Fall 2006 – cryogenics on the GBT

During Mustang's time on the telescope in the fall of 2006 over 12 hours of observation time was lost due to warm cryogenics. A combination of reduced pulse tube cooling power and a hanging heat capacity led to very long system recovery times after the telescope was pointed at low elevations. Throughout the run, cryogenics were monitored constantly and archived along with helium pressure and GBT elevation. A number of tests were carried out. Our main conclusions are:

- A large thermal mass is loosely coupled to the array which adds several hours of additional cool down time after a cycle is completed. Tests back at Penn indicate this was caused by a poorly heat sunk .3K bandpass filter and spring washers will be added next time the filter is installed.
- When cold on the telescope, the pressure differential across the PT405 was only 195-210 PSI. In the lab nominal operation is 230PSI. Increasing the absolute value of the pressures helped compensate for the reduction in mass flow but a better solution is needed.
- A large buffer volume in the helium lines at the return side of the PT405 is essential. Restrictions here greatly reduce the cooling capacity of the cold head.
- Contamination was a problem for the majority of the run. It is likely that impurities were introduced when topping up He pressures and improved procedure should eliminate this problem. Cooling capacity was increased by a factor of ~3 after a thorough cleaning of the cold head.
- Internal temperature variations are large. Faster thermometry and stabilization (active or passive) would be useful but not essential.

Each of these is discussed in more detail below.

The hanging heat capacity

The hanging heat capacity first appeared at Penn after modifications of the cryostat done in accordance with the recommendations of the IPR panel. While these were all very insightful suggestions, multiple parameters were changed in a single cool down, resulting in degeneracy in identifying causes of new phenomena. These changes included the replacement of a .3K bandpass filter (which had delaminated), the removal of Nyquist inductors, and potting of tekdata cables in the detector package in Eccosorb to mitigate possible RF. Cool downs before and after these changes are shown in Fig1. After cold modifications, an additional 3 days of repeated He3 cycling was necessary to cool down the array.

The system's response to applied heat on the array and the He3 evaporator showed that the effect was due to a large loading of 1–2mW and not a poor thermal link. This was further confirmed by the short hold time of the He3 fridge. Thermal shorts and optical loading were ruled out leaving an object of high thermal mass with a very poor thermal link to the array as the only option. Due to its ferrous composition, the Eccosorb was our primary suspicion (Fig. 2). Between the first cool down after the changes (at Penn) and the next cool down (at Green Bank), the thermal sinking of the Echosorb was improved, however little improvement in the cool down time of the array was observed. Due to unrelated problems with the detectors, Mustang was warmed up again. The Eccosorb was removed but no improvement was seen. We now suspect the thermal sinking of the 0.3K bandpass filter. Its installation is the only modification made to the .3K system which has not been ruled out as the culprit. Rough calculations of time required to cool down a mass of plastic with poor thermal contact by this system yield appropriate numbers.

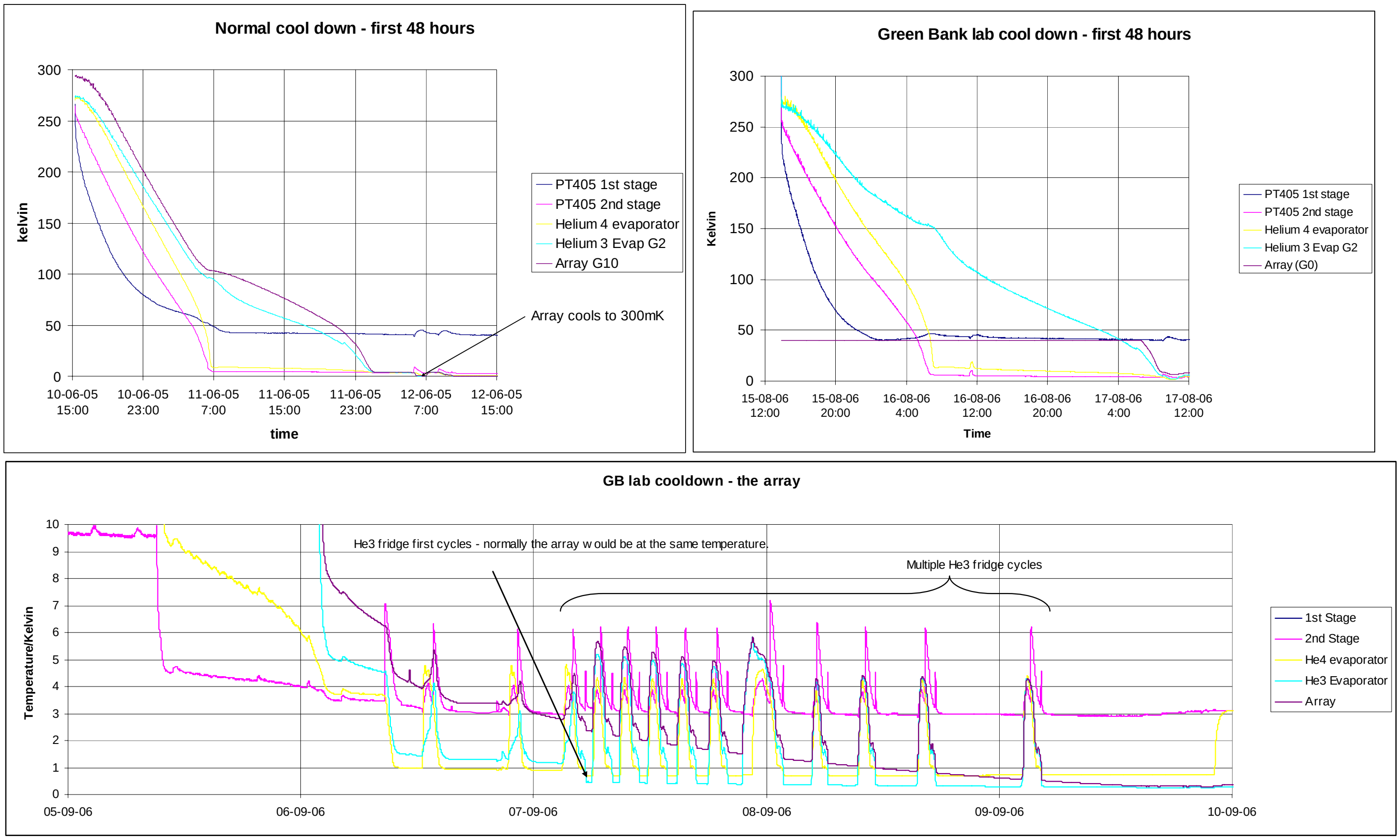

Fig 1 : Cool downs before and after modifications to the array package and the move to Green Bank. The PT405 cooled quicker at Penn using the Cryomech compressor and ¾ inch hoses as opposed to the GB compressor and ½ inch hoses. In addition, at Penn, the array first cooled to below 0.3K 40 hours after the cool down started. With the hanging heat capacity, 3 days into the cool down, the array had not cooled below 2.5K even though the He3 fridge had first cycled 54 hours into the cool down. It took 5 days and many cycles of the He3 fridge for the array to cool down to 0.350K.

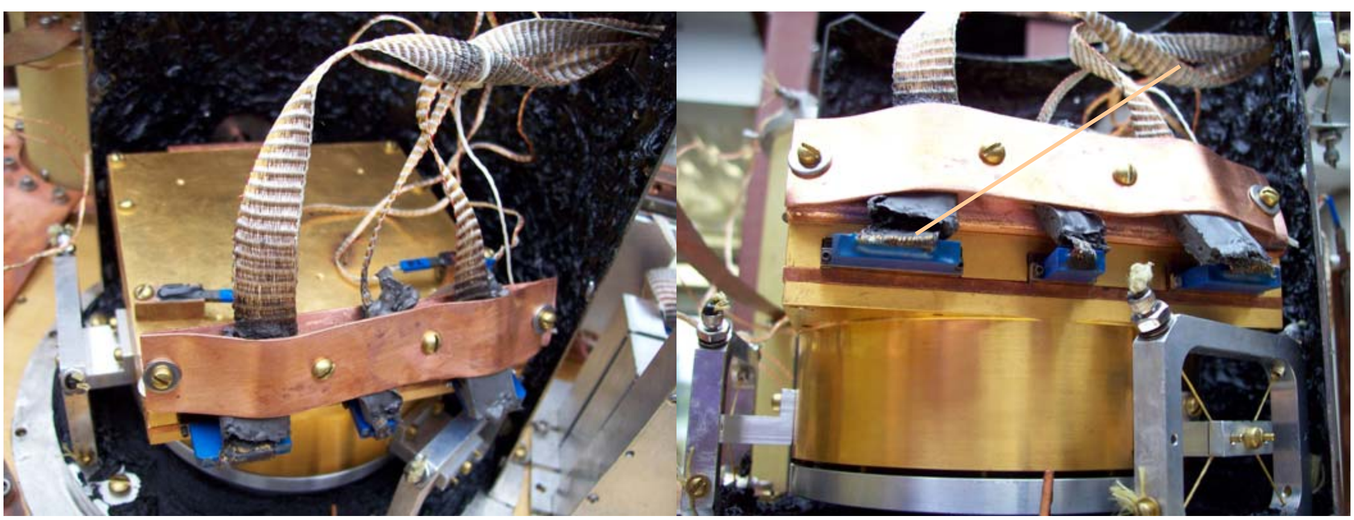

Fig. 2 : The eccosorb and its heatsinking after improvements had been made.

Observing time had already been lost and any attempt to fix this hanging heat capacity would have taken at least 5 additional days. Therefore, the decision was made to go on the telescope without mitigating this problem. Once cooled, the hanging heat capacity had no effect, however when the GBT was observing at low elevations (pulsar people?) the cryogenics warmed up. If the system was warm for more than a couple of hours the array would be at 500 to 900mK after the He3 fridge cooled and would take 1-8 additional hours to cool to the point where it could be operated. Due to the reduced cooling power from the PT405 (see below) the array spent more time warm than we anticipated and the hanging heat capacity proved to be a considerable problem.

Since returning to Penn a run of dark tests has been started with the 0.3K filter replaced by a metal plate. The Hanging heat capacity went away confirming our analysis. The addition of spring washers and the use of a little more grease should solve the problem next time the filter is installed.

PT405 performance.

The cooling power of the pulse tube is important for three reasons: More cooling power means faster recovery from low elevations; capability to go to lower elevations before warming begins and lower base temperatures are achieved. A colder baseplate is necessary for optimum performance of the series array and longer hold times of the fridges. In the lab at Penn the PT405 2nd stage operated below 2.8K and cooled from 15K in about 45 minutes. At Green Bank this performance was not achieved, either in the lab or on the telescope. The causes of this turned out to be many.

Helium pressure

At Penn before coming to Green Bank, with 20 foot long ¾ inch hoses the gauges on the front of the compressor (when the system was cold) typically read 300/70 psig (supply/return). This is consistent with the recommendations of Cryomech (a 230 to 250 psi differential). When the pulse tube is warm the differential and pressures can be much higher (375/100). On the GBT the supply and return pressures are monitored in the receiver cabin. The gauges seem to be a little off - when attached to a dormant Penn compressor both gauges read 200psi on the compressor, the gauges at the top read 209/218psig (supply/return). Initially at Green Bank, Mustang was run off Green Bank compressors with pressures of 280/90psig. The effects of topping up the pressure are shown in Fig. 3. A great increase in cooling power (due to an increase in mass flow) is observed. However, once cold, the differential pressure returned to the same range (195-205psig), not enough to get the full cooling power from the PT405. On the 6th October the cryomech compressor was installed on the GBT however little increase in performance was seen and typical pressures at the compressor were 300/100psig, similar to the Green Bank compressor and consistent with the readings in the receiver cabin.

Line thickness

The decrease in the performance of the cryomech compressor on the GBT is thought to be due to the very long lines. Most of the length is ¾ inch welded tubing but there are short lengths of flexible ½ inch tubing at the elevation axis and the turret wrap. It was found that replacing the flexible pipe on the return side that went from the center of the turret to the cryostat with a much longer ¾ inch hose significantly improved performance, but no further improvement came from bypassing the long 0.5 inch hose in the wrap. According to engineers at Cryomech, a bigger compressor may be necessary to obtain a 250psi differential on the GBT. Tests in the Penn lab with added restriction to the He lines simulating the GBT environment will be carried out upon return. A bigger compressor can then be tried to see if this restriction can be overcome. Cryomech has offered to lend us such a compressor but we may try using ACT's or building one ourselves.

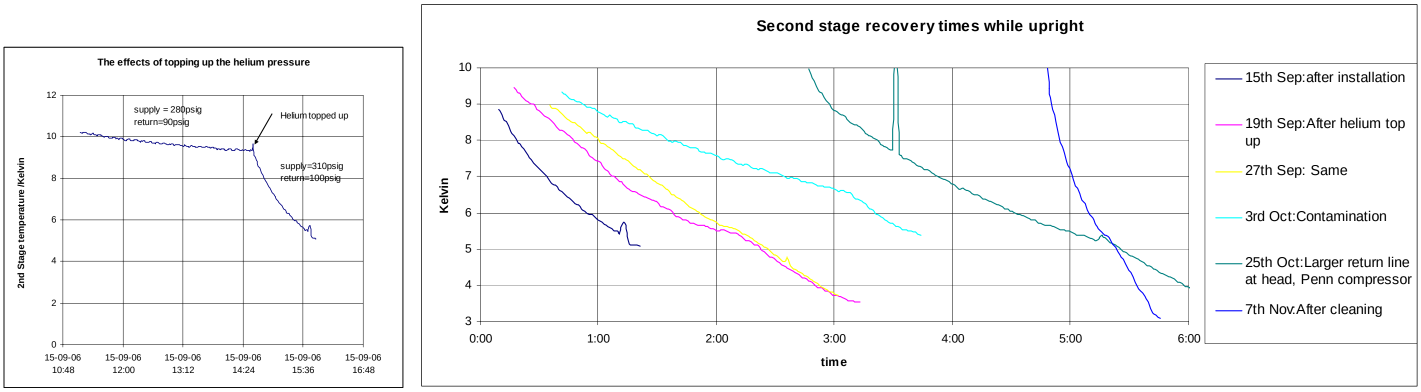

Fig. 3: The effects of topping up the helium pressure and the performance of the PT405 on the telescope at different dates during the run. Exact comparisons are hard as conditions such as the helium pressure in the lines vary with ambient temperature and the temperature of the PT405. However from when it was put up there was a clear degradation in performance over time. Large improvements were made by topping up the helium pressure, replacing the thin return line near the cryostat and by cleaning out the head.

Contamination

Although much less severe than the run in fall 2005, there was a marked decrease in the performance of the pulse tube with time. Base plate temperatures of both stages increased in a manor typical of contamination. At the end of October, the head (at 290K) was cleaned using the ‘pump and purge’ method. The system was cooled down again and a large increase in performance was observed. The improvement was substantial enough to conclude that the system was indeed contaminated. Early on in the Green Bank run, procedures for topping up helium pressures were less strict and contamination is likely to have been introduced here. Full ‘pump and purge’ along with 99.9999% gas will be used as standard procedure in the future.

Back at Penn

On returning to Penn the cryostat was cooled beck down with the detectors in the dark for further detector tests. Once cold, the low pressure helium supply was still high at 100psig and the supply side. Tip tests were carried out with the cryostat tipped over by 72 degrees for a set time before being returned upright. The longer the time spent tipped over the hotter the 1st stage gets and the slower the cooldown. When the cryostat was tipped over for long enough to warm the 1st stage up to 98K then a similar cooling rate to the 7th November on the GBT was observed (which was after the head had been cleaned). This implies that the high return pressure is still a problem and something is now wrong with the compressor. Before this could be diagnosed the motor in the head of the pulse tube broke and the whole system is now at Cryomech for repair. Should higher pressures and better cooling curves be observed once the compressor is returned then tests will need to be carried out to see if larger diameter lines are needed on the GBT (or a larger compressor). This could involve running the head in a small cryostat on the GBT and if decreased performance is seen running the head in the lab with restrictions in the pipes and testing a bigger compressor.

Temperature stability.

Most of the time on the telescope, the Helium 3 and 4 fridges were cycled using a quicker than nominal cycle. The lifetime of the cycle depends strongly on the elevation of the telescope as controlled by random observers. Several cycles were observed in which the He3 fridge lasted over 24 hours and the He4 fridge up to 19, performance similar to the lab. Most cycles were ended by the 2^{nd} stage warming above 10K for a non-negligible period. He3 lifetime was often shortened by excess loading from the hanging heat capacity. Until the trigger point for starting the He3 autocycle was increased to 1K, cycles were often triggered before the He3 fridge ran out. These effects emphasize the necessity of improving the performance of the pulse tube. By far the shortest cycles occurred when performance of the pulse tube dropped. Once the pulse tube had been cleaned, recycling could be carried out with the telescope tipped at elevations less than 40 degrees.

Large drifts in the temperature of the 1^{st} stage of the pulse tube occur with elevation and this has some effect on the data. While observing, 0.3Hz data were taken on single thermometers. The only noticeable feature was a ~20 second oscillation in the PT405 2^{nd} stage. This is almost certainly the aliased 1.4Hz fluctuations from the pulse tube. Some form of temperature control with elevation would enable observations at lower elevations (<30) to be unaffected by the performance change of the PT405. This could be in the form of a helium bath at the end of the PT405 which would massively damp 1.4Hz oscillations and heaters to take out slow drifts. Faster temperature monitoring would be of great benefit and will be looked into.