TripleSpec Cryogenics (v1.2 06 August 2009)

Cryogen resevoirs, fill ports, and vents

Figure 1 shows the internal cryogenic tank configuration for TripleSpec. In the illustrated orientation the three fill/vent necks are pointing directly downward (and thus obscured from view). The instrument contains a large crescent-shaped tank that serves as the primary cryogenic reservoir and a small cylindrical auxiliary cryogen tank dedicated to maintaining the temperature of the HAWAII-2 array. The large tank has a hole through which the fill tube for the small tank passes. The large tank has a capacity of 60-90 liters of liquid nitrogen depending on its orientation when filled. The auxiliary tank holds approximately 2 liters of LN2. Figure 2 shows the external fill port configuration for TripleSpec. There are three cryogenic fill/vent necks on the dewar. Two of the necks (those on the left in Figure 2) provide a fill (center) and vent (left) for the primary cryogen tank. The right hand neck in Figure 2 goes to the auxiliary tank. Each neck has a central fill tube that extends into the respective tank. Vent gas can emerge via a sheath surrounding the fill tube. Four small threaded holes around the base of each fill/vent port connect to this vent sheath. Following fill, the main fill and vent tubes are capped with screw-on knurled caps (visible on the left two ports in Figure 2). Evolved gas vents via the small vent ports on the side of each neck. In practice all but one of these vent ports is blocked with screw-in plugs or pop-off valves so that the slowly venting gas emerges through a single port.

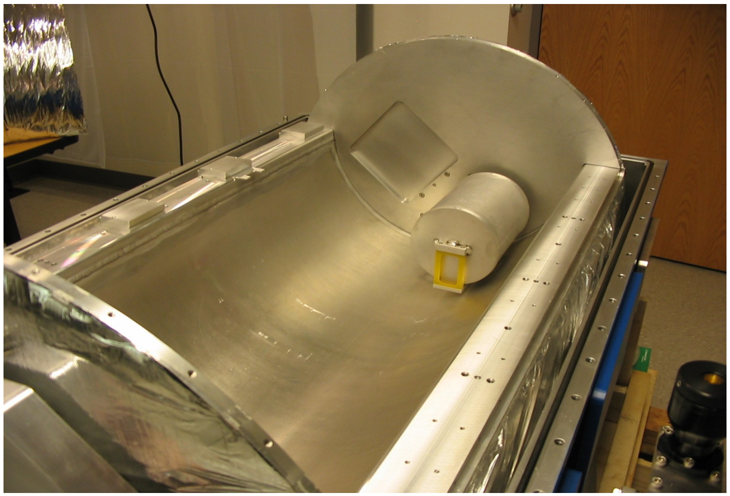

Figure 1 -The two cryogenic tanks for TripleSpec. The large cryogen tank is crescent shaped. The inner surface of this crescent tank is visible in this picture spanning most of the Dewar volume. The auxiliary cryogen tank is the cylinder toward the rear of the surface of the main tank. The TripleSpec optics mount on the flat rails that run along either side of the main tank. In the orientation illustrated here the fill necks point downward.

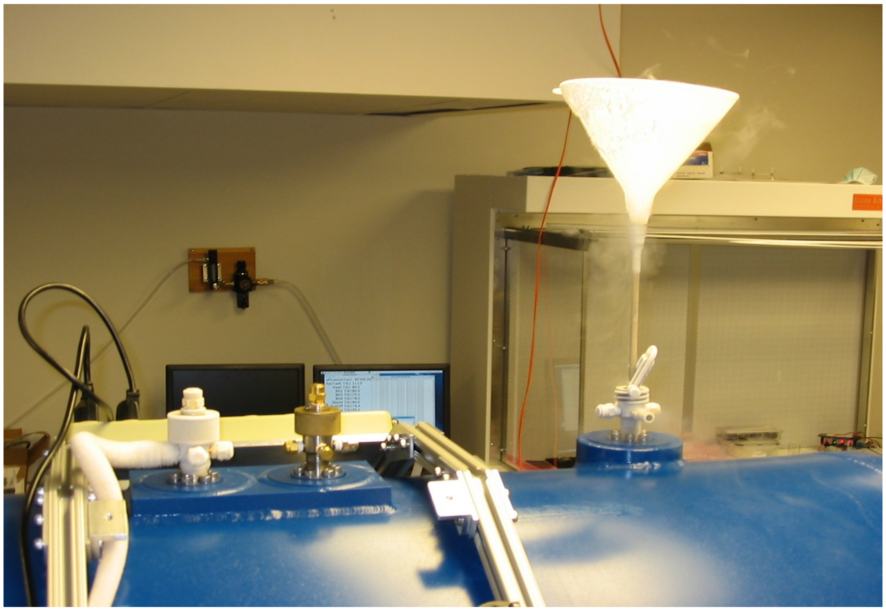

Figure 2: The three fill/vent necks on TripleSpec. The pair of necks are the fill (center) and vent (left) necks for the main cryogen tank. The fill port to the right goes to the auxiliary nitrogen tank. In this picture the main tank has been cold for some time. The fill and vent ports have been closed with knurled caps. Gas preferentially emerges from and cools the port on the left emerging from one unplugged hole in the vent sheath. The auxiliary tank is undergoing its initial fill (described later). The instrument window is on the left in this picture.

Figure 3 shows a cross section of the main tank and its internal fill tube structure. When the dewar is positioned with its necks pointing upward nitrogen will pool in the horns of the crescent. In this configuration the instrument can accept 90 liters of LN2. When the fill tubes are pointing parallel to the ground the tank will accept approximately 60 liters of LN2. The consequence of this difference is that a good portion of a maximal fill will spill on the ground if the dewar is re-oriented.

Although the expected minimum fill position is with the necks parallel to the ground (that is at the 3 or 9 o'clock position), experience has shown that the dewar will still spill nitrogen when rotated if filled at this orientation. Minimum fill is achieved with the necks nearly downward. The instrument could be filled at the 3/9 o'clock position if several hours of boiloff were permitted following the fill.

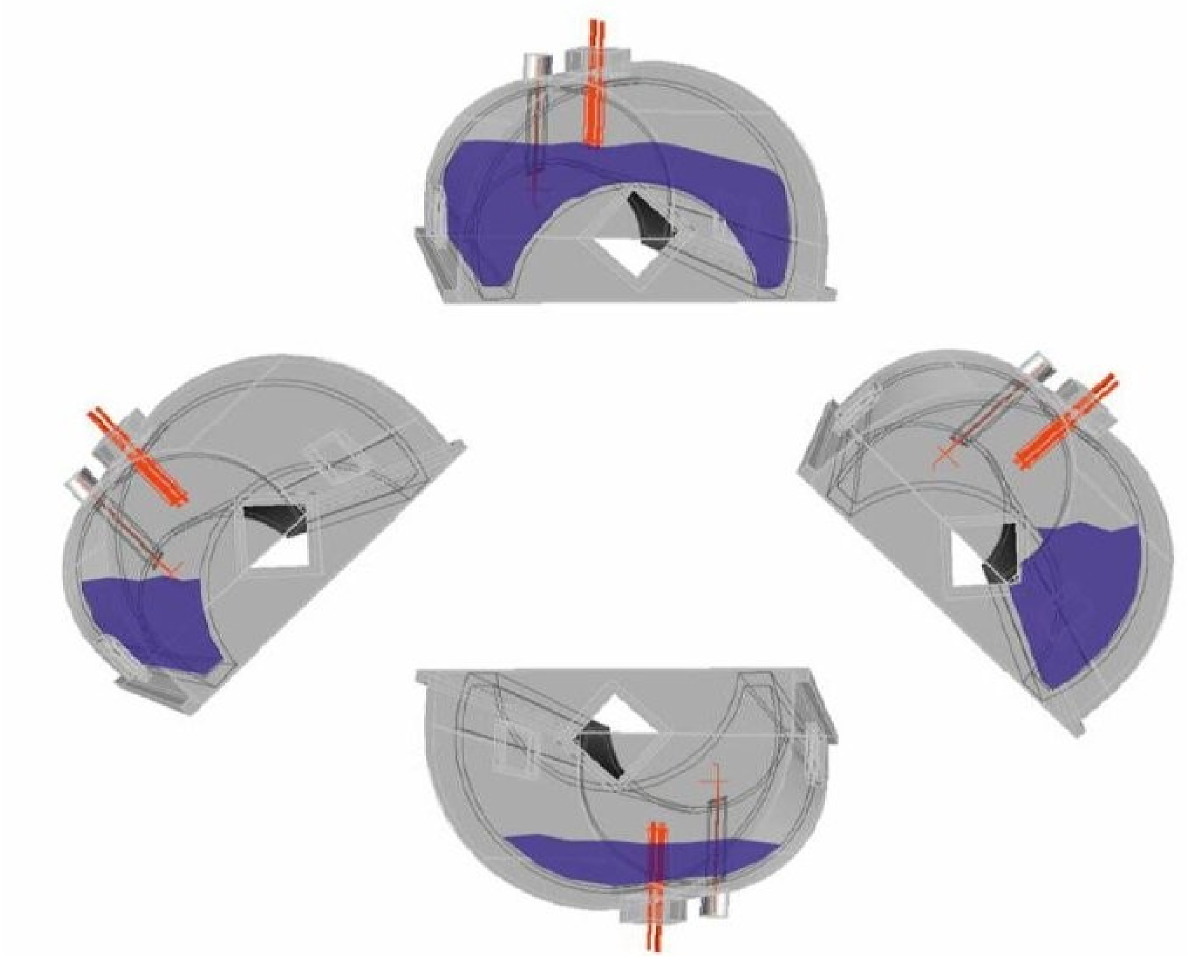

Figure 3 – Cryogen configuration and capacity as tank orientation changes. The main tank fill/vent tubes are highlighted in red.

Initial fill of the primary tank

When starting at room temperature, about 150 liters of LN2 are required for the initial fill of TripleSpec. With the custom fill hose connected to the (center) fill port and fed directly by a large LN2 storage dewar (Figure 4), it takes about an hour of filling before the cryogen reservoir begins to accumulate LN2. Another ½ hour is required to accumulate enough LN2 to last for 12 hours, another 30-45 minutes are required to fill the tank to the point where LN2 will spill out of the vent. Feeding the instrument with the full pressure of the storage dewar (20 psi) during the initial cooldown will only waste LN2. Experience has shown that the instrument cools just as quickly but with less wasted liquid if the fill occurs at lower pressure. There is no quantitative guideline for this pressure. However, a good guideline is that there is sufficient pressure when the outlet gas can be heard emerging from the dewar at moderate volume without being painfully loud (as it would with full storage dewar pressure behind the flow). Figure 5 shows the initial rate of nitrogen boiloff (in liters as a function of time). To ensure a complete fill the main tank should be filled initially until liquid emerges from the vent. After approximately 2 hours, when the rate of boiloff has decreased, the tank should be topped off.

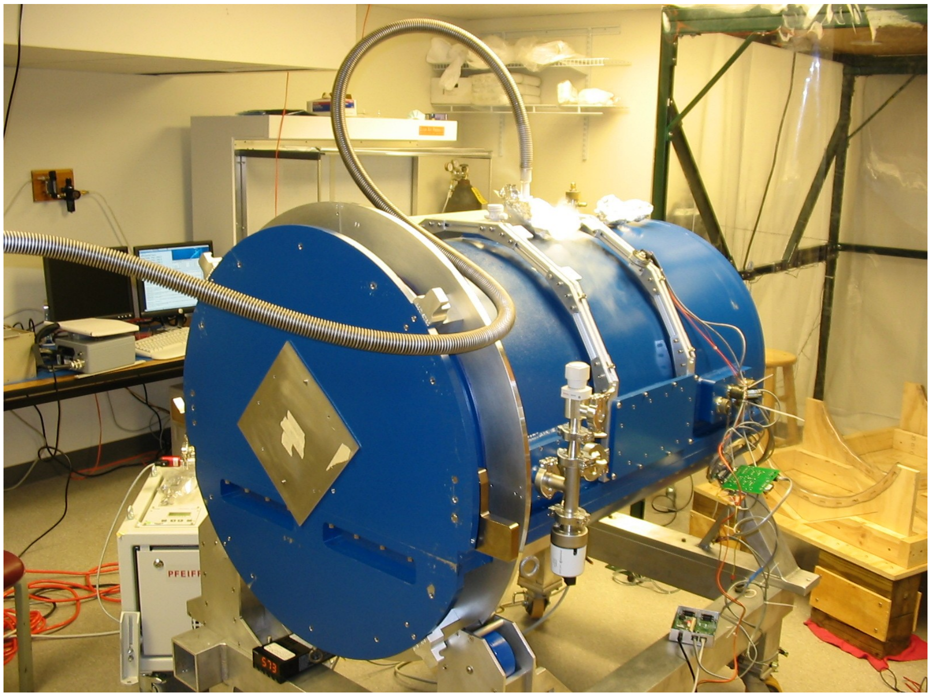

Figure 4: Fill hose connected to central vent tube for fill of primary cryogen tank.

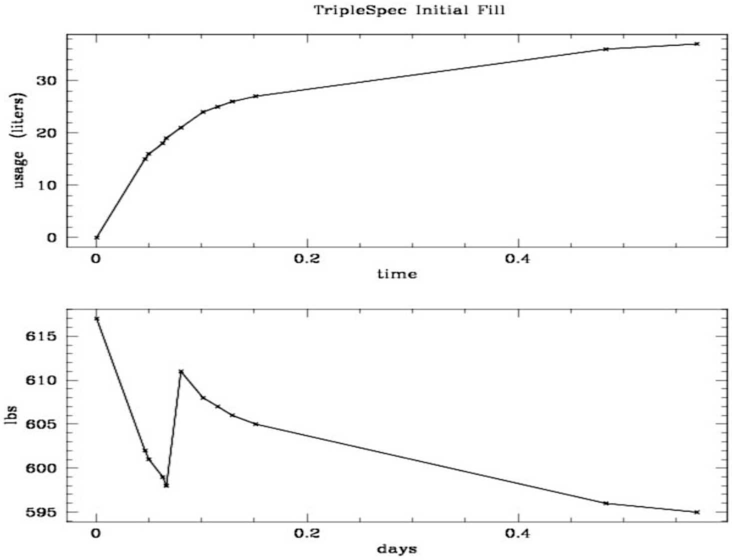

Figure 5: Nitrogen usage immediately following first fill.

The Auxiliary LN2 Tank

As described above, the auxiliary LN2 tank is significantly thermally isolated from the outside world. The tank, and the HAWAII-2 array connected to it by a robust copper heat strap (Figure 6), cool slowly if only the main cryogen tank contains LN2. This slow cooling is desirable as it protects the HAWAII-2 array from the thermal shock it would otherwise receive if liquid nitrogen were directly introduced to the auxiliary tank. After about 48 hours following the introduction of LN2 to the main tank the auxiliary tank will have cooled sufficiently that it is safe to introduce LN2 to the auxiliary tank. The fill of the auxiliary tank is accomplished with a funnel (and a little initial patience as the boiloff at the outset may be fierce). The tube on the funnel must extend to the bottom of the secondary cryogen tank. Initially, the rapid boiloff of the cryogen will prevent much LN2 from reaching the tank. With persistence the tank can be filled and will quickly stabilize at operating temperature. Once there, the boiloff is practically undetectable. Alternatively, the tank can be pressure filled, however at too high a pressure turbulence in the tank will lead to LN2 being blown out the vent as rapidly as it is introduced. The pressure fill should take place at pressure below 5(?) psi.

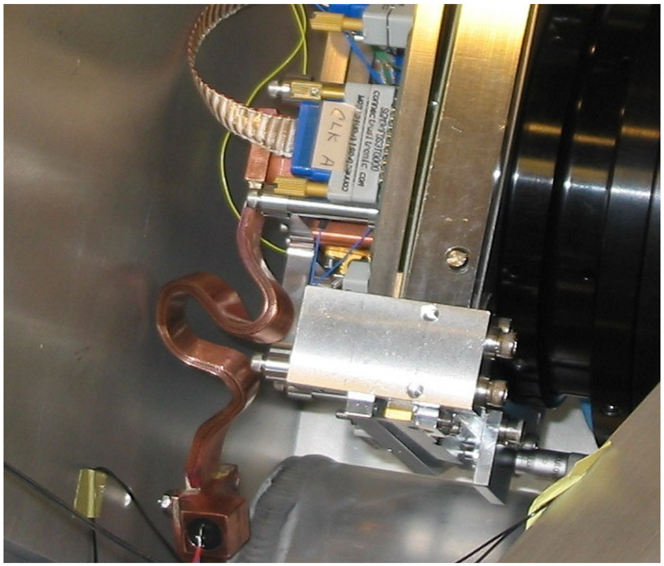

Figure 6: The connection between the auxiliary LN2 tank and the HAWAII-2 array consists of several sections of thin copper sheet brazed to mechanical connectors on either end of the cable.

Direct introduction of LN2 into the auxiliary tank will cool the array more rapidly than the recommended maximum rate of 1C/min. If the primary cryogen tank alone is cold, however, the HAWAII-2 array will cool slowly. *The auxiliary tank should be filled at least 24 hours, and preferably 48 hours after the primary tank fill to avoid thermal shock to the HAWAII-2 array.*

Temperature sensors and cooldown thermal history

Figure 7 shows a typical cooldown for the instrument. Plotted are:

- the dewar primary tank neck vent temperature (a sensor on the vent neck near where it emerges to the outside world) in blue.
- a bulkhead temperature (one of the main structural supports for the system's optics connected to the rails of the primary cryogen tank) in red.
- the slit-viewing HAWAII-1 array temperature in cyan.
- the auxiliary tank temperature in green.
- the HAWAII-2 array temperature in purple.

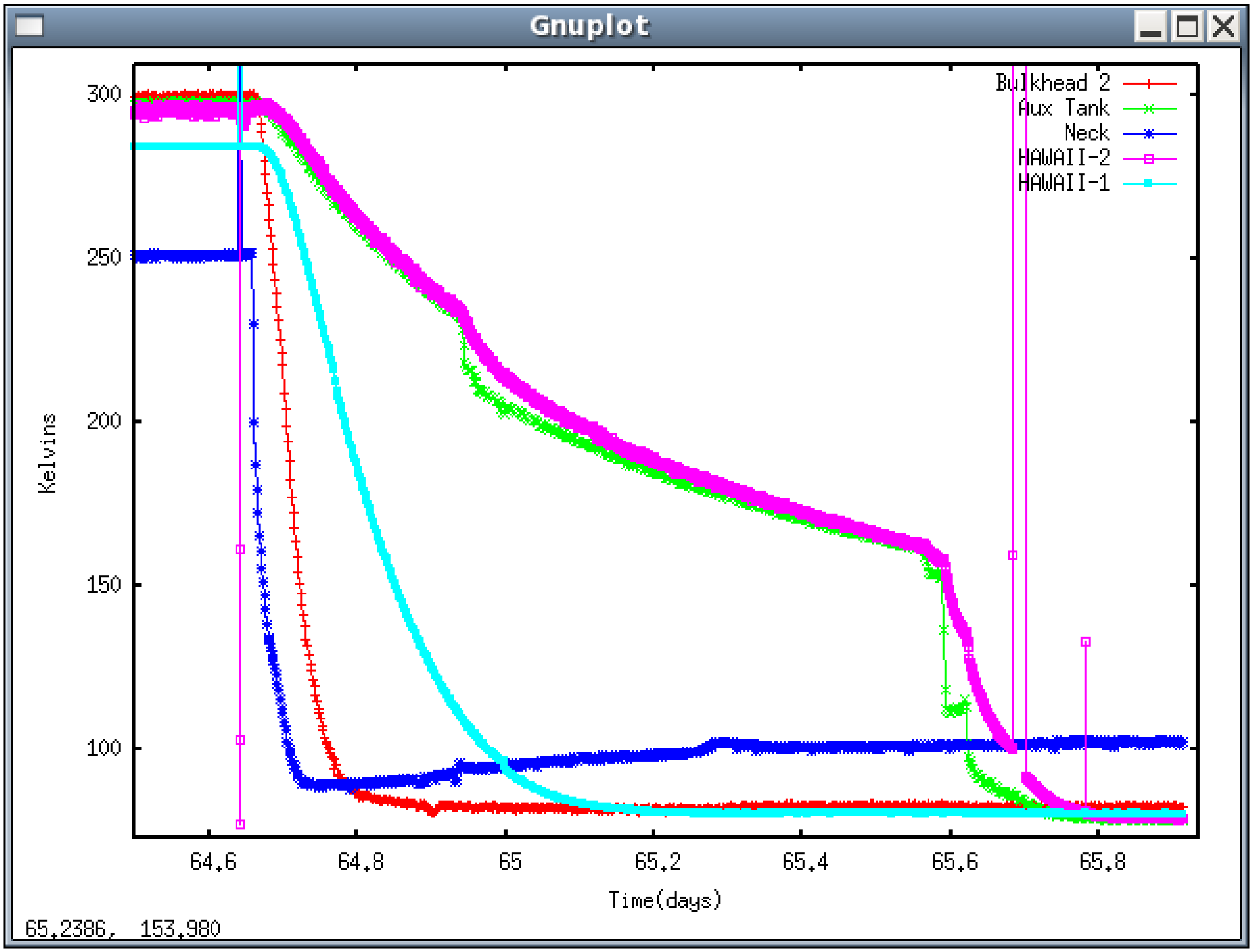

Figure 7: This plot shows several relevant temperatures during a cooldown. Nitrogen was first introduced to the main tank. The neck temperature sensor (blue) responds immediately to the flow of cold gas. Once the tank is “wet” the bulkheads (the main structural support for the internal optics) begin to cool and reach equilibrium fairly quickly. The thermal path to the HAWAII-1 (slit viewing / guiding) array is longer but still tied to the main tank, so it cools to operating temperature in about 12 hours. The auxiliary tank (green) and HAWAII-2 array (purple) are thermally isolated from the main tank. This arrangement permits a slow cooling of the HAWAII-2 array, well below the 1K/minute restriction. After one day the auxiliary tank was filled. In order to reduce thermal stress on the array the fill occurred in two steps. The first fill was just enough to wet the tank and then permitted to run out. After a short delay, the tank was then filled with a significant volume of LN2. The HAWAII-2 array reaches operating temperature within a couple of hours of filling the auxiliary tank.

Neck temperature: The rate of venting of gas from the primary cryogen tank determines the neck vent temperature. This sensor is a short distance from the warm exterior of the dewar and in the absence of cold gas flow it will reach a temperature significantly warmer than ambient liquid nitrogen temperature. The neck temperature drops most precipitously at the start of a cooldown since it is directly cooled by the rapid emergence of vent gas (Figure 8). Following a fill, the venting rate slows and the neck temperature sensor increases in temperature. This effect is the origin of the steady increase in neck temperature following the initial fill seen in Figure 8. Experience has shown that the vent rate slows as the main tank begins to run out of nitrogen, so there is a small rise in neck temperature prior to the full exhaustion of cryogen. On the right side of Figure 8 the neck temperature begins to rise as the cryogen begins to run out. The abrupt drop in neck temperature indicates a fill in progress after which the neck temperature returns to its equilibrium value. The spike in temperature after the fill likely resulted from someone capping the vent port and thus impeding the flow of cooling gas. When the main tank cryogen runs out the neck temperature rises abruptly (Figure 9 and discussed in more detail in the warmup section).

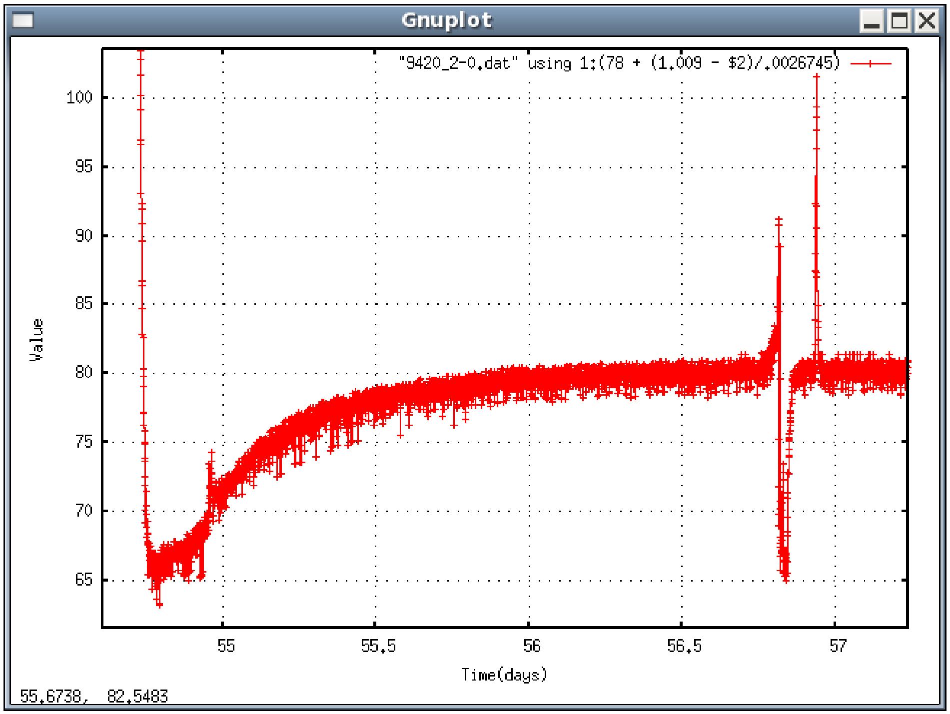

Figure 8: The neck temperature during the initial cooldown of the primary tank. The tank was permitted to run out (56.8 days) and then refilled.

Rotating the dewar sloshes LN2 onto slightly warmer surfaces of the cryogen tank. As a result the gas evolution rate varies causing variations in neck temperature. This variation occurs because portions of the tank not wet with LN2 will warm by one or two Kelvins when the dewar is held in a fixed orientation (one of the motivations for seeking the thermal stability provided by the secondary cryogen tank). When the dewar is rotated LN2 wets these warmer portions of the tank leading to a temporarily higher boiloff rate.

Bulkhead temperature: The optics of TripleSpec are supported on three connected plates referred to as bulkheads. These three bulkheads attach firmly to the cryogen tank along two rails that run the length of the interior volume of the dewar. Given this connection bulkheads (and most of the optics) cool rapidly reaching near-equlibrium with the LN2 after a few hours. There is a longer thermal path to the HAWAII-1 array and it cools more slowly, reaching a point where the array can be operated after about 8 hours.

HAWAII-2 temperatures and the auxiliary tank

The HAWAII-2 detector module is quite thermally isolated from the main cryogen tank, but directly connected to the auxiliary cryogen tank. In part this isolation arises from the need to protect the refractive camera optics from cooling too rapidly. Thus the refractive optics module is thermally isolated from its bulkhead attachment. The HAWAII-2 array attaches to the rear of these refractive optics. The only other direct thermal path to the HAWAII-2 array is a copper cold strap attaching it to the auxiliary cryogen tank (Figure 6). In the cooldown plotted in Figure 7 the HAWAII-2 array was permitted to cool slowly for a day via its weak connection to the primary cryogen tank. After that time the auxiliary tank was first marginally wet with LN2 to drop the auxiliary tank temperature by about 20K. After equilibrating further at this temperature the auxiliary tank was finally filled with LN2. This more gentle cooling was enforced in order to minimize the thermal shock to the HAWAII-2 array. The HAWAII-2 cooling rate should always be slower than 1K/minute.

Warming TripleSpec

Figure 9 below shows the warmup of TripleSpec in the lab over the course of 1.5 days. In the lab, bulkhead heaters were activated to shorten the time of the warmup. When no such urgency exists the system can be warmed passively, but over the course of several days. The only concern during warmup is that the auxiliary tank and attached HAWAII-2 array can serve as a cold sink for the system if they are not kept warmer than the rest of the system. A resistive heater is provided to keep the detector warmer than the environment.

In order to warm up the system, the auxiliary cryogen tank must first be emptied and heat applied to the auxiliary tank heater resistor. Liquid nitrogen can be purged from the tank by blowing dry nitrogen gas into one of the auxiliary tank neck vent ports at just a few PSI pressure. Upon applying pressure most of the remaining LN2 in the auxiliary tank will then flood out of the main aux tank fill tube. When the liquid flow stops the tank is mostly empty. At this point, power should be applied to the auxiliary tank resistive heater via the marked ports on the auxiliary electronics box (Figure 10). When the resistive heater is activated (maximum 30V into the 100 ohm load) the small amount of LN2 remaining in the tank will begin to boil rapidly producing a noticeable flow of gas, but yielding little temperature change at the auxiliary tank temperature sensor until the LN2 has fully boiled away. At this point the auxiliary tank will begin to warm until its temperature rises to about 20 degrees

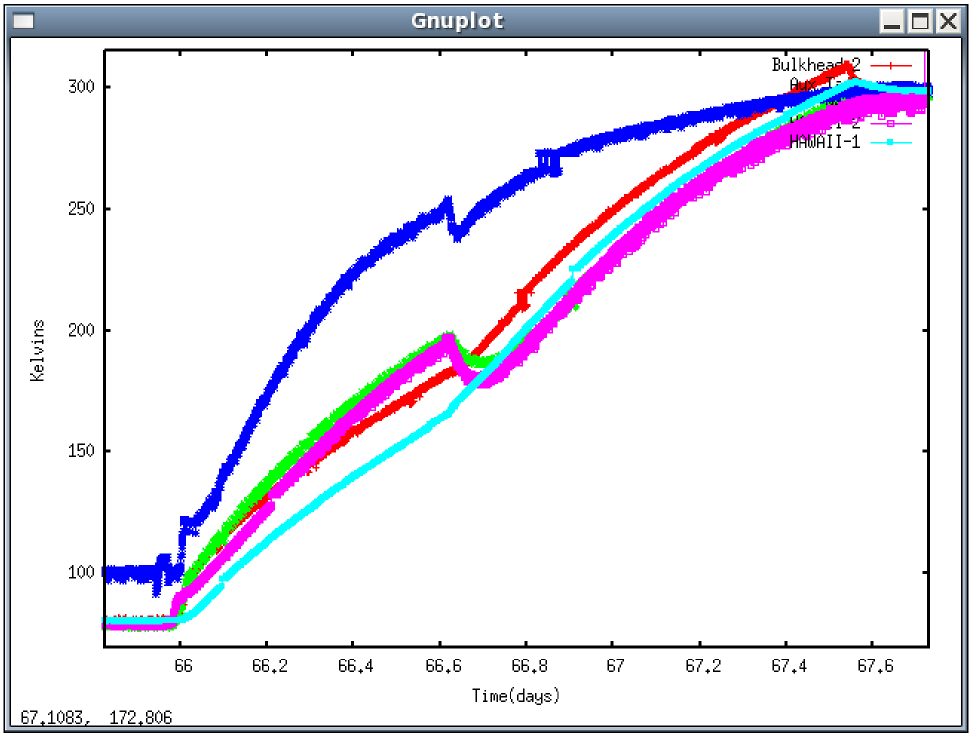

Figure 9: Warming TripleSpec in the lab over the course of 1.6 days. The main tank cryogen runs out and the neck (blue) warms at 66.0. Just prior to this the auxilary tank heater was turned on and the tank (green) and HAWAII-2 array (magenta) rise in temperature to exceed that of the main optics support structure (bulkhead2 – red). In this case, since the bulkheads were being aggressively heated, they temporarily exceed the HAWAII-2 temperature. By the time the getter gives up its gas (at 66.6) the HAWAII-2 array is safely warmer than the rest of the system. The released gas provides a thermal short between all mechanical components, so the HAWAII-2 temperature quickly drops to equilibrium with the rest of the system.

above ambient LN2 temperature. The system will reach an equilibrium here until the primary cryogen tank runs out of nitrogen afer a few days.

When the primary tank runs out of LN2 all temperatures will begin to rise.   Due to the thermal isolation of the auxiliary tank the bulk of the system will warm faster than the auxiliary tank and the HAWAII-2 array.   This situation is potentially dangerous to the array as it becomes the cold trap for gases released from the bulk of the system and from the activated charcoal getters (which are attached to the main bulkheads).   The auxiliary tank heater should be reactivated when the primary tank runs out of cryogen so that the auxiliary tank temperature (and thus the HAWAII-2 temperature) remains above the primary cryogen tank temperature until the getters release the gas they accumulated. This release happens around a primary tank temperatures of about 150K. Once this release happens, the thermal coupling of the gas keeps all of the surfaces in equilibrium. The heater is no longer required.

Current policy is that there is no need to pump on the system during warmup.

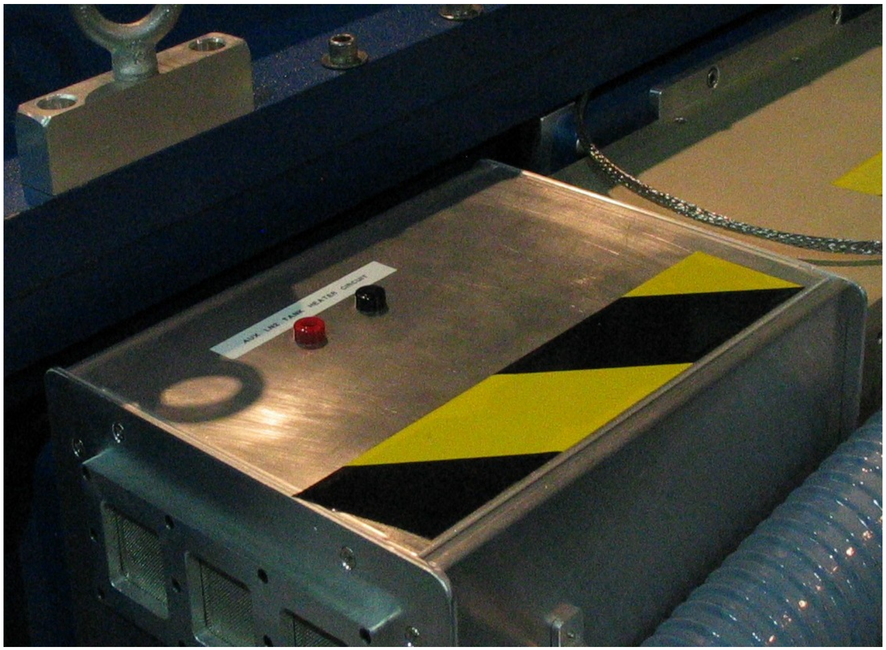

Figure 10: Banana plug inputs for the auxiliary tank heater. The heater is a 100-ohm resistor.

Vacuum Hardware

.

Vacuum Gauge (white cylinder in fig. 11)

- Pfeiffer Compact Full-range Pirani/Cold Cathode Gauge PKR 251
- Single Gauge Total Pressure Display and Control Unit TPG 261 located on the intermediate floor.
  - Connected via RS-232 interface to ICC computer. Dewar pressure reported in the Triplespec telemetry section of TUI (Inst --> TSpec --> Environment)

Ion Pump (black box in fig. 11)

- Varian Vacion Plus 20 Starcell Ion Pump w/ Ferrite Magnets (Model No. 9191145). Rated for 20 liters/sec pumping.
- MiniVac 120V controller (Model No. 9290101) located on the intermediate floor.
- Pressure is read out manually using current displayed on the controller and pressure v. current chart (see figure 12 for pressure vs. current conversion).
  - Usually the ion pump should be started once pressure < 10-4 Torr but the unit can be operated at a maximum pressure of 5 x 10-2 Torr.

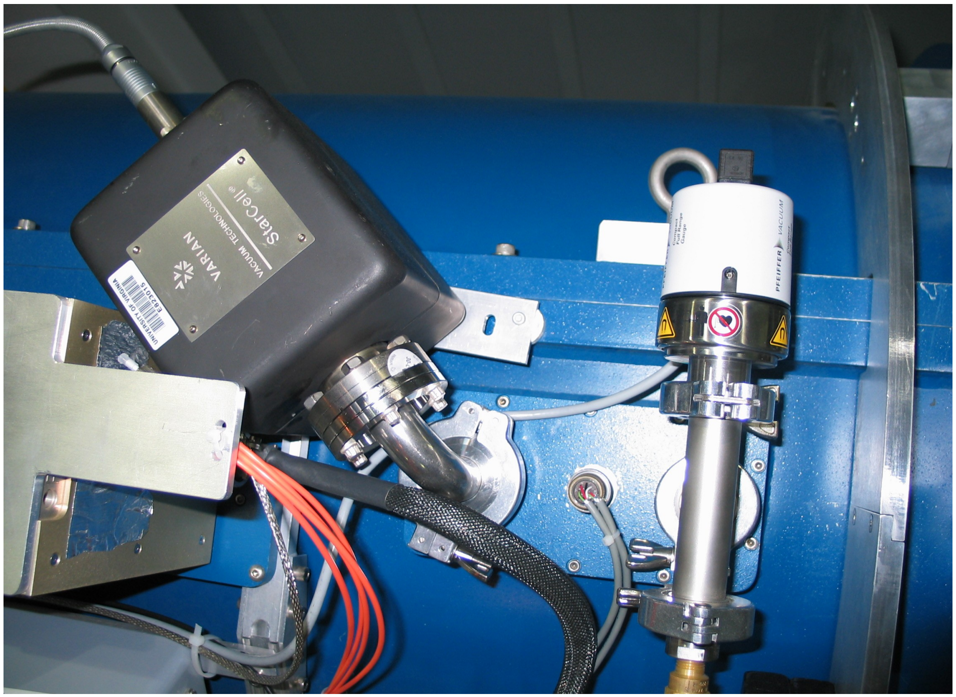

Figure 11: Vacuum hardware mounted to TripleSpec. The Varian ion pump is the black box to the left. The Pefeiffer full-range vacuum gauge is the white cylinder on the right.

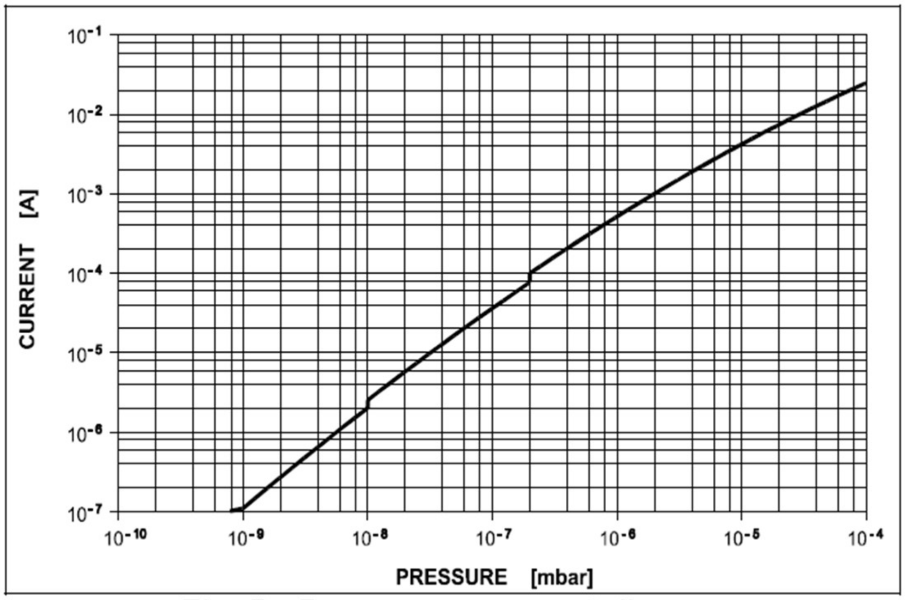

Fig. 5 - Pressure vs current diagram

Figure 12: Ion pump pressure vs. observed current conversion.

Normal Dewar Warm-up

1. Turn off power to both Leach power supplies. Intent is to remove risk of damage to detectors if condensation ever forms inside the instrument.

2. Turn off slit rotation power on the auxiliary box.

3. Turn off power to ion pump.

4. Discontinue filling of main tank.

5. Purge Auxiliary Tank of remaining LN2 using GN2 blown in (using no more than a few PSIG) at one of the 1/4" NPT threaded holes on the side of the aux tank neck, with the neck top-cap removed. Try this initially with necks-up (how it was done at UVA). It may also work in other orientations.

6. Apply <= 30VDC using a DC Power Supply across the banana plugs labeled for auxiliary tank heaters on the back right side of the instrument. This applies DC voltage across a 100 ohm, 10W, resistor bolted to the auxiliary tank. Since the spectrograph detector is strongly thermally coupled to the auxiliary tank, this will heat the detector. Monitor auxiliary tank temperature using TUI while doing this. Temperature rise will not occur until all LN2 has boiled off within the aux tank. The temperature rise should be no faster than 1K/min to avoid thermal stress on the spectrograph detector. The intent is to boil off the remaining LN2 in the auxiliary tank and start increasing the temperature of the spectrograph detector so it has the highest temperature during warm-up so that it cannot serve as the system cold sink for condensation of gasses.

7. Continue to apply modest heat (approx. 10-20 VDC) to the aux tank heater as necessary to keep the aux tank temperature well above the bulkhead temperatures until the aux tank temperature reaches approx. 200K. We want the spectrograph detector to be at this temperature when the bulkheads reach 140-160K, the temperature at which getters (bolted to the bulkheads) release trapped gases.

8. Monitor temperatures and vacuum until all temperatures are close to 293K (well above freezing) to prevent forming condensation on any optics/detectors upon opening the instrument to atmospheric pressure. Hold-time for the main tank is approx. 6 days so full warm-up could take well over a week.

9. Bring Dewar to atmospheric pressure by backfilling with GN2 using the needle valve in the TripleSpec closet mounted to the unused KF-40 valve adjacent to the gate valve. Monitor the vacuum to set a good pace for Leak-up. Goal is to avoid large movement of gas so leak-up at a pace that requires at least 1 hour or more to go from full vacuum to atmosphere. Take care to purge the needle valve vacuum fitting with GN2 prior to securing the KF fitting to minimize exposure of air to the system when valves are opened.

10. Open Dewar if necessary. Minimize time that instrument is at atmospheric pressure with vacuum fittings uncovered on dome floor to reduce susceptibility of debris entering the instrument.

11. TripleSpec uses charcoal getters. There is no need to bake the getters as they will re-generate at room temperature.

Normal Dewar Cool-down (starting with warm dewar)

1. Pump Dewar at Gate Valve until Vacuum is <= 5e-5 Torr.

2. Fill main tank with LN2 using the custom fill hose attached to a large storage dewar. A full storage dewar should be used for the initial fill as at least 150 liters will be necessary. Try to reduce the fill pressure below 20 psi to avoid wasting LN2. During an fill, including the first, the main tank exhaust neck cap should be removed to allow release of rapid boil-off/vent. After approx. 1 hour the dewar will wet and after another 30-45 minutes the dewar will be filled as indicated by spurting LN2 from the vent.

3. Top off the main tank after about 2 hours since even a full tank boils off quickly at this point and a second fill is required to hold, for example, overnight.

4. Monitor vacuum and temperatures using TUI.

5. Re-fill main tank the next day. The main tank exhaust neck cap should always be removed for a fill as well to allow release of rapid boil-off.

6. Wait at least 24 hours and preferably 48 hours after initial main tank fill before filling the auxiliary tank. The intent is to let the main tank slowly cool the spectrograph detector with its weak thermal connection as far as possible toward 77K before filling the auxiliary tank. This precaution is in place

because the aux tank is robustly coupled to the detector and we wish to minimize thermal shock to the detector. The spectrograph detector temperature should never change faster than 1K/min. To fill the aux tank use a funnel with a fill tube that reaches to the bottom of the tank. First fill just enough to wet the tank and permit this LN2 to run out. After a short delay fill with a significant volume. Taking this approach will protect the detector from thermal shock by decreasing the aux tank temperature in two stages. The green curve in Figure 7 shows the aux tank cooled in tis manner. After the passive cooling a small amount of LN2 was added to make up about ½ the remaining difference to 77K. After a pause the tank was filled completely.

7. Turn on the Leach power supplies once temperatures for their respective detectors are < 90K. Detector should not be energized above this temperature as is common practice with CCD's. The slit viewer detector, coupled to the main tank, should be cold within about 12 hours of initial fill. Obviously the spectrograph detector won't be fully cold until after cryogens are introduced to the auxiliary tank 48 hours after initial fill.

Vacuum Alarm

1. Turn off both Leach power supplies. Intent is to remove risk of damage to detectors if condensation ever forms inside the instrument.

2. Turn of the slit rotation power on the auxiliary box.

3. Turn on ion-pump using ON/OFF switch on MiniVac controller on intermediate level. Usually the ion pump should be started once pressure < 10^{-4} Torr but the unit can be operated at a maximum pressure of 5×10^{-2} Torr. Compare vacuum readings between main gauge and ion-pump to verify gauge is working properly.

4. Rotate instrument so LN2 necks are pointed down (to facilitate dumping cryogens if necessary).

5. Connect observatory turbo pump to Triplespec gate valve and start pump as soon as possible. Open gate valve to instrument as soon as pump pressure is <= 1e-6 Torr.

Notes:

At what vacuum level (if verified true) do we warm up or place on vacuum pump or just turn on ion pump and let it work?

We don't have a long enough history to know the pressure rise over a year of service through o-ring diffusion. But early indications are that cryopumping capacity from the main tank and the charcoal getter should give a one year service time. The vacuum alarm is set to 1 e-5 Torr. At this time we wish to treat vacuum alarms on a case by case basis under the assumption they are indicative of a leak or gauge malfunction and not a getter in need of regeneration. Accordingly, we prefer the ion pump be used as a back-up gauge and emergency pump and not as a means of handling day-to-day o-ring diffusion.

Temperature Alarm

1. Check that Dewar vacuum is OK. If not then vacuum alarm should have gone off. Do procedures for vacuum alarm.

2. Boil-off temp too high? Possible causes:

   - Main tank fill neck cap inadvertently left off.

   - Main tank cryogens have run out.

3. Auxiliary tank temp too high? Possible causes:

   - Auxiliary tank cryogens ran out. Check level with dip-stick.

     If the auxiliary tank is empty and the aux tank temperature is above the nominal
       - *the observer should be notified immediately,*
       - *observations should be suspended as soon as possible and the tank should be refilled.*

     Rising detector temperatures will lead to increased dark current with substantial non-uniformity across the array. Data quality/SNR will be severely compromised. Temperatures drop quite quickly once the tank is filled and observations can resume within 15 minutes.

4. See notes below to decide course of action.

Notes:

At what temp (main and/or aux) is too warm to just add cryogens and we must then start warmup ?

If the main tank temperature (as indicated by the bulkhead [BH] sensors) is above approx 120K. The instrument should be warmed to near room temperature, re-pumped, and then re-cooled. Above this temperature the charcoal getter will start to release adsorbed gases into the cryostat. The fear is that these gases can then condense onto the possibly colder spectrograph detector since it is tied primarily to the aux tank which may still be cold.

Of course as these adsorbed gases are released the pressure will rise. These gases should be removed from the system and the getter allowed to fully regenerate (by warming up to near room temperature) before cooling down. In this scenario the aux tank should be purged of remaining LN2 immediately and the aux tank heater activated so the aux tank temperature is greater than or equal to the rest of the instrument.

If the main tank temp is approx. 77K but the aux tank has run out of LN2 the aux tank temp will naturally stabilize at approx. 110-120K through radiative coupling with the rest of the instrument. The aux tank can be cooled down again following the procedures in the Care & Feeding document for a first fill (which are intended to slow the cooling rate of the spectrograph detector as much as possible).