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Manufacturing of the ESO Adaptive Optics Facility

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ABSTRACT

The ESO Adaptive Optics Facility (AOF) consists in an evolution of one of the ESO VLT unit telescopes to a laser driven adaptive telescope with a deformable mirror in its optical train, in this case the secondary 1.1m mirror, and four Laser Guide Stars (LGSs). This evolution implements many challenging technologies like the Deformable Secondary Mirror (DSM) including a thin shell mirror (1.1 m diameter and 2mm thin), the high power Na lasers (20W), the low Read-Out Noise (RON) WaveFront Sensor (WFS) camera (< 1e-) and SPARTA the new generation of Real Time Computers (RTC) for adaptive control. It also faces many problematic similar to any Extremely Large Telescope (ELT) and as such, will validate many technologies and solutions needed for the European ELT (E-ELT) 42m telescope. The AOF will offer a very large (7 arcmin) Field Of View (FOV) GLAO correction in J, H and K bands (GRAAL+Hawk-I), a visible integral field spectrograph with a 1 arcmin GLAO corrected FOV (GALACSI-MUSE WFM) and finally a LTAO 7.5" FOV (GALACSI-MUSE NFM). Most systems of the AOF have completed final design and are in manufacturing phase. Specific activities are linked to the modification of the 8m telescope in order to accommodate the new DSM and the 4 LGS Units assembled on its Center-Piece. A one year test period in Europe is planned to test and validate all modes and their performance followed by a commissioning phase in Paranal scheduled for 2014.

Keywords: Adaptive Optics, GLAO, LTAO, Deformable Secondary Mirror, Sodium Laser

1. INTRODUCTION

1.1 Project History & Status

The Adaptive Optics Facility (AOF) project has been launched in early 2006 after completion of a number of feasibility studies and formal approval by ESO Council. It constitutes a major evolution of one of the VLT unit telescopes to transform it into a laser driven adaptive telescope in which the corrective optics and the LGS Units are integrated. To this purpose the conventional Dornier M2 Unit is replaced by a Deformable Secondary Mirror with 1170 actuators, and 4 LGS Units are assembled on the telescope Center-Piece to focus 4 laser beams in the Na layer and create 4 bright artificial sources. Two adaptive optics modules GRAAL & GALACSI are developed implementing GLAO and LTAO correction to feed the instruments Hawk-I, a wide field infrared imager and MUSE and integral field visible spectrograph. All sub-systems but one have successfully exited final design phase and are now in the manufacturing phase. Procurement is about to be completed and after integration and test phase in Germany the complete system will be shipped to Paranal (Chile) for installation in the course of 2013. Note that a dedicated branch of the AOF project takes

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care of organizing and implementing the telescope modifications required for accommodating the new facility. The end of commissioning and availability to the scientific community is planned for end of 2014.

1.2 System Description

The Deformable Secondary Mirror (DSM) is the heart of the new facility. The design and manufacturing is done by Microgate and ADS (Italy) and the system is a logical evolution of the MMT and LBT adaptive secondary's. It implements all the VLT required functionalities plus the needed adaptive optics functions. 1170 force actuators are used to modify the shape of a 2 mm thick Zerodur thin shell. Voice coils are attached to a so-called cold plate that serves two functions: mechanical holding systems for the actuators and heat evacuation. The cold plate is also supporting the so-called reference body. This piece of optics, made of Zerodur, is used as an optical reference and is facing the thin shell rear surface with a gap of almost 100 microns in between. Magnets are glued onto the thin shell applying the deformation when the voice coils produce a magnetic field. Metallic coatings deposited on the reference body and co-located on the thin shell form 1170 capacitive sensors that are used in an internal control loop to maintain the mirror at the proper shape.

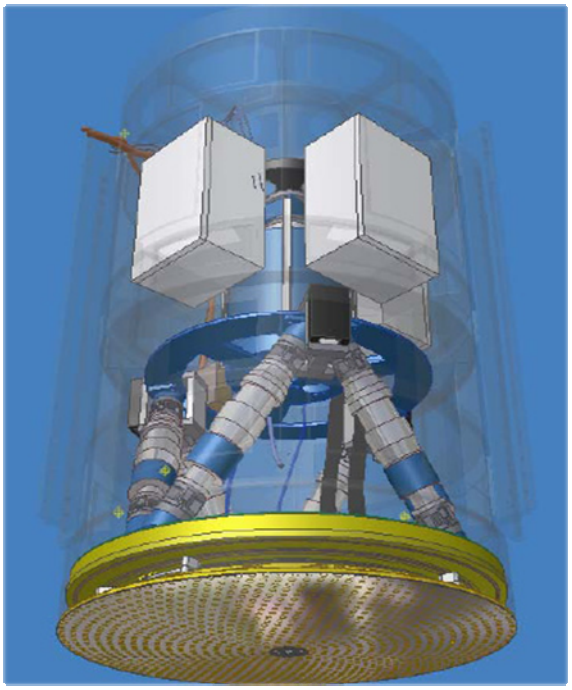

Figure 1: schematic of the DSM. The hub structure is transparent in order to show the inner components. Three electronic racks implement DSP's to control the internal loop between the voice coil actuators and the capacitive sensors. A hexapod provides the lateral and focusing motion of the mirror surface. The lowest part of the illustration show the cold plate, holding the actuators, the reference body and the 2mm thin shell mirror surface

Attached to the main structure of the telescope itself, the next more important sub-assembly of the AOF is the Four Laser Guide Star Facility (4LGSF) that provides all required hardware and software to launch the laser beams in the atmosphere. Each of the four laser units provides a 20 W beam launched through a 40 cm telescope. The laser design is based on a Raman Fiber Amplifier (RFA) technology first developed at ESO and subsequent frequency doubling realized by a Second Harmonic Generation (SHG) resonant cavity [1],[2].The laser also generates the Na D_{2a} and D_{2b} lines to promote back-pumping of the Na atoms and thus maintaining an efficient return flux for the WFS. Systems are compact and the lasers, plus beam diagnostic and launch telescopes are mounted directly on the telescope Center-Piece. Required proximity electronics are also mounted on the side of the center piece as illustrated on Figure 2.

The launch telescopes are x20 athermal beam expanders including only 2 single lenses with, in between, a 45deg steering mirror that can be tilted to point the beam at the appropriate location in a ±6 arcmin FOV. At the entrance of each launch telescope, a fast tip-tilt mirror controlled at 1 kHz is used to correct for laser jitter.

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The 4LGSF also includes safety interlocks, aircraft avoidance system and all software needed to be controlled by the AOF.

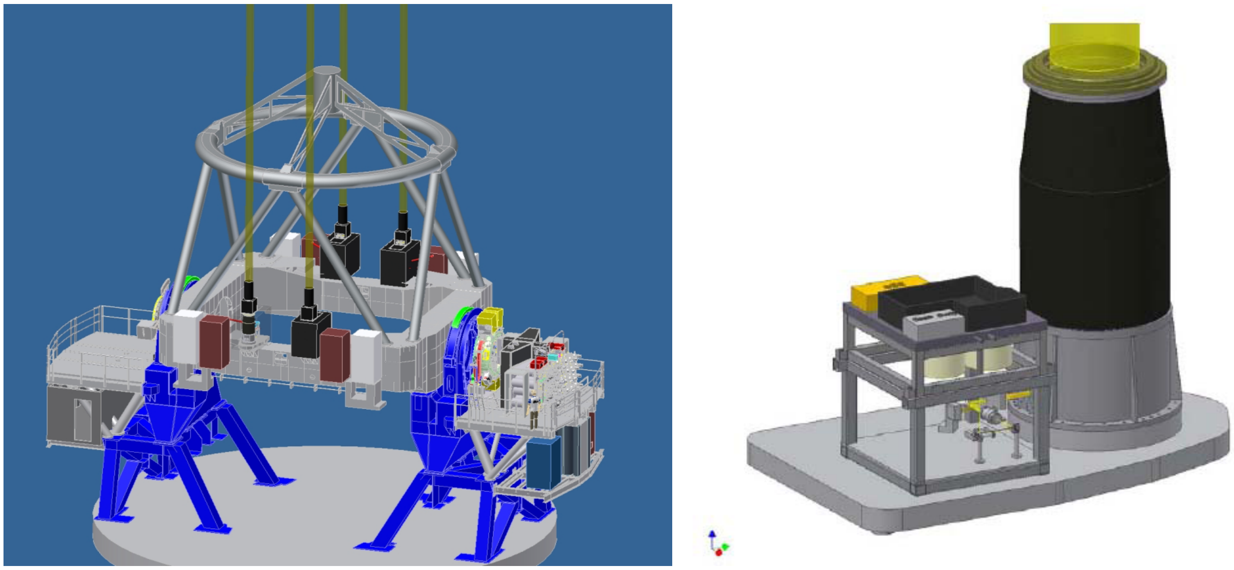

Figure 2: Left: the figure shows the telescope centerpiece, top-end and 2 nasmyth platforms of a VLT unit telescope. The black boxes represent the cover protection for the 4 launch telescopes. Lasers are located inside these covers. Two electronic cabinets per LGS Unit (proximity electronics) are also mounted on the centerpiece (here represented in brown and white). Right: the Launch Telescope assembly. The telescope can be seen on the right hand side. On the left bottom is the Beam Diagnostic & feed optics to the launch telescope. The fiber laser is sitting on top of the beam diagnostic system.

Besides the DSM and the 4LGSF, two AO modules are also developed: GRAAL and GALACSI.

GRAAL provides a GLAO correction for the Hawk-I infrared wide field imager [3]. The slopes measured by the four 40x40 subaperture Shack-Hartmann WFSs are averaged to command the 1170 actuators of the DSM. The tip-tilt is measured thanks to a Natural Guide Star (NGS) tip-tilt sensor. The WFS and tip-tilt sensor cameras used e2v L3 CCD taking advantage of their high quantum efficiency (more than 85%) and very low RON (less than 1e^{-} rms at 1 kHz frame rate). The simulations conducted so far are showing that GRAAL will reduce by 30% the diameter containing 50% of the energy in K band in the overall 7 arcmin scientific field of view of HAWK-I. The image quality in K band, as seen from HAWK-I, will be better that 0.3 arcsec almost 50% of the time, while this value is only very rarely reached without GRAAL. The probability to get an image quality better than 0.35 arcsec is doubled thanks to GRAAL. Performance is highly correlated to the concentration of turbulence in the lowest 500 m above ground.

GRAAL also includes a mode to perform natural guide star adaptive correction. This module consists in a refractive optics inserted in the beam to provide a higher detector sampling on the Hawk-I detector and feed to a natural guide star WFS. The latter is identical in design to the laser WFS used for GLAO correction. This mode will be used for the commissioning of the GRAAL system and also as maintenance mode to assess the ultimate performance of the DSM.

The second AO module GALACSI offers two correction modes to MUSE, a visible integral field spectrograph [4]: a GLAO mode very similar to GRAAL and a LTAO mode for high performance in a small FOV.

The GLAO mode is designed to increase the energy ensquared in the MUSE pixel by a factor of 2 in the visible over a 1 arcmin FOV. For this, it also makes use of four 40x40 subaperture Shack-Hartmann WFSs and one visible NGS tip-tilt sensor. The performance of GALACSI are similar to the ones of GRAAL but scaled to the visible wavelengths: 30% of the time, the image quality in the visible will be better than 0.3 arcsec, while this never happens without GALACSI, and it will be better than 0.4 arcsec for about 50% of the time.

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The LTAO performance in the visible is the greatest challenge of the AOF and requires tight error budgeting. It makes use of the same 4 WFSs as in GLAO mode, but with an IR 2x2 subaperture Shack-Hartmann Low Order Sensor (IRLOS) used to measure not only the tip-tilt, but also the defocus and the astigmatisms. The need for IRLOS comes from the indetermination of those five modes when using LGS tomography. The goal performance is a 5% Strehl Ratio at 650 nm in a 7.5 arcsec FOV, for a limiting magnitude of 15 (J-H band). Simulations performed show that GALACSI can provide this performance with a small additional margin. Performances are clearly limited by the residual tip-tilt when IRLOS is working at its limiting magnitude.

The design of both GRAAL and GALACSI (see figure 3) bears many similarities and synergies are put into play to ensure optimization of resources and moneys for the project: same real time computers, lenslet arrays, wavefront sensor cameras, ground support equipment etc.

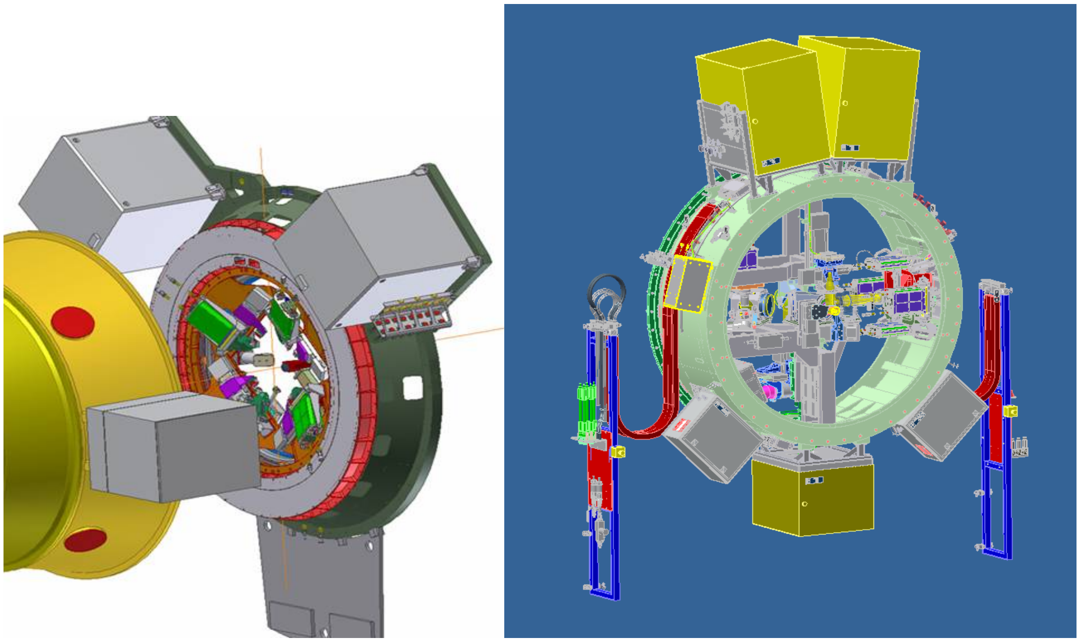

Figure 3: Left: the GRAAL module consists in a spacer sandwiched between the Nasmyth A/R and the Hawk-I infrared imager. The compact assembly implements the 4 laser guide stars WFS and the single natural guide star sensor for the maintenance mode. A critical item of GRAAL is a corotator bearing/drive system that allows rotation of the laser WFS with the pupil, while the whole GRAAL assembly rotates with the Nasmyth A/R to derotate the field on Hawk-I. Right: The GALACSI AO module. It implements four laser guide star WFS' and an optical beam allowing to pick-up the 4 laser guide sources at the 10 arcsec required for the LTAO mode and 85 arcsec for the GLAO mode. Note that MUSE is sitting on the Nasmyth platform and includes its own derotator for field derotation. Thus the Nasmyth A/R follows the pupil in order to keep the laser stars onto the 4 WFS.

And last but not least, ASSIST is the fifth major sub-assembly of the AOF. It is the AOF test facility, designed first to optically calibrate the DSM and then to provide all the tools required to test the behavior of both GRAAL and GALACSI and optimize their performance before going to sky. Due to the convex surface of the DSM, ASSIST is a complex and cumbersome test facility. It includes the so-called DSM tower (see figure 4 right), made of a 1.7 m diameter primary mirror combined to a small secondary mirror, constituting an interferometric cavity closed by the DSM. The DSM Tower will be used to optically calibrate the DSM actuators, record its influence functions and finally measure the set of forces required to “flatten” its optical surface and bring it as close as possible to the nominal optical prescription of the actual M2 Dornier.

Associated to the DSM Tower, two other modules are part of ASSIST; the Star Simulator and Turbulence Generator (SSTG) used to simulate sources (visible and IR NGSs and LGSs) and a three layer turbulence, and the VLT Focus Simulator (VFS) whose goal is to deliver a VLT-like focus and to provide mechanical interfaces to GRAAL and GALACSI. ASSIST has a 2.5 arcmin FOV diffraction limited in its central part and the distortion between the DSM and its image at the output of the VFS is constrained to 1% of the pupil diameter in the very worst case.

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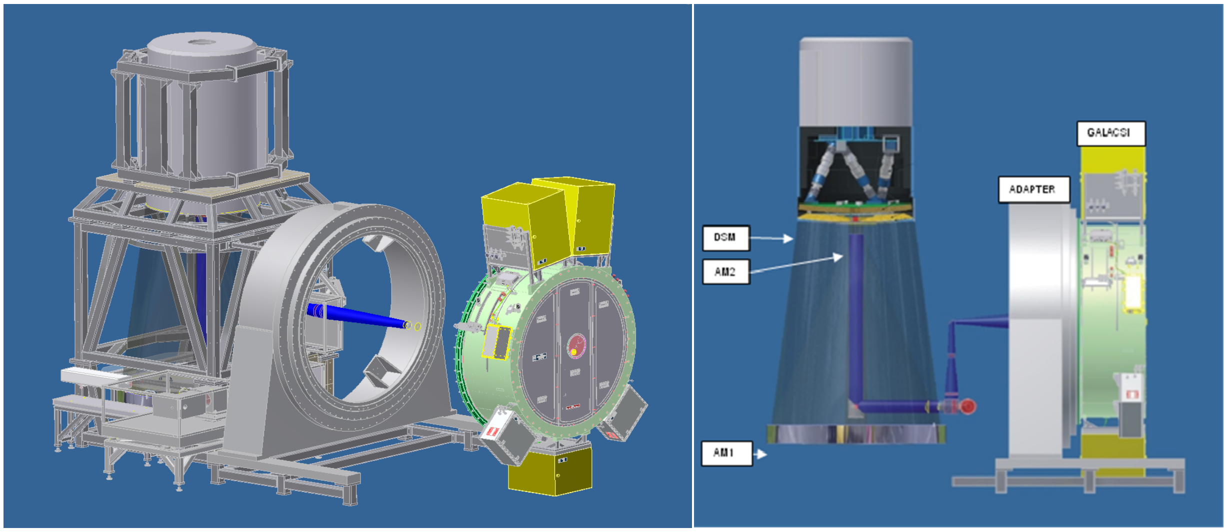

Figure 4: ASSIST the test bench for testing the AOF in Europe.

A source module will simulate a geometrical arrangements of science targets (to evaluate correction performance), and natural guide stars and laser guide stars (to feed the WFSs). A turbulence generator will simulate the seeing and turbulence layer distribution. The aberrated beam will be reflected onto the DSM and will feed the AO modules. Slightly more than one year will be required to perform the optical tests of the DSM, the performance tests of GRAAL and finally of GALACSI.

2. PROJECT PROGRESS

2.1 Deformable Secondary Mirror

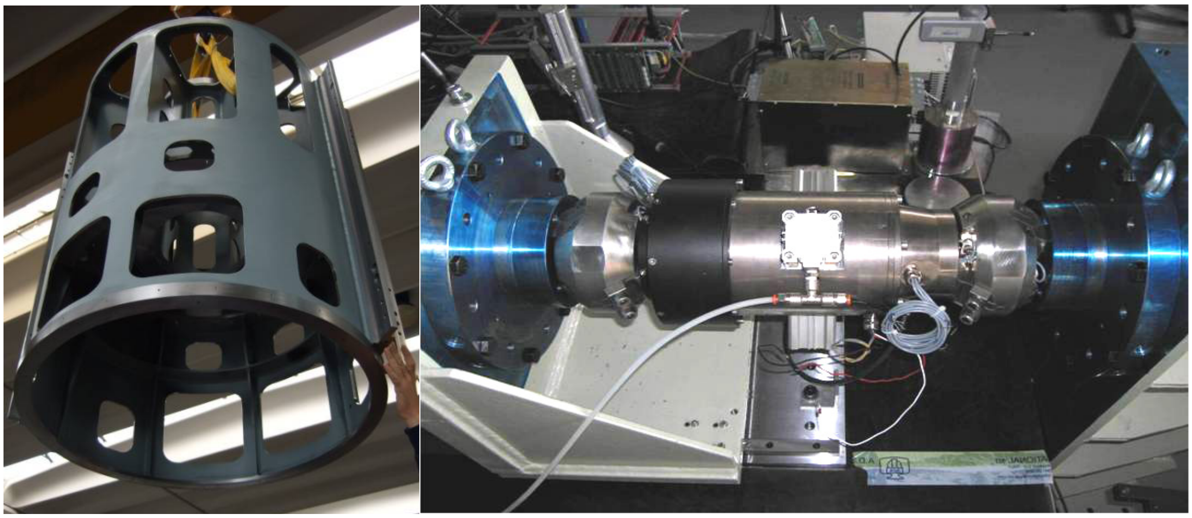

Figure 5: Left: the DSM hub structure. Right: a Hexapod actuator with flexible joints being tested.

The final design review took place in late 2007 and the main procurements are completed. The suppliers MicroGate and ADS (Italy) are proceeding with mechanical assembly and integration. The DSP-based internal control electronic is completed and SW development well advanced. Once the opto-mechanical integration is completed at ADS, the system will be shipped to MicroGate and coupled with the electronics. System integration will proceed until 2011, where most

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part will be used for final system tests and characterization. The acceptance by ESO is planned for early 2012 and delivery of the DSM to ESO Germany will follow.

The manufacturing of the 2 mm thin shell mirror is proceeding with some delays. SAGEM (France) has completed the aspherical convex polishing and is proceeding soon with the thinning process. Delivery of the first thin shell is expected for the end of 2010.

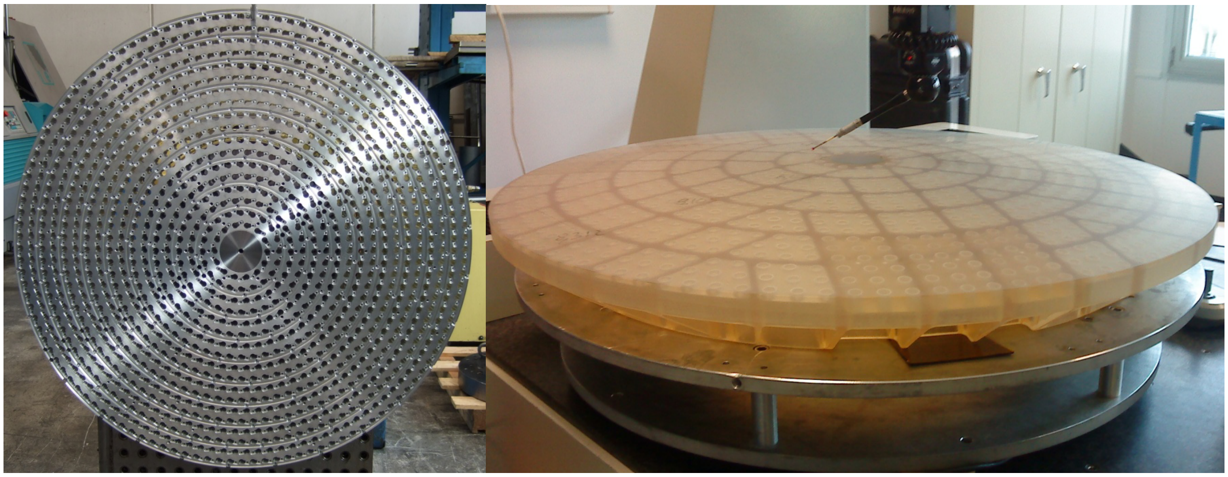

Figure 6: Left: the cold-plate. Right the Zerodur reference body: this optical component is manufactured by SESO (France) and an intricate light-weighting scheme brings the weight of this component to a mere 47 kg.

2.2 The Four Laser Guide Star Facility

The 4LGSF is made of 4 identical LGS Units. Each LGS Unit includes one laser unit, one Beam Control and Diagnostics System (BCDS) and one Launch Telescope. While the BCDSs are designed and assembled in-house, the laser units and the Launch Telescopes are outsourced.

The critical procurement of the laser units has been launched in 2009. Two potential suppliers were selected to provide a preliminary design and a financial offer for the following phase (final design and manufacturing). The competitive design reviews held in December 2009 allowed the selection of the single supplier for the final design and manufacturing. TOPTICA associated to MPBC (Germany - Canada) has been selected and will provide laser units based on RFA under ESO license.

The laser units will deliver a power of 20W, 18W in the Na D_{2a} line and 2W in the D_{2b}. The two lines will be very narrow (few MHz). The delivered beams will be diffraction limited, with high polarization purity and an excellent long term and short term power stability. The design of the laser units is amazingly simple from a conceptual point of view and shows great promises of being extremely reliable given the compactness, small number of components and low requirements on optical alignment. The high efficiency of the proposed lasers allows reducing the power and the cooling requirements.

A first laser pre-production unit will be available mid of 2011 and shall validate all ESO specifications and requirements. Then will follow the manufacturing of the 4 final laser units. Final delivery of the 4 units is slated for mid 2013.

The launch telescope assembly was outsourced to TNO (The Netherlands) and is based on an ESO design. It is a x20 afocal magnifier, with an $1/e^2$ diameter of 22 cm, diffraction limited over a ±6 arcmin FOV. It is made of two single lenses with a field steering mirror in between. A quarter wave plate is located at the entrance of the launch telescope to deliver a circularly polarized beam at its output. To maintain a high polarization quality, low birefringence glasses have been selected and a great care has been paid on the design of the mechanical mount of the exit lens (the larger one).

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The supplier has brought the initial concept to the level of a preliminary design and final design shall be completed by early fall 2010. Procurement for the blanks for the 40 cm exit lenses have been launched early this year. The launch telescopes will be delivered during 2011 and will initiate the assembly and integration phase of the 4LGSF system.

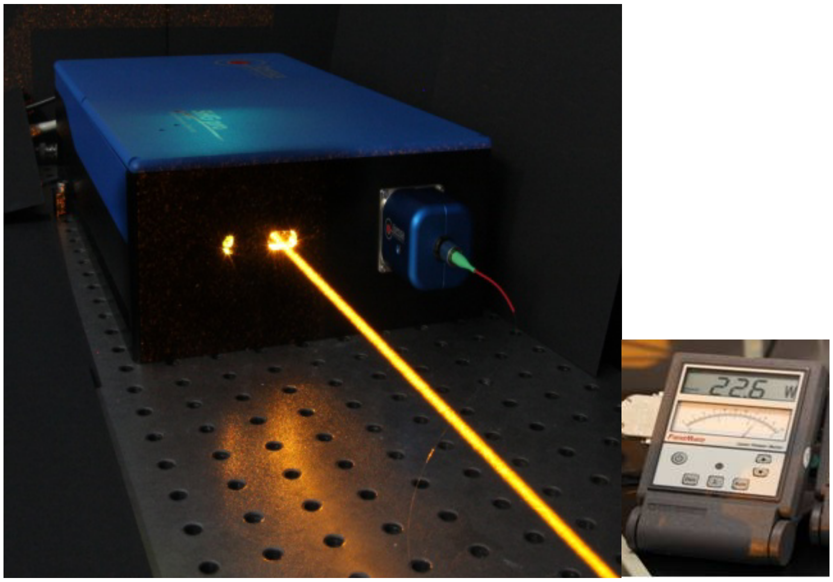

Figure 7: Prototyping of the laser unit at TOPTICA showing early on in the preliminary design phase a sufficient power to meet ESO specifications.

2.3 The GRAAL and GALACSI AO modules

The GRAAL AO module completed its final design phase in early 2009. An important procurement has been launched to supply the large mechanical structure end 2007; the contract has been placed to NTE Sener (Spain) and the delivery is expected to Garching early 2011 (see figure 8,9). The optics manufacturing is under contract by SESO (France) and should be delivered by the end of 2010. Most of 2011 will then be used to integrate the opto-mechanical modules into the mechanical structure and to start GRAAL test phase in stand-alone mode by the end of the year.

Figure 8: GRAAL Components: left, the main structure that will replace the spacer between the Nasmyth A/R and the Hawk-I instrument; it will contain all opto-mechanical components. Right: the WFS assembly pick-up arms with PI linear stages for the trombone (laser guide star focusing).

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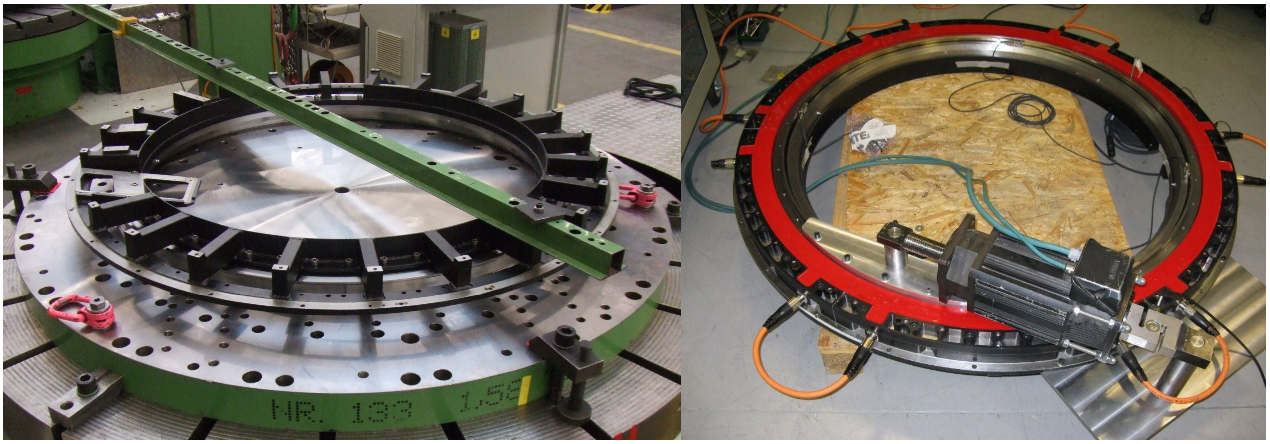

Figure 9: Left: the large bearing allowing co-rotation of the WFS assembly with the telescope pupil in order to keep the WFS pointing on the laser sources. The motorization of the assembly on the bearing is provided by a linear drive motor (right) and dedicated encoder (Phase Motion Control – Heidenhain). NTE Sener (Spain) is responsible for the manufacturing of the GRAAL Main Assembly.

The complete design, assembly and integration of GALACSI are managed by ESO. Main procurements have been launched after the Final Design Review that took place in June 2009: the main structure and a common test stand for GALACSI & GRAAL have been sub-contracted to Bossenkool (The Netherlands) while the main optics are manufactured under the same contract as GRAAL (SESO). All linear stages have been received and the Field Selector stage (part of the visible tip-tilt sensor) has been prototyped for verification against expected performance.

2.4 WaveFront Sensing Cameras

European Commission financing has been used to promote the development of high frame rate low RON CCD at e2v (United Kingdom). In the framework of this contract engineering and science devices have been delivered to ESO. In the meantime, the Laboratoire d'Astrophysique de Marseille (France) has designed and manufactured a controller, Ocam, allowing to test the critical specifications of these devices at e2v. This controller has been used as baseline for the design of the analog boards of the ESO New General Controller (NGC) associated with all the AOF WFS cameras. The ESO controller for the L3 CCD of the wavefront camera has seen first light early this year and sub-electron level RON has been measured (with gain amplification).

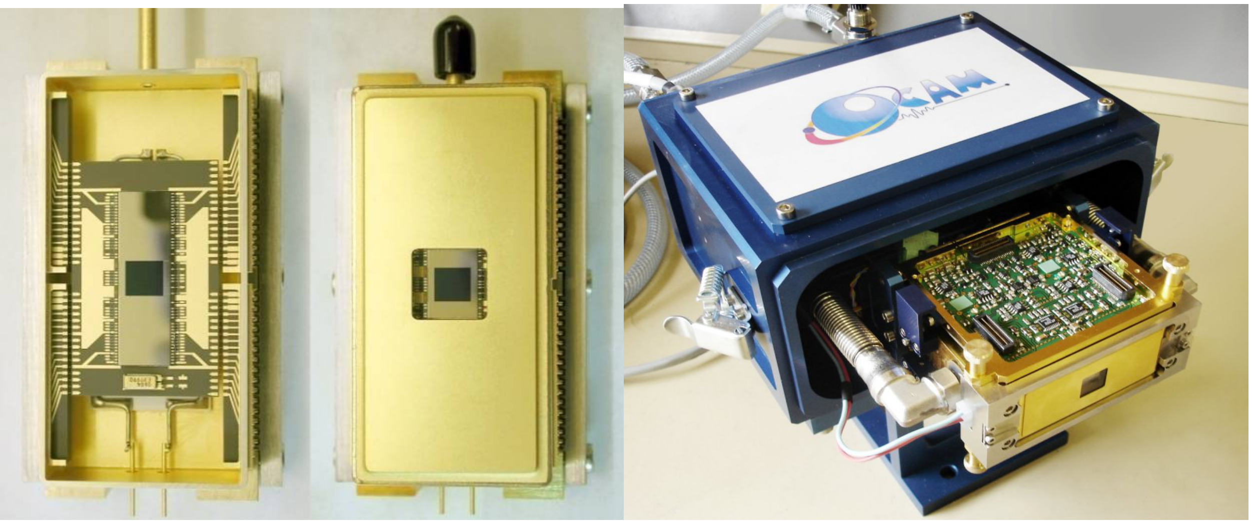

Figure 10: On the left a packaged e2v CCD220. On the right Ocam the controller developed at the Laboratoire d'Astrophysique de Marseille for the testing of the CCD220

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The e2v CCDs together with the ESO NGCs are assembled in mechanical frames providing cooling and power (see figure 11). The cameras built will be able to deliver up to 1000 frames per second with a RON lower than 1 e$^-$/pixel/frame. These are 240x240pixels cameras, equipped with 40x40 subapertures lenslet arrays.

All lenslet arrays for the wavefront sensors have been ordered to SUSS MicroOptics (Switzerland) and have been delivered.

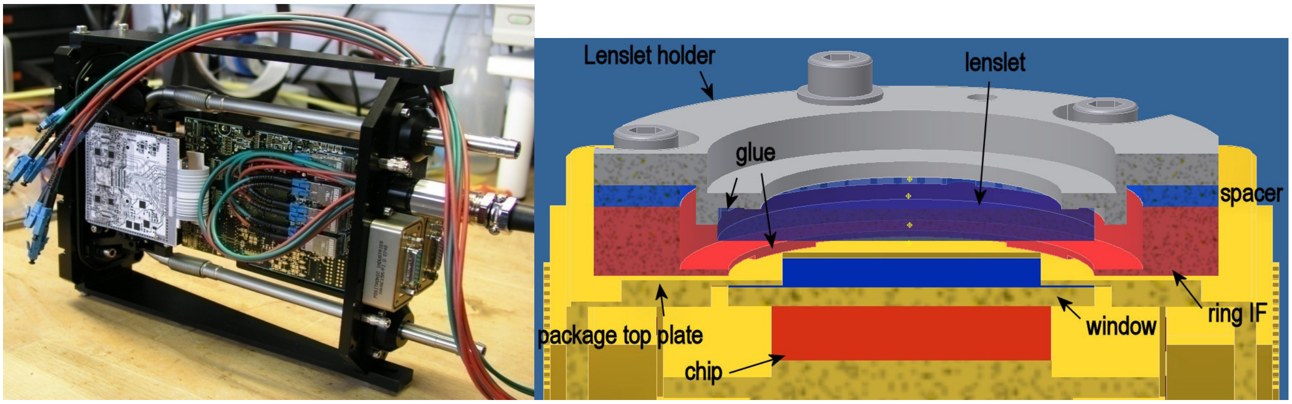

Figure 11: left the ESO controller; analog electronics is based on the Ocam one. There are severe space constraints on the housing of the controller due mainly to GRAAL and the compact design of the module. Right the ESO design for mounting the lenslets onto the CCD220.

2.5 SPARTA

The computer architecture of the AOF in charge of the real-time control of the DSM by processing the WFSs video stream is based on SPARTA [5], a highly scalable hardware and software platform developed at ESO for actual and future AO systems. The design of SPARTA is two folds (see figure 12).

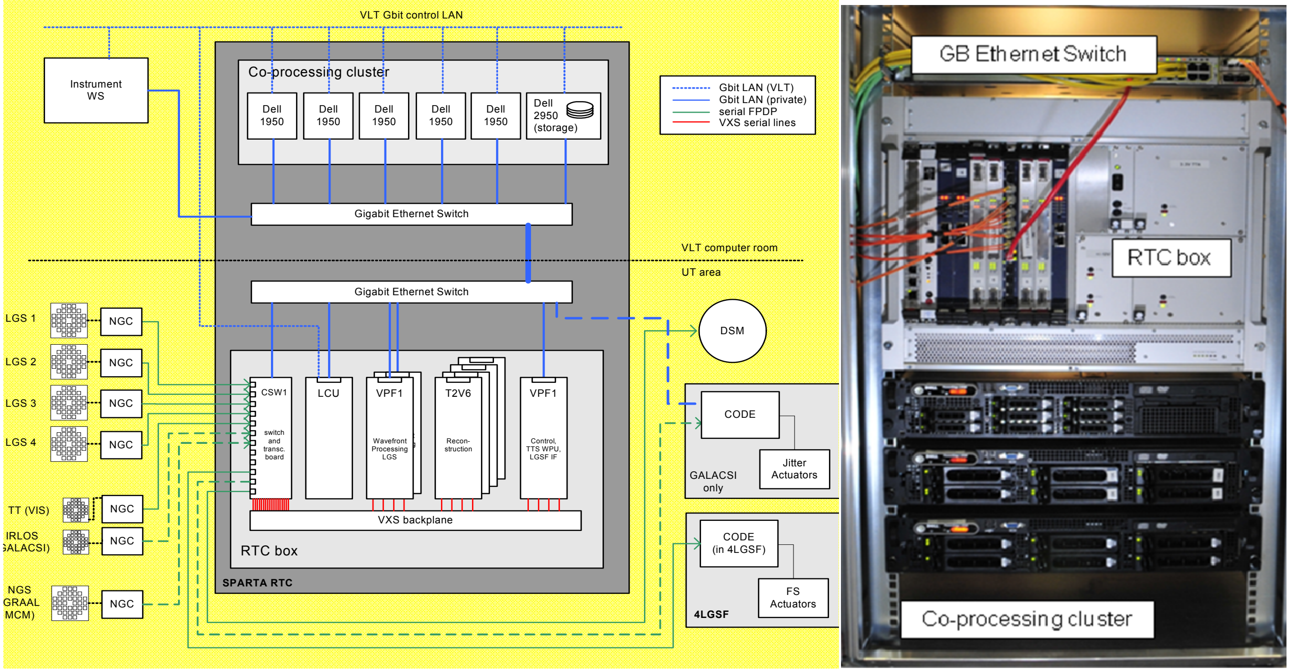

Figure 12: Left: schematics of SPARTA, with the low latency RTC (lower part) and the Supervisor (upper part). Right: the prototype of SPARTA, with the RTC designed for a single WFS “AOF” and a scaled down Co-processing cluster (Supervisor)

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A hard real-time system, the RTC box, is used to drive the AO control loops; it can receive data from multiple sensors (4 LGS WFSs + 1 NGS tip-tilt sensor for AOF) and can control multiple mirrors (the DSM + 4 LGS jitter mirrors for AOF) at high speed (1 kHz) with extremely low jitter and very low latency. The RTC is a very low total latency (<200us) multi-technology computer, using DSPs, FPGAs and CPUs depending on the relative balance between external communication requirements and computing load. FPGAs are managing real time communication, while DSPs are in charge of floating point operations and CPUs are used for monitoring and idle-time control.

A Supervisor is designed to control the real-time box, to implement the AO “business logic”, to handle computational intensive tasks like performance estimation, loop optimization, atmospheric statistics and calibration. It is based on a high-throughput, high-performance, parallel soft real-time system making use of High End Intel CPU / Multi-core / Multi-CPU and Linux based industry standard libraries and middleware.

A first prototype has already been developed (see figure 12); the end-to-end performance of the AOF instance of SPARTA have been verified to be in specifications.

2.6 ASSIST Test Bench

The ASSIST test bench is a key component of the AOF. It is expected that 2012 and part of 2013 will be used to perform complete system tests of the AOF. The first step is an optical calibration of the DSM and an ultimate validation of the system specifications. This is followed by tests with the GRAAL module using the maintenance mode. This will validate a single conjugate adaptive correction to high order. Only after this step, will the GLAO mode be tested. Finally the GALACSI system will be tested in GLAO mode and LTAO mode.

Figure 13: Polishing of the main AM1 mirror of the ASSIST test bench at AMOS (Belgium).

ASSIST is being developed by the University of Leiden; it has completed its final design phase in 2009 and is now into manufacturing. Note that the large 1.7 m aspherical mirror procurement has been launched earlier given its status of long lead item. It is being polished by AMOS (Belgium – see figure 13) and work should be completed by late 2010. The smaller secondary mirror is being polished by ASTRON (The Netherlands) while WINLIGHT SYSTEM (France) is manufacturing all the ASSIST optical modules (single lenses and doublets; plano mirrors; beam splitters). The mechanics of the main structure is being manufactured by Bossenkool (The Netherlands). The phase screens used in the input beam to feed the AO modules have been produced (SILIOS, France) and delivered. The system allows simulating a 3 layers atmospheric turbulence.

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3. PROJECT NEXT PHASES

It is expected that several important procurements will be completed by the end of 2010 and an active assembly and integration phase will start in 2011 in particular for the GRAAL and GALACSI modules. The ASSIST integration is planned for the first half of 2011 at ESO with the support of the consortium (University of Leiden).

Then the end of 2011 will see the beginning of a series of sub-systems and system tests: first acceptance tests of the DSM in stand-alone mode will occur at supplier premises in early 2012 while the GRAAL and GALACSI module tests in stand-alone mode will start late 2011.

Finally, the AOF System Test phase will start first with the DSM optical tests on ASSIST; this phase constitutes a mandatory step for the acceptance of the DSM. It will be followed by the system tests of GRAAL and GALACSI in realistic conditions with simulated star sources and turbulence. This will fully qualify the closed-loop performance of GRAAL and GALACSI modules with the DSM.

The 4LGSF proceeds independently from the other AOF systems. The first launch telescopes will arrive in the course of 2011 and will initiate the integration & test phase. The arrival of the first laser unit planned for the fall of 2012 will allow the complete sub-system 4LGSF system test phase to start.

In the course of 2011-2012, all modifications required to the VLT 8m telescope will be carried out, well in advance of the commissioning phase.

After completion of its test phase on ASSIST, GRAAL will be shipped to Chile for installation on the Nasmyth focus. This installation corresponds with the delivery of the final laser units. At this point in time and without DSM it is planned to perform some partial system tests involving GRAAL and the 4LGSF system (i.e. laser source acquisition, verification of return flux and spot size, etc...) while GALACSI goes through the last steps of its test phase in Europe. Finally, GALACSI and the DSM will be shipped to Chile and installed.

The arrival of the DSM will allow proceeding with full system commissioning. A progressive approach is planned: first the performance of the “new” AOF telescope with DSM in non-adaptive mode will be commissioned. Then, the AO mode of the AOF will verified, with first the commissioning of the DSM in SCAO mode with a natural guide star (GRAAL maintenance mode): this will give the ultimate performance of the DSM associated with a low RON WFS. Then finally the commissioning of GRAAL GLAO mode, GALACSI GLAO mode and ultimately GALACSI LTAO mode the most critical and demanding of the AOF will be performed. The full extent of the commissioning period spans an 18 months duration and is expected to be completed by the end of 2014 from which AOF will be offered to the community.

REFERENCES

[1] Kaenders, W.G., et al, “Diode-seeded fiber-based sodium laser guide stars ready for deployment”, Proc. SPIE, #7736-232, this conference (2010)

[2] Bonaccini Calia, D., et al., ”PM fiber lasers at 589nm: a 30W prototype and a portable laser system for LGS return flux studies”, Proc. SPIE, #7736-65, this conference (2010)

[3] Paufique, J., “GRAAL: a seeing enhancer for the NIR wide-field imager Hawk-I”, Proc. SPIE, #7736-60, this conference, (2010)

[4] Loupias, M., “MUSE Instrument Global performance Analysis”, Proc. SPIE, #7738-3, this conference, (2010)

[5] Fedrigo, E., et al., “SPARTA for the VLT – Status and Plans”, Proc. SPIE, #7736-88, this conference, (2010)

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