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The Auxiliary Telescopes for the VLTI: a Status Report

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1. Introduction

In June 1998, ESO signed a contract with the company AMOS (Belgium) for the supply of the Auxiliary Telescope System (ATS) for the VLTI. The original scope covered two movable Auxiliary Telescopes (ATs), as shown in Figure 1, as well as their associated site equipment including rails and interface devices for each observing station. An amendment was signed in September 1999 for the supply of a third AT and, last September, a fourth AT was ordered.

The contract with AMOS is based on top-level performance requirements and includes the design, manufacturing and testing of the complete system including all mirrors and cells, complete mechanical structure, drives, encoders, small mechanisms and low-level electronics. The main sub-contractors of AMOS are FISBA (Switzerland) for the coudé mirrors, PHASE (Italy) for the motors and CSEM (Switzerland) for the M2 hexapod mechanism.

ESO is in charge of the design and development of the telescope control hardware and software, as well as of the two star sensors located at the coudé focus.

After integration of the ESO control hardware and software, the telescope is fully tested in Europe at AMOS with the possibility of sky observation provided by an outside observing station included in the dedicated test facility. After this, ESO transports the ATs to Paranal, re-integrates them in the so-called Mirror Maintenance Building (MMB) and finally commissions them on the sky.

The project entered into manufacturing phase in mid-1999 and is now reaching the end of a very extensive testing and verification phase in Europe on AT#1 before its shipment to Paranal next year.

This article recalls the rationale at the origin of the ATS development, provides a description of the design and finally reports on the performance as measured in Europe so far.

2. Why Does the VLTI Need Auxiliary Telescopes?

The VLTI is primarily intended to combine coherently the four VLT 8-m Unit Telescopes (UTs). Obviously, the ultimate VLTI sensitivity will indeed be obtained when combining the UTs. However, the array of 1.8-m diameter ATs is a key element for the technical and scientific capability of the interferometer. The main reasons are listed below.

• It provides the best imaging capability of VLTI by complementing the array of UTs. It gives access to 30 telescope stations increasing therefore the number of accessible baseline vectors, a fundamental parameter for high-fidelity image reconstruction.

• It gives access to the longest VLTI baseline of B = 200 m versus a maximum of 130 m between UTs. This is needed to reach the ultimate angular resolution of the VLTI that scales as λ/B (i.e. 0.6 milli-arcsec in the visible and 2 milli-arcsec in the K band).

• It enables full-time use of the VLTI facilities, since the ATs are entirely dedicated to interferometric observations. This is an important factor for the VLTI scientific productivity (and for the amortization of its development cost!).

• It is required by the Narrow Angle Astrometry mode of PRIMA that

Figure 1: The first Auxiliary Telescope for the VLTI during final testing at AMOS in Liège (Belgium).

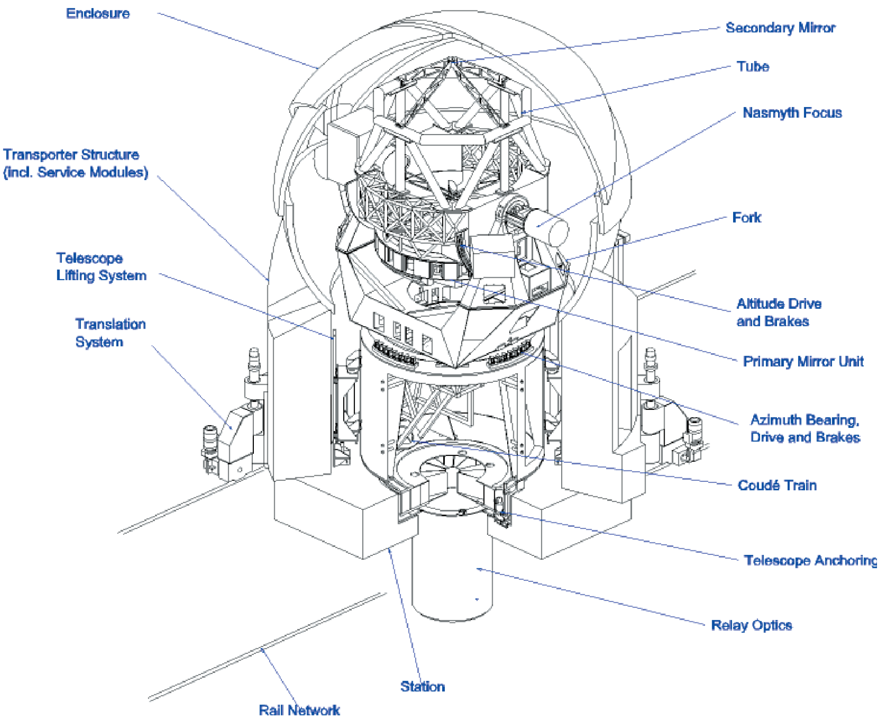


Figure 2: Overview of the Auxiliary Telescope System. The telescope is anchored on one of the 30 observing stations. It is surrounded by its built-in "Transporter" used to relocate the telescope, to support its enclosure and to house electronic cabinets and service equipment. Inside the station pit, the cylindrical structure contains the coudé sensors and the Relay Optics that sends a parallel beam to the Delay Line Tunnel trough underground light ducts.

needs regular and long-term monitoring out of reach with the highly subscribed UTs.

• It can be used for testing and commissioning of other VLTI facilities (e.g. for the 2nd generation of instruments) without using precious UT time.

For these reasons, the ATs are expected to become the 'workhorses' of the VLTI and to deliver a large amount of scientific results for those programmes that do not fundamentally need the sensitivity provided by the UTs.

The typical magnitude limits for the VLTI in the K band (2.2 μm) and in the N band (10 μm) are expected to be respectively K = 11 and N = 4 for the UTs equipped with Adaptive Optics. For the AT equipped fast tip-tilt correction only, these become K = 9 and N = 1.

The design of the VLTI infrastructure foresees up to eight Auxiliary Telescopes and eight Delay Lines. The reasons for increasing the number of telescopes in the array are essentially linked to the imaging capability. Indeed, the fourth AT has recently opened the possibility for second-generation instruments to observe 6 baselines simultaneously. This will drastically improve the snapshot imaging capability, particularly useful for variable objects. Even with a 3-beam instrument like the VLTI instrument AMBER, the 6 baselines can then be observed quasi simultaneously by a fast switching of a mirror in the VLTI optical train instead of relocating the ATs, an operation that can be done during the day only. Similarly, the number of phase closures available per AT configuration will increase from 1 to 3. This represents a three-fold increase in observing efficiency in this powerful imaging mode where the phase errors introduced by the atmosphere can be cancelled out in order to retrieve the phase of the object, a critical parameter for image reconstruction. A fourth AT will also increase the limiting magnitude by using the so-called 'boot-strapping' technique where the fringes are tracked on the relatively short intermediate baselines while the low-visibility fringes are integrated on the extreme baseline. In addition, the fourth AT will permit to dedicate two ATs for the PRIMA astrometry mode while two others are being used by MIDI or AMBER. This may prove a fundamental advantage during the challenging commissioning phase of PRIMA by alleviating the possible conflicts with the regular VLTI science observation.

3. Specifications and Design Description

3.1 Basic conceptual choices and main specifications

The ATS specifications originate from its dedication to interferometric observations down to visible wavelengths. This calls for an extreme mechanical stability, at the level of a few nano-meters, together with the capability to easily relocate the telescope.

The following conceptual choices were made as a result of early feasibility studies.

• Primary mirror diameter 1.8 m, as a compromise between science capability and cost.

• Self-contained autonomous Telescope with built-in 'Transporter' enabling relocation of the telescope on observing stations connected by a rail network and built-in Enclosure ensuring survival in outdoor conditions (wind, earthquake).

• No active optics to limit control complexity already inherent in the interferometer, but 5-axis M2 support for remotely controlled alignment.

• Field acquisition and fast tip-tilt sensors at the coudé focus and provision for later implementation of Adaptive Optics.

• Stiff Alt-Az mount with Altitude axis 5 m high as a compromise between stiffness and 'ground seeing' effects.

• Pseudo-kinematic interface between telescope and ground for high position and angular repeatability so that only fine remotely controlled alignment is required after a relocation.

• Mechanical bearing for both axes to limit maintenance and avoid hydraulic connections at station or on-board pumps.

• Direct drives for improved controllability associated with high accuracy optical encoders and analogue tachometers.

Table 1 summarizes the main performance requirements specified for the Auxiliary Telescope System. The most stringent ones imposed by interferometry are the excellent image quality, the high tracking accuracy and the Optical Path Length (OPL) stability. Other constraints imposed by the site

Table 1: Main AT performance requirements.

Optical quality of the complete telescope	< 110 nm r.m.s WFE
Wavelength range:	0.4 to 25 μm
Telescope position repeatability:	± 10 arcsec, ± 0.1 mm after any relocation
First telescope eigenfrequency:	> 10 Hz
Pointing accuracy:	< 1 arcsec r.m.s.
Tracking accuracy (blind):	< 0.1 arcsec r.m.s.
Tracking accuracy (Field Stab.):	< 0.025 arcsec r.m.s.
Optical Path Length Stability:	< 30 nm rms over 10 msec
Time to relocate to any station:	< 3 hours with 2 operators
Total Mass:	< 30 Tons
Design volume:	H < 7.1m, W < 5.4 m & L < 5.8 m

▲ *Figure 3: The 1.8-m primary mirror in its cell during integration into the telescope at AMOS. The mirror is lightweighted to reduce its mass by a factor about 2. A 54-points wiffle-tree axial support was selected to comply with the stringent image quality requirements.*

Figure 4: The 140-mm diameter secondary mirror is mounted on an hexapod to enable remotely controlled focus, centring and angular alignment. The hexapod, built by CSEM (Switzerland) is a very compact, very high accuracy mechanical device featuring a resolution smaller than 0.2 microns and a very small cross-coupling between focus and tilt motions to avoid mispointing while re-focusing the telescope. ▶

infrastructure such as the total mass and the design volume are also driving factors for the overall AT design.

3.2 Optical design

The AT optical design is similar to that of the UT and includes 11 mirrors. The first three (M1-M3) constitute a *Ritchey-Chrétien telescope* with a 1.8-m diameter primary mirror. A fast f/1.4 primary mirror was selected to provide a compact tube design and limit wind buffeting of particular concern for interferometric application where nanometer-level stability is required in the Optical Path Length (OPL). One consequence of that particular design is the high sensitivity of the telescope to the secondary mirror (M2) defocus & decentre which places high demand on the stiffness of the tube structure. The Nasmyth focus of the Ritchey-Chrétien is unused for normal operation. It is re-imaged by the 5-mirror *coudé train* (M4-M8) to form a coudé focus located underground. In addition, the coudé train creates an image of the telescope pupil on M6 where a fast tip-tilt mirror (and possibly later an adaptive optics mirror) is located. Just above the coudé focus, a *dichroic mirror* (M9) transmits the visible to a CCD camera and an APD module (STRAP) for acquisition and fast guiding. The infrared light reflected by M9 is collimated by the *Relay Optics* (M10-M11) to form an 18mm parallel beam sent towards the VLTI delay lines.

3.3 Telescope structure

An overview of the telescope design can be seen in Figure 2. The main drivers were the maximization of the first eigenfrequency, the minimization of the M1-M2 de-space and de-centre (typically < 10 µm) under gravity, wind load and thermal load as well as the minimization of the wind torque. This had to be achieved while complying with the constraints of mass, design volume, station interface and earthquake survival.

The *Tube* structure is a classical Serrurier strut made of hollow tubes connecting to a top-ring made out of full rods for weight balance. The M2 spiders were optimized in order to limit the design volume, to reduce the torque due to wind load on the top-ring and to increase axial stiffness in view of OPL stability. A particular feature of the tube design is the solution adopted, after several trade-offs, for the thermal compensation rendered necessary by the extreme sensitivity to M2 defocus. The compensation is provided by a proper selection of material for the Serrurier (steel), top-ring (steel) and M2 spider (invar). When the temperature increases, the tube expands and the top-ring diameter increases. This later creates a stress in the M2 spiders that results in a downward motion of M2 compensating the tube and M1 cell expansion. Several trade-offs were made on the centrepiece that is a main contributor to stiffness and wind torque. The latter constraint led to the final design based on a complex strut structure with appropriate welded box/plates interfaces to the altitude shaft, Serrurier structure and M1 cell. On each side of the centrepiece, a semi-circular plate holds the magnets for the altitude motors and tachometers and a brake disk. For the support of M3, a spider was preferred over a more classical tower solution because it provides better static and dynamic results while easing the re-alignment after an M1 removal for re-coating.

The tube is connected to the *Fork* on both sides by double row angular contact ball bearings providing high stiffness, low run-out and low friction. The Fork is a welded box structure with internal ribs highly optimized for stiffness and mass. At its lower part, the Fork connects to the Azimuth bearing, a key element to the overall telescope stiffness. The Azimuth bearing is a three-row roller bearing with very high radial, axial and tilt stiffness but, at the same time, very low friction torque necessary for the pointing/tracking accuracy.

Below the Azimuth bearing, the *Ground Interface Structure* (GIS) provides the connection to the ground through the pseudo-kinematic anchoring and clamping devices. This part of the telescope was also intensely optimized by FEM due to its importance in the first telescope eigenfrequency.

Inside the station pit the *Relay Optics Structure* (ROS), a double-skin welded box cylindrical structure, houses the Relay Optics and the coudé sensors. When relocating an AT on a new sta-

Figure 5: The first telescope on its test bench inside the dedicated hall at AMOS. In addition to tests at component level such as optical quality of each mirror, friction of the axis bearings, etc., the first telescope undergoes a thorough acceptance test programme including modal tests of the complete structure, dynamic response of the azimuth and altitude axis, OPL stability measurement, verification of structural deformation under gravity, pointing repeatability check and others.

Figure 6: The Transporter in its relocation configuration. The cylinder in the foreground houses the Relay Optics and the coudé sensors (CCD and STRAP). The light beam exits the telescope by one of the two black openings. During relocation, the cylinder is lowered underground inside the station pit before the telescope is placed on top.

tion, this structure is lowered into the station hole on soft pads, the telescope is placed on top and a centring and clamping mechanism is activated between the structure and the Ground Interface Structure. The position repeatability is such that local alignment is not required after relocation. This holds also for the repeatability of the telescope anchoring system. The only telescope alignment necessary after relocation is performed remotely from the Control Room.

3.4 Drives, tachometer and encoders

The motors selected for both Altitude and Azimuth axes are direct drive, *brushless torque motor*, similar in concept to those installed in the UT. Two curved linear motor pads are used diametrically opposed for Azimuth and one pad is attached to each side of the fork for Altitude. Each motor is equipped with internal position sensors used in particular for motor commutation.

Each axis is equipped with an AC-DC *analogue tacho-generator* using the same magnet strip and similar pads as the motor. The power amplifier is based on fast DSP technology and provides motor current control, overspeed limitation and tacho demodulation.

The axis position information is given by high accuracy Heidenhain *optical encoders*. The high interpolation factor leads to the very high angular resolution of 9 milli-arcsec on Altitude and 3 milli-arcsec on Azimuth.

3.5 Primary mirror unit

The M1 unit is shown on Figure 3. It consists of the primary mirror, its cell with axial and lateral supports and finally the interface with the telescope tube.

The *primary mirror* is made out of a 200-mm thick blank of Zerodur material from SCHOTT (Germany). Due to mass constraints, the mirror is lightweighted by drilling hexagonal pockets on its rear face as can be seen on Figure 3. It is polished to a hyperbolic shape.

The mirror *axial support* is the result of an intensive optimization by Finite Element Modelling in order to minimize the effect of gravity deflection. The selected solution compatible with the lightweight geometry and the low-level error budget is a 54-axial-point support mounted on a three-stage wiffle-tree system using flexible pivots.

For the *lateral support,* the retained optimal solution consists of 16 astatic levers using low-friction bearing and counter-weights. In addition, three radial fixed points are located inside the M1 central hole.

The *M1 cell* consists mainly of a welded steel structure with a double skin for the bottom and lateral parts to improve the cell stiffness. The structure is made of two parts to facilitate the mirror integration and maintenance. The cell's lower part interfaces with the axial support while the upper part interfaces with the lateral support. The first eigenfrequency of the M1 unit is 20 Hz and the mirror degradation in its cell under gravity is less than 11 nm RMS surface.

3.6 Secondary mirror unit

Due to the selected fast f/1.4 primary mirror, the secondary *M2 mirror* is a rather small mirror 140-mm in diameter. However, its highly aspherical and fast (f/1.3) shape makes it a difficult mirror to manufacture. It is also made out of a blank of Zerodur, 25 mm thick.

The M2 is mounted on a *hexapod support* (see Fig. 4) providing defocus, de-centring and tip-tilt motions with sub-micron and arcsecond level resolution for remote alignment. Its design is primarily driven by the very limited space available (in the shadow of M2) and the requirement to limit cross coupling between focus and tilt motion.

3.7 Enclosure

The basic enclosure concept is to provide good natural ventilation during the night to limit "dome and mirror seeing" and therefore to leave the part of the telescope above the altitude axis exposed to the outside wind (see Fig. 1). Following an analysis of the wind load, thermal requirements and mass and volume constraints, the selected design consists of composite spherical shells that open up with two hydraulic cylinders attached to each of the two upper shells. When closed, the two upper shells are clamped together by means of 6 electrical actuators and inflatable seals are inflated in-between each shell. The normal status of the enclosure is fully open or fully closed. However, it is possible to close totally or partially any of the two sides in order to act as a wind shield in case of high wind coming from S-E or N-W, the two dominant wind directions.

3.8 Transporter and Service Modules

The main function of the Transporter is to provide the handling means to relocate the telescope without the need for any additional external devices. A typical relocation sequence can be summarized as follows: (i) unclamp the Relay Optics Structure from the telescope, (ii) unclamp the Telescope, (iii) lift the Telescope, (iv) unclamp the Transporter, (v) lower down the Transporter wheel on the rails and lift the Transporter in driving position, (vi) drive the Transporter beside the station, (vii) attach the Relay Optics to its handling device integrated on the Transporter and lift it, and (viii) drive to the next station. When a change of direction is needed (at one of the rail crossing), the Transporter is stopped at the crossing, lowered and clamped on special interface plates. The wheels are lifted up and rotated by 90° before being lowered on the perpendicular rails. Unclamping and lifting the Transporter enables to drive to the next crossing. At the destination station, the reverse operations are performed.

The Transporter (see Fig. 2) consists of a *frame structure* made of hollow aluminium rectangular profiles. It has been optimized with respect to mass minimization (aluminium), space constraints and earthquake survival during observation and relocation (with telescope load). An inner cylindrical structure supports the enclosure and the Telescope lifting devices. An outer cylinder structure, covered with aluminium panels and equipped with access doors, provides protection of the electronics cabinets and the Service Modules that are fitted in-between the two cylinders. The four *drive wheel* blocks, attached to the outer cylinder, include the electrically driven wheel and hydraulically driven lifting, rotation and blocking mechanisms. The *telescope lifting device* consists of 8 lifting actuators linked to cardan shafts which are driven by two electric motors. The Relay Optics handling device uses two electric linear actuators linked by a floating shaft.

The other functions of the Transporter are to provide air conditioning, cooling liquid, auxiliary power as wells as hydraulic and pneumatic power for the various mechanisms. It also provides the space for the control electronics cabinets.

The *air conditioning system* provides temperature control during the day based on three temperature sensors located on the primary mirror, plus six other sensors distributed on the telescope structure. The mirror temperature is controlled to ±0.5°C of ambient air with the capacity to cool the mirror by 2°C in about 3 hours. The cooling power is injected with filtered, re-circulated air through a circular fabric duct with constant flow and high induction to ensure temperature homogeneity. The control is done through a PLC with an optimal set point computed by the ESO AT Control System based on outside temperature measurement and forecast for the next night.

The *liquid cooling module* is providing cooling power during observation for temperature control of electronic cabinets and heat-dissipating equipment such as motors, coudé sensors and small mechanisms. The remaining heat dissipated in the vicinity of the optical beam is maintained below 25W and surface temperatures are kept at ambient ±1.5 °C. In order to avoid the vibration of the chiller during observation, the cooling energy is stored inside a tank of heat latent nodules. The cooling capacity is 1 kW during 12 h and is re-generated during the day by running the chiller.

Figure 7: The first Transporter sees the sun light for the first time at AMOS (Liège, Belgium) during its functional tests last October. A dummy station will permit testing of the telescope on the sky before shipment to Paranal.

The *auxiliary power module* consists of a set of batteries feeding a UPS to provide uninterrupted power to the control electronics as well as an electrogen group connected to the UPS to provide electric power during relocation when the telescope is unplugged from its station socket.

The *hydraulic group* provides the required oil pressure and flow for the various hydraulic mechanisms. Such mechanisms are used for the Transporter wheels 90° rotation, the Transporter lifting, the clamping of Transporter to ground, Telescope to ground and Relay Optics Structure to Telescope, as well as for the Enclosure opening/closing.

Finally, a *pneumatic system* is used to inflate/deflate the Enclosure seals and to activate the Telescope axes brakes.

3.9 Station equipment and rails

The station equipment consists of a set of *Telescope interfaces*, *Transporter interfaces* and a *station lid*. The telescope interface is made of a plate whose upper face is machined to provide a perfect supporting plane for the telescope anchoring counterparts. These counterparts are male elements consisting of a clamping finger placed inside a cone. They come into the corresponding conical part of the telescope clamping device to form a pseudo- kinematic interface. The station Lid is a composite hexagonal cover fitted with a seal. It ensures good thermal insulation, air tightness and resists to a 500-kg central load. It can be handled by two persons.

The *rails* are standard rolled steel profile with end cut at 45° to ensure smooth load transfer at the junctions. At a crossing, a specific design enables to transfer the load from the central rolling

Figure 8: Installation of the AT interface devices inside each of the 30 observing stations at Paranal. A high-precision alignment method using theodolite and specific tools is used to reach a positioning accuracy below a millimetre and an arcminute.

surface of the wheel to its two lateral flanges. At each track end, an end-stop is installed.

3.10 Control system

The design & implementation of the control system is shared between AMOS and ESO. AMOS is responsible for the Transporter control including the complete relocation sequence and the Service Modules while ESO is in charge of the complete Telescope Control including control of the axes, the M2 support, the field stabilization loop as well as the small telescope mechanisms such as M10.

On the AMOS side, two *Programmable Logical Controllers* (PLC's) perform the control tasks. The first one (Sauter) is dedicated to the Air Conditioning and Liquid Cooling Module while the second one (Siemens) controls the other Transporter functions including those needed during relocation. For the latter, the operation is done locally from a portable control panel (see Figure 7). Both communicate with the ESO Local Control Units (LCU's) for exchange of status information and commands when needed (e.g. switch on/off air conditioning, set reference temperature, open/close enclosure, etc.)

On the side of ESO, the control system adheres to the Hardware and Software standards adopted for the VLT. It is based on a distributed architecture of *workstations* (Unix) connected to the *LCU's* (VxWorks) via a *LAN* (Ethernet). For each AT, the control electronics located on-board the Transporter is connected through the station plug and the LAN optical fibres to the VLT or VLTI Control Room from where all control is done during regular operation (i.e. except for relocation).

The design of the *Software* makes extensive re-use of the Telescope Control Software (TCS) implemented on the UT with a few modifications required by the difference in hardware.

However, two significant new approaches have been applied on the AT. On the Hardware side, a fully digital control scheme was selected in place of the former analogue velocity controllers for the telescope axes. This was one of the first applications of what has become now a new VLT standard: the generic Tool for Advance Control (TAC). Its main advantage is the possibility to configure and optimize the control algorithm in a very flexible manner even at runtime. TAC is now used for several applications in the VLT/VLTI (OPD Controller, FINITO). On the Software side, the Unified Software Development Process with the Unified Modeling Language (UML) has been introduced at the beginning of the AT project.

4. Current Status

As far as optics are concerned, the full set of 11 mirrors is complete for each of the first three ATs except the primary mirrors for AT#2 and AT#3 that are respectively under final figuring and machining. The blank for AT#4 has been ordered and light-weighting will start before the end of the year. Each mirror has been successively polished within its very tight allocated specification derived from the global telescope image quality given in Table 1. As an example, the phase map of the first primary mirror for AT#1 is shown on Figure 9. The achieved wavefront error amounts to less than 24 nm RMS. This is an excellent achievement for the first mirror of this size and short focal ratio manufactured by AMOS.

Currently, the first AT is in its last testing phase at AMOS. The telescope, fully integrated with optics, is anchored on a dedicated station (see Fig. 5) where all the major performance tests have been completed, as described in the next section. Meanwhile, the Transporter has also been fully integrated and the second telescope – partially integrated – has been placed inside in order to proceed with an extensive functional test phase during which all motions required for the relocation have been exercised and tuned (see Fig. 7). One of the main remaining activities is the testing of the relocation performance, including the time to relocate (less than 3 hours) and the repeatability of the telescope positioning (± 100 μm and ± 10 arcsec). The latter was already successfully tested on a breadboard during the design phase. The other important remaining test concerns the performance of the thermal control provided by the air conditioning during the day and by the liquid cooling module during night observation. In January, the formal technical acceptance in Europe of the first AT will take

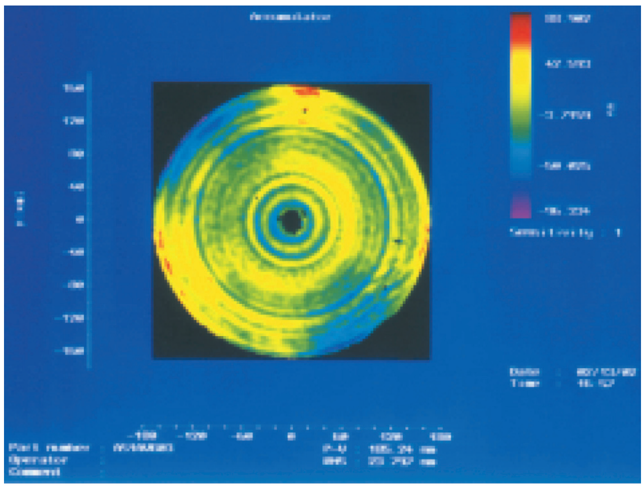
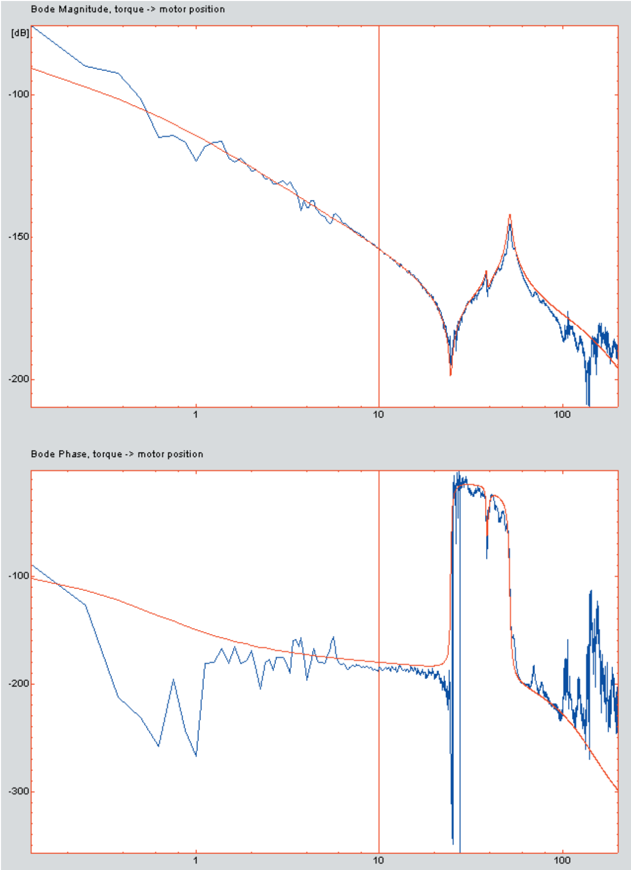
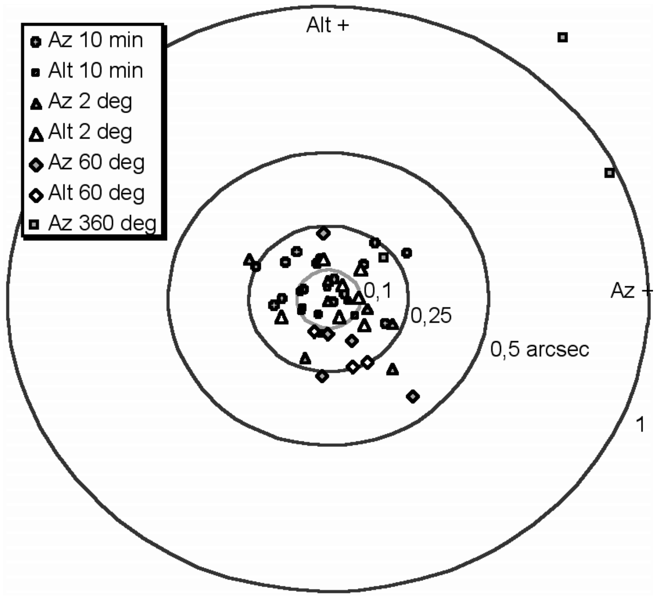


Figure 9: The 1.8-m primary mirror of AT#1 after polishing. The wavefront error is below 24 nanometers RMS





▲ *Figure 11: Overview of measured non-repeatable pointing error in arcsec on the sky for various angular motions of the altitude and azimuth axes. The circles represent the requirement specifications for the various angular ranges.*

◀ *Figure 10: Azimuth axis dynamic response (measured and fitted model) used to verify the control bandwidths needed for accurate telescope tracking.*

place. Subsequently, the system will be handed over to ESO for a 3-month test period in Europe where the ESO Control System will be tested and fine-tuned with a possibility for sky observations. The first AT will then be packed and sent to Paranal where re-integration will start mid-2003.

The second and third telescopes are currently in the assembly process. Most of the sub-contracted equipment for the telescopes such as the main drives, M2 hexapods, bearings are integrated. The Transporter for AT#2 is being assembled while the one for AT#3 is still under manufacturing.

At Paranal, the preparatory activities are taking up momentum in order to be ready to receive the first AT. The telescope interface devices have been installed and carefully aligned in each of the 30 stations (see Fig. 8) and the rail installation is about to start.

5. First Results from Telescope Performance Tests

In order to verify system-level performance requirements before the final commissioning on site, an extensive test program has been carried on AT#1 at AMOS. Some of the most important results are reported below.

5.1 Verification of the telescope axis dynamic response

The dynamic transfer function between the motor torque reference and the signals from the tachometer or the position encoder is a critical characteristic for an accurate, high-bandwidth control of the telescope axes (under the responsibility of ESO). For this reason, the dynamic responses of both altitude and azimuth axes have been specified and measured. Figure 10 shows the result of the measurement to which a simplified dynamic model of the telescope could be fitted in order to verify that the control bandwidth and stability criteria will be met when ESO plugs in its telescope control system. The results are well within the specifications of 8 Hz bandwidth for the velocity loop and 2 Hz bandwidth for the position loop.

5.2 Verification of the Optical Path Length stability

One of the most unusual and difficult requirements for the AT is the stability of the Optical Path Length (OPL) inside the telescope that is required by interferometric observations. The OPL variation was a driving parameter of the telescope mechanical design where optimization processes were necessary to fulfil the specifications. The identified contributors to the OPL variation are the vibrations resulting from the dynamic wind load, the normal micro-seismic activity and the Transporter and telescope active sources during operation. In order to verify the contribution of the telescope internal vibrations to the total OPL stability budget, a dedicated OPL test set-up was designed using a combination of laser interferometer and accelerometer measurements. The M1-M2 OPL variation was measured by means of two high-sensitivity accelerometers while the OPL variation from M2 to M11 was measured by means of an HP Doppler interferometer. The results of the OPL test were combined together with the other contributors to the OPL stability as computed by analysis such as the wind load and the micro-seismic disturbances. The consolidated budget appears to be compliant with the specifications.

5.3 Verification of non-repeatable pointing error

The pointing accuracy is particularly important for a telescope dedicated to interferometry. Indeed, the standard interferometric observing strategy consists in switching rapidly (every 1 to 3 minutes) between the scientific object and a calibrator of known diameter that is used to calibrate the time varying instrumental and atmospheric visibility losses. Poor pointing repeatability requiring full acquisition sequences can therefore seriously affect the efficiency of the observation. A test was dedicated to measure the non-repeatable part of the AT pointing accuracy for five pointing directions distributed over the operational range. A collimator and five folding mirrors were installed above the telescope. The collimated light, sent via one folding mirror, is focused at the coudé focus on a CCD. The image position is recorded before and after the telescope has been moved back and forth by a given angle (from 10 arcminutes, up to 60 or 360 degrees) in altitude and azimuth directions. Due to the very small pointing errors to be measured (0.1 to 1 arcseconds), particular attention had to be paid to the thermal environment and to the processing method in order to eliminate thermal drifts of the measurement set-up. Figure 11 gives an overview of the excellent results obtained, basically limited by the residual measurement noise of 0.13 arcsec.

6. Conclusion

This article provides an overview of the current development of the Auxiliary Telescopes for the VLTI. The main performance tests of the first telescope are completed. They have shown that the system is on track to meet the severe and specific requirements originating from its dedication to interferometry, in particular a high dynamic performance. The functional tests related to the relocation of the telescope have been successfully completed on the first Transporter and the related performance tests are currently in progress. Early next year, the first AT will be ready for a short ESO test period in Liège to tune the telescope control system developed in parallel at ESO. The year 2003 will see the installation at Paranal of the first two ATs. This will considerably boost the scientific productivity of VLTI that will, at that time, be equipped with its two first-generation instruments: MIDI and AMBER. AT#3 is expected to be ready for scientific observation in mid-2004 and AT#4 in early 2005.

Paranal Observatory – 2002

ROBERTO GILMOZZI and JASON SPYROMILIO

We live in interesting times. Last year was our first with all four 8-m telescopes in operation. We had only one instrument per telescope but we were kept busy with UVES and ISAAC working round the clock and commissioning and installations during bright time when FORS1 and FORS2 were taking a breather. Now at the end of 2002 we look at Paranal and a very different picture appears in front of us.

We continued to operate with low technical time losses. In the period from April to October 2002 the down time was 3.6% on Antu, 4.4% on Kueyen, 2.9% on Melipal, and 3.1% on Yepun. Observing time losses due to adverse weather conditions represented 12% of the science time, somewhat more than in previous years. We archived 57,810 frames on ISAAC, 34,329 frames on UVES, 22,853 frames on FORS1 and 37,847 frames on FORS2.

NAOS/CONICA has been brought into operation in a major effort by the consortia that built it, ESO instrumentation division and Paranal. All parties pulled out all the stops to start science operations on the 1st of October 2002. NACO, as we now call the otherwise unwieldly named instrument, is widely recognized as the most powerful adaptive optics facility instrument in the world. Already fabulous results have appeared in press releases and more are to come. The spectacular results on the Galactic centre have demonstrated the excellent capabilities of the instrument. UT4 now has two instruments and both dark and bright time are fully exploited for science.

Figure 1: The VST enclosure taking shape at the edge of the Paranal platform.

VIMOS appeared, somewhat overweight and with all the challenges of what in effect is four imaging, multiobject spectrographs mounted on a single frame. Starting with two arms, it then had a leg added to it and another two arms making the whole thing quite a sight to be admired on the Nasmyth B platform of UT3. All of this under the careful supervision of Paranal engineering and extensive testing and discussions to ensure that nothing untoward occurred as we pushed the rotators beyond their specified and tested range. Again with a lot of work from the consortium and the support of the instrumentation division and the ever present Sandro D'Odorico, we have now reached the stage of Paranalization of the instrument and we have a fixed date with our customers on the 1st of April 2003. Already the PI (Olivier Le Fevre) has claimed success with the execution of the entire CFR Survey executed in a single exposure.

In the mean time FLAMES arrived in parts and has slowly grown to occupy the totality of the Nasmyth A platform of UT2. First OzPoz, the fibre positioner and then GIRAFFE the spectrograph to take the 130 spectra at medium resolution simultaneously. OzPoz did puzzle us for a while. Mostly it puzzled the consortium that built it. After a few interventions on the instrument to make sure it fit to the telescope properly and to make sure it could cope with the real