Commissioning and Initial Performance of the Dark Energy Camera Liquid Nitrogen Cooling System.

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ABSTRACT

The Dark Energy Camera and its cooling system has been shipped to Cerro Tololo Inter-American Observatory in Chile for installation onto the Blanco 4m telescope. Along with the camera, the cooling system has been installed in the Coudé room at the Blanco Telescope. Final installation of the cooling system and operations on the telescope is planned for the middle of 2012. Initial commissioning experiences and cooling system performance is described.

Keyword list: DES, DECAM, CTIO, NOAO, CCD, liquid nitrogen, pump, camera cooling

1. INTRODUCTION

The Dark Energy Camera (DECam)[1], will be the primary instrument used in the Dark Energy Survey[2]. DECam will be a 3 sq. deg. mosaic camera mounted at the prime focus of the Blanco 4m telescope at the Cerro-Tololo International Observatory (CTIO). The camera imager[3] is a vacuum vessel that houses the CCD array, the focal plane support plate, and the liquid nitrogen heat exchanger used to cool the array[4]. The cooling strategy was determined by comparing various cooling techniques and methods used on other telescope instruments. The method best suited for this application was determined to be a closed loop, two phase liquid nitrogen system[5].

A prototype closed loop liquid nitrogen system was constructed in late 2008 and was used to cool the Multi-CCD test vessel[6.] A second final system was constructed with modifications from the original system to help further mitigate system thermal loads. The LN2 cooling system for the imager was then tested on the telescope simulator at Fermilab at the end of 2010[7.] In July of 2011 the LN2 cooling system was shipped and installed at CTIO. Preliminary testing was performed to ensure the cooling system was working and the slow control instrumentation was being data-logged to a web based system. In December of 2011, the imager was shipped to CTIO. The Imager was setup in the Coudè room in the 4 meter Blanco dome and was cooled down to test the system integration. Additional cool downs of the imager took place in January 2012 and April 2012. Cool down and temperature stability plots are shown from the April cool down to illustrate the cooling system performance system in the Coudè room. The on telescope utility routing and installation of the imager inside the prime focus cage is planned for August 2012.

2. THE IMAGER COOLING SYSTEM DESCRIPTION AS INSTALLED AT CTIO

The liquid nitrogen system is a closed loop, two phase circulation system. Liquid is pumped from the liquid nitrogen process vessel and circulated continuously to the imager vessel heat exchanger and back. The heat exchanger inside the imager and the functionality of the LN2 process tank are described.

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The heat exchanger inside the imager is a simple tube heat exchanger. Flexible copper straps connect the simple tube heat exchanger to the back surface of the focal plane support plate that supports the CCD array. The back of the imager vessel, internal cooling ring, and copper braids are shown in figure 1. The front of the imager with the CCD array is shown in figure 2. The focal plate operating temperature is maintained at 173K with an expected heat load of 113Watts[6]. An electric heater and Resistance Temperature Detector (RTD) are installed on each of the flexible copper straps. The power to each heater is modulated to control the CCD array temperature. The cooling fluid from the heat exchanger returns back to the liquid nitrogen vessel and is separated into liquid and gaseous phases. The gaseous phase is condensed using two cryocoolers. To maintain a closed loop system, the overall system heat load must be less than the cryocooler capacity in-order for the system to remain as a closed loop system. The expected thermal loads at the imager and the overall system thermal loads have been previously described at SPIE conferences[6].

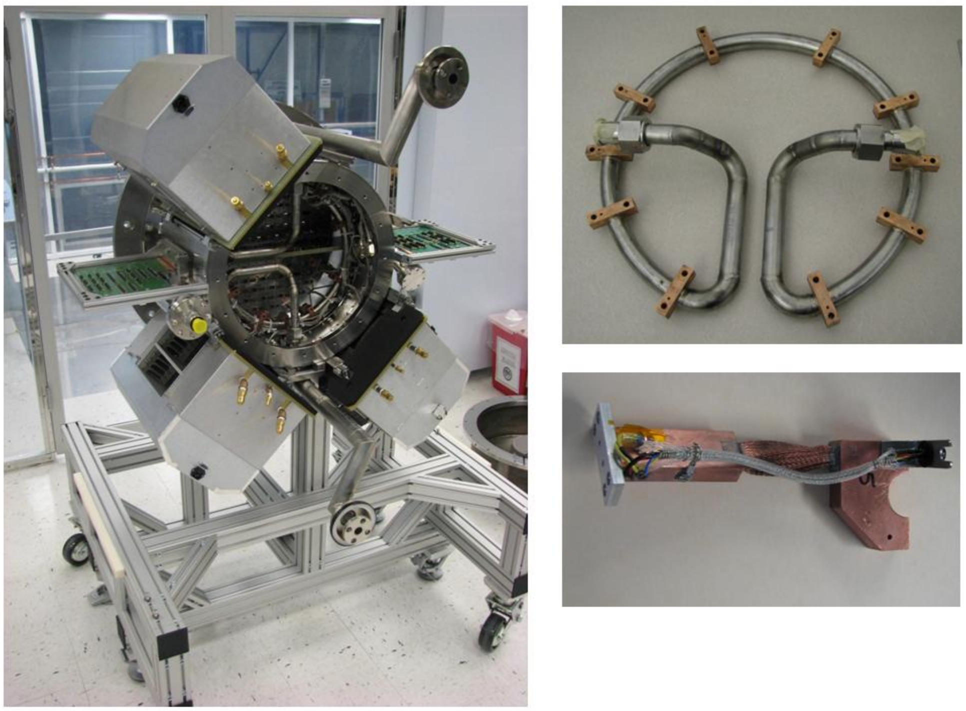

Figure 1, Left: Imager Vessel. Upper Right: Internal heat exchanger cooling ring. Lower Right: Copper braid with heater, temperature sensor, thermal protection switch, electrical isolation joint.

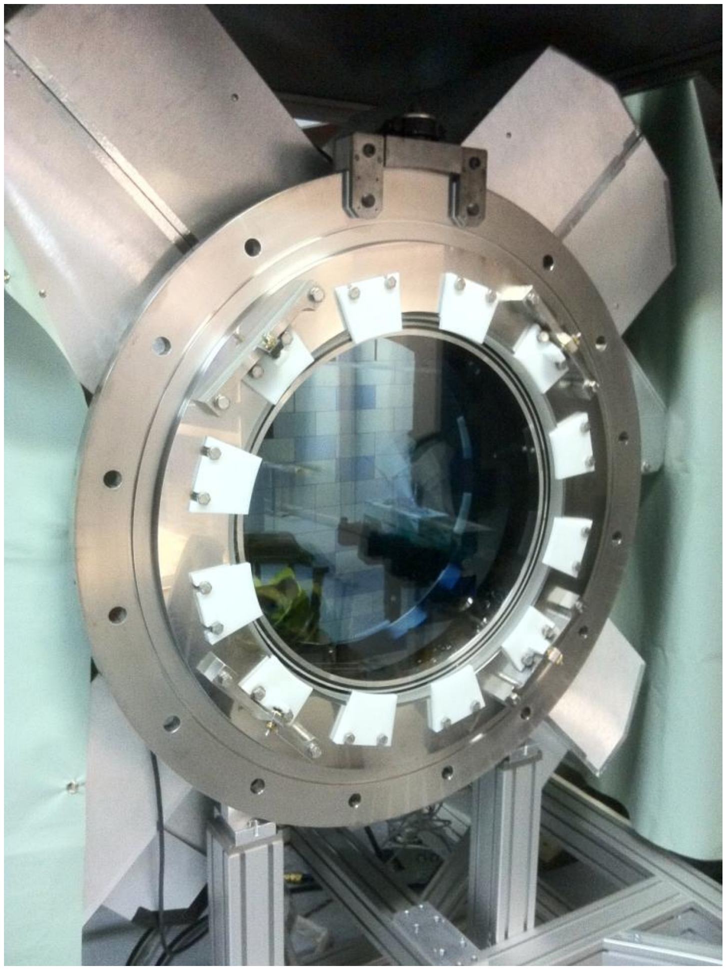

Figure 2. The imager with flat window showing the CCD array.

The LN2 process tank installed on top of the old console room at CTIO is shown in figure 3. The process tank is the LN2 reservoir containing approximately 200L of LN2. Inside the process tank at the bottom is a circulation pump. The LN2 is circulated through a valve-box then either to the Coudè room or the telescope depending on where the imager is located at the time of cool down. The old console room has the slow controls rack for the cooling system and the windows computer running National Instruments with a GUI. The slow controls monitor the LN2 flow rate, LN2 system pressures and also the other utilities such as the imager vacuum and water-glycol cooling systems. The slow control system has alarm features to warn the operator of conditions that are moving out of the normal operation parameters. Initial warnings are sent via email. As the parameters degrade, a second limit is approached, an autodialer places an automated phone call to the operator. If the parameter is severely out of range, the system goes into a self-protection mode and starts a predetermined shutdown procedure for the problem.

Figure 3. LN2 process station mounted to top of old console room roof. In the old console area is the slow controls rack. LN2 transfer lines are routed from the LN2 process station to the Coudè room and to the Telescope.

Mounted to the top of the process tank are two AL-300 Cryomech cryocoolers that condense returning vapor from the circulated two-phase LN2 flow. The crycocoolers with attached copper fins for condensation are shown in figure 4. The combined cooling capacity of the two cryocoolers is a little more than 700Watts. The overall system thermal load is less than 700 watts, allowing the system to run in a closed loop without the need to refill with LN2. The LN2 process tank pressure is maintained at 100 psig by a control system that uses heaters inside the LN2 reservoir to vaporize additional LN2 as needed to control the pressure to 100 psig. The overall system thermal load is calculated by subtracting the heater power required to maintain 100 psig in the process tank from the cooling capacity of the cryocoolers.

Figure 4. Left: Cryocooler insert. Upper right: Al-300 cryocooler. Lower right: copper gas condenser.

The current operating configuration for commissioning after shipping has the Imager in the Coudè room as shown in figure 5. Vacuum jacketed LN2 transfer lines are routed from the main valve-box on the old console room roof to the Coudè room. Utilities and slow controls related to instrumentation that will later be mounted in the prime focus cage are mounted on a rack on the left side of the imager. The prime focus cage instrumentation rack shows a black painted power distribution box and other instrumentation. The National Instruments backplanes are used to control and monitor the focal plate temperature, monitor the front end electronics water-glycol cooling, the imager ion pump, and monitors temperatures throughout the cage. An optics station for in-situ CCD testing is mounted on the right side of the imager.

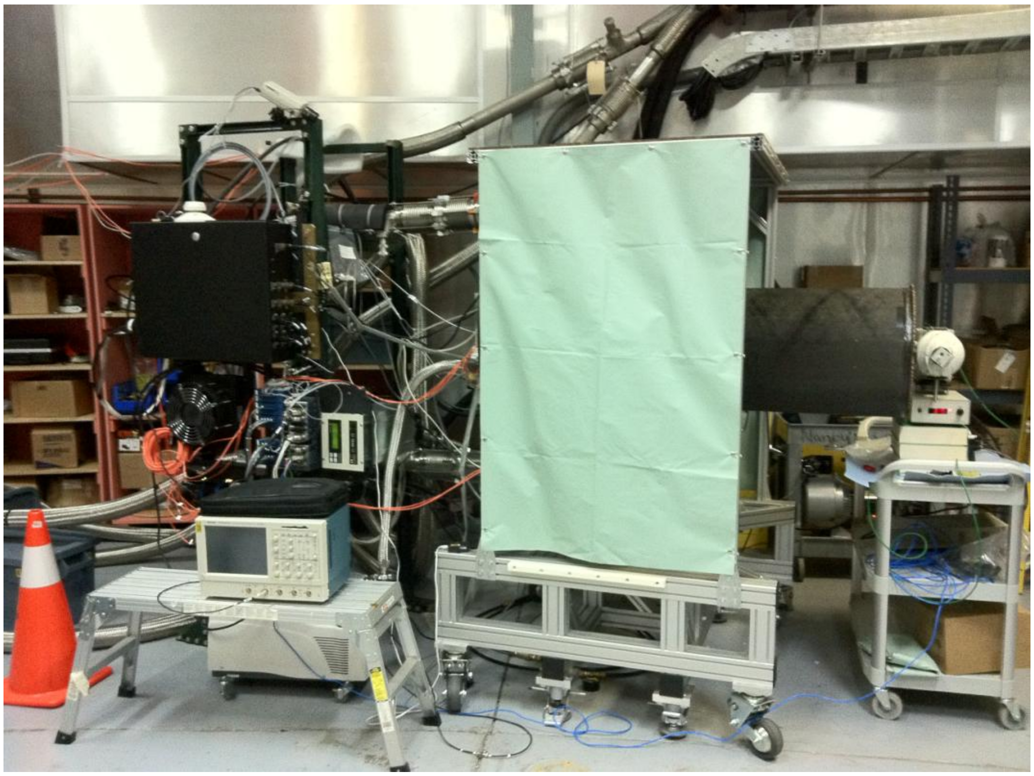

Figure 5. The DES Camera is mounted on a cart (center) in the Coudè Room.

3. INITIAL COOLING SYSTEM PERFORMANCE AT CTIO

During the April 2012 cool down and warm up of the imager the LN2 cooling system performed at CTIO with the Imager in the Coudè room as it did in testing at Fermilab. Focal plate temperature, heat loads, and vacuum level are monitored during the cooling cycles. Plots are shown.

The temperature of the focal plate near the CCDs is monitored during the cool down and warm up. The temperature is plotted as a function of calendar time in figure 6. The plot shows that it takes approximately 4 hours for the imager to cool down to -100°C and another few hours for the temperature control loop to stabilize the temperature to -100°C +/- 0.25°C[8.]. The disturbances in the plot are related to other commissioning activities. The warm up of the imager focal plate occurs passively, without heaters, and takes approximately 24 hours to warm up. There is no advantage to accelerate the imager warmup for quicker maintenance access since the LN2 transfer lines also take approximately 24 hours to warmup.

The focal plate temperature is maintained using a control loop and trim heaters. The power required by the trim heaters to maintain the focal plate temperature to -100°C is approximately 110 watts as shown in figure 7. This excess cooling capability allows for faster cool downs. The additional vapor created by the trim heaters is condensed by the AL-300 cryocoolers in the LN2 process tank without venting the excess LN2 to atmosphere. A cause of trim heater disturbances is rapid fluctuations in LN2 pressures during refilling the LN2 process tank (rare events). Another cause is power cycling the front end electronics. The amplifier power near the CCDs when power cycled is compensated by the trim heaters. The extra cooling capacity at the focal plate will be used for contingency in the event that the thermal loading on the imager is different once it is mounted to the telescope and experiences seasonal temperature variations.

The overall cooling system also has additional cooling capacity as shown by the heater power required in the LN2 process tank to maintain the coolant pressure to 100 psig in figure 8. Initially, when LN2 is not being circulated, it takes approximately 700 watts to maintain tank pressure. As the cooling system starts up and liquid is circulated throughout the system, the system heat load goes up. Then the heater power required to maintain the tank pressure decreases. Once the imager is cold, the figure shows approximately 150 watts of extra cooling capacity in the system. This includes the additional 110 watts of additional contingency at the focal plate. The rapid cycling wattage indicates that the control loop does not have optimal tuning parameters yet. If the LN2 process tank heater power decreases, it is an indication that the environmental heat load on the system has increased. It is useful as a diagnostic tool for monitoring the thermal load on the piping system. Weak vacuum on the transfer lines would cause an additional thermal load, creating more nitrogen vapor, and then the LN2 process tank heaters require less power to maintain the tank at 100 psig.

The imager vacuum pressure during the cool down is shown in figure 9. Warm the imager vacuum is approximately 5e-6 torr. Once LN2 is circulated through the imager heat exchanger, the vacuum improves approximately and order of magnitude and drops to approximately 5e-7 torr. During the warm up cycle, the vacuum level increases due to the additional load coming from gases that had condensed on the cold LN2 heat exchanger. An ion pump is mounted on the imager vessel and is used to maintain cold operation vacuum in the event the turbo pump is not available. It is planned that the turbo pump, also mounted to the imager, will run continuously with its roughing pump mounted in the cassegrain cage.

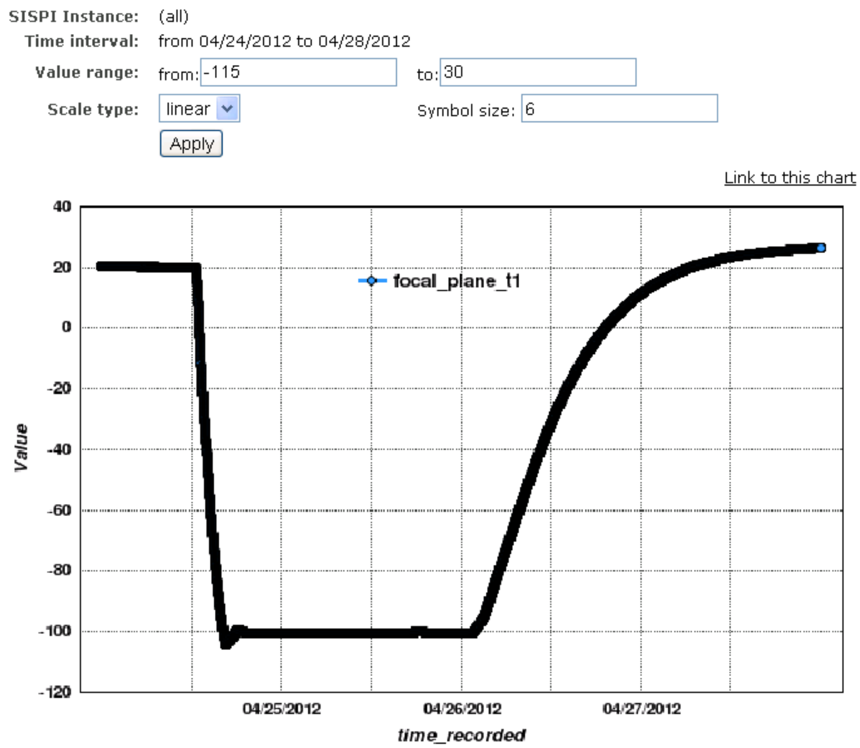

Figure 6. Temperature (°C) at the front of the imager focal plate, as a function of calendar time for the cool down.

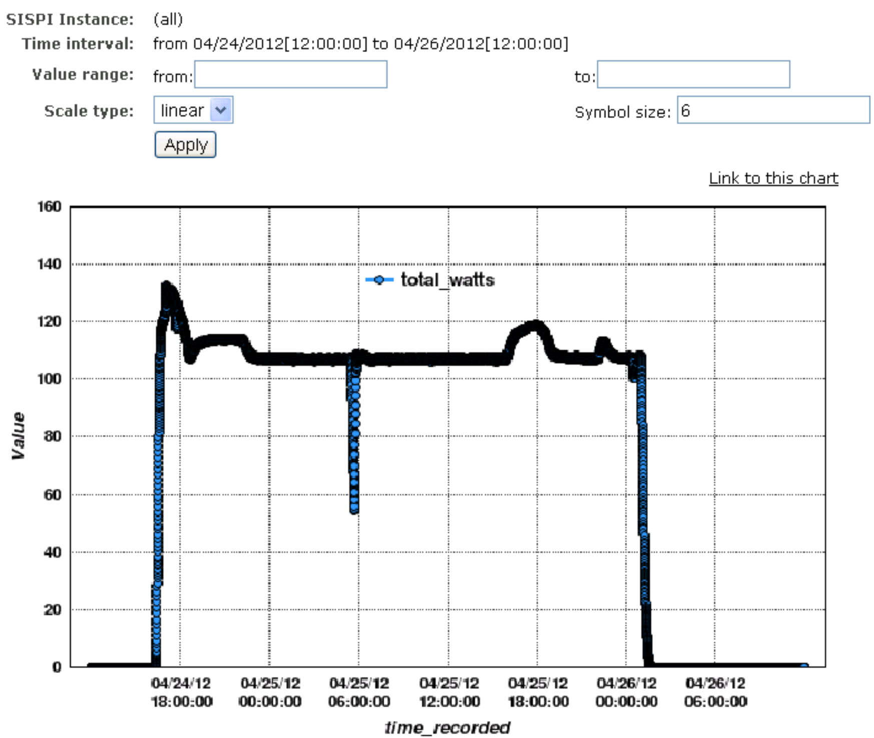

Figure 7. Power (Watts) applied to the focal plate trim heaters, as a function of calendar time, required to maintain -100°C at the focal plate.

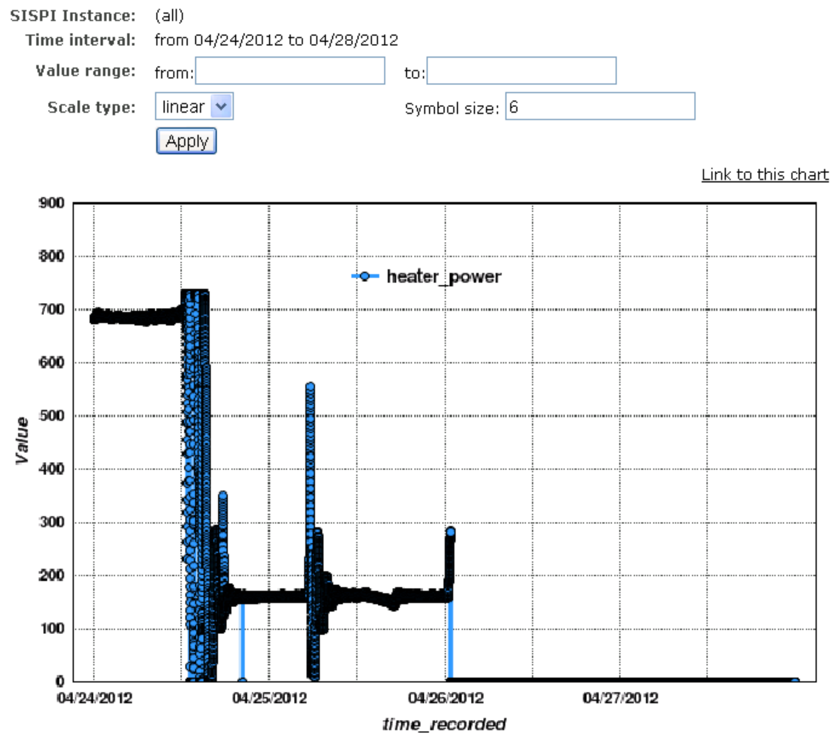

Figure 8. Power (Watts) applied to control the LN2 process tank to 100 psig.

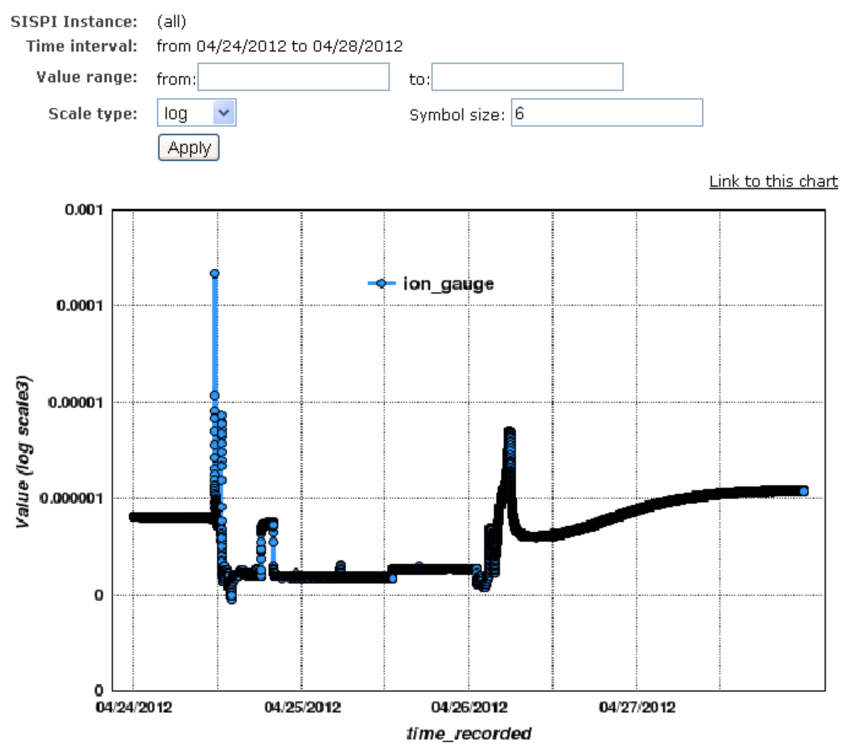

Figure 9. Imager vacuum (torr) plotted on a log scale.

4. FUTURE PLANS

The imager is planned to be installed in the prime focus cage in August 2012. Prior to that installation, the remaining utilities need to be mounted in June and July 2012 to the telescope and run to imager mounting location. The remaining transfer lines are run on the telescope in flexible wrap sections for each rotating axis. A general layout of the piping on the telescope is shown in figure 10. The transfer lines are mounted in sections using VCR joints on the internal cooling line and a retractable vacuum bellows in the vacuum jacket for access to the VCR joint. A vacuum break will be at each joint with a vacuum pump out port. There will be about 160 feet of hard pipe, 75 feet of hose in each supply and return line for a total of 470 feet of piping. Commissioning of the instrumentation took place earlier, however commissioning of the LN2 pump parameters and hose flexibility as a function of telescope orientation will take place later this year.

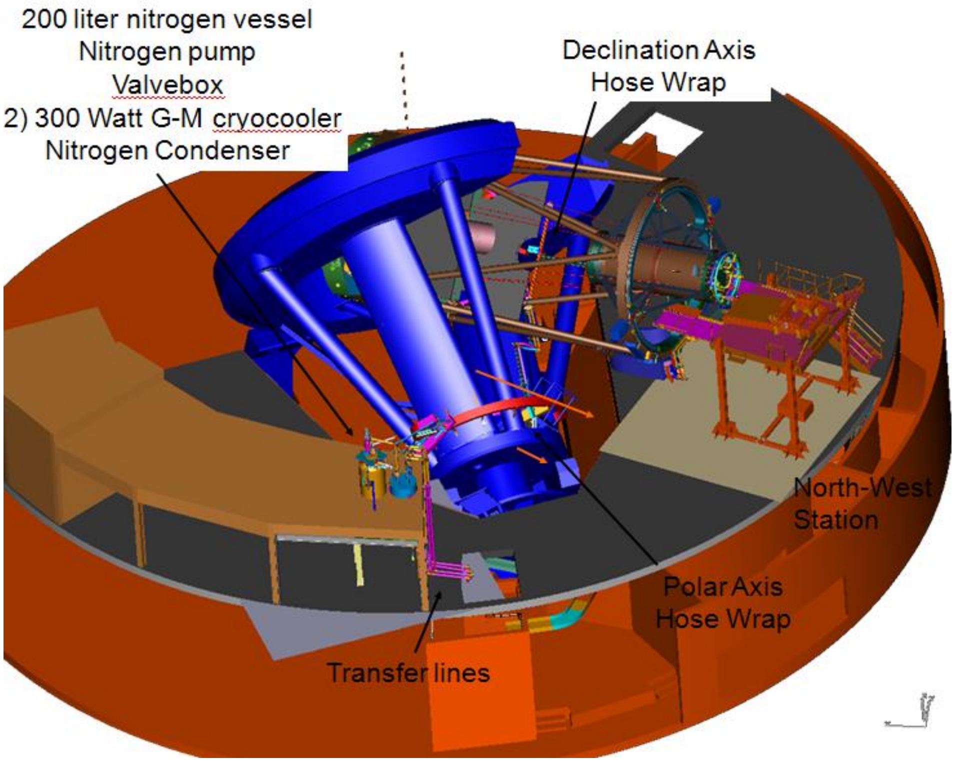

Figure 10, Piping and Equipment Layout on the Telescope at CTIO

5. Summary

The LN2 cooling system with the DES imager has been installed and operated in the Blanco Coudè room. The cooling performance sufficiently cools the imager in a closed loop mode, which can operate for extended time periods (months) without additional LN2 fills. The cool down time is 4 hours before the CCDs can be read out, and another few hours before the temperature is stable within the requirements of -100C +/-0.25C. The warmup of the imager is passive, which allows the transfer lines to warmup passively as well. The imager vacuum is maintained actively either by an ion pump or a turbo pump with the roughing pump mounted remotely in the cassegrain cage. DES is anticipating installing the remainder of the utilities and transfer lines on the telescope in June and July 2012. The Imager is planned to be installed in the prime focus cage in August 2012.

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