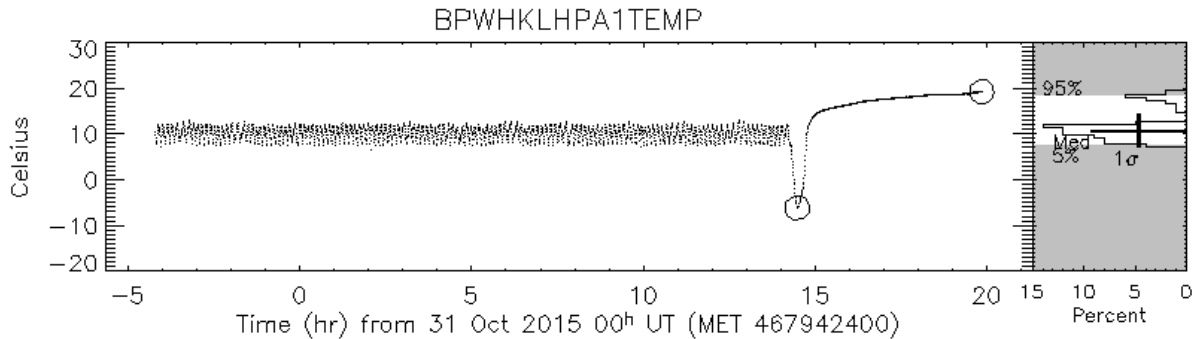


Figure 16. LHP #0 Evaporator Temperature on October 31, 2015.

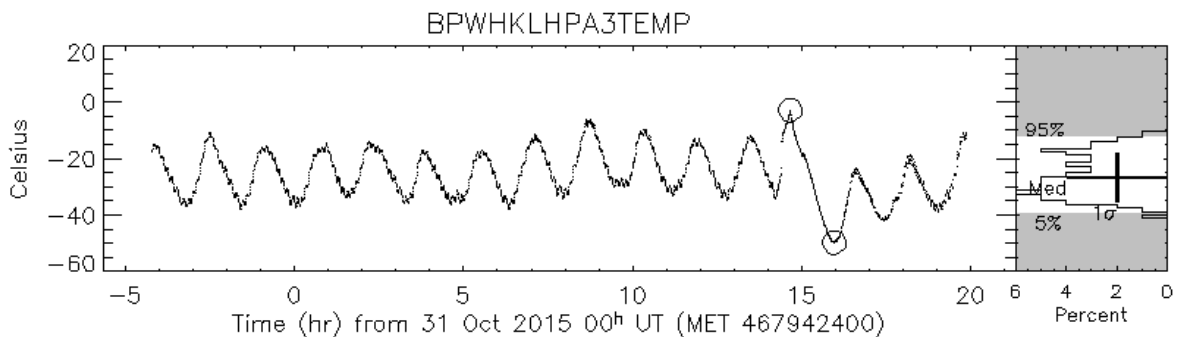


Figure 17. LHP #0 Condenser Temperature on October 31, 2015.

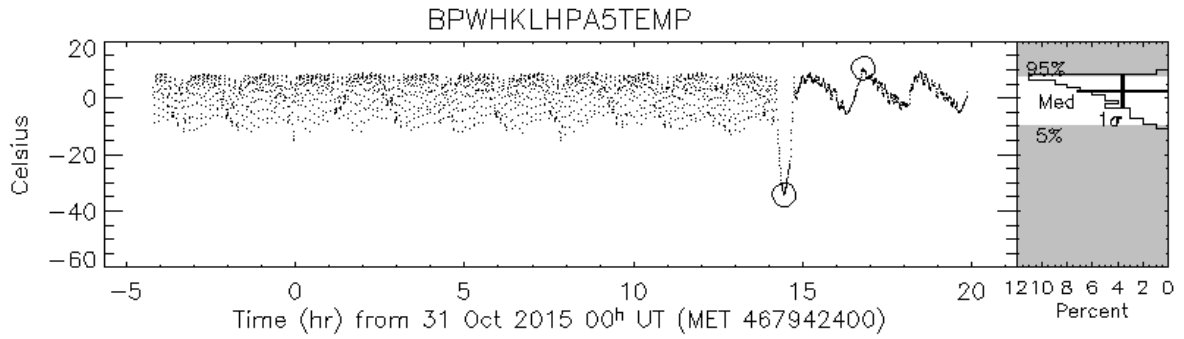


Figure 18. LHP #0 Liquid Line at CC Temperature on October 31, 2015.

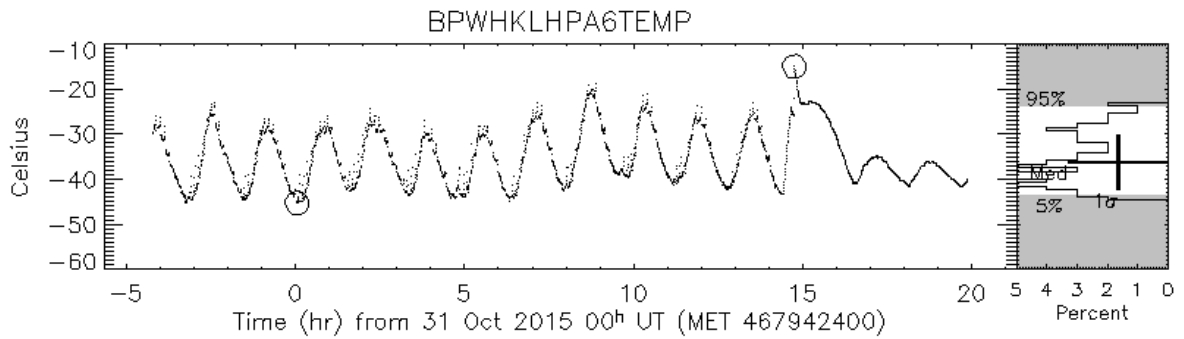


Figure 19. LHP #0 Liquid Line at Condenser Outlet Temperature on October 31, 2015.

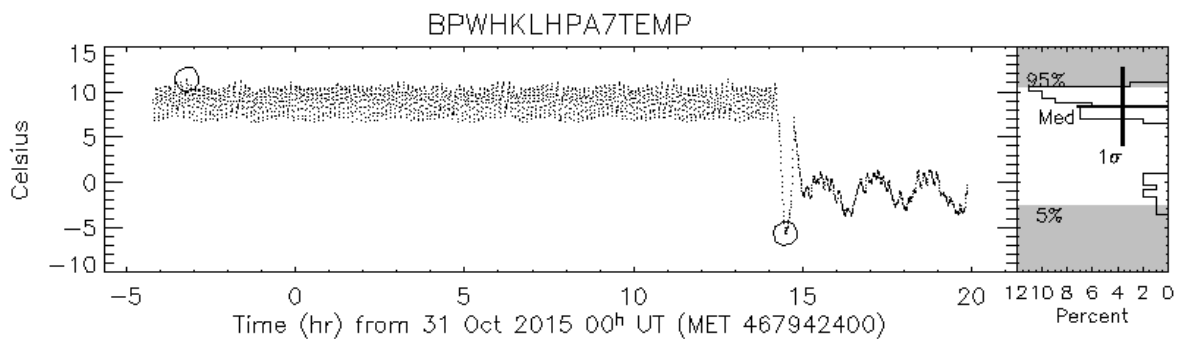


Figure 20. LHP #0 Vapor Line at Evaporator Outlet Temperature on October 31, 2015.

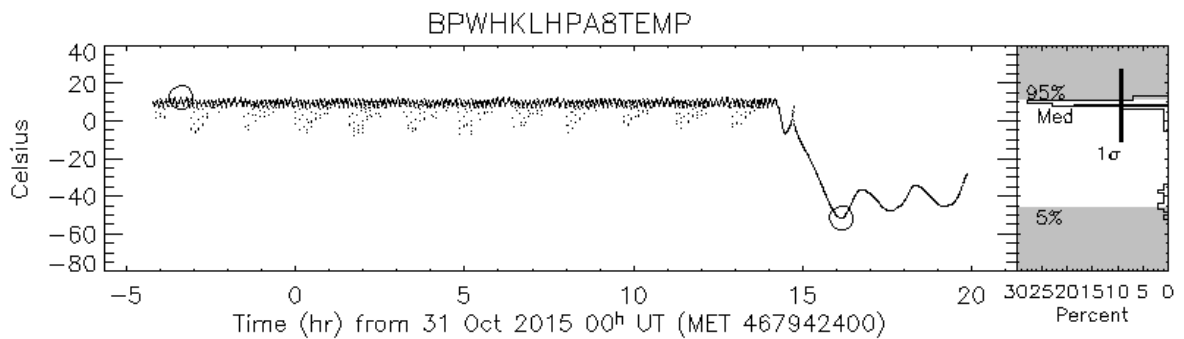


Figure 21. LHP #0 Vapor Line at Condenser Outlet Temperature on October 31, 2015.

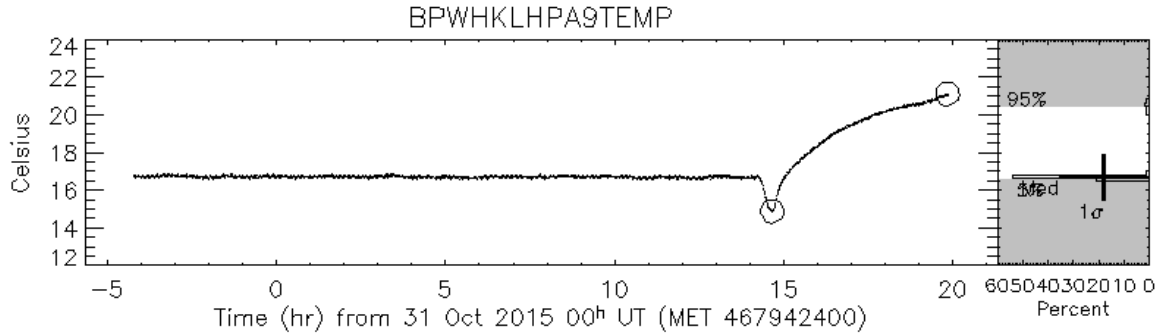


Figure 22. DM Block Temperature on October 31, 2015.

VI. BAT Thermal Recovery After LHP #0 Secondary Heater Controller Failure

With the DM XA1 temperatures nearly 5°C warmer than nominal, the detectors became noisy and had high triggering rates. It was necessary to decrease these temperatures to the nominal value. Since the average temperature of the two LHP evaporators determines the DM XA1 temperatures and the LHP #0 failed on, it was necessary to decrease the LHP #1 evaporator temperature significantly. Therefore, the LHP #1 secondary heater controller set-point was decreased gradually by 0.5°C at a time until the LHP temperatures became nearly stabilized. Decreasing the heater controller set point removes thermal energy from the LHP. A large set point change could cause large temperature instabilities and shut down the LHP. Therefore the set point (8.6°C) was decreased gradually during command passes, such as TDRSS, beginning on November 6. On November 16, the average DM XA1 temperatures was restored to the nominal temperature of 19.7°C. The LHP #1 secondary heater controller set-point decrease was completed with a 2.2°C set-point.

Also the primary DM Block heater controller set points were reduced to 15.5°C, which is about 1°C below the DM Block temperature telemetry, on November 17. It is to assure not to add heat to the DM Blocks or XA1s when there were no droops. During the droops, if the Block temperatures reach 15.5°C, the DM Block heaters will be activated. After activation, they will be deactivated when they reach 16°C. The secondary Block heater controller set points were reduced to 13.5°C, so that only the primary DM Block heaters will be activated when the Block temperatures reach 15.5°C.

Decreasing the LHP #1 heater controller set-point led to small temperature droops. The droops are caused by the VCHP, which is controlled by a channel of the same controller as the CC. Since the droops were not large, there was no risk of shutting down the LHP. Examples of droops are as follows. First, LHP #1 had four droops over 24 hours on November 21. Two were about 13 hours apart, and two were about 3 hours apart. The LHP #1 droops caused droops of 1.5°C maximum on the DM Block temperatures or about 1°C on the DM XA1 temperatures. Second, the temperature telemetry on November 22 showed that LHP #1 had two droops over 24 hours that day. The droops were about 8 hours apart. The number of droops were two less than that of November 21. The LHP #1 droops on November 22 also caused droops of 1.5°C maximum on the DM Block temperatures or about 1°C on the DM XA1 temperatures. The frequency and amplitude of the temperatures droops in the DM XA1 temperatures are acceptable to science.

Fig. 23 shows the LHP CC and evaporator flight temperature telemetry from November 14-16, 2015. The LHP #0 CC temperature was between 12°C and 17°C. The LHP #1 CC temperature was between -1°C and 5°C, except during the droops. It decreased to -11°C minimum during the eight droops over 72 hours. Fig. 24 through Fig. 28 present the LHP flight temperature telemetry on November 26, 2015. Fig. 29 and Fig. 30 present the DM Block and DM XA1 flight temperature telemetry respectively on November 26, 2015. They represent the BAT flight temperatures after its thermal control system recovery. Presently the average DM XA1 temperatures remains at 19.7°C. The BAT is operating nominally.

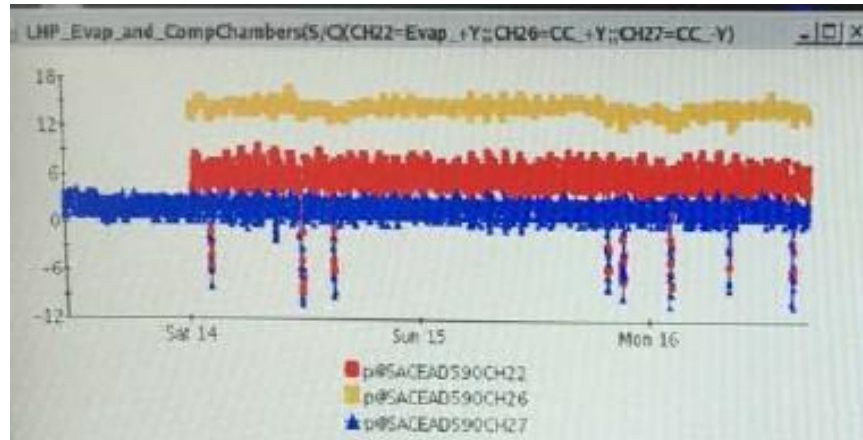
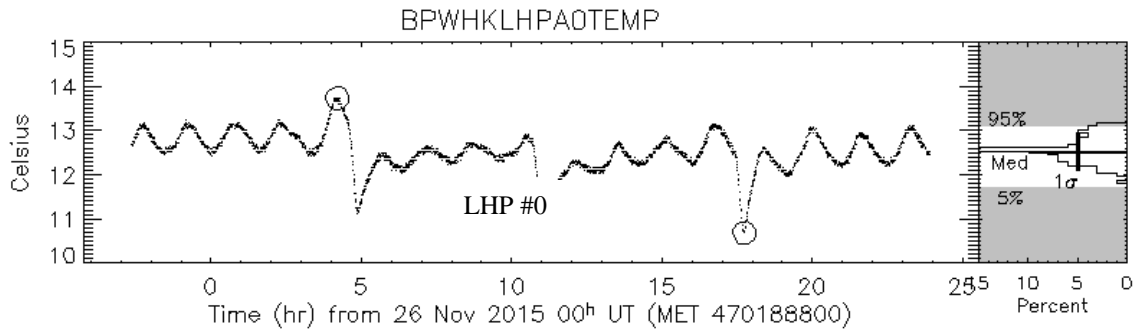


Figure 23. LHP CC and Evaporator Temperatures from 14-16 November, 2015 (S/C Sensors).



BPWHKLHPB0TEMP not shown (temperature sensor had ESD damage during I&T before launch)

Figure 24. LHP CC Temperature on 26 November, 2015.

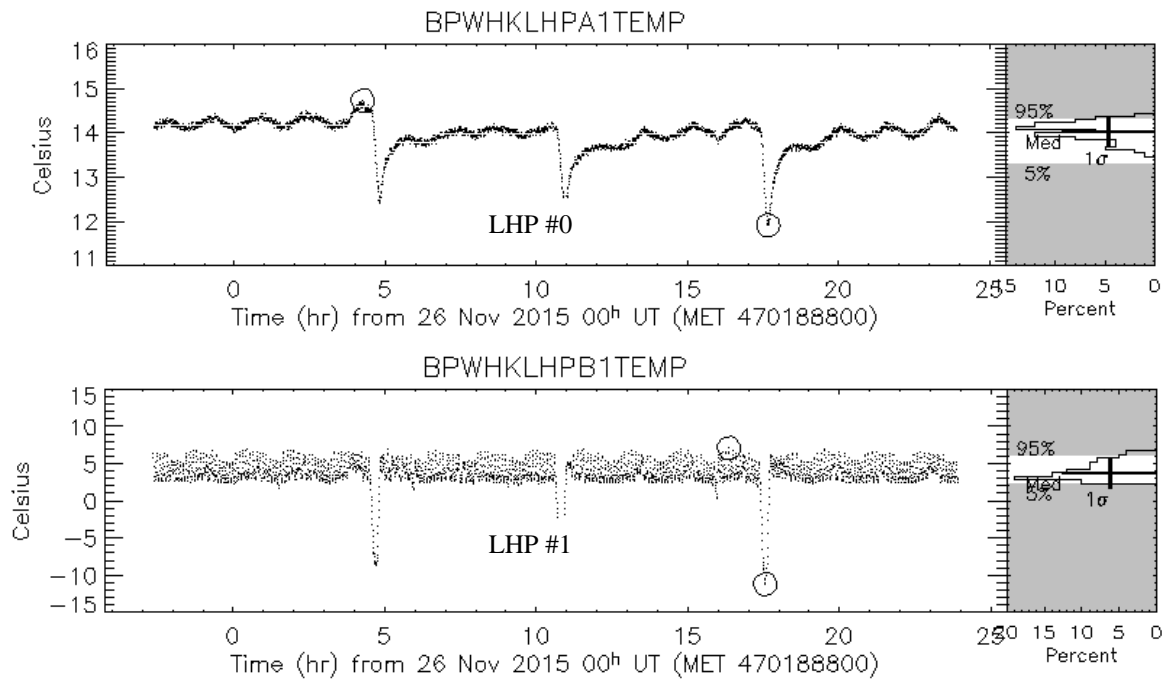


Figure 25. LHP Evaporator Temperature on 26 November, 2015.

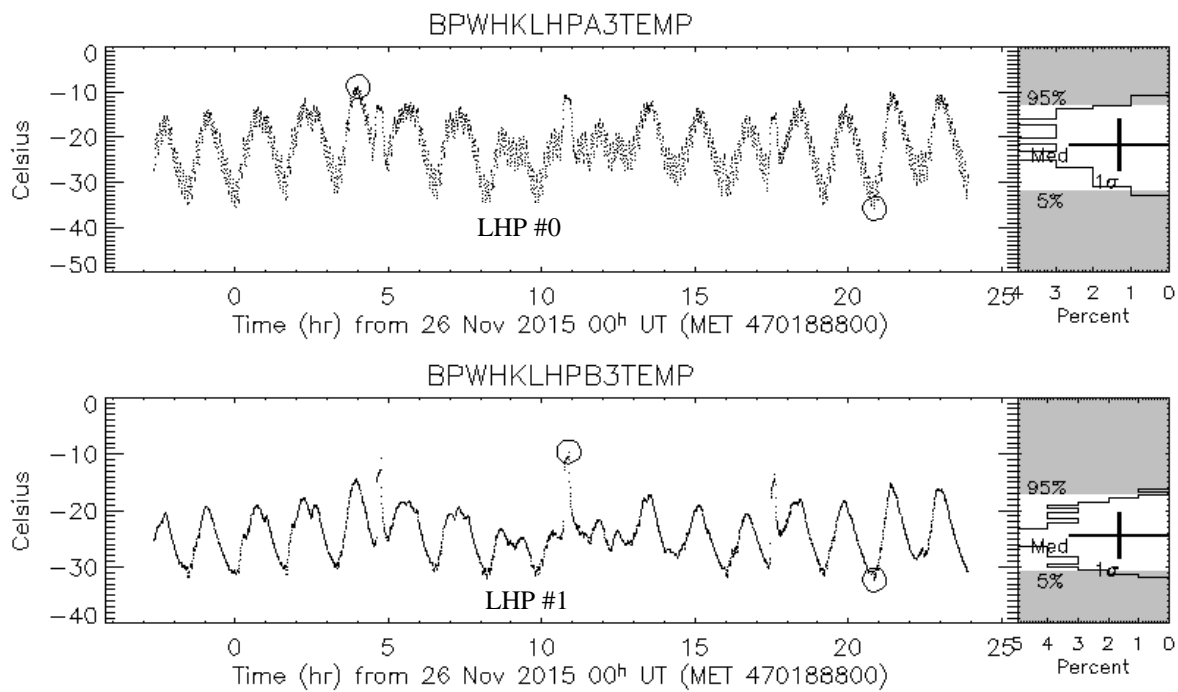


Figure 26. LHP Condenser Temperature on 26 November, 2015.

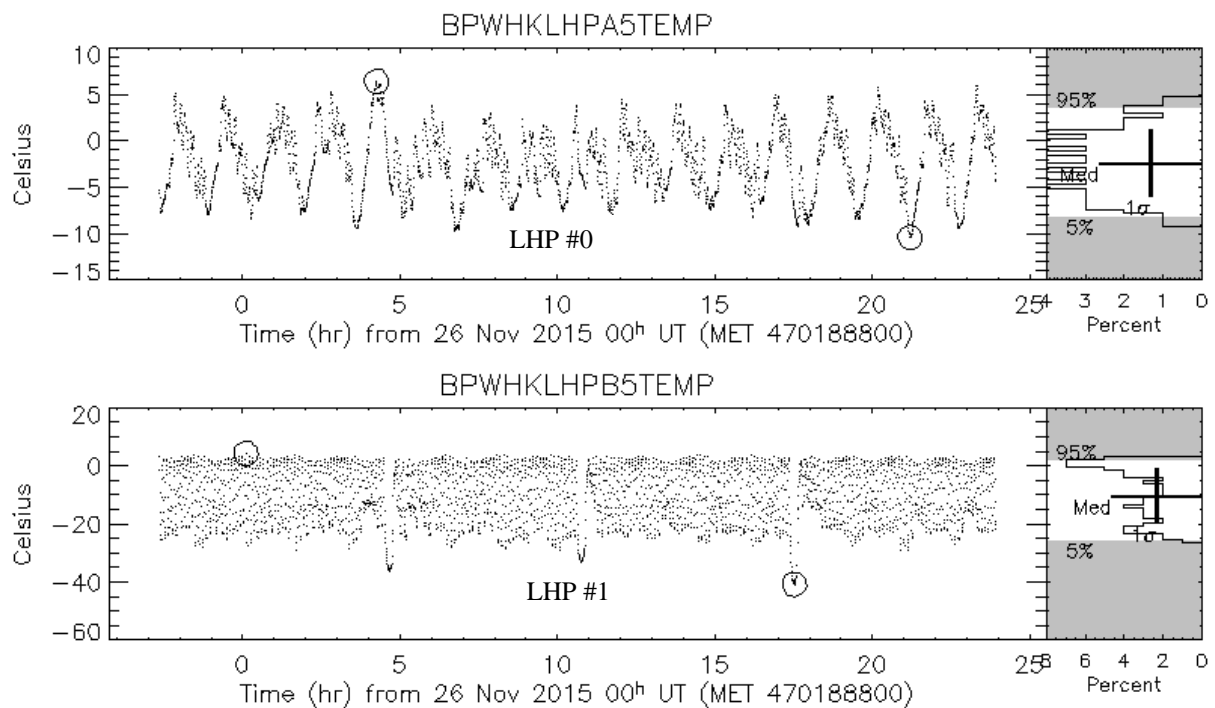


Figure 27. LHP Liquid Line at CC Inlet Temperature on 26 November, 2015.

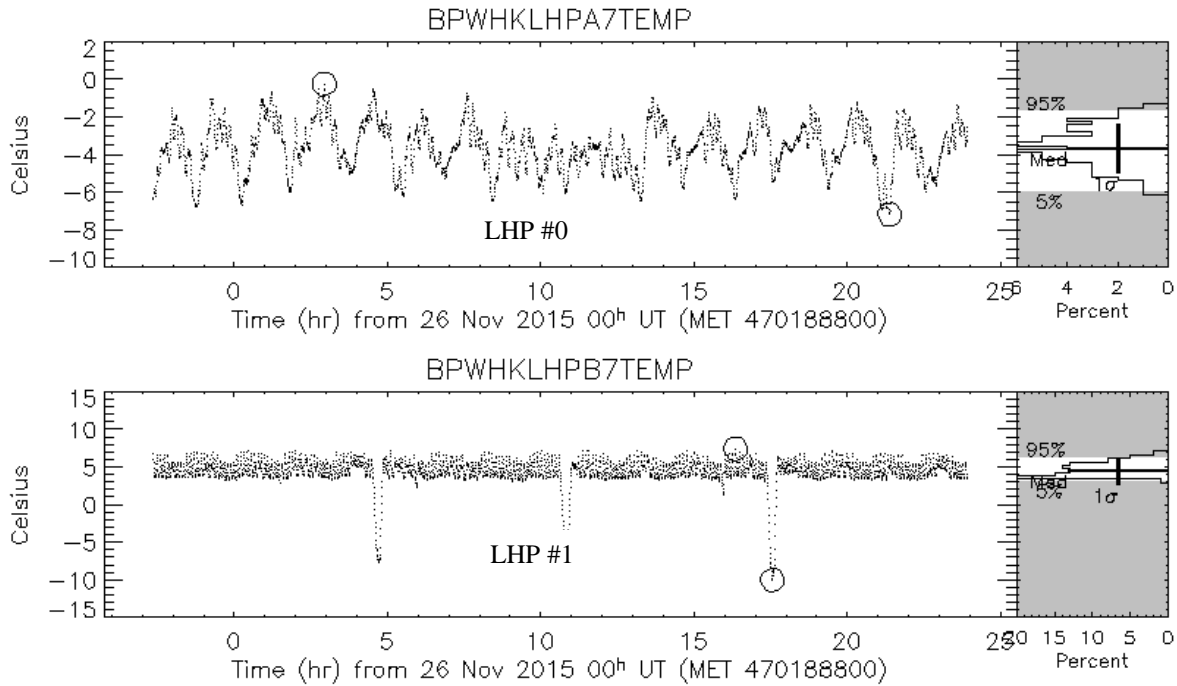


Figure 28. LHP Vapor Line at Evaporator Outlet Temperature on 26 November, 2015.

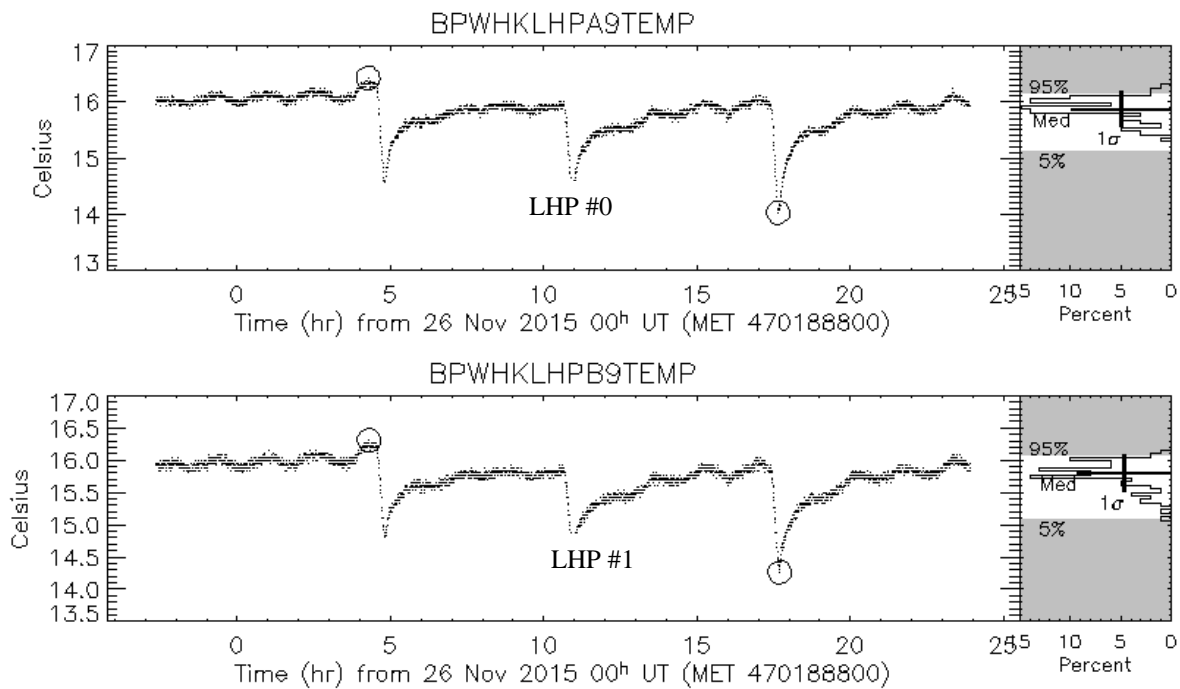


Figure 29. DM Block Temperature on 26 November, 2015.

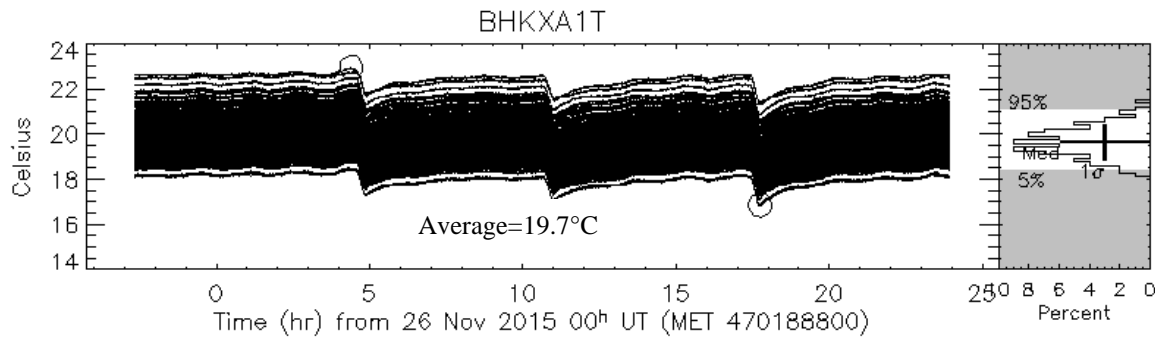


Figure 30. DM XA1 Temperature on 26 November, 2015.

VII. Conclusion

The *Swift* BAT thermal control system is robust, including redundancy of LHPs, CCHPs, heater circuits and heater controllers. The primary heater controller for LHP #0 failed on March 31, 2010. It has been disabled. On October 31, 2015, the secondary heater controller of LHP #0 failed. On November 1, 2015, the LHP #0 CC temperature was as much as 18.6°C, despite that the secondary heater controller set point was 8.8°C. It possibly failed on (i.e., 100% duty cycle). It caused the DM XA1 average temperature to increase to 25.9°C, which was 5°C warmer than nominal. As a result, the detectors became noisy and had high triggering rates. To solve this problem, the LHP#1 secondary heater controller set point was decreased in 0.5°C decrements to 2.2°C. The temperature decrease restored the average DM XA1 temperature to 19.7°C on November 16. Presently the *Swift* BAT thermal system is operating nominally.

References

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