Performances of the cryogenic system of GIANO-TNG

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ABSTRACT

GIANO-TNG is a cryogenic high resolution infrared spectrometer whose optics include large aspheric mirrors and cross-dispersing prisms mounted over a $\simeq$1.5 m^2 aluminum bench. To achieve the highest possible spectral stability and repeatability the bench is internally filled with liquid nitrogen whose boil-off pressure is actively controlled and stabilized to a fraction of mbar. The bench is isostatically mounted inside a $\simeq$2.5 m^3 cryostat. We present the characteristics and performances of the cryogenic system of GIANO which include, in particular, a temperature uniformity and long-term stability of a few mK and a remarkably low consumption of liquid nitrogen (less than 1 liter/hr).

Keywords: Ground based infrared instrumentation, infrared spectrometers

1. INTRODUCTION

GIANO is a cryogenically cooled cross-dispersed near infrared (0.9–2.5μm) spectrometer[3] which will be installed at the Italian ⌀3.58 m TNG telescope. One of the primary aims of the project is to achieve the highest possible spectral stability and repeatability in order to obtain very precise (few m/s) radial velocity measurements.

Compared to high resolution spectrographs operating at optical wavelengths, GIANO has the advantage of having the optics in a vacuum environment, i.e. the measurements are not affected by the variation of refraction index of air. The internal repeatability of the spectrum is therefore determined by the stability of the temperature of the spectrometer optics.

Following the approach used for the ESO-HARPS instrument,[4] the cryo-mechanic system of GIANO was specifically designed to achieve the highest possible temperature uniformity and stability.[1]

2. BETANK AND TEMPERATURE CONTROL SYSTEM

The instrument optics are mounted on the "BeTank" (Bench-Tank), i.e. an aluminum optical bench which also acts as liquid nitrogen tank. The direct contact with liquid nitrogen guarantees a uniform temperature distribution of the optical bench surface.

The inner part of the BeTank is divided into six pairs of vertically symmetric cells fed by vacuum-tight welded pipelines which carry the liquid nitrogen and evacuate the out-boiling gas. The cells and pipelines are organized so that the liquid nitrogen is poured and stored in the middle part of the tank. The liquid goes to the lower chambers only after the upper cells are full. A layout of the system is shown in the left-hand panel of Fig. 2 together with pictures of the BeTank during various stages of construction.

The temperature of the BeTank is monitored using ten RTD PT100 sensors. Five are positioned at the center and edges of the upper surface, and the remaining 5 are located in the corresponding positions of the lower part.

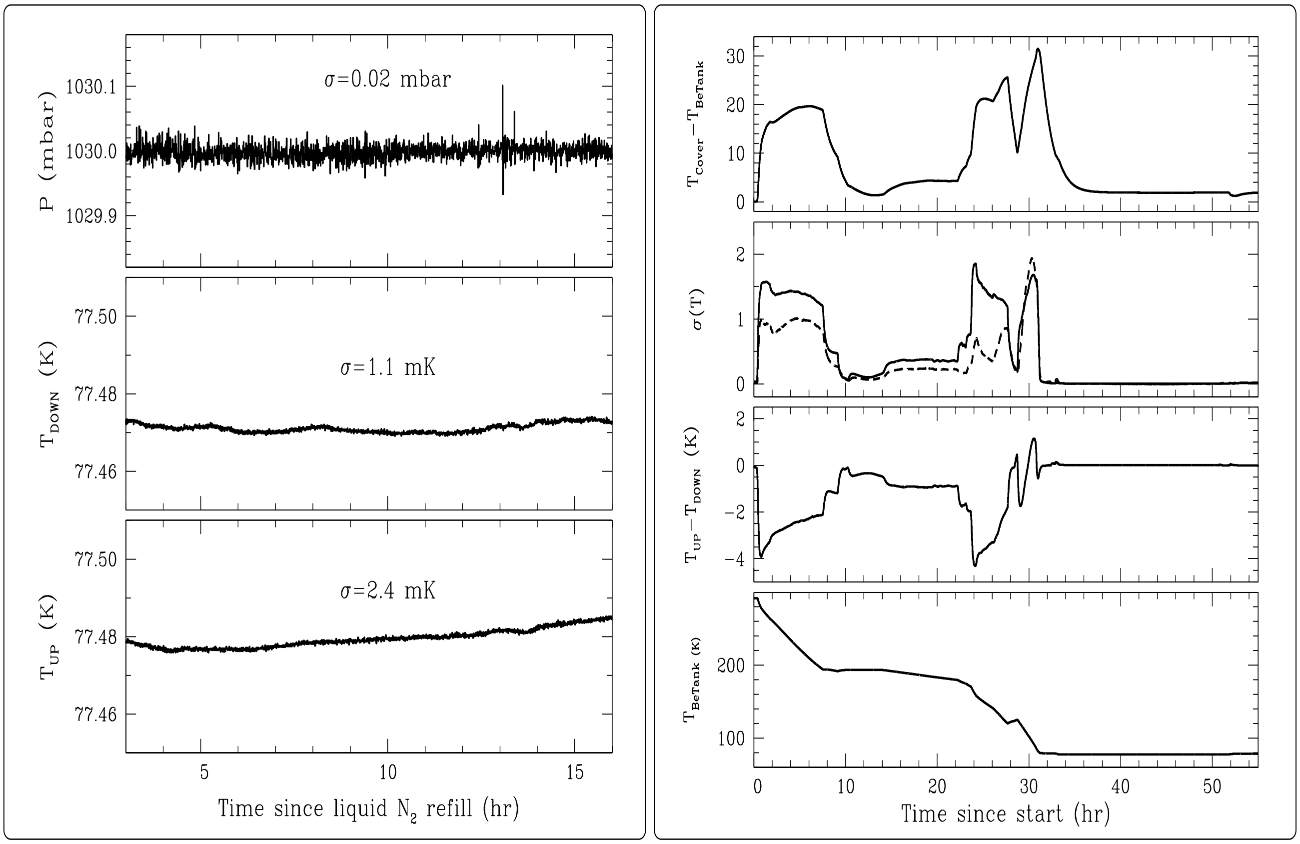

Figure 1. Left hand panel: variation of N_2 out-boiling pressure and BeTank temperature as a function of time since last refill, see Sect. 2 for details.
Right hand panel: thermal behaviour of the system during a cooling cycle, see Sect. 3

The temperature control of the BeTank is performed taking advantage of the intrinsic physical properties of liquid N_2, whose boiling temperature depends on its pressure. Specifically, for pressures between 700 and 1000 mbar one finds

$$\Delta T_{boil}/\Delta P = 0.01 \quad \text{K/mbar}$$

The GIANO cryogenic control system includes a MFC servo-valve which regulates the pressure of the out-boiling N_2 gas. Using the signal from an high precision barometer, the control system can maintain a small ($\simeq$30 mbar) over-pressure relative to the ambient value with fluctuations of a fraction of mbar.

The left panel of Fig. 1 shows the measured variation of out-boiling pressure and BeTank temperatures with the instrument in steady-state conditions during one of the acceptance tests. The time, measured since the last liquid N_2 refill, covers an interval of 13 hours. The MFC valve maintains the pressure constant to within 0.02 mbar rms. The temporal variations of temperature are extremely small, namely 2.4 mK and 1.1 mK (rms) for the upper and lower BeTank surfaces, respectively. The lower part does not show any obvious temperature trend, while the upper surface has a temperature drift of $\simeq$0.7 mK/hr. This most probably reflects the decrease of liquid N_2 level in the chambers.

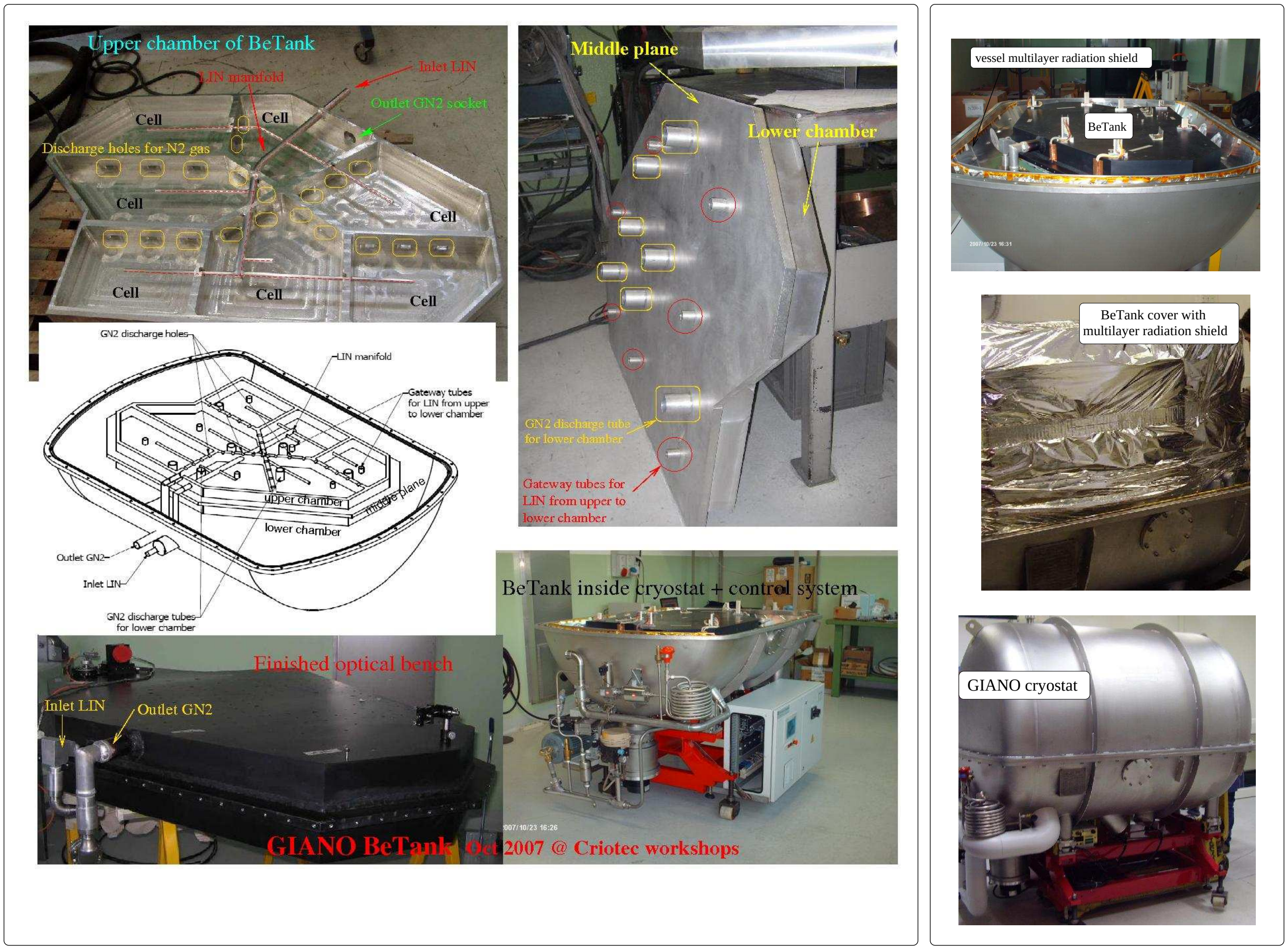

Figure 2. Left hand panel: design and pictures of the GIANO optical bench and liquid nitrogen tank (BeTank) during various phases of construction. The bottom right picture shows the system mounted inside the vacuum vessel and mounted on the structure which carries the cryogenic control system.
Right hand panel: pictures of the GIANO cryostat (low), of the BeTank cover with its multilayer radiation shield (center) and of the BeTank together with the radiation shield mounted inside the vacuum vessel (top).

3. COOLING BEHAVIOUR AND HEAT LOSSES

The peculiar two–floors structure of the BeTank is developed in order to minimize mechanical deformations produced by temperature differences between the various regions of the structure during thermal cycling. In particular, it is designed to minimize the bending of the optical bench produced by vertical temperature gradients.[1] A thick (5 mm) aluminum cover in close thermal contact with the BeTank structure is also included to minimize the heat input on the bench upper surface.

The cryogenic control system includes a servo-valve which limits the input flow of liquid N_2 during the cooling phase. The cooling tests were performed with this valve set to different values. We concentrate here on a run where the flow was maintained at $\simeq$0.3 lit/hr in the first 8 hr, then stopped and restarted with different values in the following day. The results are shown in the right-hand panel of Fig. 1.

As soon as the liquid N_2 flow is started, the temperature difference between the upper and lower BeTank surfaces rapidly reaches –4 K. After $\simeq$3 hr it stabilizes to about –2 K. Noticeably, the upper part of the BeTank cools faster. The rms scatter between the five temperatures measured on the BeTank surfaces remains $\simeq$ 1 K as long as the liquid N_2 flow remains constant. When the flow is stopped the system reaches a uniform temperature distribution in about 30 min.

The upper part of the cover remains 20-30 K warmer than the bench during the liquid N_2 filling. After this it takes about 5 hr to stabilize at a temperature 2 K higher than the BeTank. This temperature difference is in good agreement with the predicted value.[1]

To minimize the thermal input from radiation the cryostat is equipped with a double system of multilayer radiation shields. The first is mounted just inside the vacuum vessel, while the second encompasses the cover and the lower part of the BeTank (see right-hand panel of Fig. 2).

The evaporation rate of liquid N_2 measured when the instrument is stabilized is 0.9 liters/hr. The total thermal input is therefore 40 W, remarkably close to the value predicted by the cryo-mechanical model.[1] Given the large capacity ($\sim$75 liters) of the BeTank, it is therefore possible to refill the system only once a day, when the instrument is not operating, and achieve a temperature stability of a few mK during the observing night.

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