# Cryogenic cooling systems for the ELT instruments

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**ABSTRACT**

The European Southern Observatory (ESO) is building the Extremely Large Telescope (ELT), a 40-m class telescope to be installed on top of the 3046 m high mountain Cerro Armazones in the central part of Chile's Atacama Desert. Once operational the ELT will be the largest optical/near-infrared telescope in the world. Powerful facility instruments that can deliver the science cases for the ELT are under development. The instrument roadmap lists more than six scientific instruments, each of them in the 15-35 tons range. While the telescope optics operate at ambient temperature, the instrument optics structure and in particular the detectors will be cooled to cryogenic temperatures down to as low as 4 Kelvin. ESO is aiming to implement proven technologies and commercial off-the-shelf components to build the cryogenic infrastructure for the ELT instruments. A combination of open loop Liquid Nitrogen cooling and low-vibration mechanical cryo-coolers will be installed to provide the required temperature levels and cooling capacities. ESO's vacuum and cryogenic standards required major updates in order to match with the needs and challenges of this new class of huge instruments, each of them coming with up to 50 $m^3$ vessel volume and more than 5 tons cold mass.

The paper outlines the instruments vacuum and cryogenic requirements, gives a brief overview of the ESO vacuum and cryogenic standards, and of the ELT cryogenic infrastructure baseline concept. The current testing approach for selected standard components such as low-vibration cryo-coolers and vibration damping systems will be presented.

**Keywords:** ELT instruments, cryogenic cooling, vacuum technology, cryogenic infrastructure, cryo-coolers, vibration damping

## 1. INTRODUCTION

The Extremely Large Telescope (ELT) programme was approved in 2012, it is funded and managed by ESO. Construction was started 2014 with the goal of first light end of 2024 and becoming operational in 2025[1]. It will be installed on top of Cerro Armazones, just about 25 km away from ESO's VLT Observatory at Cerro Paranal in Chile. Currently the construction is progressing well according schedule and several major sub-systems have already undertaken the preliminary design review (PDR).

In 2015 ESO signed agreements with consortia of ESO member states institutes and universities for the construction of three instruments (HARMONI, MICADO, METIS) and one post-focal adaptive optics module (MAORY)[2]. These instruments are presently completing their preliminary design phases. While the HARMONI PDR took place end of 2017, the reviews of the other instruments are scheduled for the next months, to be completed in 2019. The instruments programme schedule expects their availability for first light with the ELT in 2024/25. Recently the next two instruments have been studied to conceptual design level during two year phase-A studies. While the first four instruments will populate the so-called Nasmyth-A platform of the ELT, the latter two are foreseen for Nasmyth-B.

Keeping this deadline in focus, ESO is working on the development of the ELT instrument infrastructure of which the cryogenic cooling systems are an essential part. Within the last 20 years of operating, upgrading and expanding the VLT, ESO gained a lot of experience during two generations of sophisticated instruments and their wide range of demanding requirements. Cryo-vacuum infrastructures were built to keep the VLT instrument suite operational 24/7. With the installation of the last second generation VLT instrument end of 2017, the instrument programme is entering its next phase towards the third generation with the first instruments being operational from 2021 on.

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Figure 1: The ESO Extremely Large Telescope (ELT) as expected in late 2024.

Having acquired experience from VLT we are prepared to apply know-how and lessons learned to the requirements of future extremely large instruments. Cryogenic cooling of VLT instruments is based on a combination of open loop Liquid Nitrogen (LIN) cooling and mechanical cryo-coolers which are specifically installed with each particular instrument. The pro's and con's of mechanical coolers are widely known and discussed[3]. In particular their non-negligible contribution to vibrations is one of the main concerns for highly sensitive systems like the VLT, the VLT-Interferometer (VLTI), and to similar extent for the ELT. A lot of effort has been put into understanding, quantifying and suppressing these vibrations[4][5][6]. A recent success story is the installation of MATISSE in the VLTI laboratory at the end of 2017. MATISSE's cryo-cooling system consists of two powerful 2-stage pulse tube cryo-coolers (PTC) operated in the middle of the very sensitive VLTI environment. With the existing design the vibrations are very well suppressed and no degradation of any other VLT / VLTI instrument was found. The results of MATISSE confirmed that we are on a very promising path towards the ELT cryogenic infrastructure which is described below.

As general statement, we intend to rely on proven technology and minimize unknowns. Liquid Nitrogen is reliably available in Chile, this has been proven in the last 20 years. Therefore all temperature levels down to 75 Kelvin shall be covered by this technology which is regarded as nearly vibration-free. While the VLT instruments are supplied from transportable storage dewars, involving a lot of logistics effort, as a lessons learned, the ELT will have a fully closed and automated LIN distribution system. There is no LIN plant at the VLT, LIN is frequently truck delivered and the same scenario is foreseen for the ELT. For temperatures below the boiling point of LIN, commercial off-the-shelf (COTS) cryo-coolers are proposed and dedicated effort is put into vibration damping to be compliant with the very demanding vibration requirements of the VLT(I) and ELT.

## 2. CRYOGENIC INSTRUMENTS AT ESO TODAY

ESO is operating cryo-vacuum systems in all observatories in Chile, starting at the La Silla Observatory, at VLT including VISTA and VST, and at APEX and ALMA. A lot of experience has been gained in designing and operating cryo-vacuum systems for visible and infra-red instruments requiring temperature levels as low as 4 Kelvin. The current instrument suite of the VLT counts about 20 cryogenic instruments being permanently installed and operational at the various telescope foci[7]. Typical values of today's instruments in terms of vacuum vessel volume / total instrument mass / cold mass are : 2.5 $m^3$ / 2.5 tons / 500 kg. Instruments which require temperatures below LIN level, are equipped with up to three mechanical cryo-coolers. Systems are either cooled by LIN only, or by cryo-coolers only, or by hybrid systems including both, LIN and cryo-coolers.

About 25 COTS Gifford-McMahon (GM) type closed-cycle cryo-coolers are operated non-stop at the VLT. They are mainly 2-stage coolers with cooling capacities of 1W @ 4K or 15W @ 20K at the second stage and 50W @ 60K at the first stage. The typical input power for the required Helium compressors is around 8 kW per device. Our investigations revealed that pneumatic driven displacer coolers are much worse in terms of vibration control than mechanical driven displacer versions[3]. This is the reason why some years ago ESO changed the engineering standard of cryo-coolers for VLT instruments to the latter ones and we were able to achieve very good progress in reducing vibrations making VLTI a success. Lately, end of 2017, MATISSE was the first ESO instrument being equipped with two 4-K 2-stage pulse-tube cryo-coolers (PTC) with similar capacity specifications as the GM's above. PTCs are known for producing significant lower vibration levels compared to GM coolers because of the absence of movable parts in the cold head. The results achieved with PTCs are so far excellent because MATISSE itself is able to deploy all its interferometric capabilities and most important, does not degrade any other instrument performance. Because of this we consider MATISSE as a good pathfinder towards future cryo-cooler based ELT instrumentation.

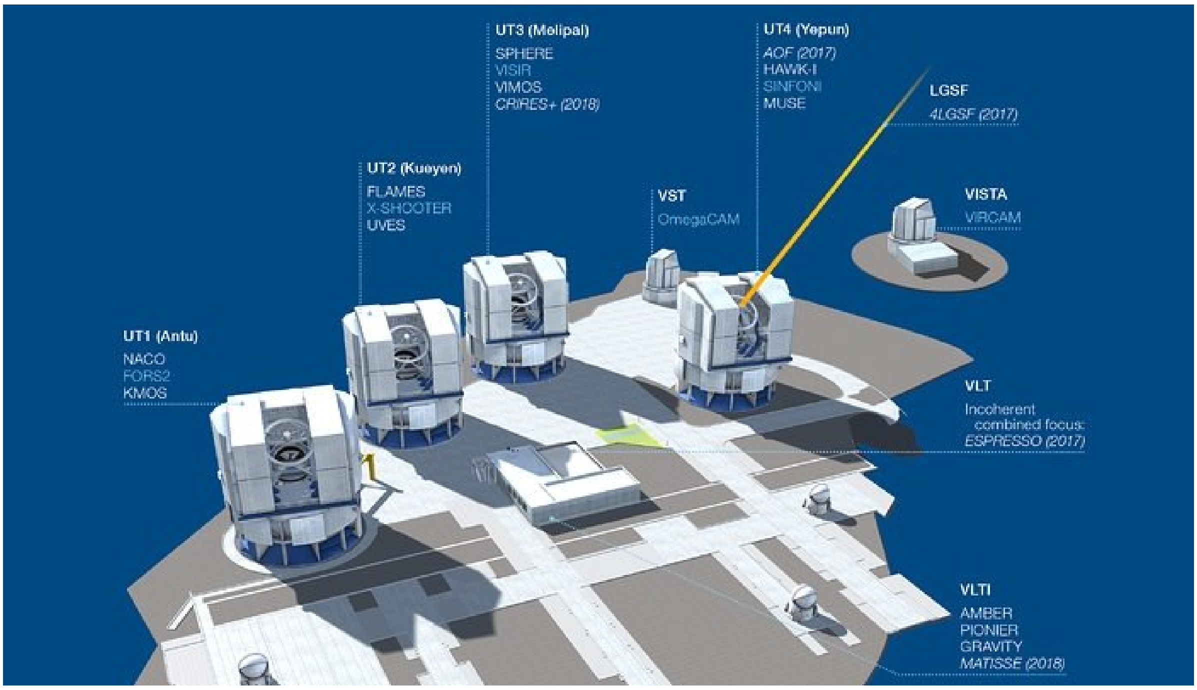



Figure 2: The VLT instrumentation suite 2018, almost all instruments are cryogenic.

Figure 3: Examples of LIN cooled instruments at VLT: X-shooter LIN refilling from portable dewar and transfer line (left), VLT 8-m mirror cell with SINFONI attached at Cassegrain focus (right).

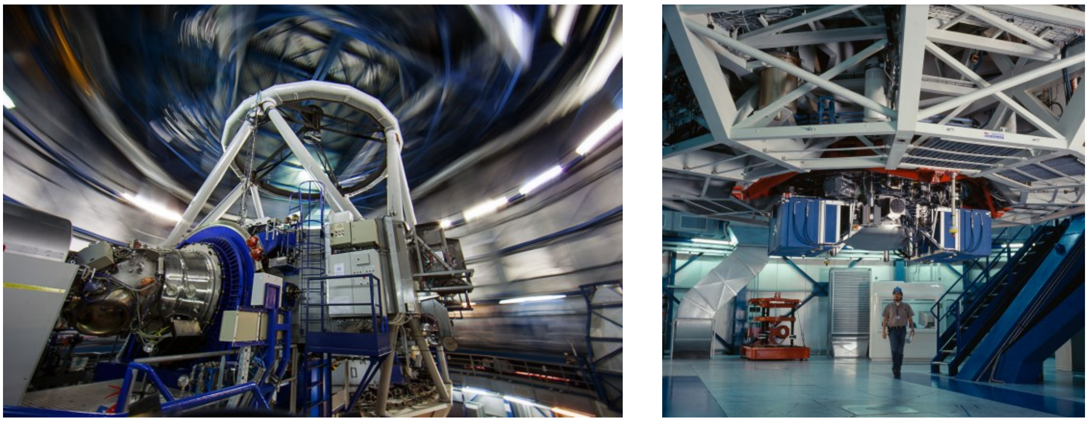


Figure 4: Example of cryo-cooler instruments at VLT: HAWK-I as hybrid system with LIN and cryo-coolers (left), VISIR with 3x 4-K GM cryo-coolers attached at Cassegrain focus (right).

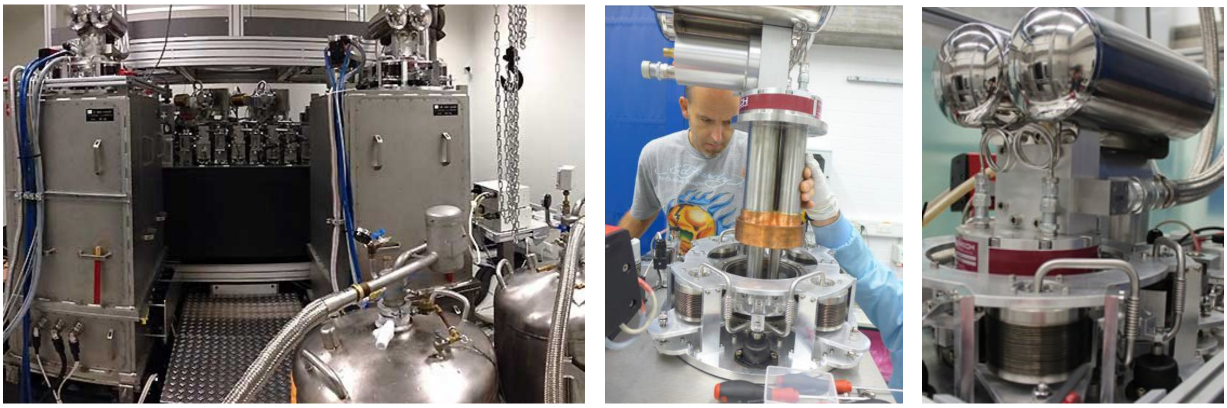
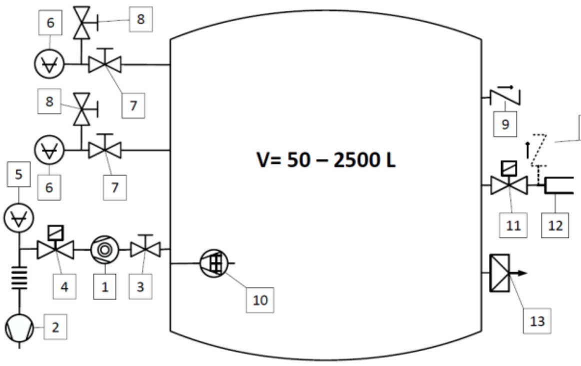


Figure 5: MATISSE was installed as the last second generation instrument in the VLTI laboratory at Paranal end of 2017, it is the first ESO instrument with 2x 4-K pulse-tube cryo-coolers.




| Nr | Acronym | Component | Key performance requirements | Interface |
|---|---|---|---|---|
| 1 | TMP | Turbo molecular pump | 500 l/s; active 5-axis magnetic bearing; incl. protection grid at inlet | DN 160 CF-F (in); DN 25 ISO-KF (out) |
| 2 | PVP | Pre-vacuum pump | 28 $m^3$/h; fully dry; low noise; with gas ballast | DN 25 ISO-KF (in); DN 25 ISO-KF (out) |
| 3 | EGV | Engineering gate valve | Manual operation | DN 160 |
| 4 | PVV | Pre-vacuum valve / insulating valve | Solenoid valve, normally closed; visible indication of open/closed | DN 25 ISO-KF |
| 5 | PSW | Pressure switch | Wide range gauge; atmosphere to $10^{-9}$ mbar | DN 25 ISO-KF |
| 6 | VAG | Vacuum gauge | Wide range gauge; atmosphere to $10^{-9}$ mbar | DN 25 ISO-KF |
| 7 | GE1 | Gauge exchange valve 1 | Manual operation valve + ISO-KF T-piece | DN 25 ISO-KF |
| 8 | GE2 | Gauge exchange valve 2 | Manual operation valve | DN 25 ISO-KF |
| 9 | SOV | Safety over-pressure valve | Opens to prevent vessel damage in case of over-pressure | DN 16 ISO-KF |
| 10 | SOP | Sorption pump | Only to be used in cryostats; operational temperature adjusted to adsorb gas | n/a |
| 11 | N2V | Re-pressurisation valve | Venting valve, normally closed; visible indication of open/closed | DN 10 ISO-KF |
| 12 | N2C | Nitrogen gas connector | Female connector; stainless steel | |
| 13 | RUD | Rupture disk | Breaks in case of instant overpressure | DN 50 ISO-KF |

Figure 6: Extract from the ESO cryo-vacuum standard showing the P&ID (piping & instrumentation diagram) of typical cryogenic VLT instruments with 2.5 $m^3$ vessel volume (left), and the specifications for each item in the table at the right.

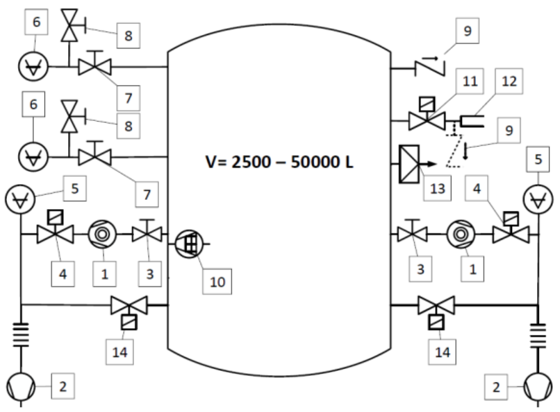
As said above, ESO is defining and maintaining engineering standards which are binding for instrument builders. These standards should homogenize the design principles and minimize the variety of spare parts later in observatory operations. The cryo-vacuum standard at ESO for example defines design principles and is specifying requirements, types, interfaces etc. of each vacuum and cryogenic component. Several vessel volume categories are defined (10 L / 50 L / 2500 L), for which pump size and pumping speed are specified to achieve a vacuum pressure <$10^{-4}$ mbar within 24 hours. Up to the second generation VLT instruments the maximum volumes we used to work with were 2.5 $m^3$ (2500 L), and we recognized quickly that for third generation instruments like MOONS (16 $m^3$) and in particular for typical ELT instruments, we had to revise and update our standards substantially.

## 3. CRYOGENICS FOR ELT INSTRUMENTS

### 3.1 Cryo-vacuum standards for ELT instruments

In order to proceed with the ELT and third generation VLT instrument design, we were updating the cryo-vacuum standards in 2016. The latest version (v.5) of this document is introducing new categories and components covering the expected vacuum vessel sizes of up to 50 $m^3$ and more. A lot of effort is put into selection and characterization of low-vibration pumping units and cryo-coolers. This is an ongoing task and it is foreseen to frequently update the standards in the coming years.

In comparison to VLT instruments of today, the typical values of large ELT instruments in terms of vacuum vessel volume / total instrument mass / cold mass are : 25+ $m^3$ / 25+ tons / 5000 kg. This is in all number roughly 10 times the typical size of VLT instruments. There is no doubt that challenges and complexity are scaling with telescope / instrument size. We have to be prepared to tackle the challenges and to minimize risks and unknowns, therefore our intention is to rely on proven technology as far as cryo-vacuum design and components are concerned. We are proposing larger pumps but we do not want to exceed certain weight / size limits in order to keep the handling of single components in an acceptable range. It is therefore proposed to multiplex several mid-size pumping units accordingly to achieve the required vacuum level of $10^{-4}$ mbar within 24 hours also for larger vessels. This approach has the additional advantage of providing redundancy. The next figure gives an example how this is implemented.




| Nr | Acronym | Component | Key performance requirements | Interface |
|---|---|---|---|---|
| 1 | TMP | Turbo molecular pump | 2000 l/s; active 5-axis magnetic bearing; incl. protection grid at inlet | DN 250 CF-F (in); DN 40 ISO-KF (out) |
| 2 | PVP | Pre-vacuum pump | 40 $m^3/h$; fully dry; low noise; with gas ballast | DN 40 ISO-KF (in); DN 25 ISO-KF (out) |
| 3 | EGV | Engineering gate valve | Manual operation | DN 250 |
| 4 | PVV | Pre-vacuum valve / insulating valve | Solenoid valve, normally closed; visible indication of open/closed | DN 40 ISO-KF |
| 5 | PSW | Pressure switch | Wide range gauge; atmosphere to $10^{-9}$ mbar | DN 25 ISO-KF |
| 6 | VAG | Vacuum gauge | Wide range gauge; atmosphere to $10^{-9}$ mbar | DN 25 ISO-KF |

Figure 7: Extract from the ESO cryo-vacuum standard version 5 describing the P&ID of large cryo-vacuum instruments up to 50 $m^3$ (left), and the specifications of components.

Table 1: Specification for multiplexing pumps for large vacuum vessels.

| Vessel volume (L) | Number of pump sets (TMP + pre-vac) |
|---|---|
| 2500 – 5000 | 1 |
| >5000 – 25000 | 2 |
| >25000 – 50000 | 3 |
| >50000 | 4 |

Taking the experience from VLT into account, the standard for cryo-coolers is strictly based on pulse-tube coolers (PTC), while Gifford-McMahon (GM) coolers are not allowed to be used at ELT. PTCs are coming along with a few significant advantages. First they are introducing a factor of about 100 lower vibrations into the system, second their mean time between maintenance (MTBM) is significantly higher than for GM coolers. While GM's require servicing every 1-2 years, PTC are known to run 4-5 years before requiring service. The latter is a major argument when we talk about the effort of warming up and cooling down large instrument with several tons of cold mass.

At the present state we selected two COTS PTCs as standard, these are the models PT410 and PT810 from CRYOMECH. The goal is to select only coolers which can run on the same compressor model, the CPA289C from CRYOMECH. As a lessons learned from VLT we will connect only one cold head per compressor, interconnected with one pair of Helium lines. PT410 is a 2-stage 4-Kelvin machine required for the mid-IR instrument METIS, PT810 is a 2-stage 20-Kelvin machine required for IR instruments HARMONI and MICADO. The listed coolers are so-called low frequency PTCs with the known drawback that their mounting orientation is strictly vertical with cold end down. However, this is no concern for the present ELT instrument designs because none of them is introducing rotations which are causing a change of gravity vector to the cold heads.

Other cooler options are presently under investigation. In particular we are looking into the small scale PTC LPT 9310 from Thales and into the Sunpower CryoTel GT AVC, a 40-K Stirling cooler with active vibration cancellation system. Other models from CRYOMECH are likely candidates, for example the single stage 30-Kelvin cooler PT63. These and other models are under test at ESO HQ.

### 3.2 The ESO cryo-cooler test facility

A multi-purpose cryo-cooler test facility (CCTF) was built at ESO, enabling not only dedicated testing of various cryo-coolers, but also all kind of vacuum standard components like larger pumps, new vacuum gauges, valves etc. The test facility offers the possibility to characterize coolers in terms of cooling capacity and vibrations. Tilting of the cold head is possible in order to measure the losses in cooling capacity relative to the tilt angle (may be relevant for future instruments). Practicing handling and integration of cold heads is an essential part of our test programme keeping in mind the later maintenance activities within the ELT environment.

Preliminary studies of the ELT cryogenic infrastructure showed that a feasible concept will require long Helium lines between PTC cold head and compressor. The standard length of 20 m is by far not enough because of the large dimensions within the ELT, and we consider 100 m as the minimum required length (including some margin). CRYOMECH was able to provide us with a PT410 system including 100 m long lines. Tests in our facility confirmed that the capacity losses of 100 m versus 20 m are marginal and acceptable, so we feel confident to continue with our concept in this direction.

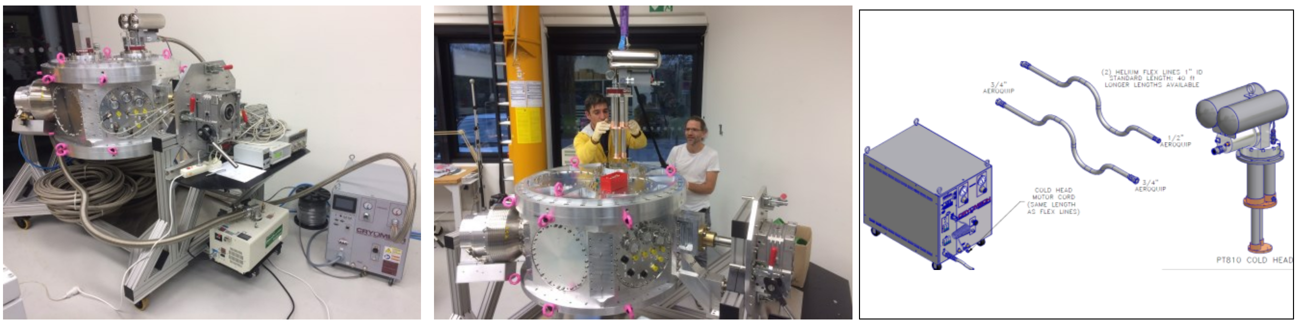



Figure 8: The ESO multi-purpose cryo-cooler test facility (left), practicing cold head integration (middle), standard PT410 system (right). For ELT applications the standard 20 m Helium lines will be replaced by 100 m long lines.

### 3.3 Cryo-cooler maintenance

An early realistic estimation of the cryo-cooler maintenance effort is important because it may have an impact on the overall observatory operations plan. Following an advice from CRYOMECH we were defining the MTBM for our compressors as 20000 hours (~2.3 years), and for the cold heads as 35000 hours (~4 years). Compressor maintenance will be performed in-situ during day time, it won't imply any instrument down time nor impact on the operations. For the cold heads we are following a conservative approach. We are planning to dismount each cold head every four years of operation and to replace it by a spare unit. Instrument teams are requested to consider accessibility for this undertaking by design allowing vertical up replacement of all cold heads.

However, having 4-5 cold heads per instrument and considering the cold mass of large instruments, we understand that the required effort is quite big. At the time being we are considering three scenarios:

1. Baseline design: cold heads are directly integrated with vacuum vessel: The estimated downtime of an instrument is about 3-4 weeks including warm-up of instrument, venting, dis-connection of thermal interfaces, replacement of cold heads, re-connection of thermal interfaces, evacuation, leak testing, cool down of instrument.
2. Alternative design: cold head integrated with double sleeve system:
   A) Conservative approach: Downtime of instrument ~2 weeks including warm up of instrument, no need to break the vacuum, no dis-connection of thermal interfaces required, replacement of cold heads, simplified leak testing, cool down of instrument.
   B) Best case approach: Instrument downtime ~1-2 days including cold swap of cold heads.

ESO has recently launched a development for a double sleeve system compatible with our standard cryo-coolers. It is foreseen to integrate the sleeve system with our CCTF to perform an extensive test and handling programme with the goal to mitigate the downtime of instruments caused by cryo-cooler maintenance. If successful the double sleeve system is going to become ESO standard to be integrated with all future ELT instruments. First test results are expected in 2018.

### 3.4 Cryo-cooler vibration testing

The VLT allows us to study vibrations in detail. This paper focuses on vibrations induced by cryo-coolers, while a lot of other sources are also known. Over the last decade, ESO and partner institutes developed a series of passive vibration damping systems, so-called anti-vibration (AV) mounts for GM and PTC cold heads and compressors. It is fair to say that the success of the VLT and VLTI is to a certain amount also the credit of these well-engineered damping systems. Up to now we have implemented only passive dampers, but some years ago a development was started to demonstrate the capabilities of active vibration damping applied to GM cold heads[4]. The baseline design for ELT cryo-coolers foresees passive vibration damping, but if further testing proves that this is not enough to meet the demanding ELT vibration requirements, we are ready to invest in further developments for active PTC damping.

For now, and this is confirmed by the results of MATISSE, we are confident that we can meet the vibration requirements with passive damping. The next figure shows existing cold head damping systems applied to various VLT instruments.

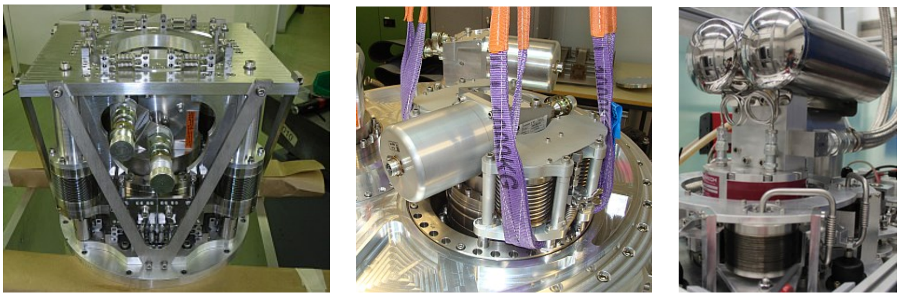


Figure 9: Passive vibration damping systems for the VLT instruments KMOS (left), HAWK-I and CRIRES (middle), MATISSE (right).

The excellent results in terms of vibration damping of MATISSE make the damping system which was explicitly designed for the PT410 cold head the most promising candidate as standard device for all PT410/810 systems in the ELT environment. Comprehensive characterization tests are ongoing in our laboratories at the moment. Results will be presented at a later stage.

A lot of effort was also invested in vibration damping of compressors. Several spring suspended compressor mounts are successfully implemented at various VLT instruments. A similar design is under development for the selected CRYOMECH compressor allowing a stackable 2-storey arrangement of an assembly of 12 compressors, as required for the instruments of one ELT Nasmyth platform. Two of these arrangements, located at the Azimuth platform, will be required for both ELT Nasmyth platforms.

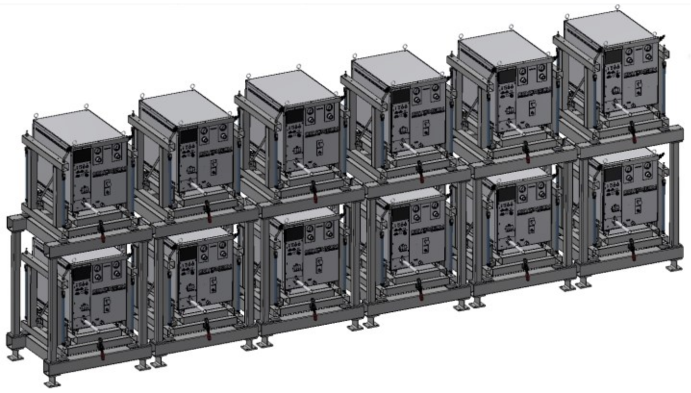


Figure 10: Preliminary design of the compressor damping system for ELT Nasmyth-A instruments.

ESO's vibration working group is active in modeling and simulating the vibration budget of the ELT[8]. As an outcome of an extensive study, the vibration budgets of all vibrational sources were analyzed. The next figure is showing as an example the vibration requirements for Nasmyth instruments in RSS of force in Newton rms per one-third octave frequency bands. It is understood that these requirements are very demanding. Our ongoing simulations and measurements will have to prove compliance with the requirements or whether improvements are necessary in certain areas.

Table 2: Vibration requirement for ELT Nasmyth platform instruments.

| Unit | Frequency Range [Hz] | | |
|---|---|---|---|
| | 1 – 4.45 | 4.45 - 56 | 56 - 110 |
| Nasmyth Instruments (RSS of force (x,y,z) [N] rms per one-third octave frequency bands) | 1 | 0.4 | 2 |

## 4. ELT INSTRUMENTS

The ELT consists of two about tennis-court sized Nasmyth platforms for the instruments, named Nasmyth-A and -B platforms. Each platform is foreseen to host 3 to 5 instruments. Instruments are built for a typical life-cycle of 10 years plus margin. Considering an ELT lifetime of 50 years, we have to plan for several generations of these 'extremely large instruments' with very demanding requirements, and increasing size and complexity.

The instruments of the Nasmyth-A platform are presently close to completing their preliminary design phases. Some of their requirements are not confirmed yet, in particular the requirements for LIN consumption and the ones concerning the quantity of cryo-coolers. However, when specifying the instrument infrastructure, we are considering a worst case scenario with comfortable contingency. In particular the requirements for Nasmyth-B instruments are not well known by now, therefore we assume the same infrastructure and configuration as for Nasmyth-A. According to the ELT schedule, Nasmyth-A will be populated with instruments in 2024/25, while Nasmyth-B will be populated some years later.

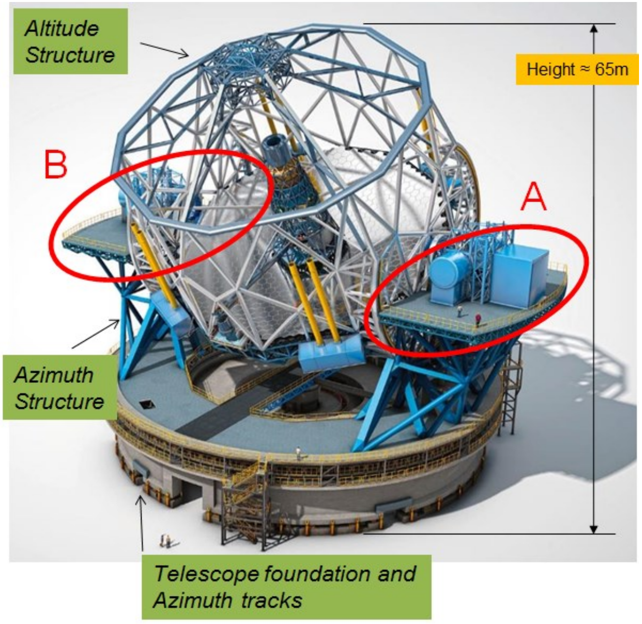



Figure 11: Illustration of the ELT Nasmyth platforms A and B populated with instruments.

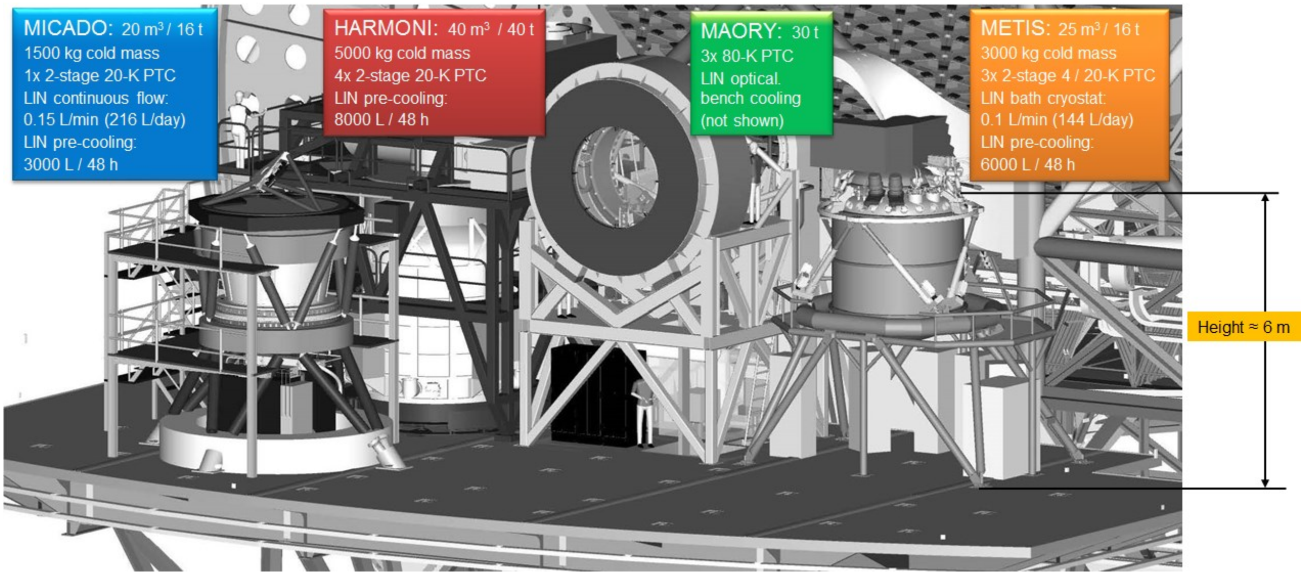



Figure 12: Preliminary architecture of the ELT Nasmyth-A instruments and their cryogenic requirements as of today. MAORY is not shown in this picture. Note: optical beam from the telescope is at 6 m height above the platform. As an example, the PTCs of METIS are also located in about 6 m height, which triggers discussions about accessibility.

The cryogenic requirements of the ELT Nasmyth-A instruments are summarized in the next table. Please note that these numbers are based on preliminary information at pre-PDR level. It is planned to finalize the requirements after instrument PDRs. (*) indicates the requirements for the three MAORY wave-front sensor cameras, while (**) refers to an ongoing study to optionally cool the MAORY optical bench with LIN to zero °C. For the conceptual design, the worst case scenario assumptions for the cryogenic infrastructure will be taken into account, independently from the final decision.

Table 3: Preliminary cryogenic requirements of the ELT Nasmyth-A instruments.

| **ELT instrument** | **Min. temp. [K]** | **Vacuum vessel volume [m$^3$]** | **Total instr. mass [tons]** | **Cold mass [kg]** | **LIN pre-cooling total volume [L]** | **Steady state LIN consumption [L/min (L/d)]** | **Quantity and type of cryo-cooler** | **Quantity and type of compressor** |
|---|---|---|---|---|---|---|---|---|
| **HARMONI** | 40 | 40 | 40 | 5000 | 8000 | 0 | 4x PT810 | 4x CPA289C |
| **METIS** | 4 | 25 | 16 | 3000 | 6000 | 0.1 (144) | 3x PT4/810 | 3x CPA289C |
| **MICADO** | 40 | 20 | 16 | 1500 | 3000 | 0.15 (216) | 1x PT810 | 1x CPA289C |
| **MAORY** | 90*<br>273** | n.a. | 30 | 3<br>8000 | n.a.<br>5000 | 0<br>0.45 (650) | 3x LPT9310<br>n.a. | 3x Thales<br>n.a. |

## 5. ELT CRYOGENIC INFRASTRUCTURE

The ELT cryogenic infrastructure is in conceptual design phase. The requirements are not final as long as not all Nasmyth-A instruments pass PDR. However the functional concept has been developed taking the current status and some assumptions into account. As said earlier, our philosophy is to build up on the experience and lessons learned from VLT, and minimizing technical risks and unknowns. Further, relying on proven technologies and using as many as possible commercial parts (COTS) to ensure the durability of standard components and availability of spare parts at least over the next 10 – 20 years and beyond.

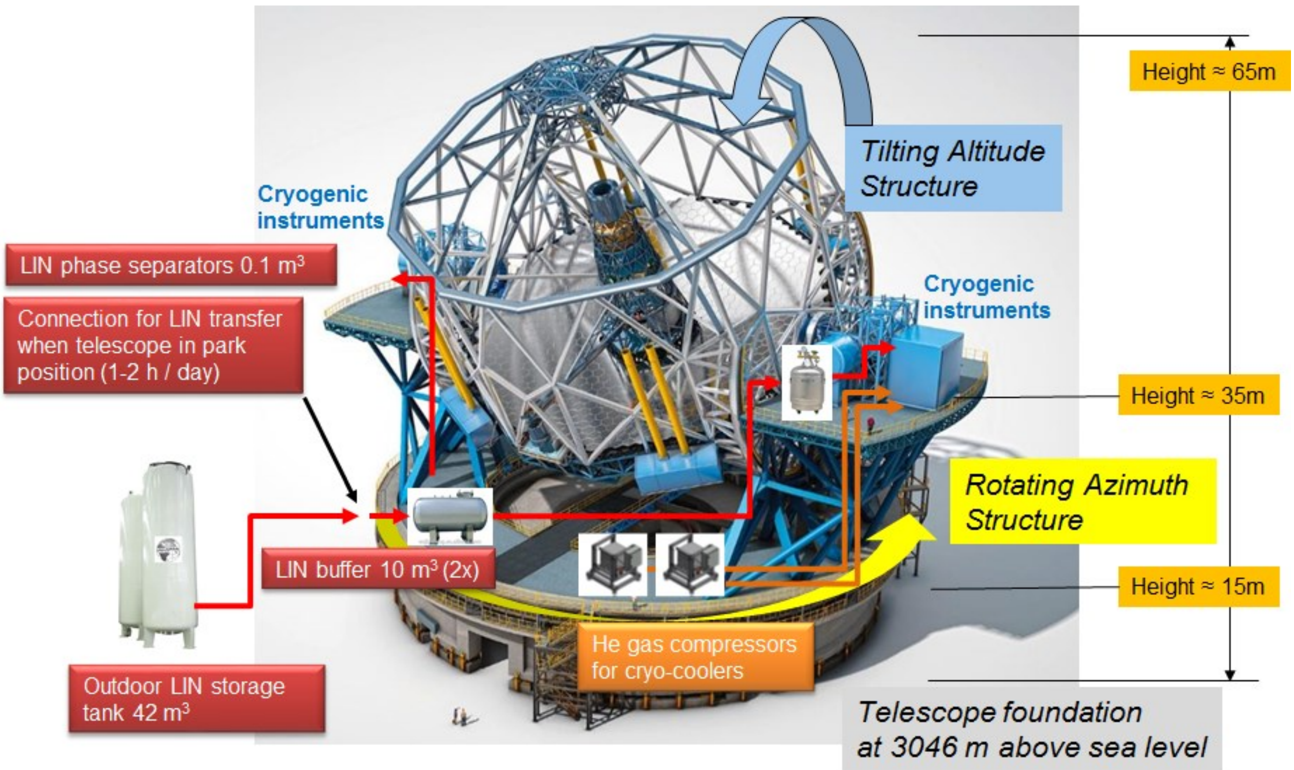



Figure 13: The ELT cryogenic infrastructure functional concept.

## 5.1 LIN infrastructure

Similar as implemented at VLT, the ELT cryogenic infrastructure will be based on LIN cooling and cryo-coolers. There will be no LIN plant at Cerro Armazones. A trade-off study confirmed us that this is not the best approach in terms of cost, complexity and maintenance effort over the next 30 years. Instead, we decided that LIN will be frequently delivered by a service company refilling the main outdoor LIN storage tank of approximately 42 $m^3$ capacity. Different than at VLT, the ELT will have a fully piped and automated LIN distribution system from the main outdoor storage up to the various users, either at the Nasmyth platforms or at other locations inside the ELT building. Portable LIN storage dewars shall be avoided and are not foreseen in our baseline concept.

One major concern is how to route the LIN piping from outside to the indoor rotating Azimuth platform. In our approach we avoid having any cryogen line routed through the main telescope Azimuth cable wrap, instead we will implement an automated LIN transfer coupling which is activated once during day time when the telescope rotation is in parking position. The baseline plan is to refill the 10 $m^3$ LIN buffer tanks located at the Azimuth platform during this period within 1 – 2 hours. There will be two 10 $m^3$ buffer tanks, one for the Nasmyth-A instruments and one for Nasmyth-B. From the buffer tanks there will be fixed piping all the way up to the Nasmyth platforms, where the LIN is distributed to the individual instruments. So-called phase separators with about 0.1 $m^3$ LIN volume (tbd) will be interconnected right before the instruments to provide them with constant LIN supply pressure. In the current concept it is not planned to have any auxiliary LIN pumps installed, LIN flow is generated by pressurized systems.

The buffer tanks are dimensioned by taking the requirements in table 3 into account. Therefore the daily steady state LIN consumption is foreseen to be around 1000 L. Adding the worst case pre-cooling consumption, in this case (HARMONI) 8000 L in 48 hours, respectively 4000 L per day, we will consider 5000 L per day. Allowing a factor of two contingency, in case the buffer tank refilling is for whatever reason not possible at a certain day, we end up with 10000 L. Note, there will be only one instrument pre-cooling at the same time, so in nominal steady state operation of all instruments, we will have comfortable margin, even if we decide not to refill the buffers daily, or we do not fill them up completely because we cannot afford exceeding a certain refilling period (e.g. max. < 1 hour).

## 5.2 Cryo-cooler infrastructure

The cryo-cooler cold heads are an integral part of the instruments. The instruments will be built and acceptance tested in Europe using the final cold head and compressor units but with temporary 20 m Helium lines. After being shipped to Armazones, the compressors will be integrated with the central compressor plant which is located at the Azimuth platform of the telescope. Including contingency and having enough units for in-situ maintenance (swapping of compressors), we plan to install 12 similar units per Nasmyth platform, in total 24 for both platforms. Figure 10 gives an impression about the preliminary design of 12 compressors in AV-mounts. It is foreseen to enclose the compressors in a thermal and sound insulation housing. Fixed piping of in total 100 m length one way will be installed between compressors and cold heads, with some meters of flexible lines at both ends. Preliminary tests confirmed that these long lines are compatible with the selected PTCs PT410 and 810.

Placing the compressors at the vibration sensitive Nasmyth platform is not considered as an option. However, in the first studies it was proposed to place them in the basement of the telescope building which would have required routing the Helium lines through the main Azimuth cable wrap. Generally, we have reasons to avoid placing cryogen lines in cable wraps, therefore there are several technical justifications to put the compressors at the Azimuth platform:

a) Routing Helium lines through the cable wrap would require much longer lines, probably around 250 m. Running PTCs with such long lines is technically excluded. We are running the first PTC system world-wide with 100 m long lines and according to the manufacturer(s) this is the upper limit.

b) Access to items in the main cable wrap is in case of damage / maintenance / upgrade etc. very difficult, and repair activities will block the telescope rotation for a longer period. This is not the case when the lines are routed from Azimuth to Nasmyth platform.

c) The Helium lines of PTCs are also a source of vibrations. It is impossible to isolate these vibrations when routing the lines through the main telescope cable wrap. Damping and specific vibration isolation is much easier to implement when routing them from Azimuth to Nasmyth platform.

### 5.3 Discussion of concerns

We have a series of concerns which will be briefly discussed below:

- High altitude: Not an issue for the proposed cryo-cooler systems. Good experience with MATISSE.
- Low humidity: Should not be an issue for the compressors. We are running two PT410 in VLT environment without problems.
- Altitude difference between foundation / Azimuth platform / Nasmyth platform: Not an issue of high pressure Helium systems as proposed. Also not an issue for the proposed LIN distribution system working with accordingly high pressure levels.
- Ambient temperature as low as -10 °C: Would probably be a problem to start the compressors cold, but they are located inside a thermal enclosure. Compressor was successfully started at -3 °C.
- Cooling water temperature: The compressors have a certain cooling water temperature vs. flow rate envelope. We have to make sure to meet this specification in the ELT environment.
- Location of compressors: The technical best solution is to put them at the Azimuth platform, in between the two Nasmyth platforms. However, this approach is not approved yet. We still have to prove that this arrangement is compliant with the vibration requirements.
- Large dimensions within ELT: Main concern were the long Helium lines. Solved for the 100 m version.
- PTC MTBM: Every 4 years of operation each cold head will be replaced by a spare unit. Accessibility implemented by instrument design. Mitigations for instrument downtime caused by cold head swap are in progress.
- Handling risks: Cold head swap requires practicing to exclude risks.
- Availability of LIN in Chile: Has been working well at VLT since more than 20 years. Not an issue for the needs of ELT.
- Avoid the logistics effort of portable LIN dewars: Our concept is eliminating portable dewars. A fully automated LIN distribution system is proposed for supplying instruments with bath cryostats, continuous flow system, and pre-cooling systems.
- Cryogen lines in cable wraps: There are no cryogen lines routed through the telescope cable wraps. Routing through instrument cable wraps and alternatives are under investigation.
- Automatic LIN transfer line coupling: This is the proposed solution for avoiding LIN transfer lines in the telescope Azimuth cable wrap. Standard solutions are available at the market, final version will be developed together with industry.
- Vibrations: This is an ongoing topic. We are progressing with simulations, requirements, measurements and the implementation of damping systems. Updates and more results will be presented in the future.

There are certainly more concerns in the loop but the list above is covering the presumably most critical issues. Fortunately we made good progress with solving already many of them.

## 6. CONCLUSION

ESO has acquired a solid background in developing cryo-vacuum systems for ground-based astronomical instrumentation. We are using the experience and lessons learned from the VLT for defining the ELT instrument requirements and for specifying the required instrument infrastructure. It is one of our major objectives to rely on proven technologies and commercial components in order to minimize technical risks and to avoid unknowns which come along naturally by entering a complete new dimension of extremely large telescopes and instruments.

As one of first tasks we were updating our cryo-vacuum standards in order to include the typical size of ELT and 3$^{rd}$ generation VLT instruments. A test facility was set up to specifically characterize cryo-coolers proposed for the ELT instruments in terms of cooling capacity and vibrations. The problem of requiring long Helium lines between pulse tube cooler cold head and compressor has been solved. A lot of effort is going into vibration simulations and measurements. Anti-vibration systems for cryo-coolers which were already successfully implemented in VLT instruments are being further developed and characterized for compliance with the demanding ELT vibration requirements.

A concept for the ELT cryogenic infrastructure which is based on a combination of open loop liquid nitrogen (LIN) cooling and powerful pulse-tube cryo-coolers (PTC) is presented, they are both proven technology with a very good perspective to be still available throughout the next decades.

After completion of the Nasmyth-A instrument PDR's in 2019, it is foreseen to finalize the cryogenic requirements. Thereafter it is planned to conclude the specifications of the ELT cryogenic infrastructure in a statement of work and continue the detailed design in partnership with an industrial partner. Due date for an acceptance tested cryogenic infrastructure is in advance of the arrival of the ELT first light instruments in 2024.


Figure 14: Artist impression of the first liquid nitrogen delivery arriving at ELT site at Cerro Armazones.

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