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A modular cryostat for large format and mosaic CCDs

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Abstract. With a growing requirement for wide field imaging, the era of mosaic CCDs is gaining importance in astronomical imaging. Large volume cryostats are needed to house large format and mosaic CCDs. A modular CCD cryostat has been developed to house the CCDs of the camera systems being built at Indian Institute of Astrophysics. The design details and performance analysis of the cryostat are reported in this paper.

1. Introduction

Scientific CCDs need to be cooled to temperatures around -100°C in order to reduce the thermally generated electrons. The most common ways to cool the CCDs are either thermoelectric cooling (TE) or cryogenic cooling methods. The TE coolers are used for smaller detectors due to their limited heat pumping capacities. The cryogenically cooled dewars are designed (Lupinno et al. 1992) to operate the CCDs at well below -100°C. Another option is recently commercialized and is based on the closed cycle refrigerator (Cryotiger, APD Cryogenics Inc). These systems are slowly gaining acceptance in astronomical CCD imagers. IIA has started developing CCD cryostats as part of the development of CCD camera systems. Initial work was earlier reported while the dewar was under development (Nagaraja Naidu et al. 1998). The dewar since then has undergone a few modifications, resulting in an improved performance. The following section describes the current version of liquid nitrogen cooled CCD dewar design and its implementation.

2. LN2 cooled dewar

The dewar comprises of two parts; one is the LN2 chamber housing and the other is the CCD Camera head. An assembly sketch of the dewar is shown in fig. 1. The chamber housing encloses a 2.4 liter capacity liquid nitrogen container, fill and vent structure, vacuum port and activated charcoal plate attached to the liquid container. The CCD camera head contains a CCD mount, an optical window and a hermetically sealed connector for electrical signals feed through. The cold connection to the CCD mount from the LN2 chamber is established through a pair of copper straps held by a compressible spring. The CCD mount also incorporates a resistor heater and a temperature sensor. The camera head and liquid chamber housing are vacuum-sealed by an O-ring and can be easily separated without any internal disconnection to the cold connection. A thin stainless tube of 200μm wall-thickness is welded to the back plate of LN2 chamber and other end of the tube is welded to a flexible SS bellow. The other end of the bellow is welded to a holder that is sealed with an O-ring against the inner surface of the outer body. The LN2 container is firmly fixed to the outer body through three-point support with 120° spacing.

2.1 Heat transfer and thermal insulation

There are three modes by which the heat enters the liquid vessel viz. i) heat transfer by gaseous conduction, ii) heat transfer by supports between the liquid vessel and the outer body and iii) heat transfer by radiation between the two surfaces. The most effective insulation between two surfaces at different temperatures is achieved when the space between them is evacuated. It is well known that the vacuum eliminates the gaseous conduction and convection and thus reduces the heat transfer. In addition to this vacuum insulation, if the heat transfer by radiation and conduction by support points are kept minimum, a good dewar can be realized. The outer surface of the liquid vessel and the inner surface of the outer body are made reflective to reduce the heat transfer by radiation. The inner surface of the outer body is buffed and cleaned to achieve the intrinsic reflectivity, while the outer surface of the liquid vessel is gold plated to reduce the radiation loses. The liquid vessel is held on the front side by three glass fiber spacers at 120° apart. Additional glass fiber bumpers are used on the back plate of the vessel at 120° spacing to avoid sagging against the outer body for side orientations. The main conduction losses occur through the liquid fill / vent structure. A thin neck-tube as shown in fig. 1 is used to reduce these conduction losses. The flexible bellow in the neck-tube assembly allows freedom for the thermal expansion / contraction and also absorbs vibrations and shocks during the handling and transportation.

2.2 Handling of out-gassing

2.2.1 During fabrication

The material surfaces facing vacuum slowly release gases when the dewar is pumped and thus slows down the evacuation process. The degassing takes very long time at room temperature. These gases can be easily removed by heating the enclosure while evacuating the dewar. It is also recommended to give heat treatment in vacuum oven for all the components to be used inside the vacuum, before assembling the dewar. Care should be taken right from the selection of materials (sources of contamination) to be used in the vacuum. PVC materials such as wires, heat-shrinking sleeves (solder joints) are to be avoided as they out-gas heavily. Fiberglass seems to produce no significant contamination in vacuum. Materials such as teflon, Kel-F and epoxy resins are recommended.

2.2.2. During cold operation

The dewar incorporates activated charcoal to absorb the residual gases when cold. The charcoal is pasted using low temperature adhesive to an aluminum plate and attached to the LN2 chamber so as to reach the low temperature of the liquid vessel. At room temperature, this adsorbent out-gases to some extent. As soon as the liquid is filled, the adsorbent becomes active

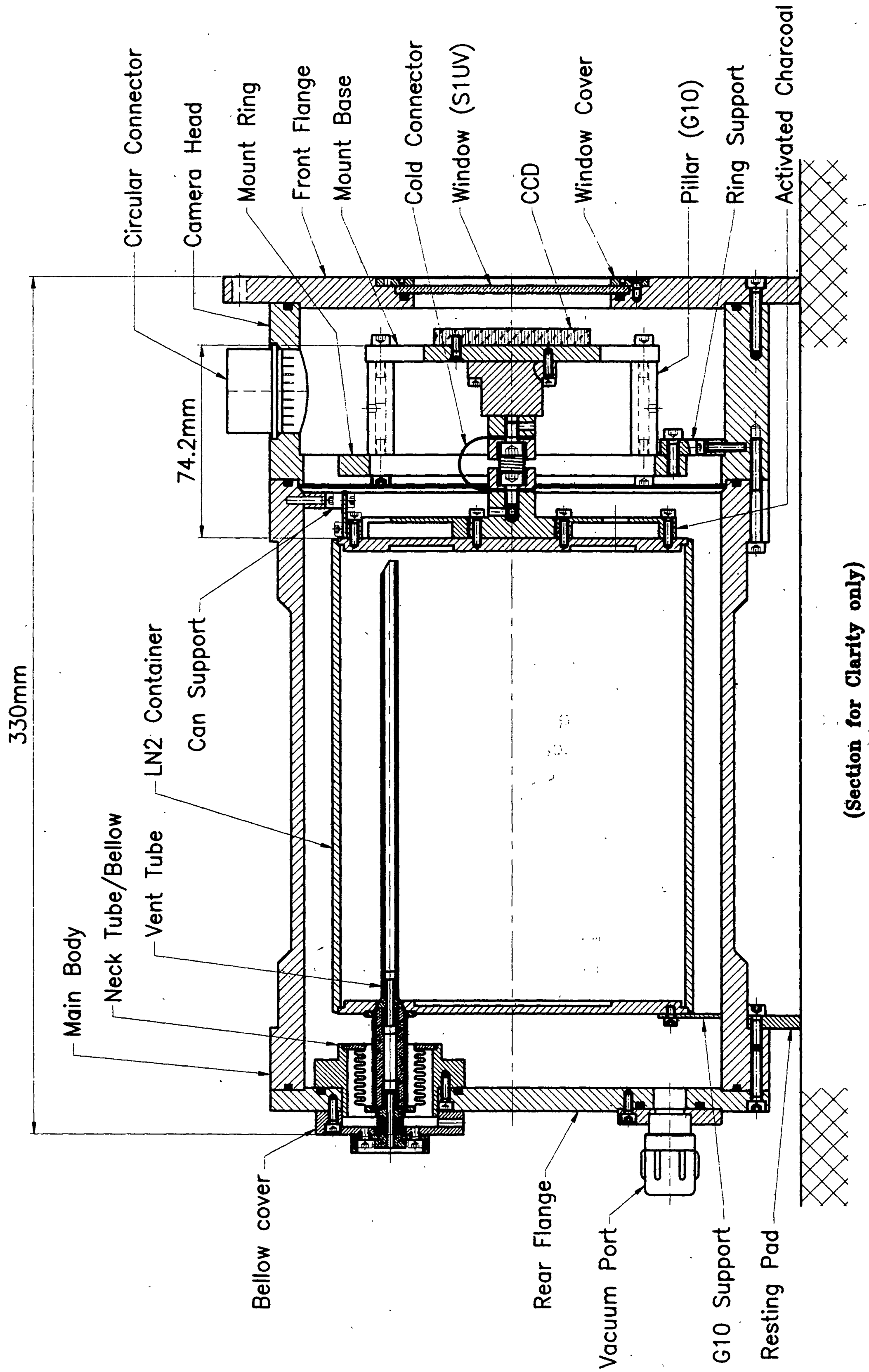

Figure 1. Modular CCD Cryostat

and takes up the residual gases and improves the vacuum inside the dewar. If the dewar is allowed to come to room temperature for quite some time, it is recommended to evacuate the dewar before filling the liquid. By incorporating molecular sieve into dewar one could eliminate water vapor from within the camera head. This prevents frost from forming on the CCD sensor when it is cooled below 0°C. Frost formation on the CCD lowers the image quality and affects the multi-layer coatings on the CCD over time. Molecular sieve requires special handling, such as keeping the sieve component in a hermetically sealed, low humidity environment prior to installation. One drawback with the molecular sieve is that its regeneration (curing) requires heating to about 200°C in vacuum for at about 20 hours. On the other hand, the charcoal getter can be re-activated just by pumping the dewar at room temperature.

3. Materials and processing

Considerable time was required in identifying the vendors for various parts used in the dewar and the processing facilities while building the dewar. We present below the list of vendors for the supply and processing of some of the specialized parts used in the dewar.

3.1 Sources of the dewar parts

One crucial part in the dewar is the thin neck tube with a bellow assembly. The bellow has wall thickness of 10 mils (0.25 mm). The bellow is welded to the neck-tube by laser welding. This assembly is fabricated and leak tested at Miniflex Corporation, USA. We used a thermally conductive epoxy, TEC-001 compound, which is Silver filled epoxy from M/s Melcor Thermal Solutions, USA to attach the activated charcoal pellets to an aluminum plate, which is mounted on the liquid container. This epoxy requires curing time of about 24 hours at room temperature. The optical window (S1UV fused silica with anti-reflection coatings on both sides), activated charcoal pellets and the vented screws are procured from GL Scientific, USA. The vacuum seal-off valve is procured from M/s Cryolab, Circleseal contols, Inc. USA, and has 6mm port size. The hermetic connectors are supplied by M/s OEN, Kerala, India.

3.2 Processing

The liquid nitrogen container is made out of a SS seamles tube and the ends are welded with two SS plates. The back plate of the container is welded to the Neck-tube collar. Welding of these parts were carried at AVAC Industries, Bangalore. The container is gold plated at Kaveri Electroplaters at Bangalore. All the dewar parts were buffed to get intrinsic reflectivity at M/s Surface Metal finishers, Bangalore.

3.3 Handling during integration

To achieve a clean cryostat free of contamination, we need to follow certain procedures while integrating the dewar parts. All the parts used in the dewar should be cleaned first with acetone or alcohol. For best results, the components should be baked in a vacuum over at about 60°C. Subsequently the parts should be handled with clean room gloves. It is advisable to integrate the system in a clean environment of class 100. After integration, the entire dewar can be baked to about +60°C while pumping to improve the vacuum. Periodic baking procedure further improves the vacuum performance.

4. Analysis and performance

The Cryostat is designed to hold liquid nitrogen for more than 24 hours in normal operation. The liquid hold-time coefficient of the dewar is calculated as follows.

Liquid hold-time coefficient = Liquid volume * Heat of vaporization of LN2
= 2400ml * 160J/ml
= 2400 160 * 2.77 * 10^{-4} Whr.
= 103.68 Whr.

In order to obtain more than 24 hours of holding time, the total heat load on the dewar should be less than 4 W.

The actual heat load on the container can be calculated by considering the three modes of heat transfer (T.M. Flynn 1997). At pressures below 1 mbar range, the rate of conduction by gas molecules is nearly proportional to the gas pressure. Since the dewar is evacuated to well below 10^{-5} mbar, and the charcoal getter keeps the dewar evacuated at around 10^{-5} mbar as long as the liquid is present, the conductive heat gain by the residual gas molecules is negligible. The conduction and radiation losses are calculated as follows.

4.1 Conduction through support structures

The heat-gain by the LN2 chamber supports, through the neck-tube/bellow assembly, CCD mount supports and due to wires are calculated using

$$Q_c = (kA/L)*(\Delta T)$$

where, A is the cross sectional area, L is the length and k is the thermal conductivity of the support member. ΔT is the difference in the temperature between the two ends. The following table lists the various conduction losses in the system. The total conduction losses add to 2.5 W.

Table 1.

Structure	Material	(k) (mW/cm.K)	A/L (cm^2/cm)	ΔT	Qc (mW)	Quantity	Total (mW)
LN2 main supports	Glass Fiber	10	0.09	220	198	3	594
LN2 side supports	Glass Fiber	10	0.03	220	66	3	198
Neck-tube	SS304	110	0.03267	220	790	1	790
CCD mount	G-10	4	0.4167	120	200	4	800
Wires	Constantan	200	0.000049	120	1.18	25	30

4.2 Radiation losses

The rate at which a surface emits thermal radiation is given by the Stefan-Boltzmann equation

$$Qr = \sigma eAT^4$$

where e is the emissivity at temperature T, A is area and σ is constant having 5.67×10^{-12} W/ ($cm^2.K^4$). So, the net exchange of radiant energy between two surfaces at two different temperatures T1 and T2 is given by

$$Qr = \sigma eA(T2^4 - T1^4)$$

where A is inner surface area. Assuming the parallel plate geometry between the LN2 container and the outer body, the emissivity can be taken of the form

$$e1e2/(e2+e1(1-e2))$$

where, e1 and e2 are the emissivities of the cold and warm surfaces at T1 and T2 temperatures.

Since the inner surface of the outer body is made reflective and the LN2 vessel is gold plated, and by using low emissive materials wherever possible the heat transfer by radiation is kept less than 400mW. The following tables lists the radiation losses due to the cylindrical and parallel surfaces in the dewar.

Table 2.

Surface	Inner Surface (Gold plate on SS) (77K)	Outer Surface (Aluminum) (300K)	Area (inner surface) (cm^2)	Qr (mW)
Cylindrical	el = 0.01	e2 = 0.03	792	274
Parallel (top)	el = 0.01	e2 = 0.03	154	54
Parallel (bot)	el = 0.01	e2 = 0.03	154	54

The CCD self-dissipation (assumed to be less than 100mW) in its normal mode of operation is also added to the total heat load. Hence the total heat gain (Qc + Qr) by the LN2 chamber is less than 3W.

4.3 Performance

Fig. 2 illustrates the liquid hold-times obtained in normal and inverted modes of operation. In the inverted modes of operation, the hold time is reduced due to the conduction losses through the vent tube that needs to be installed to avoid spilling of liquid. Liquid hold time is obtained by measuring the rate of evaporation of the liquid. Fig. 3 shows the build-up of vacuum of the dewar versus time when used with turbo molecular pump (TMP- V250). The dewar needs to be evacuated once in two months on an average for satisfactory performance. The cryostat can

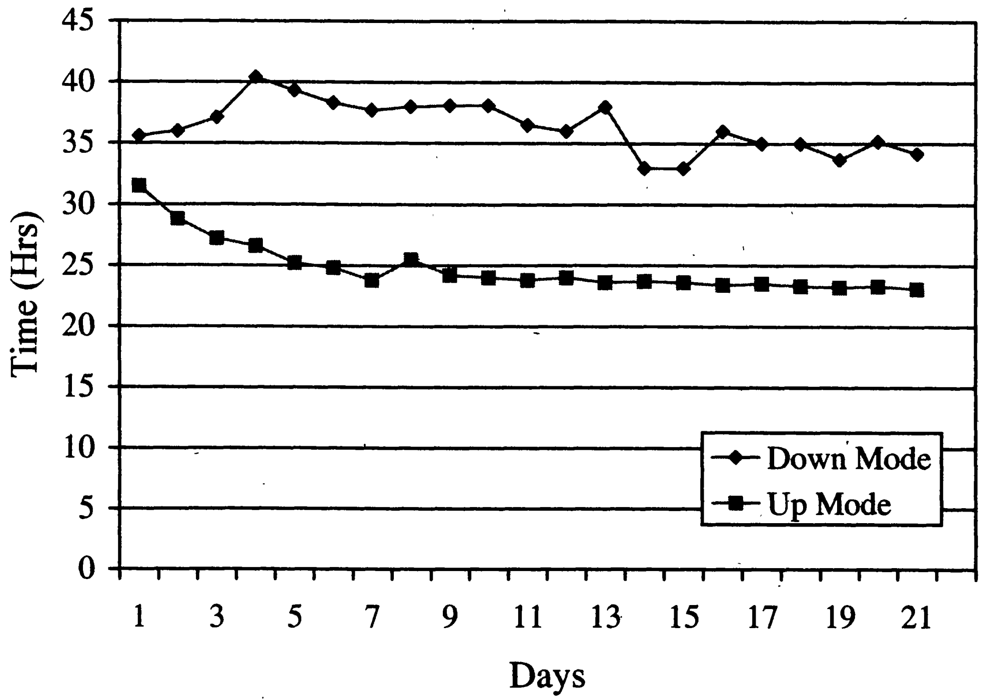

Figure 2. Liquid hold time of the cryostat

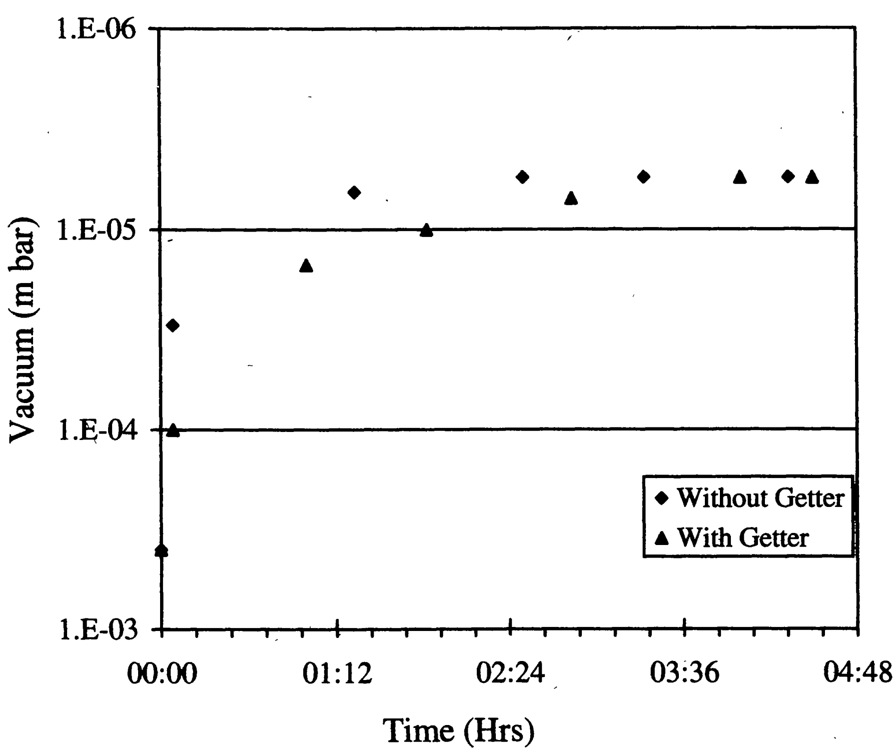

Figure 3. Vacuum building up of the cryostat

accommodate a 2 x 1 mosaic of 2Kx4K CCDs. The CCD camera head can accommodate up to 4 electrical feed-through connectors for mosaic CCD configuration. The number of copper straps in the flexible cold connection can be increased to suit the cooling requirement for additional CCDs.

5. Conclusion

The design details and performance analysis of a modular CCD cryostat fabricated at IIA are presented in this paper. The dewar's vacuum integrity is good and holds liquid nitrogen for 34 hours in normal mode and 24 hours in inverted mode of operation. The dewar is currently integrated with a SITe 2K x 4K CCD and observations are recorded using the same at Hanle (Anupama, 2001).

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