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Infrastructure Upgrade of UT1, UT2 and UT3 for the Implementation of Laser Guide Stars for the GRAVITY+ Project

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The GRAVITY+ project encompasses the upgrade of the Very Large Telescope Interferometer infrastructure and of the GRAVITY instrument to improve sky coverage, high-contrast capabilities, and faint science. The sky coverage is obtained by the use of one laser guide star on each Unit Telescope, but it first required an upgrade of the infrastructure of the telescopes, carried out over the last 18 months.

Introduction

The GRAVITY+ project (GRAVITY+ Collaboration, 2022) was launched in January 2022 after a year of conceptual study (phase A). It includes the development and implementation of one new laser guide star (LGS) single-conjugate adaptive optics (SCAO) system to replace the Multi Application Curvature Adaptive Optics modules (Arsenault et al., 2003) in operation since 2005 on each Unit Telescope (UT) of the Very Large Telescope Interferometer (VLTI). This module is implemented in the coudé path of the UTs with the deformable mirror at the position of the M8 mirror and the wavefront sensor in the coudé room which also contains the Star Separator and the Coudé Infrared Adaptive Optics Module. The LGSs are being developed in synergy with the Extremely Large Telescope programme. The design is based on those developed for the Adaptive Optics Facility (AOF; Arsenault et al., 2006, 2010, 2016) implemented on UT4. The laser itself is being developed by the German company TOPTICA and the Laser Projection Sub-unit (LPS) by the Dutch organisation TNO. The implementation of such a laser on the centrepiece of a UT necessitates a full upgrade of its infrastructure, which impacts the telescope from the top ring to the basement. Only UT4 is not affected by this upgrade requirement, given that it is already equipped with four lasers for the AOF. We require only one LGS per UT for GRAVITY+ so we decided to implement it on the side opposite (Nasmyth B) the optical coudé path used for the interferometer (Nasmyth A), so as to limit any potential vibration contamination coming from the cooling system and the electronics cabinets needed for the LGS.

Overview

A LGS is a complex system made up of several components implemented on several areas of the telescope (Figure 1).

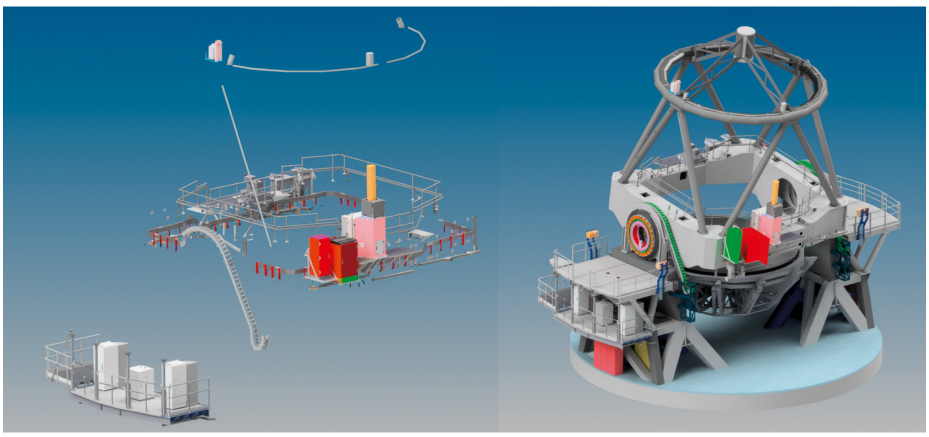
Michael Tucker Booth/ESO

Figure 1. Left: components implemented on the UT. Right: 3D view of the components on the UT.

Figure 2. Some of the team at the end of the UT2 centrepiece intervention in April 2023.

From top to bottom, we start with the Aircraft Avoidance Camera which is implemented on the top ring of the telescope and developed by the Italian company Astrel Instruments. It detects the approach of an aircraft and automatically closes the laser shutter if the aircraft gets too close to the laser beam. The Laser Pointing Camera (also from Astrel), which precisely defines the position of the laser on the sky, is also implemented on the top ring. The Laser Projector Sub-unit, a large optical tube 40 cm in diameter that is used to project the laser on the sky, is implemented on the centrepiece. Beside the optical tube lie the laser cabinet itself and the electronics cabinets for the LPS.

On the side of the telescope under the Nasmyth B platform, a new heat exchanger produced by the Italian company Tecoelettra and laser electronics Nasmyth cabinet are located on a newly implemented platform. Finally, in the basement the pumps to provide the cooling for the electronics cabinets and the laser are housed.

None of the UTs was developed — 30 years ago — with the infrastructure needed to carry such a system. The upgrade included a full adaptation of the centrepiece, an upgrade of the altitude cable wrap on side B, the implementation of a platform under the Nasmyth B (to carry the heat exchanger and one electronics cabinet) and the implementation of a cooling circuit from the basement to the sub-Nasmyth platform via the azimuth cable wrap.

These activities required two missions per telescope, corresponding to 30 nights out of operation per telescope. The adaptation of the centrepiece also required the removal of the primary (M1) mirror cell. We therefore coordinated our activities to benefit from the regular (every 18 months to 2 years) recoating of the M1 mirrors so as to minimise the number of nights out of operation. We also took the opportunity afforded by the recoating of the M1 of UT4 in May 2022 to make a thorough inspection and ensure that we had all the information needed to start work on UT3 in August 2022.

This work package had a highly constrained schedule, defined on the one hand by the recoating schedule of the M1 of the UTs (on average two UTs are recoated per year) and on the other hand by the need to deliver the work package before the Assembly, Integration, and Verification (AIV) of the GRAVITY+ adaptive optics modules planned in 2024. We decided not to follow a classical project development approach (design, then procurement, then manufacturing, etc.) but instead to do all of these activities in parallel, based on the knowledge gained from the AOF project 10 years ago. It required us to work with a lot of unknowns that could only be addressed progressively and we were able to correct errors thanks to the fact that we required two missions per telescope; we planned each set of two missions with enough time between them to prepare the needed corrections.

Finally, we also used the synergy with the upgrade of the Visible and Infrared Survey Telescope for Astronomy (VISTA) needed for the 4-metre Multi-Object Spectrograph Telescope (4MOST; De Jong et al., 2019) to employ a dedicated team from Paranal contractor LINKES to work on both projects. Around 60 people (Figure 2) participated in at least one of the seven missions that covered this global upgrade. It corresponds to 7.5 staff years of work and 36 missions from Europe to Chile.

Safety

This upgrade necessitated working at height, crawling inside the centrepiece, manipulating heavy loads, drilling, grinding etc. Safety was therefore one of the most fundamental aspects of the project. A scaffold (Figure 3) was necessary to safely access all the parts of the telescope, and the staff working on the top of the centrepiece were equipped with harnesses fixed on safety lines. Each manipulation of a heavy load was made by certified persons. Some specific tasks, such as the reconnection of the motors of the M1 cover (which protects the primary mirror), also required the use of an aerial lift.

All the activities were coordinated with the Paranal Safety Office and every morning the work started with a reminder of the safety rules applicable to that day. We succeeded in avoiding any injuries, but we did have few near-miss incidents, all linked to dropping small objects such as screws. The largest object dropped was a one-litre plastic bottle, from the dome roof during cleaning.

We also implemented a safety barrier all around the centerpiece to allow better protection than afforded by the former safety line (Figure 4).

Scaffolding

We had two different versions of the scaffolding, depending on the type of activity. The larger one was dedicated to the upgrade of the centrepiece and the smaller one was for the work on the altitude cable wrap B. The implementation of the scaffolding was contracted to the Chilian company AKSIOM, which allowed it to be fully designed, tested, and certified. The larger one, which weighed 9 tonnes, required a day to implement by 10 persons.

Centrepiece

The centrepiece is the backbone of the telescope; it supports on its lower side the primary mirror cell and on its upper side the Serrurier truss which in turn supports the top ring, the spider, and the secondary mirror. The centrepiece rotates around the altitude axis, so the power, cooling, and data transmission needed to control the secondary mirror and the primary mirror cell are transferred via the altitude cable wraps and the centrepiece. Upgrading the centrepiece

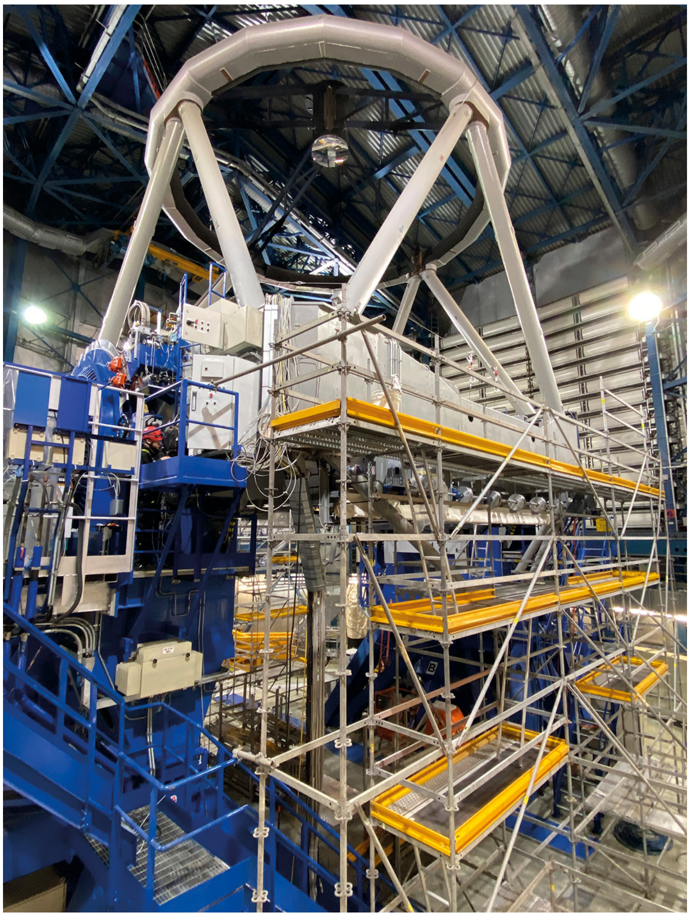

Figure 3. Scaffold erected on UT3 during the upgrade of the centrepiece in August 2022.

Juan Beltran/ESO

Figure 4. UT2 centrepiece at the end of the intervention in April 2023.

Figure 5. Inside the centrepiece of UT1 in August 2023.

required the transfer of all the cables, hoses, and pipes from on top to inside the centrepiece (Figure 5), the drilling and tapping for the later implementation of the LGS, the implementation of cable trays, cables and hoses dedicated to the LGS and the integration of a safety barrier to ensure that no one could fall when working on the LGS. This upgrade required around 1200 holes per UT to be drilled and more than 500 threaded, several areas to be cut and ground (Figure 6) to allow a better interface contact, 100 metres of cable trays to be added inside and on the side of the centrepiece, and 120 metres of hoses and a kilometre of cables to be fixed onto the cable trays.

Amusingly, inside each centrepiece, in the same area on the side of Nasmyth B, we found the remains of one cigarette butt left by workers during the manufacturing of the centrepiece 30 years ago, as if it was a kind of signature.

Altitude Cable Wrap

The altitude cable wrap routes all the cables and hoses needed for the centrepiece, the primary mirror cell, and the secondary mirror. Each UT has two altitude cable wraps, one on each Nasmyth side. The LGS, that projects a laser of 20 W, requires a lot of electrical power and consequently a lot of cooling power. A high-speed data transmission line is also needed to allow its control. All these hoses, cables and fibres must go via the altitude cable wrap. We only needed to upgrade the altitude cable wrap on side B. These cable wraps have been in operation for 25 years (first light of UT1 was in May 1998; see Giacconi, 1998). They carry the marks of age and of good service. We used the opportunity of the upgrade to replace all the roller bearings and plates, in hopeful expectation of 25 more years of good service.

The extraction of the altitude cable wrap, which weighs around 400 kilograms, is a complex intervention which requires 10 people and the use of the dome crane and several chain hoists (Figure 7). It is lowered centimetre by centimetre onto the azimuth platform. The replacement was even more complex than the extraction as we had to take care to not damage any cables or fibres inside the cable wrap.

The cable wrap, when installed, is connected on its two sides to so-called junction boxes. They contain hundreds of electrical and optical connections. These two cabinets also had to be removed and replaced with bigger ones to allow the needed connections for the LGS and the implementation of the controllers for the Aircraft Avoidance Camera and the Laser Pointing Camera, which are both installed on the top ring of the UT. This reconnection takes on average four days by five to six persons.

Sub-Nasmyth B Platform

The sub-Nasmyth B platform is located 3 metres directly under the Nasmyth platform. It is made of two structural sections, the largest one being 8.5 metres wide and weighing a bit more than one tonne. They were manufactured in Europe and transported by ship. They were the largest elements of this upgrade. It took six people over four days to implement the two platform structures (Figure 8). The structure of the telescope had to be ground, drilled, and tapped to allow a good surface contact at the bolted connection between the platform and the structure. This platform is linked to the Nasmyth platform by four pillars. It will carry three cabinets for a total load of around one tonne.

The implementation of each platform section was basically made in two steps: first the dome crane was used to bring the platform close to its final position then several chain hoists were used to allow the precise positioning before being bolted. The grating and the handrails could then be fixed on to the platform.

Figure 6. Grinding the surface of the telescope structure to ensure a smooth interface.

Figure 7. Implementing the upgraded cable wrap at Nasmyth B on UT2 in June 2023.

Figure 8. Transfer of the largest part of the sub-Nasmyth platform B on UT2 in June 2023.

Cooling from basement to centrepiece

The pumps for the cooling are in the basement of the telescope. It means that the two cooling circuits needed for the LGS must be routed via the azimuth wrap, the altitude wrap, and through the centrepiece, to finally reach the electronics cabinets attached to it. One circuit requires very precise temperature control for the laser itself and then it is connected to the heat exchanger on the sub-Nasmyth platform. The second circuit follows the standard implementation on Paranal, and its temperature is controlled compared to the dew point. Finalising the implementation of the cooling is the last step of the upgrade and it is planned to be completed in the first semester of 2024.

Conclusion

The upgrade of the UTs was the first step in implementing the LGSs on the UTs. The LGSs themselves will be implemented in late 2025. They are being installed to increase the capabilities of the VLTI; the use of the LGSs for GRAVITY and the VLTI will increase the sky coverage by an order of magnitude compared to the current capability.

But it will also be possible to use them for future instruments or if existing instruments are upgraded with the LGS SCAO system. This UT upgrade has also been done in such a way that it is already possible to implement several additional LGSs per telescope without a major intervention necessitating the dismounting of the M1 or of the cable wrap.

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