The VLTI Auxiliary Telescopes; commissioning of AT1

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ABSTRACT

The Very Large Telescope Interferometer (VLTI) that currently combines the four VLT 8.2-m Unit Telescopes (UTs) is now being equipped with its dedicated array of Auxiliary Telescopes (ATs). This array includes four 1.8-m telescopes which can be relocated on thirty observing stations distributed on the top of the Paranal Observatory. This array, albeit less sensitive than the array of UTs, is a key element for the scientific operation of the VLTI.
After more than five years of design, development, manufacturing and extensive testing in Europe by the company AMOS (Belgium), the first AT arrived on Paranal in October 2003 where it was re-assembled in two months. This was followed by the final testing on the sky, the so-called 'commissioning', that took place in January and February 2004.
This paper describes the recent activities from the delivery of AT1 in Europe up to its commissioning at Paranal. It presents a few results from the commissioning and reports the achieved performance. The status of the other ATs is also briefly described.

Keywords: Interferometry, Very Large Telescope, VLTI, Auxiliary Telescope, Telescope testing, Commissioning

1. INTRODUCTION

The first of four Auxiliary Telescopes for the VLT Interferometer (VLTI)[1] was installed at Paranal in January 2004. These telescopes, described in detail in previous papers[2, 3], have primary mirrors of 1.8-m diameter and are installed in compact domes. In contrast to the four VLT 8.2-m telescopes and, indeed, to any other telescopes in the world of this size, they can be moved along a system of tracks on Paranal. Their light beams are sent into the subterranean Interferometric Tunnel from where they are directed to the central Interferometric Laboratory.

This is the first of four ATs that will be installed in 2004-2006. These compact, high-tech telescopes are built by the AMOS company in Liège (Belgium). When placed in different configurations on the tracks, they will enable the VLTI to operate with great flexibility (also when the large telescopes are busy with other observations) and to obtain extremely high angular resolution on baselines up to 200 meters.

Most of the time the large 8.2 metre telescopes are used for other purposes. They are therefore only available for interferometric observations during a limited number of nights every year. Thus, in order to exploit the VLTI each night and to achieve the full potential of VLTI, some other (smaller), dedicated telescopes are necessary.

These telescopes, known as the VLTI Auxiliary Telescopes (ATs) are mounted on tracks and can be placed at precisely defined observing positions on the observatory platform. From these positions, their light beams are fed into the same common focal point via a complex system of reflecting mirrors in an underground system of tunnels.

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2. TRANSPORT FROM EUROPE TO CHILE

On September 4th 2003, the AT1 was provisionally accepted at AMOS in Liège after having passed the extensive acceptance tests in Europe[2]. The transport from Europe to Chile, under ESO responsibility, could start. A serious problem was caused by the last-minute refusal of the sea transport company to accept the AT1 cargo. Although this happened just two weeks before the pick-up date, a satisfactory back-up solution could be worked out using a 'charter' vessel.

The transport started with the pickup at AMOS on September 12th (Figure 1). Due to the dimension of the largest crate, a 6 x 5.4 x 5.5 m crate containing the fully integrated Transporter/Enclosure, and due to the fragile primary mirror, this transport contracted to the company Gondrand (France) required special care and exceptional transport permits. It went very smoothly without any incident. On October 22nd, AT1 arrived safely on Paranal (Figure 1).

Figure 1: Transport of AT1 from AMOS (Belgium) to Paranal: pick-up in Liège on 12/9/03, loading on the sea vessel in Antwerp, driving into the Atacama desert and arriving at Paranal. The largest crate is a 6-m cube containing the complete Transporter/Enclosure and imposes special transport means and authorizations.

3. ASSEMBLY AND INTEGRATION

The re-assembly and integration of AT1 started on November 7th. This task was performed by ESO, following assembly, integration and alignment procedures elaborated by AMOS. In spite of various minor difficulties typical of the first-time installation of such a complex system, the integration team made of ESO staff from both Garching and Paranal succeded to complete the re-assembly within the planned one-month schedule (Figure 2). During that time, the M1 primary mirror was aluminized for the first time using the VLT coating plant and was installed inside the telescope (Figure 3). Functional tests of each of the many sub-systems could then be carried out by the Garching Software team who left the mountain shortly before Christmas.

Figure 2: AT#1 at the end of the assembly phase inside the Mirror Maintenance Building (MMB) at the Paranal base camp, late November 2003. One sees the dummy docking station (red circular plate) on which the telescope can be anchored and the structure (white cylinder) housing the Relay Optics (mirrors M9 to M11) that redirect the parallel optical beam into the VLTI light duct and Delay Line Tunnel.

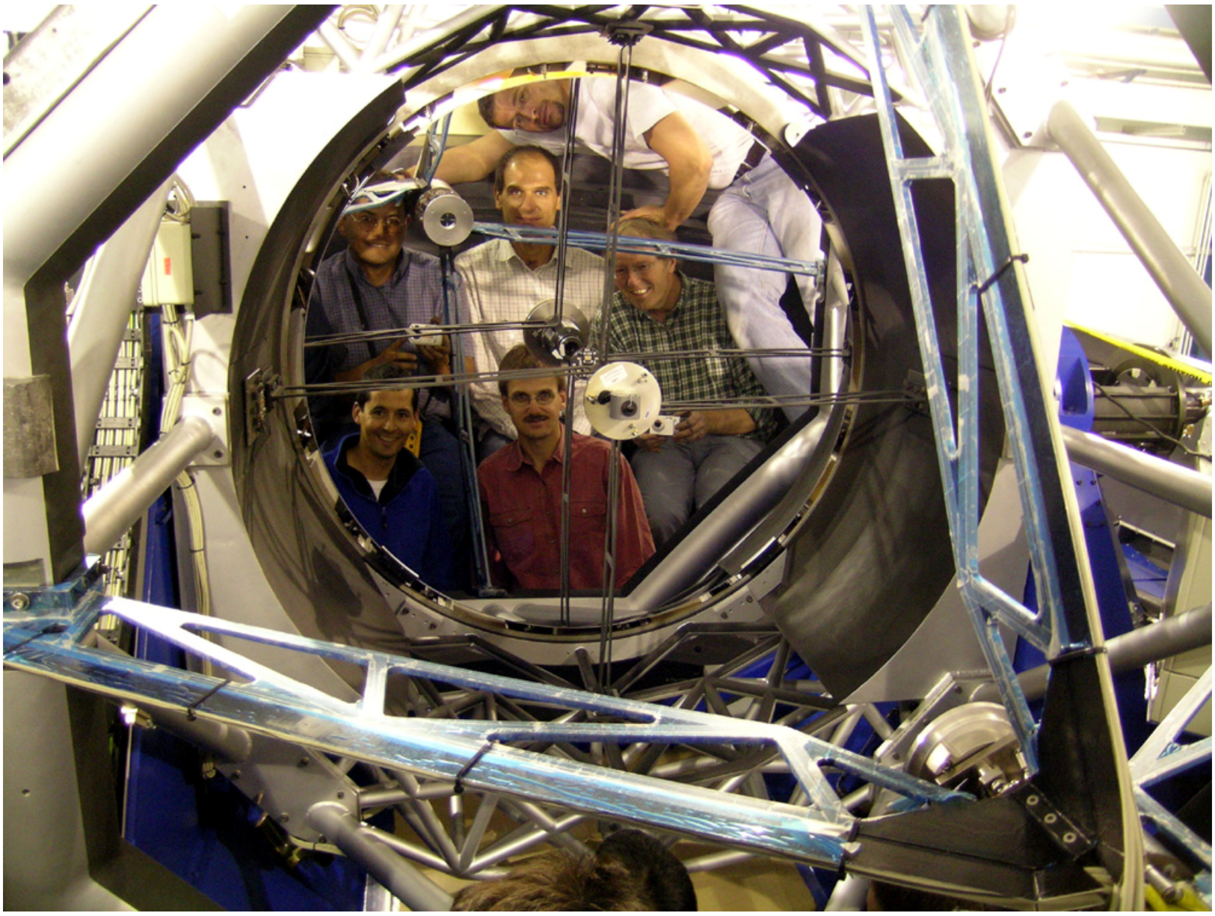

Figure 3: The Paranal integration team feels relieved after the first mounting of the primary mirror (M1) inside the telescope early December 2003. All mirrors were delivered silver-coated except M1 that was coated with Aluminum by ESO, using the VLT coating plant on Paranal (*Photo: P. Giordano*)

4. MOVE TO THE OBSERVATORY TOP

On January 12th, with only four days delay with respect to the original planning, the first move of an AT from the Mirror Maintenance Building (MMB) to the Observatory platform could start. For this move, the completely assembled AT was attached to an ESO-developed handling tool that lifts the complete AT and loads it onto a rented hydraulic trailer pulled by a truck. The day started around 7h at the MMB and was a rather intense day for the nerves of the project engineers, in particular when the 33 tons of the complete AT and what it represents in terms of cost and development effort started to be lifted for the first time by the four lifting legs developed by ESO engineers (Figure 4). After a careful 2-h drive (Figure 4), and some some iteration to adjust the position of the truck over the rails, the AT was finally lowered on its rail network between UT3 and UT4, not far from the VST (Figure 4).

5. COMMISSIONING

The commissioning program started on January 13th with day time tests of the 'Relocation' process during which the AT is moved from one observing station to another. The excellent repeatability of the telescope position after a relocation (<0.1mm lateral and vertical and <10 arcsec angular) had been already measured in Europe as part of the acceptance tests. These values could be confirmed with the AT stations in place at Paranal. This characteristic is particularly important for such a movable telescope in order to avoid lengthy optical re-alignment after a 'relocation'. Indeed, the only necessary fine alignment will be done remotely from the control room at the beginning of the observing night.

Figure 4: The first Auxiliary Telescope is transported from the MMB to the Observatory Top on 12/1/04. The fully integrated AT weighting 33 tons is lifted with a specially-designed tool and is loaded onto a hydraulic trailer. (*Photo: R. Tamai*)

Another awaited confirmation concerned the first resonance frequency of the telescope specified to be above 10 Hz on a perfectly rigid ground. A detailed modal survey had been undertaken in the factory in Europe[3]. It had shown a first resonance at 7.2 Hz, however strongly influenced by the relatively weak telescope foundation in AMOS factory. The tests at Paranal showed a first resonance varying between 9.8Hz and 10.9Hz depending on the Azimuth position of the telescope. This dependence is explained by the geometry of the telescope anchoring to the ground on four non-symmetric points. The minor 0.2Hz non-compliance possibly originates from the very rigid, but not infinitely rigid, Paranal ground and is not relevant at the level of the global telescope performance.

Further daytime tests were then performed to verify basic functionality of the Transporter such as the Air Conditioning and the Liquid cooling modules and performances not requiring night observation such as Electromagnetic Compatibility (EMC), etc.

Sky observation started on 23rd January (Figure 5, Figure 6) with the build-up of a first pointing model and the measurement of defocus and coma due to M1-M2 residual misalignment. After one iteration of the fine alignment of the primary mirror M1, the first light was obtained on the next night around 23h local time with images limited by the seeing of the order of 1 arcsec FWHM (Figure 7). At the end of the commissioning period, further images (Figure 8) were taken with a seeing around 0.5 arcsec FWHM confirming the seeing-limited performance of the telescope at its Coudé focus, after 8 mirrors .

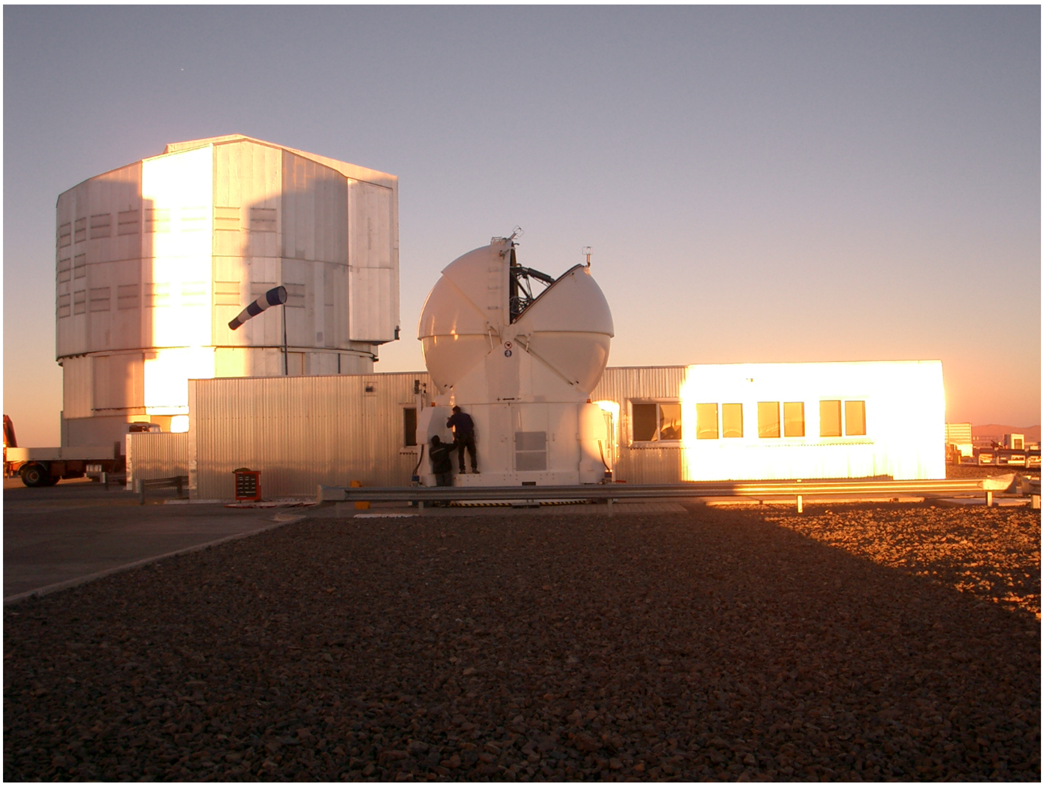

Figure 5: AT#1 at sun set. The ‘baby telescope’ breaks its egg! (*Photo: P.Giordano*)

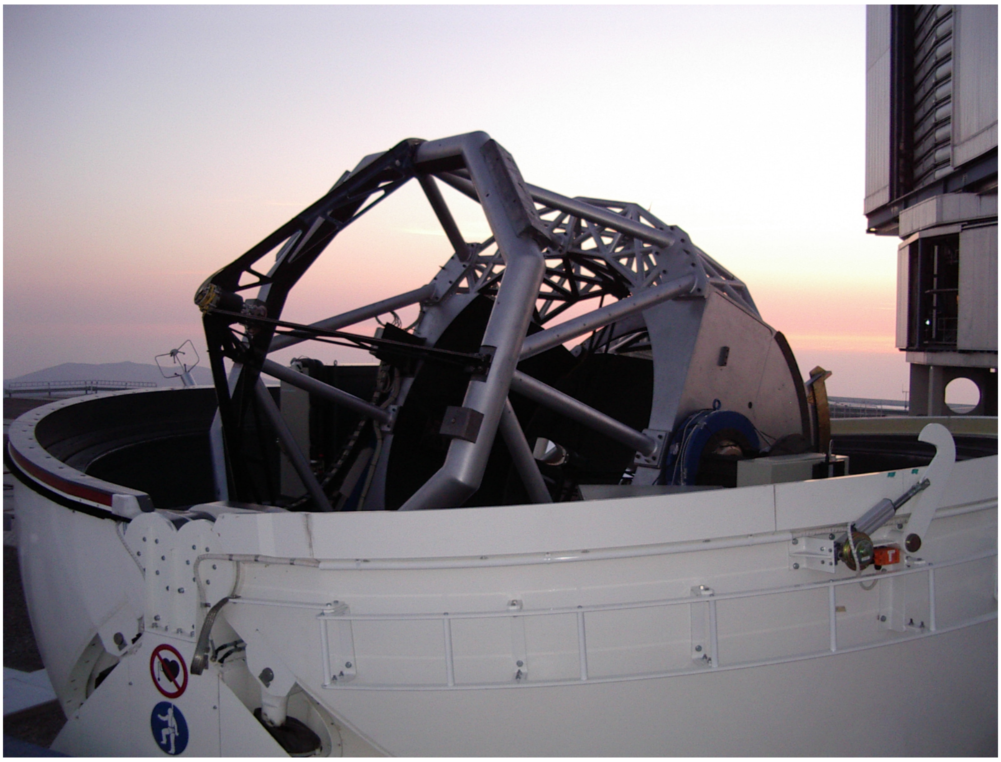

Figure 6: AT#1 before a night of commissioning. UT#1 is in the background (*Photo: F. Gonté*)

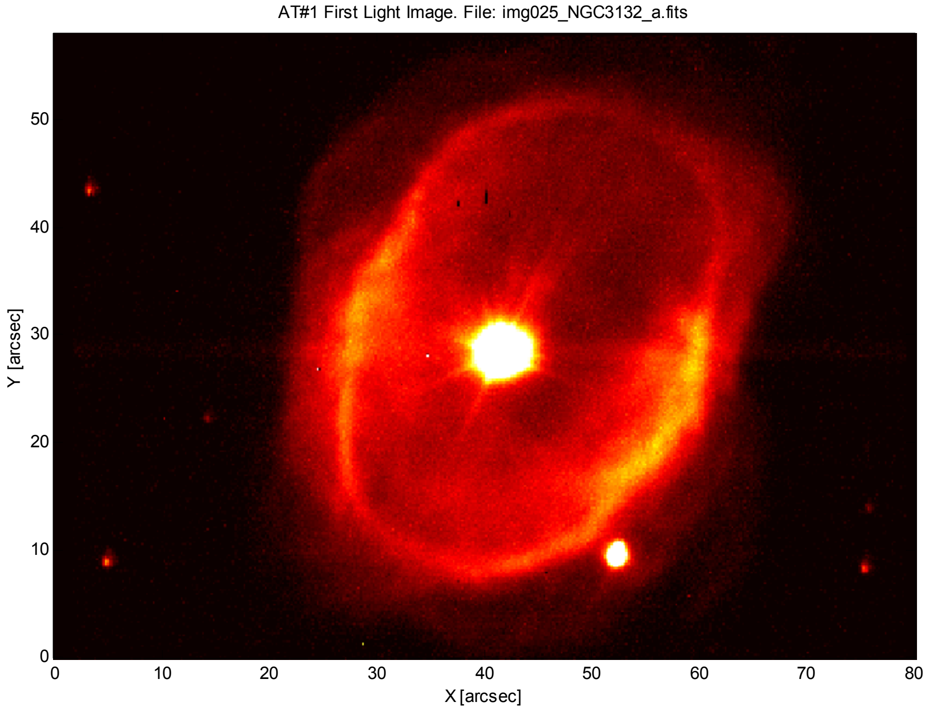

Figure 7: First light images taken at the Coudé focus: planetary nebula NGC 3132, magnitude 9.2, exposure 10 s Seeing: 0.8-1.2”.

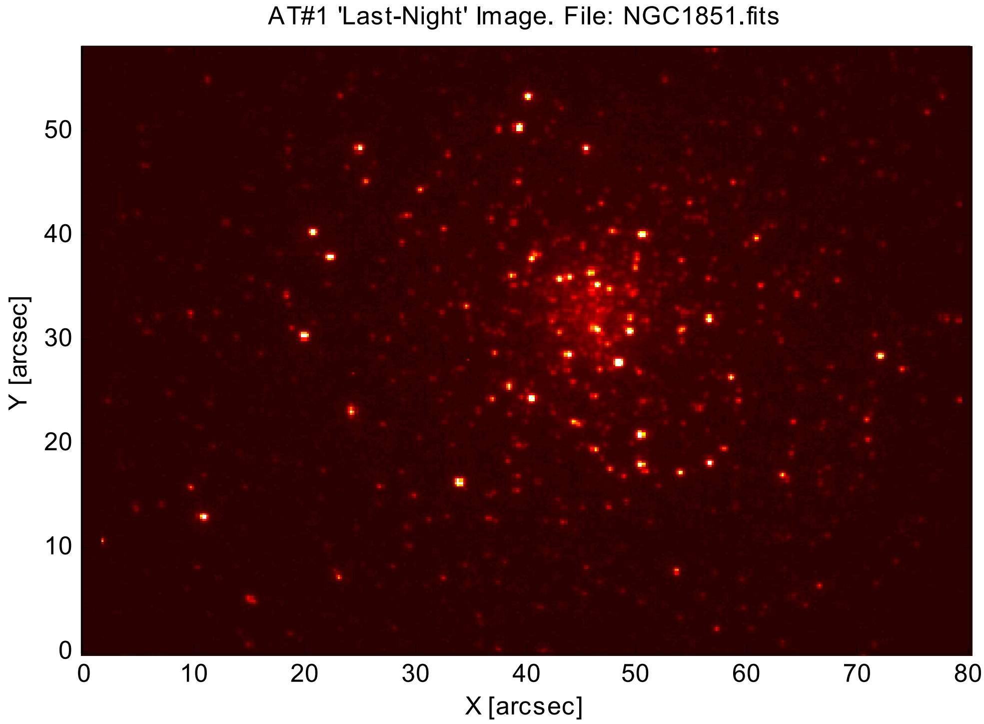

Figure 8: "Last-Night' image of globular cluster NGC 1851 taken during the last hours of the commissioning period with an excellent seeing of 0.56".The images of the stars within the >1 arcminute field of view at the Coudé focus (after 8 mirrors) are seeing limited.

The rest of the commissioning program was then carried out until the planned date of 18 February 2004 when the VLTI building and Paranal engineers had to be freed for the integration and commissioning activities of the VLTI instrument AMBER. Most of the tests could be carried out successfully except a few for which the failure of a measuring equipment or problems with a particular subsystem prevented reaching a definite conclusion. This was the case for the final verification the optical Path Length (OPL) stability and of the daytime air conditioning module. These tests that are meant as final verifications of performances already checked in Europe will have to be performed in a second phase of commissioning.

As one of the most basic telescope performance, the pointing accuracy was measured first. The result is shown on Figure 9, where an output of the TPOINT pointing model software is reproduced. The pointing accuracy measured after fitting a simple pointing model with 6 geometric terms using TPOINT is about 1 arcsec RMS, well within the specification of less than 2 arcsec RMS (with a goal of 1 arcsec RMS) on all sky.

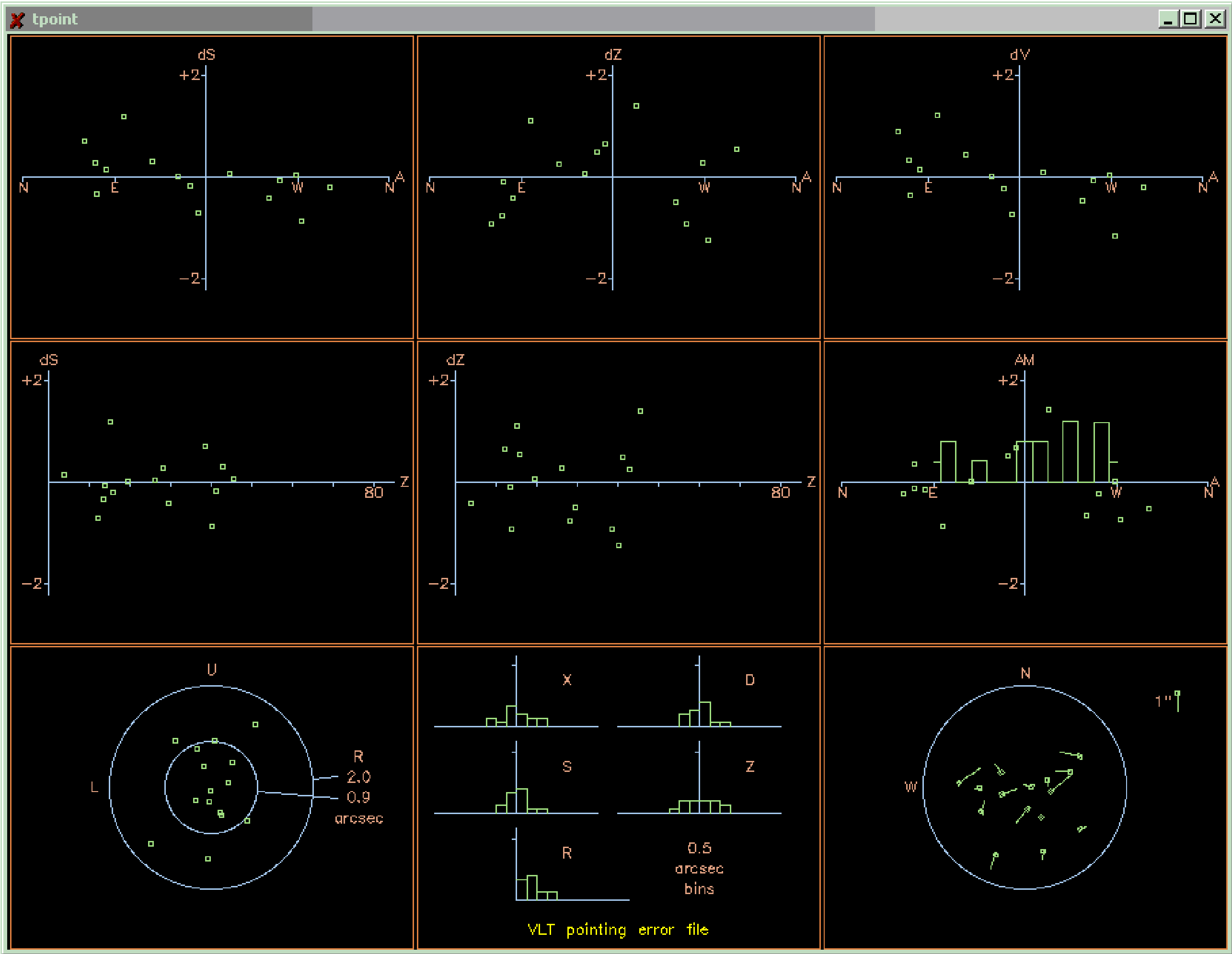

Figure 9: Residual pointing errors after fitting of a simple pointing model with TPOINT using 6 geometrical terms on 15 stars. The residual root-mean-square (RMS) error is 0.91 arcsec for a specification of <2 arcsec. The same model applied to 16 other stars (without additional fitting) provide a poiting accuracy of 1.1 arcsec RMS.

The telescope tracking performance was then measured and found to be < 0.1 arcsec RMS for a specification of less than 0.2 arcsec RMS (goal 0.1 arcsec RMS). Figure 10 shows a sequence of tracking error versus time while Figure 11 shows the tracking performance for different telescope positions (and therefore rotation speeds of the axes).

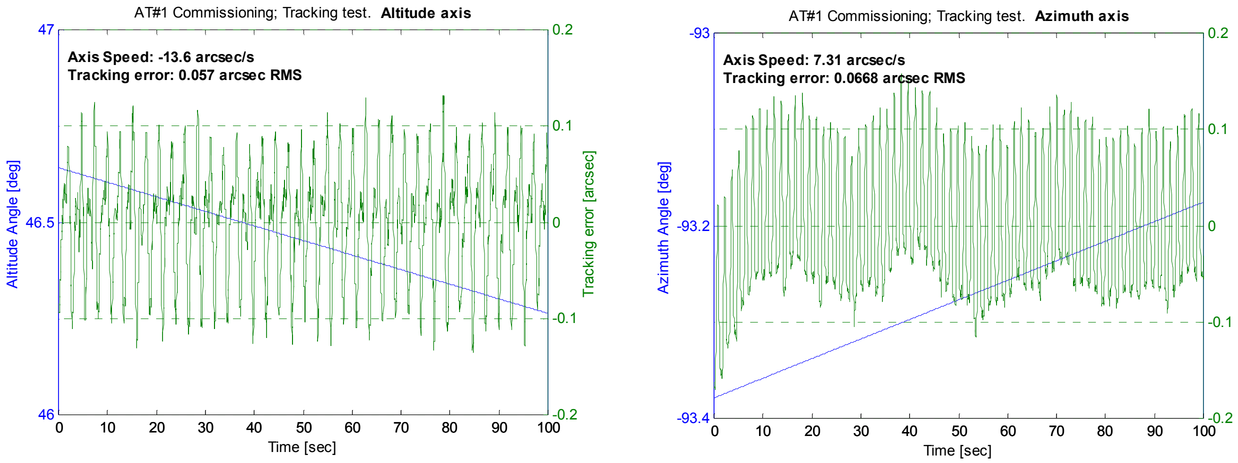

Figure 10: Tracking error time history for Altitude axis (left) and Azimuth axis (right). The performance is well below the specification of <0.2 arcsec RMS.

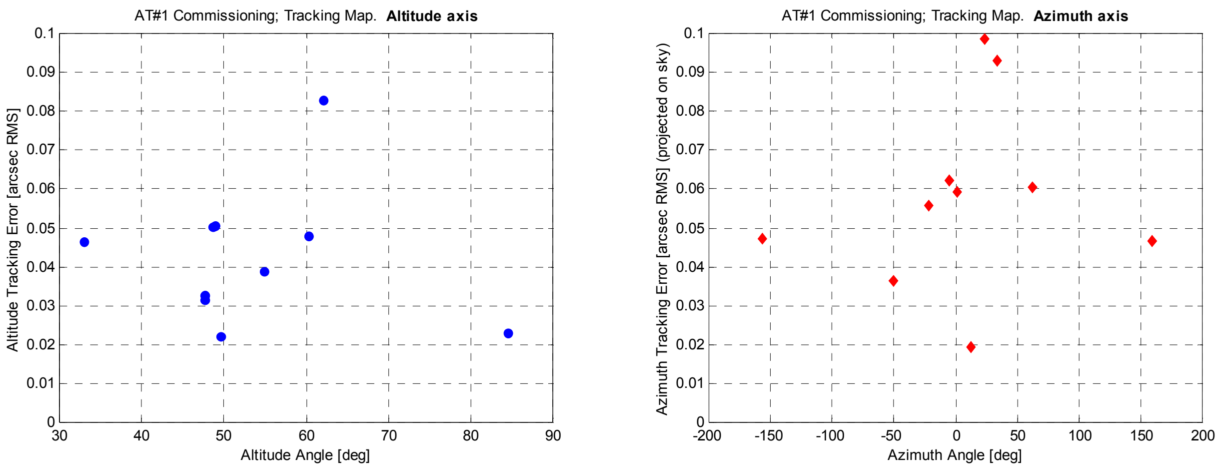

Figure 11: Tracking error mapping showing the telescope tracking error in arcsec RMS when tracking various objects corresponding to different Altitude and Azimuth angles and velocities. The performance is always below the specification of <0.2 arcsec RMS.

The last major test was the detailed, quantitative verification of the telescope image quality. This focused on two quantities that could not easily be measured in Europe to the required level of confidence: the spherical aberration (to verify the so-called optical 'matching' of M1 and M2) and the evolution of astigmatism with altitude angle (to verify the performance of the M1 lateral support). The image quality was measured using a portable Shack-Hartmann wave front sensor called ANTARES developed by ESO. Results are shown on Figure 12 and Figure 13. The main conclusion is that a final adjustment of the M1 lateral support is needed to remove a residual optical aberration (astigmatism) that varies with the telescope altitude angle from <10nm wave front error RMS at Zenith to about 200nm at 30º altitude. Even with this residual astigmatism, corresponding to lambda/10 in the K-band close to horizon, the telescope can be already considered of good optical quality for the work in the infrared. The adjustment of the M1 support in a second phase of commissioning will however be needed to meet the stringent VLTI error budget requirements of 110nm (90 nm focus removed) wave front error RMS for the AT. Recent tests on AT2 in Europe have shown that simple adjustments of the M1 lateral support enable to modify the behavior of the astigmatism, giving confidence that a compliant solution will be found during the next commissioning period.

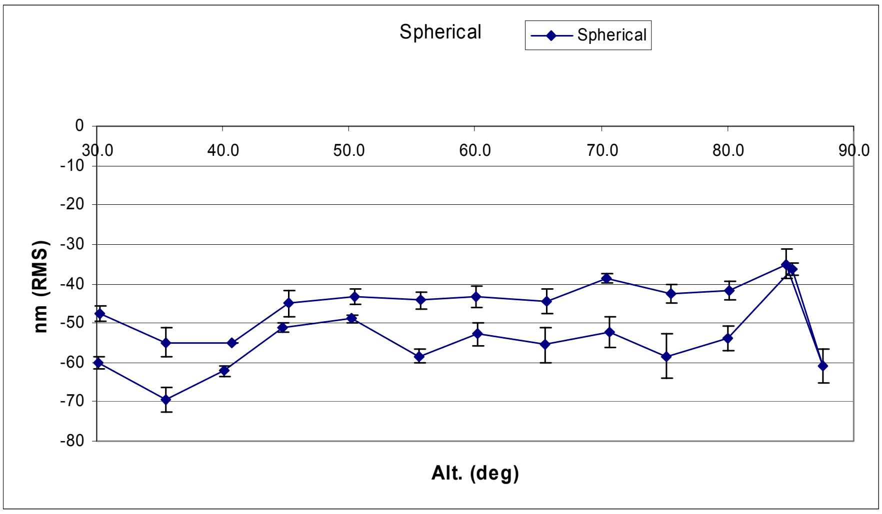

Figure 12: Wave front error (Spherical aberation) versus altitude angle measured with the ANTARES portable wave front sensor installed at the Nasmyth focus. The upper curve was obtained when going up in altitude angle and the lower one when going down. The difference is due to the evolution of the temperature during the night and is not related to mechanical hysterisis.The average value is around 50 nm RMS wave front error.

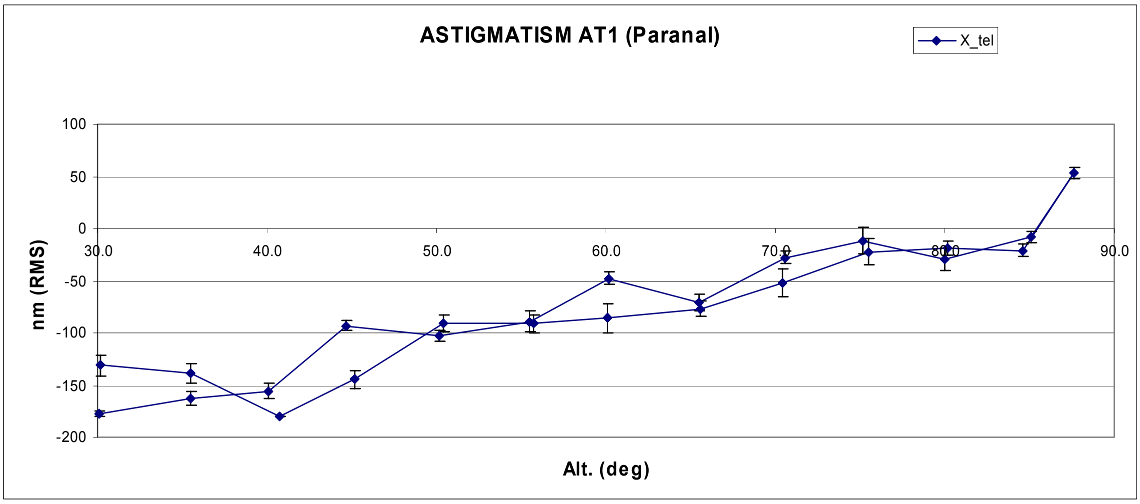

Figure 13: Wave front error (Astigmatism) versus altitude angle measured at the Nasmyth focus. The evolution indicates an influence of the lateral support of the primary mirror M1. The value of 150 nm obtained close to the horizon (altitude=30°) is still acceptable for the current VLTI wavelength of observation (2.2 µm K-band) but requires an improvement to meet the specification for the future shorter wavelengths. This should be achieved by a fine adjustment of the M1 lateral support before the end of 2004.

All in all, and in spite of the need for a second commissioning phase to fine tune a few elements, the commissioning of AT1 can be considered very satisfactory. It has proven that the system is healthy and has already reached a remarkable level of performance and reliability rarely reached by any other telescope so quickly after installation. Only one night out of 26 was lost due to a technical problem, namely the failure of a standard ESO electronic board.

6. STATUS OF AT2-4

The second Auxiliary Telescope (AT2) has passed all its acceptance tests in the factory. At the time of writing, the ultimate verification of image quality is being undertaken based on sky observation at AMOS in Liege (Belgium). This is done on a dummy observing station located outside the AMOS assembly hall. After this, a number of minor modifications/improvements based on the experience gained with AT1 re-assembly and commissioning will be implemented on AT2. The dismounting and packing shall then follow with an excepted delivery in Europe in September 2004.

The testing of AT3 telescope and Transporter is well underway. The critical path remains the polishing, by AMOS, of the primary mirror M1. The grinding and asphérisation is now completed with 10 microns PTV surface error. The figuring under visible interferometric testing has just started. The expected delivery in Europe of AT3 is currently February 2005.

As far as AT4 is concerned, the machining of its primary mirror (70% light weighting, pad gluing, acid etching, etc.) is completed and the manufacturing of the main mechanical elements of the Telescope, Transporter and Enclosure is finished. Delivery in Europe is presently awaited in June 2005.

The VLTI first fringes with two Auxiliary Telescopes are currently scheduled for early 2005.

Figure 14: The enlarged telescope family with a VLTI Siderostat (foreground), the first VLTI Auxiliary Telescope (next to the VLTI building) , three of the four Unit Telescopes and the VST enclosure (background). (Photo: P. Kervella)

7. ACKNOWLEDGMENTS

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