# Commissioning of the Unit Telescopes of the VLT

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In the June 1998 issue of *The Messenger* (No. 92) there was an article describing the hectic days and months before the first light for UT1. First light was a great public event and of great significance for the project and the organisation. From a technical point of view however, it was a non-event. The telescope had met all specifications for first light ahead of time and the weeks before the official announcement were more a sit tight, don't tell and don't break it time. Following the big event we were free again to work on the machine. For those with keen eyes looking back at the beautiful images taken for the first light, flaws could easily be found. In fact a number of messages and private comments arrived at Paranal describing in great detail what we already knew. A lot of work lay ahead of us.

The working schedule was set out. During the day Peter Gray, Toomas Erm, Gerd Hudepohl, Marc Sbaihi and Juan Osorio would fix all the things we broke during the night and continuously improved the opto-mechanical and electronic robustness of the system. During the night Jason would sleep on his sofa while the others tested out the latest and newest ideas that had been implemented the day before. Pretty pictures, which before first light were obtained when the seeing was better than 0.6 arcseconds, were banished to be taken at times when the seeing was better than 0.5 arcseconds. Then the limit was changed to 0.4 arcseconds as seeing was good too often and test time was being limited. It was often said that the seeing was best when Jason was asleep in the control room. Ivan Muñoz and Anders Wallander set out to prove this by obtaining a 0.27 arcsecond image in June under those operating conditions. A press release on the subject – politely avoiding the sleeping issue – can be found on the web.

Antu, or UT1 as it was still known in those early days, suffered from wind shake. The telescope was not stiff enough to remove the effects of the wind on the focal plane. This was not a surprise since from the design phase already it was known that the UTs would be susceptible to such problems. Before first light Gianlucca Chiozzi and Robert Karban had done a splendid job in getting field stabilisation to work in a matter of a couple of weeks. Now was the time to tune it up, remove the lag as much as possible and get every last millisecond out of the loop. Working with a 33 MHz 68040 processor as the central engine was a challenge. However, together with Birger Gustafsson, Antonio Longinotti and Philippe Duhoux (M2 and CCD experts) the field stabilisation was brought to an effective update frequency of 20 Hz. Now was the chance to have some real fun. Out of the drawer Birger produced the latest and best toy. A Power PC processor for our guiding LCU. It was tested on the control model in Garching, deemed to be good and hey presto! 50 Hz frequency on the M2. The secondary mirror of the VLT is 1.2 metres across. Moving it at 50 Hz is not for the weak of heart. If you got time on the VLT and you have got some data, the 'little' mirror at the top of the telescope was moving about all the time making the focal plane stay put while the big thing (telescope) shook in the wind. The weakness of the telescope in windshake rejection was thought to be with us for life. Toomas Erm would not accept that and continued working on this problem.

Before first light we only needed the telescope to point to 10 arcseconds or so. Even for a big machine like UT1 this was not very difficult to achieve thanks to the full integration of the pointing model into the tracking software. Now we had the real specifications to meet. Pointing any telescope to 1 arcsecond rms all over the sky is hard enough. Doing it with the UTs of the VLT is an interesting challenge. First we had to stabilise the pointing model which was varying from night to night. It does not take a rocket scientist to work out that if the primary mirror moves inside the cell then the pointing errors of the telescope change. Keeping the mirror in position was provided for with the mirror cell hardware, which permits us to position the mirror in x,y,z as well as the three angles about these axes. By re-positioning the mirror after each pre-set we stabilised the pointing model. A new set-up keyword for the telescope was needed and the food theme on Paranal began. When TEL.PSOUP (pronounced pea soup) is set to true the m1 cell Passive SuppOrt moves the mirror UP. Now we had a stable pointing solution and we could start worrying about the actual performance of the telescope. Trying as hard as we might, neither the residual of the fit nor the actual pointing performance could be brought below 1.5 or so arcseconds rms, and often the performance was worse. But then again we asked ourselves why are we bothering with this. The telescope guide probe moves automatically to find a guide star. Why not offset the telescope position to make the guide star land where the guide probe expected it to be. The pre-setting accuracy would then be equivalent to the as-

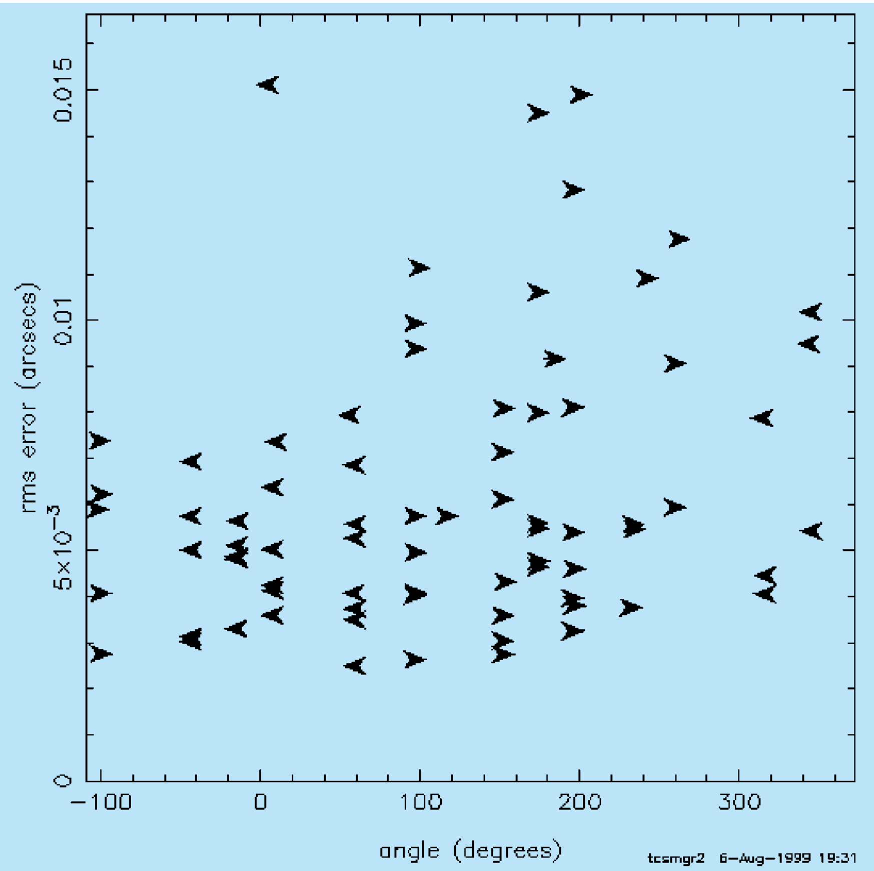


*Figure 1: The plot shows the rms tracking error as measured on the telescope encoders for Azimuth on Kueyen. The specification is 0.1 arcsecond and the achieved performance is clearly much better than that. The direction of the arrow indicates the direction the telescope was moving during the measurements.*

trometric accuracy of the guide star. Two birds killed with one stone. One was the pointing of the telescope. The other was the reproducibility of the pointing. The latter was to show its true worth later when FORS1 was being commissioned.

Now that some basic things were out of the way we could start having fun. Again Gianlucca Chiozzi and Robert Karban were set to work. We want to chop and field stabilise at the same time. Sure they said. It is part of the specs. One beam is always under control while the other is the sky beam that no one cares about. Somewhere in the specifications this had slipped through. Maybe it came from the days of single-element IR detectors. In any case, the new more complex specification was given out. Assuming the guide star is going to land on chip in both beams of the chop then we wish to field stabilise on both beams. Back to the drawing board. Philippe Duhoux to the rescue with a port of the DIMM software to the guider and again our wish was fulfilled. ISAAC folks would be happy. But what about the comet and moving-target community? Of course the VLT can track on a moving target. But could it guide on it as well? So the challenge was set. How would this be done? Back to the original design to see what was thought to be the way. Move the guiding box on the CCD with the appropriate speed and everything will be OK was the theory. But why do that? Why not tell the guide probe to simply track its star. Then if the centre moved or not was not a problem since the guide probe would happily hunt down its guide star. It actually turned out that Birger Gustafsson had already coded almost all of this simply to be able to pre-set the probe to the guide star. All he had to do was to keep the probe alive at all times. Easier said than done but, as usual, nothing is more fun than the impossible. So having this working, we could now chop and field stabilise while the telescope tracked a moving target. Unfortunately, in doing this we broke the combined offset mechanism. Traditionally the probe is offset in the other direction to the telescope. By making the probe live when the telescope offset the probe would automatically follow its own star. After a bit of soul searching we realised that this was actually the better way of doing things. The autoguider was promoted above the tracking software as the master and we were back in business.

While all of this was going on, from nowhere came a couple of Nasmyth adapters and were miraculously mounted on the telescope without interfering with our work (we suspect a phantom Francis Franza and his twin Paul Giordano had something to do with this but Martin Cullum denies all knowledge as to how this miracle occurred). The engineering crew was growing by the day. George Harding, the two Pablos (Gutiérrez and Barriga) and the formidable Patricio Ibanez all started putting their stamp on things. Toomas Erm kept worrying

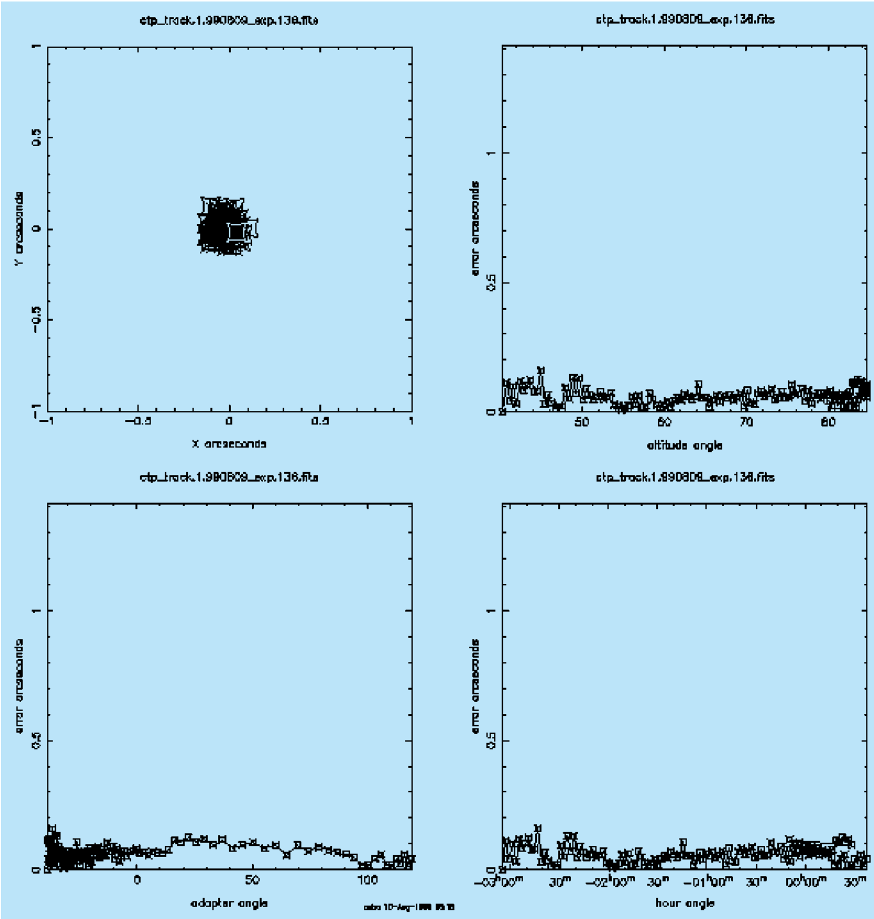


*Figure 2: The top left plot shows the measured centroid for a star during successive 30 second exposures taken during a 3.5 hour track. The difference in the centroid between the first image and all successive images is the measured error in tracking. The three other plots show the error in tracking as a function of altitude, adapter angle and hour angle. The telescope crossed the meridian during this test and the peak error was below 0.15 arcsecond during the entire experiment.*

about this wind shake thing. Gerd Hudepohl and Pierre Sangaset would fret about the cell while Gustavo Rahmer was finally about to get some serious work to do. Thanh Phan Duc would come and go and let us all know exactly how many cell operations we had made and would fix whatever needed fixing. It was like having a policeman checking up all the time. Ricardo Schmutzer moved between Garching and UVES and Paranal and the test camera without missing a beat on either of them. FORS1 arrived on the mountain and immediately aroused suspicions. Did they really think that big yellow thing would fit under our delicate telescope?

Meanwhile the final phases of the commissioning of another telescope on Paranal were taking place. The ASM (Astronomical Site Monitor) was getting to the phase where it could be left alone. Stefan Sandrock and Rodrigo Amestica would try to make our robotic telescope work. Anders expressed wishes that the UTs be so simple to operate. Switch it on and the ASM will know when to open and when to close, where to find a star and what to measure. Not too hard a requirement really. Only the ASM was having problems finding alpha Cen let alone any other star. A bit of investigating on the pointing problem and a few ingenious solutions by Stefan and Rodrigo and the ASM was up and running. Now the radio need not sound all night long with the call: “Julio! What is the seeing?”

Before putting FORS1 on to the telescope we had to satisfy another client. Bruno Leibundgut together with Mark Ferrari and Eline Tolstoy arrived for science verification with the test camera. Brilliant plans were laid out, astronomical challenges and problems to be solved. The first couple of nights went fine. In fact, a new image quality record was set at 0.26 arcseconds, the image taken with the ADC mounted. Then the weather changed, the seeing became poor, the control room was not a happy place and before you could say “bad luck” the two weeks of SV were over. Bruno took a copy of the data with him and the video conference to Garching fell silent.

Soon afterwards The FORS1 team led by Professor Appenzeller together with Gero Rupprecht as the ESO responsible put their pride and joy on the Cassegrain focus of UT1 and then had to take it off again due to a broken cooling pipe inside the adapter which dripped water inside their instrument. We apologised, helped to clean up the mess and on went FORS1 again. The moment of excitement arrived. The shutter was opened and the first im-

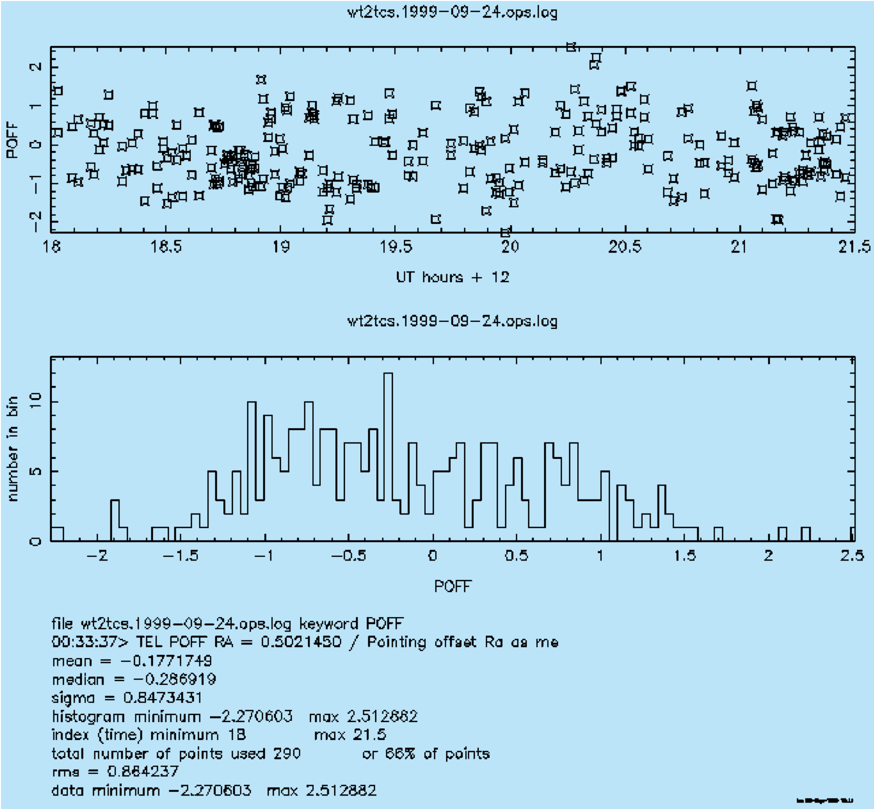


*Figure 3: Measured pointing errors on 140 astrometric stars covering the whole sky. The measured rms pointing on this night was 0.85 arcsecond.*

age obtained. The image quality was quickly derived to be 0.6 arcseconds. A quiet note of satisfaction was felt across the control room and now the real work commissioning FORS1 could start in earnest. A separate article on the FORS1 commissioning has already been published, so not much more will be said here.

In the mean time ISAAC was sitting in the integration lab waiting to be installed on the telescope. Jean-Luis Lizon had been working furiously under difficult conditions to complete the re-integration of the instrument. In the couple of weeks between FORS1 and ISAAC we checked out the Nasmyth A focus and verified all was well. ISAAC went on to the telescope on schedule and also produced beautiful images straight away. Finally we had an instrument that could exercise the telescope in all the weird and wonderful ways that only infrared astronomers can find. Alan Moorwood, Jean-Gabriel Cuby and Chris Lidman all worked furiously at characterising the instrument. Our first fellow on Paranal, Monica Petr, arrived around this time and immediately started learning and driving both instruments and telescope. Joar Brynnel finally could see all his electronics work used for astronomy rather than just tests. Manfred Meyer and Gert Finger got the last ounce of efficiency out their IRACE system to read the ISAAC detectors. Peter Biereichel was always at hand to make the instrument software that little bit better. Nicolas Devillard demonstrated the latest pipeline capabilities.

It was Christmas time by now and the FORS1 crew were back. To welcome them we put water inside their instrument again, but by now we were all experts at dismounting and cleaning FORS1 up. Our apologies were gracefully accepted again and we started to work together towards the final integration of the instrument into its new home. Unfortunately the weather did not co-operate and most of the second commissioning run was lost. We scheduled another run for January and with the help of Thomas Szeifert, Bernard Muschielok and Wolfgang Gaessler the instrument was Paranalised. Following this it was handed to Fernando Comerón to system test. Of course, Fernando kept on finding things we had missed. Roberto Gilmozzi would agree with him and then we had to change everything again. It was fun.

Time had come to welcome ISAAC back. Remember how well the telescope and instrument had behaved in the first commissioning run. Well, this time things were not to be so easy going. The UTs' direct drive motors (big fancy magnets with a protective metal cover) move the machine silently and very elegantly around the sky. On side A (not the ISAAC side) one of the covers came off and got crunched inside the motor. Patricio Ibanez, Pablo Gutiérrez, Gustavo Rahmer and Hans Gemperlein worked non-stop for a week to disassemble one whole side of the telescope and put it back together again. The badge of honour at the time was a piece of yellow duct tape, which was worn with great pride for the duration of the work. You might have thought that the control room would have been a quiet place with a broken telescope. Taking advantage of the absence of the head of commissioning, Michael Loose, our architect on Paranal, transformed the control room into Beirut at the height of the Lebanon troubles. The floor and the ceiling disappeared. If a small thermonuclear weapon had gone off it would have made a smaller mess. In spite of this, Jean-Gabriel, Jens Knudstrup and a few other brave souls continued working, wearing surgical masks to limit the amount of dust entering their lungs and the ear-plugs to reduce the noise level to that of a firing range.

All was brought together just in time for the end of the commissioning of ISAAC and we were ready for the operations dry runs which were scheduled for March. In the mean time two big events were on the horizon. UT2 (soon to be renamed to Kueyen) was getting ready for first light and the inauguration of Paranal was also rapidly approaching. Without commissioning really noticing, Peter Gray and his crew, with some help from the usual suspects in Garching – Bruno Gilli, Max Kraus and Fabio Biancat Marchet come immediately to mind – had another 8-metre telescope ready to go. Cells moving up and down the mountain, mirrors coated, servo loops tuned and all the things necessary to make a telescope ready somehow were all done without slowing UT1 work. Two telescopes running before the inauguration and a nice image to show from Antu would make a good showing. Massimo in a typically challenging order stated that nothing worse than a third of an arcsecond for the image from Antu would satisfy him. On the night before the inauguration, UT1 had already been handed to Science Operations for their dry runs. The telescope was theirs. What could they do? Just to set the standard for the future, Hermann Boehnhardt and Roberto Gilmozzi were at the controls with Massimo directing that FORS1 be switched to high-resolution mode since the seeing was good. It is a well-known fact that the presence of the director on Paranal improves the seeing. The combination of all of the effects described resulted in a 600-second I band image with quality better than 0.25 arcseconds. Now that the first goal was met we could have some extra fun. Lothar Noethe and Stephane Guisard had been labouring for some time to make the telescope spell its own name. Anyone they said could do it moving the telescope around until the star trails spelt out VLT. Even the NTT managed that. So they took charge of the shape of the primary mirror and they made stars whose shapes spelt out VLT! True control of the shape of the primary was demonstrated beyond a doubt.

On Kueyen as soon as we had a primary and a secondary mirror installed we had a look. It was not going to be as easy as Antu but it would work. Lothar Noethe, Stephane Guisard and Roberto Abuter set about their merry way to make the thing make stars that looked round.

Krister Wirenstrand sorted out the pointing with a bit of help from a big piece of paper being held at the Nasmyth Focus and using a real bright star. Two telescopes working and the best ever image. We now felt that the observatory could be inaugurated.

Before the telescope was released into full operations we threw away the old software. Giorgio Filippi came down with a present from Garching. A Y2K compliant system had been fully tested on the Garching control model and was installed on all systems on Paranal. Carlos Guirao brought some new data flow computers and Michèle Peron, Nick Kornweibel, Michele Zamparelli, Gerhard Mekiffer, Klaus Banse, Miguel Albrecht, Paola Amico, Reinhard Hanuschik, Palle Møller, Michael Rauch, Almudena Prieto, Dave Silva and Maurizio Chavan all spent quite some sleepless nights on Paranal ensuring the data-flow system was fully operational before and immediately after Antu was released.

Somewhere earlier in this story Toomas Erm was still worrying about this wind-shake problem. So, after a long think about it all, he asked if Stefan Sandrock could give him a helping hand with an idea he had. A couple of days later a new version of our tachometer was implemented in software and the enchilada was born (a soft taco being an enchilada). Wind shake is not a thing of the past but Kueyen is now stiffer than we had ever dreamed of. Enchilada gave way to Enchilada turbo and by now the azimuth axis of Kueyen was exceeding tracking specifications by over an order of magnitude and altitude was in great shape also exceeding specifications by a factor of 2 under most operating conditions. The windscreens of the enclosure have been improved and tested and retrofitted thanks to the work of Martina García (who somehow also managed to have a baby while all of this was happening) and Erich Bugueno. Juan Osorio fixed things on the electronics of the enclosure and German Ehrenfeld never seemed to stop making things and moving big pieces around. Nelson Montano is now our hydrostatic pad man and routine preventative maintenance started in earnest. The benefits of having more than one telescope to work on were coming to the fore. In any normal telescope observatory Antu would have been released and the improvements coming from Kueyen would have been implemented in some distant future. At Paranal the cycle still has some way to run.

On Antu, for each activity undertaken by commissioning, a test procedure was supposed to be followed documenting exactly how each test was to be performed. This was to be a self-documenting system with the procedure also providing the final documentation for the test. In some cases, such as tracking and field-stabilisation maps, this was done while for others the procedures were developed during the commissioning, as we better understood what needed to be done. On Kueyen this documentation effort was much improved and expanded. Also automation of a number of tests was undertaken. The use of the engineering data stream was expanded dramatically to provide input for preventive maintenance but also to better understand the system. The VLT control-system engineering-data stream includes for example every aberration measured by the system. In any given month, as many as 20 thousand active-optics corrections are made. Looking at the logs and using parallel measurements with the test camera wavefront sensor, we identified some cross-talk between defocus and spherical aberration. The effect was small resulting in additional noise in the system of order 0.03 arcseconds in the average image quality delivered. Lothar was looking at the data in Garching and promised a solution by the birth of his son. On schedule on the 3rd of August the problem was identified and corrected for. A baby boy was also born on the same day. The cross-talk was identified as being due to an incorrect sign in the force setting on the primary. The improvement in the stability of the defocus was obvious (the rms value of the aberration was reduced by 500 nanometres). The value of the engineering data stream cannot be overstated.

Continuing on the food theme (pea soup, enchilada) we started worrying about the sausages the telescope was producing. Close to the zenith and the meridian, when 430 tons of glass and metal are spinning around at an impressive pace, the stars were not coming out round but rather long like sausages. Here was a problem that had to have a solution. So we all worked on it. Krister changed the tracking software. Stefan changed it back and then back again and once more. Rodrigo and Anders measured in ever more imaginative ways. In parallel, continuous improvements in the system were made, all contributing in their own ways in attacking this problem and other annoyances. Mario Kiekebusch automated the adapter calibration procedures and gave us smarter secondary guiding. Ivan Muñoz made the pointing modelling trivial by automating it and introduced us to Pinky and the Brain. Francisco Delgado kept improving the active optics software to allow us to better control the mirror position. Sausage measurements were made, analysed, models and simulators written. The sausage problem was reduced by a factor of 10 and is now an operational annoyance. We keep working on it. Same with the pointing that has been measured as good as 0.85 arcseconds all over the sky. Roberto Rojas has inherited the thermal control software, from Roberto Abuter who escaped to Enteferometry [sic], and put it into full operation. This promises in the medium to long term to provide a significant improvement in how we manage the telescope environment.

This article is being written as UVES ended its first commissioning run on Kueyen. UVES is looking good. Very good! FORS2 is already mounted on the telescope and has seen stars. Kueyen is well on its way to be released on schedule for Period 65. Norma Hurtado and Julio Navarrete are driving the telescope and providing valuable operator feedback to the commissioning team. Baring unforeseen events in 2000 both Melipal and Yepun will have their first lights and we have new ideas for further improvements to the system.

To know who has made all of this possible, access the web and get a list of all ESO staff irrespective of location, position or function. We would like to thank Krister Wirenstrand personally for his tireless efforts towards building and commissioning the telescopes.

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# The Science Verification Plan for FORS2 and UVES at UT2/Kueyen

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## 1. Introduction

The Science Verification (SV) observations for FORS2 and UVES at Kueyen (UT2) will follow the same approach and policy as already described for the SV of Antu (UT1) and its instruments (www.eso.org/science/utlsv/). SV observations are now planned as follows:

- UVES SV: February 6–17 (New Moon is February 5)
- FORS2 SV: February 28 – March 10 (New Moon is March 6). Raw, calibration and calibrated data will be made publicly available to the ESO community as soon as the reductions are completed and the data prepared for re-