The Very Large Telescope Interferometer: 2010 edition

Pierre Haguenauer*[a], Jaime Alonso[a], Pierre Bourget[a], Stéphane Brillant[a], Philippe Gitton[a], Stéphane Guisard[a], Sébastien Poupar[a], Nicolas Schuhler[a], Roberto Abuter[b], Luigi Andolfato[b], Guillaume Blanchard[a], Jean-Philippe Berger[a], Angela Cortes[a], Frédéric Derie[b], Françoise Delplancke[b], Nicola Di Lieto[b], Christophe Dupuy[b], Bruno Gilli[a], Andreas Glindemann[b], Serge Guniat[a], Gerhard Hudepohl[a], Andreas Kaufer[a], Jean-Baptiste Le Bouquin[a], Samuel Lévêque[b], Serge Ménardi[b], Antoine Mérand[a], Sébastien Morel[a], Isabelle Percheron[b], Than Phan Duc[b], Andres Pino[a], Andres Ramirez[a], Sridhar Rengaswamy[a], Andrea Richichi[b], Thomas Rivinius[a], Johannes Sahlmann[b], Markus Schöller[b], Christian Schmid[b], Stanislav Stefl[a], Guillermo Valdes[a], Gerard Van Belle[b], Stefan Wehner[a], Markus Wittkowski[b]
[a]European Southern Observatory, Casilla 19001, Santiago, Chile;
[b]European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching, Germany

ABSTRACT

The ESO Very Large Telescope Interferometer (VLTI) offers access to the four 8-m Unit Telescopes (UT) and the four 1.8-m Auxiliary Telescopes (AT) of the Paranal Observatory located in the Atacama Desert in northern Chile. The two VLTI instruments, MIDI and AMBER deliver regular scientific results. In parallel to the operation, the instruments developments are pursued, and new modes are studied and commissioned to offer a wider range of scientific possibilities to the community. New configurations of the ATs array are discussed with the science users of the VLTI and implemented to optimize the scientific return. The monitoring and improvement of the different systems of the VLTI is a continuous work. The PRIMA instrument, bringing astrometry capability to the VLTI and phase referencing to the instruments has been successfully installed and the commissioning is ongoing. The possibility for visiting instruments has been opened to the VLTI facility.

The current status of the VLTI is described and prospects on future evolution presented.

Keywords: Optical long baseline interferometry, Very Large Telescope Interferometer

1. INTRODUCTION

The Paranal Observatory is located on the top of Cerro Paranal in the Atacama Desert in the northern part of Chile, about 120 km south of the town of Antofagasta and 12 km inland from the Pacific Coast. A close site has been recently chosen by ESO as a baseline for the installation of its E-ELT (Extremely Large Telescope).

The Very Large Telescope Interferometer (VLTI) is one of the largest optical interferometer in the world with its four fixed 8.2-m Unit Telescopes (UTs) and four 1.8-m Auxiliary Telescopes (ATs) that can be relocated on any of the 30 available stations. This unique array allows access to baselines between 47-m and 130-m with the UTs, and between 8-m and 202-m with the ATs. The baselines offered by the eight telescopes and the reconfiguration capability with the ATs make the VLTI a unique interferometer. The four ATs are now offered simultaneously, giving access to six baselines each night for science observations. The array re-configuration, by moving the ATs between stations, is done in two hours during daytime and the VLTI is offered back for operation on the same night, following a pre-define set of tests done on the whole system.

The VLTI is a very versatile facility with six operational delay lines (DLs) and the numerous possibilities of configuring the beams at the entrance of the interferometric laboratory to best fit the needs of the instruments. Dual-feed capability will be available with the star separators (STS) of the ATs and the differential delay lines (DDLs), both systems being integrated together with the PRIMA facility. Systems are installed to control the interferometer and ensure the delivery of good scientific beams to the instruments; the wavefront distortions induced by the atmosphere are corrected in real time by adaptive optics systems, the MACAO curvature wavefront sensors on the UTs, and the STRAP tipt-tilt sensors on the ATs; the IRIS guiding camera delivers a stable focal point for the instrument; the FINITO fringe tracker is now offered on ATs and UTs allowing for real time correction of the optical path difference (OPD) between three telescope beams. Two instruments are currently offered for science: the MIDI N-band two-beam combiner, and AMBER combining three-beams in J, H, and K bands. The PRIMA facility has been installed at Paranal in July and August 2008 and is currently being commissioned.

2. SECURE A POWERFUL VLTI

The VLTI has been designed as a powerful machine to be delivered to interferometric observations. But to reach its objectives performances and ensure that scientific data are delivered according to specifications, one needs to evaluate the system constantly and revisit its functionalities and performances. On the VLTI, a specific system engineering approach is followed and the interferometer is monitored and upgraded by all actors of its daily life: engineers, daily maintenance, operators, and astronomers. The reports from users and the scientific return on their observations are used as valuable inputs.

This global and systematic approach at all levels brings the following drivers for the work being done on the VLTI:

- To make progress on the interferometer, you need to understand its limitations, i.e. look for all possible issues that could lead to a lowering of the performances and monitor all the accessible parameters.
- A system that has been in operation without problems for years is not necessarily a system that is performing well, i.e. check if all systems are really delivering expected performances, and if not look for problems.
- Reliable and efficient operation is the key for good science.
- Don’t forget that first fringes on the VLTI were already some time ago, i.e. look for signs of fatigue and plan preventive maintenance before the failures arrive.
- If a major limitation is found, put a strong and dedicated effort on understanding and solving it.
- Learn to know your instruments, i.e. isn’t there something to gain there also?

And most important, the VLTI is a scientific telescope, i.e. listen to the community needs and wishes.

3. SOME SUBSYSTEMS UPDATES

Developing a system while in operation is not an easy task. One has to find the right equilibrium between time dedicated to analysis of the performances and tests of new technical solutions, and the time given to science. Our goal is to keep as much as possible the interferometer ready for operation every night all year round. To comply with this major constraint, testing is done as much as possible during the day, simulating the normal behavior of the interferometers. Many tools are developed and made available to be able to analyze the interferometer performances, without using precious nighttime. Still the ultimate testing needs of course access to the sky to verify the progresses by observing scientific targets. Dedicated technical periods, from a couple of hours to few nights, are planned and used when science pressure is lower.

We report here some examples of systems where a specific effort has been and still is done.

3.1 AT upgrade

Four ATs are available for observations with the VLTI. Only three of them at maximum can be combined together for the moment with the AMBER instrument (see section 5.2). But the second generation of VLTI instruments (see section 6) will make use of the four ATs simultaneously, and in the current scheme of operation the four ATs can be used during the same night to access any of the six available baselines thanks to the easy reconfiguration of the optics in the interferometric tunnel and laboratory.

Offering constantly four 1.8-m telescopes is a challenge and ones want to keep failures at a very low level. One has to deal here with the fact that the ATs are of different ages (seven years for the first, AT1, and four years for the last one, AT4), and are thus different in construction and showing different problems and issues. An important project has thus been to start a constant monitoring of the ATs, to solve possible recurrent problems and implements upgrades that can bring better performances and more reliability. The “Paranal Problem Reporting System” (PPRS) is a powerful tool to analyze the health of the telescopes (and all system in general). Through a statistical analysis of the problems reported and the time spend solving them, one can get a very clear picture of where to put priorities and efforts. Example of this statistical analysis is presented on **Figure 1** for the period from October 2006 to end of March 2009. One can clearly see the amount of work increasing of the years. The same statistical analysis made on the time lost in operation due to problems showed it was stable over the years. We thus managed to maintain all the ATs at the same level of operation, but with an increasing cost in engineering manpower.

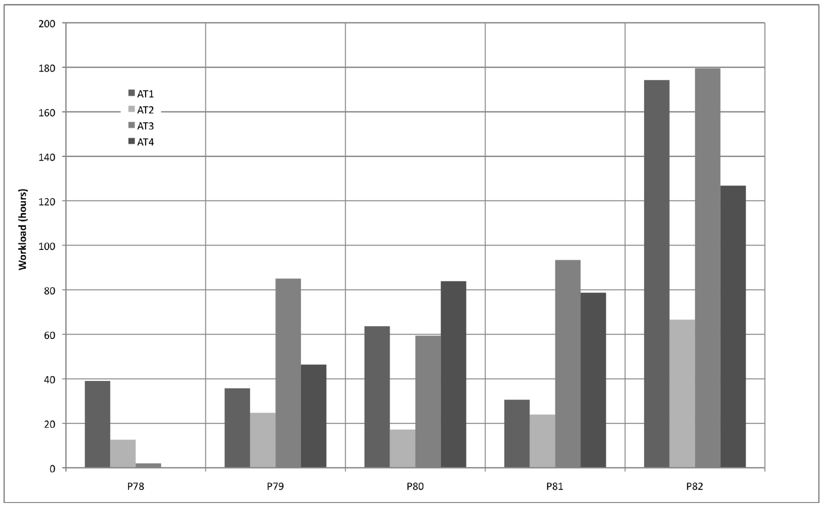

Figure 1 - ATs manpower statistics.

But this behavior is not a fate, and our analysis clearly pointed at some specific aspects of the telescopes where some dedicated effort today can save time and improve reliability tomorrow. In the following, we describe some of the points where we have dedicated our work.

Quality and stability of the pointing and image quality are of course key parameters of a telescope. A complete analysis of all the guiding loops as thus been performed. The control of the axes is important to have a smooth movement and to avoid unwanted displacement of the image at the instrument level. One also wants this control to be strong enough to react and compensate for all possible external conditions. The dome of the ATs being fully open during observation, the structure of the telescope itself is exposed to the wind. Therefore, depending on the direction of the wind and on the direction of pointing, the control of the telescope axis can have to counteract external disturbances of very different amplitude. Work is thus been done to verify and optimize the performances of the tracking close-loop.

Due to temperature changes during the night, the telescope optics needs to be adjusted to compensate for the thermal expansion of the telescope structure. This is achieved via the M2 mirror, actuated by its hexapod mount. A thermal model, refined by on-site measurements, allows setting the M2 position to deliver a correctly focused image towards VLTI instruments. Fine adjustments to cope with exact conditions at the telescope are done by the operators, using the image quality in the laboratory (close to the instruments) as a driver. A hexapod is used here to bring the five degrees of adjustment, three translations and two rotations, needed to create a pure focus without introducing other aberrations. To ensure a correct focus at VLTI, the M2 positions needs to be adjusted with a precision of about 5 microns, making it thus a very sensitive high-precision system. Work is thus performed in order to improve its control with two goals: first making it reliable and precise, and second avoid unwanted or unnecessary movements that will reduce its accuracy and/or lifetime. In the same time, and as technology has evolved since this system was designed, the possibility of upgrading the M2 control with a new design is investigated, as hexapods are becoming more and more off-the-shelves components.

To improve the image quality of the ATs, a project of adaptive optics (AO) for the ATs is being developed at ESO. The NAOMI, New Adaptive Optics Module for Interferometry, shall be installed on all telescopes in place of the current STRAP tip-tilt sensors. The requirements for this AO system is to deliver a Strehl ratio higher than 50% in H-band with guiding star up to $m_V = 12$, and if 25% up to $m_v = 15.5$. Studies are currently ongoing both in house and in external partners to build these AO systems. In the time before implementation of the NAOMI system on the ATs, an active optics system is currently being installed and commissioned on the telescopes, called OBAMA (Optical Bidule for Aberration Measurement on the ATs). This deployment of the OBAMA units is ongoing and shall be finished by end of 2010. OBAMA will measure the wavefront quality of the incoming beam with 12x12 sub-apertures Shack-Hartmann, and correct for low order aberrations using the M2 mirror. In a first step, it will be used at each preset of the telescope to a new object to measure and correct the image quality. In a second step of development, the use of OBAMA to provide real-time low frequency corrections during observations is envisioned. **Figure 2** presents the first on-sky image obtained with AT4. This image was obtained with the almost final design of the system, to test the functionality of the measurement. Part of the telescope pupil is missing in this image, but this will be corrected in the final design by implementing a bigger TCCD and/or slightly modifying the optical design of OBAMA.

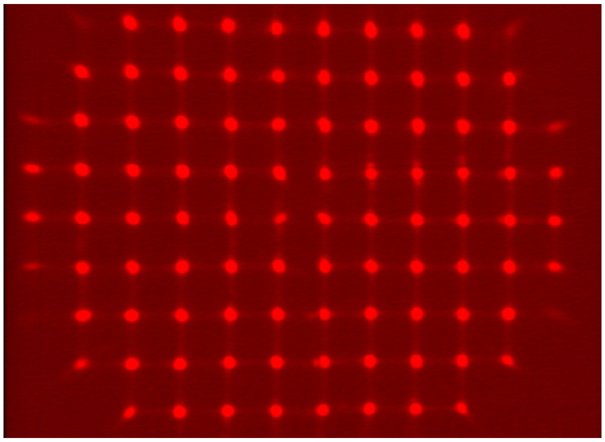

Figure 2 - First on-sky image of the OBAMA active optics for the ATs.

3.2 STRAP

The ATs are currently equipped with the STRAP (System for Tip-tilt Removal with Avalanche Photodiodes) tip-tilt corrector. It is based on a four-quadrant measurement of the tip-tilt of the incoming wavefront, working in close loop. The corrections are sent at 1kHz to the pupil-plane M6 mirror mounted on a piezo-actuator.

A deep analysis of the performances of the STRAP during operation at Paranal, has led to identify possibilities of improvement of the hardware and software. The STRAP is using four APDs in a 2x2 square arrangement with a set of four lenses to send the flux on each APD. In the original design, the lenses were mounted on a ceramic support to interface them to the APD module. This was causing a loss of flux in the center (see **Figure 3** left), which was impacting the quality of the correction. This effect was particularly important in good seeing conditions. A change in the mounting of the lenses (gluing) allowed removing this problem (see **Figure 3** right). In the new design, one can still see some flux losses at the contact between the lenses, but much reduced compared to the original design and most important, the blind spot in the middle of the four lenses has disappeared. The gain in term of flux is between three in average weather conditions (when the blind spot effect was less important) and five in good conditions, improving thus the limiting magnitude for guiding. The upgraded system has now been deployed on all four ATs.

In addition to this new design of the STRAP measuring heads, the full system hardware and the guiding loop are investigated to improve their performances. New criteria for the acceptance of the units from the manufacturer have also been derived from the Paranal on-site measurements with the ones already installed. The calibration procedure of the units once mounted on the telescope has also been completely reviewed, leading to modifications when not accurate enough and to the addition of new steps that were identified as missing. Modifications on the loop control are being implemented to both increase the performances and decrease the time needed to close the guiding loop.

Upgrades are still being brought to the STRAP, but a number of them have already been implemented and validated in operation, with a clear improvement of the guiding quality. As an example, **Figure 4** is showing the residual tip-tilt on the image from the ATs after correction by the STRAP. The lower points show a clear improvement in performances of an optimized system installed on AT3, compared to older systems (AT2 and AT4 here; these systems have been upgraded since these measurements). If the performances are similar at the brighter visible magnitudes, the gain starts to be important from m_V=10 onward.

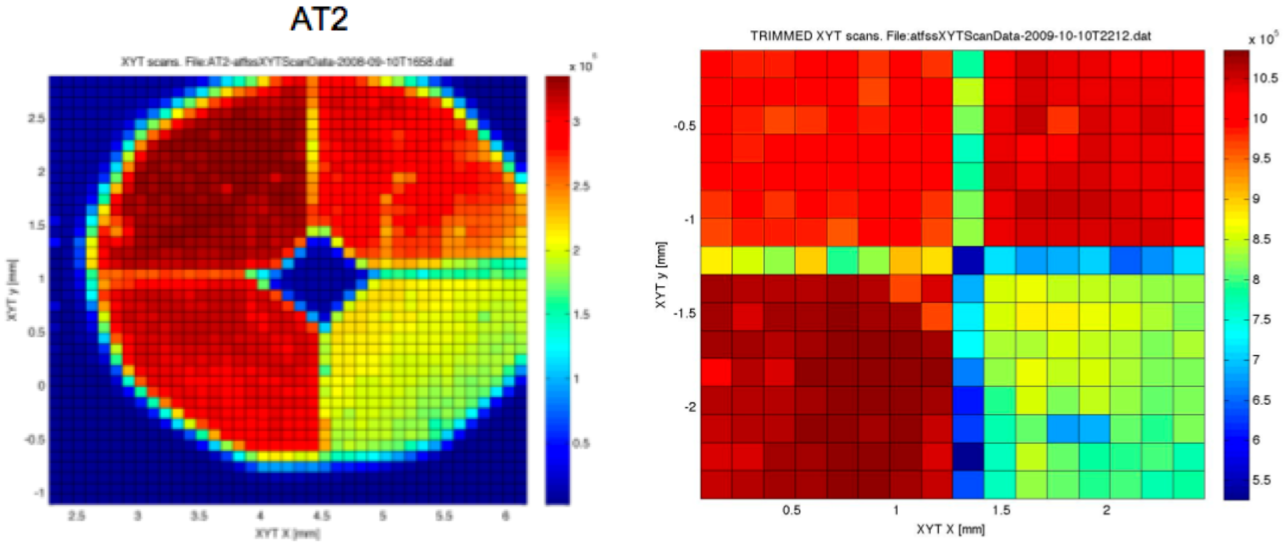

Figure 3 – Scan of the flux transmission of the STRAP tip-tilt correctors: old design (left) and new ones (right, close view on the central region).

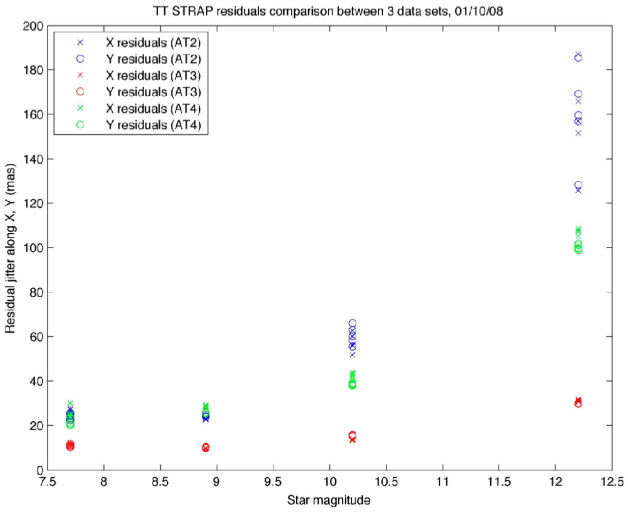

Figure 4 – Comparison of on-sky STRAP performances between the new optimized STRAP (lower points) and old design.

3.3 Delay Lines

The VLTI is equipped with six delay lines (DLs) for the necessary compensation of the difference of optical path between the beams. These DLs are used in double path for the light, allowing for additional optical path length (OPL) of up to 120 m for each DL. They are based on a cat-eye system to ensure the parallelism of the input and output beams. The position of the DLs must be controlled with a precision of only 50 nm over the full range of OPL. The position is controlled by coarse linear motors and a fine piezo-actuator supporting a mirror. A laser metrology is used to ensure the positioning of the DLs with the desired accuracy. To compensate for the change in the optical characteristics of the VLTI when the DLs are moved, a variable curvature mirror (VCM) is installed at the focus of the cat-eye system. This allows maintaining continuously the longitudinal position of the pupil at the same position for the instruments in the laboratory. To allow for this VCM to work optimally, the rails over which the DLs are moving must be maintained flat at all time with a precision of 5 microns over their 60 m length.

As one can see from above, the DLs need a very high-level control and stability to deliver the required OPL and beam quality for the interferometric instruments. And in addition to the compensation of the OPL due to the position on the sky of the object, the DLs are also the actuator for fringe tracking, receiving commands from either of the fringe sensors (MIDI, FINITO, FSUs). This real time correction of the piston needs to be done at the time scale of the atmosphere coherence time. So we just need to be very precise and very fast. Reaching this goal is not an easy task and, following our modus operandi (see section 2), a strong effort was put at Paranal to verify the DLs performances and ensure their optimal functionalities.

One first result, from the maxim "never think that your systems are performing well", was the identification of a discrepancy in the originally installed DLs electronics. Testing solutions to this wrong hardware implementation showed that an important gain in performances could be brought to the DLs. **Figure 5** and **Figure 6** present the results of this optimization. As one can see, together with increasing the cut-off frequency for the applied commands (here in the case of DL1 from 223 Hz to 409 Hz!), the robustness of the control loop is also improved (instabilities to strong amplitude commands seen of left of **Figure 6** have disappeared in the new setup). The change in the electronics that lead to these outstanding results is small but the work necessary for an implementation in operation is important. Since the DLs are involved in many control loops of the VLTI (tracking on sky, fringe tracking, vibration control), even a small change has far reaching consequences. The correction of the discovered discrepancy thus requires a complete retuning and verification of all these loops. The complete testing and implementation is currently ongoing and shall be finalized in a close future.

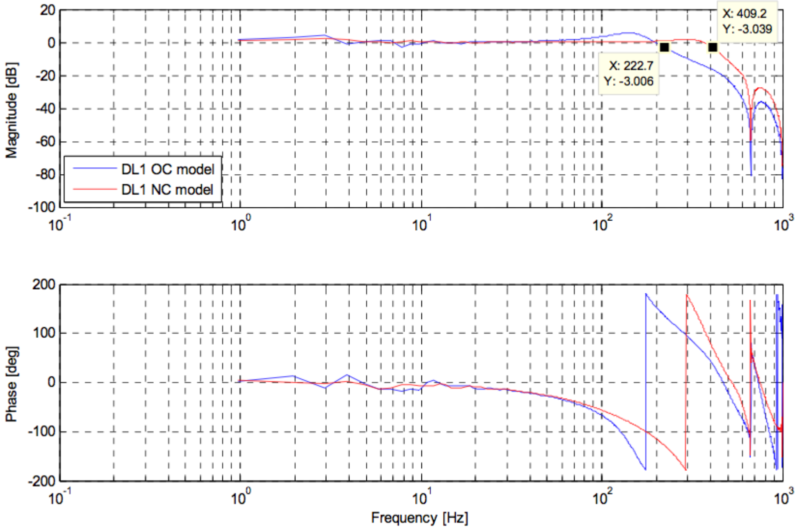

Figure 5 – DL1 close loop response with the old and new electronic solutions.

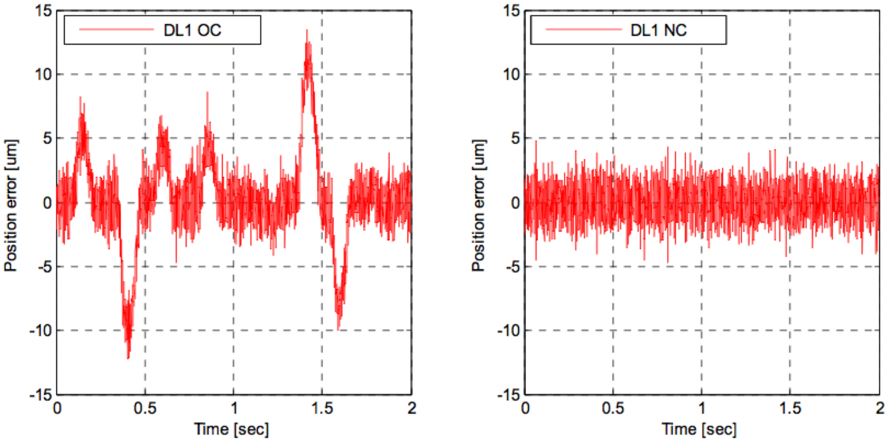

Figure 6 – DL1 response to 1-micron rms noise excitation: old setup (left) and new setup (right).

As said before, for accurate operation of the DLs, on needs to ensure a smooth and flat movement of the carriage on the rails. So from the maxim “look how your systems are evolving with time”, improvement could be brought to the DLs daily operation. To avoid failures, we started a regular monitoring of the DLs, which defined actions to be performed to maintain their high level performances. A perfect example of the consequences of aging on a system was the identification of the decreasing performances due to drying grease in the bearing of the DLs wheels. The power being supplied to the carriage through its wheels, this drying effect led to power drops and by cascade irregularities in the operations. Again we are facing something that looks like a small problem but leads to an important amount of work. Changing and greasing bearings on these wheels is not like for your car; it requires a full week of work and requires a team of engineers from all domains. New procedures and controls where defined while performing these tasks to ensure that the DLs were brought back to their full capacity. The result of this careful and deep analysis done at Paranal is a great improvement of the reliability during operation. **Figure 7** presents the result of this work for DL4. As previously said, we need a smooth movement of the DLs and the source of disturbance are multiple: rail non-flatness, wheels hysteresis, error of centering of the wheel to its axes, phasing of the wheels, … A long procedure is executed to check and correct for these defaults one by one. **Figure 7** shows the tilt in horizontal and vertical directions before and after the procedure was applied. The most affected direction is the vertical tilt as it is the direction where the wheels have the biggest impact. As seen on the right side of the figure, the gain is important in that direction, resulting in a better stability of the laser metrology and of the pupil delivered to the instruments.

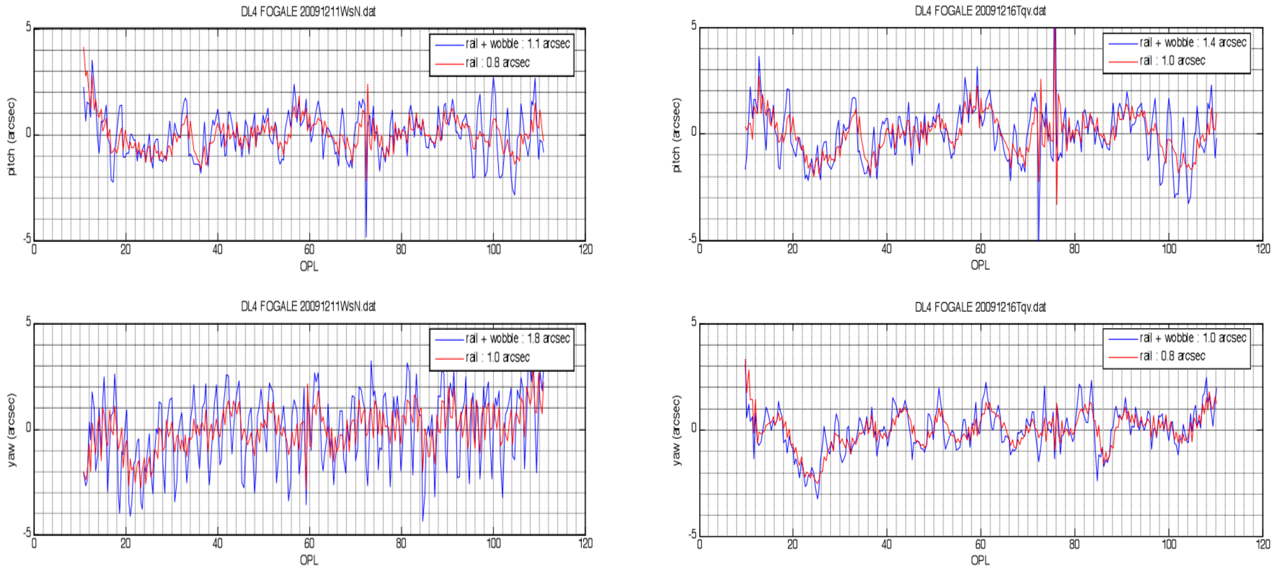

Figure 7 – Tip and tilt of the carriage of DL4 before (left) and after (right) full refurbishment.

4. UT VIBRATIONS

The vibrations generated at the level of the UTs were identified as an important source of OPD perturbation while the FINITO fringe tracker was brought to operation. Various systems (Manhattan2 accelerometers system, vibration tracking) have been developed and implemented to counteract the effect of the vibrations on the interferometric measurements. Because it is always better and more efficient to reduce directly the sources of the perturbations than to correct for them, a strong effort was put on identifying all the possible generators of vibrations and decrease them. A systematic study was thus started to: analyze each UT vibration signature, identify the vibration sources and study their possible damping, and determine the minimum level of OPL to reach with a “quiet” system. This work is described in more details in another paper in these proceedings [1], and we will only show here some results.

When this effort was started, the following statements applied:

- The vibrations are affecting the four UTs and their stability.

- The vibrations are affecting the operation of all instruments, including the UT ones. The degradation of performances is not limited to VLTI instruments; they are just more sensitive as working in the nanometer world.
- The UT instruments generate most of the vibrations.

The Manhattan2 seven accelerometers on each UTs (4 on M1, 1 on M2 and 2 on M3) are used not only for the vibration fight during observations, but also to monitor the status of each individual UT. **Table 1** presents the level of OPL generated on the three first mirrors of the UTs, for each UT, in early 2009 and in mid-2010. From these numbers, one has to keep in mind that:

- These values are not the total amount of vibrations on each individual UT. Other mirrors are affected, but at a lower level.
- The level of vibrations seen by an interferometric instrument is the quadratic sum of the vibrations of the two UTs involved in each baseline.

From **Table 1** one can see that great progresses have been made on UT1 and UT2, while unfortunately not on UT4 for the moment. **Figure 8** shows a very good example of the effect of the UT instruments on the vibration level, and of the fact that this problem is not unavoidable. A careful design taking into account this potential problem allows to reduce the impact. This was proven with CRIRES, which, after its installation, was generating a level of vibrations far from being compatible with interferometric observations. A successful upgrade of its cooling system allowed damping the vibrations by a huge factor. For UT3, the situation has even degraded. Looking at **Figure 9**, one can see in this specific case that all is not negative. Along the time, UT3 got even worse than it currently his, due to the installation on this telescope of the VISIR instrument and later on with the migration of ISAAC instruments (this was of course to the benefit of other UTs, vibrations are following their instruments). But the constant monitoring and the knowledge acquired now at Paranal on this matter allowed to optimize the situation, even in a degraded environment.

Table 1 – Status of the OPL induced by vibrations on the UTs. These values include on mirrors M1 to M3. The OPL range for 2009 and 2010 are reported.

	UT1	**UT2**	**UT3**	**UT4**
OPL rms (nm) early 2009	380-400	300-450	130-160	280-320
OPL rms (nm) 2010	170-190	150-170	220-240	280-320

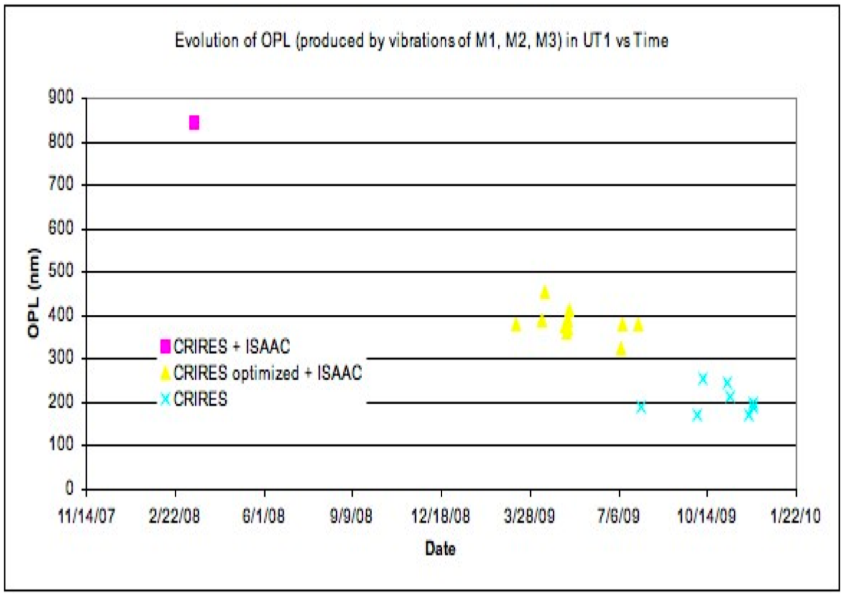

Figure 8 - Evolution with time of the level of vibration of UT1.

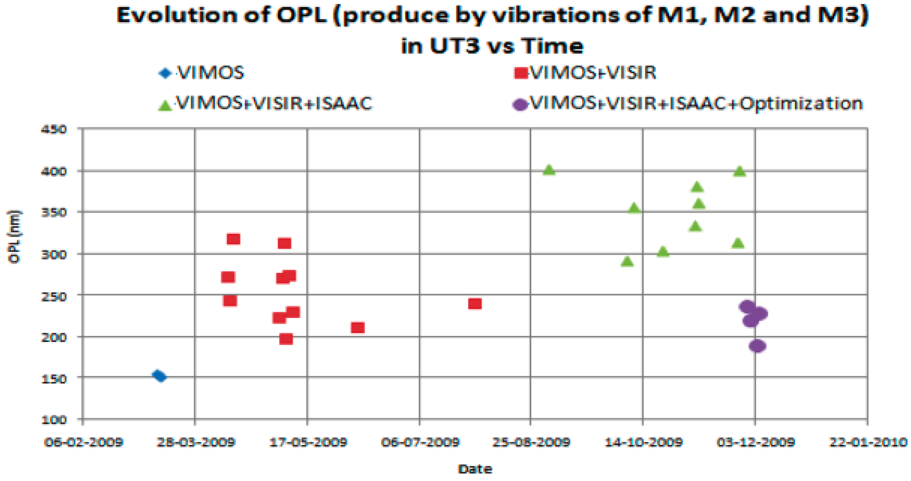

Figure 9 – Evolution with time of the level of vibration of UT3.

5. VLTI IN OPERATIONS

5.1 Baselines and operation

The goal of the VLTI and all the effort put into its operation is of course not to just make it a nice interferometric machine. The progresses made on the global system and the great capabilities that are possible through its design, has put us in the position to be able to try to offer to the community what is best for science. The full status of the changes of operation and configuration of the VLTI are reported in two papers in these proceedings. The VLTI has now been in operation for eight years and it is thus a good time to see where we are and what has been done [2]. This exercise also allows meditating on where we are going and want to go. If we are taking care of the VLTI for its everyday operation, we are doing this work to satisfy the science needs form the interferometric observers. This is why we are regularly asking all the users for their inputs on what configurations of the ATs would fit their needs best. These demands are then looked at according to the VLTI on-site operation constraints, and new baselines can be offered [3]. The accuracy of the OPD models to preset the full VLTI to the fringes positions is important for fast acquisition of the interferometric signal, but the knowledge and accuracy of the associated baseline solution is of even higher importance for high accuracy astrometry as envisioned with PRIMA. The quality of the OPD models and all the possible sources of offsets (from hardware and/or software) in their computation are being checked and monitored (see [4]).

5.2 Instruments

MIDI, the N band two-beams combiner is delivering scientific observations without major downtime. Still, the instrument performances are closely monitored. The main work performed regarding MIDI is measuring the exact position and stability of the VLTI field of view to ensure that the MIDI one is well centered on it, as this is critical for this infrared instrument.

The potential for a new mode of observation with MIDI and the PRIMA FSUA, to reach fainter targets with fringe tracking are presented in [5].

AMBER, the J, H K band three-beams combiner is being closely investigated to verify its performances compared to the specified ones. The investigations started by Paranal include the alignment wrt VLTI, the optical transmission, the mechanical stability, and the accuracy of the spectral calibration. The current status of AMBER investigation and prospective for performances improvements are presented in [6].

6. LOOKING TO THE FUTURE

6.1 PRIMA

The AIV (Assembly, Integration, Verification) of the PRIMA facility (Phase Referencing Imaging and Microarcsecond Astrometry) took place in July/August 2008. PRIMA is currently being commissioned. The number of subsystems newly implemented at the VLTI with PRIMA makes its integration a real challenge. It will bring dual-feed capability, allowing therefore either to achieve high accuracy astrometric measurements when using the two PRIMA FSUs (Fringe Sensor Units), or phase referencing when used with AMBER or MIDI.

Current results and status of PRIMA are reported in these proceedings ([7], [8]).

6.2 PIONIER

As done for the UTs, the possibility for visiting instruments has been opened at the VLTI. PIONIER was proposed in this context by the Laboratoire d'Astrophysique de Grenoble. PIONIER is a four-beam combiner based on integrated optics, with the goal to deliver high accuracy visibility and phase closure measurements. By combining four telescopes, PIONIER is also an important step towards imaging capabilities at the VLTI. PIONIER will be able to work in H or K band, with a limited spectral resolution of about 40 (this can easily be extended in further upgrades).

The exact schedule of the integration and first science with PIONIER is still under discussion, but it is expected to be integrated at VLTI in November 2010 and first science could be done in December. A more detailed description of the instrument can be found in [9].

6.3 GRAVITY

GRAVITY is a four-beam combiner, dedicated at imaging with a 10-microarcsec astrometric capability. Spectrometric and polarization analysis capabilities will also be available. GRAVITY will use the light in K-band of the on-axis beam as a reference for fringe tracking, while measuring on the off-axis beam. The combination of the two times four beams (on and off-axis) will be performed with a fibered integrated optics component, performing the modal filtering, compensation of differential delay and adjustment of polarization. A low-resolution (5-pixels) spectrometer provides internal phase- and group-delay tracking on the fringe-tracking star, so that long integrations become possible on the second channel, usually a fainter science object. A dedicated metrology will monitor the optical path length from the beam combiner to the M2 spider.

GRAVITY is currently in the final design step and its installation at Paranal is planned for the horizon 2013-2014. A more detailed description is given in [10].

6.4 MATISSE

MATISSE will be a mid-infra-red spectro-imager working in L, M and N bands and combining up to four telescopes beams. It will thus open new wavelength windows with the M and N bands, and also bring closure phase capability to the N band. MATISSE will allow to perform interferometric spectroscopic with three different spectroscopic resolutions in the range R~30-1250.

MATISSE is currently in the preliminary design phase and its installation at Paranal is planned for the horizon 2014-2015. A more detailed description is given in [11].

ACKNOWLEDGMENTS

We would like to thank here all the work done by the VLTI groups in Garching and Paranal. The continuing support of the AMBER and MIDI consortia after the installation of the instruments was very valuable in the improvement of the scientific data quality. Fruitful discussions over the years with the interferometric community have brought valuable inputs to the development of the VLTI. The current and future VLTI status also benefited from collaboration with the teams studying the second generation of instruments.

REFERENCES

[1] Poupar, S., et al., "Status of the VLTI-UT performances with regards to vibrations," Proc. SPIE 7734-116 (2010).
[2] Pino, A., Cortes, A., Brillant, S., "Eight years of operation at the VLTI," Proc. SPIE 7734-25 (2010).
[3] Brillant, S., et al., "Configuration of the auxiliary telescopes at VLTI: a status report," Proc. SPIE 7734-26 (2010).
[4] Brillant, S., et al., "OPD models for the VLTI," Proc. SPIE 7734-69 (2010).
[5] Mueller, A., et al., "First results from MIDI observation with PRIMA FSU as a fringe sensor," Proc. SPIE 7734-130 (2010).
[6] Mérand, A., et al., "AMBER current performances and prospects," Proc. SPIE 7734-27 (2010).
[7] Sahlmann, J., et al., "First results from fringe tracking with the PRIMA fringe sensor unit," Proc. SPIE 7734-73 (2010).
[8] Schmid, C., et al., "Status of PRIMA for the VLTI or the quest for user-friendly fringe tracking," Proc. SPIE 7734-14 (2010).
[9] Berger, J.-P., et al., "PIONIER a visitor instrument for VLTI," Proc. SPIE 7734-114 (2010).
[10] Gillessen, S., et al., "GRAVITY: a four telescope beam combiner instrument for the VLTI," Proc. SPIE 7734-33 (2010).
[11] Petrov, R., et al., "The potential performance of the mid-infrared second-generation VLTI instrument MATISSE," Proc. SPIE 7734-35 (2010).