Progress on the VLT Adaptive Optics Facility

Robin Arsenault[1]
Pierre-Yves Madec[1]
Jérôme Paufique[1]
Stefan Ströbele[1]
Jean-Francois Pirard[1]
Élise Vernet[1]
Wolfgang Hackenberg[1]
Norbert Hubin[1]
Liselotte Jochum[1]
Harald Kuntschner[1]
Andreas Glindemann[1]
Paola Amico[1]
Miska Lelouarn[1]
Johann Kolb[1]
Sébastien Tordo[1]
Robert Donaldson[1]
Christian Sönke[1]
Domenico Bonaccini Calia[1]
Ralf Conzelmann[1]
Bernard Delabre[1]
Mario Kiekebusch[1]
Philippe Duhoux[1]
Ivan Guidolin[1]
Marco Quattri[1]
Ronald Guzman[1]
Bernard Buzzoni[1]
Mauro Comin[1]
Christophe Dupuy[1]
Jutta Quentin[1]
Jean-Louis Lizon[1]
Armin Silber[1]
Paul Jolly[1]
Antonio Manescau[1]
Peter Hammersley[1]
Javier Reyes[1]
Andreas Jost[1]
Michel Duchateau[1]
Volker Heinz[1]
Clémentine Bechet[1]
Remko Stuik[2]

[1] ESO
[2] Huygens Laboratory, University of Leiden, the Netherlands

The Very Large Telescope (VLT) Adaptive Optics Facility is a project that will transform one of the VLT's Unit Telescopes into an adaptive telescope that includes a deformable mirror in its optical train. For this purpose the secondary mirror is to be replaced by a thin shell deformable mirror; it will be possible to launch four laser guide stars from the centrepiece and two adaptive optics modules are being developed to feed the instruments HAWK-I and MUSE. These modules implement innovative correction modes for seeing improvement through ground layer adaptive optics and, for high Strehl ratio performance, laser tomography adaptive correction. The performance of these modes will be tested in Europe with a custom test bench called ASSIST. The project has completed its final design phase and concluded an intense phase of procurement; the year 2011 will see the beginning of assembly, integration and tests.

Overview

The ESO VLT Adaptive Optics Facility (AOF) is upgrading one of the Unit Telescopes (UTs) with a new secondary mirror (M2) unit. This unit includes an adaptive secondary mirror (with 1170 actuators), four laser guide stars (LGS) formed by four 22 W sodium beacons launched from the telescope centrepiece and a dedicated adaptive optics (AO) instrument park to provide users with optimised AO correction modes. The two AO components are GALACSI, the AO module for MUSE that will provide ground layer adaptive optics (GLAO) correction and a laser tomography correction for MUSE's narrow-field mode for high Strehl ratio correction in the visible spectral range, and GRAAL, the AO module for HAWK-I, which will provide only ground layer adaptive optics correction. The Adaptive Secondary Simulator and Instrument Testbed (ASSIST) will be used for a complete test phase of the AOF in Europe. This project constitutes a major stepping stone towards the European Extremely Large Telescope (E-ELT).

GALACSI is a module mounted at the Nasmyth focus; it contains four LGS wavefront sensors (WFS), a natural star tilt sensor and an infrared low-order sensor. The laser guide stars and WFSs can be tuned to two different fields of view: a 1-arcminute field of view for GLAO correction, producing a gain of two in ensquared energy at 750 nm; and a 7.5-arcsecond field of view for laser tomography correction, providing a high Strehl ratio in the visible (5 % at 650 nm) on-axis.

GRAAL is similar in design to GALACSI, but only applies a GLAO correction to improve the ensquared energy in the *K*-band by a factor of two over the 7.5-arcminute field of view of HAWK-I. The four LGS WFSs are mounted on a rotating bearing inside the Hawk-I housing, while a natural guide star tilt sensor picks up a star in a ring outside the Hawk-I field of view. An additional natural guide star WFS is used for calibration and maintenance operations of the deformable secondary mirror (DSM).

The GALACSI and GRAAL real-time computers share identical SPARTA hardware architecture and most software features. SPARTA is a standard platform for real-time applications developed by ESO's Adaptive Optics Department and uses a hybrid architecture of a field programmable gate array, digital signal processor and central processing unit. It is designed to be flexible by offering sophisticated software control and post-processing features while accommodating various combinations (numbers) of WFSs and deformable mirrors. All WFS cameras and tilt sensor cameras are identical and use as detectors e2v CCD220 devices controlled by the New General Controller (NGC; Baade et al., 2009) developed by the ESO Optical Detector Team.

Status of the project

GALACSI

The GALACSI AO module design and manufacture is led by the ESO AO Department with the support of other ESO divisions (the Technology Division, Integration Department of the Instrumentation Division and Software Development Division). The main mechanical structure and optics have been outsourced to industry and off-the-shelf components are being purchased for the electro-mechanisms. The control software is being developed in-house and integration will be undertaken by the Integration Department. The mechanisms are controlled via the remote motor controller switching system based on the controller area network protocol. The final design review was held in June 2009 and several important procurements were launched at that stage. GALACSI's main structure, manufactured by Bossenkool (the Netherlands), has gone through final

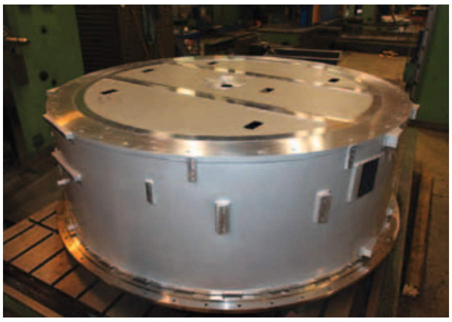


Figure 1. GALACSI's main mechanical structure is shown during acceptance at Bossenkool (the Netherlands) in September 2010.

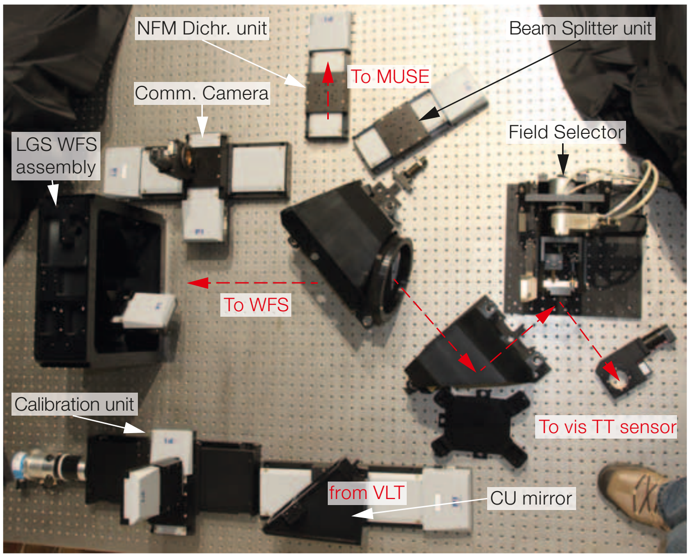


Figure 2. Several smaller mechanical components of GALACSI's optical train are shown.

acceptance and was delivered to ESO in October 2010; it is shown in Figure 1. The optics is being manufactured by SESO (France) and delivery is expected in December 2010. Several smaller mechanical components have already been received and are being tested and some are shown in Figure 2. The field selector is a critical key system and the positioning stages manufactured by Physik Instrumente have been received and are currently being tested. The electronic control is progressing steadily and several VME racks are complete and have been integrated into the cabinets.

The assembly and integration of GALACSI started in the ESO integration hall during the autumn of 2010 and will continue throughout 2011. The stand-alone test for the GALACSI module (without the DSM) will begin in 2011 to validate the whole assembly without the other major subsystems of the AOF. The complete system test phase for GALACSI with the DSM on ASSIST is expected to start in early in 2013 after GRAAL has completed its corresponding phase.

GRAAL

The GRAAL module is also led by the AO Department with support from the same departments as GALACSI, but with one main difference: a major contract has been issued for the important task of manufacturing and integrating the main structure and opto-mechanics, including all stages (provided by ESO) and the WFS co-rotator. This contract is being undertaken by NTE SENER S.A. (Spain) and will be completed in early 2011. This scheme will give the integration activities a strong start in Garching. The optics is also being manufactured by SESO and delivery is expected in December 2010. Several software modules are being developed in common for GRAAL and GALACSI and there are synergies between both. During summer 2010, a VLT standard software module was delivered to NTE SENER S.A. with the corresponding hardware to control the co-rotator (consisting of an internal bearing and drive system to rotate the four LGS WFSs) and is being used by NTE SENER S.A. for their integration and testing process, as shown in Figure 3.

When the GRAAL main structure is delivered to Garching early in 2011, the optics will be integrated with the rest of the electronics and software. GRAAL tests in stand-alone mode should start by late 2011 to prepare for a system test phase with the DSM on ASSIST in 2012.

Deformable secondary mirror

The deformable secondary mirror is being outsourced to MicroGate and ADS (Italy) and is the heart of the Adaptive Optics Facility. This contract completed its final design review in December 2007 and assembly started at the end of 2009. Several key components have been received by the suppliers and work is progressing along two parallel paths at MicroGate, where the electronics and software are being developed, and at

Figure 3. GRAAL's main structure is shown being integrated and tested at NTE SENER S.A. in Spain.

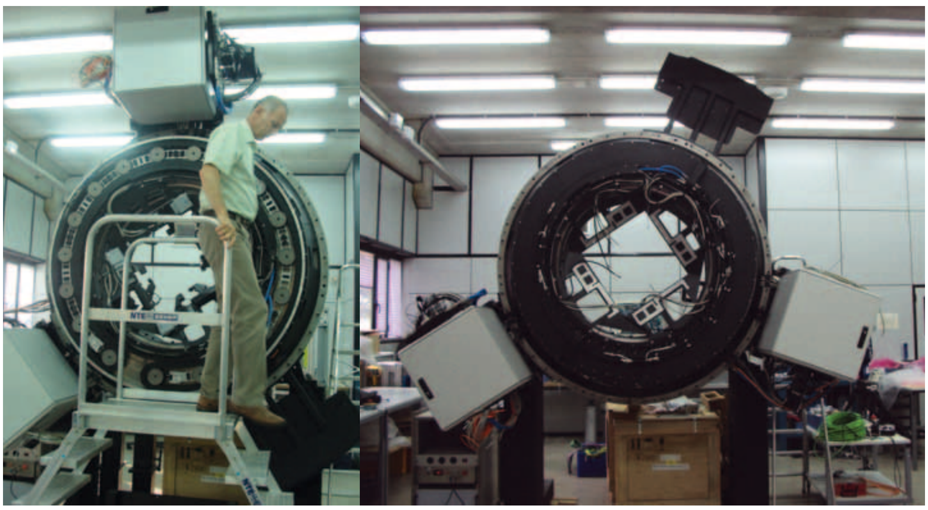


Figure 4. Part of the DSM reference body made by SESO in France (see the image on p. 4, upper, for the whole DSM). The intricate rib structure is literally sculpted from a monolithic block of Zerodur. The 1170 circular holes allow passage for the actuators. This process, known as lightweighting, reduces the mass by 80 % to a mere 35 kg.

ADS where the electro-mechanics is being assembled and manufactured. The main highlight of 2010 has been the delivery of the reference body, a Zerodur 1.1-metre lightweighted optical component that provides the reference surface for the thin shell mirror, shown in Figure 4 (and featured in an ESO announcement[1]).

SAGEM (France) is continuing its efforts on the thin shell contracted to them by MicroGate. The convex side has been polished successfully to specifications and the thinning process from the backside is starting. Note that SAGEM is proceeding carefully and made a detailed analysis of the thinning process before finalising the details. Figure 5 shows the integration and service stand for the DSM and M2 hub. Figure 6 shows some of the electronic control boards for the DSM. The next step is a milestone in mid-2011 to review the progress of the integration. Delivery of the DSM to Garching is planned for early 2012, when the system test phase in Europe will begin.

The Four Laser Guide Star Facility

The Four Laser Guide Star Facility (4LGSF) project includes two important contracts contributing to the design and manufacturing of this system. TOPTICA Photonics, a company located near Munich, is responsible for the laser design and manufacture. TOPTICA has been selected as the preferred supplier after an initial call for tender and a competitive preliminary design with another supplier. The manufacturing contract was signed in June 2010. A final design review will be conducted in June 2011 and six months later a pre-production unit will be ready so that all the laser specifications can be verified. Then the four units will be produced. They consist of 1178 nm infrared fibre Raman lasers, doubled in frequency by second harmonic generation to 589 nm (see Bonaccini Calia et al. [2010] for details); Figure 7 shows the test laser setups. These lasers have very few components, require minimal optical alignment and occupy a small volume, all contributing to a greater reliability. This represents a major milestone in terms of simplicity, compactness and improved reliability. The current LGS system uses the PARSEC laser, which delivers 5 W of Na power and sits on a large optical bench located in the laser cleanroom below the Nasmyth platform of UT4. In contrast the TOPTICA 22W laser fits in a volume of half a cubic metre (excluding the electronics cabinets)!

TNO Science & Industry (the Netherlands) holds the second important contract. They will finalise the reference design provided by ESO and manufacture the optical tube assembly, which is the telescope part of the launch telescope system (see Figure 8). This is based on a two-lens design, the largest being 40 cm in diameter while a 30 cm beam is launched into the atmosphere. A 45-degree mirror steers the beam and allows the laser guide star to be pointed to the appropriate off-axis distance.

The ESO 4LGSF team is focusing on the rest of the laser system design: beam diagnostics and jitter control for fast beam pointing; optical and mechanical design; electronic and software design; and analysis of the whole system. Interfacing the 4LGSF with the UT and the

Figure 5. Integration and service stand for the DSM. The M2 hub, including the DSM, is mounted inside.

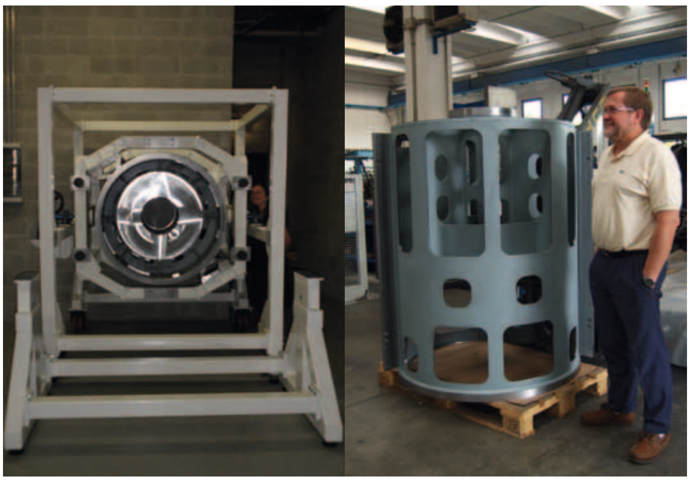
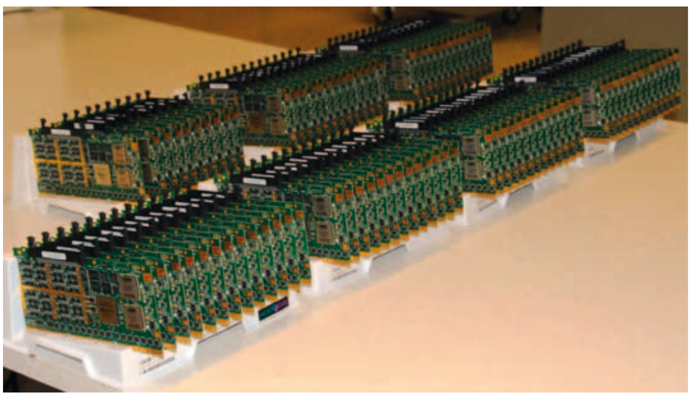


Figure 6. Electronic control boards for digital signal processing for the DSM. Each board controls 16 channels.



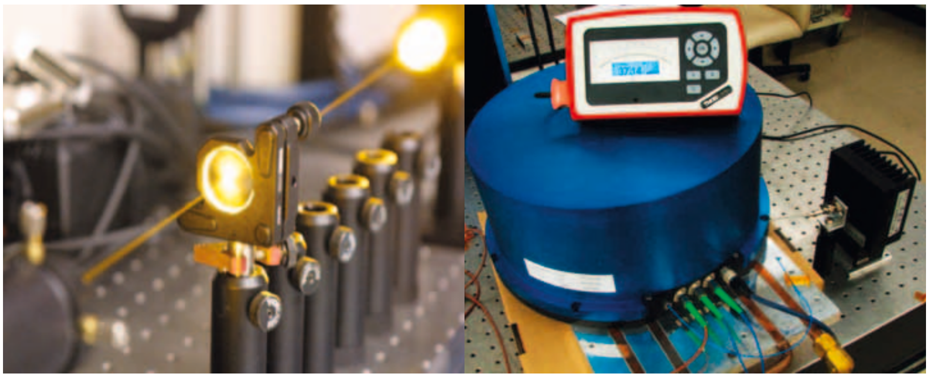


Figure 7. Left: The ESO Raman fibre laser used to test laser optics coatings for the launch telescope. Right: The single arm Raman fibre amplifier from MPB/TOPTICA showing the required 37.4 W of infrared 1178 nm power for the proper Na wavelength output power (image from April 2010).

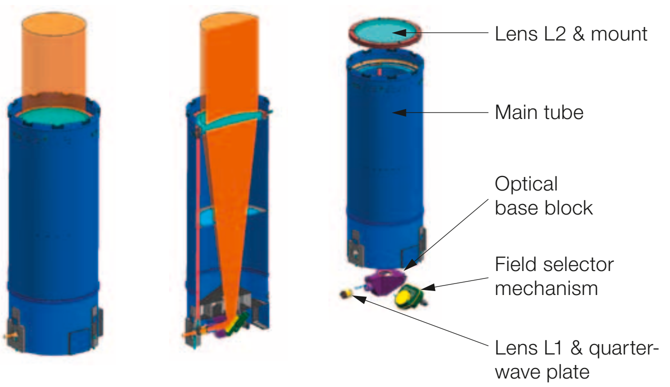


Figure 8. The optical tube assembly being developed by TNO Science & Industry. Together with the beam control and diagnostics system this assembly makes up the launch telescope system for the 4LGSF. Four similar units are mounted on the centrepiece of the UT to launch the four laser guide stars at 90 km altitude.

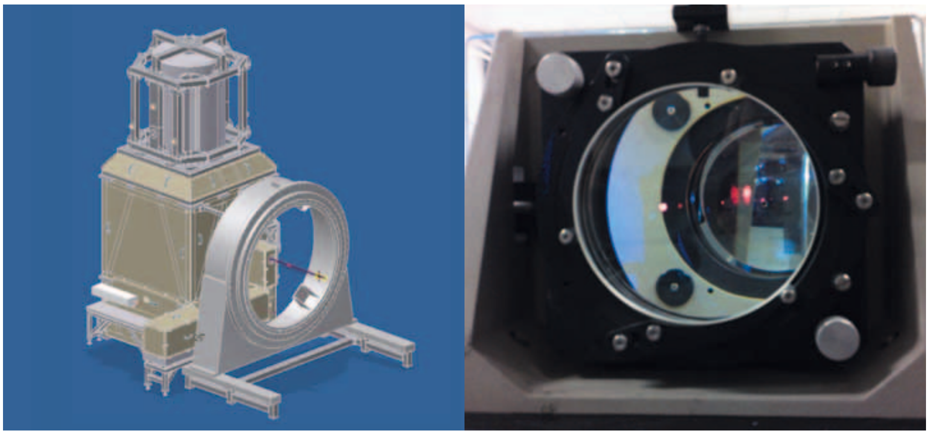


Figure 9. The ASSIST test bench (left) with the new generation M2 unit on top of the structure. The large 1.7-metre mirror is at the bottom (hidden by the light covers in this illustration) and the Nasmyth adaptor/rotator test bench can be seen on the right-hand side to allow the AO modules to be mounted. On the right is the secondary mirror (AM2), a 140 mm convex aspherical mirror manufactured by ASTRON, that completes the main tower optics of ASSIST.

mechanical design of the lasers and optical tube assembly interfaces also requires the team's full attention. Safety is important when designing with 22 W lasers as components and is taken very seriously by the team. A consultant has been contracted to provide support to the safety analysis and much has been learnt during the design of the current 4LGSF system.

The final design documentation for the 4LGSF is complete and the final design review will take place in January 2011. Procurement will then start for the opto-mechanical and electronic system assembly. A first optical tube assembly unit is expected for the summer of 2011 and the final design of the laser will be reviewed in mid-2011.

ASSIST

The ASSIST test bench is a key component of the Adaptive Optics Facility. It will allow full characterisation of the AOF in Europe before installation and commissioning in Paranal. It also offers stable, known and reproducible conditions of turbulence (simulated by phase screens) to establish whether the whole assembly (wavefront sensors, real-time computer, deformable mirror and the algorithms implemented) meet the performance specifications.

The most striking feature of ASSIST is that it requires a large 1.7-metre main mirror to feed the light onto the M2 convex deformable mirror. This mirror is manufactured by AMOS (Belgium) and is in the last stages of aspheric polishing (see Figure 9). Acceptance is planned for late 2010.

The bench consists of a tower with the 1.7-metre mirror at the base and the new generation M2 unit (hosting the DSM) on top (see Figure 10). A system of 45-degree mirrors will feed artificial sources from the side. A star simulator and turbulence generator feeds ASSIST with sources simulating natural and laser guide stars (with different focus positions) and three phase screens located at different altitudes. This setup allows realistic testing of the AO modules and complete testing of all the functionalities. ASSIST will be delivered to Garching in spring 2011 for integration in the large tower with the mirrors well in advance of the arrival of the DSM, planned for early 2012.

Unit Telescope upgrade

In April 2008 it was recognised by the project and upper management that the scope of modifications required to the UT that will receive the AOF were substantial and needed detailed planning and careful

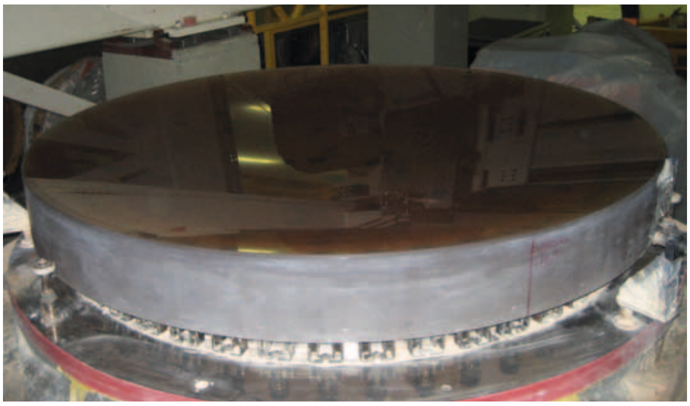


Figure 10. The main 1.7-metre mirror of ASSIST is shown at AMOS in Belgium during the last step of aspherical polishing.

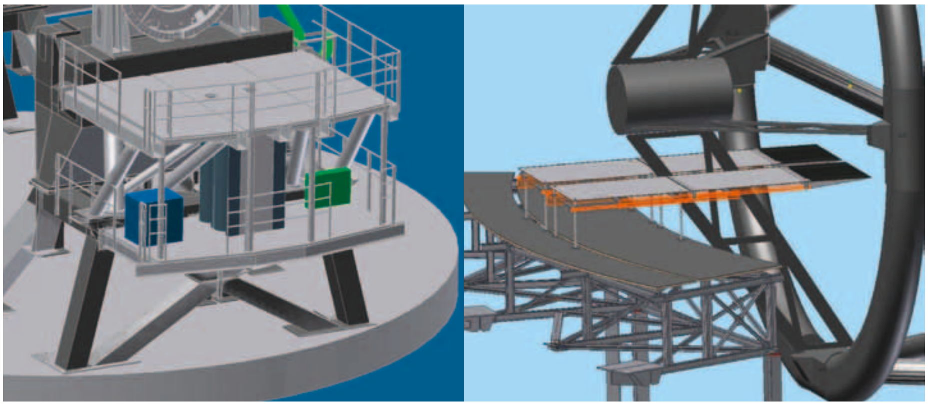


Figure 11. Left: Concept of a Nasmyth platform extension for the 4LGSF electronic cabinets and heat exchangers below the existing platform. Right: One of the two concepts for a deployable M2 maintenance platform to enable quick maintenance work on the new generation M2 unit.

implementation. A specific branch of the AOF project was created to manage this effort. At the AOF system final design review, held in April 2010, a large number of documents focused on this aspect and received the approval of the review board and the Paranal management. This review constituted the kick-off for this sub-project. The basis for the definition of the requirements is all the non-conformances identified in the Interface Control Document between the AOF and the VLT. This sub-project will implement: mechanical interfaces between the UT and the 4LGSF electronics cabinets and launch telescopes on the UT centrepiece (see Figure 11 left); overhaul of the cooling system and electrical supply; implementation of platform extensions to accommodate all the electronics cabinets; modification to the Nasmyth guider arm to accommodate the longer back focal distance of GALACSI–MUSE; definition of all cable (for power, signals, fibres, etc.) routing in the UT; development and implementation of a new, easier to deploy, M2 maintenance platform (see Figure 11 right); and specification of all the required assembly, integration and testing facilities needed in Paranal.

Complementary systems

There are a few important components of the AOF that are being developed as sub-contracts to other firms or to ESO departments. The real-time computer SPARTA for GRAAL and GALACSI is managed by a sub-group of the AO Department. The two identical real-time computers will be delivered to the AOF after SPHERE is delivered. SPHERE is a single conjugate AO system using a natural guide star on axis; the required functionalities will be re-used by the maintenance mode of GRAAL (for the natural guide star on-axis). The GLAO functionalities will build on this for the GLAO mode of GRAAL and GALACSI. These aspects will be completed by laser tomography AO functionalities for the MUSE narrow-field mode of GALACSI. The ESO Optical Detector Team is using the fast readout OCam (developed by LAOG, LAM and OHP; see Release eso0922[2]) to develop an NGC controller for the e2v CCD220 detector that will be used for the WFS cameras. Fifteen units have been ordered for SPHERE and the AOF.

Project outlook

The year 2011 will be an exciting one during which all the AOF project subsystems will start assembly and testing. The first science thin shell mirror and the GRAAL main assembly should be delivered during the first quarter of the year. GALACSI integration will already be underway and preliminary tests of the two AO module subsystems will take place in the course of the year. ASSIST will be delivered to Garching and integrated during the second half of 2011.

The AOF system test phase will start when the DSM is delivered in the first quarter of 2012 and will proceed with optical testing of the DSM, full system tests of GRAAL and then GALACSI. This will last for slightly more than one year. The 4LGSF integration and test proceeds in parallel to these activities and the first shipments to Paranal and the beginning of the commissioning activities will take place during the second half of 2013. This shipment will trigger intense commissioning activities involving the whole AOF team until the end of 2014, which is the project goal for provisional acceptance Chile.

References

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Baade, D. et al. 2009, The Messenger, 136, 20
Bonaccini Calia, D. et al. 2010, The Messenger, 139, 12
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Stuik, R. et al. 2010, Proc. SPIE, 7736, 3M

Links

1 Deformable secondary mirror: http://www.eso.org/public/announcements/ann1056/
2 OCam: http://www.eso.org/public/images/eso0922b/