An hybrid liquid nitrogen system for the cooling of the ESO OmegaCAM detector

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ABSTRACT

OmegaCAM is a wide field camera housing a mosaic of 32 CCD detectors. For the optimal trade-off between dark current, sensitivity, and cosmetics, these detectors need to be operated at a temperature of about 155 K. The detectors mosaic with a total area of 630 cm^2 directly facing the Dewar entrance window, is exposed to a considerable radiation heat load. This can only be achieved with a very performing cooling system.

The paper describes the cooling system, which is build such that it makes the most efficient use of the cooling power of the liquid nitrogen. This is obtained by forcing the nitrogen through a series of well designed and strategically distributed heat exchangers.

Results and performance of the system recorded during the laboratory system testing are reported as well. In addition to the cryogenic performance, the document reports also about the overall performance of the instrument including long term vacuum behavior.

Keywords: Cryogenics, detectors, liquid nitrogen

1. INTRODUCTION

The 2.6-m VLT Survey Telescope will be equipped with the optical wide angle camera OmegaCAM, which features a field of view and pixel scale that perfectly match the VST and Paranal seeing, respectively. OmegaCAM will be mounted in the Cassegrain focus, and the focal plane is populated with a mosaic of thirty-two 2K x 4K CCDs plus 4 virtually identical auxiliary CCDs for auto-guiding and image analysis. For the optimal trade-off between dark current, sensitivity, and cosmetics, these detectors need to be operated at a temperature of about 155 K. The detectors fill total areas of 630 cm^2 and for obvious reasons are facing the Dewar entrance window which, however, is in direct contact with the ambient air and temperature. Through this window, the detector is exposed to a considerable radiative heat load of roughly 30 Watts. This is the factor dominating the thermal balance. But a detailed analysis shows that all other contributions (thermal conductance through the mechanical support structures and cables, dissipation in the electronics, etc.) add up to the same amount, bringing the total heat load to 60W.

2. REFLEXION

Various cryo-cooling systems were considered but none of them shows a perfect suitability for this rather special task. Eventually, a decision in favor of liquid nitrogen (LN2) was made, not at last because ESO has a long experience with CCD cooling using bath cryostats. However, from the Wide Field Imager (WFI), OmegaCAM's predecessor mounted on the 2.2-m telescope at La Silla, we knew that in the case of large heat loads, a plain bath cryostat to directly heat-sink the mosaic would not be efficient enough. The most important limitation of such a system comes from the large change in cooling power depending of the nitrogen level in the tank. This required developing a new system. It still uses an internal storage tank but employs a sophisticated flow of liquid nitrogen in order to be independent of filling level and telescope position.

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3. DESIGN, PRINCIPLE

Figure 1 schematically illustrates the principle, which permits the heat to be extracted where it is required (at the level of the detector mosaic) and makes optimal use of the LN2 enthalpy:

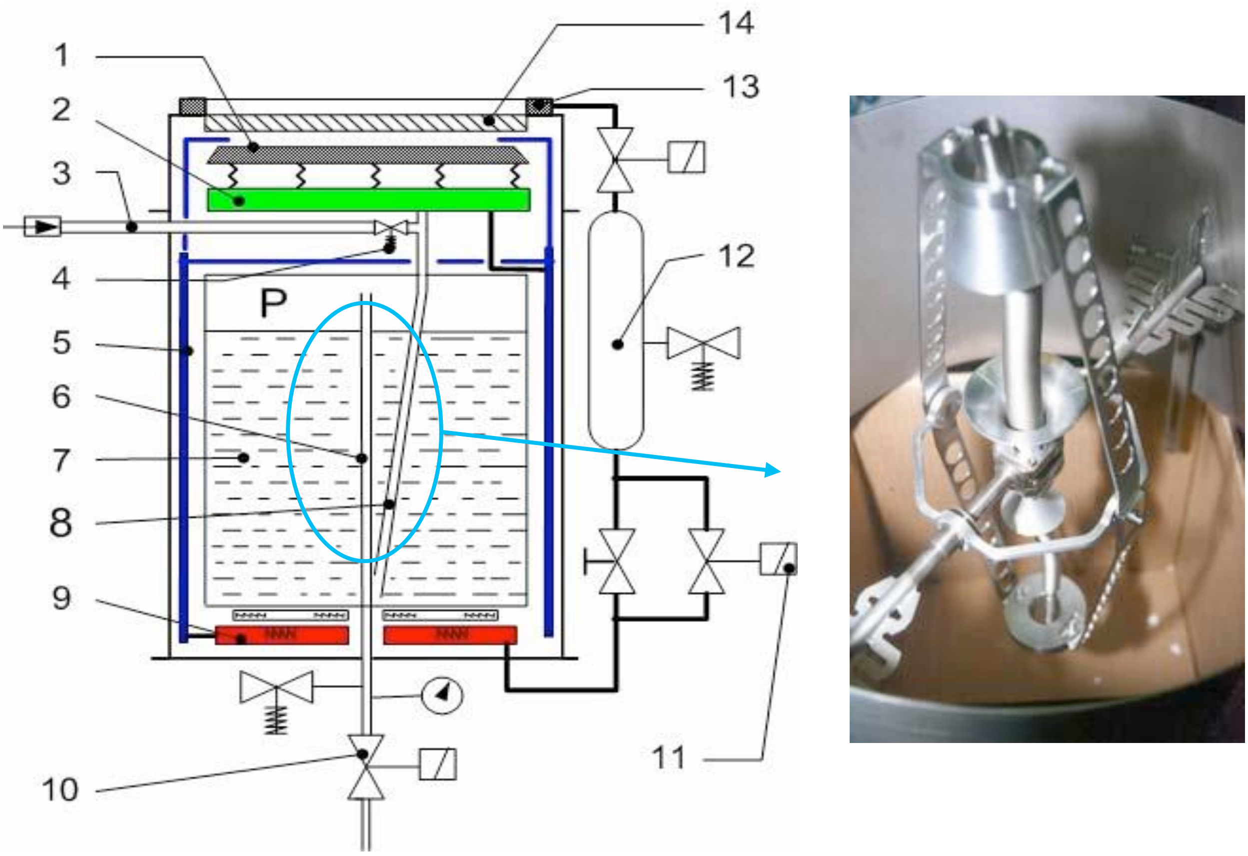

Figure 1: Cooling system principle and anti-overflow system

By its own pressure (P), the LN2 is forced to flow from the storage tank (7) through pipe (8) to and through a heat exchanger (2) which is in direct thermal contact with the mosaic base plate (1). The heat exchanger consists of three parallel bars in order to ensure good temperature homogeneity across the mosaic. After having absorbed the heat load, the now gasified nitrogen circulates through a special annular heat exchanger (5) which acts as radiation shield for the storage tank. A final heat exchanger (9) is used to (electrically) heat the gas to room temperature. On its way out of the instrument, the gas is captured in a small tank (12). Because it is now warm and anyway perfectly dry, it can serve a second purpose and be safely blown over the Dewar entrance window (14) to prevent the condensation of air humidity. The special distribution system (13) is used for this purpose.

The thermal regulation employs a valve (11), which is supervised by a PID controller in order to maintain a constant operating temperature of the heat exchanger (2). The refilling of the internal tank is done from a standard 120 l storage tank via a vacuum-insulated line. When the latter is connected to refilling tube (3), this is detected by a proximity sensor, and valve (10) is opened in order to depressurize the internal tank so that the filling can begin. The valve is automatically closed when the tank is full (which is reported by a temperature sensor). The refilling port is fitted with a small spring loaded valve (4) which is activated by the end of the refilling tube. This allows keeping the operating pressure while removing the tube. The tank has been dimensioned such as to contain some 40 liters in order to reach a hold time of 30 hours so that refilling would be necessary only once a day. Thanks to a special anti-overflow system, which allows the cooling tube (8) to be permanently at the lower position (in the liquid) and the vent tube (6) to be permanently at the highest position (in the gas), 90% of this capacity can be used without spilling (up to the nominal pointing limit of 60 degrees zenith distance).

A dedicated thermal clamp system has been designed in order to allow an easy separation of the detector head from the cooling system it-self. Figure 2 shows (on the left side) the top of the cooling system with the 12 thermal clamps and (on the right side) the bottom of the mosaic plate with the 12 thermal heat-sinking points. Figure 3 shows a detail of the thermal clamping system which is activated from outside via a vacuum tight bellows. The thermal heat sinking is ensured through a pure silver foil which links directly the copper jaw of the clamp to the heat exchanger.

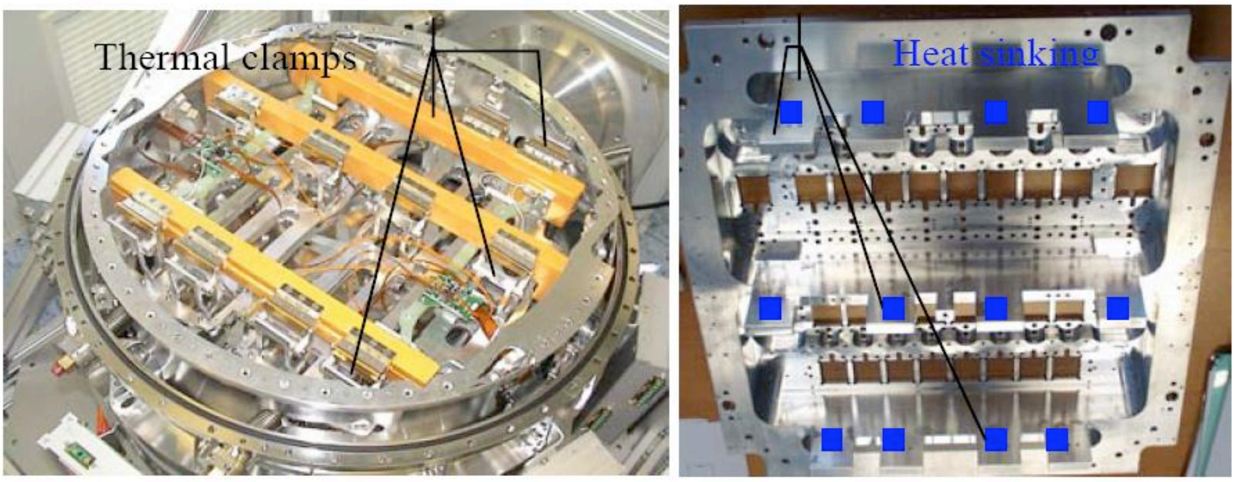

Figure 2: Thermal clamping of the mosaic plate

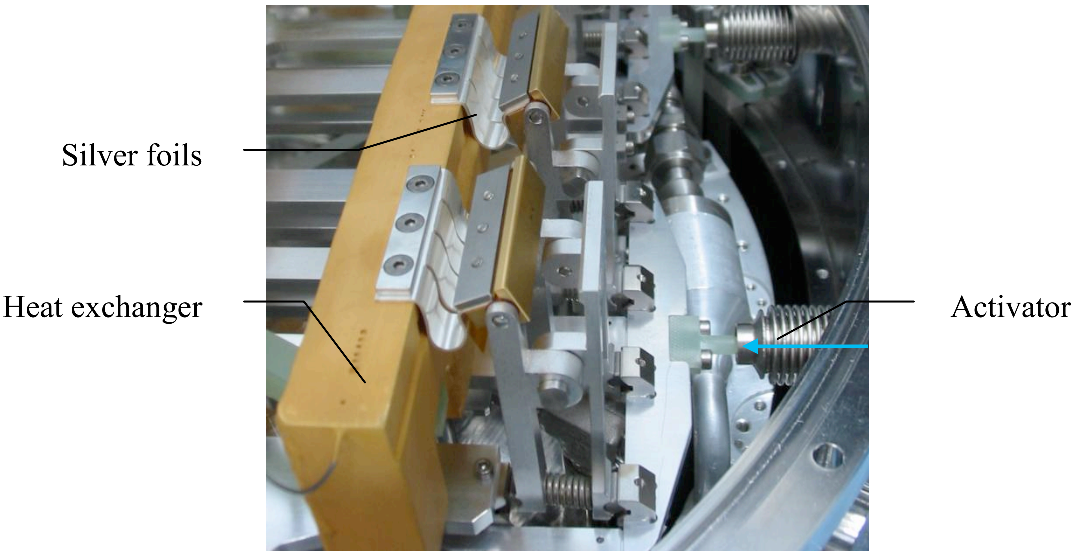

Figure 3: Detail of a thermal clamp

4. PERFORMANCES

The system has been build and is already fully integrated. The following chapter reports about the performance recorded during the laboratory testing in Europe. Some delays with the VST telescope gave us some opportunities for an extended test period during which the vacuum and cryogenic performances have been carefully assessed.

4.1 Cryogenic performances

Beside the normal operation mode (described before) where the internal tank is filed every day and then supply the coolant to the heat exchanger, the cryostat can also be used in a so called “tank mode”. In this mode of operation, the cryostat remains permanently connected to an external storage tank. This mode which allows increasing almost indefinitely the autonomy of the system has been used extensively used during the test phase.

Thermally the most critical goal was the operating temperature of the detector mosaic which was specified to be equal or lower than 155K. This objective has been largely met; the cooling system allows cooling the CCD detectors down to a temperature of 128K.

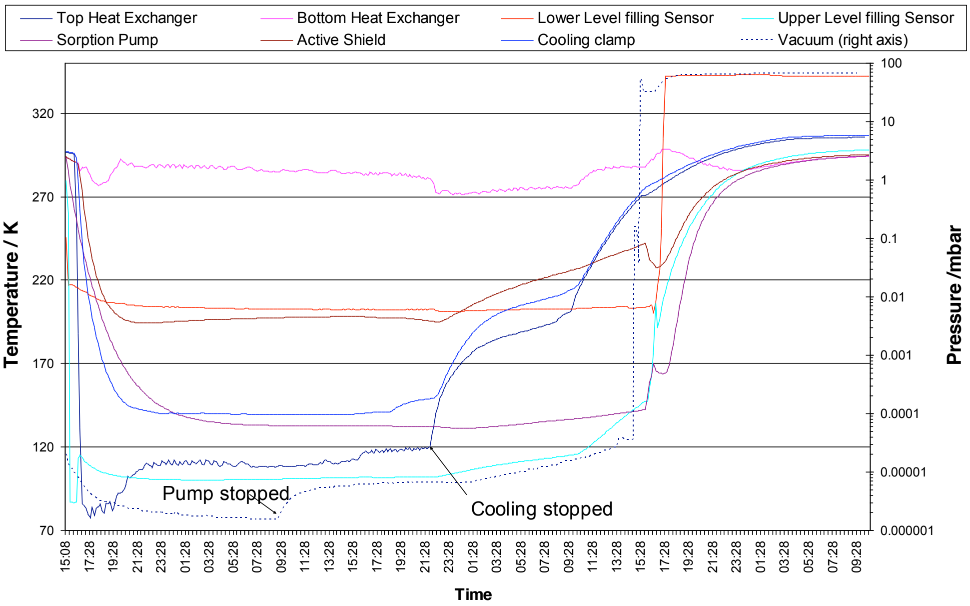

Figure 4: Thermal behavior

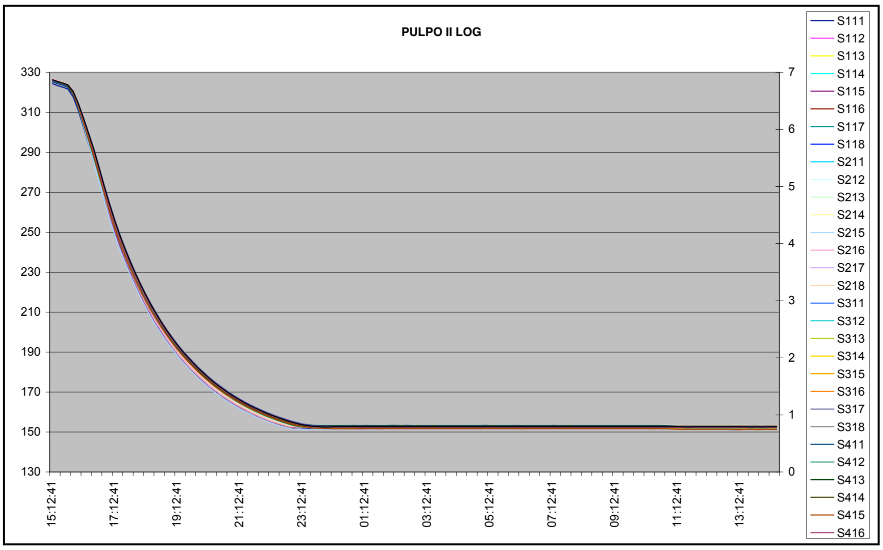

Figure 5: Cooling of the CCD detectors

Figure 4 shows the evolution of the temperatures of the cryostat during a cooling cycle. Figure 5 shows the temperature evolution of various CCD chips during cool-down. The entire mosaic cools homogenously with a maximal gradient which remains less than 4 K.

The next critical point was the holding time of the internal tank which was specified to a minimum of 30 hours in order to allow largely a full day of operation. The tests have shown that in simulated operation (with motion of the instrument) one refilling of the tank allows some 40 hours of operation.

4.2 Vacuum performances

A good vacuum is absolutely necessary not only to ensure an optimal thermal insulation but also to prevent any contamination of the sensitive area of the detectors. As usual the cryostat is efficiently evacuated before cooling. Later on, in operation on the telescope, only a sorption pump is available to keep the vacuum. Practically a copper basket attached directly onto the bottom plate of the LN2 tank acts as sorption pump. The sizing and the efficiency of this pump should guaranty a few months of operation without need for external pumping.

It is always difficult to simulate a long life test during the laboratory testing. As we encountered some problems with the vacuum it was decided to dedicate a long series of tests to this aspect. The figure 6 shows the evolution of the vacuum during these 50 days of operation.

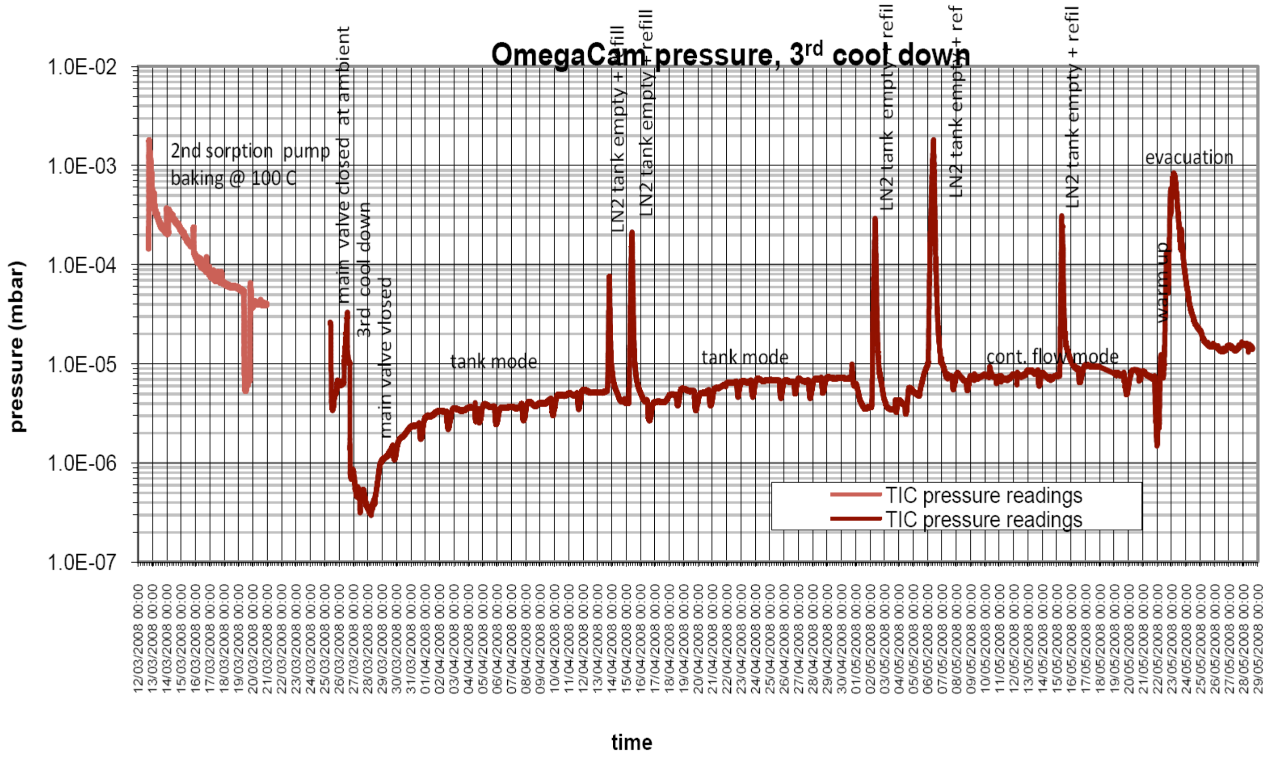

Figure 6: Pressure behavior during the “life test”

During this test, the instrument has been kept at cryogenic temperature for a total of 50 days. During this period, the pressure rose from 3.0*e-6 mbar to 7.5*e-6 mbar, which corresponds to a pressure increase rate of +0.09*e-6 mbar/day.

During the test period, the cryostat ran 5 times out of nitrogen (13.04, 15.04, 02.05, 06.05 and 15.05) indicated by the pressure peaks in figure 6. In all cases the system recovered the vacuum without any auxiliary pumping, which shows the efficiency of the sorption pump. From the 09.05, the system has been operated also temporarily in continuous flow mode without affecting the performance.

With this low pressure rising rate OmegaCAM could be operated for ~1000 days without re-evacuation before reaching the critical limit of 10-4 mbar.

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