The LINC-NIRVANA IR cryostat

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ABSTRACT

The MPIA is leading an international consortium of institutes building an instrument called LINC-NIRVANA[1]. The instrument will combine the light from the two 8.4 m primary mirrors of the LBT. The beam combiner will operate at wavelengths between 1.1 and 2.4 microns, using a Hawaii2 detector. A volume of about 1.6 m high with a diameter of about 0.65 m is required for the cold optics. The size of the instrument and the high requirements on vibrations brought us to a new approach for the cooling of the cryostat, which has never been tried in astronomy. The cryostat will be cooled by a flow of Helium gas. The cooler which cools the gas will be placed far away on a different level in the telescope building. The cold helium will be fed through long vacuum isolated transfer lines to the instrument cryostat. Inside the cryostat a tube will be wrapped around the mounting structure of the cold optics. The first hardware arrived at the MPIA in 2005 and the system will soon be tested in our labs.

Keywords: IR instrumentation, cryogenics, closed-loop cooling

1 INTRODUCTION

Using Gifford McMahon (GM) coolers is a common method to cool an IR instrument[2]. Nevertheless, the low frequency vibrations are not easy to damp. Interferometric instruments have the highest requirements on vibration stability. Using an industrial Stirling cooler with high cooling capacity far away from the instruments, transfer lines along the telescope, and a heat exchanger for 60 K Helium are technical challenges. This article shows our solutions in detail for this unusual method of cooling.

2 THE STIRLING COOLER

2.1 History

The Stirling cycle is a thermodynamic closed cycle that was invented in 1816 by a Scottish minister, Robert Stirling. It was used in the so called hot air engine, which was considered at the time to be capable of replacing the steam engine. This was partly because the boilers used in early steam engines were prone to explosion.

The counterpart of the hot air motor, the refrigerator, was first discovered in 1832. In 1938, Philips Research Laboratories was looking for a means of generating electricity to power radios in remote areas, where there was no electricity supply. The practically forgotten hot air motor attracted attention. In 1946 Philips started studying the cooling techniques used in the Stirling cycle. The result was the development of the cold gas refrigerator which is nowadays mainly used for liquefying air or Nitrogen[3].

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2.2 Principle of operation

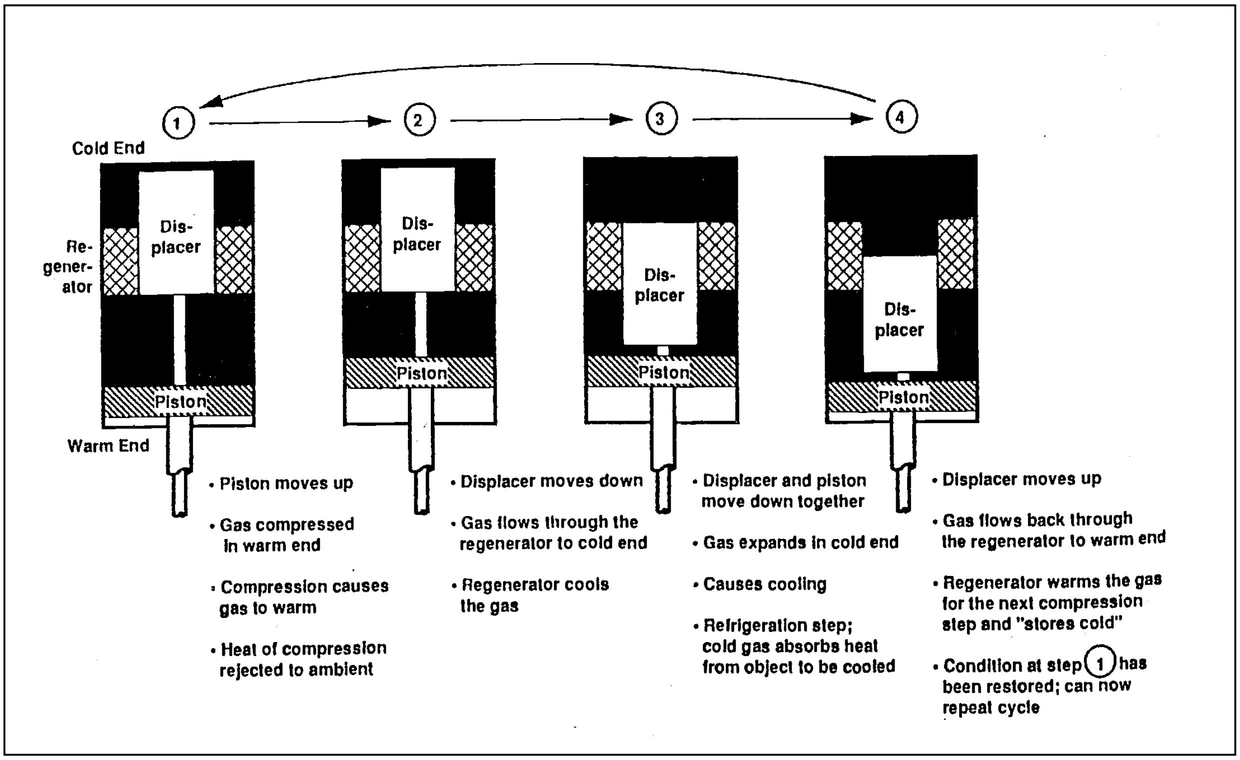

Figure 1 principle of the Stirling cooling cycle[4]

2.3 Dimensions

Stirling coolers are build in two sizes, very small and very big. The small ones are used for IR detector cooling or other small things, where only about 1 Watt of cooling power is needed. The very big ones are used for liquefying air or Nitrogen. This is the size of cooler we use. It is a one-cylinder machine with a 15 kW motor. Beside the cooler we need space for the following parts:

- 50 l Helium bottle for refill of eventual loss of gas (see figure 2)
- 50 l bottle as a buffer volume for the Helium working gas of the machine (see figure 2)
- A buffer volume of 1200 l for the gas volume of the transfer lines, here we use 2 bundles of Helium gas bottles (see figure 4)
- Electronic rack with frequency converter (see figure 2)

The cooler together with the electronics will be built in a housing for noise and vibration reduction, as well as for temperature stabilization (see figures 2 and 3)

2.4 Temperature control

The temperature of the cryostat will be controlled by the cooling power of the Stirling cooler. From the cryostat the cooler gets a temperature sensor signal which is used for the control loop. The cooler can reduce its cooling power by changing the rotation speed of the motor or by changing the pressure of the working gas. The quickest change comes from the rotation speed, which can be varied between 900 rpm and 1500 rpm. This results in a change of cooling power of about 40%. Changing the working gas pressure is a very slow control. The maximum pressure 30 bars gives the maximum power, which can be reduced by 40% at 18 bars. Both loops can reduce the maximum cooling power by about 60%.

The first results with a test cryostat showed that a stability in the range of ±0.2 K is easy to reach. With the final cryostat we can optimize the control parameters and it should easily be possible to reach a stability better than ±0.1 K.

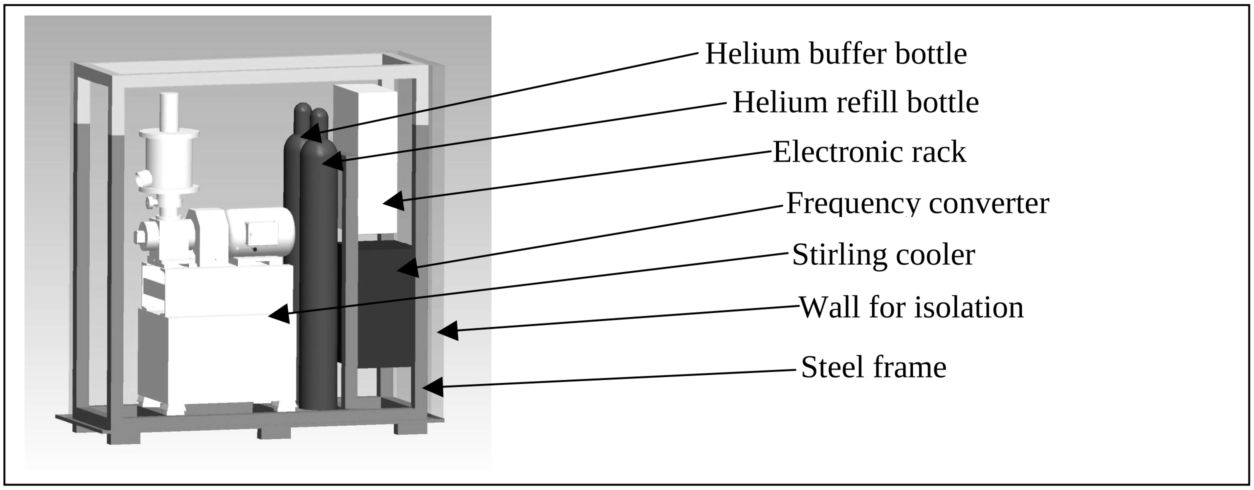

Figure 2: Stirling cooler with housing, walls removed

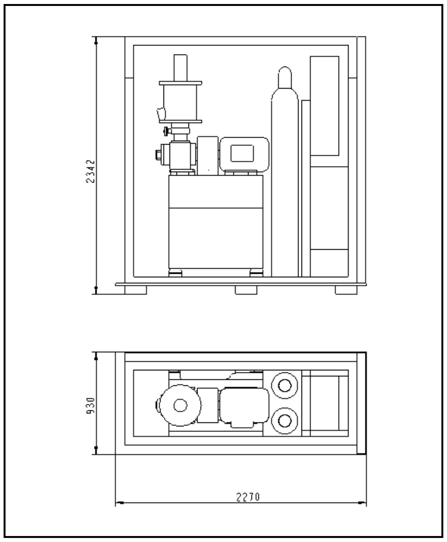

Figure 3: dimensions of the housing

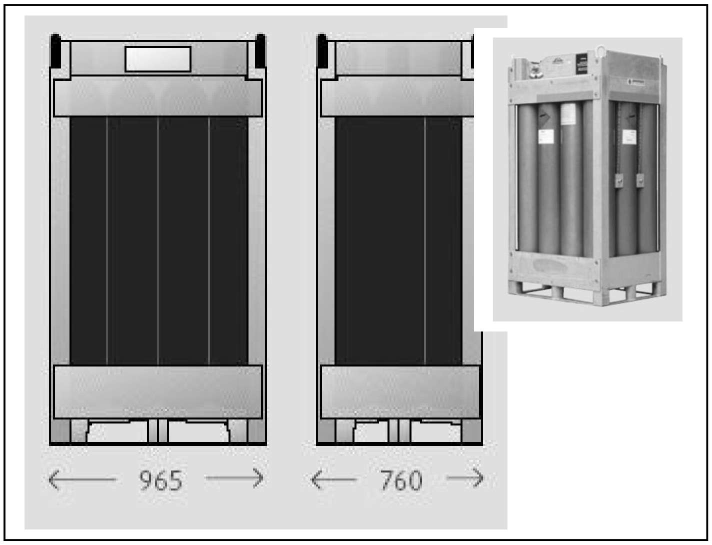

Figure 4: dimension of the Helium buffer

3 CRYOSTAT

The cryostat consists of a heat exchanger which is build in a vacuum can. The heat exchanger is connected to the vacuum can with spacers from glass-fiber reinforced plastic. Radiation will be reduced by using multilayer insulation to get a constant temperature and a low temperature gradient over the surface of the shield.

3.1 Heat exchanger

The heat exchanger has to cool the cold structure inside the cryostat by using the cold helium gas coming from the Stirling cooler. It has to transport heat from conductivity, radiation, convection and electrical power dissipation away from the cold structure. In addition, it is the cold structure on which all the inner components are mounted. Together with the top cover and the baffling system for the fringe tracker[5], the heat exchanger provides a light-tight shield around the cold optics. The heat exchanger is made out of a massive aluminum cylinder. This cylinder is turned close to the required dimensions. A groove going around the cylinder is machined. An aluminum tube with an inner diameter of 20 mm is welded to this cylinder. After welding, the heat exchanger will be thermally cycled to reduce the stress. Then, the final machining will be done to give the precision required for the mounting surfaces.

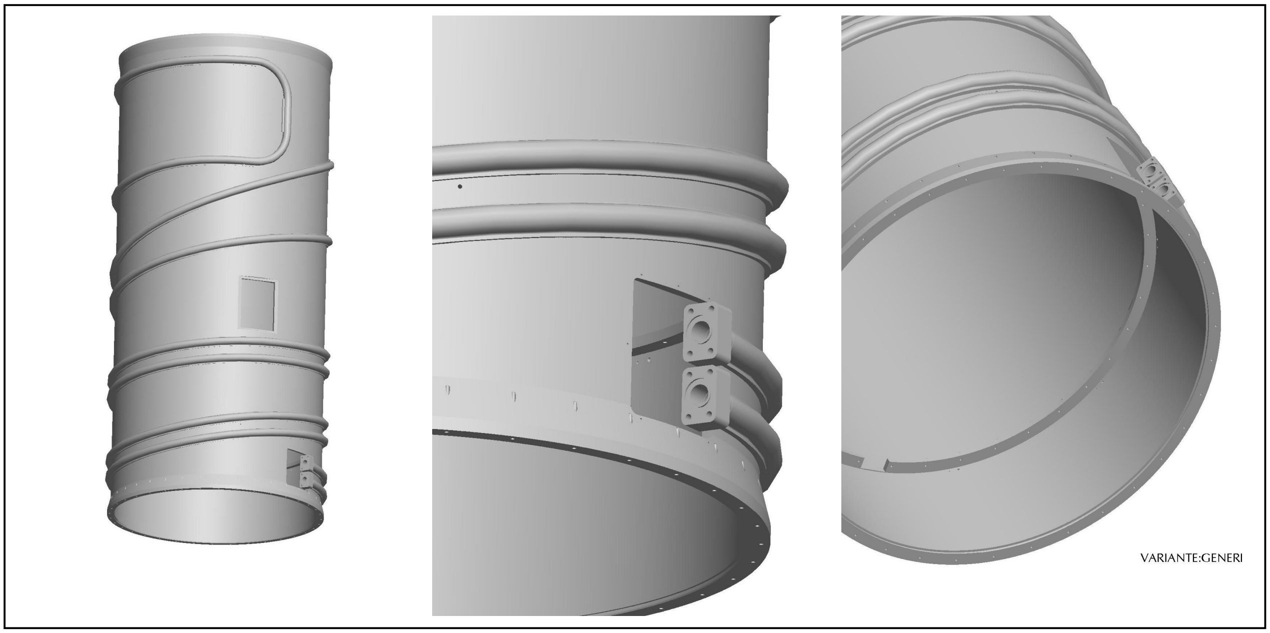

Figure 5: left: complete heat exchanger; middle: tube endings with connection flange for Helium in and out; right: connection flange for the fringe and flexure tracker unit and the inside flange for the cold optics

3.2 Mounting surface for the cold optics

The cold optics is mounted as one unit on a separate structure to an inner rim inside the heat exchanger. This inner flange is used for heat transfer and for mechanical connection to the cold optics structure (see figure 5, right picture).

3.3 Mounting flange for the fringe and flexure tracker

The fringe and flexure tracker is mounted to the lower end flange of the heat exchanger[5] (see figure 5, right picture).

3.4 Cooling of the detector

The detector is continuously rotated during observations. The power dissipation of the motor and of the detector, including fanout board has to be compensated with sufficient cooling power. While the motor is mounted to the cold structure and could so be cooled, the rotating part can only be cooled by using a flexible coupling with conducting braids or metal foils. The dissipation of the fanout board is about 4 –5 Watt and is the major thermal load on the rotating part of the unit. The detector temperature itself will be controlled by a heater and a temperature sensor with a controller in the loop. The maximum rotation angle is 30° with a maximum speed of 12°/min. Figure 6 shows the detector with the flexible coupling.

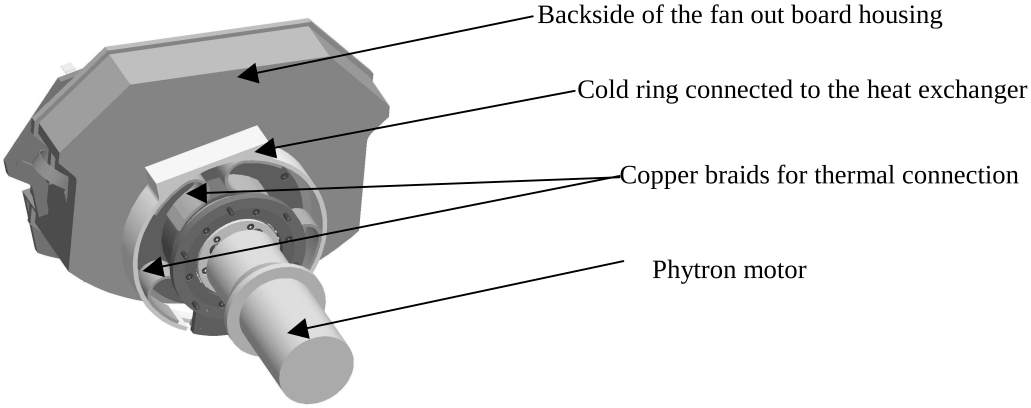

Figure 6: thermal connection of the rotating detector

3.5 Cooling of the fringe and flexure tracker

In addition to the science detector, the fringe and flexure tracker detector is moving continuously[5]. Here, the motors are in the warm and we don't have to compensate the motor power dissipation at cryogenic temperatures. As heat load we have the thermal conductivity of the support tube and the cables from the warm actuators to the cold detector. Besides we have the power dissipation on the detector fan out board. All together, this is less then 1 Watt. Two pairs of copper foils are used for the thermal connection from the cold outside ring to the centre with the moving detector. Also, here the temperature of the detector will be controlled by a controller with heater and temperature sensor.

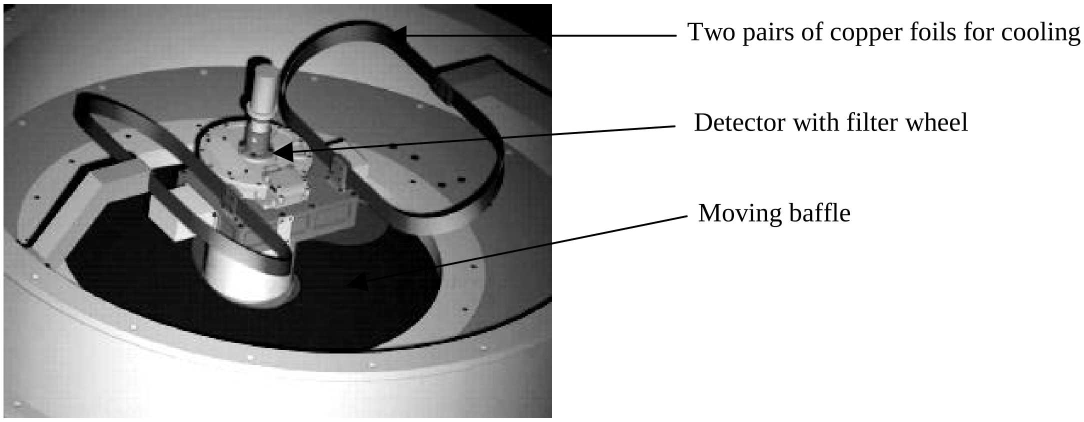

Figure 7: thermal connection of the fringe and flexure tracker

4 VACUUM CAN

The vacuum can is simply the enclosure of the heat exchanger with the cold optics and the detector. It needs at least the same mechanical stability as the heat exchanger, because every flexure of the vacuum can may results in flexure of the cold optics. It also needs the same precision for the mounting surfaces.

4.1 Spacers

The functionality of the spacers is similar to other cryostats. Spacers should give high stability with low thermal conductivity. In addition, they should compensate differential thermal shrinking between the warm outside and the cold inside. With the growing size of cryostats and requirements on mechanical stability, the spacers are more and more not just a standard add in.

4.1.1 Upper spacers

A ring of spacers is mounted on the top flange of the cryostat (figure 8). They allow thermal shrinking in the radial direction but they are stiff in the tangential direction. To reduce the stress in the cold, the spacers are bent half way out when the cryostat is warm and half way in when it is cold. Finite element analysis were done to verify the stiffness.

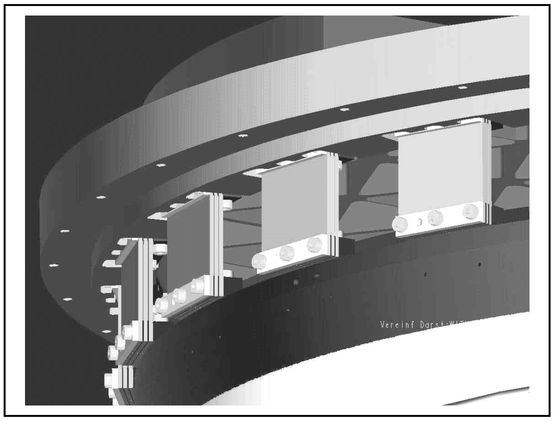

Figure 8: upper spacers

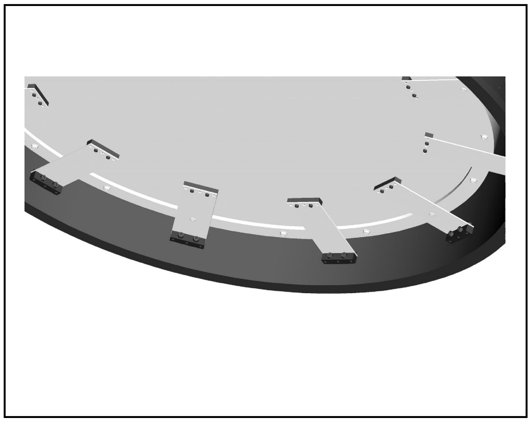

Figure 9: lower spacers

4.1.2 Lower spacers

The lower spacers are mounted to the bottom of the fringe and flexure housing, which is at room temperature (figure 9). The temperature difference between inside and outside should be small. This has the advantage that we don't have to compensate thermal shrinking in the radial direction. Nevertheless, the complete shield will shrink by about 6 mm. This means that the bottom of the fringe and flexure housing will go up when cooling. Therefore, the spacers have to be very flexible in the vertical direction.

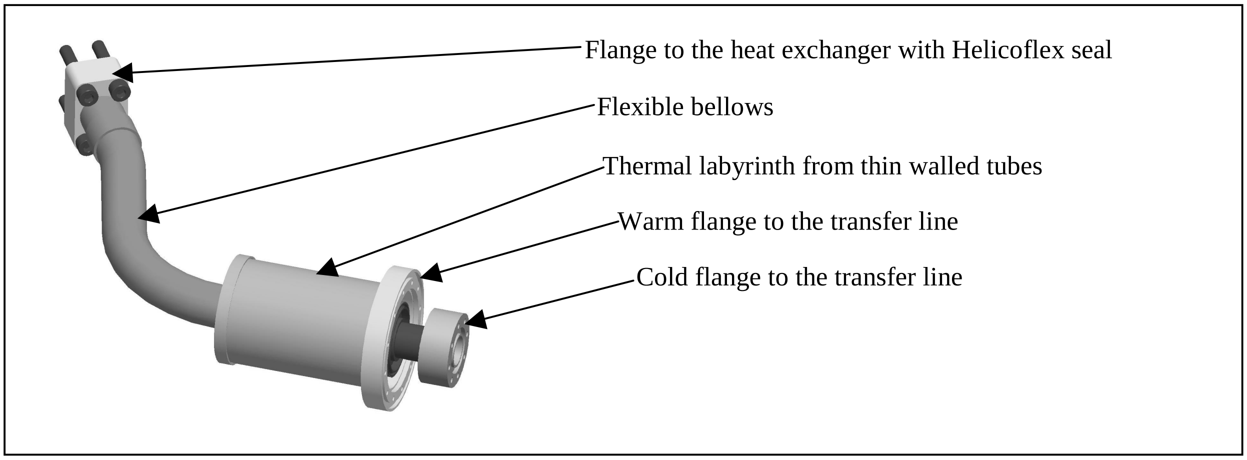

Figure 10: Helium feedthroughs

4.2 Helium feedthroughs

To bring the cold Helium gas in and out of the heat exchanger the top flange would be the best place. Unfortunately, this is not possible because this place is already occupied with warm optics. We therefore have to go in from the side, which has several disadvantages. The most critical is the compensation of the thermal shrinking, which brings a mismatch between the vacuum can flange and the heat exchanger cold connections. We want to compensate this by using flexible bellows. Another critical point is the connection between the aluminum heat exchanger and the stainless steel flexible bellows. The commercial Al/SS connections need considerable space which we do not have. We therefore chose Helicoflex gaskets, which can be used almost like O-rings to connect the two materials in the cold. We tested the junction in the cold with an internal pressure of 40 bars of Helium and could not detect a leak >1e-9 mbar*l/sec.

To allow the cryostat to have the vacuum separate from the vacuum of the transfer lines, we use a labyrinth which is vacuum tight with a low thermal leak. The feedthrough is shown in figure 10.

5 HELIUM TRANSFER LINES

5.1 Special requirements

The transfer lines from the cooler to the instrument have a length of about 40 m. To ensure a sufficient flow of Helium gas we need an inner diameter of about 20 mm. The heat input from the outside world to the cold gas has to be less then 1 W/m. This sort of transfer line is made by several companies for LN_2 or other cold gases. The inside gas pressure of up to 40 bars and the bending radius of 500 mm make our lines a special.

5.2 Routing on the LBT

The cooler is located on level 4. This is just below the telescope platform and is a part of the rotating building. Level 4 is not connected to the central pier on which the telescope is resting. It is in the outer foundation with the enclosure of the telescope where the cooler is placed.

The He transfer lines will go up along the inside of the outer wall of the rotating enclosure. From the rotating part of the building to the telescope, the lines will hang in a loop. This loop compensates the movement of the telescope relative to the rotating building. The minimum bending radius is 500 mm. On the telescope, the lines are fixed below the mirror on their way to the instrument platform. The complete length of one line will be about 40 m.

6 CURRENT STATUS

The Stirling cooler has been in house for some time. With a simple test cryostat, we have conducted some first cold runs and tested the performance. The cooling capacity seems to be sufficient to cool the heat exchanger down to 60 K. The required temperature stability was reached. First vibration measurements show that we do indeed have some vibration in the lines. This needs further investigation. The cooler is shown in figure 12 at the left.

The complete heat exchanger will be manufactured at a Swiss company. The big cylinder is preformed and welded. For stress reduction the cylinder was also tempered. The cylinder can be seen in figure 12 in the middle. In the picture, the long welding seam is not finished.

The vacuum can is almost finished and is expected to be delivered in April 2006. The upper part of the can is shown on the machine in figure 12 on the right.

The special Helium feedthroughs are ordered and will be available when the cryostat is assembled.

The MPIA workshop is building the spacers. They are already finished and wait for assembly.

Figure 11 left: Stirling cooler at the MPIA; middle: Aluminum cylinder for the heat exchanger; right: vacuum can on the machine

7 OUTLOOK, CONCLUSION

We expect all components of the cryostat be in Heidelberg at the end of May 2006, so that we can assemble the cryostat and do a first cool down in June.

The new set up brought several unexpected difficulties to light. This is to be expected for a nove approach. Some details needed complicated rather then straight forward solutions. So far, it is too early to judge whether this is really the future method of cooling large instrumentation. We hope to report soon the first results and our experience with the performance of this system.

REFERENCES

1. T. M. Herbst, *Beyond the fringe: an update on the construction of LINC-NIRVANA, a Fizeau imaging interferometer for the LBT,* Proc. 6268-72 (2006)
2. W. Laun, *Cooling of ground based telescope instrumentation, the LINC-NIRVANA cryostat*, Proc. SPIE 5492, p.1725 (2004)
3. *Product data sheet*, Stirling Cryogenics & Refrigeration BV, Eindhoven, Netherlands
4. T. M. Flynn, *Cryogenic engineering*, Marcel Dekker, New York, 1997
5. T. Bertram, *The LINC-NIRVANA Fringe and Flexure Tracker: Cryo-Ambient Mechanical Design*, Proc. SPIE 6268-133 (2006)